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Abstract 5-08

Tsunami effects in subionospheric VLF signals

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One of the few experimental techniques which can monitor perturbations of the ionization within the lower ionosphere uses long-wave (i.e., VLF and LF) probing. Here we present the first measurements of the response of the lower ionosphere driven by tsunamis caused by the November 15, 2006 (Kuril region) and the March 11, 2011 (Tohoku region) earthquakes.

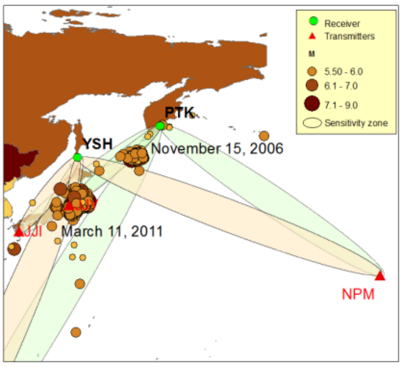

Fig. 1. A map showing the position of the receivers in Petropavlovsk-Kamchatsky (PTK) and Yuzhno-Sakhalinsk (YSH) and transmitters NPM (21.4 kHz), JJI (22.2 kHz) and JJY (40 kHz). The solid circles show position of the earthquake epicenters for the period November 1-30, 2006 and March 1-31, 2011 (from USGS/NEIC http://neic.usgs.gov/neis/epic/epic_global.html). The ellipses are projections of the fifth Fresnel sensitivity zone on the Earth's surface.

We use data from VLF ground based receiver stations in Petropavlovsk-Kamchatsky (PTK) and Yuzhno-Sakhalinsk (YSH) in Russia. Fig. 1 shows the observation geometry of the various subionospheric VLF propagation paths together with the location of earthquakes and subsequent aftershocks associated with the above mentioned events.

The first earthquake taken for our analysis is the main shock that occurred on November 15, 2006 near Simushir Island in the central Kuril region at 11:14 UT (M=8.3, depth =34 km). To analyze the VLF signal variations observed after this event the subionospheric NPM – PTK path was used because it lies along the propagation direction of the tsunami. The results were compared to signals propagating along the paths JJY-PTK, JJI-PTK and NWC-PTK as shown by the light green ellipses in Fig. 1.

Fig. 2 shows amplitude and phase measurements of the VLF/LF signals from the transmitters NWC, JJY, JJI, and NPM recorded at Petropavlovsk-Kamchatsky on November 15, 2006 together with monthly averaged signal.

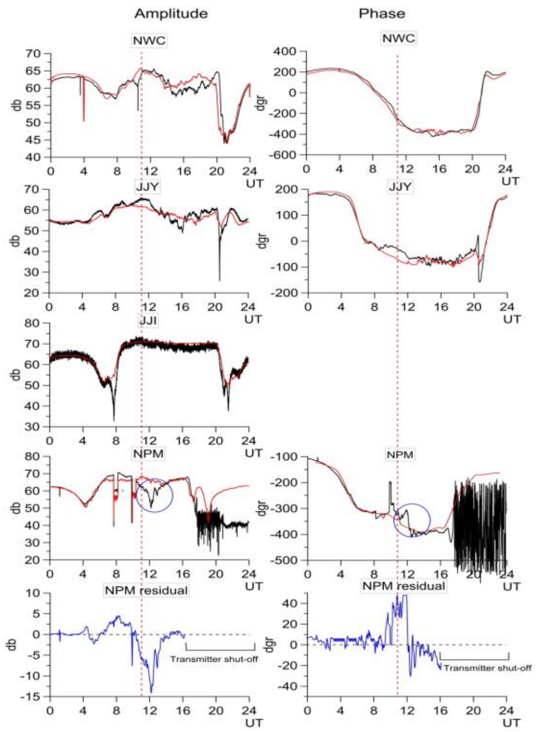

Fig. 2. Amplitude (left) and phase (right) of the signals from four transmitters - NWC (19.8 kHz), JJY (40.0 kHz), JJI 22.2 (kHz) and NPM (21.4 kHz) recorded in Petropavlovsk-Kamchatsky on November 15, 2006. Black and red lines are the observed and averaged signals, respectively. In the bottom panels the difference between the observed and averaged signals from the NPM transmitter is shown. The red vertical line shows the occurrence time of the earthquake on November 15, 2006. The circles highlight the perturbation in the amplitude and phase of VLF signal related to the tsunami.

It is clear that the measurements of amplitude and phase for all transmitters except NPM closely follow the quiet day measurements within the limits of two standard deviations. The signal propagating along the path NPM-PTK, however, exhibits a significant decrease in amplitude (about 10-15 db) during nighttime observations together with phase variations of up to 40 degrees relative to the averaged signal. It should be noted that the increase in phase and reduction in amplitude before the onset of the earthquake were due to regular switch off of the transmitter. The time interval from the main shock to the maximum of the signal anomalies is estimated to be about 1-1.5 hours.

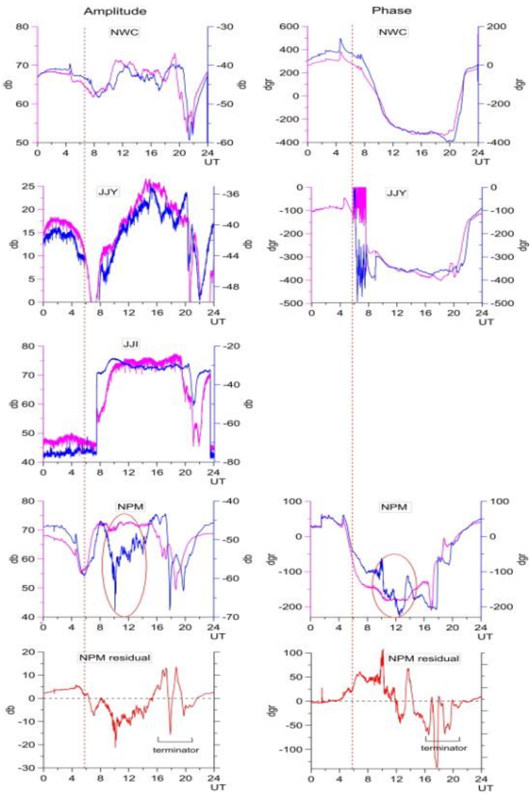

Fig. 3. Amplitude (left) and phase (right) of the signals from four transmitters - NWC (19.8 kHz), JJY (40.0 kHz), JJI (22.2 kHz) and NPM (21.4 kHz) recorded in Petropavlovsk-Kamchatsky (pink line) and Yuzhno-Sakhalinsk (blue line) on March 11, 2011. In the bottom panels the difference between the NPM signal in Petropavlovsk-Kamchatsky and Yuzhno-Sakhalinsk shown. Vertical line shows the occurrence time of the earthquake on March 11, 2011. The ellipses highlight the perturbations in amplitude and phase of VLF signal related to the tsunami.

The second earthquake was preceded by the foreshock that occurred on March 9, 2011. The main shock occurred on March 11, 2011 at 05:46 UT (M=9, depth ~25-30 km). This earthquake generated a devastating tsunami whose height attained several tens of meters. To study the case of the Tohoku earthquake we employed data from two receivers: 1) Petropavlovsk-Kamchatsky with subionospheric propagation paths NPM–PTK, JJY–PTK, JJI-PTK and NWC–PTK, and 2) Yuzhno-Sakhalinsk using the propagation paths NPM–YSH, JJY–YSH, JJI–YSH and NWC-YSH as indicated by the light brown ellipses in Fig. 1. We note that from results of the Tsunami Travel Time software the first tsunami (2006) propagates approximately along the Hawaii – Petropavlovsk-Kamchatsky VLF path whilst that for the

2011 event lies close to the Hawaii – Yuzhno-Sakhalinsk VLF path.

Fig. 3 shows the amplitude and phase measurements of VLF/LF signals on March 11, 2011 using the receivers in Petropavlovsk-Kamchatsky and Yuzhno-Sakhalinsk from the transmitters NWC, JJY, JJI, and NPM. It is clearly seen that the signals received at both stations (PTK and YSH) are very similar except for those propagating along the NPM-PTK and NPM-YSH paths which show large differences in comparison to the other transmitters. For this particular pair of propagation paths the signal recorded in Petropavlovsk-Kamchatsky travels along an undisturbed path whereas that measured at Yuzhno-Sakhalinsk clearly shows an anomalous decrease in amplitude of about 10 db together with an increase in phase of up to 50 degrees. The apparent delay from the main shock to the maximum of the signal anomaly is about 3-3.5 hours, a longer period than that observed for the November 15, 2006 event. However, the difference is probably due to the fact that the Tohoku earthquake occurred at a time coincident with a strong signal perturbation caused by the evening terminator. As a result, the actual onset of the signal anomaly can be hidden.

Fig. 4 shows the waveforms for the phase and amplitude of the nighttime data recorded along the NPM-PTK propagation path. The wavelet spectrograms of the data reveal the frequency of the maximum spectral amplitude in the range of periods of 8-30 min which corresponds to the internal gravity wave periods. These periods are in compliance with the periods observed in data recorded by the DART sensor buoys.

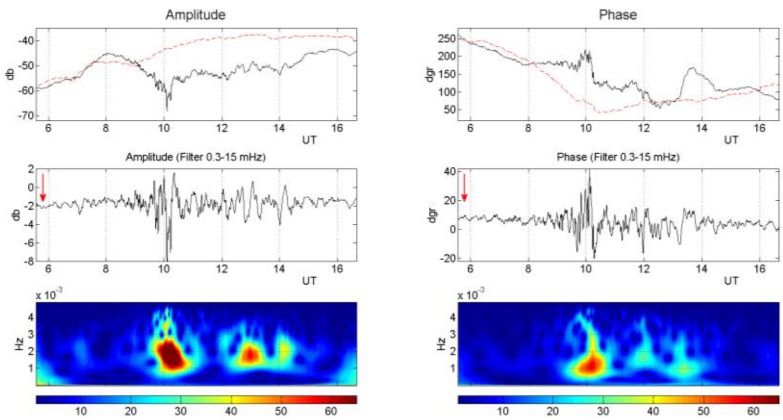

Fig 4. Top panels show the phase (left) and the amplitude (right) of the signal from the NPM (21.4 kHz) transmitter recorded on Mach 11, 2011 in Yuzhno-Sakhalinck. Dotted lines are the averaged signals. The middle panels show the signals filtered in the range 0.5-15 mHz. The bottom panels show the wavelet spectra of the filtered signals.

A qualitative interpretation of the observed effects is suggested in terms of the interaction of internal gravity waves with lower ionosphere.