Orbiting Carbon Observatory

Using SCIAMACHY and Ground-based FTS Measurements to Test the OCO X_{CO2} Retrieval and Validation Approach

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Space-based CO_2 Measurements

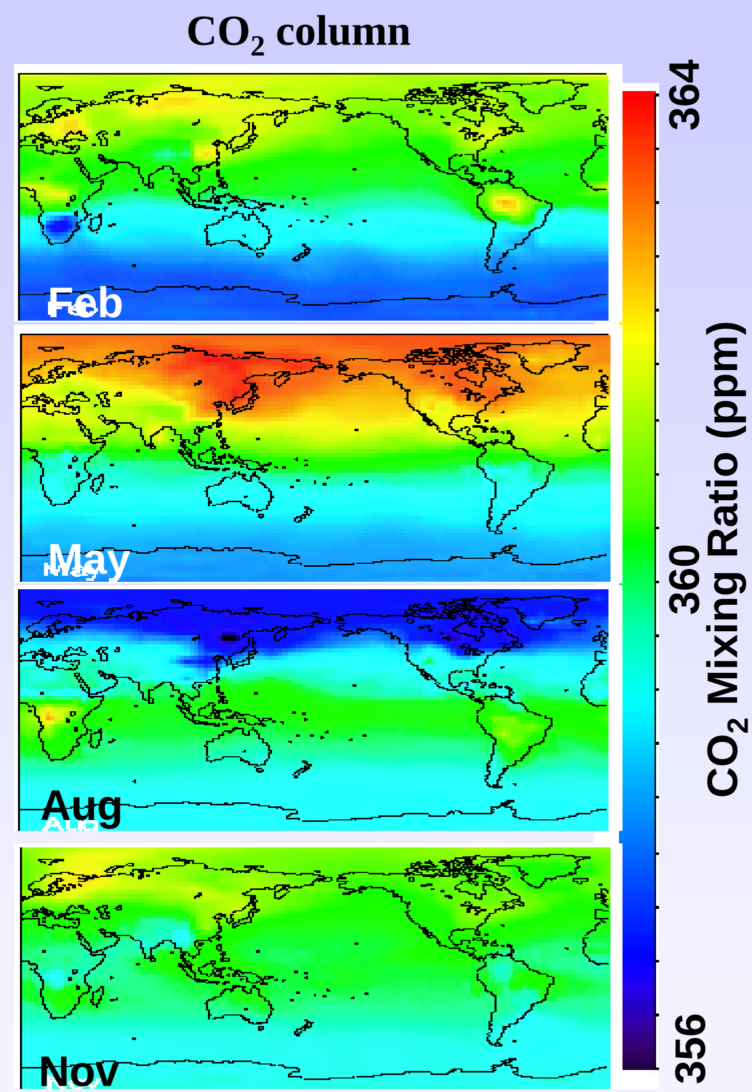
Space-based measurements of **column-averaged CO_2 dry air mole fraction, X_{CO2}**, could dramatically improve understanding of carbon sources and sinks [*Rayner & O'Brien*, 2001] if

- acquired globally (land/ocean)
- random errors less than 1-2 ppm (0.3 – 0.5%) on regional scales to resolve

    ~8 ppm pole to pole gradients

    ~8 ppm *XCO2 s*easonal cycle in the Northern Hemisphere

- they have **no** significant systematic **bias** on regional to continental scales

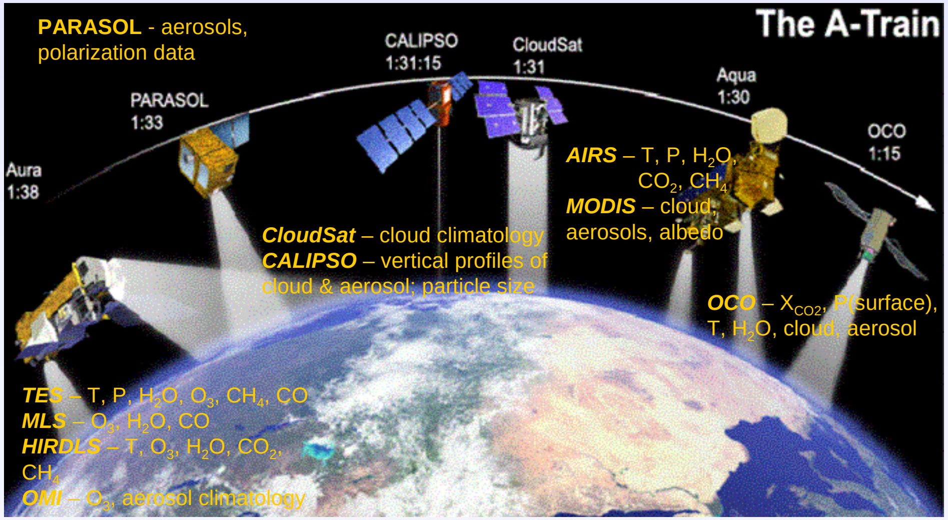


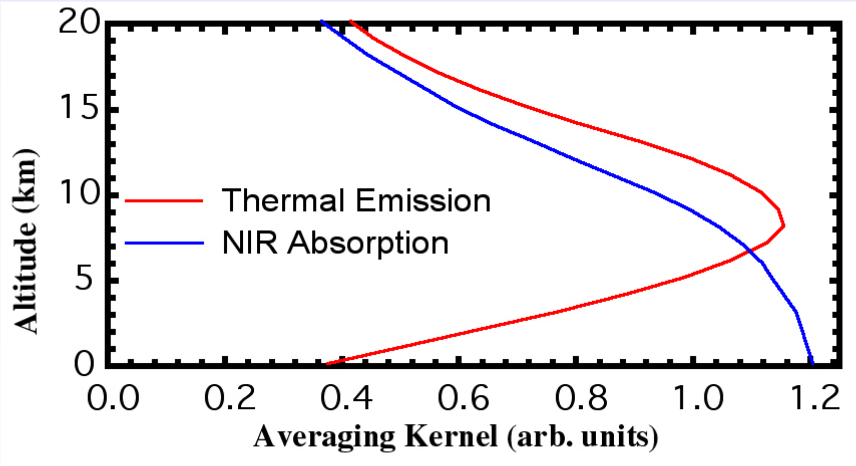
MATCH/CASA model calculation [Olsen and Randerson, 2004]

OCO Mission

Global, space-based observations of atmospheric CO_2 with precision, resolution, and coverage needed to monitor sources and sinks:

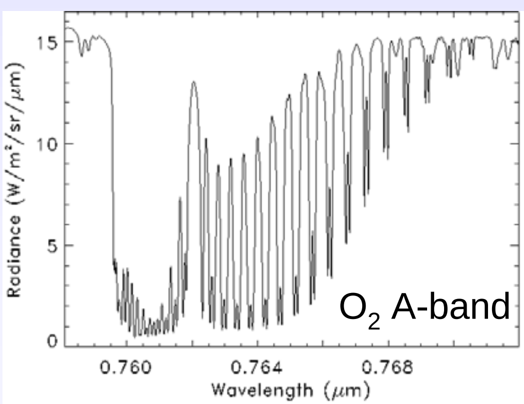
- Spectra of reflected/scattered sunlight in NIR CO_2 and O2 bands used to estimate X_{CO2} with large sensitivity to surface
- A-train orbit (1:15 PM polar sun sync)
- 16 day repeat cycle samples seasonal cycle on semi-monthly intervals
- NASA ESSP (Earth Space System Pathfinder) scheduled for Sept 2008 launch; 2 yrs lifetime



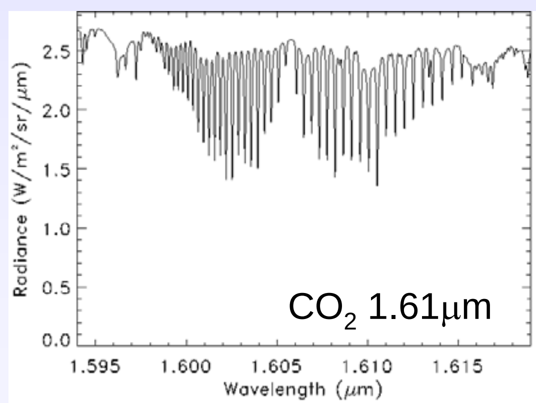


OCO Retrieval Strategy

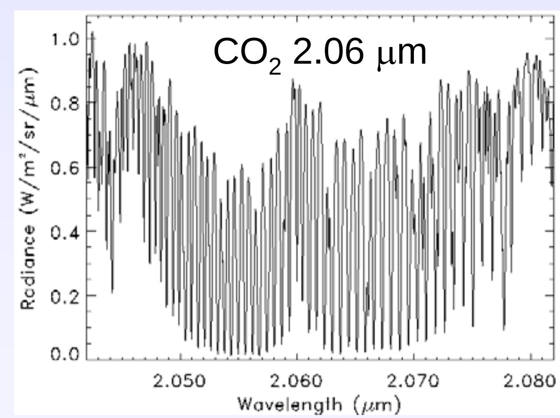
- Simultaneous fit to 3 NIR bands with sophisticated remote sensing retrieval algorithms
  - **Forward Model** computes synthetic radiance spectrum using multiple scattering RT code Radiant [M. Christi, CSU]
  - **Inverse Method** adjusts assumed state with optimal estimation technique
- Column-integrated CO_2 abundance
  - 1.61 μm CO_2 bands – CO_2 measurements with maximum sensitivity near the surface
  - O_2 A-band and 2.06 μm CO_2 band provide: Surface pressure, albedo, atmospheric temperature, water vapor, clouds, aerosols



Clouds/Aerosols, Surface Pressure, Temperature



Column CO_2

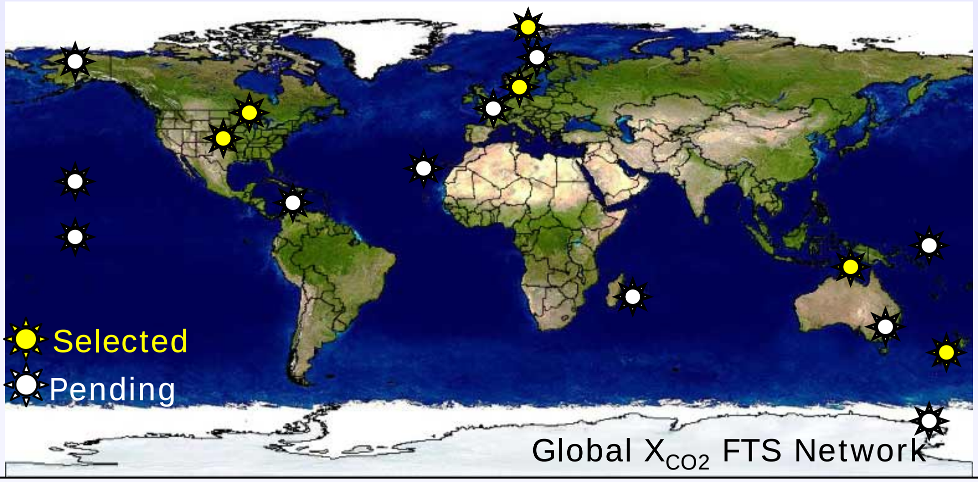


Clouds/Aerosols, H_2O Temperature

Validation Approach

- OCO validation is based on network of ground-based FTS sites measuring direct sunlight:
  - **critical test of spectroscopy**: same absorption bands as OCO, but much higher spectral resolution
  - **insensitive to aerosol or ground effects**
  - **Minimize risk of algorithmic biases**: one algorithm for space-based OCO and ground-based FTS spectra
- Sites represent different geophysical well characterized (aerosol, temperature etc.)
- Validation of FTS measurements with in-situ tower and aircraft data in order to tie FTS soundings to in-situ calibration standard [R. Washenfelder and P. Wennberg]

⇒ **ensures accuracy and allows to identify and correct regional-scale biases**



SCIAMACHY NIR Measurements

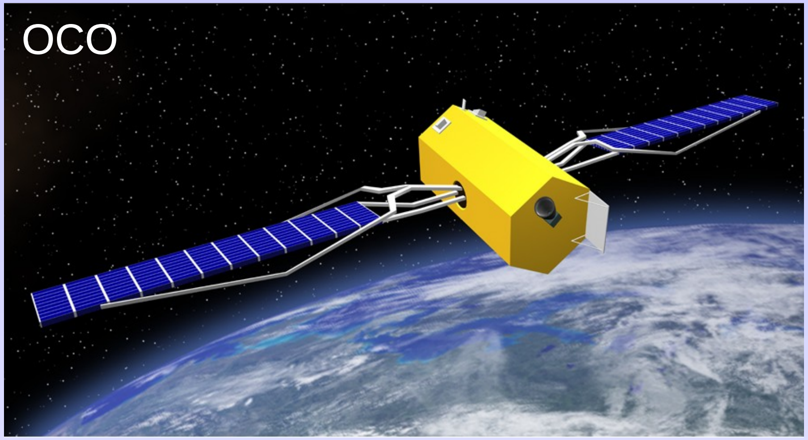
SCIAMACHY provides space-based NIR measurements that are similar in viewing geometry to OCO, thus allows

⇒ Testing the OCO Level 2 retrieval algorithm using real space-based spectra

⇒ Testing and applying the OCO validation concept

⇒ Carbon/Greenhouse gas science using SCIAMACHY data

OCO – SCIAMACHY Comparison

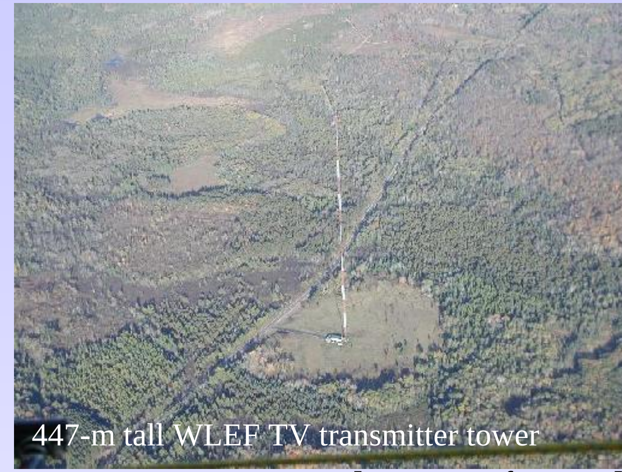


	OCO	**SCIAMACHY**
Objective	CO_2 solely	Many atmospheric trace gases
Modes	Nadir, glint, target	Nadir, limb, occulation
Range	3 narrow NIR bands	8 Channels from UV to NIR
Resolution	High: 0.05 nm – 0.1 nm	Low/medium: 0.2 – 1.5 nm
Ground Pixel	3 km^2	60 x 30 km^2

Measurement Location

Park Falls / WI (46 N, 90 W):

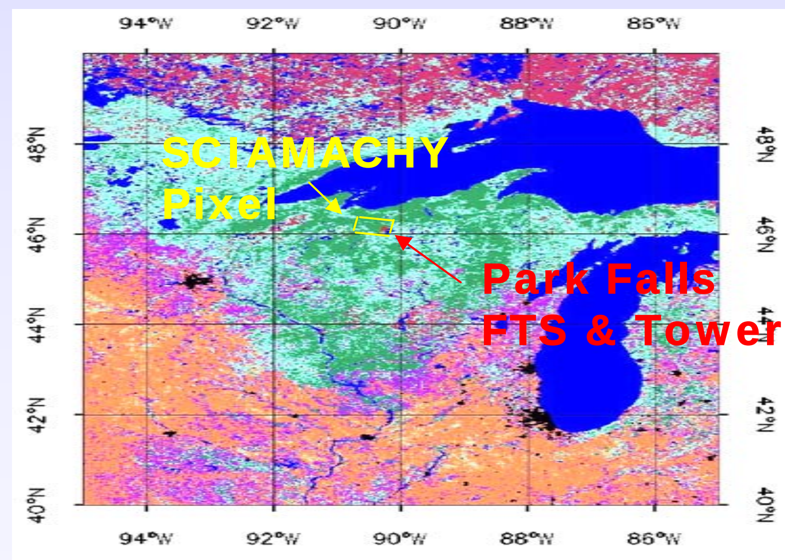
- Relatively homogenous region, but lake nearby
- In-situ CO_2 measurements from WLEF tower
- FTS installed next to tower



[Courtesy of CMDL]

SCIAMACHY spectra and coincident FTS spectra for SCIAMACHY overpasses (< 150 km):

- Jul. - Oct. 2004 and Feb. – Aug. 2005
- SCIAMACHY spectra have been cloud-cleared ($p_{surface}$ > 900 mbar)



[Courtesy of CSU]

SCIAMACHY CO_2 Retrieval

Spectral Bands:

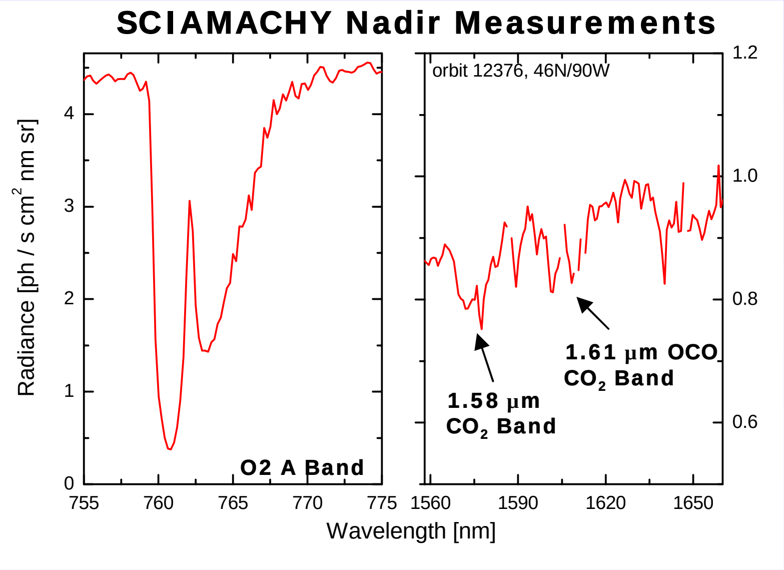
- O_2 A-band - Channel 4, FWHM = 0.5 nm
  1.58 µm CO_2 band - Channel 6, FWHM = 1.5 nm
- Not used: 2 µm CO_2 band in Channel 7 (FWHM = 0.22 nm) due to icing on detectors

Simplified retrieval:

- CO_2 vmr profile
- Surface pressure
- H_2O scaling
- Surface albedo
- Spectral shift

Assumptions:

- Aerosol optical depth of 0.1
- Temperature from NCEP
- Neglect of polarization

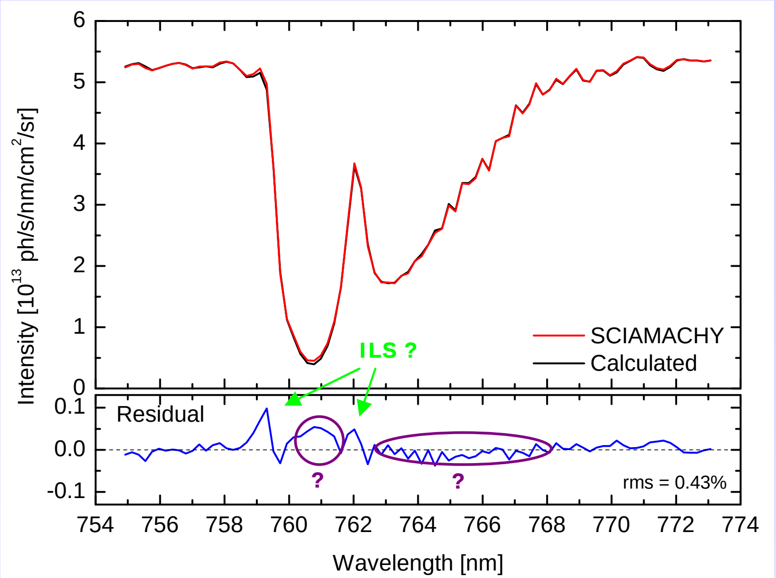


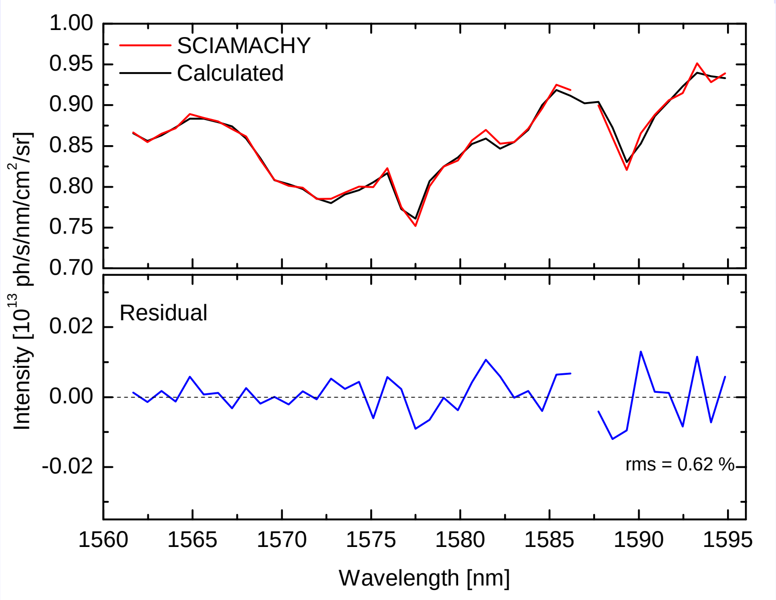
O_2 and CO_2 Spectral Retrieval

- Retrieval performs reasonable well
- rms of ~ 0.5% (≈ 3 × noise)
- Systematic residual structures clearly correlated with O_2

⇒ inadequate description of transfer of radiation through atmosphere and/or instrument

⇒ biases in X_{CO2} ?





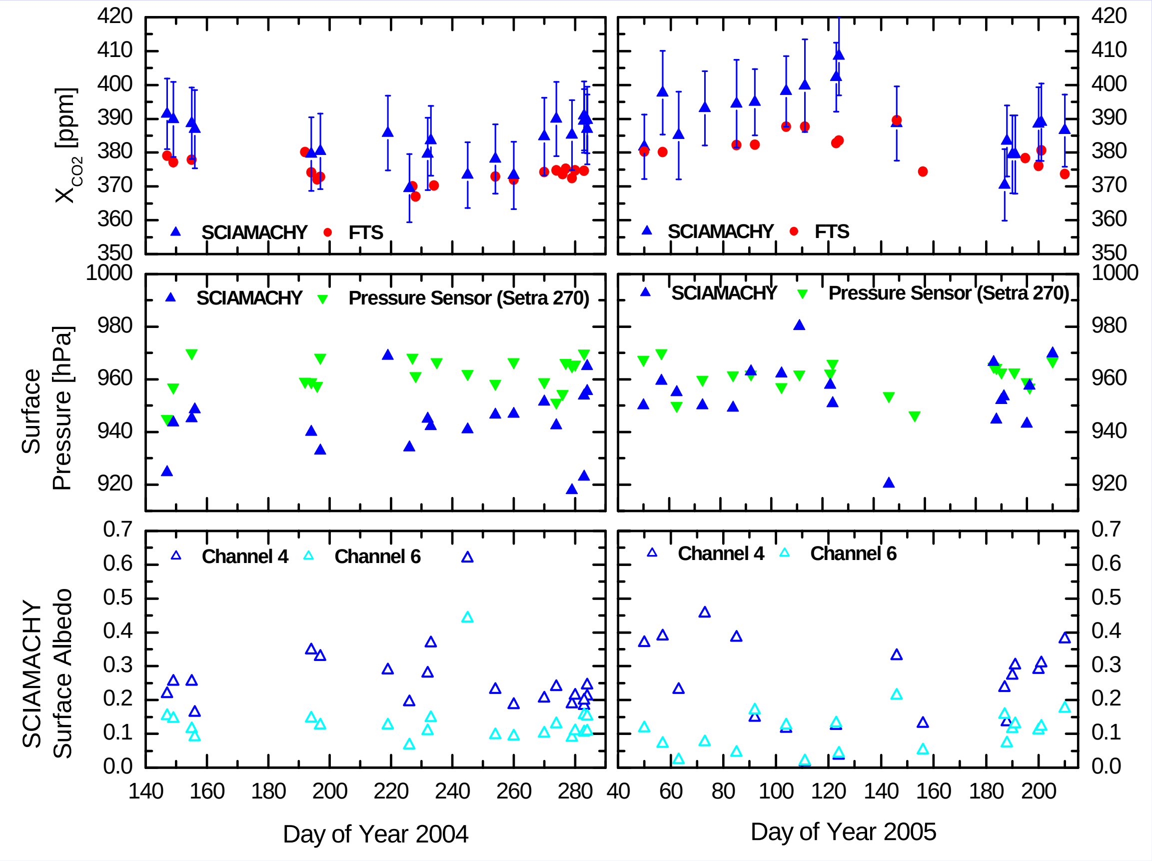
Results

Positive bias in SCIAMACHY X_{CO2} (~ 10 ppm)

Negative bias in surface pressure

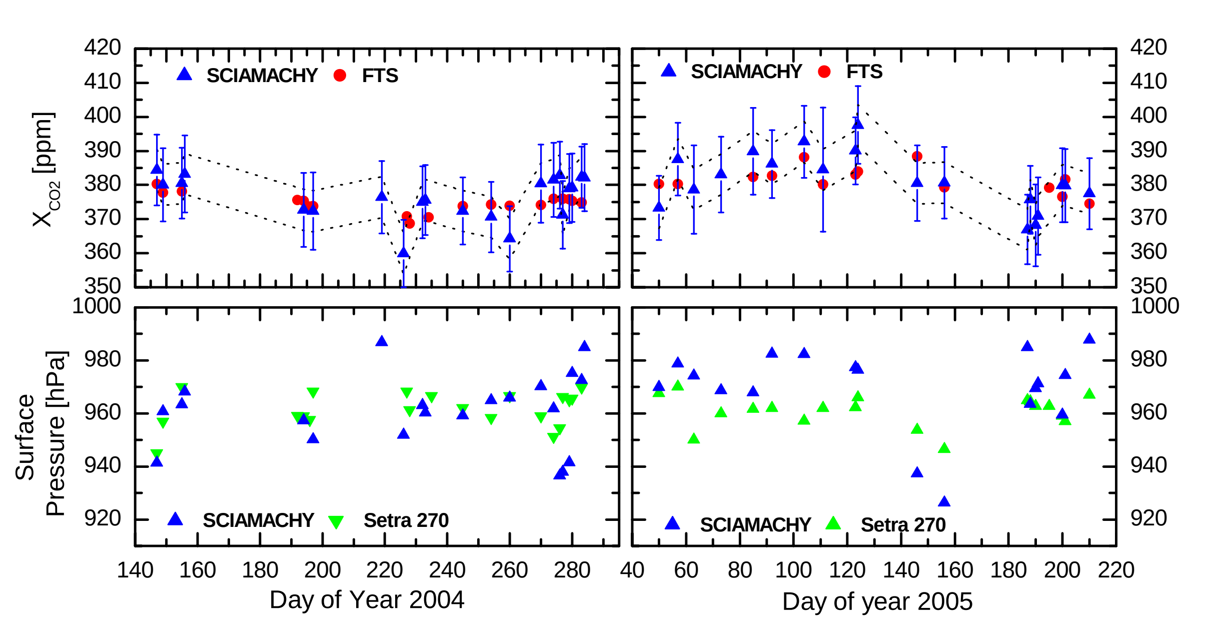
Large scatter in space-based data due to
- lower precision than FTS
- variation in aerosol loading
- some undetected clouds
- topography (surface pressure)

Surface Albedo helps to characterize the scene (lake, snow, vegetation, clouds, ...)



Results 2

First order correction of spectral artifacts: adding 1% intensity offset to calculated O_2 spectra

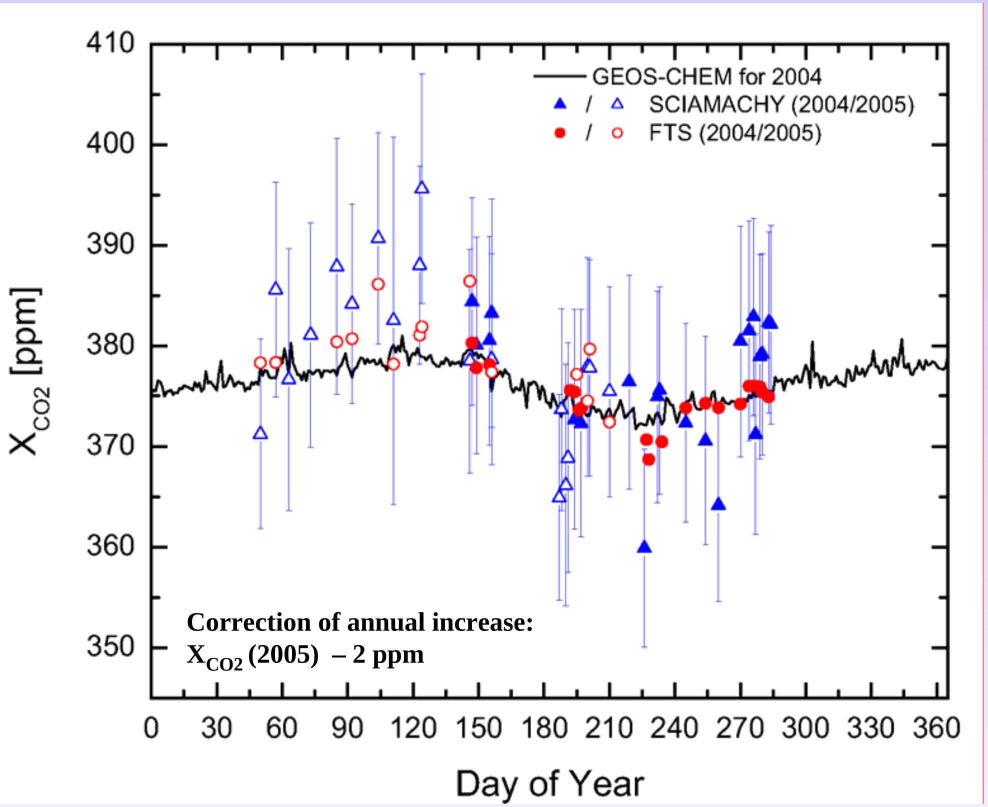


- Largely improved comparison in X_{CO2} and surface pressure
- No clear bias in X_{CO2} anymore
- Standard deviation ~ 6ppm (1.6 %)

Comparison with Model

GEOS-CHEM

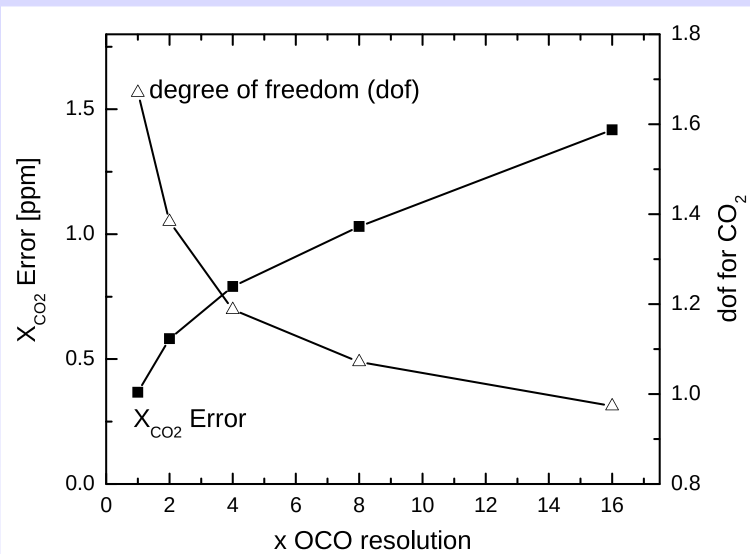
- 2^0 x 2.5^0 with 30 vertical levels
- Global emission inventories for fossil fuel and biofuel combustion, biomass burning, seasonal exchange with terrestrial biosphere, and air-sea fluxes
- Model run for 2004
- Modelled CO_2 profiles for Park Falls convolved with SCIAMACHY averaging kernels

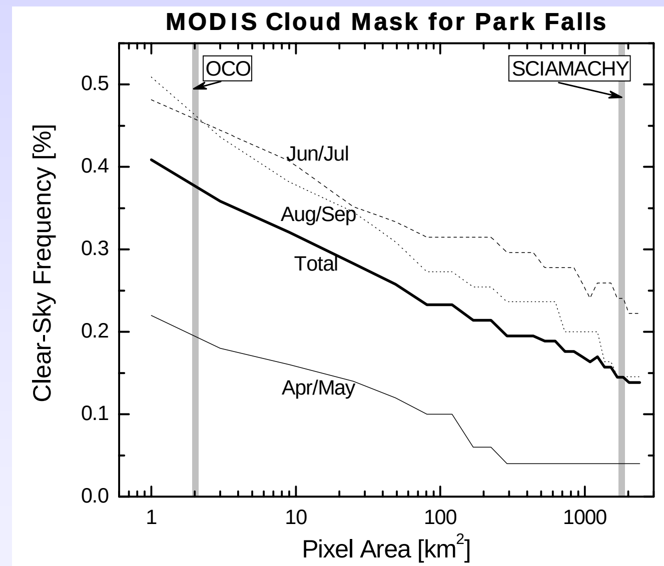


- Good qualitative agreement
- Underestimation of seasonal amplitude by model
- Proper derivation of seasonal cycle requires averaging large number of measurements

Implications for OCO

- X_{CO2} retrievals from SCIAMACHY look very promising (SCIAMACHY was designed to address a broad range of scientific objectives)
- 2 μm CO_2 band in channel 7 data will significantly improve SCIAMACHY results
- OCO is a dedicated CO2 instrument with high spectral and spatial resolution





⇒ Higher precision can be achieved by increasing spectral resolution

⇒ Spectral artifacts can be more easily identified and corrected

⇒ Small footprints increase number of cloud-free scenes

⇒ Minimizes spatial inhomogeneities (partly cloud cover, topography ...)

Summary

- Initial comparison of SCIAMACHY and FTS retrievals for Park Falls:
  - Positive bias in X_{CO2} of ~ 10 ppm
  - Negative bias in surface pressure

- After correction of spectral artifacts in O_2 A band:
  - Largely improved agreement between SCIAMACHY and FTS X_{CO2} (without clear bias) and in surface pressure
  - Standard deviation of SCIAMACHY X_{CO2} ~ 6 ppm

- Good qualitative agreement with GEOS-CHEM, with GEOS-CHEM underestimating seasonal cycle

- OCO is a dedicated CO_2 instrument and will achieve much higher accuracy and precision
  - much higher spectral resolution (by factor of 20)
  - smaller ground pixels (by factor of 600)

Acknowledgements

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