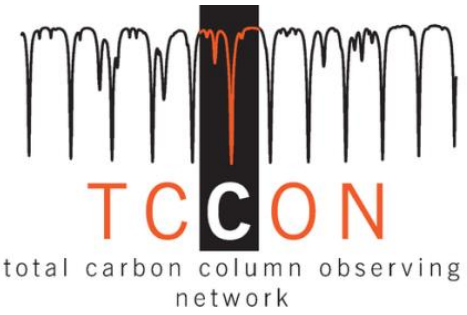
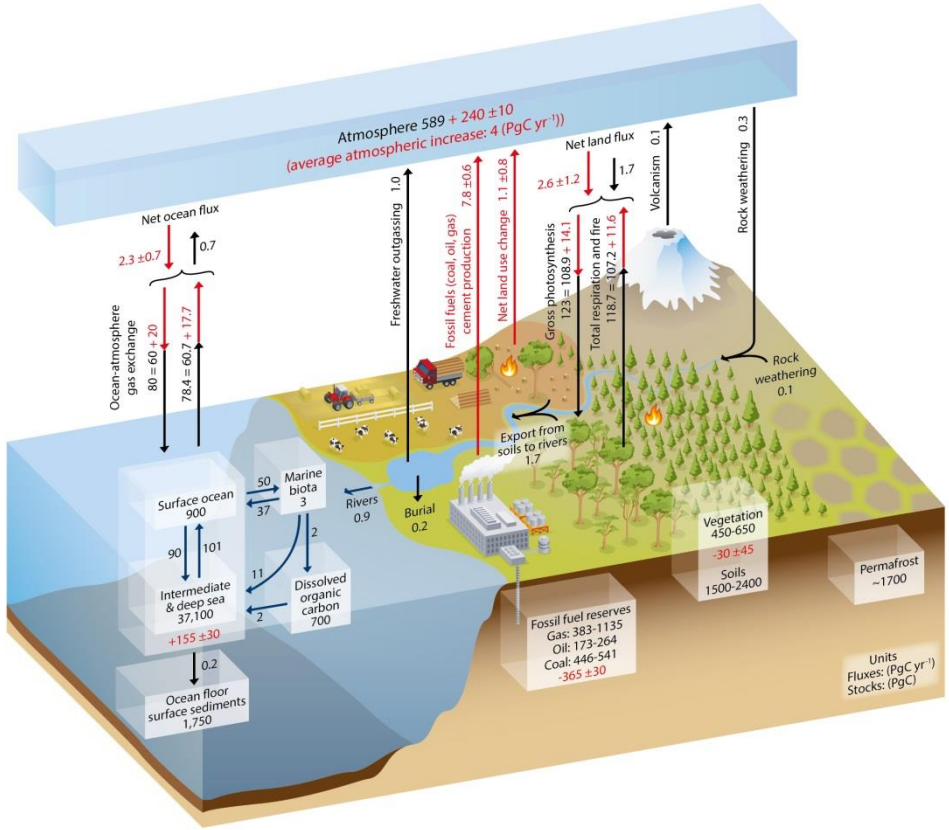
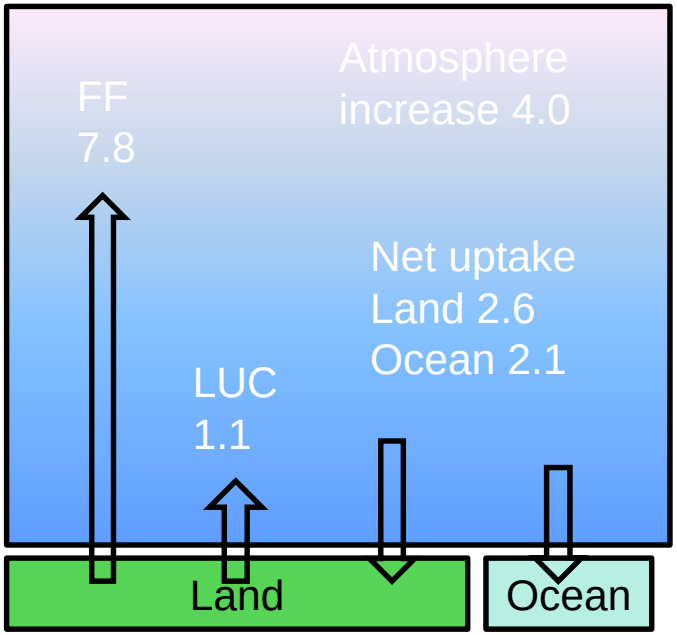


Total Carbon Column Observing Network

Paul Wennberg, David Griffith, Justus Notholt,
Tae-Young Goo & TCCON network partners

The carbon cycle





TCCON - The Total Carbon Column Observing Network

Paul Wennberg, Justus Notholt, David Griffith, co chairs

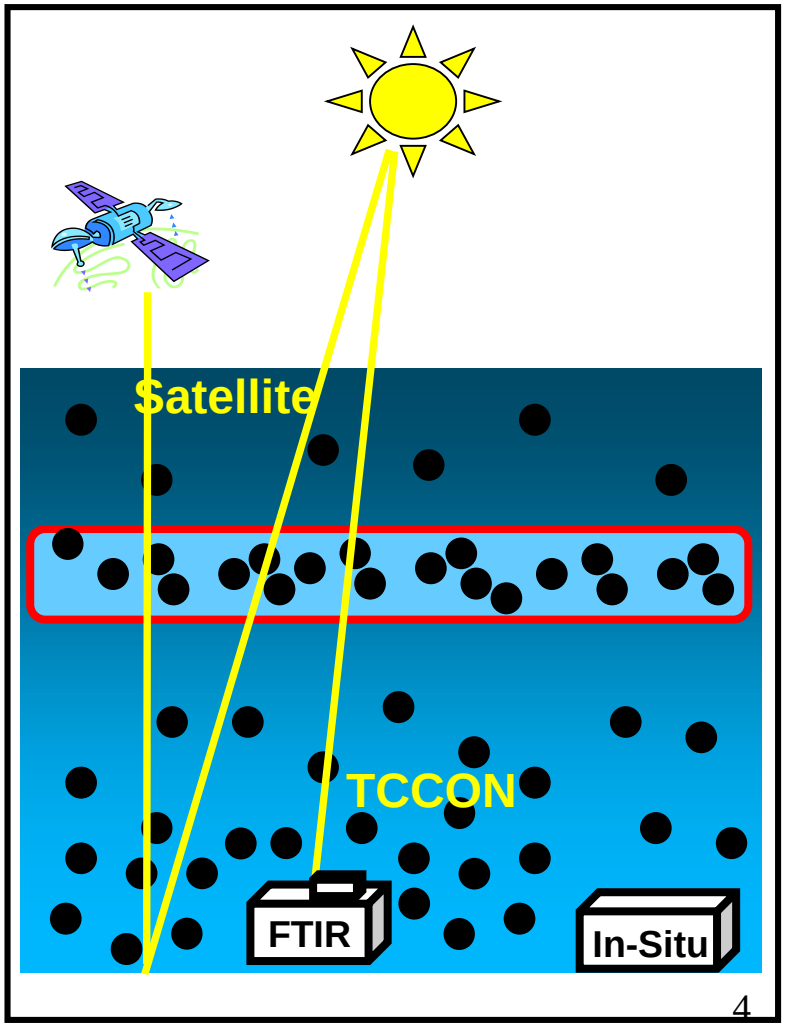
> 20 partners / site PIs

TCCON
total carbon column observing network

Figure by D. Feist, MPI-Jena

TCCON: Remote sensing of total column CO_2, CH_4, N_2O, CO …

- Direct-sun solar absorption spectroscopy in the near IR
- Retrieve total column amounts
- Derive column average dry air mole fractions (e.g. X_{CO2})
  - Using column O_2 as internal standard
  - $X_{CO2} = CO_2/O_2 \times 0.2095$



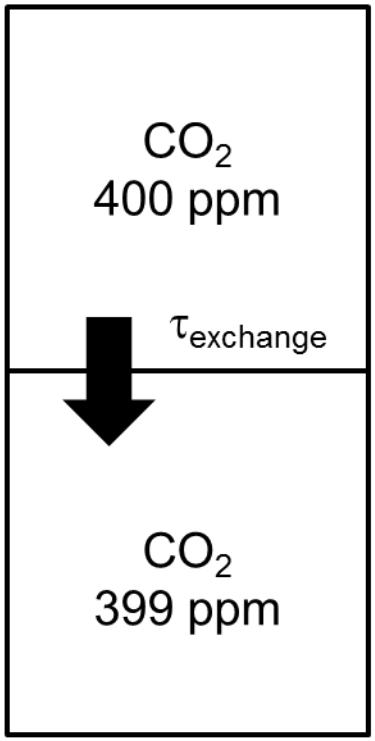
Why TCCON?

Why total column measurements?

TCCON
total carbon column observing network

- Total column measurements :
  - Are less influenced by local sources and sinks than in situ
    - They have a larger footprint
  - Are less influenced by vertical transport
    - Do not alias diurnal and seasonal boundary layer transport into the measured column amount
- Is useful in 2 main ways
  - As a standalone network - model comparisons
  - For satellite validation, past, present and future
    - SCIAMACHY, GOSAT, OCO-2, Tansat …
- Must be:
  - accurate and precise
  - traceable to WMO mole fraction scales
    - To compare with in situ scales

Why do we need to be so accurate?



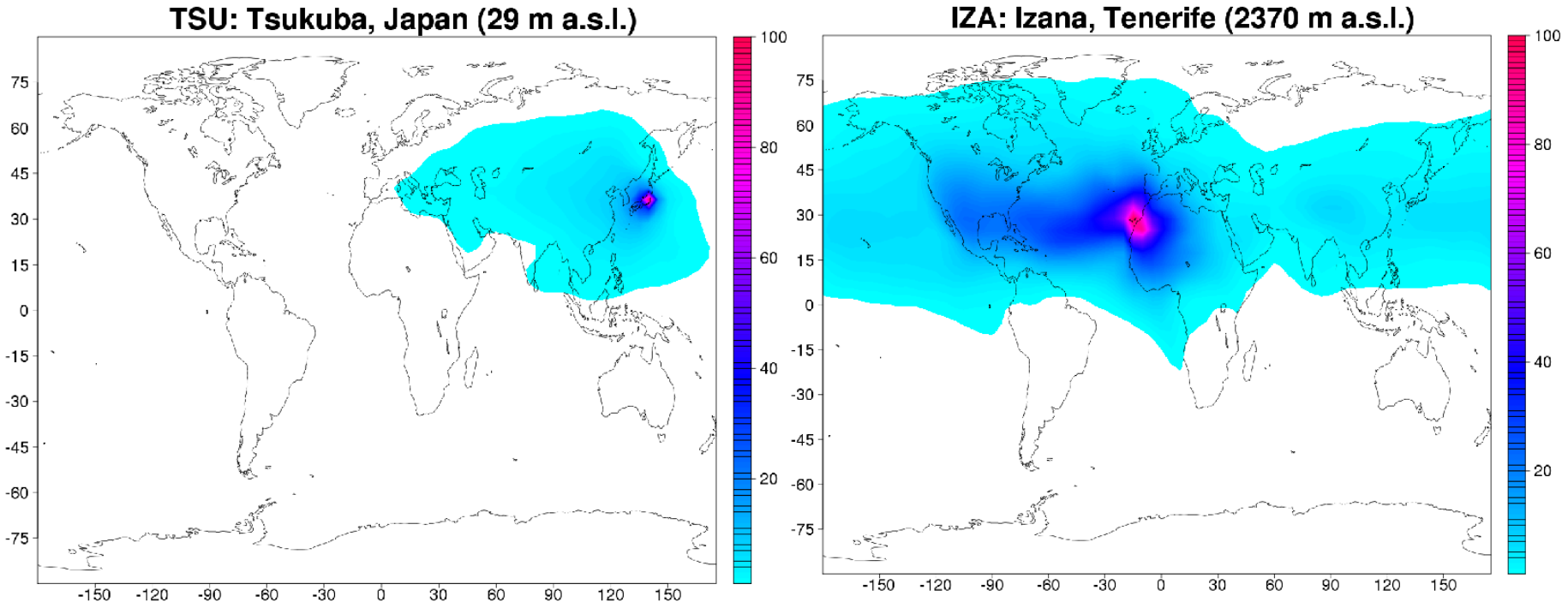
2-box model of global atmosphere

For a CO_2 gradient of 1 ppm:

- Exchange time 1 year
  (Interhemispheric transport)
  - Flux CO_2 ~ 1 Pg yr^{-1}
- Exchange time 1 month
  (E-W transport)
  - Flux CO_2 ~ 10 Pg yr^{-1}
- cf total budget ~ 9 Pg yr^{-1}
- We aim for CO_2 accuracy and lack of bias between measurements of ~ 0.1 ppm or better

TCCON station footprints

(Dietrich Feist, MPI)



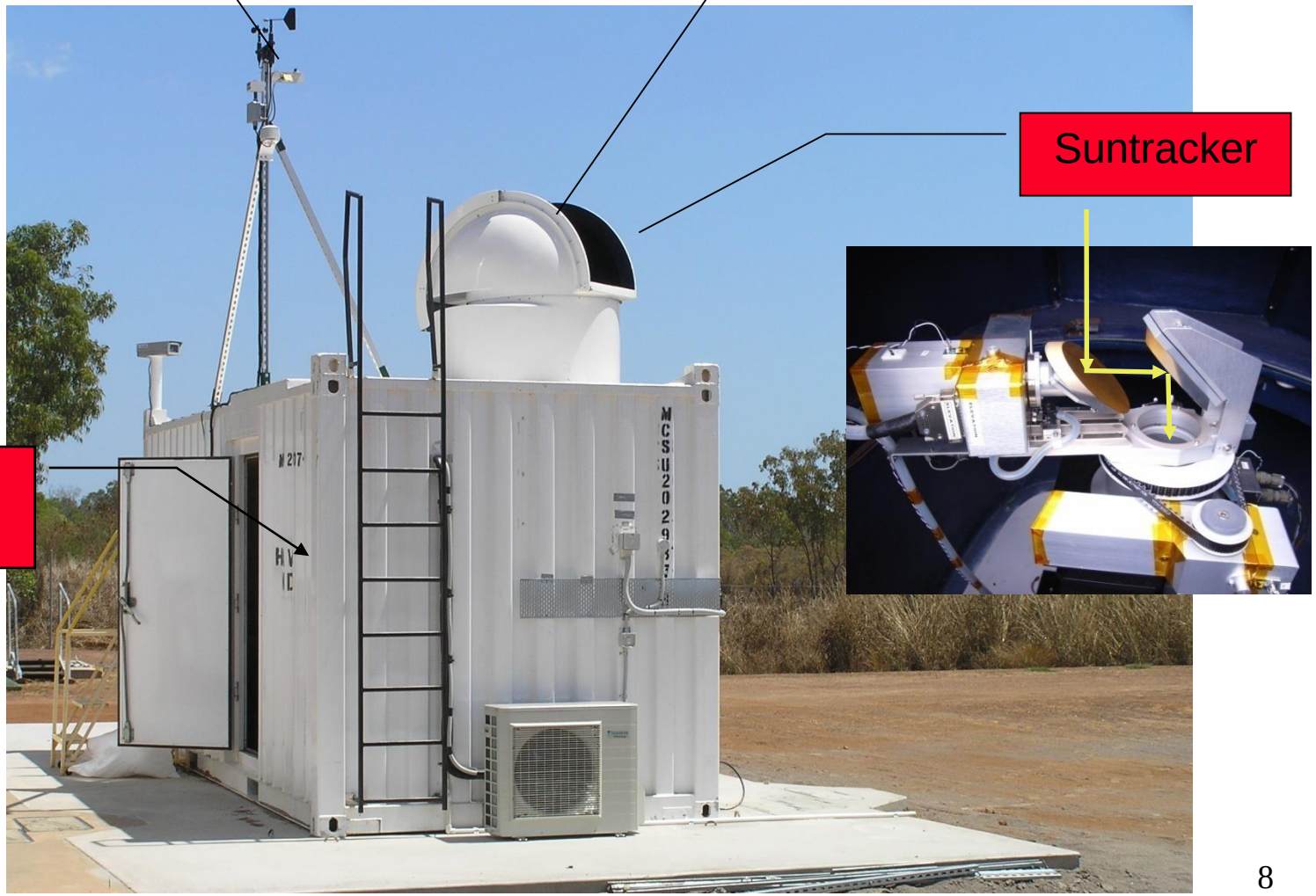
Darwin TCCON container

Weather station

Protective Dome

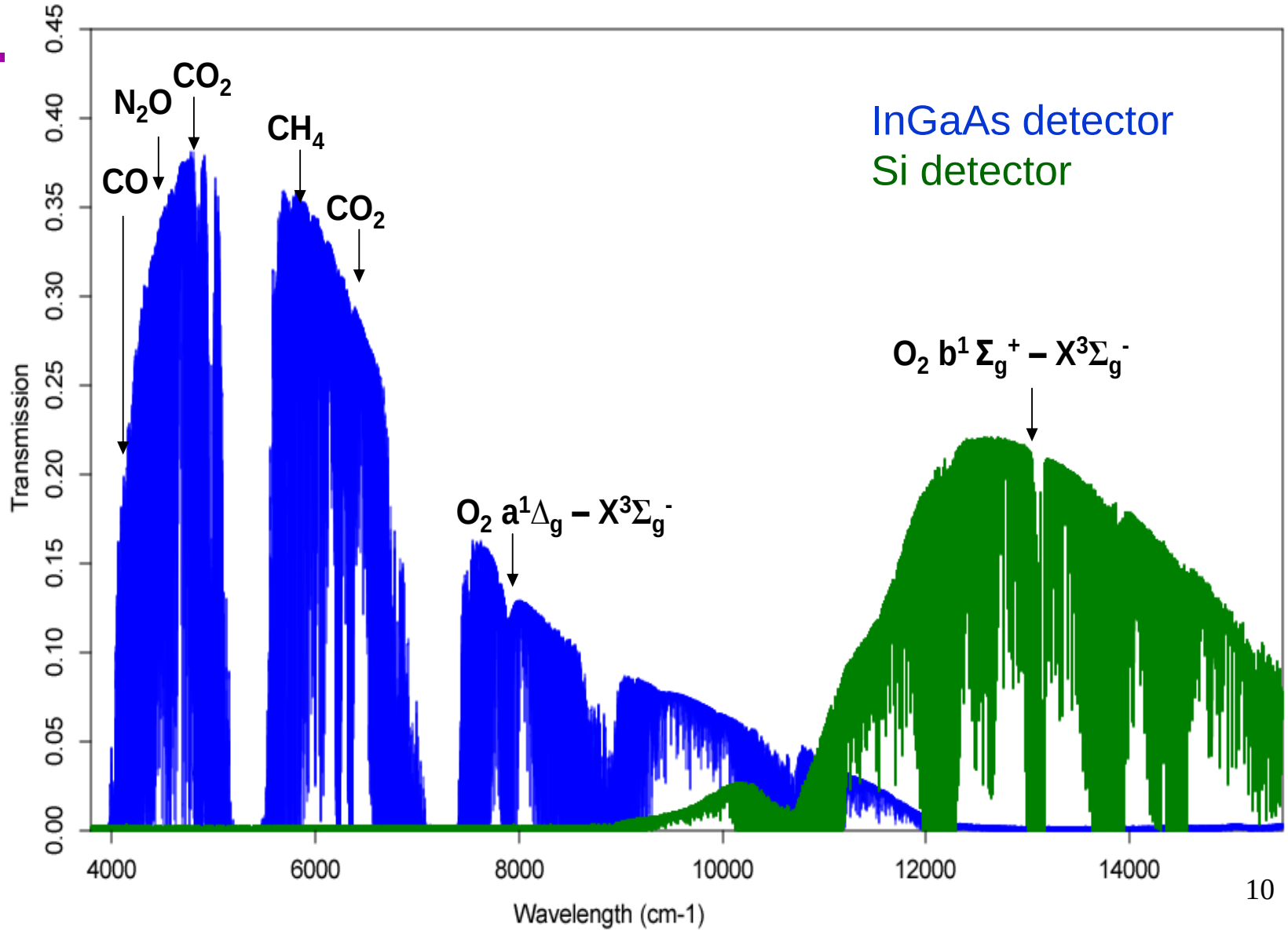
Suntracker

Bruker IFS125

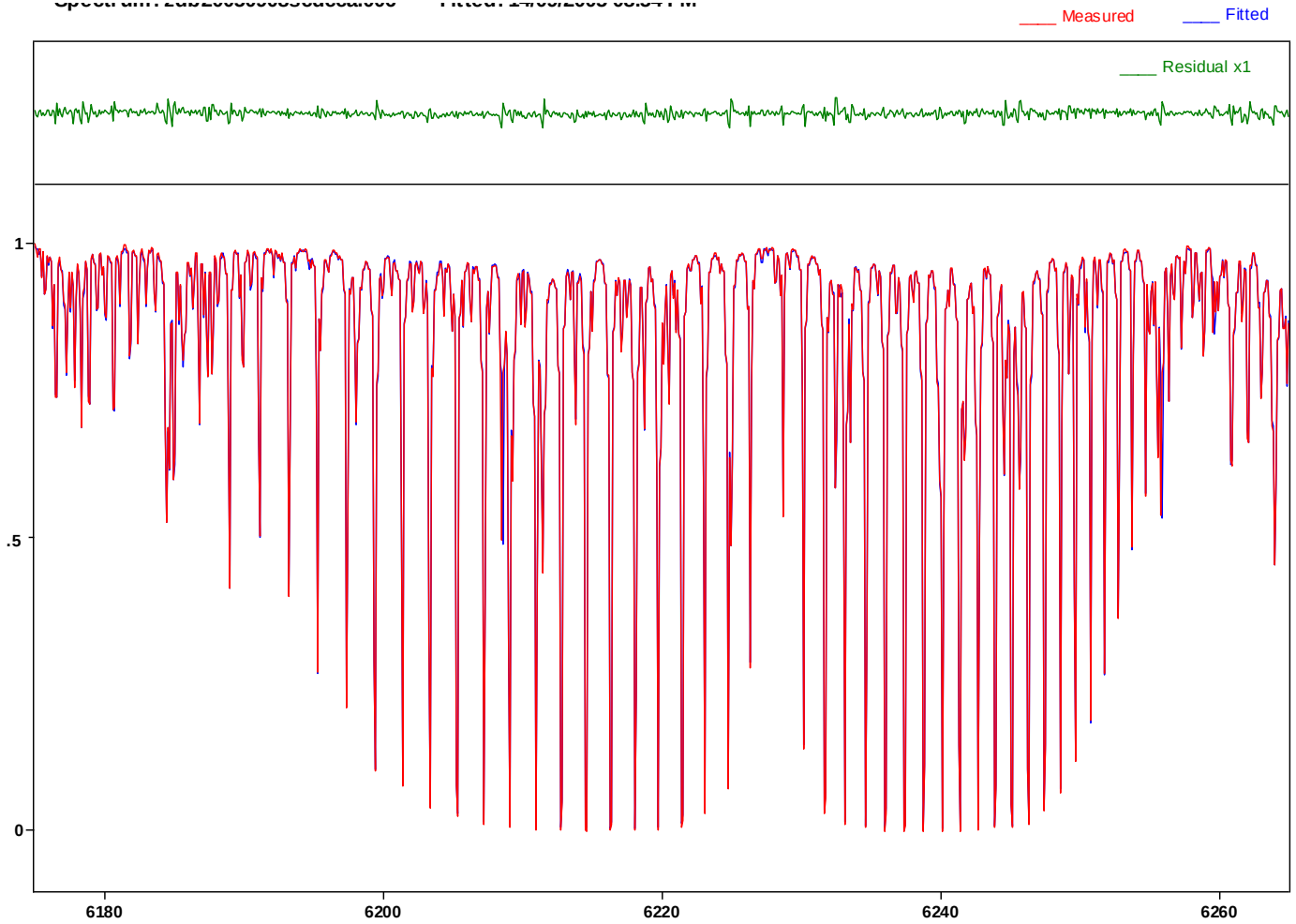



IFS 125HR

Near IR solar absorption spectrum overview



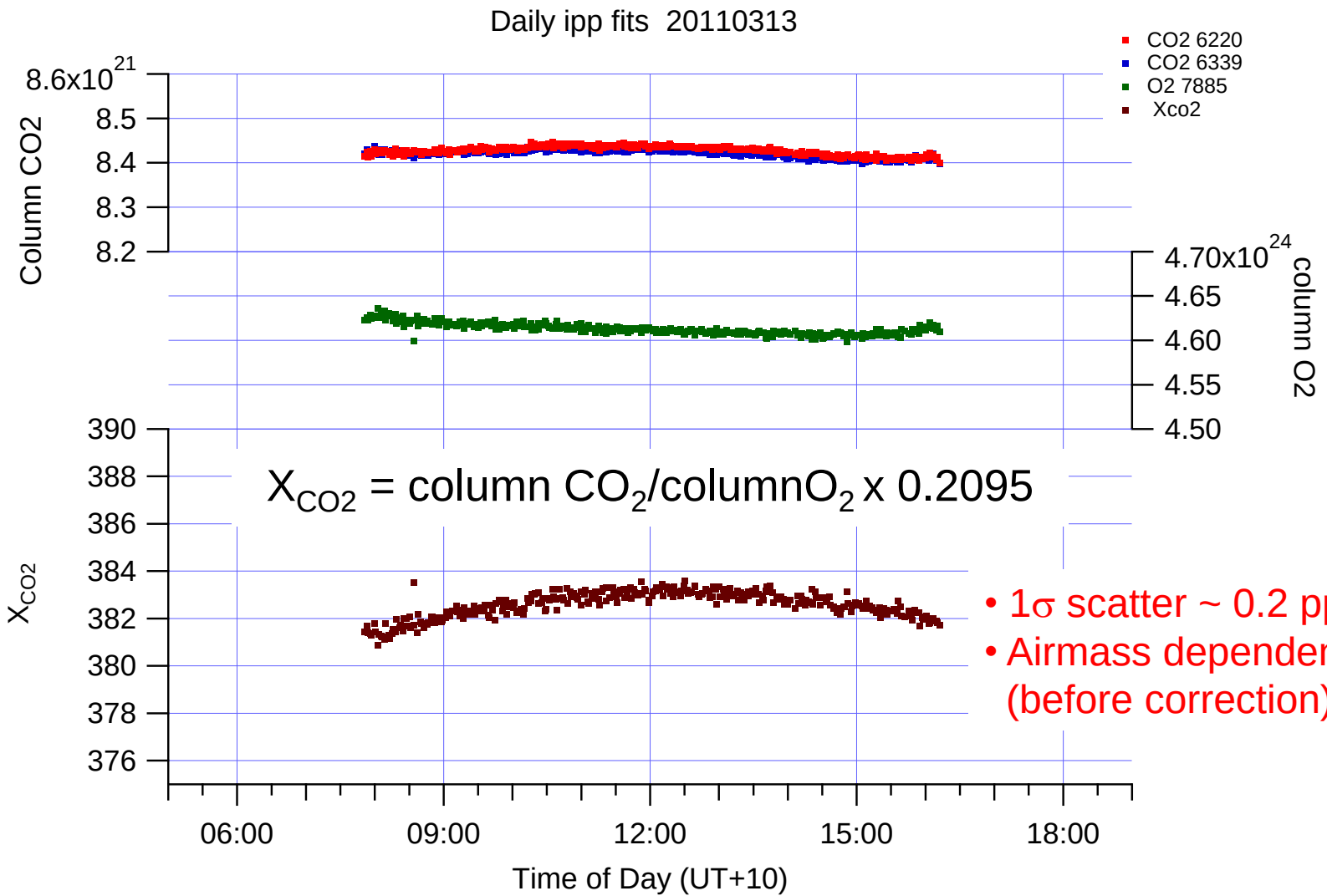
Analysis by spectrum fitting
(GFIT, profile scaling)
e.g. 6230 cm^{-1} CO_2 band



co2 = 8.16E+21 (1.09E+20)

SZA: 73.904 Zobs: .03

Raw daily column measurements Wollongong, clear sky day



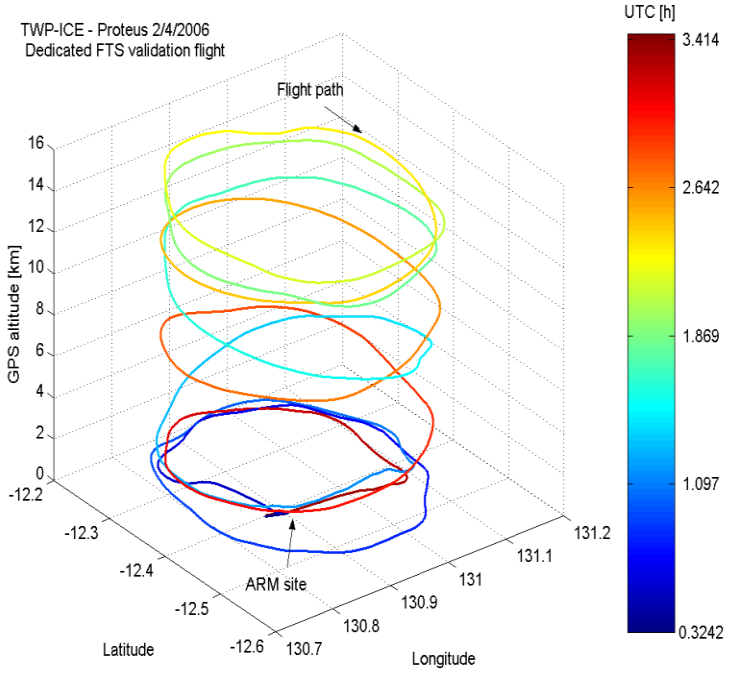
- 1σ scatter ~ 0.2 ppm (0.05%)
- Airmass dependence ~ 2ppm (before correction)

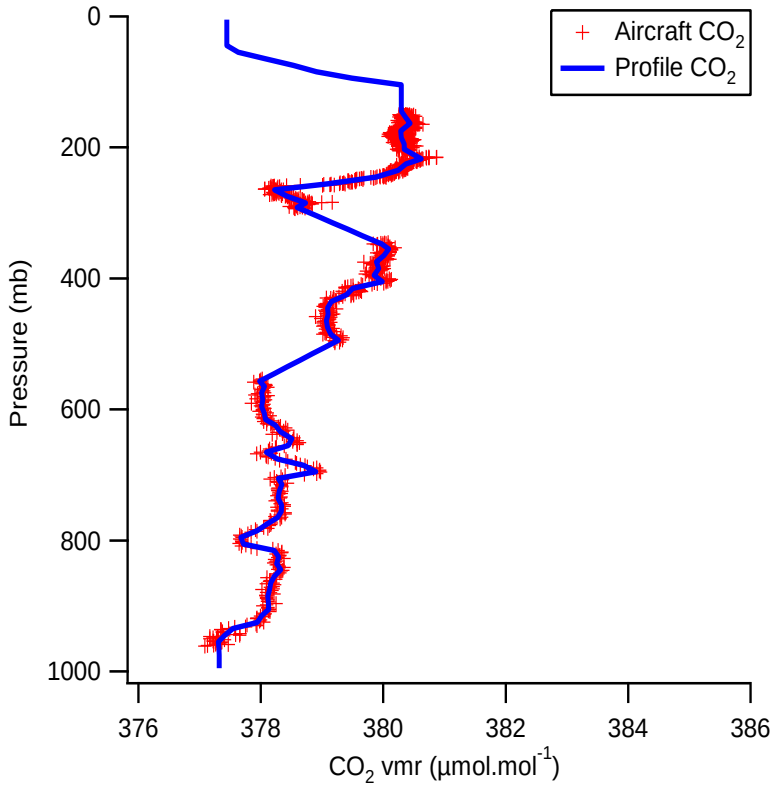
Precision and accuracy: CO_2

- *Precision* achieved: repeatability <0.2 ppm
  - 1-σ repeatability, single measurements
- *Accuracy* by comparison of TCCON total columns with integrated aircraft in situ profiles using WMO-calibrated instruments
  - eg. HIPPO, TWP-ICE, IMECC
  - Extrapolated to top and bottom of the atmosphere

Validation – relation to WMO scales

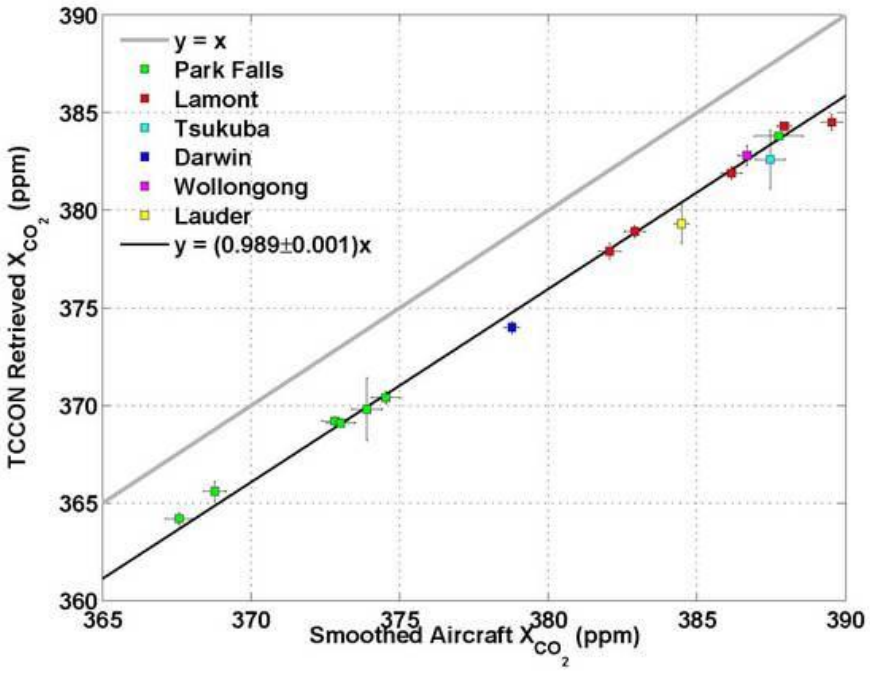
- eg TWP-ICE Darwin 2006
- CO_2 analyser on board
  - 1Hz CO_2, 0.1ppm precision
- Integrate vertical profile
- Also HIPPO, all species



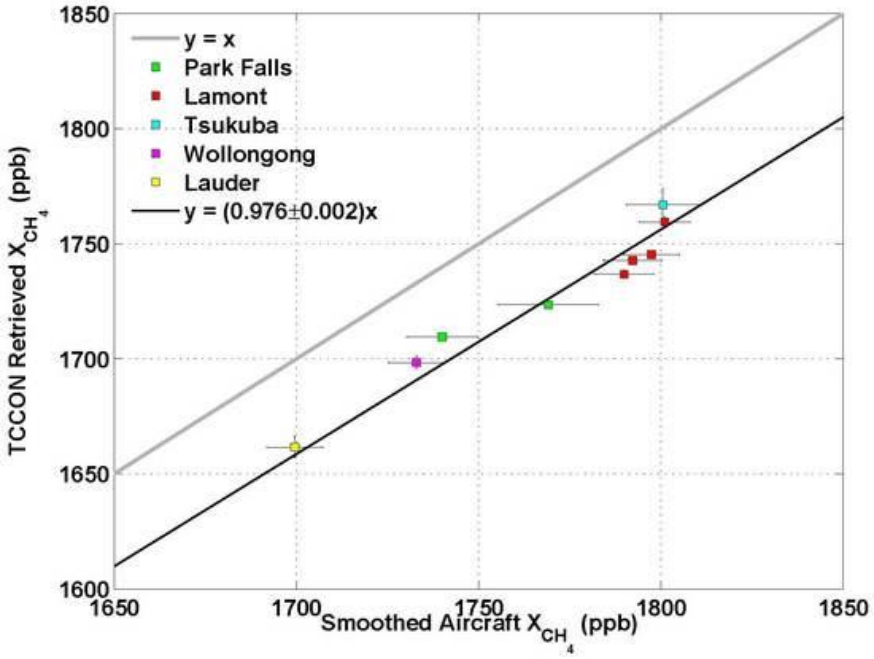


TCCON validation against aircraft profiles CO_2 and CH_4

CO_2 (1σ 0.1%)



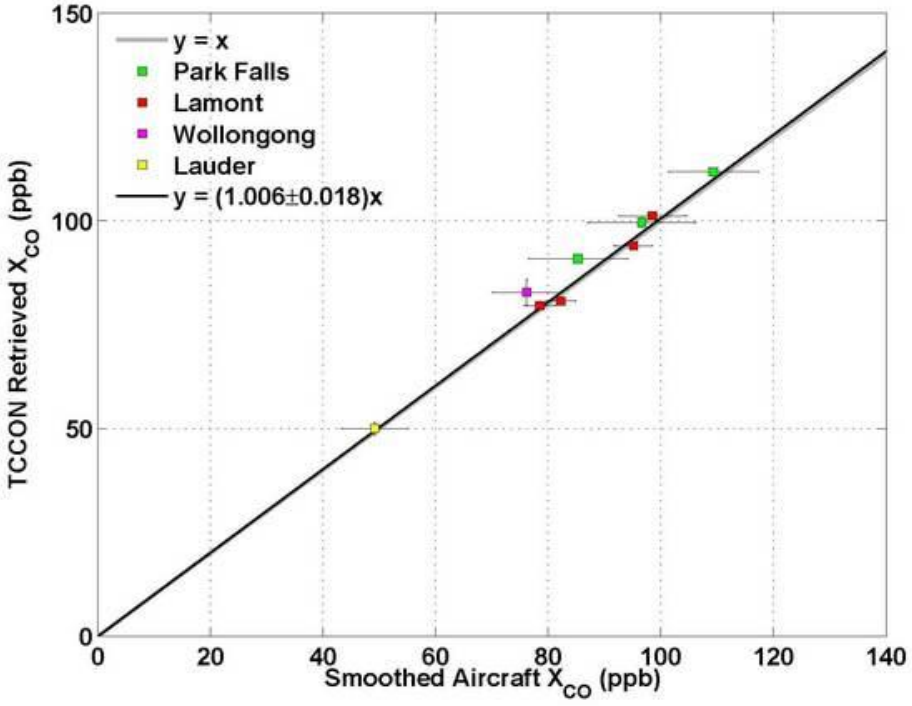
CH_4 (1σ 0.2%)



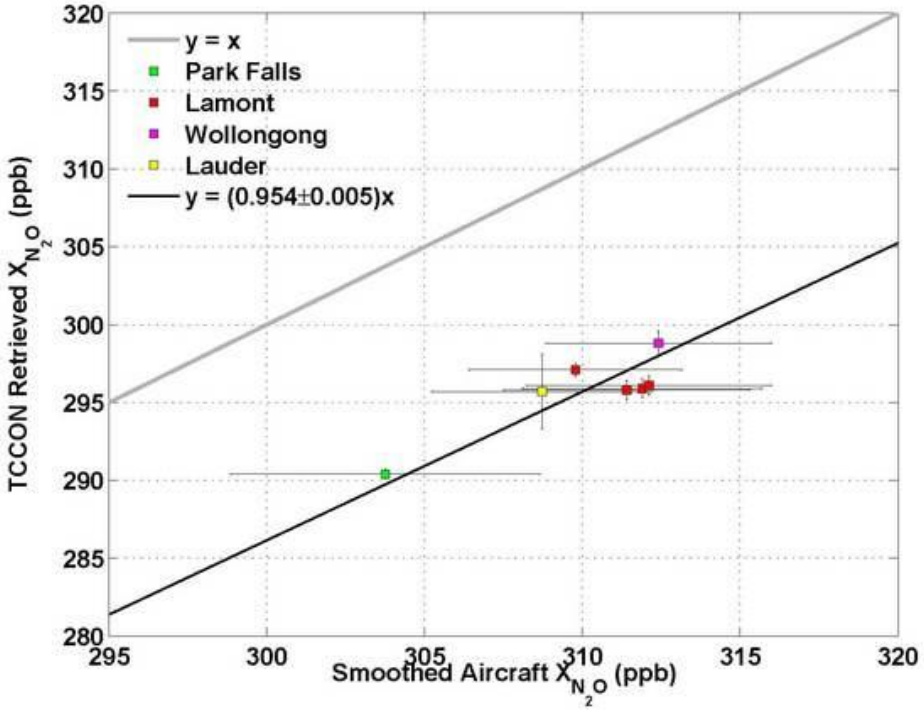
- Further detail:
  Wunch, D., et al. (2010), Calibration of the Total Carbon Column Observing Network using Aircraft Profile Data, *Atmos. Meas. Techn., 3, 1351-1362.*

TCCON validation against aircraft profiles CO and N_2O

CO (1σ 2%)



N_2O (1σ 0.5%)



- Further detail:
  Wunch, D., et al. (2010), Calibration of the Total Carbon Column Observing Network using Aircraft Profile Data, *Atmos. Meas. Techn., 3, 1351-1362.*

Uncertainty overview (CO_2)

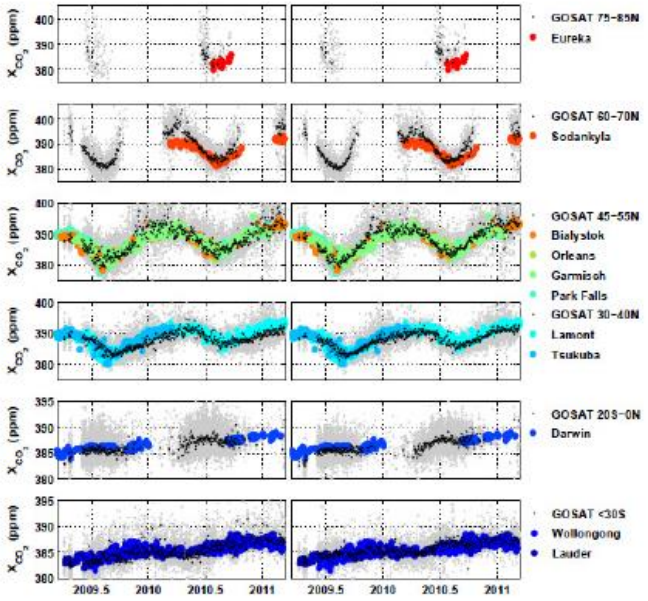
Effect	relative	Total column
Repeatability (spectrum-spectrum)	0.05%	0.2 ppm (1σ)
Comparability across network	0.1%	0.4 ppm
Uncorrected airmass dependence		0-2 ppm (high sza) <0.5 ppm (GOSAT)
Ghosts	< 0.2%	< 1ppm most sites
ILS	< 0.2%	< 1 ppm
Smoothing error (profile shape)	< 0.1%	< 0.4 ppm

More detail:

Wunch, D., et al. The Total Carbon Column Observing Network (TCCON), Phil. Trans. Roy. Soc. A, 369, 2087-2112, 2011.

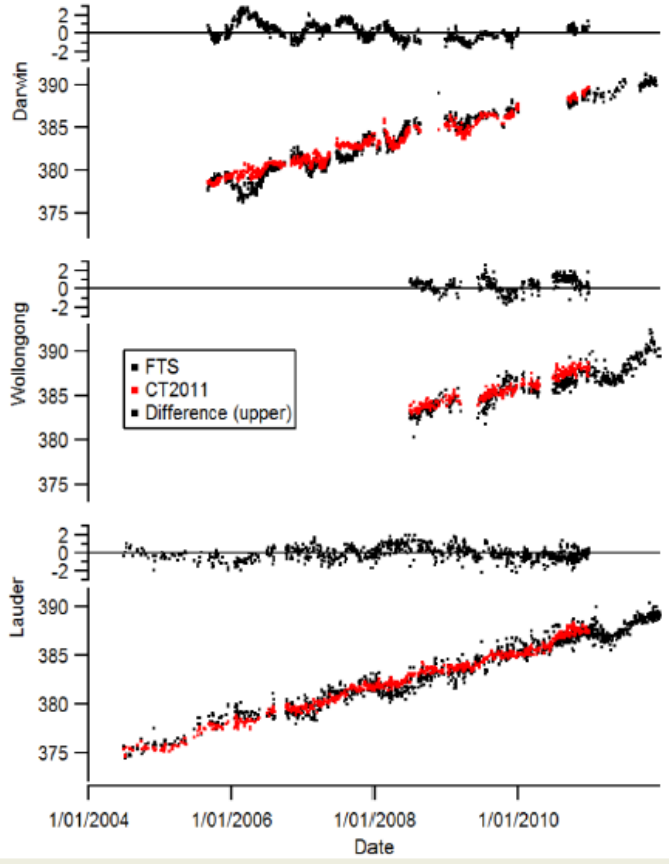
Satellite validation

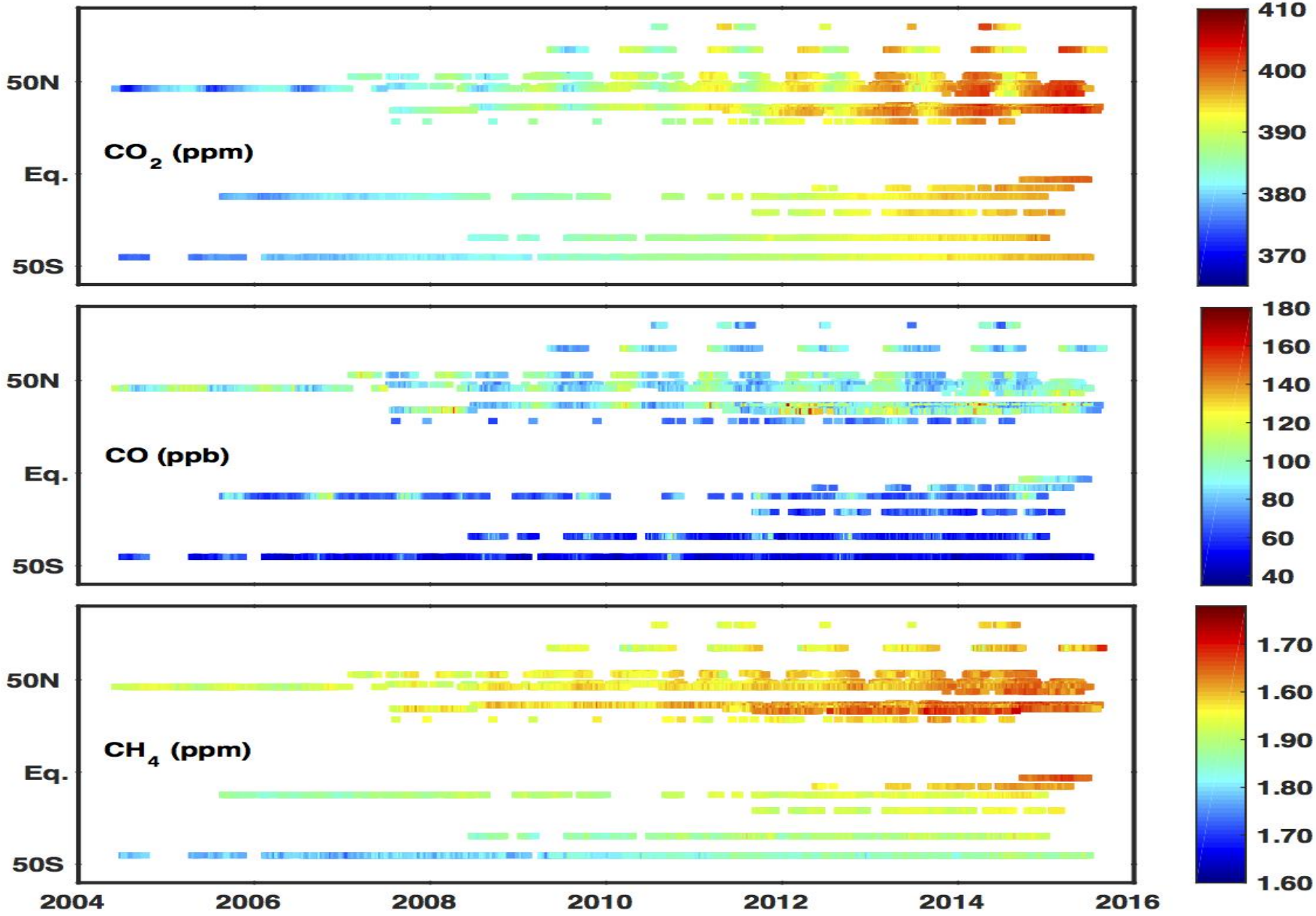
- Primary validation for GOSAT, OCO-2, SCIAMACHY GHG columns
- Several GOSAT retrieval algorithms
  - SH TCCON used to help derive satellite bias correction
  - TCCON used to assess algorithms (GHG-CCI)



SH Measurement-model comps

- Comparison to CarbonTracker 2011 shows model-measurement mismatch at Darwin in 2005-6 wet season





www.tccon.onrl.gov

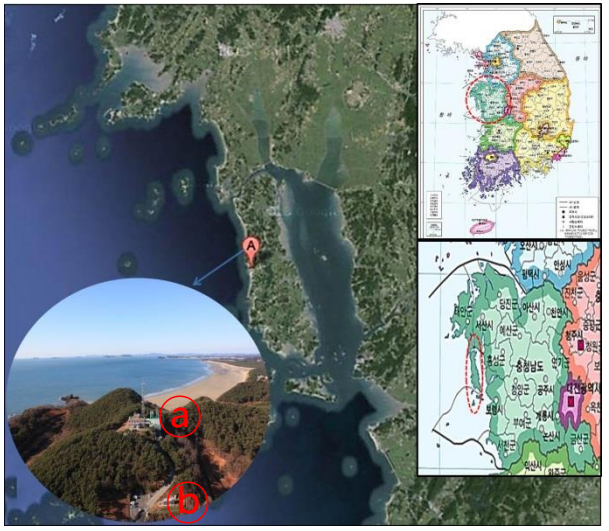
New and Upcoming TCCON Stations

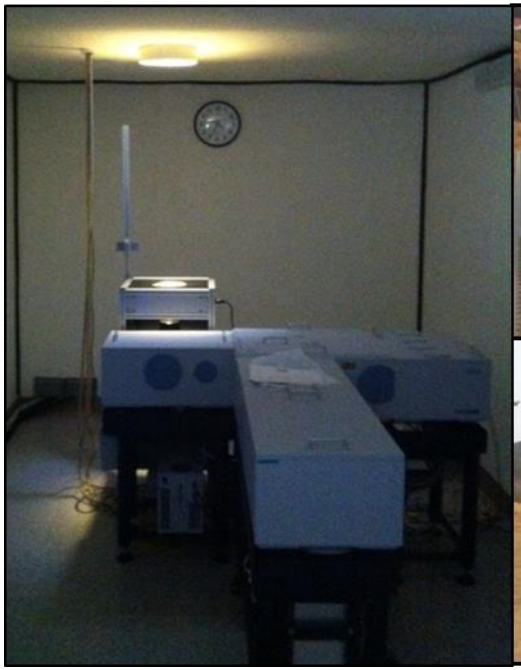
- Newly operational: Anmyeondo (South Korea)
- Setup phase: Burgos (Philippines), Hefei (China)

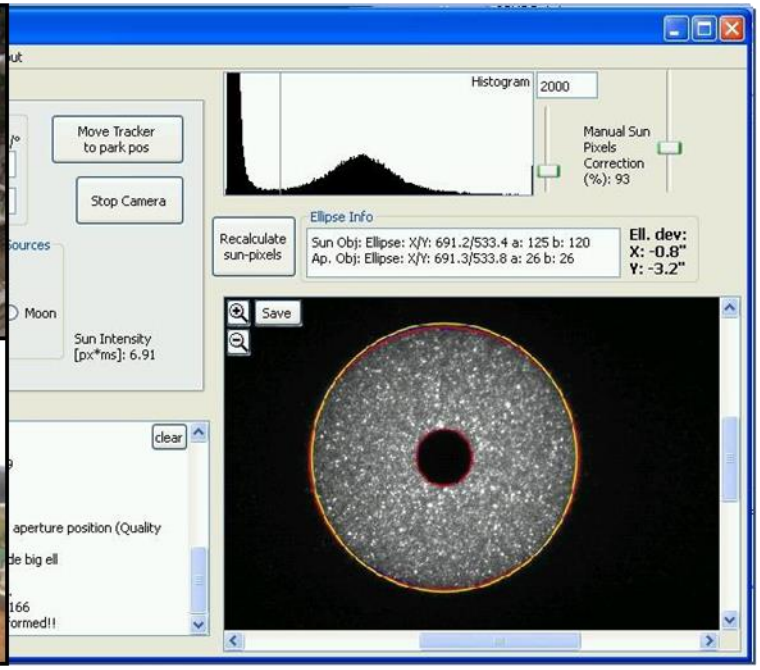
Figure by D. Feist, MPI-Jena

Anmyeondo, Korea

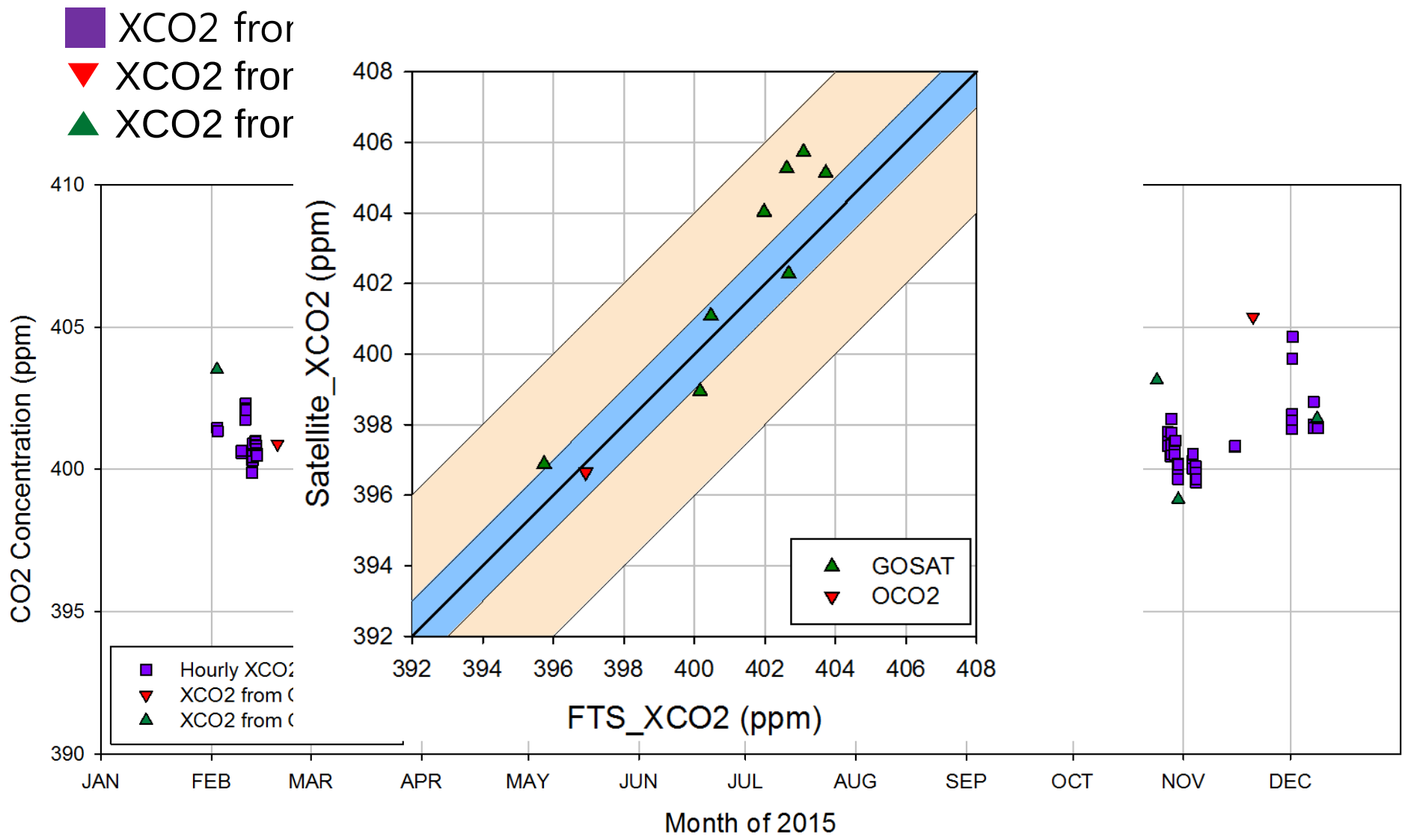
- ❖Anmyeondo is operational TCCON site located at mid-west Korea
- ❖Lat/Lon/Alt: 36°32N / 126°19E / 30 ma
- ❖A: WMO Regional GAW station
- ❖B: FTS site
- ❖IFS-125HR / A547N solar tracker / Camtracker
- ❖InGaAs, Si diode / CaF2 / NIR source
- ❖OASIS (Operational Automatic System for Intensity of Sunray)







Comparison of XCO2 from FTS, OCO-2 and GOSAT at the Anmyeondo site



TCCON Software Update (from 2014)

- GGG2014 data publicly available via CDIAC: **ftp://tccon.ornl.gov/2014Public/documentation/**
  - Permanent archiving
  - DOIs assigned to the datasets (please cite)
  - netCDF format

- Updated spectroscopy
- Updated solar line list
- Updated a priori profiles (small changes)
- Updated TCCON calibration curves

See also: https://tccon-wiki.caltech.edu/Network_Policy/Data_Use_Policy/Data_Description

Data use policy
Co-authorship and acknowledgement

1. Data are publically available
2. For planned publishable work, *please contact site PIs*
    1. Abstract of intent
    2. Allow site PI inputs as appropriate
3. Co-authorship or acknowledgement case by case
4. Manuscript drafts to TCCON PIs well in advance
    1. Allow reasonable time for comment

5. Future publication in data journal/archives with DOI ?
6. See wiki reference:
   https://tccon-wiki.caltech.edu/Network_Policy/Data_Use_Policy

TCCON data uptake and usage

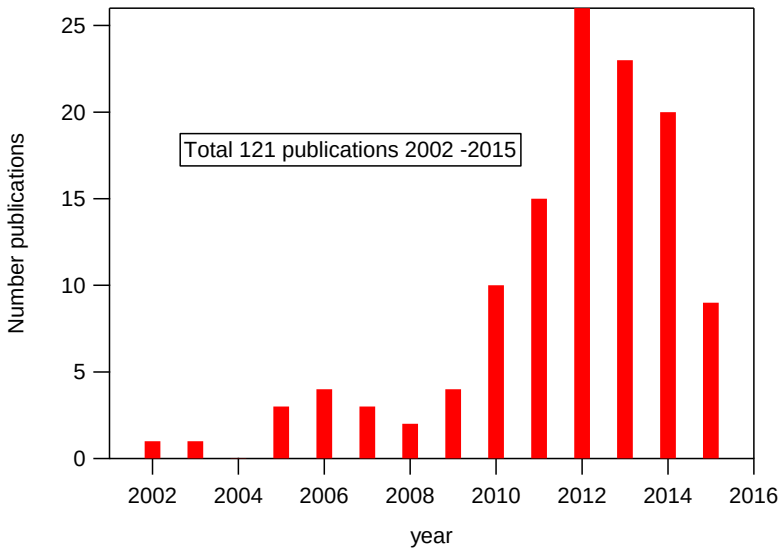
Modelling

- Inversions, carbon tracker …
- Source-sink estimations and distributions
- Emissions verification

Satellite validation

- GOSAT, OCO-2, CarbonSat …
- Satellite retrieval algorithms

› 120 TCCON publications



Conclusions

- TCCON is growing and starting to cover more of the gaps on the carbon cycle map.
- TCCON data continue to be heavily used in validation and science.
- Data delivery to archive has been timely
- Network continues to expand:
  - Missing: some parts of China, India, Siberia, Brazil
- TCCON is mission-critical to a number of current and future GHG satellite missions.
- TCCON data is freely available. Observe the data policy!
- While TCCON data is free, operation of TCCON is not. Setting up and running a TCCON station anywhere in the world for 10 years: ~1.5 MEUR