THE SOUTH PACIFIC SEA LEVEL & CLIMATE MONITORING PROJECT

MONTHLY DATA REPORT

NO. 172

OCTOBER 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 October 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

October 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.

October 2009

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

- A tsunami was detected on a number of SEAFRAME stations on 7th October 2009 following a magnitude Mw7.6 earthquake near Vanuatu and a Mw7.3 aftershock an hour later. The trough to peak tsunami height recorded by the SEAFRAME at Port Vila some 600km away was 60cm. Smaller tsunami signals of less than 10cm were detected on other SEAFRAME stations.

- Sea levels during October were higher than normal at the equatorial stations Kiribati and Nauru, in connection with warmer than normal ocean temperatures. Monthly mean sea levels were the highest on record at Kiribati and the highest since 2001 at Nauru. Sea levels along the South Pacific Convergence Zone, as observed by the stations at PNG, Solomon Islands, Tuvalu and Samoa, were slightly lower than normal as a result of weaker than normal Trade Winds.

- Ocean temperatures warmed across the central equatorial Pacific in response to a weakening of the easterly Trade Winds. Atmosphere and ocean conditions are now showing patterns typical of a mature El Niño.

- The majority of international climate models predict El Niño conditions will persist early into next year, with equatorial Pacific sea surface temperatures expected to begin cooling by March 2010.

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 October, 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	0.0
Fiji	17°36'17.7"S / 177°26'17.7"E	Oct 1992	+5.8	0.0
Vanuatu	17°45'19.2"S / 168°18'27.7"E	Jan 1993	+6.4	+0.1
Samoa	13°49'36.4"S / 171°45'40.7"W	Feb 1993	+5.8	-0.1
Tuvalu	8°30'8.9"S / 179°11'42.6"E	Mar 1993	+5.2	-0.1
Kiribati	1°21'54.2"N / 172°55'58.8"E	Dec 1992	+4.0	+0.2
Nauru	0°31'45.9"S / 166°54'36.2"E	Jul 1993	+4.9	+0.2
Solomon Is.	9°25'44.1"S / 159°57'19.3"E	Jul 1994	+8.2	-0.2
PNG	2°2'31.5"S / 147°22'25.6"E	Sep 1994	+7.8	-0.1
FSM	6°58'49.9"N / 158°12'0.8"E	Dec 2001	+18.4	-0.8
Marshall Is.	7°6'21.7"N / 171°22'22.1"E	May 1993	+4.1	-0.1

INTRODUCTION

Welcome to the October 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.

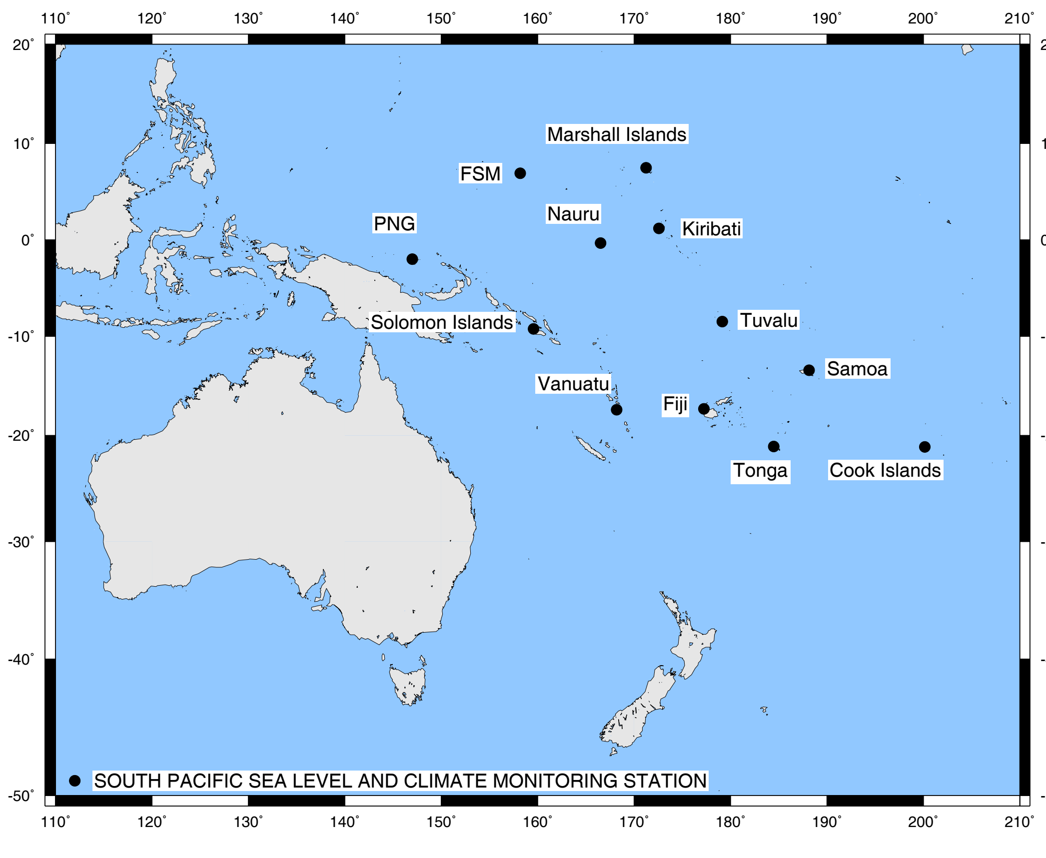

Figure A: *South Pacific Sea Level and Climate Monitoring Stations*

OCTOBER CLIMATOLOGY

El Niño climate conditions strengthened across the equatorial Pacific during October. Ocean heat content increased across the central equatorial Pacific as a result of a sustained weakening of the Trade Winds. The Southern Oscillation Index fell sharply in response to the maturing El Niño. The majority of international climate models predict that El Niño climate conditions will persist through to the early part of 2010.

The Southern Oscillation Index (SOI) fell sharply from its September value of +4 to an October value of –15, a value now typical of El Niño, and indicates the atmosphere is finally responding to warmer than average ocean temperatures across the equatorial Pacific (**Figure B**).

Sea surface temperatures warmed across the central and eastern equatorial Pacific during October. Meanwhile sea surface temperatures cooled in the far western equatorial Pacific, where previously unusually warm conditions for El Niño were observed. The sea surface pattern across the Pacific is now typical of an El Niño (**Figure C**). Sea surface temperature anomalies across the central equatorial Pacific, which are in excess +2ºC in some areas, are the highest they have been since the start of the year.

Subsurface ocean temperatures also warmed steadily during October as a result of weaker than normal Trade Winds. A large body of warmer than normal subsurface water is now established across the central equatorial Pacific, with anomalies exceeding +4.0ºC in some areas (**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 October 2009 the easterly Trade Winds were weaker than average across most of the tropical Pacific (**Figure E**). A strong westerly wind burst occurred in the western equatorial Pacific and is associated with warming ocean heat content in the central equatorial Pacific and sudden fall in the SOI. Although cloudiness near the dateline was at near average levels during October significantly enhanced cloudiness occurred west of the dateline. This pattern although unusual is similar to what was observed during the recent 2006 El Niño.

The majority of seven international computer models surveyed by the Bureau of Meteorology predict El Niño conditions will persist through the southern hemisphere summer, with sea surface temperatures across the equatorial Pacific beginning to cool by March 2010.

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/.

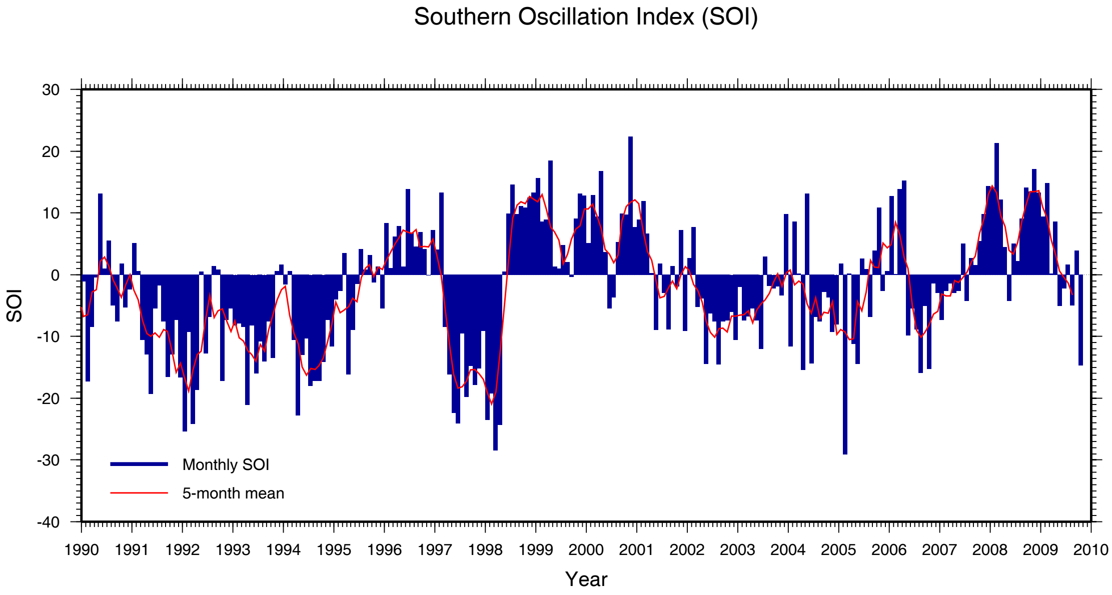

Figure B: *The five-month weighted mean and individual monthly means of the Southern Oscillation Index (SOI). The SOI is ten times the monthly anomaly of the difference in mean sea level pressure between Tahiti and Darwin, divided by the long-term standard deviation of that difference for the relevant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

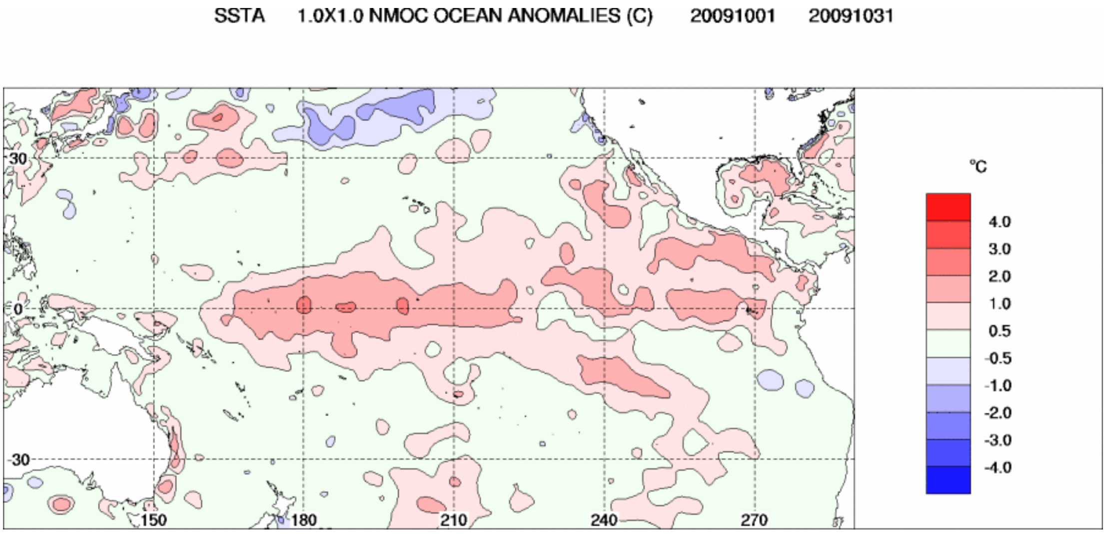

Figure C: *Sea surface temperature anomaly (°C) for October 2009.*

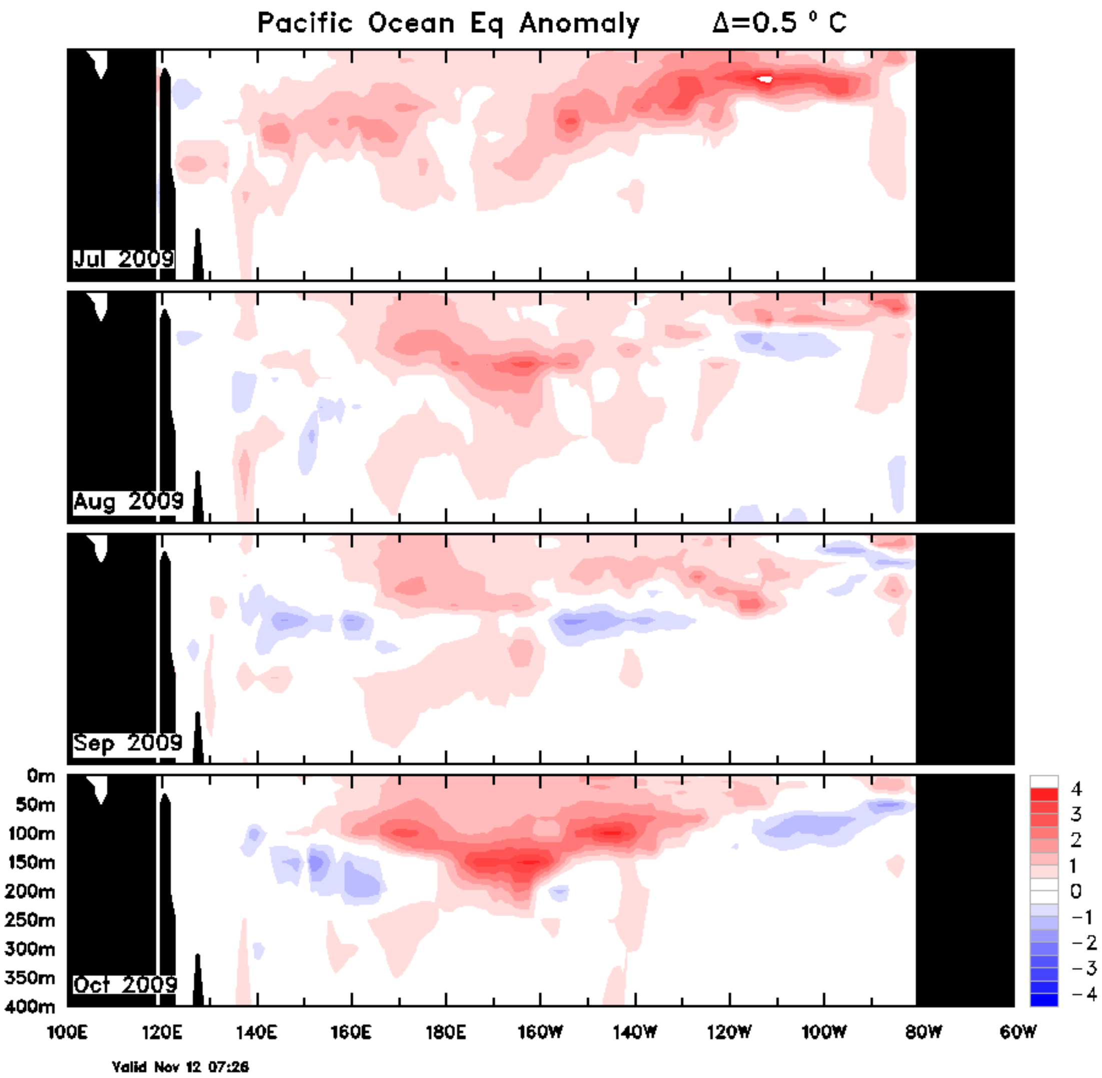

Figure D: *Equatorial depth-longitude section of ocean temperature anomalies for July 2009 through to October 2009. Contour interval is 0.5°C.*

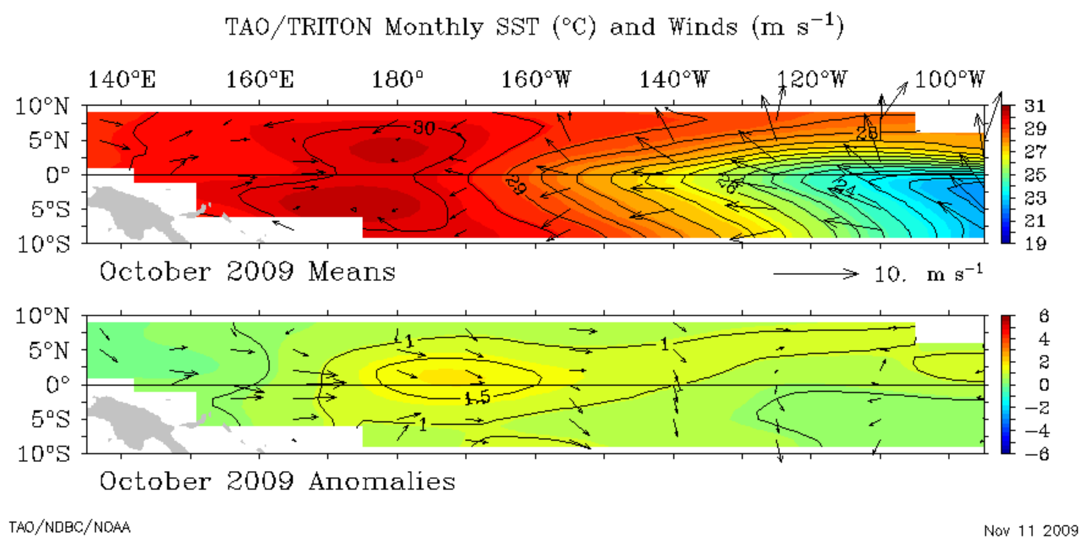

Figure E: *Monthly mean wind vectors (top) and anomalies (bottom) for October 2009. The colour-shaded contours represent the monthly mean sea surface temperatures (top) and anomalies (bottom).*

OCTOBER 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 October and a new moon on the 18th of October 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.

Following the destructive Samoa tsunami of 29th September 2009, the Pacific region was on high alert when 3 undersea earthquakes struck in the vicinity of Vanuatu during October 2009. A magnitude Mw7.6 earthquake at 22:03 UTC on 7th October, located around 600km north-northwest of Port Vila, was followed by an aftershock of magnitude Mw7.3 at 23:13 UTC on the 7th October (just over an hour later) and another aftershock of magnitude Mw6.8 at 8:28 UTC on the 8th October. The SEAFRAME network detected tsunami waves, likely generated from both the first and second earthquake. A tsunami signal can be seen in the 6-minute residual sea levels at Vanuatu (Figure 2), and small tsunami signals can also be seen at Fiji, Tonga, Samoa and Solomon Islands. The 1-minute sea level data that is transmitted in real time from the SEAFRAME stations (and made available to international tsunami warning agencies) showed a trough-to-peak tsunami height of 60cm at Vanuatu, as well as small tsunami signals less than 10cm at Fiji, Tonga, Samoa, Solomon Islands, Kiribati and Marshall Islands. Other tide gauges in the region also detected the tsunami, including a 25cm signal at Luganville, Vanuatu.

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 Vanuatu prevailed from the northeast 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 minimum October air temperature of 19.6°C was recorded at Nauru and a new maximum October air temperature of 31.3°C was recorded at FSM. New maximum October water temperatures of 32.7°C and 31.3°C were recorded at Kiribati and Nauru, due to the influence of the warmer than normal sea surface temperatures across the central equatorial Pacific shown in Figure C.

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. The monthly mean sea level observed at Kiribati during October 2009 is the highest on record, exceeding the previous high set in March 1997. At Nauru, the October 2009 monthly mean sea level is the highest since December 2001.

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 October 2009 sea levels at the equatorial stations Kiribati and Nauru were more than 10cm higher than normal in connection with warmer than normal ocean temperatures. Slightly lower than normal sea levels were observed at PNG, Solomon

Islands, Tuvalu and Samoa as a result of weakening Trade Winds and hence reduced convergence along the South Pacific Convergence Zone. Sea levels were around 5cm higher than normal at Vanuatu, almost 10cm lower than normal at FSM and near normal at the remaining stations of Marshall Islands, Fiji, Tonga and Cook Islands.

Sea Level Trends

The **short-term sea level trends** at individual stations as at October 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*.

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Kiribati	1°21'54.2"N / 172°55'58.8"E	Dec 1992	+4.0	+0.2
Nauru	0°31'45.9"S / 166°54'36.2"E	Jul 1993	+4.9	+0.2
Solomon Is.	9°25'44.1"S / 159°57'19.3"E	Jul 1994	+8.2	-0.2
PNG	2°2'31.5"S / 147°22'25.6"E	Sep 1994	+7.8	-0.1
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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 October 2009 barometric pressures were near to slightly lower than normal across the region. The barometric pressure anomalies have generally increased in comparison to what they were a month ago, with the exception of Samoa and Cook Islands.

The **water temperature anomalies (Figure 15)** indicate slightly warmer than normal conditions were observed at Marshall Islands, FSM, Kiribati and Nauru through October 2009. Water temperatures at Kiribati were almost 1°C warmer than is normal for this time of the year. On the other hand, water temperatures were around 0.5°C cooler than normal at Fiji, Tonga and Cook Islands. Near normal water temperatures were observed at PNG, Solomon Islands, Tuvalu, Samoa, and Vanuatu.

The **air temperature anomalies (Figure 16)** show similar patterns to the water temperature anomalies during October 2009, with warmer than normal conditions recorded at Marshall Islands and Kiribati and cooler than normal conditions at 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 October 2009. At Nauru problems with the primary sea level sensor were encountered but data from the secondary sea level sensor was available for the entire month.

Various problems were encountered with ancillary meteorological sensors including the air temperature, water temperature and barometric pressure electronic circuit at Marshall Islands, where resulting erroneous data were removed from the record. Occasional erroneous water temperature data at Kiribati, Tonga and Vanuatu were encountered and also removed from the record.

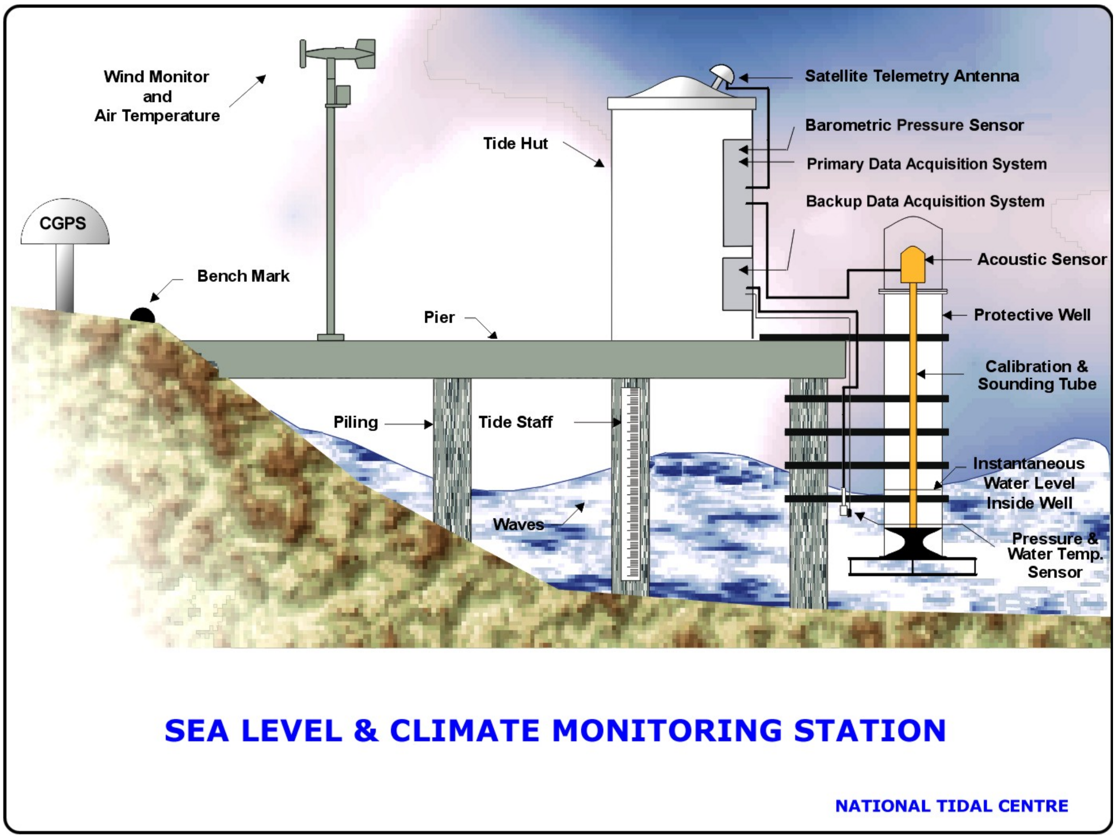
SEAFRAME STATIONS

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

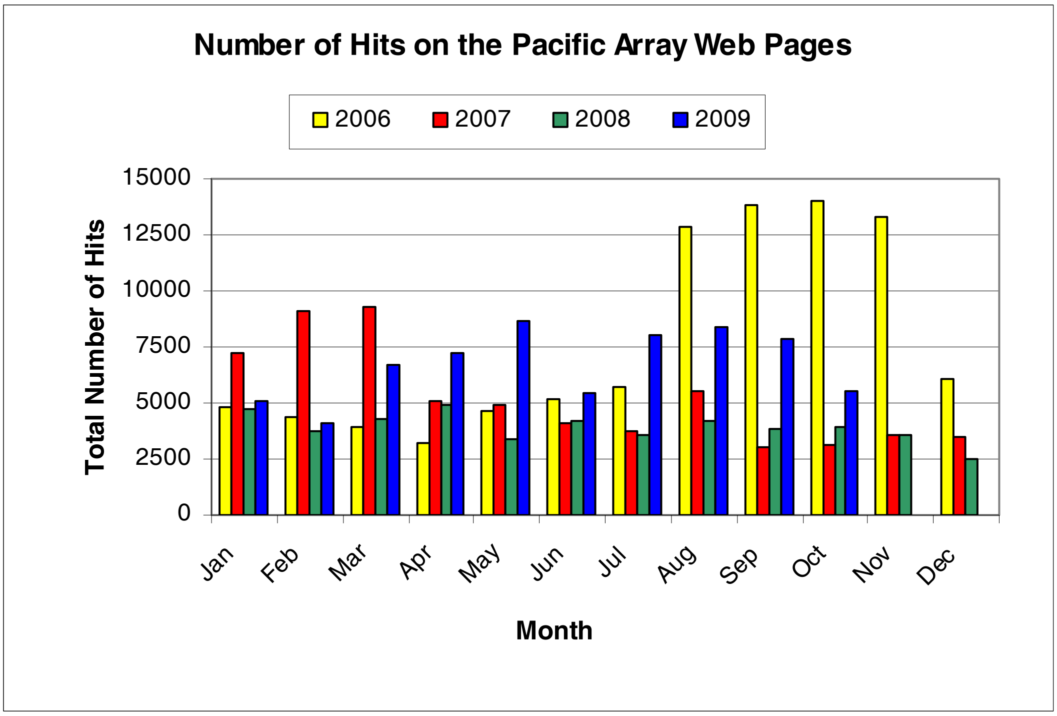
(2) Secondary water level (or backup) using a Druck pressure transducer mounted close to the seabed.

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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Fax: (+618) (08) 8366 2693
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:

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

OCTOBER 2009
SIX MINUTE WATER LEVEL OBSERVATIONS (m)

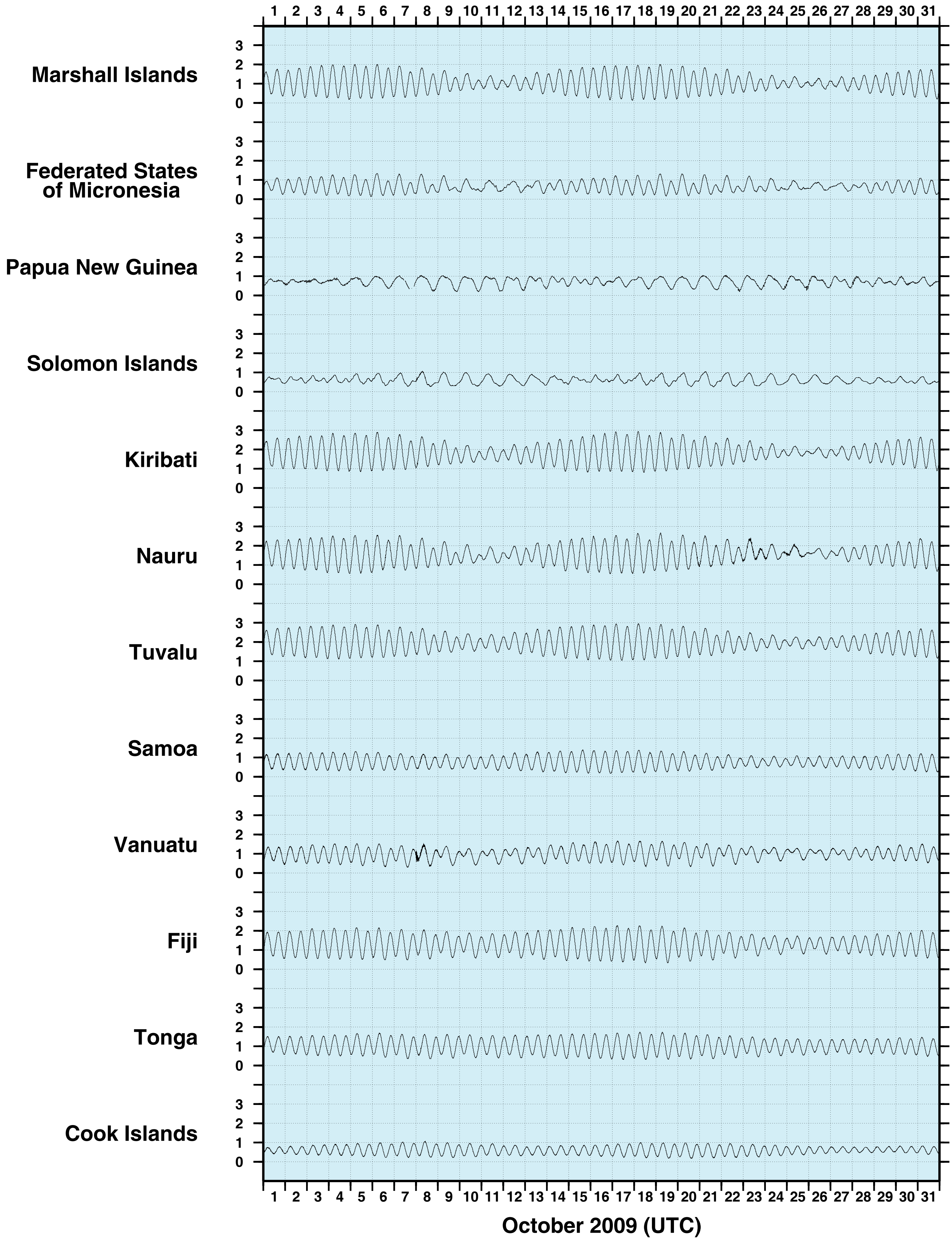


Figure 2

OCTOBER 2009
SIX MINUTE RESIDUAL WATER LEVELS (m)

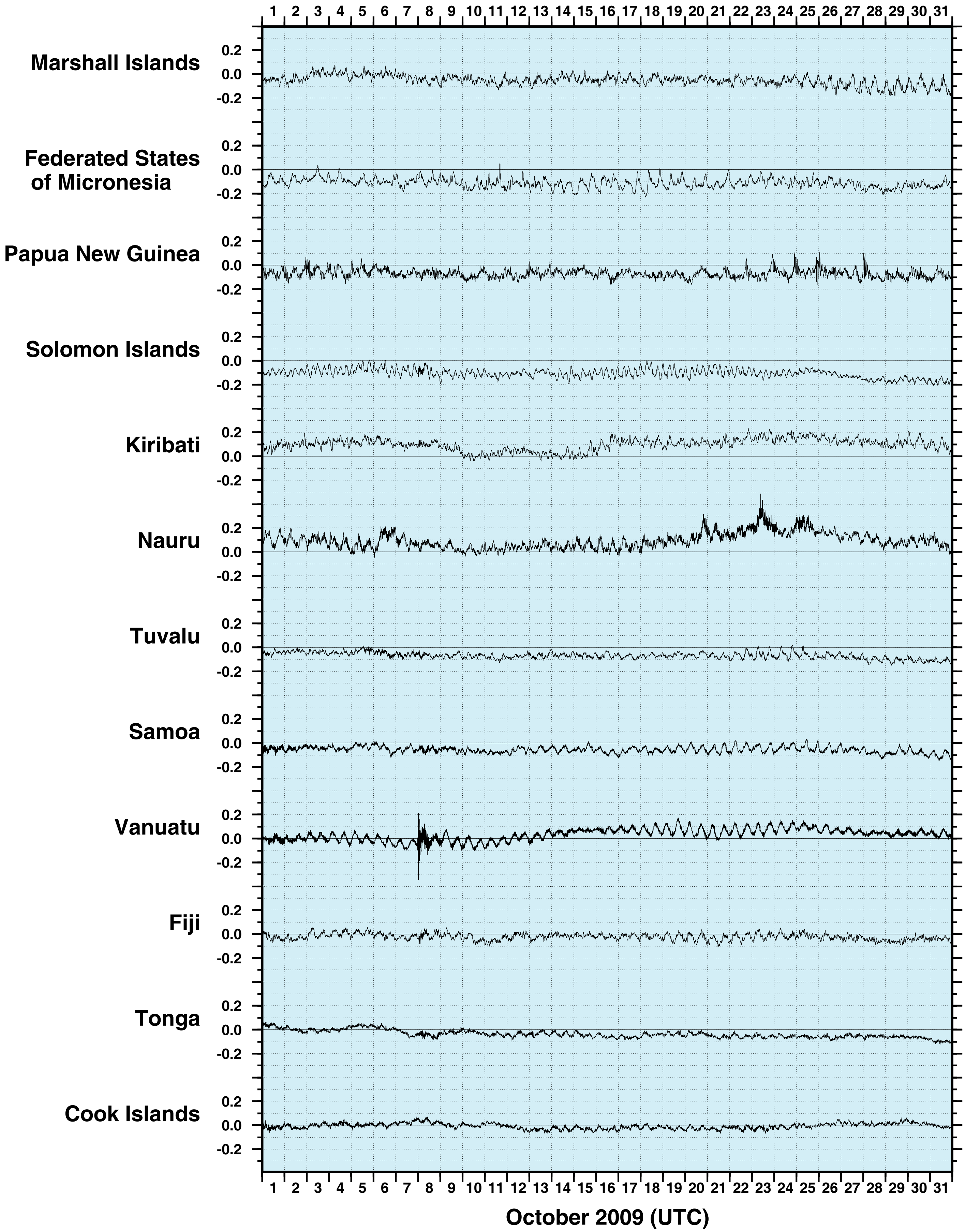


Figure 3

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

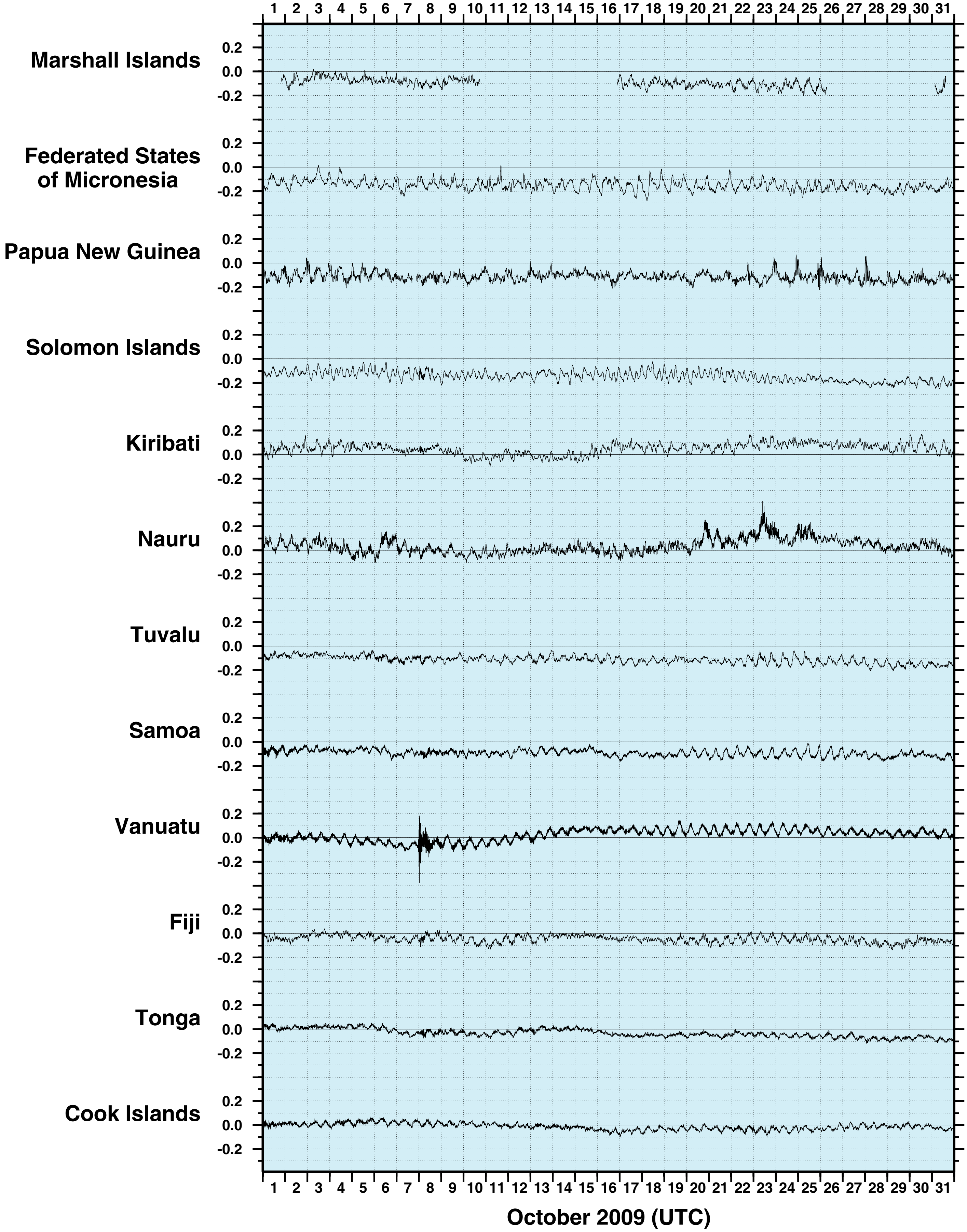
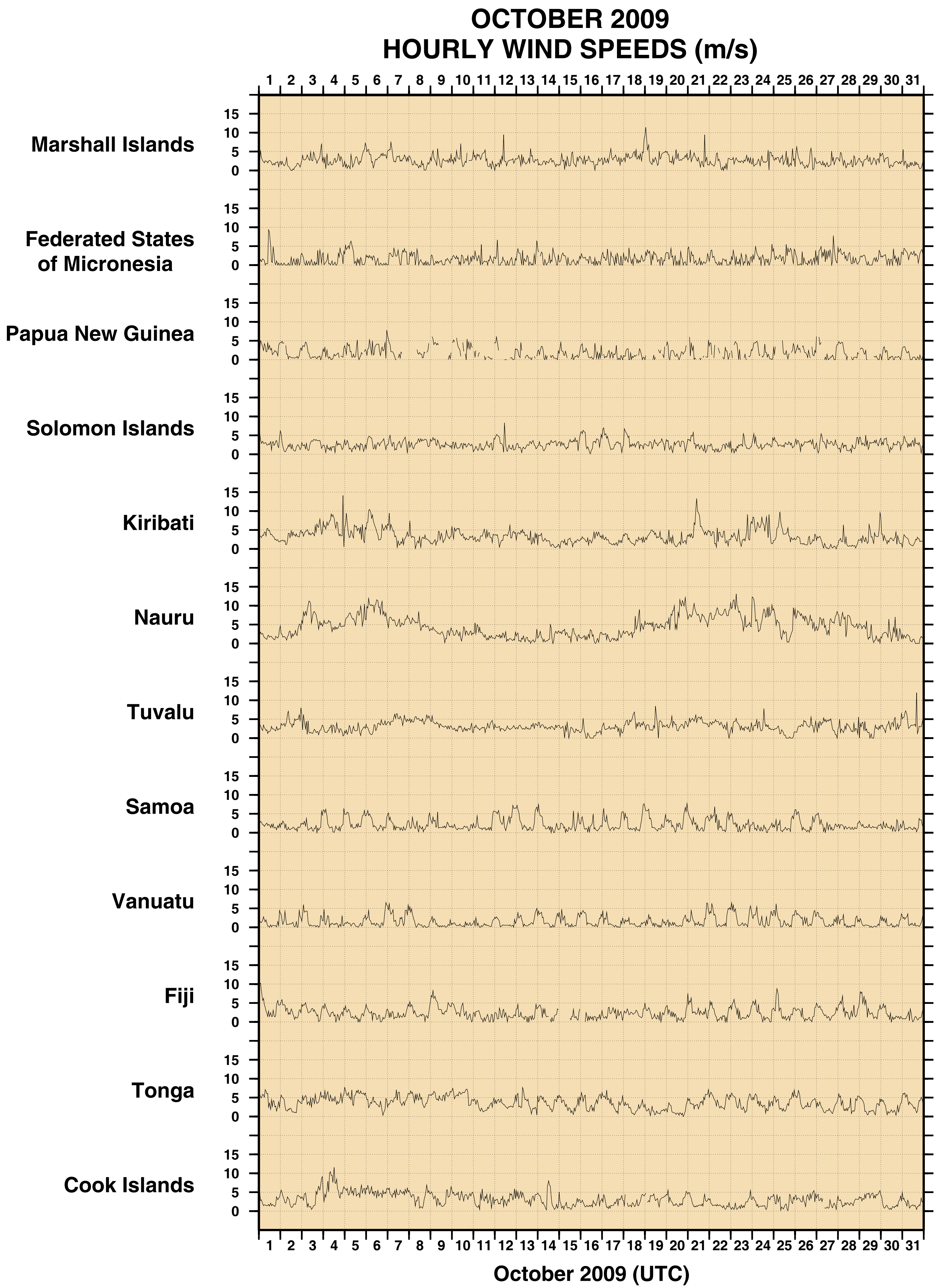
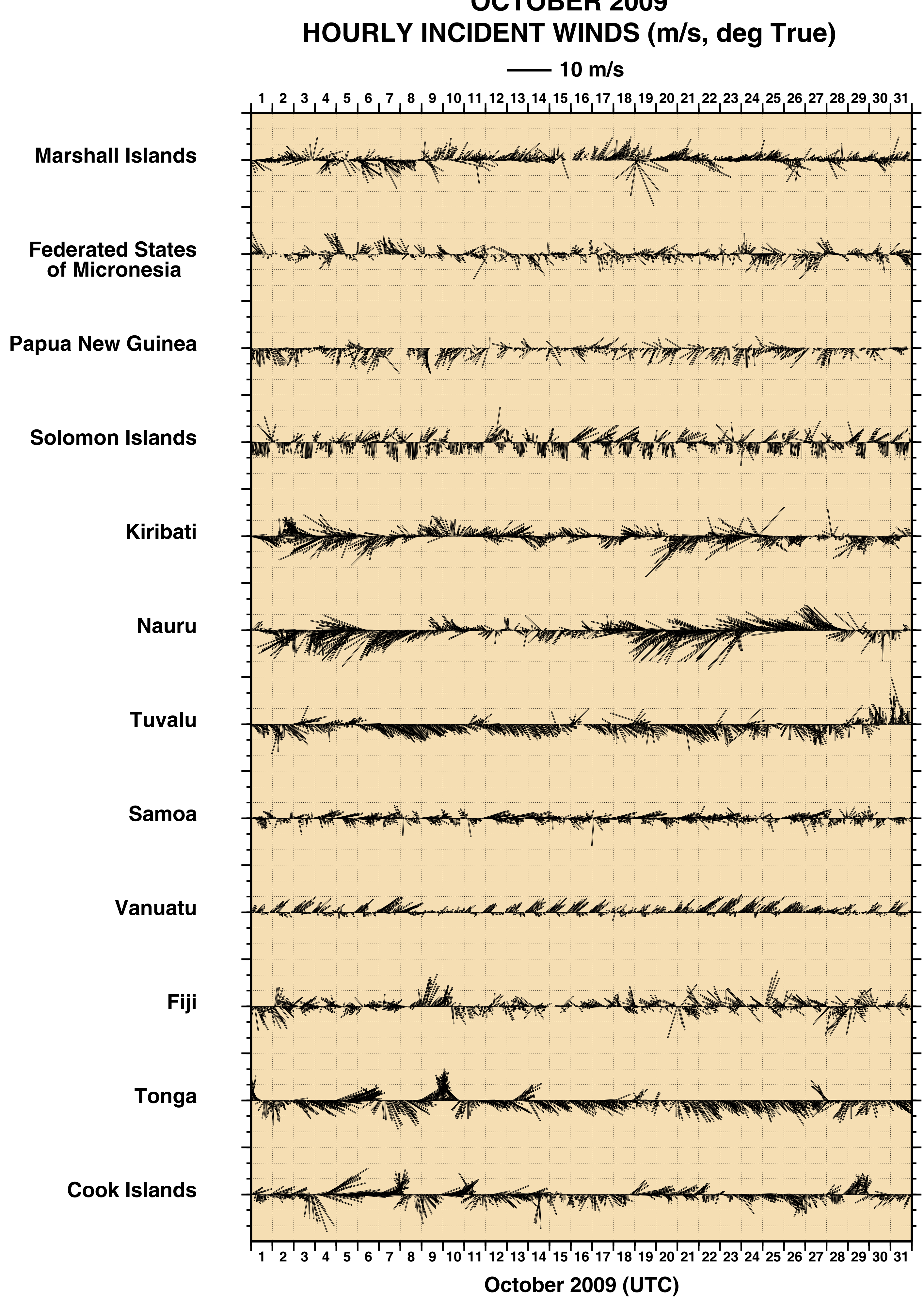


Figure 1


OCTOBER 2009
HOURLY WIND SPEEDS (m/s)
Marshall Islands
Federated States of Micronesia
Papua New Guinea
Solomon Islands
Kiribati
Nauru
Tuvalu
Samoa
Vanuatu
Fiji
Tonga
Cook Islands
0
5
10
15
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 31
October 2009 (UTC)



OCTOBER 2009
HOURLY INCIDENT WINDS (m/s, deg True)
10 m/s
Marshall Islands
Federated States of Micronesia
Papua New Guinea
Solomon Islands
Kiribati
Nauru
Tuvalu
Samoa
Vanuatu
Fiji
Tonga
Cook Islands
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 31
October 2009 (UTC)

Figure 6

OCTOBER 2009
HOURLY MAXIMUM WIND GUSTS (m/s)

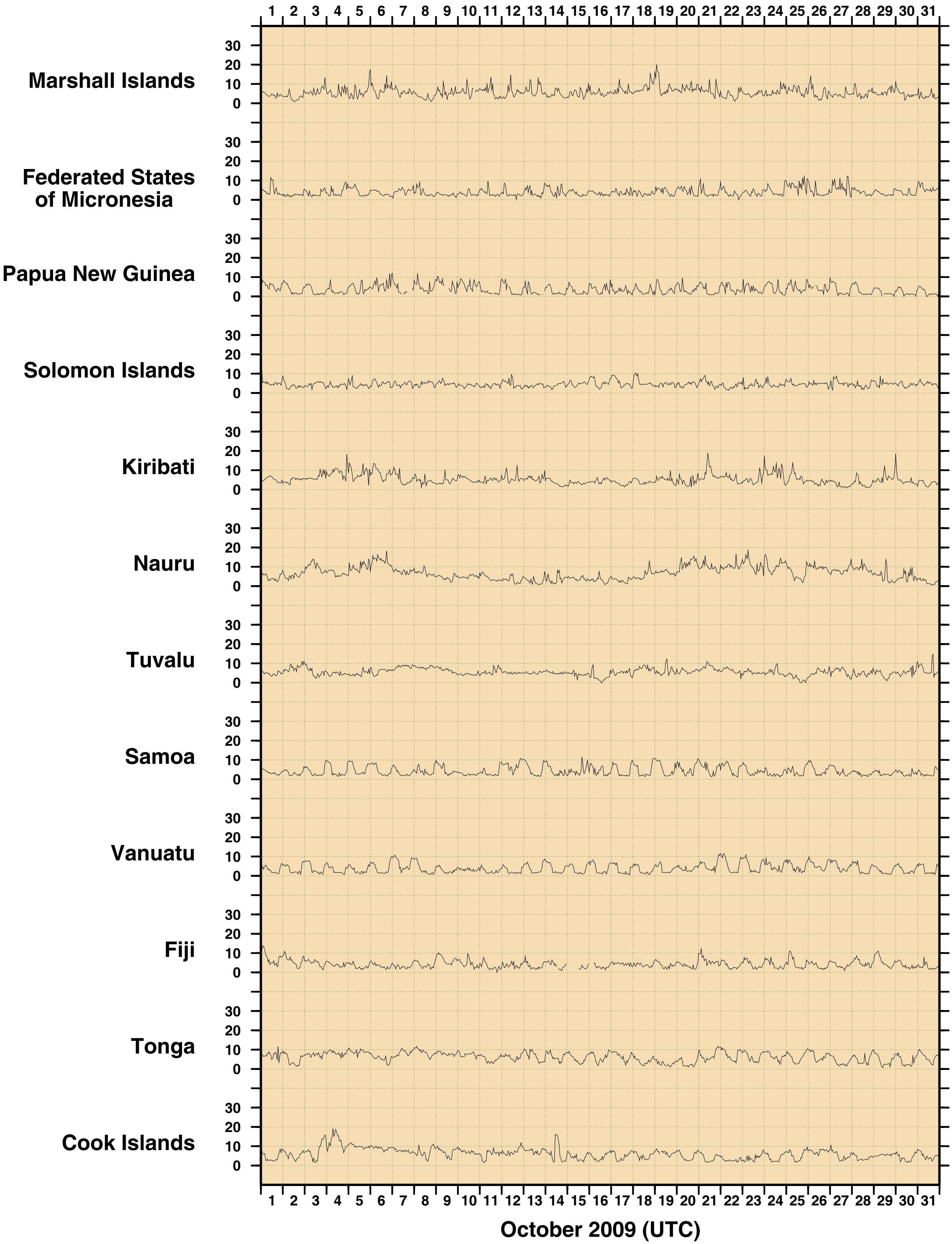


Figure 7

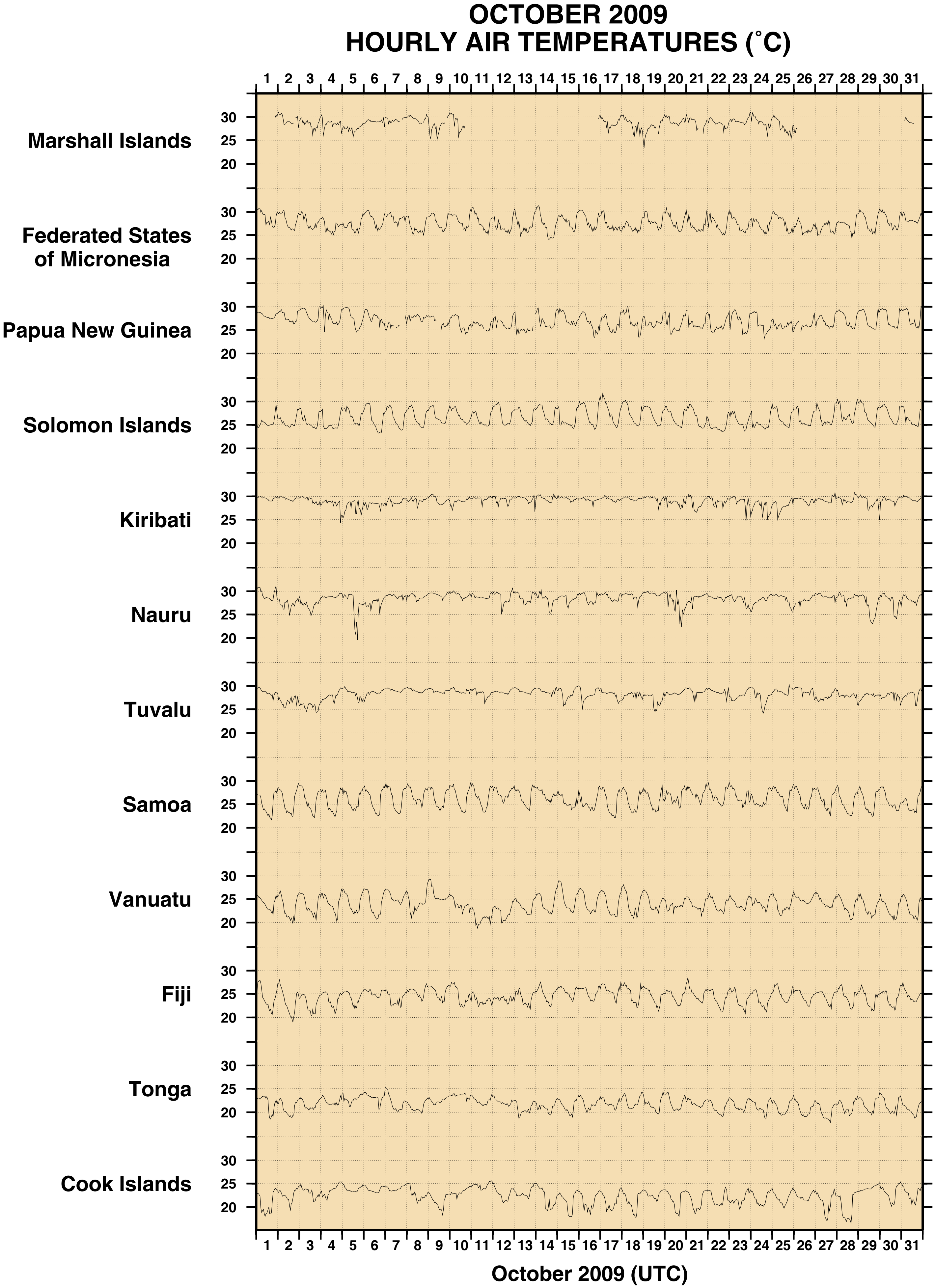

OCTOBER 2009
HOURLY AIR TEMPERATURES (˚C)
Marshall Islands
Federated States of Micronesia
Papua New Guinea
Solomon Islands
Kiribati
Nauru
Tuvalu
Samoa
Vanuatu
Fiji
Tonga
Cook Islands
30
25
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
October 2009 (UTC)

Figure 8

OCTOBER 2009
HOURLY WATER TEMPERATURES (˚C)

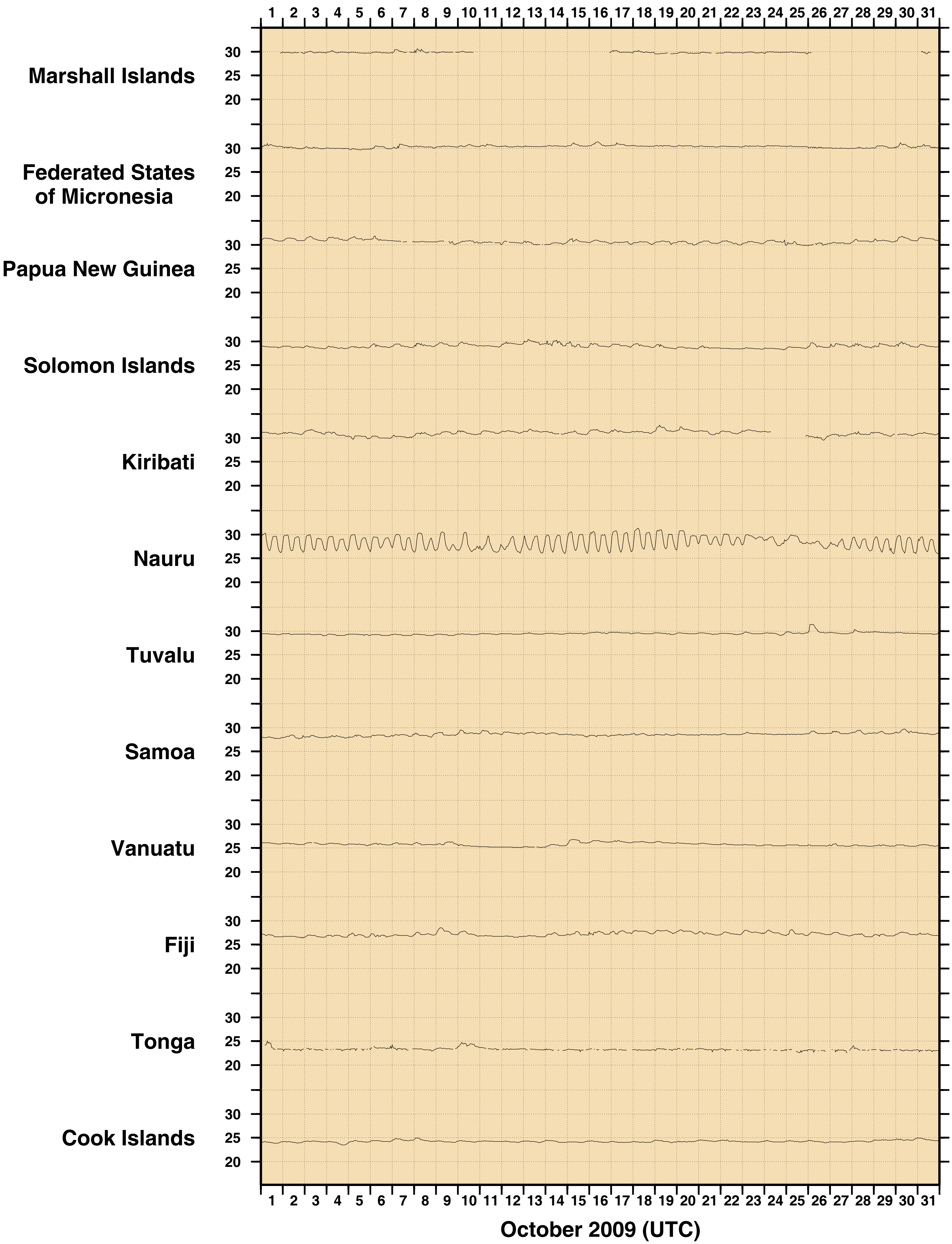


Figure 9

OCTOBER 2009
HOURLY ATMOSPHERIC PRESSURE (hPa)

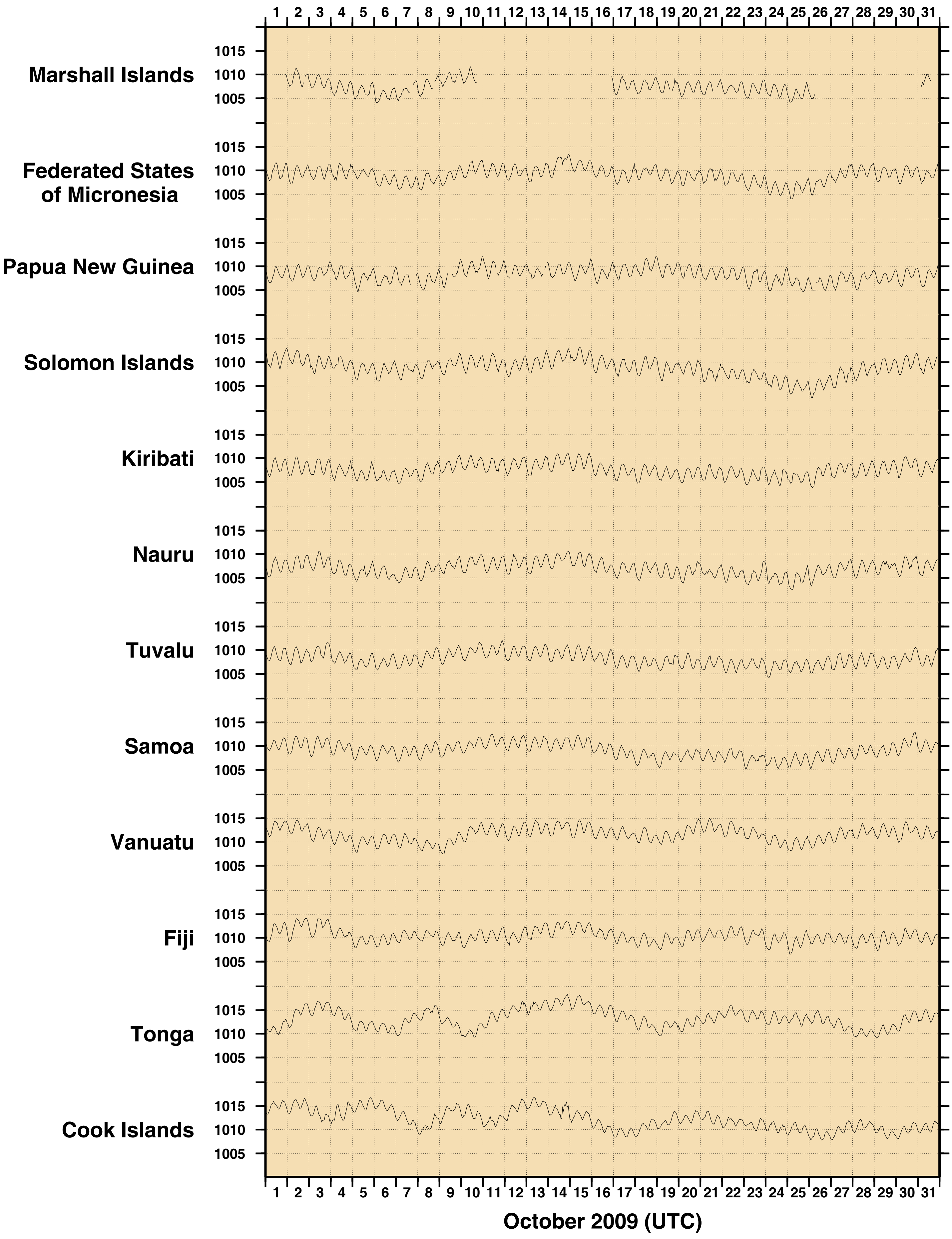


Figure 10

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

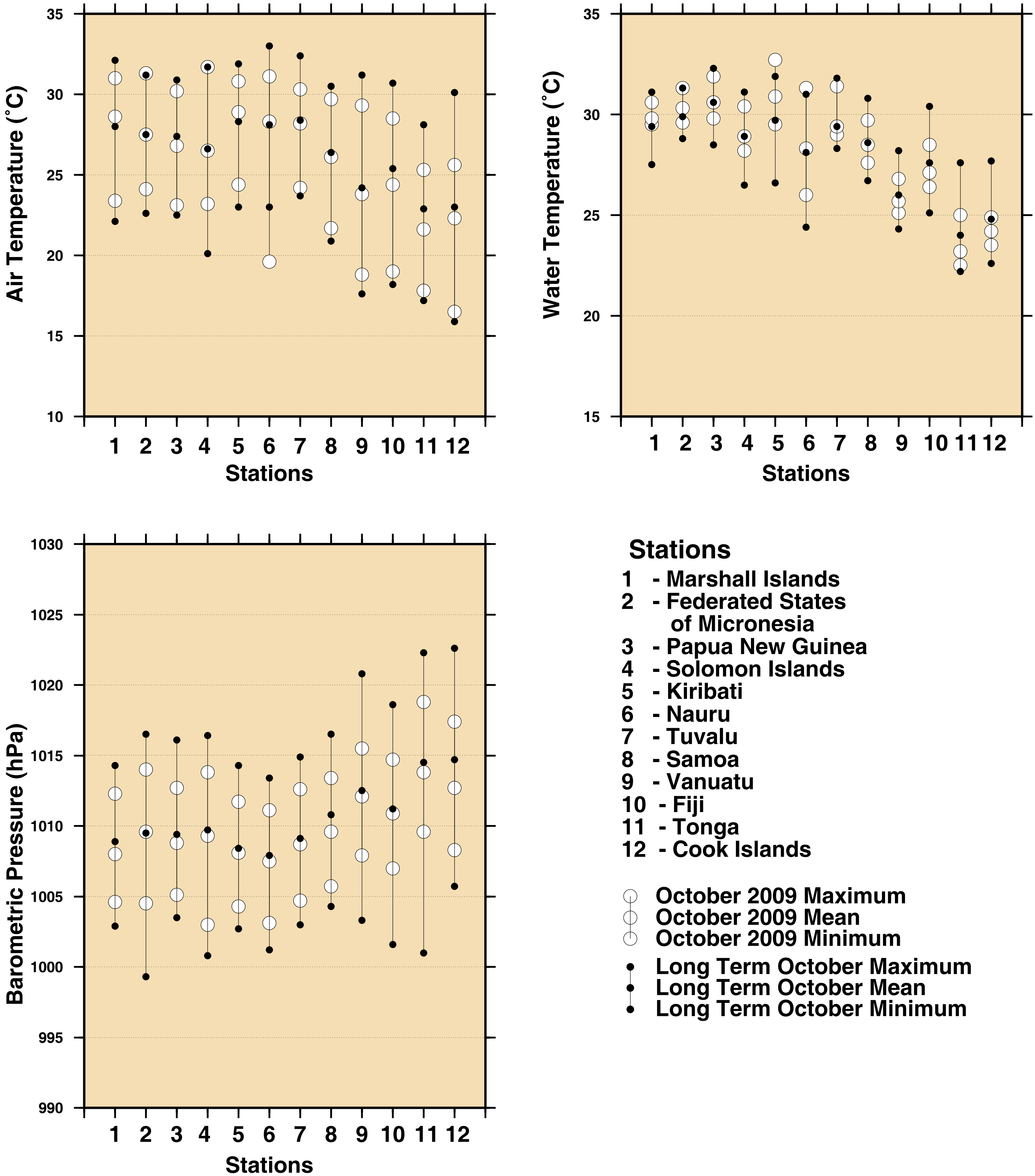


Figure 11

MONTHLY MEAN SEA LEVELS TO OCTOBER 2009 (m)

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

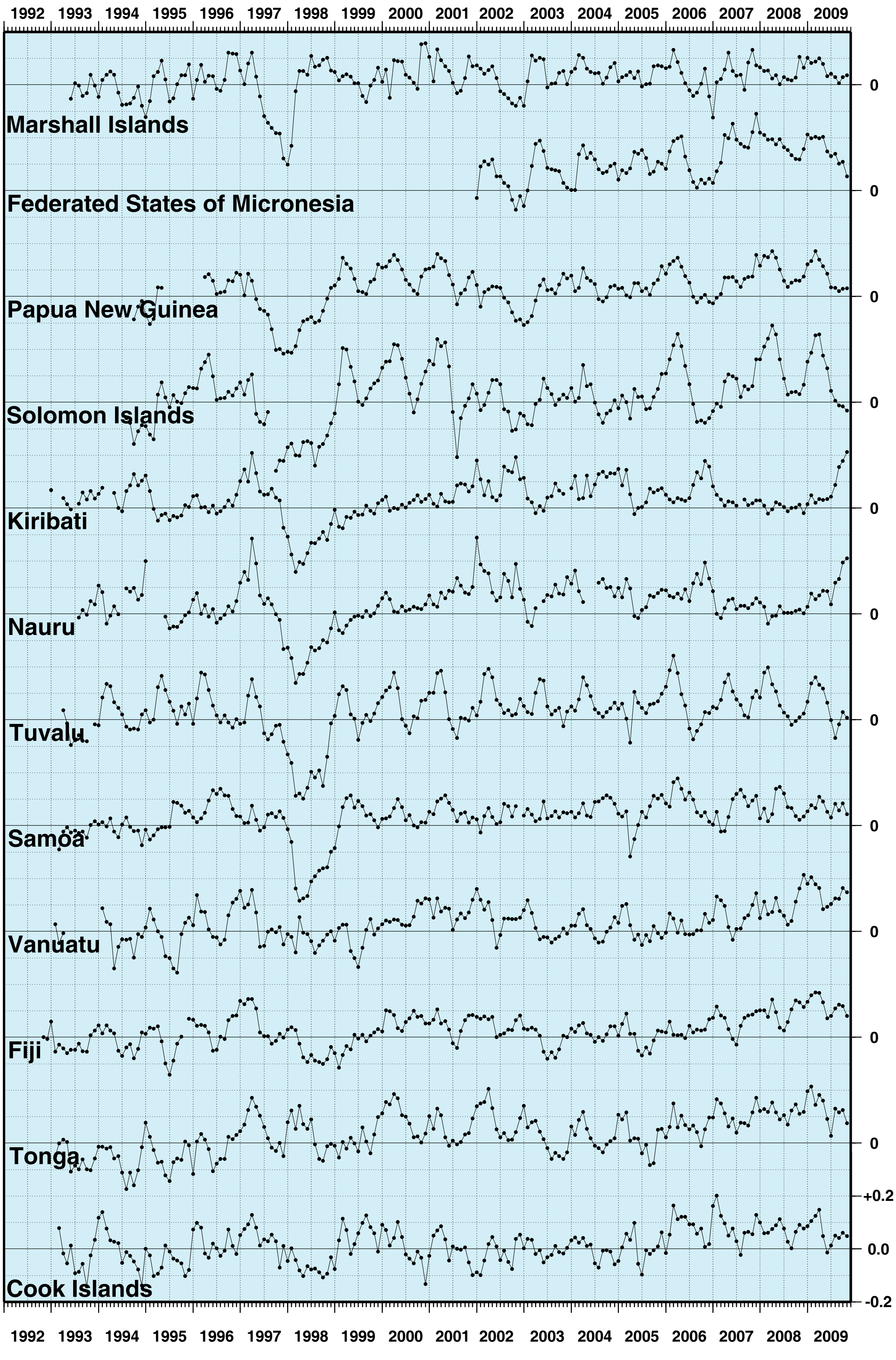


Figure 12

SEA LEVEL ANOMALIES THROUGH OCTOBER 2009 (m)

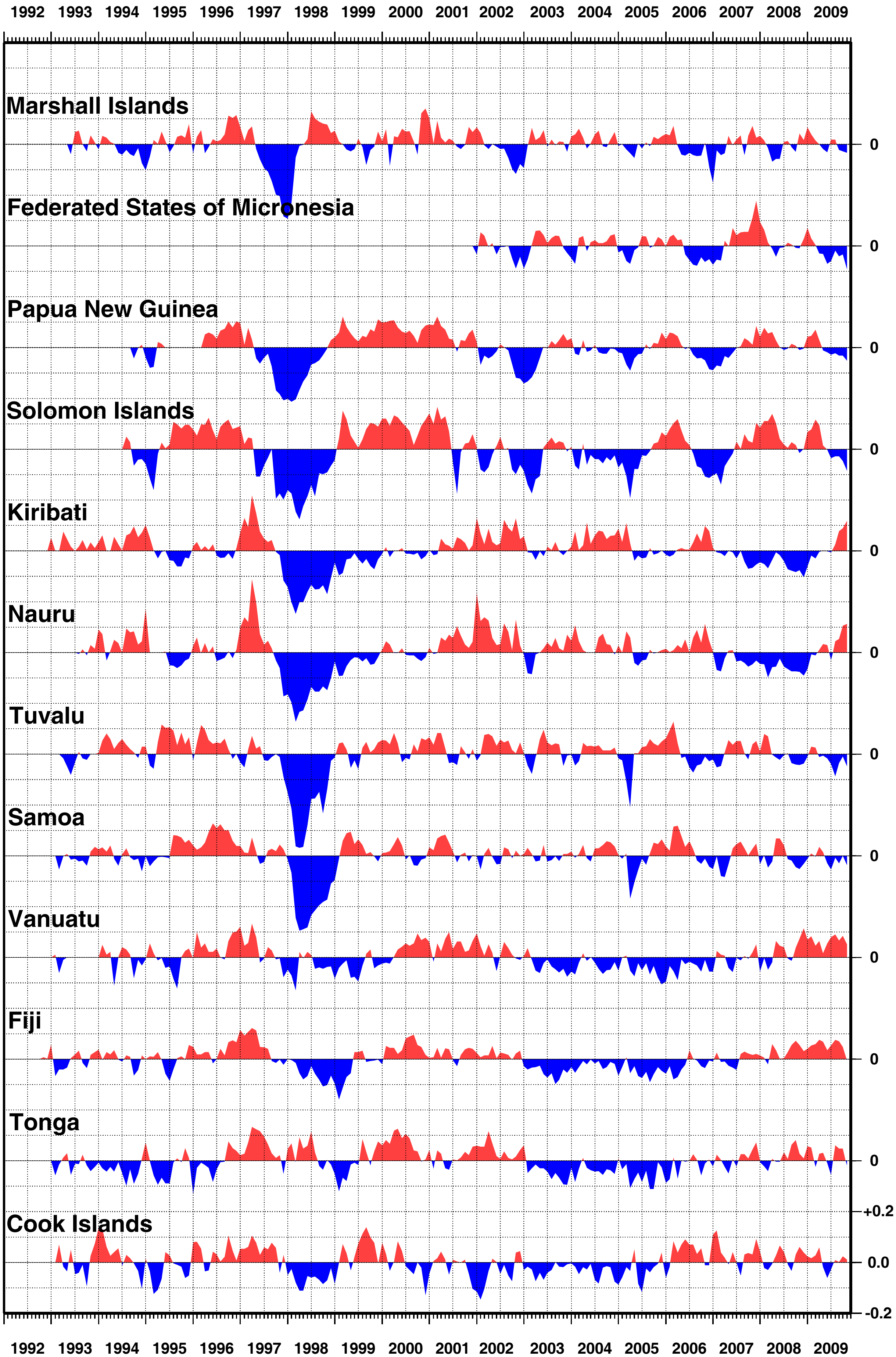


Figure 13

SEA LEVEL TRENDS THROUGH OCTOBER 2009 (mm/year)

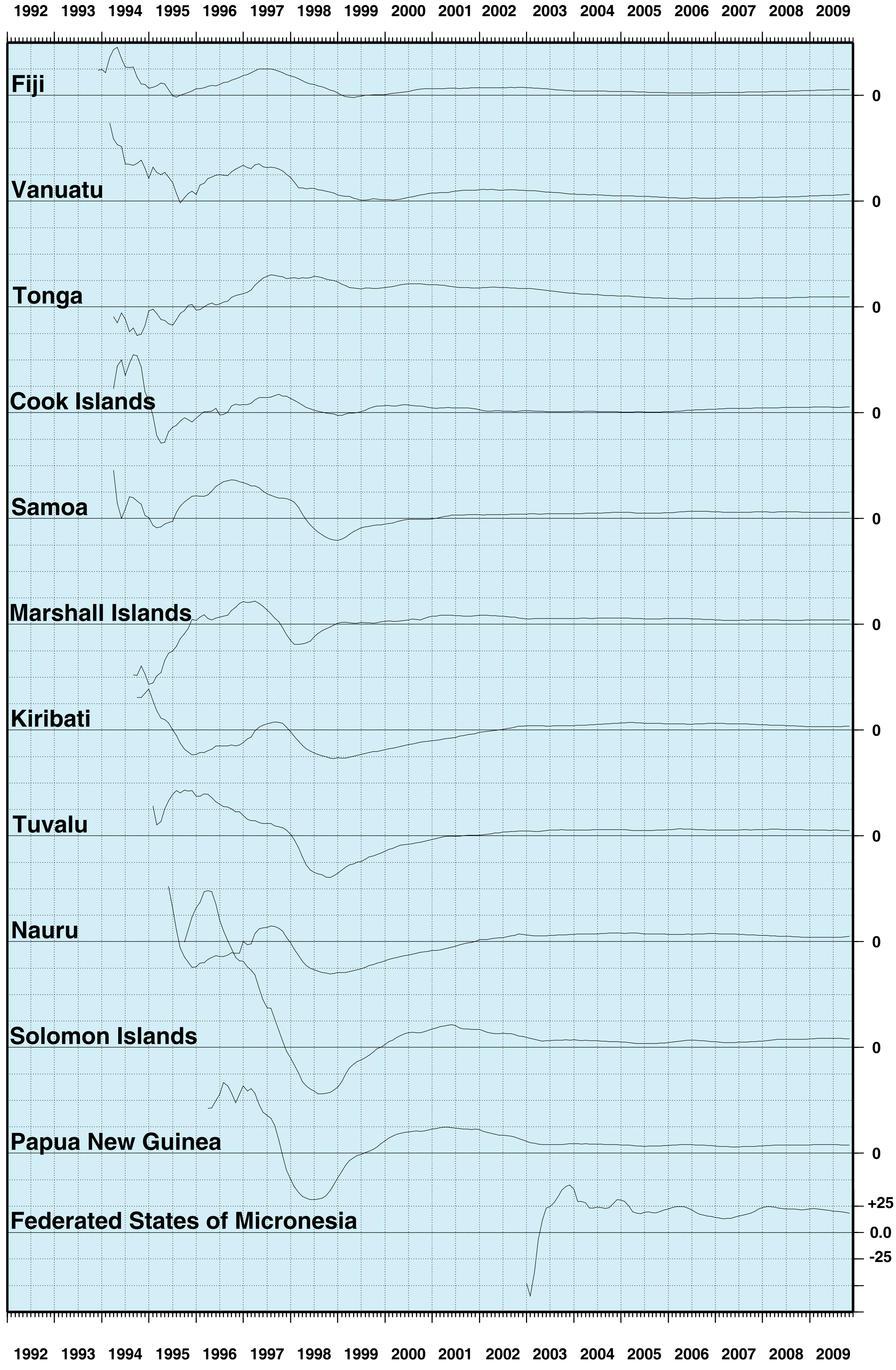


Figure 14

BAROMETRIC PRESSURE ANOMALIES THROUGH OCTOBER 2009 (hPa)

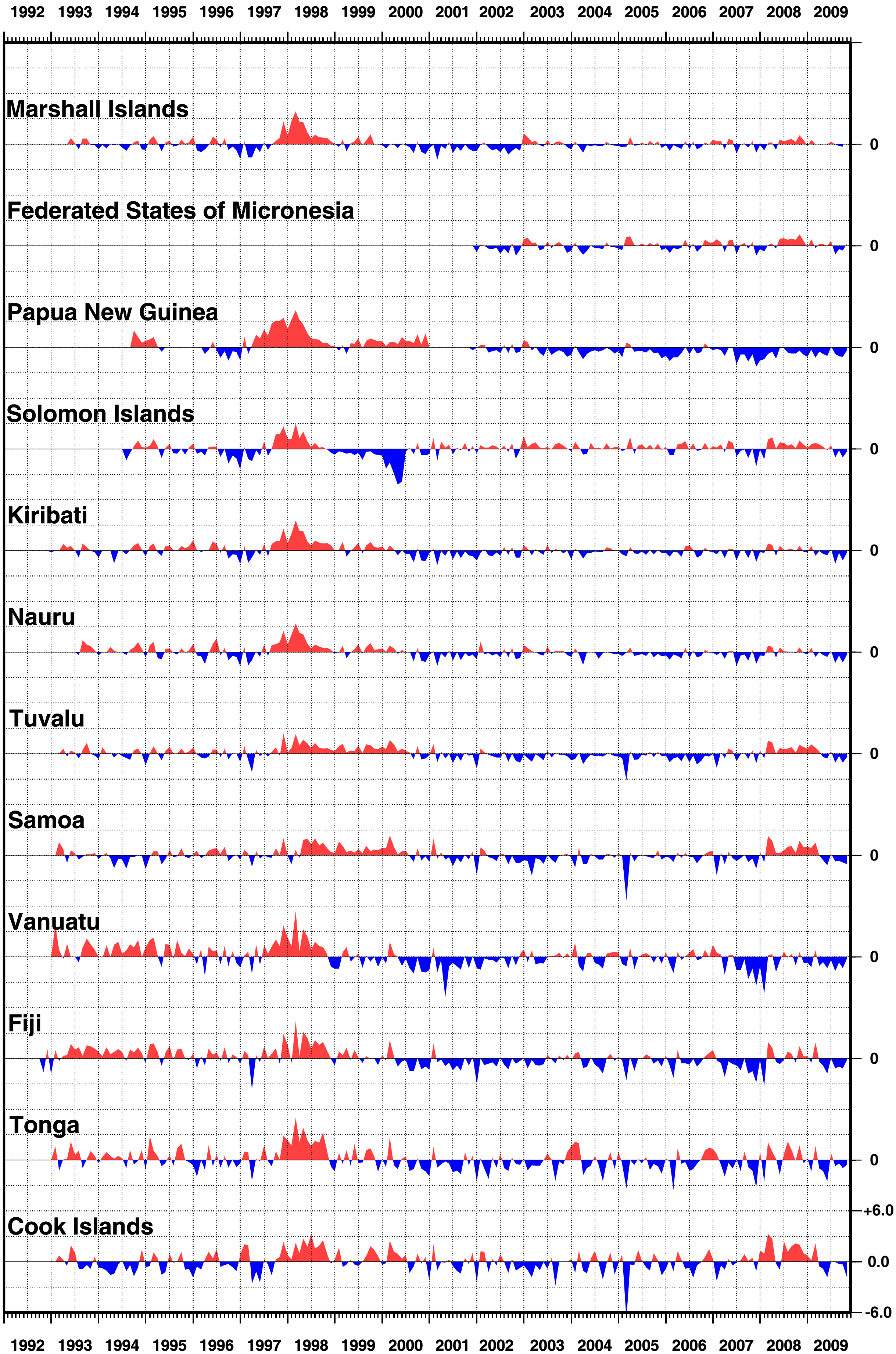


Figure 15

WATER TEMPERATURE ANOMALIES THROUGH OCTOBER 2009 (˚C)

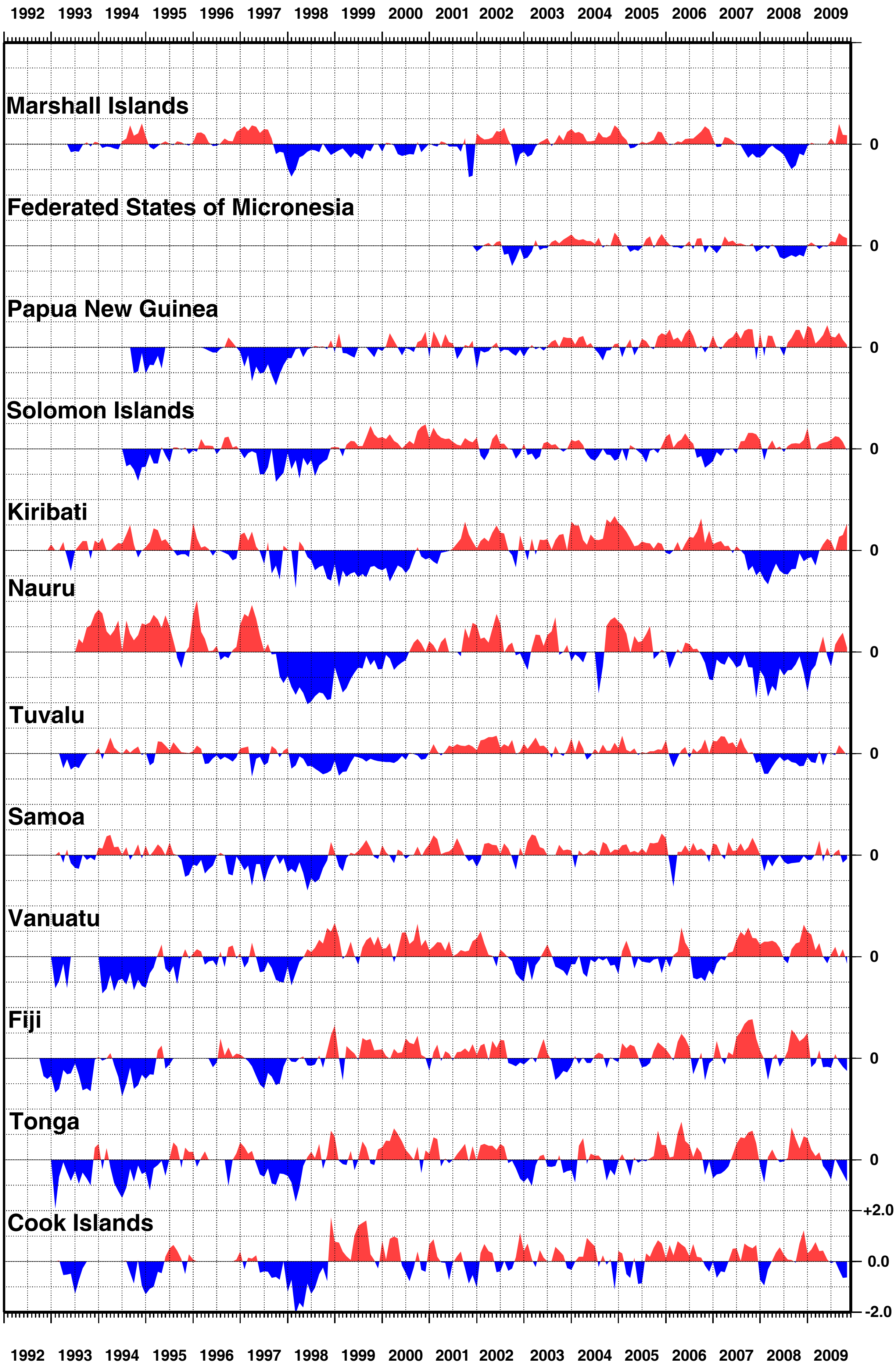
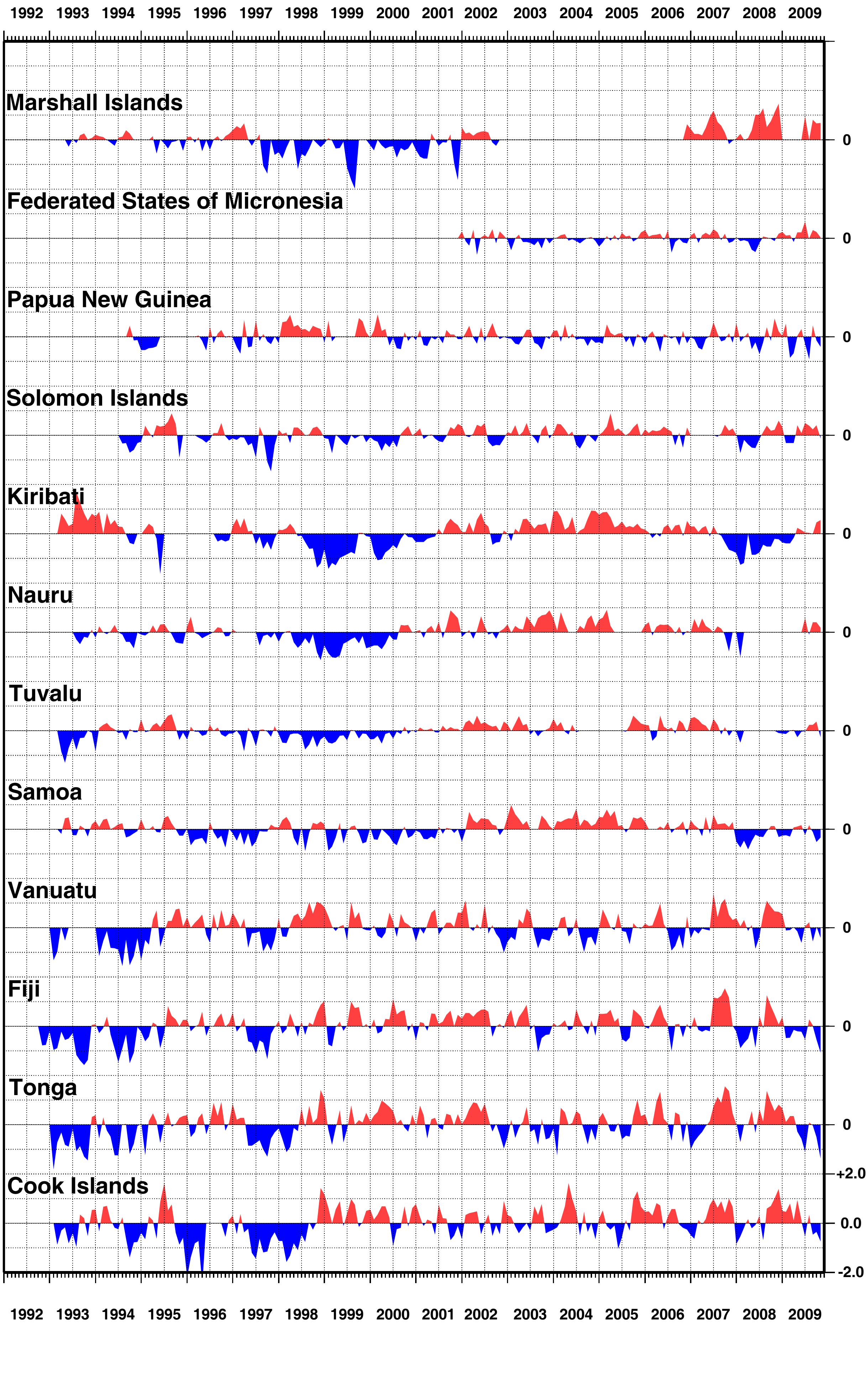


Figure 16

AIR TEMPERATURE ANOMALIES THROUGH OCTOBER 2009 (˚C)



THE NUMBER OF DAYS OF GAP ARE INDICATED
GAPS INCLUDE TRANSMISSION, POWER AND LOGGER FAILURE
* Patchy record