Climate and Oceans Support Program in the Pacific

Australian Government
Bureau of Meteorology

Monthly Data Report - March 2015

Pacific Sea Level Monitoring Project

Australian Government

Bureau of Meteorology

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Executive Summary

This summary, and the overview that follows, are intended to provide a synopsis of the recent month's observations in addition to longer term variations over the life of the project to date.

March 2015

- The SEAFRAME network continued to collect high quality sea level and associated meteorological information for monitoring climate variability and climate change.
- The overall rate of sea level data return for March was 89.9%, lowered mainly as a result of station power supply problems at FSM and sea level sensor faults at Nauru.
- Tropical Cyclone Pam, one of the strongest tropical cyclones ever seen in the region, devastated Vanuatu causing loss of life and property. The cyclone passed Port Vila on 13th March 2015, where a SEAFRAME station measured a 60 cm surge in sea level, as well as strong winds and record-low barometric pressure.
- Monthly-average sea levels were 15-20 cm higher than normal at Kiribati and Nauru, but around 10 cm lower than normal at Marshall Islands, PNG, Solomon Islands, Vanuatu and Tonga. The monthly average sea level at Kiribati surpassed the record high of March 1997.
- Monthly barometric pressure anomalies trended down slightly across the network. Monthly air temperatures were generally warmer than normal across the network, while monthly water temperature anomalies varied from as much as +1.6 °C at Nauru to -1.1 °C at PNG.

Introduction

Welcome to the March 2015 Monthly Data Report for the Pacific Sea Level Monitoring Project (PSLMP). 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 events and the interpretation of sea level fluctuations in the context of related astronomical tide, weather and climate variations.

The PSLMP continues the work of the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP) under a wider Climate and Oceans Support Program in the Pacific (COSPPac) initiative. The SPSLCMP was originally 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 with the principal objective of 'the provision of an accurate long term record of sea level in the South Pacific for partner countries and the international scientific community which enables them to respond to and manage related impacts'.

The project's sea level monitoring network consists of 12 SEAFRAME stations providing wide coverage across the Pacific Islands Forum region (Figure 1). The SEAFRAME stations not only measure sea level, but also observe a number of "ancillary" variables - air and water temperatures, wind speed, wind direction and atmospheric pressure.

An associated geodetic measurement program, implemented by Geosciences Australia, supports levelling surveys to first order, to determine shifts in the vertical of the sea level sensors due to local land movement, as well as continuous Global Positioning System (CGPS) stations to determine the vertical movement of the land with respect to the International Terrestrial Reference Frame.

Observations collected by the sea level monitoring network are routinely processed into a range of quality-controlled data products. The monthly data report is the primary source of up-to-date information relating to these data products.

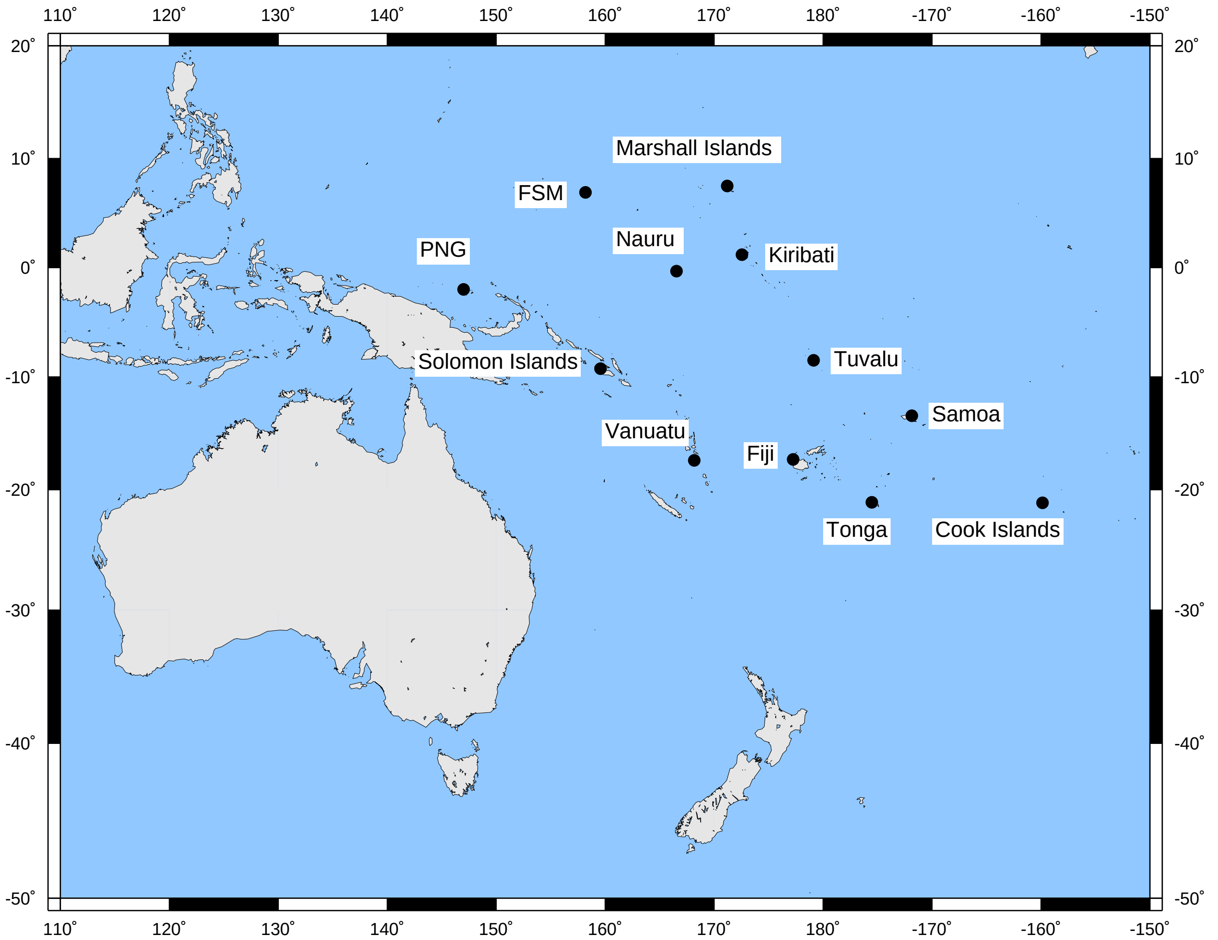

Figure 1. Pacific Sea Level Monitoring Network of SEAFRAME stations.

Sea Level and Climate

Astronomical tides and weather conditions are largely responsible for daily perturbations in sea level, but over monthly, seasonal and longer timescales sea levels in the tropical Pacific are largely influenced by fluctuations in climate and ocean heat content across the Pacific.

The El Niño – Southern Oscillation climate cycle plays a key role in sea level variability. During El Niño sea levels are generally lower than normal across the western equatorial Pacific, as measured by the project's sea level network, in response to weaker than normal easterly Trade Winds, cooler than normal ocean temperatures and higher than normal barometric pressures in this region. On the other hand during La Niña the easterly Trade Winds are typically stronger than normal, ocean temperatures are warmer than normal and barometric pressures are lower than normal across the western Pacific, which often results in higher than normal sea levels at many of the project stations.

The sea level stations at PNG, Solomon Islands, Tuvalu and Samoa lie along a zone of convergent winds, known as the South Pacific Convergence Zone. Sea levels at these stations may become higher or lower than normal depending on the strength of these convergent winds or the shifting position of the convergence zone relative to its climatological mean. The sea level stations at Nauru and Kiribati lie very close to the equator and can both be influenced by sea level signals propagating along the equatorial waveguide.

A summary of recent and past climate conditions across the equatorial Pacific is provided by the Bureau of Meteorology in its monitoring of the El Niño – Southern Oscillation cycle at http://www.bom.gov.au/climate/enso/

Further climate information for Pacific Island countries is provided by the Climate and Ocean Monitoring and Prediction (COMP) Project under the Climate and Oceans Support Program in the Pacific (COSPPac).

March SEAFRAME Data

Monthly Sea Level and Environmental Data

The observed sea levels (Figure 3) 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). Where the tides follow a semi-diurnal pattern the greatest tidal variations are called spring tides, which tend to occur around the time of the full and new moons. There was a full moon on the 5th of March and a new moon on the 20th of March. The spring tides around the time of the new moon were notably larger than those of the full moon earlier in the month. This was because the moon was orbiting nearer to the earth at the time of the new moon but further away at the time of the full moon.

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

The residuals (Figure 4) are the differences between the observed sea levels and the astronomical tidal predictions. They highlight non-tidal sea level fluctuations, such as those due to the effects of weather or tsunamis. Tropical cyclones can produce storm surges where the combination of low barometric pressure and strong winds raise sea levels well above the predicted astronomical tides for a period of a day or more. This is what occurred on 13th March 2015, when severe Tropical Cyclone Pam, one of the strongest cyclones ever seen in the region, passed over Vanuatu. Sea levels at Port Vila surged 60 cm above predicted astronomical tides as a result of record-low barometric pressure and strong winds.

The non-tidal sea level fluctuations can be amplified or sustained by the shape of the harbour in which the gauge is located. Some of the SEAFRAME stations are located in harbours that exhibit 'sloshing' under certain conditions (a phenomenon referred to as a seiche), such as at PNG when the wind suddenly changes strength or direction, at FSM during smaller neap tides and at Nauru during strong westerly winds.

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 fluctuations were to persist they would form part of the astronomical tide prediction and thus not appear as residuals. Consequently semi-diurnal and diurnal residual fluctuations will always be transient in nature.

The barometrically corrected residuals (Figure 5) have had the effect of atmospheric pressure fluctuations removed from the sea level residuals of Figure 4. 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). This is well illustrated at Vanuatu on 13th March 2015, where the inverse barometer correction accounted for virtually the entire surge associated with Tropical Cyclone Pam. In contrast, the inverse barometer

correction does not account for much of the elevated seas observed at Nauru on the 5th - 6th and 13th - 14th March, which are caused by the persistent westerly winds observed at that time.

The winds, temperatures and barometric pressures are plotted in Figure 6 through Figure 11. The incident winds in Figure 8 follow the meteorological convention, that is, they point in the direction the wind is coming from. For example, the winds at Marshall Islands prevailed from the northeast for most of the month.

Wind gusts to 27 m/s (52 knots or 97 km/h) were recorded by the SEAFRAME station at Port Vila, Vanuatu during the passing of Tropical Cyclone Pam on 13th March 2015, but it is worth noting the station is not highly exposed to winds.

Air and water temperatures (Figure 9 and Figure 10) 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. Solomon Islands) 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 interactions between tides and terrestrial (land-based) water discharging into the wharf area. The water temperature fluctuations there are usually more pronounced during the larger spring tides.

Barometric pressures (Figure 11) 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 farther away from the equator such as Cook Islands and Tonga.

The monthly sea level and ancillary data are put into perspective by Figure 12. 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 Pacific Sea Level Monitoring Project data, which have been collected since October 1992 when the first station was installed at Fiji. The data from Federated States of Micronesia (FSM) has only been collected since December 2001.

During this month new March maximum sea levels were recorded at Samoa (1.671 m) and Cook Islands (1.214 m), while a new March minimum sea level was recorded at Marshall Islands (-0.063 m). New March maximum air temperatures were recorded at Kiribati (32.0 °C), Nauru (34.9 °C), Samoa (33.3 °C) and Tonga (31.5 °C). At Fiji, a new March minimum air temperature (21.7 °C) and March maximum water temperature (32.4 °C) were recorded. New March minimum barometric pressures were recorded at Marshall Islands (998.1 hPa), Kiribati (998.8 hPa) and Vanuatu (942.9 hPa), the latter being due to Tropical Cyclone Pam.

Further sea level and meteorological statistical information is available at http://www.bom.gov.au/oceanography/projects/spslcmp/data/monthly.shtml

Monthly Means and Anomalies

Figure 13 through Figure 16 show the monthly means, or simple arithmetic averages, for sea level, barometric pressure, water temperature and air temperature. Averaging over a month removes tidal and daily fluctuations, which helps reveal the seasonal, annual and longer-period variations in the records. Tuvalu, for example, normally experiences an annual sea level cycle of about 0.2 metres, reaching a peak around February or March. One effect of the El Niño of 1997-1998 was very low sea levels which disrupted the annual sea level cycle at many of the SEAFRAME stations.

The monthly mean sea level at Kiribati for March 2015 is the highest on record, eclipsing the previous record of March 1997 by 1.8 cm.

Figure 17 through Figure 20 show the monthly mean sea level, barometric pressure, air temperature and water temperature anomalies. The sea level anomalies are the monthly-averaged residuals after tides, annual and semi-annual seasonal cycles and linear slope have been removed, by way of a harmonic tidal analysis of the complete record. The annual sea level cycle at Tuvalu (which has the largest consistent annual cycle) is quite noticeable in Figure 13 but less apparent in Figure 17. 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.

Figure 17 shows monthly sea levels during March 2015 were lower than normal at Marshall Islands (-8 cm), PNG (-10 cm), Solomon Islands (-11 cm), Vanuatu (-8 cm) and Tonga (-12 cm). Sea levels were higher than normal at Kiribati (+15 cm) and Nauru (+19 cm), but close to normal elsewhere across the network.

The anomalies of barometric pressure, water and air temperature are determined in the same manner as the sea level anomalies, except the linear slope is not calculated.

The barometric pressure anomalies (Figure 18) show substantially higher than normal barometric pressures were observed at SEAFRAME stations during the 1997-1998 El Niño. In March 2015 there was a downward trend, particularly south of the equator where slightly lower than normal barometric pressures developed at Samoa (-1.2 hPa), Vanuatu (-1.6 hPa), Fiji (-1.1 hPa), Tonga (-2.1 hPa) and Cook Islands (-1.9 hPa).

The monthly water temperature anomalies (Figure 19) show warmer than normal conditions persisted through March 2015 at Kiribati (+0.9 °C), Nauru (+1.6 ºC) and Tuvalu (+0.6 °C), while cooler than normal water temperatures were observed at PNG (-1.1 °C) and Vanuatu (-0.6 °C).

The monthly air temperature anomalies (Figure 20) show warmer than normal conditions across most of the network during March 2015, notably Nauru (+1.3 °C) and Samoa (+1.0 °C). 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.

Overall Rate of Movement in Sea Level

Table 1 shows the overall rate of movement in sea level at individual Pacific stations based on the data so far collected at those sites. For many of the sites, the underlying data sets are around twenty years in length.

The overall rates of movement are updated every month by calculating the linear slope during the tidal analysis of all the data available at individual stations.

Please exercise caution in interpreting the overall rates of movement of sea level – the records are too short to be inferring long-term trends.

Table 1. Updated overall rates of sea level movement based on SEAFRAME data from installation through March, 2015.

Location	Latitude	Longitude	Date of first data	Rate (mm/yr)	Change in rate from previous month (mm/yr)
Marshall Is.	7°6'21.7"N	171°22'22.1"E	May 1993	5.2	-0.1
FSM	6°58'49.9"N	158°12'0.8"E	Dec 2001	11.6	0.0
PNG	2°2'31.5"S	147°22'25.6"E	Sep 1994	7.3	-0.1
Solomon Is.	9°25'44.1"S	159°57'19.3"E	Jul 1994	6.5	-0.1
Kiribati	1°21'54.2"N	172°55'58.8"E	Dec 1992	4.4	+0.2
Nauru	0°31'45.9"S	166°54'36.2"E	Jul 1993	6.2	+0.2
Tuvalu	8°30'8.9"S	179°11'42.6"E	Mar 1993	4.3	0.0
Samoa	13°49'36.4"S	171°45'40.7"W	Feb 1993	7.9	+0.1
Vanuatu	17°45'19.2"S	168°18'27.7"E	Jan 1993	3.2	-0.1
Fiji	17°36'17.7"S	177°26'17.7"E	Oct 1992	5.1	0.0
Tonga	21°8'12.5"S	175°10'50.5"W	Jan 1993	8.0	-0.1
Cook Is	21°12'17.1"S	159°47'5.2"W	Feb 1993	4.6	0.0

Instrument Performance

In Figure 21, which shows sea level data return, the columns represent the percentage of quality-controlled data returned from the gauge each month.

Sea level data return from the network during March 2015 was lower than usual, at 89.9% (Table 2). Power supply problems continued to hamper data collection from FSM, while 79.3% of sea level data from Nauru was recovered from the radar back-up sensor.

Additional problems encountered with the ancillary sensors during March included irregular water temperature readings at Marshall Islands, Samoa and Tonga, which require further examination.

Table 2. Rates of sea level data return.

Location	Installation Date	Data Return Since Installation (%)	Data Return in March 2015 (%)
Cook Is	Feb 1993	96.9	100
Tonga	Jan 1993	98.5	99.9
Fiji	Oct 1992	98.9	100
Vanuatu	Jan 1993	95.4	100
Samoa	Feb 1993	96.7	100
Tuvalu	Mar 1993	96.6	100
Kiribati	Dec 1992	94.3	100
Nauru	Jul 1993	92.1	79.3
Solomon Is.	Jul 1994	98.6	100
PNG	Sep 1994	92.4	100
FSM	Dec 2001	94.3	0
Marshall Is.	May 1993	98.3	100
Network Average		**96.1**	**89.9**

SEAFRAME Stations

Standard SEAFRAME stations now employ a TELMET (previously 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 SEAFRAME station is shown in Figure 2.

Water level sensors include:

1. Primary water level using a Bartex 'AQUATRAK' acoustic-in-air sensor,

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

3. Tertiary water level using a Vega-puls62 radar sensor mounted above the water.

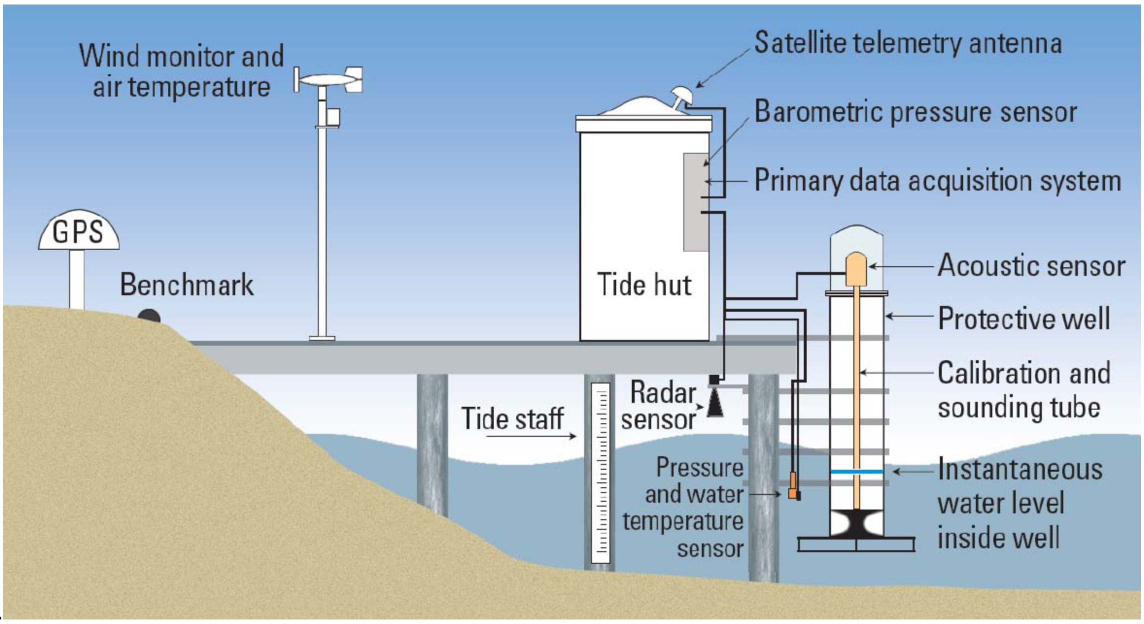

Figure 2. Schematic diagram of a SEAFRAME sea level monitoring station.

Observation Network Upgrade Project

The Observation Network Upgrade Project (ONUP) upgraded all Pacific SEAFRAME stations from March 2011 to December 2013 with modernised TELMET data loggers, real-time satellite communications and additional radar-type water level sensors. The dates of installation of the original SUTRON loggers and dates of the station upgrades are given in Table 3.

Table 3. Schedule of SEAFRAME station equipment upgrades.

Location	Latitude	Longitude	SUTRON Installation Date	TELMET Upgrade Date
Cook Is	21°12'17.1"S	159°47'5.2"W	Feb 1993	Oct 2012
Tonga	21°8'12.5"S	175°10'50.5"W	Jan 1993	Mar 2011
Fiji	17°36'17.7"S	177°26'17.7"E	Oct 1992	Jun 2011
Vanuatu	17°45'19.2"S	168°18'27.7"E	Jan 1993	May 2012
Samoa	13°49'36.4"S	171°45'40.7"W	Feb 1993	Aug 2011
Tuvalu	8°30'8.9"S	179°11'42.6"E	Mar 1993	Nov 2013
Kiribati	1°21'54.2"N	172°55'58.8"E	Dec 1992	Oct 2011
Nauru	0°31'45.9"S	166°54'36.2"E	Jul 1993	Jul 2013
Solomon Is.	9°25'44.1"S	159°57'19.3"E	Jul 1994	Nov 2011
PNG	2°2'31.5"S	147°22'25.6"E	Sep 1994	Aug 2012
FSM	6°58'49.9"N	158°12'0.8"E	Dec 2001	Apr 2013
Marshall Is.	7°6'21.7"N	171°22'22.1"E	May 1993	Dec 2012

Tide Prediction Extension Project

A tide prediction extension project is aimed at extending the network of locations at which accurate tide predictions are available. Activities include the deployment of portable tide gauges in strategic locations, with the intention of observing sea levels for a sufficient length of time, ideally 1 year, to allow a thorough analysis of astronomical tides.

A portable tide gauge was installed at Neiafu, in the Vava’u group of islands in Tonga, in September 2013 and efforts to link the sea-level data from the portable gauge to a local land reference via levelling survey were also made.

Further Information

Online Resources

COSPPac Web site: http://www.bom.gov.au/cosppac/

PSLMP Web site: http://www.bom.gov.au/oceanography/projects/spslcmp/spslcmp.shtml

ENSO Wrap-Up - El Niño / La Niña information: http://www.bom.gov.au/climate/enso/

Geoscience Australia South Pacific Regional GNSS Network (Levelling Survey and Continuous GPS Monitoring):
http://www.ga.gov.au/earth-monitoring/geodesy/gnss-networks.html

Acknowledgement

The Monthly Data Report is prepared for Australian Aid (formerly AusAID) by the Bureau of Meteorology under the Pacific Sea Level Monitoring (PSLM) Project, Climate and Oceans Support Program in the Pacific (COSPPac).

Further enquiries about the Monthly Data Report may be made to:

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Website: http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml

Please also note the following:

Appendix 1: SEAFRAME Data Figures

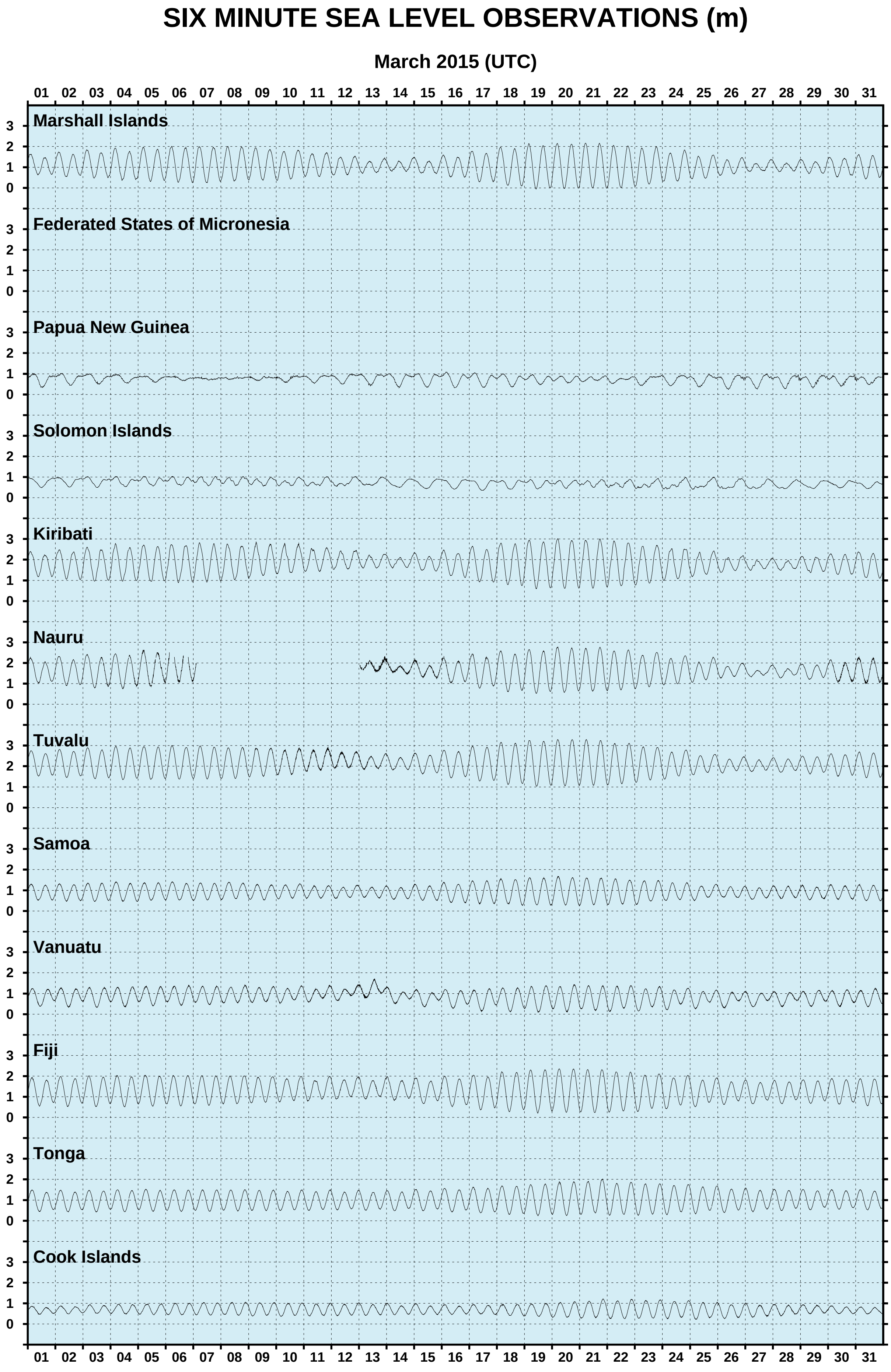

Figure 3. Sea level observations during March 2015.

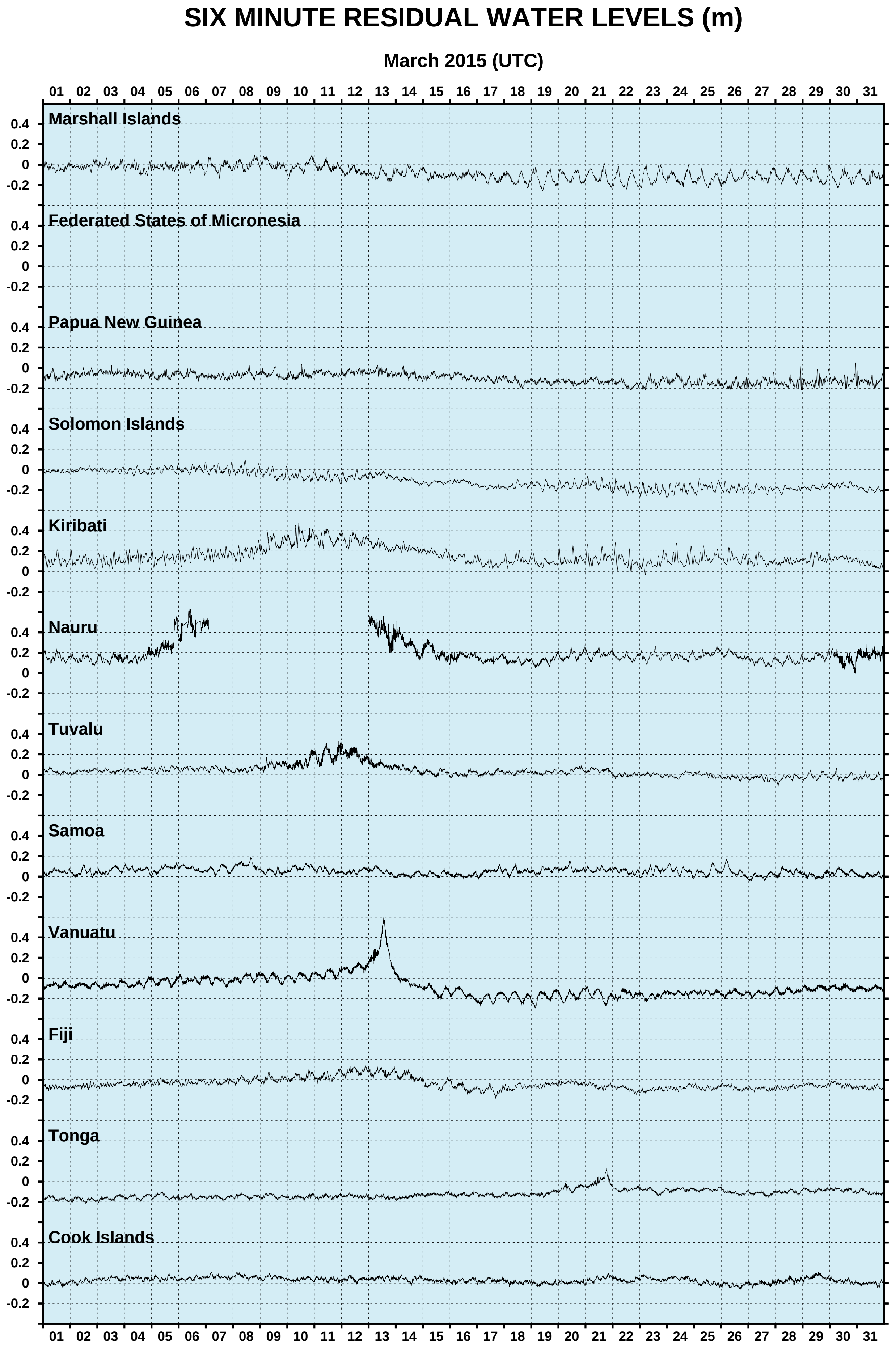

Figure 4. Residual sea levels during March 2015.

SIX MINUTE RESIDUALS
ADJUSTED FOR BAROMETRIC PRESSURE (m)

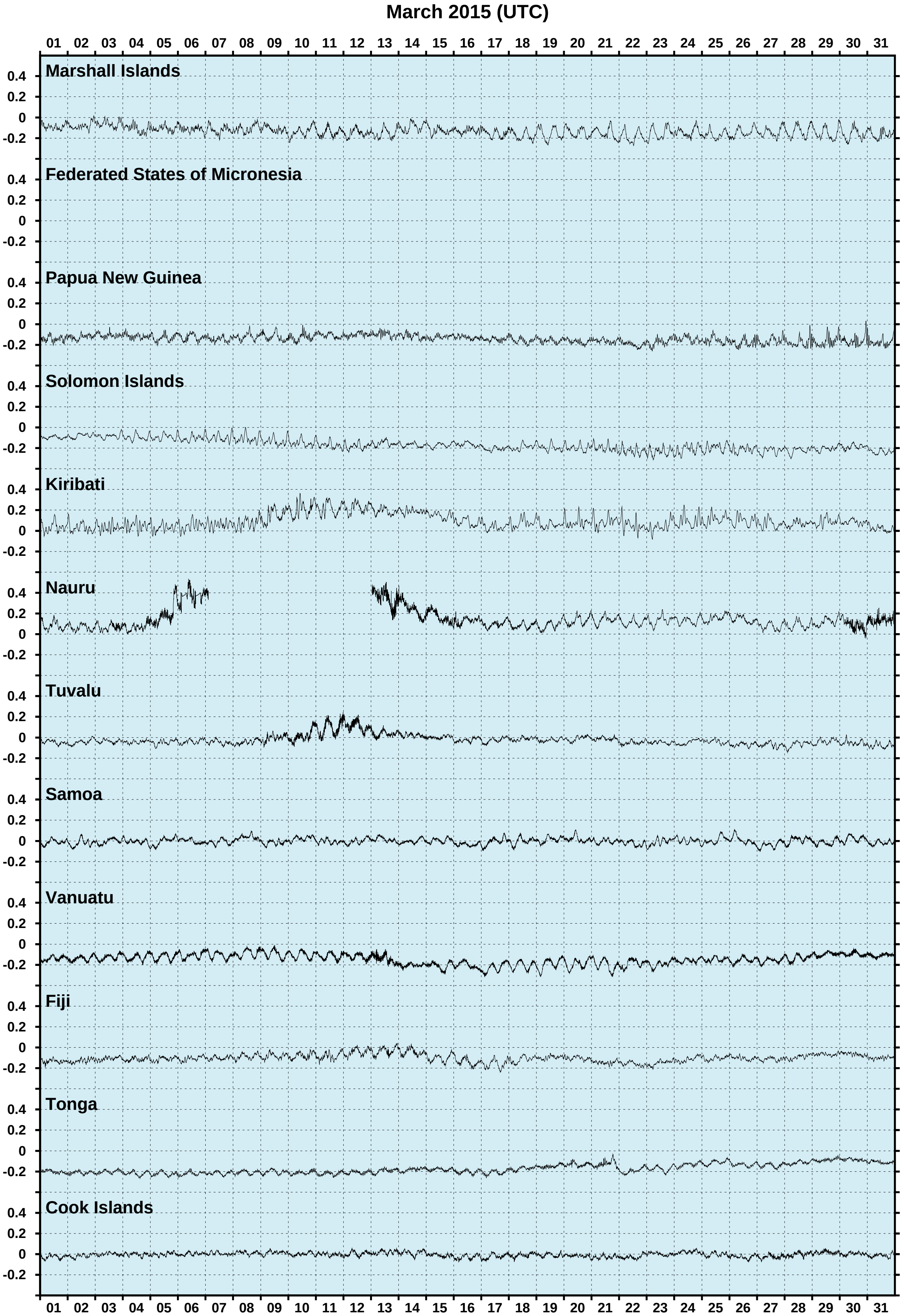

Figure 5. Residual sea levels adjusted for barometric pressure during March 2015.

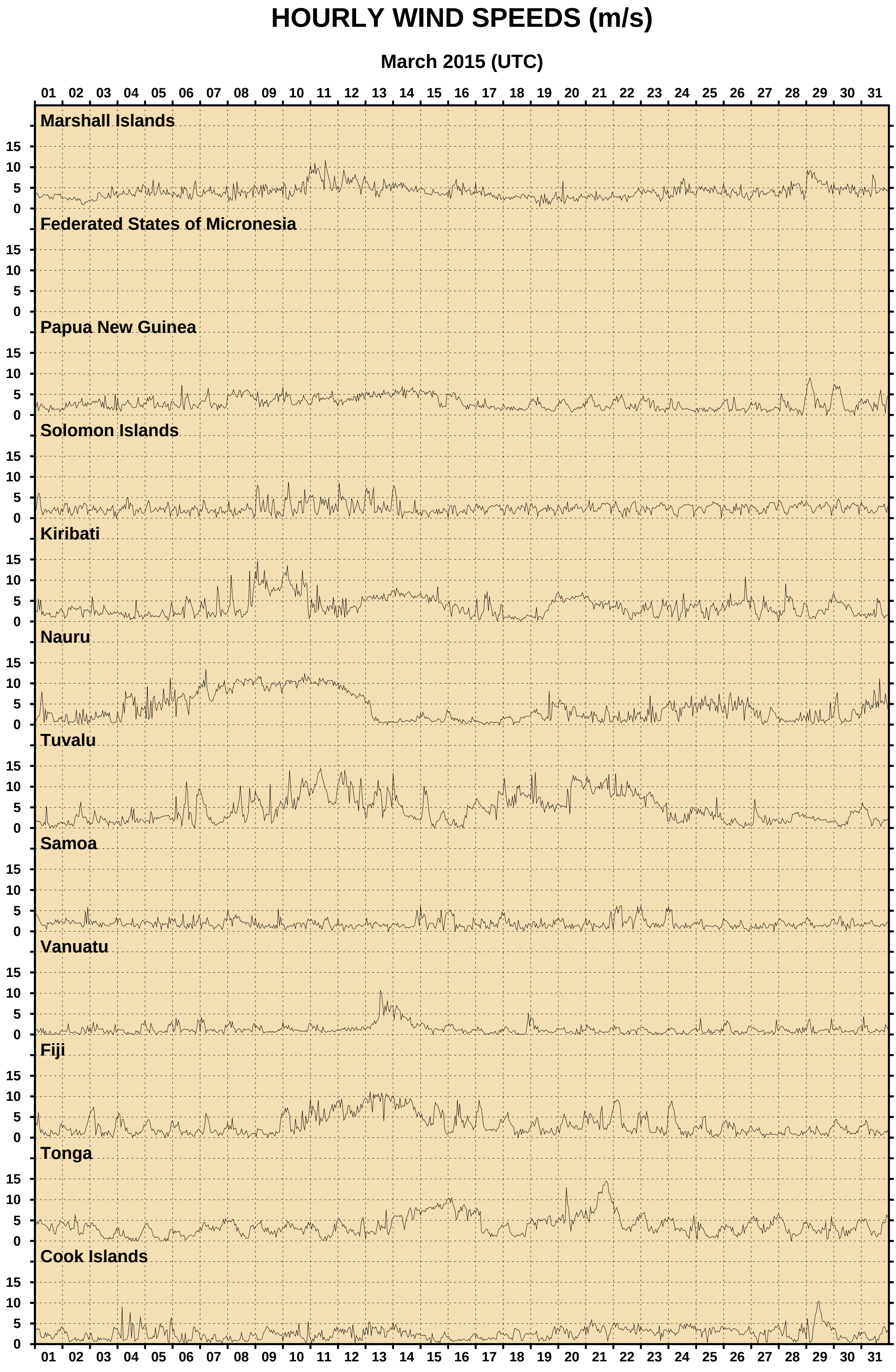

Figure 6. Wind speeds during March 2015.

HOURLY MAXIMUM WIND GUSTS (m/s)

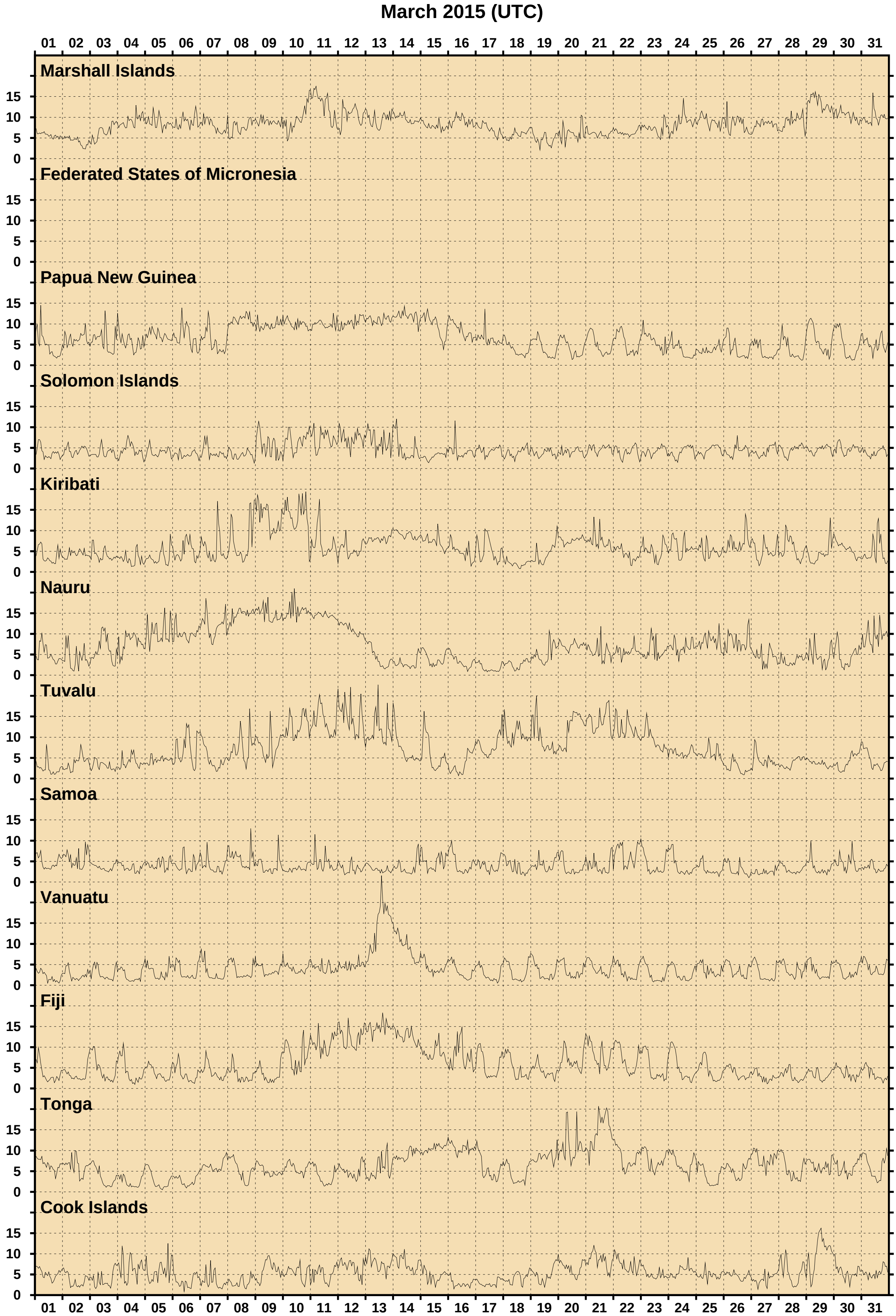

Figure 7. Wind gusts during March 2015.

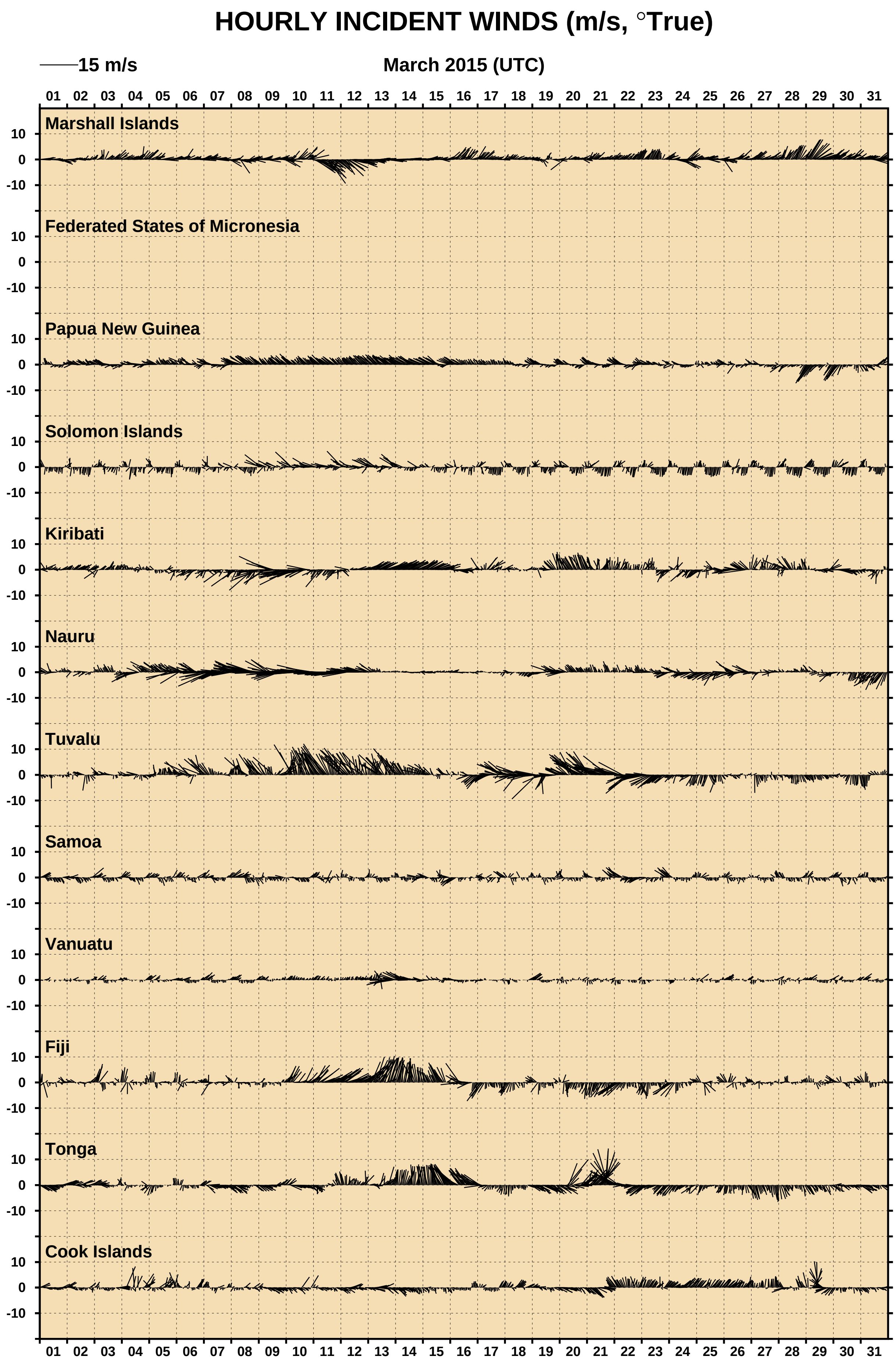

Figure 8. Incident winds during March 2015

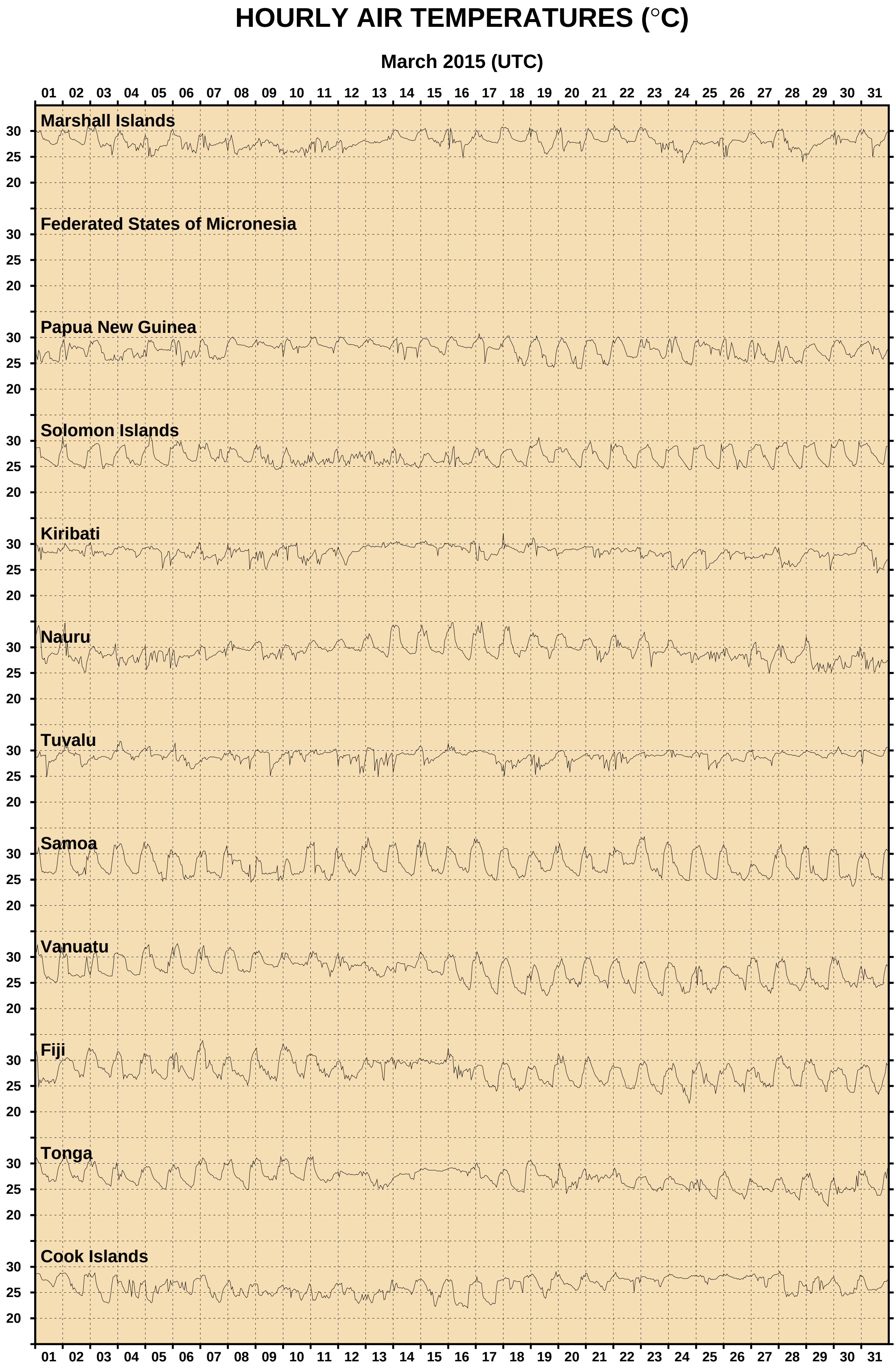

Figure 9. Air temperatures during March 2015.

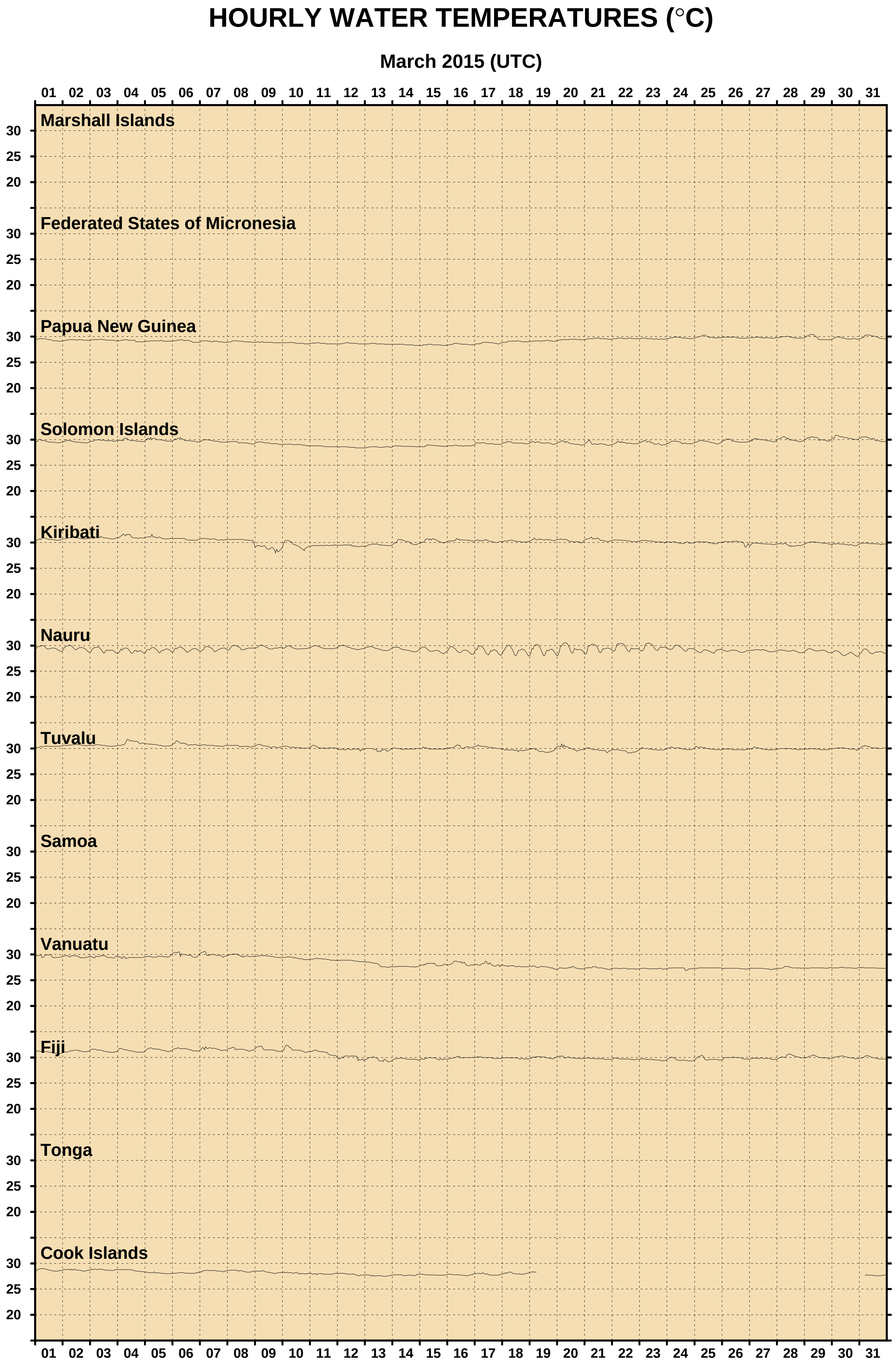

Figure 10. Water temperatures during March 2015.

HOURLY BAROMETRIC PRESSURE (hPa)

March 2015 (UTC)

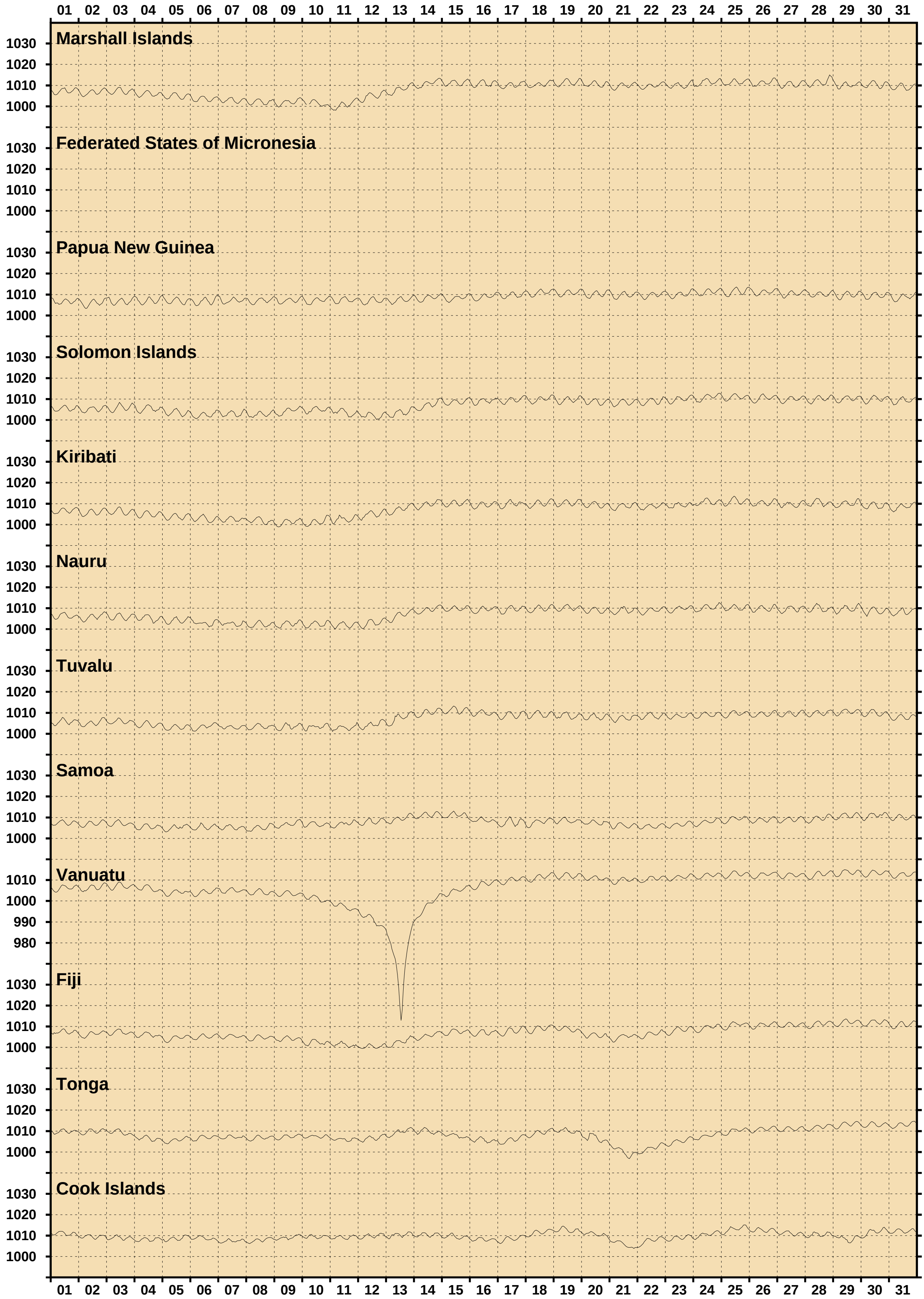

Figure 11. Barometric pressures during March 2015.

COMPARISON OF MARCH 2015 MAX,MIN AND MEAN WITH LONG-TERM MARCH VALUES

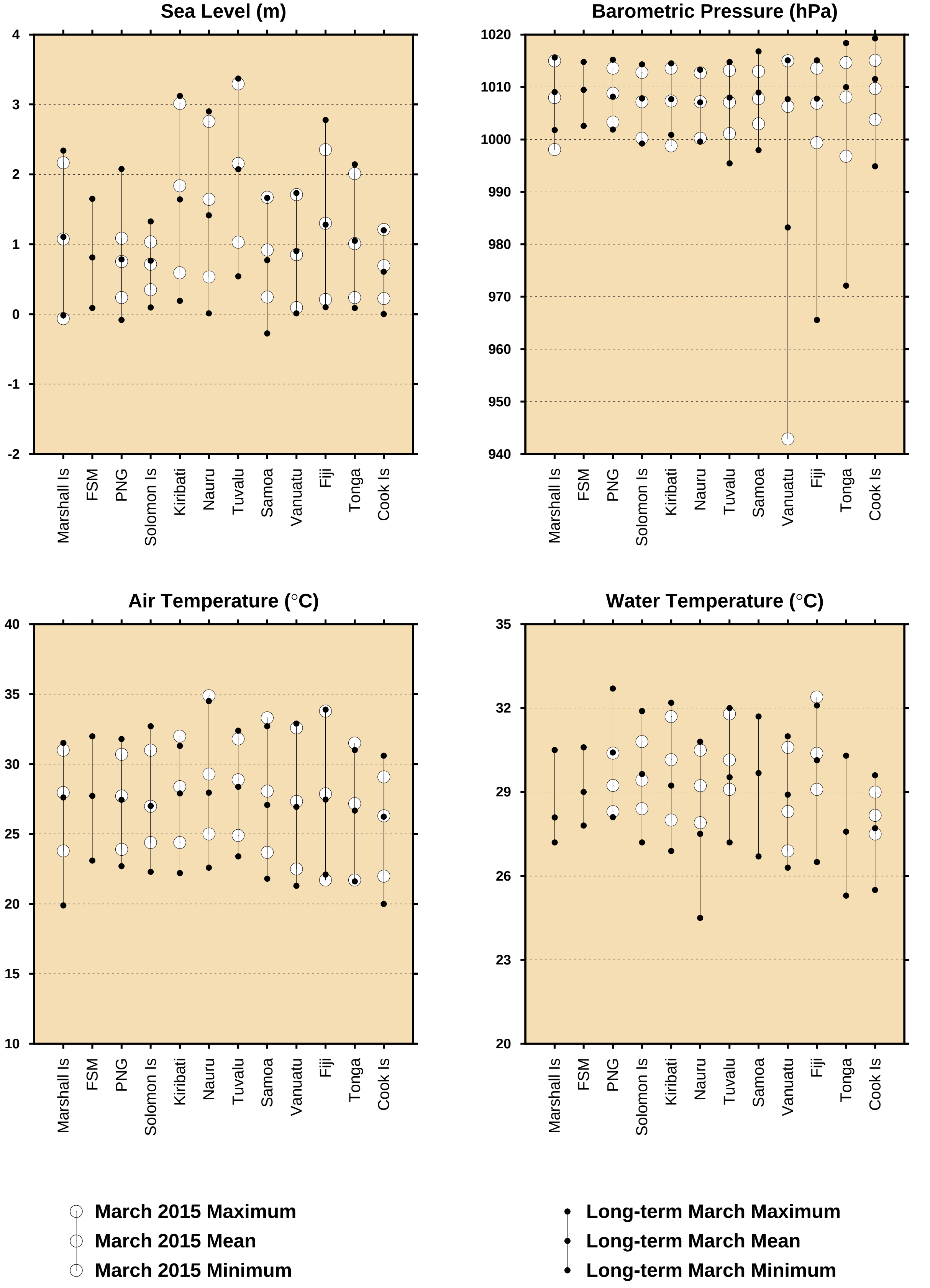

Figure 12. Comparison of March 2015 data with long term March values.

MONTHLY MEAN SEA LEVELS THROUGH MARCH 2015 (m)
(The zero line represents mean sea level)

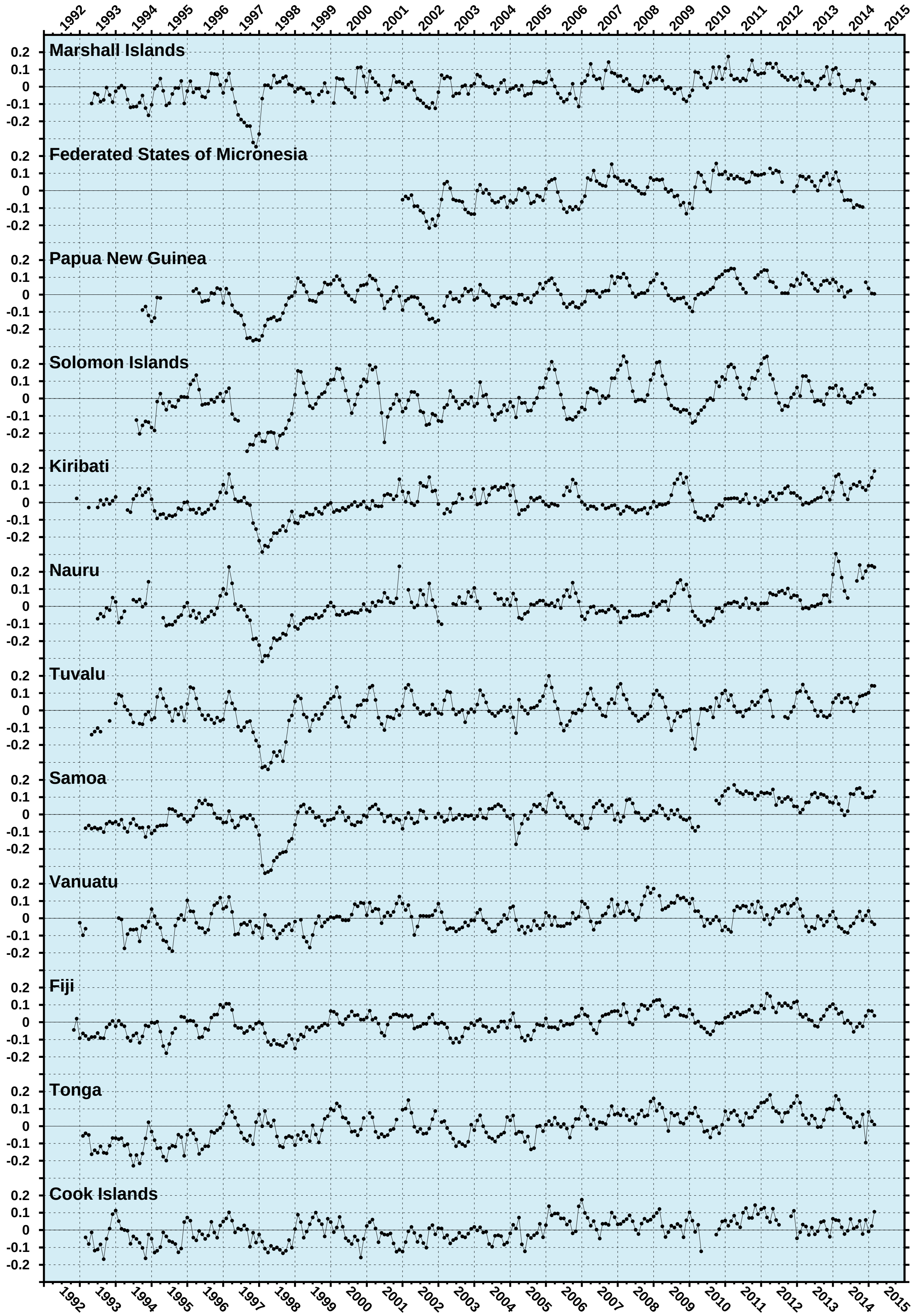

Figure 13. Monthly mean sea levels to March 2015.

MONTHLY MEAN BAROMETRIC PRESSURES THROUGH MARCH 2015 (hPa)

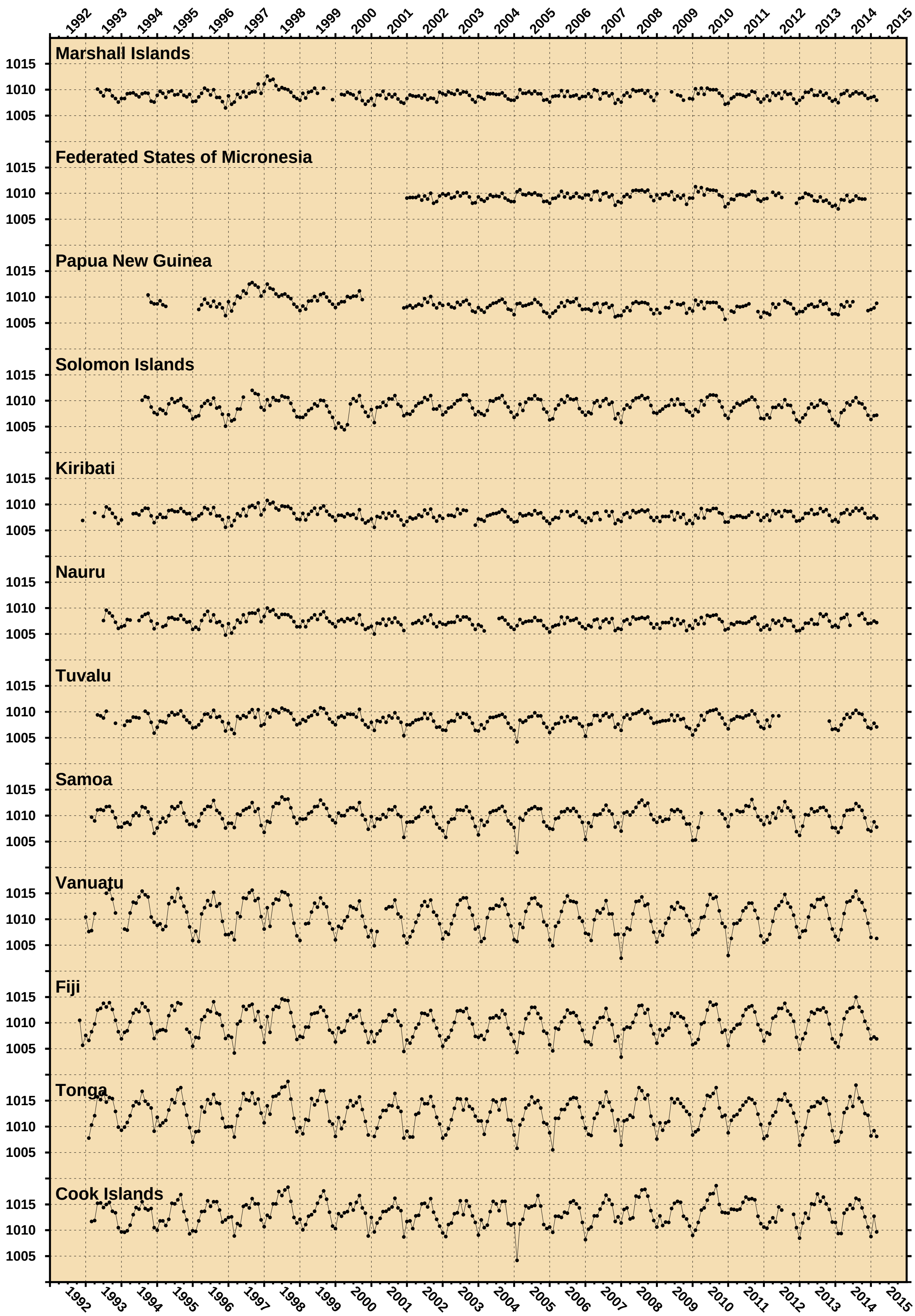

Figure 14. Monthly mean barometric pressures to March 2015.

MONTHLY MEAN WATER TEMPERATURES THROUGH MARCH 2015 (°C)

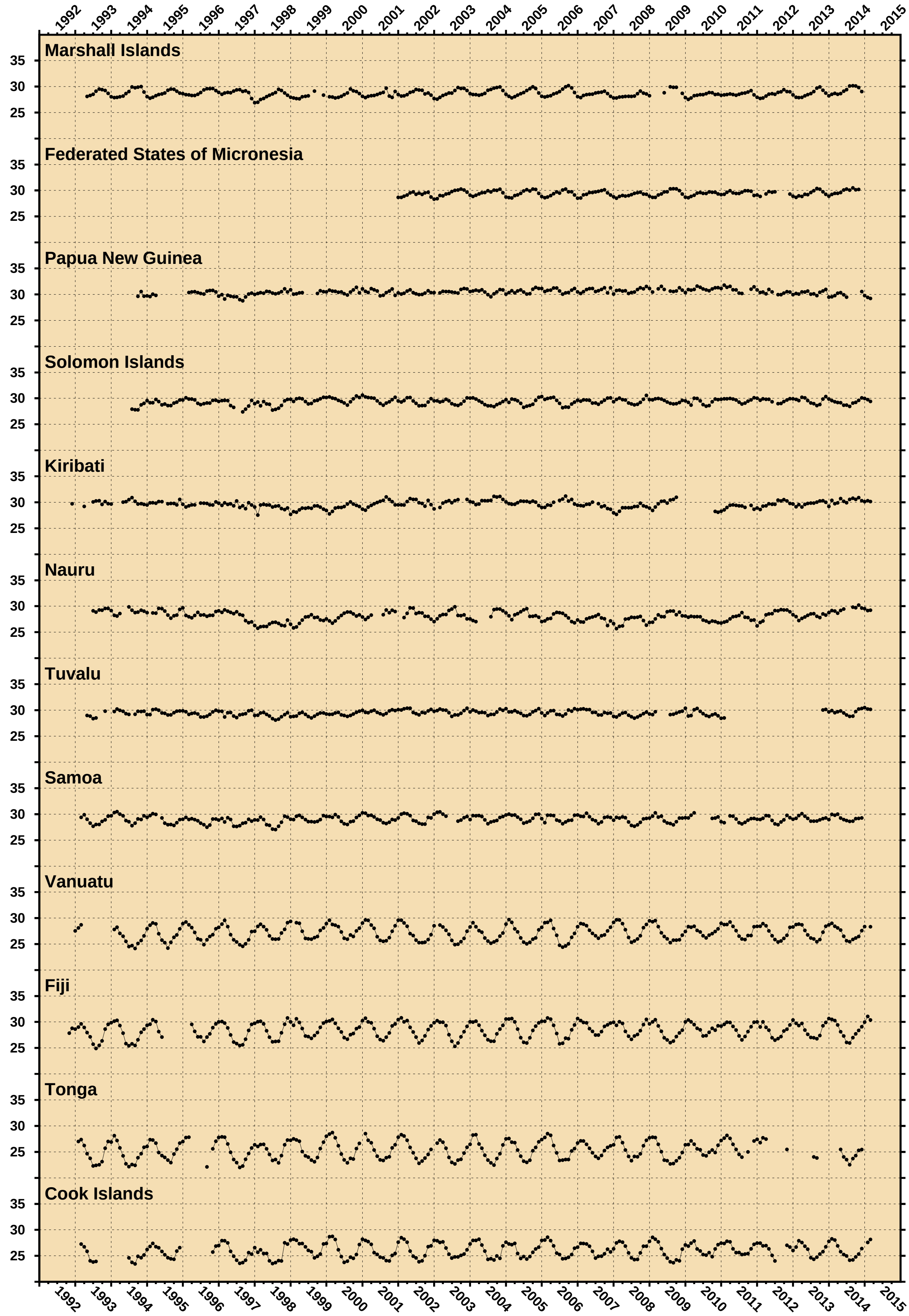

Figure 15. Monthly mean water temperatures to March 2015.

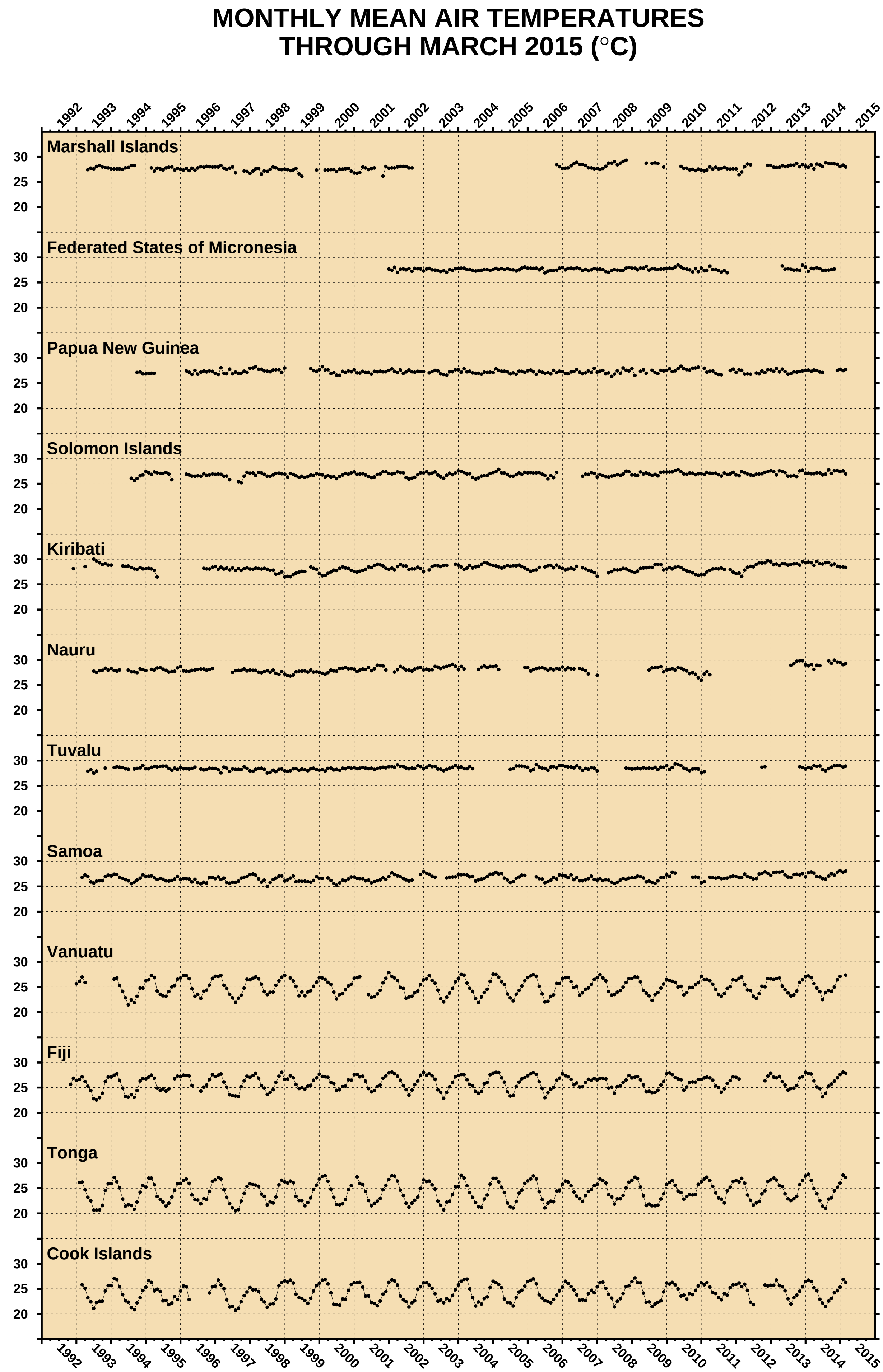

Figure 16. Monthly mean air temperatures to March 2015.

SEA LEVEL ANOMALIES THROUGH MARCH 2015 (m)

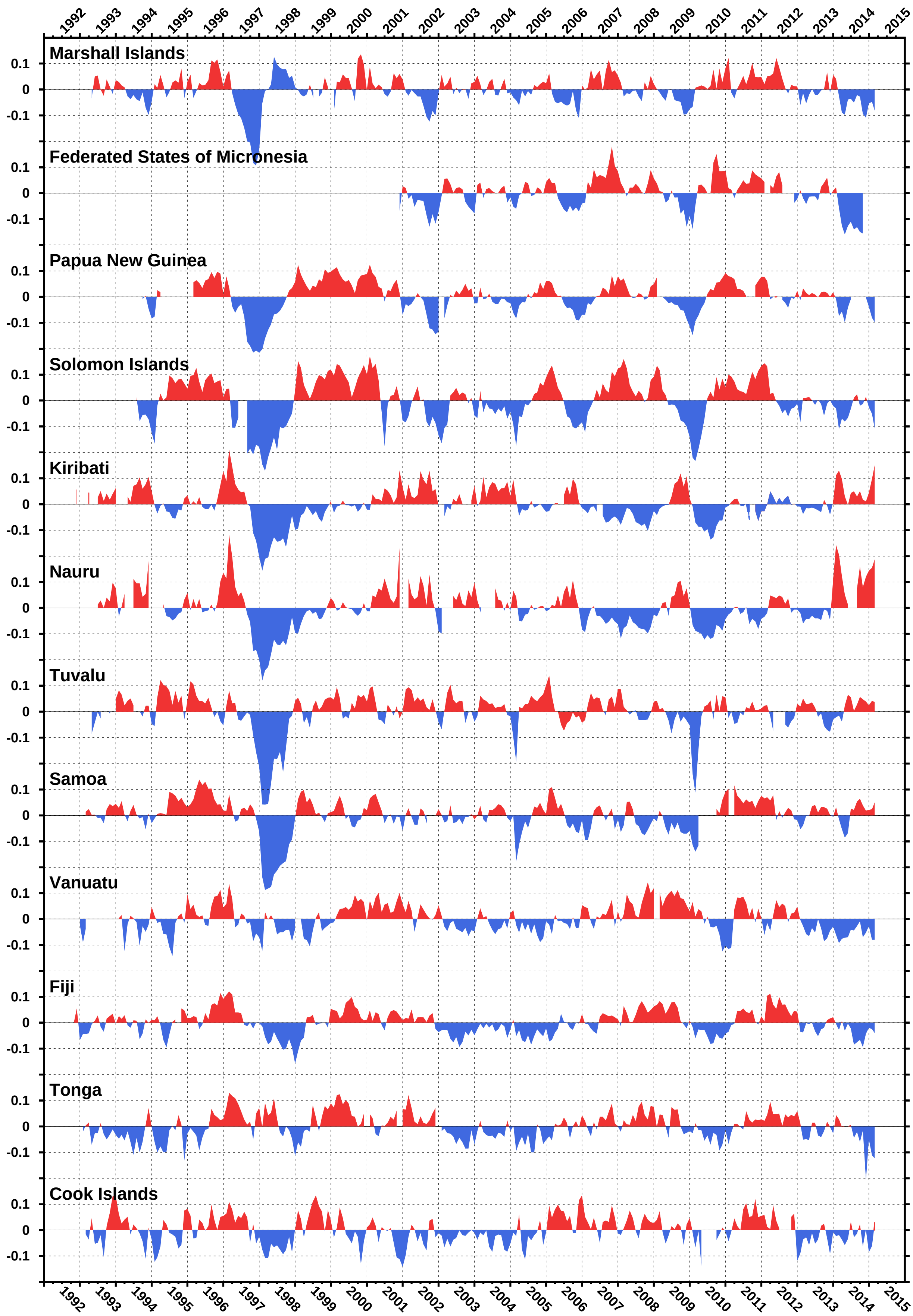

Figure 17. Monthly sea level anomalies to March 2015.

BAROMETRIC PRESSURE ANOMALIES THROUGH MARCH 2015 (hPa)

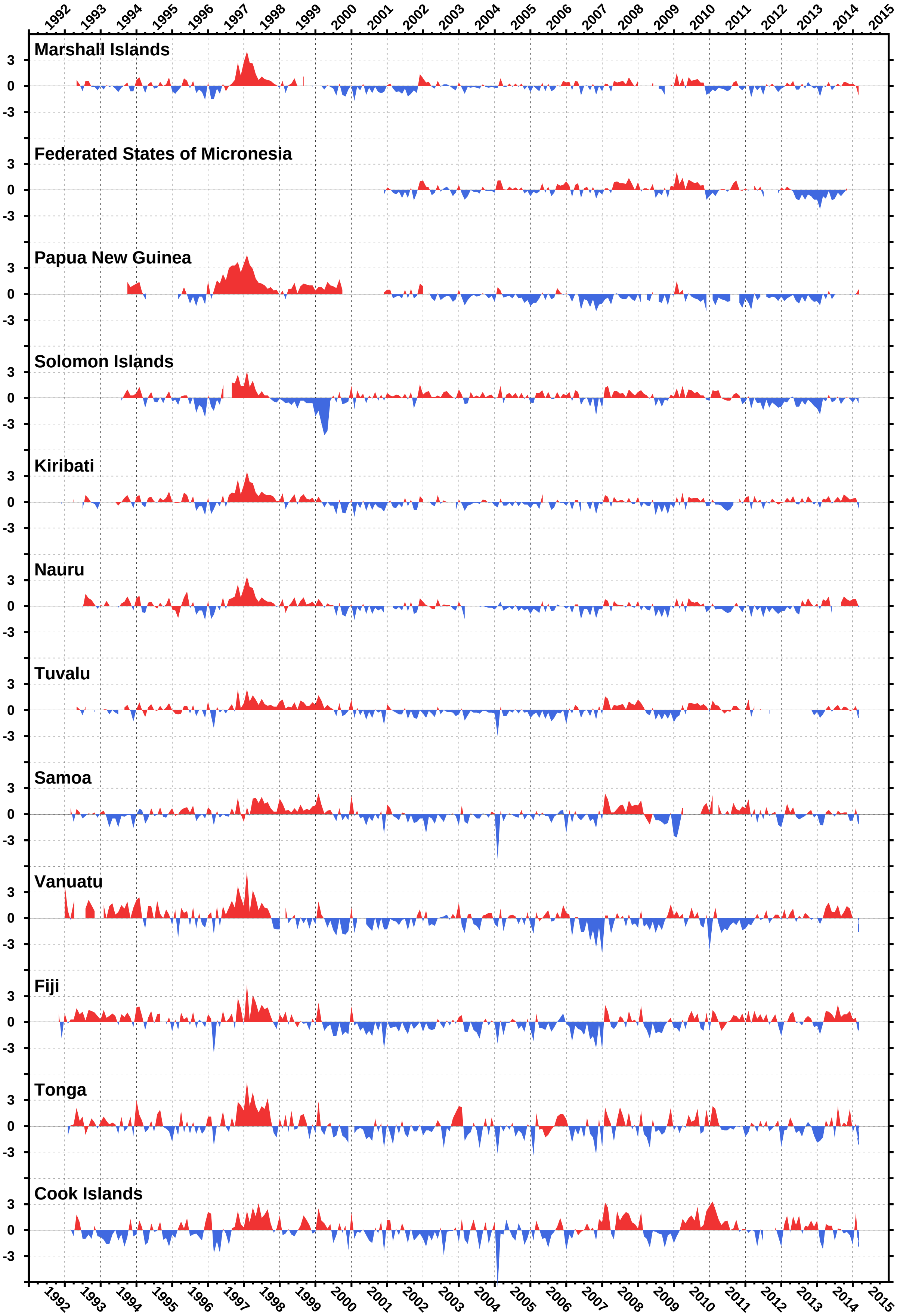

Figure 18. Monthly barometric pressure anomalies to March 2015.

WATER TEMPERATURE ANOMALIES THROUGH MARCH 2015 (°C)

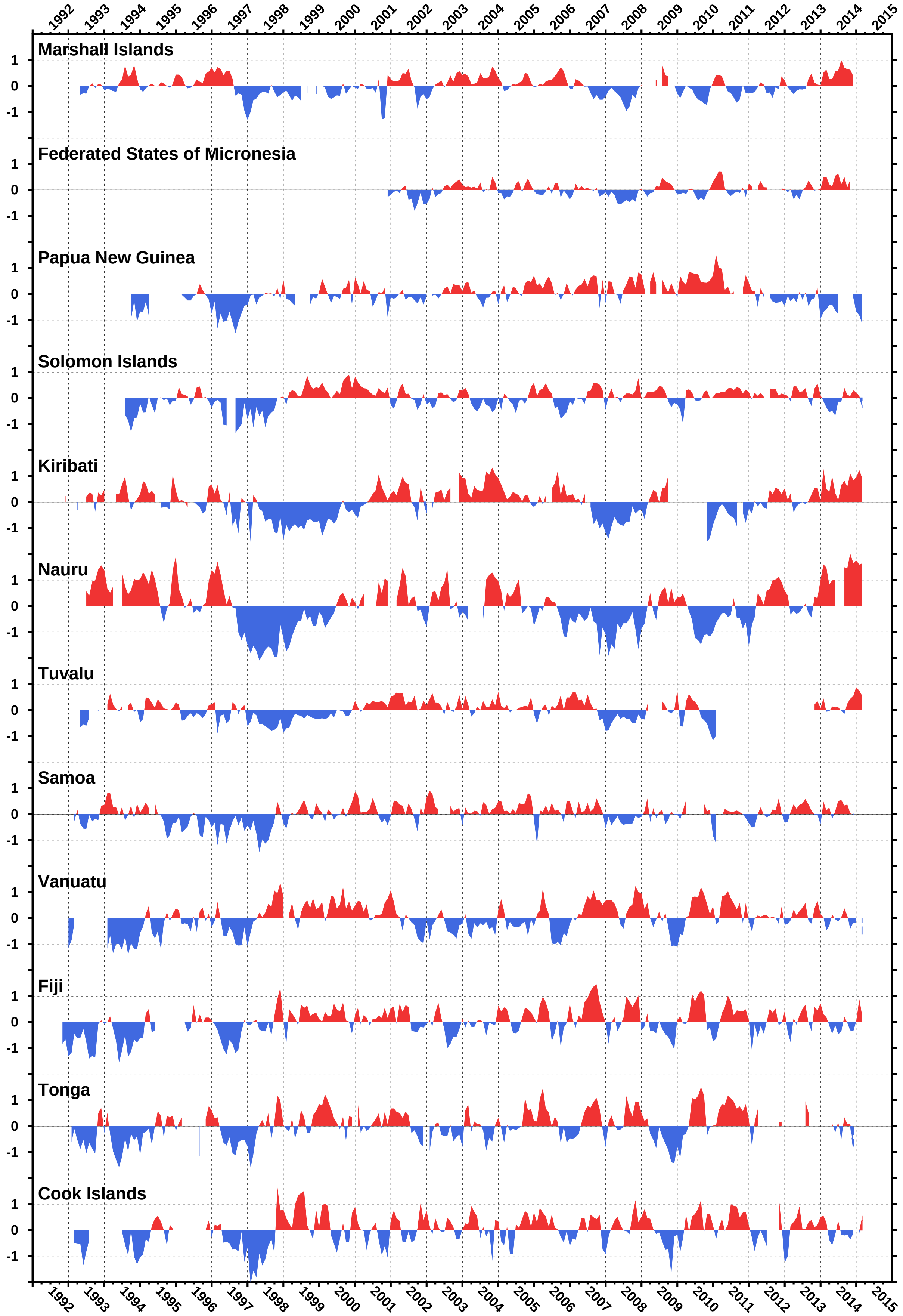

Figure 19. Monthly water temperature anomalies to March 2015.

AIR TEMPERATURE ANOMALIES THROUGH MARCH 2015 (°C)

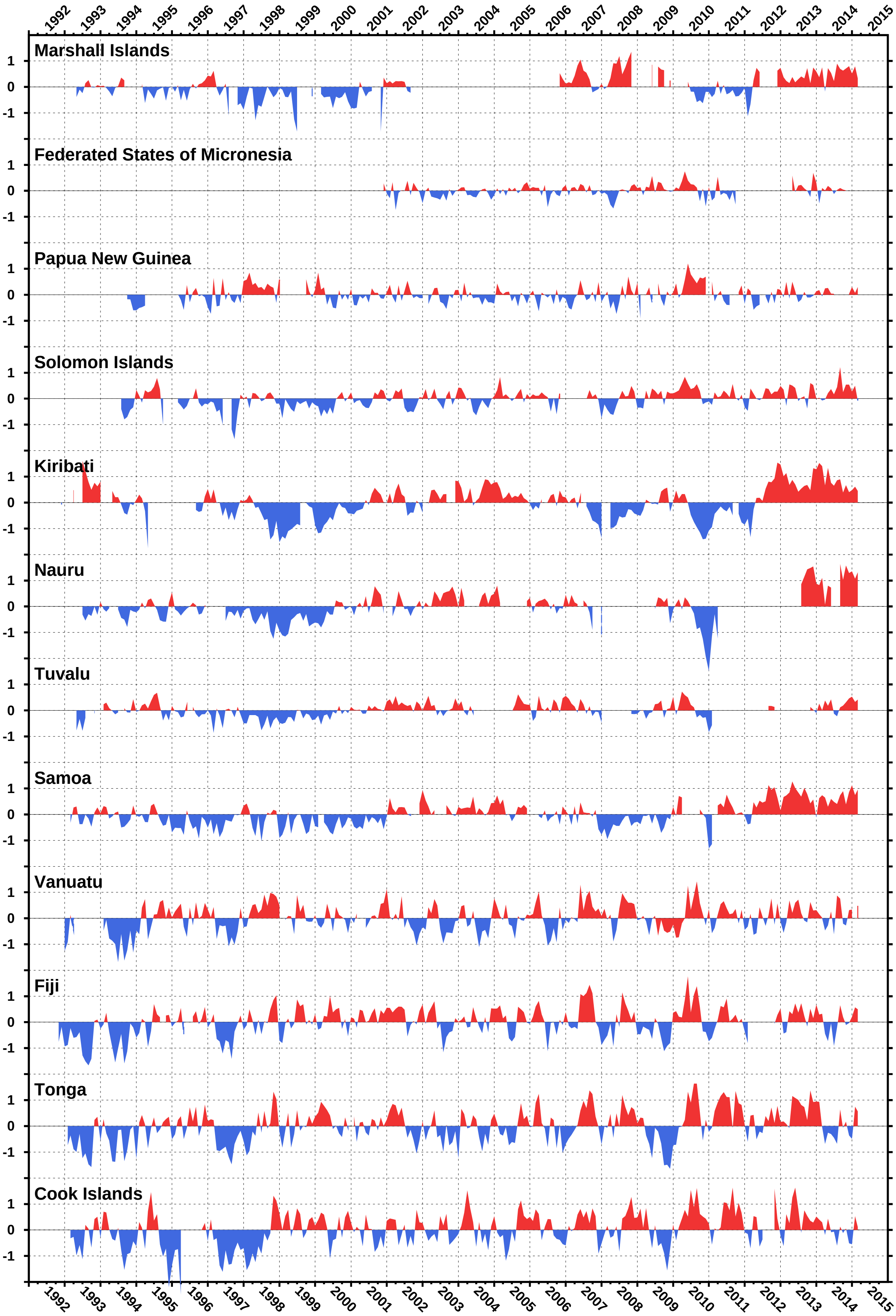

Figure 20. Monthly air temperature anomalies to March 2015.

MONTHLY SEA LEVEL DATA RETURN THROUGH MARCH 2015 (%)

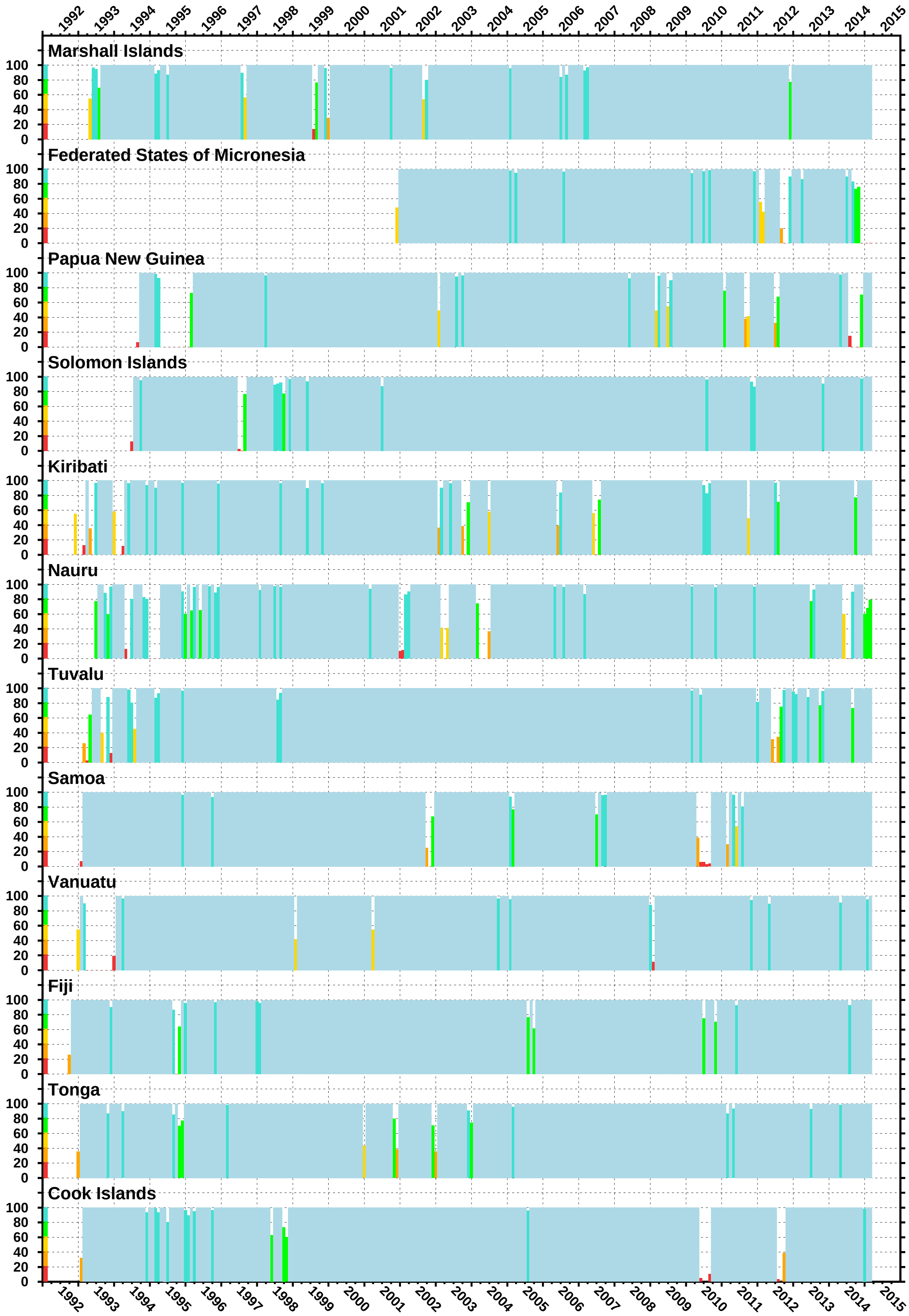

Figure 21. Sea level data return.