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Quiet variability of equatorial $\mathbf{E} \times \mathbf{B}$ drifts during a sudden stratospheric warming event

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[1] We present strong evidence that during the January 2008 minor sudden stratospheric warming (SSW) event, the equatorial vertical $\mathbf{E} \times \mathbf{B}$ drifts exhibit a unique and distinctive daytime pattern. We do not think one event causes the other, however both events might be related through the global effects of planetary waves. The drifts were measured by the Jicamarca Incoherent scatter radar located under the magnetic equator. We have observed an anomalous temporal variation of the vertical $\mathbf{E} \times \mathbf{B}$ drifts during the minor SSW event, showing a semidiurnal variation with very large amplitudes lasting for several days. Large differences in the $\mathbf{E} \times \mathbf{B}$ drifts were observed during a period of large increase of temperature and a large decrease of mean zonal wind, in the high latitude stratosphere (60°–90°N). This high correlation is an unexpected finding which might shed new light on sources and mechanisms of quiet-time ionospheric variability. **Citation:** Chau, J. L., B. G. Fejer, and L. P. Goncharenko (2009), Quiet variability of equatorial $\mathbf{E} \times \mathbf{B}$ drifts during a sudden stratospheric warming event, *Geophys. Res. Lett.*, *36*, L05101, doi:10.1029/2008GL036785.

1. Introduction

[2] The electrodynamic $\mathbf{E} \times \mathbf{B}$ plasma drifts play important roles on the plasma distribution and dynamics in the low latitude ionosphere. The climatology of these drifts have been derived from more than 35 years of incoherent scatter observations at the Jicamarca Radio Observatory (JRO) (11.95°S, 76.8°W) for different times of the day, seasons, solar conditions, and magnetic activity. Moreover, their characteristics for different longitude sectors have been obtained from few years of satellite observations [e.g., *Scherliess and Fejer*, 1999]. In these studies, a large day-to-day variability has been observed. Its understanding is fundamental for the development of realistic ionospheric and thermospheric models.

[3] For magnetically active times, the variability is associated mainly with magnetospheric disturbances [e.g., *Fejer and Scherliess*, 2001]. During geomagnetically quiet periods, the equatorial plasma drifts results from the combined effects of *E* and *F* region magnetic field-line-integrated thermospheric winds weighted by the integrated Pedersen conductivity [e.g., *Richmond*, 1995]. The thermospheric winds are highly variable as a result of changes in the global tidal forcing, and effects of irregular winds, planetary, and gravity waves, most of these changes originating in lower atmospheric regions. For example, atmospheric tides generated in the troposphere and stratosphere propagate upward and dominate the dynamics of the lower thermosphere [e.g., *Hagan et al.*, 2001].

[4] Using Jicamarca data, *Fejer and Scherliess* [2001] studied the quiet-time variability of the equatorial *F*-region vertical plasma drifts. They showed that the daytime average upwards drifts do not vary much with solar activity and the variability is dependent on local time, season, and solar cycle. For example, the largest standard deviations were found for the dawn-noon sector, particularly during solar minimum conditions. During high solar activity, the *F*-region dynamo is more efficient, therefore the altitudinal and latitudinal contributions smear out the quiet time variability resulting from the mesospheric and lower thermospheric processes, that in turn are associated to processes originating in the lower atmospheric regions.

[5] In this letter we present the variability of Jicamarca daytime $\mathbf{E} \times \mathbf{B}$ drifts observed during quiet time, December solstice, and solar minimum conditions as part of World Days runs in support of sudden stratospheric warming (SSW) campaigns. A SSW is an event where the polar vortex of westerly winds in the Northern winter hemisphere abruptly (i.e., in a few days time) slows down (minor event) or even reverses direction (major event), accompanied by a rise of stratospheric temperature by several tens of degrees. As a large-scale meteorological process in the winter polar region, it strongly affects vertical coupling in a large range of altitudes, from stratosphere to mesosphere. It has been under extensive observational and theoretical investigation for many years [e.g., *Andrews et al.*, 1987].

[6] The key mechanism for SSW events is the growth of planetary waves propagating upward from the troposphere and their non-linear interaction with the zonal mean flow [*Matsuno*, 1971]. At high latitudes, the interaction decelerates and/or reverses the eastward winter stratospheric jet and also induces a downward/upward circulation in the stratosphere/mesosphere causing adiabatic heating/cooling [e.g., *Hoffmann et al.*, 2002; *Liu and Roble*, 2002]. While the effects associated with SSW are relatively well studied at polar latitudes, there are only few reports on low-latitude response to SSW. At stratospheric altitudes, warming at polar latitudes is associated with opposite changes at low-midlatitude, i.e., cooling in temperature and an anomalous increase of zonal mean wind [*Mukhtarov et al.*, 2007]. Some studies indicate that this pattern continues up to the mesosphere and lower thermosphere [e.g., *Shepherd et al.*, 2007; *Pancheva et al.*, 2008, and references therein], but the evidence is sparse. Moreover, the coupling between high and tropical latitudes

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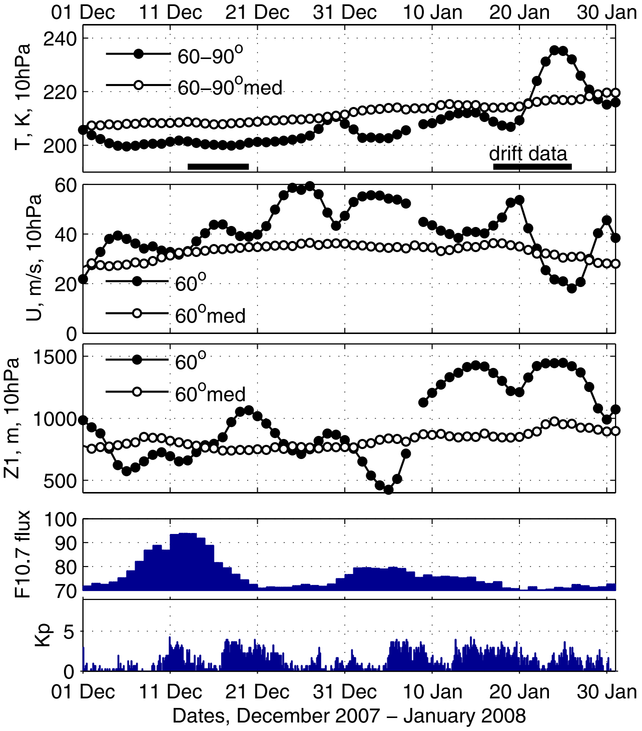


Figure 1. Main NCEP stratospheric polar parameters (zonally averaged temperature, zonal wind, and planetary wave 1 amplitude) along with their corresponding solar and magnetic parameters for December 2007 and January 2008. Thirty-year median values are shown with open circles. A minor SSW event occurred around January 24, 2008.

is not restricted to SSW, for example, signatures of the equatorial quasi-biennial oscillation (QBO) have been observed at middle and high latitudes. Moreover, *Labitzke* [1987] has suggested that QBO can trigger the SSW events.

2. January 2008 Sudden Stratospheric Warming

[7] The evolution of the January 2008 minor SSW event is outlined in Figure 1. Stratospheric high latitude data is obtained from the National Center for Environmental Prediction (NCEP). The top panel shows zonal mean temperature at 10hPa (~32 km) and 60-90°N latitude for December 2007 - January 2008 period in comparison with 30-year mean temperature. After staying at very low levels in December 2007 and first part of January 2008, stratospheric temperatures began increasing on January 21 and reached the maximum on January 24, indicating sudden stratospheric warming. The dark bars on the top panel show periods of Jicamarca data availability in December 2007 and January 2008. The zonal mean zonal wind averaged over 60°N decreased to ~20 m/s, but have not reversed direction as required for a major sudden stratospheric warming. The planetary wave 1 amplitude of geopotential height at 10 hPa and 60°N shows a large increase, but starting earlier (January 10th).

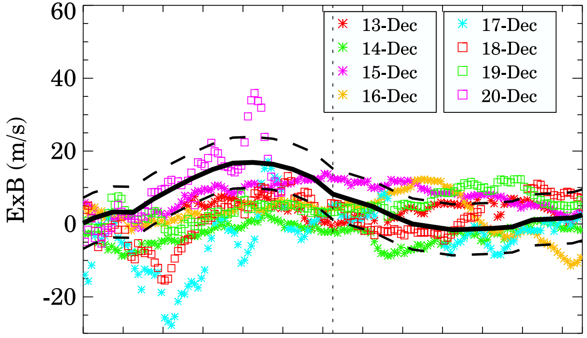
[8] The region of warm temperatures started to descend to lower altitudes (not shown), propagating to 30 hPa (~23 km) in 2–3 days. The December 2007 - January 2008 period was characterized by low solar and geomagnetic activity, enabling easier interpretation of observations due to low variations in magnetospheric and geomagnetic drivers. We note that Jicamarca observations in January 2008 commenced before the rise in stratospheric temperature, allowing studies of temporal development in ionospheric features, but ended while stratospheric temperatures were still elevated.

3. Jicamarca Vertical Drifts

[9] Between December 13–20, 2007 and January 17–26, 2008, vertical plasma drifts were measured at JRO using the incoherent scatter radar (ISR) technique described by *Kudeki et al.* [1999]. JRO vertical drifts were obtained every 5 minutes and every 15 km, between 140 and 900 km. In Figure 2, we show the average in altitude (200–400 km) daytime *F*-region vertical plasma drifts for the December 2007 (control) and January 2008 (around SSW) days as function of time of the day. The accuracy of the vertical drift measurements is excellent (<1 m/s). Over Jicamarca, a vertical drift of 40 m/s corresponds to a zonal electric field of about a 1 mV/m. During December solstice, nighttime ISR measurements are usually contaminated by strong coherent echoes coming from equatorial spread *F* (ESF) irregularities. Therefore, in this study we will focus on the daytime results.

[10] The data of each day is indicated with different colors and symbols. The expected quiet time value for a

(a) Control days (Dec-2007)



(b) Around SSW days (Jan-2008)

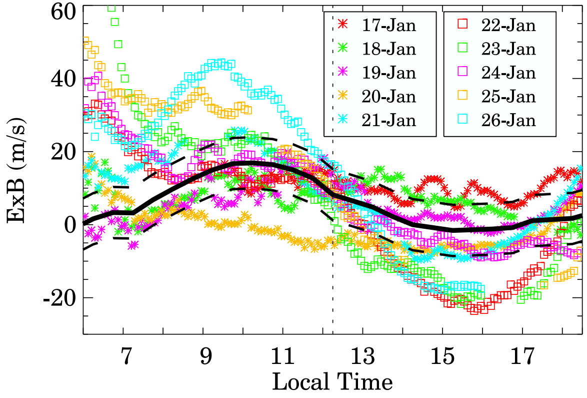


Figure 2. Daytime vertical **E** × **B** drifts measured over Jicamarca on (a) December 13–20, 2007 (control days) and (b) January 17–26, 2008 (around SSW days), as function of local time. Data for different days are indicated with different symbols and colors. The expected average and standard deviation quiet-time values are indicated with black solid and dashed curves, respectively.

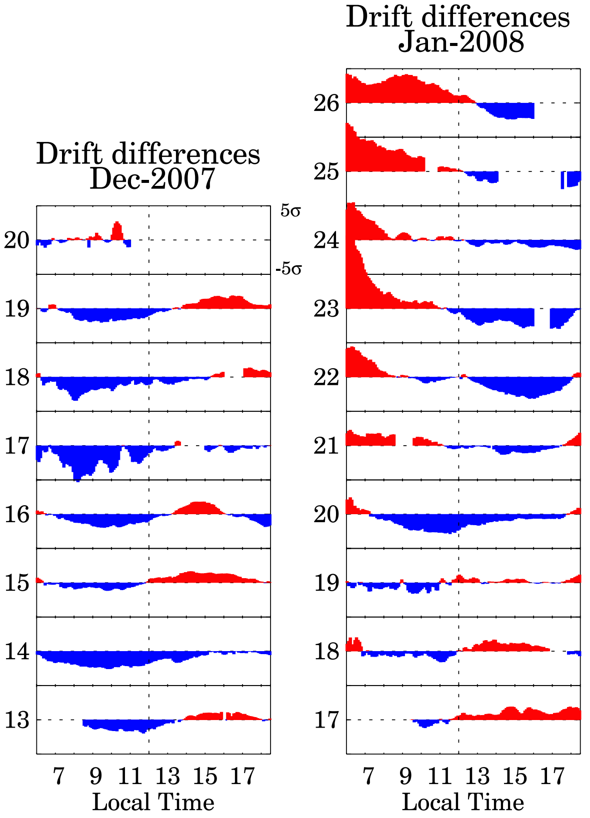


Figure 3. Normalized daytime **E** × **B** differences as function of local time for each of the day: (left) December 2007 and (right) January 2008. Differences are obtained with respect to the average quiet time value and normalized to the standard deviation (σ). Positive/negative values are represented in red/blue. The scale for each day is $\pm 5\sigma$.

solar flux of 80 is represented with a thick black curve. The dashed black curves represent the standard deviation (σ). From *Fejer and Scherliess* [2001, Figure 2], the morning standard deviation is slightly larger (~7 m/s) than the afternoon values (~5 m/s). Here we are using a conservative constant value of 7 m/s. Very similar values are expected for December and January days.

[11] As shown in Figure 1, most of the data were obtained during magnetically quiet conditions ($K_p < 3.0$) except for the December 17 and 20, showing large variability for few hours. It is clear that the January 2008 days present much larger amplitudes than the December 2007 days, not related to magnetic activity since the January days were quieter than the December days.

[12] Figure 3 shows the normalized difference between the measured drifts and the expected quiet time values as function of time of the day for each day: (a) December 2007 (left) and (b) January 2008 (right). Positive/negative values are indicated in red/blue. By morning (afternoon), we have considered data taken between 0630 and 1215 LT (1215 and 1830 LT).

[13] The large departure of the January drifts from the long-term mean values has a distinctive pattern and is different from the behavior expected due to solar drivers. It is characterized by a semidiurnal wave with large positive (morning) and negative (afternoon) amplitudes, increasing with time (day), particularly after January 20. The largest difference (~10σ) is observed around 0700 LT on January 23. In contrast, the largest quiet-time difference in the December 2007 data (excluding December 17–18 magnetically active period) does not exceed 2σ.

4. Discussion and Concluding Remarks

[14] Comparing the average drift differences and the SSW parameters of Figure 1, the larger quiet time differences occur around the time of a sudden increase of stratospheric temperature. To show this correlation, in Figure 4, we compare the difference of some selected stratospheric high-latitude parameters with respect to their 30-year median values, against the average morning and afternoon equatorial drift differences. There is very good correlation/(anticorrelation) with the stratospheric polar temperature/(zonal wind). Note that the amplitudes of the afternoon values are shown with reverse signs. The correlation is higher using the morning averages, with values of 0.86 and −0.91 using temperature and zonal wind data, respectively. On the other hand, the correlation values using the December data are less than 0.2.

[15] As shown by *Liu and Roble* [2002], the key mechanism for the generation of SSW is the growth of upward-propagating planetary waves from the troposphere and the interaction between the transient wave and the mean flow. The resonant wave amplification under winter conditions is the main mechanism for planetary wave amplification. Therefore large diurnal and semidiurnal variations could be created in high latitude mesosphere and lower thermosphere

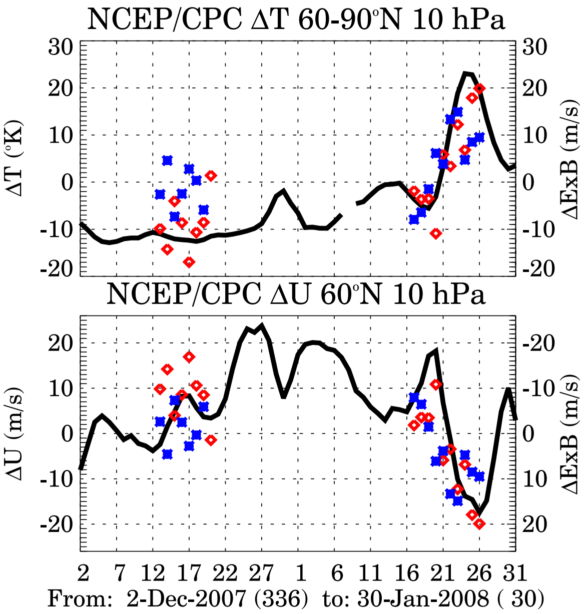


Figure 4. Stratospheric polar differences with respect to the 30-year median values for the December 2007 and January 2008 period: (top) stratospheric temperature difference at 60–90°N, and (bottom) stratospheric zonal wind difference at 60–90°N. The morning/afternoon averaged vertical **E** × **B** differences are overplotted in red/blue (◇/⋆ symbols) (see scale in the right y-axis). Note that signs have been reversed for the zonal wind plot.

in association with SSWs. However, such variations are not expected at low latitudes, particularly at ionospheric altitudes.

[16] Our observations of increase daytime vertical drift differences are consistent with earlier reports of increases in vertical drift with multi-day periodicities, which are interpreted as characteristics of planetary wave modulation [*Fuller-Rowell et al.*, 2008; *Forbes and Leveroni*, 1992]. The presence of multi-day periodicities in the mesosphere-lower thermosphere was demonstrated in both numerical simulations [e.g., *Fuller-Rowell et al.*, 2008] and experimental data [e.g., *Pancheva et al.*, 2008]. Nevertheless, it is not clear if planetary waves are generated in-situ or propagate upward all the way from the troposphere. The interaction between planetary wave and migrating tides generates non-migrating tides; superposition of different tidal modes results in increased variability in tidal amplitudes and phases. Since the occurrence of SSW is related to the growth of planetary waves, our observations of increased semidiurnal signature in the *F*-region vertical drift during SSW can be interpreted as direct evidence of modulation of *E*-region dynamo by planetary wave.

[17] Prior to the January 2008 experiment, SSW events were not associated with effects occurring at ionospheric altitudes. Analysis of ISR data shows that during the January 2008 SSW event unusual signatures are seen across large range of latitudes and in various ionospheric and thermospheric parameters, demonstrating the global nature of the effects. Besides increased variations in equatorial vertical drift, unusual electron density was observed at lower mid-latitude (18°N) by Arecibo ISR, M. Sulzer, private communication, 2008), changes in ionospheric temperatures were reported at middle latitude (42.6°N) by Millstone Hill ISR [*Goncharenko and Zhang*, 2008], and an increase in tidal amplitudes of lower thermospheric winds was found at high amplitude (65.1°N) by PFISR (M. Nicolls, private communication, 2008).

[18] The January 2008 SSW event, present unique peculiarities that might be useful to isolate, for the first time, the important contributions of the lower atmospheric forcing to the variability of the equatorial plasma drifts, particularly its effects in the *E*-region dynamo. These peculiarities are: (a) the magnetic activity was very low, much lower than December 2007, (b) the solar flux was low making the *F* region influence less important, and (c) this event has been observed by many instruments around the world. This unique dataset in conjunction with coupled models could help not only in the understanding on the SSW events and the quiet-time variability of equatorial drifts, but also on how the different altitudinal and latitudinal regions are coupled. We have observed similar semidiurnal patterns in the equatorial drifts coincident with three stratospheric warming periods (Dec 2000, Jan 2003, Jan 2004), and a careful analysis of these periods will be presented in a future study.

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References

Andrews, D., J. R. Holton, and C. B. Leovy (1987), *Middle Atmosphere Dynamics*, pp. 259–294, Academic, London.

Fejer, B. G., and L. Scherliess (2001), On the variability of *F*-region vertical plasma drifts, *J. Atmos. Sol. Terr. Phys.*, *63*, 893–897.

Forbes, J. M., and S. Leveroni (1992), Quasi 16-day oscillation in the ionosphere, *Geophys. Res. Lett.*, *19*(10), 981–984.

Fuller-Rowell, T. J., et al. (2008), Impact of terrestrial weather on the upper atmosphere, *Geophys. Res. Lett.*, *35*, L09808, doi:10.1029/2007GL032911.

Goncharenko, L., and S.-R. Zhang (2008), Ionospheric signatures of sudden stratospheric warming: Ion temperature at middle latitude, *Geophys. Res. Lett.*, *35*, L21103, doi:10.1029/2008GL035684.

Hagan, M. E., R. G. Roble, and J. Hackney (2001), Migrating thermospheric tides, *J. Geophys. Res.*, *106*, 12,739–12,752.

Hoffmann, P., W. Singer, and D. Keuer (2002), Variability of the mesospheric wind field at middle and arctic latitudes in winter and its relation to stratospheric circulation disturbances, *J. Atmos. Sol. Terr. Phys.*, *64*, 1229–1240.

Kudeki, E., S. Bhattacharyya, and R. F. Woodman (1999), A new approach in incoherent scatter *F* region $\mathbf{E} \times \mathbf{B}$ drift measurements at Jicamarca, *J. Geophys. Res.*, *104*, 28,145–28,162.

Labitzke, K. (1987), Sunspots, the QBO and the stratospheric temperature in the north polar region, *Geophys. Res. Lett.*, *14*, 535–537.

Liu, H.-L., and R. G. Roble (2002), A study of a self-generated stratospheric sudden warming and its mesospheric-lower thermospheric impacts using the coupled TIME-GCM/CCM3, *J. Geophys. Res.*, *107*(D23), 4695, doi:10.1029/2001JD001533.

Matsuno, T. (1971), A dynamical model of the stratospheric sudden warming, *J. Atmos. Sci.*, *28*, 1479–1494.

Mukhtarov, P., et al. (2007), Large-scale thermodynamics of the stratosphere and mesosphere during the major stratospheric warming in 2003/2004, *J. Atmos. Sol. Terr. Phys.*, *69*, doi:10.1016/j.jastp.2007.07.012.

Pancheva, D., et al. (2008), Latitudinal wave coupling of the stratosphere and mesosphere during the major stratospheric warming in 2003/2004, *Ann. Geophys.*, *26*, 467–483.

Richmond, A. D. (1995), Modeling the equatorial ionospheric electric fields, *J. Atmos. Terr. Phys.*, *57*, 1103–1115.

Scherliess, L., and B. G. Fejer (1999), Radar and satellite global equatorial *F*-region vertical drift model, *J. Geophys. Res.*, *104*, 6829–6842.

Shepherd, M. G., D. L. Wu, I. N. Fedulina, S. Gurubaran, J. M. Russell, M. G. Mlynczak, and G. G. Shepherd (2007), Stratospheric warming effects on the tropical mesospheric temperature field, *J. Atmos. Sol. Terr. Phys.*, *69*, 2309–2337.

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