A Geomagnetic and Geological Study in the South Atlantic Islands

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Abstract

The present study intends to analyze the Sq variations in the geomagnetic components D, Z and to correlate these results with their geologies. Data from three observatories are been used. Two of them are South Atlantic Islands and another one in a continent. The results of this preliminary study confirm that the SAMA can be related to the morphology of the curves obtained for D and Z. We also compare the Sq variations to disturbed days for further interpretations of the SAMA.

Introduction

The South Atlantic Ocean is a region of large interest due to its anomalous geomagnetic field, caused by the South Atlantic Magnetic Anomaly (SAMA). In this region the strength of the internal magnetic field is significantly lower when compared to elsewhere in the world. The SAMA originates from an inverse magnetic flux at the core mantle boundary beneath South America and South Africa, which existence is noted over the last 200 years (Gubbins et al., 2006). The low geomagnetic field in this region causes a strong increase of radiation due to the distortion of the inner van Allen radiation belt, affecting satellites when passing through the SAMA (Heirtzler et al., 2002). The growth of this reversed flux region may be related to the Earth's magnetic field attempting to reverse (Gubbins, 2008).

It is especially hard to monitor the SAMA activity since there are no a big number of geomagnetic observatories located in the South Atlantic. Only few islands are close to SAMA center, like TDC.

There is a geomagnetic observatory on TDC and the geomagnetic measurements from this island are very significant for the understanding of the SAMA behavior.

The studied islands all have an interesting feature in common: they are volcanic islands. The nature of these islands can influence the magnetic records, including the morphology of Z component, which is the geomagnetic element that is related to the geology of the area.

The purpose of this paper therefore is to analyze the Sq variations in the D and Z geomagnetic field components at three different stations in also different longitudes and to correlate the behavior of Z component with the geology of these regions. A preliminary geological study of the region of the stations is described in this paper.

In this paper we discuss the morphology of the SAMA in the South Atlantic and South America region based on data during the period of September 5th, 2014 to September 24th, 2014 from 3 permanent observatories (TDC, VSS and ASC). The disturbed condition was also examined. Figure 1 shows the geographic distribution of these stations. Table 1 gives the coordinates of all stations. The geomagnetic Coordinates for TDC and VSS refer to IGRF-11 for 2010 and the geomagnetic coordinates for ACS refer to the 12th generation IGRF at epoch 2015.5.

	Geographic		Geomagnetic	
Observatory	Latitude (°)	Longitude (°)	Latitude (°)	Longitude (°)
Tristan da Cunha (TDC)	-37.067 South	347.685 West	- 41.35 North	67.20 East
Ascension Island (ASC)	7.949 South	345.624 West	2.809 South	057.530 East
Vassouras (VSS)	- 22.4 South	316.35 West	13.43 South	27.11 East

Table 1. Geographic and Geomagnetic coordinates of the stations.

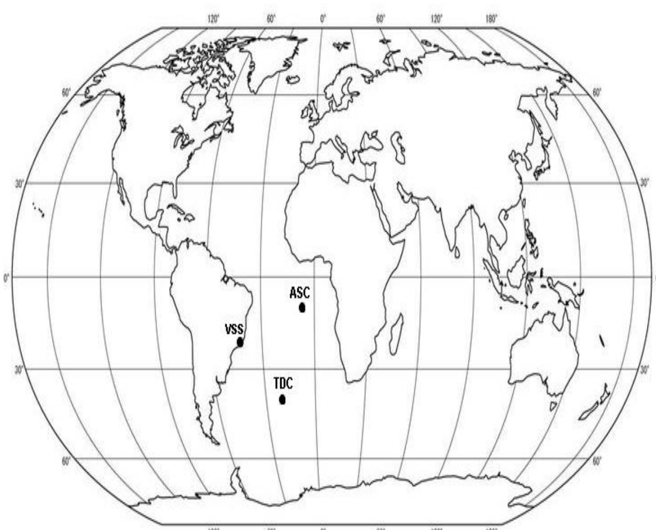

Figure 1. Geographic distribution of the stations used in this study.

Method

The study started with the selection of the magnetically quiet days. The two quiet days chosen were those which the greatest value of the planetary geomagnetic disturbance index Kp is less than or equal to 2+. The two disturbed days chosen were those which the Ap index is greater than or equal to 20. The Kp and Ap indexes are provided by the International Service of Geomagnetic Indices (ISGI).
The data used has one-minute resolution and one-hour median values were derived. Our focus is to minimize the effect of the crustal and secular field, for this we used a quiet level baseline for each day as the mean of six nighttime values (0000, 0100, 0200, 2200, 2300 and 2400 UT). dD and dZ were computed by subtracting the base line from H, and Z geomagnetic components (Yamazaki, Y., et al., 2011).
In this present paper, "quiet daily geomagnetic field variation" means the variation defined by equation (1) for geomagnetically quiet conditions.

$$dD(UT) = D(UT) - \frac{D(0)+D(1)+D(22)+D(23)+D(24)}{6} \quad (1)$$

The quiet geomagnetic field variation (dZ) was computed by the same equation above.
The study proceeded with the research of the geological features of each region. After that, we compared the morphology of the curves on Z component to the geology of the regions. This gave us an idea about how much the Z component is affected by the geology of the areas.

Geological considerations

The British Overseas Territory of Ascension and Tristan da Cunha is made up of some of remotest islands on earth. It spans a huge distance of 3,642km and runs along the Mid Atlantic Ridge in the South Atlantic Ocean. Both islands are volcanic, but are formed by hotspots rather than being part of the ridge itself. Figure 2 shows the locations of these two islands and the Mid Atlantic Ridge.
Hotspots are places where anomalously hot mantle rises in a plume and burns a hole in the overlying crust, creating an active volcano. Their cause is not fully understood, with some scientists arguing it may be due to convection within the mantle and others that the plume could be caused by the remnants of sub ducted plates finally melting near the mantle/core boundary.
The chemistry of the lava on each island is different, showing each hotspot derives from a different source. The Tristan lavas contain the chemical signature of sediments and the Ascension Island lavas show they have been heavily mixed by lavas from the Mid Atlantic Ridge.
The main island of Tristan da Cunha is a large oceanic volcano rising from the floor of the ocean, made up of alternating layers of volcanic ash and lava flows. If measured from the sea floor, the volcano is 5,500m high, with only the 2,200m rising above sea level.

Referring to the geography of Tristan da Cunha, the peak of the island is predominantly composed of pyroclastic deposits erupted from the central vent. The base and main cliffs predominantly are composed of thin basaltic lava flows, commonly separated by thin pyroclastic layers. Also, on the peak and base are numerous scoria cones, which are individual vents where magma has reached the Earth's surface. A geological map of Tristan da Cunha is in figure 3.
Tristan da Cunha Island can be represented by igneous rocks, like basalt, which is the main rock found on the island.

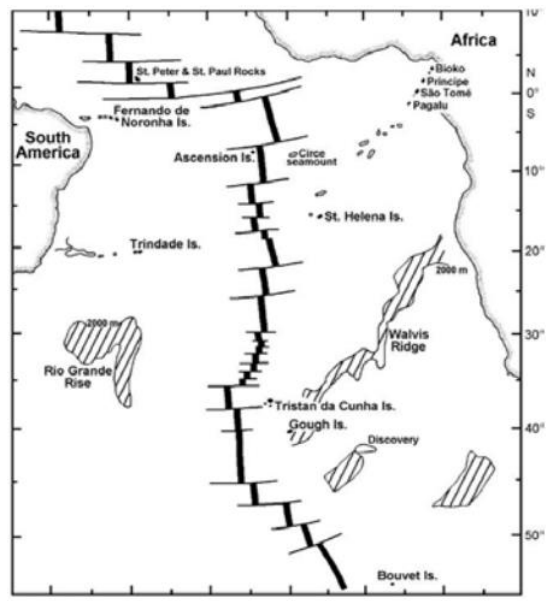

Figure 2. Location map of the territory, showing the submarine ridges and chain of islands, which were created by the hotspots.

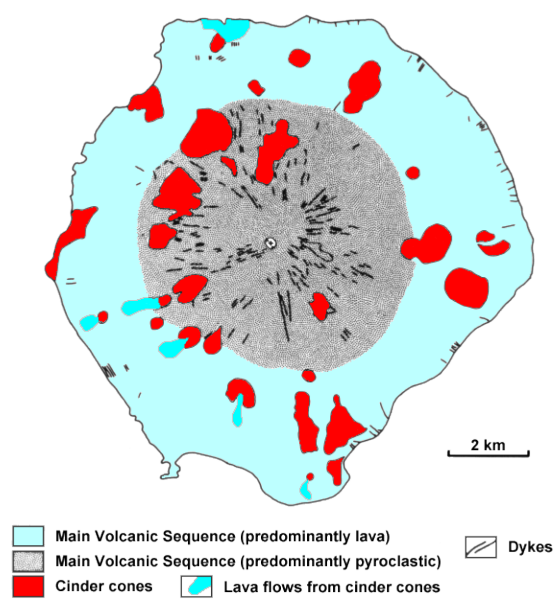

Figure 3. Simplified geological map of Tristan da Cunha Island.

Ascension is a volcanic island, but although there are lots of vents on the island, it is only a single volcano. In fact, the area above the water level is only 1% of the volcanic landmass.

Ascension lies on the South American plate, while the hotspot is on the other side of the Mid Atlantic Ridge under the African plate (Figure 2), and the magma flows along the ridge to reach Ascension Island.

Larger explosive eruptions produce pumice and ash. The ash and pumice can be laid down in two main ways, as pyroclastic fall and pyroclastic flow, both of which are found on Ascension. Pumice is a very light volcanic rock filled with holes, from the rapidly expanding gas that drove the eruption.

Most of the outcrops are scoria cones. These are built up during relatively small-scale explosive eruptions where red-hot rocks are thrown from the vent into the air, cool and then land. The magma on this island is usually basaltic.

Mafic and silicic pyroclastic deposits are distributed across Ascension Island, much of them are trachyte, rhyolite and obsidian, all igneous rocks. These types of rocks have a medium magnetic susceptibility, which is considerable for correlation to Z component. A geological map of Ascension is in figure 4.

The two South Atlantic islands of this paper are better represented by igneous rocks, and basalt is the most common one in both islands. The iron oxide content of basalt can vary from 3.8 to 8.1%, and because of this high iron content magnetite is a common mineral in basalts. The magnetic susceptibility of basalt (as in all igneous rocks) is relevant as well, and this is an important feature that can affect the behavior of Z component in these two islands.

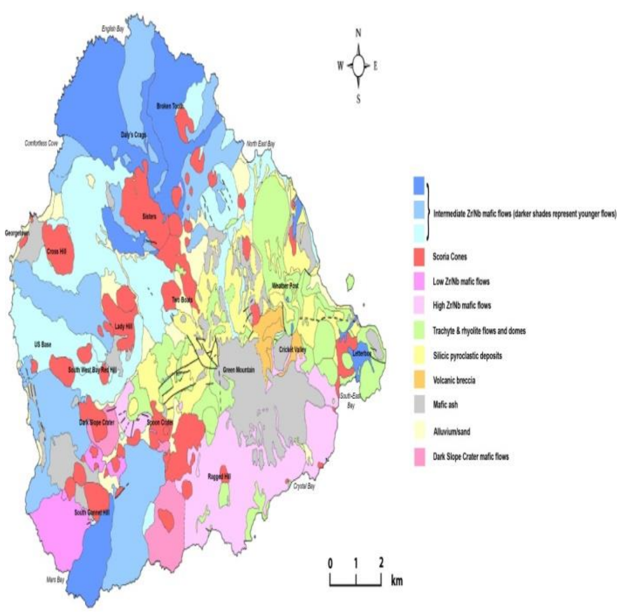

Figure 4. Geological map of Ascension Island.

Vassouras's geology can be more represented by metamorphic rocks, like gneiss, migmatite, amphibolite and quartzite, with some dykes of basic rocks (basalt, gabbro). Some minerals such as biotite and hornblende can be found in Vassouras as well. These minerals can have large amounts of magnetic materials like iron.

Biotite and hornblende compose lots of metamorphic rocks in the region, which indicates reasonable levels (medium to high) of magnetic susceptibility.

For a better understanding of the influence with Z component, an association with the individual magnetic materials content of each type of rock or mineral found in the outcrops is necessary in all of the three stations studied.

Figure 5 shows a geological map of Vassouras's region.

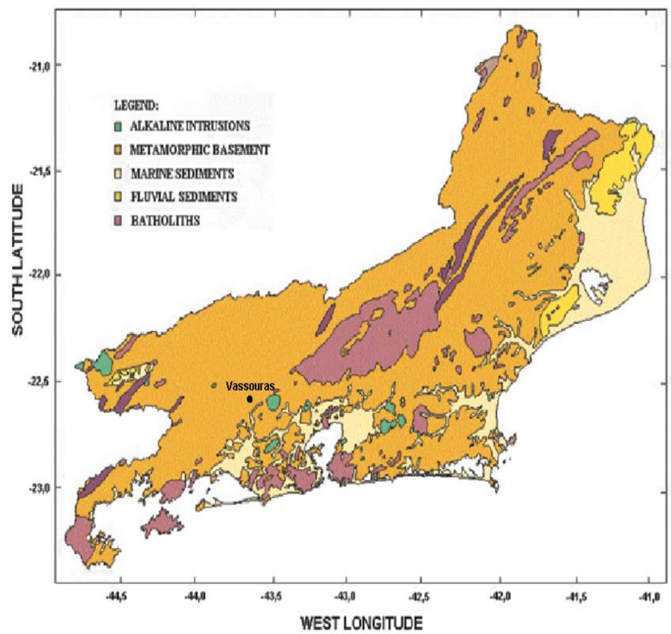

Figure 5. Geological map of Rio de Janeiro. Vassouras is shown.

Results

The quiet daily variations for the two quiet days are in figure 6 for D component and in figure 7 for Z component. A pattern on D component can be seen on September 14 and 15. D decreases around noon and has its maximum between 14 and 16 UT in all stations studied. From the planetary index of geomagnetic activity, Kp, the geomagnetic field condition for Sept. 14 and 15 is rather quiet, and the geomagnetic variations are mainly due to the solar quiet daily variation (ionospheric Sq-currents).

The diurnal variation curves in Z component for the three stations might be interpreted according to the geology of the regions studied. The morphology of the curves in VSS has a more pronounced diurnal variation when compared to TDC and ASC. This might be due to VSS location, which is close to the SAMA foci. VSS's geology is more represented by metamorphic rocks, which has minerals

with medium to high magnetic susceptibility, influencing Z component.
TDC is the station with the highest amplitude of Z component. Tristan da Cunha, as said, is a volcanic island, so as expected the geology affects more TDC than the other stations. ASC is a volcanic island either, and its amplitude varies in a similar morphology to TDC, but TDC is closer to SAMA foci than ASC.
Figure 8 shows the curves of the two disturbed days for D component and figure 9 for Z component. TDC is the station with the more pronounced variation and amplitude of D component. The pattern is the same for disturbed days, the curves decrease around noon and show a peak around 16 UT.

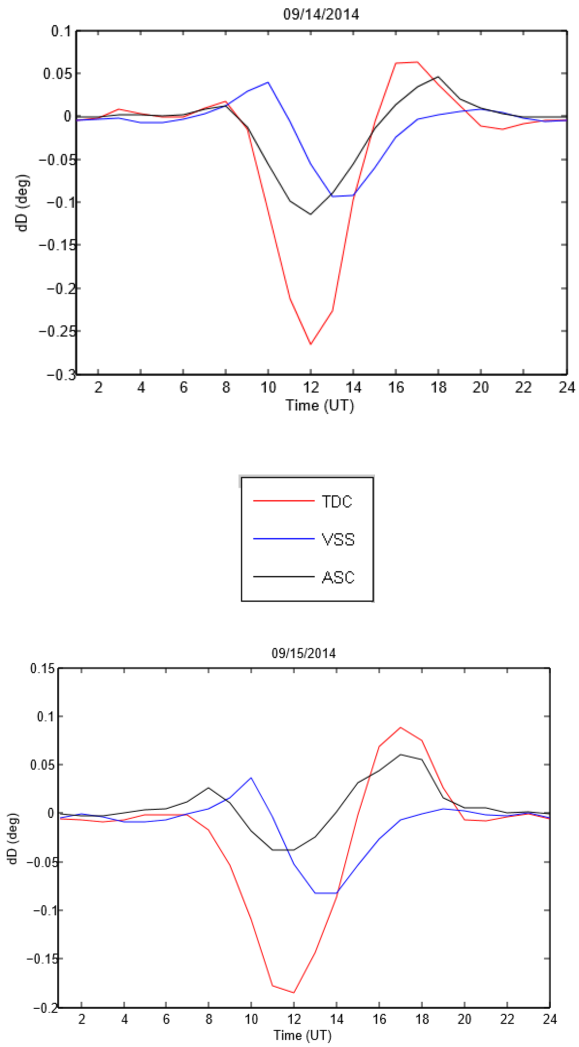

Figure 6. Quiet daily variations of D component for the two quiet days.

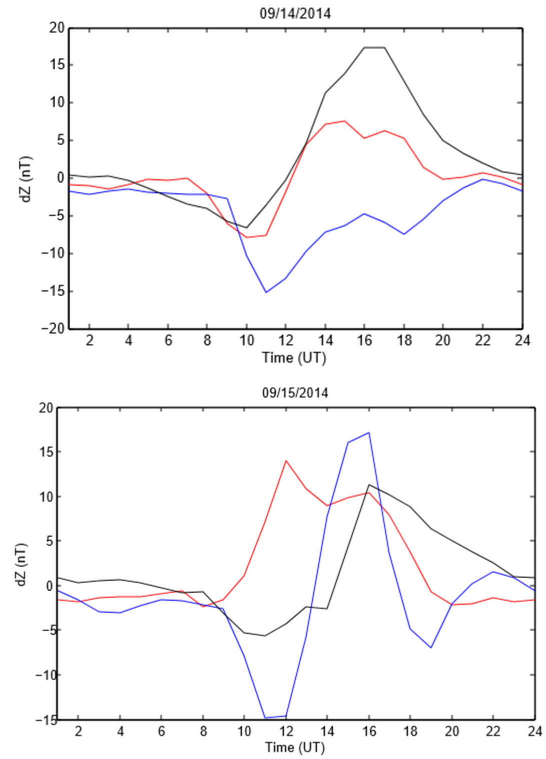

Figure 7. Quiet daily variations of Z component for the two quiet days.

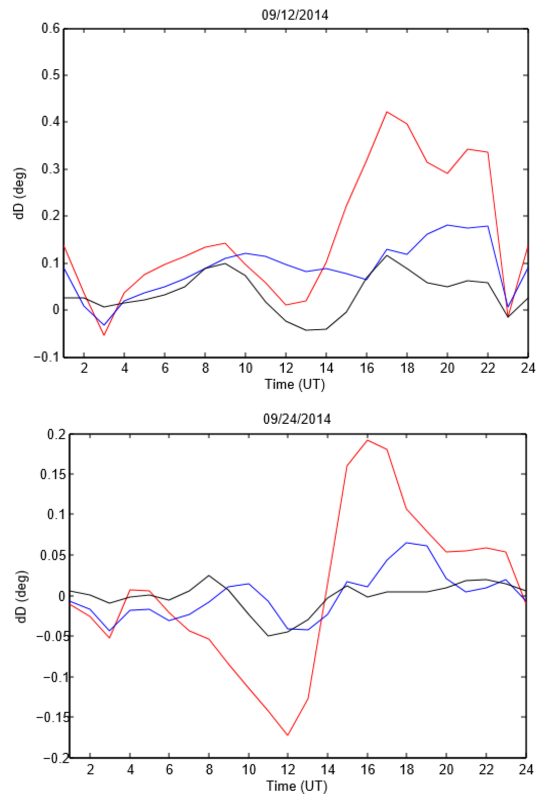

Figure 8. Declination for the two disturbed days.

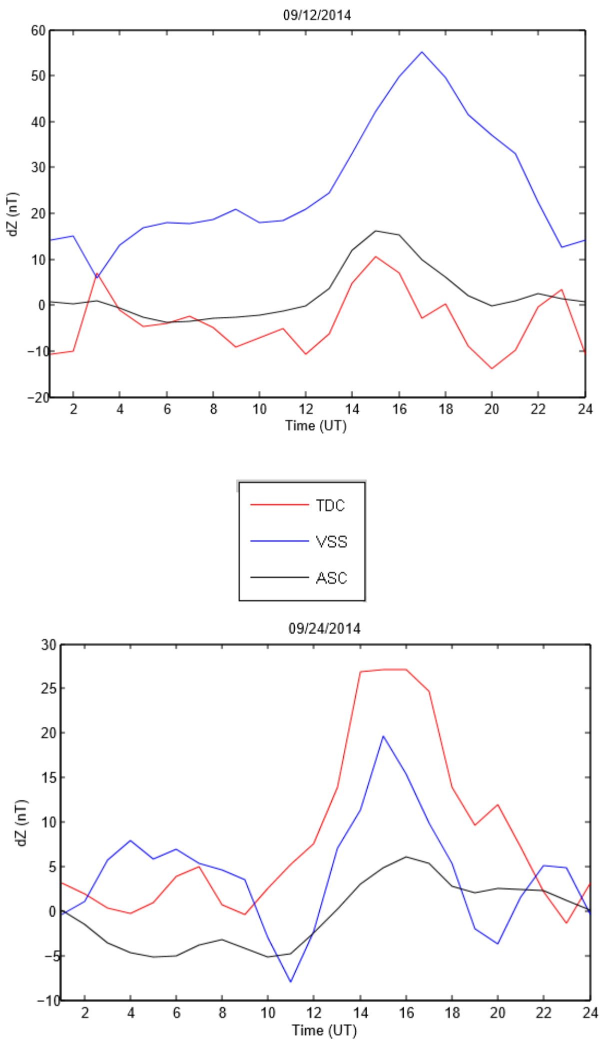

Figure 9. Vertical component for the two disturbed days.

Conclusions

This study brought some interesting results about the stations studied. There seems to be regular increase of ionization in the ionosphere of SAMA region, greater increase at the center of the SAMA compared to away from it.

It is argued that Tristan da Cunha represents an ideal location to continuously record geomagnetic field variations for studying the SAMA. For instance, induction effects are less pronounced for an island than for a continental coastal location.

The data of Z component from TDC and ASC can be a problem in some cases, because the local bias field can change with time, for instance due to volcanic activity, erosion, magnetization of the volcanic rocks due to lightning strikes, or a variation of the rock magnetization with temperature. The local bias field is also very inhomogeneous and slight positional changes (e.g. in the height of the sensor) have effects.

For a better understanding of the relation between Z component and the geology of the regions studied, an association with the individual magnetic materials content of each type of rock or mineral found in the outcrops is necessary in all of the three stations.

This is a work in progress with some initial assumptions according to a preliminary study of these places.

Acknowledgments

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