Report on a possible meteotsunami event occurred in January 2009 along the central east U.S. coast.

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In the following report we will investigate event n°4 using several tide gauges located along the eastern coast of USA during october 2011 (see figure 1). The following stations will be studied (from South to North): Oregon, Duck, Ocean City, Lewes and Atlantic City. Atlantic City and Duck's tide gauges are located on a pier directly exposed to the open Ocean, while tide gauges at Oregon, Ocean City and Lewes are located on piers inside inlets.

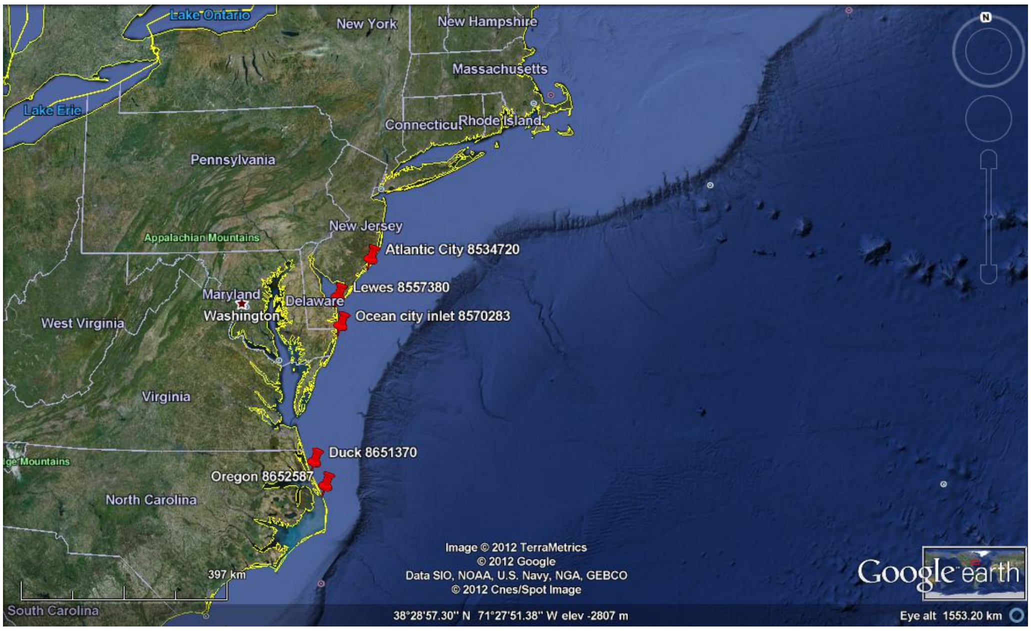


Figure 1: Location of tide gauge stations used for analysis of event n°4.

Sea level time series at these tide gauges have been downloaded at http://opendap.co-ops.nos.noaa.gov/axis/webservices/ and consist of 1 month long time series with 1min time-resolution. Tide gauge at Oregon has 6min time-resolution. Time series have been visually checked for abnormal sea level variations, which have been removed from the time-series. Then, sea level time series have been detided and high-pass filtered to keep periods shorter than 6h.

Most of the stations show a strong activity during the morning of the 29/01/2009 (see Figure 2). Oscillations were stronger at Duck and Atlantic City, where maximum peak to peak values reached respectively 65cm and 55cm. Stronger values at these stations may be related to the fact that tide gauges are directly exposed to the open ocean. This may explain also why both stations tend to have more energetic high frequency oscillations. At other stations, maximum peak to peak values range from 10cm to 20cm. Those are not particularly strong values, but they confirm that the event tends to occur at the same time all along the coast. The oscillations during the event don't have the same pattern regarding the stations. To better explain that, it is worth noting that Atlantic City, Lewes and Ocean City are quite close from each other, and far away from Duck and Oregon (these two are not far from each others). Sea level variations at Atlantic City and Lewes behave almost in the same way, only differing on magnitude. An increase of the sea level occurs around 22h and is followed 2h later by a drop of sea level. At Ocean City, located just South of Lewes, there is no increase around 22h, but a significant drop of water level is still present slightly before the event of Atlantic City and Lewes. Oscillations at Duck behave a bit differently. We note a fast increase of sea level immediately followed by a sharp drop. This event occurs at the same time than the drop at previously described stations, lasts approximately 1h and is followed 3h later by another increase of sea level, of weaker amplitude. Just below Duck, Oregon's station, which is normaly really calm, shows an abrupt increase of 10-12cm which last 1h, during the same period than Duck's event, and then comes back to a normal state.

By applying a high pass filter to keep periods shorter than 1hr (figure 3), we see that most of the oscillations reported before are still present. Consequently, periods shorter than 1hr contribute significantly to the observed oscillations. This is confirmed in the following by spectral and cross spectral analysis.

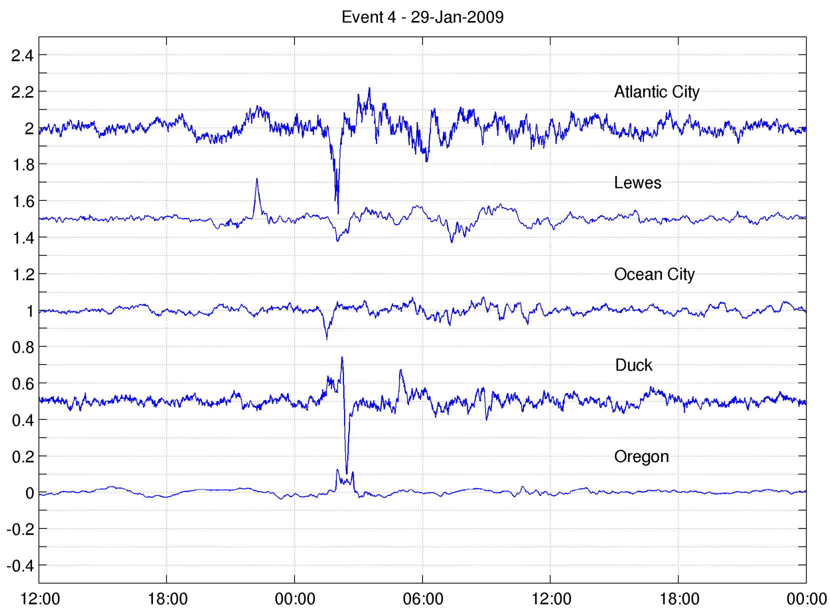


Figure 2: Filtered sea level time series (6hr high pass filter) collected at several stations during event 4.

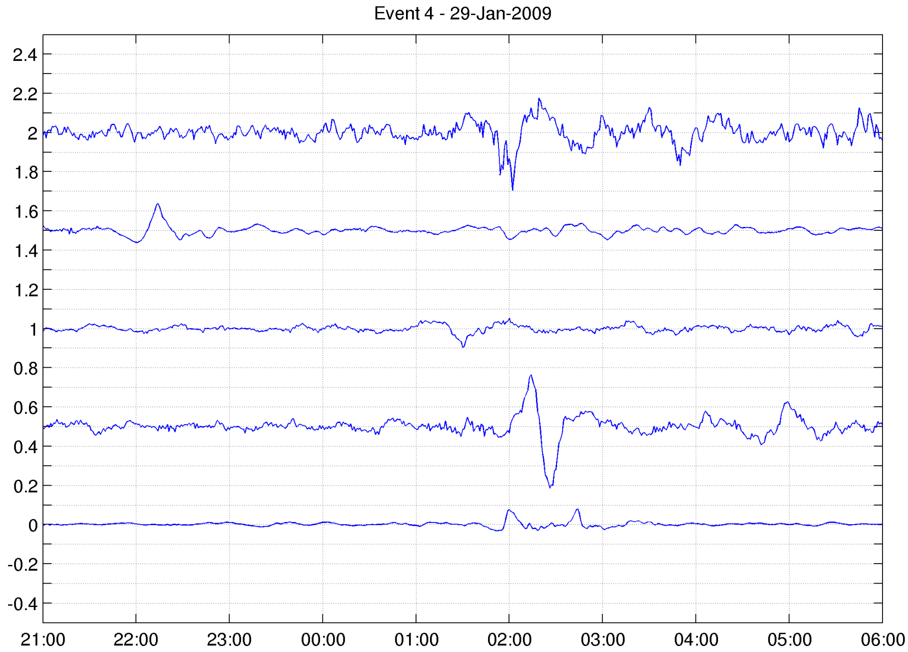


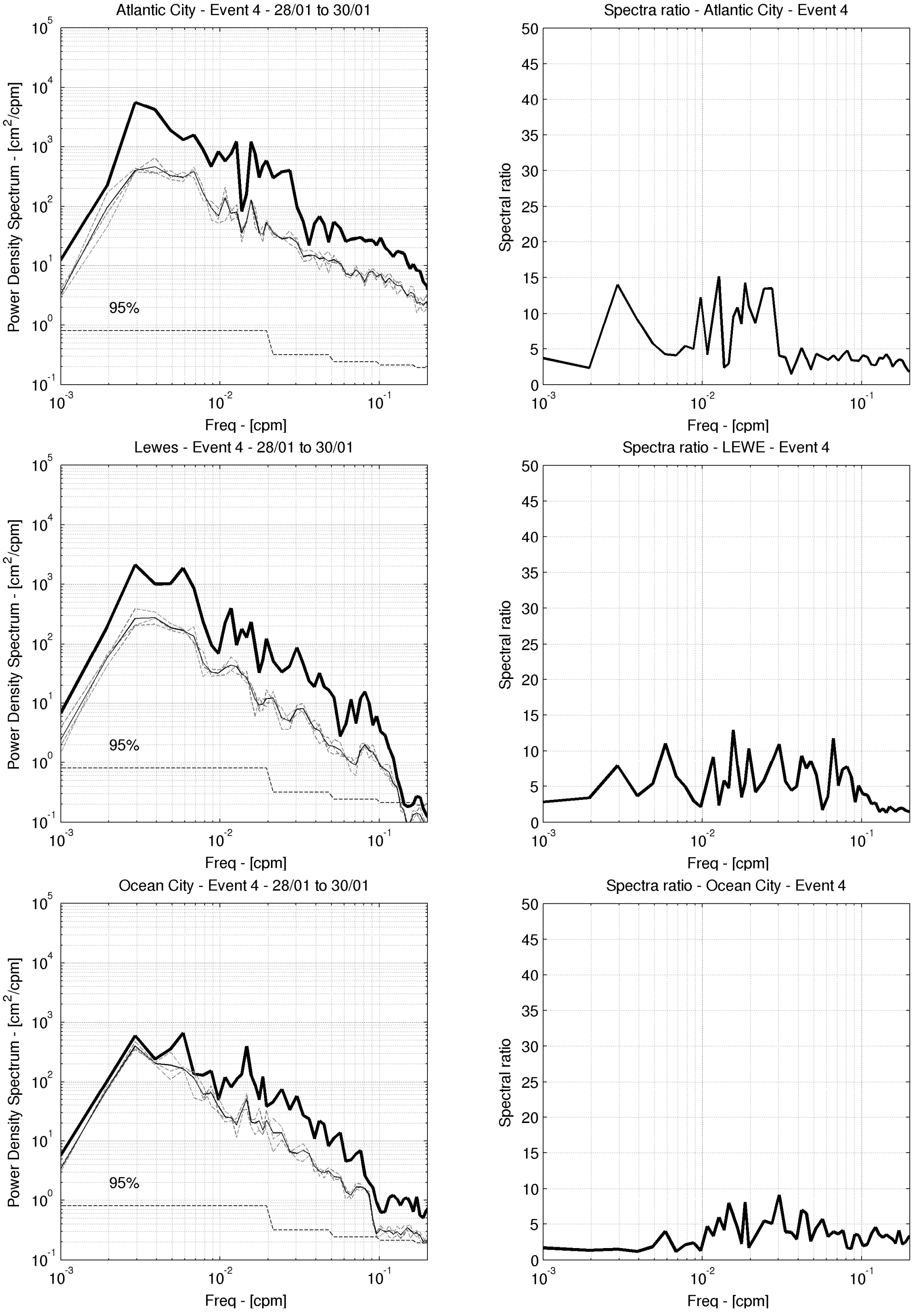
Figure 3: Filtered sea level series (6hr and 1h high pass filter) collected at all stations during event 4, zoomed over 9h.

In order to better investigate the dominating frequencies, some spectral analyses are performed on each stations, using a 1024 points length KB window, 50% overlapped. Additional frequency averaging with variable window has been performed in order to smooth high-frequency oscillations (Rabinovich and Monserrat, 1996). These spectral analyses are performed on a two days period (2880 points) for the event. 3 background spectra are computed on 5 days periods, out of the event, and are averaged together for each stations, in order to make a mean background spectra and have the topographic response of the sea level. Spectral ratios are then computed by doing the ratio between event spectra and background spectra. The power density spectra as well as the spectral ratios are represented on figure 4 for all stations.

As expected, strongest spectral ratios are found at Duck, with maximum values ranging in periods from 20min to 140min. A strong proheminant peak is found at 43min, which is likely to be associated with the strongest wave of the event. At Oregon, which is located just below, and inside an inlet, strongest values are in the high frequency band (periods ranging from 40min to 10min). No proheminant peak is found at 45min, the strongest signal at Duck. Generally, we note that at Atlantic City, Lewes and Ocean City the low frequency content of spectral ratios tends to decrease with latitude. At Atlantic City,spectral ratio is strong in the band ranging from 100 to 33min. The maximum peaks have periods of 77 and 55min, which correspond well to the oscillations that can be visually inferred from the time serie, especially on 1hr highpass filtered time serie. At Ocean City and Lewes, spectral ratios don't vary much in the frequency domain. Some cross spectral analysis are then performed between Duck (station with strongest oscillations) and all other stations, in order to study the link of frequency content between each stations. In all cases, we can observe peaks of high coherence level (significative regarding 95% confidence level). But it should be noted that that almost all the high coherent peaks are not associated with highest spectral peaks nor highest spectral ratio peaks. In all the cases, we note that the peaks of high coherence are usually: 1h30, 55min, 40min, 20min, with some same small variations (+/- 3min).

It is important to keep in mind that Oregon and Duck are really close (45km alongcoast distance) while along coast distance between Duck and Ocean City is much larger (around 260km), and Atlantic City and Lewes are again more distant. It may lower the coherence level, and also explains the shift in frequency of the peaks. But it explains also why the coherence level between Duck and Oregon is particularly high at higher frequencies.

During this event, we saw that several caracteristics were identical at all stations. The strong oscillation occuring at Duck and associated with a peak to peak value of 65cm has a signature on other stations at the same moment. Spectral ratios and cross spectral analysis tend to confirm the links between all these stations, by showing that similar periods where associated with more energy at all stations, with however small variations in frequencies. Periods of the strongest peaks range from 1h30 to 20min. Given that these oscillation occur more or less at the same time (only the gap in time series at Ocean City occurs slightly earlier), it is unlikely that these waves are edge waves, as it has been shown during events 1, 6 and 7. Like during events 8 and 9, these strong sea level variations could be generated by the atmosphere. The stong amplitudes observed could be explained by different mecanisms of resonance which could amplify oscillations generated by a pressure jump (for example, Proudman resonance, shelf resonnance or harbour resonnance). To confirm this hypothesis, additionnal analysis must be done on atmospheric data. Also, resonnant frequencies associated with the shelf could be performed.


Atlantic City - Event 4 - 28/01 to 30/01
Spectra ratio - Atlantic City - Event 4
Lewes - Event 4 - 28/01 to 30/01
Spectra ratio - LEWE - Event 4
Ocean City - Event 4 - 28/01 to 30/01
Spectra ratio - Ocean City - Event 4
Power Density Spectrum - [cm^2/cpm]
Spectral ratio
Freq - [cpm]
95%

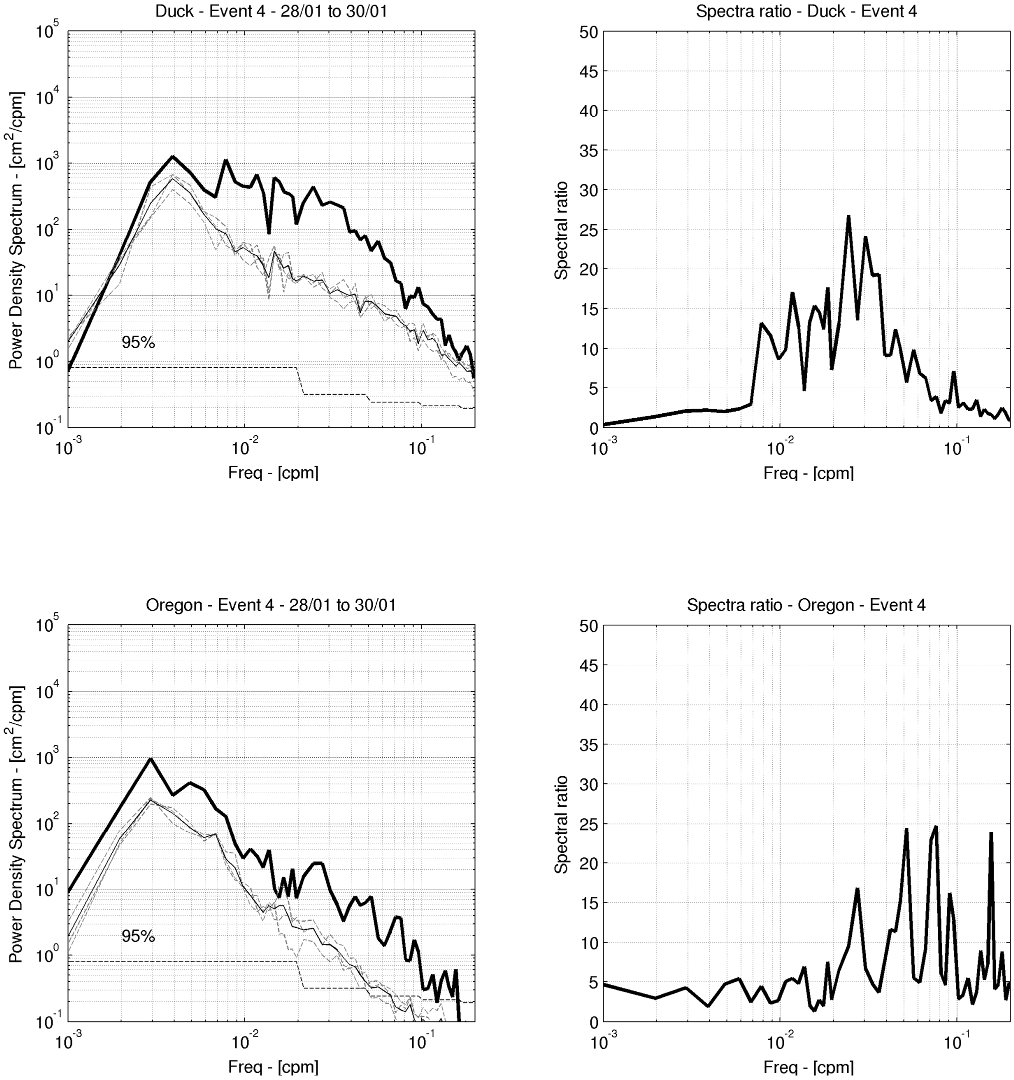
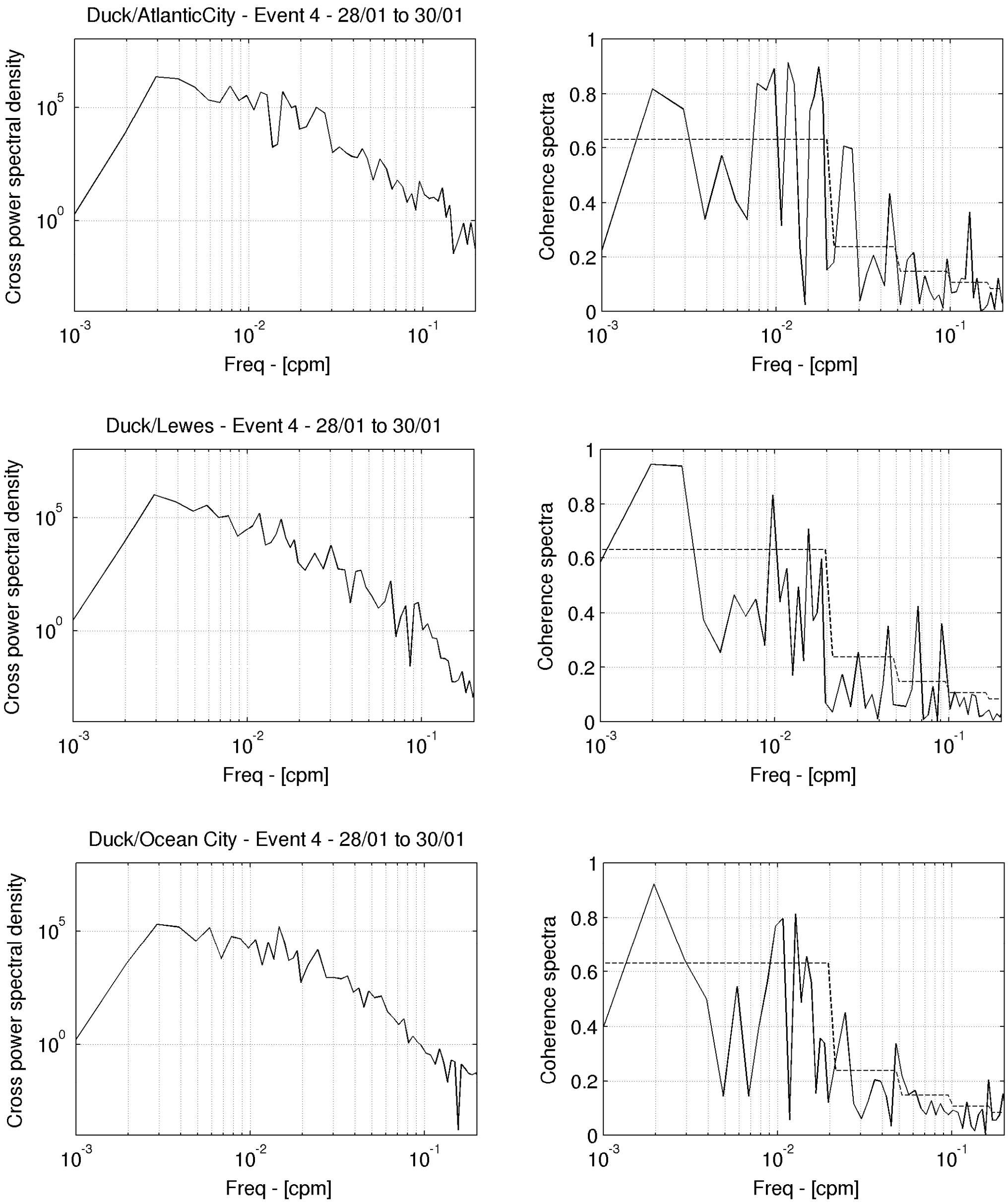


Figure 4: Event (thick) and background (thin) spectra (left) and spectral ratios (right) at different stations during event 4.Dashed lines represent 95% confidence limit.



Duck/AtlanticCity - Event 4 - 28/01 to 30/01
Cross power spectral density
Coherence spectra
Freq - [cpm]
Duck/Lewes - Event 4 - 28/01 to 30/01
Cross power spectral density
Coherence spectra
Freq - [cpm]
Duck/Ocean City - Event 4 - 28/01 to 30/01
Cross power spectral density
Coherence spectra
Freq - [cpm]

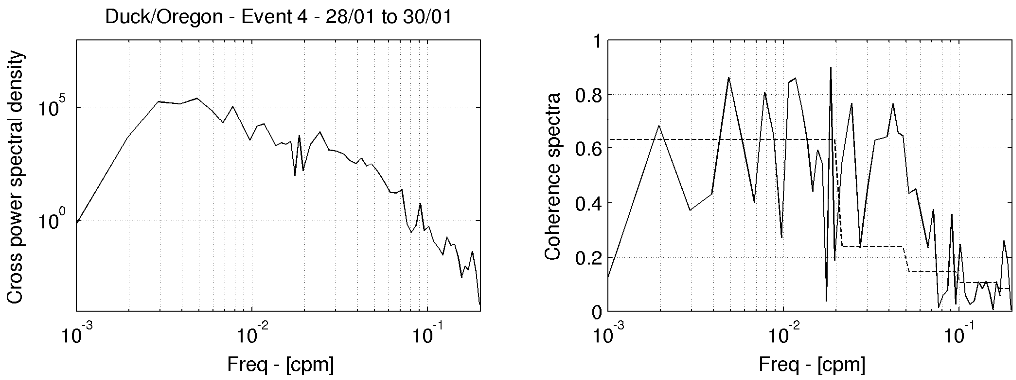


Figure 5: Cross-spectra between different pairs of stations estimated during event 4.Dashed lines represent 95% confidence level for the squared coherence.