Estimation of Geomagnetically Induced Currents at Low Latitude and Equatorial Regions of Brazil During Two Great Magnetic Storms of 2015

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Abstract

The South American longitudinal sector presents the unique feature of the presence of daytime equatorial electrojet currents (EEJ) and the South Atlantic Magnetic Anomaly (SAMA), where the global minimum intensity of the geomagnetic field is observed. Enhanced amplitudes are observed in the horizontal magnetic components recorded on the ground within the areas of influence of both the EEJ and the SAMA and therefore it is expected that significant enhancements of GIC magnitude also occur in these regions. We use here geomagnetic field variations data recorded by fluxgate magnetometers from the Brazilian space weather program (EMBRACE) to evaluate GIC effects during two strong geomagnetic storms in March (Dst = -222nT) and June (Dst = -204nT) 2015. Among the available geomagnetic stations, we selected those with information about the underground electrical conductivity structure and that can be approximated by 1-D models for calculation of the geoelectric field. GIC levels are estimated using a realistic local power grid model located in the central region of Brazil, artificially moved to the sites where the geomagnetic measurements are available. Maximum GIC amplitude of about 8 A was estimated at an equatorial station positioned over high resistivity underground, associated with the arrival of an interplanetary pressure pulse just behind two other pulses during the June storm. The results are also interpreted in terms of the ionospheric currents over the measurement sites and the conductivity distribution beneath these sites. It is observed that both EEJ and SAMA increase the GIC amplitudes, with the greatest effects associated with EEJ. In relation to the underlying conductivity structure, the higher GIC effects are associated with low conductance at crustal depths, with upper mantle depths showing minor effect.

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EFFECTS OF IONOSPHERIC CONDUCTIVITY AND GROUND CONDUCTANCE ON GEOMAGNETICALLY INDUCED CURRENTS DURING SEVERE GEOMAGNETIC STORMS: CASE STUDIES AT LOW LATITUDE AND EQUATORIAL REGIONS

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1. ABSTRACT

Geomagnetic field variations recorded by fluxgate magnetometers are used to evaluate geomagnetically induced currents (GICs) under **the Equatorial Electrojet (EEJ) and South Atlantic Magnetic Anomaly (SAMA)** during two geomagnetic storms in **March and June 2015.** Geomagnetic stations with information about the underground electrical conductivity structure and that can be approximated by **unidimensional (1-D) models** for calculation of the geoelectric field are selected. GICs levels are estimated using a realistic local power grid model located in the central region of Brazil, artificially moved to the sites where the geomagnetic measurements are available. A relative analysis was carried out to estimate the **individual contribution** of the Earth's **conductivity profiles** and the rate of change of the **geomagnetic field** for GICs generation. Effects related to the underground conductivity are governed by variation of the surface impedance and the sampling rate of geomagnetic field (1 min). A DC level in the Nyquist frequency significantly control the magnitude of the induced surface electric field. The GICs amplification due to geomagnetic field effects is related to the enhancement in overlying ionospheric conductivity. During daytime, a greater effect of the EEJ was observed. **A cut-off frequency was identified for both the EEJ and SAMA** so that signals with frequencies lower than 2mHz (periods longer than 500s) are not affected by the ionospheric currents.

2. BACKGROUND

Geomagnetically induced currents (GICs) are driven in any grounded network of conductors due to rapid variations in the Earth's magnetic field **related to extreme solar events**. The GIC issue has been widely studied at high latitudes. However, studies have shown that GICs may also be of concern to power networks at lower latitudes (PULKKINEN, 2017) and some transformer failures have been reported (GAUNT and COETZEE, 2007). Other works have focused on the large rate of change of the geomagnetic field, especially in the equatorial region, which increase the susceptibility to GIC (CARTER et al., 2015, 2016). **South American longitudinal sector has the unique feature of the presence of the Equatorial Electrojet (EEJ) and the South Atlantic Magnetic Anomaly (SAMA),** where energetic particle precipitation is observed in local ionosphere due to the global minimum intensity of the geomagnetic field.

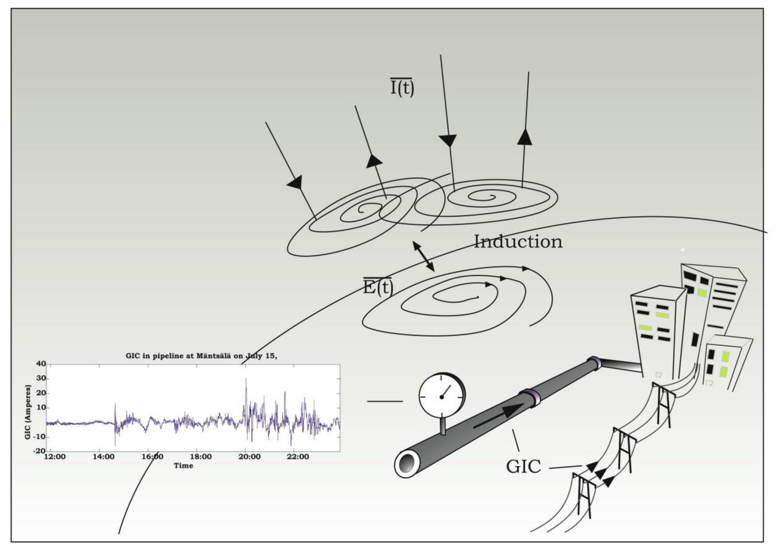

Figure 1. Scheme of the production of GIC.

3. METHODOLOGY

- During the **two largest geomagnetic storms** occurred in **2015.**

Storm	Interval	$Dst\ (nT)$
S1	March $16-18$	-222
S2	June $21-23$	-204

Table 1. Selected storms of the 2015.

- We selected **four geomagnetic stations** with information on underground electrical conductivity structure and that can be approximated by 1-D models.

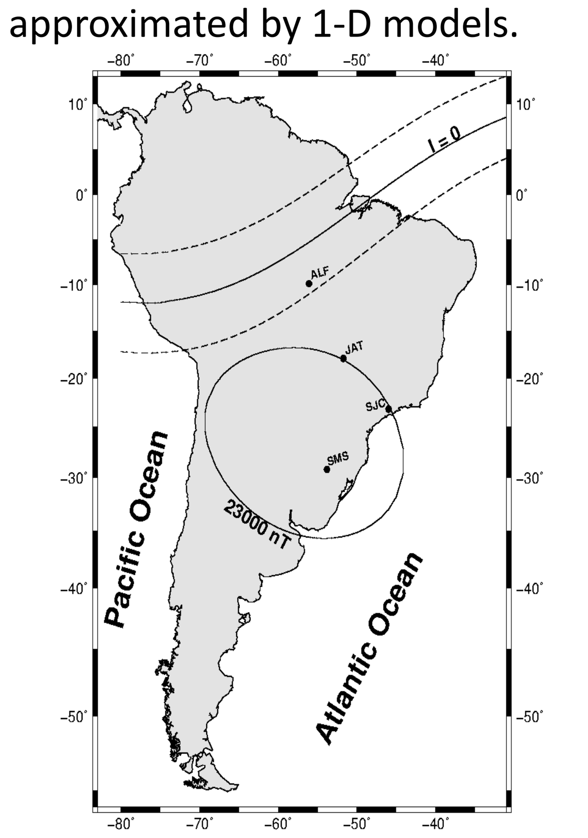

Figure 2. EMBRACE Magnetometer Network stations used in the study.

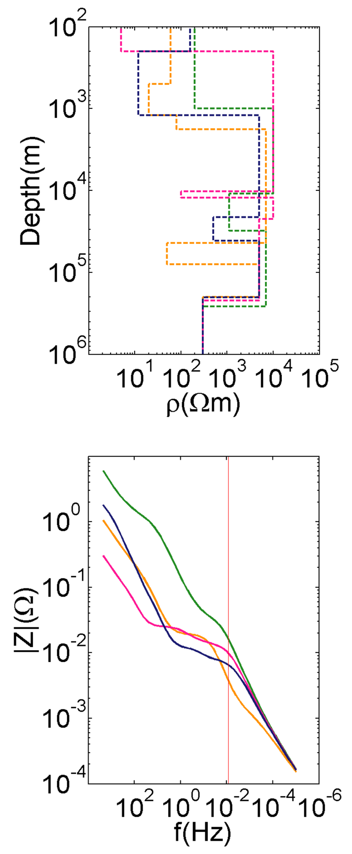

Figure 3. Resistivity ρ and impedance $|Z|$.

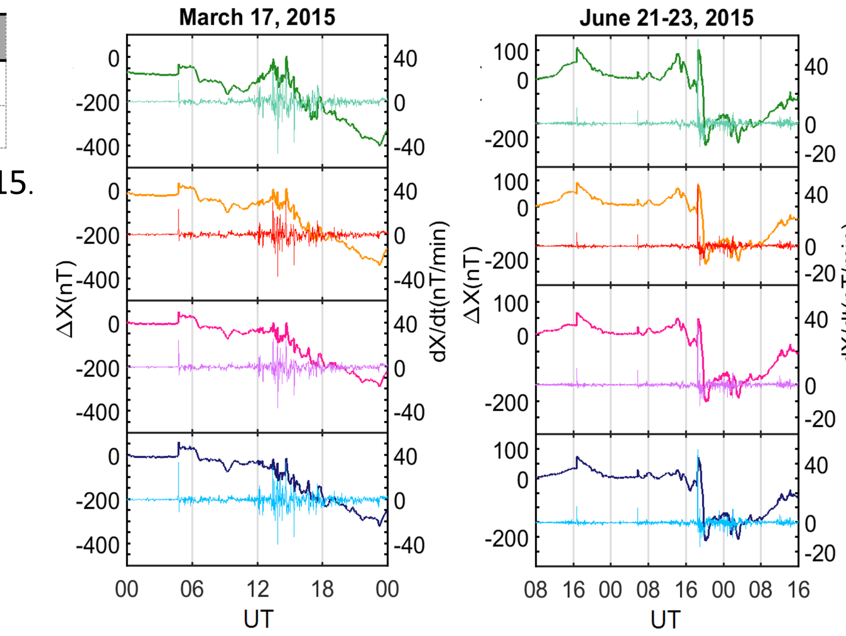

Figure 4. Geomagnetic variations field.

Instant	Attribute	S1	S2
ssc	Station	SMS	ALF
	$\frac{dX}{dt}\left(\approx\frac{nT}{min}\right)$ max	34	11
	UT	$04{:}47$	$16{:}50$
Principal phase	Station	ALF	ALF
	$\frac{dX}{dt}\left(\approx\frac{nT}{min}\right)$ max	-47	58
	UT	$13{:}54$	$18{:}33$

Table 2. Maximum dX/dt.

- GICs amplitudes are estimated using a realistic local power grid model situated in the central region of Brazil (BARBOSA et al., 2015), **artificially moved to the stations** where the geomagnetic measurements are available.

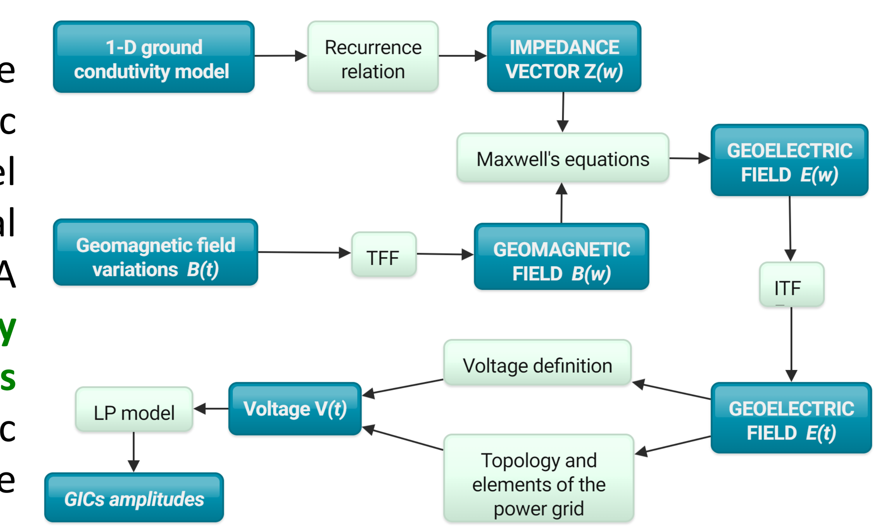

Figure 5. Schematics algorithm for calculation of GIC.

4. RESULTS

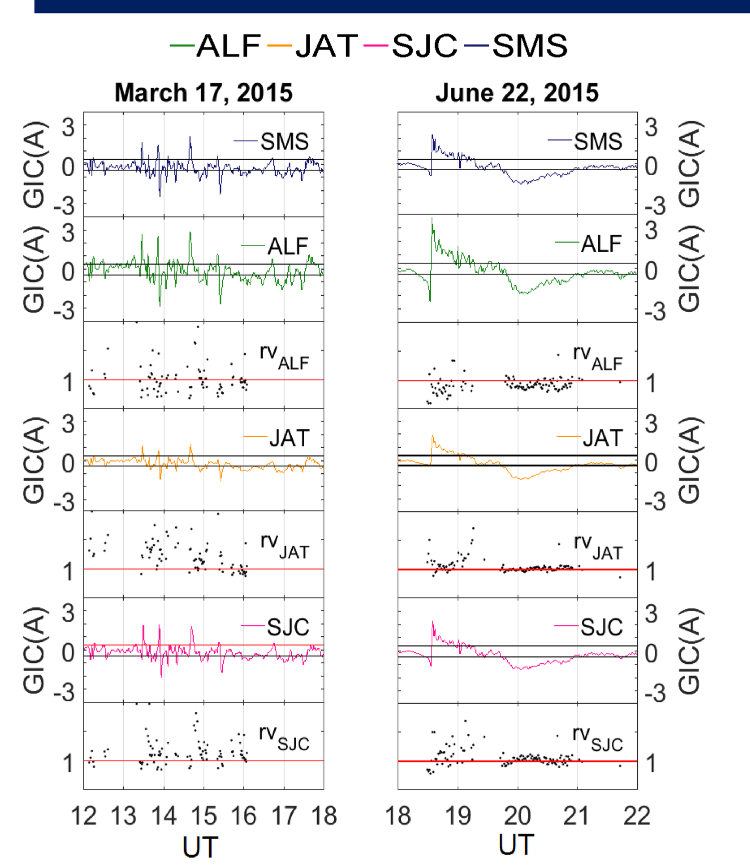

Figure 6. Absolute and relative GICs amplitudes during the main phase (using SMS as reference.

- The peaks with higher amplitude are larger in ALF than in SMS.
- The amplitudes in JAT and SJC are markedly smaller than in SMS.
- An interesting behavior is observed in the **low-frequency GICs**, whose amplitudes **are approximately the same in all stations.**

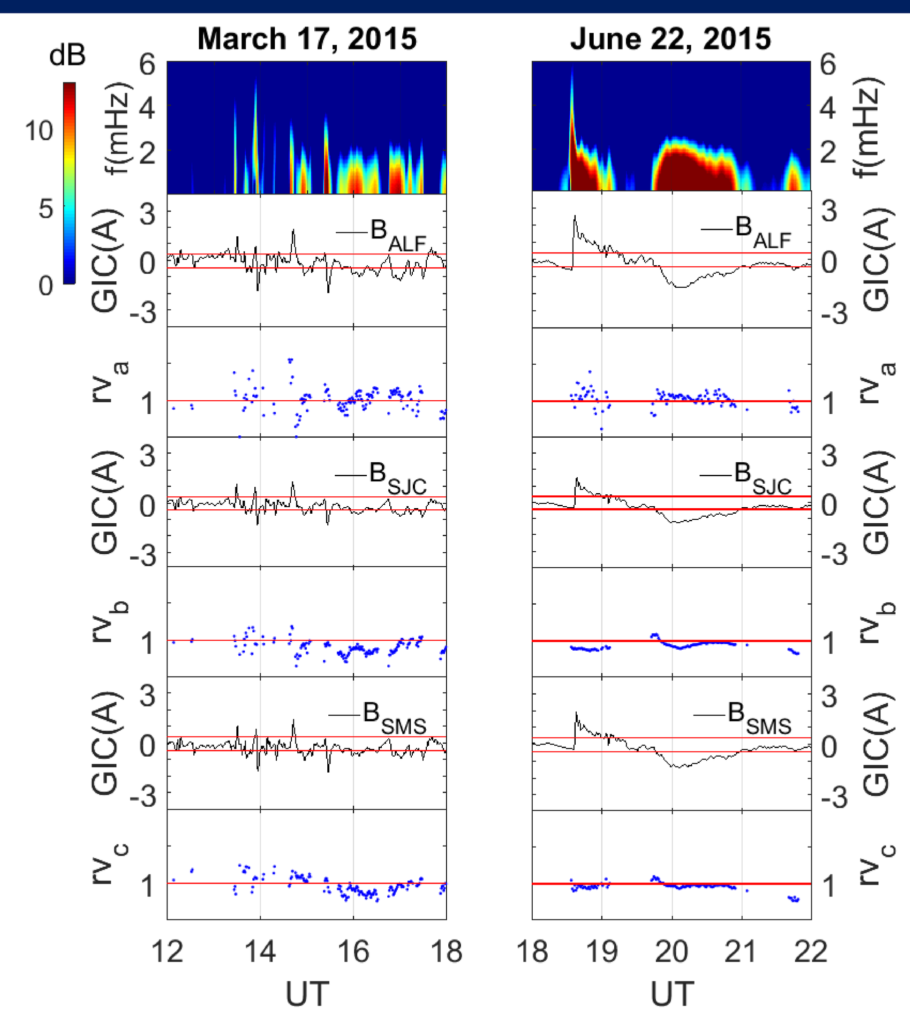

Figure 7. Absolute and relative amplitudes during the storm main phases to assess how geomagnetic variations alone drive GICs (impedance input fixed).

- **EEJ and SAMA** act in the **amplification** of GICs in high frequency bands (**f > 2 mHz**), with larger effects by the daytime EEJ.
- There is no ionospheric effect for low frequencies signals (f < 2 mHz).

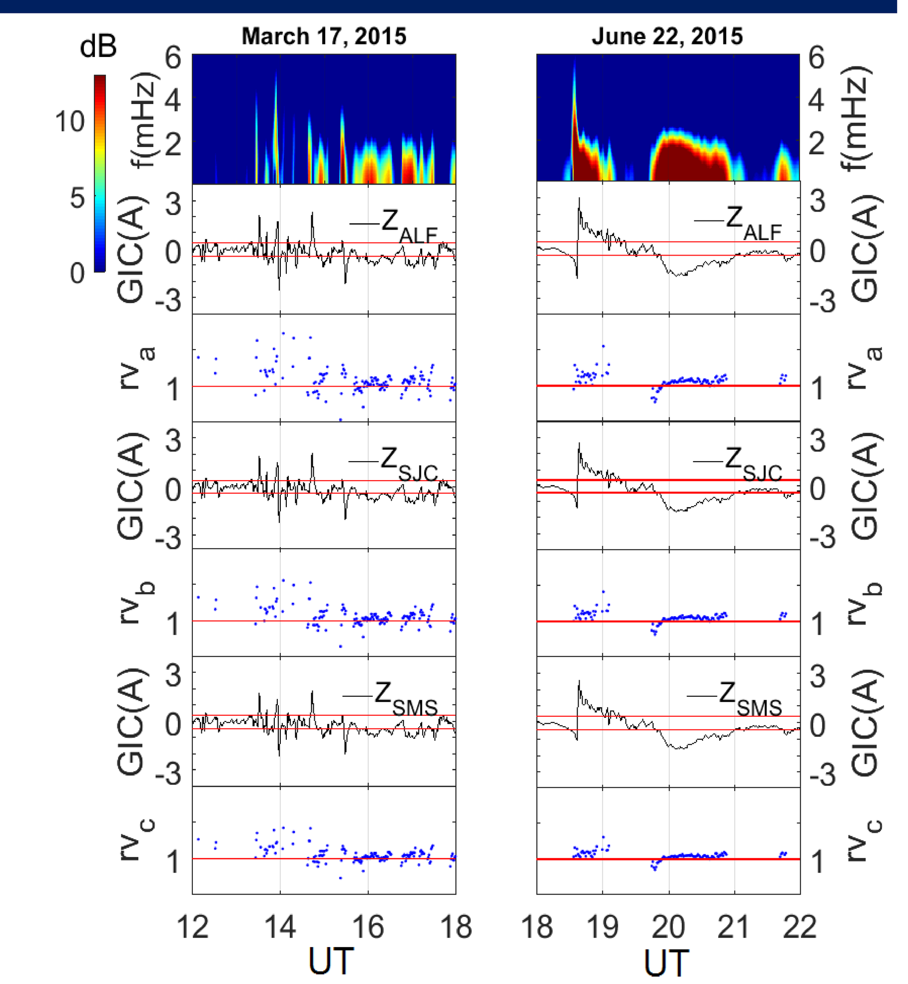

Figure 8. The same as Fig. 7 to assess how surface impedance alone drive GICs (geomagnetic variations fixed).

- Effects related to the underground conductivity reproduce the curve of surface impedance as a function of frequency.
- DC level in the **Nyquist frequency control** the magnitude of the induced surface electric field.

5. CONCLUSIONS

- A rough estimate of the individual effects of the Earth's conductivity profiles and the rate of change of the geomagnetic field on the GIC magnitude under EEJ and SAMA are presented during two geomagnetic storms.
- Due to the low sampling rate of the geomagnetic field (1 min), effects of ground conductivity in shallower layers **appear as a DC level at the Nyquist frequency.** This DC level influences the GIC magnitude.
- **Increase in overhead ionospheric conductivity** associated with the EEJ and SAMA **amplify** the GICs measured at the Earth's surface for geomagnetic variations with frequency higher than **2 mHz**. No enhancement effect is observed for frequencies lower than 2 mHz.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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