Climate and Oceans Support Program in the Pacific

Australian Government
Bureau of Meteorology

Monthly Data Report - December 2019

Pacific Sea Level and Geodetic Monitoring Project

Australian Government
Bureau of Meteorology

Published by Bureau of Meteorology

Table of Contents

List of Tables

List of Figures

Executive Summary

This summary, and the overview that follows, is 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.

December 2019

- 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 returned from the network during December was 99.7%.
- The station at Kiribati received a scheduled calibration and maintenance service, at which time the primary sensor was raised to enable it to better monitor astronomical king tides and extreme events.
- Tropical Cyclone Sarai brought strong winds, low barometric pressure and surging seas to Fiji, Tonga and Niue. Heavy rainfall and flooding in Fiji caused two deaths and more than 2000 people to evacuate their homes.
- Monthly mean sea levels were +9 cm higher than normal at Kiribati, but -9 cm lower than normal at FSM and Niue.
- Monthly mean barometric pressures were near normal for this time of year.
- Monthly mean air and water temperatures were warmer than normal at many sites, particularly Marshall Islands, Kiribati, Nauru and Tonga.

Introduction

Welcome to the December 2019 Monthly Data Report for the Pacific Sea Level and Geodetic Monitoring Project (PSLGMP). The report details the month by month operation of the SEAFRAME sea level 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 PSLGMP 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 13 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.

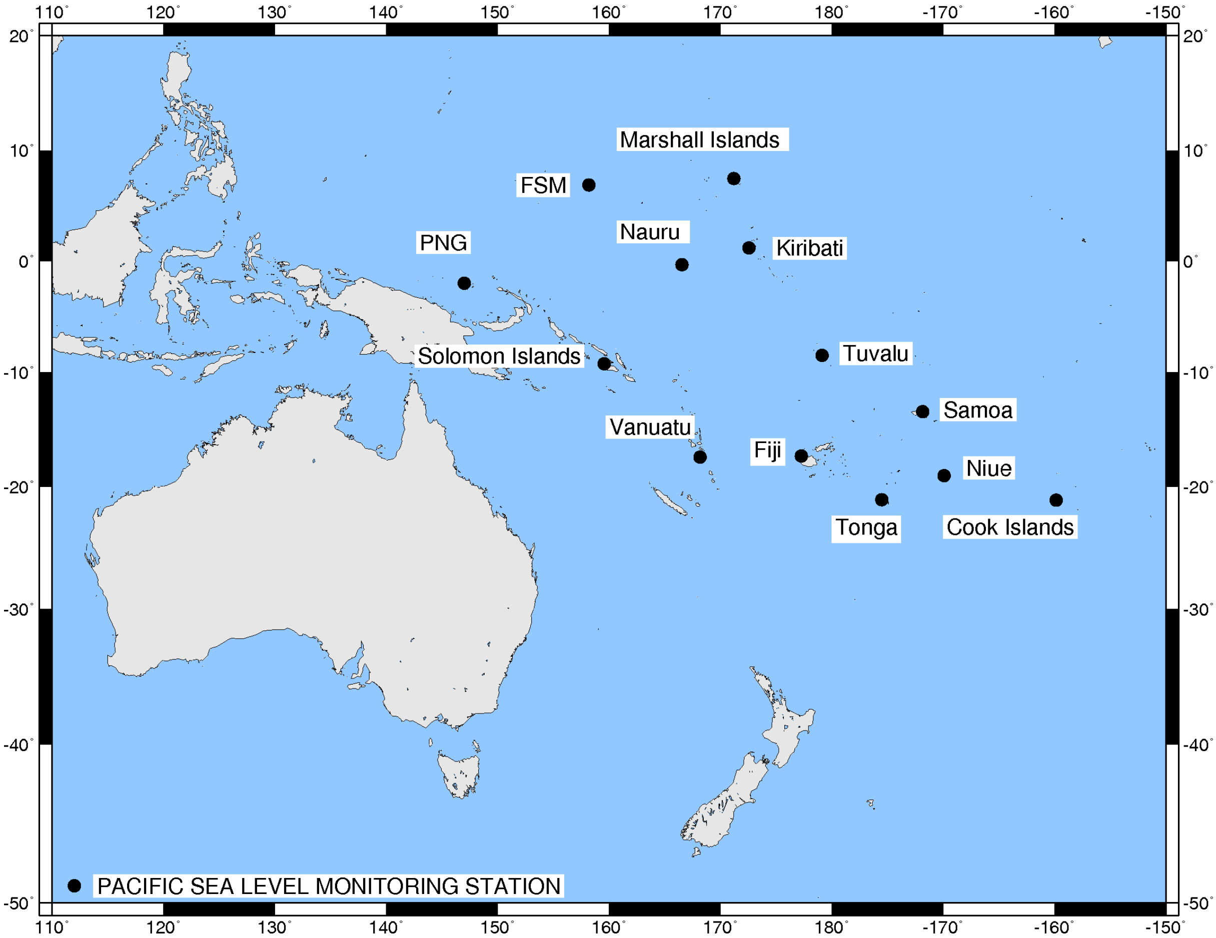


Figure 1. Network of SEAFRAME sea level monitoring stations in the Pacific.

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 Oceans Support Program in the Pacific (COSPPac) at http://cosppac.bom.gov.au/.

December 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 new and full moons. A full moon fell on the 12th of December while a new moon fell on the 26th of December.

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.

Tropical Cyclone Sarai passed through the region from the 23rd of December to the 2nd of January and its effects were observed at Fiji, Tonga and Niue. Sea levels surged to 0.4 m above predicted astronomical tides at Fiji and Tonga, and 0.8 m at Niue. Peaking as a category 2 cyclone, it brought damaging winds, heavy rainfall and flooding to Fiji where two people died from the floodwaters and more than 2,000 people were evacuated.

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 at certain stages of the tide or when the wind suddenly changes strength or direction, at FSM during smaller neap tides and at Nauru during strong westerly winds. A westerly wind burst at Nauru around the 23rd of December caused sea levels to surge by 0.4 m.

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). The effect is well demonstrated at Fiji and Tonga, where

the storm surges associated with Tropical Cyclone Sarai are smaller when corrected for barometric pressure.

The winds, temperatures and barometric pressures are plotted in Figure 6 through Figure 11. Wind gusts associated with Tropical Cyclone Sarai peaked at 27 m/s (97 km/h) at Fiji, 25 m/s (90 km/h) at Tonga and 20 m/s (72 km/h) at Niue (Figure 7). 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 Cook Islands prevailed from the south-southeast for most of the month.

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 sometimes observed that 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. With regards to Tropical Cyclone Sarai, barometric pressure fell to 995.8 hPa at Fiji, 987.0 hPa at Tonga and 994.9 hPa at Niue.

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 and Geodetic Monitoring Project data, which have been collected since October 1992 when the first station was installed at Fiji. Two of the stations have shorter records than the rest of the network; Federated States of Micronesia (FSM) was installed in December 2001 and Niue was installed in August 2015.

A record-high December sea level of 1.936 m was observed at Niue, which exceeds the previous record by almost 30 cm. A record-high December air temperature of 32.6 ºC was observed at Marshall Islands. Record-low December water temperatures were observed at Federated States of Micronesia (27.9 ºC) and Niue (25.9 ºC). Record-high December barometric pressures were observed at Nauru (1013.5 hPa) and Cook Islands (1019.7 hPa), while a record-low December barometric pressure of 994.9 hPa was observed at Niue.

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 (Figure 13).

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.

Monthly mean sea levels for December 2019 were +9 cm higher than normal at Kiribati and +5 cm higher than normal at Nauru, while they were -9 cm lower than normal at FSM and Niue. Elsewhere, sea levels were near normal for this time of year (Figure 17).

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.

Higher than normal barometric pressures were observed at SEAFRAME stations during the 1997-1998 El Niño and to a lesser extent the 2015-2016 El Niño (Figure 18). Monthly barometric pressures during December 2019 were near normal across the network.

Monthly mean water temperatures during December were warmer than normal at Kiribati (by +0.9 ºC), Marshall Islands (+0.7 ºC), Tuvalu (+0.6 ºC) and Tonga (+0.5 ºC), while they were -0.7 ºC cooler than normal at Cook Islands (Figure 19).

Monthly mean air temperatures during December were warmer than normal at many stations, with the largest anomalies observed at Nauru (+0.9 ºC), Marshall Islands (+0.8 ºC), Tonga (+0.8 ºC), Kiribati (+0.7 ºC) and Vanuatu (+0.5 ºC) (Figure 20).

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 relative 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 now over 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 quality-controlled data available at individual stations. The rates are relative to the SEAFRAME sensor benchmark, whose movement relative to inland benchmarks is monitored by Geosciences Australia with assistance from the Pacific Community. Collaborative efforts are being made to investigate the vertical land motion, in order to provide corrections that are as rigorous as possible.

Please exercise caution in interpreting the overall rates of movement of sea level – the records are too short to be inferring long-term trends and have not been corrected for land movement or other parameters that may influence the reported rates.

Table 1. Updated overall rates of sea level movement based on SEAFRAME data from installation through December 2019.

Location	Latitude	Longitude	Date of first data	Rate[1] (mm/yr)	Change in rate from previous month (mm/yr)
Marshall Is.	7°6'21.7"N	171°22'22.1"E	May 1993	4.9	0.0
FSM	6°58'49.9"N	158°12'0.8"E	Dec 2001	5.2	-0.1
PNG	2°2'31.5"S	147°22'25.6"E	Sep 1994	5.3	0.0
Solomon Is.	9°25'44.1"S	159°57'19.3"E	Jul 1994	3.9	0.0
Kiribati	1°21'54.2"N	172°55'58.8"E	Dec 1992	4.5	+0.1
Nauru	0°31'45.9"S	166°54'36.2"E	Jul 1993	5.6	0.0
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	9.6	0.0
Vanuatu	17°45'19.2"S	168°18'27.7"E	Jan 1993	0.4	0.0
Fiji	17°36'17.7"S	177°26'17.7"E	Oct 1992	3.6	0.0
Tonga	21°8'12.5"S	175°10'50.5"W	Jan 1993	6.6	0.0
Cook Is	21°12'17.1"S	159°47'5.2"W	Feb 1993	3.9	0.0
Niue	19°3'9.7"S	169°55'15.2"W	Aug 2015	1.3	-1.8

[1]Relative to SSBM (SEAFRAME Sensor Bench Mark)

Instrument Performance

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

Sea level data return from the network was 99.7% during December 2019 and 96.6% overall since the start of the project (Table 2).

The station at Kiribati received a scheduled calibration and maintenance service, at which time the primary sensor was raised 50 cm to enable it to better monitor astronomical king tides and extreme events.

With regards to the ancillary meteorological and oceanographic sensors, the water temperature sensors at Nauru and PNG remained faulty while those at Kiribati and Cook Islands were returned to service. The barometric pressure sensor at Tuvalu also remains faulty.

Table 2. Rates of sea level data return.

Location	Installation Date	Data Return Since Installation (%)	Data Return in December 2019 (%)
Cook Is	Feb 1993	97.5	100
Tonga	Jan 1993	98.8	100
Fiji	Oct 1992	99.1	100
Vanuatu	Jan 1993	96.2	100
Samoa	Feb 1993	96.9	100
Tuvalu	Mar 1993	96.0	100
Kiribati	Dec 1992	95.7	98.6
Nauru	Jul 1993	92.5	100
Solomon Is.	Jul 1994	97.9	100
PNG	Sep 1994	92.6	97.5
FSM	Dec 2001	94.9	100
Marshall Is.	May 1993	98.6	100
Niue	Aug 2015	98.7	100
Network Average		**96.6**	**99.7**

SEAFRAME Stations

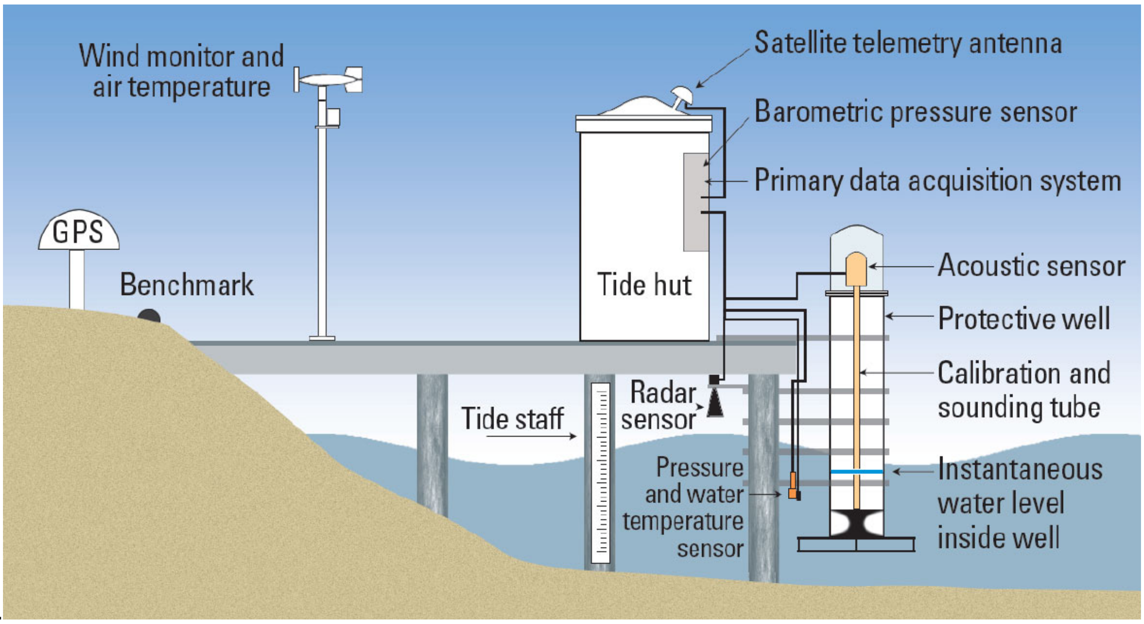
Standard SEAFRAME stations now employ a TELMET (previously SUTRON) programmable data logger, water level gauges and other sensors. The data logger and associated electronics are normally housed in fibreglass huts. A sketch of a typical SEAFRAME station is shown in Figure 2.

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.

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 was retrieved in February 2015. The data has been analysed for astronomical tides and the results will enable tide predictions to be issued into the future.

Data from a portable tide gauge deployed by the Pacific Community (SPC) at Vaitupu atoll, Tuvalu, from June 2015 to September 2015 has also been analysed and will similarly form the basis of tide calendars into the future.

Sea level data for Kanton (January 1972 to December 2017) and Kiritimati (January 1974 to December 2017) in Kiribati were downloaded from the University of Hawaii Sea Level Centre (UHSLC) and will be used for the basis of tide predictions at those locations, on request by the Pacific Community (SPC) who gained approval from UHSLC.

Further Information

Online Resources

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

PSLGMP Web site: http://www.bom.gov.au/pacific/projects/pslm/index.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

http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/pacificsealevel

Acknowledgement

The Monthly Data Report is prepared by the Bureau of Meteorology under the Pacific Sea Level and Geodetic Monitoring (PSLGM) Project, Climate and Oceans Support Program in the Pacific (COSPPac).

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

Bureau of Meteorology
Level 4, 431 King William Street
Adelaide SA 5000
Tel: +61 8 8366 2730
Email: tides@bom.gov.au
Website: http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml

Please also note the following:

Appendix 1: SEAFRAME Data Figures

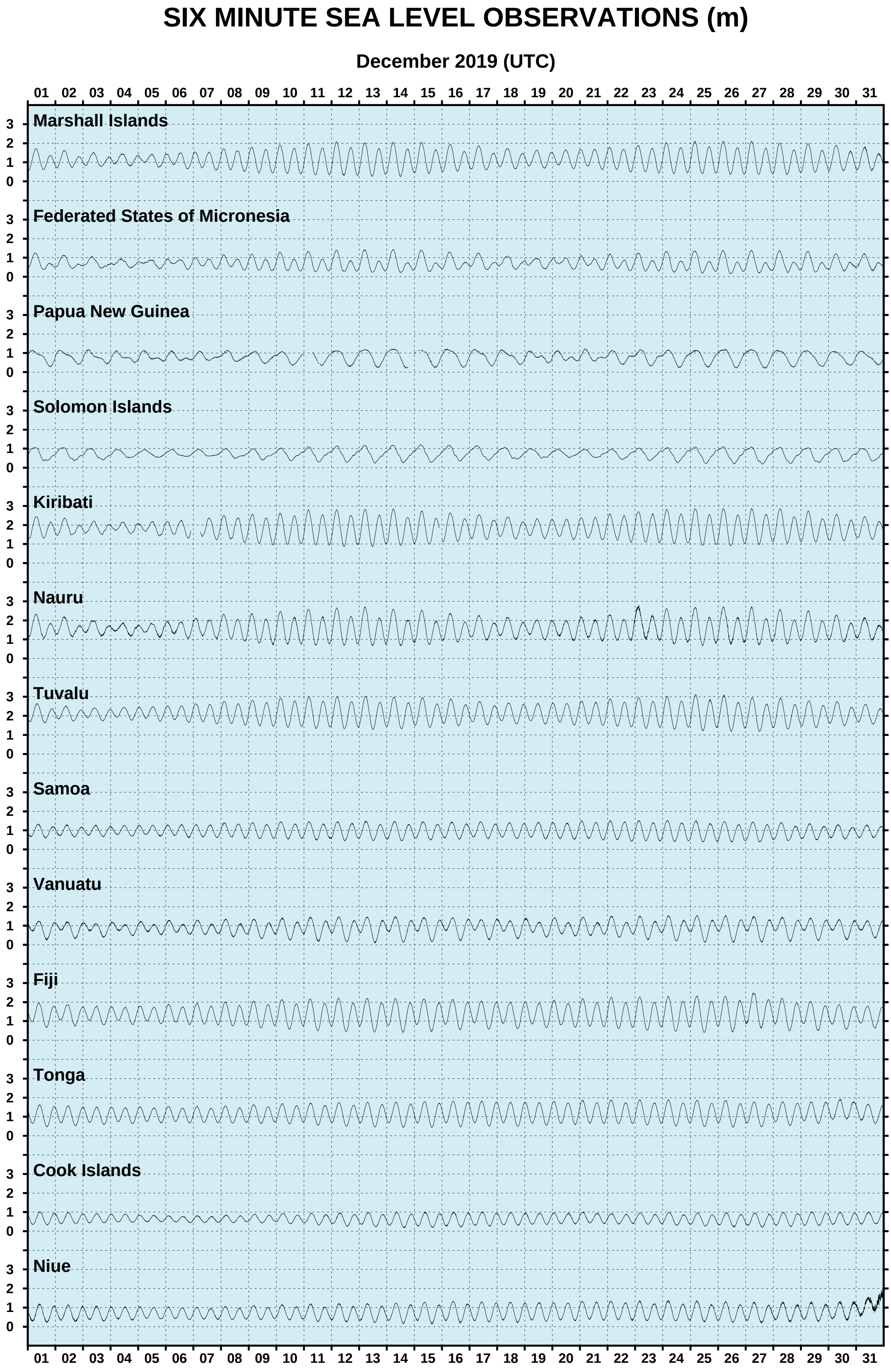


Figure 3. Sea level observations during December 2019.

SIX MINUTE RESIDUAL WATER LEVELS (m)

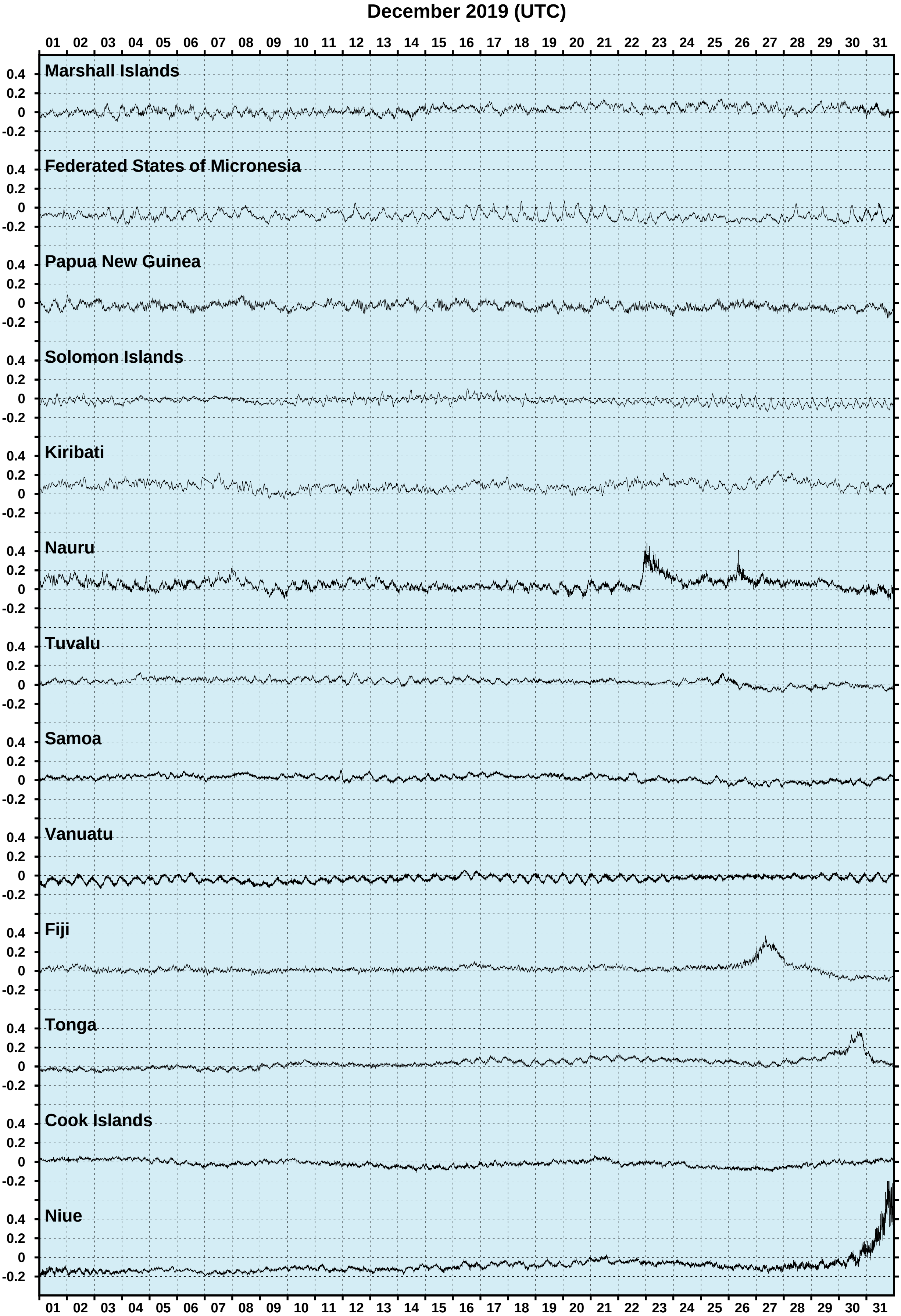


Figure 4. Residual sea levels during December 2019.

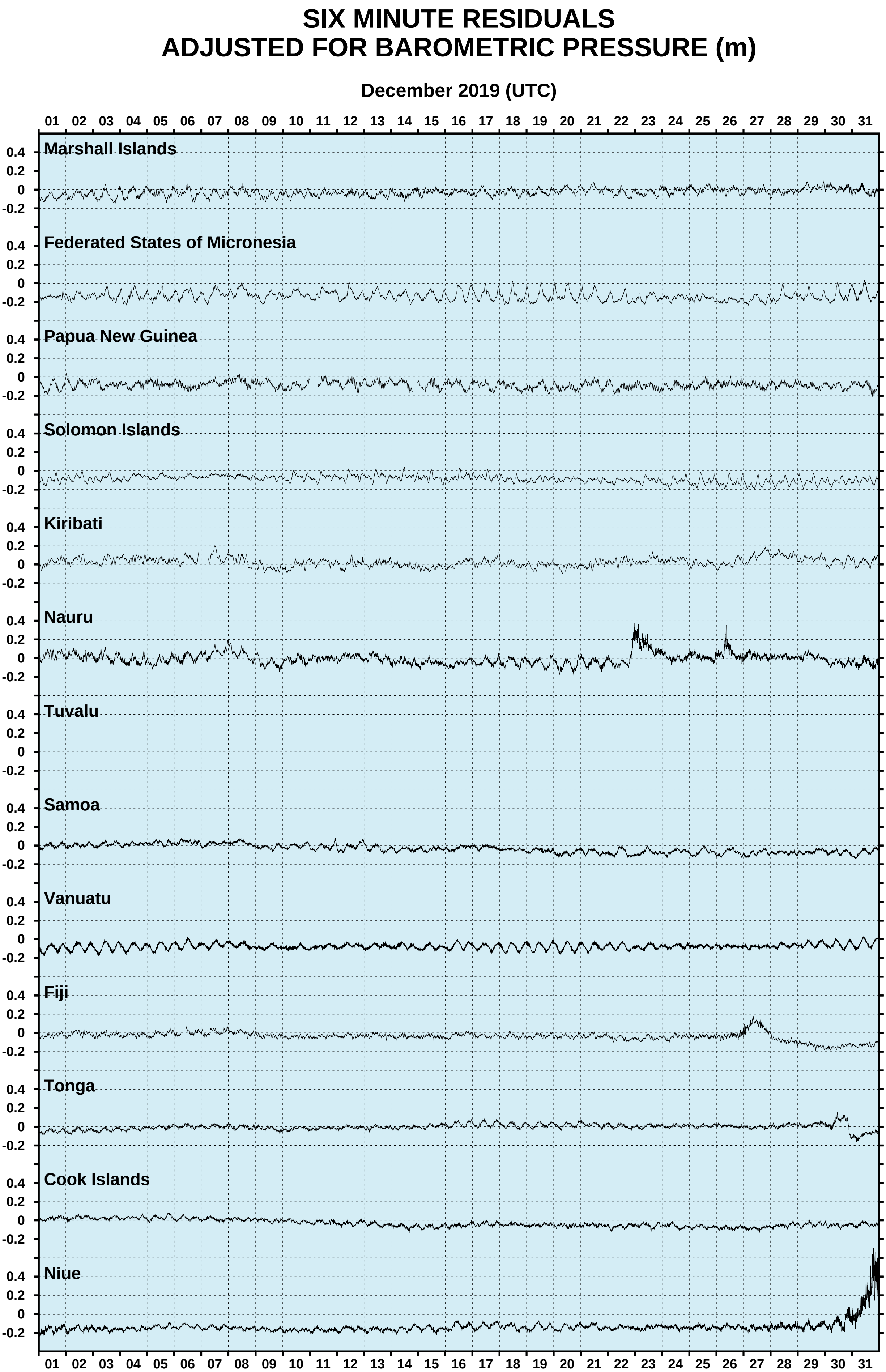


Figure 5. Residual sea levels adjusted for barometric pressure during December 2019.

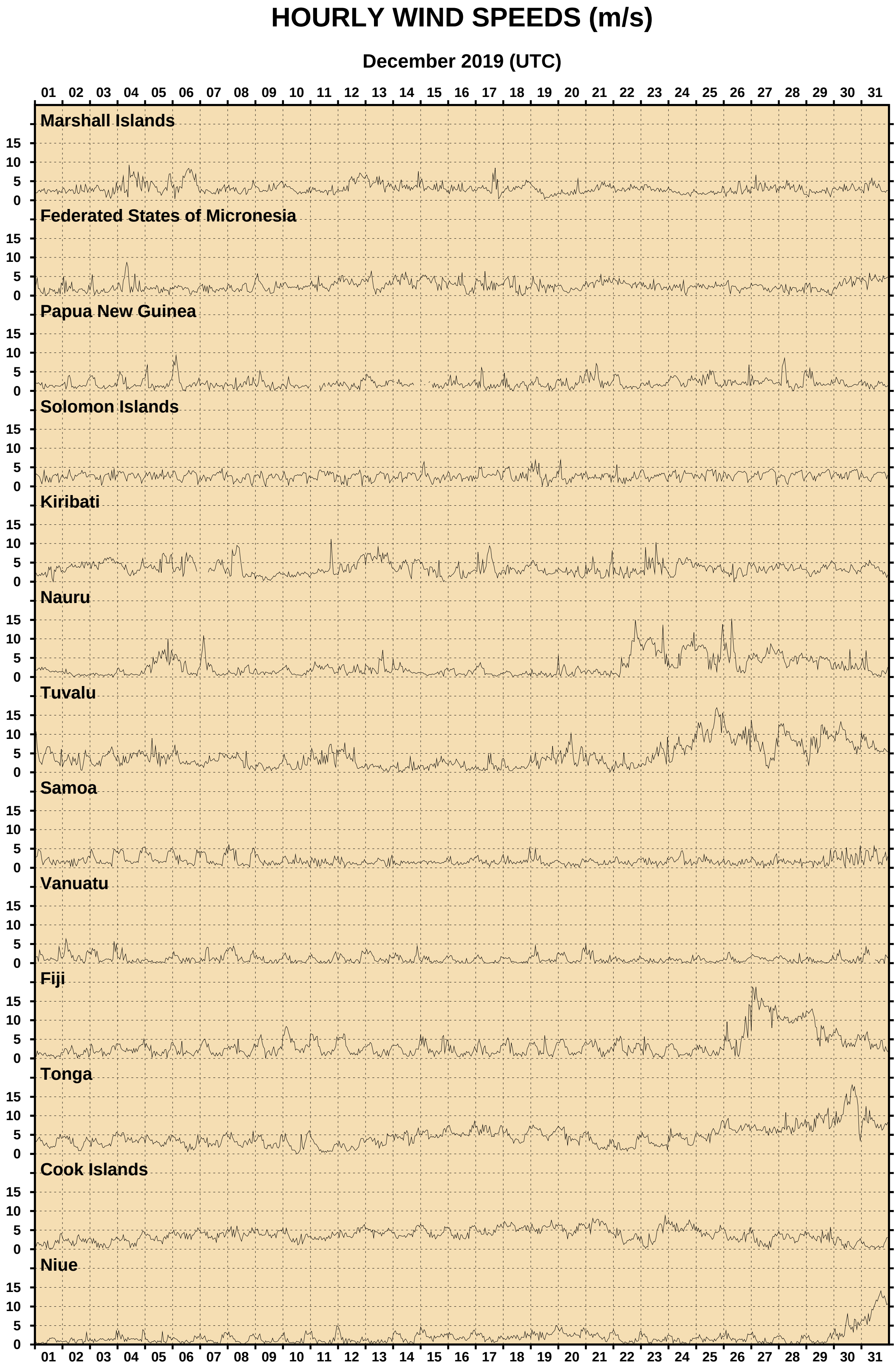


Figure 6. Wind speeds during December 2019.

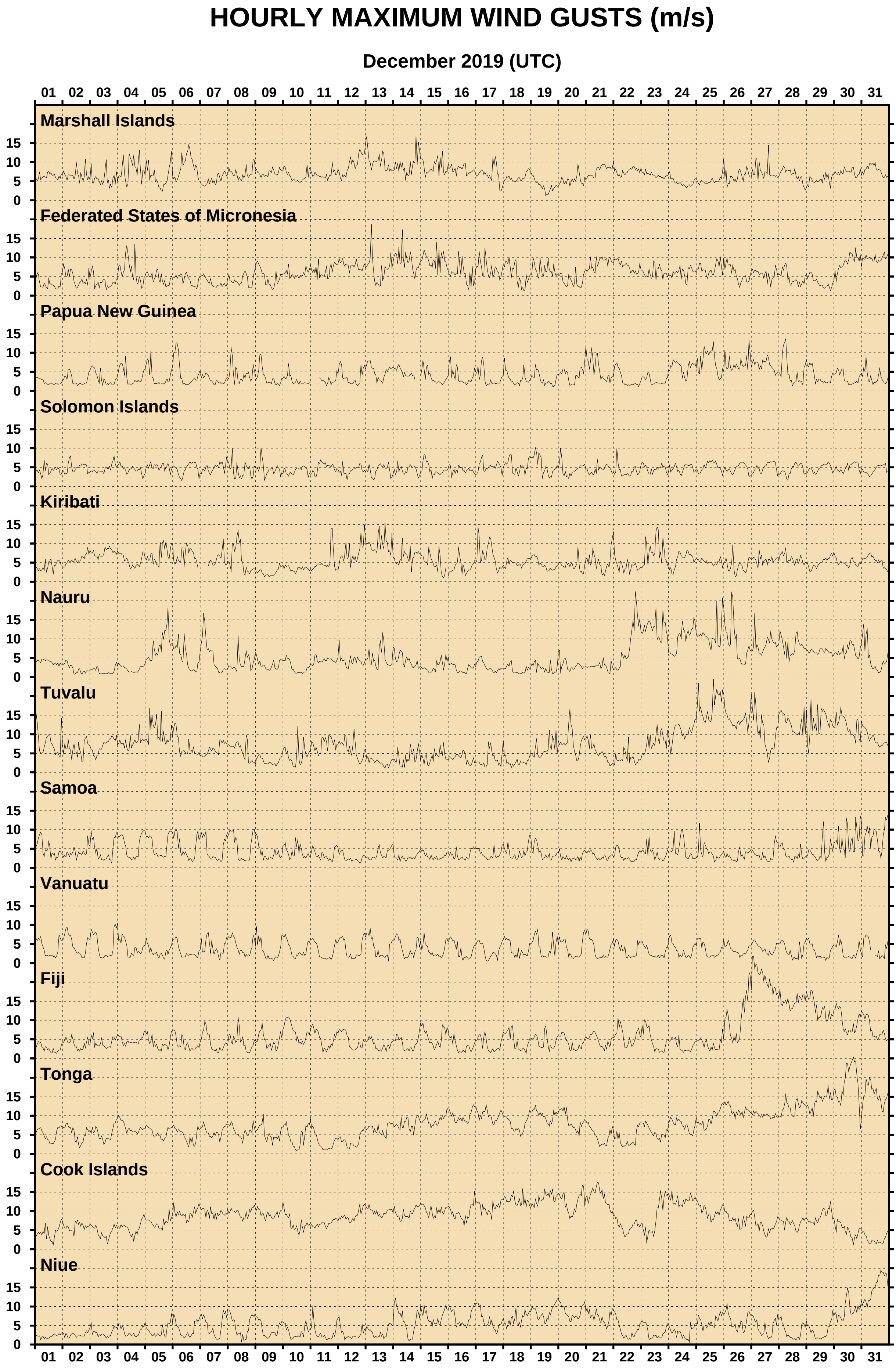


Figure 7. Wind gusts during December 2019.

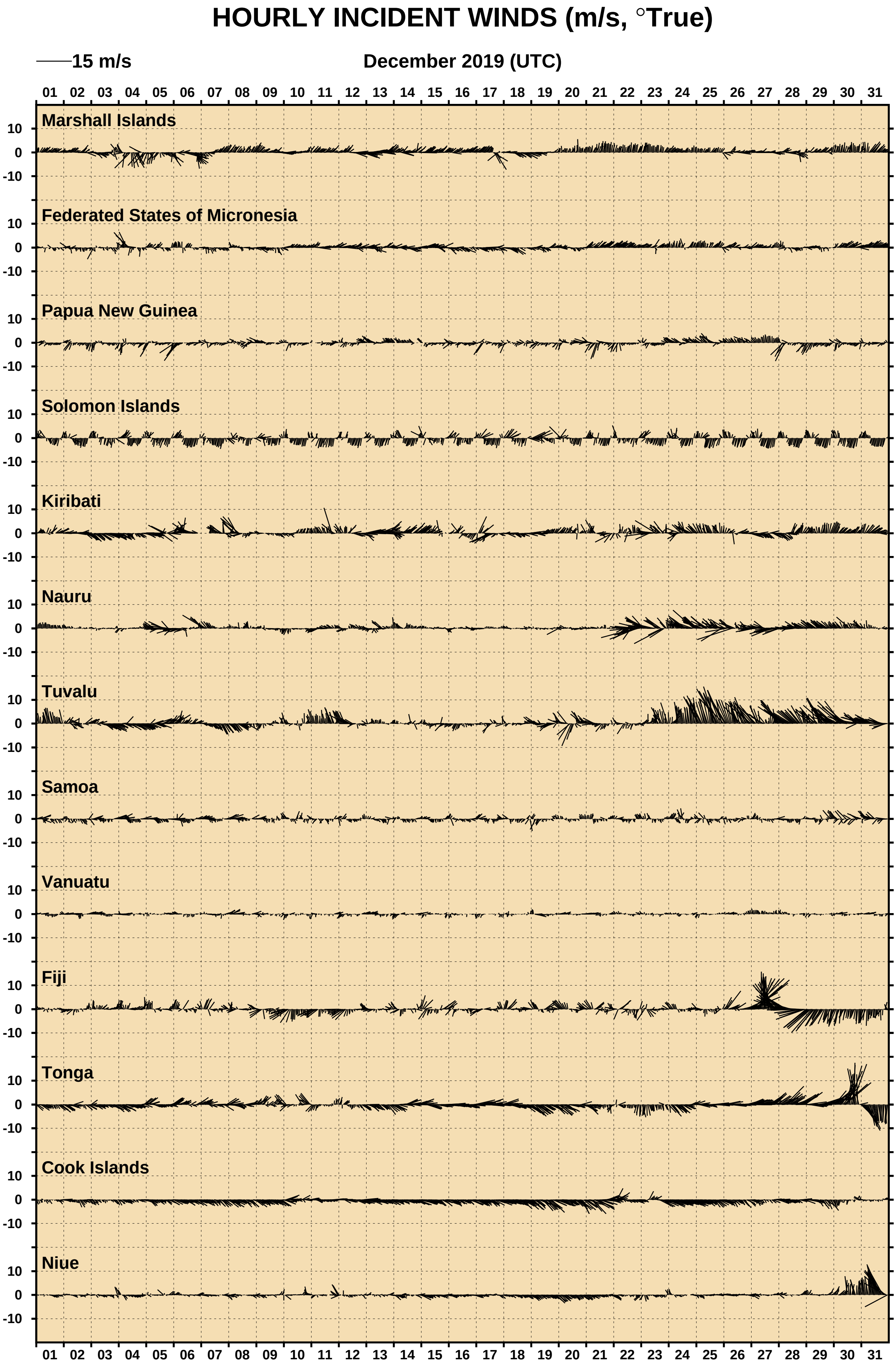


Figure 8. Incident winds during December 2019

HOURLY AIR TEMPERATURES (°C)

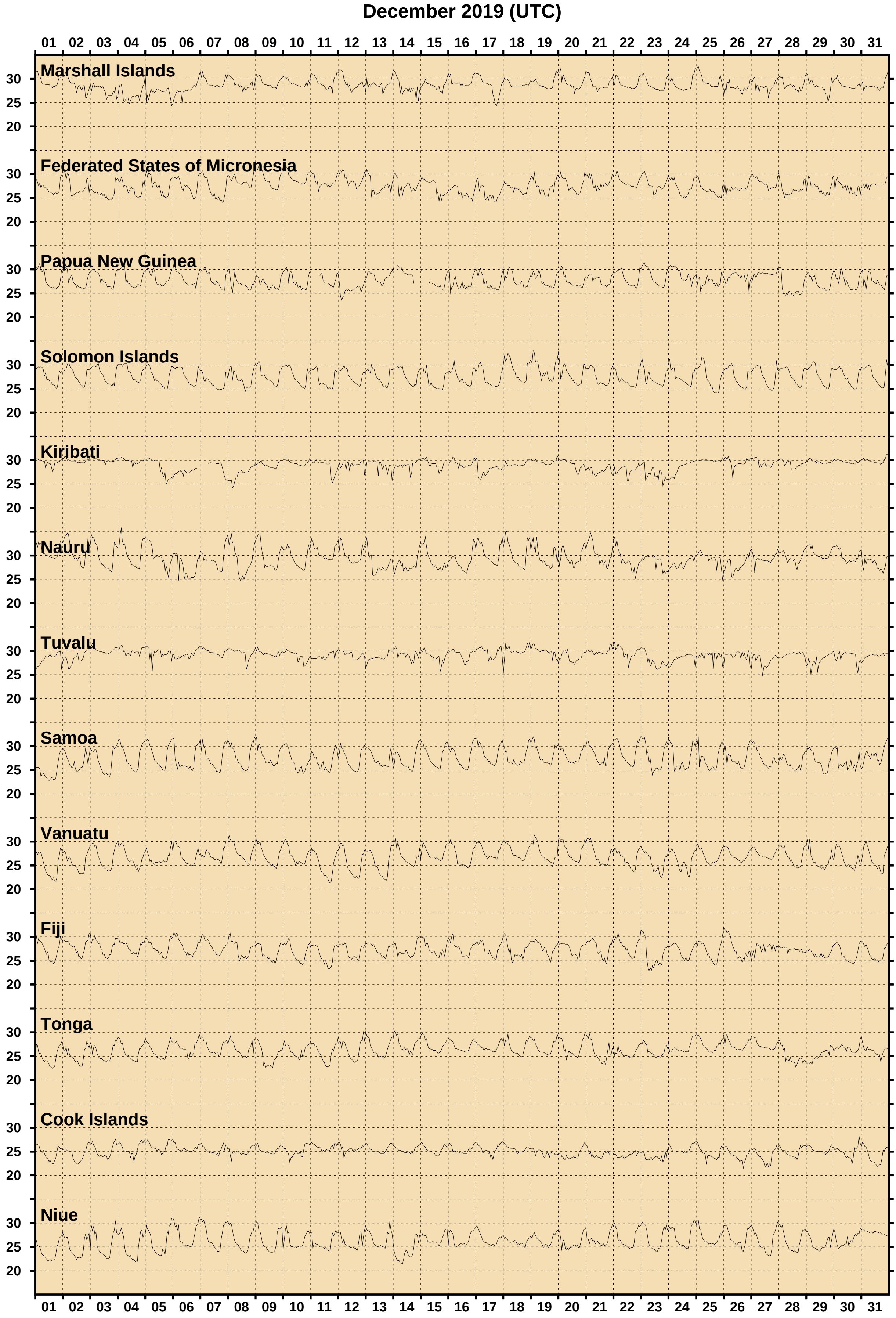


Figure 9. Air temperatures during December 2019.

HOURLY WATER TEMPERATURES (°C)

December 2019 (UTC)

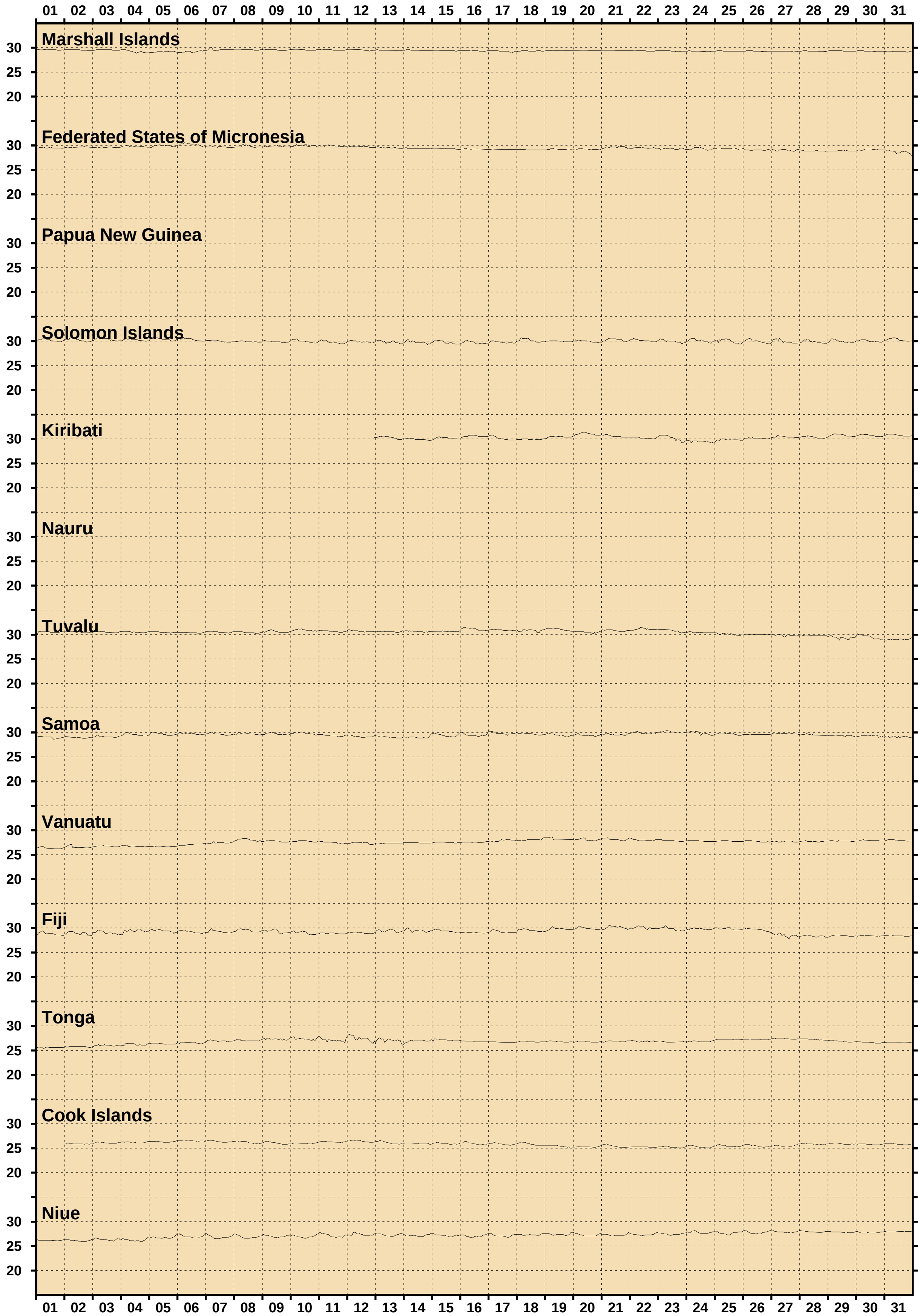


Figure 10. Water temperatures during December 2019.

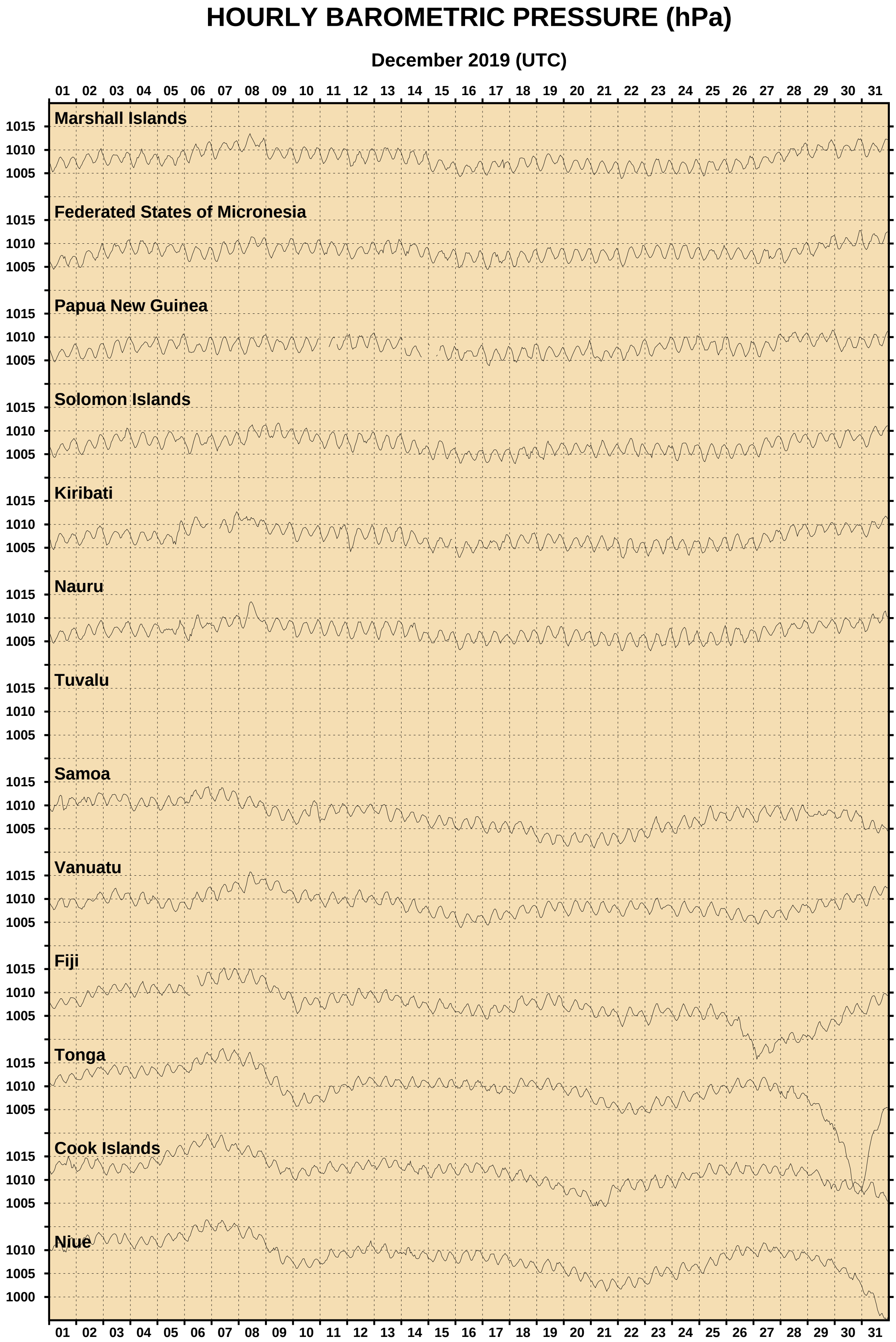


Figure 11. Barometric pressures during December 2019.

COMPARISON OF DECEMBER 2019 MAX,MIN AND MEAN WITH LONG-TERM DECEMBER VALUES

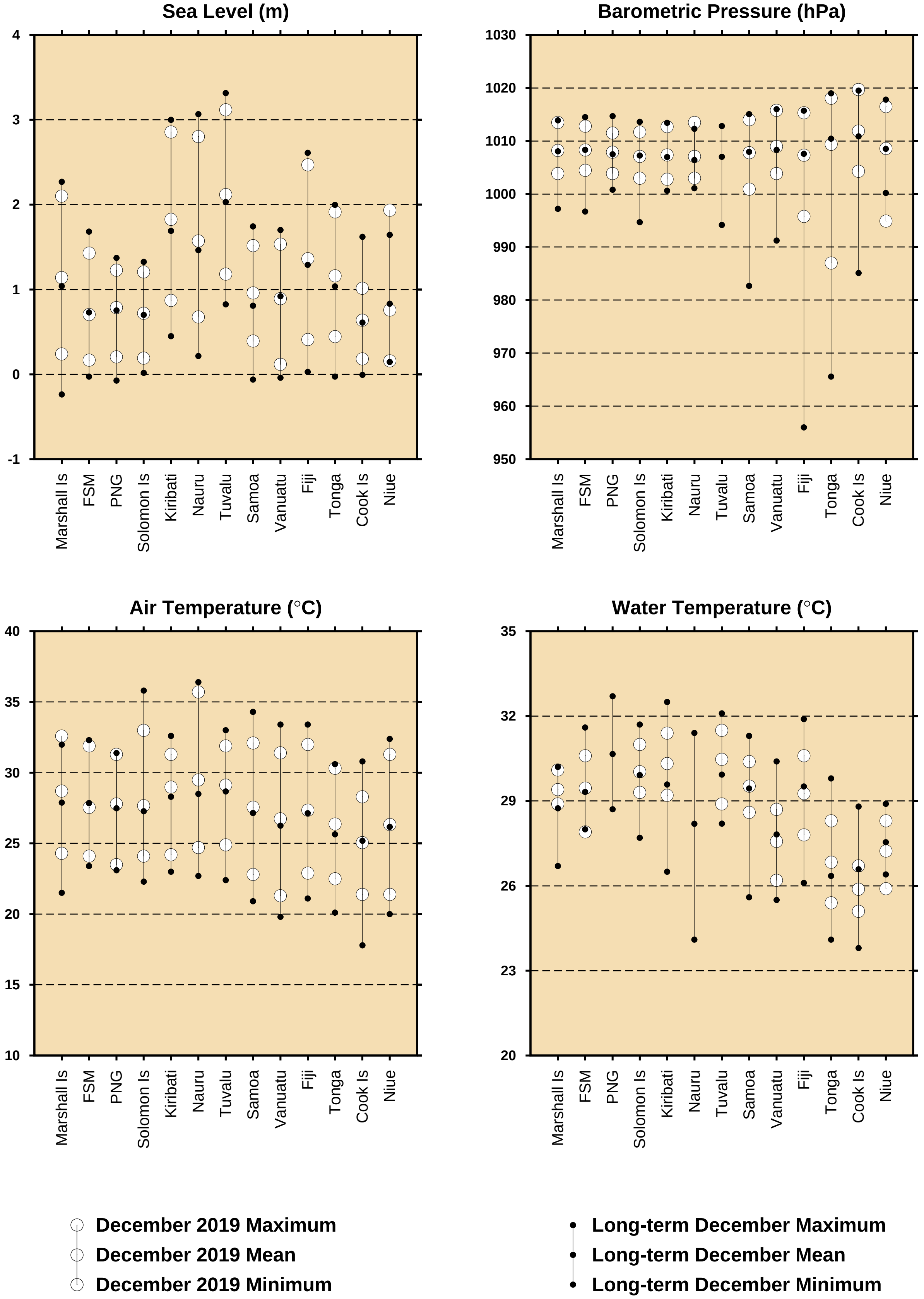


Figure 12. Comparison of December 2019 data with long term December values.

MONTHLY MEAN SEA LEVELS THROUGH DECEMBER 2019 (m)
(The zero line represents mean sea level)

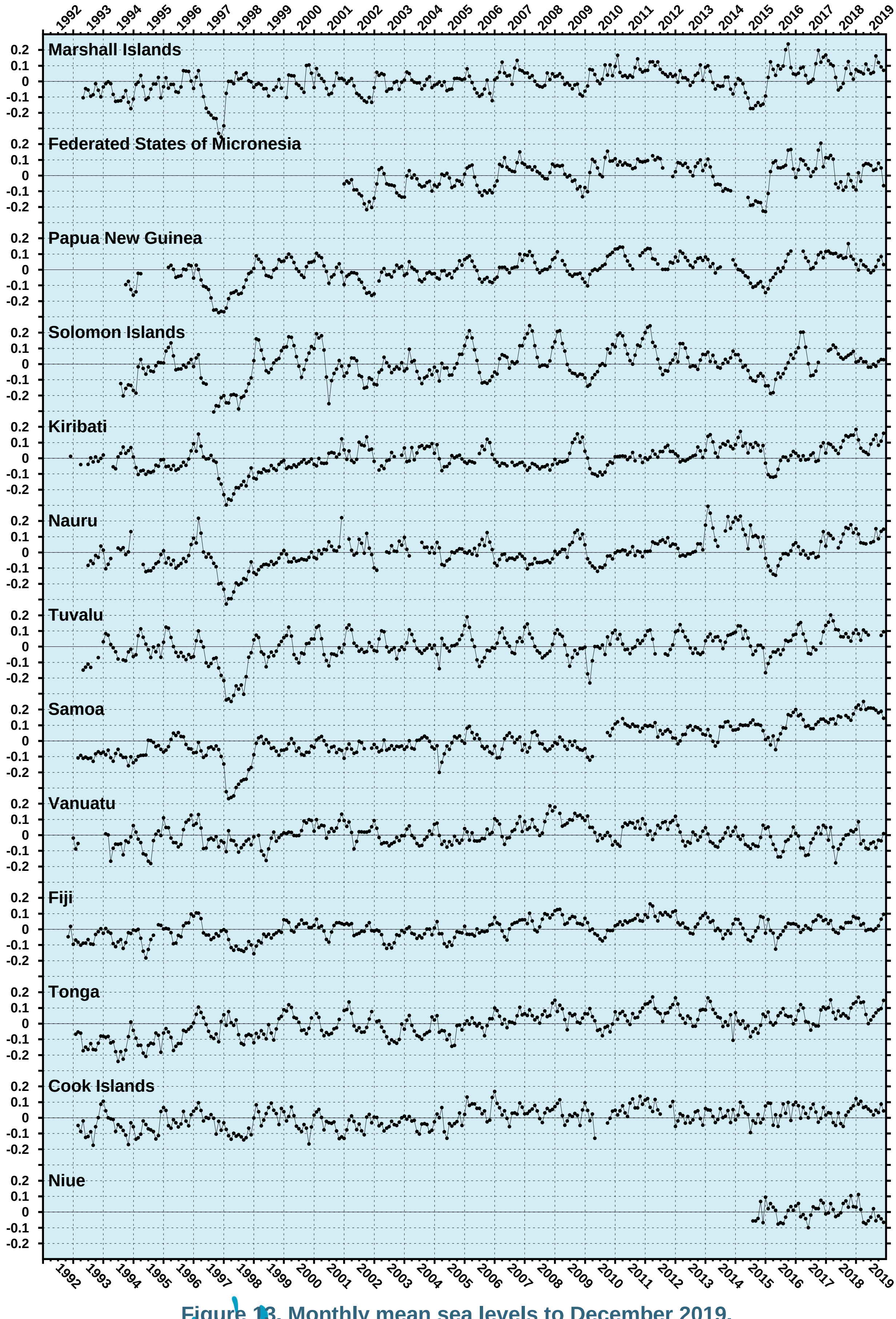


Figure 13. Monthly mean sea levels to December 2019.

MONTHLY MEAN BAROMETRIC PRESSURES THROUGH DECEMBER 2019 (hPa)

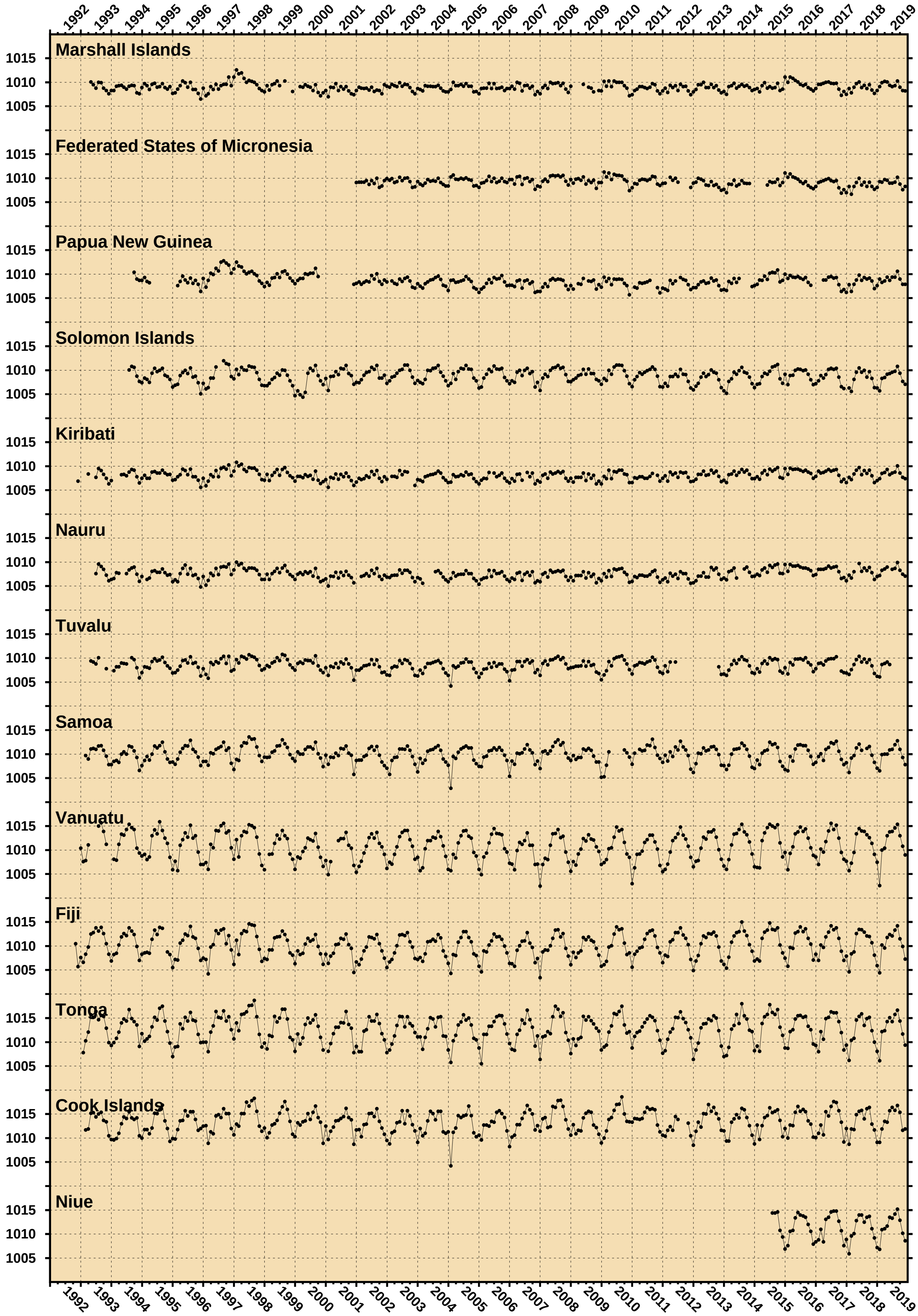


Figure 14. Monthly mean barometric pressures to December 2019.

MONTHLY MEAN WATER TEMPERATURES THROUGH DECEMBER 2019 (°C)

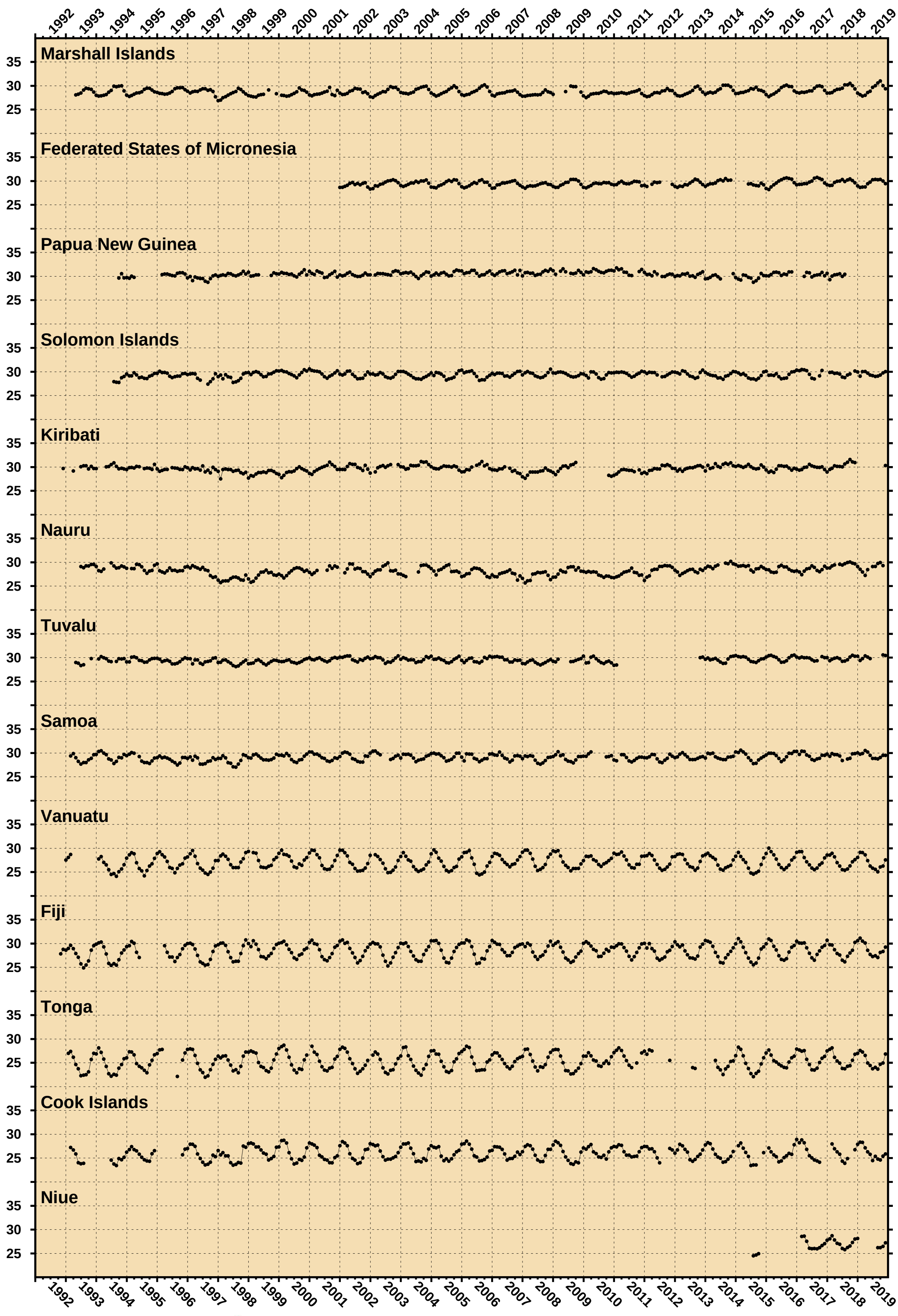


Figure 15. Monthly mean water temperatures to December 2019.

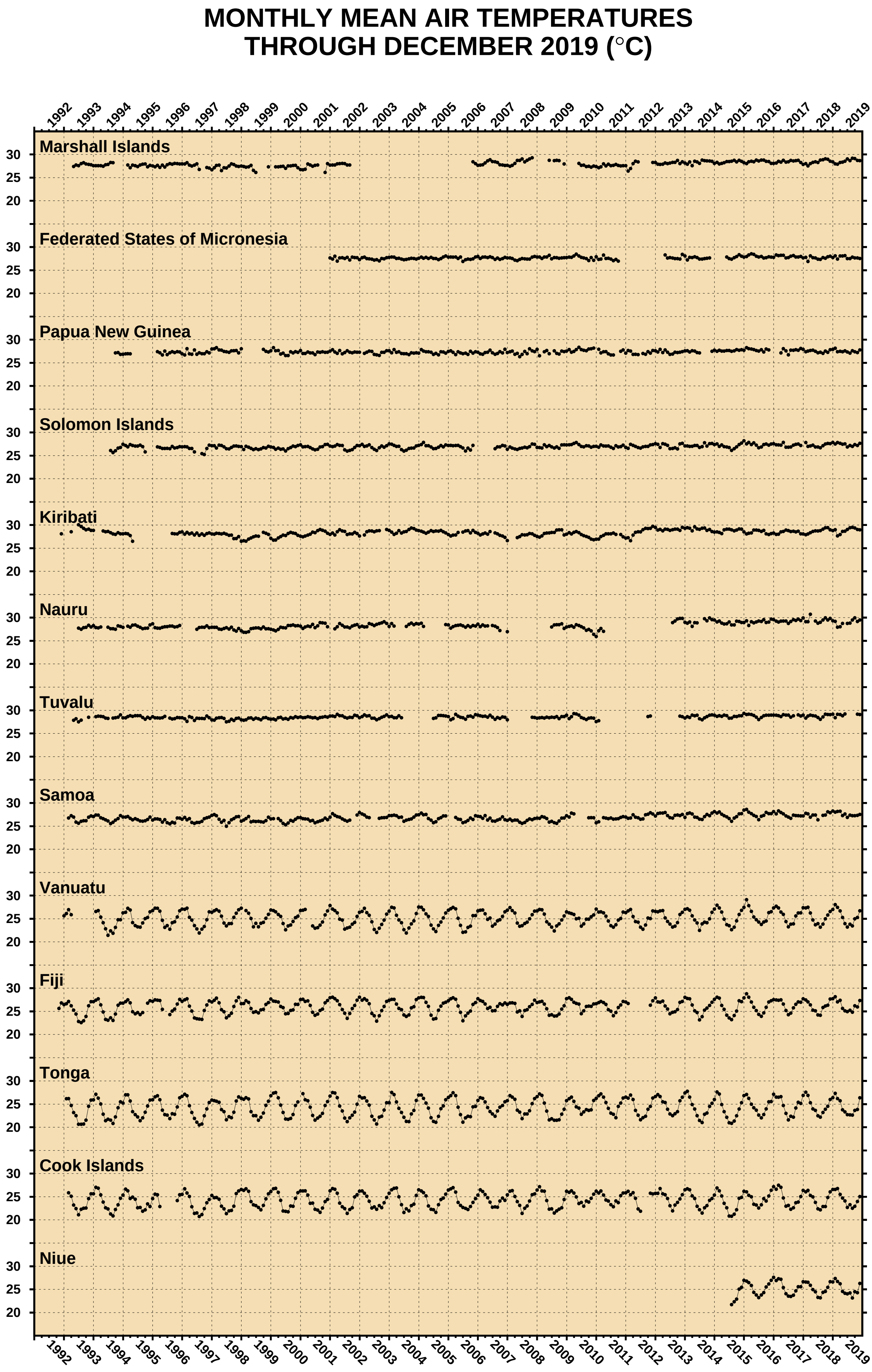


Figure 16. Monthly mean air temperatures to December 2019.

SEA LEVEL ANOMALIES THROUGH DECEMBER 2019 (m)

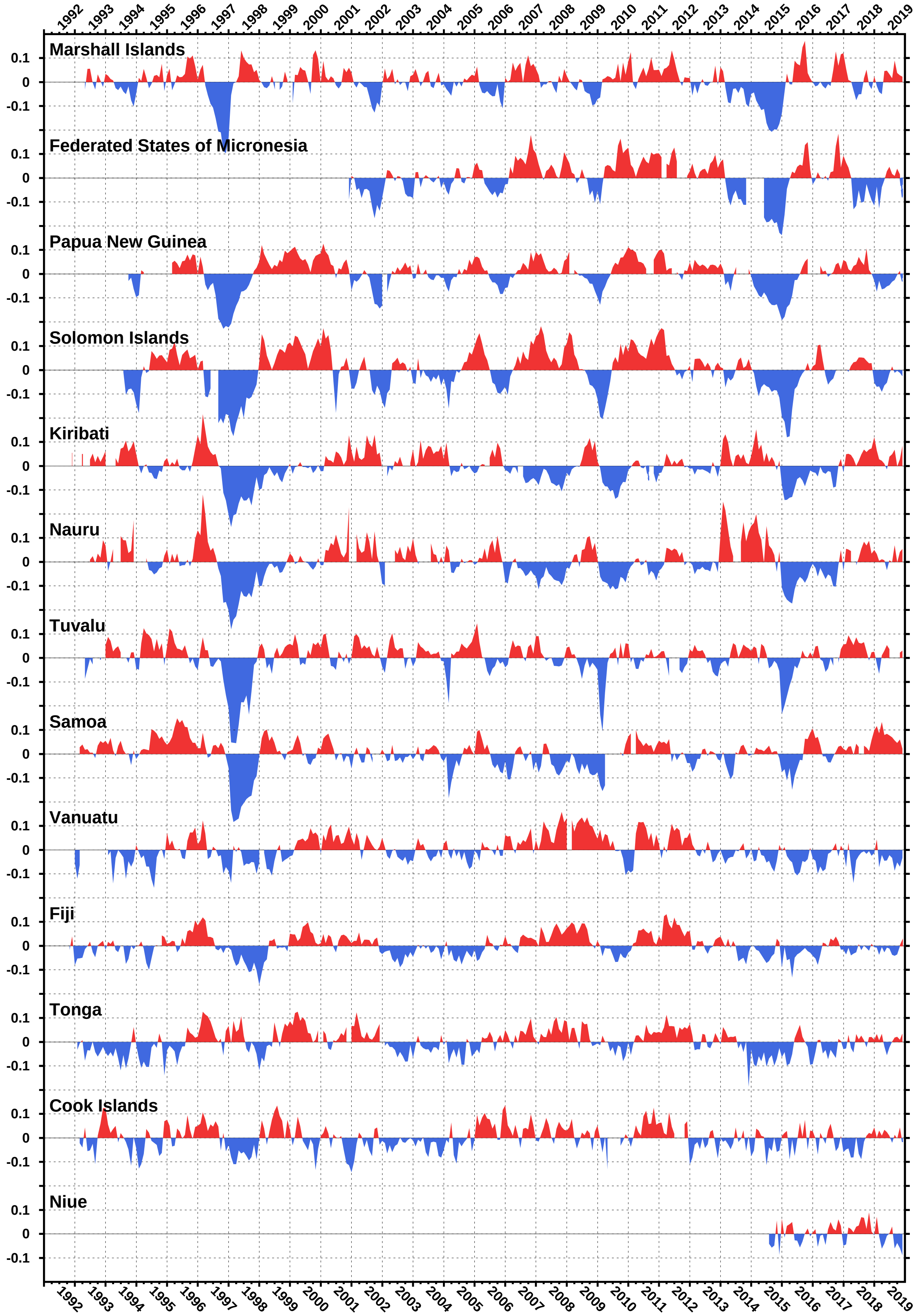


Figure 17. Monthly sea level anomalies to December 2019.

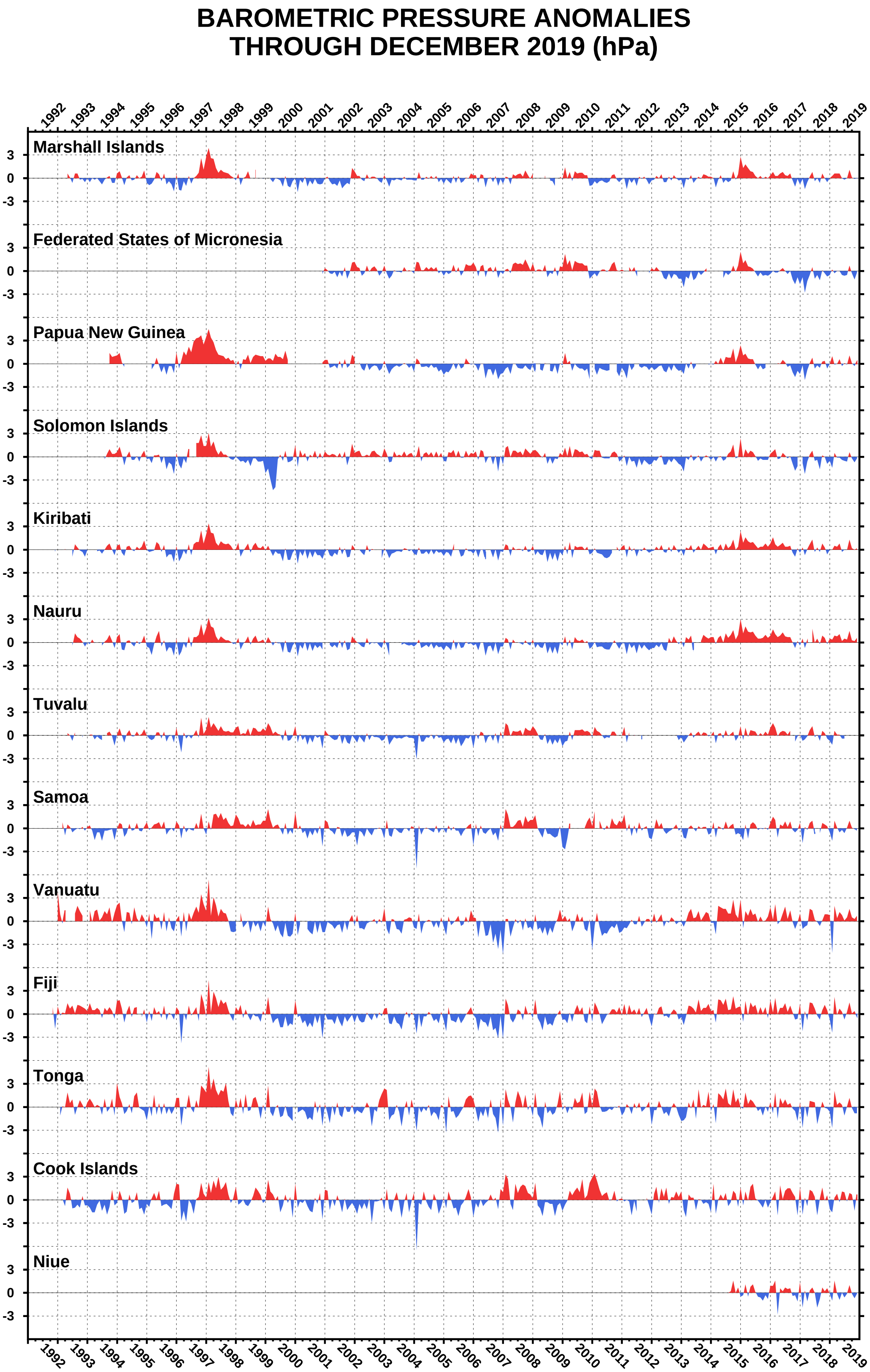


Figure 18. Monthly barometric pressure anomalies to December 2019.

WATER TEMPERATURE ANOMALIES THROUGH DECEMBER 2019 (°C)

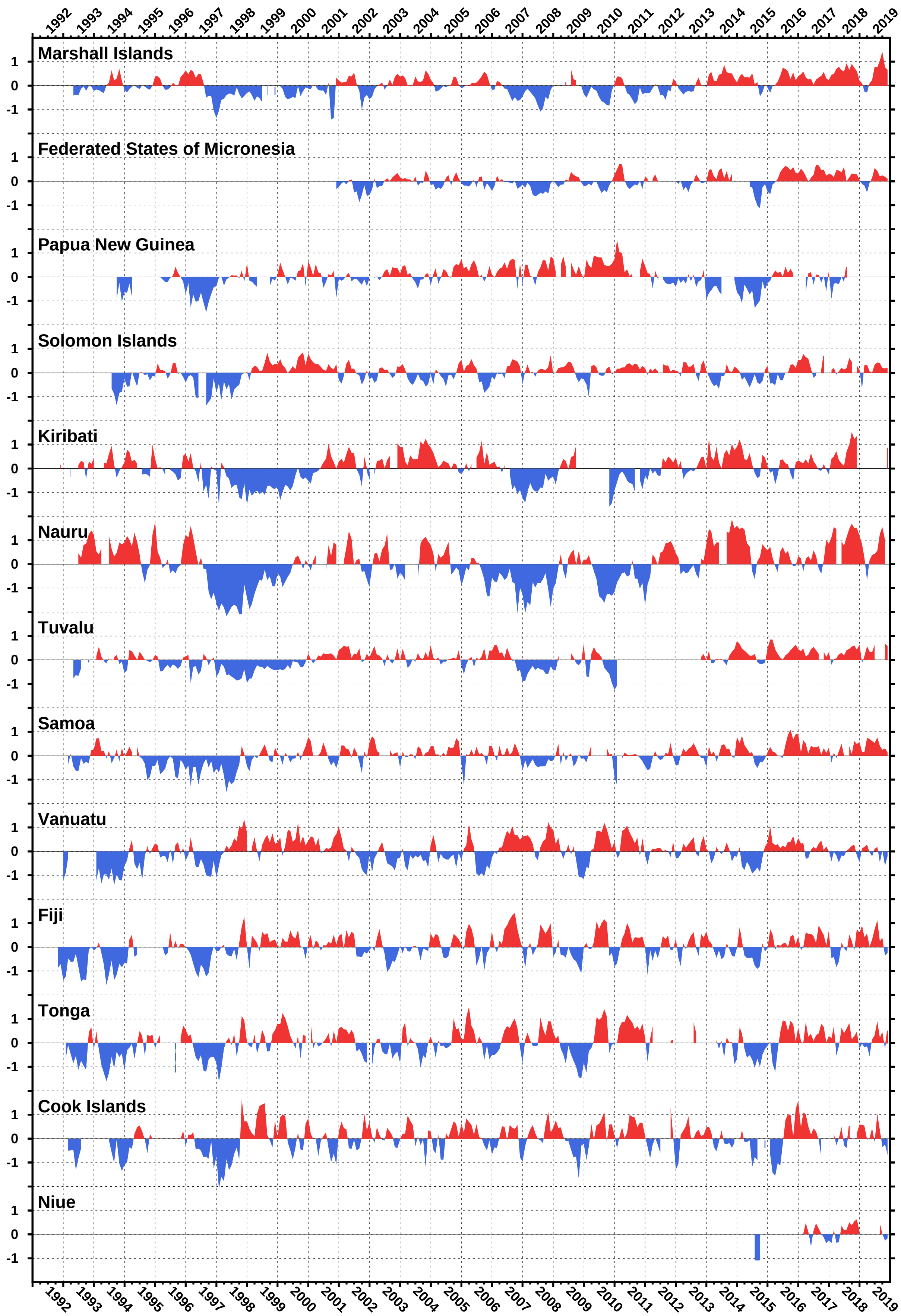


Figure 19. Monthly water temperature anomalies to December 2019.

AIR TEMPERATURE ANOMALIES
THROUGH DECEMBER 2019 (°C)

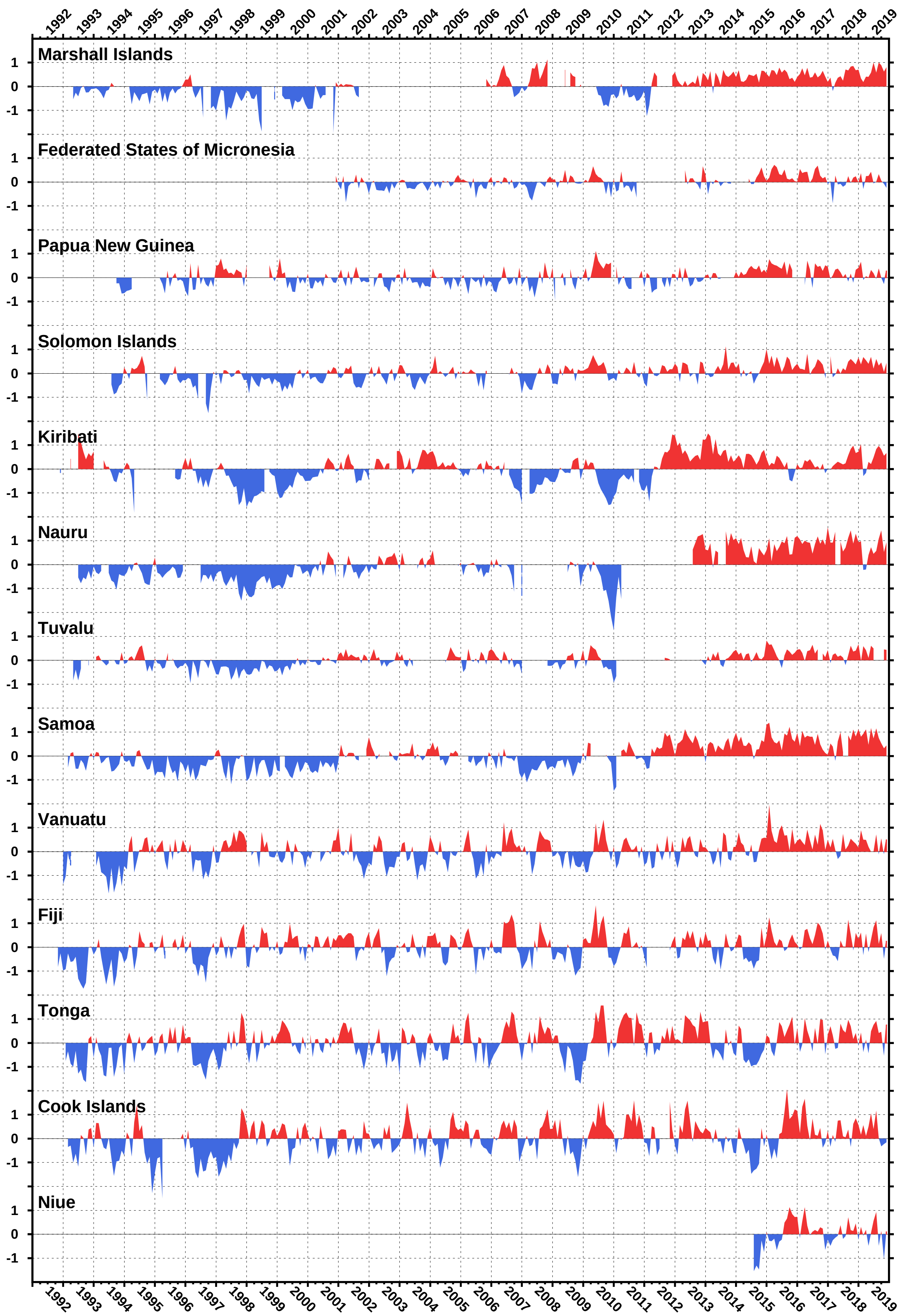


Figure 20. Monthly air temperature anomalies to December 2019.

MONTHLY SEA LEVEL DATA RETURN THROUGH DECEMBER 2019 (%)

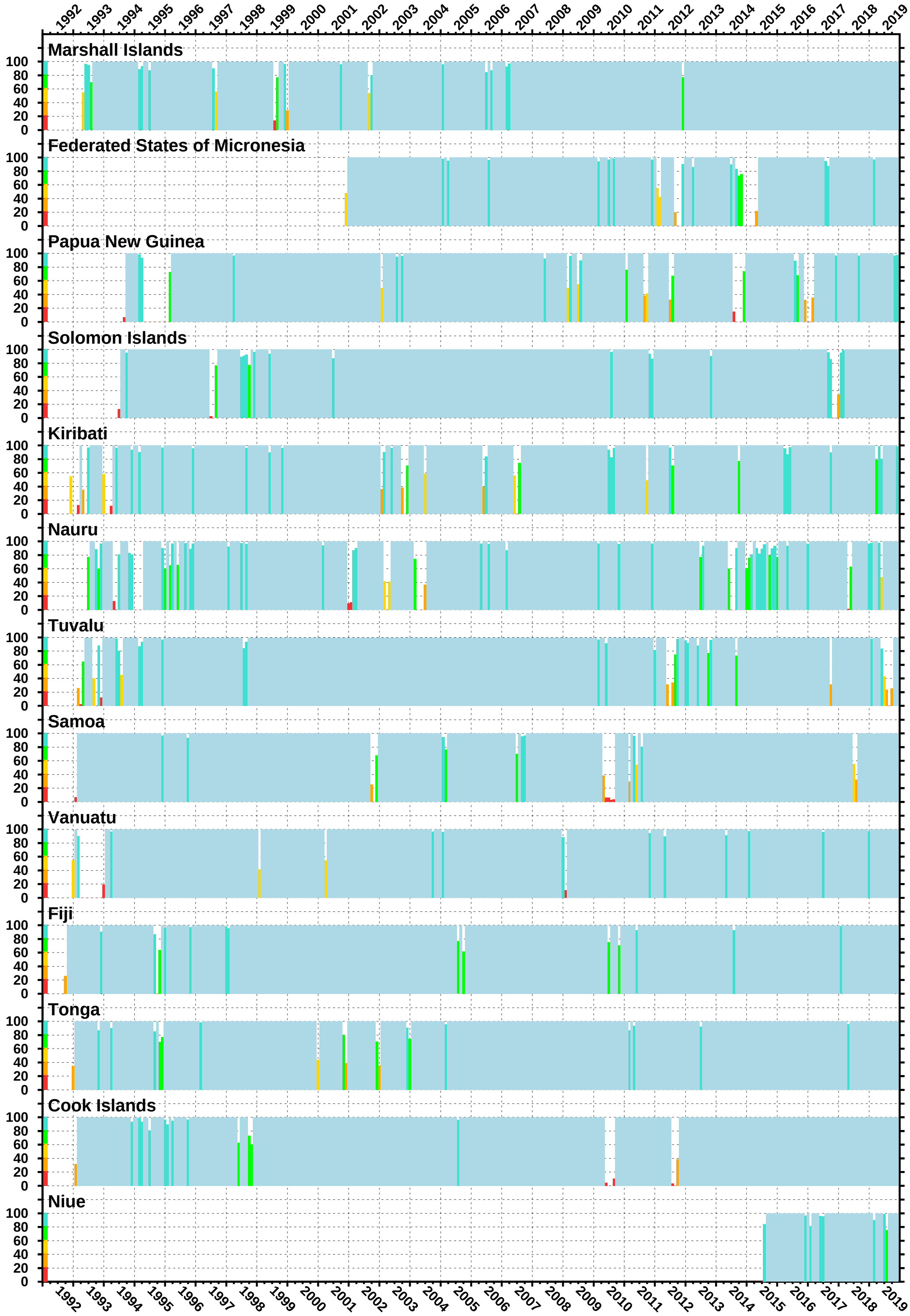


Figure 21. Sea level data return.