Pc5-Pulsations in conjugate stations to investigate the South Atlantic Magnetic Anomaly effects: a case study

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Abstract

In this work, Pc5 magnetic pulsations are studied using data from geomagnetically conjugate stations as a case study. The effort proposes a nonlinear-multiscale methodology to investigate the Pc5 to aid in a comprehensive low latitude investigation, mainly involving the South Atlantic Magnetic Anomaly (SAMA). The data refer to the horizontal magnetic component collected during a peculiar geomagnetic storm at San Juan, Puerto Rico, and Sao Martinho da Serra, Brazil. The former is in the northern hemisphere, and the latter is the other hemisphere in a region affected by the SAMA. The approach to evaluating the dynamical phenomena characteristics are based on spectral techniques, obtaining signal characterizations and coherence analysis to highlight the Pc5 process dynamics. The case study results support complete research involving the low latitude stations and comparisons with the Pc5 development in the SAMA

1.Introduction

The South Atlantic Magnetic Anomaly (SAMA) is nowadays one of the most critical features of the Earth's magnetic field. This anomaly extends from the East Pacific to South Africa, in which the main magnetic field has a significant low intensity of the order of 22,000 nT, approximately one third compared to the maximum magnetic field value. The SAMA minimum value currently in northern Argentina, considered its center, which has historically displaced from Southern Africa to South America over the last 300 years. A consequence of the significant magnetic magnitude reduction in this region is that high energy Van-Allen-radiation-belt particles penetrate deeper into the upper atmosphere in this region than anywhere else on the Earth. Due to the electrodynamics acting upon this region, some effects have also been detected on the surface as disturbances in communications and induced currents in pipelines, transmission lines, and power grids.

Other significant phenomena that occur within the region dominated by the geomagnetic field are Pc5 magnetic pulsations, characterized as ultralow-frequency (ULF) magnetohydrodynamic (MHD) waves, with frequencies between 1.6-7 mHz, often observed during intervals of disturbances on the geomagnetic field. Studies on magnetic pulsations are essential to extend a knowledge of their characteristics and effects inside the magnetosphere ionosphere system. To sum up, the magnetic pulsations analysis helps us understand the energy transfers between areas of different latitudes through waveguides and magnetic flux lines, even eventual interactions with charged particles, both in the ionosphere and in the upper regions.

Two points on the Earth's surface, each located at a distinct geomagnetic hemisphere, are considered geomagnetically conjugate if they are on opposite ends of the same geomagnetic field line. In principle, geophysical phenomena generally exhibit a similar behavior during an event or a phenomenon in a delimited area around the conjugate points. Several works showed that there is a very close correlation of magnetic activity in the time of occurrence, form, and amplitude in magnetic signals (H component) in conjugate points.

The main objective of this work is to analyze data from conjugate stations at the SAMA region, during a geomagnetic storm. For our case study, the magnetic data used were simultaneously recorded at one conjugate pair stations. Pair stations are located in the America-SAMA region, which allows us to do a comparative analysis. We search for comparison patterns of the Pc5 pulsations at conjugate stations to characterize the pulsations behaviors. We establish a methodology composed by two significant signal analysis techniques.

2. Data

2.1 Geomagnetic dataset

We use the geomagnetic horizontal (H) component recorded on the ground. The record sampling rate is of seconds for all stations. The data used concern the period between 09:00UT on 25th and 21:00UT on 26th October 2016, which corresponds to the main and recovery phases of a moderate geomagnetic storm (Dst = -52 nT), which presented an abrupt magnetic increase related to a magnetopause compression produced by a solar wind pressure pulse. Fortunately, the period of the storm was close to the September equinox. This condition creates inter-hemispheric symmetry and similarities both in conductivity and atmospheric electric current systems between the conjugate stations .

2.2 Ground-Based stations

Theoretically, the stations are close to the feet of the same magnetic field line (conjugate points). The locations were obtained according to Altitude Adjusted Corrected Geomagnetic (AACGM) coordinates. Stations used here are San Juan (SJG), Puerto Rico, and São Martinho da Serra (SMS), Brazil. Figure 1 shows the locations of the conjugate stations.

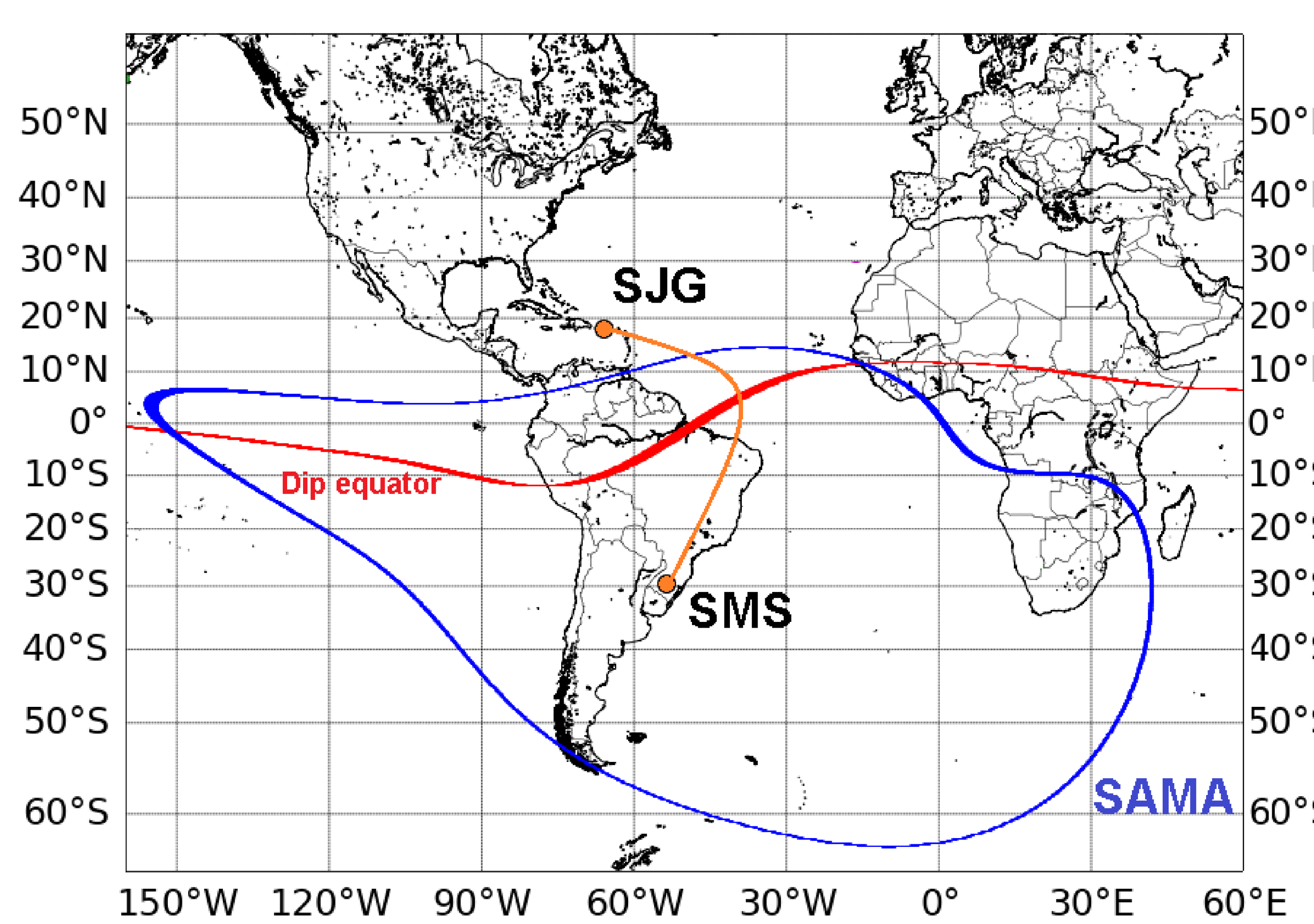

Fig.1: Map of conjugate stations, indicated by circles. The line (in red) crossing the map is the dip equator and the closed line (in blue) surrounds the SAMA region.

3. Methodology

Continuous Wavelet Transform (CWT) Wavelet analysis is becoming a common tool since it allows the decomposition of data, functions, or operators into different frequency or scale components. This allows to **quantitatively monitor the evolution of signals**, decomposing a time series in time-scale domain. The advantage of CWT analysis is that it is suitable for **studying both non-stationary and nonlinear signals.**

$$\mathcal{W}_f^{\psi}(a,\tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t)\, \overline{\psi(\frac{t-\tau}{a})}\, \mathrm{d}t \qquad a > 0\,,$$

Wavelet coherence is a tool useful **for analyzing nonstationary signals**, and for analyzing the correlation and phase lag between two signals in the time-frequency domain.

$$\mathcal{C}^2_{\mathcal{W}}(a,\tau) = \frac{|S(a^{-1}\mathcal{W}^{\psi}_{f,g}(a,\tau))|^2}{S(a^{-1}|\mathcal{W}^{\psi}_f(a,\tau)|^2)\; S(a^{-1}|\mathcal{W}^{\psi}_g(a,\tau)|^2)}$$

4. Results and Analysis

During the geomagnetic storm main phase, in the SAMA region, an enhancement of Pc5-pulsation amplitude occurs. The scalograms show the most intense Pc5 pulsations in the first two-time intervals (Figure 2, “a”), which correspond to the main phase of the magnetic storm.

In the second place, SJG-SMS stations show weak coherence (0.2 < Cxy < 0.4), see figure 2, “b”. The corresponding magnetic line reaches the altitude heq ~ 1260 km (or L-shell (~ 1.28), which implies that the line that interlinks the two conjugate stations is inside the ionosphere. At last, the pair SJG-SMS presents strong phase variation in some intervals (two, three, four, and five), where almost vertical arrows indicate $\pi/2$ or quarter-cycle (quadrature) phase lag between SMS and SJG.

The enhancement of Pc5 amplitudes and phase lag at SMS, in a location close to the SAMA center, could be attributed to precipitation of particles besides increased ionospheric conductivity gradients due to ionization rate in the D and E layers.

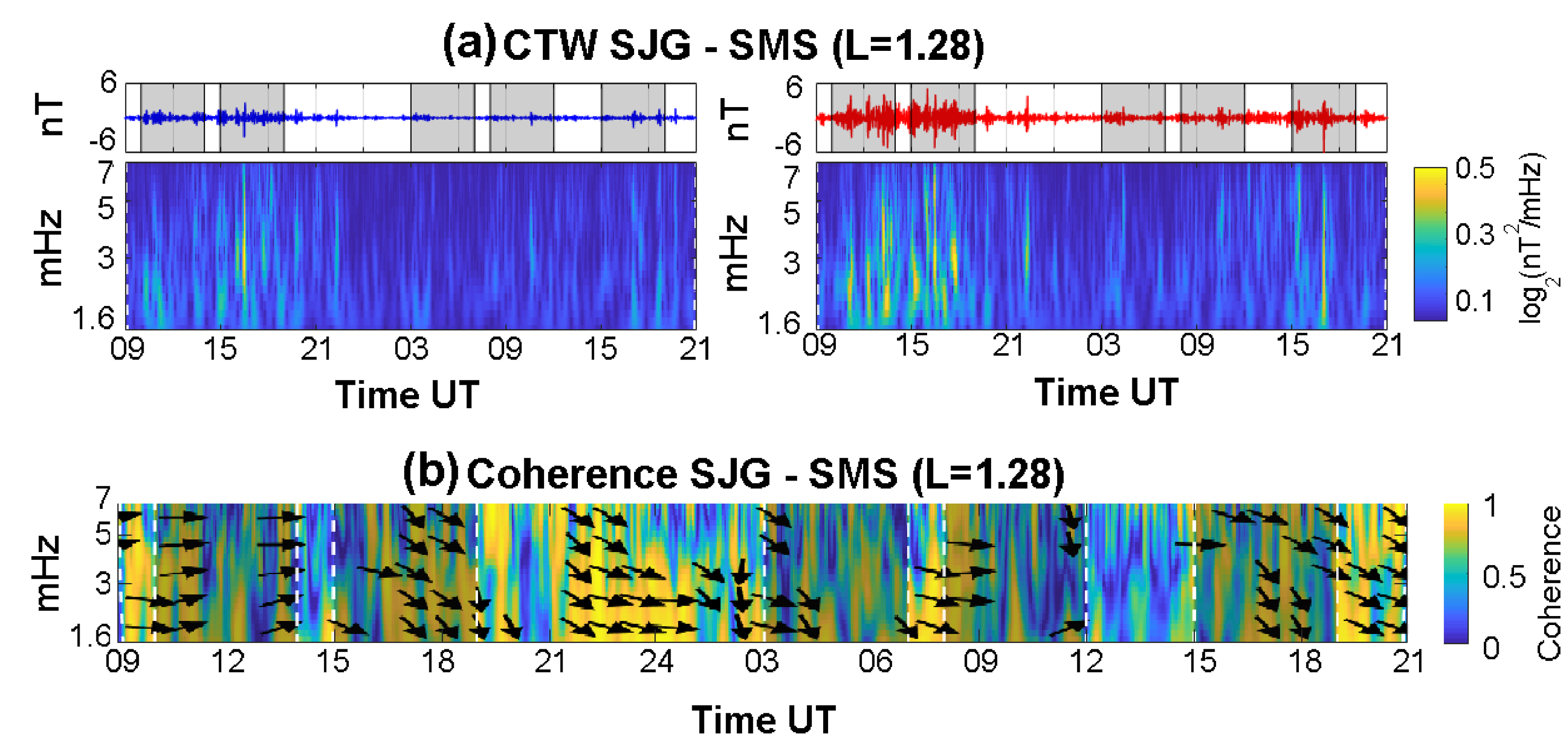

Fig.2: (a) Pc5 pulsations (top) and squared-wavelet coefficients scalograms (bottom) for each pair of conjugate station. **(b)** Wavelet coherence. Color-map indicates the amplitude, and arrows the phase where the amplitude is larger than 0.8.

5. Conclusion

- Notably, for stations close to minima in the SAMA, higher amplitudes occur during the main phase of the geomagnetic storm or in significant magnetic decreases during recovery.
- Enhancements of Pc5-pulsation amplitudes occur associated with the probable electron precipitation into the higher ionosphere in the SAMA.
- In the America-SAMA region, the Pc5 pulsations showed moderate to low signal coherences and phase lags.