Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Research Paper

Influence of sudden stratospheric warming and quasi biennial oscillation on western disturbance over north India

R. Remya [a,*], Ajil Kottayil [b], K. Mohanakumar [b]

[a] Department of Atmospheric Sciences, Cochin University of Science and Technology, Cochin 682016, India
[b] Advanced Centre for Atmospheric Radar Research, Cochin University of Science and Technology, Cochin 682022, India

ARTICLE INFO

Keywords:
Sudden stratospheric warming
Quasi-biennial oscillation
Western disturbance
El Nino southern oscillation

ABSTRACT

This study demonstrates the variability in Western Disturbance during the sudden stratospheric warming (SSW) period and its eventual influence on the north Indian weather pattern. The modulations in the north Indian winter under the two phases of the Quasi-biennial oscillation (QBO) during SSW periods are also examined. The analysis has been carried out by using the ERA interim reanalysis dataset for different pressure levels in the stratosphere and upper troposphere during the time period of 1980–2010. The daily minimum surface temperature data published by India Meteorological Department from 1969 to 2013 has been used for the analysis of temperature anomaly over north India during SSW. The period of intense stratospheric warming witnesses a downward propagation and intensification of kinetic energy from stratosphere to upper troposphere over the Mediterranean and Caspian Sea. When QBO is in easterly phase, the cooling over north India is much larger when compared to the westerly phase during instances of SSW. SSW coincident with the easterly phase of QBO causes an intensified subtropical jet over the mid-latitude regions. The modulation in circulation pattern in stratosphere and upper troposphere when ENSO occurs during SSW period is also analysed separately. This study provides the link among SSW, Western Disturbances and the north Indian cooling during winter season.

1. Introduction

Sudden stratospheric warming is a high latitude winter phenomenon, which often results in complete reversal of the zonal wind structure over middle stratosphere of high latitudes. After the occurrence of SSW, westerly wind reverses direction to easterlies and the temperature in the region enhances by about 50° C or more within a span of 10 days.

SSW is mainly forced by planetary scale waves which propagate upwards from the lower atmosphere (Matsuno, 1971). The eddy heat transport from the equatorial latitudes to the polar regions is also a factor for SSW (Schoeberl, 1978). However, it is seen that eddies are primarily responsible for the transport of planetary scale waves. This indicates that the warming occurs due to an increase in the upward flux of eddy geopotential from the low latitude troposphere to the high latitude stratosphere. The global extent of higher latitude stratospheric winter warming was first observed by Fritz and Soules (1970) in the thermal structure of the tropical as well as the subtropical atmosphere using Nimbus-3 satellite radiance data. Labitzke (1982), observed the relationship between high latitude SSW and low latitude quasi biennial oscillation (QBO). During the easterly phase of the equatorial QBO, there is a tendency for an enhanced development of height wave 1 in early winter which often leads to the development of a major warming during midwinter and hence to a generally warmer polar region. The large increase in the polar stratospheric temperatures during polar stratospheric warming events results in an enhancement in the downward longwave radiation flux emitted by the stratosphere (Ramanathan, 1977). It is shown that roughly ninety percent of the downward longwave radiative flux emitted by ozone occurs in the polar stratosphere. The increase in the downward longwave flux in the high latitude troposphere and the decrease in the low latitude troposphere cause a net reduction in the tropospheric available potential energy during winter. This highlights the importance of stratospheric circulation and radiative energy transfer to the tropospheric circulation in the lower latitudes during the period of SSW.

Several studies have focused on understanding the tropical stratospheric cooling and its association with high latitude warming (Reed et al., 1963; Labitzke et al., 1965; Dunkerton et al., 1981; Appu, 1984; Mukherjee et al., 1985a,b, 1987; 1990) based on satellites, ground based radar and other meteorological observations. These studies describe the dynamics of SSW and its influence on the tropical and subtropical systems. The changes in meridional circulation associated with winter

* Corresponding author.
E-mail address: rr.remya22@gmail.com (R. Remya).

http://dx.doi.org/10.1016/j.jastp.2017.05.011
Received 28 June 2016; Received in revised form 15 May 2017; Accepted 17 May 2017
Available online 20 May 2017

Table 1
The temperature and wind anomaly at 10 hPa level for SSW years.

Year	Peak day	Temperature ΔT (°C)	Zonal wind ΔU (ms^{-1})	Phase of QBO	ENSO phase
1983/1984	Feb 25, 1984	19.64	−34.94	East	La Nina
1984/1985	Jan 02, 1985	30.49	−56.32	East	La Nina
1987/1988	Dec 11, 1987	25.21	−43.97	West	El Nino
1988/1989	Feb 20, 1989	19.28	−32.22	West	La Nina
1990/1991	Jan 28, 1991	17.49	−32.95	West	Normal
1994/1995	Jan 30, 1995	21.13	−30.87	West	El Nino
1997/1998	Dec 27, 1997	17.43	−32.60	West	El Nino
1998/1999	Dec 17, 1998	29.33	−52.69	East	La Nina
2001/2002	Dec 29, 2001	26.86	−33.39	East	Normal
2002/2003	Jan 17, 2003	19.39	−34.98	West	El Nino
2003/2004	Dec 28, 2003	22.73	−46.09	East	Normal
2005/2006	Jan 23, 2006	18.87	−55.63	East	Normal
2007/2008	Feb 23, 2008	17.85	−36.53	East	La Nina
2008/2009	Jan 23, 2009	34.78	−45.19	West	Normal
2009/2010	Jan 31, 2010	17.75	−34.30	East	El Nino

stratospheric warming of polar region cause temperature decrease in the equatorial lower stratosphere and the upper troposphere (Kodera, 2006). Shepherd (2002) showed that sub-tropical mesosphere experiences cold anomaly with downward propagation of 1 km day^{-1}. A study by Yoshida and Yamazaki (2011) showed that the tropical tropopause experienced cold anomaly during the 2009 SSW event. During the polar warming, there is a corresponding cooling in the tropical and subtropical troposphere (Resmi et al., 2013). The above studies reveal that whenever there is high latitude stratospheric major warming, a corresponding decrease in the temperature occurs in the stratosphere of the tropics of both the hemispheres. A rapid change in the tropical convection and general circulation is observed during strong SSW events (Eguchi and Kodera, 2010). A recent study by Eguchi et al. (2015) shows enhanced tropical convection associated with SSW events.

The tropical weather patterns are also influenced by middle latitude weather systems like Western Disturbances (WD). The Western Disturbances arise as extra-tropical frontal systems at their region of origin over Mediterranean Sea/Caspian Sea but gradually lose the frontal characteristics as they move eastwards across Afghanistan/Pakistan towards India. WD often develops in the pre-existing westerly trough of the subtropical jet (STJ) and STJ provides the necessary upper level divergence for the intensification of WD (Karekar, 2009).

During winter, the variability in weather parameters of the mid-latitude region causes changes in weather pattern over north India. Heavy snowfall, gale wind and snow avalanches can occur in the Himalayan ranges and produce severe cold wave in association with WD (Guharay and Sekar, 2012).

Though several studies have looked into the synoptic aspects of Western Disturbance associated weather phenomena over north India (Venkiteshwaran, 1939; Malurkar, 1947; Mull and Desai, 1947; Pisharoty and Desai, 1956; Mooley, 1957; Ramaswamy, 1966; Datta and Gupta, 1967; Chakravarti, 1968a,b; Rao and Srinivasan, 1969; Singh and Kumar, 1977; Mohanty et al., 1998; Lang and Barros, 2004; Dimri and Niyogi, 2012, Dimri and Chevuturi, 2013), no attempt has been made so far to understand the association of polar SSW with the formation and development of western disturbances and its consequent effect on the north Indian weather. Our study focuses on examining the role of Western Disturbance in the background of SSW and the abnormal cooling that occurs in the north Indian region. Further, we also study the modulation in the weather pattern over northern India with respect to different phases of QBO.

The paper is structured as follows. Section 2 discusses the data and methodology; Section 3 presents the results and discussion and concludes with section 4.

2. Data and methodology

The incidents of SSW are usually characterized by abrupt increases in polar stratospheric temperatures, accompanied at times with change of zonal winds from westerly to easterly. The daily temperature and zonal wind data from the ECMWF (European Center for Medium Range Weather Forecast) ERA interim reanalysis at 10 hPa for the period 1980–2010 are used in this study. The temperature and zonal wind anomalies are calculated over the region lying within 60–90°N and 0–360°E. The anomalies in the daily temperature (ΔT) and zonal winds (ΔU) are computed based on the deviations from the long term climatological means (T and U) derived from 31 years of data.

The peak day of the event is the day where the maximum temperature anomaly over the winter polar stratosphere coincides with the zonal wind anomaly. We selected fifteen sudden stratospheric major warming events, 1983/1984, 1984/1985, 1987/1988, 1988/1989, 1990/1991, 1994/1995, 1995/1996, 1997/1998, 1998/1999, 2001/2002, 2003/2004, 2005/2006, 2007/2008, 2008/2009 and 2009/2010 based on the temperature and wind anomaly (Table 1). These fifteen major warming events were further classified into two based on the two phases of QBO. Table 1 shows the temperature and zonal wind deviation from climatologically mean value at the peak day of major sudden stratospheric warming period and the phase of QBO and ENSO for these years. The QBO is in its easterly phase for 1983/1984, 1984/1985, 1998/1999, 2001/2002, 2003/2004, 2005/2006, 2007/2008, 2009/2010 and in westerly phase for 1987/1988, 1988/1989, 1990/1991, 1994/1995, 1997/1998, 2002/2003, 2008/2009, respectively. The phase of QBO is identified from the Freie University Berlin analyses (FUB-analyses), monthly mean stratospheric charts analysed by Muench and Borden (1962) and is available from http://www.geo.fu-berlin.de/en/met/ag/strat/produkte/northpole/index.html.

Western Disturbance originates in the middle latitude region where its picks up moisture from the Mediterranean Sea and the Caspian Sea. Hence, for the analysis of WD, we chose the Mediterranean Sea and Caspian Sea region (5° W- 55° E; 30° N – 47° N) and also estimated the kinetic energy per unit mass from surface to upper stratosphere over this region. Meteorological parameters such as zonal, meridional wind and temperature were obtained from the European Center for Medium-Range Weather Forecasts Interim (ERA Interim; 0.75° x 0.75° resolution) dataset from surface (1000 hPa) to upper stratosphere (1 hPa) pressure level during the time period of 1980–2013 at 12.00 UTC (Dee et al., 2011). The kinetic energy per unit mass is calculated using the formula, ½(V^2), where V is the wind speed.

Out of the fifteen major stratospheric warming years, eight have occurred in the easterly phase of the QBO and remaining years are in the westerly phase. In the easterly phase events, four events are La Nina years (1983/84, 1984/85, 1998/99 and 2007/08), three years are normal years (no La Nina/El Nino event) and a moderate El Nino occurred during an year (2009/10). Similarly, for the westerly phased events, four years are El Nino (1987/88, 1994/95, 1997/98 and 2002/03) years, one is a La Nina (1988/89) year and the remaining two are normal years. This indicates that most of the La Nina events occur during the easterly phase of QBO while El Nino events occur in the westerly phase. ENSO events have been identified from the Oceanic Nino Index (ONI) which is the de-facto standard that NOAA uses for identifying El Nino (warm) and La Nina (cool) events in the tropical Pacific (Huang et al., 2015).

We selected 6 regions lying north of 20°N latitude in the Indian subcontinent for analysing the changes in the surface temperature minimum associated with SSW. The regions were selected based on topographical features. Region I is the northern part of India lying in the high altitude (Himalayan ranges) region. The desert region is represented in region III and region II represents the area lying between the high altitude region and the desert area. Region IV is low altitude region, and the north eastern India is represented in region V. The central plains of India are taken as region VI.

The daily surface temperature minimum data issued by the India Meteorological Department for the period 1969 to 2013 with resolution of 1°x 1°was used in the present study. The surface temperature deviations from the climatological mean (1969–2013) values were