Middle-Upper Tropospheric Methane and Nitrous Oxide Retrievals from Metop/IASI within the project MUSICA

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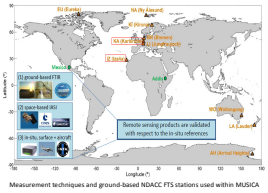
Based on the IASI (Infrared Atmospheric Sounding Interferometer) sensor, the MUSICA project provides a comprehensive space-based database, including tropospheric water vapour isotopologues observations as well as middle-upper tropospheric methane (CH4) and nitrous oxide (N2O) retrievals. This work presents the MUSICA/IASI CH4 and N2O products as well as their validation by using the HIAPER Polo-to-Pole Observations (HIPPO) campaigns. Particular attention will be paid on the analysis of the geographical uniformity of the MUSICA/IASI CH4 and NO retrievals. Moreover, we will explore how the co-retrieved N2O estimates could be successfully used for reducing common errors in the CH4 retrievals.

MUSICA PROJECT

The European Research Council MUSICA project (MUlti-platform remote Sensing of Isotopologues for investigating the Cycle of Atmospheric water, https://www.imk-asf.kit.edu/musica.php) was born to provide to the scientific community with consistent, long-term, high-quality and area-wide observational data of H_2O and δD by combining infrared remote sensing measurements performed from ground and space. The former with g-b high-quality Fourier Transform Infrared spectrometers (FTS), operating within the Network for the Detection of Atmospheric Composition Change (NDACC) since the 1990s, and the latter with the sensor IASI onboard Metop satellites.



Measurement techniques and ground-based NDACC FTS stations used within MUSICA

MUSICA/IASI CH4 and N2O products

RETRIEVAL STRATEGY

Volume Mixing Ratio (VMR) CH4 and N2O profiles are retrieved in 1190-1400 cm^{-1} spectral window using the retrieval code **PROFFIT-Nadir** [Schneider and Hase, 2011]. This code considers the Earth-atmosphere thermal emission, but not the solar reflection (not critical for simulating IASI radiances <2000 cm^{-1}).

Significant H2O interference, thereby a dedicated H2O retrieval is crucial to further improve the overall quality of the IASI CH4 and N2O observations.

All the a priori information is kept constant, thereby all the retrieved variability is introduced by the IASI measurements.

Optimal estimation of tropospheric H2O and δD concentrations [Schneider and Hase, 2011; Wiegele et al., 2014; Schneider et al., 2016].

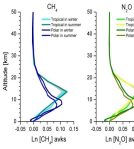
CH4 and N2O VMR profiles are obtained as side products by scaling WACCM climatological profiles

WACCM: Whole Atmosphere Community Climate Model-version 5 (http://www.cesm.ucar.edu/)

MUSICA strategy is able to provide IASI CH4 and N2O global distributions in the upper troposphere (at 350-300 hPa)

VERTICAL SENSITIVITY AND RESOLUTION

Row averaging kernels (avks) for CH4 and N2O in the high Northern Hemisphere (75°N) and the tropics (12°S) over ocean pixels.

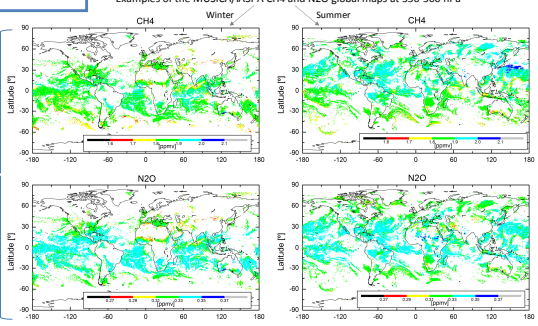


Colored lines represent the IASI maximum sensitivity: 9km and 14km for polar and tropics, respectively.

MUSICA/IASI products are well sensitive to the upper tropospheric CH4 and N2O variability.

FWHM of sensitivity: ~10km

Examples of the MUSICA/IASI-A CH4 and N2O global maps at 350-300 hPa



CH4 A-POSTERIORI CORRECTION

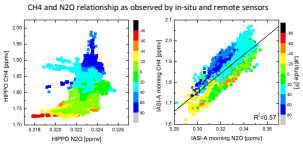
1) The radiative response of CH4 and N2O similarly behaves to common errors, such as temperature, clouds and emissivity.

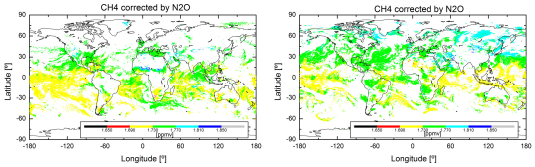
2) The atmospheric N2O concentrations are rather stable (much more than CH4 values) → could be well represented by the a-priori information.

The observed deviations from the a-priori profile (N2O residues) are assumed to be introduced by the common errors and are used to correct the CH4 estimates according to Razavi et al. [2009], Worden et al. [2012]:

$$x'_{CH_4} = \hat{x}_{CH_4} - (\hat{x}_{N_2O} - x_a)$$

$x'_{CH_4}, \hat{x}_{N_2O}, x_a$ are the co-retrieved CH4 and N2O profiles, and a priori N2O profile, respectively, in logarithmic scale.



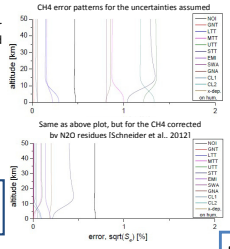


THEORETICAL ERROR ESTIMATION

Uncertainty sources and assumed values for the error estimation, based on Schneider and Hase [2011] and Wiegele et al. [2014], following to Rodgers [2000]:

Error source	Uncertainty
Measurement Noise (NOI)	$2x10^{-9}$ $\mu W/cm^2/sr/cm^{-1}$
Ground Temperature (GNT)	+1K
Temperature Profile (LTT, MTT, UTT, STT)	+1K
Emissivity (EMI)	+5%
Swath angle (SWA)	0.01 rad
Ground altitude (GNA)	20 m
Low Clouds at 1 km (optically thick, CL1)	5% cloud coverage
High Clouds at 10 km (CL2)	Transmittance 98%
Spectroscopy for CH_4 and N_2O (S and γ)	+2%, and 2%
Spectroscopy for H_2O (S, γ and Γ_a/Γ_{H_2O})	+1%, +1%, and +5%
Spectroscopy for HDO (S, γ and Γ_a/Γ_{HDO})	+2%, +2%, and +10%

The N2O post-correction significantly reduces the impact of the all uncertainties sources on CH4 retrievals, except for the measurement noise.

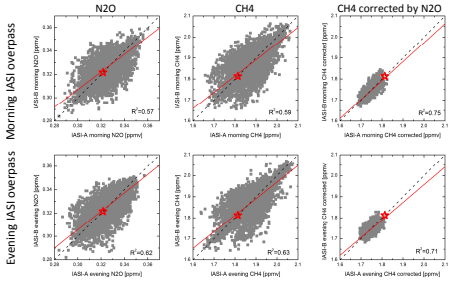


IASI-A and IASI-B CONSISTENCY

IASI sensors are flying on-board the EUMETSAT Metop-A and Metop-B meteorological satellites, so-called IASI-A and IASI-B, since 2007 and 2012, respectively. The inter-comparison of both IASI sensors shows the high consistency of the variability observed by IASI-A and IASI-B and, thereby, the suitability of IASI-B for continuation of the IASI-A time series.

The post-correction on CH4 significantly improves the agreement between the retrievals from both IASI sensors by reducing the co-related variabilities.

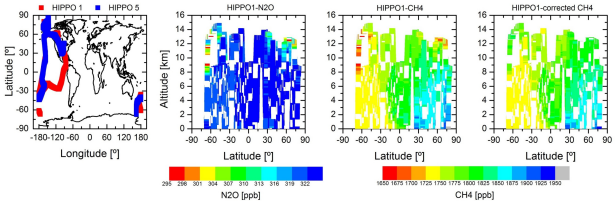
Example of IASI-A and IASI-B consistency assessment on 16/08/2014, where the IASI-A and IASI-B observations at a global scale were paired in boxes of ±0.25º. The starts indicate the a priori used for the IASI retrievals, the red lines the least square fits and the black dashed lines the diagonals.



EMPIRICAL VALIDATION

HIPPO PROJECT

The HIAPER Pole-to-Pole Observations (HIPPO) project (http://hippo.ucar.edu/) investigated carbon cycle and greenhouse gases by sampling the atmosphere from approximately 67°S to 80°N mostly over the Pacific Ocean, from the surface to ~14km and spanning all the seasons between 2009-2011. In total five measurement missions were conducted, aboard HIAPPER, a modified Gulfstream V (GV) aircraft. In this study we focus on the mission HIPPO-1 in January 2009 and HIPPO-5 in August/September 2011 (see figure below). During these missions, the CH4 and N2O measurements were performed with a QCLS (quantum-cascade laser spectrometer) analyzer at 1Hz frequency with a precision of 0.5 and 0.09 ppb for CH4 and N2O, respectively, and an accuracy of 1.0 both trace gases [Santoni et al., 2014].



VALIDATION STRATEGY

- The comparison strategy is based on previous space-based sensor validation studies using HIPPO aircraft observations [Wecht et al., 2012; Xiong et al., 2013].

- Each HIPPO vertical profile (covering ~220 km, 2.2° latitude, and ~20 minutes) is characterised by a mean location (latitude and longitude) and a mean time.

- We considerer all the IASI observations within the box ±2° latitude/longitude centred at each HIPPO mean location and ± 12h around every HIPPO mean profile.

- The highly-resolved HIPPO profile observations are smoothed by applying the avks of the vertically poorly resolved IASI profiles:

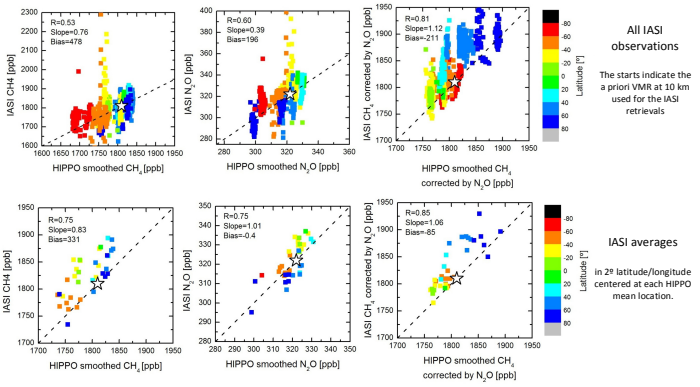
$$x'_i = A(\hat{x}_i - x_a) + x_a$$

being i, CH4 or N2O, and A, and x_a are the corresponding IASI avks and a priori profile

- Beyond the top of the HIPPO profiles (~14km) we use the monthly and zonally averaged CH4 and N2O climatology from the Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE-FTS) observations between February 2004-February 2009 [Jones et al., 2012].

- Only the layer, where IASI is well sensitive, is compared to HIPPO observations (VMR at 10 km).

SUMMARY OF THE MUSICA/IASI and HIPPO COMPARISON



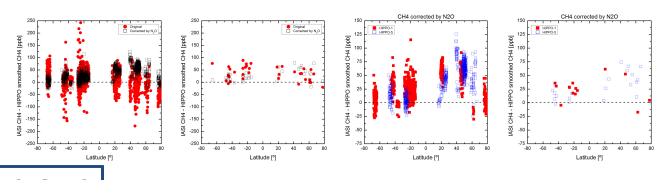
All IASI observations

The starts indicate the a priori VMR at 10 km used for the IASI retrievals

IASI averages

in 2º latitude/longitude centered at each HIPPO mean location.

Difference between MUSICA/IASI CH4 and HIPPO smoothed CH4 versus latitute and season (i.e, HIPPO mission)



CONCLUSIONS

- Space-based CH4 and N2O observations are rather difficult, since their atmospheric variability is weak and difficult to be observed in the measured IASI radiances. BUT…
- Together with the high-quality IASI water vapour products (tropospheric humidity profiles and middle tropospheric δD), the MUSICA retrieval strategy is able to provide IASI CH4 and N2O global distributions in the upper troposphere (at 350-300 hPa).
- The inter-comparison of the two IASI sensors, currently in orbit (IASI-A and IASI-B), shows the high consistency of the variability observed by both sensors and, thereby, the suitability of IASI-B for continuation of the IASI-A time series.
- Experimentally, the quality assessment has been done by comparing to coincident high precision aircraft vertical profiles taken within HIAPER Polo-to-Pole Observations project.
- Here, we focus on the missions HIPPO-1 (in winter) and HIPPO-5 (in summer) to cover the CH4 and N2O seasonal variations. The correlations between MUSICA/IASI products and HIPPO observations found are of 53% and 75%, respectively, when considering all the IASI-HIPPO pairs, and of 75% for the 2ºx2º averages.
- MUSICA/IASI CH4 and N2O retrieval products seem to show no latitudinal bias with regard to HIPPO data, but further analysis are needed.
- We prove theoretically and experimentally that an a posteriori correction applying the co-retrieved N2O estimates can successfully be used for reducing common errors in the CH4 retrievals. The correlation between MUSICA/HIPPO CH4 significantly increases by 85%. Therefore, when correcting with N2O, IASI might even be able to measure synoptical scale CH4 variability correction (for the upper troposphere).

ACKNOWLEDGEMENTS

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REFERENCES

Jones et al., Atmos. Chem. Phys., 12, 5207-5220, 2012.
Santoni et al., Atmos. Meas. Tech., 7, 1509-1526, 2014.
Schneider and Hase, Atmos. Chem. Phys., 11, 11207-11220, 2011.
Schneider et al., Atmos. Meas. Tech., 5, 3007-3027, 2012.
Schneider et al., Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2015-330, in review, 2016.
Razavi et al., Atmos. Chem. Phys., 9, 7889-7899, 2009.
Rodgers, C., World Scientific Publishing Co., 2000.
Wecht et al., Atmos. Chem. Phys., 12, 1823-1832, 2012.
Wiegele et al., Atmos. Meas. Tech., 7, 2719-2732, 2014.
Worden et al., Atmos. Meas. Tech., 5, 397-411, 2012.
Xiong, et al., Atmos. Meas. Tech., 6, 2255-2265, 2013.