Journal of Atmospheric and Solar-Terrestrial Physics 105-106 (2013) 15–29

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Effect of polar sudden stratospheric warming on the tropical stratosphere and troposphere and its surface signatures over the Indian region

E.A. Resmi *, K. Mohanakumar, K.S. Appu

Department of Atmospheric Sciences, Cochin University of Science and Technology, Cochin 682016, India

ARTICLE INFO

Article history:
Received 7 May 2012
Received in revised form
7 May 2013
Accepted 10 July 2013
Available online 27 July 2013

Keywords:
Sudden stratospheric warming
Tropical response
Latitudinal variation

ABSTRACT

Polar and tropical stratosphere is known to undergo coupling during the stratospheric sudden warming (SSW) during winter. This coupling effect is studied over the different locations of India based on four typical cases of major warmings that has occurred in the years 1984–85, 1987–88, 1998–99 and 2008–09. The analysis has been carried out using the ECMWF interim reanalysis data from 1000 hPa to 1 hPa levels. The six Indian stations extending from northern to southern regions were selected to study the effect of SSW over Indian subcontinent. The study reveals the presence of a strong cooling in the entire tropics (30°N–30°S) associated with SSWs. Over the Indian region, the cooling became intense of the order 10–15 °C during the peak phase of the warming. The intensity of the cooling is computed based on the deviation from the mean values. The temperature during such occasions attains the lowest values of the season or the year. The near-surface (1000 hPa) temperature anomalies over the Indian regions also exhibit a lower temperature prior to the peak of high latitude warming. Before the peak of warming, an upwelling started in the tropical tropospheric layer that induces a lower temperature in the surface layer. Thus the cooling first appears in the lower surface layers. When the polar stratosphere attains the maximum temperature, the tropical stratosphere shows the annual minimum temperature. It indicates the existence of a strong coupling between the low and high-latitudes associated with SSWs. The possibility of a severe cold stratosphere over the tropical Indian region can be anticipated when a major warming develops over the polar region. The sudden strong cooling of the tropical stratosphere appears to alter the prevailing dynamical and radiative processes in the troposphere and lower stratosphere.

1. Introduction

The sudden stratospheric warming (SSW), also known as stratwarm, is one of the most dramatic meteorological phenomena occurring in the high latitude middle atmosphere during winter. After its discovery by Scherhag (1952), several studies were carried out on the different aspects of the warming phenomenon, especially after the emergence of rocket and satellite data (Labitzke, 1972; Labitzke and Barnett, 1973). The basic dynamics of the SSW is explained in terms of the propagation of planetary waves from the troposphere to the stratosphere (Matsuno, 1971). The SSWs are mainly classified as 'major' and 'minor' by World Meteorological Organisation (WMO). A major warming is defined as a thermal pulse increasing towards the pole of 60°N and followed by a reversal of the prevailing westerly wind to easterly at 10 hPa levels. The minor warming events are characterized by an increase in the temperature (at least 25 °C in a period of a week or even less) at any stratospheric level in any area of the winter hemisphere followed by the weakening in the stratospheric zonal wind directions (McInturff, 1978). During major warming, the polar vortex is either split in to two or displaced from the pole. Consequently the zonal wind anomalies undergo downward movement from stratosphere to troposphere. These anomalies can alter the tropospheric circulation features through a large flux of heat and momentum by waves smaller than wave number 3 (Limpasuvan et al., 2004).

One of the dynamical aspects of SSW is to cool the stratosphere over the tropics. The tendency of this cooling in the tropical stratospheric levels is initially reported by Reed et al. (1963) and later by Julian and Labitzke (1965). They analyzed the polar temperature increase and the corresponding cooling in the tropical and subtropical stratosphere up to 10°N. A clear picture on the global extent of SSW was first reported by Fritz and Soules (1970, 1972) from the radiance data obtained from Nimbus-3 satellite. They found that stratwarms are accompanied by a slight cooling in the stratosphere over the tropics and subtropics of both hemispheres. This out of phase variation is also explained by Dunkerton et al. (1981). The warming event in January 1977 is followed by tropospheric warming in polar region and cooling in middle latitudes (Quiroz, 1977) and

* Corresponding author. Tel.: +09503092869.
E-mail addresses: reshmiea@gmail.com, resmi@tropmet.res.in (E.A. Resmi).

1364-6826/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jastp.2013.07.003

correspondingly the anticyclonic circulation anomalies descended to earth's surface. It shows a clear indication of stratosphere–troposphere coupling during the stratwarm phase.

Several studies have been performed on the potential effects of high latitude sudden stratospheric warming on the tropical middle atmosphere (Mukherjee and Ramana Murty, 1972; Appu, 1984; Mukherjee et al., 1987; Mukherjee, 1990; Siva Kumar et al., 2003). Sivakumar et al. (2004) reported that the planetary wave activity and the effect of SSW over equatorial low latitudes are interlinked. Their calculations on Eliassen–Palm (E–P) flux using ECMWF reanalysis data shows a clear evidence of an equatorward propagation of planetary waves consecutive to the major warming episodes over polar region. The studies show that the SSWs are not only focused towards high/mid-latitudes, but also its effects can extend to low latitude's stratospheric and mesospheric fields. Tropical (5–15°N) mesospheric temperature field shows a cold anomaly during stratospheric warming events (Shepherd et al., 2007) and the wind field also enhanced by a westward propagating 7 and 16 day stationary planetary waves. Vineeth et al. (2008) pinpointed the connection between tropics and polar region through quasi 16-day wave that propagates from equator to pole with a persistent zero wind line, approximately 60 days prior to the major SSWs.

A composite of twelve stratwarms was used to explain the meridional circulation change in the troposphere and the stratosphere (Kodera, 2006) which leads to a see-saw convective activity. As a result, convective activity increases over the tropical southern hemisphere (i.e., 10°S-equator), and it decreases over northern hemispheric tropics (5–15°N). Mukhtarov et al. (2007) illustrates the out-of-phase relationship between the stratospheric temperatures at high- and low-latitudes during 2003/04 SSW event. The warming at polar latitudes is associated with a cooling at low-middle and tropical latitudes.

The dynamical effects of stratospheric warming over the tropical station at Gadanki were studied by using Indian MST Radar observations at Gadanki (13.5°N, 79.2°E). Sridharan et al. (2009) reported an enhancement in the stratospheric temperature due to the large gravity wave activity preceding to the major warming event in 2006. The latitudinal coupling is also explained through mass transport from low to high latitude during the stratospheric warming event in 2007 (Guharay and Sekar, 2012) over the above station with lidar data. Furthermore, an abrupt change in the tropical circulation induces a high humidity and low tropopause temperatures, which enhances the cirrus cloud formation over the grid 70–90°E (Sridharan et al., 2011).

In the present paper, we provide certain features of the tropical response of SSW emphasizing the Indian region from the surface to the upper stratosphere in four typical cases of major warmings. This paper is organized as follows. Section 2 describes the data and methodology, and the results and discussions are reported in Section 3. The out of phase temperature variations and the annual minimum temperature over tropics and over Indian regions are explained in Sections 3.2 and 3.3 respectively. In Section 3.4 we provide insights to the surface temperature decrease. The tropical upwelling and the downward propagation of cooling, over tropics are detailed in Sections 3.5 and 3.6. The summary is given in Section 4.

2. Data and methodology

The ECMWF interim reanalysis temperature data with a spatial resolution of 1.5° × 1.5° (Dee et al., 2011) is used in this study. The four stratwarm events were selected as case studies, which are (i) 1984/85 (mid-winter), (ii) 1987/88 (early), (iii) 1998/99 (double pulse) and (iv) 2008/09 (mid-winter). Stratospheric temperatures at 2 hPa, 5 hPa, 7 hPa and 10 hPa levels over the latitude of 80°N were used to examine the stratospheric warming intensities over the polar region during December to March period. Data at 1000 hPa level is considered to represent the surface level. The daily anomalies were calculated for the winter period (December through March) from the long term mean of 1980–2010 for the latitudinal belt of 30°N–30°S.

Six locations over the Indian region were selected to examine the intensity of stratospheric cooling associated with the four events. The selected stations are (1) Delhi (28°38′N, 77°12′E), (2) Jodhpur (26°18′N, 73°04′E), (3) Ahmedabad (23°00′N, 72°40′E), (4) Hyderabad (17°22′N, 78°02′E), (5) Bangalore (12°58′N, 77°35′E), and (6) Trivandrum (08°04′N, 77°0.02′E), and the locations are shown in Fig. 1. To examine the annual temperature variation for the selected stations, 31-day running mean is applied to the climatology of temperature (Nishii et al., 2009) for the stratospheric levels. Near-surface (1000 hPa) temperatures anomalies were computed from the extended winter mean (November–March) over the Indian stations. Vertical velocity is averaged over tropics (20°N–20°S) at 850 hPa, 500 hPa, 100 hPa, 50 hPa and 10 hPa levels. The propagation of cooling in the tropics is analyzed by taking the temperature anomalies from upper (1 hPa) to the surface (1000 hPa) levels. The anomalies were calculated from the seasonal means for each winter period separately. Seven day running mean is applied to the vertical velocity as well as in the vertical cross section of temperature anomalies. The following notations as are used in this study.

M_w: Major warming,
M_c: Cooling associated with M_w,
P_0: Peak day of the warming (the day of maximum temperature observed),
P_-/P_+: Pre/post phase of the P_0,
P_{-x}/P_{+x}: where X denotes no. of dates in P_-/P_+ phase.

3. Results and discussion

3.1. Polar stratospheric temperature variations during the four major warming events

Fig. 2 depicts the time series of the zonal polar upper stratospheric temperatures at 2 hPa (thick solid line), 5 hPa (dashed line), 7 hPa (gray line) and 10 hPa (thin solid line) levels over 80°N latitude during the major stratospheric warming events on 1984/85 (mid-winter warming), 1987/88 (early warming), 1998/99

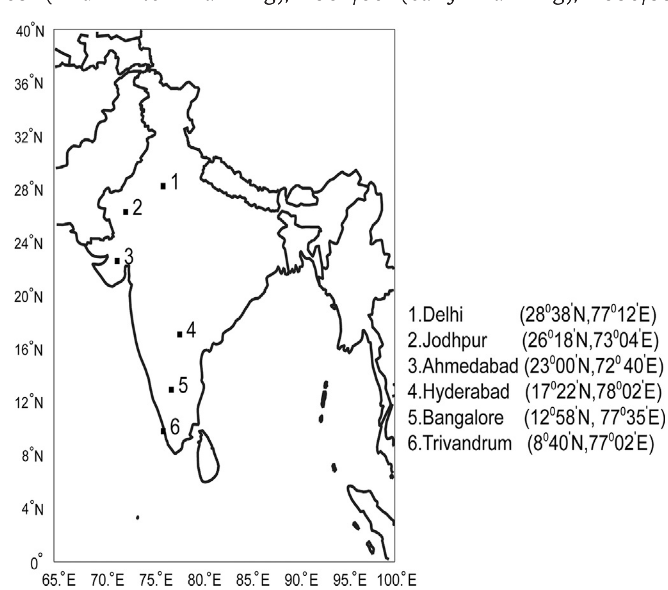

Fig. 1. Map of India to show the six selected locations.