CEOI 5th and 6th Open Calls
Final Review

Concept Studies for a Methane Emission Imager

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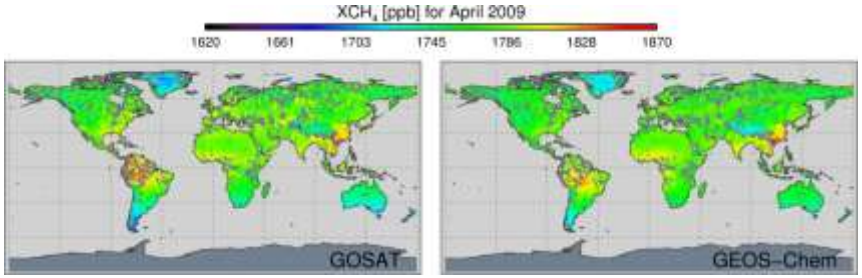
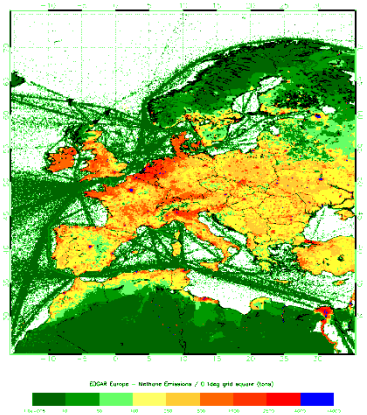
Project Introduction

- Methane (CH_4) is a strong greenhouse gas with warming potential 20 times higher than for CO_2 (CH_4 emissions need to be reported to UNFCCC and EU)
- There is now good heritage on global monitoring of CH_4 from space that provides constrains on large-scale emissions.
- Move towards missions that can monitor CH_4 on smaller scales to monitor point sources for CH_4 or CO_2 (landfills, power plants) and contribute to verification of national inventories.
- The CH_4 proxy observation method (based on CH_4/CO_2 ratio) is of interest since it has low sensitivity to aerosol/clouds and since it does not require high spectral resolution which can allow small National, bi-lateral or opportunity-based or commercial missions



Satellite (GOSAT) CH_4 Retrieval compared to a Model (GEOS-Chem)



Estimated annual methane emissions over Europe

Project Objective

Project Goal: Use the mature concept of CH_4 proxy detection for a small and focused instrument to target CH_4 emissions on small spatial scales

Specific project objectives:

- Define a novel concept for measuring atmospheric concentrations of the important greenhouse gas methane (CH_4) based on the use of discrete shortwave infrared spectral bands
- Investigate its characteristics in terms of size and spatial resolution
- Show its potential application to the SSTL TechDemoSat platform as a demonstrator mission

Project Team

Hartmut Boesch, Earth Observation Science Group, University of Leicester:

- Greenhouse gas remote sensing
- SWIR spectroscopy and radiative transfer simulations

Dan Lobb, Ferhat Culfaz, Surrey Satellite Technology Ltd.

- Optical systems
- SWIR spectrometer design

Paul Palmer, School of GeoSciences, University of Edinburgh

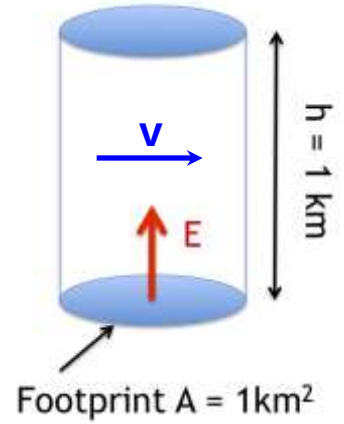
- Atmospheric modelling
- Greenhouse gas budgets

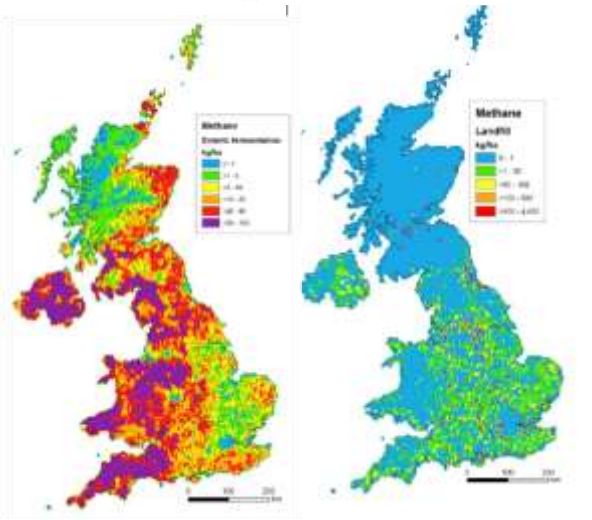
Science Requirements

- To infer requirements, we have applied a mass balance approach to UK CH_4 (and CO_2 point) sources, reflecting largest uncertainties associated with current inventories:
  - Enteric fermentation
  - Landfills
  - Power plants
  - Chemical industry

- CH_4 emission imager needs:
  - single sounding measurement error of ≤ 1%
  - ground pixel of ≤ 1km^2
  - swath width of 50 - 100 km to capture outflow

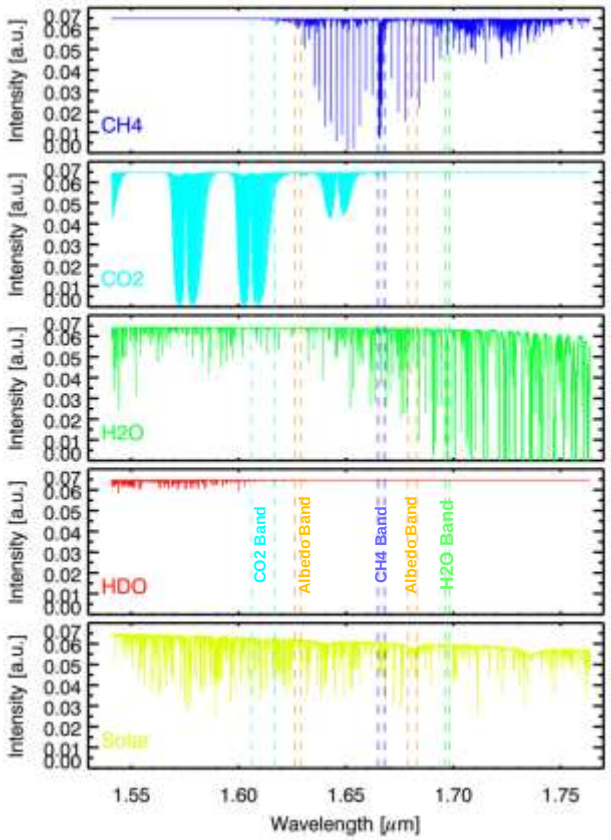
Schematic of mass balance calculation





Band Setup and SNR

- Discrete wavebands for CO_2, CH_4 and H_2O columns and surface albedo
- Atmospheric simulations showed that
  - SNR > 1,000 is needed to achieve errors of 1%
  - Narrow bandwidth (~4nm) is needed for CH_4 band, but other bands can be much wider
  - High radiometric calibration accuracy (<0.1%) needed between albedo and gas bands
- Wide bands centred around gas bands might be needed to mitigate uncertainties from surface albedo variations

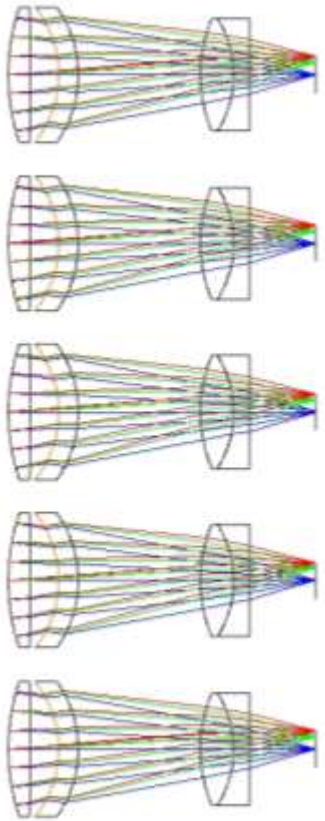


	CH_4 Band	CO_2 Band	H_2O Band	Albedo 1	Albedo 2
Range /nm	1665-1668	1606 – 1617	1696-1698	1626 – 1629	1679-1683
Centre/nm	1666.5	1611.5	1697	1627.5	1681
Width/ nm	3	11	2	3	4

Technical Feasibility

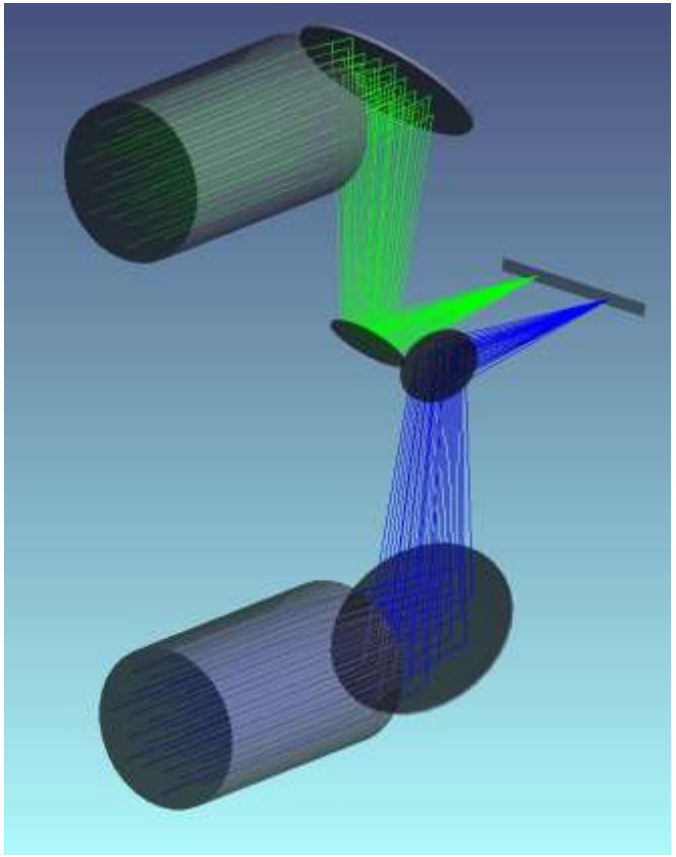
- Study has been limited to InGaAs linear array detector due to low cost and only moderate cooling requirement
- Filters are feasible but likely to be expensive
  - Possibly $20k for 2-3nm bandwidth at 1666nm
- SNR is feasible for ~1km GSD at 20mm aperture
- Main problems:
  - Relative response drifts >0.1% between detectors
  - Need precise spatial registration of channels
  - Reference albedo channels need to be close to CH_4, CO_2 absorption channels

Concept with five independent channels



Solution 1 – Separated Channels

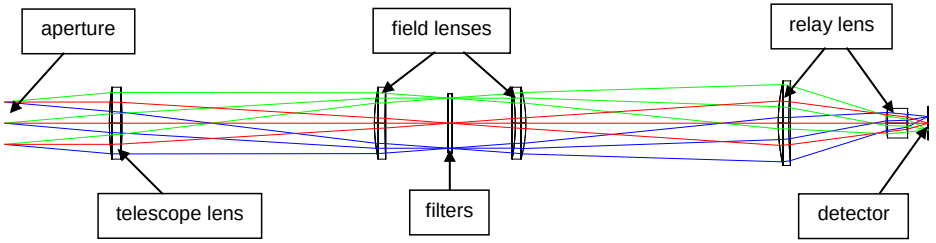
- Separate lengths of a single detector, for the absorption and reference bands
- Relatively complex folding of optical paths due to large diameters of lenses
- Advantages:
  - Offset and gain changes will be similar for the absorption and reference bands
- Residual problems for <0.1% errors
  - Differential drifts in offset and gain
  - Differential non-linearity



Solution 2 – Oscillating filters

- Oscillating filters
  - For each CO_2 and CH_4 band, oscillate between narrow and wide filter
- Filters vibrated so that the beam passes through each in turn.
- Same detector for absorption and reference readings
  - eliminating detector drifts and non-linearity
- Large scene image is formed by a telescope lens, eg at f/10, and relayed onto a detector at f/2.
- More elaborate arrangements possible

Time-sharing filter system for CH4 or CO2 view along-track



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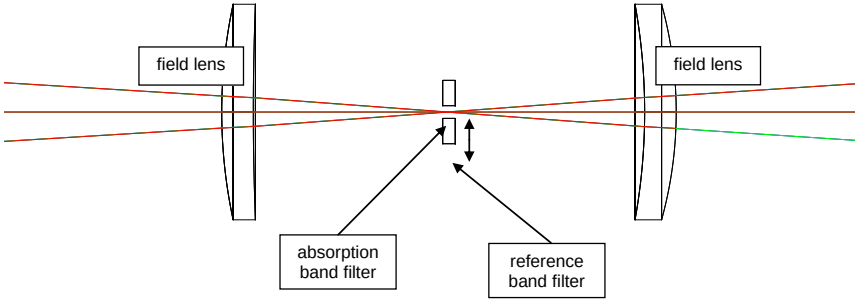

Achievements against goals

- Defined a measurement concept for CH_4 detection based on a number of discrete bands in the shortwave infrared and analyzed measurement performance with simulations (Obj. 1)
- Developed a basic instrument concept and investigated a number design options (Obj. 2)
- Discussed the possibility of developing an instrument suitable for the SSTL TechDemoSat platform (Obj. 3)

Issues and Problems Encountered

As expected for a exploratory seedcorn study several technical issues have been encountered and investigated:

- High SNR requirement *(feasible)*
- Band pass filter:
  - Need for narrow bandwidth *(expensive but feasible)*
  - Shift of filter transmission with angle *(limit cone angle and use filters in front of optics)*
- Errors due to detector and optics drift errors
  - Need for calibration system *(feasible but increased weight)*
  - Use same detector/optics for gas and albedo bands *(possible with oscillating filters, but needs a* solution for spatial co-registration *)*
- Surface albedo variations *(use overlapping wide and narrow band filters or gas cells; will require higher signal-to-noise)*

Positioning achieved and Other Achievements

- There is significant interest by UK space industry on GHG monitoring and related downstream services and project represents a first step towards new measurement approaches relevant for commercial applications from very small satellites
- Project has strengthened collaboration between key groups in UK with interest in GHG remote sensing from satellites (SSTL, University of Leicester and University of Edinburgh)
- Project has fostered direct interaction between team members which has resulted in significant exchange of knowledge between SSTL and University groups in key areas SWIR spectroscopy, optical design etc.
- Project has been presented to wider audience at CEOI Event 'Innovations in Remote Sensing Event' in London

Roadmap

- **Short-term**
  - More detailed trade-offs between the approaches that have been developed in this study: use of separate detectors, or at least separate detector-areas (solution 1) or use of time-sharing (chopping, solution 2) to measure absorption and reference channels at the same detector elements
  - More detailed investigations in detector characteristics (offset and gain stabilities and linearity), especially for systems with separate detectors
  - Further investigate filter options, especially use of gas calls appears an interesting option.
- **Mid-term**
  - Development of breadboard or airborne demonstrator
  - Seek funding from ESA, UKSA or private sector