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Bela G. Fejer, *Utah State University*
M. E. Olson
J. L. Chau
C. Stolle
H. Luhr, et al.

Lunar-dependent equatorial ionospheric electrodynamic effects during sudden stratospheric warmings

B. G. Fejer,[1] M. E. Olson,[1] J. L. Chau,[2] C. Stolle,[3] H. Lühr,[3] L. P. Goncharenko,[4] K. Yumoto,[5] and T. Nagatsuma[6]

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[1] We have used plasma drift and magnetic field measurements during the 2001–2009 December solstices to study, for the first time, the longitudinal dependence of equatorial ionospheric electrodynamic perturbations during sudden stratospheric warmings. Jicamarca radar measurements during these events show large dayside downward drift (westward electric field) perturbations followed by large morning upward and afternoon downward drifts that systematically shift to later local times. Ground-based magnetometer measurements in the American, Indian, and Pacific equatorial regions show strongly enhanced electrojet currents in the morning sector and large reversed currents (i.e., counterelectrojets) in the afternoon sector with onsets near new and full moons during northern winter warming periods. CHAMP satellite and ground-based magnetic field observations indicate that the onset of these equatorial afternoon counterelectrojets is longitude dependent. Our results indicate that these large electrodynamic perturbations during stratospheric warming periods are due to strongly enhanced semidiurnal lunar wave effects. The results of our study can be used for forecasting the occurrence and evolution of these electrodynamic perturbations during arctic winter warmings.

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1. Introduction

[2] The quiet time low-latitude ionospheric electric fields are generated by dynamo action of thermospheric neutral winds [e.g., *Richmond*, 1995a; *Heelis*, 2004]. In the equatorial region the zonal electric fields drive strong daytime lower *E* region eastward currents, called equatorial electrojets, in narrow latitudinal bands centered at the dip equator [e.g., *Richmond*, 1995b]. The zonal electric fields also drive equatorial *E* and *F* region vertical plasma drifts which have been studied extensively using radar and satellite measurements [e.g., *Fejer*, 1997].

[3] The initial geomagnetic field measurements near the magnetic equator have already indicated the large variability of the equatorial electrojet intensity. *Bartels and Johnston* [1940] reported the occasional occurrence of afternoon depressions in the electrojet horizontal magnetic field component (ΔH) below their nighttime values during geomagnetic quiet days. They suggested that the largest variations, on so-called "big L days," were due to the superposition of highly magnified lunar tides on the normal quiet time variation. Morning and afternoon quiet time anomalous equatorial electrojet current reversals, called counterelectrojets, have been extensively studied since the nineteen sixties [e.g., *Gouin*, 1962; *Gouin and Mayaud*, 1967; *Hutton and Oyinloye*, 1970; *Rastogi*, 1973]. Comprehensive reviews of these studies were by published by *Mayaud* [1977] and *Marriott et al.* [1979]. The quiet time current reversals are confined to the equatorial electrojet region and are most common during low solar activity years [*Rastogi*, 1974b]. They can occur for a week or so, but not necessarily on the same days, at longitudes separated by more than a few hours. Afternoon counterelectrojets occur mainly near new and full moons (lunar ages 0000 and 1200); morning counterelectrojets are most common after the lower and upper transits (lunar ages 9 and 21) [*Onwumechilli and Akasofu*, 1972; *Hutton and Oyinloye*, 1970; *Rastogi*, 1974a, 1975].

[4] In the Indian sector, counterelectrojets are most frequent in the afternoon hours of the June solstices; in the American sector, counterelectrojets are most common in the morning hours of December solstices [*Patil et al.*, 1990]. However, as pointed out by *Mayaud* [1977], it is remarkable that all published examples of magnetically quiet time very large

[1]Center for Atmospheric and Space Sciences, Utah State University, Logan, Utah, USA.
[2]Radio Observatorio de Jicamarca, Instituto Geofisico del Peru, Lima, Peru.
[3]Helmholtz Centre Potsdam, GeoForschungsZentrum, Potsdam, Germany.
[4]Haystack Observatory, Massachusetts Institute of Technology, Westford, Massachusetts, USA.
[5]Space Environment Research Center, Kyushu University, Fukuoka, Japan.
[6]Applied Electromagnetic Research Center, National Institute of Information and Communications Technology, Tokyo, Japan.

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counterelectrojet events are from the December solstice. Several studies suggested that these events result from the superposition of the lunar semidiurnal wave over the solar daily wave, but they also noted that highly enhanced lunar tides would be required to explain the occasionally observed very large semidiurnal current perturbations since lunar tides can normally account only for much smaller variations. *Bhargava and Sastri* [1977] derived a semidiurnal magnetic field component with a maximum around 1000 LT and a minimum near 1500 LT superposed on the electrojet horizontal field during afternoon counterelectrojet events, and *Alex et al.* [1986] suggested that these perturbations were due to lunar-solar tidal waves. Lunar controlled counterelectrojets persist for several days, exhibit a systematic change in the diurnal pattern, and tend to occur over longer longitudinal ranges [*Rangarajan and Rastogi*, 1993].

[5] Numerous studies examined the effects of lower atmospheric processes on equatorial electric fields and currents. *Stening* [1977] suggested an association of equatorial counterelectrojets and stratospheric warmings. *Chen* [1992] showed 2 day oscillations in the intensity of the equatorial ionization anomaly, which is driven by the vertical plasma drift (zonal electric field). *Forbes and Leveroni* [1992] identified a quasi 16 day oscillation on the electrojet ΔH intensity during a large northern winter stratospheric disturbance possibly due to the upward penetration of a free Rossby mode excited in the winter stratosphere. *Somayajulu et al.* [1993] reported westward meteor zonal winds in the altitude region of 90–105 km at Trivandrum (8.5°N, 77°E) during five afternoon counterelectrojet days in January 1987, and eastward winds during normal electrojet days. *Stening et al.* [1996] pointed out that this and other counterelectrojet events during northern winter were accompanied by eastward-to-westward upper atmosphere wind reversals at a height of 99 km at Saskatoon, Canada (35°S, 107°W), and that they generally occurred during sudden stratospheric warming (SSW) periods. On the other hand, northern summer counterelectrojet events at Trivandrum, sometimes persisting for several days, were not associated with changes in the Saskatoon winds. *Stening* [1989] and *Gurubaran* [2002] pointed out that equatorial counterelectrojet events could result from the dynamo effects of global wind changes. *Stening et al.* [1997] used numerical simulations to show that lunar tidal amplitudes and phases undergo large changes during stratospheric warmings. *Rastogi* [1999] suggested that quiet time counterelectrojet events during low solar activity northern winter months result from changes in the ionospheric wind system associated with stratospheric warmings.

[6] Sudden stratospheric warming (SSW) is a large-scale meteorological process in the winter polar region caused by the rapid growth of quasi-stationary planetary waves and their interaction with the stratospheric mean circulation [*Matsuno*, 1971]. These events strongly affect the background wind, temperature, chemistry and wave activity of the middle atmosphere, as well as the vertical thermodynamic coupling in a large range of altitudes and latitudes [e.g., *Labitzke*, 1981; *Andrews et al.*, 1987; *Liu and Roble*, 2002; *Hoffmann et al.*, 2002; *Shepherd et al.*, 2007; *Pancheva et al.*, 2008].

[7] Low-latitude mesospheric and lower thermospheric effects associated with polar stratospheric warmings have been the subject of intense recent scientific interest [e.g., *Vineeth et al.*, 2007; *Sridharan and Sathishkumar*, 2008]. Recently, *Chau et al.* [2009] reported a unique semidiurnal signature lasting for several days on equatorial *F* region vertical plasma drifts measured at the Jicamarca Radio Observatory (11.9°S, 76.8°W; dip latitude 1°N) during a minor SSW event in January 2008. *Vineeth et al.* [2009] suggested that SSWs lead to higher occurrence of quasi 16 day periodicity of equatorial counterelectrojets and that stronger counterelectrojets are associated with more intense warmings. *Sridharan et al.* [2009] used magnetic field and mesospheric wind measurements in the Indian region to show that major arctic SSW events affect the day-to-day variability of equatorial counterelectrojets through the enhancement of semidiurnal tides.

[8] In this study, we use Jicamarca radar measurements and global satellite and ground-based magnetic field observations during 2001–2009 northern winters to study, for the first time, the longitude-dependent equatorial electrodynamic perturbations during SSW events. Our results suggest that these large electrodynamic perturbations most likely result from strong sudden enhancements of longitude-dependent lunar tidal wave effects during stratospheric warmings.

2. Data

[9] We have used vertical plasma drifts obtained from Doppler radar measurements of 150 km echoes by the Jicamarca Unattended Long-term Ionosphere and Atmosphere (JULIA) radar system at the Jicamarca Radio Observatory (11.9°S, 76.8°W; 0.8°N magnetic), near Lima, Peru. These measurements are generally made between about 0900 and 1600 LT with a time resolution of 5 min and also provide accurate estimates of the *F* region vertical plasma drifts and ionospheric zonal electric fields [e.g., *Kudeki and Fawcett*, 1993; *Chau and Woodman*, 2004]. However, they were only made during a relatively small number of days during our 2001–2009 northern winter periods of interest.

[10] We have determined the strength of the equatorial electrojets in the American, Indian, and Japanese sectors from the difference of the horizontal magnetic fields measured at pairs of stations, one close to the geomagnetic equator and another a few degrees off. These stations are Jicamarca and Piura (5.2°S, 80.6°W; 6.8° magnetic) in the American sector, Tirunelveli (8.7°N, 77.8°E; 0.5°S magnetic) and Alibag (18.6°N, 72.9°E; 10°N magnetic) in the Indian region, and Yap (9.3°N, 138.5°E; 0.5°N magnetic) and Biak (1.1°S, 136.0°E; 9.7°S) in the Pacific sector. We have also used the magnetic field measurements in the Peruvian region to estimate ionospheric vertical plasma drifts (zonal electric fields) using the methodology developed by *Anderson et al.* [2002]. These derived drifts are generally in good agreement with the vertical drifts measured by the Jicamarca radar, except between dawn and about 1000 LT, when they often underestimate the measured upward drifts.

[11] The polar-orbiting Challenging Minisatellite Payload (CHAMP) satellite has been making high-quality magnetic field (accuracy of about 0.1 nT) measurements since July 2000. The satellite has an orbital period of 93 min and advances about 23° westward from orbit to orbit. Equatorial electrojet current distributions are determined from CHAMP measurements by first removing magnetic field contributions from other sources, and then using a very general current model which makes the results independent of the satellite altitude

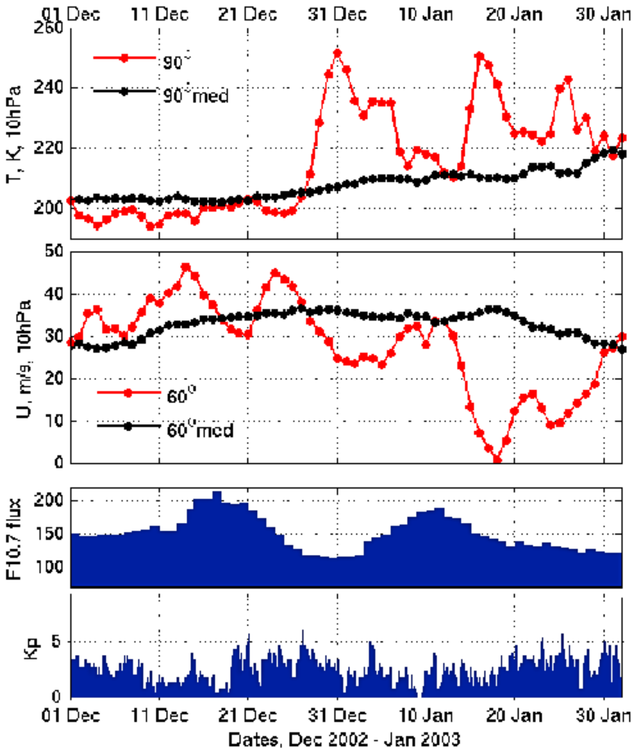

Figure 1. Stratospheric polar zonally averaged temperature, zonal wind (positive eastward), from the National Center for Environmental Prediction, and decimetric solar flux and *Kp* indices for December 2002 to January 2003. The median values are shown as black circles.

and ambient field geometry [e.g., *Lühr et al.*, 2004; *Manoj et al.*, 2006]. In this study, we present CHAMP equatorial magnetic field measurements in the afternoon sector from late December 2002 through January 2003.

3. Results

3.1. Electrodynamic Effects During December 2002 and January 2003

[12] Figure 1 shows the development of the December 2002 to January 2003 minor stratospheric warming events. The top plots present the zonal mean temperatures at 10 hPa (about 32 km) at 90°N, the mean zonal winds averaged over 60°N, and the corresponding 30 year mean temperatures and zonal winds obtained from the National Center for Environmental Prediction (NCEP). The bottom plots give the daily solar decimetric flux and the 3 h *Kp* indices.

[13] Figure 1 indicates that the December 2002 high-latitude stratospheric temperatures and zonal winds were mostly above and below their 30 year mean values, respectively. The temperature started to increase rapidly on 28 December, reached its maximum on 31 December, and then slowly decreased until about 12 January; the second and third warmings started on 14 and 24 January and reached peak values on 16 and 26 January. During the first two warmings, the longitudinal averaged eastward winds decreased by about 10 and 30 m/s below their average values, respectively.

[14] Figure 2 shows the daytime vertical plasma drifts obtained from Doppler measurements of 150 km echoes over Jicamarca during the first 2002–2003 warming and the corresponding quiet time averages. Figure 2 shows large downward drift (westward electric field) perturbations during 30 December to 1 January, which is indicative of an abnormally large reduction in the ionospheric daytime eastward electric fields. This was followed by a very large and sudden increase in the morning upward drifts on 2 January. The resulting very large semidiurnal drift perturbations (upward in the morning and downward in the afternoon) shifted gradually to later local times from 2 January through 6 January. Incoherent scatter radar measurements during the stronger January 2008 SSW event presented by *Chau et al.* [2009] show basically an identical perturbation drift pattern after about 0900 LT, and even larger upward drift enhancements in the early morning period.

[15] The vertical drifts derived from Jicamarca and Piura magnetic field measurements during December 2002 to January 2003 are presented in Figure 3. The slant line indicates the local times of the equatorial crossings of the CHAMP satellite. The December data show large drift day-to-day variability. Figure 3 also shows small upward morning and large downward afternoon drifts during 29–31 December, large sudden increase in the upward morning and downward afternoon drifts on 2 January, and the gradual shift of the semidiurnal-like perturbation drift pattern to later local times

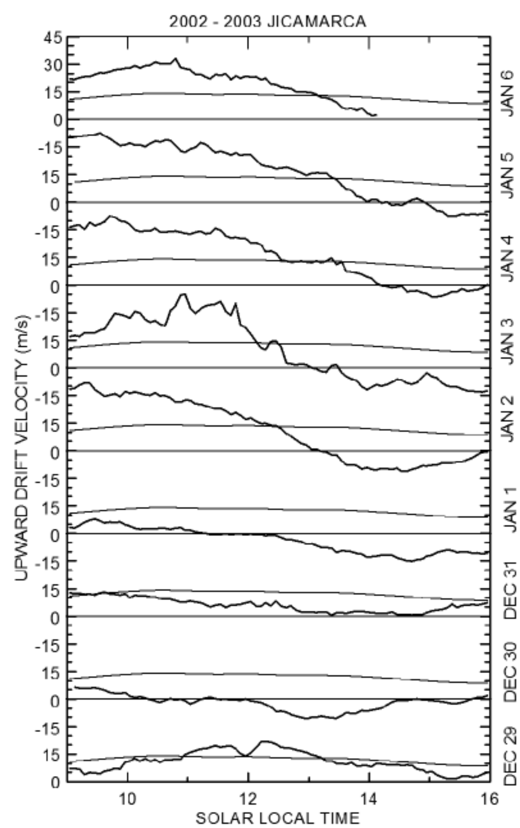

Figure 2. Vertical plasma drift velocities of 150 km radar echoes measured with the Jicamarca Unattended Long-term Ionosphere and Atmosphere system. The smooth curve denotes the mean drifts.

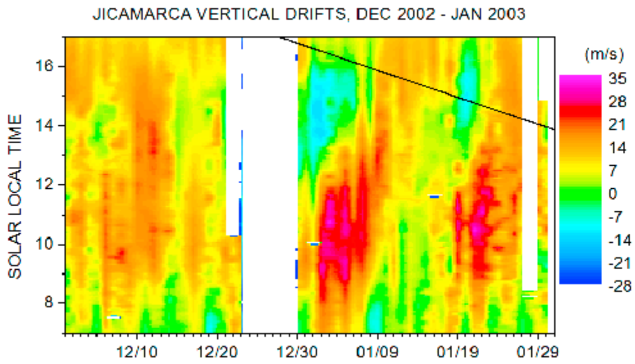

Figure 3. Vertical plasma drift velocities (positive upward) over Jicamarca derived from magnetic field observations. The slant line indicates the local time coverage of the CHAMP satellite.

over a period of a few days leading to increased upward drifts in the afternoon and decreased or reversed drifts in the morning. A smaller but weaker perturbation drift pattern also occurred during 19–25 January after an interval of much smaller daytime drifts on 15–18 January. Figure 3 also show relatively large 2 day modulations on the vertical drifts.

[16] Figure 4 shows the daytime ΔH, which reflects the intensity of the equatorial electrojet, in the Peruvian, Indian, and Pacific sectors between 1 December 2002 and 29 January 2003. In this period, new moons occurred on 4 December and 2 January, and full moons occurred on 19 December and 18 January. The December data illustrate the typical day-to-day variability of the daytime electrojet currents with the absence of correlated large temporal perturbation drift patterns in these longitudinal sectors. After the late December warming onset, the electrojet intensities first weakened for about 2 days and then, around new moon, suddenly developed very similar multiday perturbation patterns with largely enhanced morning eastward and afternoon westward currents that systematically shifted to later local times. Strong morning counterelectrojets were seen around the first and last quarters (10 and 25 January). The morning and afternoon current perturbations occurred first and were strongest in the American sector and developed last and were weakest (particularly in the afternoon) in the Pacific sector. Similar, but weaker, current perturbations developed near full moon after the second warming, when the high-latitude wind perturbations were even larger. These perturbation events are about 14 days apart, as expected for the lunar semimonthly tide [*Stening*, 1989].

[17] Figure 5 illustrates in more detail the longitude-dependent daytime magnetic field perturbations during the first SSW episode. We can see again that the afternoon counterelectrojets occurred first and were strongest in the American sector and the shift of the perturbation current pattern to later local times. In particular, there is a clear increase in the time of the counterelectrojet minimum as the days progress. Figure 5 also shows the effect of geomagnetic activity on the electrojet intensity, which was strongest during 3–4 January.

[18] The onset of strong semidiurnal electrojet intensity perturbations close to new and full moons and the shifts of the current perturbation patterns to later local times with lunar age suggest the occurrence of highly enhanced lunar semidiurnal wave effects over a broad range of longitudes during these SSW events. The shift of the current perturbation patterns are consistent with the difference in the lengths of the solar and lunar days.

[19] Figure 4 also shows the occurrence of strong 2 day wave perturbations on the strength of the electrojet currents

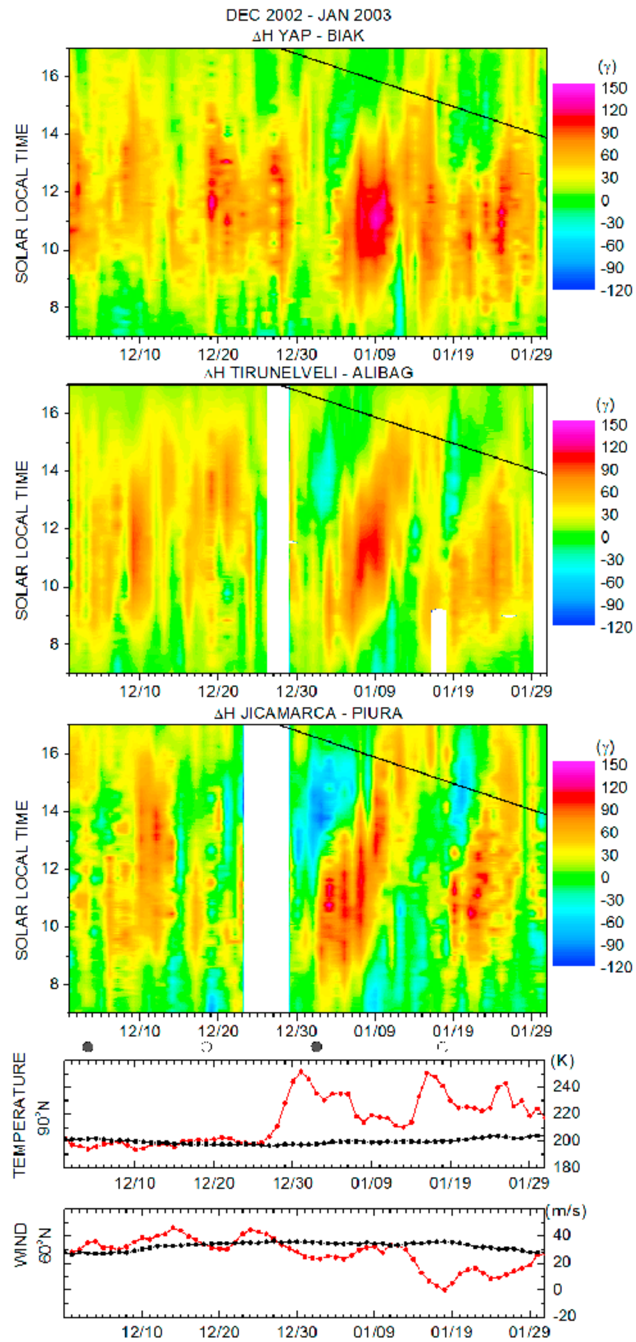

Figure 4. Equatorial horizontal magnetic field components in three longitudinal sectors and high-latitude zonally averaged stratospheric temperatures and zonal winds during December 2002 and January 2003. The days of new and full moons are indicated by open and solid circles, respectively.

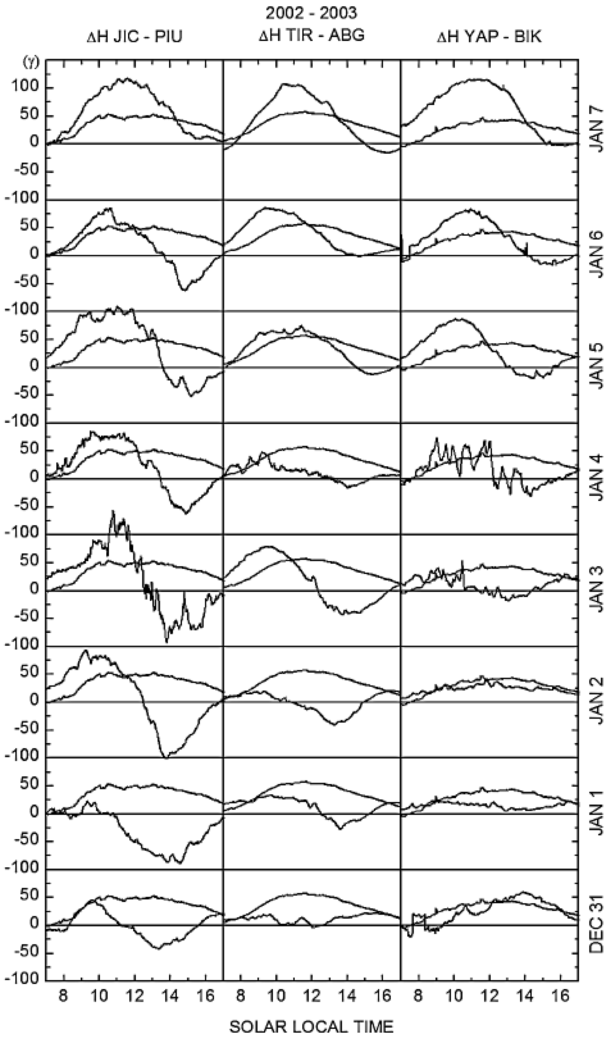

Figure 5. Equatorial horizontal magnetic field components close to the 2 January new moon period during the first December 2002 to January SSW event. The smooth curves denote the quiet time values before the SSW onset.

in our three longitudinal sectors. These perturbations appear to be strongest during SSW events. *Pancheva et al.* [2006] studied in detail the global occurrence of 2 day wave activity during this period, and *Aveiro et al.* [2009] reported their signatures on the equatorial electrojet and *E* region electric fields in the Brazilian sector.

[20] The polar-orbiting CHAMP satellite made equatorial electrojet magnetic field measurements in the afternoon sector between late December 2002 and mid-February 2003. These measurements made with an orbital period of 93 min provided about 18 equatorial daytime crossings. Figure 6 presents the equatorial electrojet current densities in the afternoon sector between late 27 December 2002 and 30 January 2003. The horizontal lines denote the average longitudes of the ground stations used in our study. We note that the CHAMP electrojet current densities, obtained by fitting the full latitudinal profile of the geomagnetic field data, provide more accurate estimates of the electrojet intensities than derived from geomagnetic data from pairs of stations. We note that the current maxima are about 14 days apart. Figure 6 indicates that following the first warming, afternoon counterelectrojets occurred at all longitudes and that their onset times increased toward the east, which is in good agreement with our ground-based data. Figure 6 also shows more irregular occurrence of afternoon counterelectrojets during the second warming, which could be partly due to the precession of the satellite to earlier to local times.

3.2. Observations During Other Periods

[21] We have examined the currently available Jicamarca vertical drifts and magnetic field ground-based measurements in the Peruvian and Indian equatorial regions during the other December solstices from 2001 to 2009. In these periods, there were only very limited radar drift measurements. Strong stratospheric warmings occurred during 2001–2002, 2003–2004, 2005–2006, and 2008–2009, with the last being by far the strongest, and there were occurrences of minor warmings during the other northern winter periods except for 2004–2005.

[22] Figure 7 shows the equatorial ΔH data from the Peruvian and Indian sectors, and the high-latitude temperatures and winds at 10 hPa from 10 December 2001 to 23 January 2002. Moderate geomagnetic activity on 16, 21, 24 and 31 December and on 10, 11, and 19 January resulted in noticeable short-term (less then a few hours) ΔH electrojet variability, especially in the Peruvian region. Figure 7 shows large ΔH perturbations with strongly enhanced morning eastward and afternoon westward currents starting near new moon and about nine days after the warming onset, and the shift of the perturbation patterns to local times.

[23] Figure 8 shows the ΔH data from Peru and the corresponding high-latitude temperatures and zonal winds during the magnetically quiet period from 20 December 2008 to 28 February 2009. In this period, new moons occurred on

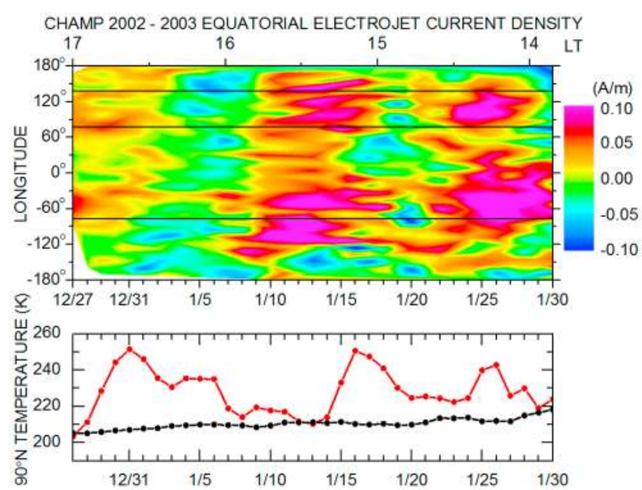

Figure 6. Equatorial electrojet afternoon current density measurements by the CHAMP satellite and high-latitude stratospheric parameters between late December 2002 and January 2003. The horizontal lines denote the longitudes of our ground-based stations.

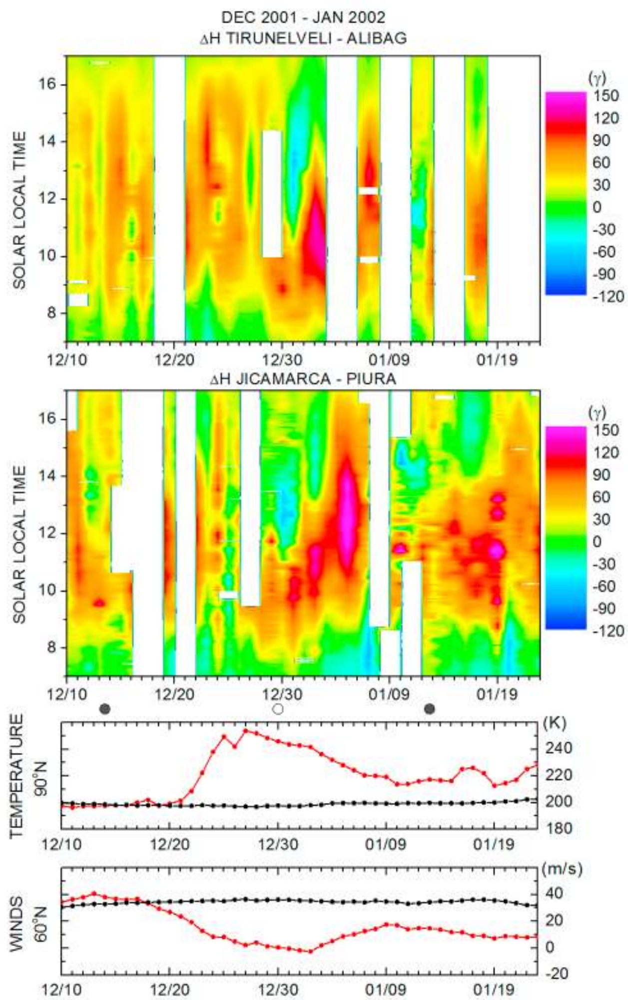

Figure 7. Equatorial horizontal magnetic field measurements in the Indian and Peruvian sectors and high-latitude stratospheric parameters during December 2001 and January 2003. The days of new and full moons are also shown.

27 December and 26 January and full moons on 11 January and 9 February. The high-latitude data indicate the occurrence of a very strong large SSW event from mid-January through mid-February. The equatorial data do not show any unusual ΔH perturbations prior to the SSW onset. After the warming, however, there were again very large decreases in the electrojet morning and afternoon currents on 23–24 January, followed by large sudden increases in the morning eastward and afternoon westward currents and a continuous shift of the current reversals to later local times after the new moon on 27 January.

[24] Figure 9 shows the ΔH data from the Peruvian region during 24–28 January 2009 and the corresponding average values prior to the SSW event. Figure 9 illustrates in more detail the very large increase in the intensity of the early morning electrojet intensities from 26 to 27 January and the following gradual shift of the current reversal times. Jicamarca incoherent scatter radar measurements (not shown) indicate that the F region upward drift velocity at about 0900 LT increased from about 20 m/s on 25 January to about 50 m/s on 27 January.

[25] The morphology of Jicamarca vertical plasma drift during the January 2008 SSW event reported by *Chau et al.* [2009] is fully consistent with the results presented above. In that event full moon occurred on 22 January, the Jicamarca morning upward plasma drifts strongly increased on 22–23 January. One day later, the Indian ΔH data (not shown) show small increases in intensity of the morning electrojet and strong afternoon counterelectrojet conditions. The same sequence of events appears to have occurred during the strong 2003 and 2004 warming period, although in this case there were no plasma drift measurements and the Peruvian magnetometer data are less reliable partly due to geomagnetic effects. The morphology of equatorial ΔH perturbations described above has also been inferred from equatorial measurements during the 2006–2007 SSW event.

[26] We have seen that during SSW events large semidiurnal perturbations in equatorial plasma drifts and electrojet currents are associated with lunar tidal wave effects. It is important to note, however, that lunar tidal effects frequently modulate the equatorial electric fields and current as reported in earlier studies. During northern winter, these effects are seen more often in the Peruvian than in the Indian sector, as reported in earlier studies. Figure 10 shows the equatorial ΔH data from the Peruvian and Indian sectors and the high-latitude stratospheric temperatures and winds during December 2004 and January 2005, a northern winter period without stratospheric warmings. In this case, the short-term enhancements in the intensities of the electrojet currents were associated with increase geomagnetic activity. Figure 10 shows afternoon counterelectrojets and shifts of the perturbation patterns occurred around the time of the new moon period on 9 January, and perhaps also close to the new

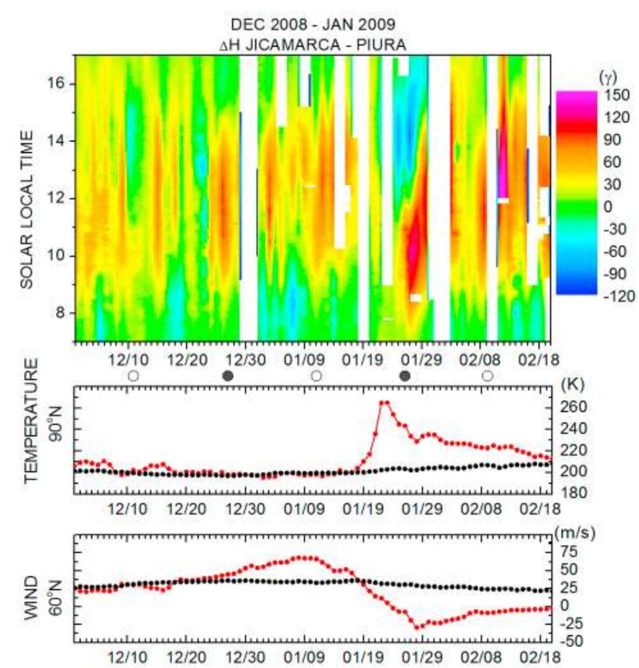

Figure 8. Equatorial horizontal magnetic field measurements in the Peruvian sector and high-latitude stratospheric parameters during December 2008 and January 2009. The days of new and full moons are also shown.

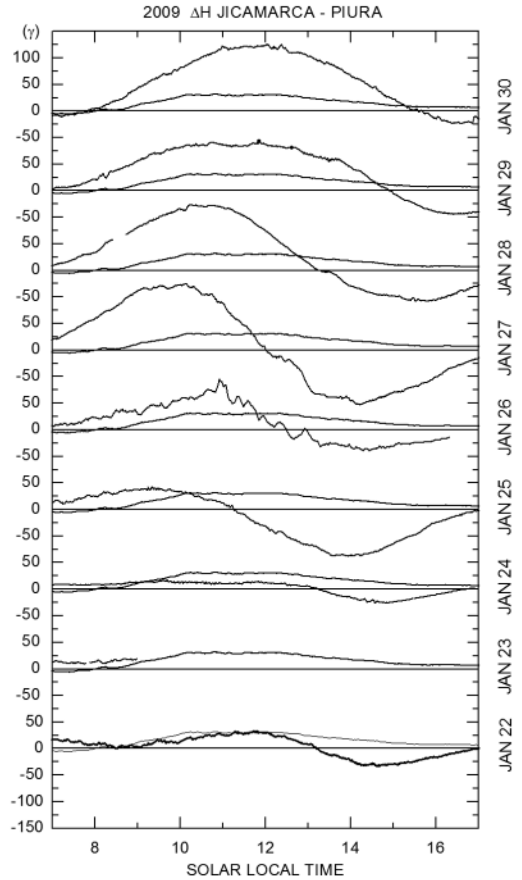

Figure 9. Horizontal magnetic field measurements in the Peruvian equatorial region during the very large 2009 SSW event. The smooth curve denotes the average values before the SSW onset.

moon period on 24 January. However, these semidiurnal current perturbations had only fairly small magnitudes.

4. Discussion

[27] We have shown large temporal electrodynamic perturbations in the equatorial vertical drifts (zonal electric fields) and electrojet intensities in three widely spaced longitudinal sectors during SSW events from the end of December through early February. These large semidiurnal like perturbations were preceded by about two days of largely reduced eastward electric fields and electrojet intensities. The sudden onset of the large semidiurnal perturbations occurred during the SSW events and close to the new and full moons (lunar ages 00 and 12 h) and systematically shifted to later local times with lunar age. Later, large electric field and electrojet current reversals in the morning occurred near the first and last quarters (lunar ages 0600 and 1800 h). In the absence of SSW events, the electric field and current had much smaller perturbations. These results indicate the large amplification of lunar tidal wave effects in the equatorial zonal electric fields and electrojet intensities during arctic stratospheric warmings.

[28] The large electrojet current perturbations during SSW events shown above occurred first in the American and last in the Pacific sector. This is consistent with the longitudinal dependence of afternoon counterelectrojet onsets inferred from the 2002–2003 CHAMP data. Magnetometer derived vertical plasma drifts during the 2002–2003 and 2003–2004 SSW events also indicate the earlier occurrence of large perturbations in the Peruvian than in the Philippine sector (D. Anderson, private communication, 2009). On the other hand, magnetic field measurements during the January 1989 SSW event studied by *Rangarajan and Rastogi* [1993] suggest the occurrence of large electrojet current perturbations earlier in the Indian than in the American sector. This indicates that detailed additional studied are needed to fully characterize the longitudinal dependence of SSW associated equatorial electrodynamic disturbances.

[29] Our data suggest that the electric field and current perturbations are most pronounced during December, but there are indications that SSW-enhanced electrodynamic perturbations also occur during equinoctial periods [e.g., *Stening et al.*, 1996]. Figure 5 of *Fejer and Scherliess* [2001], for example, shows an unusually large increase in the morning

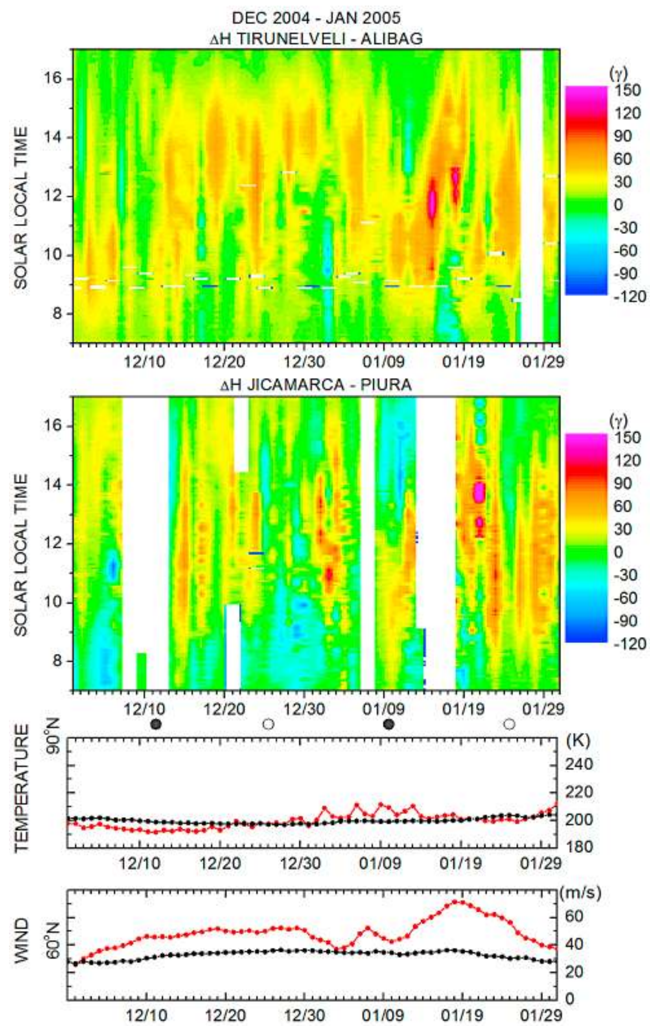

Figure 10. Equatorial horizontal magnetic field measurements in the Indian and Peruvian sectors and high-latitude stratospheric parameters during December 2004 and January 2005, which was a period without SSW events. The days of new and full moons are also shown.

and early afternoon *F* region upward plasma drifts over Jicamarca from 17 to 18 March 1988. This large quiet time drift increase also occurred on a new moon during a SSW event and the enhanced upward drifts lasted for at least three days (the radar measurements ended on 20 March). In this case, however, there were only very small decreases in the afternoon drifts relative to their average values. This suggests that the equatorial electrodynamic signatures of SSW events might change with season. We note that over Jicamarca, afternoon vertical drift reversals and corresponding counter-electrojet events are less frequent during equinox than during the December solstice.

[30] Simulation studies using the NCAR TIME-GCM show that, owing to their nonlinear interaction with quasi-stationary planetary waves, both the migrating and non-migrating tides have largest changes at low latitudes and in the ionospheric *E* region [*Liu et al.*, 2010]. They also indicate that equatorial plasma drifts and, therefore, equatorial electrojet intensity changes are longitude- and local-time-dependent with large upward drift (i.e., eastward electric field) perturbations near 0500 LT around 70°W, and largest downward drift perturbations around 70°E at the same local time. Our observations consistently show larger morning eastward electric field perturbations in the American than in the Indian sector in good agreement with these simulations. We note, however, that the large variability of the electrodynamics of the low-latitude ionosphere during SSW events often also involve strong gravity, 2 day and longer period planetary wave effects [e.g., *Sathishkumar and Sridharan*, 2009; *Abdu et al.*, 2006].

[31] The equatorial vertical plasma drifts and electrojet intensities exhibit sudden distinctive signatures during SSW events which can also be identified in earlier observations. This suggests that the study of historic global equatorial magnetic field measurements, which now go back over a century, could provide additional information on the equatorial electrodynamic effects of SSWs over several decades. We note that the meteorological analysis of arctic winter SSW data extends back only to 1978–1979 and that the historical stratospheric temperature data presented by *Manney et al.* [2005] extends to 1958–1959. The use of global equatorial magnetic field measurements to infer the occurrence of SSW events during other seasons and earlier periods will be a subject of a future study.

5. Summary

[32] We have studied Jicamarca vertical plasma drift and global equatorial magnetic field measurements during 2001–2009 arctic SSW events. Our observations show that this strong high-latitude meteorological process gives rise to large global equatorial electrodynamic perturbations lasting for several days. These equatorial perturbations are longitude dependent and have distinctive magnetic field signatures which have been reported for several decades. Our results indicate that lunar semidiurnal tidal wave effects highly enhanced during SSW events are the most likely source of these unusual electrodynamic perturbations.

[33] **Acknowledgments.** We thank A. Bhattacharyya and the Indian Institute of Geomagnetism for the Tirunelveli and Alibag data. We thank NICT for the Yap data and the Solar Terrestrial Environmental Laboratory, Nagoya University, for managing the database of the 210 MM magnetic observations. We also thank D. Siskind and S. Larson for useful discussions. The work at Utah State University was supported by the Aeronomy Program, Division of Atmospheric Sciences, through grant ATM-0534038 and by the NASA Living With a Star (LWS) Program through grant NNX06AC44G. The Jicamarca Radio Observatory is a facility of the Instituto Geofisico del Peru, Ministry of Education, and is operated with support from the NSF cooperative agreement ATM-0432565 through Cornell University.

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J. L. Chau, Radio Observatorio de Jicamarca, Instituto Geofisico del Peru Apartado 13-0207, Lima 13, Peru 2.

B. G. Fejer and M. E. Olson, Center for Atmospheric and Space Sciences, Utah State University, Logan, UT 84222-4405, USA. (bela.fejer@usu.edu)

L. P. Goncharenko, Haystack Observatory, Massachusetts Institute of Technology, Westford, MA 01886-1299, USA.

H. Lühr and C. Stolle, Helmholtz Centre Potsdam, GeoForschungsZentrum, Telegrafenberg, 14473 Potsdam, Germany 3.

T. Nagatsuma, Applied Electromagnetic Research Center, National Institute of Information and Communications Technology, Tokyo 184-8795, Japan.

K. Yumoto, Space Environment Research Center, Kyushu University, Fukuoka 812-8581, Japan.