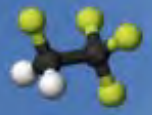

Integrated non-CO_2 Greenhouse gas Observing System

Remote sensing of methane from the (*ground, air and)* space

Hartmut Boesch, Will Hewson, Neil Humpage, Robert Parker, Harjinder Sembhi, Peter Somkuti, Hannah Sonderfeld, Alex Webb

Earth Observation Science Group
Department of Physics and Astronomy
University of Leicester

+ colleagues from TCCON, InGOS, GHG-CCI and NCEO

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

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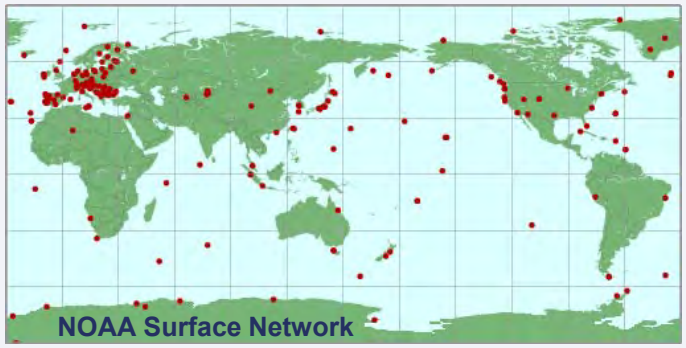
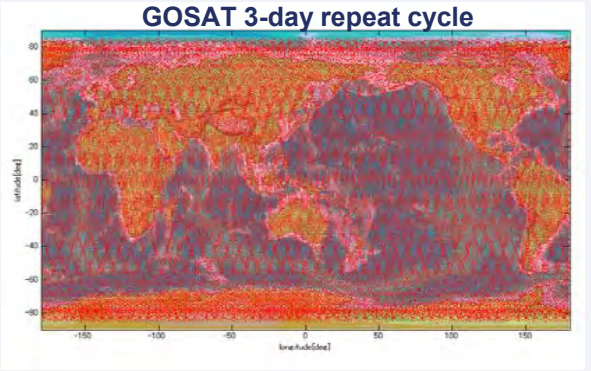
What do space based observations of GHG offer?

- **Advantages**
  - Global
  - Uniform
  - Dense
  - Frequent
  - ➢ Complement surface network
  - ➢ Source/sink estimation, especially for undersampled regions (Tropics, Asia …)



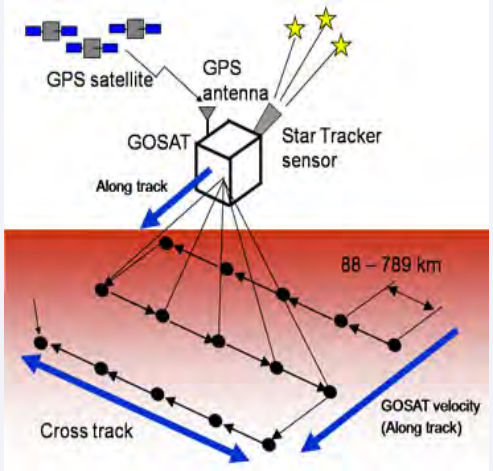


- **Challenges**
  - Column measurements
  - High precision and accuracy is needed
    - Clouds, aerosol, albedo …
  - Sensitivity to surface-near air

Greenhouse gases Observing SATellite (GOSAT) launched January 23rd 2009

Mission objectives:

1) To monitor the density of greenhouse gases precisely and frequently worldwide.
2) To study the absorption and emission levels of greenhouse gases per continent or large country over a certain period of time.
3) To develop and establish advanced technologies that are essential for precise greenhouse-gas observations.



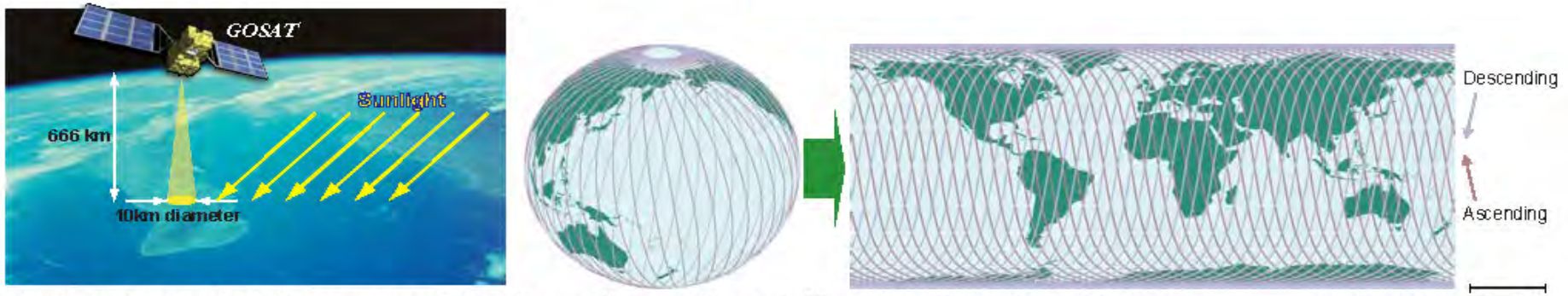


Figure 6. Conceptual diagram of GOSAT observation and the satellite orbits (three days, 44 orbits)

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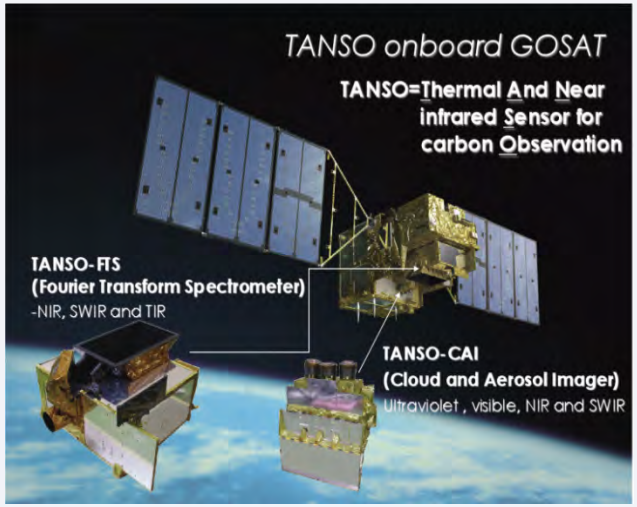
The GOSAT Payload

TANSO - FTS

Provides spectrally-resolved radiances for 4 shortwave-IR (polarized) and thermal-IR bands

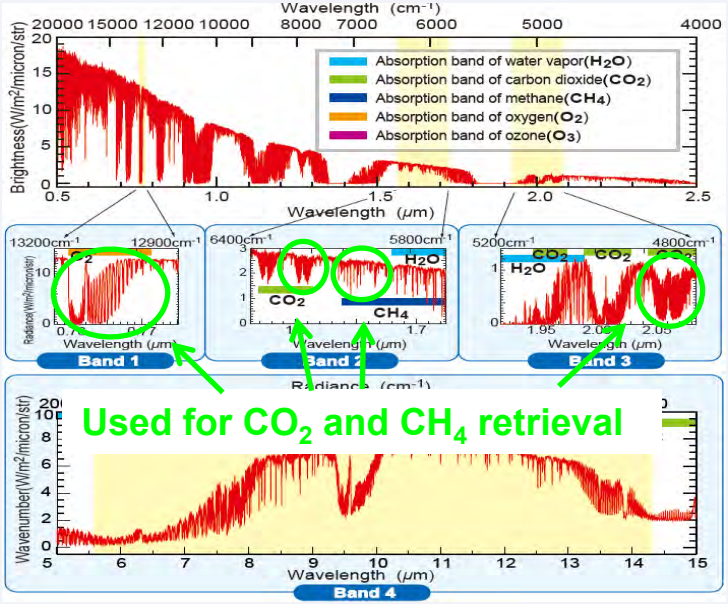
Covers several absorption bands of CO_2, CH_4, O_3 and H_2O (and others) and O_2

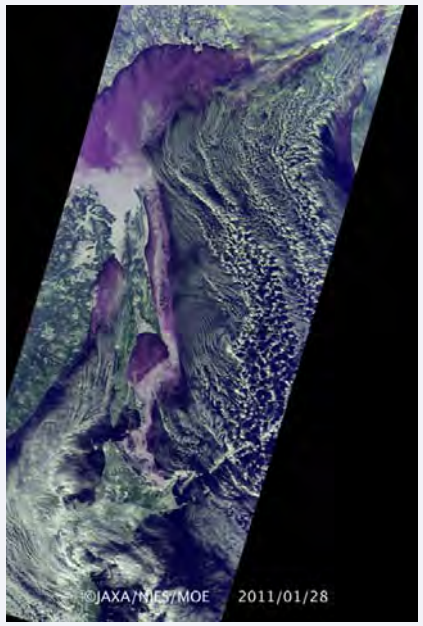


TANSO - CAI

4 broadband channels from UV to SWIR with high spatial resolution

Provides aerosol and cloud information required for the greenhouse gas retrieval





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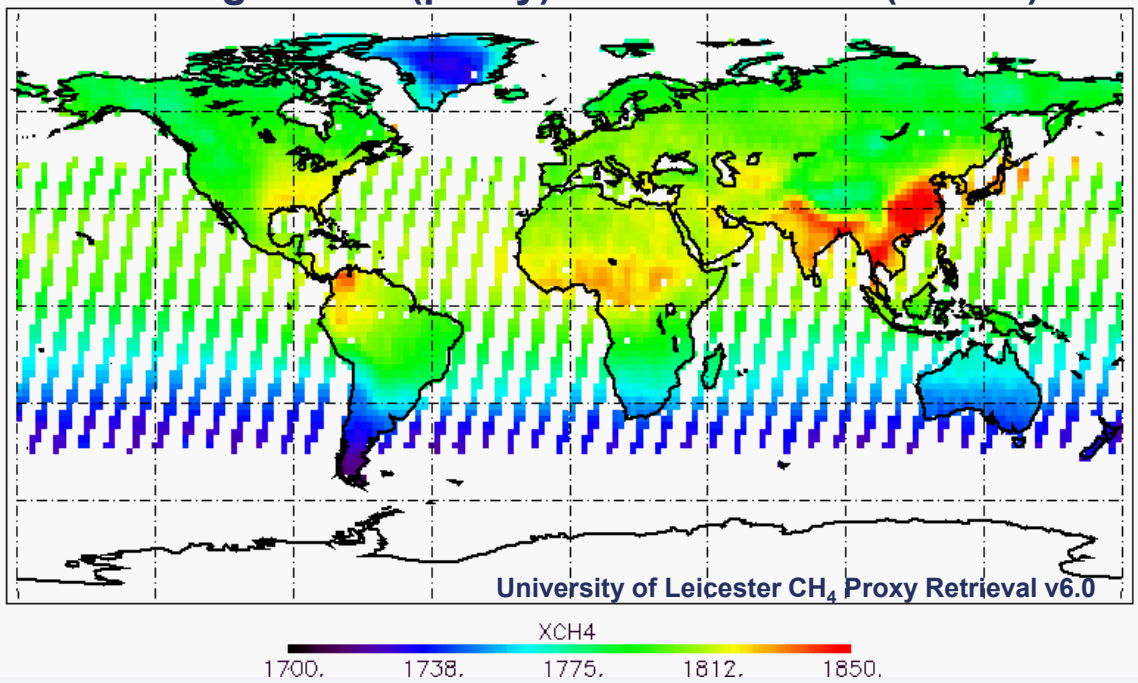
GOSAT CH_4 Data

- GOSAT proxy XCH4 retrieval based on retrieval of CH_4/CO_2 ratio
- 'Full-physics' and thermal-IR (free-troposphere) CH_4 retrieval also available
- A priori based on ECMWF/MACC (troposhere) + TOMCAT (stratosphere)

Average XCH4 (proxy) for 2009 – 2014 (2° x 2°)



- Good global coverage over land (1.3 M soundings)
- Oceans partly covered thanks to sunglint mode (540 k soundings)
- But, limited spatial resolution due to sampling and repeat pattern (especially since autumn 2010)

GOSAT-TCCON Comparisons: Parker et al., GRL, 2011; Assessment of Uncertainties: Parker et al., AMTD, 2015

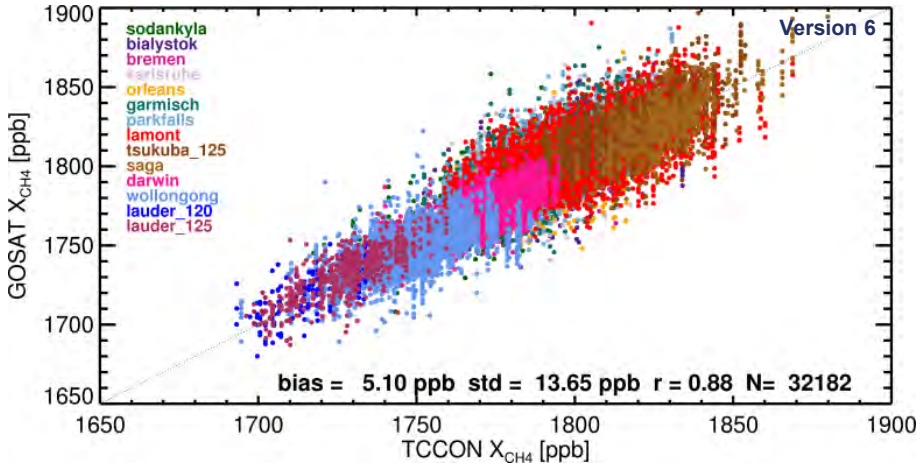
Validation Against TCCON

TCCON Network

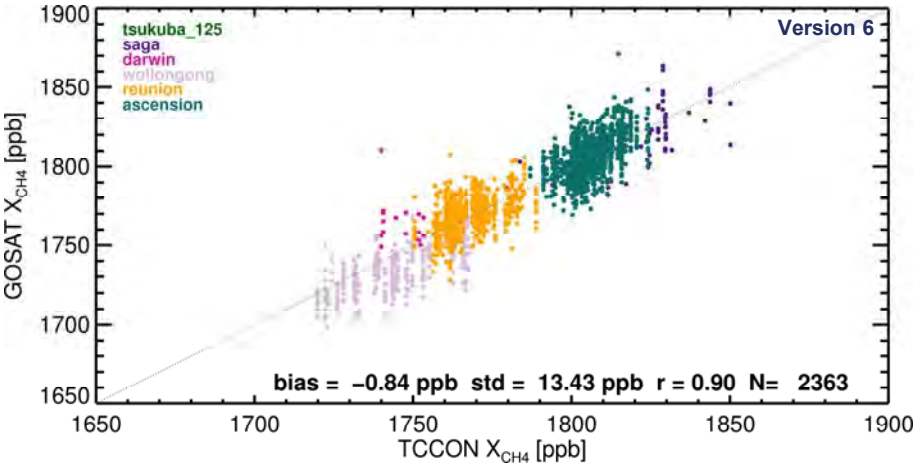
- **TCCON (Total carbon column observing network) network of ground-based Fourier Transform Spectrometers**
- **Provides precise, accurate total columns of CO_2, CH_4 and others gases calibrated against in-situ profiles**

https://tccon-wiki.caltech.edu/

Nadir Retrievals



Sunglint Retrievals



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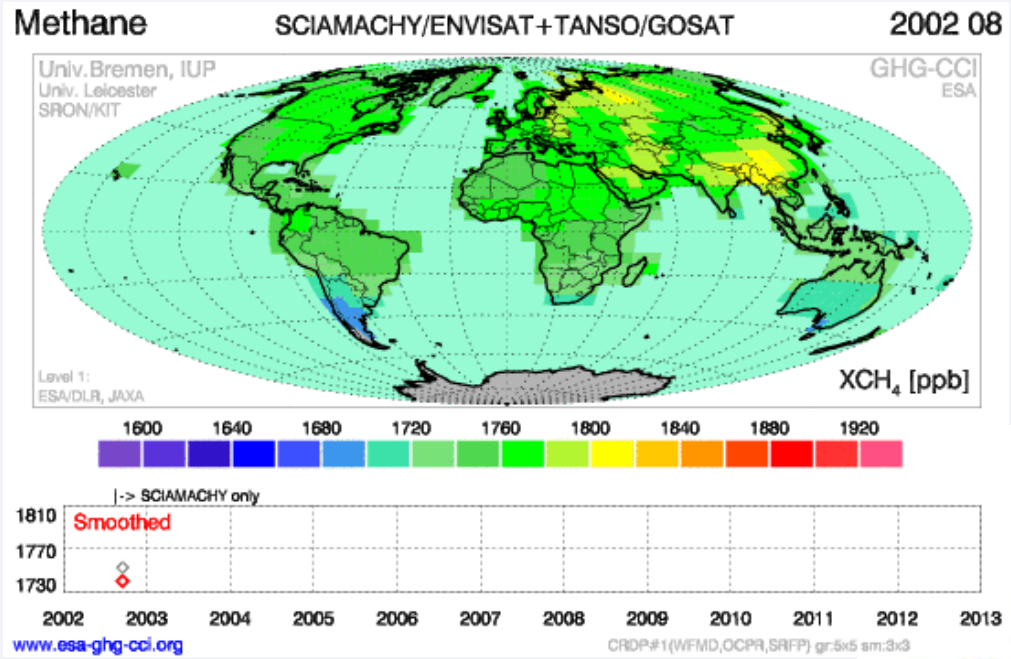
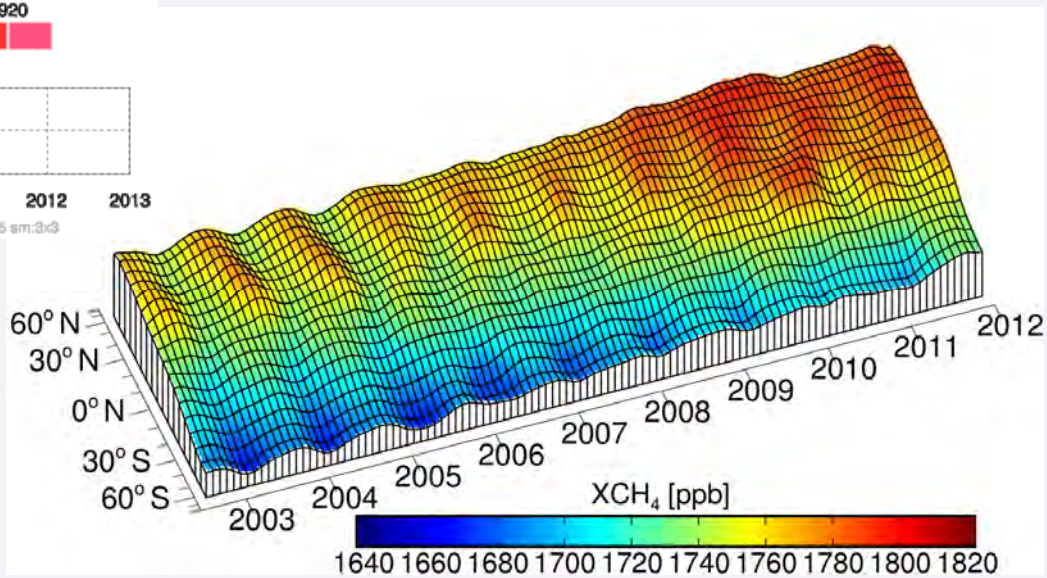
More than 10 Years of Methane Observations from Space



- **Combined record of SCIAMACHY and GOSAT provides global observations from 2002 to present**



Buchwitz et al., RSE, 2015

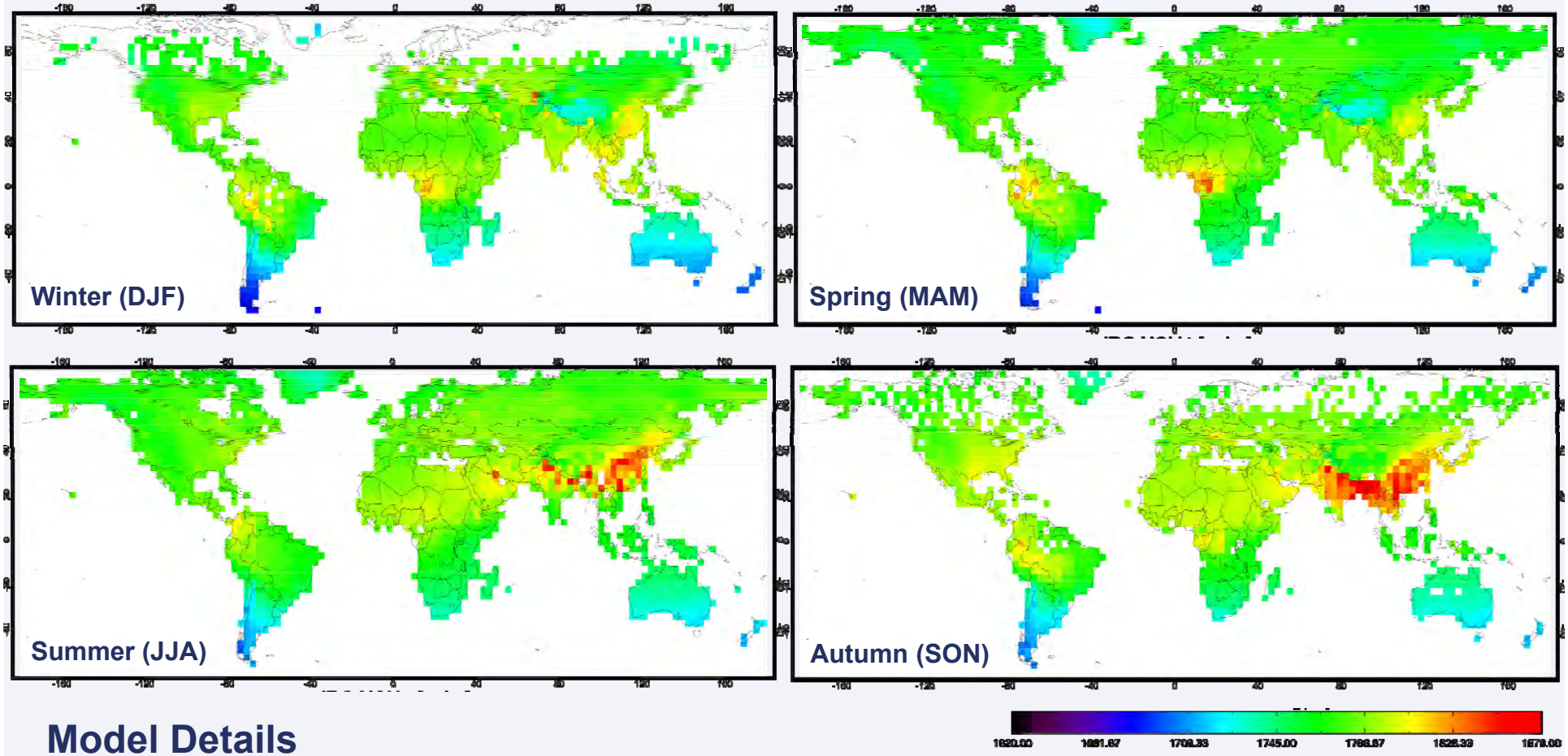
GHG-CCI

http://www.esa-ghg-cci.org/

Assessment of Model Calculations

TM5-4DVar model run (InGOS Model)

Year 2010



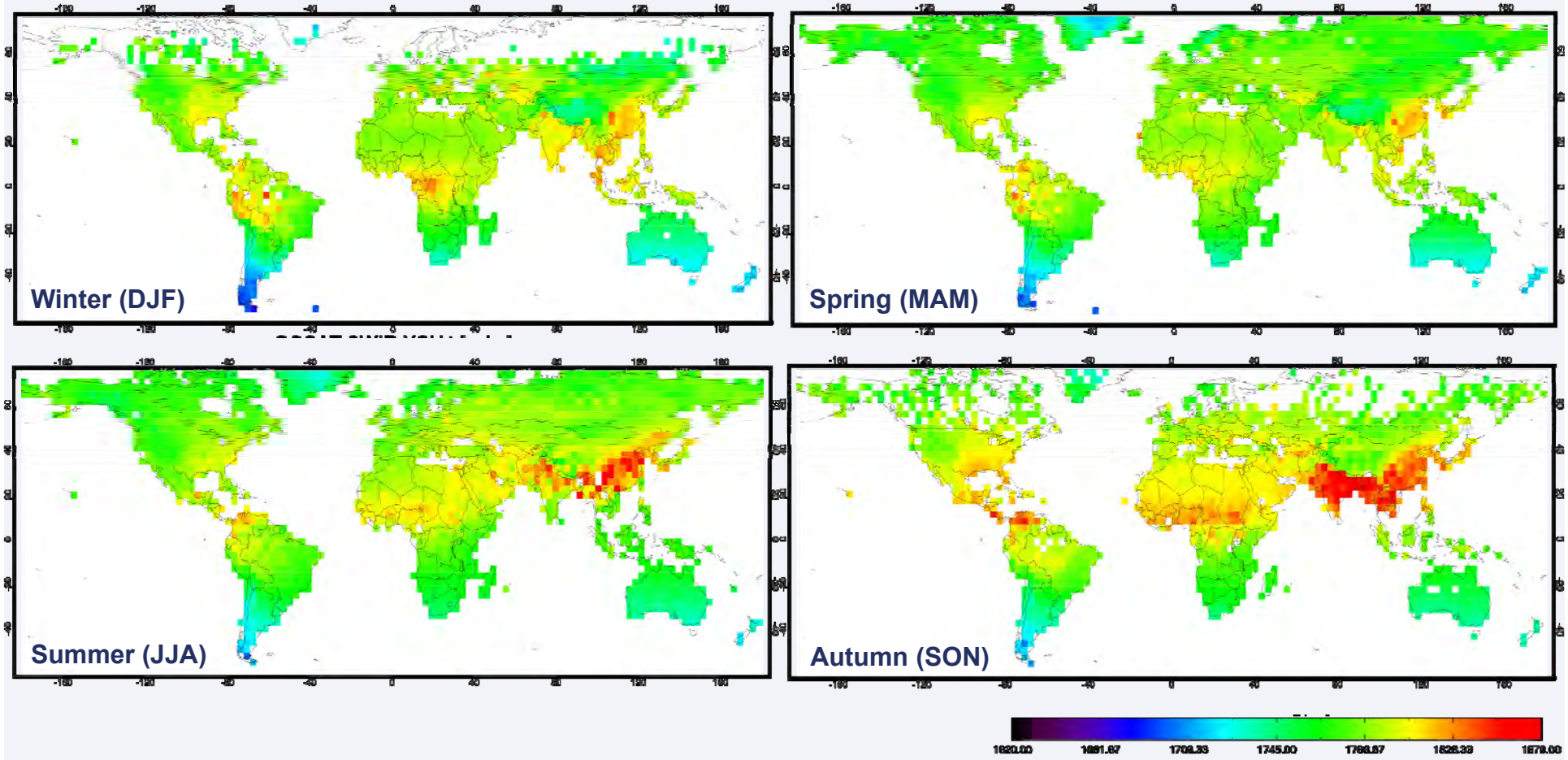
Model Details

- 1° x 1° (Europe) and 4° x 6° (globally)
- Fluxes optimized with surface in-situ data (InGOS + NOAA)
- A priori emissions: Edgar (anthropogenic), Kaplan (wetland), GFED (fire)

Assessment of Model Calculations

GOSAT XCH4 (proxy retrieval, version 5)

Year 2010



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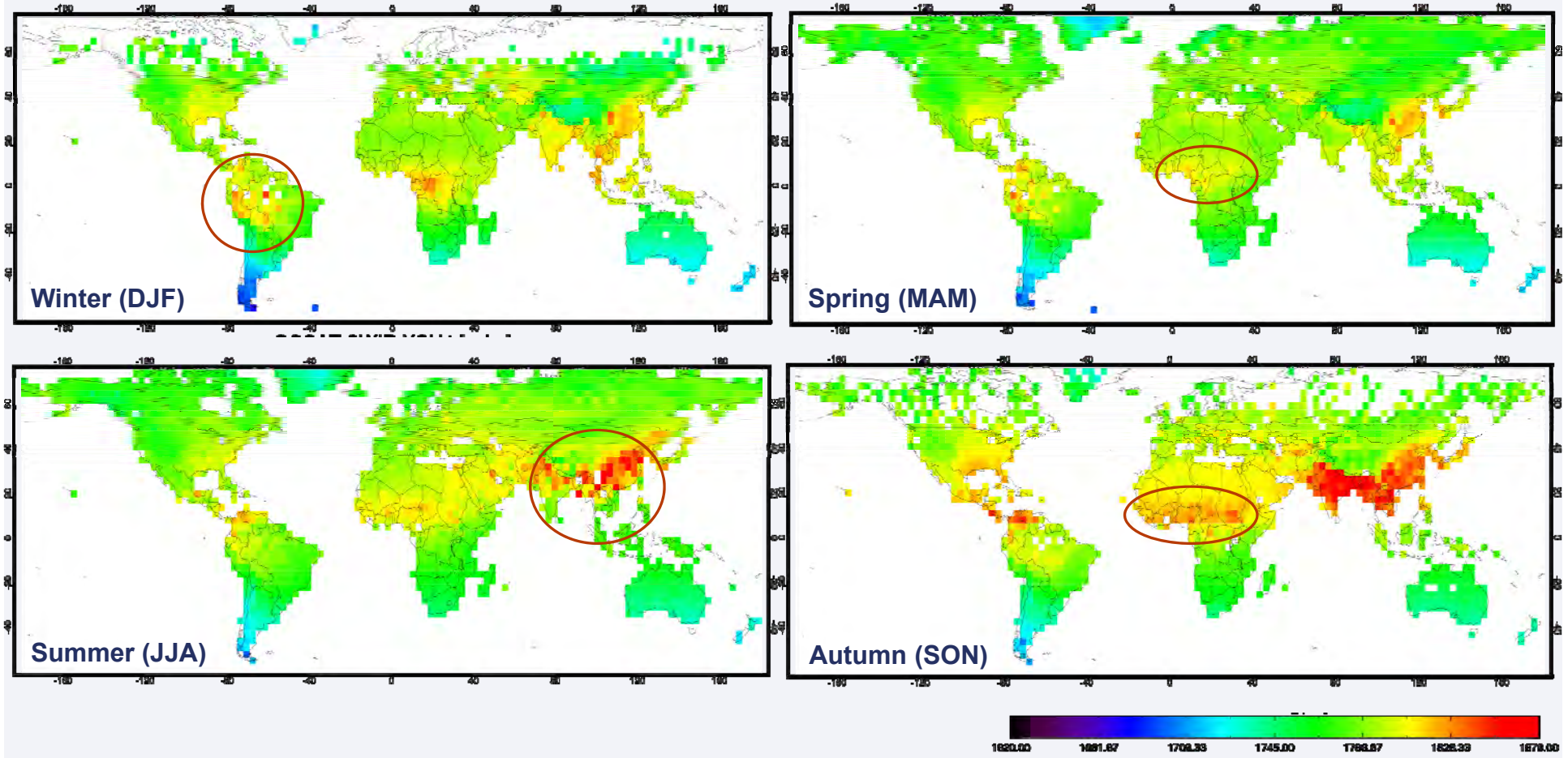
Assessment of Model Calculations

GOSAT XCH4 (proxy retrieval, version 5)

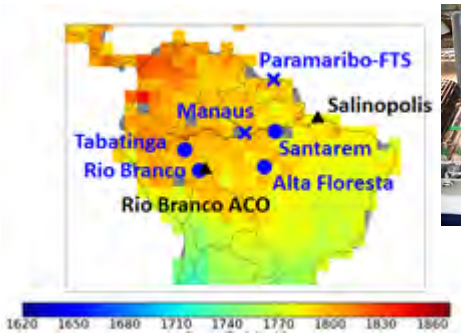
Year 2010



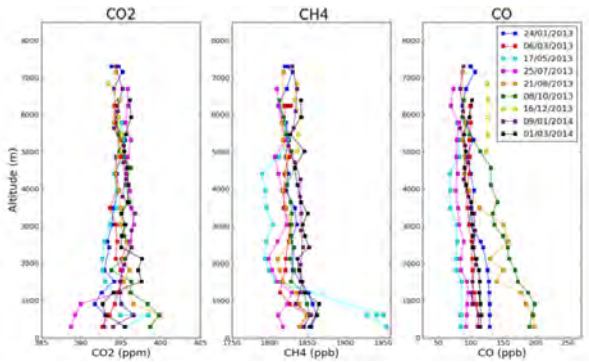
Information provide by GOSAT on fluxes exploited in several inverse modelling studies (Alexe et al., 2014, Berchet et al., 2014, Cressot et al., 2014, Fraser et al., 2013, 2014, Turner et al., 2015, Wecht et al., 2014)

Validation over the Amazon

NERC/FAPESP Amazonian Carbon Observatory



(GOSAT Proxy XCH_4 ppb)



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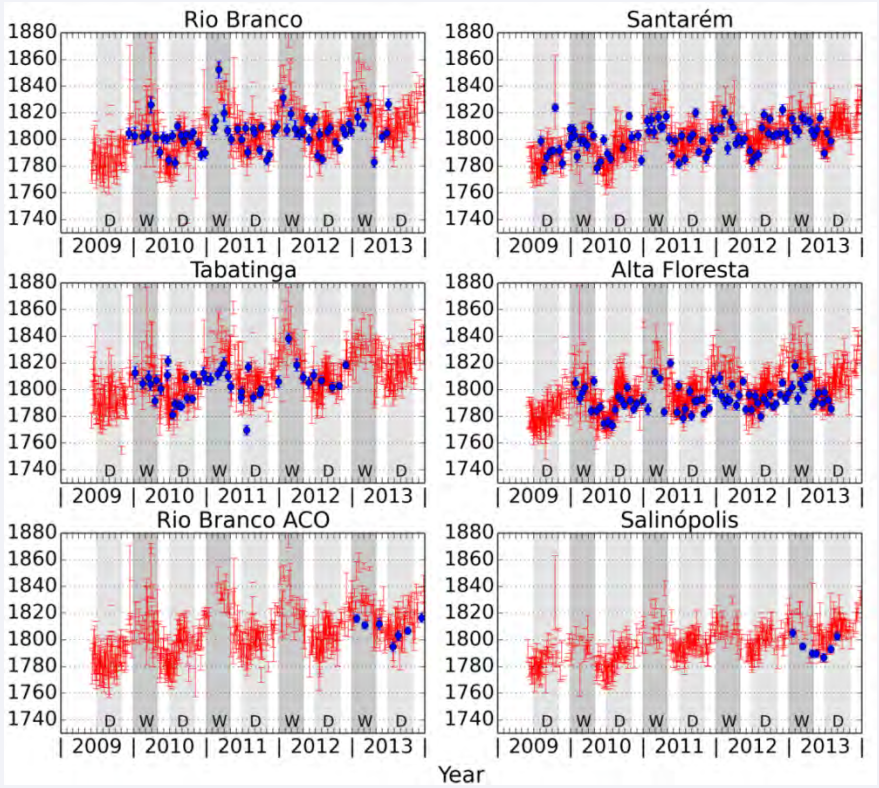
www.leos.le.ac.uk/GHG/ACO/



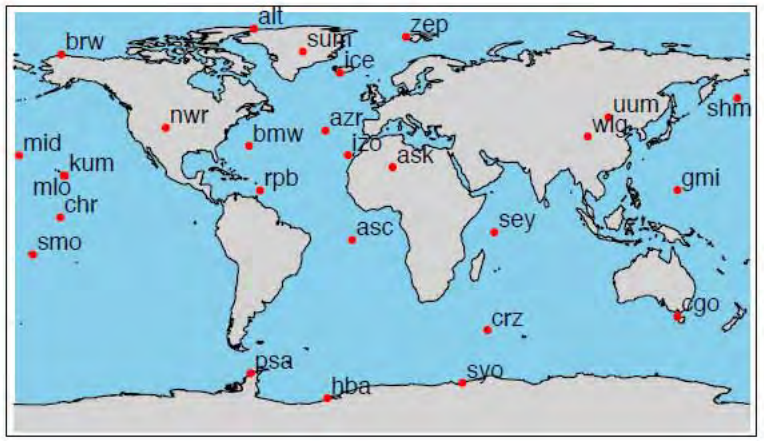
- **Aircraft flask sample profiles up to 7.5 km (ACO) and 4.5 km (AMAZONICA)**
- **Very good agreement between aircraft profiles and GOSAT retrievals for all sites with mean differences < 6 ppb (except Salinopolis)**

A. Webb et al., GRL, submitted

Estimating Amazonian Methane through 4D-Var Inverse Modelling

CH_4 observations (NOAA + GOSAT)

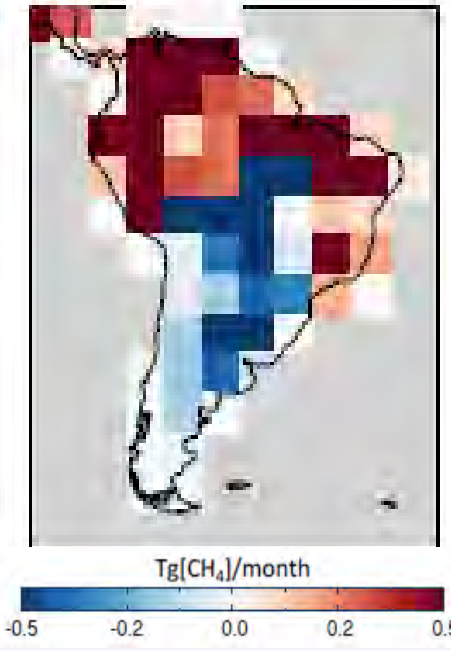
- INVICAT assimilates measurements from 26 NOAA surface stations (right), ~1500 obs/year
- GOSAT XCH4 also assimilated (provided by U. Leicester group (H. Boesch, R. Parker)), ~200,000 obs/year



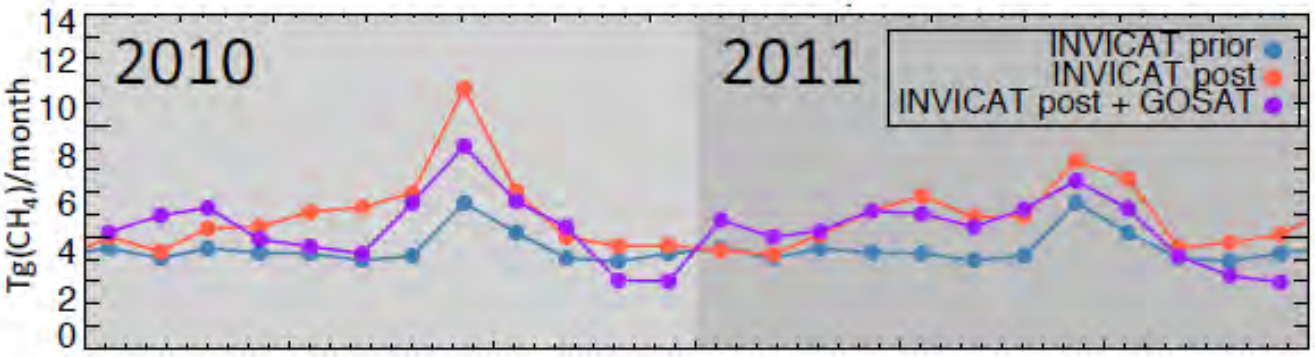
- Independent inversions carried out for 2010 and 2011 (spin up from 2000)
- A priori emission errors = 100% in each grid cell
- INVICAT: 4D-Var inverse model based on TOMCAT (Wilson et al., 2014)

Estimating Amazonian Methane through 4DVar Inverse Modelling

Posteriori minus prior emissions for Tropical S.-America for Aug. 2010



Methane Fluxes for Tropical S.-America



- **GOSAT provides a strong constraint on emissions for the Amazon**
- **Posteriori emissions are larger than priori emissions in 2010 and 2011**
- **GOSAT leads to a clear spatial re-distribution of priori fluxes**

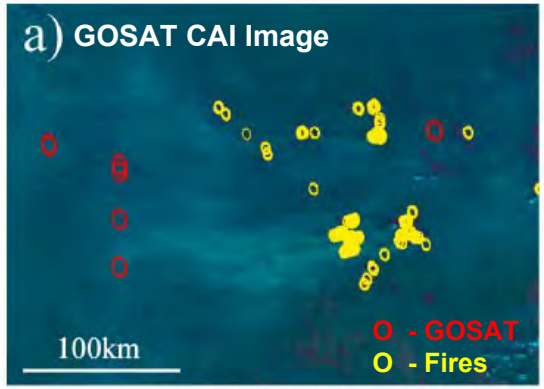
National Centre for Earth Observation

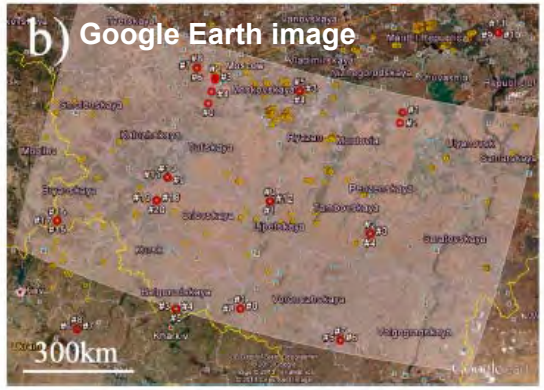
C. Wilson, M. Chipperfield, E. Gloor (University Leeds)

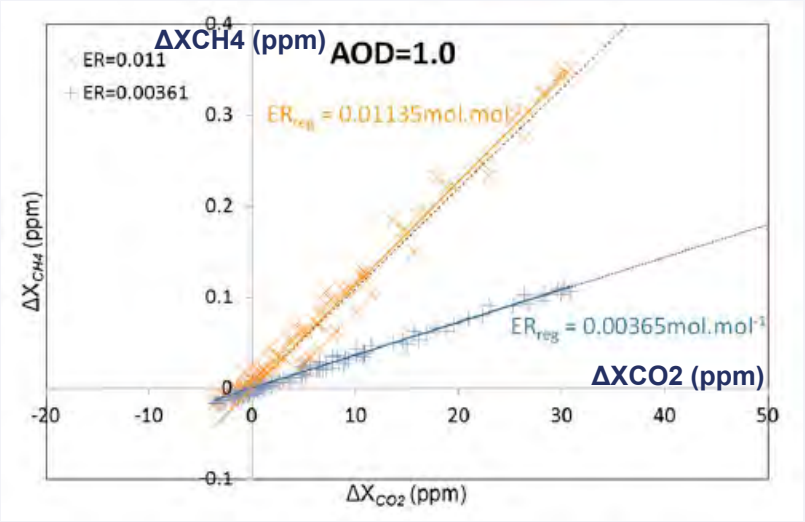
New Applications: CH_4/CO_2 Emission Ratio from Fires

Identification of fire scenes:

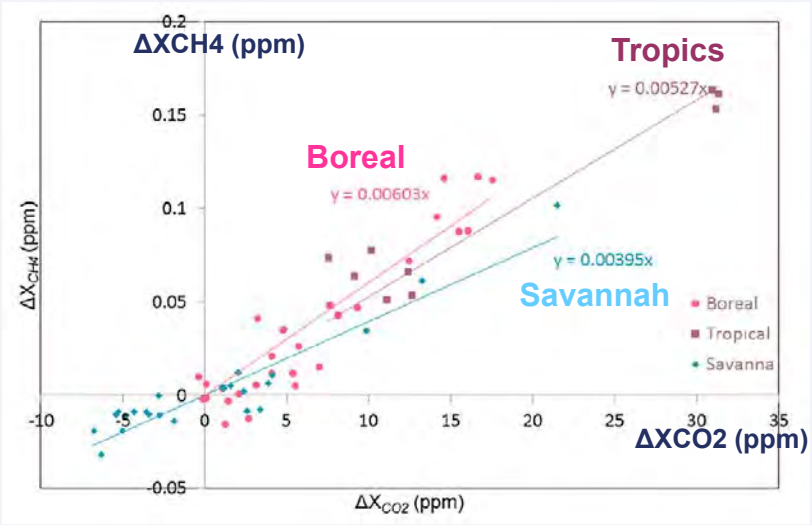
- Wildfire location (MODIS , AATSR …)
- Inspection of smoke plume from CAI images
- NH_3 index (from TIR)







Simulations: Ratio of CH_4 to CO_2 has much reduced sensitivity to aerosols in plume

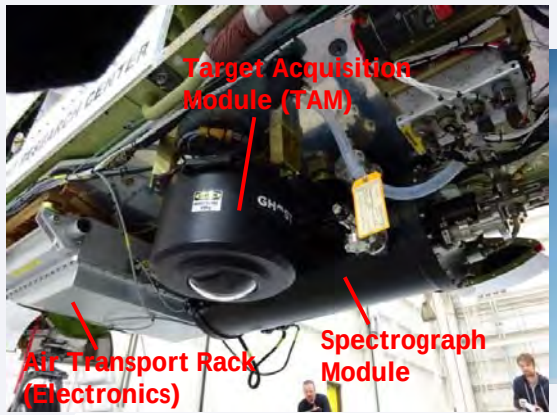


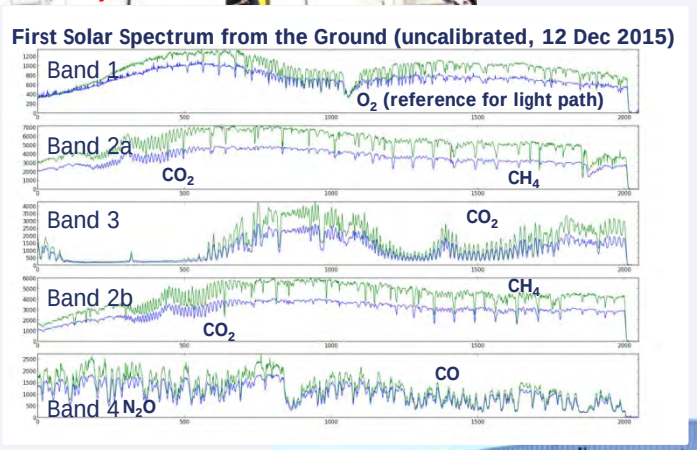
Emission ratios from GOSAT

Ross, Wooster, Boesch, Parker, GRL, 2013

Airborne Remote Sensing with GHOST

- Airborne remote sensing is well suited for regional (transects) and local scale (point sources)
- U. Leicester, U. Edinburgh and UK ATC have jointly developed a new SWIR spectrometer for CO_2, CH_4 and CO columns
- GHOST has been deployed on NASA Global Hawk (CAST-Attrex) during large transects over Pacific ocean in March 2015
- GHOST has also been flown on NERC ARSF aircraft to target point sources (landfill, power station, wildfire plume) in April/May 2015

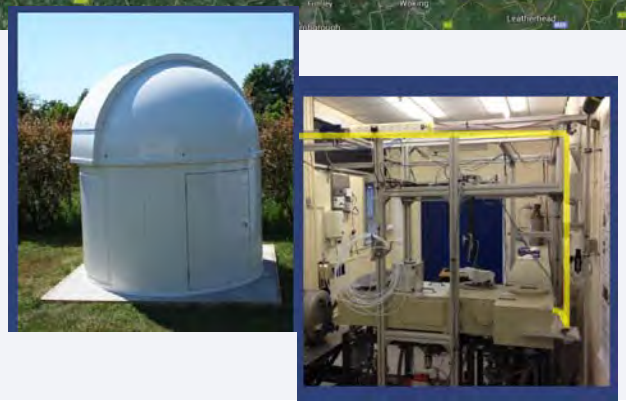




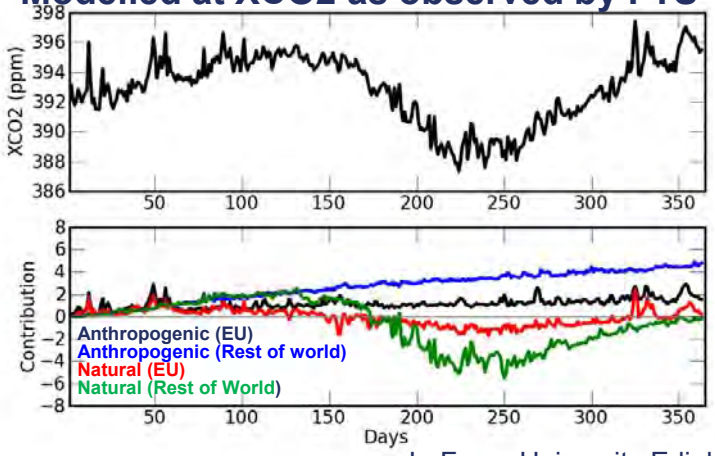
GHOST
GREENHOUSE GAS OBSERVATIONS OF THE STRATOSPHERE AND TROPOSPHERE

New uplooking FTS site in the UK

- Observations from ground-based FTS provide
  - continuous datasets to test our understanding of regional carbon and methane budgets
  - a powerful tool for validation of satellites
- New UK FTS site has been installed at Rutherford Appleton Laboratory (RAL) located 60 miles west of London.
- Bruker 125HR spectrometer upgraded to accommodate a DC-enabled TEC cooled InGaAs detector.
- NPL solar tracker that is housed in purpose built observatory
- Site should be operational by end of the year and ready to join TCCON



Modelled at XCO2 as observed by FTS



L. Feng, University Edinburgh

Summary

- GOSAT provides high-quality global observations of CH_4 columns since 2009 (available from GHG-CCI webpage)
- The importance of GOSAT lies in its ability to provide new constraint on magnitude and spatial distribution of surface fluxes especially for regions poorly covered by surface networks
- Additional application possible from satellites (eg. emission ratios, point source detection)
- A limitation of GOSAT is its coarse sampling and future sensors such as S5P and S5 promise a major step forward with daily global coverage