THE AUSTRALIAN BASELINE SEA LEVEL MONITORING PROJECT

ANNUAL SEA LEVEL DATA SUMMARY REPORT

JULY 2005 - JUNE 2006

This report was prepared under the Australian Greenhouse Science Program for the Australian Greenhouse Office, supported by the National Tidal Centre, Bureau of Meteorology.

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Quality Certification:

I authorise the issue of this Australian Baseline Sea Level Monitoring Project Annual Sea Level Data Summary Report for July 2005 - June 2006 in accordance with the quality assurance procedures of the National Tidal Centre, Australian Bureau of Meteorology.

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EXECUTIVE SUMMARY

This report provides a consolidated overview of the data collected, analysed and presented in the monthly sea level data reports for the Australian Baseline Sea Level Monitoring Project (ABSLMP) to June 2006, with a particular focus on the last twelve months. The monthly data reports will continue to be available via the project website: http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml.

This report provides a summary of the key observations and some additional commentary on how the results relate to broader scientific findings of the international community concerning sea level rise as the result of climate change.

The main findings during the July 2005 – June 2006 period include:

- The monthly mean sea levels at Spring Bay in December 2005 and Port Kembla in April 2006 were the highest on record.
- A tsunami was detected by Australian tide gauges following a magnitude Mw7.9 undersea earthquake near Tonga on 3 May 2006.
- Climate patterns reminiscent of a weak La Niña were experienced in January and February 2006 following a cooling trend across the equatorial Pacific.
- The La Niña-like climate conditions lasted only briefly and no adverse impacts were observed in Australia.
- Neutral El Niño-Southern Oscillation conditions were restored by April 2006 as temperatures across the equatorial Pacific warmed.
- Data collected from project stations was consistent with the regional climatology. The cool phase in the Pacific coincided with higher than normal sea levels and lower than normal barometric pressure around southern Australia. As the equatorial Pacific warmed sea levels fell around southern Australia and barometric pressure rose.
- While the duration of the record from the ABSLMP stations remains relatively short there are a number of clear results emerging. The sea level records for all stations, when corrected for local land movement and the inverted barometer effect, are beginning to demonstrate coherent sea level rises. These trends are in line with global trends estimated from satellite-based altimeters.
- The largest sea level trends over the duration of the project are being observed in the northern and western Australian region.
- The quality-controlled observations collected by the ABSLMP stations continue to be used for research into sea level, climate variations and climate change, while their real-time data streams allow for the monitoring of tsunamis, storm surges and under-keel clearances at ports.
- It remains the aim of the project that the high-quality sea level observations will provide an accurate means of long-term sea level monitoring, especially as the length of record increases.

This report and the monthly sea level data reports are available in electronic form on the NTC web site: http://www.bom.gov.au/oceanography

Sea level monitoring station at Portland.

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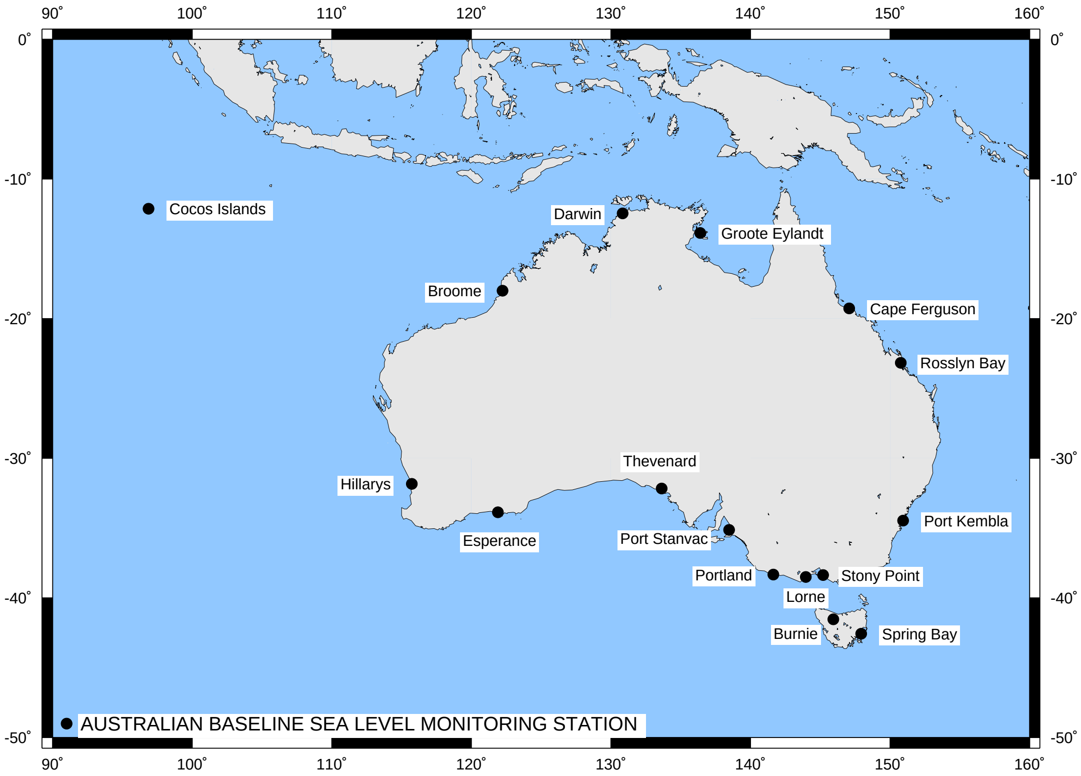
1. BACKGROUND

The management and operational support of the Australian Baseline Sea Level Monitoring Project (ABSLMP) is partly funded by a grant under the Greenhouse Climate Change Research Program. This is a long-term project, currently in its fourteenth year, designed to monitor sea level and climate around the coastline of Australia. The primary goal is to identify long period sea level changes, with particular emphasis on the enhanced greenhouse effect sea level signal. In addition, the project underpins the advanced technologies gathering global observations for climate change research. The in-situ sea level observations from tide gauges are essential for calibrating satellite altimeters and for understanding coastal impacts that are not adequately sampled from space.

Long term sea level trends and their projected acceleration are a focus of the Intergovernmental Panel on Climate Change (IPCC) as a primary indicator of climate variation and change. Accelerated sea level rise would be deemed to be a consequence of an enhanced Greenhouse Effect, due to the increased emission of Greenhouse gases as a result of industrialisation and other anthropogenic effects. The IPCC Scientific Assessment predicts that the rate of sea level rise will increase by up to four times over the next century. More information on the IPCC can be found at http://www.ipcc.ch/.

The project involves maintenance of an array of SEAFRAME (SEA-level Fine Resolution Acoustic Measuring Equipment) stations, which measure sea level very accurately, and also record meteorological parameters. The array consists of fourteen standard stations supported by National Tidal Centre (NTC) as well as two customised stations supported by the private sector; Lorne by the Victorian Channels Authority (VCA) and Stony Point by Toll WesternPort. The installation of three of the standard stations (Darwin, Spring Bay and Cocos Islands) was supported by the National Oceanographic and Atmospheric Administration /National Ocean Service of the U.S. The Division of Marine Research, CSIRO and the TOPEX/POSEIDON satellite altimetry experiment supported the installation of the gauge at Burnie.

The NTC is responsible for maintaining the ABSLMP sea level monitoring network and data analysis activities as part of its operations. More information on the NTC and its functions can be found at http://www.bom.gov.au/oceanography/.



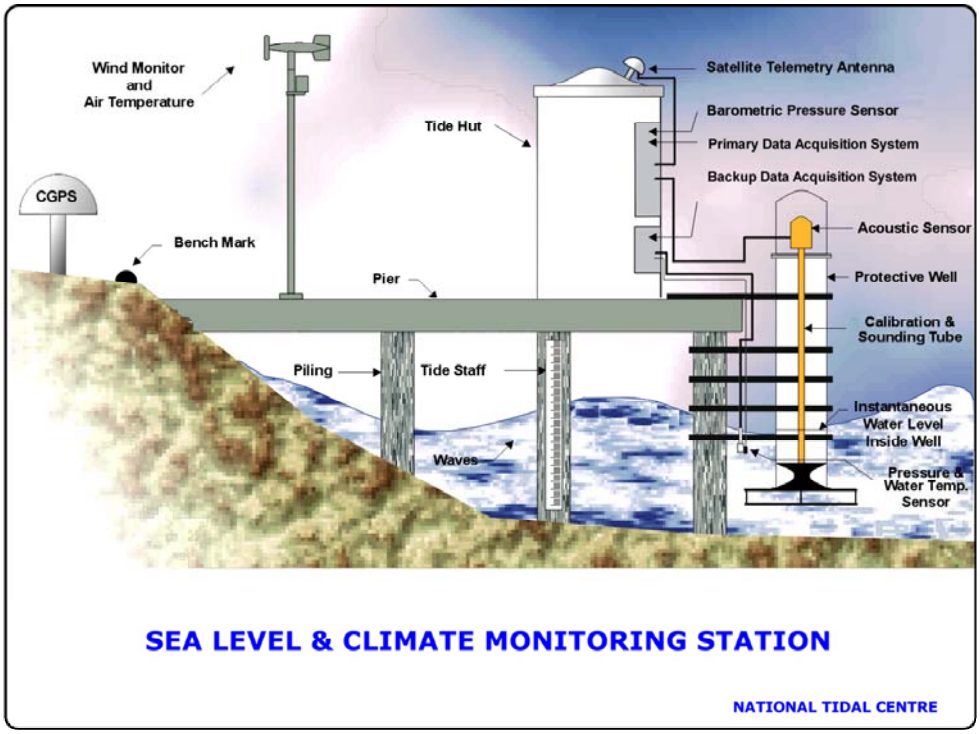


Figure 1. *Australian Baseline Sea Level Monitoring Project sites (top) where SEAFRAME stations (bottom) are installed.*

2. SEA LEVEL MONITORING NETWORK

The project's monitoring network consists of 14 standard SEAFRAME stations at representative sites around the Australian coastline, as well as 2 customised stations at Lorne and Stony Point (Figure 1 and Table 1). SEAFRAME gauges not only measure sea level by two independent means, but also observe a number of "ancillary" variables - atmospheric pressure, air and water temperatures, wind speed and direction.

The SEAFRAME observations are integrated with analyses performed by the National Climate Centre of the Australian Bureau of Meteorology to determine the climatic and oceanographic conditions for the region. Other major projects that utilize the data include BLUElink - Ocean Forecasting Australia through partnership between the Bureau, CSIRO and the Australian Navy as well as the Global Sea Level Observing System (GLOSS) under the auspices of the World Meteorological Organisation (WMO) and Intergovernmental Oceanographic Commission (IOC).

Through its membership of the Intergovernmental Committee on Surveying and Mapping (ICSM) Permanent Committee on Tides & Mean Sea Level (PCTMSL), NTC strives to sustain a geodetic levelling program supported by the state surveying organisations and Geosciences Australia. Periodic surveys at each SEAFRAME site are necessary to relate the gauge to a nearby array of deep benchmarks and monitor any vertical movements of the instrumentation.

Station	Latitude	Longitude	Installation Date
Cocos Islands	12° 07' S	096° 53' E	Sep 1992
Groote Eylandt	13° 50' S	136° 30' E	Sep 1993
Darwin	12° 28' S	130° 51' E	May 1990
Broome	18° 00' S	122° 13' E	Nov 1991
Hillarys	31° 49' S	115° 44' E	Nov 1991
Esperance	33° 52' S	121° 54' E	Mar 1992
Thevenard	32° 10' S	133° 40' E	Mar 1992
Port Stanvac	35° 06' S	138° 28' E	Jun 1992
Portland	38° 20' S	141° 36' E	Jul 1991
Lorne	38° 30' S	143° 59' E	Jan 1993
Stony Point	38° 22' S	145° 13' E	Jan 1993
Burnie	41° 03' S	145° 57' E	Sep 1992
Spring Bay	42° 33' S	147° 56' E	May 1991
Port Kembla	34° 29' S	150° 55' E	Jul 1991
Rosslyn Bay	23° 10' S	150° 47' E	Jun 1992
Cape Ferguson	19° 17' S	147° 03' E	Sep 1991

Table 1. *Locations and installation dates for the Australian Baseline sea level array.*

3. CLIMATIC AND OCEANOGRAPHIC CONDITIONS

Sea level is affected by the combination of tidal, weather, climate and oceanographic conditions as well as geodynamic processes. These effects are described in more detail below, including a summary of the present conditions.

3.1. Extreme Events

Extreme sea levels arise when reinforcing combinations of tides, short-term weather effects, tsunamis or climate conditions occur. Abnormally high sea levels can cause flooding, coastal erosion and property damage. Abnormally low sea levels can be hazardous for navigation and reduce under-keel clearances for shipping operations in ports.

Tsunamis are small to potentially large waves caused by seismic disturbances that can result in extremely high (or low) sea levels if their arrival coincides with a high (or low) tide. Storm surges refer to periods of elevated sea levels lasting several hours to several days as a result of wind and wave activity and low barometric pressure. Conversely, high barometric pressure and strong offshore winds can produce depressed sea levels. Over longer periods, sea levels along the coast are influenced by sea surface gradients spun-up by wind driven surface currents or depth-integrated geostrophic flow. The frequency and intensity of extreme events are modulated by climate variability. Australia typically experiences more tropical cyclones during La Niña episodes for example. Rising sea levels will reduce the average return interval of dangerously high sea levels.

A useful datum to distinguish abnormally high sea levels is the *Highest Astronomical Tide* (HAT), the highest level that can be predicted to occur under any combination of astronomical conditions. Likewise the *Lowest Astronomical Tide* (LAT) is the lowest level that can be predicted under any combination of astronomical conditions. To properly determine HAT and LAT tidal predictions must span at least 18.6 years, which is the period of a full rotation of the moon's orbital plane about the ecliptic.

The monthly maximum (minimum) sea levels recorded above HAT (or below LAT) at SEAFRAME stations (Figures 2 and 3) illustrate occurrences of extreme sea levels over the duration of the project. Extreme sea levels are observed more frequently along the southern Australian coastline from Hillarys to Port Kembla due to regular low-pressure systems tracking across the Southern Ocean. Elevated sea levels, which are more prominent during winter months, can often be tracked from one station to the next moving as a coastally trapped disturbance around the southern Australian coastline. Along the northern Australian coastline the occurrence of atmospheric and oceanographic conditions conducive to extremely high (or low) sea levels is less common. Nevertheless when such conditions arise the effects can be dramatic, such as was observed at Groote Eylandt in February 2001 when sea levels reached 1.3 m above HAT at the time of Tropical Cyclone Winsome.

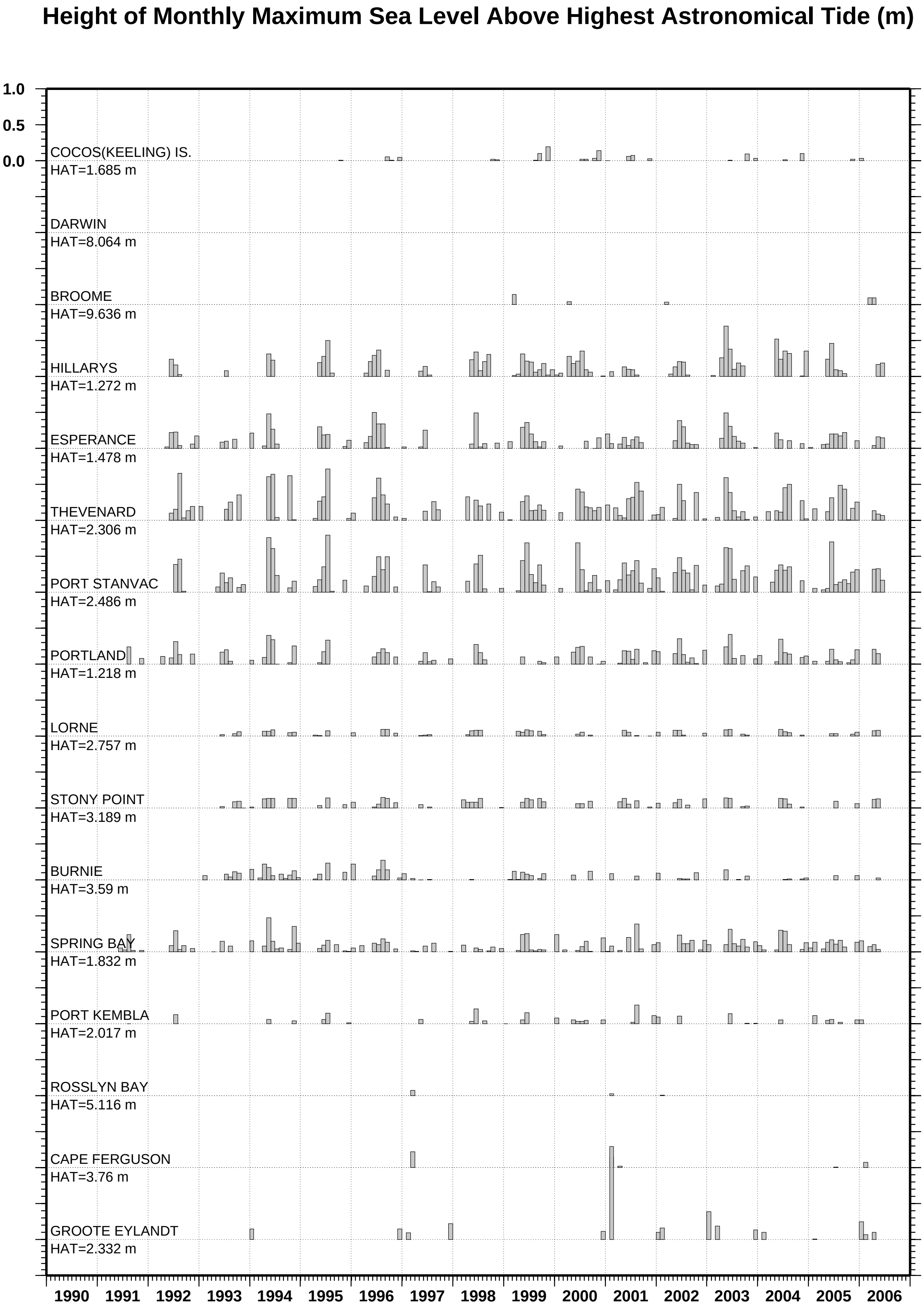


Figure 2. *Monthly maximum sea levels at SEAFRAME stations that have exceeded the Highest Astronomical Tide (HAT).*

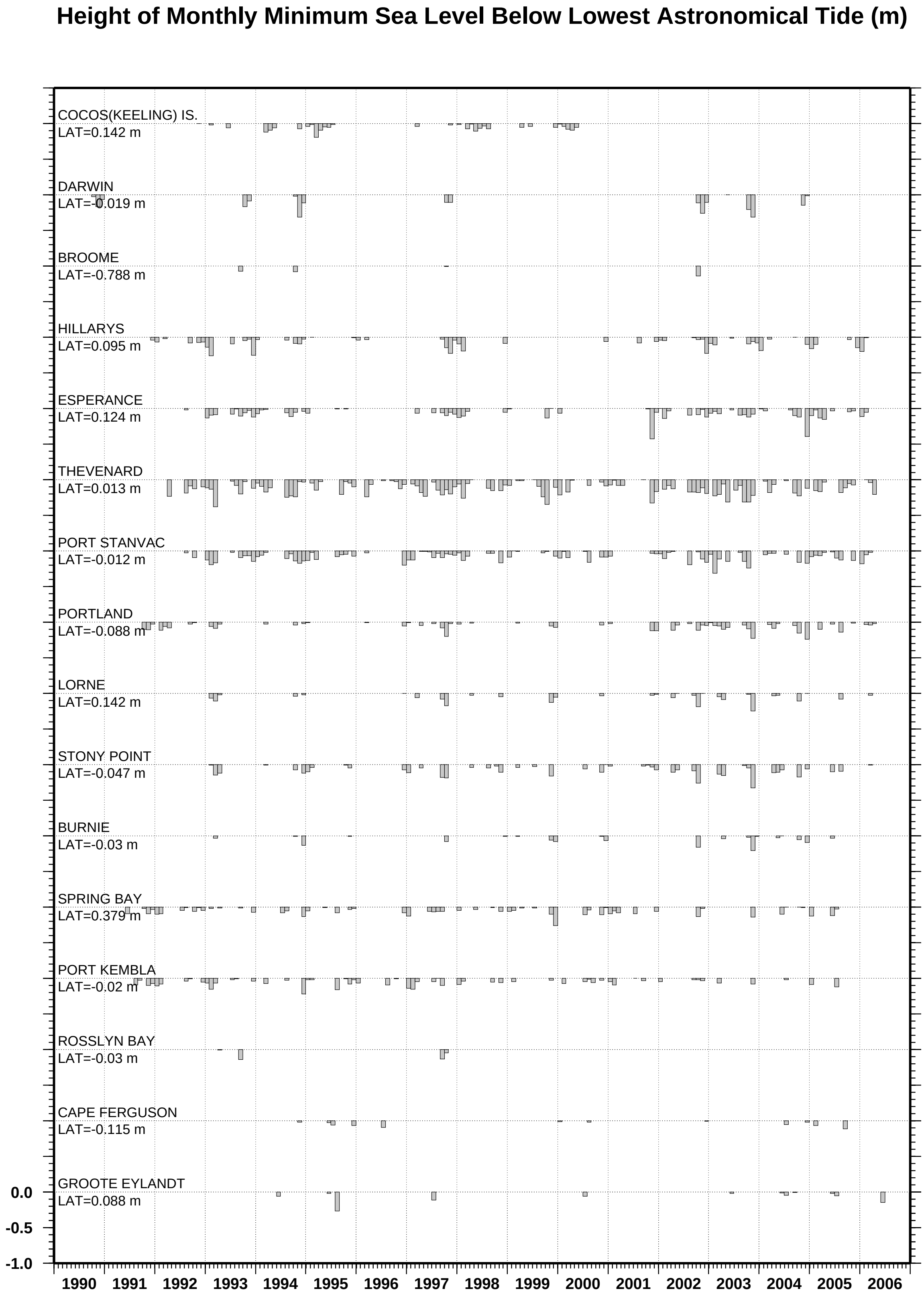


Figure 3. *Monthly minimum sea levels at SEAFRAME stations that have fallen below the Lowest Astronomical Tide (LAT).*

3.1.1. Tsunamis

The SEAFRAME stations established under the ABSLMP project are also an integral part of sea level monitoring networks associated with Australian and international tsunami programs such as the Australian Tsunami Warning System, the Pacific Tsunami Warning System and the proposed tsunami warning system for the Indian Ocean. Further information about these programs may be found at
http://www.bom.gov.au/oceanography/tsunami/atws_summary.shtml
http://ioc3.unesco.org/ptws/
http://ioc3.unesco.org/indotsunami/

One tsunami event was observed in Australian territory in the twelve-month report period from July 2005 to June 2006. On 3 May 2006 a magnitude Mw7.9 undersea earthquake near Tonga in the South Pacific generated a tsunami that was detected by the ABSLMP SEAFRAME tide gauge at Port Kembla.

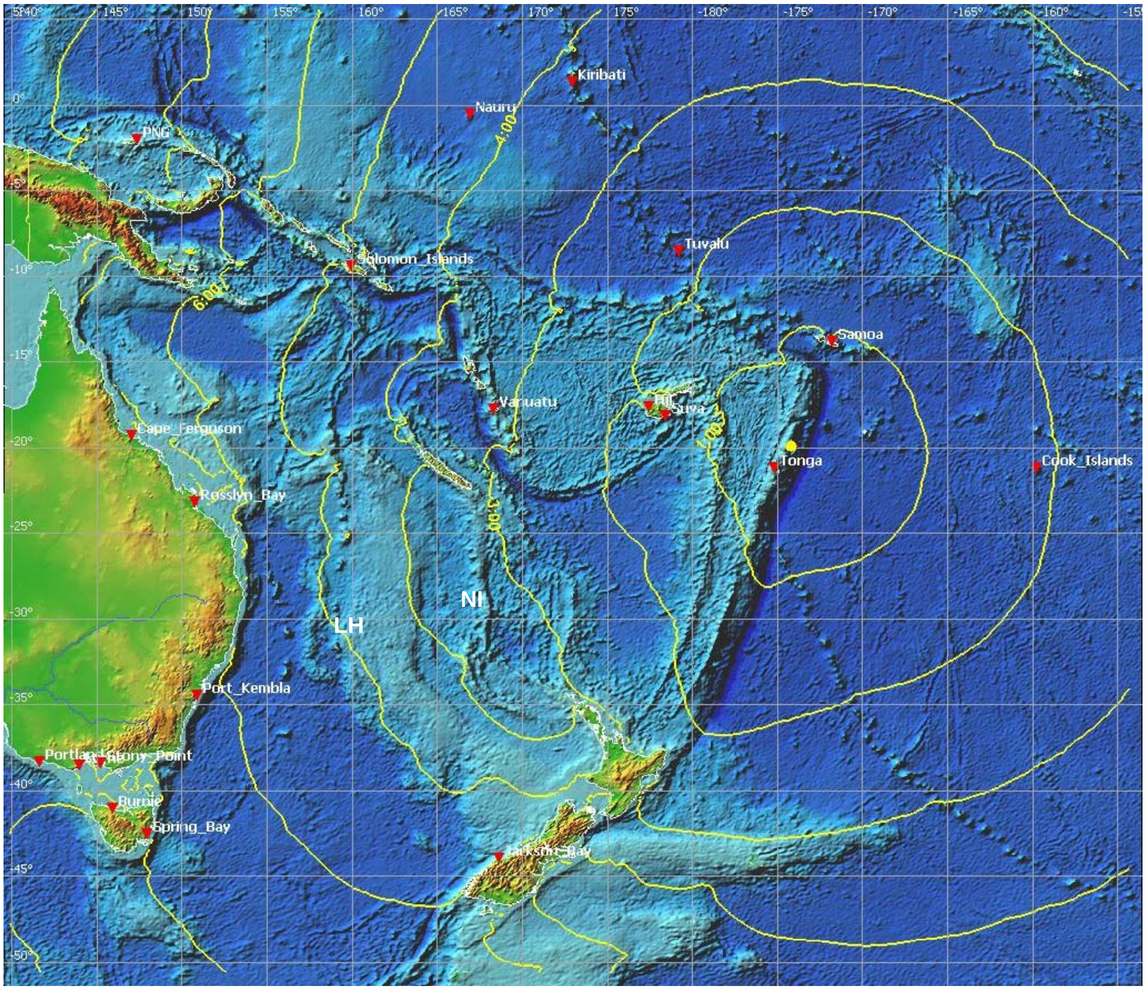


Figure 4. *Computed tsunami travel time contours (hours) for the 3 May 2006 magnitude Mw7.9 earthquake near Tonga (yellow dot), SEAFRAME stations operated by the Bureau of Meteorology (red triangles) and the location of Norfolk Island (NI) and Lord Howe Island (LH) where Manly Hydraulics Laboratory operate tide gauges.*

The tsunami was also detected by the tide gauges at Australia's Norfolk Island (0.15m) and Lord Howe Island (0.15m), which are operated by Manly Hydraulics Laboratory, and the Bureau-operated SEAFRAME tide gauges in the South Pacific including Tonga (0.4m), Samoa (0.15m), Cook Islands (0.28m), Fiji (0.1m), Vanuatu (0.5m) and Jackson Bay, NZ (0.2m).

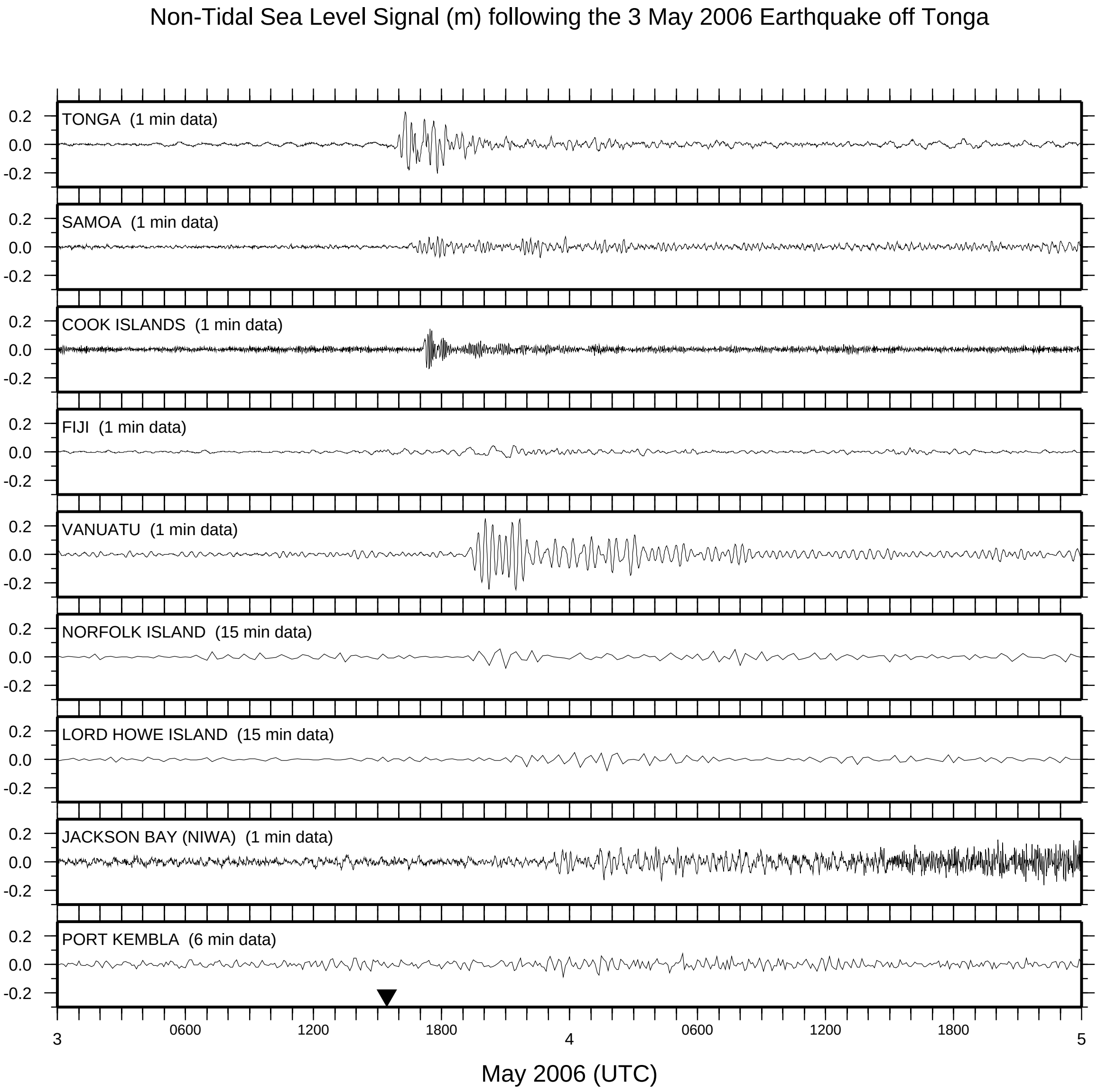


Figure 5. *Non-tidal sea levels (metres) at SEAFRAME stations and Manly Hydraulics Laboratory gauges at Norfolk and Lord Howe Island before and after the 3 May 2006 magnitude Mw7.9 earthquake near Tonga. The time of the earthquake is indicated by the triangle.*

3.1.2. Tropical Cyclones

The major tropical cyclones (TC) that affected Australia during the 2005/2006 season included TC Clare (7-10 January), TC Glenda (15-31 March), TC Larry (17-21 March) and TC Monica (16-25 April). Further information about these tropical cyclones is available from the Bureau of Meteorology website at http://www.bom.gov.au/announcements/sevwx/

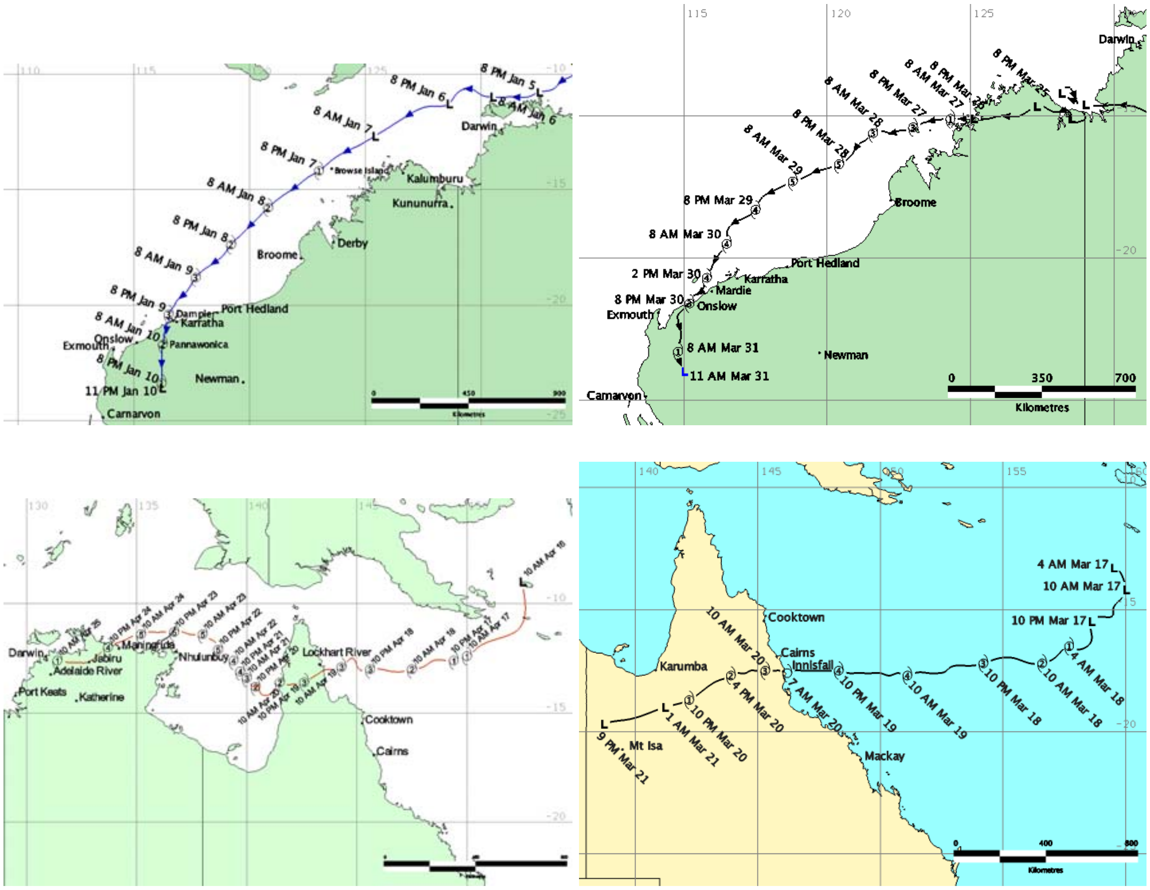


Figure 6. *The tracks and strength of the major tropical cyclones affecting Australia during the 2005/2006 season: (Clockwise from top left) TC Clare, TC Glenda, TC Larry and TC Monica. Category 5 is the strongest cyclone category.*

The following conditions were observed at SEAFRAME stations as a result of these tropical cyclones.

TC Clare – At Broome sea levels rose to 0.3m above the predicted tide from the 8-9 January and wind gusts were recorded at 18 m/s (35 knots) on 8 January.

TC Glenda – At Broome wind gusts exceeding 15 m/s (30 knots) were recorded from 26-29 March, the maximum wind gust being 40 knots on 28 March. There was no significant surge in the sea level.

TC Larry – At Cape Ferguson sea levels rose to 0.6m above the predicted tide and wind gusts reached 20 m/s (39 knots) from 19-20 March.

TC Monica – At Groote Eylandt sea levels rose above the predicted tide from 22-25 April. The surge reached a maximum of 0.9m above the predicted tide on 24 April. Wind gusts of over 15 m/s (30 knots) were observed from 20-24 April.

3.2. Climate Variability

Variations in sea level and climate are inextricably linked, with both undergoing interrelated seasonal, interannual and interdecadal fluctuations. Quasi-periodic fluctuations associated with natural phenomena such as the El Niño – Southern Oscillation can be large and cause significant social and economic impacts. Particularly noisy or low frequency variations can conceal the underlying long-term trend in sea level records that are shorter than several decades.

3.2.1. El Niño – Southern Oscillation (ENSO)

The El Niño – Southern Oscillation (ENSO) refers to the periodic change (between four to seven years) in atmospheric and oceanic patterns in the tropical Pacific Ocean.

During neutral conditions (middle panel of Figure 7) easterly trade winds blow across the tropical Pacific and the sea surface is about 50 cm higher and 8°C warmer in the far-western Pacific adjacent Indonesia than in the eastern Pacific adjacent South America. Rainfall is found in rising air over the warmer western waters, and hence the east Pacific is relatively dry.

During El Niño events (top panel of Figure 7), the trade winds relax in the central and western Pacific resulting in an eastward shift of the circulation over the tropical Pacific. Lower than normal sea levels and cooler than normal sea surface temperatures are experienced in the far-western Pacific, while higher than normal sea levels and warmer than normal sea surface temperatures are experienced in the central and eastern equatorial Pacific. Impacts during El Niño may include increased cyclone activity in the central Pacific, flooding in Peru or drought in Indonesia and Australia. Large-scale teleconnections may also force changes to the climate of regions far removed from the tropical Pacific.

The opposite phase of El Niño is called La Niña (bottom panel of Figure 7). La Niña is characterised by unusually cold ocean temperatures in the equatorial Pacific, as compared to El Niño, which is characterised by unusually warm ocean temperatures in the equatorial Pacific. Global climate anomalies associated with La Niña tend to be opposite those of El Niño.

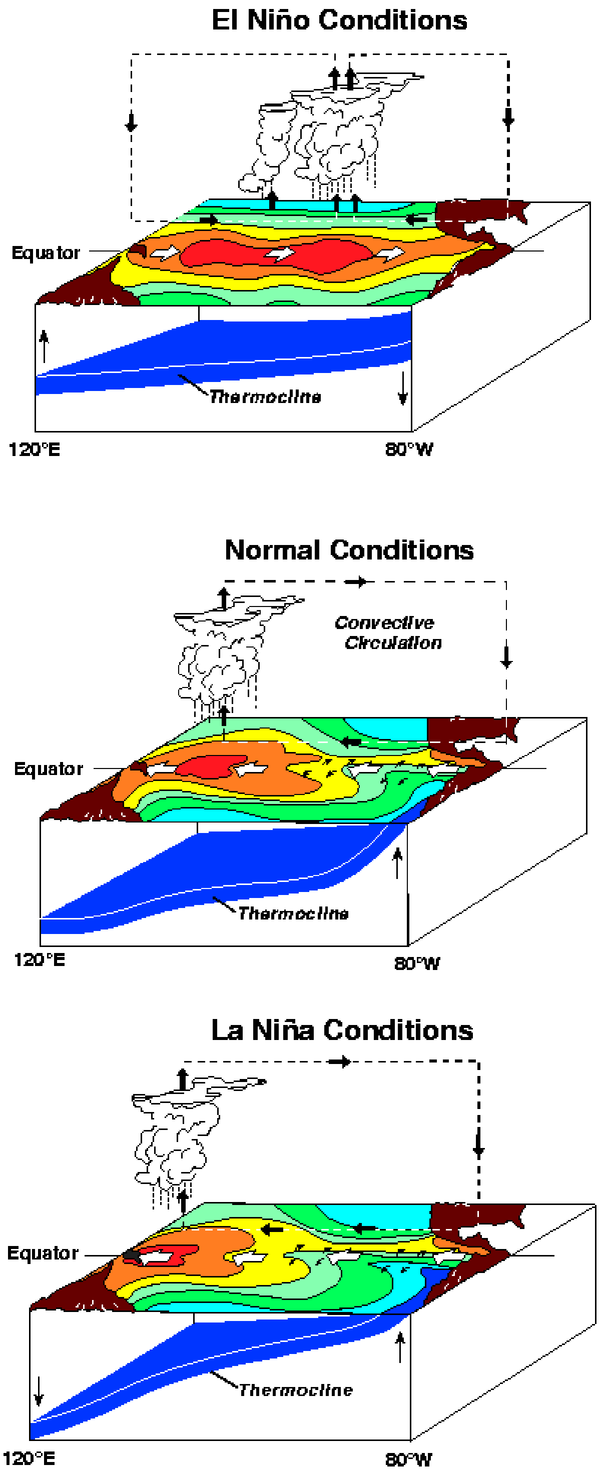


Figure 7. *Schematic of atmospheric and ocean conditions associated with El Niño and La Nina.*

With regard to the ENSO cycle during the twelve-month report period from July 2005 to June 2006, the equatorial Pacific experienced a cooling trend and climate patterns characteristic of a weak La Niña developed in January and February 2006. Trade winds at this time were stronger than normal across the central to western equatorial Pacific and cooler than normal sea surface temperatures suppressed cloud formation and rainfall across the central equatorial Pacific. In the far western equatorial Pacific sea surface temperatures remained warmer than average. A horseshoe pattern of warmer than average sea surface temperature extended across the North, West and South Pacific in an envelope around the cooler central and eastern equatorial Pacific. The cool trend was highlighted by a steady rise in the Southern Oscillation Index (Figure 8).

However history showed that no La Niña event of any significance has ever developed so early in the year, and the typical Australian La Niña impacts such as widespread above average rainfall, floods, and increased tropical cyclone numbers did not materialise.

From March 2006 equatorial Pacific temperatures began to warm and the climate patterns reminiscent of a weak La Niña began to decay. By May 2006 the cool ENSO phase was over and the equatorial Pacific was clearly neutral. The outlook in June 2006, based on the majority of international climate forecast models, was that ENSO-neutral conditions were expected to prevail in the following months.

For further information see: http://www.bom.gov.au/climate

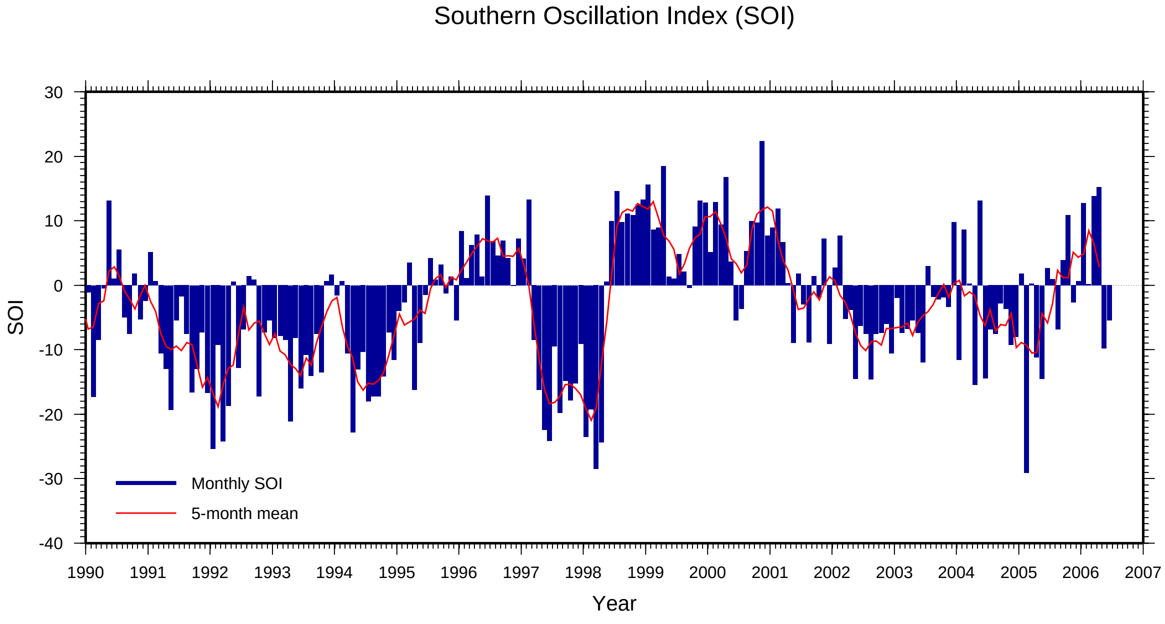


Figure 8. *Southern Oscillation Index*

3.2.2. Inter-decadal variability

Sea level and climate can vary about a long-term climatological mean from one decade to the next. The project to date has only spanned one complete decade, so it is important to recognise that the sea level change observed over this time is largely a consequence of decadal *variability*. Continued monitoring is needed to isolate the long-term trend that is associated with climate *change*.

An example of inter-decadal variability is the Pacific Decadal Oscillation (PDO), which is postulated as a fluctuation of the Pacific Ocean that has similarities to El Niño, but operates over a much longer time period of 20 – 30 years. During the negative phase of the PDO, the eastern equatorial Pacific experiences lower than normal ocean temperatures and sea surface height while a pattern of higher than normal ocean temperatures and sea surface height connects the north, west and south Pacific. During the positive phase, this situation is reversed (Figure 9). The PDO Index reveals how climate and sea level has fluctuated within the Pacific on decadal timescales since 1900 (Figure 10).

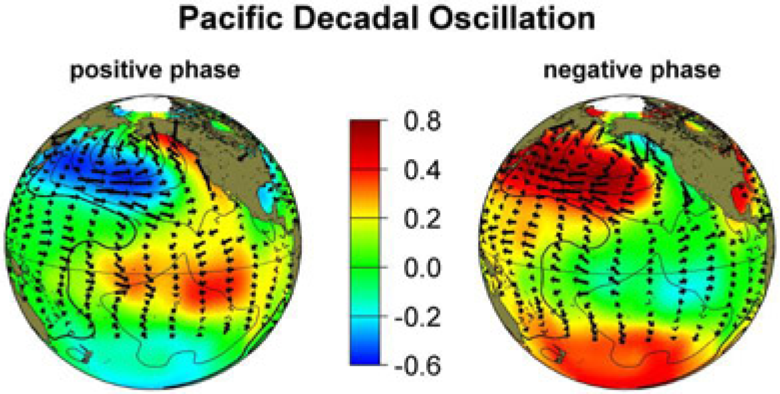


Figure 9. *Schematic of sea surface temperature (°C) and wind stress anomalies during positive and negative phases of the Pacific Decadal Oscillation. Figure courtesy of University of Washington.*

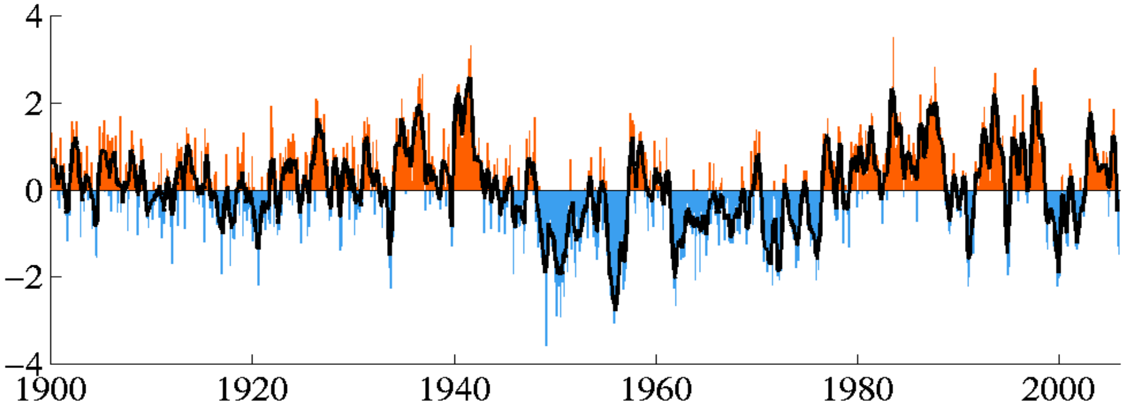


Figure 10. *Monthly values for the Pacific Decadal Oscillation Index: Jan 1900-November 2005. Figure courtesy of University of Washington.*

3.3. Climate Change

As discussed in detail by the Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report (IPCC TAR, 2001), sea level change is an important consequence of climate change, both for communities and the environment.

“Mean sea level” at the coast is defined as the height of the sea with respect to a local land benchmark, averaged over a period of time, such as a month or a year, long enough that fluctuations caused by waves and tides are largely removed. Changes in mean sea level as measured by coastal tide gauges are called “relative sea level changes”, because they can come about either by movement of the land on which the tide gauge is situated or by changes in the height of the adjacent sea surface (both considered with respect to the centre of the Earth as a fixed reference). These two terms can have similar rates (several mm/yr) on time-scales greater than decades.

To detect sea level changes arising from changes in the ocean, the movement of the land needs to be subtracted from the records of tide gauges and geological indicators of past sea level. Widespread land movements are caused by the isostatic adjustment resulting from the slow viscous response of the mantle to the melting of large ice sheets and the addition of their mass to the oceans since the end of the most recent glacial period (“Ice Age”). Tectonic land movements, atoll decay, rapid displacements (earthquakes) and slow movements (associated with mantle convection and sediment transport) can also have an important effect on local relative sea level.

The IPCC TAR, 2001, estimates that global average eustatic sea level change over the last century was within the range 0.10 to 0.20 m (1-2 mm/yr). Eustatic sea level change results from changes to the density or to the total mass of water. Both of these relate to climate change. Density is reduced by thermal expansion, which occurs as the ocean warms. Thermal expansion is expected to contribute the largest component to sea level rise over the next hundred years.

Because of the large heat capacity of the ocean, thermal expansion would continue for many centuries after climate had been stabilised. Using the latest coupled ocean-atmosphere global climate computer models, sea level is projected to rise between 0.09 to 0.88 m between 1990 and 2100. According to the IPCC TAR, 2001, while coupled models have improved considerably in recent years, and there is general agreement between the observed and modelled thermal expansion contribution, the models’ ability to quantitatively simulate decadal changes in ocean temperatures and thus thermal expansion has not been adequately tested. Given the poor global coverage of high quality historical tide gauge records and the uncertainty in the corrections for land motions, the observationally based rate of sea level rise this century needs careful assessment. The high-accuracy sea level stations installed for the ABSLMP will help address these issues in future.

Sea level change is not expected to be geographically uniform, so information about its distribution is needed to inform assessments of the impacts on coastal regions. The pattern depends on ocean surface fluxes, interior conditions and ocean circulation. The most serious impacts are caused not only by changes in mean sea level but by changes to extreme sea levels, especially storm surges and exceptionally high waves, which are forced by meteorological conditions. Climate-related changes in these phenomena therefore also have to be considered.

For more information on sea level change under climate changes see:

http://www.ipcc.ch/

For a discussion of the sea level trends being observed in the ABSLMP, see section 4.3.

4. SEAFRAME DATA ANALYSIS

4.1. Monthly mean sea levels

The monthly mean sea levels at the SEAFRAME stations (Figure 11) undergo climate related changes such as seasonal and annual cycles, transient events such as the effects of El Niño and La Nina and decadal fluctuations. Underlying these fluctuations lies a longer-term secular sea level rise. The annual sea level cycle is the most apparent feature and ranges from around 15cm at Burnie up to 60 cm at Groote Eylandt. One effect of the 1997/98 El Niño was to disrupt the normal annual sea level cycle at many of the stations. In the twelve-month report period of July 2005 to June 2006, the highest monthly mean sea levels on record were experienced at Spring Bay (in December 2005) and Port Kembla (in April 2006).

4.2. Anomalies

The following section describes the anomalous observations in the records from the SEAFRAME stations, that is, the departures from normal conditions.

4.2.1. Sea level anomalies

Sea level anomalies are calculated by removing the predicted tides, seasonal cycles and linear trend. The sea level anomalies at the SEAFRAME stations (Figure 12) highlight irregular events such as lower than normal sea levels during the 1997/98 El Niño and higher than normal sea levels that followed during the subsequent La Niña.

The sea level anomalies around Australia generally follow the Southern Oscillation Index (SOI)- high sea levels coincide with high values of the SOI (La Niña) and low sea level coincides with low values of the SOI (El Niño). The El Niño - Southern Oscillation cycle is a major influence on sea levels around Australia.

During the twelve-month report period from July 2005 – June 2006 in particular, higher than normal sea levels were experienced around the southern Australian seaboard in December and January, in association with positive SOI values (Figure 8) and La Niña-like climate patterns in the Pacific. Sea levels subsequently proceeded to fall to below average levels in association with the falling SOI values and warming trend in the equatorial Pacific.

4.2.2. Barometric pressure anomalies

The barometric pressure anomalies around Australia are also strongly influenced by the ENSO cycle, with higher than normal pressure over Australia being a feature of the 1997/98 El Niño (Figure 13). There is a relationship between barometric pressure and sea level, known as the inverse barometer effect, in which sea levels typically rise (fall) by 1 cm for every 1 mbar fall (rise) in barometric pressure.

During the twelve-month report period, barometric pressure anomalies at SEAFRAME stations around Australia were predominantly negative, although a substantial increase was observed from April 2006 to June 2006 when barometric pressures were higher than normal at many stations. The increase in barometric pressure anomalies is in accordance with the decrease in sea level anomalies.

4.2.3. Water temperature anomalies

The water temperature anomalies over the duration of the project (Figure 14) have not been as spatially coherent as either sea level or barometric pressure. Local effects, such as coastal upwelling of cooler subsurface water for example, are influential in addition to the broad scale regional climatic conditions. Water temperatures at the SEAFRAME stations were mostly warmer than average in the latter half of 2005 but proceeded to cool in the first half of 2006.

4.2.4. Air temperature anomalies

The air temperature anomalies are similar to the water temperature anomalies in that they show elements of regionally coherent changes due to broad scale climate conditions as well as localised variability (Figure 15). The air temperatures underwent a cooling trend in the twelve-month report period and were cooler than normal at all stations by June 2006.

MONTHLY MEAN SEA LEVELS TO JUNE 2006 (m)

The zero line represents an arbitrary fixed offset from the zero of the tide gauge.

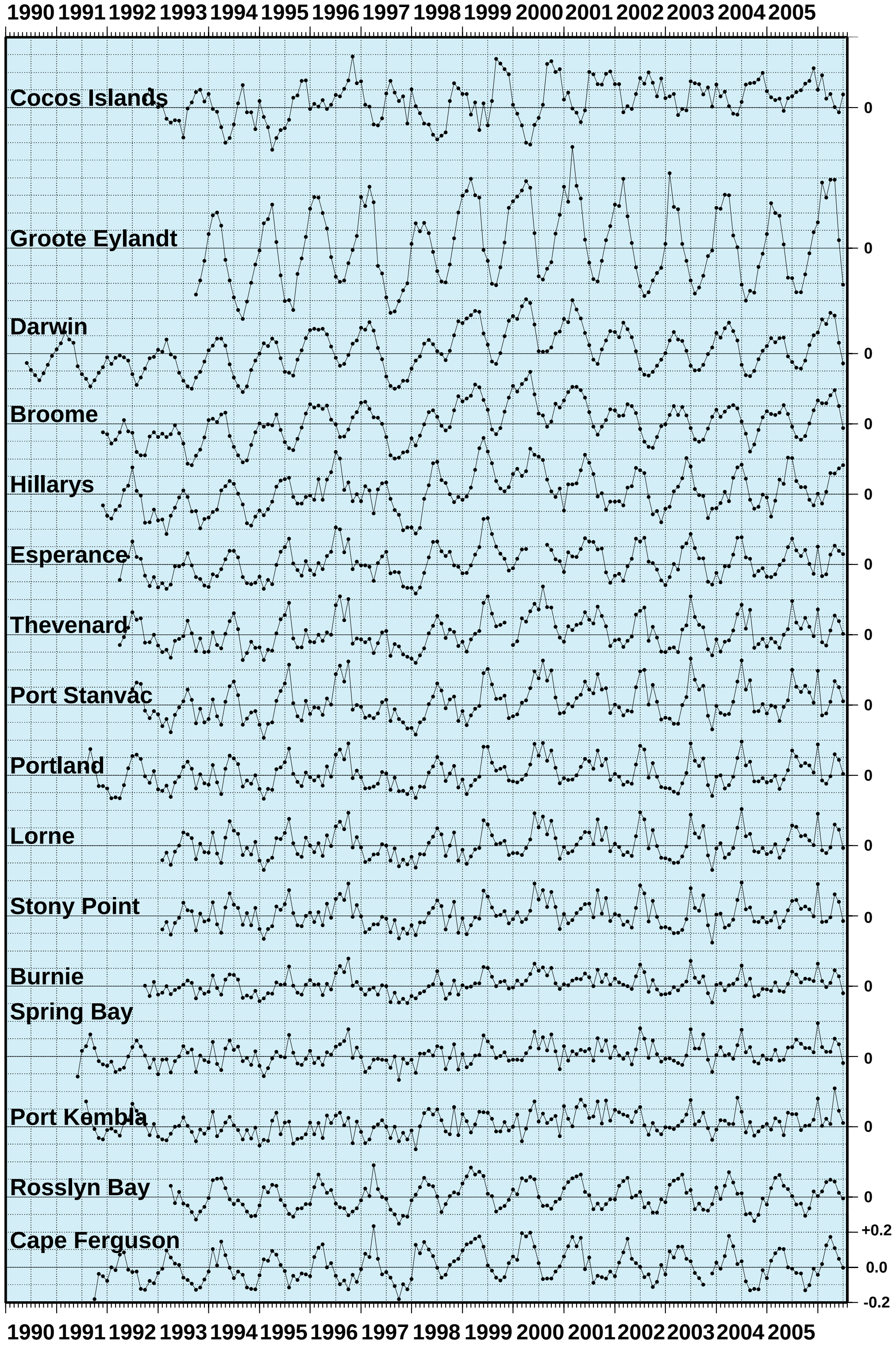


Figure 11. *Monthly mean sea levels to June 2006.*

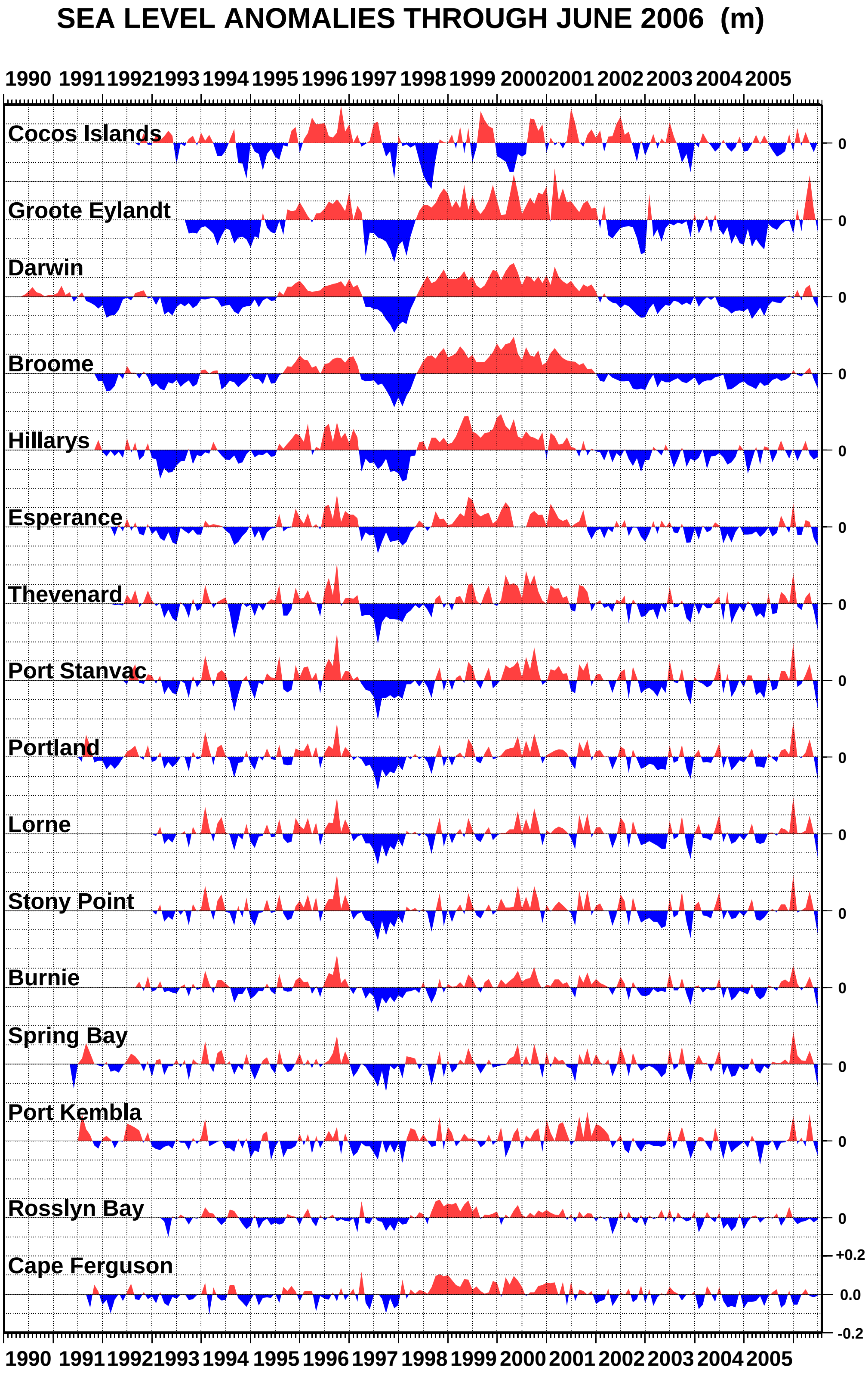


Figure 12. *Sea level anomalies to June 2006.*

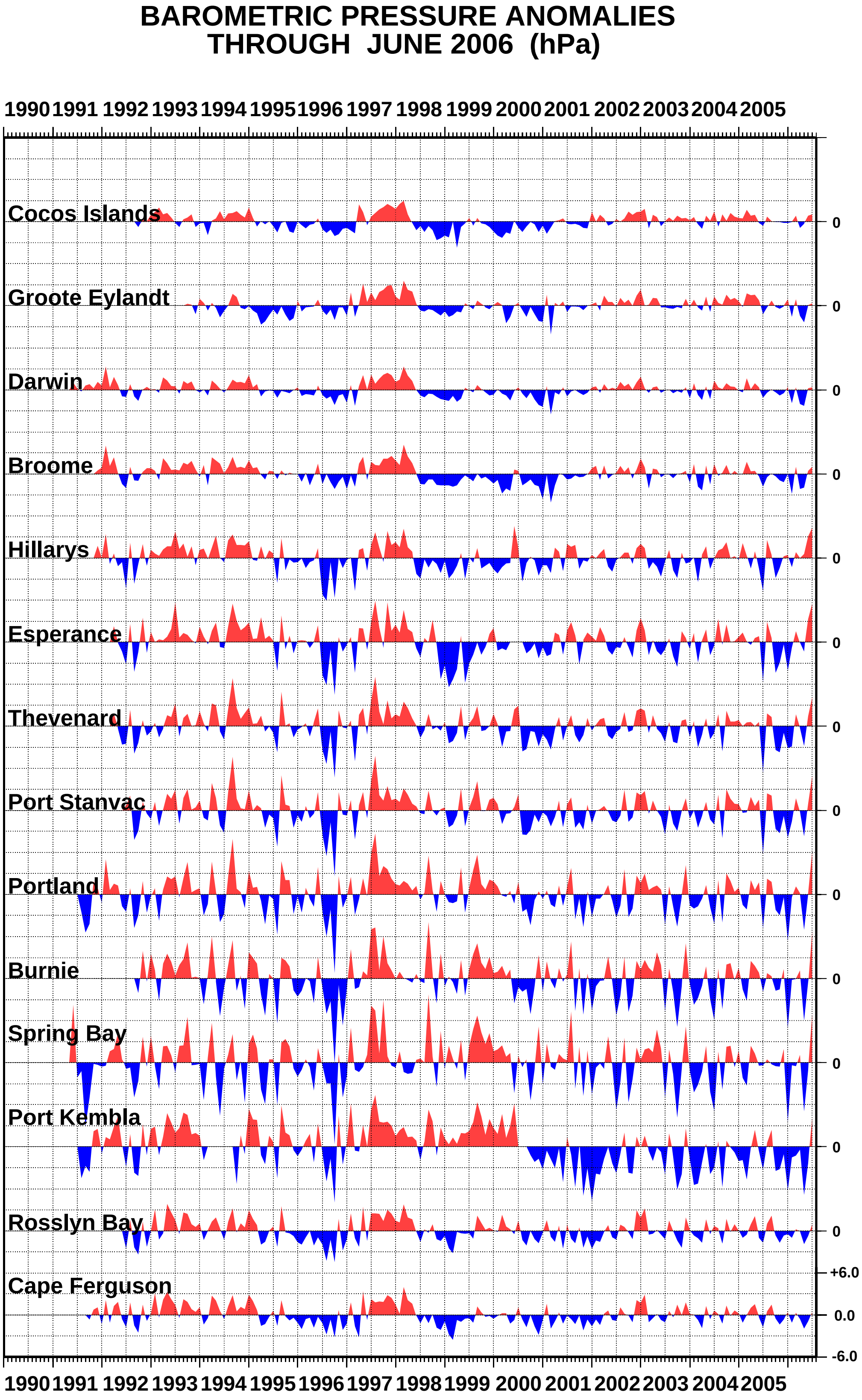


Figure 13. *Barometric pressure anomalies to June 2006.*

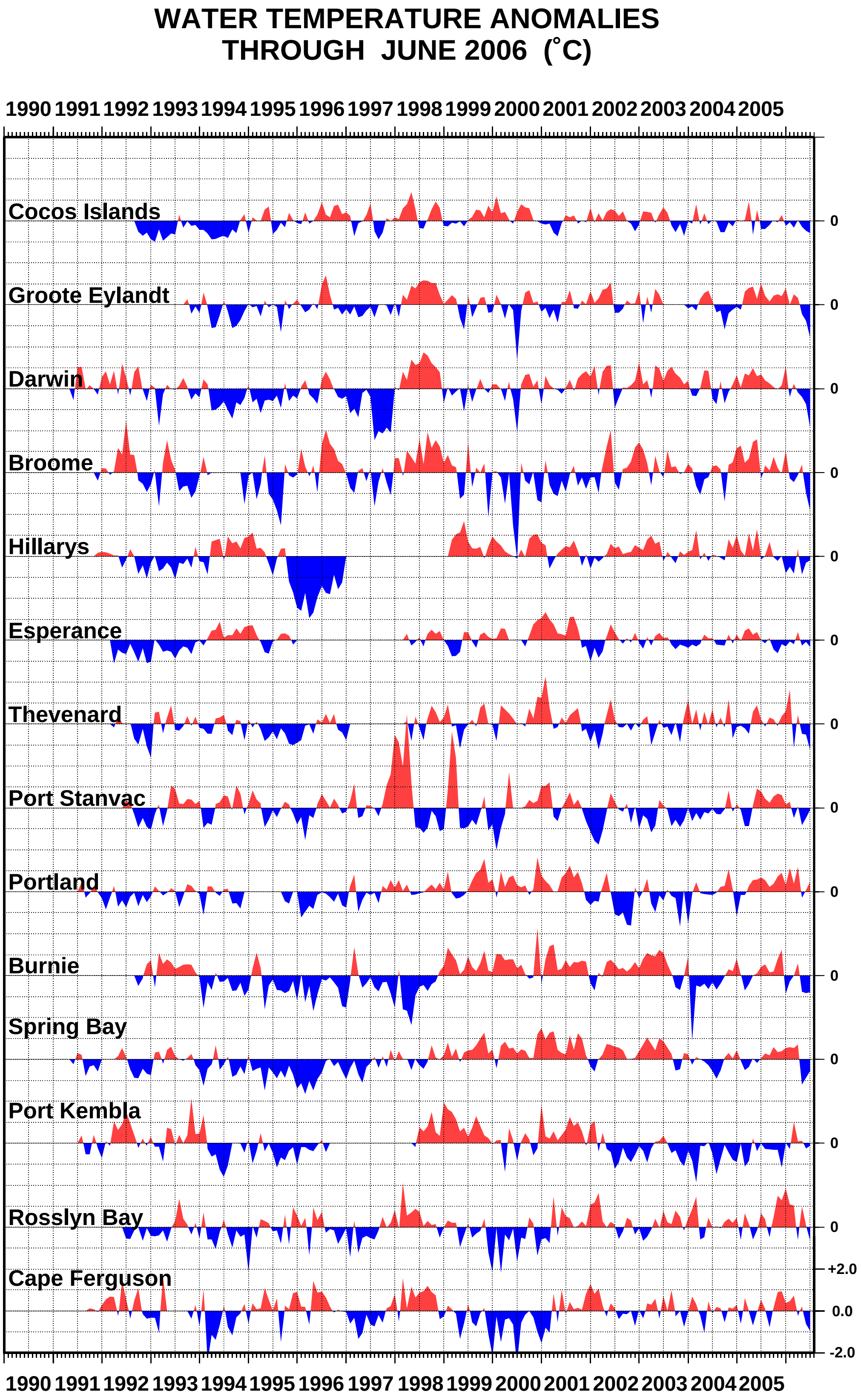


Figure 14. *Water temperature anomalies to June 2006.*

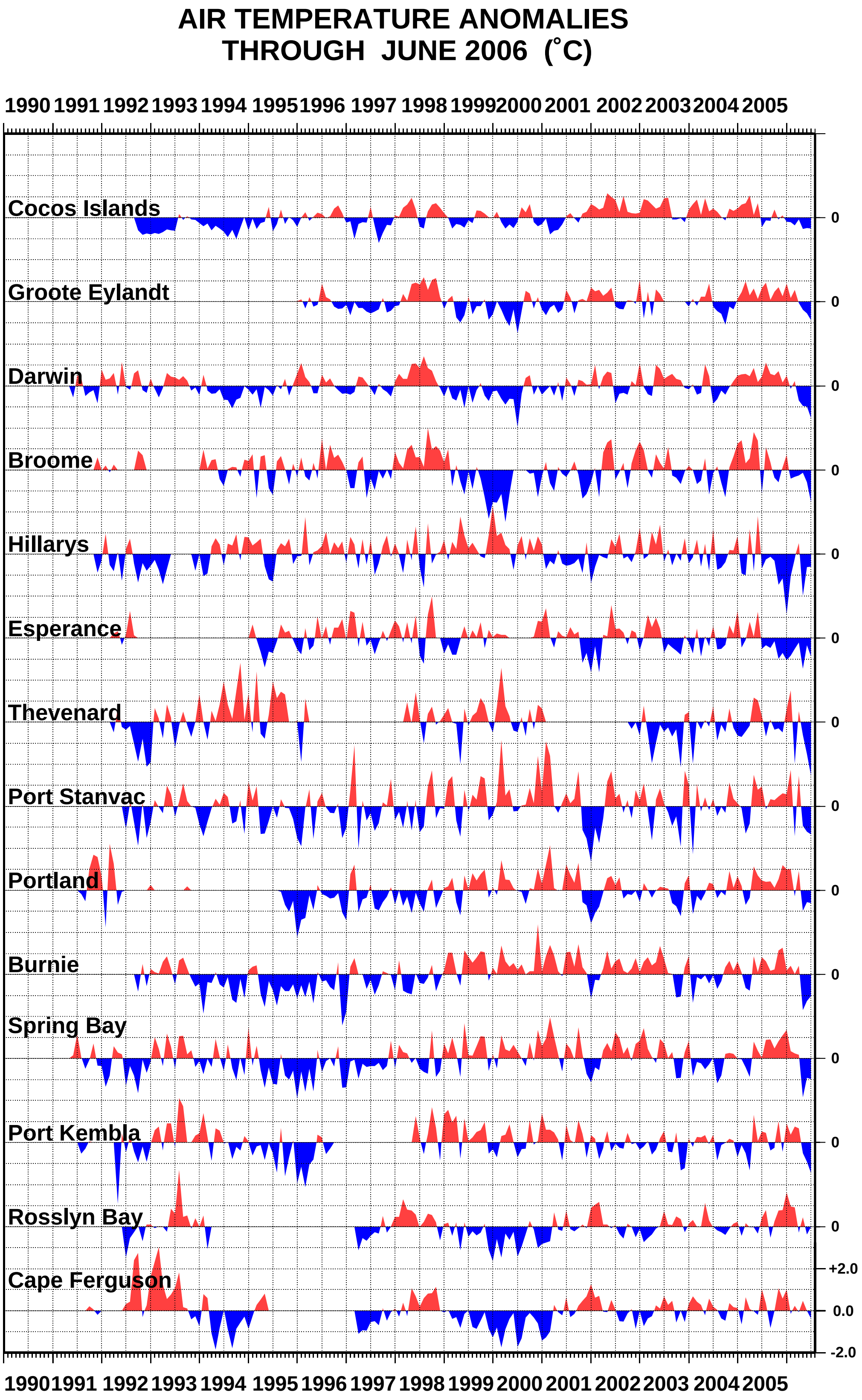


Figure 15. *Air temperature anomalies to June 2006.*

4.3. Sea Level Trends

4.3.1. Relative sea level trends

Sea level is influenced by natural climate variation (e.g. El Niño, Pacific Decadal Oscillation) in addition to long-term climate change (e.g. global warming, sea level rise). Over the short term, large fluctuations in climate such as El Niño and Pacific Decadal Oscillations can conceal the longer-term climate change.

The vertical stability of the SEAFRAME stations also needs to be monitored. Differential leveling of the SEAFRAME to land-based benchmarks is essential for effective long-term relative sea level monitoring. Ideally, sea levels should also be referenced to an absolute frame of reference by tying the benchmark network to the International Terrestrial Reference Frame using methods such as a continuous GPS measurement program.

It is important to emphasise that as the ABSLMP sea level records increase in length, the sea level trend estimates will continue to stabilise and become more indicative of longer-term changes (Figure 16). Caution must be exercised in interpreting the 'short-term' relative sea level trends listed in Table 2 as they are still undergoing large year-to-year changes.

Location	Installation Date	Sea Level Trend (mm/yr)	Change from June 2005
Cocos Islands	Sep 1992	10.6	-0.4
Groote Eylandt	Sep 1993	7.8	+0.5
Darwin	May 1990	8.0	-0.1
Broome	Nov 1991	9.7	-0.7
Hillarys	Nov 1991	7.8	-0.5
Esperance	Mar 1992	5.1	-0.4
Thevenard	Mar 1992	4.5	+0.1
Port Stanvac	Jun 1992	5.9	+0.2
Portland	Jul 1991	3.3	+0.7
Lorne	Jan 1993	2.8	+0.9
Stony Point	Jan 1993	2.4	+0.8
Burnie	Sep 1992	2.9	+0.5
Spring Bay	May 1991	3.8	+0.6
Port Kembla	Jul 1991	4.3	+0.3
Rosslyn Bay	Jun 1992	2.2	-0.4
Cape Ferguson	Sep 1991	2.9	-0.5

Table 2. *Recent short-term relative sea level trends based upon SEAFRAME data to June 2006.*

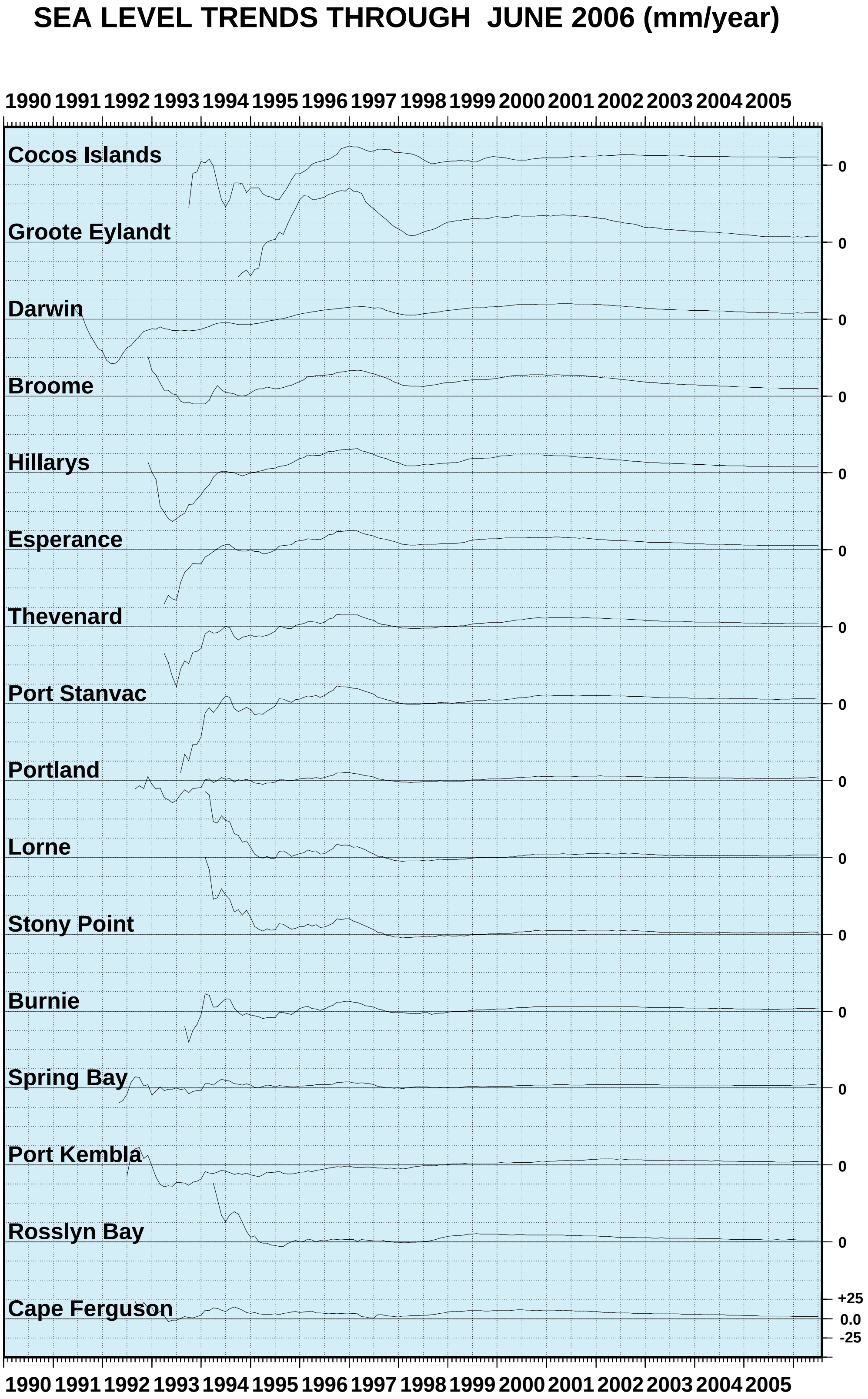


Figure 16. *Monthly sea level trend estimates. The trends will continue to stabilise as the length of records increase.*

4.3.2. Precise levelling

Precise levelling support for the Australian Baseline Sea Level Monitoring Project is provided by relevant state agencies and Geosciences Australia. The purpose of levelling sea level monitoring gauges is to establish whether they are moving vertically with respect to the land. An array of coastal benchmarks must be surveyed periodically to allow stable benchmarks to be identified and used as a reference for the tide gauge. Further information about geodetic support for the Australian Baseline Sea Level Monitoring Project may be found at http://www.ga.gov.au/geodesy/slm/abslmp/.

The surveyed heights of the SEAFRAME stations with respect to the local primary tide gauge benchmark available to date have been analysed and the rates of vertical movement are summarised in Table 3 and Figures 17 and 18. The SEAFRAME at Cocos Island appears to have undergone subsidence at a rate of 0.8 mm/yr, and a correction for this movement will reduce the observed relative sea level trend. Stations around the Australian mainland appear more vertically stable, although there is evidence of both subsidence and emergence at some stations. Corrections to the measured sea level trends are applied in section **4.3.4. Combined net rate of relative sea level trends.**

Location	Installation Date	Trend in the Datum of the Sea Level Sensor (mm/yr)
Cocos Islands	Sep 1992	-0.8
Groote Eylandt	Sep 1993	+0.1
Darwin	May 1990	+0.3
Broome	Nov 1991	-0.2
Hillarys	Nov 1991	+0.0
Esperance	Mar 1992	-0.3
Thevenard	Mar 1992	+0.2
Port Stanvac	Jun 1992	+0.0
Portland	Jul 1991	+0.0
Lorne	Jan 1993	-0.1
Stony Point	Jan 1993	-0.2
Burnie	Sep 1992	+0.0
Spring Bay	May 1991	-0.2
Port Kembla	Jul 1991	+0.0
Rosslyn Bay	Jun 1992	-0.0
Cape Ferguson	Sep 1991	+0.1

Table 3. *Trends in the datum of the SEAFRAME sea level sensor as determined from precise levelling between the sensor and the tide gauge benchmark.*

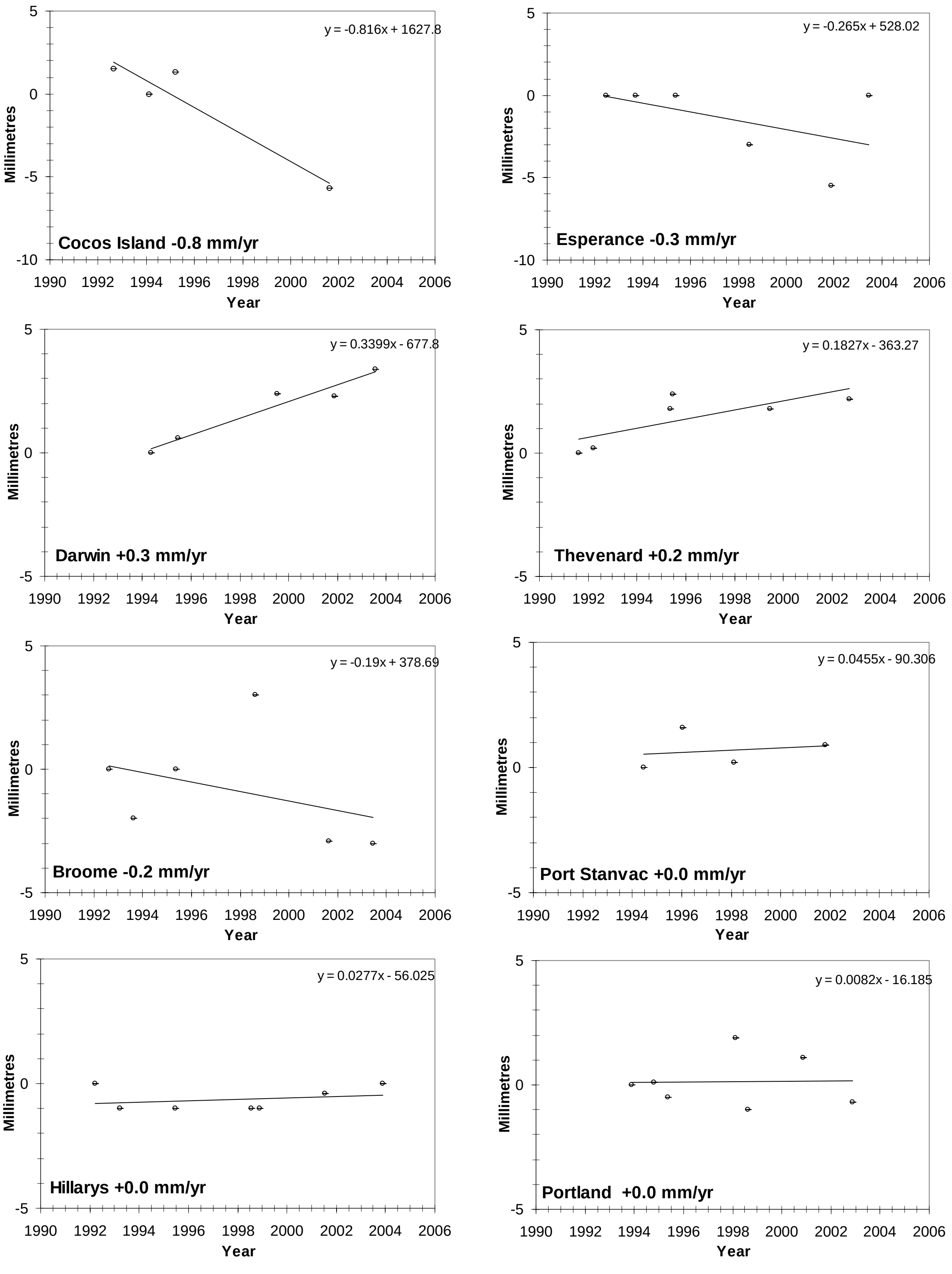


Figure 17. *Surveyed heights of the SEAFRAME sea level sensor relative to the primary tide gauge benchmark and the overall trend in the datum as determined from precise levelling.*

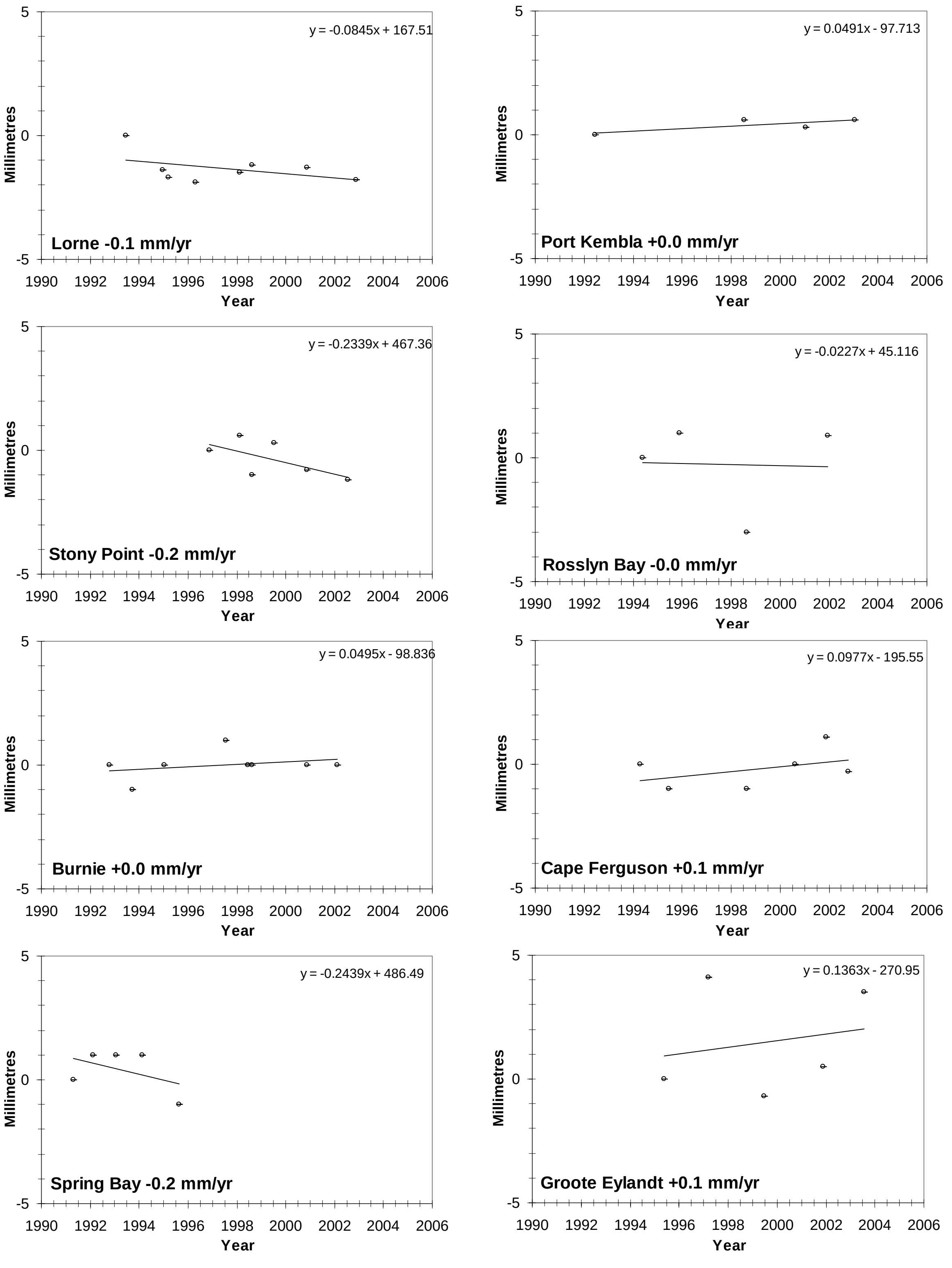


Figure 18. *Surveyed heights of the SEAFRAME sea level sensor relative to the primary tide gauge benchmark and the overall trend in the datum as determined from precise levelling.*

4.3.3. Inverted barometric pressure effect

Another parameter that influences the estimates of relative sea level rise is atmospheric pressure. Known as the inverse barometer effect, if a 1 hPa fall in barometric pressure is sustained over a day or more, a 1 cm rise is produced in the local sea level (within the area beneath the low pressure system). Therefore, if there are trends in the barometric pressure recorded at the tide gauge sites, there will be a contribution to the observed relative sea level trends. The contribution will be a 10 mm/year increase (decrease) in relative sea levels for a 1 hPa/year decrease (increase) in barometric pressure.

Table 4 contains the estimates of the contribution to relative sea level trends by the inverted barometric pressure effect in mm/year at all SEAFRAME sites over the period of the project. The contributions have been mostly positive, so a correction for the inverse barometer effect will reduce the observed relative sea level trends at most stations.

Location	**Installation Date**	**Barometric Pressure Contribution to Sea Level Trend (mm/yr)**	**Change from June 2005 (mm/yr)**
Cocos Islands	Sep 1992	-0.1	0
Groote Eylandt	Sep 1993	-0.4	+0.3
Darwin	May 1990	+0.5	+0.1
Broome	Nov 1991	+0.8	0
Hillarys	Nov 1991	+0.4	-0.3
Esperance	Mar 1992	+0.7	-0.1
Thevenard	Mar 1992	+0.7	0
Port Stanvac	Jun 1992	+0.6	0
Portland	Jul 1991	+0.3	+0.1
Lorne	Jan 1993	N/A	N/A
Stony Point	Jan 1993	N/A	N/A
Burnie	Sep 1992	+0.9	0
Spring Bay	May 1991	+0.2	+0.1
Port Kembla	Jul 1991	+2.5	0
Rosslyn Bay	Jun 1992	+0.5	0
Cape Ferguson	Sep 1991	+0.6	0

Table 4. *Recent short-term barometric pressure trends expressed as equivalent sea level rise in mm/year based upon SEAFRAME data to June 2006.*

4.3.4. Combined net rate of relative sea level trends

The effects of the vertical movement of the platform and the inverse barometer effect are removed from the estimated relative rates of sea level change and presented in Table 5. Sea level change over the duration of the project has not been geographically uniform, with the largest trends observed around the north and west Australian coastline adjacent to the Indian Ocean (Figure 19). This pattern, which is based on just over a decade of observations, is in agreement with maps of sea level change derived from satellite altimetry data. With ongoing sea level monitoring the expectation is that the signal to noise ratio will improve - the longer-term sea level change signal will continue to emerge from the noise of decadal fluctuations. The changes to the net sea level trends upon addition of another year of data to June 2006 are shown in Table 5 and Figure 20, and show increases for southeastern Australian stations and Groote Eylandt, and decreases elsewhere.

Location	Installation Date	Net Relative Sea Level Trend (mm/yr)	Change from June 2005 (mm/yr)
Cocos Islands	Sep 1992	9.9	-0.4
Groote Eylandt	Sep 1993	8.3	+0.2
Darwin	May 1990	7.8	-0.2
Broome	Nov 1991	8.7	-0.7
Hillarys	Nov 1991	7.4	-0.2
Esperance	Mar 1992	4.1	-0.3
Thevenard	Mar 1992	4.0	+0.1
Port Stanvac	Jun 1992	5.3	+0.2
Portland	Jul 1991	3.0	+0.6
Lorne	Jan 1993	2.7	+0.9
Stony Point	Jan 1993	2.2	+0.8
Burnie	Sep 1992	2.0	+0.5
Spring Bay	May 1991	3.4	+0.5
Port Kembla	Jul 1991	1.8	+0.3
Rosslyn Bay	Jun 1992	1.7	-0.4
Cape Ferguson	Sep 1991	2.4	-0.5

Table 5. *The net relative sea level trend estimates after vertical movements in the observing platform and the inverted barometric pressure effect are taken into account.*

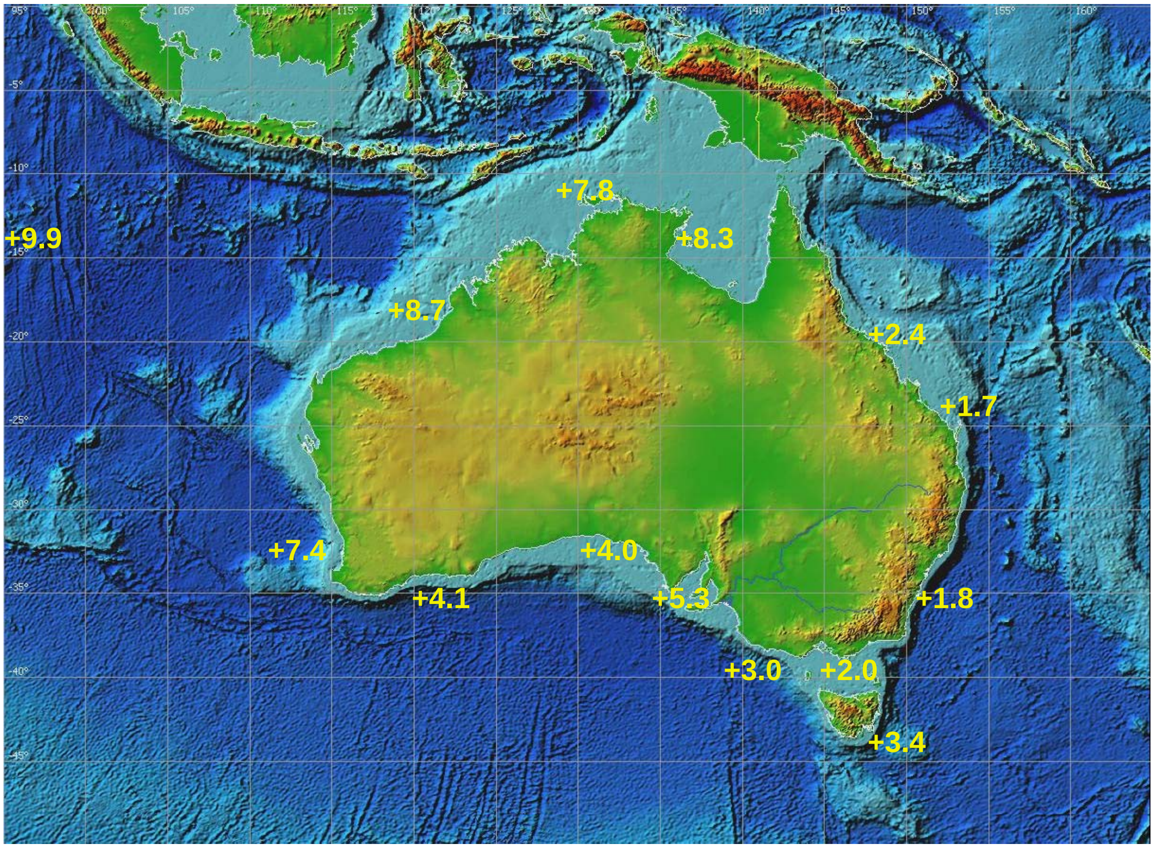


Figure 19. *The net relative sea level trend in mm/year after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure effect utilising all the data collected since the start of the project up to the end of June 2006.*

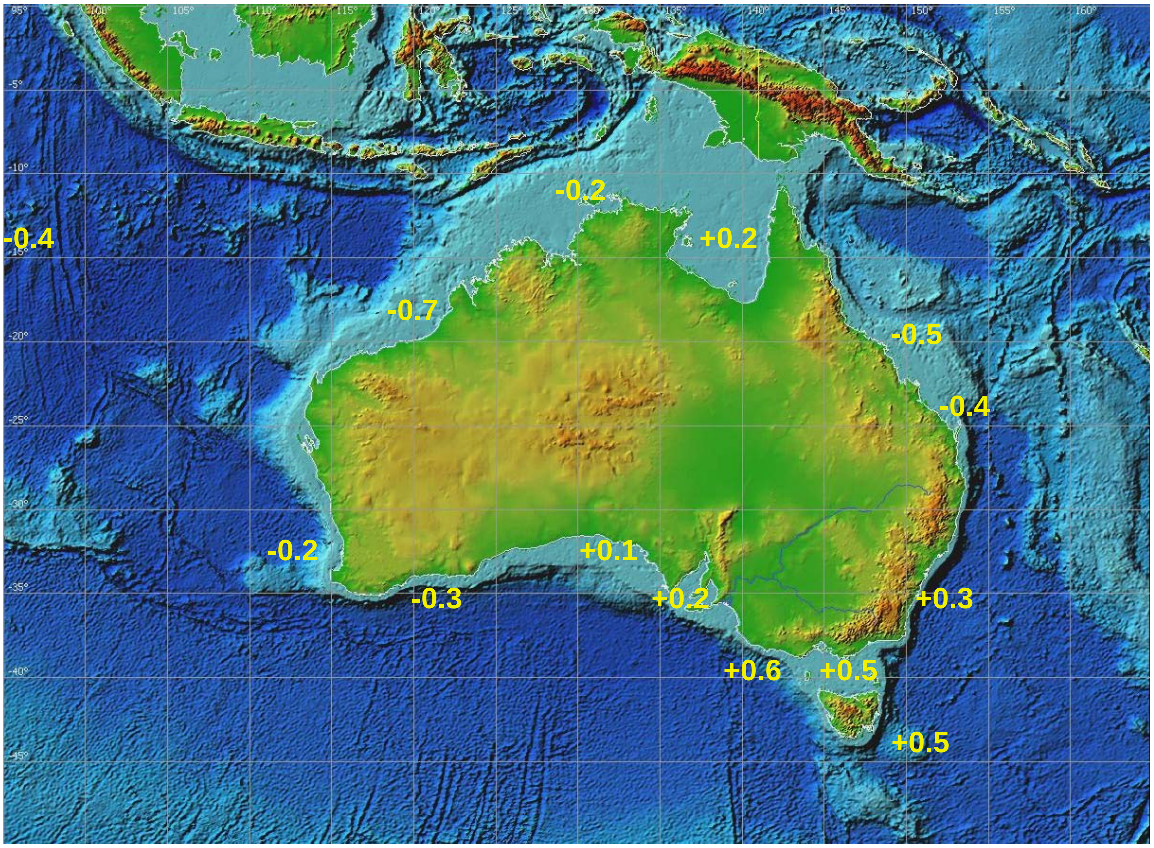


Figure 20. *The change in the net relative sea level trend in mm/year in the twelve months to June 2006. The net trend is defined to be the relative sea level trend after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure effect.*

The TOPEX/Poseidon (T/P) and subsequent Jason-1 satellite altimeter missions have enabled sea levels to be measured on a global basis every 10 days since late 1992, around the time the ABSLMP began. The SEAFRAME stations have provided important ‘ground-truth’ sea level data for calibration and validation of the satellite altimeters. In shallow coastal waters satellite altimeter measurements become inaccurate and tide gauges are a necessity not only for monitoring long-term sea levels but also extreme events.

The global distributions of satellite-altimeter derived sea level trends with and without corrections for the inverse barometer effect are presented in Figure 21. They show that since measurements began in 1992 sea levels have risen across the western Pacific and fallen across the eastern Pacific. This Pacific-wide decadal ‘slosh’ is characteristic of inter-decadal sea level variability as described in section 3.2.2. The differences to the global sea level trends after inverse barometer corrections are applied are not negligible, particularly around Australia, and show the importance of measuring barometric pressure and other meteorological parameters in conjunction with sea level.

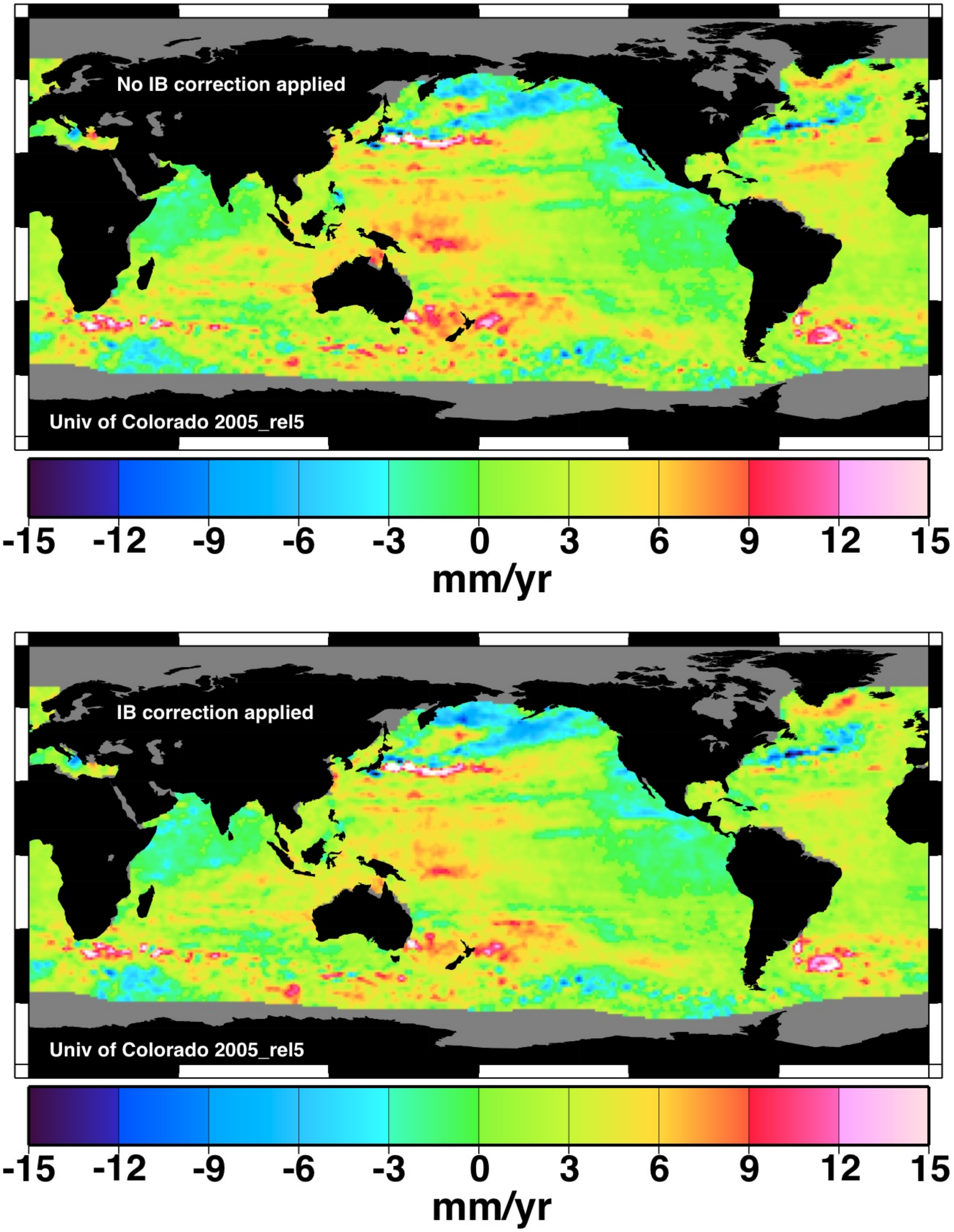


Figure 21. *Global distribution of sea level trend (mm/yr) derived from Topex/Poseidon and Jason-1 satellite altimeter measurements from Dec 1992 to Aug 2005. The lower figure has been corrected for the inverse barometric pressure effect. Figures courtesy of University of Colorado.*

5. SEAFRAME INSTRUMENT PERFORMANCE

For the period July 2005 to June 2006, the following instrumentation problems were encountered and calibration and maintenance undertaken:

Stony Point – Intermittent erroneous wind speed data was recorded in July 2005 and through March-June 2006.

Broome – At Broome a loss of two days of data occurred from 22-24 July 2005 due to power problems. A calibration and maintenance visit was performed from 15-16 November 2005.

Darwin – A calibration and maintenance visit was performed from 18-22 November 2005.

Cocos Island – Small data gaps on 8 September 2005 were unable to be retrieved from the log by dial-up communications. Data from the back-up sea level sensor was used in August 2005 and November 2005. A calibration and maintenance visit was performed from 13-17 October 2005.

Groote Eylandt – A calibration and maintenance visit was performed from 11-13 November 2006. Spikes in the sea level data were experienced in November 2005, and from February 2006 onwards.

Lorne – A technical failure resulted in a loss of data from 23-30 October 2005. Outages in the phone line to the gauge were experienced from 5-9 January 2006 and 20-23 February 2006. On 2 March 2006 a small data gap occurred when the gauge was reset.

Hillarys – A calibration and maintenance visit was performed from 10-12 October 2006.

Esperance – A calibration and maintenance visit was performed from 18-20 October 2006.

Port Kembla - A calibration and maintenance visit was performed from 28 February – 2 March 2006.

Cape Ferguson – A calibration and maintenance visit was performed from the 7-9 March 2006.

Rosslyn Bay – A calibration and maintenance visit was performed from the 4-6 March 2006.

Thevenard – A calibration and maintenance visit was performed from 8-9 February 2006.

Location	Installation Date	Sea Level Data Return Since Installation (%)	Sea Level Data Return Since June 2005 (%)
Cocos Islands	Sep 1992	99.1	100
Groote Eylandt	Sep 1993	99.3	100
Darwin	May 1990	99.9	100
Broome	Nov 1991	97.3	99.2
Hillarys	Nov 1991	99.9	100
Esperance	Mar 1992	95.9	100
Thevenard	Mar 1992	99.3	100
Port Stanvac	Jun 1992	99.4	100
Portland	Jul 1991	98.9	100
Lorne	Jan 1993	99.2	96.4
Stony Point	Jan 1993	98.4	100
Burnie	Sep 1992	98.0	100
Spring Bay	May 1991	99.6	100
Port Kembla	Jul 1991	99.4	100
Rosslyn Bay	Jun 1992	99.6	100
Cape Ferguson	Sep 1991	97.9	100

Table 6. *Sea level data return from project SEAFRAME stations*

6. COMMUNICATION OF RESULTS

Figure 22 shows the number of times the ABSLMP web pages have been visited, by month since January 2003. An increase in the number of web hits occurred after February 2005 when the pages became incorporated into the Bureau of Meteorology website at http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml. A proportion of this increase is due to a change in the method of summarising internet usage statistics.

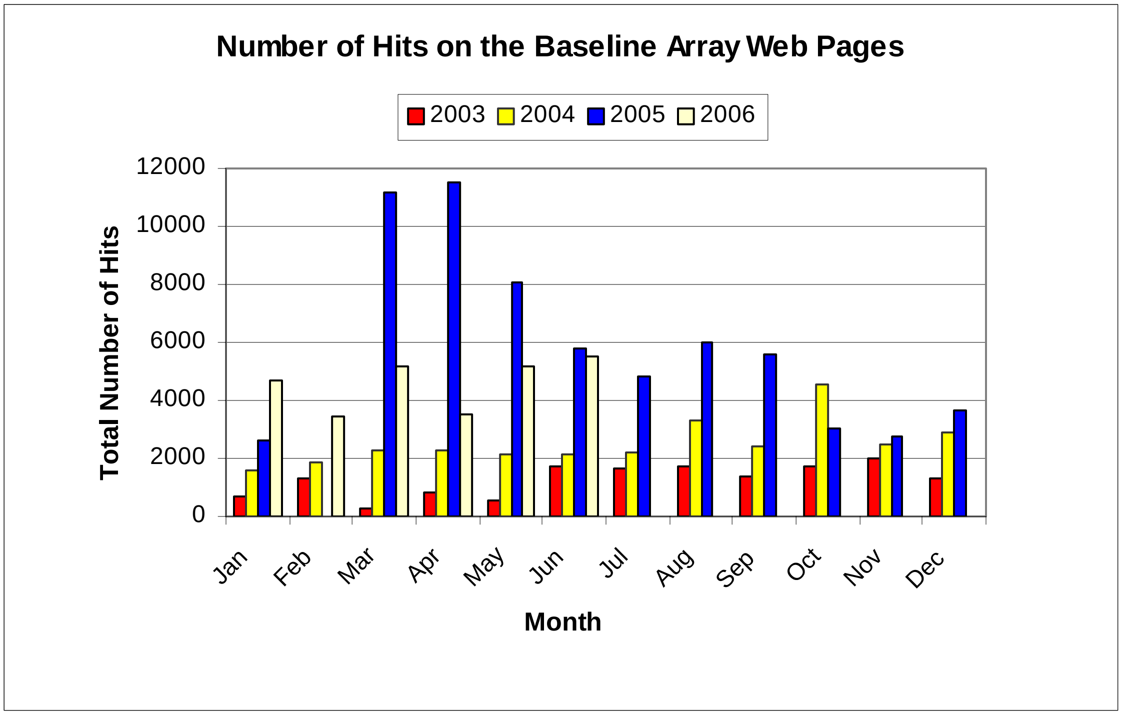


Figure 22. *Number of Hits on the NTC Australian Baseline Array Web Page*

7. FURTHER INFORMATION

Further information about the *Sea Level Data Reports* for the *Australian Baseline Sea Level Monitoring Project* can be obtained from:

National Tidal Centre
Australian Bureau of Meteorology
PO Box 421
Kent Town SA 5067
Tel: (+618) 8366 2730
Fax: (+618) 8366 2651
Email: ntc@bom.gov.au
Website: http://www.bom.gov.au/oceanography/