Authors' Response to Reviews of

Evaluation of tropospheric water vapour and temperature profiles retrieved from Metop-A by the Infrared and Microwave Sounding scheme

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RC: ***Reviewers' Comment***, AR: Authors' Response, ☐ Manuscript Text

1. Reviewer #1

RC: ***The Meteorological Operational satellite (Metop) series of platforms operated by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) have provided valuable observations of the Earth's surface and atmosphere for meteorological and climate applications. These datasets will provide a continuous data record out to 2045. Therefore, Metop data products are an invaluable source for climate data records (CDRs). The authors present a comprehensive assessment of profile data produced using the Infrared and Microwave Sounding (IMS) scheme with the European Space Agency (ESA) Water Vapour Climate Change Initiative (WV_cci) against radiosondes from the Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN) and Analysed Radio Soundings Archive (ARSA) data records, and found that the results from this study demonstrate the real potential for tropospheric water vapour and temperature profile CDRs from the Metop series of platform. The manuscript is generally well-written and the scope is well-within the journal. I have two minor comments below, some focused on data visualization that I hope will help the authors as they consider a revision of their manuscript before recommending acceptance.***

AR: We would like to thank the referee for taking the time to review our manuscript. Below we reply to the issues raised by the referee. The original reviewer comments (RC) are given in bold italics, with the author's responses (AR) in plain text. Where we have updated the manuscript, the extract is included in a quote box with the original removed text in red and struck out. New text appears in blue and is underlined.

1.1.

RC: ***First, I don't learn more about the Metop series of platform, but I think it would be better to show global distributions of tropospheric water vapour and temperature profile CDRs from the Metop data against the ARSA or ERA5 reanalysis, which can help us see how well the Metop data match other references for a global scale.***

AR: The scope of the paper is the analysis of only Metop-A, which is why we do not discuss Metop-B/C or the upcoming Metop-SG series of platforms.

Regarding the suggestion about showing global distributions of IMS water vapour and temperature profiles, we propose including a new figure that shows the differences between IMS and ERA5. The distribution of ARSA profiles does not lend itself to such a plot. Therefore, we show the differences for IMS profiles matched to ERA5 for both temperature and water vapour as a latitudinal average. In addition, this figure includes the standard deviation for the latitudinal means:

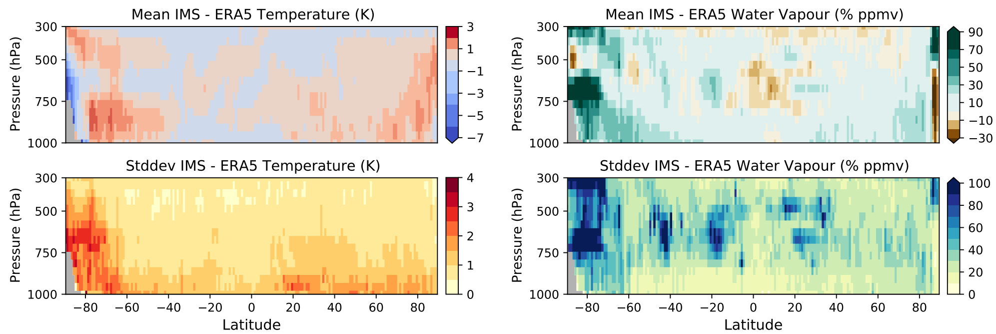

Figure 1: Example of the global mean differences between IMS temperature and water vapour profiles and ERA5 reanalysis for the 15^{th} June 2012. Also included are the standard deviations (Stddev) for the differences. Reanalysis has been interpolated to the observation time and the centre of the IASI instantaneous field view. Before differences were calculated, the IMS averaging kernels were applied to the reanalysis profiles. For further discussion on averaging kernels, refer to Section 3 (Methodology).

To support this figure, we also propose updating the text:

> This study evaluates a 9.5-year record of temperature and humidity profiles from IASI and its companion MW instruments onboard Metop A, retrieved using the RAL IMS scheme ~~,~~ and produced as part of the European Space Agency (ESA) Water Vapour Climate Change Initiative (WV_cci). ~~Validation of this~~ While modern NWP systems assimilate some spectral information from IASI and other satellites, the IMS product is designed to be independent of reanalysis. Therefore, in addition to climate model evaluation, tropospheric profile information from IMS can be used for comparative studies of reanalysis for both meteorological and climate applications. This is especially true for geographic regions which little or no *in situ* information with which to constrain the reanalysis. An example of this application is shown in Figure 1, where ERA5 has been collocated with IMS water vapour and temperature profiles. Here we see the daily differences between the satellite and reanalysis, with the biggest differences observed over polar regions. The assertion here is that the IMS will look to maximise information content from each set of measurements in a way that is too computationally expensive for reanalysis. However, for users to be confident of the use of IMS in such a manner, profiles need to be validated so that their performance is characterised.

1.2.

RC: ***Second, the reference data, i.e., the GRUAN and ARSA also have certain biases. The differences between them would be better to be addressed somewhere in this manuscript.***

AR: We agree that the differences in bias and limitations of each record may not be clear to readers unfamiliar with the these radiosonde archives. Therefore, we propose updating section 2.2 to clarify these points:

> **2.2 Radiosonde Reference Measurements**
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> This section outlines the two radiosonde records used as reference measurements in this study. The first source of radiosonde measurements used has been taken from the GCOS Reference Upper-Air Network (GRUAN) (Immler et al., 2010; Dirksen et al., 2014) archive, locations of the sites can be seen

in Figure 4a. The scope of GRUAN is to provide long-term fiducial measurements, i.e. inclusion of uncertainty estimates) that can be used for calibration/validation exercises, study studying atmospheric processes and determine determining trends. These high-resolution soundings are reported on time intervals of 2 seconds during the flight from the surface into the Upper Troposphere/Lower Stratosphere (UTLS) rather than the set pressure grid used by operational radiosonde archives. An advantage of the higher resolution of GRUAN measurements is that it captures changes in humidity gradients and temperature inversions which can be missed or underrepresented by standard and significant pressure levels. It should be noted that the soundings from GRUAN feature only the Vaisala RS92 radiosondes measurements and not the more recent RS41.

inter-comparison of retrieved satellite geophysical parameters. The ARSA database is a global archive with observations from approximately 1450 stations. In the first instance, raw radiosondes observations with measurements between the surface and 300 hPa for water vapour and 30 hPa for temperature profiles are extracted from the ECMWF archive. These radiosonde observations are then extended above their highest measured point to 0.1 hPa with collocated data from ERA-Interim. Finally, level profile data from the SciSat Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) is used to complete the profile between 0.1 and 0.0026 hPa. The vertical resolution of ARSA varies within the profile, where the lowest part of the troposphere ranging from the surface to 800 hPa, has a resolution of 0.5 km. Between 800 and 200 hPa, the resolution is 0.8 km, increasing to 1.5 km from 200 hPa to 100 hPa. Above 100 hPa to the top-of-atmosphere (TOA), the resolution further reduces to 2.5 km. Unlike GRUAN, which applies a number of corrections to the raw measurement, e.g. correction to water vapour due to incident solar radiation on the radiosonde casing, rather the validation of every ARSA profile relies upon analysing the bias and standard deviation between observed satellite and simulated radiances (Scott, 2015).The ARSA measurement record starts started in January 1979 , and is regularly updated on a monthly basis. Locations of 587 sites present in the archive during the study period can be seen in Figure 4b. For this study, we use the current version 2.7 archive, which has been in use since 2005.

Finally, it is worth noting that while radiosondes provide a source of reference data for profile validation, they are not without their own limitations and caveats of use:

- Model type: Corrections made to radiosondes are highly dependent on the make and model type, especially with older radiosondes (e.g. Miloshevich et al. (2001, 2006)). Both archives used in this study have different approaches to correct radiosondes, with GRUAN applying empirical corrections (Dirksen et al., 2014) and ARSA using a radiative transfer modelling to test for consistency between stable satellite radiances (Scott, 2015; Calbet et al., 2017).
- Time series consistency: Radiosonde archives are subject to semi-regular observation system changes, some of which are recorded by the WMO. For GRUAN, their certified sites undergo periodic auditing of their measurement programs in addition to annual reviews to ensure all sites continue to meet practice standards. It is not clear how well this approach scales would scale from $\approx$30 sites to 500+ found in a global network. ARSA uses the long-term statistics from the radiance intercomparisons to ensure quality consistency across the archive. This approach allows for a common method to be applied to a global network of up to 1450 sites, however, this relies on the radiometric stability of the reference satellite instrument.
- Sources of uncertainty: Radiosondes are subject to a number of sources of uncertainty which

can be difficult to characterise fully. The GRUAN provides a comprehensive error budget for their products as their correction process allows estimates for each step. However, ARSA, like other global datasets, does not give an uncertainty on the profiles it provides do the complexity of such an exercise. In Trent et al., it was demonstrated that the uncertainty on operational records reduces to a few % ppmv with large collocation numbers.

- Distribution of sites: One of the strengths of operational radiosonde records is a large number of global sites available for match-ups. While ARSA does quality filter these, it still has over 500 sites within the study period. For GRUAN, there are only a small number of sites, though they try to sample major climate regimes to provide some global representation. A key weakness for any radiosonde archive is the lack of sites in the southern hemisphere, especially for GRUAN (Figure 4a).