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Comparison of the dynamical response of low latitude middle atmosphere to the major stratospheric warming events in the Northern and Southern Hemispheres

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ABSTRACT

This study presents comparison of low-latitude dynamical responses to boreal 2008/09 and austral 2002 winter Major Stratospheric Warming (MSW) events, as both events are of vortex split type. During these winters, planetary wave (PW) variability and changes in low-latitude circulation are examined using European Center for Medium Range Weather Forecasting (ECMWF) reanalysis (ERA)-interim data sets and mesospheric wind data acquired by the MF radars at Tirunelveli (8.7°N) and Rarotonga (22°S). Eliassen-Palm diagnostic is used to provide an evidence for the lateral PW energy propagation from high to low-latitudes during both the MSW events. The PW flux reaches much lower latitudes during the boreal event than during the austral event. The low-latitude westward winds at stratospheric heights are stronger (weaker) during the boreal (austral) MSW. Weak (strong) PW wave activity at low latitude mesospheric heights during boreal (austral) MSW indicates the influence of low-latitude stratospheric westward winds on the vertical propagation of PW to low-latitude mesosphere.

1. Introduction

Major stratospheric warming (MSW) is characterized by a rapid increase of polar stratospheric temperature (about 50 K in a week) accompanied by stratospheric polar night jet reversal. This is due to the interaction of anomalous planetary (Rossby) waves which are propagating from the troposphere along with the background flow (Matsuno, 1971; Manney et al., 2009). Contribution of planetary wave with wavenumber 1 or 2 that occurred prior to the onset of MSW can determine the polar vortex as “vortex displacement” or “vortex split” type (Charlton and Polvani, 2007). Numerous observations have supported Matsuno's concept of sudden warming caused by planetary wave critical level interaction by using Eliassen-Palm flux as a diagnostic (e.g., Palmer, 1981; O'Neill and Youngbult, 1982; Kanzawa, 1982; Gille and Lyjak, 1984). Analysis of stratospheric data by Krüger et al. (2005) prior to the first SH major warming revealed the existence of interactions among eastward propagating waves with periods nearly 10 days, quasi stationary planetary waves and the zonal mean flow. Palo et al. (2005) showed from TIMED/SABER observations during the 60 days before the onset of SH major MSW on 26 September 2002 that the interaction between the eastward propagating 10 day waves with zonal wavenumbers 1 and 2, and a stationary planetary wave with zonal wavenumber 1 took place prior to major MSW during September 2002. Earlier, Shiotani (1986) described the planetary wave activity between the troposphere and the stratosphere from December 1981 to March 1982 in the NH winter using Eliassen-Palm diagnostics. His results reveal that the EP flux vectors in the troposphere and lower stratosphere regularly point upward in the month of February and March, while they branch off equatorward and poleward around tropopause during December and early January period. The convergence of poleward branch of PW flux leads to decrease or reversal of eastward wind at high-latitude stratospheric heights (Ryoo and Chu, 2005 for example). Similarly, the equatorward branch of PW flux converges to low-latitudes contributes to low-latitude circulation changes.

These Rossby waves contribute to the MSW to propagate meridionally towards the weak stratospheric winds in the tropics

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leading to the subtropical wave breaking, which triggers the transport of tropical air to middle latitudes (Randel et al., 1993; Waugh, 1993; Polvani et al., 1995). In a modeling study employing the TIME-GCM, Liu and Roble (2002) showed that the interaction between planetary waves and mean flow decelerates and/or could reverse the westerly winter stratospheric jet, induce a downward circulation in the stratosphere and upward circulation in the mesosphere, which in turn lead to adiabatic warming (cooling) in the stratosphere (mesosphere).

Though extensive analysis has been carried out to study the effects of MSW on the high and mid latitude middle atmosphere (e.g., Labitzke and Naujokat, 2000; Whiteway and Carswell, 1994 and references therein), only a very few reports have been devoted in understanding the effects of MSW on tropical middle atmosphere. Fritz and Soules (1970) first noted the sudden warming at high latitudes was accompanied by simultaneous cooling in the tropical winter stratosphere. Using weekly rocket temperature and wind observations over Thumba (8.5°N, 76.9°E) and Balasore (21.5°N, 86.9°E) during the SSW of 1984–85, Mukherjee et al. (1990) observed strong westward winds in the upper stratosphere and lower mesosphere. Mukhtarov et al. (2007) studied the large scale thermodynamics of the stratosphere and mesosphere during 2003/04 MSW and found connection between the westward anomalies at high latitudes and alternating regions of eastward anomalies at low-mid and tropical latitudes and again westward anomalies at equatorial latitudes. The vertical coupling of the stratosphere and mesosphere through quasi-stationary and traveling planetary waves present in the horizontal neutral winds during the 2003/04 MSW has been studied by Pancheva et al. (2008). Using UKMO zonal mean winds, Sathishkumar et al. (2009) noted enhanced westward flow in the upper stratosphere and lower mesosphere and eastward flow in the lower stratosphere during the MSW events.

A number of studies have examined the influence of MSW on high latitude Mesosphere and Lower Thermosphere (MLT) circulation and they reported that MSW events frequently led to a decrease of the eastward zonal prevailing wind, or even wind reversal (Gregory and Manson, 1975; Jacobi et al., 1997 and references therein), although in some cases, Jacobi et al. (2003) noted zonal wind reversal over middle and high latitude sites and the reversal was apparently associated with a planetary wave oscillation of ~10 day. Hoffmann et al. (2002) noted latitudinal dependence of the wind reversal of eastward directed winds with reduced magnitudes towards the equator during MSW in 1998–99.

There are not many studies on the low-latitude circulation changes and planetary wave activity due to the SSW events. The present study investigates work the dynamical response of low latitude middle atmosphere to boreal and austral MSW events of 2009 and austral 2002 winters respectively using MLT winds over Tirunelveli (8.7°N), Rarotonga (22°S), ECMWF zonal mean wind and temperature. The Boreal 2008/09 MSW event is a remarkable event with extended period of nearly one month of polar vortex split type and the eastward wind reversal reached down to lower stratosphere (Manney et al., 2009). An unusual MSW event was observed in September 2002 austral winter that revealed comparable development in both duration and strength as that of the boreal event. We made a comparative study on the influence of these two events (NH 2008/09 and SH 2002) on the circulation change and planetary wave variability at low-latitudes, as both were of split polar votex type.

2. Observations and data analysis

2.1. ECMWF data

Information about prevailing meteorological and dynamical conditions in the stratosphere is addressed using ERA Interim reanalysis. It is archived on the ECMWF (European Centre for Medium-Range Weather Forecasts) website, http://data-portal.ecmwf.int/data/d/interim_daily/. The present study uses dynamical variables such as wind and temperature components with the grid size of 1.5° × 1.5° from 1000 to 1 hPa pressure levels.

In order to gain realistic perceptive about the dynamical processes, mainly planetary wave forcing and breaking that occurs during stratospheric warming events, Eliassen-Palm (EP) flux vector and its divergence are computed using ECMWF data sets. The EP flux has been widely used to represent the wave propagation and zonal wave forcing in the meridional plane. It is defined by the following equations in spherical and log-pressure coordinates (Andrews et al., 1987):

$$\boldsymbol{F}^{(\phi)} = \rho_0 \boldsymbol{a} \cos\phi \left(\overline{\boldsymbol{u}}_{\boldsymbol{z}} \frac{\overline{\boldsymbol{v}'\theta'}}{\overline{\theta}_z} - \overline{\boldsymbol{u}'\boldsymbol{v}'} \right) \tag{1}$$

$$\boldsymbol{F}^{(z)} = \rho_0 \boldsymbol{a} \cos\phi \times \left\{ \left[\boldsymbol{f} - \left(\boldsymbol{a} \cos\phi \right)^{-1} \left(\overline{\boldsymbol{u}} \cos\phi \right)_{\phi} \right] \frac{\overline{\boldsymbol{v}'\theta'}}{\overline{\theta}_{\boldsymbol{z}}} - \overline{\boldsymbol{u}'\boldsymbol{w}'} \right\} \tag{2}$$

$$\nabla.\, \boldsymbol{F} = \left(\boldsymbol{a} \cos\phi \right)^{-1} \frac{\partial}{\partial\phi} \left(\boldsymbol{F}^{(\phi)} \cos\phi \right) + \frac{\partial}{\partial \boldsymbol{z}} \boldsymbol{F}^{(z)} \tag{3}$$

$$\boldsymbol{D} = \frac{1}{\rho_0 \boldsymbol{a} \cos\phi} \nabla.\, \boldsymbol{F} \tag{4}$$

The terms in Eqs. (1)–(4) correspond to the standard notation of Andrews et al. (1987). Overbars and primes denote the zonal means and the deviations with their respective means. The subscripts ϕ and z denote the meridional and vertical derivates respectively. The direction of PW propagation can be identified from the orientation of EP flux vectors. Negative (Positive) EP flux divergence i.e., $\nabla.F < 0$ ($\nabla.F > 0$) corresponds to strong EP flux convergence (divergence). The convergence (divergence) of EP flux indicates the piling up (export) of wave activity in the polar stratosphere. Wave driving (D) is proportional to the EP flux divergence ($\nabla.F$).

2.2. MF radar zonal winds

The 1.98 MHz medium frequency radar at Tirunelveli (8.7°N, 77.8°E) has been installed and operated by the Indian Institute of Geomagnetism since November 1992 (Rajaram and Gurubaran, 1998) and MF radar at Rarotonga (22°S, 200°E) started since 2002. It provides horizontal wind information in the altitude region 68–98 km for every 2 km height interval and 2 min time interval. The pulse width of 30 μs limits the height resolution to around 4.5 km so that there is a certain overlap of adjacent height gates. The raw winds for every 2 min are averaged for every hour and are used for further analysis. The daily averaged zonal wind data for the winters 2008–09 and 2002 are taken in the present study.

3. Results and discussion

3.1. State of SH winter during 2002 and NH winter during 2008–09

Fig. 1a shows the daily variation of ECMWF zonal mean temperature difference between the latitudes 90°N and 60°N (DT (90–