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Leda Sox

*Utah State University*

Vincent B. Wickwar

*Utah State University*

Chad Fish

Joshua P. Herron

*Utah State University*

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# TEMPERATURE DEVIATIONS IN THE MIDLATITUDE MESOSPHERE DURING STRATOSPHERIC WARMINGS AS MEASURED WITH RAYLEIGH-SCATTER LIDAR

Leda Sox<sup>1\*</sup>, Vincent Wickwar<sup>1</sup>, Chad Fish<sup>2</sup>, Joshua P. Herron<sup>3</sup>

<sup>1</sup>*Center for Atmospheric and Space Sciences and Physics Department, Utah State University, UT 84322, USA, \*leda.sox@gmail.com*

<sup>2</sup>*Atmospheric & Space Technology Research Associates (ASTRA), Boulder, CO USA*

<sup>3</sup>*Space Dynamics Laboratory, Utah State University, Logan, UT 84322, USA*

## ABSTRACT

While mesospheric temperature anomalies associated with Sudden Stratospheric Warmings (SSWs) have been observed extensively in the polar regions, observations of these anomalies at midlatitudes are sparse. The original Rayleigh-scatter lidar that operated at the Atmospheric Lidar Observatory (ALO; 41.7°N, 111.8°W) in the Center for Atmospheric and Space Sciences (CASS) on the campus of Utah State University (USU) collected an extensive set of temperature data for 11 years in the 45–90 km altitude range. This work focuses on the extensive Rayleigh lidar observations made during six major SSW events that occurred between 1993 and 2004, providing a climatological study of the midlatitude mesospheric temperatures during these SSW events. An overall disturbance pattern was observed in the mesospheric temperatures during these SSWs. It included coolings in the upper mesosphere, comparable to those seen in the polar regions during SSW events, and warmings in the lower mesosphere.

## 1. INTRODUCTION

SSWs are major disturbances in the polar region of the winter hemisphere that are defined by major changes in stratospheric temperature and circulation. SSWs are characterized by a temperature increase of tens of degrees Kelvin, averaged over 60°–90° latitude at 10 hPa (roughly 32 km), and a weakening of the polar vortex that persists for the order of a week at 60° and 10 hPa level [6]. Polar vortices are cyclones centered on both of the Earth's poles that are present throughout the stratosphere in the winter hemisphere. Strong eastward zonal winds define the polar vortices. 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, under normal winter conditions, westward propagating GWs dominate. The atypical wintertime GW filtering and the resulting dominance of eastward 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 [5] they have not been observed at midlatitudes often [2], [10].

## 2. METHODOLOGY

### 2.1 Classifying SSWs from 1993-2004

In this initial study of the mesosphere's response to northern hemisphere SSWs above Logan, UT, we will focus on periods when there were major SSW events during the USU Rayleigh-Scatter Lidar's (RSL's) original 11-year operational run. Here, a major SSW is defined by both a stratospheric temperature increase averaged over the latitudes 60° to 90° N at 10 hPa and a complete reversal of the zonal-mean winds from eastward to westward at 60° N and 10 hPa, as seen in NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA) reanalysis dataset [8]. This creates a complete change in the circulation, or a breakdown, of the polar vortex [6]. Two major SSWs (one in mid-December and one in late February), at northern latitudes, can be identified in Figures 1 (a) and (b). The blue vertical lines mark the wind reversal, or onset as it is referred to in this study.

### 2.2 Calculating temperature deviations

The original RSL system ran at a midlatitude site, on the campus of Utah State University from 1993–2004. It was comprised of a Nd:YAG laser operating at 30 Hz and either 18 or 24 W at a

wavelength of 532 nm. The receiving telescope had a diameter of 44 cm, and thus a receiving aperture of 0.15 m<sup>2</sup>. The USU RSL measured relative densities that were then used to determine absolute temperatures using a slight variation of the Chanin-Hauchecorne method [1], which assumes hydrostatic equilibrium and employs the ideal gas law. The initial temperature values used in this analysis came from either the Colorado State University Sodium Lidar climatology [8] or the Mass Spectrometer and Incoherent Scatter Radar (MSISE90) model [3]. A composite year temperature climatology was created by averaging over a window 31 nights wide centered on each night and 11 years deep, for the USU RSL data [4].

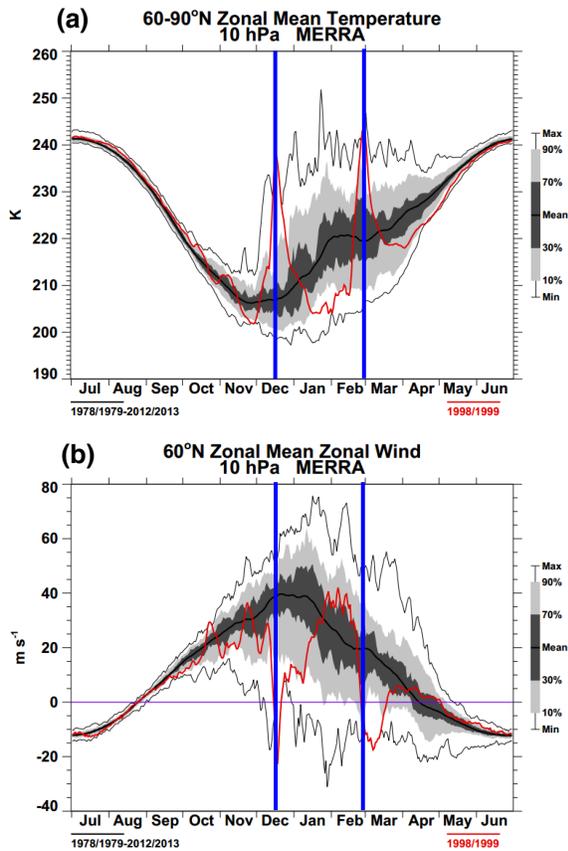


Figure 1. (a) Zonal mean temperatures at 10 hPa, averaged over 60°–90° N and (b) zonal mean zonal winds at 10 hPa and 60° N. Vertical blue lines indicate major SSWs

In order to define coolings and warmings during an SSW event, relative to the RSL climatology, temperature difference plots [Figs 2 (a-f)] were created by subtracting each night of the SSW

event's temperatures by the temperature profile from February 3<sup>rd</sup> of the RSL climatology.

Between the six SSW events, the annual range of these events spans December 15<sup>th</sup> to April 9<sup>th</sup>. February 3<sup>rd</sup> was selected because it was in the middle of this range and because the climatological days about each SSW also included the SSW temperatures. In Figure 2 (a-f), the red vertical lines indicate the SSW onset date. The SSW onset date is defined here as the date when the zonal mean zonal winds switch from eastward to westward [Figure 1 (b)]. In other words, this is the date on which the SSW is distinguished as a major SSW, rather than a minor one. The temperature differences were then smoothed in time with a window of 5 days.

### 3. RESULTS

To characterize these warmings, temperature difference, or deviation, plots are given in Figure 2 (a-f). While the data coverage and deviations from the climatological background temperatures vary from event to event, in general, a pattern of warmings in the lower mesosphere and coolings in the upper mesosphere becomes apparent after the onset date of the SSW. In Figure 2, the red vertical lines indicate the onset date for each SSW event period. The upper mesospheric coolings are located from ~70–95 km and the lower mesospheric warmings are located from ~45–70 km. Both the observed coolings and warmings 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 [5] and range from less than –50 K (coolings) to more than +50 K (warmings). The warming/cooling pattern shown here also indicates that the midlatitude lower mesospheric warmings extend higher in altitude and the coolings start higher in altitude than their polar counterparts [5].

During a major SSW event, the polar stratosphere switches from typical winter conditions to summer conditions, e.g. Figure 1, for the order of a week. At approximately the same time, we see that the midlatitude mesosphere, shown here, undergoes a similar abrupt, season-like switch in its temperatures. For example, the range of temperatures, between 45 and 90 km, is

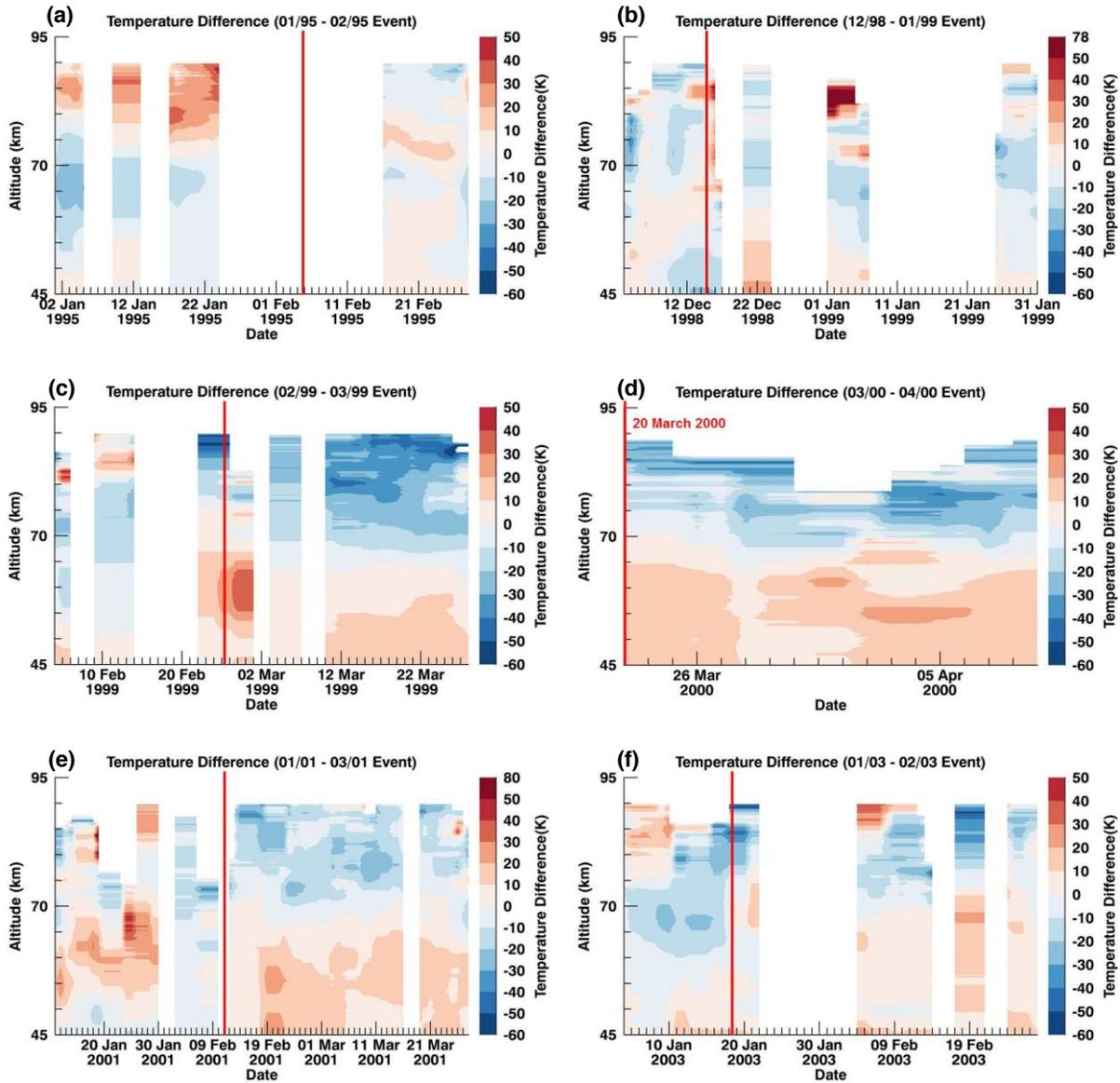


Figure 2. Temperature difference plots from the six SSW event periods in which RSL data was obtained between 1993 and 2004. Temperature differences were calculated by subtracting the climatological February 3<sup>rd</sup> temperature profile from the temperature profiles from each night of the SSW period. Negative values represent coolings and positive values represent warmings. Red vertical lines indicate SSW onset date. Note that some plots have different color contour ranges.

~265–180 K in the undisturbed winter and ~280–160 K in the summer and during major SSWs [not shown]. The transition from winter to summer temperatures in the mesosphere results in a cooling of the upper mesosphere and a warming of the lower mesosphere [4]. These temperature deviations can be seen in all six event periods given in Figure 2. This suggests that the coupling of the stratosphere and mesosphere during SSWs extends to midlatitudes for *most* major SSW

events and that this coupling at lower latitudes is not a rare occurrence.

#### 4. CONCLUSIONS

In this study, we explored the temperature structure of the midlatitude mesosphere during the time periods of six major sudden stratosphere warmings that occurred in the Northern Hemisphere from 1993–2004. Data were used from both the NASA MERRA reanalysis database

and from the dense temperature dataset acquired by the USU Rayleigh lidar that overlapped significantly with the six SSWs. One important finding was that 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. A second important observation was that the mesospheric temperature deviations from the RSL winter climatology, i.e. 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. The data presented here also suggests that the extension of SSW-related anomalies to midlatitudes is not a rare occurrence. Rather, these anomalies are seen during every major SSW observational period. These results imply that sudden stratospheric warmings are not only coupled to different atmospheric regions, but are coupled to different latitudinal regions, as well.

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