Bursty Pi1 activity at the South American equatorial zone during the 29 October 1994 magnetic storm

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[1] The effects of the great magnetic storm of 29 October 1994 on the daytime equatorial ionosphere have been studied by a ground-based array of fluxgate magnetometers in South America. The array covers around 2 h in magnetic local time and spans dip angles from 6.7°N to 10.8°S, with additional very-low latitude and nightside dip equator stations as reference. Following an abrupt increase in the AE index during the storm main phase, bursty Pi1 activity is seen over a wide region around the prenoon dip equator. This is the first observation of such pulsations at these latitudes. The pulsations are strongly attenuated not propagating outside the equatorial zone and sometimes may present differences in time onset at different longitudes. It is proposed that they may have been originated by instabilities in the equatorial electrojet currents triggered by prompt penetration of high latitude electric fields. INDEX TERMS: 1530 Geomagnetism and Paleomagnetism: Rapid time variations; 2415 Ionosphere: Equatorial ionosphere; 2435 Ionosphere: Ionospheric disturbances; 2788 Magnetospheric Physics: Storms and substorms; 9360 Information Related to Geographic Region: South America. Citation: Padilha, A. L., M. V. Alves, N. B. Trivedi, T.-I. Kitamura, and M. Shinohara, Bursty Pi1 activity at the South American equatorial zone during the 29 October 1994 magnetic storm, Geophys. Res. Lett., 30(19), 2006, doi:10.1029/2003GL017999, 2003.

1. Introduction

[2] Pi1Bs are impulsive short-lasting broadband magnetic pulsations in frequencies higher than 25 mHz which have been associated with auroral particle precipitation during intense substorm onsets and intensifications. It is generally accepted that they represent the ground signature of over-head ionospheric currents created by enhanced conductivity due to the precipitation. Their properties have been derived from studies in space and along ground profiles at high and midlatitudes [e.g., Arnoldy et al., 1998, and references therein]. As it is not expected that they will be observed outside these regions, no detailed study with a dense chain of stations at equatorial latitudes has been reported so far.

[3] A strong magnetic storm took place on 29 October 1994, with sudden commencement at 0025 UT. Unfortu-
limit around 0.7 nT/s was defined to ignore quick and huge variations. The clock of the data logger was calibrated automatically by global radio signals, which kept the time accuracy to within 100 ms during the acquisition.

[7] The main morphological features of the ground-observed perturbations on 29 October 1994 are shown in Figure 2 through geomagnetic indices. For comparison, the figure also includes geomagnetic data in the two horizontal components at one of our equatorial stations (ALC). These data were band-pass-filtered using a zero-phase shift Butterworth function with unit response between 10 and 100 mHz.

[8] The storm main phase started around 9 UT, with a depression in Dst and increase up to 7 in Kp. It had a two-step development, an indicative that a second particle injection took place before the ring current had decayed to the prestorm level. Dst reached its first minimum of 102 nT at 11–12 UT, with AE around 500 nT. At 13 UT, AE showed an abrupt increase of 600 nT, probably related to a major substorm onset resulting from another energy deposition in the auroral region. For the next three hours, AE remained very high with peaks larger than 2000 nT. Dst reached its second minimum of 123 nT at 15–16 UT, recovering substantially near the end of the day. This was the only storm with such signatures during the whole observation period.

[9] Data from station ALC show that the activity enhanced considerably since 6 LT (dawn sector), in accordance with the beginning of the storm main phase. An additional amplification occurred after 10 LT (prenoon), coincident with the sharp increasing of the AE curve. Amplitude of D-component is much smaller than that of H-component, an indicative of enhanced E-W ionospheric currents.

3. Pi1 Activity

[10] Preliminary data analysis was undertaken using FFT spectral estimates. Spectrograms were calculated at each station and inspected to identify signatures of high power and high coherency across the array. Figure 3 contains 10- to 100-mHz spectrograms from the 12 stations for the time interval in which the maximum geomagnetic activity was observed. Regarding local time, the beginning of the period (1300 UT) corresponds to the prenoon sector at South American stations, ranging from 0812 LT (site ANC) to 1013 LT (site EUS), and nighttime at POH (2305 LT).

[11] Starting just after 1300 UT, broadband bursts are observed in irregular intervals at the South American sites closest to the dip equator. These bursts have similar signature to the high-latitude Pi1B pulsations, but probably their source mechanisms are different. Some of the events have intense power in the whole frequency band (up to 100 mHz) and show a dependence on distance from the dip equator with increased power at stations ANC, PRM, and ALC. From Pi1B studies at mid and high latitudes, the source

![Figure 1](https://example.com) Map of South America showing the sites from which data are used in this study. Solid line is a schematic representation of dip equator in October 1994 and dashed lines are ±10° dip angles at the same time.

![Figure 2](https://example.com) Indices of global geomagnetic activity compared to equatorial ground magnetometer data on 29 October 1994. (a) Dst (solid line) and Kp (bars) indices; (b) AE index; (c) band-pass-filtered H-component for site ALC; (d) band-pass-filtered D-component for site ALC.

| Table 1. Geographic and Geomagnetic Coordinates, Dip Angles and MLT of the Stations |
|-----------------------------------------|----------------|----------------|----------------|
| Station | Geographic | Geomagnetic | Noon in UT (MLT) |
| | Lat  | Long | Lat  | Long | Dip Angle | UT (MLT) |
| BLM | −1.22 | 48.53 | 1.27 | 25.58 | 6.7 | 1519 |
| POV | 8.80 | 63.90 | 2.63 | 7.65 | 5.7 | 1607 |
| ARI | −9.56 | 63.04 | 1.68 | 8.38 | 3.9 | 1604 |
| ANC | −12.08 | 77.02 | 1.29 | 354.58 | 1.1 | 1648 |
| PRM | −11.20 | 61.80 | 0.55 | 9.44 | 0.3 | 1600 |
| ALC | −2.34 | 44.41 | 0.55 | 29.32 | 0.1 | 1506 |
| VIL | −12.72 | 60.13 | 1.85 | 10.64 | −3.4 | 1555 |
| COL | −13.70 | 59.80 | 2.87 | 10.77 | −5.4 | 1554 |
| EUS | 3.85 | 38.42 | 0.14 | 34.77 | 9.7 | 1447 |
| CUI | −15.35 | 56.05 | 5.64 | 13.89 | −10.8 | 1542 |
| SMA | −29.72 | 53.72 | 19.28 | 13.36 | 32.9 | 1535 |
| POH | 7.00 | 158.33 | 0.13 | 229.24 | 0.5 | 0155 |

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region of these pulsations may not have been far away from the dip equator [Bösinger and Wedeken, 1987]. Unfortunately, the low sampling rate of data acquisition prevents observation of the power enhancements frequently seen in frequencies higher than 100 mHz [Heacock and Hunsucker, 1981]. Also, some of the events have intervals with quick variations of very large amplitude that sometimes exceed the time differential limit of the recording system. These intervals appear in our graphics as data gaps.

Along the dip equator, the signal is only observed at daytime sector, an indicative of its close connection with the influence of Cowling conductivity effects. Some isolated events of very short duration, as for example the one between 1354 and 1359 UT in Figure 3, have variable time delay between the stations ALC, PRM, and ANC. Also, no clear direction of propagation is discernible for these events. Accordingly, they can not be associated with the passage of an east-west traveling surge. Fast magnetosonic mode waves propagating directly from the magnetosphere are also discarded because these waves would have to be detected as well at the other near equatorial stations (BLM, EUS, and CUI) [Tanaka et al., 1998]. Here, a model including isolated ionospheric sources seems more appropriate.

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[13] Within the time interval of Figure 3, the event commencing around 1330 UT was the most intense recorded and was selected to be examined more closely at the sites along the meridian $10^\circ$. To isolate the Pi1 most prominent band, the data were band-pass-filtered between 25 and 100 mHz. Figure 4 shows stacked plots of the filtered data in the H-component for the interval 1325–1340 UT, when the pulsation train was well developed.

[14] The event is observed simultaneously at all stations from POV to COL, covering distances of at least 350 km north and south from the dip equator (site PRM), an indicative that the ionospheric activity must be of large dimensions and/or the occurrence of an efficient propagation along geomagnetic field lines. It is not seen at CUI (770 km south from PRM), which has the same geomagnetic signature of SMA. This is corroborated by cross-correlation analysis that shows that CUI has stronger correlation with SMA than with their neighboring equatorial stations. Moreover, it can not be attributed to the well known equatorial amplification experienced by geomagnetic variations at daytime because it has been reported that for the typical periods of Pi1 (less than about 30 s) the daytime equatorial signals suffer attenuation rather than amplification [Sarma and Sastry, 1995].

**Figure 3.** Spectrograms of band-pass-filtered H-component data from sites identified on the right for the 29 October 1994 event. The scale of the spectrograms is logarithmic between $10^{-1}$ (black (blue online)) and $10^{-4}$ (white (red online)) in units of nT$^2$/Hz.

**Figure 4.** Stacked plots of band-pass-filtered H-component variations along the meridian $10^\circ$ for the time interval 1325–1340 UT on 29 October 1994.
4. Discussion and Conclusions

[15] Take into account the time resolution of 3 s of our data, this disturbance has an apparent velocity larger than 120 km/s and an effective damping lesser than 750 km. However, these quantitative results must be regarded with caution because ground-based magnetometers integrate the effects of ionospheric currents up to 150–200 km distant [Engelbreton et al., 1995].

[16] It can be then concluded that these pulsations are locally generated close to the dip equator but are also strongly attenuated at the equatorial zone, similar to what is observed with Pi1Bs at high latitudes [Bösinger and Wedeken, 1987]. On the other hand, the stations are located over very different geologic structures, which generates different induction effects avoiding the comparison of pulsation amplitudes.

[17] It is known that the equatorial ionosphere disturbances are the extensions of the very complex electrodynamic changes in the magnetosphere-ionosphere system resulting from solar wind-magnetosphere interactions. In particular, ground-based magnetometers respond mainly to changes in E-region currents and can be used to record the ionospheric signatures of the magnetospheric energy transfer process.

[18] Theoretical models have shown that this energy transfer to low latitude can be explained by the effect of short-lived (1–2 h) penetration of the primary convective electric field which is regulated by shielding effects associated with field-aligned currents and/or storm-time thermospheric winds from high latitudes which lead to the generation of dynamo electric fields that propagates equatorward with latitude-dependent time delays. The timing between the substorm onset in the auroral zone and the maximum bursty activity across the equatorial array favors the mechanism of prompt penetration of electric fields from high latitudes [e.g., Kikuchi and Araki, 1979]. In fact, many features of our results are in good agreement with the general empirical model proposed by Fejer and Scherliess [1997] for storm-time equatorial electric fields. In this model, following a sudden increase in the AE index, high latitude electric fields penetrate nearly instantaneously into the low latitude ionosphere since the region 2 field-aligned current lags behind the change in the polar cap potential drop. Under these shielding conditions the equatorial perturbation vertical drifts will generate eastward electric fields during the day. Less than 2 h after the increase in the AE index, these prompt penetration drifts essentially vanish, as the shielding is re-established.

[19] It is speculated here that the transient penetration of these high latitude electric fields produces intense instabilities in the daytime E-region currents of the equatorial ionosphere (equatorial electrojet). Both experimental and theoretical studies have shown that such instabilities may locally excite some ULF magnetic disturbances. Saka et al. [1998] have demonstrated some varieties of irregular responses of the electrojet amplitude during storm periods. Fedorov et al. [1999] have shown the possibility of ionospheric propagation of disturbances produced by variation of the electrojet currents. In this model, wide-band pulsations would be generated in the lower ionosphere and those with periods in the gyrotropic MHD modes would be trapped into the E-layer propagating away from the dip equator source.

[20] Time differences in activity onset along the dip equator can be ascribed to differences in overhead ionospheric properties. It is known that the South American equatorial sector presents large longitudinal differences in many of its ionospheric parameters [e.g., Kane, 1984; Abdu et al., 1993]. However, absence of additional information on ionospheric parameters during this day prevents to conclusively attribute the events entirely to local ionospheric conditions.

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References


