High precision FTIR measurements of atmospheric trace gases

1. **Multi-species in situ FTIR analyser**
2. **Total Carbon Column Observing Network (TCCON)**

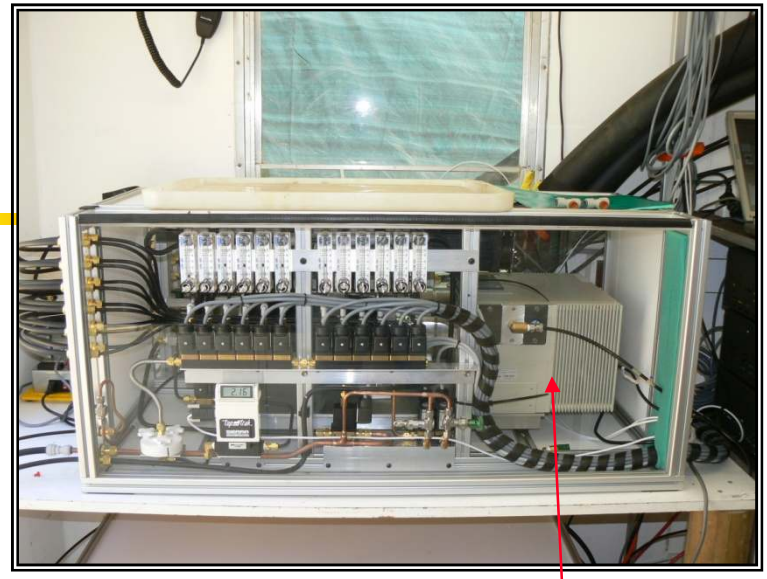
David Griffith
University of Wollongong
Australia

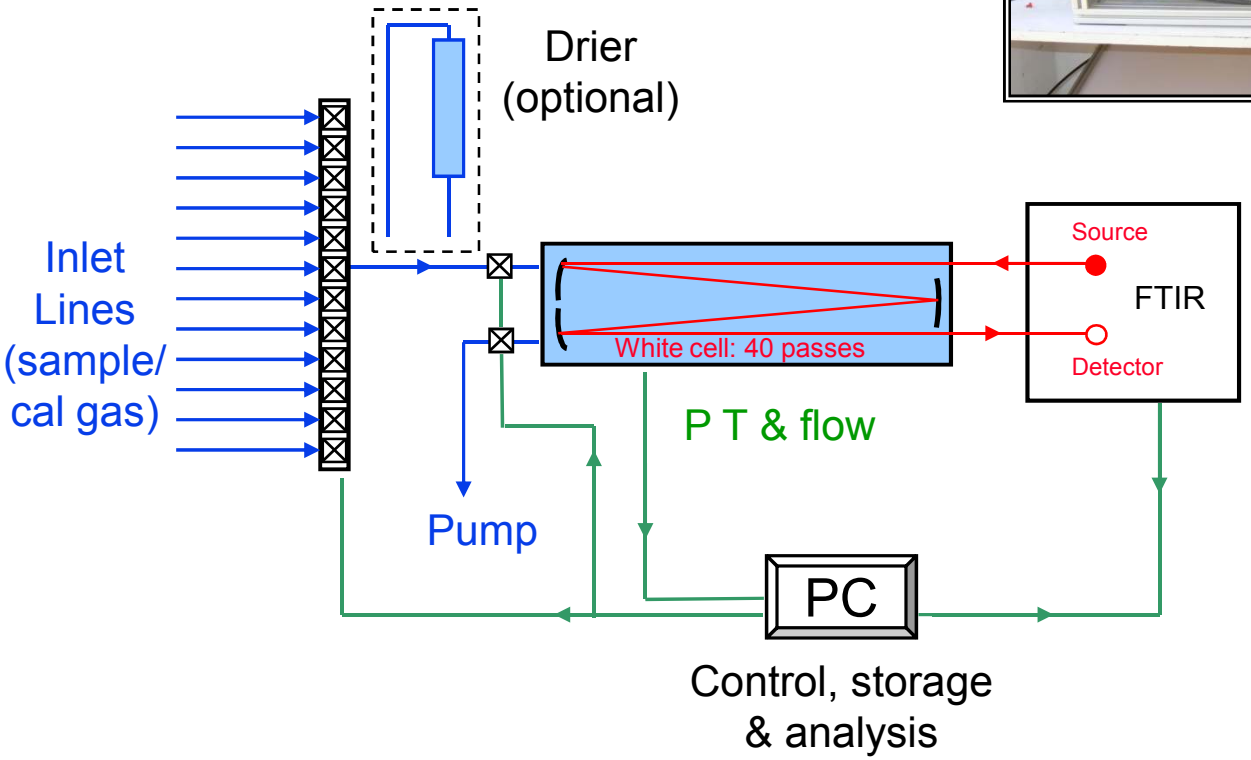
University of Wollongong

Centre for Atmospheric Chemistry

Atmospheric Chemistry & Spectroscopy

1. FTIR trace gas analyser



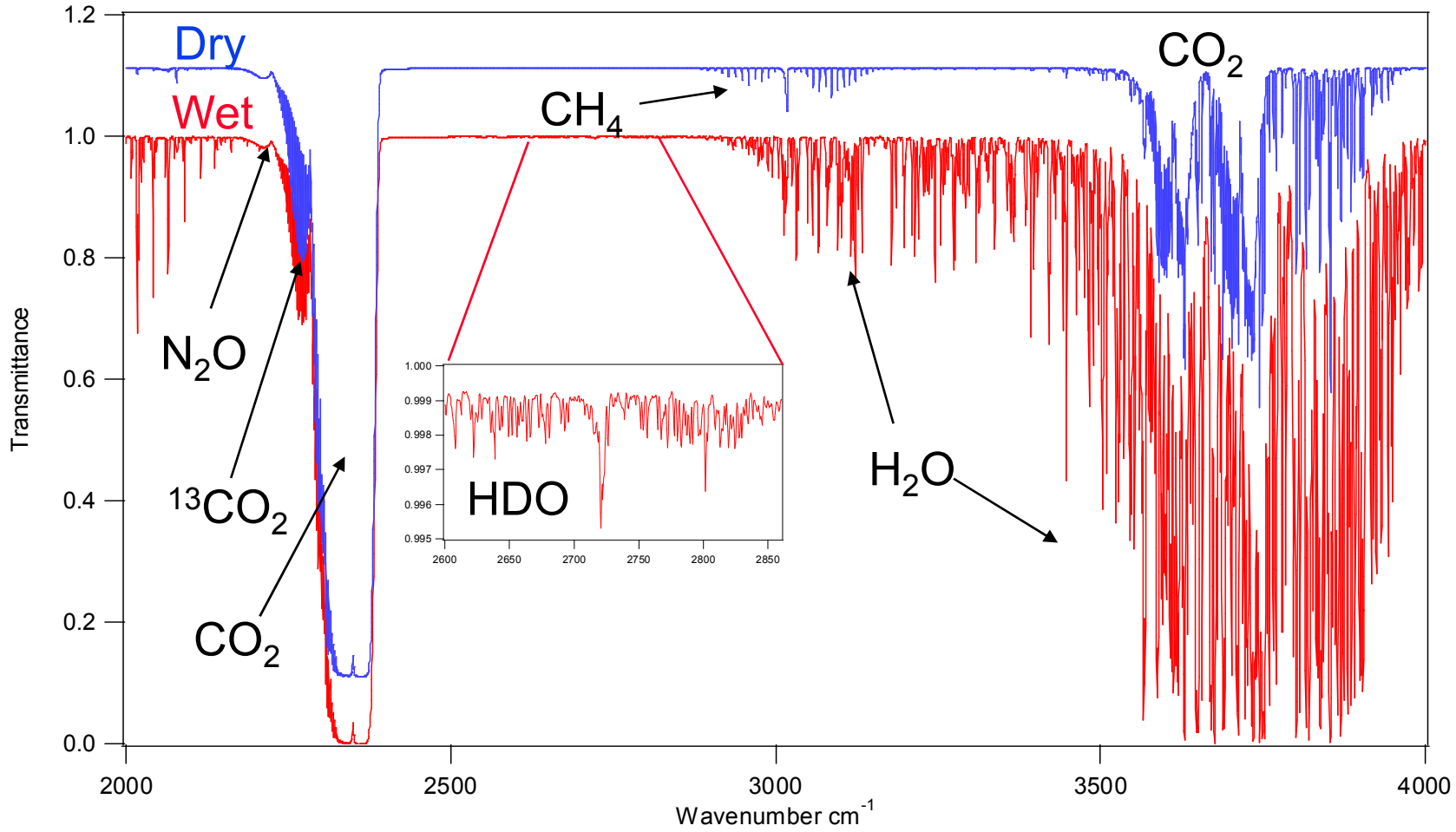


Bruker "IRcube" FTIR

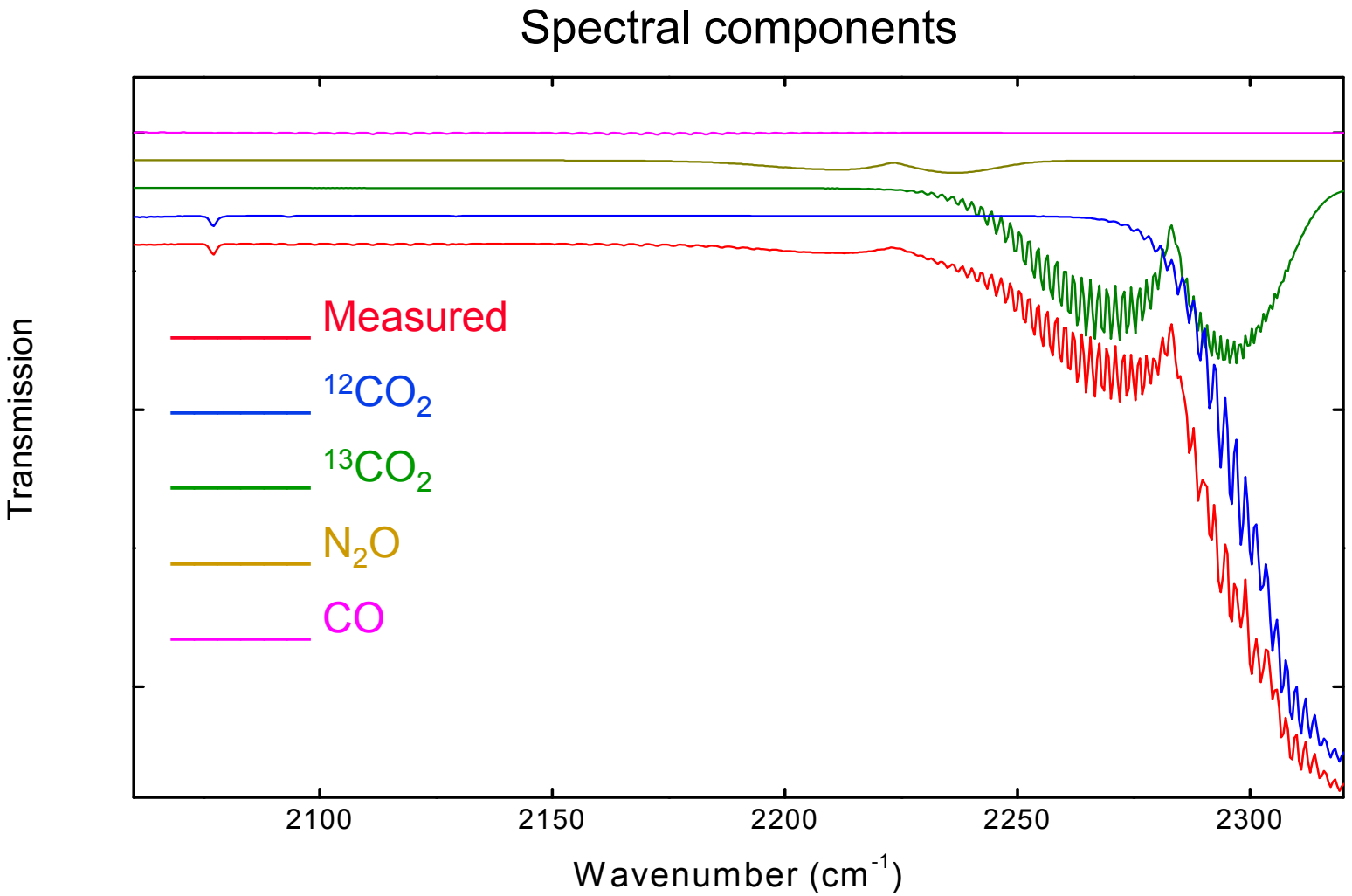
Fully automated PC control of all sample handling, spectrum collection, spectrum analysis, logging and data storage

FTIR and cell

Mid-infrared spectrum of clean air

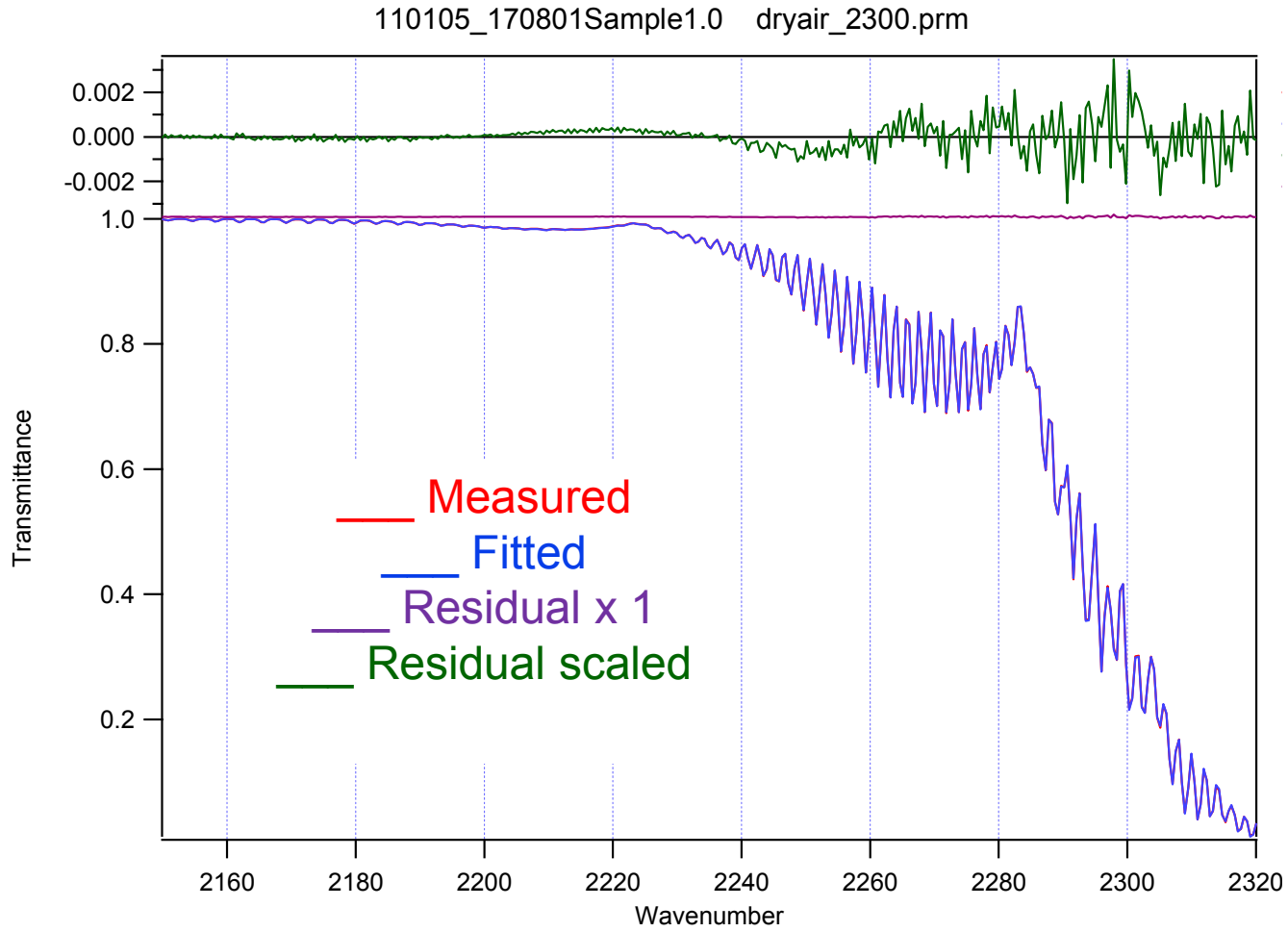


IR spectrum of clean air ~ 2200 cm^{-1}



Spectrum analysis: least squares fitting

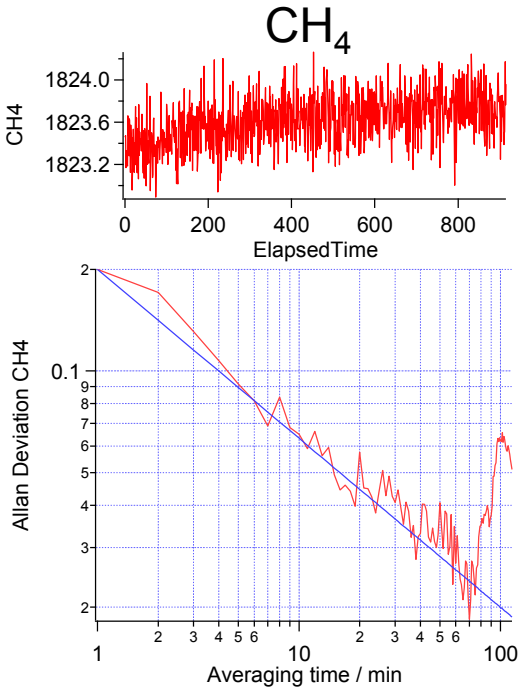
MALT model, Hitran database

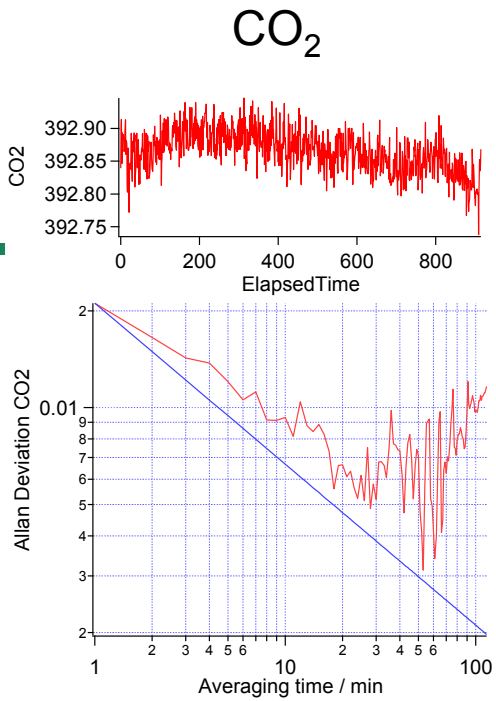


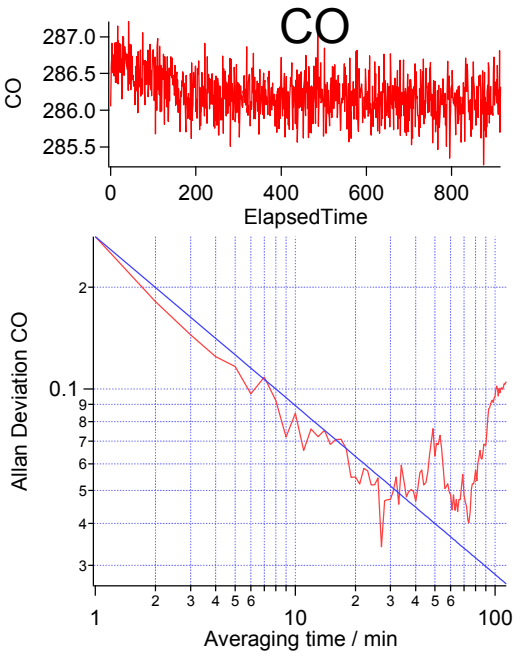
- Measured spectrum fitted with calculated spectrum for minimum residual (least squares)
- Different regions to fit for CO_2, $^{13}CO_2$, CH_4, N_2O, CO, etc.
- Precision typically <0.1%

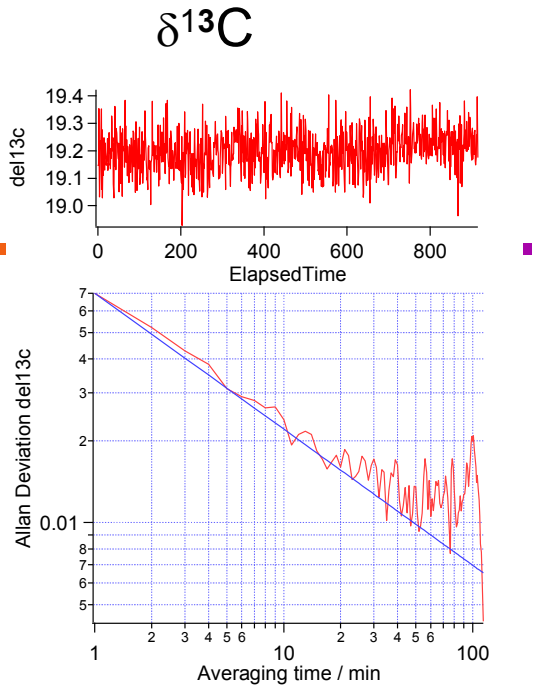
Allan deviations

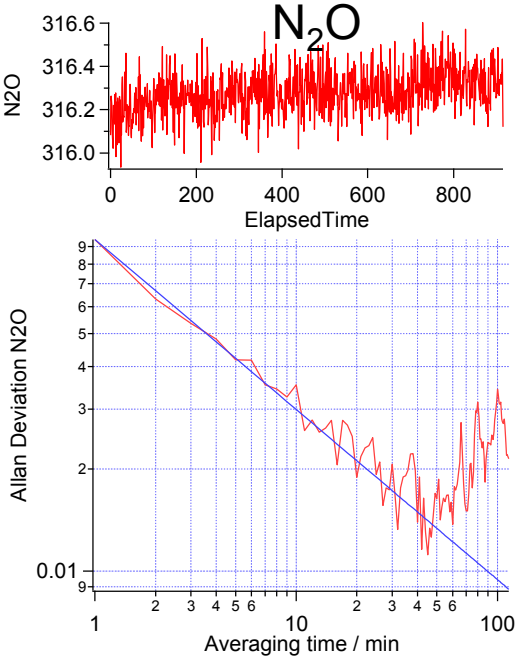
- Simultaneous determination of repeatability from a whole air sample









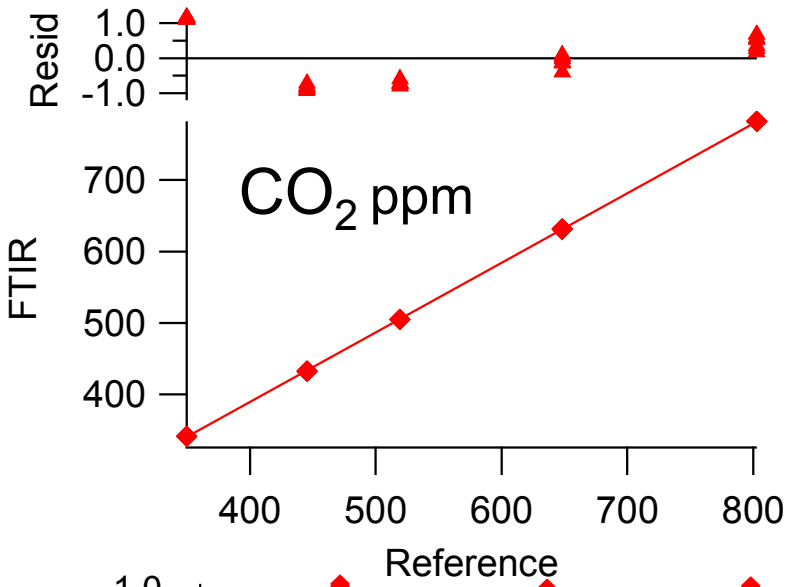


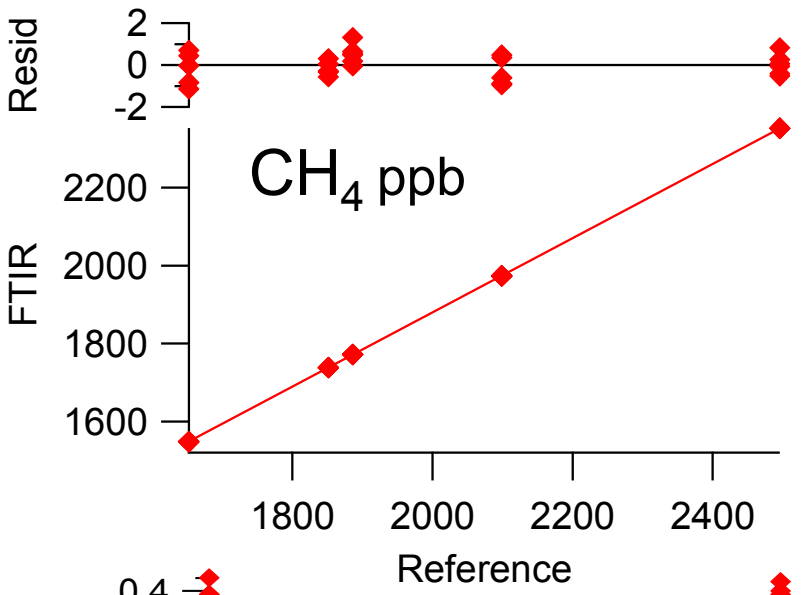
Allan deviation - summary

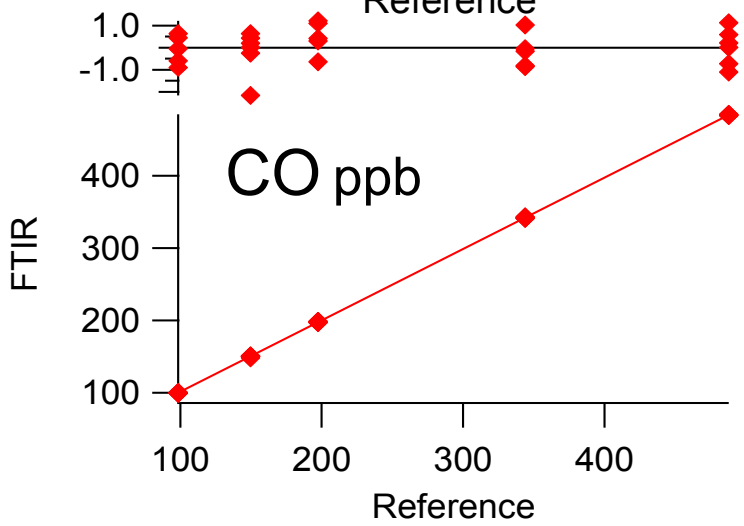
Species	FTIR		GAW recomm.
	1 min	10min	
CO_2 µmol mol^{-1}	0.02	0.01	0.1 (0.05 in SH)
CH_4 nmol mol^{-1}	0.2	0.1	2
CO nmol mol^{-1}	0.3	0.1	2
N_2O nmol mol^{-1}	0.09	0.04	0.1
$\delta^{13}C$ in CO_2 ‰	0.03	0.02	0.01
δD in H_2O ‰	1.2	0.5	-
$\delta^{18}O$ in H_2O ‰	0.5	0.2	-

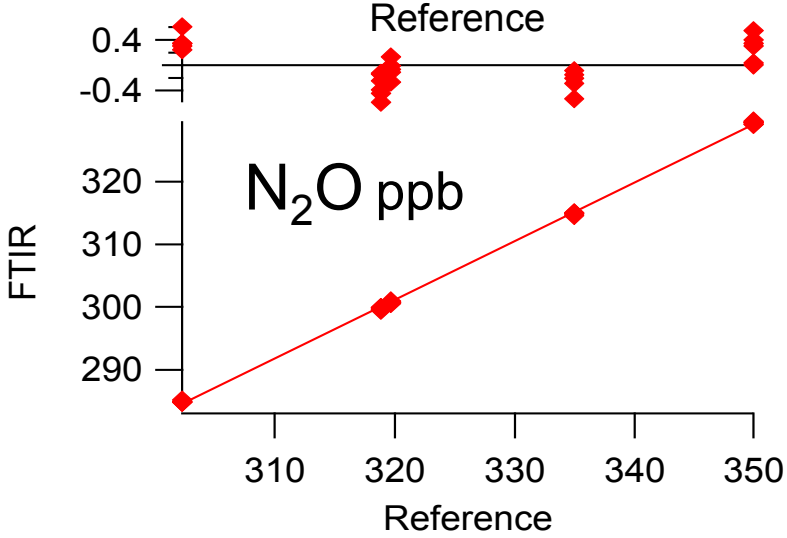
Calibration

FTIR vs reference gases (MPI-Jena)



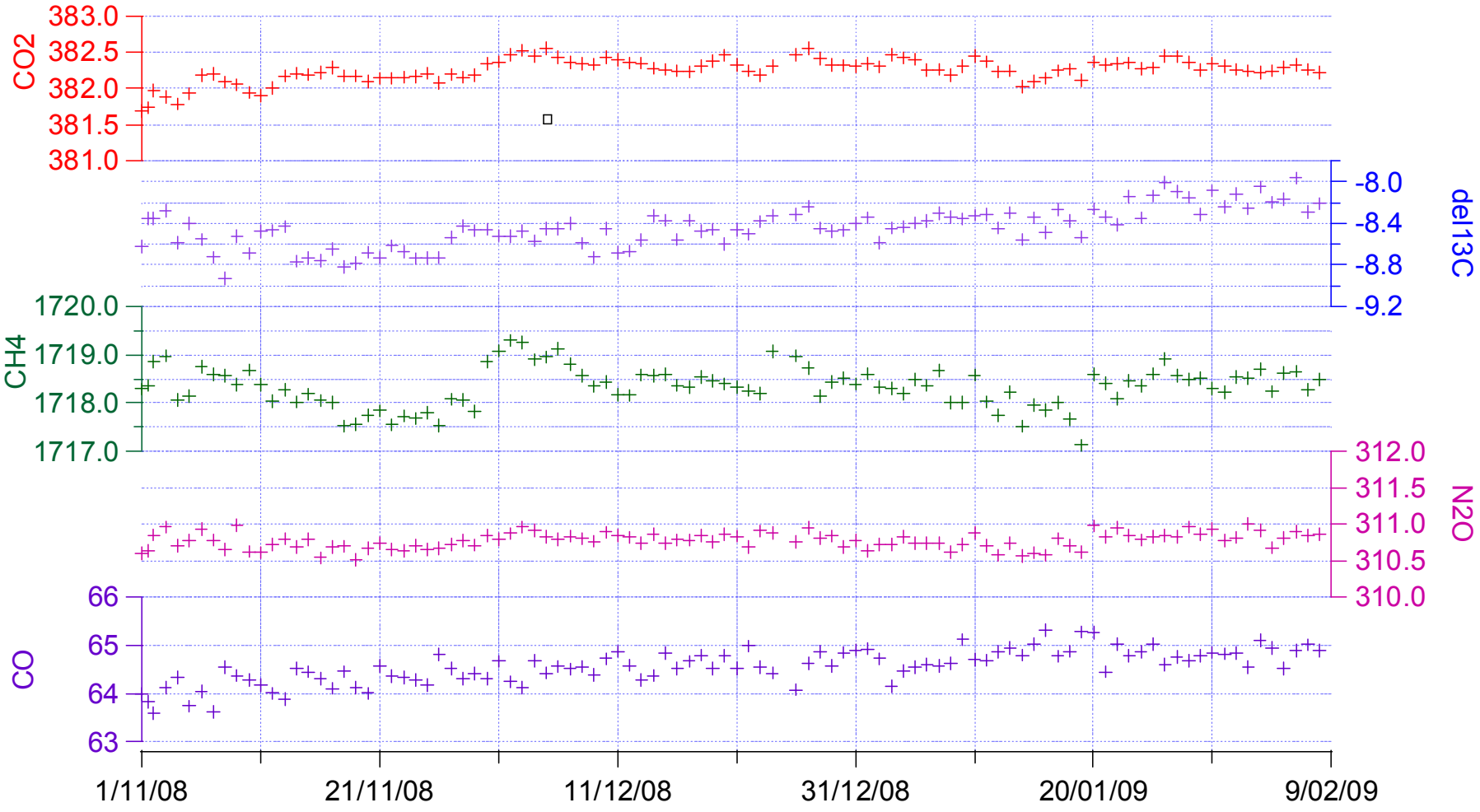






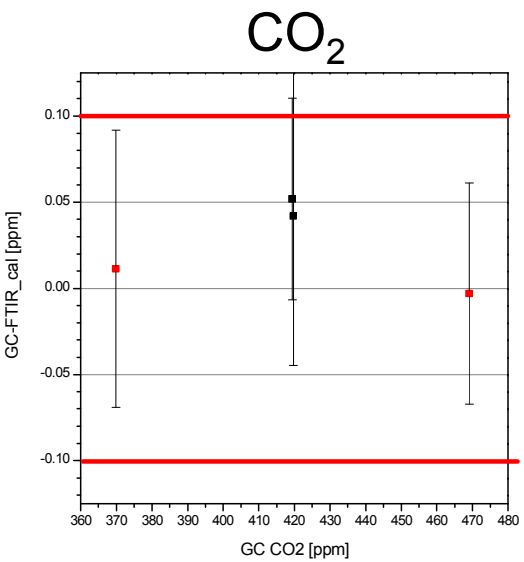
Calibration: stability

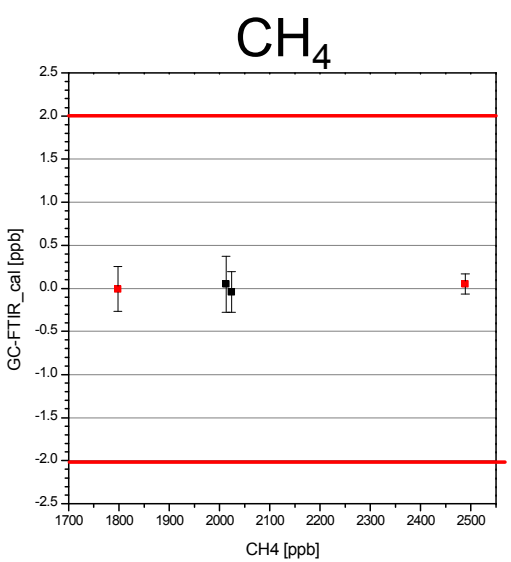
100 daily target tank raw measurements

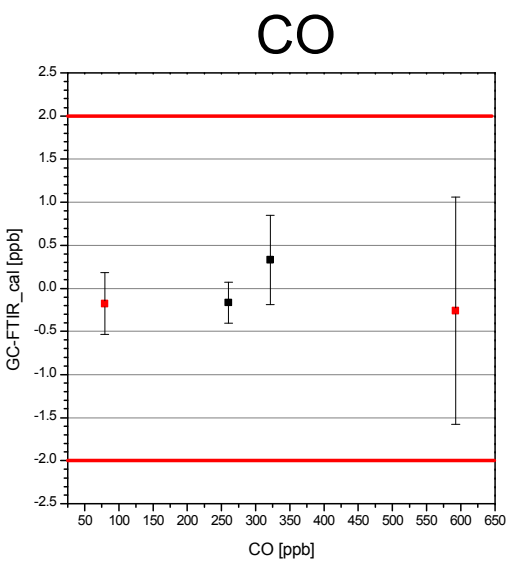


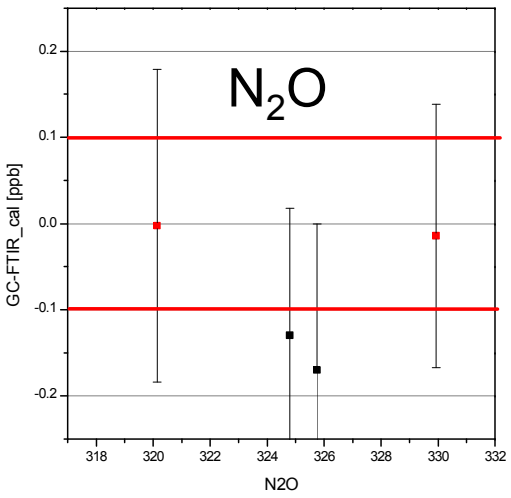
ICOS reference tank measurements

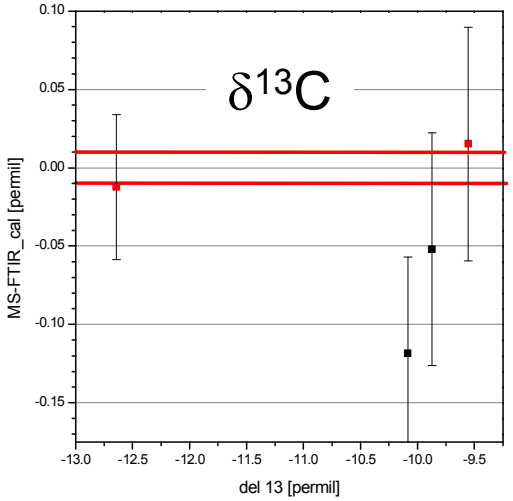
thanks to Sam Hammer, U. Heidelberg







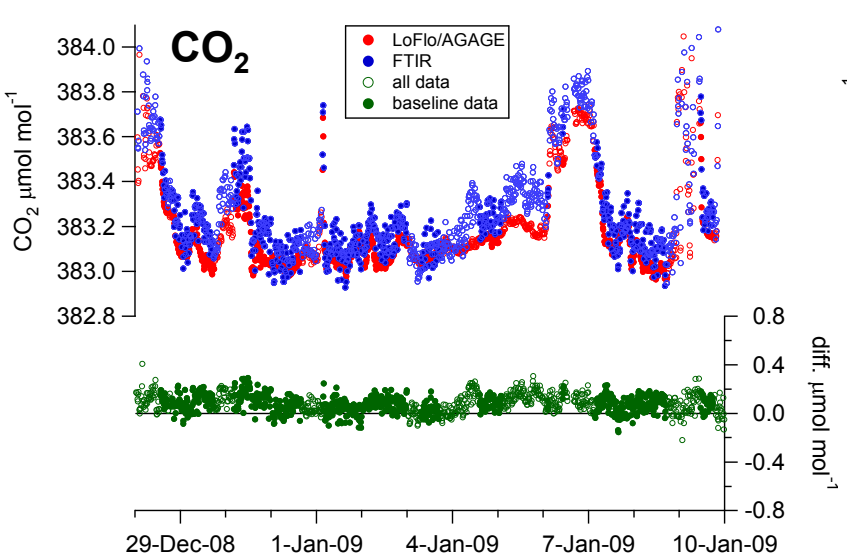


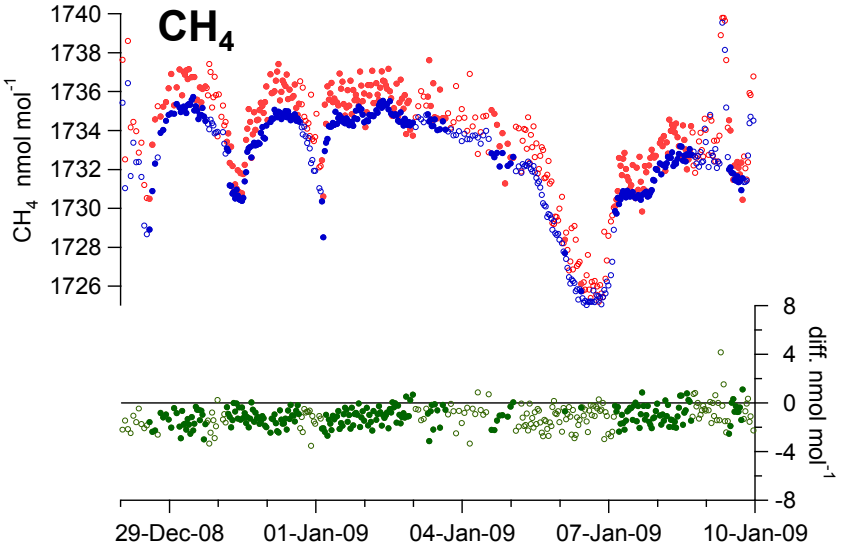


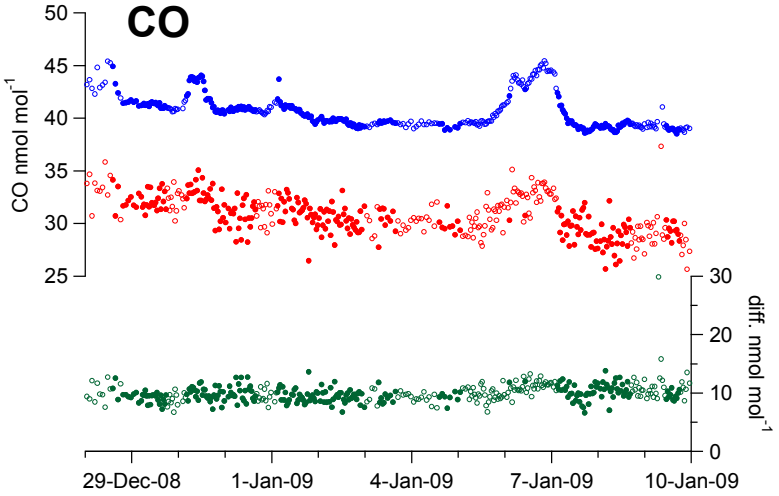
GAW recommended accuracy

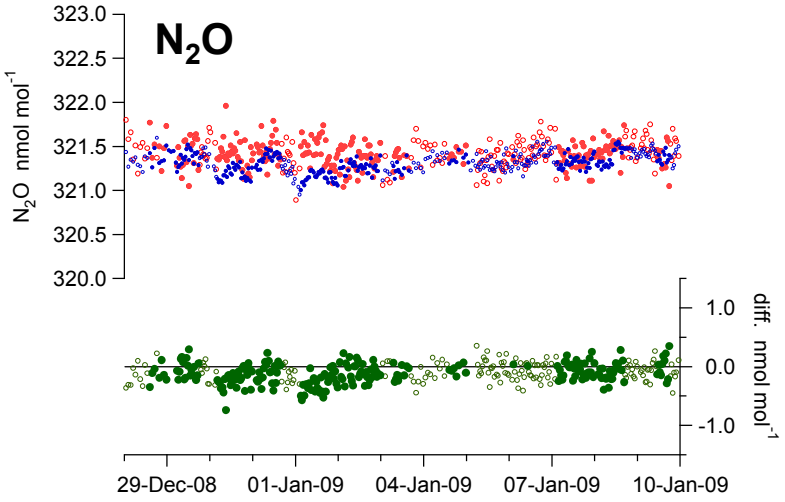
FTIR vs LoFlo / AGAGE @ Cape Grim

FTIR Loflo/AGAGE



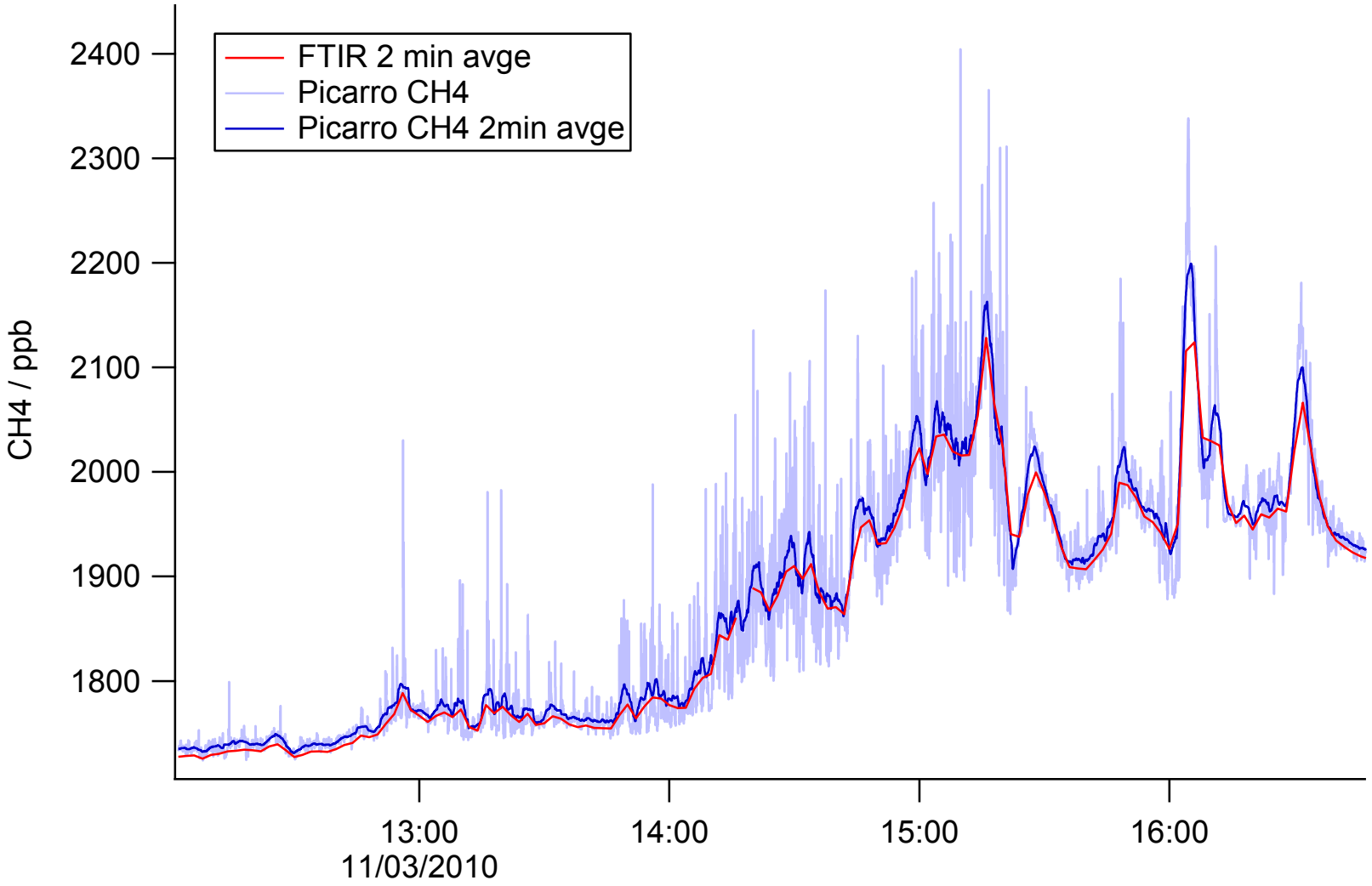






FTIR-Picarro comparison: CH_4

GASLAB March 2010



FTIR vs laser

FTIR

- Broadband spectrum ☺
  - Multiple components
  - Save spectra - reanalysable
- Thermal source – globar ☹
  - Low brightness
  - => best time resoln. ~ 1 sec
- Mid IR, atmospheric pressure ☺
  - Strong absorption
- Wide spectrum band fit ☺
  - more spectral information
  - Good stability

Laser

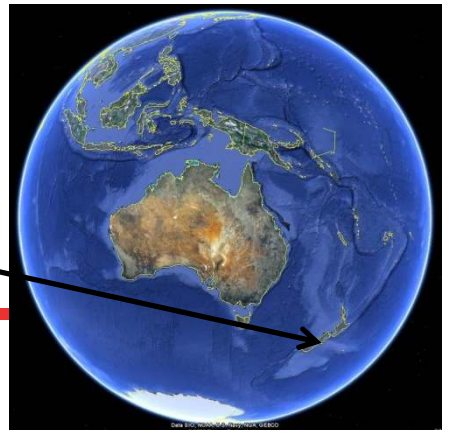
- Narrowband, single lines
  - 1-3 species (per laser)
- Laser source ☺
  - High brightness
  - => high SNR, fast meas.
- Near IR, low pressure ☹
  - Weak absorption
  - MIR lasers becoming available
- Narrow band fit ☹
  - less spectral information
  - Drift, more freq. calib.

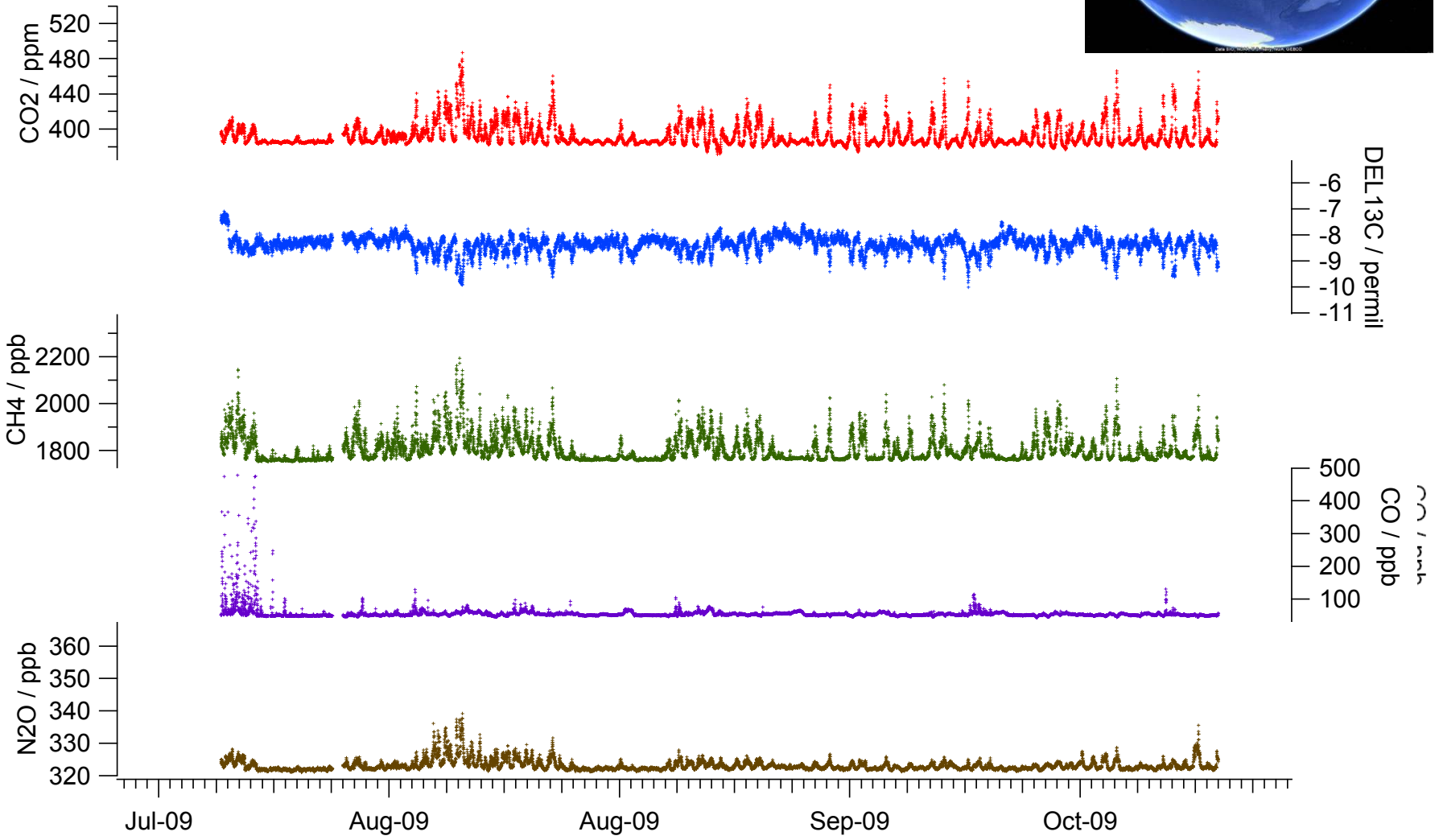
Net result: similar precision

Applications

- Continuous multispecies trace gas measurement
  - Clean, urban, agricultural air
  - Limestone caves
  - Mobile platforms (e.g. train)
- Flux measurements (esp. agriculture)
  - Tower profiles
  - Micromet. methods
  - Automated soil flux chambers
- Open path FTIR spectrometer
  - Tracer methods (multicomponent measurements)

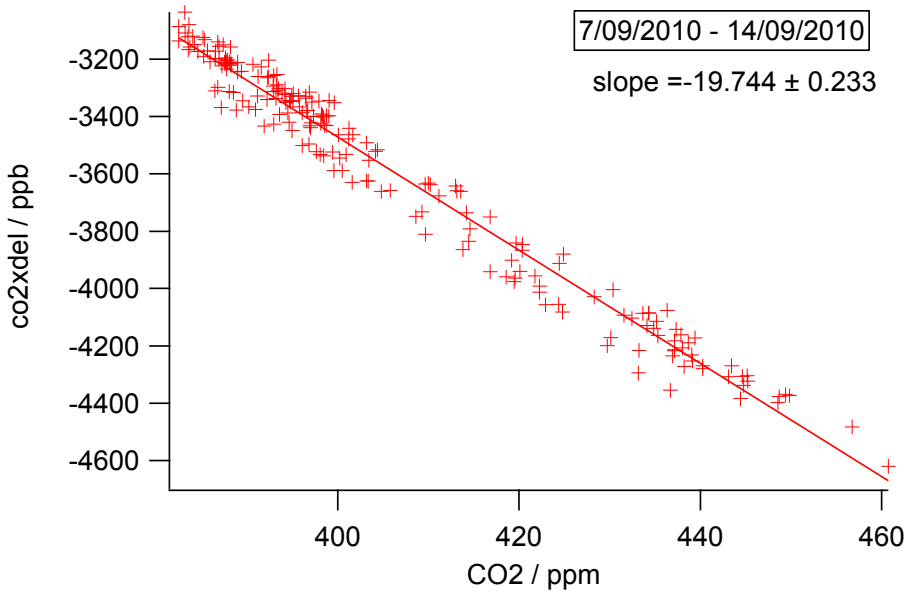
Long term clean air measurements Lauder NZ



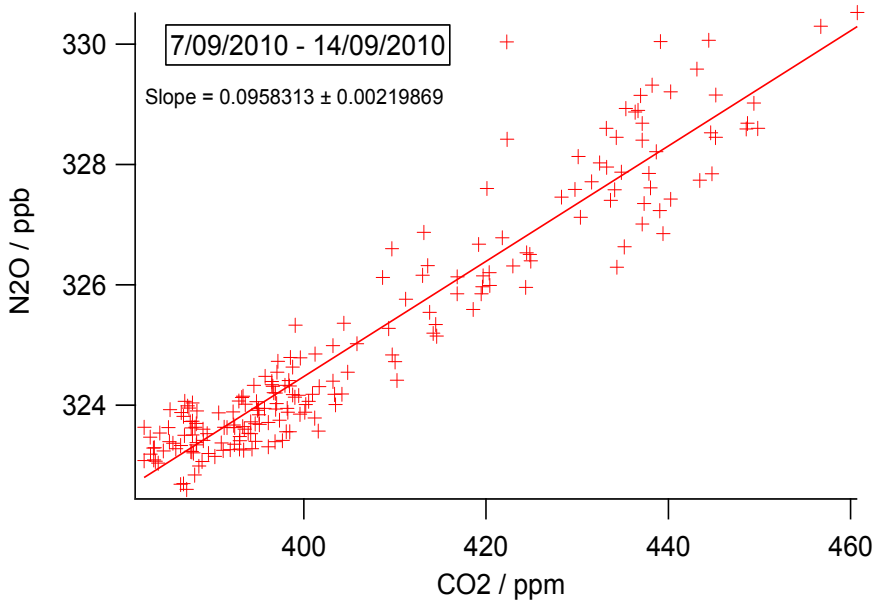


Trace gas correlations
Utilising the multi-component advantage

$\delta^{13}C.CO_2$ vs CO_2

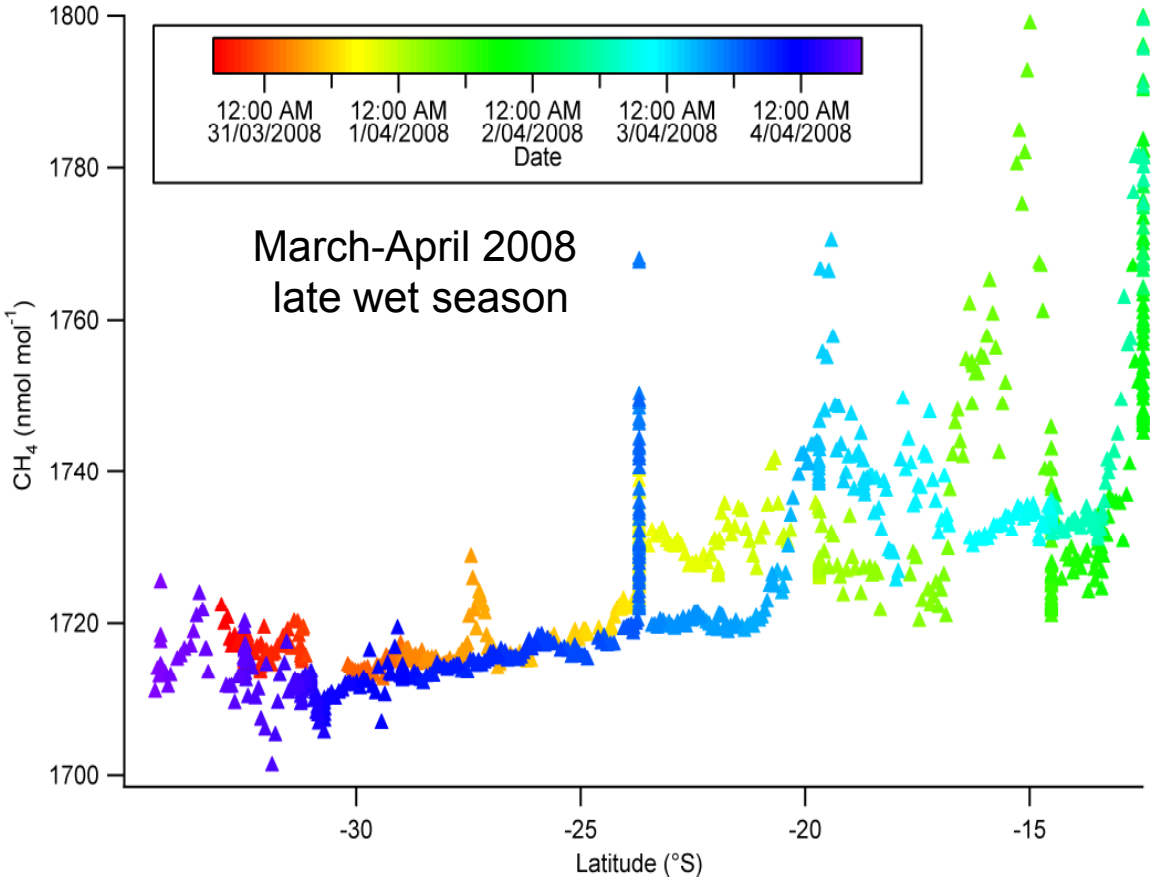


N_2O vs CO_2

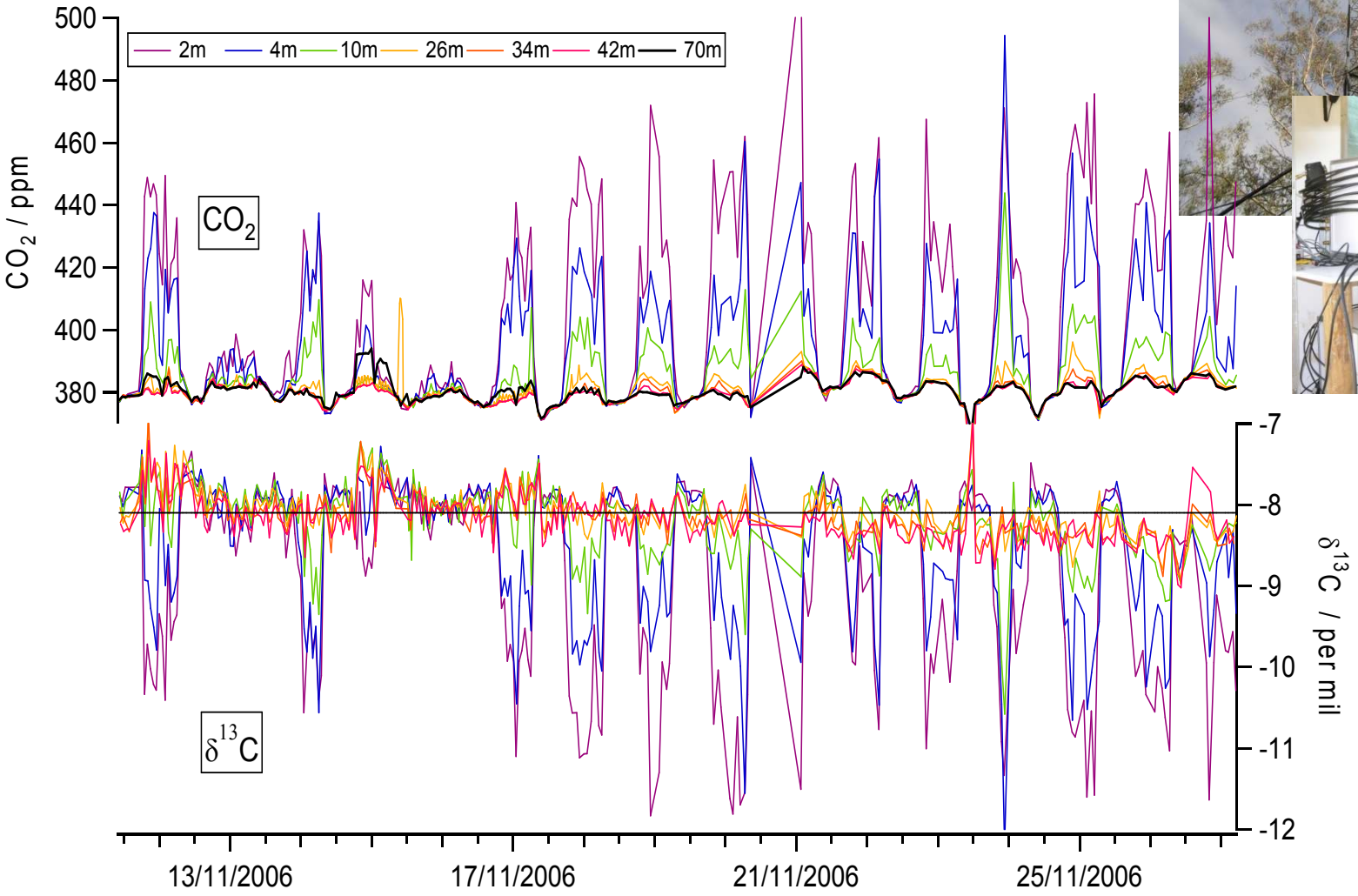


Mobile measurements:
Transects of the Australian continent

Enhanced methane concentrations in the tropical wet season

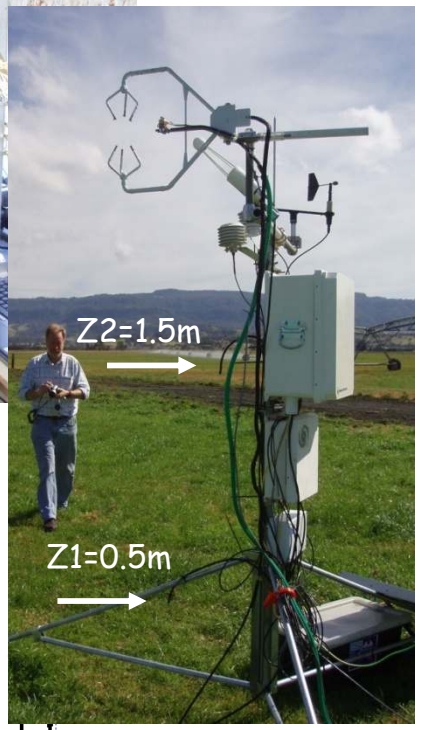


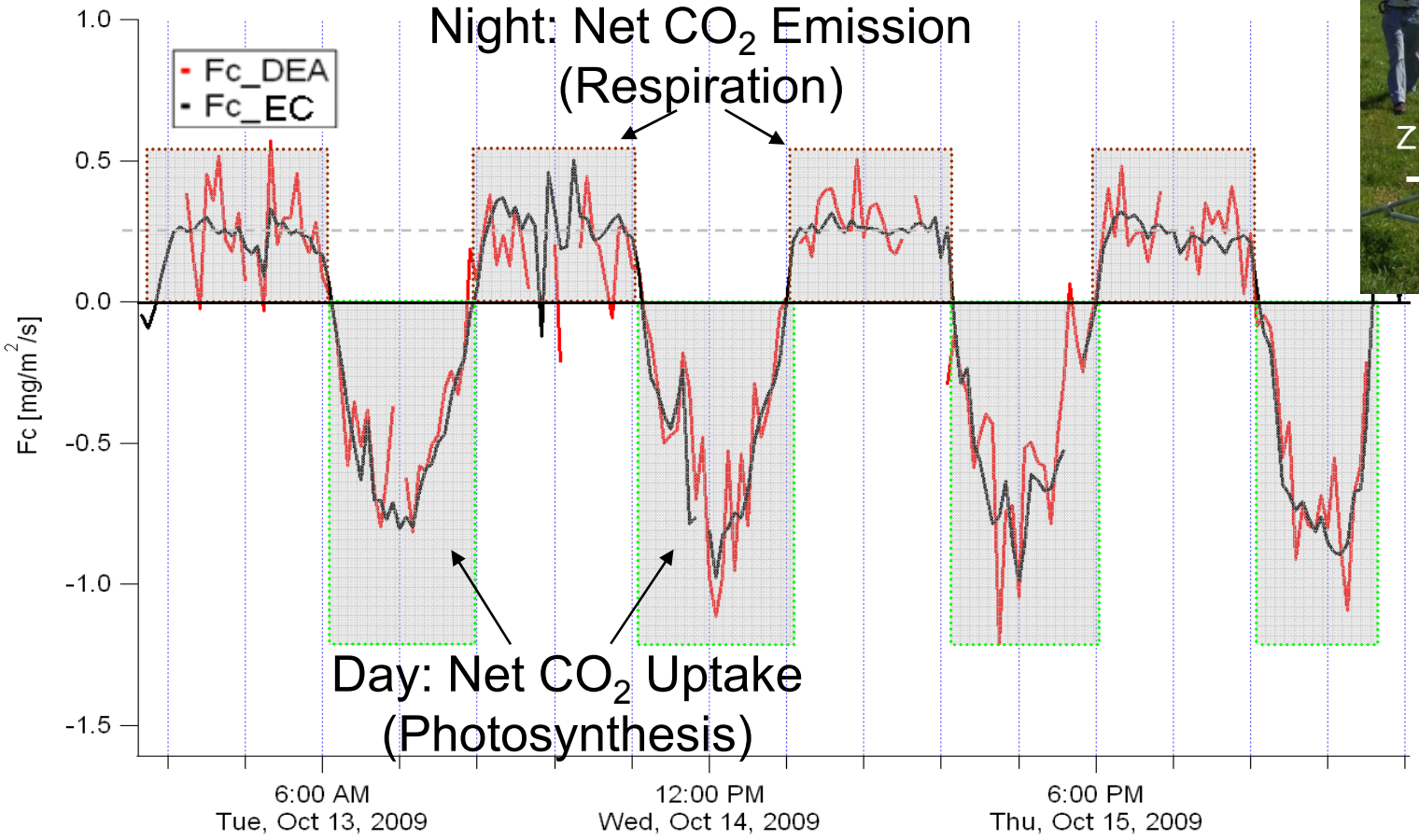
Forests: using vertical profiles of trace gases and isotopic fractionation to partition C and H_2O exchange



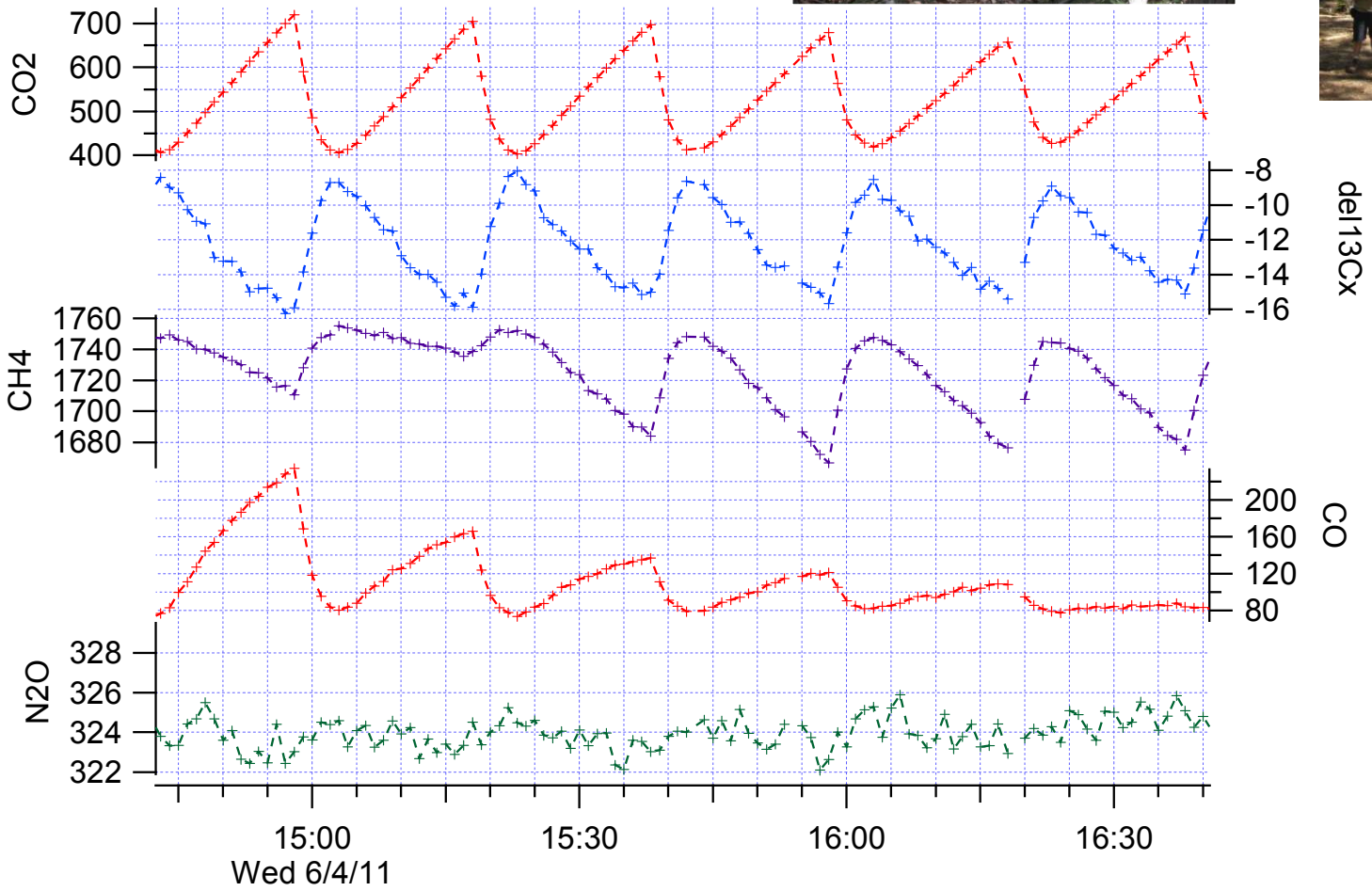
Fluxes: flux gradient and eddy accumulation methods

Here: Disjunct Eddy Accumulation



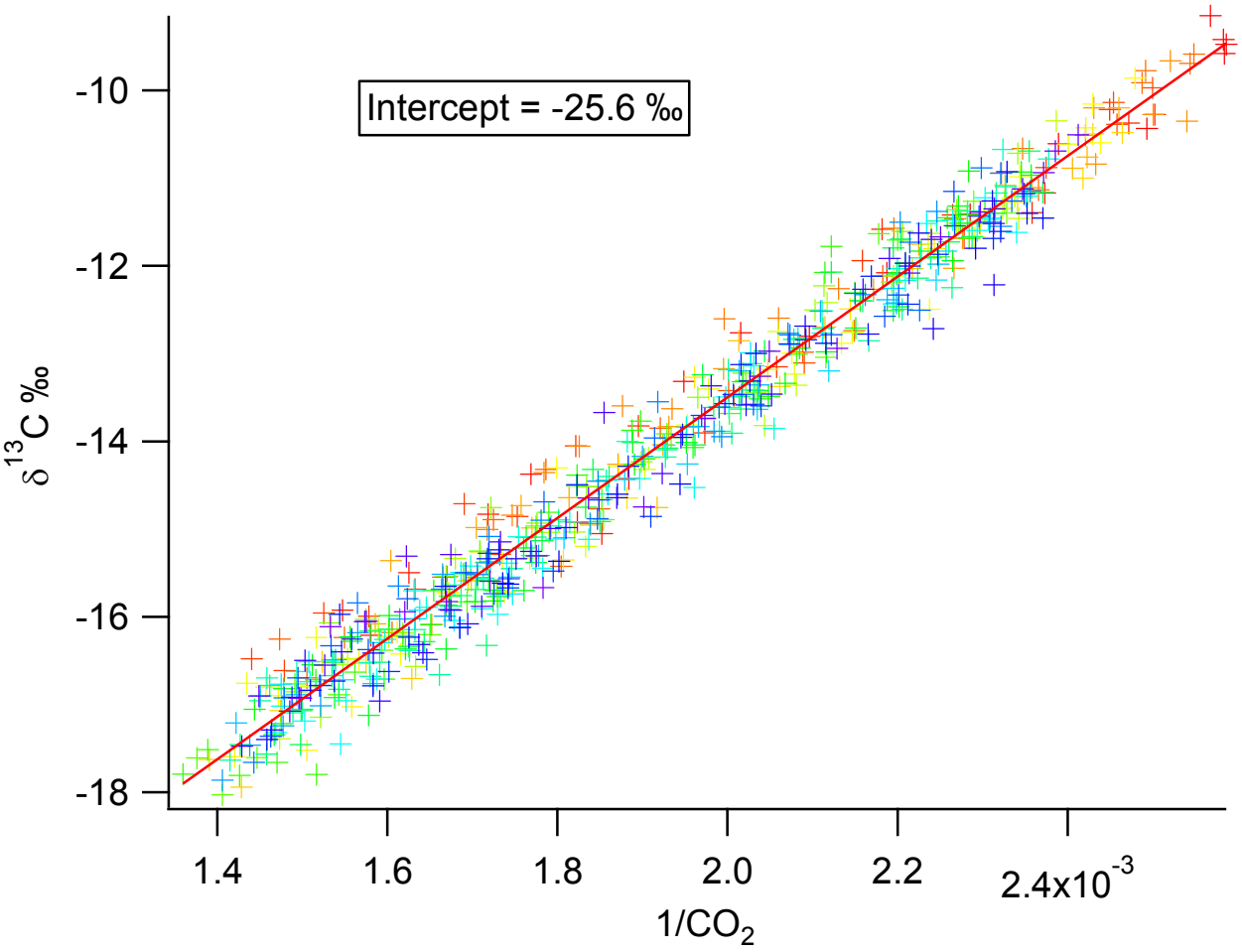


Chamber fluxes:
Forest soils, agriculture



Steve Livesley, Stefan Arndt, Benedikt Fest, Nina Hinko-Najera, Uni Melbourne

Keeling plot, all chambers, 12 hours



Summary: FTIR analyser

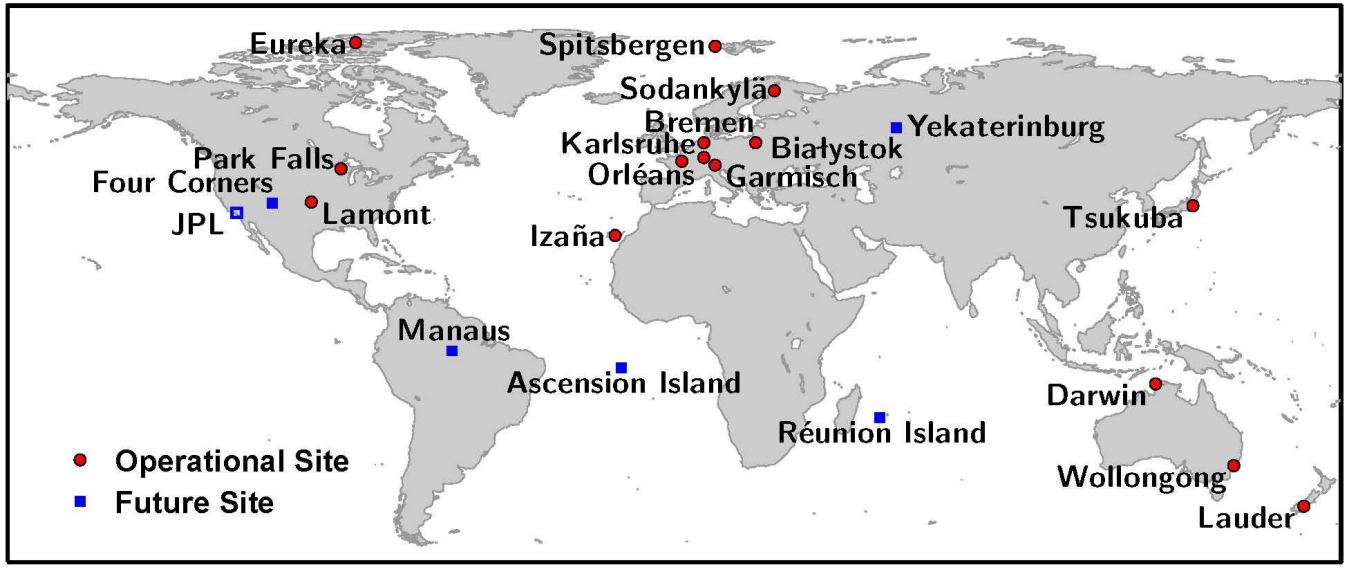
- Continuous, simultaneous, multispecies analyser
- CO_2, CH_4, CO, N_2O, $\delta^{13}C$
- High precision and accuracy
- Low maintenance
- Now available from Ecotech, Australia
  - www.ecotech.com
  - www.knj-eng.co.kr in Korea

… now to TCCON…

TCCON: Total Carbon Column Observing Network

TCCON
total carbon column observing network

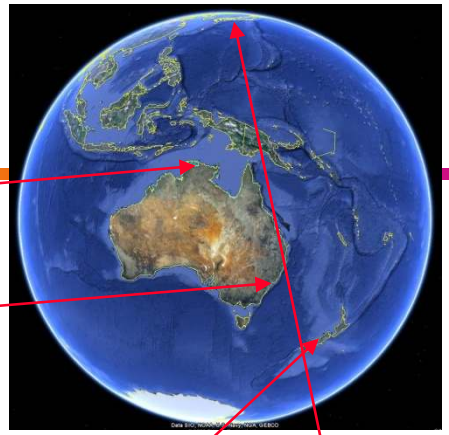
- Remote sensing of total column CO_2, CH_4, N_2O, CO …
  - Direct-sun solar absorption spectroscopy in the near IR
- Derive column average dry air mole fractions (e.g. X_{CO2})
  - Using column O_2 as internal standard
- Calibrated against NOAA/WMO in situ reference scales
- Currently ~15 sites



Why TCCON?

- Total columns measurements :
  - Are less susceptible to local sources and sinks than in situ
  - Are less sensitive to vertical transport errors in models
    - Do not alias diurnal and seasonal boundary layer transport into the measured column amount
  - Can be used for satellite validation
    - GOSAT
    - OCO-2
    - CarbonSat

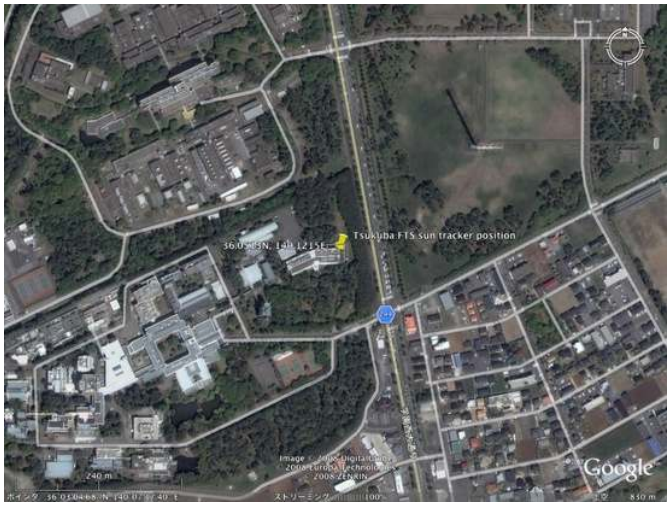
Southern Hemisphere & Asia TCCON stations



Darwin

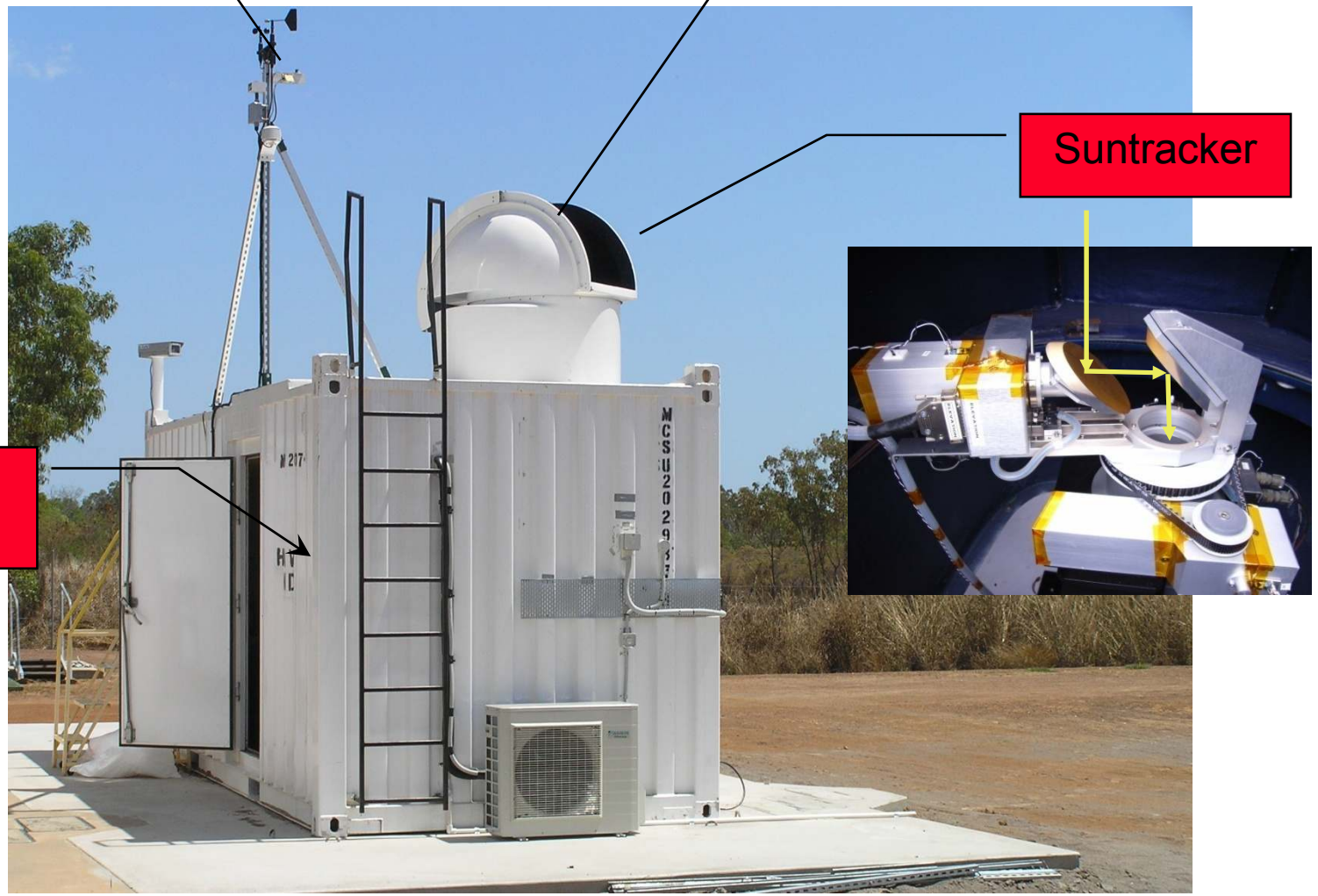
Wollongong

Tsukuba



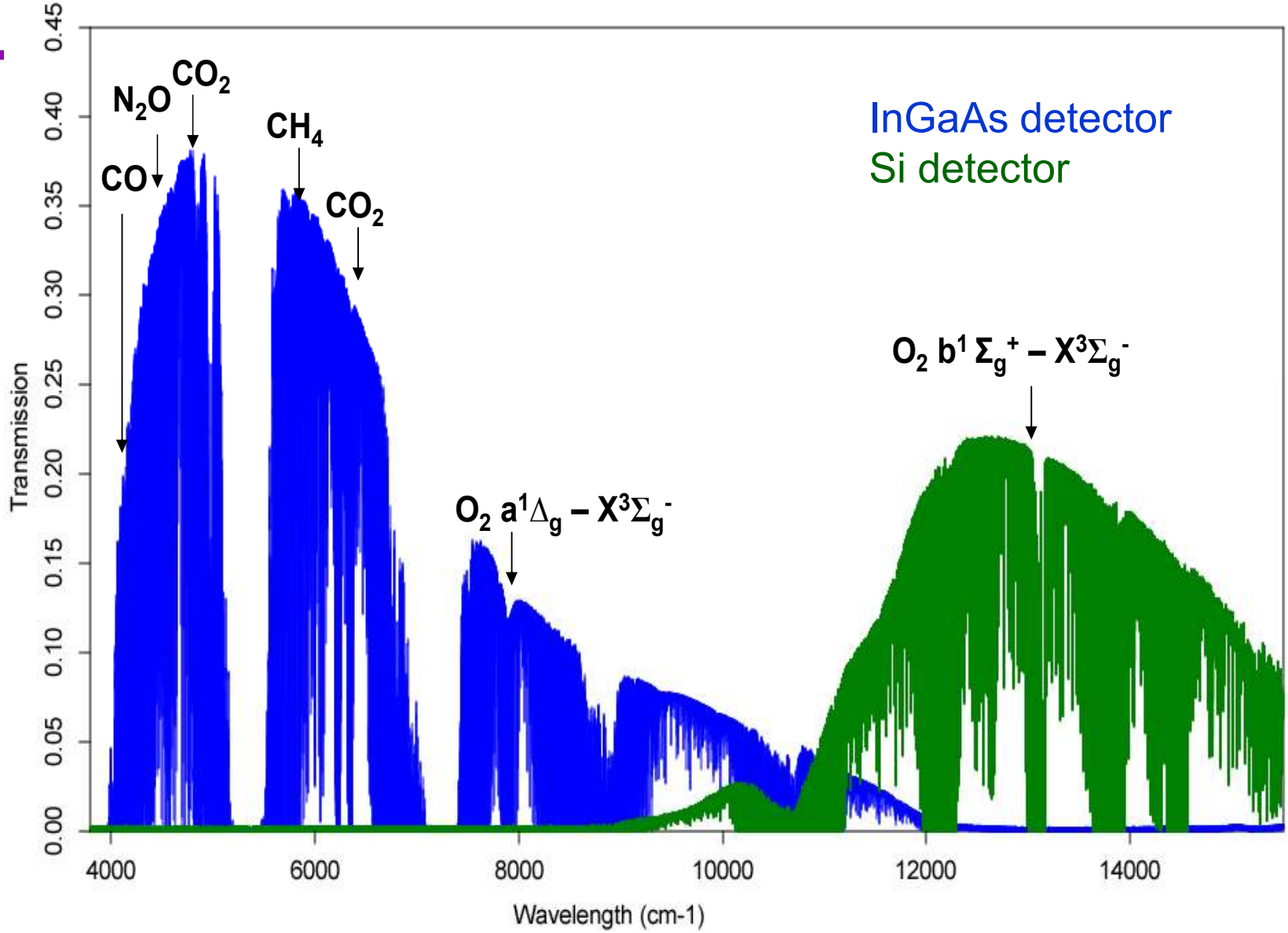
Lauder

Darwin TCCON container



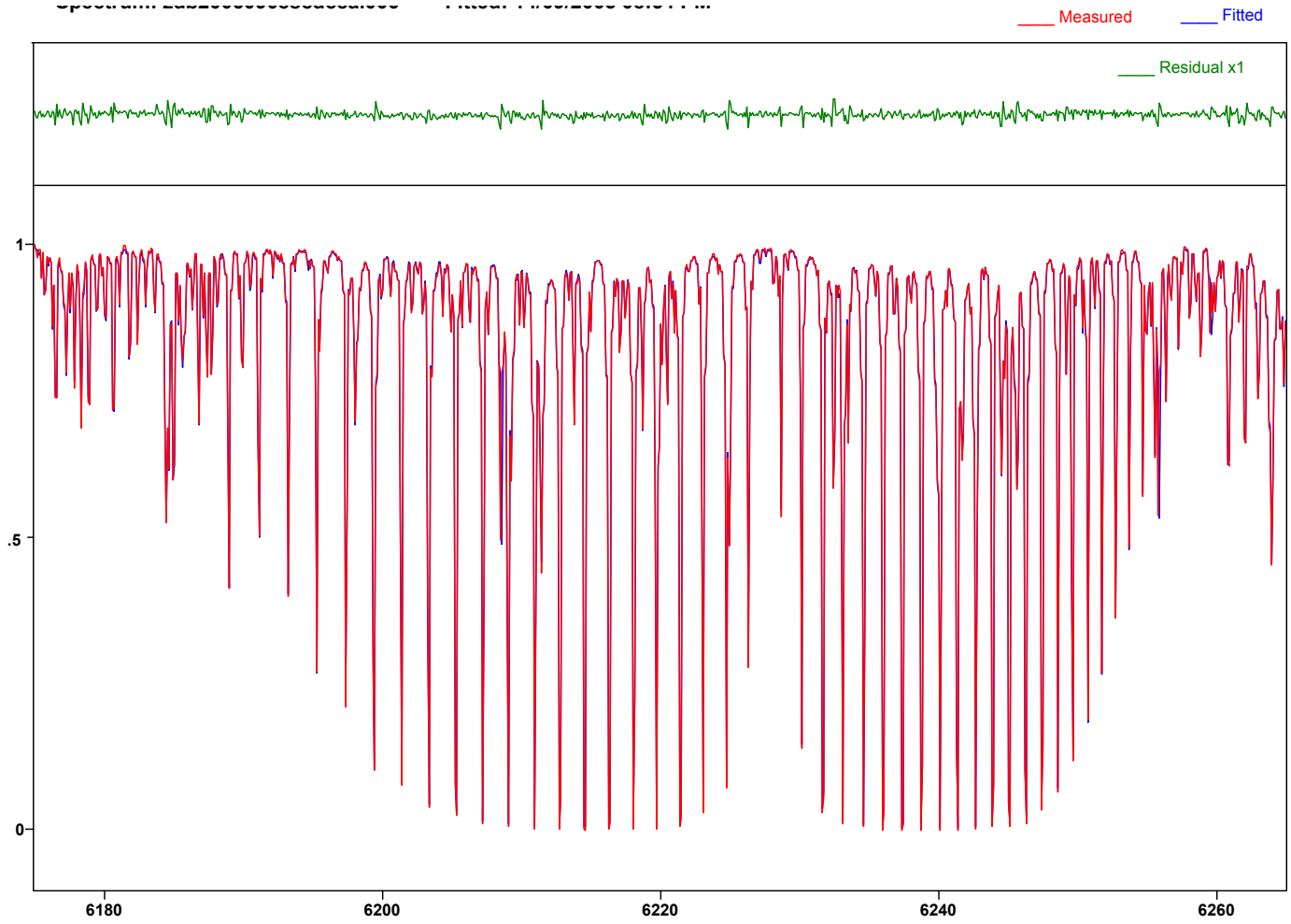

BRUKER
IFS 125HR

Near IR solar absorption spectrum overview



Analysis by spectrum fitting

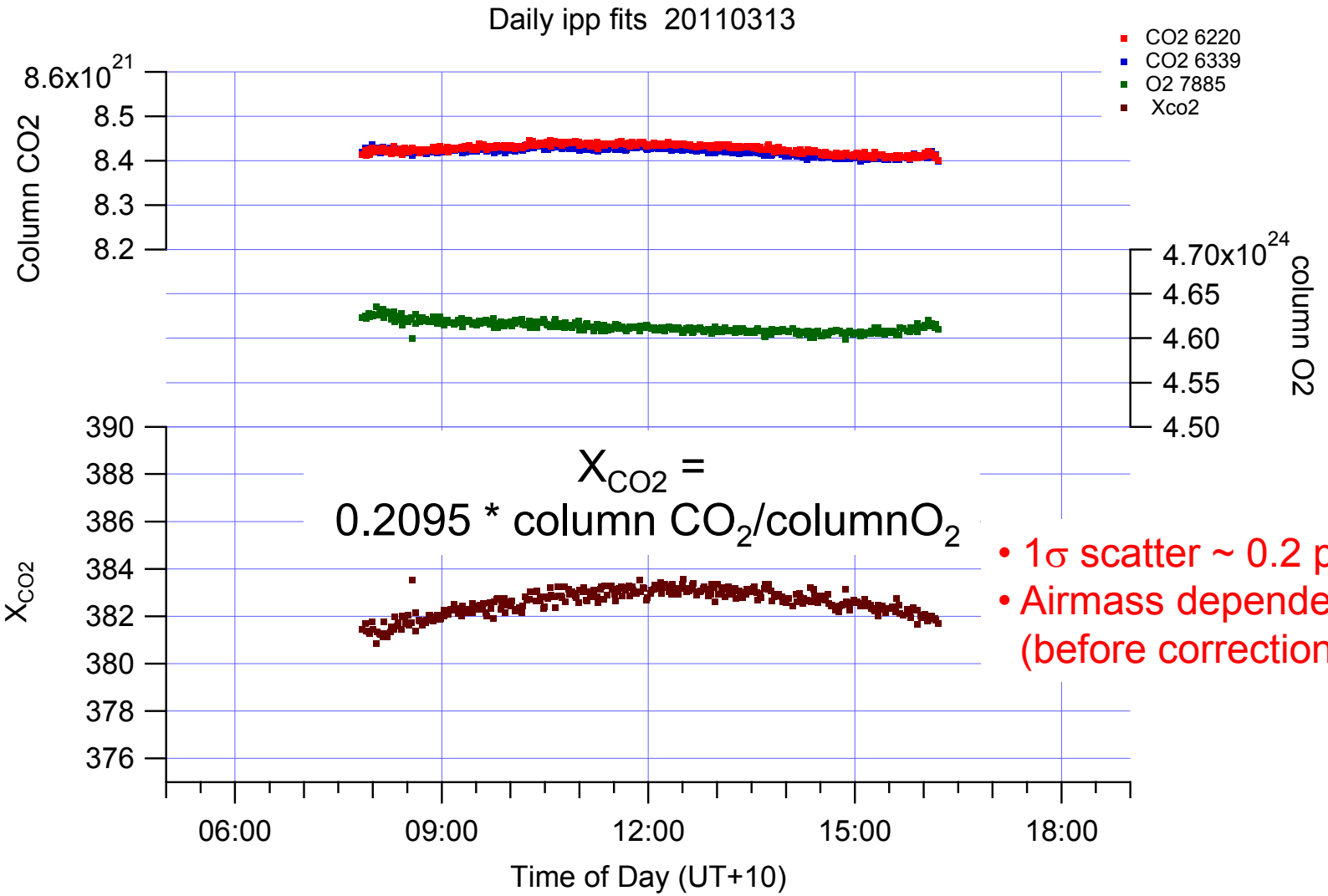
e.g. 6230 cm^{-1} CO_2 band



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

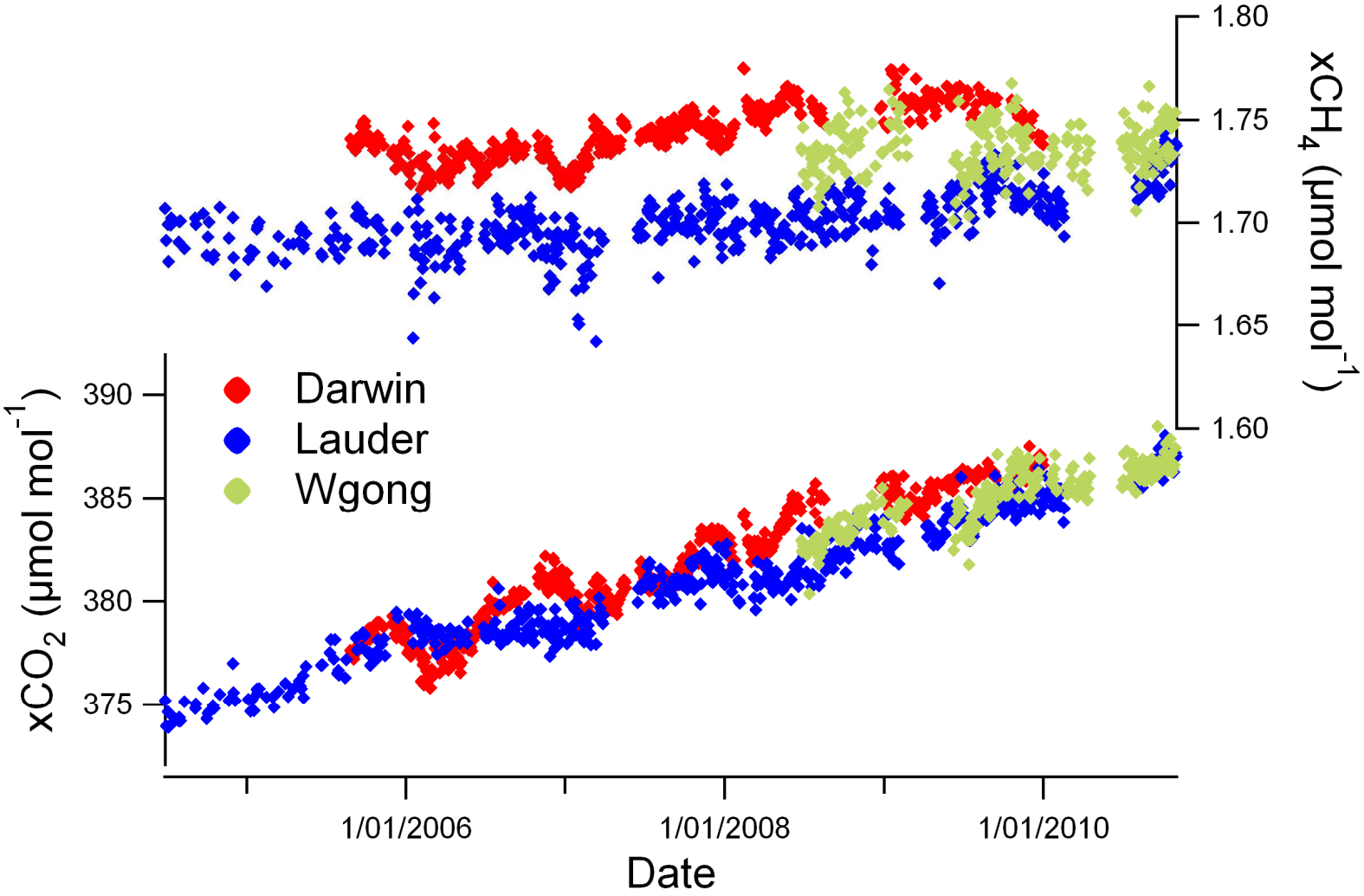
SZA: 73.904 Zobs: .03

Raw daily column measurements Wollongong, clear sky day

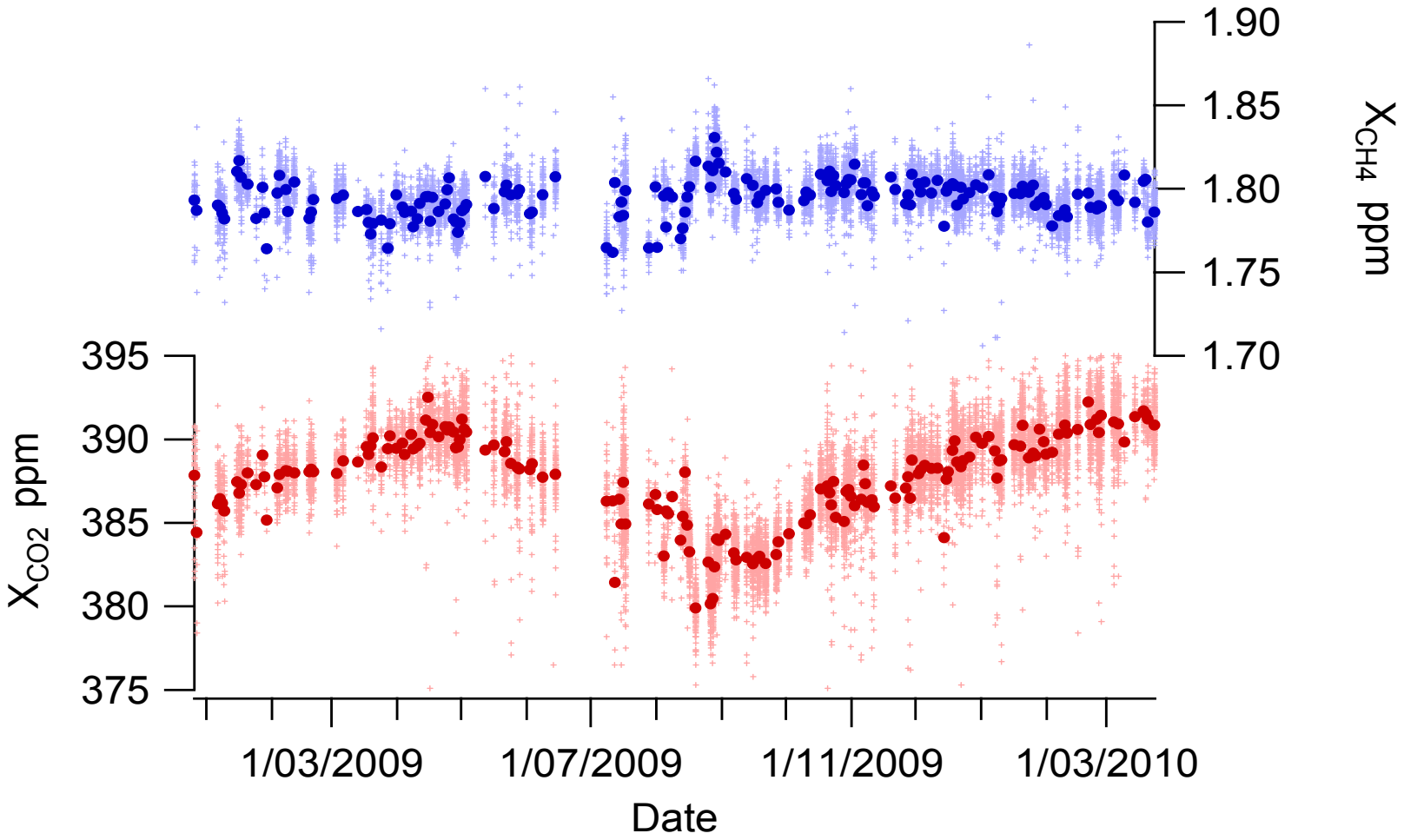


- 1σ scatter ~ 0.2 ppm (0.05%)
- Airmass dependence ~ 2ppm (before correction)

The TCCON SH data set



TCCON data - Tsukuba

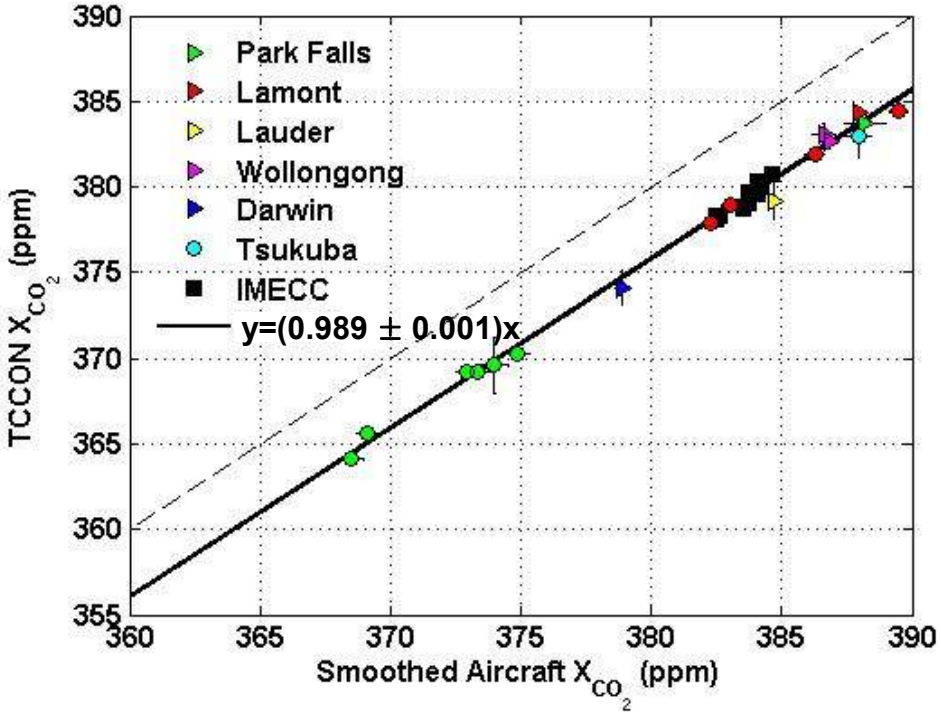


TCCON precision, accuracy and calibration CO_2

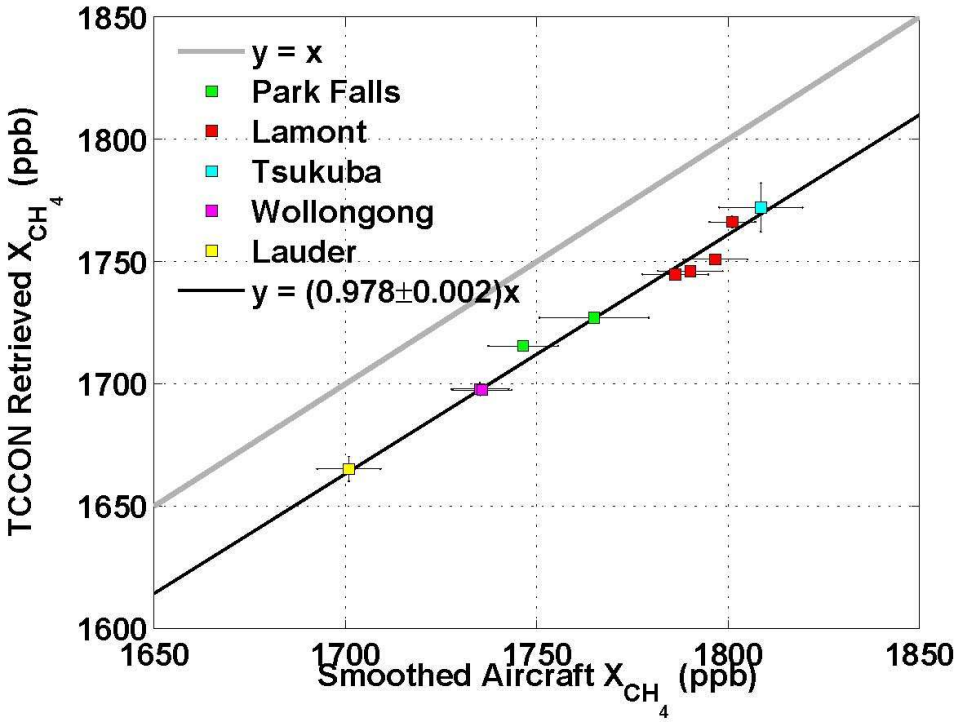
- *Precision* (1-σ repeatability) achieved: <0.2 ppm
- *"Absolute" calibration* by comparison of TCCON total columns with integrated aircraft in situ profiles using WMO-calibrated instruments
  - eg. HIPPO, TWP-ICE, IMECC
  - Extrapolated to top and bottom of the atmosphere
- *Accuracy* achieved: ~ 0.4 ppm (1-σ) across the network
  - This accuracy (0.1%) is unprecedented in remote sensing
  - Measurements and analysis standardised to avoid bias
  - Ongoing work to improve:
    - Instrumentation, software, spectroscopy

TCCON calibration against aircraft profiles CO_2 and CH_4

CO_2 (1σ 0.1%)



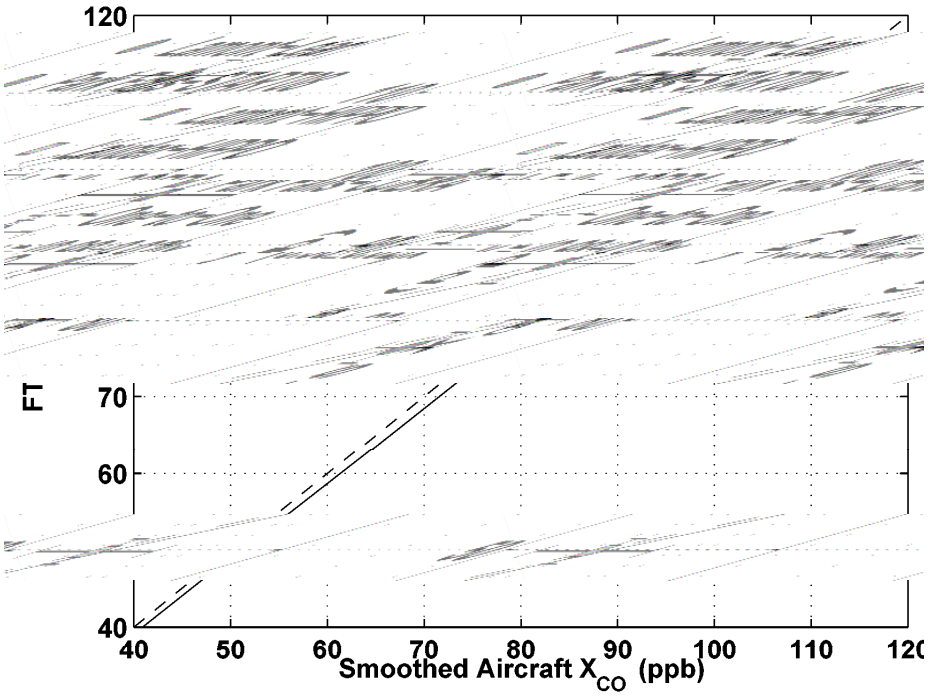
CH_4 (1σ 0.2%)



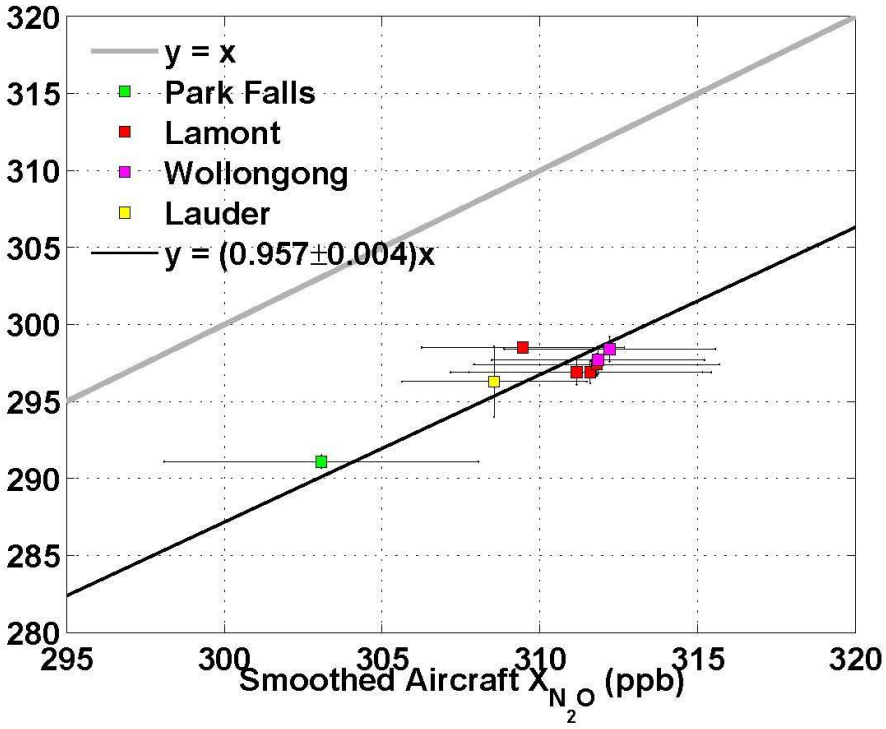
- Further detail:
  Wunch, D., et al. (2010), Calibration of the Total Carbon Column Observing Network using Aircraft Profile Data, *Atmos. Meas. Techn., 3, 1351-1362.*

TCCON calibration against aircraft profiles CO and N_2O

CO (1σ 2%)



N_2O (1σ 0.4%)



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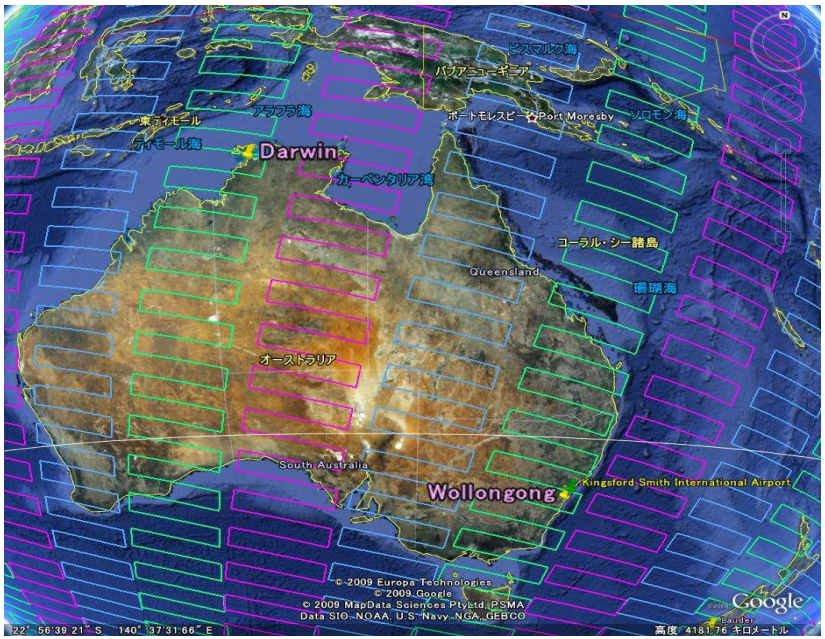
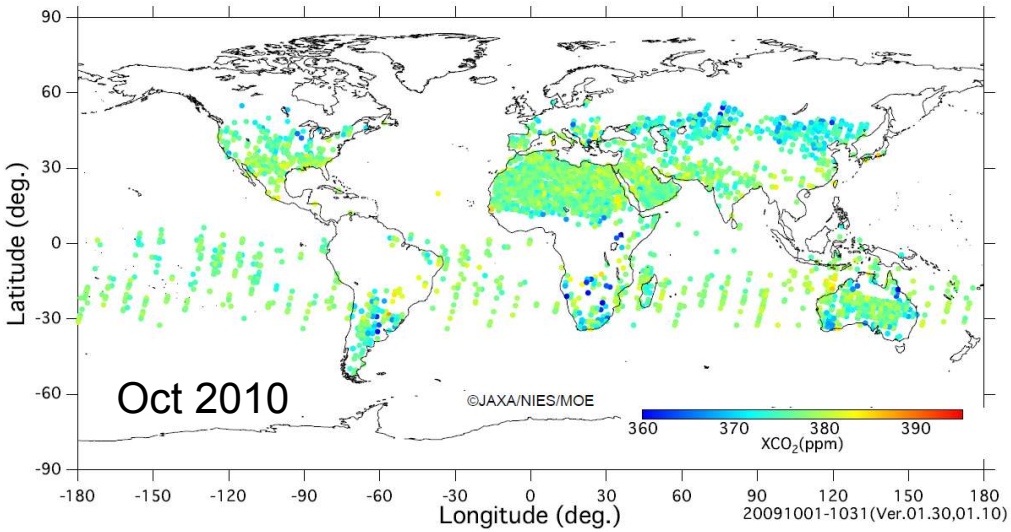
GOSAT

Greenhouse gas Observing SATellite

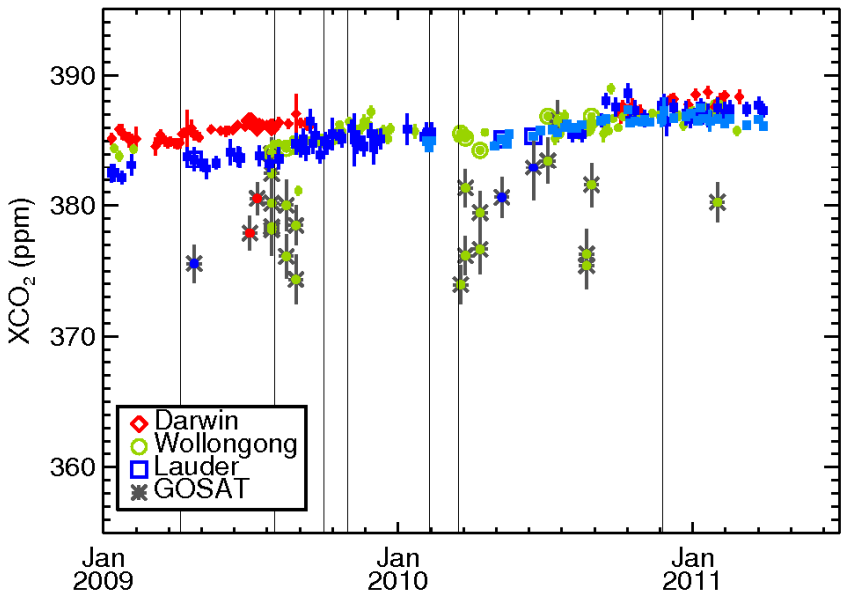
- FTIR spectrometer, backscattered solar NIR
- CO_2, CH_4 analysis
- Launched Jan 2009 by JAXA, Japan
- 3 day repeat orbit
- Validation by TCCON overpasses

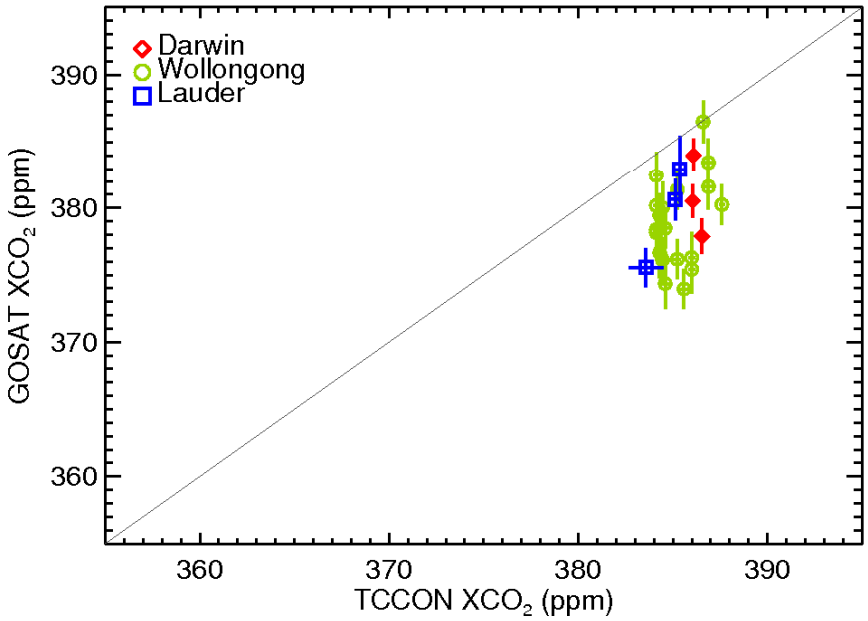




GOSAT-TCCON SH validation
CO_2

- TCCON : 1-2 hour average around GOSAT overpasses
- GOSAT: 2 x 2° region around TCCON sites



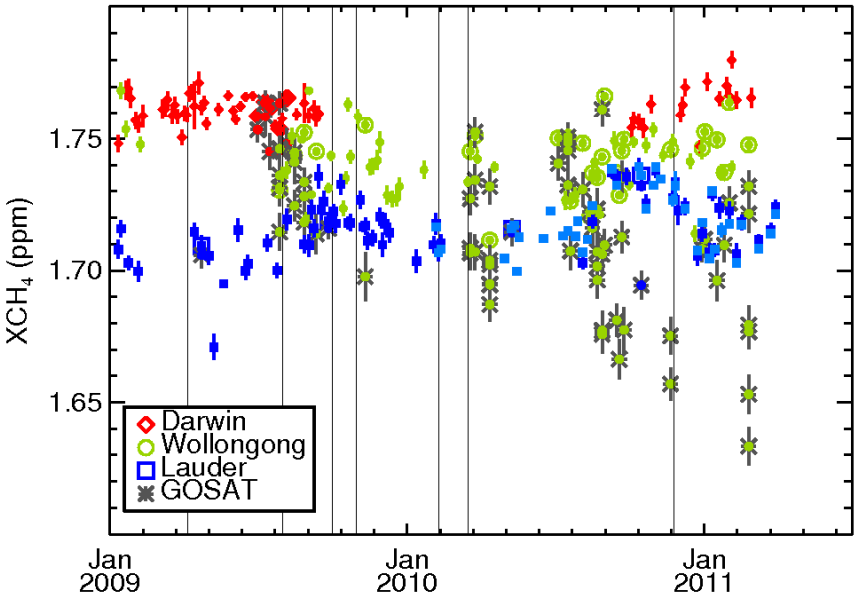


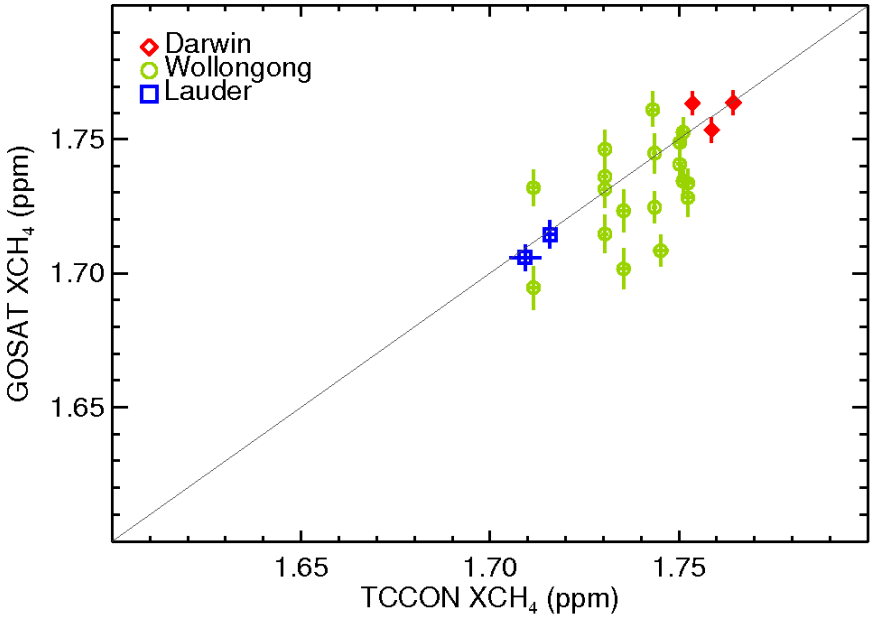
Also GOSAT retrievals from ACOS, SRON

- lower bias
- AOD and scattering corrections

GOSAT-TCCON SH validation
CH_4

- TCCON : 1-2 hour average around GOSAT overpasses
- GOSAT: 2 x 2° region around TCCON sites





Thank you

FTIR Analyser

UoW: Nick Deutscher, Chris Caldow, Graham Kettlewell, Martin Riggenbach

CSIRO: Paul Fraser, Paul Krummel, Marcel Vanderschoot, Zoe Loh

U. Heidelberg: Sam Hammer, Ingeborg Levin

TCCON

UoW: Nick Deutscher, Ronald Macatangay

NIWA, NZ: Vanessa Sherlock

Cal Tech: Debra Wunch, Paul Wennberg