

Review of ACP manuscript acp-2017-640

Title: Accuracy and precision of lower stratospheric polar reanalysis temperatures evaluated from A-train CALIOP and MLS, COSMIC GPS RO, and the equilibrium thermodynamics of supercooled ternary solutions and ice clouds

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The authors present an evaluation of stratospheric temperatures at high latitudes in reanalyses by using temperatures from different satellite based observations including Microwave Limb Sounder (MLS) and GPS radio occultation (RO) measurements.

They furthermore use observed regimes of different types of Polar Stratospheric Clouds (PCs) for deriving temperature references based on the thermodynamics of supercooled ternary solutions and ice clouds.

The paper is well written but overall it is quite lengthy and includes 21 figures. At several places the content could easily be condensed and streamlined without losing information and thus presented in a more compact way. A sincere restructuring of the text in some sections is recommended and a restructuring/merging of figures. Furthermore, clarifications are needed regarding the definition of precision and accuracy, the choice of pressure levels, and the description of comparison methods (please see comments below).

I recommend publishing the manuscript after revision taking into account the reviewer's recommendations and providing necessary clarifications. Please find a list of major and minor comments below.

Major comments:

Abstract: The abstract is much too long and definitely should be shortened by half. Only essential information and results should be stated. E.g., line 10 to 16 on page 2 could be deleted.

Is the statement on GPS RO uncertainties correct: "accuracy <0.2 K, precision > 0.7K" (also in paper text and conclusion section)? To my knowledge it should be vice versa. The precision is about 0.25 K and the accuracy in the tropopause region about 0.7 K increasing exponentially in the stratosphere (see also comment below).

Methods:

Computation of pressure levels:

"The synoptic gridded reanalysis temperatures are interpolated to a common vertical pressure grid (100–10 hPa), with 6 levels per decade ..."

Why are the pressure levels chosen this way for the reanalyses and the radio occultation observations, e.g., levels of 61 hPa or 46 hPa, etc.? Is there a specific reason for this? I strongly recommend using standard pressure levels or pressure levels with 10 hPa steps, i.e., plain numbers, as used later in the manuscript anyway. What does "fixed pressure levels per decade" mean?

"For convenience we interpolated the COSMIC temperature profiles to a set of fixed pressure levels with 24 levels per decade ..., approximately 2/3 km vertical resolution. "

Please revise the last statement.

The vertical resolution of GPS RO observations ranges from a 0.5 km (100 m in case of wave optics processing) in the troposphere to about 1.5 km in the stratosphere. By interpolating the vertical levels you change the sampling of the height/pressure levels.

Section 2.4:

Please explain explicitly how the reanalyses are compared with the radio occultation observations. As I understand you compare the gridded reanalyses data with individual COSMIC temperature profiles (supposedly averaged in the respective grid or zonal mean). Doing it this way you would not account

for the different sampling of the observations. A comparison should be either performed by subsampling the reanalyses at the locations of the RO observations (i.e., comparing collocated profiles) or by comparing monthly-mean zonal-mean reanalyses data with zonal-mean sampling-error corrected RO climatologies

Cite Schreiner et al. (2007; doi:10.1029/2006GL027557) in section 2.4 as they made the first analysis on the precision of COSMIC data. Their results were confirmed by Alexander et al. (2014), who derived a precision of about 0.1% in refractivity between 8-25 km (larger above 30 km) which translates to about 0.25 K. No strong dependence of the estimated precision on latitude or season was found.

Is this consistent with your statement in the abstract and conclusion section on precision and accuracy?

Please include a definition of precision and accuracy in the method section before values for the different data sets are discussed and give an explicit description on how precision and accuracy are computed in your study.

Move method descriptions from the results section to the method section (see comments below on restructuring).

Structure of the manuscript:

Introduction:

Page 4, 3rd paragraph: This paragraph already describes the methodological approach in some detail and would rather fit at the beginning of the method section.

Page 4, line 29: "However, lack of sufficient statistics in the Arctic precludes a robust conclusion for ICE PSCs." This is a result and the sentence should be moved to the conclusion section or/and the results section.

Page 4, line 31-33: Detailed description of investigated dates should be moved to the beginning of the methods section.

Method section:

I recommend slight restructuring: Start with the reanalyses description. The information in the first paragraph does not really fit here at the beginning and should be moved to sections 2.2 where CALIOP observations are described and to section 2.3 where MLS is described.

Section 2.1: The information on all the reanalyses could be summarized in a Table and would give a more compact overview.

Streamline page 7 and 8 as you recapitulate several studies in quite a lengthy way.

Results sections:

The results sections include method descriptions such as section 4.6 describing how the comparison of reanalyses temperatures to LIQ and ICE reference points is performed and in section 4.8.2 (last paragraph) on difference computations. These method descriptions should be moved to the method section.

Furthermore some results sections are very short and could be merged into one section such as sections 4.4, 4.5, and 4.7. There is no need to make a separate section for each figure but rather to comprise related topics in one section. The merged section 4.4 could be entitled, e.g., "PSC types from CALIOP and their representation in MLS observations"

Section 4.8 Polar temperature reference points: – remove sub-sub-sections and streamline the text. Section title could be "Reanalysis temperatures compared to LIC and ICE temperature reference points".

Figures:

General: You often provide the same information twice in the figure captions and in the description of figures in the text. Please give the technical description of the figure in the caption and provide explanations and description of the scientific results in the text, e.g., Fig. 13.

Fig. 5: The latitudinal structure from 60S/N to 90S/N is rather uniform for the median and the standard deviation. A structure in temperature differences is mainly visible in the vertical domain. Averaging over 60S-90S and 60N-90N would give a condensed overview. Median and standard deviation profile could be shown in one panel. Fig. 5 could be condensed in 2 rows for the Arctic and Antarctic. In Figure 6 the information on latitudinal differences and vertical differences is given again, anyway.

Fig. 6: The vertical boxes should also be centered around a zero line as done for the latitudes.

Fig. 9: Please condense information. Fig.9a is the same Figure as already shown in Fig. 8. Fig.9b does not really give much information, it can be stated in the text. Please check whether this figure is really needed or the information could be stated in the text.

Fig. 11: What is the reason for showing the information twice? Why do you show inverse temperature? It is distracting to the reader unless there is a specific reason for it. I suggest plotting a logarithmic y-axis, using temperature for the x-axis, and showing only 2 plots in Fig. 11.

Fig. 12: Suggest having a similar design as for Fig. 11, i.e., plotting the temperature axis from 175 K to 200 K and removing the inverse temperature x-axis.

Fig. 18 and 19: The standard deviations (Fig. 18.d-f) could be easily plotted in Fig. 18 a-c by extending the x-axis to -3K to 3K. The same could be done for Fig. 19. Fig. 18 and 19 could then be merged to one Fig. showing SH in the upper panels and NH in the lower panels. So the reader would be provided with compact information.

Fig. 14 and 15:

Please compile the information printed in the different panels in a Table. Fig. 14 and 15 could be removed and information of section 4.8.1 could be streamlined. The description at page 16, line 10 to 18, could be removed and the main information stated in one sentence.

Minor comments:

The title is very long and contains 5 acronyms. It should be shortened. I think it is not necessary to list all the sensors explicitly in the title, could be replaced by "satellite observations". Also the term "supercooled ternary solutions" might not be a familiar term for many readers. Maybe use "polar stratospheric cloud types or polar stratospheric cloud regimes" instead.

Reanalysis: More than one reanalysis is evaluated, rather use "reanalyses" in the title.

Page 2, line 19: "significant low bias in MLS temperature of up to 3 K" ? Do you mean "large bias"?

Page 2, line 31: What does "(one-off research satellites)" mean, check singular/plural.

Page 2, line 32: What is "temperatures measured with the Geophysica": Please be explicit. What is the Geophysica, how were the temperatures measured, state the instrument?

Page 6, line 26: "-2-0 K" change to "-2 K to 0 K"

Page 7, line13: "requires a number of assumptions because of the long ray path through a non-uniform atmosphere. Therefore, corrections are required for ionospheric effects, variations in water

vapor, and gradients in in temperature along the ray path.”
This statement is not fully correct. Please reformulate/clarify.

Initialization (of bending angles) at high altitudes is performed where the signal to noise ratio of the measurement becomes low. An ionospheric correction is applied through differencing of the two GPS frequencies to remove the ionospheric contribution to the measurement and to gain information on the neutral atmosphere only. Refractivity then includes information on the dry and moist part of the atmosphere (see Smith and Weintraub formula, as you explain on the next page). In a dry atmosphere, temperature can be retrieved without any further correction or initialization. In a moist atmosphere, i.e., in the mid- to lower troposphere, additional background information is needed to separate temperature and humidity information (usually through a 1DVar retrieval).

However, as you investigate temperatures at high latitudes in the stratosphere, you can use dry temperatures only. The discussion on wetPrf temperatures can be removed as they are not used.

Page 7: line 34: Remove “similar results were obtained over data sparse (Pacific) and data dense (USA) regions”. This is distracting as one might think it is RO data sparse and dense regions (but RO has almost equal distribution globally) but actually it relates to observations assimilated into ECMWF.

Page 8, line 21,22: insert “about” before “14 km” and before “9 km”.

Page 9, line 20: Why a pressure range of 68 to 21 hPa and not 70 to 20 hPa.

Page 10, Eq.3: correct to “J kg⁻¹” and through paper text.

Page 11: “A decrease in the spread of the temperature differences of reanalysis data compared to COSMIC should be detectable by rejecting the temperature profiles from consideration that are expected to have lower fidelity to the true atmosphere.”

What is meant by fidelity to the true atmosphere? The truth is actually not known.

Rejecting observational profiles with higher variance will of course improve the difference between reanalyses and observations if observations show a higher variance than the reanalyses at high latitudes, which is well known for RO. I actually do not understand the purpose of rejecting profiles with higher variance.

Page 12, line 28: What do you mean with “the geophysical structure”? The vertical structure versus the latitudinal structure at high latitudes is shown.

Page 13, line 2: Use clear wording in description of Fig. 6. Rather than saying the “box heights” it is the differences in the vertical between reanalyses and RO.

Page 13, line 22: Why do you show the 46 hPa level?

Page 14, end of section 4.5: Please give percentage of scenes analyzed with respect to available scenes.

Page 17: The last part of section 4.8.2 (page 18, first paragraph) is very hard to read. Please reformulate and streamline info.

Page 44, Fig. 16, caption: Correct to: “Median (diamonds) and mean (triangles)...”

Section titles: Please remove Tre-Tro, Tre-Teq, and similar in section titles.