November to February coastal damage

Nothing too unusual, but another wake up call.

Over the period between November 2007 and February 2008 Kosrae experienced high sea levels which caused severe flooding of coastal land and further coastal erosion, particularly along the southern coastline of Malem. This article attempts to answer questions relating to the wave and sea-level conditions that caused the damage and whether they were unusual. To answer this we have to a look at a number of components that cause high sea levels around Kosrae.

The most significant component of sea level is that of the astronomical tide, the actions of the moon and sun on water levels which are most commonly observed causing the daily rise and fall of water levels, and the Spring-Neap tidal cycle every two weeks. However, these astronomical influences also cause a number of other cycles that result in higher than normal tides most noticeably around December (November to February) and June (May to August) on Kosrae. This is because the diurnal (once daily) tide component is important on Kosrae (the reason why in each day one of the tide ranges is higher than the other). This tide component is largest in June and December around the summer and winter solstices when the sun's contribution is greatest. As astronomical tides can be predicted, these higher tides can be seen in Figure 1 which shows high and low tides between October 2007 and October 2008.

There are two further astronomical characteristics that are important in this discussion. Firstly there is the lunar cycle, known as the *lunar declinational cycle* which reaches a maximum twice every tropical month of 27.32 days when the moon is at its maximum angle (or declination) north of the equator and again at a maximum declination south of the equator. When the moon is at its maximum declination this causes higher tides on Kosrae. Secondly, due to the elliptical orbit of the moon around the earth every 27.5 days, there are times when the moon is closer to the earth than others. When the moon's orbit is at its closest point to the earth (once every 27.5 days), this is called the *lunar perigee*, and again results in higher tide levels.

When Spring tides coincide with, or are close to, the time when the moon is in perigee and / or at its maximum lunar declination, high spring tides can be quite a bit higher than normal (often known as *King Tides*). Figure 2 shows the tides heights between November 2007 and March 2008, with the times of the maximum lunar declination and lunar perigee marked. It can be seen that these times coincide with high Spring tides, particularly in November and December, a little less so in February and March. One final factor, like the moon around the earth, the movement of the earth around the sun also follows an elliptical path, with the closest point between the earth and sun (known as the *perihelion*) occurring on 2 January 2008 – again exacerbating tide heights slightly. Whilst the combination of astronomical forcings has not quite produced the highest astronomical tides possible on Kosrae, the tides experienced in November and December are likely to have been around the highest 2-3% of all astronomical tides.

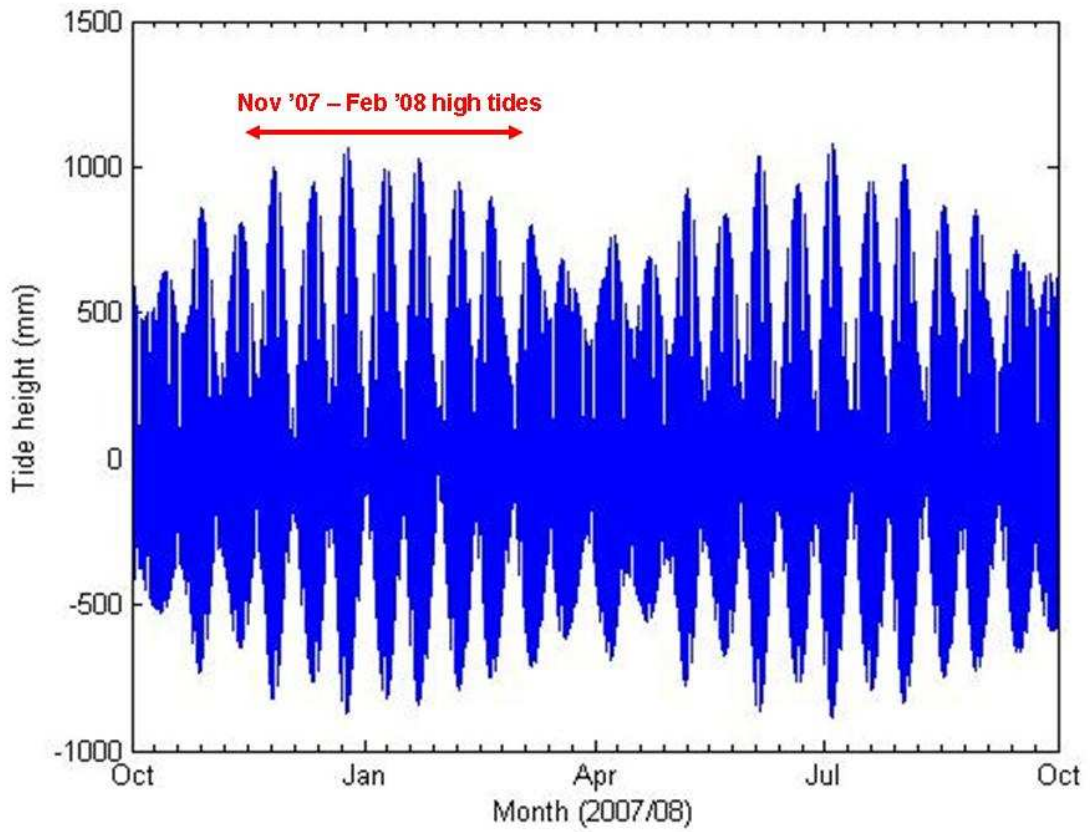

Figure 1: Predicted high and low tides between October 2007 and October 2008.

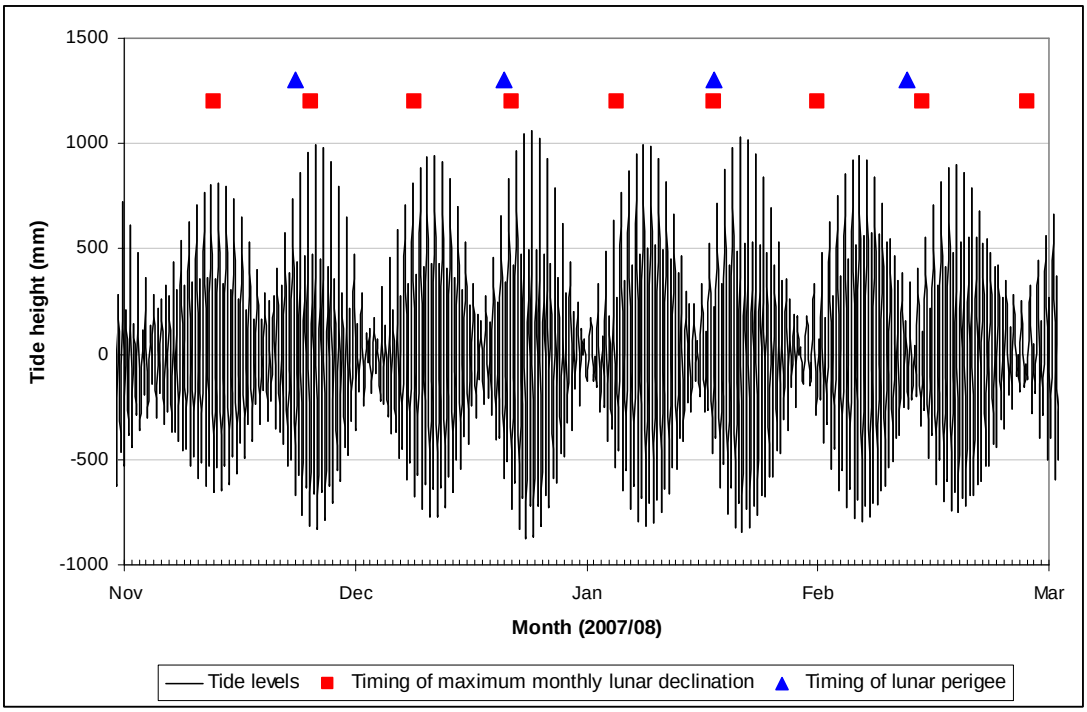

Figure 2: Predicted high and low tides between November 2007 and March 2008 showing also the timing of the maximum lunar declination and lunar perigee.

However, there are also a number of other factors at play. Firstly tides tend to be higher between November and April due to the sustained trade winds from the north-east which tends to push water up higher in the Western Pacific. Secondly the effect of the strong La Nina that has been occurring over the Pacific for much of 2007 and 2008 is also playing a significant role at present. During phases of El Niño, sea levels around Kosrae tend to be depressed. The opposite occurs during La Nina phases when sea levels tend to be elevated. The difference in sea level in the Kosrae region between a strong El Niño and La Nina can be as much as 0.25 m (10 inches).

The last time we had strong La Nina conditions was in late 1999/early 2000 when high tides caused flooding and damage just before Christmas (22-23 December 1999) and a couple of months later over the 20-21 February 2000. However, it is possible that we may see more of these types of conditions over the next couple of decades than we perhaps have done over the last few decades. In addition to the cycle of El Niño/La Lina phases (El Niño Southern Oscillation or ENSO), there is another, longer period climate fluctuation that occurs in the Pacific known as the Pacific Decadal Oscillation, (PDO) - also known as the Interdecadal Pacific Oscillation. The PDO occurs over a timescale of 20 to 30 years, with one effect of it being to influence the occurrence and strengths of El Niño and La Nina conditions. Over the period between the late 1970s to the late 1990s we have been in a phase of the PDO where El Niño conditions have tended to be more common and stronger (hence a tendency for lower sea levels). The PDO now seems to have flipped out of this phase and in to one where La Nina conditions may now be more common and stronger than they have been for the 20 to 30 years up to the end of the last century. This is primarily why sea levels may have appeared to have been higher over the last few years than they have been over the latter part of the last century. It is also means that we are possibly going to see conditions such as those that have occurred between November and February more often round these months over the next 10 to 20 years (irrespective of any effects of climate change induced sea-level rise).

So far we have only talked about astronomical tide and large scale climate variability affects on sea level. The coastal damage that occurred may also be due to weather events, such as a storm, coinciding with these high sea level conditions. An assessment of wind conditions measured at the weather station on Kosrae (atmospheric pressure data was not available) and from the closest prediction point to Kosrae of the NOAA Wavewatch III wave model do not suggest that there were any significant storm events during the November to February period that coincided with the high tide conditions, and hence no significant storm surge. Figure 3 shows the wind speed and direction measured on Kosrae between November 2007 and March 2008. Wind speeds are generally less than 30 km/hr (moderate to fresh breeze) and typical of this time of year.

Figure 4 shows the comparison of wave height from the NOAA Wavewatch III model[1] and high tides during this period. This shows wave heights generally between 2 m to 2.5 m. Again this is fairly typical of wave conditions experienced off the north east coast of Kosrae during the trade wind season. A comparison of wave height over this period with a longer term dataset for the Kosrae region between 1986-1999 from the UK Meteorological Office wave model suggests there was a higher percentage of waves of between 2 to 2.5 m in height and less waves of between 1 to 2 m over this period, Figure 5 and 6. However, the difference does not look significant given that we would expect a higher frequency of wave conditions around this wave height over the trade wind season. During this period significant wave

[1] See http://polar.ncep.noaa.gov/waves/historic.html for an animation of wave conditions for each month.

heights are all less than 3 m suggesting no severe storm event, although significant wave heights in excess of 2 m have coincided with high spring tides particularly in November and February and from wave directions that will have affected the Malem coast.

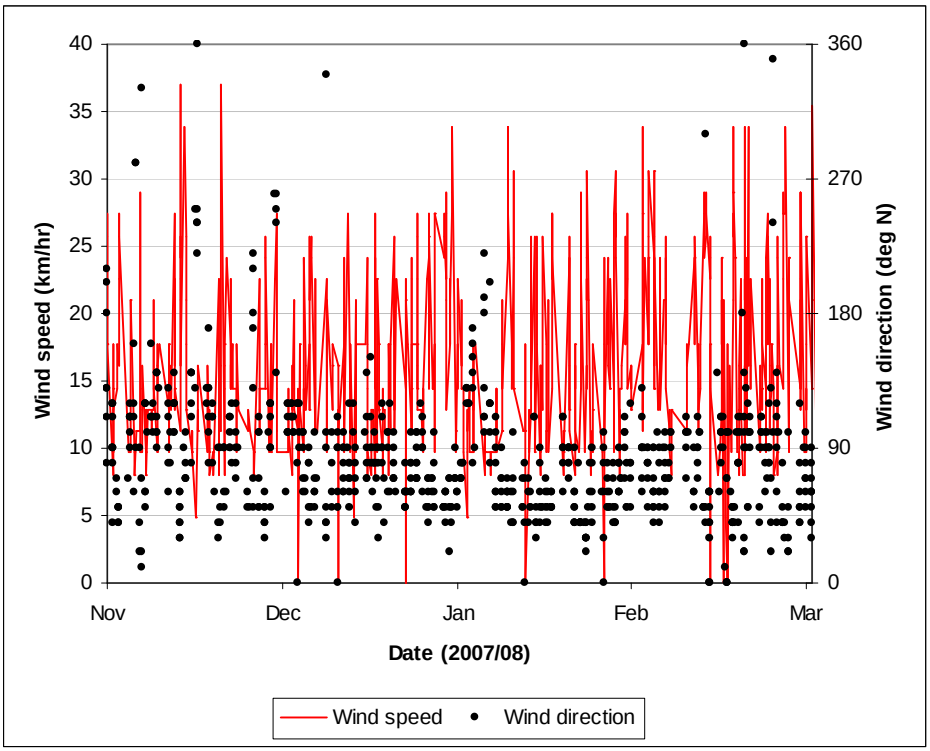

Figure 3: Measured wind speed and direction on Kosrae between November 2007 and Mar 2008 (Station 913560).

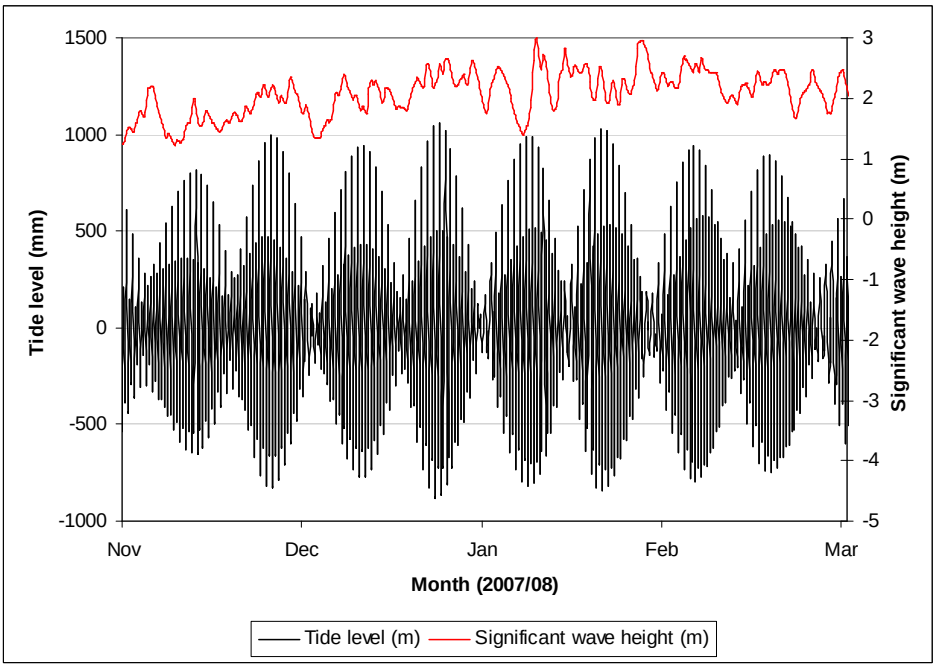

Figure 4: Comparison of high tide and wave conditions between November 2007 and February 2008.

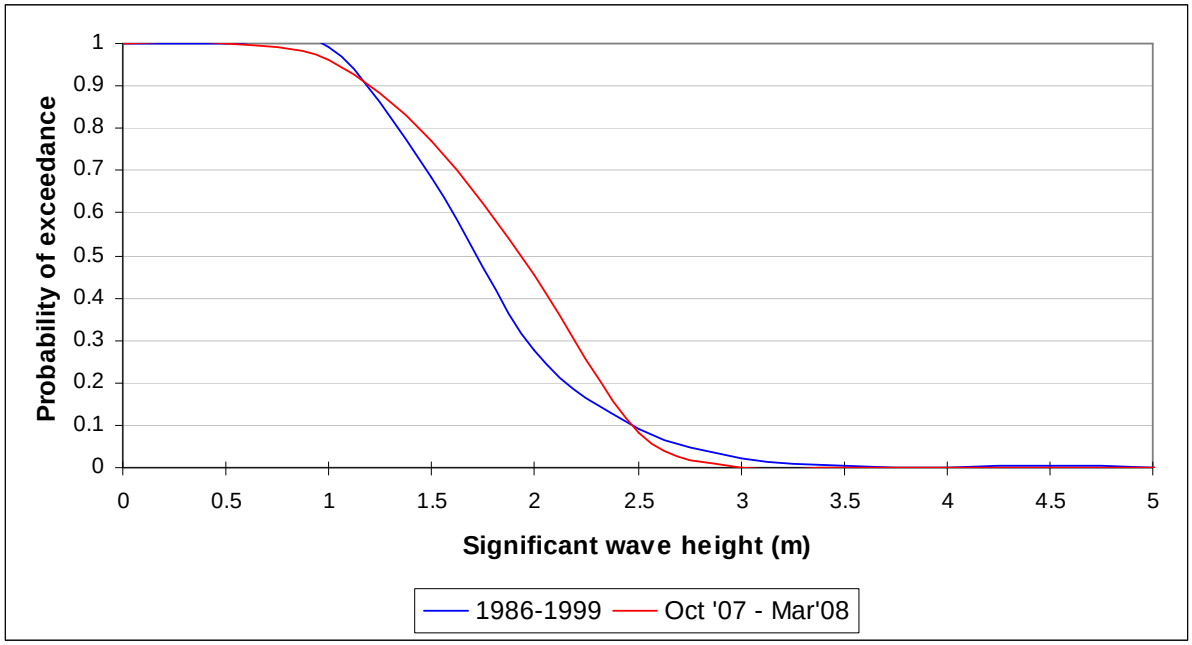

Figure 5: Comparison of the probability of exceedance of significant wave height between 1986 to 1999 (blue line) and the period between October 2007 to March 2008 (red line).

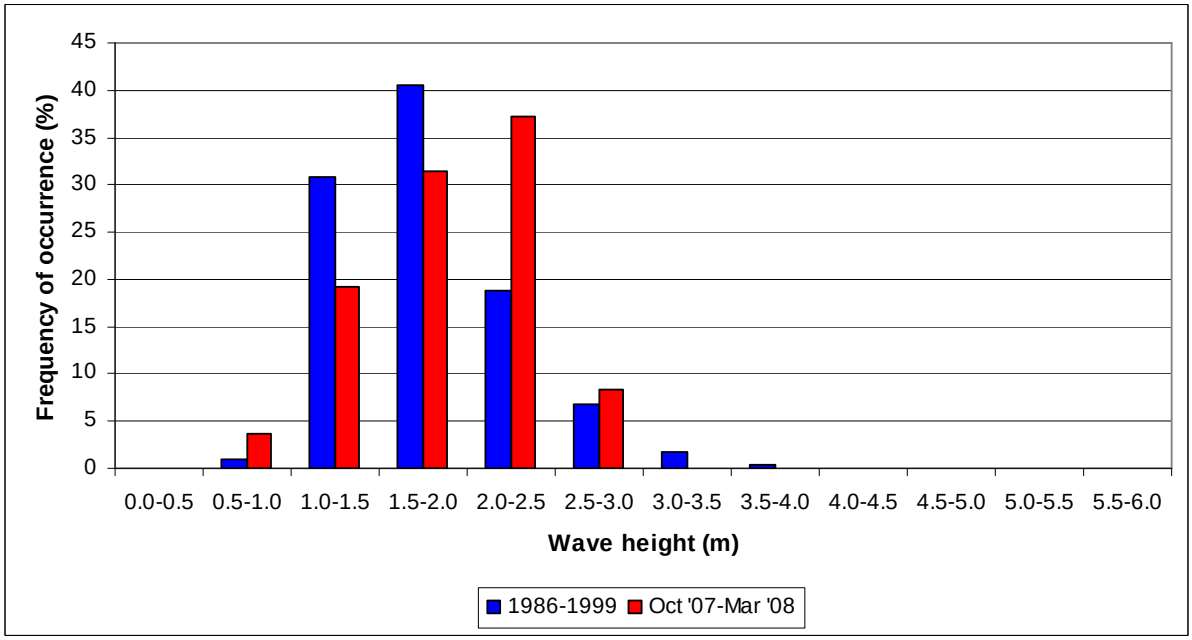

Figure 6: Comparison of the frequency of occurrence of significant wave height between 1986 to 1999 (blue line) and the period between October 2007 to March 2008.

Wave periods varied between approximately 6 s and 14 s, with wave direction dominantly from the north-east quadrant (larger swell events from the north), again all fairly typical for the trade wind season (see additional plots appended to this document).

The high water levels experienced result in less wave breaking on the edge of the fringing reef causing more wave energy reaching the shoreline at high tide. In turn his results in wave run-up and overwashing of the coastal land backing the beach, causing inundation, sand and coral rubble to be washed over land or the road.

This is a natural process and the process that has built the land upon which much property and the road is located. The height of this coastal land is closely related to the height that waves run-up and overwash, and typically about 2% to 4% of all wave conditions would be expected to naturally overwash in this way. However, there are areas on Kosrae which are more prone to overwashing or retreat of the beach under such conditions. One of the most at risk areas is the section of coast to the south of Malem (Fukrin/Kotfwa/Pal/Pukensukar area). In part this is due to the way that this section of the coast has evolved over the last 100 years or so, and in particular the influence of the longshore movement of sand and coral rubble southward along the coast. A significant influence is also the ongoing effect that the removal of large volumes of coral rubble from the reef flat along the Malem coast over the last 40 to 50 years has had – the detrimental effects of which will be ongoing for many years to come.

Conclusions

In summary the conditions experienced between November 2007 and February 2008 were not particularly unusual being a combination of:

- The high astronomical tides experienced at this time of year and a combination of astronomical factors that periodically increase tide heights.
- The north-east tradewinds
- The strong La Nina conditions that have prevailed over the Pacific region for much of 2007 and the early part of 2008.
- Moderately large (although normal for this time of year) wave conditions coinciding with these high tide levels.

Furthermore the conditions that occurred are likely to be typical of conditions that may be more commonly occurring over the next 10 to 20 years compared to the last few decades of the last century. Of course when events like this occur, climate change and sea-level rise are often blamed. Whilst sea levels globally have risen by an average of 0.17 m (±0.05 m) over the last 100 years, in the case of the conditions experienced on Kosrae between November and February these can be explained by natural processes and have very little to do with sea-level rise associated with climate change.

However, given that the conditions experience are not particularly unusual or extreme it highlights just how vulnerable much of the human development that has occurred over the last 50 or so years around the coast of Kosrae is. It would prudent over the next few decades to start reducing this vulnerability.

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May 2008

Additional wave analysis plots

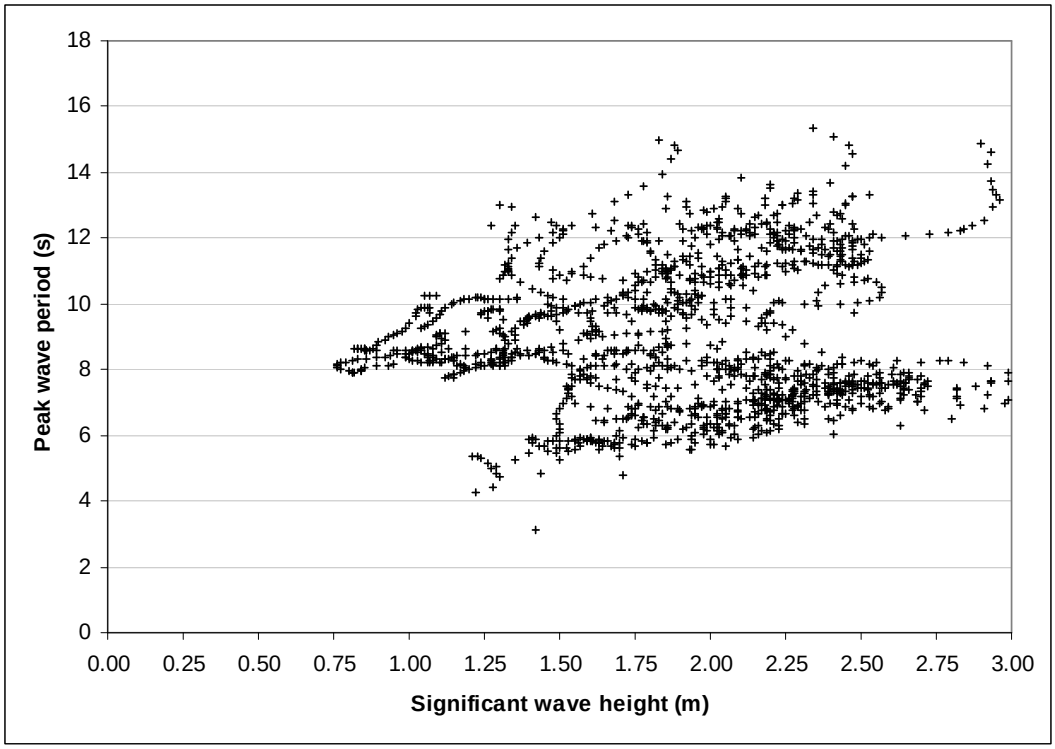

Figure 7: Comparison of significant wave height against wave period for the period between 1 October 2007 to 31 March 2008.

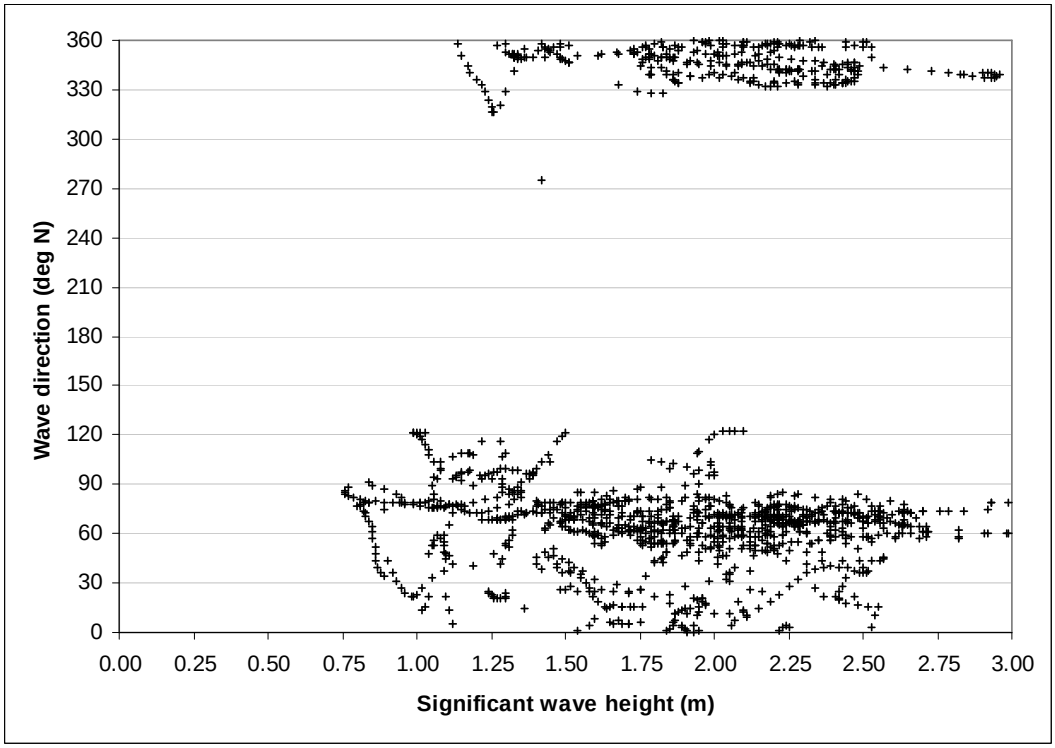

Figure 8: Comparison of significant wave height against wave direction for the period between 1 October 2007 to 31 March 2008.

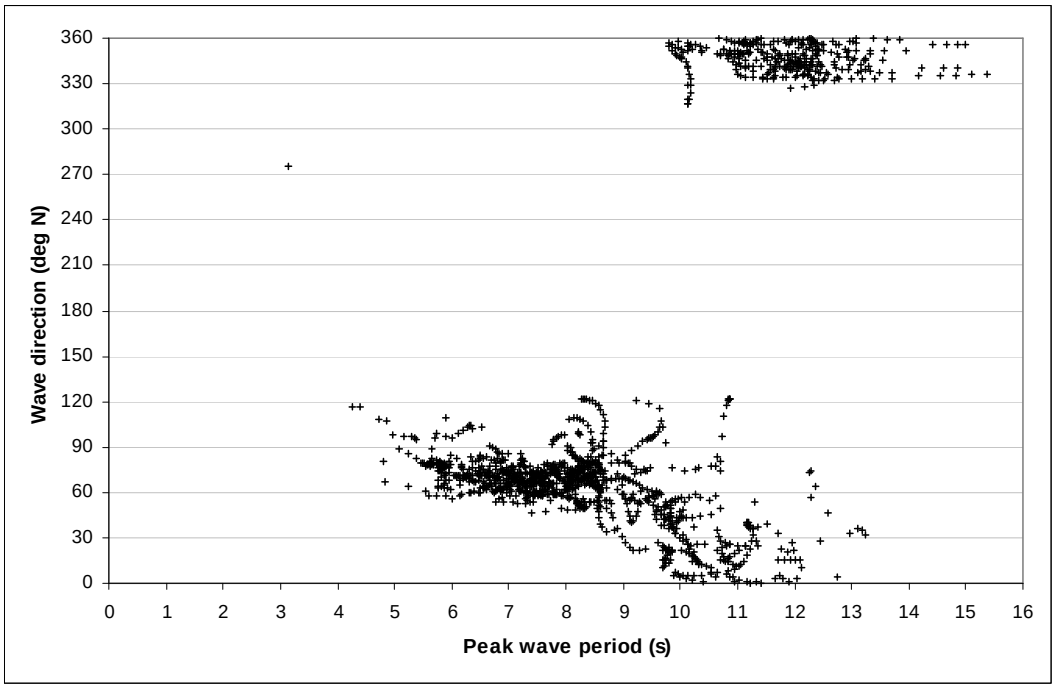

Figure 9: Comparison of peak wave period and wave direction for the period between 1 October 2007 to 31 March 2008.

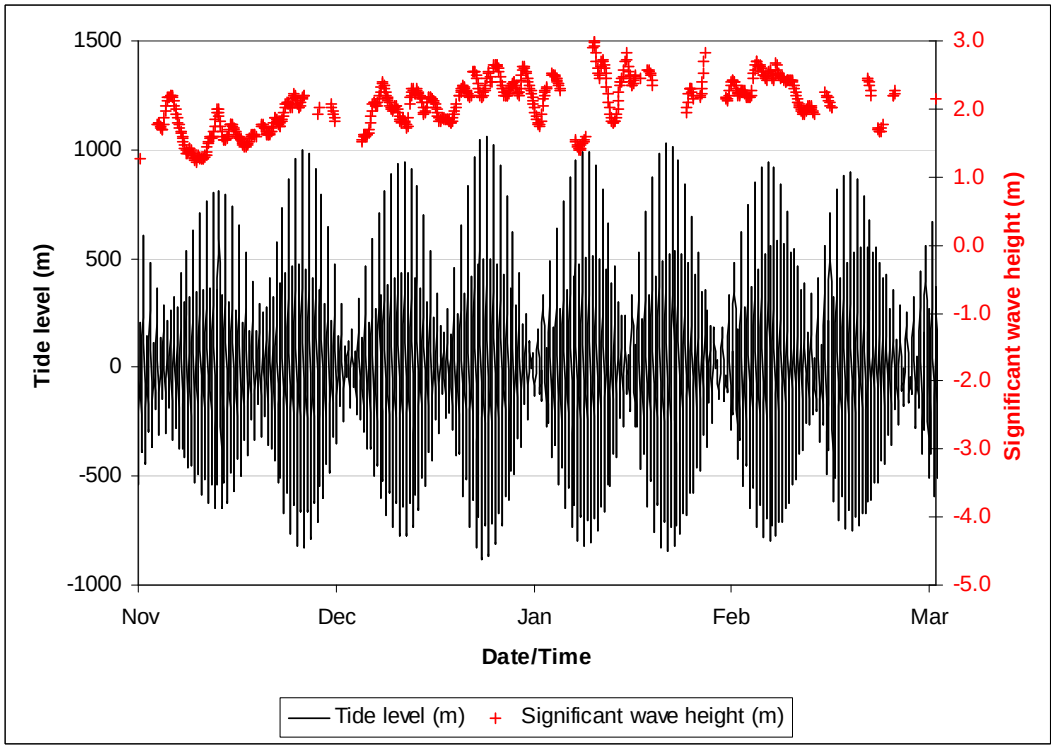

Figure 10: Comparison of high tide and wave conditions between November 2007 and February 2008 – as Figure 2 but only include waves from between 30 deg N and 130 deg N to reflect wave conditions affecting the Malem coast.