Wave-like structures prior to very recent southeastern Mediterranean earthquakes as recorded by a VLF/LF radio receiver in Athens (Greece).

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Introduction

- In this investigation we searched for anomalies in VLF nighttime amplitude signal in order to study three recent strong mainshocks that have happened in southeastern Mediterranean on September and October of 2021.

- We used the VLF amplitude data from VLF station (receiver) [call sign: UWA] at University of West Attica which has been installed inside the department of Electrical and Electronics Engineering from March of 2020.

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Wavelet analysis in VLF nighttime amplitude recordings for three mainshocks on September and October of 2021

- We chose the transmitter with call-sign “ISR” which is located in Negev (Israel) with frequency at 29700 Hz.
- The locations of the epicenters of these three EQs are close or within the 5th Fresnel zone of the propagation path between transmitter and receiver pair (ISR – UWA)
- In this work we computed the morlet wavelet analysis of nighttime amplitude recordings which is similar to the other works that have been presented in bibliography (e.g. see ref. [**2**]). More specifically, we searched for any anomaly that could indicate the existence of AGW (atmospheric gravity waves) prior to any examined EQ .
- Also, we searched for any other global extreme phenomenon such as geomagnetic storms and solar flares, which may have occurred exactly in time with the found AGW-related anomalies and they could have a contaminating impact on the obtained results.

[2] *Biswas, S., Kundu, S., Ghosh, S., Chowdhury, S., Yang, S.-S., Hayakawa, M., Chakraborty, S., K. Chakrabarti, S., & Sasmal, S. (2020). Contaminated effect of geomagnetic storms on pre-seismic atmospheric and ionospheric anomalies during Imphal earthquake. Open Journal of Earthquake Research, 09(05), 383–402. https://doi.org/10.4236/ojer.2020.95022*

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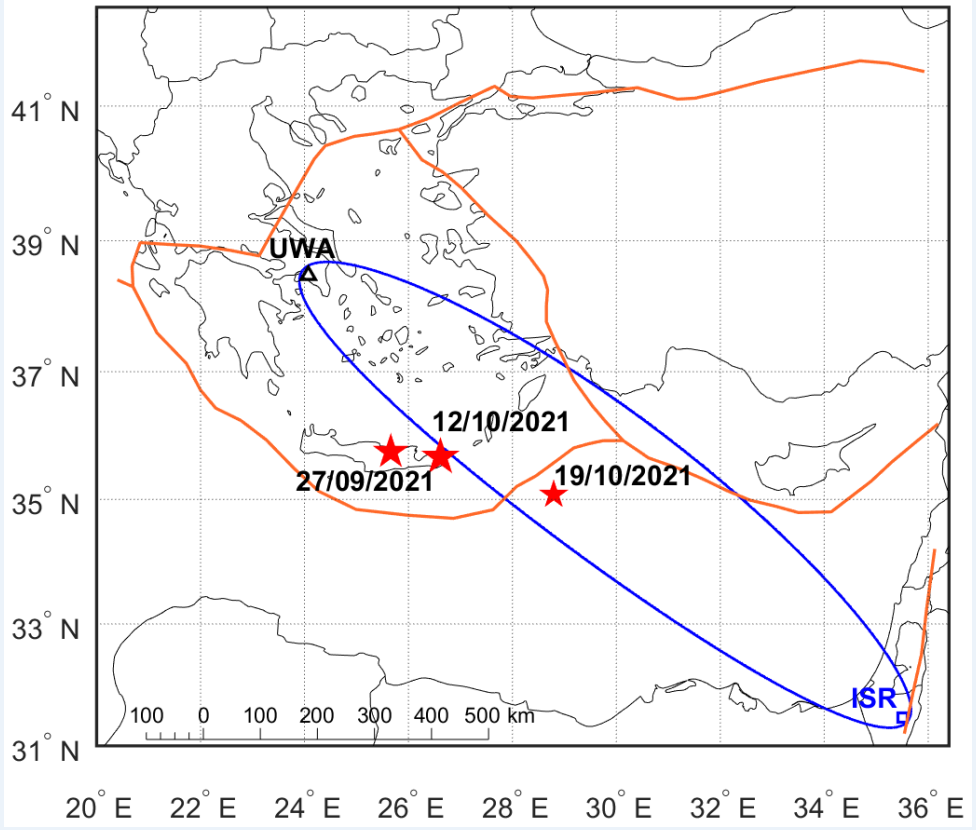
Studied earthquakes



- **First EQ:** A strong EQ with magnitude 6 Mw and depth 6 km was occurred on 27/09/2021 (06:17:21 UT) at Thrapsanon (Greece)
- **Second EQ:** A strong EQ with magnitude 6.7 Mw and depth 20 km was occurred on 12/10/2021 (09:24:05 UT) at Palekastro (Greece)
- **Third EQ:** A strong EQ with magnitude 5.9 Mw and depth 43.9 km was occurred on 19/10/2021 (05:32:32 UT) at Karpathos (Greece)

Figure 4: Map showing with red pentagrams the locations of the epicenters. The 5th Fresnel zone of the propagation path UWA-ISR is shown with blue solid line while the borders of the geotectonic plates are shown with solid line of orange color.

*All presented information for these three earthquakes are searched from US Geological Survey (earthquake catalog).

Procedure (steps) for applying Wavelet analysis:

1. We process the nighttime amplitude data (in dB) by choosing the nighttime interval from 22:00 LT to 5:30 LT.
2. We remove any kind of non-natural fluctuation (such as noise, or technical parts due to the operation of the transmitter) from the signal.
3. After, we resample the nighttime excerpts of the signal from 1 second to 1 minute.
4. Next, we calculate the running mean of 10 minutes and we subtract each value of the initial vector.
5. Finally, we apply the wavelet analysis in the fluctuation of the amplitude computed from the previous step by calculating the wavelet power spectrum (WPS) as proposed by Torrence & Compo (see ref. **[3]**).

[3] *Torrence, C., & Compo, G. P. (1998). A practical guide to wavelet analysis. Bulletin of the American Meteorological Society, 79(1), 61–78.*

Results : First EQ

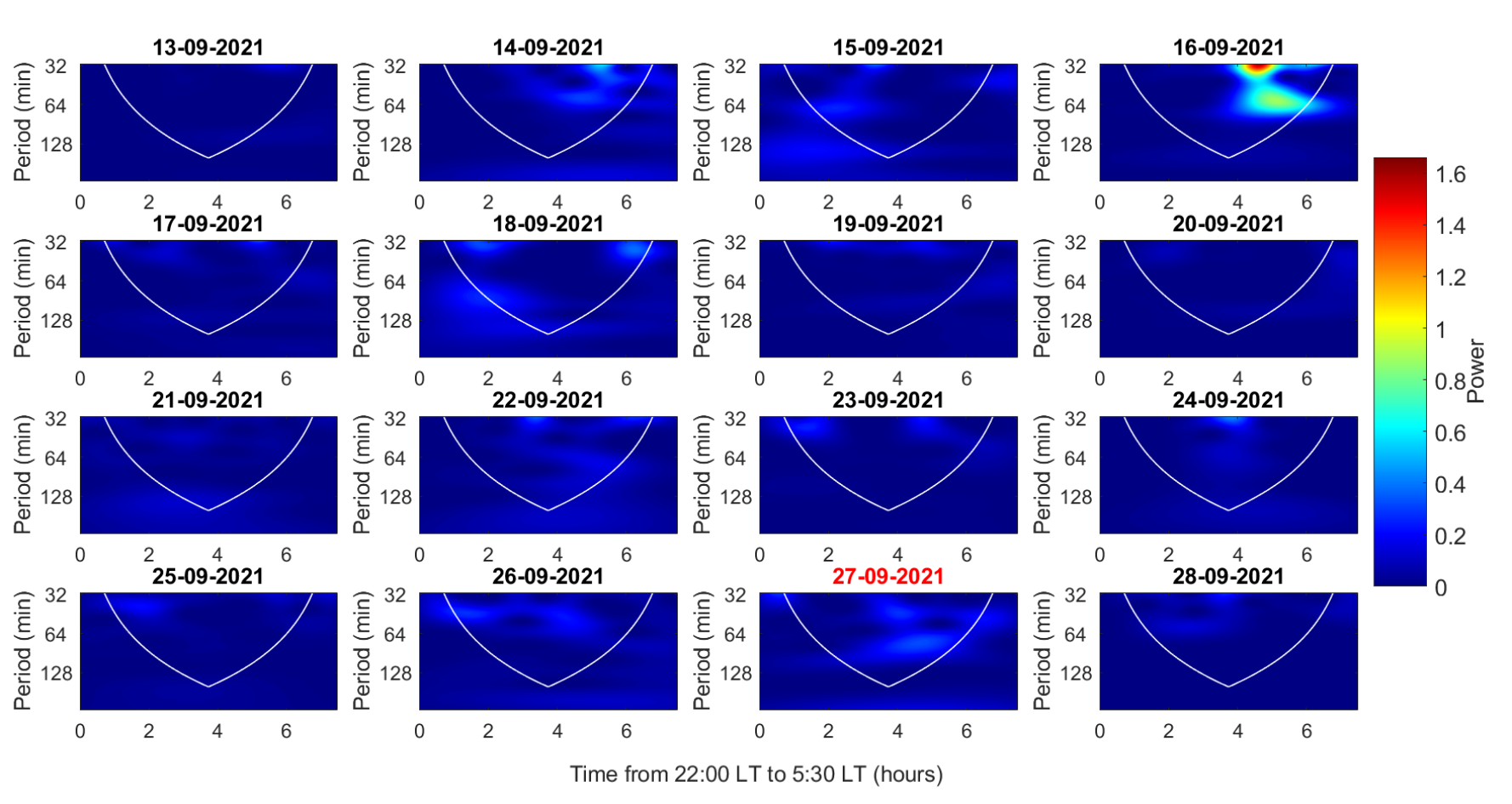


Figure 5: Wavelet power density spectrum of nighttime VLF amplitude signal. The X-axis denotes the time in hours, Y-axis indicates periodicity of wave structure in minutes and the color-bar represents the power of the WPS. The red colored label of date indicates the date of the EQ.

Results : Second EQ

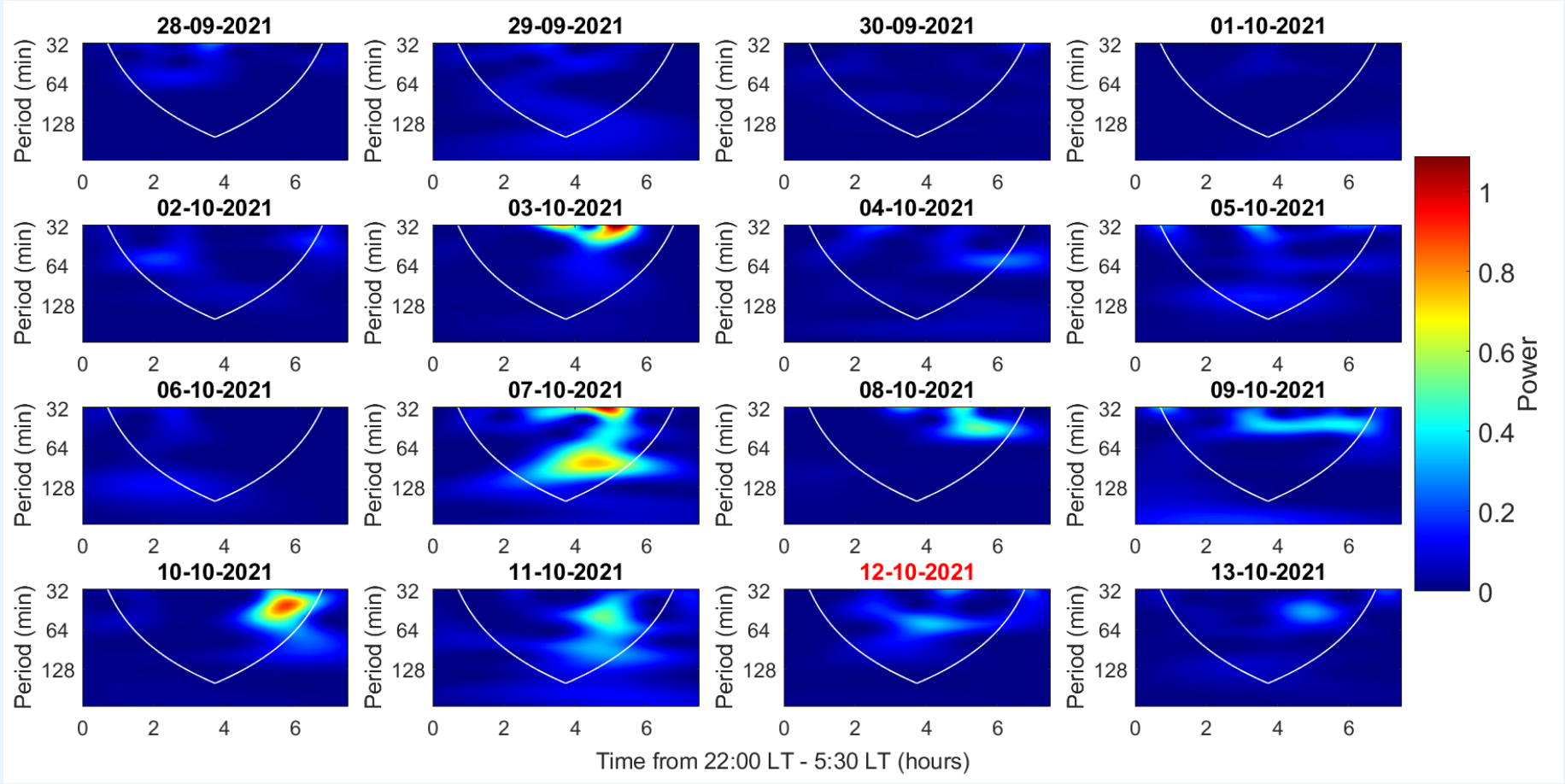


Figure 6: Wavelet power density spectrum of nighttime VLF amplitude signal. The X-axis denotes the time in hours, Y-axis indicates periodicity of wave structure in minutes and the color-bar represents the power of WPS. The red colored label of date indicates the date of the EQ.

Results: Third EQ

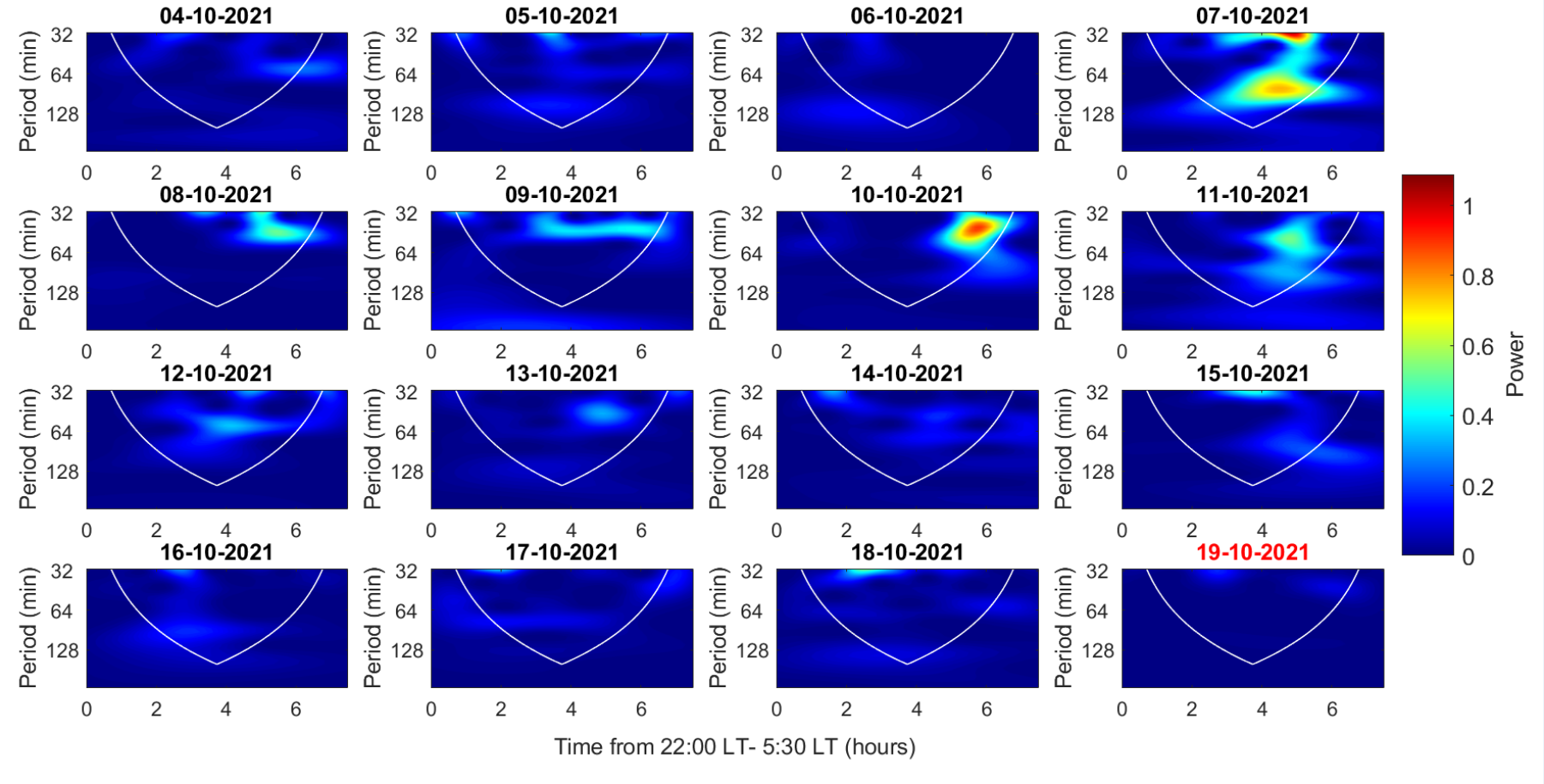


Figure 7: Wavelet power density spectrum of nighttime VLF amplitude signal. The X-axis denotes the time in hours, Y-axis indicates periodicity of wave structure in minutes and the color-bar represents the power. The red colored label of date indicates the date of the EQ.

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Geomagnetic indices & Solar flares

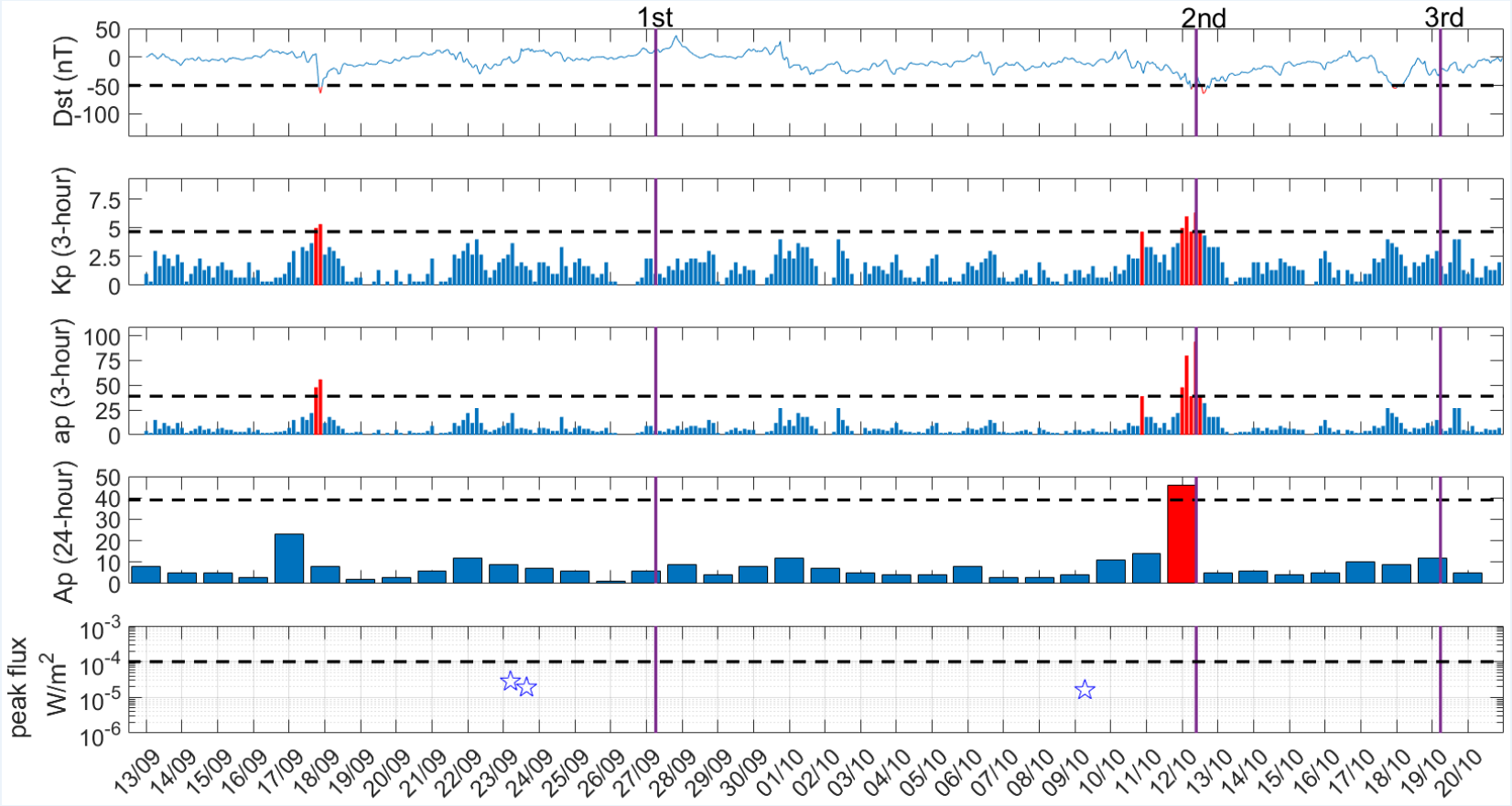

Figure 8: The variation of geomagnetic indices from 13/09/2021 to 20/10/2021 are shown in the first four panels, while the last 5th panel indicate the peak flux (w/m^2) for solar flares. The purple vertical solid lines indicate the time of occurrence of the each EQ. Deviation (marked as red) from the limit for each index in the first four panels indicate the existence of geomagnetic phenomenon, while the limit in the 5th panel shows the limit between M and X class solar flare.

Summary & Conclusions

- From the results of wavelet analysis we can see **significant** AGW-related anomaly on 16/09 prior to the first EQ, while for the second EQ significant anomalies are existed on 03/10, 07/10, 08/10, 10/10 and 11/10. For the third EQ, we observe significant AGW-related anomalies are on 07/10, 08/10, 10/10 and 11/10 which are also contaminated from the second EQ.

- The 9/10 is probably contaminated from a M class solar flare. The is no any other contamination effect during the studied period of three EQs.

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Thank you