IASI for Surveying Methane and Nitrous Oxide in the Troposphere: MUSICA products and its validation

Omaira García (ogarciar@aemet.es), M. Schneider, B. Ertl, F. Hase, C. Borger, E. Sepúlveda, T. Blumenstock, Uwe Raffalski and A.J. Gómez-Peláez

1. Remote Sensing of CH_4 and N_2O
   - I. General retrieval characteristics
   - II. A posteriori calculated difference between CH_4 and N_2O
2. Theoretical Characterisation
   - I. Representativeness
   - II. Error Assessment
3. Validation by using a Multi-Platform Reference Database
   - I. HIPPO
   - II. GAW in situ, and NDACC/FTIR
4. A posteriori CH_4 Correction
5. Summary and Outlook

Agencia Estatal de Meteorología

Karlsruhe Institute of Technology

IRF

1. Remote sensing of CH_4 and N_2O

General Retrieval Characteristics

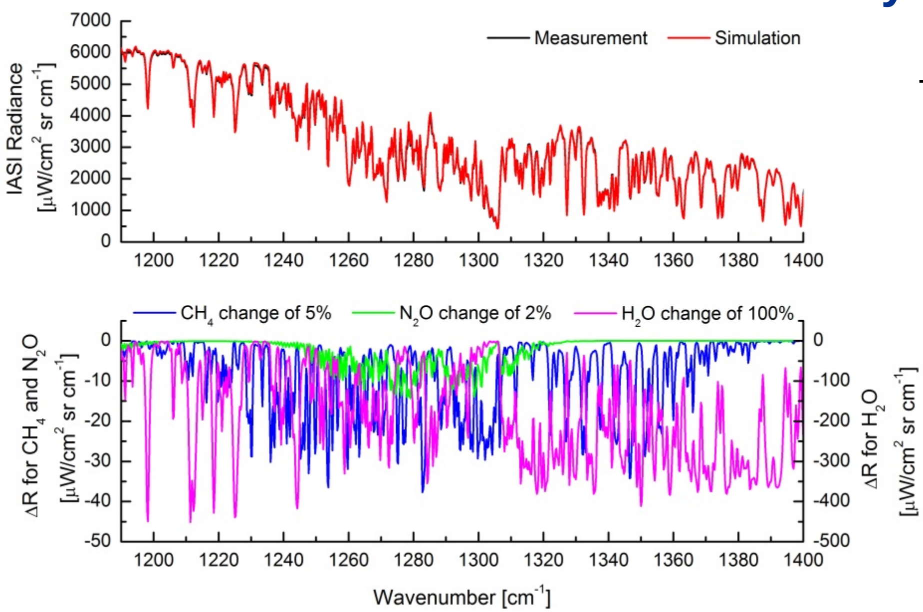
IASI processor developed during the ERC project MUSICA (**MU**lti-platfrom remote **S**ensing of **I**sotopologues for investigating the **C**ycle of **A**tmospheric water), based on the retrieval code PROFFIT-nadir [Schneider and Hase, 2011]

Optimal estimation retrieval: combine a priori information with the measured IASI spectra and estimate the most likely atmospheric state.

A priori information is kept constant (no variation in space and time), i.e., all the retrieved variability is introduced by the IASI spectra.

Simultaneous retrieval of $H_2^{16}O$, $HD^{16}O$, CH_4, N_2O and HNO_3 (+CO_2), atmospheric and skin temperature on log. scale.

Key!!



The spectral signatures of H_2O variations are more than an order of magnitude stronger than the signatures of CH_4 and N_2O

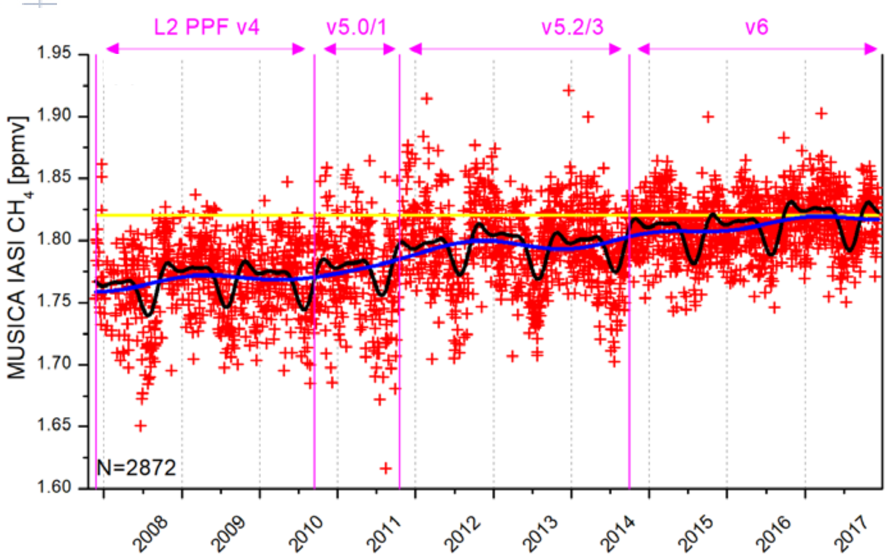
Quality of CH_4 and N_2O products strongly depends on a correct interpretation of H_2O intereferences

MUSICA IASI incorporates a sophisticated H_2O isotopologue retrieval and water continuum contributions (MT_CKD v2.5.2)

1. Remote sensing of CH_4 and N_2O

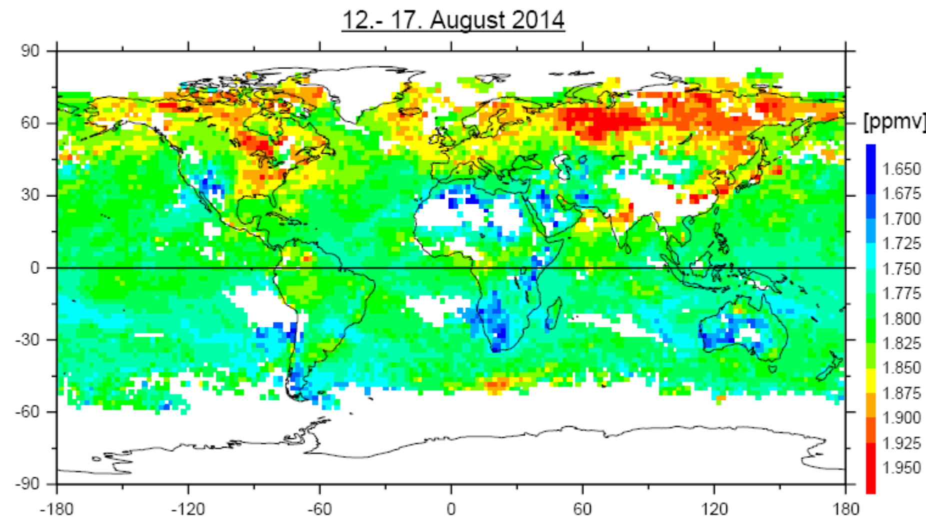
Long-term monitoring

Example of continuous time series of MUSICA IASI CH_4 daily mean data retrieved at 4.2 km altitude in the surroundings of Tenerife Island between 2007 and 2017.



Global coverage

Example of global geographical distribution of the free tropospheric MUSICA IASI CH_4 product retrieved at 4.2 km altitude, filtered for c_{sen} < 50% and averaged for an latitude x longitude area of 2ºx2º.

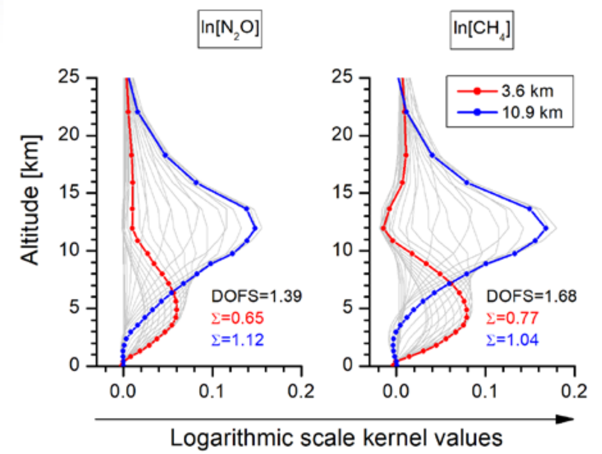


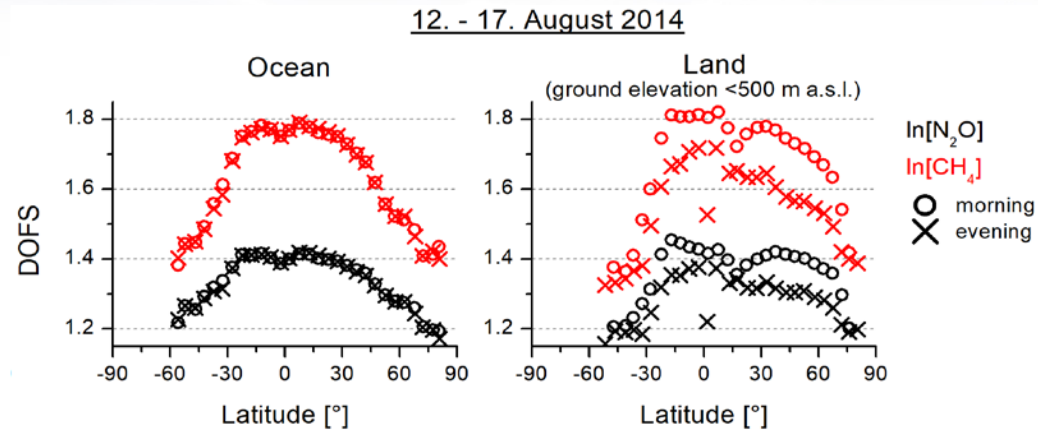
IASI has a great potential for CH_4 and N_2O monitoring and for greenhouse gas cycle studies

2. Theoretical Characterisation

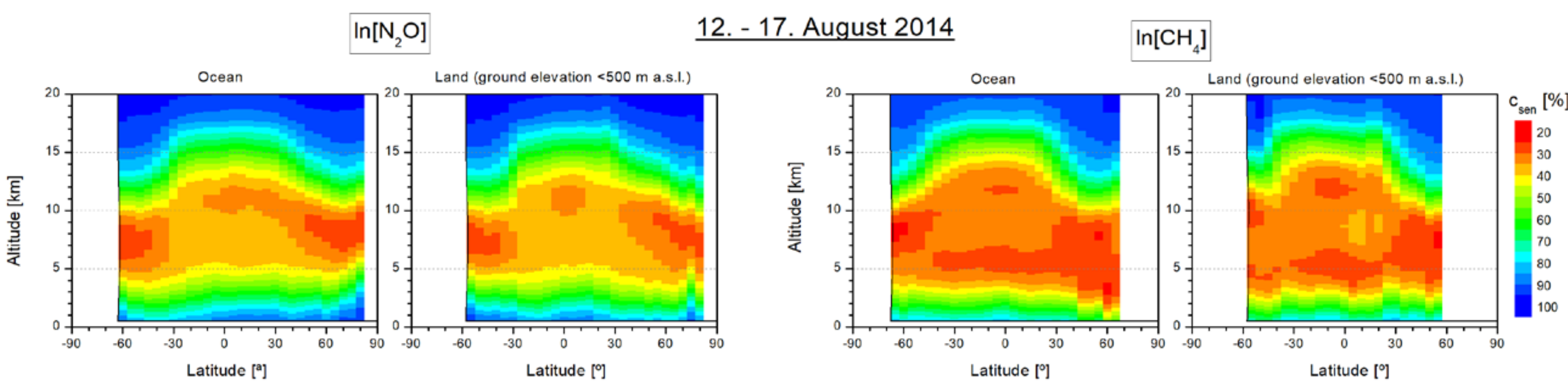
Representativeness: Averaging Kernels

Example for mid-latitude summer land pixel



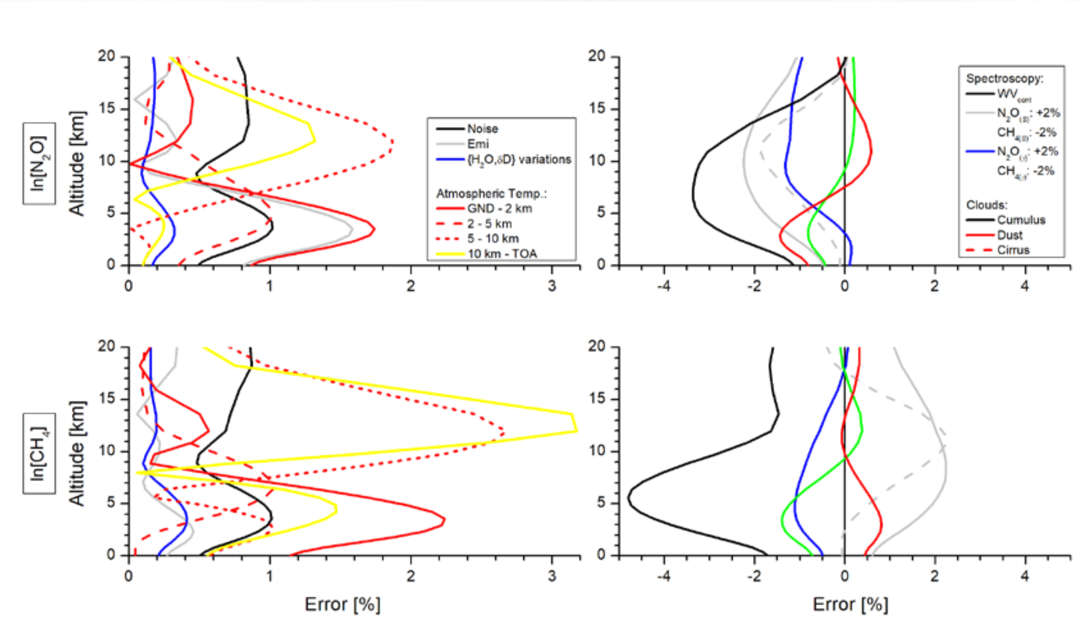


- ✓ **Altitude regions that well-detectable by MUSICA IASI products: c_{sen}<50%**
- ✓ **MUSICA IASI products can capture atmospheric variations of CH_4 and N_2O between 2-16 km with a vertical resolution of 5-8 km**
- ✓ **MUSICA IASI CH_4 data offer a better sensitivity than N_2O data**



2. Theoretical Characterisation

Example for mid-latitude summer land pixel



Error Assessment

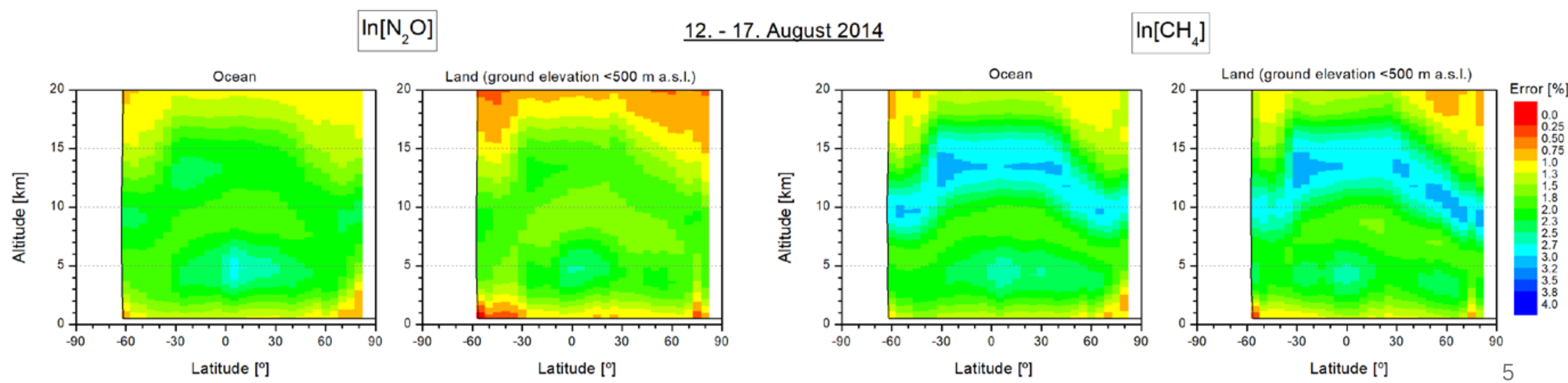
Statistical sources (Gaussian distribution):

- ✓ Measurement noise < 1%
- ✓ Emissivity < 0.5%
- ✓ H2O cross-dependency < 0.5%
- ✓ **Atmospheric temperature ~ [0-3]%**

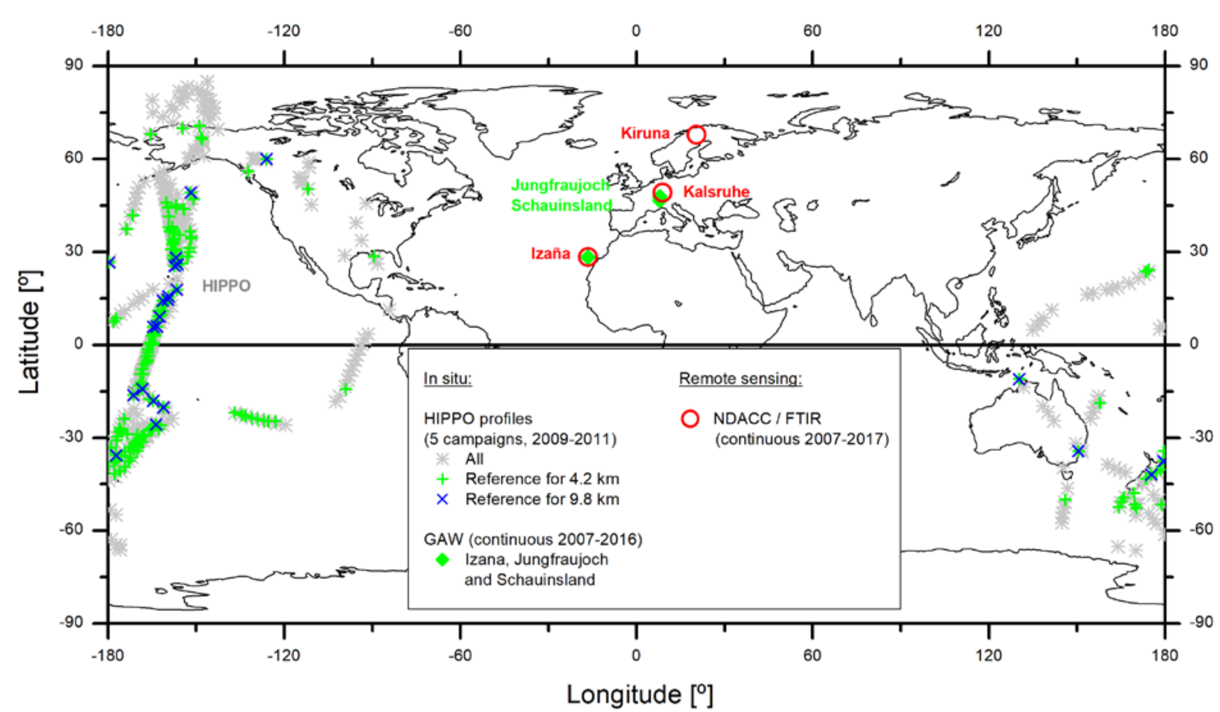
Non-Gaussian sources:

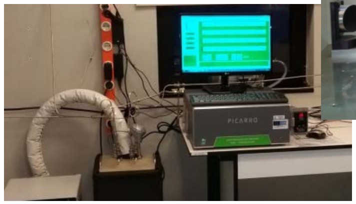
- ✓ Spectroscopy ~ [-2, 2]%
- ✓ Water continuum ~[-1,0]%
- ✓ **Clouds ~[-4.5, 1]%**

Latitudinal Cuts of Leading Errors (atmospheric temperature and measurement noise)



3. Validation by using a Multi-Platform Database





In situ Picarro

Ground-based NDCC/FTIR

HIPPO (HIAPER Polo-to-Pole Observation) aircraft profiles

High precision&accuracy, high vertical resolution, good latitudinal coverage (67ºS-80ºN, Pacific Ocean)

Accuracy, precision, profiling capability and latitudinal gradients

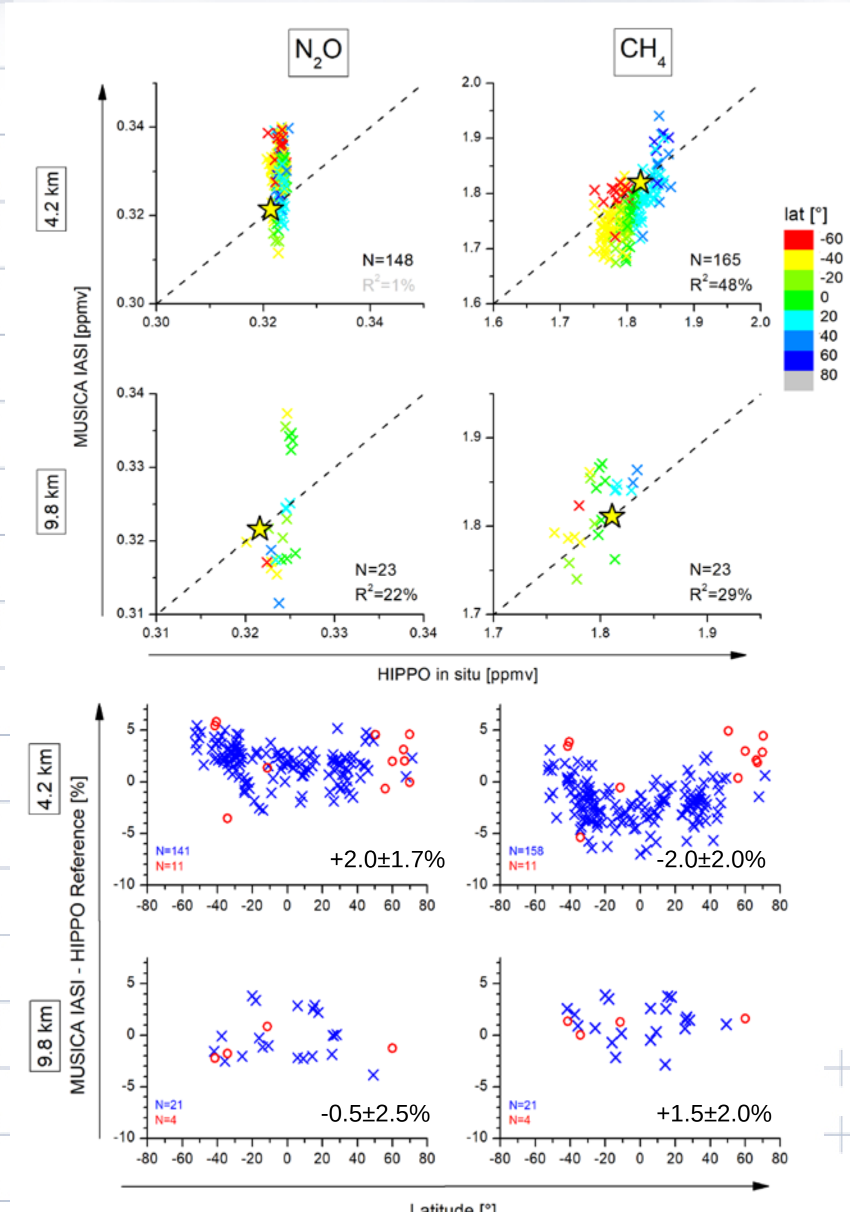
GAW (Global Atmosperic Watch) in situ and NDACC/FTIR (Fourier Transform Infrared Spectrometer)

High precision&accuracy, continuous (GAW), quasi continuous (daytime, FTIR), long-term series

Precision, profiling capability and temporal signals that are detectable

[Details on collocation, data treatment and filtering are given in Extra Material slides]

3. Validation by using a Multi-Platform Database



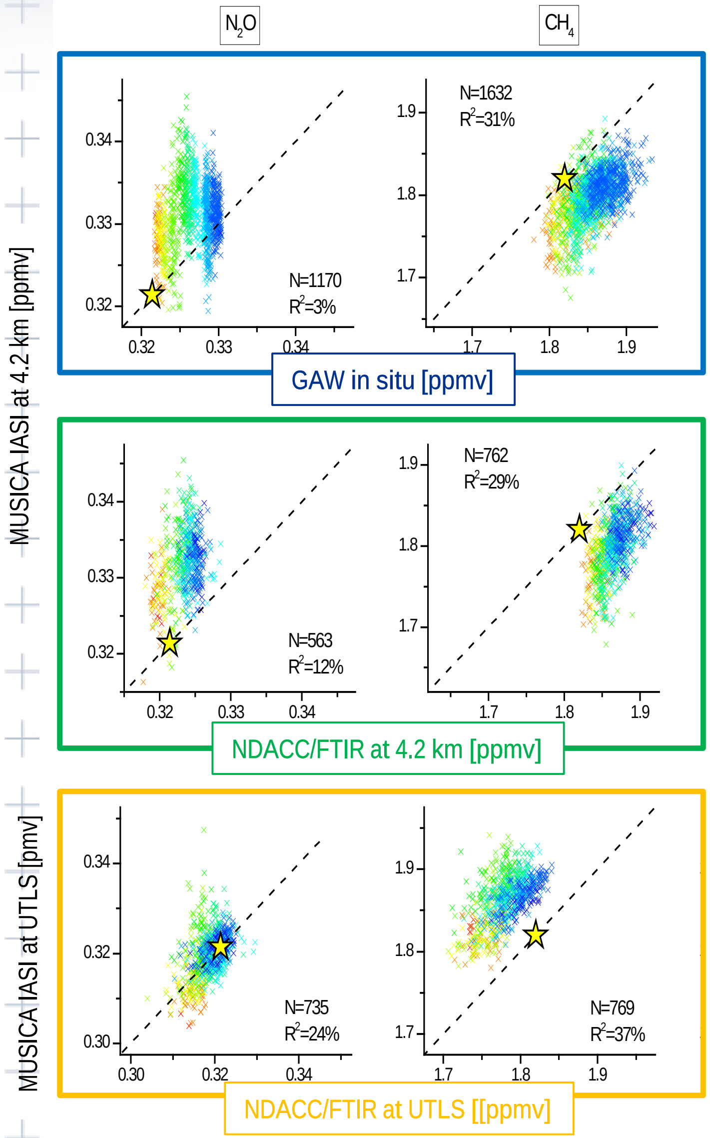
HIPPO1 (January 2009)
HIPPO2 (November 2009)
HIPPO3 (March/April 2010)
HIPPO4 (June 2011)
HIPPO5 (August/Sep 2011)

- ✓ MUSICA IASI data capture well CH_4 latitudinal gradients, but not for N_2O (very small variations).

- ✓ Latitudinal dependency of bias (according to IASI sensitivity).
- ✓ Precision: 1.5-2.5%
- ✓ Accuracy: ±2%

3. Validation by using a Multi-Platform Database

Agencia Estatal de Meteorología



GLOBAL ATMOSPHERE WATCH

NDACC

Tenerife, 28ºN, 2007-2017
Karslruhe, 49ºN, 2010-2017
Kiruna, 68ºN, 2007-2017

✓ GAW and NDACC/FTIR comparison confirms the HIPPO results over time.

✓ The overall precision: 1-2% for N_2O and 1-3% for CH_4 (free troposphere and UTLS).

But, what temporal signals are really detectable by the MUSICA IASI products?

Temporal decomposition of a time series into signals belonging to different timescales:

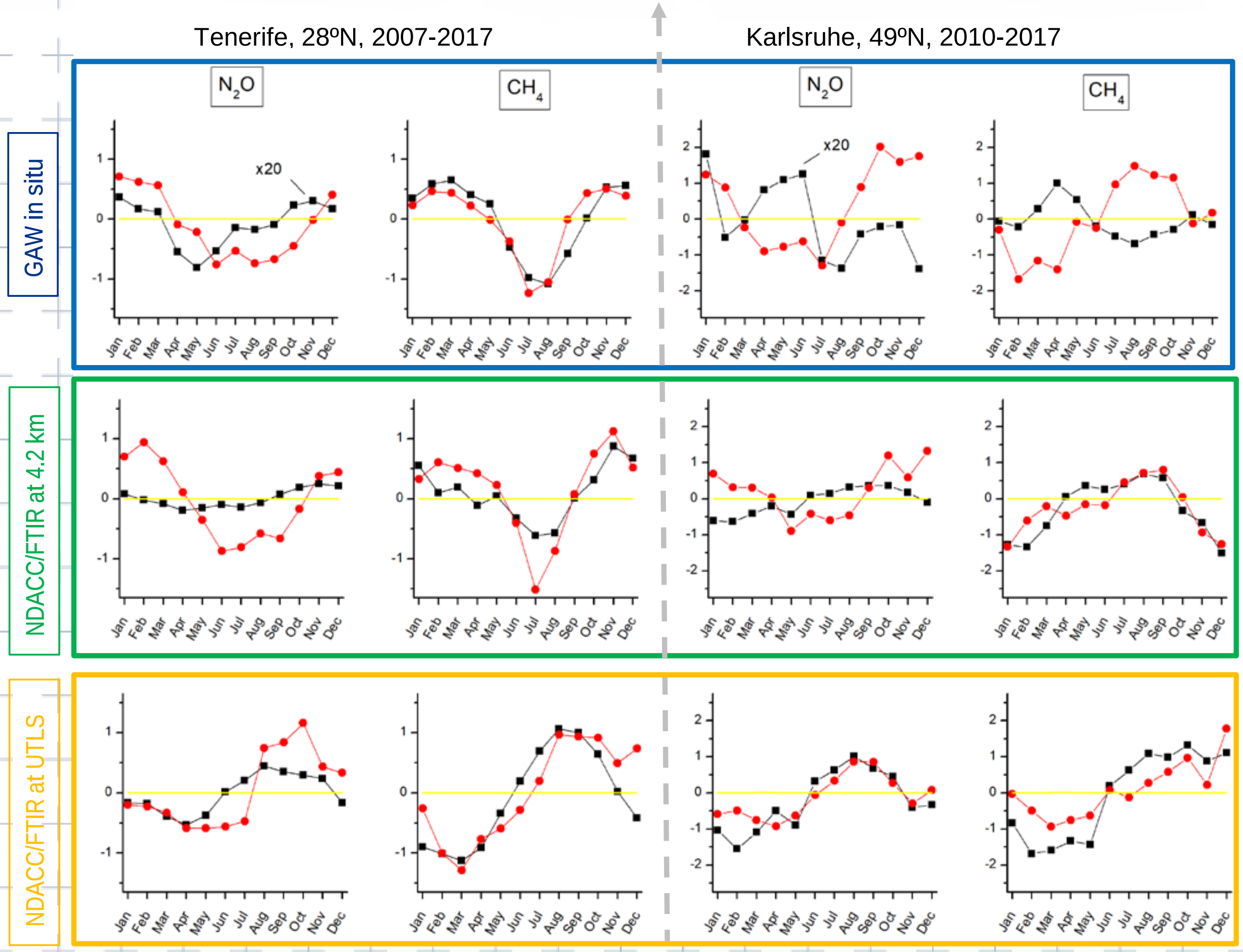
$$x(t) = \underbrace{\overline{x_m([t_1,t_2])}}_{\text{Reference value}} + s(t) + l(t) + d(t)$$

- $s(t)$: Seasonal cycle
- $l(t)$: Long-term signal
- $d(t)$: Day-to-Day variations

[Comparison for Karlsruhe and Kiruna is shown in Extra Material slides]

3. Validation by using a Multi-Platform Database

Seasonal cycle relative to long-term background [%]



MUSICA IASI red, GAW and NDACC/FTIR black

Temporal Decomposition

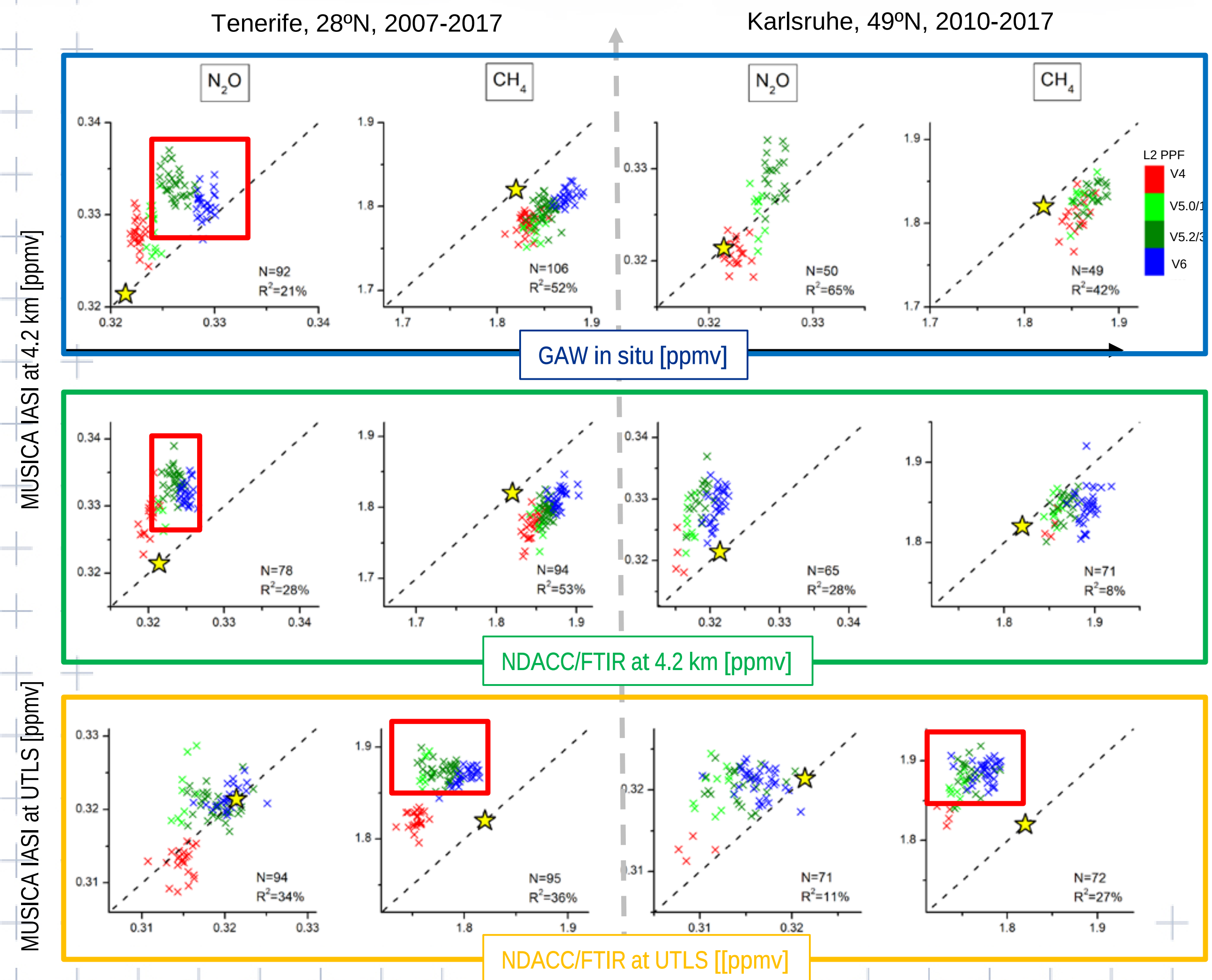
$$x(t) = \overline{x_m([t_1,t_2])} + s(t) + l(t) + d(t)$$

- ✓ MUSICA IASI data capture well the CH_4 seasonal cycles (phase and amplitude) at free troposphere only at subtropical latitudes.
- ✓ Not for N_2O (very small variations in free troposphere).
- ✓ For all latitudes and for both N_2O and CH_4 MUSICA IASI data capture well the seasonal cycles (phase and amplitude) in the UTLS.

3. Validation by using a Multi-Platform Database

Agencia Estatal de Meteorología

Long-term signals: Deseanolised montlhly mean



Temporal Decomposition

$$x(t) = \overline{x_m([t_1,t_2])} + s(t) + l(t) + d(t)$$

- ✓ MUSICA IASI data are affected by an inconsistency between the versions EUMETSAT L2 PPF v5.2/3 and V6 (used as a priori information).
- ✓ When this inconsistency is not considered (Karlsruhe) the agreement with GAW in situ suggests that MUSICA IASI data detects the long-term variations in the free troposphere up to mid-latitudes.

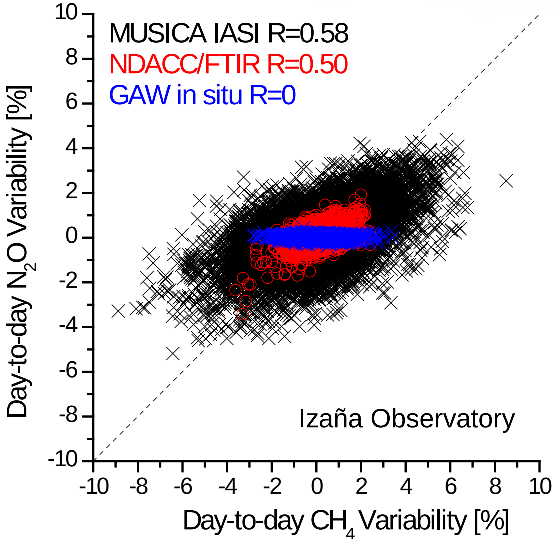
GLOBAL ATMOSPHERE WATCH

NDACC

The colour code identifies the four different EUMETSAT L2 Products Processing Facility (L2 PPF) software versions. [Details on L2 PPF versions are given in Extra Material slides].

4. A posteriori CH_4 Correction

A posteriori calculated difference between CH_4 and N_2O



N_2O concentrations show a rather low short-term variability and their long-term increase is very stable

Significant variations in the N_2O retrievals are due to errors

Assuming that N_2O and CH_4 have correlated errors (e.g. temperature, clouds,…) and common signals (e.g. UTLS shift)

Combining co-retrieved N_2O and CH_4 to generate a combined product with reduced errors and common signals, and then better representativeness of sources/sinks signals

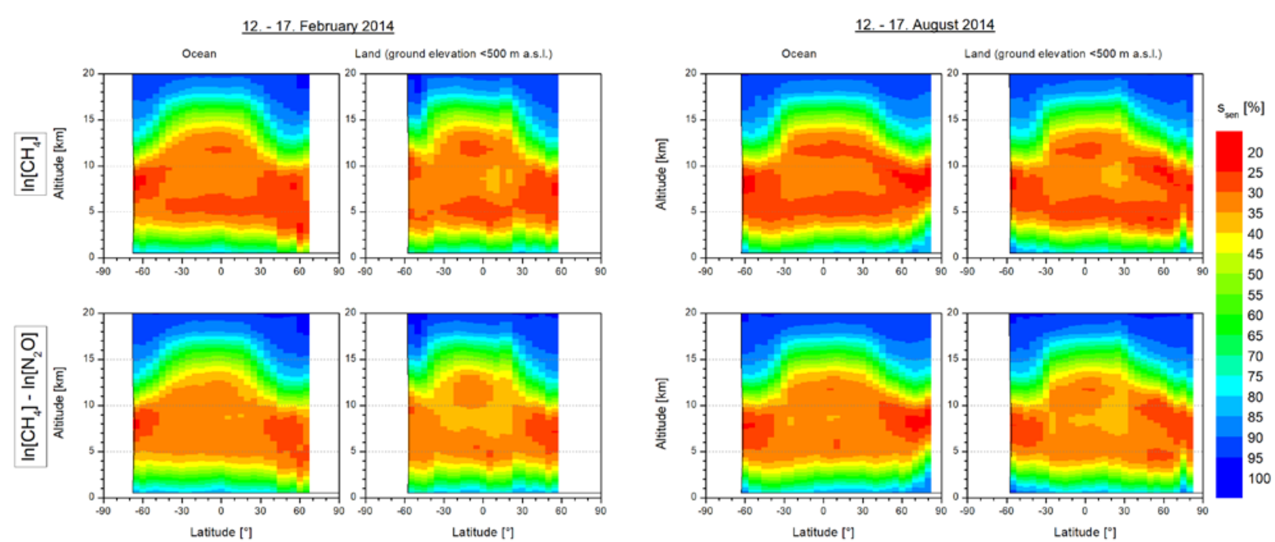
$$\underbrace{\hat{x}_{\mathrm{CH_4}} - \hat{x}_{\mathrm{N_2O}}}_{\text{Retrieved states}} = \underbrace{x_{a,\mathrm{CH_4}} - x_{a,\mathrm{N_2O}}}_{\text{A priori}} + \mathbf{A}_{\mathrm{CH_4}}(x_{\mathrm{CH_4}} - x_{a,\mathrm{CH_4}}) - \mathbf{A}_{\mathrm{N_2O}}(x_{\mathrm{N_2O}} - x_{a,\mathrm{N_2O}}) + \underbrace{\Delta x_{\mathrm{CH_4}} - \Delta x_{\mathrm{N_2O}}}_{\text{Difference of errors is smaller than individual erros}}$$

Averaging kernels

We propose two approaches for calculating the combined products based on:
(1) N_2O model simulations (CH_4*) and (2) N_2O climatology (CH_4') (details on Extra Material slides).

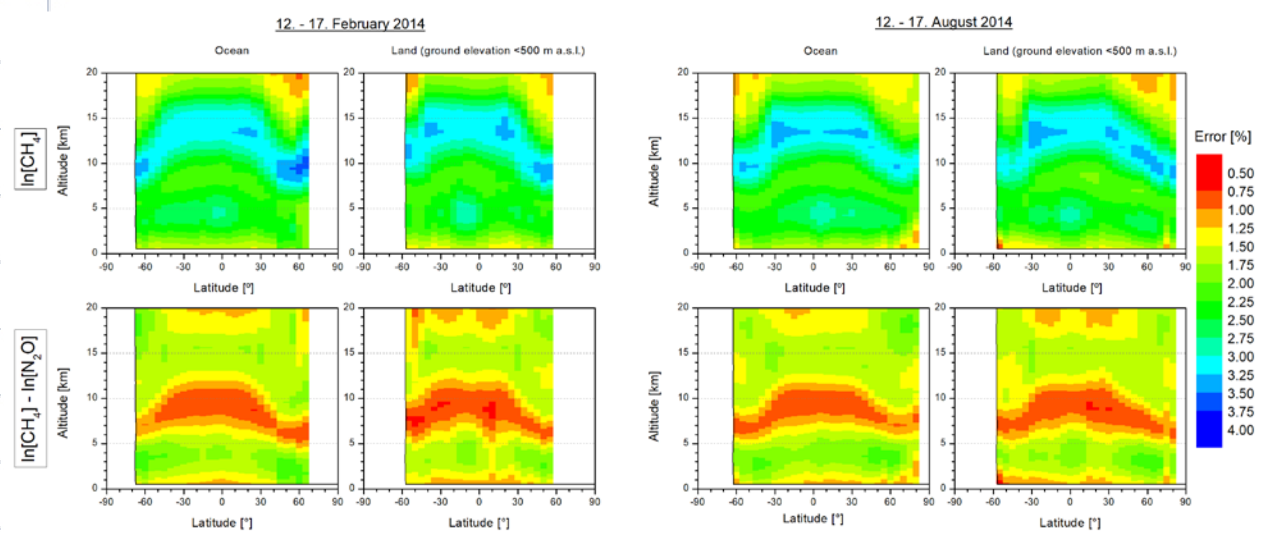
But, both can be characterised by the {(ln[CH_4] - ln[N_2O])} state.

4. A posteriori CH_4 Correction



Sensitivity

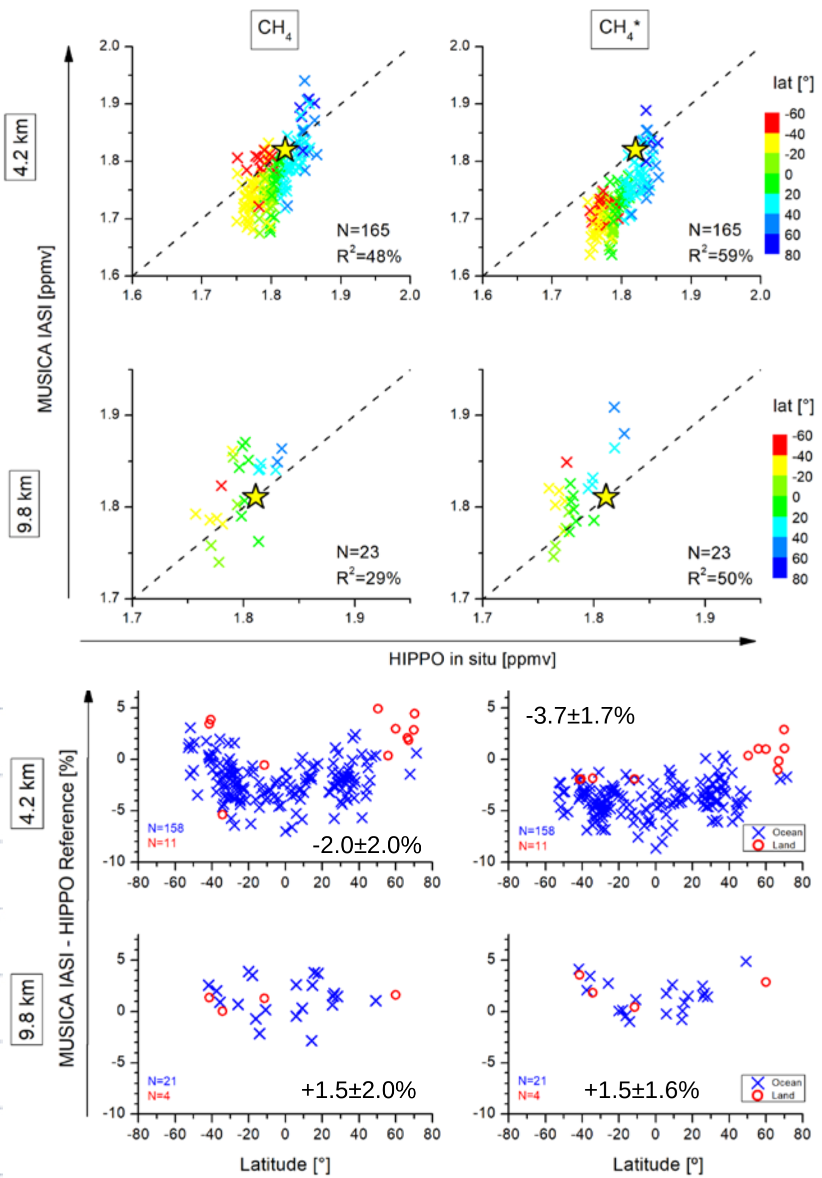
Similar vertical distribution, but slightly lower sensitivity for the combined product



Leading Errors

The a posteriori CH_4 correction with co-retrieved N_2O offers better precision!!!

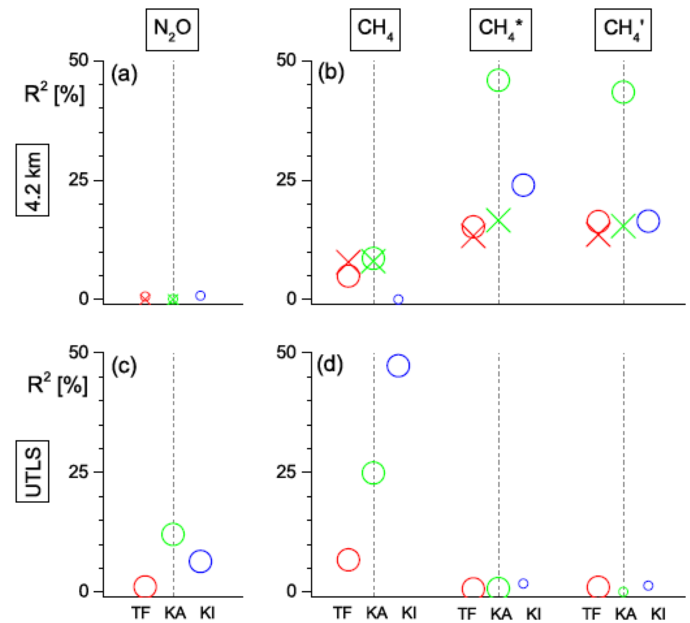
4. A posteriori CH_4 Correction



✓ Better estimation of latitudinal gradient

✓ High precision

$$x(t) = \overline{x_m([t_1, t_2])} + s(t) + l(t) + d(t)$$



5. Summary and Outlook

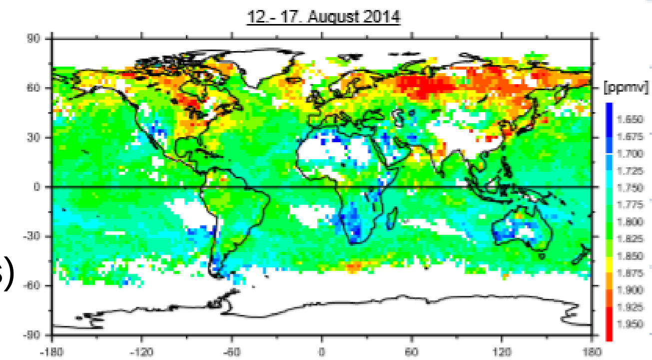
- ✓ The MUSICA IASI data capture signals that are larger than 1-2%, like the latitudinal gradients, the long-term increase and the seasonal cycles in the UTLS region.
- ✓ While for N_2O the sensitivity is mainly limited to the UTLS region, for CH_4 at low latitudes the MUSICA IASI processor can detect variations that take place in the free troposphere independently from the variations in the UTLS region.
- ✓ Room for improvements, but the benefits are limited (other sophisticated retrievals point out the same results, e.g. rough profile capability only for lower and middle latitudes).

Our next plans:

(1) Performing retrievals for many orbits

(producing data globally for longer time periods)

IASI A+B measures about 2.5 Millions spectra per day!
We focus on the about 10% that are cloud-free (0.25 Millions)

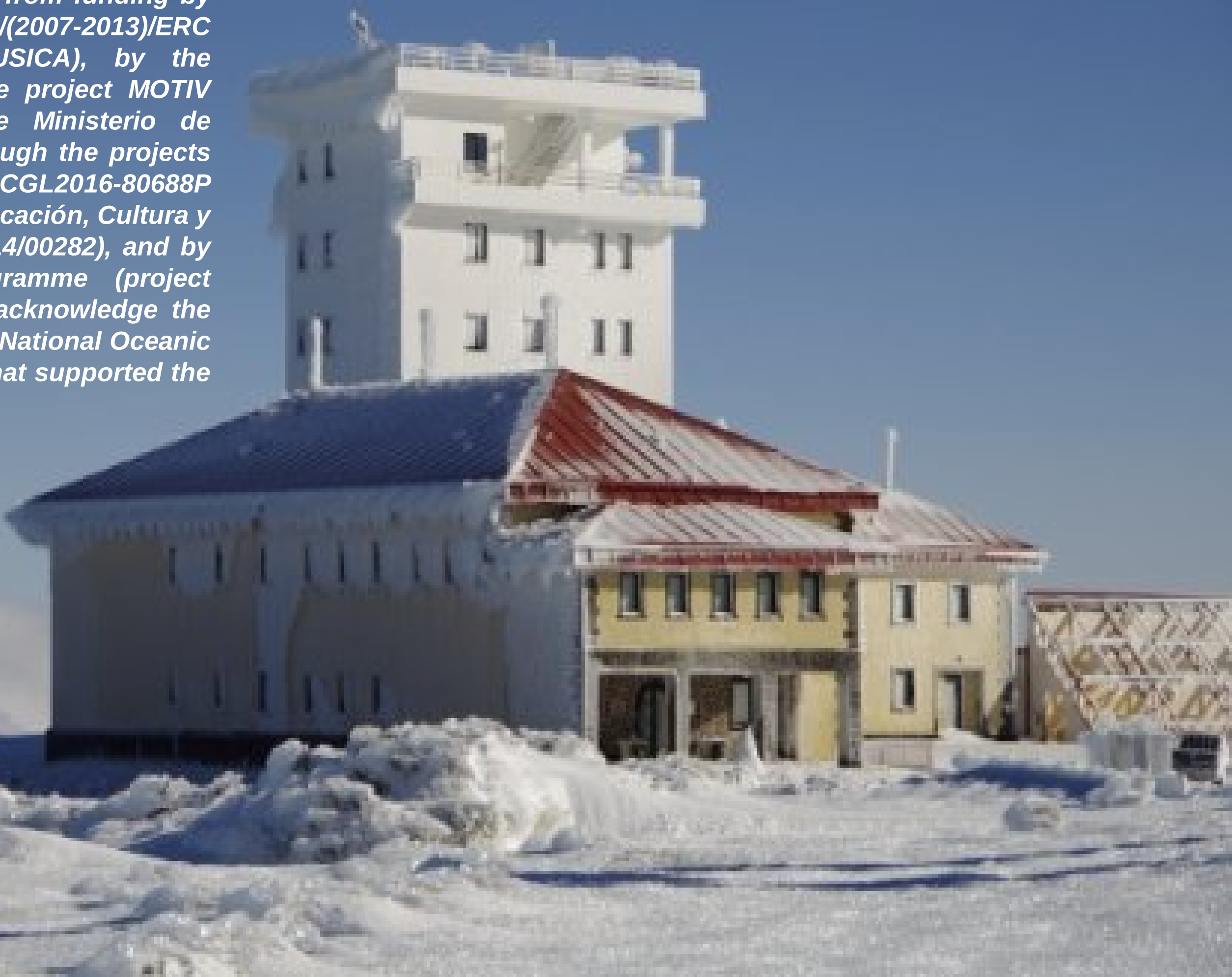


(2) Examining the usefulness of IASI CH_4 and N_2O data for source/sink studies

By combining IASI space-based observations and model estimates, we will investigate the kind of CH_4 and N_2O sink/source signals at a global scale that can be captured by high quality IASI observations, and the transport of the CH_4 and N_2O in the atmosphere.

Many Thanks for your Attention!!

Acknowledgements: ***This work has benefit from funding by the European Research Council under FP7/(2007-2013)/ERC Grant agreement n◦256961 (project MUSICA), by the Deutsche Forschungsgemeinschaft for the project MOTIV (Geschäftszeichen SCHN1126/21), by the Ministerio de Economía y Competitividad from Spain trough the projects CGL2012-37505 (project NOVIA) and CGL2016-80688P (project INMENSE), by the Ministerio de Educación, Cultura y Deporte (Programa "José Castillejo", CAS14/00282), and by EUMETSAT under its Fellowship Programme (project VALIASI). Furthermore, we would like to acknowledge the National Science Foundation (NSF) and the National Oceanic and Atmospheric Administration (NOAA), that supported the collection of the original HIPPO data.***



Izaña Atmospheric Observatory
http://izana.aemet.es

References

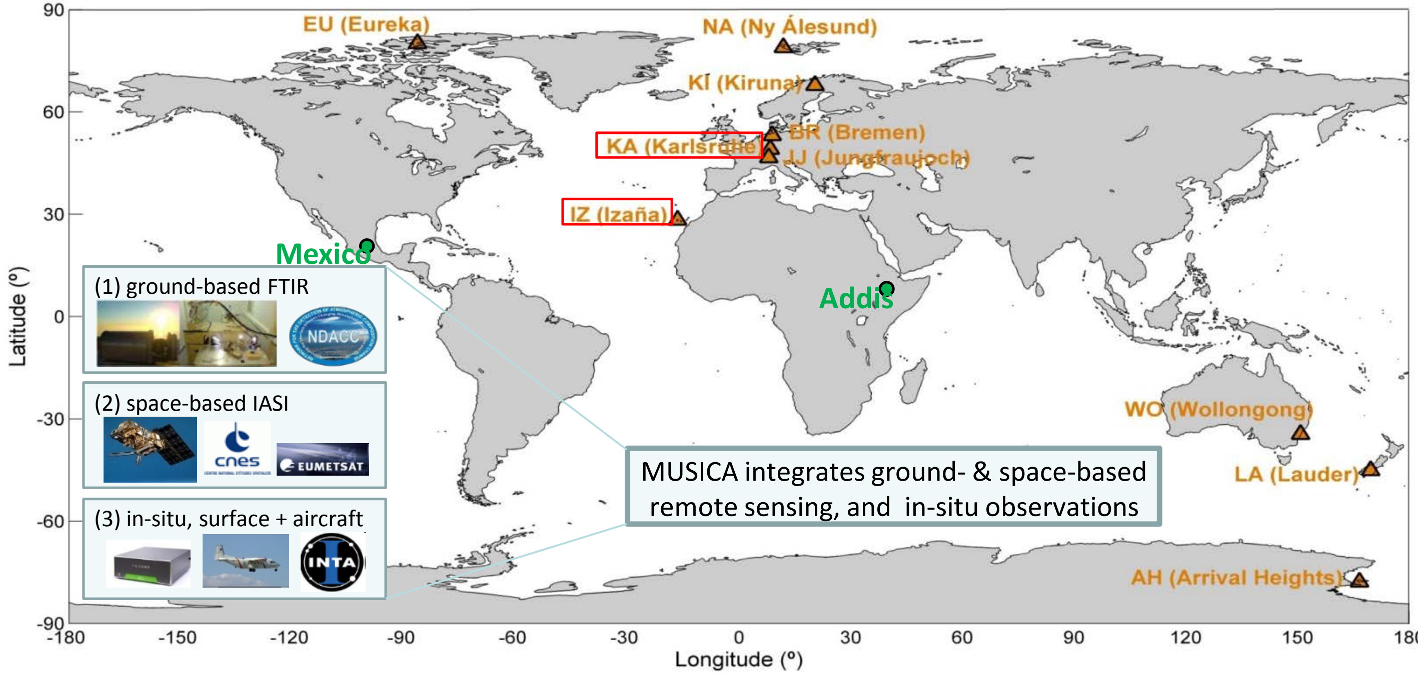
- Barthlott, S., et al.: Using XCO2 retrievals for assessing the long-term consistency of NDACC/FTIR data sets, Atmos. Meas. Tech., 8, 1555-1573, https://doi.org/10.5194/amt-8-1555-2015, 2015.
- Barthlott, S., et al., : Tropospheric water vapour isotopologue data (H216O, H218O, and HD16O) as obtained from NDACC/FTIR solar absorption spectra, Earth Syst. Sci. Data, 9, 15-29, doi:10.5194/essd-9-15-2017, 2017.
- Borger, C., et al.: Evaluation of MUSICA MetOp/IASI tropospheric water vapour profiles by theoretical error assessments and comparisons to GRUAN Vaisala RS92 measurements, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2017-374, in review, 2017.
- Christner, E.: Messungen von Wasserisotopologen von der planetaren Grenzschicht bis zur oberen Troposphäre zur Untersuchung des hydrologischen Kreislaufs, Dissertation, Karlsruhe Institute of Technology (KIT), Germany, 2015 .
- Christner, E., et al.: The influence of snow sublimation and meltwater evaporation on δD of water vapor in the atmospheric boundary layer of central Europe, Atmos. Chem. Phys., 17, 1207-1225, doi:10.5194/acp-17-1207-2017, 2017.
- Dyroff, C., et al.: Airborne in situ vertical profiling of HDO/H216O in the subtropical troposphere during the MUSICA remote sensing validation campaign, Atmos. Meas. Tech., 8, 2037-2049, 2015, doi:10.5194/amt-8-2037-2015.
- García, O. E., et al.: Upper tropospheric CH4 and N2O retrievals from MetOp/IASI within the project MUSICA , Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2016-326, in review, 2017.
- González, Y., et al.: Detecting moisture transport pathways to the subtropical North Atlantic free troposphere using paired H2O-δD in situ measurements, Atmos. Chem. Phys., 16, 4251-4269, doi:10.5194/acp-16-4251-2016, 2016.
- Rodgers, C.: Inverse Methods for Atmospheric Sounding: Theory and Praxis, World Scientific Publishing Co., Singapore, 2000.
- Rodgers, C. and Connor, B.: Intercomparison of remote sounding instruments, J. Geophys. Res., 108, 4116–4129, doi:10.1029/2002JD002299, 2003.
- Schneider, M. and F. Hase: Optimal estimation of tropospheric H2O and δD with IASI/METOP, Atmos. Chem. Phys. , 11, 16107-16146, 2011.
- Schneider, M., et al.: Ground-based remote sensing of tropospheric water vapour isotopologues within the project MUSICA, Atmos. Meas. Tech., 5, 3007–3027, doi:10.5194/amt-5-3007-2012, 2012.
- Schneider, M., et al.: "Fourier Transform Infrared Spectrometry", Chapter 6 of "Monitoring Atmospheric Water Vapour - Ground-Based Remote Sensing and In-situ Methods", ISSI Scientific Report Series, Vol. 10, Kämpfer, Niklaus (Ed.), ISBN 978-1-4614-3908-0, 2013.
- Schneider, M., et al..: Empirical validation and proof of added value of MUSICA's tropospheric δD remote sensing products, Atmos. Meas. Tech., 8, 483-503, doi:10.5194/amt-8-483-2015, 2015.
- Schneider, M., et al.: Accomplishments of the MUSICA project to provide accurate, long-term, global and high-resolution observations of tropospheric {H2O,δD} pairs – a review, Atmos. Meas. Tech., 9, 2845-2875, doi:10.5194/amt-9-2845-2016, 2016
- Schneider, M., et al.: MUSICA MetOp/IASI {H2O,δD} pair retrieval simulations for validating tropospheric moisture pathways in atmospheric models, Atmos. Meas. Tech., 10, 507-525, doi:10.5194/amt-10-507-2017, 2017.
- Wiegele, A., et al.: The MUSICA MetOp/IASI H2O and δD products: characterisation and long-term comparison to NDACC/FTIR data, Atmospheric Measurement Techniques, 7, 2719–2732, doi:10.5194/amt-7-2719-2014, 2014.

Extra Material

Project MUSICA

MUlti-platfrom remote **S**ensing of **I**sotopologues for investigating the **C**ycle of **A**tmospheric water, European Reseach Council, 2011-2016.

Objetive: Generating robust tropospheric {H_2O, δD} pairs using ground-based NDACC/FTIR (Fourier Transform Infrared Spectrometer) and space-based MetOp/IASI (Infrared Atmospheric Sounding Interferometer).



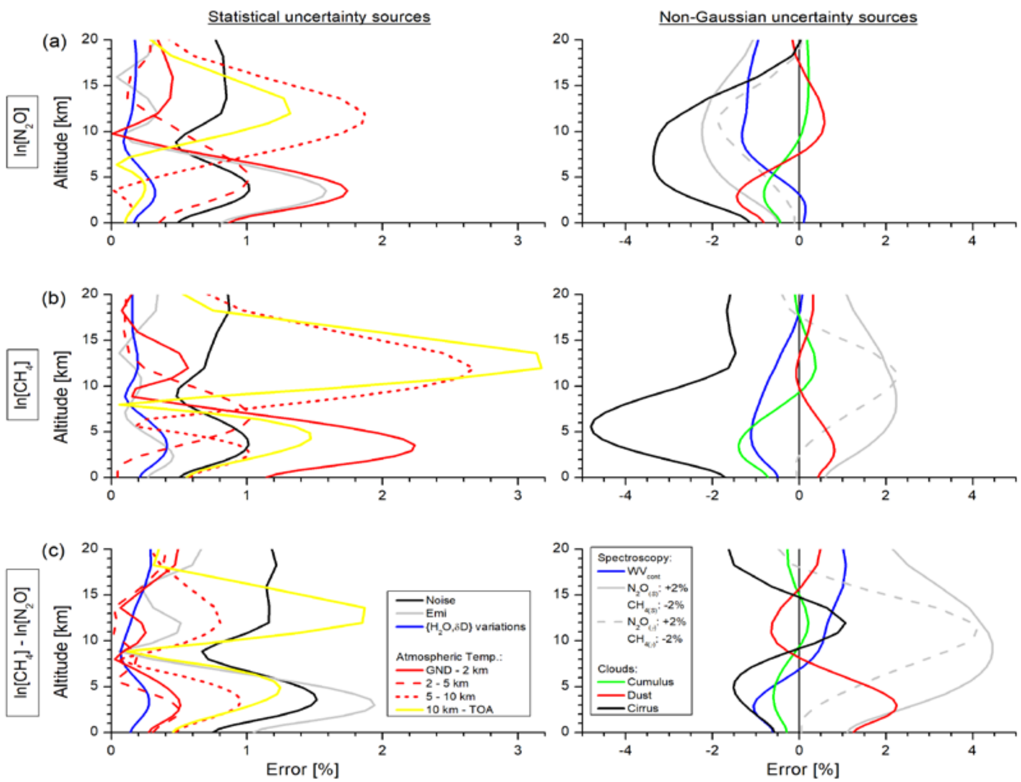
Publications: Schneider and Hase, 2011; Schneider et al., 2012; Schneider et al., 2013; Wiegele et al., 2014; Barthlott et al., 2015; Christner, 2015; Dyroff et al., 2015; Schneider et al., 2015; González et al., 2016; Schneider et al., 2016; Barthlott et al., 2017; Borger et al., 2017; Christner et al., 2017; García et al., 2017; Schneider et al., 2017.

And more than 20 publications related with MUSICA activities.

Theoretical Characterisation (Continuation)

Assumed Uncertainties in the Error Assessment

Uncertainty Source	Uncertainty Value	Uncertainty Source	Uncertainty Value
Measurement noise	Pequignot et al. (2008)	Line intensity and pressure broadening N2O	2%
Temperature 0-2km	2K	Line intensity and pressure broadening CH4	-2%
Temperature 2-5km, 5-10km	1K	Opaque cumulus cloud	10% fractional cover with cloud top at 1.3, 3.0 and 4.9 km
Temperature above 10km	1K	Cirrus cloud	Particle properties OPAC “Cirrus3” 1km thickness, 50% fractional cover with cloud top at 6, 8, 11 and 14 km
Surface emissivity	1% at 1185, 1240, 1295, 1350, and 1405 cm^{-1}	Mineral dust cloud	Particle properties OPAC “Desert” Homogeneous coverage for layers: ground-2 km, 2-4 km and 4-6km
Water vapour continuum	10% underestimation	$\{H_2O,\delta D\}$ variations	{10%,10%}, with 2.5km of correlation length



Error vertical profiles for a mid-latitude summer land pixel

Collocation, Data Filtering and Data Treatment

Collocation and data filtering

HIPPO:

I. All IASI observations within 2ºx2º latitude/longitude box around the mean location of each HIPPO profile, ±12h around the mean time of each HIPPO profile.
II. Altitude of HIPPO profiles: free troposphere (4.8 km) up to 8 km, for ULTS (9.8 km) up to 12.5 km

GAW&NDACC/FTIR:

I. All IASI observations within ~110 km box south of GAW&NDACC/FTIR stations
II. Night-time means (GAW in situ), ±8h (NDACC/FTIR), evening and morning overpass (IASI)

MUSICA/IASI:

c_{sen}<50%, cloud free pixels, residual-to-signal in the fitted window<0.004, skin temperature>275K

HIPPO Data Treatment

I. The vertically highly-resolved HIPPO profiles are degraded applying the IASI averaging kernels:

$$\hat{h} = \mathbf{A}(h - x_a) + x_a.$$

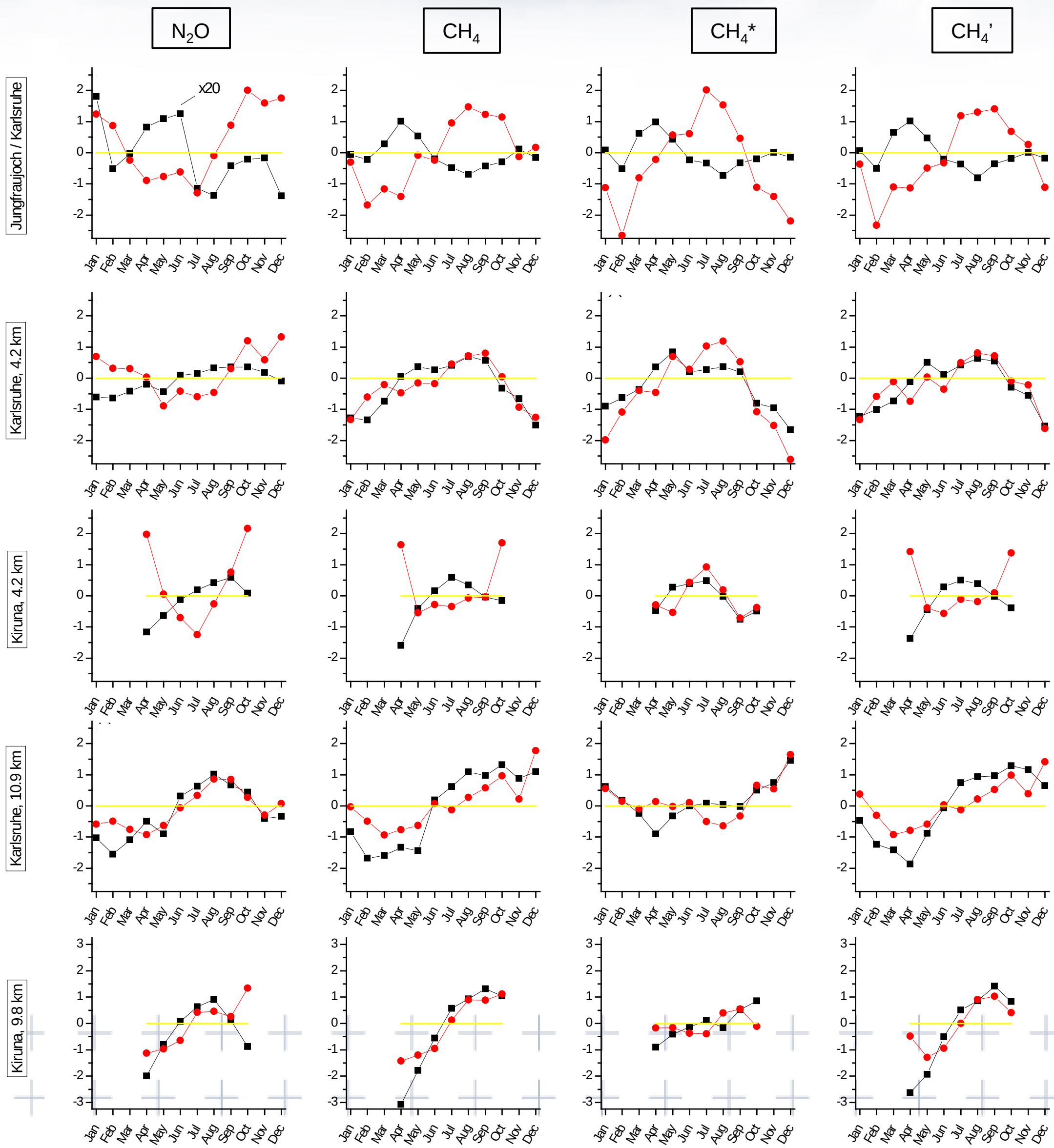
II. The HIPPO profiles are extended by the a priori data used by the MUSICA IASI processor.

Comparison of MUSICA IASI and NDACC/FTIR remote sensing data

I. The NDACC/FTIR data are adjusted to the unique MUSICA a priori data by adding $(A_{FTIR} - I)(x_a - x_{a;FTIR})$ to the NDACC/FTIR retrieval results (being A_{FTIR} and $x_{a;FTIR}$ the averaging kernels and a priori state corresponding to the NDACC/FTIR retrieval, respectively) [Rodgers and Connor, 2003].

II. MUSICA IASI N_2O data are compared with smoothed NDACC/FTIR data at all altitudes. The free tropospheric MUSICA IASI CH_4 and CH_4^* data are also compared to smoothed NDACC/FTIR data. However, in the UTLS region the MUSICA IASI and NDACC/FTIR CH_4 and CH_4^* data are directly compared (no prior smoothing of the NDACC/FTIR data).

Validation by using a Multi-Platform Database (Continuation)



Temporal Decomposition

$$x(t) = \overline{x_m([t_1, t_2])} + \boxed{s(t)} + l(t) + d(t)$$

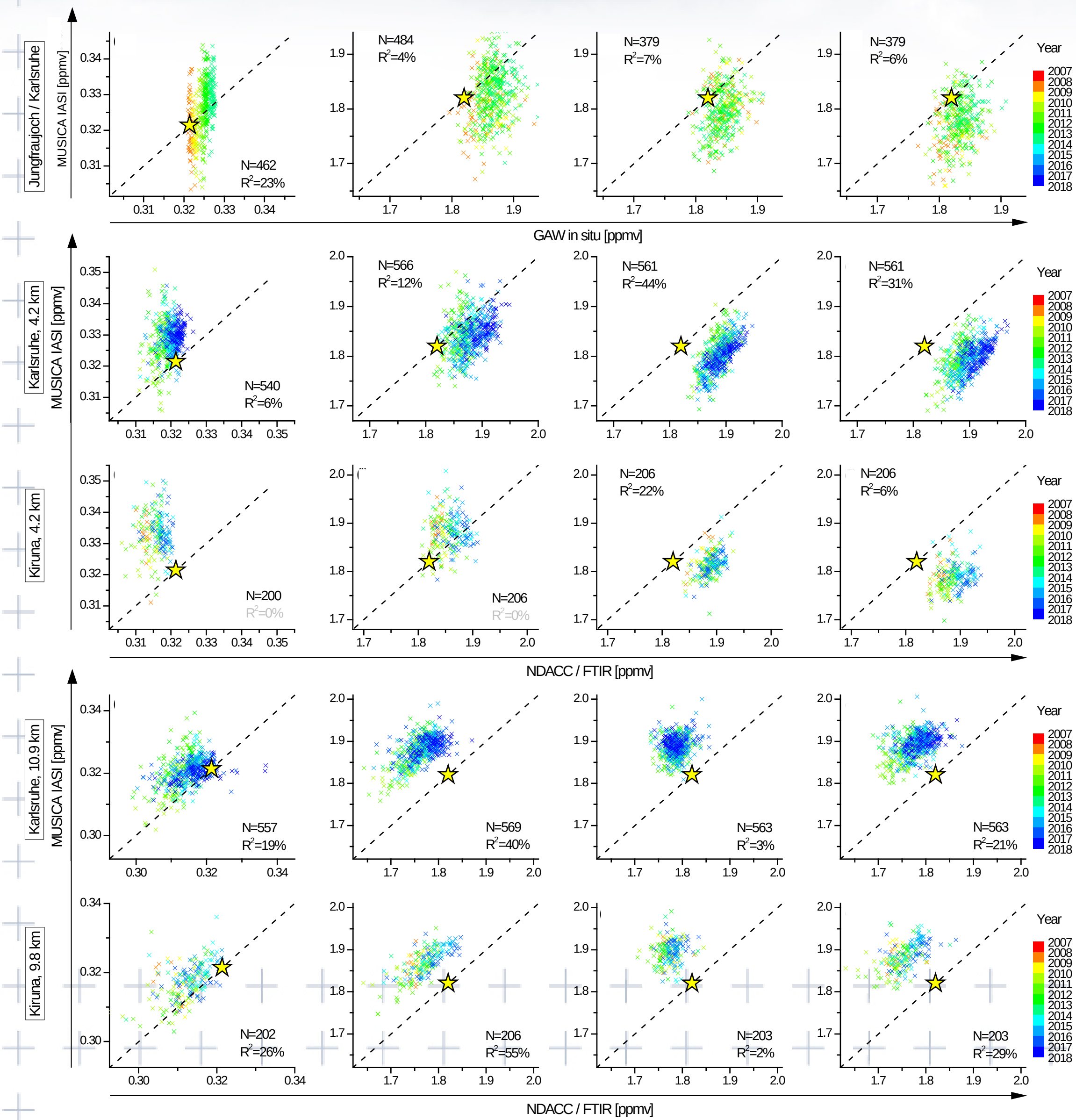
Seasonal cycle relative to long-term background [%]

Karslruhe, 49ºN, 2010-2017

Kiruna, 68ºN, 2007-2017

MUSICA IASI red, GAW and NDACC/FTIR black

Validation by using a Multi-Platform Database (Continuation)

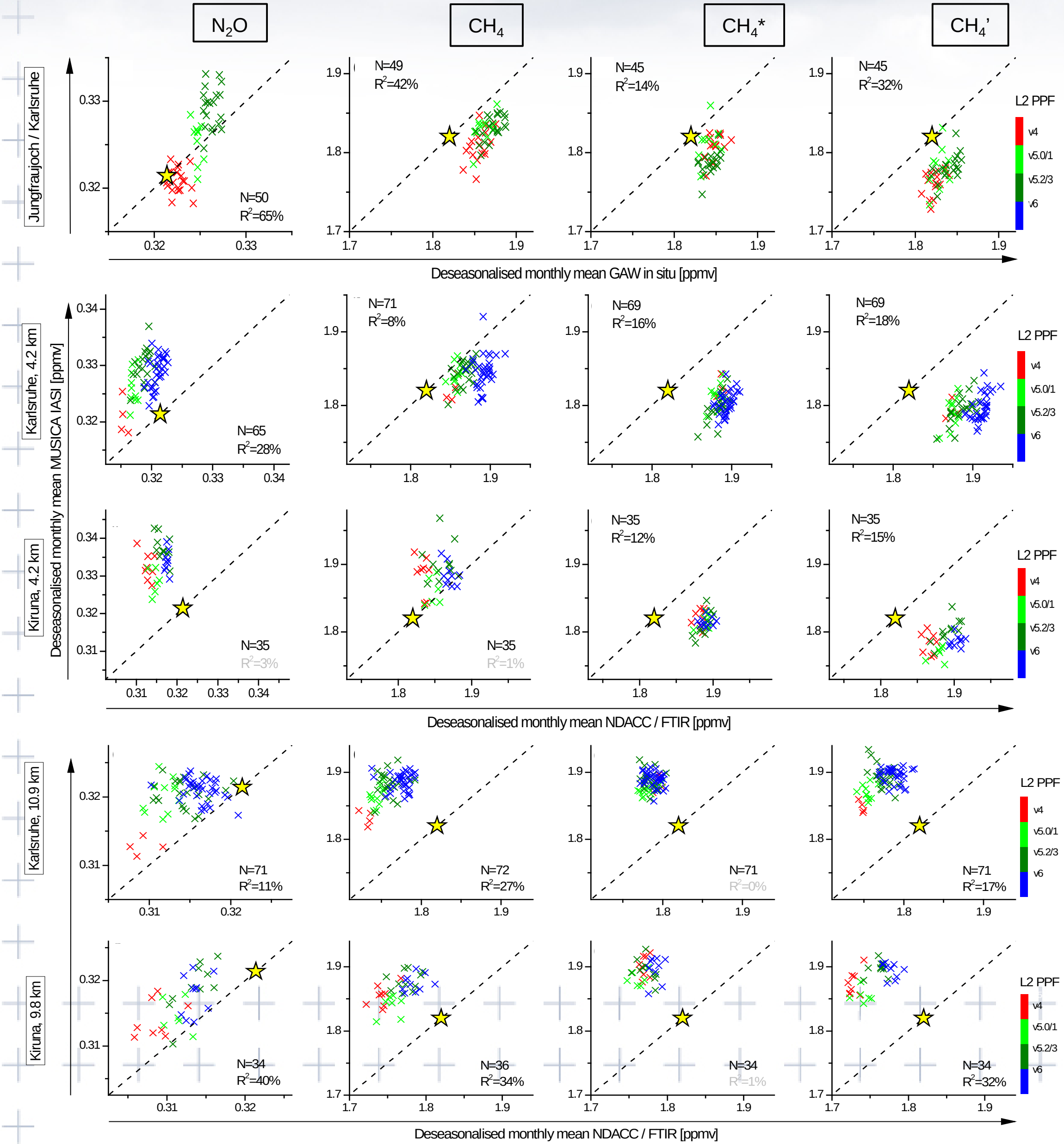


Daily Observations

Karslruhe, 49ºN, 2010-2017

Kiruna, 68ºN, 2007-2017

Validation by using a Multi-Platform Database (Continuation)



Temporal Decomposition

$$x(t) = \boxed{\overline{x_m([t_1,t_2])}} + s(t) + \boxed{l(t)} + d(t)$$

Long-term signals:
Deseanolised montlhly mean

Karslruhe, 49ºN, 2010-2017

Kiruna, 68ºN, 2007-2017

A posteriori CH_4 Correction (Continuation)

(1) N_2O Model Simulations

Approach: As N_2O is very stable, the horizontal, vertical and temporal N_2O variations can be captured well by model simulations. Then, the corrected CH_4 state is:

$$\hat{x}^{c}{}_{CH_4} = \underbrace{(\hat{x}_{CH_4} - \hat{x}_{N_2O})} + \mathbf{A}_{N_2O}(m_{N_2O} - x_{a,N_2O}) + x_{a,N_2O}.$$

A posteriori calculated difference   Model simulations

But, we are interested in quantifying the errors in the corrected CH_4 products only due to errors in the MUSICA IASI retrievals, not in model simulations. Thereby, we assume $m_{N_2O} = x_{a,N_2O}$

$$\boxed{\hat{x}^{*}{}_{CH_4} = (\hat{x}_{CH_4} - \hat{x}_{N_2O}) + x_{a,N_2O}}$$

(2) N_2O Climatology

Approach: Temporal decomposition of a time series into signals belonging to different timescales

$$x(t) = \underbrace{\overline{x_m([t_1, t_2])}} + s(t) + l(t) + d(t)$$

Reference value; Seasonal cycle; Long-term signal; Day-to-Day variations

Assuming that seasonal and long-term CH_4 variations are well captured by MUSICA IASI CH_4 products, we only correct for short-term signals

$$\hat{x}^{c}_{CH_4}(t) = \hat{x}_{CH_4}(t) - \underbrace{\left(\overline{\hat{x}_{m,N_2O}[t_1,t_2]} + \hat{x}_{d,N_2O}(t)\right)} + \mathbf{A}_{N_2O}\left(\underbrace{\overline{m_{N_2O}[t_1,t_2]}} - x_{a,N_2O}\right) + x_{a,N_2O}$$

Co-retrieved N_2O product N_2O climatology

Assuming again $\overline{m_{N_2O}[t_1,t_2]} = x_{a,N_2O}$

$$\boxed{\hat{x}'_{CH_4}(t) = \hat{x}_{CH_4}(t) - \left(\overline{\hat{x}_{m,N_2O}[t_1,t_2]} + \hat{x}_{d,N_2O}(t)\right) + x_{a,N_2O}}$$

The correction (1) strongly depends on the quality of N_2O model simulations, while (2) not.

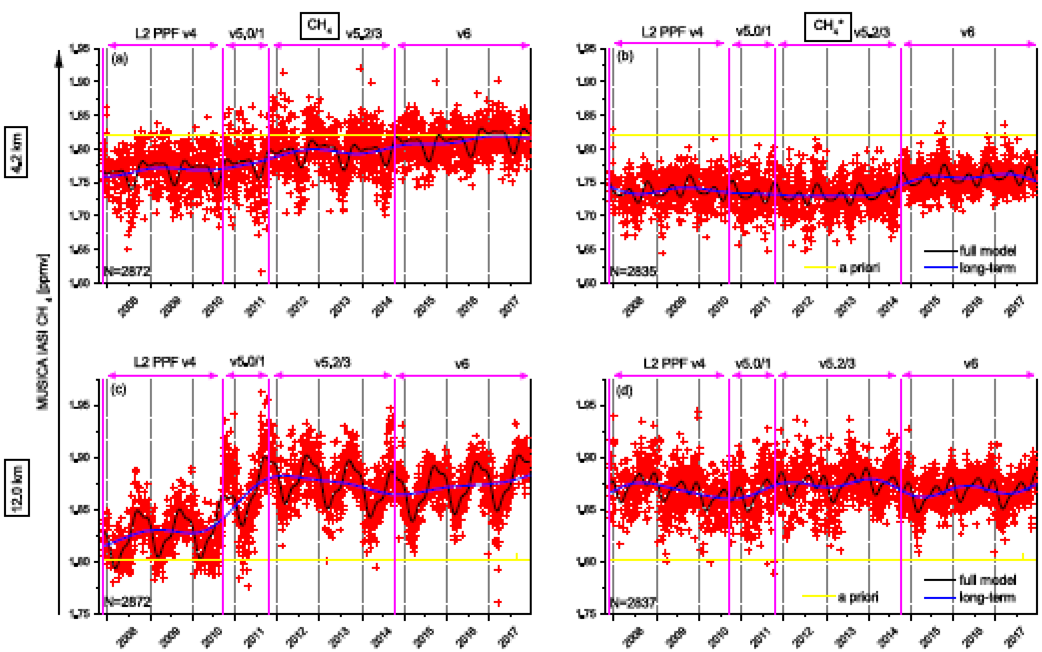
Time Series Model and Long-term Data Consistency

The modelled time series, for estimating the mean values for a reference period and for a first guess separation of seasonal cycle and long-term signals, is obtained by a multi-regression fit of different coefficients that consider variations on different timescales:

$$x_m(t) = \overline{x_m([t_1,t_2])} \longrightarrow \text{Reference value}$$

$$\underbrace{+A_0 + A_1 t}_{\text{Linear trend}} + \underbrace{\sum_{1\le i\le \frac{\Delta t}{2a}} \left\{A_{\sin,i}\sin\left(\frac{2\pi i}{\Delta t}t\right) + A_{\cos,i}\cos\left(\frac{2\pi i}{\Delta t}t\right)\right\}}_{\text{Inter-annual variation}} + \underbrace{\sum_{1\le i\le \frac{\Delta t}{a/4}} \left\{B_{\sin,i}\sin\left(\frac{2\pi i}{\Delta j}j(t)\right) + B_{\cos,i}\cos\left(\frac{2\pi i}{\Delta j}j(t)\right)\right\}}_{\text{Intra-annual variation}}$$

Example of continuous time series of MUSICA IASI CH_4 and CH_4^* daily mean data retrieved in the surroundings of Tenerife Island between 2007 and 2017.



The yellow line is the a priori data used. The results of the multi-regression fit of the time series model are depicted as black line and the time series model components describing the long-term behavior are represented by the blue line.
The periods with different EUMETSAT L2 PPF software versions that can affect the MUSICA IASI products are indicated by magenta colour.

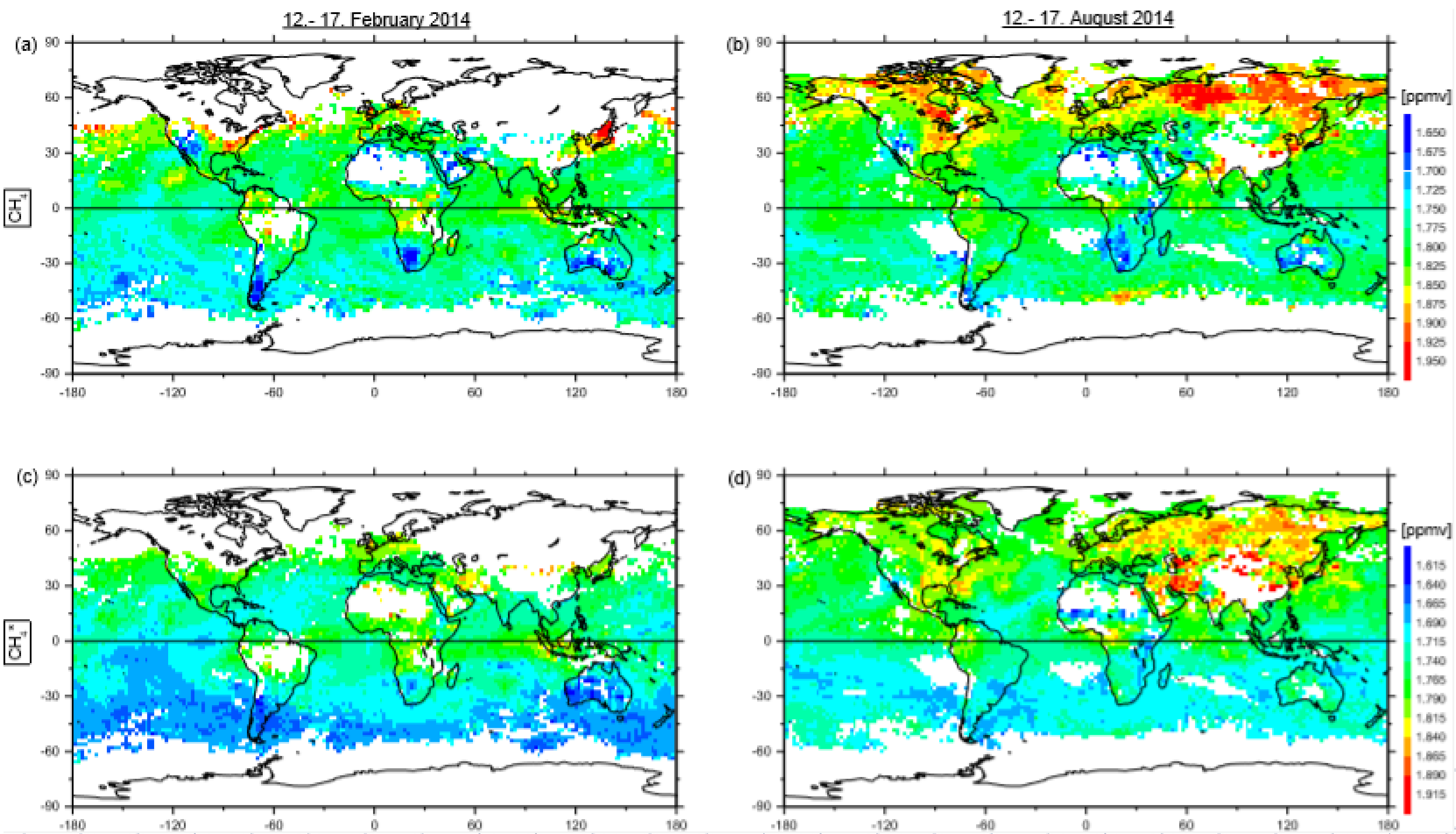
Time Series Model and Long-term Data Consistency

History of EUMETSAT Level 2 PPF software modification and EUMETSAT Level 2 data usage that can potentially affect the MUSICA IASI products.

Start date	PPF software	Relevance for MUSICA IASI product
27/11/2007	v4.0	Start of EUMETSAT operational Level 2 data dissemination.
14/09/2010	v5.0.6	Improvement of the EUMETSAT Level 2 middle/upper tropospheric temperatures (August et al., 2012), which are subsequently used as a priori by the MUSICA processor.
20/10/2011	v5.2.1	Change of the radiative transfer model used for EUMETSAT Level 2 cloud-free optimal estimation retrievals of atmospheric temperatures (EUMETSAT, 2017), which are subsequently used as a priori by the MUSICA processor.
30/09/2014	v6.0.5	Start using of EUMETSAT Level 2 land surface emissivities (instead of IREMIS, Seemann et al., 2008) for MUSICA processing over land. Change of pressure gridding used by the EUMETSAT Level 2 cloud-free optimal estimation retrievals of atmospheric temperatures (EUMETSAT, 2017), which are subsequently used as a priori by the MUSICA processor.

Geographical Coverage

Examples of global geographical distribution of the free tropospheric MUSICA IASI products retrieved at 4.2 km altitude, filtered for c_{sen} < 50% and averaged for an latitude x longitude area of 2ºx2º. (a) and (b) for CH_4; (c) and (d) for CH_4^* . The maps are shown separately for mid February 2014 (a and c) and mid August 2014 (b and d).



Geographical Coverage

Same as previous figure, but for the 10.9 km retrieval altitude.