State of the Climate in the South-West Pacific

2023

WEATHER CLIMATE WATER

WORLD
METEOROLOGICAL
ORGANIZATION

WMO-No. 1356

WMO-No. 1356

Chair, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03
Email: publications@wmo.int

ISBN 978-92-63-11356-9

Cover illustration: Atafu atoll, a group of 52 coral islets within Tokelau in the South Pacific Ocean.
Credit: NASA Johnson Space Center.
Key messages page:
Beautiful morning view, Indonesia. Panorama. Landscape: paddy fields with beautiful colour and sky. Natural light.
Generative AI. Source: iStock

Contents

We need your feedback

This year, the WMO team has launched a process to gather feedback on the State of the Climate reports and areas for improvement. Once you have finished reading the publication, we ask that you kindly give us your feedback by responding to this short survey. Your input is highly appreciated.

Key messages

The year 2023 was substantially warmer than the previous several years in the South-West Pacific region, with the elevated temperatures associated with the transition from La Niña to El Niño conditions. The mean annual temperature for the region was 0.29 °C [0.26 °C–0.33°C] above the average for the 1991–2020 reference period, making the year one of the three warmest on record, depending on the dataset considered.

Over the first four months of the year, rainfall was above average for much of the Maritime Continent, Australia, Papua New Guinea, and the Pacific Islands, in line with typical La Niña conditions. Conversely, in the last four months of the year, rainfall was below average for much of these regions. The central Pacific Islands experienced a drier-than-average start to 2023 but received an above-average amount of rainfall in the latter part of the year, consistent with typical El Niño conditions.

The most prominent and persistent marine heatwave in 2023 occurred in a large area around New Zealand. This heatwave was categorized as extreme and lasted approximately six months.

Sea levels continued to rise at rates higher than the global mean in several parts of the region.

The South-West Pacific region is extremely prone to disasters associated with hydrometeorological hazards, especially storms and floods. Overall, 34 reported hydrometeorological hazard events in 2023 led to over 200 fatalities and impacted more than 25 million people.

From 21 to 27 July, Typhoon *Doksuri* severely impacted the South-East Asia region. *Doksuri* brought heavy rainfall to the Philippines, displacing approximately 1 200 people before making landfall on 26 July. After landfall, *Doksuri* resulted in widespread devastation to the country, claiming at least 45 lives and displacing almost 313 000 people.

In August, the deadliest single wildfire of the year globally occurred in Hawaii. At least 100 deaths were reported, the most in a wildfire in the United States of America in more than 100 years.

Approximately 95% of WMO Members in WMO Regional Association V (South-West Pacific) provide climate predictions to support disaster risk reduction activities. However, climate projections and tailored products are provided by fewer than 70% of Members in the region. These services in particular are needed to inform risk management and adaptation to and mitigation of climate change and its impacts.

Foreword

Climate change has become a global crisis and is the defining challenge that humanity currently faces. Communities, economies and ecosystems throughout the South-West Pacific region are significantly affected by its cascading impacts. It is increasingly evident that we are fast running out of time to turn the tide.

The report on the State of the Climate in the South-West Pacific 2023 provides details regarding temperature, precipitation, tropical cyclones, extreme events, and their socioeconomic impacts. The transition from La Niña to El Niño conditions in the course of 2023 influenced weather and climate patterns in the region. However, although the 2023/2024 El Niño event is ending; climate change continues to accelerate.

Sea-level rise is above the global average in many parts of the region, disrupting economies, displacing communities and threatening the very existence of small island developing States (SIDS).

In March 2022, United Nations Secretary-General António Guterres, launched the "Early Warnings for All" initiative with the goal of ensuring that every person on Earth is safeguarded by early warning systems. This initiative underscores the urgency of protecting vulnerable communities worldwide, particularly in SIDS, where the need for early warning systems is critical. SIDS face many challenges exacerbated by climate change.

Early warning systems serve as a lifeline for SIDS, providing timely and accurate information to governments, communities, and other stakeholders. These systems play a crucial role in saving lives and mitigating the socioeconomic impacts of disasters by facilitating proactive measures such as evacuation plans, resource allocation, and infrastructure reinforcement. However, despite their critical importance, early warning systems are only available in one third of SIDS globally. This disparity underscores why WMO and its partners are spearheading concerted action to bridge the gap in early warning infrastructures and services.

WMO remains steadfast in its commitment to monitoring the climate system and providing authoritative information to leaders and the public alike. Through robust collaboration across the United Nations family and with partners and donors, we are empowered to deliver impactful services grounded in reliable information.

The spirit of collaboration and partnership has been instrumental in the creation of reports such as this one. I extend my sincere gratitude to our Members, our sister United Nations agencies, and all the experts from both the South-West Pacific region and around the world for their invaluable contributions to the scientific coordination and authorship of this report.

(Prof. Celeste Saulo)
Secretary-General, WMO

Preface

The impact of increased atmospheric, land and ocean heat was evident as severe heatwaves swept through the South-West Pacific region in 2023. While droughts affected the largest number of people, floods and storms compounded their impacts and were primarily responsible for the resulting fatalities and economic costs.

An early warning system is one of the most effective ways to reduce mortality and economic losses from natural hazards. A 24-hour warning of an incoming storm or heatwave can potentially reduce damages by up to 30 per cent. An analysis of the status of early warning systems reveals that there is a critical gap in knowledge and understanding of disaster risks. Addressing this gap is key to implementing the Global Executive Action Plan on Early Warnings for All in this subregion.

The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) has responded by configuring the Risk and Resilience Portal to deepen knowledge of risks, especially in hotspots where risks are intensifying under various warming scenarios. Another important aspect of a people-centred early warning system is the need to incorporate sector-specific forecasts that translate expected impacts on the ground into early warnings and anticipatory action. This is highlighted, for example, in the case of the Anticipatory Action Protocol for Agricultural Drought in Timor-Leste, presented in the current report.

The 2023 edition of the ESCAP Asia-Pacific Disaster Report underscores that the region has a narrow window to increase its resilience and protect its hard-won development gains from the socioeconomic impacts of climate change. In the absence of immediate action, temperature rises of 1.5 °C and 2 °C will cause disaster risk to outpace resilience beyond the limits of feasible adaptation and imperil sustainable development.

In this context, the State of the Climate in the South-West Pacific 2023 report is timely as it unpacks the interconnection between climate indicators and the Sustainable Development Goals (SDGs) and helps bridge gaps between science and policy. ESCAP and WMO, working in partnership, will continue to invest in raising climate ambition and accelerating the implementation of policy actions. This includes working together to bring early warnings to all in the region so that no one is left behind as our climate change crisis continues to evolve.

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

Global climate context

The global annual mean near-surface temperature in 2023 was 1.45 °C ± 0.12 °C above the 1850–1900 pre-industrial average. The year 2023 was the warmest year on record according to six globally averaged datasets.[1] The nine years 2015 to 2023 were the nine warmest years on record in all six datasets.[2]

Atmospheric concentrations of the three major greenhouse gases reached new record observed highs in 2022, the latest year for which consolidated global figures are available, with levels of carbon dioxide (CO_2) at 417.9 ± 0.2 parts per million (ppm), methane (CH_4) at 1 932 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 335.8 ± 0.1 ppb, respectively 150%, 264% and 124% of pre-industrial (before 1750) levels (Figure 1). Real-time data from specific locations, including Mauna Loa[3] (Hawaii, United States of America) and Kennaook/Cape Grim[4] (Tasmania, Australia) indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2023.

Over the past two decades, the ocean warming rate has increased; the ocean heat content in 2023 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 4.77 mm per year between 2014 and 2023, reaching a new record high in 2023. Between 1960 and 2021, the ocean absorbed about 25% of annual anthropogenic CO_2 emitted into the atmosphere;[5] CO_2 reacts with seawater and lowers its pH. The limited number of long-term observations in the open ocean have shown a decline in pH, with a reduction of the average global surface ocean pH of 0.017–0.027 pH units per decade since the late 1980s.[6] This process, known as ocean acidification, affects many organisms and ecosystem services[7] and threatens food security by endangering fisheries and aquaculture.

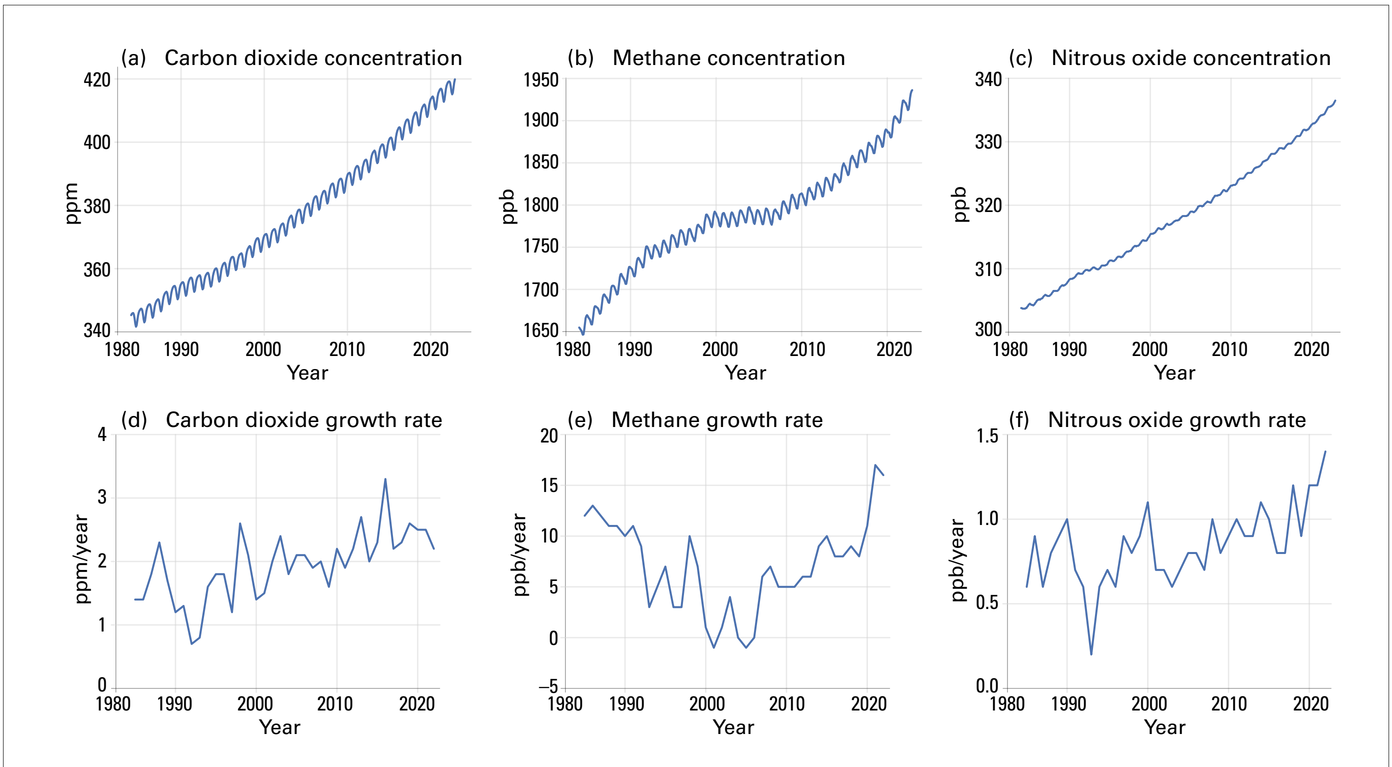


Figure 1. Top row: Monthly globally averaged mole fraction (measure of atmospheric concentration), from 1984 to 2022, of (a) CO_2 in parts per million, (b) CH_4 in parts per billion and (c) N_2O in parts per billion.
Bottom row: Growth rates representing increases in successive annual means of mole fractions for (d) CO_2 in parts per million per year, (e) CH_4 in parts per billion per year and (f) N2O in parts per billion per year.

Regional climate

The following sections analyse key climate indicators in the South-West Pacific region[8] during 2023. One important indicator, surface temperature, is described in terms of anomalies, or departures from a reference period. For global mean surface temperature, the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC)[9] uses the reference period 1850–1900 for calculating anomalies in relation to pre-industrial levels. However, this pre-industrial reference period cannot be used in all regions of the world as a baseline for calculating regional anomalies due to insufficient data for calculating region-specific averages prior to 1900. Instead, the 1991–2020 climatological standard normal is used for computing anomalies in temperature and other indicators. Regional temperature anomalies can also be expressed relative to the WMO reference period for climate change assessment, 1961–1990. In the present report, 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 is influenced by a number of drivers of regional climate variability,[10] including the El Niño–Southern Oscillation (ENSO). ENSO strongly influences the climate over most of the tropical Pacific, as well as many other parts of the world. The Indian Ocean Dipole (IOD) strongly influences the climate over the tropical Indian Ocean and adjacent countries, particularly Australia and Indonesia. 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.

After three consecutive years of La Niña, which ended in early 2023, the tropical Pacific Ocean began experiencing El Niño conditions in the 2023 boreal summer. However, the atmosphere was slower to respond, and it was not until early September that El Niño conditions were well established in both the atmosphere and the ocean. The El Niño event contributed to above-average rainfall along the equatorial tropical Pacific area as well as below-average rainfall over much of the off-equatorial South Pacific.

A strong positive IOD was present in the second half of 2023; the longer-than-usual duration of this event was associated with the active El Niño. The SAM was positive in early 2023, then generally negative between the austral autumn and winter, before transitioning to positive in late 2023.

There were a number of active phases of the MJO, which are associated with increased rainfall and a higher risk of tropical cyclone formation. A notably strong MJO was present in the western Pacific during the first quarter of 2023, coinciding with Severe Tropical Cyclone *Judy* and Severe Tropical Cyclone *Kevin* over the western South Pacific. The MJO was active near the Maritime Continent and into the western Pacific during September, coinciding with multiple typhoons and tropical storms over the North-West Pacific basin.

TEMPERATURE

The annual mean surface temperature averaged over both land and ocean areas in 2023 in the South-West Pacific region ranked between the first and third warmest on record, depending on the dataset considered. It was 0.29 °C [0.26 °C–0.33 °C] above the 1991–2020 average and 0.62 °C [0.49 °C–0.68 °C] above the 1961–1990 average[11] (Figure 2). 2023 was substantially warmer than the previous several years in the region, largely as a result of the transition from La Niña to El Niño conditions. El Niño years are typically warmer than the preceding non-El Niño years in the South-West Pacific region.

Temperatures in 2023 were higher than normal in many areas of the region. The most significant warmth was over an area extending from south-east Australia to east of New Zealand (Figure 3). The central and eastern equatorial Pacific were also warmer, reflecting El Niño conditions in the second half of the year. Across these areas, temperatures were generally 0.5 °C to 1.0 °C above the 1991–2020 average. New Zealand had its second warmest year on record, with an average temperature of 0.87 °C above the 1991–2020 average.

Negative temperature anomalies were seen over a part of northern Australia and the eastern part of the tropical Indian Ocean, consistent with the positive IOD in the second half of 2023.

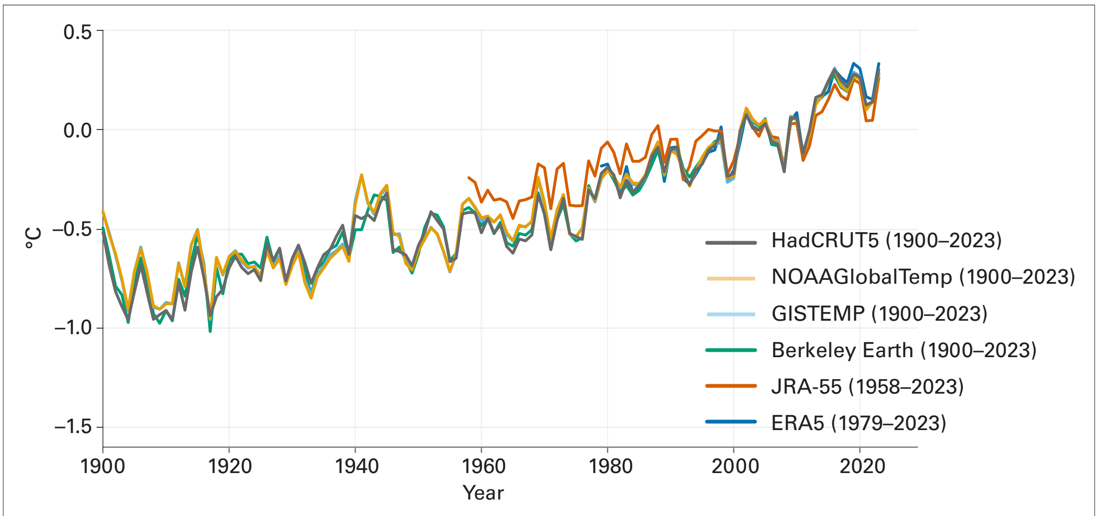


Figure 2. Annual regional mean land and ocean temperature for WMO Region V, South-West Pacific (°C, difference from the 1991–2020 average) from 1900 to 2023.

Source: Data are from the following six datasets: Berkeley Earth, ERA5, GISTEMP, HadCRUT5, JRA-55, NOAAGlobalTemp.

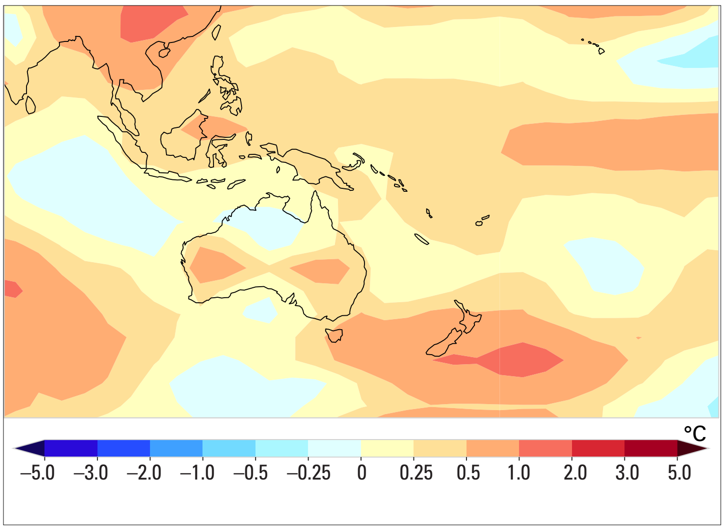


Figure 3. Annual near-surface temperature anomalies (°C, difference from the 1991–2020 average) for 2023. Data shown are the median of the following six datasets: Berkeley Earth, ERA5, GISTEMP, HadCRUT5, JRA-55, NOAAGlobalTemp.

PRECIPITATION

Precipitation is a key climate parameter, closely related to indispensable resources for human activities such as water for drinking and domestic purposes, agriculture, and hydropower. It also drives major climatic events such as droughts and floods.

Rainfall patterns in the South-West Pacific region are largely influenced by the ENSO state, which transitioned from La Niña at the beginning of 2023 to El Niño in the second half of the year. Over the first four months of 2023, rainfall was above average for much of the Maritime Continent, Australia, Papua New Guinea, and Pacific Islands including Vanuatu and Niue, in line with a typical La Niña. Conversely, in the last four months of the year, rainfall was below average for much of these areas. The central Pacific Islands, including Kiribati, Tuvalu, Nauru, and the northern Cook Islands, experienced a drier start to the year, followed by above-average rainfall in the latter part of the year, also in line with the ENSO conditions.

In 2023, the largest precipitation deficits (measured as a percentage of the average) were observed in the Hawaiian Islands and south-western Australia (Figure 4). Other areas with below-average rainfall amounts were New Caledonia, Tuvalu, parts of Fiji, Tonga and the Cook Islands, parts of northern Australia, Tasmania, the southern South Island of New Zealand, some areas in the Greater Sunda Islands (Indonesia) and parts of Luzon (Philippines). Based on time series analyses (not shown), it was unusually dry (below the 10th percentile) in southern Borneo, south-west and East Australia (around Brisbane) and some central Pacific islands.

Above-normal precipitation amounts were recorded around the Solomon Sea, the Solomon Islands, Vanuatu, Samoa, Niue, the Line Islands, the southern Philippines, northern Borneo, the Malay Peninsula, Sumatra, large parts of New Zealand, and northern Central Australia.

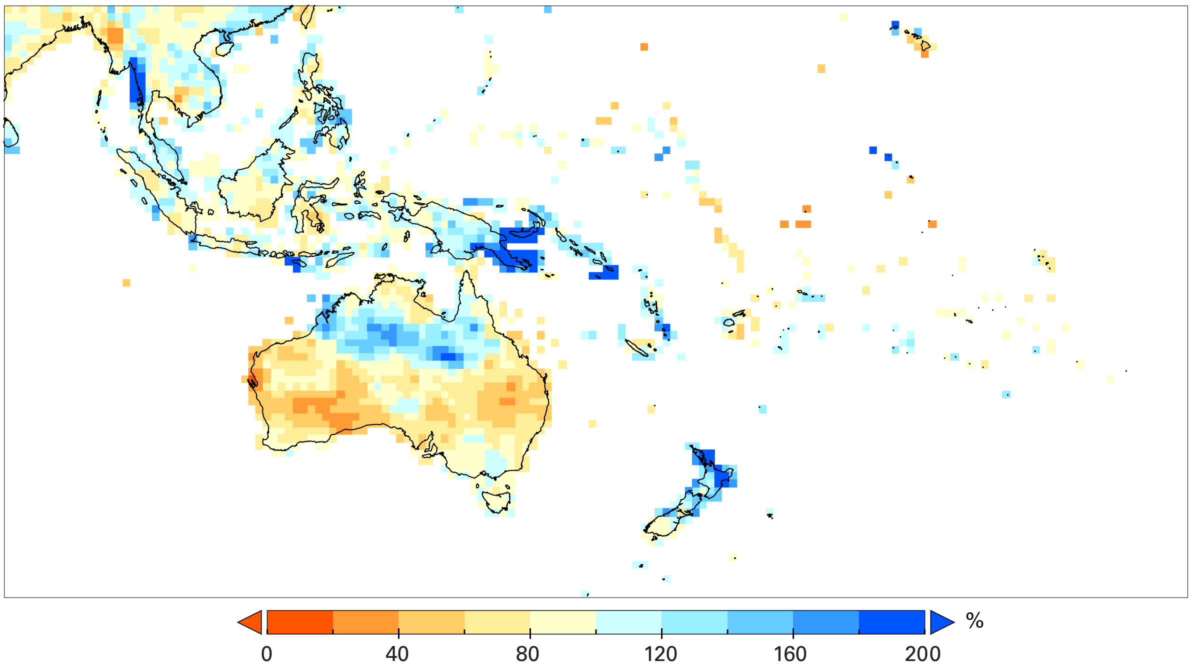


Figure 4. Precipitation anomalies for 2023, expressed as a percentage of the 1991–2020 average
Source: Global Precipitation Climatology Centre (GPCC), Deutscher Wetterdienst (DWD), Germany

CRYOSPHERE

Snow is rare or unknown at low elevations over most of the region; however, snow and ice occur in some mountain areas. 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 New Guinea. There is significant seasonal snow cover in the highland areas of New Zealand and southern Australia.

New Zealand's seasonal snow is monitored via twelve National Institute of Water and Atmospheric Research (NIWA) snow and ice monitoring sites. Data from these sites show that the average and maximum snow depths were almost universally below average[12] in 2023. Winter maximum depths were between 36% and 96% of the climatological values. Both the maximum and average snow depths followed a general latitudinal trend, with sites further north recording lower percentages of the climatological values. The Ivory Glacier (West Coast, 1 390 m elevation) had the lowest fraction of average snow depth, at only 15% of its climatological average. At Mueller Hut (Canterbury, 1 818 m elevation), snow depths were at record-low levels for most of the season and melt out (no snow remaining) occurred on 3 December 2023, one month earlier than average (and the earliest on record for this site).

In Australia, mountain snowpacks were generally below average. There was a near-average start to the season, with the longest-running snow depth measurement site, Spencers Creek (near Perisher Valley in New South Wales, 1 830 m elevation), reaching a depth of 1.31 m on 13 July, which proved to be its seasonal peak. Snow depths at this location remained between 1 m and 1.3 m until mid-September before the snow rapidly melted during near-record temperatures in the second half of the month, with the last snow gone by 10 October. The peak depth was about 30% below average, and both the seasonal peak and the melting date were abnormally early. There were also few significant low-elevation snowfalls, although an unusual early-season event brought snow on 7 May to an elevation above 700 m in north-eastern Victoria and south-eastern New South Wales. On 19 December, a kona low system (a subtropical cyclone that occurs during the cool season in the north central Pacific) brought blizzard-like conditions to the higher elevations in Hawaii. The summit of Mauna Kea reported 3 m snow drifts and gusts over 160 km per hour.

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.[13] SST is an essential parameter in weather and climate prediction and is important for the study of marine ecosystems.[14] While the global mean SST is increasing, there is variability around this average, with different regions and locations experiencing different responses. These responses vary in terms of both trend and variance on different timescales and 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 the open ocean.[15]

Over the period 1981–2023, for which observation data from satellites are available, nearly the entire South-West Pacific region shows ocean surface warming, reaching rates of more than 0.4 °C per decade north-east of New Zealand, south of Australia and at the northern margin of this area (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 0.15 °C ± 0.01 °C per decade.[16]

In 2023, all subregions, except for the area west of Indonesia, experienced warm anomalies reaching sup to +0.5 °C (Figure 5(b), Box(3)). Warming rates comparable to or exceeding the global mean rates prevailed in all sub-areas except for the central Pacific zone, where changes in sea-surface temperature are known to be dominated by ENSO.

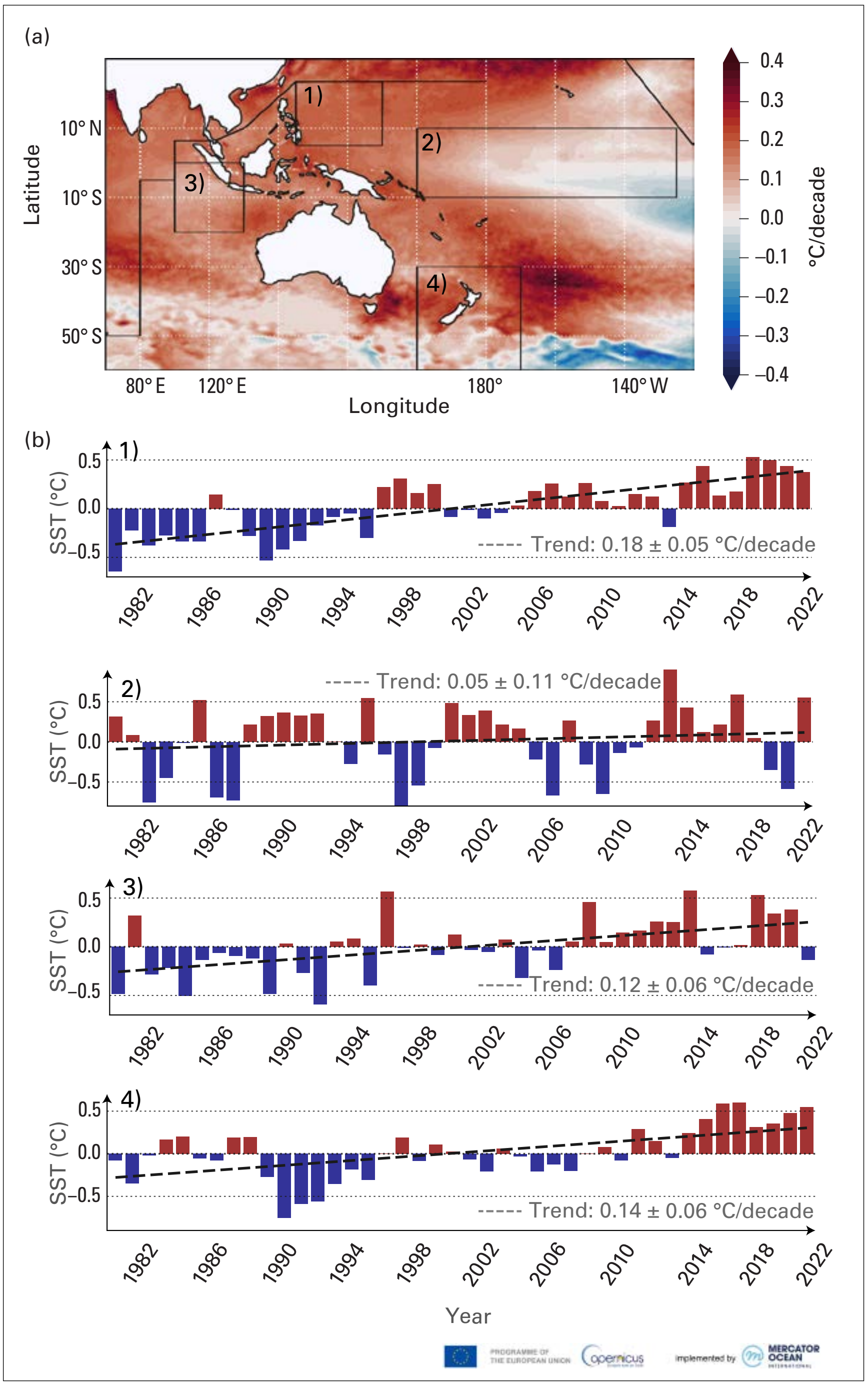


Figure 5. (a) Sea-surface temperature trend (in °C per decade) over the period 1982–2023.
(b) Area-averaged time series of SST anomalies (°C) relative to the 1982–2022 reference period for the four areas indicated in 5(a).
The linear trend over the full period is indicated as a dashed line

Source: Derived from the Copernicus Marine Service remote sensing products available at https://doi.org/10.48670/moi-00168 (for 1982–2022) and https://doi.org/10.48670/moi-00165 (for 2023)

OCEAN HEAT CONTENT

Due to emissions of heat-trapping greenhouse gases resulting from human activities, the global ocean has warmed. It has taken up more than 90% of the excess heat in the climate system, making climate change irreversible on centennial to millennial timescales.[17] Ocean warming contributes about 40% of the observed global mean sea-level rise through the thermal expansion of seawater.[18] It is altering ocean currents, indirectly altering storm tracks[19] and increasing ocean stratification,[20] which can lead to changes in marine ecosystems.

Most of the areas in the South-West Pacific show upper-ocean (0–700 m) warming since 1993. Warming is particularly strong, with rates exceeding 2–3 times the global average warming rates, in the Solomon Sea and east of the Solomon Islands; in the Arafura, Banda and Timor Seas; east of the Philippines; along the southern coast of Indonesia and in the Tasman Sea (Figure 6(a)). The latter sub-area witnessed a high upper-ocean heat content during 2023 (Figure 6(b), Box 4), matching the record high set in 2022. 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 redistributed from the surface down to deeper layers of the ocean, and from the tropics to the subtropics.[21]

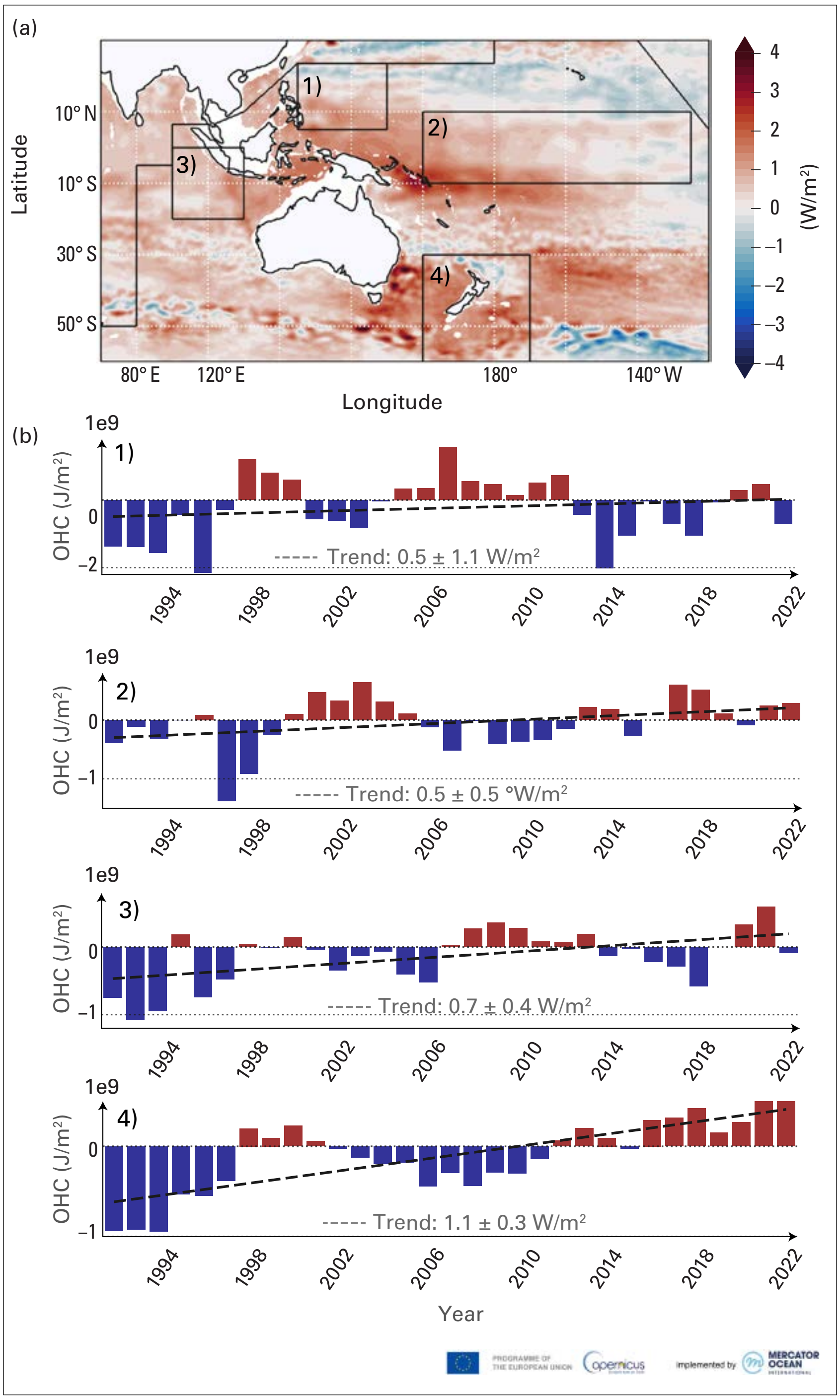


Figure 6. (a) Ocean heat content (OHC) trend (units: watts per square metre, W/m^2) over the period 1993–2023, integrated from the surface down to 700 m depth. Ocean warming rates in areas with water shallower than 300 m have been masked in white due to product limitations.
(b) Area-averaged time series of upper 700 m OHC anomalies relative to the 2005–2022 reference period (joules per square meter (J/m^2)) for the four areas indicated in 6(a). The linear trend over the full period is indicated as a dashed line.

Source: Derived from the in situ-based Copernicus Marine Service product available at https://doi.org/10.48670/moi-00052.

SEA LEVEL

In 2023, the sea level continued to rise globally and regionally as shown by high precision satellite altimetry measurements. The average global mean sea level rise (GMSL) was 3.4 mm +/- 0.3 mm/year over the January 1993 to May 2023 period.

However, the rate of rise is not the same everywhere. Figure 7 shows the sea-level trend over the January 1993–May 2023 period as measured by satellite altimeters. In the South-West Pacific region, the sea-level rise of the last three decades exceeds the global mean sea-level rise. Altimetry-based sea-level time series from January 1993 to May 2023 have been averaged over two areas within the region (Figure 7, bottom left and bottom right). The mean rate of sea-level rise in both areas is significantly higher than the global mean (4.52 mm +/-0.25 mm/year in area 1 and 4.13 mm +/-0.08 mm/year in area 2). The sea-level time series in area 1 (Figure 7, bottom left) displays strong inter-annual variability, mostly driven by ENSO (see the strong sea-level drops in 1997/1998 and 2015/2016). Sea-level rise is more regular in area 2 except for a steep increase around 1998.

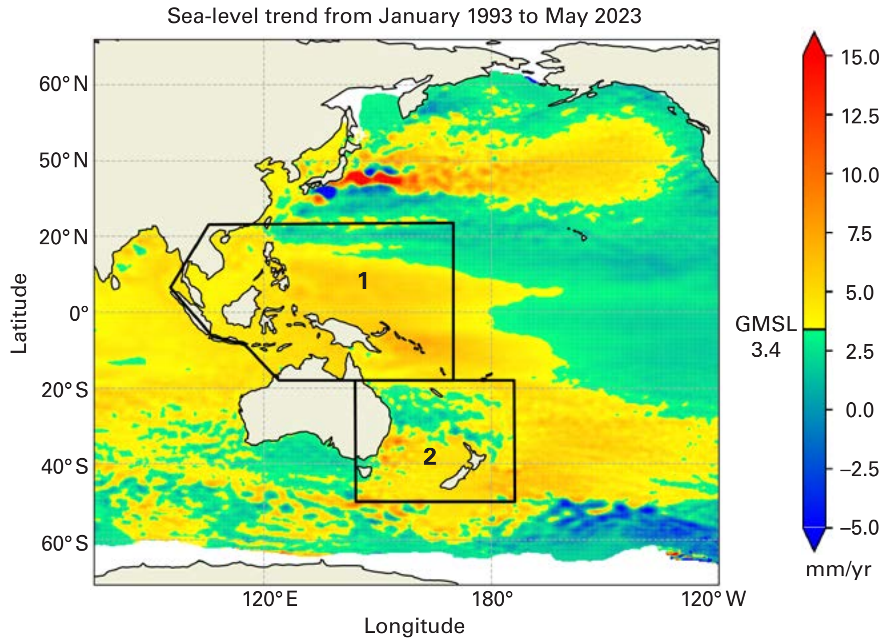
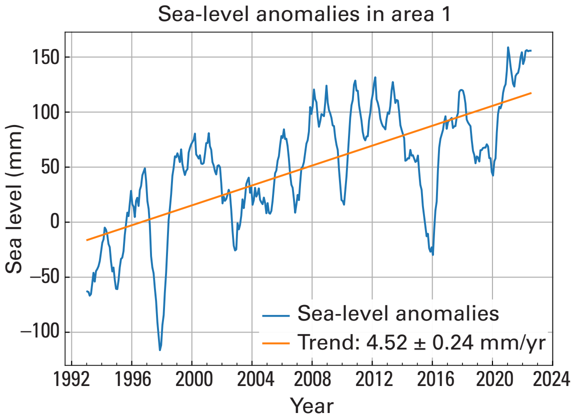
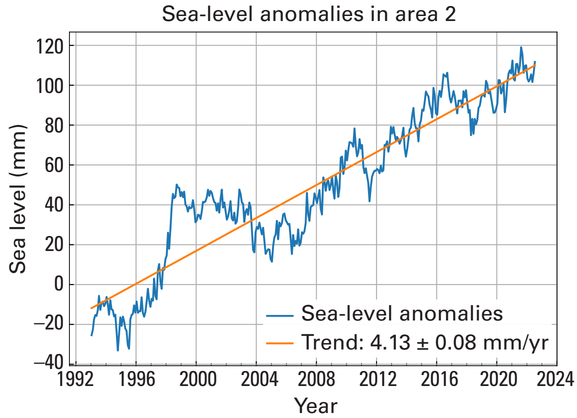


Figure 7. Altimetry-based coastal sea-level time series (m) from January 1993 to May 2023 for the western Pacific and eastern Indian Oceans. The map (top) shows the annual mean sea-level trend and location of areas summarized in the plots at the bottom left and bottom right. The transition from green to yellow corresponds to the 3.4 mm per year overall trend in global mean sea-level rise. The plots show mean sea-level anomalies (blue) and estimated trend (orange line) for the South-East Asia and southern Oceania regions, respectively.

Source: Copernicus Climate Change Service (C3S) – https://climate.copernicus.eu/sea-level, and Laboratory of Space Geophysical and Oceanographic Studies (LEGOS), France





Extreme events

TROPICAL CYCLONES

The South-West Pacific encompasses the Australian and South Pacific tropical cyclone areas (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 areas. In this region, the 2022/2023 tropical cyclone season was below average in terms of the total number of tropical cyclones that formed in both the South Pacific and Australian basins, although several of the storms which did form were severe. Over the South Pacific area, there were four named storms, including three which were considered severe tropical cyclones (category 3 or above): Tropical Cyclones *Gabrielle*, *Kevin* and *Judy*, which all developed during February 2023. The Australian area had six named storms over the season, including five which were considered severe tropical cyclones; of these, Tropical Cyclones *Darian, Herman* and *Ilsa* reached category 5 – during December 2022, March 2023, and April 2023, respectively. It was the first season since 1998/1999 which recorded at least three category 5 systems in the Australian area.

The pattern of tropical cyclone activity in the southern hemisphere was somewhat atypical of La Niña conditions, which typically result in increased tropical cyclone activity in the western South Pacific close to Australia and decreased activity further east. 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 conditions (although there is a high level of variability from year to year), but that increase was also absent during the 2022/2023 season.

In the South-West Pacific, the most significant cyclones of 2023 were those which formed during February over the South Pacific area. Tropical Cyclone *Gabrielle* brought significant rainfall, causing major impacts to the eastern North Island of New Zealand during its post-tropical phase (see *Heavy Precipitation and Flooding* below).[22] Severe Tropical Cyclones *Kevin* and *Judy* were notable for making landfall on the island nation of Vanuatu within 48 hours of each other in March, causing more than 80% of the population to experience winds above 88 km/h (above a category 2 system),[23] with the eye of *Judy* passing directly over the capital, Port Vila. Cyclone *Lola*, which made landfall on Vanuatu on 24 October, affected 91 000 people in Malampa, Penama, Shefa and Torba provinces; as a result, the Government of Vanuatu declared a six-month state of emergency in these provinces.

Overall, the western North Pacific had a below-average total number of tropical cyclones in 2023, although the number of intense cyclones was near average. The most significant event of 2023 in the northern hemisphere part of the region was Typhoon *Doksuri* (known as *Egay* in the Philippines). From 21 to 27 July, *Doksuri* severely impacted the South-East Asia sub-region. *Doksuri* brought heavy rainfall to the Philippines before making landfall on 26 July, displacing approximately 1 200 people.[24] After landfall, *Doksuri* resulted in widespread devastation to the country, claiming at least 45 lives and displacing almost 313 000 people.[25] The Association of Southeast Asian Nations (ASEAN) Coordinating Centre for Humanitarian Assistance on Disaster Management (AHA Centre) and the National Disaster Risk Reduction and Management Council (NDRRMC) of the Philippines responded quickly to the disaster, dispatching vital supplies to impacted areas, including water filtration systems, shelter repair kits, and personal hygiene kits. To lessen the effects of such catastrophic weather events, improved disaster planning and resilient infrastructure are essential, as demonstrated by the response efforts.[26]

In Fiji, on 12 November, before the arrival of gale force winds from Severe Tropical Cyclone *Mal*, various parts of the country experienced continuous rains. RKS Lodoni, in the Central Division, recorded its highest November 24-hour rainfall, 178 mm, since automatic weather station (AWS) observations started in September 2013. This heavy rainfall led to flash flooding in low-lying areas, causing several bridges and crossings in the Central and Eastern Divisions to close and become inaccessible. From 13 to 16 November, *Mal* brought fresh to strong winds, which affected most parts of the country, with near gale force winds impacting the Yasawa and Mamanuca Groups, western Viti Levu, Kadavu and the nearby smaller islands. Vulnerable infrastructures, livestock, and agriculture were damaged.

These events underscore the importance of robust disaster risk management strategies and resilient infrastructure to mitigate the impacts of extreme weather events.[27]

HEAVY PRECIPITATION AND FLOODING

The North Island of New Zealand suffered under repeated extreme rainfall and flooding events in January and February. The most significant was on 13 to 14 February, when Cyclone *Gabrielle* passed just east of the North Island as a post-tropical system. Daily rainfalls exceeded 500 mm in parts of the eastern North Island. Extreme flooding occurred in the Gisborne and Hawke's Bay areas, and Northland, Auckland and the Coromandel Peninsula were also badly affected. A more localized event on 27 to 28 January brought record rainfalls to the Auckland area. Eleven deaths were reported as a result of *Gabrielle* and four from the Auckland floods, with total economic losses from the two events estimated at US$ 5.3 to US$ 8.6 billion,[28] by far the costliest non-earthquake natural disaster ever recorded in New Zealand.

Parts of northern Australia experienced major flooding during the early months of 2023. The remnants of Tropical Cyclone *Ellie*, which made landfall on 22 December 2022 in the western Northern Territory, brought major flooding to the Kimberley area of northern Western Australia and adjacent parts of the Northern Territory in late December and early January. The Fitzroy River at Fitzroy Crossing exceeded its previous record level by more than a metre, and the main road bridge was destroyed, severing the only road links between the east Kimberley area and areas further south and west for several months. A second major flood affected the far north-west of Queensland and the eastern Northern Territory in early March. The Gregory River reached record levels, and the town of Burketown was evacuated, although it ultimately escaped full inundation. Several Indigenous communities were also evacuated for extended periods.

At the start of the 2023/2024 season, Tropical Cyclone *Jasper* made landfall on 13 December near Wujal Wujal, north of Cairns, as a category 2 system. This marked the earliest landfall of a cyclone-intensity storm on the east coast in the satellite era. *Jasper* then stalled for several days, resulting in exceptionally heavy rainfall and severe flooding in the area. Whyanbeel Valley received 2 085.8 mm of rain over the six days from 14 to 19 December, including 699.8 mm on 18 December, while Mossman South received 714.0 mm the same day, an Australian record for December.

In January, a wet spell occurred in Malaysia. Several stations broke their records of daily or monthly totals. Floods were reported from six states, and more than 22 000 people were evacuated.[29]

Heavy precipitation, favoured by the prevailing La Niña conditions in the first months of 2023, caused numerous flash flood events in Indonesia. In March 2023, Indonesia faced a devastating landslide triggered by intense rainfall in the Serasan District (Natuna Regency, northern Riau Islands). The toll on residents was severe, with 54 lives lost and more than 2 800 people affected.[30] Authorities in charge of the disaster relief effort attributed the incident to high-intensity rainfall and unstable soil conditions. Severe weather conditions hindered rescue and relief efforts, blocking roads and disrupting telecommunications networks.[31] The landslide in Indonesia underscores the critical need for robust disaster preparedness and resilient infrastructure to mitigate the impacts of such natural hazards.

DROUGHT AND WILDFIRES

The transition from La Niña to El Niño resulted in changes in the drought situation in the equatorial Pacific. La Niña conditions influenced the spatial distribution of rain in the first months of 2023, while El Niño prevailed in the second half of the year. Even though the rainfall deficit was smaller than in the previous year, some islands in the Pacific had their second consecutive year with drier-than-usual conditions. These included the Hawaiian Islands, Tuvalu, Kiribati, the Republic of the Marshall Islands and French Polynesia, as well as parts of New Zealand's South Island and Tasmania. Some areas in south-west Australia also had their second consecutive year of drier-than-normal conditions. El Niño conditions led to the drought easing in these areas but intensifying in Indonesia, where the August to November period was dry in many parts of the country. Rice planting was delayed for the 2024 harvest in Indonesia, particularly in Java, where the wet season began later than usual. During the September to November period, the area planted with rice was 54% smaller than it was for the same period in 2022. Authorities declared a drought emergency in Bali in October. Wildfire activity in Indonesia was higher than it had been in the previous three years but well below that experienced during the 2015/2016 El Niño.

Much of Australia outside the tropics had average to below-average rainfall in 2023 after widespread wet conditions in 2021 and 2022, and winter crop production is forecast to be slightly below the 10-year average and 33% lower than the record high levels in 2022. The August to October period was especially dry; averaged over the continent, this period was the country's driest three-month period on record, although rainfall returned to average or above-average levels in November.

Several large wildfires were reported in the interior of Australia. Fires to the east and west of Tennant Creek, in Australia's Northern Territory, burned a total of over 13 million hectares, mostly in very sparsely populated areas.[32] Very large fires in interior Australia are typical of post-La Niña periods because La Niña-related precipitation excess causes abnormal vegetation growth, resulting in increased fuel loads. Major wildfires occurred in a number of locations in late October and early November in inland parts of southern Queensland and north-eastern New South Wales, in areas which had been especially dry. Extremely large fires also occurred during spring in the central Northern Territory following heavy grass growth during and after the very wet 2022/2023 monsoon season.

In August, the deadliest single wildfire of the year globally occurred in Hawaii, on the western side of the island of Maui. Extreme fire weather conditions, with low humidity and strong, gusty winds driven by a pressure gradient between strong high pressure to the north and the circulation of Hurricane *Dora* well to the south combined with pre-existing drought to favour the development and rapid spread of intense fires. The worst affected area was around the town of Lahaina, which was largely destroyed, with over 2 200 structures lost. At least 100 deaths were reported,[33] the most in a wildfire in the United States of America in more than 100 years. Wildfires of such intensity and speed of movement are extremely rare in the tropics. Drought had redeveloped from May onwards over much of Hawaii after temporarily easing earlier in the year, with most of the state in severe to extreme drought as of the end of November.

EXTREME HEAT

A major and prolonged heatwave affected much of South-East Asia in April and May. Although its most significant impacts were further north, the heatwave extended into the South-West Pacific region. Singapore experienced high temperatures, with the year's highest maximum temperature of 37.0 °C at Ang Mo Kio on 13 May matching the national record set in 1983.

Many high temperature extremes occurred throughout the year at island locations in the tropical Pacific, driven by high SSTs. With La Niña having a cooling influence over much of the continent, heat extremes were limited over Australia during the 2022/2023 summer, although significant heat extremes occurred in parts of the country during spring, particularly in the southern half of Western Australia, where many monthly records were set during September, October and November. Summer temperatures in New Zealand were well above average; the season was marked more by persistent warmth than by individual extremes, but some records were set on the west coast of the South Island, including at Greymouth (30.9 °C on 8 January) and Milford Sound (29.4 °C on 4 February).

MARINE HEATWAVES

Analogous to heatwaves on land, marine heatwaves are prolonged periods of extreme heat that affect the ocean and can have a range of consequences for marine life and dependent communities. Marine heatwaves have become more frequent over the twentieth and twenty-first centuries; satellite retrievals of SSTs are used to monitor them. They are categorized as moderate when the SST is above the 90th percentile of the climatological distribution for five days or longer; the subsequent categories are defined with respect to the difference between the SST and the climatological distribution average: strong, severe or extreme, if that difference is, respectively, more than two, three or four times the difference between the 90th percentile and the climatological distribution average.[34]

In 2023, the most prominent and persistent marine heatwaves occurred in a large area around New Zealand, affecting the Tasman Sea and the ocean area east of New Zealand up to about 150°W. This marine heatwave was extreme and lasted about six months (Figure 8). The emergence of the 2023 El Niño is also visible in the evaluation of marine heatwaves in the eastern Pacific Ocean. Signatures of the persistent severe to extreme marine heatwave observed in 2022 south of Papua New Guinea in the Solomon and Coral Seas were still evident in 2023, but at lower categories (strong to severe), with less extension and for a shorter duration (about two months).

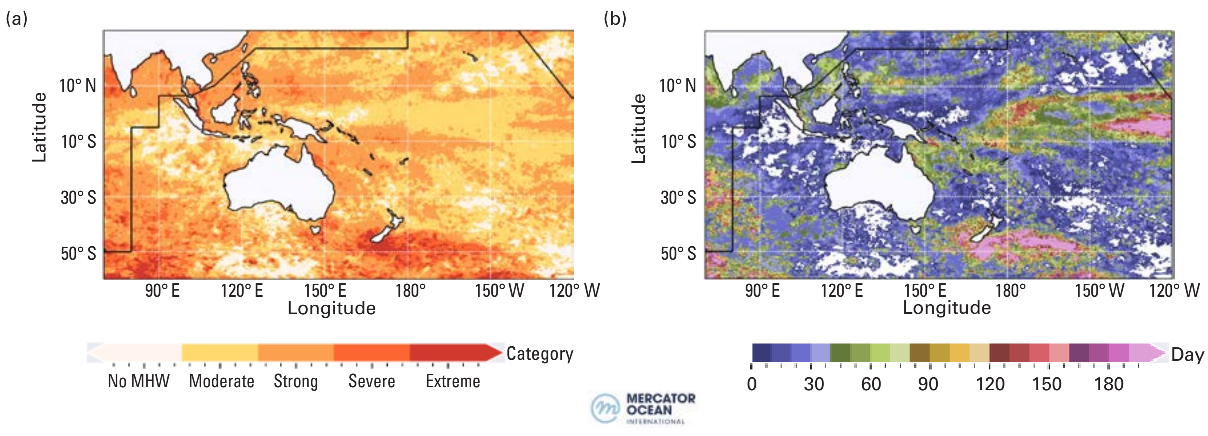


Figure 8. (a) Maximum categories of marine heatwaves, and (b) maximum duration of marine heatwaves in 2023. The colours in (a) indicate the highest category of marine heatwave for the year 2023 at each grid point, and the colours in (b) indicate the duration of the marine heatwave at the highest level for each grid point.

Source: Mercator Ocean International, France, derived from the Copernicus Marine Service remote sensing products available at https://doi.org/10.48670/moi-00168 (for 1982–2022) and https://doi.org/10.48670/moi-00165 (for 2023)

Climate-related impacts and risks

AFFECTED POPULATION AND DAMAGE

In 2023, a total of 34 hydrometeorological hazard events were reported in the South-West Pacific according to the International Disaster Database (EM-DAT),[35] of which over 90% were flood and storm events. These reported hydrometeorological hazard events resulted in over 200 fatalities, most of which were associated with floods, storms, and landslides (Figure 9). Over 25 million people were directly affected by these hazards, and they caused total economic damage of close to US$ 4.4 billion. Floods were the leading cause of death, whereas drought was the natural hazard type that affected the greatest number of people. Storms were the hazard type that caused the greatest economic damage, followed by floods. In March, a landslide triggered by flooding in north-western Indonesia resulted in 54 fatalities, more than 2 800 displaced people[36] and 27 buried houses.[37] This disaster event caused the greatest number of fatalities in the South-West Pacific in 2023, highlighting the importance of understanding the multiple and cascading impacts of natural hazard events.

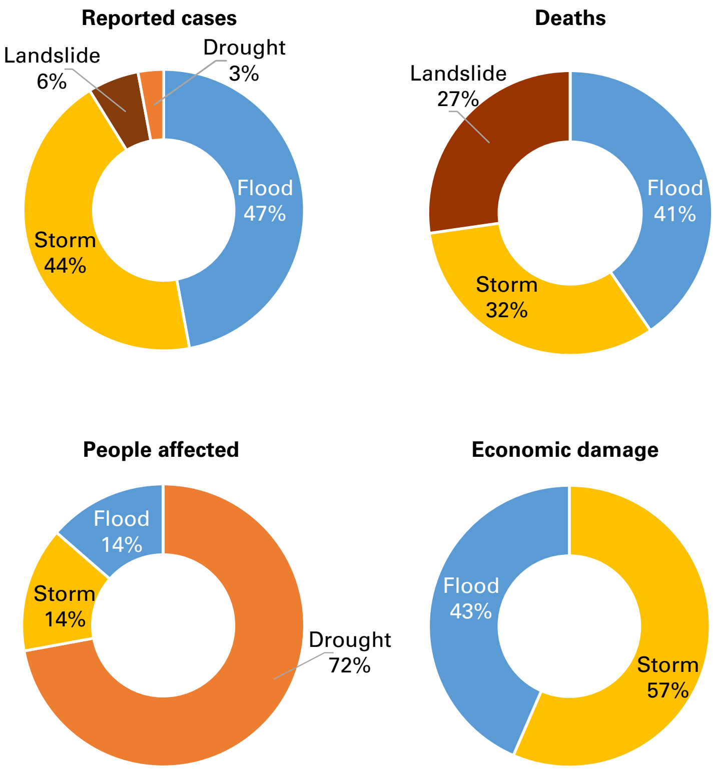


Figure 9. Overview of 2023 disasters in the South-West Pacific region. Note: The economic damages resulting from some disasters are not presented in the diagram due to data unavailability. Only cases reported in EM-DAT are considered in the diagram.

Source: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) calculations based on EM-DAT data, accessed on 8 January 2024

STATUS OF EARLY WARNING SYSTEMS IN THE SOUTH-WEST PACIFIC

According to the Global Status of Multi-Hazard Early Warning Systems 2023 report, only half of the world's countries are covered by an early warning system. Even in places where early warning systems exist, varying levels of maturity are seen across the four multi-hazard early warning system pillars of disaster risk knowledge, observations and forecasting, warning and dissemination, and preparedness to respond.[38]

In the South-West Pacific region, 13 countries (59%) reported on the status of their early warning system in the Sendai Framework Monitor (Figure 10). The average of the composite score for Target G of the Sendai Framework for Disaster Risk Reduction 2015–2030 (Indicator G-1, which measures the overall progress towards having a multi-hazard early warning system) was 0.57 out of 1. It is of note that out of the 13 reporting countries, over 60% (eight countries) reported on all four key indicators (Indicators G-2 to G-5). These indicators are used to understand the comprehensiveness of each of the four pillars of an early warning system. The pillar which is the strongest is observations and forecasting; of the 12 countries which reported on this indicator, the average score was 0.83. The second-strongest pillar is warning and dissemination; of the 10 countries which reported on this indicator, the average score was 0.78. The pillar which most needs strengthening is disaster risk knowledge; only nine countries reported on this indicator, and the average score was 0.43, significantly lower

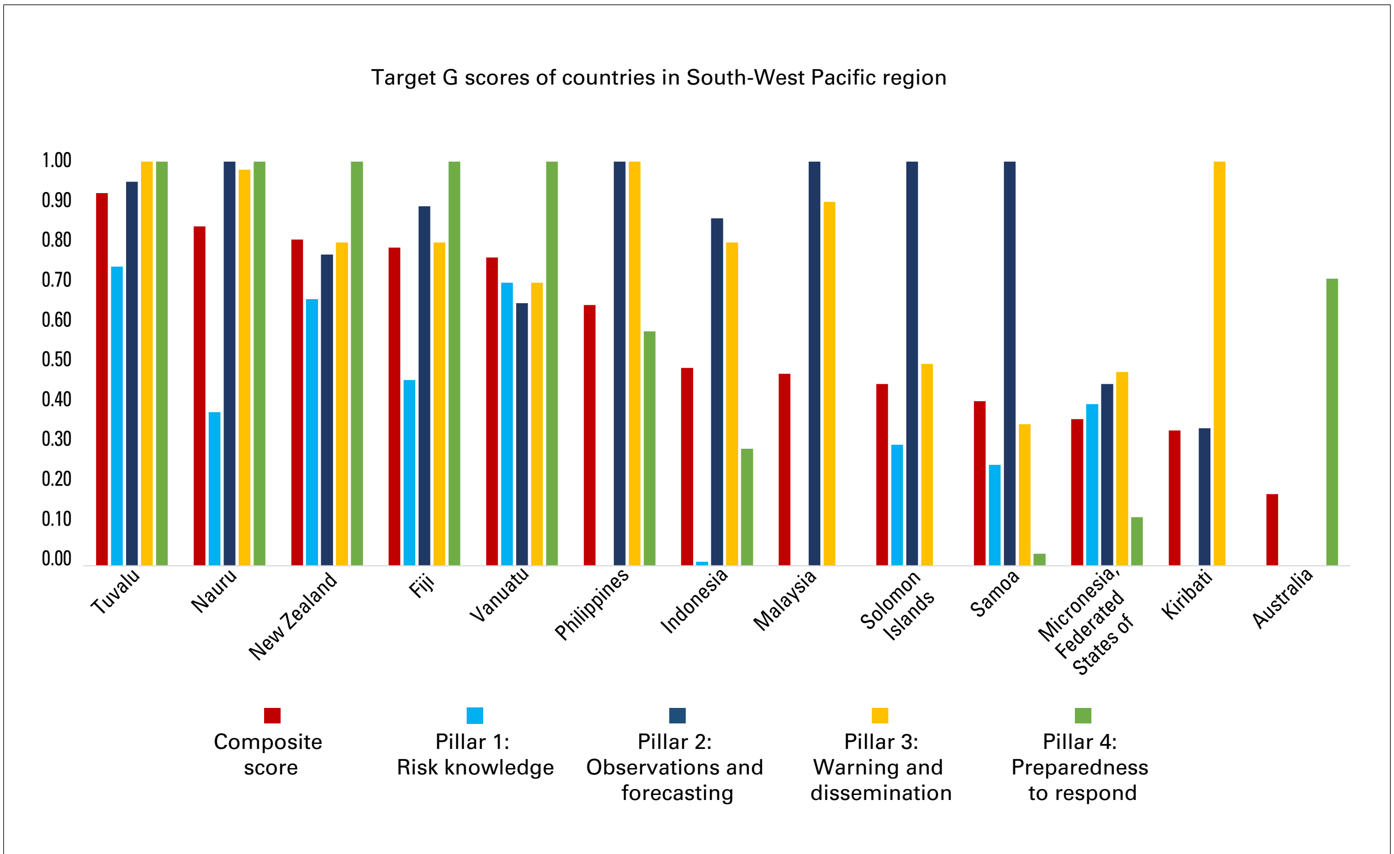


Figure 10. Sendai Target G scores of countries in the South-West Pacific region as of 2023, as reported by the countries themselves through the Sendai Monitor

Source: United Nations Office for Disaster Risk Reduction (UNDRR) than the average score for the other pillars. Ten countries reported on the remaining pillar, preparedness to respond, and the average score was 0.67. Based on the reporting, there is much room for improvement, especially with respect to disaster risk knowledge. It should also be noted that monitoring and progress reporting will be greatly improved if more countries report on all four indicators.

EARLY WARNINGS AND ANTICIPATORY ACTION IN THE SOUTH-WEST PACIFIC

WMO and the United Nations Office for Disaster Risk Reduction (UNDRR) are co-leading the Early Warnings for All (EW4All) initiative to ensure that everyone on Earth is protected by early warnings by 2027. The EW4All Executive Action Plan[39] was launched by United Nations Secretary-General António Guterres at the twenty-seventh session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) in Sharm-El-Sheikh, Egypt in November 2022. Given the high benefits relative to costs and the high visibility of the EW4All initiative, early warnings and anticipatory action have been gaining momentum in the South-West Pacific region.

One demonstrative case during 2023 was in Timor-Leste, where to address the growing agricultural drought, the government and the Food and Agriculture Organization of the United Nations (FAO) developed the Anticipatory Action Protocol for Agricultural Drought, which outlines the step-by-step process of connecting information from the Combined Drought Index (CDI) to anticipatory activities that will mitigate the expected impacts.

The first phase of activities focused on communicating early warnings to drought-vulnerable communities and training to enhance their capacity for anticipatory drought management, including implementing community-specific anticipatory action plans tailored to individual villages. These plans were developed in partnership with local communities, and the activities in the plans included repairs to existing water-access systems, installing pumps and water-harvesting measures, expanding facilities for water storage, diversifying food production, cash-for-work schemes, and the allocation of multi-purpose cash through adaptive social protection measures for the most vulnerable households.

Moving forward, customizing impact-based forecasting to meet sector needs, including developing and refining specific thresholds, is critical to improving the accuracy of the CDI model and to developing a more targeted approach to anticipatory action.

CHALLENGES AND OPPORTUNITIES

Between 1970 and 2021, about 1 500 disasters due to weather, climate and water extremes were reported in the South-West Pacific. They resulted in approximately 67 000 deaths and US$ 185.8 billion in economic losses. Tropical cyclones were the leading cause of reported weather- and climate-related deaths.[40] In March 2023, two tropical cyclones, *Judy* and *Kevin* hit Vanuatu, bringing destructive hurricane-force winds, heavy rainfall, thunderstorms, and rough seas. As a result, the homes of 19 152 households were damaged, and 185 000 people experienced disruptions to healthcare services.[41] These figures highlight the critical importance

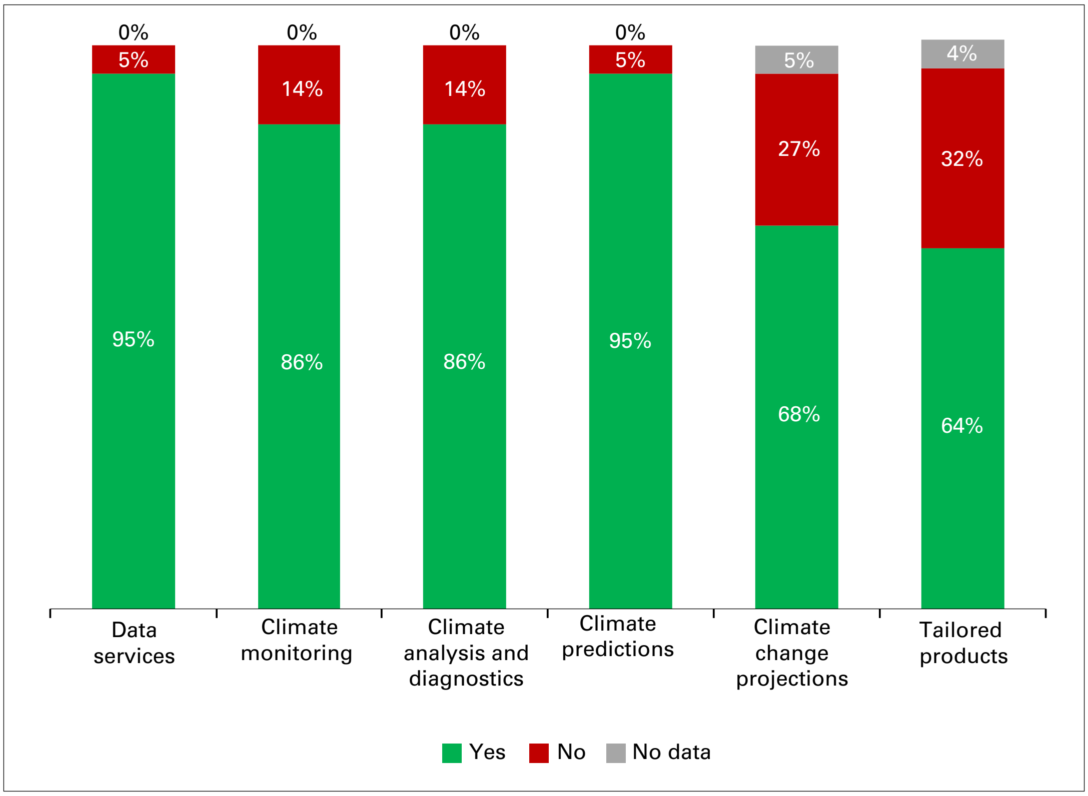


Figure 11. Percentage of National Meteorological and Hydrological Services (NMHSs) providing climate services for disaster risk reduction

of disaster risk reduction initiatives in the region. Data gathered from 22 Members in the South-West Pacific region through the WMO climate services checklist show that about 95% of Members provide climate predictions to support disaster risk reduction (Figure 11).

However, more can be done with regard to providing tailored products and climate projections for disaster risk reduction efforts. National Meteorological and Hydrological Services play a crucial role in delivering these products and services, yet at present, they are provided by fewer than 70% of WMO Members in the region. WMO Members in the South-West Pacific region have assessed their level of engagement with disaster risk reduction stakeholders using a scale from 1 to 6, where 1 represents “initial engagement”, and 6 represents “full engagement”. According to the available data, the average score across the region is 3.3, indicating that most of the engagement is in the initial stages.[42] This suggests that the focus is primarily on identifying needs (between 1 and 3 on the scale), rather than on providing tailored products and services to address the requirements of the disaster risk reduction community (between 4 and 6 on the scale). There is an urgent need to advance efforts to provide these tailored products and services in order to effectively mitigate disaster risks and adapt to climate change.

Furthermore, based on information from international financing sources for disaster-related activities in the Pacific between 2012 and 2020, data from the Organisation for Economic Co-operation and Development (OECD) Creditor Reporting System (CRS) reveals that disaster risk reduction-related official development assistance (ODA) has fluctuated over the past decade, averaging around US$ 46 million per year.[43] In the region, the majority of the funding, approximately 86%, is channelled through project-based interventions facilitated primarily by multilateral and bilateral donor organizations. Direct budget support and sector budget support each account for only 1% of the climate finance.[44] The amount of climate finance mobilized in the Pacific has increased in recent years, in line with the rollout of the Green Climate Fund (GCF) and other flows from multilateral and bilateral development partners.[45]

To ensure the success of the EW4ALL initiative in the South-West Pacific region, the WMO Regional Conference of Regional Association V (South-West Pacific) held in September 2022 recommended that consideration be given to establishing a special task group to analyse the current status of and critical gaps regarding early warning systems and that an initial action plan be developed in order to enable the regional association to move forward. In addition, the Weather Ready Pacific (WRP) Programme was endorsed by Pacific Leaders in 2021, and its implementation plan was adopted at the Pacific Island Forum (PIF) Leaders' Meeting in November 2023. Pacific ministers responsible for Meteorological Services, at the Sixth Pacific Meteorological Council meeting in August 2023, concluded in the Namaka Declaration that "WRP will be the key vehicle for EW4All delivery in the Pacific". Members and partners are now defining how EW4All can complement and supplement what is being taken forward under WRP to ensure that Pacific early warning systems are multi-hazard, people-centred, and end-to-end.

Datasets and methods

TEMPERATURE DATA

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

Regional mean temperature anomalies were calculated relative to 1961–1990 and 1991–2020 baselines using the following steps:

1. Read the gridded dataset;

2. Regrid the data to 1° latitude × 1° longitude resolution. If the gridded data are higher resolution, take a mean of the grid boxes within each 1° ×1° grid box. If the gridded data are lower resolution, 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 1991–2020;

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

The following six datasets were used:

Berkeley Earth: Rohde, R. A.; Hausfather, Z. The Berkeley Earth Land/Ocean Temperature Record. *Earth System Science Data* **2020**, *12*, 3469–3479. https://doi.org/10.5194/essd-12-3469-2020. The data are available here.

ERA5: Hersbach, H.; Bell, B.; Berrisford, P. et al. *ERA5 Monthly Averaged Data on Single Levels from 1940 to Present*; Copernicus Climate Change Service (C3S) Climate Data Store (CDS), 2023. https://doi.org/10.24381/cds.f17050d7.

GISTEMP v4: GISTEMP Team, 2022: *GISS Surface Temperature Analysis (GISTEMP), version 4*. NASA Goddard Institute for Space Studies, https://data.giss.nasa.gov/gistemp/. Lenssen, N.; Schmidt, G.; Hansen, J. et al. Improvements in the GISTEMP Uncertainty Model. *Journal of Geophysical Research: Atmospheres* **2019**, *124*, 6307–6326. https://doi.org/10.1029/2018JD029522. The data are available here.

HadCRUT.5.0.2.0: Morice, C. P.; Kennedy, J. J.; Rayner, N. A. et al. An Updated Assessment of Near-Surface Temperature Change From 1850: The HadCRUT5 Data Set. *Journal of Geophysical Research: Atmospheres* **2021**, *126*, e2019JD032361. https://doi.org/10.1029/2019JD032361. HadCRUT.5.0.2.0 data were obtained from http://www.metoffice.gov.uk/hadobs/hadcrut5 on 17 January 2024 and are © British Crown Copyright, Met Office 2024, provided under an Open Government Licence, http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.

JRA-55: Kobayashi, S.; Ota, Y.; Harada, Y. et al. The JRA-55 Reanalysis: General Specifications and Basic Characteristics. *Journal of the Meteorological Society of Japan*. Ser. II **2015**, *93*, 5–48. https://doi.org/10.2151/jmsj.2015-001. The data are available here.

NOAA Interim: Vose, R. S.; Huang, B.; Yin, X. et al. Implementing Full Spatial Coverage in NOAA's Global Temperature Analysis. *Geophysical Research Letters* **2021**, *48*, e2020GL090873. https://doi.org/10.1029/2020GL090873.

PRECIPITATION DATA

The following Global Precipitation Climatology Centre (GPCC) datasets were used in the analysis:

- First Guess Monthly, https://doi.org/10.5676/DWD_GPCC/FG_M_100
- Monitoring Product (Version 2022), https://doi.org/10.5676/DWD_GPCC/MP_M_V2022_100
- Full Data Monthly (Version 2022), https://doi.org/10.5676/DWD_GPCC/FD_M_V2022_100
- Precipitation Climatology (Version 2022), https://doi.org/10.5676/DWD_GPCC/CLIM_M_V2022_100

OCEAN HEAT CONTENT DATA

Data are from the in situ-based product Multi Observation Global Ocean 3D Temperature Salinity Height Geostrophic Current and MLD, downloaded from Copernicus Marine Service.

SEA-SURFACE TEMPERATURE DATA

Data are from the Copernicus Marine Service remote sensing products Global Ocean OSTIA Sea Surface Temperature and Sea Ice Reprocessed for 1982–2021 and Global Ocean OSTIA Sea Surface Temperature and Sea Ice Analysis for 2022, downloaded from the Copernicus Marine Service.

SEA LEVEL DATA

Regional sea-level trends are based on gridded C3S altimetry data, averaged from 50 km offshore to the coast, by the Laboratory of Space Geophysical and Oceanographic Studies (LEGOS).

EXTREME EVENTS DATA

Meteorological characteristics and statistics are based on reports from WMO Members in Regional Association V (South-West Pacific). Associated socioeconomic impacts are based on reports from WMO Members, EM-DAT data (see below) and reports from United Nations organizations.

EM-DAT DATA

EM-DAT data (www.emdat.be) were used for historical climate impact calculations. 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, number affected and total damages (in thousands of US dollars), respectively.

CLIMATE SERVICES

WMO analysis of nationally determined contributions

Checklist for Climate Services Implementation (Members' climate services capacities, 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)

List of contributors

CONTRIBUTING EXPERTS (IN ALPHABETICAL ORDER BY SURNAME)

Gregor Macara (lead author, New Zealand), Soomi Hong (lead author, United Nations Economic and Social Commission for Asia and the Pacific (ESCAP)), Sanjay Srivastava (lead author, ESCAP), Blair Trewin (co-lead author, Australia), Thea Turkington (co-lead author, Singapore), Rusali Agrawal (ESCAP), Rachel Allen (World Food Programme (WFP)), Nurizana Amir Aziz (Malaysia), Omar Baddour (WMO), Arieta Daphen Baleisolomone (Fiji), Joseph Basconcillo (Philippines), Jessica Blunden (United States of America), Anny Cazenave (Laboratory of Space Geophysical and Oceanographic Studies (LEGOS)), Elise Chandler (Australia), Xuan Che (United Nations Office for Disaster Risk Reduction (UNDRR)), Sarah Diouf (WMO), Ahmad Fairudz (Malaysia), Atsushi Goto (WMO), Veronica Grasso (WMO), Flora Gues (Mercator Ocean International), Peer Hechler (WMO), Christopher Hewitt (WMO), Erkin Isaev (Food and Agriculture Organization of the United Nations (FAO)), Zaridah Mohd Jalal (Malaysia), Catherine Jones (FAO), Animesh Kumar (UNDRR), Konamauri Lenny (Solomon Islands), Lancelot Leclercq (LEGOS), Jacqueline Lim (Singapore), Jochen Luther (WMO), Amirui Nizam Marodzi (Malaysia), Nakiete Msemo (WMO), Arona Ngari (Cook Islands), Claire Ransom (WMO), Karina von Schuckmann (Mercator Ocean International), Jose Alvaro Silva (WMO), Ana Liza Solis (Philippines), Ardhasena Sopaheluwakan (Indonesia), Jothiganesh Sundaram (WFP), Tessa Tafua (WMO), Henry Taiki (WMO), Naina Tanwar (ESCAP), Markus Ziese (Germany)

EXPERT TEAM ON CLIMATE MONITORING AND ASSESSMENT (REVIEWERS)

John Kennedy (lead, United Kingdom of Great Britain and Northern Ireland), Jessica Blunden (co-lead, USA), Randall S. Cerveny (USA), Ladislaus Benedict Chang'a (United Republic of Tanzania), Liudmila Kolomeets (Russian Federation), Renata Libonati (Brazil), Atsushi Minami (Japan), Awatif Ebrahim Mostafa (Egypt), Serhat Sensoy (Türkiye), Ardhasena Sopaheluwakan (Indonesia), Jose Luis Stella (Argentina), Blair Trewin (Australia), Freja Vamborg (European Centre for Medium-Range Weather Forecasts (ECMWF)), Zhiwei Zhu (China)

CONTRIBUTING ORGANIZATIONS

FAO, LEGOS, Mercator Ocean International, ESCAP, UNDRR, WFP, WMO

CONTRIBUTING WMO MEMBERS (IN ALPHABETICAL ORDER)

Australia, Cook Islands, Fiji, Indonesia, Malaysia, New Zealand, Philippines, Singapore, Solomon Islands, USA

Endnotes

1. Data are from the following datasets: Berkeley Earth, ERA5, GISTEMP v4, HadCRUT.5.0.1.0, JRA-55, NOAAGlobalTemp v5. For details regarding these, see the datasets and methods section in the *State of the Global Climate 2023* (WMO-No. 1347).

2. World Meteorological Organization (WMO). *State of the Global Climate 2023* (WMO-No. 1347). Geneva, 2024.

3. http://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html

4. https://www.csiro.au/greenhouse-gases/

5. Friedlingstein, P.; O'Sullivan, M.; Jones, M. W. et al. Global Carbon Budget 2022, Earth System Science Data, 14. 4811–4900. https://doi.org/10.5194/essd-14-4811-2022.

6. Intergovernmental Panel on Climate Change (IPCC). Summary for Policymakers. In IPCC Special Report on the Ocean and Cryosphere in a Changing Climate; Pörtner, H.-O.; Roberts, D. C.; Masson-Delmotte, V. et al., Eds.; Cambridge University Press: Cambridge, UK and New York, USA, 2019. https://www.ipcc.ch/site/assets/uploads/sites/3/2022/03/01_SROCC_SPM_FINAL.pdf.

7. Intergovernmental Panel on Climate Change (IPCC). Special Report on the Ocean and Cryosphere in a Changing Climate; Pörtner, H.-O.; Roberts, D. C.; Masson-Delmotte, V. et al., Eds.; Cambridge University Press: Cambridge, UK and New York, USA, 2019. https://www.ipcc.ch/srocc/.

8. The South-West Pacific (WMO Regional Association V) is a vast region composed of: Australia, Brunei Darussalam, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Indonesia, Kiribati, Malaysia, Nauru, New Caledonia, New Zealand, Niue, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Timor-Leste, Tonga, Tuvalu and Vanuatu.

9. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds.; Cambridge University Press: Cambridge, UK and New York, USA, 2021. https://www.ipcc.ch/report/ar6/wg1/.

10. Further information on the climate drivers described in this section is available through the Australian Bureau of Meteorology at http://www.bom.gov.au/climate/about/.

11. Only five datasets where all the data were available were used in the assessment relative to 1961–1990.

12. New Zealand snow depths are expressed with respect to the average of all years of available data, starting in 2010 at most locations.

13. Gulev, S. K.; Thorne, P. W.; Ahn, J. et al. Changing State of the Climate System. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al. Eds.; Cambridge University Press: Cambridge, UK and New York, USA, 2021. https://www.ipcc.ch/report/ar6/wg1/.

14. See, for example, Bindoff, N. L.; Cheung, W. W. L.; Kairo, J. G. et al. Changing Ocean, Marine Ecosystems, and Dependent Communities. In IPCC Special Report on the Ocean and Cryosphere in a Changing Climate; Pörtner, H.-O.; Roberts, D. C.; Masson-Delmotte, V. et al. Eds.; Cambridge University Press: Cambridge, UK, and New York, USA, 2019. https://www.ipcc.ch/srocc/.

15. Deser, C.; Alexander, M. A.; Xie, S.-P. et al. Sea Surface Temperature Variability: Patterns and Mechanisms. Annual Review of Marine Science 2010, 2, 115–143. https://www.annualreviews.org/doi/abs/10.1146/annurev-marine-120408-151453.

16. Copernicus Marine Service (CMEMS), Ocean Monitoring Indicator Framework. https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/global-ocean-sea-surface-temperature-time-series-and-trend.

17. von Schuckmann, K.; Cheng, L.; Palmer, M. D. et al. Heat Stored in the Earth System: Where Does the Energy Go? Earth System Science Data 2020, 12 (3), 2013–2041. https://doi.org/10.5194/essd-12-2013-2020.

18. WCRP Global Sea Level Budget Group. Global Sea-Level Budget 1993–Present. Earth System Science Data 2018, 10 (3), 1551–1590. https://doi.org/10.5194/essd-10-1551-2018.

19. Intergovernmental Panel on Climate Change (IPCC). Global warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty; Masson-Delmotte, V.; Zhai, P.; Pörtner, H. O. et al., Eds.; Cambridge University Press: Cambridge, UK and New York, USA, 2018. https://www.ipcc.ch/sr15/.

[20] Li, G.; Cheng, L.; Zhu, J. et al. Increasing Ocean Stratification over the Past Half-century. Nature Climate Change 2020, 10, 1116–1123. https://doi.org/10.1038/s41558-020-00918-2.

[21] Cheng, L.; Trenberth, K. E.; Fasullo, J. T. et al. Evolution of Ocean Heat Content Related to ENSO. Journal of Climate 2019, 32 (12), 3529–3556. https://doi.org/10.1175/JCLI-D-18-0607.1.

[22] World Meteorological Organization (WMO). Significant Weather and Climate Events in 2023; WMO, 2023. https://wmo.int/sites/default/files/2023-12/Supplement.pdf.

[23] https://reliefweb.int/report/vanuatu/vanuatu-tropical-cyclones-judy-update-and-kevin-gdacs-jtwc-vmgd-media-echo-daily-flash-06-march-2023

[24] https://reliefweb.int/report/philippines/philippines-taiwan-china-tropical-cyclone-doksuri-gdacs-jtwc-pagasa-adinet-echo-daily-flash-24-july-2023.

[25] https://reliefweb.int/disaster/tc-2023-000121-chn, with additional information from EM-DAT (http://www.emdat.be)

[26] https://reliefweb.int/disaster/tc-2023-000121-chn

[27] Council for International Development. End of South Pacific Cyclone Season Report 2022–2023; Council for International Development, 2023. https://reliefweb.int/report/vanuatu/end-south-pacific-cyclone-season-report-2022-2023.

[28] New Zealand Treasury. Impacts from the North Island Weather Events; New Zealand Treasury, 2023. https://www.treasury.govt.nz/sites/default/files/2023-04/impacts-from-the-north-island-weather-events.pdf.

[29] https://experience.arcgis.com/experience/5cb119c71c6c4f8a89b837bf5cf353b8

[30] Association of Southeast Asian Nations (ASEAN) Coordinating Centre for Humanitarian Assistance on Disaster Management (AHA Centre). ASEAN Disaster Information Network (ADINet). Indonesia, Landslides in Natuna Regency (Riau Islands); AHA Centre, 2023. https://adinet.ahacentre.org/report/indonesia-landslides-in-natuna-regency-riau-islands-20230306.

[31] Davies, R. Indonesia – Heavy Rain Triggers Deadly Landslides in Riau Islands; FloodList, 2023. https://floodlist.com/asia/indonesia-landslide-riau-islands-march-2023.

[32] https://experience.arcgis.com/experience/5cb119c71c6c4f8a89b837bf5cf353b8

[33] National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI). U.S. Billion-Dollar Weather and Climate Disasters; NOAA NCEI, 2024. https://www.ncei.noaa.gov/access/billions/events/US/2023?disasters[]=wildfire.

[34] Hobday, A. J.; Oliver, E. C. J.; Sen Gupta, A. et al. Categorizing and Naming Marine Heatwaves. Oceanography 2018, 31 (2), 162–173. https://www.jstor.org/stable/26542662.

[35] https://www.emdat.be/ Note: Only meteorological, hydrological, and climatological hazards are included.

[36] https://adinet.ahacentre.org/report/indonesia-landslides-in-natuna-regency-riau-islands-20230306

[37] https://reliefweb.int/report/indonesia/indonesia-landslide-update-bmkg-bnpb-echo-daily-flash-09-march-2023

[38] United Nations Office for Disaster Risk Reduction (UNDRR); World Meteorological Organization (WMO). Global Status of Multi-Hazard Early Warning Systems 2023; UNDRR: Geneva, 2023. https://www.undrr.org/reports/global-status-MHEWS-2023#download.

[39] World Meteorological Organization (WMO). *Early Warnings for All. The UN Global Early Warning Initiative for the Implementation of Climate Adaptation. Executive Action Plan 2023-2027*; WMO: Geneva, 2022.

[40] World Meteorological Organization (WMO). *Economic Costs of Weather-related Disasters Soars but Early Warnings Save Lives* [Press release]. 22 May 2023.

[41] https://reliefweb.int/report/world/pacific-islands-ifrc-network-mid-year-report-january-june-2023-19-december-2023

[42] World Meteorological Organization (WMO). *2023 State of Climate Services: Health* (WMO-No. 1335). Geneva, 2023.

[43] United Nations Office for Disaster Risk Reduction (UNDRR). Disaster Risk Reduction Financing in Asia and the Pacific: Scoping Study for the Midterm Review of the Sendai Framework for Disaster Risk Reduction 2015–2030; UNDRR, 2023. https://www.undrr.org/publication/disaster-risk-reduction-financing-asia-and-pacific-scoping-study-midterm-review-sendai

[44] United Nations Office for Disaster Risk Reduction (UNDRR). Disaster Risk Reduction Financing in Asia and the Pacific: Scoping Study for the Midterm Review of the Sendai Framework for Disaster Risk Reduction 2015–2030; UNDRR, 2023. https://www.undrr.org/publication/disaster-risk-reduction-financing-asia-and-pacific-scoping-study-midterm-review-sendai

[45] United Nations Development Programme (UNDP). Climate Finance Effectiveness in the Pacific: Are We on the Right Track? Discussion Paper; UNDP, 2021. *UNDP-Climate-Finance-Effectiveness-in-the-Pacific-Disussion-Paper.pdf*.

For more information, please contact:

World Meteorological Organization

7 bis, avenue de la Paix – P.O. Box 2300 – CH 1211 Geneva 2 – Switzerland

Strategic Communications Office
Cabinet Office of the Secretary-General

Tel: +41 (0) 22 730 83 14 – Fax: +41 (0) 22 730 80 27

Email: communications@wmo.int

wmo.int

JN 24831