Phase effects in subionospheric VLF/LF signals observed at middle and low latitudes during the August 21, 2017 total solar eclipse

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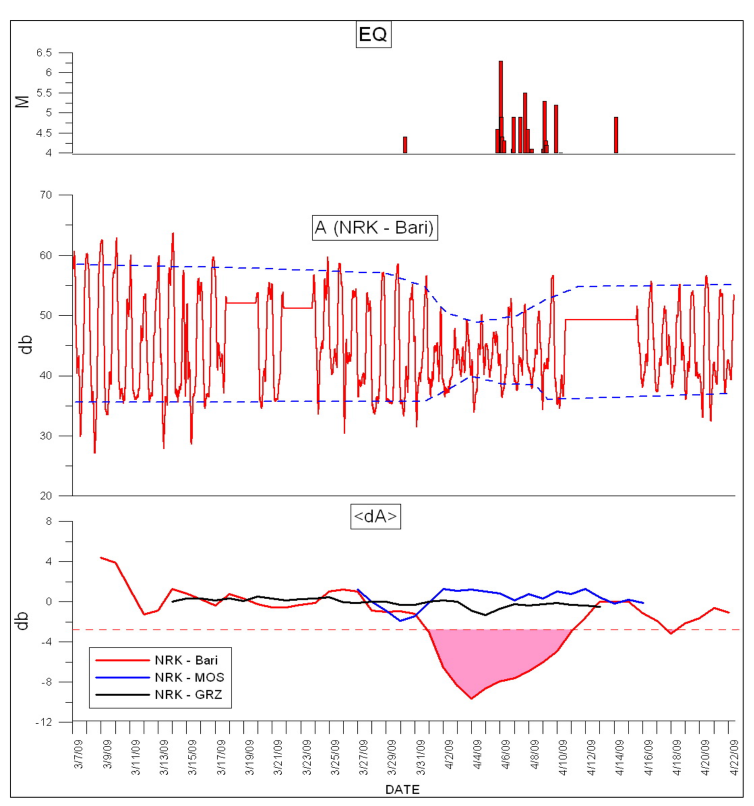
Abstract

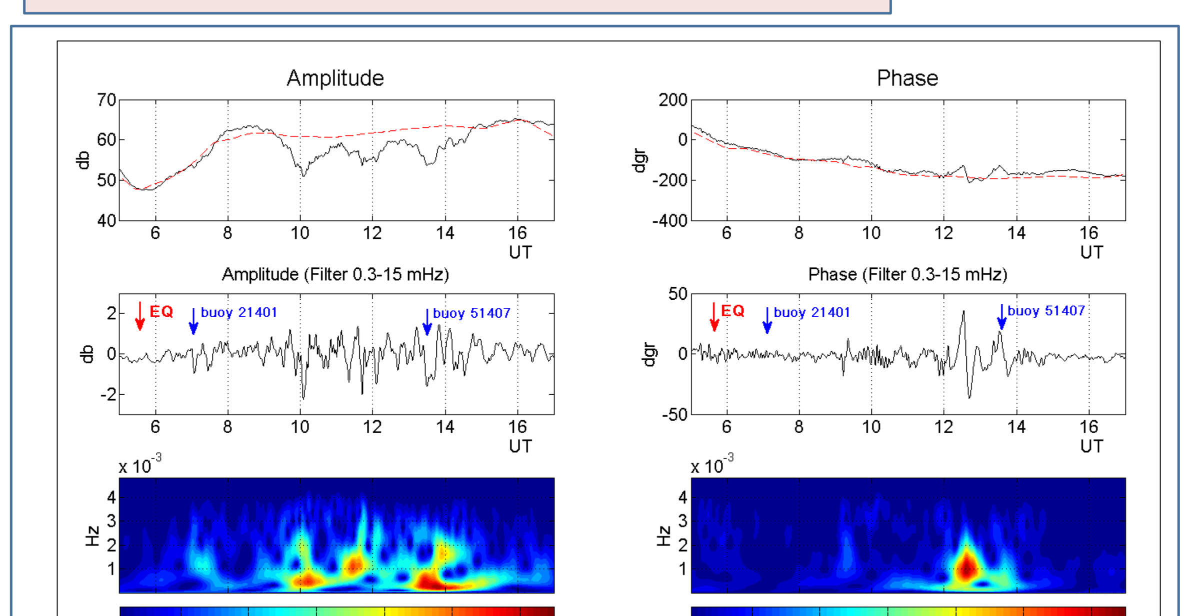
Experimental study of the phase and amplitude observations of sub-ionospheric very low and low frequency signals is performed to analyze the response of the lower ionosphere during the August 21, 2017 total solar eclipse in the United States of America. Three sub-ionospheric wave paths have been investigated. The length of the paths varied from 2200 to 6500 km, signal frequencies were 21.4 kHz, 25.2 kHz and 40.8 kHz. Two paths crossed the region of total eclipse and the third path was in the region of 40-60% of obscuration. None of the signals revealed any noticeable amplitude changes during the eclipse while negative phase anomalies (from -35° to -95°) were detected for all three paths. It was shown that the effective reflection height of the ionosphere in low and middle latitudes has been increased by 3.5-5 km during the eclipse.

Effects from earthquakes



The upper panel indicates the magnitude of the main earthquakes from 26 March to 17 April 2009. The next panel shows the amplitude of NRK signal recorded in Bari in the period 7 March–22 April, 2009. The signal propagated just over seismic area. In the last panel the nighttime residual amplitude (dA) for the paths NRK-Bari, NRK-MOS and NRK-GRZ are shown. The last two paths were far away from seismic area. The color fill zone indicates values exceeding the 2 sigma level, represented by a horizontal dotted line, for the NRK-Bari path (Rozhnoi et al., NHESS, 2009, 9, 1727-1732).

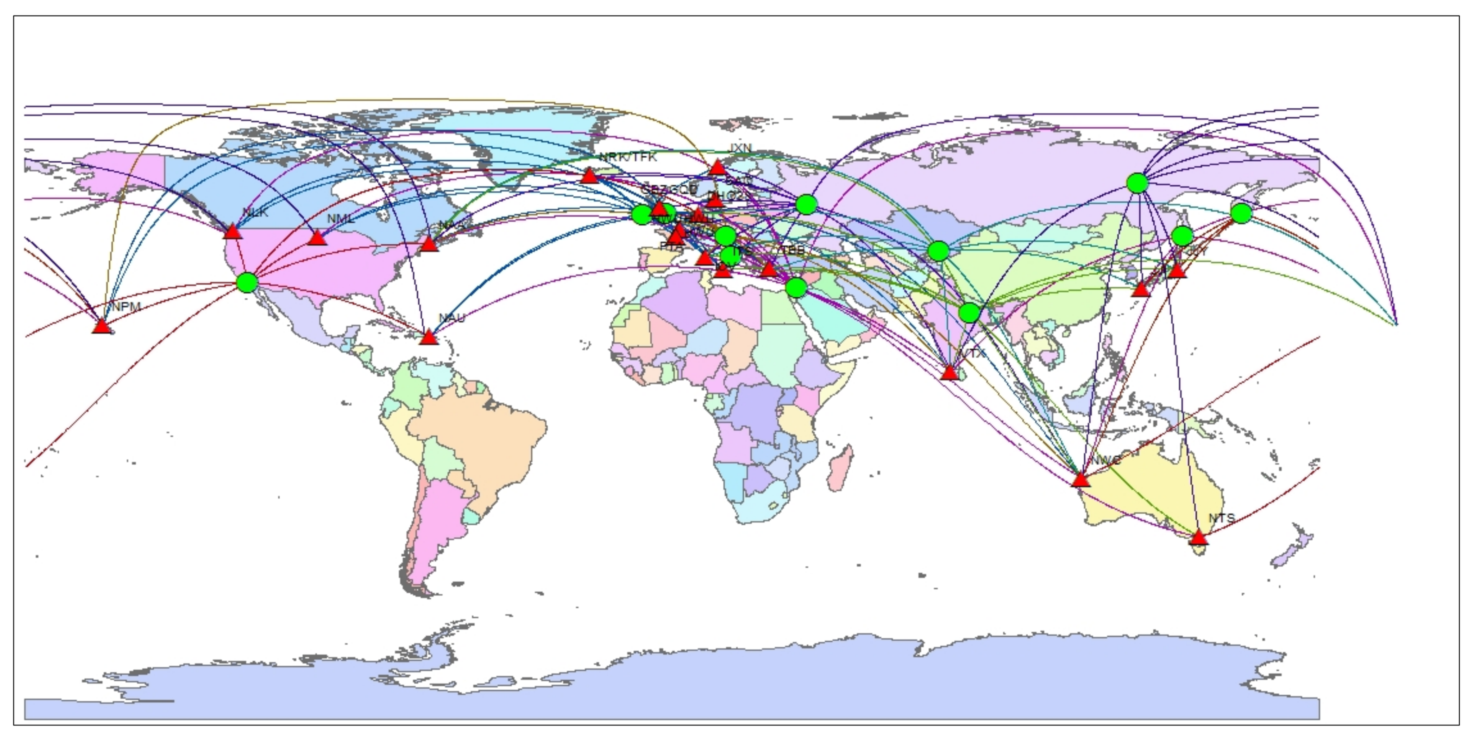
Effect from tsunami propagation



Top panels show the amplitude (left) and the phase (right) of the signal from the NPM (21.4 kHz, the Hawaiian Islands) transmitter recorded on March 11, 2011 in Moshiri station (Japan). Dotted lines are the monthly averaged signals. The middle panels show the signals filtered in the range 0.3-15 mHz. The bottom panels show the wavelet spectra of the filtered signals. Arrows in the middle panels show the occurrence time of the earthquake and arrival time of the tsunami to the DART buoys 21401 (near Japan) and 51407 (near the Hawaiian Islands). (Rozhnoi et al., Geomatics, Natural Hazards and Risk, 2014, 5, Issue 4, 285-292).

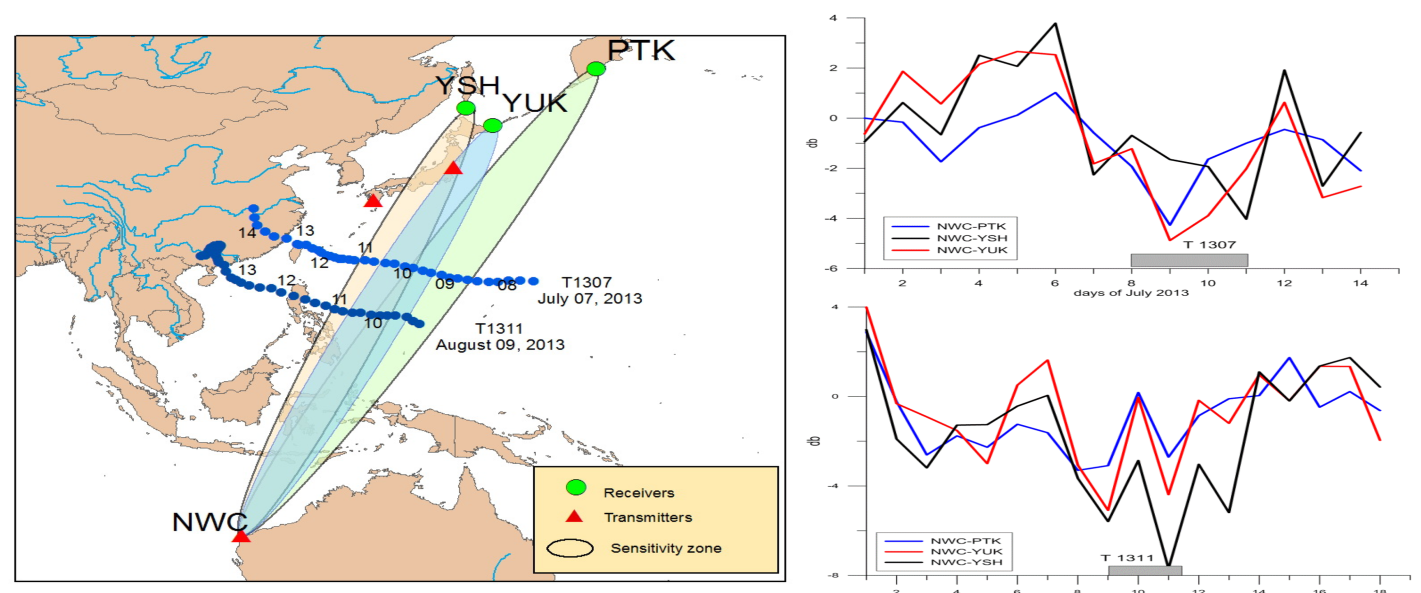
VLF/LF network

Our VLF/LF network was developed during last years due to joint cooperation of scientists from different countries. At present the network consists from 11 receiving stations deployed in Europe (Moscow, Sheffield, Graz), the Far East (Kamchatka, Sakhalin, Kuril Islands) , Asia (Bishkek, Varanasi) and the USA (Chapman University, Orange, CA). All the stations are equipment with the UltraMSK receivers (http://ultramsk.com/). The receivers measure the amplitude and phase of the signals from the transmitters which are situated in Europe, Asia, America and Australia. So, our network covers the all high seismic active regions in the North Hemisphere, including Pacific and Mediterranean-Asian seismic belts. Using data from our network we can investigate influences of different natural hazards events, such as earthquakes, magnetic storms, tsunami propagations, typhoons, Cosmic Weather and others. Some examples of the effects observed during natural hazards events we give here. Besides, our network gives us possibility to study the changes in the D region of ionosphere during solar eclipses when the solar radiation changes abruptly.



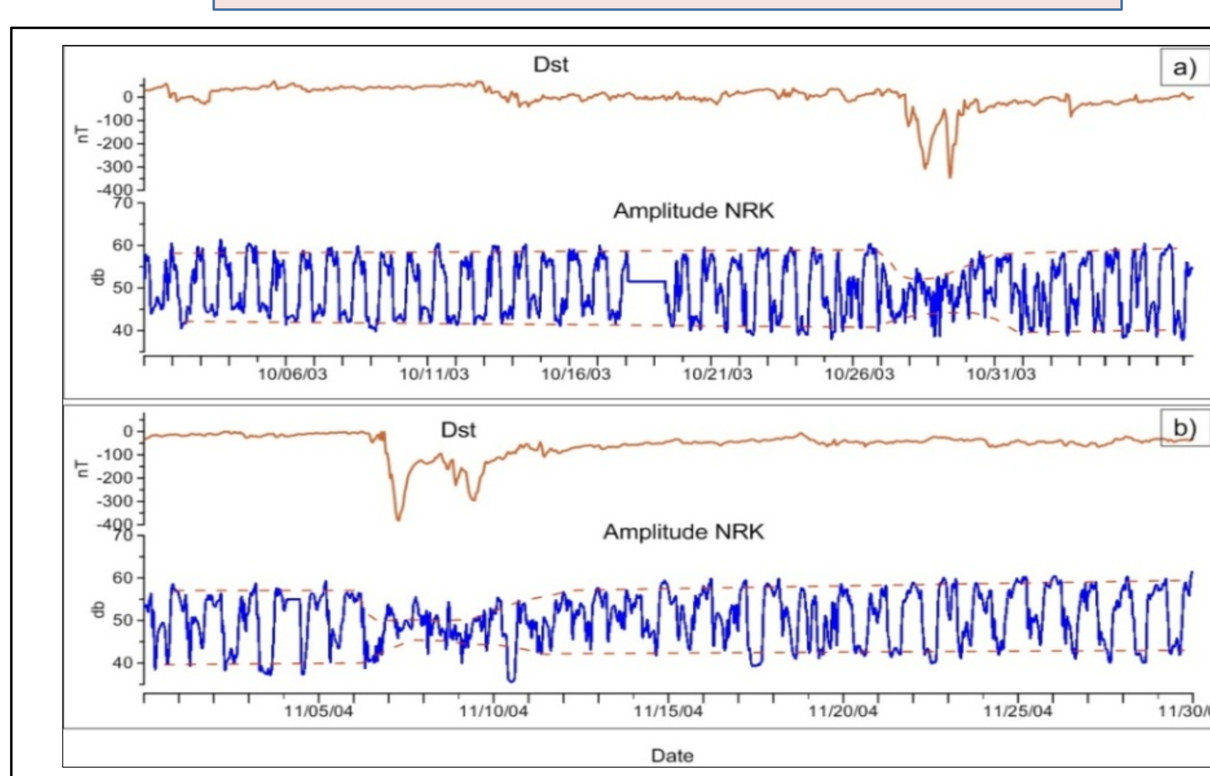
The VLF/LF network. Green circles show the positions of receiving stations. Red triangles show the positions of transmitters. Lines are the paths of VLF/LF signals propagations from the transmitters to receivers.

Effect from typhoons



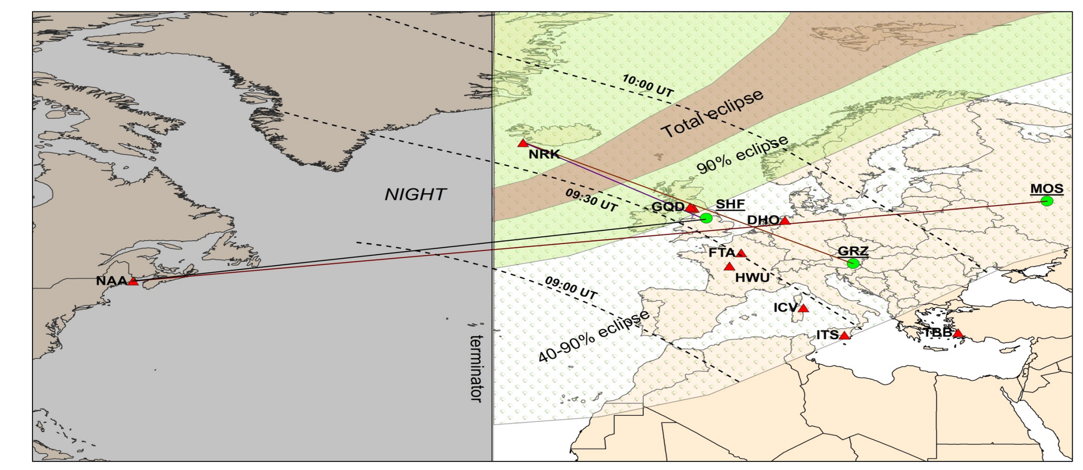
The anomalies in the NWC signal recorded at three stations during the passage of the TC Soulik (1307) (the top right panel), and the TC Utor (1311) (the bottom right panel). Horizontal grey bars on the abscissa show the periods when the TCs crossed the sensitivity zones of the paths under consideration. The position of the TCs centers are shown in the left panel. (Rozhnoi et al., NHESS, 2014, 14, 2671-2679).

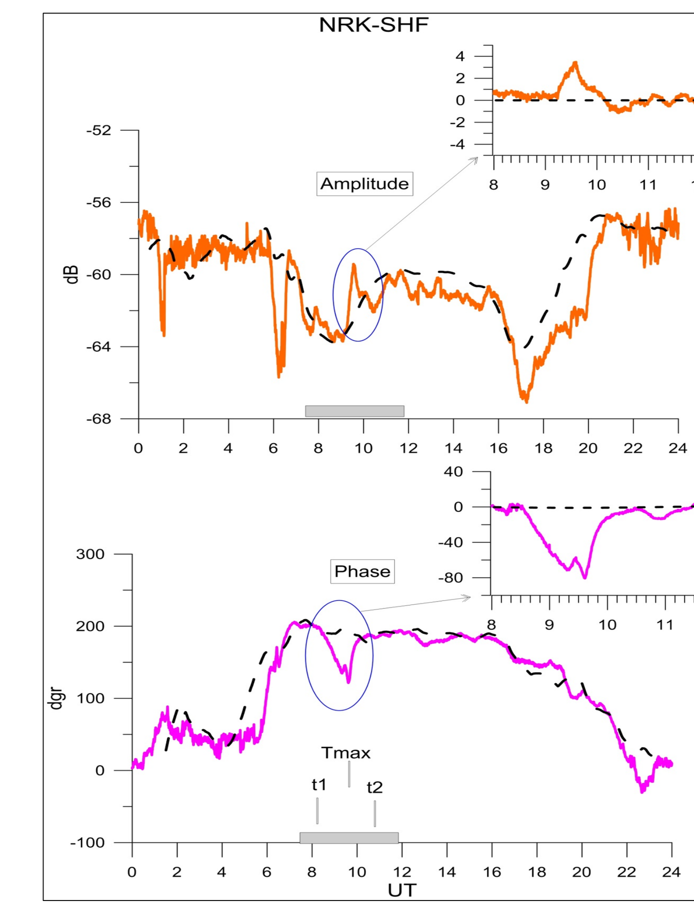
Effects from strong magnetic storms



Examples of the influences of two super strong magnetic storms (Dst~-400 nT) on variations of the LF signal in the path Iceland-Bari (Italy). (Rozhnoi et al., Ann. of Geoph., 2012, 55, 1, 181-186).

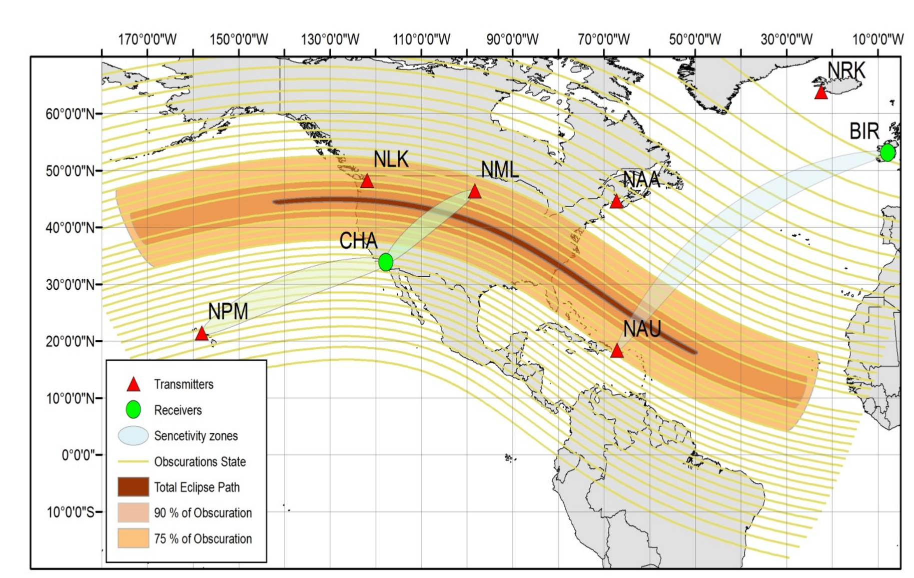
Effect from the total solar eclipse on March 20, 2015



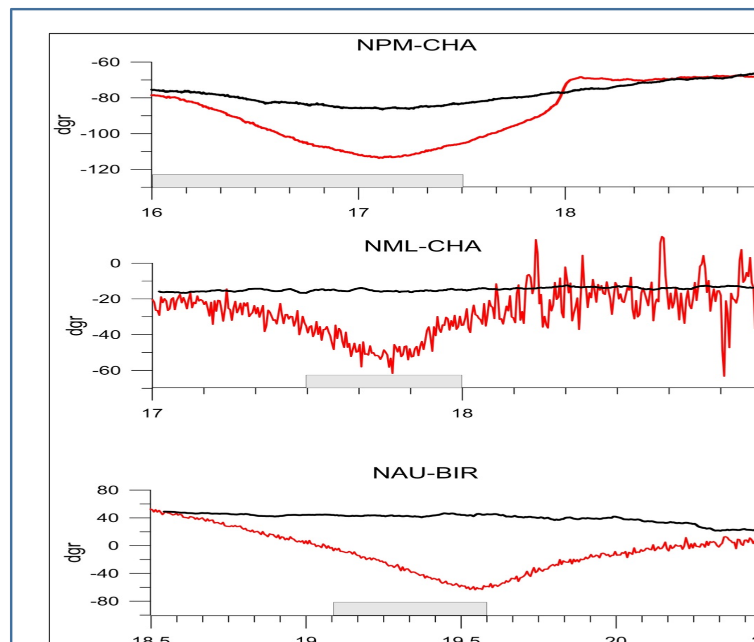


On the left: The VLF/LF network in Europe and the areas of obscurations during eclipse on March 20, 2015 (from timeanddate.com). The positions of receivers are shown by green circles.. The triangles are transmitters. Four long paths which crossed the area of 90-100 of obscuration are show by lines. The vertical double line shows the position of morning terminator in 07:40 UT. On the right: the amplitude and phase variations of the NRK (37.5 kHz) signal, measured in Sheffield (SHF) on March 20, 2015. The solid lines show the current amplitude and phase of signal, dotted lines are the monthly average of signal. The eclipse period are shown by the grey rectangles on X axis. The ellipses highlight the anomalies in signal connected with the eclipse. T max indicates the time of the greatest eclipse in the transmitter place (97%). (Solovieva et al., J. Geomagnetism and Aeronomy, 2016, 56(3), 323-330).

Effect from the total solar eclipse on August 21, 2017



Relative positions of the receivers and transmitters together with the obscuration's degree (the last information has been taken from: https://www.timeanddate.com/eclipse/solar/2017-august-21). The positions of the receivers in Birr, Ireland (BIR) and Orange, CA, the USA (CHA) are shown by green circles. The positions of transmitters NPM (21.4 kHz), NML (25.2 kHz) and NAU (40.8 kHz) are shown by red triangles. (Present work).



Results of the phase analysis for three wave paths (from top to bottom): NPM-CHA, NML-CHA and NAU-BIR. Red lines show the phase variations on August 21, 2017. Black lines are the averaged phase values. Grey rectangles on the X-axes show periods when large part of a path has been obscured.

Conclusions

The recent development of observation systems can provide useful information on the properties and position of the perturbation region in connection with natural hazards events. The use of a network of observation makes it possible to separate the local VLF/LF perturbations connected with earthquakes, volcanic eruptions, tsunamis, typhoons, cyclones from large-scale or global anomalies related to planetary waves, magnetic storms and substorms, solar flares or energetic particle precipitation into the ionosphere. By utilizing multi-station observations it is possible to determine the area of impending earthquake.

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