Ground based remote sensing of greenhouse gases – recent developments and their use for model- and satellite validation

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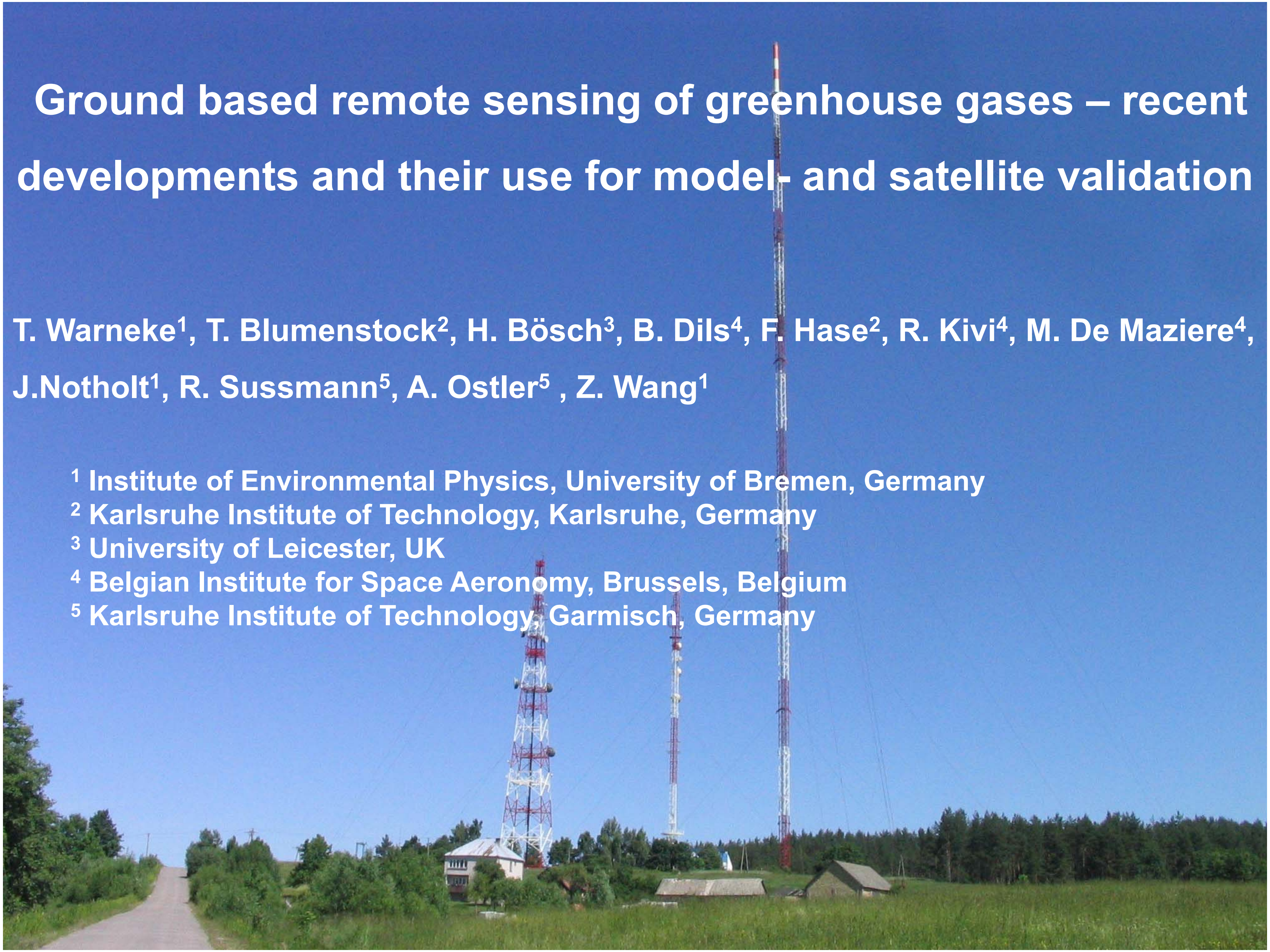
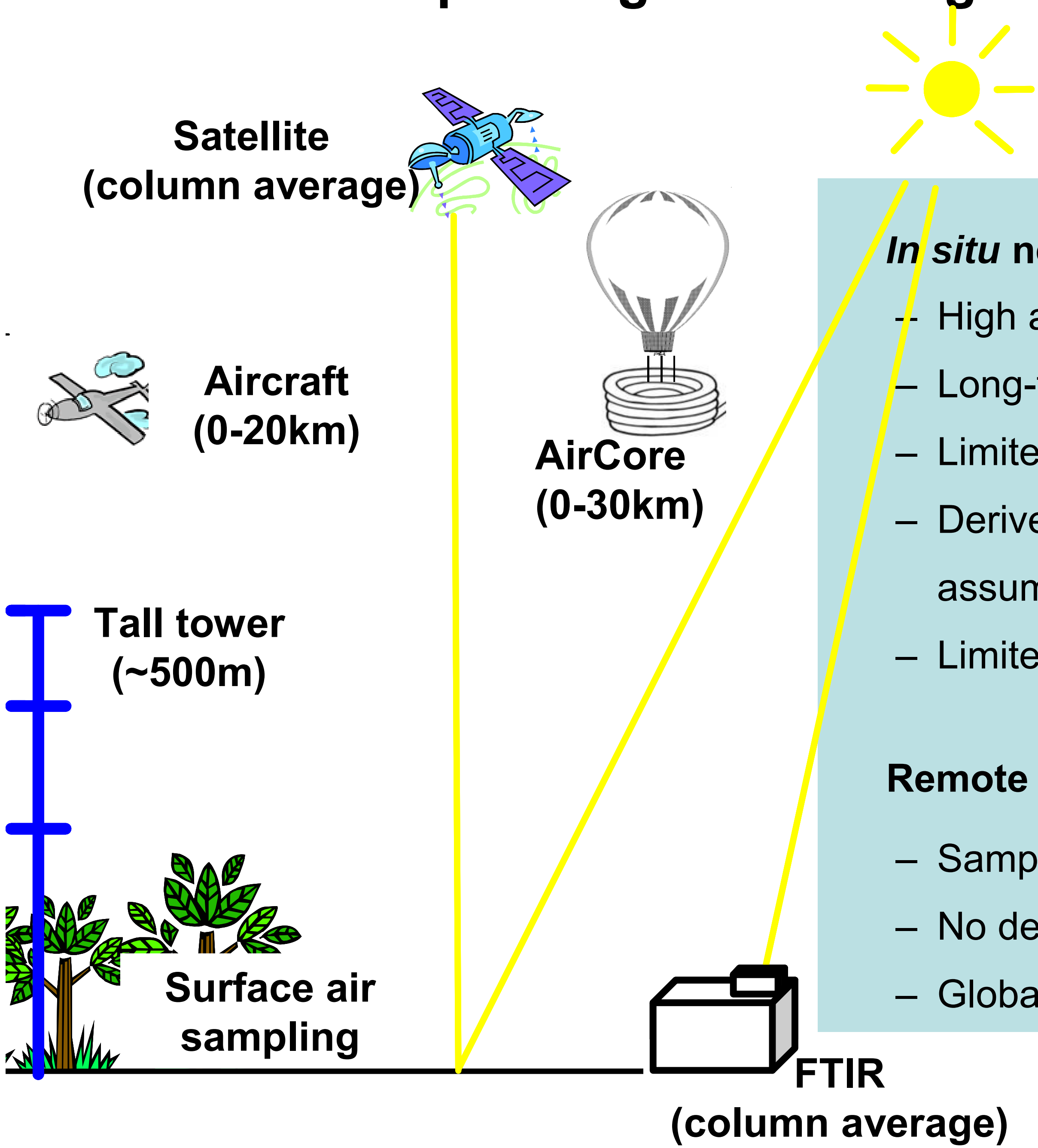


Atmospheric greenhouse gas observations



***In situ* network**

- High accuracy
- Long-term data record
- Limited spatial coverage
- Derived fluxes are sensitive to assumed vertical transport
- Limited usefulness for satellite validation

Remote sensing measurements

- Sample the whole atmosphere
- No dependency on vertical mixing
- Global coverage provided by satellites

Ground based solar absorption FTIR-spectroscopy

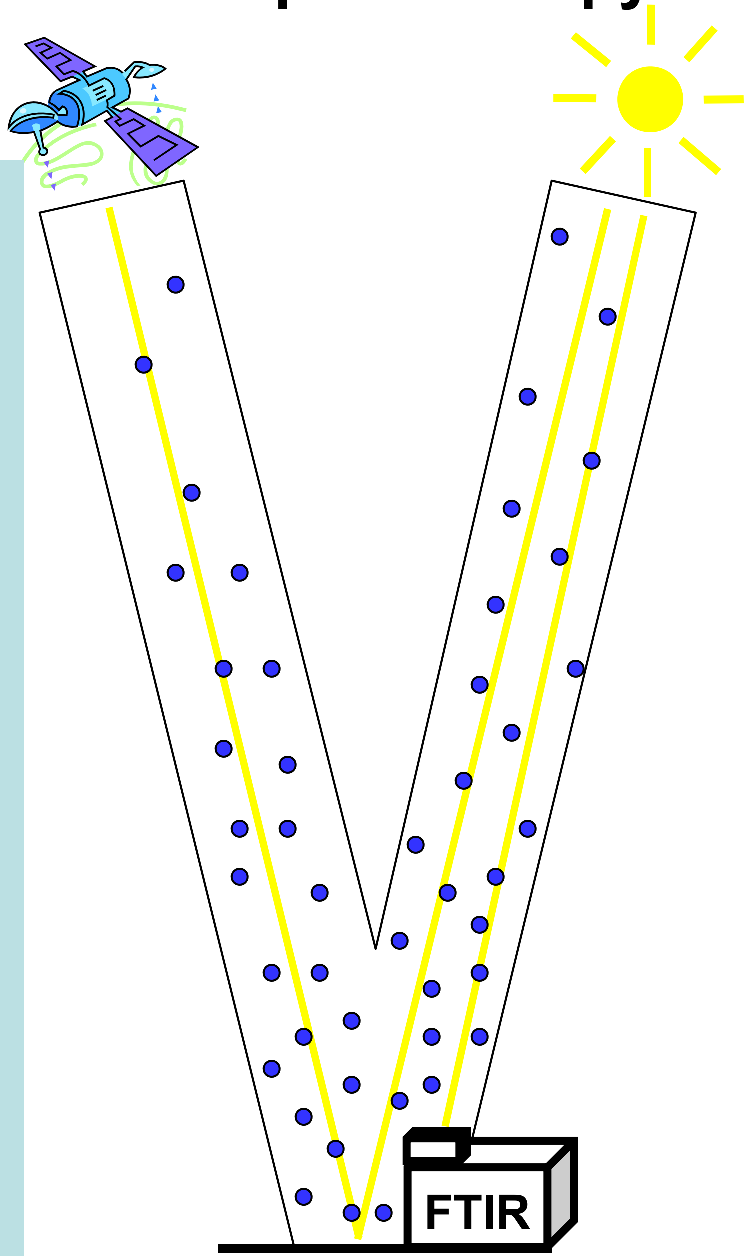
Solar absorption FTIR-spectrometry

- is the only ground-based remote sensing technique that has demonstrated the required precision
- measure the same quantity as the satellites but do so at a fixed point making it amenable to direct comparison with aircraft

→ Calibrate satellite retrievals against the existing in situ measurements

- shows a very good instrumental comparability

→ Global network of FTIR spectrometers (TCCON) is able to detect a spatial bias and/or temporal drift in the satellite data



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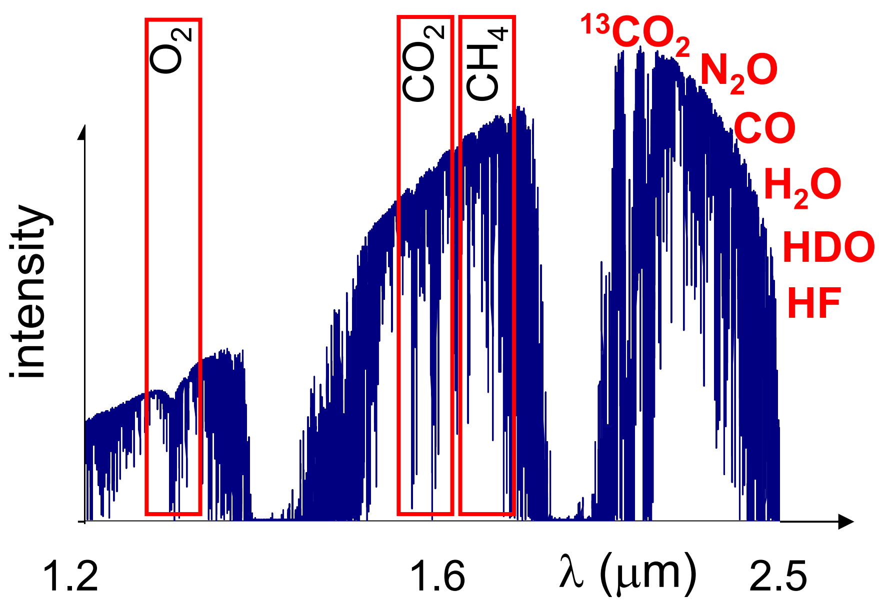
TCCON data product



Near-IR spectral region

- Less interferences than in the mid-IR
- Contains O_2, which can be used as an internal standard
- Same spectral region as satellites with high sensitivity to the ground (GOSAT, OCO-2)

TCCON data product (column scaling, software Gfit):

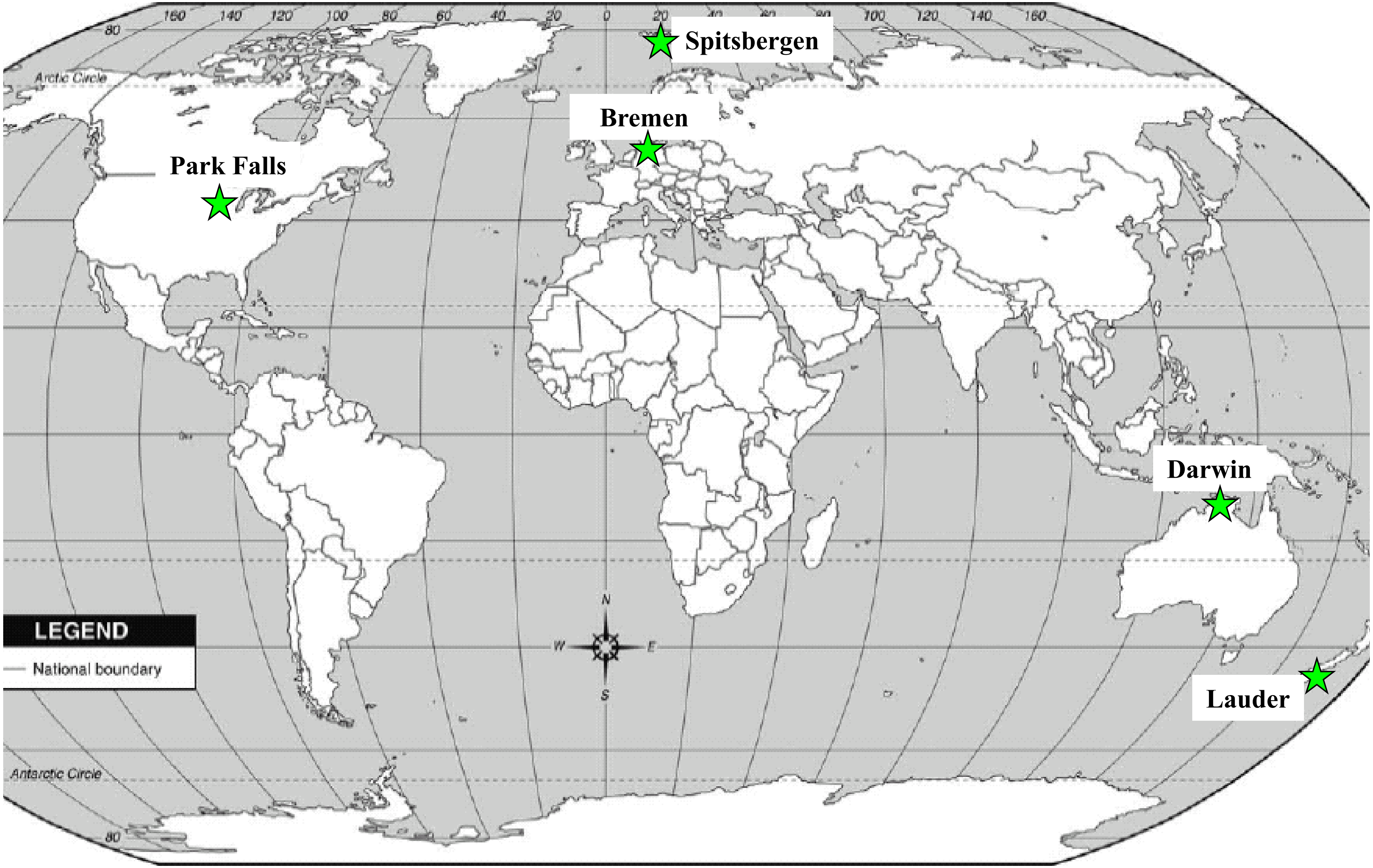
1) Division by O_2 column. $XCO_2 = 0.2095 * CO_2\text{-column} / O_2\text{-column}$
   Partial cancellation of systematic errors (e.g. ILS, surface pressure, H_2O, …)

2) Correction for airmass-dependent biases (spectroscopy)
   - Causes: Errors in the line widths, no line-mixing, etc
   - Common to all instruments

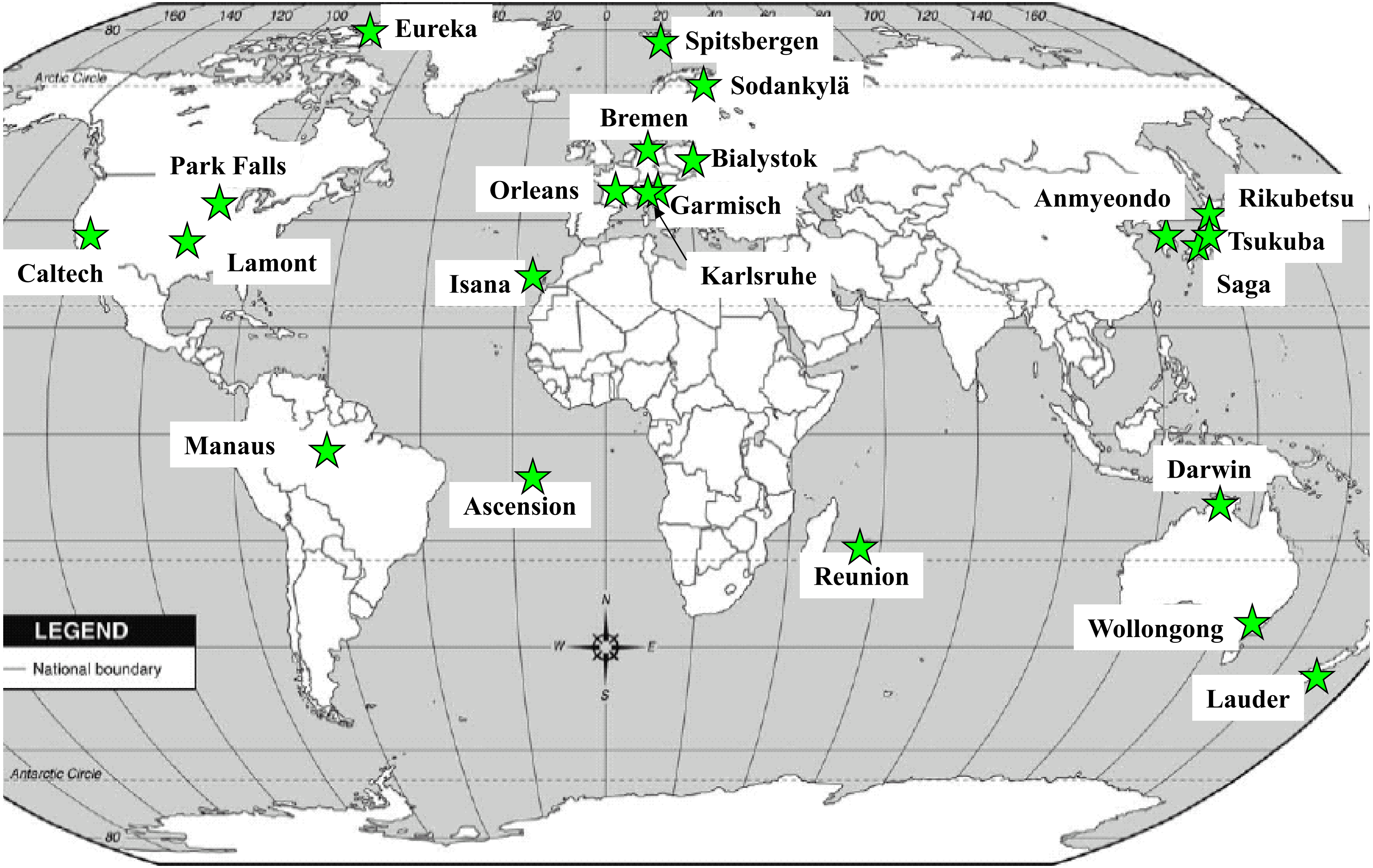
3) Correction for „Ghosts“ (older spectra)

4) Correction for bias with respect to in situ measurements based on comparisons with in situ profiling using instrumentation linked to WMO standards.

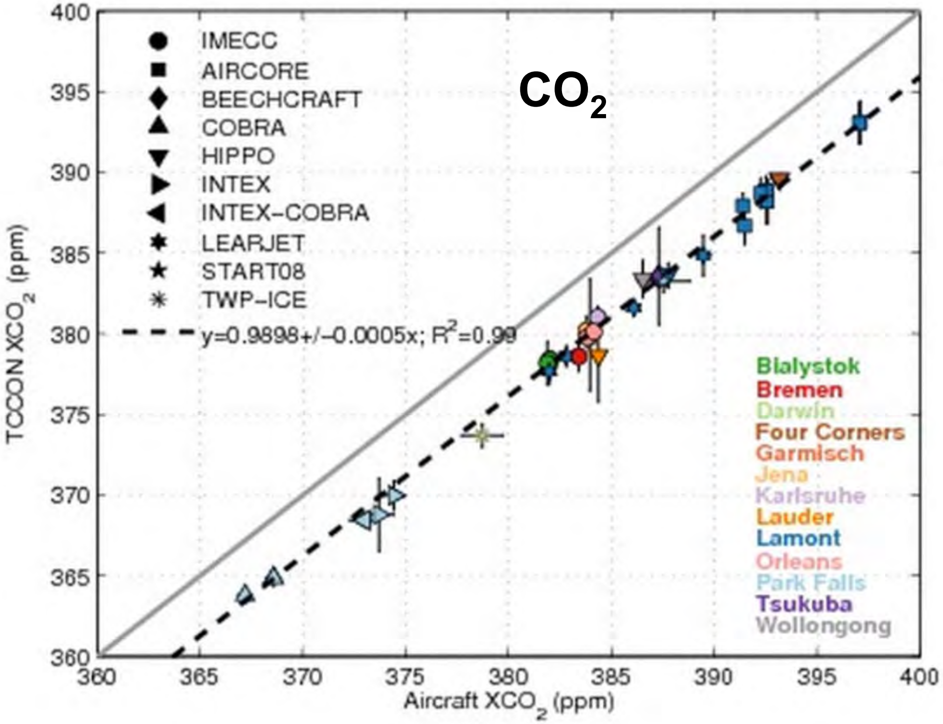
Total Carbon Column Observing Network (TCCON) in 2005

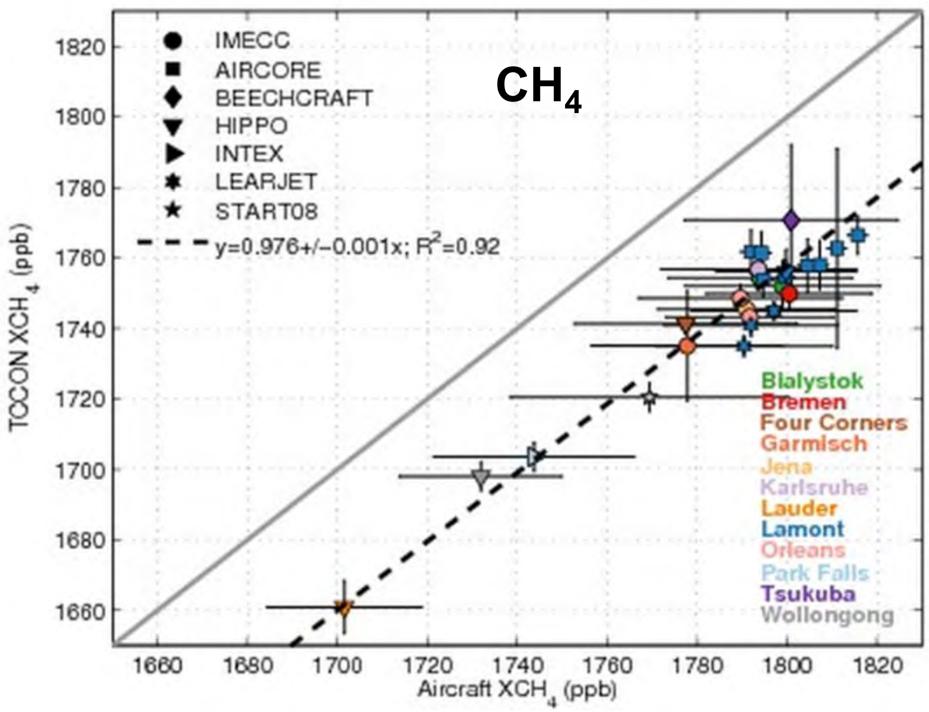


Total Carbon Column Observing Network (TCCON) in 2015



TCCON calibration by *in situ* measurements





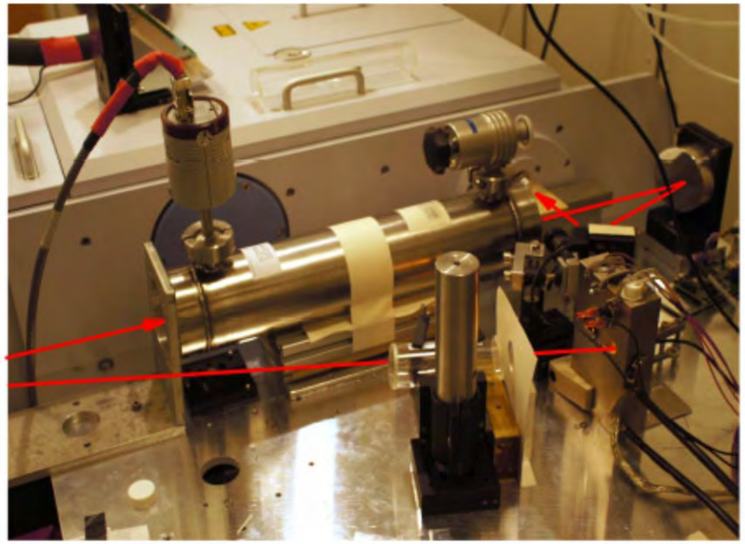
Courtesy of Geoff Toon, NASA-JPL

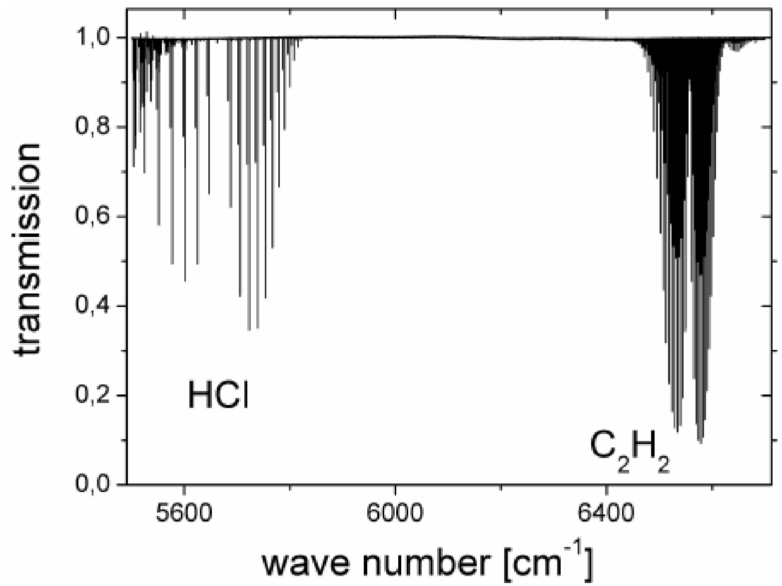
2 σ standard error by comparison with in situ profiles

CO_2: 0.8 ppm
CH_4: 7 ppb
N_2O: 3 ppb
CO: 4 ppb

Improving network consistensy

1) Monitoring of the instrumental line shape of the FTIR-spectrometers





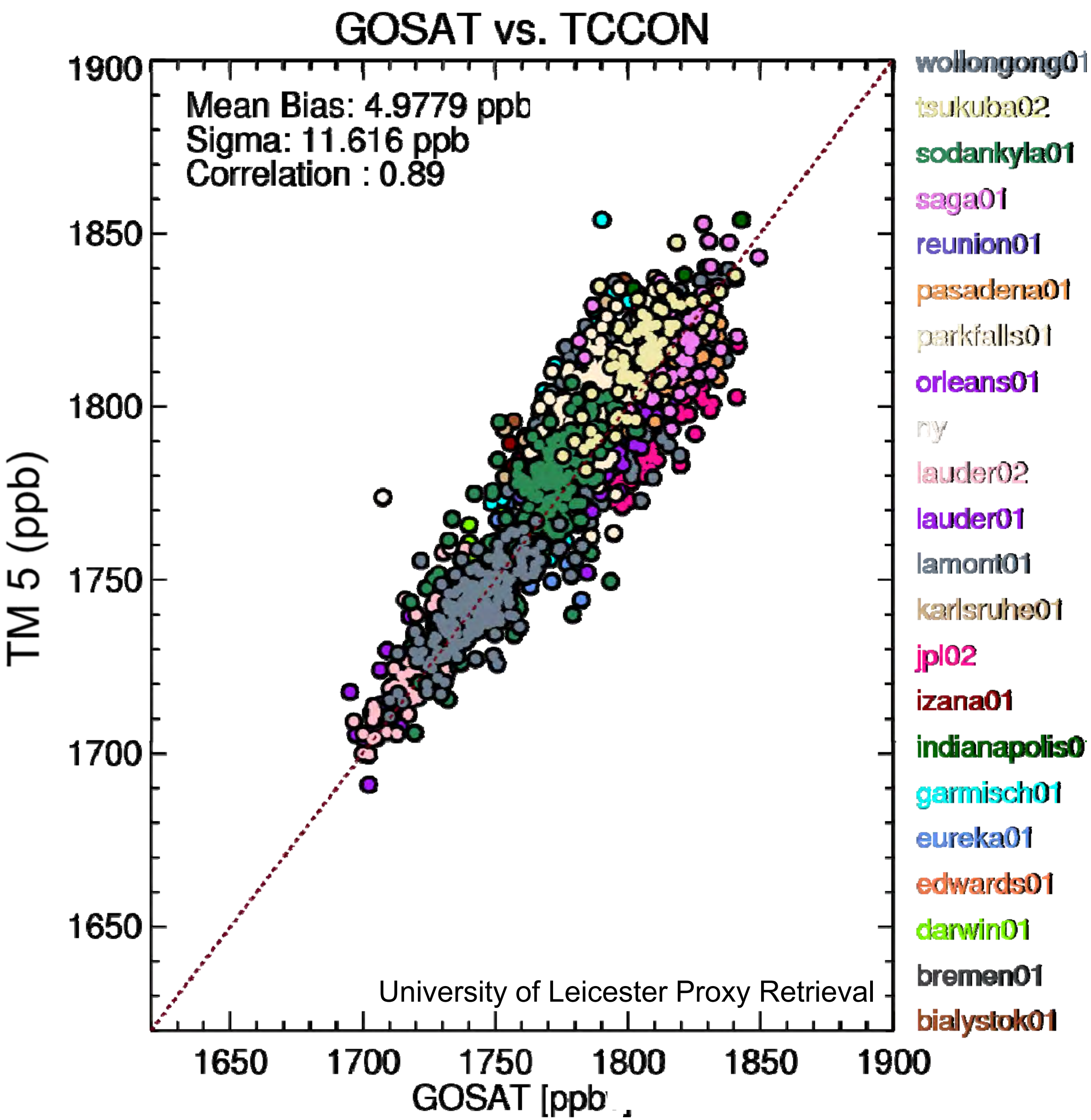
Regular calibration of gas cells ensures consistent characterisation of the instruments, reducing the instumental bias to below 0.05% for XCH_4. (InGOS-activity, which is now adapted by most sites globally)

2) Comparison of the retrieved O_2 mole fractions

3) Future: Travelling instrument

(Hase et al., 2013)

Satellite validation



Tropospheric XCH_4

Stratosphere:

A linear relationship exists between CH_4 and N_2O.

Troposphere:

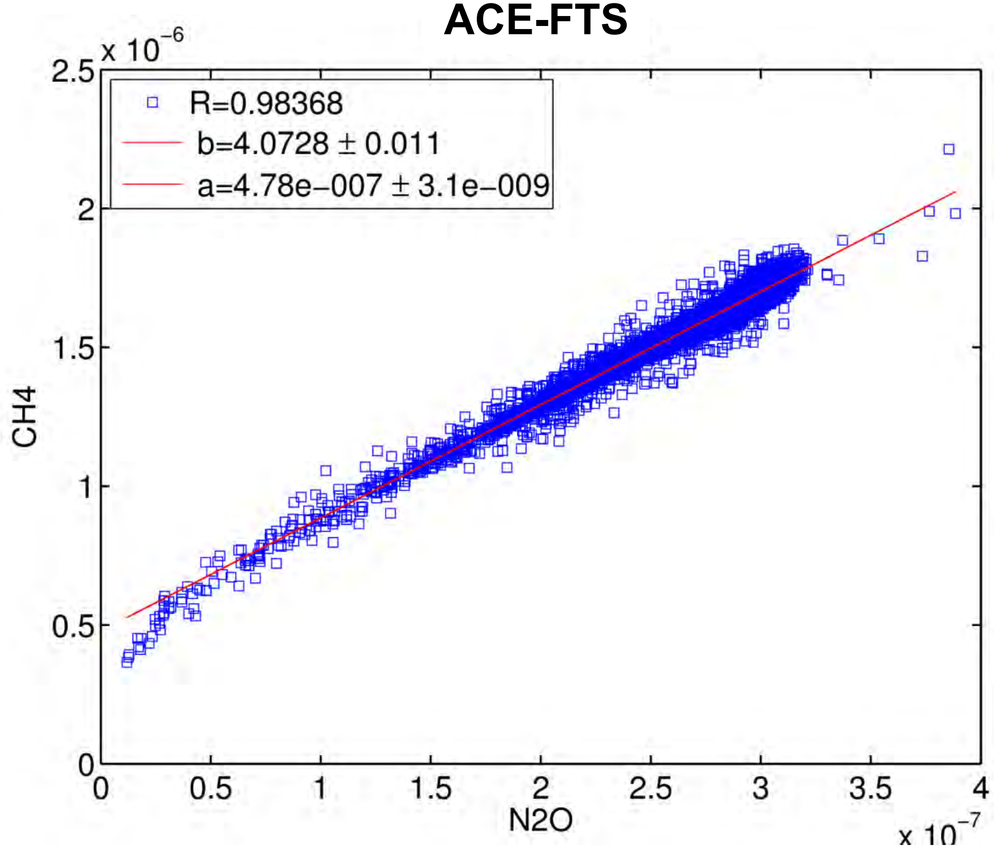
N_2O is quite uniform and predictable within about 2 ppb except for regions with significant sources.

Subtracting the tropospheric N_2O from the total column of N_2O allows to derive a stratospheric N_2O column.

The stratospheric CH_4 is calculated based on the stratospheric N_2O and , the CH_4 – N_2O correlation in the stratosphere.

Tropospheric CH_4 is then the total CH_4 column minus it's the stratospheric CH_4.

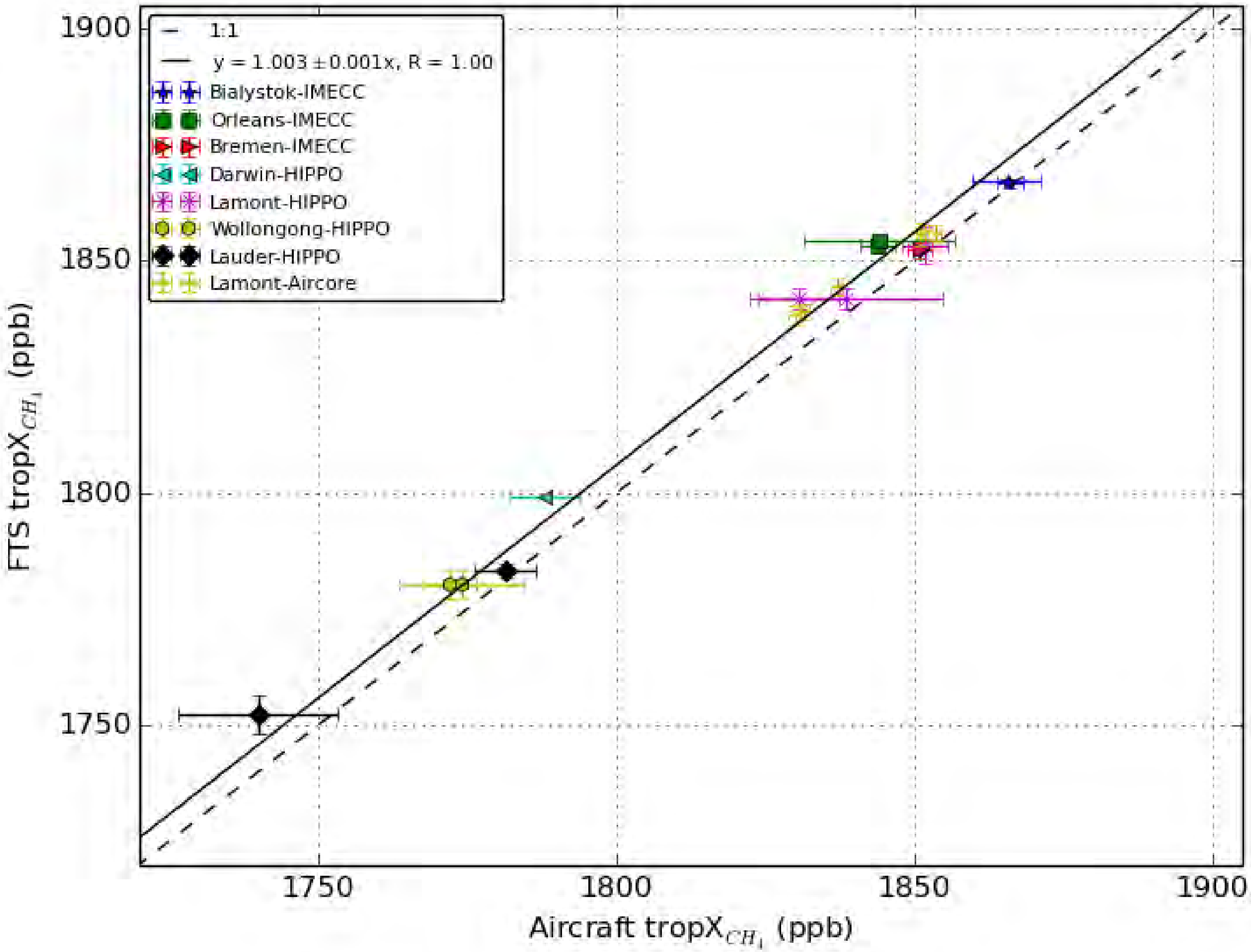
ACE-FTS



The tropospheric XCH_4 is not a TCCON dataproduct, but available via the InGOS project.

(Wang et al., 2014)

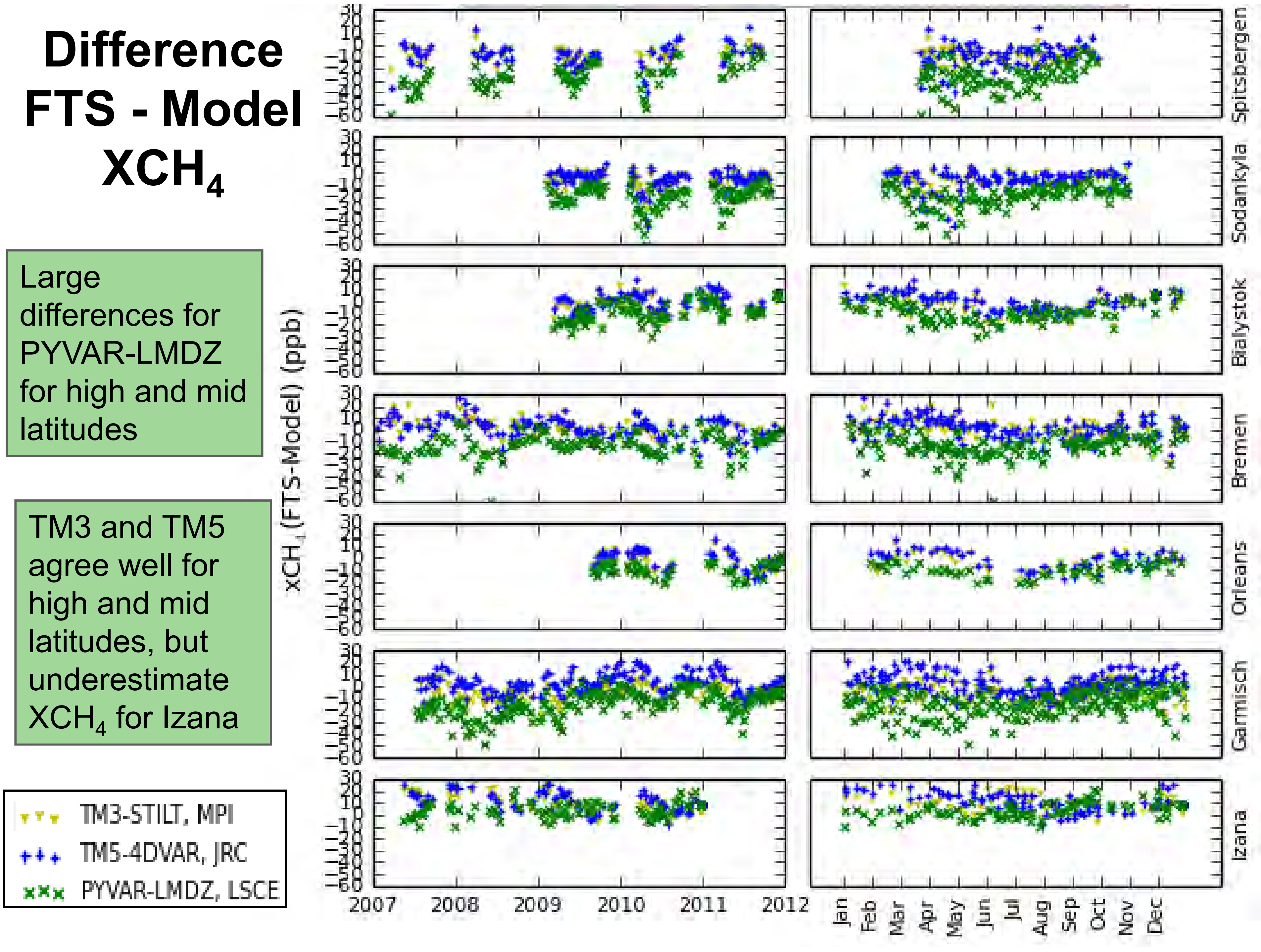
Calibration of tropospheric XCH_4



Difference FTS - Model XCH_4

Large differences for PYVAR-LMDZ for high and mid latitudes

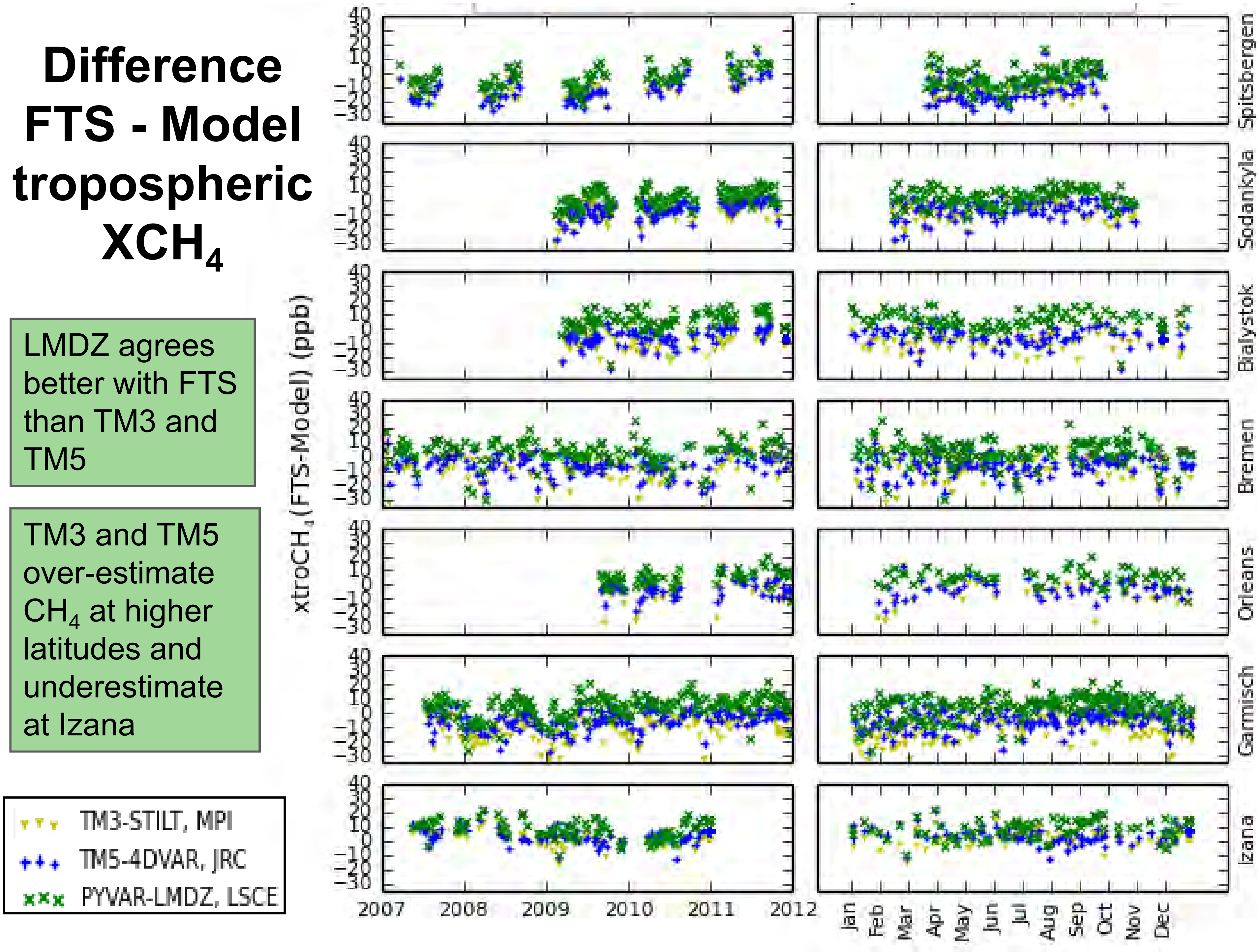
TM3 and TM5 agree well for high and mid latitudes, but underestimate XCH_4 for Izana



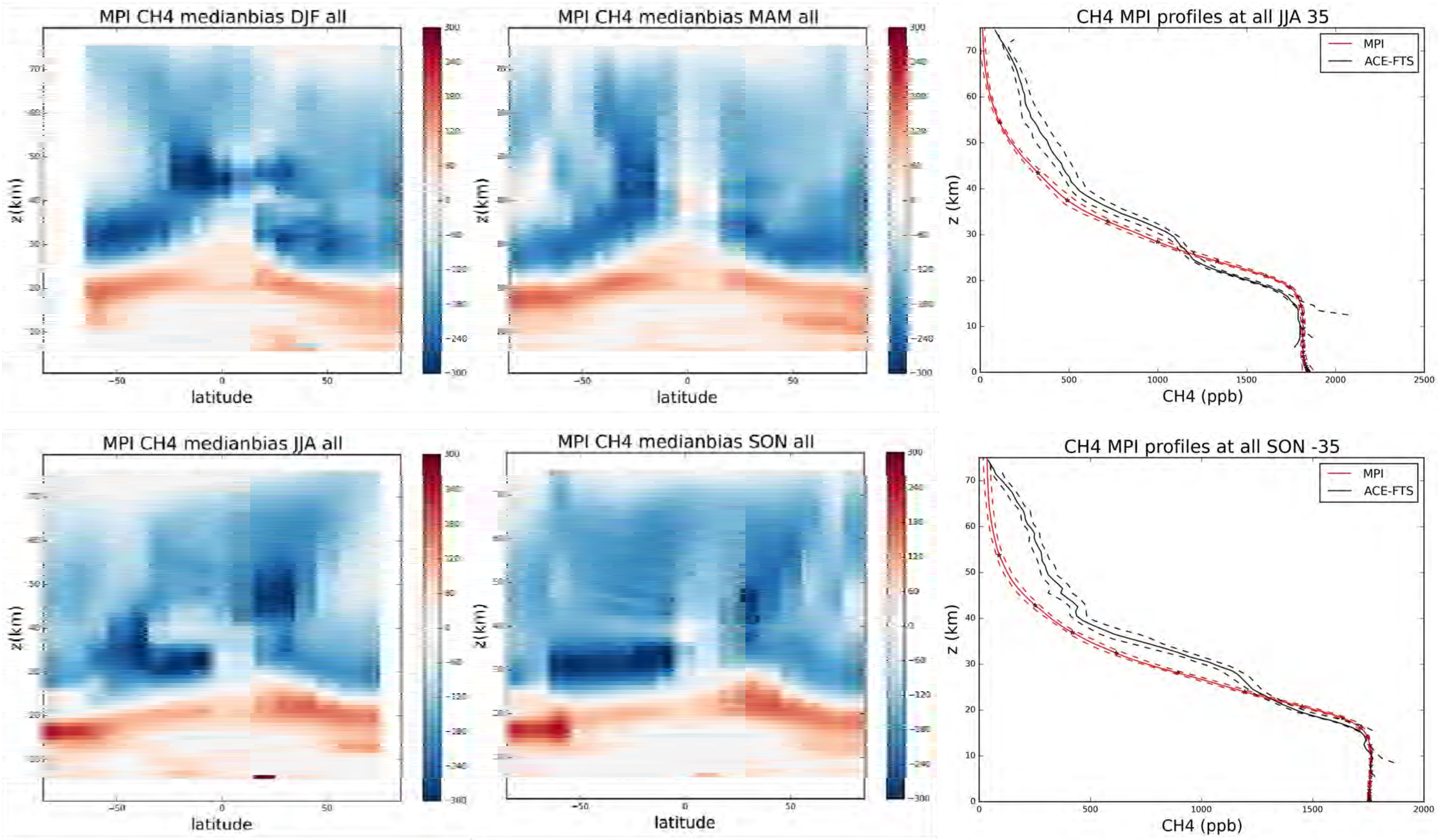
Difference FTS - Model tropospheric XCH_4

LMDZ agrees better with FTS than TM3 and TM5

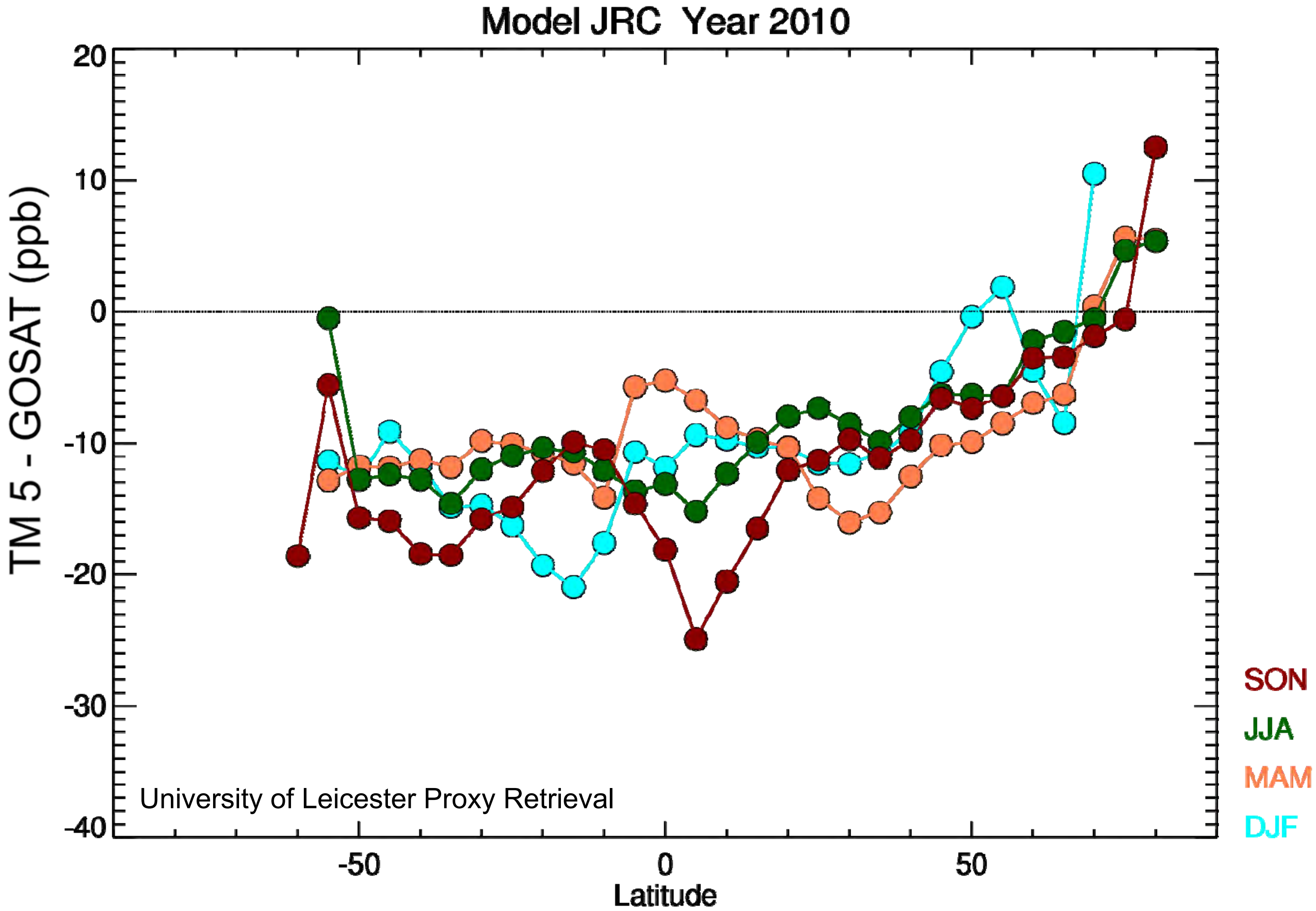
TM3 and TM5 over-estimate CH_4 at higher latitudes and underestimate at Izana



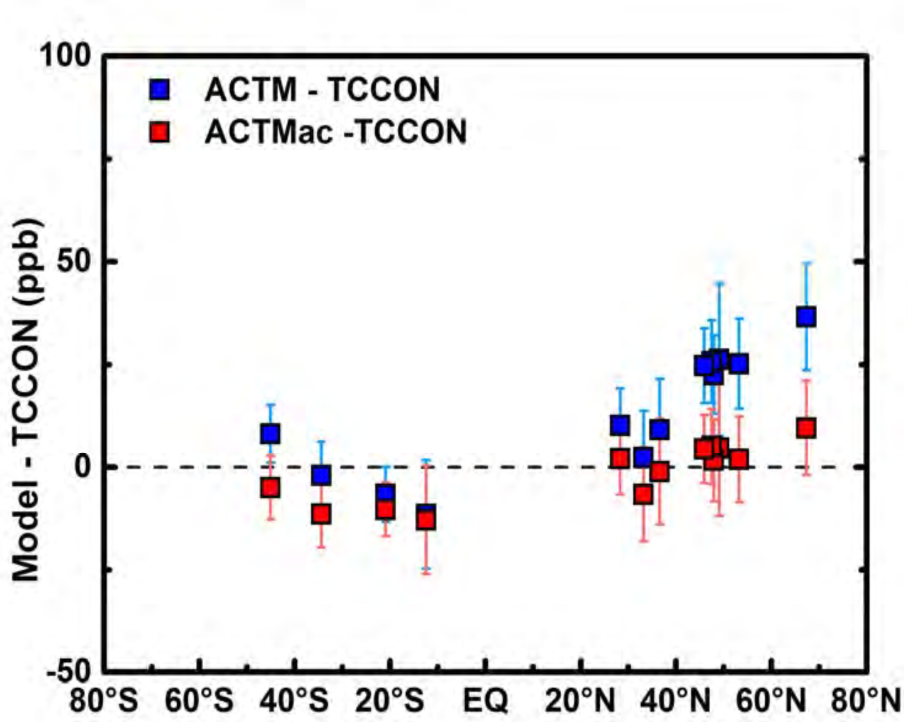
Differences between TM3 and ACE-FTS

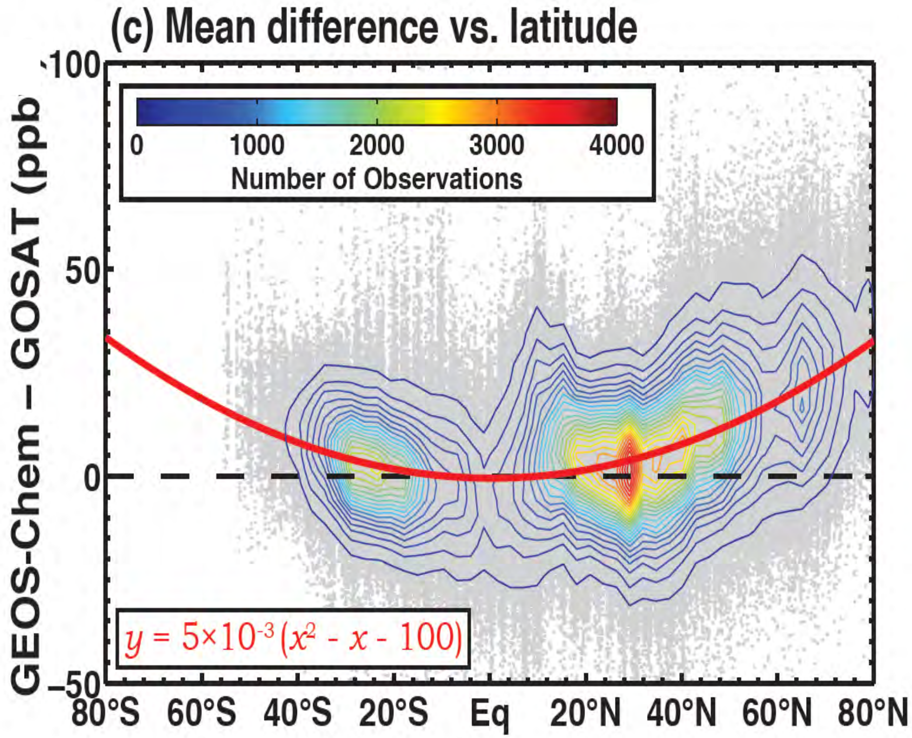


Latitudinal pattern of TM5 - GOSAT



Imprint of stratospheric transport on column-averaged methane

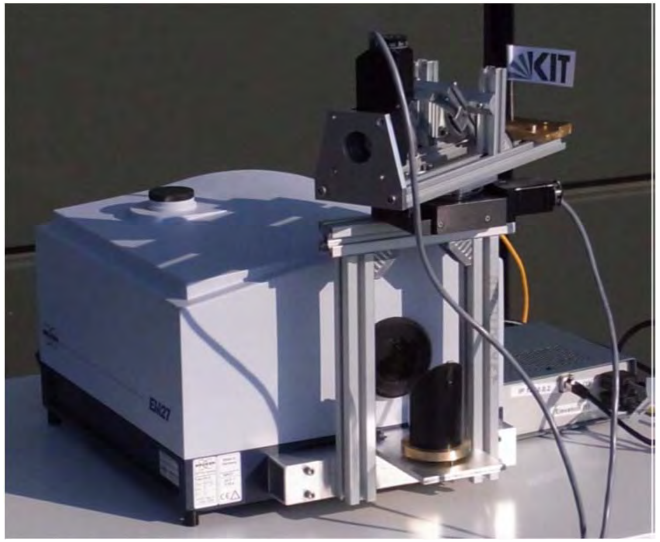




from Turner et al., ACP (2015)

(Ostler et al., 2014) talk in the inverse modelling session

Collaborative Carbon Column Observing Network (COCCON)
(Initiative by the Karlsruhe Institute of Technology)



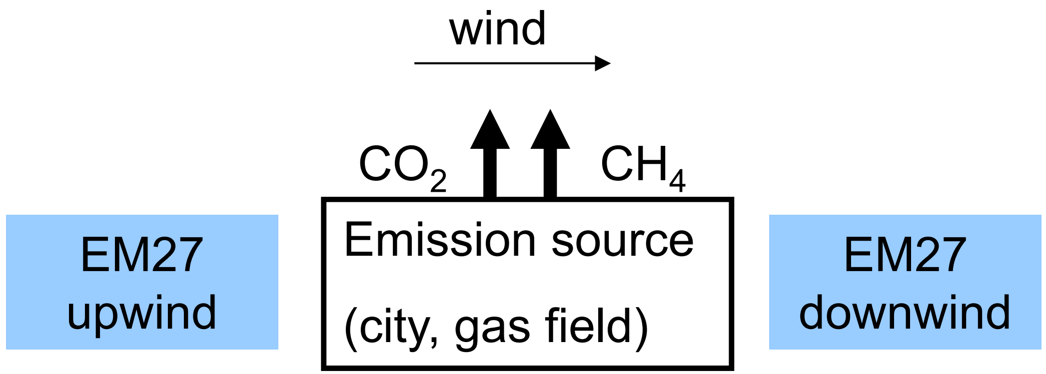
EM27 solar absorption spectrometer

- small portable spectrometer
- resolution 0.5 cm^{-1} (TCCON 0.02 cm^{-1})
- calibration by side-by-side compaison with TCCON

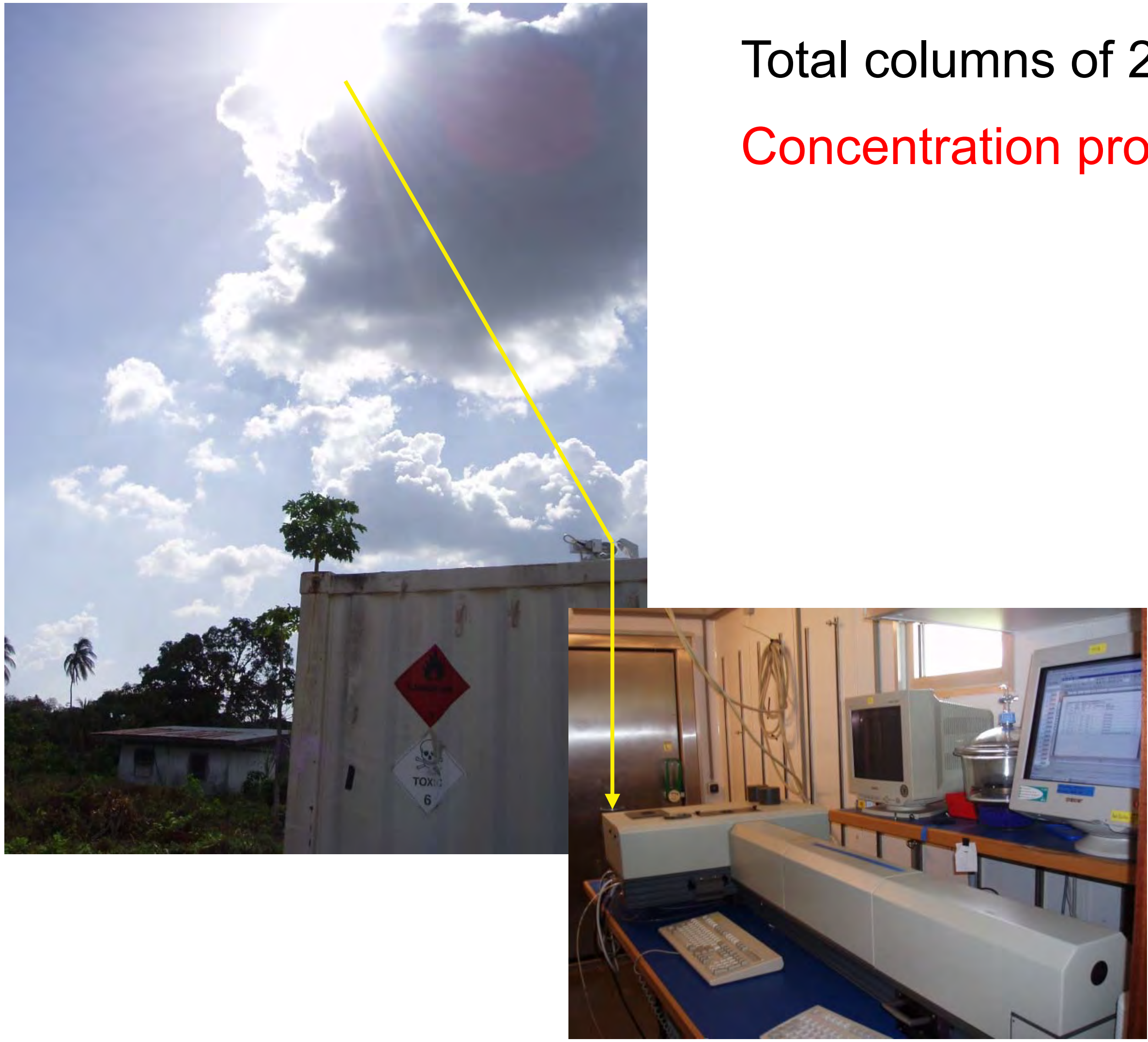
1) Complementing TCCON

- tropics
- low / high surface albedo
- short term campaigns
- moving platforms (e.g. ships)

2) Quantify emissions by column budgeting



Solar absorption measurements in the mid-IR (NDACC)



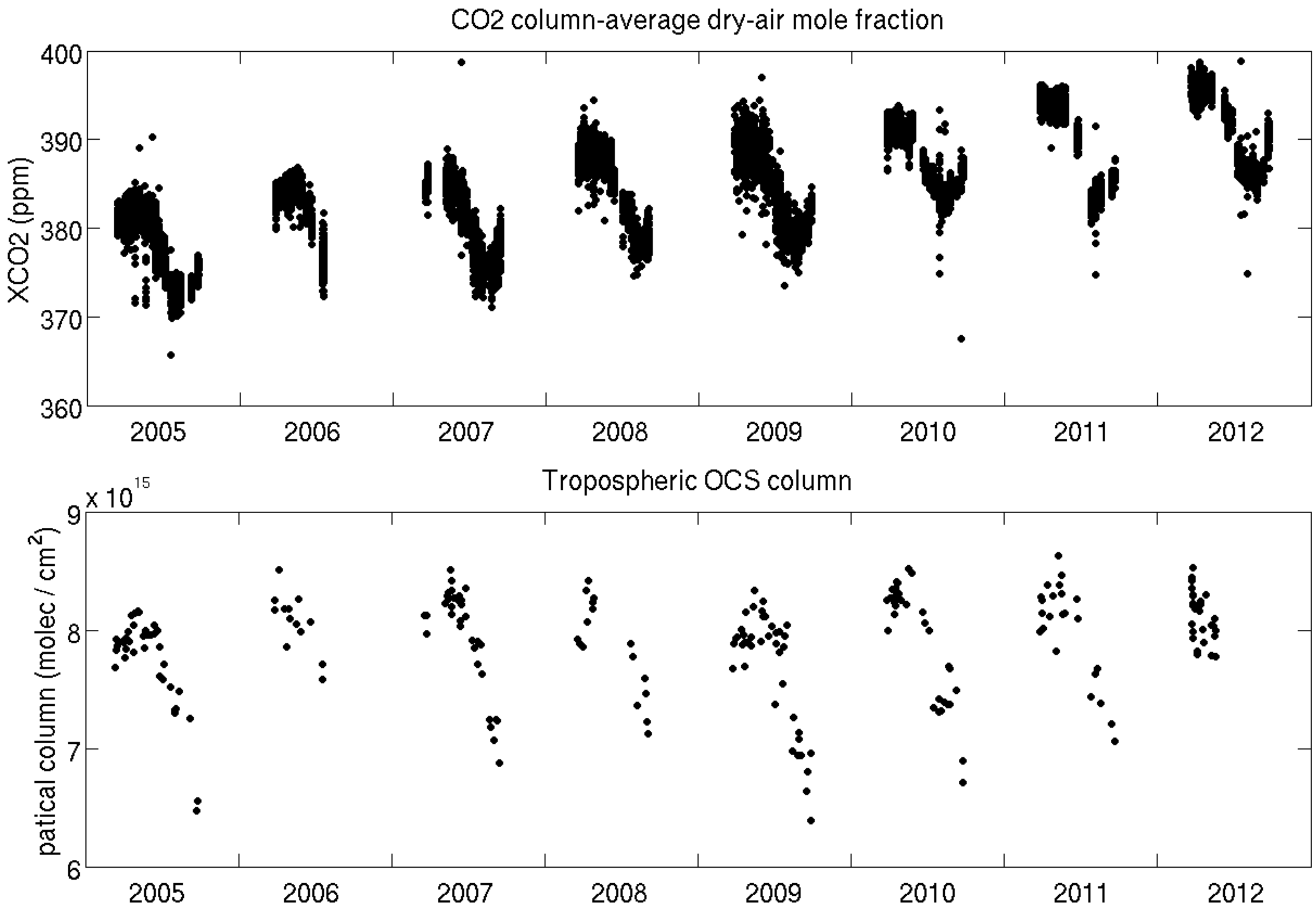
Total columns of 20-30 trace gases

Concentration profiles

1. constant
   N_2 , O_2
2. long lived
   CO_2, N_2O, CH_4,
   CFC-11, CFC-12, CFC-22
3. troposphere
   C_2H_2, C_2H_6, CH_2O, CO,
   HCN, OCS, SF_6, NH_3, H_2O
4. stratosphere
   O_3, HCl, ClO, $ClONO_2$,
   HNO_3, NO_2, NO, COF_2

Several additional gases of interest for the carbon cycle

Combination TCCON - NDACC, e.g. tropospheric OCS



Summary

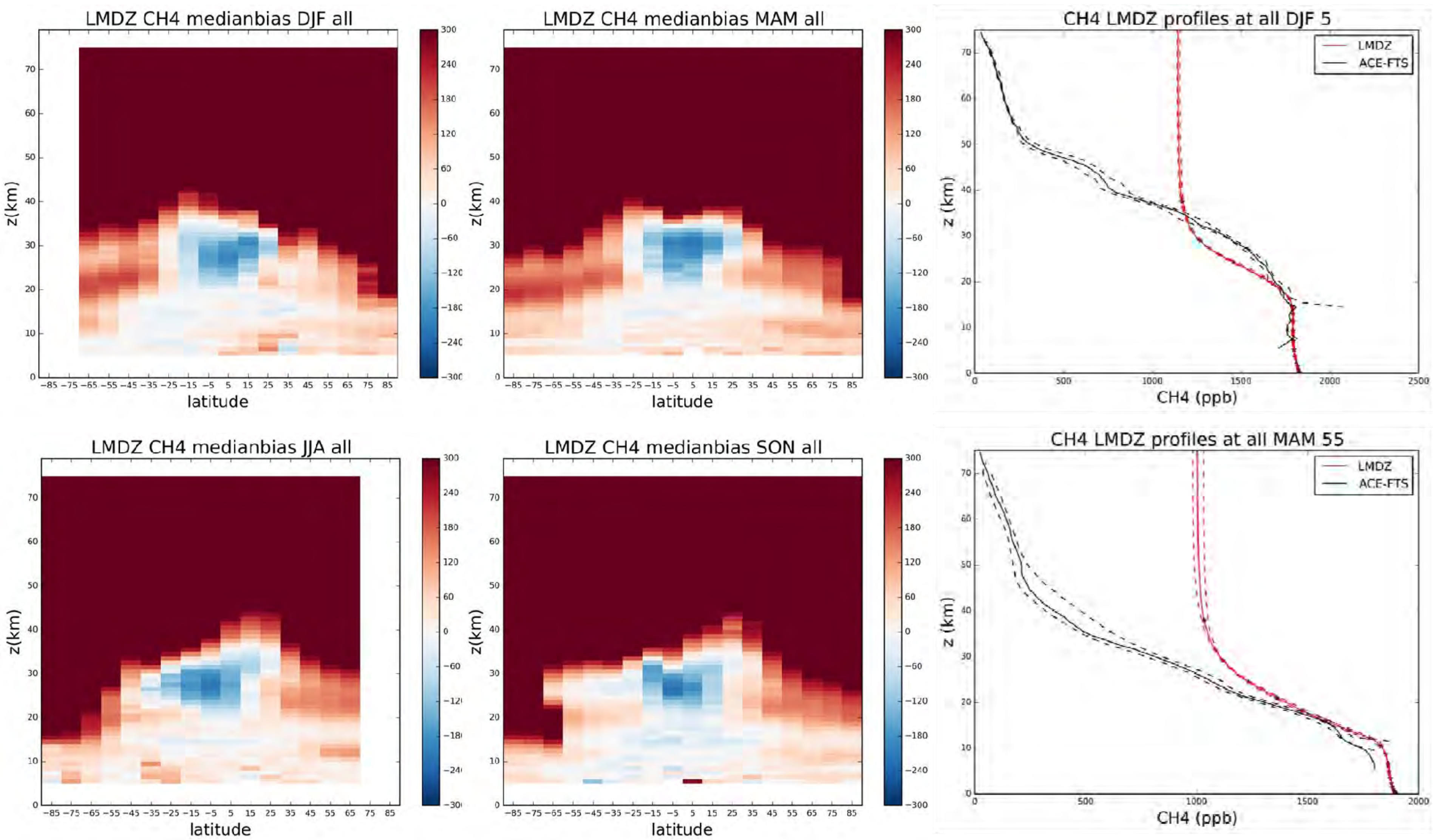
- TCCON is the reference network for the validation of GHG satellite retrievals and enables to link satellite retrievals to the WMO reference scale. TCCON has grown significantly over the last 10 years. Currently it is not part of the ICOS infrastructure.

- The network consistency has been improved by regular characterisation of gas cells. Using this method the site to site bias, which originates from the alignment of the FTIR-spectrometer is below 0.05% for XCH_4.

- A tropospheric XCH_4 dataproduct based on a stratospheric correction using N_2O has proven to be highly valuable for model validation.

- The models used for global CH_4 flux inversions seem to have deficiencies in the stratosphere, which has an impact on the derived flux estimates using satellite measurements.

Differences between LMDZ-model and ACE-FTS



Differences between TM5 and ACE-FTS