Validation and calibration of GHG satellite observations by ground based remote sensing measurements

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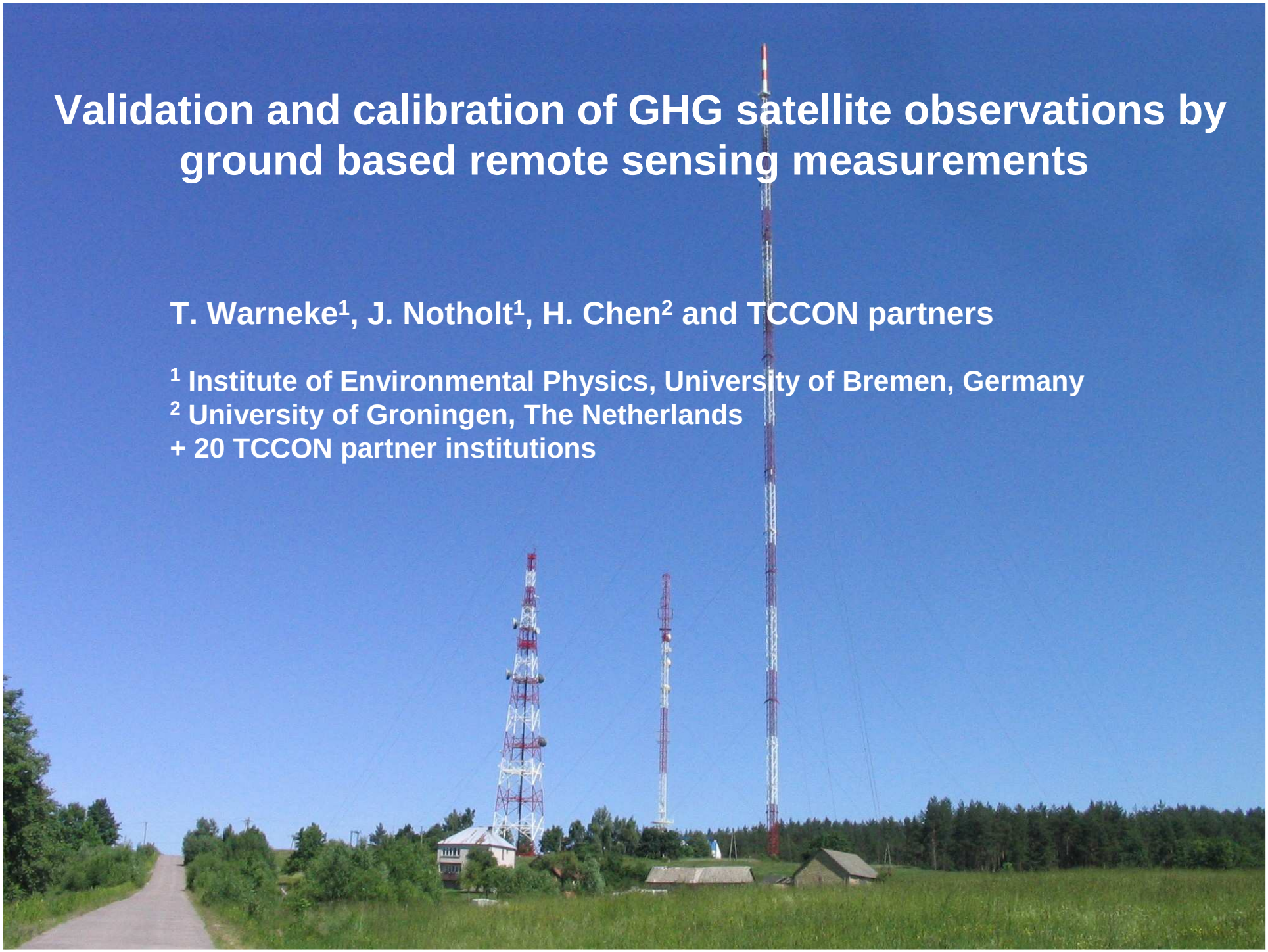
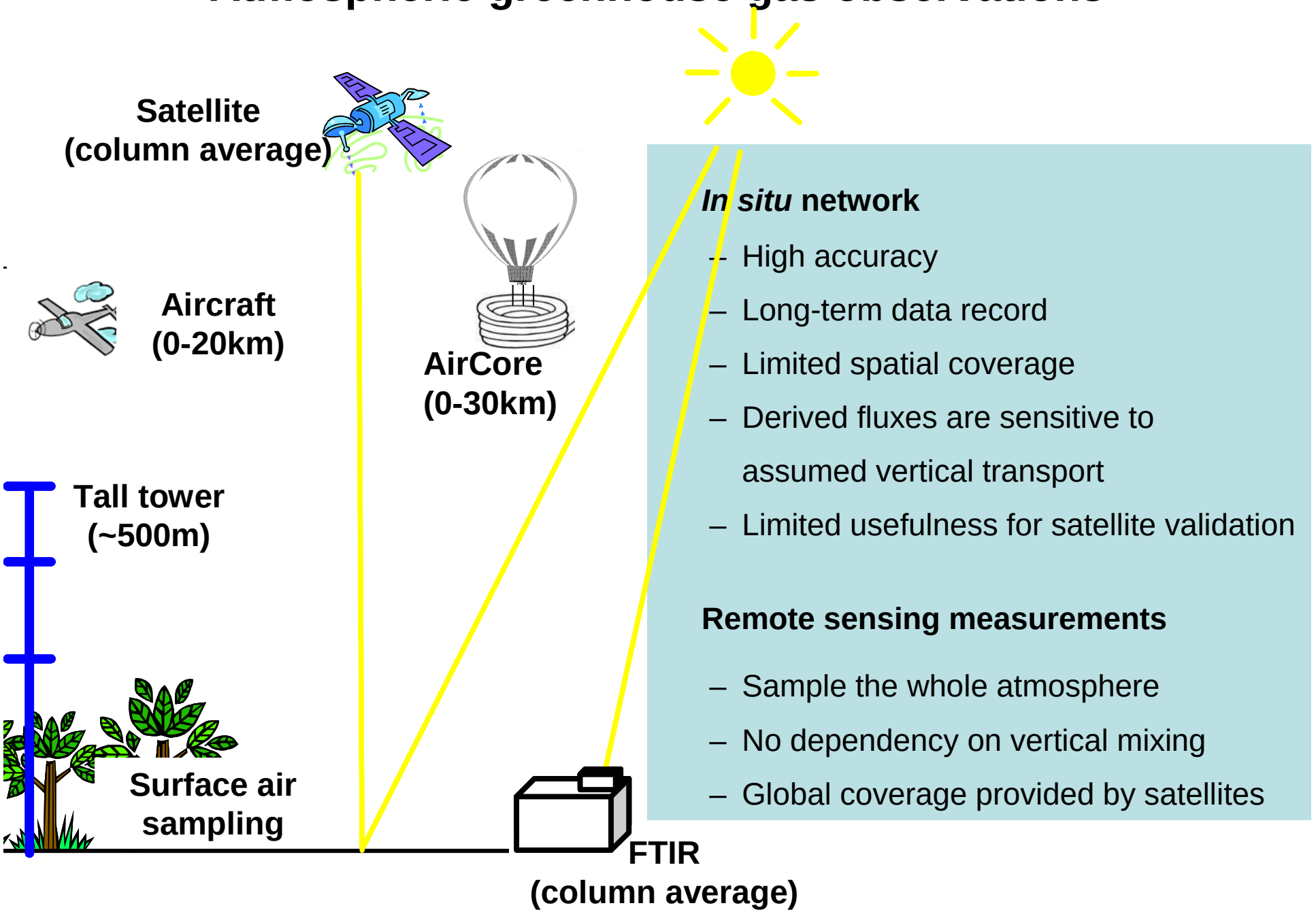
+ 20 TCCON partner institutions



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

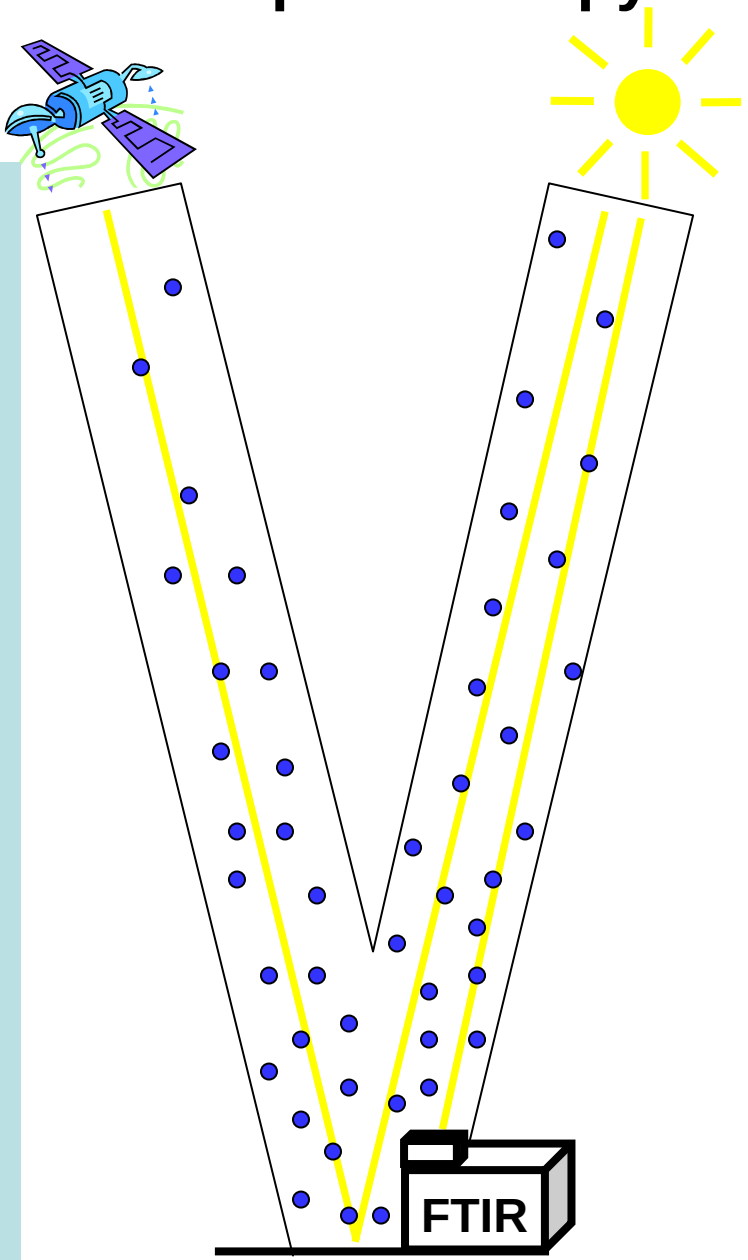
Solar absorption FTIR-spectrometry

- **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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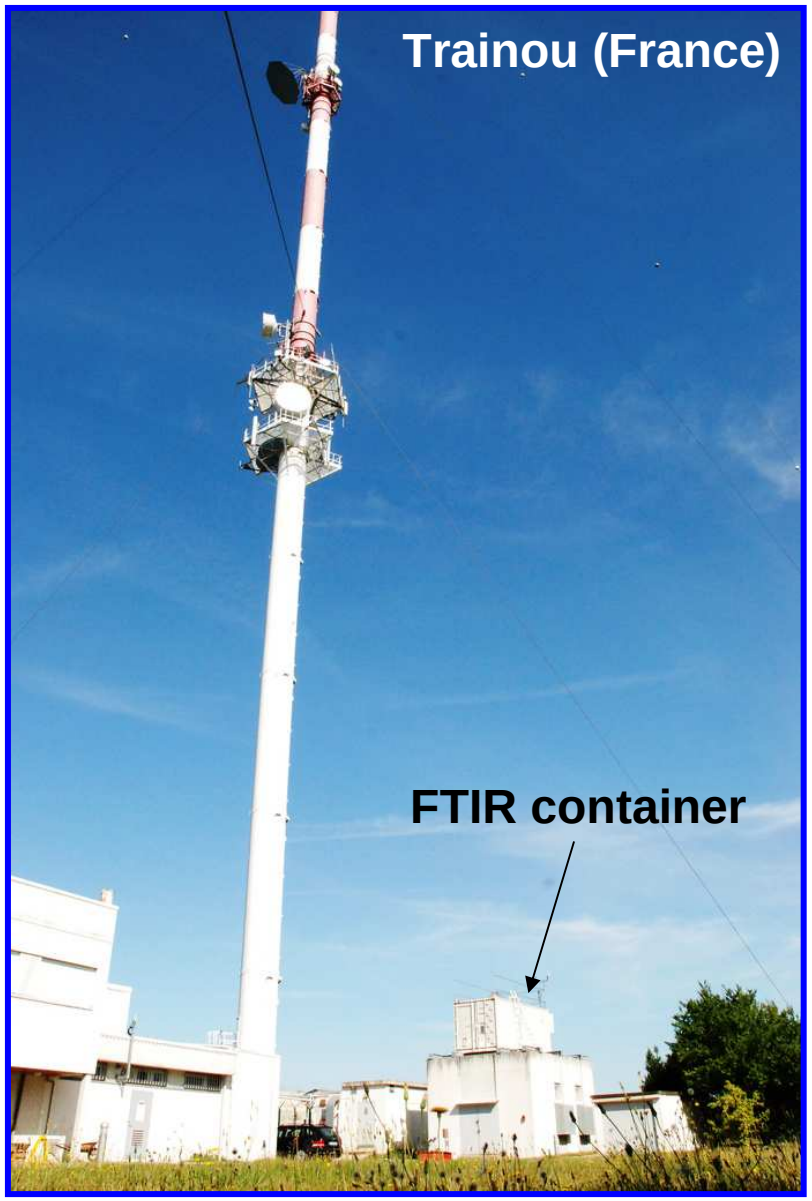
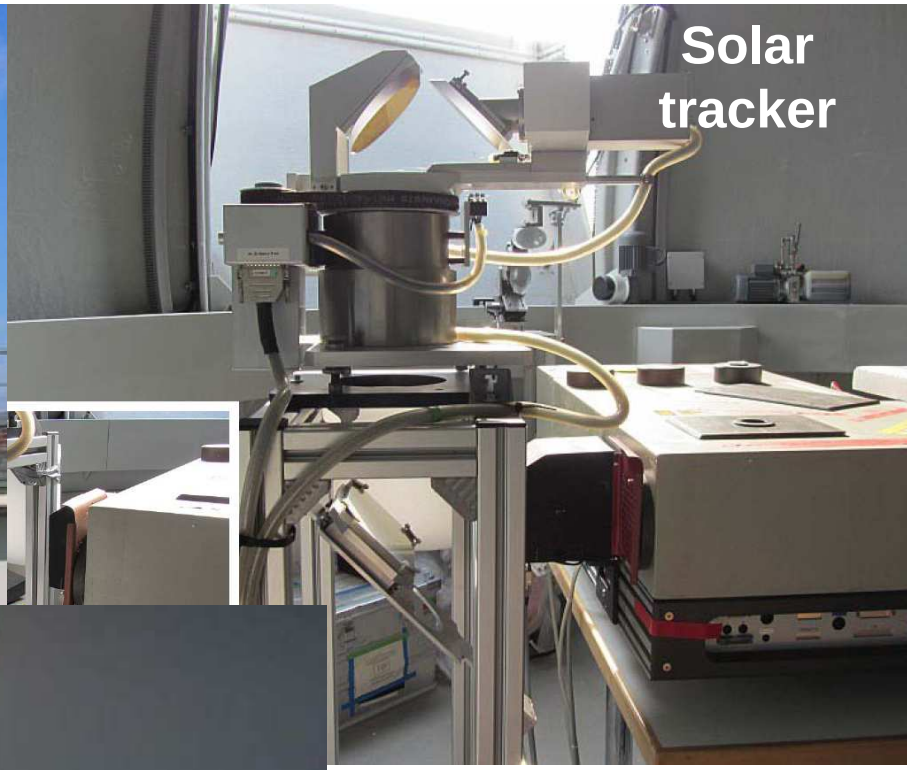
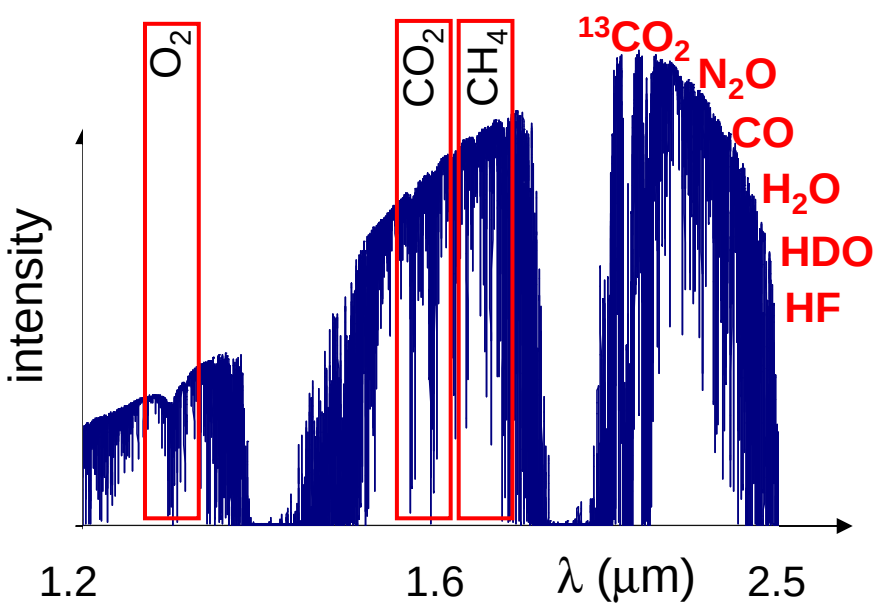


Components of a TCCON observatory



TCCON data product



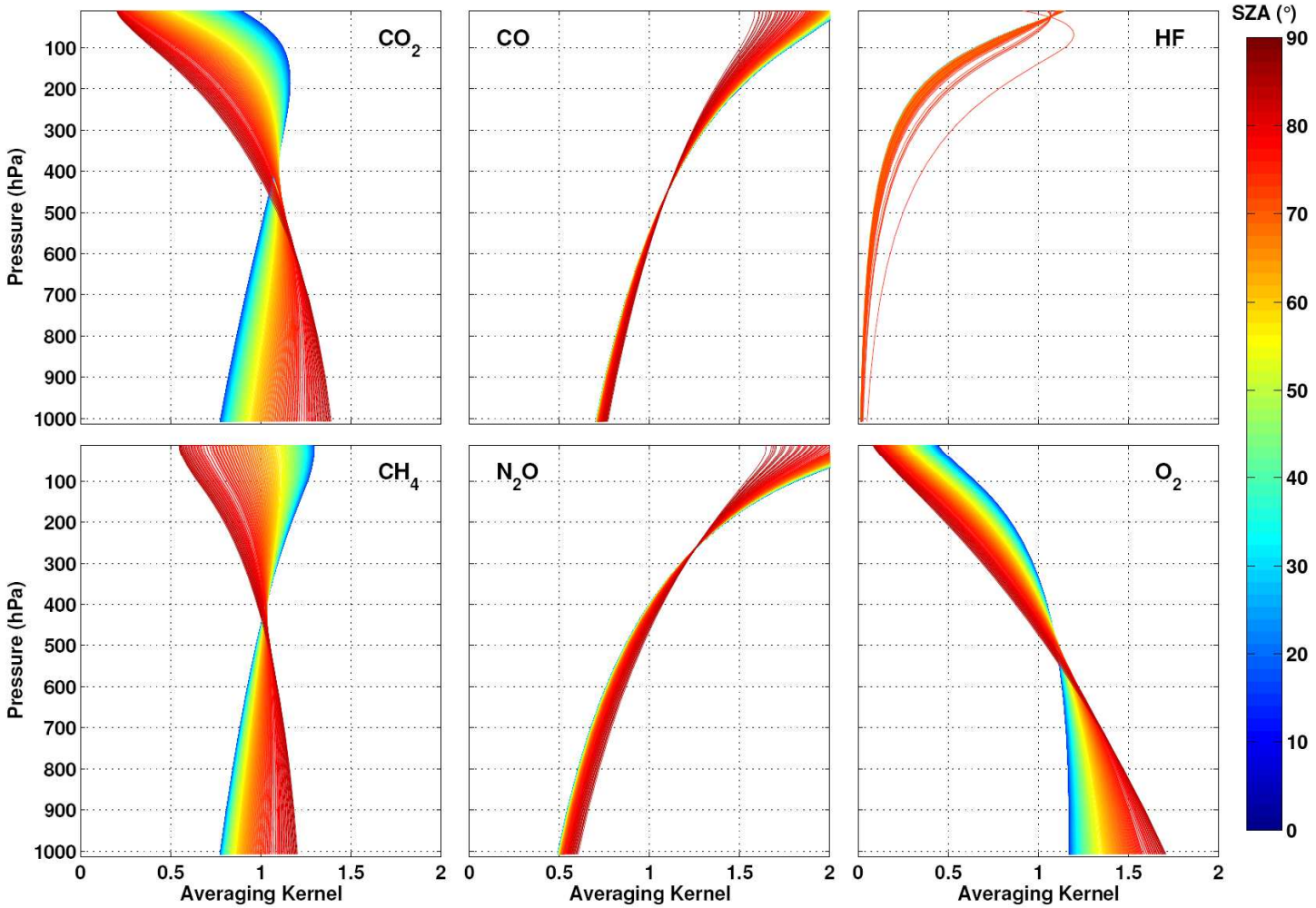
Near-IR spectral region

- 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):

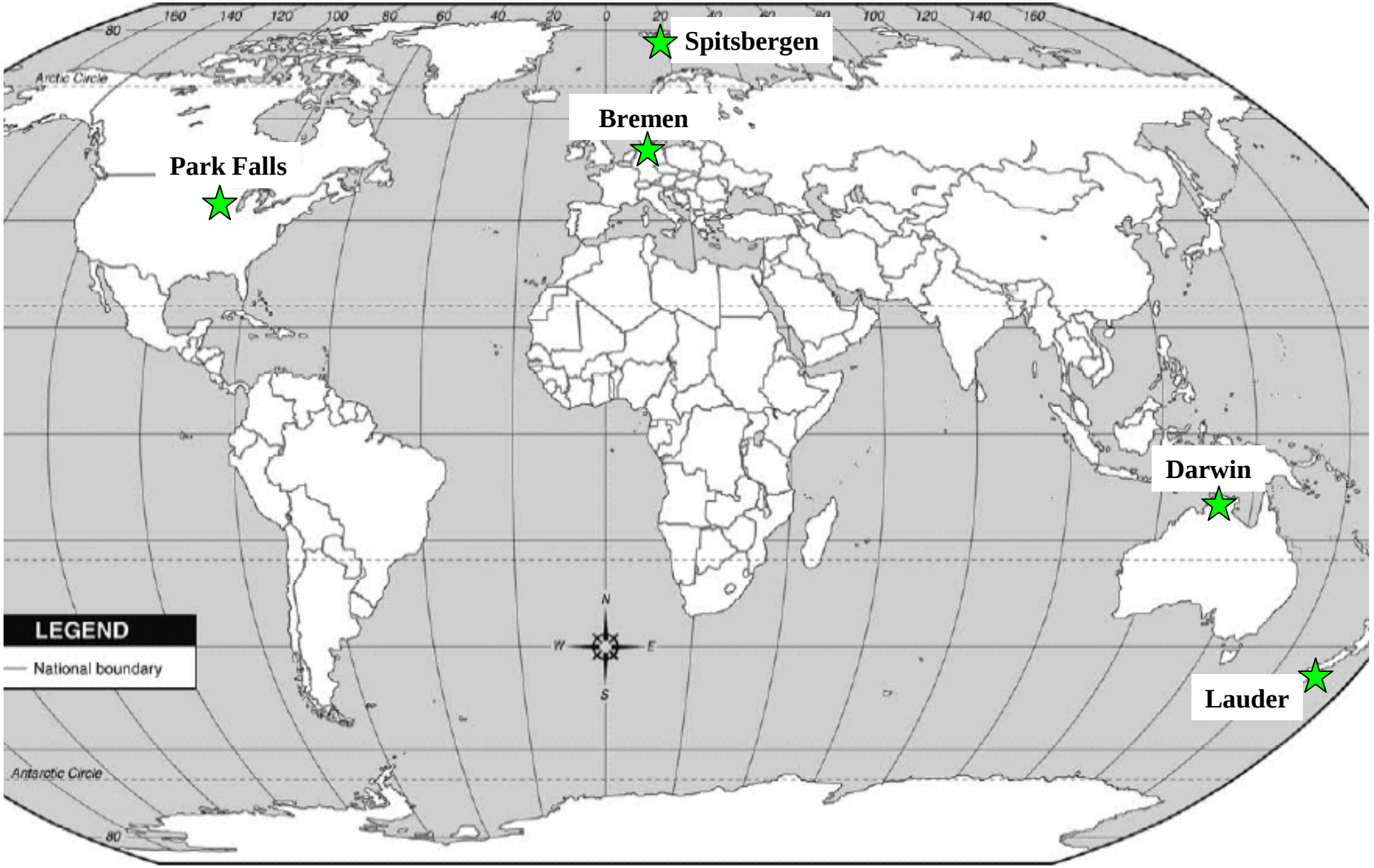
1) Division by O_2 column. XCO_2 = 0.2095 * CO_2-column / O_2-column
   Partial cancellation of systematic errors (e.g. ILS, surface pressure, H_2O, …)
2) Correction for airmass-dependent biases (spectroscopy)
   - Causes: Errors in the line widths, no line-mixing, etc
   - Common to all instruments
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.

Averaging kernels

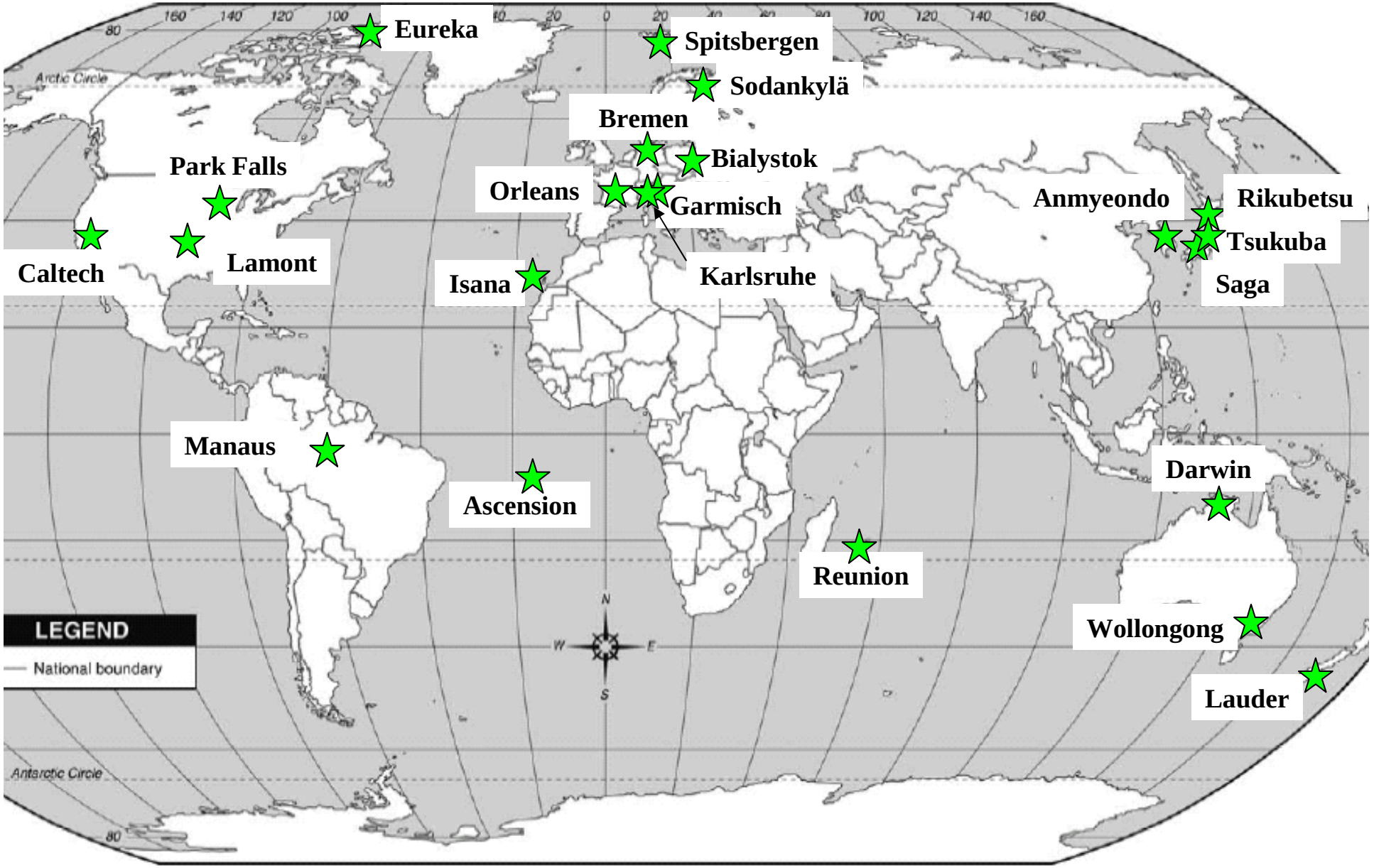


Wunch et al., 2011

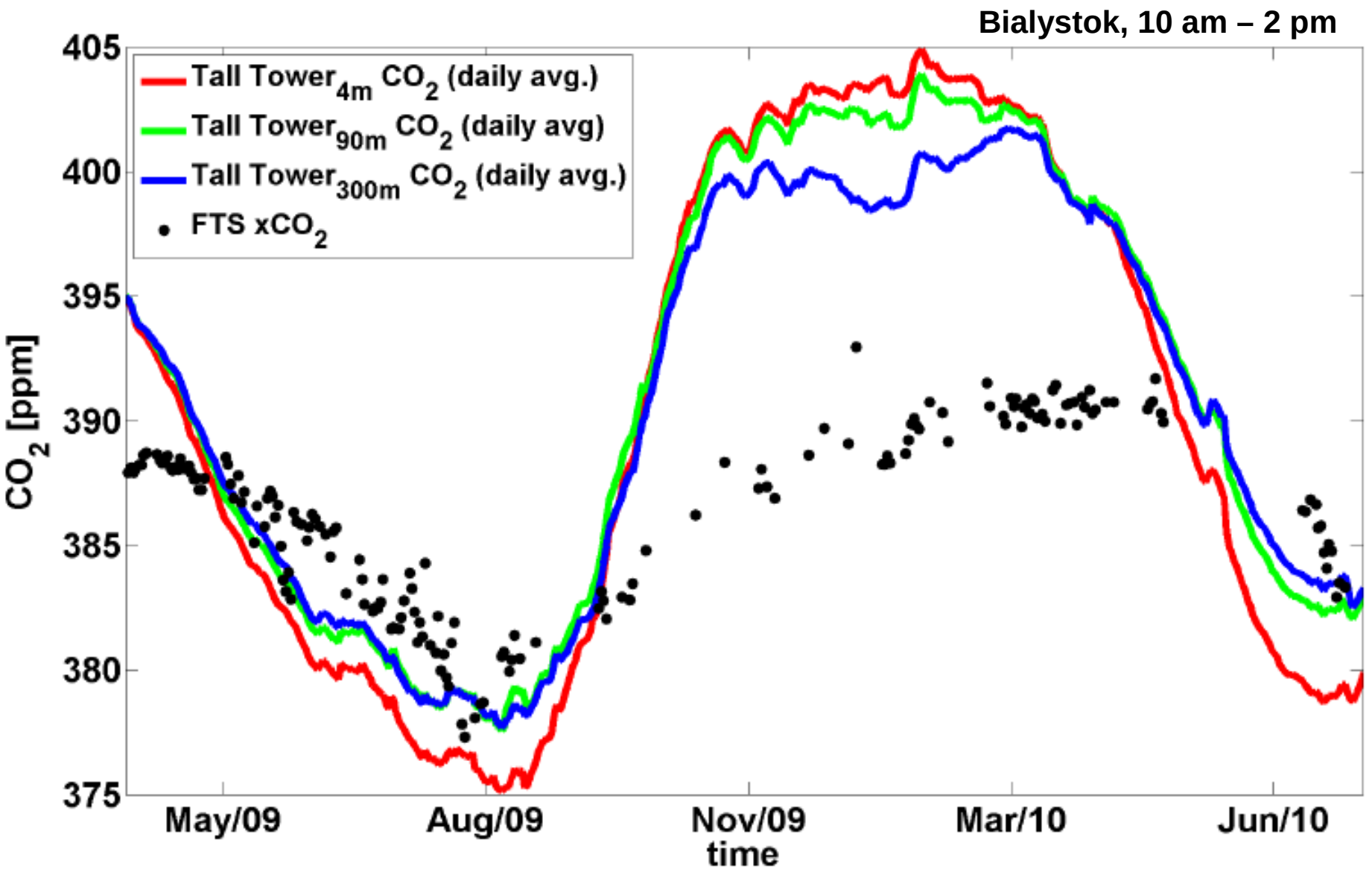
Total Carbon Column Observing Network (TCCON) in 2005



Total Carbon Column Observing Network (TCCON) in 2015



Seasonal cycle: Comparison of with tall tower (daytime values only)



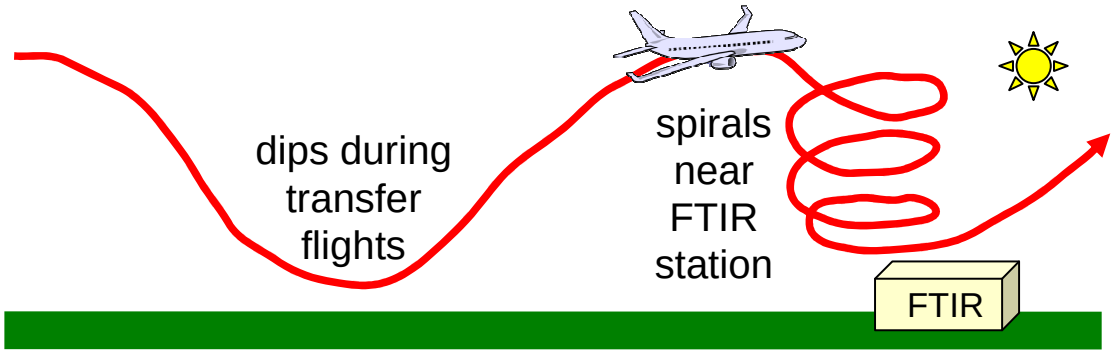
Establishing the link to the WMO standards by aircraft measurements

e.g. campaign within EU-IMECC

- **Purpose:** validation of European TCCON measurements
- **Aircraft measurements:** in-situ GHG profiles near stations from **300-12000 m** (spiral) + dips during transfer flights
- **Schedule:** September 30 to October 9, 2009
- **Platform:** Learjet 35A operated by Enviscope/GfD

Results:

- Systematic differences between FTIR and in situ measurements is well within spectroscopic errors, e.g. FTIR-CO_2-column is ~1% lower than the „in situ“ column
- Very good agreement with similar measurements outside Europe
- Accuracy limited by uncertainties in GHG profiles above aircraft ceiling.



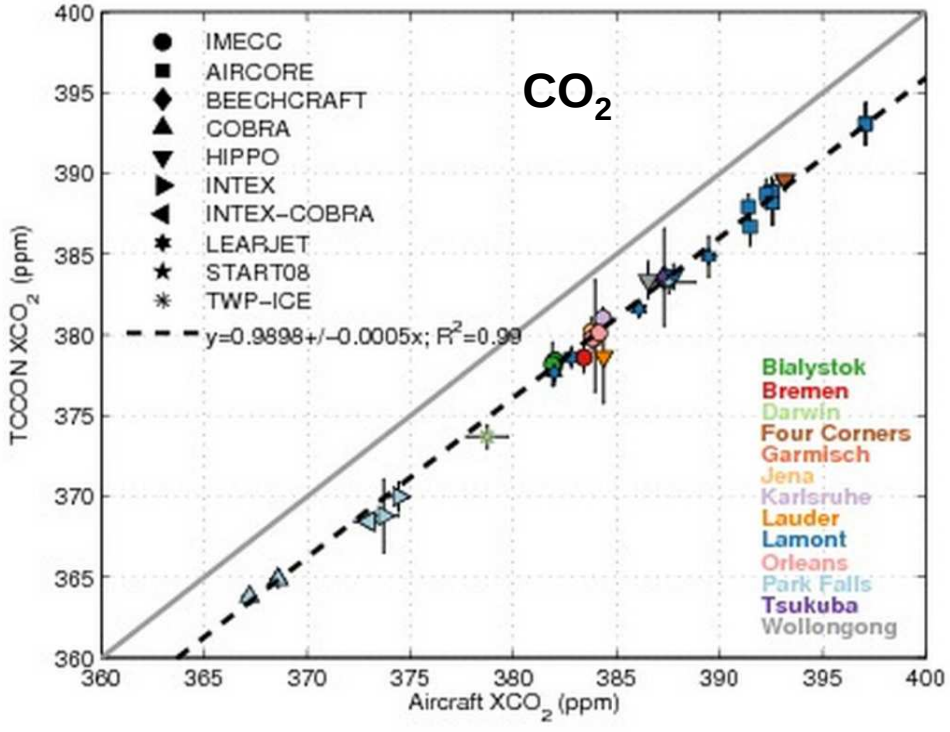
(courtesy of D. Feist, MPI-BGC)

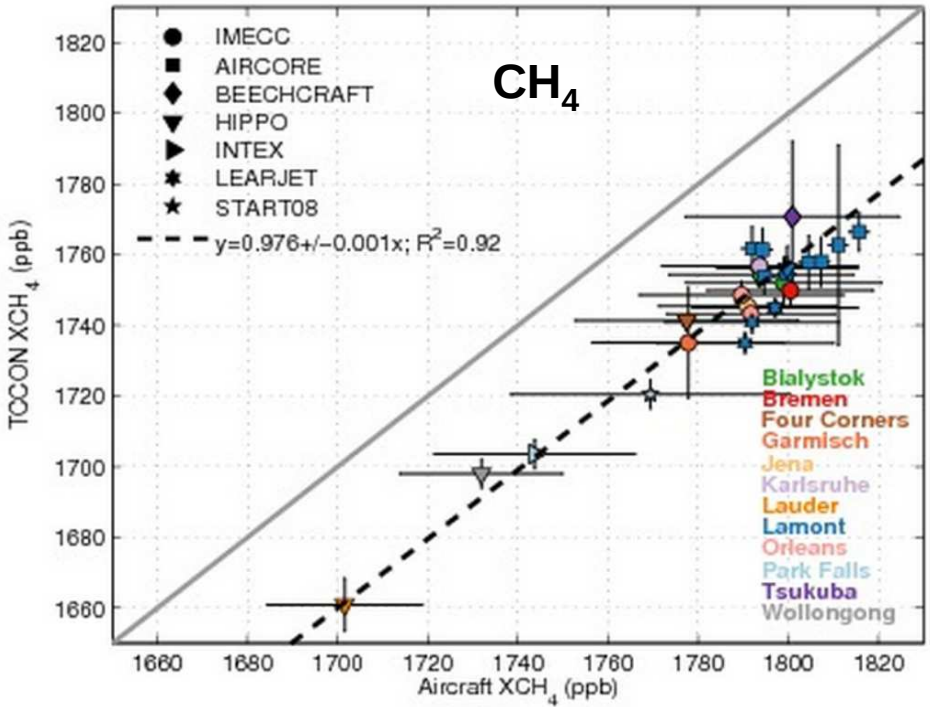
Establishing the link to the WMO standards by AirCore measurements

The AirCore with magnesium perchlorate driers and shut-off valves attached on each end, 152 m long, 7 kg
[Karion et al. 2010]

(courtesy of H. Chen)

TCCON calibration by *in situ* measurements





Courtesy of Geoff Toon, NASA-JPL

2 σ standard error by comparison with in situ profiles

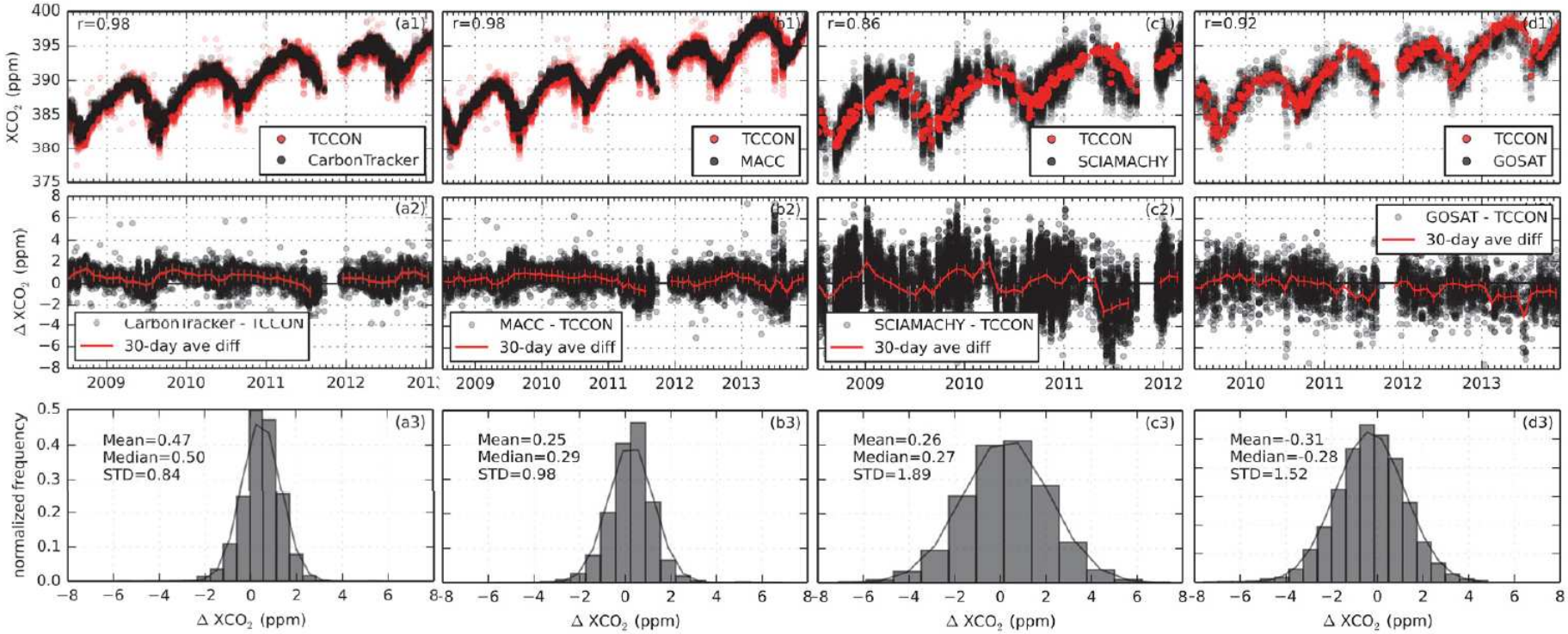
CO_2: 0.8 ppm

CH_4: 7 ppb

N_2O: 3 ppb

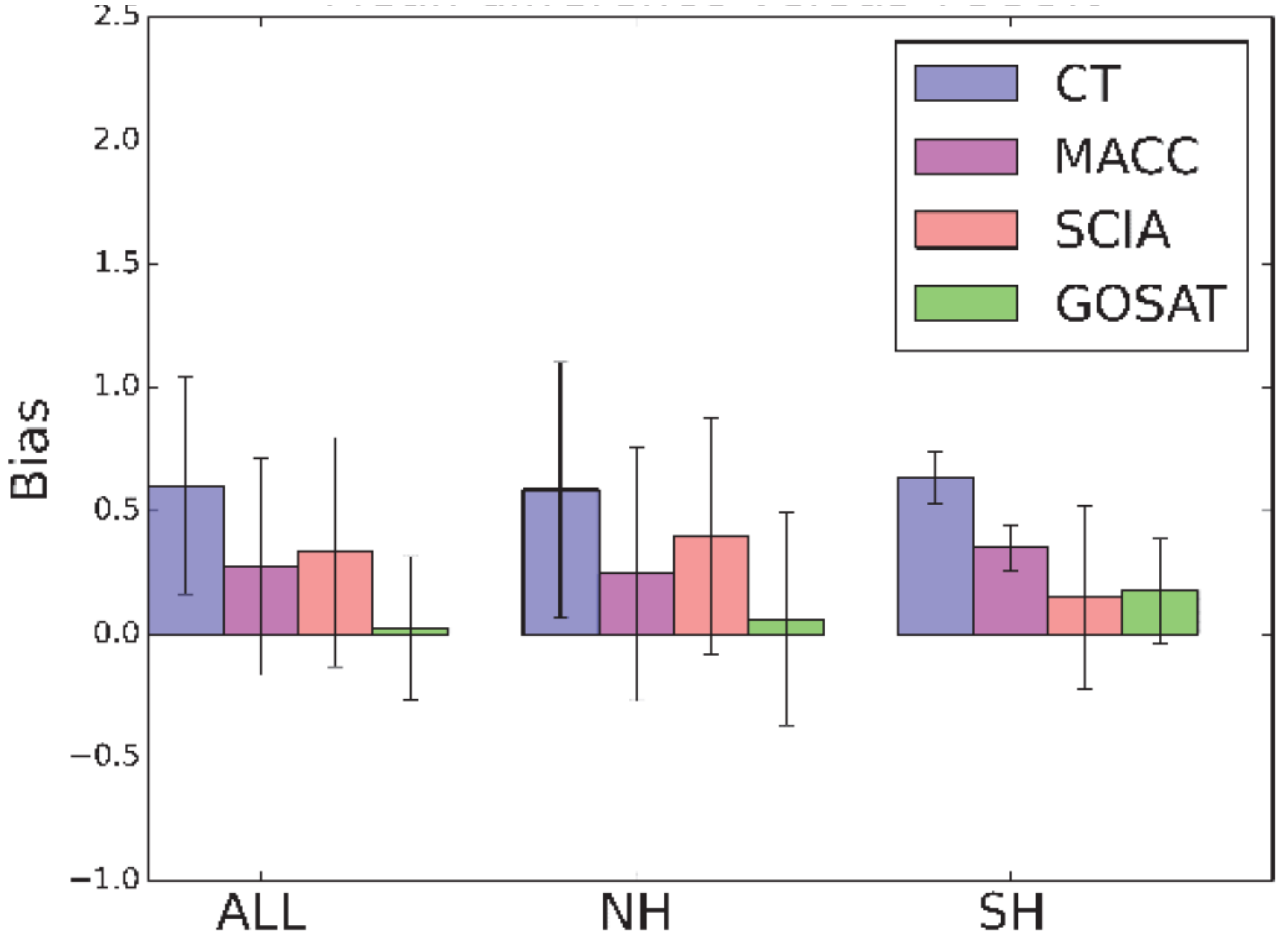
CO: 4 ppb

Model and satellite comparison for the TCCON site Lamont



Kulawik et al., AMTD 2015

Mean difference versus TCCON



Kulawik et al., AMTD 2015

Satellite validation OCO-2

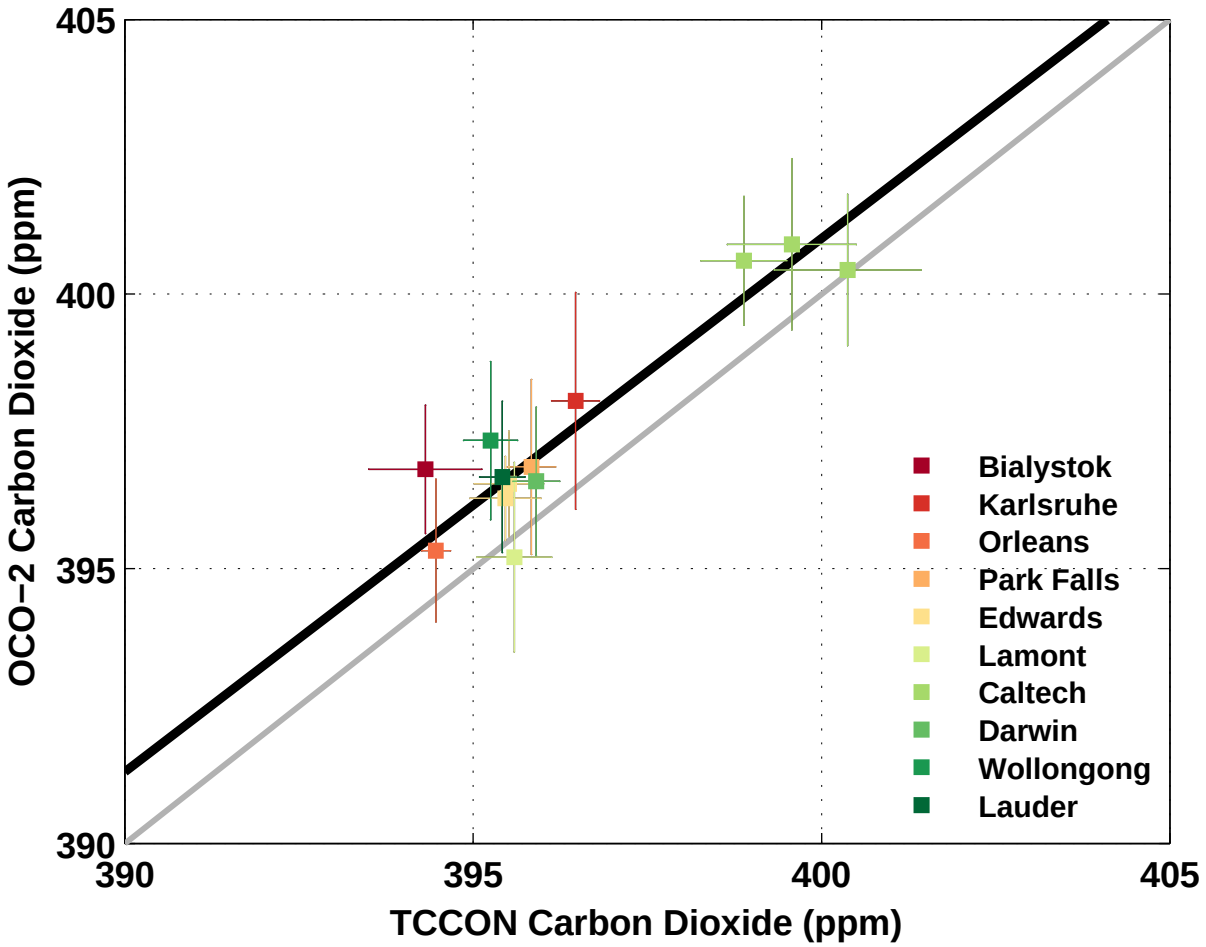
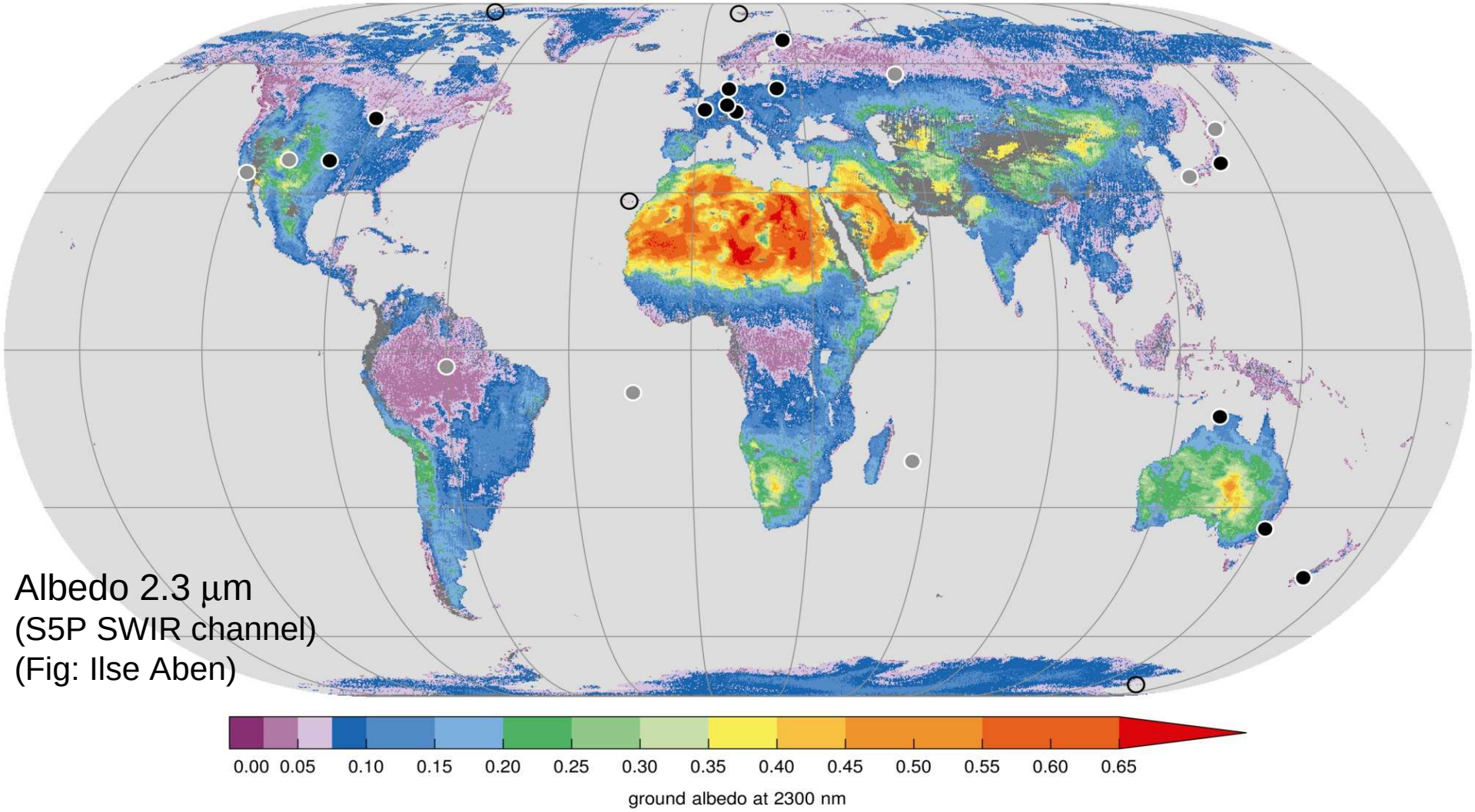


Figure from AGU Press Conference, 2014)

TCCON coverage of regions with different albedo

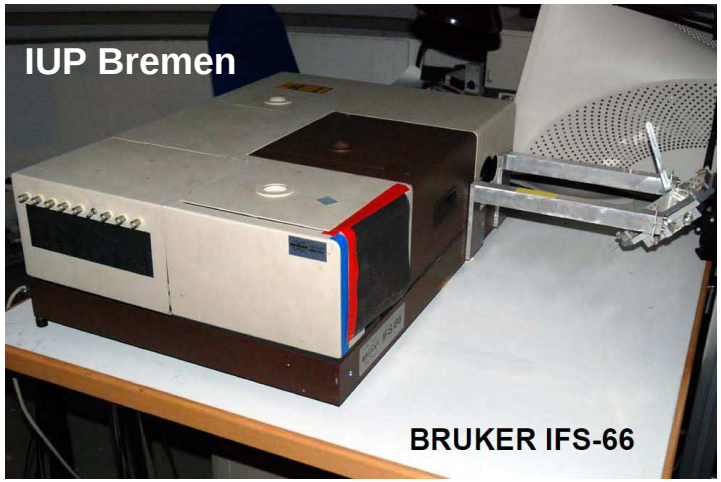


Albedo 2.3 µm
(S5P SWIR channel)
(Fig: Ilse Aben)

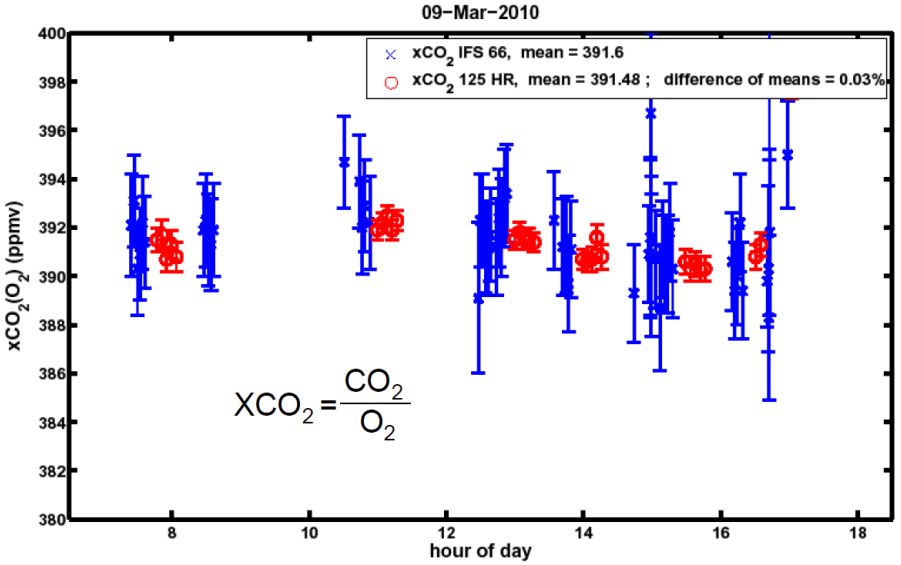
High and low land surface albedo regions currently not covered by TCCON

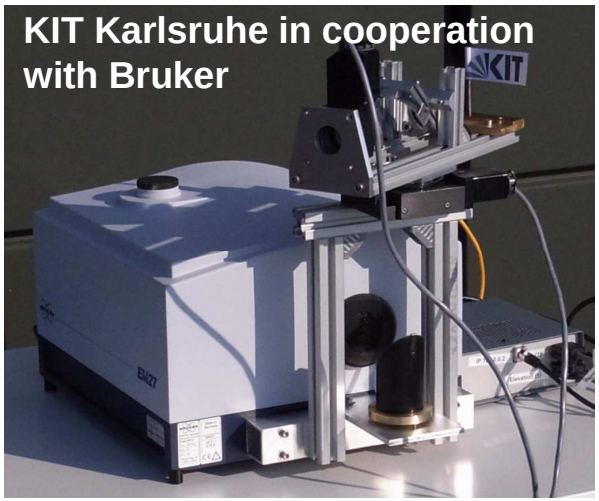
→ Problem for satellite validation, because high and low albedo conditions are most difficult for satellite retrievals

Extension using low resolution FTIR- instruments

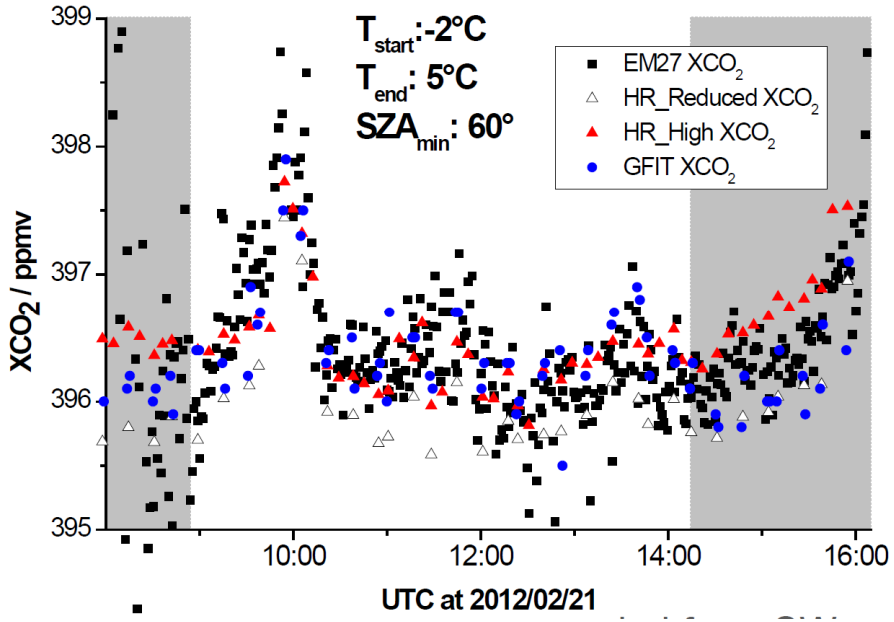


Petri et al., AMT 2012

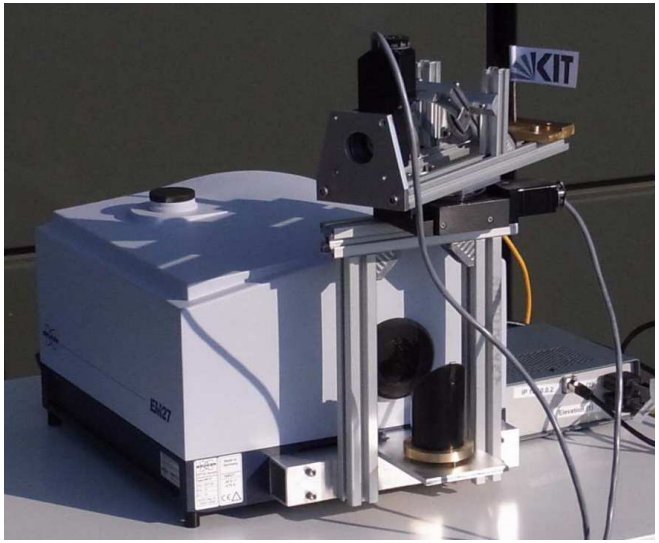




Gisi et al., AMT 2012



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



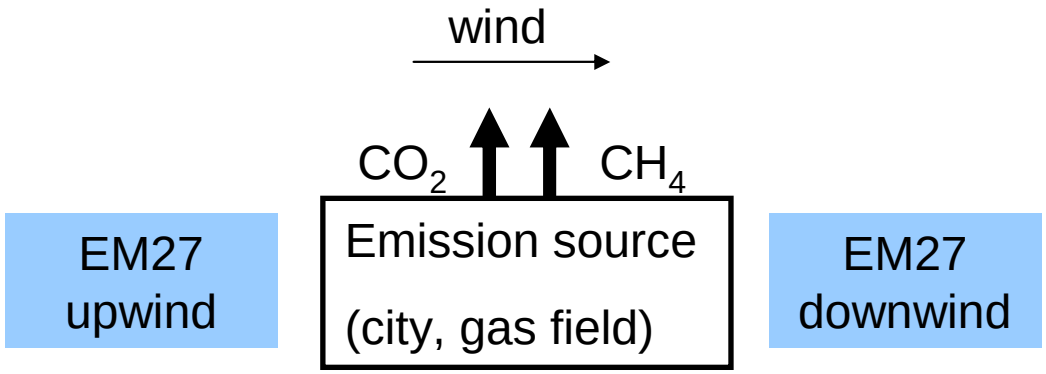
EM27 solar absorption spectrometer

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

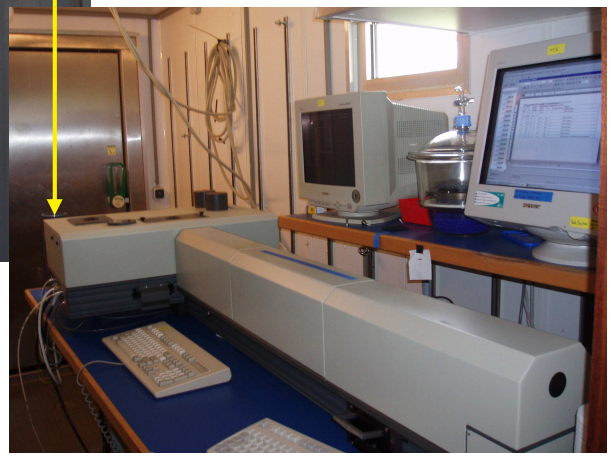
1) Complementing TCCON

- 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)



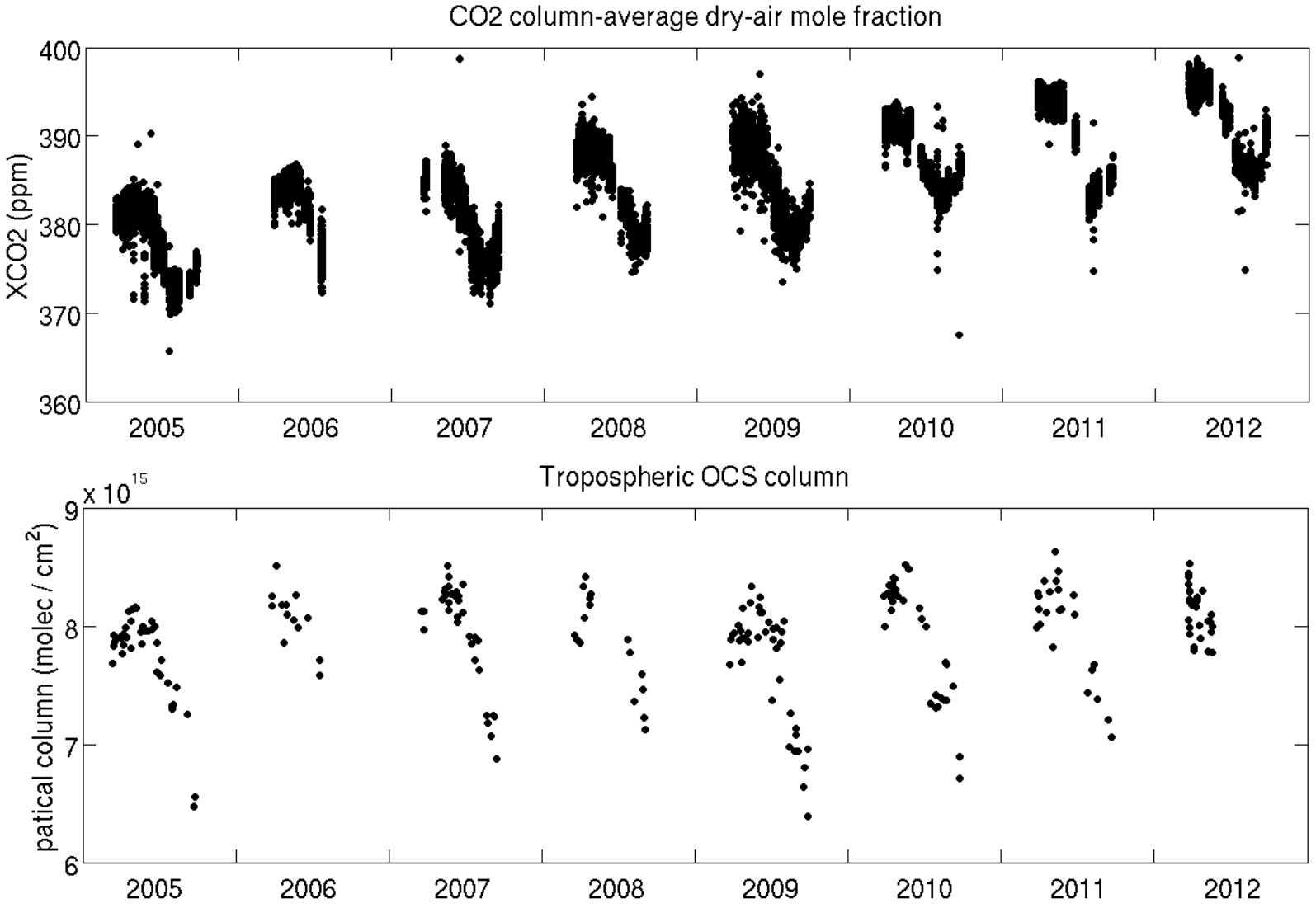
Total columns of 20-30 trace gases

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, COS, 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.

- The calibration against the in situ reference scale is done by vertical resolved in situ measurements using aircrafts or AirCore. AirCore offers to sample the column up to 30km.

- Mobile, low resolution instruments might become useful to expand the network in certain regions or at hot spots (e.g. cities, gas field, larger ecosystems)

- Mid-IR measurements using the same technique are performed within the Network for the Detection of Atmospheric Composition Change (NDACC). In principle all TCCON instruments could cover this spectral region, which would add several gases, which are of interest to the carbon cycle.