Tropospheric Methane Retrievals from GOSAT Thermal Infrared Soundings

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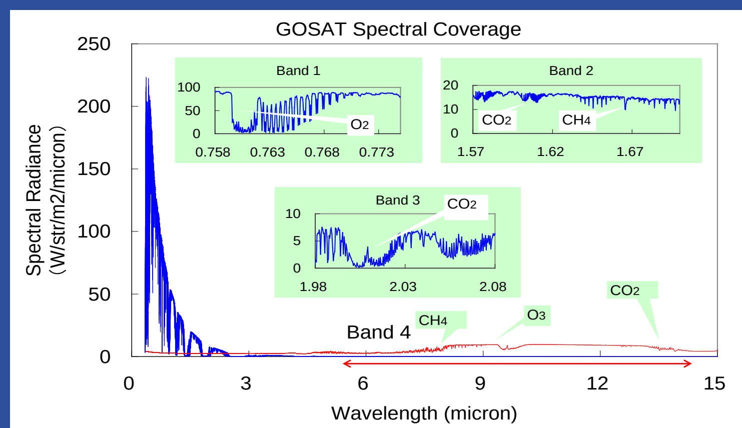
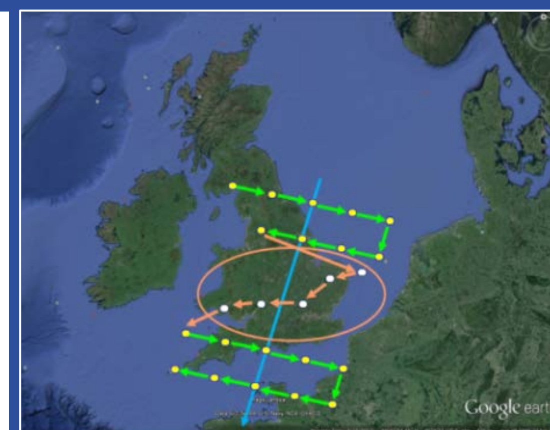
Greenhouse gases Observing SATellite

- Thermal and Near Infrared sensor for carbon Observation – Fourier Transform Spectrometer (TANSO-FTS) & Cloud and Aerosol Imager (CAI)
- Global measurements: April 2009 – present
- IFOV = 10.5 km, Swath = 750 km, Repeat cycle = 3 days





Band	Spectral Range (μm)	Spectral Sampling (cm^{-1})	SNR (pre-launch)	Calibration
1	0.75 - 0.77	0.2	>340	Solar Irradiance Deep Space, Lunar, Diode Laser
2	1.56 - 1.72	0.2	>320	
3	1.92 - 2.08	0.2	>410	
4	4.5 - 14.3 (700 - 2000cm^{-1})	0.2	> 280	Deep Space, On-board Blackbody

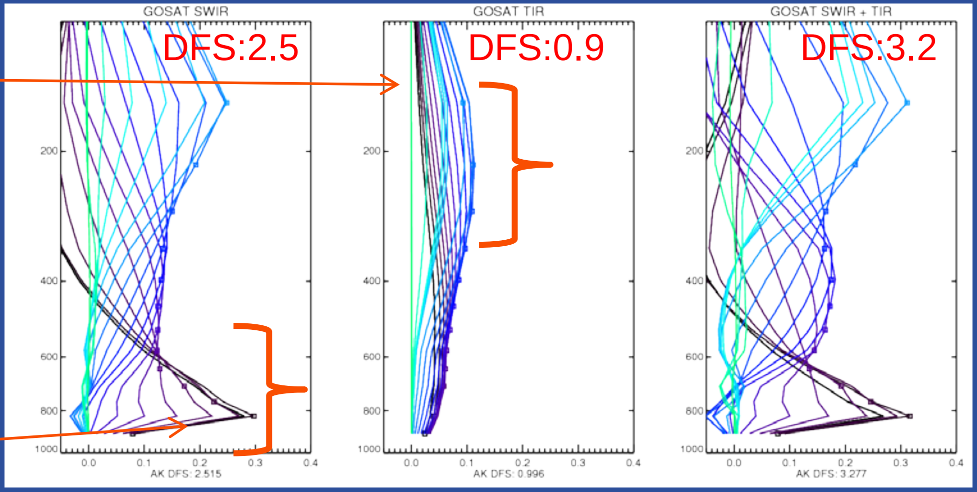
Motivation

- Tropospheric methane (CH_4) retrievals from nadir thermal infrared measurements – AIRS (Xiong et al, 2008), IASI (Razavi et al,2009, Crevoisier et al, 2009) & TES (Payne et al, 2009, Worden et al, 2012)
- Thermal Infrared (TIR) measurements -> complement shortwave Infrared (SWIR) retrievals
  - maximum TIR sensitivity in mid-troposphere -> provides additional information of tropospheric gas concentrations
  - GOSAT TIR & SWIR sample the same air mass -> avoid uncertainties in combining information from different sensors (e.g. combining GOSAT & IASI)
- Combination of SWIR –TIR information -> potential for increase in DFS & better vertical representation of tropospheric methane

Vertical sensitivity of GOSAT SWIR and TIR

TIR: mid- & upper-troposphere sensitivity

SWIR: near surface sensitivity



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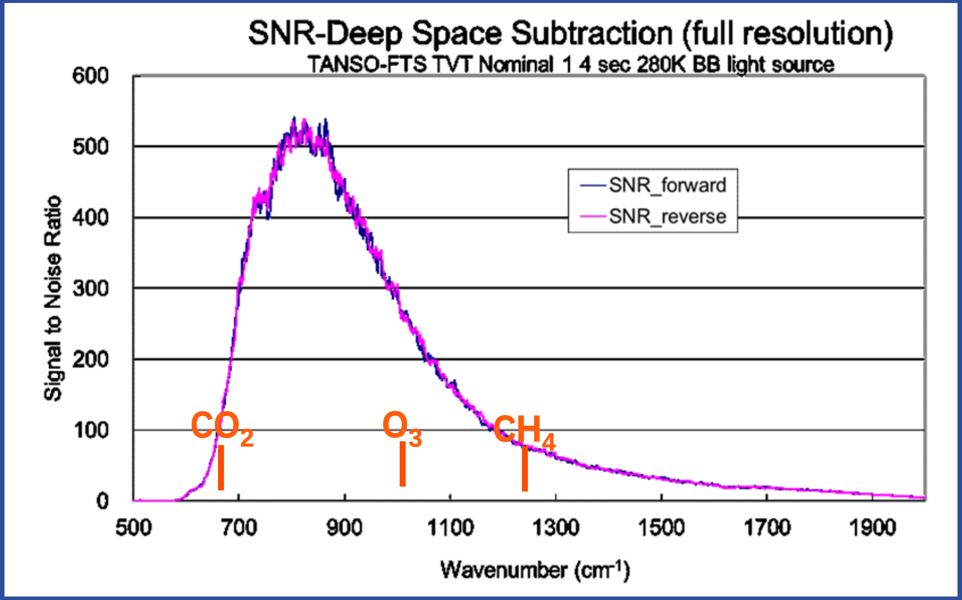
Thermal Infrared Spectra

- Current version of GOSAT Level 1b data (V1.60+) -> optimised TIR spectral calibration (polarisation & blackbody emissivity)
- Uncertainties in pre-launch calibration -> TIR spectra a) are likely systematically biased (based on JAXA/NIES - U. Wisconsin TIR calibration campaigns) & b) low signal-to-noise ratio



SNR < 70 in CH_4 spectral region ($1200 – 1300\ cm^{-1}$)

- Calibration errors (A. Kuze, 2015):
  - Internal blackbody temperature & pointing mirror
  - Produces different spectral response across methane spectral band

Reference: Kuze et al, 2015, GOSAT TIR WG.

UOL GOSAT TIR Processor

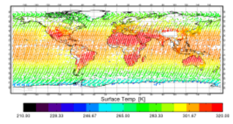
GOSAT SWIR Pre-Processing:

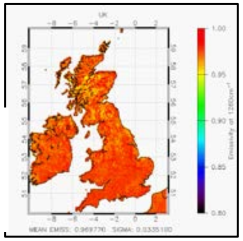
- CH_4 (MACC+TOMCAT)
- H_2O + TEM (ERA Interim) a priori
- Surface pressure & (SRTM DEM) topography

Cloud Filtering:

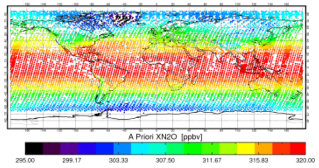
Land*: SWIR O_2 A-band cloud pressure retrieval
Ocean*: CAI cloud mask (channels 0.66 µm, 0.87 µm, 0.38 µm, 1.60 µm)

Surface: CIMSS MODIS High Spectral Resolution Emissivity
ECWMF Skin Temperature





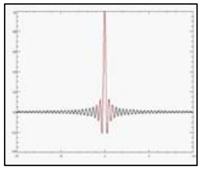
Profiles: Slimcat N_2O & Initial Guess (IG2) climatological species

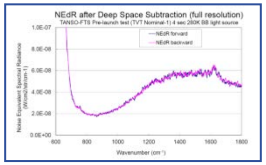


OUTPUT:
XCH4 (total column, concentration profiles, a posteriori uncertainties (with TEM, H_2O, SFC-TEM)

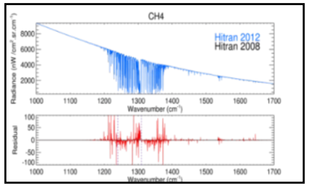
OE Retrieval
V1.60 TIR L1B (Oxford Reference Forward Model, Levenberg Marquardt iterations)

Instrument: Line Shape and Radiometric Noise





Line & Cross Sections: HITRAN 2012 Spectroscopy

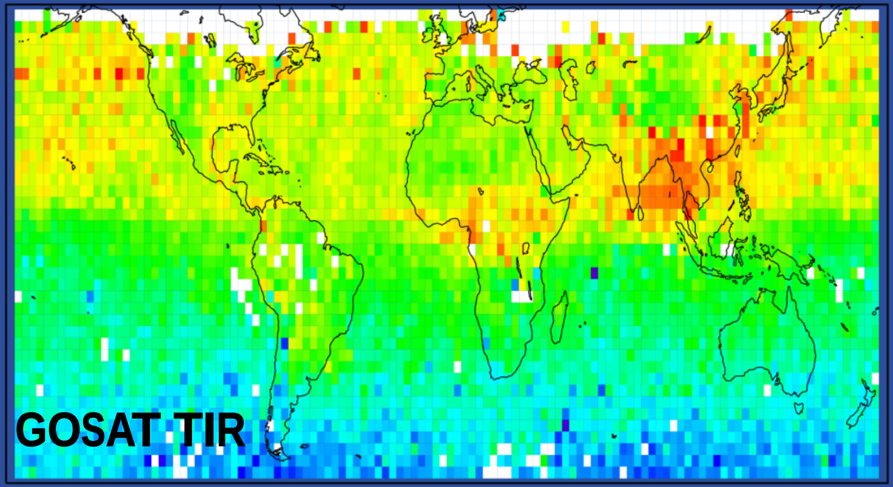


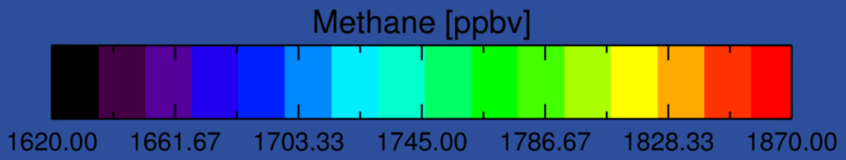
- State Vector: [CH_4,H_2O, TEM, SFC-TEM, SPECTRAL SHIFT]
- 1240 – 1305 cm^{-1} and NESR: 50 $nWcm^2.sr.cm^{-1}$ (SNR <70)
- Retrieval levels 40 equidistant pressure levels

* Extract TIR brightness temperature differences for TIR cloud mask using clear-sky thresholds (not yet implemented)

UoL GOSAT TIR XCH4 V1.0 Retrievals

XCH4: GOSAT TIR: November 2009

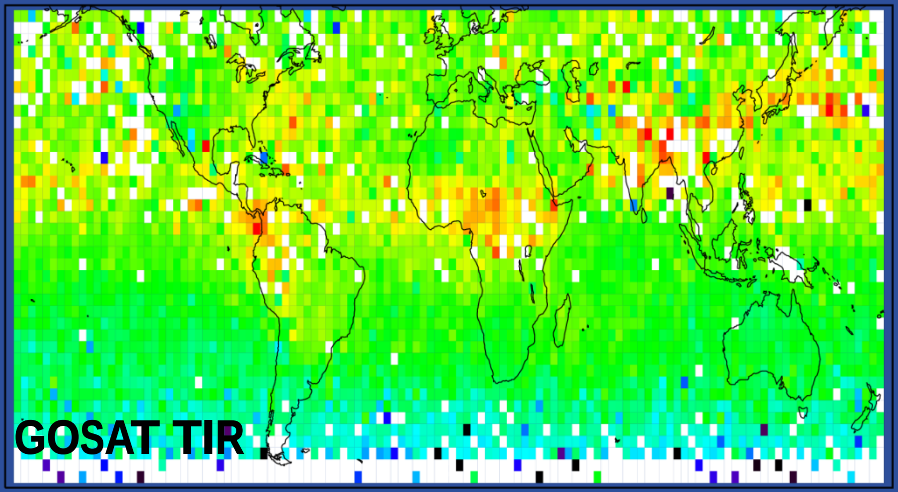


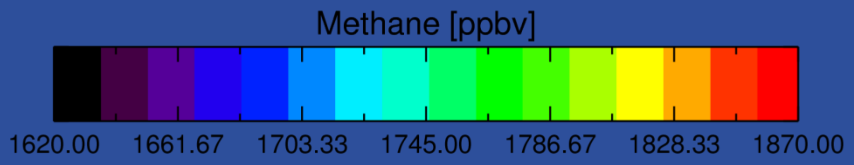


XCH4: Total Column

AT PROXY XCH4 (SWIR)
http://www.iup.uni-bremen.de/sciamachy/NIR_NADIR_WFM_DOAS/CRDP_REG/

XCH4: GOSAT TIR: June 2011





XCH4: Total Column

AT PROXY XCH4 (SWIR)

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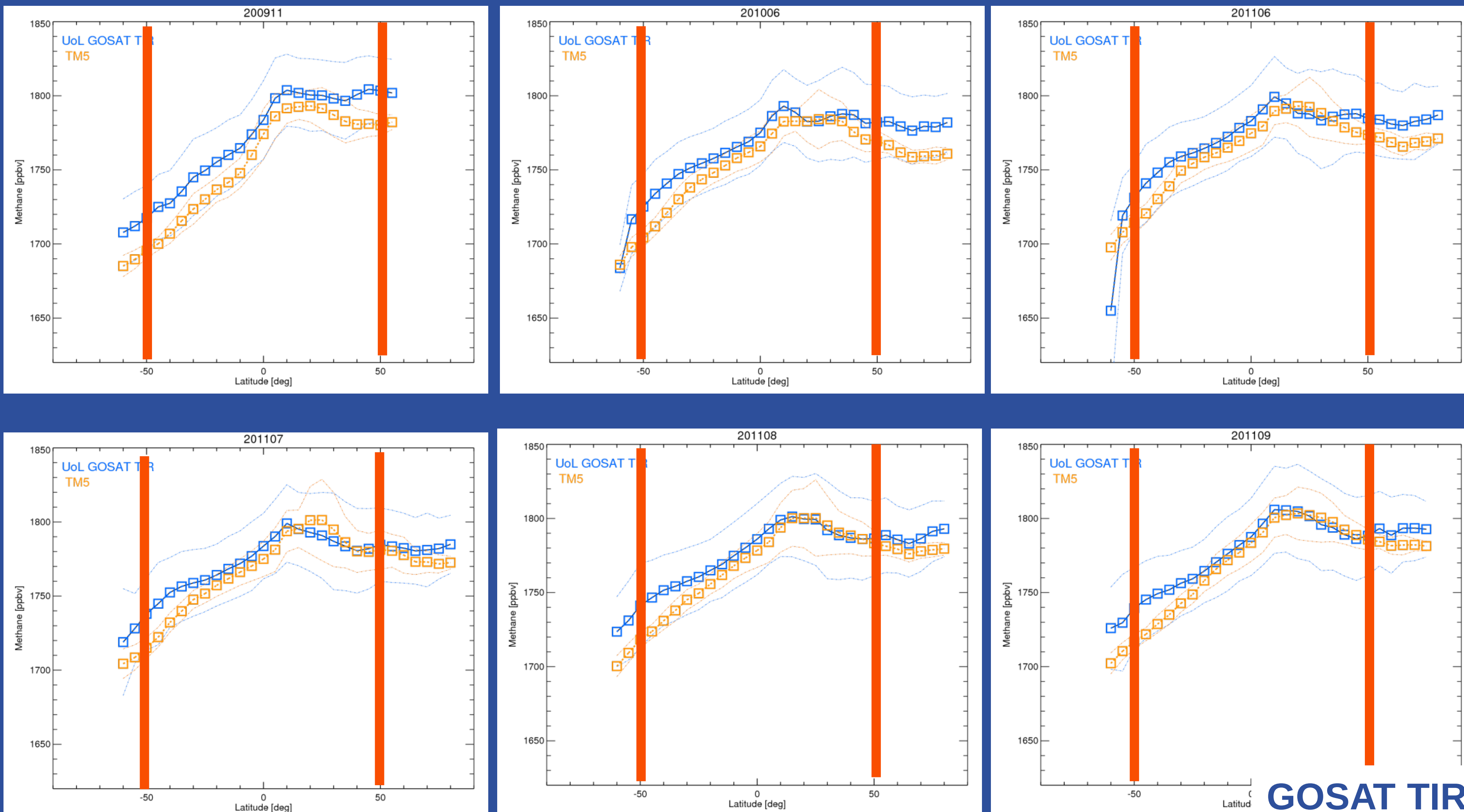
GOSAT TIR vs. MACC- TM5 XCH4: Zonal Average



GOSAT TIR
MACC TM5

MACC- TM5 CH_4, Bergamaschi et al., JGR, 2013 – Assimilates surface observations

UoL GOSAT TIR XCH4 V1.0
Aircraft Inter-comparisons

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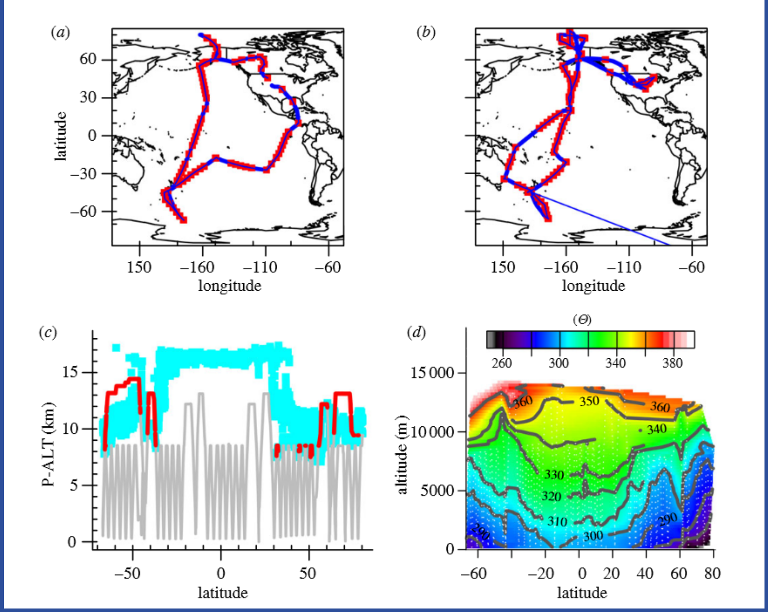
HIAPER Pole-to-Pole Missions

- NOAA Gulfstream V aircraft -> transects across Pacific Ocean from 85°N to 85°S with vertical profiles every ~ 2.2° latitude
  - Surface to tropopause, pole to pole CH_4 measurements
  - ideal for validation of TIR mid/upper troposphere sensitivity

Wofsy et al, 2011

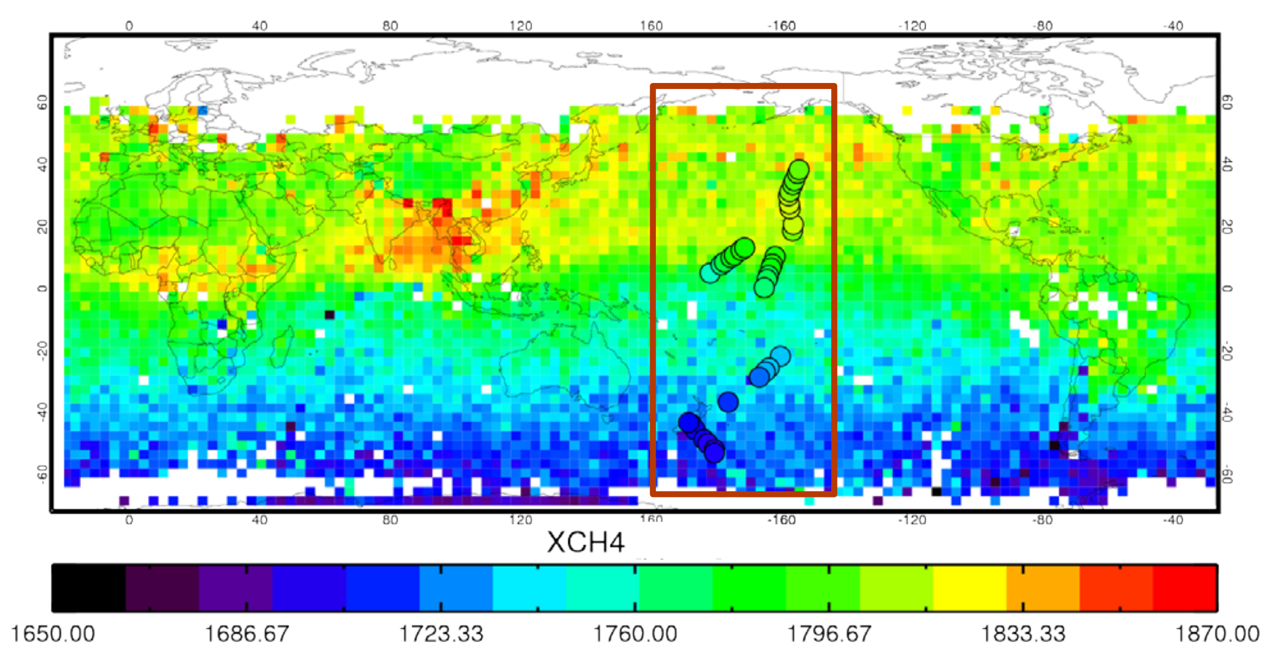


http://www.eol.ucar.edu/field_projects/hippo

HIPPO mission	Dates	Number of Profiles
1	2008 Dec - 2009 Jan	138
2	2009 Oct - 2009 Nov	148
3	2010 Mar - 2010 Apr	136
4	2011 Jun - 2011 Jul	175
5	2011 Aug - 2011 Sep	190

File:HIPPO_profiles_100m_intervals_20140519.tbl

GOSAT & HIPPO inter-comparisons

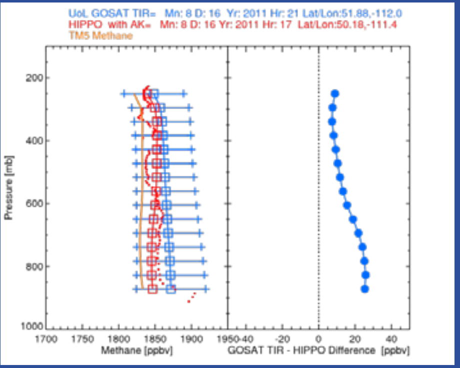


GOSAT average XCH4 vs. HIPPO -2 XCH4: 2009-11

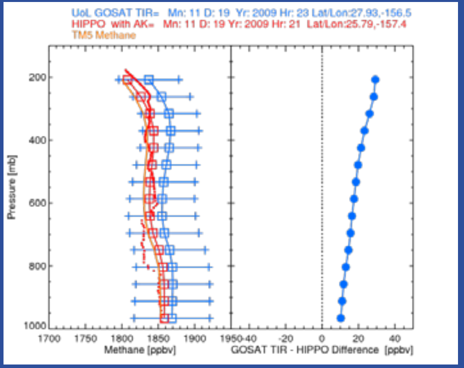
- ± 300km, ± 6 hours
- HIPPO profiles are merged with a priori methane profiles above top altitude
- Application of co-located averaging kernel and pressure weighting function

$$x_{truth} = x_{apriori} + A_{gosat}\left(x_{truth-highres} - x_{apriori}\right)$$

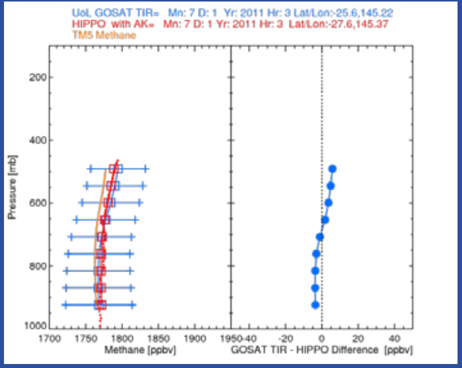
Matched profile examples



NH



TROPICS



SH

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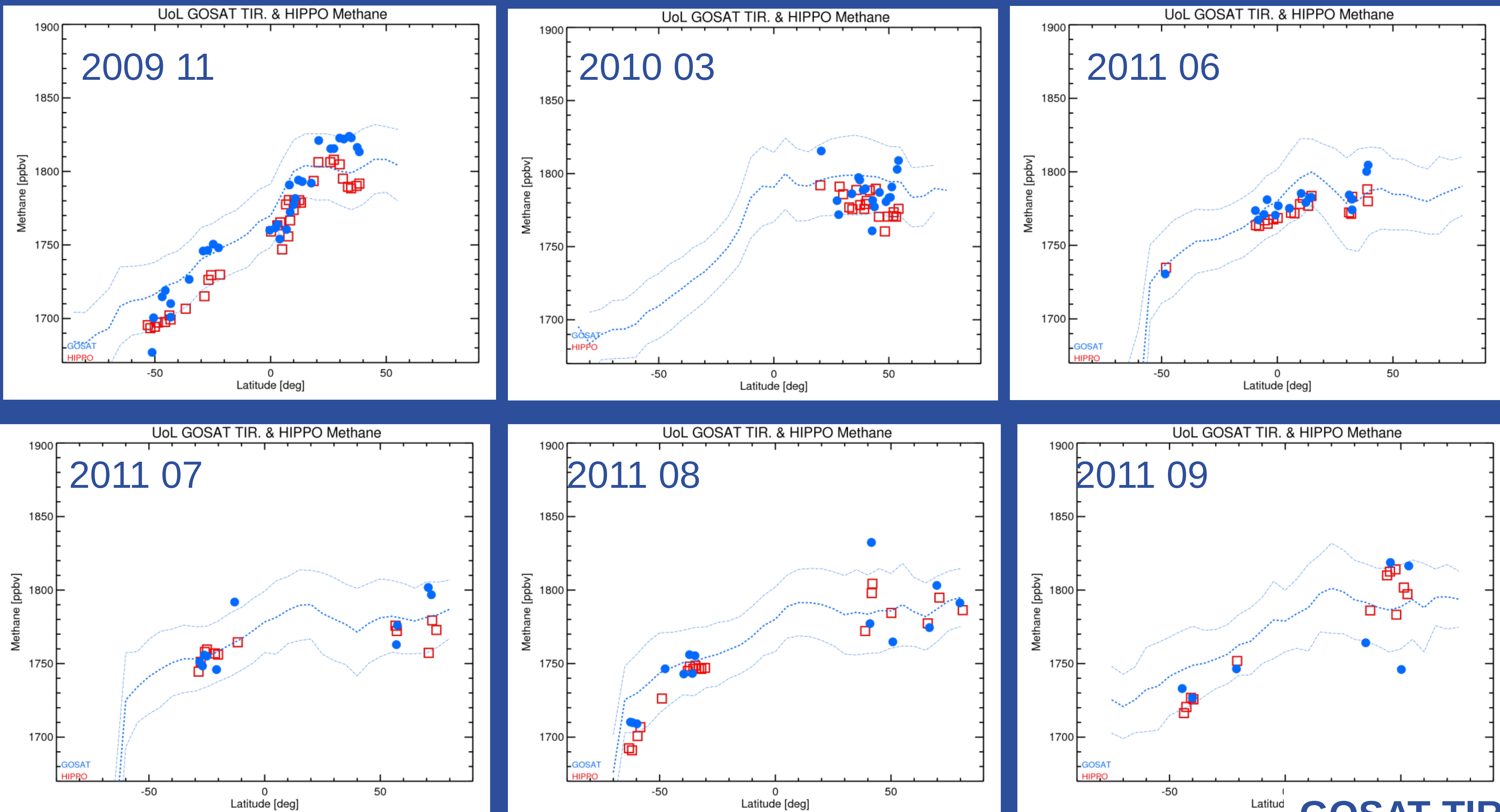
GOSAT TIR vs. HIPPO XCH4: Zonal Average



GOSAT TIR
HIPPO

Zonal average = GOSAT measurements across HIPPO flight transect

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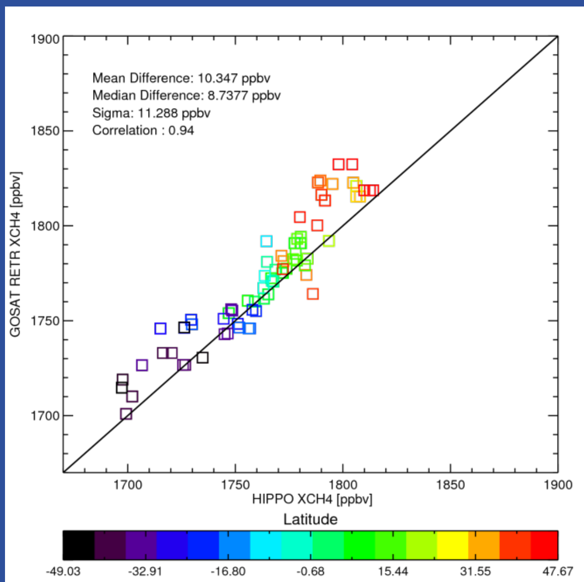
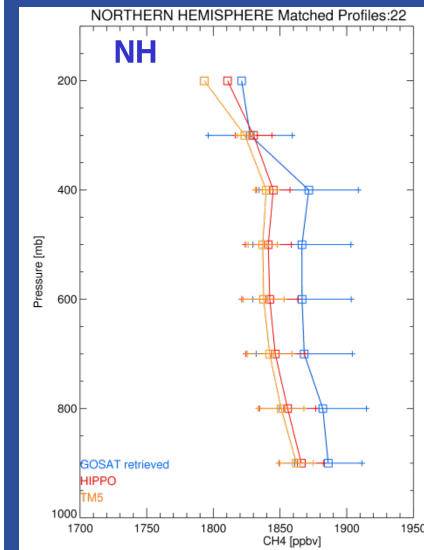
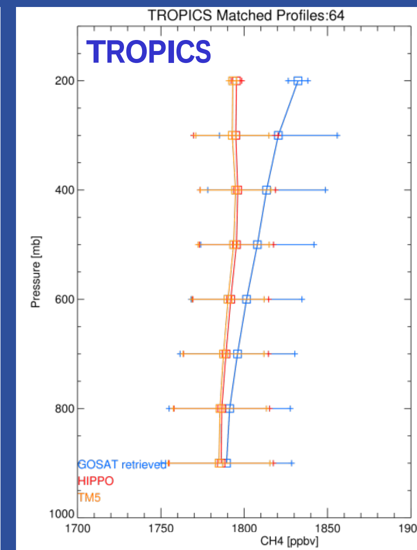
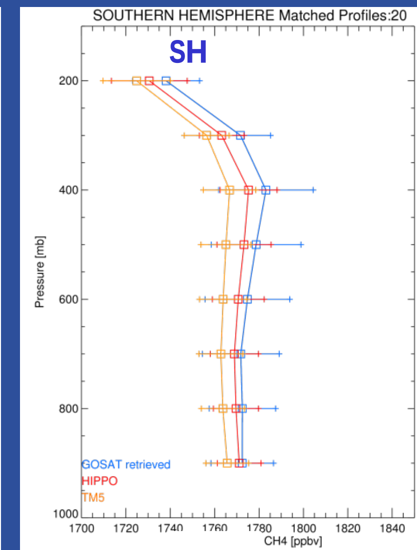
GOSAT vs. HIPPO XCH4

GOSAT TIR
HIPPO
MACC TM5









GOSAT - HIPPO	NH [ppbv]	Tropics [ppbv]	SH [ppbv]
Mean Difference	18.27	7.84	9.63
Median Difference	24.58	7.04	8.00
Maximum Difference	34.41	30.69	21.41
Sigma	15.18	9.05	9.14
Correlation Coefficient	0.65	0.92	0.88

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Summary

- We have performed GOSAT TIR methane profile retrievals (2009 to 2011) that show a good agreement with UoL GOSAT (SWIR) proxy XCH4 and MACC TM5 model
    - Capture large-scale features and north-south gradient
    - Positive bias in XCH4 compared to in-situ HIPPO measurements: 25 ±15ppbv in the Northern hemisphere
    - Likely causes a combination of TIR CH_4 spectroscopy, instrument calibration and interfering species

- Further Improvements:
    - Testing TIR spectral bias correction with JAXA to improve spectra prior to retrieval
    - "Proxy"-type retrieval using co-retrieved N_2O profiles correct CH_4 profile (to remove systematic errors that affect both CH_4 and N_2O) has shown promise (improved agreement with TM5) but requires information on TIR bias correction
    - CH_4 & N_2O spectroscopy updates (particularly line mixing)
    - GEOS-Chem (Edinburgh) model inversions assimilating both GOSAT SWIR & TIR data

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Thank you

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Extra Slides

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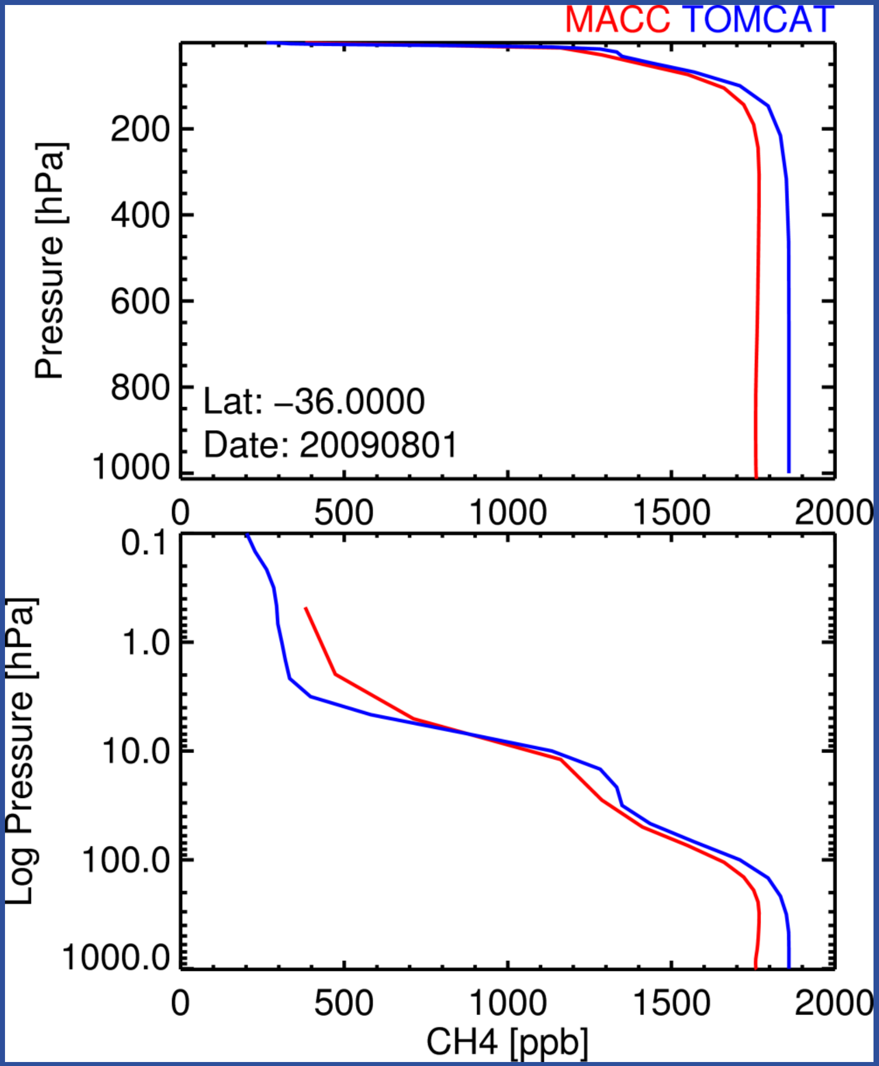
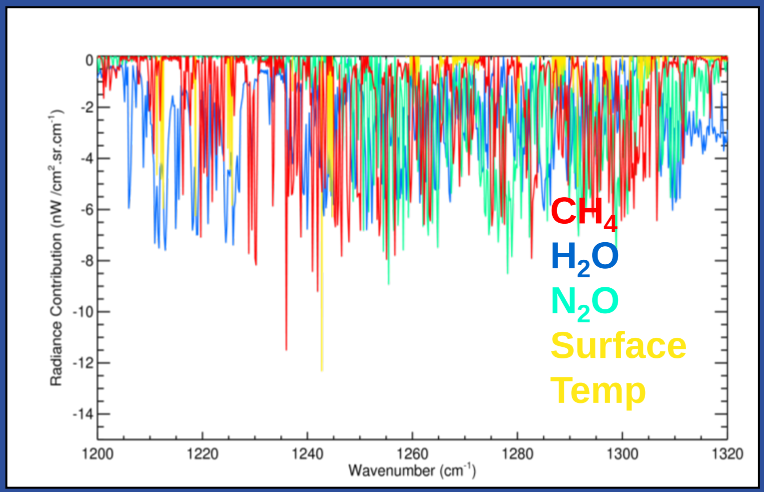
Methane A Priori Profiles

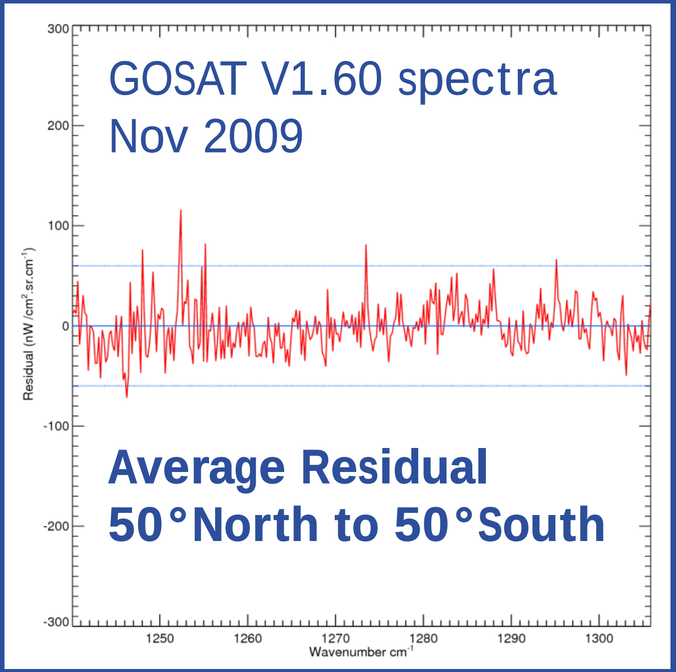


- A priori taken from MACC-II NOAA assimilation run
- Uses monthly mean TOMCAT stratospheric model run (University of Leeds) to improve stratospheric a priori stratospheric
- TOMCAT run is just monthly mean run
- MACC is daily and assimilates surface network
- TOMCAT has many more stratospheric level but constant troposphere
- MACC is coarse in stratosphere but has good troposphere
- Complement each other well
- Not massively dissimilar in stratosphere anyway
- Above 50 hPa we replace MACC profile with TOMCAT profile
- Weight the percentage of each profile for a smooth transition between the two

CH$_4$ spectral sensitivity in GOSAT band 4



Residual = real – simulated GOSAT spectra



- Degrees of freedom signal: 0.6 – 0.8 mid-latitude, 0.8 - 1.2 tropics
- Average chi-square ~ 1.2
- A posteriori error < 3%

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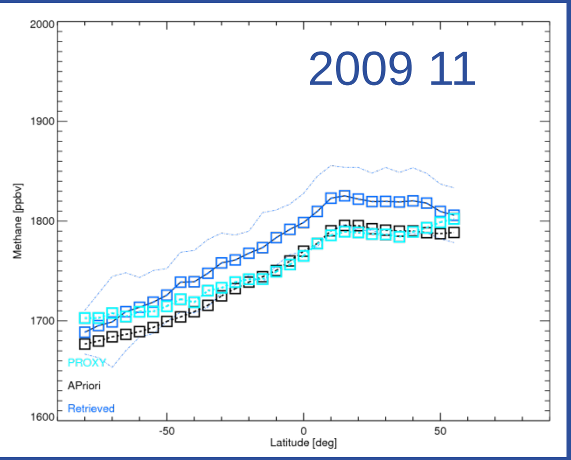
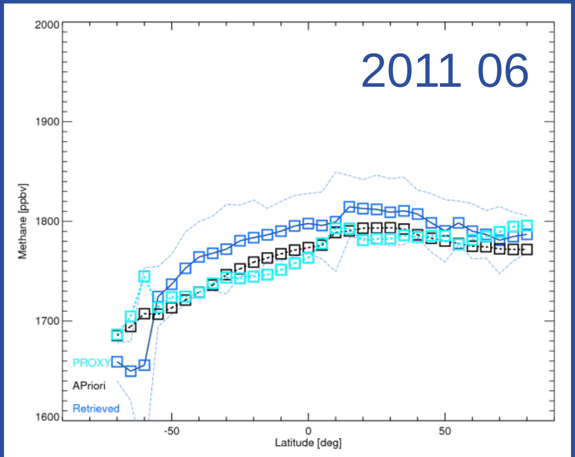
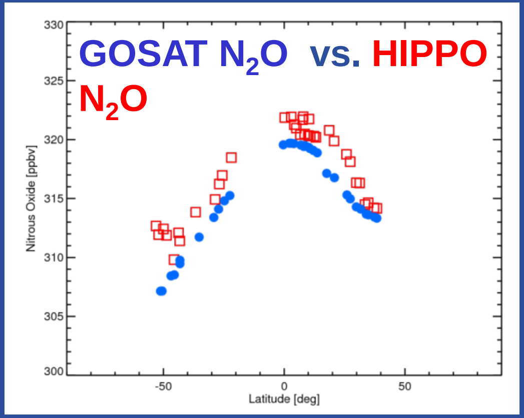
N2O Correction

- Razavi et al, (2009), Worden et al (2012) shown that TIR CH4 can benefit from proxy type N_2O correction
  - Minimise impact of systematic effects on retrieval (water vapour continuum, instrumental..)
  - Can assume errors affect CH4 also affect co-retrieved N2O
- “Proxy” type retrieval

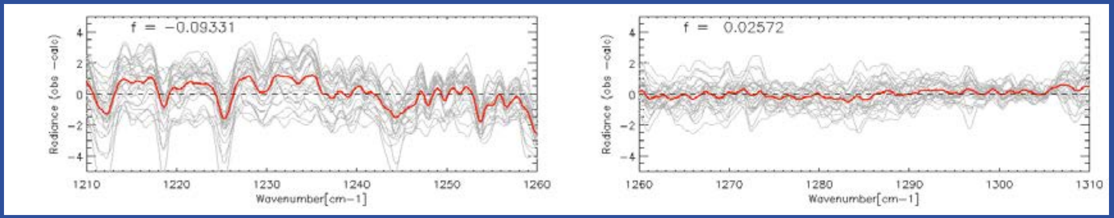
$$XCH_4 = \frac{\widetilde{XCH_4}}{\widetilde{XN_2O}} XN_2O$$



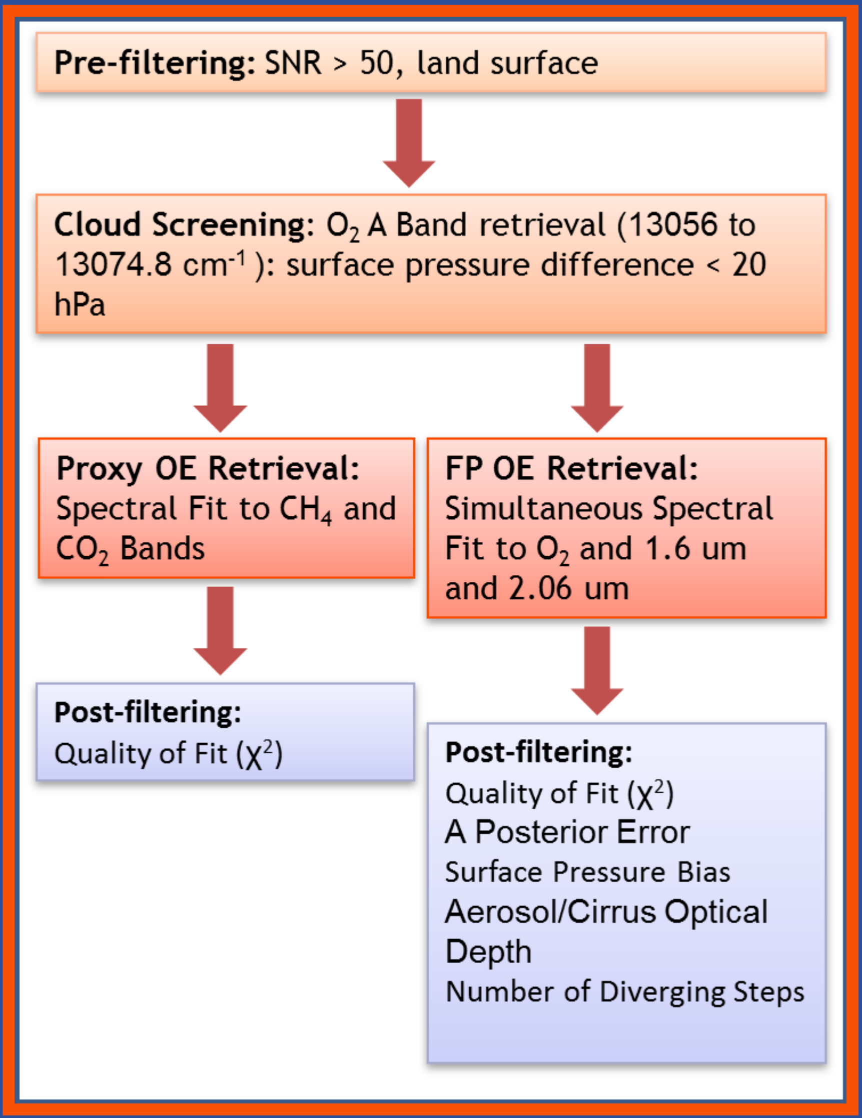




Kuze, A., 20150527



UoL GOSAT SWIR Retrieval

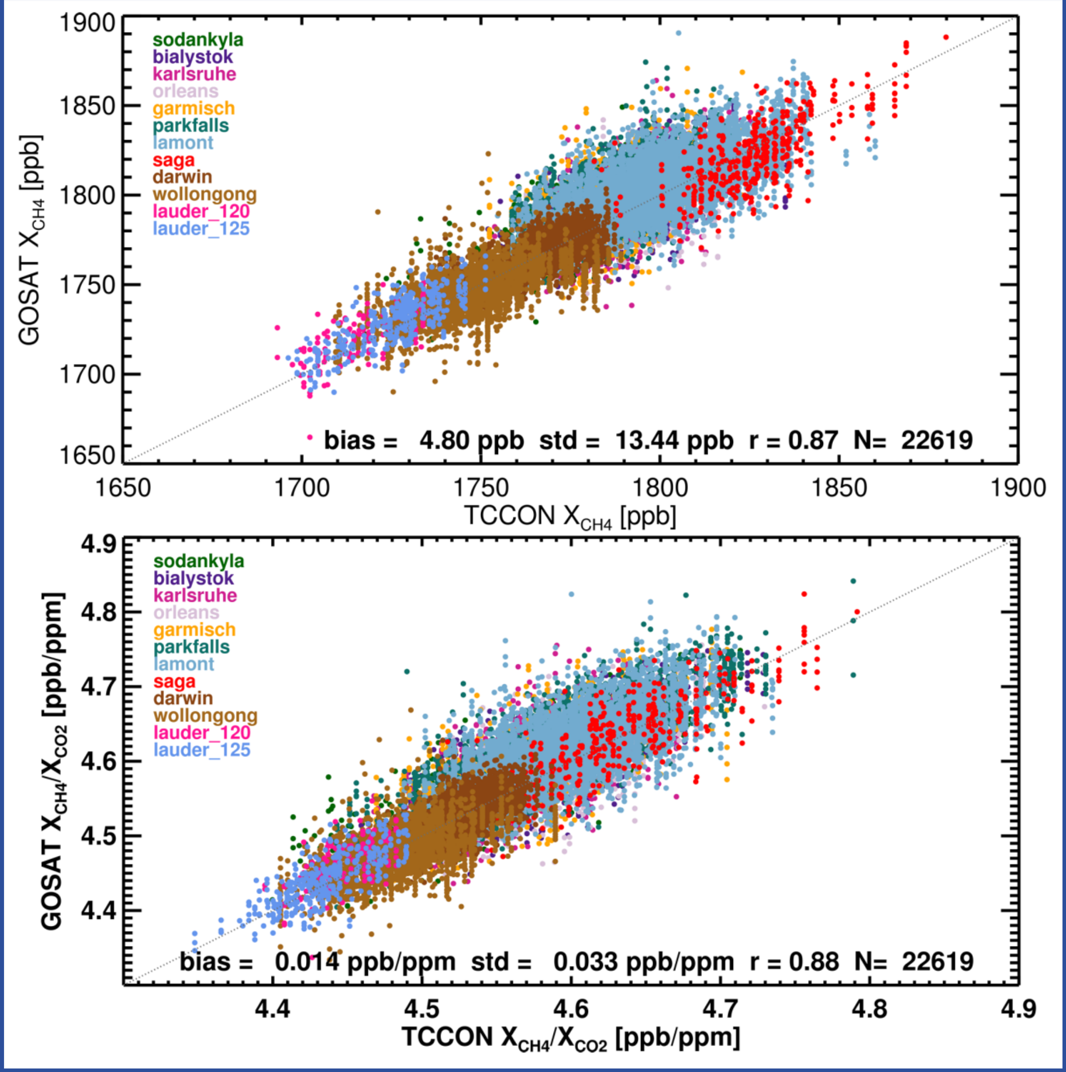


- **Algorithm:** OCO (ACOS) Full Physics Optimal Estimation algorithm
- **L1B files:**
  - Spectra and calibration provided by NIES/JAXA
  - Noise estimated from spectra
- **Full-Physics Retrieval:**
  - Fit to O_2 A Band, 1.61μm & 2.06μm bands
  - Retrieved parameters: CO_2, H_2O, CH_4, temperature, surface Pressure, albedo, dispersion, O_2 zero level offset, aerosol and cirrus
- **Proxy Retrieval (CH_4/CO_2):**
  - Fit to CO_2 Band at 1.61μm + 1.65 μm CH_4 Band
  - Retrieved parameters: CO_2 and CH_4, H_2O, temperature, albedo and dispersion
  - CO_2 acts as a “proxy” for the light-path and allows majority of scattering effects to ratio out.

Key Contacts: Robert Parker & Hartmut Boesch, Leicester, UK

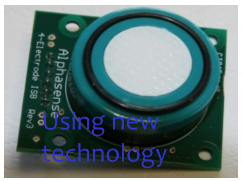
Validation Results

- Small bias of 4.8 ppb (0.27%)
- Single-sounding precision of 13.4 ppb (0.74%)
- The station-to-station bias (a measurement of the relative accuracy) is found to be 4.2 ppb
- For the first time the XCH_4 / XCO_2 ratio component of the Proxy retrieval is validated:
    - Bias of 0.014 ppb/ppm (0.3%)
    - Single-sounding precision of 0.033 ppb/ppm (0.72%).



Greenhouse gAs Uk and Global Emissions (GAUGE): Quantifying UK anthropogenic GHG emissions

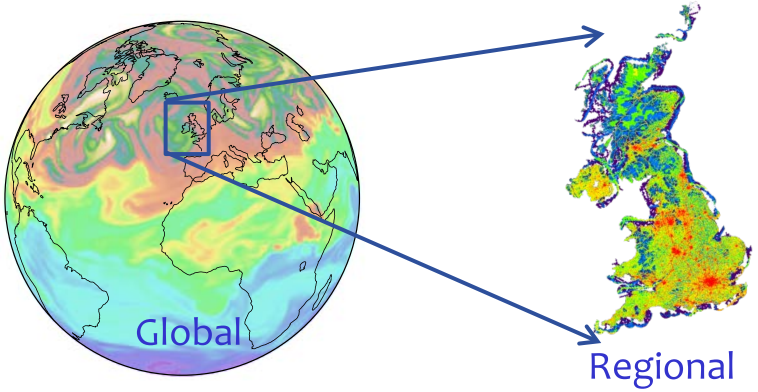
Inter-calibrated atmospheric GHG measurements



From the ground

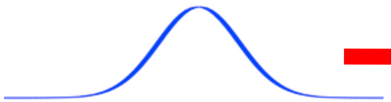
Old
New
Isotopes

Cutting-edge models of atmospheric transport



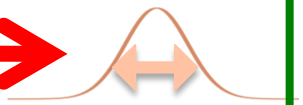
Using the world-class meteorological analyses and the latest prior emission inventories

Estimating posterior emissions by combining measurements and models



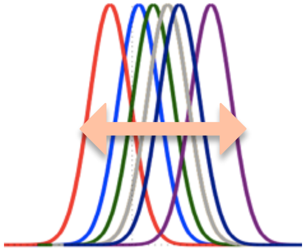
Inputs: 1) Measurements and uncertainty and 2) prior emissions uncertainty

Single model inversion



Output: Posterior emission estimates and uncertainty

Facilitating better decisions: ensemble of emissions estimates provide uncertainty



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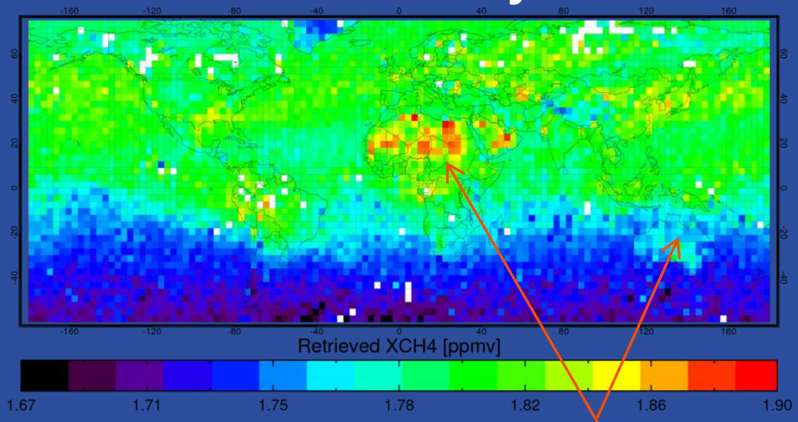
XCH4: Emissivity effects

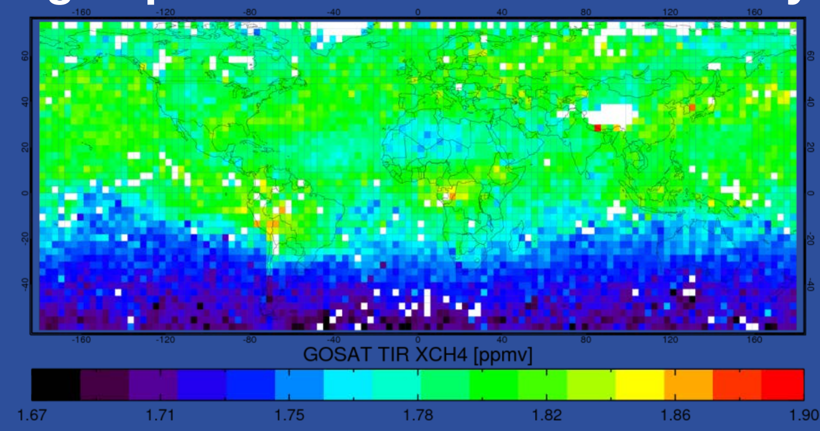
- UOL GOSAT TIR retrieval: V1.01 used CIMSS baseline emissivity database. Updated to high spectral resolution emissivity database (Knuteson, Borbas et al.)

Baseline Emissivity



Emissivity effects

High spectral Resolution Emissivity



- Most significant improvements observed: Saharan desert, Australia

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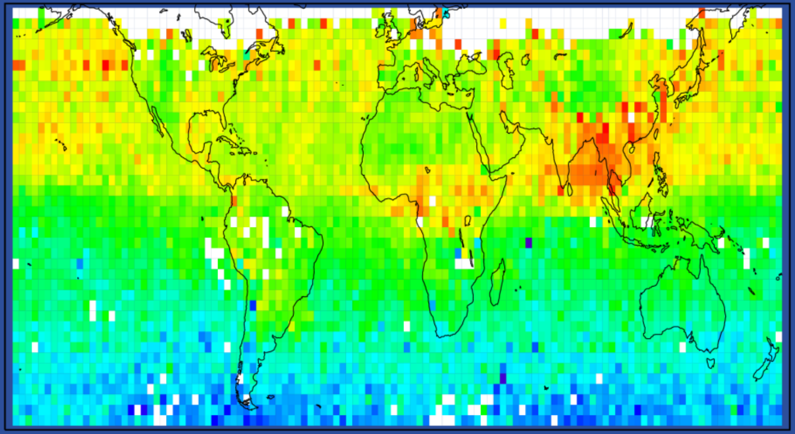
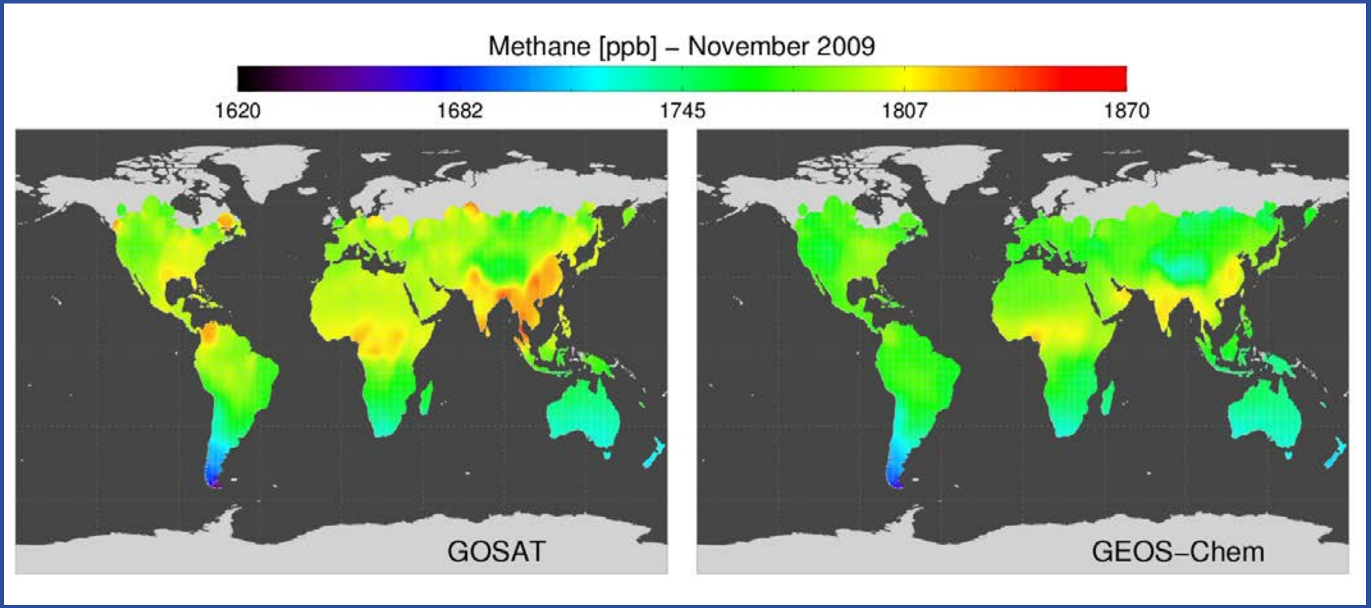
Cloud Filtering

Mn	CAI Cloud Fraction	SWIR Delta PSURF [hPa]	SWIR Clouds Hit [%]	SWIR Clear pixels Hit [%]	SWIR Missed Cloud [%]	SWIR False Alarm [%]	TIR Clouds Hit [%]	TIR Clear pixels Hit [%]	TIR Missed Cloud [%]	TIR False Alarm [%]
03	0.2 - 1.0	30.0	80.9	71.9	19.1	28.0	78.5	81.3	21.5	18.6
04	0.2 – 1.0	30.0	83.3	70.3	16.0	29.0	83.8	82.3	16.1	17.7
05	0.2 – 1.0	30.0	88.3	71.1	11.0	28.9	86.1	83.8	13.9	16.2
06	0.2 – 1.0	30.0	94.3	72.8	5.7	27.1	88.2	84.0	11.8	16.0
07	0.2 – 1.0	30.0	95.8	73.2	4.10	26.2	88.3	84.9	11.6	15.0

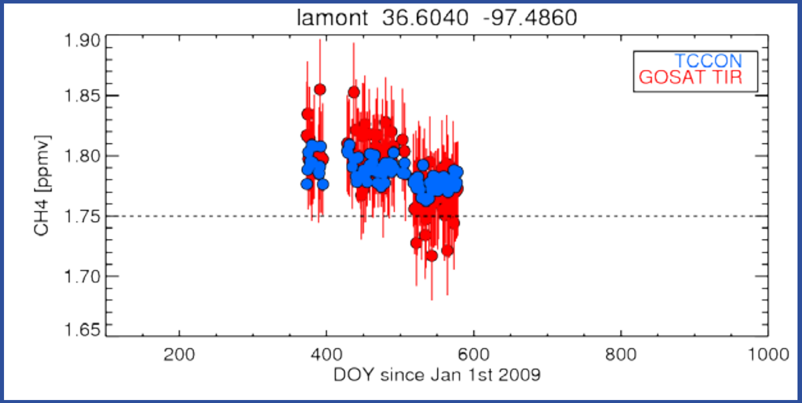
Inter-comparison of SWIR cloud mask and TIR cloud Mask vs. CAI cloud mask

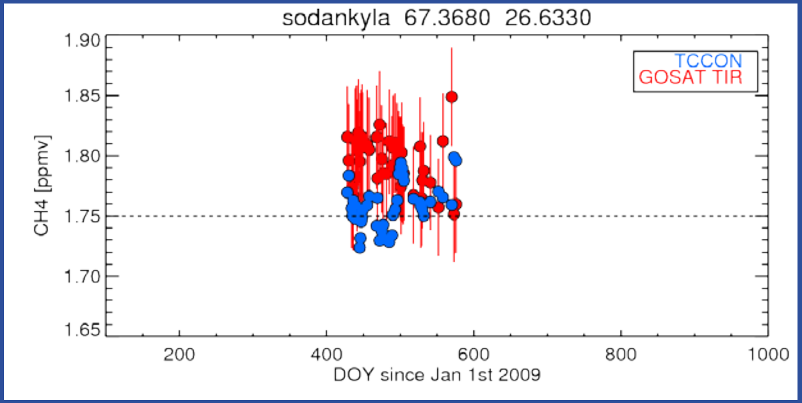
XCH4: GOSAT TIR vs. GEOS-Chem (Edinburgh)

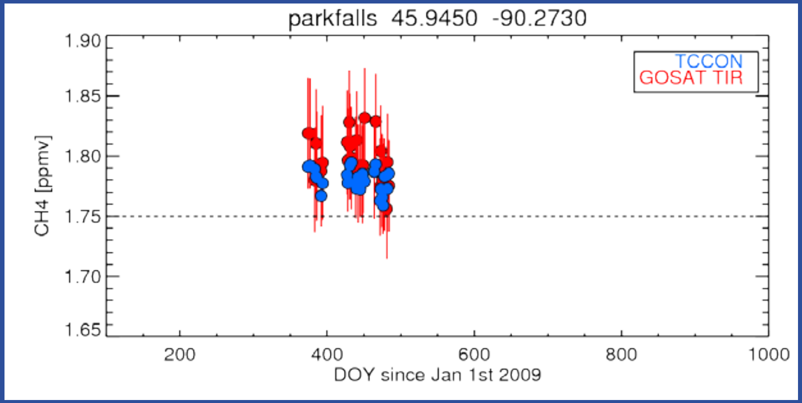


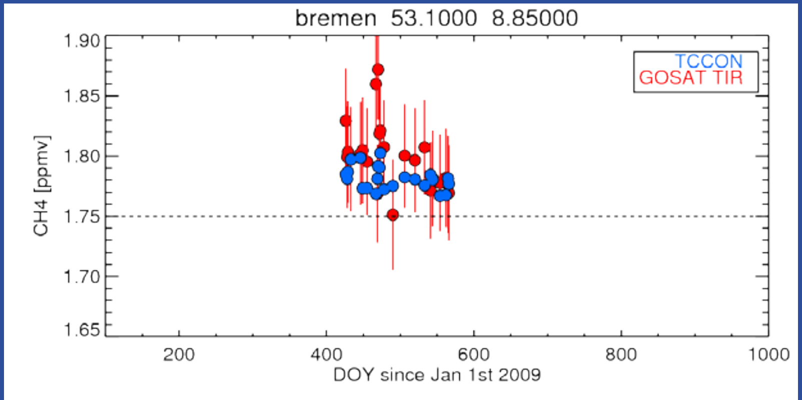


XCH4: GOSAT TIR vs TCCON









Vertical Cross Section: GOSAT TIR – TM5