Journal of Atmospheric and Solar-Terrestrial Physics 140 (2016) 55–64

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Mesospheric signatures observed during 2010 minor stratospheric warming at King Sejong Station (62°S, 59°W)

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ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form
4 February 2016
Accepted 5 February 2016
Available online 6 February 2016

Keywords:
Sudden Stratospheric Warming (SSW)
Mesosphere
Mesospheric Radars
MLS
SD-WACCM
Coupling
Mesosphere cooling

ABSTRACT

A minor stratospheric sudden warming (SSW) event was noticed in the southern hemisphere (SH) during September (day 259) 2010 along with two episodic warmings in early August (day 212) and late October (day 300) 2010. Among the three warming events, the signature of mesosphere response was detected only for the September event in the mesospheric wind dataset from both meteor radar and MF radar located at King Sejong Station (62°S, 59°W) and Rothera (68°S, 68°W), Antarctica, respectively. The zonal winds in the mesosphere reversed approximately a week before the September SSW event, as has been observed in the 2002 major SSW. Signatures of mesospheric cooling (MC) in association with stratospheric warmings are found in temperatures measured by the Microwave Limb Sounder (MLS). Simulations of specified dynamics version of Whole Atmosphere Community Climate Model (SD-WACCM) are able to reproduce these observed features. The mesospheric wind field was found to differ significantly from that of normal years probably due to enhanced planetary wave (PW) activity before the SSW. From the wavelet analysis of wind data of both stations, we find that strong 14–16 day PWs prevailed prior to the SSW and disappeared suddenly after the SSW in the mesosphere. Our study provides evidence that minor SSWs in SH can result in significant effects on the mesospheric dynamics as in the northern hemisphere.

1. Introduction

Numerous studies have been done on stratospheric sudden warmings (SSW) and their possible dynamical impacts on the mesosphere, especially in the northern hemisphere (NH) (Charlton and Polvani (2007), Kishore et al. (2012), De la Torre et al. (2012) and references there in). However, such studies are relatively few in the southern hemisphere (SH) (Baldwin et al., 2003; Hoppel et al., 2003; Shepherd et al., 2005; Dowdy et al., 2004; Mbatha et al., 2010). SSWs are less frequent in the SH and this hemispheric disparity may be attributed to less topographic forcing of planetary waves (PWs) (Andrews et al. (1987), Chandran et al. (2014) and references there in). According to the World Meteorological Organization (WMO) definition, minor SSWs are events having reversal of temperature gradient at 10 hPa pole ward of 60°, while major warmings, in addition to the temperature gradient reversal, require reversal of the mean zonal wind to westward at 60° (Labitzke and Naujokat, 2000; Chandran et al., 2014). Minor SSWs are seen more frequently than major SSWs in the SH and one such minor SSW was observed in 2010 (Chandran et al., 2014). Earlier studies (Coy et al., 2005; Siskind et al., 2010; Chandran et al., 2013) on minor warmings have stressed their effects on the mesosphere. The disturbed winter conditions cause profound effects on stratospheric ozone densities that are greatly reduced especially during major warmings in the NH (Manney et al., 2009). A similar effect was also observed in the SH during the recent 2010 minor warming (de Laat and van Weele, 2011).

The first observational study on SSWs was made over 60 years ago (Scherhag, 1952). However, there are still advances to be made in the understanding of SSW effects on atmospheric dynamics, coupling and composition. It is generally accepted that SSWs are produced by the interaction of PW with mean flow in the

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http://dx.doi.org/10.1016/j.jastp.2016.02.007
1364-6826/

stratosphere (Matsuno, 1971). This interaction decelerates and even reverses the zonal mean eastward winter stratospheric jet and forces poleward/downward flow in the winter-time polar stratosphere resulting in adiabatic heating in the stratosphere. At the same time, the slow/reversed stratospheric jet reduces/reverses the normal westward gravity wave forcing in the winter polar mesosphere. The net eastward forcing due to gravity wave breaking in the MLT, resulting in zonal wind reversal from westward to eastward. The associated mean residual circulation changes from downward to upward, leading to gravity wave induced adiabatic cooling in the mesosphere (Liu and Roble, 2002; Chandran et al., 2014).

At high-latitudes, in general, the stratospheric and mesospheric winds and temperature can be subjected to significant changes during disturbed winters (Liu and Roble, 2002; Cho et al., 2004). Mesospheric cooling (MC) has been reported for both hemisphere during major SSW events; in the NH, Cho et al. (2004) documented the MC using the ground-based Spectral Airglow Temperature Imager and in the SH using the OH and O_2 airglow observations by Azeem et al. (2005). MC has also been detected during minor SSW (sometimes also referred to as Upper Stratosphere Lower Mesosphere (USLM) disturbances) in lidar, Michelson interferometer, rocketsondes, satellite radiometry and meteorological analyses (Labitzke, 1972; Fairlie et al., 1990; Greer et al., 2013; Thayer and Livingston, 2008; Siskind et al., 2005; von Zahn et al., 1998). Recently de Wit et al. (2015) noticed cooling about 10 km below the mesopause over Trondheim, Norway (63°N, 10°E) using the MLS temperature data for the January 2013 major SSW.

Using long-term (1979–2006) satellite observations, Hu and Fu (2009) demonstrated that the occurrence rate of SSW in SH is maximized in the late winter and spring season (September–October) by temperature increase up to ~7 to 8 °C. They also showed a close correlation between SSW in SH and increase of sea surface temperature (SST) as a consequence of the increasing greenhouse gasses due to anthropogenic activity.

In the SH, the only reported major SSW event occurred in 2002 (Baldwin et al., 2003) and its impact on mesospheric dynamics was well studied by Dowdy et al. (2004) using simultaneous MF radars over Antarctica region and by, Mbatha et al. (2010) with HF radar. In the context of planetary waves and tide interaction, mesospheric winds have been studied with a meteor radar at Rothera (68°S, 68°W) by Mthembu et al. (2013). However, the impact of minor SSW events on mesospheric dynamics has only been studied to a limited degree in both hemispheres, except a few model simulations (Siskind et al., 2010; Chandran et al., 2013). To the best of our knowledge no experimental study, especially with meteor radar data, has been reported for the influence of minor SSW on the SH mesospheric dynamics.

Here, we present the mesosphere features over the Antarctica region during a minor SSW event, which occurred in September 2010. We analyze the mesospheric winds and occurrence of MC in conjunction with the minor SSW by using simultaneous measurements of a meteor radar at King Sejong Station (KSS) (62°S, 59°W) and a Rothera MF radar, together with the Microwave Limb Sounder (MLS) temperature measurements. Furthermore, we verify the dynamical response of the polar mesospheric region for the 2010 minor SSW with a simulation of a global circulation model (GCM), which shows a clear link between stratosphere and mesospheric region. Section 2 provides the data used in the present study, the results and discussion are given in Section 3, followed by the summary in Section 4.

2. Data

2.1. Mesospheric radar data

In the present study, we use combined observations of King Sejong Station Meteor Radar (hereafter called KSS MR) and Rothera MF radar (MF radar), which provide wind information in the mesospheric region during the period of 2007–2014.

The meteor radar was installed in March 2007 near the tip of Antarctica peninsula (Kim et al., 2010), and has been operated in all-sky interferometric mode with 1 transmitting antenna and 5 receiving antennas at 33.2 MHz. The radar transmitted with a maximum peak power of 8 kW until March 2012 and the power was upgraded to 12 kW afterward. The wind measurement technique is similar to the standard method given in Holdsworth et al. (2004) and the radar provides winds at altitudes of 80–98 km at 1 h and 2 km resolutions (Lee et al., 2013).

Rothera MF Radar is a coherent, spaced-antenna system and has been operated since 1997 (Jarvis et al., 1999). The radar employs a single broad-beam transmitting antenna and three spaced receiving antennas in a triangular array. The radar operates with a transmitting power of 25 kW at a frequency of 1.98 MHz (Hibbins et al., 2007) and provides winds in the mesosphere and lower thermosphere at 4 km altitude resolution every hour and these data were re-sampled to 2 km height resolution. The winds measured by a MF radar are usually in agreement with those measured by a meteor radar up to an altitude of ~94 km, above which a MF radar tends to underestimate the winds compared to those observed by a meteor radar (Manson et al., 2004; Portnyagin et al., 2004; Rao et al., 2014). In the present study we made use of winds at 82 km to characterize the mesosphere response to the 2010 minor SSW.

2.2. EOS MLS data

The Earth Observing System (EOS) Microwave Limb Sounder (hereafter called MLS) is one of the four instruments aboard NASA's Aura satellite, launched on 15 July 2004. The MLS is a radiometer that retrieves temperature from bands near the O_2 spectral line at 118 and 239 GHz. It measures temperatures at 316–0.001 hPa pressure levels with a track resolution of 230 km for global coverage from 82°S to 82°N with ~15 orbits per day, providing ~30 samples daily for given latitude. The vertical resolution is 3 km at 31.6 hPa, degrading to 6 km at 316 hPa and to ~13 km at 0.001 hPa. Details of the MLS and temperature validation are given in Schwartz et al. (2008). In the present study, we have used the zonal mean temperatures derived at 80°S.

2.3. ERA-interim database

We also make use of stratospheric zonal mean zonal winds and temperatures obtained from ERA-Interim reanalysis (Dee et al., 2011) datasets provided by the European Center for Medium-range Weather Forecasts (ECMWF). ERA-Interim is the latest global atmospheric reanalysis dataset produced by the ECMWF for the period from 1 January 1979 onwards (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim). The ERA-Interim dataset covering the pressure levels 1000 and 1 hPa (~0–48 km) with a latitudinal and longitudinal grid of 1.5° × 1.5° is used in this study, though higher spatial resolutions are now available. The data set consists of results from reanalysis conducted at six-hour intervals at 1.5° latitude–longitude resolution, using both ground-based and space-born observations. In the present study we have utilized zonal mean temperature and zonal winds at 10 hPa.