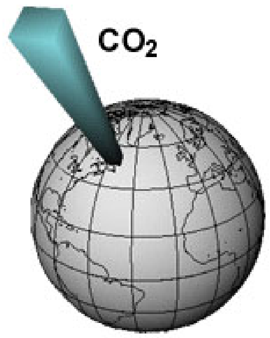
Measuring atmospheric CO_2 with SCIAMACHY using Full Spectral Initiation (FSI) WFM-DOAS



Michael Barkley, Alan Hewitt and Paul Monks
EOS, University of Leicester, Leicester, UK

Udo Frieß
Institute of Environmental Physics, Heidelberg, Germany

R. L. Mittermeier and H. Fast
Meteorological Service of Canada (MSC), Ontario, Canada

S. Körner and M. Heimann
Max Planck Institute for Biogeochemistry (MPI-BGC), Jena, Germany

Richard Engelen
European Centre for Medium-Range Weather Forecast, Reading, Uk

Outline

- How do we measure CO_2?
  - The FSI WFM-DOAS algorithm
- "Validation"
  - Comparison to ground based FTIR data
  - Comparisons to the TM3 chemistry transport model
  - Comparisons to AIRS
- Summary

The FSI approach & algorithm

- Why do we want to measure atmospheric CO_2?
  - Help identify surface sources/sinks and reduce uncertainties in the carbon cycle fluxes
- How do we measure atmospheric CO_2?
  - WFM-DOAS retrieval technique (Buchwitz et al., JGR, 2000) designed to retrieve the total columns of CH_4,CO, CO2, H_2O and N_2O from spectral measurements in NIR made by SCIAMACHY
    - Least squares fit of model spectrum + 'weighting functions' to observed sun-normalised radiance
  - We use WFM-DOAS to derive CO_2 total columns from absorption at ~1.56 µm
- Key difference to Buchwitz's approach:
  - No look-up table
  - Calculate a reference spectrum for every single SCIAMACHY observation i.e. to obtain 'best' linearization point – no iterations
    - **See "Measuring atmospheric CO_2 using Full Spectral Initiation (FSI) WFM-DOAS" , Barkley et al., ACPD, 6, 2765-2807,2006**
  - Computationally expensive ☹

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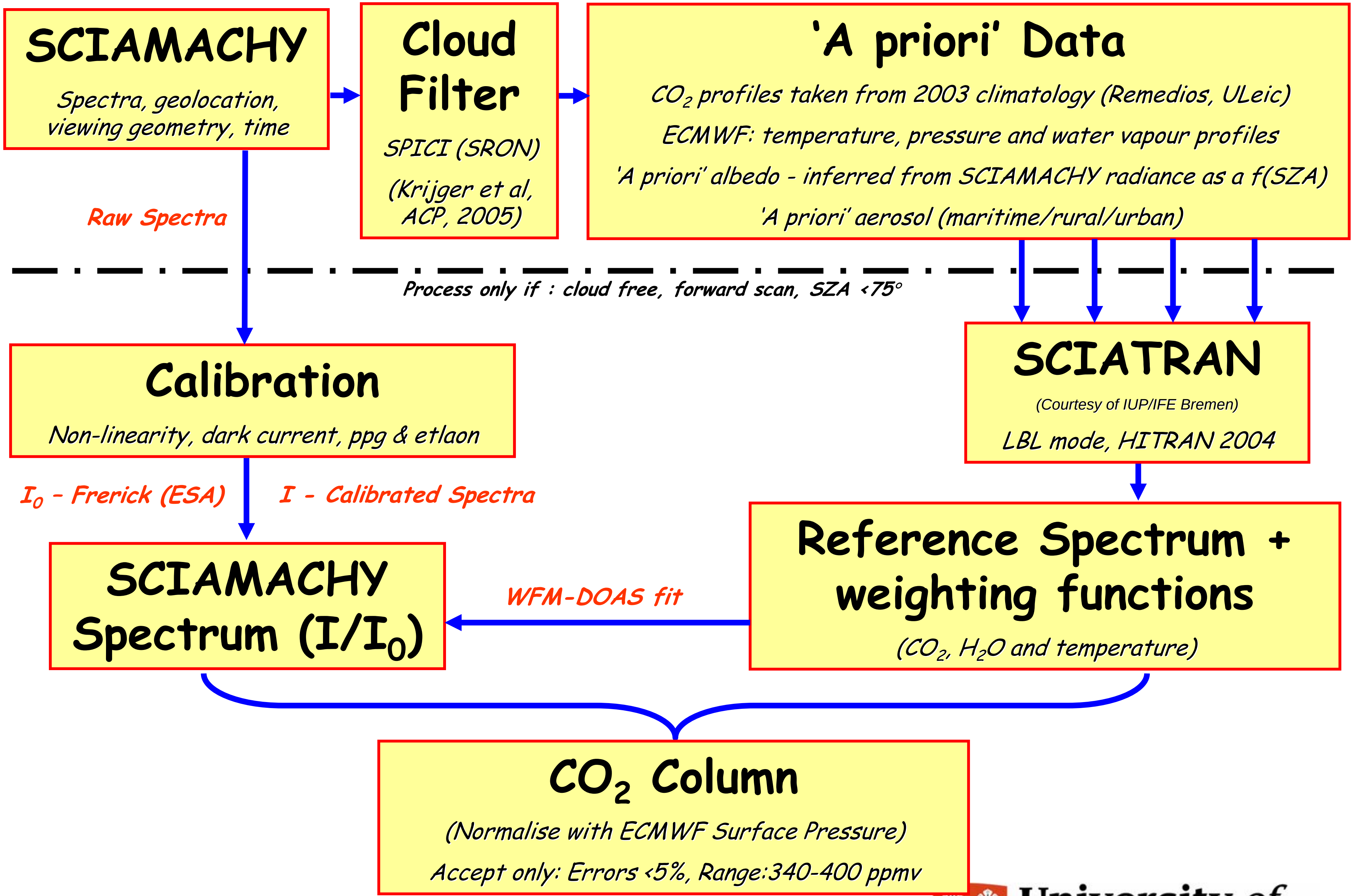
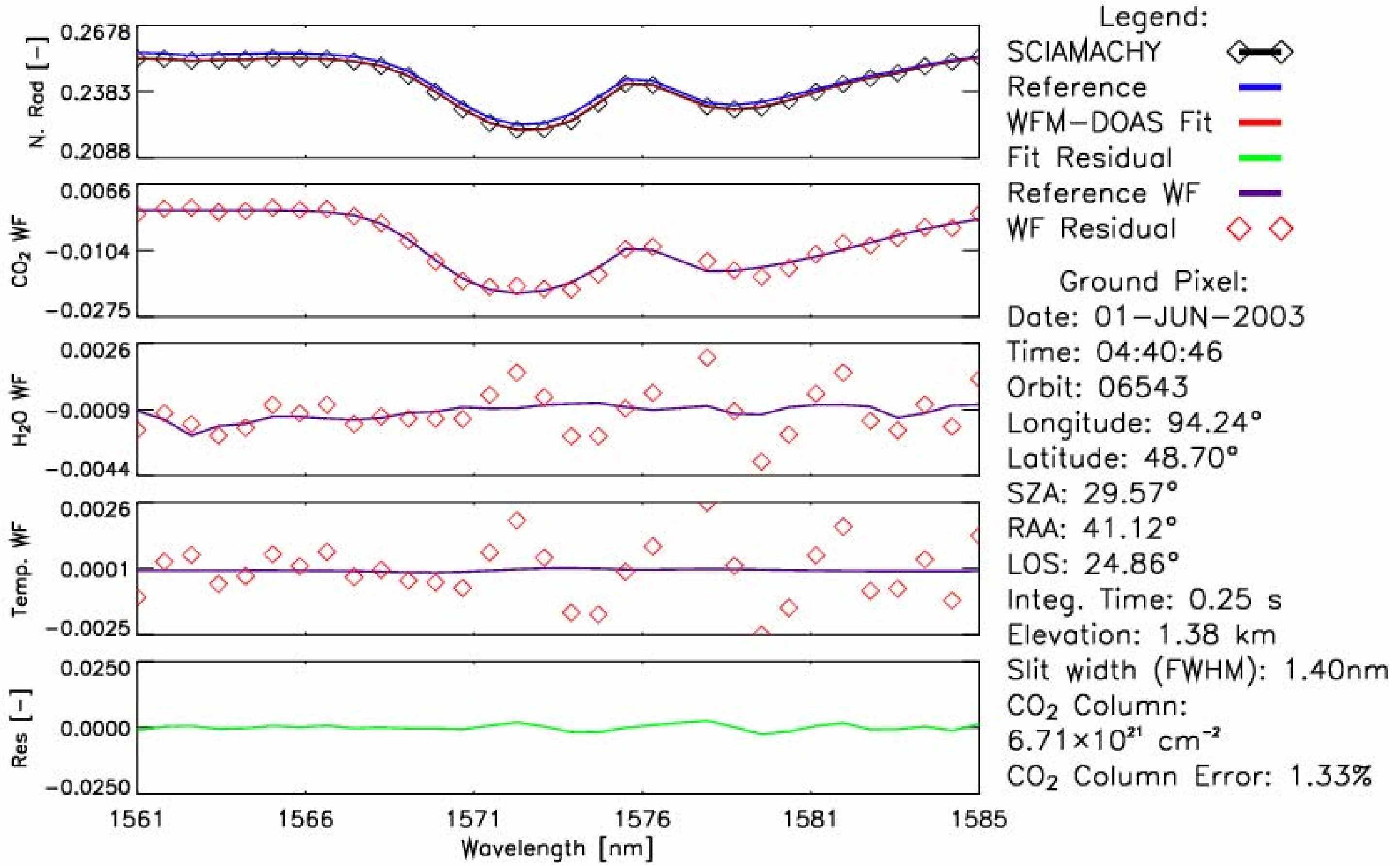
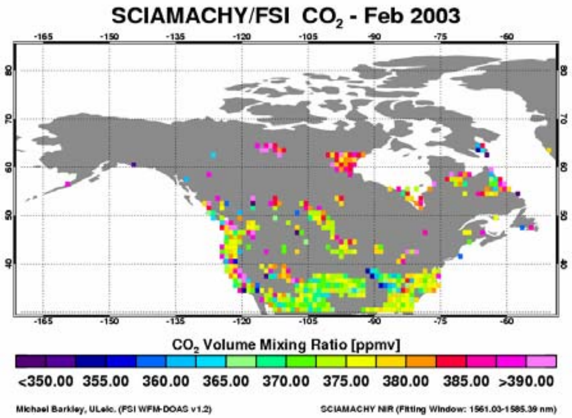
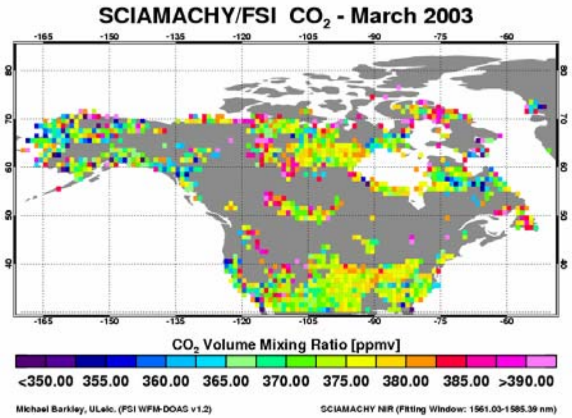

SCIAMACHY
Spectra, geolocation, viewing geometry, time
Cloud Filter
SPICI (SRON)
(Krijger et al, ACP, 2005)
'A priori' Data
CO_2 profiles taken from 2003 climatology (Remedios, ULeic)
ECMWF: temperature, pressure and water vapour profiles
'A priori' albedo - inferred from SCIAMACHY radiance as a f(SZA)
'A priori' aerosol (maritime/rural/urban)
Raw Spectra
Process only if : cloud free, forward scan, SZA <75°
Calibration
Non-linearity, dark current, ppg & etlaon
SCIATRAN
(Courtesy of IUP/IFE Bremen)
LBL mode, HITRAN 2004
I_0 - Frerick (ESA)
I - Calibrated Spectra
SCIAMACHY Spectrum (I/I_0)
WFM-DOAS fit
Reference Spectrum + weighting functions
(CO_2, H_2O and temperature)
CO_2 Column
(Normalise with ECMWF Surface Pressure)
Accept only: Errors <5%, Range:340-400 ppmv

Example FSI spectral fit



- Good sensitivity to CO_2 concentration


SCIAMACHY/FSI CO_2 - Feb 2003
CO_2 Volume Mixing Ratio [ppmv]
<350.00 355.00 360.00 365.00 370.00 375.00 380.00 385.00 >390.00
Michael Barkley, ULeic. (FSI WFM-DOAS v1.2)
SCIAMACHY NIR (Fitting Window: 1561.03-1585.39 nm)


SCIAMACHY/FSI CO_2 - March 2003
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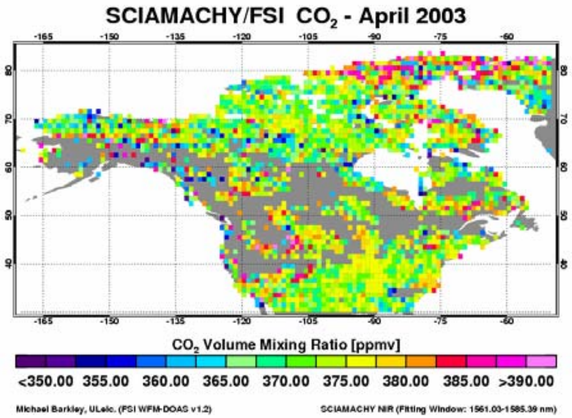
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CO_2 Volume Mixing Ratio [ppmv]
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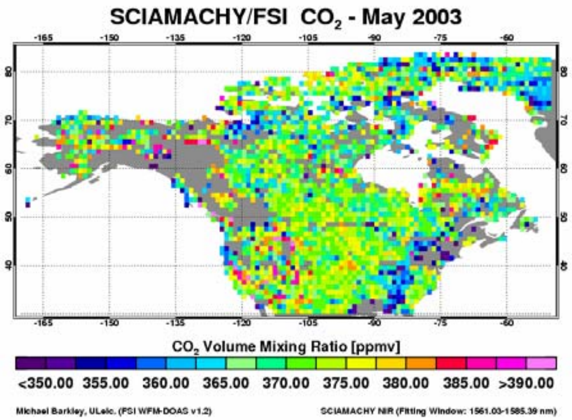
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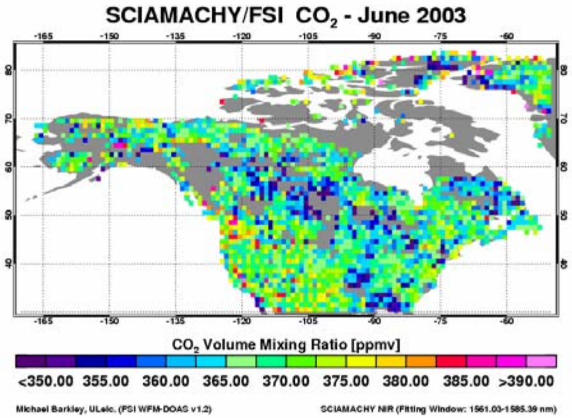
SCIAMACHY/FSI CO_2 - June 2003
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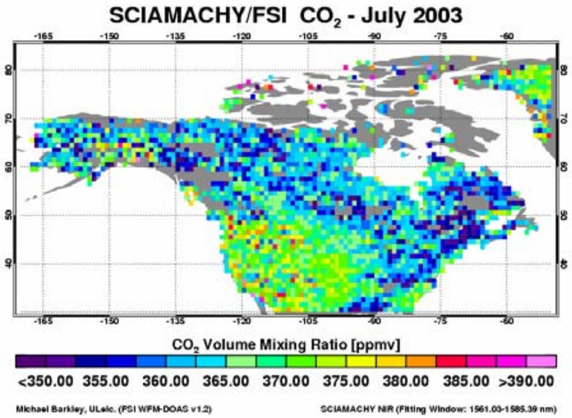
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CO_2 Volume Mixing Ratio [ppmv]
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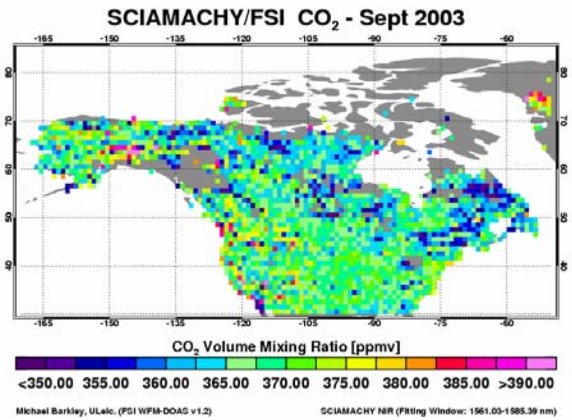
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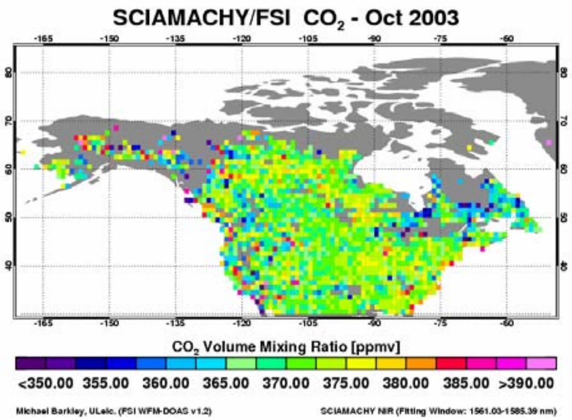
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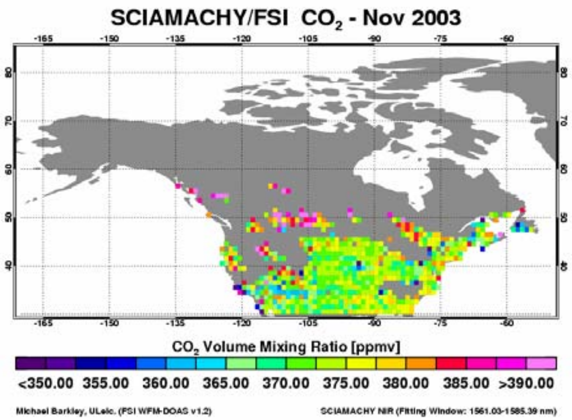
SCIAMACHY/FSI CO_2 - Nov 2003
CO_2 Volume Mixing Ratio [ppmv]
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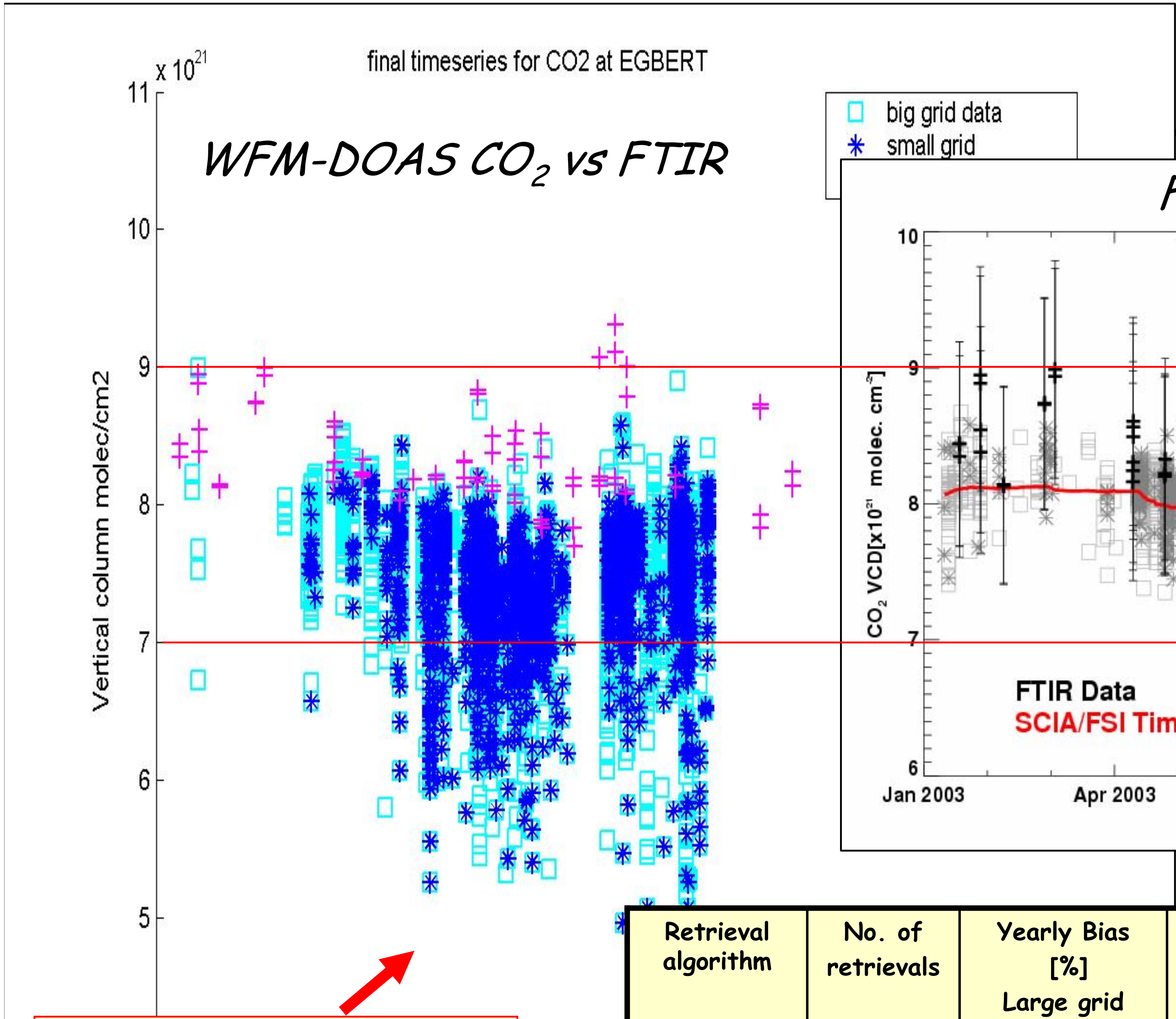
SCIAMACHY NIR (Fitting Window: 1561.03-1585.39 nm)

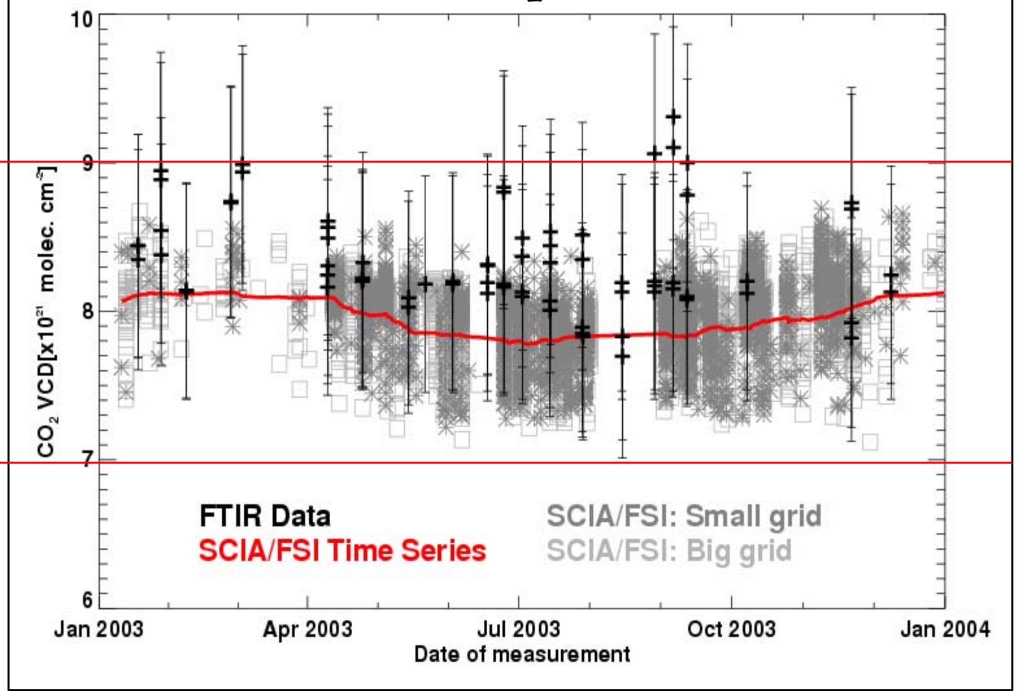
Comparisons to ground based FTIR data

- FTIR spectrometer based at Egbert, Canada
  - Location : 44.23°N , -79.8°E Altitude : 251 m
  - Accuracy of CO_2 columns [molec/cm^2] : ± 8.9%
- During 2003:
  - 74 FTIR measurements
  - 5150 valid FSI retrievals
    - Large grid: ±10.0° lon, ±2.5° lat of station
    - Small grid: ±5.0° lon, ±2.5° lat of station
- Compare FSI columns to 3rd order polynomial fit to FTIR data (see Dils et al., ACPD, 2005)
- Normalize FTIR with ECMWF pressure
  - Compare to 'final' FSI product

WFM-DOAS CO_2 vs FTIR



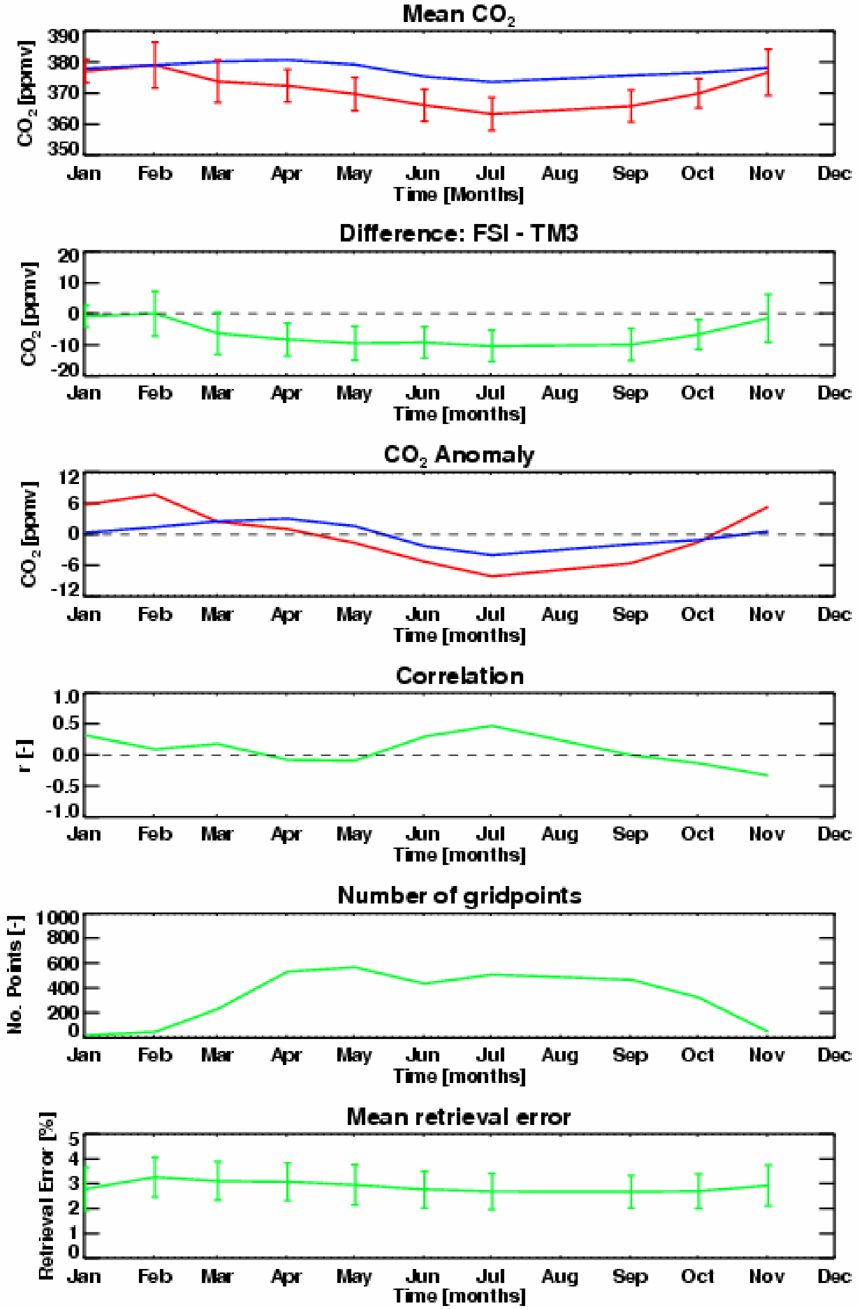
FSI CO_2 vs FTIR



WFM-DOAS CO_2 results presented in Dils et al, ACPD, 2005.

Retrieval algorithm	No. of retrievals	Yearly Bias [%] Large grid	σ_{Bias} [%] Large grid	Yearly Bias [%] Small grid	σ_{Bias} [%] Small grid
FSI	5150	-4.1	3.0	-4.0	3.0
WFM-DOAS	2232	-12.0	7.4	-11.3	5.7

Comparisons to the TM3 model



Canada/Alaska

TM3 vs SCIA

The TM3 model

- Atmospheric transport: TM3, driven by NCEP meteorological data
  - Fossil fuel CO2 emissions:
  - Ocean air-sea fluxes:
  - Terrestrial biosphere:

Comparison approach

- Model adjusted for optimal match with in situ observations at the South Pole
  - i.e. calibrated
- Model is sampled at times & locations of observations
- SCIA/FSI averaging kernel has been applied to model data
- FSI/TM3 retrievals averaged onto 1°x1° grid
  - Time series of monthly scene averages
  - Spatial distribution

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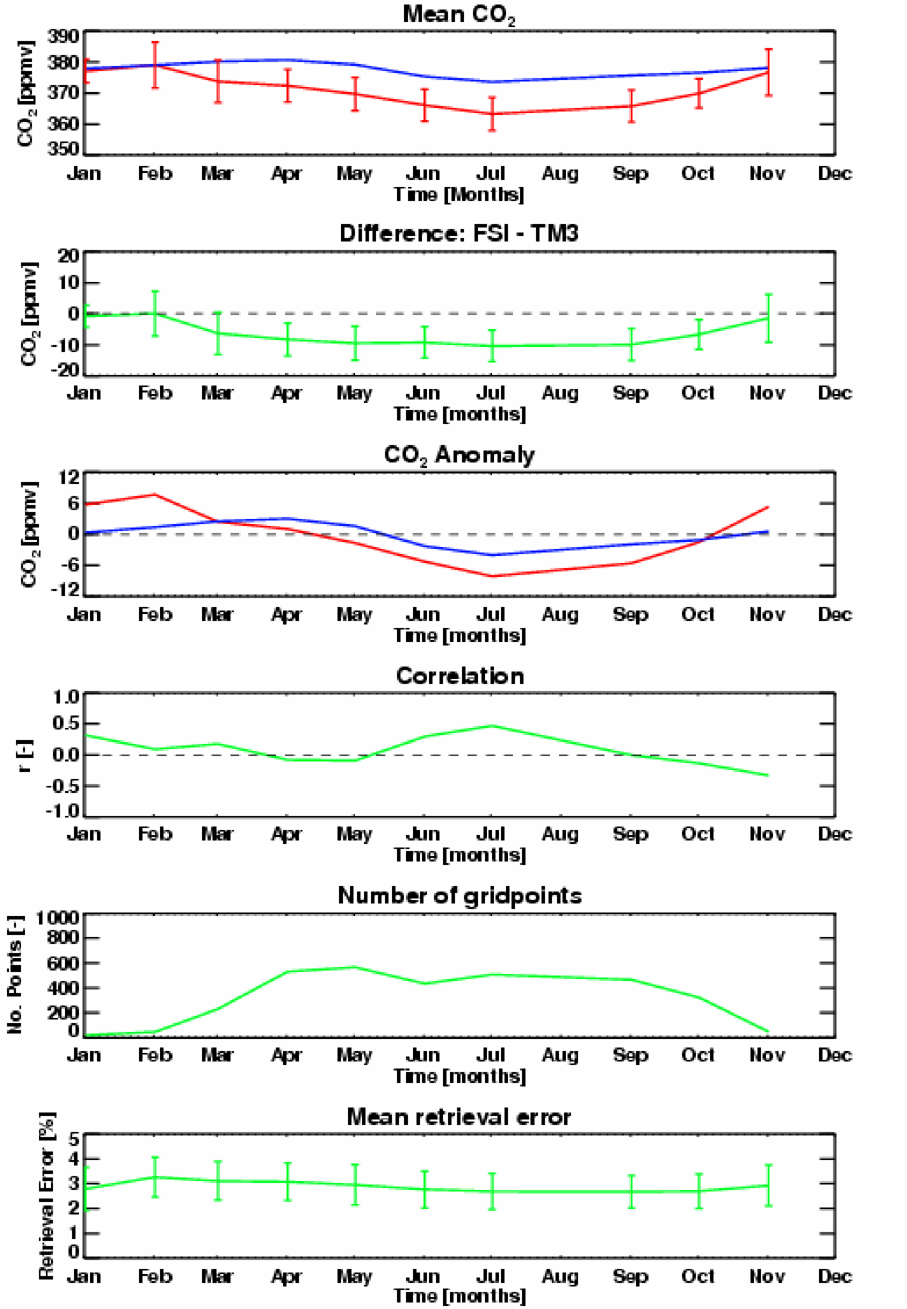
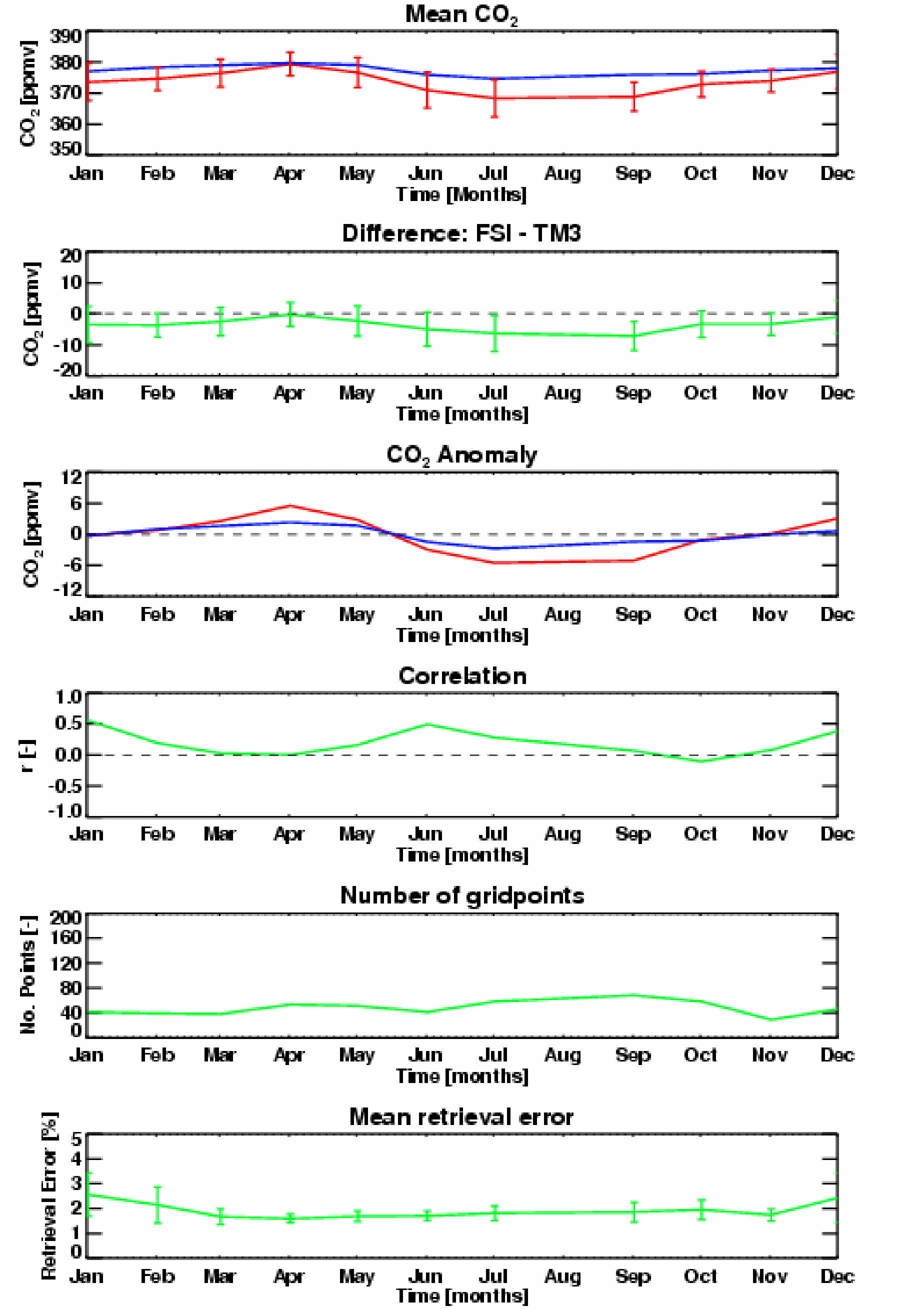
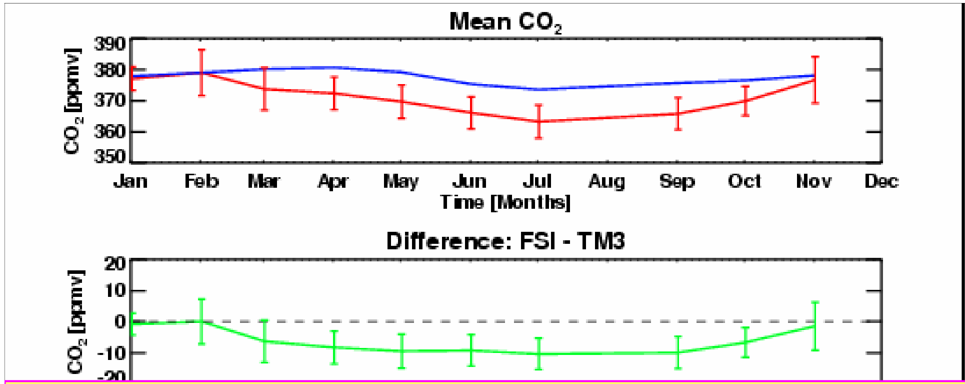


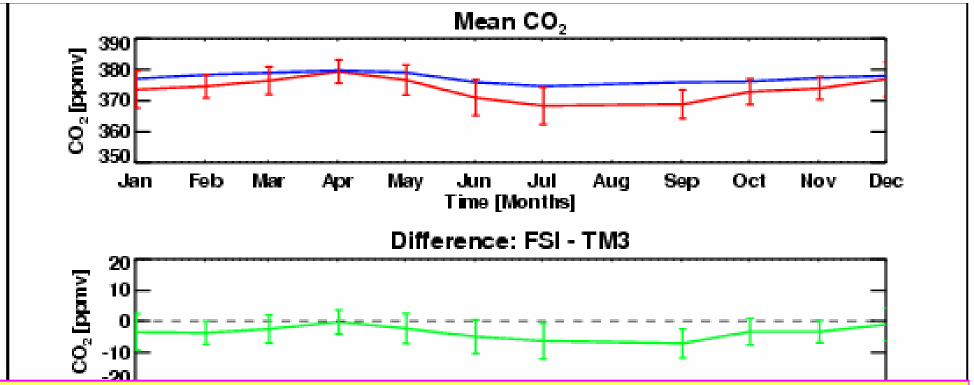


Canada/Alaska

TM3 vs SCIA

Gobi desert





Correlation between time series typical greater than 0.7

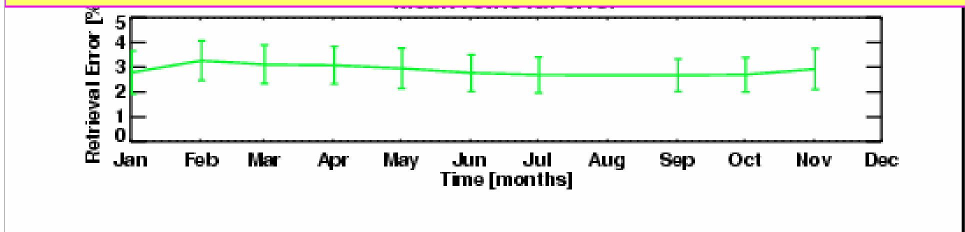
(Note: No scaling of FSI data)

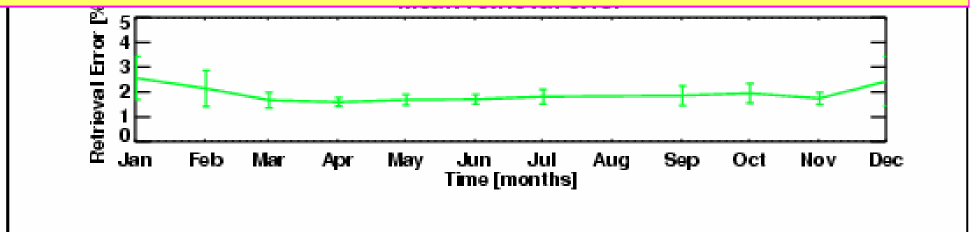
Typical -2% bias in FSI yearly means & -2% difference (though Gobi Desert → -1%)

Bias of TM3 to FTIR data (using same method) ~ -2%

Assuming model & FTIR correct:

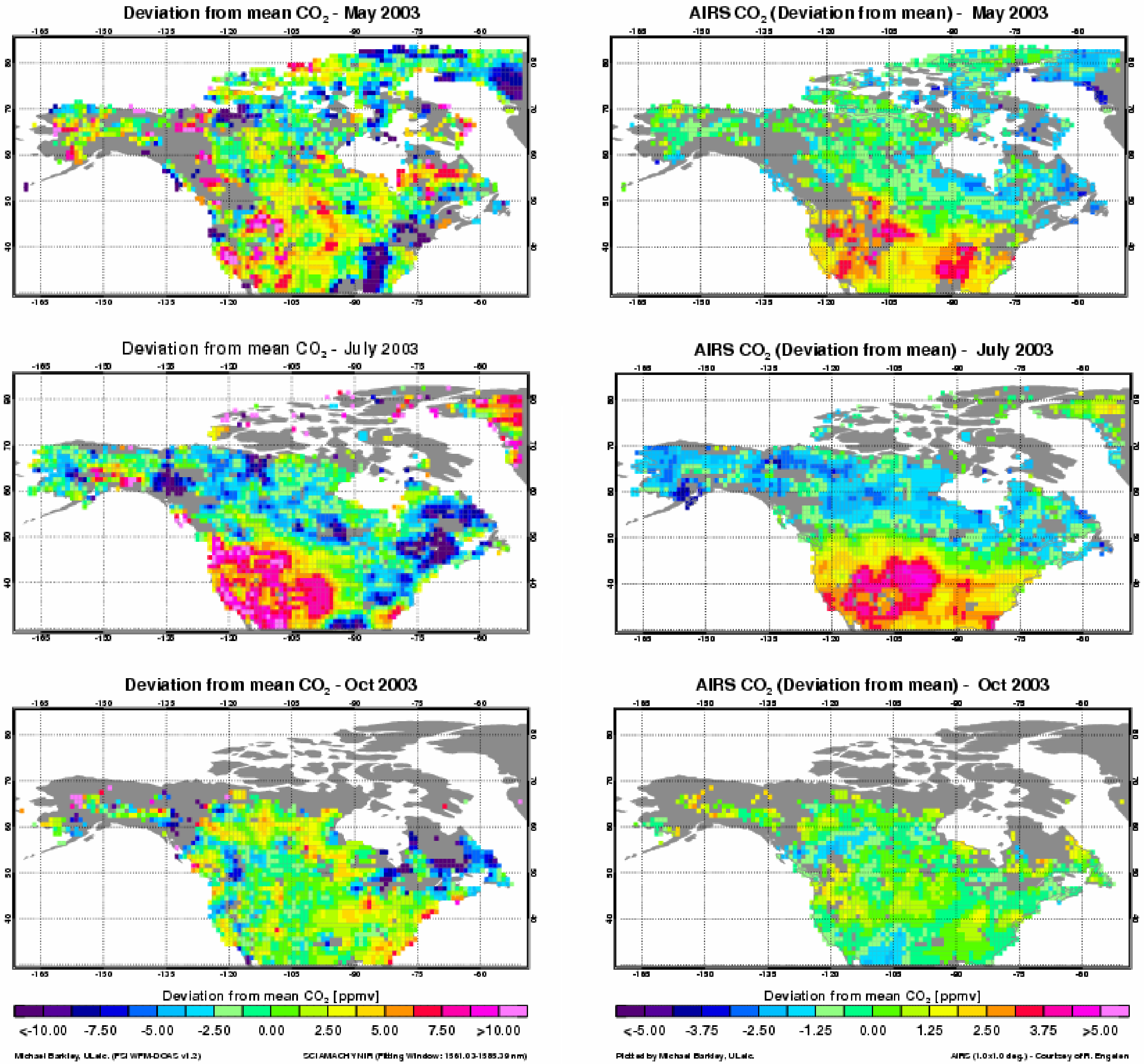
Bias of approx.-4% of FSI CO_2 to 'true' CO_2



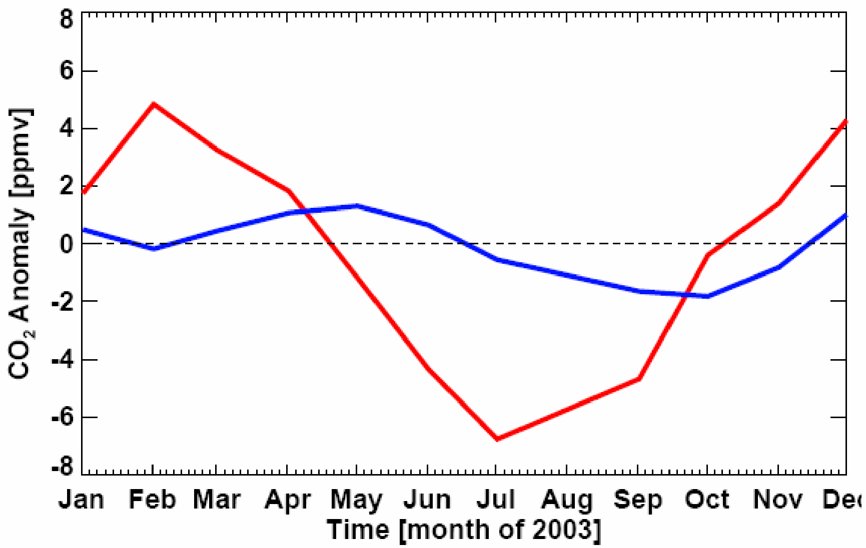


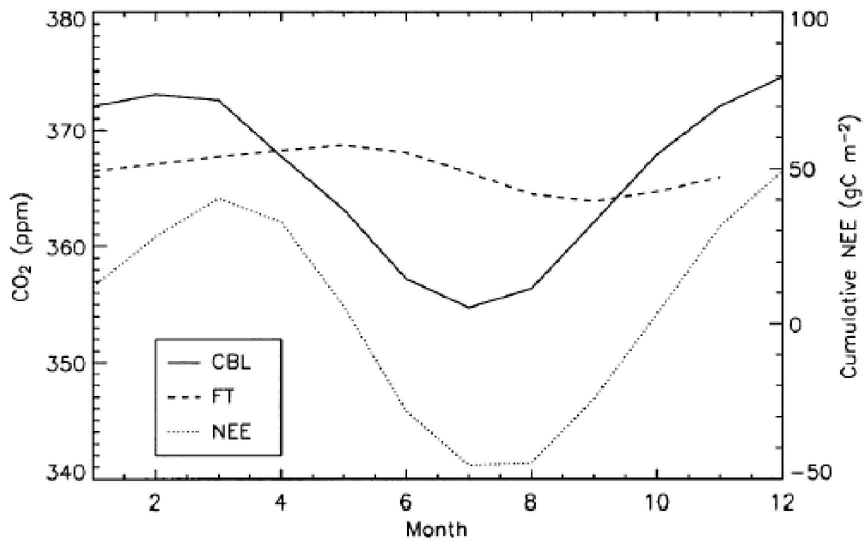
Canada/Alaska | **TM3 vs SCIA** | **Gobi desert**

Comparison of SCIA vs AIRS



SCIA vs AIRS Time Series



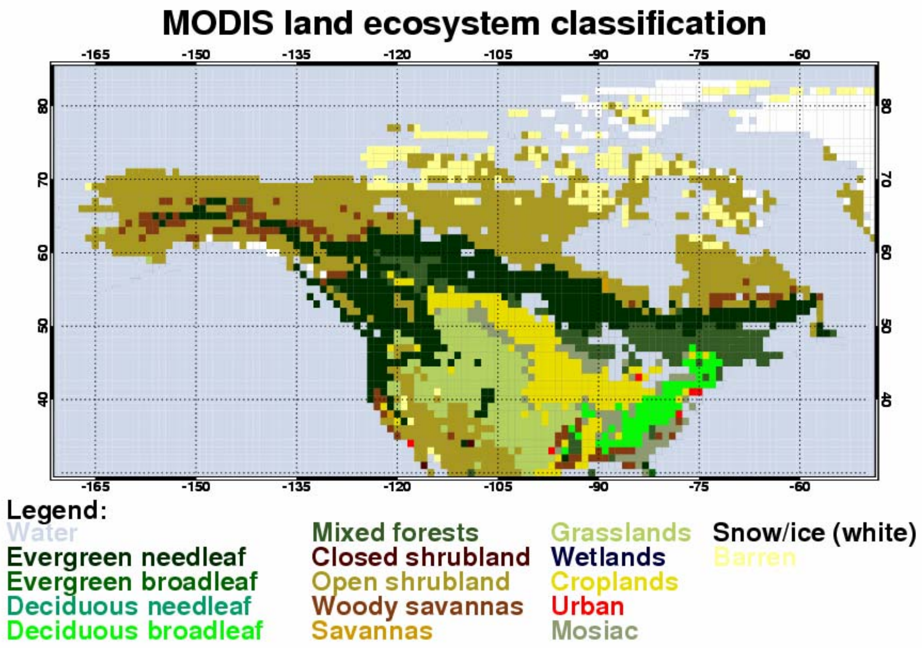


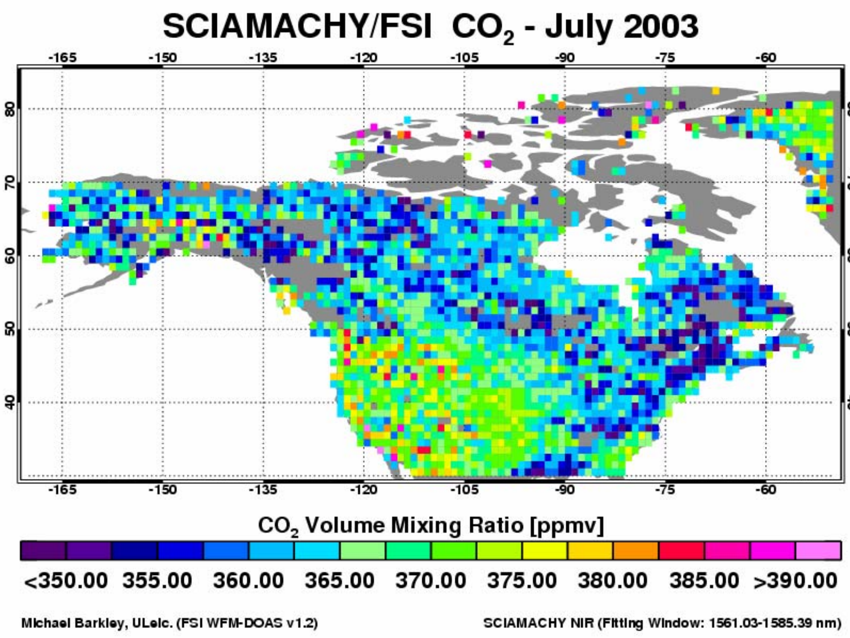
- For North America 2003:
  - SCIAMACHY
  - AIRS

- CBL → 396 m TV Tower near Park Fall, Wisconsin
- FT → Aircraft flights near Carr, Colorado

(Hurwitz et al, J. Atmos Sci.,2004)

Can we learn anything?





- Greater CO_2 uptake by forests compared to crops & grass plains?
- Identification of sub-continental CO_2 sources/sinks ?

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Summary

- Full Spectral Initiation Algorithm → use 'a priori' data
- Encouraging first results…
  - Good agreement with FTIR station at Egbert (bias -4%)
  - Good agreement with TM3 model (more uptake in summer)
    - "Comparisons between SCIAMACHY atmospheric CO_2 retrieved using (FSI) WFM-DOAS to ground based FTIR data and the TM3 chemistry transport model", Barkley et al., *submitted ACPD, 2006.*
  - Good agreement with AIRS CO_2
    - "Comparisons of SCIAMACHY and AIRS CO_2 measurements over North America during 2003", Barkley et al., *GRL Paper in preparation,2006.*

…but still a long way to go…

  - Improve
    - 'A priori data' (e.g. use TM3 CO_2 profiles ?)
    - Calibration
    - Aerosols ☹ (e.g. Houwelling et al, 2005)
    - Cloud contamination
    - Dual retrieval with Oxygen (O_2) ?
      - CO_2 [ppmv] = (CO_2 / O_2) x 0.295
- Can we measure atmospheric CO_2 from space?
  - **Yes !**
  - **First (tentative!) steps to identify surface sources/sinks and to provide modellers with CO_2 satellite data**

2nd Example Scene: Siberia