Response to Referee #2

Manuscript Number: amt-2010-203
Manuscript Title: An assessment of differences in lower stratospheric temperature records from (A)MSU, radiosondes, and GPS radio occultation
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We thank the Referee for the detailed review and the important topics addressed. We have carefully considered the suggestions and will revise the manuscript accordingly.

P2132, line 10 *"'The bulk temperature of the TLS . . . These two channels closely match each other purposely, to ensure . . . '*
Here the authors imply AMSU ch9 weighting function is very close to MSU ch4 weighting function (e.g., AMSU TLS is equivalent to MSU TLS). This is simply not true. Accordingly to Mears, et al., (2008, Jtech), AMSU ch9 weighting function has a very complex relation relative to that of MSU ch4, and it will need to take lots of effort to "merge" MSU data (before 2004) and AMSU data (mainly after 2004) into one consistent dataset."
This similarity of MSU ch4 and AMSU ch9 was stated by Christy et al. (2003, p. 617): "The vertical profile of T4 (MSU4) is very similar to AMSU9, . . . " and was the source of this statement here. After reviewing Mears and Wentz (2009), we agree that this statement needs to be reformulated accordingly. Please see comments below.

P2134, line 7 *"'. . . are based on TLS layer-average brightness temperature (MSU-equivalent)'*
As stated above, since MSU TLS is different form AMSU TLS, please explain why MSU-equivalent TLS is used here (why don't use AMSU- equivalent TLS where AMSU data are dominated after 2004 ?)"
As stated in Mears and Wentz (2009, p. 1052), the differences of MSU and AMSU are accounted for in their merging procedure so that the time series matches the MSU data. They write:

"Because of the difference between the MSU and AMSU weighting functions for corresponding channels, there are small differences between the measured antenna temperatures that depend on the local atmospheric profile and surface temperature. We remove these differences on average by calculating the mean difference between MSU and AMSU measurements as a function of earth location and time of year. We then subtract the difference from the adjusted gridded monthly AMSU averages so that they match the corresponding MSU-only data."

The homogenization procedures of the different (A)MSU working groups attempt to correct for biases and errors in the time series of MSU-AMSU instruments to ensure a time-continuous dataset. Therefore we use MSU-equivalent TLS temperatures in this study.

P2134, line 12 *"'We use RTTOV ... to compute layer-average TLS from RO and the collocated ECMWF temperature profiles'*
Although it is not mentioned explicitly here, I assume a similar approach is also applied to RAOBCORE data to define TAOBCORE TLS (as shown in Figures 6, 7 ...). Please clarify that if a similar approach is also applied to RAOBCORE data? Since the vertical resolution between RAOBCORE and RO and ECMWF are very different, it would be good to know what are the vertical resolution of RO, ECMWF and RAOBCORE profiles and how will that affect the TLS estimates using RTTOV? Are RAOBCORE profiles on standard vertical levels only (200 hPa, 100 hPa, 50 hPa etc)? Does RAOBCORE have high enough vertical resolution to compute equivalent TLS like RO and ECMWF? Are RAOBCORE and RO and ECMWF TLS differences due to vertical resolution mismatch negligible? If they are not negligible, how do you justify the rest of the sample error estimates when there is still TLS vertical sample mismatch (between ECMWF and RAOBCORE, and between ECMWF and RO, and between RAOBCORE vertical sampling errors and RO vertical sampling errors)? These further descriptions are necessary to provide sufficiently complete and precise information to allow their reproduction by fellow scientists (traceability of results)."
Thanks for raising this important point. In the original manuscript weighting functions have been used to calculate TLS equivalents from RICH/RAOBCORE, as used in several recent radiosonde data intercomparison papers (e.g., Haimberger, Tavolato and Sperka 2008). In the revised paper we compute RICH/RAOBCORE TLS MSU-equivalents using RTTOV. Thus the computational procedure is now consistent between RO and radiosondes.

Additionally, the vertical resolution is increased by adding more pressure levels for radiosonde data. The vertical levels used for the original weighting function approach were 30/50/100/150/200/250/300 hPa. With RTTOV we use all available layers between 30 hPa and 850 hPa (850 hPa, 700 hPa, 500 hPa, 400 hPa, 300 hPa, 250 hPa, 200 hPa, 150 hPa, 100 hPa, 70 hPa, 50 hPa, 30 hPa), specifically we also included the 70 hPa layer. Using RTTOV instead of weighting functions and, specifically, adding information at the 70 hPa layer have small but noticeable effects on both anomaly time series and trends from RICH/RAOBCORE. While the vertical resolution in radiosonde data is still lower than that achievable with RO or ECMWF model level data, it is the best achievable resolution from radiosonde standard pressure level data.

This is especially important in the tropics where the main contribution to the TLS stems from around the tropopause.

With the improved processing of radiosonde data the TLS differences between radiosondes and RO generally appear further reduced.

Page 2135, line 15 *"'We do not consider sampling error for (A)MSU because we can assume that the error reaches virtually zero due to high horizontal resolution of the dataset.'*
Is this also a true assumption for temporal coverage ? It is mentioned in the introduction section that 'Further errors affecting (A)MSU data including shift in the diurnal vari-

ation' etc. Are you assuming RSS, UAH, and STAR data have no 'temporal' sampling errors ? Are there any references to support this assumption ?"
It is true that temporal sampling is also somewhat a problem for (A)MSU homogenization. We will therefore add references to detailed descriptions of how diurnal drifts etc. are adjusted (Christy, Spencer and Lobl 1998; Mears and Wentz 2009).

Page 2136, section 3.3 *"The manuscript describes the TLS anomaly values as being obtained by first removing the seasonal climatology for 2002–2009 and then removing the sampling errors. In this way seasonal variations in the sampling errors (e.g. Figure 5) re-introduce seasonal variability into the de-seasonalized data. For anomaly comparisons, the sampling errors should be removed first before the 2002–2009 seasonal climatology is calculated and removed. Please revise all related plots."*
Sorry that we left room for misunderstanding here, it is the de-seasonalized sampling error that is subtracted from the data. To clearly state this in the manuscript now, the sentence on Page 2136, line 19, will be amended to: "… subtracting the respective de-seasonalized sampling error from … "

Page 2137, line 4–5 *"'In Fig. 5 the resulting sampling error for radiosondes and RO is shown for 20 zonal bands from 90 S to 90 N'*
Shall it be from 70 S to 70 N?"
Figure 5 shows indeed the range 90 S to 90 N, which is not fully consistent with the study range of interest (also a comment of Referee #1 referred to this). Thus we will change the range in this figure to 70 S to 70 N.

"The RO sampling changed in 2006 with the advent of COSMIC. Why is there no indication of a corresponding change in the magnitude of the sampling error (Figure 5 bottom)?"
For the considered monthly-means zonal-means, the fairly homogeneous distribution of CHAMP RO events is already capturing most of the atmospheric variability. Additional occultation events generally occur close to existing ones, thus not substantially improving the sampling situation. To provide a remark on this and suitable references, and since other readers may ask themselves the same question, we will include two sentences after line 8 as follows:
"The additional COSMIC multi-satellite data in 2006 provide only moderate reduction of the RO sampling error. For the monthly and zonal means considered in this study, the essential atmospheric variability is already captured by one single satellite (Foelsche et al. 2008, 2009; Pirscher et al. 2007)."

Page 2137, line 21 *"'Temporal sampling of radiosondes (00:00 UTC and 12:00 UTC) seems to be sufficient to capture the diurnal cycle'*
The manuscript cannot claim to capture the diurnal cycle based on the sentences that follow."
We agree that we only checked capturing of the diurnal variation up to the semi-diurnal

cycle (as more cannot be done with four time layers). The sentence will thus be reformulated to "... to basically capture the diurnal variation up to the semi-diurnal cycle."

Page 2140, line 2 *"'Comparing the RO reference climatology with radiosondes, we showed the importance of taking into account these error characteristics also for radiosondes'*
The manuscript refers to "climatology" when it should refer to "anomaly". All references to climatology in the manuscript should imply the mean seasonal variations over the 2002–2009 time period. All references to anomalies should imply the monthly mean values which have had their climatology removed."
This inaccuracy in terminology will be resolved according to the suggestion of the Referee.

Page 2140, line 10 *"'We conclude that this results from the radiosonde network missing the atmospheric variability over the oceans, particularly in NH winter'*
This conclusion should be supported by partitioning the data according to land/ocean"
Thanks for this important point. Partitioning the data in land/sea shows the surprising result that the limited radiosonde coverage of land regions already leads to the large NH winter sampling error. That is, considering only land masses for the radiosonde sampling error, the sampling error in the NH remains largely unaffected. To illustrate this for the reviewers convenience, we add Figure 1 showing the changes in sampling error (left) for one particular month (January 2007). As can be seen in Figure 1 (right), the statement holds that the radiosonde station network misses the atmospheric variability, but it does so even if looking at land masses only.

We will update the respective statements in the manuscript accordingly.

Page 2140, line 28 *"'We suppose that the time range in Steiner et al. (2007) was still too short to detect significant trends in all latitude ranges.'*
This supposition could readily be supported by applying the methodology of this manuscript to the shorter time period 2001–2006."
We will change this sentence to the following, more appropriate one: "The difference trend values are smaller compared to Steiner et al. (2009), using the most recent versions of RO and (A)MSU data. The overall conclusion in Steiner et al. (2009) that multiple independent datasets are needed for detecting weaknesses in climate records remains valid."

Page 2141, line 4 *"'This indicates that a better vertical resolution (than provided by layer-average TLS of the (A)MSU instrument) is of advantage'*
The purpose of applying of the RTTOV forward model to RO profiles is so that TLS temperatures with the same vertical resolution can be compared to each other. This conclusion should be removed."
We agree that "This indicates that ..." is not a good way to express this statement.

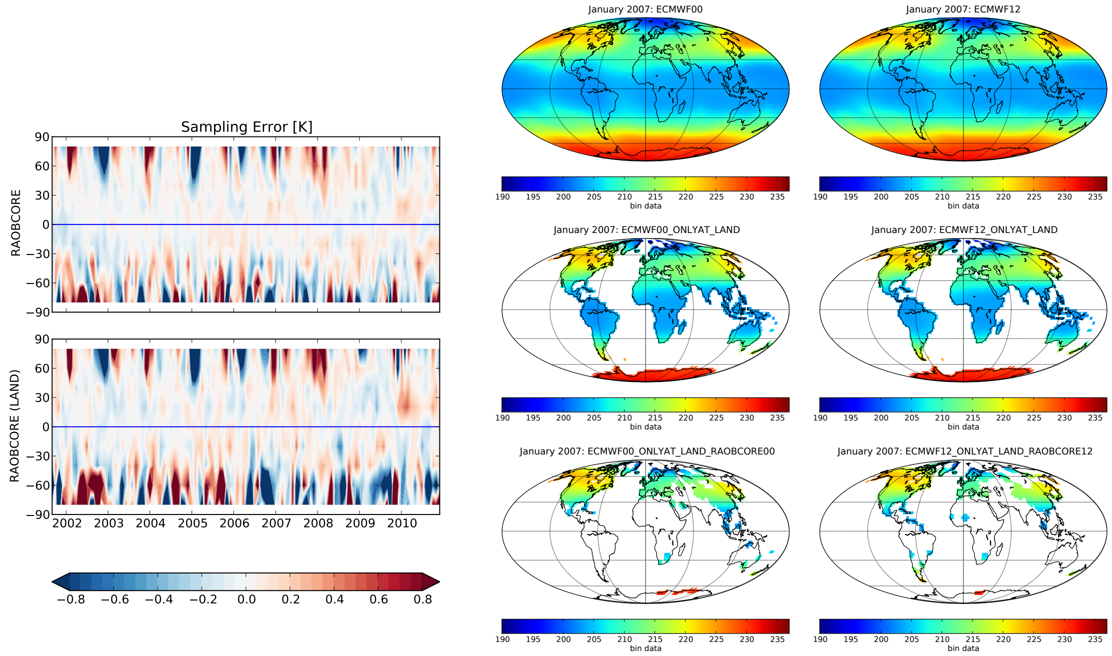

Figure 1: Left: Radiosonde sampling error, (Top) Considering whole field (Bottom) Only land; Right: (Top) Whole ECMWF temperature field in 2.5x2.5 degrees resolution for 00 UTC and 12 UTC (Center) Same, but only land masses (Bottom) Same, but only landmasses at radiosonde stations.

The sentence, and its follow-on sentence, will thus be reformulated to: “The good vertical resolution of the RO and radiosonde data (compared to the layer-average TLS of the (A)MSU instrument) will be of advantage to further analyze and understand the differences. We expect the remaining differences to be easiest to explain . . . ”

Page 2133, section 2.4 *“Exactly what ECMWF data is being used? Will the sampling error estimates change if some other dataset is used as a reference? What is the uncertainty introduce by this method ?”*
We use the ECMWF operational analysis fields at resolution T42 (comparable to the horizontal resolution of RO) for all available model levels for the RO sampling error estimate. For radiosondes, we use gridded ECMWF operational analysis fields at 2.5x2.5 degrees resolution on 25 pressure levels (from 1 hPa to 1000 hPa). The vertical resolution was increased in 2007, but additional levels after 2007 were introduced only below 500 hPa, which has no effect on the TLS temperature.

Scherllin-Pirscher et al. (2011) performed a detailed analysis of errors in RO climatologies. They estimated a residual sampling error (the error left after subtracting the ECMWF-estimated sampling error) of less than 30 % of the original one. In another recent study (unpublished, currently written up for submission) ERA-Interim data were used for the sampling error estimation, confirming these results.

Page 2133, Section 3.1 *"GPSRO, radiosonde, and ECMWF all have different vertical resolutions. The manuscript should clarify how RTTOV is applied consistently to each"* See above for the vertical resolution of the various datasets. RTTOV uses internally 43 levels, and input profiles are interpolated to these levels. When extending outside the input level range, the input profile is extrapolated at constant value. This information will be added to the "Method" section (section 3) of the manuscript.

Page 2157, Figure 9 *"Find a way to get the labels "XXX-RO" lined up for clarity."* We intend to improve the labels for the revised manuscript, if feasible.

References

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Scherllin-Pirscher, B., A. Steiner, G. Kirchengast, Y.-H. Kuo and U. Foelsche (2011). 'Empirical analysis and modeling of errors of atmospheric profiles from GPS radio occultation'. In: *Atmos. Meas. Tech. Discuss.* 4, pp. 2599–2633. DOI: 10.5194/amtd-4-2599-2011 (cit. on p. 5).

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