Reply to

Interactive comment on “Two decades of in-situ temperature measurements in the upper troposphere and lowermost stratosphere from IAGOS long-term routine observation” by Florian Berkes et al.

Anonymous Referee #2

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This paper analyzes passenger-aircraft IAGOS temperature observations in the UTLS for the period 1995-2012, focusing on long-term trends. Comparisons with the ERA-Interim reanalysis data are also made, and change points in ERA-Interim are identified and discussed. Very careful data analysis has been made, and the discussion on ERA-Interim is very interesting. I think the manuscript can be published in ACP after considering the following comments.

We thank the referee for her/his comments, which we address (in bold) point by point in our reply below.

1. As the authors explain in Introduction, the aircraft AMDAR data are known to have warm biases. I would like the authors to add some more explanations why the IAGOS data are considered to be without such biases. Specifically, please consider

(1) to add a similar figure to Figure 1 for the automated temperature instrument and

<u>Answer:</u> The aircraft temperature sensor position and Rosemount housing are located at three different spots at the nose region of the aircraft (may differ from airline to airline), but the system is equivalent to the IAGOS system and this is shown.

(2) to add some technical descriptions for it in the last paragraph of Section 2.2. Is the temperature sensor material same? Is the instrument housing same? Is the correction method for adiabatic compression same? Are there other data processing procedures for both?

<u>Answer:</u> Moninger et al. (2003) summarized that the aircraft temperature sensor can be affected by moisture, and dirt (insects and other materials), which can lead to a coating of the probe and to a drift of the sensor signal. The sensor type is also a platinum resistance sensor, as used in IAGOS. Temperature measurement uncertainties increase due to the adiabatic temperature correction, which includes the uncertainties of the static pressure and Mach number (calculated from the aircraft speed). The aircraft temperature correction of the adiabatic compression is calculated by the avionics of the aircraft itself. The entire procedures and uncertainty determination are given in Stickney et al., 1994 and Helten et al., 1998. The aircraft temperature is provided from avionics of the aircraft with a precision of +/- 0.5 K and maximum uncertainty of +/- 2 K based on AMDAR quality criteria (WMO, 2003). Please note, we wrote in the introduction of the manuscript: ” However, Ballish and Kumar (2008) and Drüe et al. (2008) identified that the AMDAR aircraft temperature is strongly affected by a warm bias, which can fluctuate by altitude, aircraft type and phase of flight, while the reason for this bias is not fully understood (Ingleby et al., 2016).”

IAGOS changes regularly (currently 2-3 months interval) the temperature/humidity sensors to avoid drifts of the signal (e.g. due to dirt) and the quality of each sensor is checked before and after each deployment in the laboratory. Also for each 4-s data point we provide a quality flag and the uncertainty is calculated, which is not the case for the aircraft temperature data. As far as we know, AMDAR temperature measurements aren't considered if they differ more than 2 K from the NWPs. So we think that we might be able to avoid a warm temperature bias, because we have a more frequent control and exchange of the temperature sensor.

We included additional information in the last paragraph of Sec 2.2 in the revised version.

2. Please also describe the instruments for positions, pressure, and aircraft and wind speed/direction? The pressure measurement uncertainty may be important for analyzing temperature trends because there are temperature gradients in the UTLS so that pressure errors would result in slightly different temperature values. Aircraft/wind speed/direction might be important for the correction of adiabatic compression (or not?).

Answer: **The instruments might vary for each aircraft type, a general overview about the uncertainty of the aircraft data within the IAGOS project was given by Petzold et al., 2015. It is true that the aircraft speed is crucial for the correction of the adiabatic compression, which is applied for each individual aircraft based on the in-situ measurements. The correction factor is calculated using the following equation:**

$$T_{total} / T_{ambient} = (1 + (\gamma-1)/2)\, M^2)$$

With T_{total} as the total air temperature measured from the sensor. γ is the ratio of the specific heats of air at constant pressure and volume, respectively. M is the Mach number which is calculated using the aircraft speed divided by speed of sound in air. The total uncertainty of the temperature measurements is calculated with 0.5 K and includes the temperature sensor uncertainty of 0.25 K plus the uncertainty for the correction of the adiabatic compression (Helten et al., 1998). At cruise altitude, the Mach number is rather constant at M= 0.81+-0.01. More details are given in the standard operation procedure (SOP) of the IAGOS capacitive Hygrometer (ICH), available at www.iagos.org.

The aircraft pressure measurements are used to derive the aircraft position relative to the thermal tropopause calculated from ERA-Interim. The uncertainty from the pressure sensor (0.35 hPa) which is small compared to our range of the tropopause layer (+/- 15 hPa). Note, we wrote in the manuscript, that we evaluate the vertical position of the aircraft using in-situ measurements of CO, O3 and PV.

We added additional information at different parts in the manuscript.

3. I have some questions related to the data analysis methods. (Please note that I am not asking the authors to re-do the data analysis.)

3-1. Are there any sampling biases/trends in vertical within each layer? Because there are temperature gradients in the UTLS, if the flight level would have changed systematically over the period, we would get apparent temperature trends.

3-2. Similarly, are there any sampling trends in horizontal? My understanding is that the pilots are trying to avoid turbulences i.e., the regions with strong (horizontal) shears. If the westerly jets have some trends in their locations (cf. Davis and Rosenlof, 2012; Williams, 2017), the aircraft paths may have some systematic changes that could give apparent temperature trends.

<u>Answer:</u> We looked at the beginning in detail at the horizontal and vertical data coverage for each specific region, and we did not find a shift of the data coverage within each region over the study period. Over most regions the aircraft fly along distinct routes. Over the North Atlantic and Tropical Atlantic regions, the spread of the fight tracks is larger, which corresponds to flight routes with different destinations and avoiding severe weather conditions. However, we agree with the reviewer that it would be worth to look more into details of the aircraft measured wind fields to study changes of the wind pattern, which, however, is not the focus of this study.

3-3. For comparison with ERA-Interim, another way could be to pick up 6 hourly data (i.e., at the times when the reanalysis data are provided) from the IAGOS data. Linear interpolations to 1 min from 6 hourly data may produce unnecessary spreads in the difference of the two data.

<u>Answer:</u> The ERA-Interim data is interpolated along the flight path for every 4s and then averaged to 1 min to reduce the amount of data. If we compare point by point, the spread is large between the temperature of ERA-I and in-situ as we wrote in the manuscript and show in Fig 9. However over 93% of this spread is smaller than 2 K for the North Atlantic, which reflects the generally good agreement between these two data sets. Of course the IAGOS data could be interpolated on a model grid with the same time resolution, but from our point of view, this would lead to a new study with the focus on the evaluation the ERA-Interim model. For such study, it would be favorable to include additional data sets (e.g MERRA2, JRA-55 and others), which in fact is subject of ongoing work.

4. Page 7, lines 23-24 and Figure 7. The warm phase during 2006-2008 might be related to a volcanic eruption (the Soufrière Hills at 16N on 20 May 2006). See Vernier et al. (2011).

<u>Answer:</u> The reviewer is right that the mentioned warm phase could be related to the volcanic eruption. However, this hypothesis is speculative and we decided to avoid it and leave it for a future study.

References:

Sean M. Davis, S. M., K. H. Rosenlof (2012), A Multidiagnostic Intercomparison of Tropical-Width Time Series Using Reanalyses and Satellite Observations, J. Clim., 25, 1061-1078, https://doi.org/10.1175/JCLI-D-11-00127.1.

Vernier, J.-P., et al. (2011), Major influence of tropical volcanic eruptions on the stratospheric aerosol layer during the last decade, Geophys. Res. Lett., 38, L12807, doi:10.1029/2011GL047563.

Williams, P.D., Increased light, moderate, and severe clear-air turbulence in response to climate change, Adv. Atmos. Sci. (2017) 34: 576, https://doi.org/10.1007/s00376-017-6268-2.