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Monthly Data Report – September 2020

Australian Baseline Sea Level Monitoring Array

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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.

September 2020

- The Australian Baseline Sea Level Monitoring Array (ABSLMA) network continued to collect high quality sea level and associated meteorological information to support long-term sea level monitoring around Australia.
- The overall rate of sea level data returned from the operating network during September was 99.6%.
- Monthly mean sea levels were slightly lower than normal for this time of year from Portland to Port Kembla, ranging from -3 cm to -1 cm. Sea levels were higher than normal elsewhere including Cape Ferguson (+9 cm anomaly), Thursday Island (+6 cm), Broome (+6 cm), Cocos Island (+5 cm), Darwin (+4 cm), Hillarys (+4 cm) and Rosslyn Bay (+4 cm).
- The Thevenard SEAFRAME was removed in May 2019 to allow for wharf refurbishment but will be re-established in the future. Flinders Ports are operating a nearby gauge in the interim.

Introduction

Welcome to the September 2020 Monthly Data Report for the Australian Baseline Sea Level Monitoring Array (ABSLMA). The report details the month by month operation of SEAFRAME sea level monitoring stations around Australia, including operational problems with the network and the occurrence of abnormal sea level events in the context of related astronomical tide, weather and climate variations. A companion array of SEAFRAME sea level monitoring stations in Pacific Island Countries is supported under the Pacific Sea Level and Geodetic Monitoring Project.

The ABSLMA was originally developed and supported from grants under the Australian Climate Change Science Program through the Department of Climate Change and Energy Efficiency, with a primary goal to monitor long-period sea level changes around Australia focussing particularly on the enhanced greenhouse effect. Operation of the array continues to be supported by the Bureau of Meteorology, underpinning the advanced technologies gathering global observations for climate change research as well as providing real-time information for tidal monitoring and tsunami detection.

The Baseline sea level monitoring array consists of 15 standard SEAFRAME stations operated by the Bureau of Meteorology at representative sites around Australia, as well as two customised, privately-owned stations at Lorne and Stony Point (Figure 1). The SEAFRAME at Port Stanvac was removed in November 2010 to allow Mobil Refining Australia to decommission the oil refinery. Re-establishment of a tide gauge near Port Stanvac is being investigated.

The standard SEAFRAME stations not only measure sea level, but also observe several “ancillary” variables - air and water temperatures, wind speed, wind direction and barometric pressure. The privately-owned stations at Lorne and Stony Point do not measure the ancillary variables, although winds are measured at Stony Point.

The Bureau of Meteorology and Geosciences Australia, through their membership on the Intergovernmental Committee on Surveying and Mapping (ICSM) Permanent Committee on Tides & Mean Sea Level (PCTMSL), strive to sustain geodetic levelling programs implemented by various state surveying organisations in order to monitor shifts in the vertical of the sea level sensors due to local land movement.

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.

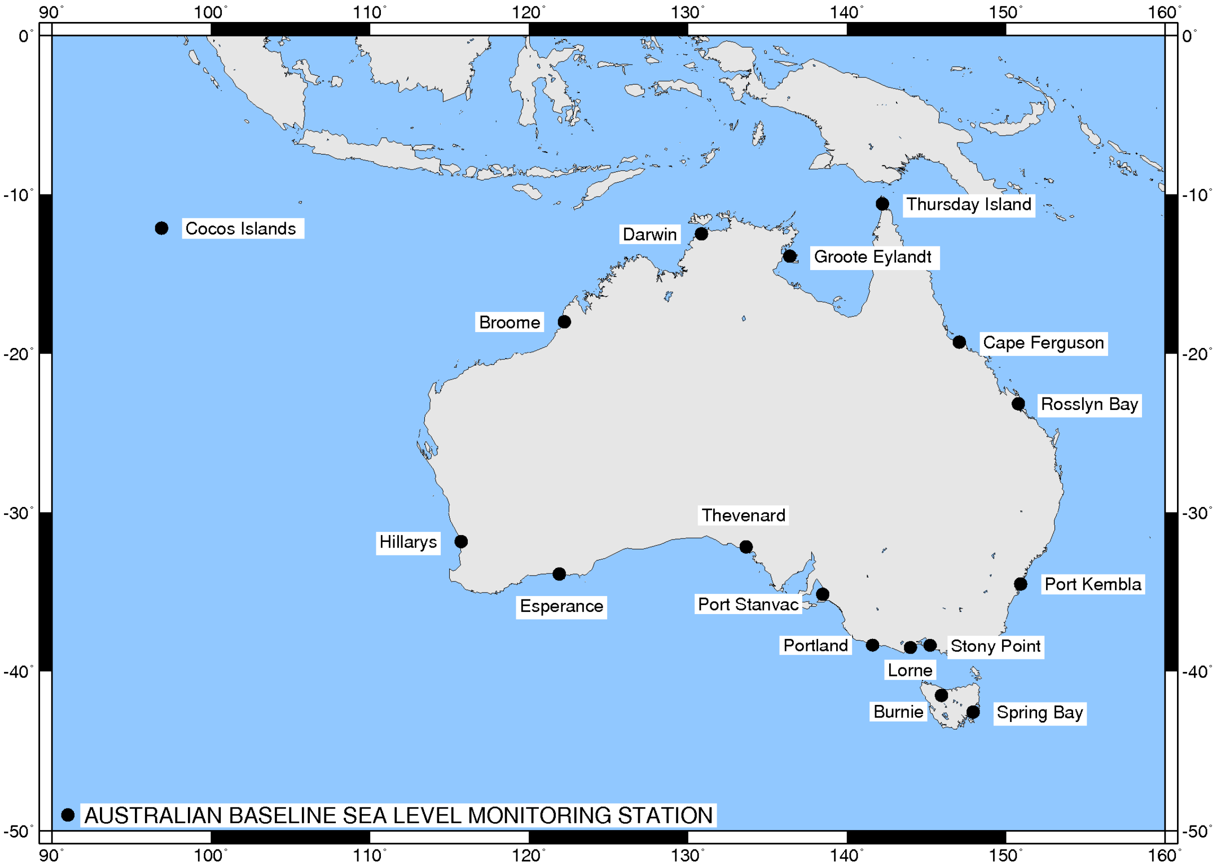

Figure 1. Australian Baseline Sea Level Monitoring Network of SEAFRAME stations.

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 around Australia are largely influenced by fluctuations in climate and ocean heat content.

Intra-annual or seasonal changes in sea level are closely linked to the annual solar radiation cycle and associated shifts in weather patterns and ocean current systems. Across southern Australia, sea levels tend to be at their highest during winter, while the opposite is true across northern Australia, where sea levels tend to be higher during the summer wet season. Further information relating to seasonal climate variations around Australia is provided by the Bureau of Meteorology at http://www.bom.gov.au/climate/

Inter-annual sea level variations are largely influenced by the El Niño – Southern Oscillation climate cycle, particularly across the northern and western Australian coastlines. Sea levels are generally lower than normal around Australia during El Niño, in response to cooler than normal ocean temperatures and higher than normal barometric pressures that are brought about by weaker than normal easterly Trade Winds across the Pacific. Conversely, during La Niña sea levels around Australia are generally higher than normal, in association with warmer than normal ocean temperatures and lower than normal barometric pressures, due to stronger than normal easterly Trade Winds across the Pacific.

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

September 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 Groote Eylandt and Hillarys 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. The full moon fell on the 2nd of September while a new moon fell on the 17th of the month.

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.

Low pressure systems 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 bay or 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).

The sea level residuals at all stations from time to time and 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 a major part of 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 to 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 Cocos Island were light from the south-east for much of September.

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.

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, particularly those along the southern Australian coastline.

The monthly data extremes 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 the ABSLMA data, which have been collected since May 1990 when the first station was installed at Darwin.

The SEAFRAME station at Thursday Island has only been collecting data since April 2015, and the monthly data extremes do not include data from an earlier tide gauge.

A record-high September sea level of 3.386 m was observed at Thursday Island this month.

A record-high September water temperature of 28.4 °C was observed at Broome during September 2020.

Further sea level and meteorological statistical information is available at http://www.bom.gov.au/oceanography/projects/abslmp/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. The monthly means demonstrate the seasonal variations of the recorded parameters. Groote Eylandt, for example, normally experiences an annual sea level cycle of about 0.6 m that peaks around February of each year.

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 residuals after tides, annual and semi-annual seasonal cycles and linear slope have been removed by way of harmonic tidal analysis of the complete record. The annual sea level cycle at Groote Eylandt (which has the largest consistent annual cycle) is quite notable 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 around much of Australia during the 1997/98 El Niño.

Monthly mean sea levels were slightly lower than normal in the south-eastern region of Australia from Portland to Port Kembla with anomalies ranging from -3 cm to -1 cm. Significant positive sea level anomalies include Cape Ferguson (+9 cm), Thursday Island (+6 cm), Broome (+6 cm), Cocos Island (+5 cm), Darwin (+4 cm), Hillarys (+4 cm) and Rosslyn Bay (+4 cm).

The anomalies of barometric pressure (Figure 18), water and air temperature (Figure 19 and Figure 20 respectively) are determined in the same manner as the sea level anomalies, except the linear slope is not calculated.

Significant barometric pressure anomalies were observed at Port Kembla (+3.2 hPa), Rosslyn Bay (+1.8 hPa), Spring Bay (+1.7 hPa), Burnie (+1.5 hPa), and Cape Ferguson (+1.2 hPa). Barometric pressures at all other locations were near or slightly lower than normal for this time of the year.

Water temperatures were generally near normal for this time of the year except for Broome (+2.2 °C anomaly), Darwin (+0.8 °C) and Cocos Island (+0.6 °C).

Air temperature anomalies were positive at all locations this month with significant anomalies being observed at Broome (+1.6 °C), Cocos Island (+1.0 °C), Groote Eylandt (+1.0 °C), Darwin (+1.0 °C) and Hillarys (+1.0 °C).

Overall Rate of Movement in Sea Level

Table 1 shows the overall rate of movement in sea level at individual Australian Baseline stations based on the data so far collected at those sites. For most sites, the underlying data sets now exceed twenty years in length, Thursday Island being the exception.

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. The rates are relative to the SEAFRAME sensor benchmark, whose movement relative to inland benchmarks is monitored by Geosciences Australia.

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 September 2020.

Location	Latitude	Longitude	Date of first data	Rate[1] (mm/yr)	Change in rate from previous month (mm/yr)
Cocos Island	12°07'07.1"S	96°53'30.9"E	Sep 1992	7.0	0.0
Groote Eylandt	13°51'36.2"S	136°24'56.1"E	Sep 1993	3.9	0.0
Darwin	12°28'18.4"S	130°50'45.1"E	May 1990	5.4	0.0
Broome	18°00'03.0"S	122°13'07.1"E	Nov 1991	5.5	0.0
Hillarys	31°49'32.0"S	115°44'18.9"E	Nov 1991	6.2	0.0
Esperance	33°52'15.2"S	121°53'43.3"E	Mar 1992	4.3	0.0
Thevenard[3]	32°08'56.2"S	133°38'28.8"E	Mar 1992	4.1	0.0
Port Stanvac[2]	35°06'31.0"S	138°28'1.3"E	Jun 1992	4.7	0.0
Portland	38°20'36.4"S	141°36'47.4"E	Jul 1991	2.8	0.0
Lorne	38°32'49.4"S	143°59'19.8"E	Jan 1993	2.4	0.0
Stony Point	38°22'19.7"S	145°13'28.9"E	Jan 1993	2.5	0.0
Burnie	41°03'0.3"S	145°54'54.0"E	Sep 1992	2.9	0.0
Spring Bay	42°32'45.1"S	147°55'57.8"E	May 1991	3.5	0.0
Port Kembla	34°28'25.5"S	150°54'42.7"E	Jul 1991	3.5	0.0
Rosslyn Bay	23°09'39.7"S	150°47'24.6"E	Jun 1992	4.9	0.0
Cape Ferguson	19°16'38.4"S	147°03'30.4"E	Sep 1991	4.7	+0.1
Thursday Island	10°35'11.4"S	142°13'18.8"E	May 2015	9.3	+1.1

[1]Relative to SSBM (SEAFRAME Sensor Bench Mark)
[2]Port Stanvac decommissioned November 2010
[3]Thevenard decommissioned May 2019

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 operating network during September 2020 was 99.6% (87.9% when Thevenard and Port Stanvac are included in the network) (Table 2). The Thevenard SEAFRAME was removed in May 2019 to allow for wharf refurbishment and Port Stanvac was removed in November 2010.

The re-location of the Broome SEAFRAME was successfully completed on the 15th of April 2020 and all sensors are now operational.

The performance of the meteorological sensors was generally satisfactory this month; the water temperature sensors at Groote Eylandt, Rosslyn Bay and Cape Ferguson remain faulty. Uncertainty remains as to the accuracy of the Stony Point anemometer and the winds have not been published. The anemometer at Burnie appears to be failing and wind data from the 27th has been removed.

Table 2. Rates of sea level data return.

Location	Installation Date	Data Return Since Installation (%)	Data Return in September 2020 (%)
Cocos Islands	Sep 1992	98.3	99.9
Groote Eylandt	Sep 1993	98.3	100
Darwin	May 1990	99.8	98.0
Broome	Nov 1991	97.2	100
Hillarys	Nov 1991	99.9	100
Esperance	Mar 1992	98.0	100
Thevenard[2]	Mar 1992	94.5	0.0
Port Stanvac[1]	Jun 1992	85.2	0.0
Portland	Jul 1991	99.3	100
Lorne	Jan 1993	95.6	99.7
Stony Point	Jan 1993	98.9	100
Burnie	Sep 1992	98.8	100
Spring Bay	May 1991	99.5	96.6
Port Kembla	Jul 1991	99.6	100
Rosslyn Bay	Jun 1992	99.3	100
Cape Ferguson	Sep 1991	98.0	100
Thursday Island	May 2015	97.6	100
Network Average		**97.5**	**87.9**

[1]Port Stanvac decommissioned November 2010
[2]Thevenard decommissioned May 2019

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.

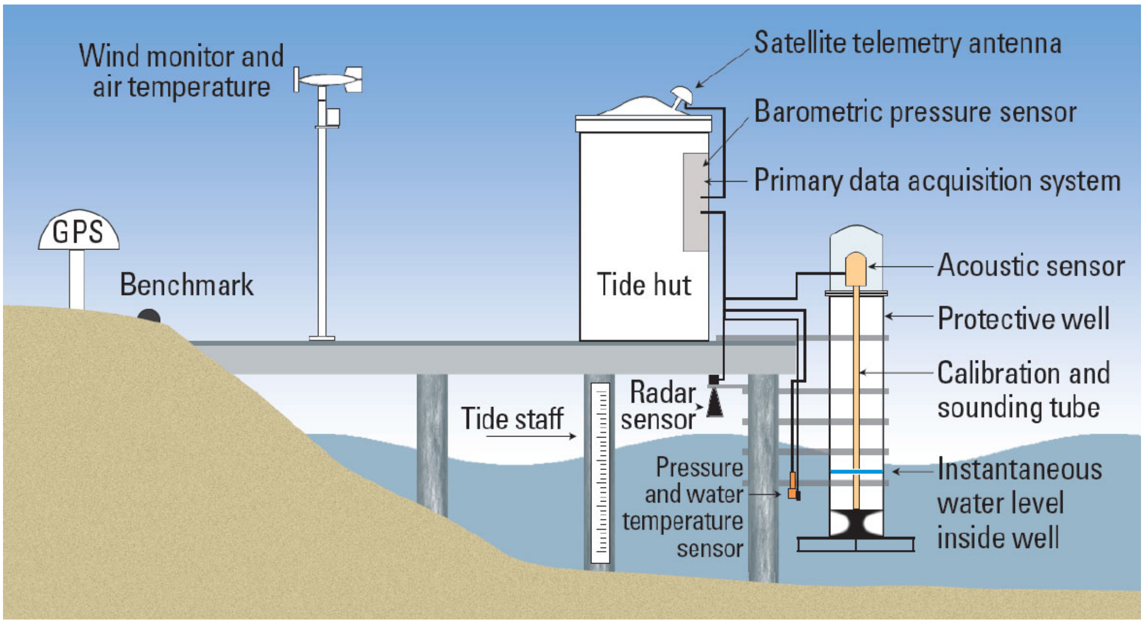

Figure 2. Schematic diagram of a SEAFRAME sea level monitoring station.

Further Information

Online Resources

ABSLMA Web site: http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml

ABSLMA Levelling Survey (Geosciences Australia): ftp://ftp.ga.gov.au/geodesy-outgoing/local_tie/TideGaugeLeveling/ABSLMA/

Ocean Forecasts: http://www.bom.gov.au/oceanography/forecasts

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

Sea Level Rise (CSIRO): http://www.cmar.csiro.au/sealevel/index.html

Acknowledgement

The Monthly Data Report is prepared by the Bureau of Meteorology.

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

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Please also note the following:

Appendix 1: SEAFRAME Data Figures

Please note: The privately-owned stations at Stony Point and Lorne do not record air temperature, water temperature and barometric pressure data and are not present in Figures 5, 9, 10, 11 and 12. The tide gauge at Lorne does not record wind data and is not present in Figures 6, 7 and 8.

The anemometers at Esperance and Spring Bay have been removed.

SIX MINUTE SEA LEVEL OBSERVATIONS (m)

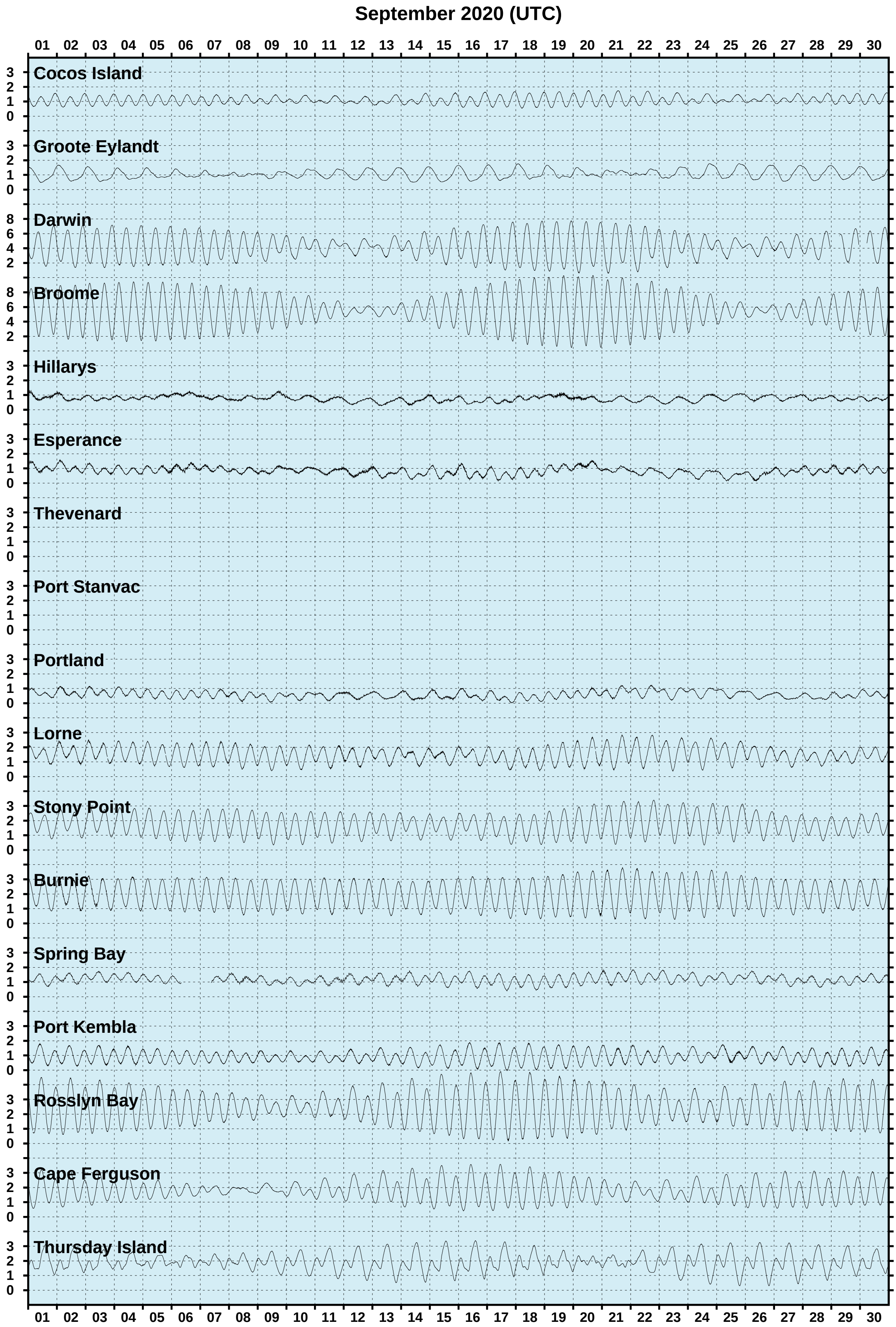

Figure 3. Sea level observations during September 2020.

SIX MINUTE RESIDUAL WATER LEVELS (m)

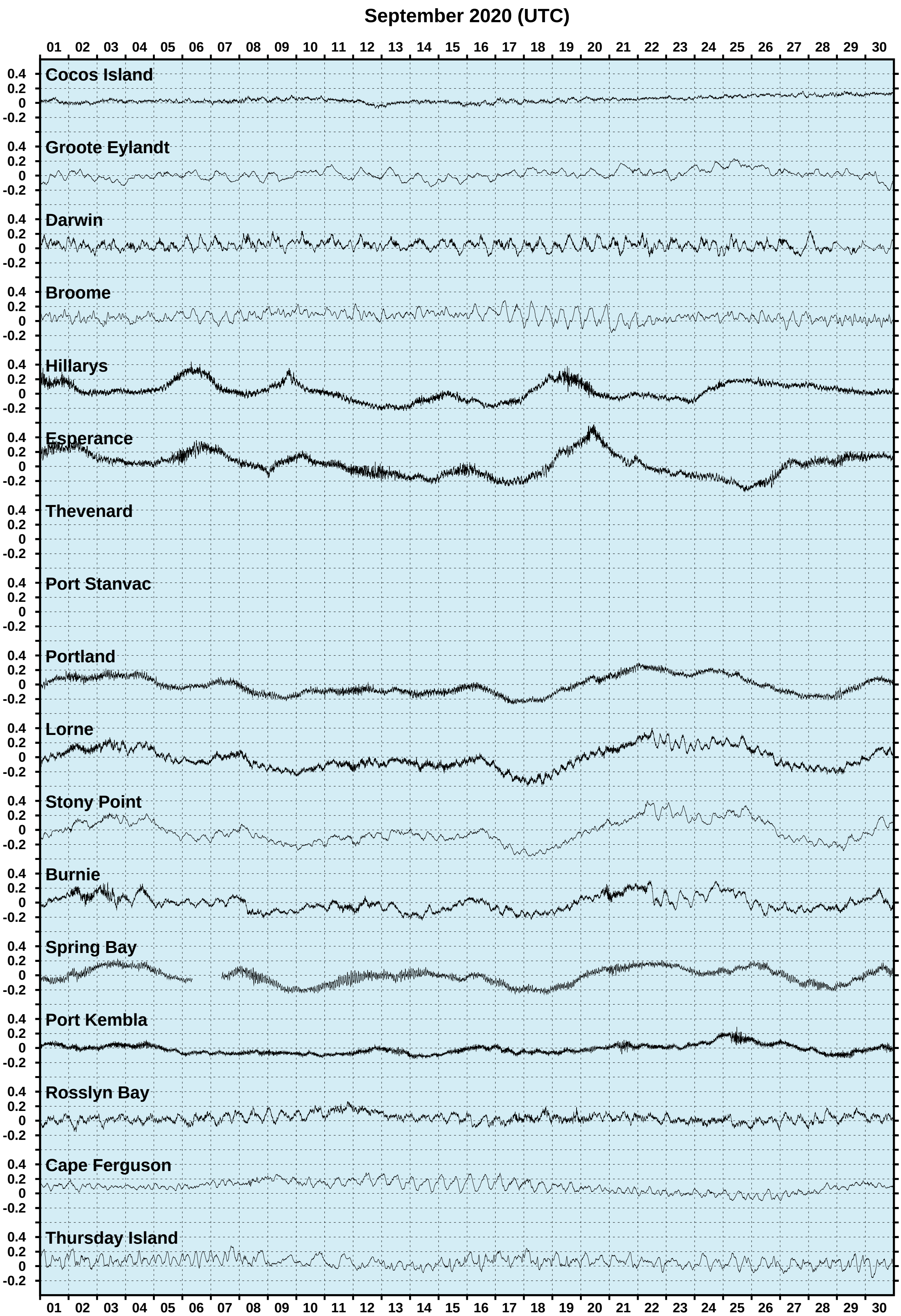

Figure 4. Residual sea levels during September 2020.

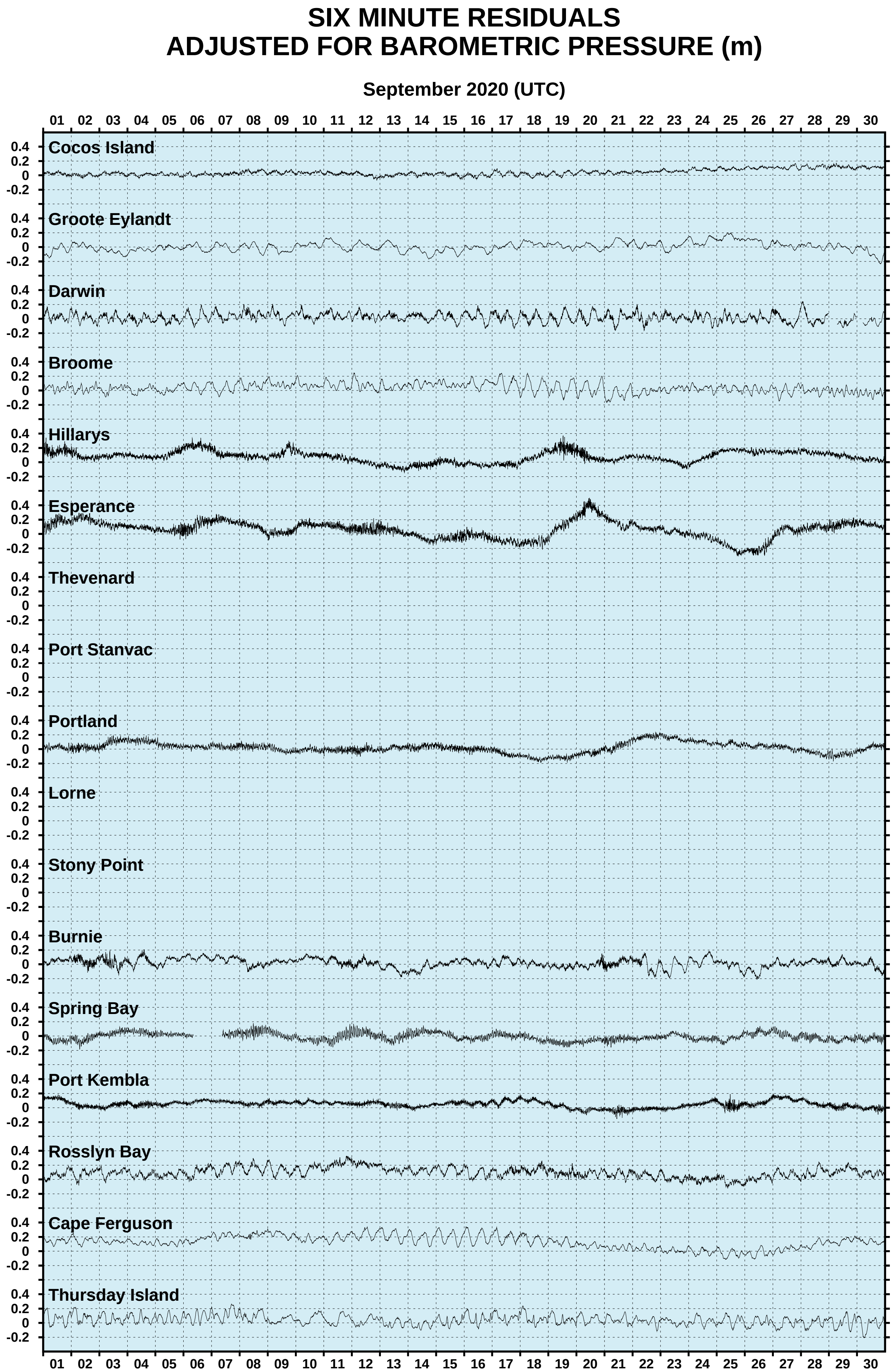

Figure 5. Residual sea levels adjusted for barometric pressure during September 2020.

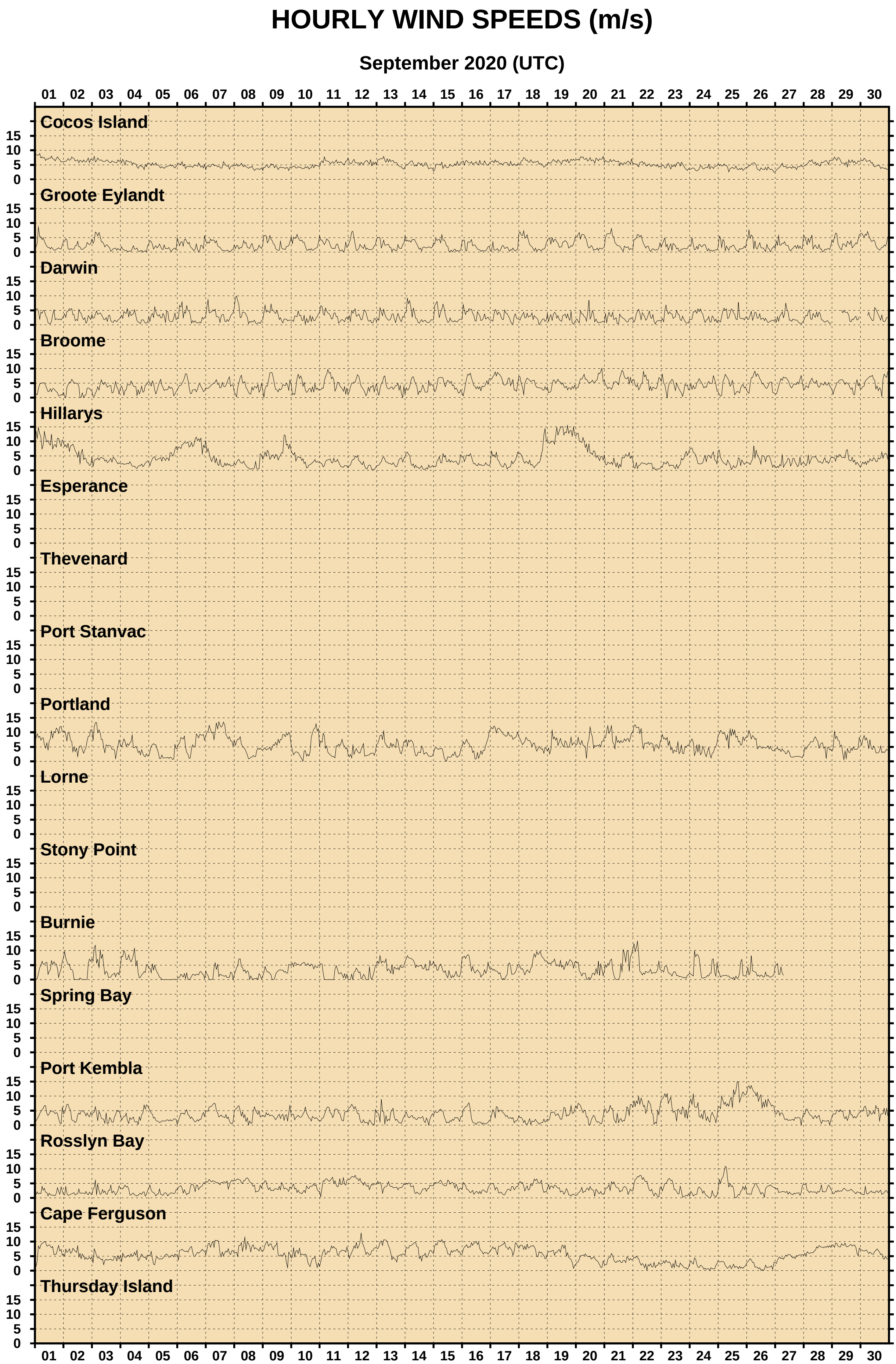

Figure 6. Wind speeds during September 2020.

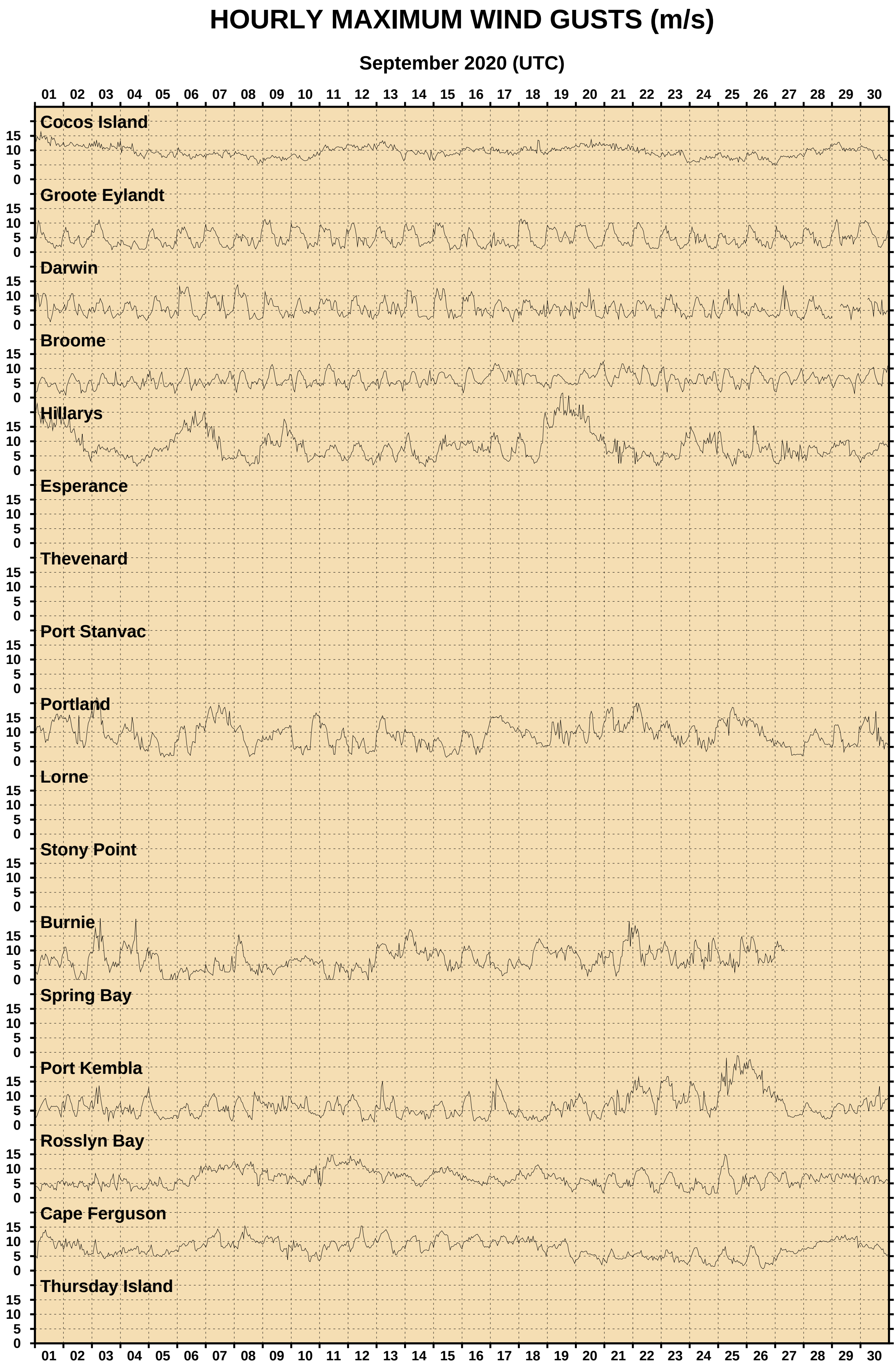

Figure 7. Wind gusts during September 2020.

HOURLY INCIDENT WINDS (m/s, °True)

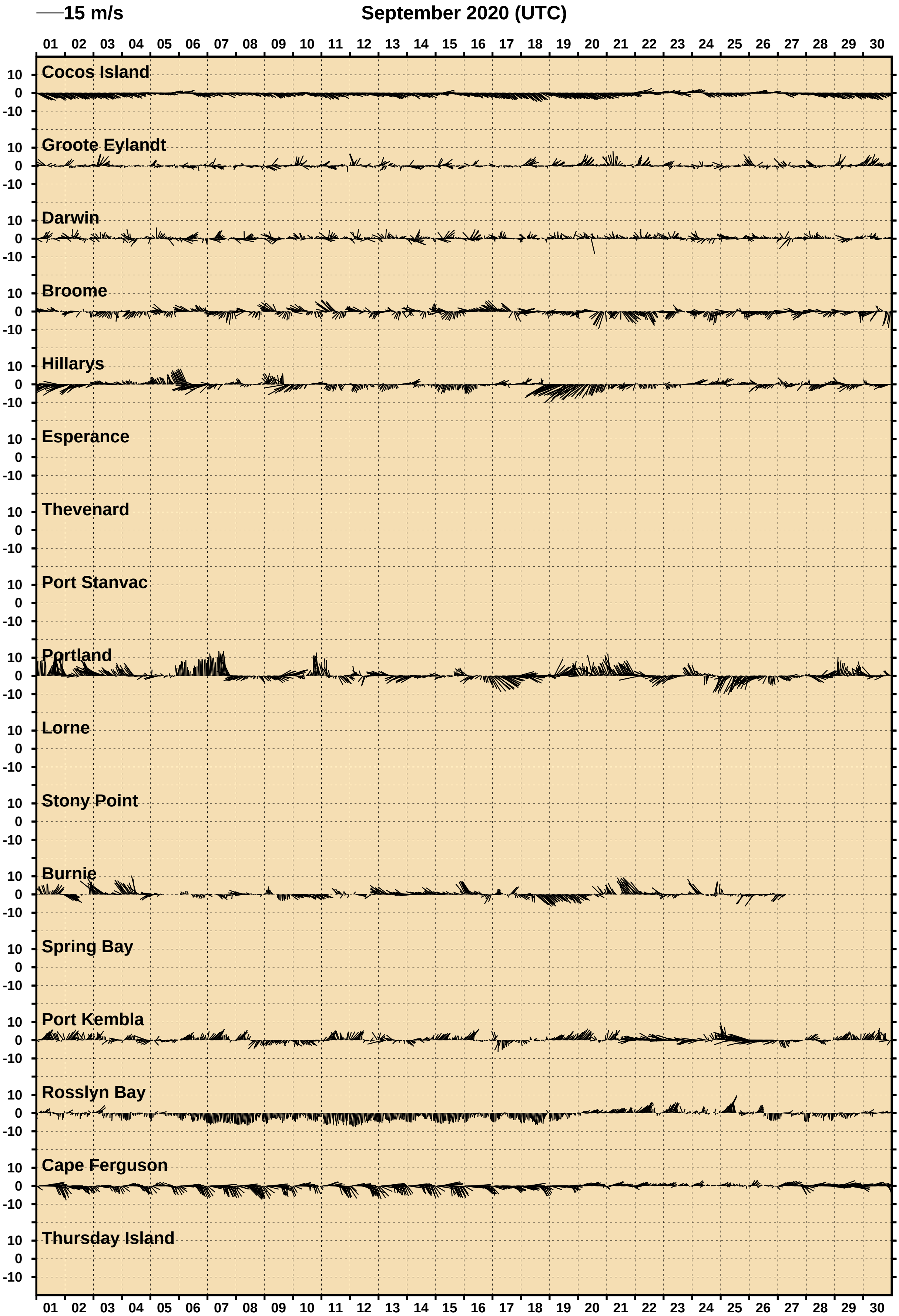

Figure 8. Incident winds during September 2020.

HOURLY AIR TEMPERATURES (°C)

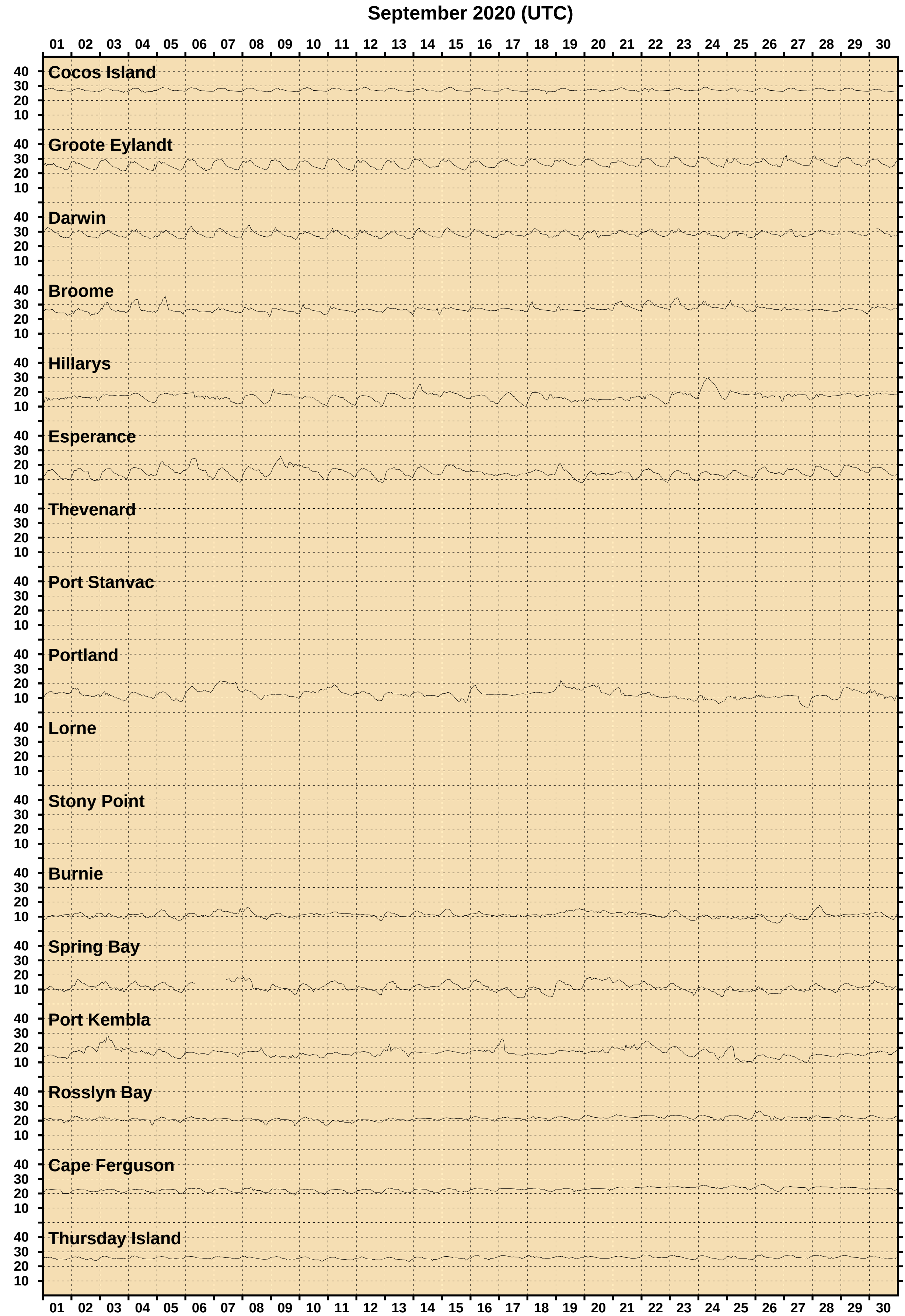

Figure 9. Air temperatures during September 2020.

HOURLY WATER TEMPERATURES (°C)

Figure 10. Water temperatures during September 2020.

HOURLY BAROMETRIC PRESSURE (hPa)

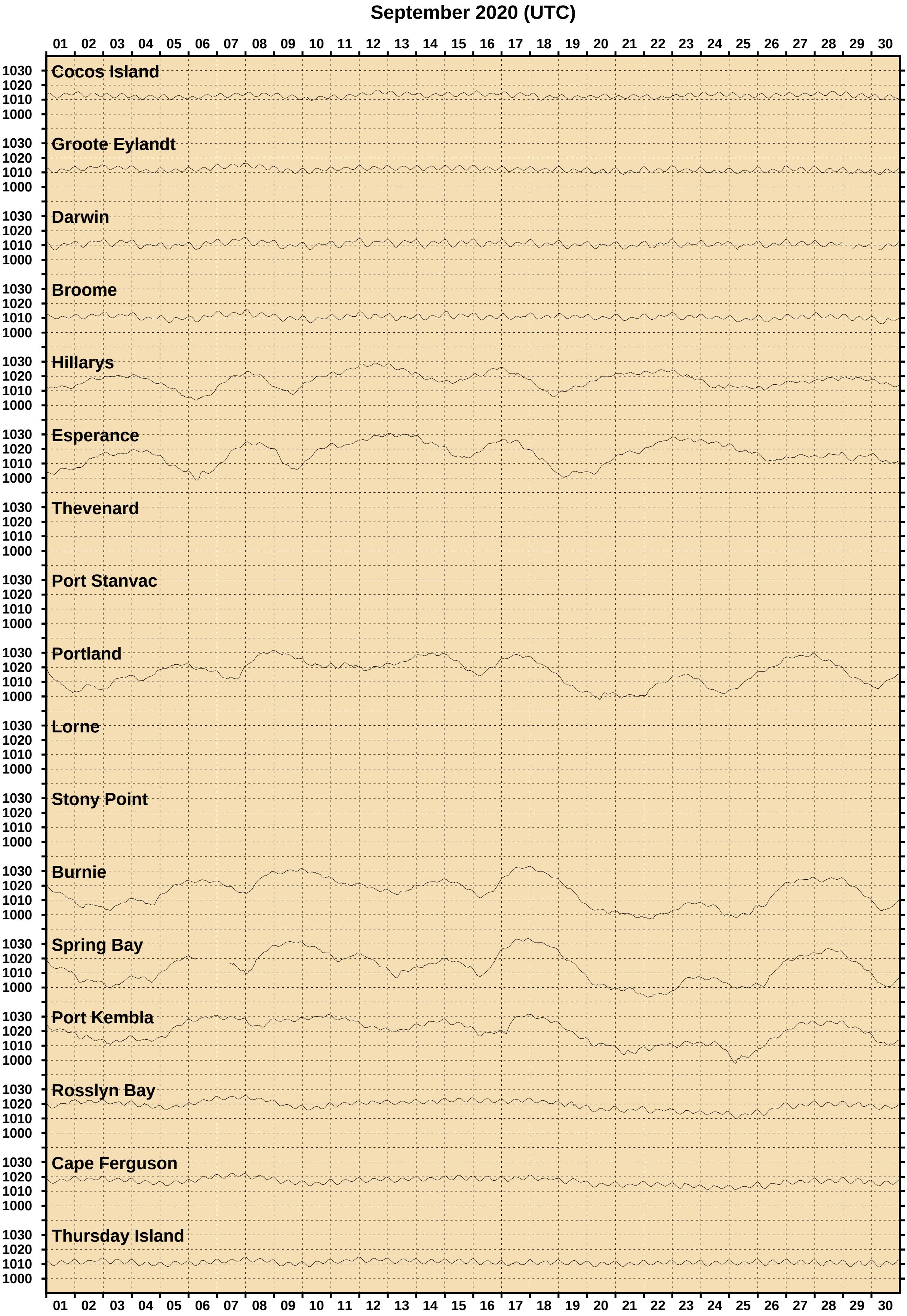

Figure 11. Barometric pressures during September 2020.

COMPARISON OF SEPTEMBER 2020 MAX,MIN AND MEAN WITH LONG-TERM SEPTEMBER VALUES

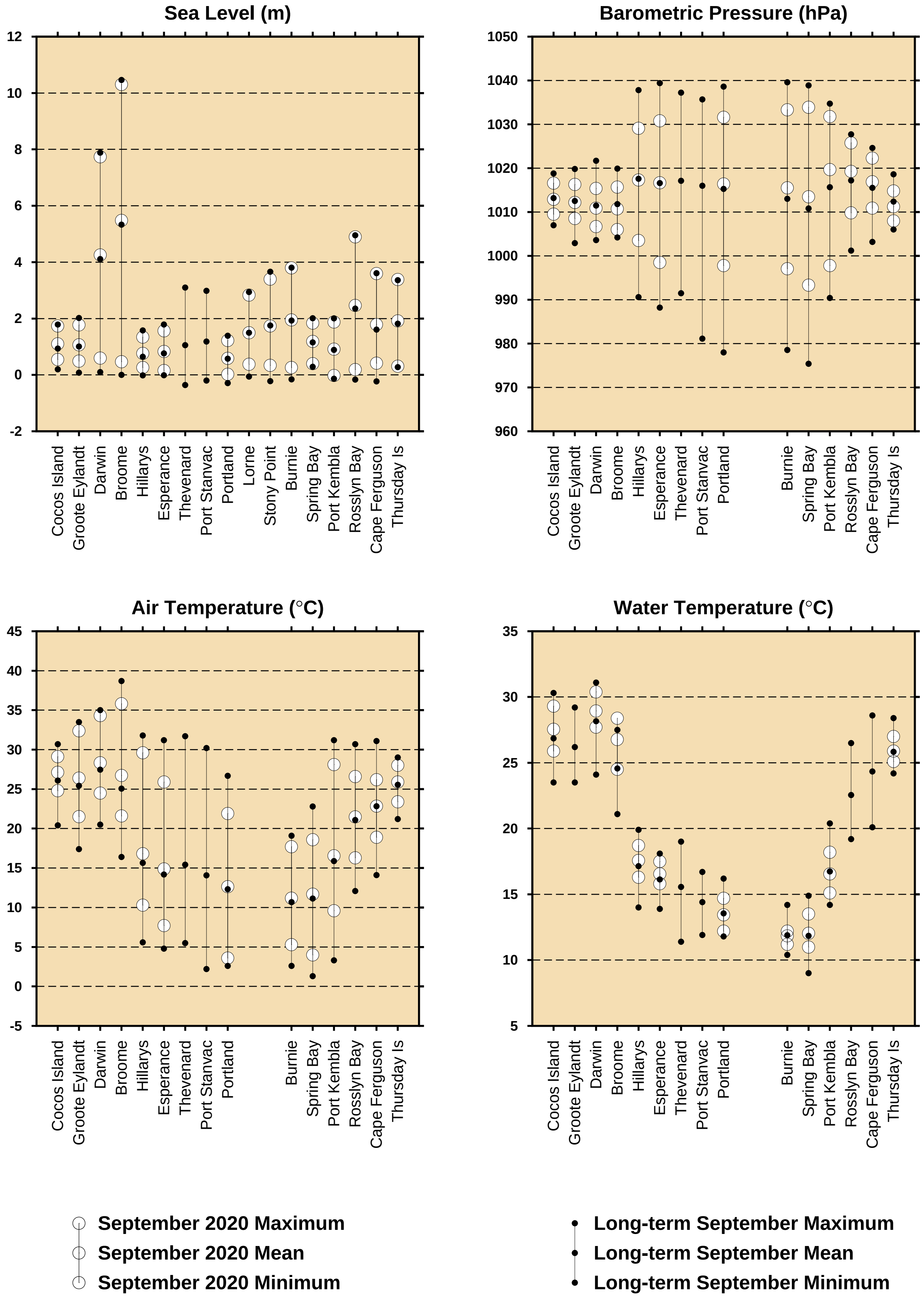

Figure 12. Comparison of September 2020 data with long-term September values.

MONTHLY MEAN SEA LEVELS THROUGH SEPTEMBER 2020 (m)
(The zero line represents mean sea level)

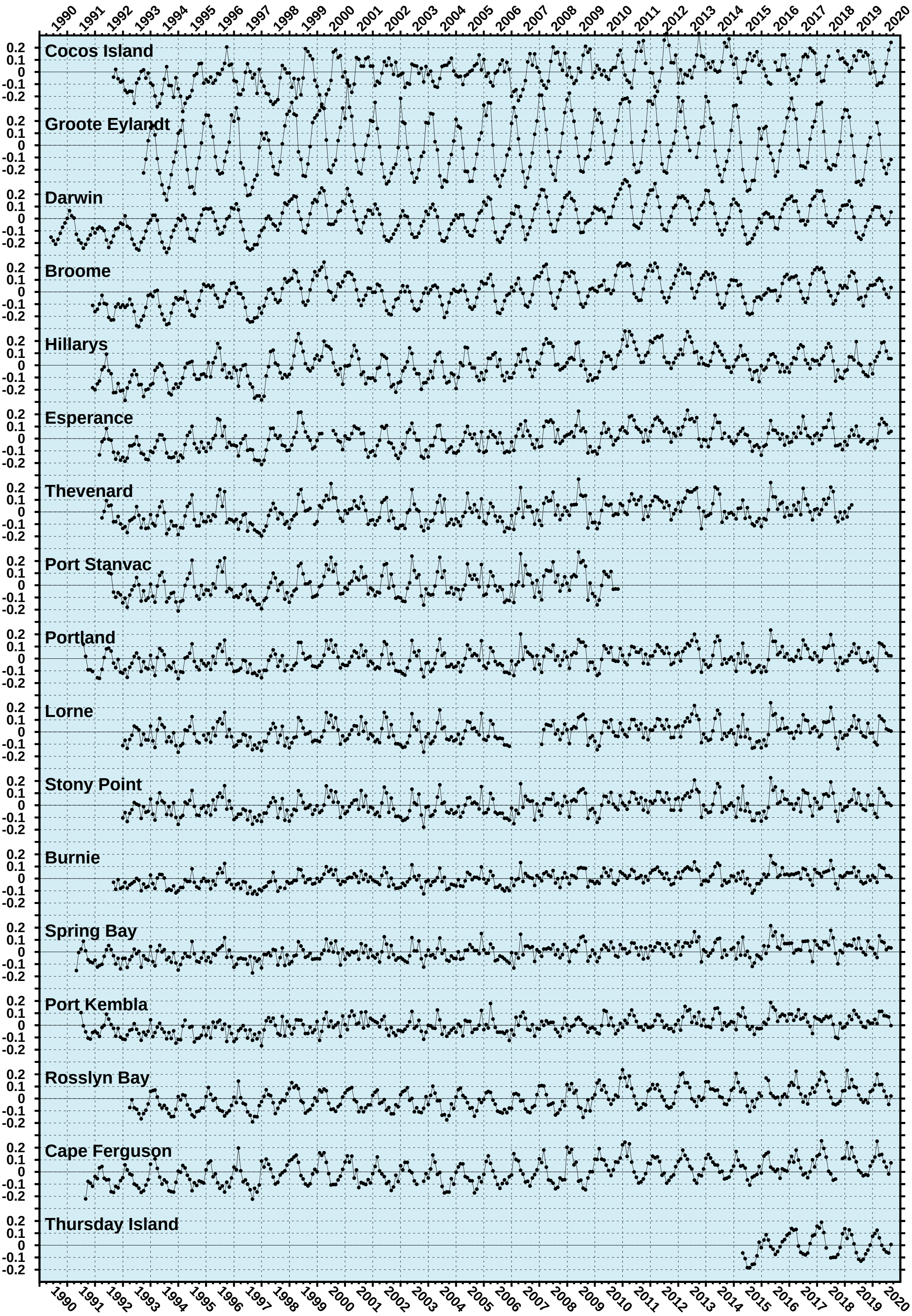

Figure 13. Monthly mean sea levels to September 2020.

MONTHLY MEAN BAROMETRIC PRESSURES THROUGH SEPTEMBER 2020 (hPa)

Figure 14. Monthly mean barometric pressures to September 2020.

MONTHLY MEAN WATER TEMPERATURES THROUGH SEPTEMBER 2020 (°C)

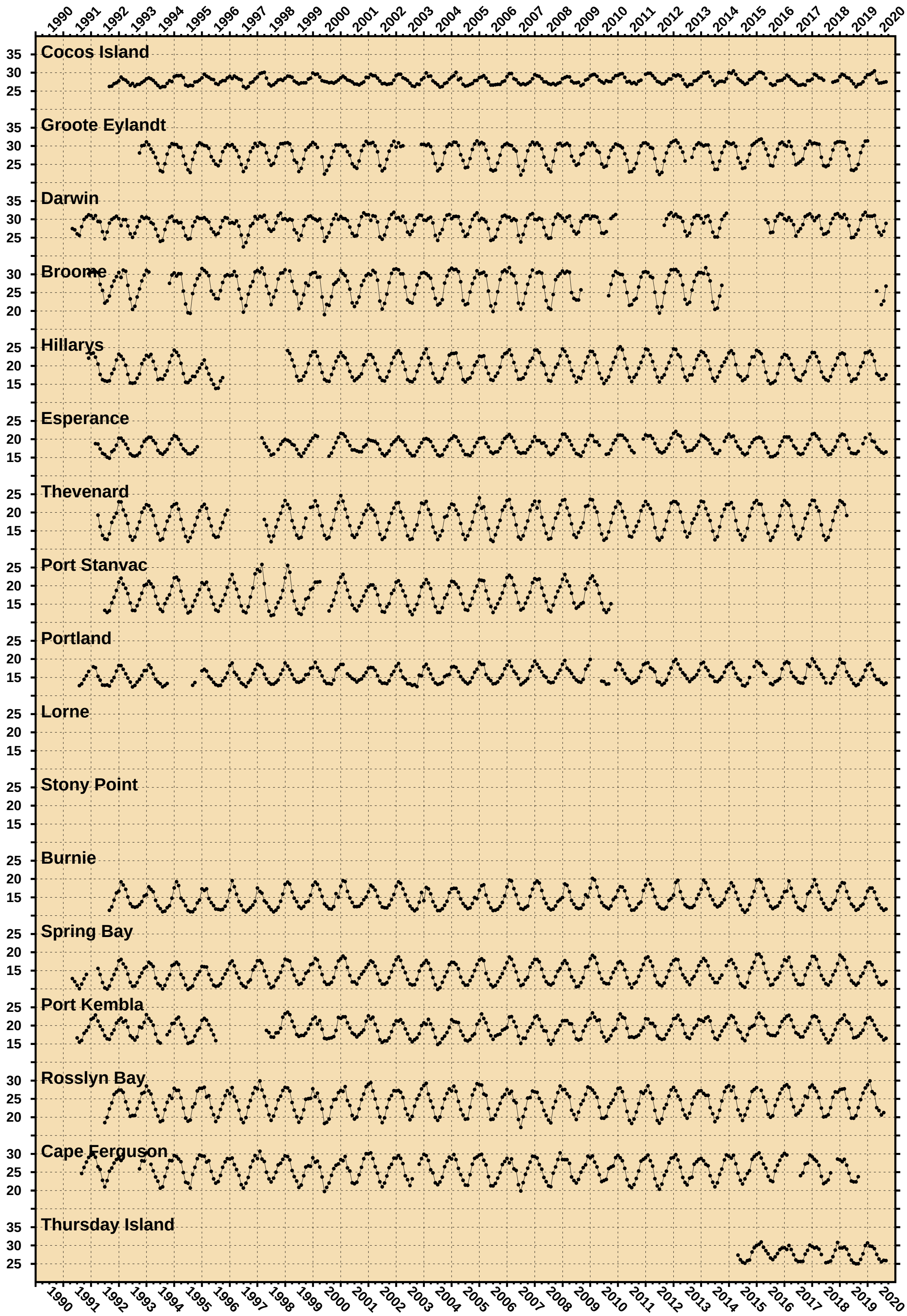

Figure 15. Monthly mean water temperatures to September 2020.

MONTHLY MEAN AIR TEMPERATURES THROUGH SEPTEMBER 2020 (°C)

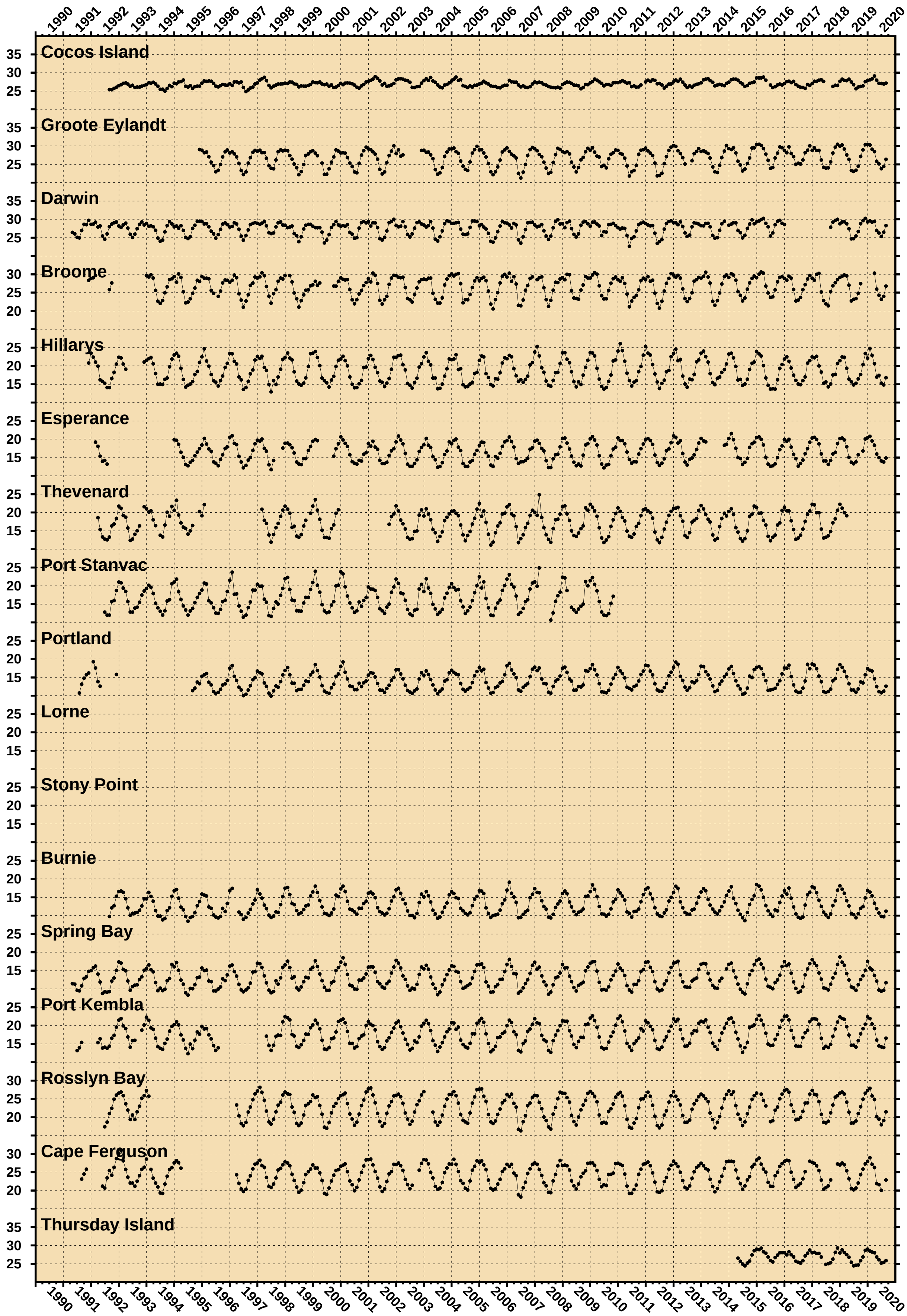

Figure 16. Monthly mean air temperatures to September 2020.

SEA LEVEL ANOMALIES THROUGH SEPTEMBER 2020 (m)

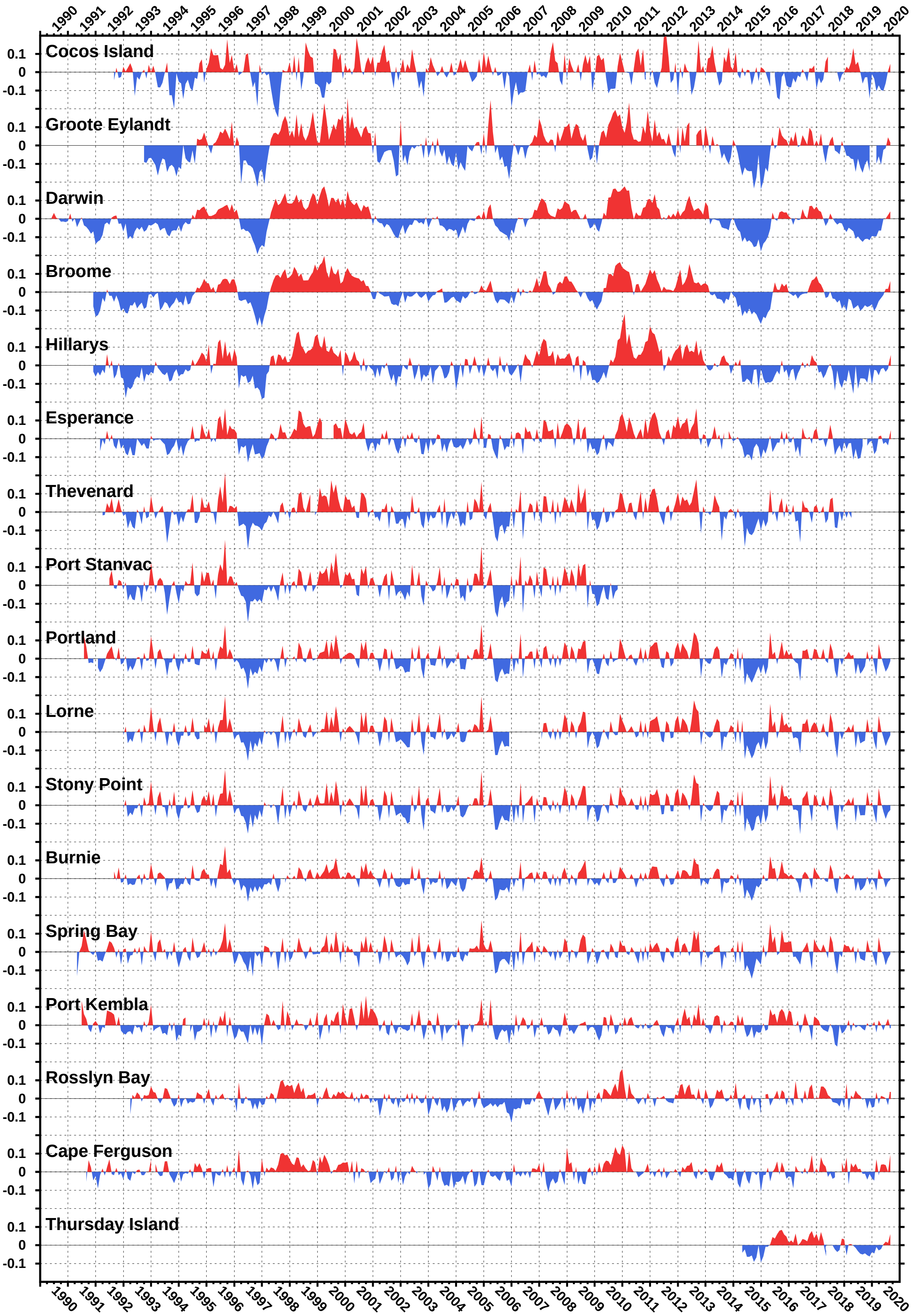

Figure 17. Monthly sea level anomalies to September 2020.

BAROMETRIC PRESSURE ANOMALIES THROUGH SEPTEMBER 2020 (hPa)

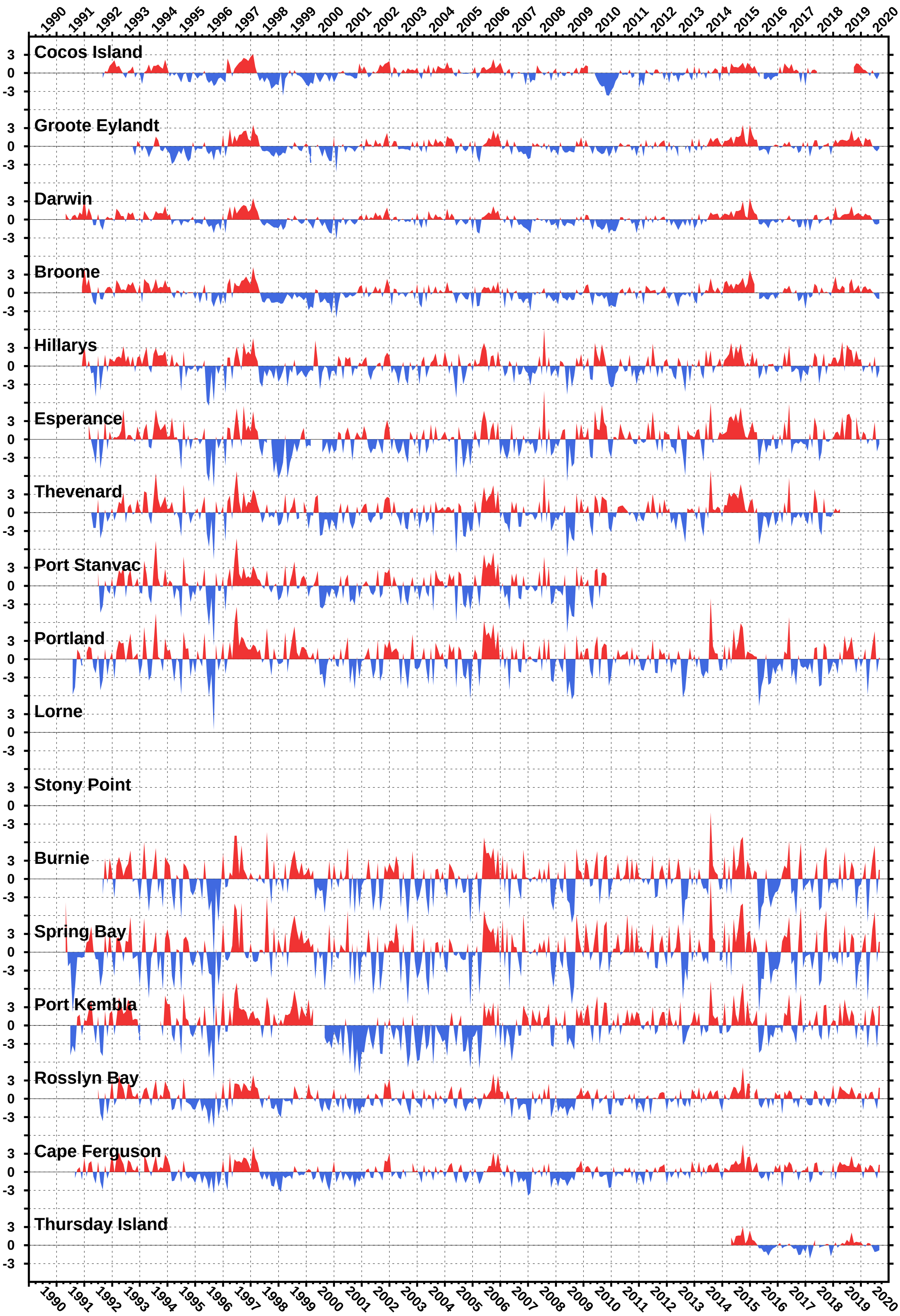

Figure 18. Monthly barometric pressure anomalies to September 2020.

WATER TEMPERATURE ANOMALIES THROUGH SEPTEMBER 2020 (°C)

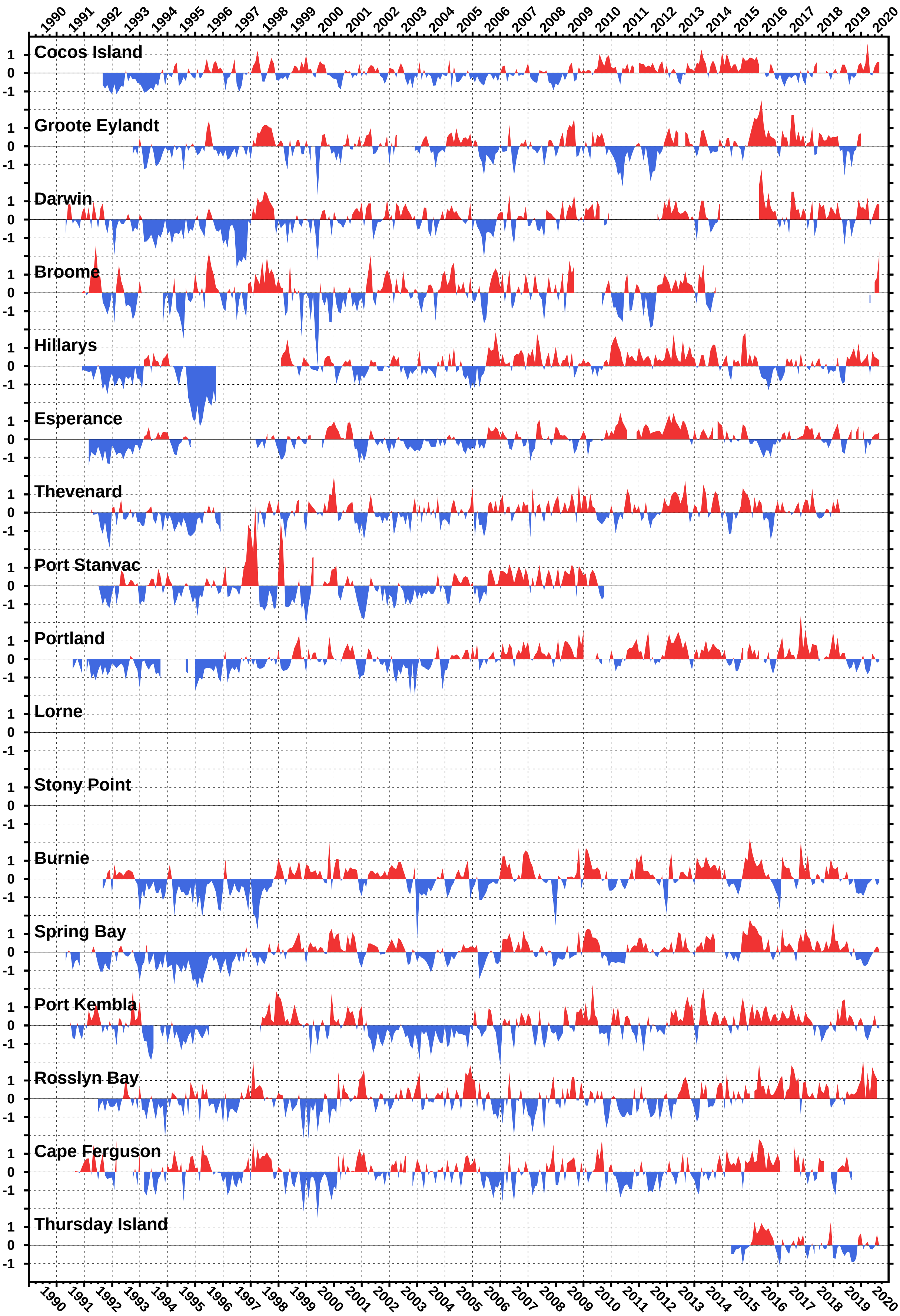

Figure 19. Monthly water temperature anomalies to September 2020.

AIR TEMPERATURE ANOMALIES
THROUGH SEPTEMBER 2020 (°C)

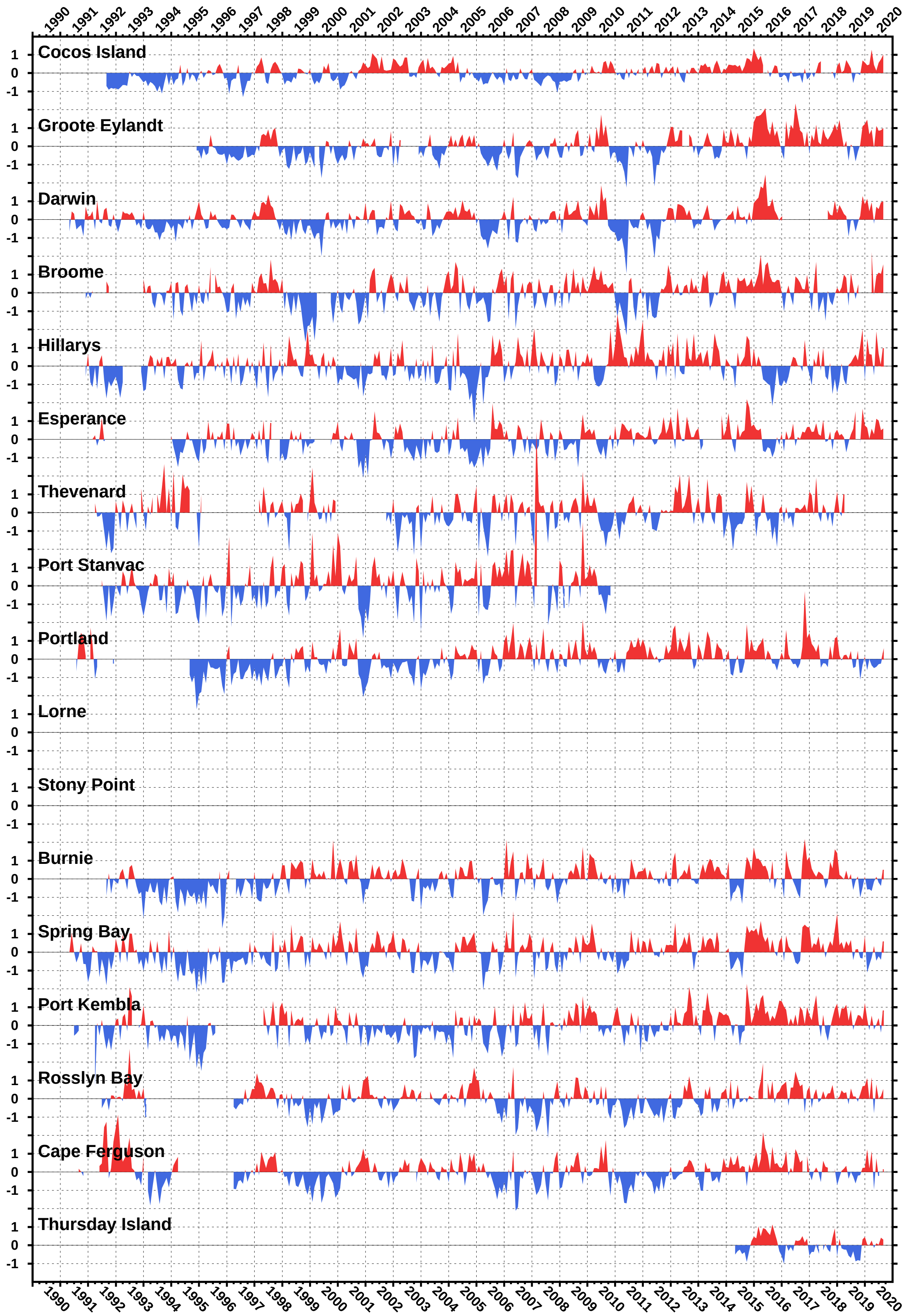

Figure 20. Monthly air temperature anomalies to September 2020.

MONTHLY SEA LEVEL DATA RETURN
THROUGH SEPTEMBER 2020 (%)

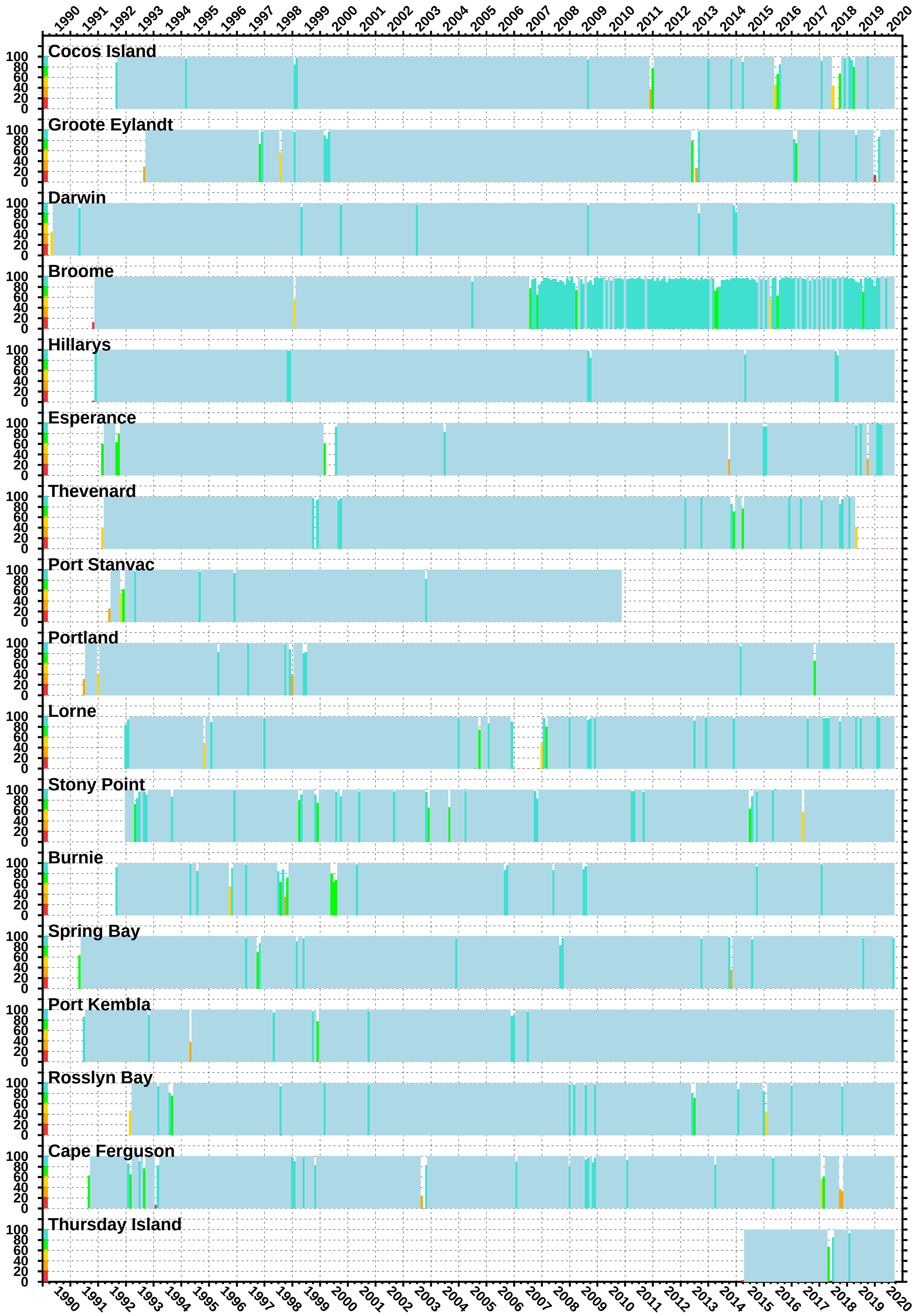

Figure 21. Sea level data return.