Narrowband VLF measurements as a tool to study gravity waves in the lower ionosphere

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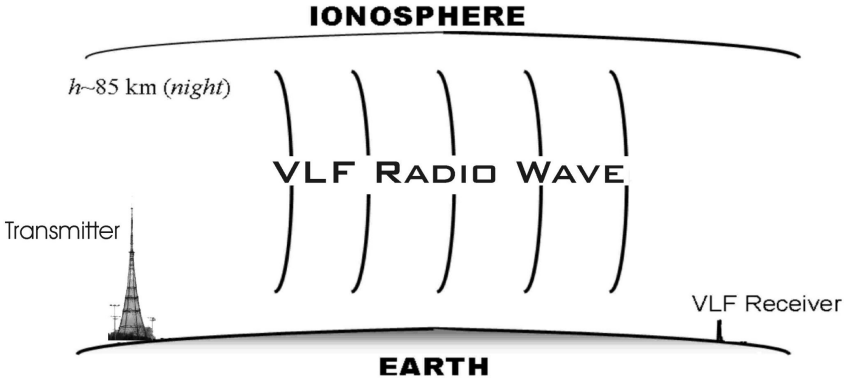

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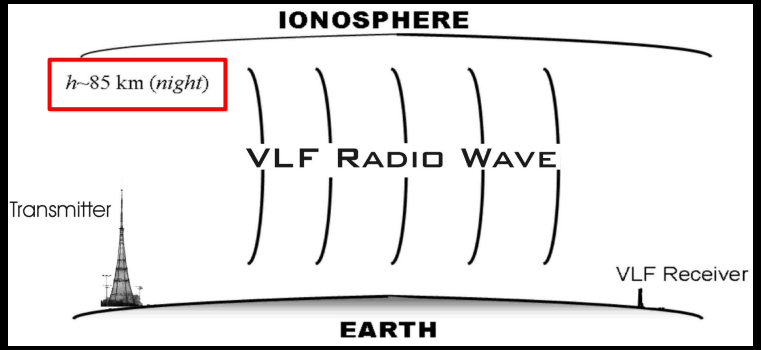
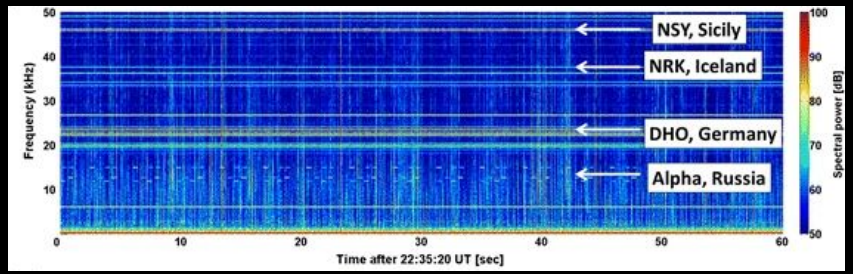
Concept of NB VLF measurements



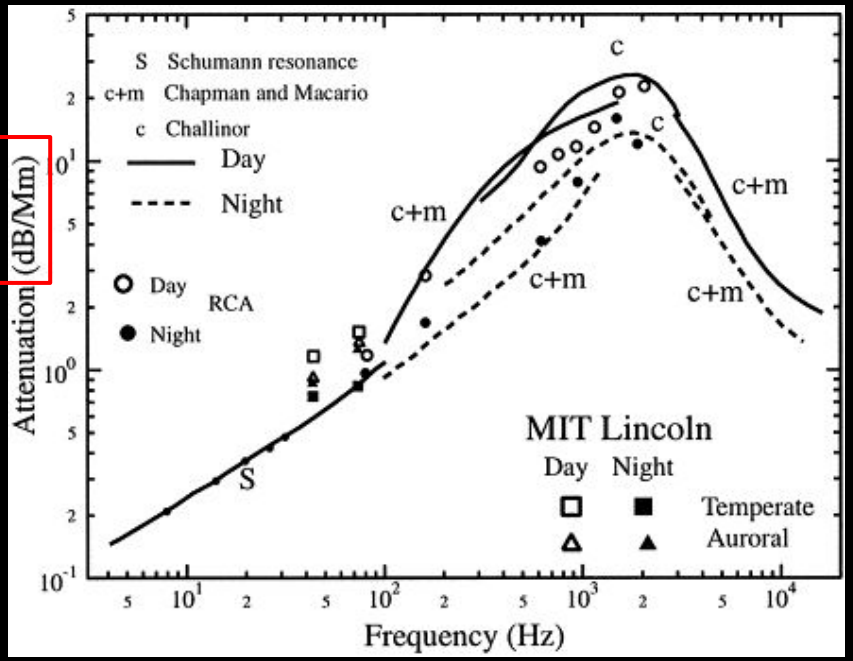
(AARDDVARK webpage)

Appearance of NB VLF signals



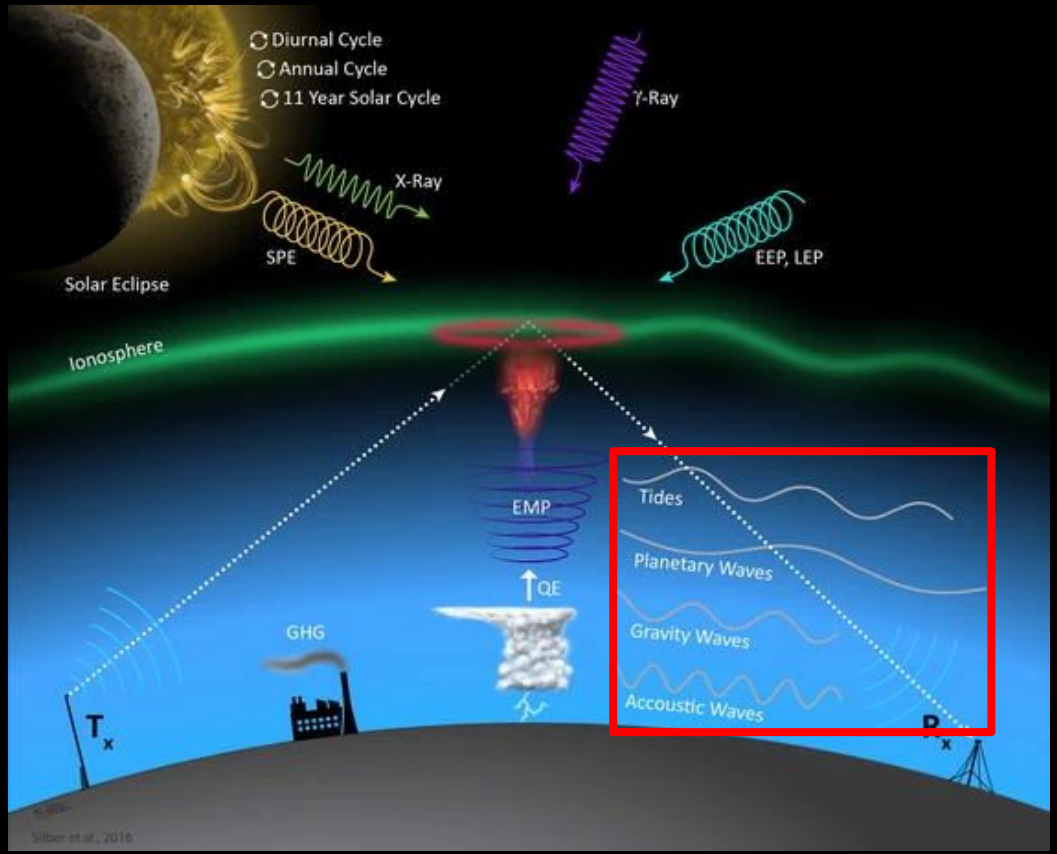
(Silber and Price, 2017)

Attenuation of ELF/VLF waves



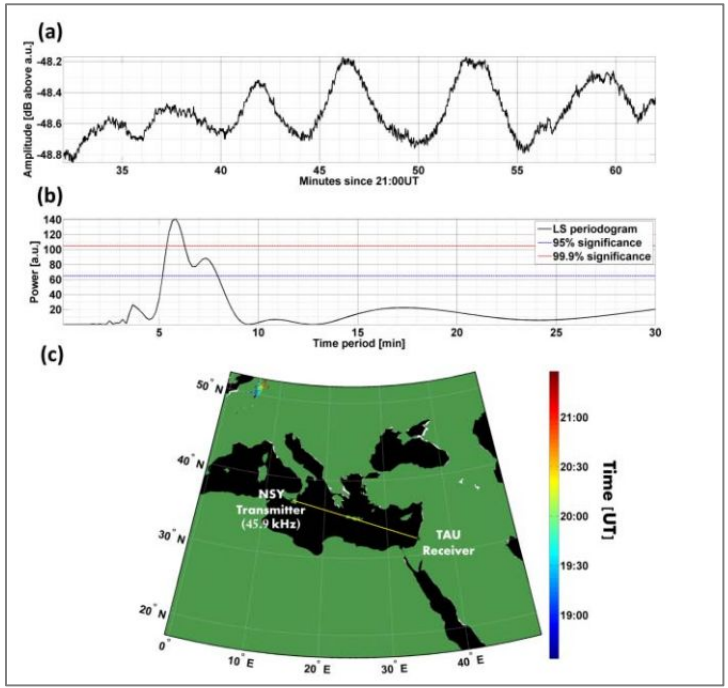
(Barr et al., 2000)

Various phenomena affecting NB VLF measurements

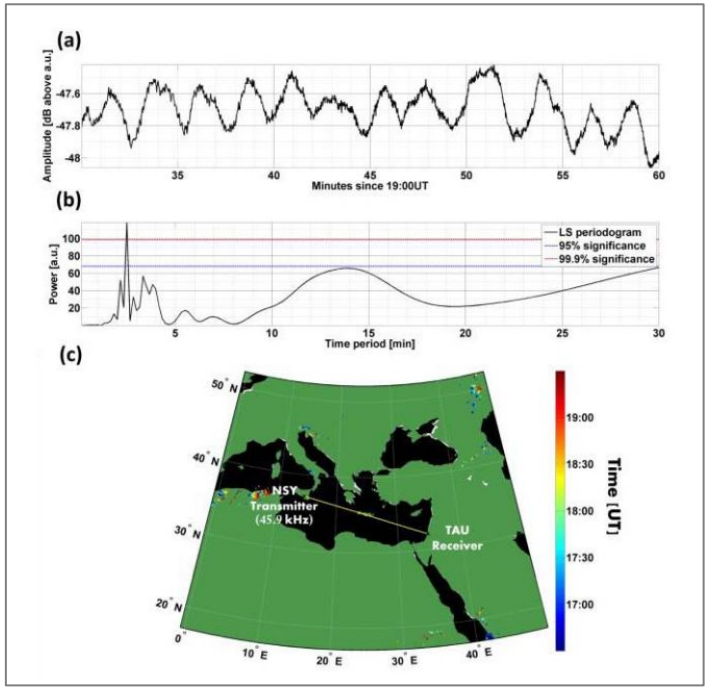


(Silber and Price, 2017)

Earlier studies I. - Silber and Price (2017b)



Gravity wave signatures observed along the NSY-TAU propagation path.

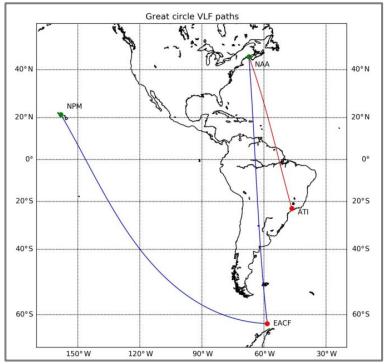


Acoustic wave signatures observed along the NSY-TAU propagation path.

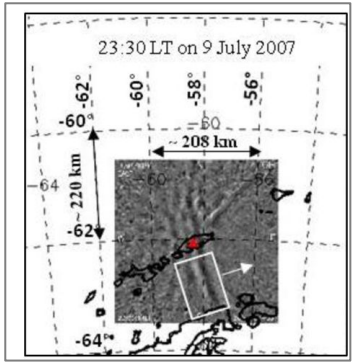
	Gravity waves	Acoustic waves
Number of days with events	28	2
Maximum peak-to-peak amplitude/ amplitude change	0.80 dB (0.40 dB during daytime)	0.45 dB
Nighttime events percentage	86%	100%

Summary of VLF perturbations detected during one year of VLF measurements.

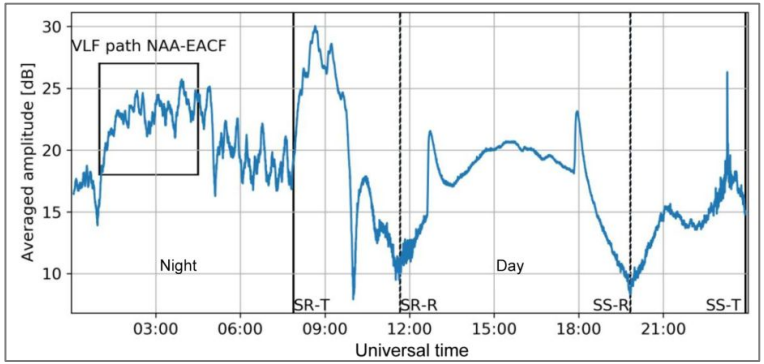
Earlier studies II. - Correia et al. (2020)



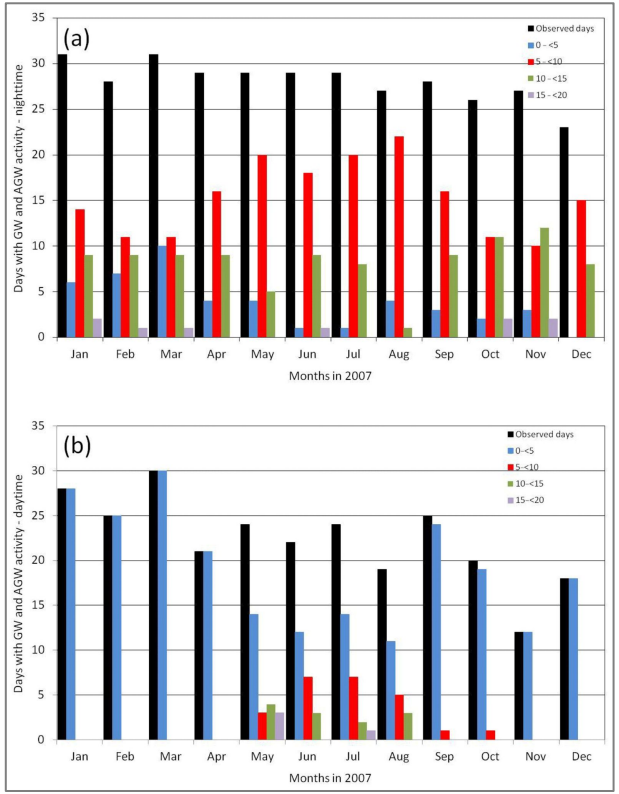
VLF propagation paths.



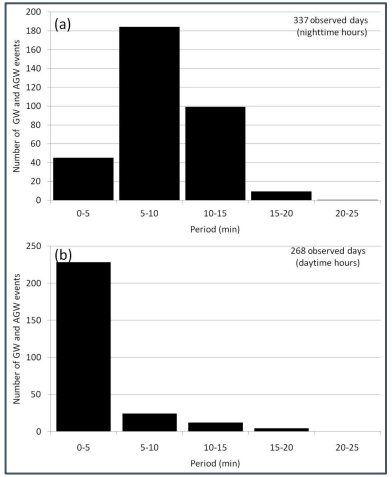
Airglow observation.



VLF amplitude observation.



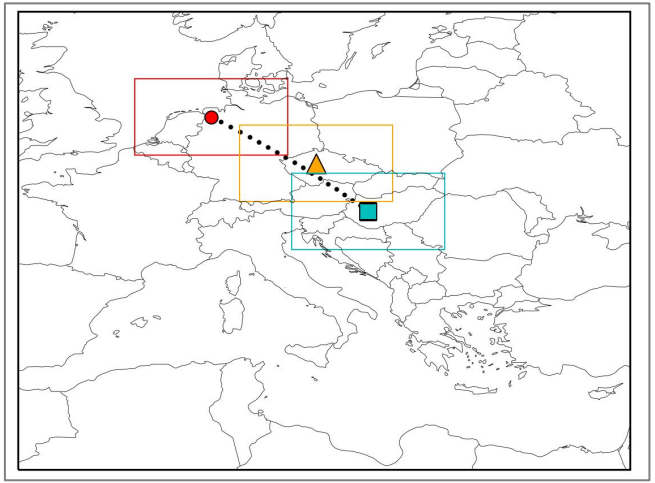
Occurrence statistics of AGW activity.



Histogram of wave periods.

Research objectives

- Investigate the occurrence of acoustic and gravity wave-like fluctuations in the lower ionosphere based on narrowband VLF measurements recorded at the **Tihany Geophysical Observatory** (TGO, Hungary).
- Compare the observed activities to **lightning** (characterizing lower atmospheric sources) and **Doppler** (characterizing AGWs in the F region) observations.

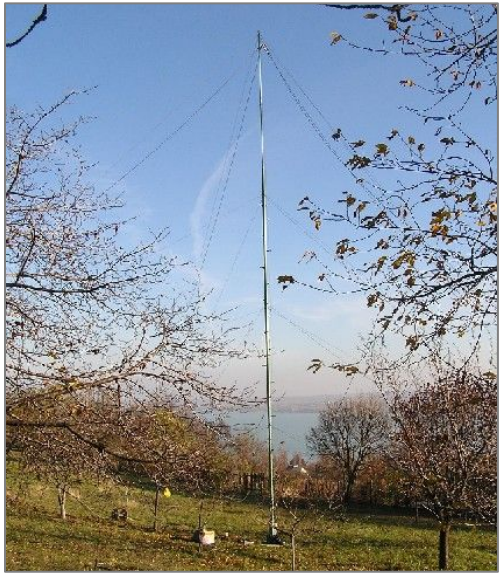


VLF transmitter (DHO, Germany; 23.4 kHz)

VLF receiver (Tihany) => **lower ionosphere**

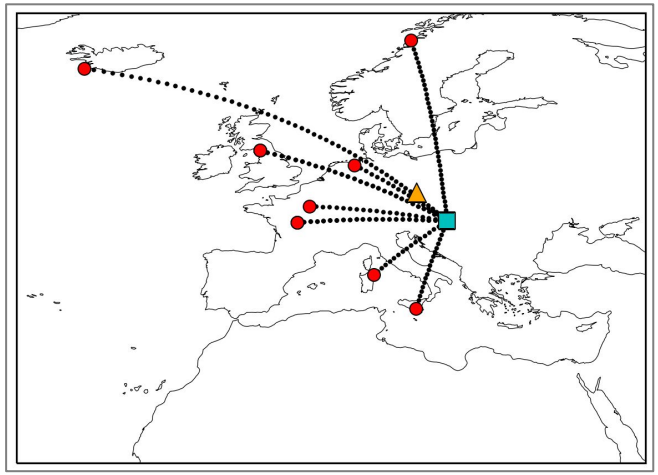
Doppler system (Czechia) => **F region**

Lightning (WWLLN) => **lower atmosphere**



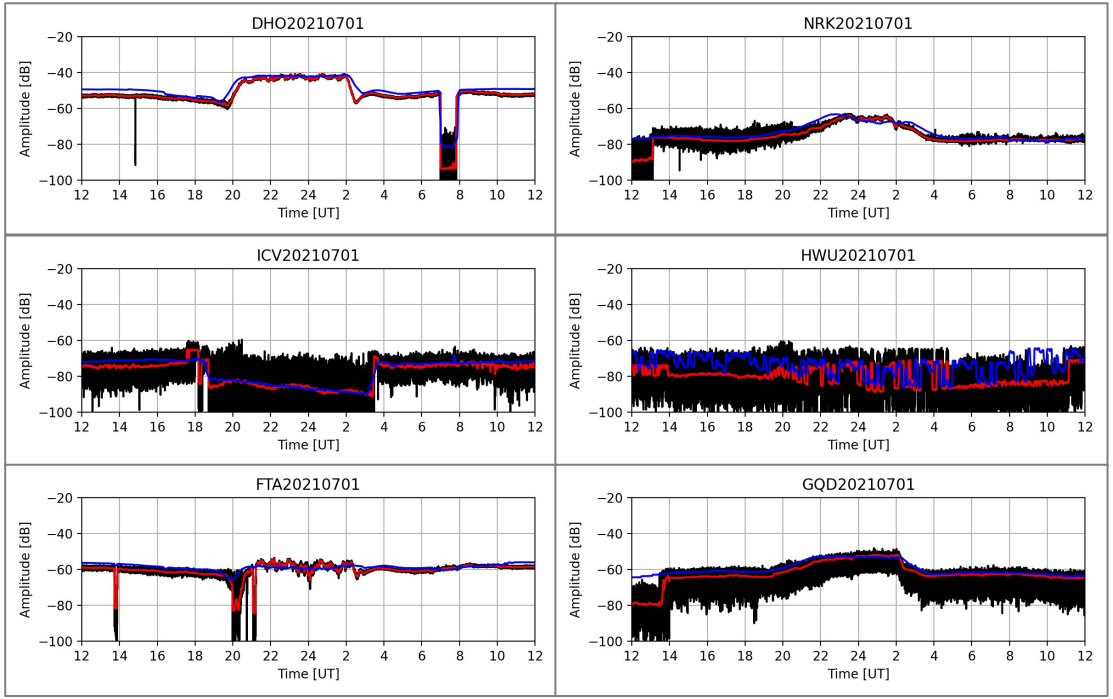
VLF antenna in Tihany (Hungary) with Lake Balaton in the background.

Selection of propagation paths



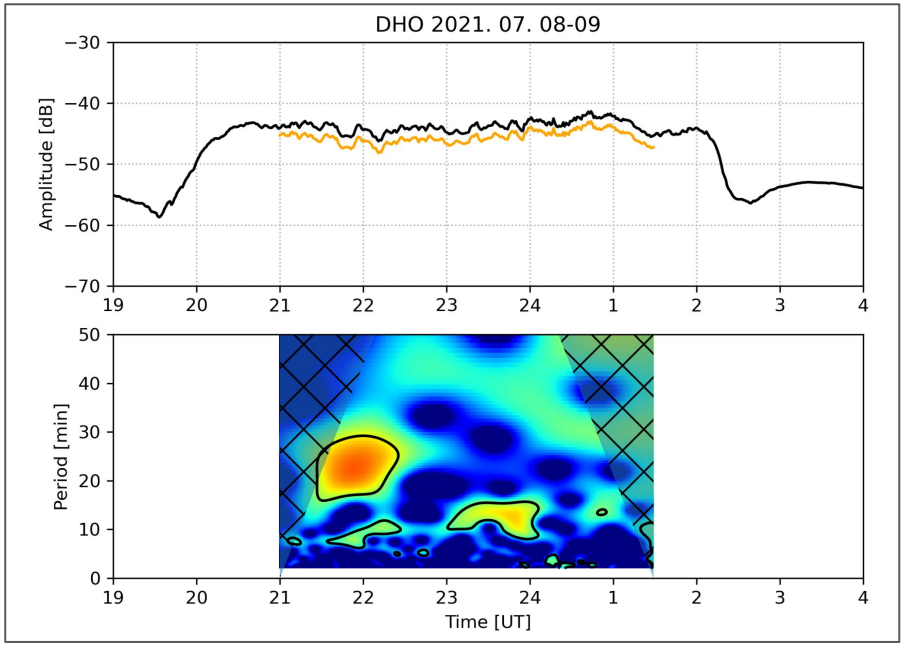
Propagation paths corresponding to the 8 European VLF transmitters detected at Tihany.

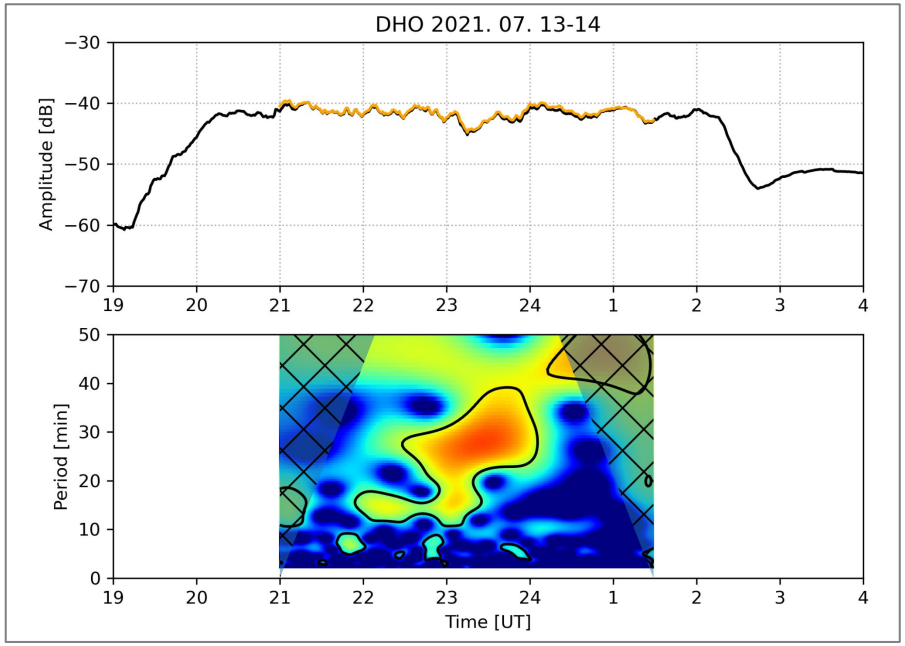
The visual inspection of the records showed that only the German VLF transmitter signal was stable enough to perform the planned analysis.



Recorded VLF amplitudes from 6 European transmitters on July 1, 2021.

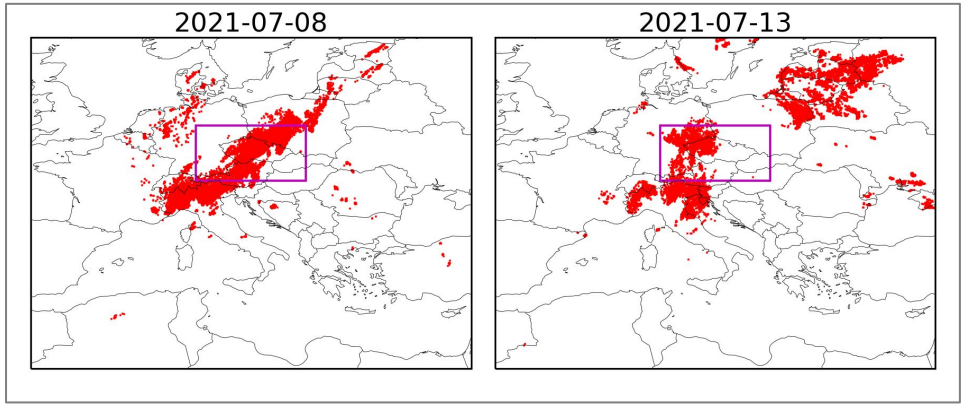
Data processing



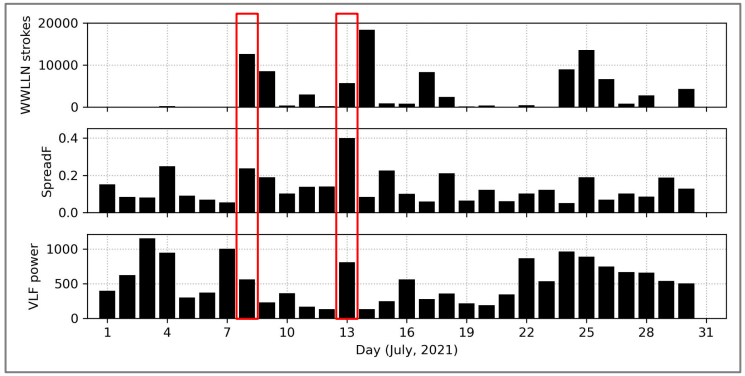


Demonstration of the wavelet transform-based technique applied to process narrowband VLF data.

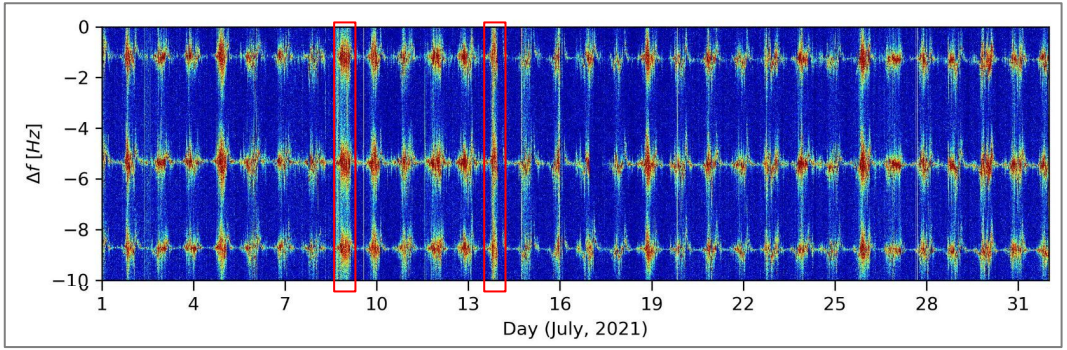
Results I.



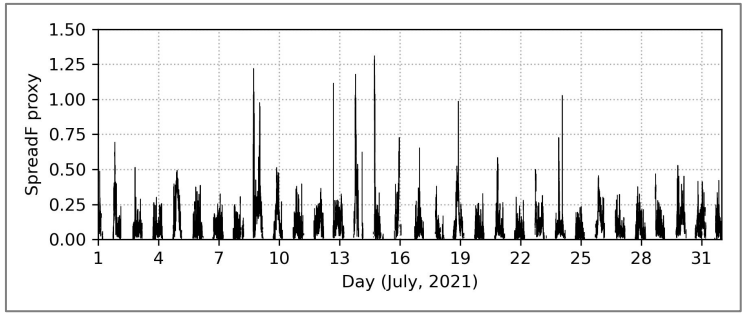
WWLLN lightning locations on 8 and 13 July 2021 (after 12 UT).



Total WWLLN stroke numbers, average spreadF proxy and summed VLF power in the 2-50 minute period range in July 2021.

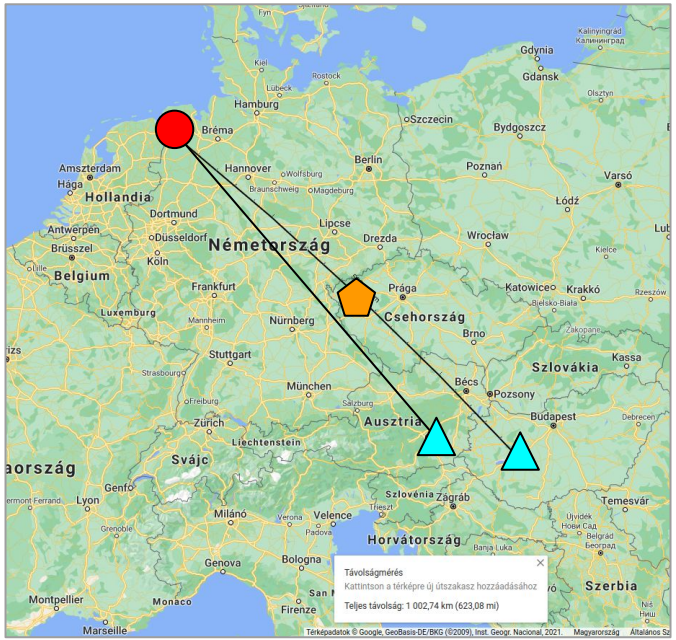


Doppler shifts observed at three different frequencies in July 2021.

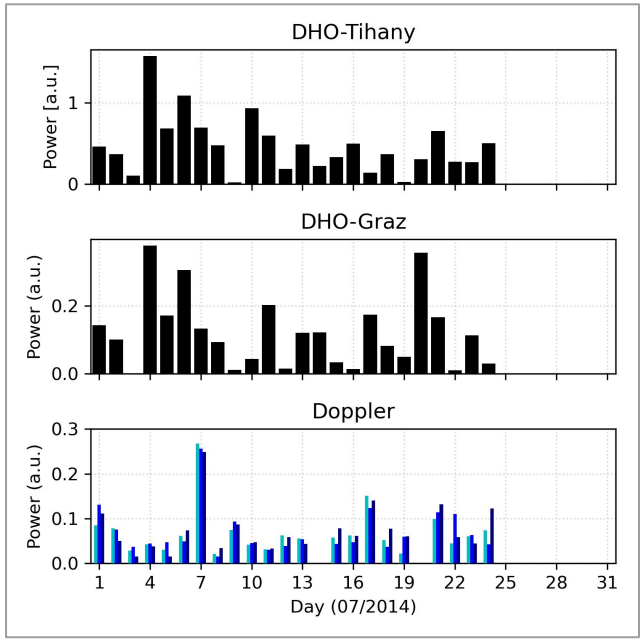


SpreadF proxy in July, 2021.

Results II.



Map of the two nearby VLF propagation paths (DHO-Tihany, DHO-Graz).

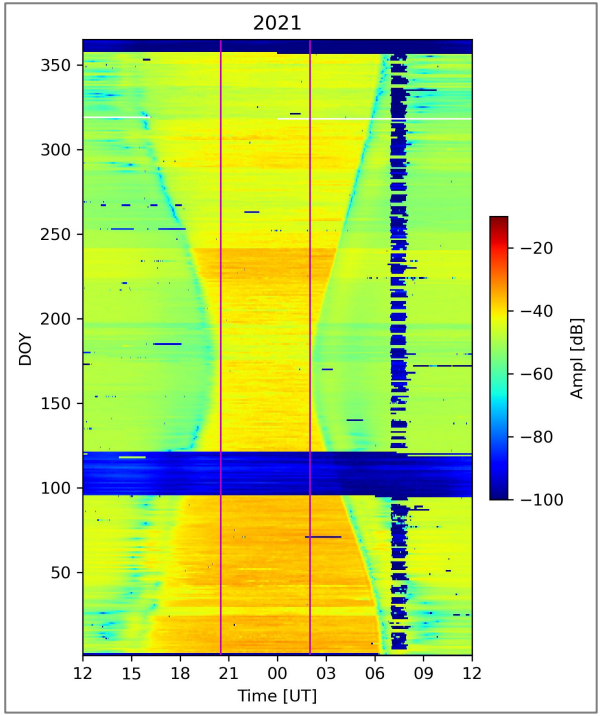


Summed wavelet power in the 2-50 minute period range for the DHO-Tihany (upper), DHO-Graz (middle) VLF propagation paths and the Doppler measurements at three frequencies (bottom) in July 2014.

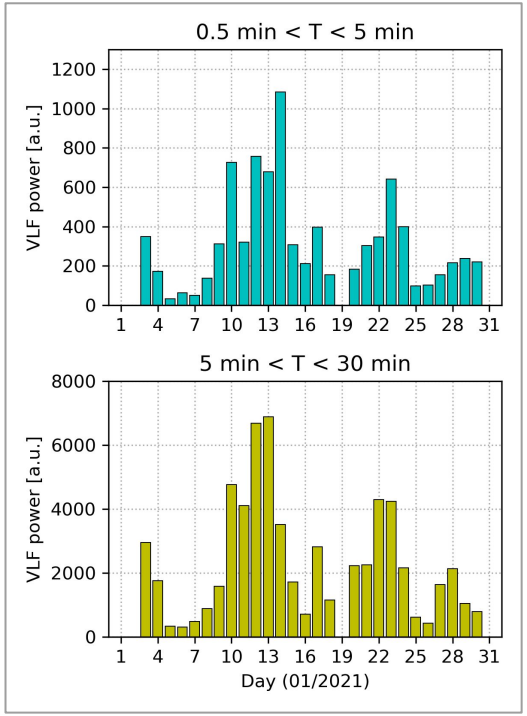
Correlation coefficients:

- THY-GRZ: **0.61**
- THY-D1: 0.01
- THY-D2: -0.05
- THY-D3: -0.02
- GRZ-D1: 0.10
- GRZ-D2: 0.06
- GRZ-D3: 0.03
- D1-D2: 0.90
- D1-D3: 0.92
- D2-D3: 0.85

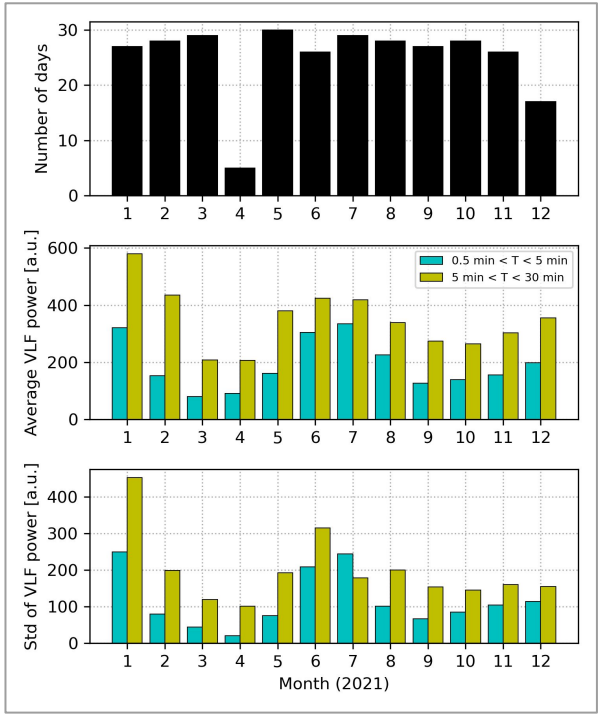
Results III.



VLF amplitudes in 2021 (DHO-Tihany).

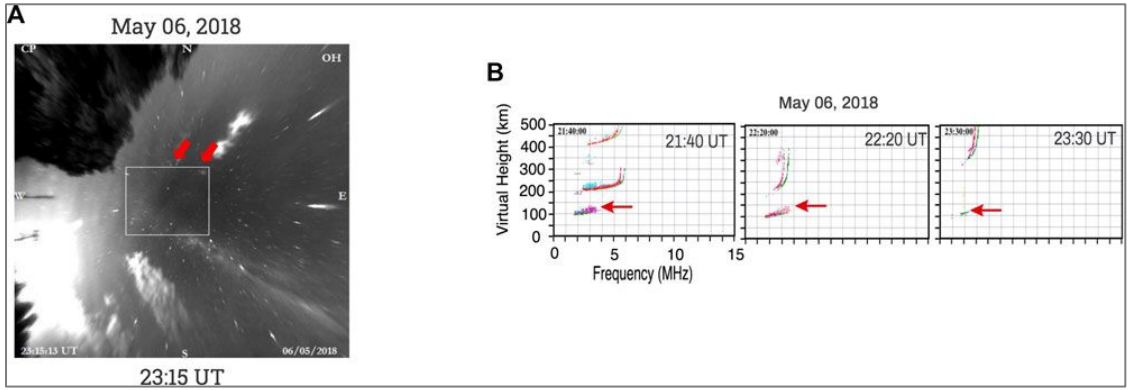


Summed wavelet power in the 2-50 minute period range in January 2021.



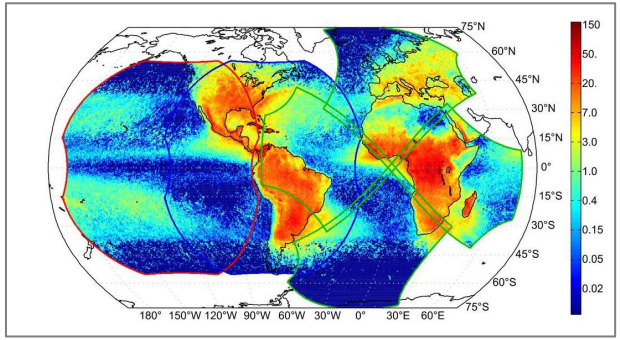
Monthly average wavelet power in the 2-50 minute period range in 2021.

Future perspectives

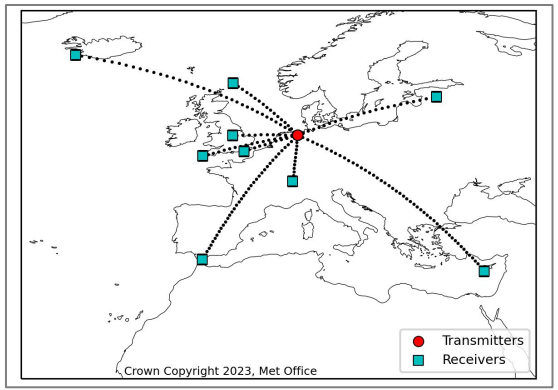


OH image showing gravity waves (left) simultaneously with a spreading Es layer observation (right) from Resende et al. (2023).

Several previous works have investigated GW activity in the mesosphere-lower thermosphere (MLT) region using narrowband VLF measurements, but there is a need to **use this technique in conjunction with other measurements** to promote it and make it part of larger efforts to study GWs and other atmospheric waves.



Lightning detection from GEO.



VLF receivers operated by MetOffice.

Thank you for your attention!

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I would like to express my sincere gratitude to the PITHIA TNA programme for making it possible for me to visit IAP and to Jaroslav Chum for hosting me.