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T1.4-P15 ThunderSeis: Seismic analysis of thunder infrasound

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LIGHTNING AND WAVEFORM DATA

On May 2, 2018, AlpArray working group observed strong signals of thunder in the Viennese region in both infrasound and acoustical ranges. Those observations lead to the further systematical measurements of thunder infrasound and its manifestation on seismic stations.

The AlpArray network provides wide coverage over a multi-year time span, suitable for studying those phenomena. The comprehensive Austrian lightning database ALDIS (*Fig.1*) is very useful in this context since it allows comparing lightning detections (*Fig.3*) with the recorded seismic signatures of thunder. This is a new and innovative approach ("Emerging Field") that allows AlpArray working group to gain insight into both thunder generation, regional infrasound propagation in the Alpine region, and seismo-acoustic coupling.

ALDIS is an Austrian part of a larger European lightning location system EUCLID.
This network combines time-of-arrival and direction finding techniques at low frequency to geolocate lightning discharges (see *Poelman, 2016*).

AlpArray (*Fig.2*) is a European initiative to advance understanding of orogenesis and its relationship to mantle dynamics, plate reorganizations, surface processes and seismic hazard in the Alps-Apennines-Carpathians-Dinarides orogenic system. The initiative integrates present-day Earth observables with high-resolution geophysical imaging of 3D structure and physical properties of the lithosphere and of the upper mantle, with a focus on a high-end seismological array (see *Hetenyi, 2017*).

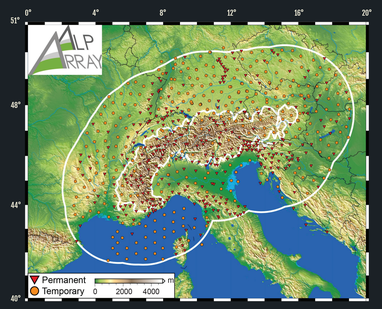


Fig. 2. Map of AlpArray temporary and permanent seismic station (modified after Hetenyi, 2017)

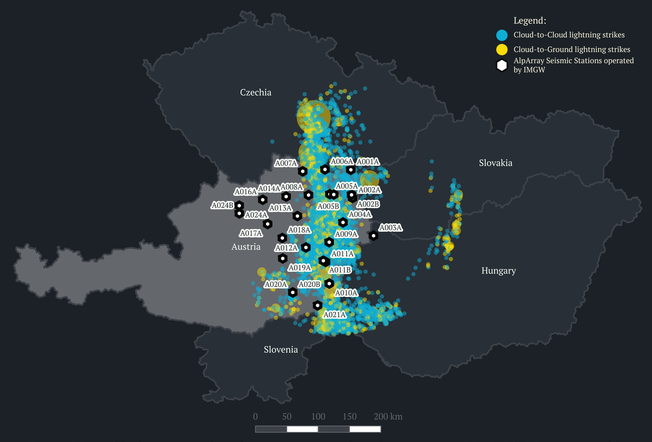


Fig. 1. Map of lightning strikes during a severe thunderstorm on 2018-05-02 registered by the EUCLID system in the Vienna region and observed on AlpArray stations operated by the University of Vienna. Marker size represents the absolute amplitude of the lightning in kA.

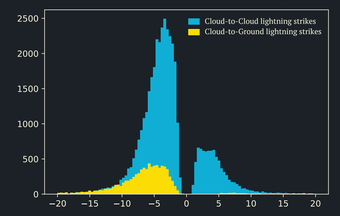


Fig. 3. Distribution of amplitudes for Cloud-to-Cloud and Cloud-to-Ground lightning strikes.

THUNDER GENERATION

The mechanism of thunder generation proposed by *Few, 1974* is illustrated in *Fig. 4*. First, temperature inside the lightning channel rise to 30000 K, which in turn, creates an increase in pressure on the walls of this channel. It is believed that the radial thermal expansion due to the sudden heating of the air in the lightning channel leads to the generation of the compressional (shock) wave and is responsible for the audible part of the thunder spectrum (see *Fig. 5*).

Lightning flashes typically contain 3-5 return strokes, separated by time intervals of ~60 ms. During an interstroke, the acoustic pulse from a preceding stroke will have propagated about 20 m from the channel, so that the newly generated shock wave can be treated as independent of the previous one (*Few 1974*).

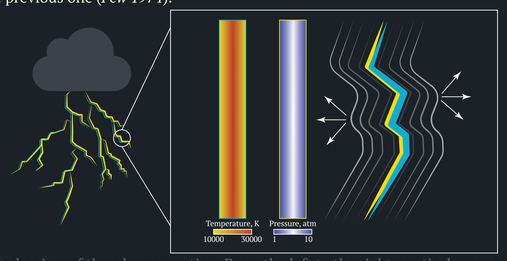


Fig. 4. Mechanism of thunder generation. From the left to the right: vertical cross sections of temperature and pressure inside of the lightning channel; shock wave propagation.

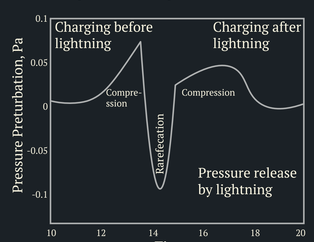


Fig. 5. The temporal behavior of the generated infrasound pressure, based on the model of *Dessler, 1973* which describes pressure perturbation during lightning strikes. It is expected to observe an initial compression pulse, i.e., positive pressure perturbation, followed by rarefaction and again compression pulses. These pulses propagate along vertical raypaths, essentially without geometrical attenuation. The power spectra should peak in the frequency range of 0.2– 2 Hz. (after *Pasko, 2009*)

WEATHER DATA PROCESSING

Meteorological data were downloaded and pre-processed in order to obtain interpolants of temperature (*Fig. 6*), wind speed, and wind direction (*Fig. 7*) by triangulating the input data, and on each triangle performing linear barycentric interpolation (for details see *SciPy documentation, 2019*).

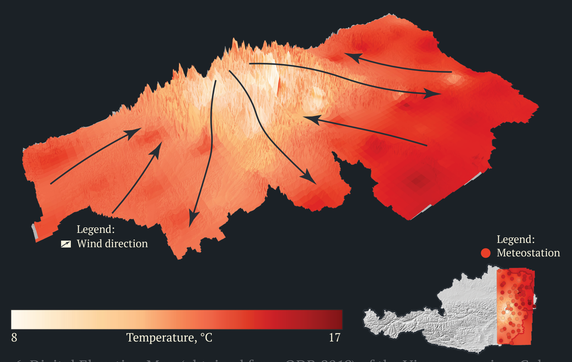


Fig. 6. Digital Elevation Map (obtained from *ODP, 2019*) of the Viennese region. Color depicts interpolated temperature. Arrows show the schematical direction of the wind.

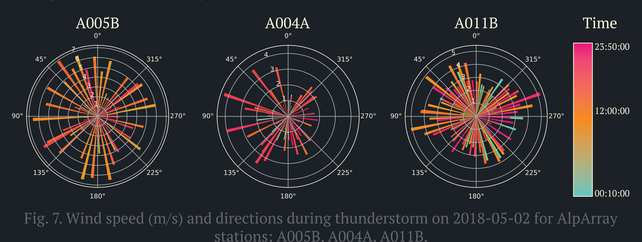


Fig. 7. Wind speed (m/s) and directions during thunderstorm on 2018-05-02 for AlpArray stations: A005B, A004A, A011B.

ARRIVAL TIME ESTIMATION

Lightning is often accompanied by strong acoustic energy (thunder), both at frequencies of sound (above 20 Hz) and/or in the infrasound frequency band (below 20Hz).

It has been pointed many decades ago by *Wilson, 1920* that sudden reduction of the electric field inside a thundercloud immediately following a lightning discharge should produce a low-frequency acoustic (i.e., infrasound) signature. That electrostatic mechanism has been detailed by *Dessler, 1973*. He demonstrated that the mutual repulsion of the charged water droplets causes the atmospheric pressure to be reduced within the charged regions of the cloud, and an acoustic rarefaction pulse is generated following a lightning discharge as atmospheric pressure equilibrium tends to be restored in the region from which charge is removed. In the case of a horizontally extended charge region, the signal should be best observed by detectors placed directly below or above the cloud due to a beaming effect.

In order to model thunder signal propagation, information about temperature, wind speed, and direction were extracted along a straight ray path from each lightning to each station as shown in *Fig. 8* and *10*. Then the corresponding speed of sound was computed as dependent from temperature by the following relation (*Fig.10*):

$v(t) = 331\ m/s + 0.6 * T$,

where T - is temperature, °C.

Wind also affects sound propagation. Its influence was estimated as a resultant force:

$v_{resultant} = \sqrt{(v_{thunder}{}^2 + v_{wind}{}^2 + 2 * v_{thunder} * v_{wind} * cos(\alpha))}$,

where $v_{thunder}$ - the speed of thunder sound propagation, v_{wind} - wind speed, and α is an angle between thunder propagation and wind direction.

The actual speed of acoustical thunder propagation was computed for each cell. Geometric parameters of cells are known, therefore travel time can be computed as:

$t = D/v_{resultant}$,

where D - the is the distance traveled by thunder sound in one grid cell.

With this rather simple technique, it is possible to predict the arrival of the acoustic wave generated by the thunder signal to the seismic station with a relatively small error of 5-10% of the travel time. Yet, this is not good enough for clear identification of multiple lightning strikes that are expected to arrive at the receiver at the approximately same time.

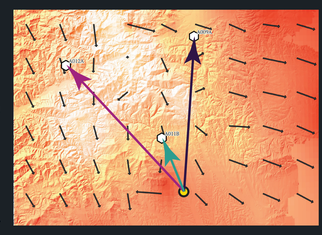


Fig. 8. Close-up of interpolated temperature and wind maps in the vicinity of A012A, A011B, and A009A AlpArray stations. Colored arrows illustrate propagational profiles from the lighting to the corresponding station.

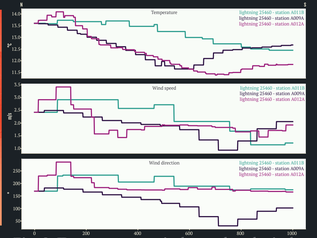


Fig. 9. Temperature, wind speed and wind direction profiles along the lines: Lightning 25460 - station A011B, Lightning 25460 - station A009A, Lightning 25460 - station A012A.

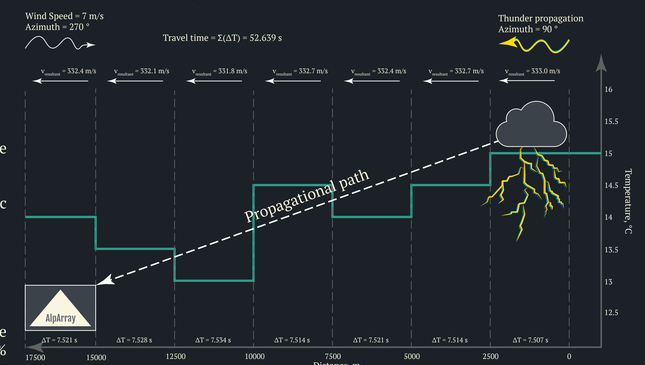


Fig. 10. Schematic drawing of travel time estimation based on the gridded weather model.

THUNDERSEISM

During the thunderstorm, a large number of strong seismo-acoustic signals on stations of the AlpArray network was recorded. *Fig. 11* shows such signals that were recorded in a 5-minute time window by the station A005B, located near Stockerau, to the Northwest of Vienna (see *Fig. 1* for orientation). All impulsive signals correspond to individual lightning strokes. Thunder signatures can manifest themselves at the distances of 30-40 km from seismic stations. The biggest signals follow after strong (> 20 kA current) strokes within less than 7 km distance and are strong enough to induce very long-period movements of the seismometer inertial mass.

Seismological studies of thunder have suggested that the signal frequencies are broadband from approximately 5–100 Hz, with small peaks at frequencies ranging from 6–13 Hz *(Kappus and Vernon, 1990)*. That study has not detected peaks in the audible range as previously predicted by theory based on rapidly expanding gases. Analysis of the frequency content as a function of time shows that the individual bursts have similar frequency distributions. *Kappus and Vernon, 1991* show a significant horizontal component to the lightning channel itself, based on the polarization of the seismic signal.

Current research confirms records of more than 1000 thunder seismic signatures on AlpArray stations with associated lightning parameters as measured by ALDIS. At the moment polarisation and height estimation studies are ongoing.

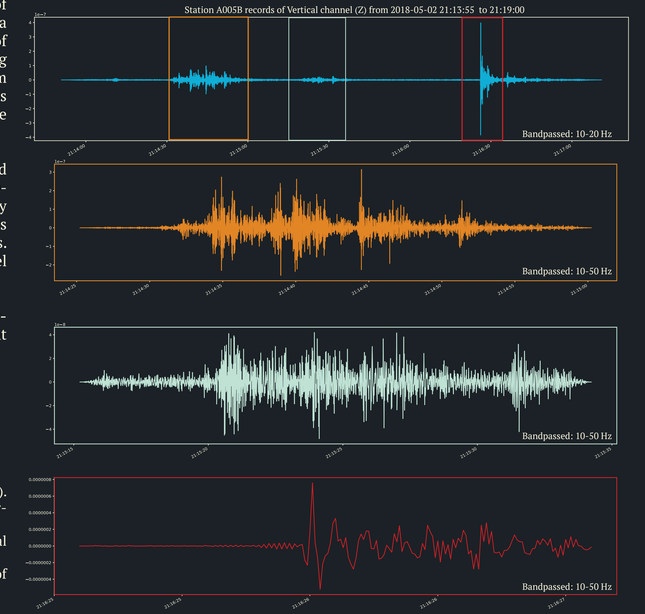


Fig. 11. A) Thunder seismic signatures as recorded by AlpArray station A005B on Vertical channel (Z), at 100 Hz sampling rate from 2018-05-02 21:13:55 to 21:19:00. B) and C) Close-up of multiple-lightning recordings. D) Record of the lightning 52743 of amplitude 68.56 kA that occurred at the distance of 6728 m from A005B.

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