GHOST - Green House gas Observations of the Stratosphere and Troposphere

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Motivation

Improved understanding of sources and sinks (natural and anthropogenic)

• Surface fluxes inferred from GHG observations coupled with an inverse model
• Uncharacterised transport model errors can lead to significant biases in surface flux estimates
• Particular challenge for CO$_2$, CH$_4$: relatively small perturbations on large background concentrations
Observation concept

- Observe shortwave infrared spectral radiances (1.2 to 2.4 μm) at high spectral resolution.
- Gases of interest absorb solar radiation at specific wavelengths – absorption related to concentration averaged over the total atmospheric column.
- Scattering in the atmosphere lengthens the atmospheric path → measure O₂ absorption lines to estimate optical path length.
- Tracking mode: when over ocean observe direct solar reflection to maximise signal.
# Instrument Requirements

<table>
<thead>
<tr>
<th>Function</th>
<th>Band 1</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud/aerosol surface pressure</td>
<td>CH$_4$ and CO$_2$ columns</td>
<td>Cloud/aerosol, CO$_2$ columns</td>
<td>CO, CH$_4$, H$_2$O, HDO columns</td>
<td></td>
</tr>
<tr>
<td>Spectral Band (µm)</td>
<td>1.25 – 1.29</td>
<td>1.59 – 1.68</td>
<td>2.04 – 2.09</td>
<td>2.31 – 2.39</td>
</tr>
<tr>
<td></td>
<td>1.235 – 1.305</td>
<td>1.584 – 1.676</td>
<td>1.980 – 2.095</td>
<td>2.254 – 2.385</td>
</tr>
<tr>
<td>Spectral resolution (nm, FWHM)</td>
<td>&lt;0.1</td>
<td>&lt;0.25</td>
<td>&lt;0.15</td>
<td>&lt;0.25</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>0.13</td>
<td>0.17</td>
<td>0.19</td>
</tr>
<tr>
<td>SNR (at Lref)</td>
<td>150</td>
<td>80</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>389</td>
<td>204</td>
<td>181</td>
<td>137</td>
</tr>
</tbody>
</table>
Instrument Requirements

Molecular Vibrations

Electron transitions

Rot.

UV
Visible
NIR
SWIR
MidIR

Water
CO\textsubscript{2}
CH\textsubscript{4}
CO

I
J
H
K

Wavelength (nm)

Vertical transmittance

Science & Technology Facilities Council
UK Astronomy Technology Centre
GHOST: GreenHouse Observations of the Stratosphere & Troposphere

- Part of the NERC/STFC funded CAST consortium project
- Technologies developed for the JWST-MIRI instrument
- Designs based on studies of a low mass OCO-2 equivalent
- Fly on a NASA Global Hawk from California (NASA Armstrong)
Global Hawk

Good for Scientists...

- Can straddle Stratosphere and Troposphere
  → Interesting dynamic processes
- Long duration flights
  → Up to 30hrs
- Very stable platform
  → Enables high pointing accuracy
- Extreme flexibility in measurement location
  → Can travel up to 14,000 km

...tricky for Engineers

- 65,000ft \( \Rightarrow \begin{cases} 0.05 p_0 \\ 0.07 \rho_0 \\ T_a = -65\degree C \end{cases} \)
- Defines amount of cryogen
- Large data storage
- High pointing spec
- Unmanned operation
- $$$$$
  Only two flights to shake down
Range and Loiter from AFRC
Target Acquisition Module

Air Transport Rack

Cryostat Module
Why such a large instrument

Noise and cost

The SNR requirements of the objective are quite extreme so we have to cool to reduce the thermal noises, the worst of which is the detector dark current. A closed cycle cooled design would have been smaller but more expensive.
Build for Global Hawk

- Flight Duration (>20hrs) consumables & data
- Global Hawk – Unmanned aircraft (automation) & ITAR restrictions
- Load Tests
- Vacuum tests, ATR pressure tests
- Cryogenic tests

\[ 65,000\text{ft} \rightarrow 0.05\rho_0, \quad 0.07\rho_0, \quad T_a = -65^\circ \text{C} \]
TVAC Testing

-65°C 0,05 bar & 40°C atmospheric pressure (operational)
Vibration testing

Each module, each axis, operational to 3g
Communications and operations testing
Installation
GHOST range flight test, 02/26/15.
Control Centre
Global Hawk range and science flights

- 26th February 2015 (0700 local, 6.5hr duration)
- 5th March 2015 (2000 local, 21hr duration)
- 10th March 2015 (0900 local, 11.5hr duration)
2nd science flight: satellite overpasses

2140 UTC: OCO-2 Overpass

2121 UTC: GOSAT Overpass

Edwards TCCON site:
34.96N, 117.88W, 699 m
GHOST science data
03/05/15, Tropical Eastern Pacific
Real time instrument data

- Temperature of Focal Plane
- Temperature of ATR (electronics)
- Zenith Angle
  - Switch to Nadir over clouds
- Azimuth Angle
  - GH Telemetry
  - GHOST

GH Telemetry
GHOST
Hartmut Boesch  
Neil Humpage  
Piyal Samara-Ratna

Paul Palmer

Andy Vick  
Phil Parr-Burman  
Naidu Bezawada  
Martin Black  
Xiaofeng Gao  
David Pearson  
Jonathan Strachan  
Martyn Wells  
George Davidson  
Tom Baillie  
Brian Woodward  
Andy Born
Lessons learned

Icing on TAM dome

Typical flight profile
Lessons learned

Satellite communication

There were 2 satellite bands available:
- Iridium – low bandwidth
- KU band – high bandwidth
Lessons learned

Don’t use epoxy

Cryostal electrical feedthrough  ATR vessel near heat exchanger
Successes

• Cryostat hold time – much longer than expected (> 30 hours)
• Cryostat (instrument) stability
• Automation, with intermittent comms.
• Environmental stability of equipment
• Pointing and tracking
• Flights
• Data ?

Problems

• Cryostat external fixings (leaks)
• Bad communications
• Dome icing (visibility)
• Lengthy process
• Operations