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 #1

Received and published: 22 July 2017

This study presents a very valuable data set of 18 years of IAGOS temperature measurements in the UTLS region. Trend estimates are derived and compared with ERA-Interim reanalyses. The results are relevant and novel, and the paper is generally well written. However, a few very important aspects of the study are not clear and require clarification. I therefore recommend to accept the paper subject to major revisions.

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

Major comments:

A) An 18-year time period is short for trend analyses. I still think that the trend calculations in this study are useful, and I very much appreciate the efforts of the author team to produce such a long high-quality data set, but the time period issue must be discussed in the paper. I would like to see two additional trend calculations: (i) for IAGOS, how do the trends change if you skip the first or last year of your 18-year time series? Such a "sensitivity test" could be interesting to assess the robustness of trend values from 18 years compared to 17 years. The additional values could be included in Fig.8.

<u>Answer:</u> The robustness of the trend analysis was tested with the Mann-Kendall test using different lengths of the time series. In order to further clarify this point, we have now added one sentence in section 3.2 and updated table S4 in the supplement:

"The robustness of temperature trends was tested by skipping the first or last year of the 18-year period. Within all layers and all regions each trend keeps the same sign and the trend values varied within the standard error. The only exception was the upper troposphere over North America where the temperature trend changed from slight positive trend (18 years) to neutral when the final year was removed. "

(ii) for ERA-Interim, you could compare the trends for the 18-year period with the full ERA-Interim period. Again, this would tell us something about how trends depend on the duration of the time period considered. A brief discussion of this should also be included in the concluding section.

<u>Answer:</u> We agree that the full time period would give additional information about the behavior of the ERA-Interim data, but the ERA-I temperature data is interpolated along the flight tracks, therefore it covers only the IAGOS period. We could create artificial flight tracks for other years, however the focus of this study is to present the IAGOS temperature measurements and not to evaluate ERA-I.

B) I appreciate the efforts in data calibration, but I find it a bit disappointing that IAGOS data is only available until December 2012. Adding some of the recent years would also help with the issue mentioned above. Is there no way how you could include a few more years?

<u>Answer:</u> Between 2011 and 2014 some MOZAIC aircraft were still operating. The first IAGOS aircraft started to measure in July 2011 and the second in June 2012. The IAGOS temperature and humidity data validation tool had to be re-developed and is currently under evaluation for measurements past 2013. The data coverage of the MOZAIC aircrafts for the period past 2013 is too sparse for a meaningful extension of our trend analysis. Therefore we limited our data analysis to the period until 2012.

C) Unfortunately, I don't understand the method to distinguish between LMS, TPL and UT. I understand how you determine the pressure of the thermal TP from ERA-Interim; so the TPL is a 30-hPa deep tropopause-following layer, which varies in space and time (is this correct)? Then I am lost what "max(TPL)" and "min(TPL)" mean on p. 5: max and min over what? time or space? and how to you measure max/min? does it refer to pressure? It seems to me as if TPL is tropopause-following, but LMS and UT have fixed horizontal bounds, I find this very confusing.

<u>Answer:</u> We are sorry for the confusion. TPL is related to the range of the pressure altitude of the tropopause +-15 hPa. Max/min is related to the upper/lower limit of this range around the tropopause. To clarify, all three layers are tropopause-following and we improved the layer definition in the manuscript:

LMS : $p < p_{TPHWMO} - 15$ hPa, which is limited by the maximum cruise altitude ($p \sim 190$ hPa)

TPL: $p = p_{TPHWMO} \pm 15$ hPa

UT: $p > p_{TPHWMO} + 15$ hPa, limited to 350 hPa

D) p. 6 lines 13-15: It is very important whether IAGOS data has been assimilated in ERA-Interim, or not. This is not clear from the text. The first sentence says that "aircraft and other" data are assimilated in ERA-Interim, it seems that this does not include IAGOS. The next sentence then says "Note that IAGOS ... observations are not assimilated in any other NWP model ..." which sounds as if IAGOS is assimilated only in ERA-Interim, but I assume it is not assimilated by any reanalysis system. Then the "other" would be very misleading. Please clarify.

<u>Answer:</u> IAGOS temperature measurements are not assimilated into ERA-Interim or any other model. We deleted the word "other" and apologize for the confusion.

Minor comments:

1) p. 1 line 21: "temperature bias between observation and model data" sounds strange to me; do you mean the bias of the observations or the bias of the "model data" (note that reanalyses are not really just model data) or do you mean that both have a bias but that the biases differ?

<u>Answer:</u> We agree with the reviewer that it is not very clear. We exchanged the word "bias" by "difference".

2) p. 1 line 28: delete ";" after reference to Seidel et al., 2016

<u>Answer:</u> Done

3) p. 2 line 7: "suffers" –> "suffer"

<u>Answer:</u> Changed

4) p. 2 line 15: first introduce abbreviation for LMS

<u>Answer:</u> Done

5) p. 2 line 29: "Petersen et al., 2015" should read "Petersen, 2016" (single author, and paper appeared one year later)

<u>Answer:</u> Sorry for the mistake, the reference is updated.

6) p. 2 line 30: "including" is strange here, do you mean "assimilating"?

<u>Answer:</u> Changed

7) p. 2 line 31: "Drue" –> "Drüe"

<u>Answer:</u> Changed

8) p. 3 line 12: not clear what is meant by "both types of profile measurements"

<u>Answer:</u> Should read: *"… with temperature profiles from in-situ measurements and from the model…"*

9) p. 4 line 22: most readers are not familiar with the AIRTOSS-ICE campaign. What "research aircraft" has been used, and what type of temperature sensor?

<u>Answer:</u> We included the information in the text

"During this campaign, the IAGOS temperature instrument was installed on the research aircraft (Learjet 35A), and provides the opportunity to compare both temperature measurements. The aircraft temperature measurement was made with Pt-100 thermistor mounted in the same type of Rosemount as for the IAGOS temperature measurements. The temperature sensor of the research aircraft has been calibrated regularly with an uncertainty of about 0.5 to 1.0 K."

10) p. 4 line 31: I understand "air temperature" but what is "total air temperature"?

<u>Answer:</u> We included into the text:

"The total air temperature is defined as the ambient air temperature plus the temperature increase due to adiabatic compression in the Rosemount housing."

11) p. 5 line 3: "maintained" sounds strange, maybe "made"?

<u>Answer:</u> We changed "*maintained*" to "*performed*".

12) p. 5 line 4: I find this a strange remark, it sounds as if the DWD model was used as a reference to test the accuracy of the observations ... maybe delete this sentence.

Answer: We agree with the reviewer that the sentence leads to misunderstanding and deleted it.

13) p. 5 line 21 and in other places: use "p" as symbol for pressure, not "P"

Answer: Changed

14) p. 5 line 30: it is fine that you use here the thermal tropopause, but the long list of chemical,…tropopauses does not help the reader and is not relevant here. I suggest to delete the last 3.5 lines on this page.

Answer: We follow the suggestion of the reviewer and delete the different tropopause definitions.

15) p. 6 line 2: of course the Coriolis parameter is defined near the equator, but it is zero! Therefore PV goes to zero and the 2-pvu surface is not defined.

Answer: Thanks for the correction. We changed the sentence to:

The thermal tropopause is valid within all latitude bands, whereas the dynamical tropopause cannot be used in tropical regions, because the Coriolis parameter is zero, therefore PV goes to zero and the 2-pvu surface is not defined (Boothe and Homeyer, 2017).

16) p. 6 line 19: Reichler et al. 2003 is not in the list of references

Answer: Sorry for the mistake. It is now included.

17) p. 6 line 21: this statement is very strange, the time resolution of ERA-Interim is 6 hours, so it cannot be reduced to 1 minute. Please explain how you interpolated 1-min values from ERA-Interim, by linear interpolation in time?

Answer: The ERA-I data is linearly interpolated (time and space) along the flight path in 4 s temporal resolution equivalent to the in-situ measurements. Afterwards the in-situ data and the ERA-I data were averaged to 1 min to reduce the size of data as written on p. 4 line: 19.

18) p. 8 line 3: "it is assumed ...": do you have a reference for this?

Answer: We included the reference *"Kandhu et al. 2016"* at the end of the sentence:

Khandu, Awange, J. L. and Forootan, E.: Interannual variability of temperature in the UTLS region over Ganges–Brahmaputra–Meghna river basin based on COSMIC GNSS RO data, Atmos. Meas. Tech., 9(4), 1685–1699, doi:10.5194/amt-9-1685-2016, 2016.

19) p. 8 line 6: "in this region" appears twice in the same sentence

Answer: We rephrased the sentence.

"Another reason could be related to a higher variability of the temperature due to large scale influence or simply that the data coverage is still too poor in this region, which might lead to a higher variability of the local temperatures which then mask the temperature trend."

20) p. 8 line 12: what do you mean by "local tropopause", maybe delete "local"?

Answer: We agree with the reviewer and deleted local.

21) p. 8 line 30: "where" –> "when"

Answer: Changed

22) p. 9 line 21: "then" –> "than"

Answer: Changed

23) p. 9 line 26: "annual averages of the monthly deviation": sounds complicated to me and it should be the same as just "annual deviation"?

Answer: Changed as suggested

24) p. 10 line 16: references should be in chronological order

Answer: Corrected

25) p. 10 line 19: I don't understand this sentence: what aircraft measurements are you using here? IAGOS or AMDAR, and what is assumed to be similar?

Answer: We demonstrated that using only the aircraft temperature measurements ("AMDAR like") the aircraft temperature trend follow mostly the ERA-Interim temperature trend, which is an indication that here is a positive bias in the aircraft data. However, the aircraft temperature data were not validated after the AMDAR recommendations, therefore we wrote: "…, which we assume to be comparable to AMDAR measurements". We included the "(T_{AC})" to be more specific.

26) p. 11 line 20: what is meant by "use IAGOS observations as anchor point"? Do you suggest to calibrate AMDAR data with IAGOS? And why do you not suggest that IAGOS observations should be assimilated in, e.g., ERA-5?

Answer: The amount of IAGOS temperature measurements are much less compared to the amount of AMDAR temperature measurements and the benefits would be minor in respect to additional measurements. However, both temperature measurements (AMDAR and IAGOS) could be assimilated into ERA5, than IAGOS data could be uses as anchor point for the bias correction of the AMDAR data.

27) p. 15 line 13: I did not find a reference to Kuo et al. in the text

Answer: Sorry for the mistake. The reference is an artefact from an earlier version of the manuscript.

28) p. 16 line 9: volume and page numbers are missing

<u>Answer</u>: Fixed

Table S4: Temperature trends of ERA-I and from the IAGOS observations within the LMS, TPL and UT as shown in table3 and compared to temperature trends derived from 17 years skipping the first (light gray) or last year (dark gray) in the analyses.

Region	ERA-I				IAGOS			
	ΔT_{18yr} K/dec	SE K/dec	$\Delta T_{17yr, first}$ K/dec	$\Delta T_{17yr, last}$ K/dec	ΔT_{18yr} K/dec	SE K/dec	$\Delta T_{17yr, first}$ K/dec	$\Delta T_{17yr, last}$ K/dec
LMS								
Greenland	-0.79	0.29	-1.03	-0.83	-1.39	0.29	-1.48	-1.45
North America	-0.25	0.21	-0.38	-0.21	-0.71	0.21	-0.73	-0.76
North Atlantic	+0.56	0.17	+0.53	+0.59	-0.05	0.17	+0.02	-0.01
Europe	+0.11	0.19	+0.12	+0.14	-0.53	0.20	-0.49	-0.62
TPL								
North America	+0.29	0.19	+0.11	+0.45	+0.23	0.20	-0.02	+0.42
North Atlantic	+0.46	0.15	+0.42	+0.62	+0.25	0.16	+0.20	+0.38
Europe	+0.20	0.15	+0.17	+0.19	-0.44	0.17	-0.46	-0.57
UT								
North America	-0.92	0.17	-0.99	-0.82	-1.08	0.18	-1.16	-1.00
North Atlantic	+0.38	0.18	+0.52	+0.58	+0.22	0.20	+0.33	+0.43
Europe	-0.24	0.14	-0.21	-0.29	-0.59	0.15	-0.55	-0.71
Central Asia	+0.66	0.33	+0.55	+0.91	+0.32	0.33	+0.27	+0.54
Tropical Asia	-0.58	0.39	-0.43	-0.24	-0.54	0.04	-0.30	-0.21