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Response of equatorial and low latitude mesosphere lower thermospheric dynamics to the northern hemispheric sudden stratospheric warming events

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A B S T R A C T

The changes in zonal mean circulation and meridional temperature gradient brought about by Sudden Stratospheric Warming (SSW) events in polar middle atmosphere are found to significantly affect the low latitude counterparts. Several studies have revealed the signatures of SSW events in the low latitude Mesosphere- Lower Thermosphere (MLT) region. Using meteor wind radar observations, the present study investigates the response of semidiurnal oscillations and quasi 2-day waves in the MLT region, simultaneously over low latitude and equatorial stations Thumba (8.5°N, 76.5°E) and Kototabang (0.2°S, 100°E). Unlike many case studies, the present analysis examines the response of low and equatorial latitude MLT region to typical polar stratospheric conditions viz., Quiet winter, Major SSW winter and Minor SSW winter. The present results show that (i) the amplitudes of semidiurnal oscillations and quasi 2-day waves in the equatorial and low latitude MLT region enhance in association with major SSW events, (ii) the semidiurnal oscillations show significant enhancement selectively in the zonal and meridional components over the Northern Hemispheric low latitude and the equatorial stations, respectively (iii) The minor SSW event of January 2012 resulted in anomalously large amplitudes of quasi 2- day waves without any notable increase in the amplitude of semidiurnal oscillations. The significance of the present study lies in comprehensively bringing out the signatures of SSW events in the semidiurnal oscillations and quasi 2-day waves in low latitude and equatorial MLT region, simultaneously for the first time over these latitudes.

1. Introduction

A Sudden Stratospheric Warming (SSW) is a spectacular meteorological event in which the prevailing eastward winds in the winter polar stratosphere are decelerated or in the extreme case entirely reversed to westward winds accompanied by an increase in background temperature in a short span of a few days. During a typical SSW, stratospheric temperatures increase dramatically as much as 25 K or more, thereby reversing the meridional temperature gradient. As put forward by Matsuno (1971), the phenomenon involves upward propagation of planetary waves from the troposphere and their interaction with the zonal mean flow resulting in either displacement or splitting of the polar vortex. If there is an increase in stratospheric temperature poleward of 60° latitude at or below 10 mb and an associated circulation change from zonal mean eastward flow to westward flow, the warming is categorized as major. Whereas, if there exists no wind reversal at 10 mb level the warming is termed minor (Labitzke, 1977; Schoeberl, 1978). Owing to the relatively stronger planetary wave activity, the Northern Hemispheric (NH) polar region experiences larger number of SSW events as compared to their Southern Hemispheric counterpart. SSW events are capable of coupling different regions of the atmosphere both vertically (Baldwin et al., 2001; Chau et al., 2009; Funke et al., 2010; Goncharenko et al., 2012; Chandran et al., 2014) and laterally (Kodera et al., 2000; Chau et al., 2012; Shepherd et al., 2007).

SSW events, by virtue of modifying the dynamical structure of the middle atmosphere, have significant effects in the Mesosphere Lower Thermosphere (MLT) region as well. The MLT region is dominated by the deposition of energy and momentum by gravity and planetary waves propagating from the lower atmosphere. With the advancement of satellite based measurements, the study of dynamical aspects of SSWs gained a considerable progress. On theoretical, experimental as well as observational grounds, the signatures of SSWs in high latitude MLT region have been well documented. The MLT region observations over high latitudes during SSW events reported cooling of these regions. Holton (1983) suggested that the filtering of orographically generated stationary gravity waves by the zero wind line formed during SSW events to be the reason for mesospheric cooling observed by Labitzke (1971). However, the reversal of zonal wind in the mesosphere during SSW is found to be weaker and earlier compared to their stratospheric counterpart, for the Antarctic polar vortex also (Dowdy et al., 2007). Further, Liu and Roble (2002) using the coupled NCAR TIME/GCM-CCM3 model simulations reported that the filtered gravity waves reaching MLT altitudes can force planetary waves. The authors suggested that the variability in MLT region during SSW events can be contributed by the growth and interaction

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of these planetary waves with tides. Using observations from meteor radar and European incoherent scatter UHF Radar over Tromso (69.6°N, 19.2°E) during the warming event of January 2009, Kurihara et al. (2010) reported the downward propagation of zonal wind reversal starting from around 100 km and reaching the stratosphere in about 10 days. Mbatha et al. (2009) studied the Antarctic SSW of 2002 and observed similar downward propagation of circulation change from mesosphere to stratosphere in about 7 days in addition to the presence of planetary wave of period ~14 days. Amplification of a planetary wave of 4-day period in the OH airglow temperature measurements was elucidated by Azeem et al. (2005) prior to mesospheric cooling in association with stratospheric warming in Antarctic 2002 event. In a more recent study, using the Specified Dynamics version of the Whole Atmosphere Community Climate Model (SD-WACCM), Chandran et al. (2014) divulged the nature of polar stratopause to be controlled by planetary waves during the beginning phase and by gravity waves during the recovery phase of SSW. Thus there are ample evidences for the signatures of SSW in the polar and high latitude MLT region.

Over middle and low latitudes, there have been relatively fewer studies dedicated to investigate the effects of SSWs in the MLT region. Using rocketsonde observations from the low latitude station Thumba (8.5°N, 76.5°E), Mukherjee and Ramanamurthy (1971) observed substantial cooling in the mesospheric region in conjunction with the Northern Hemispheric SSW event of 1971. Shepherd et al. (2007) observed mesospheric cooling as well as stratospheric warming for the latitudes of 5°N to 15°N during the time of SSW. The response of midlatitude mesopause region to SSW was investigated by Yuan et al. (2012) and they found that the temperature at 80 km was lesser by as much as 30 K from the climatological mean, which was observed to be a disturbance that propagated from polar region to the observation location, Fort Collins (41°N, 105°W). Using the extended version of the Whole Atmosphere Community Climate Model (WACCM-X) Sassi and Liu (2014) demonstrated the propagation of planetary waves from northern hemispheric mid-latitudes to tropics in association with SSW events. The authors postulate that such a cross equatorial propagation of wave activity together with strong eastward meridional wind shear can result in modification of tidal amplitudes in the tropical lower thermosphere region. In a modelling study, compiling the responses of MLT region to SSW events with elevated stratopause, Limpasuvan et al. (2016) observed planetary wave driven upwelling and adiabatic cooling in the tropical stratosphere which eventually resulted in enhanced ozone concentrations. This enhancement was found to amplify the migrating semidiurnal tidal mode with zonal wavenumber 2. Sathishkumar et al. (2009) noted the reversal of wind from eastward to westward preceding the SSW as observed using MF Radar at Tirunelveli (8.7°N, 77.8°E). In the study, middle atmospheric region over Tirunelveli (8.7°N, 77.8°E) and Collm (52°N, 15°E) were found to respond in different ways to warming events at high latitudes. Sathishkumar and Sridharan (2009) reported enhanced gravity wave activity and suppressed planetary wave activity during the major SSW of 2005/06 in zonal winds at 84–98 km height over Tirunelveli (8.7°N, 77.8°E). Rayleigh Lidar observations at Gadanki (13.5°N, 79.2°E) revealed the mesospheric warming and enhanced gravity wave activity during a major SSW that occurred in 2009 (Sridharan et al., 2010). Vineeth et al. (2009) observed the occurrence of Equatorial Counter Electrojet (CEJ) with a quasi 16-day periodicity over a low latitude location Trivandrum (8.5°N, 76.5°E) during SSW events. The periodic occurrence of CEJ is attributed to the interaction of planetary waves from the lower atmosphere with the tides. Making use of the TIME- GCM with the lower part constrained by the WACCM-X/MERRA/NOGAPS-ALPHA, Yamazaki et al. (2014) examined the influence of lower atmospheric forcing on ionospheric variability. It was shown that the day-to-day variability in the noontime electrojet correlates with the westward wind at 100–120 km near the magnetic equator. These studies clearly demonstrate the effect of SSW events in middle and low latitude MLT region, providing evidences for lateral coupling in association with SSW events.

It is envisaged that owing to the modification of background conditions in the middle atmosphere right from polar to equatorial latitudes during SSW events, the propagation of gravity waves, planetary waves and tides may also get affected significantly. Especially, SSW events occurring in the Northern Hemispheric Polar Regions are reported to affect tides and quasi 2-day waves in the low and equatorial regions. Bhattacharya et al. (2004) reported increase in amplitude of semidiurnal tide during SSW onset and reduction in amplitudes of semidiurnal tide during the cool period between two warming events at high latitude mesospheric regions. Observation of tidal amplitudes over Tirunelveli (8.7°N, 77.8°E), a low-latitude station by Sathishkumar and Sridharan (2013) showed enhancement of semidiurnal tidal amplitudes and subsequent occurrence of CEJ during SSW event. The authors speculated that the enhancement of the observed semidiurnal tides may be due to the changes in the convective activity in the troposphere and changes in stratospheric ozone associated with SSW. Using simulations of the January 2009 SSW by the Whole Atmosphere Model, Wang et al., (2011) delineated the global response of MLT region tides to the SSW event. In the study, the amplitude of terdiurnal westward propagating wave was found to enhance and that of semidiurnal westward propagating tidal wave was found to diminish during the warming event. Semidiurnal tidal wave amplitudes appeared to be enhanced after the peak warming and the tidal responses were found to be global in nature. Sassi et al. (2013) calculated the ratio of total vorticity to planetary vorticity averaged from 30°S to 30°N over the height range 70–90 km to investigate the indirect effect of winds on tidal waves by modifying the width of the tropical waveguide. It was found that the change in the diurnal tidal amplitude during the SSW period is closely related to the changes in the tropical zonal mean vorticity. Analysis of meteor radar data of Northern Hemispheric winters of 2004-05, 05-06 and 06-07 from Sao Joao do Cairi, Brazil (7.4°S, 36.5°W) by Lima et al. (2012) revealed enhancement of both semidiurnal tidal and quasi 2-day wave amplitudes in association with major SSW events. Quasi 2-day wave amplitudes were enhanced during the 2013 SSW event, which was revealed by a chain of meteor radar observations at Mohe (52.5°N, 122.3°E), Beijing (40.3°N, 116.2°E), Wuhan (30.5°N, 114.6°E) and Sanya (18.3°N, 109.6°E) and the amplification was seen to be most pronounced over the low latitudes (Ma et al., 2017).

Even though there are a number of studies which bring out the relationship between SSW events and variabilities in the low latitude MLT system, still the comprehensive explanation for the response of the MLT region to SSW events is far from complete as each of the individual SSW events are dynamically unique and show significant variability from event to event. The results on the response of low-latitude MLT region to SSW reported earlier are not very coherent. There are no comprehensive studies on semidiurnal and quasi 2-day wave amplification during SSW events over low- and equatorial latitude MLT region as most of the reported results are from case studies. In this regard, the present study focuses on delineating the observed dynamical features in equatorial and low-latitude MLT dynamics during Northern Hemispheric SSW events using eight years of simultaneous observations of MLT winds over Thumba (8.5°N, 76.5°E) and Kototabang (0.2°S, 100°E). It is envisaged that the present results will shed light on: Whether the observed enhancement in semidiurnal oscillations and quasi 2-day wave is consistent during all SSW events? Whether minor warming events have any signature in the equatorial and low-latitude MLT region? Whether enhancement is observed in both zonal and meridional components of semidiurnal oscillations? Besides addressing these questions, an attempt is also made to discuss the mean climatologies of winds, semidiurnal oscillations and quasi 2-day waves. Section 2 describes the meteor radars at Thumba and Kototabang. Section 3 discusses the results and concluding remarks are provided in Section 4.

2. Data and methodology

The present study uses meteor radar observations of MLT winds in the