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Geomagnetic-induced tropopause temperature and wind variation over low latitude

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The present study reports the effect of geomagnetic storm on 200 mb altitude temperature and wind at a low latitude (8.7°N, 77.8°N) Indian region. The severe and strong geomagnetic storm (Dst < – 100 nT) between 2000 and 2005 has been studied. The impact of the geomagnetic activity on temperature and wind variation is affected by the QBO (Quasi-Biennial Oscillation) phase. The tropopause temperature increases by ~ 2.5 K during W-phase of QBO and decreases by ~ 1.5 K during E-phase of QBO. The time lag between the onset of the event and the maximum change in temperature becomes a minimum during the transition phase of QBO. The horizontal wind velocity shows a pronounced effect over the east coast of India. The effect has not been observed during the onset of the south-west monsoon. The vertical wind velocity at 200 mb shows increase (or decrease) during W- (or E-) phase of the event.

Keywords: Storms and substorms, Tropical meteorology, Wind variation, Tropopause temperature
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1 Introduction

One of the earliest works on geomagnetic forcing of the lower atmosphere is by Macdonald and Woodbridge[1]. The time delay between a geomagnetic event and changes in atmospheric circulation at different locations was studied by various workers[2-5]. Lastovicka *et al.*[6] and Lastovicka[7] formulated meteorologically induced changes of the tropospheric response to geomagnetic storm. Occurrence probability of solar-geomagnetic-weather relations has been studied by several workers[8-17]. Xiong *et al.*[18] studied the planetary wave type oscillations in the ionosphere and found the relationship with the geomagnetic activity.

In order to further ascertain the solar-geomagnetic-weather relation over the Indian continent and the time delay between geomagnetic event and changes in tropopause temperature (or wind), the 5 years NCEP[19]-NCAR reanalysis data are analyzed in this paper. The southern part of India is located near the ocean coast, which provided further advantage to study the influence of mountain-land-ocean on the upper tropospheric variations.

2 Data sets

2.1 The NCEP-NCAR reanalysis

The National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) have completed a reanalysis project with a current version of the Medium Range Forecast (MRF) model[20]. This data set is a reanalysis of the global observational network of meteorological variables (wind, temperature, geopotential height, humidity on pressure levels, surface variables, and flux variables like precipitation rate) with a "frozen" state-of-the-art analysis and forecast system at a triangular spectral function of T62 to perform data assimilation throughout the period.

2.2 Geomagnetic index

In the present study, the geomagnetic storm that occurred during solar cycle 23 has been analyzed in detail. As many as 73 severe and strong (Dst < – 100 nT) geomagnetic storms were observed from January 2000 to December 2005. The data of geomagnetic activity index is obtained from the web site : http://swdcwww.kugi.kyoto-u.ac.jp/index.html. The minimum value of the Dst index (in nT) has been chosen as a zero day, and the corresponding tropopause temperature and wind variation for ± 10 days has been presented.

3 Results

Figure 1(a) shows the temperature variation at 200 mb, before and after the onset of the geomagnetic

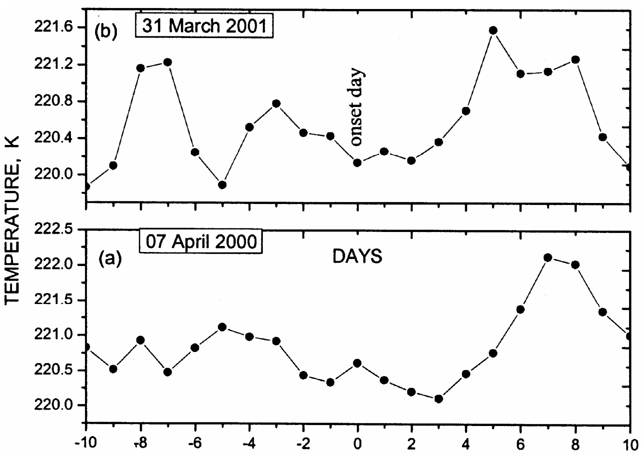

Fig.1—Tropopause temperature during geomagnetic event and W-phase of QBO: (a) geomagnetic event of 07 Apr. 2000 and, (b) geomagnetic event of 31 Mar. 2001

event on 07 Apr. 2000. The equatorial magnetic activity index (Dst) was – 288 nT. This was a case of severe geomagnetic storm. An increase in tropopause temperature by about 2 K after 6 days of the onset of the event was found. The stratospheric (50 hPa) zonal wind velocity over the equatorial region was 12.7 m/s in April 2000. This was a case of W-phase of QBO (Quasi-Biennial Oscillation), high solar activity ($F_{10.7}$ = 185), and pre-monsoon period.

Figure 1(b) shows the temperature variability at 200 mb level during geomagnetic event of 31 Mar. 2001. The W-phase of QBO was present during January-April, 2001 and E-phase of QBO was present during the rest of the year. The magnetic activity index (Dst) was < – 387 nT. The tropopause temperature increased by ~ 2 K after 5 days of the onset of the event.

Figure 2(a) shows the tropopause temperature during the geomagnetic event of 28 Oct. 2001. The maximum magnetic activity index (Dst) was < – 157 nT. The zonal wind velocity at 50 hPa in October 2001 was – 19.9 m/s, when tropopause temperature decreased by ~ 1.5 K and E-phase of QBO was present. It shows the presence of upper tropospheric jet, which might have increased the time lag between the onset of geomagnetic event and the maximum change in temperature.

Figure 2(b) shows the tropopause temperature obtained during the geomagnetic event of 11 Feb. 2004. The maximum magnetic activity index (Dst) was – 109 nT. The lower stratospheric (50 hPa) zonal wind velocity was – 19.2 m/s with E-phase of QBO. It shows the presence of lower stratospheric jet over equatorial latitude. The temperature is found to decrease by ~ 2 K on the day of the event.

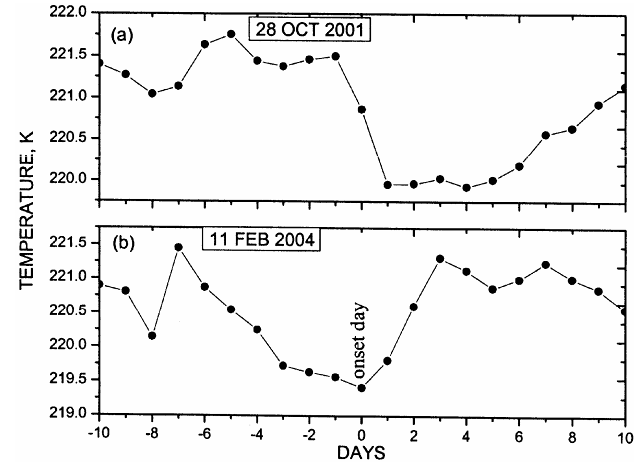

Fig. 2—Tropopause temperature during E-phase of QBO and severe geomagnetic storm of (a) 28 Oct. 2001 and (b) of 11 Feb. 2004

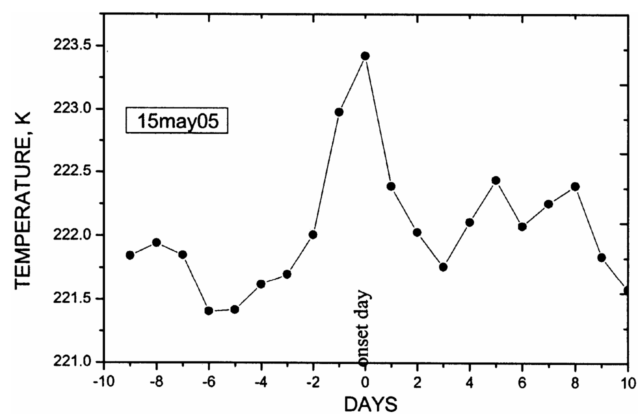

Fig. 3—Tropopause temperature during geomagnetic event of 15 May 2005 (This was the time for transition phase of QBO)

Figure 3 shows the tropopause temperature during the geomagnetic activity of 15 May 2005. The maximum magnetic activity index (Dst) was < – 263 nT. The lower stratospheric zonal wind velocity in May 2005 was 5.0 m/s and it was the transition phase of QBO. The time lag between onset of geomagnetic event and maximum increase in temperature was zero and the lower stratospheric zonal wind velocity was low. The increase in tropopause temperature was ~ 2 K.

Figure 4 shows the horizontal wind variation over 200 mb height during the geomagnetic activity of 18 June 2003. The maximum magnetic activity index (Dst) was < – 145 nT. The lower stratospheric zonal wind velocity in June 2003 was 1.4 m/s, which was the transition phase of QBO. The horizontal wind velocity at 200 mb changes to about 15 m/s after the onset of the event. The time lag between maximum

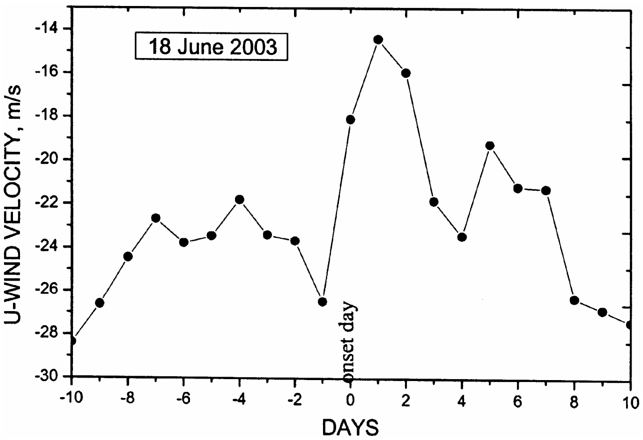

Fig. 4—The horizontal wind velocity at 200 mb during strong geomagnetic storm of 18 June 2003 (This was the period of W-phase of QBO.)

magnetic activity index and changes in maximum zonal wind velocity was one day.

Figure 5 shows the horizontal wind velocity variation during 16 July 2003 at 200 mb height. The maximum magnetic activity index (Dst) on 16 July 2003 was – 117 nT. The horizontal wind velocity at 200 mb height changes to ~ 12 m/s after onset of the event. The lower stratospheric zonal wind velocity over the equatorial region has been found to be about 1.0 m/s in July 2003; it was the transition phase of QBO, and the solar activity index $F_{10.7}$ = 132. There was no time lag between maximum magnetic activity index and changes in maximum horizontal wind velocity.

Figure 6 shows the horizontal wind velocity during geomagnetic storm on 31 Oct. 2003. The maximum magnetic activity index (Dst) was – 401 nT. The

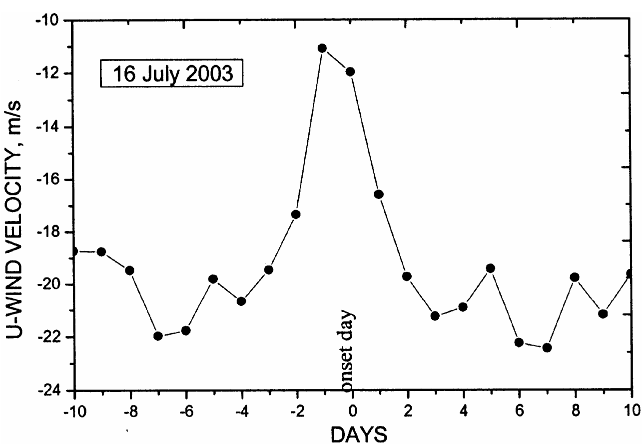

Fig. 5—The tropopause horizontal wind variation during geomagnetic event of 16 July 2003 (This event was the transition phase of QBO.)

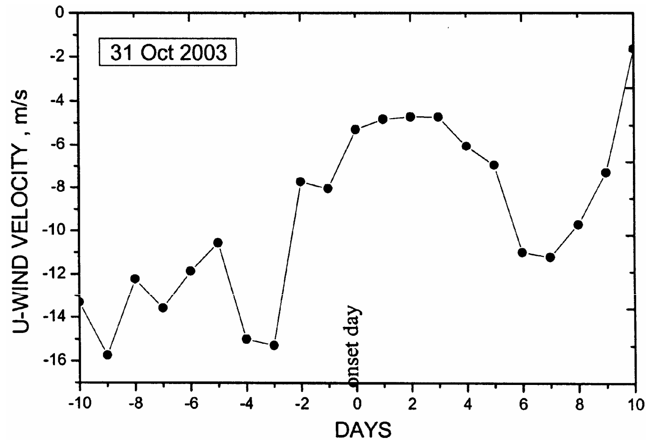

Fig. 6—The tropopause wind velocity during severe geomagnetic event of 31 Oct. 2003 and E-phase of QBO

lower stratospheric zonal wind velocity over the equator was – 13.3 m/s in October 2003 and it was E-phase of QBO. The horizontal wind velocity at tropopause height decreased to about 12 m/s after the onset of the event. The time lag between maximum magnetic activity index and changes in maximum horizontal wind velocity is 5 days. This increase in time lag compared to Fig. 5 event is due to the presence of lower stratospheric jet during this event. Also, the North-East monsoon was active during this period; it shows the bearing of the magnetic activity on the N-E monsoon.

During the period 29-30 Oct. 2003, three geomagnetic storms were observed. The first geomagnetic storm was associated with an abrupt decrease of the equatorial Dst-index, with a peak of – 180 nT at ~ 0900 hrs UT. The southward turning of the IMF B_z component, combined with high solar wind velocities, caused the next storm with a peak Ap-index of 300 nT and a Dst-index of – 401 nT at 2315 hrs UT on 30 Oct. 2003. After the third storm main phase, the Dst value recovered[21] to around 0 nT on 2 Nov. 2003.

Figure 7 shows the horizontal wind velocity at 200 mb altitude during the geomagnetic event of 14 Oct. 2000. The maximum geomagnetic activity index (Dst) on 14 Oct. 2000 was – 107 nT. The lower stratospheric equatorial zonal wind velocity in October 2000 was 7.0 m/s. This was the period of W-phase of QBO and maximum solar activity. The horizontal wind velocity decreased by ~ 7 m/s after 4 days of the onset of the event. The time lag between maximum geomagnetic activity and maximum changes in wind velocity as well as lower stratospheric zonal wind velocity is 4 days.

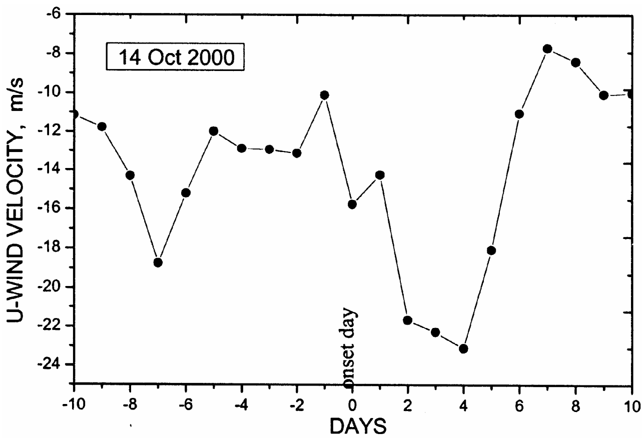

Fig. 7—The horizontal wind velocity during geomagnetic event of 14 Oct. 2000 and W-phase of QBO

Figure 8 shows the upper tropospheric horizontal wind velocity during the geomagnetic activity of 4 Apr. 2004. The maximum geomagnetic activity index (Dst) was – 112 nT. The equatorial lower stratospheric zonal wind velocity in April 2004 was 1.1 m/s. The horizontal wind velocity increases by about 7 m/s after 2 days of the onset of the event. The influence of geomagnetic activity on 200 mb horizontal wind velocity is found to be a maximum during the solar minimum activity period. The upper troposphere during solar minimum activity is unstable; therefore, the influence of magnetic activity has been seen on the dynamical parameters more effectively in solar minimum than the solar maximum activity condition. The time lag between maximum geomagnetic activity and maximum changes in wind velocity is 2 days. This shows the influence of lower stratospheric zonal wind velocity on the time lag between geomagnetic activity and tropospheric wind variation.

Figure 9 shows the vertical wind velocity at 200 mb altitude during the geomagnetic event of 4 Apr. 2004. The maximum geomagnetic activity index (Dst) was – 112 nT on 4 Apr. 2004. The equatorial lower stratospheric zonal wind velocity at 50 hPa in April 2004 was 1.1 m/s. The vertical wind velocity at 200 mb increased to ~ 12 m/s on the day of the onset of the event. This event was in solar minimum, W-phase of QBO, minimum stratospheric zonal wind velocity, and not affected by the monsoon condition.

Figure 10 shows the vertical wind velocity at 200 mb altitude during the geomagnetic activity event of 11 Feb. 2004. The maximum geomagnetic activity index (Dst) was – 109 nT on 11 Feb. 2004. The vertical wind velocity increased to ~ 15 m/s after 4 days of the onset of the event. The zonal wind velocity over the equatorial lower stratospheric region in February 2004 was – 19.2 m/s. The lower stratospheric jet stream and E-phase of QBO might have caused the increase in wind velocity to about 5 m/s after 4 days of the onset of the event.

Figure 11 shows the vertical wind velocity at 200 mb altitude during the geomagnetic event of 21 Nov. 2002. The maximum geomagnetic activity index (Dst) on 21 Nov. 2002 was – 128 nT. The zonal wind velocity over the equatorial lower stratospheric region in November 2002 was 6.8 m/s and it was the W-phase of QBO. The maximum increase in the wind velocity has been obtained after 5 days of the onset of the event by about 7 m/s. The north-east monsoon was active in November 2002. The N-E monsoon might have increased the time delay between the onset of the event and its effect on upper tropospheric wind velocity.

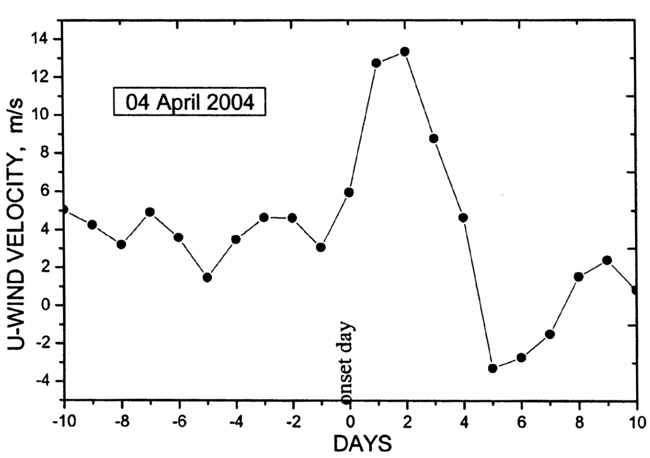

Fig. 8—The horizontal wind velocity during geomagnetic event of 04 Apr. 2004 and transition phase of QBO

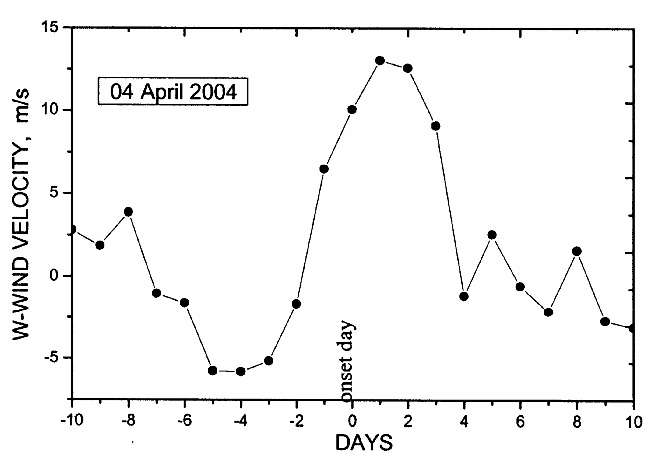

Fig. 9—The vertical wind velocity over 200 mb during geomagnetic event of 04 Apr. 2004 and transition phase of QBO

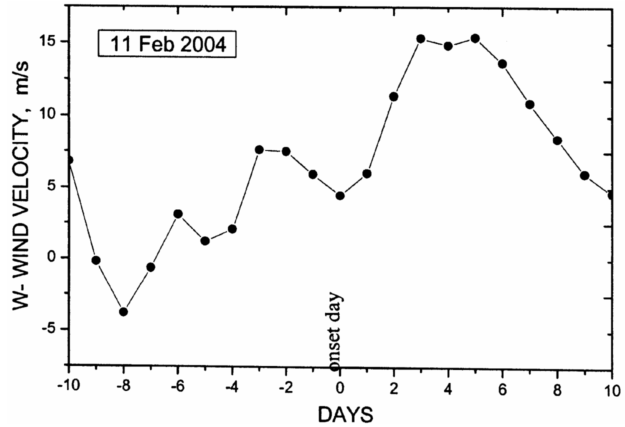

Fig. 10—The vertical wind velocity obtained during geomagnetic activity of 11 Feb. 2004 and E-phase of QBO

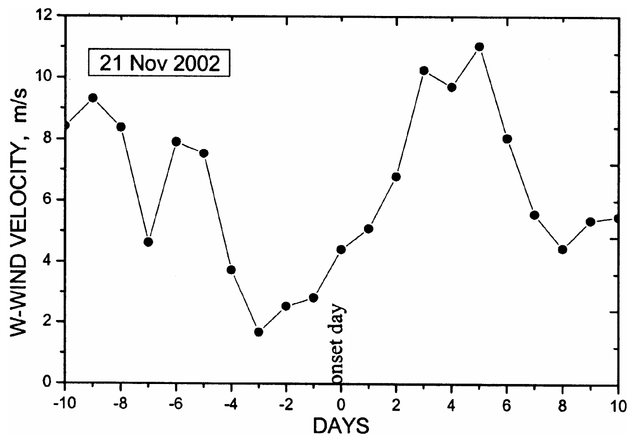

Fig. 11—The vertical wind velocity obtained over 200 mb during geomagnetic event of 21 Nov. 2002 (This was the W-phase of QBO and return monsoon period.)

Figure 12(a) shows the vertical wind velocity at 200 mb during the geomagnetic activity of 24 Nov. 2001 over the Indian continent. The maximum geomagnetic activity index (Dst) on 24 Nov. 2001 was – 221 nT. This event corresponds to maximum solar activity, E-phase of QBO, winter condition, unstable atmosphere, over the continent and the equatorial zonal wind velocity of – 20.5 m/s. The time lag between the onset of the event and its effect is 2 days and velocity decreased by 6 m/s. The variability over the ocean has also been shown. Figure 12(b) shows the vertical wind velocity over the Bay of Bengal. The vertical wind velocity over the ocean shows the time delay between maximum geomagnetic activity and its effect on increase in vertical wind velocity by 6 m/s after ~ 4 days.

4 Discussion

Despite a large number of studies examining the possibility that geomagnetic activity influences the

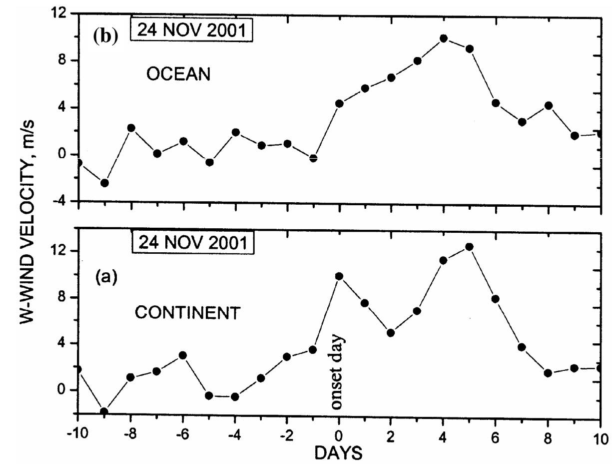

Fig. 12—The 200 mb vertical wind velocity obtained during geomagnetic event of 24 Nov. 2001 and E-phase of QBO corresponding to (a) the continent region and (b) the ocean region

lower atmosphere, there is no definable 'current understanding' in this field. Danilov and Lastovicka[15] suggest that the tropospheric response to solar activity is more developed in winter, because the winter atmosphere is less stable. This view is shared by Gabis and Troshichev[17], who suggest that stratification in stratospheric zonal circulation is depressed in winter and greatest in summer. Macdonald and Roberts[3] reported that the time delay between geomagnetic event and changes in atmospheric circulation is not constant, and subsequently the geographic nature of the relationship varies as each individual trough maximizes at different locations. Lastovicka *et al.*[6] formulated three specific features of the tropospheric response to geomagnetic storm: (i) Tropospheric responses have a microregional character, possibly due to changes in circulation and orography. (ii) The tropospheric response to geomagnetic storm is much more pronounced in winter than in summer, possibly because the direct solar radiation input to the troposphere is lower, and the atmosphere is less stable in winter. (iii) The winter response of the troposphere substantially depends on the phase of the QBO.

Researchers have found that geomagnetic-weather links are stronger during particular QBO phase[22, 23]. Although the role of the QBO within daily solar-weather link is, like their annual counterparts, also unclear, Tinsley and Deen[24] suggest it could be related to its role in the dynamic coupling of the stratosphere to the troposphere and the resultant chemical transport.

5 Conclusion

Using the NCEP-NCAR reanalysis data the present authors have studied the influence of severe geomagnetic storms on the Indian equatorial 200 mb temperature, and wind variation. The severe and strong (Dst < – 100 nT) geomagnetic storm between 2000 and 2005 has been studied in the present work. The change in the 200 mb temperature and wind velocity over Indian continent followed by the geomagnetic storm is found to be influenced by the QBO phase. The 200 mb temperature increases by about 2.5 K during W-phase of QBO and decreases by about -3 K during E-phase of QBO. The three-to-five days time lag has been observed between the onset of the event and the change in temperature. The time delay between onset of the event and the maximum change in temperature becomes a minimum during the transition phase of QBO. The decrease in horizontal wind velocity before the onset of the event during E-phase of QBO has been observed. The pronounced effect on wind velocity has been observed over the east coast of India, but it does not show any effect during the monsoon period. Similar to the horizontal wind velocity, vertical wind velocity also shows changes followed by the onset of the magnetic storm.

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