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Geomagnetic anomalies observed at volcano Popocatepetl, Mexico

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Abstract. Results of the ULF geomagnetic monitoring of the volcano Popocatepetl (Mexico) and their analysis are summarized and presented for the period 2003–2006. Our analysis reveals some anomalies which are considered to be of local volcanic origin: the EM background in the vicinity of the volcano was found to be significantly noisier than at other reference stations; sporadic strong noise-like geomagnetic activity was observed in the H-component; some geomagnetic pulsations were observed only at the Tlamacas station (located at 4 km near the volcano). The results are discussed in terms of a physical mechanism involving the presence of a second magmatic chamber within the volcano and, finally, further perspective directions to study volcanic geodynamical processes besides the traditional ones are given.

1 Introduction

The Popocatepetl volcano (nick named El Popo, Central Mexico, Long. 261.37, Lat. 19.02, 5465 m elevation) is one of several active volcanoes that form the Trans-Volcanic Belt of Mexico (also know as Neo-Volcanic Axes) and its existence is related to the geodynamics of the North American and Coco plates. El Popo is a major geological hazard in Mexico, because its sudden eruption threatens one of the world's most populated areas (Mexico City situated about 70 km southeast) and the nearby population of Puebla (about 45 km west) and Cuernavaca (about 60 km northeast) among others. A major eruption would have serious consequences for 30 millions people living in communities on the flanks of the volcano, and ash from such an eruption could also endanger aircraft using Mexico City international airport (Macías Vázquez et al., 1995).

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Different long-term observatories on the electro-magnetic (EM) environment of volcanoes are studied in different countries with high volcano hazards (Currenti et al., 2005; Enomoto et al., 2006; Fujinawa et al., 2006; Hata et al., 2001; Kotsarenko et al., 2007), and reliable physical models for their interpretation are established (Kagiyama et al., 1995; Kopytenko and Nikitina, 2004). In terms of this, the main aim of our study was to analyze the geomagnetic data observed at the Tlamacas station, Popocatepetl, obtained during the period 2003–2006 in order to find anomalies which could be related to geodynamical processes produced by the volcano Popocatepetl.

2 Experiment and methodology

Permanent geomagnetic observations at volcano Popocatepetl started in March 2002 at the seismic station Tlamacas (CENAPRED, Long. 261.37, Lat. 19.07), situated 4 km north from the volcano crater. The first data were obtained by a Torsion type 3-axial magnetometer (GPS-synchronization, 50 Hz sample frequency, designed at St.-Petersburg IZMIRAN Dept.) which appeared to be contaminated by an intensive periodical multi-band noise coming from the near-buried seismograph cables, and the precision of the instrument went down. The next stage of the observations covers the period 2003–2004 when we installed a 3-coordinate flux-gate magnetometer (GPS, 1 Hz, designed at UCLA). All the results presented in this paper are based on the data recorded by this last instrument. Some of them, related to the period during 2003–2004 (Kotsarenko et al., 2005a), have a good quality but cover relatively short time intervals (40 days for the longest permanent series) due to the power cuts that frequently occurred at the observation site. Eventually, a powerful no-brake UPS system was established in the 2005, hence we collected long series of reliable data (2005–2006) for a systematic analysis.

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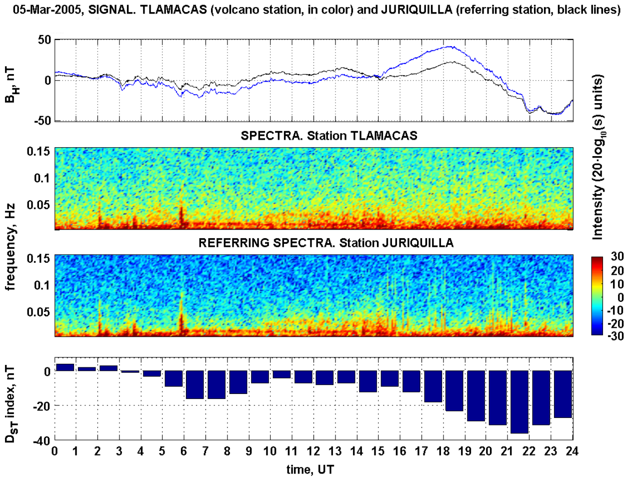

Fig. 1. The spectral intensity of the noise background is higher in the Tlamacas, 2nd panel: domination of more intensive orange colors in dynamic spectra contrary to the weaker green and blue seen at the 3rd panel, Juriquilla (the reference station). Top panel: H-component signals, Tlamacas (blue line) and Juriquilla (black). 2nd and 3rd panel: Tlamacas and Reference spectrogram dynamic spectra. Bottom panel: Dst index of geomagnetic activity.

Our study includes the analysis of dynamic spectra as a part of a traditional analysis for the continuous component of the magnetic field and the analysis of geomagnetic micro-pulsations for the pulse component. Temporal intervals with a high geomagnetic activity (estimated by equatorial D_{st} index) are discarded from the analysis. To distinguish the local character of the observed phenomena from the global ones, we compared our results with those calculated for a station of reference: the closest Mexican station Juriquilla (JU2) integrated to the Mid-Continent Magneto-seismic Chain (McMAC, see Chi et al., 2005) equipped with the same instrument.

3 Results and their discussion

The analysis of the results shows, first of all, an average level of the background electro-magnetic (EM) noise in the vicinity of the volcano markedly stronger than in the reference station (Fig. 1). This observation becomes important since we take into account the following considerations. The volcanic station Tlamacas operates in the electromagnetically quiet zone, free from human or industrial activities. On the contrary, the reference station Juriquilla is situated at a University campus near the north industrial part of Queretaro city, where the EM background is definitely greater. In fact, this increased EM background was permanent during all the monitoring period. The possible sources of the perturbed magnetic field seem to be: re-magnetization processes in the rock medium due to thermal heating and self-induction of the conductive magmatic currents in the geomagnetic field.

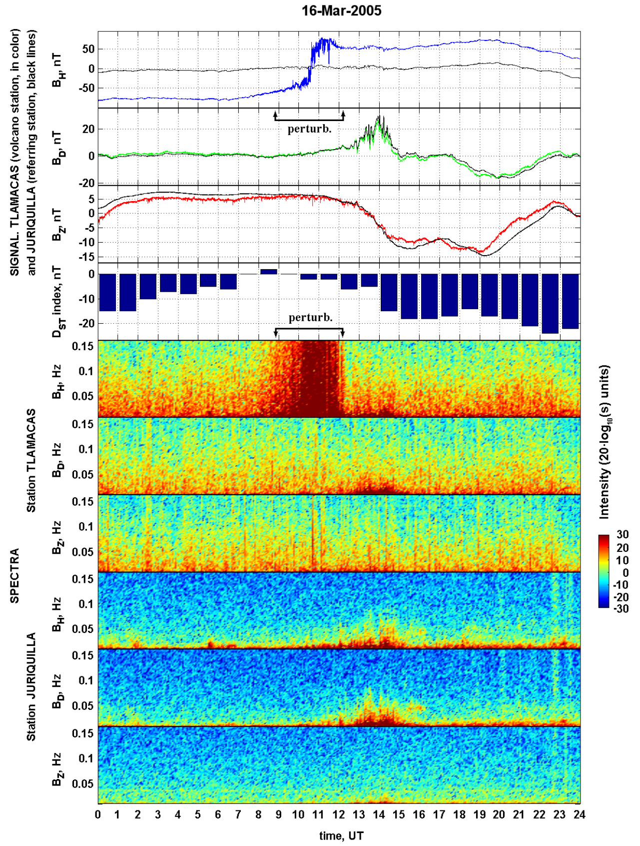

Fig. 2. The intensive (100 γ change of the base value, up to 50 γ in the noise amplitude) perturbation observed in H-component of the signal at Tlamacas station (1st panel, blue line) compared to the reference signal at station Juriquilla (back line) and its dynamic spectra (panels 5). Panels 2 and 3 (signal), 6 and 7 (spectra): the background noise level in D- and Z-components is also enhanced but much lower than in H-. Reference (not-perturbed) Juriquilla spectra (lowest panels, 8–10) observed under geomagnetically quiet period (panel 4: D_{st} index of geomagnetic activity).

Further, there was a strong noise-like geomagnetic activity in the horizontal (H-) component of the magnetic field with an intensity of up to tens of gammas (nT) and duration from several hours up to 1–2 days (Fig. 2) 39 times within the observation period 2003–2006. In the other components, declination (D-), and vertical (Z-), the signal is very small compared with the horizontal component. The events were only few times accompanied by weak and moderate volcano eruptions (mostly gas or water), local seismic events, and tremors. Several times the mentioned perturbations entailed a shift at the signal base line, with a level greater than 100 γ also shown in the Fig. 2. Similar links to the observed phenomena were presented in Martin-Del Pozzo et al. (2002). The significant differences between these results and ours are that these authors used a total field magnetometer system and, therefore, could not distinguish the polarization of the observed signals. The actual polarization of the perturbations, mostly expressed in the horizontal component, makes the re-

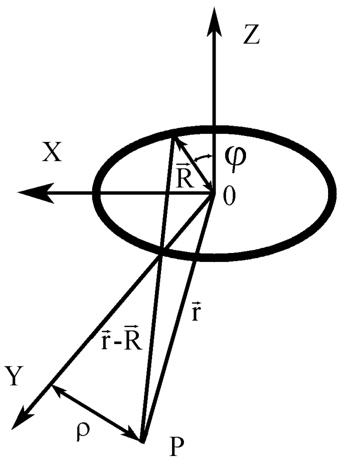

Fig. 3. Schematic source configuration for the flat magmatic camera (ring) for the calculation of the magnetic field in the observation point (P).

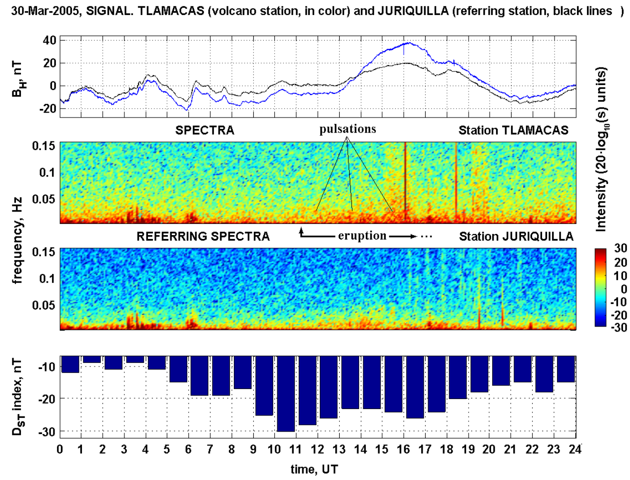

Fig. 4. The table of symbols is the same as in Fig. 1. The example of locally generated geomagnetic micro-pulsation observed during a long fumarolic eruption of several hours.

cently obtained result important because it indicates a certain anisotropy for their generation, or a specific geometry of the source system. The majority of natural physical mechanisms capable of producing similar perturbations, such as the already mentioned re-magnetization and magmatic flows are, in general, isotropic. Another suitable mechanism, magnetostriction, implies friction in the rock medium, i.e. tectono-volcanic events (tremors) and therefore does not match the evidence, because most of the observed perturbations occur under seismically quiet periods.

Here we present an original mechanism of the generation, which can theoretically explain the strict polarization of the perturbations. It is based on the specific geometry of the source. We propose the possible existence of an additional lateral magmatic camera (or broad magmatic channel) besides the main magmatic reservoir. This camera should have *flat* geometry and be oriented strictly perpendicular to the line S-N, which almost coincides with the axis Station Tlamacas – Popocatepetl Crater with a very small deviation. From this, circular motions in that hypothetical flat camera will produce manifestations of the H-component of the geomagnetic signal only.

To estimate a possible current configuration that could yield the measured values and directions of the magnetic field, let us consider the simplest circular closed loop with current (see Fig. 3). It is well-known (Batygin, Toptygin, 1978) that the magnetic field of the loop with electric current is given by the formula:

$$B_\rho = \frac{\mu_0 I}{2\pi}\frac{y}{\rho[(R+\rho)^2+y^2]^{1/2}} \times \left[-K(k) + \frac{R^2+\rho^2+y^2}{(R-\rho)^2+y^2}E(k)\right];$$

$$B_y = \frac{\mu_0 I}{2\pi}\frac{1}{[(R+\rho)^2+y^2]^{1/2}} \times \left[K(k) + \frac{R^2-\rho^2-y^2}{(R-\rho)^2+y^2}E(k)\right];$$

$$B_\varphi = 0; \quad k^2 = \frac{4R\rho}{[(R+\rho)^2+y^2]} \tag{1}$$

Here I is the value of the electric current, $K(k)$ and $E(k)$ are the elliptic integrals of the first and the second kinds. We assume that the volcanic rocks are nonmagnetic. In our case, the magnetic component in one specified direction dominates. A possible origin of such a field can be the loop with electric current oriented in the vertical direction, when the normal vector to the area of the loop is directed along the line S-N. Under conditions $\rho \ll R$, $y \sim R$ we have:

$$B_\rho \approx 0; \quad B_y \approx \frac{\mu_0 R^2 I}{2(R^2+y^2)^{3/2}} \tag{2}$$

In this configuration, the measured magnetic field is directed along y-axis. For the estimations, we use R=2 km (a possible size of current loop within the volcano's body), y=2 km, B_y=100 nT. From Eq. (2), one can get $I \approx 10^3$ A.

Assuming the shape of the ring as a torus with the radius of its internal cross-section $a \ll R$, it is possible to estimate a possible density of the current within such a torus:

$$j \approx \frac{I}{\pi a^2} \tag{3}$$

The estimations for realistic values of such a radius a=200 m give $j \approx 0.01$ A/m^2.

Of course, this model is still very hypothetic. However, some encouraging support came from ours colleagues: analysis of the spatial distribution of magnitudes of the local seismicity in the vicinity of volcano Popocatepetl points out a possible existence of a new volcano magma chamber (Zúñiga and Valdés, 2007). Eventually, to prove this hypothesis, permanent simultaneous observations at different points (at least 4) separated by distances of 1–10 km and situated at different heights are desirable. But, of course, a more solid confirmation can be obtained from geophysical and geological studies in the area of the volcano.

Finally, we detected geomagnetic micro-pulsations with arbitrary elliptical polarization, locally generated in the vicinity of the volcano, not observed in the reference station. The event presented in the Fig. 4 was observed during an intense and long-duration fumarolic eruption (it started at 11:21 by UT, and the cloud raised to 1.5 km moving in the N-W direction). We estimate that their possible sources could involve collective properties of the extending aerosol (dusty) plasma like the generation of different plasma instabilities due to the motion of the ionized (and metallic) particles erupted from the crater. Unfortunately, the precision of the instrument (noise power is 10^{-3} nT^2/Hz at 1 Hz) prevent us to confidently resolve them from the enhanced noise level, especially at the time when the eruption began.

4 Conclusions

In the present paper we have described geomagnetic anomalies observed in the volcano Popocatepetl and have discussed possible mechanisms of their generation. The first two phenomena observed, EM noisy background and strong burst-like activity, reveal manifestations of the internal dynamics of the volcano related to the local geomagnetic field, and, therefore, their future analysis could be useful to obtain some latent processes at the body of the volcano, which are difficult to locate by traditional methods. The last phenomena, the locally generated magnetic pulsations, can also serve as a marker for the direction and velocity of the intensive fumarolic motion (using triangulation technique in the case when the geomagnetic station set is greater than 4) and, therefore, can be also useful for an efficient prevention of the pollution in the air and nearby populated lands.

From the considerations presented here, one can see the need for further measurements of the geomagnetic field in the vicinity of the volcano at different locations, separated by distances of 1–10 km and situated at different heights, in order to reconstruct the distribution of the electric current within the body of the volcano and monitor intensive fumarolic eruptions. In conclusion, more precise instruments (magnetometers) are desirable now for the accurate resolution of the observed events. Finally, geophysical and geological studies are needed for the interpretation of the obtained results, and first of all, to prove our hypothesis about the possible existence of a new magmatic reservoir.

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