Airborne GeoSciences

Small Manned and Unmanned Aircraft as Demonstrator Platforms

John Moncreiff, Caroline Nichol, Tom Wade

Introduction

Objectives

1. Airborne GeoSciences Facility (UoE) – Overview
2. Small Manned and Unmanned Platforms - Strengths & Limitations

Airborne GeoSciences Facility, UoE

Mission Statement

Airborne GeoSciences exists to conduct and support research into our physical environment using advanced airborne sensing techniques.

Airborne GeoSciences Facility, UoE

What we actually do:

- Sensor System Development & Integration (manned aircraft /unmanned aircraft system)
- Research & survey flight operations (manned/unmanned aircraft system)
- Training & equipment loan for independent UAS operations

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NERC Recognition & User Access

- Recognised status – ‘kite mark’ of NERC approval, but no core funding
- ‘Pay-as-you-go’ access available (at Steering Group discretion)
- Collaborative research much preferred

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Aircraft

1. Conventional Platform – Diamond ECO Dimona

2. Remotely Piloted Aircraft Systems (RPAS, also known as UAVs, or 'Drones') for research & training
   - Fixed Wing
   - Multi-rotor

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Instrumentation

1. **Diamond ECO Dimona:**
   - Meteorology
   - Chemistry
   - Hyperspectral Imaging
   - Laser range-finding
   - Ortho-photography
   - Core support & nav. systems
2. **RPAS:**
   - Ortho-photography
   - Laser range-finding

Small Manned Aircraft

Small Manned Aircraft

Diamond HK-36 TTC ECO-Dimona

- 'Touring Motor Glider' with certified infrastructure for additional measuring equipment
- Dedicated payload areas and 28 VDC electrical system (~900 W)
- Scientific payload max. 150 kg
- Crew - Pilot/observer or single pilot
- Endurance 2.5 – 5.5 hrs
- ~ 12 kg fuel / hour

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Small Manned Aircraft

ECO Dimona Payload Areas

Panel (13kg)	Rear Cabin (30 kg	Under-wing pods (55 kg)
		

Small Manned Aircraft

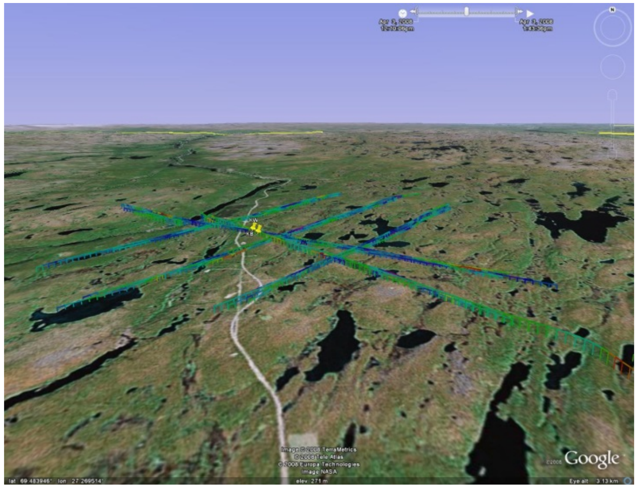
Small Manned Aircraft – The Niche

Low, Slow

- Boundary layer processes, especially direct measurement of land-atmosphere exchange of heat, water & trace gases
- Very high resolution remote sensing

Intermediate spatial scales

On demand



Small Manned Aircraft – Other Strengths

Low Operating & Fixed Costs

- Sensor development and trials
- Protracted deployments e.g. several weeks or months at fieldsite, seasonal or event driven science ('sit-and-wait')

Very Low environmental impact

Small Crew

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Small Manned Aircraft

Small Manned Aircraft – Key Challenges

- Restricted weight, space, power, balance
- Challenging sensor environment:
  - T, P, humidity
  - Vibration
  - Contamination
  - Limited in-flight access
  - **Installations need certification!**
- Practical operational limitations
- Human resources, skills & core funding

Remotely Piloted Aircraft Systems

Small Unmanned Aircraft Systems (SUAS)

(Remotely Piloted Aircraft Systems (RPAS))

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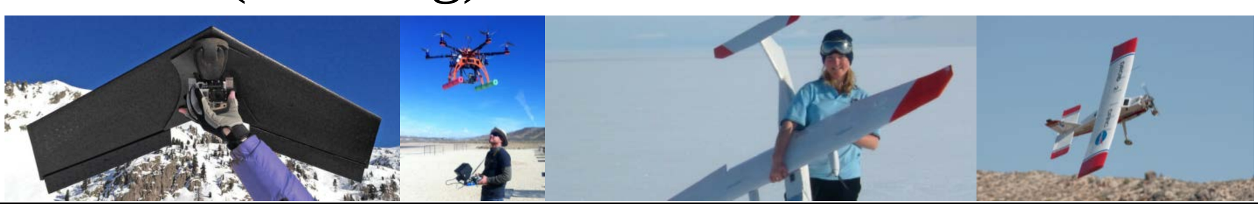
Remotely Piloted Aircraft Systems

UK RPAS Classification (UK CAA CAP722)

1. UAS (> 150 kg)

2. Light UAS (> 20 kg, <= 150kg)

3. Small UAS (<= 20kg)



Remotely Piloted Aircraft Systems

Bormatec UAV Explorer

- Main fixed wing RPAS survey platforms
- Payload ~ 2.5 kg
- Endurance ~ 45 mins (+)
- Highly / fully automated flight
- 2 aircraft for redundancy / fast turn around

Remotely Piloted Aircraft Systems

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Tarot 680 Pro Hexacopter

- Multi-rotor training / survey platform
- Payload ~ 1.2 kg
- Endurance ~ 15 mins
- Highly / fully automated flight
- Very useful where space is restricted, but spatial coverage is compromised
- Good for radiometric work where hovering allows longer integration times

Small RPAS - Strengths

- Potentially **higher resolution** photo-imagery and DTM (1-2 cm)
- More economic for **small spatial scales**, high temporal frequency measurements
- Suitable for **independent operation in remote places**
- Small systems **don't need certification or Pilot Qualification** (normally)
- 'Dull / Dirty / Dangerous' operations

Remotely Piloted Aircraft Systems

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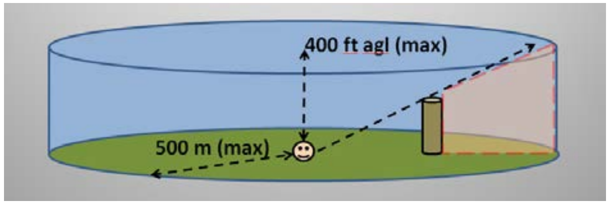
Small RPAS - Limitations

- VERY limited weight, space, power
- Questionable reliability – risk to high value sensors?
- Small spatial scales – Primarily due regulations on 'Visual Line of Sight'
- Normally not within or very near to urban areas; or very close to people/structures etc.



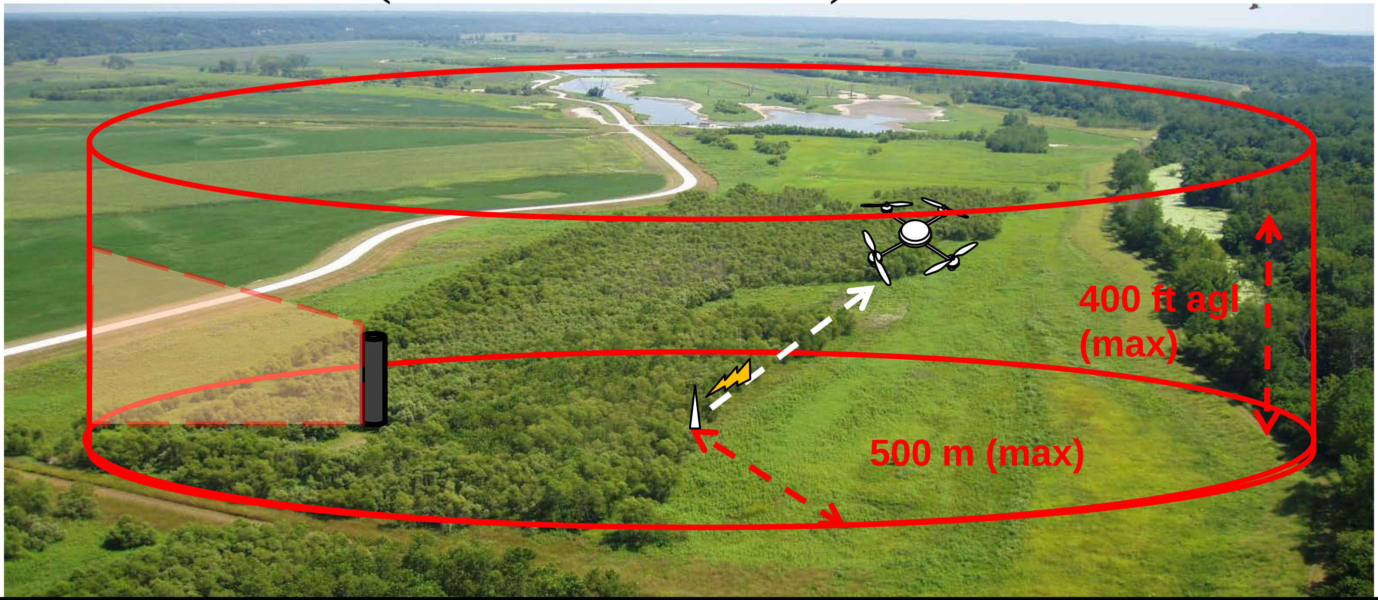
Remotely Piloted Aircraft Systems

Visual Line Of Sight (VLOS)

- Normally Max. 400 feet above ground level

(CAP722, but see also ANO Article 166(4 c)

- Within the visual range of the Remote Pilot, to a maximum range of 500 metres (whichever is less) *(CAP722)*



Small Manned & Unmanned Aircraft

- Each have niche capabilities that supplement those of larger platforms
- In particular, smaller sensor packages can be well supported and flown economically, with great user control, over extended periods – within practical operating limitations
- Smaller doesn't necessarily mean easier!

Platform Selection Considerations

End

Any Questions Please?

Platform Selection Considerations

Extra Material…

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Using Small Airborne Platforms

Platform Selection (1)

	Light Aircraft	Small UAS (< 20 kg)
Payload	Limited (typically < 100 kg)	VERY limited (100s g to a few kg)
Space	Limited (e.g. Dimona pod 30 x 60 x 80 cm)	VERY Limited (e.g. Explorer UAV 8 x 8 x 60 cm)
Power	Limited (e.g. Dimona ~ 900W)	VERY limited (e.g. a few W or 10s of W)
Flight Envelope	Largely unrestricted	Limited by regulations

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Using Small Airborne Platforms

Platform Selection (2)

	Light Aircraft	Small UAS (< 20 kg)
Certification	Required	Usually NOT required
Sensor Environment	Very Challenging (wide & rapid changes in T, P, humidity; vibration; contamination)	Usually less challenging (limited flight envelope)
Crew Qualification	Commercial pilot license	Usually not required
Cost	Relatively high	Potentially VERY low

Using Small Airborne Platforms

Aircraft Selection – Sensor Considerations

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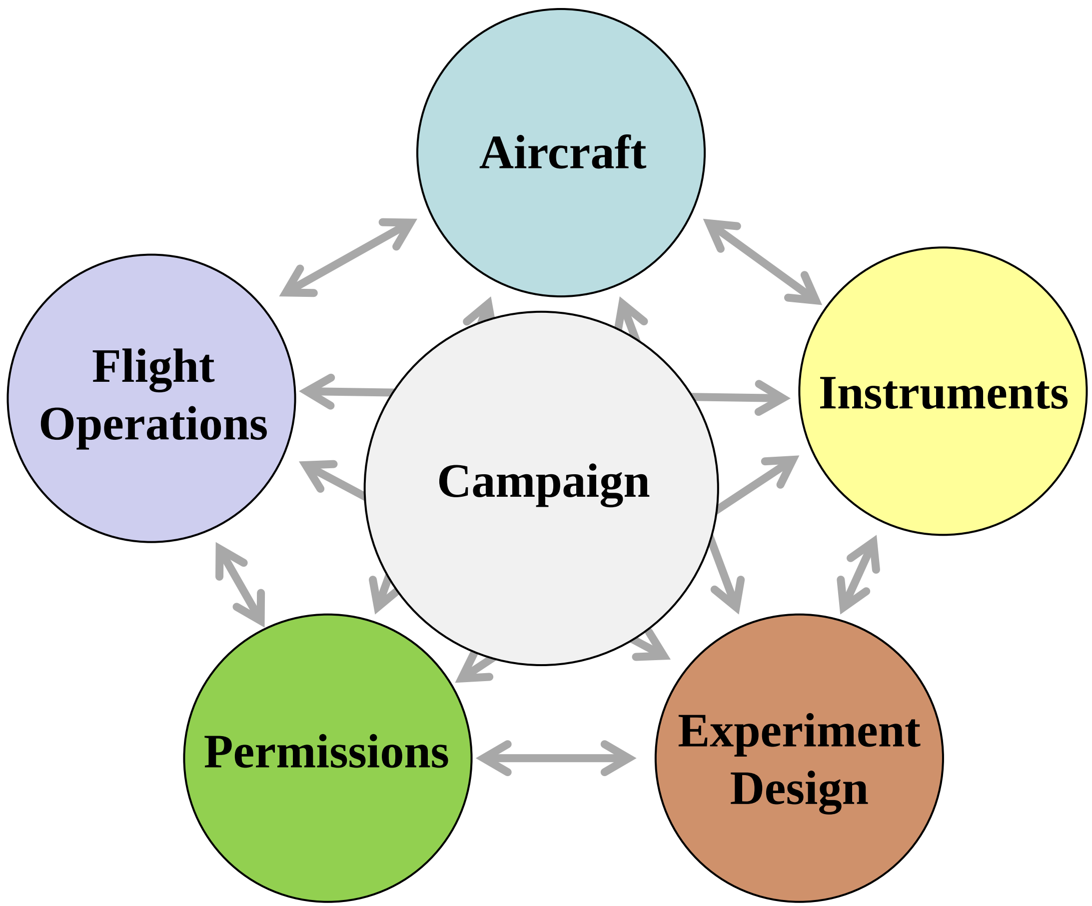
Platform Selection Considerations

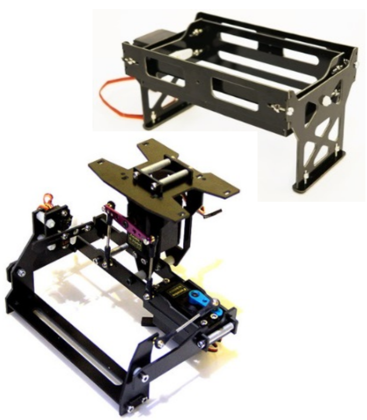
Components of an Airborne Campaign



RPAS Sensors

Cameras & Laser range finder

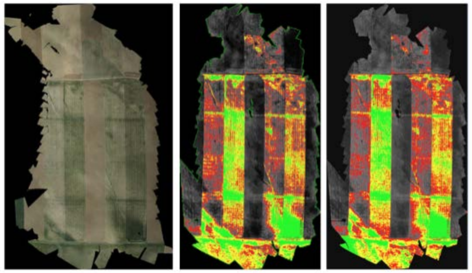
- Sony A6000 24.3 Mp compact system camera (16 -50 mm lens)
- 2 x Canon S110 12.1 Mp compact cameras
- Lightware SF10/C laser rangefinder (100 m, 1 cm res., 16 Hz)
- 2-Axis, 1-Axis gimbals

RPAS Applications

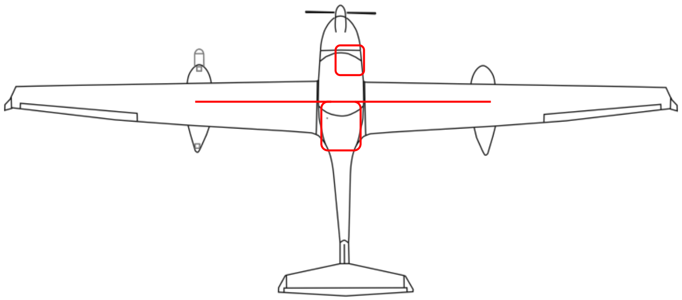
Initial Applications

- High resolution imagery / DTM, NERC GREENHOUSE fieldsites
- Proof of concept / R&D work, forest degradation mapping, African rainforest
- ‘NDVI’ mapping for agricultural applications (joint SRUC PhD)
- Proof of concept / R&D work, structural mapping in heavily crevassed zones
- Training for upcoming fieldwork

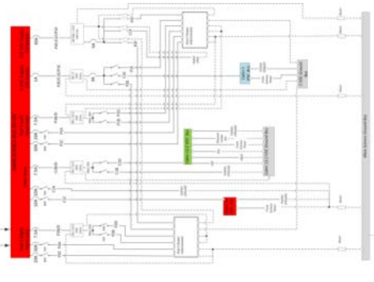


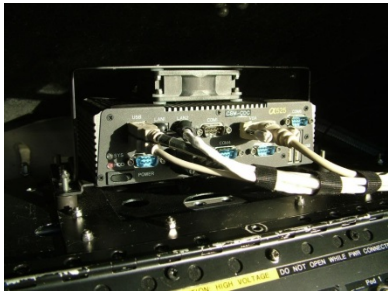
Instrumentation – Core Systems

Central Services Module



- Power conditioning and distribution
- Signal distribution/conditioning
- Air sample distribution
- HMI (custom MFD, switching)
- Automation (inc. Geo-fence logic)
- Core logging, control, network
- Synchronisation via GPS/NTP Time server
- Skyward sensor mount
- External connectivity





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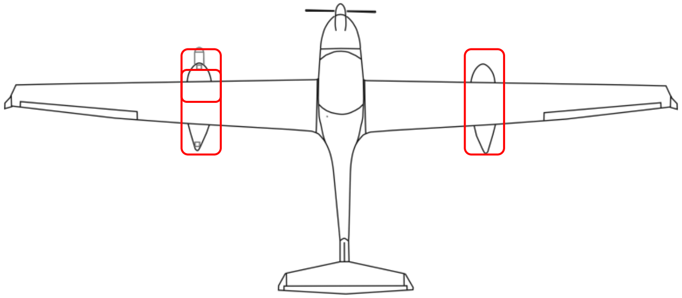
Instrumentation – Core Systems

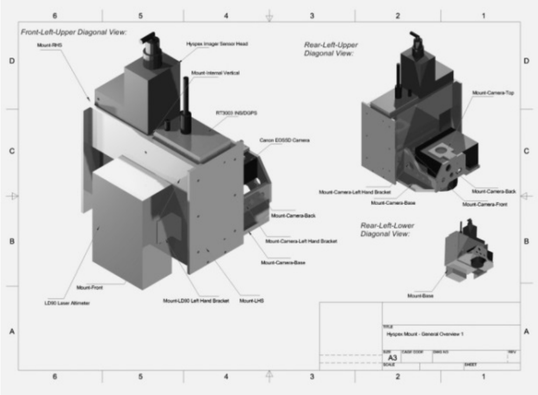


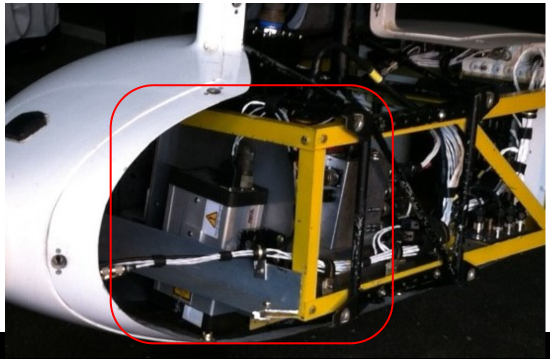
Pod Modifications

- Ports
- Mounting infrastructure changes

Navigation – Alignment System

- INS / DGPS – position, attitude, rates
- Laser Altimeter (range to surface)
- Mounting / alignment system for optical sensors
- Offset from pod axes to point to nadir in normal flight
- Serial and UDP real-time outputs





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Measuring Systems

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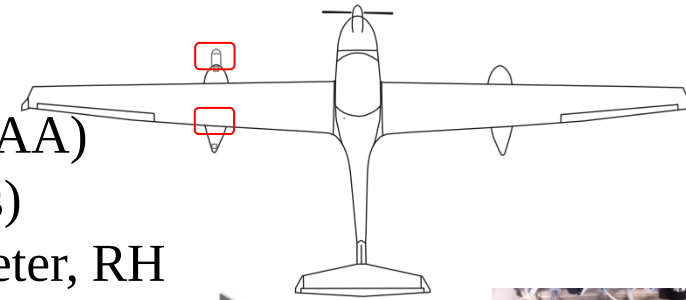
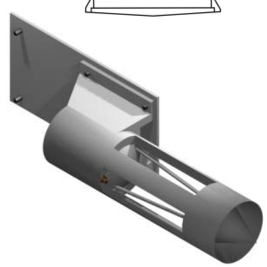
Instrumentation – Measuring Systems

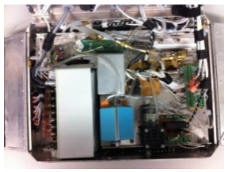
Met System

- **Turbulence** – BAT probe with updated (NOAA) logging system (also logs other 'fast' sensors)
- **Humidity** - modified chilled mirror hygrometer, RH sensor, Li7500
- **Temperature** -assorted custom fine wire TC, micro-bead thermistor, dedicated custom Total Air Temperature (TAT) probe*
- **Pressure** - turbulence probe, custom pitot-static probe*
- **Fast CO_2** - Li7500 in custom housing, incorporates T & P sensors, co-located intakes for Picarro, humidity sensors and Tedlar bag system and 'one-stop' multi-sensor calibration
- **PAR** (up- and down-welling sensors)

** May not be available for Greenhouse due to certification timing*







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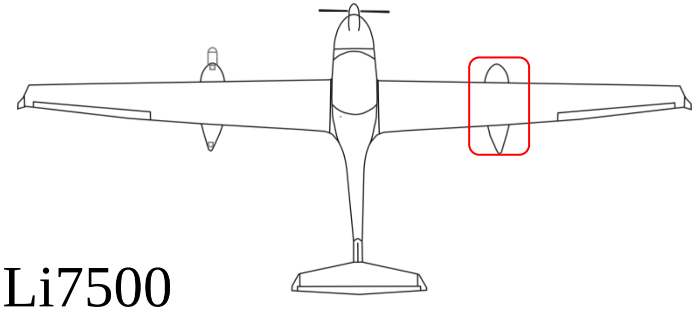
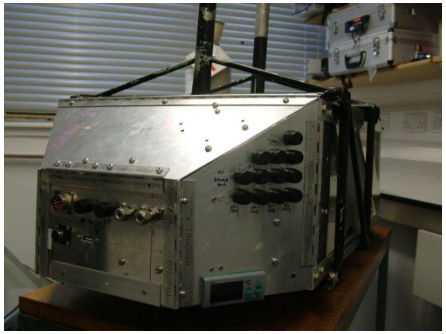
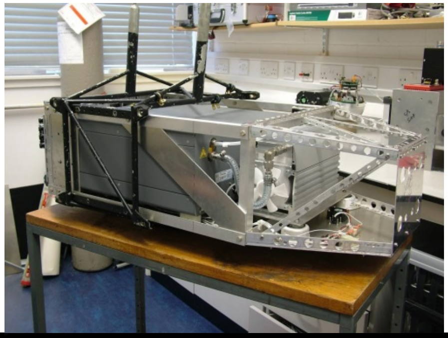
Instrumentation – Measuring Systems



Picarro G2301m Gas Analyser (CO_2, CH_4, H_2O)

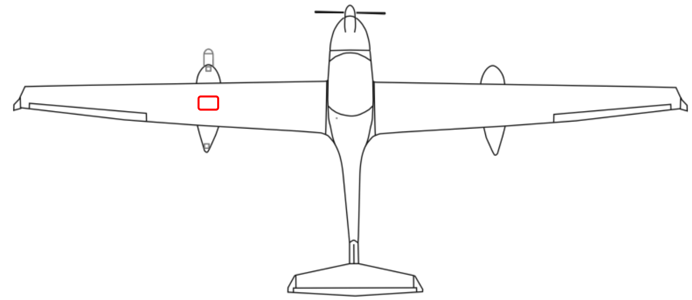
- Environmentally controlled enclosure
- Local / remote intakes (co-located with Li7500 and Tedlar intake)
- Planned option to resample from Tedlar bags (e.g. in flight calibrations)
- Dual redundant remote data-logging
- Remote monitoring and control over RDP Synchronised via NTP





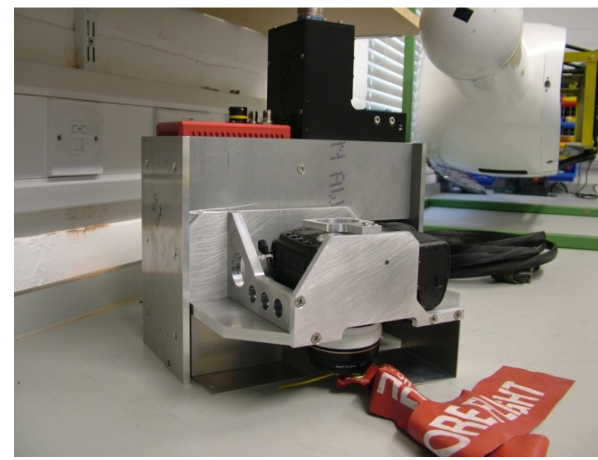
Instrumentation – Measuring Systems

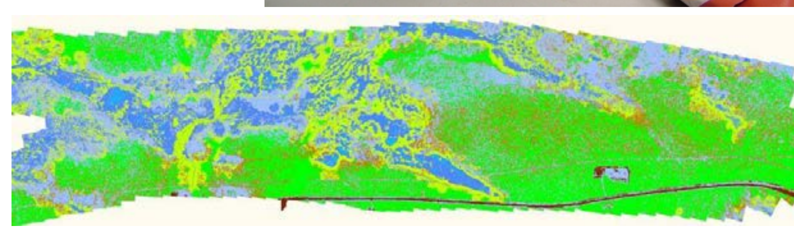
Ortho-Photography System



- Canon EOS5D DSLR
- Rigidly mounted to Nav-Alignment System
- Remote control and automation via Central Services Module
- Precise mid-exposure pulse logging against navigation data*
- Camera upgrade if time / funds permit

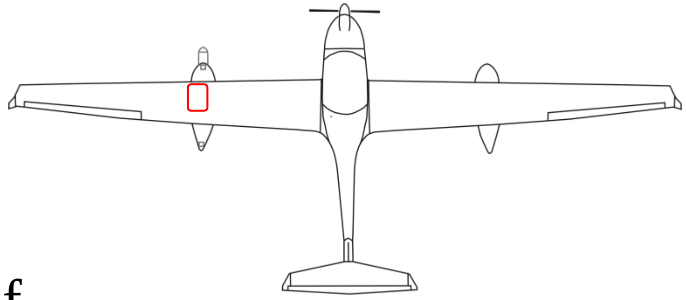
** May not be available for Greenhouse*



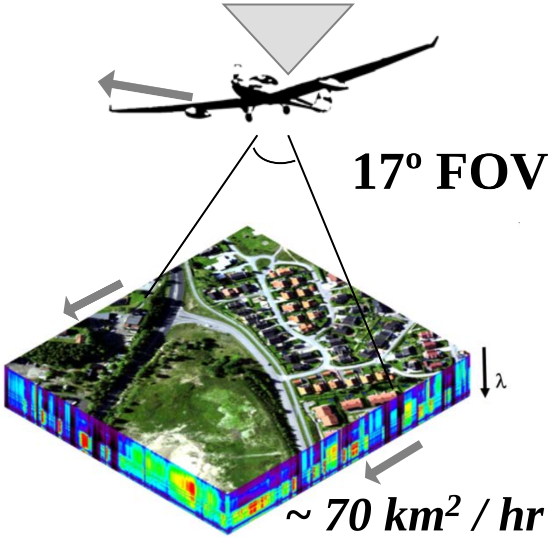


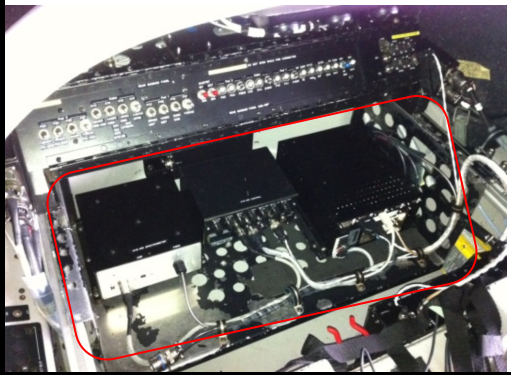
Instrumentation – Measuring Systems

Hyperspectral Imaging System



- NEO Hyspex VNIR 1600
- Rigidly mounted to INS/DGPS
- Supporting equipment on removable shelf in rear cabin
- Remote control and automation via CSM
- Synchronised to INS/DGPS
- Simultaneous irradiance measurement





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THE UNIVERSITY OF EDINBURGH

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Instrumentation – Measuring Systems

Tedlar Bag System

- ~ 50 x1 litre samples in 3 litre bags
- Variable fill rate – from ~ 4-5 s to 5 mins
- Multiple simultaneous samples if required
- In-situ re-analysis by Picarro if required
- Remote control and automation via Central Services Module
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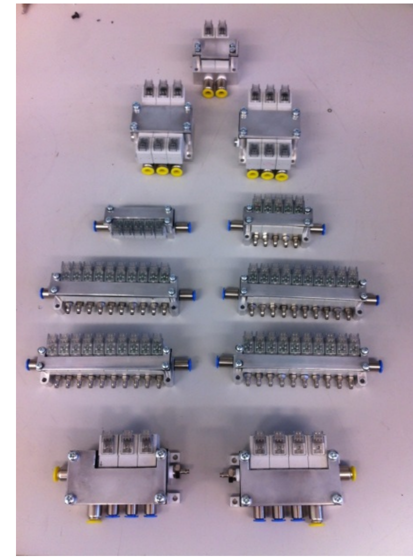
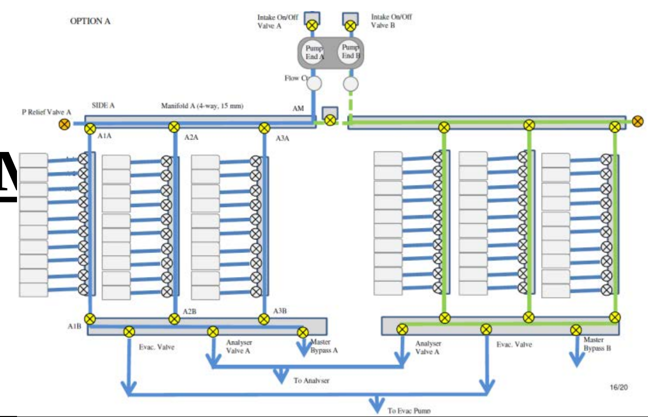
- Removable shelf in rear cabin
- **Analysis TBC; have approached FAAM**





Instrumentation – Supporting Systems

Airside Support Unit

- External power supply, network and IC
- Embedded PC for remote access
- Large volume data transfer / management via hot-swap drives
- Local backup via internal RAID array

Workstation

- High performance workstation, custom built for data management /processing
- Local data archiving on redundant hot-swap drives
- Transportable rugged case

Airborne GeoSciences

Remotely Piloted Aircraft Systems (RPAS)

RPAS within Airborne GeoSciences

- New capability for facility, in place by late spring 2015
- Fixed-wing and multi-rotor platforms
- Builds upon existing multi-rotor capability within School
- Facility aims to provide:
    - Training and standards for School RPAS operations
    - Supported field operations (i.e. with crew)
    - Equipment / skills for independent field operations
    - Core skills and knowledge-base
    - Support for teaching / student projects etc
    - R & D, proof of concept work supporting proposals

Remotely Piloted Aircraft Systems (RPAS)

Airborne GeoSciences

Why RPAS?

- Potentially higher resolution photo-imagery and DTM (1-2 cm)
- More economic for small spatial scales, high temporal frequency measurements
- Suitable for independent operation in remote places
- Small systems don't need certification
- 'Dull / Dirty / Dangerous' operations

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Remotely Piloted Aircraft Systems (RPAS)

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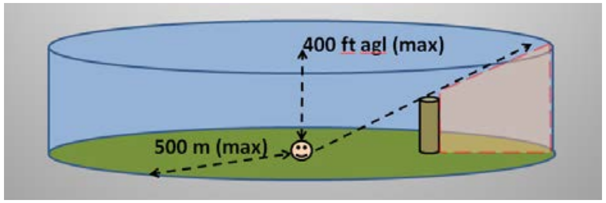
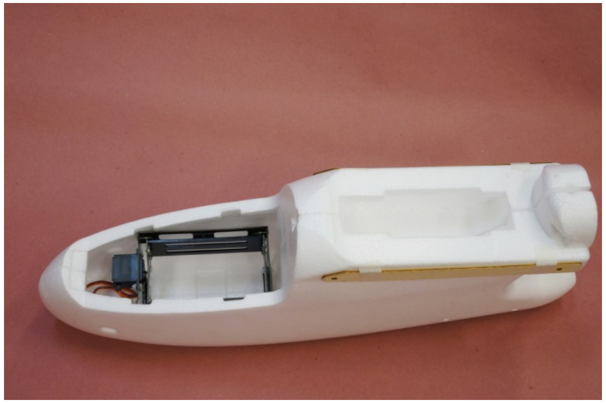
RPAS Limitations

- Small spatial scales (regulatory (<500m) & technical reasons)
- Low payload – narrow capability, possibly low quality sensors
- Questionable reliability – hence low cost sensors, limited quality





RPAS Platforms

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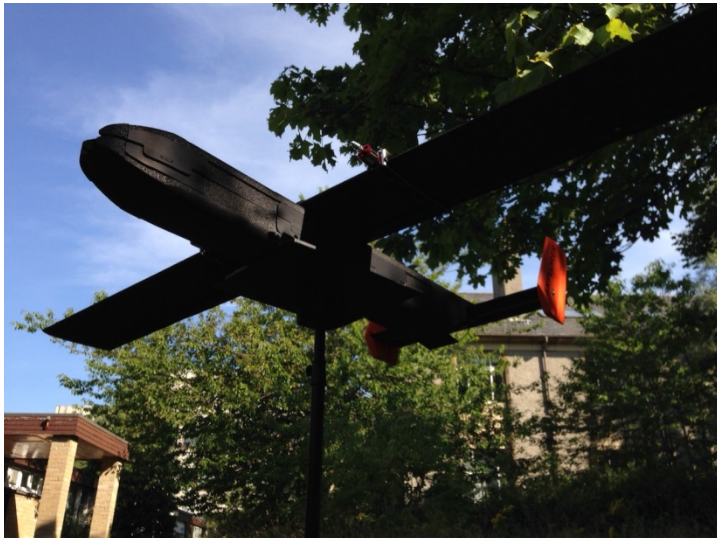

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RPAS Sensors

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- 2 x Canon S110 12.1 Mp compact cameras
- (2 x Mobius HD cameras modified for NDVI)
- Lightware SF10/C laser rangefinder (100 m, 1 cm res., 16 Hz)
- 2-Axis, 1-Axis gimbals

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RPAS Applications

Initial Applications

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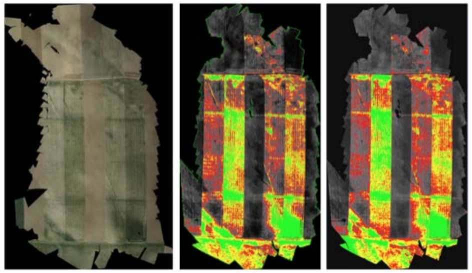

Instrumentation – Supporting Systems

Calibration Equipment

- High quality reference systems – T, P_{abs}, P_{diff}, uV, humidity
- 'Portable' cylinder rack for gases if needed
- Bench and field deployable

Environmental Test Chamber

- 0.8 x 3 m chamber, -20 to +40C, ~+/- 2C per minute
- Optionally pressure controlled ~ 600hPa – 1050 hPa

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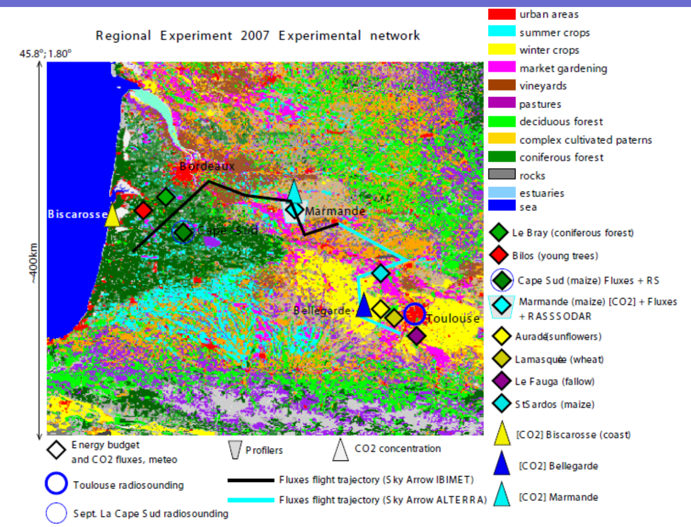
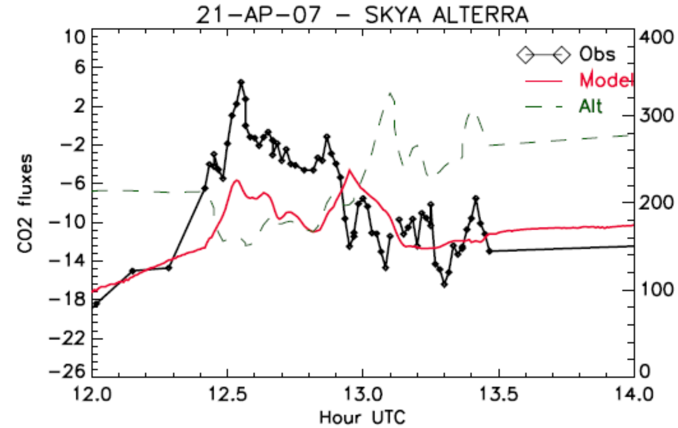
Methodology – Airborne EC

‘Basic’ Airborne EC

- E.g. Sarrat et al 2009
- Spatially contiguous averaging
- Many approaches in the literature
- No accepted ‘standard’ approach
- But some groupings around similar initial processing





Modelled vs Aircraft Obs fluxes, CERES

Methodology – Airborne EC

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Wavelet techniques

- E.g. Mauder et al 2008
- Wavelet flux calculation at 100m scale, but noisy,
- Multiple error correction steps and averaging
- 3 km gridded map produced
- Quite complex

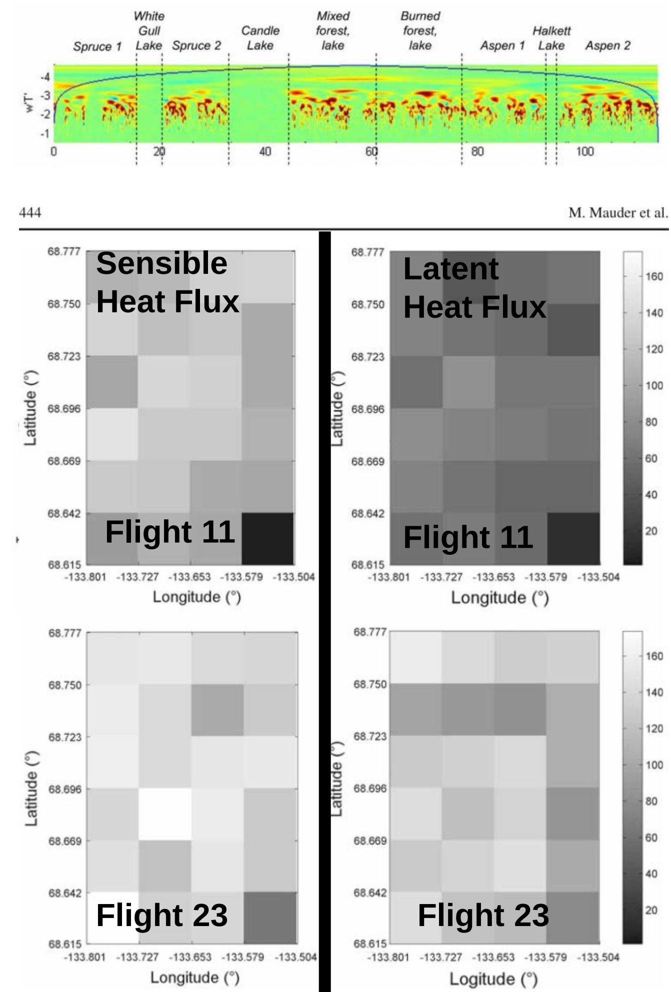

Fig. 4 Surface flux maps for the sensible (left) and latent (right) heat flux in W m^{-2} for flight 11 (top) and 23 (bottom)

3km Grid

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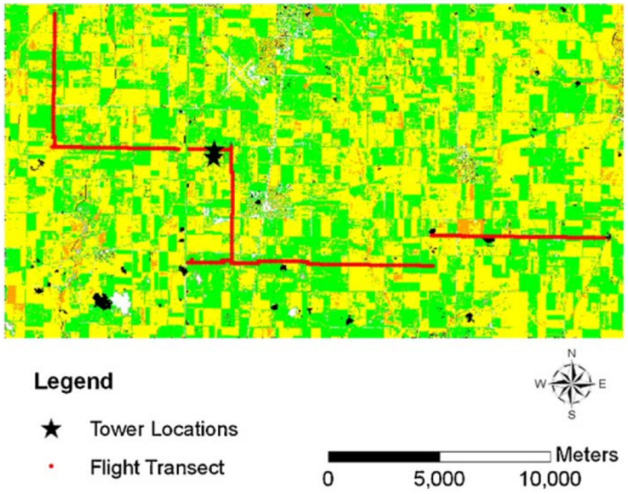
Methodology – Airborne EC

Flux Fragmentation Method

- E.g. Kirby et al 2008
- Bin 1s 'flux fragments' according to land-class (e.g. maize / soybean) within footprint
- Average within the land-class



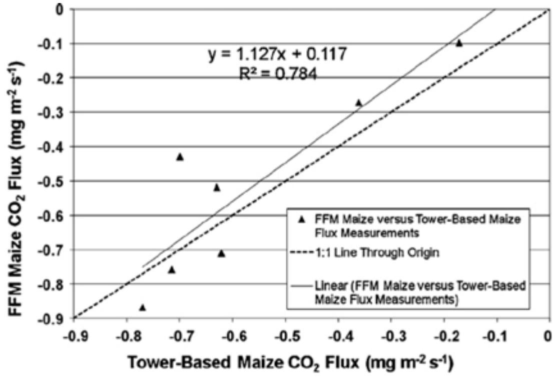


Fig. 7 – FFM maize vs tower-based maize CO_2 flux measurements.

Instrumentation – Measuring Systems

Tedlar Bag System

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- Variable fill rate – from ~ 4-5 s to 5 mins
- Multiple simultaneous samples if required
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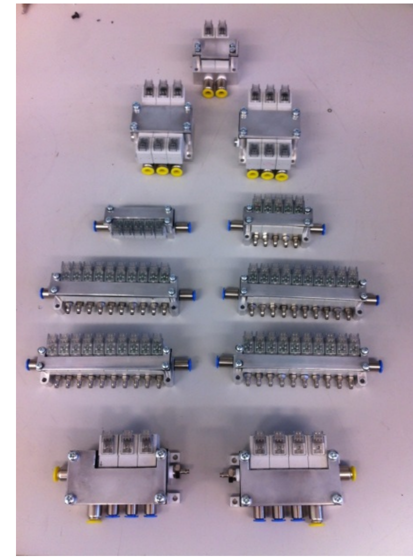

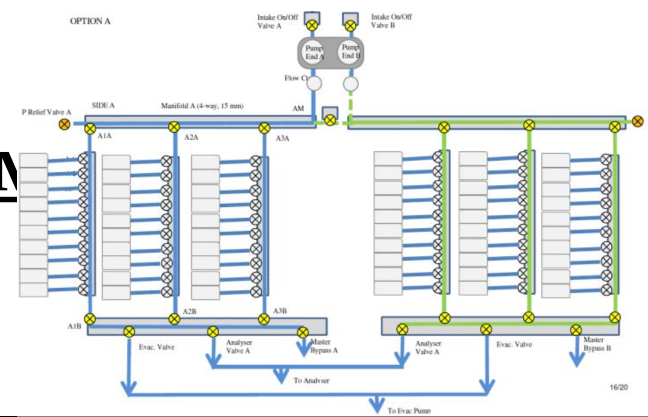

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- Embedded PC for remote access
- Large volume data transfer / management via hot-swap drives
- Local backup via internal RAID array

Workstation

- High performance workstation, custom built for data management /processing
- Local data archiving on redundant hot-swap drives
- Transportable rugged case

Methodology – Airborne EC

Detailed Flight Planning
- Lengths, levels, terrain, land class etc
- Airspace, habitation, hazards, regs

Measure
- P distribution, T, Humidity - Flow angles and velocity
- Probe position, attitude, velocities
- Scalars (CO_2, CH_4, H_2O, T,)

Calibrate / Correct / Calc. Wind
- Dynamic effects, flow distortion etc.

Calc. fluxes (at aircraft level)
- Various methods available
- Sampling statistics critical

Correct fluxes (at aircraft level)
- Low/high freq. losses, biases

Scale fluxes to surface
- E.g. divergence (plan implications)

Relate fluxes spatially to surface
- Footprint model

Quantify Errors/ Uncertainties

Analyse against geospatial data
- Model outputs, EO, LCM etc

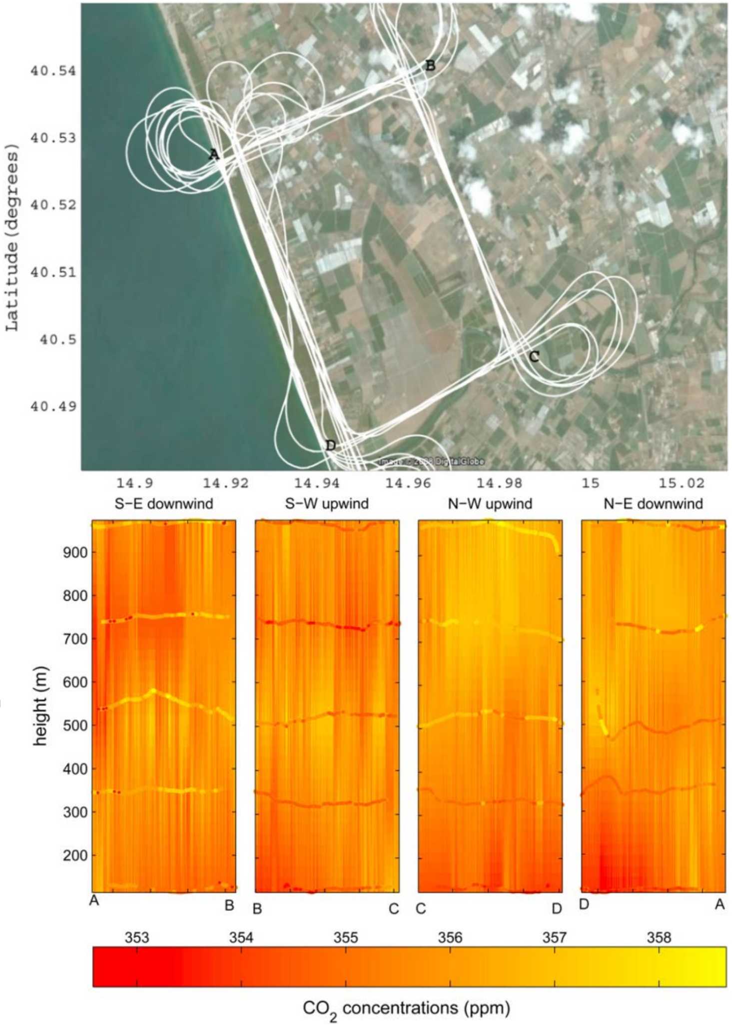
Methodology

Mass Balance Technique

Airborne GeoSciences

Methodology – Mass Balance Technique

- E.g Alfieri et al. 2010
- Measure advective fluxes through side walls of a volume (various levels & interpolate)
- Model entrainment flux across PBL top
  (or we could measure top surface fluxes by EC)
- Surface flux accounts for the remainder
- Better for inhabited areas
- Possibility of using Tedlar samples for N_2O



Airborne GeoSciences

Methodology – Mass Balance Technique

Detailed Flight Planning
- Lengths, levels, repetition etc
- Airspace, habitation, hazards, regs

Measure
- P distribution, T, Humidity - Flow angles and velocity
- Probe position, attitude, velocities
- Scalars (CO_2, CH_4, H_2O, T, ***N_2O***)

Calibrate / Correct / Calc. Wind
- Dynamic effects, flow distortion etc.

Calc. fluxes (at aircraft)
- Instantaneous advective fluxes
- Turbulent fluxes

Interpolate fluxes across ‘wall’
- Produce estimate of net flux each face

Model / measure top face flux
- Identify PBL top
- Entrainment flux model Or by EC

Estimate surface flux

Quantify Errors/ Uncertainties

Analyse against geospatial data
- Model outputs, EO, LCM etc

Methodology – Progress

General

a) Discussed in broad terms but details not laid down

b) Rob has reviewed some aspects of the basic EC and mass balance techniques and written up a technical note on the subject

Flux Processing / Analysis tools

a) Some historic code available, but never truly 'operational' and needs to be updated due hardware and logging changes

b) Many areas not covered here at all and need development from scratch (e.g. divergence, mass balance, wavelet/FFM techniques)

c) Turbulence probe calibrations/ corrections need review and development

Flight & Campaign Planning

NATURAL ENVIRONMENT RESEARCH COUNCIL

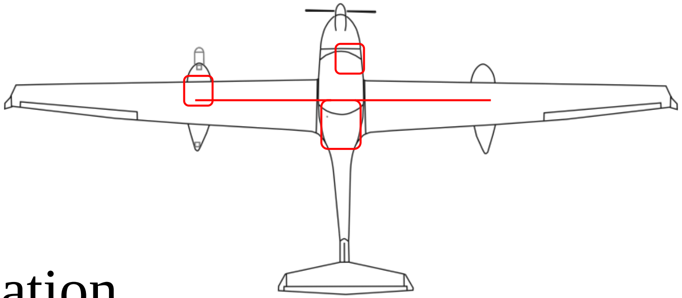
SAGES Scottish Alliance for Geoscience, Environment and Society

THE UNIVERSITY OF EDINBURGH

Airborne GeoSciences

ECO-Dimona Instrumentation

Central Services Module



- Power & signal distribution, logging
- Air sample distribution
- HMI (custom MFD, switching) & Automation
- Synchronisation via GPS/NTP Time server

Navigation – Alignment System

- INS / DGPS – position, attitude, rates
- Laser Altimeter (range to surface)
- Mounting / alignment system for optical sensors

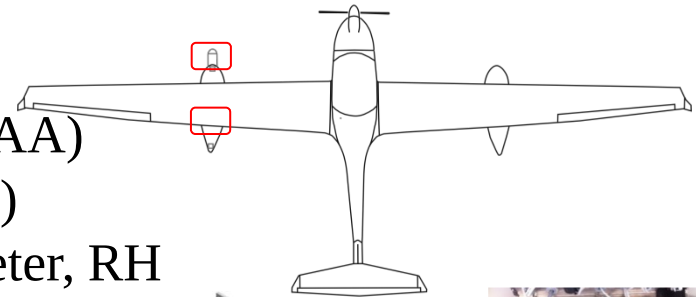
Airborne GeoSciences

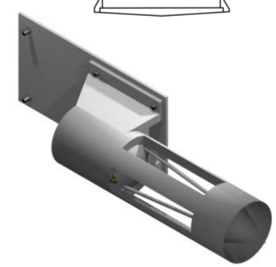
ECO-Dimona Instrumentation

Met System

- **Turbulence** – BAT probe with updated (NOAA) logging system (also logs other ‘fast’ sensors)
- **Humidity** - modified chilled mirror hygrometer, RH sensor, Li7500
- **Temperature** -assorted custom fine wire TC, micro-bead thermistor, dedicated custom Total Air Temperature (TAT) probe*
- **Pressure** - turbulence probe, custom pitot-static probe*
- **Fast CO_2** - Li7500 in custom housing, incorporates T & P sensors, co-located intakes for Picarro, humidity sensors and Tedlar bag system and ‘one-stop’ multi-sensor calibration
- **PAR** (up- and down-welling sensors)

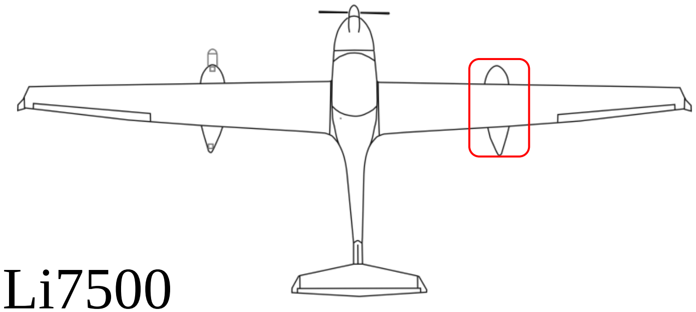
** May not be available for Greenhouse due to certification timing*



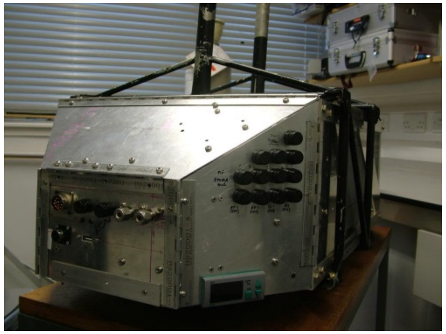


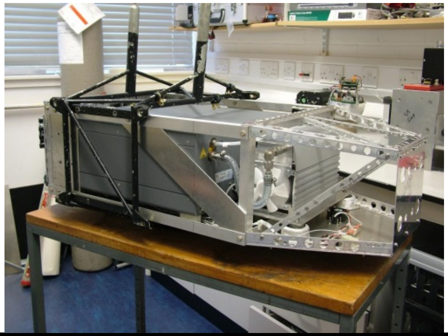
ECO-Dimona Instrumentation

Picarro G2301m Gas Analyser (CO_2, CH_4, H_2O)



- Environmentally controlled enclosure
- Local / remote intakes (co-located with Li7500 and Tedlar intake)
- Planned option to resample from Tedlar bags (e.g. in flight calibrations)
- Dual redundant remote data-logging
- Remote monitoring and control over RDP Synchronised via NTP

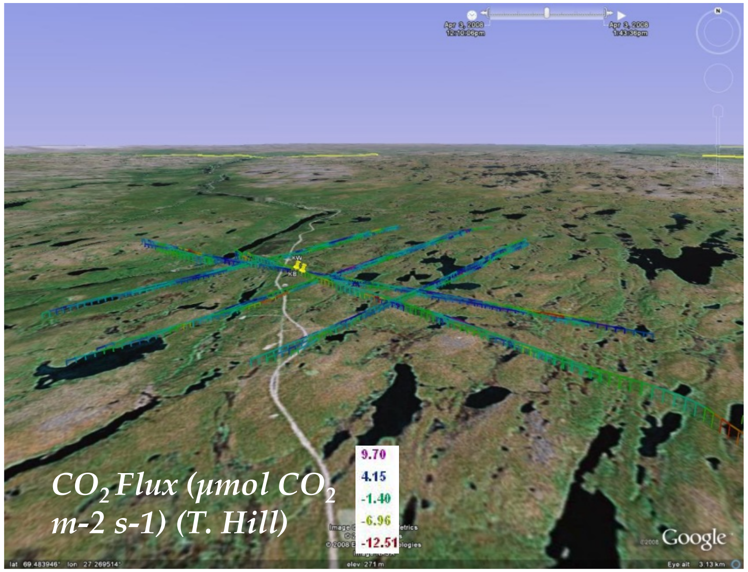




Applications – Met and Picarro Systems

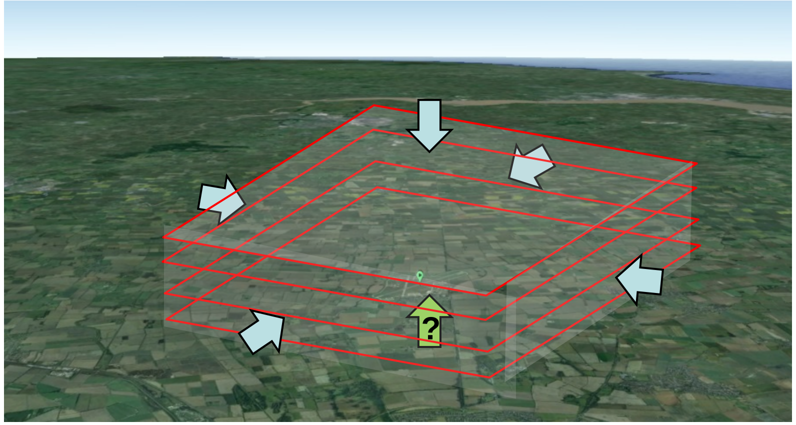
1. Airborne Eddy Covariance

- Low level flight path
- Measure fluxes via EC
- Fast in-situ measurements (CO_2, CH_4, T, humidity, W)
- No N_2O, restrictions level



2. Mass Balance Technique

- Measure fluxes through side walls
- Model (or measure) fluxes through top (e.g. PBL top)
- Estimate surface flux
- May be possible to use Tedlar bags for N_2O, avoids restrictions



Planning – Flight Planning

Experimental Flight Planning

a) Discussed in broad terms but specifics not laid down

b) Will need a set of 'missions' to be specified, each with:
   i. A priority level
   ii. Waypoints / route / altitudes /repetitions
   iii. Sampling requirements, data marker codes
   iv. Weather constraints, other dependencies etc.

c) Pre-campaign:
   i. Waypoints, routes etc. will be uploaded to nav. systems
   ii. Sampling requirements coded into automation systems and tested via simulator
   iii. Briefing cards / in-flight reference documents drawn up
   iv. Arrange notifications / permissions as required

Planning – Campaign Planning

Campaign Planning & Training

a) Discussed in broad terms but specifics not laid down

b) Aim to adopt a flexible approach as far as possible due:

   i. Weather limitations
   ii. Uncertainties regarding staff availability
   iii. Residual risks e.g. certification and serviceability

c) Identify suitable windows for activity at each site

   i. To address specific seasonal science questions
   ii. To link with other GREENHOUSE activity
   iii. To link with GUAGE activity (meeting 27 Feb)

d) Staff / crew still to be identified and trained

Airborne GeoSciences

Planning – Campaign Planning

<u>Lincolnshire</u>

a) 9 x 2.5 hr flights

b) Base – Gamston, fall-back Cranfield

Airborne GeoSciences

Planning – Campaign Planning

Northern

a) 9 x 2.5 hr flights
b) Base – Fife, with Carlisle for local support