NSW Ocean Water Levels

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Manly Hydraulics Laboratory (MHL) has collected ocean water level and tide data on behalf of the Office of Environment and Heritage (OEH) for over 20 years, at over 20 key locations on the NSW coast. This provides a dense spatial distribution of ocean water level data over a sufficient period to allow detailed analysis of the tide and climatic influences on water levels. With the longstanding Fort Denison tide gauge (managed by Sydney Ports Authority) recording hourly tide data for over 90 years, sufficient context is provided to couch the OEH records within the context of long-term trends and cycles. OEH commissioned MHL to study and publish analysis on the tide climate and long-term trends in the data record, resulting in the report MHL1881 NSW Ocean Water Levels.

The published report provides essential information and analysis for planning on the NSW coast, and includes a detailed review of actual occurrences of tides, storm surge and long-term trends and cycles. This includes frequency distributions of measured levels and tidal anomalies, joint probability analysis, extreme value analysis and ranking of major events.

With sea level rise being an important consideration in current coastal planning practices, this was a key area of research for NSW. The Fort Denison record shows long-term sea level rise, but also significant oscillations that give rise to periods of no water level rise, and periods of accelerated sea level rise. Ultimately this demonstrates that records under 40 years cannot correctly represent sea level rise. However, the OEH record can be used to examine climatic effects on a decadal period. Correlations are shown between NSW water levels and the climatic indices Southern Oscillation Index and Interdecadal Pacific Oscillation.

This paper presents the key findings of the report and outlines some applications for communities on the NSW coast.

NSW Ocean Water Levels

Current discourse on ocean water levels is generally preoccupied with global average sea level rise. While this is important for assessing one aspect of climate change on a global scale, it is regional oceanic behaviour that directly impacts coastal communities, and is the main focus of our work in NSW.

Ocean water levels are influenced by a wide range of forces, from regular astronomical forcing, irregular meteorological-driven variability, long period oceanic and climate change effects. The analysis of these influences requires detailed monitoring over long periods.

NSW is blessed with both a dense coastal recording network – the Office of Environment and Heritage (OEH) tide network, operated by Manly Hydraulics Laboratory (MHL), and a long tide record – the Fort Denison tide gauge, managed by Sydney Ports Authority (SPA). The OEH network alone provides a rich data supply covering up to 25 years of data from ocean gauges, upstream sites, offshore island sites and submerged offshore recorders. The Fort Denison gauge provides a broader context for analysis of long-term trends and cycles.

A report developed by MHL and OEH aimed to use tidal data from the OEH network of tide gauges and other sources to determine, study and quantify the major influences on water levels in NSW. A detailed report was produced that will provide guideline values for planners, engineers, scientists and those involved in managing the NSW coastline, and is available from MHL.

This paper presents some of the analyses currently used to expand the knowledge of NSW water level activity. It aims to investigate long-term rates of sea level rise, as well as identify periods of unusually high storm activity, and demonstrate relationships with climatic indices. Short period anomaly drivers such as storm setup, coastally trapped waves, freshwater events and others are addressed in detail in MHL1881.

NSW Tide Network

The OEH Ocean Tide network consists of 21 gauges considered to have a clean tidal signal. We categorise these into groups according to the characteristics of the tide record: open ocean bays and ports (representative of the open ocean without freshwater influences and a stable datum), offshore ocean (bottom-mounted pressure sensors that accurately capture tidal action but do not have a persistent datum), island sites (open ocean sites that are well removed from the mainland) and river entrance sites (that are representative of ocean tides but may be flood-affected).

The tide climate of NSW is largely uniform, with a very slight increase in tidal range to the north of the state, as shown for the five open ocean gauges in Figure 1. Tidal ranges are determined from the four major tidal constituents (M2, S2, K1, O1) given by the harmonic analysis.

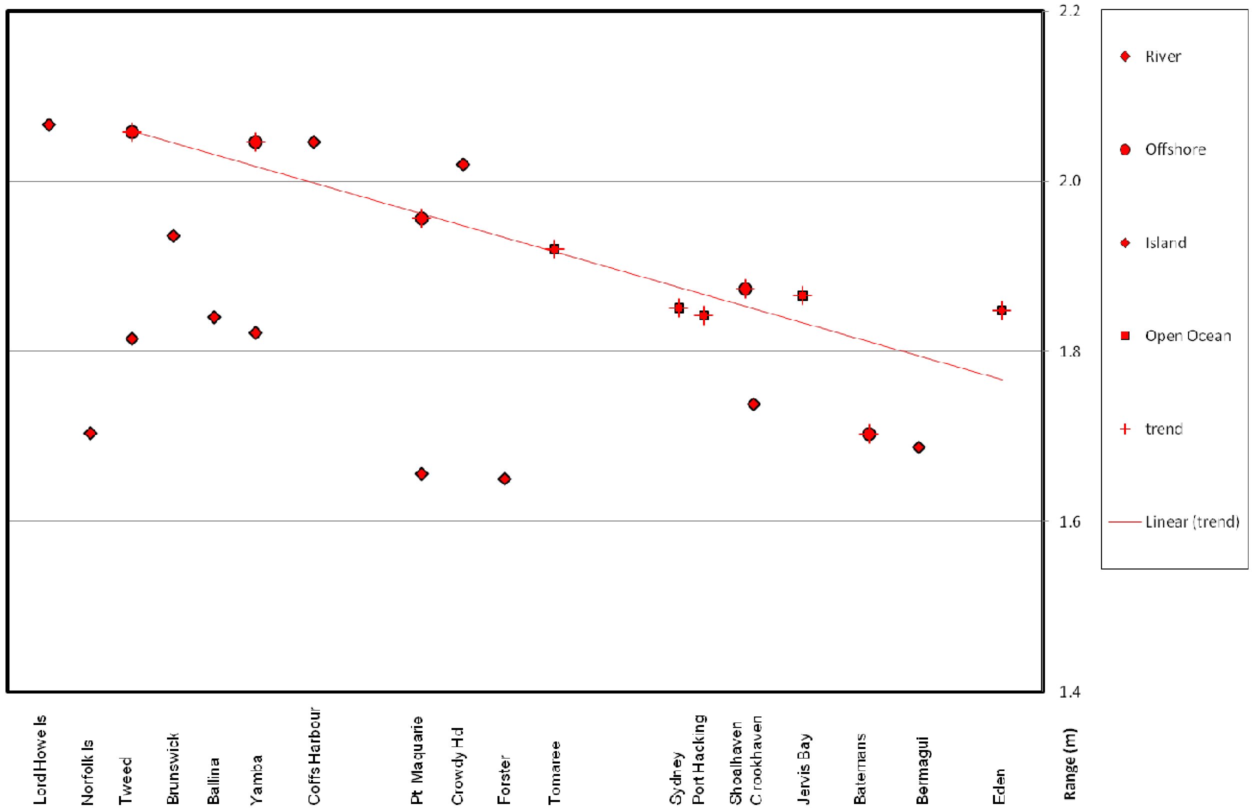

Figure 1 Total Ranges for OEH Gauges, with chainage of sites to scale along the coast. Total range is M2+S2+1.2*K1+1.2*O1. Open ocean and offshore sites give consistent tidal range results, with more variability from sites within river entrances.

Similarly, tidal anomalies are consistent across the state for ocean sites, with a slight trend for higher anomalies to the north. Some of the larger anomalies are recorded at flood-affected sites (such as Tweed Heads, Brunswick Heads, Port Macquarie, Crookhaven). This is shown in Figure 2.

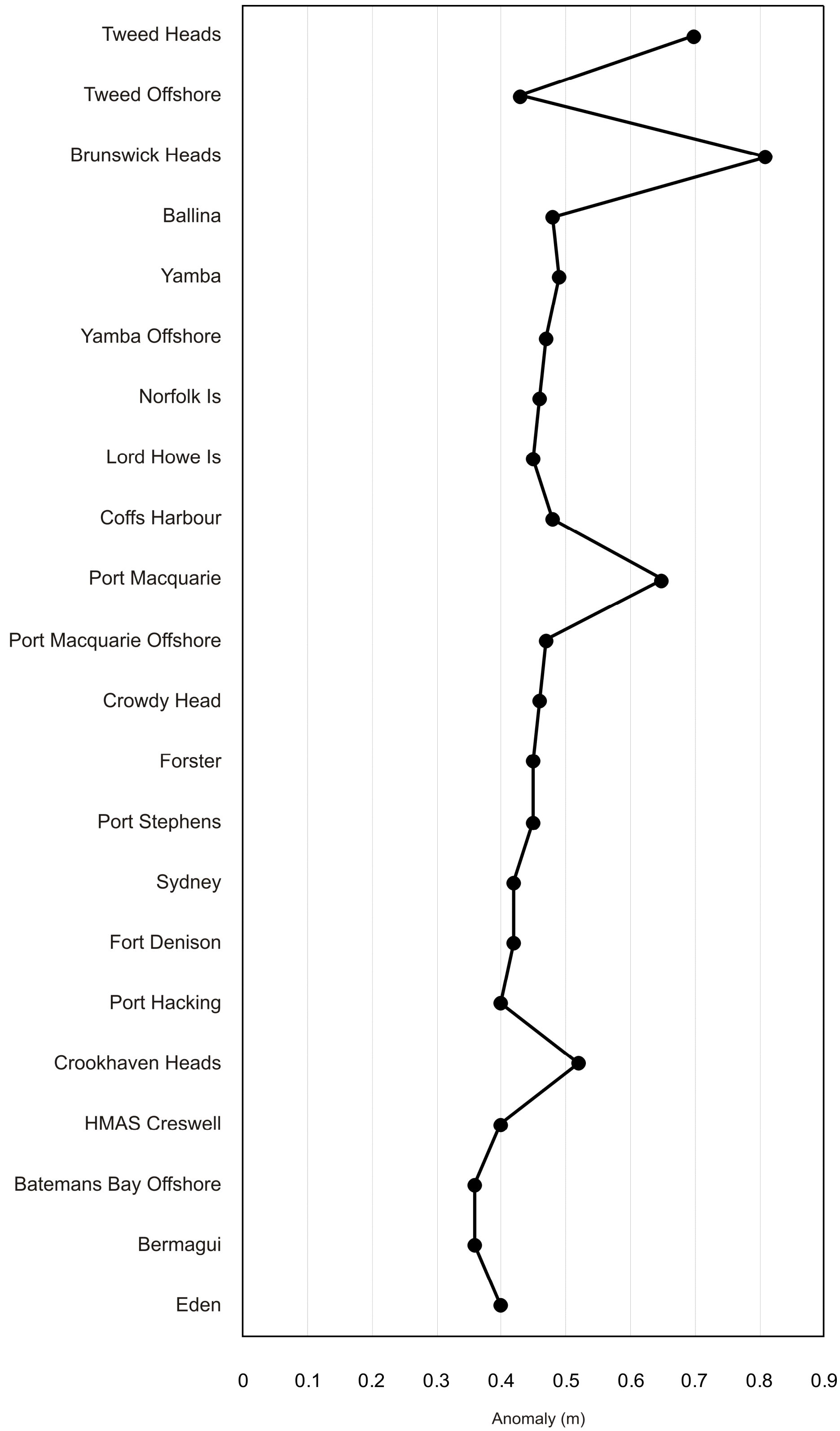

Figure 2 One-year annual occurrence of tidal anomalies for NSW tide gauges, with a slight increase towards the North. Sites with high anomalies are flood affected gauges.

Open ocean sites provide the most representative ocean tidal data and give the most robust analytical results for long-term water level behaviour. However, the lack of a suitable site to the north of Port Stephens leaves the north coast of NSW less well defined. A recent upgrade to 1-minute data logging has provided new insights into water level behavior at some sites. Coffs Harbour and Crowdy Head have both been known to have issues with seiching, as the gauges are located within a harbor. This leads to spurious anomaly peaks and a reduced accuracy in tide measurement and predictions. The 1-minute data now gives information about the seiching such as period, amplitude at the gauge, and the ability to correlate the seiche to particular ocean conditions. And it allows us to clearly resolve the tide signal from the tide gauge record as seen in Figure 3.

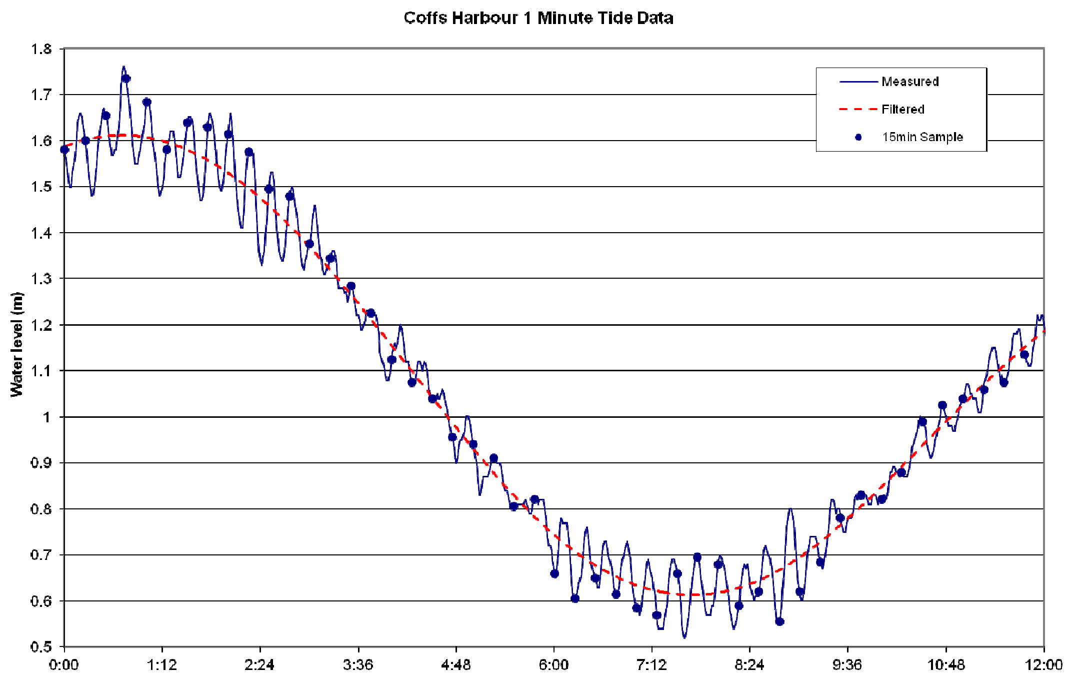

Figure 3 A tide cycle at Coffs Harbor, demonstrating the effect of a seiche of approximately 20 minutes. The dashed line is a low-pass filtered 1-min signal that better represents the true tide

Preliminary investigations into sea level trends demonstrated that the deployment period had a marked influence over linear trends. Datasets less than a tidal epoch (18.6 years) are unsuitable for the analysis of sea level rise and other long cycles as the normal astronomical forcing will not be fully captured. We can further argue that long period oceanic cycles will not be captured with datasets less than 30-40years. This was explored in detail using the Fort Denison data.

Fort Denison Tidal Data

The Fort Denison tidal dataset managed by Sydney Ports Corporation is one of the most valued tidal records in Australia, and is invaluable when addressing long-term changes to east Australian water level, and the south-west Pacific Ocean state. For this analysis it provides a context in which to interpret long-term levels of the OEH network of tide gauges.

Figure 4 shows monthly average and yearly averaged water level data from Fort Denison. The record has not been adjusted for anomaly drivers (such as MSLP), so represents the measured water level at the gauge. The long-term sea level trend of 0.94 mm/year is clearly apparent, as are variations to the average rate of rise.

The last 20-year period, covering the data range of the other MHL gauging sites, is associated with sustained El Nino conditions, generally associated with drier, less stormy conditions in Australia. This causes a depressing of regional sea levels and is seen as a slowing of sea level rise in the Fort Denison data to 0.4 mm/year for 1986-2007 (MHL1881). This would imply that gauges across NSW with datasets of approximately 20 years will underestimate sea level rise.

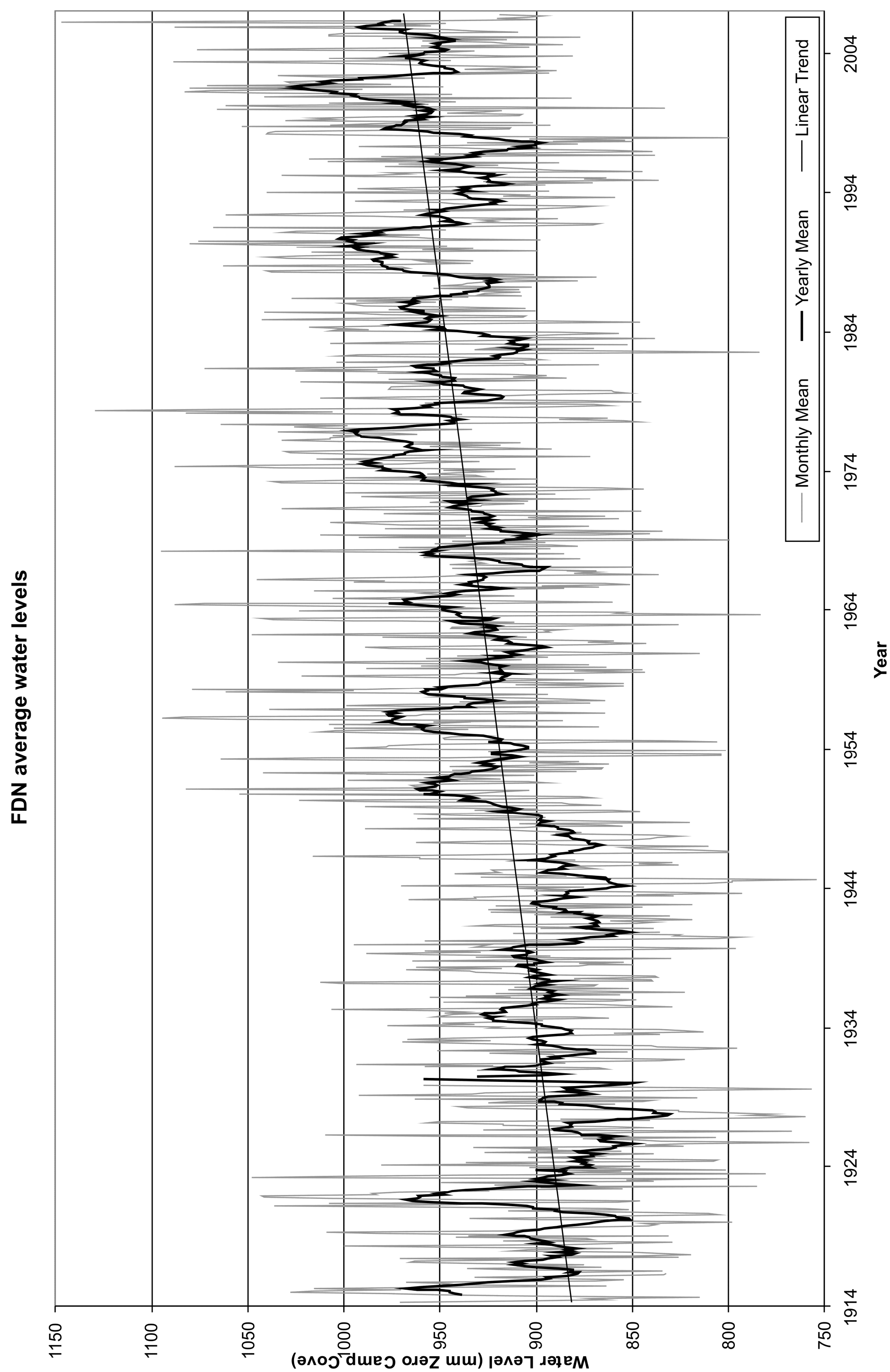

Figure 4 Fort Denison monthly and yearly averaged water levels, with a linear trend of 0.9 mm/year

Southern Oscillation Index

The Southern Oscillation Index (SOI) is a measure of the difference in atmospheric pressure between Tahiti and Darwin, and is a key indicator of El Nino/El Nina (ENSO) weather patterns.

$$SOI = \frac{\left(P_{diff} - P_{diffave}\right)}{SD(P_{diff})} \tag{7.1}$$

Pdiff = (average Tahiti MSLP for the month) - (average Darwin MSLP for the month),
Pdiffave = long-term average of Pdiff for the month in question, and
SD(Pdiff) = long-term standard deviation of Pdiff for the month in question.
(Bureau of Meteorology, http://www.bom.gov.au/climate/glossary/soi.shtml)

SOI/ENSO may affect coastal water levels through a range of mechanisms: pressure difference across the Pacific, trade wind strength, frequency and severity of storm events in the Tasman and western Pacific, sea surface temperatures, east Australian current (EAC) variability, oceanic Rossby waves and others. These mechanisms are complex and often interrelated, for example Holbook and Goodwin (2009) have demonstrated that Rossby waves in the Pacific affect both EAC and long period sea level changes. The nature of these relationships is beyond the scope of this paper, however the SOI has been compared to NSW water levels to determine the correlation between them.

A comparison of two-year average water levels for Fort Denison with two-year SOI averages shows a strong relationship between the two (Figure 6). Some lag of water level behind SOI is evident. For a lag of nine months the correlation between Fort Denison water level and SOI is 0.59. Figure 5 shows that the variability in water level associated with the SOI can be up to approximately 0.1 m.

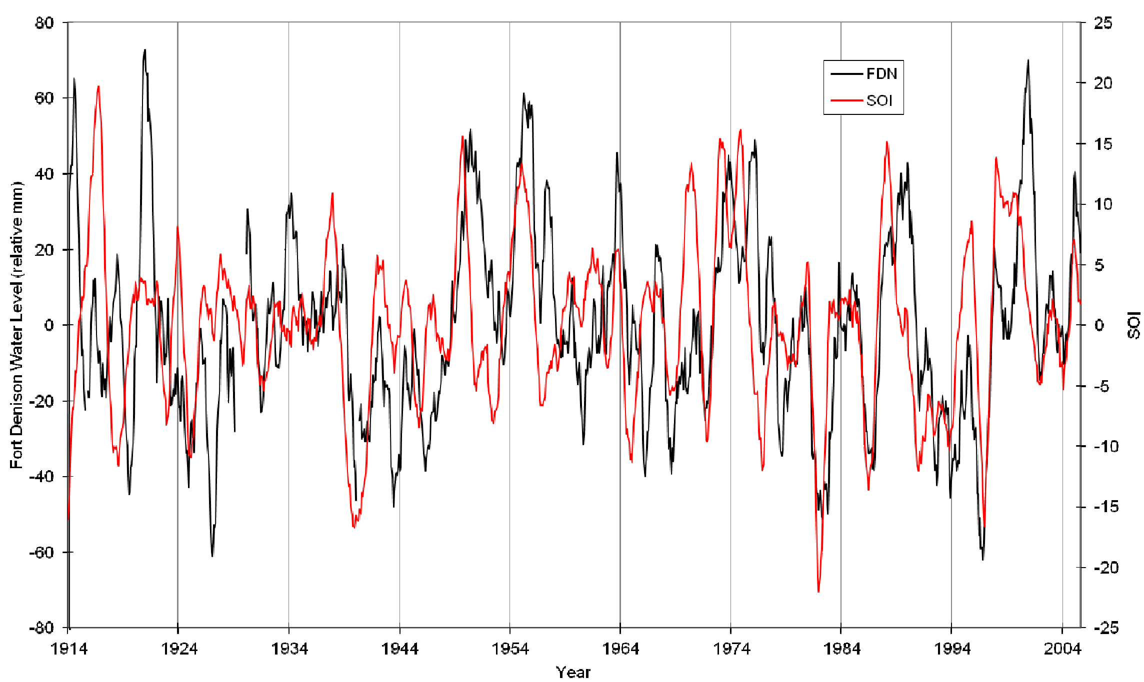

Figure 5 Southern Oscillation Index and Fort Denison (detrended yearly average)

Interdecadal Pacific Oscillation

Another index of long period pacific ocean variability is the Interdecadal Pacific Oscillation (IPO). A positive phase of the IPO is detected as a warming of surface waters in the eastern Pacific with an associated cooling in the west. In comparison with SOI/ENSO this effect is apparent throughout the Pacific rather than within the tropics, and operates on longer periods, with events lasting 20-30 years rather than 1-2 years. Details of the method for determining IPO can be found in Folland et al. (1999).

The data used in this analysis was determined by Chris Folland of the Met Office Hadley Centre for Climate Change, Exeter, and obtained from the Met Office website (July 2010).

The comparison between long-term rolling average water level at Fort Denison (monthly average calculation of 10-year average) and the IPO is given in Figure 6. This demonstrates a strong relationship with the sea level lagging by several years.

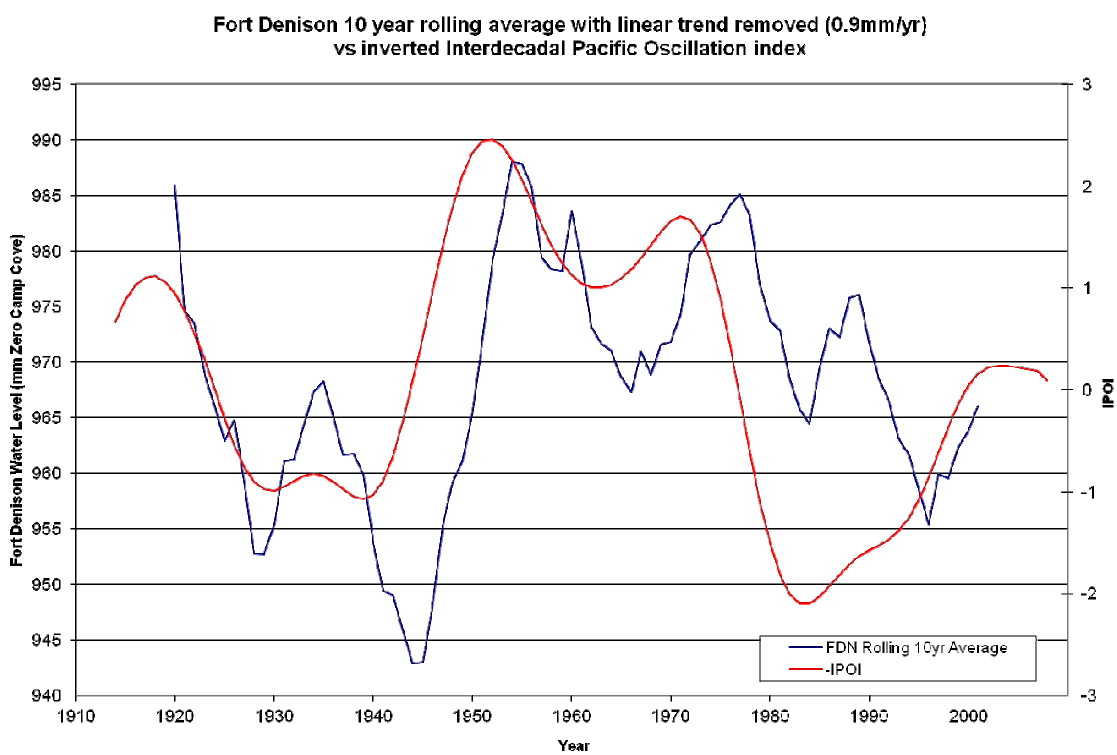

Figure 6 Fort Denison detrended 10-year rolling average water level and the Interdecadal Pacific Oscillation Index

Conclusions

Investigations into NSW tides and anomalies show several key influences on water levels. The drivers presented here provide some of the most pronounced impacts on sea level, but there are clearly other influences that are either unknown or the complex interaction of several drivers.

Very long period, global scale effects can be seen in long tidal records, in particular the Southern Oscillation Index has been found to show a strong correlation to water levels over long periods.

The Fort Denison data clearly shows a period of reduced sea level rise over the period 1986-2007 of 0.4 mm/year as opposed to 0.9 mm/year over the length of the dataset. This is assumed to be associated with long period cycles rather than a slowing of sea level rise. For the majority of gauges presented in this report, this would imply that the measured rate of sea level rise over approximately 20 years is less than what would be measured over longer periods.

Acknowledgements

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