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Midlatitude Mesospheric Temperature Anomalies During Major SSW Events as Observed with Rayleigh-Scatter Lidar

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Introduction

Sudden Stratospheric Warmings (SSWs) are major disturbances in the polar region of the winter hemisphere that cause major changes in stratospheric temperature and circulation. SSWs are characterized by a temperature increase of tens of degrees Kelvin, averaged over 60°-90° latitude, and a weakening of the polar vortex that persists for the order of a week at the 10 hPa level (roughly 32 km) [*Labitzke and Naujokat*, 2000]. The polar vortices are cyclones centered on both of the Earth's poles that are present throughout the stratosphere. Strong eastward zonal winds define the polar vortices in the winter. Increased planetary wave (PW) activity in the winter hemisphere leads to increased PW breaking in the polar stratosphere and the deposition of the PW's westward momentum in the polar vortex. This weakens the polar vortex, and in the case of major SSWs, can reverse the zonal wind direction to westward. The reversal of the stratospheric jet allows more eastward propagating gravity waves (GWs) to travel up into the mesosphere where, in normal winter conditions, westward propagating GWs dominate. The atypical wintertime GW filtering and the resulting dominating westward GWs induce an equatorward circulation in the mesosphere, similar to what it is in summer, which leads to the cooling of the upper mesosphere. While these mesospheric coolings have been observed in the polar regions for several decades [*Labitzke*, 1972], they have only recently been observed at mid-latitudes [*Yuan et al.*, 2012].

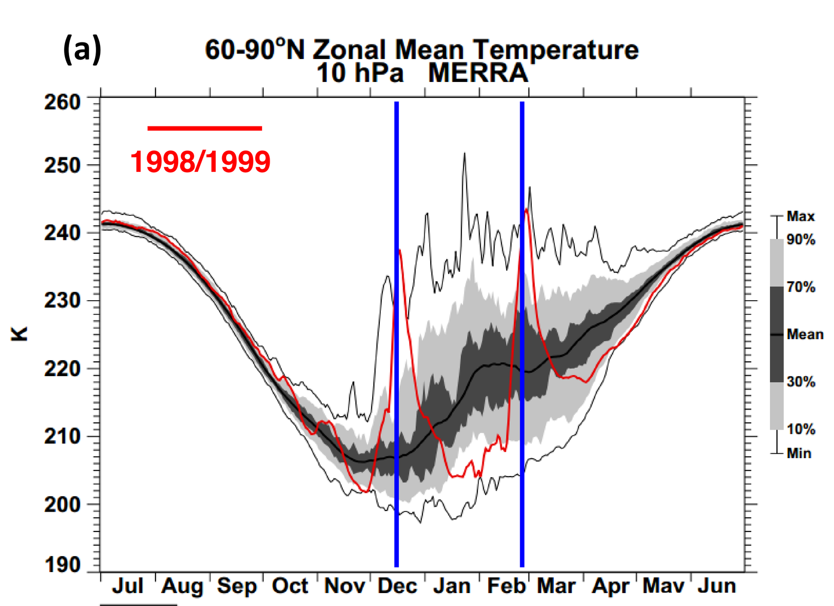
SSWs and USU Rayleigh Lidar Temperatures from 1993-2004

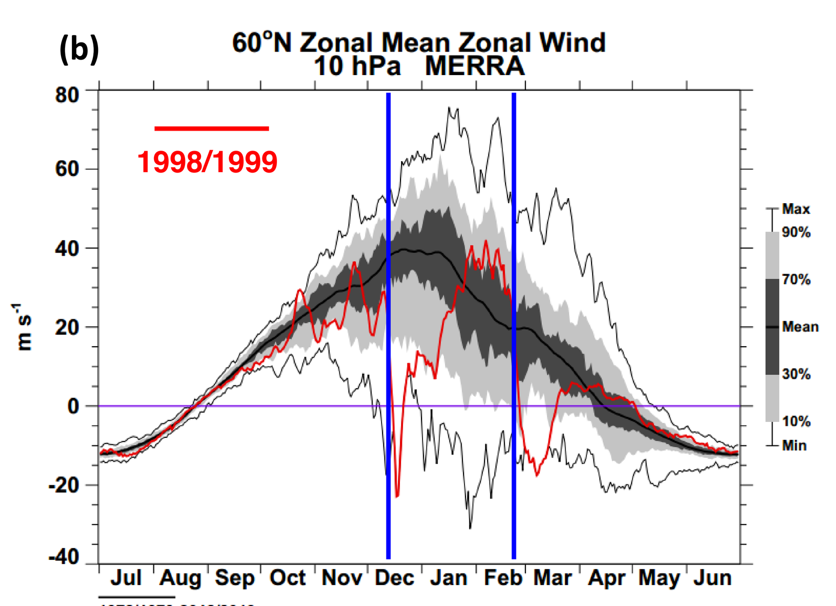
In this initial study of the mesosphere's response to SSWs above Logan, UT, we will focus on periods when there were major SSW events during the Utah State University Rayleigh-Scatter Lidar's (RSL's) original operational run from 1993 to 2004 [Table 1]. A major SSW is characterized by both a stratospheric temperature increase averaged over the latitudes 60° and poleward at 10 hPa and a complete reversal of the zonal-mean winds from eastward to westward at 60° at 10 hPa (as seen in NASA's Modern-Era Retrospective Analysis for Research and Applications reanalysis dataset [*NASA MERRA*]) . This creates a complete change in the circulation, or a breakdown, of the polar vortex [*Labitzke and Naujokat*, 2000]. Two major SSWs, at northern latitudes, can be seen in Figures 1 (a) and (b).

SSW Event	Peak Date	Nights of Data
Jan-Feb 1995	03/02/95	18
Dec 1998- Jan 1999	15/12/98	16
Feb-Mar 1999	03/03/99	19
Mar-Apr 2000	15/03/00	9
Jan-Mar 2001	15/02/01	33
Feb-Mar 2002	15/02/02	8
Jan-Feb 2003	14/01/03	18

Table 1. List of major SSWs, their peak dates (when zonal wind direction reversed), and the nights of RSL data from 1993-2004.

The original RSL system ran at a midlatitude site (41.7° N, 111.8° W), on the campus of Utah State University from 1993-2004. The RSL measured relative densities that were then used in the Chanin-Hauchecorne method [*Hauchecorne and Chanin*, 1980], which uses hydrostatic equilibrium and the ideal gas law to give absolute temperatures. The initial temperature values for the downward integration came from the CSU climatology [*She et al.*, 2000].





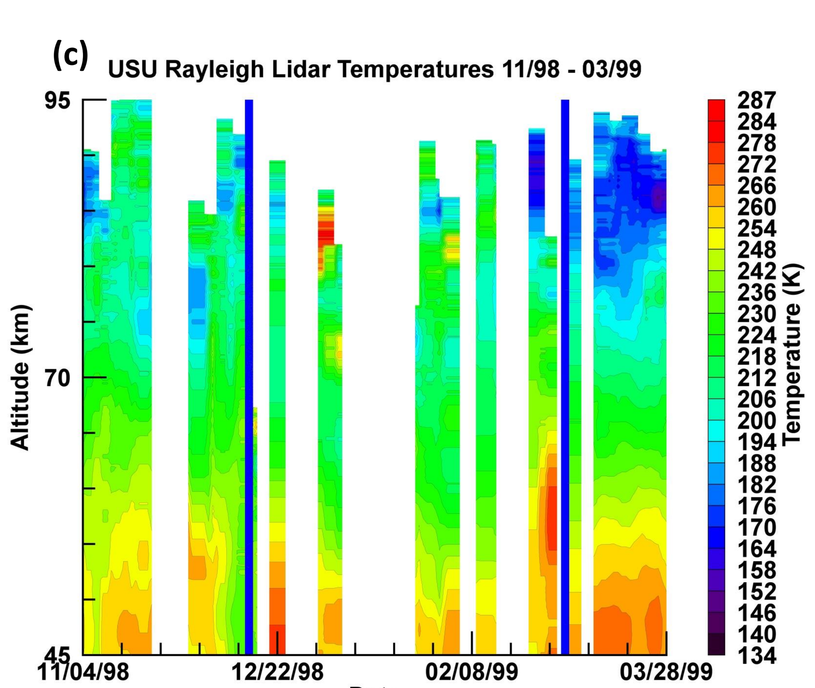


Figure 1. (a) Zonal-mean temperatures averaged between 60 – 90 N and (b) zonal-mean zonal winds at 60 N from NASA's MERRA database. Vertical blue lines indicate (a) temperature increases and (b) wind reversals that occur during two major stratospheric warmings. An example of the USU RSL temperatures before, during and after these two consecutive major SSWs is shown in (c).

Figure 1 (c) depicts a winter period in the RSL data that includes a pre-SSW period in November 1998, then two consecutive major SSWs in December 1998 and February 1999 and ends with a post-SSW period in March 1999. One may note warmer regions in the lower mesosphere and colder regions in the upper mesosphere before and after the peak dates of the two SSWs.

USU Rayleigh Lidar Temperature Climatology

The composite year temperature climatology [Figs 2 (a) and (b)], which will be used for comparisons, was created by averaging over a window 31 nights wide and 11 years deep, centered on each night [*Herron*, 2007].

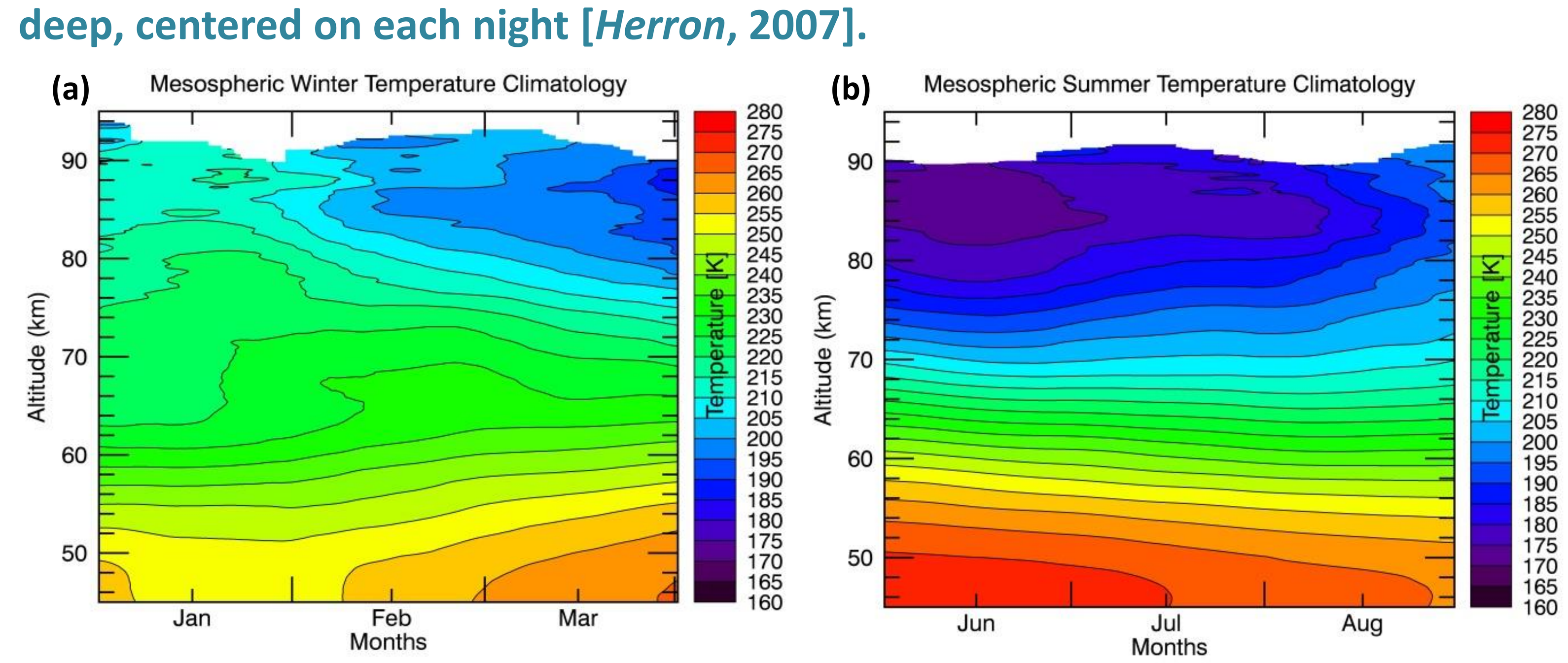


Figure 2. USU Rayleigh lidar (a) summer and (b) winter mesospheric temperature climatologies.

Midlatitude Mesospheric Temperatures during Major SSWs

The RSL observations made during seven SSW events show a temperature range (~160–280 K), from high to low altitudes, more characteristic of the summer climatology [Fig 2 (a)] than the expected winter climatological temperature range (~180–265 K). This temperature reversal from winter to summer conditions most often starts at the peak date and continues for several weeks [Figs 3 (a-g)].

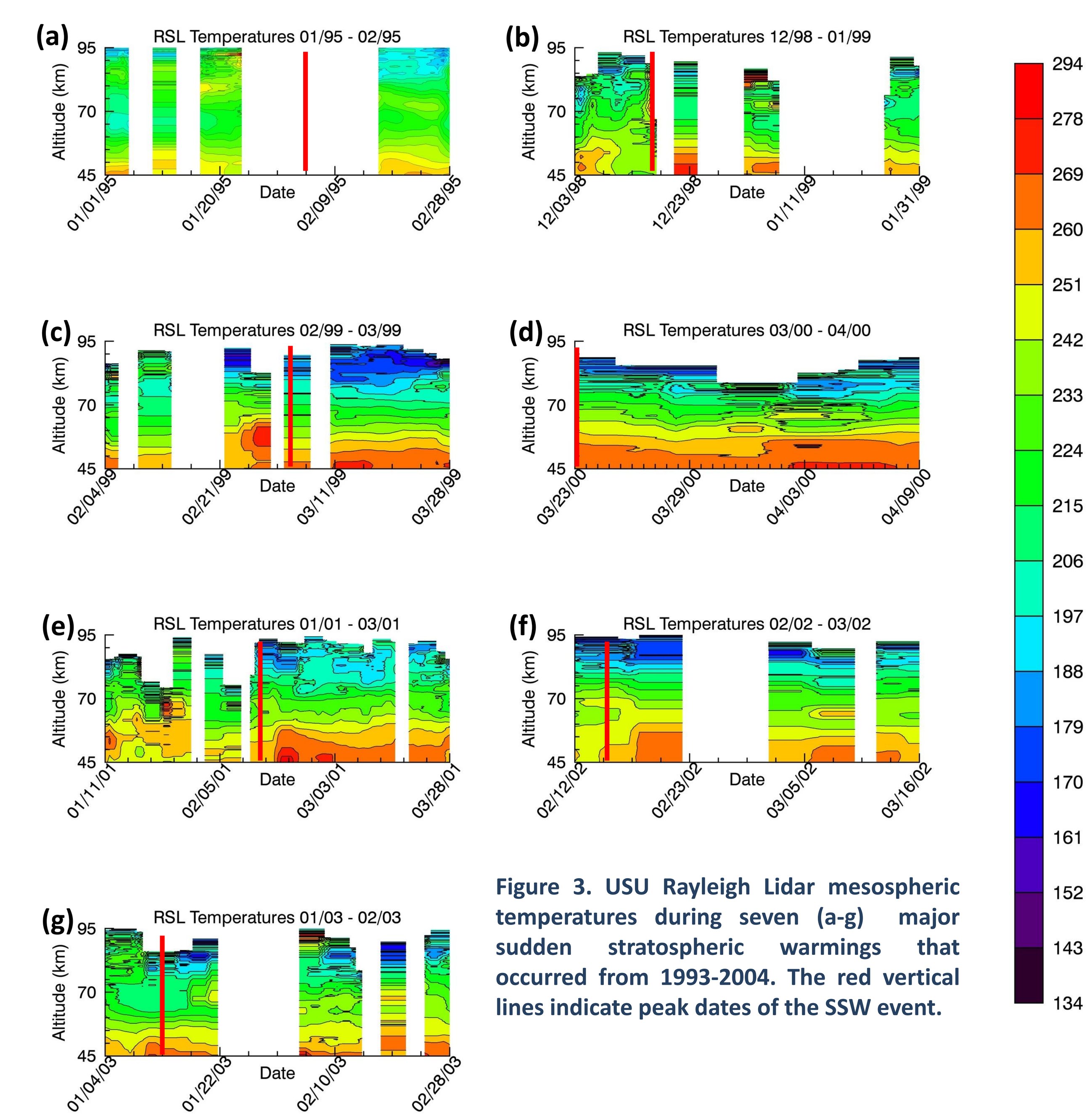


Figure 3. USU Rayleigh Lidar mesospheric temperatures during seven (a-g) major sudden stratospheric warmings that occurred from 1993-2004. The red vertical lines indicate peak dates of the SSW event.

Upper Mesospheric Coolings and Lower Mesospheric Warmings

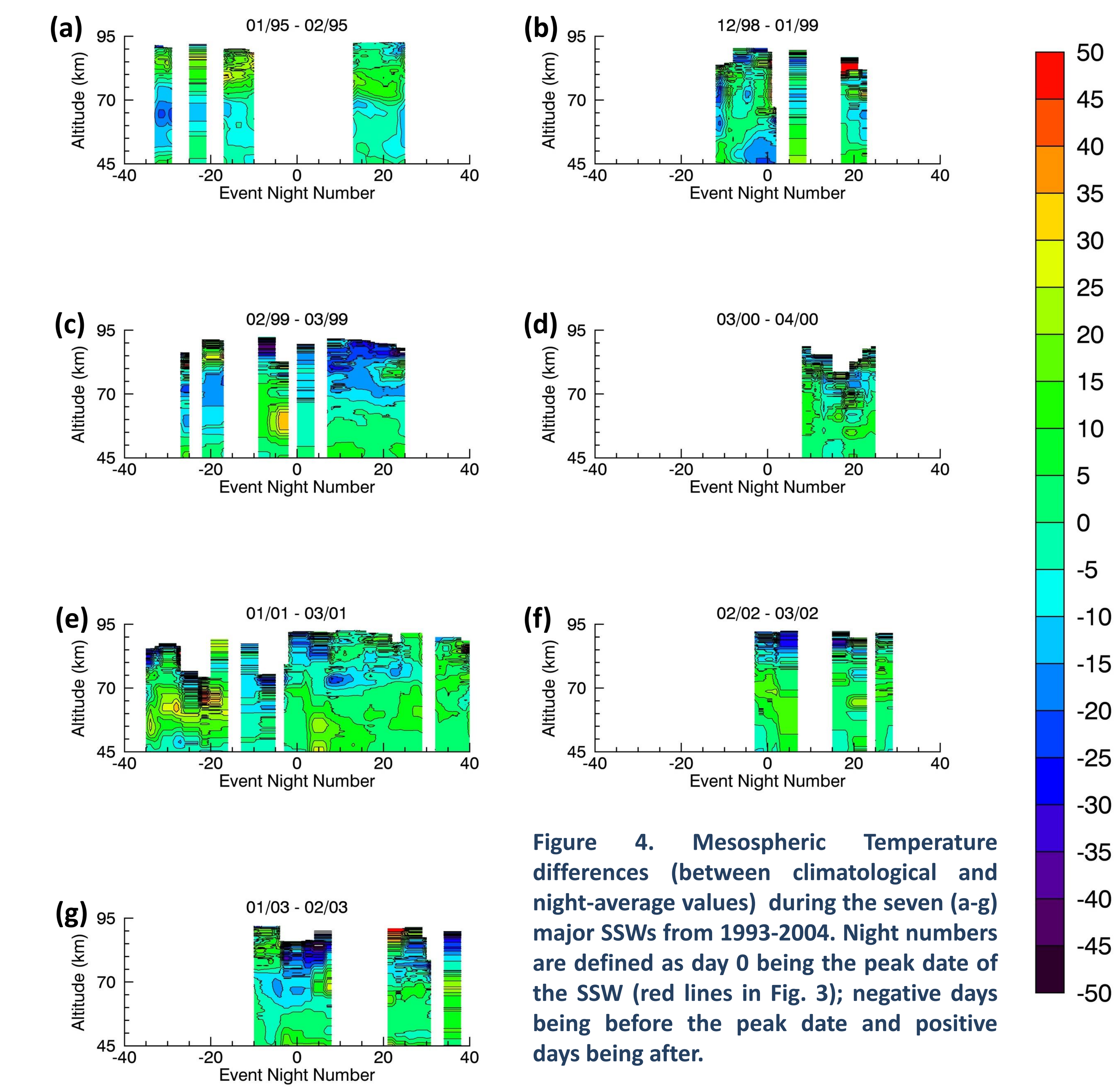


Figure 4. Mesospheric Temperature differences (between climatological and night-average values) during the seven (a-g) major SSWs from 1993-2004. Night numbers are defined as day 0 being the peak date of the SSW (red lines in Fig. 3); negative days being before the peak date and positive days being after.

In order to better define coolings and warmings during an SSW event, as compared to the RSL climatology, temperature difference plots [Figs 4 (a-g)]. were created by subtracting the climatological night's temperatures [Fig 2 (a)] from the individual night's averaged temperatures [Fig 3]. The upper mesospheric coolings, that are typically located from 70-95 km, and the lower mesospheric warmings, from 45-70 km, are roughly one order of magnitude higher than those predicted in Liu and Roble, [2002] for midlatitudes. They are more comparable to the coolings and warmings that have been found in the polar mesosphere [*Labitzke*, 1972] and range from less than −50 K (coolings) to more than +50 K (warmings).

Conclusions and Future Work

Conclusions from this study about the midlatitude mesosphere include:

- A dense temperature dataset acquired by the USU Rayleigh lidar has overlapped significantly with nearly all of major SSW event from 1993-2004, giving a better understanding of the midlatitude mesosphere's behavior during these events.
- The whole mesosphere tends to switch from the climatological temperature range of winter to that of summer from the time of the stratospheric zonal wind reversal at 60 N.
- The mesospheric temperature anomalies, coolings in the upper mesosphere and warmings in the lower mesosphere, are roughly the same magnitude at midlatitudes as they are in the polar regions.

This work will be furthered by examining the climatological aspects of these midlatitude temperature anomalies and by pushing the observational range into the lower thermosphere, in future observations, through a series of upgrades to the USU Rayleigh lidar that are currently underway.

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