THE SOUTH PACIFIC SEA LEVEL & CLIMATE MONITORING PROJECT

MONTHLY DATA REPORT

NO. 171

SEPTEMBER 2009

Australian Government

Bureau of Meteorology

This project is sponsored by the Australian Agency for International Development (AusAID), and is managed by the Bureau of Meteorology with its National Tidal Centre (NTC) providing key technical support.

Australian Government

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Quality Certification:

I authorise the issue of this South Pacific Sea Level and Climate Monitoring Project Monthly Data Report for September 2009 in accordance with National Tidal Centre Quality Assurance procedures.

William Mitchell
Manager - National Tidal Centre

South Pacific Sea Level and Climate Monitoring Project

Monthly Data Report

September 2009

EXECUTIVE SUMMARY

This summary, and the overview that follows, are intended to provide a synopsis of the Monthly Data Report and of the trends observed over the life of the project to date.

September 2009

- The SEAFRAME network continued to collect high quality sea level and associated meteorological information for monitoring climate variability and climate change.

- A destructive tsunami generated by a magnitude Mw8.0 undersea earthquake near Samoa on 29 September 2009 caused loss of life and property, particularly in exposed coastal regions of Samoa and American Samoa. SEAFRAME stations across the region detected the tsunami, the largest signals being 140cm at Samoa and 165cm at Cook Islands.

- Sea levels during September were within 10cm of what is normally observed at this time of the year. Slightly higher than normal sea levels were observed at Kiribati, Nauru, Vanuatu, Fiji and Tonga. Barometric pressures were generally lower than normal across the region, which contributed to the lowest September values on record at FSM, Nauru, Tuvalu, Samoa, Fiji and Cook Islands.

- Warmer than normal ocean temperatures continued to be observed across the equatorial Pacific. However abnormally warm sea surface temperatures in the western equatorial Pacific and subsurface cooling has hindered the development of atmospheric circulation patterns typical of El Niño.

- The majority of international climate models predict equatorial Pacific surface temperatures will remain warmer than normal for the remainder of 2009, although the extent of warming is more moderate than in previous forecasts.

Short-Term Trends

It is important to stress that as the sea level record becomes longer, the short-term trend estimate becomes more stable and reliable. Observed trends in sea level include natural

variability, for example, events such as El Niño and effects due to many other atmospheric, oceanographic and geological processes. Longer-term data sets for all stations are required in order to separate the effects of the different signals. ***Please exercise caution in interpreting the short-term trends in the table below*** **–** they will almost certainly change over the coming years as the data set increases in length. Figure 13 later in this report provides the "time history" of the short-term trend at all project locations.

Recent short-term sea level trends in the project area based upon SEAFRAME data through September, 2009

Location	Lat / Long	Installation Date	Trend (mm/yr)	Change from previous month
Cook Is	21°12'17.1"S / 159°47'5.2"W	Feb 1993	+5.4	0.0
Tonga	21°8'12.5"S / 175°10'50.5"W	Jan 1993	+9.7	+0.1
Fiji	17°36'17.7"S / 177°26'17.7"E	Oct 1992	+5.8	+0.1
Vanuatu	17°45'19.2"S / 168°18'27.7"E	Jan 1993	+6.3	+0.2
Samoa	13°49'36.4"S / 171°45'40.7"W	Feb 1993	+5.9	0.0
Tuvalu	8°30'8.9"S / 179°11'42.6"E	Mar 1993	+5.3	0.0
Kiribati	1°21'54.2"N / 172°55'58.8"E	Dec 1992	+3.7	+0.2
Nauru	0°31'45.9"S / 166°54'36.2"E	Jul 1993	+4.7	+0.2
Solomon Is.	9°25'44.1"S / 159°57'19.3"E	Jul 1994	+8.4	-0.1
PNG	2°2'31.5"S / 147°22'25.6"E	Sep 1994	+7.9	-0.1
FSM	6°58'49.9"N / 158°12'0.8"E	Dec 2001	+19.2	-0.3
Marshall Is.	7°6'21.7"N / 171°22'22.1"E	May 1993	+4.1	-0.1

INTRODUCTION

Welcome to the September 2009 Monthly Data Report for the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP). The report details the month by month operation of the SEAFRAME monitoring stations in the Pacific, including operational problems with the network or with satellite communications, the occurrence of abnormal sea level or climate events, interpretation of sea level fluctuations in the context of El Niño and the emergence of trends in the data.

The SPSLCMP was developed as an Australian response to concerns raised by the member countries of the South Pacific Forum over the potential impacts of global warming on climate and sea levels in the Pacific. Support was provided for the installation of SEAFRAME monitoring stations across the South Pacific Forum region.

SEAFRAME gauges not only measure sea level by two independent means, but also observe a number of "ancillary" variables - air and water temperatures, wind speed, wind direction and atmospheric pressure. There is an associated programme of levelling to first order, to determine shifts in the vertical of the sea level sensors due to local land movement. Continuous Global Positioning System (CGPS) measurements

are now also being made to determine the vertical movement of the land with respect to the International Terrestrial Reference Frame.

The AusAID funded project has, as its principal objective ***'the provision of an accurate long term record of sea level in the South Pacific for partner countries and the international scientific community, that enables them to respond to and manage related impacts'***.

The project's monitoring network consists of 12 SEAFRAME stations, providing a wide coverage across the Southwest Pacific basin. All of these stations (see Figure A), with the exception of the Pohnpei (FSM) gauge, which was established in December 2001, have been operational since October 1994.

The monthly data report, one of a range of information products produced by the project, is the primary form of SPSLCMP data dissemination. Its content is designed to provide up-to-date access to the project's data products.

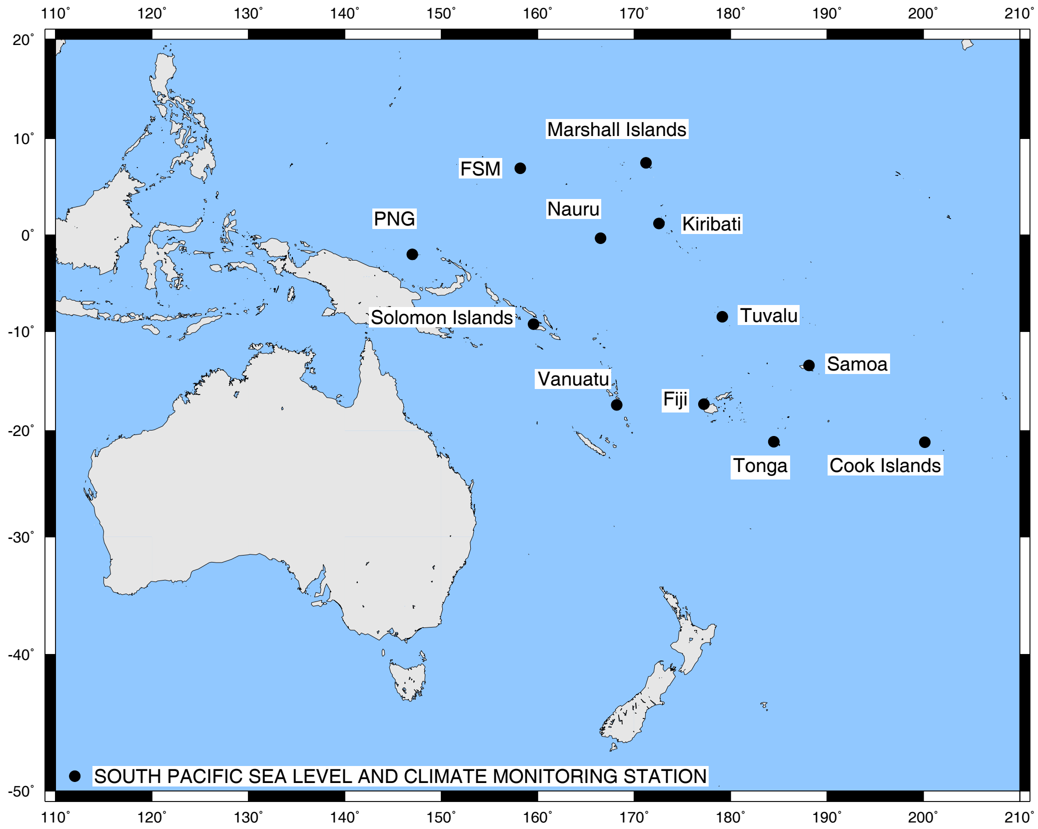

Figure A: *South Pacific Sea Level and Climate Monitoring Stations*

SEPTEMBER CLIMATOLOGY

Climate conditions across the equatorial Pacific during September continued to resemble a weak, albeit unusual, El Niño. Ocean heat content remained warmer than average across the central and eastern equatorial Pacific, although slight cooling of subsurface temperatures has been observed in recent months. Atmospheric conditions such as the Southern Oscillation Index and Pacific Trade Wind and cloud patterns are yet to show any consistent El Niño behaviour. The lack of reinforcement between the ocean and atmosphere is potentially due to persistent warmer than average ocean temperatures in the far western tropical Pacific and Coral Sea, which is uncharacteristic for El Niño. The majority of international climate models predict that sea surface temperatures across the equatorial Pacific will remain above El Niño thresholds for the remainder of 2009.

The Southern Oscillation Index (SOI) is usually consistently below –7 during El Niño events. The SOI remained neutral at +4 during September and has not shown any El Niño trend, having risen from the August value of -5 (**Figure B**).

Sea surface temperatures were warmer than normal across the entire equatorial Pacific during September and exceeded El Niño thresholds west of the dateline (**Figure C**). Anomalies in excess of +1ºC were observed across much of the central and eastern equatorial Pacific. Sea surface temperature in the western equatorial Pacific and Australasian region remained warmer than average during September, whereas they are typically average or cooler than average during El Niño.

Subsurface ocean heat content has cooled steadily since June, but remained slightly warmer than average across the equatorial Pacific Ocean during September. In some areas subsurface temperature anomalies continue to exceed +2.0ºC (**Figure D**).

During El Niño (warm-episode) conditions there is a sustained weakening of the Trade Winds across much of the equatorial Pacific and an increase in cloudiness in the central Pacific particularly near the dateline. During La Niña (cold-episode) conditions there is a reversal of this situation, with stronger Trade Winds and a decrease in cloudiness in the central Pacific. During September 2009 the easterly Trade Winds were generally of near average strength across the central and eastern equatorial Pacific, and weaker than normal in the western equatorial Pacific (**Figure E**). Above average cloudiness was observed over the equatorial Pacific near the dateline during September in keeping with a developing El Niño, but this trend has been relatively weak in comparison to previous El Niño events.

The majority of seven international computer models surveyed by the Bureau of Meteorology predict sea surface temperatures will remain above El Niño thresholds for the remainder of 2009. However all models are now predicting the extent of warming to be more moderate than in previous forecasts.

The preceding description of the climatology of the Pacific region, and Figures B, C and D are based on information sourced from the National Climate Centre of the Australian Bureau of Meteorology at http://www.bom.gov.au/climate/. Figure E was generated from the Tropical Atmosphere Ocean project website courtesy of PMEL, NOAA at http://www.pmel.noaa.gov/tao/.

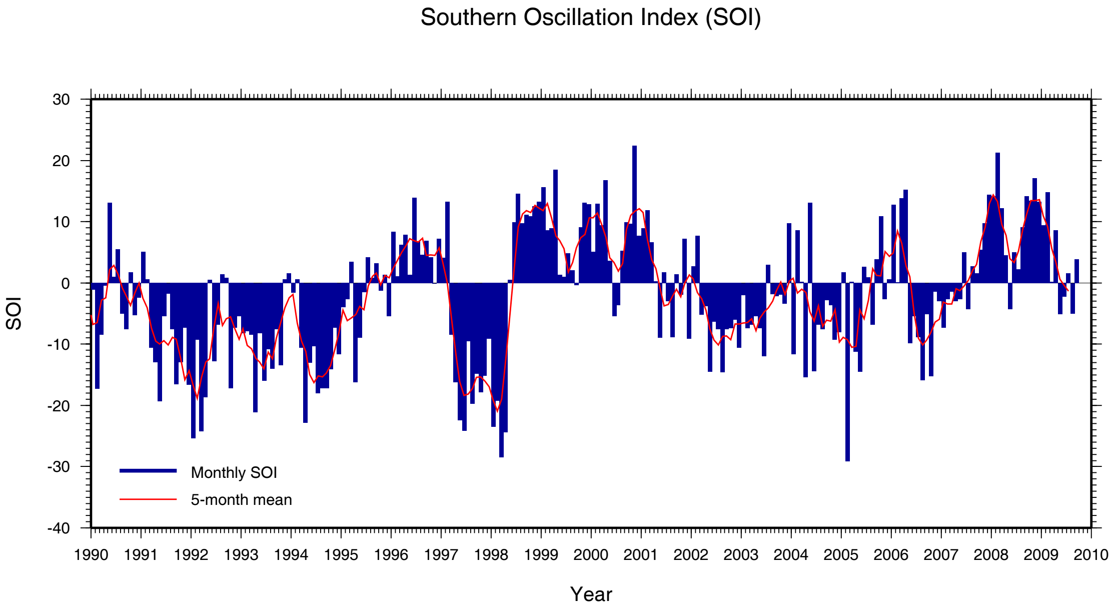

Figure B: *The five-month weighted mean and individual monthly means of the Southern Oscillation Index (SOI). The SOI is ten times the monthly anomaly of the difference in mean sea level pressure between Tahiti and Darwin, divided by the long-term standard deviation of that difference for the relevant month.*

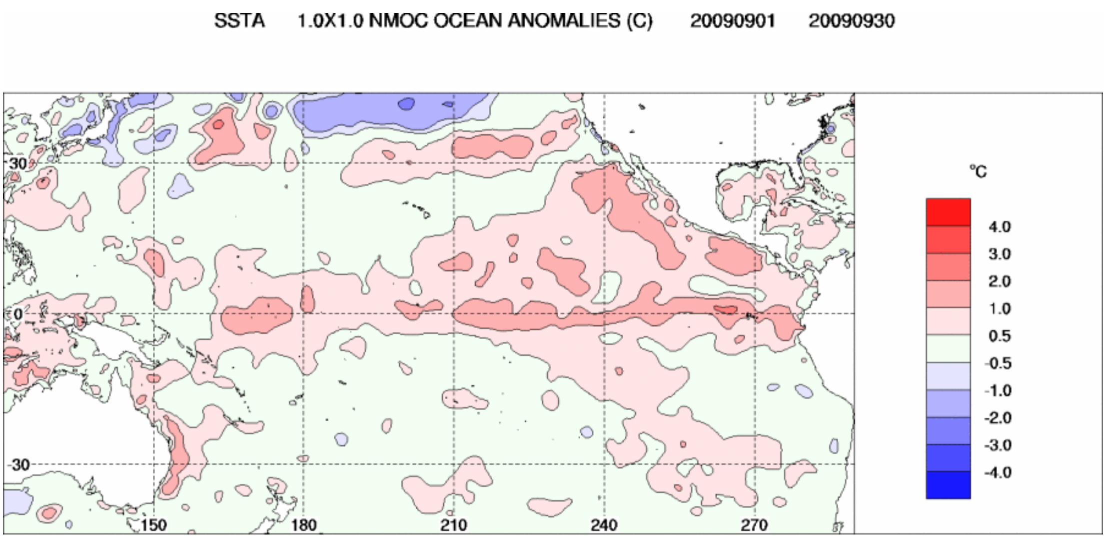

Figure C: *Sea surface temperature anomaly (°C) for September 2009.*

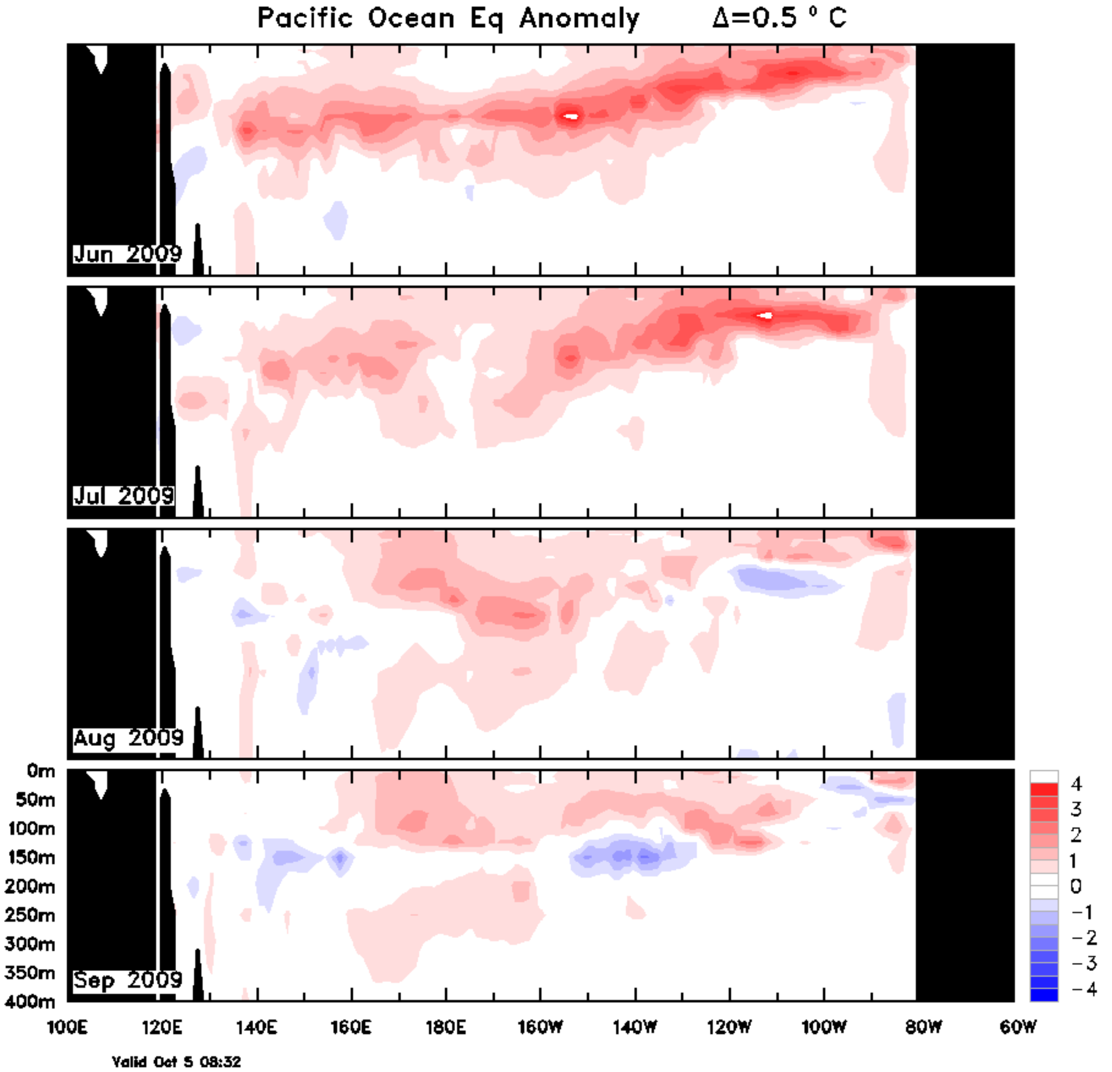

Figure D: *Equatorial depth-longitude section of ocean temperature anomalies for June 2009 through to September 2009. Contour interval is 0.5°C.*

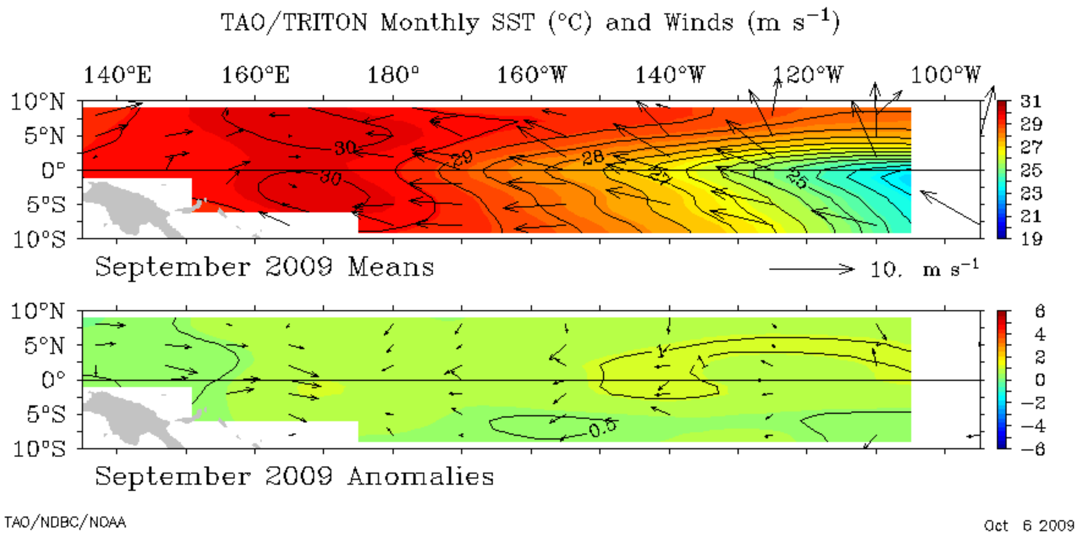

Figure E: *Monthly mean wind vectors (top) and anomalies (bottom) for September 2009. The colour-shaded contours represent the monthly mean sea surface temperatures (top) and anomalies (bottom).*

SEPTEMBER SEAFRAME DATA

Monthly Sea Level and Environmental Data (Figures 1-10)

The **observed sea levels (Figure 1)** are dominated by the daily oscillations of the tide. In most cases, the tide rises and falls twice per day (semi-diurnal), but at PNG and the Solomon Islands the tide tends to have a single high and low per day (diurnal). The greatest variations are called spring tides and tend to occur close to the full and new moon. There was a full moon on the 4th of September and a new moon on the 18th of September UTC.

Gaps in the data are the result of instrumental errors or data retrieval problems and are discussed under **Instrument Performance**.

The **residuals (Figure 2)** are the differences between the observed sea levels and the tidal predictions. They highlight the non-tidal sea level fluctuations such as those due to the short-term effects of weather or tsunamis. Residual sea level fluctuations may also be amplified or sustained by the shape of the harbour in which the gauge is located. Persistent sloshing of water within a bay or harbour, for example, is known as a seiche. Seiches are often recorded at PNG when the wind suddenly changes strength or direction. Large non-tidal sea level fluctuations are sometimes observed at FSM during periods of reduced tidal range known as neap tides.

A destructive tsunami was generated following a magnitude Mw8.0 earthquake under the sea floor around 190km south of Apia, Samoa at 17:48 UTC on 29th September 2009. The tsunami caused the loss of life and property, particularly along exposed coastlines of Western Samoa and American Samoa. Tsunami signals are clearly evident in the 6-minute residual sea levels at Samoa, Vanuatu, Fiji, Tonga and Cook Islands shown in Figure 2. The Pacific Tsunami Warning Centre based in Hawaii issued a tsunami warning across the region and monitored 1-minute sea level data that are transmitted in real time from the SEAFRAME stations. The 1-minute sea level data showed trough to peak tsunami heights of 140cm at Samoa, 35cm at Vanuatu, 10cm at Fiji, 40cm at Tonga, 165cm at Cook Islands and 7cm at Kiribati. Smaller tsunamis below 5cm in height were also recorded at Tuvalu, Solomon Islands, FSM and PNG.

The sea level residuals at all stations, to some degree, exhibit semi-diurnal or diurnal fluctuations, which last a few days or weeks and then disappear. If these peaks were to persist, rather than appear as occasional ‘transients’, then the tidal analysis would be able to account for them, and the end result would be virtual eradication from the residuals.

The **barometrically corrected residuals (Figure 3)** have had the effect of atmospheric pressure fluctuations removed from the sea level residuals of Figure 2. The rule of thumb for the ‘inverse barometer effect’ is that a 1-hPa fall in the barometer, if sustained over a day or more, produces a 1 cm rise in the local sea level (within the area beneath the low pressure system).

The **winds**, **temperatures** and **barometric pressures** are plotted in **Figures 4** to **9**. The short lines in **Figure 5** follow the meteorological convention, that is, they point in

the direction the wind is coming *from*. For example, the winds at Tuvalu prevailed from the southeast for most of the month.

Air and water temperatures **(Figures 7** and **8)** are plotted using the same vertical scale for the purpose of comparison. The air temperatures are seen to fluctuate over a much wider range than the water temperatures. At some sites (e.g. FSM) the water temperature shows almost no variation, although the air temperature varies by several degrees between night and day. At Nauru a twice-daily fluctuation in water temperature is related to the tide, as it is usually more pronounced during the larger spring tides.

Barometric pressures **(Figure 9)** tend to fluctuate by around 3 hPa twice-daily at all stations as a result of atmospheric tides, which are largest in the tropical regions and reduce to near zero toward the poles. The longer-term barometric pressure fluctuations that occur over periods of days to weeks are due to passing weather systems. These fluctuations tend to be larger at sites further away from the equator such as Cook Islands and Tonga.

The **meteorological data** are put into perspective by **Figure 10**. In this figure, if an open circle falls above (below) a solid dot, a new maximum (minimum) for the particular month has been set. *The data sets only include South Pacific Sea Level and Climate Monitoring Project data, which have been collected since October 1992 when the first station was installed (Fiji). The data from FSM has only been collected since December 2001.* A new maximum September air temperature of 31.8°C was recorded at Nauru and a new maximum September water temperature of 31.2°C was recorded at Marshall Islands. Barometric pressures were generally lower than normal across the region and new minimum September barometric pressures were recorded at FSM (1002.6hPa), Nauru (1001.5hPa), Tuvalu (1003.4hPa), Samoa (1005.0hPa), Fiji (1005.4) and Cook Islands (1006.4).

Mean Sea Level and Anomalies (Figures 11-13)

Figure 11 shows the **monthly mean sea levels**, which are simple arithmetic averages of the sea levels, relative to an arbitrary zero. The figure shows that Tuvalu, for example, normally experiences an annual cycle of about 0.2 metres, reaching a peak around February or March. One effect of the El Niño of 1997/1998 was to disrupt the annual sea level cycle at many of the SEAFRAME stations.

Figure 12 shows the monthly mean **sea level anomalies,** or departures from normal conditions after tides, annual and semi-annual seasonal cycles and the sea level trend have been removed. The annual cycle at Tuvalu (which has the largest consistent annual cycle) is quite notable in **Figure 11** but less apparent in **Figure 12**. By removing the seasonal cycles, the anomalies help to bring out irregular features, such as lower than normal sea levels across the region during the 1997/98 El Niño.

In September 2009 sea levels continued to be 5-10cm higher than normal at Kiribati, Nauru, Vanuatu, Fiji and Tonga. Slightly lower than normal sea levels were observed at Marshall Islands, FSM, PNG and Solomon Islands. Sea levels at Tuvalu, Samoa and Cook Islands were near average during September.

Sea Level Trends

The **short-term sea level trends** at individual stations as at September 2009 are shown in the following table. Sea level trends are updated every month by allowing for a linear trend term in the tidal analysis of all the data available at individual stations. *Please exercise caution in interpreting the trends* – they will continue to change over the coming years as the data sets increase in length. The evolution of the monthly trend values (in mm per year) at each station from one year after installation to present is depicted in **Figure 13**. This figure illustrates that as the sea level record becomes longer, the relative sea level trend estimates become more stable and reliable. The reason for this is that the trends from short sea level records are affected by the natural sea level variability occurring on inter-annual, El Niño and decadal timescales due to atmospheric, oceanographic and geological processes. Longer-term data sets for all stations are required in order for the underlying trend to emerge from these short-term variations. Further details are available from the *National Tidal Centre (NTC), Australian Bureau of Meteorology*.

Recent short-term sea level trends in the project area based upon SEAFRAME data through September, 2009

Location	Lat / Long	Installation Date	Trend (mm/yr)	Change from previous month
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Vanuatu	17°45'19.2"S / 168°18'27.7"E	Jan 1993	+6.3	+0.2
Samoa	13°49'36.4"S / 171°45'40.7"W	Feb 1993	+5.9	0.0
Tuvalu	8°30'8.9"S / 179°11'42.6"E	Mar 1993	+5.3	0.0
Kiribati	1°21'54.2"N / 172°55'58.8"E	Dec 1992	+3.7	+0.2
Nauru	0°31'45.9"S / 166°54'36.2"E	Jul 1993	+4.7	+0.2
Solomon Is.	9°25'44.1"S / 159°57'19.3"E	Jul 1994	+8.4	-0.1
PNG	2°2'31.5"S / 147°22'25.6"E	Sep 1994	+7.9	-0.1
FSM	6°58'49.9"N / 158°12'0.8"E	Dec 2001	+19.2	-0.3
Marshall Is.	7°6'21.7"N / 171°22'22.1"E	May 1993	+4.1	-0.1

Barometric Pressure, Water Temperature and Air Temperature Anomalies

The anomalies of barometric pressure, water and air temperature (**Figures 14** to **16**) are determined in the same manner as the sea level anomalies (**Figure 12**), except the trend is not calculated.

The **barometric pressure anomalies (Figure 14)** show substantially higher than normal barometric pressures were observed at SEAFRAME stations during the

1997-1998 El Niño. In September 2009 barometric pressures trended toward being slightly lower than normal across the region, which contributed to the lowest September barometric pressures on record at a number of stations (Figure 10).

The **water temperature anomalies (Figure 15)** show slightly warmer than normal water temperatures continued to be observed during September 2009 at Marshall Islands, FSM, PNG, Solomon Islands, Kiribati and Nauru. Slightly cooler than normal water temperatures developed at Fiji, Tonga and Cook Islands.

The **air temperature anomalies (Figure 16)** show similar patterns to the water temperature anomalies during September 2009, with slightly warmer conditions recorded at Marshall Islands, FSM, Solomon Islands, Kiribati, Nauru and Tuvalu and slightly cooler than normal conditions at Samoa, Fiji, Tonga and Cook Islands. Over the duration of the record the air temperature anomalies generally (although not always) follow the water temperature anomalies, which is an indication of the large influence the ocean has upon the climate of the Pacific Islands.

Instrument Performance

In **Figure 17,** which shows **sea level data return,** colour is used to distinguish five-year project phases. The number of missing days is noted in gaps in the bars.

Sea level data return was excellent across the network during September 2009. At Nauru problems with the primary sea level sensor were encountered and data from the secondary sea level sensor were used where possible.

Various problems were encountered with ancillary meteorological sensors including the air temperature, water temperature and barometric pressure electronic circuit at Marshall Islands and the resulting erroneous data were removed from the record. The water temperature sensor at Tonga experienced problems and likewise erroneous data were removed.

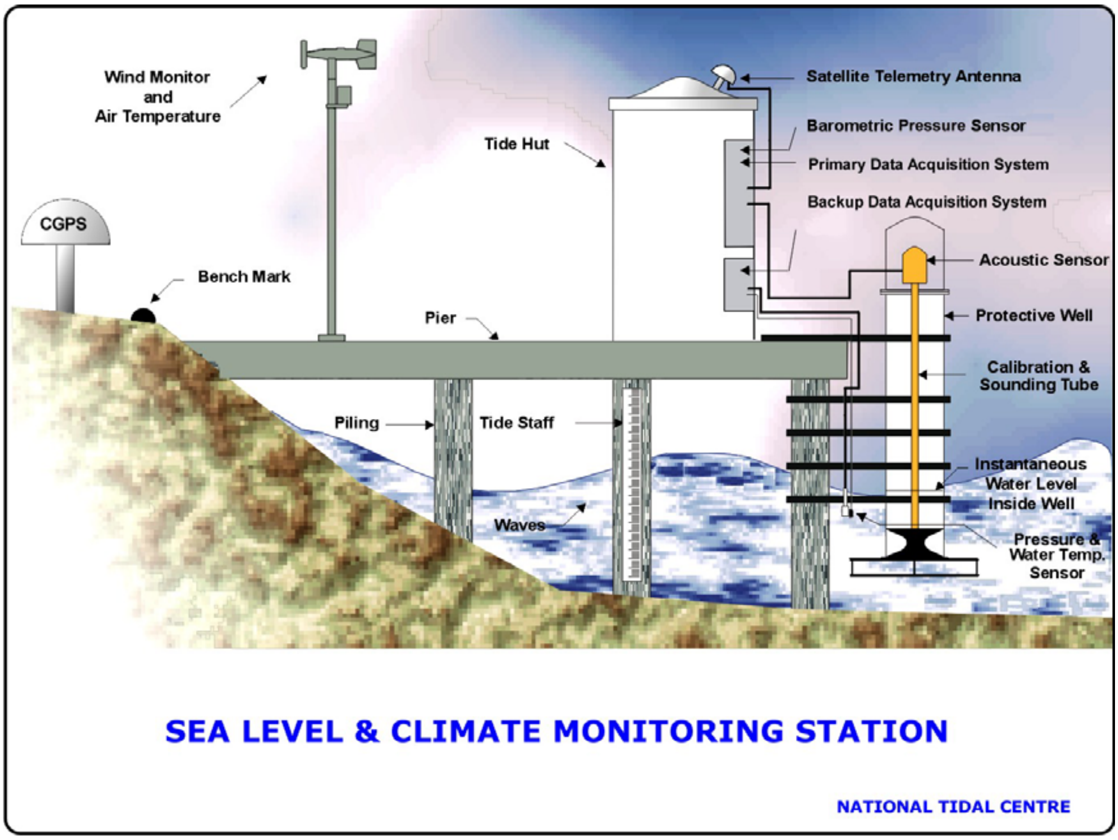
SEAFRAME STATIONS

SEAFRAME stations employ a SUTRON programmable data logger, water level gauges and other sensors. The data logger and associated electronics are normally housed in fibreglass huts. A sketch of a typical station is shown in the following figure. Water level sensors include:

(1) Primary water level using a Bartex 'AQUATRAK' acoustic-in-air sensor, and

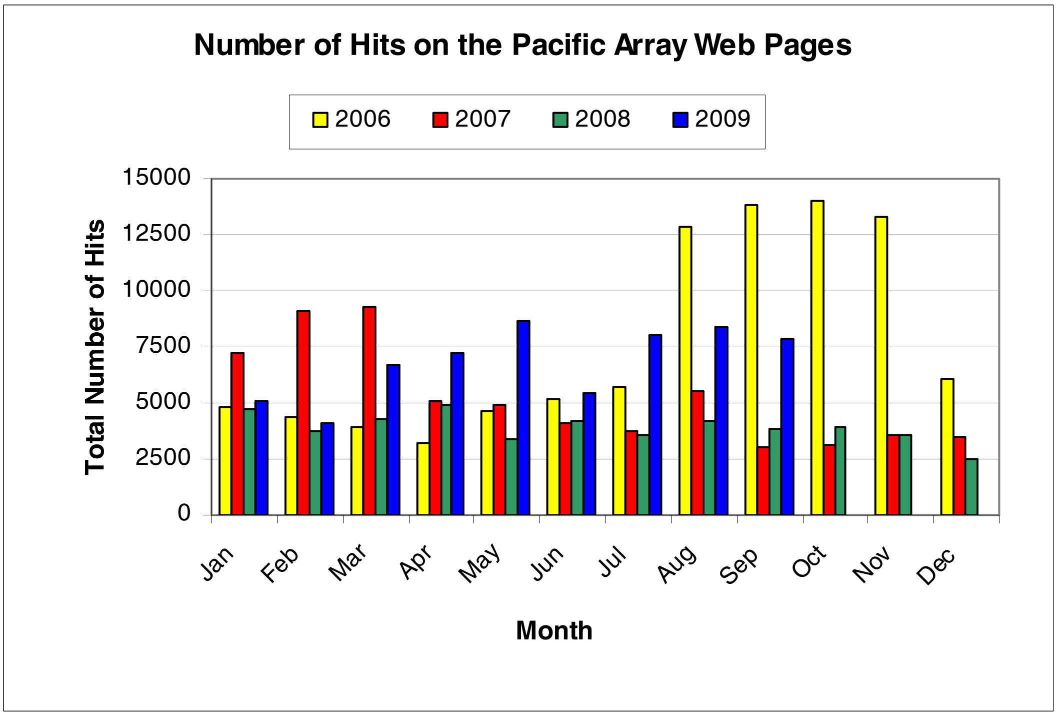
(2) Secondary water level (or backup) using a Druck pressure transducer mounted close to the seabed.

The primary and backup water level sensors provide water level values, which are averaged over three minutes and are logged every six minutes. The data logger has the memory capacity to store approximately one month of data. The meteorological sensors are logged to the SUTRON data logger on an hourly basis.



Web Hits

The following chart shows the number of times the Pacific pages on the *NTC* web site have been visited, by month since January 2006.



The *Monthly Data Report* is prepared by *NTC* for *AusAID*.

NTC would appreciate feedback from readers on the content and presentation of the *Monthly Data Report*.

Please spare a few moments to let us know your constructive opinion.

Further communication on the *Monthly Data Report* may be made to *NTC*. Anyone interested in a more detailed account of the project should contact:

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Website: http://www.bom.gov.au/oceanography/tides.shtml

Or visit the project website at http://www.bom.gov.au/pacificsealevel

Please refer to: http://www.bom.gov.au/oceanography/projects/spslcmp/spslcmp.shtml for details.

Please also note the following:

While care has been taken in the collection, analysis, and compilation of the data, it is supplied on the condition that neither the *Commonwealth of Australia* nor *NTC* shall be liable for any loss or injury whatsoever arising from the use of the data.

Individuals and organisations are advised that quality controlled six-minute or hourly data from these stations are available on request from *NTC*. Some handling fees may be charged. For commercial agencies requesting data, some additional costs may be levied.

Figure 1

SEPTEMBER 2009
SIX MINUTE WATER LEVEL OBSERVATIONS (m)

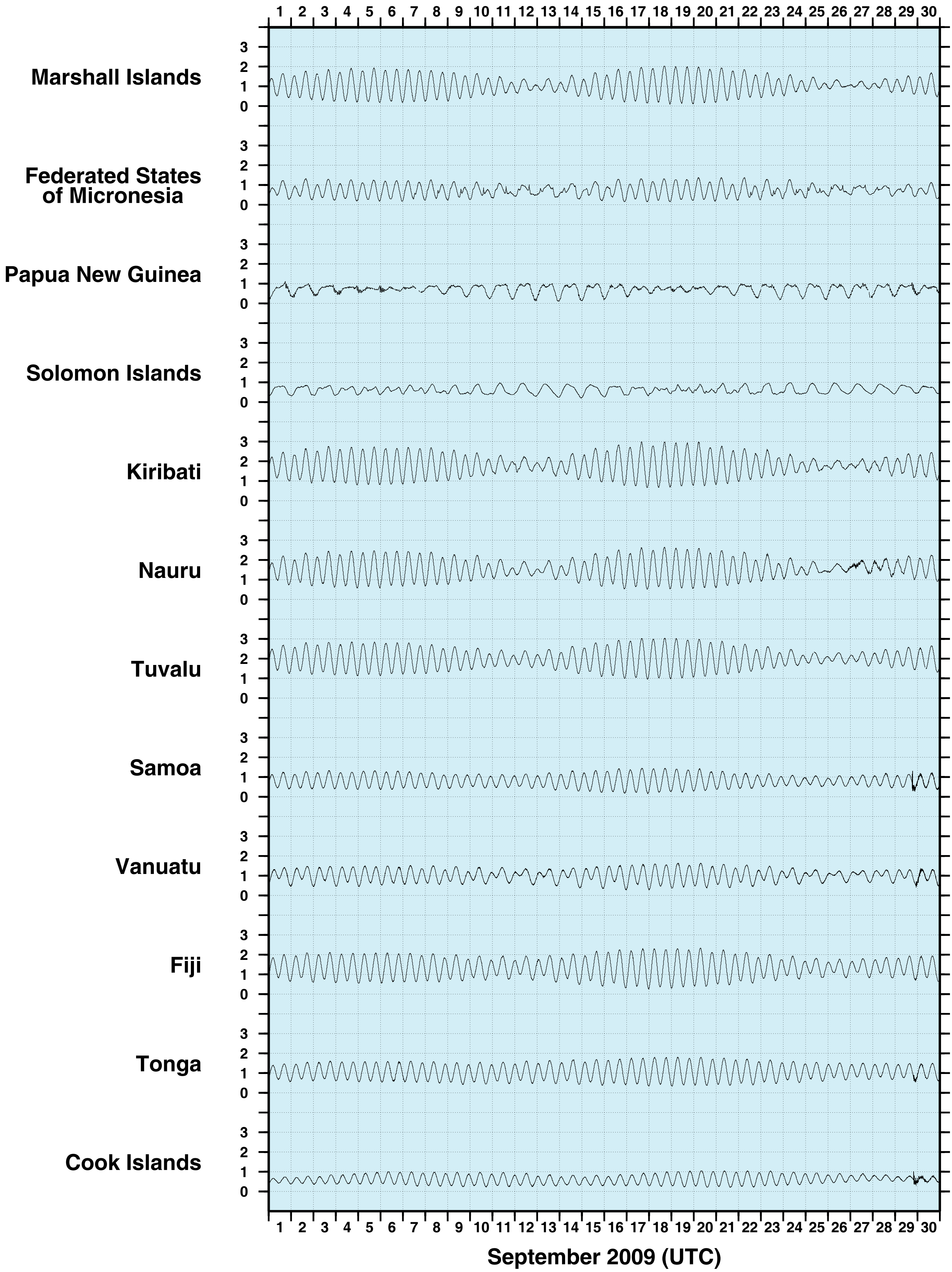


Figure 2

SEPTEMBER 2009
SIX MINUTE RESIDUAL WATER LEVELS (m)

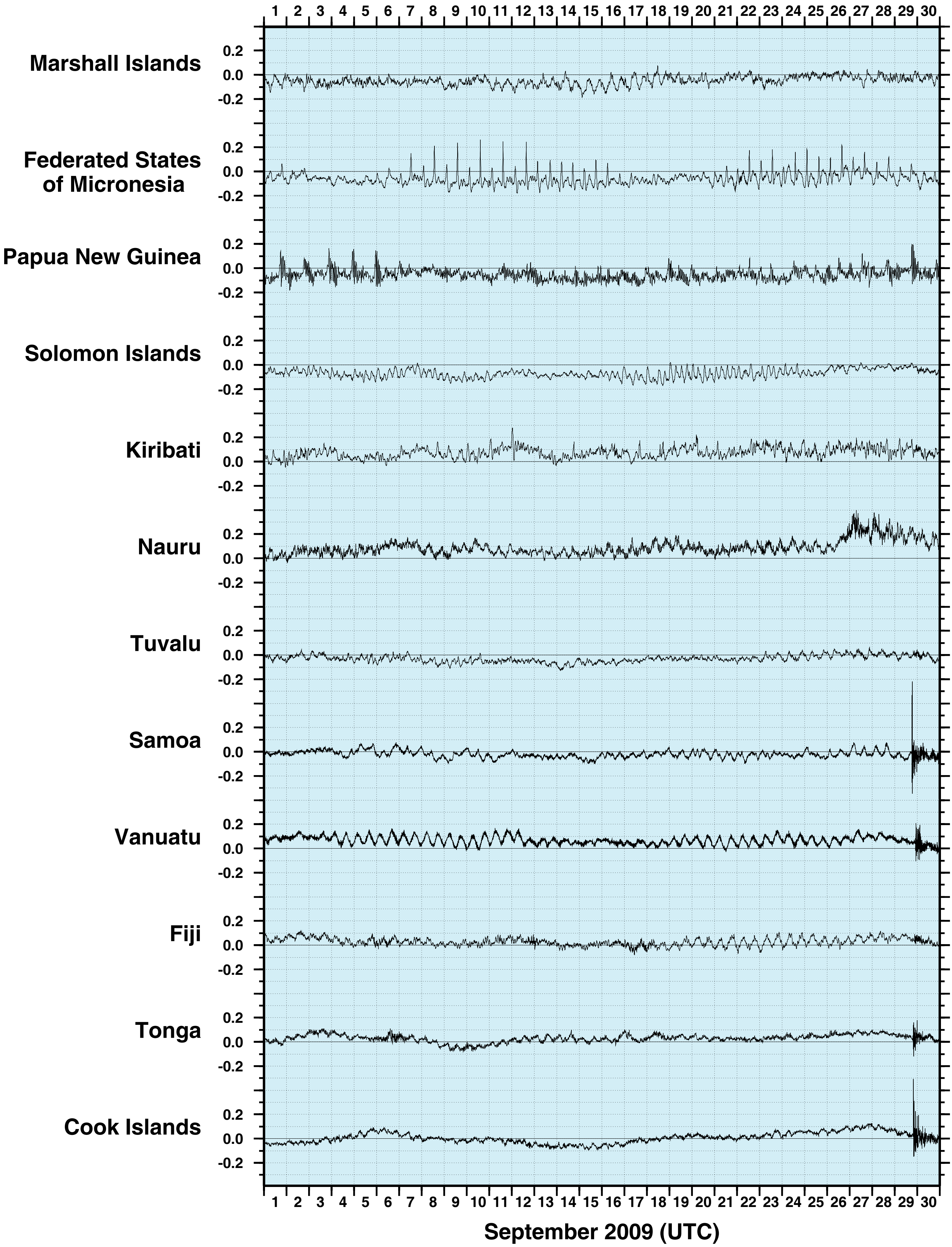


Figure 3

SEPTEMBER 2009
SIX MINUTE RESIDUALS
ADJUSTED FOR ATMOSPHERIC PRESSURE (m)

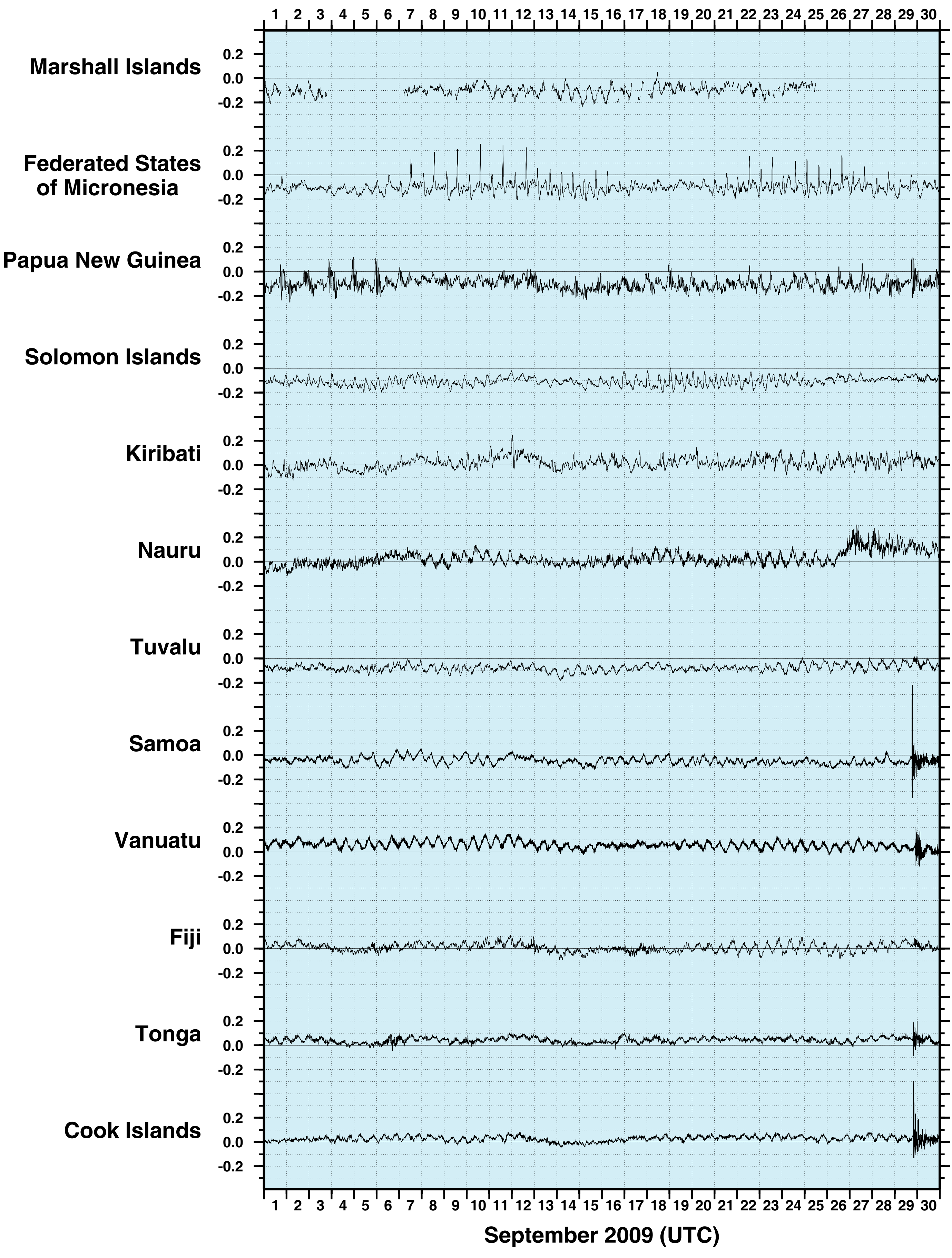


Figure 4

SEPTEMBER 2009
HOURLY WIND SPEEDS (m/s)

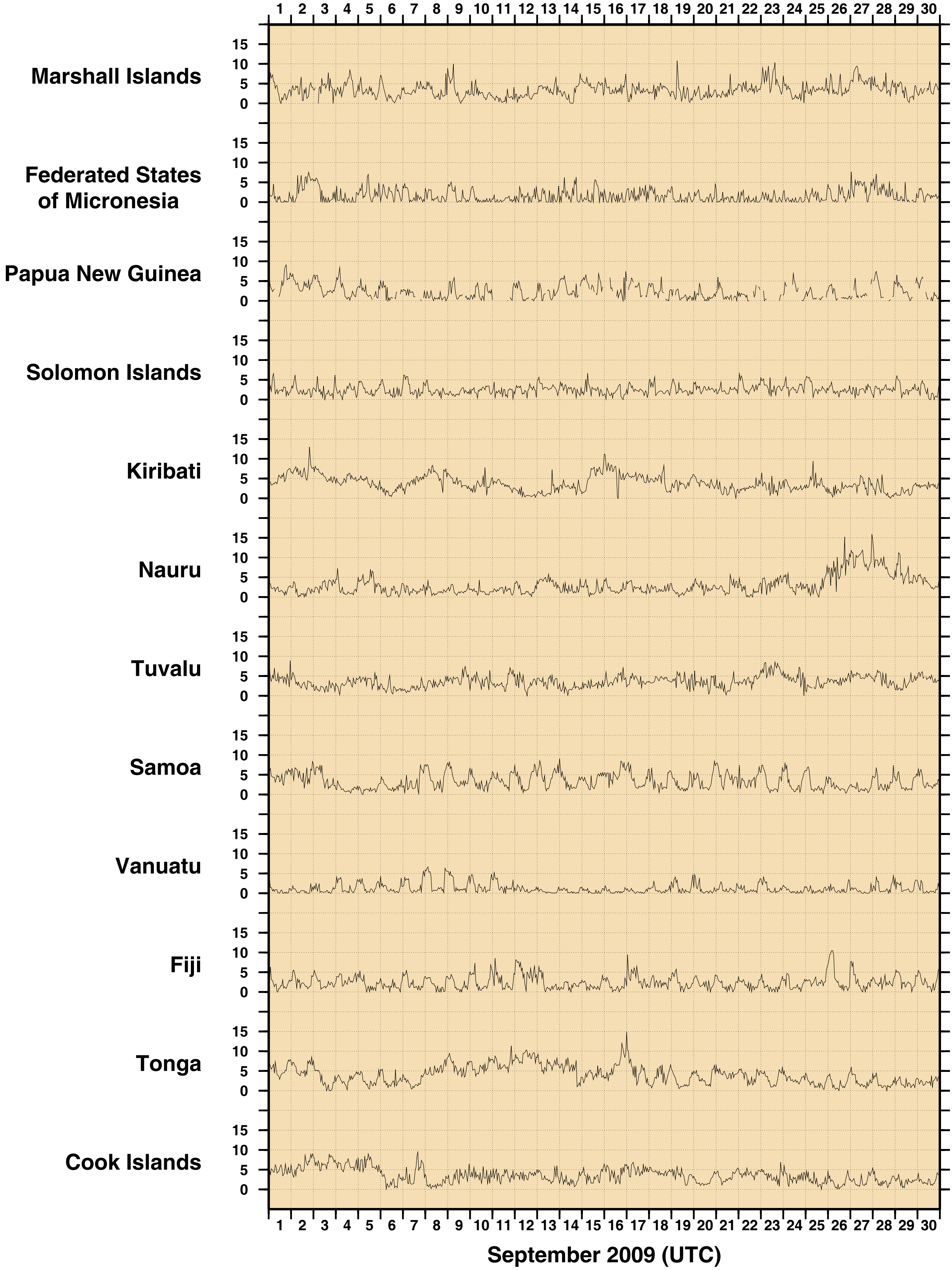


Figure 5

SEPTEMBER 2009

HOURLY INCIDENT WINDS (m/s, deg True)

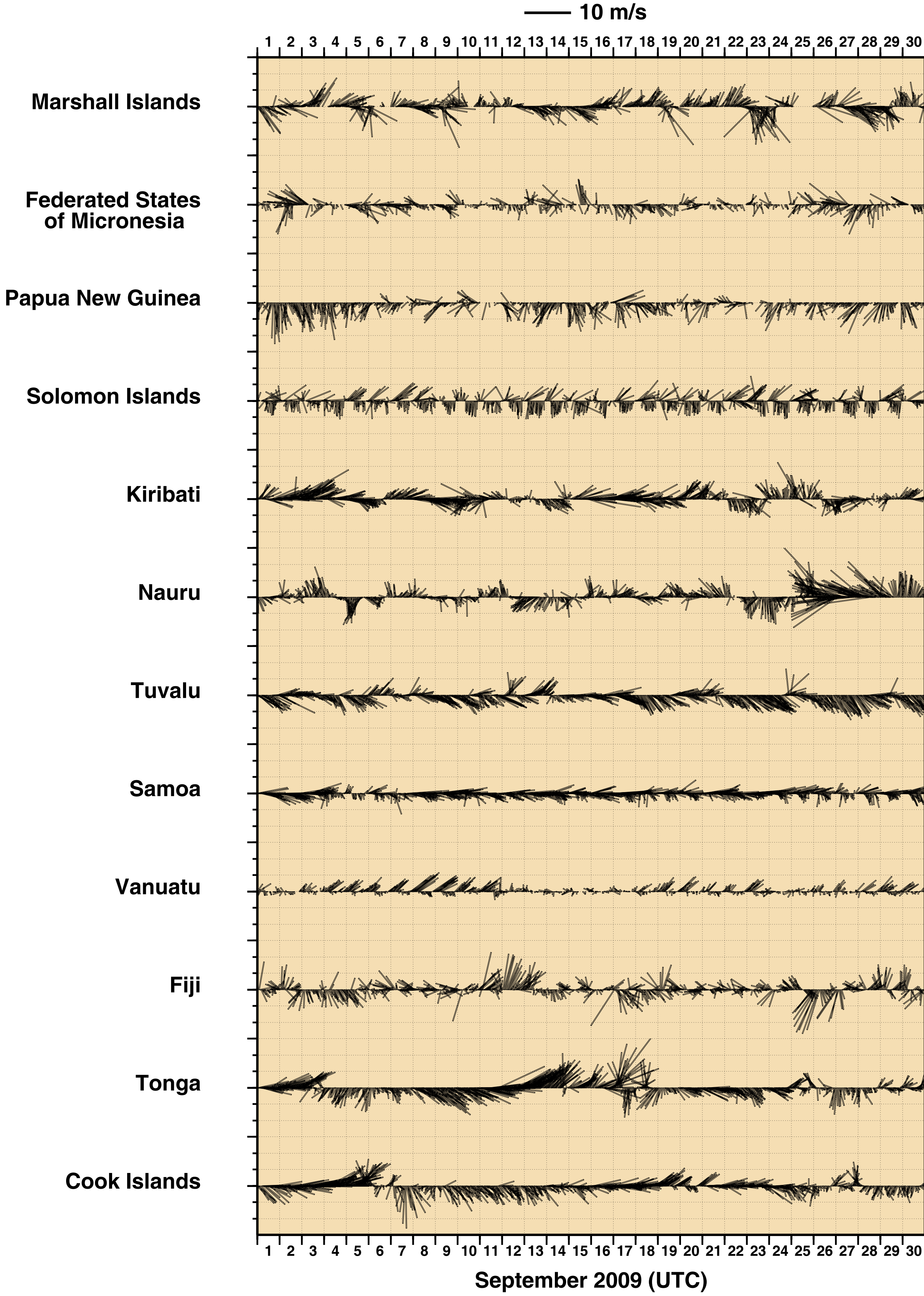


Figure 6

SEPTEMBER 2009
HOURLY MAXIMUM WIND GUSTS (m/s)

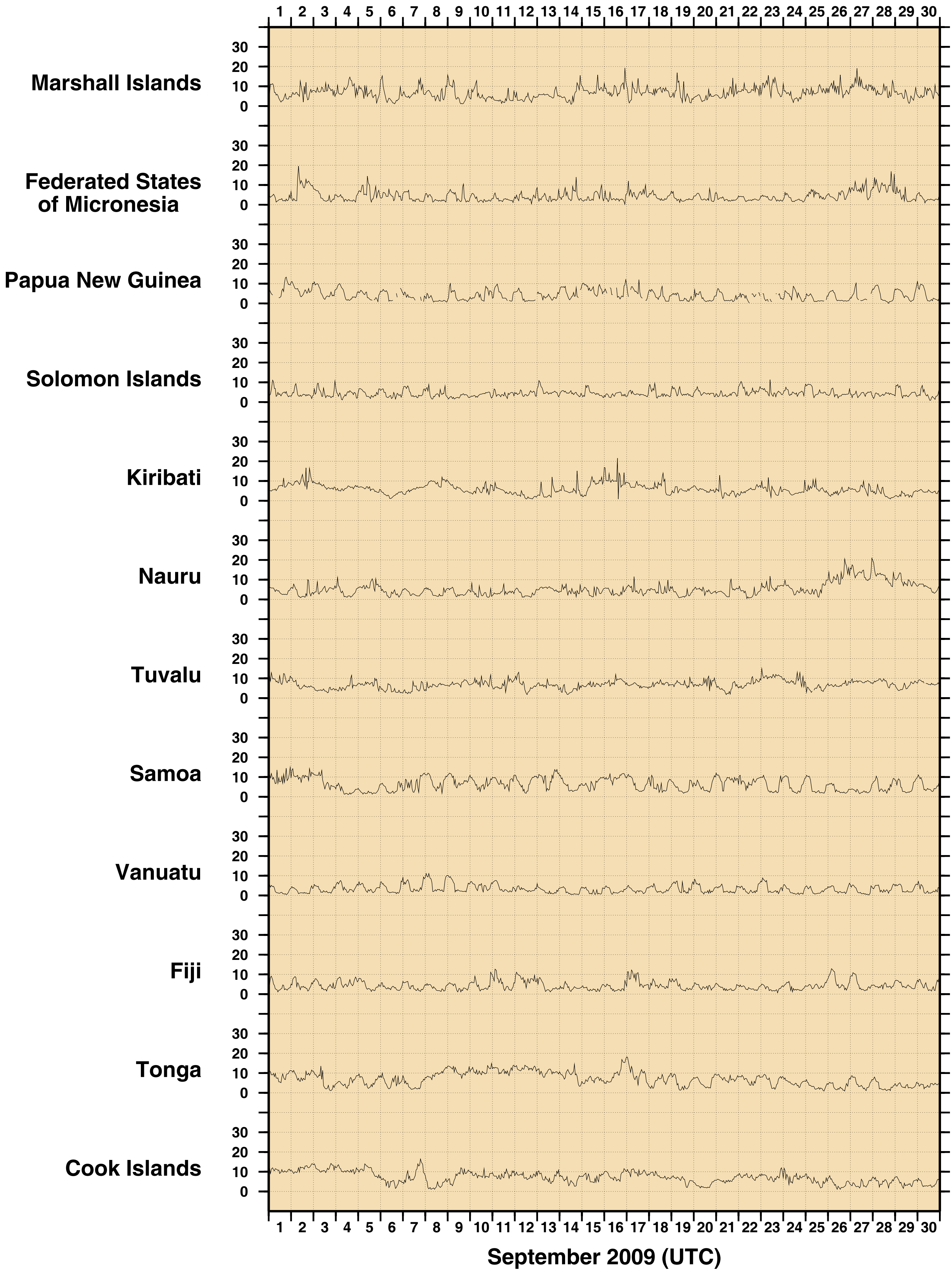


Figure 7

SEPTEMBER 2009
HOURLY AIR TEMPERATURES (˚C)

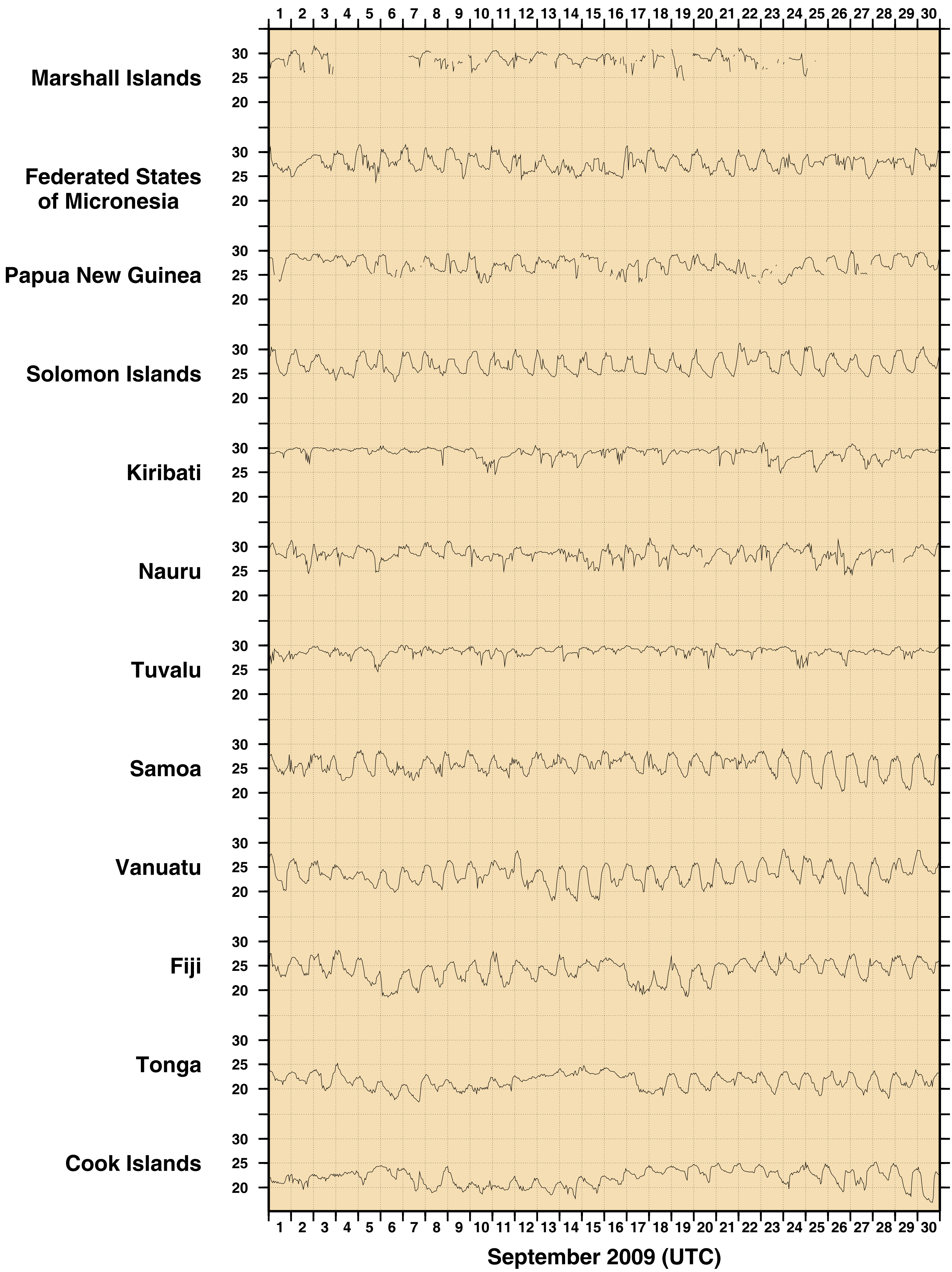


Figure 8

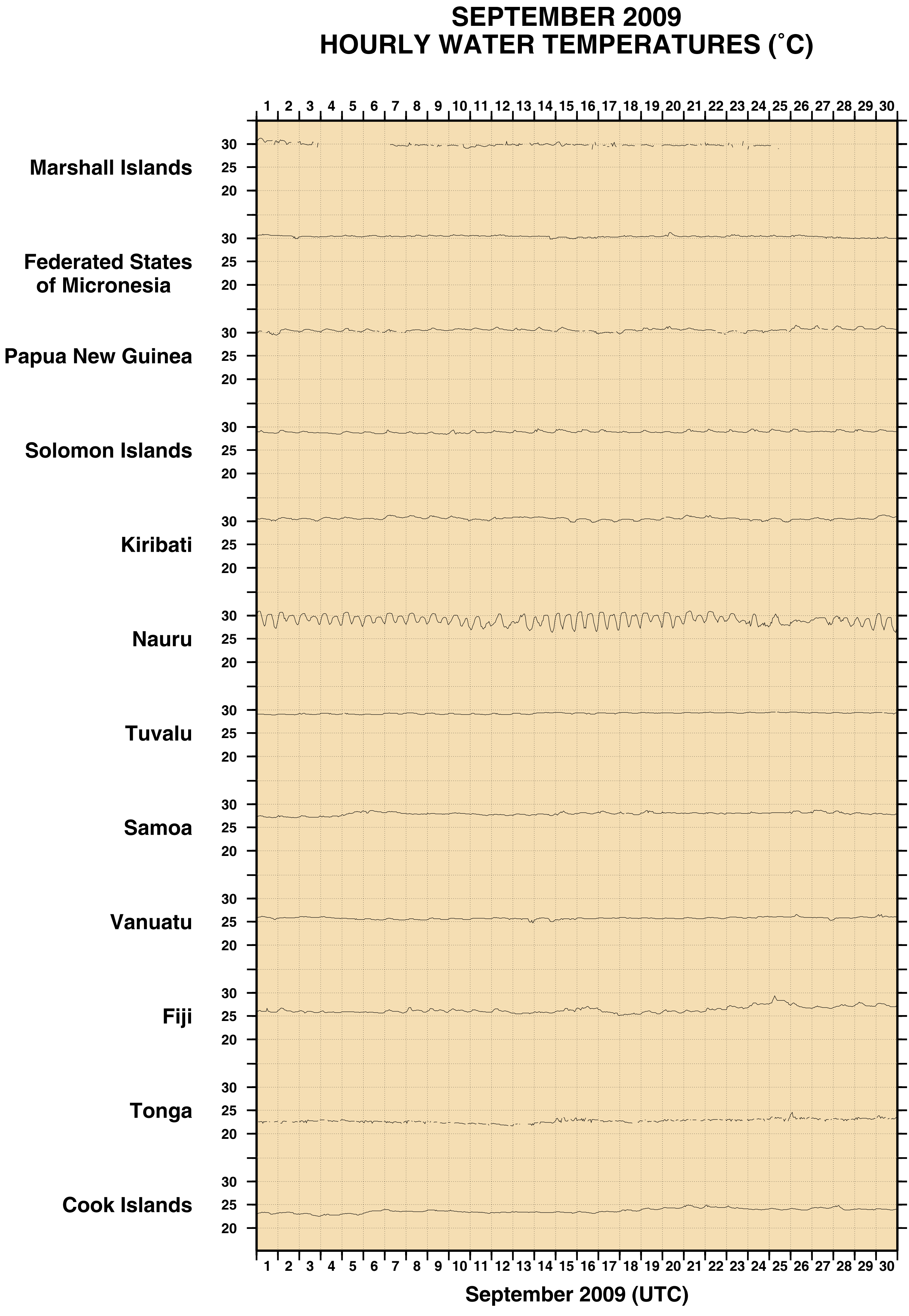

SEPTEMBER 2009
HOURLY WATER TEMPERATURES (˚C)
Marshall Islands
Federated States of Micronesia
Papua New Guinea
Solomon Islands
Kiribati
Nauru
Tuvalu
Samoa
Vanuatu
Fiji
Tonga
Cook Islands
30
25
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
September 2009 (UTC)

Figure 9

SEPTEMBER 2009
HOURLY ATMOSPHERIC PRESSURE (hPa)

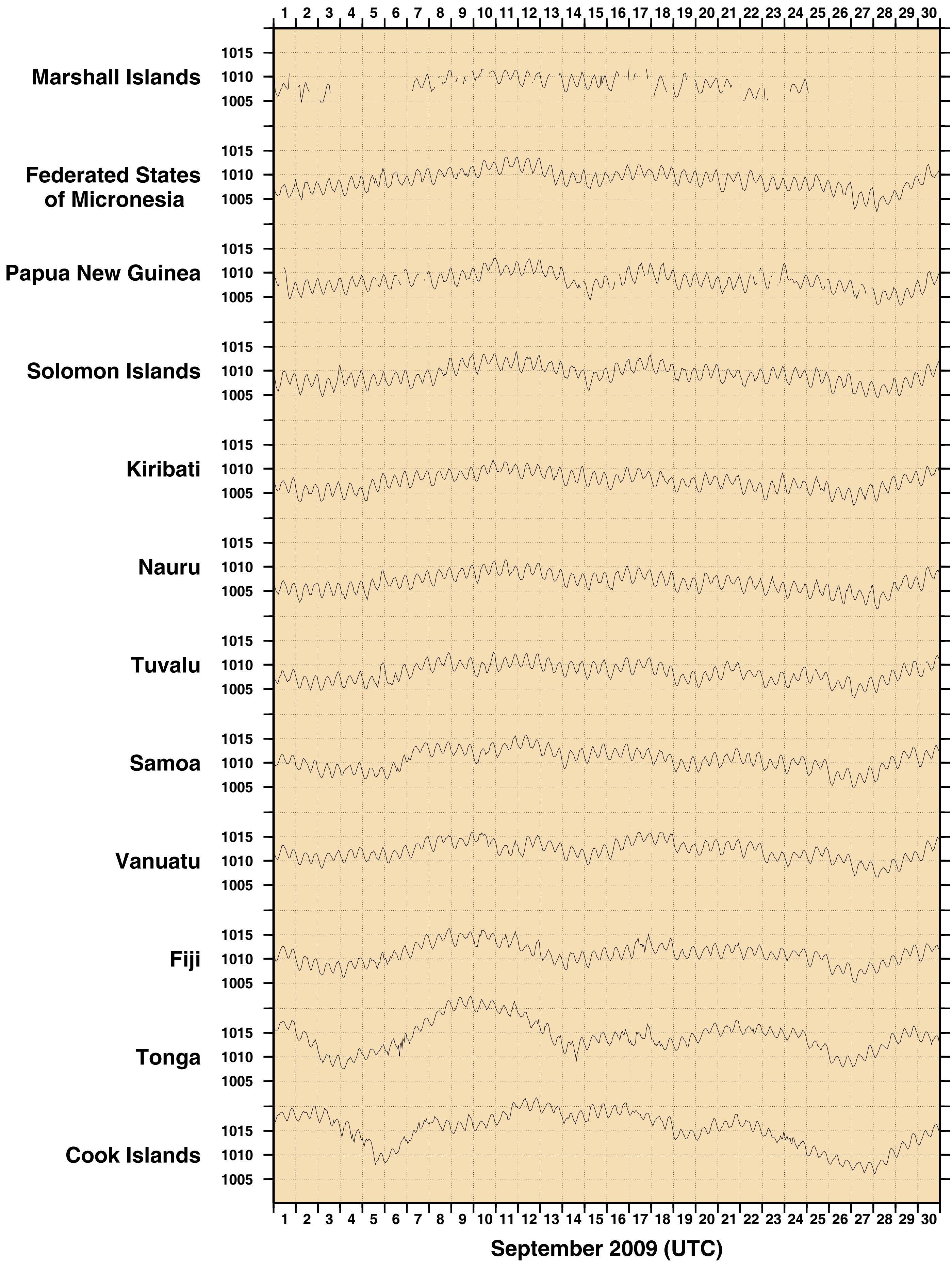
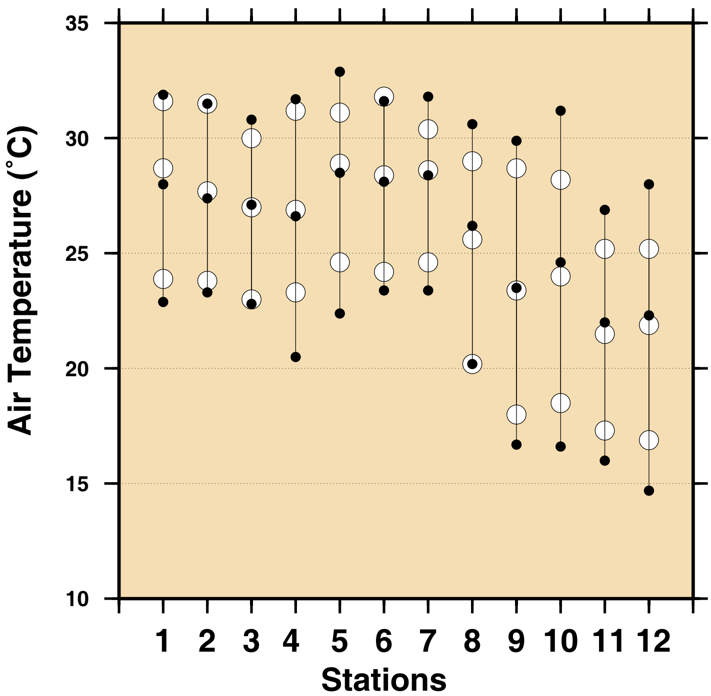
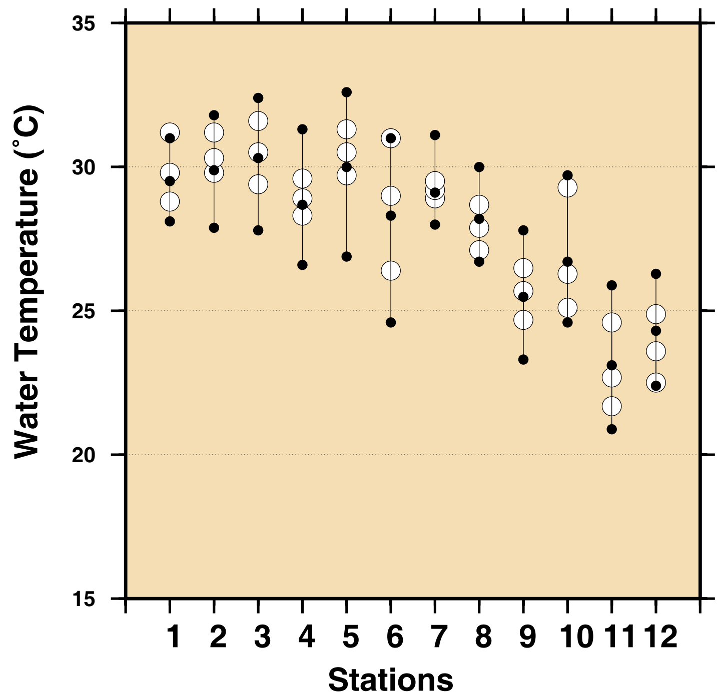
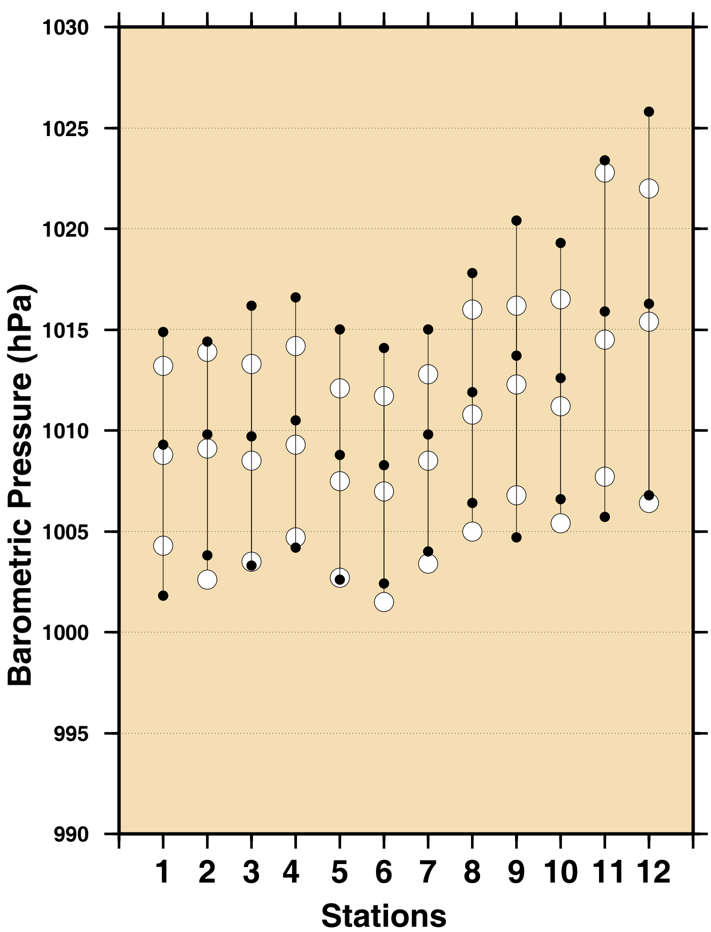


Figure 10

Comparison of September 2009 Max, Min & Mean with Long Term September Values







Stations

1 - Marshall Islands
2 - Federated States of Micronesia
3 - Papua New Guinea
4 - Solomon Islands
5 - Kiribati
6 - Nauru
7 - Tuvalu
8 - Samoa
9 - Vanuatu
10 - Fiji
11 - Tonga
12 - Cook Islands

○ September 2009 Maximum
○ September 2009 Mean
○ September 2009 Minimum

● Long Term September Maximum
● Long Term September Mean
● Long Term September Minimum

Figure 11

MONTHLY MEAN SEA LEVELS TO SEPTEMBER 2009 (m)

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

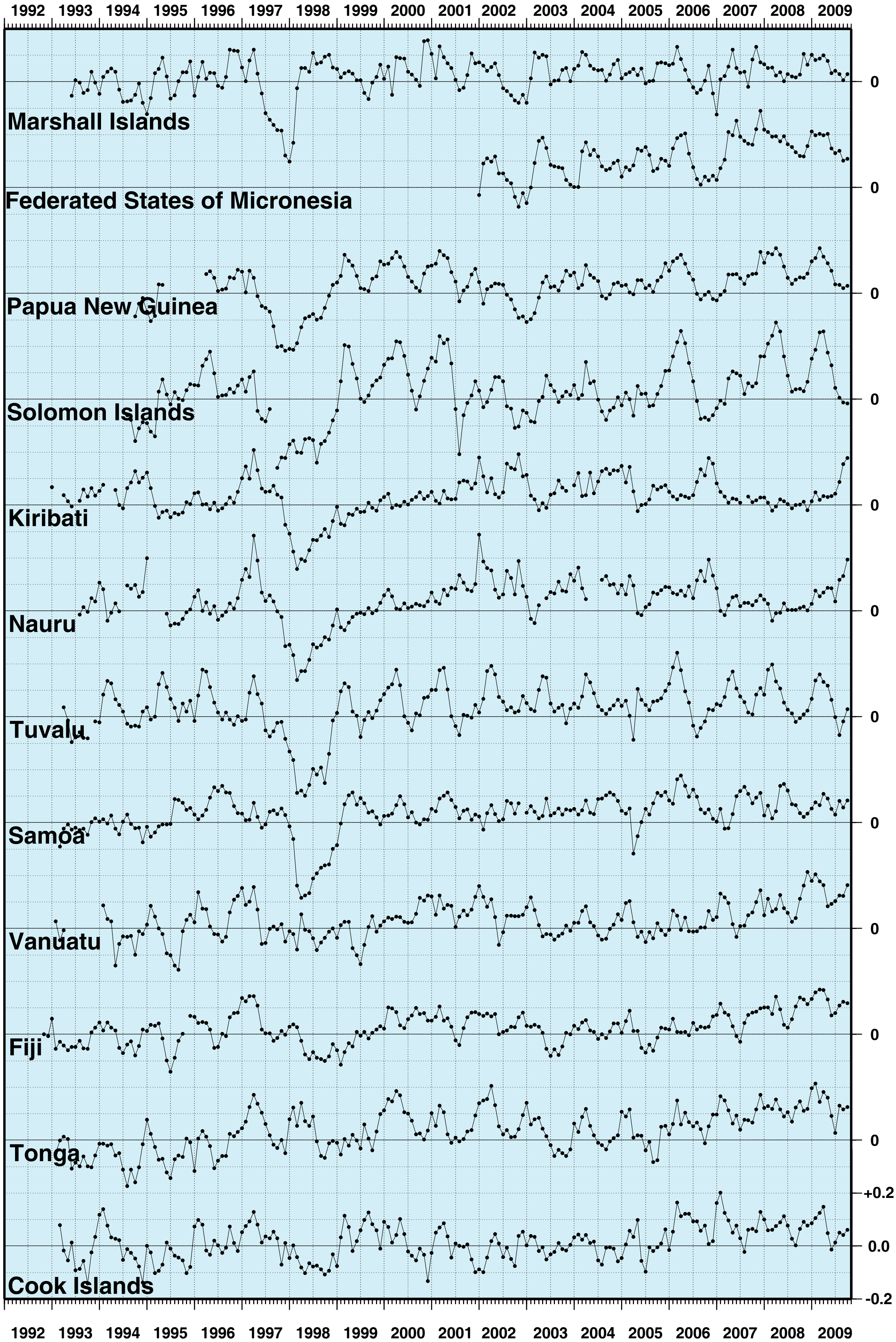


Figure 12

SEA LEVEL ANOMALIES THROUGH SEPTEMBER 2009 (m)

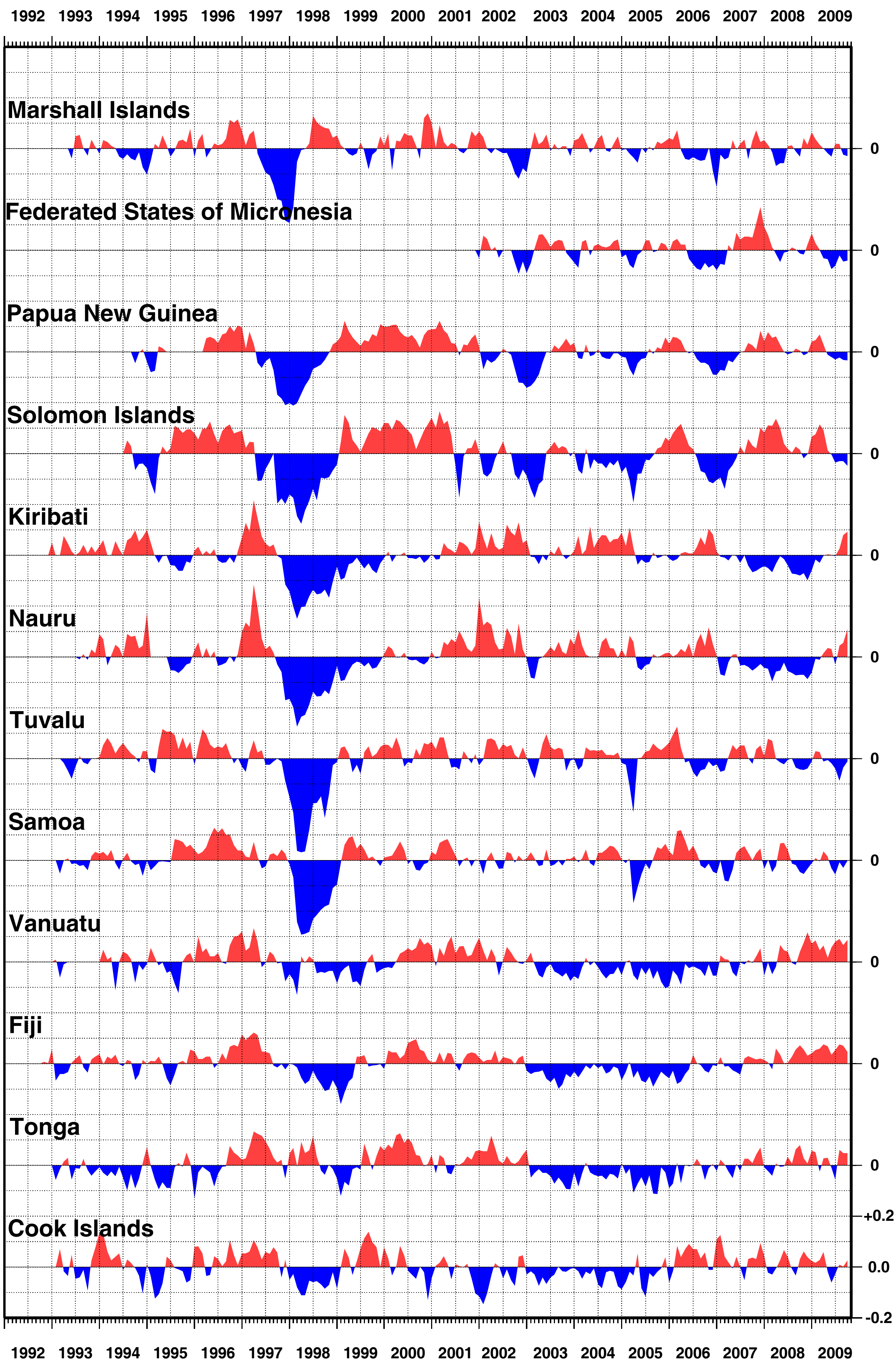


Figure 13

SEA LEVEL TRENDS THROUGH SEPTEMBER 2009 (mm/year)

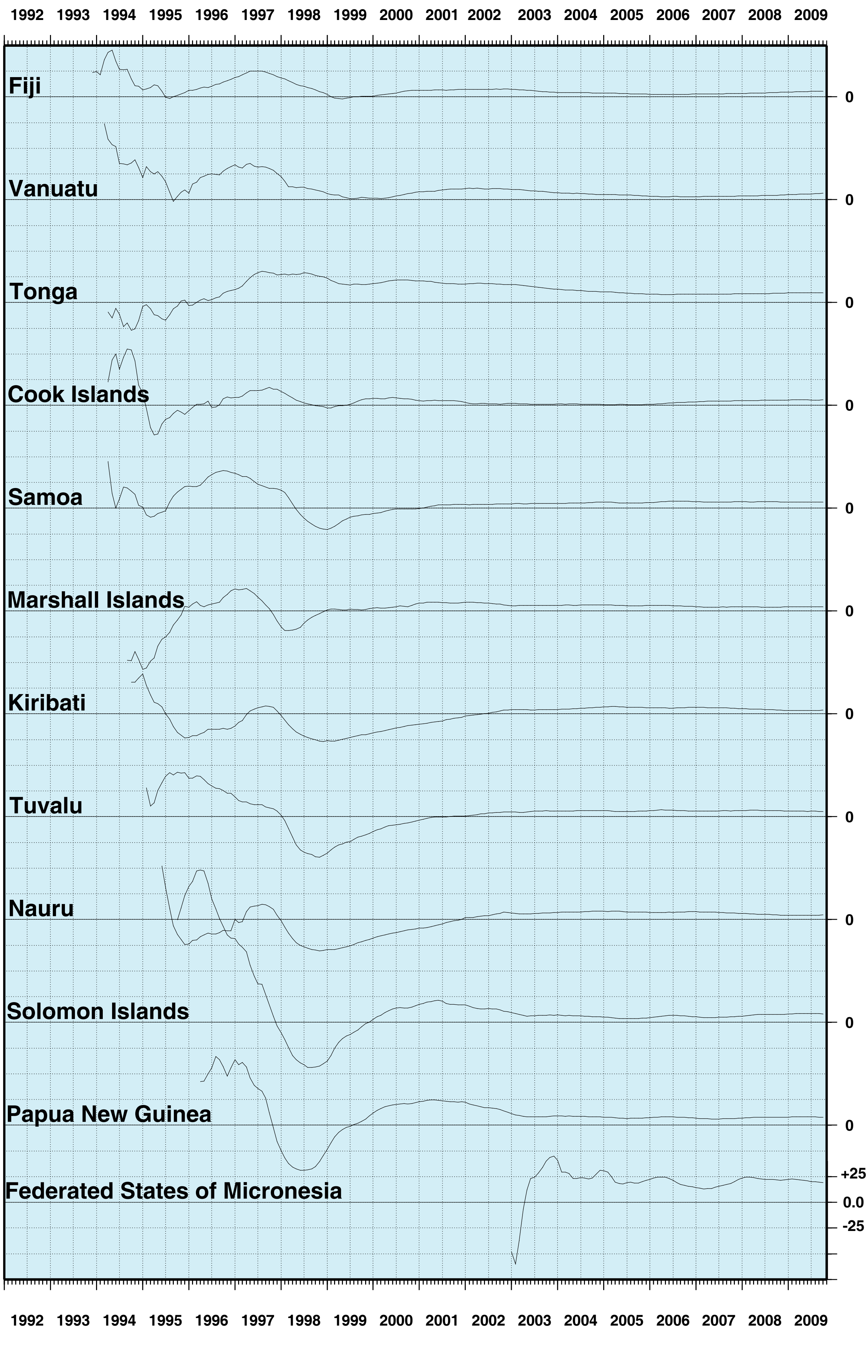


Figure 14

BAROMETRIC PRESSURE ANOMALIES THROUGH SEPTEMBER 2009 (hPa)

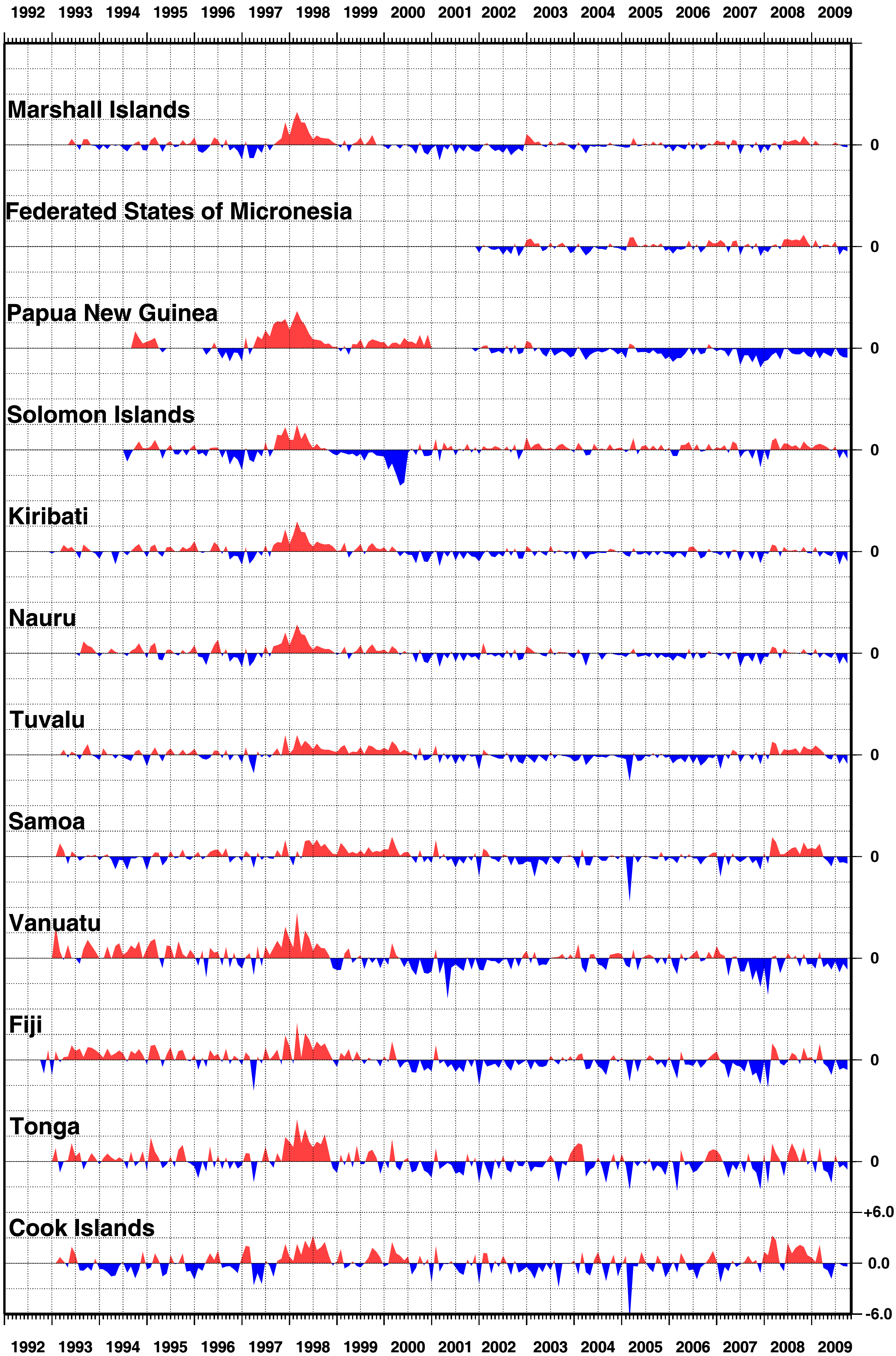


Figure 15

WATER TEMPERATURE ANOMALIES THROUGH SEPTEMBER 2009 (˚C)

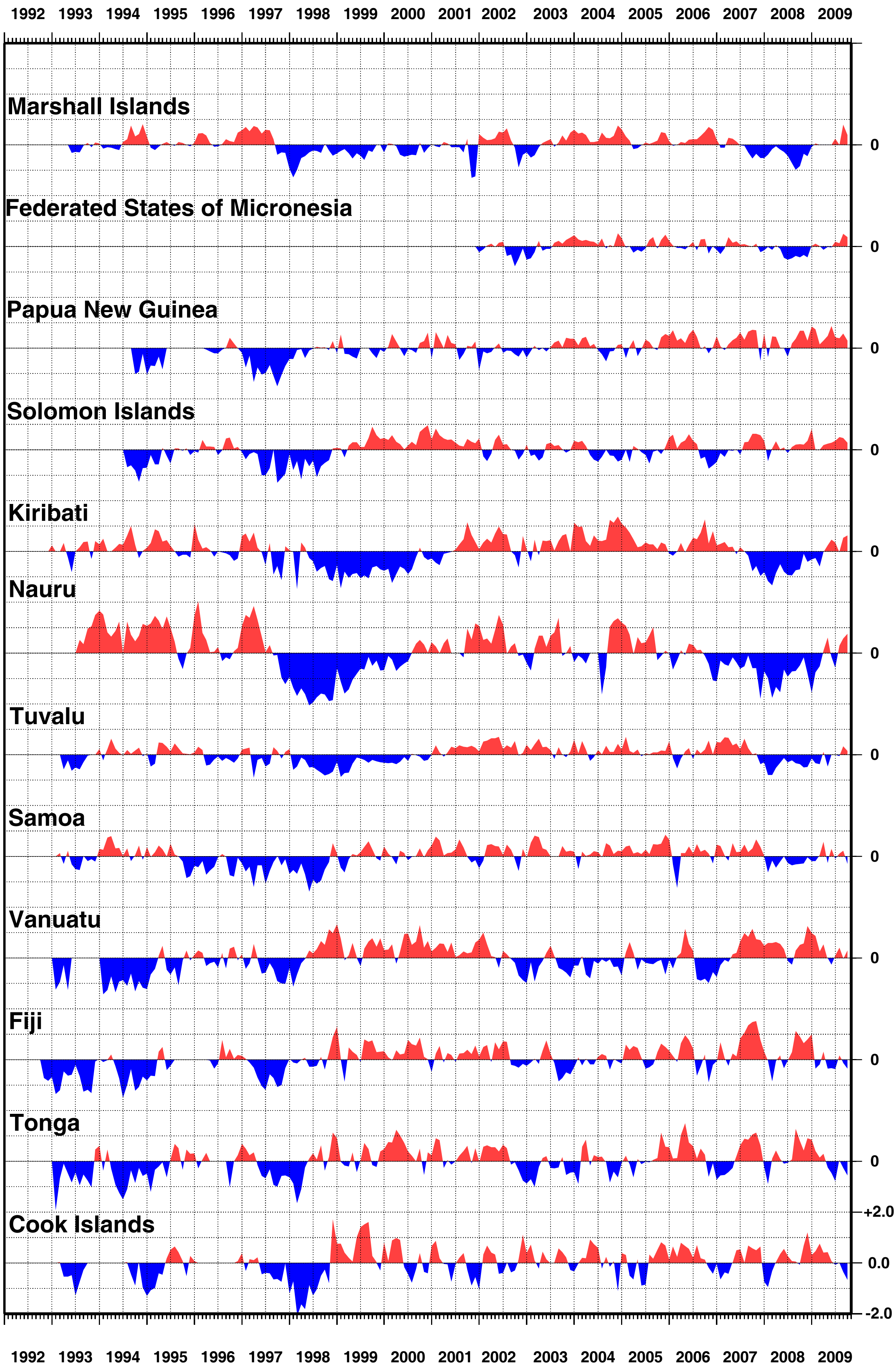


Figure 16

AIR TEMPERATURE ANOMALIES THROUGH SEPTEMBER 2009 (˚C)

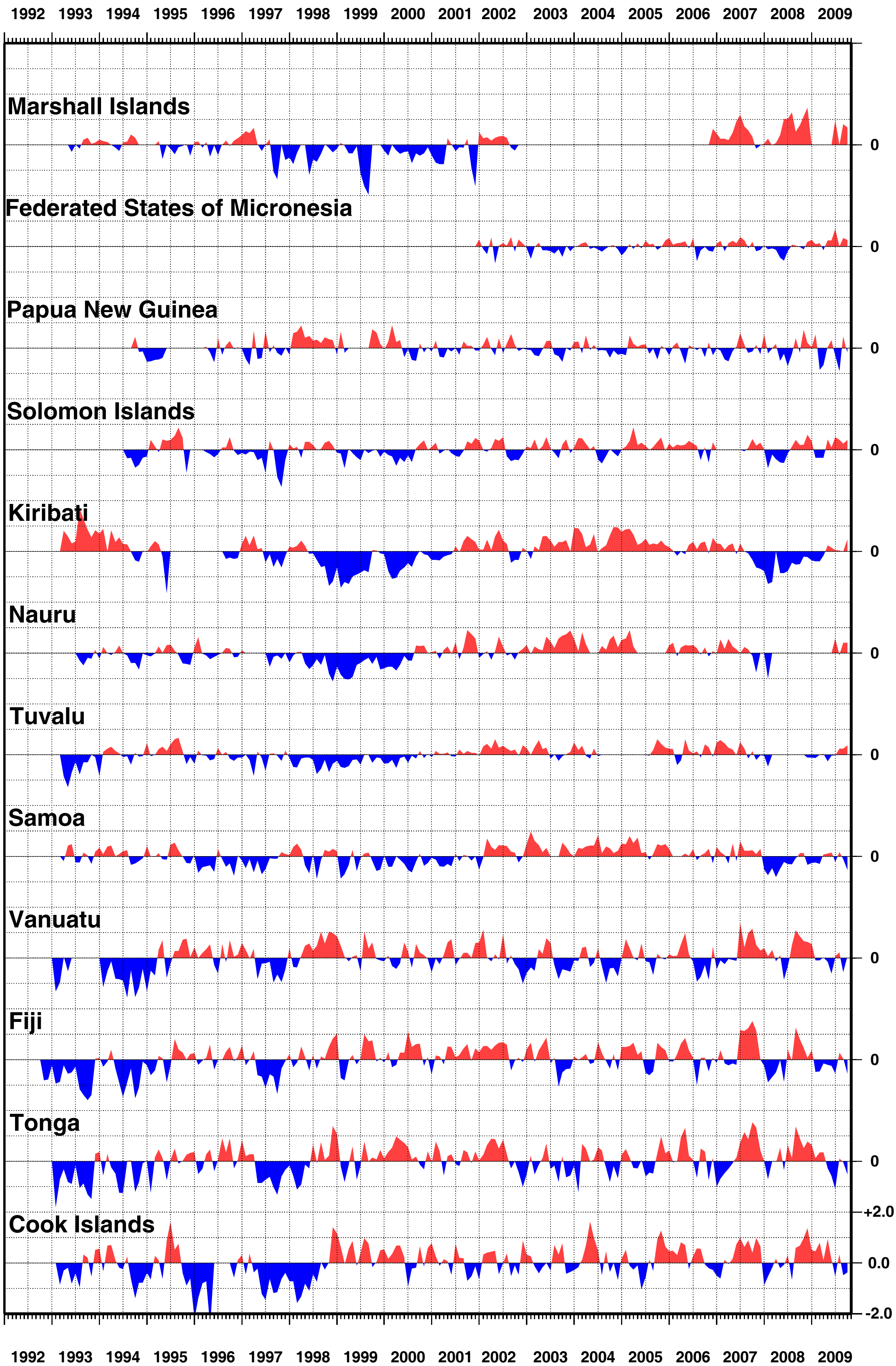


Figure 17

SEA LEVEL DATA RETURN

THE NUMBER OF DAYS OF GAP ARE INDICATED

GAPS INCLUDE TRANSMISSION, POWER AND LOGGER FAILURE

* Patchy record