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Differences in near-mesopause summer winds, temperatures, and water vapor at northern and southern latitudes as possible causal factors for inter-hemispheric PMSE differences

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Abstract. We report the results of a recent study to examine possible causal factors that could explain the observed differences in PMSE intensity in the northern and southern hemispheres. A variety of satellite data, models and ground-based radar observations in the two hemispheres during local summer have been examined in this attempt. We will show results of inter-hemispheric comparisons of temperatures, winds, and water vapor. The primary conclusions that can be drawn from these studies are that, while water vapor differences in the two hemispheres are difficult to interpret at near-mesopause altitudes, the inter-hemispheric temperature comparisons show clearly that the southern hemispheric mesopause is indeed a few degrees warmer. Moreover, southern summer mesospheric mean winds are considerably weaker than they are in the north. These results provide support for earlier speculations that were made to explain the observed inter-hemispheric difference in PMSE occurrence.

Introduction

Observations of PMSE (Polar Mesosphere Summer Echoes) at high northern and southern latitudes show a significant difference in PMSE occurrence and intensity [Balsley et al., 1993; Balsley et al. 1995; Woodman et al., 1996; 1999]. Relative to the echoes seen in the northern hemisphere at Poker Flat (65°N), much weaker PMSE have been recorded over the past five years using the VHF radar at the Peruvian base "Machu Picchu" located on King George Island in Antarctica at 62°S. The southern-hemispheric PMSE are more sporadic and are at least 34 dB to 44 dB weaker than their northern-hemispheric counterparts [Balsley et al., 1995; Woodman et al., 1996].

One reason proposed for the weaker and more sporadic PMSE returns in the southern hemisphere is that the summer upper mesospheric temperatures in that hemisphere are somewhat warmer [Balsley et al., 1995; Hall, 1995; Woodman et al., 1999]. Verification of this idea is difficult, since, until recently, only a few studies of high-latitude summertime upper mesospheric temperatures in the two hemispheres have been published [Labitzke and Barnett, 1981; Barnett and Corney, 1985; Thomas, 1995].

Another proposed cause for the inter-hemispheric differences of PMSE lies in possible differences of water vapor content in the two high-latitude polar summer mesospheres. Balsley and Huaman [1997] showed the lack of a one-to-one seasonal correspondence between low mean mesopause temperature and PMSE occurrence. They concluded that PMSE occurrence must be governed by more than just low mesospheric temperatures. According to Balsley and Huaman [1997], the most likely possibility for the observed ~2 week delay in the seasonal occurrence of PMSE relative to the observed temperature decrease is that summertime mesospheric water vapor maximizes somewhat later than the minimum in mesospheric temperature [Garcia,1989]. The presence of enhanced water vapor later in the season could provide a more hospitable environment for PMSE generation and could thereby account for the observed delay.

Finally, since we know that gravity waves play a fundamental role in driving the circulation and thereby in determining the thermal state of the middle atmosphere, an improved understanding of upper mesospheric winds would be particularly important in studying the causal factors governing PMSE generation. Specifically, reduced gravity wave activity in the southern hemisphere measured by Vincent [1994] using Mawson MF radar data (67°36'S) suggests that reduced PMSE occurrence may also somehow be related to reduced gravity wave activity and the resulting reduced mesospheric circulation. Vincent [1994] also showed preliminary results of a much weaker mean meridional velocity in the southern hemisphere.

In this paper we will document differences in temperature, water vapor and winds between the two hemispheres to gain an insight into the relationship between one or more of the quantities and their relationship to inter-hemispheric differences in PMSE activity.

Data Presentation

Mesospheric temperatures

Six different temperature data bases (four from satellites and two from models) are used to study the high-latitude upper mesospheric inter-hemispheric temperature differences: SME (Solar Mesosphere Explorer), PMR (Pressure Modulator Radiometer), HALOE (Halogen Occultation Experiment), HRDI (High Resolution Doppler Imager), MSISE-90 (extension of the Mass-Spectrometer-Incoherent-Scatter) and CIRA86 (COSPAR International Reference Atmosphere 1986).

The HRDI data base gives us the most reliable information of all the different data bases because of its remarkably good quality, continuity, and length of coverage. The other data bases either do not have quality information, extensive data bases, or are the result of a combination of measurements with models. Never-the-less we consider all of the data bases in order to demonstrate the consistency of these independent measurements of inter-hemispheric mesopause temperature difference during the local summer. We

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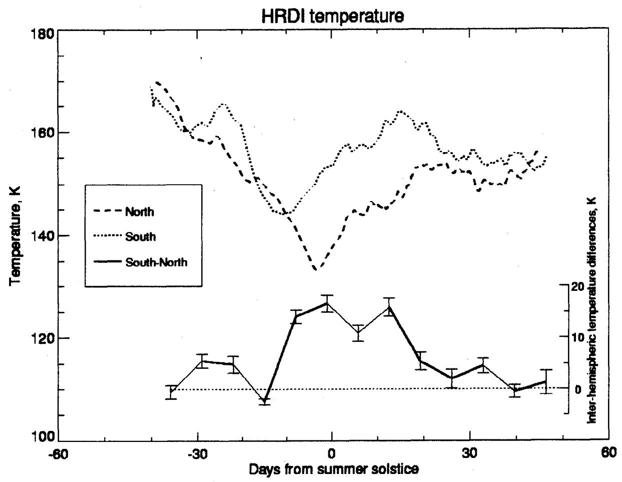

Figure 1. Weekly running-averaged HRDI temperature curves centered at 84 ± 1.5 km for the northern (dashed line) and southern (dotted line) hemispheres at 64° latitude. We also show the weekly-averaged values of the inter-hemispheric temperature differences as a solid line. Vertical bars represent standard deviations of the weekly-averaged data. The result shows a predominant warmer southern hemisphere around the summer solstice.

define the summer season as extending from May until August in the northern hemisphere and from November until February in the southern hemisphere, and centered on the solstice.

The HRDI data base provides us with continuous temperature information for the mesosphere from December 1991 to December 1998. It is important to note that the precession of the UARS satellite assures that the data are representative of all longitudes and all local times. We present first in Figure 1 the clearest piece of evidence for a significant difference in summer mesopause temperatures at high latitudes obtained from the HRDI data base. The upper set of curves in Figure 1 depict the weekly running-averaged HRDI temperatures centered at 84 ± 1.5 km and at 64° ± 2° latitude in both northern and southern hemispheres. Northern hemisphere measurements (dashed curve) refer to 15 May - 10 August, 1994, while the southern hemisphere results (dotted curve) extend from 15 November until 10 February, 1994. Only data having a "quality factor" of 98% (uncontaminated) have been included. Note that this factor does not refer to the accuracy of the data, but rather to the amount of external contamination. The stated accuracy of the individual data points appears to be of the order of ± 7 K [DAAC documentation on the web], a value that includes both statistical errors and possible undetermined biases.

Examination of the upper two curves in Figure 1 shows a clear temperature difference between summer mesopause temperatures in the two hemispheres, with the southern temperatures appearing to be at least a few K warmer during most of the summer season. However, in view of the fact that the stated measurement errors are of the same order of these apparent differences, it is important to establish reasonable estimates of the accuracy of the computed differences. Such estimates are included in the bottom curve of Figure 1, which shows weekly-averaged values of the inter-hemispheric temperature difference (southern hemisphere minus northern hemisphere). The vertical bars centered on each weekly value of temperature difference have been calculated using the independent temperature values available for that week modified by adding a ± 7 K random error to each value to account for the statistical errors inherent in the measurements. Individual northern hemisphere values are then subtracted from corresponding southern hemisphere values, and then the weekly averages are computed, along with the standard deviation of the individual points that compromise each average. These average values are then plotted as points in the bottom curve of Figure 1, with the vertical bars representing the standard deviation of each mean divided by the square root of the number of samples included in the mean computation. The magnitude of these bars represents a "worst case" scenario, since the ± 7 K value includes possible biases (offsets) that would be cancelled out in the above subtraction process.

The observed temperature differences are highly significant ranging from close to zero near the beginning and end of the PMSE season, to around 15 K near the solstice. The mean seasonal difference (the average of these values) is close to 6 K.

It is interesting to note, in passing, that an even smoother temperature difference curve could be obtained by shifting the southern hemisphere temperature values later by 1-2 weeks. A similar discrepancy is noted later in this paper, when we discuss mesospheric wind differences in the two hemispheres. Both comparisons are seen to improve with a forward shift of the southern hemispheres temperature values.

Further evidence for a warmer southern mesopause can be demonstrated in similar studies garnered from data obtained from other satellite-and-rocket-determined temperatures, as well as from models using these data and ground based measurements. While these studies do not carry the same overall accuracy as those provided by the HRDI data, they collectively show the same results. Compilation of a variety of temperature difference measurements appears in Figure 2.

The HRDI curve (solid line) shows the daily-averaged temperature differences betweeen latitudes 64-68° in both hemispheres over an altitude range of 84-87 km for the entire seven year period of data available. The HALOE curve (dash-dotted line) was calculated using almost 6 years of data from all latitudes greater than 60°S and 60° N between 85 and 86.5 km. The SME curve (dash-triple-dotted line) corresponds to monthly-averaged temperature differences between 55°S and 55°N at a height of 86.5 km. The PMR curve (dashed line) reflects daily-averaged values and has been calculated using 64°S and 64°N PMR data between 1975 and 1978, at a height of approximately 86 km. The average temperature difference data obtained from the MSISE-90 model (long-

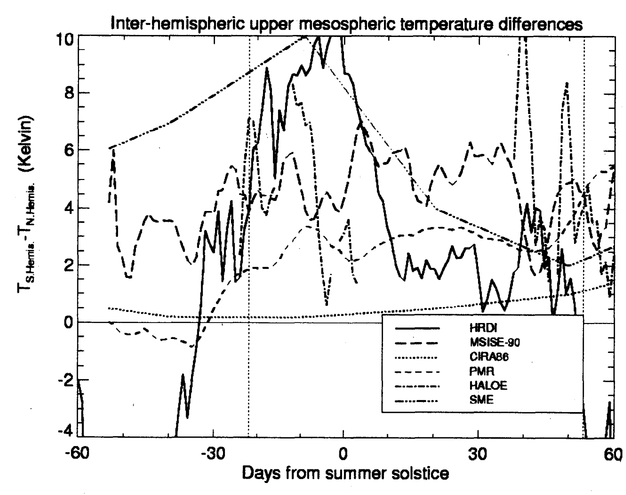

Figure 2. Estimates of inter-hemispheric high-latitude upper mesospheric temperature differences using 6 different data bases. The dotted vertical lines indicate the approximate period of PMSE occurrence at Poker Flat from Balsley and Huaman [1997].

dash line) uses daily data for 64°S and 64°N at 86 km. In order to calculate the temperature values for this case, the time of day was set to be noon and the year chosen to be 1994. Both choices were arbitrary. The CIRA86 curve (dotted line) corresponds to monthly values at 65°S and 65°N at a height of 86.3 km.

In general, the above comparison show a remarkable similarity in the results between all of the data sets, as well as with the HRDI results in Figure 1, namely that southern hemisphere upper mesosphere temperatures are consistently warmer than they are in the northern hemisphere.

Mesospheric water vapor

Our study of the water vapor content of the mesosphere incorporates both HALOE and MLS (Microwave Limb Sounder) data. In the process of this study, we found a major limitation involving the limited coverage of the instruments. Often, during the summer, the satellite was not programmed to measure polar water vapor. Because of this limitation, it was necessary to combine daily averages of water vapor data when summer measurements were available (6 years for HALOE and 2 years for MLS) at latitudes greater than 60°.

With this limitation, the water vapor content of the two polar summer mesospheres from both HALOE and MLS data are presented in Figure 3. In this figure, the average water vapor values for each hemisphere (solid line for south and dashed line for north) are shown for the height range 83-85 km. We also show the inter-hemispheric water vapor difference as a solid-thick line in the same figure.

Obvious discrepancies in the two data sets are apparent during the period when both instruments were providing data, i.e., between 35 and 48 days following summer solstice. This troublesome discrepancy must be due to systematic measurement errors in one or both of the instruments. Systematic errors have been addressed by Harries et al., [1996] and Pumphrey and Harwood [1997] for HALOE and MLS, respectively. Both of these studies question the accuracy of water vapor retrievals in the upper mesosphere. We are therefore limited to examining only relative differences on the same instrument as a function of time, or between hemispheres.

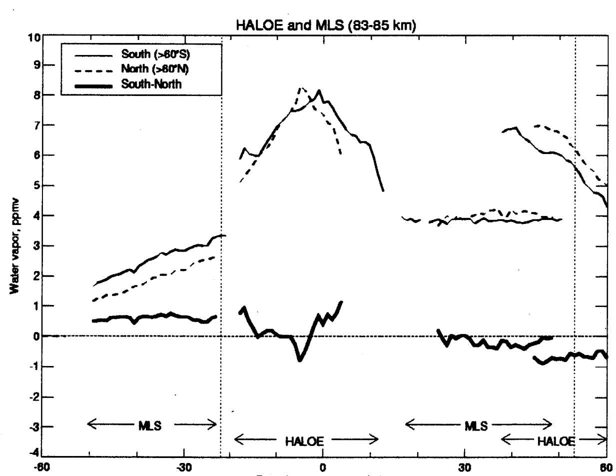

Figure 3. Water vapor content of the polar summer mesosphere using HALOE and MLS data in both hemispheres with the southern hemisphere results shifted by six months. Inter-hemispheric water vapor difference (south minus north) is plotted by the thick-solid line calculated when both south and north water vapor data were available.

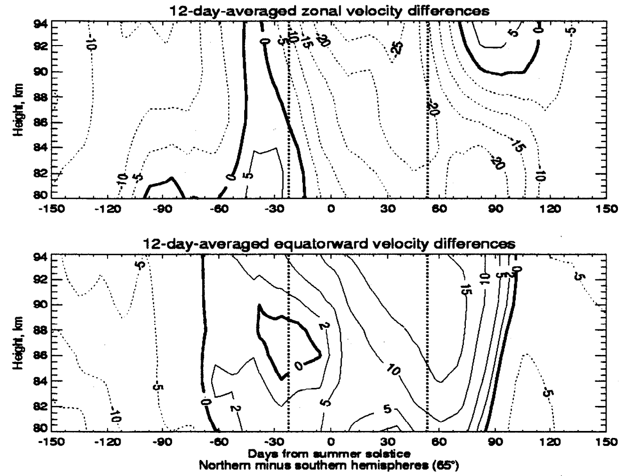

Figure 4. Differences in zonal and equatorward winds between the northern and southern hemispheres at 65°. The horizontal axis corresponds to days from summer solstice in either hemisphere. Negative/positive contours of wind differences in the upper/lower panel indicates that wind magnitudes in the northern hemisphere are larger.

Examination of possible inter-hemispheric differences in water vapor content in figure 3 are inconclusive. What is extractable from these results, however, is that the trend seen by both instruments shows a relative increase of water vapor with time in the high-latitude summer mesosphere. The relative values of mesospheric water vapor are appreciably larger some 20-50 days after solstice than they are for the comparable period before solstice. Model results [Garcia, 1989] show a similar trend.

Mesospheric Winds

This section deals with possible differences in upper-level (horizontal) wind fields in the two hemispheres. This comparison involves a comparative analysis of winds obtained from radar measurements at Poker Flat (65°N) and at Mawson (67°S) and at McMurdo (78°S).

Each of these data sets use at least 2 years of data. Although Poker Flat uses the MST (beam-swinging) technique at VHF to calculate velocities, and McMurdo and Mawson use the space-antenna technique at MF, such differences should not be a problem when comparing observed velocities [Portnyagin et al, 1993]. To make an inter-hemispheric comparison (after, of course, the six-month shift outlined above), it is only necessary to change the sign of the northern-hemispheric meridional winds, since equatorward winds are by convention positive/negative in the southern / northern hemisphere, while zonal winds retain the same sign in both hemispheres. Following this modification, we have subtracted southern hemispheric wind values from those in the north. Thus, a negative difference in zonal velocities implies that the northern hemispheric (easterly) winds are stronger. Similarly, the positive differences in the lower panel imply that the northern equatorward flow is stronger.

The inter-hemispheric difference in zonal and equatorward winds between 80 km and 94 km at 65° (North and South) are shown in Figure 4. Here, we have obtained values of both zonal and equatorward winds at 65°S by extrapolating McMurdo (78°S) and Mawson (67°S) values.

Examination of Figure 4 shows that both the zonal and equatorward summer velocities at near-mesopause levels at 65° are typically much stronger in the northern hemisphere than they are in the southern hemisphere. This is particularly apparent in the zonal winds beginning some 30 days before solstice. It is also equally apparent in the equatorward flow starting about 10 days before solstice. In general, it appears that the magnitudes of the summer northern-hemispheric winds at these levels and latitudes are roughly double those of comparable values on the south. It is worthy of note in passing that these differences become even more consistent over the entire summer season if the southern-hemisphere values are shifted by an additional 2-3 weeks.

Summary and Conclusions

The speculation of a warmer polar summer mesosphere in the southern hemisphere is confirmed by the current studies. Based on the one-year analysis of HRDI data (Figure 1), we find that the mean southern high-latitude upper mesospheric temperatures are approximately 6 K warmer than their northern counterparts. This difference appears to be roughly independent of the data base used, as it was shown in Figure 2.

In view of the close relationship between PMSE and Noctilucent Clouds (NLC) --which are associated with frozen water vapor particles-- it has been assumed that water vapor might also be a strong factor in PMSE occurrence. Assuming that the water vapor comparisons are only sufficient to provide an indication of the trend of water vapor content during the summer, we find that the occurrence of a water vapor maximum coincides with the temperature minimum in both hemispheres. However, we find very little, if any, consistent differences in water vapor in the two hemispheres. If we further assume that the relative water vapor values are hemisphere independent, it also appears that post-solsticial relative water vapor values may be somewhat larger than comparable pre-solsticial values in both hemispheres. This last result is consistent with the speculation [Balsley and Huaman, 1997] that the observed lag in the PMSE occurrence curve relative to the seasonal temperature variation may be due to higher water vapor values toward the end of local summer.

In addition to the significant temperature differences, we also find that, mesospheric winds are generally weaker in the southern hemisphere by at least 50% relative to the northern hemisphere, corroborating the preliminary results by Vincent [1994] and speculations by Balsley et al. [1995]. Further examination of the contour plots of seasonal wind patterns also suggests that the winds may tend to change direction earlier in the season in the southern hemisphere. Although not shown here, it is important to mention that we have found that the wind reversal appears to occur some 2-3 weeks earlier in the southern hemisphere. A similar result can be seen in the temperature data. We have not been able to find an explanation for this behavior at this point.

We conclude that both warmer temperatures and weaker winds may play an important role in the occurrence of weaker and more sporadic PMSE observed near the southern hemisphere high-latitude mesopause relative to their northern counterparts.

A few possible problems and limitations should be mentioned relative to our observations and conclusions: One problem lies in the fact that the measurements in the two hemispheres are not concurrent but separated by 6 months. A second possible problem lies with inter-hemispheric wind comparisons, since the northern and southern hemispheric radars operated at different frequencies (VHF in the north and MF in the south). In addition, although we have tried to account for possible latitude trends in wind magnitudes, the latitude of the radar sites were also somewhat different in the two hemispheres.

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