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TROPOMAG - Influence of geomagnetic storms on the TROPOsphere dynamics: Can the Earth’s MAGnetic field be considered a proxy of climate changes? Some results

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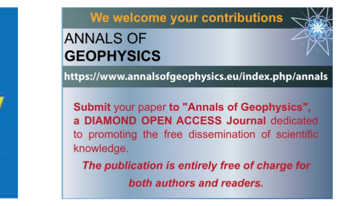

INTRODUCTION

The TROPOMAG project investigates the possible effects of changes of the Earth’s magnetic field on the atmosphere and weather conditions with the aim to better quantify the natural sources of the atmospheric variability. This need raises to assess the observed climate trends more correctly, with a consequent better understanding of man made effects on climate. Specifically, this work explores possible connections between atmospheric pressure anomalies and the occurrence of geomagnetic storms. Indeed, meteorological variability induced by geomagnetic storms is investigated as an accelerated time scale model of the mutual interactions between climate and geomagnetic field on longer time scales. To accomplish this task pressure data, recorded over some Italian volcanic areas, are analysed according to different methods and considering geomagnetic indexes. We decided to investigate the Italian active volcanic areas (Etna, Stromboli, Vulcano and Vesuvio), including those where only hydrothermal activity is present, because volcanoes generate thermal anomalies and input in the atmosphere solid and gaseous particles, creating a vertical corridor connecting different atmospheric layers. For accomplishing these goals, we are using a multidisciplinary approach, based on applied geophysical and geochemical methodologies, as the analysis of the geomagnetically driven ionospheric and tropospheric components of the GNSS signal, geomagnetic field data, anomalies of geochemical parameters acquired in the ground-based monitoring networks of the studied volcanoes.

The «Wilcox» effect [Wilcox et al, 1974]

A preliminary study, by Madonia et al., [2014], suggested for these volcanic areas the possible existence of a ground level, Wilcox-like, solar perturbation of the troposphere.

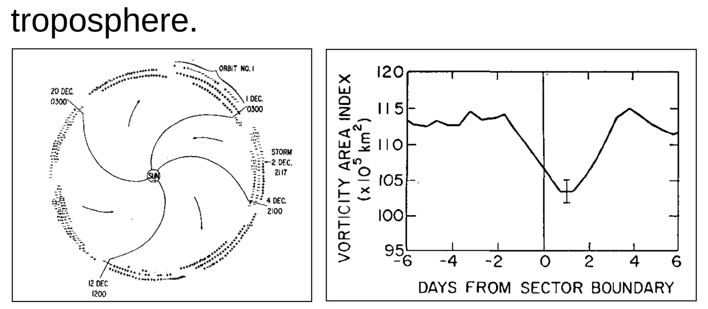

Figure1. On the right, Vorticity Area Index (VAI) = ratio between N-S and E-W dimensions of winter low pressure (cyclonic) areas in the Northern Emisphere. VAI minima 1 day after the Magnetic Sector passage (on the left a sector representation of the interplanetary magnetic field. [Wilkox et al, 1974]

Formation of wintertime **low pressure troughs**, developing or moving into North Pacific region and showing anomalous deepenings 2-4 days after a bright aurora or a **geomagnetically disturbed day**.

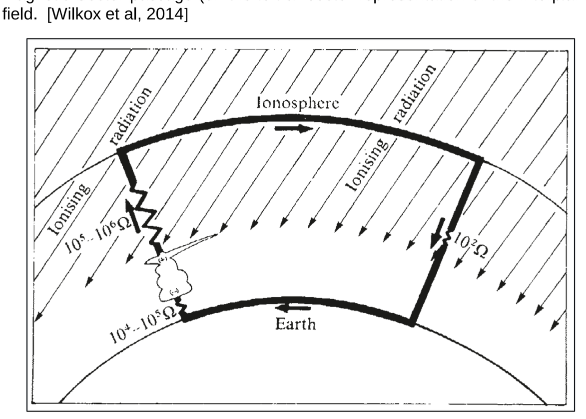

Figure 2. The atmospheric electrical global circuit [Markson, 1978]. Arrows indicate flow of positive charge.

Galactic Cosmic Rays collide with particles in atmosphere inducing electrical charges on them, and finally nucleate clouds. Solar modulated variations in ionising radiation, occurring in the volume above the thunderstorm generator, change its resistance, thus causing a **worldwide increase in electric field intensity**, which would explain enhanced electric fields following solar flares. Atmospheric electricity would influence thunderstorm development or cloud physical processes, producing stronger precipitation.

Instrumentation and data acquisition

The map on the right show the geographic location of the acquisition network. The measured parameters are: air temperature, atmospheric pressure, telluric currents, soil temperature and dielectric properties, CO2 flux from soil.

Figure 3. Map of the acquisition network

Stations Code	Lat (°) N	Lon (°) E	Elev (m)	Parameters
STR-VLZ	38.806	15.221	219	Dielectric Properties (DP)
VES-GCO	40.824	14.426	1243	Atm. Press. & Air T, DP
VES-TDG	40.778	14.378	49	Atm. Press. & Air T
SAL-MFF	38.554	14.849	927	Atm. Press. & Air T
SAL-SMS	38.557	14.871	8	Atm. Press. & Air T
ETN-POZ	37.672	15.188	67	Atm. Press. & Air T
ETN-TOP	37.719	14.998	2508	Atm. Press. & Air T
PAL-MPP	38.162	13.358	569	Atm. Press. & Air T
PAL-OTB	38.111	13.358	10	Atm. Press. & Air T, DP
VUL-FOS	38.405	14.956	199	DP, Telluric Currents, CO2

Table 1. Geographic coordinates of installed project stations and measurements parameters.

The acquisition network of air temperature and atmospheric pressure, set up on Etna (ETN), Salina (SAL), Stromboli (STR), Vulcano (VUL) and Vesuvio (VES), with an external, non-volcanic control point (Palermo, PAL) consists of one pair of stations in each site, one at the base (BTM) and the other one close to the top of the mountainous structure (TOP), with an acquisition rate of a measure every 30 minutes. Both the stations in each site are providing data from June 30th, 2021(last download September 4th, 2023).

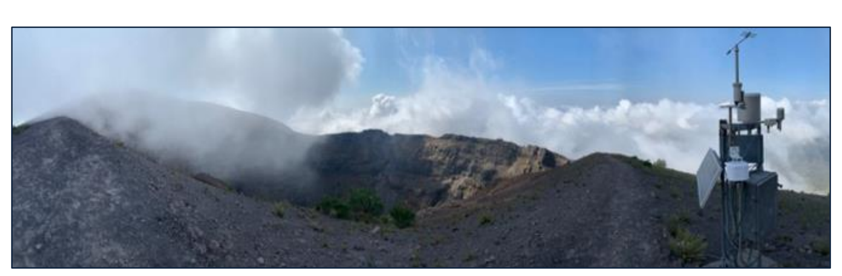

Figure 4. View of a meteorological station of the TROPOMAG ground network, installed on the top of Vesuvio (VES)

Figure 5. Atmospheric pressure sensors with a resolution 0.14 hPa, memory 21,700 data

Analysis of ground level pressure disturbances

Figure6 show the Pearson correlation coefficient (*r*) between hourly instant values of atmospheric pressure measured at the top of Salina (SAL-TOP) and at a lower elevation station (SAL-LEN), with data available prior of the start of the TROPOMAG project. The values of *r* are calculated for moving time windows of 24 hours. It is evident a decorrelation between the signals recorded by the two stations after the peak of the two considered geomagnetic storms. The peak intensity of the storm is indicated by the occurrence of the minimum value of the Dst index indicated by the yellow bar.

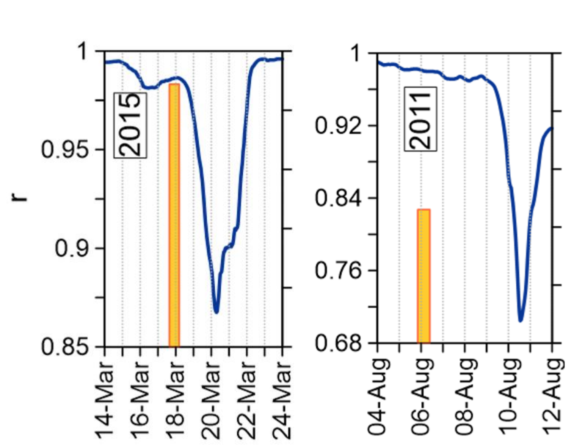

Figure 6. Decoupling of lower troposphere pressures & Sun storms shown two examples in 2015 and 2011.

TROPOMAG data besides atmospheric pressure data

A) Total Electron Content: to investigate local ionospheric anomalies during geomagnetically disturbed periods.
B) GNSS data: to estimate tropospheric delays. The time-varying zenith wet delays (ZWD) will be transformed into estimates of the **Precipitable Water Vapor.** This will allow analyzing atmospheric water vapor variability.
C) Telluric currents: to verify the possible building up of currents induced by the occurrence of geomagnetic storms

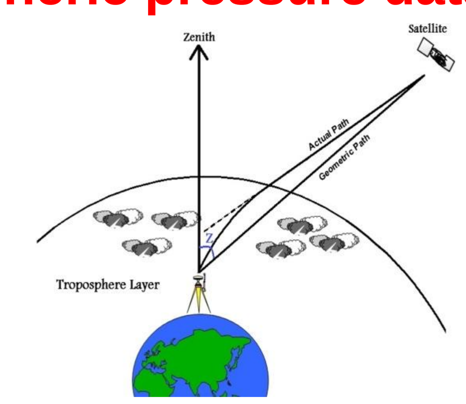

Figure 7. Scheme of GNSS signal receivers used for determining tropospheric delays.

Use of GNSS data for tropospheric delays estimation

We analysed the data collected by the permanent GNSS monitoring network of Mt. Etna volcano since 2004 to estimate the tropospheric time-delay parameters in the zenith direction. As we are interested in the water vapour content of the atmosphere, we converted the zenith wet delays in PWV (Precipitable Water Vapour). PWV is a measure of the equivalent height (expressed in millimetres) of the column formed if all the water vapour was condensed and collected at the ground surface.

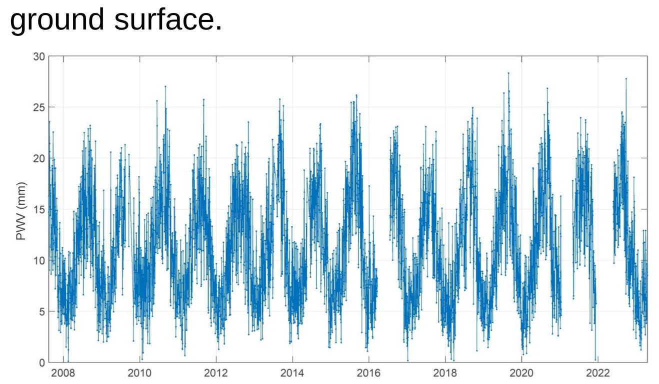

Figure 8. Daily mean PWV time series at site EMSG, in the western flank of Mt. Etna (1478 m a.s.l.).

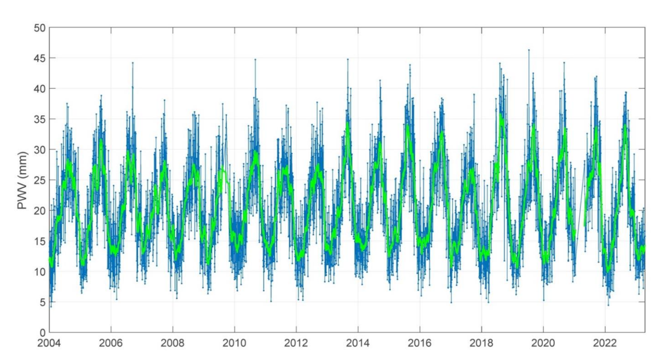

Figure 9. Daily mean PWV time series at site EIIV (blue points) and the monthly moving average (green curve).

As expected, the PWV depends on the height of the tropospheric column over the station. Taking into account the sites EIIV (in Catania) and EMSG (in the western flank of the volcano), that are placed at 89 and 1478 m a.s.l., respectively, we obtained average PWV of about 20 mm/yr and 11 mm/yr, respectively (Figures above). PWV shows also the presence of a clear annual cycle. Daily values at EIIV site range from 5 mm in winter to almost 45 mm in summer and early autumn, when the air capacity to hold moisture increases. The signal also shows evidence of variability, responding to the passage of water vapour carried by meteorological systems. After removing the annual component, the trend of the residual signal at EIIV shows an increase in PWV of 0.5 mm/decade .

Telluric current measurements at Island of Vulcano

Telluric current measurements are achieved by recording the potential difference between two electrodes pairs placed along the North-South direction and installed about 40 and 80 meters apart, at the base of La Fossa cone. The potential difference values between the two pairs of electrodes, show a perfectly synchronous trend that highlights how the measurements are little influenced by sites effects and effectively reflect the overall trend of the natural potential difference in the survey area. Two different modes of variability of the signals have been identified: one effectively linked to magnetic storms and the other linked to rainy events. This demonstrates that geomagnetic storms are able to induce changes in the telluric currents in the survey area. As a result, we can actually, proceed to the second step and investigate whether the telluric current variations induced by magnetic storms can modify the release of gases from the soils.

Island of Vulcano

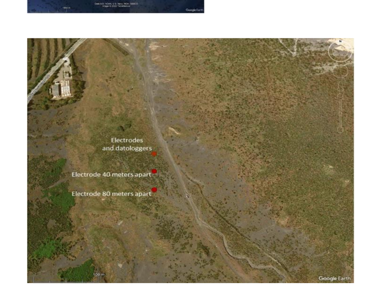

Figure 10. Location of the electrode pairs on the east flank of La Fossa Crater at Vulcano Island

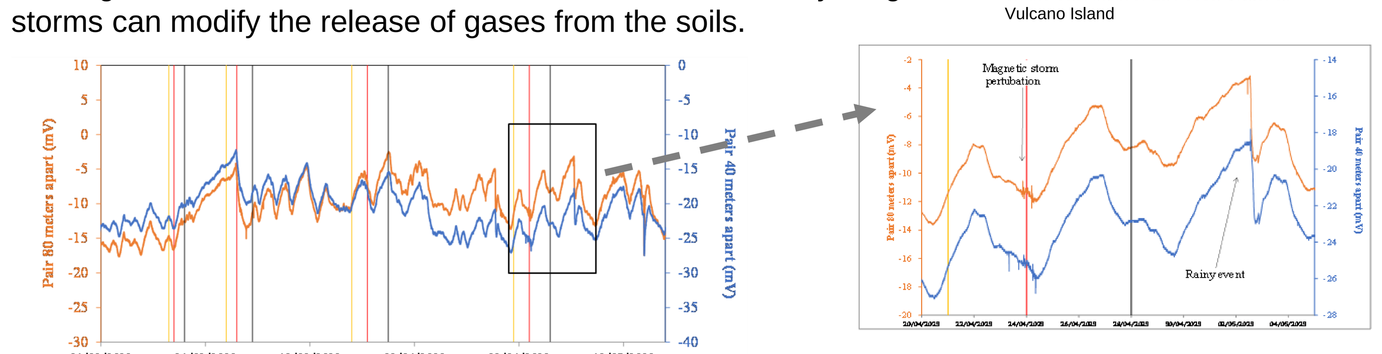

Figure 11. Potential difference values related to the telluric currents between the two pairs of electrodes, 80 and 40 meters apart .Magnetic storms onset (yellow line)-Minimum DST(red line)-End of the disturbed days (black line). Zoom of the box signals in corrispondence with the geomagnetic storm of April 2023 is shown on the right .

Geomagnetic activity

The goal of this research is to look for a possible relationship between tropospheric disturbances and changes in the Earth's magnetic field. In order to find a link between geomagnetic activity and troposphere dynamics, the first step from a geomagnetic perspective is to define the periods of disturbed geomagnetic conditions. This is accomplished using a global index that characterizes geomagnetic activity. In this scenario, we choose to use the Dst index as a proxy for the strength of geomagnetic storms.

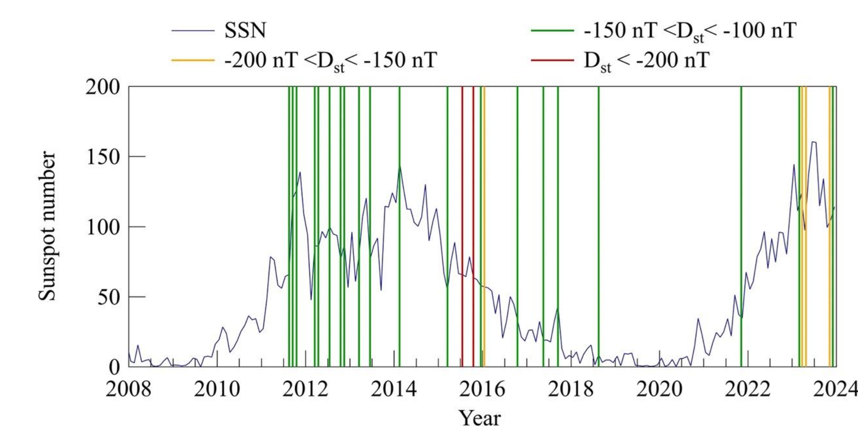

Figure12. Plot shows the Sunspot number (SSN, blue line), that is a proxy of solar activity, and the occurrence of those geomagnetic storms characterised by a minimum Dst lower than -100 nT. Geomagnetic storms are denoted by vertical lines, with varying colors indicative of different levels of geomagnetic activity, progressing from green to orange and red. Conversely, Figure13 displays the trend of the Dst index starting from January 1, 2020.

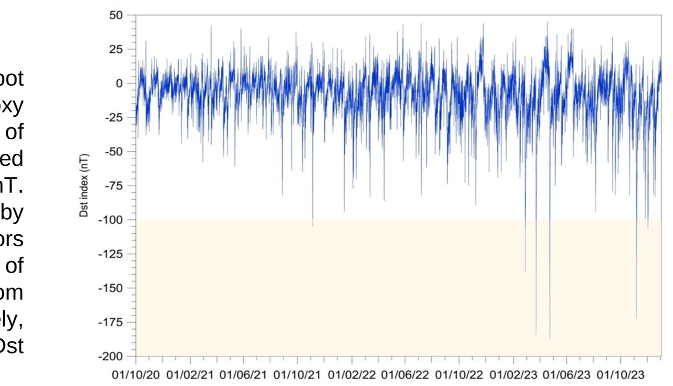

Figure 13: Dst index for the period October 2020-October 2023

Start dist.period	End dist.period	Dst minimun day	Dst minimum value
28/02/21	02/03/21	01/03/21	-58
11/05/21	14/05/21	12/05/21	-61
26/08/21	30/08/21	27/08/21	-82
16/09/21	19/09/21	17/09/21	-64
03/11/21	08/11/21	04/11/21	-105
12/01/22	19/01/22	14/01/22	-94
29/01/22	17/02/22	03/02/22	-77
13/03/22	16/03/22	13/03/22	-83
13/04/22	17/04/22	14/04/22	-86
25/05/22	31/05/22	28/05/22	-57
06/07/22	10/07/22	07/07/22	-82
17/07/22	21/07/22	19/07/22	-61
04/08/22	10/08/22	08/08/22	-52
15/08/22	22/08/22	17/08/22	-53
01/09/22	12/09/22	04/09/22	-74
13/10/22	15/10/22	14/10/22	-73
21/10/22	24/10/22	22/10/22	-75
05/11/22	12/11/22	07/11/22	-89
07/12/22	10/12/22	07/12/22	-65
02/01/23	05/01/23	04/01/23	-65
14/02/23	17/02/23	15/02/23	-69
25/02/23	02/03/23	27/02/23	-138
21/03/23	28/03/23	24/03/23	-184
21/04/23	28/04/23	24/04/23	-187

Table 2. Intervals of disturbed days of the geomagnetic storm occurred during Tropomag acquisition period and relatives minimum Dst values.

As seen in the Figure 12, the period 2020-2023 contains a low level of solar activity and the start of the ascending phase of the 25th solar cycle, therefore only a few geomagnetic storms with a minimum Dst of less than -100 nT have occurred. The most interesting happened in November 2021 (with a minimum Dst of -105) and between the end of February and April 2023, when three powerful geomagnetic storms were seen. As we approach the peak of solar activity expected in 2025, it's probable that the rising number of sunspots, which is leading to an increase in geomagnetic storms, will provide us with the opportunity to conduct a more statistically robust analysis of the Tropomag project.

As an initial step towards investigating the potential impact of solar storm activity on atmospheric pressures, we examined the temporal variations of pressure between stations located at higher and lower altitudes in the ETN, VES, and SAL regions, focusing on signal frequencies. Subsequently, in exploring Sun-Earth interactions as a potential contributing factor to the observed pressure anomalies, we overlaid the Dst index trend onto spectra. The power spectral density (PSD) of pressure signals was estimated from two years of data collected at both the top (TOP) and bottom (BTM) stations.

Dynamic power spectra are calculated using Burg’s method over 10-day window by progressively moving it one day at a time: each interval's length is 480 data points (representing 10 days) with a time step between individual spectra of 48 data points. As an example, we present the results for the VES stations.

From both Figure14 and Figure15 of the dynamic spectra a more intense horizontal trace clearly emerges on the lower frequencies at around 0.023 mHz (corresponding to a period of 12 hours), and other more or less equally spaced bands (f24 =1/ (24*3600) =0.0116 mHz; f12 = 1/ (12*3600) =0.0231 mHz and so on) that clearly emerge from the average spectrum in Figure 16 too. Moreover looking at the dynamic spectra, some intense bands are observed. By overlapping the behavior of the Dst index to these colored vertical bands we looked for a possible correspondence with geomagnetic storms listed in Table 2. This correspondence is sometimes verified, some others not (for example there weren’t storms in December 2021, but an orange/red stripe is evident).

Analysis: Power Spectral Density estimate

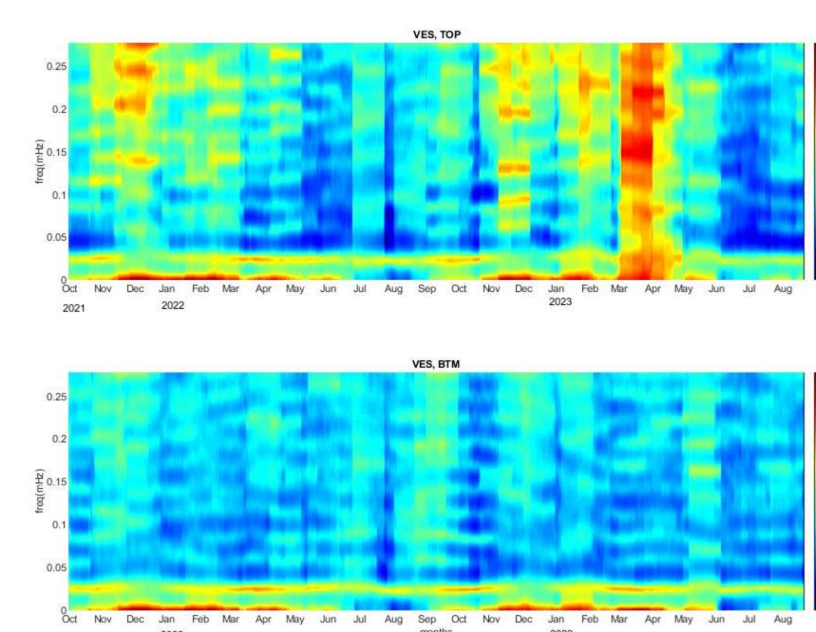

Figure 14. Dynamic spectra (30 days window) for the ETN_top and ETN_BTM stations with one-day step for the two approximately years of acquisition (2021-2023).

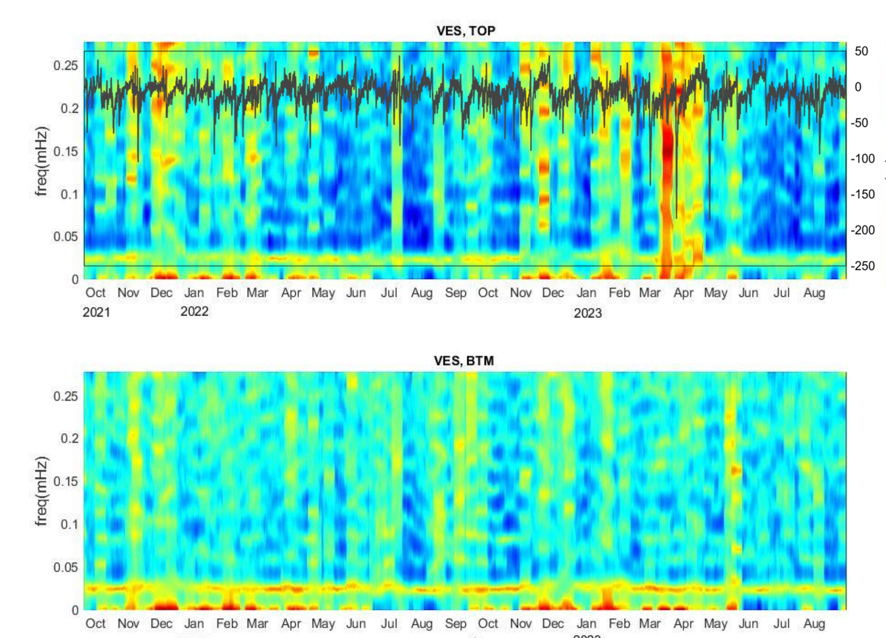

Figure 15. Dynamic spectra (30 days window) for the ETN_top and ETN_BTM stations with one-day step for the two approximately years of acquisition (2021-2023).

Average spectra

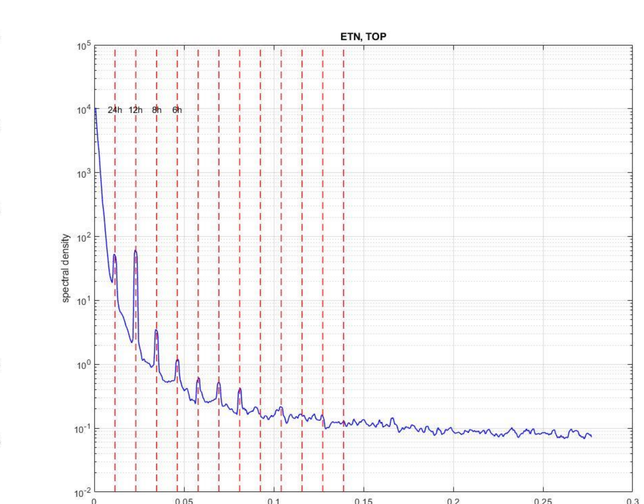

Figure 16. An average spectrum over the entire interval. We used 690 days (34512 data), FFT length: 30 days (1440 data), and a moving average of the spectral densities over 5 bands (NP = 5).

Considering positive correspondences that could be inferred, the initial peak from the left side across all frequencies observed at the VES_TOP station (located on the left in Figure14) aligns with the timeframe from the end of February to April 2023, notable for the occurrence of three particularly intense geomagnetic storms (refer to Table 2). This period encapsulates all three of the aforementioned storms, with a 14-day overlap between each consecutive window. Specifically, the storms of February 25, 2023 (Dst= -138), March 21, 2023 (Dst= -184), and April 21, 2023 (Dst= -187) contribute to this prominent peak, each exhibiting significant intensity. This correlation between pressure spectra and storms appears to hold true. While additional peaks are evident, particularly at VES_TOP, they correspond to other storms with smaller Dst values.

Conclusion

The primary objective of the TROPOMAG project is to detect potential anomalies in tropospheric and ground-level parameters induced by geomagnetic storms, thereby identifying potential indicators of interactions between climate and the Earth's magnetic field on broader space-time scales.

In this context, we present our initial observations on telluric currents and the analysis of atmospheric pressure data in correlation with geomagnetic activity, with a particular focus on sunspots and the Dst index. While we have not yet arrived at a definitive answer to the project's central question, our work remains ongoing, and we anticipate that intriguing findings may emerge as we approach the peak of solar activity expected in 2025.

We are aware that the influence of space weather on Earth atmospheric pressure field is not easy to be understood and it is very complex subject. Since the pioneering works of Macdonald and Roberts [1960] and Wilcox et al. [1974], the scientific community is involved in a debate that, lasting for over 60 years, seems not under the way of a simple conclusion. A decisive proof of such a relationship has been not yet found with an unresolved ambiguity of the results, but it is important to continue investigations in a progress direction, as Tropomag efforts understandings.

References

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