State of the Climate in the South-West Pacific

2021

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

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Cover photo: Vanessa Mazarese/WMO.

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Key messages

The La Niña event that prevailed for the greater part of 2021 strongly influenced the climate in the region. It contributed to significant rainfall anomalies, namely the particularly dry conditions in much of the equatorial Pacific, and the wet conditions over the Maritime Continent[1] and parts of Australia.

Temperatures in 2021 were substantially cooler than the previous few years in the region, largely as a result of La Niña conditions. The year 2021 ranked between the seventh and tenth warmest on record, depending on the data set considered. Temperatures were 0.25 [0.22–0.31] °C above the 1981–2010 average, and 0.47 [0.44–0.50] °C above the WMO 1961–1990 reference period for climate change.

Marine heatwaves occurred in various parts of the region during 2021, although the La Niña event limited their extent compared with previous years. There were significant coral bleaching events reported in some areas, especially in waters around Papua New Guinea and the Solomon Islands, although bleaching in the Great Barrier Reef was limited in 2021 compared with recent years.

The coastal sea-level rise rates were, in general, slightly higher than the global mean rate, approaching 4 mm per year in several areas, except in southern Australia, where the rate was similar to the global mean.

New Zealand's glacier ice volume reduced by 35% between 1978 and 2020, and the cumulative ice loss has accelerated in recent years, with 93% of the overall loss occurring since 2005. In Indonesia, satellite estimates showed a total ice area in the western part of the island of Papua in July 2021 of 0.27 km^2, a decrease of about 20% from the previous assessment of 0.34 km^2 in May 2020.

The tropical cyclone season was slightly below average overall in the western North Pacific and close to average in terms of total numbers of tropical cyclones in both the Australian and South Pacific regions. Among tropical cyclones in the region, *Seroja* was the most significant cyclone in the southern hemisphere in 2021, bringing severe damage to Indonesia and Australia. Tropical Cyclone *Rai* also brought severe damage to the Philippines. Tropical cyclones with strong winds and heavy rainfall destroyed many of the small hold farms and individual gardens upon which around 80% of all Pacific Islanders rely for agricultural produce, thereby contributing to increased food insecurity in the region.

Kiribati and Tuvalu, where annual rainfall was widely less than 50% of average, were the worst affected by drought, while the Federated States of Micronesia and the Republic of the Marshall Islands also experienced significant drought at times.

The South-West Pacific region is prone to disasters, especially floods and storms. In 2021, the region reported 57 natural hazards, 93% of which were floods and storms. Overall, 14.3 million people were directly affected by these disasters, causing total economic damage of US$ 5.7 billion. More than 90% of the natural hazards that hit the region were floods and storms.

Strengthening early warning systems can play a pivotal role in taking anticipatory action, enhancing preparedness and reducing the impact of these hazards. However, there is also a clear need to prioritize the development of multi-hazard early warning systems and climate forecasts, not only for tackling natural hazards and achieving Sustainable Development Goal (SDG) 13 (Climate Action), but also for accelerating progress of multiple associated SDGs.

Foreword

After the successful publication of the first WMO report on the *State of the Climate in South-West Pacific 2020* (WMO-No. 1276) last year, I am pleased to see the timely publication of this second edition. This second report has involved National Meteorological and Hydrological Services (NMHSs) and several research institutions, as well as an increased number of contributing United Nations agencies and international and regional organizations.

The report summarizes the state of the climate, extreme events and their socioeconomic impacts in the South-West Pacific region in 2021. Temperatures in the region were cooler than the previous few years largely because of La Niña conditions which prevailed for much of the year. La Niña also brought dry conditions in much of the equatorial Pacific, and wet conditions over parts of South-East Asia and Australia. Floods and tropical cyclones brought severe socioeconomic damages and casualties in these areas.

The present report also shows that sea-level rise has continued in the region. Given that there are many island countries in the region and most large cities are in coastal zones, this trend could exacerbate vulnerabilities in the region with respect to storm surges, coastal inundation and erosion, food and water security, and ultimately habitability and sustainability of the region.

Considering the trends in climate indicators shown in the present report, strengthening early warning systems can play a pivotal role in taking anticipatory action, enhancing preparedness and reducing the adverse impacts of hydrometeorological hazards. Despite the continuous efforts in strengthening multi-hazard early warning systems, the report clearly points out that there are still significant gaps to be addressed to strengthen these. In this regard, WMO leads efforts through the United Nations Global Early Warning Initiative, including strengthening earth system observations and monitoring, and predictive and warning capabilities.

The information in the present report is built on observing systems coordinated by WMO and its partner organizations. The WMO Integrated Global Observing System (WIGOS) provides basic weather and climate information and the Global Climate Observing System (GCOS) defines a broader set of Essential Climate Variables (ECVs) that are needed to monitor the global climate and support mitigation and adaptation.

While the evidence for climate change in the region is unequivocal, the most recent Intergovernmental Panel on Climate Change (IPCC) reports show that significant gaps remain in the observation of some variables over the region, particularly precipitation, but also the basic variables defined in the WMO Global Basic Observing Network (GBON). GBON, and the Systematic Observations Financing Facility that supports it, will provide critically needed observations for numerical weather prediction, and will help substantially strengthen climate monitoring and early warning systems.

I take this opportunity to congratulate the experts from the region and around the world for leading the scientific coordination and authorship of this report, and thank WMO Members and sister United Nations agencies for their continuous commitment to supporting this publication, through providing input and contributing to the report review process.

Prof. Petteri Taalas
Secretary-General, WMO

Preface

The South-West Pacific is a diverse region with multiple small island nations, coastal livelihoods and rich natural ecosystems. However, the "riskscape" of the South-West Pacific is expanding and intensifying with climate change, combined with further challenges emanating from our ongoing mission of COVID-19 recovery.

In 2021, torrential rains, severe winds and floods brought on by Typhoon *Rai* wreaked havoc in multiple provinces of the Philippines. These events not only caused many fatalities but also impacted large portions of agricultural lands and fisheries. Strong winds and heavy rainfall brought by Tropical Cyclone *Ana* affected the livelihood and food security of large proportions of Fiji's population. Multiple flood events in the South-West Pacific continue to cause fatalities and substantial economic losses, with Indonesia and Malaysia particularly affected in 2021.

These events point to the urgency of implementing key adaptation solutions. The Glasgow Climate Pact boosts adaptation action as it aims for a decade of transformative climate action. However, policy pathways for adaptation must be solidly rooted in scientific evidence.

The Economic and Social Commission for Asia and the Pacific (ESCAP) *Asia-Pacific Disaster Reports* 2021 and 2022 estimate that in the South-West Pacific, investments in adaptation would need to be highest in Indonesia, at US$ 8.8 billion, followed by the Philippines at US$ 5.5 billion. As a percentage of the country's GDP, the highest cost is estimated for Vanuatu at 9.6%, followed by Tonga at 8.6%.

Given that floods and tropical cyclones account for the highest economic losses, adaptation investment must be directed towards prioritizing anticipatory action and preparedness for these events. Notwithstanding the progress in establishing early warning systems, further strengthening is needed as climate change intensifies. Similarly, new infrastructure needs to be made more resilient, alongside improvements in water resources management and dryland agriculture crop production, while nature-based solutions bring durable and wide-ranging benefits. Investing in these solutions would also ensure progress on Sustainable Development Goal (SDG) 13 (Climate Action) and accelerating progress on multiple associated SDGs, including Goal 1 (No Poverty), Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-being), Goal 9 (Industry, Innovation, and Infrastructure), and Goal 11 (Sustainable Cities and Communities).

In this context, the *State of the Climate in the South-West Pacific 2021* is timely, as it unpacks the interconnections between climate indicators and the SDGs, and helps bridge gaps between science and policy practice. ESCAP and WMO working in partnership will continue to invest in raising climate ambition and accelerating the implementation of climate policy actions. To this end, the ESCAP Risk and Resilience Portal, which uses the latest climate information and identifies risk hotspots and adaptation measures by country and subregions, provides much of the evidence base for this report. Policymakers are invited to use the Portal to help streamline evidence-based decision-making.

Armida Salsiah Alisjahbana
Under-Secretary-General of the United Nations and Executive Secretary of ESCAP

Global climate context

The global annual mean temperature in 2021 was 1.11 ± 0.13 °C above the 1850–1900 pre-industrial average – less warm than in some recent years owing to cooling La Niña conditions at the start and end of the year. The year 2021 was between the fifth and seventh warmest year on record according to six data sets (Figure 1).[2] The past seven years, 2015 to 2021, were the seven warmest years on record. The year 2016, which started during a strong El Niño, remains the warmest year on record in most data sets.

Atmospheric concentrations of the three major greenhouse gases reached new record highs in 2020, with levels of carbon dioxide (CO_2) at 413.2 ± 0.2 parts per million (ppm), methane (CH_4) at 1 889 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 333.2 ± 0.1 ppb – respectively 149%, 262% and 123% of pre-industrial (before 1750) levels. Real-time data from specific locations, including Mauna Loa (Hawaii) and Cape Grim (Tasmania) indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2021. Increasing greenhouse gas concentrations lead to an accumulation of heat in the climate system, much of which is stored in the ocean.

Over the past two decades, the ocean warming rate strongly increased, and the ocean heat content in 2021 was the highest on record. Ocean warming and accelerated loss of ice mass from the ice sheets contributed to the rise of the global mean sea level by 4.5 mm per year between 2013 and 2021, reaching a new record high in 2021. The ocean absorbs about 23% of annual anthropogenic emissions of CO_2 into the atmosphere, thereby helping to alleviate overall warming; however, CO_2 reacts with seawater and lowers its pH. This process, known as ocean acidification, affects many organisms and ecosystem services, and threatens food security by endangering fisheries and aquaculture.[3,4]

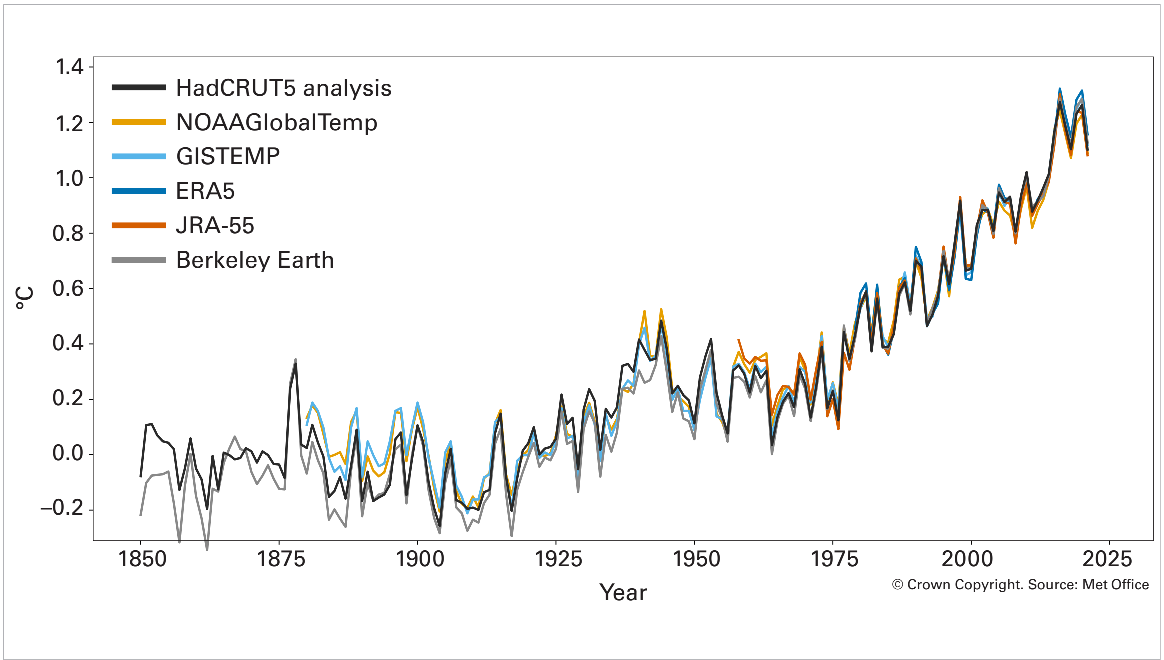


Figure 1. Global annual mean temperature difference from pre-industrial conditions (1850–1900) for six global temperature data sets. For further explanation and details of the data sets, see *State of the Global Climate 2021* (WMO-No. 1290).
Source: Met Office, United Kingdom of Great Britain and Northern Ireland

Regional climate

The following sections analyse key indicators of the state of the South-West Pacific regional climate. One important such indicator, temperature, is described in terms of anomalies, or departures from a reference period. For global mean temperature, the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC)[5] uses the reference period 1850–1900 for calculating anomalies in relation to pre-industrial levels. However, the pre-industrial reference period cannot be used as a baseline for calculating regional anomalies, due to insufficient data for calculating region-specific averages prior to 1900. Regional temperature anomalies are therefore expressed relative to the 30 year 1961–1990 reference period. This is the fixed reference period recommended by WMO as a consistent and stable reference period for assessing long-term climate change, especially for temperature. The 1981–2010 climatological standard normal period is also used in some cases, for computing anomalies in temperature and other indicators with reference to more recent climate average conditions. Exceptions to the use of these baseline periods for the calculation of anomalies, where they occur, are explicitly noted.

MAJOR CLIMATE DRIVERS

The climate in the South-West Pacific region[6] is influenced by a number of drivers of regional climate variability,[7] including the El Niño-Southern Oscillation (ENSO). ENSO strongly influences the climate over most of the tropical Pacific, along with many other parts of the world. The Indian Ocean Dipole (IOD) strongly influences climate over the tropical Indian Ocean and adjacent countries, particularly Australia. The Madden-Julian Oscillation (MJO) influences intraseasonal climate variability in tropical areas, with active phases increasing the chances of heavy rainfall and tropical cyclone formation in the affected longitudes, while the Southern Annular Mode (SAM) impacts the southern hemisphere extratropics.

The climate in 2021 was strongly influenced by La Niña. La Niña conditions prevailed for the greater part of the year. The La Niña event, which was moderate in strength, began in late 2020 and continued into the first quarter of 2021. Conditions returned to neutral by May, but La Niña redeveloped in the second half of the year and again reached moderate intensity by the end of the year. La Niña contributed to significant rainfall anomalies in the region during 2021, particularly dry conditions in much of the equatorial Pacific, and wet conditions over the Maritime Continent and parts of Australia.

The IOD was in a negative phase in the second half of 2021, the first such event since 2016. This contributed to high winter and spring rainfall in parts of Australia and combined with La Niña to be a major driver of Australia's wettest November on record. The SAM was predominantly positive through the year, contributing to wet conditions in some eastern parts of Australia, especially New South Wales.

There were a number of active phases of the MJO. During an active phase in the western Pacific region in late January, four tropical lows (three of which became cyclones) formed in the South Pacific within a few days, while an active phase in late March and early April in the Maritime Continent region coincided with the formation of Tropical Cyclones *Seroja* and *Odette* in the eastern South Indian Ocean.

TEMPERATURE

For land and ocean areas in the South-West Pacific region, temperatures in 2021 ranked between the seventh and tenth warmest year on record, depending on the data set considered. Temperatures were 0.25 [0.22–0.31] °C above the 1981–2010 average (and 0.47 [0.44–0.50] °C above the 1961–1990 average)[8] (see Figure 2). The year 2021 was substantially cooler than the previous few years in the region, largely as a result of La Niña conditions which prevailed for much of the year. La Niña years are typically substantially cooler than other years in the South-West Pacific region. Temperatures in 2021, although lower than those over the 2015 to 2020 period, were 0.2 °C to 0.3 °C warmer than those during the last strong La Niña period in 2011.

The most significant warmth was in the western tropical Pacific, and in the South Pacific over a region extending from New Zealand to French Polynesia (see Figure 3). Over these regions, temperatures were generally 0.5 °C to 1.0 °C above the 1981–2010 average, locally exceeding 1 °C above average over ocean areas east of New Zealand. Within this area, Rapa (in southern French Polynesia) had its warmest year on record. New Zealand also had its warmest year on record, with an average temperature 0.95 °C above the 1981–2010 average, while some ocean areas east of the Philippines also had their warmest year on record.

It was cool over much of the equatorial Pacific and over many parts of southern Australia, although only a few locations were more than 0.5 °C below average. New South Wales had its coolest year since 1996, with temperatures 0.3 °C below the 1981–2010 average.

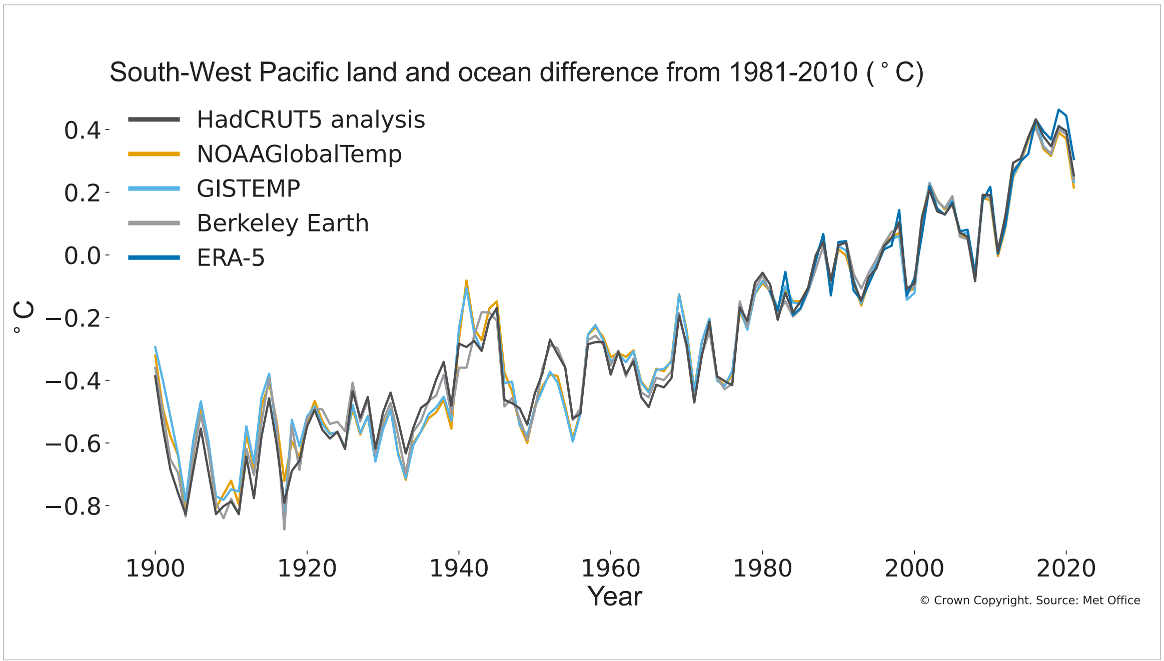


Figure 2. Annual average temperature anomalies (relative to 1981–2010) for WMO Regional Association V South-West Pacific. Data are from five different data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth and ERA5.
Source: Met Office, United Kingdom

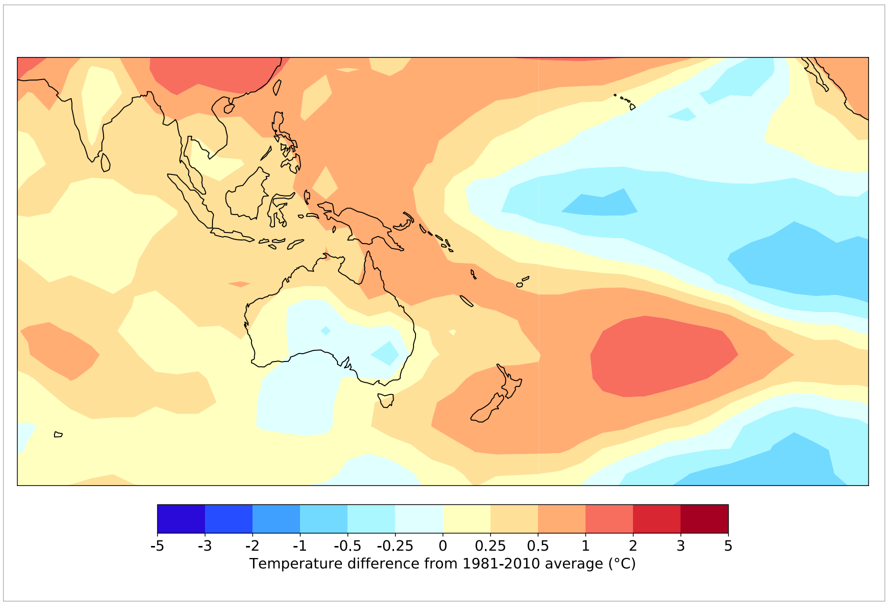


Figure 3. Annual temperature anomalies for 2021, relative to the 1981–2010 average, using a median of the five temperature data sets shown in Figure 2. *Source:* Met Office, United Kingdom

PRECIPITATION

Rainfall patterns over many parts of the region were consistent with La Niña conditions which prevailed early and late in 2021. Annual rainfall was well below average over most equatorial regions east of 150°E, with especially strong dry anomalies over Kiribati and Tuvalu. Other regions that experienced significantly below-average rainfall in 2021 include southern parts of the Federated States of Micronesia and the Republic of the Marshall Islands, along with northern and central parts of French Polynesia. Rainfall was more than 50% below average on the Marquesas and Tuamotu Islands. Annual rainfall was below the 10th percentile at numerous locations across all these regions.

In contrast, rainfall was average to above average over most of the Maritime Continent region. In the wetter parts, many locations recorded annual rainfall above the 90th percentile. Singapore had its second-wettest year since 1980, with January being especially wet. Parts of Malaysia, along with the southern half of the Philippines, also had rainfall well above average. In Papua New Guinea, rainfall was above the 90th percentile at Port Moresby for both January–March and October–December. New Caledonia was also wet, having its third-wettest year on record with a national average 50% above normal.

Annual rainfall in the South Pacific near and south of the South Pacific Convergence Zone was generally close to average. This region includes Vanuatu, Fiji, Tonga, the Solomon Islands and the Cook Islands. In the North Pacific, Hawaii was very dry through the middle of 2021, with Honolulu having its driest April–November on record, although heavy rain fell early and late in the year, resulting in annual totals generally near average. The northern half of the Philippines had rainfall close to average.

In Australia, nationally averaged rainfall was slightly above average. The most significant wet conditions were in the eastern half of New South Wales, which experienced major flooding in March. Some locations near the New South Wales-Queensland border had their wettest year on record in 2021, after having their driest year in 2019. It was also a relatively wet year in the south-west of Western Australia, which has experienced long-term rainfall decline, with Perth (892 mm) having its wettest year since 1995. Many parts of northern and interior Australia had near-average rainfall despite La Niña conditions, although November was very wet over large areas and was the country's wettest on record.

Annual rainfall in New Zealand was close to average at most locations despite some very wet and very dry periods during the year, with prolonged dry spells in many areas, and major floods affecting the South Island in May and July. It was wetter than average in many western and interior parts of the South Island, and relatively dry in the northern North Island and the far south of the South Island.

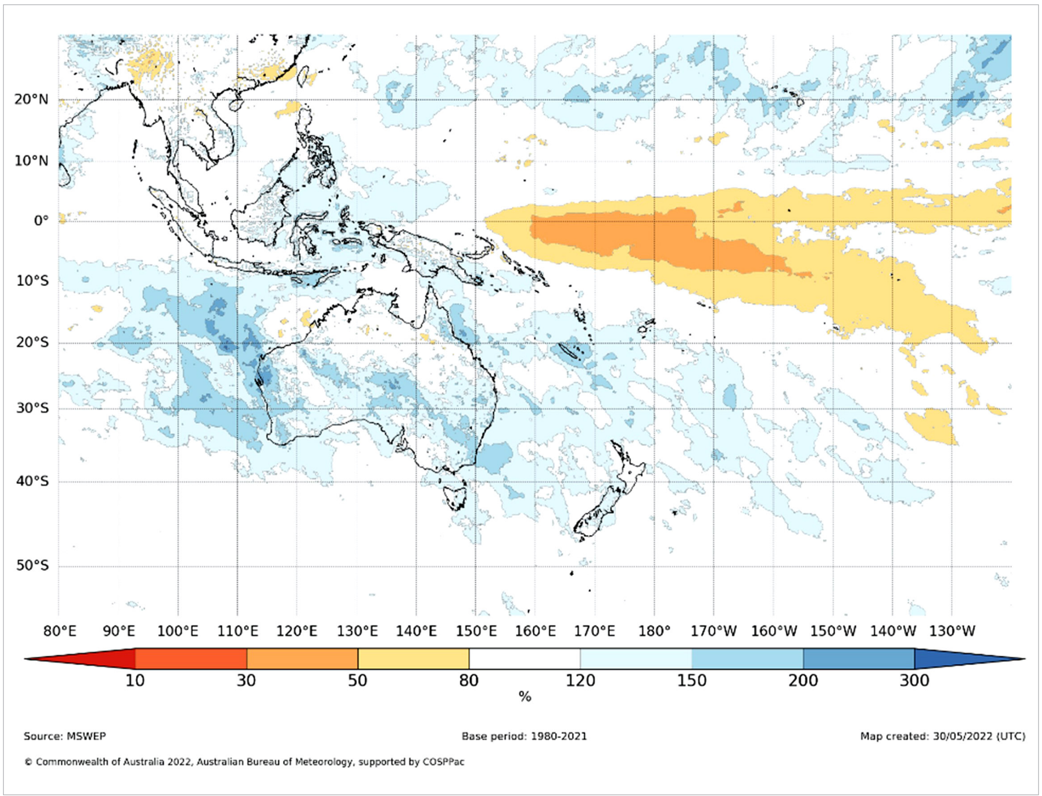


Figure 4. Rainfall in 2021 as % of normal (1980–2021), from the satellite-based Multi-Source Weighted-Ensemble Precipitation (MSWEP v2.8) data set

CRYOSPHERE

Snow is rare or unknown at low elevations over most of the region, however snow and ice occur in some mountain regions. There are glaciers in the mountains of New Zealand, mostly on the South Island, and on the highest peaks of the western part of the island of Papua. There is significant seasonal snow cover in the highland regions of New Zealand and southern Australia.

New Zealand's seasonal snow in 2021 experienced a marked elevational divide, with below-average snow depths at lower elevations (< 1 500 m), and average or above-average snow depths at higher elevations (> 1 500 m). This reflects the overall climate patterns experienced in New Zealand: it was the country's warmest winter on record with an anomaly of 1.3 °C above the 1981–2010 average, surpassing the previous record observed in 2020; and precipitation was typically higher than normal over the South Island's mountainous terrain.

Data from nine of the National Institute of Water and Atmospheric Research (NIWA, New Zealand) Snow and Ice Monitoring sites show that the average snow depth for the year was as low as 16% of average[9] at Albert Burn (Otago, 1 280 m elevation). However, average annual snow depths were above average at six of the sites, while the median value across all nine sites was 115% of annual average snow depth.

The year 2021 was unique for the station at Mt Potts (Canterbury, 2 128 m elevation). On average, snow depth at Mt Potts peaks near the start of August, and melts to a negligible depth by the end of September. In 2021, the peak snow depth of 1.74 m (259% of the average annual peak snow depth) was measured on 31 May, associated with extremely heavy precipitation in the Canterbury region which resulted in floods at lower elevations (see Heavy precipitation and flooding), and the snowpack remained until early November.

At the remaining NIWA Snow and Ice Monitoring sites, peak snow depths for 2021 ranged from 0.41 m (69% of average) at Murchison Mountains (Southland, 1 140 m elevation) to 3.42 m (119% of average) at Mueller Hut (Canterbury, 1 818 m elevation).

In Australia, mountain snowfall was generally above average early in the season and below average late in the season. At the longest-running snow depth measurement site, Spencers Creek (near Perisher Valley in New South Wales), the seasonal peak depth of 183.6 cm was reached on 29 July. The peak depth was close to the long-term (1954–2021) average, but it is only the third time that the seasonal peak has occurred in July. The other two occurrences have been since 2011, consistent with a long-term trend towards earlier seasonal peaks.

Research published in 2021 shows that New Zealand's glacier ice volume reduced by 35% between 1978 and 2020).[10] The cumulative ice loss has accelerated in recent years, with 93% of the overall loss occurring since 2005. In Indonesia, satellite estimates show a total ice area in the western part of the island of Papua in July 2021 of 0.27 km^2, a decrease of about 20% from the previous assessment of 0.34 km^2 in May 2020.

SEA-SURFACE TEMPERATURE

Sea-surface temperature (SST) is an important physical indicator for Earth's climate system. Changes in SST play a critical role for the coupling between the ocean and the atmosphere, as they can trigger the transfer of energy, momentum and gases (including water vapour evaporating and ocean uptake/release of greenhouse gases) between the two Earth system components.[11] SST is an essential parameter in weather prediction and atmospheric model simulation, and is also important for the study of marine ecosystems.[12] Each of the last four decades has been successively warmer than any decade that preceded it since 1850 as a consequence of anthropogenic warming (Figure 1). Global SST was 0.88 [0.68–1.01] °C higher in 2011–2020 than 1850–1900, compared with the larger increases over land (1.59 [1.34–1.83] °C).[13] While the global mean SST is increasing, there is variability around this average with different regions and locations experiencing different responses, both in terms of the trend and variance on different timescales, and which are linked to climate modes (such as ENSO) and ocean dynamics such as ocean fronts, eddies, coastal upwelling and exchanges between the coastal shelf and open ocean.[14]

In 2021, SSTs in the central tropical Pacific were below average and linked to La Niña conditions (Figure 5(b), Box 2), with the region east of 160°E having its coolest year since the strong La Niña of 2011. Over most remaining parts of the region, SSTs were above average, with some areas east of New Zealand more than 1 °C above the 1981–2010 average. SSTs were also abnormally warm in the western tropical North Pacific. Over the region east of the Philippines (Figure 5(b), Box 1), they were only slightly below the record set in 2020.

The area-averaged SST anomalies reached record values again (nearly +0.5 °C) in the north-western part of the region, including the Philippine Sea (Figure 5(b), Box 1). In that area (Box 1), surface ocean warming has occurred at rates slightly higher than the global average. Changes in SST in the tropical western Pacific (Figure 5(b), Box 2) and the tropical eastern Indian Ocean (Figure 5(b), Box 3) are affected by climate variability at interannual timescales, and in these areas surface ocean warming occurs at rates below the global average (Figure 5(a)). In the tropical Pacific, ENSO is a major driver of lower- and higher- than-average SST values from one year to another. The ocean area around New Zealand, including the Tasman Sea, shows a regional average warming trend slightly below the global SST warming rate (Figure 5(b), Box 4).

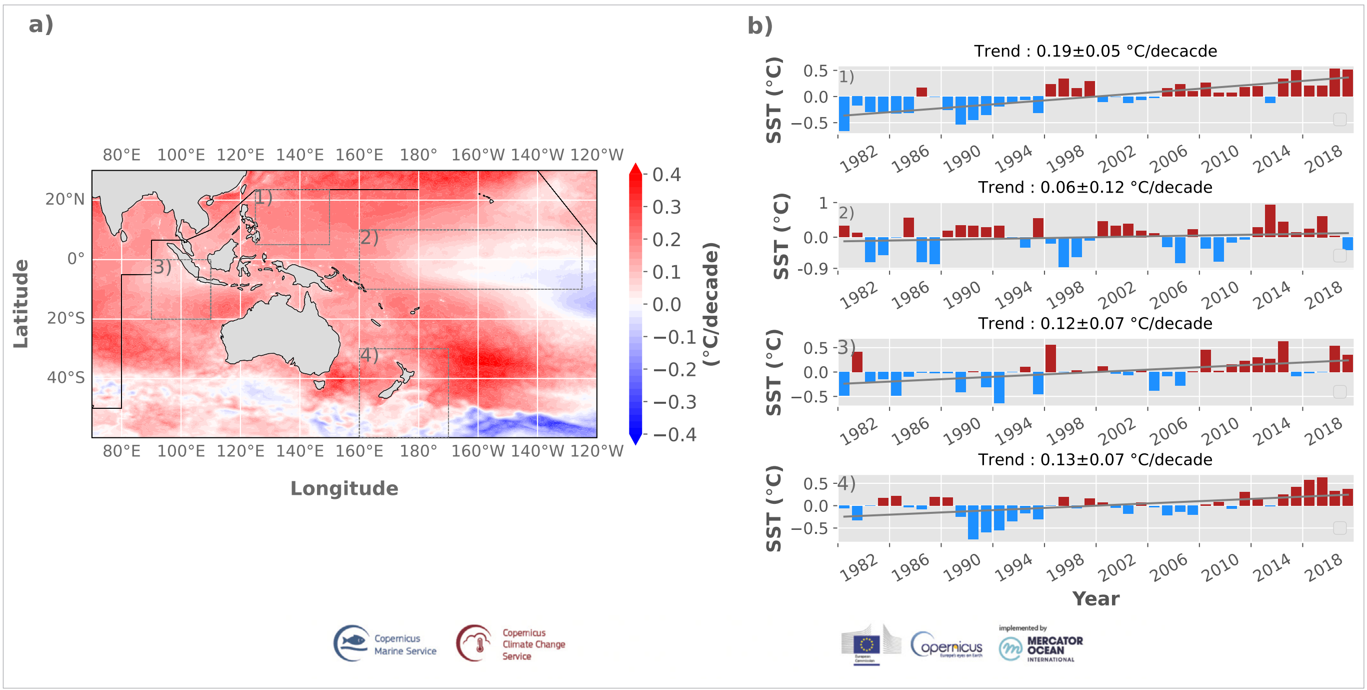


Figure 5. (a) Trends of SST (°C per year) over the period 1982–2021. (b) Area-averaged time series of SST anomalies (°C) relative to the 1982–2021 reference period for the areas indicated in grey dashed lines on 5(a).
Source: Derived from the remote sensing product SST_GLO_SST_L4_REP_ OBSERVATIONS_010_024 downloaded from Copernicus Marine Service

The ocean area of the South-West Pacific region shows overall surface ocean warming in satellite data over the 1982–2021 period. This is particularly so in the Tasman Sea, in the areas between 20°S and 40°S in the Indian and Pacific Ocean, and in the west of the Timor Sea, at rates of more than 0.04 °C per year (Figure 5(a)). This is about three times faster than the global surface ocean warming rate. For comparison, global mean SST has increased over recent decades at a rate of 0.015 ± 0.001 °C per year.[15]

OCEAN HEAT CONTENT

Owing to emissions of heat-trapping greenhouse gases resulting from human activities, the global ocean has warmed from absorbing more than 90% of the excess heat in the climate system.[16] Since 1993, the rate of ocean warming has likely more than doubled, and it will continue to warm throughout the twenty-first century.[17,18] Ocean warming contributes about 40% of observed global mean sea-level rise through thermal expansion of seawater.[19,20,21] Ocean warming is altering ocean currents and indirectly altering storm tracks,[22,23,24] as well as reducing mixing between layers of the ocean.[25] Together with ocean acidification and deoxygenation, ocean warming can lead to dramatic changes in ecosystem assemblages, biodiversity impacts, population extinction, coral bleaching, infectious diseases and changes in animal behaviour (including reproduction), as well as the redistribution of habitats.[26,27,28,29]

Most of the areas in the South-West Pacific region show upper-ocean (0–700 m) warming since 1993, which is particularly strong in the Tasman Sea and in the area between 20°S and 40°S in the Pacific Ocean, with ocean heat content increasing at rates exceeding 2 watts per square meter (W/m^2) (Figure 6). This is more than three times faster than the global rate of 0.6 W/m^2.[30] In addition, upper-ocean warming in the region is strongly affected by natural variability. For example, in the tropical Pacific, the average upper-ocean warming is dominated by natural variability (for example, ENSO) whereby large amounts of heat are re-distributed from the surface down to deeper layers, and from the tropics to the subtropics.[31]

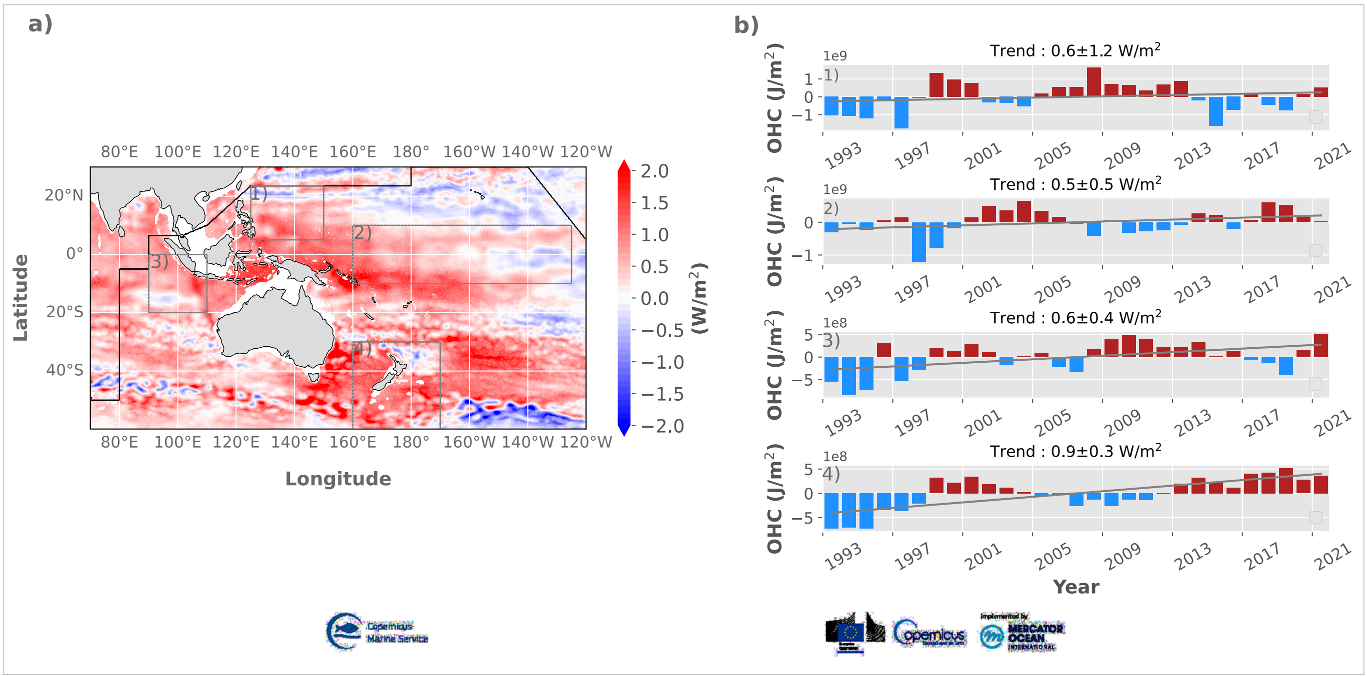


Figure 6. (a) Trends of ocean heat content (OHC) (in W/m^2) over the period 1993–2021, integrated from the surface down to 700 m depth. Ocean warming rates in areas with water shallower than 300 m have been masked in grey owing to product limitations. (b) Area-averaged time series of upper 700 m OHC anomalies (joule per square meter (J/m^2)) for the four areas indicated in grey dashed lines on 6(a). For each area, the linear trend over the full period is provided.
Source: Derived from the in situ-based product (MULTIOBS_GLO_PHY_TSUV_3D_MYNRT_015_012) downloaded from Copernicus Marine Service

SEA LEVEL

Sea level at the coast has been measured by tide gauges in the South-West Pacific region for more than 100 years. In more recent years, the number of tide gauges in operation has grown, and records from these have been complemented by high-precision altimeter satellites.[32] Since the early 1990s, these satellites indicate that the global mean sea level has risen at an average rate of 3.3 ± 0.4 mm per year in response to ocean warming and land-ice melt. In addition to the global trend, there is substantial interannual variability at the regional scale driven by broadscale climate drivers. For example, in El Niño years, sea levels are typically anomalously low in the tropical western Pacific and anomalously high in the east, due to different rates of thermal expansion and weakened easterly winds through the tropical Pacific.

Figure 7 shows the total sea-level trend over the 1993–2020 period as measured by tide gauges and satellite altimeters in the South-West Pacific region. The map shows that rates of sea-level rise in the western tropical Pacific Ocean are substantially higher than the global mean. These regional variations are mostly due to thermal expansion being greater in those areas which are warming faster (generally consistent with the SST changes shown in Figure 5).[33]

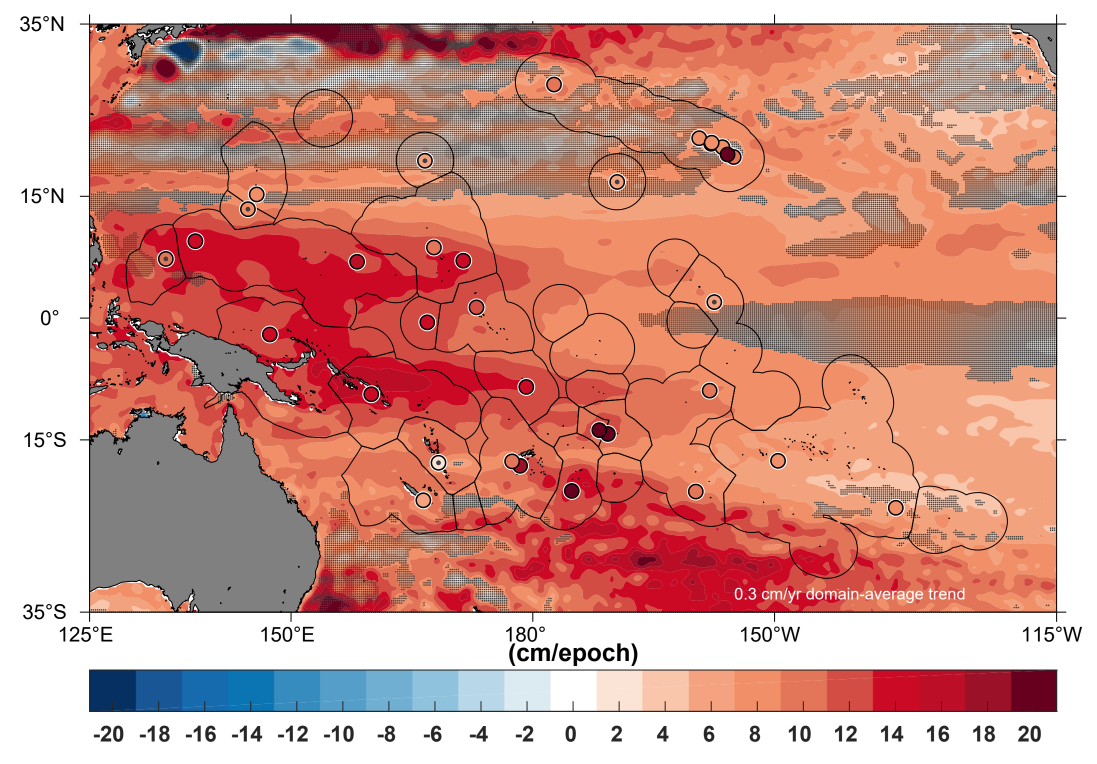


Figure 7. Regional sea-level trends from satellite altimetry and tide gauges. The map shows the total sea-level rise over the 1993–2020 period from satellite altimetry (coloured contours) and from tide gauges (circles). Hatching and circles with dots, of the altimetry and tide gauges respectively, indicate trends less than interannual variability as determined by the standard deviation of sea level monthly anomalies. *Source:* Reproduced with permission from the authors of *Pacific Islands Climate Change Monitor: 2021*[34]

A recent tide gauge-based study from Australia shows that the sea-level rise over the post-1993 period in this region has been faster than it was prior to 1993.[35] This is shown in Figure 8. The annual trend from 1966 to 2019 was 1.94 mm per year, but the trend from 1993 to 2019 was 3.74 mm per year.

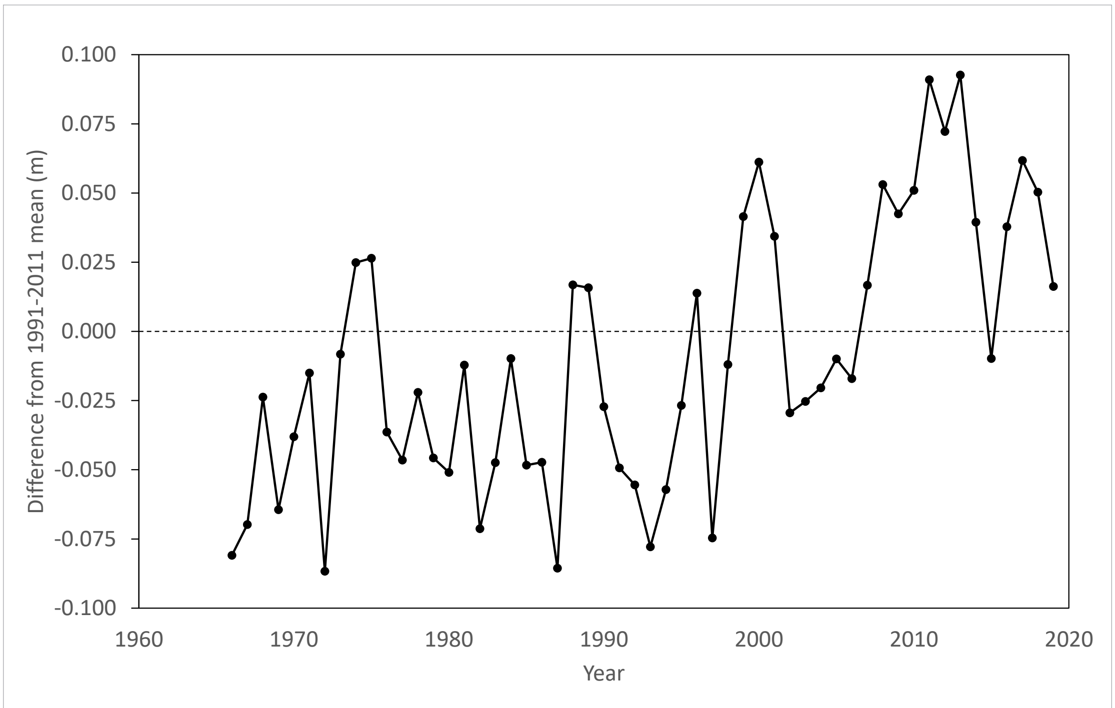


Figure 8. Trend in Australian annual mean sea level, obtained via a weighted average of 38 homogenized sea level records. *Source:* Modified based on Hague et al. (2022), with permission

Also shown (Figure 9) are the time series of coastal sea level in three oceanic regions relevant to the domain covered by the present report, including: south-east Indian Ocean, South-East Asia (western part of the tropical Pacific) and southern Australia. The coastal sea-level time series in Figure 9 shows strong interannual variability, mostly driven by ENSO and the IOD, as well as some decadal variability. The curves show temporary coastal sea-level drops up to 10 cm amplitude in the South-East Asia region during the 1997–1998 and 2015–2016 El Niño events, while the south-east Indian Ocean shows similar short-term drops during the strong positive IOD events of 1997 and 2019. The coastal sea-level rise rates are, in general, slightly higher than the global mean rate, approaching 4 mm per year in several areas, except in southern Australia, where the rate is similar to the global mean.

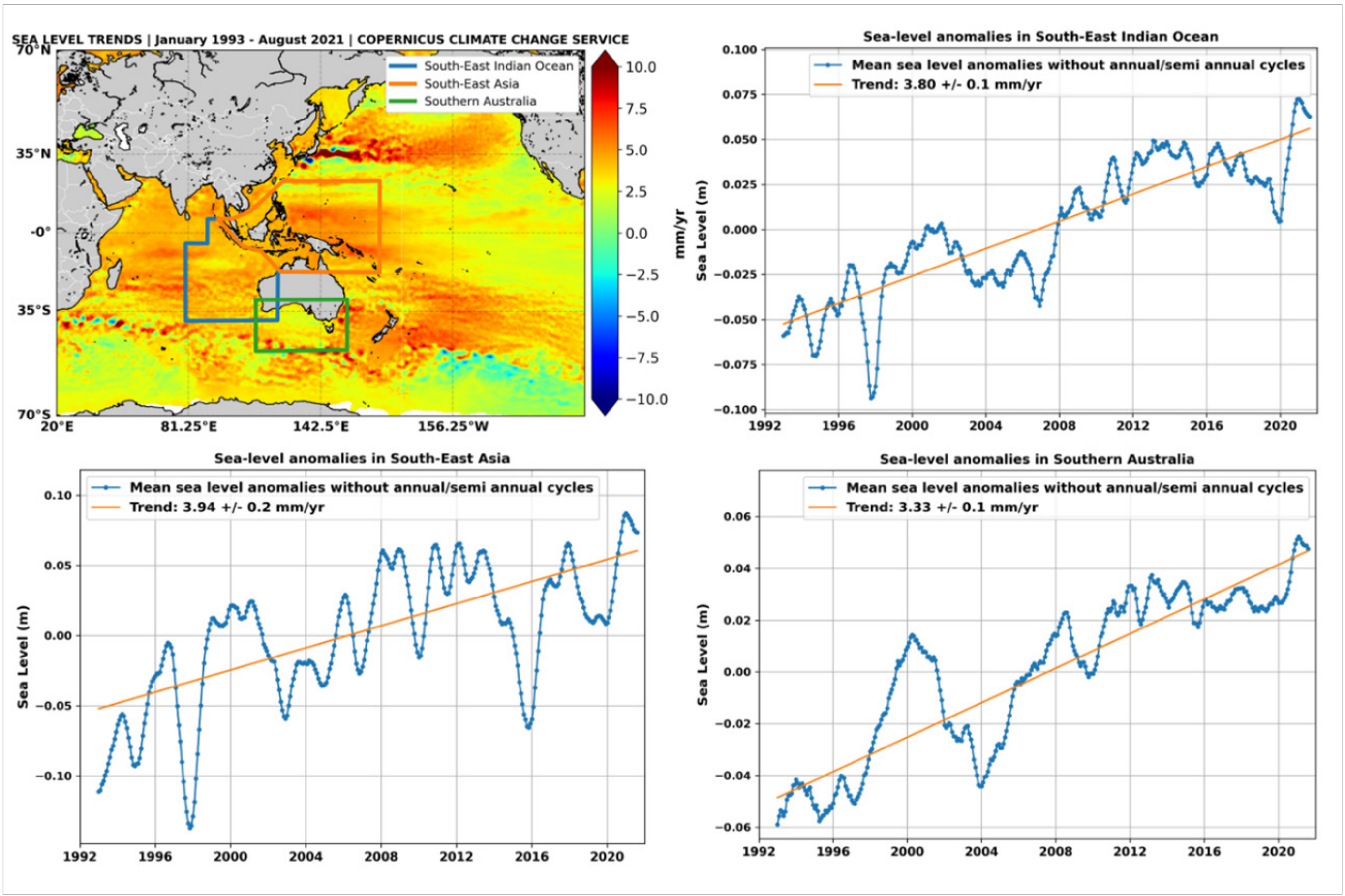


Figure 9. Altimetry-based coastal sea-level time series (m) from January 1993 to August 2021 for Indian Ocean and Pacific regions. Seasonal cycle was removed; glacial isostatic adjustment correction was applied. Top left shows annual mean sea-level trend and location of regions summarized in top right and bottom left and right, which show mean sea-level anomalies (blue) and trend (orange line) for each of the south-east Indian Ocean, South-East Asia and Southern Australia regions, respectively.
Source: Laboratory of Space Geophysical and Oceanographic Studies (LEGOS), France

Extreme events

TROPICAL CYCLONES

The South-West Pacific encompasses the Australian and the South Pacific tropical cyclone regions (covering the southern hemisphere from 90°E eastward to 120°W, up to the equator) as well as part of the western and central North Pacific regions. It is an active region for tropical cyclones with most countries affected. The South Pacific and Australian tropical cyclone season of 2020/2021 coincided with an active La Niña in the tropical Pacific. La Niña typically acts to shift tropical cyclone genesis farther west in the South Pacific towards Australia, along with the shift in warmer sea-surface temperatures westward that is associated with La Niña. La Niña also often increases tropical cyclone numbers in the eastern Indian Ocean off the Australian coast when compared to either an El Niño or ENSO-neutral[36] condition, although there is a high level of variability from year to year.

In the southern hemisphere parts of Regional Association V, the 2020/2021 tropical cyclone season was close to average in terms of total number of tropical cyclones in both the Australian and South Pacific regions, with each region experiencing eight tropical cyclones in total, with three of them being severe tropical cyclones (category 3 status or above). This included category 5 Tropical Cyclone *Niran* which formed during March 2021 and impacted both regions. *Niran* was also the first category 5 storm since *Veronica* in March 2019 to impact the Australian region.

Over these regions, the most significant cyclone in 2021 was *Seroja* in April. *Seroja* formed south of Indonesia and tracked south-east towards Western Australia. It made landfall near Kalbarri on 11 April as an (Australian) category 3 cyclone, the strongest landfall so far south in Western Australia since 1956. *Seroja's* most severe impacts were from flooding and associated landslides from its precursor system in Timor-Leste, and in the Indonesian region of East Nusa Tenggara. Kupang (the capital of East Nusa Tenggara) received 700.4 mm of rainfall in the four days from 2 to 5 April (see also Affected population and damage).

Tropical Cyclone *Ana* formed on 30 January near the Fiji islands and made landfall as a category 2 cyclone. Labasa recorded its worst flood since the flood associated with severe Tropical Cyclone *Ami* in 2003. The highest 8-hour rainfall recorded during the cyclone was 563 mm at Nadarivatu, in the interior of Viti Levu (see also Agriculture and food security).

Tropical Cyclone *Niran* formed close to the north-eastern Australian coast in early March 2021, bringing high winds and rainfall, including localized flooding to northern Queensland (see Figure 10). *Niran* then tracked in a south-easterly direction away from Australia towards New Caledonia, passing close to New Caledonia's main island of Grande Terre. The strongest winds remained offshore, and by that stage, *Niran* had weakened to a category 3 storm.

Figure 10. Damage to banana crops from Tropical Cyclone *Niran*. Photograph: Australian Banana Growers' Council

In the northern hemisphere, the tropical cyclone season in the western North Pacific was slightly below average overall, although there were still several landfalls with major impacts in the Philippines. The most significant was Typhoon *Rai (Odette)*, which crossed the central Philippines on 16 December, making landfall at near-peak intensity, with a minimum central pressure of 915 hPa, after rapidly intensifying prior to landfall. It re-intensified on 18 December after entering the South China Sea, before weakening and dissipating without making further landfall (see Agriculture and food security). Tropical Storms *Choi-wan (Dante)* (in May), *Lionrock (Lannie)* (in October) and *Kompasu (Maring)* (in October) also resulted in loss of life and significant damage in the Philippines (see also Agriculture and food security), while Typhoon *Chanthu (Kiko)* in September passed through the Batanes Islands at category 5 intensity, with significant damage but no casualties reported.

HEAVY PRECIPITATION AND FLOODING

Malaysia experienced severe flooding in mid-December as a result of a monsoon surge combined with nearby tropical depression. The worst impacts were in central Peninsular Malaysia, particularly around Kuala Lumpur and in the states of Selangor and Pahang. Selangor received over 300 mm of rainfall in 48 hours, with monthly totals in the region above 600 mm, more than double the monthly average.

In Australia, persistent heavy rainfall in mid-March resulted in major flooding in eastern New South Wales. The week from 18 to 24 March was the wettest on record averaged over coastal New South Wales. The most severe flooding was along the Hastings, Karuah and Manning Rivers north of Sydney, although there was also significant flooding in other areas, including parts of western Sydney. Many inland rivers also experienced flooding, which led to substantial recovery in water storages severely depleted by the 2017–2019 drought. There was further flooding in New South Wales in November, which was Australia's wettest November on record.

Major flooding affected Canterbury, on the South Island of New Zealand, from 29 to 31 May, after a prolonged period of heavy rain. The town of Springfield was evacuated, many farms were damaged, and roads and bridges closed. A total of 16 locations had their highest May daily rainfall on record, including 186 mm at Lake Coleridge on 29 May. There was further flooding in mid-July, this time affecting the western and northern South Island, with 697 mm of rain in 72 hours at Ivory Glacier, and the Buller River reaching its highest levels since 1926. Westport, where at least 200 homes were declared uninhabitable, was the hardest hit. Post-event analyses found that the heavy rainfalls associated with both events have become more likely as a result of climate change.[37]

Floods and associated landslides affected parts of Indonesia at various times during 2021, especially in the early months of the year (see also Affected population and damage). Singapore and Malaysia also experienced heavy rainfall and flash flooding at various stages during the year, with significant flash flooding in Singapore in April after daily rainfalls of up to 170 mm. Flash flooding and landslides were also reported in parts of Hawaii in mid-March, and Guam and Palau in October.

An intense low-pressure system affected south-eastern Australia between 7 and 10 June. The most severe impacts were in Victoria, where there was major wind damage in elevated areas to the north and east of Melbourne, particularly the Dandenong Ranges and Central Highlands. There was also significant flooding in west Gippsland, especially around Traralgon. Very cold conditions affected New South Wales, with southerly winds on the western side of the storm. On 10 June, Sydney recorded its coldest day (10.3 °C) since 1984, with some sites in western Sydney having their coldest day on record. Some areas above 1 200 meters in northern New South Wales had their heaviest snowfalls since 1984.

Several severe thunderstorm outbreaks affected eastern Australia in mid-October. Hail up to 16 cm in diameter, the largest verified measurement in Australia, fell at Yalboroo (between Mackay and Proserpine, Queensland) on 19 October, while a hailstorm in the Coffs Harbour area on 20 October caused extensive damage, including a partial roof collapse in a shopping centre. Tornadoes were reported at Armidale on 14 October and in the eastern suburbs of Brisbane on 21 October.

In New Zealand, a likely tornado on 19 June caused extensive damage in Papatoetoe, in the southern suburbs of Auckland, with approximately 240 homes impacted. One worker was killed when shipping containers were toppled at a Port of Auckland freight hub.

HEATWAVES, WILDFIRES AND DROUGHTS

With 2021 being a relatively cool year in much of the region due to the effects of La Niña, extreme heat on land was less prevalent than in most recent years. Some of the most significant heatwaves of the year occurred in New Zealand, particularly on the South Island. Akaroa (38.0 °C) and Cheviot (37.9 °C) set all-time record high temperatures on 26 January, while Christchurch reached 35 °C on 26 and 27 January, only the second time that 35 °C has been reached there on two successive days. Later in the year, Orari Estate, near Timaru, reached 31.7 °C on 4 April, a national record for April.

A prolonged heatwave affected parts of Western Australia at the end of the year. Perth had four successive days above 40 °C from 25 to 28 December, equalling the city's record. Some coastal locations, including Jurien Bay north of Perth (46.0 °C), experienced their highest temperature on record.

The most significant drought conditions in 2021 affected the equatorial Pacific. Kiribati and Tuvalu, where annual rainfall was widely less than 50% of average, were the worst affected, while the Federated States of Micronesia and the Republic of the Marshall Islands also experienced significant drought. Water storage capacity on many islands in this region is very limited, meaning that even short dry periods can lead to shortages, and crop production can be considerably impacted. There was also significant drought in many parts of French Polynesia, particularly on the Marquesas, Society and Tuamotu Islands. Some wildfires were reported on the Marquesas.

In the early months of the year, parts of New Zealand were affected by drought, particularly on the North Island and the south of the South Island. Water use restrictions were imposed in some areas and hydro-electric production on the South Island was reduced. Conditions eased with increased rainfall from May onwards. Drought conditions, which had been in place since 2019 or earlier, persisted in some parts of eastern Australia, particularly the Wide Bay and Burnett regions of eastern Queensland, until being largely eliminated by heavy rain in November.

The cool and humid conditions in much of eastern Australia during 2021 resulted in low levels of wildfire activity compared with recent years. The most significant fire in Australia during the year occurred east of Perth in early February, with 98 homes and over 100 other structures being lost. It was also a year of below-average wildfire activity in Indonesia.

MARINE HEATWAVES

Marine heatwaves occurred in various parts of the South-West Pacific region during 2021, although the La Niña event limited their extent compared with previous years. The most significant marine heatwaves were in the areas with the largest annual sea-surface temperature anomalies, in the region east of New Zealand extending into southern French Polynesia (see Figure 11). Marine heatwaves in the severe category occurred in this region, while strong marine heatwaves occurred in many parts of the western Pacific away from the Equator.

There were significant coral bleaching events reported in some areas, especially in waters around Papua New Guinea and the Solomon Islands, which experienced conditions favourable to bleaching both early and late in the year. Bleaching in the Great Barrier Reef, however, was limited in 2021 compared with recent years. Significant marine heatwaves also occurred in New Zealand waters, with sea-surface temperatures more than 3 °C above average around most parts of the South Island coast.

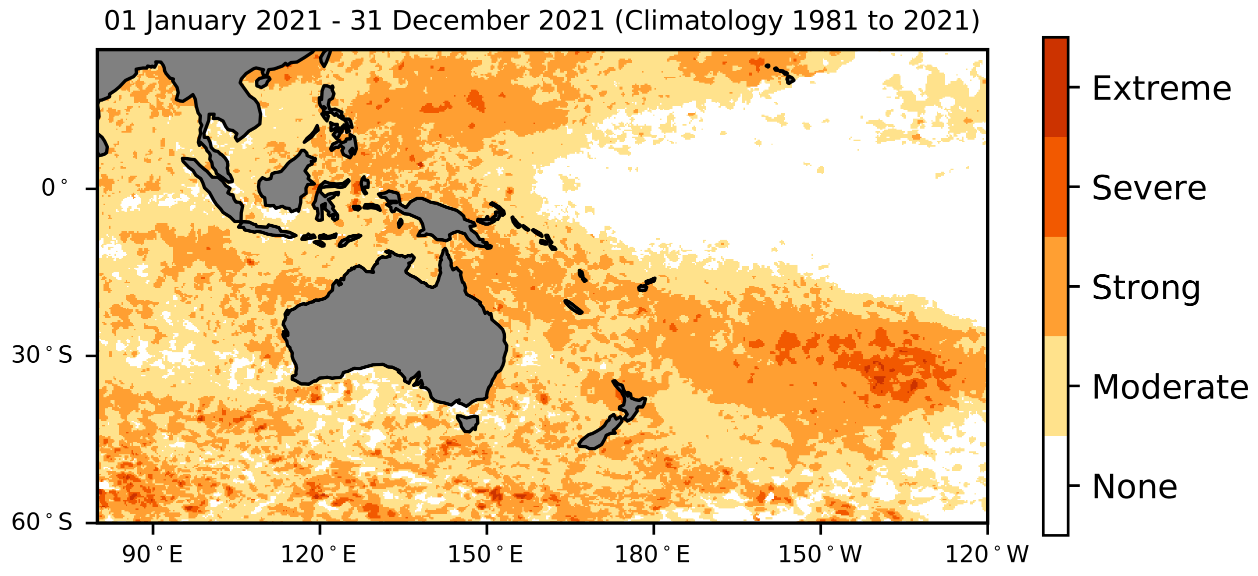


Figure 11. Strength of marine heatwave experienced in 2021 according to the categories defined in Hobday et al. (2018).[38]
Source: Bureau of Meteorology, Australia

OTHER EXTREME EVENTS

Papua New Guinea (PNG) experienced higher-than-normal tides over the period from 4 to 6 December, triggering coastal flooding. The combination of spring tides, a westerly wind burst and La Niña contributed to the increased sea level that resulted in extreme high tides around PNG. Elsewhere in the region, coastal inundation was reported in the Mariana Islands in March, while monthly mean sea levels in January were the highest on record for a number of Hawaiian sites.

Figure 12. Damage from the high tide event in Papua New Guinea in December 2021. *Source:* Papua New Guinea National Weather Service

FILLING THE GAPS IN OBSERVATION

While the evidence for climate change in the South-West Pacific region is unequivocal, the most recent Intergovernmental Panel on Climate Change (IPCC) reports show that significant gaps remain in the observation of some variables over this area, particularly precipitation. The current gaps in global surface-based data-sharing significantly impact the quality of weather and climate information locally, regionally and globally. While some parts of the globe provide a reliable feed of these data, many others contribute only limited amounts and, in several instances, the amount of data shared is even declining.

Reliable climate analysis as well as weather forecasts are essential for public services that help save lives, protect property and foster economic prosperity. This is all made possible by continued access to a wealth of real-time environmental observations from the entire globe. Against these backgrounds, the World Meteorological Congress and its 193 member countries and territories agreed to establish the Global Basic Observing Network (GBON) in 2019. GBON is a landmark agreement and offers a new approach in which the basic surface-based weather observing network is designed, defined and monitored at the global level. GBON sets out a clear requirement for all WMO Members to acquire and internationally exchange the most essential surface-based observational data at a minimum level of spatial resolution and time interval. Therefore, GBON consists of a fundamental element of the WMO Integrated Global Observing System (WIGOS) and provides basic weather and climate information that are needed to monitor the global climate and support mitigation and adaptation. Once fully implemented, GBON will improve the availability of the most essential surface-based data, which will have a direct positive impact on the quality of climate information.

To achieve sustained compliance with the GBON requirements, substantial investments, strengthened capacity and long-term resources for operation and maintenance are needed in many countries. For this purpose, the Systematic Observations Financing Facility (SOFF) was established to provide technical and financial assistance in new, more effective ways. SOFF will support countries to generate and exchange basic surface-based observational data critical for improved weather forecasts and climate services, with three novel design features to provide effective long-term financing and technical assistance:

1. **Applying internationally agreed metrics to guide investments:** SOFF support is based on the global optimal and internationally agreed design to guide investments – the GBON. By using the GBON concept, SOFF will be in a position to allocate scarce resources most effectively.

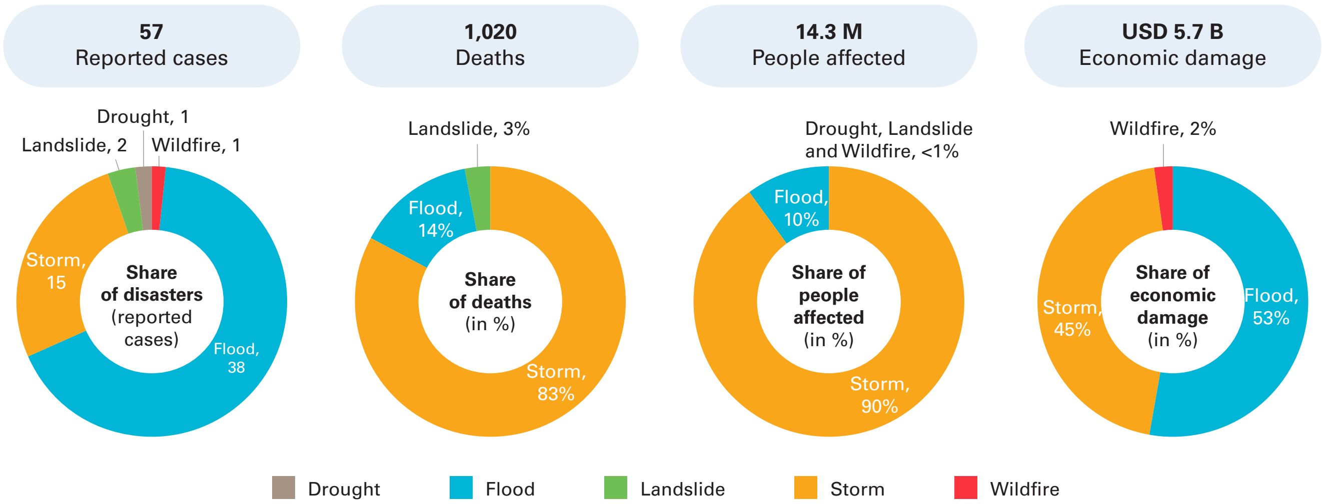
2. **Using long-term, sustained data-sharing as a measure of success:** SOFF will provide grant support to least developed countries (LDCs) and small island developing States (SIDS) for capital investments, and contribute to cover operations and maintenance. This will ensure that the benefits of investments in observational capacity are sustained, and translate into long-term weather data-sharing.

3. **Creating local benefits while providing a global public good:** In addition to local and regional benefits, better weather data from LDCs and SIDS will improve the quality of weather forecasts globally, especially medium- to long-range forecasts, with benefits for all countries, in all sectors.

Climate-related impacts and risks

AFFECTED POPULATION AND DAMAGE

The South-West Pacific region is prone to disasters, especially floods and storms. In 2021, the region reported 57 natural hazards, 93% of which were floods and storms. Overall, 14.3 million people were directly affected by these disasters, causing total economic damage of US$ 5.7 billion. While storms accounted for the highest fatalities and people affected, floods caused the highest economic damage (Figure 13).



Source: ESCAP calculations based on EM-DAT, accessed on 30 April 2022
Note: The economic damages of some disaster occurrences are not presented in the diagram due to data unavailability.

Figure 13. Overview of 2021 disasters in the South-West Pacific region.
Note: ESCAP – Economic and Social Commission for Asia and the Pacific; EM-DAT – Emergency Events Database.

In 2021 in the South-West Pacific, hazard events with the highest impact in terms of fatalities, affected population and economic damage overwhelmingly consisted of storm events. Storms in the Philippines and Indonesia were associated with the highest fatalities. This highlights the high vulnerability of the South-West Pacific region, especially to storms. Notable floods and storms during the period included:

- **Tropical Cyclone *Seroja*, Indonesia, Australia:** This first affected Indonesia and Timor-Leste in its formation stage and peaked in intensity as it affected Western Australia by 10 April.[39] In Indonesia, it brought floods, flash floods, strong winds and landslides, causing dams in four sub-districts to overflow, and inundating houses and rice fields. Overall, the cyclone caused 226 fatalities and affected 509 625 persons in Indonesia[40] (see also Tropical cyclones). A total of 44 deaths were also reported in Timor-Leste, and one indirect death in Australia.

- **Flash floods, Malaysia:** These displaced over 125 000 people in December 2021 and left 61 dead.[41,42] Approximately 70 000 people were directly impacted and over 67 000 people were evacuated. The flood led to major infrastructure damage to roads, buildings and electricity, resulting in total economic damage of US$ 1.4 billion.[43,44]

- **Floods, Indonesia**: High-intensity rainfall that accompanied severe winds and brought flooding affected many parts of Indonesia. Between 15 and 21 January, flash floods caused 21 fatalities and affected over 210 000 people.[45] Over 39 000 people were displaced and over 10 000 houses, 28 schools and 46 places of worship were also fully submerged due to flood waters (see also Heavy precipitation and flooding).[46]

- **Tropical Cyclone *Conson*, the Philippines**: Between 6 and 12 September, Tropical Cyclone *Conson* made several landfalls in the Philippines and subsequently in Viet Nam. As reported on 14 September 2021, floods induced by the storm affected five regions in the Philippines. Overall, the hazard caused 19 fatalities, affected approximately 310 000 people and displaced around 30 000 people. In addition to damaging infrastructure such as houses, roads and bridges, the storm impacted nearly 1 000 hectares of agricultural area. Total damage to agriculture and infrastructure amounted to US$ 21.2 million.[47]

AGRICULTURE AND FOOD SECURITY

The Pacific Islands are confronting some of the most severe effects of climate change, while facing a decrease in available arable land. Around 80% of all Pacific Islanders rely on food supply from their own gardens or from small hold farmers to support or to supplement their diets.[48] This results in a risk to food security which is further exacerbated by climate change.

Tropical Cyclone *Ana* wreaked havoc in various parts of Fiji, with strong winds and heavy rainfall at the beginning of the year. As a result of its associated impacts, the percentage of the population suffering food insecurity increased, particularly in the northern region of the country, where food insecurity increased from 4.2% in December 2020 to 11.4% in February 2021.[49] (See also Tropical cyclones).

Tropical Cyclone *Kompasu* brought heavy rain, flooding and landslides in the Philippines between 11 and 12 October. It led to 59 fatalities and affected 1.1 million people. Infrastructure such as roads, bridges, houses and buildings were also impacted, causing a loss of nearly US$ 39 million in damages.[50] Additionally, US$ 46.8 million worth of agricultural damage left many families and victims suffering from food insecurity; as a result, about 300 000 family food packs and other food and non-food items worth US$ 14.2 million were made available[51] (see also Tropical cyclones). Also in the South Pacific, tropical cyclone *Niran* in March caused significant losses to Australia's banana crop.

On 16 December, Typhoon *Rai*, locally called *Odette*, caused devastation on the islands of Visayas and Mindanao, in the Philippines, with torrential rain, severe winds and floods leading to more than 450 deaths[52,53] (see also Tropical cyclones). As of February 2022, the Department of Agriculture reported a total damage and loss at over US$ 261 million, with over 533 000 farmers and fisherfolk and more than 462 000 hectares of agricultural areas affected, amounting to a production loss of about 273 000 metric tons. Furthermore, around 2 100 fisherfolk were affected, with a loss of US$ 3.5 million in seaweed, milkfish, tilapia and shrimp production. These implications exacerbate the food insecurity of regions where people are already vulnerable to low nutrition and where the prevalence of stunting is high.[54]

IMPACT ON THE ECONOMY

A comparison of the economic loss from disasters in the South-West Pacific region in 2021 to the average over the past 20 years shows that the amount of economic damage (approximately US$ 5.7 billion in total) is on the rise for the two major disaster types – storms (including tropical cyclones) and floods (Figure 14). More specifically, economic damage from storms has increased by 30% and more than doubled for floods, compared to the past two decades. In terms of countries, Australia has suffered the highest proportion of economic losses due to floods in the region (US$ 2.5 billion), followed by New Zealand (US$ 247 million), and Malaysia (US$ 200 million). In New Zealand, insured losses for the July floods in the western South Island exceeded US$ 40 million, the third highest in the last 50 years for a weather-related disaster in New Zealand. In Australia, windstorms in Victoria in June caused US$ 160 million in economic losses and caused power outages to more than 200 000 households. Cyclones also caused significant damage, which was most heavily experienced in the Philippines (US$ 1 billion), followed by Indonesia (US$ 800 million) and Australia (US$ 685 million).

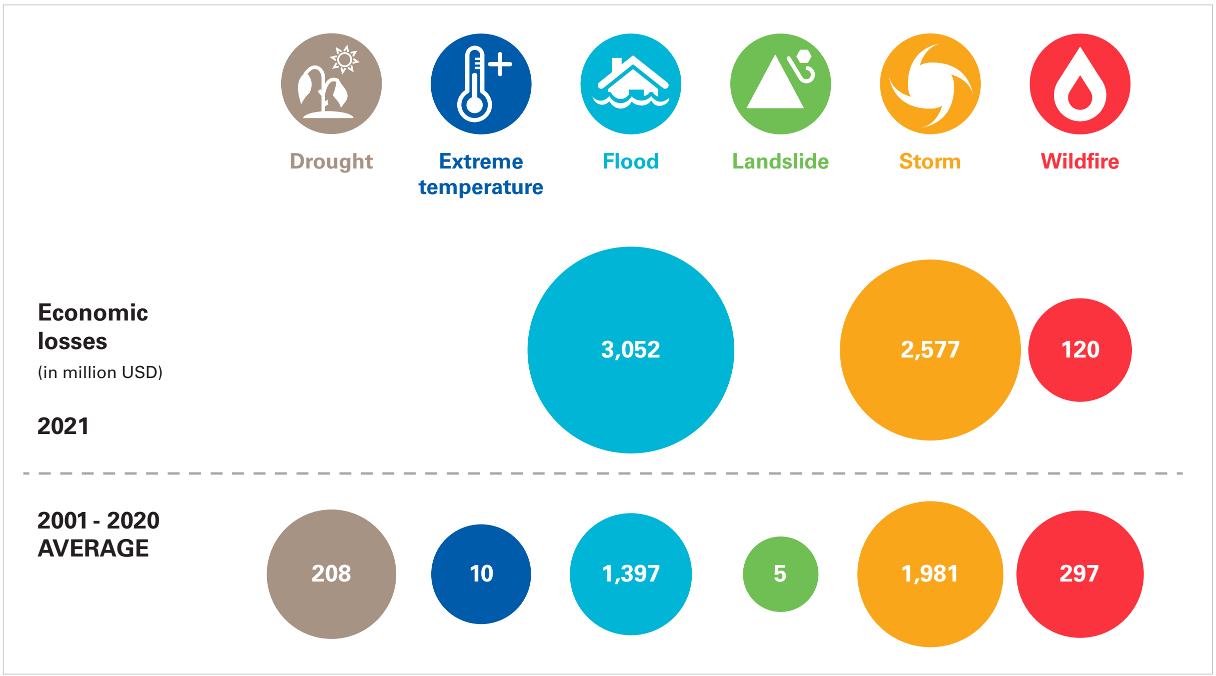


Figure 14. Economic loss in the South-West Pacific region in 2021 from disasters, compared to the 20-years average (2001–2021). *Source:* United Nations ESCAP calculation based on EM-DAT, accessed on 30 April 2022. (Note: The economic damages of some disaster occurrences are not presented in the diagram due to data unavailability.)

Heavy floods hit eastern Australia between 18 and 24 March, killing two people and affecting 18 000. Severe flooding interrupted many industry operations and resulted in a total economic loss of US$ 2.1 billion. The coal sector was especially impacted due to train lines being shut down during the flood. More than 15 000 homes were damaged and 1 196 were deemed uninhabitable. In addition, 376 schools and 244 early care facilities were forced to close owing to flooding threats (see https://knowledge.aidr.org.au/resources/flood-new-south-wales-2021/).

Severe Tropical Cyclone *Niran* began developing off the north Queensland coast as a low-pressure system on 27 February. A total of 6 000 people were affected and total economic damage amounted to US$ 155 000 as a result of the heavy rainfall which led to flash flooding and flooding of low-lying areas.[55] The banana plantations along the Cassowary Coast faced major impact while some growers around the town of Innisfail reported total loss of their crop.[56]

Enhancing climate resilience and adaptation policies

CLIMATE POLICY AND ACTION

The Paris Agreement[57] identifies adaptation as a global challenge. It establishes the global goal on adaptation that includes enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change. Seven years after the adoption of the Paris Agreement, the Sixth Assessment Report of the IPCC[58] notes that adaptation planning and implementation continues to grow, with at least 170 countries having included adaptation in their policies and planning processes, with decision support tools and climate services in place.

As of June 2022, 194 Parties have already submitted a Nationally Determined Contribution (NDC), of which 20 are from the South-West Pacific. Mitigation of climate change has been prioritized by all Parties in this region as reflected in their NDCs. These highlight energy, transport, agriculture, waste, and land use/land-use change/forestry (LULUCF) as top priority areas for reducing greenhouse gas (GHG) emissions, although the contribution of some of the Parties in the region to global GHG emissions is relatively small. A majority of SIDS included climate change mitigation efforts in their NDCs, with ambitious goals for reducing GHG emissions (less than 1% of global emissions come from SIDS and most emissions in these island nations arise from the importation of fossil fuels[59]). In addition, 85% of Parties have prioritized adaptation, with the majority highlighting agriculture and food security (fisheries), coastal zone, water, infrastructure/cities/urbanization, ecosystem and biodiversity, and health as their top priority areas for adaptation (Figure 15).

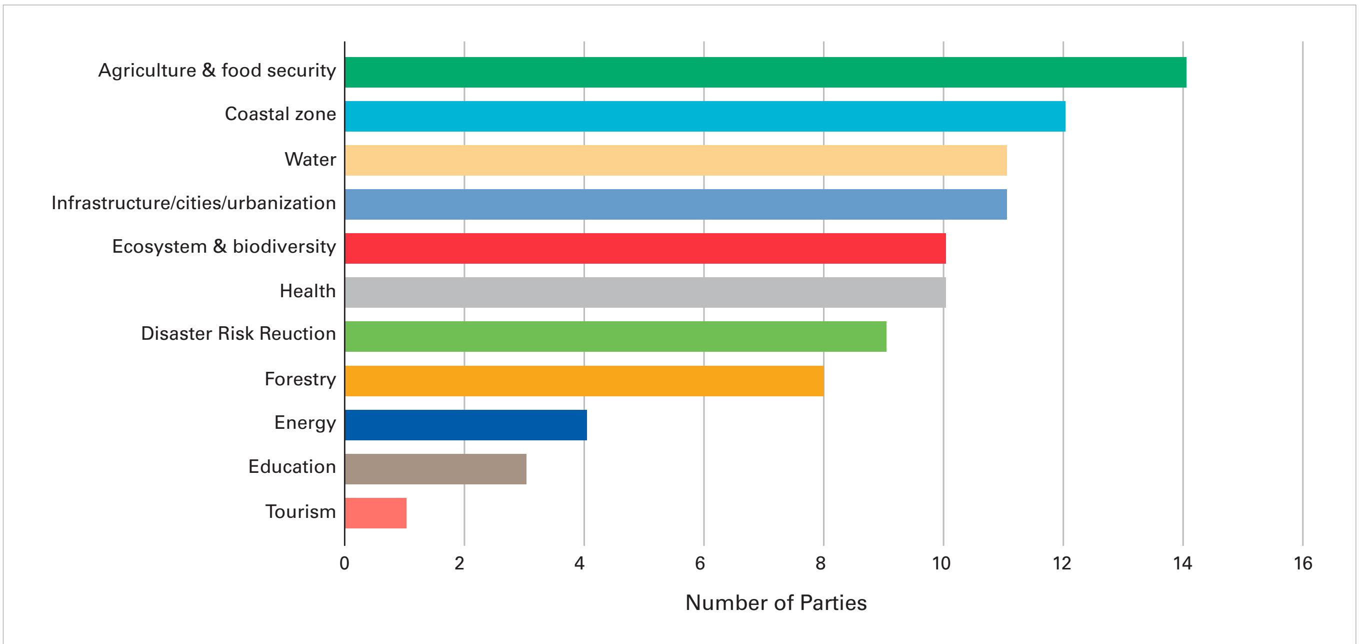


Figure 15. Priority areas for adaptation for the South-West Pacific region.
Source: WMO analysis of the NDCs of 20 Parties in the South-West Pacific from 2016 to March 2022. Updated in June 2022.

However, there are still adaptation gaps between the current levels of adaptation and the levels needed to respond to climate risks and impacts. The *Asia-Pacific Disaster Reports 2021 and 22*[60] estimate the annual adaptation cost for climate and biological hazards[61] in each country under the RCP 8.5 climate change scenario (that is, a high greenhouse gas emission future without effective climate change mitigation policies and used in the assessment in the IPCC Fifth Assessment Report[62]). In the South-West Pacific, the highest adaptation cost[63] is estimated for Indonesia, at US$ 8.8 billion, followed by the Philippines at US$ 5.5 billion, and Australia at US$ 4.6 billion. As a percentage of the country's gross domestic product (GDP), the highest cost is estimated for Vanuatu at 9.6%, followed by Tonga at 8.6%, and the Federated States of Micronesia at 4.7%. The cost as a percentage of GDP is the highest for the Pacific SIDS.

A key driver of policy action is the target to achieve the global 2030 Agenda for Sustainable Development, pillared on the 17 Sustainable Development Goals (SDGs). The ESCAP *Asia and the Pacific SDG Progress Report 2022*[64] shows that none of the goals have been sufficiently progressed in the South-West Pacific. In fact, Goal 13 on Climate Action continues to show a reverse trend. Hence, decision makers must prioritize policy actions that not only build climate resilience, but also catalyse progress on achieving multiple SDGs.

IMPROVING MULTI-HAZARD RISK-INFORMATION SYSTEMS, CLIMATE POLICY AND CLIMATE SERVICES

In the past 50 years, the South-West Pacific region recorded a total of more than 1 400 weather-, water- and climate-related disasters that led to the loss of over 65 000 lives and economic losses of US$ 163.7 billion. Most of these disasters were associated with storms and floods. Storms accounted for 45% of weather-, water- and climate-related disasters, 71% of deaths and 46% of economic losses. Floods accounted for 39% of disasters, 17% of deaths and 24% of economic losses (Figure 16).

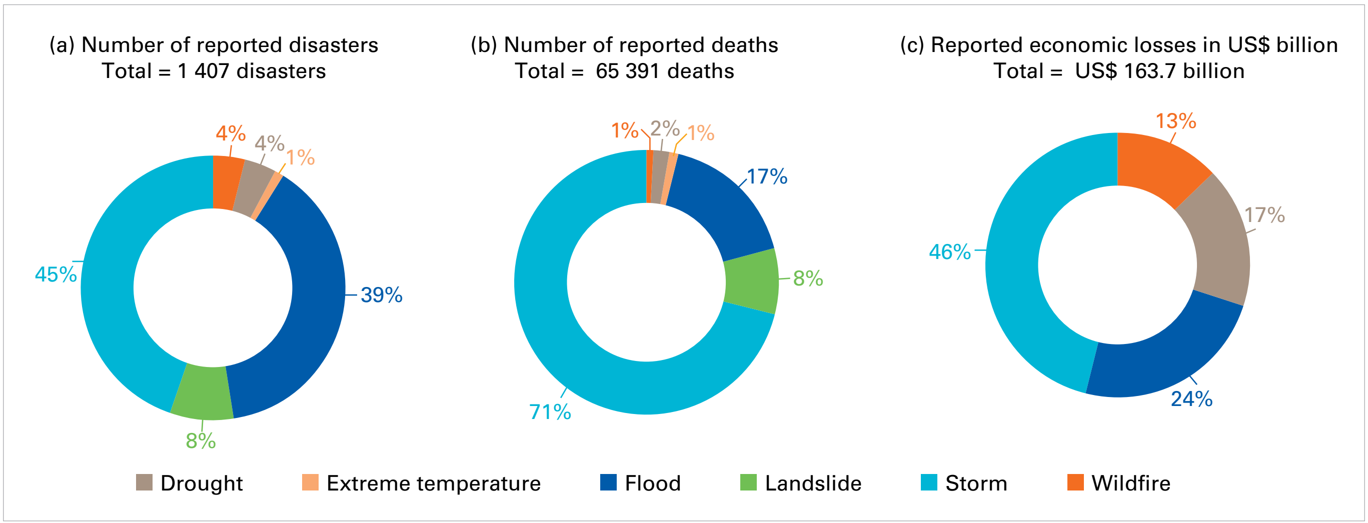


Figure 16. Overview of weather-, water- and climate-related disasters, deaths and economic losses reported in the South-West Pacific (1970–2019).
Source: WMO *2021 State of the Climate Services: Water* (WMO-No. 1278)

In this context, and building on five adaptation priorities highlighted by the Global Commission on Adaptation[65] with high investment cost-benefits, top adaptation priorities informed by the "riskscape" in the South-West Pacific can be identified. In the South-West Pacific, key adaptation solutions include strengthening early warning systems and making water resources management more resilient, followed by building new resilient infrastructure, improving dryland agriculture crop production and implementing nature-based solutions. Investing in these policy actions will catalyse progress in achieving multiple SDGs as well as yield cross-sectoral benefits, aligning with the NDCs and National Adaptation Plan (NAP) commitments of countries in the South-West Pacific.

MEMBERS' CAPACITIES: CLIMATE SERVICES AND EARLY WARNING

In 2021, floods and storms caused the highest fatalities as well as economic losses in the South-West Pacific (Figure 14). Strengthening early warning systems can play a pivotal role in taking anticipatory action, enhancing preparedness and reducing the impact of these hazards, as indicated in Figure 17. Early warning systems not only protect lives and livelihoods, but also help protect development gains in the long term.[66]

Figure 17. Tackling the extent of humanitarian crises by anticipatory action.
Source: The Economic and Social Commission for Asia and the Pacific (ESCAP)

Based on responses from 17 Members for which data are available, most WMO Members (53%) in the region provide climate services at an average level (as of 16 June 2022), and 12% of Members provide climate services at a basic level.

Six Members have responded to the WMO survey for assessing capabilities in providing services for riverine floods, flash floods and drought. Three Members reported having inadequate riverine flood forecasting/warning services, and two are providing the needed services at a Full/Advanced capacity level. Five Members in the region reported having inadequate flash flood forecasting/warning services and just one Member is providing those services at a Full/Advanced level. Three Members reported having inadequate drought forecasting/warning services, and two are providing the needed services at a Full/Advanced capacity level (Figure 18).

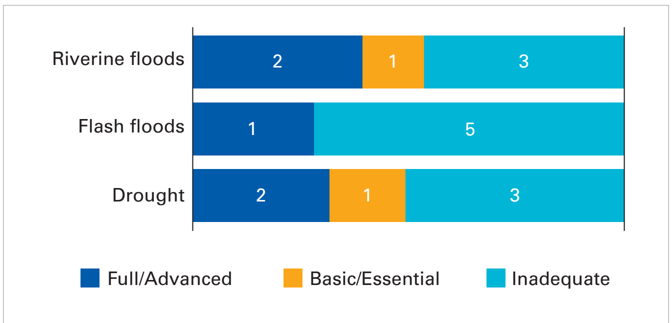


Figure 18. Number of WMO Members in the South-West Pacific with early warnings available to the population at risk, by hazard type, based on data provided by WMO Members. Member capacities are categorized as Inadequate (0–33%), Basic/Essential (34–66%) and Full/Advanced (67–100%), according to the estimated percentage of the population at risk that receive early warnings. Note: For each hazard, the category "Inadequate" includes Members (providing data) reporting that no end-to-end early warning system (EWS) for the hazard is in place, as well as those whose end-to-end EWSs do not reach more than 33% of the at-risk population.

Substantially increasing availability and access to early warning systems and disaster risk reduction information is also a key target of the Sendai Framework for Disaster Risk Reduction 2015–2030.[67] As shown in Figure 18, only two Members have fully operational early warning systems for riverine floods and one Member for flash floods. It should be noted that the data was only obtained from a very limited number of WMO Members, and there is a substantial need for improved data from all Members in the region to obtain a clearer picture of the gaps and needs moving forward. However, there is also a clear need to prioritize the development of multi-hazard early warning systems and climate forecasts, not only for tackling natural hazards and achieving SDG 13 (Climate Action), but also for accelerating progress on multiple associated SDGs including 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-being), 9 (Industry, Innovation, and Infrastructure) and 11 (Sustainable Cities and Communities).

With this objective, for example, the ESCAP Asia-Pacific Risk and Resilience Portal[68] is designed to support the monitoring and implementation of climate and disaster-related SDGs. It aims to strengthen the capacity of Members in Asia and the Pacific to identify multi-hazard risk hotspots, estimate economic losses due to cascading hazards in the present and future climate change scenarios at the country, subregional and regional levels, and invest in key resilience measures for adaptation.

Observational basis for climate monitoring

Climate monitoring is performed by a network of observing systems covering the atmosphere, the ocean, hydrology, the cryosphere and the biosphere. Each of these areas is monitored in different ways by a range of organizations. Cutting across all these areas, satellite observations provide major contributions to global climate monitoring.

In 1992, the Global Climate Observing System (GCOS) was established jointly by WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Science Council (ISC) to coordinate and facilitate the development and improvement of global climate observations. GCOS has identified a set of Essential Climate Variables (ECVs)[69] that together provide the information necessary to understand, model and predict the trajectory of the climate as well as plan mitigation and adaptation strategies.

ECVs are physical, chemical or biological variables or a group of linked variables that critically contribute to the characterization of Earth's climate system, and include atmospheric, oceanic and terrestrial components. GCOS currently specifies 54 ECVs (see Figure 19).

ECV data sets provide the empirical evidence needed to understand and predict the evolution of climate, to guide mitigation and adaptation measures, to assess risks and enable attribution of climate events to underlie causes, and to underpin climate services. They are required to support the work of the United Nations Framework Convention on Climate Change (UNFCCC) and the IPCC.

2016 Essential Climate Variables (ECVs)

Atmospheric	Surface	Precipitation, surface pressure, surface radiation budget, surface wind speed and direction, surface temperature, surface water vapour
	Upper air	Earth radiation budget, lightning, upper-air temperature, upper air water vapor, upper-air wind speed and direction
	Composition	Aerosol properties, carbon dioxide, methane and other greenhouse gases, cloud properties, ozone, aerosol and ozone precursors
Oceanic	Physical	Ocean surface heat flux, sea ice, sea level, sea state, sea-surface salinity, sea-surface temperature subsurface currents, subsurface salinity, subsurface temperature
	Biogeochemical	Inorganic carbon, nitrous oxide, nutrients, ocean colour, oxygen, transient tracers
	Biological/ecosystems	Marine habitat properties, plankton
Terrestrial	Hydrology	Groundwater, lakes, river discharge, soil moisture
	Cryosphere	Glaciers, ice sheets and ice shelves, permafrost, snow
	Biosphere	Above-ground biomass, albedo, fire, fraction of absorbed photosynthetically active radiation, land cover, land surface temperature, latent and sensible heat fluxes, leaf area index, soil carbon
	Human use of natural resources	Anthropogenic greenhouse gas fluxes, anthropogenic water use

Figure 19. Essential Climate Variables (ECVs) identified by GCOS

Data sets

TEMPERATURE

Six data sets (cited below) were used in the calculation of regional temperature.

Regional mean temperature anomalies were calculated relative to 1961–1990 and 1981–2010 baselines using the following steps:

1. Read the gridded data set;

2. Regrid the data to 1° latitude × 1° longitude resolution. If the gridded data are higher resolution, then take a mean of grid boxes within each 1°×1° grid box. If the gridded data are lower resolution, then copy the low-resolution grid box value into each 1°×1° grid box that falls inside the low-resolution grid box;

3. For each month, calculate the regional area average using only those 1°×1° grid boxes whose centres fall within the region;

4. For each year, take the mean of the monthly area averages to obtain an annual area average;

5. Calculate the mean of the annual area averages over the periods 1961–1990 and 1981–2010;

6. Subtract the 30-year period average from each year.

Note that the range and mean of anomalies relative to the two different baselines are based on different sets of data, as anomalies relative to 1961–1990 cannot be computed for ERA5 which starts in 1979.

The following six data sets were used:

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GLACIERS

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The description of glaciers in Indonesia is based on the contribution from the Badan Meteorologi, Klimatologi, dan Geofisika (BMKG, Indonesia).

OCEAN HEAT CONTENT

Copernicus Marine Service, Multi Observation Global Ocean 3D Temperature Salinity Height Geostrophic Current and MLD (MULTIOBS_GLO_PHY_TSUV_3D_MYNRT_015_012) product. https://resources.marine.copernicus.eu/product-detail/MULTIOBS_GLO_PHY_TSUV_3D_MYNRT_015_012/INFORMATION.

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Global climate sea-surface temperature (SST) analyses generated by the European Space Agency (ESA) SST Climate Change Initiative (CCI) and the Copernicus Climate Change Service (C3S) (product SST-GLO-SST-L4-REP-OBSERVATIONS-010-024). Merchant, C. J.; Embury, O.; Bulgin, C. E. et al. Satellite-based Time-Series of Sea-Surface Temperature Since 1981 for Climate Applications. *Scientific Data* **2019**, *6*. https://doi.org/10.1038/s41597-019-0236-x.

SEA LEVEL

Tide gauge data is from the University of Hawaii Sea Level Center (UHSLC) Fast-Delivery database, http://uhslc.soest.hawaii.edu/data/?fd.

Thirty-one tide gauge (TG) stations met either Level 1 or Level 2 data criteria and had at least 70% coverage between 1980 and 2020. Level 1 criteria requires the TG to have years with 80% of the record, missing no more than 2 months; months with 80% of days, missing no more than 5 days and no more than 3 consecutive days; and days with at least 4 regularly spaced observations (that is, every 6 hours). Level 2 criteria requires the TG to have years with 75% of the record, missing no more than 3 months; months with 75% of days; and days with at least 1 observation in every 6-hour interval. A year is defined as 01 May–30 April. https://www.pacificmet.net/sites/default/files/inline-files/documents/PICC%20Monitor_2021_FINALpp_0.pdf.

Satellite data is from the SSALTO/DUACS multi-mission data set distributed by the European Copernicus Marine Environment Monitoring Service (CMEMS), https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/data-acces.html#c12195.

EM-DAT DATA

EM-DAT data were used for historical climate impact calculations: www.emdat.be. EM-DAT is a global database on natural and technological disasters, containing essential core data on the occurrence and effects of more than 21 000 disasters in the world, from 1900 to the present. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université catholique de Louvain located in Brussels, Belgium.

The indicators used for mortality, number of people affected and economic damage were total deaths, no. affected and total damages ('000 US$) respectively.

CLIMATE SERVICES

WMO Analysis of NDCs

Checklist for Climate Services Implementation (Members' climate services capacity, based on responses to this Checklist, can be viewed here)

WMO Hydrology Survey, 2020

2020 State of Climate Services: Risk Information and Early Warning Systems (WMO-No. 1252)

2021 State of Climate Services: Water (WMO-No. 1278)

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Endnotes

1 "Maritime Continent" is a term commonly used by meteorologists, climatologists and oceanographers to describe the region between the Indian and Pacific Oceans, including the archipelagos of Indonesia, Borneo, New Guinea, the Philippine Islands, the Malay Peninsula and the surrounding seas.

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