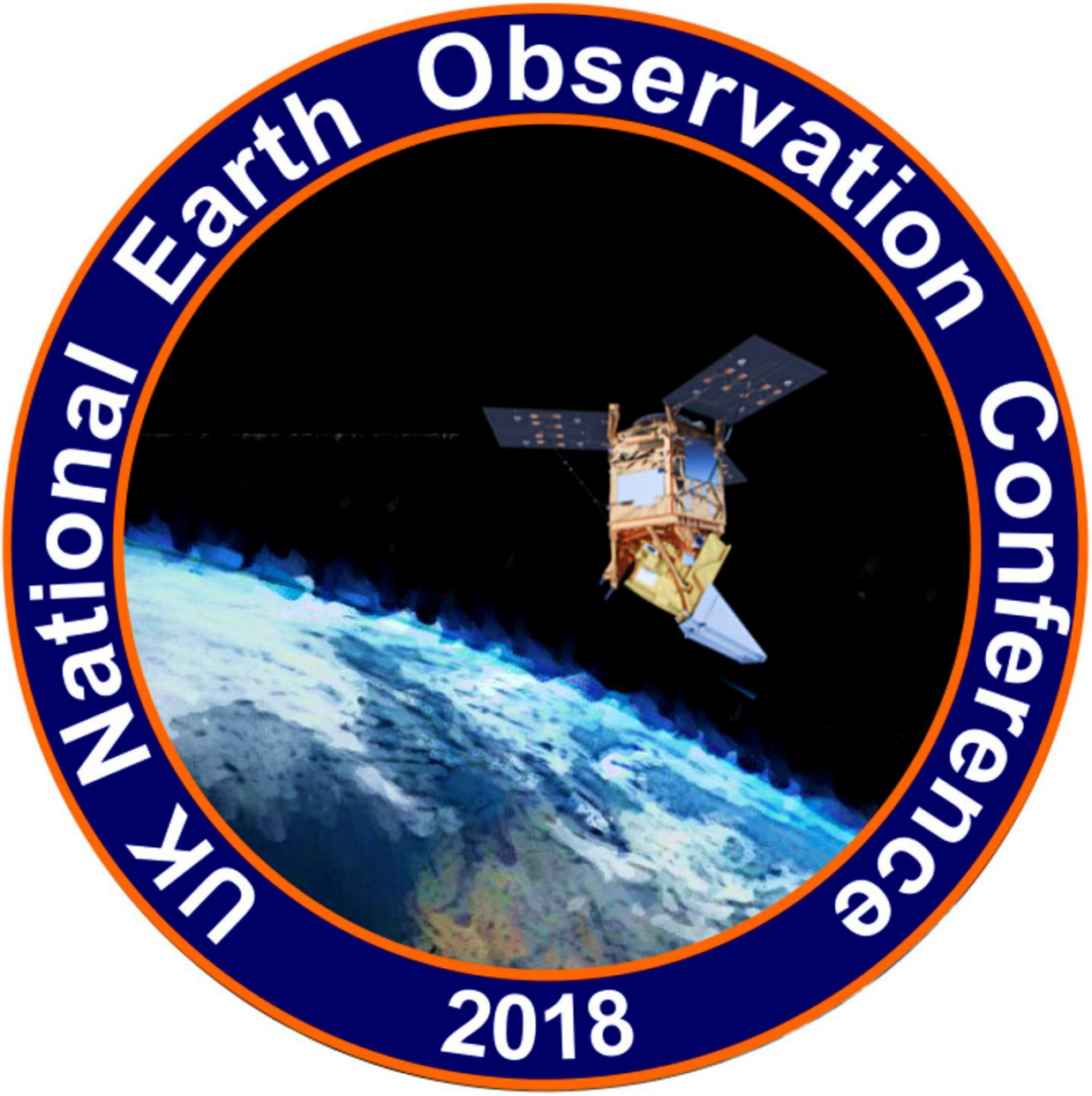

Earth Observation into the Future

Birmingham University

4-7 September 2018

Contents

NERC SCIENCE OF THE ENVIRONMENT

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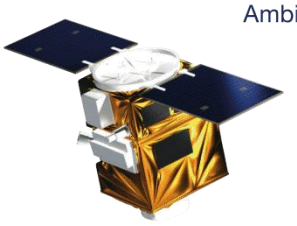

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living planet symposium

MILAN
13–17 May
2019

UNDERSTANDING THE EARTH SYSTEM

Scientific results advancing our understanding of the different earth systems and their interactions.

SPACE 4.0 AND EARTH OBSERVATION

Disruptive technologies impact on Earth Observation missions, data analysis and applications.

BENEFITS FOR A RESILIENT SOCIETY

Integration of Earth Observation-based services with local, national and global initiatives for sustainability and resilience.

PUBLIC AND PRIVATE SECTOR INTERACTIONS

New partnerships stimulating cross fertilization between public and private actors.

Deadlines

Session Proposals	Abstracts	Registration	
17 June 2018	11 November 2018	April 2019	lps19.esa.int

European Space Agency

Real-Time Spectral Imaging Was Once the Future ....

... the future is now with NEO's advanced hyperspectral imagers, which provide real-time, high resolution spectral images, which are ideally suited to airborne, UAV, field, industrial and laboratory applications.

At Pro-Lite, we don't just supply state-of-the-art spectral cameras, we also supply field-portable UV-VIS-NIR spectroradiometers from Spectral Evolution and Permaflect large area, diffuse reflectance targets from Labsphere. For calibrating remote sensing instrumentation, Labsphere Helios integrating sphere uniform light sources provide calibrated radiance at world-class levels of traceable uncertainty.

Hyperspectral Imaging

Field-Portable UV-VIS-NIR Spectroradiometers

Diffuse Reflectance Calibration Targets

Integrating Sphere Calibration Sources

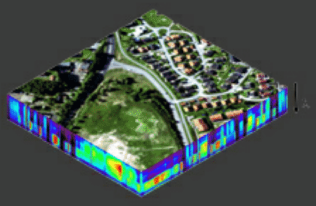
Remote Sensing

Spectral Imaging & Spectroscopy

PRO-LITE TECHNOLOGY

Hyperspectral Imaging

Whether it's push-broom or snapshot, hyperspectral or multispectral that you need for your application, Pro-Lite supply a range of imaging solutions. The HySpex cameras provide the highest quality high spatial and spectral resolution images for laboratory, industrial, airborne and field based imaging.



Cubert produce novel real-time snapshot hyper- and multi-spectral imagers. The new LightShift cameras from Surface Optics provide multimodal snapshot spectral and polarization imager with video-rate acquisition and processing together with the flexibility of selecting filter wavebands. Pixelteq manufacture 3 to 9 band multi-channel snapshot cameras with their dichroic filter arrays.

And there's more…
make sure you talk to us about your spectral imaging requirements!

Field-Portable UV-VIS-NIR Spectroradiometers

Portable and laboratory single-point spectroradiometers from Spectral Evolution provide full range measurements of reflectance, transmittance, radiance (up-welling) and irradiance (down-welling) in the range from 280-2500nm (UV-VIS-NIR-SWIR) for applications in remote sensing, ground truth hyperspectral imagery, radiometric transfer in the calibration of satellite instrumentation and verification of solar simulator classification.

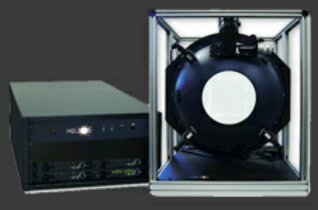
With an all-solid-state design, Spectral Evolution instruments employ array spectrometers (silicon for UV-VIS-NIR, one or two InGaAs arrays for SWIR). They are compact and robust and feature no moving parts that can go wrong, making them ideal for field applications.

Applications include:

> Remote sensing: vegetation; geological; soil; water; ground truth hyperspectral imagery
> Mining: exploration; mineral analysis
> Lab/general photonics: portable radiometric transfer for calibrating satellite imaging instruments; solar simulators (verification of class A-B-C)

Calibration Sources & Reflectance Targets

Labsphere's new HELIOS line of uniform sources of luminance and radiance offers a modular,scalable product family combining the best features from Labsphere's 35+ years of uniform source product innovation.



All systems are delivered with LabVIEW® software drivers and intelligent system components for active system control from within your existing infrastructure. HELIOS uniform sources are offered in a wide range of standard and custom models to meet your unique technical needs and budget, each one calibrated with the lowest commercially available uncertainty in the industry.

Additionally, HELIOS' modular design, open architecture software, flexible spectra and future-proofed expand-ability enables users to meet demanding testing challenges in hyperspectral, multispectral, SWIR and VIS-NIR bands.

Diffuse Reflectance Calibration Targets

Pro-Lite offers a range of reflectance targets which are used to test and calibrate remote sensing instruments, spectroradiometers and image sensors used in autonomous vehicle technology.

PRO-LITE TECHNOLOGY

Pro-Lite Technology Ltd
Innovation Centre
University Way
Cranfield
MK43 0BT
United Kingdom

Tel: +44 (0) 1234 436110
Fax: +44 (0) 1234 436111
info@pro-lite.co.uk
www.pro-lite.co.uk

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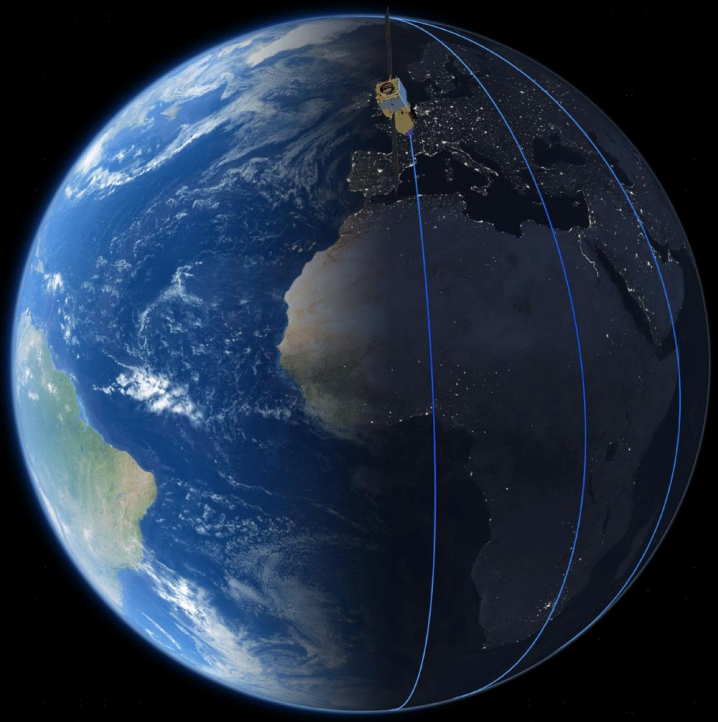

S4C@the-iea.org

the-iea.org/space4climate

@Space4Climate

IMAGE: ESA/ATG medialab

Satellite Applications Catapult

The Satellite Applications Catapult is one of a network of UK technology and innovation companies which aim to drive economic growth through the commercialisation of research. The aim of the Satellite Applications Catapult is to support UK industry by accelerating the growth of satellite applications and to contribute to capturing a 10% share of the global space market predicted by 2030. We are achieving this by exploiting the innovation potential in the UK industrial and academic communities. We strive to be a focal point where SMEs, large industry and end users can work together with researchers to challenge barriers, explore and develop new ideas, and bring these to commercial reality.

The Data Discover Hub (DDH) offers quick and simple access to satellite Earth observation (EO) data for everyone. The DDH links to a large number of EO and Geospatial datasets which can be applied across multiple market areas to suit the requirements of the user. Following a recent upgrade, the DDH now features an intelligent search function, further widening access to non-data experts.

The Sentinel Data Access Service (SEDAS) is a mechanism designed to allow end users to search and download Sentinel data from an extensive archive.

The service aims to lower barriers and create the foundations for an integrated approach to satellite data access. The SEDAS portal contains a 30 day rolling archive of Synthetic Aperture Radar (SAR) data from Sentinel 1A and 1B, as well as Optical data from Sentinel 2, all of which is available for immediate download. Data beyond this archive is also available on request.

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Satellite Applications

Welcome

It is our pleasure to welcome you to Birmingham for the UK National Earth Observation Conference 2018.

Monitoring the Earth's natural and anthropogenic processes has never been more crucial. Today's society is global and increasingly hungry for up-to-date information via simplistic tools and interfaces. Continuous data from satellites provides a global view, current and historic, combined with terrestrial systems to generate powerful insights for individuals, market sectors, and government policy and delivery.

The UK National Earth Observation Conference is the main UK event in Earth Observation and photogrammetry, bringing together the UK community from across research, Government and industry to discuss how EO research, technological innovation, products and services will impact upon wider society, through a mixture of presentations, Keynote speakers, Plenary sessions, exhibitors, networking opportunities and social events.

The theme of this conference is 'Earth Observation into the Future' where the Conference will focus around a broad and exciting technical programme together with a selection of invited international keynote speakers and plenary discussions. The programme will provide a forum to introduce research opportunities around current and future Earth Observation programmes, for the international community to demonstrate exciting applications and recent advances in the processing and analysis of Earth Observation and photogrammetric data, and for companies to showcase their latest products and services.

We would like to thank the conference organisers and the partnership organisations for bringing their expertise and enthusiasm in generating what we hope will be a vibrant Conference.

We wish you all a productive and enjoyable Conference.

Convenors

- John Remedios (NCEO)
- Janet Fillingham (NCEO)
- Richard Armitage (RSPSoc)
- Kay Smith (RSPSoc)
- Mick Johnson (CEOI)

Conference Organisers

Remote Sensing and Photogrammetry Society (RSPSoc)

RSPSoc is the UK's leading Society for remote sensing and photogrammetry and their application to education, science, research, industry, commerce and the public service. As a charity, its remit is to inform and educate its members and the public. It supports networking between the university, business and government sectors. As an international society, RSPSoc is also active in Europe and on the world stage

National Centre for Earth Observation (NCEO)

NCEO is a distributed NERC centre of over 100 scientists from UK universities and research organisations. NCEO provides the UK's Natural Environmental Research Council with national capability in Earth observation science – monitoring the health of our planet through satellite instruments and more – with world-class capability in interpreting the data

Centre for Earth Observation Instrumentation (CEOI)

The CEOI was established in 2007 in order to realise an excellent, internationally competitive national Earth observation instrument and technology research and development programme. The CEOI is funded by the UK Space Agency with parallel technology investment from industry. Its key aim is to develop UK innovative technologies to observe Earth from space through the teaming of scientists and industrialists.

In partnership with:

The UK National Earth Observation Conference 2018 aims to deliver a conference that attracts a very significant gathering of the UK EO community across research, government and industry to bring close association with the conference and its eventual success. The organising committee is delighted to partner with the British Association of Remote Sensing Companies (BARSC), Department for Environment, Food and Rural Affairs (Defra), European Centre for Space Applications and Telecommunications (ESCAT), Natural Environment Research Council (NERC), Satellite Applications Catapult (SAC), UKSpace and the UK Space Agency (UKSA).

Conference Sponsors

Sponsors of the Conference Dinner

Thursday 6th September

National Conference Centre and National Motorcycle Museum

Sponsors of the Social Event: BBQ

Wednesday 5th September

The Duck and Scholar, The Vale

Sponsors of the Space Placement in INdustry (SPIN) event

Friday 7th September

Aston Webb Buildings

Conference Venue

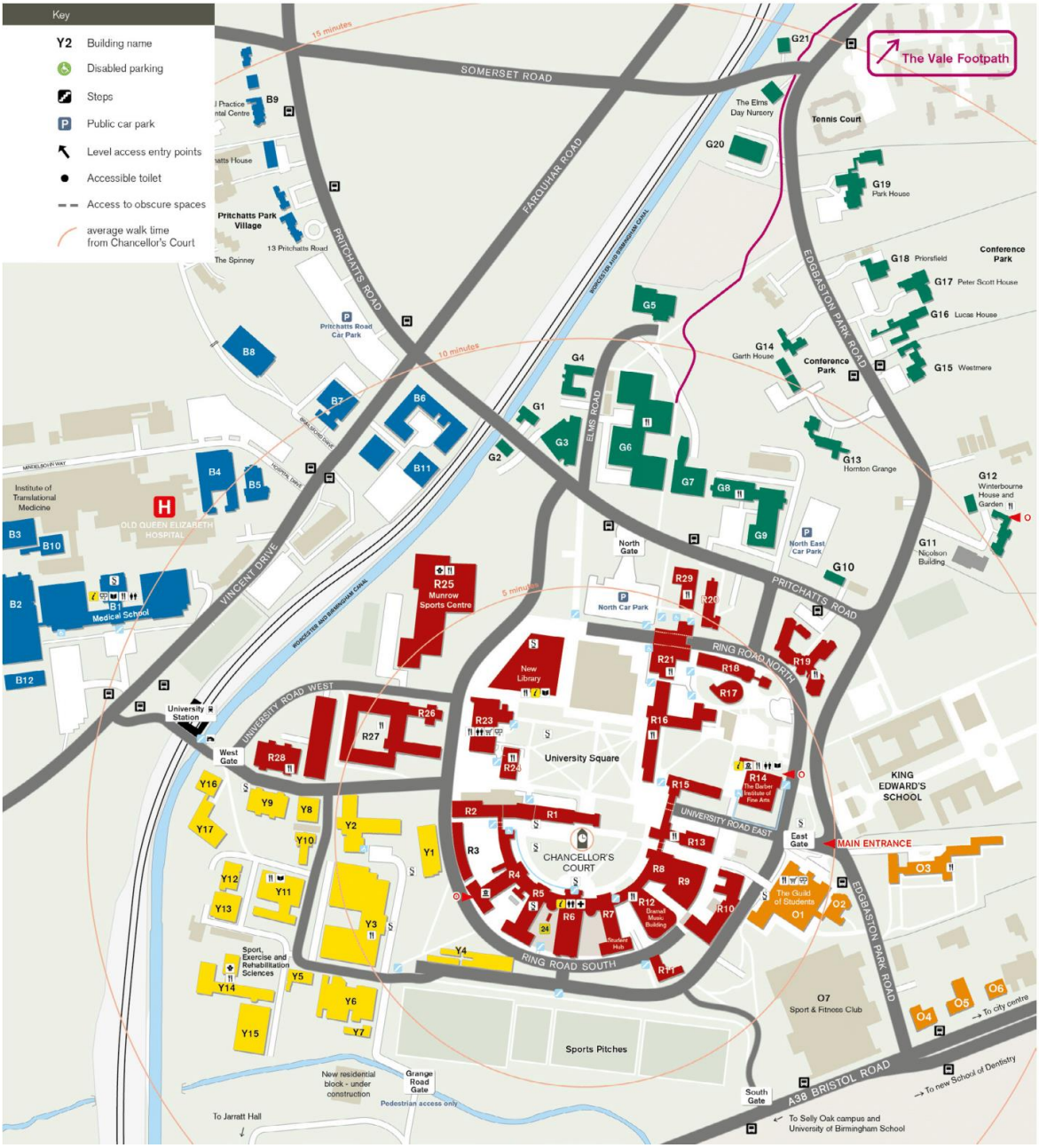
The University of Birmingham grew out of the radical vision of the first Chancellor, Joseph Chamberlain. Founded in 1900, Birmingham represented a new model for higher education. This was England's first civic university, where students from all religions and backgrounds were accepted on an equal basis.

The University of Birmingham is in the midst of one of the most transformational campus redevelopments since the first phase of building on the Edgbaston campus was completed in 1909 under the auspices of Sir Aston Webb.

The Edgbaston campus is set in 250 acres and has all the facilities of a busy town. Lawns, mature trees and walkways contribute to the peaceful atmosphere and make the campus a wonderful spot for picnics and walking.

The main heart of the conference will be in the Aston Webb buildings in Chancellor Court. The Great Hall will host the Exhibitors, the Poster Sessions and all the catering, with sessions occurring in other lecture theatres and rooms within the building. All Keynotes, Plenaries and some technical session are being held in the Elgar Concert Hall in the Bramall Building. The Noble Room in Staff House will be the first venue for the Icebreaker reception on Tuesday evening when our first Keynote address will take place after the informal buffet dinner.

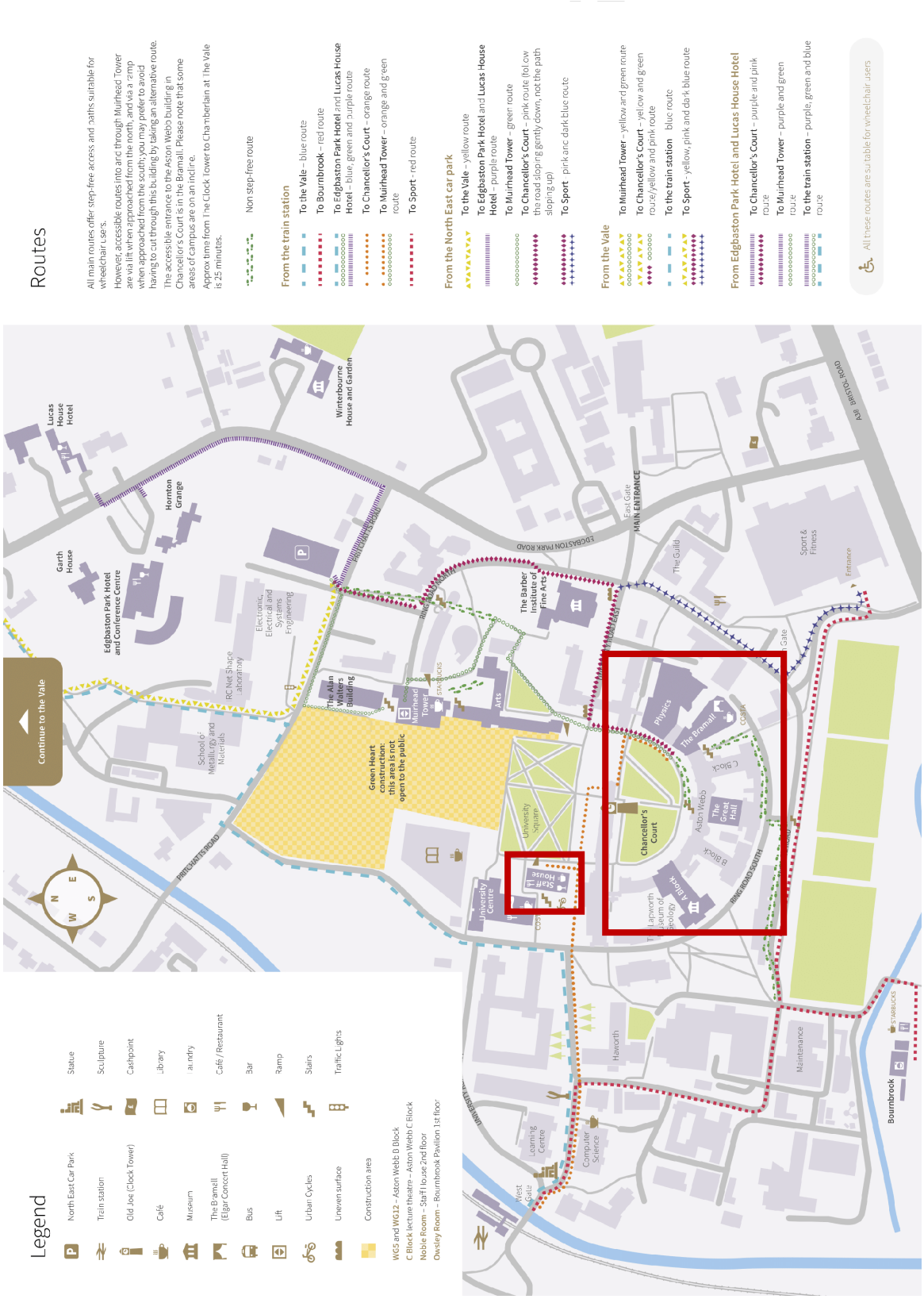
Edgbaston Campus Maps



Conference buildings in the central red zone:

- R24: Nobel Room, Staff House
- R6: Aston Webb - Great Hall
- R12: The Bramall
- R13: Poynting Building

Walking Routes around Campus



Venue Plan


University of Birmingham
Great Hall
Chancellors Court
Edgbaston
Birmingham
B15 2TT
1
Senate Chamber / Senate Meeting Room
Great Hall Rotunda
Stairs
Toilets
Disabled Toilets
Lift
G
Great Hall – Catering, Posterboards, Exhibition
Great Hall Foyer – Registration, Dinner
Beale Room
Lecture Theatre – G33, WG5, WG12
The Bramall – Elgar Concert Hall
Stairs
Toilets
Disabled Toilets
Lift
Poynting Building
WG5
WG12
Old Joe
Clock Tower
Chancellor's Court
Disabled Entrance
G33
LG
Main Lecture Theatre - C Block
Toilets
Disabled Toilets
Lift
N
W
E
S
C Block
Lecture Theatre

The Exhibition

The exhibition space for the UK National Earth Observation Conference is located in the Great Hall in the Aston Webb Building, Chancellor Court on the University of Birmingham Edgbaston Campus

The exhibition is central to the conference and is integrated within the conference poster sessions area where the conference refreshments and drinks receptions will be hosted.

There will be a dedicated Exhibitor Session on 5th September, allowing maximum exposure of Exhibitors to the Conference Delegates from the beginning and throughout the conference.

Exhibitor Session

Date: Wednesday 5th September

Time: 13:30-14:30

Location: Great Hall

Wed 5th Sept: 07:00-11:00: Installation of exhibits
Wed 5th Sept: 11:00-19:00: Exhibition
Wed 5th Sept: 13:30-14:30: Dedicated Exhibitor Session

Thurs 6th Sept: 09:00-19:00: Exhibition

Fri 7th Sept: 09:00-15:00: Exhibition
Fri 7th Sept: 15:00-17:00: Exhibition deconstruction

Conference Exhibitors

PREMIUM Exhibitors

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

PRO-LITE TECHNOLOGY

Taylor & Francis Group
an informa business

STANDARD Exhibitors

esa

GEOSPATIAL INSIGHT

CATAPULT Satellite Applications

RAL Space
Science & Technology Facilities Council
UK Research and Innovation

SPACE CLIMATE

SPRINT

WILEY

Delegate Information

Registration

Delegate registration will be located in the entrance to the Aston Webb building within Chancellor Court. Registration will be open between the following times:

- 17:30-20:00: Tuesday 4th September in Nobel Room, Staff House
- 08:00-17:00: Wednesday 5th September at entrance to the Great Hall
- 08:00-17:00: Thursday 6th September at entrance to the Great Hall
- 08:00-14:00: Friday 7th September at entrance to the Great Hall

All enquiries should be made via the Registration desk where staff will be available to assist you. The registration desk will be staffed by a combination of: Kay Smith, Jan Fillingham, Rachel Hopkins and Uta Feinstein

Exhibition

The exhibitors are located within the Great Hall in the Aston Webb building within Chancellor Court. Lunch, tea/coffee breaks and the poster sessions will also be taking place within the Great Hall. We would like to encourage the delegates to spend time talking with the Exhibitors at their allocated stands. The exhibition is open to delegates between the following times:

- 11:00-17:00: Wednesday 5th September
- 09:00-17:00: Thursday 6th September
- 09:00-15:00: Friday 7th September

Sessions

Sessions are to be held in the Aston Webb buildings in the following areas:

- Elgar Concert Hall, The Bramall Building
- C-Block Lecture Theatre
- G33
- Senate Chamber

All Keynote and Plenary presentations are to be presented in the Elgar Concert Hall in the Bramall Building. Please see the full programme for the room designation. All rooms will be signposted and staff will be able to guide you around.

Oral presentation upload

Delegates are asked to ensure that their 10-minute PDF/Powerpoint presentations are uploaded via USB data-stick to the computer in the room assigned to their session during the break before the session starts. If you are using your own computer, please make sure of compatibility beforehand.

Poster Sessions

We are delighted to have two poster sessions in the Great Hall during the conference. Posters have been allocated their session based on the topic of their posters. On arrival please collect your Velcro patches for attaching your poster to your allocated poster board. Poster boards have been allocated in order to cluster topics together as best as possible. Please be available at your poster during your allocated session to enable interaction. Take-down of posters is requested after 15:00 on Friday 7th.

Delegates have been given a drinks vouchers with their conference badge to entitle the holder to a free drink for consumption during each poster session.

Catering

All conference catering is available in the Great Hall at designated areas. Consumption can take place anywhere EXCEPT in the lecture theatres. Catering is allocated specific time slots within the conference programme. We would like to encourage delegates to peruse the exhibition during the refreshment breaks to maximise interaction.

Accommodation

University accommodation at the Chamberlain Tower, The Vale, can be reached by following the signage on the campus. There is a brick pathway that leads from the north edge of the campus to The Vale, where the BBQ venue is also located. The walk takes between 20-25 minutes. Other accommodation that has been booked at the Edgbaston Park Hotel & Conference Centre on campus is a 10-minute walk to Chancellor Court.

Internet Access

Delegates can access the EDUROAM wifi, if already registered to that system.

Delegate Badges

Delegate badges on the lanyard must be worn at all times during the conference. Behind the name badge delegates can find drinks vouchers for the social events that they are registered to attend.

Luggage

There will be an area beneath the Elgar Concert Hall, Bramall set aside for storage of luggage during the conference. If you wish to use this facility, please ask for details at the registration desk.

Car Parking

There is no parking for delegates directly within the Chancellor Court area. If you are arriving before 18:00, Mon-Fri, you will need to park in the University's North East pay & display Car Park, on Pritchatt's Road, B15 2SA. There are other pay & display car parking facilities around campus. After 18:00, car parking is free.

Local Transport

Chancellor Court can be easily reached with a short 5-10 minute walk from University train station, which is served by frequent services to/from Birmingham New Street.

Local buses Numbers X61 and 63 also serve Edgbaston Campus, while the X64, 76 and 98 serve the nearby Medical School and Queen Elizabeth Hospital. The services run frequently from the city centre.

Twitter and Facebook

Please use the following when tweeting or posting about the conference

#EarthObsConf2018

Social Events

Icebreaker Reception

***Date*: Tuesday 4th September**

***Location*: Noble Room, Staff House**

***Time*: 18:00-21:00**

Prior to the main conference, delegates are invited to attend a 'Pre-conference' Icebreaker reception buffet. We are delighted that this will include the first of our many Keynote speakers: Christian Heipke, President of the International Society for Photogrammetry and Remote Sensing.

Barbeque (Sponsored by AIRBUS)

***Date*: Wednesday 5th September**

***Location*: The Duck & Scholar, The Vale**

***Time*: 19:30-21:00**

Following completion of the first day of the conference, delegates are invited to attend a BBQ (sponsored by Airbus) at the Duck and Scholar, one of the University of Birmingham's Catering venues

Conference Dinner (Sponsored by NERC)

***Date:* Thursday 6th September**

***Location*: National Conference Centre and National Motorcycle Museum (B92 0EJ)**

***Time*: 19:30-23:00**

The highlight of the Conference, the Conference Dinner (sponsored by NERC) will be held in the Manxman Suite of the National Conference Centre. On arrival, dinner guests will be able to take a complimentary drink and visit the adjoining National Motorcycle Museum, home to the finest and largest British motorcycle museum in the world with a collection of 350 motorcycles on display. With the earliest pioneer machine dating from 1898 through to the latest British superbikes of this century, the museum collection highlights both the development of the motorcycle as well as showcasing the UKs proud motorcycle manufacturing heritage

After the dinner, there will be the RSPSoc Awards Ceremony and an after-dinner speech before coaches return guests to their accommodation.

RSPSoc Annual Awards

The Remote Sensing and Photogrammetry Society Award: For 'services' to Remote Sensing and/or Photogrammetry through sustained and distinguished contributions to furthering the science and applications which use remote sensing or photogrammetry. This year the RSPSoc Award is presented to **Professor Nicholas Veck, MBE, Head of the CEO Office at the Satellite Applications Catapult**.

The Len Curtis Award: For an outstanding technical paper published in the International Journal of Remote Sensing (IJRS) during the preceding calendar year. Awarded to: **Oluibukun Ajayi**

EH Thompson Award: Awarded to the author(s) of the paper in The Photogrammetric Record (TPR) that most merits the award. Awarded to: **Christian Kehl**

The Taylor and Francis Remote Sensing Letters Award: Awarded for the best letter published in the Remote Sensing Letters publication during the previous calendar year. Awarded to: **Michele Meroni**

The Student Awards: The Society makes two student awards annually for the best Doctoral and Masters Theses, on the subjects of remote sensing and/or photogrammetry, accepted by a university during the previous calendar year. PhD Award: **Pedro Veiga**. MSc Award to: **Tiny Remmers**

The **President's Cup** is awarded for the best oral presentation at the Annual Conference of the Society. The President's Cup was awarded at RSPSoc2017 to: **Naomi Gatis**

The **Business Innovation Award** has been created to recognise the leading technologies, products and services the society's corporate company and individual members are delivering to users across different market sectors. This has been awarded to **SenSat,** an AI startup and the UK's largest provider of drone data for large complex infrastructure projects.

Keynote Speakers

Christian Heipke, President of the International Society for Photogrammetry and Remote Sensing

Biography

Christian Heipke is a Professor of photogrammetry and remote sensing at Leibniz Universität Hannover, where he currently leads a group of about 25 researchers. His professional interests comprise all aspects of photogrammetry, remote sensing, image understanding and their connection to computer vision and GIS. His has authored or co-authored more than 300 scientific papers, more than 70 of which appeared in peer-reviewed international journals. He is the recipient of the 1992 Otto von Gruber Award, the 2012 Fred Doyle Award, both from the International Society of Photogrammetry and Remote Sensing (ISPRS), and the 2013 Photogrammetric (Fairchild) Award from ASPRS. From 2004 to 2009, he served as vice president of EuroSDR (European Spatial Data Research, formerly known as OEEPE). From 2011-2014 he was chair of the German Geodetic Commission (DGK), from 2012-2016 ISPRS Secretary General. Currently he serves as ISPRS President.

Keynote: Remote sensing in the area of deep learning

KEYNOTE 1 | *Date*: Tuesday 4th September 2018 | *Time*: 20:00-21:00 | *Location*: Nobel Room, Staff House

Josef Aschbacher, Director of Earth Observation at the European Space Agency

Biography

Josef Aschbacher is the ESA Director of Earth Observation Programmes and Head of ESRIN, ESA's centre for Earth Observation, located in Frascati (near Rome) Italy.

Born in Austria, he studied at the University of Innsbruck, graduating with a Master and a Doctoral Degree in Natural Sciences.

His professional career in ESA began in 1990 as a Young Graduate at ESA ESRIN. From 1991-93 he was seconded as ESA Representative to Southeast Asia to the Asian Institute of Technology in Bangkok, Thailand. From 1994-2001 he worked at the European Commission Joint Research Centre in Ispra, Italy, where he was the Scientific Assistant to the Director of the Space Applications Institute. He returned to ESA HQ (Paris) in 2001 as Programme Coordinator where he was primarily responsible for advancing Copernicus activities within ESA. In 2006 he was nominated Head of the Copernicus Space Office, where he led all activities for Copernicus within the Agency and with external partners, in particular the European Commission. In 2014, he was promoted to Head of Programme Planning and Coordination at ESRIN, where he was responsible for planning ESA's Earth Observation programmes and for formulating and implementing programmatic and strategic decisions across the Directorate. He took up duty as Director of Earth Observation Programmes on 1 July 2016.

Keynote: Earth Observation at ESA in the coming decades

Professor Tim Wright, Professor of Satellite Geodesy and Director of NERC-COMET

Biography

Tim Wright is Professor of Satellite Geodesy at the University of Leeds. His work has been at the forefront of developing the use of satellite radar interferometry (InSAR) for measuring tectonic and volcanic deformation. Major achievements include the first demonstration that inter-seismic strain can be measured using InSAR, the investigation of a series of major earthquakes using geodesy, seismology and geomorphology, and the discovery of a major rifting episode in Afar, Ethiopia. He has published more than 90 articles in major international journals, and his work is highly cited. He led the NERC-funded Afar Rift Consortium, a £3M project that is using a wide range of geophysical, geochemical and geologic techniques to investigate how the crust grows at divergent plate boundaries, and co-leads LICS, a NERC large grant to "Look Inside the Continents from Space". In 2014 he received the AGU Geodesy Section Award, and in 2015 he was the British Geophysical Association's Bullerwell lecturer and received the Rosenstiel Award from the University of Miami. He was the Royal Astronomical Society's 2017 Harold Jeffreys Lecturer. He is director of the NERC Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) and co-founder of SatSense Ltd, a University of Leeds spinout company

Keynote: Monitoring our deforming planet with Sentinel-1: from colliding continents to subsiding houses

The Sentinel-1 constellation represents a major advance in our ability to monitor movements of our planet's dynamic surface operationally. Sentinel-1 uniquely offers routine acquisitions with short revisits, a commitment to a long-duration mission, systematic wide-area coverage, good orbital control, and a free and open data policy. Together, these give us the unprecedented ability to respond to most earthquakes and eruptions and to build the long deformation time series that are required to resolve slow deformation. In this talk, I will present the latest progress from COMET-LiCS (*), where we are now providing processed products and derived results to the community for volcanoes and the tectonic belts (**).

COMET's work on earthquakes and volcanoes can be split into response and preparedness. We now respond routinely to most significant earthquakes that occur in the continents, providing interferograms and interpretations to the community rapidly – Sentinel-1 allows us to do this within a few days for most earthquakes. For example, after the M7.8 Kaikoura (New Zealand) earthquake, on 14 November 2016, and with assistance from ESA, we supplied a processed interferogram to the community at 1 pm on 15 November, just 5 hours and 37 minutes after the Sentinel-1 acquisition. This data set was used extensively by colleagues at GNS in New Zealand to help them identify faults that had failed in the earthquake – vital in this case as it was one of the most complex earthquakes ever to have occurred. The fault models that resulted from the InSAR data (from Sentinel-1 and ALOS) completely changed the local and USGS estimates of ground shaking, and are likely to lead to

modifications to seismic hazard codes worldwide. We are currently automating our response systems to take advantage of the guaranteed acquisitions that Sentinel-1 offers.

Preparing for earthquake and volcanic hazard first requires identification and characterisation of the hazard. Deformation data are now becoming a key piece of information in that process. For example, Biggs et al (Nature Communications 2014) showed that there is a strong diagnostic link between volcanoes that deform and volcanoes that erupt. Of equal importance, they showed that volcanoes that do not deform only rarely erupt. At fault zones, strain energy accumulates over long periods of time around faults that eventually fail in earthquakes. By mapping the accumulation of strain, we can place constraints on how often earthquakes can occur in a given region. To make an impact for volcano and fault zone monitoring, we need to be able to measure deformation rates on the order of 1 mm/yr or less. This requires mass processing of long time series of radar acquisitions. In COMET, we are currently processing interferograms systematically for the entire Alpine-Himalayan belt, which stretches over 9000 km from Italy through to China, and is up to 2000 km wide, and making interferograms and coherence products available to the community. We are also processing all ~1500 volcanoes on land that have erupted in the Holocene. We plan to provide average deformation rates and time series for all these areas. Results will be made available through our dedicated portal (**), and are being linked to the G-TEP portal and EPOS during 2018.

I will show the latest wide area results for tectonics and volcanism, and discuss how these can be used to build value-added products, including (i) maps of tectonic strain (ii) maps of seismic hazard (iii) volcano deformation alerts. The accuracy of these products will improve as the number of data products acquired by Sentinel-1 increases, and as the time series lengthen. Finally, I will show results from University of Leeds spinout, SAT**SENSE** Ltd, which is using Sentinel-1 data to monitor movements on a much smaller scale in the UK.

*COMET is the UK Natural Environment Research Council's Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics: http://comet.nerc.ac.uk; LiCS is a NERC large grant that aims to use Sentinel-1 to "Look inside the Continents from Space".

**Data are available for download at http://comet.nerc.ac.uk/COMET-LiCS-portal/

Massimiliano Vitale, General Manager and SVP Berlin Operations, Planet Labs

Biography

Massimiliano leads Planet operations in Germany and the global data pipeline team, and has over 20 years of experience in integrating and operating ground segment systems for Earth Observation satellites. He joined RapidEye in 2006 and since 2011 has been responsible for the ongoing success of RapidEye Mission Operations. Additionally, Massimiliano played a key role in developing ground segment systems from concept to routine operations, and built a team that successfully completed a number of multimillion data delivery projects. Prior to joining RapidEye, from 1997 to 2006, he was Project Leader with Datamat SpA (a Telespazio company) and participated in a number of Earth Observation ground segment projects for the European Space Agency (ESA) and other national space agencies. During his last years at Datamat, Massimiliano was in charge of the engineering team that supported six different ESA ground segment facilities in Europe. He received an M.Sc. with honors in Computer Engineering from the University of Rome Tor Vergata.

Keynote: Planet's novel approach to Earth Observation – challenges and opportunities

Session 1A: Earth Observation to Constrain the Terrestrial Carbon Cycle

Session Chair: Jeff Exbrayat (University of Edinburgh)
Date: Wednesday 5th September 2018
Time: 10:00-11:00
Location: Bramall Hall

A model of reflectance change to assess the effects of fire on vegetation

Jose L Gómez-Dans[1,2], James Brennan[1,2], Philip Lewis[1,2], David Roy[3], Luigi Boschetti[4]
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Fire is an important disturbance agent, responsible for an important injection of greenhouse gases into the atmosphere. At smaller spatial scales, fire has significant effects on plant distribution. Earth Observation methods for monitoring fire have mostly been concerned with monitoring fire activity, either as burned area maps (e.g. burned/unburned pixel) from optical data, or counts of thermal anomalies. Recent advances in thermal remote sensing have also provided top-down estimates of biomass combustion from fire radiative power measurements. Methods to assess the impact of the fire in the vegetation have been developed, but these have usually been based on empirical approaches.

In this contribution, we present a method that models the change in reflectance due to a fire using a linear model that assumes the post fire reflectance is a linear combination of an unaffected response and a fire signal. These two components are related by fcc, the product of the fraction of the pixel affected by the fire and the (radiometric) combustion completeness. We further develop a spectral signal model to be used for the burned component of the linear mixture. Putting these two elements together, a method to infer fcc and the properties of the post-fire signal is introduced.

We demonstrate the proposed methods with data from Sentinel-2, Landsat 8 and MODIS, as well as present some comparisons with other datasets and include some suggestions for using this new approach in a number of modelling scenarios

Impacts of El Niño amplified by forest edges and topography in human modified tropical landscapes

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Droughts associated with El Niño Southern Oscillation (ENSO) events can lead to leaf loss, tree mortality and a net biomass loss in tropical rainforests, but it remains unclear whether some forest types are more susceptible than others. Here, we use airborne LiDAR surveys made in 2014 and 2016 to produce high-resolution maps of canopy height change across 300 km2 of heterogeneous human-modified landscape in Malaysian Borneo within which degraded forests and oil palm plantations are mixed. The region was affected by El Niño droughts during this period, and we hypothesised that edge forests would be particularly affected, whilst mature forests in damp valley bottoms would remain unscathed. Forests lost 2 m height, with the greatest losses occurring along edges. Topography had a major influence on drought response but this topographic effect was only seen in areas distant from forest edges - exposed hilltop forest lost 3 m height while damp valley-bottom forests lost 1 m. Accompanying field surveys demonstrate that height loss was caused by abscission of leaves, not the death of trees. The study provides evidence that forests near edges and on hilltops responded more

strongly to El Niño drought events, consistent with these sites have greater evaporative demand and poorer water supply, respectively. Repeat-survey LiDAR surveys are a valuable tool for uncovering environmental controls on forest canopy dynamics over unprecedented scales.

Forward modelling of Solar Induced Fluorescence for UKESM

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Solar induced fluorescence (SIF) is becoming widely used as a proxy for gross primary productivity (GPP), in particular with the advent of its measurement by Earth Observation satellites such as OCO and GOSAT. A major attraction of SIF is that it is independent of the assumptions embedded in light use efficiency based GPP products derived from satellite missions such as MODIS. The assumptions in such products are likely not compatible with any given land surface model and hence comparing the two is problematic. On the other hand to compare land surface model predictions of GPP to satellite based SIF data requires either (a) translation of SIF into estimates of GPP, or (b) direct predictions of SIF from the land surface model itself. The former typically relies on empirical relationships, whereas the latter can make direct use of our physiological understanding of the link between photosynthesis and fluorescence at the leaf scale and is therefore preferable.

Here I use a two stream model for fluorescence that is capable of translating between leaf scale models of SIF and the canopy leaving radiance taking into account all levels of photon scattering and use it to forward model SIF observations from JULES (the Joint UK Land Environment Simulator) which is the land surface model of the new UK Earth System Model (UKESM). The model is run at a number of sites where SIF measurements are available from both field and satellite observations. Results show that it is possible to reproduce the observed SIF signal, but that understanding the magnitude of non-photochemical quenching is key to making correct predictions.

Quantifying regional tropical carbon fluxes using GOSAT and OCO-2

Paul Palmer[1], Liang Feng[1], David Baker[2], Frederic Chevallier[3], Hartmut Boesch[4], Peter Somkuti[4]
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Tropical ecosystems store large amounts of carbon, but are particularly vulnerable to changes in climate. The sparseness of ground-based measurements has precluded verification of whether these ecosystems are a net annual source or sink of atmospheric carbon. Using new column observations of atmospheric carbon dioxide (CO2) from the Japanese GOSAT and NASA OCO-2 satellite instruments and different a priori inventories, we show that independent atmospheric transport models converge to consistent tropical a posteriori CO2 flux estimates from 2015 to 2016. This is a step forward in our understanding tropical carbon cycle. We report continental-scale budgets and distributions of CO2 fluxes inferred from different models and data, and interpret them using independent satellite observations of hydrology, biomass burning, leaf phenology, and solar induced fluorescence.

Session 1B: ESA Business Applications – Enabling Commercial Services with Earth Observation

Session Chair: Ian Downey (UK Ambassador Platform, ESA Business Applications)
Date: Wednesday 5th September 2018
Time: 10:00-11:00
Location: C-Block Lecture Theatre

This session presents examples of (EO-related) activity and opportunities from ESA's Business Applications funding. The examples cover land, sea and air applications and the utilisation of active and passive EO systems. Space-based systems and services already play an important role in many commercial sectors, but there is still significant potential for developing viable, commercially sustainable operational services (possibly involving new EO capabilities) that benefit society. The vision for ESA Business Applications is to help improve people's lives by enabling and supporting businesses to commercialise and apply space data and technology for everyday services. It focuses on the development and pilot operations of new and innovative service solutions that make use of at least one space technology or space-enabled capability including Earth Observation. ESA Business Applications aims to attract existing space companies, new entrants and non-space sector players to propose new commercially promising space-based applications or services via either direct negotiation (co-funded) or competitive opportunities.

The Ground Instability Risk Profiler (GIRP) Project

Luke Bateson

British Geological Survey

Property Assure Ltd. are relative newcomers to the space sector. The GIRP Project assessed the technical feasibility and commercial viability of a solution to provide the insurance sector with the ability to better assess ground instability risks. Subsidence due to clay shrinkage is the largest ground instability issue affecting residential property in the UK. InSAR data can track wider area changes in ground movement, integrated with GNSS and core data profiling for quality and reliability. Property Assure Ltd (part of the CET Group) are now delivering this capability to the market as party of its HiGround™ service.

Tim Vallings

Rezatec

Rezatec provides Big Data geoanalytics using proprietary algorithms and advanced machine learning techniques to deliver strategic, commercial insight for customers. Their Data-as-a-Service landscape intelligence is delivered via an online decision support portal. Rezatec has engaged with ESA's Business Incubation Centre (BIC) at Harwell and with Business Applications to develop a range of projects and services over a number of years, covering forestry, food and agriculture, water, cities and commodities. The company has achieved high rates of growth and recently relocated to a newly built global headquarters on the Harwell Science and Innovation Campus in Oxfordshire, the UK's commercial space hub.

Prof. Roland Leigh

EarthSense

Earthsense is a newly formed company, which aims to be a global leader in accurate air quality monitoring, modelling and data for decision-making. Key members of the EarthSense team have significant expertise in utilising EO data for air quality applications. Previously at University of Leicester, Prof. Leigh supported the ESA funded UTRAQ project led by TRL Ltd. to deploy EO data in city-wide traffic congestion and air quality control systems. More recently, Earthsense has been developing the "CARAMEL" App with ESA Kickstart funding to help identify clean air routes in cities.

Richard Flemmings

TCarta

TCarta is a leading global provider of innovative geospatial products and Earth observation analysis services with a focus on providing customer focused solutions to solve challenging problems. With the support of ESA Business Applications, TCarta developed the International Satellite Derived Shallow Water Bathymetry Service, a web-based service to provide immediate, off-the-shelf, online access to bathymetry derived from very high resolution satellite imagery. They are now providing bathymetric and seafloor mapping data for marine applications and geospatial solutions to meet the needs of multiple end user groups.

Session 1C: CEOI Meeting – Future EO Missions, Instruments and Technologies

Session Chair: Mick Johnson (CEOI)
Date: Wednesday 5th September 2018
Time: 10:00-11:00
Location: G33

This session is open to everyone, and will present fourteen new ideas in 60 minutes for an exciting future for EO, with subjects including new detectors, new instruments and new mission concepts. The short 'elevator' pitches will also be an introduction to some of the posters in EO technology that will be on display in the poster session later in the conference.

Plenary 1: The Future of Downstream EO

Session Chair: Terri Freemantle (Satellite Applications Catapult)
Date: Wednesday 5th September 2018
Time: 11:30-12:30
Location: Bramall Hall

AI-Assist mapping toolbox for augmenting human capabilities

Mark Wronkiewicz
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Earth observation (EO) data is increasingly available, and machine learning (ML) has shown promise in keeping EO analysts above water in this deluge of data. However, there are a number of open questions on how to best incorporate ML into these processing streams. One critical question asks: In what way (if at all) should humans remain involved in future EO analysis? At Development Seed, we believe that a promising answer is an "AI-Assist" toolbox. This toolbox is aimed at empowering human mappers by multiplying their efforts rather than completely replacing them. We're particularly interested in using ML to improve the process of mapping infrastructure (e.g., outlining buildings or tracing roads). Our presentation will focus on how we've used ML (specifically, deep learning) to automatically detect infrastructure in satellite imagery, compare it with the infrastructure in existing maps, and use the difference to prioritize and augment human efforts. We will also discuss some lessons learned from putting these AI-Assist tools in the hands of actual mappers. ML certainly has shown the power to improve EO analysis, but we should continue searching for the optimal blend of humans and machines rather than relying solely on one.

Practical Considerations for Implementation of an EO Data Cube

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Data Cubes are increasingly recognised as a significant advance in enabling increased access and usability of EO data to real-world end users; Data Cubes are an effective solution to the problem of capturing the ever-increasing volume and variety of satellite data sources and packaging these into an accessible form.

Data Cubes offer the ability to conveniently access, manipulate and visualise long time series of geospatial data in order to monitor or detect changes or gain deeper insights. They are particularly well suited for managing 'Analysis-Ready' Data (ARD), which are data that have been processed and organized in a standardised structure so that users are not required to invest the time, resources and specialized skills needed to pre-process it (e.g. corrections for instrument calibration, geolocation, radiometry).

A small number of Data Cube solutions have been developed, including the Open Data Cube (ODC) was initially pioneered by Geoscience Australia (GA) and is now managed as an Open Source project with strong support in particular from Committee on Earth Observation Systems (CEOS) who actively promote deployments worldwide. CEOS estimates that over 25 open data cubes will be operational or in various stages of development by 2020.

The successful implementation of an operational Data Cube presents a number of challenges, decisions and compromises, particularly when data from multiple sensors are combined into the same resource and used to produce real-world end-user products.

RHEA and its partners are implementing an Open Data Cube intended for use as a National Resource of EO data in Uganda. This presentation will introduce Data Cube concepts and give insights into the practical experiences and challenges faced, together with some views on evolution of data cube solutions within the wider EO community.

Getting to the answers – The Earth-i Insight Development Approach

Owen Hawkins
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Satellite video and image technologies are coming of age, with collection capabilities becoming better suited to their expected applications. These improved data sources, together with the burgeoning growth of artificial intelligence tools to analyse the data and extract insights offers great potential. The challenge to bring these together into well-focussed and scalable product offerings is something that is dominating discussions currently. Earth-i will present some of the principles of how it develops products and will forecast some potential future applications.

Radiant.Earth: Innovating for the Global Development Community

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The Radiant.Earth is a non-profit organization committed to ensuring the global development community (GDC) has greater access to Earth imagery, analytical tools and knowledge for transformative global impact. Founded in 2016 in response to continuous calls by the GDC to improve discovery remote-sensing data, our primary foci are open data resources including satellite, aerial, and drone imagery, and machine-learning tools for data analysis. R.E provides an open technology platform that connects the GDC to vast Earth imagery resources, geospatial data sets, tools and knowledge, to accelerate improved decision-making and fuel new discoveries and innovations. In this presentation Ms. Miglarese will review Radiant's technology development activities around Open Labelled Satellite imagery and science as well as the deployment of blockchain technology on the Platform

Session 2A: Observing Water from Space

Session Chair: Christopher Kidd (NASA/Goddard Space Flight Center and UMD/Earth System Science Interdisciplinary Center) & Alessandro Battaglia (University of Leicester)
Date: Wednesday 5th September 2018
Time: 15:00-17:00
Location: C-Block Lecture Theatre

Observing global precipitation: status and future directions

Christopher Kidd[1], Alessandro Battaglia[2], Gail Skofronick-Jackson[3], George Huffman[3]
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The estimation of precipitation (rain and snow) from Earth Observation satellites is now well established. A constellation of geostationary and low Earth orbiting satellites carry a range of visible/infrared, passive microwave and active microwave sensors that provide routine observations of the Earth and its' atmosphere. Techniques have been devised to retrieve precipitation from these observations to provide quantitative maps of global precipitation.

Despite the advances made in satellites, sensors and techniques, much work remains to be done. On the physical modelling side, a greater understanding of the interaction between the radiation stream and the hydrometeors is needed to improve the modelling of the observed radiances, this is particularly true for frozen hydrometeors. Although many techniques now use multi-sensor, multi-source observations, investigations into the optimal combination of information are ongoing. There is also ongoing work to improve the calibration and validation of these satellite products to better assess the accuracy and quality of the estimates.

The future direction of satellite precipitation estimation will be outlined. At present many of the current operational spacecraft and sensors are in extended lifetime mode. However, a number of new missions are planned in the near future that will help to refresh and replace aging sensors, including the EUMETSAT EPS-SG series with the MicroWave Imager (MWI), MicroWave Sounder (MWS) and Ice Cloud Imager (ICI), and the ongoing NOAA Advanced Technology Microwave Sounder (ATMS). In addition the plans for the Japanese third Advanced Microwave Scanning Radiometer (AMSR-3) and the US Defense Weather Satellite System (DWSS) are advancing. In addition, the US NSF Decadal Survey provided a positive outlook for future precipitation missions.

Inverse modelling of the global energy and water cycles

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We present an optimised determination of the Earth's energy and water budgets following the NASA Energy and Water Study (NEWS: L'Ecuyer et al., 2015 and Rodell et al., 2015). Earth observation (EO) derived flux datasets for TOA and surface radiation, turbulent fluxes and precipitation are adjusted, within uncertainties and atmospheric and surface constraints, to close the energy and water budgets for a mean seasonal cycle.

However the NEWS optimised solutions have obvious weaknesses, especially over ocean basins. The North Atlantic and Arctic stand out in particular as having too little heat loss when we know the AMOC

transports large amounts of heat into the basin. We currently have three different approaches to improving the NEWS solutions: using Atmospheric reanalysis transports (as in Liu et al. 2015); using ocean reanalysis transports (e.g. Valdivieso et al 2014); introducing spatially correlated structural errors for the EO derived fluxes (see separate talk by Dong et al.).

More generally we have ambitions to extend this inverse modelling approach. A modified spatial structure would allow better use of observational datasets, e.g. WOCE or RAPID array transports, and allow climate diagnostics to be assessed, e.g cross equatorial heat and water fluxes. Interannual timescale variability may also be assessed to look for trends and climate mode signatures in energy and water fluxes e.g. during ENSO. In the longer term we also have ambitions to couple a carbon flux and budget analysis to the inverse model.

Detecting the influence of the land surface properties on intense rainfall in West Africa

Cornelia Klein[1], Christopher M. Taylor[1,2]

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Intense rainfall poses a severe hazard for West African populations, causing flash flooding, and damaging infrastructure and crops. We have a solid observationally-based understanding of how land surface properties affect the initiation of convective storms - spatial patterns in sensible heat fluxes on scales of 10s kilometres create convergence zones in which afternoon deep convection is favoured. However, the majority of rain in the region falls within mature Mesoscale Convective Systems (MCS), often initiated several hundred kilometres upstream. The physical processes by which land surface fluxes influence rainfall within a propagating storm, with its own well-organised circulation, are expected to be quite different from the case of afternoon initiation. In this study, we use data from geostationary Meteosat satellites to identify robust relationships between land surface characteristics and convective cores responsible intense rainfall.

We use a wavelet scale decomposition to identify deep convective cores within MCSs, defined as sub-cloud features smaller than 35km with a cloud top temperature below -65˚C. We then analyse the frequency of these convective cores with respect to measures of both pre-storm soil moisture, and vegetation cover. The soil moisture analysis focuses on the Sahel zone, where transient land surface temperature features provide a qualitative mapping of soil moisture from storms in recent days. We also examine the impact of mesoscale forest patches in the deforestation hotspot of Ivory Coast. From analysis of multi-year datasets, we find surprisingly strong effects on rainfall intensity in both examples, suggesting that significant anthropogenic changes, such as deforestation and agricultural transformation, could not only alter the location of MCS initiation but also subsequent rainfall amounts throughout MCS life cycles.

British and Irish Validation of Version-5 Surface Rain Rate Products from the Global Precipitation Measurement Mission

Daniel Christopher Watters[1], Alessandro Battaglia[1,2], Kamil Mroz[2], Frederic Tridon[1]

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Estimates of instantaneous surface rain rates from the Global Precipitation Measurement Mission Core Observatory (GPM-CO) are compared to those produced by the UK Met Office's (UKMO) ground-based radar network. In particular, validation of two 5 km resolution GPM-CO rain rate products is conducted: the GPM-CO dual-frequency precipitation radar product (DPR), and the GPM-CO

combined DPR and microwave imager product (CMB). The agreement of these two space-borne products with the ground-based 1 km resolution UKMO Radarnet 4 product is assessed in the period May 2014 – April 2017. Temporal and spatial collocation of the products is conducted before comparing them at both 5 km and 25 km resolution. Comparison statistics are considered with regards to orography, season, rainfall intensity, uniformity of beam filling, and accuracy of clutter classification. At 5 km resolution, the DPR and CMB products under-predict Radarnet surface rain rates from within 75 km range of a ground-based radar by 19% and 6% with standard deviations of 108% and 110%, respectively. Such large deviations are a consequence of random collocation errors and instrument limitations. Both GPM-CO products are found to be in worse agreement with the Radarnet product in winter months due to issues measuring reduced vertical extents of precipitation, and in orographic regions due to difficulties capturing rainfall there. Ground-based radars are found to have difficulties with estimating surface rainfall intensities at ranges beyond 150 km, whilst some radars may possibly have calibration issues. Agreement between the GPM-CO products and the Radarnet product becomes more variable as beam filling uniformity reduces, and issues with incorrect clutter classification by the space-borne products appears to explain some of the discrepancies between the products.

Cloud and precipitation retrievals from A-Train to EarthCARE

Shannon Leigh Mason[1], Robin J Hogan[2,1], Alessio Bozzo[2], Christine J Chiu[3]

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EarthCARE will build on the success of the A-Train of satellites, maximising the synergy of active and passive sensors, introducing novel radar and lidar measurements of clouds and precipitation, and linking atmospheric processes with top-of-atmosphere radiation. The first Doppler cloud radar in space will measure the vertical motion of hydrometeors, revealing new information about the microphysics of rain and snow.

The “CAPTIVATE” optimal estimation algorithm for radar--lidar--radiometer synergy retrievals will provide official cloud and precipitation data products for EarthCARE, and is also configurable for applications to other instruments. In this study we demonstrate CAPTIVATE retrievals of clouds, aerosols and precipitation from the synergy of A-train satellites, and present an evaluation of a numerical weather model. Looking to EarthCARE, we demonstrate the contribution of Doppler radar measurements to estimates of precipitation using airborne and ground-based radar. Airborne measurements provides insights into the microphysics of tropical cloud and rain, and ground-based instruments are used to study snow and mixed-phase cloud at high latitudes. EarthCARE synergy retrievals exploiting Doppler radar will facilitate improved estimates of the properties of precipitating hydrometeors, and of microphysical processes through the atmospheric profile. Looking beyond EarthCARE, we discuss the potential for additional insights from dual-frequency Doppler radar satellite missions.

Observing Water Vapour in the Planetry Boundary Layer from the Short-Wave Infrared

Tim Trent[1,2], Hartmut Böesch[1,2], Peter Somkuti[1,2], Noelle Scott[3], John Remedios[1,2]

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Long-term satellite records of tropospheric water vapour are dominated by observations from thermal infrared (TIR) and microwave (MW) sounders. It is these data sets which are often used in climate analysis as well as being assimilated (at the radiance level) by numerical weather prediction (NWP) centres. However, from their nadir geometries these observations provide either estimates of the total column, and more recently coarse profiles of the troposphere. Measurements over land have a reduced sensitivity to lower-tropospheric water vapour, making it difficult to independently resolve the contribution from the near-surface. This is important as water vapour is transported from the surface to the upper-atmosphere via vertical mixing. Gaps in the global observation system mean our knowledge of these fluxes is incomplete, with around of 50% of the variance seen in climate models being associated with convective mixing between the lower and mid-troposphere.

In this study, we present the first estimates of bulk water vapour from the Planetary Boundary Layer (PBL) using GOSAT. Additionally, we validate these new measurements at global radiosonde sites demonstrating low biases as a function of both latitude and season. Finally, with the imminent launch of GOSAT-2, we discuss the potential for a GOSAT PBL water vapour ECV.

WIVERN: A New Satellite Concept to Provide Global In-Cloud Winds, Precipitation and Cloud Properties

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We describe a conically scanning spaceborne Dopplerized 94-GHz radar Earth science mission concept: Wind Velocity Radar Nephoscope (WIVERN) that has been proposed to ESA in response to the recent call for Earth Explorer missions. WIVERN aims to provide global measurements of in-cloud winds using the Doppler-shifted radar returns from hydrometeors. The conically scanning radar could provide wind data with daily revisits poleward of 50°, 50-km horizontal resolution, and approximately 1-km vertical resolution. The measured winds, when assimilated into weather forecasts and provided they are representative of the larger-scale mean flow, should lead to further improvements in the accuracy and effectiveness of forecasts of severe weather and better focusing of activities to limit damage and loss of life. It should also be possible to characterize the more variable winds associated with local convection.

Polarization diversity would be used to enable high wind speeds to be unambiguously observed; analysis indicates that artifacts associated with polarization diversity are rare and can be identified. Winds should be measurable down to 1 km above the ocean surface and 2 km over land. The potential impact of the WIVERN winds on reducing forecast errors is estimated by comparison with the known positive impact of cloud motion and aircraft winds. The main thrust of WIVERN is observing in-cloud winds, but WIVERN should also provide global estimates of ice water content, cloud cover, and vertical distribution, continuing the data series started by CloudSat with the conical scan giving increased coverage. As with CloudSat, estimates of rainfall and snowfall rates should be possible. These nonwind products may also have a positive impact when assimilated into weather forecasts.

Scientific discoveries and technical advances with GNSS-Reflectometry on TechDemoSat-1

Giuseppe Foti[1], Christine Gommenginger[1], Matthew Hammond[1], Meric Srokosz[1], Martin Unwin[2], Phil Jales[2]

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GNSS-Reflectometry (GNSS-R) is an innovative and rapidly developing Earth Observation technique that exploits reflected signals from Global Navigation Satellite Systems (GNSS) to observe Earth surface properties such as near-surface ocean winds. Based on bistatic forward scattering of signals of opportunity from GNSS satellites, dedicated GNSS-R receivers correlate the direct and reflected GNSS signals to produce the so-called Delay-Doppler Map (DDM) of scattered electromagnetic power, from which information about the Earth surface can be derived.

GNSS-R receiver technology has now reached a relatively mature stage, with compact, light-weight, off-the-shelf receivers now readily available and demonstrate in orbit. Modestly-sized hardware, low-power demand and cost-effectiveness make GNSS-R an attractive remote-sensing technique to potentially deliver global coverage at high temporal resolution, for example with a constellation of GNSS-R instruments or flying as payloads of opportunity on larger platforms.

GNSS signals are modulated on an L-band carrier frequency (~1.5 GHz); at this frequency, signal propagation is not significantly affected by atmospheric water vapour or precipitation. This more robust all-weather capability compared to higher microwave frequencies, together with high sampling density, makes GNSS-R particularly attractive for applications relating to monitoring weather, including in high-precipitation conditions such as those frequently found near the eye-wall and inner rain bands of tropical cyclones.

TechDemoSat-1 (TDS-1) is a UK-led mission launched in 2014 and originally conceived as a technical demonstrator. Following the ground-breaking scientific findings obtained from data collected by its GNSS-R payload, the mission has now been extended and reconfigured to run a pilot project aiming at providing the first-ever global 24/7 GNSS-R-based weather data service. This paper presents some of the most prominent scientific discoveries and technical advances achieved by the TDS-1 mission, including the more recent findings obtained in the new 24/7 phase of the mission.

Session 2B: Forest Carbon and Forest Change

Session Chair: Shaun Quegan (University of Sheffield)
Date: Wednesday 5th September 2018
Time: 15:00-17:00
Location: G33

Vertical leaf-only foliage profiles from full-waveform dual-wavelength terrestrial laser scanning: from tree to plot scale

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Measuring the three dimensional distribution of foliage in forest environments remains a significant challenge in forest ecology. Vertical leaf foliage profiles, leaf area index and leaf angle distributions affect the interception of light, and the exchange of gases between the canopy and the atmosphere, and these in turn drive the net primary productivity of forests. Only non-destructive measurements can be used for monitoring forest dynamics at a site, but current methods, including manual measurement or the use of hemispherical photography, are both time-consuming and error-prone. A new generation of terrestrial laser scanners (TLS), including the full-waveform dual-wavelength Salford Advanced Laser Canopy Analyser (SALCA), is now being used to automatically generate three-dimensional leaf distributions in forests. This paper reports the first results of an international collaborative experiment to measure forest structure using a range of TLS including SALCA at Harvard Forest, MA. The work involved the acquisition of TLS data in three forest stands using six different TLS operated by groups from the US, UK, Canada, Belgium, and Australia. Comprehensive mensuration and destructive sampling of trees in the three plots provided data on the foliage distributions of 16 individual trees, and estimate of LAI for each plot. SALCA data were acquired a multiple sample points within each plot and three-dimensional stand models created. Two methods were used to classify the point clouds into leaf and wood points, a 'spectral' approach using a normalised difference index (NDI) based on the dual wavelength data, and a 'spatial approach' using three-dimensional point pattern analysis. The paper compares the vertical leaf foliage profiles derived from each method and compares the tree leaf area estimates against the destructively sampled estimates. There was generally poor agreement between the spectral and spatial approach.

Characterising the vertical distribution of tree and forest plot woody volume

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A large proportion of terrestrial Above Ground Biomass (AGB) is stored in the woody components of forests globally. Yet, there is still large uncertainty regarding the quantity and location of this pool, even at the plot and tree scale. Terrestrial Laser Scanning (TLS) coupled with Quantitative Structural Modelling (QSM) is a new method that can quantify the volume of individual tree stems and branches by iteratively fitting cylinders to the TLS point cloud to reconstruct the tree. TLS-QSM has previously been used to estimate plot level AGB for woodland, urban and forest sites; here we use this technique to characterise the vertical distribution of wood volume at the individual tree and plot scale.

Preliminary results indicate that for large trees, wood volume is concentrated towards the top of the canopy. Furthermore, up to 30% of a trees wood volume can be contained in branches with a diameter of <10 cm. A similar pattern is seen at the plot scale where wood volume is concentrated towards the top of the canopy, a pattern repeated across a range of forest types. These results have a number of implications, for example, interpretation and calibration of satellite mission such as BIOMASS, GEDI and NiSAR, the derivation of allometric equations for estimating AGB and the theoretical modelling of tree function and structure.

Assessing Forest Aboveground Biomass in Kenyan forests and woodlands

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The most detailed spatial assessment of forest aboveground biomass (AGB) to date for Kenya was generated using in situ forest inventory data, in combination with multispectral Landsat 8 and synthetic aperture radar (SAR) ALOS-2 PALSAR-2 satellite imagery. The in situ measurements were collected during the period 2013-2015 in the main woody biomes of the country. Pantropical tree level allometries (Chave et al, 2014) were used to estimate the AGB pools considered in this study (i.e. trees, bamboos and lianas). A non-parametric random forests algorithm was calibrated within a k-fold framework to retrieve AGB at 30m spatial resolution for the whole of Kenya. The accuracy assessment found coefficients of determination (R2) ranging from 0.64 to 0.90, root mean square errors (RMSE) from 35.9 t/ha to 65.2 t/ha, and biases from 2.4 t/ha to 6.1 t/ha. The results showed that the highest AGB densities are found in the dense tropical forests with values up to 530 t/ha (average 92 t/ha). However, the large area of wooded grassland in Kenya potentially stores around 58% of the total AGB in the country.

The role of Kenya's forests in the terrestrial carbon cycle

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Kenya has a constitutional target to achieve 10% forest cover by 2030. It has a field-based forest inventory and is using visual interpretation of Landsat images to update its national forest extent maps. We set out to quantify the carbon stocks and fluxes in Kenya's forests using new methods for Earth Observation data and terrestrial carbon modelling.

Within the NCEO ODA programme, we have mapped the aboveground biomass of Kenya's forests from a combination of SAR, optical and DEM data with a random forest regression.

Experimental work with the Landsat data archive is investigating ways of identifying forest degradation and deforestation in Kenya using automated algorithms.

A CARDAMOM modelling experiment aimed to estimate the non-biomass carbon pools and fluxes using the biomass map, and to identify areas of Kenya that have the highest carbon sequestration potential under a scenario of afforestation / reforestation.

Preliminary results from the ODA Foundation Award will be presented and future research challenges described.

Monitoring the conversion of peat swamp forest to oil palm agriculture in Peninsular Malaysia

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The environmental consequences of tropical deforestation for agricultural production are well known. The most rapidly expanding and controversial equatorial crop is oil palm. Malaysia is one of the world's largest palm oil producers and has seen widespread conversion to oil palm from primary forest, including peat swamp forest. Peatland conversion is especially damaging, leading to significant loss of ecosystem services, especially carbon storage. This study aims to quantify loss of forest and peatland, and encroachment by oil palm and other agriculture, in and around North Selangor Peat Swamp Forest (NSPSF) reserve in Peninsular Malaysia over the last 30 years. Land cover classification was conducted on three multispectral Landsat images acquired in 1989, 2001 and 2016. Reference data for training and validation were collated from fieldwork, secondary images, historical data and stakeholder interviews. Overall classification accuracy ranged between 82 and 87%. Post-classification comparison was conducted to determine land cover change over time, and the results show a near tripling in oil palm coverage from 272 ha in 1989 to 714 ha in 2016, while at the same time forest cover shrank from 1457 ha to 886 ha. While the regional picture is worrying, with very widespread conversion from forest to oil palm, NSPFS represents a relative conservation success story at the local scale. Environmental legislation to prohibit peat swamp forest conversion in the protected area has been observed in the main, with only sporadic attempts at illegal oil palm encroachment around the reserve boundary. Moreover, vegetation index maps of the multitemporal Landsat images show improvements in peat swamp forest health since the reserve came into being three decades ago, aided especially by a logging moratorium around 15 years ago. In the face of rapidly increasing oil palm agriculture in southeast Asia, conservation initiatives like NSPSF are crucial for sustainable environmental development.

Estimating past and future impact of land use change on pantropical carbon stocks

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Terrestrial ecosystems mitigate climate change by absorbing ~25% of human emissions of carbon dioxide. However, this land-based sink is partly offset by emissions from Land Use and Land Cover Change (LULCC), primarily tropical deforestation. Effective climate change mitigation therefore benefits from protecting above ground biomass (AGB) stocks in natural landscapes and regrowth where feasible. Multiple international initiatives have been introduced to mitigate climate change by reforesting previously cleared areas and restoring degraded forests (e.g. UN-REDD, Bonn Challenge). However, future AGB stocks under projected climate and land use change remain uncertain which challenges the design of effective reforestation strategies.

Here, we present a machine-learning approach to integrate satellite observations of AGB with climate and land use data. We derive data-driven relationships between AGB stocks and environmental variables for the present and predict the evolution of AGB stocks according to past and future changes in climate and land use. We focus on tropical biomes because they hold substantial AGB stocks in intact forests which are threatened by LULCC, but also because of the availability of high confidence remotely-sensed estimates of AGB.

Across the tropics our results indicate that past land use has led to a net loss of 75.6 Pg C (with a confidence range of 67.9 / 80.7) compared to pre-industrial stocks. It represents a significant opportunity for carbon sequestration and climate mitigation through management strategies promoting forest restoration. However, future land use scenarios used by models participating in the sixth phase of the Coupled Model Intercomparison Project (CMIP6) all yield losses of pantropical AGB stocks throughout the 21st century. The contrast between these projections and the carbon sequestration potential of these biomes represents a missed opportunity to support the goals of the Paris Agreement to achieve zero net emissions and maintain warming to under 2°C.

Progress in delivering the BIOMASS mission

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Selection of the Biomass mission by ESA in 2015 marked just the beginning of the process of building the satellite and ensuring its measurements delivered the products needed to meet mission objectives. This paper will describe the significant progress made in addressing two major challenges: instrument external calibration (including ionospheric correction) and definition of the final algorithms to be implemented to deliver biomass and height products over the whole region covered by the satellite (globally except for the area within line of sight of the US Department of Defense Space Object Tracking Radars: this excludes Europe, North America and the Arctic).

External calibration is essential as it will not be possible to fully characterise the instrument on the ground or by internal means. BIOMASS presents special problems because: (1) unlike at lower frequencies the rainforest cannot be used as a stable reference target; (2) the special orbits needed to support global coverage by polarimetric interferometry (Pol-InSAR) and tomography mean that calibration devices are only visited several months apart so cannot be used for routine system monitoring; (3) ionospheric effects affect all aspects of calibration. Methods to surmount these difficulties will be described.

Height retrieval algorithms are well-established and the remaining issues are largely about algorithm optimisation and combining data from ascending and descending passes. For biomass, the major steps forward come from two recent developments: (1) the ability to measure just the volume contribution of the backscatter using either Pol-InSAR or tomography: (2) development of a method to solve for the parameters of the associated physical scattering using a minimum of ground data. Also significant are Terrestrial Laser Scanner measurements showing the importance of the layer between 20-40 m for estimating tropical forest biomass. How these developments fit together will be described.

Session 2C: Technology for Earth Observation

Session Chair: Christopher Brownsword (QinetiQ Ltd), Owen Arthur Hawkins (Earth-i), Paul Jerram (Teledyne-e2v) & Andrew Paliwoda (Alba Orbital)
Date: Wednesday 5th September 2018
Time: 15:00-17:00
Location: Bramall Hall

The Compact Infrared Imager and Radiometer (CIIR)

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Rory Evans, University of Oxford on behalf of the CIIR consortium.

Measurements of the effect of aerosols, clouds and the behaviour of stratospheric trace gases on the Earth's radiation budget are key to understanding our current climate and its subsequent evolution.

The Compact Infrared Imager and Radiometer (CIIR) is an Earth observation instrument concept that is tightly integrated into a 6U CubeSat spacecraft. CubeSats are modular systems of standard 10 x 10 x 10 cm cubes and launch adapter. This allows them to be included as additional payloads if the primary customer for a launch vehicle leaves spare capacity, providing access to space at significantly lower cost than traditional Earth Observation satellites. The CIIR described in this presentation is a miniature multi-channel imaging filter radiometer. CIIR combines an integrated black body calibration target for radiometric accuracy and a thermal infrared microbolometer array for medium resolution imaging. We present the CIIR spacecraft/instrument concept and the results of an ongoing study, supported by the Centre for Earth Observation Instrumentation, that is investigating the instrument's calibration and pointing performance.

Trade-Off Study for High Spectral, High Resolution Thermal Infrared Mission for Surface Applications

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Infrared satellite sensors such as SLSTR on Sentinel-3 and VIIRS on JPSS Suomi typically offer spatial resolutions of order 1 km. ESA studies are currently in progress for potential thermal imagers with 100m spatial resolution for land surface temperature measurements. While this is sufficient for many applications of global surface temperatures, there is a strong user application and science requirements for higher spatial resolution (<100m) higher spectral (hyper-spectral or multi-spectral <50nm) resolution IR (HHRTII) imagers.

A pathfinder project funded under CEOI-10 has recently been completed to explore the range of potential applications and the corresponding instrument requirements, and to determine the physical limits of instruments in the wavelength range 3-14μm. We present the findings of this study and the potential implications on the design for a thermal imaging system for surface applications.

NIMCAM: a new instrument concept for observing atmospheric methane from a CubeSat platform

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Methane is a significant greenhouse gas, however recent variations and trends in atmospheric methane concentrations are poorly understood. Available satellite data on methane concentrations provide global coverage, but suffer from low resolution (several kilometres per pixel), often poor sensitivity to methane in the planetary boundary layer (PBL), and low temporal resolution. The Near Infrared Multispectral Camera for Atmospheric Methane (NIMCAM) is a proposed methane-specific instrument that aims to address these issues and improve the quality and quantity of methane concentration data.

Design drivers for NIMCAM are: suitability for CubeSat deployment - compact, robust, low-power; good sensitivity to methane in the PBL; high spatial resolution; low cost. A low-cost instrument suitable for a CubeSat platform would enable a constellation deployment, substantially reducing re-visit intervals from days to hours.

The instrument concept is based on an ultra-narrow-band multispectral imager operating in the near-infrared, with technology developments anticipated in areas including ultra-narrow-bandpass near-infrared filters with non-standard optical geometries, high-resolution near-infrared imaging arrays, and image acquisition and processing algorithms. Three 1nm bandpass filters located around 1640 nm provide three spectral channels, allowing retrieval of surface albedo, water vapour concentration, and methane concentration. A high resolution detector is used to provide a ground pixel size of the order of 100 metres across a 100 km swath width. Synchronising the imaging rate with the satellite ground track such that the surface image grid moves one pixel per frame interval enables several hundred co-additions to be made per pixel, significantly improving SNR.

This presentation will discuss outcomes from completed computer modelling of the instrument, and ongoing work to develop a laboratory demonstrator to prove out the engineering concept.

Real-time detection of clouds on high-resolution satellite videos using deep learning

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Over the last decades, major progress in the digital technology and engineering has allowed the extensive acquisition and dissemination of high-resolution satellite imagery. High-resolution image datasets have significantly increased the value of satellite products and have augmented the functionalities of satellite data applications. One of the most promising future directions would be to replace image acquisition with capturing video (or even 3D video) streams. However, the data volume of high-resolution video streams raises issues with the efficient downlinking of the data back to Earth, which needs to be resolved before such a technology becomes broadly available.

A promising solution to this issue would be to develop machine learning and computer vision algorithms for onboard processing, which would reduce the overall data volume. We are currently developing such pipelines within CEOI OVERPaSS project, starting with the automatic detection of clouds within satellite videos. The goal of this algorithm is the real-time estimation of a cloud mask per video frame, which would be subsequently used to ignore pixels corresponding to surface that is obscured by clouds. A second output would be a quantitative estimation of the number of clouded pixels.

The pipeline that will be presented builds upon the research conducted to automatically detect clouds on satellite imagery [1], updated to include the recent progress in deep learning and additionally taking into account the temporal redundancy present on video frames and real-time detection requirements. The presentation will further include a brief discussion about the future directions of this research, mostly related to the automatic detection of thick clouds/thin clouds/haze subclasses within the cloud class, as well as the formatting and optimisation of the algorithm outputs.

References

[1] X. Hu et al., Automatic Recognition of Cloud Images by Using Visual Saliency Features, IEEE GRSS Letters, Vol. 12 (8), pp. 1760-1764, 2015

MAGiGAN: multi-view and deep learning based super-resolution restoration for targeted and global applications

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Very high spatial resolution imaging data is playing an increasing role in many commercial and scientific applications of Earth observation. Previously within the EU FP-7 PRoViDE project (http://provide-space.eu), we developed a novel super-resolution algorithm called GPT-SRR (Tao & Muller, PSS, 2016) to restore distorted features from multi-angle observations using advanced feature and an area matcher, Gotcha (Shin & Muller, PR, 2012) and regularization approaches, achieving a breakthrough factor of up to 5x enhancement in resolution (Tao & Muller, ISPRS, 2016; Bridges et al., RSOS, 2017).

More recently within the CEOI SuperRes-EO project, we have further developed the SRR system using advanced machine learning algorithms, applied to EO data including stacks of 275m MISR multi-angle images, 4m (MS band) repeat-pass Deimos-2 images, and the "point-and-stare" 1m Carbonite-2 multi-angle video sequences. The new machine learning features are based on the Mutual shape adapted (Tao & Muller, Icarus, 2016) Features from Accelerated Segment Test (O-FAST; Rosten et al., IEEE, 2010) and Convolutional Neural Network (CNN; Fischer et al., CVPR, 2014) feature matching and the Generative Adversarial Network (GAN; Ledig, CVPR, 2016) deep learning based super-resolution refinement. The new MSA-FAST-CNN-GPT-GAN (MAGiGAN; Tao & Muller, 2018 in preparation) system not only retrieves subpixel information from multi-angle distorted features from the original GPT algorithm, but also uses the loss calculated from feature maps of the GAN network to replace the pixel wise difference based content loss of the original GPT algorithm to retrieve higher frequency texture detail.

The MAGiGAN system is being tested and integrated on an in-house NVIDIA® Jetson TX-2 GPU board prior to implementation on a GPU computing cloud. In this paper, we will show MAGiGAN processing results from MISR and Deimos-2 data with a rich GAN network training dataset consisting of multi-instrument (resolution) images.

Acknowledgments

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Hyper Spectral Microwave Sounder (HyMS): Preliminary test results

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A new atmospheric remote sounding radiometer is being developed by a team led by RAL, and including STAR Dundee and JCR Systems. The radiometer employs a hyper-spectral microwave imaging technique in which hundreds of contiguous detection channels, spread across a wide instantaneous bandwidth, simultaneously sample molecular absorption features associated with O2 at 60 GHz. This measurement technique substantially increases the precision of atmospheric profile retrievals and our laboratory prototype instrument, HyMS, provides a first realisation of a future spaceborne Earth observation tool that will enhance weather forecasting.

Developing a hyper-spectral imager is hugely challenging as it demands a significant reduction in the detector system noise in order to meet the required radiometric precision. Our instrument concept combines a state-of-the-art low noise amplifier with a heterodyne down-convertor and ultra-high-speed digital backend data processor. This system architecture provides a powerful and highly integrated remote sounder that exhibits ultra-high radiometric sensitivity (<0.4K) and exquisite spectral resolution (3 MHz). Moreover, it is suitable for future test via an airborne observation platform and targets eventual deployment in space as a next generation operational meteorological observation tool. A description of the HyMS system configuration and associated preliminary test results will be presented.

SEASTAR: a new mission concept for high-resolution imaging of ocean surface current and wind vectors from space

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SEASTAR is a new satellite mission concept being proposed to the European Space Agency through the Earth Explorer 10 call for mission ideas. The scientific objectives of SEASTAR are to support oceanographic research of mesoscale and submesoscale processes, upper ocean dynamics and air-sea interactions with the delivery of high-precision high-resolution two-dimensional maps of total ocean surface current vectors and wind vectors at a spatial resolution of 1 km. SEASTAR consists of a single satellite carrying a single Ku-band dual-polarization instrument payload based on an ATI-based solution with two squinted look-directions. It will provide for the first time observations of the total ocean current vector field including ageostrophic components, with coincident measurements of wind vectors and waves. SEASTAR addresses challenging and immediate observational needs by providing essential data at key open ocean sites and over coastal and continental shelf seas and marginal ice zones to produce improved understanding, modeling and forecasting capability, and ultimately, deliver better environmental information where scientific and societal needs are greatest and most pressing. The paper considers the geophysical inversion strategy and achievable retrieval performance using numerical simulations.

SPIDER Proof of Concept Campaign

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The SPIDER (Ship Position and Detection Radar) is a novel low SWaP payload, based on COTS components, and is tailored to support persistent and reliable maritime monitoring and security applications from HAPS. SPIDER is specifically designed for ship position, detection, and tracking. It is complementary to and can provide cueing to other maritime sensors. The SPIDER design is compatible with deployment on Zephyr S with the potential to also be implemented as a low-cost spaceborne payload.

The SPIDER Proof of Concept Campaign (PoCC) proposal was submitted to CEOI under the 10th Earth Observation Technology Call and was approved for funding in April 2017. The objectives of the PoCC were the design, implementation, validation and verification of the SPIDER PoCC demonstrator. This includes demonstration of the SPIDER radar concept in a controlled environment on an aircraft and demonstration of the processing principle and radar operation for maritime surveillance.

The PoCC demonstrator is representative of the HAPS radar design and uses largely the same COTS components but without PCB integration. The instrument was deployed on a Piper Navajo. The airborne campaign was undertaken in November 2017 and consisted of an initial shake-down flight centred on Sywell, followed by a number of data acquisition runs over the Solent and English Channel on subsequent days, with data collected in both SPIDER ship detection and SAR modes.

The results of the SPIDER demonstrator PoCC are presented and discussed, and next steps outlined.

Poster Session 1

Date: Wednesday 5th September 2018
Time: 17:00-19:00
Location: Great Hall

Session Topics:

- Earth Observation to constrain the terrestrial carbon cycle
- Forest carbon and forest change
- Observing water from space
- Technology for Earth Observation
- The future of downstream EO

Scanning Compressive Sensing for EO

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We present a new method of compressive sensing using single pixel camera (SPC) techniques that is suitable for EO from LEO. The SPC has previously been developed for terrestrial applications but is ill-suited to rapidly passing scenes. Here, we modify the SPC for scanning operation, similar to that of a conventional pushbroom imaging instrument, but with the benefits of scene optimised, adaptive, and compressive sensing.

The new imaging concept is suitable for implementation of a compact multispectral instrument deployable on a nanosatellite/CubeSat. The instrument can perform adaptive sensing that greatly reduces both the amount of data sampled and processing bandwidth, making it suitable for large-scale constellations performing event-driven monitoring. The data reduction is achieved via an optical processor (digital micromirror device) that can perform physically adaptive active selection of pre-defined data as well as applying various data processing and image analysis algorithms at the acquisition stage. This reduces on-board processing and the need for computationally demanding compression after data sampling. We present examples of physical adaptive data acquisition algorithms for our device.

We discuss features that distinguish our method from conventional techniques, in particular from a multispectral pushbroom architecture. Our method is characterised by

greater operational flexibility, vastly reduced data handling requirements together with a shared aperture multispectral mode that enables a compact payload. Additionally, comparing our imager with a pushbroom imager with the same detector parameters and aperture size we observe significantly better performance in terms of the signal to noise ratio for SWIR bands. These features all contribute to overcoming the essential bottlenecks of nanosatellite-based imaging performance.

Climate variability and change and the role of Earth's energy budget

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Energy is accumulating in the climate system at around 0.6 Watts per square metre, due primarily to the inexorable increases in greenhouse gas concentrations caused by human activities. Where this energy accumulates in the ocean determines the decadal rate of surface temperature rise as well as how large-scale atmospheric circulations and precipitation patterns evolve over time. Updates of

recent satellite and ground-based observations of decadal changes in surface temperature, water vapour, precipitation and the Earth's energy budget will be presented. A new reconstruction of the energy balance at the top of Earth's atmosphere and the surface as part of the DEEP-C and SMURPHS projects are combined with reanalyses and climate models to understand regional changes in the energy budget and the importance of ocean mixed layer energy budget in determining global temperature changes. The energy balance perspective is exploited in understanding systematic climate model biases including Southern Ocean surface temperature and inter-hemispheric precipitation asymmetry.

Evaluating clouds, precipitation and climate over West Africa

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A multi-sensor analysis of clouds, precipitation and the energy budget is presented for southern West Africa, a region of large and growing population that relies on highly variable monsoon rainfall that is subject to uncertain future responses to climate change. Large differences exist between monthly mean cloud cover estimates from satellites, which range from 68 to 94%. Furthermore, systematic biases in climate model and reanalysis simulations of cloud and precipitation seasonality are apparent over the region. Exploiting CERES-CloudSat-CALIPSO-MODIS (CCCM) data, the effects of low clouds and their biases is quantified. The failure of simulations to represent a double rainy season over coastal regions is identified and linked to biases in Atlantic sea surface temperatures. Future projections of precipitation seasonality over the region will be discussed.

Lake mixing regimes under future climate change

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In response to surface air temperature increases in many regions, decreasing winter ice cover and rising lake surface water temperatures are expected. These changes will have corresponding implications for lake mixing regimes. We assess this using a combination of satellite-derived and in-situ water temperature observations to tune and validate a lake model. The lake model is forced by four 21st century climate model projections, under two Representative Concentration Pathway (RCP) scenarios. Projected mixing regimes for 669 lakes worldwide are investigated. The lake-model projections quantify many behaviours that would be qualitatively expected under these climate change scenarios. Under RCP 6.0 by 2080-2100, many lakes are projected to have reduced winter ice cover, with ~25% of seasonally ice-covered lakes becoming permanently ice-free. Surface waters are projected to warm in the annual mean, the median warming across lakes being 2.3°C, and the most extreme warming 5.4°C. The projections of lake mixing regimes suggest that 25% of the lakes increase their mean duration of thermal stratification by more than the present inter-annual variability. 96 of the studied lakes are projected to undergo marked changes in their seasonal mixing regimes. 25% of those which are currently undergoing one mixing event in most years will become permanently stratified meromictic systems, and 17% of lakes which are currently dimicitc (mixing twice per year) will become monomictic. We conclude that mixing regimes will be modified by climate change, with implications for lake ecosystems as well as the ecosystem services in which they provide.

Advances in Frequency Selective Surface Technology for Future Space Science Missions

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This paper describes the design and manufacturing methods used to create a new type of frequency selective surface (FSS). These structures provide multispectral capabilities for passive remote sensing instruments by separating the scene radiation into separate frequency channels. Ultra-low-loss spatial beam splitting allows high-sensitivity receivers to detect weak molecular emission from millimeters to sub-millimeter wavelengths. Reconfigurability adds further advantages in the control of signal transmission to calibration targets and scene radiation in the quasi-optical network.

The ESA Earth Explorer 10 Candidate Mission LOCUS

Daniel Gerber[1], Brian Ellison[1], Peter Huggard[1], Alexander Valavanis[2], Edmund Linfield[2], A. Giles Davies[2], Giorgio Savini[3], Neil Bowles[4], Simon Calcutt[4], Martin Crook[5], Matthew Hills[5], Tom Rawlings[5], Steve Parkes[6], Stuart Mills[6]
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We present the ESA Earth Explorer candidate mission LOCUS. LOCUS is under evaluation for Phase-0 Study in the current 10th ESA Earth Explorer Call (EE10). It is a UK mission proposal for an upper atmospheric research satellite that uses disruptive receiver technology to make novel atmospheric measurements.

At the core of the LOCUS instrument is a heterodyne Schottky receiver. Such receivers have long been used very successfully for satellite Earth Observation in the millimetre- and submillimetre-wave range. But the desire to extend the observation frequencies into the THz range has been met with fundamental technological difficulties, namely the lack of high-power Local Oscillator (LO) sources to pump the frequency down-conversion process (i.e., frequency mixing) at THz frequencies. This is known as the “THz-Gap”.

The development of novel Quantum Cascade Laser (QCL) local oscillators in the UK would make it possible, for the first time, to build THz and supra-THz heterodyne remote sensing instrument in a very compact, low power implementation, with very moderate cooling requirements (2–3-W heat-lift at ~70 K). This combination of novel technologies is ideally suited to bring down the cost of potential space-borne deployment. The CEOI has played a major role in the past to develop THz Schottky receivers at RAL Space, QCL devices at the University of Leeds, miniature space-coolers at STFC Technology, and high-resolution, wide-band digital spectrometers at STAR-Dundee.

The scientific motivation that drive this UK technology development is captured in the LOCUS missions: To measure the composition of atomic oxygen (O) in the Mesosphere – Lower Thermosphere (MLT). O is the main component of the MLT, but because it can only be measured remotely at two distinct THz frequencies (4.7 & 2.0 THz), its abundance, and particularly its global and temporal variability is still largely unknown.

Remote sensing of zooplankton swarms: A case study for near-real time cruise support

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Ocean colour remote sensing is traditionally regarded as being influenced by water, phytoplankton, sediments and coloured dissolved organics. However, there are widespread reports of other materials appearing in sufficient abundance to cause visual colouration of natural water bodies. In this study a research expedition set out to investigate reports of the zooplankton Calanus finmarchicus forming super swarms that cause seawater to turn pink/red. Near-real time cruise support provided by NCEO-NEODAAS was crucial in allowing researchers to identify the position of swarms from atmosphere-corrected VIIRS RGB data and to adapt sampling strategies to optimise capture of major swarm features. Resulting in situ sampling with net trawls, underwater imagers, hyperspectral radiometry and analysis of inherent optical properties demonstrated conclusively that red pixels in the EO data corresponded to locations where Calanus finmarchicus occurred in very high density in the top 5 m of the water column. PSICAM absorption measurements revealed strong signals in the blue associated with astaxanthin, a pigment associated with Calanus, which resulted in reductions in blue reflectance. This is the first confirmed observation of Calanus swarms from space, and suggests use of remote sensing for stock assessment of this commercially harvested species. The impact of Calanus on blue reflectance degraded the performance of standard Chl and K490 algorithms. These results imply that mm-size class particles may be able to influence bulk inherent optical properties, despite relatively low numerical abundances. There is, therefore, a potential systemic mis-match between in situ sensors operating on mL sample volumes, and remote sensing imagers operating with pixel dimensions of 100s of m, that is particularly acute when mm size class particles accumulate in this manner. The extent of this problem is currently unknown, but spawning events, larval transport and other zooplankton aggregation events (e.g. krill in the Southern Ocean) are potentially of interest.

SPRINT for Space - Supporting SMEs to compete and grow using space technologies and applications

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SPace Research & Innovation Network for Technology (SPRINT) is a space sector focused SME high growth programme, which will engage 400 businesses and support 150 over 3 years, with a target of delivering +£70M GVA and 500 jobs in support of the UK Space Sector Growth Strategy. SPRINT will allow SMEs to access the HEI Knowledge Base, interact with other support structures such as the Satellite Applications Catapult, Regional SME growth projects and facilitate commercial deal flow to investors, optimising the scale up of businesses who are enabled by space data and technology. The SPRINT project is led by the University of Leicester and is delivered by a consortium of partners including Universities of Surrey, Southampton and Edinburgh, along with the Open University. It has been awarded £4.8M for 3 years through the Research England Connecting Capabilities Fund. This paper will describe the programme and how it can support SMEs working in EO and downstream applications of EO data.

Evaluation of Detection Capabilities for Distressed Refugee Boats Using Satellite Radar Data

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Existing research in (semi-)automatic marine target detection using Synthetic Aperture Radar (SAR) data concentrates on the detection and classification of large, metallic targets--mainly ships. This project focuses on the detection of small, non-metallic targets, in particular inflatable rubber vessels. Such vessels are increasingly used by migrants attempting to cross from Africa to Europe.

The talk will discuss the background, rationale and results of a project that collected multi-platform satellite data holding "sea truth" to a rubber inflatable vessel. Data was collected in the Müggelsee, a lake near Berlin, Germany, which functioned as a test bed for the open sea. To identify indices of detectability, the backscattering properties of the vessel and the water surface were evaluated. Different levels of speckle, which can reduce ship-to-sea contrast and hence impair vessel detection were investigated. Sensor and scene setting thresholds for detection were defined.

The primary motivation of this research is to mitigate the ongoing humanitarian crisis at Europe's southern Sea border. The applicability of the project's results to the setting of the open sea, where stronger winds and seas could interfere with radar detection, will be discussed. This project builds a foundation to develop satellite based detection systems for inflatable rubber boats. Such systems could be integral to search and rescue infrastructure in reducing the number of lives lost at sea.

Development of Ka-band Radar Interferometric Duplexer for the SWOT Mission

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Our desire for interferometric data to augment altimetry data is driving ever more complex RF instruments to deliver our understanding of land and sea topology, deepening our understanding of ocean currents and enabling the extension of oceanography techniques to lakes and rivers. A recent example of one such instrument is the Ka-band Radar Interferometer instrument, KaRin, for the Surface Water Ocean Topography (SWOT) mission which has required the most complex RF payload ever to be built, utilising an unprecedented number of ferrite switches, couplers and electronics boards to route and control multiple interferometric swaths to the receivers in order to enable these new measurements. An engineering overview of the technical advances and obstacles that had to be overcome to achieve this, the lessons learned and what this makes possible in the next generation of RF payloads will be presented. The Ka-band frequency design provides a high vertical resolution; An accuracy of 10mm is targeted when measuring water height.

PBGeoSAR: a low-cost geosynchronous radar mission concept

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PBGeoSAR is a novel mission concept for low-cost radar imaging from geosynchronous orbit (GEO). It is developed from earlier projects to design a synthetic aperture radar (SAR) mission for GEO. In particular, GeoSTARe was a mission concept for a communication satellite (comsat) hosted payload which could achieve high spatial resolution imaging for a wide range of significant applications across Europe. However, it was difficult to envisage a satisfactory business case to justify full

implementation. The innovation of our approach is to design a "good enough" rather than high performance radar which nevertheless still serves important applications, but at much reduced cost.

PBGeoSAR is a passive bistatic GEO SAR which can be implemented as a hosted payload on standard comsats. It is passive since it re-uses transmissions from other comsats with suitable power and bandwidth for radar imaging, and bistatic because the transmitter and receiver are separate (on different comsats). It would require an additional receiver to be added to the host comsat, but could re-use an existing antenna: re-use of existing transmitters and hardware reduces cost significantly. Comsat power intensity is about 20 dB weaker than required for standard spaceborne radar imaging: PBGeoSAR is thus restricted to applications which use coarse spatial resolution. However this still includes significant applications such as atmospheric humidity mapping for high resolution meteorology and soil moisture at watershed scale.

Initial design studies suggest that the mission is technically feasible and could be implemented for a cost around £10M. Remaining technical challenges include system synchronisation, clutter interference, and phase compensation. If successful, the mission would provide useful services in its own right and be a technology demonstrator for more ambitious GEO SAR missions.

MISRlite - a convoy mission for Sentinel-3 for vertical updraft measurement of convective systems and preliminary results from AirMISRlite

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Clouds and their interactions with aerosols (ACI) represent one of the greatest uncertainties in climate forecasting. For example, estimates of the climate forcing by ACI range from close to zero to -1.3 W m−2, in contrast to forcing by CO2 of 1.7±0.4 W m−2 (2011 relative to 1750) [1,2]. Clouds and ACI, in turn, are governed by vertical velocity (updraft speeds) and the impact of different updraft speeds and associated mass flux, entrainment and mixing processes on the formation of cloud liquid and ice and their drop size and number concentrations, which in turn determine cloud extent, optical properties, rainfall, downdrafts, but also the vertical transport of mass, energy and momentum [1]. MISRlite (Multi-angle Infrared Stereo Radiometer) addresses the retrieval of the 3D wind-field (u,v,w) in the thermal IR using uncooled microbolometers operating in Time Delay Integration (TDI) mode on tandem spacecraft positioned 60 seconds ahead and behind Sentinel-3 (S3). The synergy between the cloud [3] and aerosol retrieval of microphysical properties from SLSTR and OLCI on S3 and the accurate temperature calibration of SLSTR to cross-calibrate the MISRlite cameras will allow atmospheric dynamics to be coupled to cloud thermodynamics and microphysics, including particle concentrations, for the first time ever. MISRlite will allow geometric cloud-top heights to be retrieved alongside cloud-top advective winds and by observing the time variation of CTHs (Cloud-Top Heights), the vertical velocity can be retrieved alongside the change in temperature of the cloud-tops. We will

show examples of the aircraft MISRlite prototype as well as cloud-top height results using optical flow compared against simultaneous scanning laser altimetry and numerical simulations from EarthCARE Simulator.

Acknowledgments

The research leading to these results has received partial funding from CEOI contract no. RP-16002.

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A novel approach to passive microwave radiometry applying the emerging technique of sub-millimetre-precision satellite formation flight

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Recent advancement in precision satellite formation flying has opened the possibility to develop an entirely new class of missions thanks to the kilometre-scale structures that these satellite formations can deploy in space. Formation flying uses a fleet of satellites which maintain a precisely controlled formation in orbit, allowing them to operate as a single system with a single rigid structure. These "virtual structures" will enable for the first time the deployment of the very large apertures required for geostationary microwave radiometry, achieving unprecedented spatial and temporal resolution.

The motivation behind geostationary radiometry has been strong for many years. The quality of Numerical Weather Prediction can be significantly improved if the continuous observation of the rapidly evolving meteorological phenomena, including atmospheric temperature, wind, humidity and precipitation distribution, can be delivered by a geostationary platform. The diffraction limit however has held that such a mission would require a microwave aperture in excess of ten metres in diameter.

We propose this, as well as the many other applications that benefit from continuous global observation in the microwave band - never has such a capability been available - will soon become possible thanks to the rapidly maturing techniques of precision formation flight.

We have recently shown that a constellation of one satellite, comparable in size to SMOS, and nine cubesats will be capable of synthesising a microwave aperture 14.4 m in diameter, achieving a spatial resolution of 16.6 km at the 53 GHz oxygen band from the geostationary orbit. This can be further improved by increasing the number of cubesats. The required sub-millimetre accuracy in sensing the satellites' relative positions for this concept will soon be available, as already demonstrated by such missions as PROBA-3 and LISA pathfinder.

Wheat Clutter model for Geosynchronous SAR Missions

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Scattering from "clutter" is potentially an important limit on image quality for synthetic aperture radar (SAR) in geosynchronous orbit (GEO). Power scattered by moving vegetation (clutter) is spread across the image (as in the familiar azimuth shift of moving vehicles in SAR images) and appears as additional noise. The low satellite speed and long slant range in GEO SAR mean that clutter power can spread 100 km or more), so a strong distant scatterer could hide a weak target. This important clutter reduces the effective signal to noise ratio of the image. RETURN

In order to estimate the realistic performance of a GEO-SAR mission (e.g. G-CLASS, GeoSTARe) a model accounting for clutter is needed. Existing models (e.g. Billingsley's clutter model) are not applicable in our case, and so a new physics-based model is proposed. The required clutter model is a function of landcover class (season), weather (primarily windspeed), wavelength, incidence angle and satellite speed. We started with wheat (to represent short vegetation) and other classes will be

forest (tall vegetation) and rough water (in addition to static surfaces such as bare soil / rock and urban). RETURN

Using a wheat motion database for different wind conditions we simulated the focusing of a GEO-SAR image (modelling the power in central peak and in sidelobes) for different satellite azimuth speeds, for different wavelengths and incidence angles. Then we fitted the clutter Probability Density Function (PDF) and correlated the model parameters with the windspeed, wavelength, etc., in order to develop the clutter model for the system performance estimation methodology. This clutter model will complete the core of our end-to-end simulator for GEO SAR mission design, and enable us to predict imaging performance in a wide range of application scenarios.

Geosynchronous SAR Mission System Performance Estimation Methodology

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The idea of Geosynchronous SAR (GEO-SAR) mission has attracted growing attention worldwide thanks to its capability of daily or better coverage. An end-to-end (E2E) simulator for estimating mission performance is under development at Cranfield University. RETURN

This simulator will be useful especially for some GEO-SAR mission (e.g. G-CLASS, GeoSTARe) where the achievable performance is affected by moving vegetation and atmospheric turbulence. The low azimuth speed (few x 10 m/s), and the long integration time (up to hours) cause these challenges. RETURN

Moving targets can be an issue due to the potentially large azimuth shift of their signal for GEO-SAR. For example, the signal of a strong target (e.g. a wheat field or a forest moving in blowing wind) can be smeared 100 km or more (due to satellite azimuth speed) and can hide a weaker target. RETURN

The methodology aims at deriving statistical estimates of mission performance relative to user-defined requirements. To simulate the Signal to Clutter Ratio (SCR) we use a clutter power model that is function of land cover, wavelength, antenna pattern, orbit and weather conditions (wind speed, etc.) given by the target region and seasonality. RETURN

All these parameters need to be known for all the azimuth swath but the methodology allows also to have time-dependent parameters and thus the E2E simulator will be capable of simulating dynamic weather conditions. RETURN

Currently, we have developed the wheat clutter model and the next steps will be the forest and water clutter models. We are already able to simulate a landscape with three land cover classes: wheat (as source of clutter), bare land (as weak target) and urban areas (as strong target). The goal is to be able to simulate GEO-SAR imaging performance for a wide range of landscapes and weather conditions, and thus to obtain representative system performance statistics.

A new TDI CMOS image sensor for Earth Observation

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We will describe a new technology that is under development that will enable the manufacture of a time delay and integration (TDI) CMOS image sensor for high resolution earth observation applications.

The first CMOS approach was to carry the TDI functionality using digital summation. This approach quickly demonstrated limitations in terms of line rate and power consumption as the entire sensor has to be read for every line on the ground that is sampled. More recently CMOS technology has

matured the charge domain CCD approach with comparable electro-optical performance to CCDs while offering higher speed, smaller pixel pitch and high level of integration.

This latest technology step has also considerably eased the integration of the sensor into the satellite, opening new opportunities to produce focal planes at significantly lower cost with much reduced power dissipation, size and weight. The challenge has been to establish a CCD on CMOS technology that can obtain a similar full well capacity and charge transfer (CTI) performance to CCDs. This CCD on CMOS technology has now reached the point where the performance is comparable to CCDs but with very much lower operating voltages.

This paper will present the evolution of earth scanning image sensors with a focus on the latest TDI CMOS technology including the recent results obtained with the latest CMOS technology using TDI in charge domain approach. These results will include FWC, CTI, radiation performance as well as results from very high speed, up to 3.2Gbs output stream, and highly integrated readout circuitry.

Finally we will provide details of new devices that will provide a very significant improvement in imaging capability

A Wideband Spectrometer

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A team of scientists and engineers from several organisations in the UK is working on an atmospheric limb sounding instrument to operate in the, largely unexplored, THz region of the electromagnetic spectrum which would be used to probe the physics and chemistry of the Mesosphere and Lower Thermosphere (MLT) region of the atmosphere. An engineering model of the THz radiometer for the LOCUS (Low Cost Upper-Atmospheric Sounder) is being developed by RAL, UCL, University of Leeds, STAR-Dundee and other partners in the UK. STAR-Dundee is responsible for the design of the backend spectrometer for this instrument.

STAR-Dundee has designed a high-performance FFT processor for spectrometer applications. The design has evolved through a series of wideband spectrometer (WBS) versions, which are listed below.

Initially, WBS I, using a single ADC (3 Gsamples/s) and DAC for testing;

WBS II with two 3 Gsamples/s ADCs operating as an I and Q pair to give 2.8 GHz bandwidth which was processed with a 2k point FFT into around 1.5 MHz bands;

WBS III, an airborne version of the WBS II, built into a hermetically sealed box

WBS IV, a prototype spaceflight version using the Microsemi Igloo2 FPGA in preparation for a design with the radiation tolerant Microsemi RTG4 FPGA.

WBS V, which uses the radiation tolerant Microsemi RTG4 FPGA, with commercial versions of radiation tolerant ADCs and other critical components, and operates at 2.4 Gsamples/s.

This paper will describe the most recent development, the WBS V, which implements a 1 k-point FFT in a Microsemi RTG4. Operating with dual 2.4 Gsamples/s ADCs it provides 2 GHz bandwidth with a FFT bin size of 2.4 MHz. The architecture, implementation and results of this spectrometer are described.

Demonstrating multi-view spectroscopy for greenhouse gas remote sensing using the GHOST airborne spectrometer

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GHOST (GreenHouse gas Observations of the Stratosphere and Troposphere) is a novel, compact shortwave infrared grating spectrometer, designed for remote sensing of tropospheric columns of greenhouse gases (GHGs) from an airborne platform. GHOST observes solar radiation at medium to high spectral resolution which has been reflected by the surface, using similar methods to those used by polar orbiting satellites such as the JAXA GOSAT mission, NASA's OCO-2, and the Copernicus Sentinel 5-Precursor.

Here we present the initial results from the CEOI CO2 Multi-View project. In late 2017 through to early 2018 GHOST underwent an instrument upgrade and full laboratory based calibration, before installation on the British Antarctic Survey (BAS) Twin Otter aircraft at Cranfield Airport in May 2018. The main instrument upgrade involved implementation and testing of a ground target tracking system, which uses real time GPS information to point the GHOST fore-optics at a specific location in latitude-longitude-altitude space. This enables us to make multiple observations of the same ground target from a range of viewing angles as the aircraft flies past, allowing us to investigate whether multi-angle views can improve the quality of our GHG retrievals through better characterisation of the effect of scattering on our measured spectra.

In June 2018 we completed science flights over the UK, targeting a number of sites including known GHG emission sources and ground-based remote sensing instruments (including the TCCON site operated by STFC-RAL at Harwell, and the Chilbolton Observatory). This work describes the GHOST instrument upgrade, laboratory calibration, and installation on the Twin Otter, as well as presenting the first analysis of measurements taken during the science flights.

Change detection in spatiotemporal SAR data for deforestation monitoring

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Advances for change detection in multitemporal SAR images are presented, with applications in deforestation and forest degradation monitoring. The suggested approach moves away from a pixel-wise change detection method and the necessity of a priori time series models by detecting breaks in the spatio-temporal context. By taking advantage of the high temporal frequency of Sentinel-1 data, the timeliness in deforestation detection can be improved without relying on multi-annual time series for training and modelling seasonality. Instead, pixels of similar land cover type are clustered in an unsupervised manner by their time series similarity. Changes are then detected as anomalies in both time and cluster. Change detection using this new methodology is compared to the method outlined in *Conradsen et al* (2016) which uses test statistics based on the complex Wishart distribution to detect pixel-wise changes.

Introducing spatial cross-correlations into the INVICAT carbon trace gas inversion system

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INVICAT is the variational analysis system for the TOMCAT chemical transport model. The analysis estimates the initial 3D fields, and the surface flux fields of a trace gas over some time window, by assimilating trace gas observations and a-priori information with the evolving model.

All information that is assimilated has errors. The current version of INVICAT assumes that a-priori errors are spatially uncorrelated, i.e. that the error in the initial 3D field, or surface flux, in one grid box does not correlate with that in another. This assumption is likely to be incorrect and therefore will lead to sub-optimality of the analysis.

This work attempts to introduce spatial a-priori correlations into INVICAT in an efficient way, starting with horizontal correlations. To do this the horizontal part of the a-priori error correlation matrix is assumed to be diagonal in terms of spherical harmonics, with a correlation spectrum that is a function of total wave-number only. This implies homogeneous and isotropic correlations in space with a prescribed length-scale.

The correlation spectrum forms the elements of the diagonal matrix mentioned above, and weights how much each spherical harmonic pattern is allowed to contribute to the analysis fields. The problem of determining this spectrum in order to imply the correct length-scale is discussed, together with how anomalous oscillations – akin to Gibbs phenomenon – in the implied correlations can be avoided. Other aspects of correlation modelling are discussed, e.g. 3D correlations for the initial fields.

Sentinel-3A PLRM Waveform Re-tracking using ALES

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Satellite altimetry has increasingly become a powerful tool for remote sensing of the ocean. However, traditional approaches resulted in data in coastal areas being contaminated by land and calm water in the altimeter and radiometer footprints.

The Adaptive Leading-Edge Subwaveform (ALES) re-tracker was originally developed at the National Oceanography Centre (NOC), Southampton (Passaro et al. 2014). ALES is capable of retrieving data in coastal areas by avoiding echoes from bright targets in the trailing edge portion of the waveform. It has the capability to maintain the processing accuracy in both the coastal area and the open ocean by adapting the width of the estimation window based on the significant wave height (SWH).

ALES has been recently used at NOC to re-track waveforms from Jason-1, Jason-2, Envisat and, more recently, Jason-3 missions. Now this approach is being extended to encompass Sentinel-3's pseudo low resolution mode (PLRM) emulated from the SAR mode using the reduced SAR mode technique.

The NOC version of ALES underwent some alterations to re-track the 20 Hz PLRM Sentinel-3A data. The relationship between the SWH and the width of the re-tracking window (which is a defining feature of ALES) has been estimated using Monte Carlo simulations, as for the original ALES algorithm, but with an increased number of simulations. The new algorithm coefficients have been used to fit the waveform from the Sensor Geophysical Data Record (SGDR) products.

Here we present samples of output from the ALES processing chain for the Sentinel-3A mission and compare this against the recent Jason-3 data.

GACOS: A free online service for InSAR atmospheric correction

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Tropospheric effects represent one of the major error sources of repeat-pass InSAR, and limit the accuracy of InSAR derived surface displacements. We have developed and released the Generic Atmospheric Correction Online Service (GACOS) with notable features: (i) global coverage, (ii) all-weather, all-time useability, (iii) correction maps available in near real-time, and (iv) indicators to assess the correction performance and feasibility. The model integrates operational high resolution ECMWF data (0.125 degree grid, 137 vertical levels, 6-hour interval) and continuous GPS tropospheric delay estimates (every 5 minutes) using an iterative tropospheric decomposition model. GACOS's performance for correcting atmospheric effects on SAR interferograms was tested using globally-distributed SAR data, achieving a phase precision and displacement accuracy of approximately 1 cm for the corrected interferograms even with a wide coverage (e.g. 250 km x 250 km). Indicators describing the model's performance have been developed to provide quality control for subsequent automatic processing, and provide insights of the confidence level with which the generated atmospheric correction maps may be applied.

Recent advances and ongoing developments of the CARbon DAta MOdel framework (CARDAMOM)

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The CARbon Data MOdel framework (CARDAMOM) is a model-data fusion tool that produces re-analyses of the terrestrial carbon cycle in agreement with available observations and ecological theory. CARDAMOM has been applied from local scale, using flux data and forest inventories, to global scale, using remotely sensed observations of leaf area and biomass stocks. Here we present some of CARDAMOM's recent applications focused on the impact of adding new observations and/or processes on the accuracy and uncertainty of parameter retrievals. At local scale, analyses of managed forests have demonstrated that repeated woody biomass observations help constrain both plant and soil carbon dynamics. At global scale, fire-prone ecosystems present shifts toward more productivity and more allocation to resistant plant pools. We also present preliminary results of ongoing developments such as the representation of drought stress on plant productivity. They will make CARDAMOM a tool of choice to take full advantage of upcoming satellite missions dedicated to observing tropical forests.

CEDA and JASMIN Services

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The Centre for Environmental Data Analysis (CEDA) provides the data archive component for NCEO and provides access to over four petabytes of EO data. This includes data from the Sentinel, Landsat and ENVISAT missions in addition to data from the NERC ARF as well as many other missions. CEDA provides access to this data via a number of methods, not least fast access via the JASMIN environment which allows users access to the data using a world class fast parallel processing cluster. JASMIN has recently undergone a further upgrade to allow 44 PB of high performance storage as well as almost 11500 computing cores. The CEDA Satellite Data Finder is a web tool that allows users to quickly find many CEDA EO datasets. Users can access this via a conventional GUI or by an OpenSearch

interface. CEDA is consistently engaged in developing systems to manage the large volumes of data curated as well as tools to find and access this data.

Ice microphysics from multi-frequency suites of active and passive remote sensing instruments

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Ice clouds play an important role in the planetary radiative energy budget as well as in global precipitation patterns. Nevertheless, uncertainties in ice parameterization continue to exist as highlighted by the spread in global average ice water paths by one order of magnitude across various climate models. In order to expand on our knowledge and understanding of ice cloud microphysical processes we utilize ground based and spaceborne remote sensing techniques, complementing the sparser in-situ observations.

The deployment of an unprecedented number of multi-wavelength active and passive remote sensing systems at the McMurdo site on the southern tip of Antarctica's Ross Ice Shelf during the Atmospheric Radiation Measurement West Antarctic Radiation Experiment (AWARE) field campaign offers the opportunity of overcoming the scarcity of cloud information at southern high latitudes. The combined observations of triple-frequency radars operating at X, Ka, and W bands, microwave radiometer liquid water paths (LWP), high resolution spectral Lidar echoes (HSRL), and radio soundings constitute a unique dataset for unraveling structures and processes related to cloud and precipitation physics at high temporal and spatial resolution.

The scope of the current project principally revolves around the analysis of the aforementioned campaign in an effort to relate triple frequency radar signatures with ice growth processes (riming, aggregation). In this paper we will present the first results pertaining to data quality control (calibration and attenuation correction), a link between visible extinction coefficient and effective reflectivity, and the identification of triple signature radar signals of ice processes for select case studies, which will then be exploited in subsequent retrievals. Further studies involve the development of an ice microphysical retrieval for ice water content and characteristic size, and the establishment of climatological records at southern high latitudinal regions.

Identifying Blooming Algae in Antarctic Remote Sensing Observations

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In Antarctica terrestrial life is able to flourish only on areas that are ice-free for at least part of the year, an estimated 0.18% of the continent's surface. But even here only a small proportion of this area is vegetated. Along the Antarctic Peninsula for example, although it is the most vegetated region of Antarctica, only 1.34% of exposed ground is covered. However, this may be a gross underestimate of the true area as ground-validation of

satellite imagery has revealed that in many places the vegetation comprises not just patches of land plants on exposed ground, but also snow algae, which are often well developed in coastal snow-fields as highly visible red and green patches below and

on the snow surface (Fig. 1B supp). This poster reports on our work to date collecting spectral reflectance information for Antarctic snow algae communities and in scaling these ground measurements to Sentinel 2 observations across the Antarctic Peninsula.

Satellite-based Disaster Mitigation

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The field of (semi-)automatic marine target detection with Synthetic Aperture Radar (SAR) data has been dominated by research concentrating on large, metallic targets. Even though this abstract describes a project which contributes to that research field in the broader sense, it represents a niche since it tries to build the basis for the development of detection mechanisms for small, non-metallic vessels. This project focusses on those rubber inflatables which have regularly been used in recent years by migrants to leave Africa for Europe.

The poster illustrates the concept of a data acquisition campaign which was undertaken to gather a genuine, first-hand, multiple-platform collection of radar data, holding 'sea truth' of an original refugee inflatable. This campaign took place in the Müggelsee, a lake near Berlin, Germany, functioning as a test bed.

The underlying motivation of this research is to mitigate the ongoing humanitarian crisis at Europe's southern Sea border. This research should build the basis for the development of a vessel detection system for chosen special targets. It could represent the central building block of a satellite-based surveillance infrastructure to support search and rescue missions and to reduce the number of losses of human lives at the open ocean.

A Novel Multi Angle Polarimeter for Retrieval of Aerosol Properties from Orbit

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Measurement of atmospheric aerosols via multi-angle multi-spectral polarimetry from orbit has been previously flight demonstrated (POLDER instrument) and is the subject of several on-going instrument developments (e.g. 3MI). Aerosol retrieval permits a greater understanding of environmentally damaging aerosols, offering the chance to improve public health on a global scale. Additionally, aerosol knowledge is important for reducing the error in the simultaneous retrieval of other atmospheric constituents, e.g CO2. It is for these roles that a new generation of compact polarimeters is being developed.

A UK Multi Angle Polarimeter (MAP) is currently potentially proposed for the future Copernicus missions. The compact nature of the instrument offers a scalable concept in enabling low cost access to space through inclusion as a hosted payload as well as on dedicated small satellites and constellations. This is a novel multi-spectral instrument which is complimentary to many large scale space missions such as EarthCare and ground based aerosol retrieval systems such as Aeronet.

This paper briefly introduces the retrieval concept, and describes the initial instrument design including some discussion of certain critical technologies involved in the approach.

Deployment of a greehouse gases laser heterodyne radiometer (LHR) for the FRM4GHG ESA campaign

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Following the 2017 ESA FRM4GHG (Fiducial Reference Measurements for GreenHouse Gases) campaign during which a carbon dioxide compact version of the RAL Space LHR was deployed to the Finnish Arctic research station, the instrument has been updated and augmented to include a methane measurement channel at ~8 microns. Following instrumental improvements, the GHG LHR

has recently been re-installed to carry on measuring in 2018 and participate to a TROPOMI S5P validation campaign.

The conclusion from CO2 measurements from the 2017 phase of the campaign, the instrumental improvements carried out to prepare the 2018 campaign, and the early results on CH4 measurements will be presented.

Latest revolution in Coastal Mapping

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Through a professional lifespan begun with the star *Fundamentalkatalog*, theodolites and tables and which saw the successive advent of pocket computers, GPS and satellite images, the author is witnessing another quiet revolution taking place under the Coastal Cartographer's eyes: the unlimited horizontal precision offered by modern satellites and their yet untapped power of revisit time.

Until yesterday, coastal mapping was based on a mosaic of satellite images requiring orthorectification, tie-points and compensation to achieve a homogeneous horizontal precision. This disappeared overnight when users were informed, almost confidentially thanks to the March 2018 ESA Data Quality Report, that Sentinel-2 offers now a global 12 m absolute precision at 95 %. No need to trudge with receivers along the cost any longer when a satellite image can now provide the cartographer in his air-conditioned office a precision superior to the best nautical chart with the advantage of being fully compliant with Mariners' GPS.

For the sake of Safety of Navigation, the absence of Revisit makes it an obligation for International charts to replicate *usque ad nauseam* doubtful shoals sighted 150 years ago by clippers under sail that no one had a chance to challenge but which might still represent – who knows? - a danger to shipping. Thanks to its 5-day revisit time, **Sentinel-2** can now confirm or disprove these suspicious blotches and validate sea bottom structures as long as they are visible from space.

This presentation proposes to review the changes brought to coastal mapping for the past twenty years that include **SDB**, horizontal precision, revisit time and open GIS software that should make it possible for Developing Countries to draw charts from virtually any offices without having to acquire the knowledge that made ancient hydrography and cartography a science seemingly unapproachable to non-specialists.

Wood density and biomass: non-destructive estimates using sound velocity

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Aboveground biomass (AGB) estimated from satellite observations and field surveys is based on the assumption that wood density of trees in the same species is the same, as well as constant within a tree. Wood density is one of the largest uncertainties in AGB estimation at global scales, and as a result it is important to quantify variation in wood density. Here, we propose a noninvasive approach to estimate wood density from sound velocity measurements derived from PiCUS sonic tomograph. This instrument records the speed of sound across a tree diameter, from a number of measurement points. From this, the internal structure of the tree at that height can be inferred, albeit qualitatively as the measurements are not calibrated. Here, we evaluate the variability of wood density within a single tree, within species and between species, as a function of environmental conditions and locations. We measured two tree species, lime (*Tilia x europaea*) and London plane (*Platanus x hispanica*), with diameter-at-breast height (DBH) from 40 to 80 cm. For each tree, three cross-sections

were measured at vertical intervals of 50 cm. These trees grow in various environments such as public gardens, along the street and within the UCL campus. We develop a model of the velocity of sound in wood to estimate wood density of each measured cross-section. Through repeat measurements, the uncertainty of these estimates caused by environmental factors is evaluated, such as temperature and humidity, and measurement errors such as placement of sensors and equipment. We then discuss the resulting variations in wood density of these two species of trees and the implications of this for uncertainty of AGB estimated from satellite observations. Finally, we discuss how this method can be applied more widely to reduce uncertainty in the calibration and validation of biomass maps.

Next generation EO data available today – and for free!

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The Natural Environment Research Council (NERC) Airborne Research Facility (NERC-ARF), formerly the ARSF, has acquired data for the scientific community for over 35 years. Over this period it has collected data from many sites across the United Kingdom as well as farther afield with regular remote sensing campaigns in Europe, Iceland, Greenland and Ethiopia and one campaign in Malaysia. For some sites a rich time series exists giving valuable insights into change.

A complete archive of these data is freely available from the Centre for Environmental Data Analysis (CEDA) and provides unique opportunities for new research. By 2009 the instrument suite included hyperspectral imaging spectrometers, covering visible to shortwave infrared wavelengths and in 2014 a hyperspectral thermal imager was added. Data from these instruments are at a higher spectral resolution than the current generation of satellite sensors. These continuous series of narrow spectral bands allow the development of techniques and data products applicable for the next generation of instruments. Archived data were processed using the best available methods, with a focus on well-documented and reproducible processing chains to aid their reuse. Most LiDAR data since 2010, in addition to offering high resolution topographic information, includes full waveform returns. Full waveform LiDAR are of particular relevance given the planned launch of the NASA GEDI LiDAR system in November 2018, to be operated on the international space station. Scanned aerial photographs provide a unique snapshot and a valuable part of time series analysis.

This talk will highlight some of the datasets within the archive and show some of the innovative data processing developments that have been made as well as opportunities for future research using it. Given the amount of data held in the archive, NERC-ARF data are likely to continue playing an important role in research long into the future.

Structural error diagnostics using multiple earth observation (EO) products and in situ data, for application in energy and water cycle budgets

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EO flux products from satellites are likely to exhibit spatially correlated errors for various reasons. The largest scales and most persistent error covariances are likely due to shared errors in retrieval assumptions especially over large areas of spatially homogeneous surface such as the oceans. The presentation by Thomas et al. shows that such error covariances can have large impact on inverse model solutions for the energy and water cycles.

Here we assess different components of error (i.e. spatially correlated and uncorrelated errors) in EO derived flux products using a novel procedure. We use multiple EO flux products along with in-situ

calibration observations to develop these structural and regional error models. Turbulent fluxes over the oceans have so far been assessed in this way.

We use EOFs of the differences between multiple EO flux products, along with the differences against the in situ observations, to show the large-scale spatially coherent patterns which we identify with structural product errors in both the time mean and seasonal cycle EO fields. The generally larger structural differences between EO products and the in situ observations than between EO products themselves suggests that in situ observations, considered as ground "truth", need to be incorporated into the Thomas et al. inverse model in order to more accurately represent the flux errors and thus to have an improved energy budget solution. We also propose an innovative method to make maximum use of the spatiotemporally inhomogeneous in situ observations for estimating errors of the EO data and their spatial error covariance.

Agri-LIDAR to support crop and economic growth in the UK

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There is an urgent need for improvement in precision agriculture in order to increase food output to feed expanding populations, both globally and in the UK, particularly in the shadow of impending climate change. By 2050 the world's farms will need to produce enough food to feed an additional 2.4 Billion people. Without innovation UK farmers will also lose competitiveness to other developed countries. We therefore propose a high resolution Agricultural LIDAR (Agri-LIDAR) instrument on an innovative Skimsat platform designed for long term operation in Very Low Earth Orbit (VLEO). The Agri-LIDAR is the combination of innovation in both payload and platform to create a new dataset of agricultural intelligence to inform farmers in the UK and beyond.

The Agri-LIDAR payload is envisioned to have two modes, the first being a biomass measuring altimeter for estimating the yield of crops and forestry as well as measuring water drainage channels and potentially harbour bathymetry. The second mode is an active chlorophyll fluorescence measurement system for directly determining the heath of crops via their leaf chlorophyll content, helping to spot disease earlier. This is complementary to passive fluorescence measurement systems being used, for example, on Sentinel-3 and ESA's upcoming FLEX mission.

The use of the Skimsat VLEO platform enables the instrument to meet the demanding signal to noise requirements due to the significantly reduced range between satellite and target. Skimsat makes use of advances in electrical propulsion and atmospheric drag reduction techniques to maintain an orbit in VLEO for several years and at the end of life there is guaranteed to be no orbital debris left due to the "self cleaning" nature of VLEO.

Rapid characterisation of tropical forest structure with a handheld laser scanner

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A large proportion of terrestrial Above Ground Biomass (AGB) is stored in the woody components of tropical forests, yet there is still large uncertainty regarding quantity and location of this pool. Traditionally, AGB has been assessed by measuring the height and diameter of individual trees which are then used to estimate AGB via allometric equations. Advances in laser scanning technology (airborne and terrestrial LiDAR) over the past decade have allowed for more accurate estimates to be derived over large spatial domains; however, these methods are still costly and require expert users to acquire and process the data. More recently, lightweight, low-cost laser scanners (e.g. mounted on UAV's, vehicles and handheld) have allowed for rapid characterisation of forest plots; here we present a new method and results for rapid assessment with a handheld lasers scanner. A ZEB-REVO

scanner (GeoSlam, UK) was used to capture two 1 ha plots in the Tambopata Forest Reserve, Peru; coincident high-resolution TLS was also captured and used as reference data set. For each 1 ha plot, 81 scans were captured in a “chain-mail” configuration and coregistered using tree stem locations as tie-points. Stems were extracted from the coregistered data and stem density, dbh and stem volume (to a height of 5 m) were derived. Preliminary results suggest that this method can capture a 1 ha plot in ~1 day (compared >4 days for TLS) and that stem location (for stems where dbh >0.2 m), dbh and volume can be characterised to acceptable levels of accuracy. Rapid and accurate characterisation using low-cost instrumentation could prove an important component of carbon accounting systems such as REDD+ MRV.

Demonstration of GNSS Reflectometry For Ocean Winds Service on TDS-1

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The SGR-ReSI instrument flying on UK TechDemoSat-1 since 2014 has demonstrated that GNSS signals can be used as a bistatic radar source for sensing the Earth's surface from space, and has also been used as the payload on the NASA CYGNSS small satellite hurricane sensing constellation. TDS-1 has been given a life extension, and the SGR-ReSI is now collecting data at a higher rate than before. Ocean wind measurements from TDS-1 are being released from the web-site MERRByS with a short delay to demonstrate the feasibility of the use of GNSS reflectometry for an operational wind and wave sensing service. Recent results from an ESA-sponsored study called TGSCATT have shown an agreement with the best weather knowledge of better than 2 m/s for lower wind speeds.

Furthermore, data from TDS-1 has allowed the development of new potential GNSS-Reflectometry applications for ice, snow, soil moisture and flood sensing, amongst others. Preliminary work is being undertaken into a constellation of small satellites called ORORO with an instrument that can collect both reflectometry and radio-occultation measurements simultaneously to provide new measurements for numerical weather prediction assimilation purposes with unprecedented spatial and temporal coverage of the ocean surface.

This presentation will show the latest results from TDS-1, and look to the potential for a future small satellite constellation dedicated to an operational service.

Coherent GNSS Reflectometry for Altimetry over Ice and Land CGRAIL

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The SGR-ReSI is CEOI-sponsored GNSS Reflectometry demonstrator flown on UK TDS-1 in 2014, and used as payload on 8 NASA CYGNSS satellites.

In normal operation, signals are incoherently averaged to measure ocean scattered amplitude of GNSS signals, relating to wind and wave behaviour.

Alternatively coherent ranging is possible from the code and carrier phase of GNSS. Over oceans this is difficult due to weak signal and fading effects, but over the ice, very strong signals are seen, suggesting signals are coherent. Similarly strong reflections are seen off rivers and wetlands and are visible through the rain forest canopies in South America. If coherent, resolution improves down to the Fresnel zone of the signal, around 500 metres. Research by IEEC found TDS-1 reflections off sea ice agreed with sea surface height model to approx. 3 cm, and indicated the possibility of direct ice draft measurement. Such L-band measurements could complement Cryosat well, providing an alternative way of measuring thinner ice more challenging for radar satellites.

It is proposed that a small satellite demonstrator is flown to explore the coherent reflected GNSS signals from ice and wetlands. Modifications can be made to the SGR-ReSI to optimise it for open loop collection of coherent signals. A small satellite platform based on the SSTL-42 could carry this plus other instruments. A complementary technology could be a Ka-Band beacon transmitter for testing very high data rates required for future generations of Earth Observation satellites.

GNSS Reflectometry is paradigm shift for EO, and still relatively new technology, and a demonstration such as this could find scientific and commercial value. Ice thickness knowledge is important for both climate science, but also for off-shore energy and navigation. Similarly soil moisture and inundation are parameters important to climate but also agriculture and disaster management.

GRaCE: A G-band Radar for Cloud Evaluation

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The design, predicted performance and scientific benefit of a pulsed 200 GHz ground based cloud profiling radar are described. The radar is called GRaCE: a G-band Radar for Cloud Evaluation. The GRaCE instrument is being built as a de-risking technology demonstrator for a future space instrument. The small wavelength of a 200 GHz space radar provides enhanced global information on the distribution of small droplets in the Earth's atmosphere. When operated in tandem with existing lower frequency space radars, the dual wavelength observations will enable better characterisation of the microphysical properties of hydrometeors in water and ice clouds. Such information is needed to improve the accuracy of numerical weather prediction models.

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Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS): Enabling a Space based Climate-Calibration Hyperspectral Observatory

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TRUTHS is a proposed multi-disciplinary science-driven mission which, in addition to delivering hyperspectral data, operationally upgrades the performance of EO assets like the Sentinels & constellations of micro-sats ensuring they deliver data of quantifiable quality, through reference in-flight calibration, triggering a new epoch in climate science.

TRUTHS has recently demonstrated readiness for implementation following a series of CEOI funded projects. optimising its design. TRUTHS has been endorsed as an essential component of a space-based climate-observing system by international organisations including CEOS, WMO, GCOS and GEO. A prospective national/UK led mission, TRUTHS not only showcases UK innovation and technology but also provides the 'Rosetta-stone' to unlock the full potential of EO data and the resultant scientific and economic benefit underpinning UK ambitions.

High-accuracy, globally inter-operable data (on-demand) is required to serve the next generation of EO information customers: science, government and commercial. Most notably in terms of accuracy, climate and applications sensitive to associated risks, where unequivocal detection of a signal/trend in the shortest possible time is a societal imperative to mitigate and adapt to climate driven change. The size of the signals requires harmonization of multiple sensors, typically spanning decades, to reach a detectable level and thus generation of trustable underpinning FCDRs need an invariant unequivocal reference.

Commercial services derived from ARD/data-cubes e.g. agriculture, forestry, finance etc. all require unambiguous combination of data from different sensors together with an assigned 'fit-for-purpose' quality metric - again needing a robust reference. The demand for data has fueled the launch of constellations of micro/nano-sats, too small for on-board calibration systems, they require vicarious methods to exploit temporal benefits into quality-assured science-ready data. High-accuracy hyperspectral data from TRUTHS not only delivers some of the necessary data but can be convolved to the bands of others sensors anchoring them to a gold-standard.

Unmapped blanket bog in North Spain, how long before it is gone? An exploration of conventional and novel techniques

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Blanket bogs are rare and protected priority habitats that form extensively in oceanic climate conditions in the Northern Hemisphere. In Spain, blanket bogs are only protected and studied in Galicia and Bizkaia, but further significant areas of blanket bog exist in the regions of Cantabria and Castilla y León. These areas are unprotected and to date unmapped, but there is no information on the rate of peat loss.

This study used conventional methods to determine the extent and depth of peat in five areas in Cantabria and Bizkaia (Zalama, Ilsos de Zalama, Motas del Pardo, La Marruya and Collado de Hornaza), and more novel Terrestrial Laser Scanning (TLS) to understand rates of surface change, including erosion in both, restored and unrestored blanket bogs. Using TLS it was possible to evaluate ultra-high resolution (<2 mm) 3-dimensional surface change in all five blanket bogs over one year.

The total volume of peat estimated for all study sites was 13,811 m3 and erosion was identified in each site. At Zalama, where bare peat stabilization and fencing has been undertaken, very little change was determined. In the other areas where peat is exposed to trampling, significantly greater rates of change where identified, particularly in summer months when livestock densities are greatest.

The rates of erosion determined over a period of one year in unprotected areas are extremely high for peatland ecosystems, and greater than the global mean annual rate of peat erosion. Restoration actions appear to have had a significant impact on these, and this may predominantly relate to the installation of a fence to exclude livestock. This study highlights that urgent identification and restoration of unmapped blanket bog in North Spain should be undertaken to preserve this habitat.

Assimilating MODIS albedos for LAI retrieval

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Earth observation datasets offer an accurate and globally rich source of information and when used in conjunction with mathematical models can improve our knowledge of the true state of Essential Climate Variables (ECVs). The Sellers model of terrestrial radiative transfer, due to its relative computational inexpensiveness, is currently used in state of the art land surface schemes including the Joint UK Land Surface Environment Simulator (JULES). Here we confront the model with remotely-sensed white sky and black sky surface albedo products in the visible and near-infrared spectral wavebands to retrieve an optimal Leaf Area Index (LAI) time series along with improved model parameter estimates and uncertainty information. Preliminary results and scope for improved model and observation error covariances are presented.

A microphysical retrieval of snow for the dual-frequency precipitation radar

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Clouds play a key role in the water cycle and in modulating the Earth's radiative balance. Despite their importance, the number of direct measurements of ice particles is very limited due to the high cost of aircraft-based measurements. Remote sensing can bridge this observational gap. This talk presents a method for retrieving the microphysical properties of snow above the stratiform rain from dual-frequency radar measurements gathered by the Dual-frequency Precipitation Radar on board of the Global Precipitation Measurement (GPM) mission core satellite. The algorithm is based on the optimal estimation framework and uses ice scattering properties of simulated snowflakes that cover a wide range of densities and diameters. The retrieved parameters include the mean mass weighted volume diameter and the water content of both rain and ice particles. The better constrained information on liquid particles is exploited above the freezing level by imposing the mass flux continuity through the melting zone. Case studies drawn from GPM observations will be presented. The radiometric consistency of the retrieval has been tested against the GPM Microwave Imager measurements as well.

The UK prospective TCCON facility: progresses and prospects

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The need to improve understanding and monitoring of the fate of greenhouse gas (GHG) emissions and budget has driven international effort in deploying satellite-borne GHG sensors, as for example the TROPOMI instrument recently launch on-board ESA Sentinel 5P measuring methane columns.

In order to ensure ground-based validation of the satellite infrastructure, the Total Carbon Column Observatory Network (TCCON) was established. TCCON is a global network of ground-based high-resolution FTIR spectrometers that record near-infrared atmospheric spectra in solar occultation, from which accurate and precise column-averaged abundances of GHGs are retrieved. In addition, TCCON is prescriptive on experimental and data processing protocols and requirements to ensure harmonization of the global dataset ground-truthing space-borne remote sensors. It constitutes a pivotal infrastructure into which the UK is now participating.

The progresses and prospects for the establishment of a validated TCCON observatory at the Harwell site (Oxfordshire) are reported. The site is well-suited to characterize both local emissions and exchanges between continental Europe and the North Atlantic. The instrumental stability and reproducibility has been thoroughly analysed, GPS timestamping and high accuracy surface meteorology data are now part of the observatory. The UK TCCON station is now fully compliant to enter an operational phase, except for the pointing accuracy of the solar tracker which will be addressed this year through the development of an alt-azimuth cam-tracker stabilizing the image of the solar disk onto the spectrometer entrance aperture. Flight overpasses of GHG remote sounders and development of the data analysis are also underway.

Creating surface state vector by processing optical, thermal and SAR data with temporal regularization

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Changes in the Earth's surface can have very different properties and therefore can influence very different domains of the electromagnetic spectrum. If we can use these domains effectively, they can provide input to machine learning methods to help in detection of changes of earth surface. This is particularly useful for trying to detect changes in ecosystem structure and function, a potentially vital application for satellite monitoring of the Earth system.

One of the issues in combining different Earth Observation (EO) data streams is a requirement of common time and space resolution. Merging observations made by different EO sensors can increase uncertainties what can dramatically influence further processing of data streams such as classification or change detection. This issue can be solved by propagation of uncertainties through the whole processing chain, which requires estimation of EO uncertainties. We present this work as a part of the BACI (Biosphere-Atmosphere Change Index) project. We exploit temporal regularisation which allows filing gaps in the time series of parameters and explicitly characterise the output uncertainties. In this way we are able to combine data across wavelengths, with different spatial and temporal properties, into a common observation framework, which we term the surface state vector (SSV). We use these data to generate optimally smoothed and filtered time series of reflectance, albedo, LST and backscatter (SAR) as the core SSV output. Crucially, the SSV is provided with consistent uncertainties, which is key for use in downstream quantitative modelling and change detection applications, particularly to help attribute and explain detected change.

A web interface to the resulting SSV is implemented by means of GeoServer and CEMS. The resulting SSV will be made publically available by the BACI project, as it is likely to be of wider interest for various applications in ecosystem monitoring and change detection.

Improving the Simulation and Understanding of the Carbons Pumps in Marine Ecosystems using an Ensemble-Based Data Assimilation Method

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The carbon cycle between the ocean and the atmosphere is dependent on many biological processes which are components of the air-sea carbon flux. This study examines the use of ensemble-based data assimilation techniques (LETKF and IEWPF) in twin experiments with a focus to improve the representation of carbon pumps, which are used to explain these fluxes. Following this experiment, results of a LETKF reanalysis were achieved through real assimilation at two contrasting sites: station L4 and BATS. The observations in this study are based on remotely-sensed ocean colour, and the model used is the biogeochemical marine ecosystem model ERSEM, coupled to the 1D physical model GOTM

Rapid-Revisit Small Satellite Constellations

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Satellite imagery has proved to be an extremely valuable asset for numerous Earth observations applications and activities.

However most current systems consist of a single satellite, or a small constellation, which imposes a number of limitations including restricted coverage and limited revisit. The common use of sun-synchronous orbits for optical imaging satellites also means that passes are highly predictable and limited to a narrow time band each day.

These limitations can be overcome by a moderately sized constellation of satellites in a non-sun synchronous orbit which can provide multiple observations throughout the day. The key benefit of such a constellation is the ability to rapidly re-image the same area of interest throughout the day, enabling activity monitoring, change detection and Pattern of Life assessments.

Future developments in satellite mass-manufacturing, driven by the current demand for telecommunications mega-constellations, open up the possibility for more ambitiously sized Earth observation constellations. In such circumstances it is possible to envisage exciting system designs that provide near persistent observations or the ability to provide double, triple or quadruple stereo imaging, coupled with long dwell times over a region of interest. Systems such as this could unlock new applications for Earth observation data.

Building on the success in developing satellite constellations over the past 20 years, and constantly improving the efficiency of its manufacturing processes, SSTL is now using its experience to develop the Rapid Revisit Constellation. This constellation of small, low cost satellites, providing high resolution optical imagery and video data, continues the innovative approach of the Carbonite satellite programme. Operating in a low inclination orbit, in multiple planes, the constellation can provide extremely fast revisit times over key areas of interest. The proposed presentation describes these activities and goes on to explore possibilities for the future if mega-constellations were considered for EO applications.

Uncertainty for Burnt Area Products

James Brennan[1,2], Jose Gomez-Dans[1,2], Philip Lewis[1,2], Mat Disney[1,2], Maxim Chernetskiy[1], Angelika Heil[3]
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Burnt area (BA) products are usually provided as a binary mask, indicating whether within a particular time interval, a pixel has or has not burnt. However, this is an inference derived from assessing e.g. the change in reflectance due to the fire. These calculations are prone to uncertainty from a number of sources: thermal noise in the sensor, residual atmospheric correction shortcomings or insufficient temporal sampling, etc. In this contribution, we aim to provide a framework for uncertainty characterisation of BA products. The uncertainty framework is Bayesian in nature, and provides a way to propagate uncertainty from the observations, across scales, but also allows one to propagate uncertainty in algorithm parameterisation. We illustrate the framework with a simple example based on logistic regression. Finally, we discuss how the uncertainty at the pixel level can be aggregated to the climate modeller grid (CMG), providing a consistent way to treat uncertainty from the observations and algorithm parameters to the final products.

Space-borne optical-sensors intercomparison using DIMITRI database

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The Earth's climate is undoubtedly changing, consequences and rate of this change remain the subject of significant debate and uncertainty. One of the major issues in climate change policy is how to deal and mitigate this uncertainty.

A continuous observation of the Earth system by satellites provides the cost-effective acquisition of global data, that can be fed into internationally agreed key datasets; such as the Essential Climate Variables (ECVs) identified by the Global Climate Observing System (GCOS) of the United Nations.

The drawback with satellite data collection from space is the degradation of the instrument. Therefore, mitigation to monitor and correct this degradation is built in to the mission a-priori. This is the realm of Calibration and Validation (Cal\Val).

Stable calibration and high radiometric accuracy are critical in providing valuable and indisputable data for weather and climate related research and applications. Moreover, radiometric cross calibration of Earth observation sensors is crucial in order to guarantee and/or quantify the consistency of measurements from different sensors. In regularly monitoring the behavioural stability of the instrument over time, degradation can be characterized, corrected, and the new datum checked.

A dedicated Database of Imaging Multispectral Instrument and Tool for Radiometric Intercomparison (DIMITRI) developed by ESA/ESTEC and ARGANS, and used by Sentinel-2 and Sentinel-3 Mission Performance Centres (MPC) to ensure the accurate calibration and validation of the products.

In addition to Sentinel-2 and Sentinel-3, other sensors (e.g. AATSR, MERIS, MODIS, OLI) are also assessed by DIMITRI to monitor sensor performances and perform cross-sensor calibrations. This work is done using data collected over several Pseudo Invariant Calibration Sites (PICS).

This presentation describes the radiometric cross-calibration methods and shows results over different sensors. The consistency between the aforementioned sensors is found in general of ~2% up to 5% for the VNIR spectral bands that the instruments have in common.

Session 3A: GEO & CEOS

Session Chairs: Heiko Balzter (University of Leicester & NCEO) & Sophie Rose Hebden (NCEO - University of Leicester)
Date: Thursday 6th September 2018
Time: 09:00-10:00
Location: Bramall Hall

UK Joint GEO/CEOS Office: an overview

Sophie Rose Hebden[1], John Remedios[1], Zofia Stott[1], Farhana Amin[2], Beth Greenaway[3], Chris McQuire[3]

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NCEO is hosting the UK's Joint GEO/CEOS Office on behalf of the Principal Funders the UK Space Agency, Defra and NERC (via NCEO). The aim is to support UK government policy and the international activities of the UK's EO community, interfacing to two major international initiatives: the Group on Earth Observations (GEO), and the Committee on Earth Observation Satellites (CEOS). This presentation will introduce the GEO and CEOS session with an overview of these major initiatives, and highlight how the UK Office is joining up scientific expertise with policymaking, and supporting UK inputs to GEO and CEOS. We will briefly share our successes and future plans, including key UK inputs on climate and climate datasets, data sharing, forestry and carbon reporting, calibration and validation, and disaster risk reduction.

CEOS Analysis Ready Data for Land (CARD4L)

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Many satellite data users, particularly those in developing countries, still lack the expertise, infrastructure and internet bandwidth to efficiently and effectively access, pre-process, and utilise the growing volume of space-based data for local, regional, and national decision-making. Even sophisticated users of EO data typically invest a substantial proportion of their effort into data preparation. As data volumes grow, this remains a significant barrier for all users.

CEOS Analysis Ready Data for Land (CARD4L) are satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets. The call for CARD4L is being driven by practical requirements to reduce the demand for limited resources and expertise in the preparation of data, and to ensure that those preparatory steps are fully accounted and understood. These drivers are becoming stronger as the community seeks to apply rapidly growing data volumes from a range of sensors in innovative ways, especially as time series. A range of data products will be available that meet CARD4L standards and reflect the attributes of fundamental measurement products for the majority of global remote sensing users with land imaging applications, and are the minimum level required to support time series analysis and data interoperability.

A new CEOS Working Group on Cal/Val (WGCV) Land Product Validation protocol for aboveground biomass

Mathias Inguar Disney[1,2], Laura Duncanson[3,4], John Armston[3,4], Jaime Nickerson[4], Miguel Roman[4]
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Aboveground biomass (AGB) of global forests is a key component of the global carbon cycle. Estimates of AGB are typically difficult to make directly and over anything other than very small areas. As a result, large-scale estimates of AGB rely on interpolation and extrapolation of limited direct measurements, via a combination of Earth Observation across scales, field survey methods and empirical models. The wide variety of methods and data used to estimate AGB mean that the resulting values are hard to validate, have potentially large and difficult-to-quantify uncertainties, and are potentially incommensurable. Various new and forthcoming space missions have been developed which will produce estimates of AGB in different ways and at different spatial and temporal scales. As a consequence, there is an urgent need to develop consistent calibration and validation protocols to allow the resulting estimates of AGB to be compared and validated, and interpreted by the wider user community. Activities to address these issues are currently underway by both CEOS and GFOI. This paper describes the new CEOS Land Product Validation (LPV) subgroup established to develop protocols for quantitative validation of satellite-derived AGB estimates. A first draft of LPV AGB protocol has been produced by the efforts of the community, following workshops and scoping activities. We outline key elements of the protocol i.e. good practice for biomass estimation in the field, links between EO and field estimates, error propagation, independent validation and reporting, how AGB estimates can/should be used by other communities (outside EO), and knowledge gaps. We also outline the timeline for the LPV activities, and areas where additional input is needed.

CEOS WGCV IVOS: Enabling interoperability of optical EO data.

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CEOS-Working Group on Calibration and Validation (WGCV) is the principle international coordinating body on satellite product Cal/Val (pre-& post-launch) and one of the founding working groups of its mother body, CEOS, the space arm of GEO. It is not only a forum for discussion but is active on establishing international collaborative projects on infrastructure, best practices etc e.g. current initiatives on ARD/data-cubes. CEOS-WGCV has six sub-groups, one the Infrared visible and optical sensors (IVOS),is chaired by the UK.

Over the last decade there has been a significant increase in the number of satellites launched and countries operating them, including in more recent times commercial providers. This in part reflects the recognition that no-one country of agency has the resources to meet the demand for data. To ensure maximal global societal benefit, agencies need to coordinate activities ideally launching complimentary missions in an attempt to fill observational gaps (temporal, spatial and spectral etc). They also need to ensure that data from different missions and from different agencies are where possible interoperable.

Consistent Cal/Val and assessment/reporting of uncertainties is key to interoperability. To support this CEOS-WGCV and its sub-groups provide a framework for international collaboration- sharing ideas, development of infrastructure and community agreed methods/standards. IVOS for example has organised comparisons of instruments and methods used for post-launch validation of ocean and land surface reflectance, brightness temperature and MTF. It has also established a new open access service, RadCalNet, to provide radiometric calibration coefficients for medium to high resolution sensors typical of those being developed by commercial operators together with a set of 'reference deserts' for coarser resolution sensors.

The paper will describe some of the activities and plans of CEOS-WGCV and in particular its IVOS sub-group to encourage further participation and ideas from the UK EO community.

Session 3B: Photogrammetry

Session Chair: Rene Wackrow (Loughborough University)
Date: Thursday 6th September 2018
Time: 09:00-10:00
Location: G33

Determining the presence and extent of buried ice within glacial environments, a multi-disciplinary approach.

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Glacier recession commonly results in the deposition and burial of ice within the landscape and in some cases can result in the stagnation of the glacier margin and the development of large areas of "dead ice". The subsequent ablation of this ice can result in the formation of a range of distinctive features such as discrete kettle holes or more extensive areas of hummocky moraine. Within permafrost environments, the aggradation of permafrost accompanying glacier recession can cause the preservation of buried ice for millennia such that deglaciation of the landscape is incomplete. Recent work within the Canadian Northwest Territories has revealed the development and rapid expansion of "megaslumps" that result from the exposure and melt-out of buried ice in response to rapid climate change, with the resultant landscape destabilisation having potentially wide-ranging environmental and infrastructural impacts. Very little systematic research has been undertaken to identify the specific landsystem setting in which glacier ice can be buried and potentially persevered.

This presentation provides some findings from the baseline survey carried out in Skaftafell National Park, Iceland, alongside experiments in resolution, repeatability and simultaneous 4D presentation of UAV based datasets alongside geophysical data.

Digital terrain models were generated using a combination of RTK GNSS (Global Navigation Satellite Systems), high-resolution UAV, and terrestrial based structure from motion techniques. EM-31 electromagnetic conductivity surveys, coordinated with GNSS were also carried out at each site to aid identification of buried ice beneath the subsurface, and to aid horizontal quantification. Additionally, the presentation includes the results from preliminary tests to calculate and display cm scale cut and fill models to identify surface variations over time.

Airborne laser-guided imaging spectroscopy to map tropical forest biodiversity and it function

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Tropical forests are among the most structurally complex, diverse and carbon-rich ecosystems anywhere on earth. Yet, even within intact tropical landscapes, the structure, composition and function of forests can vary dramatically across very small spatial scales. Understanding what drives this fine-scale heterogeneity in forest physiognomy is critical to forecasting how tropical forests will respond to global environmental change. Working in Borneo – at a site where 70-m-tall forests in alluvial valleys rapidly transition to stunted heath forests on nutrient-depleted dip slopes – we combined field data with airborne laser scanning and hyperspectral imaging to characterise how topography shapes the vertical structure, wood density, diversity and aboveground carbon density of nearly 15 km2 of old-growth forest. We found subtle differences in topography to profoundly influence the structure, composition and diversity of the canopy, as well as the spatial turnover of species. Capturing these processes was critical to explaining landscape-scale heterogeneity in ACD, highlighting how emerging remote sensing technologies can provide new insights into long-standing

ecological questions. Following recent announcements by NASA and JAXA that they will launch hyperspectral sensors in the next few years, I will close by considering the kaleidoscope of opportunities that spaceborne imaging spectroscopy will provide environmental scientists.

Using Sentinel-2 satellite imagery to map alien tree invasions in the Valdivian temperate forests of Chile

Maria del Pilar Martin Gallego[1], Paul Aplin[1], Christopher Marston[1], Adison Altamirano[2], Anibal Pauchard[3]

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The Valdivian temperate forest ecoregion is located in south central Chile and Argentina, and it is a global biodiversity hotspot. An upsurge in exotic forest plantations has fragmented the forest and promoted biological invasion. Invasions are understudied, especially in south America, because monitoring large and inaccessible areas is difficult and costly using field-based methods. Remote sensing is a great solution for quick, cost-effective assessment and management. This project employs a remote sensing approach using Sentinel-2 (medium resolution, multispectral) imagery to assess invasion, aiming to determine the geographical extent of alien species cover, and describe it in relation to fragmentation parameters in two study areas within Chile's Valdivian temperate forest ecosystem in the Andes. The study alien species included coniferous trees from the *Pinaceae* family (*Pinus radiata*, *Pinus contorta*, *Pinus ponderosa*, *Pinus sylvestris* and *Pseudotsuga menziesii*), and broadleaved tress from the *Eucalyptus* genus (*Eucalyptus globulus* and *Eucalyptus nitens*). Both of these groups of trees are used in commercial forest plantations for wood and fibre in Chile. Land cover maps of the study areas were created using a supervised random forests classification. The overall accuracy of the vegetation maps was greater than 0.95 for both study areas. These land cover maps showed presence of alien forest patches within the protected areas in both study sites. To assess the structural characteristics of the landscape, a set of landscape and class level landscape indices were applied to the land cover classifications. The results of the landscape analysis show that the amount of alien species and the landscape level metrics have a stronger correlation with altitude change than with latitudinal change in the study areas. Contrary to expectations, landscape level indices failed to explain alien species distribution effectively in this environment. Further work will assess the efficacy of class level indices for this purpose.

Unmapped blanket bog in North Spain, how long before it is gone? An exploration of conventional and novel techniques

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Blanket bogs are rare and protected priority habitats that form extensively in oceanic climate conditions in the Northern Hemisphere. In Spain, blanket bogs are only protected and studied in Galicia and Bizkaia, but further significant areas of blanket bog exist in the regions of Cantabria and Castilla y León. These areas are unprotected and to date unmapped, but there is no information on the rate of peat loss.

This study used conventional methods to determine the extent and depth of peat in five areas in Cantabria and Bizkaia (Zalama, Ilsos de Zalama, Motas del Pardo, La Marruya and Collado de Hornaza), and more novel Terrestrial Laser Scanning (TLS) to understand rates of surface change, including erosion in both, restored and unrestored blanket bogs. Using TLS it was possible to evaluate ultra-high resolution (<2 mm) 3-dimensional surface change in all five blanket bogs over one year.

The total volume of peat estimated for all study sites was 13,811 m3 and erosion was identified in each site. At Zalama, where bare peat stabilization and fencing has been undertaken, very little change was determined. In the other areas where peat is exposed to trampling, significantly greater rates of change where identified, particularly in summer months when livestock densities are greatest.

The rates of erosion determined over a period of one year in unprotected areas are extremely high for peatland ecosystems, and greater than the global mean annual rate of peat erosion. Restoration actions appear to have had a significant impact on these, and this may predominantly relate to the installation of a fence to exclude livestock. This study highlights that urgent identification and restoration of unmapped blanket bog in North Spain should be undertaken to preserve this habitat.

Session 3C: Observation and Impacts of Fire in the Earth System

Session Chair: Martin Wooster (KCL)
Date: Thursday 6th September 2018
Time: 09:00-10:00
Location: C-Block Lecture Theatre

Biomass burning influence on ozone and precursors over the Amazon: trends and regional source contributions

Richard Pope[1,2], Stephen Arnold[1], Martyn Chipperfield[1,2], Carly Reddington[1], Barry Latter[3], Richard Siddans[3], Brian Kerridge[3], Ed Butt[1]

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Biomass burning is a large source of reactive trace gases and aerosol to the tropical atmosphere, with substantial impacts on the atmospheric radiation balance and surface air quality. In the Amazon, fires are mainly caused by human activity, being used as a tool for land clearance during conversion of forest to agricultural land. These fires produce smoke and trace gases, which are observed across widespread regions of the Amazon basin. A downward trend in deforestation over the Amazon has recently been shown, with associated reductions in biomass burning-sourced aerosol. The effects of fires and temporal changes in fire activity on ozone and precursors in the Amazon region may differ from those on aerosol, due to different emission dependencies on fuel type and fire regimes.

We use long-term satellite datasets (2005-2015) of tropospheric column NO2 and sub-column (0-6 km) ozone from the Ozone Monitoring Instrument (OMI), to investigate biomass burning contributions to NO2 and ozone concentrations over the Amazon region, and trends over the 11-year period. Large enhancements in Amazon region NO2 and ozone are detected in the satellite data during the dry season. Our model simulations show these enhancements are sourced mainly from South American biomass burning emissions, with smaller ozone contributions over the eastern Amazon from easterly import of African biomass burning emissions. The 11-year satellite time-series shows statistically significant trends in observed NO2 both in the deforestation region of the Amazon (negative trend) and in Eastern Brazil (positive trend). These trends appear to be related to trends in deforestation and savannah fire burned area in South America. We use the TOMCAT chemical transport model to investigate the effects of these trends in NO2 emissions on regional tropospheric ozone concentrations. We discuss implications of the observed NO2 trends for ozone air quality in the Amazon region.

African landscape fire activity and the impact of overlying vegetation canopy structure on fire radiative power (FRP) measurements

Gareth Roberts

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African landscape fires are widespread, temporally dynamic and, in addition to altering the land surface properties, are a large source of trace gas and aerosol emissions. Active fire observations can be used to calculate emissions in near real-time using measurements of the fire radiative power (FRP, MW) which is related to the rate of biomass combustion (Kg s-1). The SEVIRI FRP-PIXEL product, available at 15 minute intervals at 3km spatial resolution, is used to assess the spatial and temporal variation in fire activity and fuel consumption across Africa between 2004 and 2016. Annual fire radiative energy (FRE)-derived fuel consumption estimates range between 127-214 Tg in northern

hemisphere Africa and 208-299 Tg in southern hemisphere Africa. The relationship between per-fire FRE-derived fuel consumption (Tg DM) and temporally integrated MODIS productivity estimates (Tg) is strong (average r=0.96) in southern hemisphere Africa but the fuel consumption estimates are ~7% of the accumulated PSN. The disparity between the FRE-derived fuel consumption and accumulated productivity estimates is result of a number of factors, including vegetation canopy obstruction. The latter is investigated FRP using the Discrete Anisotropic Radiative Transfer (DART) model to simulate scenes containing canopies with different structural arrangements and a centrally positioned uniform emissions source. FRP measured at the sensor is found to decrease in proportion to the percentage canopy cover when the canopy is opaque. However, when the canopy is modelled as a turbid medium, the degree of FRP interception occurring at any particular canopy cover decreases (by ~ 14%), due to the fact that some fire emitted radiance is transmitted through the canopy. When corrected for canopy obscuration, annual SEVIRI FRP-PIXEL measurements across Africa increase by ~15%.

Improving landscape fire information within the CAMS Global Fire Assimilation System (GFAS) by ingesting VIIRS and geostationary sensor FRP data

Tianran Zhang[1,2], Martin Wooster[1,2], Weidong Xu[1,2], Jiangping He[1,2]

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Landscape burning is a globally prevalent but unpredictable phenomenon that in many regions displays large interannual variability. Landscape fires have a significant impact on Earth's atmosphere, as well as on many biogeochemical cycles, and affect human health and the climate through their substantial smoke aerosol, gaseous pollutant and GHG (Greenhouse Gas) emissions. Satellite remote sensing has been successfully applied in earth observations for fire detection during the last decade. The capability of thermal remote sensing to quantify the intensity and extent of fires has led to the successful construction of real time systems, such as GFAS (Global Fire Assimilation System) within CAMS (Copernicus Atmosphere Monitoring Service). One of the biggest current challenges within GFAS is small fire detection and quantification, which is very likely significantly underestimated in not only GFAS, but almost all current satellite-based emission inventories. Here we will present information on how new satellites and instruments, such as NPP-VIIRS, Himawari-8 and GOES-R are enabling continued improvement in this capability. This enables regional and global-scale routine monitoring for fire-related air pollutant and GHG transfers to the atmosphere, as well as forecasts indicating how situations of poor air quality related to new fire activity will likely develop over the coming days.

Satellite constraints on smoke plume injection heights for large-scale atmospheric modeling applications

Maria Val Martin[1], Ralph Kahn[2], Laura Gonzalez-Alonso[1], Liye Zhu[3], Emily Fischer[3]

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Biomass burning is a significant source of trace gases and aerosols to the atmosphere, and the evolution of these species depends highly on where they are injected into the atmosphere. Currently, a broad range of poorly constrained or unconstrained assumptions is used to represent the vertical distribution of fire emissions in atmospheric chemical transport, climate, and air quality models. We have developed a plume-height parameterization from statistical summaries of worldwide, region-specific, multi-year MISR space-based plume height stereoscopic imagery. The parameterization consists of fire emission fractions based on land cover units, and is stratified by altitude, region and season. We have implemented the scheme in the CAM-Chem and GEOS-Chem atmospheric chemical transport models. To assess the performance of the fire smoke injection height scheme, we have

compared the output from both models to a series of aircraft and satellite-based observations over regions with active fires. Here we present results from the development, implementation and evaluation of the MISR-based fire injection height climatology in both models and discuss any potential further testing with other models as part of the AeroCom Biomass Burning Phase 2 experiment.

Plenary 2: EO Applications for Government

Session Chair: Emily Gravestock (UKSA) & Farhana Amin (Defra)
Date: Thursday 6th September 2018
Time: 11:30-12:30
Location: Bramall Hall

Earth Observation Infrastructure: Making better use of analysis ready data

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Earth Observation (EO) data has the potential to transform delivery across many policy and operational areas within Defra. However, there are significant overheads to getting 'analysis ready' data to the end users that need it. These barriers are restricting the wider use of EO data especially in terms of informing current and future policy areas to ensure cost effective, more efficient and customer focussed service delivery.

Building on two earlier proofs of concept this project demonstrated in its Alpha Build an open by design infrastructure to provide access to 'analysis ready' data and additional geospatial and analytical functionality through cloud services. The analysis ready EO data and cloud functionality support over 20 projects in forestry, farming, fishing, environment, and marine protection to provide operational and policy insights to help achieve Defra's 25 year environmental plan.

The specific business objectives are to:

• Facilitate consistency, preclude duplication and minimise business costs by delivering a single, cost-effective source of 'analysis ready' EO data

• To facilitate more effective, customer focussed and efficient use of 'analysis ready' EO data so that Defra can extract value from the data and build it into their operational or evidence processes.

The presentation will address some of the key steps employed to automate the retrieval and processing of raw sentinel 1 and sentinel 2 data and to provide discovery, visualisation and analytical services through the cloud to support Defra's evidence and operational needs.

Value of Satellite-Derived Earth Observation Capabilities to UK Government in Nine Civil Use Cases, Today and by 2020

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The presentation of findings from an independent economic study to determine the value of satellite-derived Earth Observation (EO) capabilities to the UK Government in nine civil use cases, today and by 2020.

The study identifies the current use of EO capabilities by UK Government and estimates the value derived by government and indirect beneficiaries in the selected use cases. With the ongoing developments in data frequency and resolution, application innovation and emergence of other enabling technologies, potential use by 2020 is also revealed together with associated value gains.

The current, not insurmountable, barriers associated with realising the future uptake by government are observed and some opportunities for overcoming these barriers, are identified.

Value is presented in terms of what EO capabilities offer the UK government over alternative methods in nine specific civil use cases, domestically. This value relates to operational cost savings, exceptional cost avoidance, better policy decisions and regulation, and catalytic benefits.

The nine civil use cases include: Meteorology, Agriculture, Flood Management, Maritime, Forestry, Coastal Management, the Built Environment, Atmosphere and Transport Networks. The study does not cover Defence, Security or Official Development Assistance.

The Environment Agency's National LIDAR programme

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The Environment Agency has strategic responsibility for managing the risk of flooding. Accurate, timely and complete mapping and modelling is invaluable for informing these management decisions. An important input into this process are detailed elevation models. For many years the Environment Agency has employed LIDAR to map the floodplains of England. Recently there has been a step change in the LIDAR instrumentation available, we have developed new innovative processing techniques, and there is an emerging requirement for full catchment mapping where Natural Flood Management techniques can potentially be employed to reduce flood impacts downstream.

As well as flood management, the Environment Agency has employed it's archive of LIDAR derived elevation data to monitor illegal waste crimes, to help identify locations at risk of soil erosion, and to identify potential areas for tree planting to enhance riparian shading. Other DEFRA bodies have been using the LIDAR derived elevation data to assess wildlife habitat and to help with forest management. As the LIDAR data is Open Data, it can be employed in many ways to understand and manage agriculture, to interpret archaeology hidden in the landscape, and to inform urban planners and developers.

Because of these increasing demands for complete, timely and accurate LIDAR coverage, a decision has been made to undertake a 3 year programme to map the whole of England at 1 metre resolution. This presentation will describe this new LIDAR mapping programme, due for completion in April 2020, and explain how improved instrumentation, operational and data processing techniques will enable this to be achieved.

A new UK Geospatial Commission

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New technology is changing society. Many of the most exciting technologies are linked to location which relies on being able to access the fundamental building blocks of our digital economy, geospatial data. Most of our competitor countries have created some form of governance across the geospatial domain. At the heart of our national data infrastructure there remains a set of impediments to growth whose removal will generate revenue – and will make the UK a more attractive investment destination in an increasingly competitive market. The Chancellor announced at the last Budget that the government would create a new UK Geospatial Commission, allocating £40 million a year over the next two years to support the Commission's development and delivery of identified priorities. Earth Observations are an invaluable component of the geospatial domain, this presentation will update on progress within the Geospatial Commission implementation journey.

Session 4A: Earth Observation Data and Analysis for Rural Environment

Session Chair: Sanjay Rana (Rural Payments Agency)
Date: Thursday 6th September 2018
Time: 14:00-15:15
Location: Bramall Hall

Satellite surveillance to increase operational effectiveness of enforcement to prevent sediment runoff pollution

Crispin Hambidge, Kyle Brown
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Agricultural inputs are the largest factor in reduced water quality across much of England. Water quality is affected by soil erosion, nutrient load and herbicide and pesticide use. Policing these inputs and changing behaviours is an extremely difficult task without an understanding of where these diffuse pollution inputs come from. The Environment Agency are developing a surveillance programme that uses Sentinel-1 and Sentinel-2 data to provide timely information identifying bare-soil fields that may negatively impact water quality. These fields are visited by Environment Officers to determine if there is evidence of significant risk of them causing sediment pollution.

Timely overwinter field mapping is generally required, but use of Sentinel-2 data is cloud-dependent and so a hybrid Sentinel-1/Sentinel-2 technique has been developed. This technique uses the Sentinel-2 data to identify field types in the gaps between clouds. These fields are used to determine the characteristics of different field types in the Sentinel-1 data, which is then used to fill in the gaps. The accuracy of Sentinel-1 and Sentinel-2 for identifying bare fields in the Wye (Severn) Valley, England were tested (Overall accuracy 89% and 97%). The bare soil maps are combined with LIDAR-derived flow pathways and slope maps to identify those bare fields most likely to result in erosion. During heavy rain field surveys, of 50 fields identified by the surveillance 13 were confirmed as presenting an immediate pollution risk and 5 were actually causing pollution driven by heavy rain. This surveillance targeting approach has significantly improved the effectiveness of enforcement operations in the Wye Valley.

The paper discusses exploitation of remotely sensed data analysis by providing data in an easy to use format that end-users can operate easily, with integration of additional relevant datasets. Use of mobile web-mapping as a method of serving up data for in-field use is discussed.

Satellite-based exploration of links between Indian crop production, agricultural fires, air quality and policy

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Agriculture constitutes a significant part of India's economy, providing one of the largest employment sectors and sustenance for India's 1.2 billion population. High agricultural yields and strong productivity, particularly across Northern India, are underpinned by fertile soil and the extraction of groundwater. Unfortunately, the strong dependence on irrigation and intensified agricultural practises have resulted in significant groundwater depletion, and further environmental pressure comes from the widespread burning of the leftover rice and wheat stubble, which degrades air quality

locally and regionally during particular seasons. Over the past few years, these types of agricultural fire emissions are thought to have greatly amplified winter 'smog' episodes in Delhi for example (in Nov 2016 and 2017), resulting in widely reported and extremely poor air quality conditions. Satellite remote sensing provides observations from which the large-scale patterns of vegetation growth, water availability and fire activity can be identified, and their inter-linkages studied. We have used satellite data products from MODIS, AATSR and the Copernicus Land Service to perform a multi-year analysis of north Indian agriculture wheat and rice cropping cycles. We find significant (and sometime unforeseen) couplings between the drivers of agricultural productivity and we link these to changes in state government legislation. We demonstrate how use of such satellite-derived data-sets in the future may better inform evidence based agricultural policy development, both in northern India, and possibly in other areas of the world where similar environmental pressures are resulting from intensified agriculture.

Spectral reflectance profiles of savannah grass species indicate grazing intensity induced in-situ nutrient concentration differences in above ground tissue

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Assessing the nutrient content of grass using earth observation technologies presents opportunities for non-destructive, rapid and repetitive rangeland grass appraisals. In this work the potential to determine in-situ spatial variations in macro and micronutrient content of grass on the basis of spectral reflectance was examined using two palatable savannah species. In-situ reflectance data from the species were collected using a spectroradiometer sensitive in the 350-2500 nm range, at 3 nm resolution. Sampling was conducted at the end of the growing season, in low moisture stress conditions, on mature vigorous grass manifesting no signs of infection. Reflectance from stem and leaf material was collected from each grass specimen, by contact method, and then averaged per given specimen. Thereafter, the tissue material targeted by the spectroradiometer was collected for laboratory analysis of nutrient concentrations. The sampling was conducted in communal and wildlife rangelands representing high and medium grazing intensity, and on a private property cattle ranch representing low grazing intensity. A private estate with no grazing served as control site in the experimental design. A rangeland size-stratified total of 62 grass samples per species was used on the adjacent study sites. Since grazing promotes nutrient recycling through deposition of dung, ANOVA revealed statistically significant differences ($p < 0.05$) in sample nutrient concentrations, with the samples from high grazing intensity rangelands having higher nutrient concentrations. Low nutrient concentrations, notably N, P, and K, tended to increase reflectance in the visible (≈ 580 – 700 nm) and near infrared (≈ 780-1100 nm) spectral ranges in both species, though with subtle differences. Consequently the position of the red-edge zone of reflectance increase shifted with variations in nutrient concentration. The results indicate possibilities for in-situ, non-destructive assessment of spatial differences in nutrient concentrations due to grazing regimes on savannah rangelands, using hyperspectral sensors on earth orbiting satellites.

High resolution vegetation productivity mapping for Wales as an indicator of habitat condition and biodiversity

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Above-ground Net Primary Productivity (ANPP) can be used as an indicator of habitat condition and biodiversity. However, current products are not available at fine enough spatial resolution to observe differences in ANPP at the between-field and within-field scales, limiting their application for management. Hence, the aim of our study was to develop an operational method for high spatial resolution vegetation productivity mapping over wide areas. We have developed a novel empirical approach which combines NDVI imagery from high resolution sensors with widely distributed ground-based ANPP measurements.

Our method searches through all available NDVI imagery to identify the images which give the best relationship between NDVI and ANPP and then the derived relationships are applied to predict ANPP values outside of field survey plots. This approach differs from conventional methods that use annually-integrated NDVI as it enables the use of the high spatial resolution (30 m) Landsat 8 sensor in cloudy areas despite its low revisit frequency.

When tested against a reserved validation dataset, our method was able to estimate ANPP with a RMSE of 15 – 21%. The strongest NDVI-ANPP relationships occurred during the spring 'green-up' period. This is one of few studies to investigate the NDVI-ANPP relationship across a wide range of temperate habitats and strong correlations were observed (R2 = 0.706), which increased when only grasslands were considered (R2 = 0.833).

We will present a general methodological framework for mapping of ANPP, with the potential to be applied in any region with a pronounced vegetation green up period. Results will also be presented showing the relationship between ANPP, NDVI and various biodiversity indicators, demonstrating the potential of our approach for high spatial resolution mapping of habitat condition and biodiversity at a scale fine enough for decision-making and sustainable land management.

Working towards a national habitat map for Northern Ireland: County Fermanagh

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There is an increased effort to conserve unique ecosystems throughout Northern Ireland, and remote sensing can be an effective to monitor and support nature conservation. The focus of this work is to create a habitat map for the county of Fermanagh. Applications from the outputs are wide ranging and can play a key role in decision making within the Northern Irish environment, nature conservation and planning sectors. One of the key deliverables is to enable collaboration between different public-sector organisations.

The work undertaken builds on open source methods for mapping habitats, the Living Maps project developed by Natural England. Sentinel-1 and Sentinel-2 imagery are primary data sources, with additional ancillary open spatial datasets supplied, to map the county of Fermanagh in Northern Ireland. Once the process is established, work will begin to scale up the process, generating a national habitat map. Fermanagh is a distinct county with a geographically diverse landscape, driven by climatic and glacial processes. The maritime temperate oceanic climate of the area means the county experiences cold winters and mild humid summers. This creates a rich ecological landscape with a

high degree of floristic diversity, consisting of numerous aquatic communities, upland and lowland mires and heaths, and scrub woodland. The expansive waterways account for 30% of the county, with a further 14% of the county covered in forest.

A unique classification scheme, devised with colleagues in the Northern Ireland Environment Agency (NIEA) is used. The scheme reflects spatial consideration and the diverse landscape of Fermanagh, alongside what is relevant when scaling up to the rest of Northern Ireland. The combination of Sentinel-1 and Sentinel-2 successfully distinguishes numerous habitats, particularly in the challenging wetland areas around Lough Erne. The resulting classification achieved accurate (>70% overall accuracy) outputs for 25 detailed habitat classes.

Session 4B: Trace Gases in the Troposphere and Stratosphere from Satellite

Session Chair: Jeremy J. Harrison (NCEO, University of Leicester)
Date: Thursday 6th September 2018
Time: 14:00-15:15
Location: G33

Tropical African methane emissions inferred from GOSAT XCH4 retrievals

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Tropical Africa contains the second largest river basin in the world and substantial wetland areas. Wetlands represent the largest individual contribution to natural methane emissions, and up to 20% of these wetland emissions have been estimated to be from tropical Africa based on process model studies. Past work has shown the value of using satellite observations of column methane to infer tropical methane emissions, especially in regions where surface observations are lacking. We use GOSAT XCH4 retrievals, the GEOS-Chem chemical transport model and a Bayesian inversion approach to infer methane fluxes from tropical Africa. We develop a simple model of wetland fluxes based on water table depth and temperature, and use the GOSAT data to fit flux model parameters that describe the spatial and temporal variability of the wetland fluxes. We investigate the extent to which satellite observations of column methane can reduce uncertainties in regional methane fluxes, and evaluate the contribution of regional patterns in wetland emissions to global trends of methane.

Optimal Estimation of Ammonia from IASI

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Ammonia is a highly reactive and soluble alkaline gas, whose atmospheric emissions can have a large impact upon the ecosystem through acidification and eutrophication. Further, ammonia readily reacts with acid pollutants to form ammonium particulate aerosol. These particulates have a longer lifetime, allowing transport over greater distances, and are known to have adverse effects on air quality and human health causing respiratory and cardiovascular diseases. It is therefore key to accurately monitor and quantify ammonia's emission sources. Satellite observations allow global emission sources to be measured daily, providing a significant improvement to emission inventories based solely on local in-situ data.

We present results from ammonia retrievals obtained using the Multispectral Orbital Retrievals using Sequential Estimation (MORSE) retrieval algorithm. MORSE is an iterative optimal estimation algorithm, initially developed for use with the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), which has been adapted for the Infrared Atmospheric Sounding Interferometer (IASI) and utilises the Reference Forward Model (RFM), a line-by-line model, for radiative transfer calculations.

Despite the potential for improved accuracy, optimal estimation retrievals of ammonia from IASI have not previously been pursued due to the high computational costs involved. These costs have been mitigated by the development of monochromatic look-up tables, containing pre-calculated absorption cross sections, within the RFM. This allows the simulation of IASI radiances to be possible at a more operational pace. We compare the results from MORSE with previous methods based on fast linear retrieval algorithms.

IASI observations of hydrogen cyanide (HCN) over Indonesia during the 2015 El Niño event

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Forest fires in Indonesia are a seasonal occurrence, largely due to the agricultural practice of slash and burn in which land is cleared for new planting by cutting back vegetation and setting it on fire. During late 2015, the agricultural fires were particularly severe, due to it being an El-Niño year, impacting regional air quality.

The land in Indonesia contains a lot of peat, which easily burns to emit a variety of trace gases including hydrogen cyanide (HCN). Satellite limb instruments such as the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) instrument and Microwave Limb Sounder (MLS) have measured vertical profiles of HCN, revealing an unprecedented amount of HCN emitted from Southeast Asia during September–November 2015 and transported into the upper troposphere and lower stratosphere.

Here we present nadir observations of HCN total columns derived from the Infrared Atmospheric Sounding Interferometer (IASI) during September–November 2015. IASI observations of carbon monoxide (CO) using the University of Leicester IASI Retrieval Scheme (ULIRS) are used to calculate enhancement ratios of HCN relative to CO and ultimately derive new emission factors for Indonesian peatland which will be used to improve chemical transport models. These satellite-derived data are compared to those already in emission databases such as GFED.

Nitrogen oxides in the global upper troposphere: interpreting cloud-sliced NO2 observations from the OMI satellite instrument

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Nitrogen oxides (NOx = NO + NO2) in the upper troposphere (UT) have a large impact on global tropospheric ozone and OH (the main atmospheric oxidant). New cloud-sliced observations of UT NO2 at 450-280 hPa (~6-9 km) from the OMI satellite instrument produced by NASA and KNMI provide global coverage to test our understanding of the factors controlling UT NOx. We find that these products offer useful information when averaged over coarse scales (20° × 32°, seasonal), and that the NASA product is more consistent with aircraft observations of UT NO2. Correlation with LIS/OTD satellite observations of lightning flash frequencies shows that lightning is the dominant source of NOx to the upper troposphere except for extratropical latitudes in winter. We infer a global mean NOx yield of 280 moles per lightning flash, with no significant difference between the tropics and mid-

latitudes, and a global lightning NOx source of 5.6 Tg nitrogen per year. There is indication that the NOx yield per flash increases with lightning flash footprint and with flash energy.

Is the ozone layer recovering?

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As a result of the 1987 Montreal Protocol and its amendments, the atmospheric loading of anthropogenic ozone-depleting substances is decreasing. Accordingly, the stratospheric ozone layer is expected to recover and there is evidence that the Antarctic ozone hole is decreasing in size. However, short data records and atmospheric variability confound the search for clear signs of recovery. Moreover, climate change is masking ozone recovery from ozone-depleting substances in some regions and will increasingly affect the extent of recovery. Here we discuss the nature and timescales of ozone recovery, and explore the extent to which it can be currently detected in different atmospheric regions. We use height-resolved and total column satellite observations and 3-D chemical transport model (CTM) simulations to study stratospheric ozone variations during 1980-2017 as ozone-depleting substances increase and then decline.

Moreover, a particular issue has emerged for the tropical lower stratosphere. A recent paper (Ball et al., ACP, 2018) has argued that rather than recovering ozone in this region decreased through 2016. However, we (Chipperfield et al., GRL, 2018) find that in 2017 extrapolar lower stratospheric ozone displayed a strong positive anomaly following much lower values in 2016. This points to large interannual variability rather than an ongoing downward trend, as reported by Ball et al. The observed ozone variations are well captured by our CTM throughout the stratosphere and are largely driven by meteorology. Model sensitivity experiments show that the contribution of past trends in short-lived chlorine species to the tropical ozone changes after 1998 is small. Similarly, the potential impact of modest trends in natural brominated short-lived species is small. These results confirm the important role that atmospheric dynamics plays in controlling ozone in the extrapolar lower stratosphere on multiannual timescales, and the continued importance of monitoring ozone profiles from satellite as the stratosphere changes.

Session 4C: Calibration and Validation of EO Data and Products

Session Chair: Paul David Green (National Physical Laboratory)
Date: Thursday 6th September 2018
Time: 14:00-15:15
Location: C-Block Lecture Theatre

A consistent approach to retrieve coarse resolution spectral BRDF from combined satellite data

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The addition of Sentinel-3 OLCI and SLSTR to sensors such as MODIS, Proba-V or VIIRS has resulted in an daily revisit frequency over most points of the land surface using coarse resolution data. However, these different sensors all have different spectral, angular and spatial characteristics, and also observe the land surface at different times. Combining these observations is challenging. The parting assumption in this contribution is that the main observable to be derived from any of these sensors is an inference of the bi-directional reflectance density function (BRDF) over a set of narrow spectral bands. We present a a generic method to combine observations from different coarse resolution sensors and to infer these magnitudes (together with relevant uncertainties) directly from the L1b (swath) data. The method is based on using the BRDF descriptors over narrow bands to provide an a priori estimate of the surface reflectance, which is then combined with atmospheric composition data from the Copernicus Atmospheric Monitoring Service (CAMS) and an atmospheric radiative transfer model. The model is used to invert the top-of-atmosphere observations to provide an update in the surface BRDF as well as inferences of aerosol optical thickness (AOT) and other atmospheric constituents. The method uses spectral transformations to blend observations from different sensors.

The BRDF descriptors are are then processed further to calculate broadband white sky albedo, and these data are then interpreted by a simple radiative transfer model to retrieve land surface parameters such as effective LAI or leave and soil optical properties. We demonstrate this approach for combining data from the MODIS and OLCI sensors.

AMT4SentinelFRM radiometric validation of Sentinel-3A OLCI

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The Atlantic Meridional Transect (AMT) programme has been one of the most valuable sources of high quality in situ measurements for remote sensing over the past 20 years. The Copernicus Sentinel Atlantic Meridional Transect Fiducial Reference Measurements Campaign (AMT4SentinelFRM) makes use of the AMT platform to provide high quality Fiducial Reference Measurements (FRM) to validate Sentinel ocean colour and sea surface temperature satellite products. In this work we use above water radiometric in situ data collected during the AMT26 field campaign (September-October 2016) for the validation of Sentinel-3A OLCI (Ocean and Land Colour Instrument). We employ pre- and post-cruise calibration to generate post-cruise uncertainty budgets for our optical instruments (HyperSAS and TriOS radiometers), to quantify the overall uncertainty of each FRM and to identify and correct for biases. Quality-control procedures are then defined to ensure FRMs are of accuracy compatible for satellite validation. To match the high quality of the in situ dataset, we implement a robust match-up procedure that takes into account homogeneity, quality and spatial variability issues. Finally, we perform a comprehensive accuracy assessment of Sentinel-3 OLCI level 2 remote sensing reflectances

over a range of conditions. The FRM methodology presented here offers a clear advantage in the number and quality of match-ups over traditional techniques, providing a decisive tool for algorithm development and validation of satellite products for the Sentinel data streams.

An inverse method for the retrieval of LST and LSE from ASTER

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Understanding the changing and complex urban thermal environment is key to addressing the health and sustainability of the cities in which more than half of the world's population live. The monitoring and assessment of the thermal environment requires spatial resolution that so far has precluded air temperatures from being a viable parameter in most cities. Land surface temperatures (LSTs) offer the ability through satellite remote sensing to investigate the urban environment in a robust and consistent manner. Additionally land surface emissivity (LSE) is required to enable accurate LST estimation and characterise broad-scale thermal infra-red properties of materials.

In this work, the first optimal estimation of simultaneous LST and LSE data optimised to be robust for areas with highly complex surfaces is presented. It uses the thermal channels of the ASTER instrument with a spatial resolution of 90 m. The simulation uncertainties retrieved are better than 1 K in LST and 0.015-0.017 for LSE. This marks the first usage of an inverse method with ASTER data. Verification of the LST and LSE was undertaken, through both validation at key sites and an inter-comparison with the TES method. Results agreed well with TES with very low retrieval radiance residuals. These results show the retrieval of robust and scientifically meaningful LST and LSE data for a heterogeneous environment from ASTER.

Setting up and application of a radiometric vicarious calibration site at Gobabeb, Namibia

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RadCalNet is a network of instrumented radiometric calibration test sites being established by the Committee on Earth Observation Satellites Working Group on Calibration and Validation. Each site will have permanent instrumentation to provide ground spectral reflectance (400 nm to 2500 nm) and atmospheric data. These results are provided to a central server, where they provide a top-of-atmosphere reflectance product that can be used to calibrate, validate or compare satellite sensors.

The decision to locate the new ESA/CNES vicarious calibration site near the Gobabeb Research and Training Centre in Namibia was taken following a comprehensive global study. The final specific location was determined during a two week field measurement campaign by CNES and NPL in November 2015. The selection process involved a visual assessment of the surfaces, GSM coverage tests (to ensure reliable data transmission), and a detailed characterisation study of the spectral reflectance and homogeneity of the chosen test site.

In July 2017 the permanent instrumentation was installed. This involved mounting a CIMEL sun photometer on top of a 10 m mast from which measurements of the atmosphere and surface are taken.. A weather station and all-sky camera were also placed at the site.

The CIMEL sun photometer tracks the Sun, makes measurements of its direct irradiance, and then measures the diffuse irradiance across the sky. It also makes measurements of the ground radiance at a range of angles, both zenith and azimuth. This approximately two hour sequence is repeated throughout the day.

These data are then processed into a top of atmosphere reflectance product, which (along with the other RadCalNet sites) can be used by satellite operators or data users to assess their data and add

traceability to their results. The uncertainty involved in these comparisons is currently being assessed by NPL.

Scientific Altimetry Studies from Pole to Pole with CryoSat-2

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CryoSat-2 is Europe's first ice mission and features an advanced radar altimeter specifically designed to monitor the most dynamic sections of Earth's cryosphere. CryoSat-2 acquires data over all surfaces, including the global ocean where the altimeter operates mainly in conventional low-resolution-mode (LRM) but, over a few regions, in SAR (synthetic aperture radar) mode. A dedicated operational ocean processor has existed for CryoSat-2 since April 2014 (Baseline B) and an improved version of the processor (Baseline C) was introduced in November 2017. Baseline B has now been used to provide data for the full-length of CryoSat-2 operations (from November 2010 onwards) and this whole-mission dataset will shortly be re-processed using the improved Baseline C.

Within the ESA funded CryOcean-QCV project, the National Oceanography Centre (NOC) is responsible for routine quality control and validation of CryoSat Ocean Products. Activities include daily and monthly reports providing global assessments and quality control of Sea Surface Height Anomaly (SSHA), Significant Wave Height (SWH), backscatter coefficient (Sigma0) and wind speed, as well as a suite of validation protocols involving in situ data, model output and data from other satellite altimeter missions.

This presentation provides details of the available CryoSat-2 ocean products as well as some of the calibration and validation results obtained for SSHA, SWH and wind speed using data tide gauges, wind and wave buoys, WaveWatch III wave model output, HF radar surface current data and comparisons with Jason-2 and Jason-3.

Session 5A: EO Applications to City Sustainability

Session Chairs: Eloise Marais (University of Birmingham), Michael Barkley (University of Leicester) & Phil Wilkes (UCL)
Date: Thursday 6th September 2018
Time: 15:45-17:00
Location: Bramall Hall

Evaluating Carbon Emissions from Space-based CO2 observations

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Carbon dioxide is the most important anthropogenic greenhouse gas, where the burning of fossil fuels, gas and cement production are considered as the main sources of the anthropogenic carbon dioxide (CO2). The atmospheric concentration of CO2 has increased from 280 ppm at the start of the industrial revolution to 410 ppm till April 2018. Particularly important are the emissions from urban areas and cities, where human activities are intense and contribute about 70% of global fossil fuel emissions. In recent years several satellites have been launched, having the capability to observe the total CO2 column globally thus complementing the highly accurate but sparse in situ surface network.

We will use current satellite missions including OCO-2, GOSAT and TANSAT to evaluate signals in CO2 related to anthropogenic enhancement from city emissions. The focus will be on the Los Angeles area as a well-studied testbed and several large Chinese cities representing one of the largest emission region globally. To link the satellite observations of atmospheric CO2 to surface emission, we carry out column footprint calculations using the UK Name Office Dispersion model NAME which will then allow us to evaluate emission inventories (such as EDGAR and ODIAC) against satellite observations.

Monitoring city-wide air quality using Earth observations

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Air pollution has adverse effects on human health, but is challenging to routinely monitor throughout cities. Earth observations of atmospheric composition provide complete coverage of cities, but are cumbersome and challenging for public authorities and city councils to use. We present first steps to develop and validate a tool that end users can use to monitor city-scale air quality with Earth observations. We use surface observations of NO2 for 2011-2016 from six monitoring sites in Birmingham (UK) to validate that tropospheric column NO2 observations from the Ozone Monitoring Instrument (OMI) accurately represent temporal changes in NO2. Surface concentrations of monthly mean NO2 averaged around the satellite overpass (12h00-15h00 local time) decrease by 1.5-4.2%/a across the monitoring sites. Sites are spatially correlated ($R > 0.55$) and so are combined to obtain representative city average NO2 that is temporally correlated with OMI NO2 ($R = 0.69$). We apply OMI NO2 to estimate very significant (p-value < 0.001) decline in NO2 of 3.4%/a (95% CI: -4.3 to -2.5%/a). This is similar to the reported UK-wide decrease in NOx emissions of 3.9%/a. There is no equivalent

documented trend for Birmingham. Similar validation will be completed for Earth observations of sulphur dioxide, ozone, carbon monoxide and aerosol optical depth in Birmingham and London. This approach will then be applied to estimate air pollutant trends in rapidly developing cities like New Delhi, Kathmandu, Jakarta, Ontisha, Johannesburg and Sao Paulo.

Evaluation of a discrete-wavelength DOAS-like NO2 retrieval approach for the High-resolution Anthropogenic Pollution Imager (HAPI) instrument concept

Cristina Ruiz Villena[1], Roland Leigh[1], Paul Monks[1], Claire E. Parfitt[2], Joshua Vande Hey[1]

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Outdoor air pollution is a major environmental health risk, particularly in urban areas. Nitrogen dioxide (NO2) is one of the primary air pollutants and is monitored at a global scale using satellite instruments. These traditionally use the well-established Differential Optical Absorption Spectroscopy (DOAS) technique.

DOAS retrievals of NO2 are commonly done using high-resolution spectral information – usually hundreds of channels. This requires the use of complex hardware and provides limited spatial and temporal resolutions. Even recent developments, such as TROPOMI, with a 7x7 km spatial resolution, struggle to resolve NO2 features at sub-urban scales and provide only one measurement per day at any given location.

In the work presented here a novel approach for NO2 retrievals in the visible is evaluated for the advancement of the High-resolution Anthropogenic Pollution Imager (HAPI) instrument concept. HAPI, developed by the Air Quality group at the University of Leicester, provides increased spatial resolution by reducing the amount of spectral information used in the retrieval (< 20 channels). The use of fewer channels also allows for simpler, cheaper instrument designs that could be deployed in constellations of small satellites, which in turn would allow for lower revisit times.

Discrete-wavelength DOAS retrievals are challenging due to NO2 being a weak absorber and the limited spectral information. However, previous work using synthetic data suggests that they are possible provided there is a good signal-to-noise ratio. In the work presented here the analysis has been taken a step further: discrete-wavelength DOAS-like retrievals of NO2 are evaluated using real data from existing hyperspectral satellite instruments. Different instrument filters, retrieval parameters, and algorithms are considered. A statistical analysis of the retrieval results is conducted, including a classification by land cover type, with the aim of finding the optimal configuration for the HAPI instrument concept.

A London-wide estimate of urban forest density and structure derived using LiDAR and Sentinel-2 imagery

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Urban forests are recognised for providing a range of ecosystem services to city dwellers, including, pollution suppression, aesthetic and wellbeing benefits as well as acting as a carbon sink. This previously undervalued resource is particularly important as urbanisation of the world's population continues unabated. New methods are required to accurately quantify the properties of urban forest; however, assessment poses particular problems owing to high species diversity as well as heterogeneous and dynamic land cover. Here we present a remote sensing based approach to estimate tree density and canopy structure across the Greater London Authority (GLA) area (1572 km2). Airborne LiDAR data, freely available from the UK Environment Agency, were used to directly measure canopy structure. However, the extent of the current EA data span less than a third of the

GLA area. To extrapolate to the wider area, ALS-derived estimates of tree density, canopy cover and canopy height were used to train a Random Forest classifier on the Google Earth Engine platform, with Sentinel-2 bands used as predictor variables. Preliminary results indicate there are ~5.5m trees (34.9 trees ha-1) in the GLA area, with an average canopy height of 14.7 m. Total and per hectare canopy cover are estimated to be 270 km2 and 1740 m2 respectively, equal to 17.4% of Greater London area. Results suggest noticeably fewer trees, but greater canopy cover, than that of a previous iTree Eco survey based on 721 field plots. The new methods presented could provide government and local authorities the tools required to effectively monitor urban forests dynamics, over large spatially continuous areas as well as through time.

Evaluating EBBI, NDBI and NDBaI Techniques from Landsat 8 Data for Mapping Built-Up and Bare-Land in Urban Areas

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In urban areas of developing countries remotely sensed data have been widely used in monitoring and mapping of land use changes, which primarily occur as results of increase urbanization and urban growth. The remotely sensed data provides timely and synoptic view for land use, such as urban built-up and bare-land areas. Mapping of urban built-up areas been challenging in many land use/land cover as most widely classification techniques were unable to accurately separate urban built-up from bare-land. Thus, the objective of this study was to assess and evaluate the Enhanced Built-Up and Bare-Land Index (EBBI), Normalised Difference Built-Up Index (NDBI) and Normalised Difference Bareness Index (NDBaI) for characterising built-up and bare-land within Yola metropolis in Nigeria. The method involved the generation of these indices (EBBI, NDBI and NDBaI) from Landsat 8 data to separate built-up from bare-land within urban areas. The initial results show that EBBI performed better compared to NDBI and NDBaI in separating built-up from bare-land. The performance of EBBI over NDBI and NDBaI could be influenced by the unique spectral bands characteristics of combined near infra-red (NIR), short wave infra-red (SWIR) and thermal infra-red (TIR). Thus, EBBI has shown to be an effective technique in distinguishing built-up from bare-land within urban areas that will be valuable for urban environmental planning and policy decision making.

Session 5B: Earth Observation for Earth System Model and Evaluation

Session Chair: Robert Parker (University of Leicester)
Date: Thursday 6th September 2018
Time: 15:45-17:00
Location: G33

New monthly diurnal cycle TOA flux products from GERB designed for model evaluation

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The Geostationary Earth Radiation Budget (GERB) instruments on board the Meteosat Second Generation spacecraft provide unique observations, at high temporal resolution, of the reflected shortwave and emitted longwave energy at the top of the Earth's atmosphere. Presented here are new diurnally resolved monthly averages of the top-of-atmosphere (TOA) reflected shortwave (RSW) and emitted longwave (LW) flux products derived from the GERB-1 instrument. The GERB-1 record spans the period from 2008 to 2012 covering the region 60°N-60°S, 60°E-60°W. These hourly time-step-monthly mean fluxes are designed primarily for comparison with climate model output in response to demand from the climate modelling community, and will be submitted to the Observations for Model Intercomparison Projects (Obs4MIPs) data archive. The methods used to calculate these fluxes are described, and their associated uncertainties discussed. Examples of these new products will be provided along with comparisons between these and the latest version of monthly mean all-sky Clouds and the Earth's Radiant Energy Systems Energy Balanced Fluxes (CERES EBAF Ed.4.0). Initial results indicate that the GERB SW and LW fluxes are typically 5.4% higher and 2.0% lower than CERES, respectively when averaged over the GERB observational region. The potential origins and significance of these differences will be discussed along with the implication for their use in climate model evaluation.

Evaluating soil moisture limited evaporation regimes in HadGEM-A and UKESM1 using satellite land surface temperature

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Soil moisture availability exerts a strong control over land evaporation in many regions. However, global climate models (GCMs) disagree on when and where evaporation is limited by soil moisture. Evaluation of the relevant modelled processes has suffered from a lack of reliable, global observations of land evaporation at the GCM grid box scale. Satellite observations of land surface temperature (LST) offer spatially extensive but indirect information about the surface energy partition and soil moisture limitation on evaporation. Specifically, as soil moisture decreases during rain-free dry spells, evaporation may become limited leading to increases in LST and sensible heat flux.

We have developed a method that uses MODIS Terra and Aqua observations of LST for 2000 to 2013 and aggregated from 1 km to 0.5° to evaluate changes in the large-scale surface energy partition during dry spells lasting 10 days or longer. This temperature-based approach can diagnose the typical strength of short term changes in surface heat fluxes and, by extension, changes in soil moisture limitation on evaporation. This method is based on surface quantities that are commonly available from climate models (e.g., 2m air temperature, surface temperature, rainfall) to facilitate the comparison between those models and observations. Here we use this framework to assess the land surface behaviours in several versions of a climate model (HadGEM2-A, HadGEM3-A and UKESM1) running AMIP simulations.

Implementation and evaluation of soil nitrogen fluxes in the Community Earth System Model (CESM) for enhanced rock weathering applications

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The Community Earth System Model (CESM) is a fully coupled Earth System model, which includes atmosphere, land, ocean and sea-ice components. CESM has participated in many climate experiments, e.g., CMIP and CCMI, to improve our understanding of the Earth System. Within CESM, we implemented and improved a suit of soil nitrogen flux schemes to study the effect of enhanced weathering, a CO2 removal strategy, on trace gas emissions (NO, N2O and NH3) and the implications for atmospheric composition (including tropospheric O3) and climate feedbacks. To assess the performance of the updated schemes, we evaluated model results against observations. We compiled a series of Earth Observations of soil nitrogen observations, from field measurements of fluxes in croplands and natural systems to larger scale satellite-based observations, and analyzed output from detailed emission inventories. Here we present results of the soil nitrogen gas fluxes evaluation and discuss the challenges in the current state of the Earth Observations for agricultural soils and natural systems.

Satellite-based retrievals of the terrestrial carbon cycle to constrain projections of the land carbon sink

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Skill-based multi-model averaging methods have been used extensively in climate and hydrological sciences as an attempt to reduce the uncertainty and determine high confidence regions in projections from large ensemble of models. Unfortunately, observations of ecosystem dynamics are not available at spatiotemporal scales relevant to apply these methods to global projections of the terrestrial carbon cycle. Here, we use the CARbon Data MOdel framework (CARDAMOM) to produce a re-analysis of the terrestrial carbon cycle constrained by remotely sensed observations of leaf area and biomass stocks. CARDAMOM relies on a Bayesian Markov Chain Monte-Carlo model-data fusion to retrieve confidence intervals of model parameters that regulate ecosystem properties. Furthermore, the model-data fusion approach ensures that retrievals of carbon fluxes, stocks and allocation are part of a representation of ecosystem dynamics in agreement with ecological knowledge.

Using CARDAMOM retrievals of the current terrestrial carbon cycle, we then perform a pixel-wise Reliability Ensemble Averaging (REA) of 30 global projections of 21st century NPP by ISIMIP models under a 'business as usual' emissions scenario. We find that the REA supports an increase in global NPP by the end of the 21st century that is ~2% stronger than the ensemble ISIMIP mean value of 24.2 Pg C y-1. Using REA also leads to a 68% reduction in the global uncertainty of NPP projections, which strengthens confidence in the resilience of the CO2-fertilization effect to climate change. This reduction in uncertainty is especially clear for boreal ecosystems. Conversely, large uncertainties remain on the sign of the response of NPP in semi-arid regions.

In conclusion, we demonstrate how satellite-driven model-data fusion approaches can help (i) retrieve the modern terrestrial carbon cycle with confidence intervals, (ii) constrain projections from global vegetation models and (iii) delineate regions where uncertainties remain large to inform further model development.

Comparing apples and pears: Evaluating aerosol within the UKESM

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Aerosols affect the climate directly by scattering and absorbing radiation and indirectly by altering the properties of clouds or influencing plant growth. A realistic distribution of aerosol is thus necessary to represent the Earth's radiation budget within a climate model. The UKESM accurately reproduces the monthly average aerosol optical depth (AOD) reported by the MODIS instruments. However, there are substantial differences between the AOD fields reported by other instruments and/or algorithms due to differences in sensitivity and quality filtering, making it unclear what satellite data the models should be evaluated against. This presentation will introduce the mechanisms that produce such differences and outline a methodology to compare a climate model to the ensemble of satellite observations. That method will be applied to the most recent output from the UKESM, demonstrating that the representation of aerosol has improved since the project's inception but still needs improvement in the Asian outflow.

Session 5C: EO Applications as Part of Official Development Assistance

Session Chair: Ray Fielding (UKSA)
Date: Thursday 6th September 2018
Time: 15:45-17:00
Location: C-Block Lecture Theatre

An Earth Observation-based dengue early warning system for Vietnam

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Before 1970 only nine countries had experienced severe dengue epidemics. Today the disease is endemic in 141 countries, affecting 390 million people globally. The total global annual cost of dengue fever has been estimated to be almost US$9 billion per year, which is three times that of cholera and over four times that of gastroenteritis. Since 2000, there has been an increase of over 100% in the number of cases of dengue fever in Vietnam, with 122,000 cases occurring in 2016.

In Vietnam there is currently no system to forecast the probability of future dengue outbreaks. Recently the epidemiological situation in Vietnam has been worsened by the failure to maintain adequate control of the *Aedes aegypti* species of mosquito that spread dengue fever and also Zika. This project is developing a forecasting system that will allow public health authorities to identify areas of high risk for disease epidemics before an outbreak occurs, in order to target resources to reduce epidemic spreading and increase disease control. The project is funded by the UK Space Agency's International Partnership Programme.

Earth Observation (EO) datasets will be combined with health and water availability information to produce a new integrated dengue forecasting model. The model will link EO data with weather forecasts and a hydrological model to predict the likelihood of future dengue epidemics up to eight months in advance. The tools produced will also be used to increase the understanding of climate change-related health risks during a period when Vietnam is developing an updated National Adaptation Plan in line with its Paris Agreement obligations.

The dengue forecasting tool will also include a water availability module, which will help to improve water management in Vietnam's transboundary river basins where there is a paucity of hydro-meteorological information.

Slavery from Space: Remote Sensing Holds an Important Key to Abolition

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The most recent Global Slavery Index estimates that there are 40.3 million people enslaved globally. The UN's Agenda 2030 for Sustainable Development Goal number 8, section 8.7 specifically refers to the issue of forced labour: ending modern slavery, including child labour, in all forms by 2025. Although there is a global political commitment to ending slavery, one of the biggest barriers to doing so is having reliable and timely, spatially explicit and scalable data on slavery activity. The lack of these data compromises evidence-based action and policy formulation. Thus, to meet the challenge of ending modern slavery new and innovative approaches, with an emphasis on efficient use of resources are needed. This presentation demonstrates the fundamental role of remote sensing as a source of evidence. The Brick Industry in south Asia will be used as a focus; slavery is known to be prevalent in this industry (e.g., up to 70% of labour is bonded in Indian kilns).

A number of approaches to using satellite data and data types for slavery prevalence estimation will be presented – ranging from an estimate of the number of brick kilns using a using a robust design-based inferential method that can be easily adopted by key agencies for evidence-based action (i.e. NGOs) and is based on freely available and accessible remotely sensed data, through to the use of machine learning and citizen science for mapping. We will show that using these data from remote sensing we can also calculate the impact of slavery beyond that of the enslaved people themselves, on, for example, environmental change and impacts on ecosystem services – this links to other Sustainable Development Goals. As the process of achieving key Sustainable Development Goal targets will show, there are development benefits to ending slavery and remote sensing is an important key to doing so.

From bug to satellite: a 21st century pest risk information service (PRISE) for Africa

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Pests can decimate crops and are estimated to cause around a 40% loss of yield across sub-Saharan Africa. These losses can impact on food security and impede supply chains and international trade. The UK Space Agency IPP Project PRISE - 'Pest Risk Information Service' - aims to reduce this problem by forecasting in advance the threats that farmers face. Supporting farmers in up to six countries across sub-Saharan Africa, PRISE will accomplish its goals by combining satellite Earth observation and meteorological data inputs with biological pest and pathogen models, using this combination to provide better risk warnings to users. Model outputs will be fed back to local farmers by a team of in-country 'plant doctors', who can access the forecasts and related information via mobile phone. Feedback from the plant doctors and their farming communities provides forecast evaluation and improvement. The early iteration of the PRISE system is now operational in Zambia, Ghana and Kenya. Prior to PRISE, mathematical models for pest and disease lifecycles have been driven by temperature and rainfall data gathered from sparse meteorological stations and/or coarse resolution global weather models. One of the novel aspects of PRISE is its use of very high temporal resolution metrological satellite data and machine-learning driven downscaling to estimate both surface temperature, 2-m air temperature, and in-canopy temperatures, with the aim of driving the biological models with the most relevant thermal data for each pest. All data generated for use in PRISE is being collated into a 'data cube' to facilitate rapid access to the spatially consistent set of environmental information relevant to pest modelling. In addition to real-time data, historical data and climatologies will be included to compare information on previous pest outbreaks to past conditions and detect any anomalous events.

Mapping resilience, and impacts of natural disasters in the Caribbean British Overseas Territories: a natural capital approach.

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The UK Government provides strategic support to the Overseas Territories (OTs) which includes promotion of sustainable economic prosperity whilst meeting the social, economic and environmental needs of the islands, their inhabitants and visitors. As part of this support, JNCC is implementing a suite of projects under the work programme 'Enhancing Economic Security through Environmental Resilience'. Many of the projects use satellite data to map and model both marine and

terrestrial environments, to discover the value of the natural environment (natural capital) and provide guidance for decision making and extreme event management.

The work, which began in early 2017, produced spatial maps that inform on risk to life and infrastructure based on the impacts of hurricanes. There is a focus on the environment's role in mitigation and protection, as it is often overlooked. In addition to the current state, modelling scenarios of degraded and enhanced ecosystems were used as part of economic evaluations for each territory. 2017 Hurricanes Irma and Maria provided an unfortunate opportunity to validate the work based on actual damage of infrastructure, with the results producing accuracies of >95% of mapping and modelling outputs. Working together with the OTs, the maps can be used to provide critical information to aid planning decisions during recovery and for coastal developments, securing long term resilience of infrastructure, and the economic and social benefits provided.

How EO4cultivar is using satellite data to improve understanding of food supply chains

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High value agriculture in South America is a major contributor to global food supply chains and local economies. Peru and Colombia use sophisticated production and shipping practices to deliver 4% of food consumed in the UK. There is a need for technologies that provide producers and buyers with increased visibility over these complex supply chains and Earth observation has an important role to play.

EO4cultivar is a four year project funded by the UK Space Agency that is developing EO-based solutions that can be easily disseminated and incorporated into local and national management practices. Working with commercial and government stakeholders in Peru and Colombia, the project is delivering information frequently and rapidly within the growing season via trusted channels.

In this talk we will focus on the solutions EO4cultivar is developing for asparagus producers in Peru. In particular we will focus on how seasonal time series of Sentinel-1 synthetic aperture radar (SAR) imagery provides high spatial resolution and wide area coverage that allows both local and regional assessments of the asparagus crop. At the local scale, we will outline how these data are being used to monitor the performance and target management of individual fields by producers. We will also outline how this targeted information can be supported by estimates of regional production status to provide new insight into the market, allowing producers to adapt their management accordingly.

Poster Session 2

Date: Thursday 6th September 2018
Time: 17:00-19:00
Location: Great Hall

Session Topics:

- Calibration and validation of EO data and products
- Earth Observation data and analysis for the rural environment
- Earth Observation for Earth system model evaluation
- EO applications as part of official development assistance
- EO applications for government
- EO application to city sustainability
- GEO and CEOS
- Observations and impacts of fire in the Earth system
- Photogrammetry and image processing for the Earth and environmental sciences
- Trace gases in the troposphere and stratosphere from satellite

Working Group on Earth Observations for Ecology and Epidemiology of Water-associated Diseases

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Several million cases of water-associated disease are reported globally each year from water-borne or vector-borne pathogens. A large number of cases may be avoided through improved access to water and sanitation, and a further number could be saved by improving prediction of disease outbreaks and health risks, using an integrated approach involving in situ observations, laboratory experiments, remote sensing and modelling. We are proposing a new Working Group to identify benefits, best practices and feasibility of incorporating Earth observation measurements into early-warning systems for water-associated diseases. It would provide a forum to exchange useful information, share data and coordinate activities where feasible, to maximise benefits to society. The WG aims to engage with specialists in the fields of ecology, epidemiology, bioinformatics, genetics, remote-sensing, modelling, climate, limnology and oceanography, and link with end-users, including local communities, governments, health services, intergovernmental organisations, and policy makers. This new initiative has been recognised as an important GEO Blue Planet activity, and further adding value to GEO health community of practice and AquaWatch initiatives.

ECOPOTENTIAL: Using Earth Observation to Protect Natural Ecosystems

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Earth Observation missions, and in particular recent European Sentinels, now provide information at unprecedented high spatial and temporal resolution on every corner of our Planet. Novel approaches for blending these advanced technologies with field work and conservation issues aimed at understanding and modelling status and changes of ecosystems are at the heart of ECOPOTENTIAL, a large European H2020 project with 47 partners, running from 2015 to 2019. ECOPOTENTIAL works on 25 protected areas (PAs) in Europe and beyond, spanning all biogeographical regions of Europe and focusing on mountain, arid and semiarid, coastal and marine environments. ECOPOTENTIAL has

strong links with other international research programmes, such as GEO ECO, eLTER, GEO BON and LifeWatch. In particular, all data, models and knowledge will be available on common and open platforms through a virtual laboratory contributing to the GEOSS, the Common Infrastructure of the Group on Earth Observation (GEO). The project also include a wide programme for building a community of practice through seminars, training, citizen science actions and outreach. This talk will present the concepts underlying ECOPOTENTIAL and results from three years of the project.

Evaluating Climate Model Outputs with the ESMValTool

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We present an overview of the **ESMValTool**, a community driven diagnostic and performance metrics tool for evaluating Earth System Models (ESMs) that are part of the Coupled Model Intercomparison Project (CMIP). ESMValTool's newest release, version 2.0 includes a data preprocessing engine and a large library of diagnostics based on peer-reviewed scientific literature covering inter-model as well as model to observational data comparisons

The preprocessor functionality in the ESMValTool offers standardized data analysis operations that are common to a large number of diagnostics. It supports variable derivations, regridding, masking, extracting temporal and level specific data as well as producing multi-model statistics. The output consists of netCDF files that can be easily assimilated into pre-existing as well as novel diagnostics. The ESMValTool thus enables evaluation by standardizing the input and preparation of data hence allowing users to develop and employ diagnostic software for their specific needs.

We illustrate the ESMValTool's capabilities in the context of evaluating climate model estimates for gross primary productivity (GPP). GPP is the rate at which carbon is taken up by plants during the process of photosynthesis. Reliable estimation of GPP by climate models is therefore important for us to better compute the global carbon budget.

An objective approach towards determining necessary oceanographic model resolution to capture SST variability in the Southern Ocean

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We present an objective analysis of the Nucleus for European Modelling of the Ocean (NEMO) model skill in representing sea surface temperature (SST) in the Southern Ocean (SO) by comparing three model resolutions: 1/12 degree, 1/4 degree and 1 degree. The results show that 4-5 times resolution scale is sufficient for the model to reproduce the magnitude of satellite Earth Observation (EO) SST spatial variability to within +- 10 %. This agreement improves further with scale, and above approximately 500 km each of the models matches the EO to within +- 3%. However, by increasing model resolution from 1 degree to 1/12 degree, model representation of large scale (750 km) EO variability patterns improves by more than 50%. The model input SST drivers are classified based on their variability scales: the drivers with large scale variability (85% of 1500 km variability resolved at the 80 - 100 km scale) are identified as incoming short-wave radiation, wind stress and wind speed; whereas eddies and wind stress curl are drivers with small scale variability (85% of 1500 km wind stress curl variability resolved at the 10 - 20 km scale). Bathymetry and atmospheric heat fluxes have medium scale variability (85% of 1500 km variability resolved at the 20-40 km scale). The SST and SST driver variability scale with two power law regimes separated by a scaling break. The SST scaling

regimes are explained by comparing SST and SST driver horizontal anisotropy and by comparing how the magnitude of SST and SST driver variability distributes across the 7 - 1500 km range of scales.

GEO Climate Workshop: Earth Observations for the Paris Agreement

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The Paris Climate Agreement, which was adopted in 2015 (and entered into force in 2016), calls on Parties to "strengthen scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making" (Article 7.7c). While the potential for Earth observations (EO) to support effective policy and decision making for climate change mitigation and adaptation is fairly well established, it remains unclear how well it is currently positioned to provide direct support to key pillars of the Paris Agreement (i.e., Adaptation, Loss & Damage, Capacity Development/ Technology Transfer, National Reporting/ Global Stocktake, Mitigation), and where immediate gaps and opportunities are.

This presentation will review some of the outcomes of the Group on Earth Observations (GEO) Climate workshop that was held in June 2018. In particular, it will highlight the results of the mapping exercise of the GEO activities and national (including the UK) perspectives to the Paris Agreement, the gap analysis and opportunities, and the list of recommendations and actions.

Estimating percentage bare peat from Landsat data, using Random Forest Regression

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Peat bogs are an important habitat and carbon sink; storing 50% of global terrestrial carbon. However, large areas of British peat bogs are in poor condition, with areas of exposed peat. Bare peat is an obvious sign of erosion and carbon loss, typically due to atmospheric pollution and land management strategies. Consequently, it is important to ensure the condition of peat bogs is maintained, or improved, to optimise their potential as a carbon sink.

Long term, large scale peat bog monitoring is difficult as field surveys are time consuming, labour intensive and costly. Aerial photography has long been used to investigate broad scale habitat changes, however there are financial and logistical difficulties in getting a regular supply of timely, good quality, high-resolution imagery from planes and UAV's. This causes difficulties for the continuous monitoring of peat bog condition.

The method proposed here uses aerial photography to provide training data, which is used to train a Random Forest Regression (RFR) model that can be applied to Landsat data. The first stage is to classify bare peat on aerial photography. The high spatial resolution of the aerial photography makes it possible to obtain percentages of bare peat within the individual, lower resolution Landsat pixels. The second stage is to train the RFR model and apply it to the Landsat data to estimate percentage bare peat. The method was then validated using a separate set of pixels. The method was tested and validated using aerial photography for four 3km x 3km areas of the Peak District.

The RFR predictions were found to have an accuracy of over 70%. The process can be applied quickly once developed, making it a viable method for long term, large scale peat condition monitoring.

Crop yield mapping from Sentinel-2

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Accurate yield predictions is required for multiple applications including precision agriculture, government and industry decision making, and monitoring food security. EO data offers many opportunities for improving crop yield estimation with the potential for better spatial coverage, more regular updates, reduced costs of mapping and better resolution globally. Combined with suitable training data EO has the potential to provide reliable high resolution crop yield maps on multiple scales.

In this study the capability of Sentinel-2 to estimation within-field wheat yield variation on a landscape-scale is assessed. This study focuses on five key questions which explore the impact of data resolution and data availability through the season. This achieved by varying the input data/variable combinations and assessing the impact on the accuracy of yield estimation. Yield data collected by combine harvesters was used to train Random Forest models, using different dataset combinations, to estimate within-field yield variation. In this study wheat was chosen as the crop of interest due to its high prevalence within the available dataset. However, as other studies have demonstrated, similar techniques can be used to estimate yield for a variety of crops, so it is likely the methods used here for wheat are transferable to other crops.

The results show that accuracy is higher when working at 10m resolution compared to 20m resolution and Random Forest produces better results than using simpler vegetation index based methods. Results are presented for over 20 different combinations of input data. The highest accuracies are produced when using spectral data and ancillary data, with a RMSE achieved of 0.61 tonnes per hectare.

Integrating Geographic-Object-Based Image Analysis with soft classification for land cover mapping in the Niger Delta: A precursor to understanding the impacts of the oil industry

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Land cover information is crucial in society because it provides information on the distribution of both anthropogenic and natural features, which can be used by individuals, corporate bodies and government institutions for a variety of different applications (e.g., urban planning, conservation, monitoring the environment). Land cover maps are often generated based on remote sensing, however, for a map to serve its intended purpose, the techniques and dataset employed for such mapping must be carefully considered. This work aims to map land cover types in the Niger Delta region of Nigeria, for the purpose of understanding land cover change driven by the oil industry. A number of different mapping approaches are compared, including both pixel- and object-based, hard and soft classification techniques that are applied to Landsat 8 imagery. The combination of geographic-object-based image analysis and soft classification was found to produce the most accurate land cover maps, mainly because it helped to overcome the problem of mixed pixels that affect the traditional per-pixel approach. The land cover mapping results for the year 2016 shows that the broadleaf forest is the dominant land cover type covering about 32% of the area, followed by mangrove (22%), sparse vegetation (19%), bare ground/wasteland (12%), water (11%), built up (4%) and sand (0.2). Accurate multi-temporal land cover maps produced using the optimum approach can now be used to better understand the nature and magnitude of land cover change in the Niger Delta region and attribute this to the dominance of oil in the region

Quantifying the influence of 11-year solar flux variability and volcanic aerosol on stratospheric ozone using satellite datasets and a 3-D model

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Among the various chemical and dynamical processes that affect the stratospheric ozone layer, solar flux variability and volcanically enhanced stratospheric aerosol are key natural forcings. Their impact needs to be understood in order to diagnose accurately the ozone depletion caused by human activity. Satellite datasets are now of sufficient length to provide a good constraint on these processes.

Here we use a 3D Chemical Transport Model (CTM), with different chemical and dynamical conditions, to quantify effects of solar flux variability and stratospheric aerosol changes on stratospheric ozone. Model simulations with solar fluxes from NRL solar spectral irradiance model covering almost four 11-year solar cycles (1979-2017) show somewhat different solar responses during individual cycles that could be attributed to changing stratospheric chlorine loading, as well as varying solar flux changes during different solar cycles. The model-simulated ozone solar response shows excellent agreement with that derived using satellite data sets.

The model also simulates the observed hemispheric asymmetry in mid-latitude ozone losses following the Mt Pinatubo eruption in 1991. The simulations show much smaller ozone losses following recent (since 2000) minor stratospheric eruptions (Volcanic Eruption Index (VEI) >4) that are in agreement with both satellite and ground-based total ozone measurements.

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A Scaled Linear Retrieval for IASI

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IASI is a nadir-viewing infrared spectrometer flown on the MetOp satellites, which routinely acquires over a million spectra a day. The challenge of processing such a large quantity of data has stimulated the development of a variety of fast 'linear' methods, essentially just taking the dot product of the IASI spectrum with a pre-defined 'gain' vector to extract a number representing the concentration of some molecule.

Linear methods work well enough for the qualitative detection of sporadically occurring species such as volcanic SO2, or NH3, but a fundamental limitation in deriving more quantitative estimates is that the gain vector itself depends on the atmospheric state: the size of a molecular absorption peak

depends not only on the concentration of the molecule, but also on other factors such as the temperature contrast between the earth's surface and the atmosphere.

A modified linear retrieval scheme is presented where, in addition to the standard linear retrieval, a second parameter is retrieved which represents the scaling factor for the gain vector. As well as providing a more accurate estimate of the concentration, this also generates a meaningful error estimate.

Emission Factors from boreal peat fires

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Peatland fires can emit trace gases and pollution over periods of months to years. Emissions Factors (EF), measured in g gas/kg fuel, can be used with satellite fire products such as Burned Area or Fire Radiative Power (FRP) to estimate total emissions from fires. This study aims to measure boreal peat EF at peat moisture contents and fire conditions representative to real peatland fires.

Peat samples were taken from one virgin site and one site that had previously been subjected to wildfire. The samples were dried to different moisture contents and ignited under conditions that simulated either a crown fire or a duff fire. The smoke was collected with a heated sampling line and pumped to a closed-path FTIR spectrometer, allowing more than 30 trace gases to be simultaneously measured. Forward modelling was used to convert the data to gas concentrations which were then converted to weighted EF. Pre and post fire peat chemistry (C, N, P, S, Mg, P, and K content) was measured. A correlation analysis between the EF of gases containing those elements and the sample chemistry was made.

The poster will show the variation of boreal peat EF with peat properties (chemical composition, moisture content, density, etc.), fire conditions (crown fire, duff fire) and combustion regime, and discuss their implications.

National Geohazard Mapping in Europe: Interferometric Analysis of the Netherlands

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The launch of Copernicus, the largest Earth Observation program to date, is significant due to the regular, reliable and freely accessible data to support space based geodetic monitoring of physical phenomena that result in natural hazards. Here, wide-area interferometric synthetic aperture radar (InSAR) capability is demonstrated by means of processing 436 Copernicus Sentinel-1 C-Band SAR images (May 2015 – May 2017) using the Intermittent Small Baseline Subset (ISBAS) InSAR method to produce a wide-area-product covering the Netherlands. Velocities from four interferometric stacks, containing over 10 million solutions, were mosaicked together to produce a seamless deformation product some 63,000 km2.

The Netherlands is a highly dynamic country, susceptible to land subsidence due to its geological composition and high land use intensity - particularly significant due to its low-lying topography and vulnerability to flooding. Deformations affecting the Netherlands can be broadly classified into two categories: shallow Holocene motions (up to 30 metres) induced by peat oxidation, sediment compaction and dewatering; and deeper sources driven by gas production, mining and underground water pumping. Across the mosaic the spatial distribution of deformations concurs with other independent sources of data, such as previous PSI based deformation maps and the Netherlands subsidence prognosis map, and quantitatively with GPS measurements over the Groningen gas field.

The retrieval of low-resolution measurements over soft surfaces (agricultural fields, forests, semi-natural areas and wetlands) was significant due the dominance of non-urban land cover in the Netherlands (86%). A statistical analysis of velocities reveals that intermittently coherent measurements can provide reliable, additional deformation information outside of urban areas. The regular spatial sampling aided the analysis and such measurements can provide additional insight into phenomena.

The processing flow and results presented here demonstrate the potential to derive wide-area, spatially distributed measurements over the whole of Europe and elsewhere across the globe.

Information gain from convective-scale ensemble forecasts for the sea-breeze prediction.

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In this project we quantify the information gained about sea-breeze occurrence from a dynamically downscaled convection permitting ensemble versus a statistical model obtained using Bayesian post-processing of the driving global ensemble.

A new method for automatic detection of sea-breeze fronts in convection-permitting forecasts (applicable in principle to any coastline) is proposed and used to create sea breeze forecasts. The Bayesian forecast is created using paired high-low resolution ensemble members as training dataset. In essence the method forecasts the high resolution member based on large-scale variables from low resolution model. The aim of this is twofold: -firstly to develop a method to extract information from the low resolution prior to the running of the high resolution for real time forecasting ; secondly to provide an estimate of the information gained by running the high resolution forecast beyond that which is contained in the large-scale flow conditions.

The reliability and resolution of the sea-breeze occurrence probabilistic forecasts are tested statistically for both forecasting systems.

Comparison of the two forecasting methods using area under the ROC curve, the difference between the resolution terms of the information gain score and the log-likelihood ratio test for the sufficiency all lead to the same conclusion: although the Bayesian model provides useful information about sea-breeze occurrence as it has greater resolution than climatology, the convection-permitting model has significantly greater resolution and therefore provides greater information at all forecast lead times

The production of 20+ year height-resolved ozone data from GOME-class instruments for ESA-CCI and C3S.

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RAL's ozone profile retrieval scheme for the GOME-class of solar uv/vis backscatter spectrometer has unique sensitivity to tropospheric ozone, which led to its selection for nadir ozone profile retrieval from this class of sensor in ESA's Climate Change Initiative (CCI) and inclusion in the Tropospheric Ozone Assessment Report (TOAR). The JASMIN computing facility at RAL has enabled the production of full-mission global data sets from GOME-1, OMI and GOME-2A, resulting in over 20 years of height-resolved dataset for ozone from 1995-2017, spanning both stratosphere and troposphere.

A reprocessing of data has been enabled under the Copernicus Climate Change (C3S) project and work is underway to reconcile and interpret these data time series. We present some of the retrieval scheme advancements and highlights of the latest version of the dataset.

RAL has developed an "Infrared Microwave Sounding (IMS)" scheme to retrieve ozone along with temperature and humidity profiles and surface spectral emissivity jointly from MetOp IASI, MHS & AMSU. This has been applied to the full MetOp-A mission 2007-16. Progress on improving vertical information in the upper troposphere/lower stratosphere by the combined IMS-GOME-2 ozone retrieval will also be presented.

G-CLASS: an ESA Earth Explorer mission candidate

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G-CLASS (or Geosynchronous Continental Land-Atmosphere Sensing System) has been proposed for ESA's Earth Explorer 10 mission opportunity. The geosynchronous orbit (GEO) enables almost continuous imaging over continental scales to tackle science questions which require temporal sampling of hours or better. Since radar is sensitive to water vapour in the atmosphere and water at the surface (soil moisture, snow, etc.), a GEO radar could advance our understanding of several important processes of the daily water cycle (e.g. diurnal variations of soil moisture and snow melt, development of intense storms and consequent flooding and landslides). The long range from GEO means that relatively long radar integration times will be required, and so imaging would only be possible over land surfaces (and short wavelength radars will be unable to operate over dense vegetation). Data products are expected to be 2D maps of atmospheric water vapour at ~1 km resolution every 10-20 min, surface backscatter at ~20 m every hour, and ground motion (using interferometry) several times a day.

Geophysical measurement requirements defined by the international science community (meteorology, hydrology, etc.) have been translated into corresponding radar image parameters. The resulting mission design can be implemented using existing technology (e.g. standard small-GEO satellite, 7 m lightweight antenna, C-band radar with 300-400 W output power) and within the EE10 constraints. Other practical constraints such as RF interference appear manageable.

A GEO radar would provide unique data which powerfully complement the capability of conventional low Earth orbit (LEO) radars. The intensive temporal sampling would provide temporal context for LEO observations, the coverage possible from GEO for low latitudes (e.g. Africa, southern Europe) is much better than even Sentinel can provide, and highly flexible imaging modes can be implemented without the constraints of LEO repeat periods. We believe that G-CLASS is a strong candidate for implementation.

Evaluation of temporal aggregations of Sentinel-1, Sentinel-2, and Landsat-8 data for land-cover mapping

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Land-cover mapping provides essential information about environmental processes, habitat changes, and human activities. Land-cover mapping of large areas (i.e. regional or national scale) is challenging due to the large amounts of data to acquire, process and the need to deal with clouds. Recent increases in cloud-computing mean novel approaches to land-cover mapping are emerging. One of these approaches is temporal aggregation- the use of metrics (i.e. mean or median) derived from satellite data over a period of time. Temporal aggregation might help with the challenges of mapping large areas by enabling efficient use of multi-temporal data, filling cloud gaps, and minimizing the effects of automatic pre-processing inaccuracies. However, whether the accuracy of land-cover maps

using temporal aggregation matches that of classical approaches has never been tested. Here, we assessed the accuracy of land-cover maps created with temporal aggregation of Sentinel-1 (S1), Sentinel-2 (S2), and Landsat-8 (L8) data.

35 datasets were created for Wales using temporal aggregation over different time intervals. The data included single-sensor and multi-sensor data. Google Earth Engine was used to apply automated cloud-masking and to aggregate the data. For comparison a traditional-style two-date composite was created with manually processed Sentinel-2 data. Supervised classifications were created and their accuracy was assessed using field-based reference data.

Temporal aggregation accuracy only matched the traditional-style two-date composite (overall accuracy of 77%) when an optimal combination of optical and radar data was used. Data combining S1-S2-L8 for two time intervals obtained an overall accuracy of 76%, outperforming single-sensor datasets.

Temporal aggregation is a promising tool for integrating large amounts of satellite data in a fast and efficient way. However, optimal input datasets, in terms of satellite data combinations, temporal intervals and other aggregation parameters are needed in order to match the accuracies of traditional-style manually processed image composites.

High Precision Automated Alignment Procedure for Telescope Construction

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A significant challenge in the production of earth observation satellites is the alignment of the telescope optical components. A misaligned telescope can lead to aberrated images and is a major cause of failure of satellite missions with optical imaging payloads. The current industrial approach to aligning the telescope optics during the build phase is manual. For example, in alignment of a Ritchey-Chrétien telescope the secondary mirror is aligned to the primary mirror using adjustments informed by measurements from camera images of alignment laser beams and from live interferometry. These are highly skilled heuristic and time-consuming techniques that can have a significant impact on build schedule. We have developed a strategy using adaptive optics methods to perform automated alignment of a Ritchey-Chrétien telescope for use in a realistic factory-based setting. The secondary mirror is mounted on a high precision hexapod. The misalignment of this mirror is inferred from a phase-shifting interferometer using the Zernike coefficients for tip, tilt, defocus and coma. The required corrections to the position of the secondary mirror are implemented using an integral controller and alignment is achieved within minutes, compared to days to weeks using a manual alignment process. The Zernike coefficient for each term is reduced to under 10 nm. The alignment algorithm is robust to changes in external conditions such as temperature and can also be used for other telescope designs. Future work will include the development of an alignment strategy that can be used for telescope designs that open out in space. This will involve using live images of the ground to guide the alignment, rather than interferometry.

Improving the condition number of estimated covariance matrices

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High dimensional covariance matrices arise in applications from numerical weather prediction to finance. Approximate sample covariance matrices are used in practice, but these can be ill-conditioned and lead to numerical problems. In this paper we present new theory for two existing methods that can be used to reduce the condition number of (or 'recondition') any covariance matrix: ridge regression, and the minimum eigenvalue method. These methods are used in applications, but the impact of parameter choice is not well understood. Here we address this by investigating the impact of reconditioning on variances and covariances of a general covariance matrix in both a theoretical and practical setting. Improved theoretical understanding provides guidance to users with respect to both method selection, and choice of reconditioning parameter. The new theory shows that both methods increase variances compared to the original matrix, and that the ridge regression method results in a larger increase to the variances compared to the original matrix than the minimum eigenvalue method for any covariance matrix.

We also prove that the ridge regression method strictly decreases the absolute value of off-diagonal correlations. We apply the reconditioning methods to two examples, one a simple general correlation function, and one arising from numerical weather prediction. The minimum eigenvalue method results in smaller overall changes to the correlation matrix than the ridge regression method, but in contrast can increase off-diagonal correlations.

Overcoming variation in airborne optical data sets via semi-supervised machine learning; a case study in tree species classification

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Illumination and environmental variation pose a significant problem in the analysis of vegetation from airborne optical datasets. Variability in illumination conditions during image acquisition arises due to changing solar-sensor geometry and cloud cover. Further, spectral variability in vegetation can also arise as a result of soil type, water availability and inter-species variation (e.g. provenance). This variability limits the performance of predictive models (e.g. classifiers) built using limited training samples.

This study addresses these problems with reference to the classification of tree genus in a mixed broad leaf woodland, utilising features derived from airborne hyperspectral and photogrammetric imaging. Firstly, the study attempts to mitigate all sources of variation by prioritizing pixel values which are closer to the labelled ground truth, employing a series of gradient boosting decision trees joined using ensemble undersampling principles. Secondly, the study addresses the notion of vagueness, in relation the uncertainty that ground survey includes all possible class labels i.e. tree species. The research explored both unsupervised and supervised techniques to better estimate if a pixel was within a known class or an 'unknown' class.

The results from this technique are compared with a standard methodology using metrics derived at canopy scale appropriate for end-users.

Vegetation and evapotranspiration trends in the catchment of the vanishing Lake Poopó

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Lake Poopó is an endorheic, shallow water body located in the Andean Mountain Range Plateau, in Bolivia. For decades, the extent of Lake Poopó closely mimicked the catchment precipitation patterns. However, in the last decade years, the lake has experienced an unprecedented rapid shrinkage, defying the previously observed correlation with precipitation.

This study used MODIS and PERSIANN data to reconstruct vegetation (NDVI), evapotranspiration (ET) and precipitation trends in the 103,878 km2-large Poopó catchment for the period 2000-2015. The Google Earth Engine platform was used to access and analyze time series including over 500 MODIS and PERSIANN products.

A linear trend was interpolated for the NDVI and ET values on pixel basis. The gradient was mapped, revealing the spatial distribution of different temporal trends. A clear, statistically significant NDVI and ET increasing trend was observed on cropland areas in the central and eastern part of the basin for the whole study period. Virtually no temporal trends surfaced during the dry season, while all the increments occurred in the cropping season. In contrast, no significant changes were found in the spatio-temporal distribution of the rainfall.

The observed increase in vegetation and associated ET losses in the extensive croplands of the central Poopó catchment between 2000 and 2015 coincides with the increase in quinoa production in Bolivia and with the price increase of this cereal in the international market. These results strongly suggest that crop practices exacerbated the water losses in the system, in detriment of the final recipient, which is Lake Poopó. However, the observed increase in ET over autochthonous vegetation, where NDVI and precipitation values did not augment, suggests that environmental factors, such as temperature, may have also played a role. These factors and their links to Lake Poopó's water storage are currently being investigated.

Ground-Based Observations for Validation of Copernicus Global Land Products: Land Surface Temperature

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The Copernicus Global Land Service provides a wide range of satellite and earth observation derived products focused on monitoring of the terrestrial environment. For these products to be of use for environmental decision-making they must be validated using independent data sources to ensure they are of high quality and consistency.

Validation of satellite-derived products has traditionally been through intensive field campaigns, which enable the spatial variability of the variable of interest to be well-characterised over a particular site but are limited in time and space. In recent decades, numerous ground-based monitoring sites have been established as part of several wider ground-based observation networks. The spatial variability is not as well-characterised for these sites, but they provide a better sampling of data and provide useful information in terms of temporal consistency of products.

The Ground-Based Observations for validation of Copernicus Global Land Products (GBOV) project aims to develop and distribute robust in-situ datasets from these ground-based monitoring sites for a systematic and quantitative validation of all seven Copernicus Global Land Products (CGLPs). In GBOV, observations from identified monitoring sites are processed into various point-scale reference

measurements and then upscaled in order to be more representative of the equivalent CGLP pixel, which will cover a much wider spatial area.

Here we present the methods used to upscale in situ Land Surface Temperature (LST) data for validation of the Copernicus Global Land Service LST product. We describe the derivation of in situ LST data from radiometric observations at several ground-based monitoring sites. We then outline the upscaling method used to estimate LSTs which are equivalent to a CGLP pixel from the derived point-scale in situ LSTs. We also present preliminary results comparing the validation of the Copernicus Global Land Service LST product with upscaled LST data instead of point in situ LST data.

Assessing the EUSTACE estimates of air temperature from satellite and their uncertainties: selection of reference data and validation results

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As part of the EUSTACE (European Union Surface Temperature for All Corners of Earth) project estimates of surface air temperature from satellite with uncertainties have been made for land, ocean and ice surface domains using skin to air relationships derived within the project. These from-satellite data are being used, along with in situ data, as inputs to a global air temperature analysis which will span the period from 1850 to present day.

This paper describes the selection of reference in situ air temperature observations for validation of the from-satellite and analysis air temperature estimates and the results of validation of the from-satellite data and their uncertainties.

The selection of in situ stations over land is particularly complex as ideally we would have all climate regions and all landcover types represented in the reference dataset. The ice domain presents a different challenge due to the low number of observations available.

The validation shows the EUSTACE air temperature estimates to have very small biases of a few tenths of a kelvin with robust standard deviations of less than 1 K over the ocean and around 3 K over the land and ice domains. Biases are larger over land surfaces where the skin-air temperature differences can be over 15 K.

The uncertainty estimates are validated by comparing a model which takes into account the uncertainty in the in situ data and the uncertainty in matching a station point value with a gridbox average. Results over land, ocean and ice show the EUSTACE uncertainty estimates agree well with the modelled values.

Time auto-correlated model error in the Ensemble Kalman Smoother

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Data assimilation is often performed in a perfect-model scenario, where only errors in initial conditions and observations are considered. Errors in model equations are increasingly being included, but typically using rather ad-hoc approximations with limited understanding of how these approximations affect the solution and how these approximations interfere with approximations inherent in finite-size ensembles.

We provide the first systematic evaluation of the influence of approximations to model errors on weak-constraint ensemble smoothers. In particular, we study the effects of prescribing temporal correlations in the model errors incorrectly in a Kalman Smoother, and in interaction with finite ensemble-size effects in an Ensemble Kalman Smoother.

For the Kalman Smoother we find that an incorrect correlation time scale for additive model errors can have substantial negative effects on the solutions, and we find that overestimating of the correlation time scale leads to worse results than underestimating. In the Ensemble Kalman Smoother case, the resulting ensemble-based space-time gain can be written as the true gain multiplied by two factors, a linear factor containing the errors due to both time-correlation errors and finite ensemble effects, and a nonlinear factor related to the inverse part of the gain. Assuming that both errors are relatively small, we are able to disentangle the contributions from the different approximations. The analysis mean is affected by the time-correlation errors, but also substantially by finite ensemble effects, which was unexpected. The analysis covariance is affected by both time-correlation errors and an in-breeding term.

This first thorough analysis of the influence of time-correlation errors and finite ensemble size errors on weak-constraint ensemble smoothers will aid further development of these methods and help to make them robust for e.g. numerical weather prediction.

Measuring observation influence in the Met Office's UKV assimilation system

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A measure of the influence that the observations are having in data assimilation (DA) is essential for monitoring the performance of the DA system and allows for changes to the way observations are assimilated to be assessed. Here we propose two metrics based on the degrees of freedom for signal computed using residual and innovation statistics. The first quantifies the expected influence of the observations that would be achieved if all assumptions were correct. The second quantifies the actual influence of the observations. The difference therefore gives a measure not only of how optimal the DA system is but also the harm that is being caused by the sub-optimality.

In this work these measures are applied to the assimilation of Doppler radial winds in the Met Office's UKV system. In this case it is found that underestimating the combined uncertainty in the observations and prior results in the actual influence of the observations being much larger than expected. By assimilating the radial winds with different observation operators, it is demonstrated how the differences between the expected and actual observation influence can be attributed to errors in the assumptions in the forward model, the observation uncertainties and the prior uncertainties.

Evaluation of Land Surface Albedo ECVs from QA4ECV for fitness for purpose

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In the EU-FP7-QA4ECV* project (Muller et al., EGU2017–18977), a 35 year record (1982-2016) of Earth surface spectral and broadband albedo (i.e. including sea-ice) using optimal estimation has been

developed for the land and where available, relevant sensors for "instantaneous" retrievals over polar sea-ice. For land, this requires the longest possible "a priori" dataset for land surface spectral and broadband BRDF record that is supplied by a daily summary of 16 years of MODIS Collection 6 BRDFs at 500m. The JASMIN computer at RAL was used to generate 7 spectral bands and 3 broadband BRDF with and without snow and for snow_only.

After several iterations of the input NASA-NOAA Long-Term Data Record (LTDR) of AVHRR (Franch et al., 2017) and the development of a novel snow/cloud mask using all 5 spectral bands, a 35 year record of 3 broadband albedos (0.4-0.7, 0.7-3 and 0.4-3µm) has been produced and is available through http://www.qa4ecv.eu/ecvs. For the shortwave product we ingest BRF derived from GEO for different spatio-temporal coverages. Each 0.05º and 0.5º daily and monthly pixel has an associated uncertainty derived in the processing and QA metadata compatible with EU-C3S and other international standards. We report here on the validation of this AVHRR(+GEO) product using inter-comparison with other coincident global land products (e.g. MODIS, VEGETATION/GLIOGL and GEO), with tower-based measurements from several different networks (e.g. SURFRAD, FLUXNET, BSRN) as well as upscaling studies using field PARABOLA and NASA CAR airborne measurements (Kharbouche et al., 2017; doi: 10.3390/rs9060562).

A fitness for purpose has also been assessed by the LMU group using numerical GCM modelling techniques based on AMIP which will be discussed.

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UVSAT - A low-cost UV-VIS CubeSat for air quality assessments

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Air quality is one of the most significant environmental challenges of the 21st Century. Air pollution costs $3-5 trillion in welfare costs per year, affects most people, causes 9 million premature deaths, reduces crop yields, and alters the biodiversity of aquatic ecosystems. Public awareness and concern about air quality is increasing, but many toxic air pollutants (e.g. nitrogen dioxide, NO2) are invisible and their formation pathways are complex. This poses a challenge for public authorities to develop well-informed air quality policy.

The UVSAT mission delivers a unique dataset capable of adding value to air quality services across the world. Using spectroscopy optimised for CubeSat platforms, tropospheric ozone, nitrogen dioxide and aerosol optical depth amongst other air quality indicators will be retrieved and used to rapidly validate air quality models that inform air quality management and mitigation strategies. Where emission inventories are poorly constrained, this dataset can deliver vital information for air quality management systems.

UVSAT, a Copernicus challenge awarded concept, is designed to contribute to the global challenge of monitoring air quality and emissions by delivering hyperspectral data in the ultraviolet & visible (190-800nm) range.

The instrument proposed is highly innovative, coupled with a new on-board calibration mechanism, allowing observations of air quality markers such as Sulphur and Nitrogen dioxide, Ozone and Aerosol content. This allows for low cost constellation solutions to be a service that complements larger space solutions. Shorter revisit times enhance new opportunities and provide valuable data input for industry, policy makers and governments into air quality monitoring (including maritime), forecasting systems (volcanoes), wildfire or and maritime pollution. Using broader spectral information than traditional instruments, this payload captures spectra in an exceptionally small form factor and is agile and scalable to be tailored to the specific requirements of customers.

Sentinel-2 and Landsat-8 analysis data ready system for Ghana

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The availability of observations from the Sentinel 2 and Landsat 8 missions provides an unprecedented volume of data for land surface monitoring applications. Both missions provide high resolution optical observations with similar spatial, temporal and spectral characteristics. In most land surface applications, the raw top of atmosphere observations need to be processed to compensate for the effect of the atmosphere, as well as to flag clouds, cloud shadows, etc. While pre-processing chains exist for both sensors, they are inconsistent, and this complicates blending the datasets. Also, ordering and pre-processing data is fairly involved.

In this contribution, we introduce a consistent, multi-sensor level 2 processor for high resolution sensors. We show how spatial space/time surface reflectance composites are produced for a large area in Ghana, and we show how these products are disseminated to potential users using only a standard website and a user-end API that allows easy subsetting, reprojection or resampling.

Process-Oriented Evaluation of Water Vapour in UKESM

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Water vapour is arguably the most important greenhouse gas in the atmosphere as it influences (directly and indirectly) the radiative balance of the Earth as well as surface and soil moisture fluxes. While being sufficiently abundant and short-lived that it is essentially considered under natural control. With a predominant capacity for positive feedback, water vapour acts as the largest amplification mechanism for anthropogenic climate change compared to radiative forcing from greenhouse gases. This makes water vapour a critical variable for climate studies.

In this study, we begin to set out a framework for evaluating water vapour fields from climate and Earth system models that goes beyond direct comparison of static geophysical parameters. Results will be shown for CMIP5 model runs, evaluting water vapour fields in regions of ascending/moist and subsiding/dry air. This work brings together current efforts from the GEWEX water vapor assessment (G-VAP) and ESA's Climate Change Initiative (CCI) within the scope of UKESM assessment by NCEO.

Methane source detection and quantification over UK industrial targets using Hyperspectral Remote Sensing

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With a growing concern towards mitigating greenhouse gas emissions on the short-term, methane's short lifetime in the atmosphere (compared to that of carbon dioxide) makes it a good candidate to address. For this purpose, detecting and quantifying methane point sources is key, as they are currently poorly understood. Within these sources, an emphasis on the anthropogenic component from fossil-fuels, agriculture and waste is important, where monitoring and reducing emissions is possible.

Traditionally, bottom-down methods have been used to identify and measure methane sources at a regional scale. However, we will present a top-down approach using aircraft hyperspectral imagery with metre resolution. To do so, a flight campaign was conducted with NERC-ARF over industrial targets in the UK. The target focus was on major emitters as identified in the UK emission data inventory, one of them being an oilfield where ground-based data was also collected and will be presented.

In addition to this, as Sentinel-5P data becomes available, we will use high spectral resolution satellite data to complement this ability to detect and quantify CH4 emissions with high spatial resolution using aircraft data. Overall, this will improve our understanding of different emission sources for national budgets, provide additional information that can contribute to inventory-based methods, and quantify emissions such as leaks which can become Greenhouse Gas reduction targets.

Assessing the suitability of the ULIRS to retrieve OCS profiles and total columns from simulated IASI spectra.

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The challenge in precisely quantifying the sources and sinks of atmospheric carbon dioxide (CO2) is that the CO2 taken up by plants during photosynthesis cannot be distinguished from the CO2 released by plants and micro-organisms during respiration. It has been shown that carbonyl sulfide (OCS) can be used as a proxy for photosynthesis. The relationship between OCS flux and photosynthetic uptake of CO2 has been quantified for various species of plants and ecosystems, the results of which have been used to quantify this relationship on a continental scale. The aim of this project is to both quantify the location and magnitude of the sources and sinks of atmospheric OCS, and to use these data to infer photosynthetic uptake of CO2 by vegetation on a global scale.

The Infrared Atmospheric Sounding Interferometer (IASI), onboard each of the MetOp satellites, measures top-of-atmosphere radiances from which OCS total columns can be retrieved. In order to assess the information content from an IASI OCS retrieval, we have performed retrievals from simulated IASI spectra, generated by the Reference Forward Model (RFM), using the University of Leicester IASI retrieval Scheme (ULIRS). The ULIRS is an optimal estimation retrieval scheme, utilising 30 equidistant pressure levels and a floating pressure grid.

The 3D chemical transport model TOMCAT will be adapted to include emissions of OCS, carbon disulphide (CS2) and dimethyl sulfide (C2H6S), as well as their sinks to provide a detailed representation of OCS chemistry. By using IASI spectra from October 2006 to the present day we will be able to generate a 12-year on-going global satellite dataset of atmospheric OCS.

Machine learning-enabled fire spread simulation as input to Fire Information Service

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CGI UK is developing a seamless, machine learning-based fire information system that delivers fire risk analysis offline but is also capable of providing regular short range predictions of live fire progress when provided with near real time information related to the fire forcing conditions. Post fire impact and recovery analysis could also be supported.

A customised machine learning model has been developed which is capable of being trained rapidly with large volumes of data. To provide sufficient training data, the process is performed in two stages.

Firstly a large number of ensemble runs are prepared using a physically based fire spread model run under a wide range of conditions. The inputs to, and outputs from, these model runs are used for the initial training. In a second training stage, a large volume of observed fire ignition points and spreads are input, together with their associated environmental and forcing data. This ensures that the machine learning model is as fully aligned as possible with observed outcomes. A process of cross validation is then applied to check that the model performs as expected.

To operate in near real time mode, the model will be provided with contextual data to describe the situation in which the fire has been detected as well as current and short term forecast forcing data. It will use appropriate calibration data for the ecosystem zone within which the fire has occurred along with the local static conditions to forecast the development of the fire.

For risk assessment applications, the model requires either simulated hotspot inputs which can be randomly generated across the field of interest or ignitions at specific areas of known concern. In each case, the model is run with a range of forcing conditions to establish the spatial pattern of fire risk.

Novel InSAR for national-scale monitoring of peatland condition and restoration in SE Asia

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Tropical forest fires affect 20 million+ people in SE Asia, leading to significant deteriorations in public health and associated premature mortalities. Such fires also contribute substantially to global CO2 emissions and other widespread negative environmental impacts, as was clearly evident during the extreme 2015 outbreaks. Many of these fires occur within drained peatland areas.

Climate change and existing land use trends mean that, without intervention, peat fire frequency and impact are expected to increase. The only long-term intervention is to retain the natural hydrology of intact peat swamp forests and raise water levels in disturbed areas. However, the costs of restoring and maintaining peat condition across huge peatland areas (~250K km2 in SE Asia) are enormous. The planning and prioritisation of such activities, as well as monitoring intervention effectiveness, is therefore vital. Furthermore, better observations of peat condition also enable improved understanding of the delivery of peatland ecosystem services.

Satellite observations of peat condition can play a hugely valuable role in peatland monitoring, but currently are under-exploited. A recent advance in satellite interferometric SAR (InSAR) data processing shows a remarkable capability to map peat condition (via vertical displacement), even beneath a forest canopy. The PASSES project is combining this capability with information derived from conventional satellite measurement techniques to develop a comprehensive peatland monitoring service.

PASSES is also aiming to demonstrate that wide area, routine, comprehensive monitoring of peatland is now not only technically feasible but can also be highly cost effective by combining the freely available, continuous observations from Sentinel satellites of the EU Copernicus programme, with emerging industrially hosted processing capabilities.

Validation of greenhouse gas observations from satellites using a portable FTS based in Uganda

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Tropical Africa is a key region for the global methane and carbon cycle due to its extensive wetlands, large tropical forests and significant annual biomass burning. However, the frequent presence of enhanced aerosol levels (from fire) and cirrus clouds makes satellite retrieval susceptible to bias. Yet current ground-based observation networks used for satellite validation such as TCCON or NDACC do not provide sufficient coverage in this region, often leaving satellite observations un-validated.

As part of the NERC MOYA project we will deploy a portable FTS (Bruker EM27/SUN) in Uganda for a duration of up to 12 months to acquire column observations of CO2 and CH4 (as well as other trace gases of interest such as CO) with high accuracy and precision, with the aim of providing a dataset for validation of satellite observations (e.g. from GOSAT, OCO-2, and Sentinel 5-P). An automated protection enclosure developed by TU Munich [1] will allow us to make the unattended measurements necessary for a longer time series. The instrument will be operated in conjunction with a local partner at the National Fisheries Resources Research Institute (NaFiRRI) in Jinja, Uganda, and the deployment is planned to start by the end of 2018. Here we describe the system and our plans for its deployment, as well as showing some initial results obtained during testing of the spectrometer over the summer in Leicester.

[1] Heinle, L. and Chen, J.: Automated enclosure and protection system for compact solar-tracking spectrometers, Atmos. Meas. Tech., 11, 2173-2185, https://doi.org/10.5194/amt-11-2173-2018, 2018

A sensor invariant atmospheric correction method for satellite images

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Land surface reflectance is the fundamental vari-able for the most of earth observation (EO) missions, andcorrections of the atmospheric disturbs from the cloud, gaseous,aerosol help to get accurate spectral description of earth surface.Unlike the previous empirical ways of atmospheric correction,we propose a data fusion method for atmospheric correction of satellite images, with an initial attempt to include the uncertainty information from different data source. It takes advantage of thehigh temporal resolution of MODIS observations to get BRDFdescription of the earth surface as the prior information ofthe earth surface property, uses the ECMWF CAMS Near-real-time as the prior information of the atmospheric sates, to getoptimal estimations of the atmospheric parameters. It guarantees the correction is consistent cross different satellites image tilesand even cross different sensors. The validations against theAERONET sites are also show high correlation at around 0.9,with a RMSE of about 0.02.

Temperature-based and radiance-based validation of the Copernicus Global Land Service Himawari geostationary land surface temperature (LST) product

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The Himawari satellites are the first of the next generation of geostationary satellites operated by the Japanese Meteorological Agency (JMA), and have been operational since 2015. Land surface temperature (LST) derived from the Advanced Himawari Imager (AHI) aboard Himawari is an operational product of the Copernicus Global Land Service, delivered via an adaptation of the Land Surface Analysis Satellite Applications Facility (LSA SAF) geostationary LST generalized split-window (GSW) approach. Himawari LSTs are currently estimated at an hourly temporal resolution with a spatial resolution of 2 km at nadir; LST data are then reprojected and made available to users on a regular 5/112º grid. However the validation conducted so far to evaluate their quality is still limited. In-situ data was collected in the summer of 2017 to enable validation of this product over a homogeneous grassland site in Inner Mongolia, China. Both the more conventional temperature-based (T-based) and the radiance-based (R-based) methods were used, the former based on in situ methods and the latter on simulation of LSTs and brightness temperatures via radiative transfer modelling with in radiosonde atmospheric profile and surface emissivity data. Results of the validation are presented, alongside a comparison of the two validation approaches. Each method's suitability is discussed and further work in this area suggested.

Assessment of Landslide Mitigation Measures Using Terrestrial Laser Scanning (TLS) and Synthetic Aperture Radar (SAR) and the Potential of Sentinel-1 for Landslide Detection

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Landslides are one of the most damaging hazards for human beings and can be affected by multiple factors, including the natural environment and human activities. Since the Three Gorges Dam on the Yangtze River was completed in 2003, detecting and monitoring the landslides in the upstream area has become more important in order to protect human lives and properties. Compared to conventional *in situ* measurements, various remote sensing techniques have been carried out and found capable of monitoring landslides in difficult terrain over a large area.

This study focuses on monitoring landslides in the Three Gorges Region (TGR), which is characterised by the high humidity, dense vegetation, and steep slopes. Shuping with centre coordinates of 30.996◦N, 110.609◦E and Tanjiahe with centre coordinates of 31.030◦N, 110.509◦E are the two selected study sites. Synthetic aperture radar (SAR) techniques are applied to monitor landslides in these study areas and mitigation works performed to reduce the risks of landsldies in unstable areas. To assess the accuracy of digital elevation models (DEMs) derived from interferometric SAR data, TLS data was acquired by Zhang and co-workers and this is compared with the post-mitigation 6 m TDX CoSSC DEMs, SRTM and ASTER DEMs and DEMs derived from Cosmo-Skymed Spotlight data. The assessment of mitigation is also carried out by comparing two sets of Terrestrial Laser Scanning (TLS) data of the study sites before and after remediation.

The potential and limitations of using different SAR data, especially Sentinel-1 to identify unstable regions for follow-up acquisitions of TerraSAR-X Staring Spotlight and Cosmo-Skymed Spotlight data are described. The potential of TLS techniques and the effect of mitigation in landslide area are also going to be assessed.

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A new operational land surface temperature validation site for East Africa

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Satellite derived land surface temperature (LST) products are essential to many areas of science and to certain real-time environmental monitoring applications. To ensure satellite derived LST products and their derivatives are scientifically robust and comparable between sensors they must be assessed against ground-based observations conducted with instruments subject to traceable, laboratory-based calibrations. To date, most LST validation sites are have been confined to North America and Europe, parts of Asia and southern and west Africa. We here outline a new radiometer based, operational LST validation station in Kenya, east Africa. The station will be used to first evaluate LST's derived from the Meteosat-8 satellite, which has recently been moved over the Indian Ocean. Components of the station have been supported by the UK Space Agency IPP Project PRISE, and the validation effort is being carried out in collaboration with the International Livestock Research Institute (ILIR) who will host the station on their ILRI research ranch located on the Kapiti planes, south-east of Nairobi. The vegetation in this area is subject to controlled grazing and consists of savannah scrub with some areas of more forested coverage. Four radiometer towers are planned, a primary tower that will hold two Heitronic radiometers (upwards and downwards looking) and a dual look NASA-JPL radiometer. Three secondary towers will be spread throughout the rest of the area covered by a single Meteosat pixel, mounting a downwards looking Heitronic radiometer and a dual look NASA-JPL radiometer each. Additional sensors include automated phenocams, one of which will be part of the Stamford-led worldwide phenological monitoring network, and an NCEO supported eddy-covariance system that will be used in collaboration with NASA JPL to evaluate the products to be derived from the NASA-JPL ECOSTRESS thermal sensor that has been operated from the International Space Station since July 2018.

Normalized Difference Vegetation Vigour Index: A New Remote Sensing Approach to Biodiversity Monitoring In Oil Polluted Regions

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Biodiversity loss remains a global challenge despite international commitment to the United Nations Convention on Biodiversity. Biodiversity monitoring methods are often limited in their geographical coverage or thematic content. Furthermore, remote sensing-based integrated monitoring methods mostly attempt to determine species diversity from habitat heterogeneity somewhat reflected in the spectral diversity of the image used. Up to date, there has been no standardized method for monitoring biodiversity against the backdrop of ecosystem or environmental pressures. This study presents a new method for monitoring the impact of oil pollution an environmental pressure on biodiversity at regional scale and presents a case study in the Niger delta region of Nigeria. It integrates satellite remote sensing and field data to develop a set of spectral metrics for biodiversity monitoring. Using vascular plants of various lifeforms observed on polluted and unpolluted (control) locations, as surrogates for biodiversity, the normalized difference vegetation vigour index (NDVVI) variants were estimated from Hyperion wavelengths sensitive to petroleum hydrocarbons and

evaluated for potential use in biodiversity monitoring schemes. The NDVVI ranges from 0 to 1 and stems from the presupposition that increasing chlorophyll absorption in the green vegetation can be used as a predictor to model vascular plant species diversity. The performances of NDVVI variants were compared to traditional narrowband vegetation indices (NBVIs). The results show strong links between vascular plant species diversity and primary productivity of vegetation quantified by the chlorophyll content, vegetation vigour and abundance. An NDVVI-based model gave much more accurate predictions of species diversity than traditional NBVIs (R-squared and prediction square error (PSE) respectively for Shannon's diversity = 0.54 and 0.69 for NDVVIs and 0.14 and 0.9 for NBVIs). We conclude that NDVVI is a superior remote sensing index for monitoring biodiversity indicators in oil-polluted areas than traditional NBVIs.

Providing ECV data sets in an operational context: the C3S SST example

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The Copernicus Climate Change Service (C3S), operated by ECMWF on behalf of the European Union, brings together expertise from across Europe to deliver the necessary world-leading service provision of climate information. Underpinning the data and services offered by C3S is the availability of ECV datasets, as well as seasonal forecasts, climate projections and reanalysis.

The provision of trustworthy ECV datasets as part of a climate service is crucial to the development of climate services, and for the uptake and success of such a service.

In order to provide ECV datasets suitable for use in the climate community, a different set of user needs has to be identified and addressed, as compared to say the requirements for short-term weather forecasting or near real time monitoring. For example, for climate applications the input datasets will be chosen to emphasise overall stability and absolute accuracy, whereas near real time applications may make choices based on coverage and timeliness. The principle behind the C3S provision is to utilise the advances from Research and Development activities, such as ESA's Climate Change Initiative (CCI), to provide state-of-the-art consistent Climate Data Records, the temporal coverage of which are then extended through production of Interim Climate Data Records. The CDRs and ICDRs, irrespective of their origin, are then presented through a unified data access portal, the Climate Data Store, under an operational service contract, so that users can be confident in both the quality and availability of the data.

The service for Sea Surface Temperature ECV data provision is led by Telespazio VEGA UK (a Leonardo and Thales company), supported by University of Reading, the UK Met Office, CEDA (STFC) and Brockmann Consult.

Our poster summarises the key achievements of the ESA CCI and C3S SST activities and presents the latest information on the status of the data.

Retrieval of rimed snow from Doppler and dual-frequency radars

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Our understanding of the water cycle in polar regions is limited by low confidence in satellite estimates of snow. The density of snow depends on highly variable microphysical processes, and the assumed mass-size relations of ice particles are a major contributor to uncertainties in remote-sensed estimates of accumulation in polar regions. Riming in mixed-phase clouds cannot presently be

diagnosed from spaceborne active sensors, but future satellites including EarthCARE will employ Doppler or multiple-frequency radars which may be use to improve uncertainties in estimates of global precipitation.

Using a novel optimal estimation retrieval algorithm "CAPTIVATE", we exploit ground-based Doppler radar measurements to retrieve a parameter modulating the mass, area and terminal velocity of ice particles according to their degree of riming. Retrievals of the density of ice and snow are made from two zenith-pointing Doppler radars at Hyytiala, Finland during the snow experiment (SNEX) component of the BAECC 2014 field campaign. The retrieved snow rate, particle size distribution parameters and ensemble mean ice density are compared against in-situ particle imaging measurements at the surface. While Doppler measurements allow the diagnosis of rimed snow and mixed-phase cloud, dual-frequency radar measurements provide a stronger constraint on particle size which significantly improves the retrieval of ice density. We discuss the potential for improved remote-sensing of snow from EarthCARE to provide insights into the rates of microphysical processes in mixed-phase cloud.

Satellites in Agriculture

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As populations rapidly increase, we face the global problem of producing enough food to meet society's needs without compromising the ability of future generations to meet their own needs. Growers are facing increasing regulatory and consumer pressure to produce food in a sustainable and efficient way, however measuring this, particularly at a large scale, remains a challenge. Earth Observation presents an opportunity to add to the growing suite of agri-tech tool available.

Increased availability of free, high quality, high frequency optical and radar data from the Copernicus Sentinel satellites with guaranteed continuity provides opportunities for greatly expanding the scope and quality of derived information products. The increased availability of data comes at the same time as cloud computing developments allow the processing and management of large data volumes at low cost.

Satellites in Agriculture (SiA) is a collaborative R&D project undertaken by Ecometrica, Environment Systems and Rothamsted Research. With funding from Innovate UK, the project seeks to develop wall-to-wall applications of Sentinel Earth Observation (EO) derived information products for environmental compliance and productivity monitoring in agriculture.

The current market for earth observation (EO) derived information products in agriculture is characterised by many small scale, fragmented projects with limited continuity. While these projects often demonstrate the potential value of Earth Observation, they do not, on the whole, provide the basis for broad scale, consistent mainstream applications within public agencies or most commercial users. The fragmented approach is inefficient since processing is done on a small, localised scale and intermediate data products are not routinely developed and managed in a way that they can be reused.

Leveraging increased availability of data and cloud computing capability, new information services for agriculture in the UK and foreign markets present an exciting opportunity to address the challenges faced by the agricultural network.

Testing historical reconstructions of global sea surface temperature using early satellite data

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To ensure that we have a reliable record of historical sea surface temperature (SST) it is crucial to compare different measurement systems. In 1970-71, global measurements of infrared spectral radiance were collected by the Infra-Red Interferometer Spectrometer (IRIS) on board the Nimbus-4 satellite. These early satellite measurements provide the opportunity to derive a high quality, global SST product, which we can use to test whether the in-situ based reconstructions are correct to within their stated uncertainties.

The IRIS data suffer from a systematic cold bias of 1-2K in many channels relevant to SST retrieval. It is thought that this bias is due to incorrect calibration when IRIS was in operation. We have developed a model of this bias and used it to correct all of the IRIS measurements. Following this, we developed an optimal estimation (OE) based retrieval method for IRIS. Hyperspectral radiances from IASI/MetOpA have been used to test the retrieval method, using drifting buoy SST data to validate SSTs retrieved from IASI. In this poster, we present our ongoing work to retrieve SSTs from IRIS for clear-sky and partly cloudy scenes and compare the IRIS SSTs with the in-situ based SST reconstructions. We show that IRIS SSTs can fill in data gaps in regions where in-situ measurements were very sparse in 1970-71 such as the Southeast Pacific.

Remote sensing to evaluate lowland natural flood management

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Remote sensing is being used in NERC's Natural Flood Management (NFM) project LANDWISE to evaluate NFM in lowland catchments for improving soil infiltration, evaporation and water storage, to compare NFM's catchment-scale effectiveness to more targeted engineering approaches, and to study seasonal and year-to-year variability of the processes mentioned above. The UK floods of 2007 were described as "the biggest civil emergency in British history" by Sir Michael Pitt's Final Report, which asserted that "flood risk cannot be managed by simply building ever bigger hard defences". NFM aims to manage flood risk by protecting, restoring and emulating the natural regulating function of catchments and rivers. Qualitative evidence that features such as farm vehicle tramlines, field margins and tillage direction have a strong impact on water flow and infiltration require quantification through measurement and modelling, and at the catchment scale this requires a remote sensing approach.

Small landscape features can have a disproportionate impact, so an approach combining very high-resolution imagery with the wider coverage of satellite instruments is required to provide useful catchment-scale information. For example, regularly-used vehicle tracks on farmland have an obvious impact on overall water flow, because soil compaction reduces infiltration and provides an easy path for overland water flow. A multiscale approach to Identifying such features at catchment scale is being deployed, using platforms such as drones, aircraft and satellites, and field measurements for validation, including a field equivalent of the Sentinel-1 radar. Remote sensing is being used in three Thames catchments to determine the impact of these features, via estimation of soil hydraulic properties, vegetation structure and their impact on water fluxes. This information is fed into hydrological models than can predict flooding. Model sensitivity analyses representing scenarios that reflect different approaches to land management will provide evidence on the effects of natural flood management.

Using nonlinear variable transformations to assimilate land surface albedo observations

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Surface albedo observations over vegetated areas can be inverted to retrieve parameters which determine the radiative transfer through the vegetation canopy, including leaf area index (LAI).

Data assimilation methods like the Kalman filter and related methods can be used to perform such inversions. But their applicability is hindered by the fact that these methods assume Gaussian probability distributions while albedo, being a bounded variable, cannot be adequately described by a Gaussian distribution. In particular over densely vegetated areas, surface albedo in the visible domain reaches values of 0.05 and below and its distribution becomes highly skewed. The consequences for Kalman filter-like methods can be unphysical inversion results, ie. negative values, and biased estimates.

Nonlinear transformations allow to transform non-Gaussian, bounded variables into Gaussian, unbounded variables (Gaussian anamorphosis). When such transformations are not only applied to state variables and model parameters but also to observations, the question of how to transform the observation error variance arises.

We present a new way to transform the observation error variance that retains the relation of the error variances in the physical space and compare it to a sampling-based method to transform the observation error. We further include an ensemble Kalman filter that yields accurate solutions for Gamma and Gaussian distributions instead of only for Gaussian distributions in the comparison.

Experiments are performed with a two-stream model for canopy radiative transfer and include twin experiments as well as the assimilation of real observations.

Identifying and characterising UK upland wildfires using Sentinel-1 radar

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UK peatlands represent a significant terrestrial Carbon store of >2000 Mt, while also supporting a biodiverse ecosystem (Billet et al., 2010). Severe wildfires damage peatlands, removing vegetation and burning peat, often leaving the area in a degraded state. Monitoring burn scar location and persistence is important for targeting restoration works, but mostly relies on ground surveying, with mapping using optical satellite imagery limited by cloud cover in the UK (Armitage et al., 2007). Satellite radar for burn scar mapping is well established in Boreal, Mediterranean and tropical regions (Joyce et al., 2009). ERS-2 is effective in detecting larger UK wildfires, though little has been done with more recent radar data (Millin-Chalabi, McMorrow and Agnew, 2014). Similarly, further understanding of surface factors affecting radar backscatter is required. Therefore, 3 Peak District burn scars from 2018, 2 at Dovestone Reservoir and 1 at Big Moor, are used to investigate the potential of using Sentinel-1 radar imagery for UK burn scar detection and characterisation. For pre- and post-fire images, time-series of SAR intensity and InSAR coherence products will be produced and assessed (Millin-Chalabi, McMorrow and Agnew, 2014). Ground-truth data from burn perimeter and vegetation surveys, supported by Sentinel-2 imagery, will be used to assess the accuracy of burn scar detection using the above products. The spatial and temporal variability of both intensity and coherence products will be assessed in the context of soil moisture, phenological changes and topography. This will inform the interpretation of burn scar characteristics by constraining the surface factors influencing radar backscatter differences. Upon completion, a method replicable for future UK peatland wildfire identification using Sentinel-1 radar, with quantified factors influencing backscatter variability, will be produced.

Quantifying the impact of industrial emissions on clouds

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One of the greater uncertainties in climate observation and modelling is the means by which aerosols interact with clouds. Many mechanisms have been observed and theorised, producing both positive and negative radiative effects. However, the relative real-world importance of these is unclear, which complicates the parametrization of cloud processes within models. This presentation will outline a technique to quantify the variation of cloud micro- and macro-physical properties as a function of aerosol loading. Satellite observations of localised aerosol sources, such as industrial areas or volcanoes, are used as a natural laboratory where fresh aerosols are injected into an otherwise homogeneous field. Perturbed and pristine conditions can be separated by aligning the retrievals with the wind vector. The first indirect aerosol effect is clearly observed, with weaker evidence for cloud invigoration. Liquid water path effects are observed in some circumstances.

NCEO / PML Activities in GEO

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PML/NCEO staff are involved in a number of GEO initiatives focussed on marine and freshwater science.

GEO AquaWatch has a goal of developing and building global capacity and utility of EO-derived water-quality data, products and information to support water resources management and decision making. PML staff are involved through the steering committee and are likely to contribute to Working Group 3 “Products and Information” working to facilitate routine and sustained production of products for use in the scientific community as well as information products for policy makers and decision makers. The GloboLakes data processing methods will contribute to this effort and data will shortly be available through NCEO-NEODAAS for the UK community. PML also lead WG 4 – Distribution, Access, and Visualization responsible for making products and information accessible to target audiences.

A related activity is the GEO Global Water Sustainability (GEOGLOWS) initiative taking a leading role in formulating a set of Essential Water Variables including water quality and hydrology measured in situ and from Earth Observation. The EWVs extend from inland water bodies to the coastal zone. In terms of inland water quality, there is a clear opportunity to expand current global EO services to the highest attainable resolution, and to include complementary optical measurements in the set of variables that are currently reported for SDG6.3 by UNEP GEMS.

Finally, PML/NEODAAS staff manage the ChloroGIN web site which provides medium resolution EO data across the globe: in particular, PML/NEODAAS undertakes near-real time ocean colour and SST processing for the entire coast of Africa and provides these data via GEONETCast/EUMETCast satellite links and the web for operational use in the GMES and Africa programme.

This presentation will demonstrate some of the activities, including processing systems, data and end-uses of data in these GEO contexts.

Quantifying rates of urban creep in Edinburgh, Scotland between 1990, 2005 and 2015 using random forest classifiers and true colour aerial photography

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Two objectives underlie this work:

1. To answer the question, what are the typical rates of urban creep for selected urban areas in Scotland?

2. To develop and test a transferable methodology for quantifying rates of urban creep.

Urban Creep can be defined as 'areas that traditionally are already part of the urban fabric that have been subject to a change in permeability, e.g. paving over front gardens, or extensions to existing buildings'. The impacts this has on urban catchment hydrology and urban drainage capacity is of particular concern in light of projected population growth and climate change.

Three sets of aerial images at 0.1m and 0.25 m resolution were obtained for this study . These data were rectified, enhanced and segmented using spatial analyst image classification tools in ESRI ArcGIS Pro 2018 and then classfied using a random forest classifier. The classified areas for 1990, 2005 and 2015 were each tabulated using the Ordnance Survey Mastermap framework. Finally, data on building age and structure was added to the OS polygons. This enabled the calculation of rates of urban creep and urban expansion to be calculated for different types of building structure and different ages of building. The classifications for 1990, 2005 and 2015 were validated using a stratified random sample of 200 polygons for each year.

The classification results show that urban and vegetation are always classified with > 80% accuracy and often with > 90% accuracy

the results show that urban creep is widespread across Edinburgh for both time periods (Figure 9), with only the historic centre of Edinburgh relatively unaffected. Rates of urban creep appear to be highest between 2005 and 2015.

This study has demonstrated the potential to inform a range of modelling activities, including how significant urban creep is on pluvial flooding.

Model Uncertainty Quantification for Data Assimilation in partially observed multi-scale systems

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Model uncertainty quantification is an essential component of effective Data Assimilation (DA). However, it can be a challenging task for realistic applications characterised by complex partially observed non-linear systems with highly non-Gaussian uncertainties. Stochastic Parameterisation methods have been receiving increasing attention for cases where model uncertainty arises due to unresolved sub-grid scale processes. However, these are generally only applicable when knowledge of the true sub-grid scale process or full observations of the coarse scale process is available.

Here a methodology is presented for estimating the statistics of sub-grid scale processes using only partial observations of the coarse scale process, and without relying on Gaussian assumptions. Additive errors are

estimated over a training period by minimising their conditional variance, constrained by available observations. Special is that these errors are binned conditioned on the previous model state during the minimisation process,

allowing for the recovery of complex error structures. We present the theory behind the approach along with numerical experiments using the multi-scale Lorenz 96' model. Various parameterisations

of the Lorenz 96' model are considered, along with both small and large time scale separations between slow (coarse scale) and fast (fine scale) variables. Results demonstrate improved analyses and forecasts with the proposed method compared to two existing methods for accounting for model uncertainty in DA.

IASI methane retrievals from the 7.9 and 3.7 micron spectral regions

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The RAL Remote Sensing Group has developed an optimal estimation scheme to retrieve global height-resolved information on methane from IASI using the 7.9 micron band and produced a v1 mission data set for MetOp-A (R. Siddans et al., 2017, https://doi.org/10.5194/amt-10-4135-2017). This scheme has subsequently been improved through use of pre-retrieved temperature, water vapour and surface spectral emissivity from the Infrared Microwave Sounder (IMS) scheme. The improved methane retrieval scheme has been used to reprocess the IASI MetOp-A record from 2007 to 2017, creating a 10-year v2 methane dataset.

The methane band at 3.7 microns is also observed by IASI. At this wavelength, the terrestrial Planck function is more sensitive to temperature than at 7.9 microns, and on the dayside of the orbit there can also be a significant surface-reflected solar component to top-of-atmosphere spectral radiances. The 3.7 micron band therefore offers the potential to add information on methane in the near-surface layer, where temperature contrast between the surface and atmosphere is low, which limits sensitivity in the 7.9 micron band. We also plan to investigate the potential of using S5P 2.35 micron total column measurements in combination with the 7.9 micron methane profiles.

Here we present analysis of the 10-year IASI methane v2 data set from the improved 7.9 micron scheme and an update on the 3.7 micron retrieval progress.

Impact estimation of a spectrally resolved emissivity and its far-infrared variability in GCM

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Comparisons between climate models and reanalysis show persistent biases in surface temperature over polar regions, particularly in the wintertime Arctic. A recent study using the Community Earth System Model suggests that incorporating a more realistic spectrally varying surface emissivity can substantially reduce these discrepancies. In this work we investigate whether a similar effect is seen in UK HadGEM-GA7.1 by replacing the current simplified assumptions of surface type and characteristics with observationally based estimates of snow spectral infrared emissivity. We describe the non-trivial steps involved in incorporating such a change in the land (JULES) and atmospheric components of the model and highlight the impact of the changes made.

Traceable ground-based observing system for the Cal/Val of satellite observations - the outcomes of H2020 GAIA CLIM

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The recently completed GAIA CLIM H2020 project *http://www.gaia-clim.eu/* is a collaboration between 18 international partners with the goal to address the status and use of ground-based and sub-orbital observing system for calibrating and validating satellite observations and derived Copernicus services for a number of atmospheric Essential Climate Variables (ECVs). To that end, we need truly reference, high-quality non-satellite data that are traceable to standards and that can be easily and timely accessed for comparisons with the satellite data.

Besides the contribute GAIA CLIM has made to improvements of certain key non-satellite ECV observing system components, we have made (1) a survey of the gaps that do exist in the non-satellite system and that will probably persist to some extent beyond the end of GAIA-CLIM, our so-called Gaps Assessment and Impacts Document (GAID), (2) a Recommendations Document (RD), and (3) a Virtual Observatory (VO) portal facility of co-locations and their uncertainties.

The outcomes of GAIA CLIM will be presented together with its synergies with sister projects such as QA4ECV & FIDUCEO with application to the continuing development of Copernicus services.

Fiducial Reference Measurements (FRM) for Vegetation

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Fiducial Reference Measurements for Vegetation (FRM4VEG) is a European Space Agency (ESA) funded project aiming to explore the potential of establishing protocol for consistent and SI traceable set of independent in-situ measurements to support the validation of Copernicus vegetation related products from Sentinel-2, -3, and PROBA-V. This would ultimately provide confidence to users in their application of satellite derived vegetation products and allow such validations to be considered Fiducial Reference Measurements. In particular three bio/geo physical variables are considered: surface reflectance, Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Canopy Chlorophyll Content (CCC). The project will combine data from laboratory calibration of field instruments and two dedicated field campaigns to define uncertainty, error propagation and traceability of individual measurements and satellite products. In addition, the project is planning a pilot inter comparison activity of various instruments used to measure the bio/geo physical variables with an aim to develop a protocol for an instrument round robin exercise. Two field sites have been selected to collect in-situ ground measurements for the first phase of this project, one of which is a LPV supersite (Wytham Woods, UK, mixed forest) and other with a legacy of previous ESA cal/val activities (Barrax, Spain, Agriculture). Results from the laboratory analysis and field camping will be presented with initial procedures to estimate uncertainty and guideline for traceability. Overall, it is expected that, the project will build a consensus for good practices in the measurement of vegetation bio/geo physical variables resulting in a legacy for the community and protocol for new practitioners.

The Reference Forward Model (RFM)

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The RFM is an NCEO-supported line-by-line radiative transfer model suitable for a wide range of infrared and microwave applications, such as modelling spectral observations of the earth's atmosphere from ground, air and space-based instruments.

The original code was written FORTRAN77 and developed rather haphazardly over the past 20 years as its capabilities were extended in response to user requests. However in April 2018 a new RFM v5 was officially released. This represents a complete redesign, and recoding into FORTRAN90, which makes maintenance and use more convenient, as well as being fully compatible with HITRAN2016 spectroscopic data. On the other hand, since it is entirely new code, it is inevitable that a whole new set of bugs have been introduced. So, for the present, both the old RFM v4 (F77) and new RFM v5 (F90) versions are being maintained.

Growing capability in the use of EO data for decision support

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Many developing coastal countries and island states depend on marine resources for economic stability, food security and social cohesion, but their relative poverty limits their capacity to adapt to environmental change. Low-income communities are particularly vulnerable to adverse impacts of natural variability, climate change and resource over-exploitation because of their dependence on local ecosystem services and a lack of alternatives when these deteriorate.

Sustainable development requires a mature capacity to deliver relevant and reliable information from interdisciplinary marine research – beyond the scientific capacity of many developing countries. Thus decision-makers lack the information they need to develop and implement sound options for climate change adaptation, resource management and economic development.

Conventional methods for collecting marine data are often beyond the economic capacity of a developing nation, and there is increasing recognition of Earth observation as a tool to complement and add value to sparse local observations. However, many institutions tasked with delivering decision support lack the capacity to identify, access, analyse and interpret the current plethora of marine EO data products. Growing the capacity to do this takes sustained international effort bringing together international and local experts, both scientists and stakeholders, in order to tackle the challenges facing developing countries.

The satellite oceanography group at NOC is participating in several projects to increase the capacity of both UK and developing country institutions to deliver decision-support for marine resource management and coastal development. Activities include collaborative interdisciplinary research using EO and in situ data with model output and socio-economic studies to deliver relevant information. Opportunities for 'on-the-job' research training and mentoring are supplemented with formal training courses and new e-learning resources. The presentation will provide examples of some of these activities, and share our experience of what approaches work well, and what efforts may have been less successful.

A combined model and observation approach for understanding regional ozone variations

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Tropospheric ozone is an important trace gas that at elevated concentrations has impacts on human and plant health as well as being a greenhouse gas. Broadly speaking its chemistry relies on the oxidation of volatile organic compounds (VOCs) in the presence of nitrogen oxides. These VOCs can be from anthropogenic, biogenic and pyrogenic sources. Ozone in the troposphere is also influenced by the stratosphere. We interpret observed variations of tropospheric ozone columns over the Indian subcontinent, from height-resolved NASA Ozone Monitoring Instrument (OMI) retrievals developed in NCEO at the Rutherford Appleton Laboratory (RAL), using v11-01 of the nested version of the GEOS-Chem atmospheric chemistry transport model run at 0.25 degree (latitude) and 0.325 degree (longitude) resolution. The RAL tropospheric ozone data product has been developed to optimize sensitivity to the troposphere (surface – 450hPa layer). The model is sampled at the location and time of cloud-free scenes and convolved with scene-dependent averaging kernels supplied with the RAL data product, allowing a like-for-like comparison between model and observed columns. Consistency of model and observations is evaluated. Using the model, we report on the roles of atmospheric chemistry and transport in observed column variations so that we can explore the most effective strategies to mitigate tropospheric ozone over subcontinental India.

Big data applications to boost preparedness and response to migration – BIGMIG

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Europe is being confronted with the most significant influxes of migrants and refugees in its history. The International Organization for Migration (IOM) estimates that more than 464,000 migrants and refugees crossed into Europe by sea in the first nine months of 2015, which resulted in more than 3,000 deaths. This has triggered an array of initiatives to counteract this emergency, which are aimed at supporting each of the four phases of emergency management: mitigation (preventing future emergencies or minimizing their effects), preparedness (preparing to handle an emergency), response (actions taken to save lives and prevent further damage in an emergency) and recovery (recovering from an emergency).

Stakeholders' emergency management capacity is severely hindered by the lack of timely information on migration trends, flows and rates. This information gap should be bridged through a holistic approach founded on the collection, analysis and integration of relevant direct and indirect indicators of migration flows.

In this context, big data has been recognised as a powerful tool to provide information on human migration and movements; however, its potential is largely untapped due to a number of technical and non-technical factors yet to be addressed, and the application maturity level is quite varied. In the context of migration, big data involves the collection and analysis of a plethora of information, either coming from people-centred sensing or collected by external systems (e.g. satellite, phone call detail records).

This work presents the results of the feasibility study performed by GMV-UK under the ESA's ARTES IAP programme. The main objective of the study was to characterise, define and design space-based services in support to the identification of human migration flows, assessing their technical feasibility and viability, and proposing a roadmap for their implementation. This presentation will explain the work performed during the study and the future road designed.

The ESA CCI Open Data Portal

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The European Space Agency's Climate Change Initiative (CCI) programme aims to ensure that the full potential of long-term global Earth Observation (EO) archives for a number of Essential Climate Variables (ECVs), defined by the United Nations Framework Convention on Climate Change (UNFCCC), are realised. The programme currently covers 14+ CCI projects focused on generating specific validated ECV datasets from harmonised multi-sensor satellite data, alongside additional projects to provide a CCI Open Data Portal and a CCI Toolbox. This data can then be used to provide a solid basis for climate science and modelling, specialist application development and, ultimately, European and global policy making.

This poster describes the CCI Open Data Portal (ODP), which is intended to provide the user community with a single point of free and open access to all the key ECV products produced by the CCI teams. To achieve this aim, the portal makes the data available via a wide range of protocols and interfaces to discover and access the data. The ODP dashboard provides an initial visual interface to showcase the extent of all the different ECV products available, as well as providing download links and metadata. In addition, a faceted search interface is provided alongside an option to visualise some of the datasets. Data can be downloaded via a wide range of protocols (FTP, HTTP, OPeNDAP, WMS and WCS). At the backend of the portal, the data itself is hosted by the Centre for Environmental Data Archival (CEDA)'s in the CCI Central Data Archive (CDA). The CCI CDA currently contains more than 150 datasets (incl. older versions) amounting to more than 100 TB of data, which is freely and openly available to all users.

Quantifying global emissions of CH4 using a 4D-Var inverse model and remote sensing observations from GOSAT and IASI for the period 2010 - 2016

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Methane (CH4) is a greenhouse gas that is emitted from a range of anthropogenic and natural sources, and since the industrial revolution its mean atmospheric concentration has climbed dramatically. CH4 produces a relatively high radiative forcing effect upon the Earth's climate, and its atmospheric lifetime of approximately 10 years makes it an appealing target for the mitigation of climate change.

However, the spatial and temporal variation of CH4 emissions are not well understood, though in recent years a number of top-down and bottom-up studies have attempted to construct improved emission budgets. However, top-down studies which use only observations made at the surface generally suffer from poor observational coverage in the Tropics. The GOSAT satellite has been used to retrieve global column-average CH4 concentrations since mid-2009, whilst IASI, on-board Metop-A, has also been measuring atmospheric CH4 concentrations since its launch in 2006.

We present an assessment of global CH4 emissions for 2010 through to 2016 using the TOMCAT Chemical Transport Model and the variational inverse model, INVICAT, along with the Joint UK Land Environment Simulator (JULES). These models are used to produce improved posterior emission estimates through assimilation of atmospheric observations. Whilst there is generally good agreement between the model and the observations prior to data assimilation, some high-methane

events indicated by the observations are not captured. We assimilate observations from the NOAA surface measurement network, from GOSAT "proxy" retrievals of CH4 provided by the University of Leicester and finally from IASI retrievals of CH4 provided by the Rutherford Appleton Laboratory, in order to constrain CH4 emissions for this period, and assess the uncertainty reduction provided by each measurement platform. We find that global methane emissions during 2010-16 are 540-580 Tg/yr, with year-to-year variation in geographical distribution.

UAV Based Mobile Air Quality Measurement

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Currently, most air quality measurement is carried out using permanent ground stations which together form the Automatic Urban and Rural Network. These are highly accurate but are expensive and only provide a few sample points, usually tens of kilometres apart from which air quality data is extrapolated. This paper describes a low cost, lightweight, mobile air quality monitoring device which allows measurements at varying locations and altitudes.

The system is able to monitor various gases and particulate matter at ground level or low altitudes (less than 120 metres). The system has been tested using different transport mechanisms (UAV, bicycle, body mounted,) Measured sensor data is logged, together with geolocation and other environmental quantities and transmitted to the cloud in real time and presented on a map-based web page.

During this project, air quality measurements have been taken across parts of Leicestershire including Loughborough University and Shepshed, but also other areas of the UK. Sources of inaccuracy and unreliability in the data have been identified and several design iterations have improved but not fully eradicated these. The results presented by each prototype of the system hinted possible inaccuracies and reliability issues. These problems were then attempted to be rectified for the next prototype.

Even though accuracy needs to be improved, results presented show that there is significant fine structure in the data, detecting significant localised peaks in particulate readings measured in metres across, and paving the way towards extensive future analysis to fully understand the data collected.

Detecting landslides from time series of Landsat imagery with Google Earth Engine

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Earthquakes in mountainous areas can trigger thousands of (co-seismic) landslides causing significant damage, hampering relief efforts, and rapidly redistributing sediment across the landscape. Efforts to understand the controls on these landslides rely heavily on manually mapped landslide inventories but collecting these inventories is time consuming and relies heavily on costly high-resolution imagery. Landsat imagery offers near global coverage, extending over multiple decades with high temporal resolution but relatively low spatial resolution. If an effective approach could be found to take advantage of these Landsat time series this could considerably increase the archive of landslide inventories. It might also improve the speed and accuracy with which landslide information could be provided to those responding to an earthquake. Here I develop two alternative landslide detection algorithms using Landsat time series within Google Earth Engine: 1) pixel-wise NDVI differencing approach that accounts for seasonality; and 2) a 'time since vegetated' approach that relaxes the assumption that landslides must be co-seismic. I compare classified inventories to hand mapped inventories from the 1994 Northridge, 1999 Chi-Chi, 2008 Wenchuan, and 2015 Gorkha earthquakes. In each case testing the ability of automated mapping to recover: landslide locations (using ROC

curves), landslide sizes (in terms of landslide area-frequency statistics), and their spatial distribution (by comparing density maps). I find that NDVI differencing performs best for most metrics and study areas but that the 'time since vegetated' approach can provide additional insight into post-seismic landslides, distinguishing the timing of known pre- co- and post-seismic landslides in the Gorkha case to the nearest quarter-year in most cases.

A new particle filter method to estimate the state of the ocean during the Last Glacial Maximum

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Combining ocean general circulation models with proxy data via data assimilation is a powerful means to obtain more reliable estimates of the past ocean's state as well as of model parameters. The Last Glacial Maximum (19-23 ka BP, LGM) was a climatic state substantially different from today and the large-scale ocean circulation patterns during this time remain uncertain. At present, only a few attempts on using data assimilation to estimate the ocean's state during the LGM exist and it is unclear which data assimilation methods are suitable for this application where data is comparatively sparse and uncertain.

We present a new particle filter method that combines ensemble runs of an ocean general circulation model with (pseudo-) proxy data to estimate several parameters of the atmospheric forcing used to drive the model. We employ the MIT general circulation model (MITgcm) in a global configuration that uses a cubed-sphere grid with 192 x 32 horizontal grid cells and 15 vertical levels. A water-isotopes module is also incorporated in the model.

We present our results from applying the method to estimate the state of the global ocean during the LGM. To that end, we use the seasonal MARGO sea-surface temperature reconstruction and a global collection of oxygen-isotope data from benthic and planktonic foraminifera from different sources. The next challenge is to apply the method using real proxy data to estimate the state of the global ocean during LGM. To that end, we use the seasonal MARGO sea-surface temperature reconstruction and a global collection of oxygen-isotope data from benthic and planktonic foraminifera from different sources. We will present results from these experiments and discuss climatic implications of our findings.

A revised Implicit Equal-Weights Particle Filter

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With ever increasing model resolution and more complex observation operators the data-assimilation problem becomes more and more nonlinear, asking for a fully nonlinear data-assimilation method like a particle filter. While the standard particle filter is degenerate in high-dimensional systems recent developments have opened the way for new particle filters that can be used in these systems.

The implicit equal-weights particle filter (IEWPF) is a very efficient particle filtering scheme which avoids filter degeneracy by forcing all particle to keep equal weights by construction. This allows the filter to be used in very high-dimensional systems with a large number of independent observations. To achieve this, the method uses implicit sampling whereby auxiliary vectors drawn from a proposal distribution undergo a transformation before they are added to each particle. The mapping used for the transformation includes a parameter which is different for each particle, and must be determined by solving a nonlinear scalar equation.

In the original formulation of the IEWPF, the proposal distribution has a gap causing all but one particle to have an inaccessible region in state space, which can lead to biased estimates. In this work we modify the proposal distribution to eliminate the gap, and discuss conditions that should be satisfied by the mapping in order to ensure complete coverage, keeping in mind the aim of re-sampling as few particles as possible. The resulting filter is tested in synthetic experiments using the Lorenz96 model with varying dimensions, to develop a particle filter that performs independent of the dimension of the system.

Online robust state and time-varying parameter estimation using an efficient particle filter

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This work proposes a method for robust and efficient estimation of the state and time-varying parameters in nonlinear high-dimensional systems through a sequential data assimilation process. The importance of estimating deterministic time-varying parameters lies not only in improving prediction accuracy but also in finding when the model characteristics change. The state augmentation technique, in which the parameter vector is incorporated to the state vector is a typical method for such simultaneous estimation, but the detection of parameter changes tend to fail due to the fact that the parameter estimation based on the cross covariance between states and parameters is inadequate unless there are strong enough correlations. To improve the robustness, we propose a particle filter-based method that incorporates an optimization algorithm from machine learning into the parameter time evolution model, by exploiting the freedom of the proposal density in particle filtering. However with increasing resolution of model and number of observations, filter degeneracy tend to be the main obstacle for the implementation of the particle filter. Therefore this proposed method is combined with an efficient particle filter, in which all particle weights are equal. The method is illustrated for more than 40-dimensional Lorenz-96 model where the forcing is expressed by 3 parameters, using only 10 particles. The new method is shown to be capable of robust and efficient parameter estimation, for parameter changing over time, leading to the conjecture that the proposed method is applicable to realistic geophysical, climate and other problems.

Information gain from convective-scale ensemble forecasts for the sea-breeze prediction.

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In this project we quantify the information gained about sea-breeze occurrence from a dynamically downscaled convection permitting ensemble versus a statistical model obtained using Bayesian post-processing of the driving global ensemble.

A new method for automatic detection of sea-breeze fronts in convection-permitting forecasts (applicable in principle to any coastline) is proposed and used to create sea breeze forecasts. The Bayesian forecast is created using paired high-low resolution ensemble members as training dataset. In essence the method forecasts the high resolution member based on large-scale variables from low resolution model. The aim of this is twofold: -firstly to develop a method to extract information from the low resolution prior to the running of the high resolution for real time forecasting ; secondly to provide an estimate of the information gained by running the high resolution forecast beyond that which is contained in the large-scale flow conditions.

The reliability and resolution of the sea-breeze occurrence probabilistic forecasts are tested statistically for both forecasting systems.

Comparison of the two forecasting methods using area under the ROC curve, the difference between the resolution terms of the information gain score and the log-likelihood ratio test for the sufficiency all lead to the same conclusion: although the Bayesian model provides useful information about sea-breeze occurrence as it has greater resolution than climatology, the convection-permitting model has significantly greater resolution and therefore provides greater information at all forecast lead times

Autonomous Remote Sensing of Marine Mammals using Unmanned Aerial Vehicles

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Autonomous Remote Sensing of Marine Mammals using Unmanned Aerial Vehicles

The work described is funded by NERC through the CENTA Doctoral Training Partnership and is being carried out in association with Natural England. There is a requirement to monitor marine mammal populations, particularly harbour porpoises, in a series of new marine conservation areas. The project has the aim of providing unmanned, autonomous visual and passive acoustic monitoring of cetacean species using unmanned aerial vehicles. The system is intended to operate in conjunction with more conventional monitoring methods (boat or aircraft based) but to provide the ability to loiter over a specified location for more complete monitoring. As well as photographic and video monitoring, it is intended that the vehicles will be able to land on and take off from the sea surface to capture underwater acoustic data from the animals under investigation

The selected platform utilises off-the-shelf hardware and open source software. An architecture has been designed using the Robot Operating System which will allow multiple UAV's to be coordinated to allow continuous, extended observations to be carried out. While standard UAV's will allow preliminary results to be obtained and analysed, a number of unique capabilities will be required, including unattended operation, automated recharging/battery changing, water based landing and take-off.

Retrievals of temperature, water vapour, surface emissivity, trace-gases and particulates with the RAL Infra-red Microwave Sounder (IMS) scheme

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RAL has implemented an integrated retrieval scheme for the three atmospheric sounding instrument on Metop: IASI, AMSU and MHS. Building on the Eumetsat operational IASI algorithm, the new infra-red+microwave sounder (IMS) scheme adds information from AMSU and MHS to enable joint retrieval of spectral surface emissivity and cloud parameters, along with temperature, water vapour and ozone. The scheme has been developed with NCEO funding and used to consistently process the Metop-A mission with a view to supporting retrieval of other trace-gases from IASI by RAL and other teams in NCEO. RAL methane retrievals are significantly improved when IMS data is used instead of either ECMWF analysis or the operational L2 data. IMS uses a climatological prior and is therefore independent of NWP data. Water vapour and temperature retrievals have been evaluated by comparison to ECMWF analyses. Total water vapour has been validated cf ground-based data (Suominet). Ozone and temperature fields have been compared to sondes. This dataset is now archived at CEDA and water vapour from it will be used in ESA CCI+ water vapour. Recently, advances in the RTTOV radiative transfer model have been exploited to enable (a) cloud to be retrieved in terms of optical depth, effective radius and height; (b) joint retrieval of dust/volcanic aerosol optical depth and height; (c) extension of the spectral coverage used to include the 3.7-5 micron range, enabling joint retrieval of short-wave spectral surface emissivity and carbon monoxide profiles. The new

products are shown to perform well by comparison to ECMWF CAMS analysis and independent retrievals. The scheme will soon be running in near-real time, providing input to the existing near-real time methane processor. Future plans include using the ozone and carbon monoxide from IMS in combination with GOME-2 and S5P, to improve vertical resolution within the troposphere.

GbOV: Ground-based Observations for Validation of Copernicus Climate Services surface energy products

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An international consortium of universities and SMEs are engaged in the development of an operational EO validation service for the European Commission through the JRC. In the first year of this programme, attention has been focused on developing a set of surface reflectance and albedo, vegetation, soil moisture and LST. We focus here on the reflectance and albedo products. The EO products that are being validated come from the Copernicus Land Surface. They are processed using a single satellite source, VEGETATION, and now its successor, PROBA-V from June 2014 and albedos and top-of-canopy reflectances reported at the centre of every 1/112º (≈1km) pixel for a 10-day integration time interval. In order to validate these satellite measurements, ground-based albedo measurements are required, preferably from calibrated albedometers and/or calibrated hyperspectral multispectral or preferably hyperspectral measurements. Fortunately, such tower albedometers are plentiful over CO2 flux sites associated with the global FLUXNET system and a few very well calibrated WCRP sites such as the US SURFRAD and BSRN. The QA4EO method of traceability has been applied to these albedometer measurements to propagate their uncertainties and how albedos are retrieved for sites with no diffuse measurements is described. Time series of albedometer measurements are then employed to retrieve DHR ("black sky") and BHR ("white sky") albedo measurements and these are matched to the 10-day cadence. From an examination of DHR, a BRDF of the top-of-canopy projection of the albedometer is obtained. A description of the upscaling process is given and results shown. An example of how a tower-mounted hyperspectral sensor (W. Woodgate, p.c.) could be employed in future is shown and recommendations made.

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Developing an Automated Method to Estimate Spectrally Resolved DNI for Solar Energy Applications

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Multi-junction solar cells in concentrator photovoltaic systems (CPVs) offer the potential for highly efficient, low-cost electricity generation. However, these systems are typically designed and rated against reference spectra or for standard atmospheric conditions which are often not representative of the real deployment environments. Indeed, it has been shown that the use of unrealistic spectra can impact annual energy yield estimations by up to 75%. Hence there is a need to routinely generate

spectrally resolved direct normal irradiance (DNI) estimates that are based on real observations so that CPV systems can be properly optimised for different locations.

Here we present an automated scheme to estimate spectrally resolved DNI based on the integrated use of a radiative transfer model, AERONET ground-based observations and analyses from the European Centre for Medium Range Weather Forecasting Copernicus Atmospheric Monitoring Service (ECMWF CAMS). Our approach takes particular care to account for aerosol effects, circumsolar irradiance and other relevant atmospheric parameters. The results are tested using ground-based observations from Santiago, Chile. Preliminary results have shown that the broadband irradiance can be simulated with an average bias of less than 2%. We indicate how the scheme could easily be amended to incorporate satellite retrieved aerosol optical depths, enabling global, long-term assessment of CPV solar energy generation and the possibility of near-real-time power estimates.

SIBELIUs: Improved severe-weather resilience for Mongolian herding communities using satellite Earth Observation

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Mongolia is a large country (over 6 times the size of the UK) with approximately 30% of its population dependant on livestock herding who are exposed to extreme weather events, known as dzuds, which are increasingly exacerbated by climate change and are highly damaging to Mongolia's economy and devastating for the poorest herders. A typical dzud can impact tens of thousands of herders many of who will lose all their livestock leaving them in extreme poverty, with associated impacts for the wider economy.

The SIBELIUs project, supported by the UKSA's International Partnership programme (IPP), will deliver greater dzud-resilience for herders by providing Mongolia's National Agency for Meteorology and Environmental Monitoring (NAMEM) with improved capacity for distributing new and upgraded environmental products to key stakeholders supporting herding communities. SIBELIUs will channel its benefits through three existing networks:

1. Working with insurance providers in Mongolia to develop new index based insurance products, making use of EO to measure key environmental parameters (drought, pasture, snow etc.) to increase the herding populations' resilience to extreme weather events.

2. Collaboration with the Ministry of Food, Agriculture and Light Industry to help provide better management of reserve regions where pasture is set aside only for use in dzud conditions.

3. Distributing new and improved environmental information via a mobile phone text messaging service, set up by the NGO, Mercy Corps, which provides herders with weather forecast information and advice on pasture conditions, thus supporting better decision making in the face of harsh conditions.

As a vital component of the project, SIBELIUs will work with herders at selected case study sites to analyse their information requirements, to better understand barriers to uptake of previous insurance products, and to ensure their voices and priorities are heard in the development and distribution of new satellite-based environmental products.

An equal-weight particle filter for high-dimensional systems

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Nonlinear data assimilation in high dimensional systems is challenging because of the large number of independent observations, making the likelihoods extremely peaked. These peaked likelihoods result in highly varying particle weights and particle filter collapse. Localisation, in which observations are only allowed to influence local areas of state space, is found to be problematic, and present-day implementation have to revert to ad-hoc measures to avoid particle collapse. On the other hand, equal-weight particle filters have been around for 10 years or so, but all have short-comings the influence of which in practical applications is still unclear.

Here I discuss a new equal-weight filter tailored to high-dimensional systems that has minimal bias and solves several of the problems of earlier equal-weight filters. High-dimensional applications including online parameter estimation will be discussed, and it is shown that the filter can estimate marginals of the posterior pdf with only a very small number of particles.

Remote Sensing Magic: developing tools to make the invisible visible for a range of audiences

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Probably the best know benefit of remote sensing technology is that it allows us to observe things from a distance, with charismatic satellite images of our blue planet capturing most people's imagination. A lesser-known benefit is that it enables us to use parts of the electromagnetic spectrum that are invisible to the human eye, to better understand and visualize what happens at the Earth's surface. I'd like to call this Remote Sensing Magic. Unfortunately, for people who are new to the field, related concepts, such as multi-spectral imagery, can be difficult to grasp. This most likely hinders newcomers and casual observers to fully appreciate this important strength of remote sensing technology.

In my talk, I will present the approaches taken during four sessions that were developed to introduce new audiences to remote sensing technology. Rather than just showing them pretty pictures, I have thrown them in at the deep-end by engaging them with multi-spectral image data and specifically introducing them, hands-on, to near-infrared reflectance, as a means to see more. The first session was held at a Worcester primary school, as part of a project to help students send a message to the man-on-the-moon. The second session was developed to introduce a wider audience to Remote Sensing Magic during British Science week in the Hive library in Worcester. A third session was developed as part of University of Worcester Discover Days for A-level students, and a fourth session was developed for a 4-hour teaching slot, introducing first year Geography and Environmental Science undergraduates to essential remote sensing concepts.

I will reflect on the success of these sessions, using evaluations from a number of observers and participants and use this to support some recommendations on using Remote Sensing Magic as starting point for teaching and outreach of remote sensing technology to new audiences.

METEOR: Modelling Exposure Through Earth Observation Routines.

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METEOR (Modelling Exposure Through Earth Observation Routines) is a three year project funded by the UK Space Agency International Partnership Programme to develop innovative application of Earth Observation (EO) technologies to improve understanding of exposure with a specific focus on the countries of Nepal and Tanzania.

The escalating impacts of natural hazards are caused mostly by increasing exposure of populations and assets. A major challenge when making Disaster Risk Management (DRM) decisions is poor understanding of the distribution and character of exposure in ODA countries. Exposure needs to be mapped, monitored and modelled by Governments, NGOs, affected communities and businesses, seeking to bolster resilience and growth. Robust, quantitative methods are required to justify resilience decisions and risk mitigation. Projects have aimed to map exposure using EO using a range of approaches, though the application of these in DRM has been greatly limited by the fact that many have been poorly calibrated, for instance being based solely upon readily available data, or designed only for a particular setting. METEOR takes a step-change in the application of EO exposure data by developing and delivering rigorous and open routines (protocols) and standards to allow quantitative assessment of exposure, with explicit uncertainties. These protocols and standards will be co-developed for broad application to ODA countries and will be tested and validated in two contexts (Nepal and Tanzania) to ensure they are fit-for-purpose. Geohazard footprints will also be developed for those two countries. The process of building capacity and co-delivering new consistent data will promote welfare and economic development in these countries, and demonstrate the applicability of the techniques elsewhere. METEOR will deliver country-wide openly-available exposure data for the 47 least developed ODA countries. Better-informed DRM decisions that meet the demands of international drivers (e.g. SDGs, Sendai Framework) will be underpinned by our national-scale data.

The OmniSat HAPI Mission Concept and Demonstrator for Low Cost High Resolution NO2 Imaging

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A novel mission concept for low-cost high resolution satellite imaging of nitrogen dioxide has been developed which has implications for pollution monitoring with consequential health benefits. This concept is based on adapting the Differential Optical Absorption Spectroscopy (DOAS) hyperspectral approach to a multispectral approach using a small number of spectral channels with high SNR. The major simplification of hardware for this concept and the associated compact design and cost savings means that a smallsat instrument constellation is highly affordable, enabling multiple revisit times per day over the world's most polluted cities. Spatial resolutions as high as 600 m are achievable, giving unprecedented imaging capability.

Results so far include:

1) Simulations supporting the feasibility of NO2 retrieval using this concept;

2) Development of an airborne demonstrator spectrometer;

3) Ground testing of the spectrometer indicating sensitivity to NO2;

4) Collection of first data from a demonstrator flight.

This talk provides an overview of the mission concept, results to date, potential users, and future plans.

The University of Leicester XCO2 and XCH4 datasets from GOSAT measurements: Support for ESA's GHG-CCI and Copernicus C3S programmes

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The atmospheric concentration of CO2 and CH4 have been defined as Essential Climate Variables (ECV) by the WMO, meaning that they are crucial to our understanding of the Earth's climate. Satellite observations have provided global coverage which are essential to constraining surface flux estimates and forecasting long-term emission trends. The goal of the ESA GHG-CCI and EU Copernicus C3S programmes is the retrieval, validation, and provision of these datasets to the wider scientific and non-scientific community. As part of these projects, the University of Leicester (UoL) Earth Observation Science group have applied the UoL retrieval algorithms to retrieve the dry-air CO2 (XCO2) and CH4 (XCH4) column mole fractions from near-infrared spectra measured by the JAXA Greenhouse Gases Observing Satellite (GOSAT) to generate global, long-term (2009-2017) datasets..

The UoL 'full-physics' retrieval algorithm is a state-of-the-art retrieval based on the Optimal Estimation method. One key feature of the algorithm is that a priori information for aerosols is sourced from data from near real-time forecasts from the ECMWF MACC (now CAMS) aerosol model.

To evaluate the quality of the retrieved products, we validate them against reference data from the terrestrial Total Carbon Column Observing Network (TCCON).

In this presentation, we will give an overview of recent retrieval algorithm developments and the generated CO2 and CH4 ECV datasets. We will discuss their assessment against TCCON observations and comparisons with model calculations, and present plans to expand our algorithm to process data from the new generation of high spatial resolution satellite missions, such as Sentinel 5-P and OCO-2.

Global Gas Flaring Activity between 1991 and 2018 from the ATSR and SLSTR sensors

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Fairly recent analyses have estimated that gas flaring activities contribute ~1% of global anthropogenic CO2 emissions, whilst also releasing air pollutants such as black carbon, sulphur dioxide, nitrogen oxides, and hydrogen sulphide. A number of global initiatives, such as the "Zero Route Flaring by 2030" programme initiated by the World Bank, have been established to encourage nation states to end this wasteful activity. To determine whether such programmes are working towards their end goals regular global surveys of gas flaring activity are required. One suitable approach for the monitoring of gas flares and their emissions at such spatial and temporal scales is through the use of Earth Observations satellites. Various techniques have been developed to determine the radiative heat emissions of gas flares, a measure which has been shown to be correlated to natural gas combustion and carbon dioxide emission rates. Here we present the application of a single channel technique, influenced by the MIR-radiance method developed

previously for biomass burning, applied to the Along Track Scanning and the Sea and Land Surface Temperature Radiometers. The new technique relies on nighttime observations in the shortwave infrared (SWIR) to produce estimates of gas flare radiant emissions (in MW). Flaring locations are extracted from the nighttime imagery using a dual approach: the first stage assesses the persistence of thermal anomalies through time from the SWIR imagery; the second stage segregates persistent sites into flaring and non-flaring industrial actives through a spectral ratio method. Extensive validation of the detection and characterisation stages are made against state of the art gas flares products derived from the VIIRS sensors and shown to perform well and the resulting dataset is used to assess global gas flaring activity at a national level between 1991 and 2018.

Total Particulate Matter Emissions Estimates for Landscape Fires across SE Asia during the El Niño Driven 2015 Fire Season

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Recent work by Mota and Wooster presents a novel 'top down' approach for the generation of emissions inventories that directly links measures of fire radiative energy (FRE, in MJ) to total particulate matter estimates (TPM, in g) via biome specific emissions coefficients (Ce, in g MJ-1) derived from observations of smoke plume aerosol optical depth (AOD). Developed for Southern Africa using FRE observations from the geostationary SEVIRI imager and 10km AOD retrievals from MODIS, a nine-year emissions inventory was produced and compared well to current state-of-the-art products such as the Global Fire Emissions Database (GFED) and the Global Fire Assimilation System, whilst also providing a substantial enhancement to spatio-temporal sampling. Here we present work investigating its application to the challenging conditions of the extreme, El Niño driven, September through October 2015 fires in SE Asia. Focusing on the period of peak emissions, we obtain measures of FRE (at 2km resolution) from the recently launched Himawari-8 geostationary imager. Estimates of TPM are derived using biome specific mass extinction coefficients and AOD data from the VIIRS polar orbiter (at 750m resolution) produced using a combination of standard and ORAC products, which are validated against coincident observations from AERONET. Under the challenging observing conditions, it is established that the top-down approach is best suited for emissions estimation during either the earlier stages of the extreme burning period or when there is more dynamic variation in fire activity, typically associated with above-ground biomass combustion. The emission from these earlier events or those associated with periods of more variable combustion are of considerable interest to forecast service providers for enhancing operational activities such as near real time smoke dispersion modelling and air quality warning systems, and also to national governments in prioritising their fire reduction and landscape management policies in this particularly vulnerable region.

Interpreting Model Equilibrium Climate Sensitivity Using Observational Humidity and Stability

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The equilibrium sensitivity of the climate to a doubling of CO2 is currently poorly constrained by current global circulation models, with model output from CMIP5 suggesting a warming of between 1.5 and 4.5 °C. A large contribution from this range comes from the uncertainty associated with cloud feedbacks, especially that from the marine stratocumulus regions in the tropics (Knutti et al,. 2017). The uncertainty arising from the observation and parameterization of clouds has led to the use of constraints on the environment which produce clouds, rather than on the clouds themselves. In particular, both subtropical dry zones in the mid-troposphere and changes to tropospheric stability have been used to constrain estimates of sensitivity (Fasullo and Trenberth, 2012; Ceppi and Gregory, 2017).

Here, we use observations from CERES and AIRS, as well as reanalysis, to understand and characterise the relationship between tropospheric relative humidity, stability and top-of-the-atmosphere broadband radiation flux variability in the tropics and subtropics. By testing these mechanisms, we develop a metric with which to evaluate model output submitted to CMIP5, in order to constrain model estimates of both the equilibrium and transient climate response.

Using the Local Ensemble Transform Kalman Filter (LETKF) For Upper Atmosphere Modelling

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The upper atmosphere (ionosphere and thermosphere, 60 to 2000 km) presents a distinct challenge for data assimilation. The region is sparsely sampled by data, is strongly driven by solar inputs, and densities can vary by orders of magnitudes from day to night and in response to geomagnetic storms. There are also no satisfactory covariance models for the ionosphere/thermosphere and this provides the impetus to examine the use of ensemble methods of data assimilation. This paper describes the local ensemble transform Kalman filter (LETKF) and presents the initial results of the Advanced European electron density (Ne) Assimilation System (AENeAS). AENeAS is a new physics-based data assimilation model of the ionosphere/thermosphere. The model assimilates electron density true height profiles from ionosondes and TEC measurements from GPS receivers using the LETKF.

The LETKF is an ensemble Kalman filter variant which combines the ensemble transform Kalman filter (ETKF) with the local ensemble Kalman filter (LEKF). The LETKF results are equivalent to the LEKF results but are calculated in a more efficient manner, similar to the ETKF. The LETKF allows for the analysis to be performed independently around each model grid point and facilitates parallel implementation.

Like any Kalman filter the LETKF requires a background model. One possible candidate is the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIE-GCM). However, the maximum altitude modelled by TIE-GCM is between 500-700 km (depending on solar conditions). Consequently, another model (such as NeQuick) must be used to extend above these heights so that integrated measurements of the system (i.e. total electron content, TEC) can be used.

This paper describes the development and initial results from the Advances Ensemble electron density (Ne) assimilation system that is based on the LETKF and TIE-GCM. The model assimilates electron density profiles from ionosondes and TEC derived from GPS receivers.

The Living Maps Method (LMM) – practical applications in real-world scenarios

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Since last year's presentation at RSPSoc's Annual Conference, the Living Maps Method (LMM), funded by Defra and developed by Natural England, has significantly expanded its applications. This presentation will provide an update on how and why the LMM is being used internationally to create habitat maps in the UK, the UK's overseas territories and beyond. Examples include the translation of the LMM to Google Earth Engine for mapping coastal habitats in South Georgia and the Falklands, and the learning curve of using the LMM for the creation of habitat maps in Northern Ireland, Scotland, Peru, Montserrat and Turks and Caicos Islands.

Sharing code leads to more efficient collaboration between public sector bodies, academia and industry. Additional benefits are improved standardisation and algorithm development for the generation of products that are required across multiple policy areas, such as habitat maps. The provision of open code permits the method to be run on multiple platforms, enabling evolution of the process. The focus on algorithm development, cross-sector collaborations and cost efficiencies are in line with the future direction of the Defra Earth Observation Centre of Excellence, who are continuing to work towards better integration of satellite data.

Drought and Flood Mitigation Service – helping Uganda with EO data

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Throughout Africa, farmers are both grappling with droughts and poor rainy seasons as well as having to deal with heavy downpours causing flooding of their lands. The intensity and length of the dry seasons as well as the timing and intensity of the rainy seasons are becoming more and more unpredictable. The situation in Uganda is no different: reliable and actionable weather and crop data is often not (known to be) available or inaccessible and of varying quality which leads to underperforming agricultural production and food insecurity.

The Drought and Flood Mitigation Service (DFMS) project aims to bring about a considerable improvement to this situation by creating a sustainable service that will provide robust meteorological, hydrological, and other EO information as current observations, future forecasts, and historical archives for Uganda. As Uganda's national meteorological and hydrological services build up their capacity over the coming decades, DFMS will provide the Ugandan people with an improved level of service when it becomes operational in March 2019.

DFMS will offer a range of data products (e.g. land surface temperature, soil moisture, vegetation indices, river flows) which will be provided as an online service, removing the need for capital investments by the users. A cloud-based platform built using Open Data Cube technology hosts the hydrological and meteorological models and other algorithms that transform the satellite and in-situ Earth observation (EO) inputs into these products. Satellite EO inputs come from multiple missions including the Copernicus Sentinel -1 to -3, Landsat-8, METOP-A, Terra and Aqua, and in-situ inputs include data from weather stations, stream flow data, and information gathered using tried and tested Pictorial Evaluation Tool (PET) methodologies to visually evaluate crop yield and livestock conditions.

Lunar irradiance measurement and modelling for absolute radiometric calibration of EO sensors

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The photometric stability of the Moon and lack of interference from the Earth's atmosphere, makes the Moon an ideal reference site for the radiometric calibration of Earth observation satellites post-launch. In order to use the Moon in this way we require an accurate model that describes the apparent variations in irradiance resulting from changing Earth-Sun-Moon geometries over the familiar monthly cycle as well as the 18 year Saros cycle.

Here we present an update on an ESA-funded project that is working to produce such a lunar irradiance model, dramatically reducing the uncertainty in comparison with previous models. Measurements of the Moon are being obtained under free-tropospheric conditions in Izaña Tenerife using a CIMEL lunar photometer. This photometer has been extensively characterized at the National Physical Laboratory, UK, fully traceable to relevant primary standards, which ensures the lowest possible uncertainties for the calibration. These measurements, along with a detailed analysis of uncertainties, will allow us to model the irradiance of the Moon with a target of achieving uncertainty of no more than 2%.

Hyper-spatial or hyper-spectral: best value open-source satellite imagery for detecting changes in vegetation reflectance of polluted transects.

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Earth observation apparatus are increasingly recognized as the future of environmental protection and conservation leading to rapid advancement in the sensor technology incorporated in satellites. Studies show that hyper-spectral sensors are superior in capturing detailed vegetation reflectance to multi-spectral sensors, however, this superiority comes at a price. Recently, there has been calls for even higher pixel and spectral resolution imagery which will undoubtedly cost more. Fortunately, freely available images useful in environmental research exist. These include images acquired by the Hyperion (decommissioned) and Sentinel 2 sensors. This study assessed the potential of freely available hyper-spatial (Sentinel-2A) and hyper-spectral (Hyperion) imagery for monitoring oil pollution effects on vegetation. The Sentinel 2A data-set with higher spatial resolution (10 m) was re-sampled to match the Hyperion data (30 m) to enable comparison of their performance. Vegetation indices were extracted from both data-sets and compared for their ability to differentiate between polluted and non-polluted vegetation as well as detect oil induced stress in vegetation. The Mann-Whitney U test (W) and Cohen's metric (d) were used to determine performance. The results show that chlorophyll based indices such as normalized difference vegetation index (NDVI) decreased ($N = 33$, $W = 216$, $p < 0.05$) in polluted vegetation whereas stress indicating indices such as anthocyanin reflectance index (ARI) increased ($N = 33$, $W = 367$, $p < 0.03$). Comparatively, a clear distinction in the performance of indices from both data-sets appeared. Stress indicating hyper-spectral indices performed better than the multi-spectral equivalent in detecting stress ($d = -0.16$ and -1.21) respectively for ARI-m and ARI-h. Conversely, chlorophyll-based multi-spectral indices were better at differentiating between polluted and non-polluted vegetation ($d = 1.09$ and 0.83) respectively for NDVI-m and MRENDVI-h. This result demonstrates the suitability of freely available satellite data for cost-effective monitoring of vegetation response to oil pollution

Approaches towards 3D city models using open source data: a global reality

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3D city models are already being considered as a very important resource for the developing sustainable cities. Several disciplines including urban planning, architecture, telecommunication, tourism, environmental protection, amongst others, have an increasing demand for digital 3D urban models, utilising them for a variety of applications. It is therefore undeniable that the need for 3D geospatial information is increasing rapidly. Many different remotely sensed approaches can be used to create 3D models such as LIDAR, Photogrammetry, Lasergrammetry, Radargrammetry, all of which create high resolution datasets, yet these are both expensive to procure and labour intensive to process. As a result, such data is usually not available in many poorer regions, including many developing countries where city planning for sustainability is mostly needed.

No free of cost, high resolution 3D building models are available at present. In this paper we offer a potential solution for this problem by providing a globally replicable methodology to generate 3D city models from open source 2D building data. We consider mainly OpenStreetMap, ALOS DSM and LiDAR DTM from open sources to generate 3D models. Accuracy of the resultant 3D models can be an issue when dependent on open source data. Hence we have also developed a methodology to increase the accuracy level of 3D buildings generated from open source data. We have applied these methods for two geographically different regions - the Chinese city of Shanghai and the city of Nottingham in the United Kingdom. Technical validation results after accuracy enhancement shows it is possible to generate more than 97% of buildings with an accuracy in height of +/- 2 meters.

A Machine Learning approach for the identification of maritime vessels detected by Sentinel-1

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The Sentinel-1 constellation routinely provides SAR images of the seas, which can be used for monitoring maritime vessels. Several software are now available for operational vessel detection – they typically provide the geographical position of the detected vessels and an estimation of the vessel length. However, the identification of the vessel type (for e.g. fishing, cargo, or tanker) remains challenging because of the limited spatial resolution of Sentinel-1, and because the radar signature of vessels is highly variable. In this research project involving Cranfield University and the Centre for Environment, Fisheries and Aquaculture Science (Cefas), we investigate a novel approach for vessel identification, based on a Machine Learning (ML) technique initially trained with data from the Automatic Identification System (AIS).

In practice, we train a Random Forest classifier to recognise the type of a vessel based on its position (longitude, latitude) and its length. We demonstrate the approach over the North Sea, using a large database of AIS measurements for the training phase. We then apply the trained algorithm to a collection of vessels detected by Sentinel-1 using the open-source SUMO (Search for Unidentified Marine Objects) software. In particular, our method successfully distinguishes fishing vessels from other vessel types, which enables the spatial and temporal analysis of fishing patterns. Ultimately, the combination of vessel detection with SUMO and vessel identification with our ML approach represents a cost-effective alternative to commercial AIS data, which matches Cefas' needs for long-term maritime surveillance.

Session 6A: Satellite ECV Data Sets and Climate Services

Session Chairs: Briony Turner (The Institute for Environmental Analytics) & Geoff Busswell (Telespazio VEGA UK)
Date: Friday 7th September 2018
Time: 10:00-11:00
Location: Bramall Hall

A first prototype climate data record of land surface temperature from the ATSR series

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Land surface temperature (LST) is the radiative skin temperature of the land, and is one of the key parameters in the physics of land-surface processes on regional and global scales. Earth Observation satellites provide the opportunity to obtain global coverage of LST approximately every 3 days or less. The Along-Track Scanning Radiometers (ATSRs) have been important sources of satellite-retrieved data for the approximately 20-year period from 1991 to 2012, with these instruments achieving high accuracy in measurements with extraordinary stability - an important consideration for potential climate time series analysis.

Within the framework of the GlobTemperature Project under the Data User Element of ESA's 4th Earth Observation Envelope Programme (2013-2017), which has supported the wider uptake of global-scale satellite LST by the research and operational user communities, a first attempt at providing a long-term LST dataset of climate quality from the ATSRs has been undertaken. This has been timely since LST was re-classified by GCOS as an Essential Climate Variable (ECV) in 2016.

A Climate Data Record requires SI traceability and needs to deliver the following: low bias; realistic uncertainties; full sensitivity to variability in LST; independence of in situ data; and excellent stability / homogeneity. From an initial algorithm trade-off analysis, measures towards a climate data record include: characterisation of the inter-sensor calibration; homogenisation of the brightness temperatures; a detailed uncertainty analysis; development of an improved cloud mask; investigation into aerosol detection; and assessment of stability intended to challenge the user community to exploit LST data in climate studies. Here we present an account of the first prototype Climate Data Record of LST developed for the ATSR series of instruments which is both independent from in situ measurements and adaptable to other satellite instrument which observe LST.

Comparing ECV products with the Evaluation and Quality Control function of the Copernicus Climate Change Service

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Decision makers need robust evidence in order to introduce new policies in an effort to mitigate and adapt to climate change. There is an increasing amount of environmental information available to policy makers concerning recent observations and trends relating to the climate. However, this data is hosted on a plethora of websites often with inconsistent metadata and little information relating to the quality of the data. Subsequently, the task of comparing datasets to decide which is the most appropriate for a certain purpose is very complex and often infeasible.

The Copernicus Climate Change Service will provide a Climate Data Store (CDS) where numerous ECV data products will be listed. The CDS will have an integrated Evaluation and Quality Control (EQC) function which will be responsible for the provision of user-driven information related to quality for

each product. The reports will include comprehensive detail on the product generation, quality information provided by the data producer (quality flags, known issues etc.) as well as information on the uncertainty characterisation and the validation and inter-comparison activities. The EQC function will aim to capture more information than is already available and will house it in one location with a common format.

A key feature of the EQC function will be the ability to compare data products by their quality information enabled by the standardisation of the information captured. The EQC function will act as a tool to directly compare several products based on the matters a user deems most important. It would facilitate a user to filter and compare multiple datasets and choose the most optimal for their particular application.

This presentation will demonstrate the key functionalities of the EQC function and will highlight how increased quality information can be extremely beneficial to scientific users and policy makers.

Ocean Colour Global Time Series for use in Climate Studies

Stephen Groom[1], Shubha Sathyendranath[1], Tom Jackson[1], Frederic Melin[2], Carsten Brockmann[3], Lia Santoleri[4], Bryan Franz[5], Menghua Wang[6], Vanda Brotas[7], Francois Steinmetz[8], Hajo Krasemann[9], Craig Donlon[10], Paolo Cipollini[11]

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Spectrally-resolved water-leaving radiance and chlorophyll concentration are recognised as Essential Climate Variables (ECV) by the Global Climate Observing System. Global time-series of these ECVs are key to studying phytoplankton dynamics at seasonal and inter-annual scales, and understanding the role of phytoplankton in marine biogeochemistry, the global carbon cycle and the response of marine ecosystems to climate variability.

Generation of a long time-series of ocean-colour data is not a trivial task: there are a number of atmospheric correction and product retrieval algorithms; satellites have finite life-spans, so data from individual sensors from late 1997-date, with differing sensor characteristics, need to be merged without introducing artefacts. ESA's Ocean Colour Climate Change Initiative is undertaking research addressing these requirements, with support from NOAA, NASA and a large community of global climate researchers, marine ecosystem modellers and remote sensing scientists. Products are validated against fiducial reference measurements; uncertainty characteristics, quantified on a pixel-by-pixel basis, facilitate applications and interpretations consistent with the quality of the data. Continuity in ocean-colour ECV production is vital to support continued use by the scientific community and will be sustained through the European Copernicus Climate Change Service programme.

This presentation will discuss the prospects to develop the ocean-colour ECV through: addition of new sensors, notably the Sentinel-3 OLCI series; potential increases in data resolution (e.g. spatially global 300m from OLCI and temporally though geostationary missions); and integration with in situ observing systems, notably the BioArgo programme to investigate the 3D structure of the ocean.

Developing an Automated Method to Estimate Spectrally Resolved DNI for Solar Energy Applications

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Multi-junction solar cells in concentrator photovoltaic systems (CPVs) offer the potential for highly efficient, low-cost electricity generation. However, these systems are typically designed and rated against reference spectra or for standard atmospheric conditions which are often not representative of the real deployment environments. Indeed, it has been shown that the use of unrealistic spectra can impact annual energy yield estimations by up to 75%. Hence there is a need to routinely generate spectrally resolved direct normal irradiance (DNI) estimates that are based on real observations so that CPV systems can be properly optimised for different locations.

Here we present an automated scheme to estimate spectrally resolved DNI based on the integrated use of a radiative transfer model, AERONET ground-based observations and analyses from the European Centre for Medium Range Weather Forecasting Copernicus Atmospheric Monitoring Service (ECMWF CAMS). Our approach takes particular care to account for aerosol effects, circumsolar irradiance and other relevant atmospheric parameters. The results are tested using ground-based observations from Santiago, Chile. Preliminary results have shown that the broadband irradiance can be simulated with an average bias of less than 2%. We indicate how the scheme could easily be amended to incorporate satellite retrieved aerosol optical depths, enabling global, long-term assessment of CPV solar energy generation and the possibility of near-real-time power estimates.

Session 6B: Earth Observation for Mapping and Monitoring of Landslides

Session Chairs: Zhenhong Li (Newcastle University), David Milledge (Newcastle University) & Alessandro Novellino (British Geological Survey)
Date: Friday 7th September 2018
Time: 10:00-11:00
Location: G33

Morphology-based landslide monitoring with an Unmanned Aerial Vehicle

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Landslides represent major natural phenomena with often disastrous consequences. Monitoring landslides with time-series surface observations can help mitigate such hazards. Unmanned aerial vehicles (UAVs) employing compact digital cameras, and alongside Structure-from-Motion (SfM) and modern Multi-View Stereo (MVS) image matching approaches, have become commonplace in the geoscience research community. These methods offer a relatively low-cost and flexible solution for many geomorphological applications. The SfM-MVS pipeline has expedited the generation of digital elevation models at high spatio-temporal resolution. Conventionally ground control points (GCPs) are required for co-registration. This task is often expensive and impracticable considering hazardous terrain.

This research has developed a strategy for processing UAV visible wavelength imagery that can provide multi-temporal surface morphological information for landslide monitoring, in an attempt to overcome the reliance on GCPs. This morphological-based strategy applies the attribute of curvature in combination with the scale-invariant feature transform algorithm, to generate pseudo GCPs. Openness is applied to extract relatively stable regions whereby pseudo GCPs are selected. Image cross-correlation functions integrated with openness and slope are employed to track landslide motion with subsequent elevation differences and planimetric surface displacements produced. Accuracy assessment evaluates unresolved biases with the aid of benchmark datasets.

This approach was tested in the UK, in two sites, first in Sandford with artificial surface change and then in an active landslide at Hollin Hill. In Sandford, the strategy detected a ±0.120 m 3D surface change from three-epoch SfM-MVS products derived from a consumer-grade UAV. For the Hollin Hill landslide six-epoch datasets spanning an eighteen-month duration period were used, providing a ± 0.221 m minimum change. Annual displacement rates of dm-level were estimated with optimal results over winter periods. Levels of accuracy and spatial resolution comparable to previous studies demonstrated the potential of the morphology-based strategy for a time-efficient and cost-effective monitoring at inaccessible areas.

An InSAR/GNSS integrated early warning system for landslide hazards

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Landslides are one of the costliest and deadliest geohazards in mountainous regions, which can be triggered by different mechanisms, such as large earthquakes, monsoonal rainfall or storms. Early warning on the location and timing of landslides would offer huge benefits enabling action to minimise exposure of people and even assets to landslide runout.

Spaceborne InSAR and GNSS are complementary tools to monitor topographic displacements given InSAR's high spatial sampling (meters to 10s meters) over a wide region (e.g. 250 km x 250 km for Sentinel-1) but limited temporal resolution (constrained by the frequency of satellite overpasses), and GNSS's fine temporal resolution at GNSS receiver locations. GNSS stations can be carefully selected according to the landslide motion information provided by InSAR so that an accurate continuous monitoring in time and space for an entire region will be achieved by integrating these two systems.

In this presentation, I will use a couple of recent landslides to demonstrate how InSAR and/or GNSS can be employed to reveal pre-event movements and map the source areas and boundaries of landslides, which will lead to an important implication to landslide early warning systems.

Detecting landslides triggered by the 2015 Gorkha earthquake using satellite radar

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Major earthquakes in mountainous regions trigger landslides that present a major secondary hazard and can disrupt relief efforts. Rapid post-earthquake mapping of these landslides is therefore of critical humanitarian importance but is often significantly delayed by a lack of cloud-free optical imagery. Satellite radar (SAR) data presents a possible solution as radar can penetrate cloud cover and recent increases in data acquisition frequency mean that imagery is now available globally within days of a trigger event.

For a pair of SAR images before and after an earthquake, radar coherence is a measure of the spatial similarity between neighbouring pixels in phase difference between the two images. Coherence is high for ground surfaces which change little in time between acquisitions and low when the surface is disrupted e.g. due to vegetation, water or ground failure. Maps of radar coherence and of temporal coherence change have been used previously as proxies for flooding and urban earthquake damage, but have to-date shown mixed potential for landslide detection.

We investigate the utility of radar coherence for rapid detection of earthquake-triggered landslides, using the 2015 Mw 7.8 Nepal earthquake as a case study. The Nepal earthquake triggered around 25,000 landslides, but weather conditions delayed remote mapping by several weeks. We test two existing coherence-based methods of landslide detection against high-resolution, optically-derived landslide maps and find that neither act as robust landslide classifiers, mainly due to background temporal variability in coherence. We therefore propose a new method, which incorporates multiple pre-earthquake images to mitigate this effect. We find our new method outperforms both existing methods for our test dataset. All three methods perform only slightly better than random for pixel-by-pixel (20 m) landslide classification, but when these are aggregated to 600 m pixels, our new method shows considerable potential in landslide density mapping.

Automatic long-term monitoring using Sentinel-1 for geohazards and infrastructure stability

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Interferometric synthetic aperture radar (InSAR) is now an established technique to measure ground motion using multiple satellite radar acquisitions. The European Space Agency (ESA) Sentinel-1 satellite constellation is a 20+ year operational system acquiring radar data every 6-12 days with a near global coverage.

The wealth and quantity of Sentinel-1 data mean that we can now exploit time series techniques to monitor ground motions around critical infrastructure, slow landslides, and subsidence in near-real time. However, manually processing large amounts of data is time consuming. In this presentation I will demonstrate the capabilities of a new system designed to automate the entire chain from data search, download and processing, atmospheric corrections, velocity map generation and detection of anomalies in ground motion through exploitation of time series signals.

Session 6C: Space Placement in Industry (SPIN) 2018

Session Chair: Kathie Bowden (UK Space Agency)
Date: Friday 7th September 2018
Time: 10:00-15:00 - please note the timing will include refreshments
Location: C-Block Lecture Theatre

SPIN has been developed to connect students looking for paid work placements in the space sector with opportunities within companies, research groups and not for profits who are looking to find those talented and enthusiastic people to help ensure the future success of their organisation. The scheme is managed by the UK Space Agency and supported by the Satellite Applications Catapult.

The Showcase Day on Friday 7th September will be the culmination of 8 weeks work within a range of organisations from across the sector. SPINterns will have worked on projects with different foci, learning new skills, adding to their CVs and contributing to the organisation for whom they have been working. Whilst one objective is to enable the students to showcase their own abilities, it also provides a medium for potential employers to engage with some of the brightest and best students as they approach graduation.

All of the students will give a short 2-minute elevator pitch describing their project and what they have gained from the experience and will then be ready to speak to all interested parties against the backdrop of a poster they will have prepared during their placement. All visitors will be welcomed at either or both sessions. Following lunch, UKSEDS and the UK Space Agency will host a Skills and Careers Speed Mentoring Session and Panel which will be open to all students and recent graduates attending the Conference and this event.

SPIN posters will be on display in the Great Hall for the duration of the day

Session 7C: Data & Challenges, including the ISCF Wave 3 Workshop

Session Chair: Andy German (InnovateUK) & Andy Bennett (Knowledge Transfer Network, InnovateUK)
Date: Friday 7th September 2018
Time: 10:00-13:00 - please note the timing will include refreshments
Location: Senate Chamber

ISCF Wave 3: Space Data Revolution Workshop

UK Research and Innovation invites you to join a workshop to review, challenge and validate a proposed new challenge Space Data Revolution that could form part of the next wave of the Industrial Strategy Challenge Fund (ISCF).

The Industrial Strategy Challenge Fund builds on the UK's world-class research base and delivers the science and innovation that business needs to transform existing industries and create new ones.

The Space Data Revolution proposal addresses the challenge that the value of geospatial data exploited commercially, especially that originating from space, is very small compared to its potential. Combining space data with other sources and applying the latest data techniques (such as AI & Machine Learning) is needed to address real-world commercial problems, and the opportunities are global.

These new proposed Challenges form an integral part of the UK Government's ambition, as part of the modern industrial strategy, to make the UK the most innovative economy in the world. The goal of the ISCF is to accelerate commercial exploitation of the most exciting technologies the UK has to offer the world to ensure that scientific investment truly delivers economic impact, jobs and growth right across the country.

We do hope that you are able to join this workshop. Your time, knowledge, expertise and experience will play a vital role in the next phase of this flagship research and innovation programme

JASMIN a platform for the development of downstream EO applications and services

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We describe the role of the JASMIN data analysis facility in the development of EO applications and services for the UK environmental sciences community and its collaborations with industrial partners. First established in 2012, it was developed directly as a response to the challenges of big data facing researchers by providing a resource to store large volume EO and climate datasets directly with the computing resources to analyse them. This model has provided an impetus for collaborative working and since its inception it has experienced a rapid development (150+ science projects hosted to date) and technical evolution.

JASMIN's cloud service plays a key role providing a hosting environment to facilitate the development of downstream services to analyse and disseminate data. Examples of hosted projects and services include the ESA Polar and Forestry Thematic Exploitation platforms, the ESA CCI Open Data Portal, and the distribution of model and observational data for the Copernicus climate services.

The current phase 4 of JASMIN's development will see a significant expansion of the cloud service. This is not a growth in capacity alone but must address how to create an environment in which to

support and nurture the development of virtual research environments (VREs) and exploitation platforms. Work is focused then on two aspects: services to enhance discovery and access to data and secondly, the development of what we have called cluster-as-a-service. Experiences with the development of VREs have shown that there are key enabling and supporting technologies to facilitate their development: notebooks (e.g. Jupyter), frameworks for parallel computing data analysis such as Spark and Dask and underlying container middleware to support the orchestration of resources. By providing these as pre-packaged components readily deployable within the cloud, we can provide EO application developers with the necessary building blocks to innovate and create new platforms and services.

Remote Sensing Sucks!

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Remote sensing today involves too much choice, too many methods, too much data and requires too many computing resources, and yet we still haven't moved on from calculating NDVI.

Or maybe not! This (hopefully lighthearted) talk will quickly list some of the issues that are pertinent to Earth observation today and will look to see why these might be causing problems for new and existing users. It will also look at some of the recent developments in the sector and how they might set out to address some of the perceived problems. We won't be able to cover everything, but together we'll have a stab at righting EO's wrongs. Possibly.

Space Data Revolution (ISCF)

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The Industrial Strategy Challenge Fund (ISCF) aims to bring together the UK's world-leading research with business to meet the major industrial and societal challenges of our time. This is part of the government's £4.7 billion investment in R&D over 4 years.

By investing in and supporting UK businesses and researchers, the fund will ensure that research and innovation takes centre-stage in the government's Industrial Strategy.

It is delivered by UK Research and Innovation.

In 2017, the UK space sector chose to focus its ISCF ambitions on the exploitation of geospatial data, in particular to address the challenge that this area has great potential of which little has been unlocked to date.

In September 2017, the proposal for a challenge entitled Space Data Revolution will be in its final stages of preparation before submission. We would like to take the opportunity of NEOCONF2018 to engage the EO community with the challenge and prepare for its launch in 2019

Session 7A: Data Assimilation: from Theory to Applications

Session Chairs: Amos Lawless (University of Reading) & Peter Jan Van Leeuwen (University of Reading)
Date: Friday 7th September 2018
Time: 11:30-13:00
Location: Bramall Hall

Data Assimilation with the JULES land surface model

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The Joint UK Land Environment Simulator (JULES) is a community land surface model used by the UK Met Office in the production of forecasts and is the land surface scheme of the UK Earth System Model (UKESM). In this talk we will discuss the implementation of a data assimilation scheme for this model and show a number of applications. These include the improvement of parameterisations of soil properties over Ghana through the assimilation of remotely sensed soil moisture and the optimisation of crop model parameters using flux tower data.

Land surface data assimilation is usually a parameter estimation problem rather than a state estimation problem due to the deterministic nature of the models. For this reason it can be preferential to use variational data assimilation techniques instead of sequential techniques in order to avoid time-varying parameters. Variational techniques require knowledge of the derivative of the model, this can prove costly to compute and maintain with the release of newer versions. In this talk we outline the hybrid technique of four-dimensional ensemble variational data assimilation as a possible solution to this problem.

Treating ensemble sample error covariances in data assimilation

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Covariance information derived from an ensemble of model forecasts is used to define the a priori error covariances required in data assimilation. Due to restrictions on sample size, ensemble covariances are routinely rank deficient and/ or ill-conditioned and marred by sampling noise; thus they require some level of modification before they can be used in a standard assimilation framework. Here, we compare two methods for improving the rank and conditioning of multivariate sample error covariance matrices. The first method, model state-space localization via the Schur product, effectively removes sample noise, but can dampen small cross-correlation signals. The second method, reconditioning, alters the matrix eigenvalues directly; this preserves the correlation structures but does not remove sampling noise. We show it is better to recondition the correlation matrix rather than the covariance matrix, as this prevents small but dynamically important modes from being lost. A combination that exploits the merits of each method is found to offer an effective alternative. Results are presented in the context of coupled atmosphere-ocean data assimilation, where the particular challenge is to identify the cross covariances linking the errors in the atmosphere and ocean variables.

Estimation of Model Error Covariances for nonlinear dynamical systems using Particle Filters and the Expectation-Maximization algorithm

Maria Magdalena Lucini[1,2], Peter Jan van Leeuwen[1,3], Manuel Pulido[1,2]

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Model error covariances play a central role in the perfomance of particle filters applied to nonlinear state-space models.However, these covariances are largely unknown in most of the applications, including models used in geophysics and engineering.

In this work, we propose the combination of the Expectation-Maximization algorithm (EM) with an efficient particle filter to estimate the model error covariance. A batch of observations is used to find the elements of this model error covariance.

Since the relation between the observations and the model error covariance is via the evolving state of the system under this covariance matrix, this is a complicated problem. Based on the EM algorithm principles, the proposed solution method encompasses two stages: the expectation stage, in which a particle filter is used with the present estimate of the model error covariance as given to find the probability density function that maximizes the likelihood of the observations, followed by a maximization stage in which this expectation is maximized as function of the elements of the model error covariance. Since the problem is highly nonlinear an analytical solution for this maximum cannot be found.

This methodology shows to be converging towards true model error covariances in twin experiments using the Lorenz-96 system, but at different rates and with different accuracies depending on system parameters. We explore the causes for these differences and discuss application to high-dimensional systems.

The variational mapping particle filter

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Nonlinear data assimilation is becoming more and more important in the geosciences, with ever increasing model resolutions and more complex observation operators. In this work, a novel sequential Monte Carlo filter is introduced that aims at efficient sampling of high-dimensional state spaces with a limited number of particles. Particles are pushed forward from the prior to the posterior density using a sequence of mappings that minimizes the Kullback-Leibler divergence between the posterior and the sequence of intermediate densities. The sequence of mappings represents a gradient flow. A key ingredient of the mappings is that they are embedded in a reproducing kernel Hilbert space, which allows for a practical and efficient algorithm. The embedding provides a direct means to calculate the gradient of the Kullback-Leibler divergence leading to quick convergence using well-known gradient-based stochastic optimization algorithms. Evaluation of the method is conducted in the chaotic Lorenz-63 system, the Lorenz-96 system, which is a coarse prototype of atmospheric dynamics, and an epidemic model that describes cholera dynamics. No resampling is required in the mapping particle filter even for long recursive sequences. The number of effective particles remains close to the total number of particles in all the experiments.

Assimilation of ocean-colour phytoplankton functional types to improve the simulation of marine ecosystem models

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We show that the novel assimilation of phytoplankton functional types (PFTs) from ocean-colour into ocean biogeochemistry models can improve the simulation, prediction and understanding of marine ecosystems. We assimilated error-characterized chlorophyll concentrations of four PFTs (diatoms, dinoflagellates, nanoplankton and picoplankton), derived from data of the ESA's Ocean Colour – Climate Change Initiative (ESA's OC-CCI), into a biogeochemical model of the North East Atlantic (ERSEM). We present two applications of this novel approach: i) a multi-annual reanalysis of carbon fluxes in the region, by using a localised Ensemble Kalman filter; ii) five-day predictions of biogeochemical indicators, by using the variational assimilation system applied operationally at the Met Office. Both the applications showed that PFT assimilation outperformed the assimilation of total chlorophyll in estimating the ocean-colour PFTs. This led us to improve the simulation of the plankton community structure, which is a key emergent property of the simulated ecosystem. Crucially, PFT assimilation improved also the model simulation and prediction of not-assimilated in situ data of pCO2, impacting the simulation of the air-sea carbon flux. The method proposed here is easily adaptable for use with other models that simulate PFTs, for, e.g., reanalysis of carbon fluxes in the global ocean, or for operational forecasts of biogeochemical indicators in other European regional seas. This work contributes to the EU Copernicus Marine Environment Monitoring Service (project "TOSCA") and to ESA's OC-CCI.

The ABC model/data assimilation system to study convective-scale data assimilation

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The data assimilation problem for convective-scale flows can be very challenging to solve for a number of reasons, e.g. the complex nature of these systems, the presence of strongly non-linear and non-Gaussian processes, and the weakening of geostrophic and hydrostatic balances. These geophysical balances are used generally in data assimilation for numerical weather prediction to help quantify background error covariances between different variables to maintain physical consistency of the analysis. Various questions emerge about whether including these balances in convective-scale data assimilation systems help or hinder the problem.

The ABC model is a two-dimensional toy model to help research into convective-scale data assimilation. The data assimilation system for this model has been purpose-built to facilitate research into convective-scale data assimilation (such as the question of balance mentioned above), while being easy to use and quick to run (even on a laptop computer), while having a broad range of scientific configurations. The ABC model and data assimilation system will be outlined, together with a demonstration of the effect of different means of modelling the background error covariances, including the use (or not) of geophysical balance conditions.

Session 7B: Integrated Surface Temperature & Remote Sensing of the Polar Regions

Session Chair: Claire Elizabeth Bulgin (University of Reading)
Date: Friday 7th September 2018
Time: 11:30-13:00
Location: G33

Land Surface Temperature CCI: approaches to long-term data for climate

Darren Ghent
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The land surface temperature (LST) CCI project aims to deliver a significant improvement on the capability of current satellite LST data records to meet the strict GCOS requirements for climate applications of LST data.

The programme of work aims to achieve some excellent results:

- Detailed climate user input into the specifications of the LST ECV products, and user assessment of these products to drive LST exploitation in climate science
- Strong buy-in from the climate science community coordinated by the Climate Research Group
- A comprehensive suite of high quality IR LST ECV Products and MW LST ECV Products for geostationary (GEO) and low earth orbit (LEO) satellites covering a range of time periods from 1995 for the earliest sensor through to 2020
- A first Merged IR CDR from input bias corrected Level-1 GEO and LEO data at 0.05° and 3-hourly to confront the expected requirements for an operational LST climate service
- A consistent long-term LST CDR of over 20 years from 1995 to 2020 for ATSR-2 through to SLSTR by bridging and filling the gap between AATSR and SLSTR
- Demonstration of a coherent and open pre-operational End-to-End processing system for delivering the LST ECV Products
- A strong validation component providing globally representative and consistent in-situ validation and intercomparison of LST products over all the major land cover types, informing the climate community of the performance of the LST ECV products
- Sustained support to the surface temperature community through dedicated effort into the well-established International LST and Emissivity Working Group (ILSTE) which is the principle forum of community expertise from data providers to users

We present here the approach to be taken to realise the full potential of long-term LST data for climate science.

Retrieval of radiatively consistent Sea Surface Temperature under clear and aerosol conditions using an optimal estimation scheme across the visible and infrared.

Caroline Vanessa Cox[1], Caroline Poulsen[1], Richard Siddans[1], Gareth Thomas[1], Roy Grainger[2], Haiyan Huang[2]
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It is important for studying long term climate trends for the surface temperature to be measured under all surface and atmospheric conditions. Aerosol types and quantity can vary significantly over the ocean. Under heavy loadings of aerosol, surface temperature retrievals over ocean are often not

attempted using the infrared. Depending on the type and amount of aerosol, if undetected, the retrievals of sea surface temperature (SST) can be significantly biased. In this study we present retrievals of SST from the Advanced Along Track Scanning Radiometer (AATSR) using the Optimal Retrieval of Aerosol and Cloud (ORAC) algorithm under clear and aerosol loaded conditions. Importantly, ORAC retrieves surface and atmospheric parameters simultaneously using the visible, short-wave infrared and thermal infrared information enabling atmospheric properties and the surface to be retrieved at the same time. In this presentation a joint SST and aerosol retrieval is performed and the results presented with uncertainties reported, across varying aerosol conditions. The SST retrieved has been validated using a global set of measurements of bulk SSTs from drifting buoys under cloud-free skies, with typical background aerosol loadings that have a mean optical depth of 0.08. The median SST bias is less than 0.1 K, the level required for climate studies. We also demonstrate that ORAC is able to retrieve the SST under dust by performing retrievals of drifting buoy matchups and of images affected by dust off the Western Sahara.

Characterising Uncertainties for Integrated Surface Temperature Products

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Uncertainty information provided with remote sensing products is fundamental to their scientific application. We present here a method of characterising uncertainties within the Earth surface temperature retrieval process, independent of external datasets, enabling validation of both the retrieved quantity and its associated uncertainty. We apply this methodology systematically to retrieval of sea, land and lake surface temperature, providing consistency across products for integrated surface temperature applications. Three types of uncertainties are provided in our data products: uncorrelated, locally correlated and large-scale correlated. Uncorrelated uncertainties arise from error sources with no spatial or temporal correlation eg. instrument noise. Locally correlated uncertainties are a function of errors introduced by retrieving surface temperature through the Earth's atmosphere and specifying Earth surface properties in the retrieval process (eg. use of prior data from numerical weather prediction (NWP) and cloud detection errors). Large-scale correlated uncertainties arise from instrument calibration and time series harmonisation errors. Providing uncertainties classified according to the correlation lengths scale of the contributing error sources facilitates propagation of these uncertainties into higher level-products by both data users and data producers.

Remote sensing of the thermal plumes around the British coast

Agnieszka Maria Walenkiewicz[1], Christopher Merchant[1], Claire Bulgin[1], Hugo Winter[2], Angus Bloomfield[2]

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Sea temperatures can affect species distributions in the coastal ecosystems around Britain and therefore power stations need to meet environmental requirements in order to be allowed to release coolant water. This presentation focuses on investigating thermal contrasts in coastal waters in the vicinity of British nuclear power stations using data from Landsat 8 and ASTER. Nuclear power stations generated almost a quarter of British electricity in 2016 and it is estimated that their contribution to overall power production will rise up to a third in the near future. All nuclear power stations in the UK are located around the coast and use sea water as a coolant for their installations, releasing warmer water back into the ocean. High-resolution satellite imagery enables us to better understand the spatial distributions of thermal plumes from nuclear power stations. In this presentation we use data from both Landsat and ASTER. Landsat products have a spatial resolution of 30m and ASTER products

15-90m depending on wavelength. Both instruments have a return time of 16 days. Ongoing work focuses on Sea Surface Temperature (SST) retrieval from brightness temperature (BT) observations and radiative transfer model (RTM) clear-sky simulations. Plume characteristics will be investigated temporally as well as spatially. Comparing SSTs spatially across the scene gives a relative understanding of the plume in relation to surrounding ambient water, the plume extent, and possible plume area. Time series enable us to investigate seasonal dependence of plume dispersal around nuclear power plants.

Towards A Combined Surface Temperature Dataset for the Arctic from the Along-Track Scanning Radiometers (ATSRs)

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Surface Temperature (ST) changes in the Polar Regions are predicted to be more rapid than either global averages or responses in lower latitudes. Observations of STs and other changes associated with climate change increasingly confirm these predictions in the Arctic. Furthermore, recent high profile events of anomalously warm temperatures have increased interest in Arctic surface temperatures. It is, therefore, particularly important to monitor Arctic climate change.

Satellites are particularly relevant to observations of Polar Regions as they are well-served by low-Earth orbiting satellites. Whilst clouds often cause problems for satellite observations of the surface, in situ observations of STs are much sparser. The ATSRs are accurate infra-red satellite radiometers, designed explicitly for climate standard observations and particularly suited to ST observations. ATSR radiance observations have been used to retrieve sea and land ST for a series of three instruments over a period greater than twenty years. This series has been extended with the launch of SLSTR sensors on Sentinel satellites 3A and 3B, which have the same key design features.

We have combined land, ocean and sea-ice ST retrievals from ATSR-2 and AATSR to produce a new ST dataset for the Arctic; the ATSR Arctic combined Surface Temperature (AAST) dataset. The method of cloud-clearing, use of auxiliary data for ice classification and the ST retrievals used for each surface-type will be described. We will establish the accuracy of sea-ice and land-ice retrievals with results from validation against in situ data. We will also discuss the issue and complexities in producing a combined surface temperature dataset for this region.

Retrieval of surface emissivity over the Greenland plateau and implications for future satellite missions

Helen Brindley[1,2], Jonathan Murray[1], Christophe Bellisario[3,2], Cathryn Fox[4], Stuart Fox[4], Chawn Harlow[4], Alan Last[1], Doug Anderson[5], Maureen Smith[5], Juliet Pickering[1]

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Recent work has shown that incorporating more realistic representations of snow and ice infrared surface emissivity in climate models can significantly reduce Arctic surface temperature biases and may play a key role in determining the pace of change in the region. However, due to a lack of 'in-situ' observations of surface emissivity over snow and ice, particularly at far-infrared (FIR) wavelengths (wavelengths > 15 microns), the emissivity representations used in the modelling studies thus far are based on theoretical estimates.

Following on from initial work by Bellisario et al (2017), which exploited near surface flights to derive the first ever aircraft based estimates of FIR surface emissivity, here we present retrievals of infrared spectral surface emissivity made from the Tropospheric Airborne Fourier Transform Spectrometer

(TAFTS) and Airborne Research Interferometer Evaluation System (ARIES), flying at altitude over Greenland during March 2015. We describe the flight campaign and instrumental setup as well as the retrieval method, including the quality control performed on the observations. The results indicate that it is possible to retrieve surface information in the FIR from altitude, with the frozen surfaces overflown showing emissivities that have distinct spatial and spectral variability.

Our results highlight a need for improvements in our understanding of the radiative behaviour of snow/ice surfaces and for further observational characterisation. They also serve as a demonstration of the sensitivity of outgoing longwave radiation to FIR surface properties in polar regions, important for NASA's planned Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE), and ESA's proposed Far infrared Outgoing Radiation Understanding and Monitoring (FORUM), satellite missions.

The Copernicus Imaging Microwave Radiometer (CIMR): Concepts and Applications for a proposed Sentinel Expansion Mission

Christopher J. Merchant[1], Craig J. Donlon[2], Paolo G. E. Laberinti[2], Felice Vanin[2]

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The Copernicus Imaging Microwave Radiometer (CIMR) is an Earth observation mission in Phase-A/B1 development at the European Space Agency. CIMR is under consideration as a next-generation addition to the Copernicus Space Programme as a priority mission identified by the European Commission (EC) to provide additional capabilities to address emerging user needs. CIMR will provide operational observations of the changing state of the Pan-Arctic regions and adjacent seas, and also global data of immense interest to oceanography. The primary mission drivers are observation of Sea Ice Concentration (SIC) and Sea Surface Temperature (SST). All specifications are provisional, but the outlines are likely to be as follows. CIMR will be a passive microwave radiometer with channels in L band (~1.4 GHz), C band (~6.9 GHz), X band (~10.7 GHz), Ku band (~18.7 GHz) and Ka band (~37 GHz).The real-aperture resolution will be <15 km in C band and <5 km in Ka band, an unprecedented requirement driven by all-weather high-resolution SIC for polar shipping navigation, which will be increasingly critical in future. Radiometric uncertainty requirements are driven by the target SST uncertainty, ~0.2 K. All-weather SST of this uncertainty with real feature resolution of <15 km at high latitudes (<10 km in warmer seas) will deliver a step-change improvement in polar and global SST quantification, with immediate impact on numerical weather prediction and operational oceanography. CIMR will fly in convoy with a Metop Second Generation satellite, giving near-contemporaneous measurement across the frequency range 1.4 GHz to 229 GHz, enabling a broad suite of oceanographic (surface) and atmospheric parameters to be obtained. As well as enhancing the primary mission objectives, this configuration will aid understanding of air-sea-ice interaction, the forecasting of dangerous polar lows ("Arctic hurricanes"), and quantification of salinity, thin sea ice, snow state, tropical cyclones, and soil moisture.

Plenary 3: EO into the Future

Session Chair: John Remedios (NCEO)
Date: Friday 7th September 2018
Time: 14:00-15:00
Location: Bramall Hall

This session will close the conference with a series of talks articulating a vision and ambition for Earth Observation and environmental science into the future. Talks will reflect and illustrate the success in their area to date and the transformative developments they would like to see in the next few years. Topics covered include:

- strategy for Earth Observation;
- developments of climate data;
- new satellites and constellations;
- funding opportunities

Dr Beth Greenaway, UK Space Agency, Director of Earth Observation

Dr Pascal Lecomte, European Space Agency, Head of the ESA Climate Office

Mt William Hosach, CEO, Orbital Micro

Prof Duncan Wingham, CEO, NERC (TO BE CONFIRMED)

Notes

Conference Programme

TUESDAY 4th	WEDNESDAY 5th	THURSDAY 6th	FRIDAY 7th
17:30-20:00 Registration Nobel, Staff House	08:00-17:00 Registration Aston Webb	08:00-17:00 Registration Aston Webb	08:00-14:00 Registration Aston Webb
18:00-20:00 Icebreaker Reception Nobel, Staff House	09:00-09:15 Welcome Bramall	09:00-10:00 Session 3A: Bramall Session 3B: G33 Session 3C: C-Block	09:00-09:45 Keynote 4 Massimiliano Vitale Bramall
20:00-21:00 Keynote 1 Prof. Christian Heipke Nobel, Staff House	09:15-10:00 Keynote 2 Dr Josef Aschbacher Bramall	10:15-11:00 Keynote 3 Prof. Tim Wright Bramall	10:00-11:00 Session 6A: Bramall Session 6B: G33 Session 6C: C-Block (Sponsor UKSA) Session 7C: Senate
	10:00-11:00 Session 1A: Bramall Session 1B: C-Block Session 1C: G33	11:00-11:30 Refreshments & Exhibition Great Hall	11:00-11:30 Refreshments & Exhibition Great Hall
	11:00-11:30 Refreshments & Exhibition Great Hall	11:30-12:30 Plenary 2 Bramall	11:30-13:00 Session 7A: Bramall Session 7B: G33 Session 7C: Senate
	11:30-12:30 Plenary 1 Bramall	12:30-14:00 Lunch & Exhibition Great Hall	13:00-14:00 Lunch & Exhibition Great Hall
	12:30-13:30 Lunch & Exhibition Great Hall	13:00-14:00 RSPSoc AGM G33	14:00-15:00 Plenary 3 Bramall
	13:30-14:30 Exhibitor Session Bramall	14:00-15:15 Session 4A: Bramall Session 4B: G33 Session 4C: C-Block	15:00 CLOSE Bramall
	14:30-15:00 Refreshments & Exhibition Great Hall	15:15-15:45 Refreshments & Exhibition Great Hall	Departing Drinks available outside Bramall
	15:00-17:00 Session 2A: C-Block Session 2B: G33 Session 2C: Bramall	15:45-17:00 Session 5A: Bramall Session 5B: G33 Session 5C: C-Block	
	17:00-19:00 Poster 1 & Drinks Great Hall	17:00-19:00 Poster 2 & Drinks Great Hall	
	19:00-19:30 Venture to The Vale Walk	19:00-19:30 Coaches to Dinner Outside Great Hall	
	19:30-22:00 BBQ, The Vale (Sponsor: Airbus)	19:30-23:00 Conference Dinner (Sponsor: NERC)	