Australian Government
Bureau of Meteorology

Monthly Data Report

Pacific Sea Level and Geodetic Monitoring Project

April 2025

COSPPac
Climate and Oceans Support Program in the Pacific

Release history

Date	Version
5 June 2025	1.0

Published by The Bureau of Meteorology

Cover image: Kiribati Tide Station on Betio Wharf, Jeff Aquilina, October 2014

Acknowledgements

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).

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1. 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.

April 2025

- 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 April was 99.3%.
- An all-time record-high sea level was observed at Solomon Islands, while record-high April sea levels were observed at PNG, Vanuatu and Niue.
- Monthly sea levels were 20 cm higher than expected at Vanuatu and over 5 cm higher than expected at Solomon Islands, PNG and Samoa. However, they were 5 cm lower than expected at Nauru, Fiji and Tonga.

2. Introduction

Welcome to the April 2025 Monthly Data Report for the Pacific Sea Level and Geodetic Monitoring (PSLGM) project. 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 PSLGM project 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.

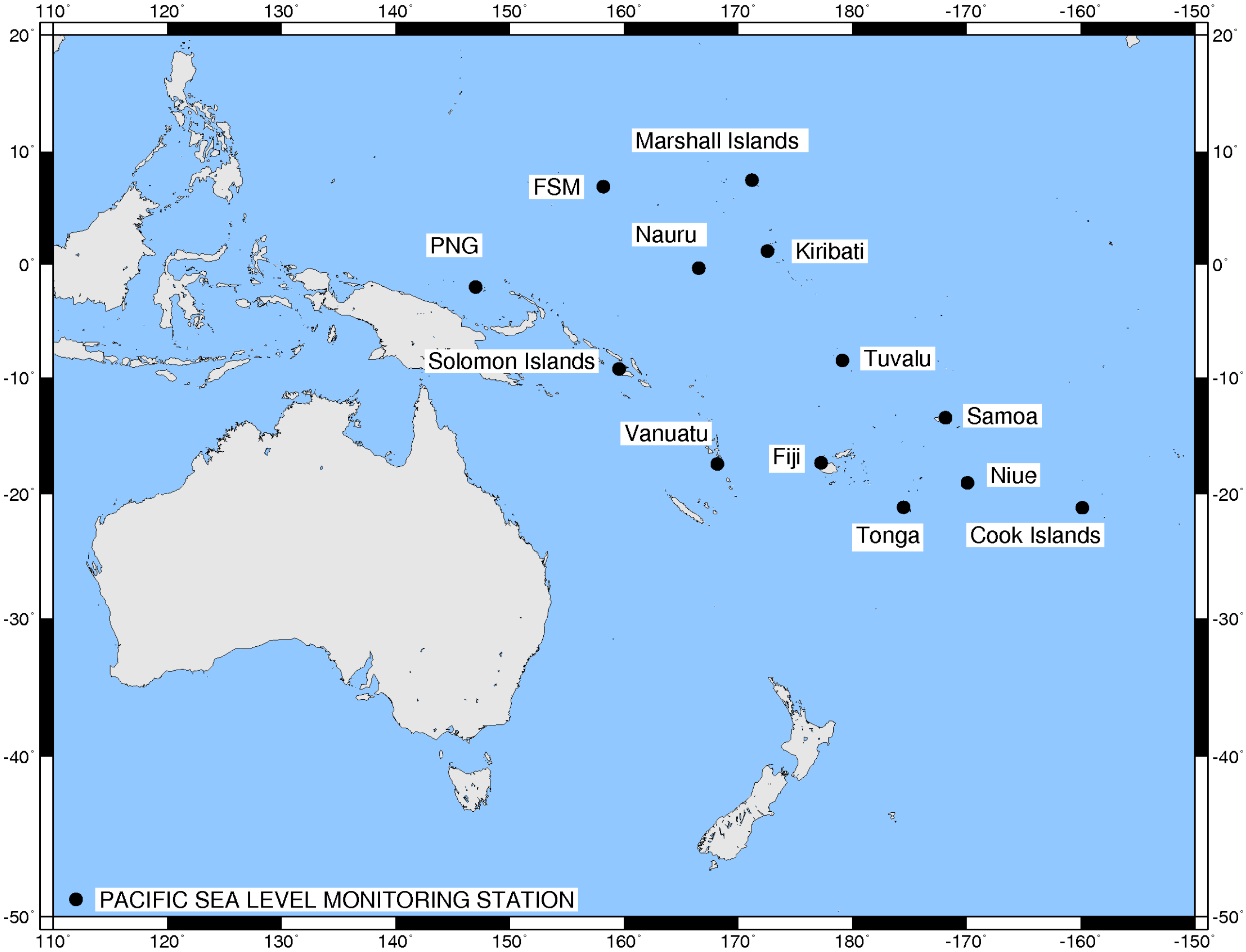

Figure 1: Network of SEAFRAME sea level monitoring stations in the Pacific.

3. 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 broader Southern Hemisphere monitoring by the Bureau of Meteorology, including the El Niño – Southern Oscillation, is available 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/.

4. April SEAFRAME Data

4.1. 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 13 April 2025 (UTC), while a new moon fell on 27 April 2025 (UTC).

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.

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 wind.

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.

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 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 Kiribati prevailed from the north-east for most of April.

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.

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 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 shorter observation period might result in extremes being exceeded on a frequent basis compared to longer observation periods.

In April 2025, the following noteworthy extremes were observed:

- An all-time record-high sea level at Solomon Islands (1.433 m)
- Record-high April sea levels at PNG (1.358 m), Vanuatu (1.769 m) and Niue (1.566 m)

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

4.2. 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. 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.

Notable monthly anomalies observed this month include:

- Positive sea level anomalies at Vanuatu (+20 cm), Solomon Islands (+7 cm), PNG (+6 cm) and Samoa (+5 cm), but negative sea level anomalies at Nauru (-5 cm), Fiji (-5 cm) and Tonga (-5 cm).
- Positive water temperature anomalies at Fiji (+0.8 °C), Vanuatu (+0.8 °C), Tonga (+0.7 °C), Nauru (+0.6 °C) and Solomon Islands (+0.5 °C).
- Positive air temperature anomalies at Tonga (+1.0 °C), Vanuatu (+1.0 °C), Fiji (+0.8 °C), Samoa (+0.7 °C), Marshall Islands (+0.7 °C), Cook Islands (+0.6 °C) and FSM (+0.6 °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.

5. 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 thirty 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 – some of 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. For example, the rate at Samoa is higher than other sites due to ongoing subsidence of the region following the tsunamigenic earthquakes on 29 September 2009.

Table 1: Updated overall rates of sea level movement based on SEAFRAME data from installation through April 2025

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	4.3	0.0
FSM	6°58'49.9"N	158°12'0.8"E	Dec 2001	6.1	0.0
PNG	2°2'31.5"S	147°22'25.6"E	Sep 1994	5.8	0.0
Solomon Is.	9°25'44.1"S	159°57'19.3"E	Jul 1994	5.5	0.0
Kiribati	1°21'54.2"N	172°55'58.8"E	Dec 1992	3.6	0.0
Nauru	0°31'45.9"S	166°54'36.2"E	Jul 1993	5.0	0.0
Tuvalu	8°30'8.9"S	179°11'42.6"E	Mar 1993	4.5	0.0
Samoa	13°49'36.4"S	171°45'40.7"W	Feb 1993	9.8	0.0
Vanuatu	17°45'19.2"S	168°18'27.7"E	Jan 1993	1.8	+0.1
Fiji	17°36'17.7"S	177°26'17.7"E	Oct 1992	3.9	0.0
Tonga	21°8'12.5"S	175°10'50.5"W	Jan 1993	7.2	0.0
Cook Is	21°12'17.1"S	159°47'5.2"W	Feb 1993	4.6	0.0
Niue	19°3'9.7"S	169°55'15.2"W	Aug 2015	6.2	+0.3

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

6. 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 99.3% during April 2025 and 92.4% overall since the start of the project (Table 2).

Noteworthy problems relating to the instrumentation include:

- The station at Tuvalu had intermittent periods where it failed to collect any data.
- The air temperature sensor at Marshall Islands remained faulty during April, having developed a fault on 8 March 2025.
- The water temperature readings at Marshall Islands were deemed suspect, while the water temperature sensors at Solomon Islands, Samoa and Tonga all experienced temporary faults during April.

Table 2: Rates of sea level data return

Location	Installation Date	Data Return Since Installation (%)	Data Return in April 2025 (%)
Cook Is	Feb 1993	97.9	100.0
Tonga	Jan 1993	98.8	100.0
Fiji	Oct 1992	99.0	100.0
Vanuatu	Jan 1993	96.3	100.0
Samoa	Feb 1993	97.0	100.0
Tuvalu	Mar 1993	95.5	91.3
Kiribati	Dec 1992	96.3	100.0
Nauru	Jul 1993	91.4	100.0
Solomon Is.	Jul 1994	96.2	100.0
PNG	Sep 1994	90.6	100.0
FSM	Dec 2001	87.3	100.0
Marshall Is.	May 1993	95.9	100.0
Niue	Aug 2015	59.0	99.9
Network Average		**92.4**	**99.3**

7. SEAFRAME Stations Layout

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:

- Primary water level using an acoustic or radar sensor mounted above the water,
- Secondary water level (or backup) using a vented pressure transducer mounted close to the seabed, and
- Tertiary water level using a radar sensor mounted above the water.

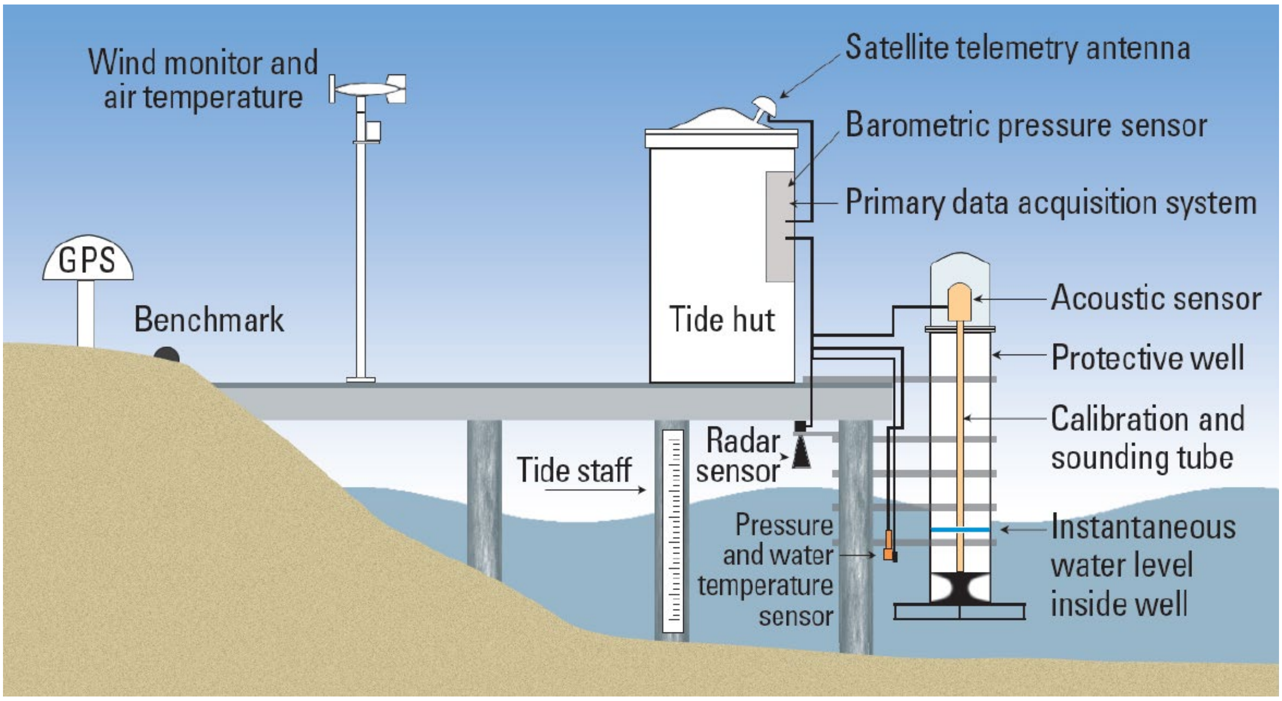

Figure 2: Schematic of a SEAFRAME sea level monitoring station.

8. Tide Prediction Extension Activities

Tide prediction extension activities are aimed at extending the network of locations at which tide predictions are available under the project (Table 3). Portable tide gauges have been deployed 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. Data from existing operational tide gauges in the region and tidal models have also been utilised. The tide predictions prepared under the project are not intended to be used for navigational purposes.

Table 3. Additional locations where tide predictions are prepared under the project.

Location	Country	Tide gauge operator	Data source
Port Moresby	Papua New Guinea	PNG NMSA	Bureau of Meteorology
Tarekukure Wharf	Solomon Islands	Bureau of Meteorology	Bureau of Meteorology
Lata Wharf	Solomon Islands	Bureau of Meteorology	Bureau of Meteorology
Luganville Wharf	Vanuatu	Bureau of Meteorology	Bureau of Meteorology
Litzlitz	Vanuatu		IOC Sea Level Monitoring Facility
Lenakel	Vanuatu	Mineral Resources Department (Vanuatu)	IOC Sea Level Monitoring Facility
Penrhyn	Cook Islands	UHSLC	UHSLC
Neiafu	Tonga	Pacific Community (SPC)	
Atafu	Tokelau	n/a	FES2014 tidal model
Nukunonu	Tokelau	n/a	FES2014 tidal model
Fakaofo	Tokelau	n/a	FES2014 tidal model
Pago Pago	American Samoa	NOAA	UHSLC
Suva	Fiji	Bureau of Meteorology	Bureau of Meteorology
Vatia	Fiji	Fiji Meteorological Service	IOC Sea Level Monitoring Facility
Port Denarau	Fiji	Pacific Community (SPC)	Pacific Community (SPC)
Vaitupu	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)
Nukulaelae	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)
Nui	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)

Table 3 (continued). Additional locations where tide predictions are prepared under the project

Location	Country	Tide gauge operator	Data source
Niutao	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)
Nanumea	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)
Nanumaga	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)
Niulakita	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)
Nukufetau	Tuvalu	Pacific Community (SPC)	Pacific Community (SPC)
Kanton	Kiribati	UHSLC	UHSLC
Kiritimati	Kiribati	UHSLC	UHSLC
Ebeye Island	Marshall Islands	Pacific Community	Pacific Community
Malakal Harbour	Palau	University of Hawaii	UHSLC

9. Further Information

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

PSLGM 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):

https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/gnss-networks

https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/pacific-sea-level-and-geodetic-monitoring

10. Appendix: SEAFRAME Data Figures

SIX MINUTE SEA LEVEL OBSERVATIONS (m)

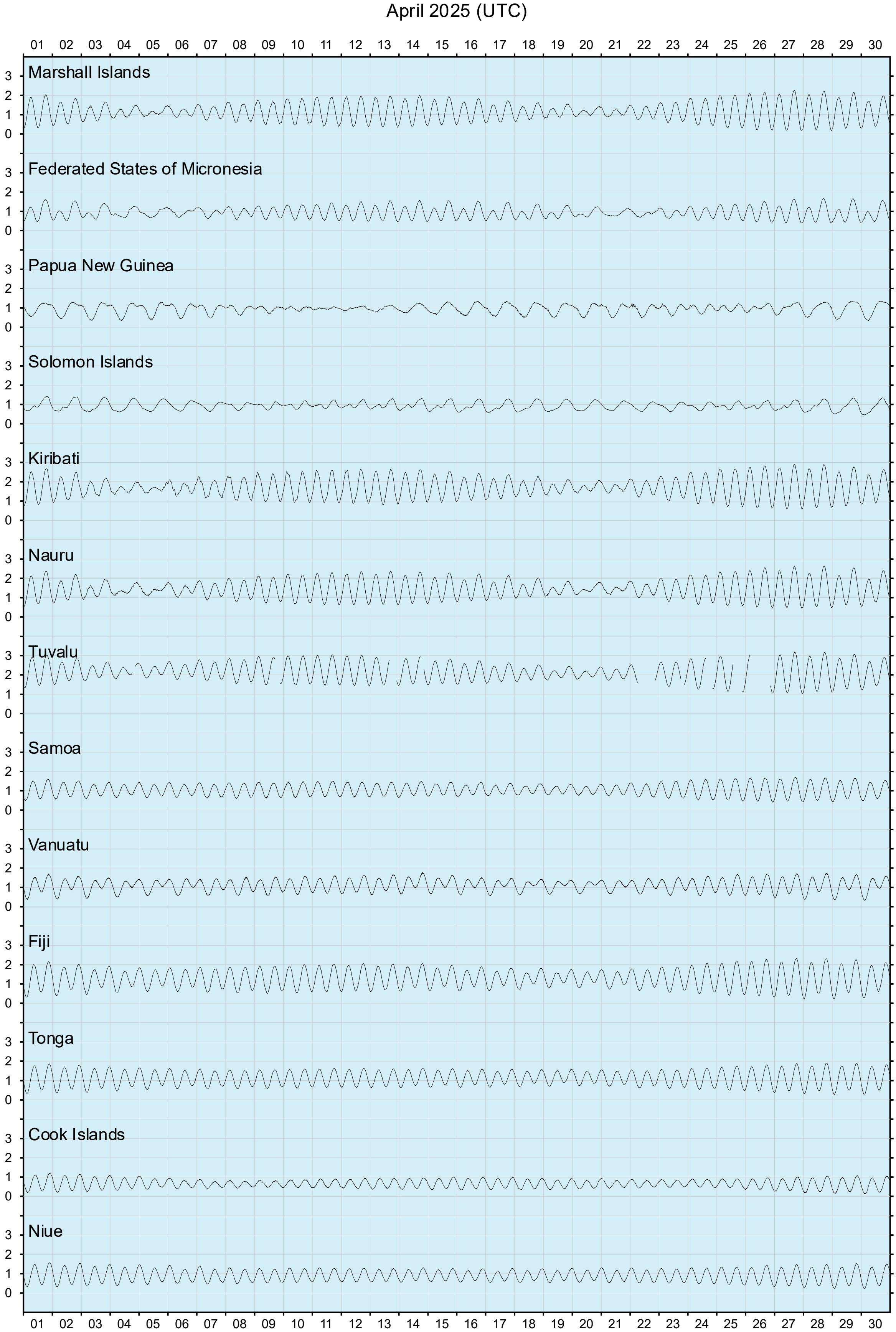

Figure 3. Sea level observations during April 2025.

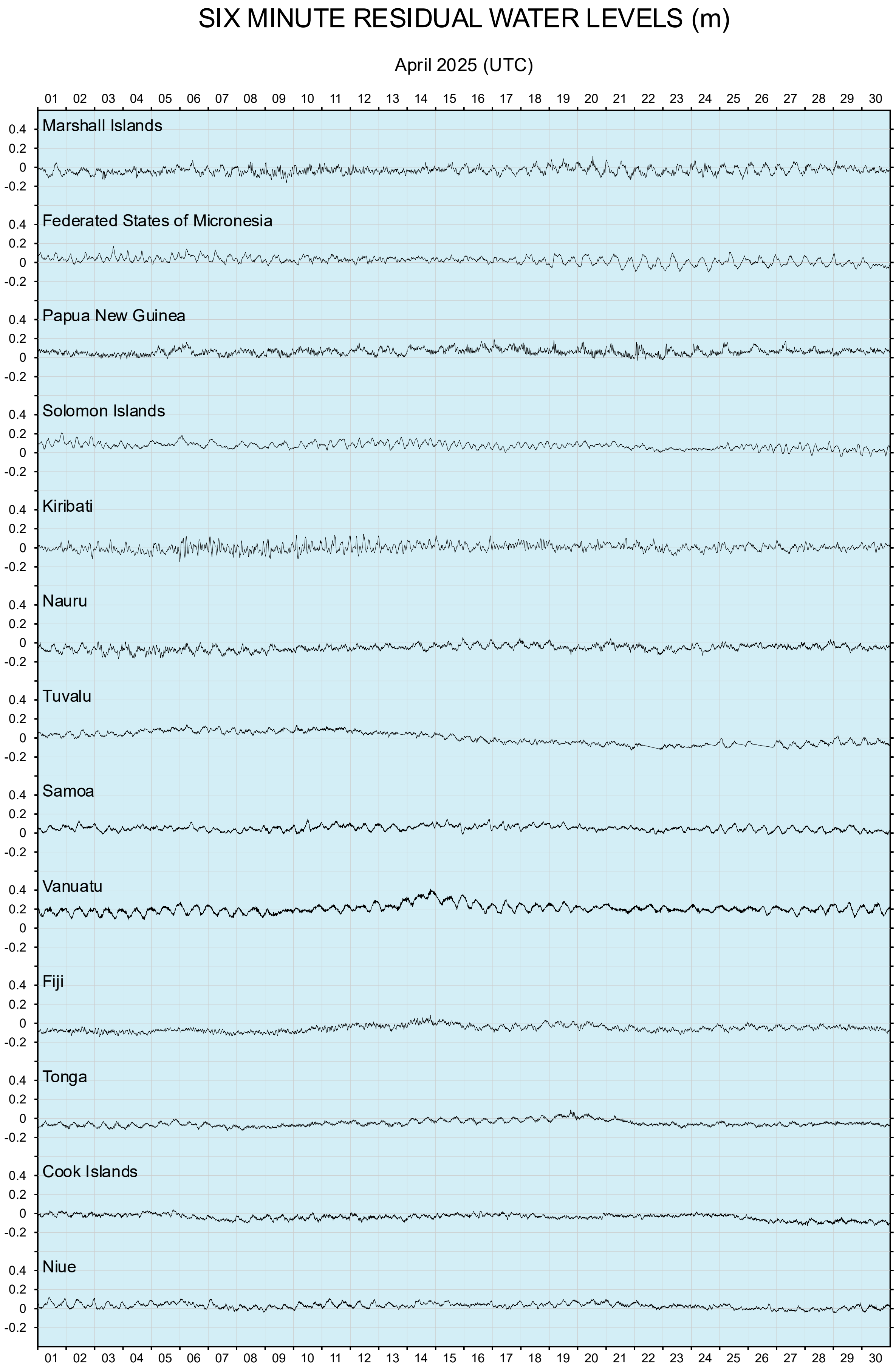

Figure 4. Residual sea levels during April 2025.

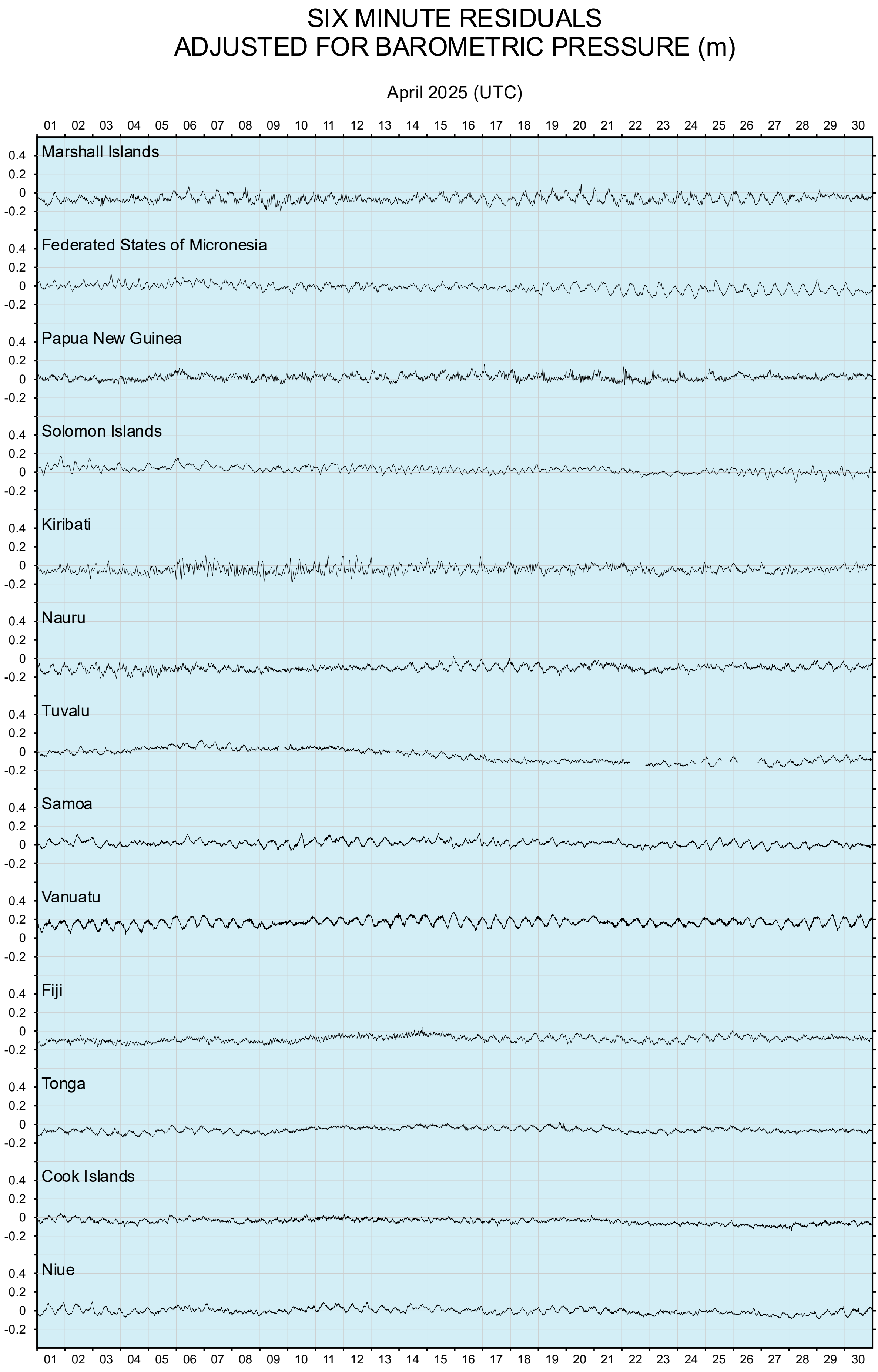

Figure 5. Residual sea levels adjusted for barometric pressure during April 2025.

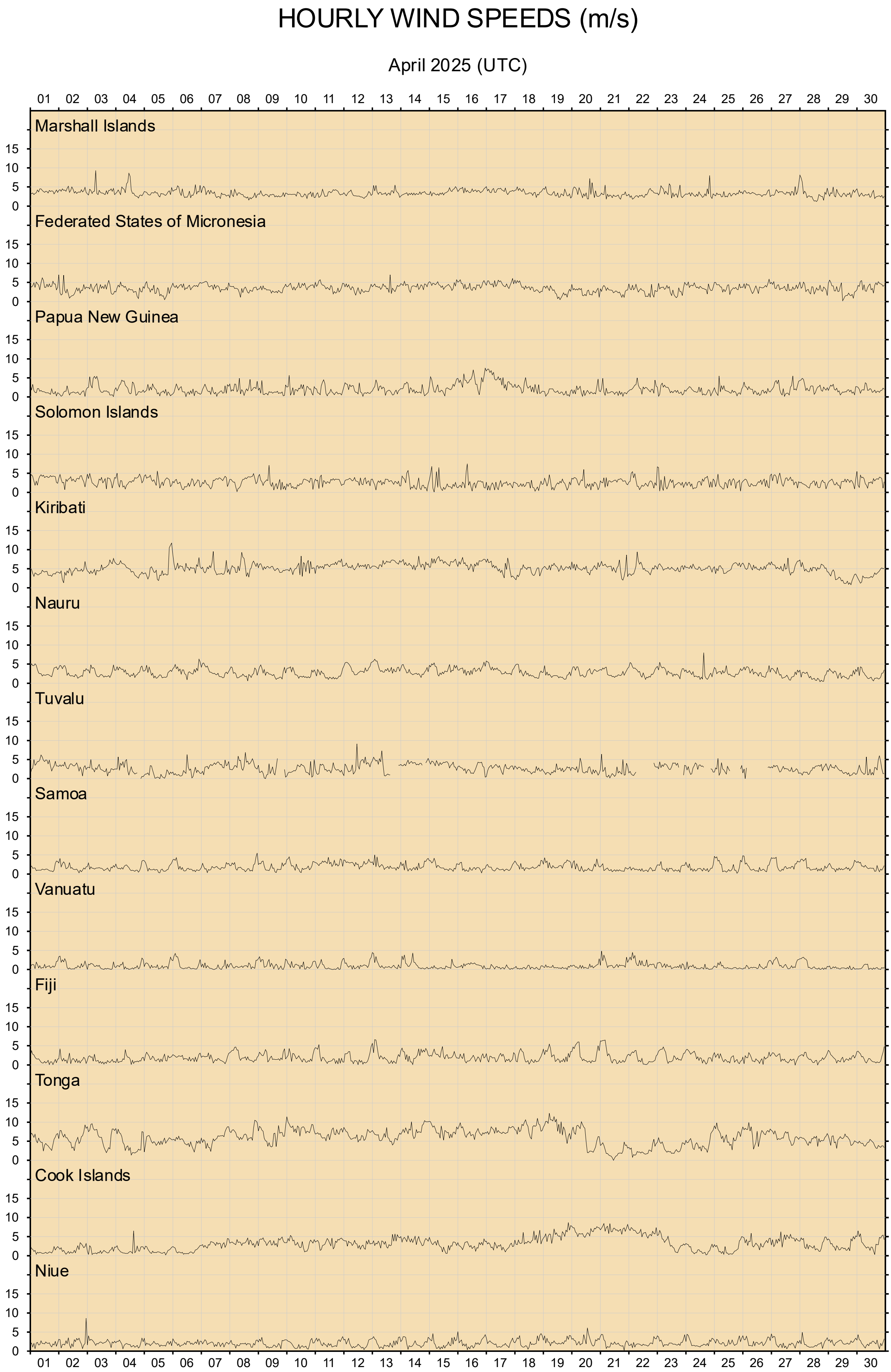

Figure 6. Wind speeds during April 2025.

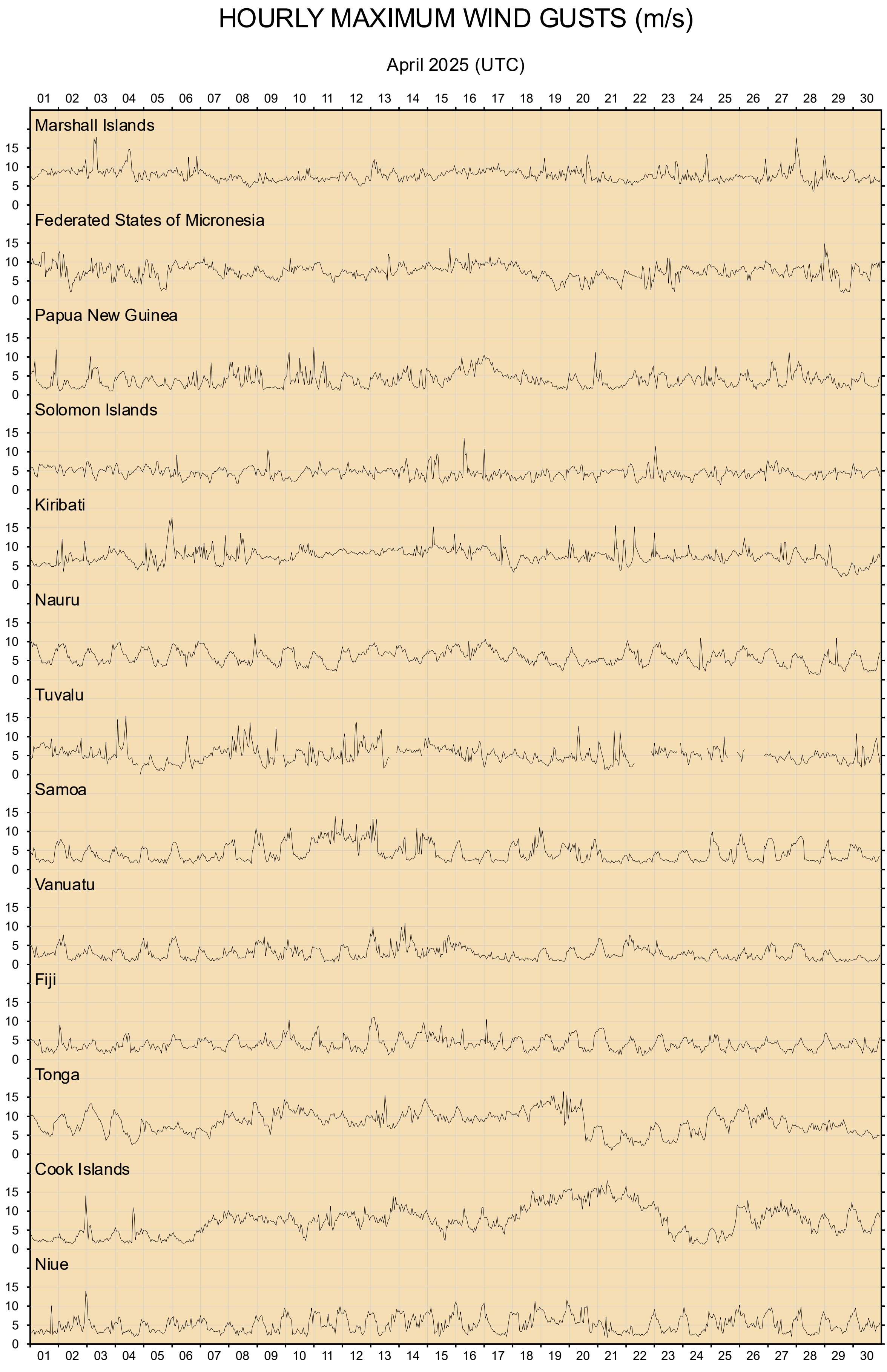

Figure 7. Wind gusts during April 2025.

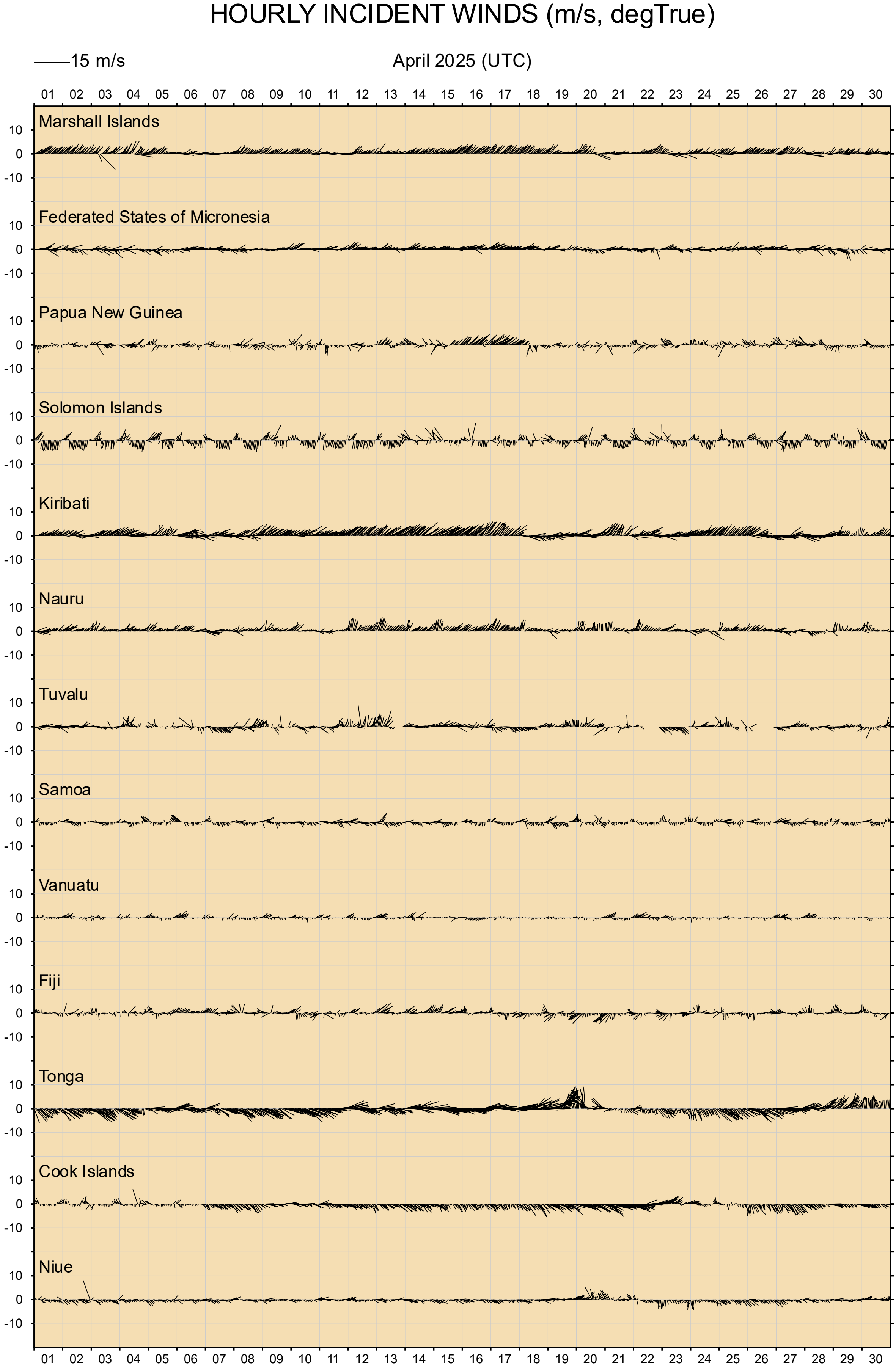

Figure 8. Incident winds during April 2025

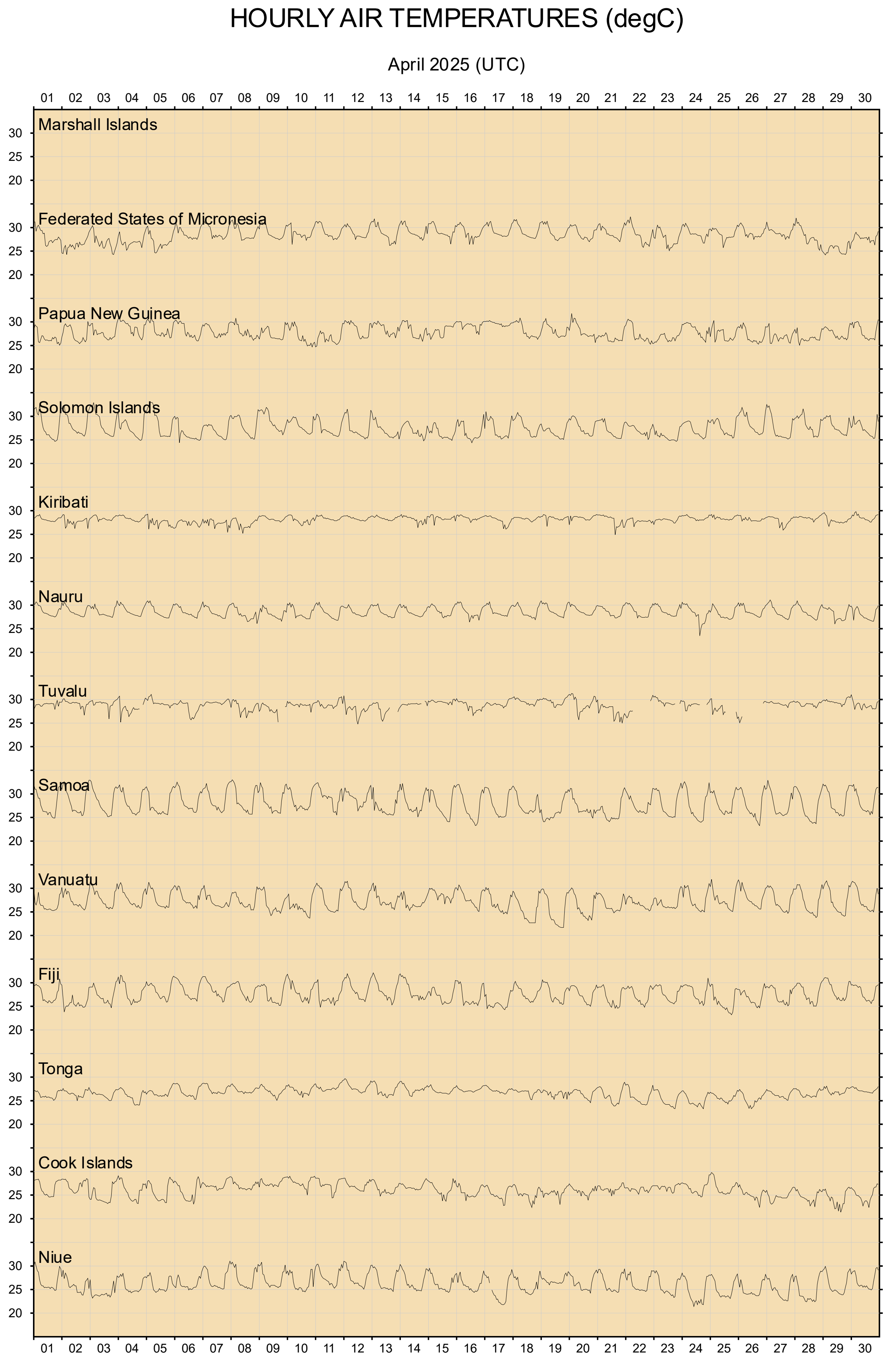

Figure 9. Air temperatures during April 2025.

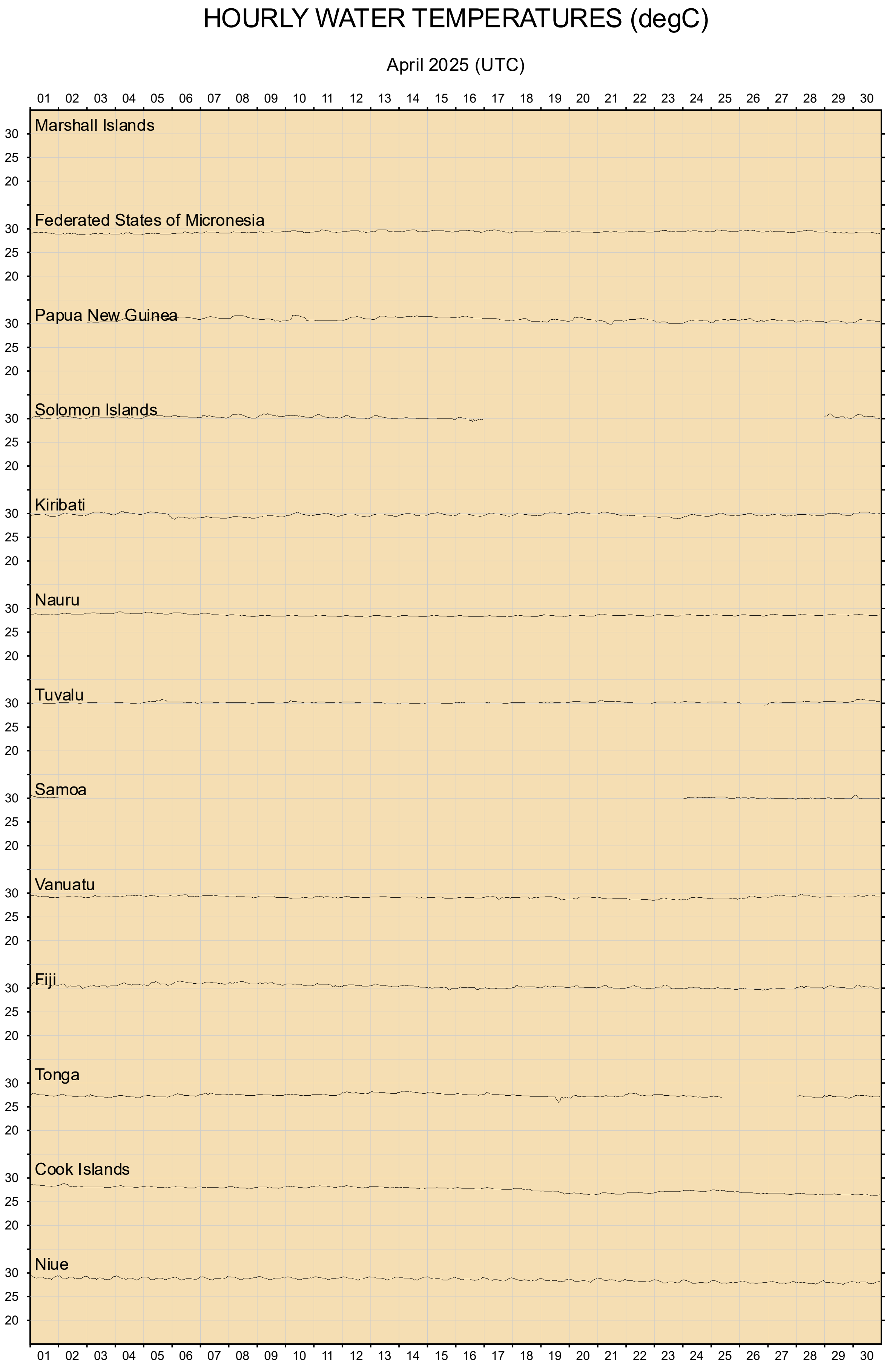

Figure 10. Water temperatures during April 2025.

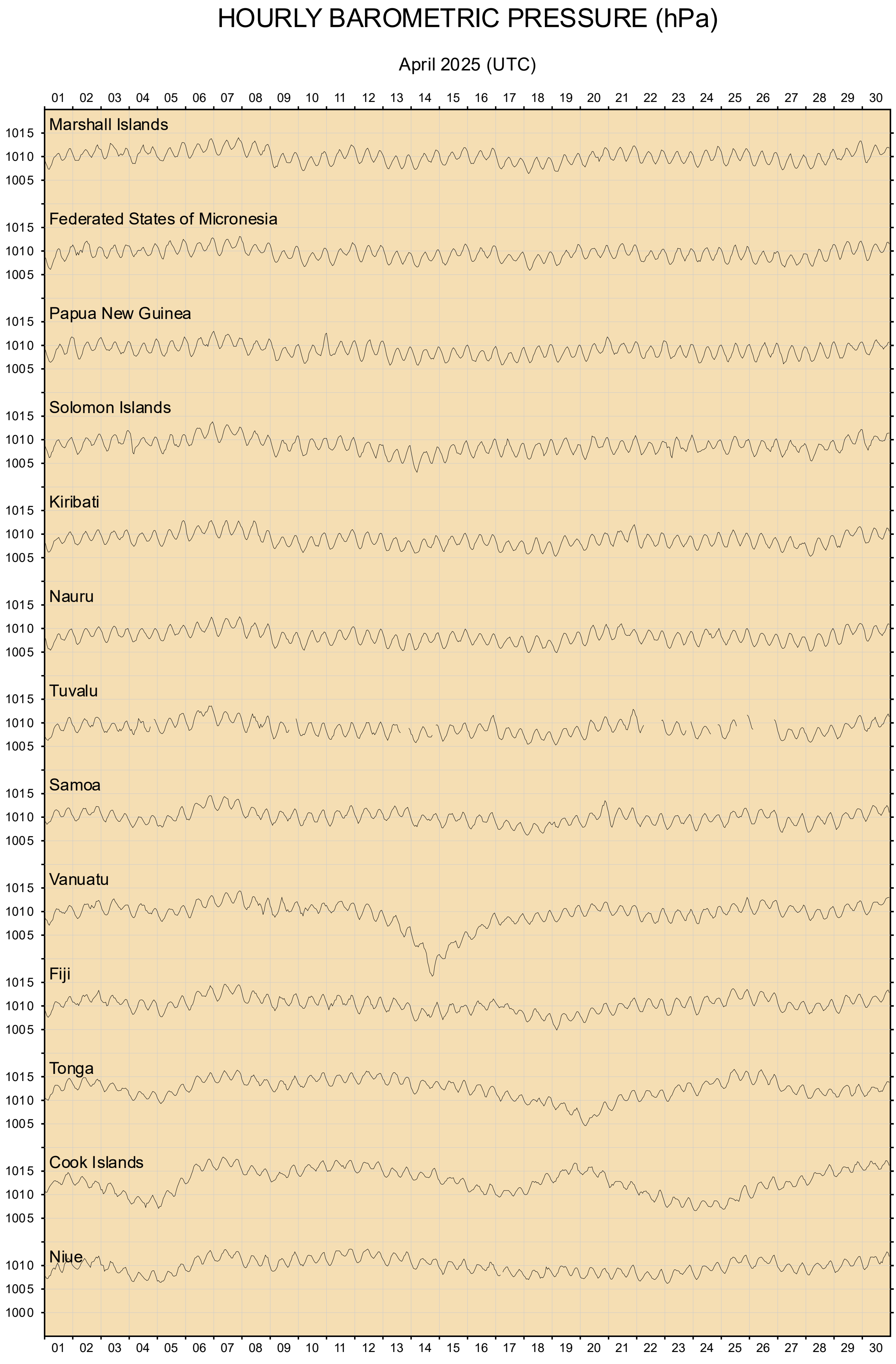

Figure 11. Barometric pressures during April 2025.

COMPARISON OF APRIL 2025 MAX,MIN AND MEAN WITH LONG-TERM APRIL VALUES

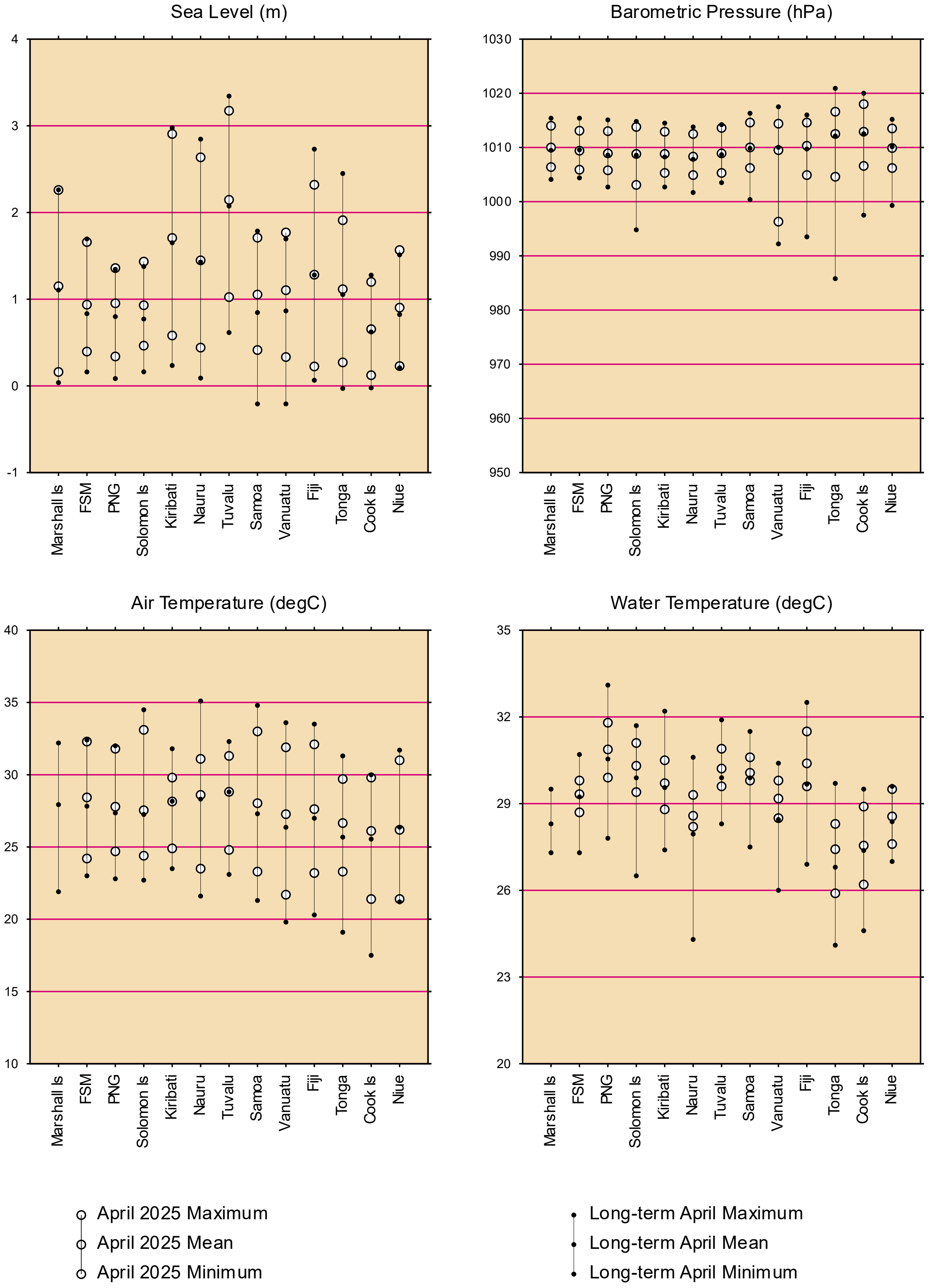

Figure 12. Comparison of April 2025 data with long term April values.

MONTHLY MEAN SEA LEVELS THROUGH APRIL 2025 (m)
(The zero line represents mean sea level)

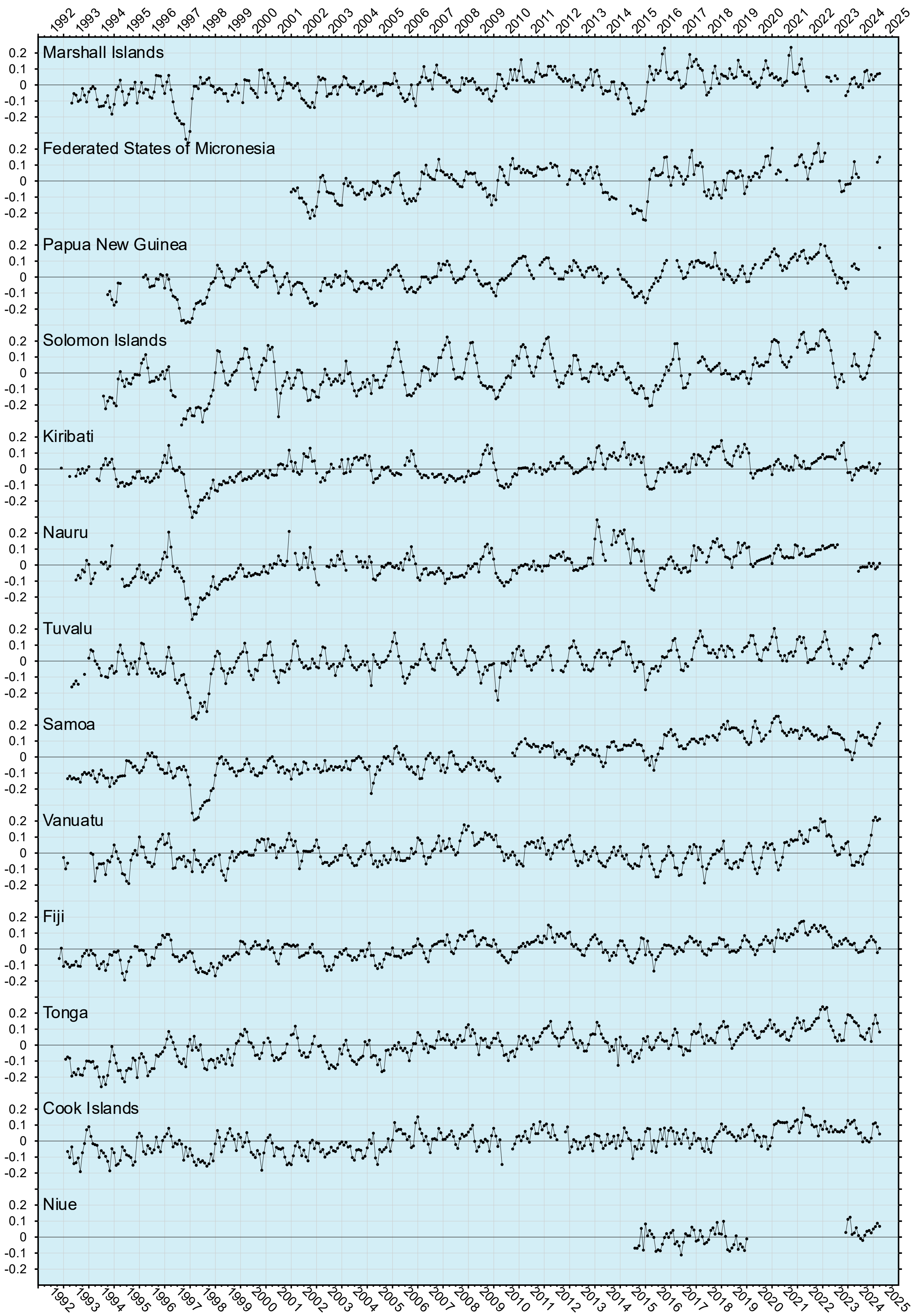

Figure 13. Monthly mean sea levels to April 2025.

MONTHLY MEAN BAROMETRIC PRESSURES
THROUGH APRIL 2025 (hPa)

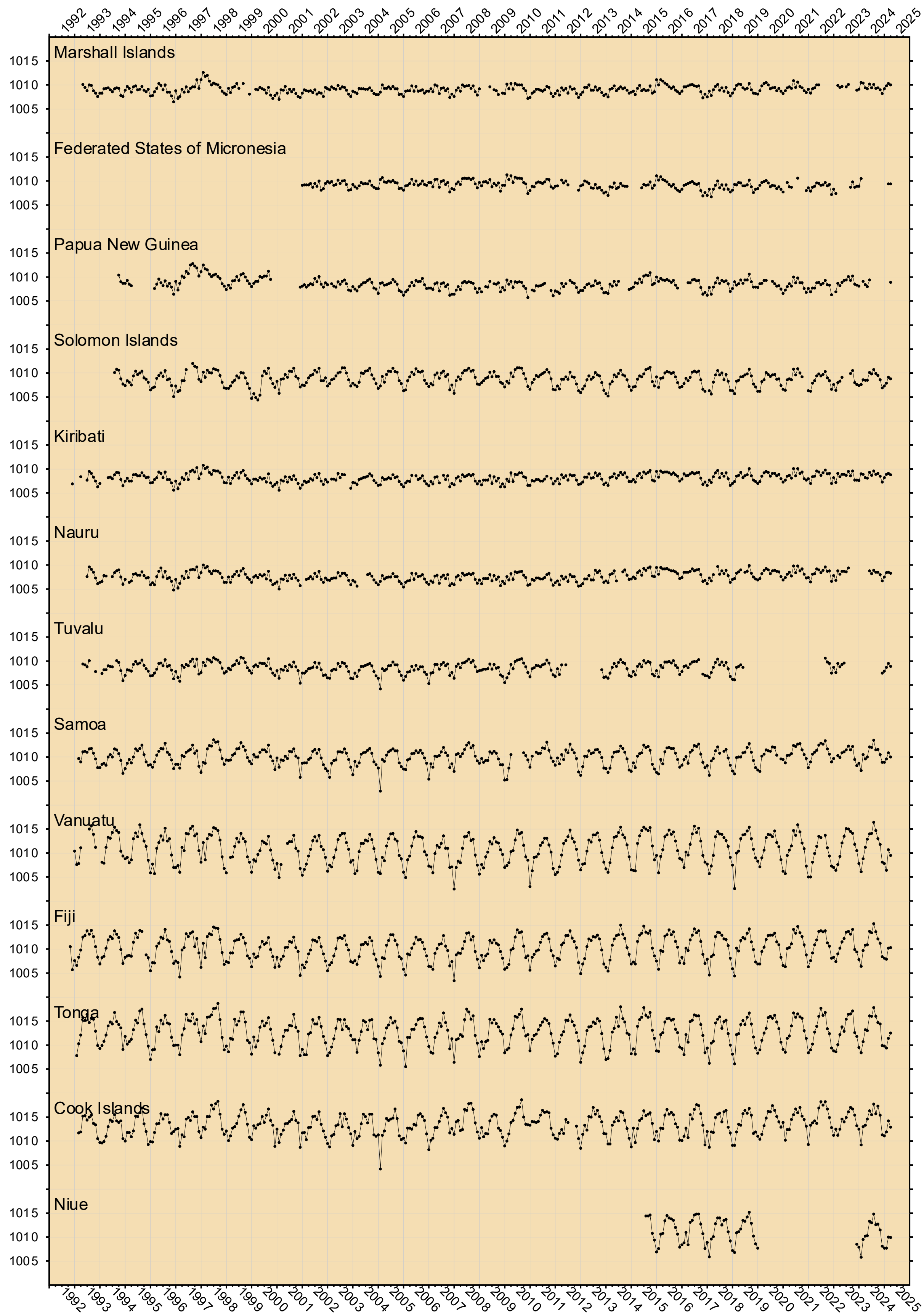

Figure 14. Monthly mean barometric pressures to April 2025.

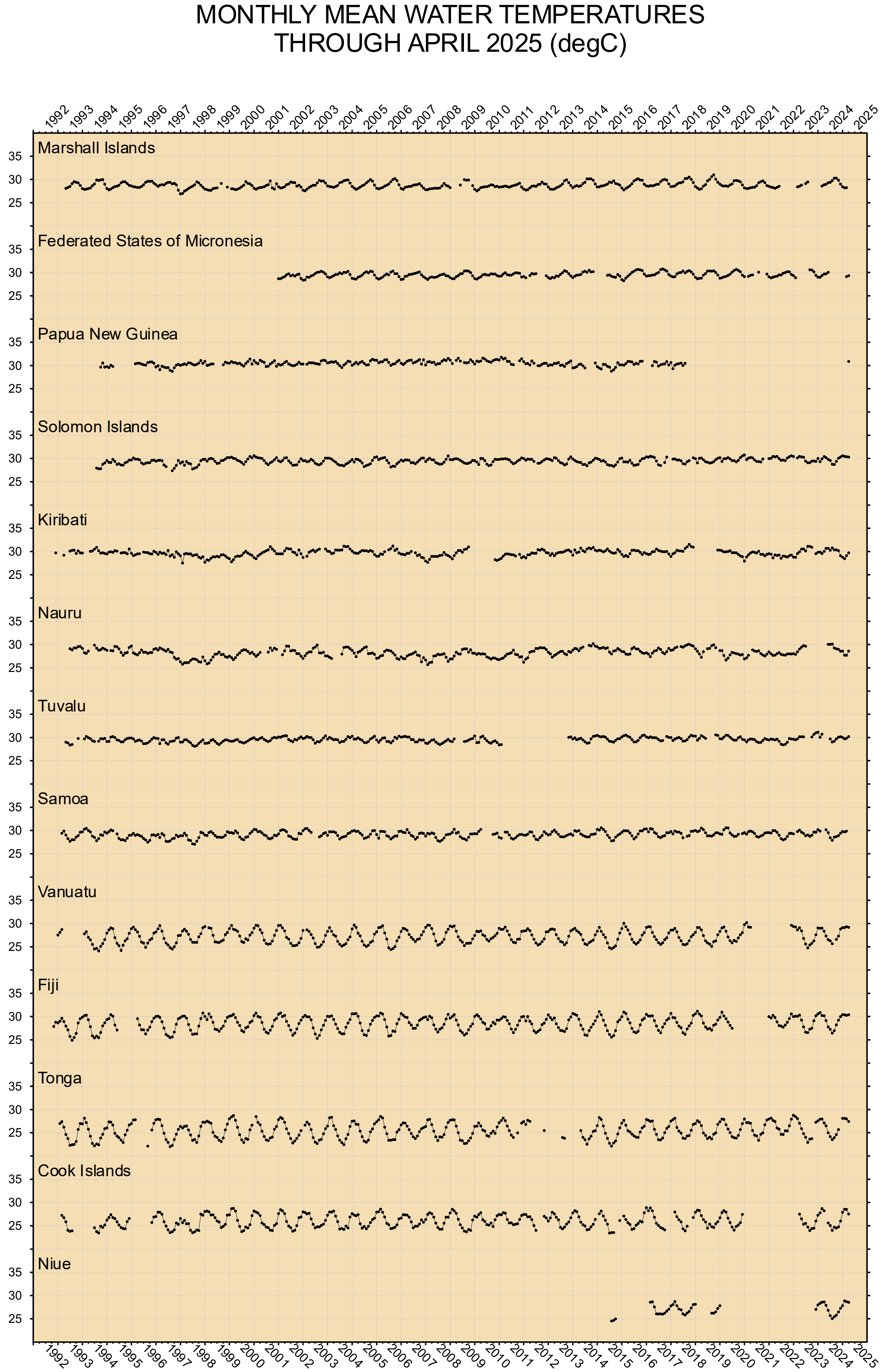

Figure 15. Monthly mean water temperatures to April 2025.

MONTHLY MEAN AIR TEMPERATURES
THROUGH APRIL 2025 (degC)

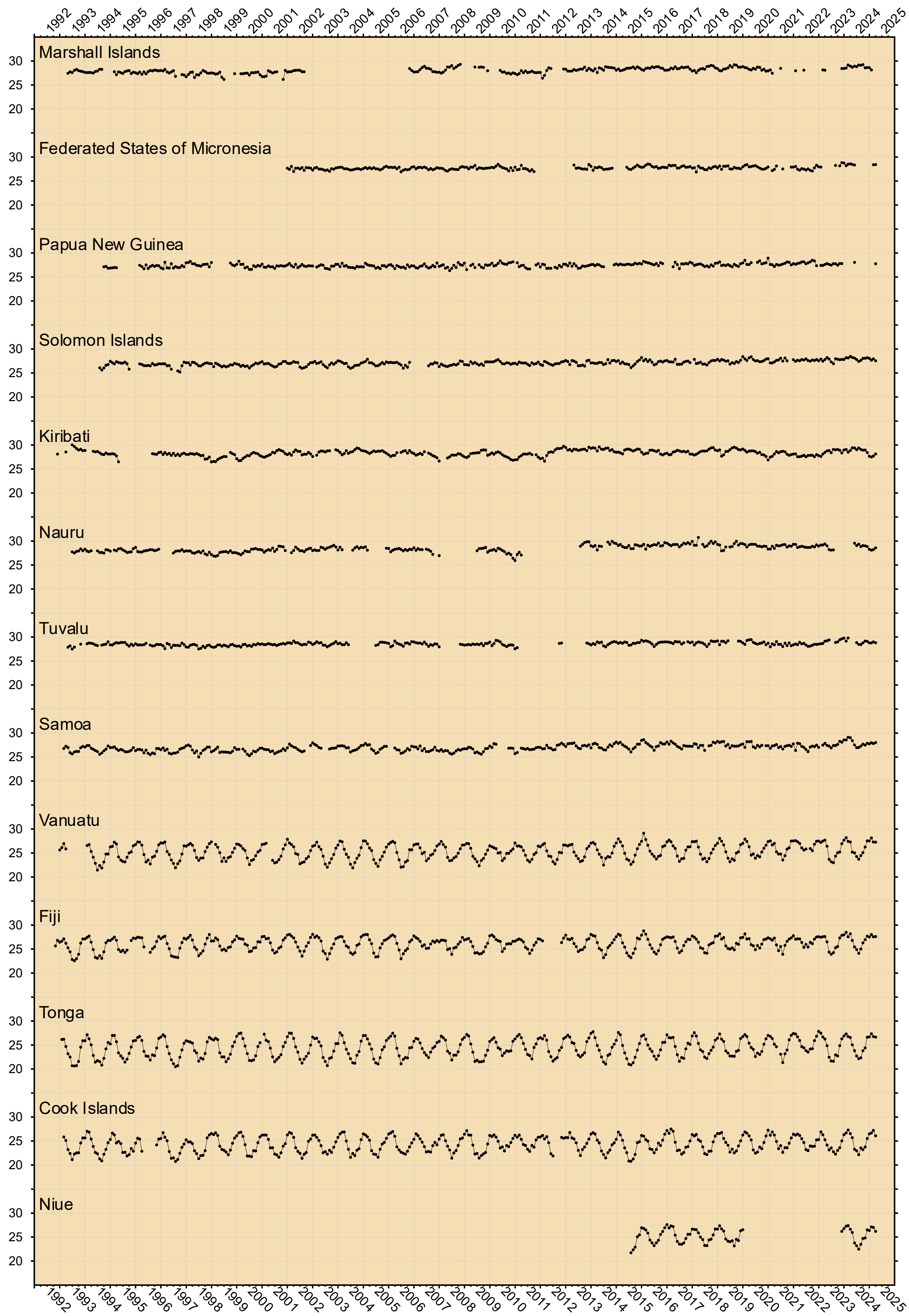

Figure 16. Monthly mean air temperatures to April 2025

SEA LEVEL ANOMALIES THROUGH APRIL 2025 (m)

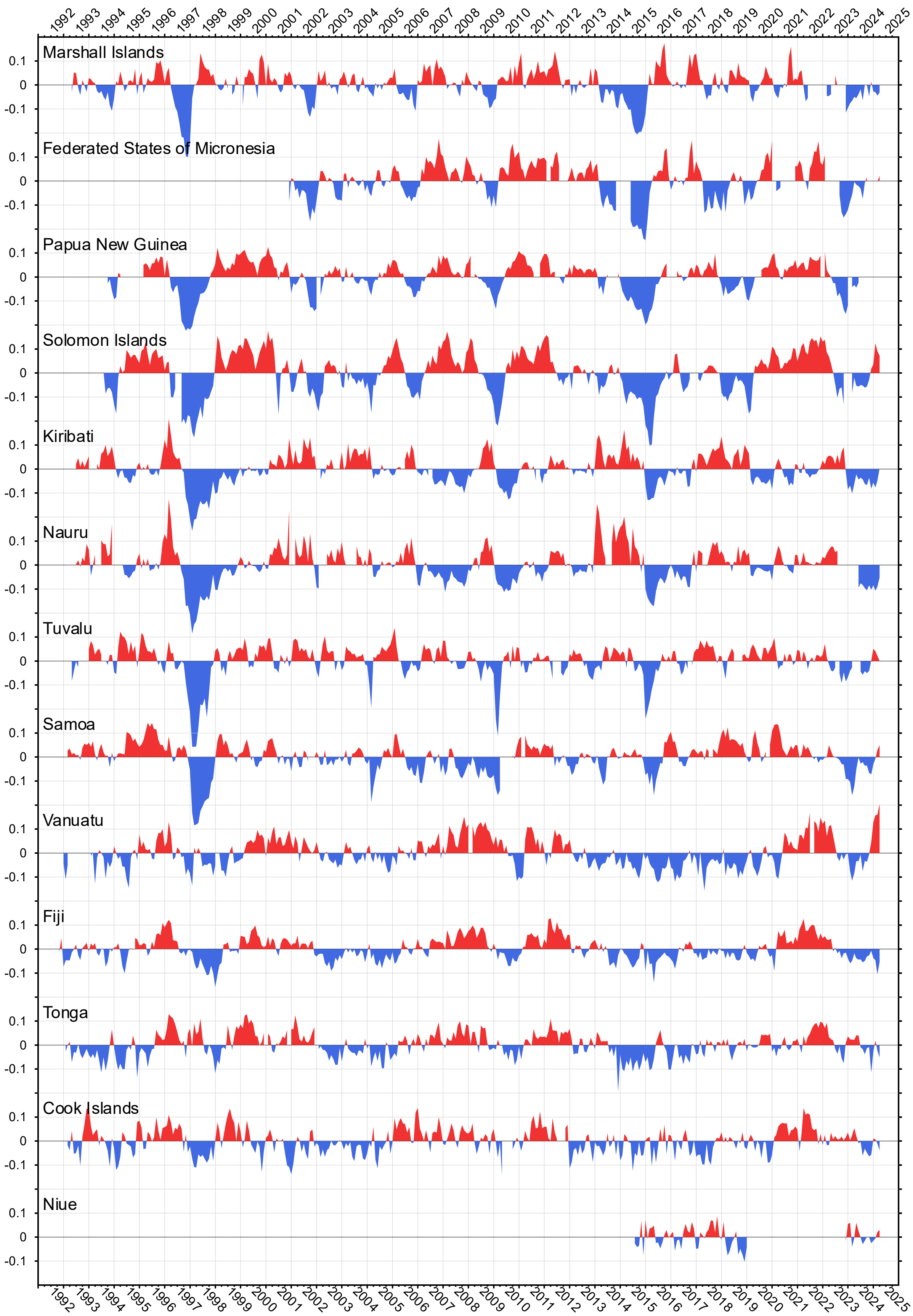

Figure 17. Monthly sea level anomalies to April 2025.

BAROMETRIC PRESSURE ANOMALIES
THROUGH APRIL 2025 (hPa)

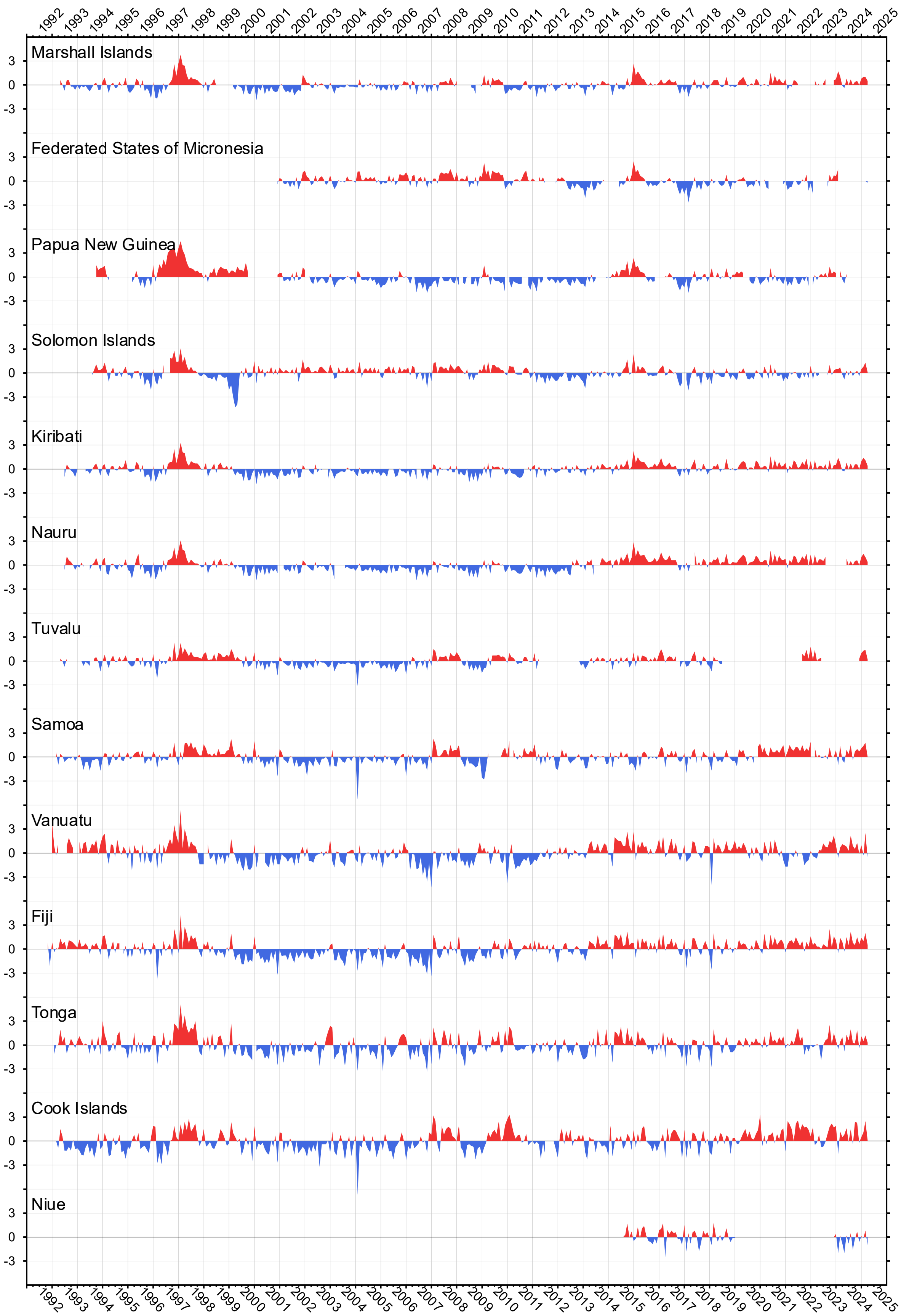

Figure 18. Monthly barometric pressure anomalies to April 2025.

WATER TEMPERATURE ANOMALIES
THROUGH APRIL 2025 (degC)

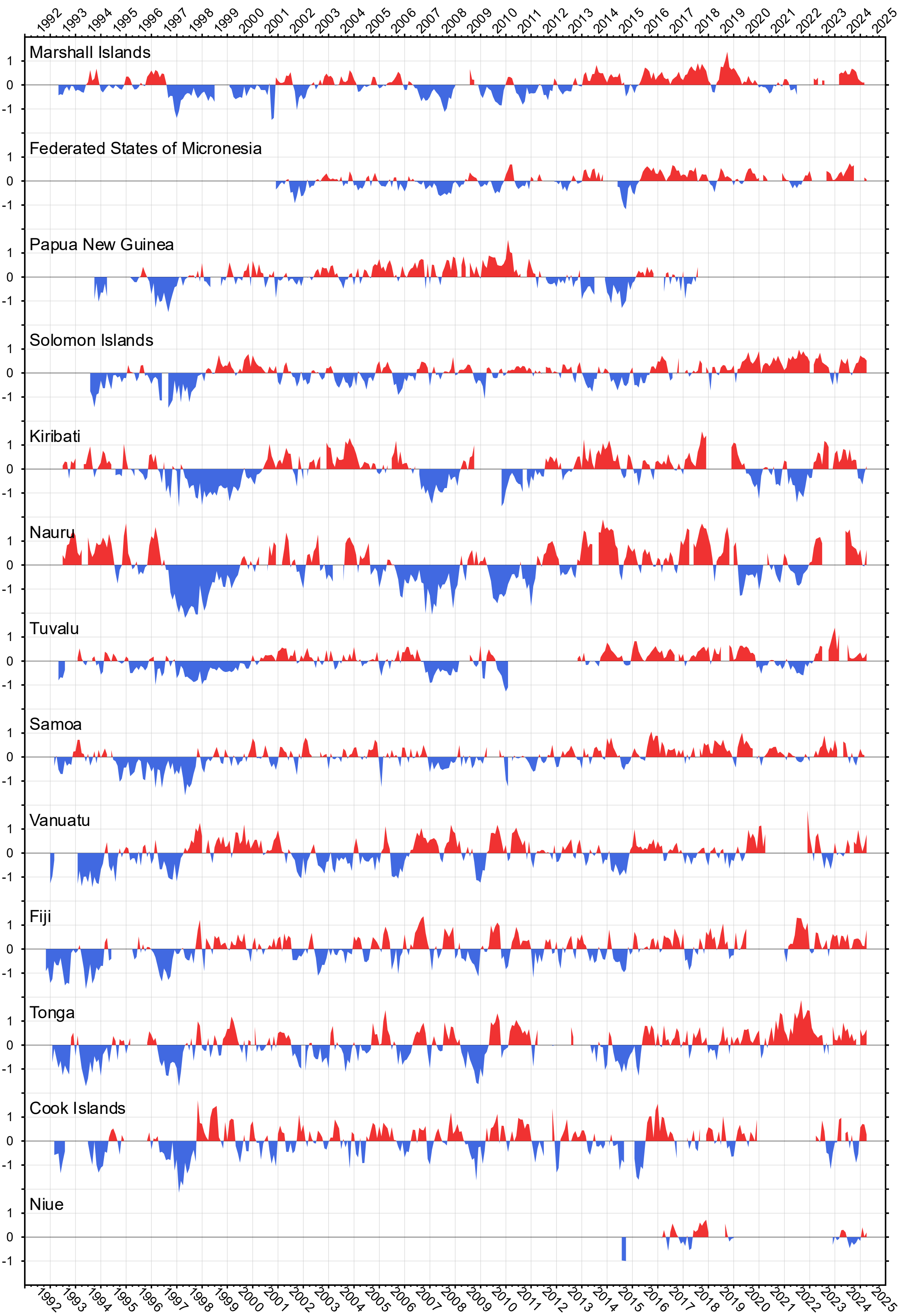

Figure 19. Monthly water temperature anomalies to April 2025.

AIR TEMPERATURE ANOMALIES
THROUGH APRIL 2025 (degC)

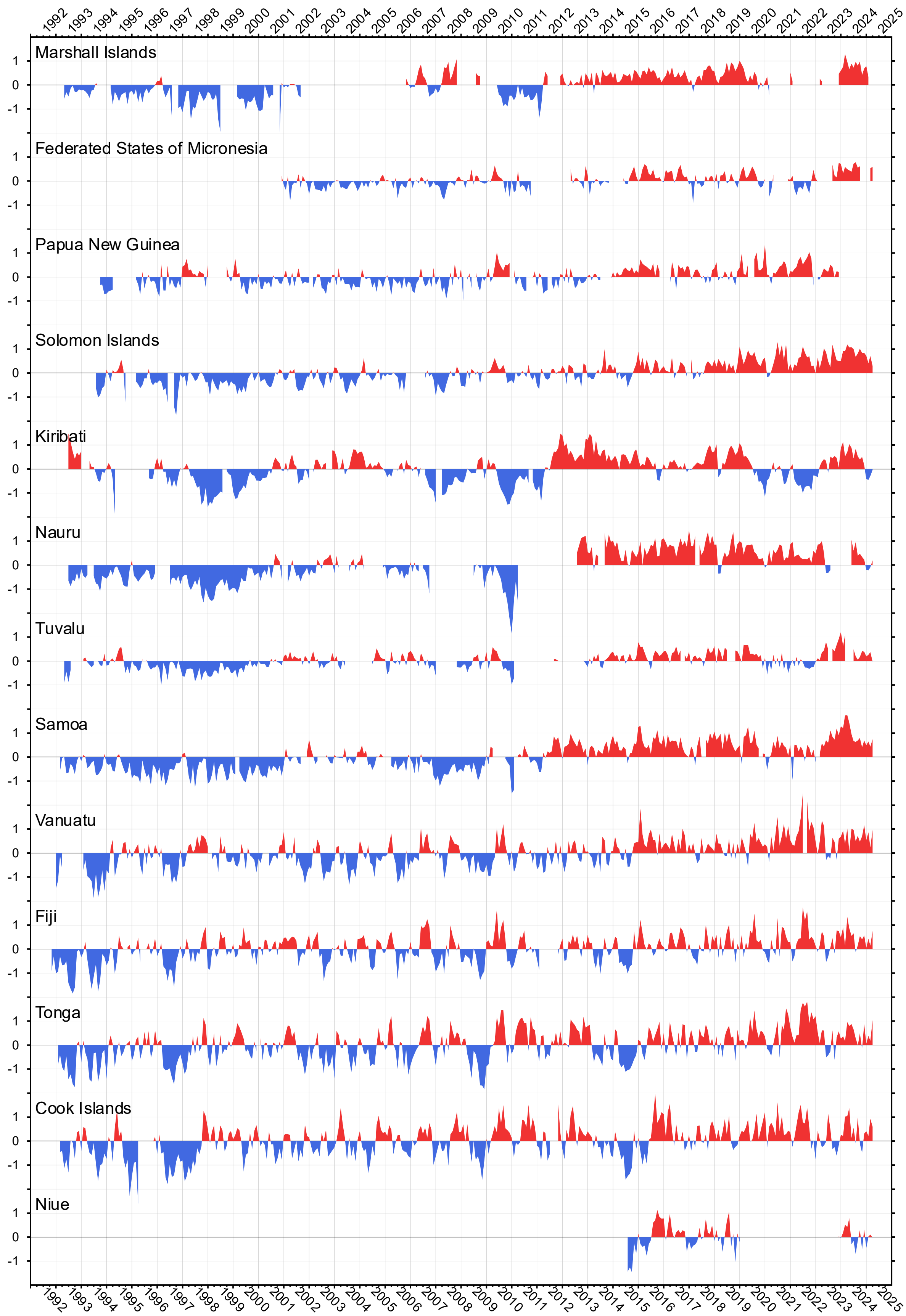

Figure 20. Monthly air temperature anomalies to April 2025.

MONTHLY SEA LEVEL DATA RETURN
THROUGH APRIL 2025 (%)

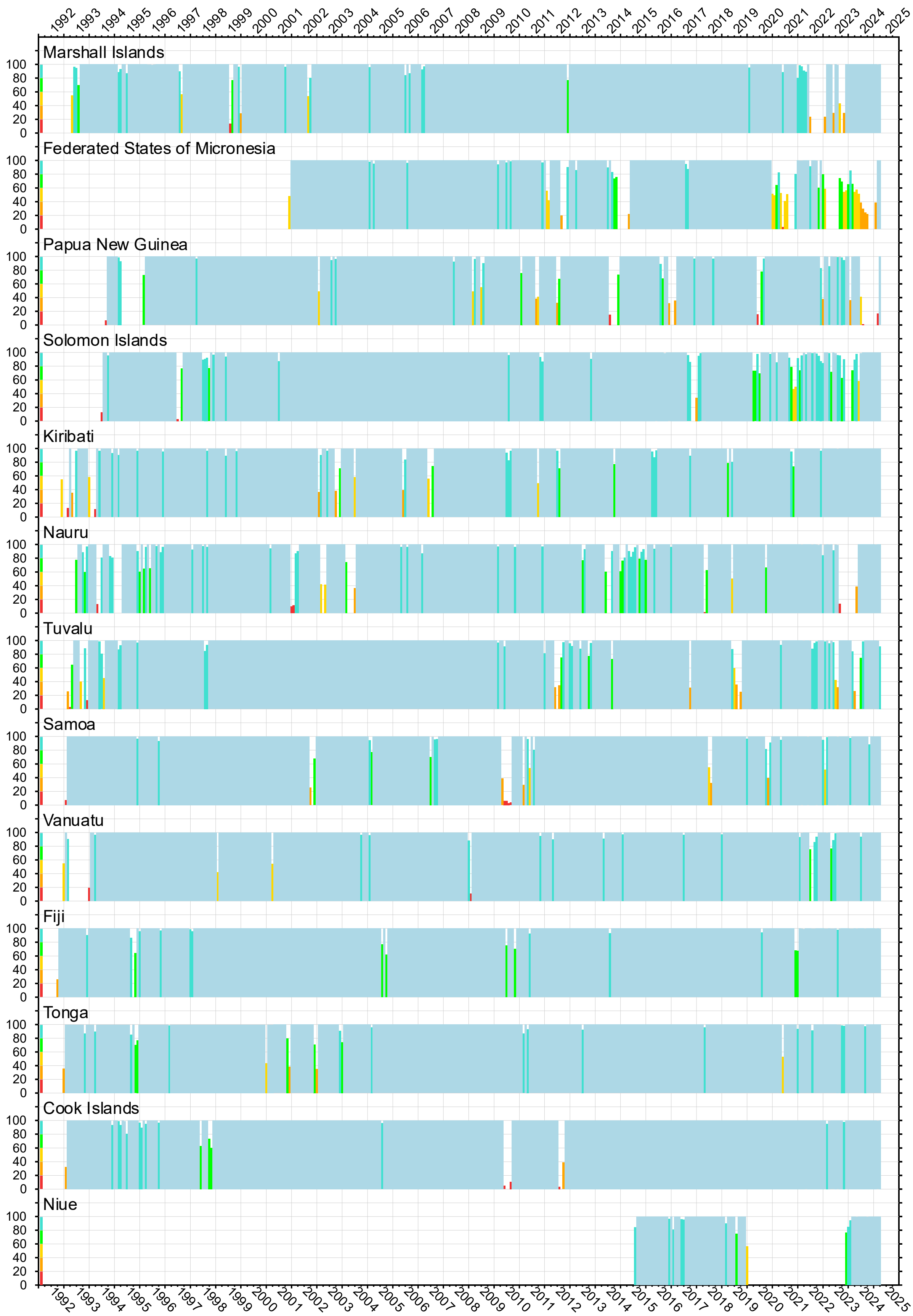

Figure 21. Sea level data return.