Measuring atmospheric CO$_2$ with SCIAMACHY using Full Spectral Initiation (FSI) WFM-DOAS

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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, CO$_2$, H$_2$O and N$_2$O 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 😞
SCIAMACHY
Spectra, geolocation, viewing geometry, time

Cloud Filter
SPICI (SRON)
(Krijger et al, ACP, 2005)

'A priori' Data
CO₂ 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)

Calibration
Non-linearity, dark current, ppg & etlaon

SCIATRAN
(LBL mode, HITRAN 2004)
(Courtesy of IUP/IFE Bremen)

Reference Spectrum + weighting functions
(CO₂, H₂O and temperature)

SCIAMACHY Spectrum (I/I₀)

Raw Spectra

I₀ - Frerick (ESA)
I - Calibrated Spectra

WFM-DOAS fit

CO₂ Column
(Normalise with ECMWF Surface Pressure)
Accept only: Errors <5%, Range:340-400 ppmv

Process only if: cloud free, forward scan, SZA <75°
Example FSI spectral fit

- Good sensitivity to CO$_2$ concentration
Comparisons to ground based FTIR data

- FTIR spectrometer based at Egbert, Canada
  - Location: 44.23°N, -79.8°E Altitude: 251 m
  - Accuracy of CO₂ columns [molec/cm²]: ± 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

Retrieval algorithm | No. of retrievals | Yearly Bias [%] | $\sigma$ Bias [%] | Yearly Bias [%] | $\sigma$ Bias [%]
--- | --- | --- | --- | --- | ---
FSI | 5150 | -4.1 | 3.0 | -4.0 | 3.0
WFM-DOAS | 2232 | -12.0 | 7.4 | -11.3 | 5.7

WFM-DOAS CO$_2$ results presented in Dils et al, ACPD, 2005.
Comparisons to the TM3 model

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
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 CO₂ to 'true' CO₂
Comparison of SCIA vs AIRS
SCIA vs AIRS Time Series

- For North America 2003:
  - SCIAMACHY
  - AIRS

- CBL $\rightarrow$ 396 m TV Tower near Park Fall, Wisconsin

- FT $\rightarrow$ Aircraft flights near Carr, Colorado

(Hurwitz et al, J. Atmos Sci., 2004)
Can we learn anything?

- Greater $\text{CO}_2$ uptake by forests compared to crops & grass plains?
- Identification of sub-continental $\text{CO}_2$ sources/sinks?

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Summary

• Full Spectral Initiation Algorithm \(\rightarrow\) 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\(_2\)

...but still a long way to go...
• Improve
  - ‘A priori data’ (e.g. use TM3 CO\(_2\) profiles ?)
  - Calibration
  - Aerosols \(\oplus\) (e.g. Houwelling et al, 2005)
  - Cloud contamination
  - Dual retrieval with Oxygen (O\(_2\)) ?
    - \(\text{CO}_2\ [\text{ppmv}] = \left( \frac{\text{CO}_2}{\text{O}_2} \right) \times 0.295\)

• 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