An Examination of Spatial and Temporal Variability in Temperature data from COSMIC/FORMOSAT-3 and Rayleigh Lidar

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Abstract
This paper details an initial study which utilises COSMIC satellite observations to examine the spatial and temporal variability of temperature observations in the stratosphere at the scale of the Northern and Southern hemispheres. This study uses Rayleigh measurements from a ground-based Fe Boltzmann temperature lidar, which was located at Rothera station in the Antarctic, to examine temporal variability.

This work focuses on short-term temporal scales (less than an hour) and small-scale horizontal separations (less than 1 km). For the COSMIC observations this requires identifying the spatial separation and the time difference between pairs of profiles measured by any of the six COSMIC satellites and then using that information to select paired observations that are within some coincidence criteria in space and time. The fundamental aim of this work is to gain an understanding of how long and over what range a measurement made in the stratosphere remains ‘representative’. However, the scales of spatial and temporal variability examined are such that the dominant variability seems to be associated with internal gravity waves in some cases. In particular, large RMS temperature differences are observed in regions related to previously identified regions of enhanced gravity wave activity at high altitudes. The change in the RMS temperature difference with altitude between observations as segregated into horizontal separation ranges also suggests the possibility of using this technique to identify variations in the characteristics of the wave field.

1: Introduction
A number of studies have examined the spatial and temporal variability of temperature. For example, work by Krichen (1999) and Sofieva et al. (2008) have examined statistics for pairs of radarsonde observations with small horizontal separations (less than 500 km) and within a few hours of each other. In this study, we use a methodology similar to that used in Krichen (2008) to examine the RMS temperature differences between COSMIC profiles separated by small horizontal distances which are observed within a few hours of each other. The work in Krichen (2008) and Sofieva et al. (2007) have examined COSMIC data in this way to determine information about the precision of the COSMIC system. Given that much of the small-scale variability in the stratosphere is related to internal gravity waves, we examine variations between pairs of profiles to examine whether they may provide information on characteristics of the wave fields. It should be noted that recent work described in Hocking et al. (2009) has also examined multiple coarsely spaced COSMIC temperature profiles to examine gravity waves.

In this study we use COSMIC data from January and July 2007 and changes to the orbits of the various satellites in the COSMIC constellation during the period mean that far fewer pairs of profiles were found in January than in July. In addition, we also use Rayleigh lidar observations to examine differences associated with different instruments and also provide details about the change in the RMS temperature difference associated with temporal variations.

2: Location and magnitude of temperature differences between paired COSMIC profiles
Figure 1 shows the distribution of paired COSMIC profiles in January 2007 with spatial and temporal separations less than 500 km and 1 hour, respectively. The temperature difference at 25 km altitude between pairs is defined as the colour of the dot. Examination of Figure 3 shows that the distribution is centred around mid-latitudes and there is a distinct hemispheric difference in temperature differences.

3: Spatial separation versus RMS temperature difference: January and July 2007
Figure 2 shows the spatial separation versus RMS temperature difference (T_RMS) derived from pairs of COSMIC data from January 2007 averaged over the Northern (blue lines) and Southern hemispheres (red lines). A linear trend is also removed to reduce large-scale background changes. Examination suggests that in both hemispheres the T_RMS increases almost linearly with horizontal separation at all altitudes. The rate of increase in T_RMS varies as a function of altitude. In the Northern hemisphere the increase in the gradient is strongest in the lower Northern hemisphere. At small separations (less than 1 km) T_RMS increases with altitude in both hemispheres. However, at large separations (greater than 500 km) the values of T_RMS remain nearly constant or grow slowly with altitude in the Northern hemisphere, but reduce with increasing altitude in the Southern hemisphere.

4: Variation of RMS temperature difference as a function of altitude
The variation of T_RMS with altitude in the Northern (a) and Southern hemisphere (b) measurements. The enhancement between 15 and 20 km is likely to be due to the strong latitudinal temperature gradients associated with the tropopause. The difference between the various spatial separations as a function of altitude also includes information about gravity waves. In particular, the values of T_RMS for different horizontal separations get closer together as altitude increases in the Northern hemisphere. Examination of the T_RMS characteristics in the Southern hemisphere suggest that the values vary more rapidly with altitude, with an increase in T_RMS at all altitudes at large separations.

5: Geographic variation of the RMS temperature difference: July 2007
Figure 5 shows the geographic variation of the T_RMS derived from pairs of COSMIC data for July 2007 at an altitude of 15 km. Note that T_RMS is calculated in 10 degree latitude and 3 degree longitude bins and values are only plotted in bins which contain more than 100 pairs. High values of T_RMS are observed towards the equator, these seem likely to be related to the large large-scale background gradients in these regions associated with the change in the tropopause level.

6: Time difference versus RMS temperature difference
Figure 7 shows the time difference versus T_RMS derived from a ground-based Fe Boltzmann temperature lidar at 38-40 km, which was located at Rothera station in the Antarctic. Results are presented in Figure 5, but in this case we ignore effects associated with spatial separation in this data since all measurements are co-located. Examination suggests a steady increase in T_RMS until time separations of approximately 5 hours and an asymptotic variation after 5 hours. This suggests that comparisons between COSMIC and lidar data, at large values of T_RMS are promising. It is interesting to note that the relatively large value of T_RMS at small time differences could be associated with instrumental affects or could be related to the position of the instrument near the Antarctic peninsula, a known gravity wave hotspot (see Figure 5).

7: Conclusions
Examination of the T_RMS between pairs of COSMIC observations separated by small horizontal distances (less than 1000 km) and short time differences (less than a few hours) suggests clear seasonal patterns and variations as a function of altitude. Some of these variations in T_RMS can be related to changes in the background temperature field, while others seem to be related to the position of the wave field. For example, the strong change in the gradients shown in Figure 3 in the Northern hemisphere summer could be related to variations in the make-up of the wave field associated with variations in the background wind or changes in the visibility of the waves. The much smaller changes observed in the Southern hemisphere patterns as a function of altitude are also suggestive of this possibility. The geographic variation observed in Figure 6 also suggests that the T_RMS metric is clearest in the Northern hemisphere, and that the variations in Figures 2, 3 and 7 suggest that studies which compare temperature observations from different instruments may need to use very closely spaced observations in space and time in order to examine instrumental variations rather than geophysical variations.

References
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Figure 1: Location of paired COSMIC observations in January 2007 and the absolute value of the temperature difference (K) between observations at 25 km.

Figure 2: Spatial separation versus RMS temperature difference between pairs of COSMIC profiles for January 2007 at an altitude of 30 km for separations less than 500 km. In this case, high values of T_RMS are not symmetric around the equator and large values of T_RMS are present towards the Southern hemisphere high latitudes. These variations could be associated with the background temperature field, but given the scales examined and the enhancement near the Antarctic peninsula, a known gravity wave hotspot, it seems likely that these variations may be related to the gravity wave field. These variations are also observed in regions of high wind speeds and thus may be associated with Doppler shifting of waves to vertical wavelengths observable by the instrument (Alexander, 1999).

Figure 3: The variation of T_RMS with altitude for different horizontal separations as a function of altitude also includes information about gravity waves. In particular, the values of T_RMS for different horizontal separations get closer together as altitude increases in the Northern hemisphere. Examination of the T_RMS characteristics in the Southern hemisphere suggest that the values vary more rapidly with altitude, with an increase in T_RMS at all altitudes at large separations.

Figure 4: T_RMS between pairs of COSMIC profiles separated by the distances identified in the legend as a function of altitude for the Northern (a) and Southern hemisphere (b).

Figure 5: RMS temperature difference at 15 km between pairs of COSMIC profiles less than 500 km and 1 hour apart as a function of geographic position.

Figure 6: As Figure 5, but for 30 km altitude.

Figure 7: Temporal separation versus RMS temperature difference between Rayleigh lidar derived temperature variations.