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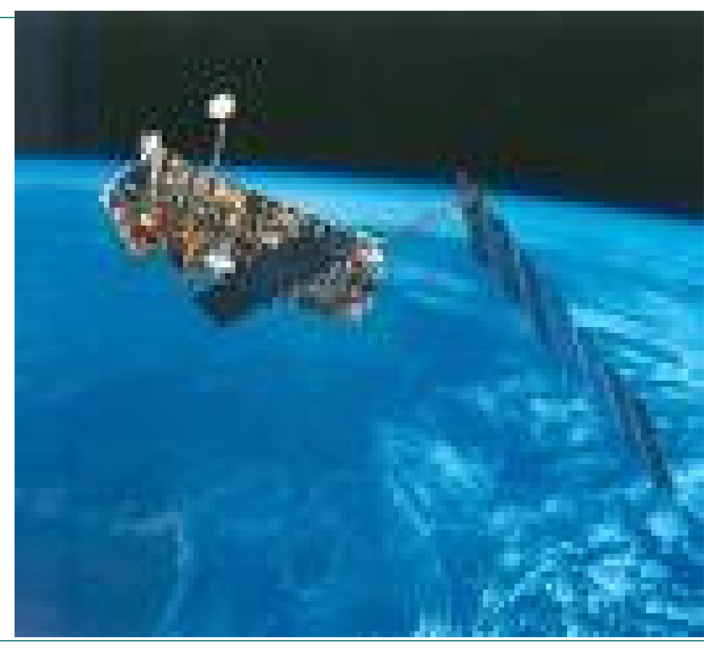

# SATELLITE VALIDATION OF COLUMN-AVERAGED METHANE ON GLOBAL SCALE: GROUND-BASED DATA FROM 15 FTIR STATIONS VERSUS LAST GENERATION ENVISAT/SCIAMACHY RETRIEVALS

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Previous work has shown that the precision of ground-based mid-infrared (MIR) FTIR spectrometry is sufficient to detect day-to-day variability of columnar methane, while first retrievals from ENVISAT/SCIAMACHY (channel 8) satellite measurements were impacted by a significant time-dependent bias due to detector icing (Sussmann et al., 2005). This prevented insight into true methane temporal variability at that time. The goal of our updated study is to investigate the precision of the last generation (channel 6) SCIAMACHY retrievals IMAP-DOAS v49 and WFM-DOAS v1.0 in comparison to retrievals from ground-based MIR measurements of the European FTIR network. We first briefly discuss the origin and magnitude of the natural variability of columnar methane. Subsequently, our study investigates all factors which can be optimized to improve precision of ground-based MIR-FTIR retrievals of columnar methane. This includes an optimized Tikhonov-type regularization tuned in a way to minimize the diurnal variability of retrieved columnar methane. We also discuss ways to select and average individual-pixel satellite data in order to reflect true day-to-day variability and make them comparable to ground-based data.

## Homogenized retrieval strategy for ground-based FTIR stations

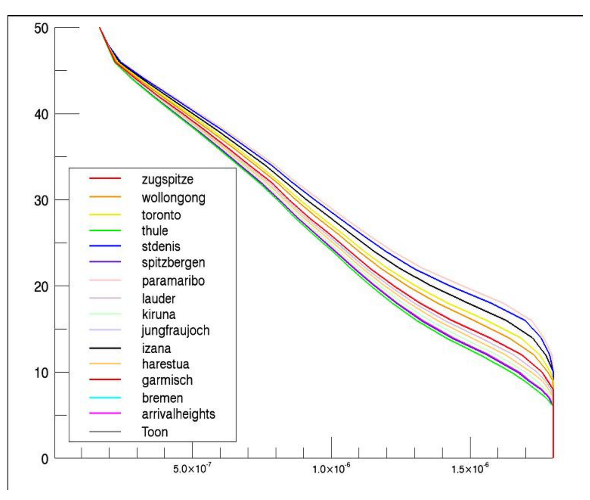



**Fig. 1.** Common Toon balloon profile adapted for tropopause altitude via the linear transformation described in Arndt Meier´s thesis for each station.

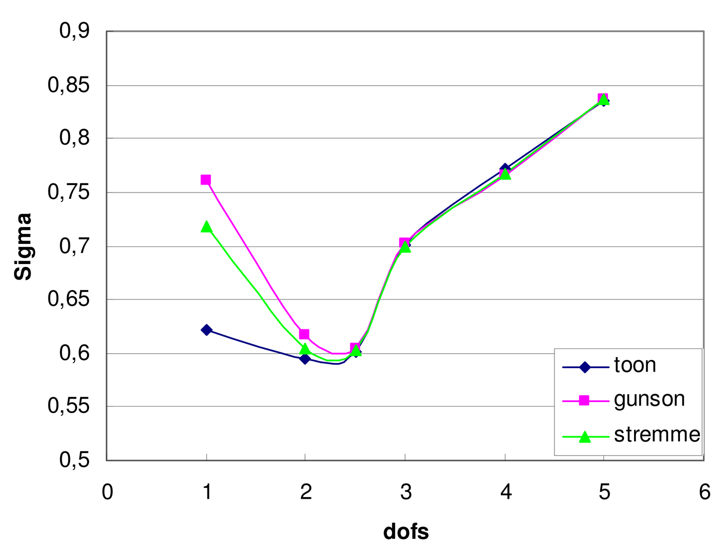



**Fig.2.** Tikhonov first derivative regularization L1 with same regularization strength α for all stations tuned for minimum $XCH_4$ diurnal variation/ minimum day-to-day variability.

$$\mathbf{R} = \mathbf{S}_a^{-1} = \alpha\,\mathbf{L}_1^T\mathbf{L}_1 = \alpha \times \begin{pmatrix} 1 & -1 & 0 & \cdots & 0 \\ -1 & 2 & \ddots & \ddots & \vdots \\ 0 & \ddots & \ddots & \ddots & 0 \\ \vdots & \ddots & \ddots & 2 & -1 \\ 0 & \cdots & 0 & -1 & 1 \end{pmatrix} \in \Re^{n \times n}$$

## Selection and averaging of individual-pixel satellite data

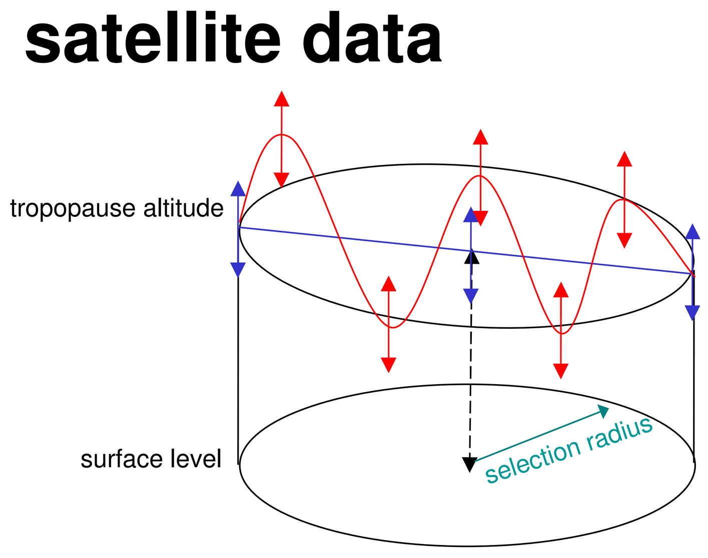
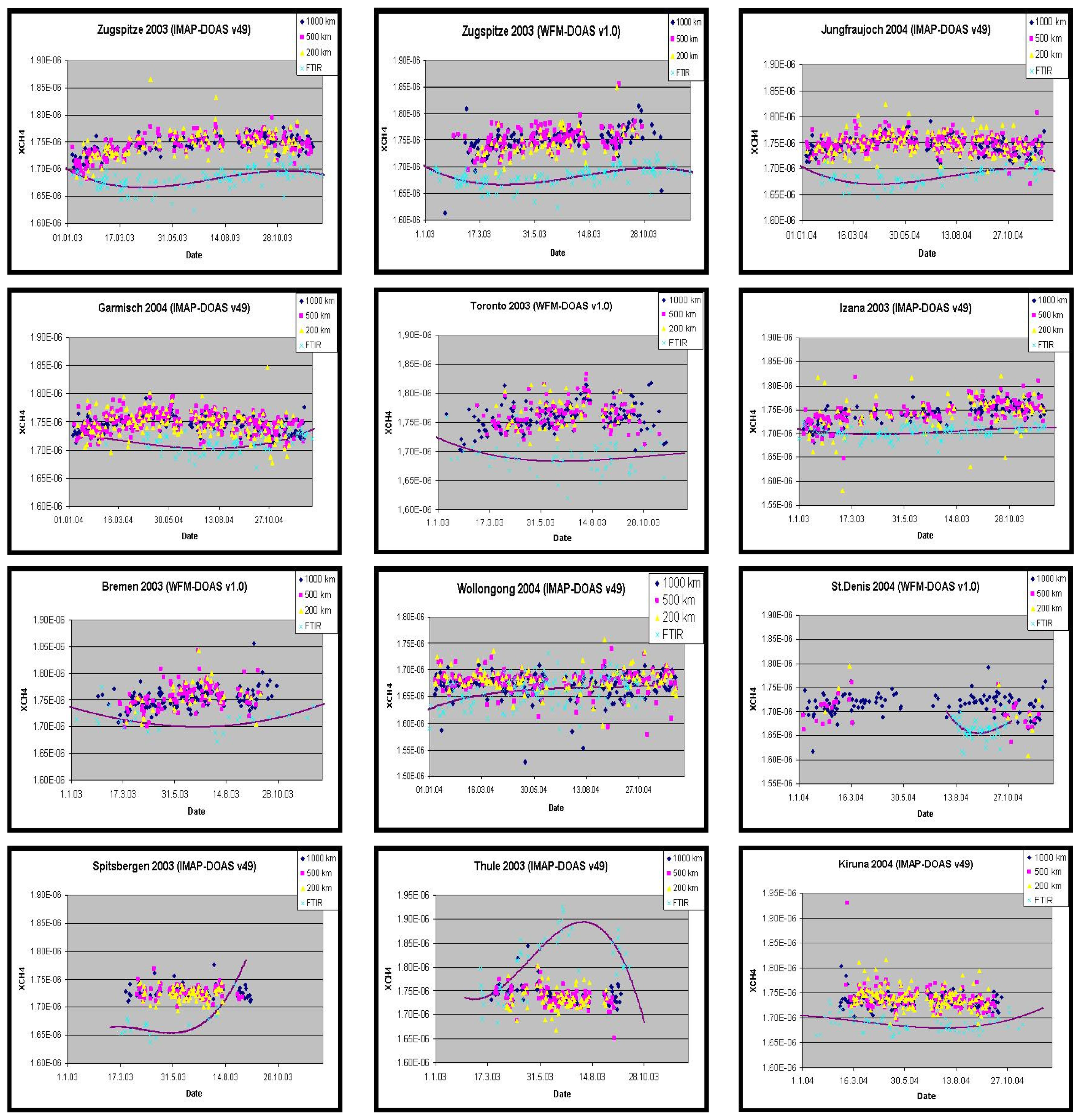



**Fig. 3.** An average of (SCIA) pixels within a certain selection radius tends to see the same (in case of the planetary wave length is bigger than the selection radius) or slightly smaller (in case of planetary wave length is smaller than the selection radius) day-to-day columns variability compared to a point-type measurement.

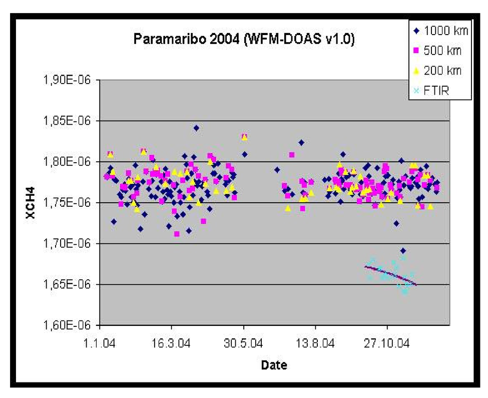
## The 15 collaborating FTIR-Stations

| station | latitude | longitude | station altitude | Number of columns in 2003/2004 | tropopause height |
|---|---|---|---|---|---|
| Spitzbergen | 78.92 °N | 11.92 °E | 20 m | 113 | 8.95 km |
| Thule | 76.53 °N | 68.74 °W | 225 m | 177 | 8.51 km |
| Kiruna | 67.84 °N | 20.41 °E | 419 m | 338 | 9.62 km |
| Harestua | 60.22 °N | 10.75 °E | 596 m | | 10.20 km |
| Bremen | 53.11 °N | 8.85 °E | 29 m | 179 | 10.74 km |
| Zugspitze | 47.42 °N | 10.98 °E | 2964 m | **999** | 11.25 km |
| Garmisch | 47.48 °N | 11.06 °E | 745 m | 498 | 11.25 km |
| Jungfraujoch | 46.55 °N | 7.99 °E | 3580 m | 702 | 11.38 km |
| Toronto | 43.66 °N | 79.40 °W | 174 m | 185 | 13.25 km |
| Izaña | 28.30 °N | 16.48 °W | 2367 m | 207 | 14.44 km |
| Paramaribo | 5.81 °N | 55.21 °W | 7 m | 64 | 16.36 km |
| St-Denis | 20.90 °S | 55.48 °E | 50 m | 141 | 15.66 km |
| Wollongong | 34.41 °S | 150.88 °E | 40 m | 633 | 12.53 km |
| Lauder | 45.04 °S | 169.68 °E | 370 m | | 10.73 km |
| Arrival Heights | 77.82 °S | 166.65 °E | 200 m | | 9.06 km |

## Comparison of ground-based FTIR-data to ENVISAT/SCIAMACHY (Selection)




| **Zugspitze 2003** (dofs=1.91) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $AV_i(n_i)$ <# of spectra> | | $AV_i(\sigma_i)$ [%] | | $AV_i(\sigma_i/\sqrt{n_i})$ [%] | | σ of daily means corrected for annual cycle [%] | | Bias [%] | |
| FTIR | 5.29 <735> | | 0.56 | | 0.26 | | 0.77 | | --- | |
| | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS |
| SCIA 200 | 13.47 | 7.71 | 1.62 | 1.45 | 0.48 | 0.59 | 1.17 | 1.33 | 3.31 | 3.75 |
| SCIA 500 | 57.38 | 23.39 | 1.80 | 1.55 | 0.33 | 0.42 | 0.76 | 1.11 | 3.25 | 4.08 |
| SCIA 1000 | 174.22 | 56.40 | 1.71 | 1.60 | 0.13 | 0.34 | 0.57 | 1.09 | 3.40 | 3.94 |




| **Garmisch 2004** (dofs=1.96) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $AV_i(n_i)$ <# of spectra> | | $AV_i(\sigma_i)$ [%] | | $AV_i(\sigma_i/\sqrt{n_i})$ [%] | | σ of daily means corrected for annual cycle [%] | | Bias [%] | |
| FTIR | 5.89 <498> | | 0.57 | | 0.26 | | 0.80 | | --- | |
| | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS |
| SCIA 200 | 20.65 | 6.04 | 1.79 | 1.83 | 0.54 | 0.82 | 1.25 | 1.52 | 1.99 | 2.69 |
| SCIA 500 | 76.15 | 15.61 | 1.63 | 1.62 | 0.25 | 0.52 | 0.86 | 1.33 | 2.33 | 2.82 |
| SCIA 1000 | 248.12 | 32.42 | 1.87 | 1.58 | 0.14 | 0.42 | 0.68 | 1.24 | 2.21 | 2.64 |

| **Bremen 2003** (dofs=2.15) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $AV_i(n_i)$ <# of spectra> | | $AV_i(\sigma_i)$ [%] | | $AV_i(\sigma_i/\sqrt{n_i})$ [%] | | σ of daily means corrected for annual cycle [%] | | Bias [%] | |
| FTIR | 4.04 <129> | | 0.65 | | 0.33 | | 1.00 | | --- | |
| | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS |
| SCIA 200 | 19.13 | 5.97 | 1.31 | 1.19 | 0.40 | 0.50 | 0.74 | 1.23 | 2.35 | 2.67 |
| SCIA 500 | 54.77 | 12.70 | 1.71 | 1.40 | 0.31 | 0.43 | 0.75 | 1.18 | 1.72 | 2.81 |
| SCIA 1000 | 158.72 | 43.86 | 1.75 | 1.55 | 0.21 | 0.31 | 0.84 | 0.92 | 1.56 | 2.91 |

| **Wollongong 2004** (dofs=2.24) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $AV_i(n_i)$ <# of spectra> | | $AV_i(\sigma_i)$ [%] | | $AV_i(\sigma_i/\sqrt{n_i})$ [%] | | σ of daily means corrected for annual cycle [%] | | Bias [%] | |
| FTIR | 2.43 <341> | | 1.81 | | 1.04 | | 1.44 | | --- | |
| | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS | IMAP-DOAS | WFM-DOAS |
| SCIA 200 | 22.51 | 7.29 | 1.95 | 1.29 | 0.55 | 0.53 | 1.25 | 1.25 | 0.96 | 1.06 |
| SCIA 500 | 89.79 | 31.97 | 2.05 | 1.33 | 0.40 | 0.35 | 1.60 | 1.09 | 1.17 | 1.36 |
| SCIA 1000 | 216.16 | 91.86 | 2.13 | 1.34 | 0.32 | 0.31 | 1.21 | 0.98 | 0.83 | 1.04 |

**1st column**: $AV_i(n_i)$, i.e. average of individual measurements $n_i$ during each measurement day and the total number of spectra.
**2nd column**: $AV_i(\sigma_i)$, i.e. average of the "single-value standard deviations" calculated from the individual measurements for different days.
**3rd column**: $AV_i(\sigma_i/\mathrm{sqrt}(n_i))$, i.e. average of the "standard deviations of the daily mean values" calculated from the individual measurements for the different days.
**4th column**: Standard deviations of the daily mean data sets normalized to the annual cycle (polynomial fit).
**5th column**: Bias between FTIR daily means and the average of all SCIAMACHY pixels of one day within the specified radius calculated by investigating pairwise "coincidences".

## References

Sussmann, R., Stremme, W., Buchwitz, M., and de Beek, R.: Validation of ENVISAT/SCIAMACHY columnar methane by solar FTIR spectrometry at the Ground-Truthing Station Zugspitze, Atmos. Chem. Phys., accepted 5 Sep 2005.

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