

**THE AUSTRALIAN BASELINE SEA LEVEL
MONITORING PROJECT**

ANNUAL SEA LEVEL DATA SUMMARY REPORT

JULY 2008 - JUNE 2009

This report was prepared under the Australian Climate Change Science Program for the Department of Climate Change and Energy Efficiency, supported by the National Tidal Centre, Bureau of Meteorology.

This report was prepared by:

**National Tidal Centre
Australian Bureau of Meteorology**

GPO Box 421
Kent Town SA 5071
Australia
Tel: (+618) 8366 2730
Fax: (+618) 8366 2651
Email: ntc@bom.gov.au
Website: <http://www.bom.gov.au/oceanography>



Australian Government
Bureau of Meteorology

Quality Certification:

I authorise the issue of this Australian Baseline Sea Level Monitoring Project Annual Sea Level Data Summary Report for July 2008 - June 2009 in accordance with the quality assurance procedures of the National Tidal Centre, Australian Bureau of Meteorology.

William Mitchell
Manager,
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 2009, 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>.

A summary of the key observations is provided with some additional commentary on how the results relate to broader scientific findings of the international community concerning sea level rise as a result of climate change.

The main findings during the July 2008 – June 2009 period include:

- Testing of a replacement data logger and OH&S assessments were undertaken as part of a program to refurbish the sea level monitoring network.
- The most recent precise levelling results show the SEAFRAME at Cocos Islands is subsiding at 4.5 mm/yr relative to the land-based primary tide gauge benchmark.
- Although tsunamis are observed in Australia every one to two years, no tsunamis were detected in Australia during the July 2008 to June 2009 period.
- The highest monthly mean sea levels on record were observed at Esperance, Thevenard and Port Stanvac in June 2009, at which time the monthly mean barometric pressure acting on the sea surface at these sites was lower than normal.
- Neutral climate conditions with respect to the El Niño – Southern Oscillation cycle prevailed across the equatorial Pacific for the duration of the July 2008 – June 2009 period. Some La Niña characteristics that included higher than normal sea levels around Australia were observed between November 2008 and February 2009, but a basin-wide La Niña did not develop and by June 2009 the equatorial Pacific appeared to be in the early stages of a developing El Niño.
- Although the length of record from Baseline stations is relatively short in climate terms there are a number of clear results emerging. The sea level records for all stations, when corrected for local land movement and changes in atmospheric pressure, demonstrate a regional pattern of sea level trends that is consistent with sea level changes detected by satellite-based altimeters.
- The largest sea level trends over the duration of the project have been observed in the northern and western Australian region.
- The quality-controlled observations collected by the Australian Baseline stations continue to be used for research into sea level, climate variations and climate change, while 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 Australian Climate Change Science Program for the Department of Climate Change and Energy Efficiency. This is a long-term project 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 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 the National Tidal Centre (NTC) as well as two customised stations supported by the private sector; Lorne by the Port of Melbourne Corporation and Stony Point by Port of Hastings Corporation. 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 United States. 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 Australian Baseline 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/>.

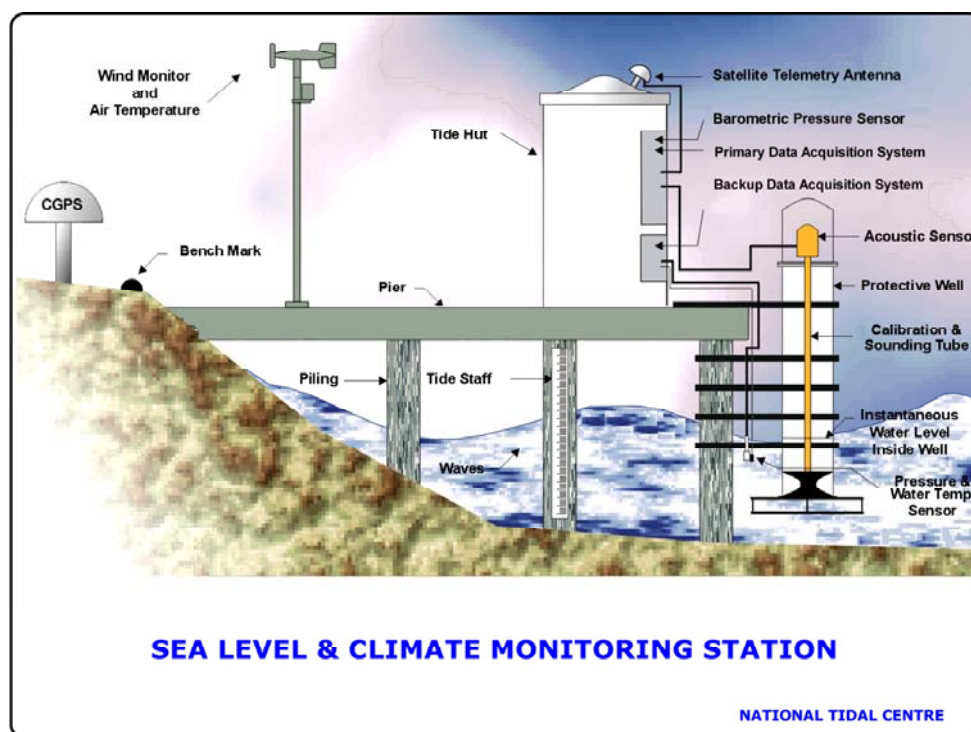
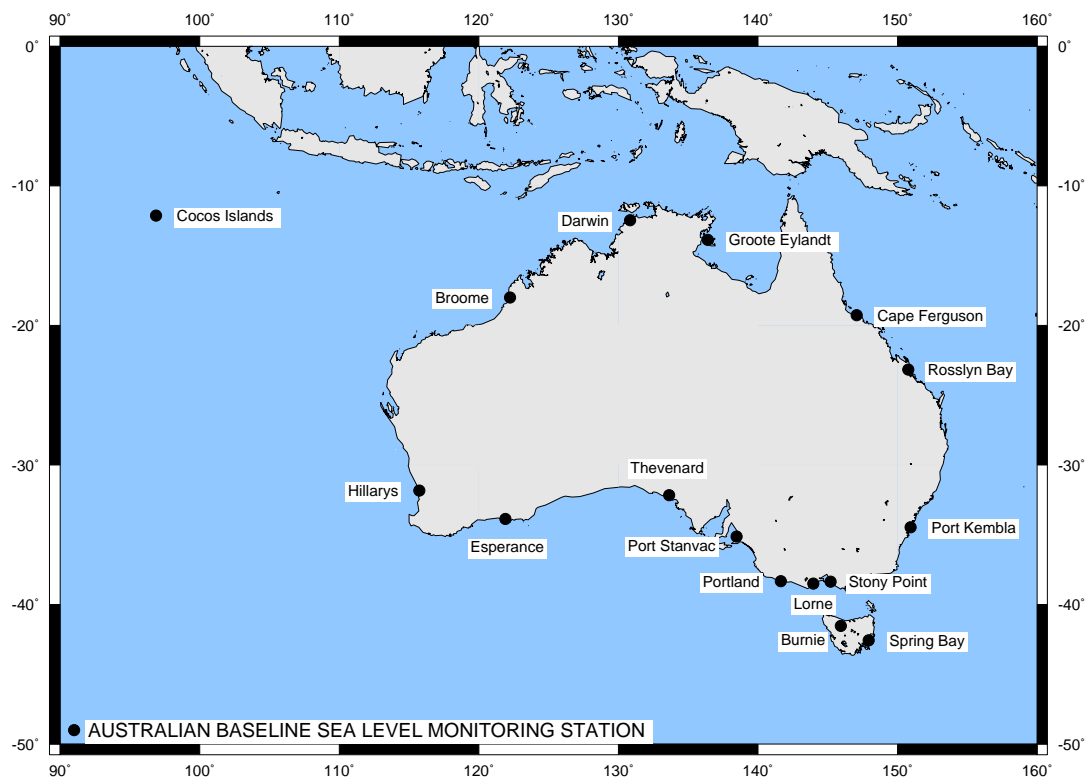


Figure 1. Australian Baseline Sea Level Monitoring Project sites (top) where SEAFRAME stations (bottom) are installed.

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. Operational users of the data include the [BLUElink](#) - Ocean Forecasting Australia project through partnership between the Bureau, CSIRO and the Australian Navy, as well as the Joint Australian Tsunami Warning Centre and other international tsunami warning agencies. Sea level data is submitted to international sea level data centres such as the University of Hawaii Sea Level Centre and the Permanent Service for Mean Sea Level. The SEAFRAME stations also contribute to 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' 0.1" S	96° 53' 30.9" E	Sep 1992
Groote Eylandt	13° 51' 36.2" S	136° 24' 56.1" E	Sep 1993
Darwin	12° 28' 18.4" S	130° 50' 45.1" E	May 1990
Broome	18° 00' 03.0" S	122° 13' 07.1" E	Nov 1991
Hillarys	31° 49' 32.0" S	115° 44' 18.9" E	Nov 1991
Esperance	33° 52' 15.2" S	121° 53' 43.3" E	Mar 1992
Thevenard	32° 08' 56.2" S	133° 38' 28.8" E	Mar 1992
Port Stanvac	35° 06' 31.0" S	138° 28' 1.3" E	Jun 1992
Portland	38° 20' 36.4" S	141° 36' 47.4" E	Jul 1991
Lorne	38° 32' 49.4" S	143° 59' 19.8" E	Jan 1993
Stony Point	38° 22' 19.7" S	145° 13' 28.9" E	Jan 1993
Burnie	41° 03' 0.3" S	145° 54' 54.0" E	Sep 1992
Spring Bay	42° 32' 45.1" S	147° 55' 57.8" E	May 1991
Port Kembla	34° 28' 25.5" S	150° 54' 42.7" E	Jul 1991
Rosslyn Bay	23° 09' 39.7" S	150° 47' 24.6" E	Jun 1992
Cape Ferguson	19° 16' 38.4" S	147° 03' 30.4" 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 long 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 (Figure 2 and Figure 3) illustrate occurrences of extreme high or low 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 wave 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.

Height of Monthly Maximum Sea Level Above Highest Astronomical Tide (m)

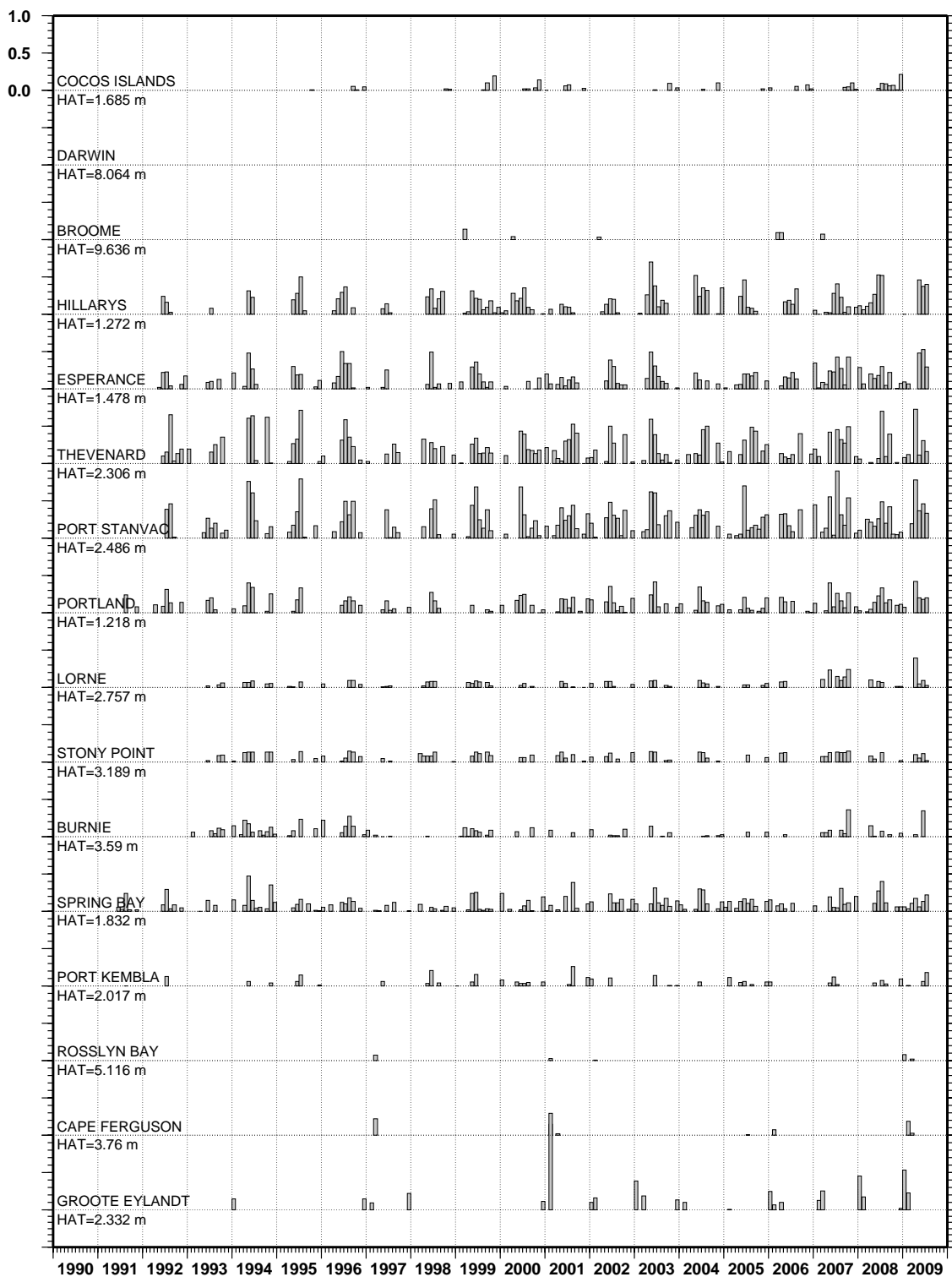


Figure 2. Monthly maximum sea levels at SEAFRAME stations that have exceeded the Highest Astronomical Tide (HAT).

Height of Monthly Minimum Sea Level Below Lowest Astronomical Tide (m)

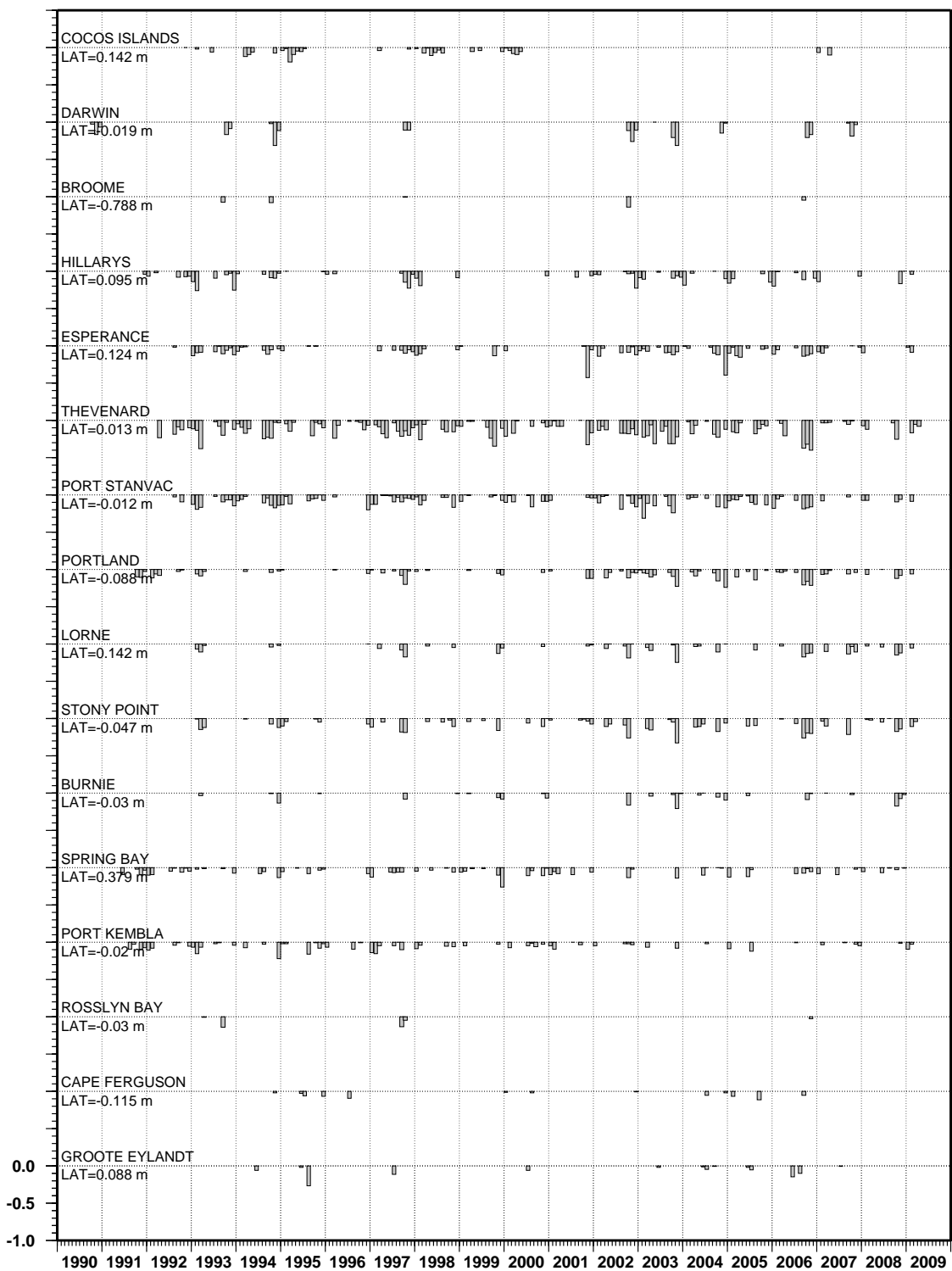


Figure 3. Monthly minimum sea levels at SEAFRAME stations that have fallen below the Lowest Astronomical Tide (LAT).

3.1.1. Tsunamis

The SEAFRAME stations established under the 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 (ATWS), the Pacific Tsunami Warning System and the proposed tsunami warning system for the Indian Ocean. Further information about these programs may be found at

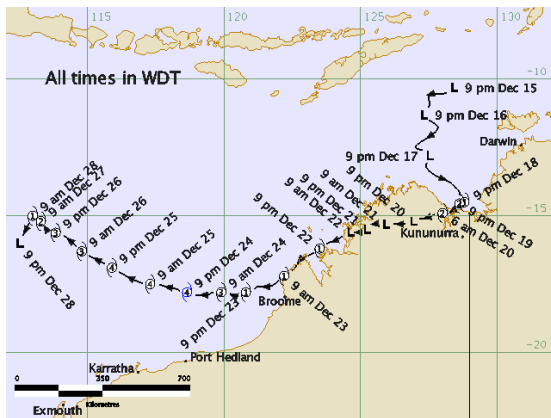
<http://www.bom.gov.au/tsunami/index.shtml>

<http://www.ioc-tsunami.org/>

Tsunamis are observed on average every 1 to 2 years in Australia. The July 2008 to June 2009 period was relatively uneventful, with no tsunami affecting Australia during this time.

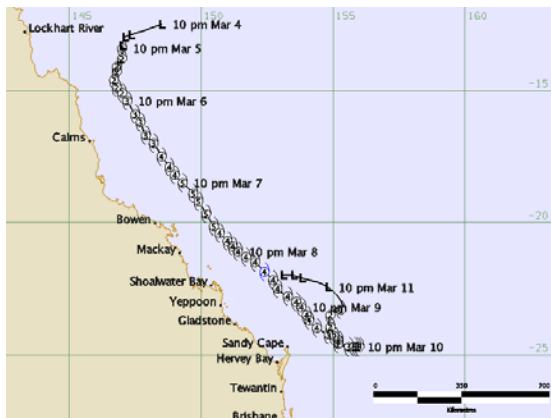
3.1.2. Tropical Cyclones

Two severe tropical cyclones (TC) made landfall on the Australian coastline during the 2008/2009 season. These were TC Billy (18-28 Dec 2008) and TC Hamish (4-11 Mar 2009). Further information about these and other less-severe tropical cyclones is available from the Bureau's website at <http://www.bom.gov.au/announcements/sevwx/>. The observed effects at SEAFRAME stations are listed below.



TC Billy 18 – 28 Dec 2008 (Category 4)

Broome: Strong offshore winds gusting to 28m/s (56knots) were accompanied by sea levels 40cm lower than the predicted tide on 22 Dec. As the cyclone moved into open waters winds turned onshore to 18m/s (36knots) accompanied by sea levels 40cm higher than the predicted tide on 24 Dec.



TC Hamish 4 – 11 Mar 2009 (Category 5)

Rosslyn Bay: Sea levels were 50cm above the predicted tide on 8 Mar and winds gusted to 18 m/s (36knots).

Figure 4. Maps showing the intensity and track of major tropical cyclones crossing the Australian coastline during the 2008/2009 season, and the effects recorded at the SEAFRAME stations: Category 5 is the strongest cyclone category.

3.2. Climate Variability

Variations in sea level and climate are inextricably linked, with both undergoing interrelated seasonal, interannual and interdecadal fluctuations. Fluctuations associated with natural phenomena such as the El Niño – Southern Oscillation can be large and cause significant social and economic impacts. The presence of low frequency variations can mask 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 5) 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 to Indonesia than in the eastern Pacific adjacent to South America. Rainfall is found in rising air over the warmer western waters and the east Pacific is relatively dry.

During El Niño events (top panel of Figure 5), 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 5). 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.

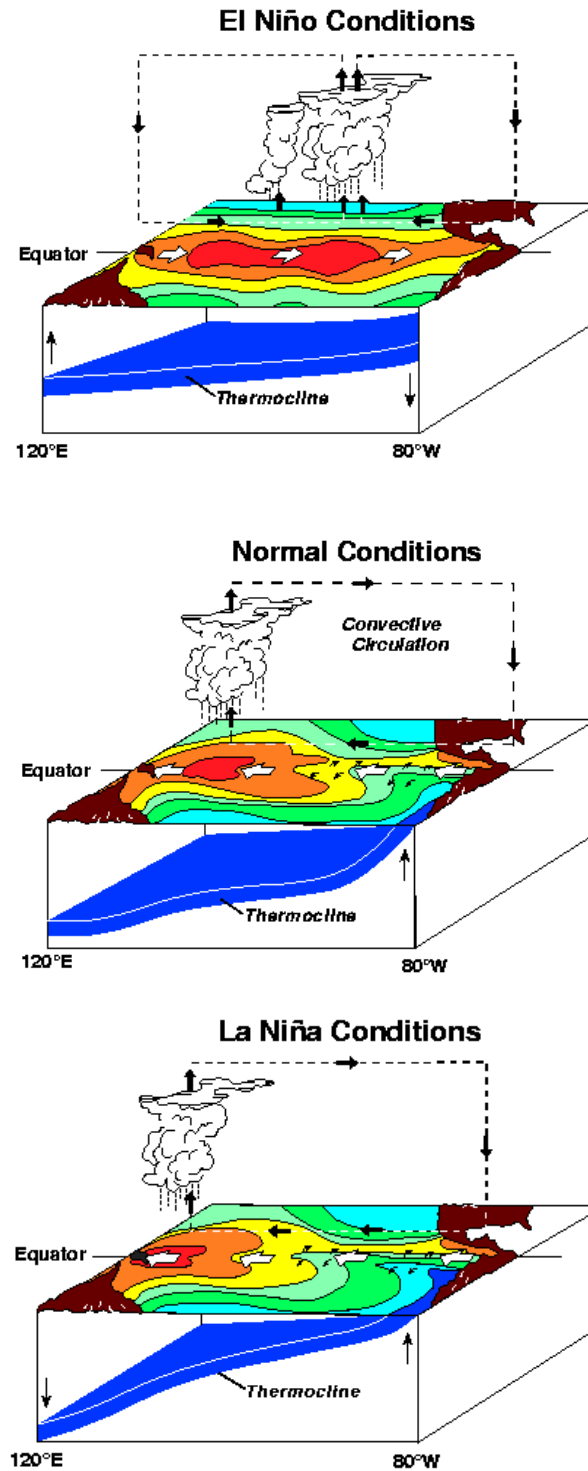


Figure 5. Schematic of atmospheric and ocean conditions associated with El Niño and La Niña.

ENSO conditions July 2008 – June 2009

Climate conditions during the July 2008 – June 2009 period were predominately neutral in terms of the El Niño – Southern Oscillation. Some La Niña characteristics were observed in the equatorial Pacific climate from November 2008 through to February 2009, including cooler than normal ocean heat content across the central to eastern Pacific, stronger than normal Trade Winds, below average cloudiness in the vicinity of the dateline and high values of the Southern Oscillation Index (Figure 6). However, equatorial Pacific temperatures did not cool to the levels required for the development of a basin-wide La Niña event.

Ocean temperatures began to warm slowly across the equatorial Pacific from March 2009 accompanied by a weakening of the Trade Winds. By May 2009 ocean heat content across the equatorial Pacific had become warmer than normal and other climate patterns were consistent with the early stages of a developing El Niño. By the end of June 2009 strong indicators of a developing El Niño continued to persist, including sea surface temperatures 1°C above normal and sub-surface temperatures as much as 4°C warmer than normal. Trade Winds were weaker than normal and cloudiness in the vicinity of the dateline was steadily increasing.

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

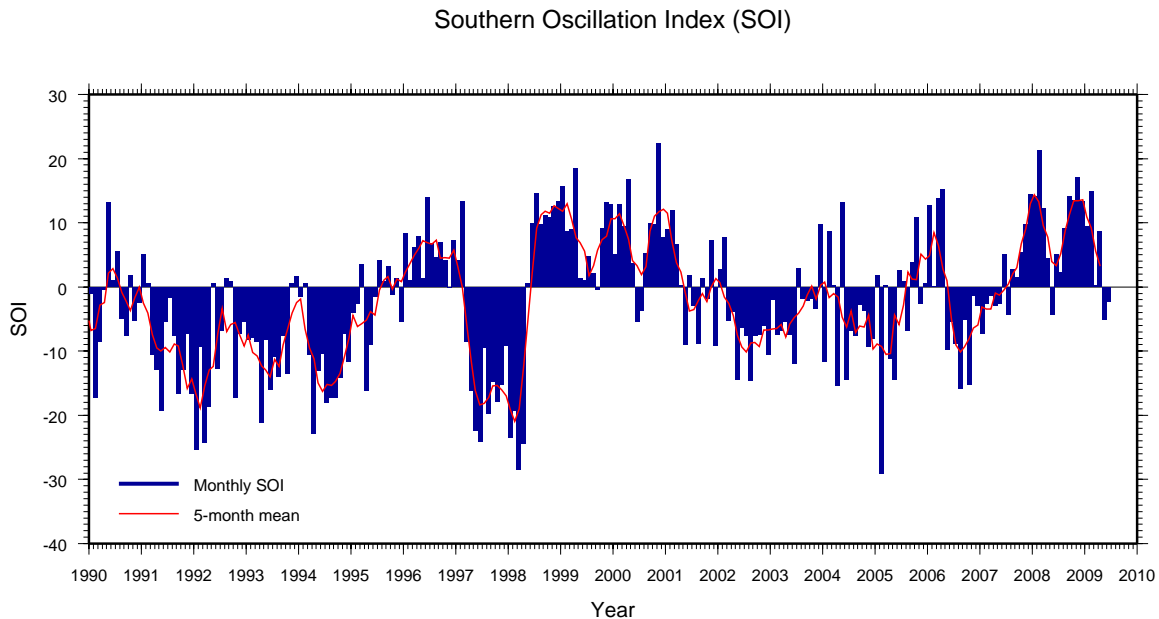


Figure 6. Southern Oscillation Index

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 is yet to span two complete decades, so it is important to recognise that the sea level change observed over this time is largely a measure of decadal *variability*. Continued monitoring is needed to quantify the longer-term trend that is associated with climate *change*.

An example of inter-decadal variability is evidence of a Pacific Decadal Oscillation (PDO), which some scientists believe is 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 lower than normal sea level while a pattern of higher than normal ocean temperatures and higher than normal sea level connects the north, west and south Pacific. During the positive phase, this situation is reversed (Figure 7). In order to track the PDO over time scientists have used temperature data to construct a PDO Index, shown plotted in Figure 8, which suggests how climate and sea level may have fluctuated within the Pacific on decadal timescales since 1900.

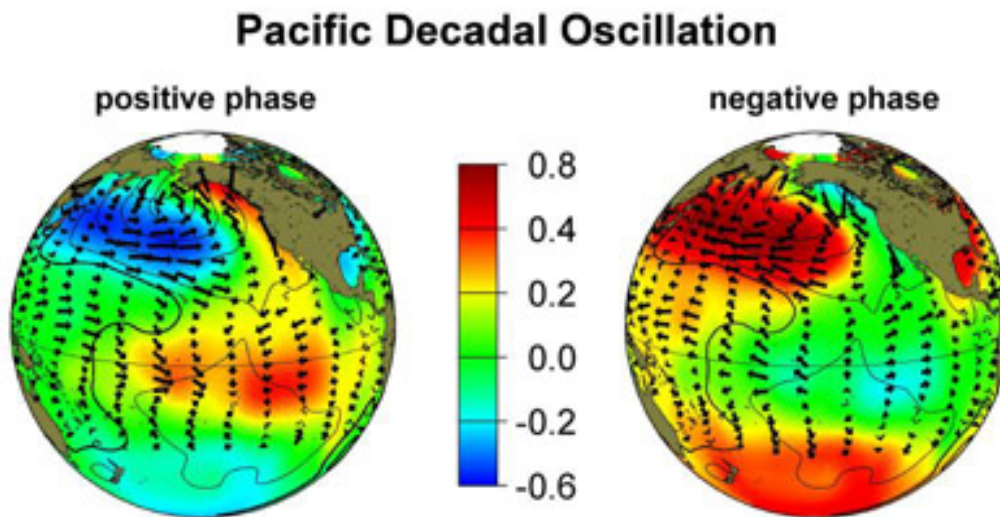


Figure 7. Schematic of sea surface temperature (°C) and wind stress anomalies during positive and negative phases of the Pacific Decadal Oscillation. Figure courtesy of University of Washington.

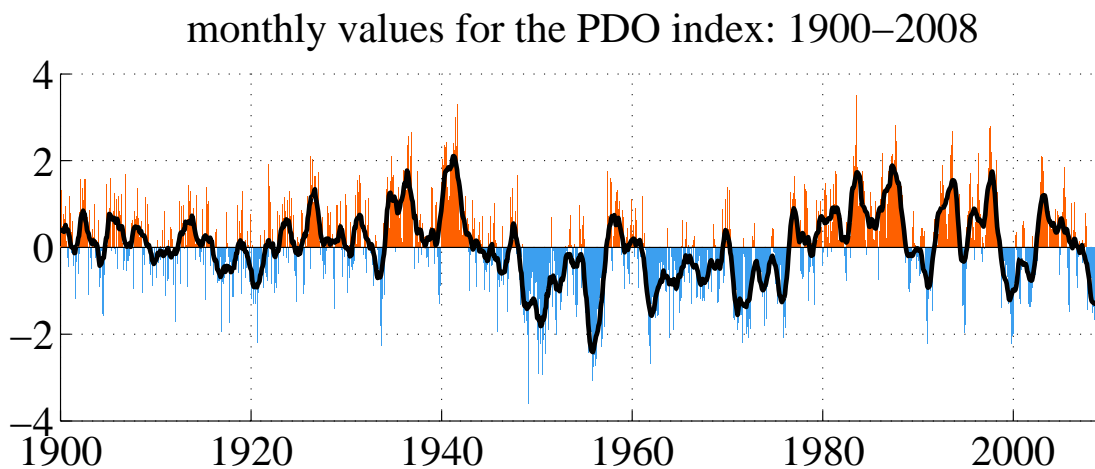


Figure 8. Monthly values for the Pacific Decadal Oscillation Index: 1900-2008. Figure courtesy of University of Washington.

3.3. Climate Change

As discussed in detail by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (IPCC AR4, 2007), 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.

Eustatic sea level change results from changes to the density or to the total mass of water, both of which are related to climate change. Density is reduced by thermal expansion, which occurs as the ocean warms. The total mass of oceanic water can change through transfers from glaciers, ice caps and the Greenland and Antarctic Ice Sheets.

The IPCC AR4, 2007 estimates that global average eustatic sea level rise over the last century was 1.7 ± 0.5 mm/yr. From 1961 to 2003, the average rate of sea level rise is estimated as 1.8 ± 0.5 mm/yr. IPCC AR4, 2007 also recognises that sea level records contain a considerable amount of inter-annual and decadal variability. For instance, the average rate of sea level rise for the decadal period 1993 – 2003 based on satellite altimetry is 3.1 ± 0.7 mm/yr. Studies have shown that comparably large rates of average sea level rise have been observed in previous decades.

Projections of future sea level rise, according to an assessment of global coupled ocean-atmosphere climate computer models in IPCC AR4, 2007, ranges from 0.18 to 0.59 m at 2090-2099 relative to 1980-1999. These projections include contributions from thermal expansion and land ice contribution. In all scenarios the thermal expansion contribution accounts for around 75 % of the total sea level rise. Thermal expansion is expected to continue well after climate stabilises because of the large heat capacity of the ocean.

Although simulations of recent sea level rise (eg 1993 to 2003) are in reasonable agreement with observations, longer-term sea level rise has not been satisfactorily

modelled. This implies a deficiency in the current understanding, which is partly related to the poor global coverage of high quality historical tide gauge records and the uncertainty in the corrections for land motions. 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 regional 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 9) undergo climate-related changes such as seasonal and annual cycles, transient events such as the effects of El Niño and La Niña as well as decadal fluctuations. Underpinning these fluctuations is longer-term relative sea level rise. The annual sea level cycle is the most apparent feature and ranges from around 15 cm 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. Record high monthly mean sea levels were observed at Esperance, Thevenard and Port Stanvac in June 2009 as a result of lower than normal barometric pressure at these sites.

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 10) 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 tend to coincide with high values of the SOI (La Niña) and low sea level coincides with low values of the SOI (El Niño). It follows that the El Niño - Southern Oscillation cycle is a major influence on sea levels around Australia.

Between July 2008 and June 2009 sea levels were generally near normal and within ± 10 cm of what is normally observed at most stations. Periods of slightly higher than normal sea levels were observed, particularly between November 2008 through to February 2009, when positive values of the Southern Oscillation Index (Figure 6) and climate conditions similar to La Niña prevailed. The record high monthly mean sea levels recorded in June 2009 at Esperance, Thevenard and Port Stanvac were associated with sea level anomalies of around +10cm.

4.2.2. Barometric pressure anomalies

The barometric pressure anomalies around Australia (Figure 11) are also strongly influenced by the ENSO cycle, with higher than normal pressure over Australia being a feature of the 1997/98 El Niño. 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 hPa fall (rise) in barometric pressure.

Between July 2008 and June 2009 a period of lower than normal barometric pressures were observed at SEAFRAME stations, particularly from November 2008 through to February 2009 when climate conditions resembled La Niña. Lower than normal barometric pressures were also recorded in June 2009 across southern Australia contributing to the record-high monthly mean sea levels at Esperance, Thevenard and Port Stanvac.

4.2.3. Water temperature anomalies

The water temperature anomalies over the duration of the project (Figure 12) 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. Between July 2008 and June 2009 warmer than normal water temperatures continued to be observed across southern Australia.

4.2.4. Air temperature anomalies

The air temperature anomalies (Figure 13) 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. Between July 2008 and June 2009 air temperatures at SEAFRAME stations were generally near normal and within ± 1 °C of what is normally observed at most stations.

MONTHLY MEAN SEA LEVELS TO JUNE 2009 (m)

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



Figure 9. Monthly mean sea levels to June 2009.

SEA LEVEL ANOMALIES THROUGH JUNE 2009 (m)

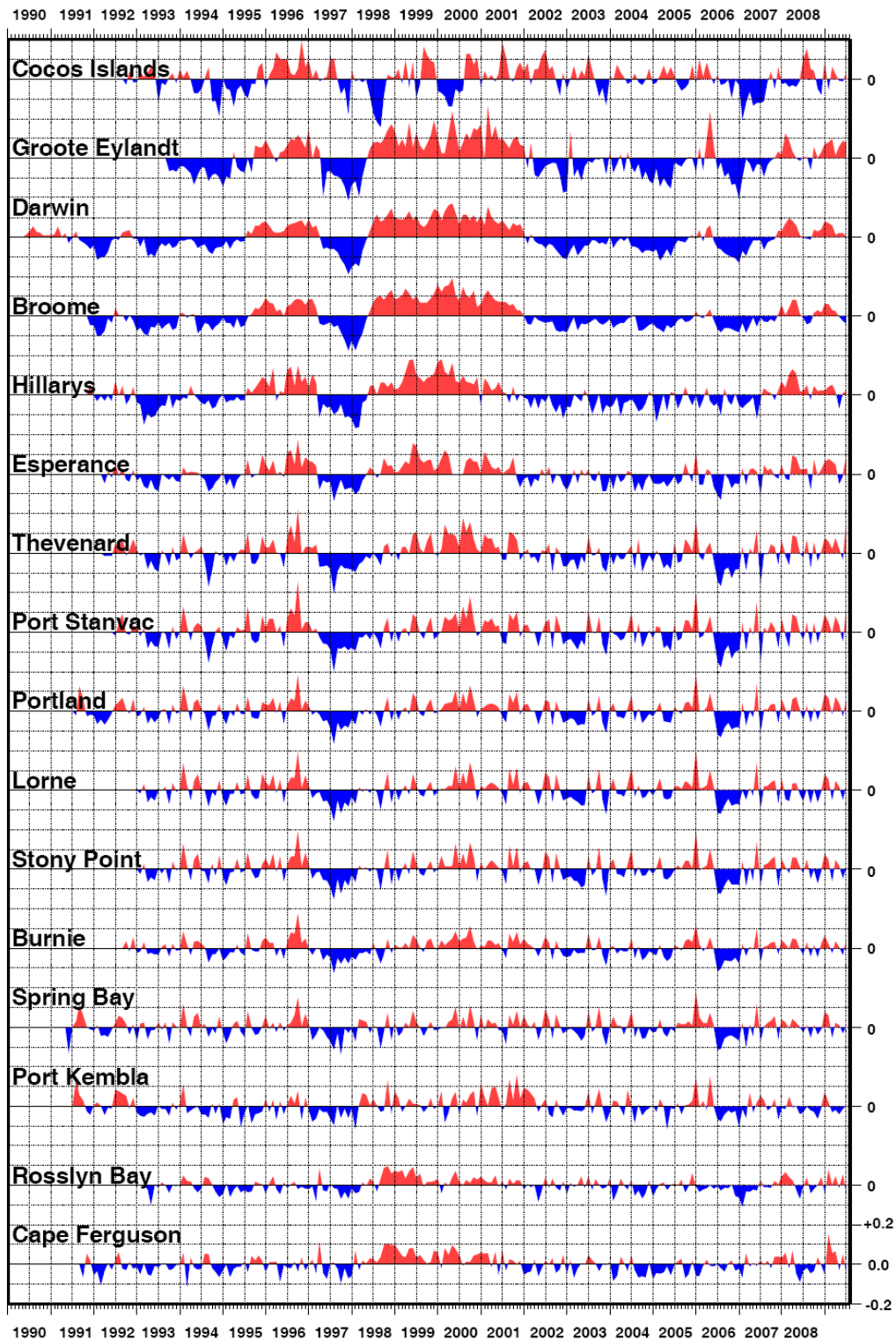


Figure 10. Sea level anomalies to June 2009.

BAROMETRIC PRESSURE ANOMALIES THROUGH JUNE 2009 (hPa)

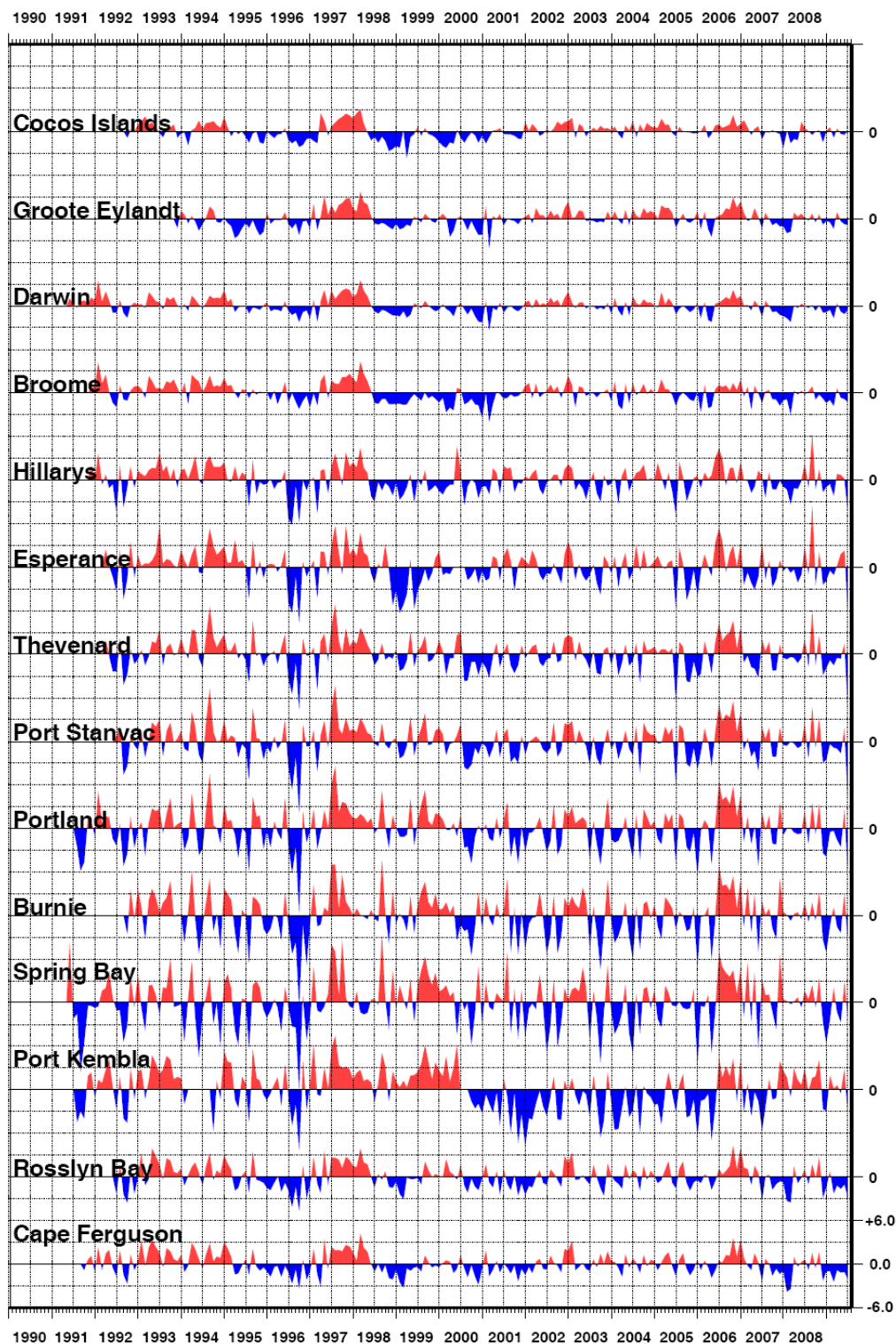


Figure 11. Barometric pressure anomalies to June 2009.

WATER TEMPERATURE ANOMALIES THROUGH JUNE 2009 (°C)

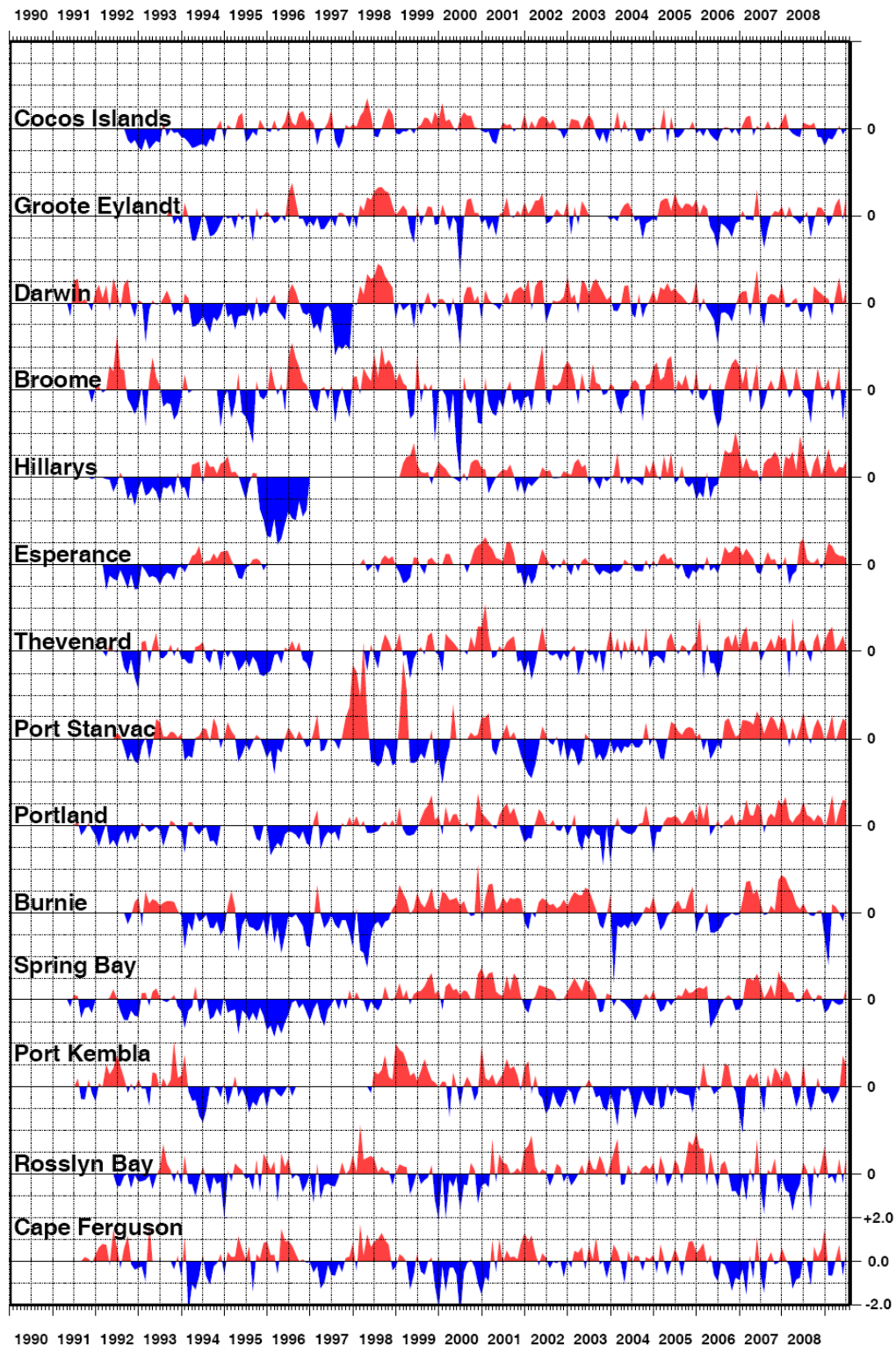


Figure 12. Water temperature anomalies to June 2009.

AIR TEMPERATURE ANOMALIES THROUGH JUNE 2009 (°C)

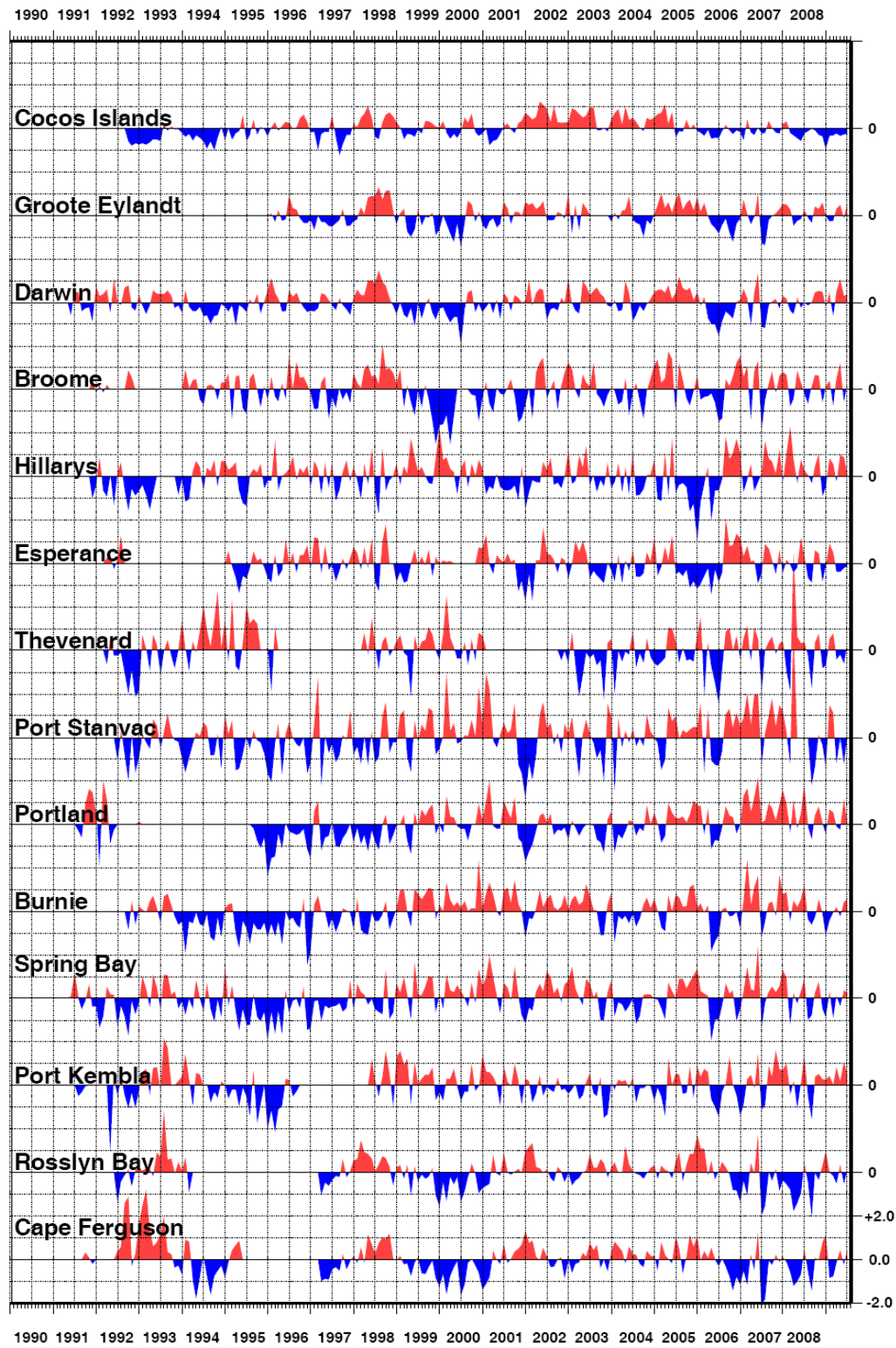


Figure 13. Air temperature anomalies to June 2009.

4.3. Sea Level Trends

4.3.1. Relative sea level trends

Sea level is influenced by natural climate *variations* such as El Niño and decadal oscillations in addition to longer-term climate *change* such as global warming. In fact over short periods of time the transient effects of climate variability are comparatively large and can conceal the slowly accumulating longer-term effects of climate change.

The vertical stability of the SEAFRAME stations also needs to be monitored. Precise levelling 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, as shown in Figure 14. Caution must be exercised in interpreting the ‘short-term’ relative sea level trends (Table 2) as they are based on short records in climate terms and are still undergoing large year-to-year changes.

Location	Installation Date	Sea Level Trend (mm/yr)	Change in trend from June 2008 (mm/yr)
Cocos Islands	Sep 1992	8.4	0.5
Groote Eylandt	Sep 1993	7.5	1.2
Darwin	May 1990	7.7	0.5
Broome	Nov 1991	8.9	0.2
Hillarys	Nov 1991	8.8	0.6
Esperance	Mar 1992	6.1	0.7
Thevenard	Mar 1992	4.5	0.8
Port Stanvac	Jun 1992	5.5	0.6
Portland	Jul 1991	3.1	0.5
Lorne	Jan 1993	1.7	0.0
Stony Point	Jan 1993	1.7	0.0
Burnie	Sep 1992	2.7	0.9
Spring Bay	May 1991	3.3	0.1
Port Kembla	Jul 1991	3.1	-0.2
Rosslyn Bay	Jun 1992	1.9	0.3
Cape Ferguson	Sep 1991	3.0	0.2

Table 2. Recent short-term relative sea level trends based upon SEAFRAME data to June 2009.

SEA LEVEL TRENDS THROUGH JUNE 2009 (mm/year)

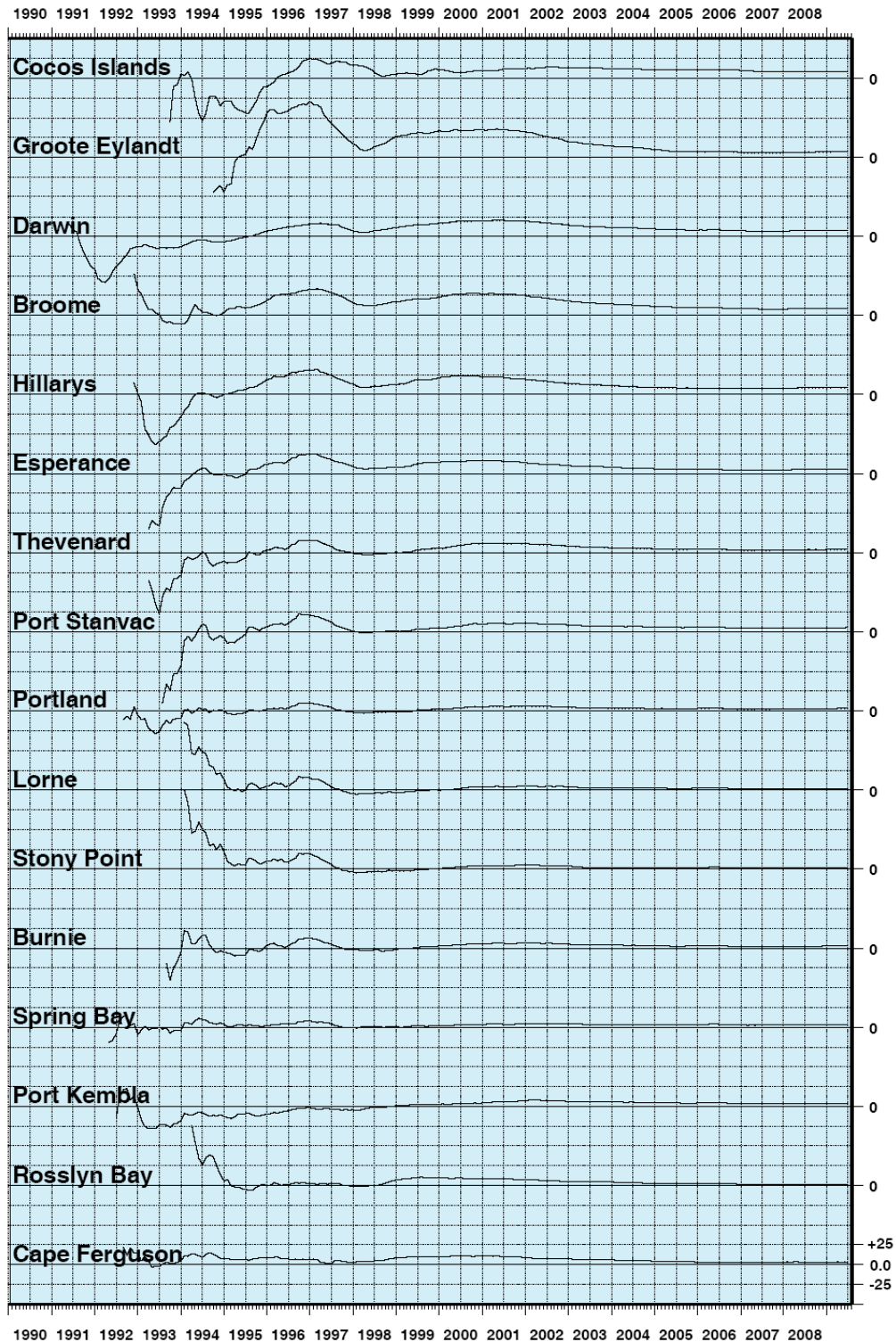


Figure 14. Monthly sea level trend estimates. The trends will continue to stabilise as the length of records increase.

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 levelled 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 Figure 15 and Figure 16. Recent levelling results for the SEAFRAME at Cocos Island shows it is subsiding at a rate of 4.5 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	-4.5
Groote Eylandt	Sep 1993	-0.2
Darwin	May 1990	0.2
Broome	Nov 1991	-0.1
Hillarys	Nov 1991	0.1
Esperance	Mar 1992	-0.4
Thevenard	Mar 1992	0.2
Port Stanvac	Jun 1992	-0.1
Portland	Jul 1991	0.1
Lorne	Jan 1993	0.1
Stony Point	Jan 1993	0.0
Burnie	Sep 1992	0.0
Spring Bay	May 1991	-0.1
Port Kembla	Jul 1991	0.0
Rosslyn Bay	Jun 1992	0.0
Cape Ferguson	Sep 1991	0.3

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.

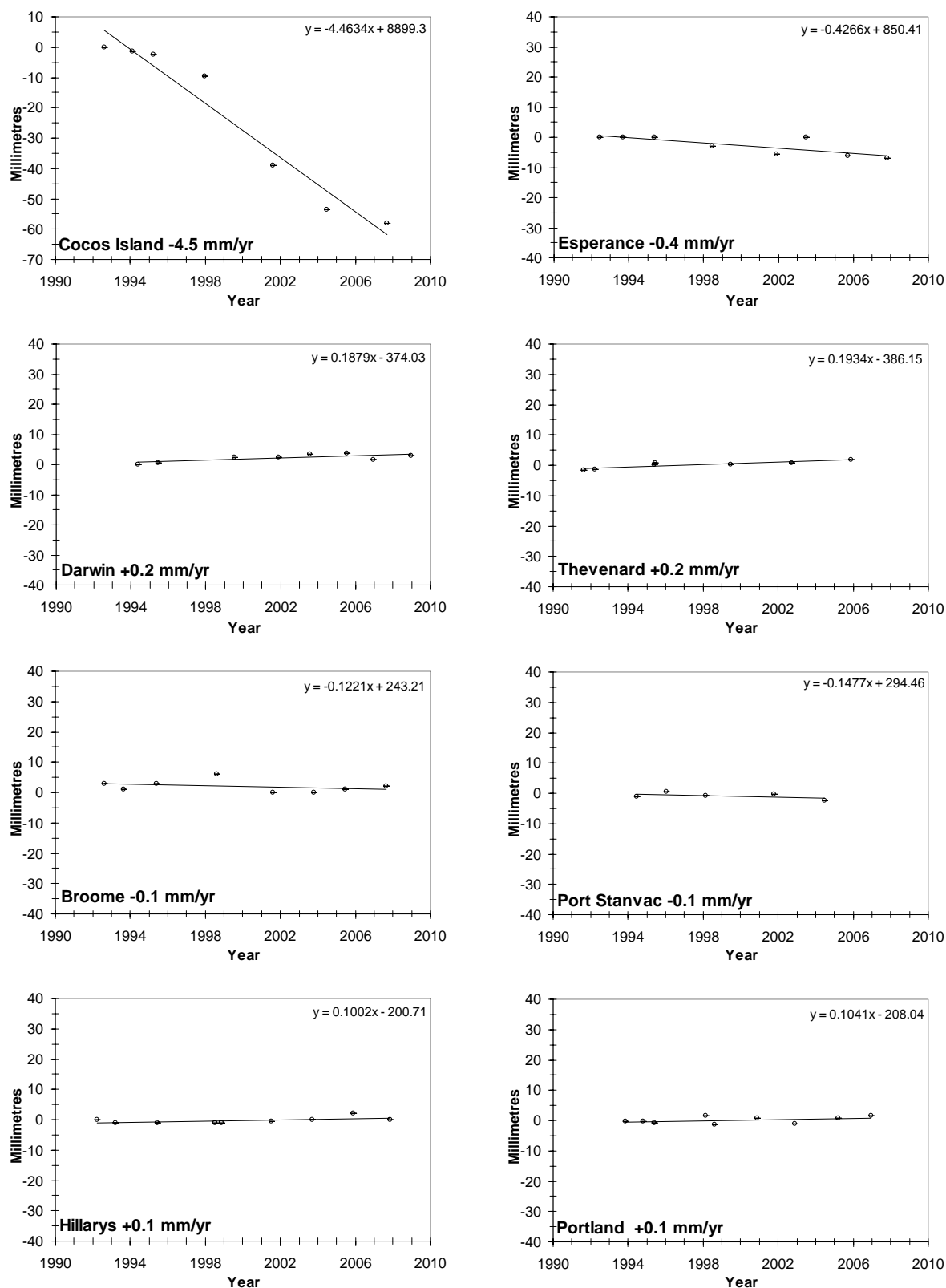


Figure 15. Surveyed heights of the SEAFRAME sea level sensor relative to the primary tide gauge benchmark and the overall trend in the datum as determined from precise levelling.

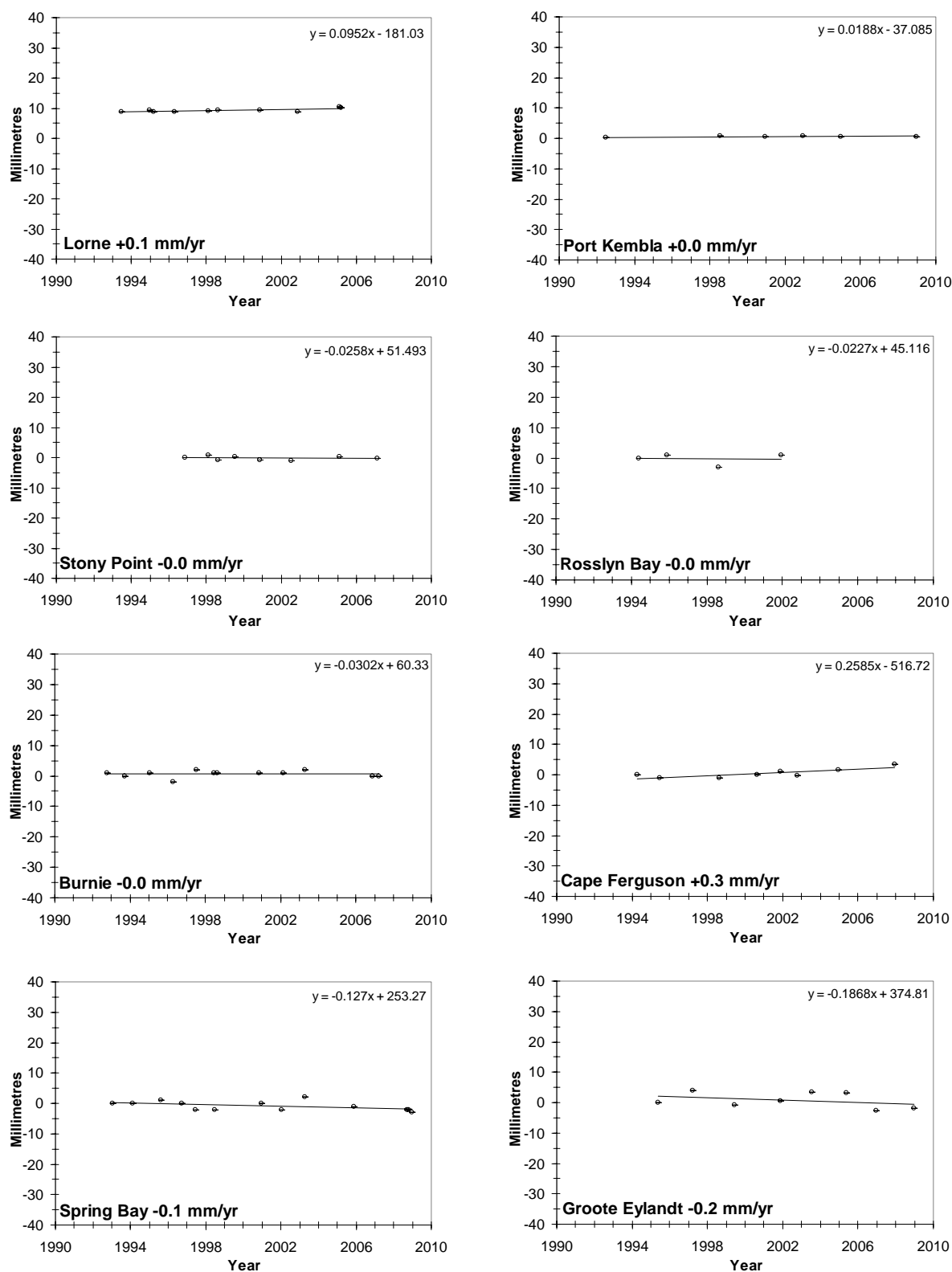


Figure 16. Surveyed heights of the SEAFRAME sea level sensor relative to the primary tide gauge benchmark and the overall trend in the datum as determined from precise levelling.

4.3.3. Inverted barometric pressure effect

Another parameter that influences the rates of relative sea level rise is barometric 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 in B.P. trend contribution from June 2008 (mm/yr)
Cocos Islands	Sep 1992	-0.1	0.0
Groote Eylandt	Sep 1993	-0.2	0.2
Darwin	May 1990	0.4	0.0
Broome	Nov 1991	0.7	0.0
Hillarys	Nov 1991	0.3	0.0
Esperance	Mar 1992	0.4	-0.1
Thevenard	Mar 1992	0.5	0.1
Port Stanvac	Jun 1992	0.3	0.1
Portland	Jul 1991	0.1	0.2
Lorne	Jan 1993	0.0	0.0
Stony Point	Jan 1993	0.0	0.0
Burnie	Sep 1992	0.3	0.2
Spring Bay	May 1991	-0.2	0.1
Port Kembla	Jul 1991	1.2	-0.3
Rosslyn Bay	Jun 1992	0.4	0.1
Cape Ferguson	Sep 1991	0.5	0.0

Table 4. Recent short-term barometric pressure trends expressed as equivalent sea level rise in mm/year based upon SEAFRAME data to June 2009.

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 observed rates of relative sea level change and presented in Table 5. Sea level rise 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 17). This pattern, which is based on less than two decades of observation, is in agreement with maps of sea level change derived from satellite altimetry data over an equivalent period of time. With ongoing sea level monitoring the expectation is that better estimates of the longer-term sea level change signal will increasingly emerge from the ‘noise’ of decadal fluctuations. The changes to the net sea level trends upon addition of another year of data to June 2009 are shown in Table 5 and Figure 18. The overall sea level trends are mostly larger than they were 12 months ago, due in part to periods of higher than normal sea levels around Australia in the past 12 months. At Cocos Islands although the relative sea level trend actually increased by 0.5 mm/yr over the previous 12 months, the net trend shows a decrease of 3.2 mm/yr due to corrections to the precise levelling results.

Location	Installation Date	Net Relative Sea Level Trend (mm/yr)	Change from June 2008 (mm/yr)
Cocos Islands	Sep 1992	4.0	-3.2
Groote Eylandt	Sep 1993	7.5	0.9
Darwin	May 1990	7.5	0.4
Broome	Nov 1991	8.1	0.2
Hillarys	Nov 1991	8.6	0.6
Esperance	Mar 1992	5.3	0.8
Thevenard	Mar 1992	4.2	0.7
Port Stanvac	Jun 1992	5.1	0.5
Portland	Jul 1991	3.1	0.3
Lorne	Jan 1993	1.8	0.0
Stony Point	Jan 1993	1.7	0.0
Burnie	Sep 1992	2.4	0.7
Spring Bay	May 1991	3.4	-0.1
Port Kembla	Jul 1991	1.9	0.1
Rosslyn Bay	Jun 1992	1.5	0.2
Cape Ferguson	Sep 1991	2.8	0.3

Table 5. The net relative sea level trend estimates to June 2009 after vertical movements in the observing platform and the inverted barometric pressure effect are taken into account.

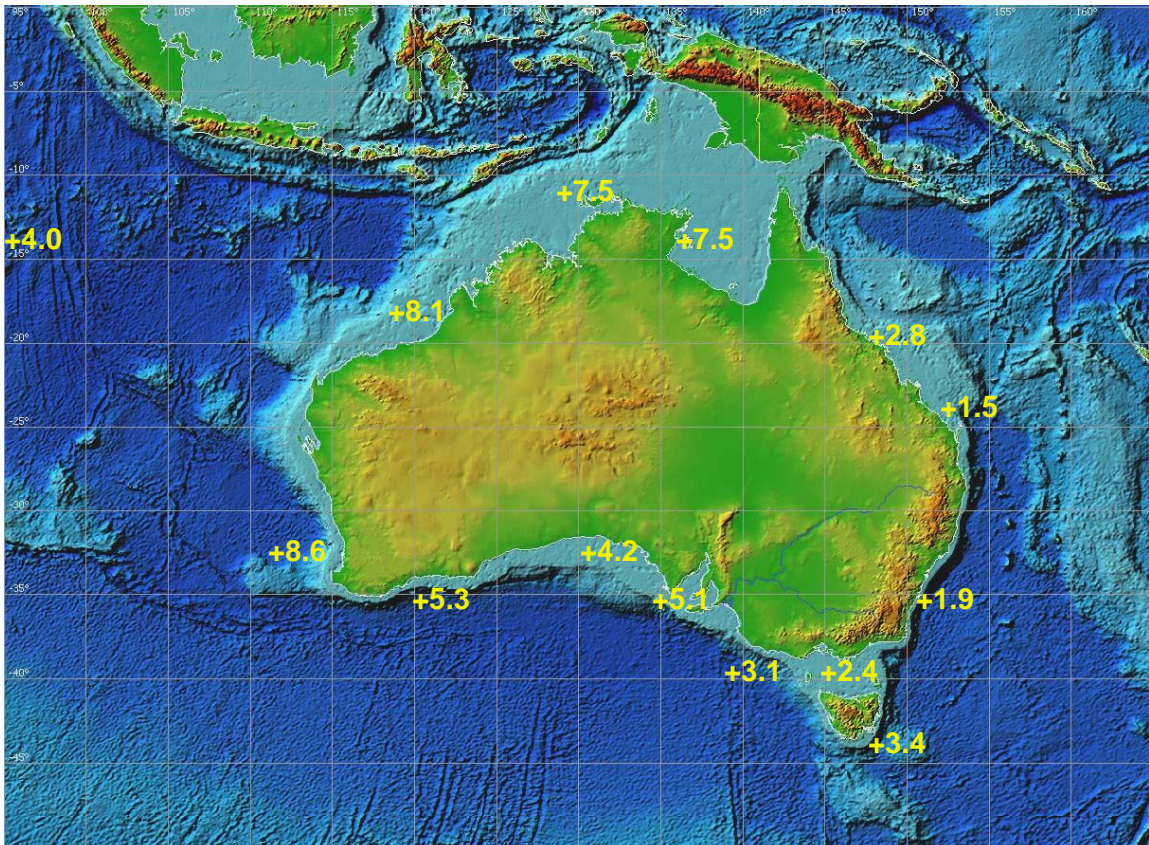


Figure 17. The net relative sea level trend in mm/year after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure effect utilising all the data collected since the start of the project up to the end of June 2009.

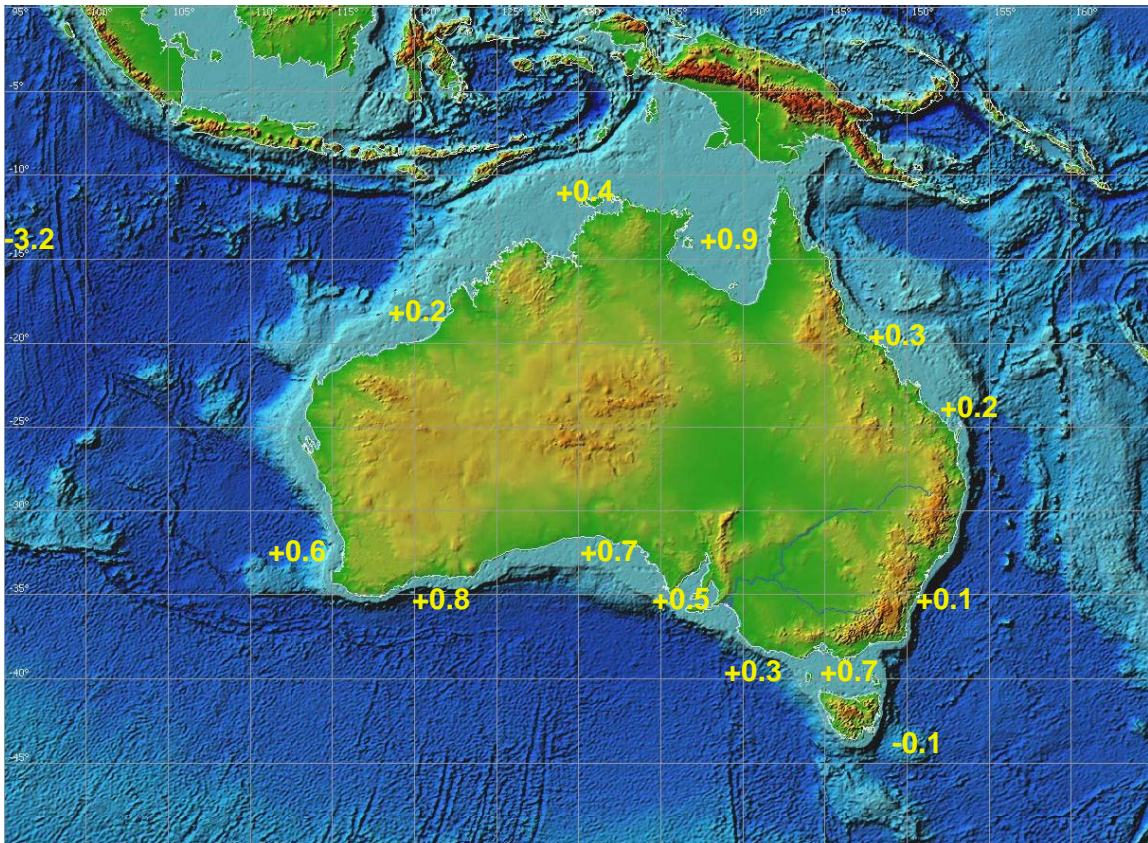


Figure 18. The change in the net relative sea level trend in mm/year between June 2008 and June 2009. The net trend is defined to be the relative sea level trend after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure effect.

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 are inaccurate and tide gauges are a necessity not only for monitoring long-term sea levels but also tides and extreme events.

The global distribution of satellite-altimeter derived sea level trends with corrections for the inverse barometer effect is presented in Figure 19. It shows that since 1992 sea levels have risen more substantially across the western Pacific than across the eastern Pacific. This geographical non-uniformity is related to inter-decadal sea level variability as described in section 3.2.2.

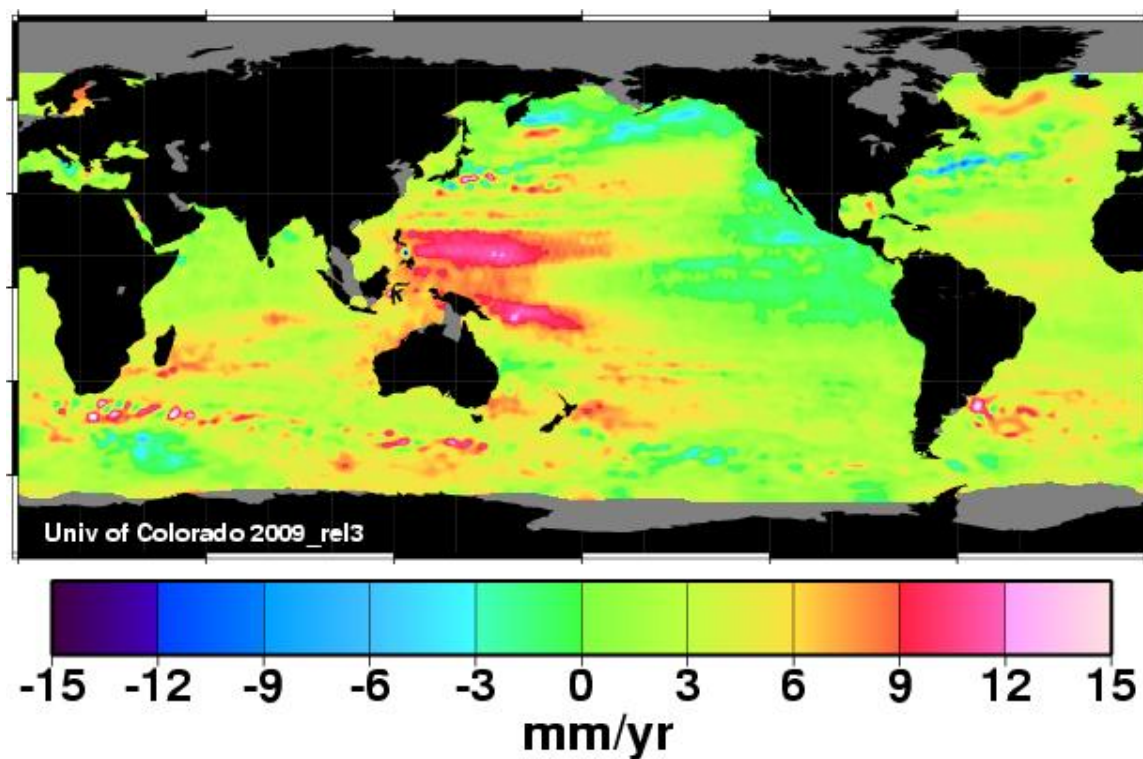


Figure 19. Global distribution of sea level trend (mm/yr) derived from Topex/Poseidon and Jason-1 satellite altimeter measurements from Dec 1992 to July 2009 with corrections for the inverse barometric pressure effect applied. Figure courtesy of University of Colorado

5. SEAFRAME INSTRUMENT PERFORMANCE

For the period July 2008 to June 2009, the Australian Baseline sea level monitoring stations continued to return high rates of quality-controlled data, as shown in Table 6, for research into sea level, climate variations and climate change. They also provided real-time data streams for the monitoring of tsunamis, storm surges and under-keel clearances at ports.

Scheduled calibration and maintenance visits were performed at Portland (August 2008), Stony Point (August 2008), Esperance (September 2008), Hillarys (September 2008), Cocos Islands (September 2008), Groote Eylandt (December 2008), Broome (December 2008), Darwin (December 2008), Thevenard (February 2009), Port Kembla (March 2009) and Cape Ferguson (March 2009).

Development and testing of a replacement data logger and assessment of the occupational health and safety at the SEAFRAME installations were undertaken as part of a network refurbishment program. Upgrades to the sea level monitoring network are to be completed in 2009-10 and will enable Australian Baseline long-term sea level monitoring to be sustained well into the future.

The major instrumentation problems encountered in 2008-09 include:

Broome – Routine shutdown of the SEAFRAME while fuel-tanker ships are in dock was required for occupational health and safety reasons, which lowered data return to 91.4%.

Spring Bay – A failure of the power supply was encountered resulting in a loss of 6 days of data. A replacement battery was installed on 2nd October 2008.

Location	Installation Date	Sea Level Data Return Since Installation (%)	Sea Level Data Return Jul08- Jun09 (%)
Cocos Islands	Sep 1992	99.9	100.0
Groote Eylandt	Sep 1993	99.4	100.0
Darwin	May 1990	99.9	100.0
Broome	Nov 1991	98.7	91.4
Hillarys	Nov 1991	100.0	100.0
Esperance	Mar 1992	97.5	100.0
Thevenard	Mar 1992	99.4	100.0
Port Stanvac	Jun 1992	99.4	100.0
Portland	Jul 1991	99.1	100.0
Lorne	Jan 1993	98.0	99.6
Stony Point	Jan 1993	98.7	100.0
Burnie	Sep 1992	98.2	100.0
Spring Bay	May 1991	99.6	98.3
Port Kembla	Jul 1991	99.4	100.0
Rosslyn Bay	Jun 1992	95.5	99.4
Cape Ferguson	Sep 1991	97.9	98.3

Table 6. Quality-controlled sea level data return from Australian Baseline SEAFRAME stations.

6. COMMUNICATION OF RESULTS

Figure 20 shows the number of times the ABSLMP web pages have been visited, by month since January 2006. The web pages are available at <http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml>

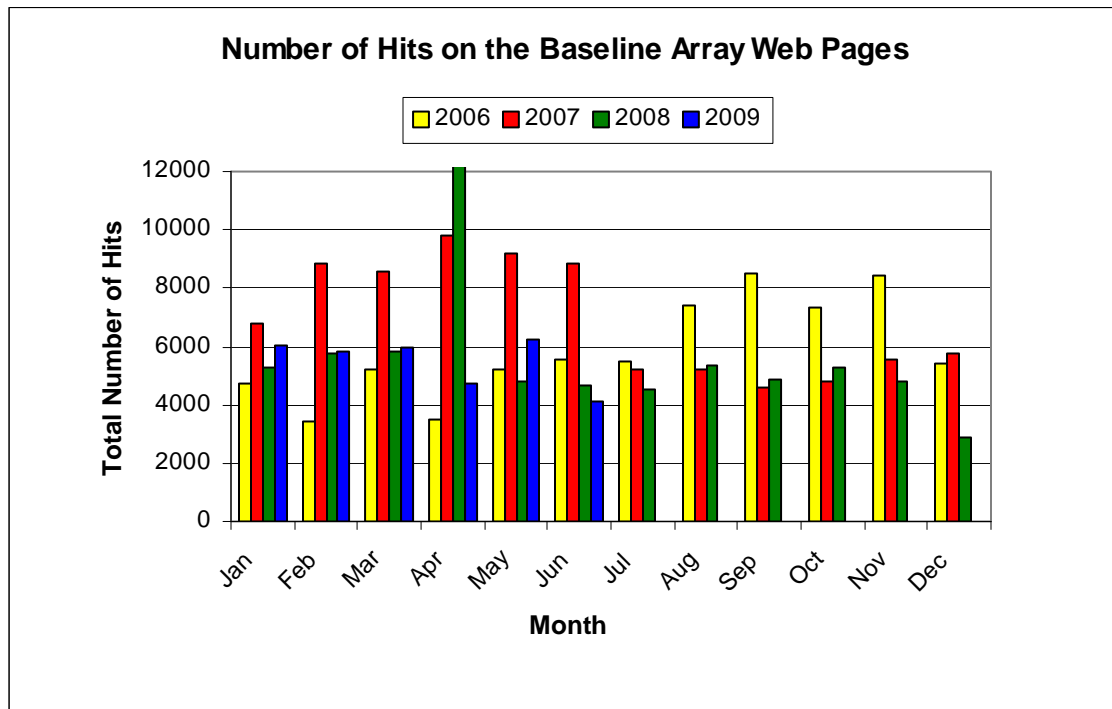


Figure 20. Number of Hits on the NTC Australian Baseline Array Web Page

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/>