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RAL Space

Retrieval of Global Tropospheric Methane Distributions from IASI

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Introduction

- Methane is one of the most important greenhouse gases in the atmosphere, and is also important for the role it plays in atmospheric chemistry.
- There is a general trend for methane to increase with time. However, this trend is not consistent and variations are not fully understood. In recent years, the increase in methane appeared to stabilise between 1999 and 2006, before starting to increase again from 2007 (e.g. Dlugokencky, 2009)

- Tropospheric methane can be measured from space by two main classes of nadir sounding instrument, providing complimentary information.
  - **Short-wave infrared:** e.g. SCIAMACHY, GOSAT =>sensitive to methane column, including the near-surface, but only over land and only in the day-time
  - **Thermal infrared:** eg AIRS, TES, and IASI.. => less sensitive near to the surface but provides height-resolved information within the troposphere, day and night, over land and sea.
- In this poster we describe methane distributions derived at RAL from the IASI instrument on MetOp (see box opposite.

Results

Data is currently available for 6 months (August 2008, April 2009, August – November 2009). Results have been extensively evaluated by comparison to TCCON ground-based observations and model intercomparisons.

Vertical sensitivity

- Figure 1 shows simulated averaging kernels (dvmr_ret/dvmr_true),for a typical IASI methane retrieval. Key features are:
  - Sensitivity to tropospheric methane, with two distinct peaks in the mid-upper troposphere
  - Limited sensitivity near the surface
- Real retrieval levels are set at 1000hPa, 422hPa, 178hPa, 100hPa and higher stratospheric levels.

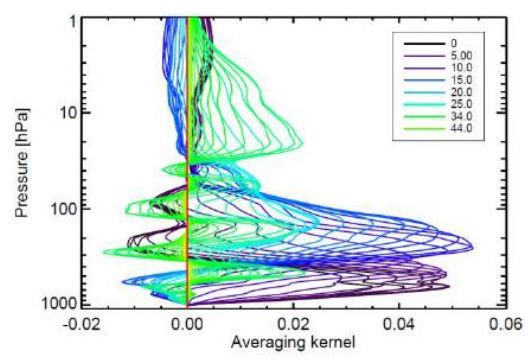

Figure 1: Profile averaging kernels for methane, based on a simulation on a 1km retrieval grid, with an apriori covariance matrix with a 6km correlation length. The legend indicates every 5th level. Each averaging kernel is shown on the internal model levels (RTTOV 100 levels with finer spacing at the lower altitudes

Global distributions and model comparisons

- IASI data is being compared to model data and other satellite instruments in the NCEO atmospheric composition theme. Monthly mean data for August 2009 is shown in Figure 2.
- Vertical and latitudinal distributions derived from IASI show good agreement with models, although biases exist in the data.
- The two most sensitive tropospheric levels are illustrated in comparison to model data with IASI averaging kernels applied. Key features can be seen in both IASI and model data.
- Particularly high values are seen over southern Asia, and continuing in a tongue between SE Asia though to Africa. High values also exist in this level at high northern latitudes which can be seen in most of the model data
- At 178 hPa the high values are more restricted to a region over southern Asia, this would be consistent with methane being emitted and uplifted to higher altitudes in the monsoon region.
- Column averaged mixing ratios have also been calculated, and the comparison with GOSAT data from the University of Leicester is shown (Parker et al, 2011). Nb. no averaging kernels are applied to the model data in this case.

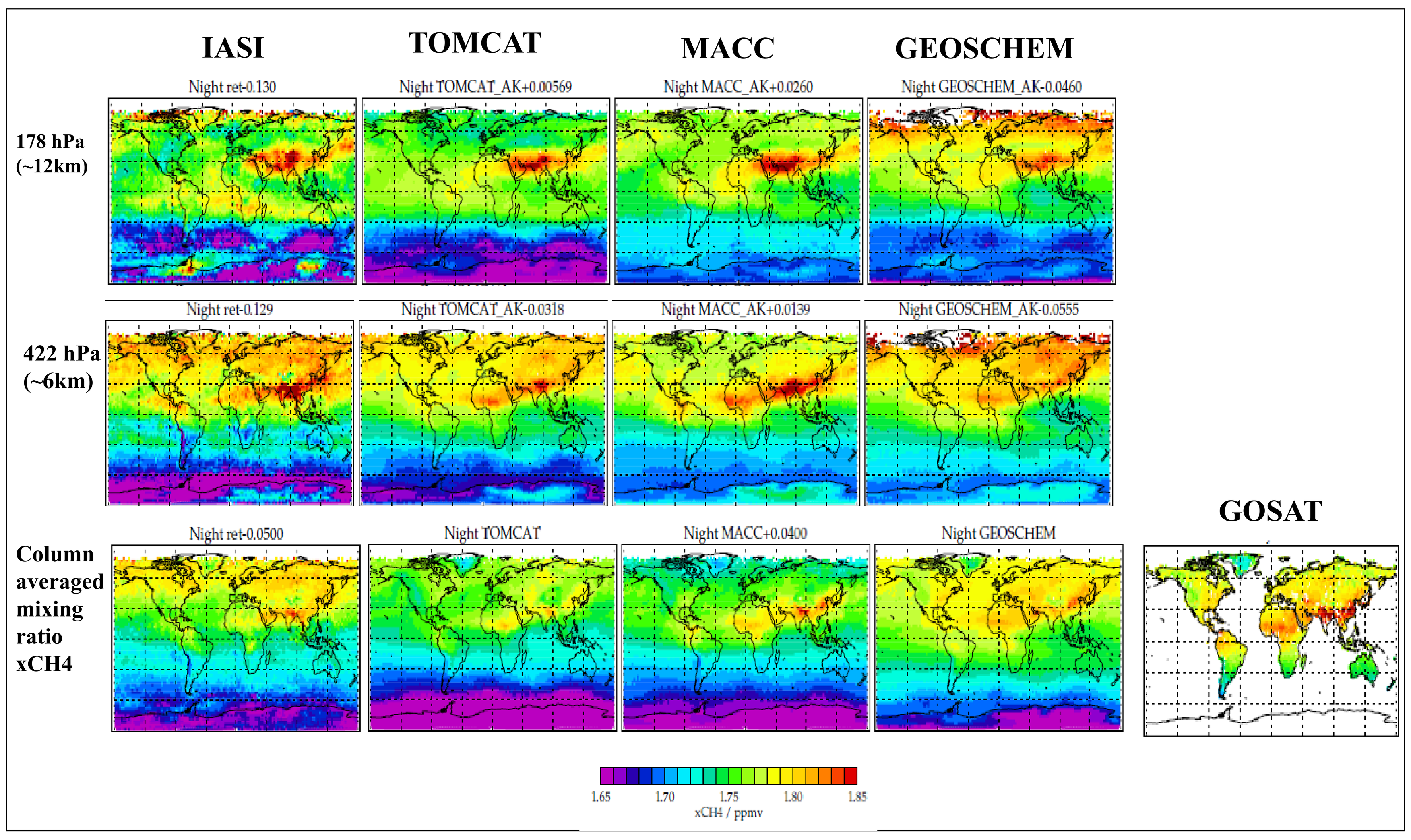

Figure 2: Monthly mean methane distributions for August 2009, 1x1 degree grid. Top two lines: CH4 vmrs for the two most sensitive IASI levels (178 hPa, 422 hPa), compared to model distributions with averaging IASI averaging kernels applied. Bottom line: column averaged mixing ratio for IASI and GOSAT, compared to model data (without averaging kernels). All datasets have had a bias added / subtracted to better illustrate the good agreement in the distributions. GEOSCHEM data was provided by A. Fraser, U. Edinburgh, and TOMCAT data by C. Wilson, U. Leeds.

Seasonal variations

Figure 3 illustrates seasonal variations in the data. GOSAT data is again shown for comparison

- IASI data shows global coverage, and the expected latitudinal gradient (starting from a constant *a priori*).
- Many similarities to GOSAT are seen. Both show the highest values in August, particularly over southern Asia, high values over S. America in April.
- IASI retrieves higher values compared to GOSAT (and several other data sources)

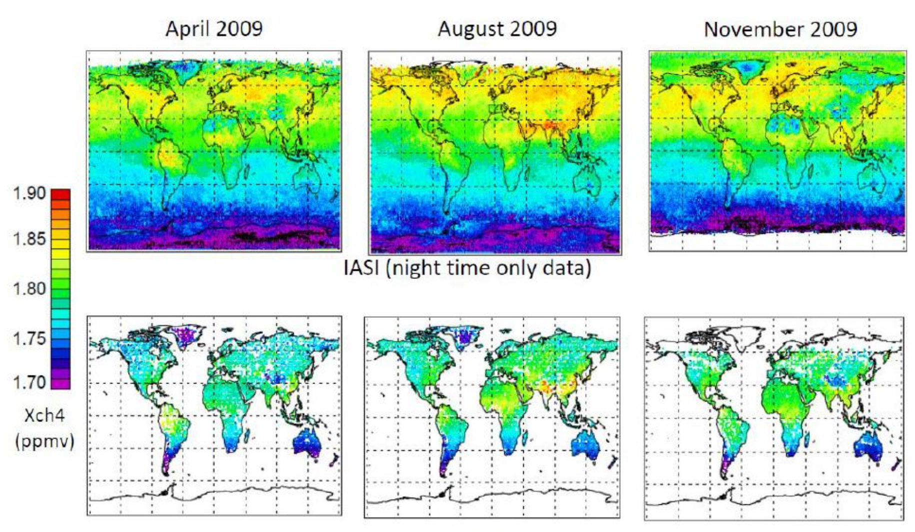

Figure 3: Seasonal variations in monthly mean methane. Plots are shown for April 2009, August 2009 and November 2009 gridded on a 1x1 degree grid for IASI nightime only data. For comparison we show GOSAT data from the University of Leicester, gridded on the same grid as IASI and on the same colour scale.

Acknowledgements:
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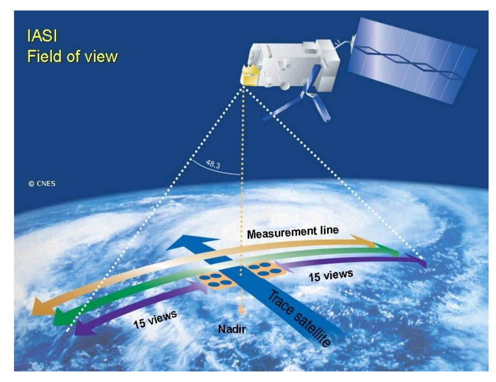
IASI

- Launched 2006 on MetOp
- Nadir viewing Fourier Transform infrared spectrometer
- Spectral range: 645-2760cm^{-1}
- Spectral resolution: 0.5cm^{-1} after apodisation
- Scans across track (2200km swath) with 12km pixel size at nadir, increasing with viewing angle



RAL CH_4 Retrieval Scheme

Retrieval Technique:	Optimal estimation
Radiative Transfer model:	RTTOV (with customised coefficients)
Spectral range:	1240-1290cm-1 (cf. Razavi et al, ACP 2009)
Retrieval species:	CH_4, N_2O, H_2O (log vmr) HDO scaling factor, surface temperature
Measurement noise:	Derived from spectral fits (dependent on scene radiance). (NB. original EUMETSAT data was found to not represent the behaviour of the noise in the methane spectral region)
Apriori + covariance matrix	Fixed a priori profile (no latitude dependence) Covariance: ~ 10% error in troposphere, increased in stratosphere, with 6km correlation length
Background profiles	Temperature, and apriori surface temperature, H2O from ECMWF

Improved handling of cloud

- To produce results shown opposite, the following quality control is used to minimise the impact of cloud:
  - Scenes with 12 micron brightness temperatures (BT) more than 3K cooler than that predicted based on ECMWF analyses (assuming no cloud) are rejected.
  - Scenes in which the co-retrieved column averaged N_2O exceeds 320ppb are rejected.
- This screening makes use of the fact N_2O has a well known mixing ratio in the troposphere. Deviations in retrieved N_2O from expected values indicate the presence of cloud in the scene.
- This approach works well for night-time retrievals when the ECMWF analyses provide better estimates of the clear sky BT. Daytime retrievals over land are still affected by cloud contamination (leading to high bias in the retrieved CH_4).
- An alternative version of the retrieval is being evaluated which further exploits the presence of N_2O in the same fit-window as CH_4. Rather than retrieve it, the profile of N_2O is assumed based on ECMWF potential vorticity, together with climatological distributions of N_2O from the ACE-FTS solar occultation instrument. With N_2O fixed, the CH_4 retrieval state vector is extended to include effective cloud fraction and height. I.e. Knowledge N_2O is used to fit cloud .
- Figure 4 shows retrieval simulations of the impact of cloud on the standard and new schemes.
- Figure 5 shows the observed bias against TCCON from the standard and new schemes are a function of cloud parameters derived from Metop AVHRR.
- Figure 6 shows the agreement of the new scheme with TCCON observation from Jan 2009 to April 2010

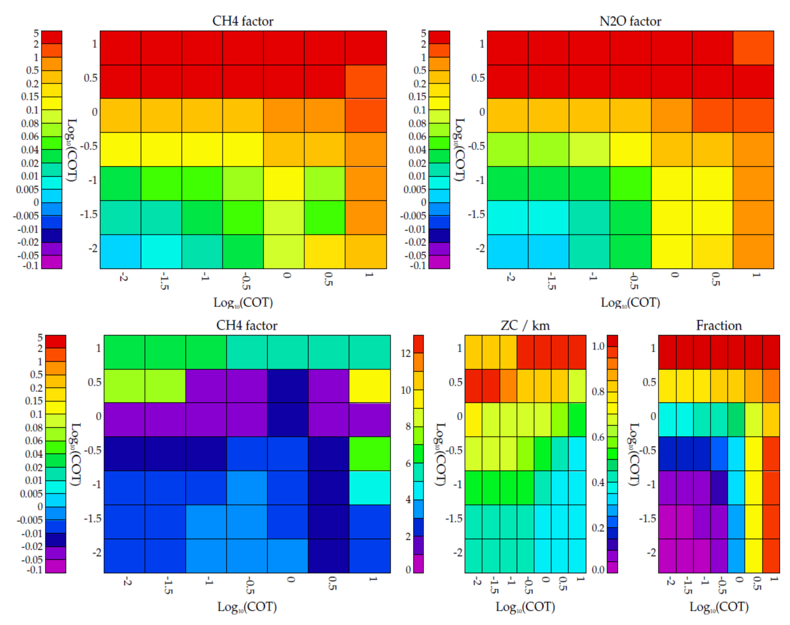


Figure 4: Retrieval simulations to quantify the impact of cloud. Simulations are conducted for a scene with 2 cloud layers, at 4 and 10km altitude, with varying optical thickness (each occupying the whole field-of-view; cloud fraction=1). The lower layer cloud optical thickness (COT) is indicated in the x-axis of each panel, and the upper layer COT in the y-axis. The top two panel show the relative error in CH_4 and N_2O for the standard scheme (in which cloud is not modelled expicitly). The bottom left hand panel shows CH_4 results from the new scheme (errors are much reduced). The bottom right hand panels show the retrieved effective cloud height (ZC) and fraction. In this case cloud is assumed to be a black body and effective fraction accomodates the varying optical thickness.

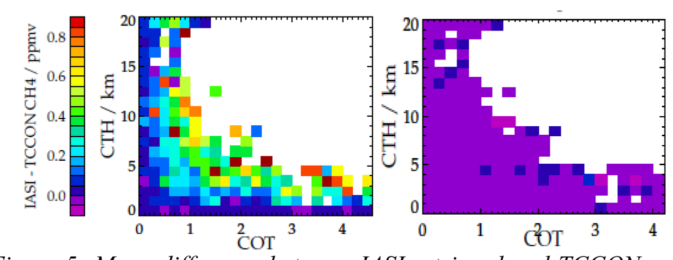


Figure 5: Mean difference between IASI retrieved and TCCON column averaged CH_4 (at Darwin in this case) as a function of RAL's AVHRR derived cloud optical thickness (COT) and height (CTH). Results from the standard scheme shown on the left. Results from the new scheme on the right. In both cases, only scenes for which the 10 micron brightness temperature is within 10K of the ECMWF predicted clear-sky BT are analysed.

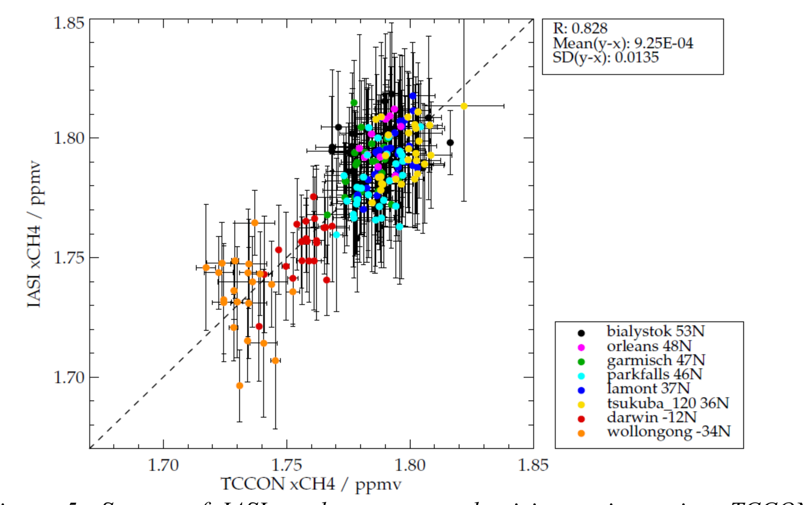


Figure 5: Scatter of IASI column averaged mixing ratio against TCCON. Individual points represent 2 week mean values. Bars show the standard deviation in the mean (~the single-profile precision). These are quite consistent with the estimated random error on a single IASI retrieval of 0.02-0.05 ppmv.

Summary

- An optimal estimation IASI retrieval scheme has been developed to retrieve CH_4 distributions.
- IASI provides height resolved information which is highly complementary to that from short-wave sensors such as GOSAT.
- Benefits of IASI include the ability to profile globally at both day and night, over land and sea and the fact that planned follow on instruments will allow long term monitoring (2006-~2030)
- Existing results clearly demonstrate the potential to distinguish some separate information on two levels within the troposphere, as well as providing an estimate of the total column. This should provide additional information to GOSAT to constrain estimates of surface fluxes via model inversion (a subject of ongoing work in the NCEO AC theme).
- Retrievals are very sensitive to cloud which, if not accounted for, causes a high bias in the data. A new scheme has been developed which strongly mitigates this sensitivity by exploiting the presence of N_2O features in the CH_4 fit range to infer effective cloud parameters. This scheme will be used as the basis for imminent processing of the MetOp mission to date.

References:

E. J. Dlugokencky, L. Bruhwiler, J. W. White, L. K. Emmons, P. C. Novelli, S. A. Montzka, K. A. Masarie, P. M. Lang, A. M. Crotwell, J. B. Miller and L. V. Gatti, "Observational constraints on recent increases in the atmospheric CH4 burden," *Geophysical Research Letters, vol. 36, no. L18803, 2009.*
Razavi et al., Characterization of methane retrievals from the IASI space-borne sounder, Atmos. Chem. Phys., 9, 7889-7899, 2009
R. Parker, H. Boesch, A. Cogan, A. Fraser, L. Feng, P. I. Palmer, J. Messerschmidt, N. Deutscher, D. W. Griffith, J. Notholt, P. O. Wennberg and D. Wunch, "Methane observations from the Greenhouse Gases Observing SATellite: Comparison to ground-based TCCON data and model calculations," *Geophysical Research Letters, vol. 38, no. L15807, 2011*
Seemann, S.W. et al, 2008, Development of a Global Infrared Land Surface Emissivity Database for Application to Clear Sky Sounding Retrievals from Multi-spectral Satellite Radiance Measurements, J. Appl. Meteor. Climatol., Vol 47, 108-123
D. Wunch, G.C. Toon, J.-F.L. Blavier, R.A. Washenfelder, J. Notholt, B.J. Connor, D.W.T. Griffith, V. Sherlock, P.O. Wennberg. The Total Carbon Column Observing Network. Phil. Trans. R. Soc. A (2011) 369, doi:10.1098/rsta.2010.0240