THE SOUTH PACIFIC SEA LEVEL & CLIMATE MONITORING PROJECT

MONTHLY DATA REPORT

NO. 174

DECEMBER 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 December 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

December 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.

December 2009

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

- Tropical Cyclone Mick passed over Fiji on the 13th and 14th of December, during which time the SEAFRAME station at Lautoka recorded extremely low barometric pressure, a storm surge of 0.3m above the predicted tide and wind gusts of up to 38 knots (70km/h).

- Higher than normal sea levels continued to be observed at the equatorial stations Kiribati and Nauru, but elsewhere a general trend toward lower than normal sea levels was observed as is typical during El Niño. However, sea levels are not expected to fall to the extremely low levels observed during the 1997/98 El Niño.

- El Niño climate conditions continued to be observed in the Pacific including warmer than normal ocean temperatures across much of the equatorial Pacific and negative values of the Southern Oscillation Index. The easterly equatorial Trade Winds were weaker than normal during December.

- The majority of international climate models predict that Pacific Ocean warming has reached its peak. El Niño conditions are expected to persist until the southern hemisphere autumn, with equatorial Pacific sea surface temperatures predicted 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 December , 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	+5.3	0.0
Tonga	21°8'12.5"S / 175°10'50.5"W	Jan 1993	+9.5	-0.1
Fiji	17°36'17.7"S / 177°26'17.7"E	Oct 1992	+5.7	-0.1
Vanuatu	17°45'19.2"S / 168°18'27.7"E	Jan 1993	+6.5	0.0
Samoa	13°49'36.4"S / 171°45'40.7"W	Feb 1993	+5.7	-0.1
Tuvalu	8°30'8.9"S / 179°11'42.6"E	Mar 1993	+5.1	-0.1
Kiribati	1°21'54.2"N / 172°55'58.8"E	Dec 1992	+4.3	+0.2
Nauru	0°31'45.9"S / 166°54'36.2"E	Jul 1993	+5.2	+0.2
Solomon Is.	9°25'44.1"S / 159°57'19.3"E	Jul 1994	+7.8	-0.2
PNG	2°2'31.5"S / 147°22'25.6"E	Sep 1994	+7.4	-0.2
FSM	6°58'49.9"N / 158°12'0.8"E	Dec 2001	+16.7	-1.1
Marshall Is.	7°6'21.7"N / 171°22'22.1"E	May 1993	+3.8	-0.1

INTRODUCTION

Welcome to the December 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.

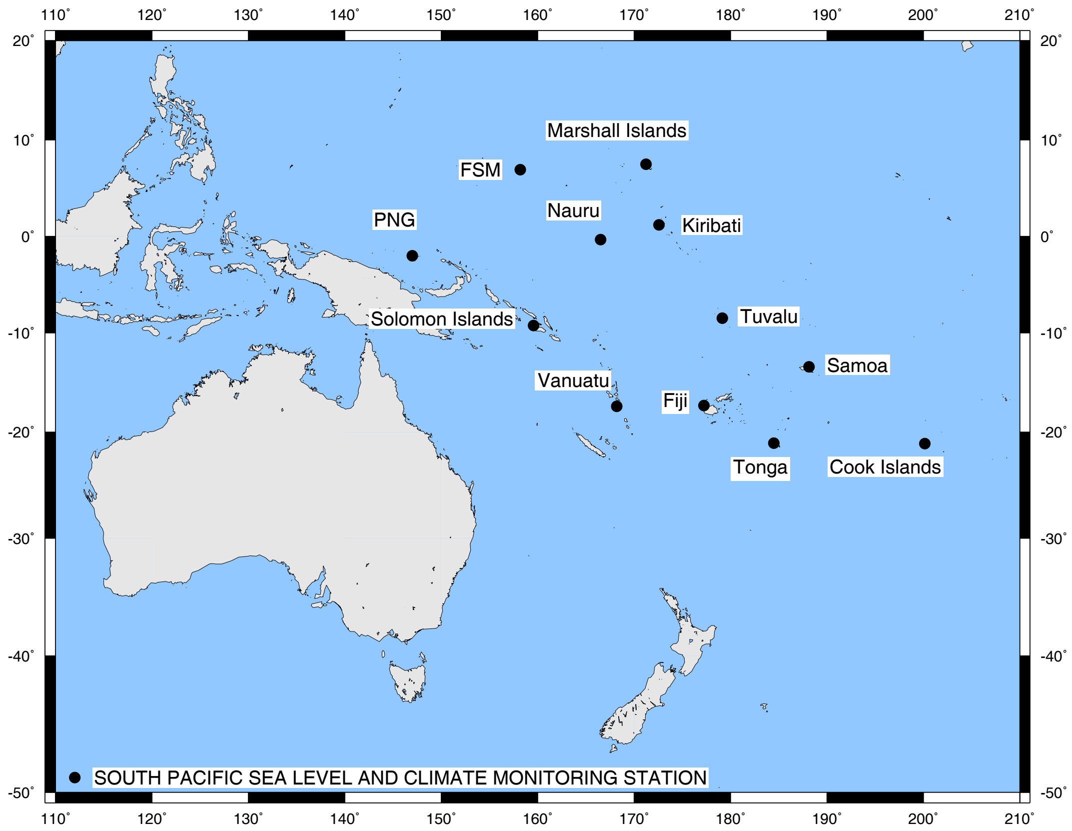

Figure A: *South Pacific Sea Level and Climate Monitoring Stations*

DECEMBER CLIMATOLOGY

El Niño climate conditions continued to be observed across the equatorial Pacific during December. Warmer than normal ocean heat content persisted across the central and eastern equatorial Pacific. The Trade Winds were weaker than normal for much of December and the Southern Oscillation Index remained at levels typical of an El Niño. The majority of international climate models predict that Pacific Ocean warming may have peaked. El Niño conditions are expected to persist until the southern hemisphere autumn.

The Southern Oscillation Index (SOI) continues to be negative and at levels typical of an El Niño event with a December value of –7, following the November value of –7 (**Figure B**).

Sea surface temperatures were more than 1ºC warmer than normal across much of the equatorial Pacific during December. In some areas of the central and far eastern equatorial Pacific sea surface temperature anomalies exceeding 2ºC were observed. Sea surface temperatures in the western equatorial Pacific remained close to normal. The sea surface temperature pattern across the Pacific remains typical of El Niño (**Figure C**).

Subsurface ocean temperatures also remained significantly warmer than average across the equatorial Pacific. Subsurface temperatures in the central equatorial Pacific cooled as a result of cool subsurface anomalies propagating eastwards from the western equatorial Pacific. Subsurface temperatures in the far eastern equatorial Pacific warmed slightly during December (**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 December 2009 the easterly Trade Winds were weaker than normal across much of the equatorial Pacific, as a westerly wind burst entered the western equatorial Pacific (**Figure E**). Cloudiness near the dateline has generally been above average in recent months, which is typical of El Niño, although a short period of decreased cloudiness was observed in mid-December.

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/.

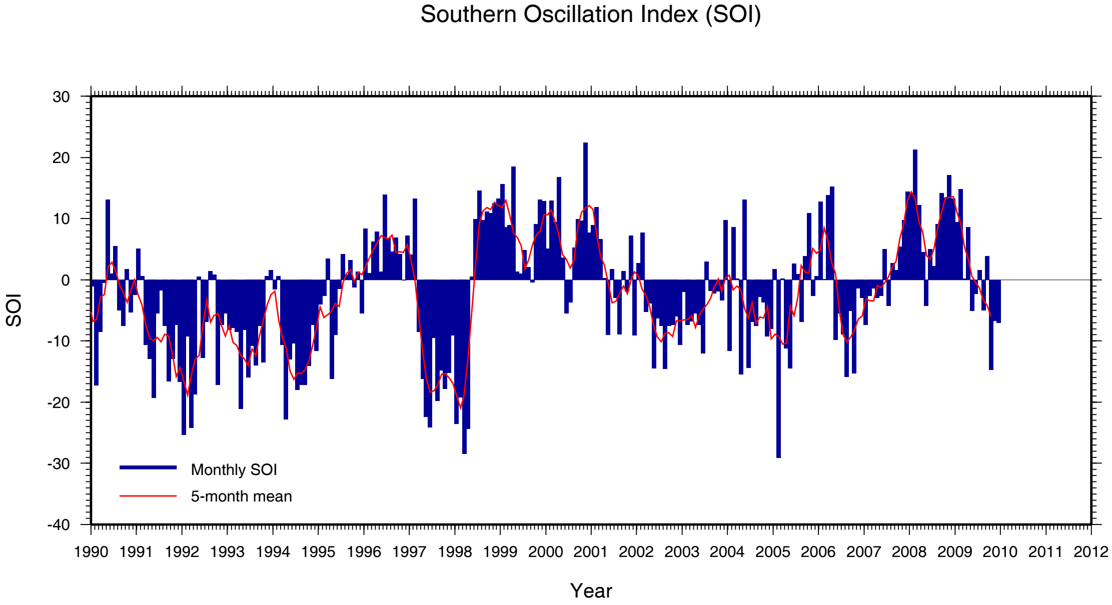

Figure B: *The five-month weighted mean and individual monthly means of the Southern Oscillation Index (SOI). The SOI is ten times the monthly anomaly of the difference in mean sea level pressure between Tahiti and Darwin, divided by the long-term standard deviation of that difference for the relevant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

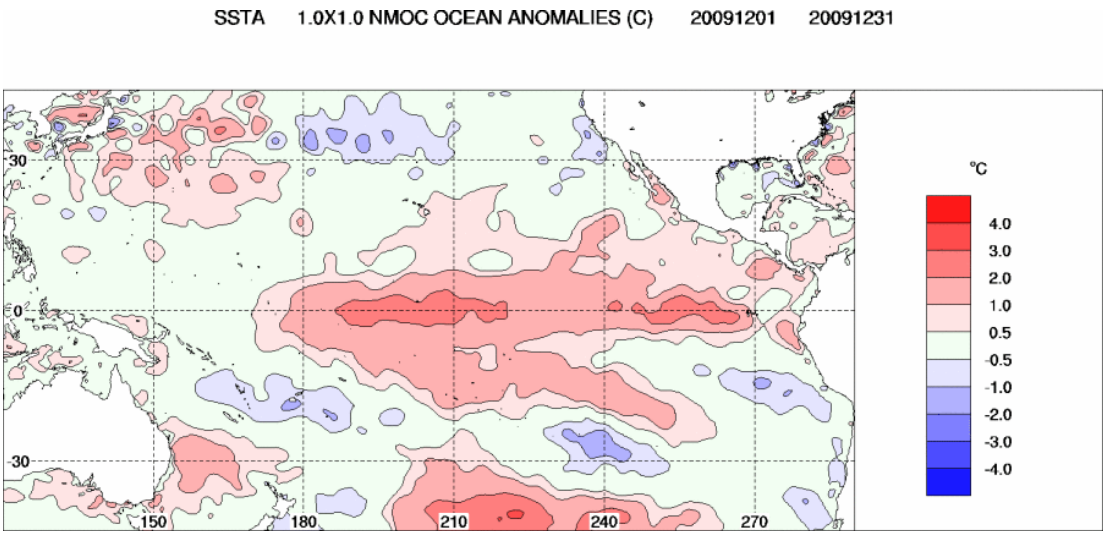

Figure C: *Sea surface temperature anomaly (°C) for December 2009.*

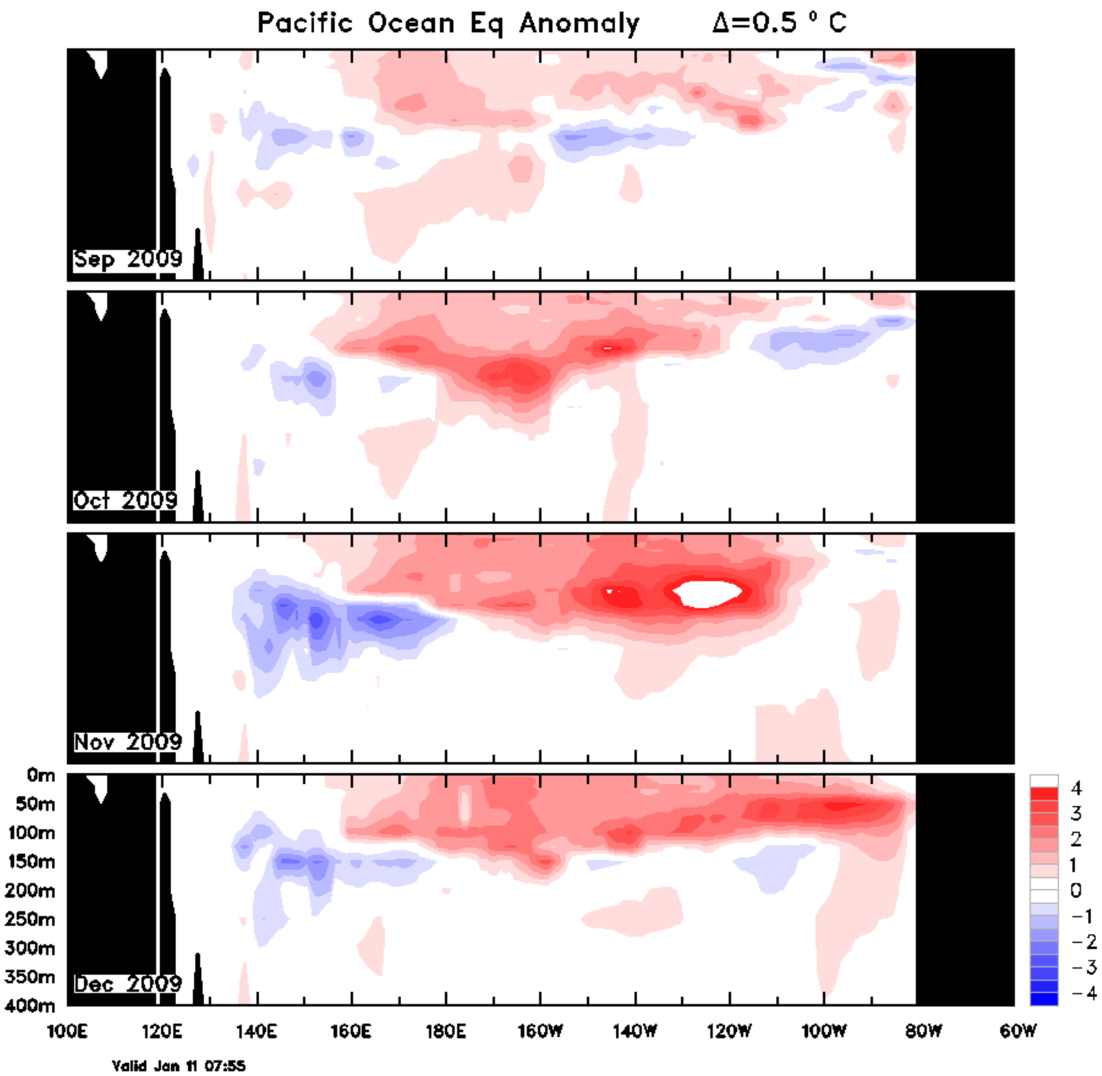

Figure D: *Equatorial depth-longitude section of ocean temperature anomalies for September 2009 through to December 2009. Contour interval is 0.5°C.*

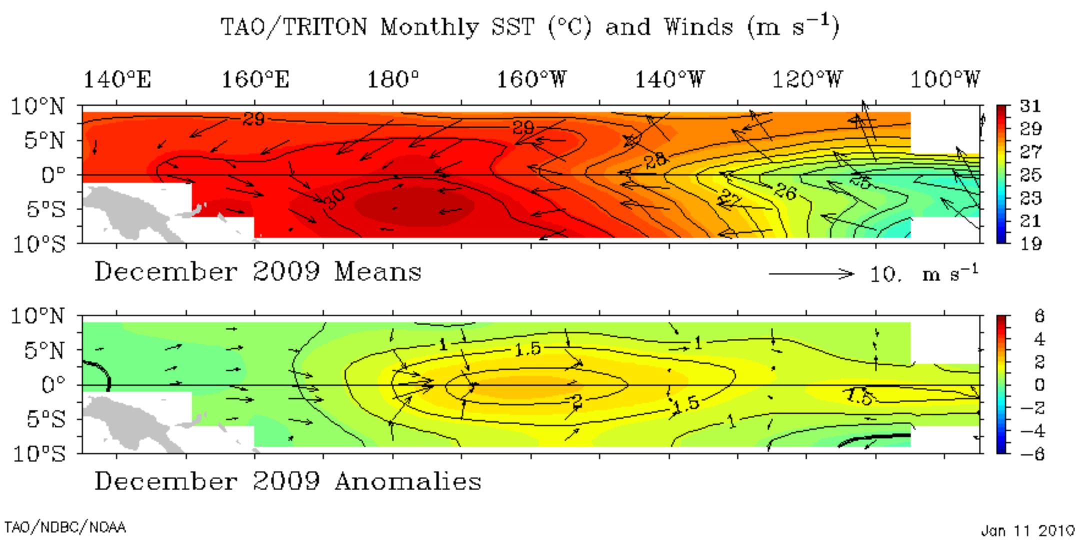

Figure E: *Monthly mean wind vectors (top) and anomalies (bottom) for December 2009. The colour-shaded contours represent the monthly mean sea surface temperatures (top) and anomalies (bottom).*

DECEMBER 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 2nd and 31st of December and a new moon on the 16th of December 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. A storm surge of 0.3m was observed at Lautoka, Fiji during the 13th and 14th of December as a result of Tropical Cyclone Mick.

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 storm surge at Lautoka, Fiji that was observed on the 13th and 14th of December during the passage of Tropical Cyclone Mick was mostly a result of low barometric pressure rather than wind and wave setup, since it is largely accounted for by the inverse barometer correction.

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. Wind gusts of up to 80knots (150km/h) were reported near the centre of Tropical Cyclone Mick on the 14th December 2009. Further away at Lautoka, Fiji the SEAFRAME station measured wind gusts of up to 38 knots (70km/h).

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. Extremely low barometric pressure was observed at Fiji on the 13th and 14th of December during the passage of Tropical Cyclone Mick.

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 December air temperature of 19.3°C and a new maximum December water temperature of 30.2°C were recorded at Marshall Islands. A new minimum December water temperature of 24.2°C was recorded at Tonga. At Fiji a new December minimum barometric pressure of 972.7hPa was recorded during the passage of Tropical Cyclone Mick.

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 December 2009 sea levels at the equatorial stations Kiribati and Nauru were around 10cm higher than normal. Slightly higher than normal sea levels were also observed at Vanuatu, although the sea level anomaly there has been falling in recent months. Lower than normal sea levels were observed at Marshall Islands, FSM, PNG, Solomon Islands, Tuvalu, Samoa, Fiji And Tonga. Lower than normal sea levels are typical during El Niño, such as has been observed during the 1997/98, 2002/03 and 2006/07 events. The current El Niño event is moderate, with sea level anomalies nowhere near the low levels observed during the 1997/98 El Niño. Sea levels observed at Cook Islands were near normal for this time of the year.

Sea Level Trends

The **short-term sea level trends** at individual stations as at December 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 December , 2009

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Nauru	0°31'45.9"S / 166°54'36.2"E	Jul 1993	+5.2	+0.2
Solomon Is.	9°25'44.1"S / 159°57'19.3"E	Jul 1994	+7.8	-0.2
PNG	2°2'31.5"S / 147°22'25.6"E	Sep 1994	+7.4	-0.2
FSM	6°58'49.9"N / 158°12'0.8"E	Dec 2001	+16.7	-1.1
Marshall Is.	7°6'21.7"N / 171°22'22.1"E	May 1993	+3.8	-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 December 2009 barometric pressures were generally near average for this time of the year.

The **water temperature anomalies (Figure 15)** indicate a general cooling trend across the region. Water temperatures at Marshall Islands, FSM, PNG, Solomon Islands, Kiribati and Nauru, which have generally been warmer than normal over the past six

months, are now close to normal. Near normal water temperatures were also observed at Tuvalu, Samoa, and Cook Islands during December. Significantly cooler than normal conditions developed at Vanuatu, Fiji and Tonga, where anomalies of -1°C or more were observed.

The **air temperature anomalies (Figure 16)** show similar patterns to the water temperature anomalies during December 2009, with cooler than normal conditions at Vanuatu, Fiji, Tonga and Cook Islands and generally near normal air temperatures elsewhere. 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 December 2009. At Nauru problems with the primary sea level sensor were encountered which required data from the secondary sea level sensor to be used. Scheduled calibration and maintenance visits were undertaken at Marshall Islands and FSM.

Various problems were encountered with ancillary meteorological sensors. The problematic air temperature, water temperature and barometric pressure electronic circuit at Marshall Islands was replaced on the 9^{th} of December during the calibration and maintenance visit, although erroneous data prior to this were removed from the record. The water temperature sensor at Kiribati continued to experience problems and data were removed from the record.

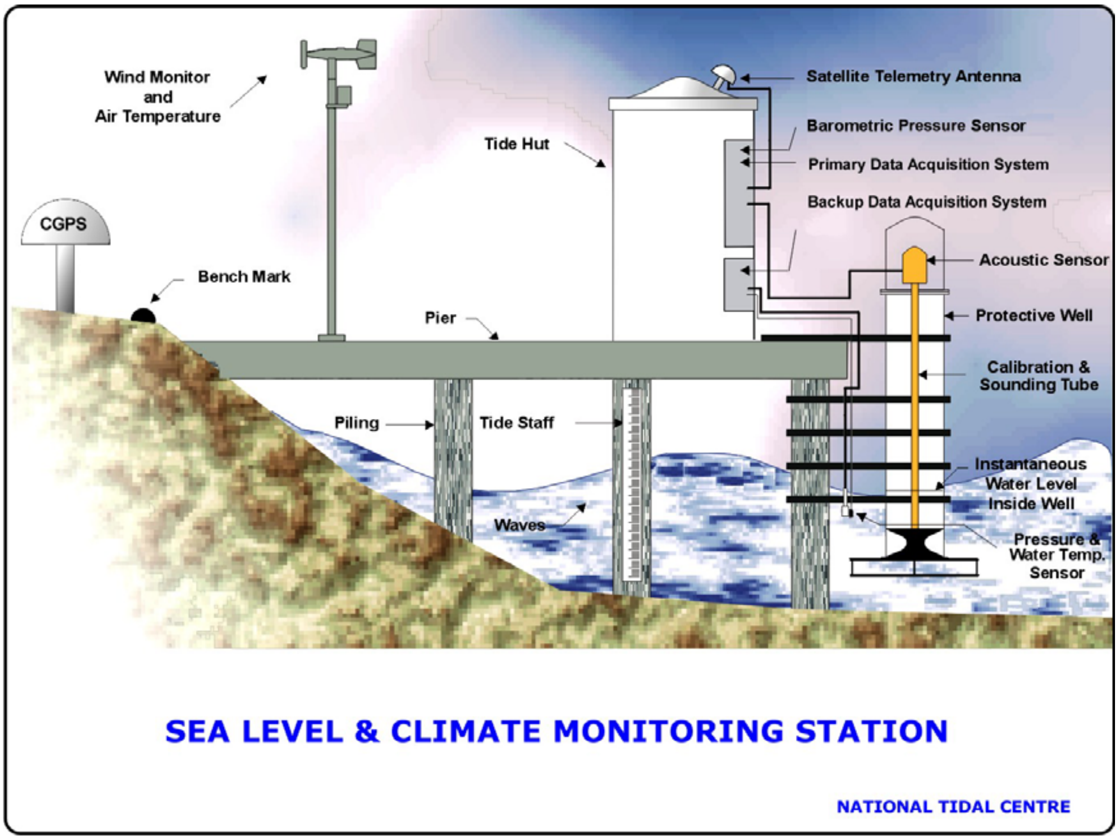
SEAFRAME STATIONS

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

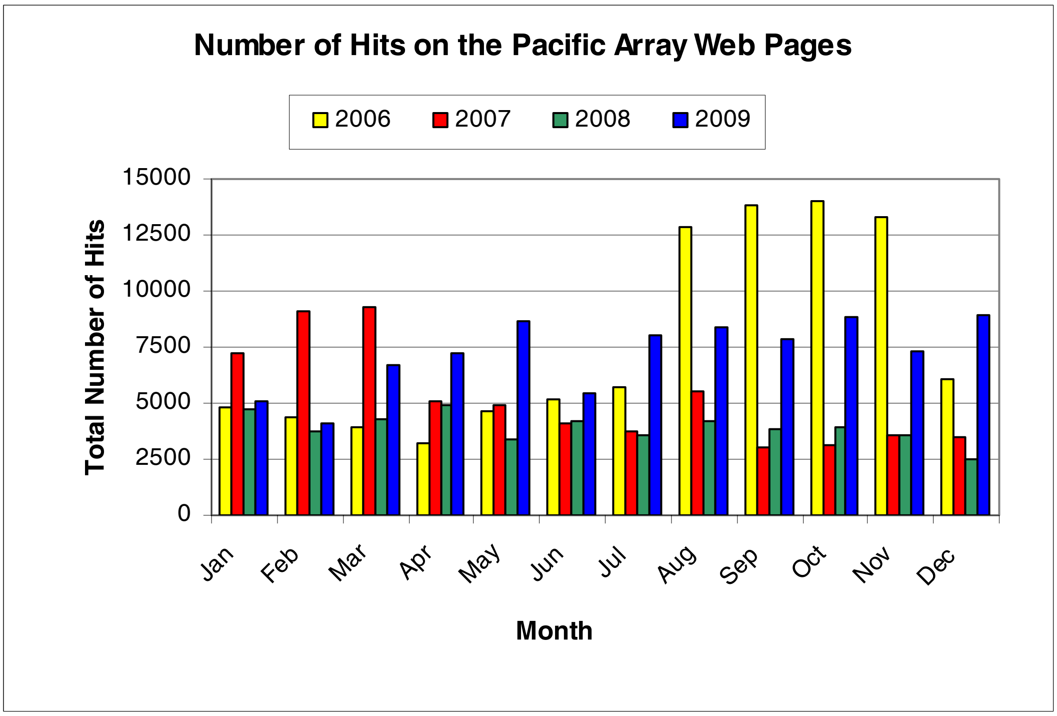
(2) Secondary water level (or backup) using a Druck pressure transducer mounted close to the seabed.

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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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

DECEMBER 2009
SIX MINUTE WATER LEVEL OBSERVATIONS (m)

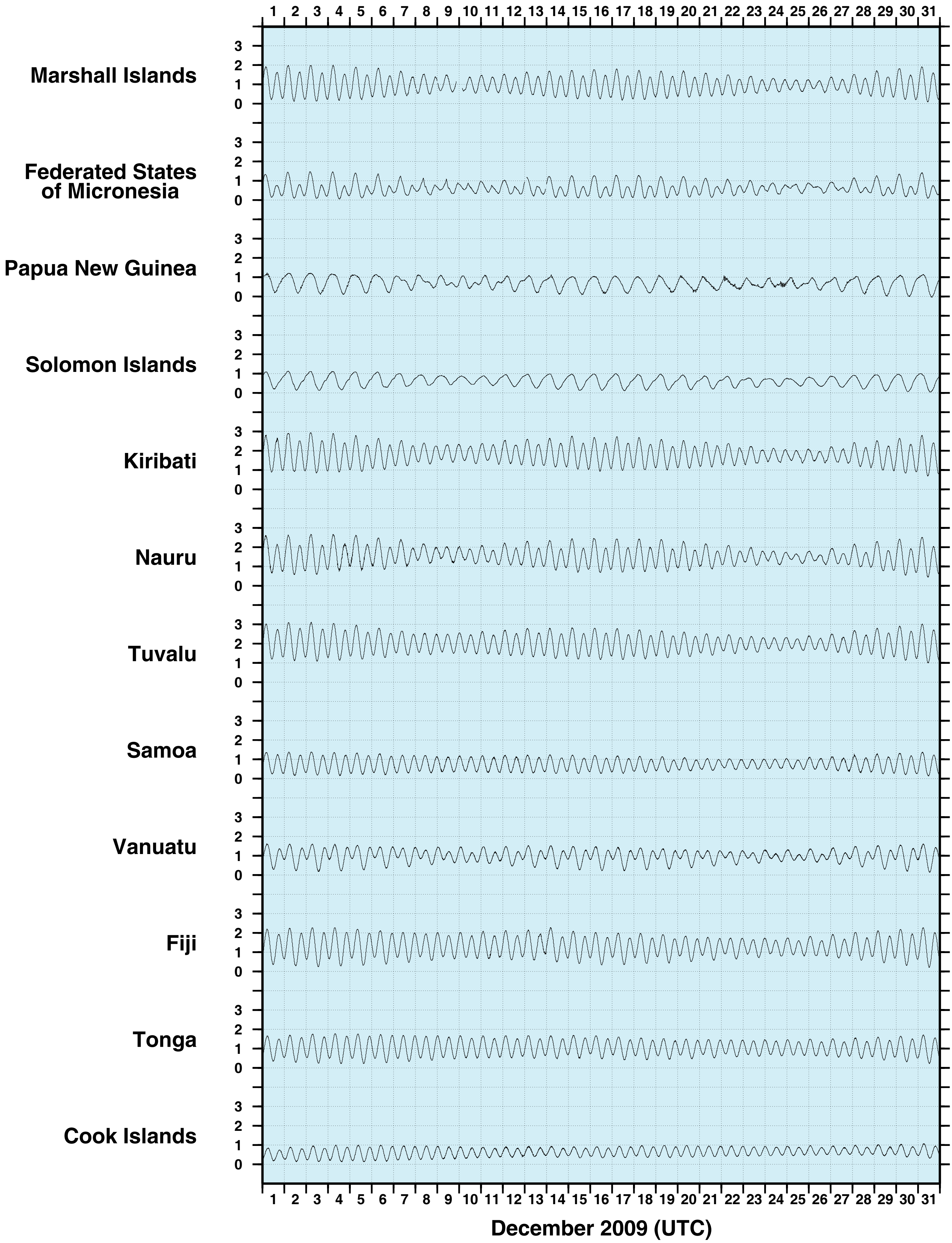


Figure 2

DECEMBER 2009
SIX MINUTE RESIDUAL WATER LEVELS (m)

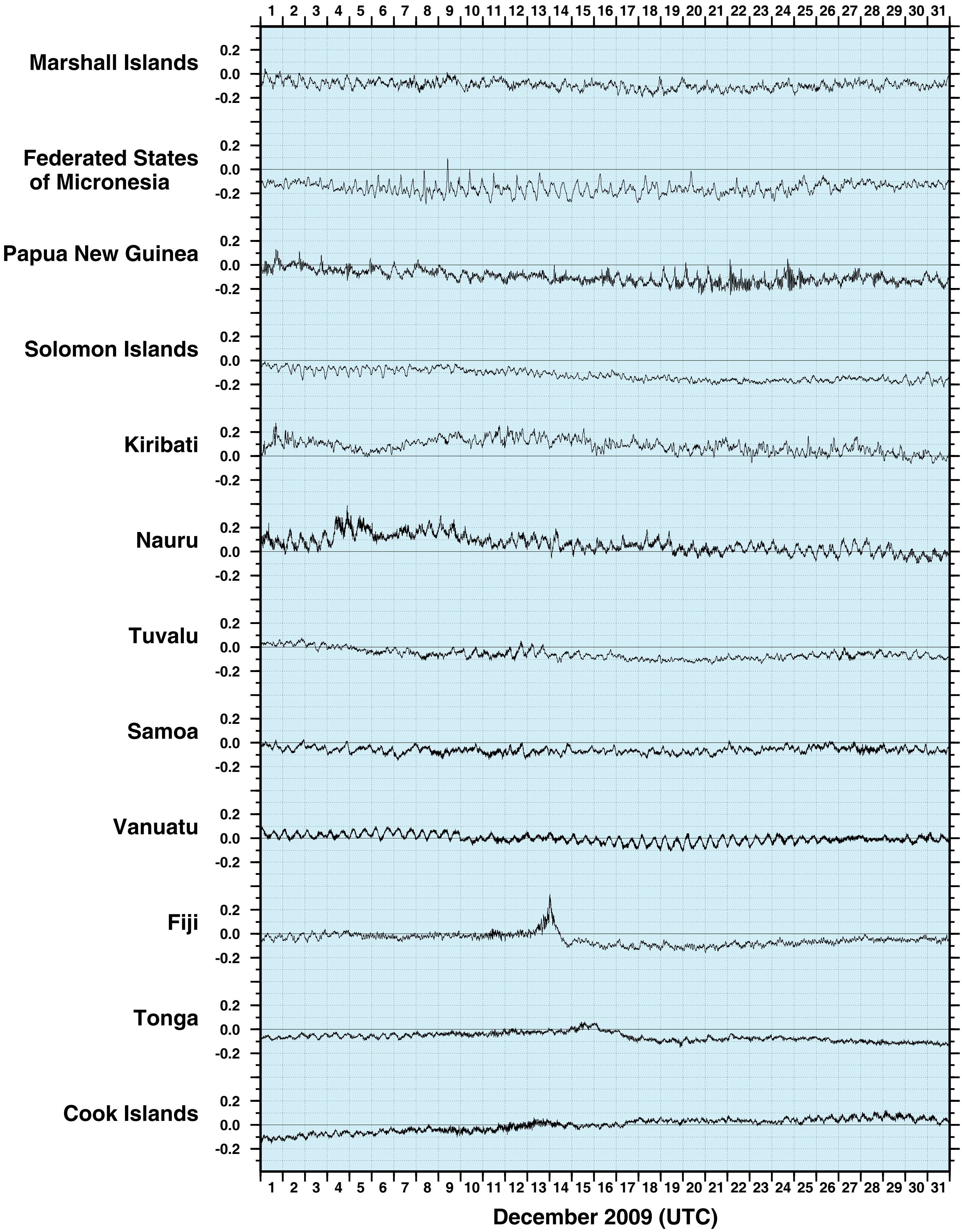
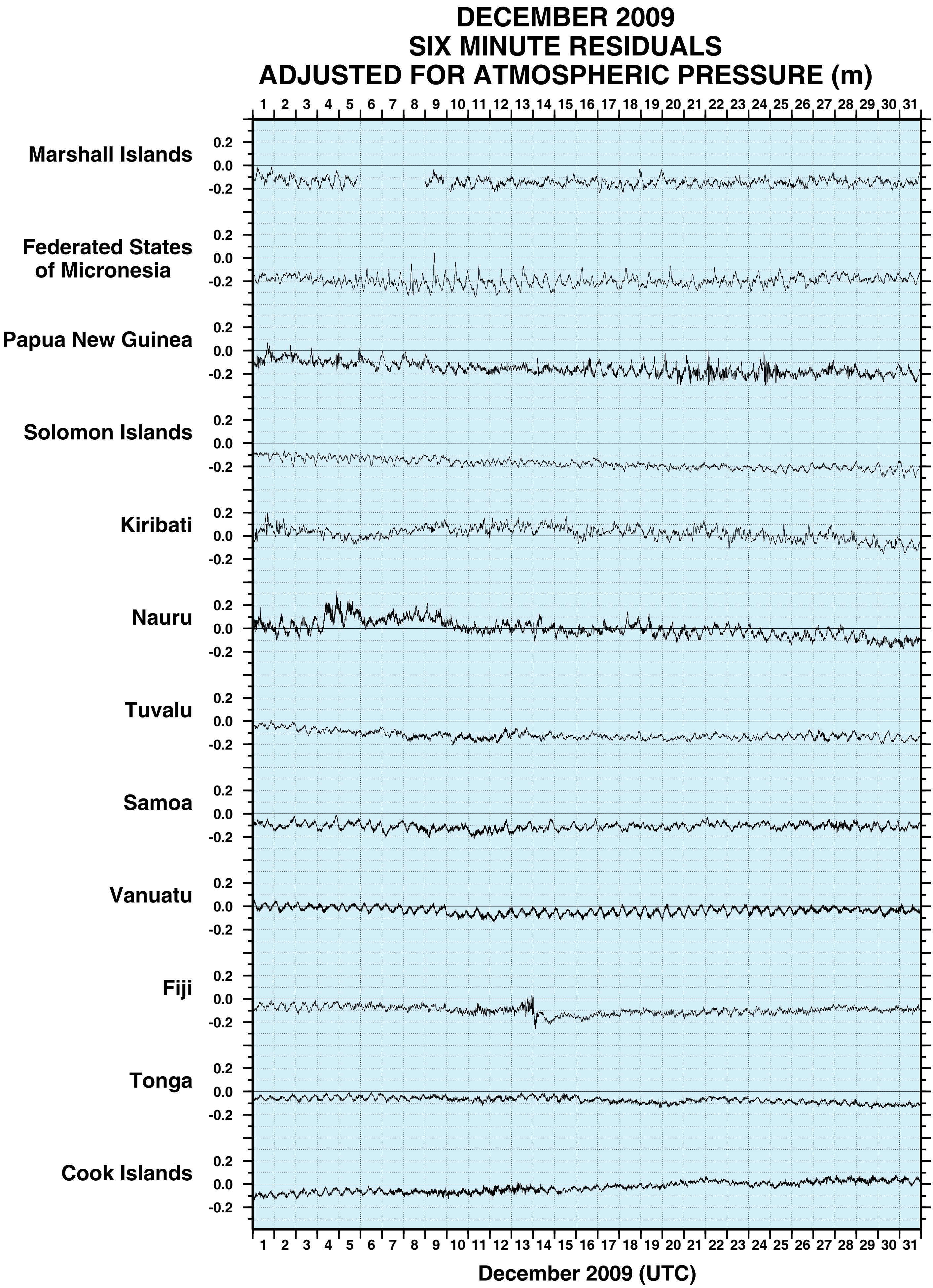


Figure 3



DECEMBER 2009
SIX MINUTE RESIDUALS
ADJUSTED FOR ATMOSPHERIC PRESSURE (m)
Marshall Islands
Federated States of Micronesia
Papua New Guinea
Solomon Islands
Kiribati
Nauru
Tuvalu
Samoa
Vanuatu
Fiji
Tonga
Cook Islands
0.2
0.0
-0.2
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
December 2009 (UTC)

Figure 4

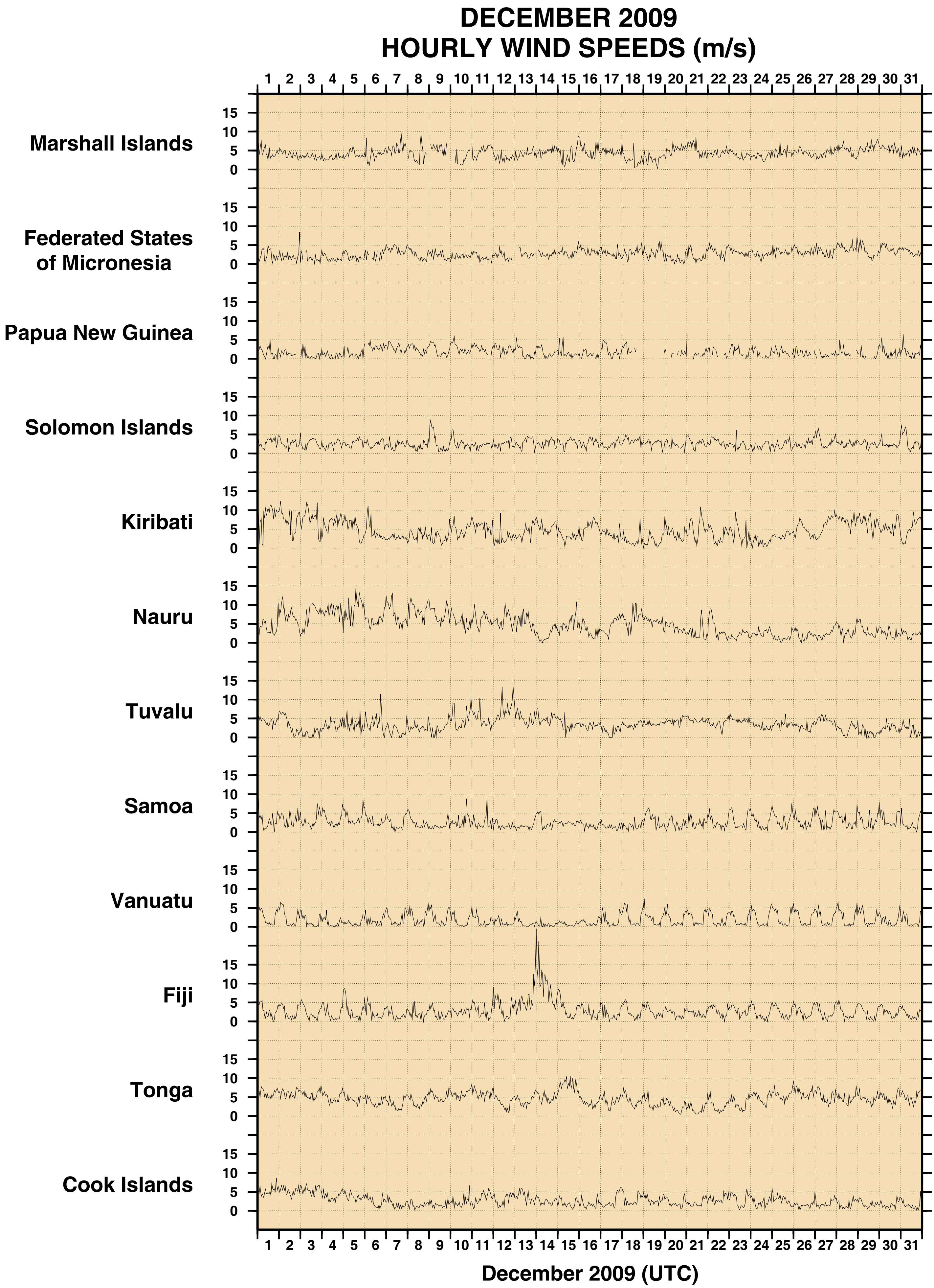

DECEMBER 2009
HOURLY WIND SPEEDS (m/s)
Marshall Islands
Federated States of Micronesia
Papua New Guinea
Solomon Islands
Kiribati
Nauru
Tuvalu
Samoa
Vanuatu
Fiji
Tonga
Cook Islands
0
5
10
15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
December 2009 (UTC)

Figure 5

DECEMBER 2009
HOURLY INCIDENT WINDS (m/s, deg True)

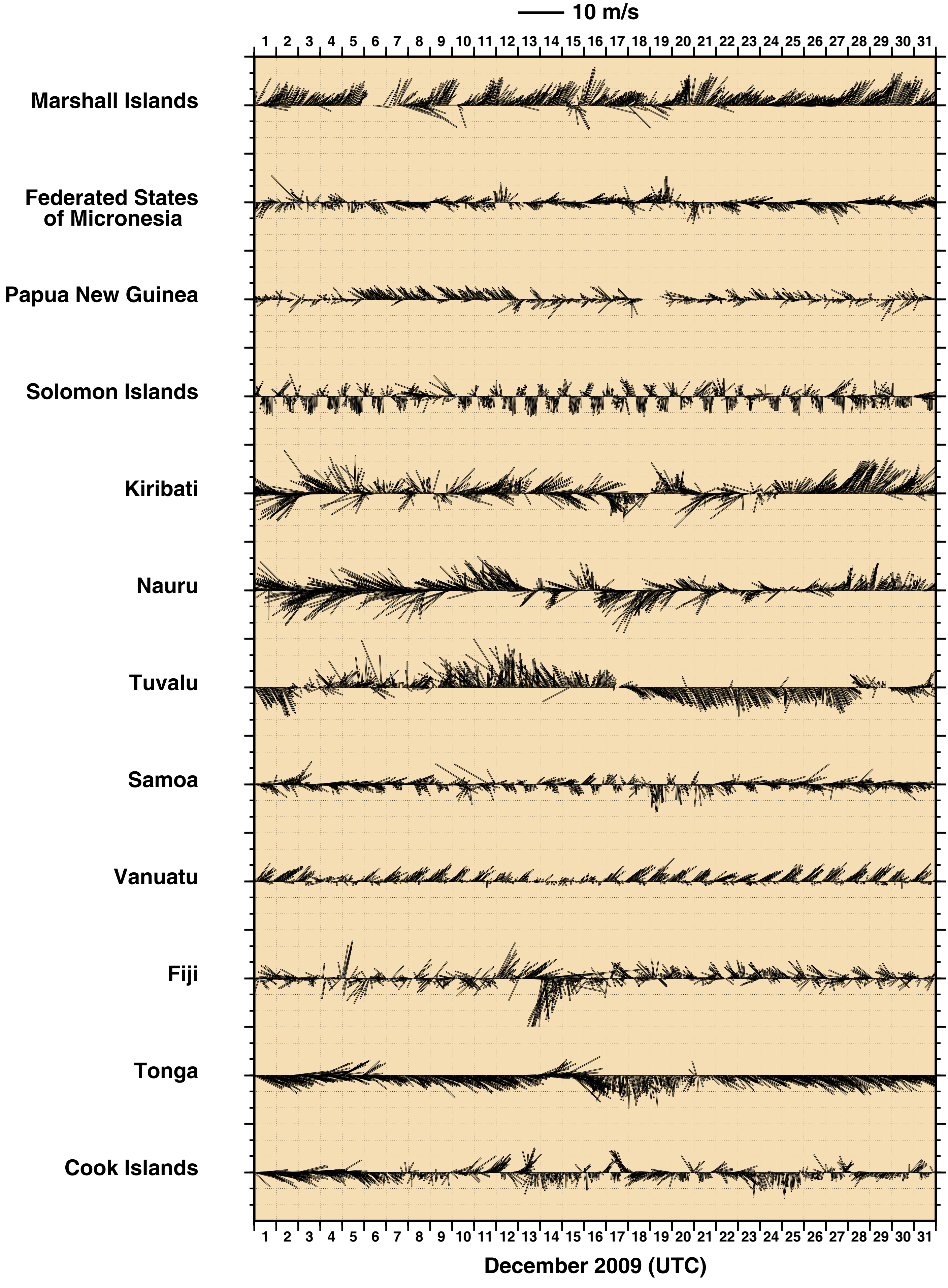
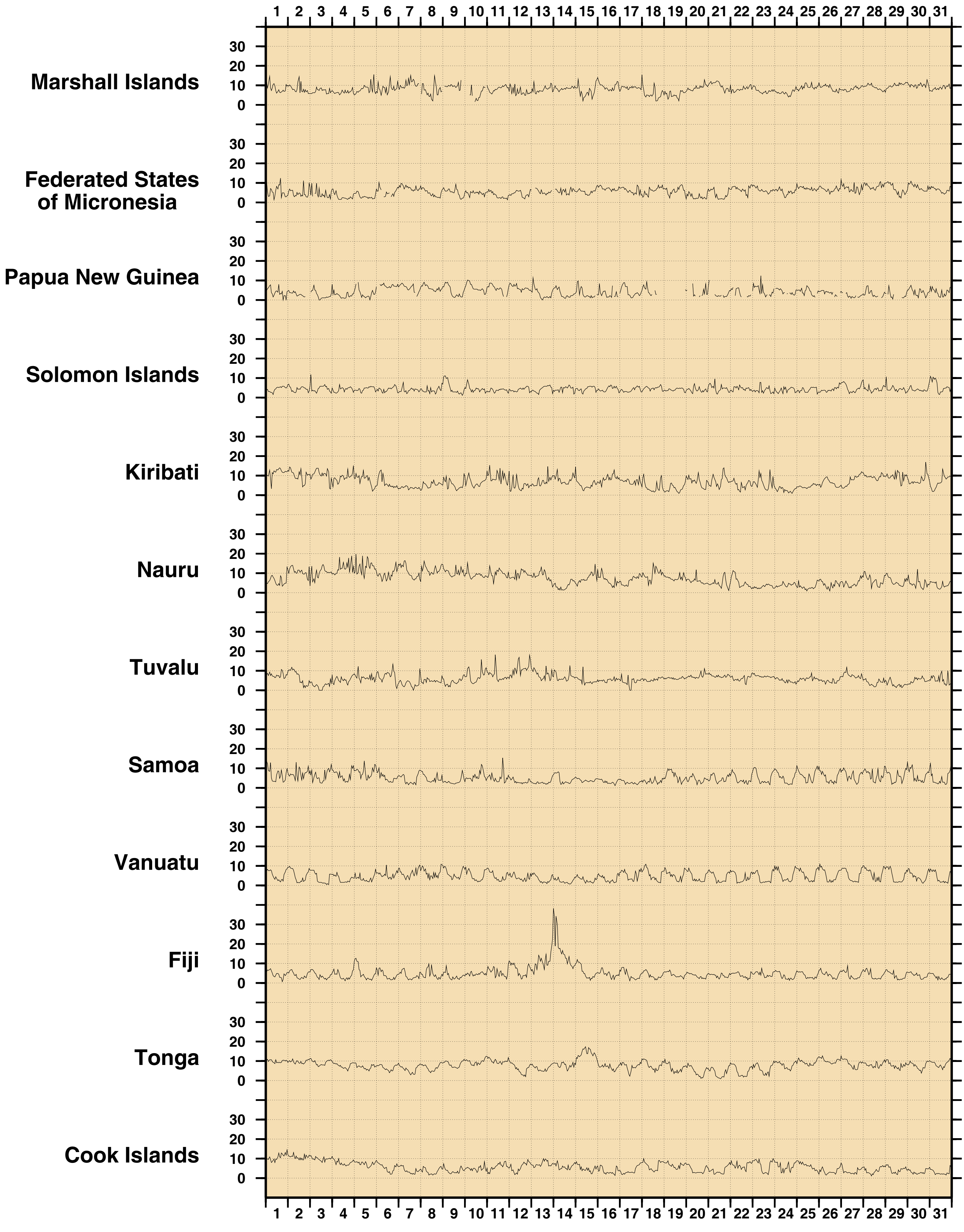


Figure 6

DECEMBER 2009
HOURLY MAXIMUM WIND GUSTS (m/s)



December 2009 (UTC)

Figure 7

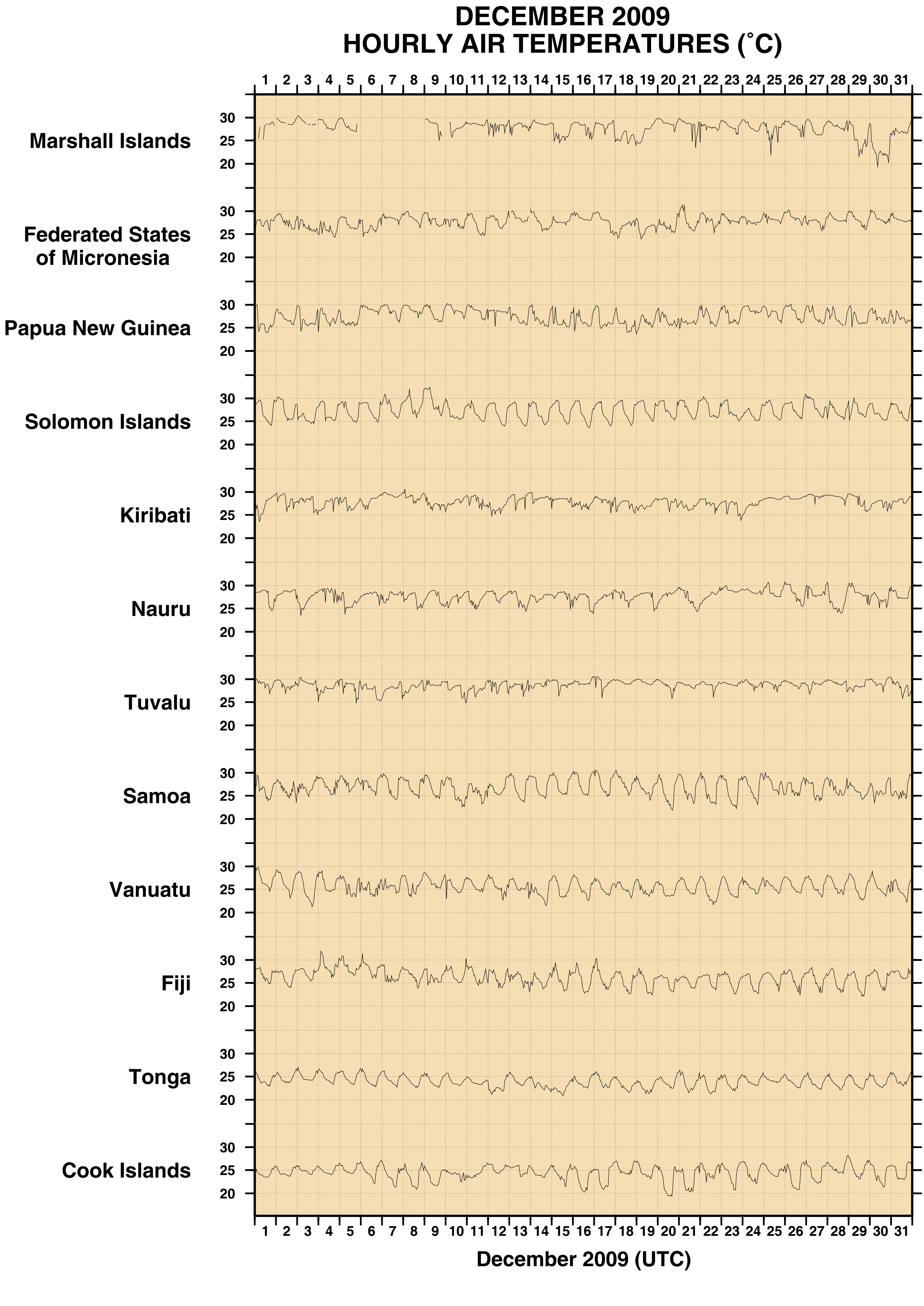

DECEMBER 2009
HOURLY AIR TEMPERATURES (˚C)
Marshall Islands
Federated States of Micronesia
Papua New Guinea
Solomon Islands
Kiribati
Nauru
Tuvalu
Samoa
Vanuatu
Fiji
Tonga
Cook Islands
30
25
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
December 2009 (UTC)

Figure 8

DECEMBER 2009
HOURLY WATER TEMPERATURES (˚C)

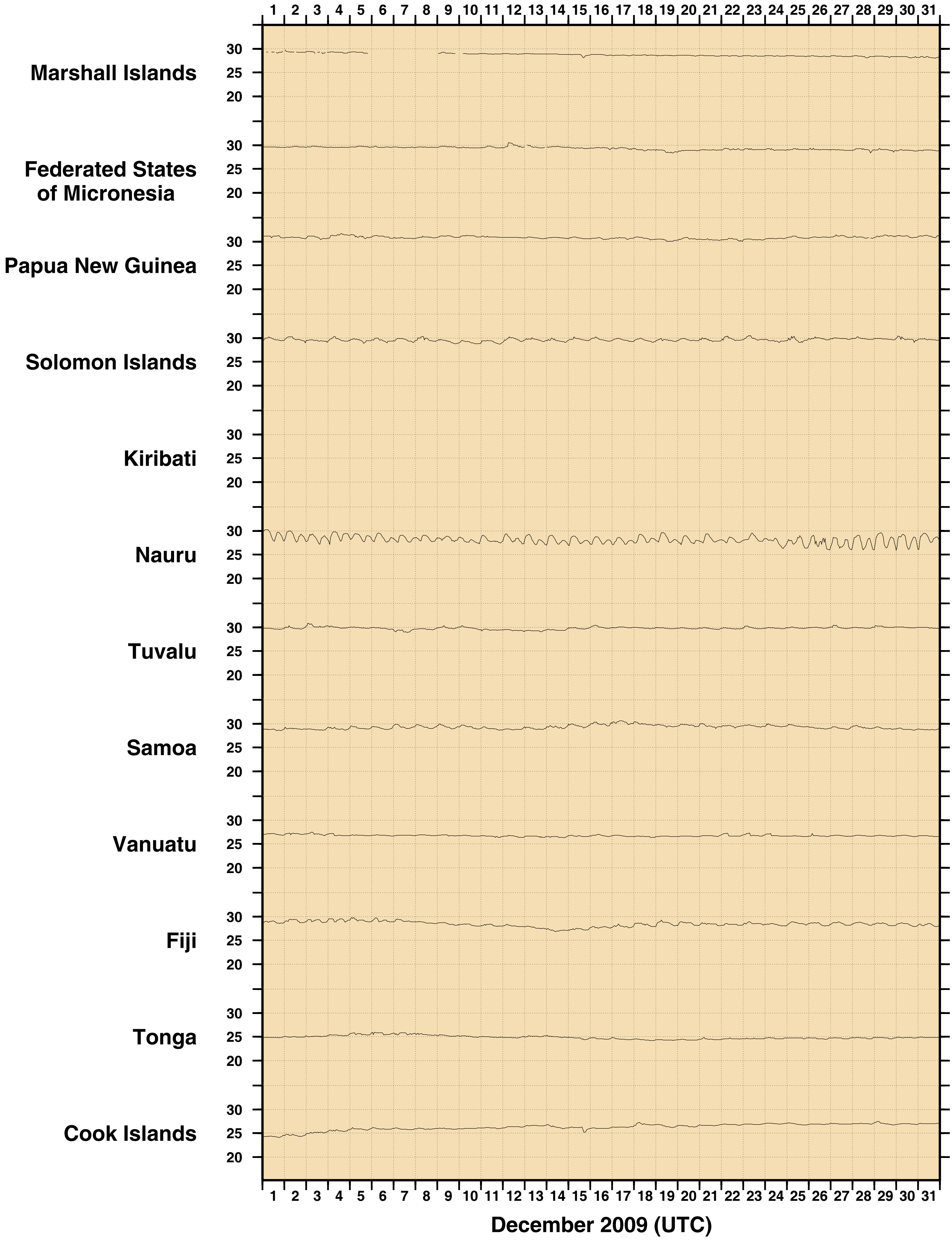


Figure 9

DECEMBER 2009
HOURLY ATMOSPHERIC PRESSURE (hPa)

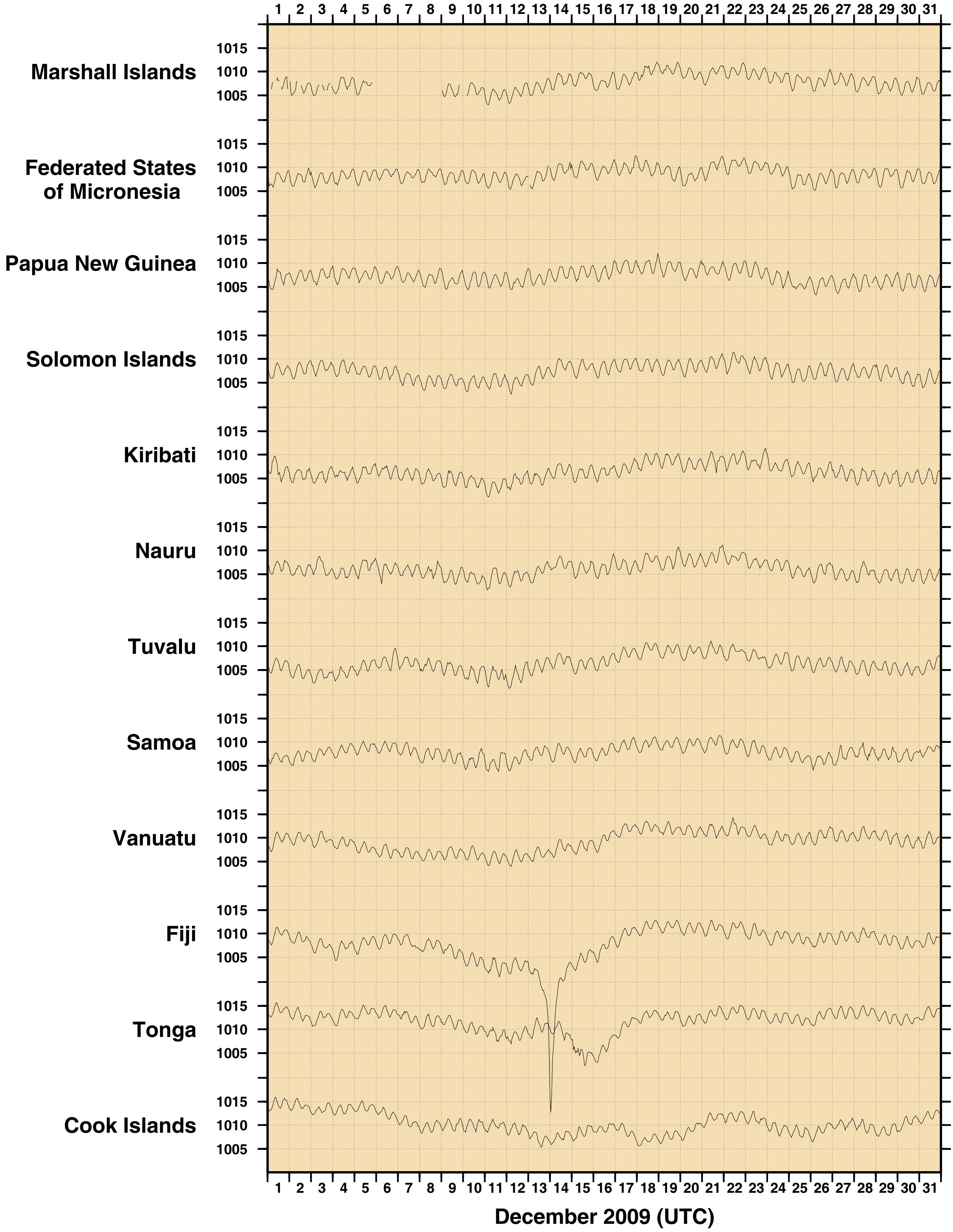


Figure 10

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

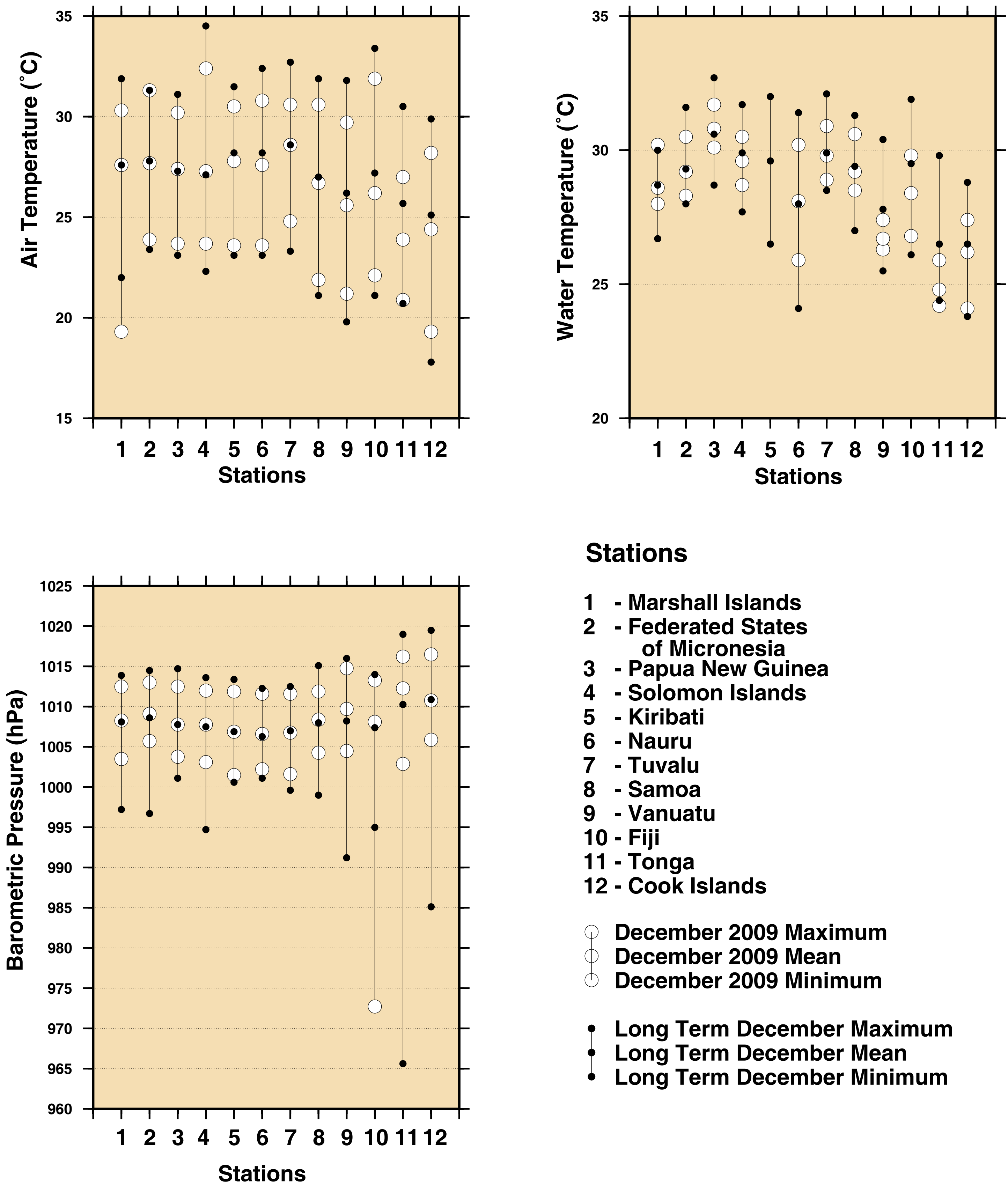


Figure 11

MONTHLY MEAN SEA LEVELS TO DECEMBER 2009 (m)

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

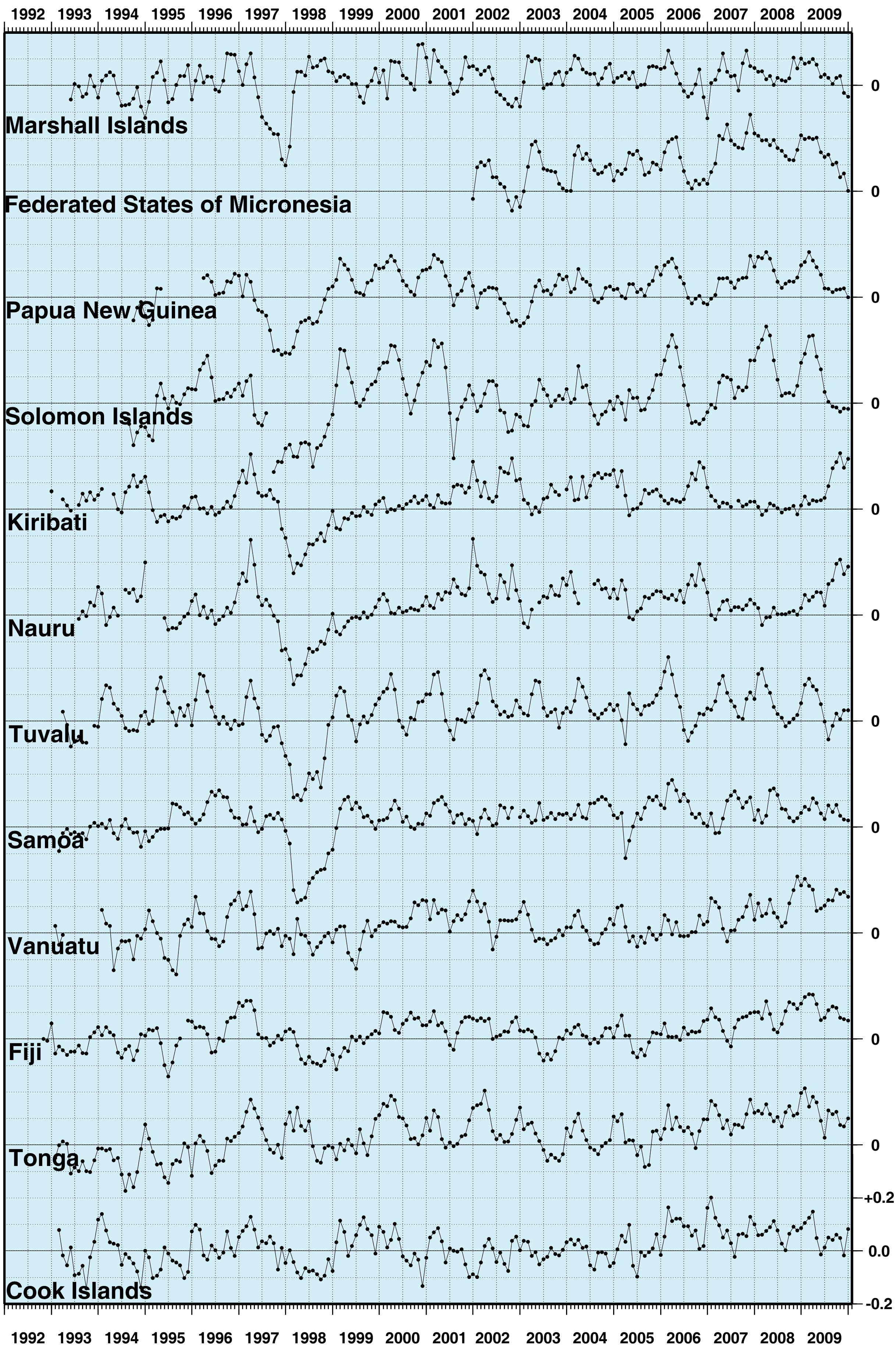


Figure 12

SEA LEVEL ANOMALIES THROUGH DECEMBER 2009 (m)

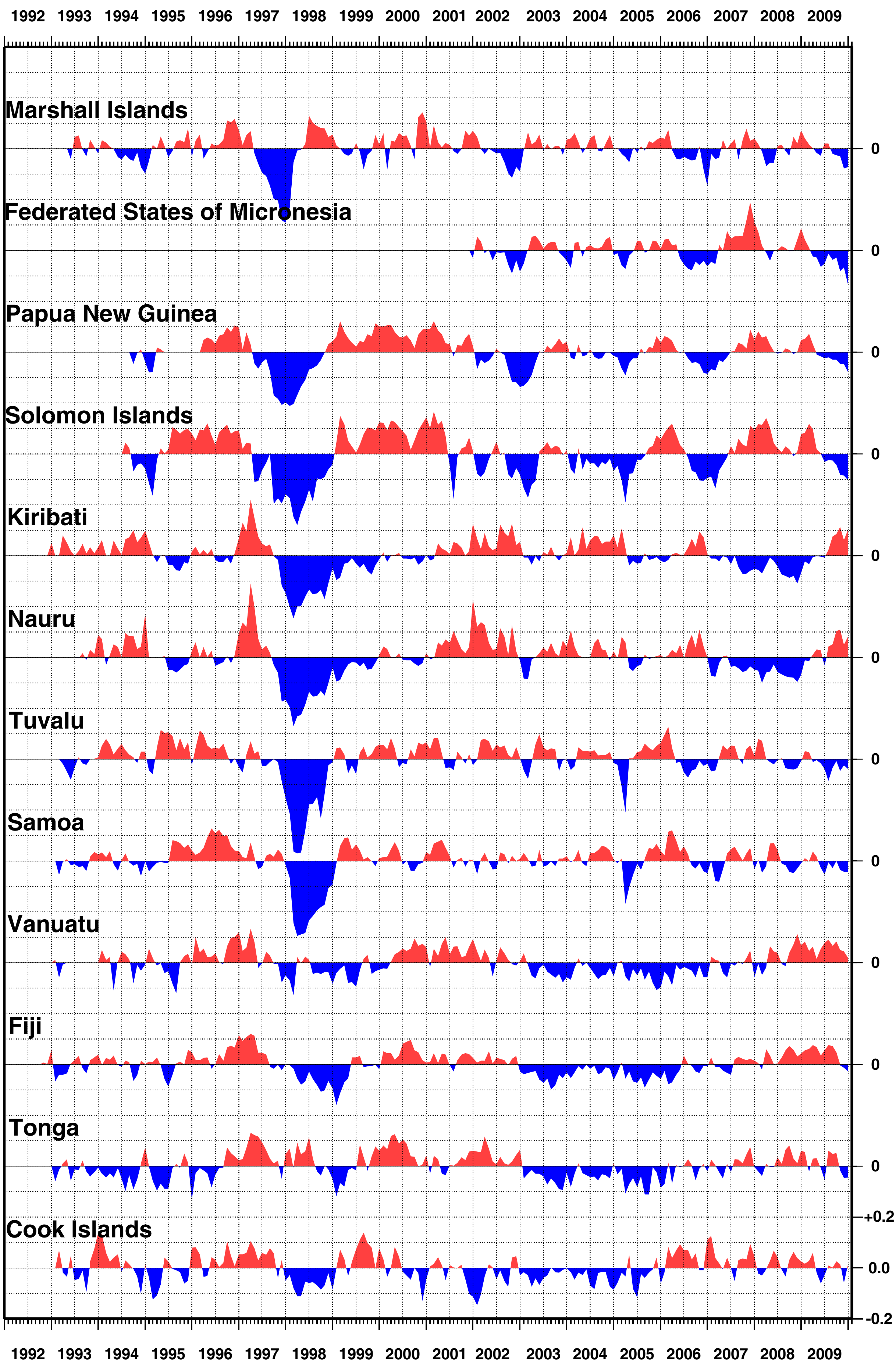


Figure 13

SEA LEVEL TRENDS THROUGH DECEMBER 2009 (mm/year)

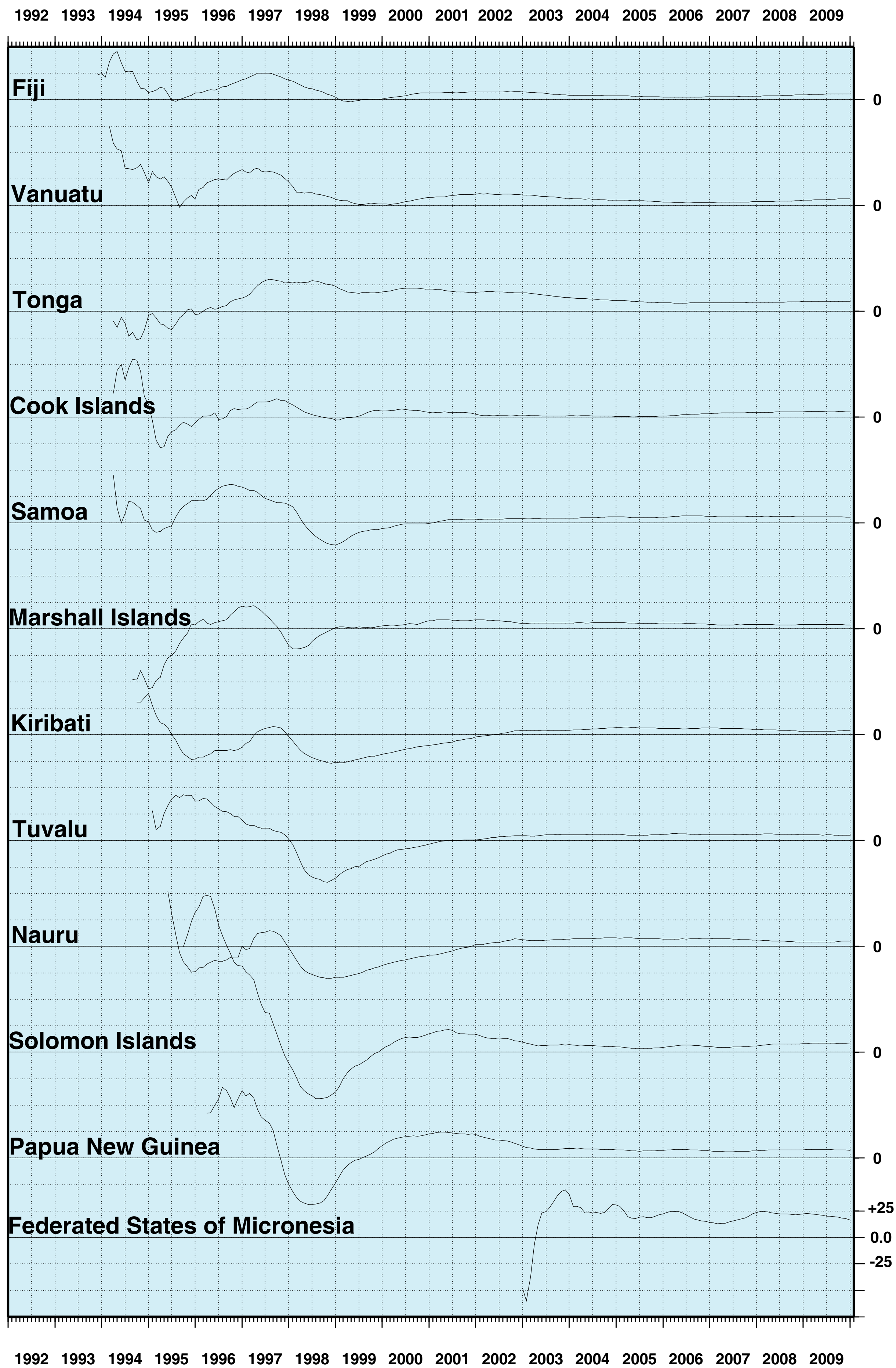


Figure 14

BAROMETRIC PRESSURE ANOMALIES THROUGH DECEMBER 2009 (hPa)

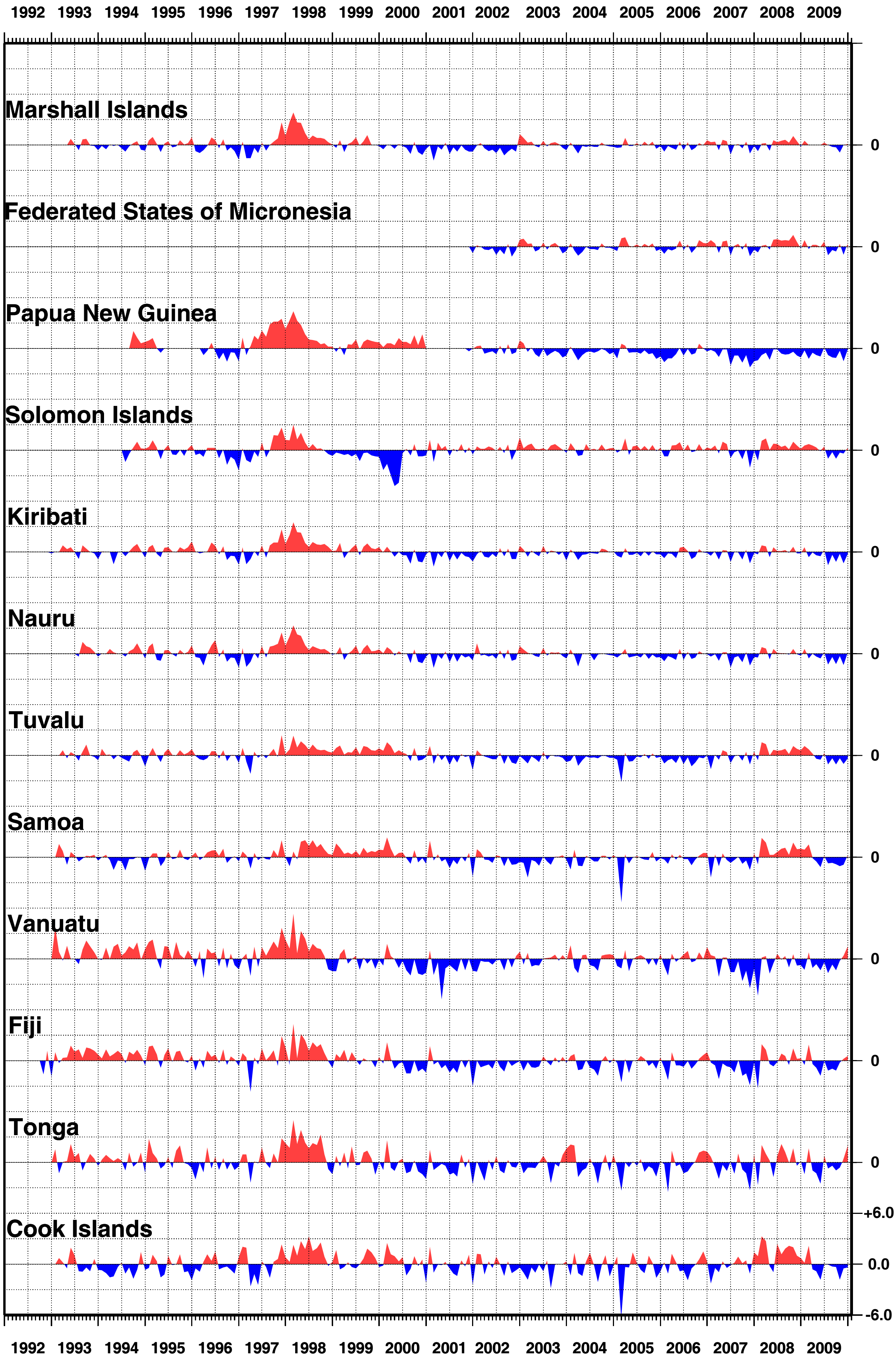


Figure 15

WATER TEMPERATURE ANOMALIES THROUGH DECEMBER 2009 (˚C)

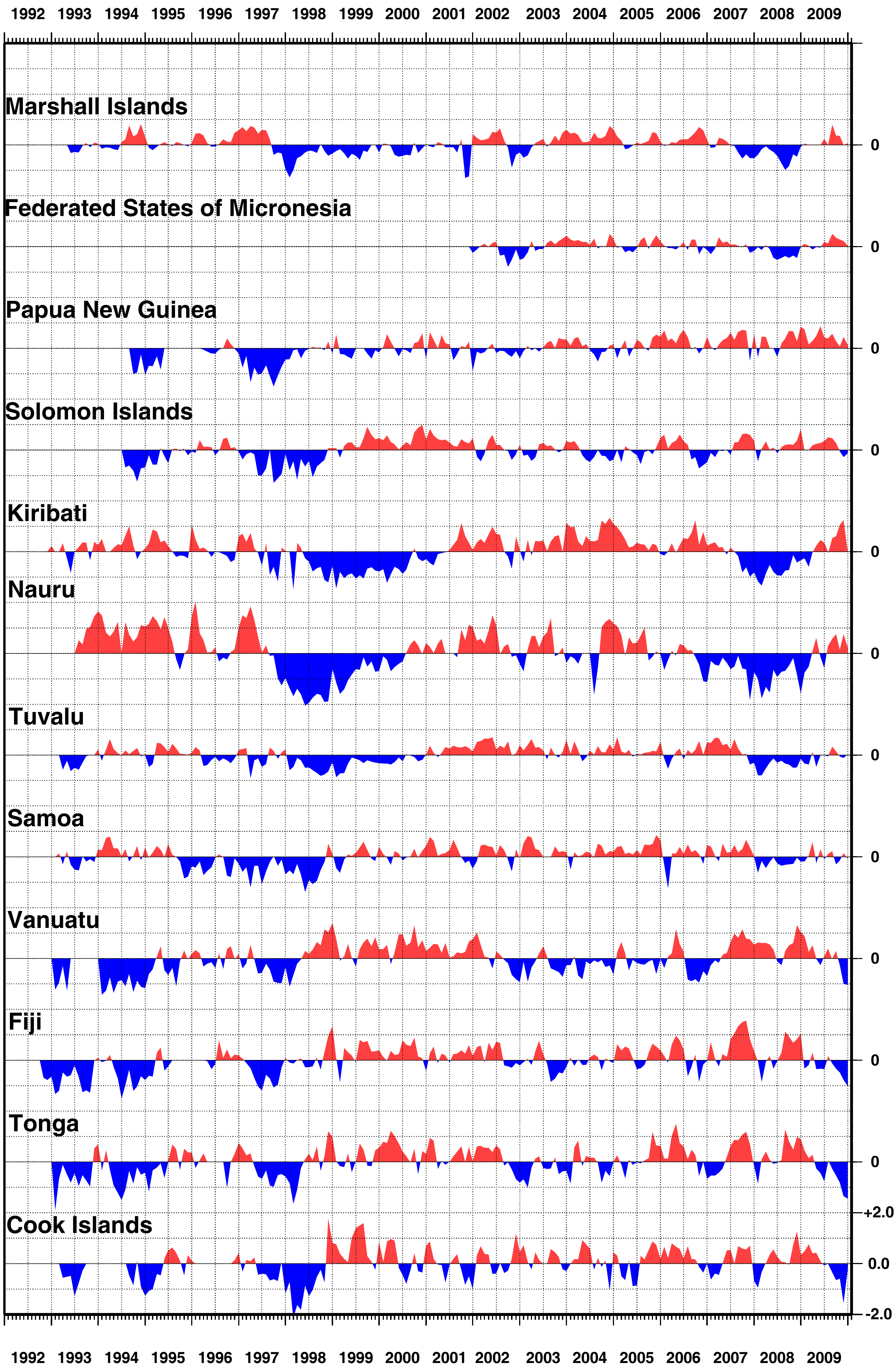


Figure 16

AIR TEMPERATURE ANOMALIES THROUGH DECEMBER 2009 (˚C)

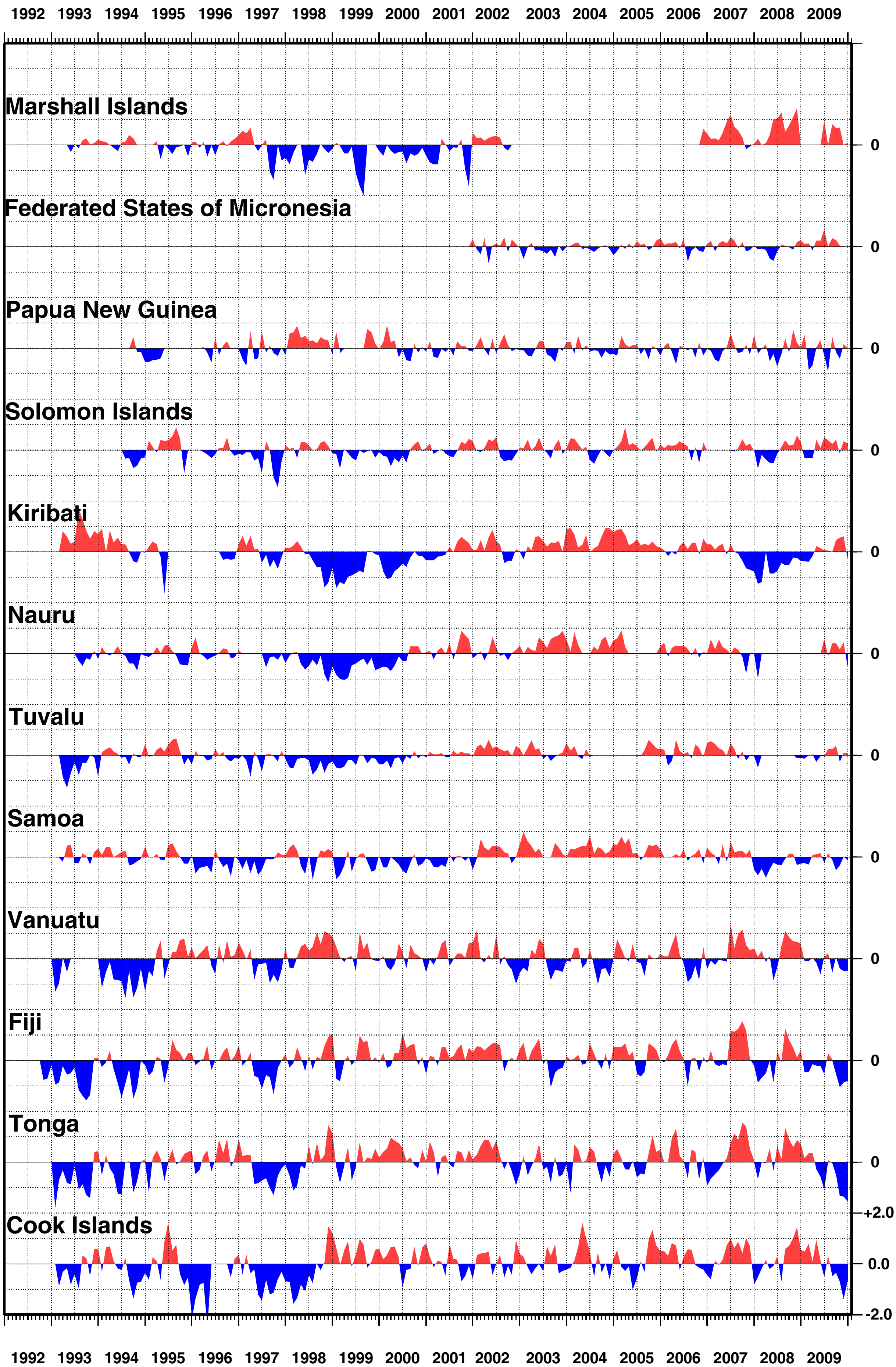


Figure 17

SEA LEVEL DATA RETURN

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