2.4 CLIMATE AND OCEANIC INDICATORS

2.4.1 Introduction

Over the past few years, the Council has incorporated climate change into the overall management of the fisheries over which it has jurisdiction. This 2020 annual SAFE report includes a now standard chapter on indicators of climate and oceanic conditions in the Western Pacific region. These indicators reflect global climate variability and change as well as trends in local oceanographic conditions.

The reasons for the Council's decision to provide and maintain an evolving discussion of climate conditions as an integral and continuous consideration in their deliberations, decisions, and reports are numerous:

- Emerging scientific and community understanding of the impacts of changing climate conditions on fishery resources, the ecosystems that sustain those resources, and the communities that depend upon them;
- Recent Federal Directives including the 2010 implementation of a National Ocean Policy that identified Resiliency and Adaptation to Climate Change and Ocean Acidification as one of nine National priorities as well as the development of a Climate Science Strategy by NMFS in 2015 and the subsequent development of the Pacific Islands Regional Action Plan for climate science; and
- The Council's own engagement with NOAA as well as jurisdictional fishery management agencies in American Samoa, CNMI, Guam, and Hawai`i as well as fishing industry representatives and local communities in those jurisdictions.

In 2013, the Council began restructuring its Marine Protected Area/Coastal and Marine Spatial Planning Committee to include a focus on climate change, and the committee was renamed as the Marine Planning and Climate Change (MPCC) Committee. In 2015, based on recommendations from the committee, the Council adopted its Marine Planning and Climate Change Policy and Action Plan, which provided guidance to the Council on implementing climate change measures, including climate change research and data needs. The revised Pelagic Fisheries Ecosystem Plan (FEP; February 2016) included a discussion on climate change data and research as well as a new objective (Objective 9) that states the Council should consider the implications of climate change in decision-making, with the following sub-objectives:

a) To identify and prioritize research that examines the effects of climate change on Council-managed fisheries and fishing communities.
b) To ensure climate change considerations are incorporated into the analysis of management alternatives.
c) To monitor climate change related variables via the Council's Annual Reports.
d) To engage in climate change outreach with U.S. Pacific Islands communities.

Beginning with the 2015 report, the Council and its partners began providing continuing descriptions of changes in a series of climate and oceanic indicators. The MPCCC was disbanded in early 2019, re-allocating its responsibilities among its members already on other committees or teams, such as the Fishery Ecosystem Plan Teams.

This annual report focuses previous years' efforts by refining existing indicators and improving communication of their relevance and status. Future reports will include additional indicators as the information becomes available and their relevance to the development, evaluation, and revision of the FEPs becomes clearer. Working with national and jurisdictional partners, the Council will make all datasets used in the preparation of this and future reports available and easily accessible.

2.4.1.1 Response to Previous Council Recommendations

There were no Council recommendations relevant to the climate and oceanic indicators section of the annual SAFE report for the PRIA in 2020.

2.4.2 Conceptual Model

In developing this chapter, the Council relied on a number of recent reports conducted in the context of the U.S. National Climate Assessment including, most notably, the 2012 Pacific Islands Regional Climate Assessment and the Ocean and Coasts chapter of the 2014 report on a Pilot Indicator System prepared by the National Climate Assessment and Development Advisory Committee (NCADAC).

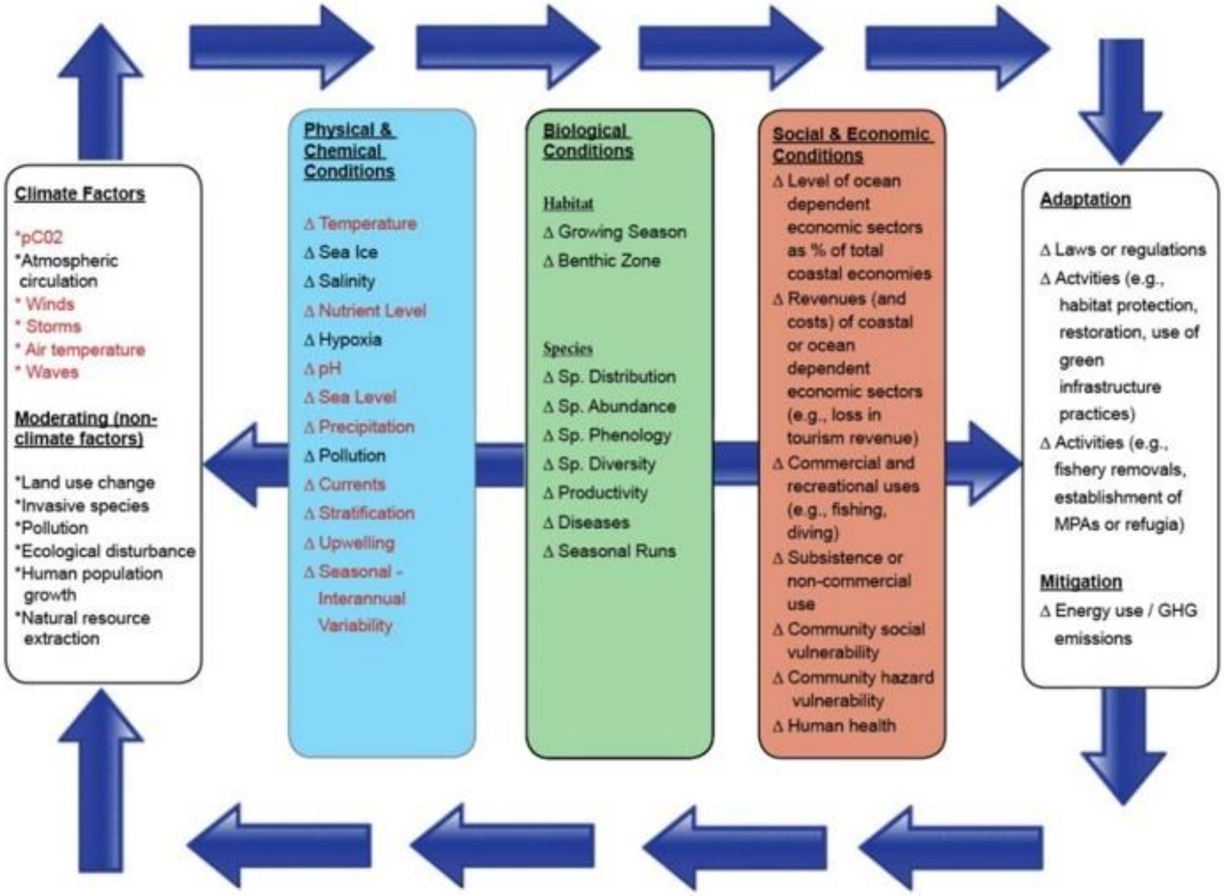
The Advisory Committee Report presented a possible conceptual framework designed to illustrate how climate factors can connect to and interact with other ecosystem components to impact ocean and coastal ecosystems and human communities. The Council adapted this model with considerations relevant to the fishery resources of the Western Pacific Region (Figure 1).

As described in the 2014 NCADAC report, the conceptual model presents a “simplified representation of climate and non-climate stressors in coastal and marine ecosystems.” For the purposes of this Annual Report, the modified Conceptual Model allows the Council and its partners to identify indicators of interest to be monitored on a continuing basis in coming years. The indicators shown in red were considered for inclusion in the annual SAFE reports, though the final list of indicators varied somewhat. Other indicators will be added over time as data become available and an understanding of the causal chain from stressors to impacts emerges.

The Council also hopes that this Conceptual Model can provide a guide for future monitoring and research. This guide will ideally enable the Council and its partners to move forward from observations and correlations to understanding the specific nature of interactions, and to develop capabilities to predict future changes of importance in the developing, evaluating, and adapting of FEPs in the Western Pacific region.

Indicators of Change to Pelagic Coastal and Marine Systems*

(Items in red to be monitored for 2015 Annual Report of the Pelagic Fishery Ecosystem Plan for the Western Pacific Region)



**Adapted from National Climate Assessment and Development Advisory Committee. February 2014. National Climate Indicators System Report. B-59.*

Figure 1. Indicators of change of pelagic coastal and marine systems; conceptual model

2.4.3 Selected Indicators

The primary goal for selecting the indicators used in this report is to provide fisheries-related communities, resource managers, and businesses with a climate-related situational awareness. In this context, indictors were selected to:

- Be fisheries relevant and informative.
- Build intuition about current conditions in light of a changing climate;
- Provide historical context; and
- Allow for recognition of patterns and trends.

In this context, this section includes the following climate and oceanic indicators:

- Atmospheric concentration of carbon dioxide (CO_2)
- Oceanic pH at Station ALOHA;
- Oceanic Niño Index (ONI);
- Pacific Decadal Oscillation (PDO);
- Tropical cyclones;
- Sea surface temperature (SST);
- Coral Thermal Stress Exposure;
- Chlorophyll-A;
- Rainfall; and
- Sea Level (Sea Surface Height).

Figure 2 and Figure 3 provide a description of these indicators and illustrate how they are connected to each other in terms of natural climate variability and anthropogenic climate change.

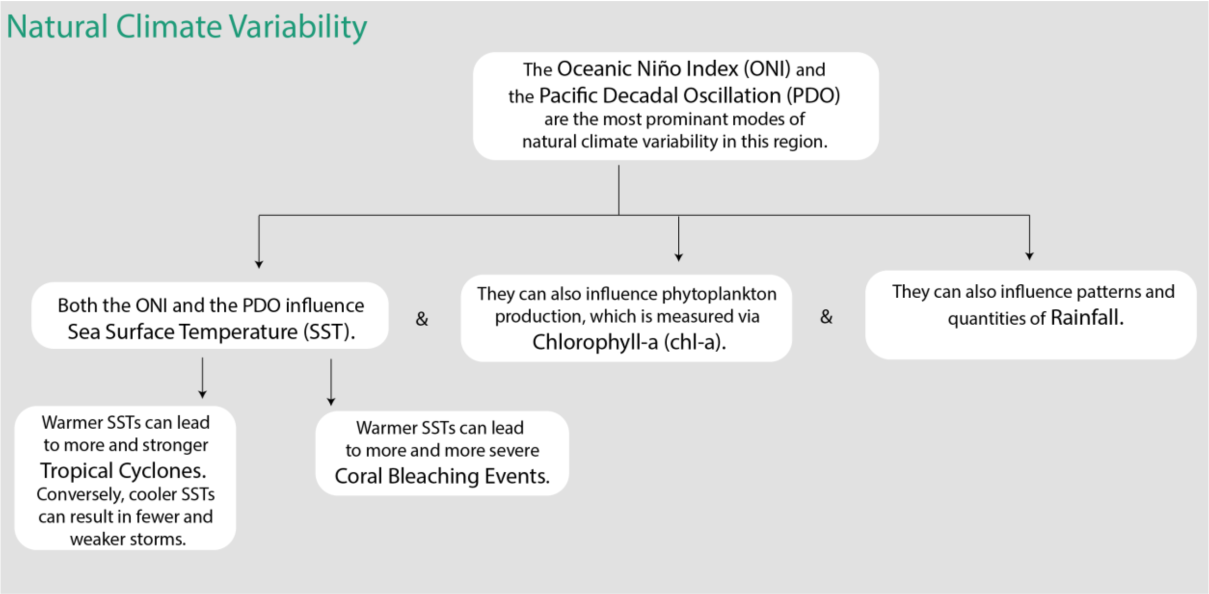


Figure 2. Schematic diagram illustrating how indicators are connected to one another and how they vary as a result of natural climate variability

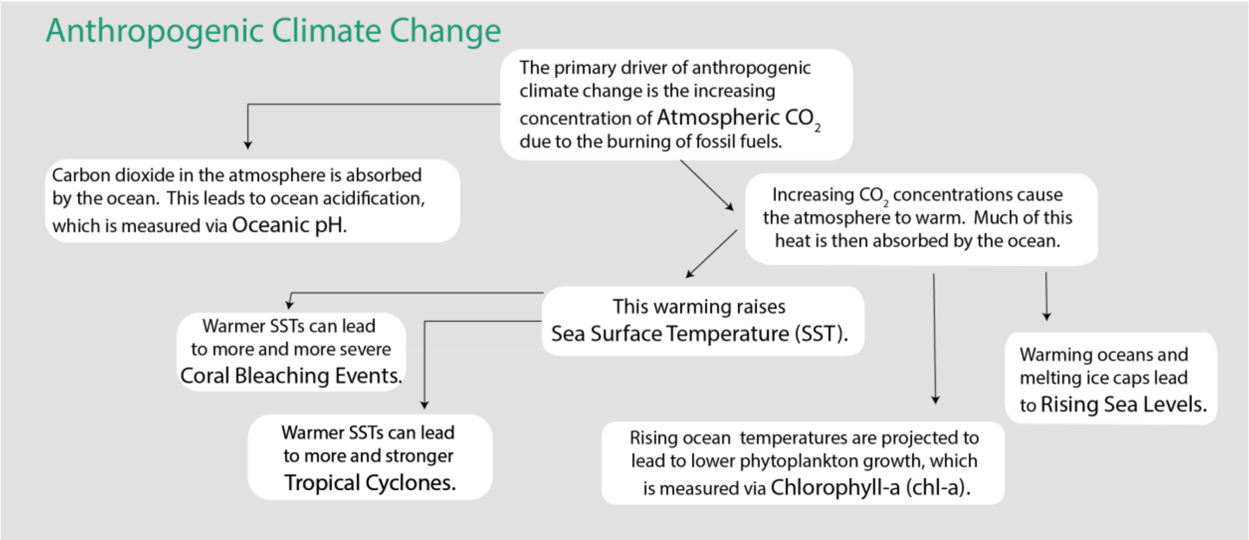


Figure 3. Schematic diagram illustrating how indicators are connected to one another and how they vary as a result of anthropogenic climate change

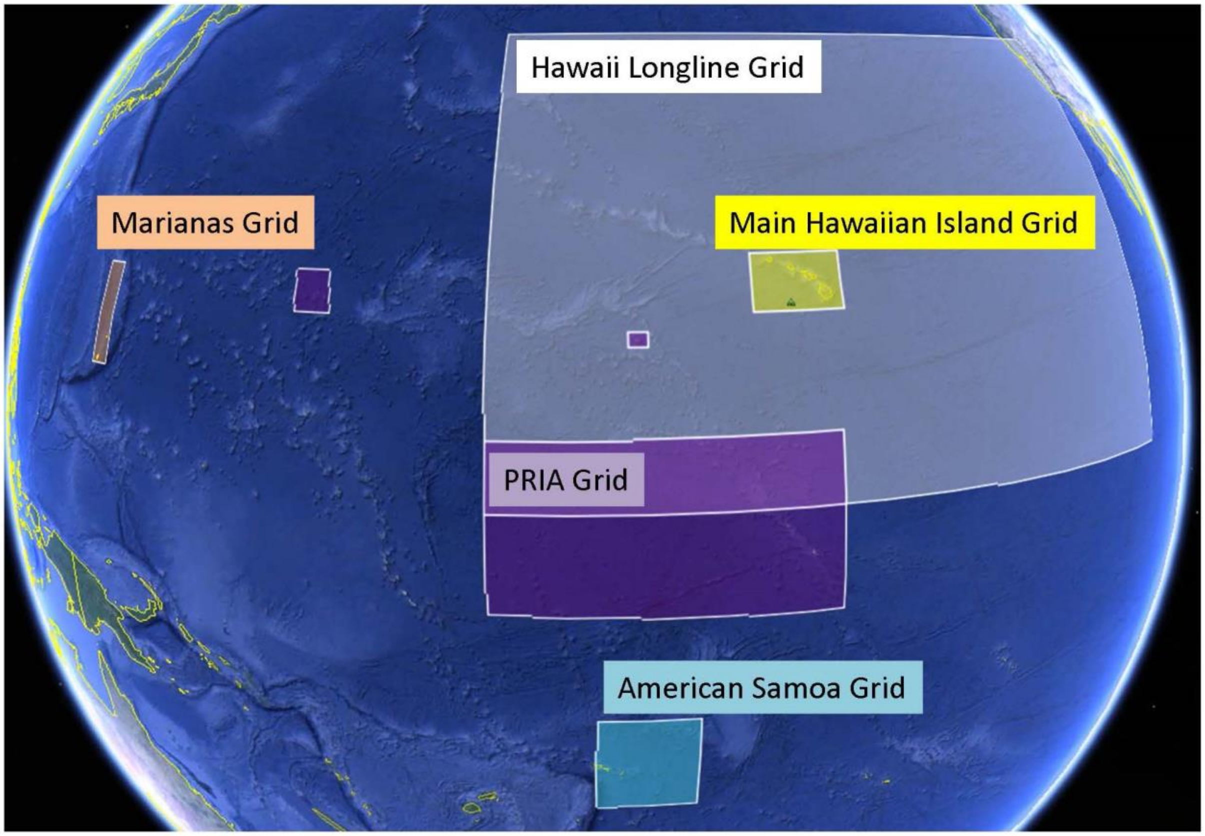


Figure 4. Regional spatial grids representing the scale of the climate change indicators being monitored

2.4.3.1 Atmospheric Concentration of Carbon Dioxide at Mauna Loa

Rationale: Atmospheric carbon dioxide (CO_2) is a measure of what human activity has already done to affect the climate system through greenhouse gas emissions. It provides quantitative information in a simplified, standardized format that decision makers can easily understand. This indicator demonstrates that the concentration (and, in turn, warming influence) of greenhouse gases in the atmosphere has increased substantially over the last several decades.

Status: Atmospheric CO_2 is increasing exponentially. This means that atmospheric CO_2 is increasing at a faster rate each year. In 2020, the annual mean concentration of CO_2 was 414 parts per million (ppm). In 1959, the first year of the time series, it was 316 ppm. The annual mean passed 350 ppm in 1988, and 400 ppm in 2015.

Description: Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawai‘i in ppm from March 1958 to present. The observed increase in monthly average carbon dioxide concentration is primarily due to CO_2 emissions from fossil fuel burning. Carbon dioxide remains in the atmosphere for a very long time, and emissions from any location mix throughout the atmosphere in approximately one year. The annual variations at Mauna Loa, Hawai‘i are due to the seasonal imbalance between the photosynthesis and respiration of terrestrial plants. During the summer growing season, photosynthesis exceeds respiration, and CO_2 is removed from the atmosphere. In the winter (outside the growing season), respiration exceeds photosynthesis, and CO_2 is returned to the atmosphere. The seasonal cycle is strongest in the northern hemisphere because of its larger land mass.

Timeframe: Annual, monthly.

Region/Location: Mauna Loa, Hawaii, but representative of global atmospheric carbon dioxide concentration.

Measurement Platform: *In-situ* station.

Sourced from: Keeling et al. (1976), Thoning et al. (1989), and NOAA (2021b).
NOAA (2021b) = Dr. Pieter Tans, NOAA/GML (www.esrl.noaa.gov/gmd/ccgg/trends/) and Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippsco2.ucsd.edu/)

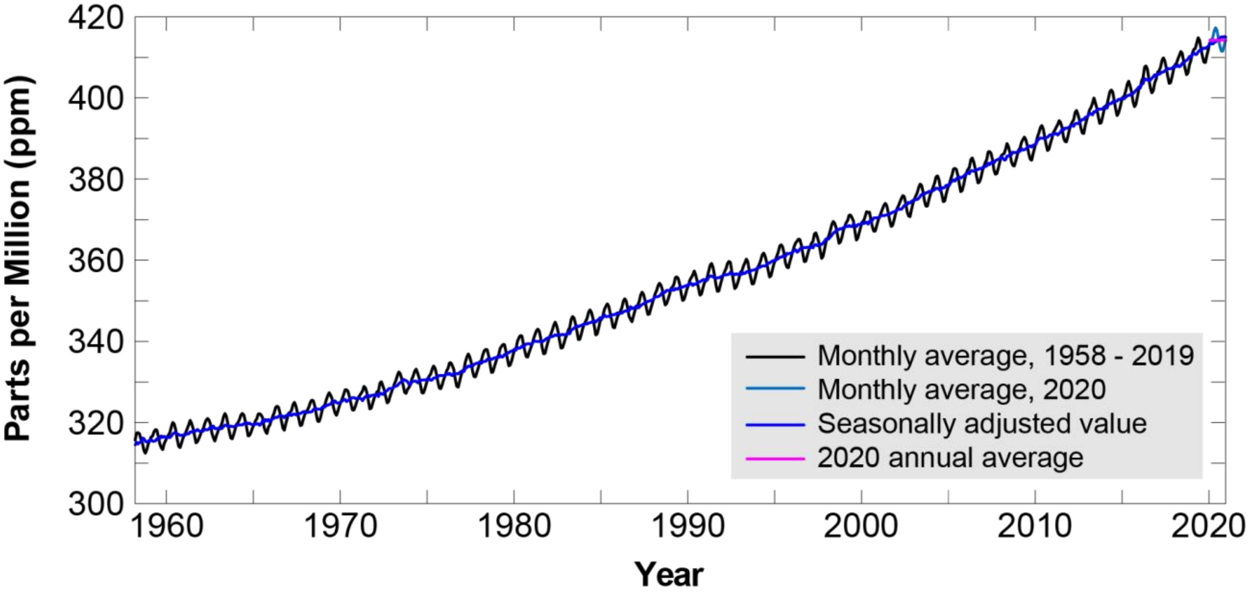


Figure 5. Monthly mean (black) and seasonally corrected (blue) atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii

2.4.3.2 Oceanic pH

Rationale: Oceanic pH is a measure of how greenhouse gas emissions have already impacted the ocean. This indicator demonstrates that oceanic pH has decreased significantly over the past several decades (i.e., the ocean has become more acidic). Increasing ocean acidification limits the ability of marine organisms to build shells and other calcareous structures. Recent research has shown that pelagic organisms such as pteropods and other prey for commercially valuable fish species are already being negatively impacted by increasing acidification (Feely et al. 2016). The full impact of ocean acidification on the pelagic food web is an area of active research (Fabry et al. 2008).

Status: The ocean is roughly 9.4% more acidic than it was 30 years ago at the start of this time series. Over this time, pH has declined by 0.043 at a constant rate. In 2019, the most recent year for which data are available, the average pH was 8.06. Additionally, small variations seen over the course of the year are outside the range seen in the first year of the time series for the third year in a row. The highest pH value reported for the most recent year (8.077) is lower than the lowest pH value reported in the first year of the time series (8.081).

Description: Trends in surface (5 m) pH at Station ALOHA, north of Oahu (22.75°N, 158°W), collected by the Hawai‘i Ocean Time Series (HOT) from October 1988 to 2019 (2020 data are not yet available). Oceanic pH is a measure of ocean acidity, which increases as the ocean absorbs carbon dioxide from the atmosphere. Lower pH values represent greater acidity. Oceanic pH is calculated from total alkalinity (TA) and dissolved inorganic carbon (DIC). Total alkalinity represents the ocean’s capacity to resist acidification as it absorbs CO_2 and the amount of CO_2 absorbed is captured through measurements of DIC. The multi-decadal time series at Station ALOHA represents the best available documentation of the significant downward trend in oceanic pH since the time series began in 1988. Oceanic pH varies over both time and space, though the conditions at Station ALOHA are considered broadly representative of those across the Western and Central Pacific’s pelagic fishing grounds.

Timeframe: Monthly.

Region/Location: Station ALOHA: 22.75°N, 158°W.

Measurement Platform: *In-situ* station.

Sourced from: Fabry et al. (2008), Feely et al. (2016), and the Hawai‘i Ocean Time Series as described in Karl et al. (1996) and on its website (HOT, 2021).

HOT, 2021 = https://hahana.soest.hawaii.edu/hot/hot-dogs/bseries.html.

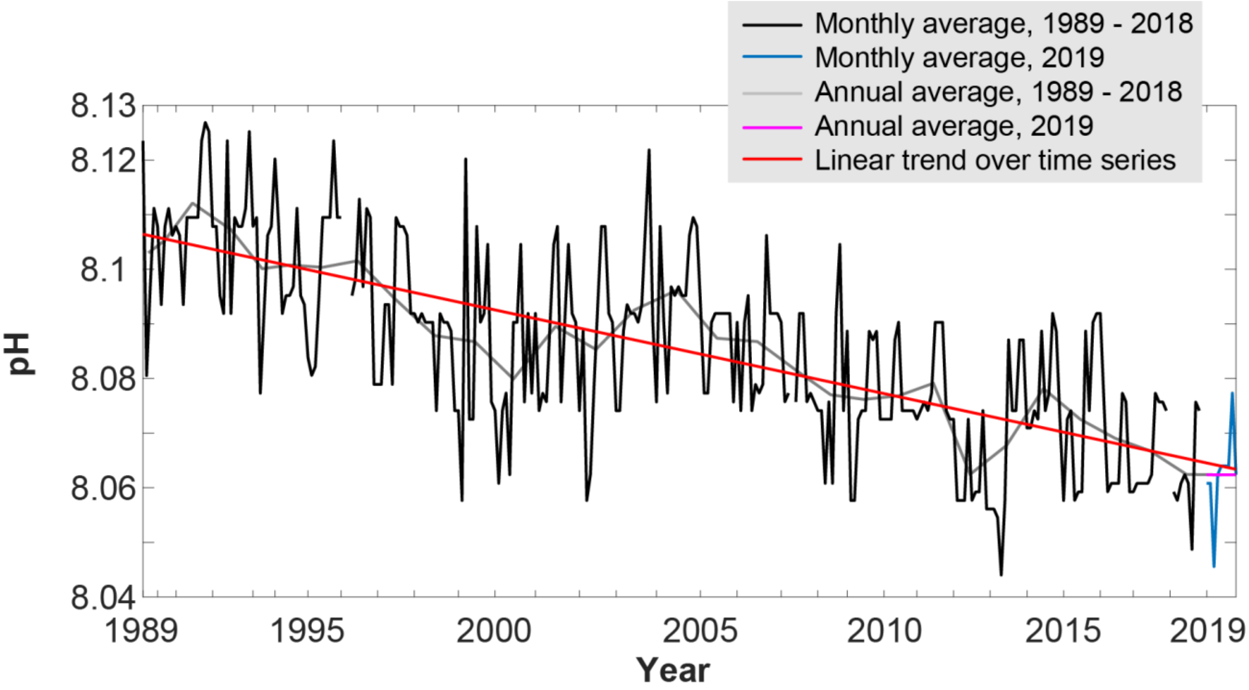


Figure 6. Time series and long-term trend of oceanic pH measured at Station ALOHA from 1989-2019

2.4.3.3 Oceanic Niño Index

Rationale: The El Niño – Southern Oscillation (ENSO) cycle is known to have impacts on Pacific fisheries including tuna fisheries. The Oceanic Niño Index (ONI) focuses on ocean temperature, which has the most direct effect on these fisheries.

Status: In autumn of 2020, the ONI transitioned from neutral to La Niña conditions. Over the year, the ONI ranged from 0.5 to -1.3. This is within the range of values observed previously in the time series.

Description: The three-month running mean of satellite remotely-sensed sea surface temperature (SST) anomalies in the Niño 3.4 region (5°S – 5°N, 120° – 170°W). The ONI is a measure of the ENSO phase. Warm and cool phases, termed El Niño and La Niña respectively, are based in part on an ONI threshold of ± 0.5 °C being met for a minimum of five consecutive overlapping seasons. Additional atmospheric indices are needed to confirm an El Niño or La Niña event, as the ENSO is a coupled ocean-atmosphere phenomenon. The atmospheric half of ENSO is measured using the Southern Oscillation Index.

Timeframe: Every three months.

Region/Location: Niño 3.4 region, 5°S – 5°N, 120° – 170°W.

Measurement Platform: *In-situ* station, satellite, model.

Sourced from NOAA CPC (2021).

NOAA CPC (2021) =
https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php and
https://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt.

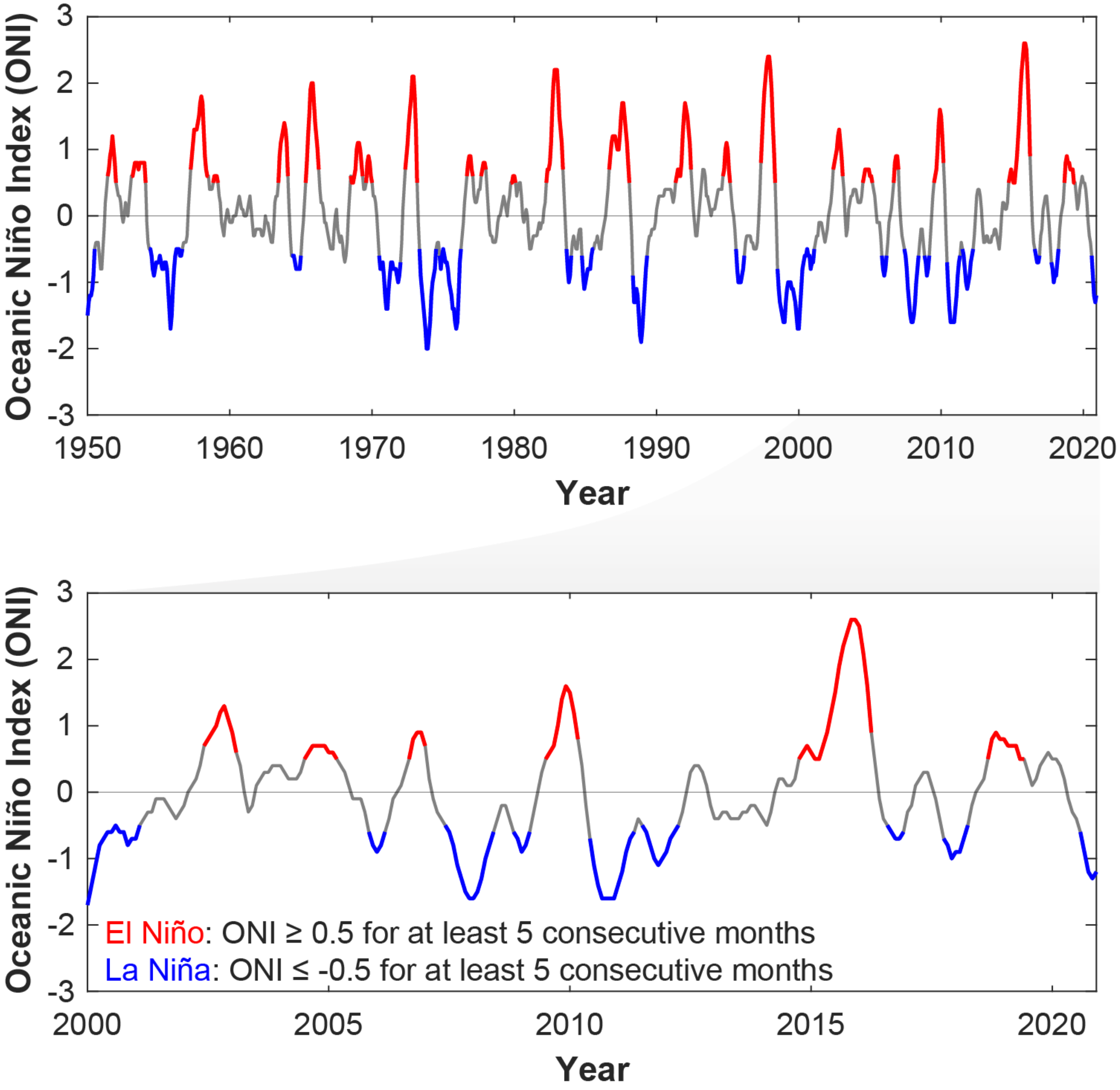


Figure 7. Oceanic Niño Index from 1950-2020 (top) and 2000–2020 (bottom) with El Niño periods in red and La Niña periods in blue

2.4.3.4 Pacific Decadal Oscillation

Rationale: The Pacific Decadal Oscillation (PDO) was initially named by fisheries scientist Steven Hare in 1996 while researching connections between Alaska salmon production cycles and Pacific climate. Like ENSO, the PDO reflects changes between periods of persistently warm or persistently cool ocean temperatures, but over a period of 20 to 30 years (versus six to 18 months for ENSO events). The climatic fingerprints of the PDO are most visible in the Northeastern Pacific, but secondary signatures exist in the tropics.

Status: The PDO was negative in 2020. The index ranged from -0.51 to -1.75 over the course of the year. This is within the range of values observed previously in the time series.

Description: The PDO is often described as a long-lived El Niño-like pattern of Pacific climate variability. As seen with the better-known ENSO, extremes in the PDO pattern are marked by widespread variations in the Pacific Basin and the North American climate. In parallel with the ENSO phenomenon, the extreme cases of the PDO have been classified as either warm or cool, as defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean. When SST is below average in the interior North Pacific and warm along the North American coast, and when sea level pressures are below average in the North Pacific, the PDO has a positive value. When the climate patterns are reversed, with warm SST anomalies in the interior and cool SST anomalies along the North American coast, or above average sea level pressures over the North Pacific, the PDO has a negative value (NOAA ESRL 2021a).

Timeframe: Annual, monthly.

Region/Location: Pacific Basin north of 20°N.

Measurement Platform: *In-situ* station, satellite, model.

Sourced from: NOAA ESRL (2021a). Mantua (2017).

NOAA ESRL (2021a) = https://www.ncdc.noaa.gov/teleconnections/pdo/.

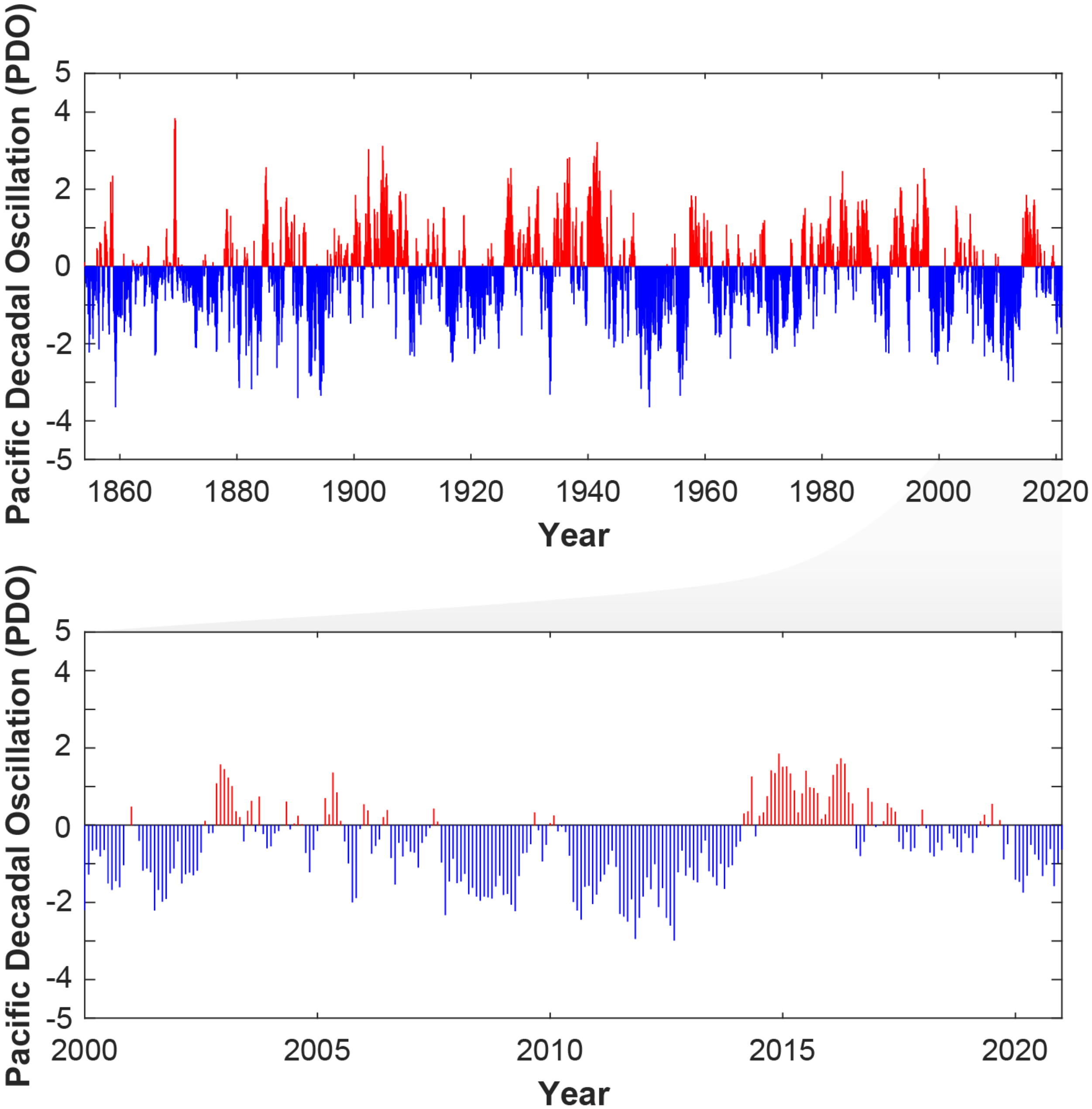


Figure 8. Pacific Decadal Oscillation from 1950–2020 (top) and 2000–2020 (bottom) with positive warm periods in red and negative cool periods in blue

2.4.3.5 Tropical Cyclones

Rationale: The effects of tropical cyclones are numerous and well known. At sea, storms disrupt and endanger shipping traffic as well as fishing effort and safety. The Hawai‘i longline fishery, for example, has had serious problems with vessels dodging storms at sea, delayed departures, and inability to make it safely back to Honolulu because of bad weather. When cyclones encounter land, their intense rains and high winds can cause severe property damage, loss of life, soil erosion, and flooding. Associated storm surge, the large volume of ocean water pushed toward shore by cyclones’ strong winds, can cause severe flooding and destruction.

Status:

Eastern North Pacific. Overall, the 2020 eastern Pacific hurricane season featured an average number of named storms, but below average hurricane and major hurricane activity. There were sixteen named storms, of which four became hurricanes and three became major hurricanes - category 3 or higher on the Saffir-Simpson Hurricane Wind Scale. This compares to the long-term averages of fifteen named storms, eight hurricanes, and four major hurricanes. There were also five tropical depressions that did not reach tropical storm strength. Two tropical storms, Odalys and Polo, formed in the basin in November. Although the long-term (1981-2010) average is one tropical storm forming in the basin every second or third year, this is the third straight November with at least one named storm forming. In fact, named storms have formed in November in six of the past seven years in the basin. In terms of Accumulated Cyclone Energy (ACE), which measures the strength and duration of tropical storms and hurricanes, activity in the basin for 2020 was below normal, more than 40 percent below the long-term average. Summary inserted from https://www.nhc.noaa.gov/text/MIATWSEP.shtml.

Central North Pacific. Tropical cyclone activity in the central Pacific in 2020 was slightly below average. While there was only one named storm, which is below the 1981 – 2010 average of three, this storm was particularly noteworthy. July's hurricane Douglas reached category 4 strength, making it a major hurricane. Its intensity fell prior to its passage just north of the main Hawaiian Islands. On average, the central Pacific sees three named storms, two hurricanes, and no major hurricanes. The 2020 ACE index was about an order of magnitude below the 1981 – 2010 average.

Western North Pacific. Tropical cyclone activity was below average in the western Pacific in 2020. There were 23 named storms, compared to an average of 26. Twelve of these developed into typhoons, and seven of these typhoons were major. An average year would see 17 typhoons, nine of which would be major. The West Pacific was unusually quiet in 2020 with less than half its normal ACE (third lowest since 1981). The West Pacific did have the strongest storm of 2020, Super Typhoon Goni, which made landfall in the Philippines as a powerful category 5 storm. The initial estimates of 195-mph winds during its landfall would be the strongest on record. Portions of the summary inserted from https://www.ncdc.noaa.gov/sotc/tropical-cyclones/202013.

South Pacific. Tropical cyclone activity in the south Pacific region was roughly average in 2020. There were ten named storms, five of which developed into cyclones and one of which – Harold – was major. The long-term average in this region is nine named storms, five cyclones, and two major cyclones. The strongest cyclone of the Southern Hemisphere season was category-5 Tropical Cyclone Harold. Harold alone accounted for more than half of the Southwest Pacific's ACE for 2020 (overall, the region's ACE index was below average in 2020). It was the first category 5 storm in the Southern Hemisphere since Tropical Cyclone Gita in 2018. Harold caused widespread damage throughout the South Pacific Islands, particularly in Vanuatu where it achieved its peak intensity. Portions of the summary inserted from https://www.ncdc.noaa.gov/sotc/tropical-cyclones/202013.

Description: This indicator uses historical data from the NOAA National Climate Data Center (NCDC) International Best Track Archive for Climate Stewardship to track the number of tropical cyclones in the western, central, eastern, and southern Pacific basins. This indicator also monitors the Accumulated Cyclone Energy (ACE) Index and the Power Dissipation Index which are two ways of monitoring the frequency, strength, and duration of tropical cyclones based on wind speed measurements.

The annual frequency of storms passing through each basin is tracked and a bar plot shows the representative breakdown of Saffir-Simpson hurricane categories.

Every cyclone has an ACE Index value, which is a number based on the maximum wind speed measured at six-hourly intervals over the entire time that the cyclone is classified as at least a tropical storm (wind speed of at least 34 knots; 39 mph). Therefore, a storm's ACE Index value accounts for both strength and duration. This plot shows the historical ACE values for each hurricane/typhoon season and has a horizontal line representing the average annual ACE value.

Timeframe: Annual.

Region/Location:

Eastern North Pacific: east of 140° W, north of the equator.

Central North Pacific: 180° - 140° W, north of the equator.

Western North Pacific: west of 180°, north of the equator.

South Pacific: south of the equator.

Measurement Platform: Satellite.

Sourced from: Knapp et al. (2010), Knapp et al. (2018), https://www.ncdc.noaa.gov/ibtracs/,

https://www.ncdc.noaa.gov/sotc/tropical-cyclones/202007

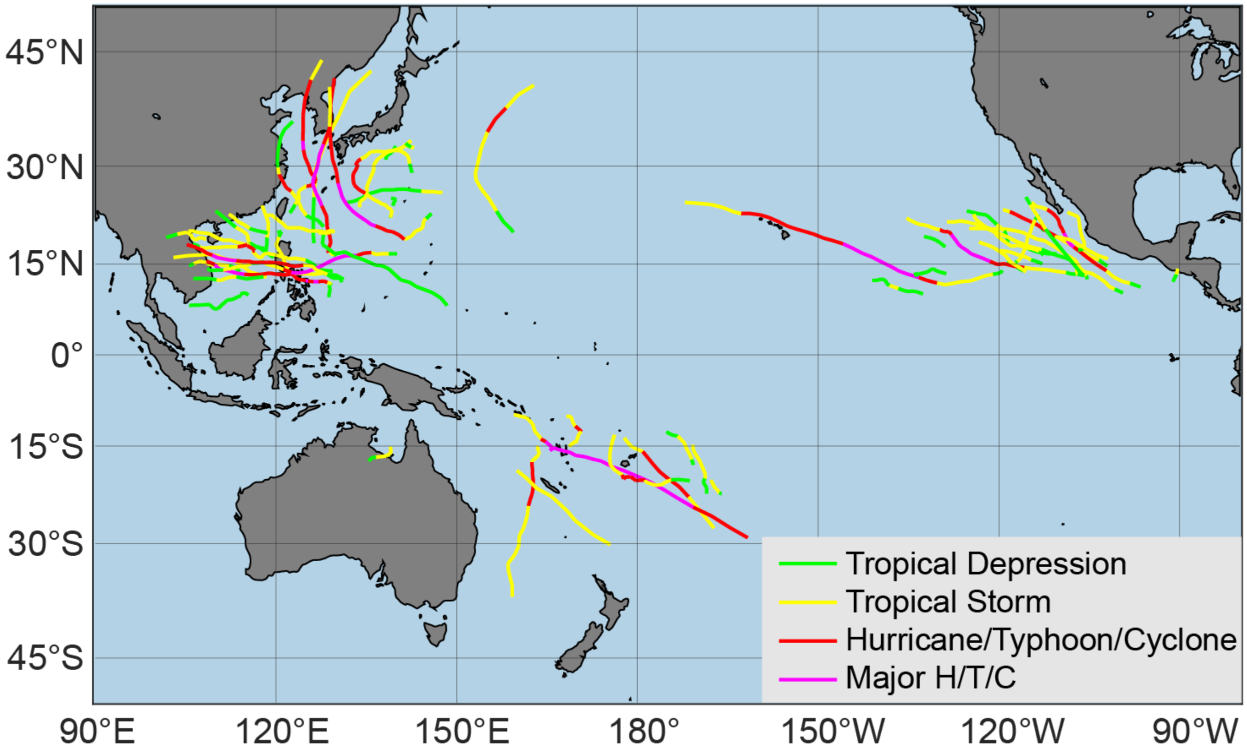


Figure 9. 2020 Pacific basin tropical cyclone tracks

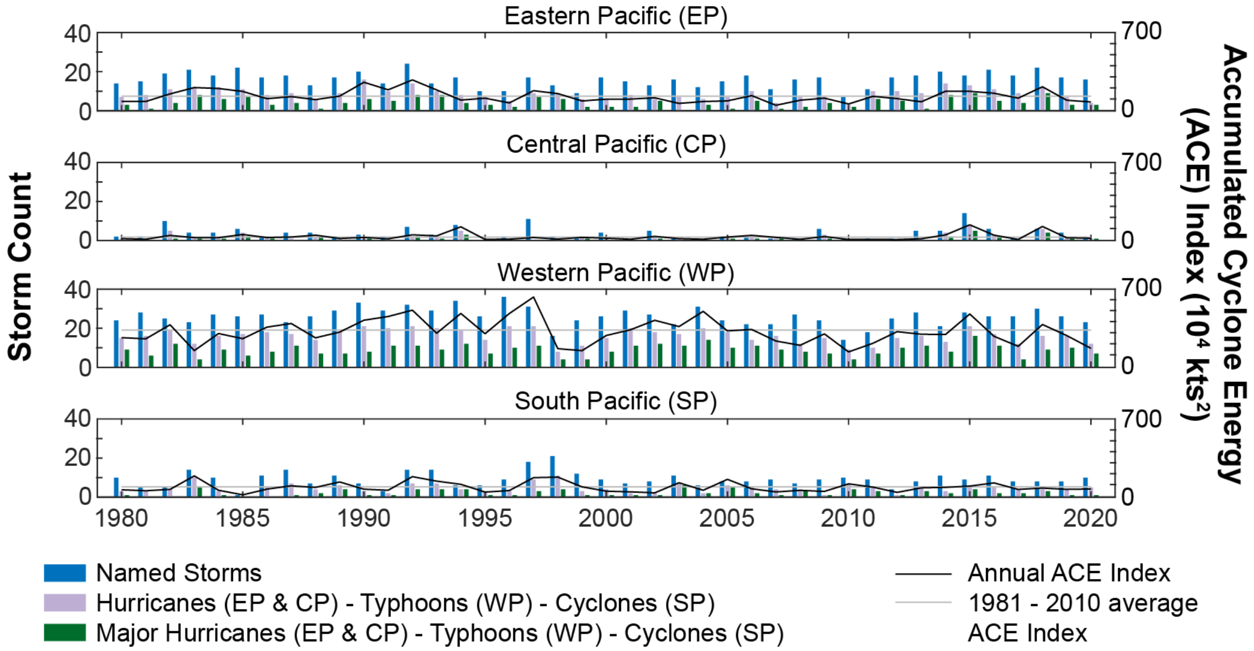


Figure 10. 2020 tropical storm totals by region

2.4.3.6 Sea Surface Temperature and Anomaly

Rationale: Sea surface temperature (SST) is one of the most directly observable existing measures for tracking increasing ocean temperatures. SST varies in response to natural climate cycles such as the ENSO and is projected to rise as a result of anthropogenic climate change. Both short-term variability and long-term trends in SST impact the marine ecosystem. Understanding the mechanisms through which organisms are impacted and the time scales of these impacts is an area of active research.

Status:

Pacific Remote Island Areas Grid: Annual mean SST was 28.11ºC in 2020. Over the period of record, monthly SST shows no significant pattern of increase or decrease. Monthly SST values in 2020 ranged from 27.02 – 28.70 ºC, within the climatological range of 25.70 – 30.10 ºC. The annual anomaly was 0.016 ºC cooler than average, with positive anomaly values in the northern part of the region.

Johnston Atoll Grid: Annual mean SST was 27.00ºC in 2020. Over the period of record, annual SST has increased at a rate of 0.018 ºC yr^{-1}. Monthly SST values in 2020 ranged from 25.51 – 27.96ºC, within the climatological range of 24.56 – 29.31 ºC. The annual anomaly was 0.31ºC hotter than average, with intensification in the northern part of the area.

Wake Atoll Grid: Annual mean SST was 27.80ºC in 2020. Over the period of record, annual SST has increased at a rate of 0.0277 ºC yr^{-1}. Monthly SST values in 2020 ranged from 25.70 – 29.56ºC, within the climatological range of 24.77 – 30.06 ºC. The annual anomaly was 0.237ºC hotter than average, with no dramatic spatial pattern.

Note that from the top to bottom in Figure 11, Figure 12, and Figure 13, panels show climatological SST (1985-2019), 2020 SST anomaly, time series of monthly mean SST, and time series of monthly SST anomaly. The white box in the upper panels indicates the area over which SST is averaged for the time series plots.

Description: Satellite remotely-sensed monthly sea surface temperature (SST) is averaged across each of the PRIA Grid (1°S – 7°N, 159° – 177°W; including Howland, Baker, Jarvis, Palmyra, Kingman Reef), Johnston Island (16° – 17°N, 168° – 170°W), and Wake Atoll (17.7° – 20.7°N, 165° – 168°W). Time series of monthly mean SST averaged over the respective grids are presented. Additionally, spatial climatology and anomalies are shown. Data are from NOAA Coral Reef Watch CoralTemp v3.1.

Timeframe: Monthly.

Region/Location: PRIA Grid (1°S – 7°N, 159° – 177°W); Johnston Atoll (16° – 17°N, 168° – 170°W), and Wake Atoll (17.7° – 20.7°N, 165° – 168°W)

Measurement Platform: Satellite.

Sourced from: NOAA Coral Reef Watch v3.1 (2021).

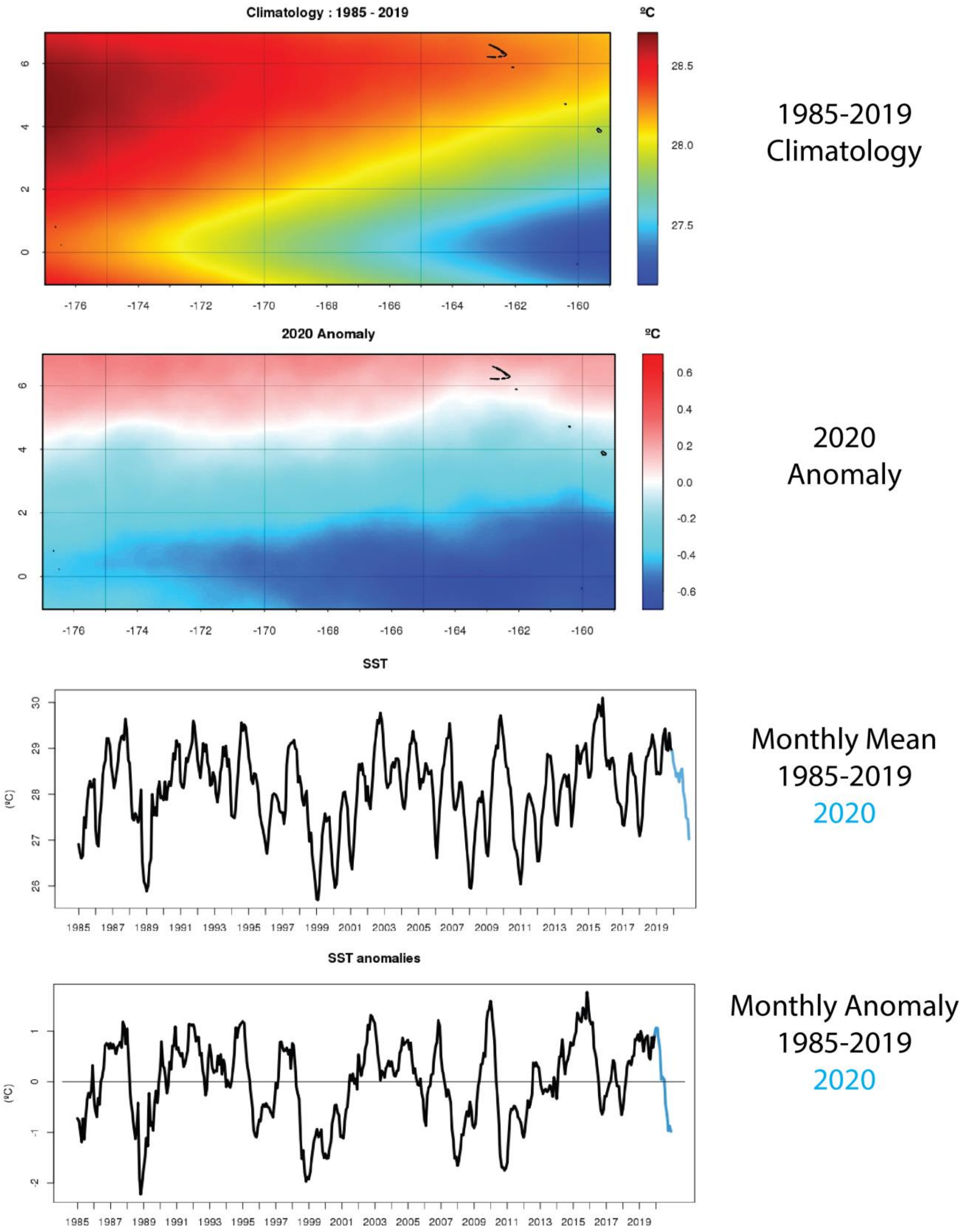


Figure 11. Sea surface temperature climatology and anomalies from the PRIA Grid

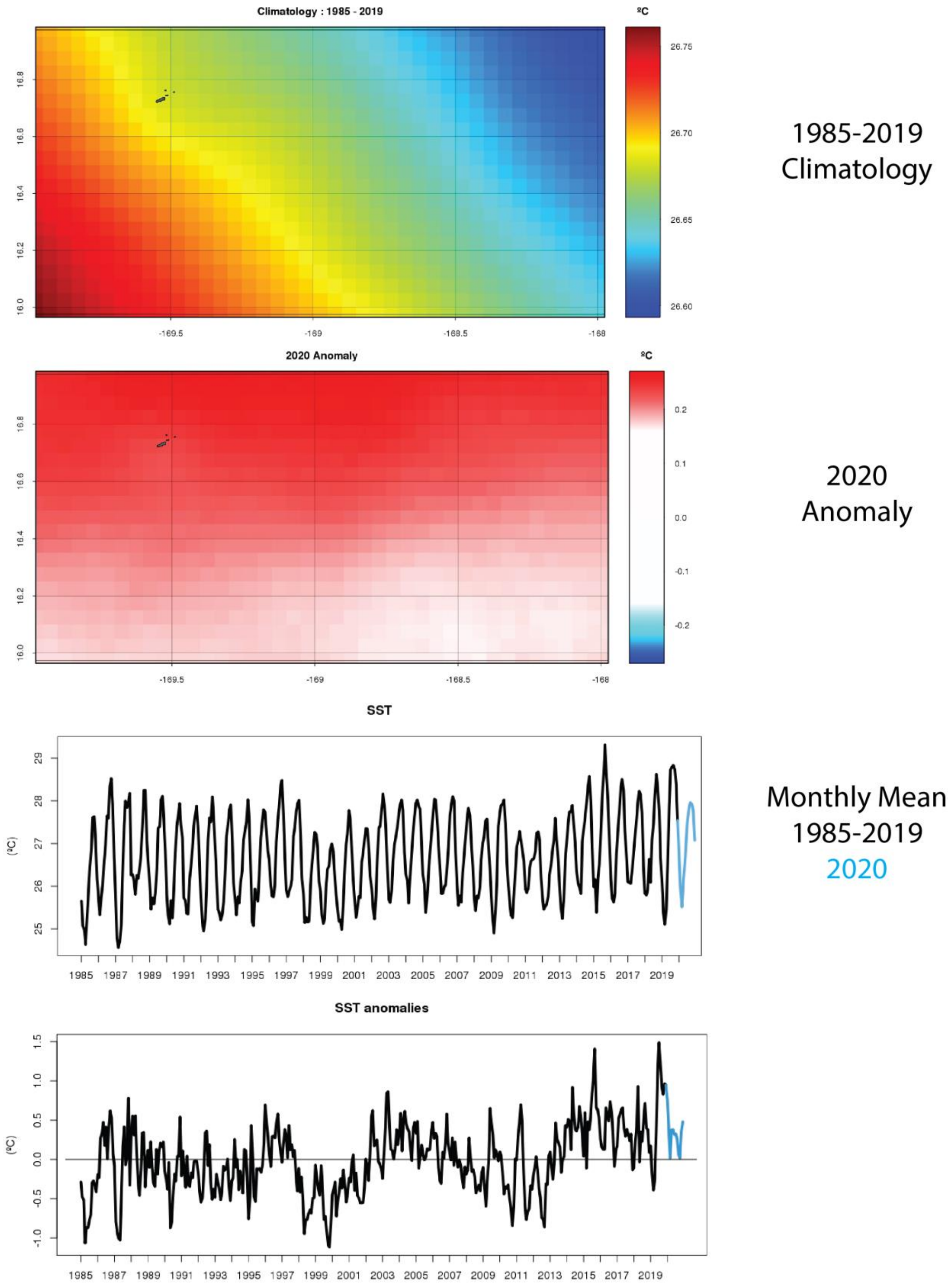


Figure 12. Sea surface temperature climatology and anomalies from Johnston Atoll Grid

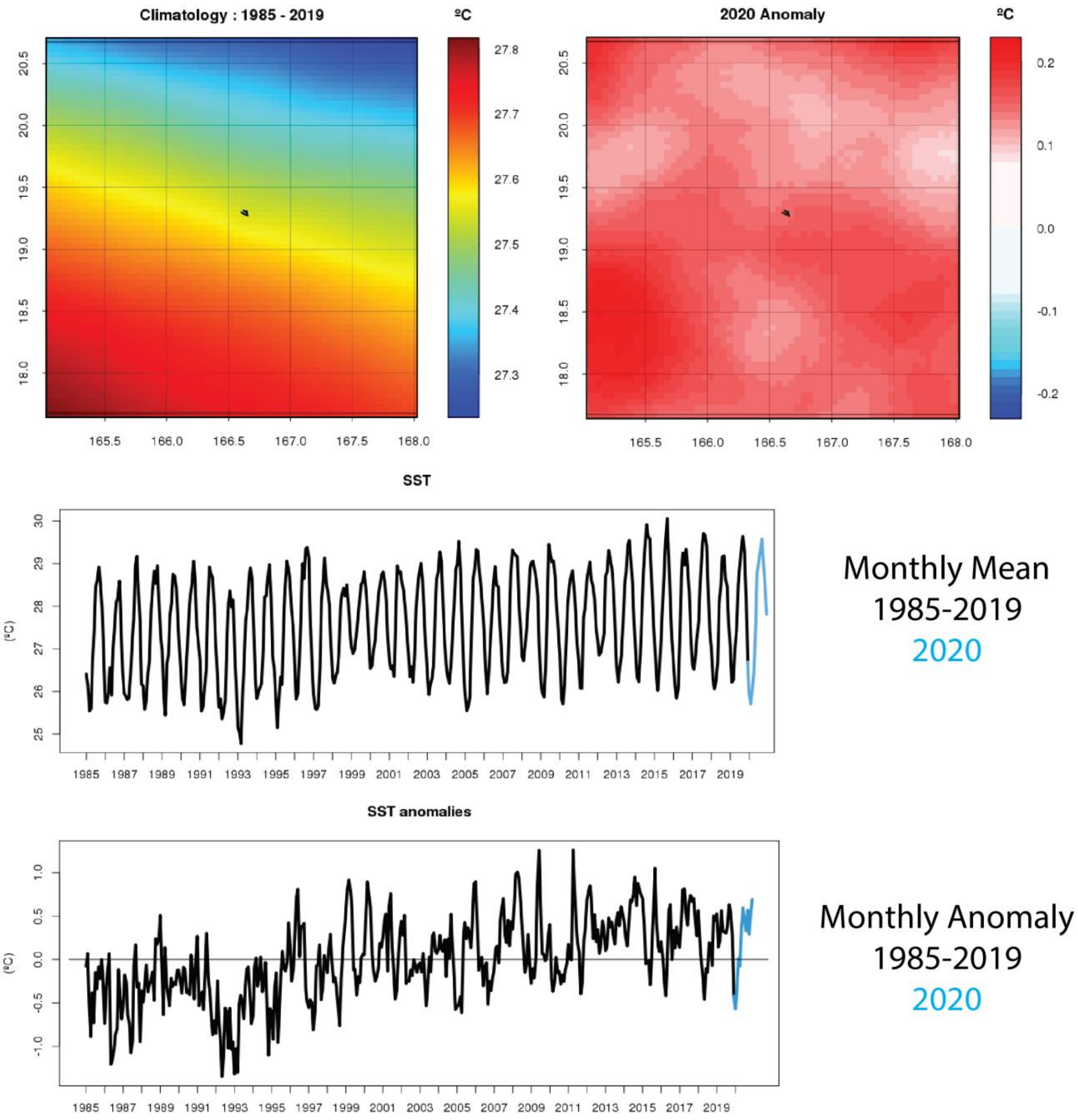


Figure 13. Sea surface temperature climatology and anomalies from Wake Atoll Grid

2.4.3.7 Coral Thermal Stress Exposure: Degree Heating Weeks

Rationale: Degree heating weeks are one of the most widely used metrics for assessing exposure to coral bleaching-relevant thermal stress.

Description: Here we present a metric of exposure to thermal stress that is relevant to coral bleaching. Degree Heating Weeks (DHW) measure time and temperature above a reference ‘summer maximum’, presented as a rolling sum weekly thermal anomalies over a 12-week window. Higher DHW measures imply a greater likelihood of mass coral bleaching or mortality from thermal stress.

Status: After experiencing major heat stress events in 2015- 2016 and 2019, only Wake Atoll experienced another minor heat stress event in 2020.

The NOAA Coral Reef Watch program uses satellite data to provide current reef environmental conditions to quickly identify areas at risk for coral bleaching. Bleaching is the process by which corals lose the symbiotic algae that give them their distinctive colors. If a coral is severely bleached, disease and death become likely.

The NOAA Coral Reef Watch daily 5-km satellite coral bleaching DHW product presented here shows accumulated heat stress, which can lead to coral bleaching and death. The scale goes from 0 to 20 °C-weeks. The DHW product accumulates the instantaneous bleaching heat stress (measured by Coral Bleaching HotSpots) during the most-recent 12-week period. It is directly related to the timing and intensity of coral bleaching. Significant coral bleaching usually occurs when DHW values reach 4 °C-weeks. By the time DHW values reach 8 °C-weeks, widespread bleaching is likely and significant mortality can be expected

Timeframe: 2014-2020, Daily data.

Region/Location: Global.

Sourced from: NOAA Coral Reef Watch v3.1 (2021).

https://coralreefwatch.noaa.gov/product/vs/data/northern_line_islands.txt
https://coralreefwatch.noaa.gov/product/vs/data/johnston_atoll.txt
https://coralreefwatch.noaa.gov/product/vs/data/wake_atoll.txt

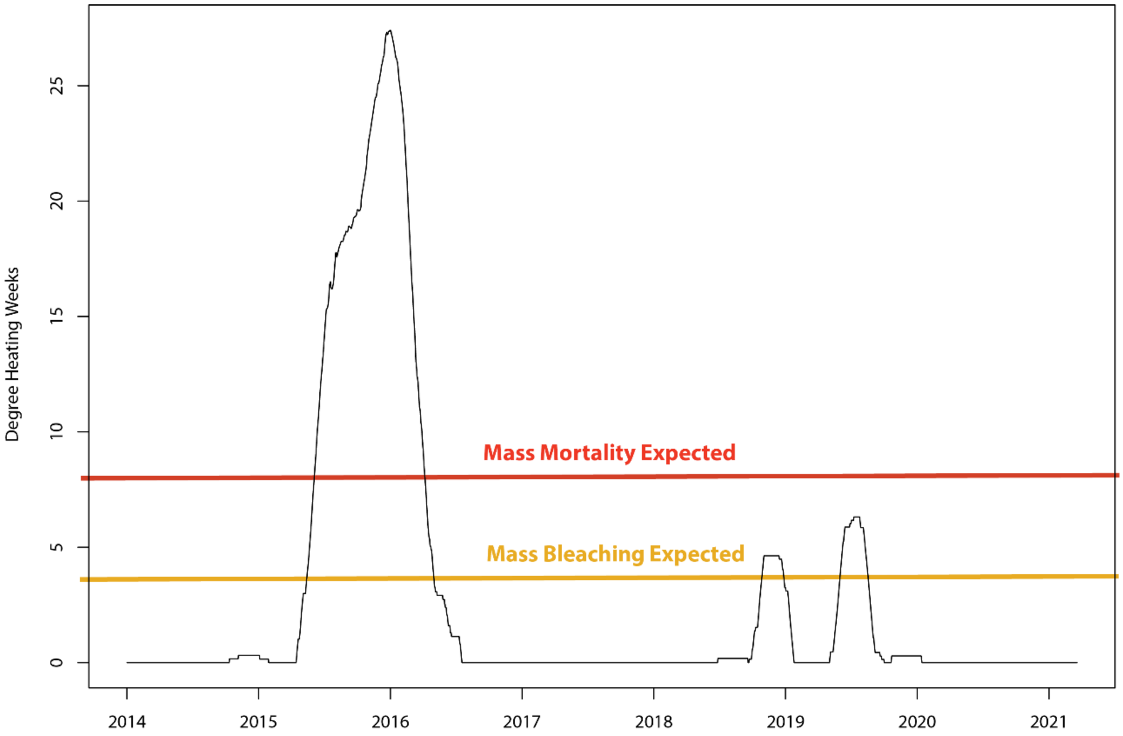


Figure 14. Coral Thermal Stress Exposure, Howland/Baker Virtual Station 2014-2019 (Coral Reef Watch Degree Heating Weeks)

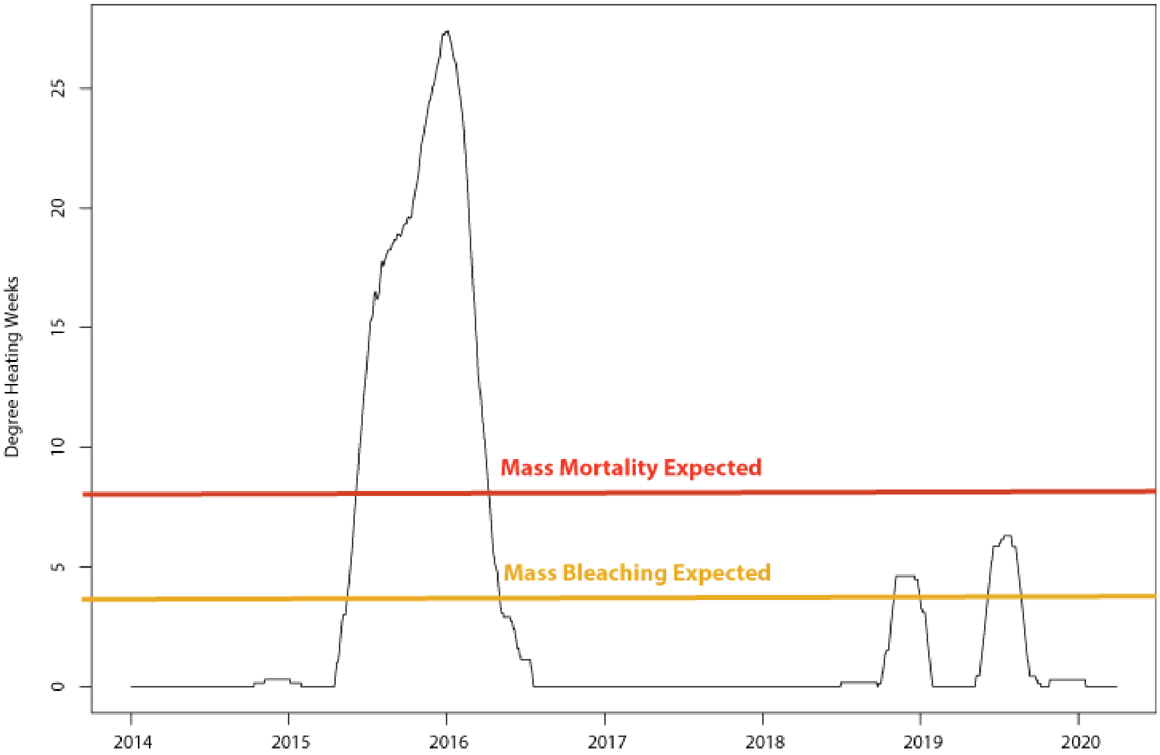


Figure 15. Coral Thermal Stress Exposure, Northern Line Islands Virtual Station 2014-2020 (Coral Reef Watch Degree Heating Weeks)

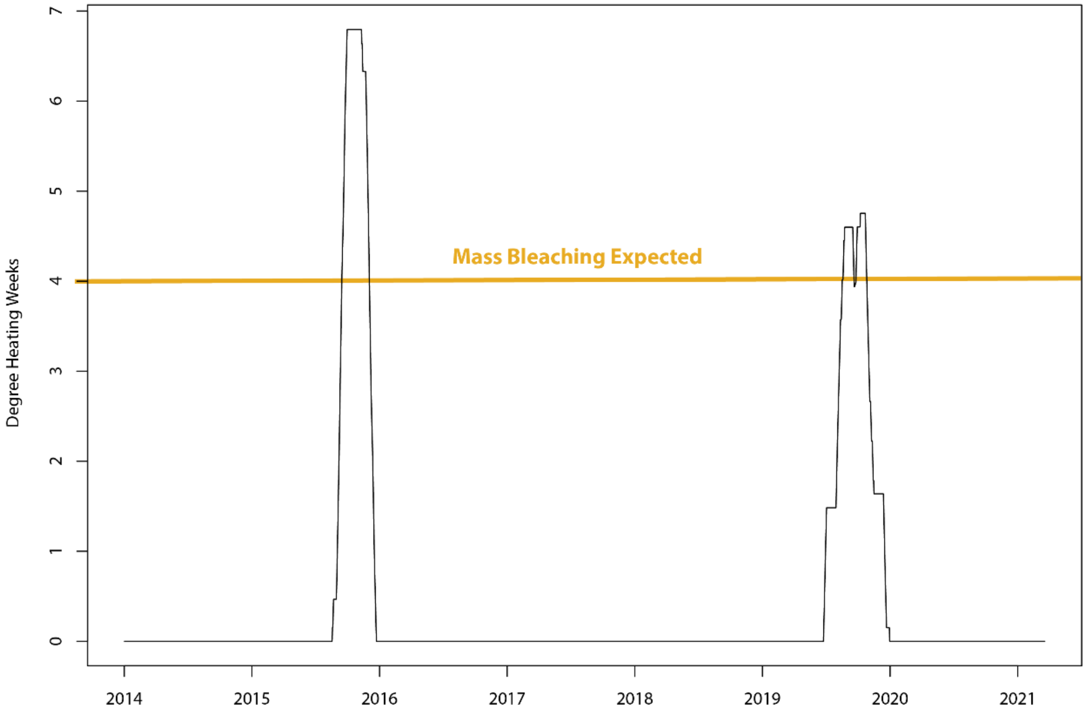


Figure 16. Coral Thermal Stress Exposure, Johnston Virtual Station 2014-2020 (Coral Reef Watch Degree Heating Weeks)

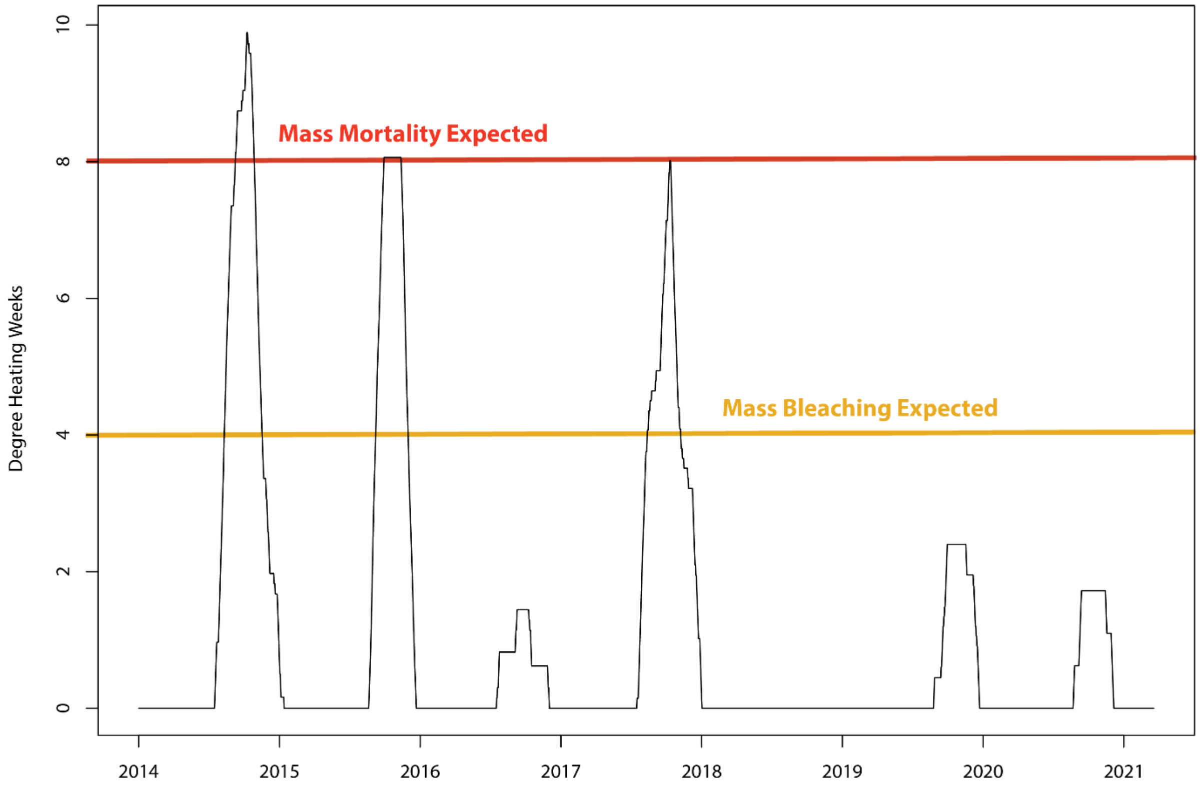


Figure 17. Coral Thermal Stress Exposure, Wake Atoll Virtual Station 2013-2018 (Coral Reef Watch Degree Heating Weeks)

2.4.3.8 Chlorophyll-A and Anomaly

Rationale: Chlorophyll-*a* (Chl-A) is one of the most directly observable measures we have for tracking increasing ocean productivity.

Status:

Pacific Remote Island Areas: Annual mean Chl-A was 0.189 mg/m^3 in 2020. Over the period of record, annual Chl-A has shown a significant linear decrease at a rate of 0.001 mg/m^3. Monthly Chl-A values in 2020 ranged from 0.163-0.216 mg/m^3, within the climatological range of 0.064 – 0.278 mg/m^3. The annual anomaly was 0.0084 mg/m^3 higher than climatological values, with negative values in the northern part of the region.

Johnston Atoll: Annual mean Chl-A was 0.055 mg/m^3 in 2020. Over the period of record, annual Chl-A has shown a significant linear decrease at a rate of 0.00025 mg/ m^3. Monthly Chl-A values in 2020 ranged from 0.043-0.081 mg/m^3, within the climatological range of 0.043 – 0.10 mg/m^3. The annual anomaly was 0.0042 mg/m^3 lower than climatological values, with positive values toward the northeastern part of the atoll.

Wake Atoll: Annual mean Chl-A was 0.043 mg/m^3 in 2020. Over the period of record, annual Chl-A has shown a weakly significant linear decrease at a rate of 0.0002 mg/ m^3. Monthly Chl-

A values in 2020 ranged from 0.036-0.052 mg/m^3, within the climatological range of 0.035 – 0.128 mg/m^3. The annual anomaly was 0.0072 mg/m^3 lower than climatological values.

Description: Chlorophyll-A Concentration from 1998-2020 derived from the ESA Ocean Color Climate Change Initiative dataset, v5.0. A monthly climatology was generated across the entire period (1998-2019) to provide both a 2020 spatial anomaly, and an anomaly time series.

ESA Ocean Color Climate Change Initiative dataset is a merged dataset, combining data from SeaWIFS, MODIS-Aqua, MERIS, and VIIRS to provide a homogeneous time-series of ocean color. Data was accessed from the OceanWatch Central Pacific portal

Timeframe: 1998-2020, Daily data available, Monthly means shown.

Region/Location: Global.

Measurement Platform: SeaWIFS, MODIS-Aqua, MERIS, and VIIRS.

Sourced from: NOAA OceanWatch Central Pacific; https://oceanwatch.pifsc.noaa.gov/

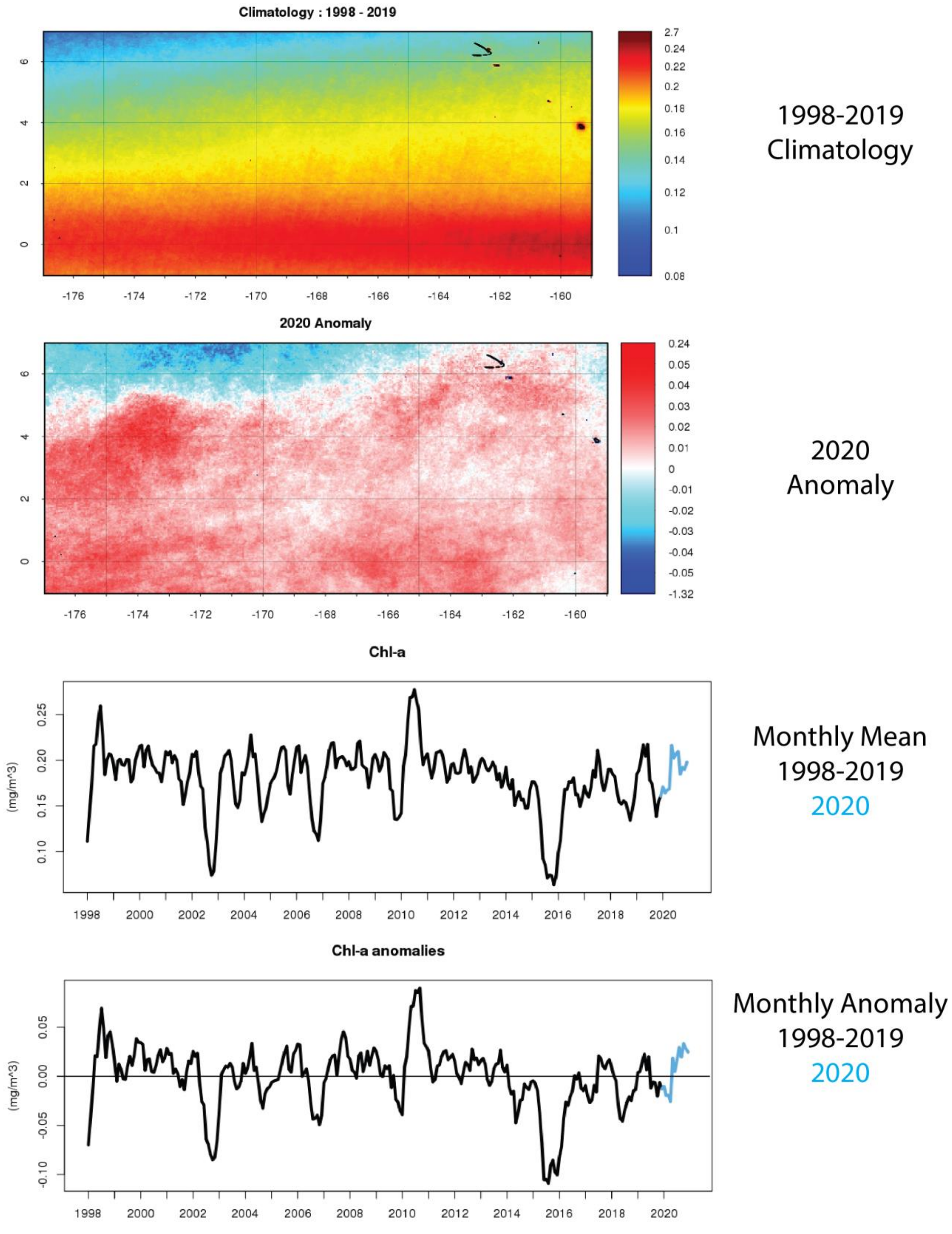


Figure 18. Chlorophyll-*a* and Chlorophyll-*a* Anomaly from the PRIA Grid

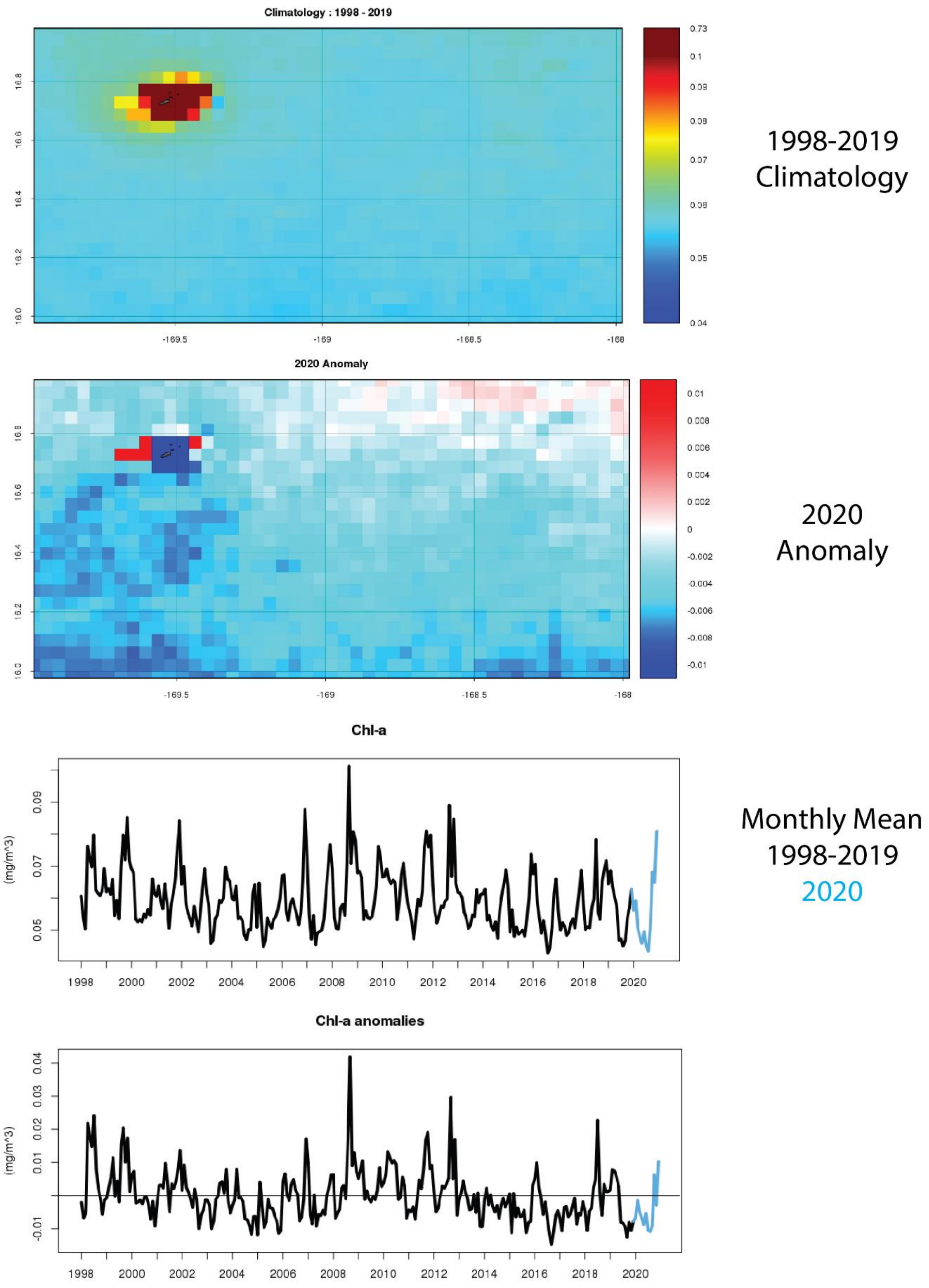


Figure 19. Chlorophyll-*a* and Chlorophyll-*a* Anomaly from the Johnston Atoll Grid

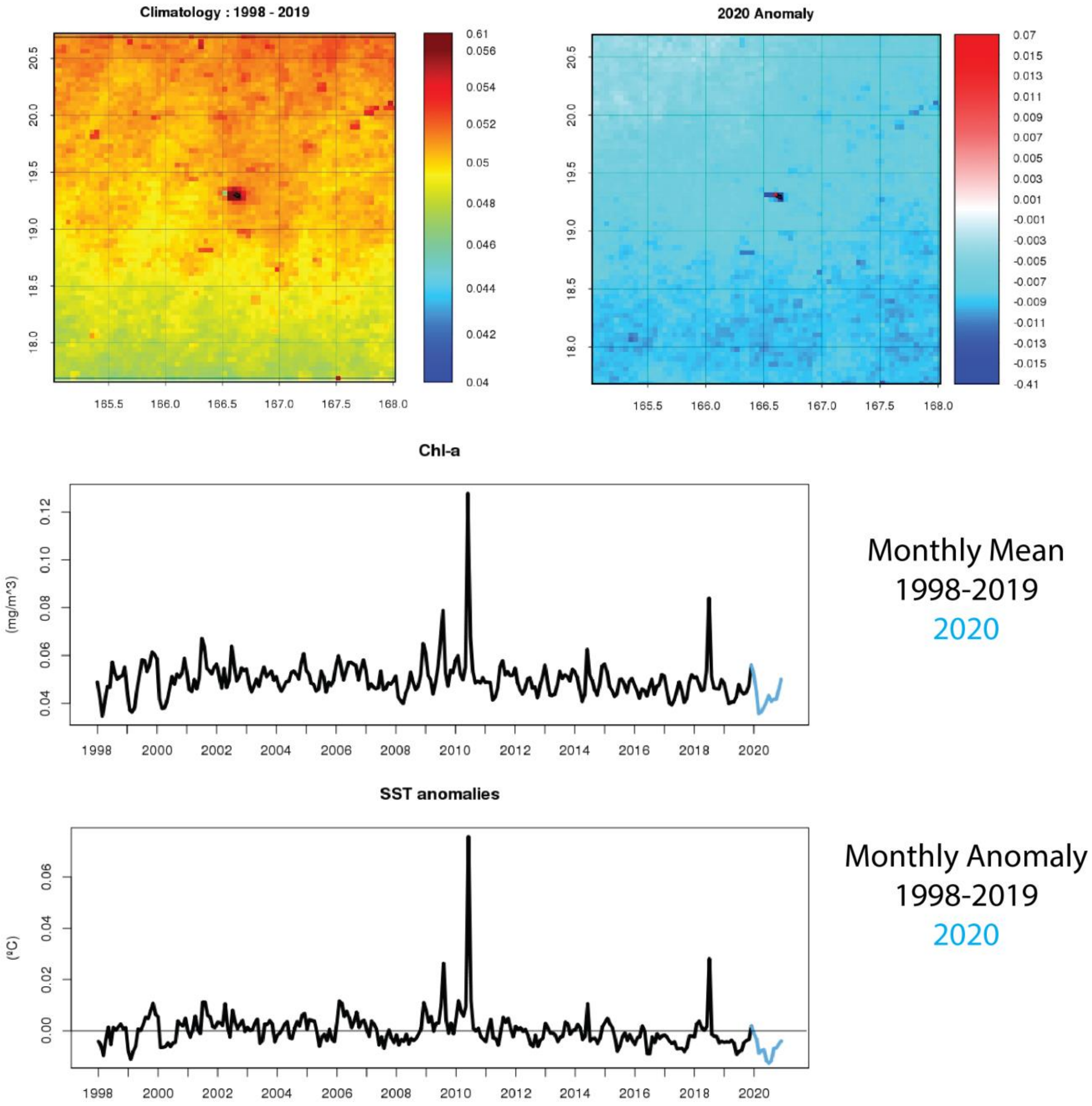


Figure 20. Chlorophyll-*a* and Chlorophyll-*a* Anomaly from the Wake Atoll Grid

2.4.3.9 Rainfall

Rationale: Rainfall may have substantive effects on the nearshore environment and is a potentially important co-variate with the landings of particular stocks.

Description: The CPC (Climate Prediction Center) Merged Analysis of Precipitation (CMAP) is a technique which produces pentad and monthly analyses of global precipitation in which observations from rain gauges are merged with precipitation estimates from several satellite-based algorithms (infrared and microwave). The analyses are on a 2.5 x 2.5-degree latitude/longitude grid and extend back to 1979. CMAP Precipitation data provided by the NOAA Ocean and Atmospheric Research (OAR) Earth Sciences Research Laboratory (ESRL) Physical Sciences Division (PSD), Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/. These data are comparable (but should not be confused with) similarly combined analyses by the Global Precipitation Climatology Project which are described in Huffman et al. (1997).

It is important to note that the input data sources to make these analyses are not constant throughout the period of record. For example, SSM/I (passive microwave - scattering and emission) data became available in July of 1987; prior to that the only microwave-derived estimates available are from the MSU algorithm (Spencer 1993) which is emission-based thus precipitation estimates are available only over oceanic areas. Furthermore, high temporal resolution IR data from geostationary satellites (every 3-hr) became available during 1986; prior to that, estimates from the OPI technique (Xie and Arkin 1997) are used based on OLR from polar orbiting satellites.

The merging technique is thoroughly described in Xie and Arkin (1997). Briefly, the methodology is a two-step process. First, the random error is reduced by linearly combining the satellite estimates using the maximum likelihood method, in which case the linear combination coefficients are inversely proportional to the square of the local random error of the individual data sources. Over global land areas the random error is defined for each time period and grid location by comparing the data source with the rain gauge analysis over the surrounding area. Over oceans, the random error is defined by comparing the data sources with the rain gauge observations over the Pacific atolls. Bias is reduced when the data sources are blended in the second step using the blending technique of Reynolds (1988). Here the data output from step 1 is used to define the "shape" of the precipitation field and the rain gauge data are used to constrain the amplitude.

Timeframe: Monthly.

Region/Location: Global.

Measurement Platform: *In-situ* station gauges and satellite data.

Source: *CMAP Precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at* https://www.esrl.noaa.gov/psd/. *NOAA (2021c).*

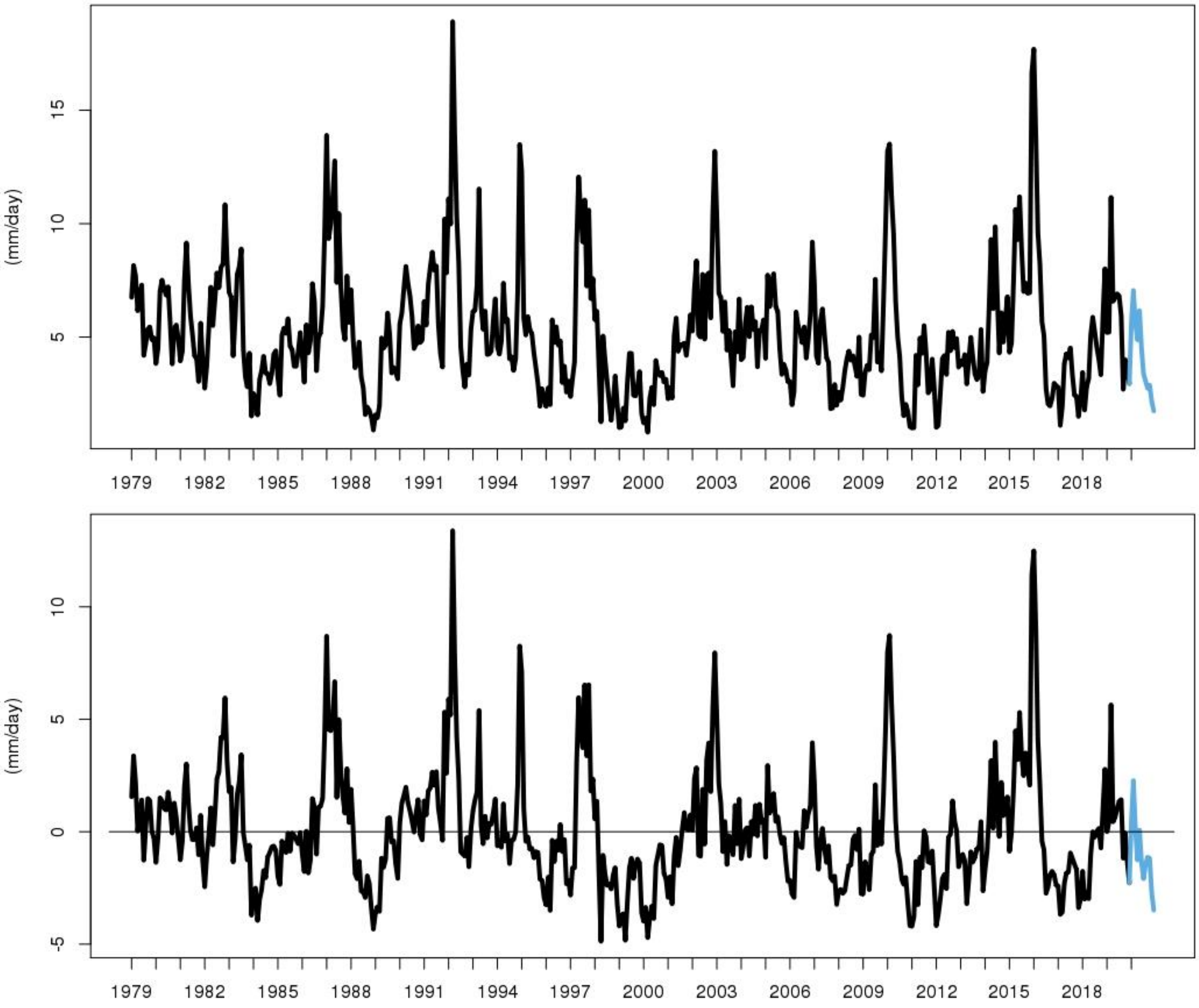


Figure 21. CMAP precipitation (top) and anomaly (bottom) across the PRIA Grid with 2019 values in blue

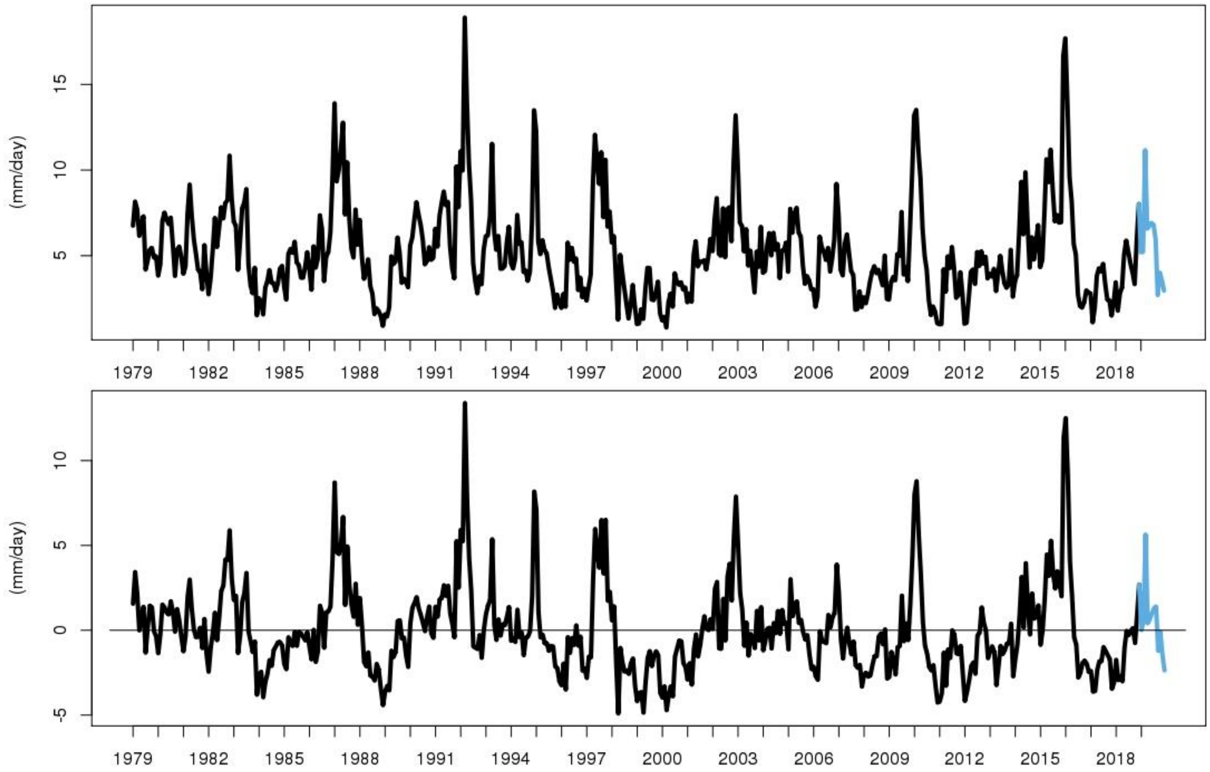


Figure 22. CMAP precipitation (top) and anomaly (bottom) across the Johnston Atoll Grid with 2020 values in blue

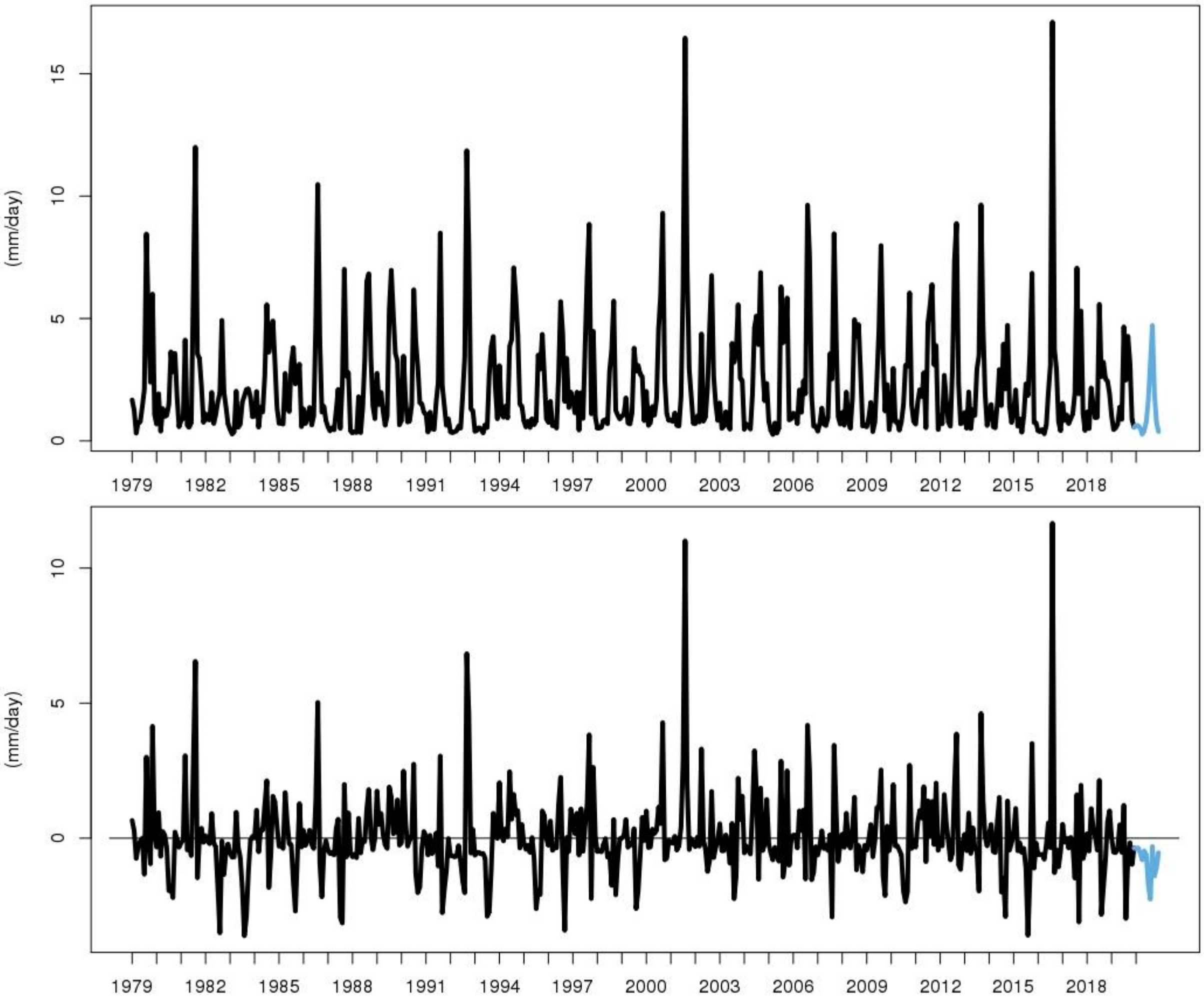


Figure 23. CMAP precipitation (top) and anomaly (bottom) across the Wake Atoll Grid with 2019 values in blue

2.4.3.10 Sea Level (Sea Surface Height and Anomaly)

Rationale: Rising coastal sea levels can result in a number of coastal impacts, including inundation of infrastructure, increased damage resulting from storm-driven waves and flooding, and saltwater intrusion into freshwater supplies.

Description: Monthly mean sea level time series of local and basin-wide sea surface height and sea surface height anomalies, including extremes.

Timeframe: Monthly.

Region/Location: Observations from selected sites across the Western Pacific.

Measurement Platform: Satellite and *in situ* tide gauges.

Source: Aviso (2021) and NOAA (2021d) at https://tidesandcurrents.noaa.gov/datum_options.html. https://bulletin.aviso.altimetry.fr/html/produits/indic/enso/welcome_uk.php.

2.4.3.10.1 Basin-Wide Perspective

This image of the mean sea level anomaly for February 2020 compared to 1993-2013 climatology from satellite altimetry provides a glimpse into how the 2020 neutral ENSO conditions affected sea level across the Pacific Basin. The image captures the fact that sea level is slightly lower in the Western Pacific and slightly higher in the Central and Eastern Pacific (this basin-wide perspective provides a context for the location-specific sea level/sea surface height images that follow).

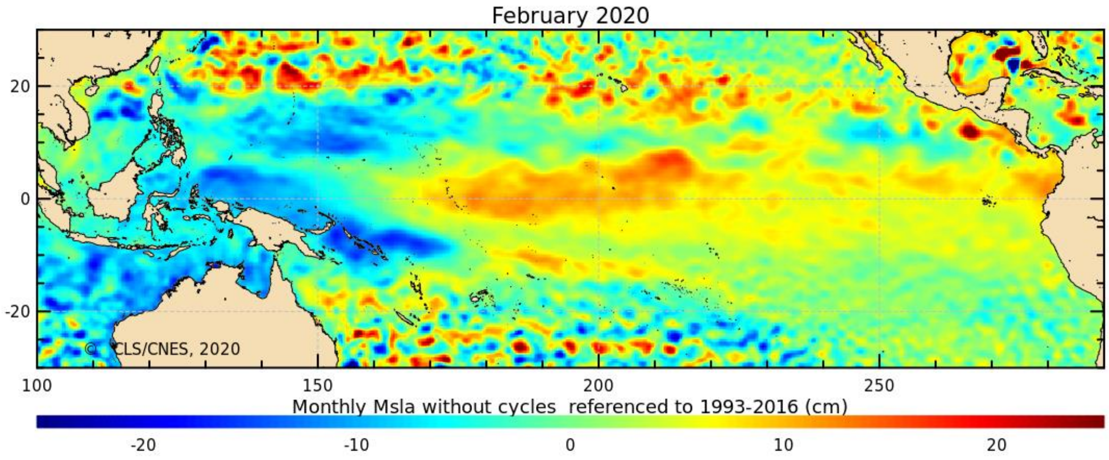


Figure 24a. Sea surface height and anomaly across the Pacific Ocean

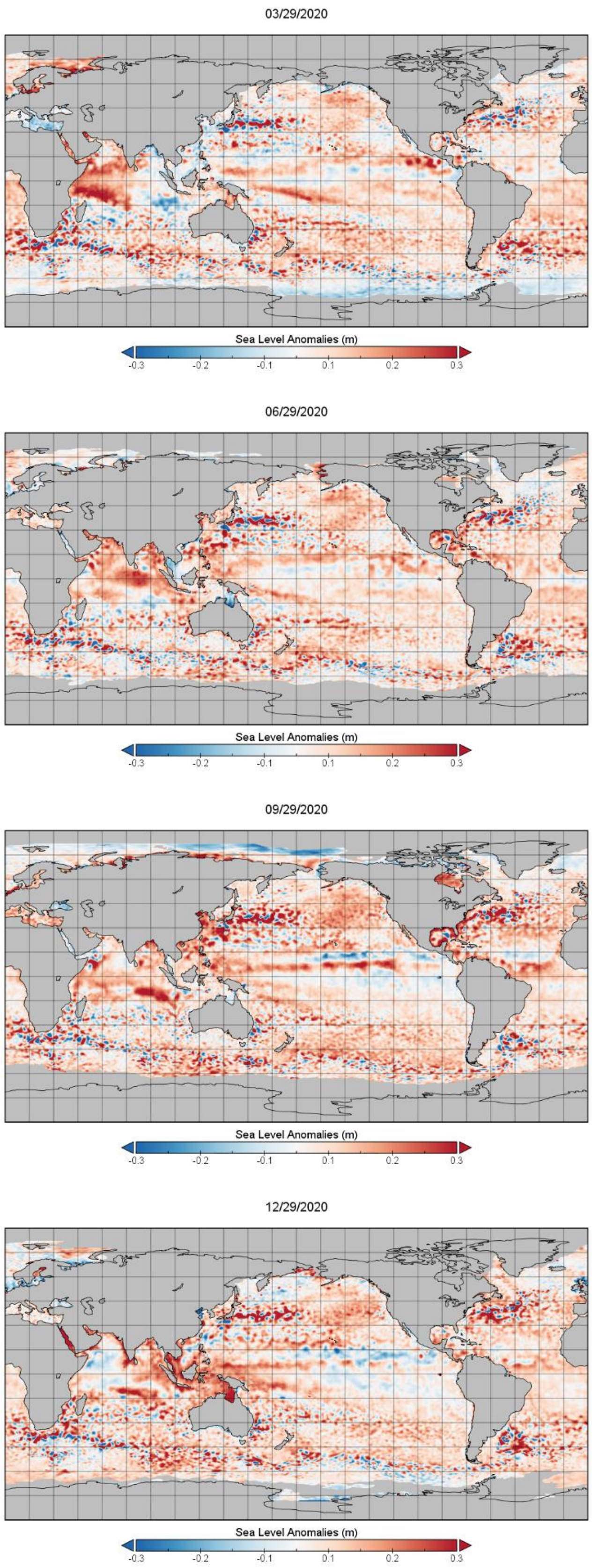


Figure 29b. Quarterly time series of mean sea level anomalies during 2020 show no pattern of El Niño throughout the year according to satellite altimetry measurements of sea level height.

Altimetry data are provided by the NOAA Laboratory for Satellite Altimetry, accessed from NOAA CoastWatch: https://coastwatch.noaa.gov/cw/satellite-data-products/sea-surface-height/sea-level-anomaly-and-geostrophic-currents-multi-mission-global-optimal-interpolation-gridded.html.

2.4.3.10.2 Local Sea Level

These time-series from *in situ* tide gauges provide a perspective on sea level trends within each Archipelago (Tide Station Time Series from NOAA Center for Operational Oceanographic Products and Services, or CO-OPS).

The following figures and descriptive paragraphs were inserted from NOAA Tides and Currents website. **Error! Reference source not found.** and Figure 25 show the monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The long-term linear trend is also shown, including its 95% confidence interval. The plotted values are relative to the most recent Mean Sea Level datum established by CO-OPS. The calculated trends for all stations are available as a table in millimeters/year and in feet/century (0.3 meters = 1 foot). If present, solid vertical lines indicate times of any major earthquakes in the vicinity of the station and dashed vertical lines bracket any periods of questionable data or datum shift.

The relative sea level rise trend around Wake Island is 2.06 millimeters/year with a 95% confidence interval of +/- 0.41 mm/yr based on monthly mean sea level data from 1950 to 2020 which is equivalent to a change of 0.68 feet in 100 years (Figure 25).

Source: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=1890000

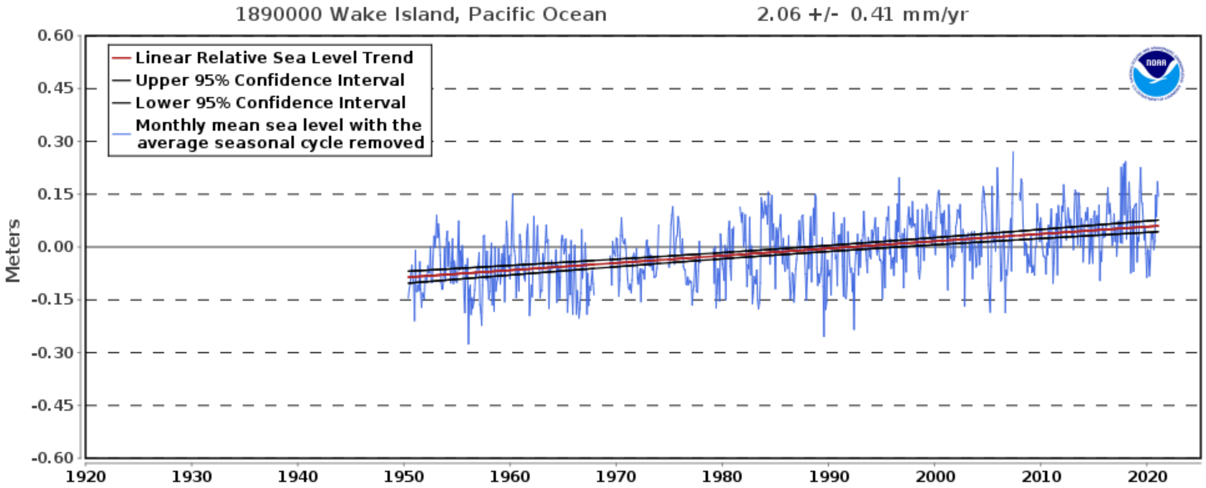


Figure 25. Monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents at Wake Island