LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO –
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Study of the wind behaviour in Hanford and its influence on the seismic motion excitation

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Abstract

We studied the wind behavior at the LIGO Hanford Observatory. We found that the recorded wind activity is not strictly correlated between weather stations, as wind gusts can be local and the buildings can modify the airflow pattern at the wind gauge. We found indications that the seismic activity attributed to wind is not necessarily correlated with the instantaneous and local wind conditions. This seems to indicate that the local drag on the buildings is not the sole source of wind induced seismic noise. The observed seismic activity can be consistent with a diffused source. One of the possible culprits could be the drag on ground generated by the turbulence of the ever-changing wind gusts, another one could be interaction between Rattlesnake Mountain and the strong airflow.

Introduction

There is a long standing observation[1] that high wind conditions can deteriorate the duty cycle of the LIGO Hanford Observatory.

High winds in Hanford are observed to be correlated with increased seismic activity at the interferometer buildings that may lead to loss of lock and observation efficiency if the wind speed reaches a fairly well defined threshold.

We studied the wind behavior around the Hanford site over 50 days[2], in an effort to understand the wind to seismic activity connection and figure out if any building modification may help reducing this problem. The data we used were from the LVEA and X Mid Station. We had some doubts about the correctness of the data provided by the other stations for the chosen period, so we decided not to rely on them.

We also examined the correlation between the wind activity and the low frequency seismic noise far from any buildings. It helped us to realize that the seismic activity cannot be strictly linked to the wind-building coupling, since seismic activity very clearly rises with increasing wind even far (~km) from the buildings (some evidence that building are not the direct culprits can be found also in G020252-00.pdf).

We also found that the recorded wind activity is not strictly correlated between weather stations. It is not really surprising, since wind gusts can be local and the buildings can modify the airflow pattern at the wind gauge[3].

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[1] This study was inspired by Joseph Betzwieser's and Nergis Mavalvala's measurement of wind vs. seismic activity on the 27th of March 2003

[2] Several small gaps, different for each data channels, were found in the data, all the time stamps were "re-aligned" before analysis to re-synchronize the readings. Some small residual de-synchronization may be present due to data recovery differences from data viewer One minute averages from data viewer were used.

[3] LIGO might want to revisit the weather station installation guidelines to minimize the degradation of the weather data due to the local structures.

There are indications that the seismic activity attributed to wind is not necessarily correlated with the instantaneous and local wind conditions. This can indicate that the local drag on the buildings is not the sole source of wind induced seismic noise and therefore the observed seismic noise can be consistent with a diffused source. This additional factor might be anything from the drag on ground generated by the turbulence of the ever-changing wind gusts to interaction between Rattlesnake Mountain and the strong airflow.

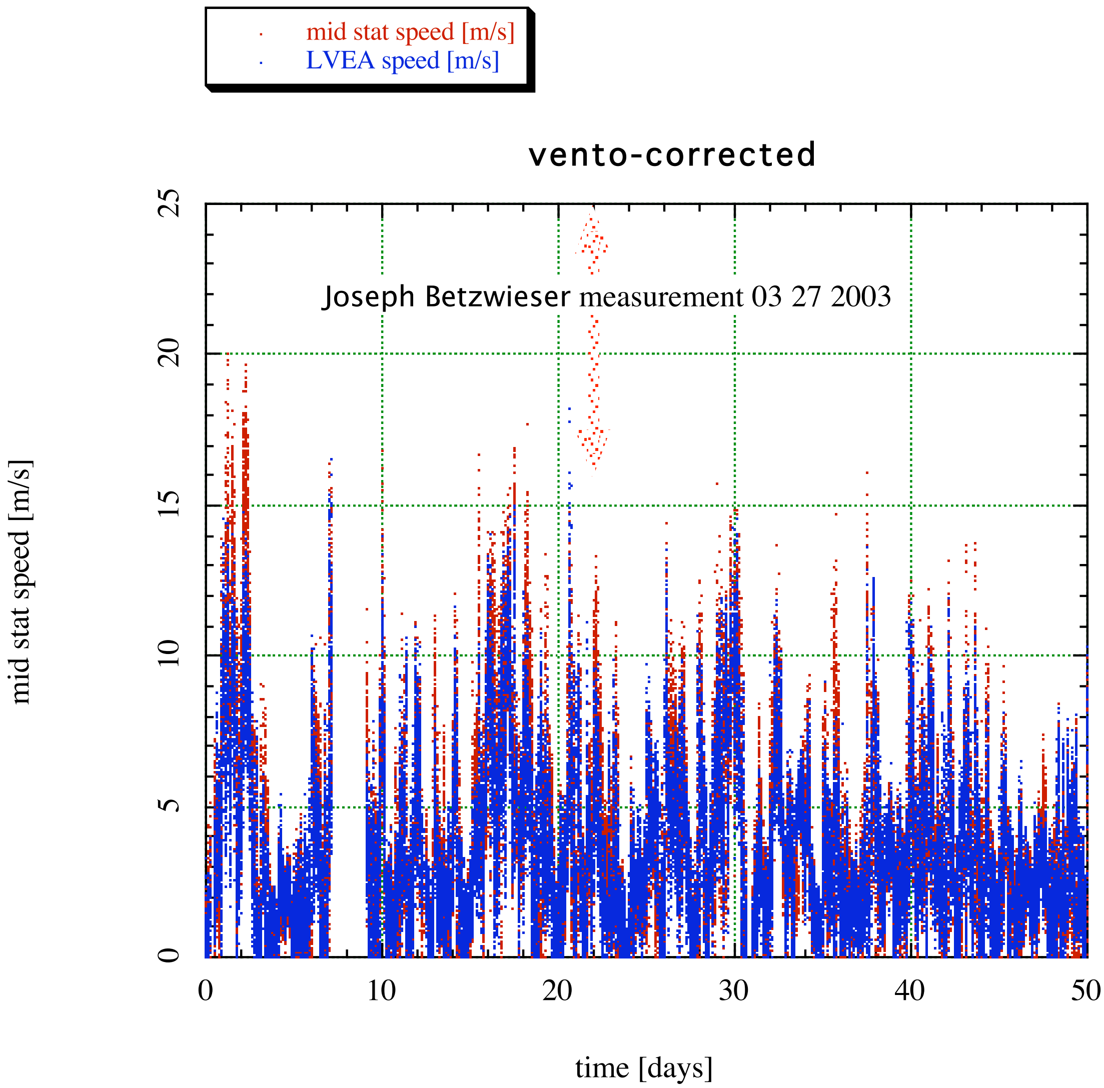

Figure 1 Wind speed minute trend at the X Mid Station during the 50 days of the data (735144000 –735244000)

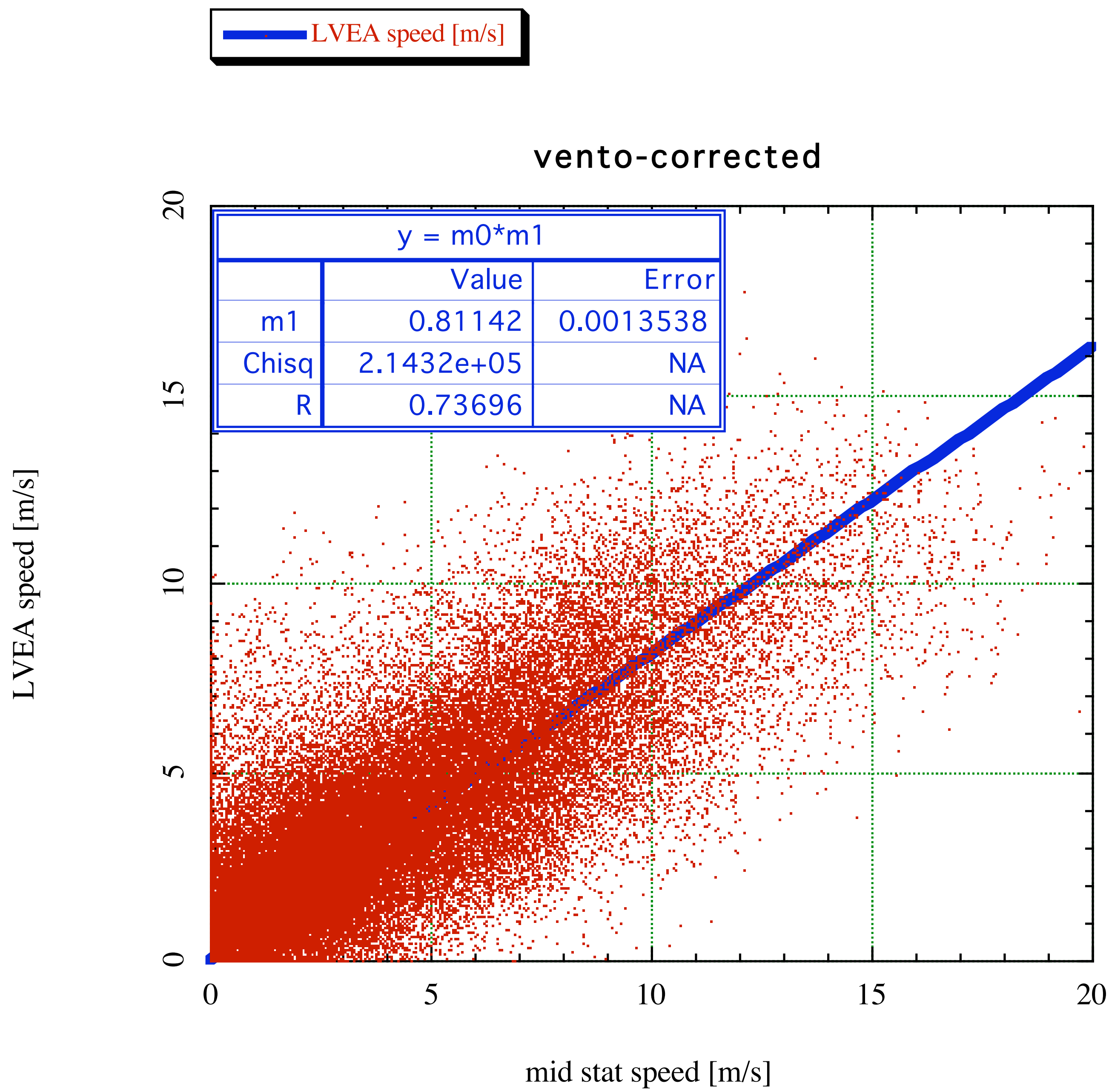

Figure 2 Scatter plot between LVEA and MX wind[4] speeds. Either the calibration of the speed meter is lower by 15%, or the wind is partially shielded to lower speed in LVEA.

[4] Vento means wind in Italian. Ric things that documents with ethnic flavors are tastier.

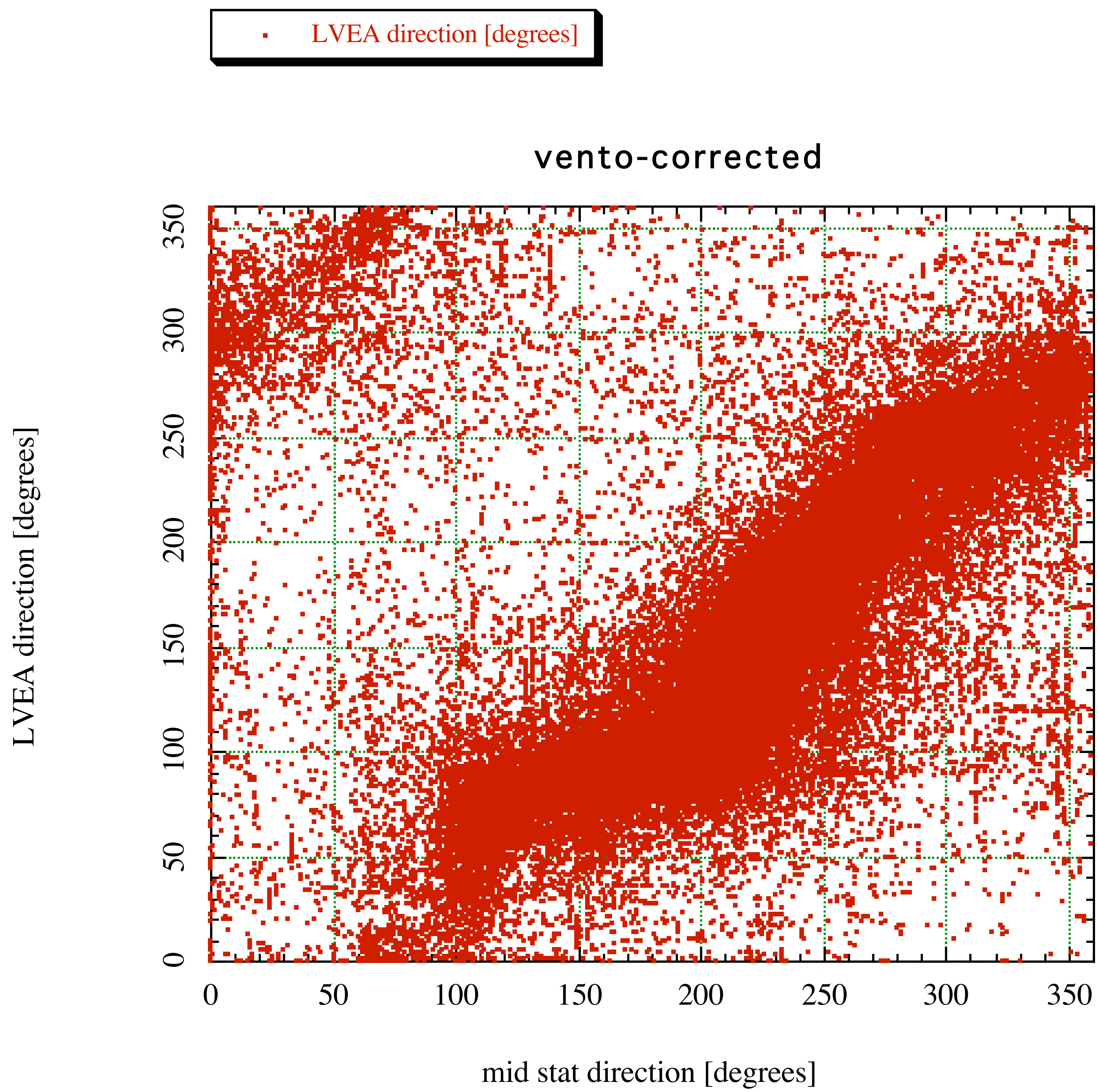

Figure 3 Scatter plot of measured (uncorrected) wind direction between the LVEA and MX. Angularly, we would have to rotate the angle of one station with respect to the other by 90 degrees in order to align the wind direction. After that we observed decent correlation[5] (next Figure).

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[5] Maybe this discrepancy should be fixed or documented.

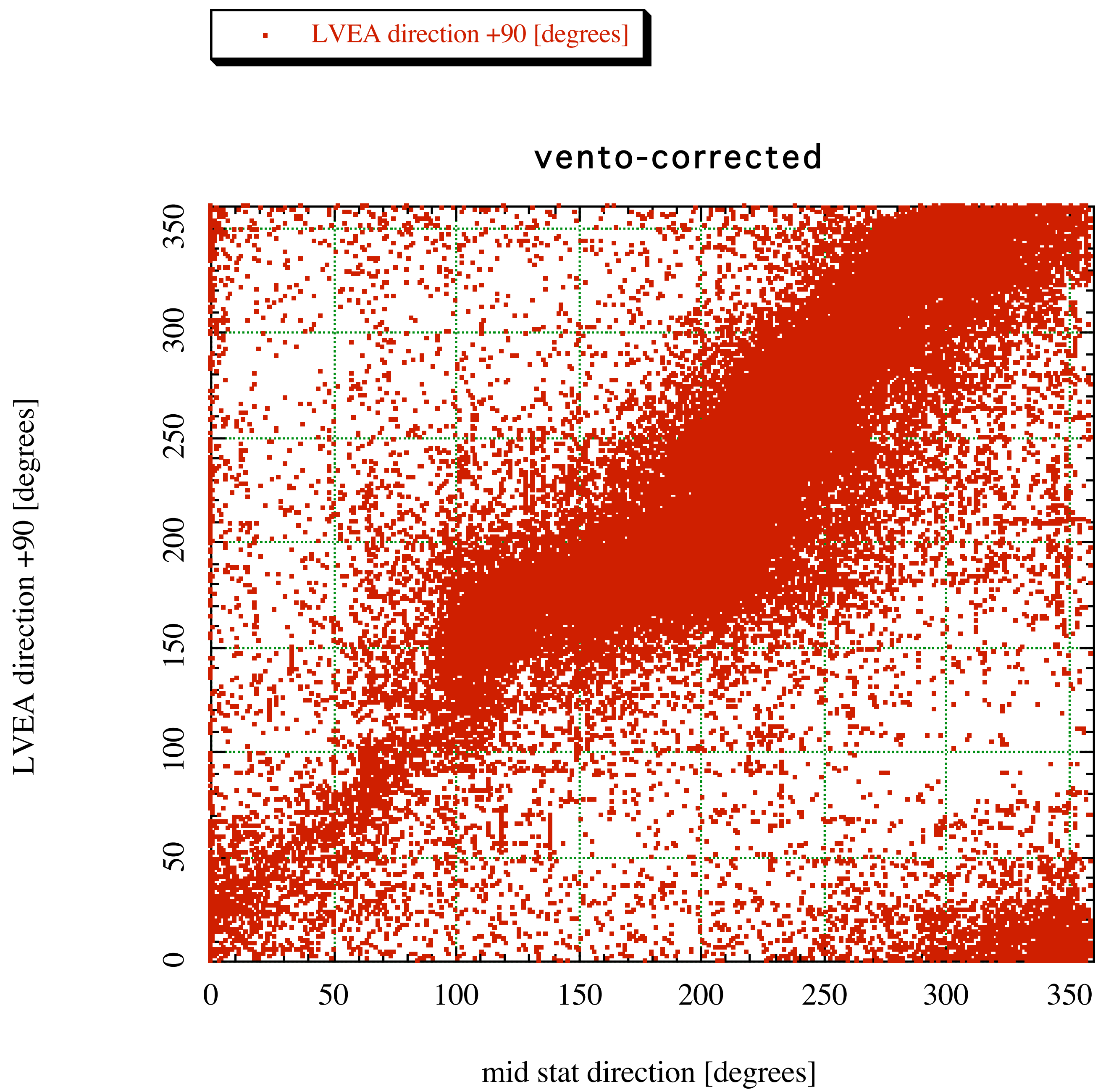


Figure 4 Scatter plot of measured (corrected) wind direction between the LVEA and MX. Angularly, we rotated the reported wind direction angle of one station with respect to the other by 90 degrees in order to align the apparent wind direction. The following plots are made using the corrected direction info[6].

[6] It is not clear what is the meaning of direction of 0 degree and the positive angular direction in terms of more widespread coordinate systems (i.e. North-South-East-West). Therefore, we will not even attempt to "translate" them.

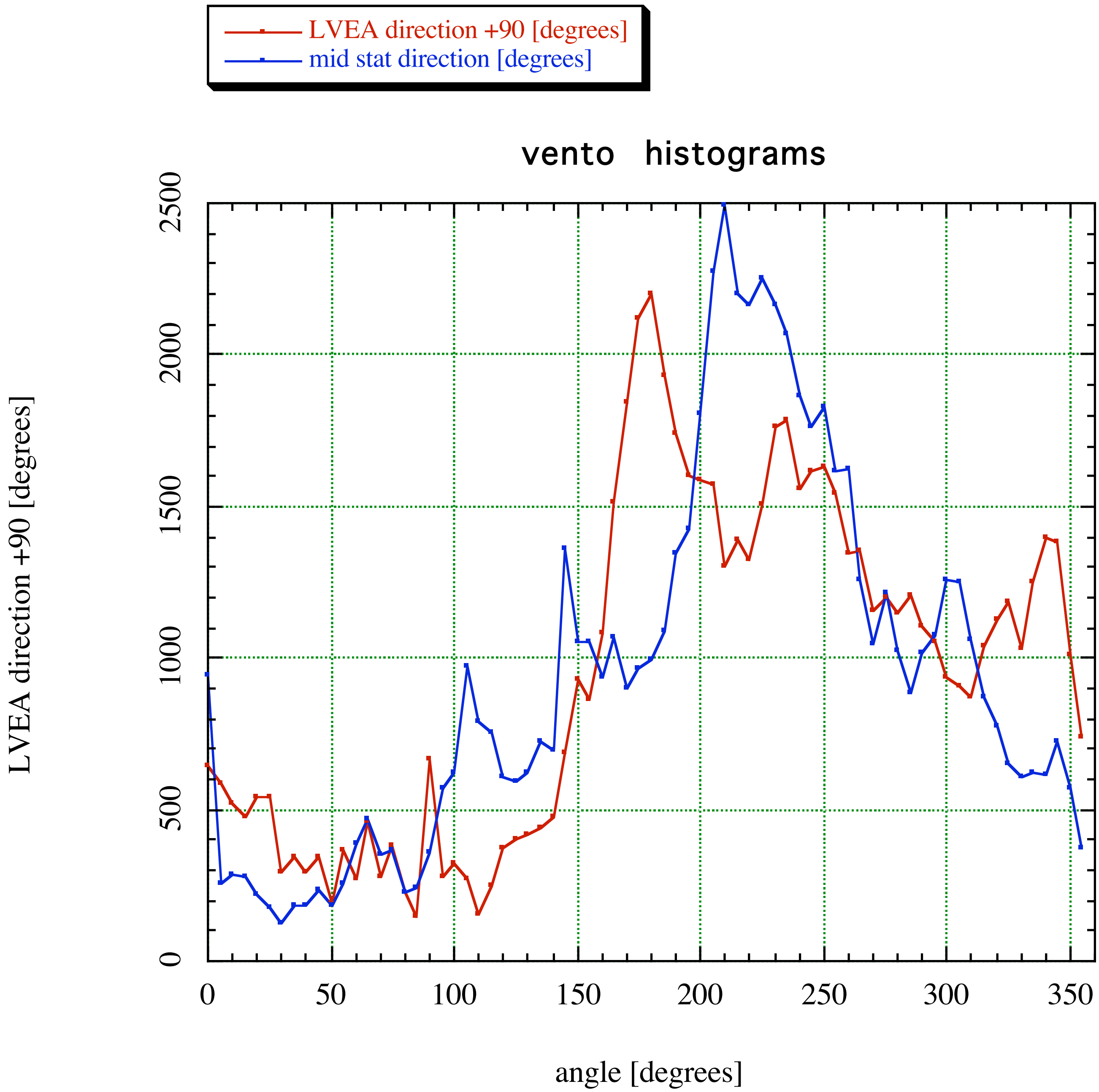


Figure 5 Histogram of wind direction measurements to detect the prevailing wind direction. There were no cuts on the wind velocities.

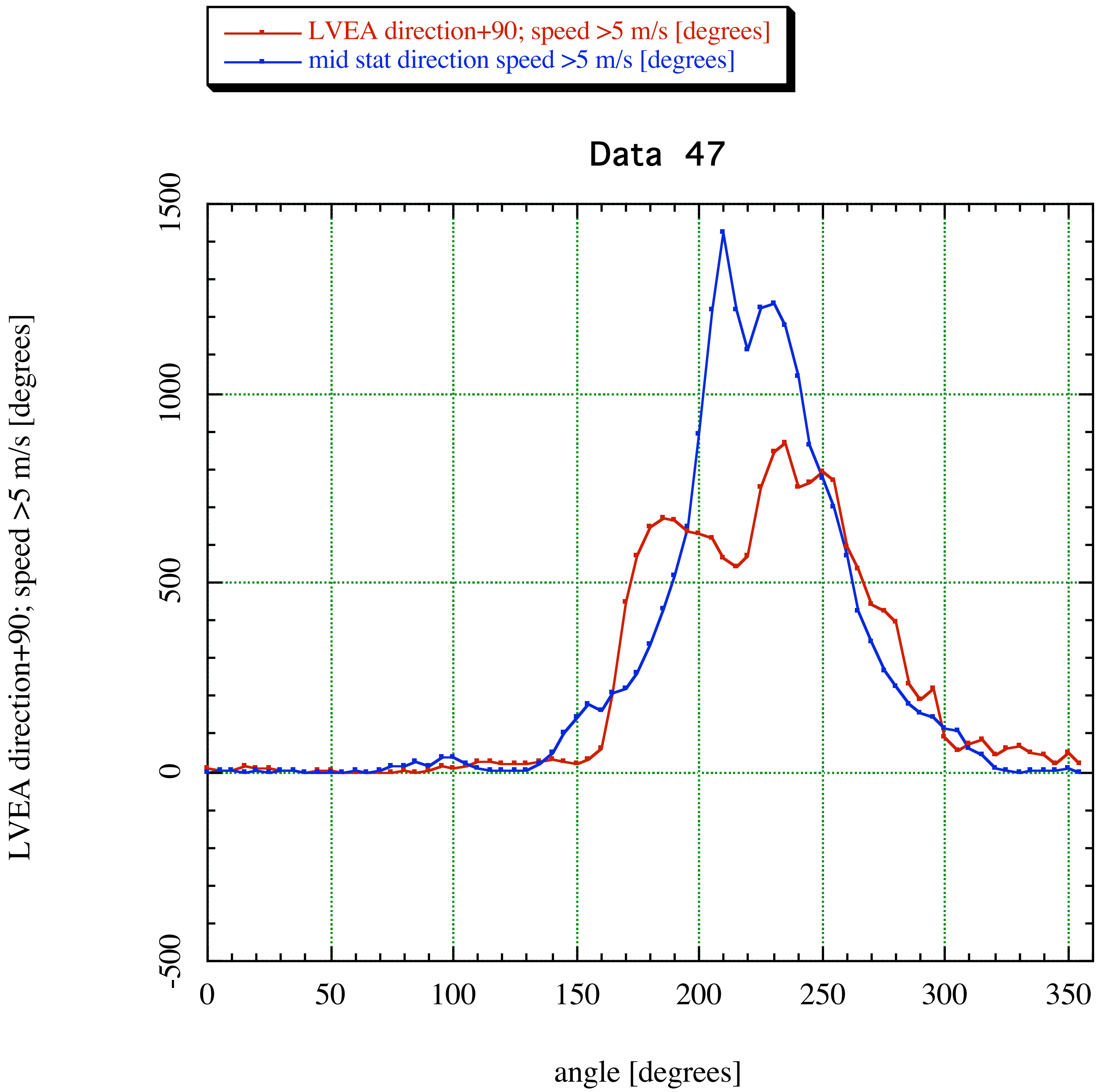


Figure 6 Histogram of wind direction measurements to detect the prevailing wind direction. We only used the wind direction data if the wind speeds were larger than 5 m/s in both anemometers Note how for higher winds, the angular peak is wider in LVEA. Is it a possible indication of stronger turbulence?

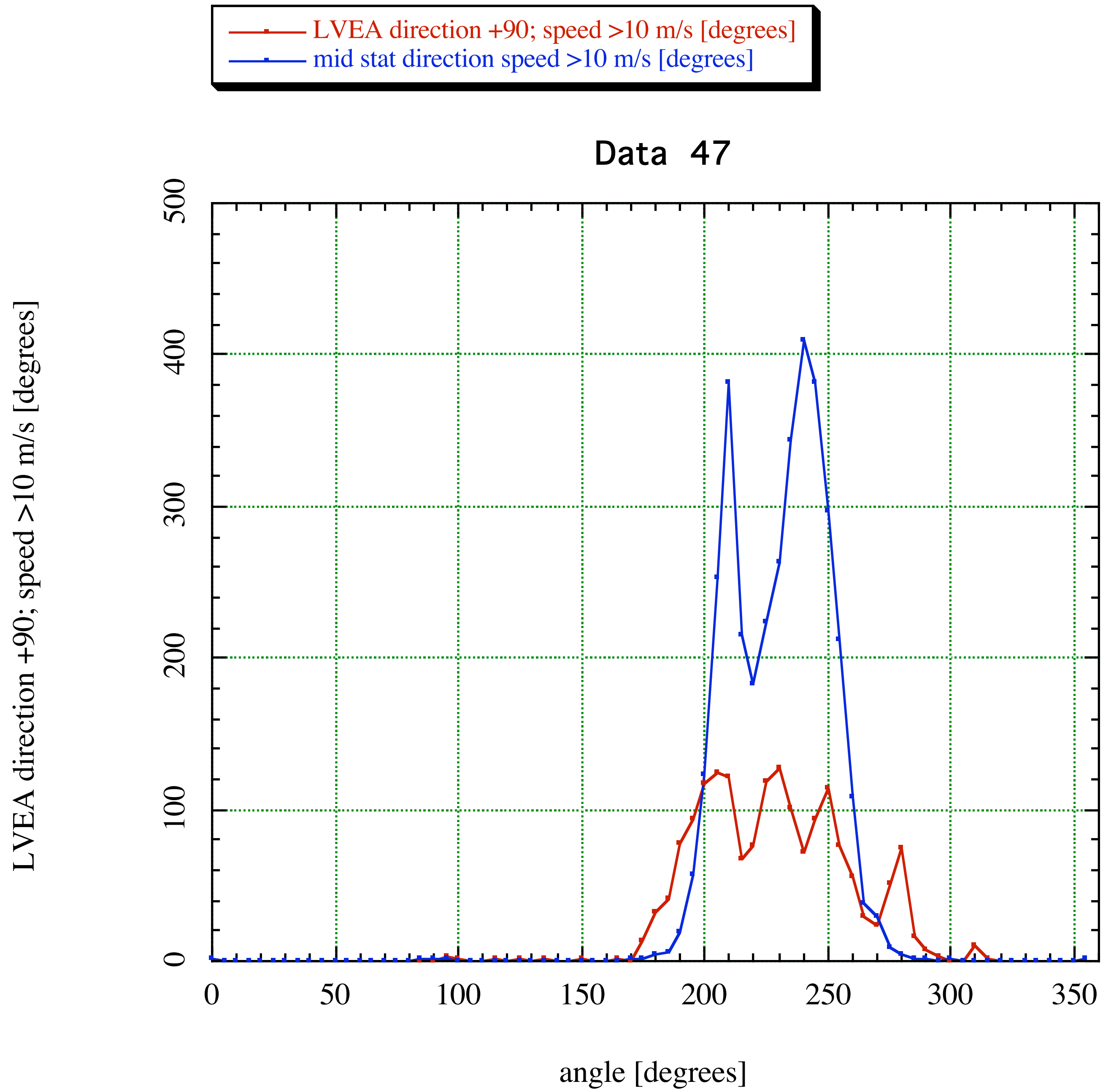


Figure 7 Histogram of wind direction measurements to detect the prevailing wind direction. We only used the wind direction data if the wind speeds were larger than 10 m/s in both anemometers.

As noted by most Hanford residents, the wind speed is directional. We can also see from the data that the wind is usually coming from a single direction with a width of 40 degrees (over the 50 days period). The anecdotal evidence is that the wind is along the Y arm and it is coming from the End Station towards the Corner Station (roughly a South-West wind).

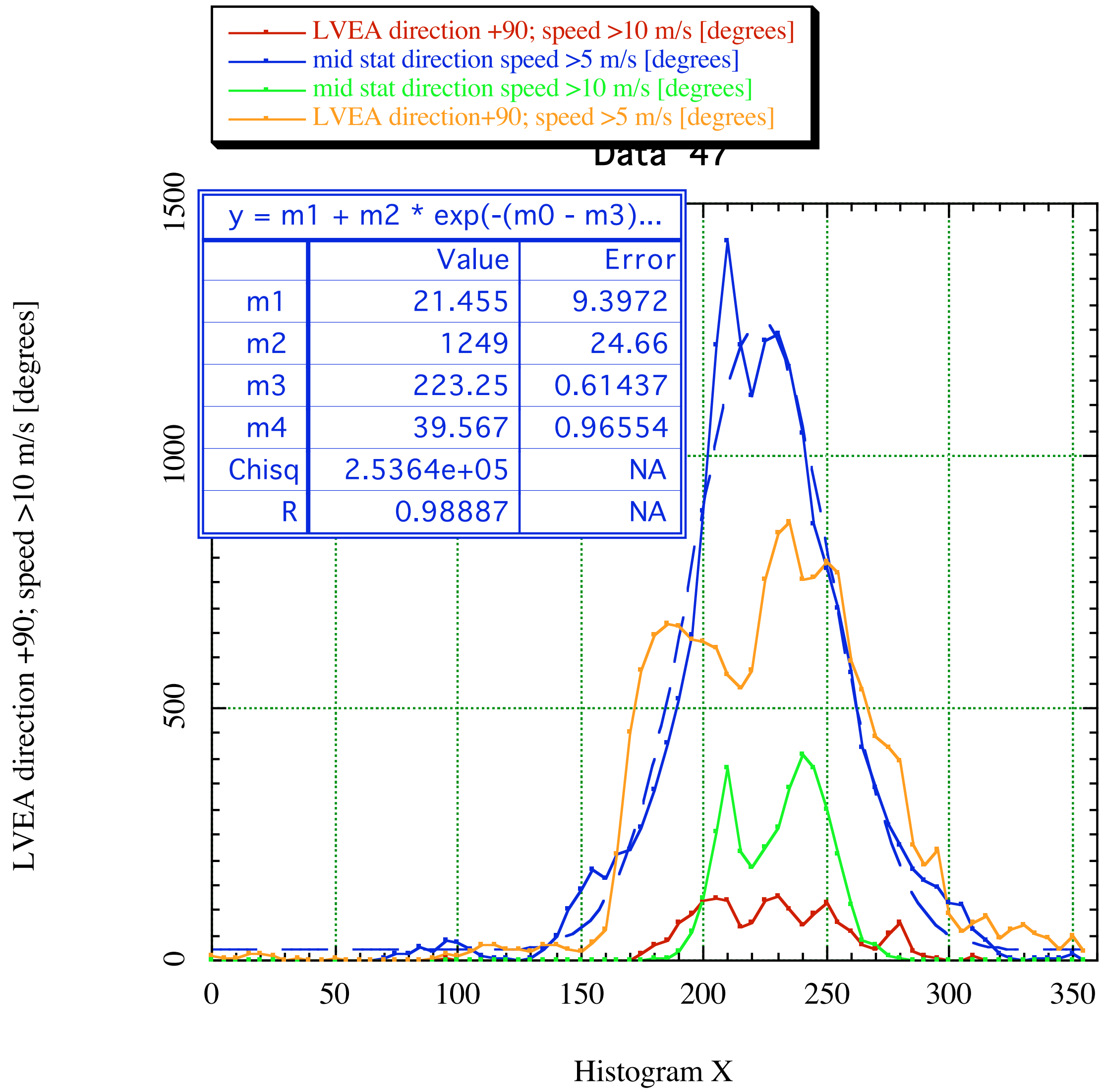


Figure 8 Histogram of wind direction measurements to detect the prevailing wind direction. The dashed blue line is a fit to the angular data of the Mid Station distribution. We see that over the duration of ~50 days strong winds mostly arrived from a well-defined and constant direction, within a standard deviation of ~40 degrees.

With such a directional wind, if the seismic problems inside the building detected by Joe Betzwieser were caused by direct coupling of the building with the wind, one might think of some kind of shielding or building shape modification. Wind deflectors similar to the ones used on tall highway bridges to deflect the wind over the passing cars and berms are both examples. It is likely that such solutions would be significantly more expensive than a simple seismic isolation on the piers and they would only work if the coupling of the wind to the seismic motion were strictly through the building's structure. Therefore, before considering such solutions it is necessary to prove that the problem is limited to the buildings or other localized structures. As it turns out, it is very likely that local coupling is not likely be the unique cause, as described in the next pages. The seismic excitation is present even in the absence of local buildings and it appears to come from a more diffused source. Unless the seismic conductivity of the ground in Hanford is spectacular or the real culprit is the beamtube, it would be hard to explain the observations only with the wind to LIGO building coupling. Seismic attenuation appears to be a more likely solution to the Hanford wind problem.

Wind to seismic coupling

In order to check if the wind/seismic coupling is through the LIGO buildings to the slab, we used data[7] from the Streckeisen STS-2 seismometer of the LI.LTH LIGO-USGS seismic station. The seismometer is installed below ground level half way between the LVEA and the X Mid Station, ~300 meters away from the beamtube towards Rattlesnake Mountain. Wind speed data was also collected for the same time period.

We used ground speed information for the entire time with a sampling rate of 0.1 Hz to assess the low frequency behaviour. Three data segments with 20Hz sampling rate were used to compare seismic behaviour differences between low and high wind conditions far from the LIGO buildings. The time coverage of the study was:

Overall of the period:

From : 735144000 2003/04/23 14:39:47 UTC

To : 735244000 2003/04/24 18:26:27 UTC

100000 sec of unfiltered data with 0.1 Hz sampling rate for direct comparison to the wind speed

We choose three demonstrative 500 second long segments and examined the unfiltered data with 20 Hz sampling rate.

High Wind ~10 m/s in MX and LVEA:

735153420 2003/04/23 17:16:47 UTC

Low Wind everywhere:

735218730 2003/04/24 11:25:17 UTC

High Wind in LVEA ~11 m/s and lower ~6 m/s in MX

735239550 2003/04/24 17:12:17 UTC

The STS-2 seismometer and DAQ system specifications are:

Data System: Quanterra Q4128 "LIGO_TriNet_Hanford"

1 digital unit = 2.38 microvolts

Wide Band Seismometer Streckeisen STS_2

~ Velocity response from 0.00833 to 50 Hz

Sensitivity: 1500 Volts / meter / sec

The data collected over the arc of two days was correlated to the LVEA and X Mid Station wind speed information. The very low frequency components ~mHz were subtracted.

[7] As it is only a pilot study, we used fairly short data segments. More detailed studies from other are on their way.

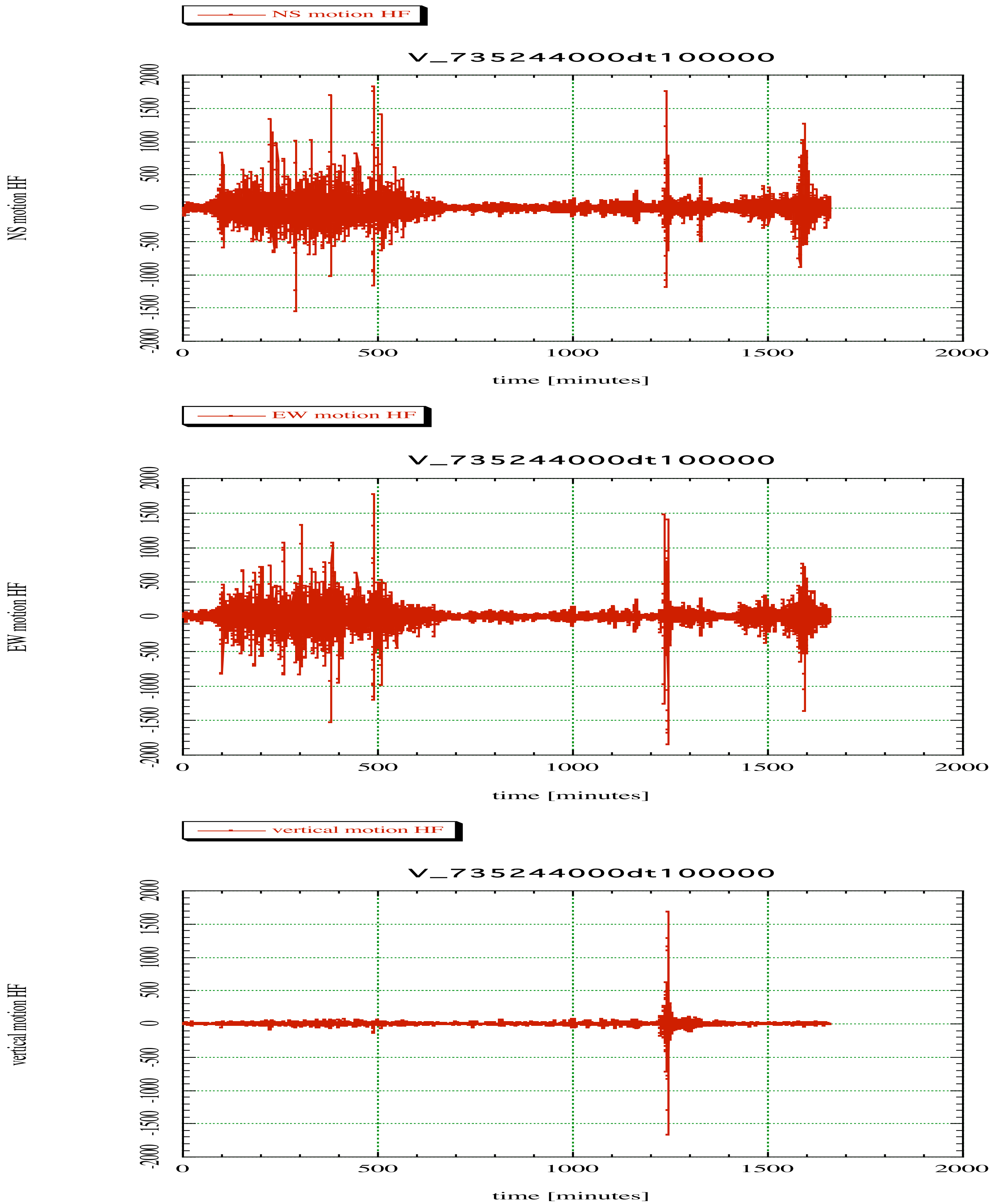


Figure 9 Low frequency seismic activity for the full time period (Top North-South : Middle East – West : Bottom – Vertical A small earthquake is visible shortly after minute 1200. The data around the earthquake was not used for the analysis. Note the significant (wind induced) activity in the horizontal directions. It is also important to observe that the general seismic activity and the earthquake signature are quite comparable on all three plots. The wind seems much less effective in exciting the vertical direction.

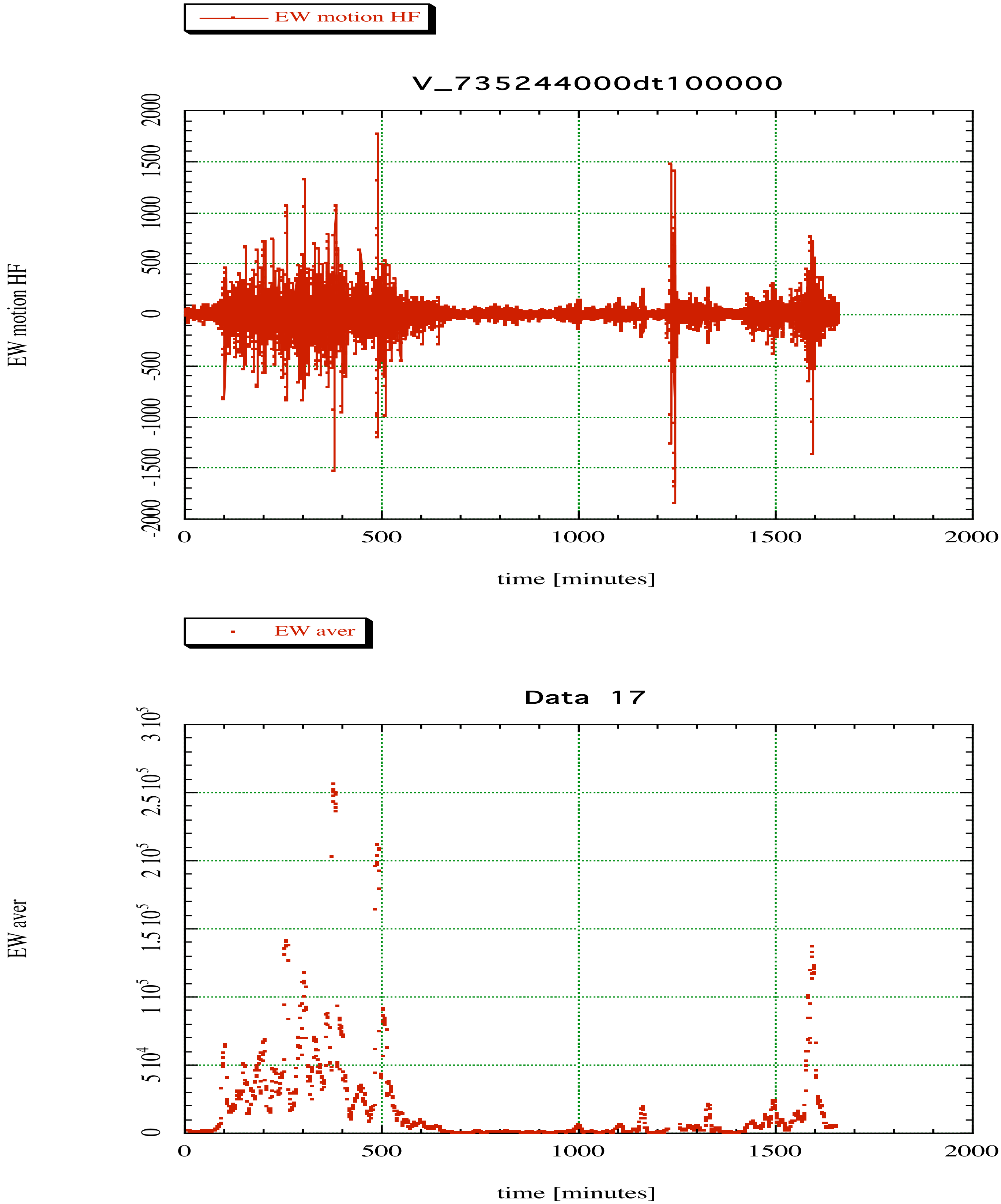
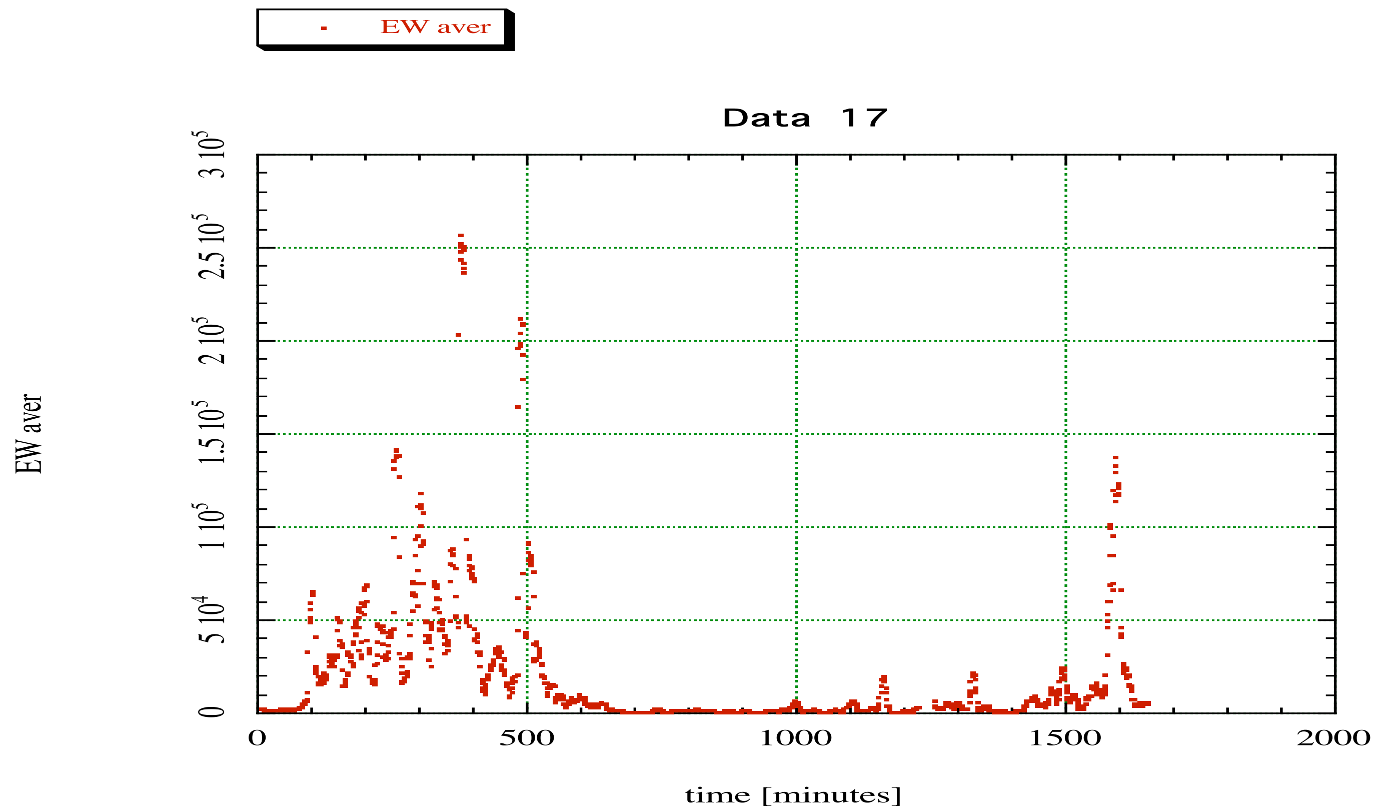


Figure 10 The RMS minute trend (bottom) of the low frequency horizontal seismic behavior compared to the original (0.1 Hz SPS data, top). The earthquake was suppressed. For simplicity we used only the East – West direction.



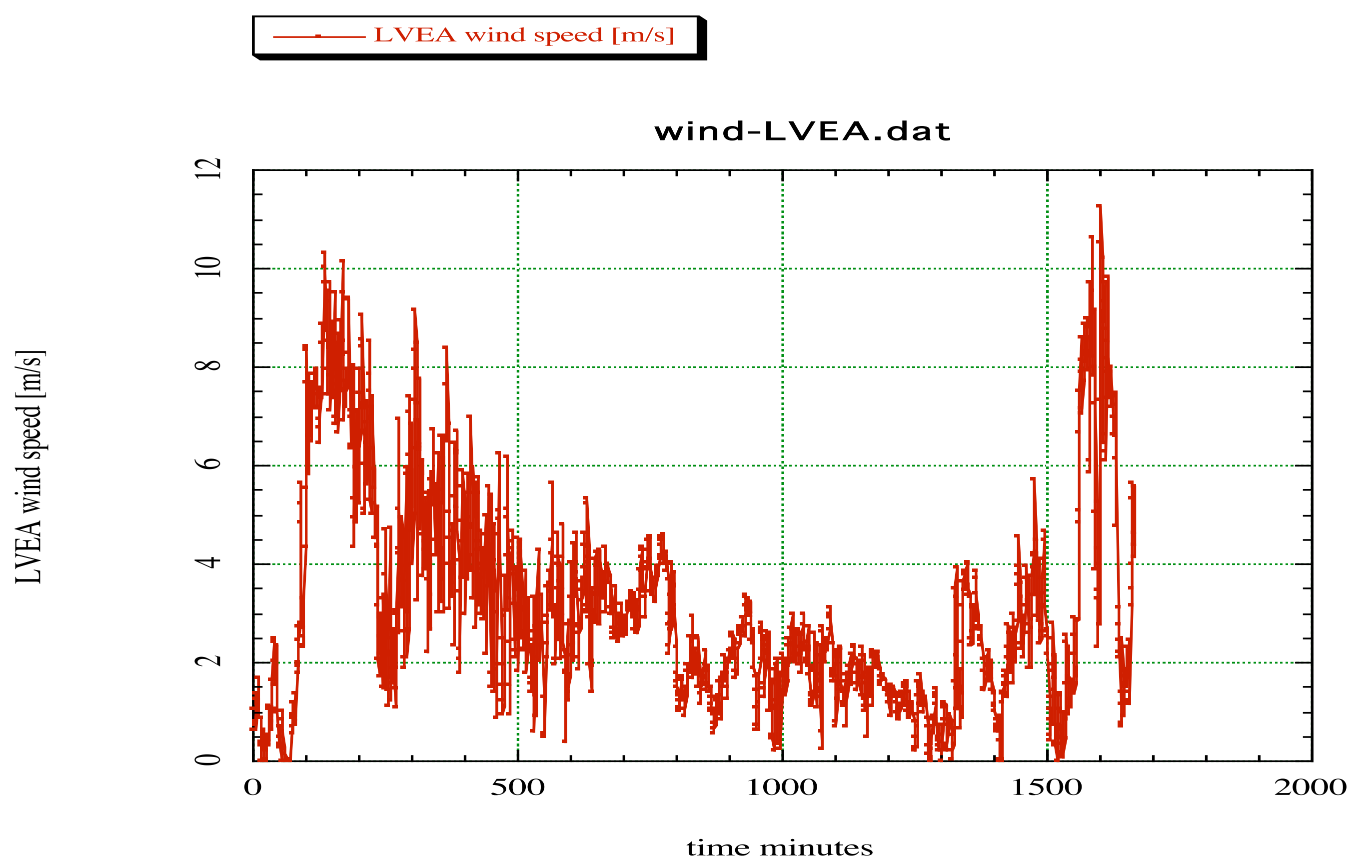
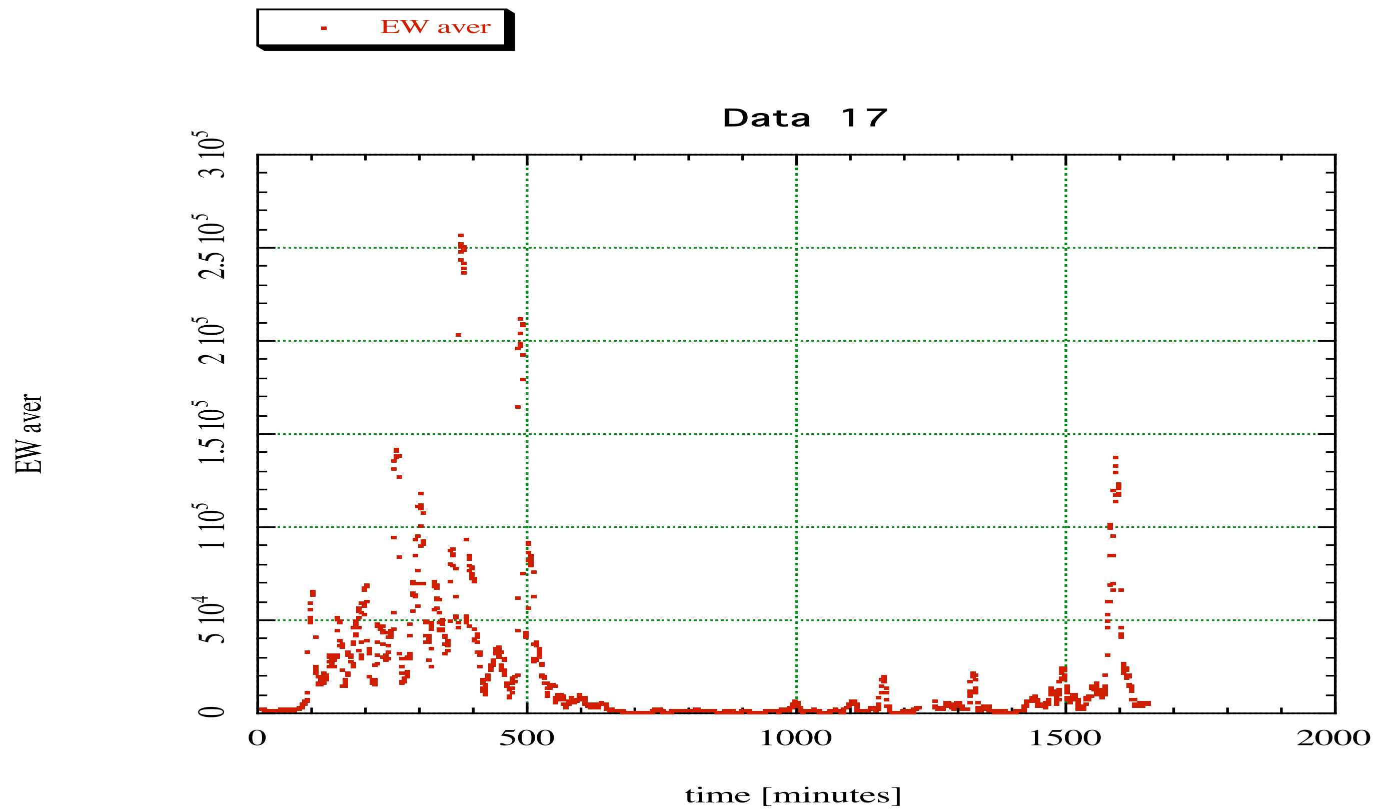


Figure 11 Comparison of the low frequency seismic RMS minute trend (top) with the corresponding LVEA wind minute trend information (bottom). The correlation is clearly observable.



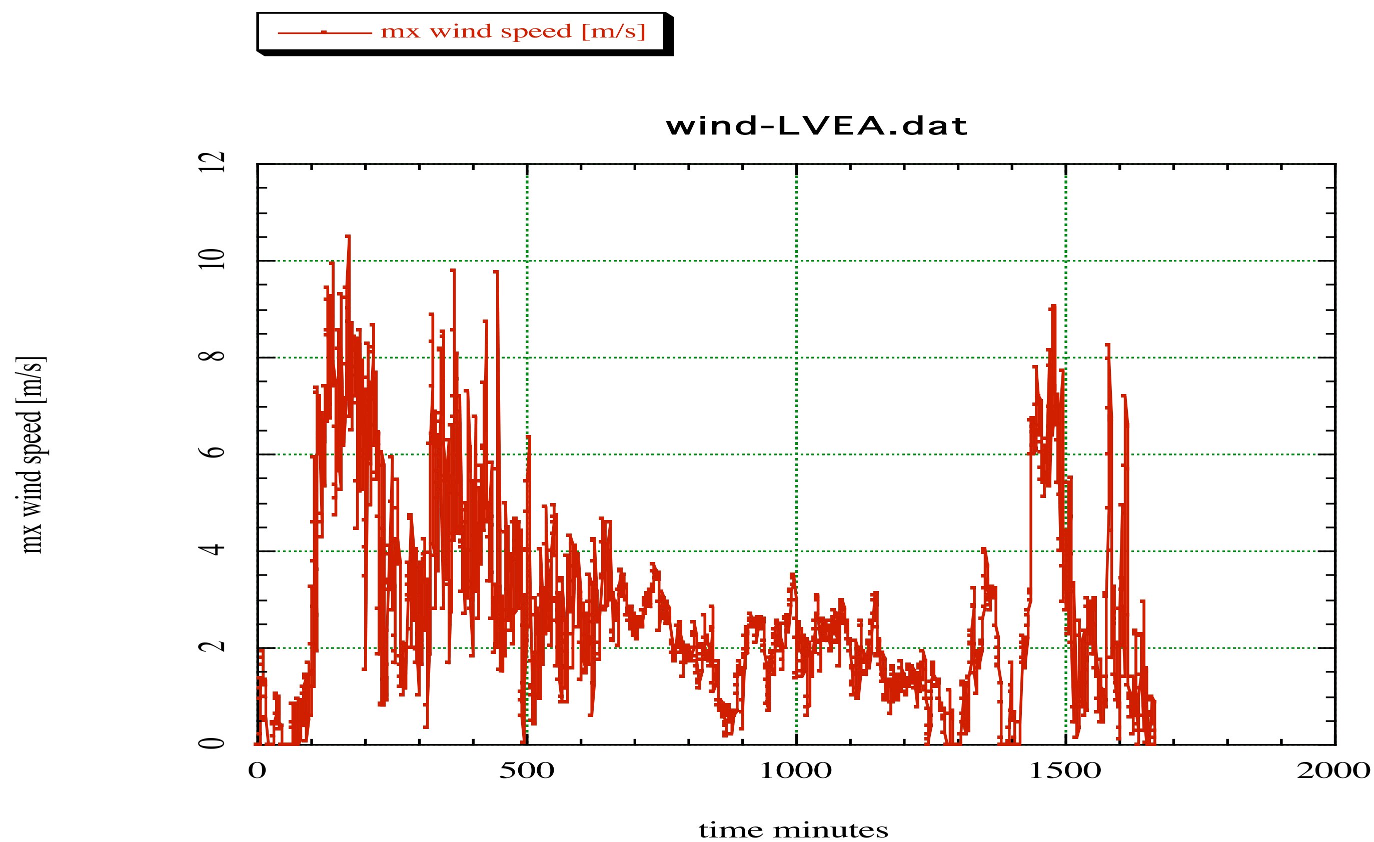


Figure 12 Comparison of the low frequency seismic RMS minute trend (top) with the corresponding Mid X wind minute trend information (bottom). The correlation is also clearly observable.

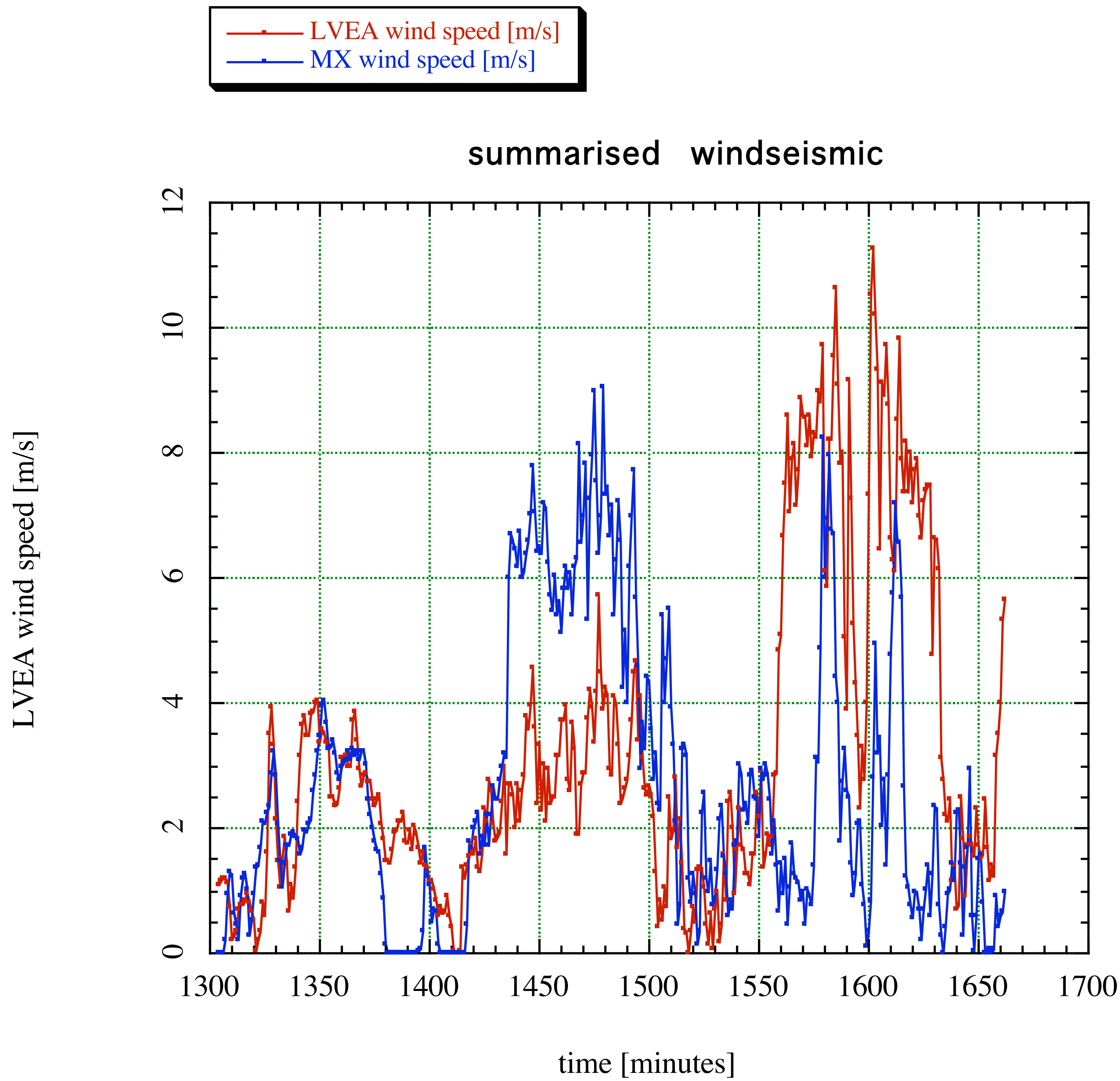


Figure 13 Note that despite the one minute averaging, the wind activity is not the same in LVEA and the middle station, as particularly evident between minutes 1500 and 1700.

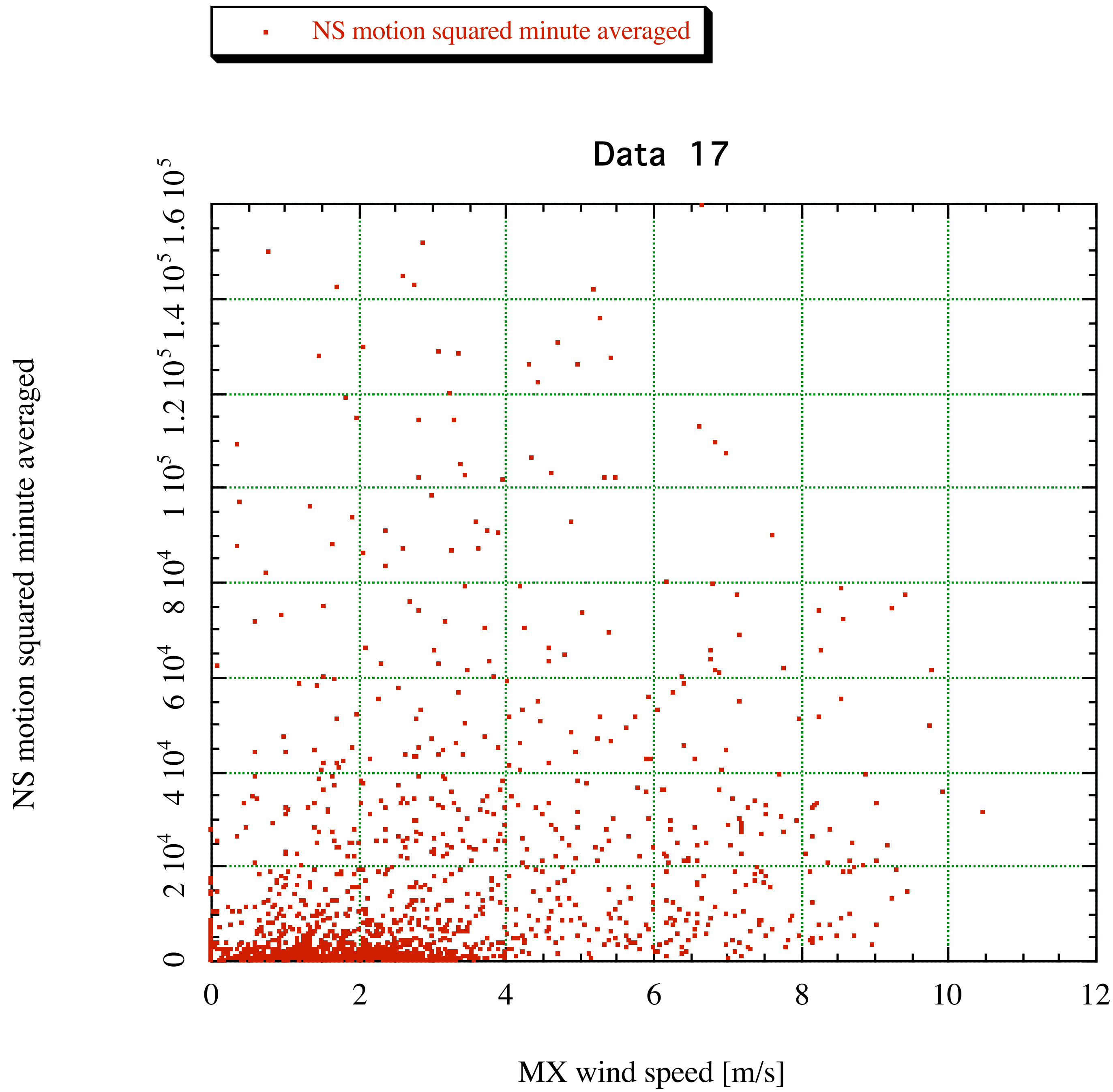


Figure 14 Correlation between Mid X wind speed and horizontal seismic motion far from the LIGO buildings. At low speed the wind shows little correlation with the seismic activity. Note though that above 4 m/s the seismic activity is always high. The transition is rather sharp. It is conceivable that the high seismic activity points for low wind speed may be attributed to local lulls of the wind (between gusts) at the weather stations with high winds closer to the seismometer.

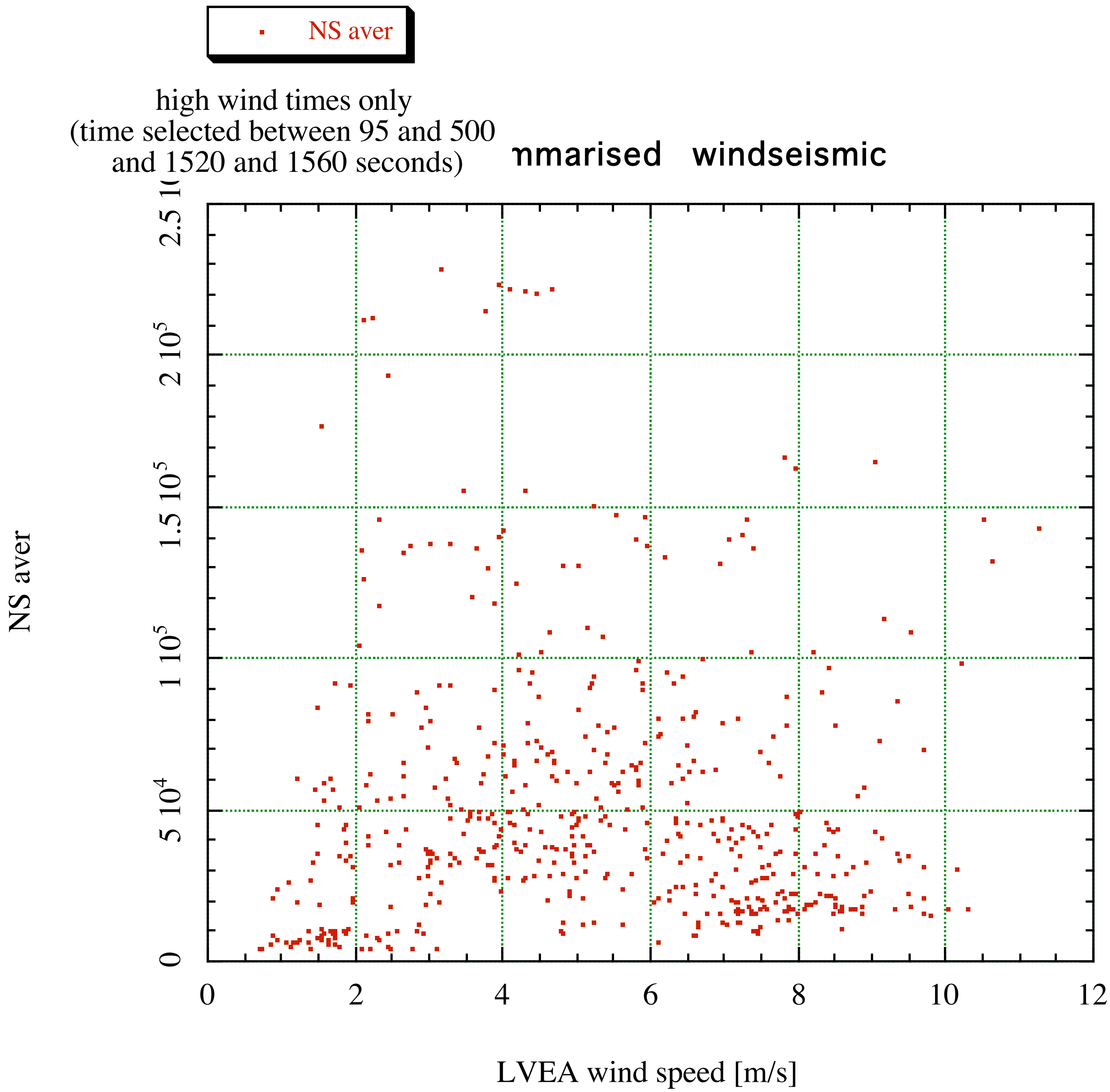


Figure 15 Correlation between the LVEA wind speed and horizontal seismic motion far from the LIGO buildings. Only periods of high wind activity were used! The low seismic activity cluster at the bottom left of the preceding graph practically disappeared.

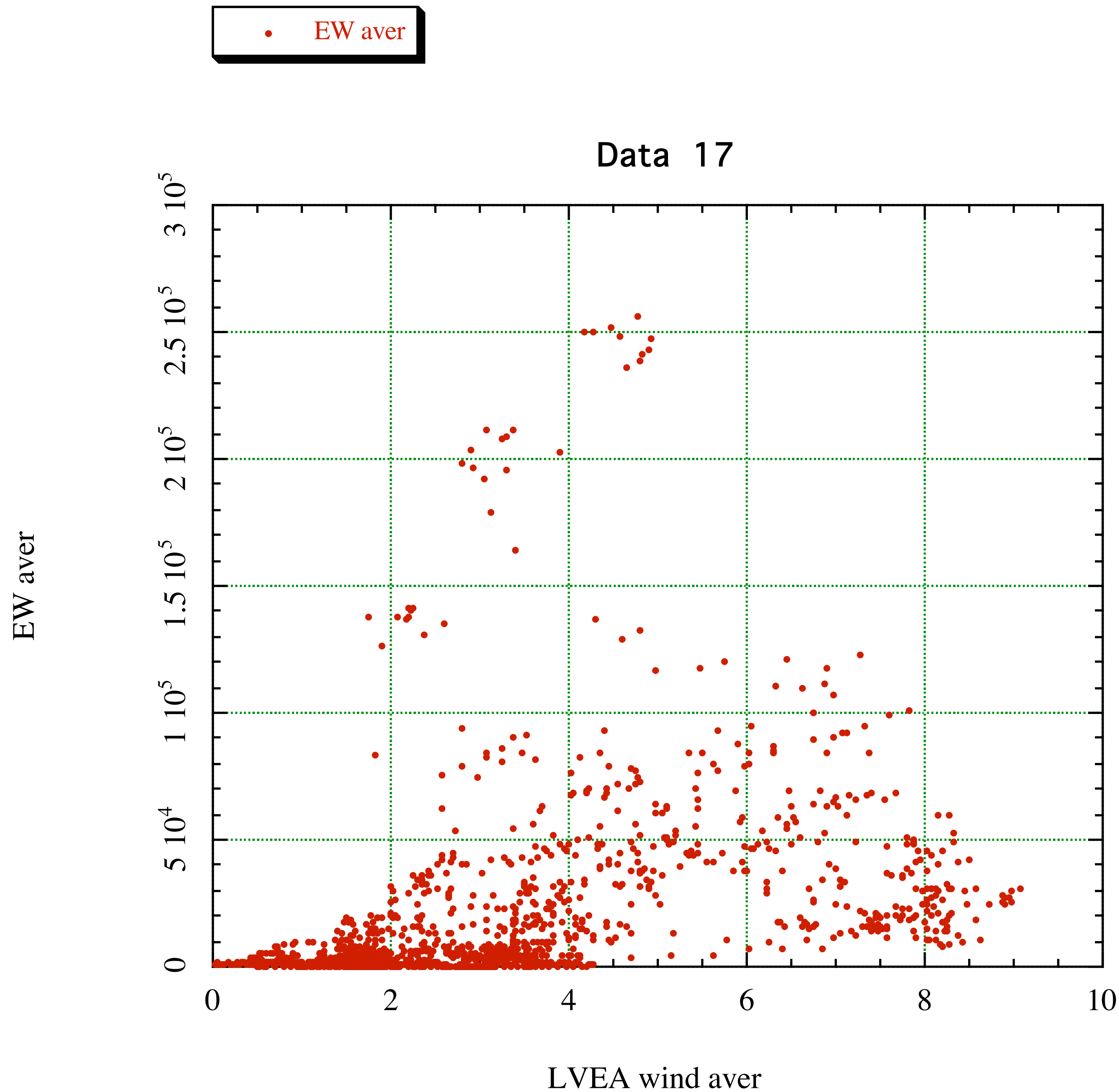


Figure 16 Correlation between the LVEA wind speed and East-West horizontal seismic motion far from the LIGO buildings. The correlation becomes more apparent after we increased the integration length to 10 minutes for the trends (averaging out gusts lulls).

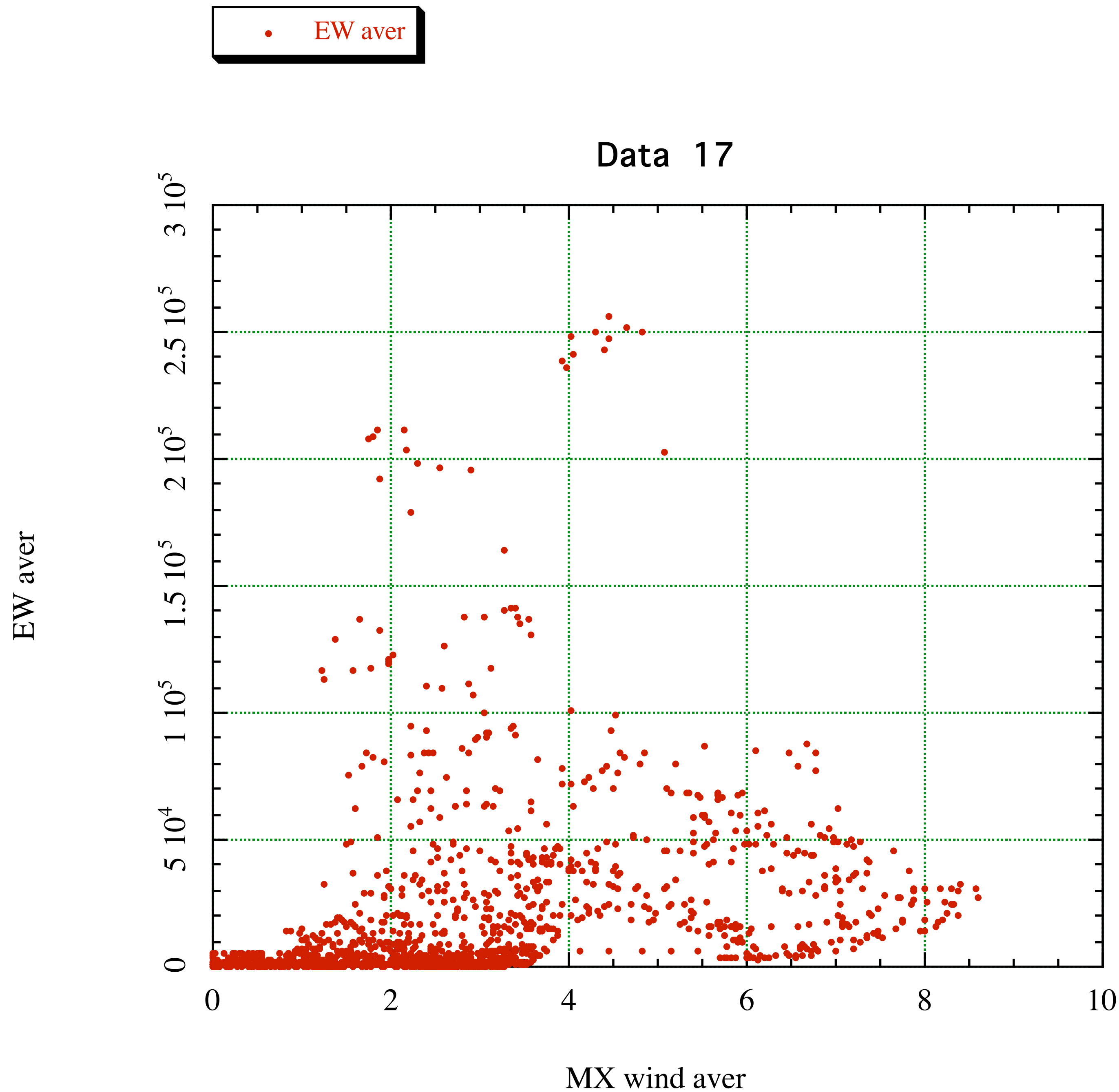


Figure 17 Correlation between the Mid X wind speed and East-West horizontal seismic motion far from the LIGO buildings. (10 minutes of integration time.)

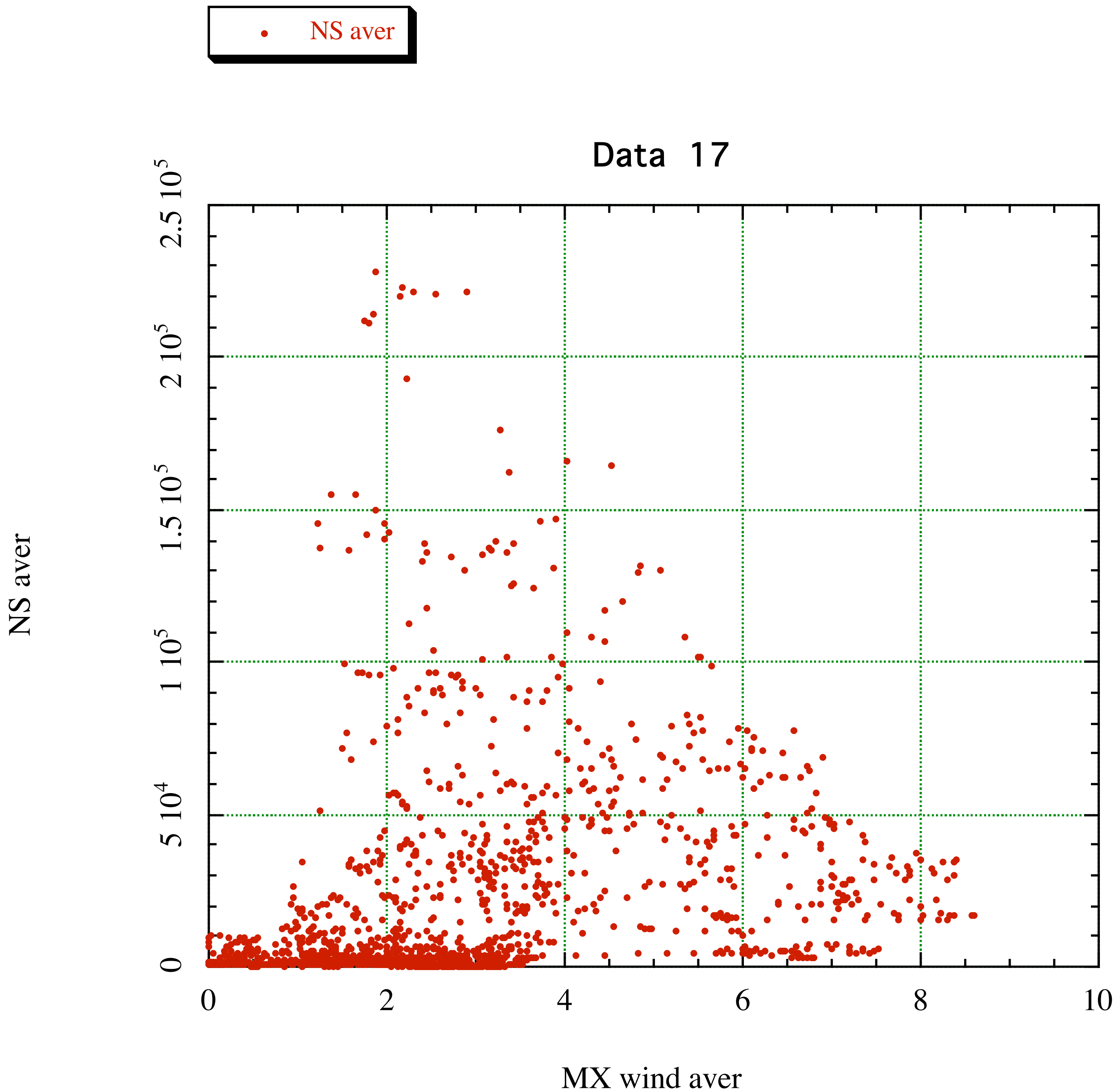


Figure 18 Correlation between the Mid X wind speed and North-South horizontal seismic motion far from the LIGO buildings. (10 minutes of integration time.)

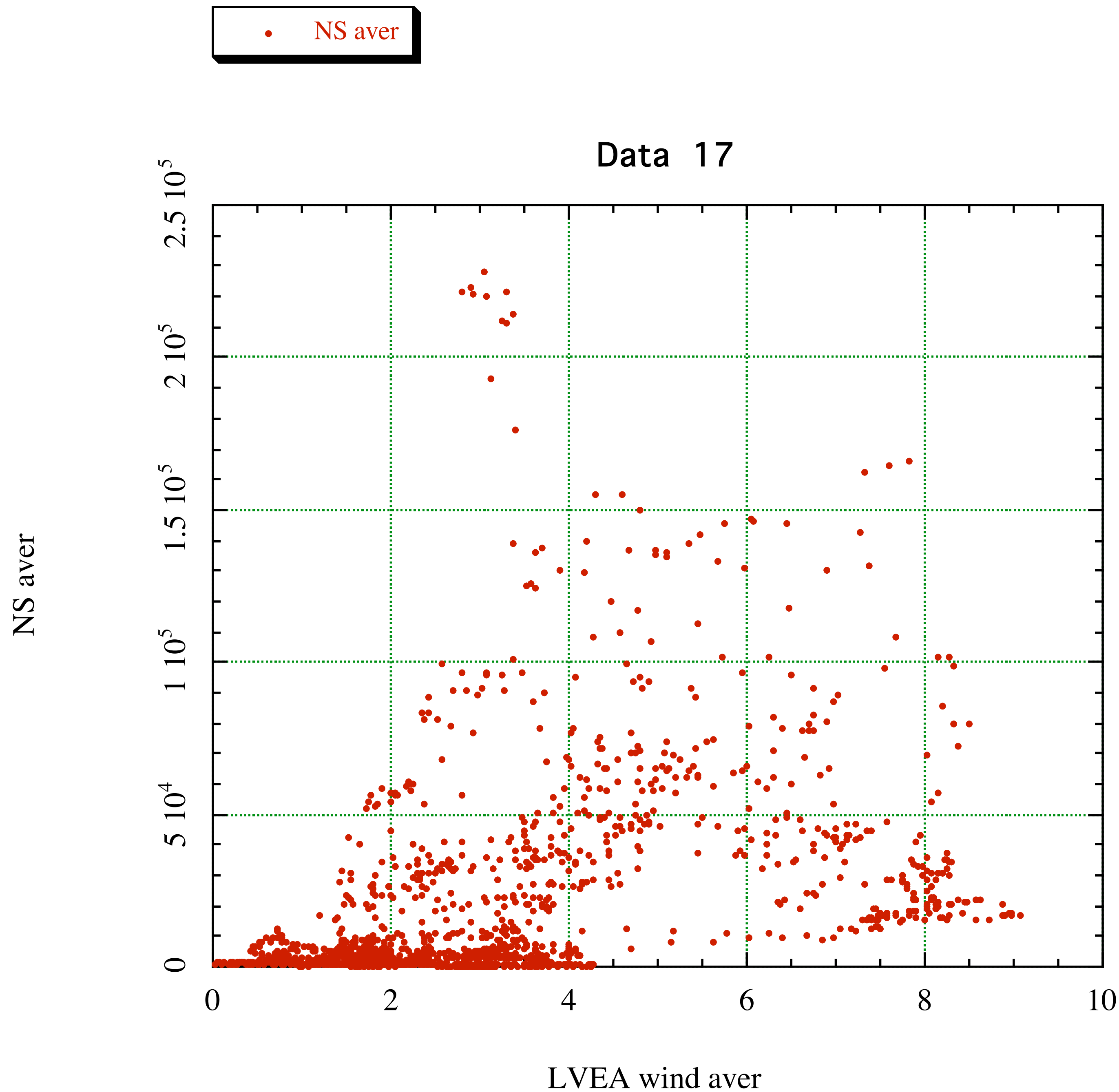


Figure 19 Correlation between the LVEA wind speed and North-South horizontal seismic motion far from the LIGO buildings. (10 minutes of integration time.)

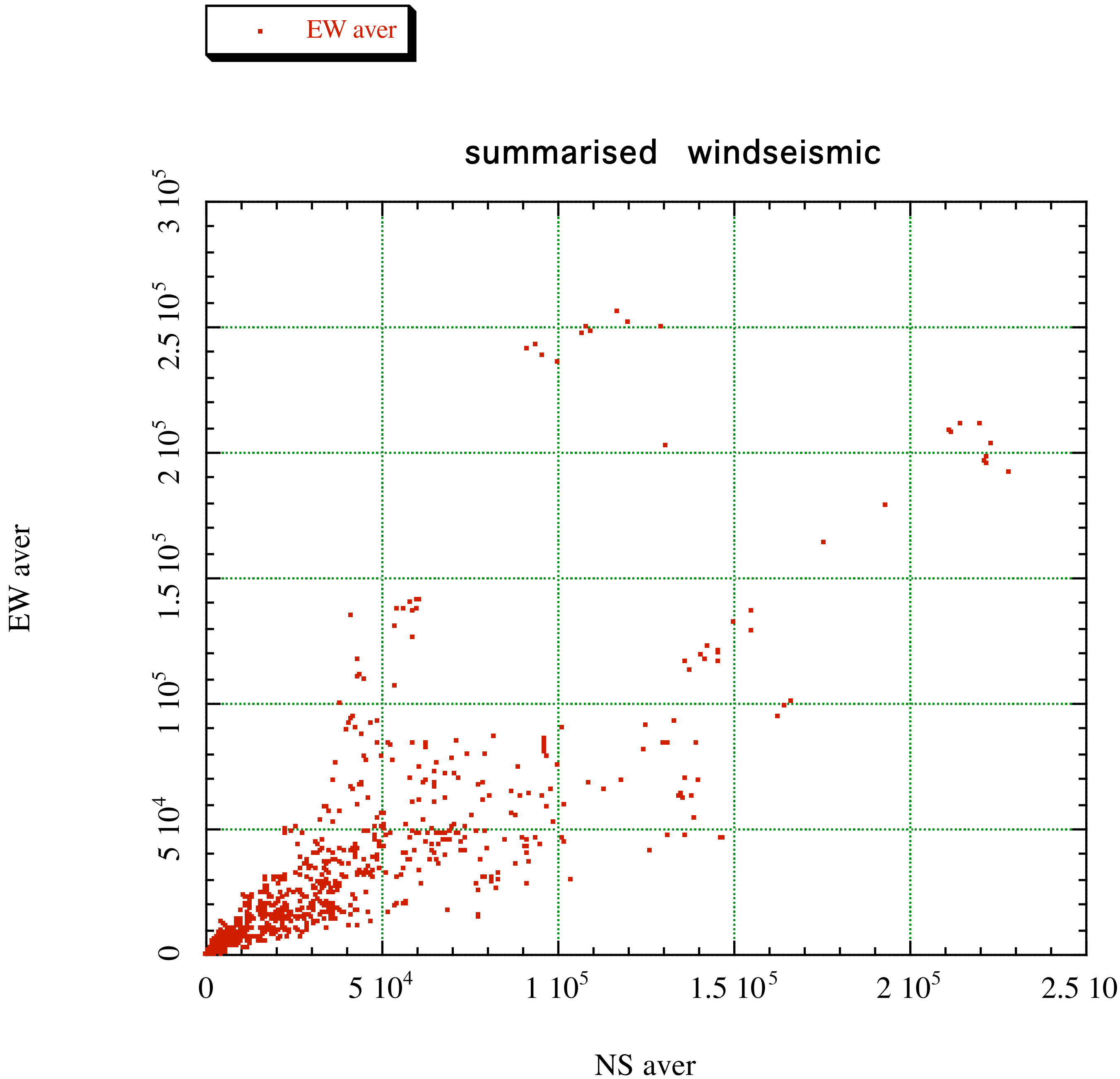


Figure 20 Correlation between the East-West and North-South horizontal seismic motion far from the LIGO buildings. Note that the seismic activity in both directions is strongly correlated (in overall intensity averaged over 10 minutes).

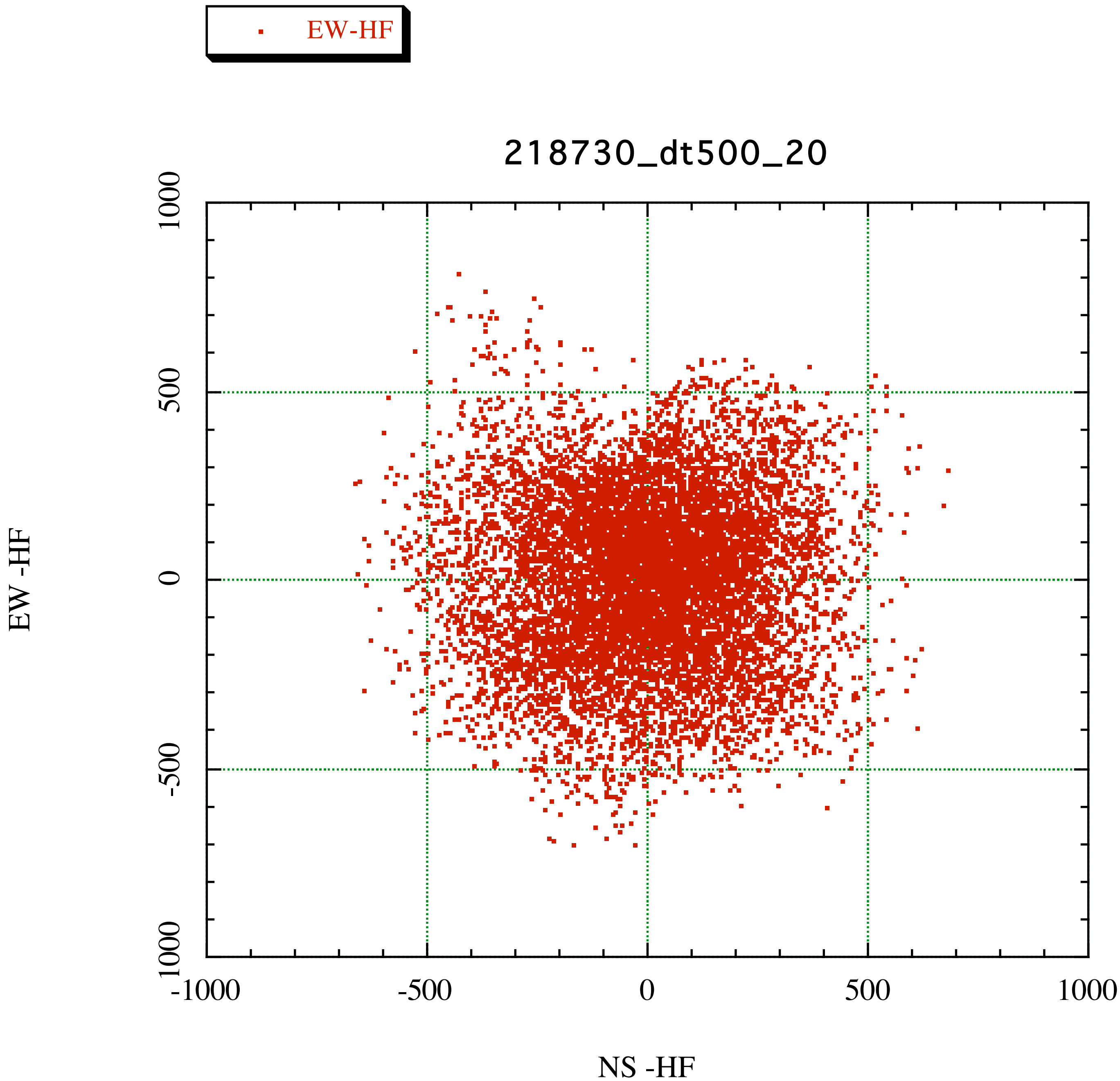
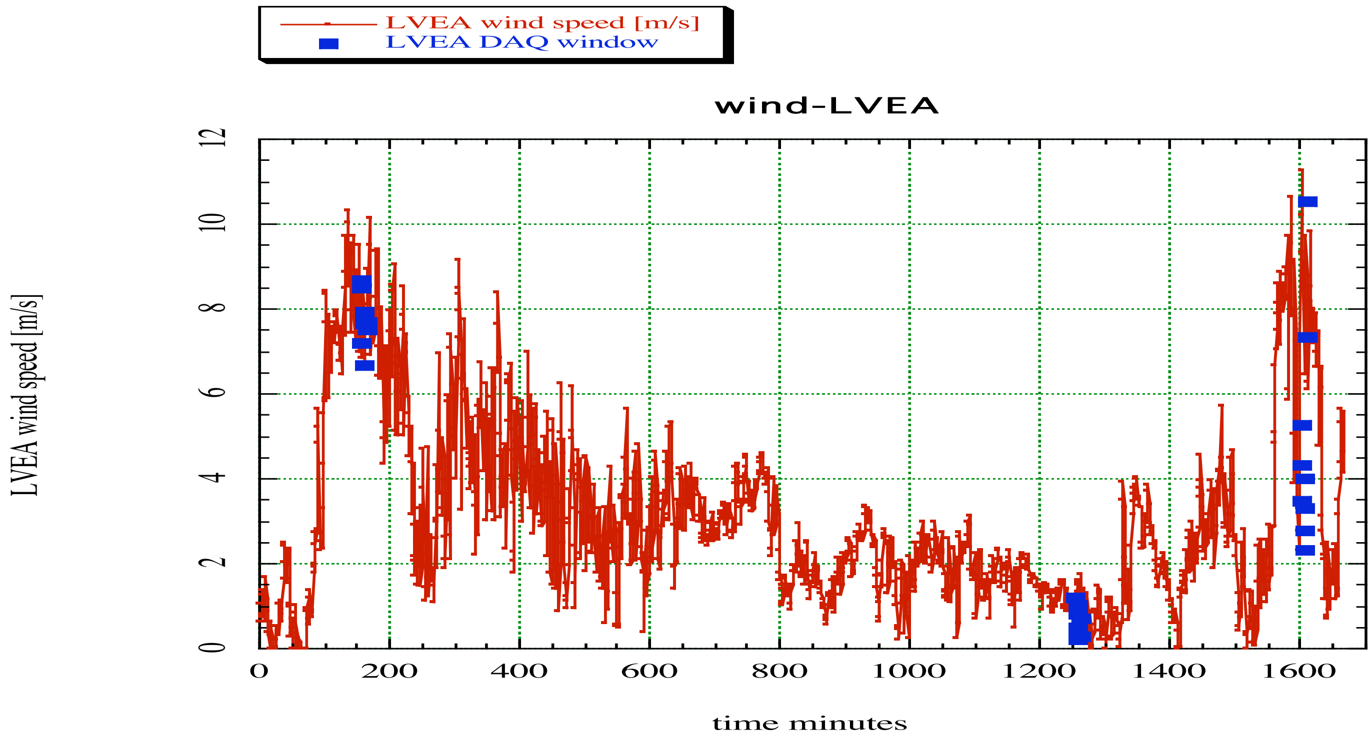


Figure 21 Correlation between the raw data values from the East-West and North-South horizontal seismic axes. We cannot observe significant correlation.

Comparison of low and high wind speed regions

Data was recorder at 20 Hz over three stretches of 500 seconds. We selected periods of different wind activity shown in the following figures.



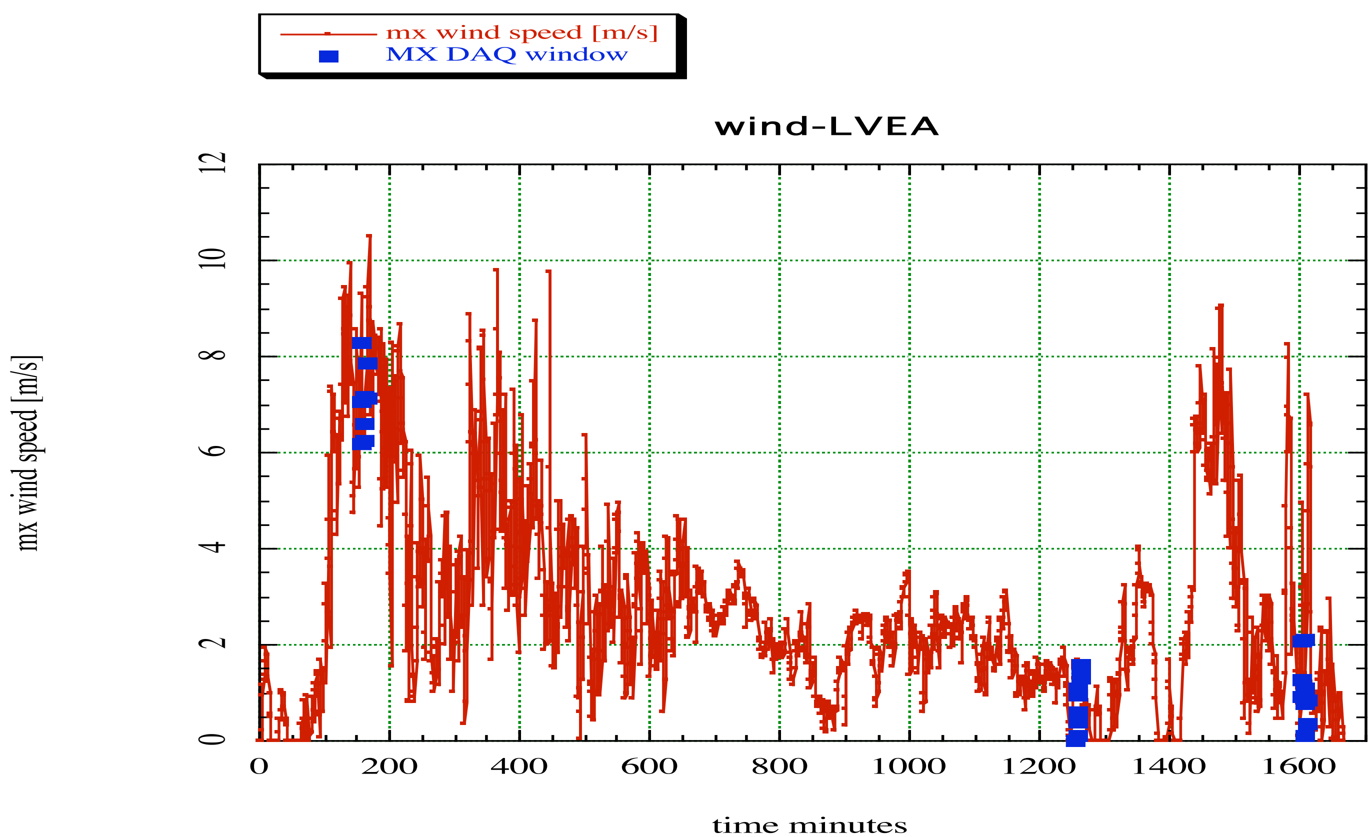


Figure 22 Location of selected high/low/high wind regions (blue sqares/ three regions).

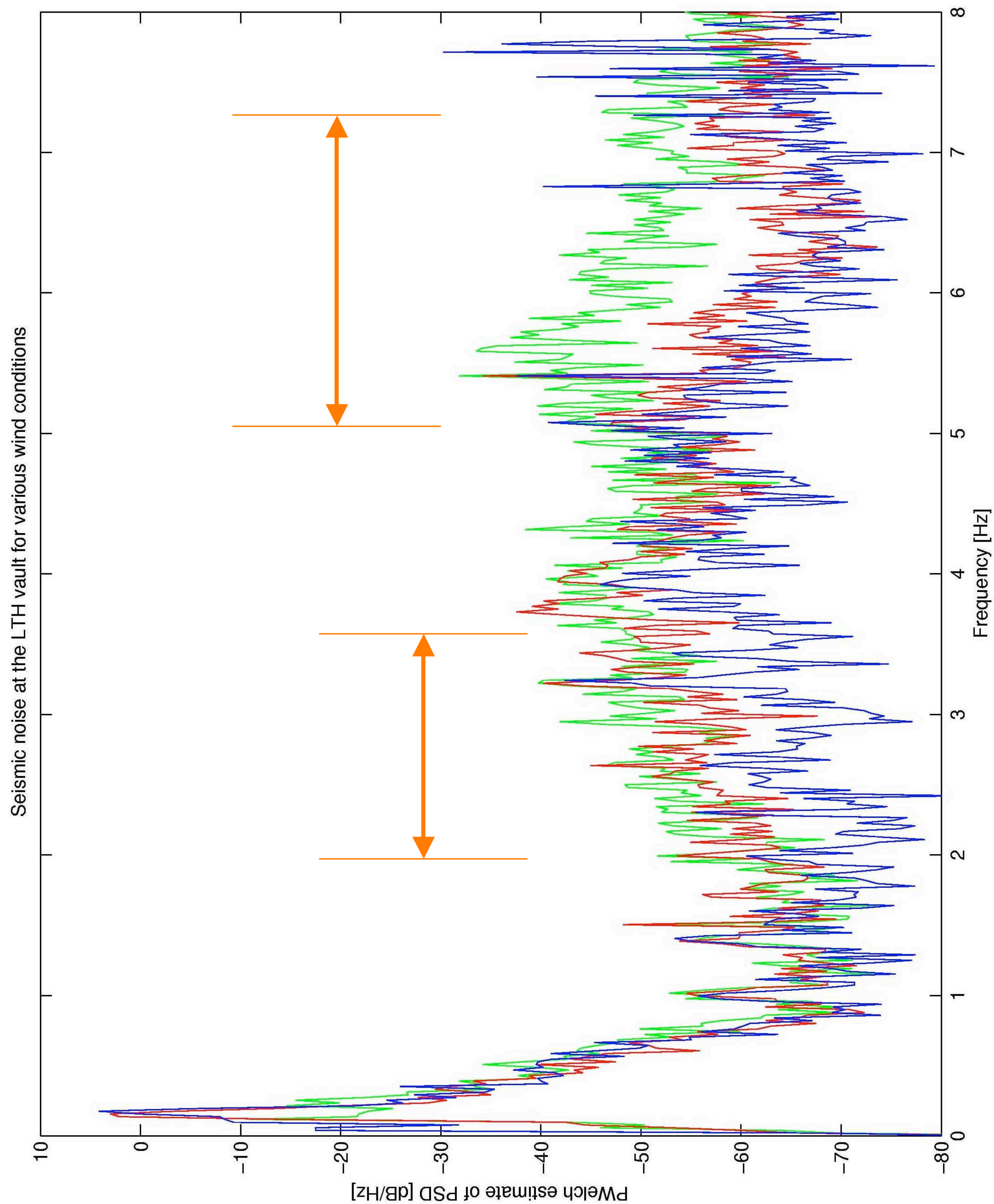
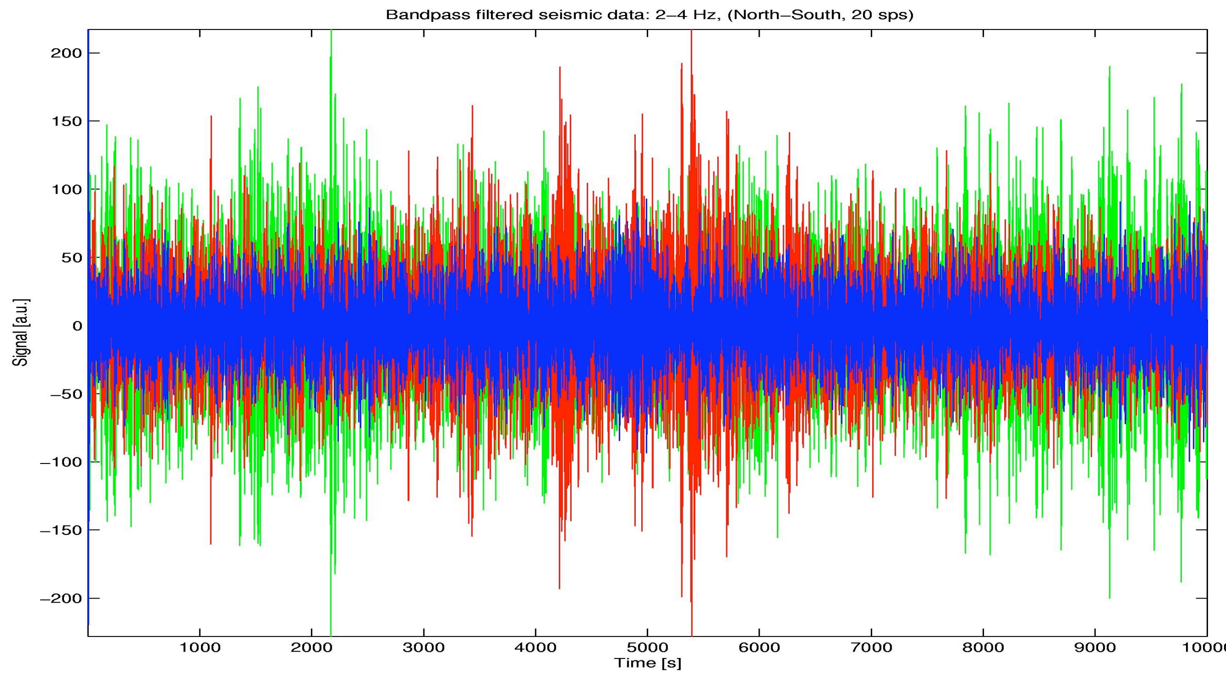


Figure 23 Seismic spectra for the three selected regions. The blue corresponds to the quiet interval at 1300 minutes while the green and the red correspond to the intervals at 170 and 1600 minutes. Most extra seismic power seems to be concentrated in the 2-4 Hz and 5-7 Hz regions as shown by the spectral analysis.



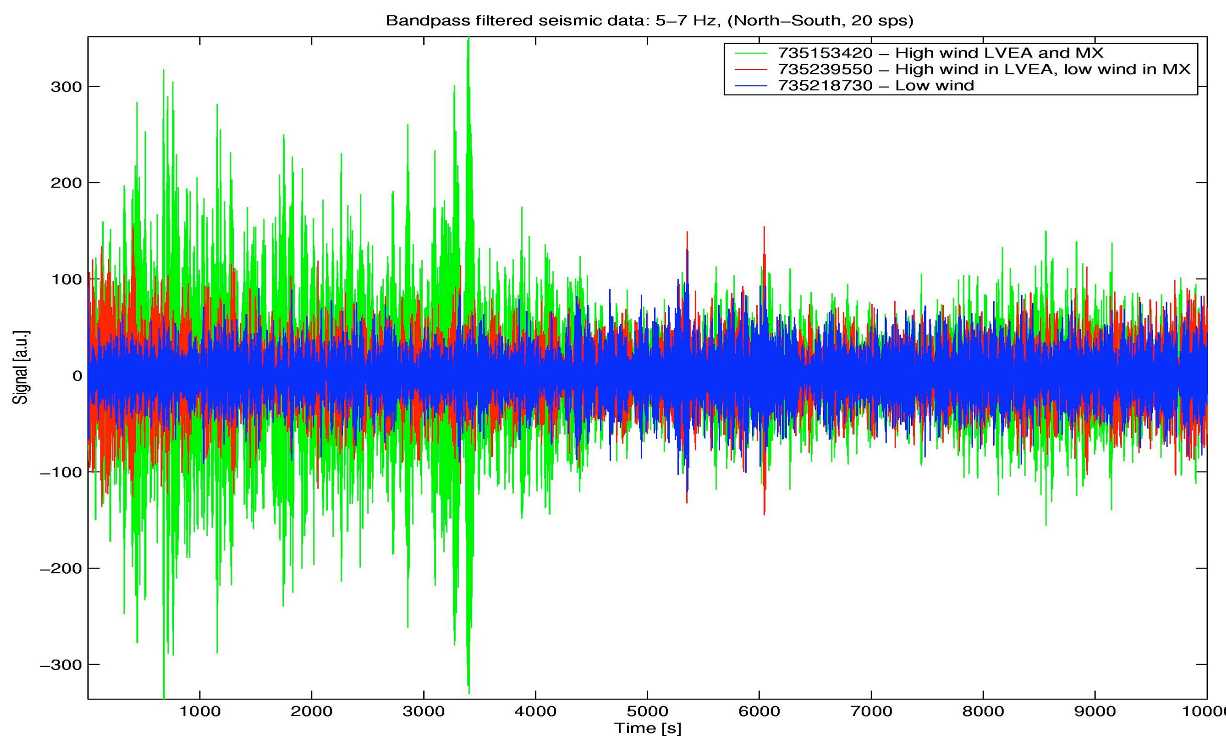


Figure 24 Filtered time series for the three selected regions. The extra seismic power seems to be concentrated in the 2-4 Hz (top) and 5-7 Hz (bottom) regions. Observe the relative non-stationarity of the traces associated with high wind conditions.

Discussion

We were looking for interesting aspects of the wind to ground coupling, which can generate significant and disturbing seismic motion for LHO. It is also a follow up study, on how this coupling has a sharp threshold at a given wind speed, as observed by Joseph and Nergis.

As well known by anybody that has been sailing or lives on a plain, gentle breeze tends to be continuous, while higher winds come in gusts. A good skipper has to know how to judge the creases of the surface to know where the best wind blows.

What happens is that gentle breezes flow mostly laminar and couple virtually no power and no, or in any case constant force on the ground. Above a critical speed the flow turns locally turbulent suddenly generating much larger grip on the surface (visible on the sea surface as creases). The destruction of the static surface laminar layer induces changes in grip of orders of magnitude. The local air mass is suddenly slowed down causing the air coming from behind to be rerouted around and further accelerate. It is a positive feedback mechanism that generates the wind gusts. As the sudden grip to the ground slows masses of air, it transfers some of its momentum to the ground, thus generating the coupling to seismic motion. The phenomenon comes in many different sizes, typical wind gust variation distances of tens to hundreds of meters are often observed, as well known by skippers at sea.

The onset of wind gusts can thus explain the threshold at roughly 10 m/s of wind generated seismic activity observed both in these measurement and in G000088-00.pdf.

This is also in qualitative accord with the observed variations between our weather stations. The duration of the turbulent events (that are also dragged along by the wind) also have different scales, typically seconds, but occasional lasting up to minutes for the largest ones, as observed in the turbulence curls left behind by airliners.

It appears then that the process generating wind gusts may be a possible mechanism to couple wind to seismic motion and it might be able to explain the observed behavior. Although man made structures (the buildings) may lower the wind turbulence threshold, the observations of seismic activity on the far seismometer does not seem to indicate that this is an important factor.

Conclusions

The seismic activity induced by the wind appears to be directly coupled to the ground. There is no strong evidence that it is particularly exacerbated around the building structures. The intensity of the observed seismic activity at the seismic station seems to be correlated to the wind speed in either the LVEA or the X Mid Station anemometers on the 10 minute integration scale, and much more weakly correlated for lower integration times, as can be expected from a diffused source.
A possible guess of the observed threshold over 5 to 10 m/s is that at that speed the wind may switch from laminar to turbulent flow, thus increasing by orders of magnitudes its drag coefficient to the ground and generating wind gusts.
It is also observed that the wind generated seismic activity injects substantial noise at frequencies in the 5 to 8 Hz region.

For further studies, if deemed necessary, it could be useful to temporarily mount a wind monitoring station near the isolated seismometer vault. New alignment, calibration and documentation for the existing stations could also help further studies.
The data suggests that, given the fact that the seismic activity seems to originate from direct coupling to the ground even in absence of buildings, any actions on the building themselves may do little to ease the LHO duty cycle and lock problem.
One sure solution would be to implement a suitable seismic attenuation stage on the piers.