Response to Referee #2

We thank the reviewer for taking the time to review this manuscript and provide valuable and constructive suggestions/comments. We have addressed all the points one-by-one raised by the reviewer (copied here and shown in black text) along with the corresponding reply from the authors (in blue text).

1) Some readers are maybe interested in a bit more details about the COCCON-XH_2O retrieval itself, maybe this could be added very easy in section 2.2. What are the used microwindows, and linelist and if the XH_2O is calibrated against TCCON or Musica in Karlsruhe, how large are these calibration factors, and how are they calculated.

The COCCON H_2O is retrieved in the spectral window of 8353.4 – 8463.1 cm^{-1}. The updated HITRAN 2009 linelist with empirical corrections is used in the PROFFAST. A universal calibration factor of 0.83 is applied to XH_2O as a post correction in PROFFAST.

2) Summary of information for different products used in this study.

The table below has been added to the manuscript.

	COCCON	TCCON	MUSICA NDACC	MUSICA IASI	TROPOMI
Spectral window (cm^{-1})	8353.4 – 8463.1	4565.2 – 6469.6 (Wunch et al., 2015)	2658 – 3053	1190 – 1400	4200.8 – 4248.1 (Scheepmaker et al., 2016)
Spectroscopic modelling	HITRAN 2009	HITRAN 2009	HITRAN 2012 with modifications to consider speed-dependent Voigt line shapes (Barthlott et al., 2017)	HITRAN 2016, Voigt line shapes Water vapor continuum model: MT_CKD v2.5.2 (Delamere et al., 2010; Payne et al., 2011; Mlawer et al., 2012)	HITRAN 2016
A priori H_2O	NCEP/ NCAR[1]	NCEP/ NCAR	Globally mean WACCM[2] profile. No latitudinal and seasonal dependence	Latitudinal-and-seasonal dependent WACCM climatology	ECMWF[3]
Calibration factor	0.830	1.0183 (Wunch et al., 2015)	0.88	None	None
Number of degrees of freedom			2.8	4-5	

[1] National Centers for Environmental Prediction/National Center for Atmospheric Research

[2] Whole Atmosphere Community Climate Model

[3] European Centre for Medium-Range Weather Forecasts

Barthlott, S., Schneider, M., Hase, F., Blumenstock, T., Kiel, M., Dubravica, D., García, O. E., Sepúlveda, E., Mengistu Tsidu, G., Takele Kenea, S., Grutter, M., Plaza-Medina, E. F., Stremme, W., Strong, K., Weaver, D., Palm, M., Warneke, T., Notholt, J., Mahieu, E., Servais, C., Jones, N., Griffith, D. W. T., Smale, D., and Robinson, J.: Tropospheric water vapour isotopologue data (H216O, H218O, and HD16O) as obtained from NDACC/FTIR solar absorption spectra, Earth Syst. Sci. Data, 9, 15–29, https://doi.org/10.5194/essd-9-15-2017, 2017.

Delamere, J. S., Clough, S. A., Payne, V. H., Mlawer, E. J., Turner, D. D. and Gamache, R. R.: A far-infrared radiative closure study in the Arctic: application to water vapor. J. Geophys. Res. 115, D17106. doi:10.1029/2009JD012968, 2010.

Mlawer, E. J., Payne, V. H., Moncet, J.-L., Delamere, J. S., Alvarado, M. J. and Tobin, D. C.: Development and recent evaluation of the MT_CKD model of continuum absorption. Phil. Trans. R. Soc. A.3702520–2556 http://doi.org/10.1098/rsta.2011.0295, 2012.

Payne, V. H., Mlawer, E. J., Cady-Pereira, K. E. and Moncet, J.-L.: Water Vapor Continuum Absorption in the Microwave. Geoscience and Remote Sensing, IEEE Transactions on. 49. 2194 - 2208. 10.1109/TGRS.2010.2091416, 2011.

Scheepmaker, R. A., aan de Brugh, J., Hu, H., Borsdorff, T., Frankenberg, C., Risi, C., Hasekamp, O., Aben, I., and Landgraf, J.: HDO and H2O total column retrievals from TROPOMI shortwave infrared measurements, Atmos. Meas. Tech., 9, 3921–3937, https://doi.org/10.5194/amt-9-3921-2016, 2016.

Wunch, D., Toon, G. C., Sherlock, V., Deutscher, N. M., Liu,C., Feist, D. G., and Wennberg, P. O.: The Total CarbonColumn Observing Network's GGG2014 Data Version, Tech.rep., California Institute of Technology, Carbon Dioxide In-formation Analysis Center, Oak Ridge National Laboratory,Oak Ridge, Tennessee, USA, https://doi.org/10.14291/tccon.ggg2014.documentation.R0/1221662, 2015.

3) A rough statement on the precision of a single XH_2O COCCON measurement and its duration and how these two numbers compare to the TCCON and NDACC-MUSICA measurements.

The COCCON instrument records one spectrum in about 58 seconds. TCCON instrument records one forward-backward scan in 156.7 seconds, i.e. one measurement takes 78 seconds. An NDACC high resolution measurement used for the MUSICA retrieval takes about 8 minutes. The precision of total column MUSICA NDACC data is theoretically estimated to 1% (see Table 3 in Schneider et al., 2012).

4) Could you calculate the impact of the different aprioris theoretically and explain the 1% difference between the MUSICA IASI and MUSICA IASI (MAP)

There is no calibration factor applied to MUSICA IASI data. The MUSICA IASI data are obtained from HITRAN 2016 Voigt line shape parameters and the continuum model MT_CKD v2.5.2. This 5% bias is likely a bias in the MUSICA IASI data and it is in line with the uncertainty of the HITRAN line list and the continuum model.

The formula mentioned by the referee is already applied to the MUSICA (MAP) products. For simulating MUSICA NDACC and MUSICA IASI data with MAP a priori, we add $g^T(AK_{MUSICA} - I)(x_{apriori\_MUSICA} - x_{apriori\_MAP})$ to the MUSCIA NDACC and MUSICA IASI retrieval data, respectively.

g: column operator

AK_{MUSICA}: MUSICA averaging kernel (maps profiles to profiles)

I: Identity operator

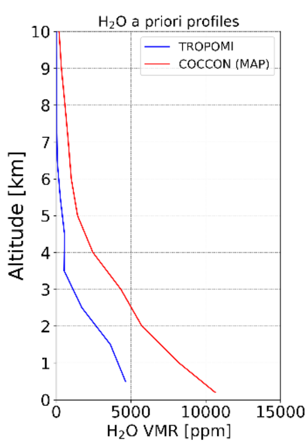
$x_{apriori\_MUSICA}$: MUSICA a priori

$x_{apriori\_MAP}$: MAP a priori

MUSICA NDACC (MAP) and MUSICA IASI (MAP) products are calculated by adding this formula to the original MUSICA NDACC and IASI data. Therefore, the 1.13% difference between the two kinds of IASI datasets (MUSICA IASI and MUSICA IASI (MAP)) at Sodankylä mainly comes from the difference of a priori profiles (WACCM and MAP).

5) "Then, if the aposteriori correction seems to work for IASI, it could maybe be applied to TROPOMI to evaluate, how much of the Bias of the 9% might be explained due to the difference in the apriori. A plot of the average apriori of COCCON and TROPOMI might also help to evaluate this."

The a priori profiles for TROPOMI and COCCON on July 2, 2018 are presented in the figure below.



Could you generate posterior a TROPOMI(MAP) product? Or Just evaluate how much would the bias change?

Yes, this comment is a very good idea. We apply the function below to calculate the bias caused by the a priori profiles of TROPOMI and MAP:

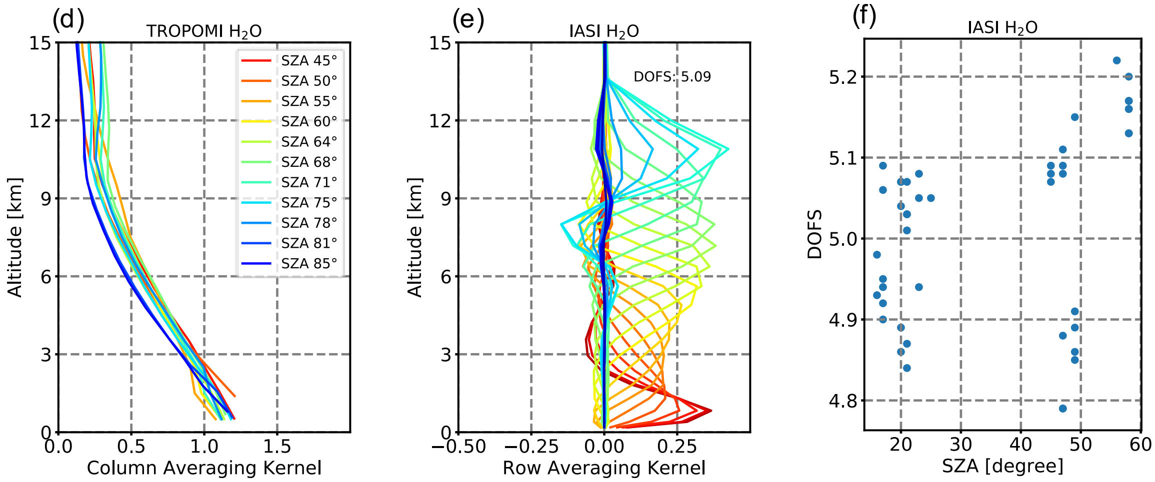
$$\Delta XH_2O = \frac{\sum_{layers}^{i}(VMR_{TROPOMI(i)} - VMR_{COCCON(i)} * f) * subcol_{TROPOMI(i)} * (1 - AK_{TROPOMI(i)})}{\sum_{layers}^{i} subcol_{TROPOMI(i)}}$$

$VMR_{TROPOMI}$ and VMR_{COCCON} are the a priori profiles of TROPOMI and COCCON. The COCCON retrievals are scaled to the a priori profiles by applying a single value. f is the ratio between the XH_2O integrated from the a priori profiles of TROPOMI and the XH_2O integrated from the a priori profiles of COCCON. $subcol_{TROPOMI}$ is the dry air sub-column of TROPOMI. $AK_{TROPOMI}$ is the column averaging kernel of TROPOMI.

The averaged relative bias $(2 \times \frac{\Delta XH_2O}{XH_2O_{COCCON} + XH_2O_{TROPOMI}} \times 100\%)$ is 1.15%. This value is similar to the relative bias change for MUSICA IASI at Sodankylä when applying different a priori profiles (1.13%).

6) I would actually ask the authors to include a typical averaging kernel of the two satellite products, maybe there is still space in Figure 5.

We add three subfigures to Figure 5 according to the referee’s comment: TROPOMI averaging kernels, row averaging kernel of IASI and IASI correlation between DOFS and SZA. We use the row averaging kernel instead of column averaging kernel for IASI because MUSICA IASI is a profile retrieval and generates profiles with DOFS of 4-6.



(d)
TROPOMI H_2O
SZA 45°
SZA 50°
SZA 55°
SZA 60°
SZA 64°
SZA 68°
SZA 71°
SZA 75°
SZA 78°
SZA 81°
SZA 85°
Altitude [km]
Column Averaging Kernel
(e)
IASI H_2O
DOFS: 5.09
Altitude [km]
Row Averaging Kernel
(f)
IASI H_2O
DOFS
SZA [degree]