State of the Climate in Asia

2022

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

WMO-No. 1321

Cover photo: Storm arriving, photo taken by Puneet Verma (India), WMO 2022 Calendar Competition.

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Key messages

The mean temperature over Asia for 2022 was the second or third warmest on record and was 0.72 °C [0.63 °C–0.77 °C] above the 1991–2020 average. The 1991–2020 average was itself 1.68 °C [1.60 °C–1.74 °C] above the WMO 1961–1990 reference period for climate change.

Drought affected many parts of the region, reducing water availability. The economic losses in 2022 as a result of the drought in China, for example, were estimated to exceed US$ 7.6 billion.

Glaciers in the High Mountain Asia region have lost significant mass over the past 40 years, and this loss is accelerating. In 2022, exceptionally warm and dry conditions exacerbated the mass loss for most glaciers. Urumqi Glacier No. 1 in the eastern Tien Shan recorded the second highest negative mass balance of -1.25 metre water equivalent (m w.e.) since measurements began in 1959.

The oceanic region within WMO Regional Association II (Asia) shows an overall surface ocean warming trend since the time series began in 1982. In the north-western Arabian Sea, the Philippine Sea and the seas east of Japan, the warming rates exceed 0.5 °C per decade, which is about three times faster than the global average surface ocean warming rate.

Pakistan experienced severe flooding that was associated with significant loss of life and economic damage. Pakistan received 60% of its normal total monsoon rainfall within just three weeks of the start of the monsoon season in 2022. According to the National Disaster Management Authority (NDMA), more than 33 million people, almost 14% of Pakistan's 2022 population, were affected.

Record-breaking winds and heavy rainfall associated with Typhoon *Nanmadol* were observed in several stations in Japan in September. *Nanmadol* was associated with five deaths, affected over 1 300 people, and caused estimated economic damages in excess of US$ 2 billion.

According to the Emergency Events Database (EM-DAT), in 2022, 81 natural hazard events were reported in Asia; of these, over 83% were flood and storm events. These events led to over 5 000 fatalities, 90% of which were associated with flooding. Overall, natural hazard events directly impacted more than 50 million people and resulted in over US$ 36 billion in damages.

Economic losses in 2022 due to disasters relating to floods exceeded the average for the 2002–2021 period. The most significant losses of this type were in Pakistan (over US$ 15 billion), followed by China (over US$ 5 billion), and India (over US$ 4.2 billion). Economic losses in 2022 associated with droughts were the next largest category, causing US$ 7.6 billion in damages (mainly in China); this exceeds 2002–2021 average (US$ 2.6 billion) by nearly 200%.

Enhancing food system resilience is a high priority in Asia, as was emphasized in the Nationally Determined Contributions (NDC) of most of the parties to the Paris Agreement in WMO Regional Association II. Monitoring the past and current climate and providing forecasts on weather and climate timescales are fundamental tools underpinning effective early warning services for agriculture and food security.

Foreword

Following the successful publication of the second WMO report on the state of the climate in Asia (*State of the Climate in Asia 2021* (WMO-No. 1303)), I am pleased to see the timely publication of this third edition. This report has been drafted with the collaboration of National Meteorological and Hydrological Services (NMHSs), several research institutions, and a number of contributing United Nations agencies and international and regional organizations.

The report summarizes the state of the climate and the extreme events and their socioeconomic impacts in Asia in 2022. The temperatures in the region were warmer than those of the previous year; 2022 was the second or third warmest year on record. Most glaciers in the High Mountain Asia region suffered from intense mass loss as a result of exceptionally warm and dry conditions in 2022.

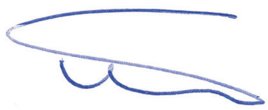
In 2022, many areas in Asia experienced drier-than-normal conditions and drought. China, in particular, suffered prolonged drought conditions, which affected water availability and the power supply. The estimated economic losses from the drought affecting many regions in China were over US$ 7.6 billion.

In view of the trends with respect to climate indicators and extreme events described in this report, and the expected increase in the frequency and severity of extreme events over much of Asia, it is clear that agriculture will continue to be impacted by climate change and climate extremes; this is especially apparent in countries where the agricultural sector is important to the economy. The importance of food system resilience is also emphasized in the Nationally Determined Contributions of parties to the Paris Agreement. As of February 2023, the most frequently chosen priority area for climate adaptation by the parties in the Asia region was agriculture, followed by water and health.

Early warnings, which empower people to make risk-informed decisions relating to food security and other areas, are one of the most effective ways of reducing damage from disasters. Despite continuous efforts to strengthen multi-hazard early warning systems (MHEWS), the present report clearly indicates that there are still significant gaps to be addressed to strengthen these systems in order to reduce the adverse impacts of hydrometeorological hazards in the region.

WMO and the United Nations Office for Disaster Risk Reduction (UNDRR) are co-leading the Early Warnings for All initiative; its Executive Action Plan was launched by United Nations Secretary-General António Guterres at the COP27 climate change conference last year. To ensure the mainstreaming of this initiative at the regional level, ministers and heads of National Meteorological and Hydrological Services from 24 countries and key regional partners issued a high-level declaration at the WMO Regional Conference in Asia. This declaration includes strong recommendations to advance the four key MHEWS pillars: risk knowledge and management; observations and forecasting; dissemination and communication; and preparedness and response.

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 to thank WMO Members and our sister United Nations agencies for their continuous commitment to supporting this publication by providing input and contributing to the report review process.



Prof. Petteri Taalas
Secretary-General, WMO

Preface

2022 marked another year of a growing intensity in climate change impacts which cascaded with and compounded a series of disasters. The devasting floods and ensuing spread of flood-borne diseases and food insecurities experienced by Pakistan is one stark example of how the world is now exposed to natural hazards at a potential scale that goes beyond what was imaginable in the past.

While compared to 2021, the number of reported disaster events decreased, their effects were much more pronounced, with fatalities, people affected and economic damage all increasing. In 2022, flood events were considered to be responsible for over 90% of disaster-related fatalities reported in the Asia region, and most can be linked to flooding in May and June in Pakistan and India. This was an increase of almost 40% compared to the previous year. In 2022, the economic cost of drought more than doubled compared to 2021, to US$ 7.6 billion, and much of the cost was attributable to agricultural losses arising from the worst drought in six decades in south-west China. This brings the need for transformative climate adaptation to a new level of urgency if development gains are to be protected and sustainable development achieved.

Food system resilience is fundamental to protecting both lives and livelihoods, especially for the most at-risk populations. This report highlights that the agriculture sector is one of the most critical sectors affected by climate related disasters, echoing the national adaptation plans of many countries in Asia. Impact-based forecasting, early warnings for all, and their translation into anticipatory action are examples of the transformative adaptation needed to strengthen the resilience of food systems in Asia. Investments in data-driven observations and forecasting, supported through regional policy coordination and cooperation based on the exchange of knowledge and cross-sectoral support, will be critical.

The United Nations Secretary-General's Executive Action Plan on Early Warnings for All, co-led in implementation by WMO and the United Nations Office for Disaster Risk Reduction (UNDRR), is more critical in Asia, which is the world's most disaster-impacted region and where the effects of transboundary climate-related disasters are on the rise. Working through a network of partnerships that includes the lead United Nations organizations at the global level, the Economic and Social Commission for Asia and the Pacific (ESCAP) Secretariat stands ready to mobilize and facilitate the necessary regional implementation.

In this context, the *State of the Climate in Asia 2022* is timely, as it unpacks the important climate indicators showing change over time as well as the impacts of extreme events and the measures needed to make risk-informed decisions. ESCAP and WMO, working in partnership, will continue to invest in raising climate ambition and accelerating the implementation of policy actions, including bringing 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 2022 was 1.15 °C [1.02 °C to 1.27 °C] above the 1850–1900 pre-industrial average. The year 2022 was either the fifth or the sixth warmest year on record according to six data sets,[1] despite the cooling effect of La Niña. The years 2015 to 2022 were the eight warmest years on record in all data sets.[2]

Atmospheric concentrations of the three major greenhouse gases reached new record observed highs in 2021, the latest year for which consolidated global figures are available, with levels of carbon dioxide (CO_2) at 415.7 ± 0.2 parts per million (ppm), methane (CH_4) at 1 908 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 334.5 ± 0.1 ppb, respectively 149%, 262% and 124% of pre-industrial (before 1750) levels (Figure 1). Real-time data from specific locations, including Mauna Loa[3] (Hawaii) and Kennaook/Cape Grim[4] (Tasmania, Australia) indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2022.

Over the past two decades, the ocean warming rate has increased; the ocean heat content in 2022 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 4.62 mm per year between 2013 and 2022, reaching a new record high in 2022. Between 1960 and 2021, the ocean absorbed about 25% of annual anthropogenic emissions of CO_2 into the atmosphere,[5] and 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. This process, known as ocean acidification, affects many organisms and ecosystem services[6] and threatens food security by endangering fisheries and aquaculture.

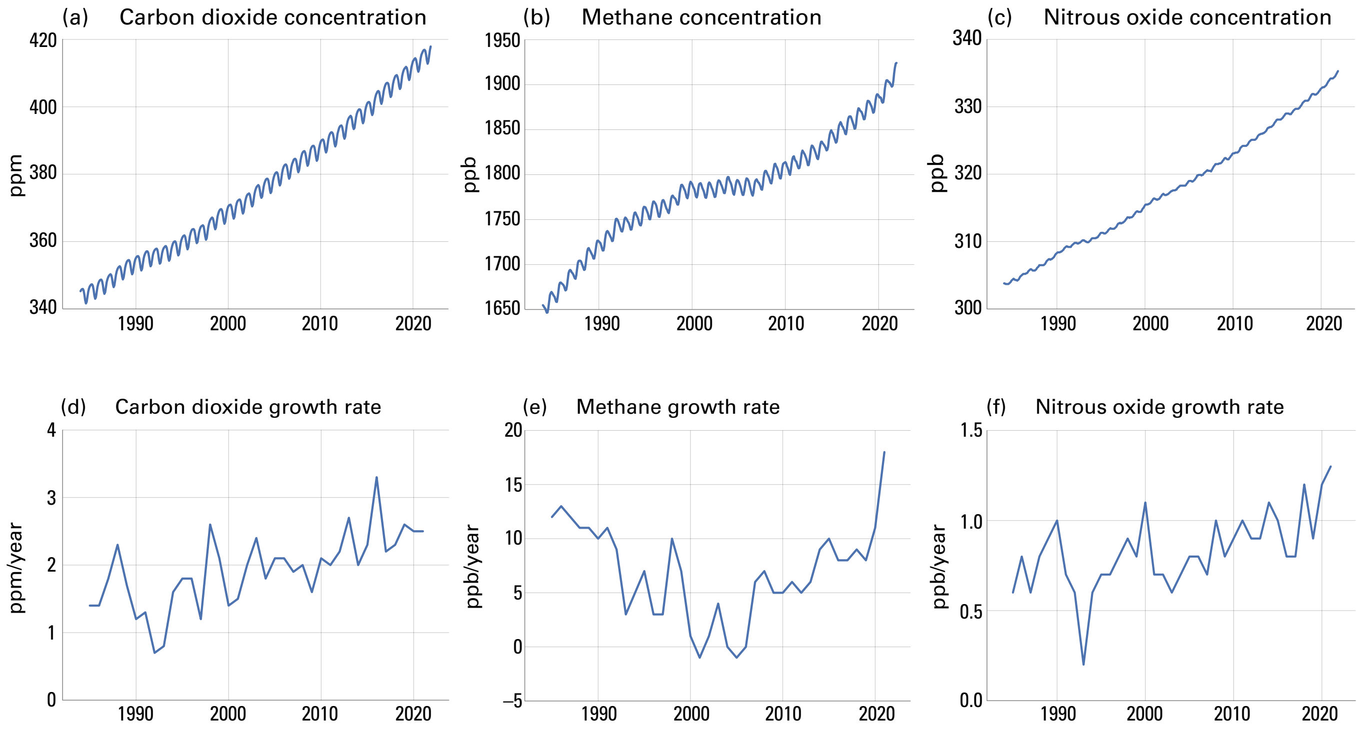


Figure 1. Top row: Monthly globally averaged mole fraction (measure of atmospheric concentration), from 1984 to 2021, of (a) CO_2 in parts per million, (b) CH_4 in parts per billion and (c) N_2O in parts per billion. Bottom row: Growth rates representing increases in successive annual means of mole fractions for (d) CO_2 in parts per million per year, (e) CH_4 in parts per billion per year and (f) N_2O in parts per billion per year

Regional climate

The following sections analyse key indicators of the state of the climate in Asia during 2022. One such indicator that is particularly important, 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)[7] 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 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 reference period is used for computing anomalies in temperature and other indicators. Regional temperature anomalies can also be expressed relative to the reference period 1961–1990. This is a fixed reference period recommended by WMO for assessing long-term temperature change. In the present report, exceptions to the use of these baseline periods for the calculation of anomalies, where they occur, are explicitly noted.

TEMPERATURE

Surface temperature and precipitation have a huge impact on natural systems and on human beings. The mean temperature over Asia[8] in 2022 was either the second or third highest on record (Figure 2), 0.73 °C [0.63 °C–0.78 °C] above the 1991–2020 average and 1.68 °C [1.60 °C–1.74 °C] above the 1961–1990 average (the WMO reference period for assessing climate change). Above average temperatures were recorded in northern Siberia (north of 60 degrees latitude), the northern Middle East, Central Asia and the western to coastal areas of China (overall, 2022 was the second warmest year on record for China). Elsewhere, near-to-normal temperatures were recorded (Figure 3).

Over the long term, a warming trend has emerged in Asia in the latter half of the twentieth century (Figures 2 and 4). In the two recent sub-periods (1961–1990 and 1991–2022), the warming trends in Asia,

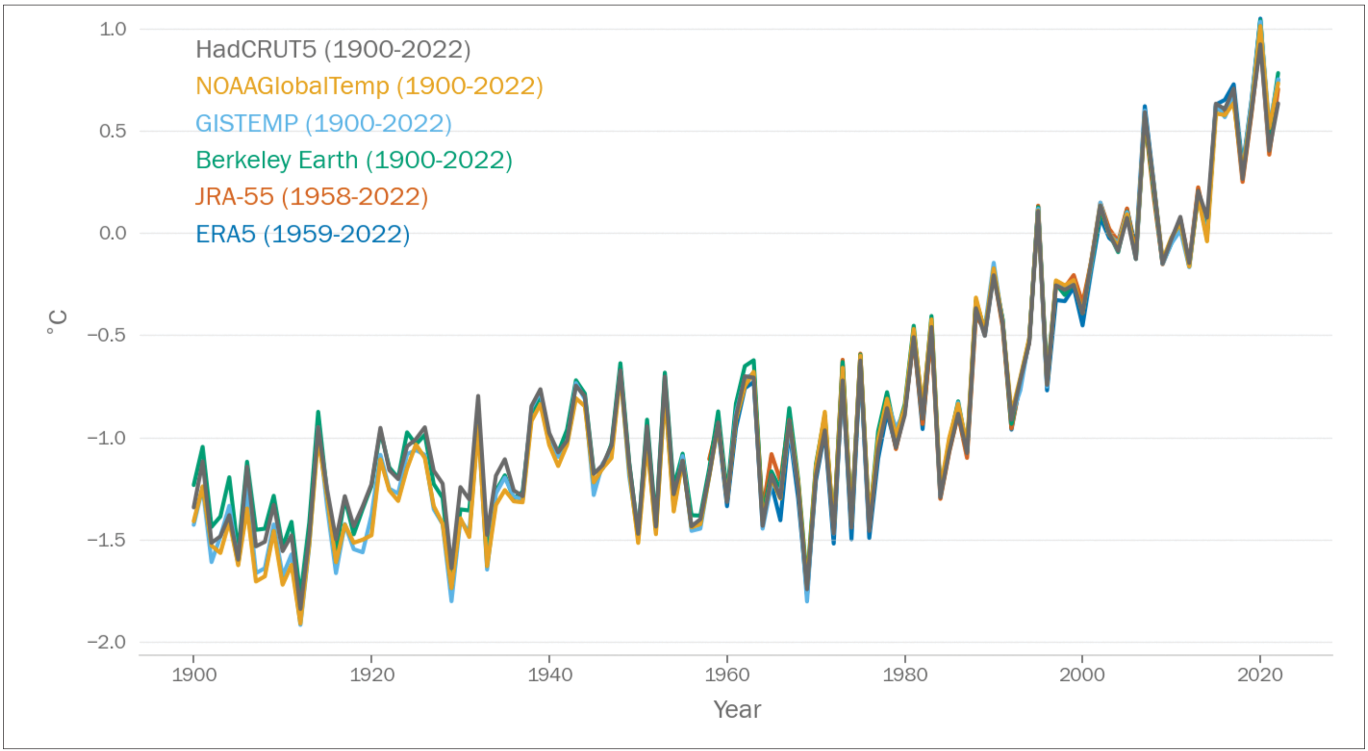


Figure 2. Annual mean temperature anomalies (°C), 1900–2022, averaged over Asia, relative to the 1991–2020 average, for the six global temperature data sets indicated in the legend
Source: HadCRUT5, Berkeley Earth, NOAAGlobalTemp and GISTEMP are based on in situ observations. ERA-5 and JRA-55 are reanalysis data sets. For details on the data sets and the plotting, see Temperature.

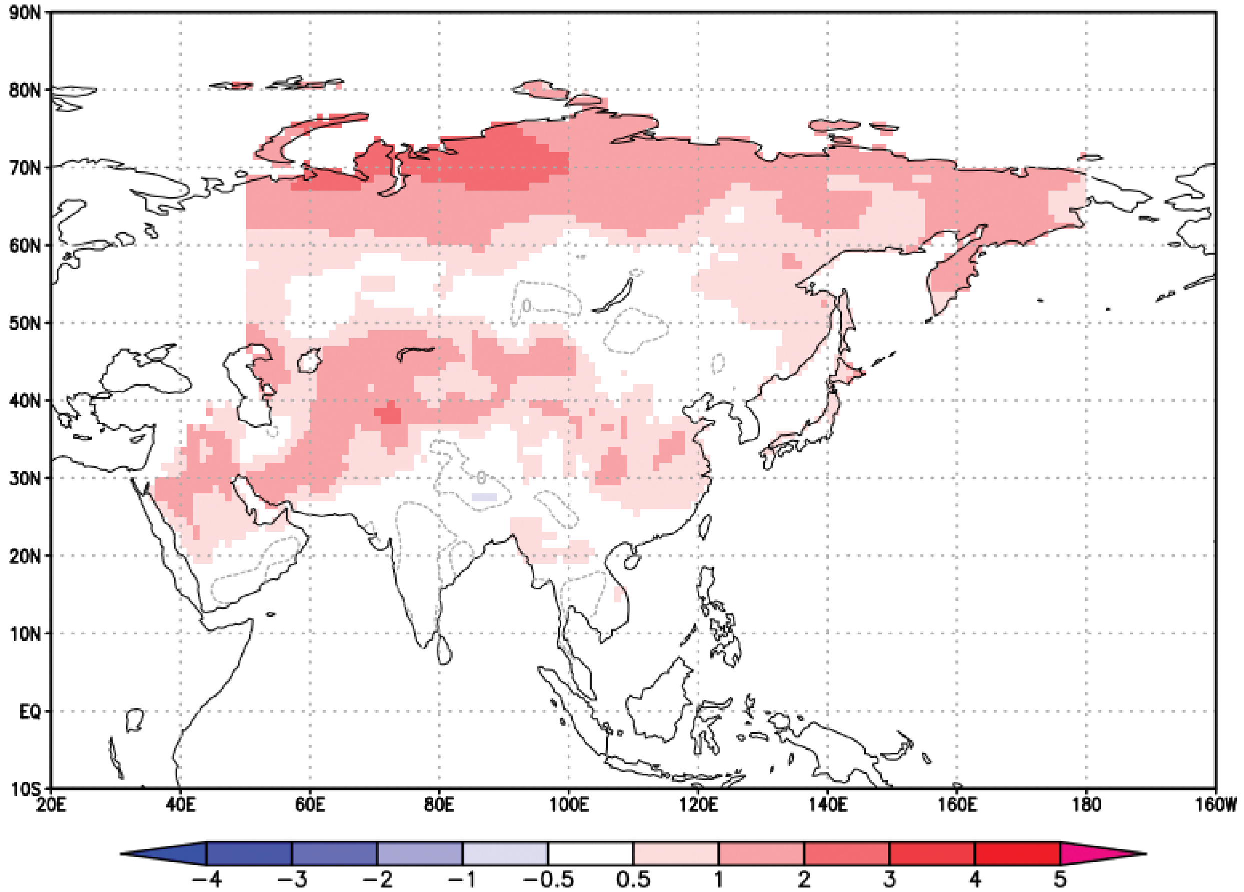


Figure 3. Temperature anomalies (°C) relative to the 1991–2020 long-term average from the JRA-55 reanalysis for 2022
Source: Tokyo Climate Center, Japan Meteorological Agency

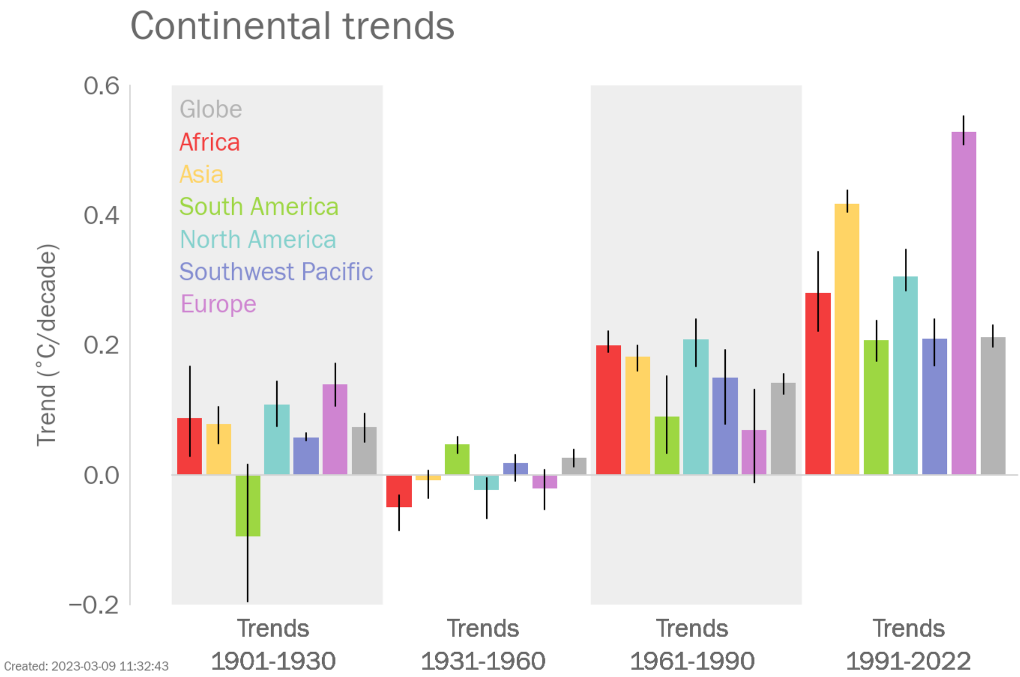


Figure 4. Trends in mean surface air temperature for the six WMO regions and the global mean (°C) over four sub-periods using the six data sets. The bars indicate the trend in the mean of the data sets. The black lines indicate the range between the largest and the smallest trends in the individual data sets.

the continent with the largest land mass extending to the Arctic, have exceeded the global land and ocean average values. This indirectly reflects the fact that the temperature increase over land is larger than the temperature increase over the ocean, as stated in the IPCC AR6 report. The warming trend in Asia in 1991–2022 was almost double the warming trend during the 1961–1990 period, and much larger than the trends of the previous 30-year periods (Figure 4).

PRECIPITATION

Precipitation is a key climate parameter, essential for society in terms of providing water for drinking and domestic purposes, agriculture, industry, and hydropower. It also drives major climate events such as droughts and floods. In 2022, the largest precipitation deficits in the region were observed in Iraq, the Hindu Kush (the high mountain range stretching from central to western Afghanistan), the lower course of the Ganges and Brahmaputra Rivers (India and Bangladesh), the Korean Peninsula, and Kyushu (the western island of Japan) (Figure 5). Other regions which had below-normal precipitation were Central Asia, the Yangtze River Basin (where a severe drought was reported) and the Huaihe River Basin in China, South-West Asia and North-West Asia, and along the Arctic coast. The largest absolute precipitation excesses were observed around the southern half of Pakistan, in South-East Asia, and in north-east China. Unusually high precipitation totals were also observed in Siberia, North-East Asia, central India, the Western Ghats (India), the eastern Himalayas (Nepal and Bhutan), along the Yellow River (northern China) and in western Tian Shan (the high mountain range in western China).

The highest daily precipitation totals were measured at the Western Ghats (India) and the Khasi Hills (India) and along the coasts of the South China Sea and the East China Sea. Tam Dao station in Viet Nam, for example, observed a daily rainfall of 464 mm on 23 May; this exceeded the previous daily record of 216 mm for May. In comparison to the long-term mean of the period 1991–2020, above-normal highest daily precipitation totals were recorded in large parts of East and North-East Asia and along the northern coast of the Arabian Sea. Positive anomalies with respect to highest daily precipitation totals were also detected in parts of Pakistan, Iran and Iraq, which shows that extreme precipitation events can also occur if the annual total is below normal (Figure 6).

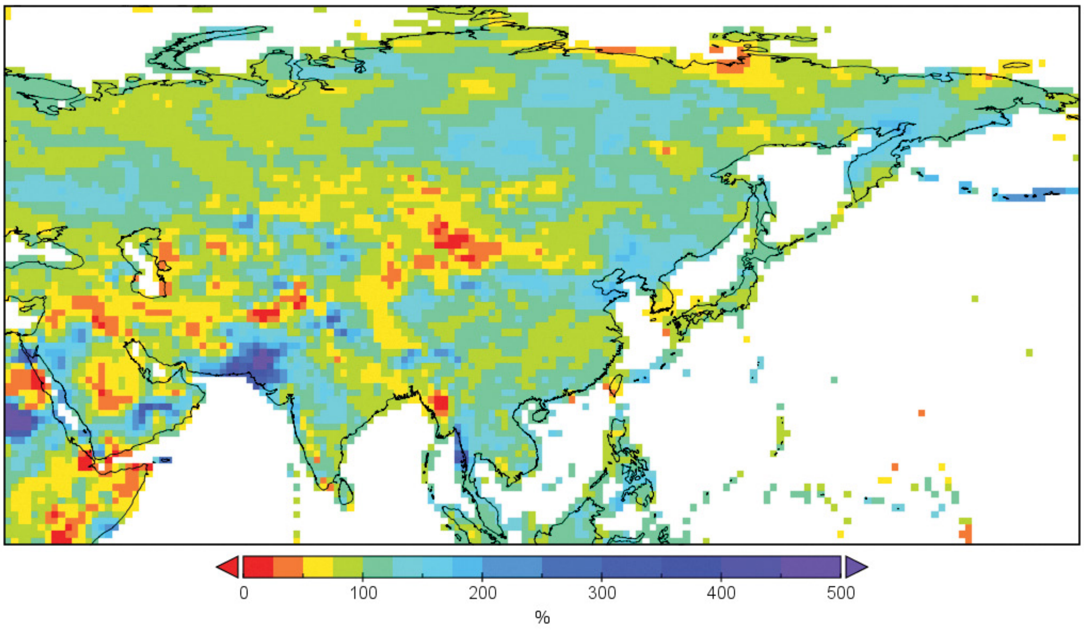


Figure 5. Precipitation anomalies for 2022, expressed as a percentage of the 1991–2020 average
Source: Global Precipitation Climatology Centre (GPCC), Deutscher Wetterdienst, Germany

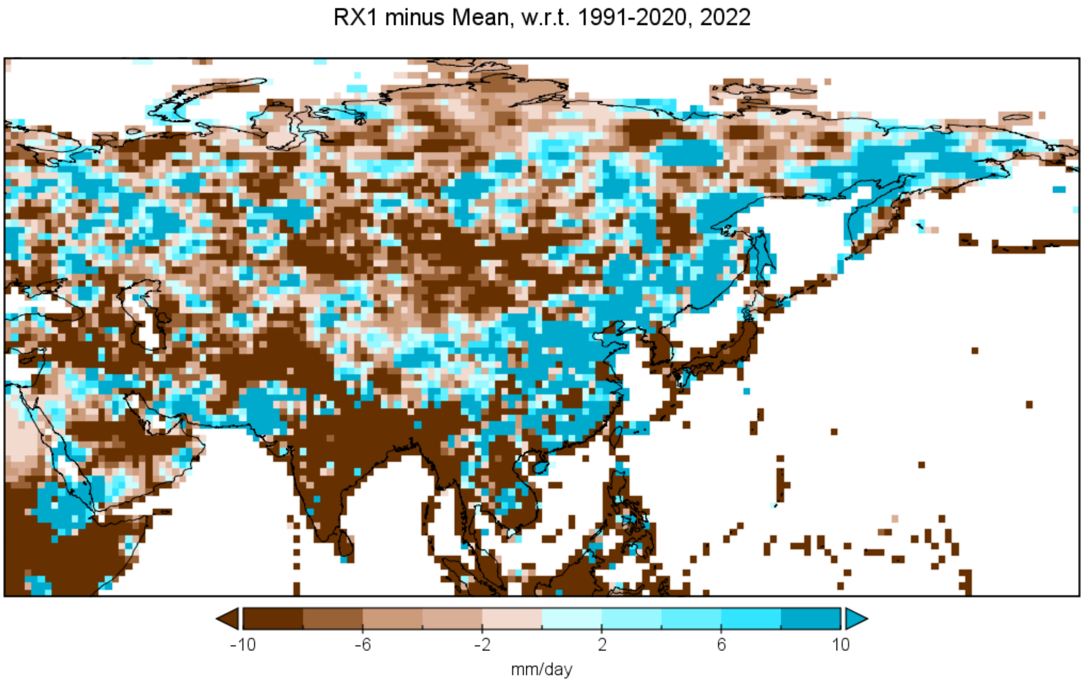


Figure 6. Difference between the highest daily precipitation totals in 2022 and the 1991–2020 long-term mean. Blue indicates the regions with more extreme daily precipitation than the long-term mean. Brown indicates the regions with less extreme daily precipitation than the long-term mean. *Source:* GPCC, Deutscher Wetterdienst, Germany

CRYOSPHERE

ARCTIC SEA ICE

Sea-ice extent is a key indicator of climate variability and climate change in the polar regions. Sea ice strongly modulates surface ocean waves and the air–sea exchanges of heat, momentum, moisture, and so forth, thereby influencing the regional climate and the global climate. According to the consensus statement of the ninth session of the Arctic Climate Forum,[9] the maximum Artic ice extent in winter 2022 (approximately 15 million km^2) was reached on 21–22 February 2022, two weeks earlier than when the maximum Artic ice extent has been reached, on average, since 1979. However, colder-than-average surface air temperature at the end of winter 2022 stimulated ice growth until the end of April 2022 and led to a greater-than-median (for 1979–2022) ice extent in the Canadian Arctic. Estimates of the total Arctic sea-ice volume continue to show its significantly decreased state – close to the third lowest for 2004–2022, after 2020 and 2021. The minimum Arctic ice extent in summer 2022 occurred on 17–18 September and was around the tenth lowest annual minimum daily extent on record. While the continental shelf areas of the Eurasian Barents Sea and the Kara Sea were completely ice free, with the ice edge significantly northward of the Svalbard Islands, the ice conditions in parts of the Laptev Sea, the East Siberian Sea, and the Beaufort Sea were close to normal, with both the North-West Passage and the Northern Sea Route formally remaining blocked in the transit straits.[10]

GLACIERS

Glacier ice mass is sensitive to changes in regional temperature, precipitation and surface radiation. The melting of glaciers impacts sea level, regional water cycles and the occurrences of local hazards such as glacier lake outburst floods. The High Mountain Asia region is the high-elevation area centred on the Tibetan Plateau; it contains the largest volume of ice outside of the polar regions, with glaciers covering an area of approximately 100 000 km^2. Over the last several decades, most of these glaciers have been retreating, with the equilibrium line altitudes (the lower topographic limit of the glaciers) gradually rising.[11,12] In the past 40 years, four glaciers in the High Mountain Asia region with more than 30 years of ongoing mass-balance measurements (Figure 7) have recorded significant mass losses, with an accelerating trend since the mid-1990s. At the same time, these four glaciers show an overall weaker cumulative mass loss than the average for the global reference glaciers (indicated by a grey line in Figure 7) during the period 1980–2022. According to the Technical Summary of the Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6), glaciers over South Asia have thinned, retreated, and lost mass since the 1970s (high confidence), although the Karakoram glaciers have either slightly gained mass or are in an approximately balanced state (medium confidence).[13]

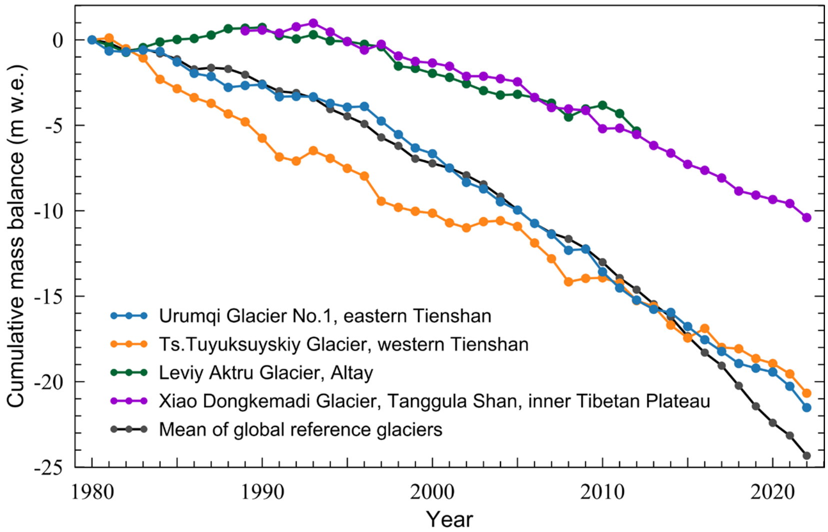


Figure 7. Cumulative mass balance (in metres water equivalent (m w.e.)) of four reference glaciers in the High Mountain Asia region and the average mass balance for the global reference glaciers
Source: Data regarding the global reference glaciers (grey), Leviy Aktru Glacier (green), Ts. Tuyuksuyskiy Glacier (orange), and Urumqi Glacier No. 1 (blue) are from the World Glacier Monitoring Service (WGMS). Data regarding the Xiao Dongkemadi Glacier (purple) are from the Chinese Academy of Sciences (CAS).

For the glaciological year 2021/2022, preliminary data available from 23 glaciers observed in the High Mountain Asia region show continued negative mass changes. Exceptionally warm and dry conditions in the Altay, most of the Tien Shan and the Hindu Kush exacerbated mass loss for most glaciers. During the period 2021–2022, Urumqi Glacier No. 1, in the eastern Tien Shan, recorded its second most negative mass balance (1.25 m w.e.) since measurements began in 1959 (Figure 8).

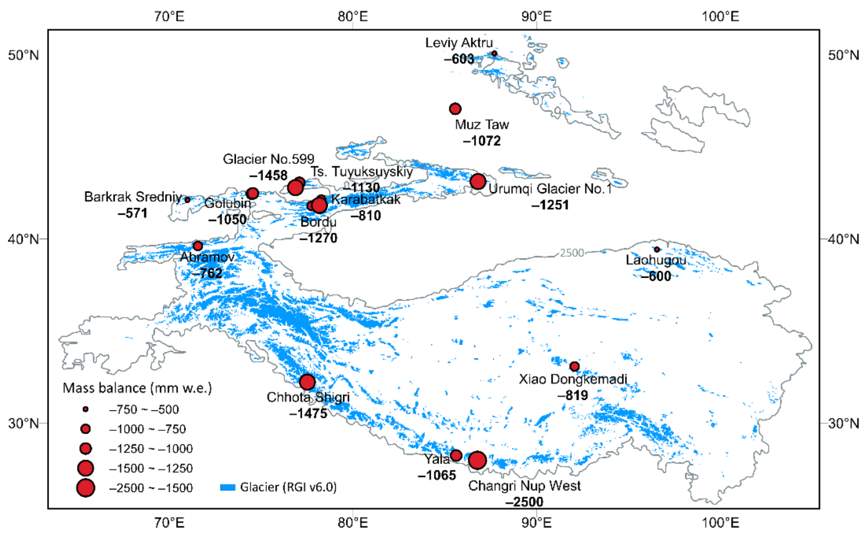


Figure 8. Preliminary estimations of the 2021–2022 mass balance of glaciers in the High Mountain Asia region. The area indicated by grey contours is 2 500 metres above sea level.
Source: WMO Third Pole Regional Climate Centre Network (TPRCC-Network) and WGMS; the original observations upon which this figure is based are from China, Kazakhstan, Kyrgyzstan, Nepal, the Russian Federation and Uzbekistan.

PERMAFROST

Permafrost is soil that continuously remains below 0 °C for two or more years and is a distinctive feature of high-latitude environments. It is characterized by two parameters: mean annual soil temperature at the top of the permafrost, and thickness of the uppermost layer of seasonally thawing soil, which is defined as active layer thickness (ALT). The data presented in Figure 9 indicate that, with rare exceptions, the ALT trends are positive on the territory of the permafrost zone of the Russian Federation, which indicates a steady trend towards an increase in the depth of permafrost thawing in the twenty-first century.[14] IPCC AR6 assessed with high confidence that increases in permafrost temperature and its thawing have been observed over recent decades over north Asia. According to the report, the ground temperature in the permafrost regions of the Tibetan Plateau (permafrost currently covers 40% of Tibetan Plateau) also increased (0.02 °C–0.26 °C per decade for different boreholes) from 1980 to 2018, and the active layer thickened at a rate of 19.5 cm per decade. IPCC AR6 estimates that thawing terrestrial permafrost will lead to carbon release (high confidence), though there is low confidence in the timing and magnitude. Furthermore, the report points out that permafrost thawing, as well as glacier melt and snow decline, are already impacting irrigation, hydropower, water supply, cultural and other services provided by the cryosphere, and populations depending on ice, snow and permafrost.

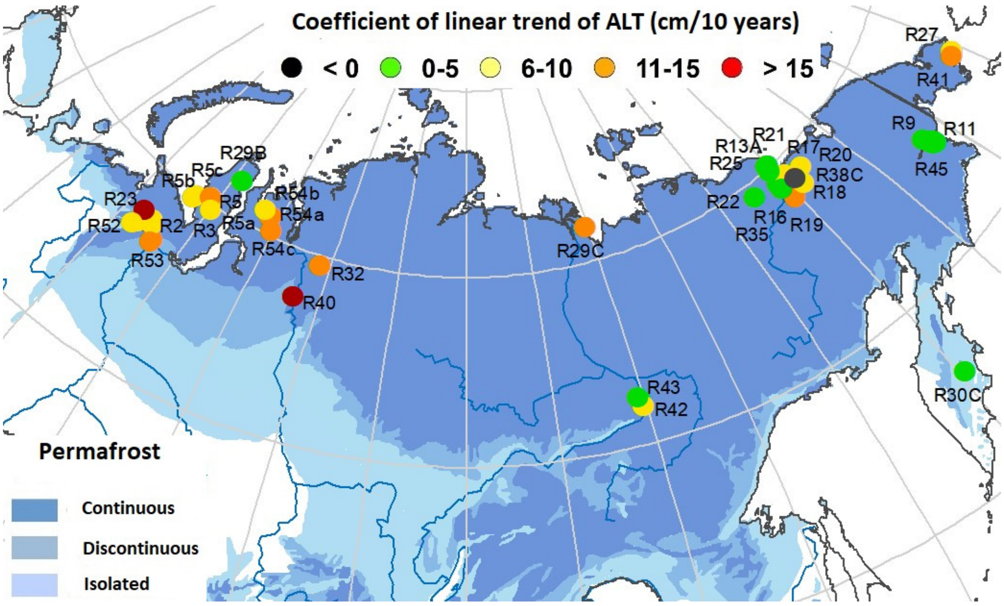


Figure 9. Long-term trend of the thickness of the uppermost layer of seasonally thawing soil (ALT in cm per 10 years) for the period 1976–2022. Permafrost is classified by coverage in continuous (90%), discontinuous (50–90%) and sporadic (10–50%) zones and isolated patches (10%), depending on the area continuity.
Source: Measurements from the Russian Federal Service for Hydrometeorology (Roshydromet) within the Circumpolar Active Layer Monitoring Program

SNOW COVER

Snow cover plays an important role in the feedback mechanisms in the climate system (such as albedo,[15] run-off, soil moisture and vegetation). Hence, it is a crucial variable for monitoring climate change. In the past 26 years, the northern hemisphere spring (March to May) snow cover extent (SCE)[16] over Asia exhibited a statistically significant decreasing trend of 270 000 km^2 per decade, with negative anomalies with respect to the 1998–2020 long term average dominating since the mid-2000s. In the spring of 2022, the SCE in Asia was about 14.56 million km^2, slightly less than the 1998–2020 average. Spatially, negative anomalies were recorded in particular in the area south of 50°N, mainly in the High Mountain Asia region. On the other hand, positive SCE anomalies dominated in a large part of the area north of 50°N (Figure 10).

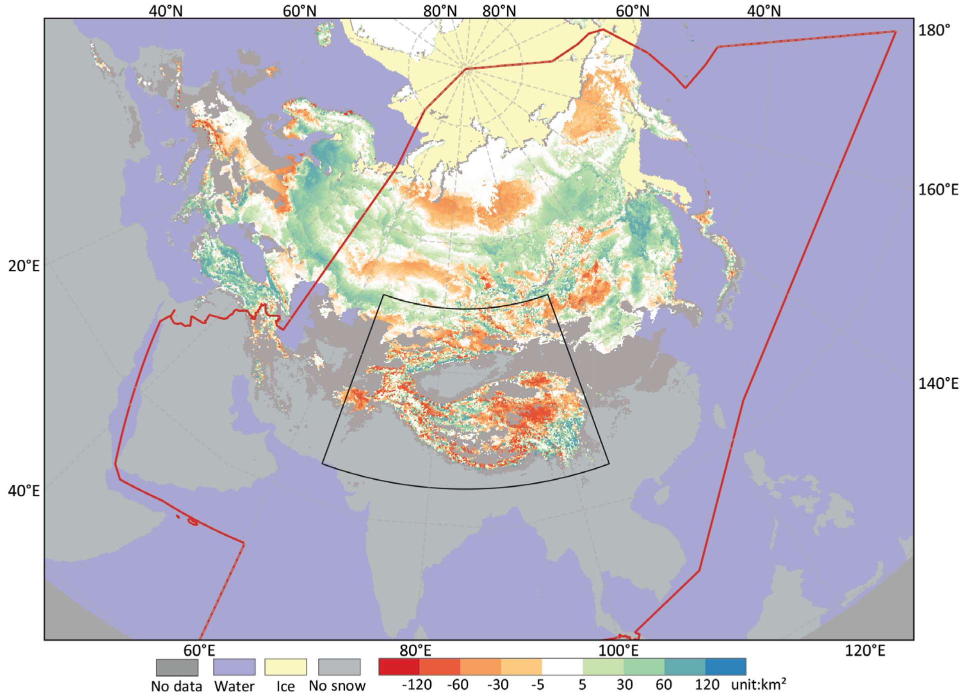


Figure 10. Anomalies of mean snow cover extent in the northern hemisphere spring of 2022 (from March to May), relative to the 1998–2020 average. To derive the monthly snow cover extent anomalies for each grid, the number of monthly snow cover days was divided by the total number of days in that month and then multiplied by the area of the grid. The red line delimits the geographical area of WMO Regional Association II (Asia). The black line delimits the High Mountain Asia region.
Source: Interactive Multisensor Snow and Ice Mapping System and data from the National Snow and Ice Data Center

SEA-SURFACE TEMPERATURE

Sea-surface temperature (SST) is an important physical indicator for Earth's climate system. Changes in SST play a critical role in the coupling between the ocean and the atmosphere, as they can trigger the transfer of energy, momentum and gases between these two Earth system components.[17]

The ocean area of WMO Regional Association II shows an overall surface ocean warming trend since 1982 at rates of more than 0.5 °C per decade in the area of the Kuroshio current system, the Arabian Sea, the southern Barents Sea, the southern Kara Sea, and the south-eastern Laptev Sea; this is more than three times faster than the global surface ocean warming rate of 0.16 °C +/- 0.01 °C per decade. In 2022, the area-averaged SST anomalies were the warmest on record in the north-west Pacific Ocean (area 2 in Figure 11) (>0.6 °C), whereas the values in the Indian Ocean (area 3 in Figure 11) were below the record values reached in 2020. The Barents Sea is identified as a climate change hotspot and illustrates the recent Arctic amplification. Surface ocean warming in this area also has a major impact on observed sea-ice loss, and there is a feedback mechanism in which sea-ice loss in turn enhances ocean warming.

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,[18] making climate change irreversible on centennial to millennial timescales. Ocean warming contributes to about 40% of the observed global mean sea-level rise and alters ocean currents. It also indirectly alters storm tracks,[19] increases ocean stratification,[20] and can lead to changes in marine ecosystems.

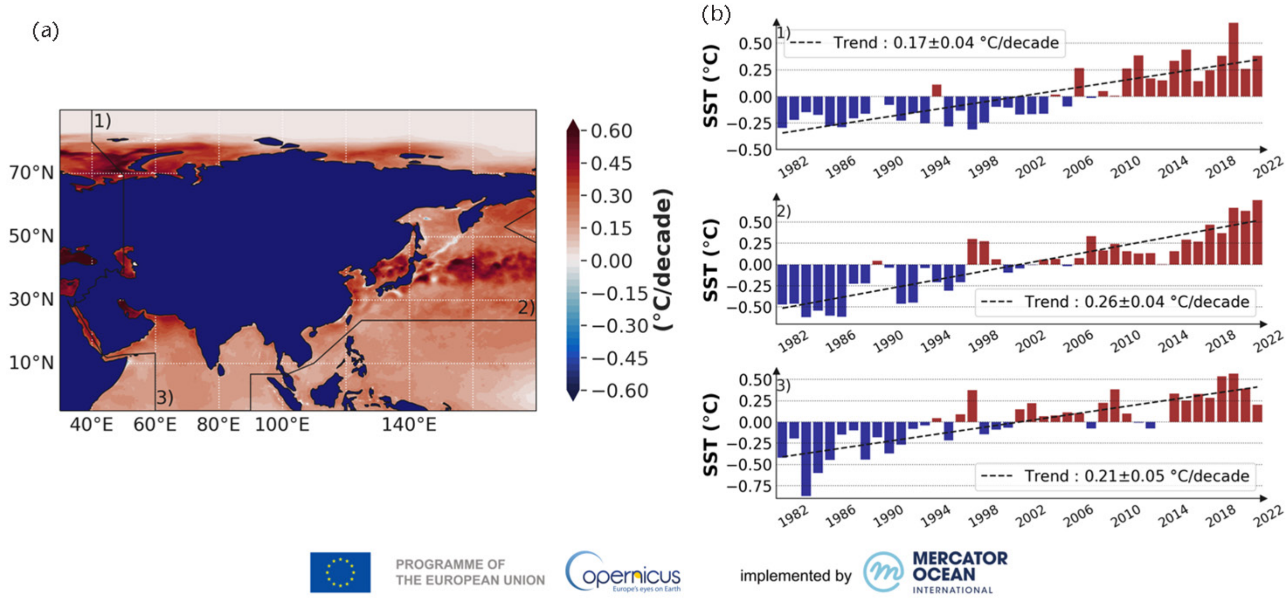


Figure 11. (a) Sea-surface temperature trend (in °C per decade) over the period 1982–2022. (b) Area-averaged time series of sea-surface temperature anomalies relative to the 1982–2022 reference period (in °C) within the three areas of WMO Regional Association II bordered by the black lines in panel (a): 1) the Arctic area north of 60°N; 2) the north-west Pacific Ocean area; and 3) the Indian Ocean area. The linear trend over the full period is indicated as a dashed line.

Source: Derived from the remote sensing product 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

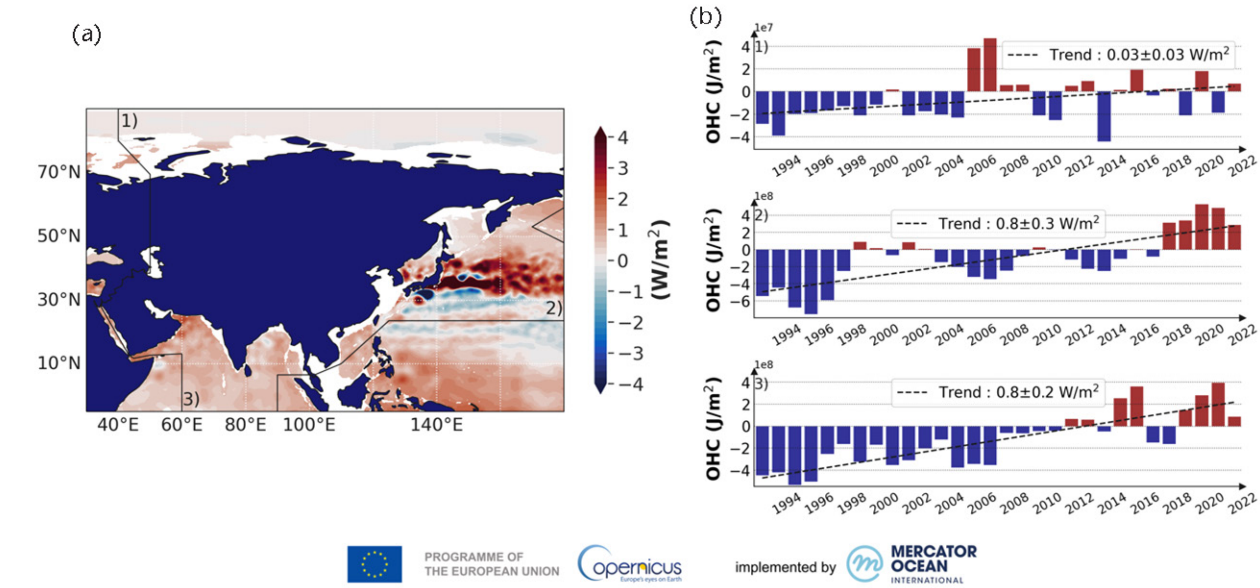


Figure 12. (a) Ocean heat content trend (units: watts per square metre, W/m^2) over the period 1993–2022, integrated from the surface down to a depth of 700 m. Ocean warming rates in areas shallower than 300 m have been masked in white due to product limitations. (b) Area-averaged time series of ocean heat content anomalies relative to the 1993–2022 reference period (units: joules per square metre, J/m^2) within three areas of WMO Regional Association II, as bordered by the black lines in panel (a): 1) the Arctic area north of 60°N; 2) the north-west Pacific Ocean area; and 3) the Indian Ocean area. The linear trend over the full period is indicated as a dashed line.

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

Most of the regions in WMO Regional Association II (Asia) have been experiencing upper-ocean (0 m–700 m) warming since 1993 (the start date of the satellite altimetry records). Warming is particularly strong – at rates exceeding 2 W/m^2 (more than three times faster than the global mean upper-ocean warming rate) – in the north-western Arabian Sea, the Philippine Sea and the seas east of Japan (Figure 12(a)). The northern flank of the Kuroshio current shows particularly strong warming rates of more than 4 W/m^2. This area is also known to undergo strong year-to-year and decadal scale variations. On average, in 2022, the upper ocean layer in this area recorded its fifth warmest year on record (Figure 12(b), 2). Both Asian parts of the north-west Pacific Ocean and the Indian Ocean are warming at a mean rate comparable to the global rate, which is estimated at 0.64 W/m^2 (Figure 12(b), 2 and 3). The northernmost Arctic area (Figure 12(b), 1) has experienced low warming rates, but it should be noted that the calculation of the rate may be affected by the limited observation of the ocean heat content in the region. The southern area of the Kuroshio current, however, experienced strong cooling in 2022.

SEA LEVEL

In 2022, the global average sea level continued to rise at a sustained rate (4.6 mm/year over 2013–2022) in response to ocean warming (via thermal expansion) and the melting of glaciers, ice caps and ice sheets. However, the rate of rise is not the same everywhere. The observed non-uniform regional trends in sea level are essentially due to non-uniform ocean thermal expansion in conjunction with salinity changes in some regions.[21,22] Table 1 summarizes the coastal sea-level trends over the period from January 1993 to June 2022 in six subregions (highlighted by the numbered boxes shown in Figure 13). The regional sea-level time series (not shown) display strong interannual variability, mostly driven by the El Niño–Southern Oscillation (ENSO), especially in the eastern Indian Ocean and tropical Pacific Ocean. The rates of sea level rise in all but one of the six subregions are slightly higher than the global mean rate over 1993–2022 (3.4 ± 0.3 mm per year[23]), with values above 4 mm/year in the north-east Indian Ocean and western tropical Pacific region.

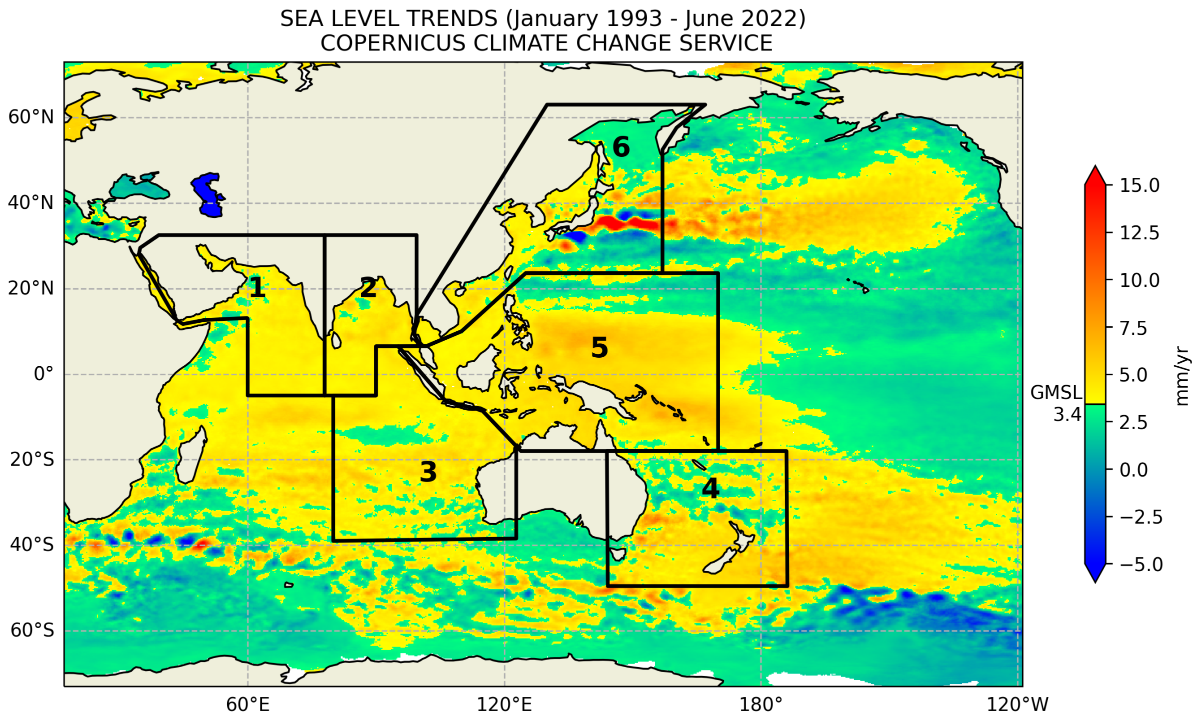


Figure 13. Spatial patterns in sea-level trends observed by altimeter satellites over the period from January 1993 to June 2022. The transition from green to yellow corresponds to the 3.4 mm/year global mean averaged trend. The boxes represent subregions where the rates of area-averaged sea-level change are provided in Table 1.
Source: Copernicus Climate Change Service (C3S)

Table 1. Rate of area-averaged sea-level change over the period from January 1993 to June 2022 according to satellite measurements. Subregions are defined in Figure 13.

Subregion number	Area	Trend in rate of sea-level rise (in mm per year)
1	North-west Indian Ocean	3.80 ± 0.1
2	North-east Indian Ocean	4.13± 0.2
3	South-east Indian Ocean	3.85 ± 0.1
4	Sea off the eastern coast of Australia	3.39 ± 0.1
5	Western tropical Pacific region	4.19 ± 0.3
6	North-west Pacific region	3.59 ± 0.1
	Global mean	3.4 ± 0.3

MAJOR CLIMATE DRIVERS

There are many modes of natural variability, often referred to as climate patterns or climate modes, which affect weather at timescales ranging from days to months, or even decades. The most relevant patterns for Asia include the El Niño–Southern Oscillation, the Indian Ocean Dipole and the Asian Monsoon. Their variations are described below.

EL NIÑO–SOUTHERN OSCILLATION

The continuing La Niña from 2020 through 2022 induced significant influence on precipitation in parts of Asia. Typically, La Niña is associated with above-normal rainfall over South Asia during the summer monsoon season.[24] India and Pakistan had above-normal rainfall in 2022; this was also the case in 2021.[25] In particular, Pakistan experienced devastating flooding associated with extreme precipitation in July and August 2022 (see Extreme events for additional details).

INDIAN OCEAN DIPOLE

The Indian Ocean Dipole (IOD) is an inherent and major mode of climate variability over the Indian Ocean. A negative IOD phase is characterized, on the one hand, by above-normal SSTs and enhanced convection in the south-eastern part of the tropical Indian Ocean, and on the other hand, by below-normal SSTs in the western part. A positive phase has the opposite SST pattern. A negative IOD developed during June 2022 and returned within the neutral range by the end of the year. In association with this negative IOD, the centre of convective activities was shifted southward, and convection and the associated rainfall was reduced over the north Bay of Bengal region.

ASIAN MONSOON

The Asian summer monsoon is one of the world's prominent monsoon systems. It is also a key driver of the seasonal changes in atmospheric circulation and precipitation (dry and wet seasons) over several countries in South and East Asia. Precipitation associated with the Asian summer monsoon is a key source of fresh water in those regions.

In 2022, the East Asia summer monsoon was weaker than normal. The Meiyu/Baiu/Changma[26] season started and ended earlier than the 1991–2020 normal, and rainfall over the Korean Peninsula during the monsoon season was significantly reduced.

The onset of the Indian summer monsoon was earlier and the withdrawal later than normal in 2022. It extended further westward than usual towards the lower course of the Indus, and the largest precipitation anomalies were recorded in the southern parts of Pakistan. This helped maintain monsoon low pressure systems, which formed over the Bay of Bengal and moved to the Sindh and Balochistan provinces of Pakistan. These conditions led to heavy precipitation with high impacts on the population (see Heavy precipitation and flooding). Except for the eastern Himalayas and the Ganges Valley, the Indian summer monsoon brought more rain than usual over the peninsular and central Indian regions. The Indian summer monsoon seasonal rainfall (ISMR) averaged over India as a whole was 106% of its climatological normal for the 1971–2020 period (Figure 14).

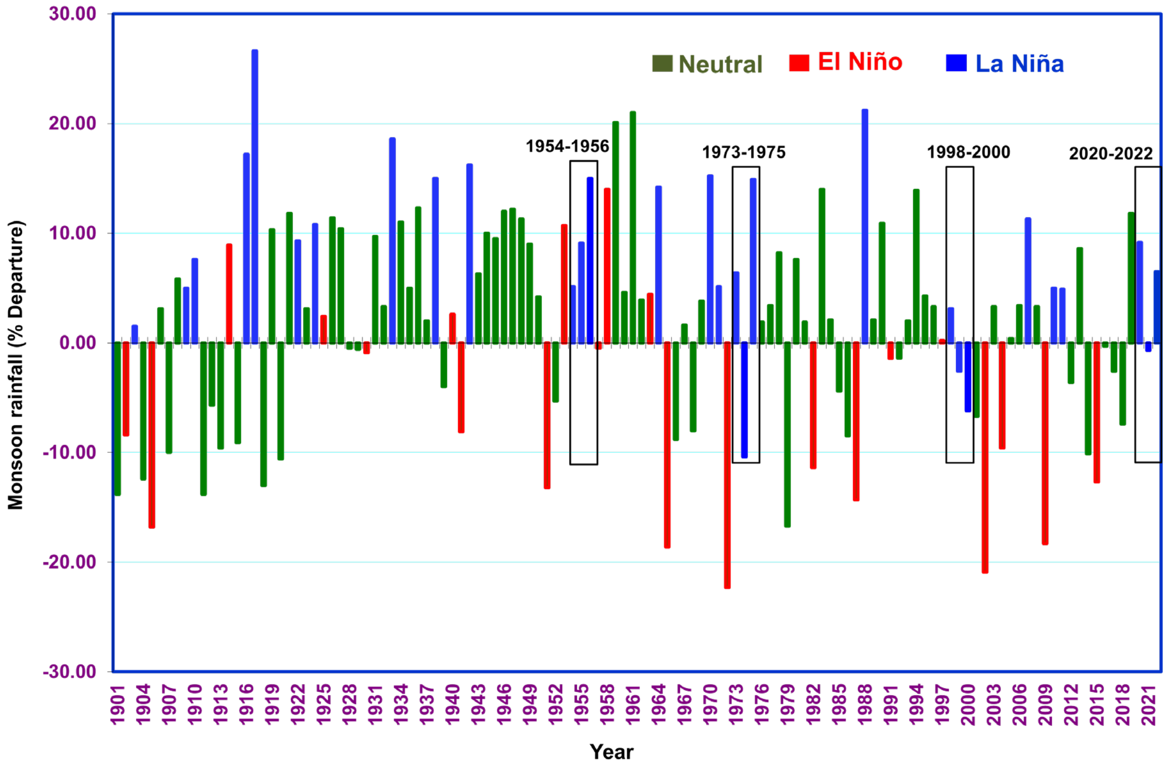


Figure 14. Time series of area-weighted rainfall anomalies over India (representative of South Asia) in the summer monsoon season (June to September) for the period 1901–2022. The red, blue and green colours indicate years with El Niño, La Niña and neutral events, respectively. The black rectangles indicate triple dip La Niña events. Anomalies are defined as a departure from the 1971–2020 average.
Source: WMO Regional Climate Centre (RCC), Pune, India

Extreme events

TROPICAL CYCLONES

WESTERN NORTH PACIFIC OCEAN AND SOUTH CHINA SEA

In 2022, a total of 25 named tropical cyclones (TCs) with maximum sustained wind speeds of ≥ 34 knots formed over the western North Pacific Ocean and the South China Sea;[27] this was almost the same as the 1991–2020 average.[28]

The strongest TC of the year, Typhoon *Nanmadol*, made landfall in the Kyushu region of Japan on 18 September. Record breaking maximum wind speeds were observed at eight stations, and record high 24-hour rainfall was observed at 13 stations. *Nanmadol* triggered evacuation orders for approximately four million people. After making landfall, it moved northward, passing through the western part of Honshu Island, causing damage to houses and injuries as it weakened to a tropical depression and dissipated in the north Pacific Ocean. Typhoon *Nanmadol* was reported to be associated with five deaths, to have affected over 1 300 people and to have caused an estimated more than US$ 2 billion in economic damages.[29]

Typhoon *Noru* formed to the east of the Philippines, crossed Luzon Island, re-intensified in the South China Sea and made landfall in Viet Nam on 27 September, bringing heavy rain and causing flooding and landslides in Viet Nam, Lao People's Democratic Republic and Thailand. In Viet Nam, in particular, heavy rainfall (a total of approximately 300 mm–600 mm) was recorded in Nghe An and Ha Tinh provinces from 28 to 30 September, with 605 mm in Quynh Luu, causing serious flooding in low-lying areas and along river areas in the Quynh Luu, Thanh Chuong, and Hung Nguyen districts of Nghe An. Flooding induced by Typhoon *Noru* affected more than 11 000 hectares of rice crops, and killed or swept away about 155 000 cattle and poultry in Viet Nam.[30]

NORTH INDIAN OCEAN

During 2022, three tropical cyclones (with maximum sustained wind speeds of ≥ 34 knots) formed over the North Indian Ocean. All three systems formed over the Bay of Bengal. Among them, Severe Cyclonic Storm Mandous, which formed during the pre-monsoon season, crossed the north Tamil Nadu, Puducherry and adjoining south Andhra Pradesh coasts on 9 December as a cyclonic storm, claiming six lives. In addition, Cyclonic Storm Sitrang (22–25 October) caused heavy rainfall in Bangladesh, leading to severe floods in the region. Rainfall reports across a large swath of the country ranged from 200 mm to 400 mm in just 48 hours. In total, 15 cyclonic disturbances (wind speed greater than 27 knots) formed over the north Indian Ocean in 2022, compared to the 1965–2021 average of 11.

HEAVY PRECIPITATION AND FLOODING

During the 2022 monsoon season, from June to September, Pakistan experienced severe flooding that was associated with significant loss of life and economic damage. The extreme precipitation in the 2022 monsoon season was much higher than the precipitation in the 2010 monsoon season, during which Pakistan suffered significant damage in association with exceptional rainfall and floods. Pakistan received 60% of normal total monsoon rainfall within just three weeks of the start of the 2022 monsoon season, and the heavy rains resulted in urban and flash floods, landslides, and glacial lake outburst floods across the country. According to the National Disaster Management Authority (NDMA), more than 33 million people, almost 14% of the population, were affected; over 1 730 people died and almost eight million people were displaced. In addition to its direct impact on the population, the flooding caused widespread damage to critical infrastructure, houses, and livestock. Rural communities were severely hit by the devastating floods of June–August 2022. The flooding wiped out 1.7 million hectares of agricultural land and 800 000 heads of livestock, pushing millions of rural households into poverty and food insecurity.[31] It remains a serious concern that many of the people displaced by the floods have relocated to places with no infrastructure, no shelter and residing on elevated areas surrounded by flood waters.[32]

In India, heavy rainfall lasting from May to September triggered multiple landslides and river overflows and floods, resulting in casualties and damage. Heavy monsoon rains in particular affected the north-eastern parts of India and Bangladesh.[33] Cumulatively, this flooding caused over 2 000 deaths and affected 1.3 million people, and this disaster event caused the highest number of casualties of any disaster event in 2022 in India.[34]

Flood events were also reported in Afghanistan (in late August 2022). A surge in atypical floods during the summer season (June–August) devastated the eastern part of the country; more than half of the flooding incidents and more than a third of the affected families were recorded in eastern Afghanistan.[35] Cumulatively, these flood events were associated with 180 deaths and affected over 18 000 people.

Flood events were also reported in Bangladesh (June and July), Sri Lanka (early August), and the Islamic Republic of Iran (late July to early August).

The eastern part of Asia also witnessed flood events associated with heavy rainfall during the summer. Heavy rainfall from 9 to 20 July caused floods of the Yana River in the Russian Federation Republic of Sakha (Yakutia). Six heavy rainfall systems affected southern China consecutively from 21 May to 21 June, and daily rainfall records for the same period were broken in 35 counties or cities in the Guangdong and Guangxi provinces. The average rainfall over the Pearl River Basin reached 440 mm, the second largest total for this period since 1961, leading to two consecutive large basin floods and more than 45 rivers passing the warning criteria (see Impact on the economy). In addition to floods and river overflows, the torrential rain affecting southern China in May also triggered landslides, resulting in casualties and widespread damage, particularly in the Guangdong and Fujian provinces.[36] These flood events were associated with 48 deaths and over US$ 5 billion in economic damages (see Heavy precipitation and flooding).[37] Tam Dao station, in Viet Nam, observed an unusually high monthly rainfall total in May 2022 of 1 140 mm; this was about 2.6 times higher than the previous historical record for May, 435 mm, observed in 2012.

DROUGHTS

In the summer of 2022, the Yangtze River Basin (south-west China) experienced the worst drought in the last six decades, and agricultural drought affected both China and Mongolia. From July to the first half of November, the middle and lower reaches of the Yangtze River valley, as well as Sichuan and Chongqing, suffered continuous high temperatures and received little rainfall, leading to continuous drought in the summer and autumn (see Impact on the economy). The number of days of moderate drought was 77, the highest number since 1961. On 27 September, the area of the main body of Poyang Lake decreased to a record low of 638 km^2. An intense and long-lasting heatwave in central-eastern China combined with a moderate precipitation deficit led to a severe drought in the Yangtze River Basin, which is one of the major river basins in the world and home to one third of China’s population. Between August and September, the Yangtze River flow was about 50% below the average for the previous five years; this severe deficit had impacts on energy production and inland shipping. Crops and vegetation, as well as the drinking water supply, were affected. The Yangtze River is an important water supply; it is used for energy production, transportation, and crop irrigation, and the Three Gorges Dam, the largest hydropower plant in the world, is also located along this river.[38] The estimated economic losses from the drought affecting many regions in China in 2022 were over US$ 7.6 billion.[39]

The Islamic Republic of Iran experienced severe precipitation shortages in the main rainfall seasons of 2022, and the resultant severe drought caused significant damage to the agriculture sector and reduced levels in the main water reservoirs of the country. 2022 was the third consecutive year of drought in the Islamic Republic of Iran and exacerbated the decrease in the surface area of Lake Urmia, which has shrunk by 95% over the past three decades.

HEATWAVES AND WILDFIRES

Many parts of the region experienced heat events in 2022. India and Pakistan experienced abnormally warm conditions in the pre-monsoon season (March–May). A daily maximum temperature of 49.0 °C was observed on 30 April in Jacobabad, Pakistan. The monthly mean temperatures in Pakistan for March and April were the highest on record since 1961 and were, respectively, 4.26 °C and 4.05 °C above normal. Kazakhstan also experienced nationwide heatwaves, in the western part of the country in February and in the eastern part in April and May. In the period from 11 to 19 April, the greatest anomalies, from 8 °C to 14 °C, were observed.

East Asia experienced extremely hot conditions in the summer. From 13 June to 20 August, 361 stations in central and eastern China recorded the highest daily maximum temperatures on record; these regions experienced a continuous heatwave for 79 days, the longest since 1961. In Hong Kong, China, with a record-breaking mean temperature of 30.3 °C, July 2022 was the hottest month since records began in 1884. In Japan, the highest temperatures since 1946 were recorded in the western and eastern parts of the country for late June (3.2 °C and 4.0 °C above normal, respectively), and in the northern part of the country for early July (3.2 °C above normal). The number of people hospitalized/treated for heat stroke in Japan in June, 15 000, was the highest for that month since 2010; in July, the number was over 27 000, the second highest for that month since 2008. The high-pressure system that brought high temperatures to Japan also affected the Republic of Korea, where the mean temperature from late June to early July, 26.4 °C, was the highest on record since 1973, and 3.5 °C above normal for that period.

Prolonged dry and hot conditions caused intense and extensive forest fires in Siberia, especially in the Krasnoyarsk region (where, by the end of the summer, approximately 1 200 fires had burned about 183 000 hectares in total).

MARINE HEATWAVES

Analogous to heatwaves on land, marine heatwaves (MHWs) are prolonged periods of extreme heat that affect the ocean. They can have a range of consequences for marine life and dependent communities and have become more frequent in the twentieth and twenty-first centuries. Satellite retrievals of SSTs are used to monitor MHWs. MHWs are categorized as moderate when the SST is above the 90th percentile of the climatological distribution for five days or longer; the subsequent categories, strong, severe and extreme, are defined with respect to the difference between the SST and the climatological distribution average. An MHW is strong if that difference is more than two times the difference between the 90th percentile and the climatological distribution average, severe if it is more than three times that difference, and extreme if it is more than four times that difference.[40]

In 2022, the most prominent and persistent severe to extreme marine heatwaves occurred in a large area including the Sea of Okhotsk, the Bering Sea and the Pacific area around 60°N of the region and lasted three to five months (Figure 15).

OTHER EXTREME EVENTS

Throughout 2022, a large part of arid Asia experienced severe dust storms. On 22 January, plumes of dust streamed from Oman, Pakistan, and the Islamic Republic of Iran, with especially thick plumes near Pakistan's coast. Visibility in Karachi, Pakistan fell to about 500 meters. In April and May, several severe dust storm events affected western Asia. Due to the event in April, airports, schools, and government offices closed in Iraq, and states of emergency were declared. On 16 and 23 May, two intense dust storms occurred over Iraq, and thousands of people were hospitalized. These dust fronts propagated downstream into the south-eastern Arabian Peninsula; north-westerly winds carried vast amounts of dust across Saudi Arabia,

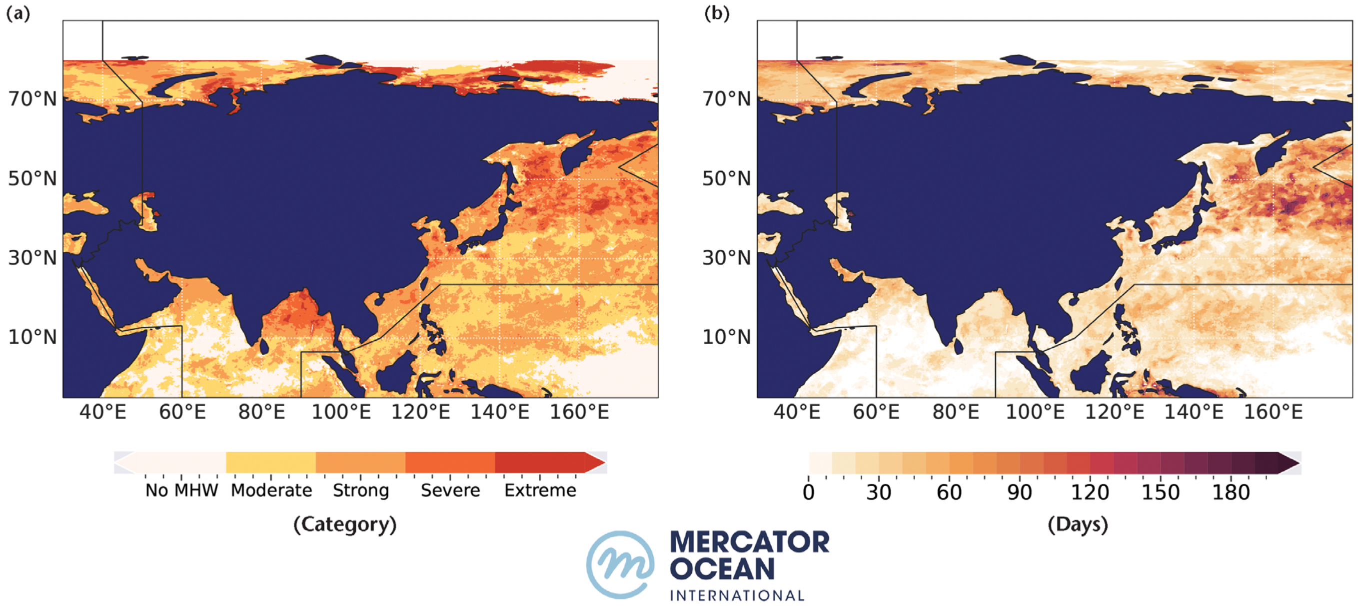


Figure 15. Maximum categories of marine heatwaves and their maximum duration in 2022
Source: Mercator Ocean International, France. Derived from the remote sensing product Global Ocean OSTIA Sea Surface Temperature and Sea Ice Reprocessed for 1982–2021 and Global Ocean OSTIA Sea Surface Temperature and Sea Ice Analysis for 2022, downloaded from the Copernicus Marine Service.

Kuwait, Bahrain, and Qatar, finally reaching United Arab Emirates. On 12 December, waves of sand and dust streamed over northern China, degrading the air quality in several cities. Airborne particulate matter from the storm created hazardous air conditions in Beijing and the surrounding areas. The IPCC AR6 report estimates that there is low confidence in the direction of change in sand and dust storms in Asia, although this does not indicate that sand and dust storms will not be affected by climate change.

The mountain regions of Pakistan are prone to frequent glacier lake outburst floods (GLOFs), snowmelt flooding and flash flooding since Pakistan is home to about 7 000 glaciers and over 3 000 glacial lakes, of which 36 were recently considered to be at high risk for outburst. In 2022, Pakistan experienced a major GLOF event regarding Shishper glacier when one of its lakes surged significantly, triggering a discharge of close to 300 m^3/s on 7 and 8 May 2022. This GLOF event, which followed events of a smaller magnitude concerning the same lake in 2019, 2020, and 2021, had widespread impacts, causing significant destruction to homes in downstream villages, to irrigation systems and agricultural lands, and to highways and bridges (Figure 16 left). This was a major event, but it was not unique in the area; northern Pakistan experienced a number of GLOFs of varying magnitudes in 2022 (Figure 16 right).

Lightning is a major hazard that claims many lives every year. It is measured by distance and duration, and WMO's Committee on Weather and Climate Extremes, which maintains official records of global, hemispheric and regional extremes, recognized new records regarding both lightening parameters last year.[41] The findings highlight that flashes can travel extremely large distances. In India, in recent years, lightning accompanied by thunderstorms has been one of the biggest killers. In 2022, thunderstorms and lightning claimed around 1 200 lives in different parts of the country. On 19–20 May, more than 34 people were killed in lightning strikes in Bihar.

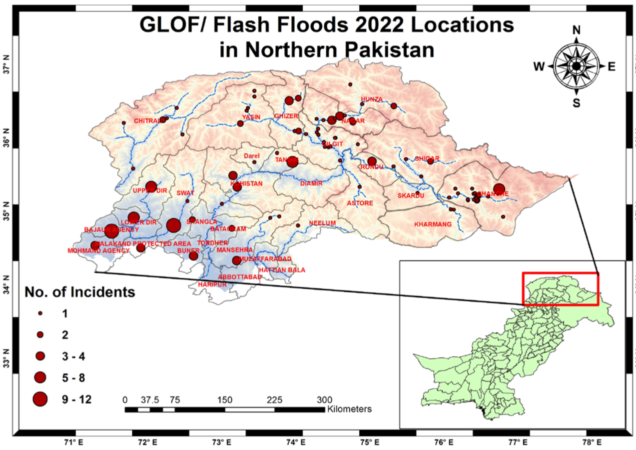


Figure 16. Left: Damage due to a major GLOF event regarding Shishper glacier on the infrastructure in Pakistan in May. Right: GLOF events observed in northern Pakistan in 2022.
Source: Pakistan Meteorological Department

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 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) that together provide the information necessary to understand, model and predict the trajectory of the climate as well as plan mitigation and adaptation strategies (Figure 17). The status of the observational basis for these ECVs is published in regular status reports. GCOS also identifies in implementation reports what is needed to improve the system.

In 2022, GCOS released its latest Implementation Plan[42] in response to the findings of the 2021 GCOS Status Report, to the implications arising from the IPCC Sixth Assessment Report and to recent scientific studies on the climate cycles. The publication provides recommendations for a sustained and fit-for-purpose Global Climate Observing System.

In addition to observations provided by the GCOS-coordinated Global Surface Network (GSN) and Global Upper-Air Network (GUAN), National Meteorological and Hydrological Services (NMHSs) of WMO Members provide a more comprehensive and widespread network of observations, acquired primarily for operational weather prediction. The WMO Global Basic Observing Network (GBON), a globally-designed network with prescribed capabilities and observing schedules, and for which international data exchange is mandatory, will provide critically needed observations for numerical weather prediction and will help substantially strengthen climate reanalysis.

In order to provide the necessary financial and technical assistance for the implementation and operation of GBON in the poorest and most poorly observed areas of the globe, WMO, the United Nations Development Programme (UNDP) and UNEP have established the Systematic Observations Financing Facility (SOFF). SOFF has raised significant funds for supporting observations in least developed countries and small island developing States and commenced its implementation phase in 2023.

Complementing the observations of the physical and dynamic properties of the atmosphere, the WMO Global Atmospheric Watch (GAW) coordinates atmospheric composition measurements, ensuring that reliable and accurate data are obtained from measurements made by WMO Members, research institutions and/or agencies and other contributing networks.

Observations of ocean physics, biogeochemistry, biology and ecosystems are coordinated through the Global Ocean Observing System (GOOS). The GOOS Observations Coordination Group (OCG) monitors the performance of these observations[43] and produces an annual Ocean Observing System Report Card. Ocean observations are generally made widely available to international users.

In the terrestrial domain, there is a wider group of observing networks. Hydrological observations are generally operated by NMHSs and coordinated through WMO. A number of specialized Global Terrestrial Networks (GTNs), for example, on hydrology (including lakes and rivers), permafrost, glaciers, land use, and biomass, also contribute to GCOS. Data exchange agreements are generally less developed for the terrestrial networks, and many important observations are not made available to international users.

The Committee on Earth Observation Satellites/Coordination Group for Meteorological Satellites (CEOS/CGMS) Joint Working Group on Climate (WGClimate) bases the development of satellite observations for climate on the ECV requirements established by GCOS. It has produced an ECV Inventory that includes records for 766 climate data records for 33 ECVs covering 72 separate ECV products, with more planned. WGClimate is also working on actions arising from the Implementation Plan. Satellite observations have near-global coverage. Used with ground-based observations, either as complementary data sets, or for validation and calibration, they form an invaluable part of the global observing system.

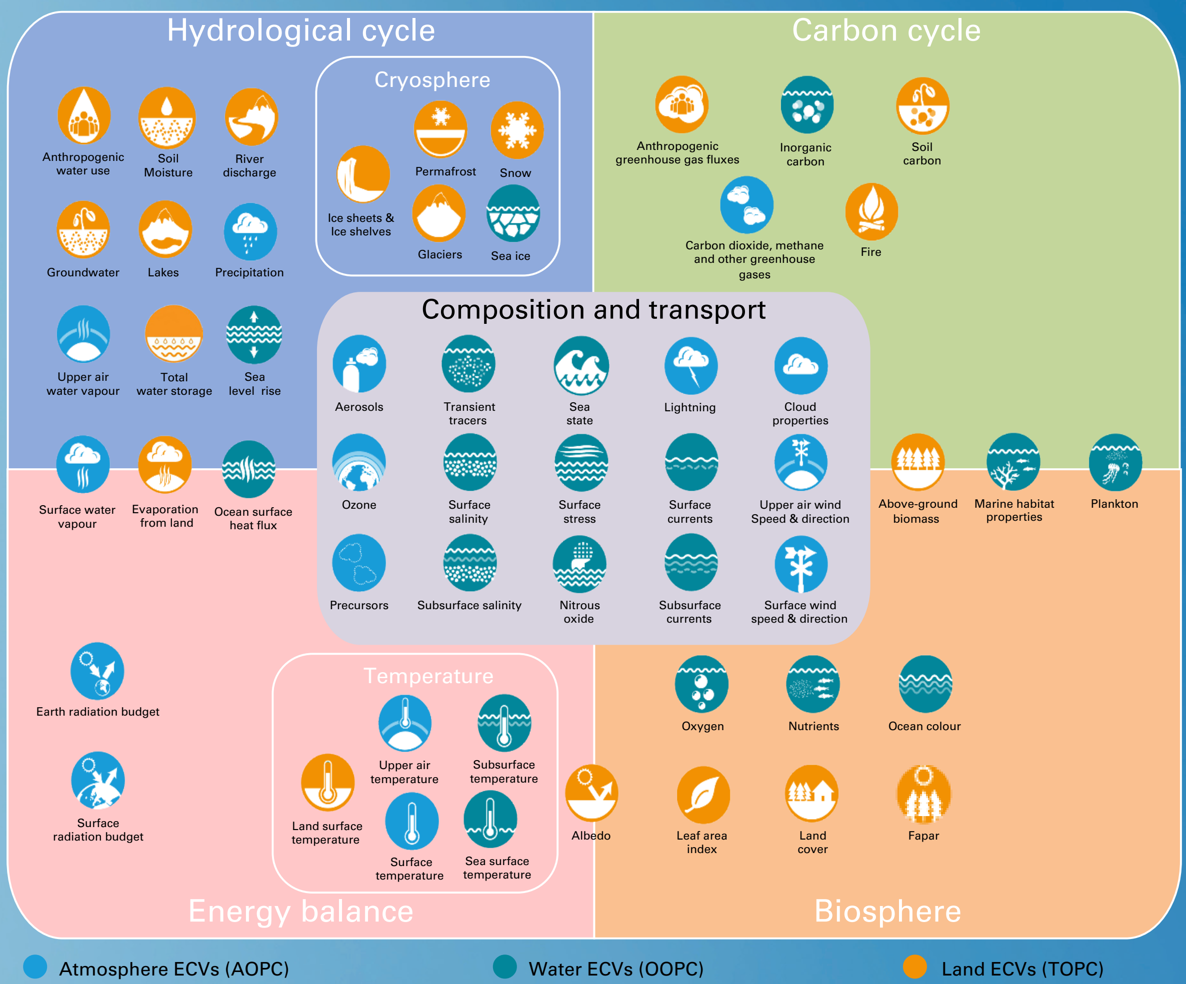


Figure 17. ECVs identified by GCOS and the climate cycles. Many ECVs contribute to understanding several different cycles – this figure only indicates the main links.

Climate-related impacts and risks

MORTALITY AND AFFECTED POPULATION

In 2022, a total of 81 natural hazard events were reported in Asia according to the Emergency Events Database (EM-DAT);[44] of these, over 83% were flood and storm events. These reported natural hazard events resulted in over 5 000 fatalities, of which over 90% were associated with flooding. Overall, more than 50 million people were directly affected by these disaster events, causing a total of over US$ 36 billion in economic damages. Floods were the leading cause of death, people affected, and economic damage in 2022 by a substantial margin. After floods, drought affected the largest number of people and caused the most economic damage during 2022 (Figure 18). In India and Pakistan, floods were the natural hazard event which caused the greatest number of fatalities, highlighting the continuing high level of vulnerability of Asia to natural hazard events, especially floods.

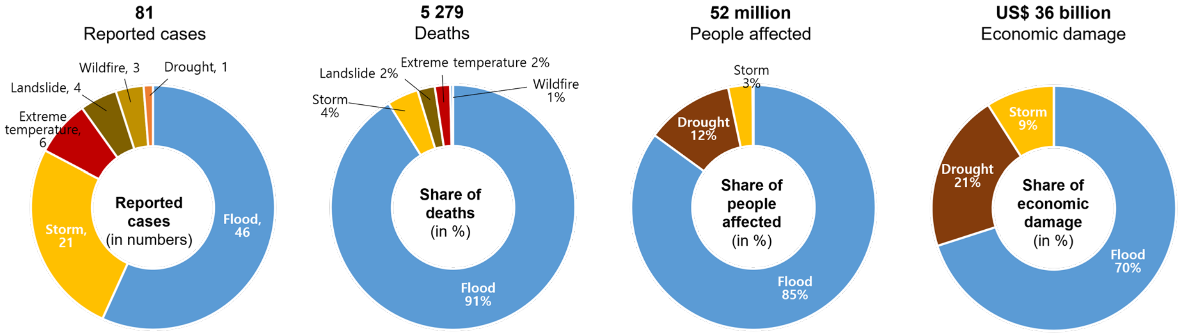


Figure 18. Overview of 2022 disasters in the Asia region.
Source: Economic and Social Commission for Asia and the Pacific (ESCAP); EM-DAT. ESCAP calculations are based on data from EM-DAT, accessed on 14 February 2023.
Note. The economic damages of some disaster occurrences are not presented in the figure due to data unavailability. In the figure, only cases reported in EM-DAT are considered.

IMPACT ON THE ECONOMY

The economic losses associated with floods in 2022 exceeded the average over the past 20 years (2002–2021). This was due to the significant economic losses from floods in Pakistan (over US$ 15 billion), China (over US$ 5 billion) and India (over US$ 4.2 billion). The economic losses associated with drought in 2022 (US$ 7.6 billion), which mainly occurred in China, exceeded by nearly 200% the 20-year average from 2002 to 2021 (US$ 2.6 billion). Fortunately, the economic damage was milder for other disasters; in particular, the damage associated with storms in 2022, US$ 3.3 billion, was almost 80% lower than the 2002–2021 average of US$ 16.2 billion (Figure 19).

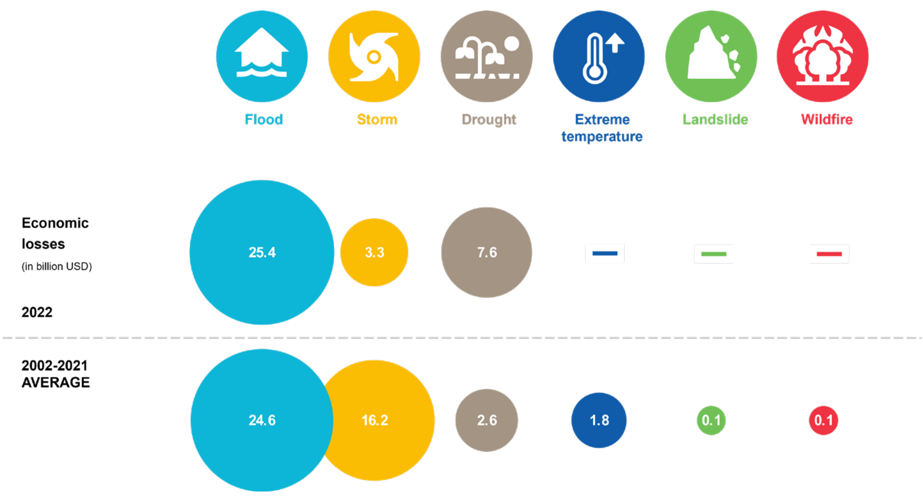


Figure 19. Economic losses in Asia in 2022 from disasters, compared to the 20-year average (2002–2021)
Source: ESCAP calculations based on EM-DAT, accessed on 14 Feb 2023
Note. The economic damages of some disaster occurrences are not presented in the figure due to data unavailability.

FOOD SYSTEM RESILIENCE: THE NECESSITY

In many aspects, 2022 was a year in which disasters compounded underlying socioeconomic vulnerabilities. Resilience to climate and weather-related shocks is often lowest in fragile and conflict-affected areas, and refugee and internally displaced person (IDP) settlements are frequently located in highly exposed areas.[45] In addition, displaced populations often have the fewest resources and the least support to cope with natural disasters. The major natural disasters of 2022 impacted areas in Asia across the development spectrum, from floods in India and Pakistan, to drought in China, to heatwaves in India, Japan and Pakistan.

The agricultural sector continues to bear the brunt of the impacts of disasters; this is especially apparent in countries where agriculture is important to the national economy. The agricultural sector employs over 30% of the labour force in developing countries. Disasters have a direct impact on the livelihoods of millions of small farmers and on rural communities in the Asia region. According to a nationwide house survey conducted in the Lao People's Democratic Republic following a severe flood which affected more than 8 000 hectares of agricultural lands and over 47 900 people, in 15% of households the food consumption was inadequate, 35% of households were applying coping mechanisms to food consumption, and 29% of households were engaging in crisis or emergency livelihood coping strategies.[46] Disasters can also change agricultural trade flows and cause losses in agriculturally dependent manufacturing subsectors such as the textile and food processing industries. The Food and Agriculture Organization of the United Nations (FAO) 2021 assessment report[47] highlights that the agriculture sector absorbed 26% of the overall impact from medium- to large-scale disasters in low- and lower-middle-income countries from 2008 to 2018. For climate-related disasters such as floods, droughts, and tropical storms, more than 25% of all damage and losses is associated with the agriculture sector. Agriculture is the sector most affected by droughts, absorbing on average about 84% of the total economic impact.

Comprehensive risk management is a critical means to making food systems – and agrifood production in particular – more resilient. Risk reduction can protect development investments in agriculture as well as markets and transportation, ecosystems and child and maternal health. The sectors and systems that support and connect food systems and food security are highly interrelated. If risks at the producer level are not effectively managed, this can have cascading effects across all components of the food value chain, potentially leading to overall food system failures. A case in point is the 2022 Pakistan floods (Figure 20),

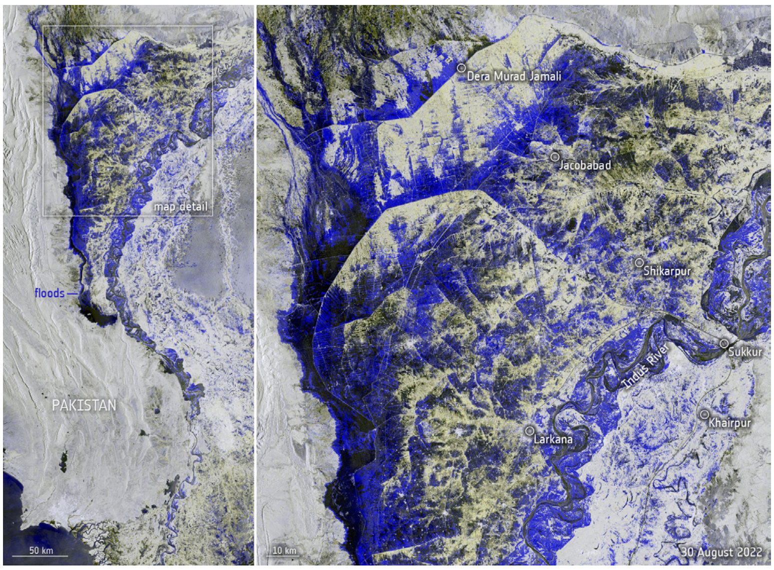


Figure 20. Satellite image of the flooding in Pakistan on 30 August. The image on the left shows a wide view of the affected area. The image on the right zooms into the area between Dera Murad Jamali and Larkana. The blue to black colours show where the land is submerged.
Source: Image from the Copernicus Sentinel-1 satellite, containing modified Copernicus Sentinel data (2022), processed by ESA, CC BY-SA 3.0 IGO. https://www.esa.int/ESA_Multimedia/Images/2022/09/Pakistan_inundated

which struck before the harvesting stage of key crops and caused unprecedented damage to crops, livestock, and entire food systems, posing the risk of an unprecedented food security crisis in the country.

The importance of food system resilience is also emphasized in the Nationally Determined Contributions (NDC) of the parties to the Paris Agreement. As of February 2023, 194 parties, 31 of which are from the Asia region, submitted NDCs, and 26 parties from Asia highlighted agriculture as a priority area for climate adaptation. Agriculture was the most frequently chosen priority area, followed by water and health (Figure 21).

According to the Global Commission on Adaptation, without adaptation, climate change may depress growth in global agriculture yields by up to 30% by 2050.[48] According to Pakistan's NDC, agriculture is the sector most impacted by climate variability and extreme weather events.[49] Globally, as well, few small-scale farmers have coping mechanisms, such as access to resilient crops, drought-proof water supplies and the necessary financing, when disaster strikes.

RESILIENT FOOD SYSTEM: IMPACT-BASED FORECASTING AND ANTICIPATORY ACTIONS

Impact-based forecasting (IBF) involves forecasting "what the weather will do" instead of "what the weather will be." By adding socioeconomic layers (such as age, gender, income level) and exposed assets (such as infrastructure and agricultural production quantity) to hazard layers (such as weather observations and climate projection data), it is possible to identify potential exposure and vulnerability to hazards in advance. For example, in Regional Climate Outlook Forums, such as in the South Asian Climate Outlook Forum (SASCOF) and the Association of South-East Asian Nations Climate Outlook Forum (ASEANCOF), IBF

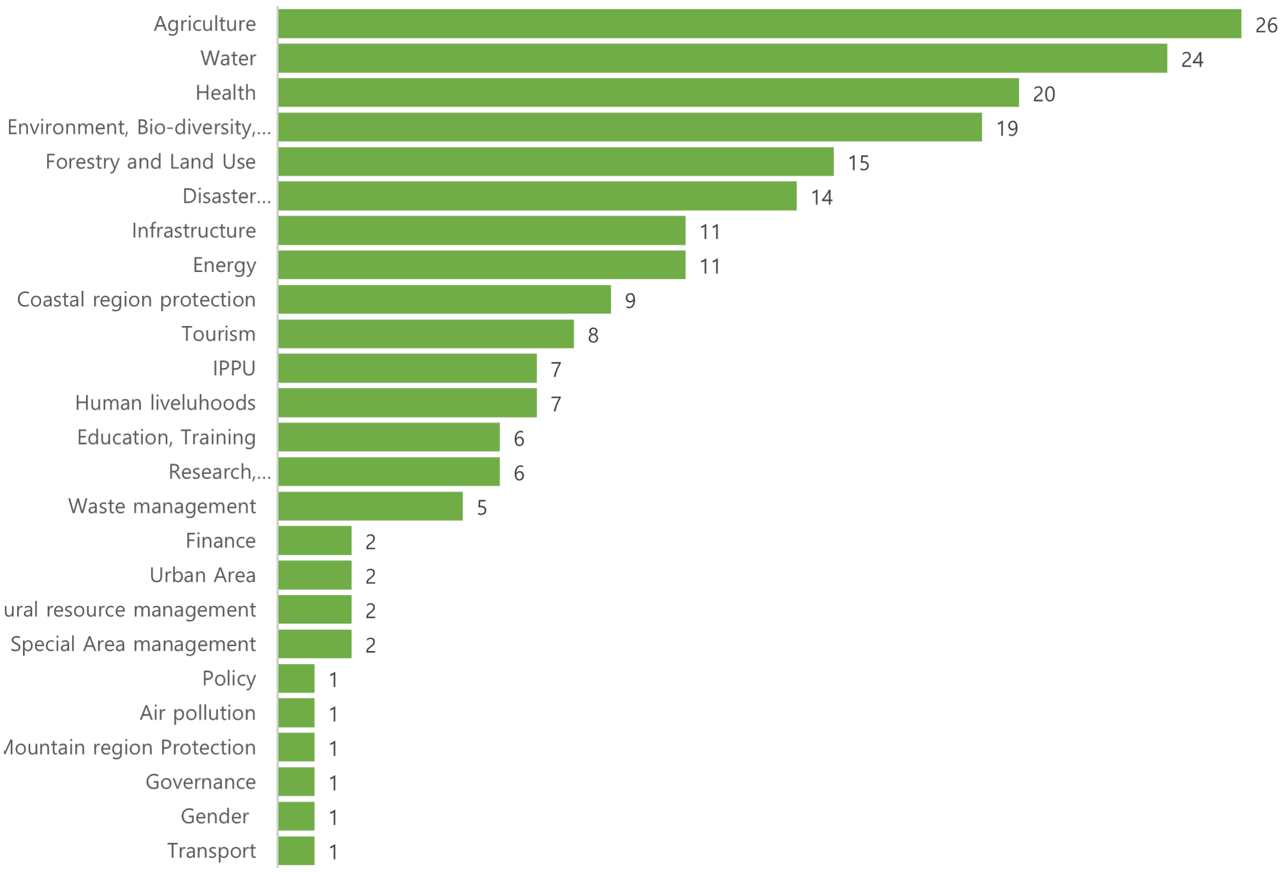


Figure 21. Priority areas for adaptation in the Asia region
Source: NDC registry, United Nations Framework Convention on Climate Change (UNFCCC), accessed on 10 February 2023

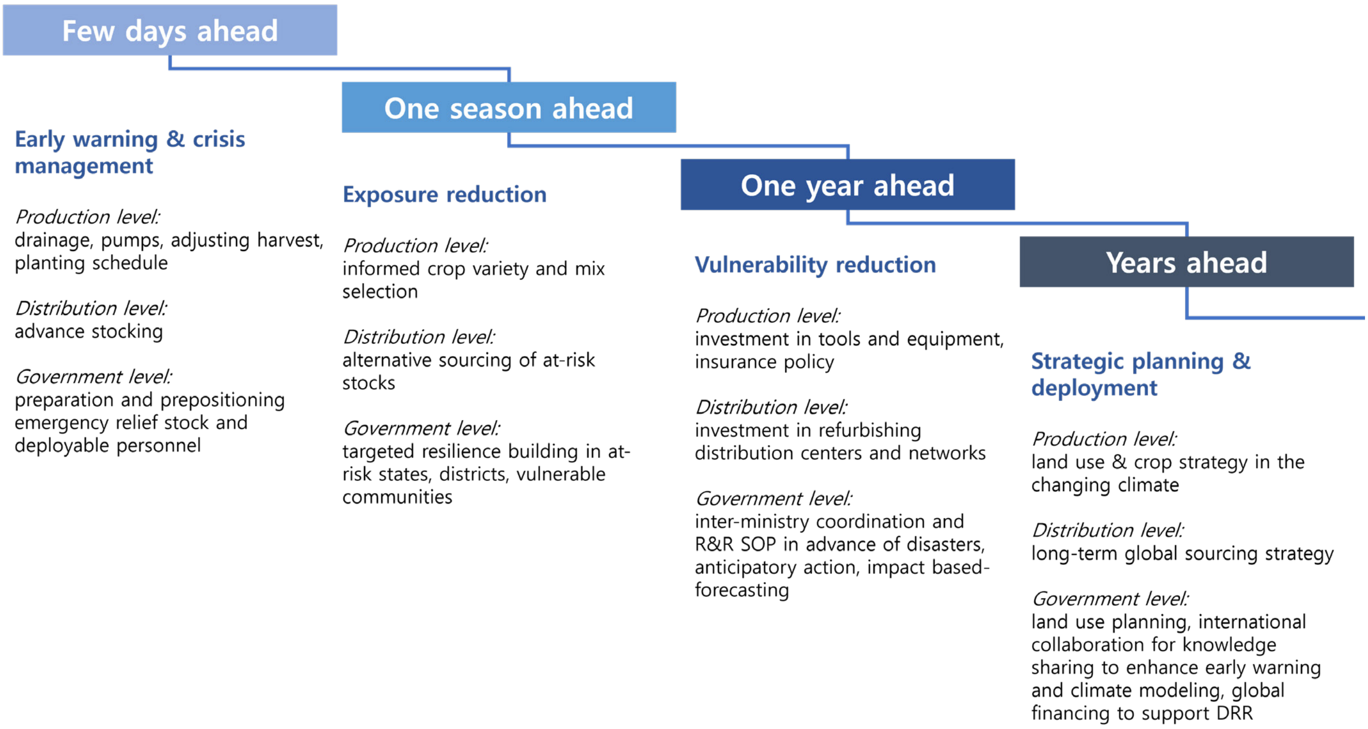


Figure 22. Examples of risk-management policies for food system resilience
Source: ESCAP

is presented using consensus-based seasonal climate information and critical exposure data, such as the vegetation health condition index, to estimate the potential exposure and the risk hotspots for agricultural crops attributable to abnormal precipitation levels. In this regard, IBF has the potential to give sufficient lead time for farmers and other relevant stakeholders (actors in the supply chain and governments) to take adaptation measures such as those presented in Figure 22.

Anticipatory action (AA) is an adaptation method which takes impact-based forecasting to the next level by systematically linking early warnings to early actions carried out before a disaster occurs. In food system resilience, this includes climate-informed food and land use systems planning, early warnings in advance of weather extremes to advise of potential damage to crops, food shocks, and global transport and trade disruptions.[50] AA in the agriculture and food security sectors, with respect to slow onset disasters, such as drought, include commercial animal destocking, animal health interventions, and pre-positioning of emergency relief at the first early warning of the onset of dry conditions. However, some key constraints need to be overcome to ensure the success of the AA; these include an insufficient observation network and forecast skill (precision), in the case of some WMO Members, as well as challenges in relation to access to financing and the lack of clear policy and legal frameworks.

OBSERVATIONS AND FORECASTING: INVESTING IN CLIMATE AND WEATHER SERVICES

Early warnings empower people to make risk-informed decisions and are one of the most effective ways of reducing damage from disasters. It is estimated that early warning systems provide more than a tenfold return on investment,[51] and a dependable multi-hazard early warning system (MHEWS) is the backbone of a comprehensive risk-management programme. Unfortunately, the hydrological and meteorological infrastructure, which is a key component in the early warning information value chain, is costly and underfunded, especially in developing countries.

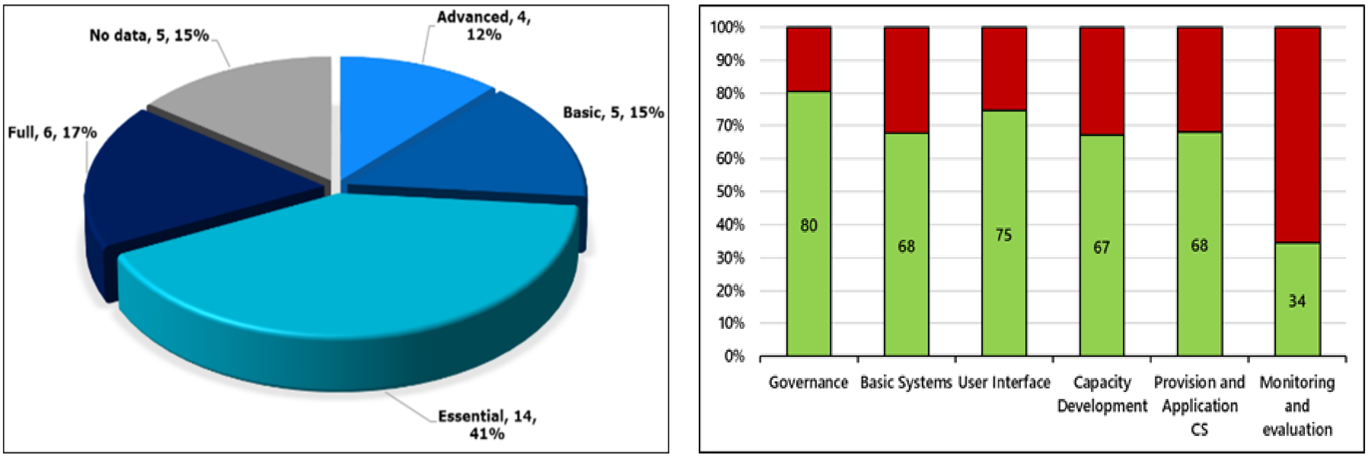


Figure 23. Left: Number/percentage of WMO Members in Asia with the capacity to provide basic, essential, full, and advanced climate services. Right: Overview of climate services by value chain component – the percentages of functionalities satisfied in the value chain components based on data from WMO Regional Association II.
Source: WMO Climate service checklist data as of February 2023

According to data from NMHSs collected by WMO, only 12% of WMO Members in the Asia region indicated that they provide climate services at an advanced level, while the largest number (41%) indicated that they provide climate services at an essential level[52] (Figure 23, left). Furthermore, monitoring and evaluation of the socioeconomic outcomes and benefits associated with climate services, capacity development and basic systems components need to be strengthened in the region, as can be seen in Figure 23, right.

With respect to sector-specific information, 77% of WMO Members in the region reported providing climate services for the agriculture and food security sectors; however, only 47% reported providing climate projections and tailored products for those sectors (Figure 24).

There are numerous existing initiatives at the international and regional levels that aim to increase the capacity of climate and weather services. At the regional level, Regional Climate Outlook Forums, such as ASEANCOF and SASCOF, bring together climate experts and sector representatives to produce consensus-based forecasts and build mutual understanding between climate service providers and beneficiaries.

Climate monitoring and predictions on multiple timescales, including climate watches and seasonal forecasts, can help with decisions, such as which variety of crops to plant and when, how much water will be needed for irrigation, whether any disease outbreaks are likely to occur, or whether to reduce the number of livestock in case of drought. Highly variable seasonal rainfall, increasing temperature trends

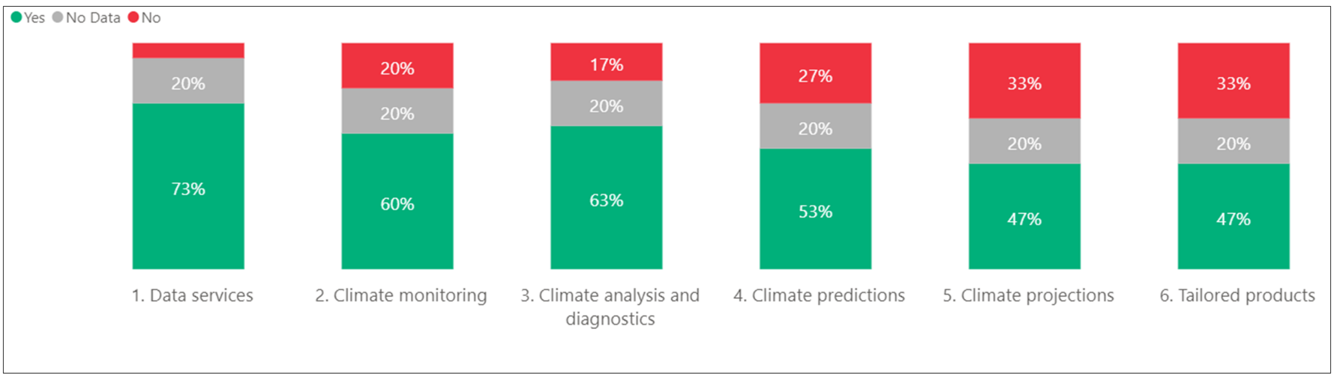


Figure 24. Percentage of NMHSs providing the above services for the agriculture and food security sectors
Source: WMO Climate services dashboard, 2023

and extreme climate events due to climate change, together with the growing demand for food and energy make food system resilience increasingly more challenging. In this context, there is a growing need for early warnings and improved climate services.

WMO and the United Nations Office for Disaster Risk Reduction (UNDRR) are co-leading the Early Warnings for All initiative to ensure that everyone on Earth is protected by early warnings in the next five years. The Early Warnings for All Executive Action Plan[53] was launched by United Nations Secretary-General António Guterres at the COP27 climate change conference in Sharm-El-Sheikh, Egypt in November 2022. To ensure the mainstreaming of this initiative in Asia, ministers, heads of NMHSs from 24 countries, and key regional partners issued a high-level declaration at the Regional Association II regional conference (RA II RECO 2023), held at Abu Dhabi in March 2023, which includes strong recommendations to advance the four key MHEWS pillars: risk knowledge and management; observations and forecasting; dissemination and communication; and preparedness and response.

Data sets and methods

REGION DOMAIN

The focus of this report is WMO Region II, the extent of which can be seen on the map in Figure 25.[54,55]

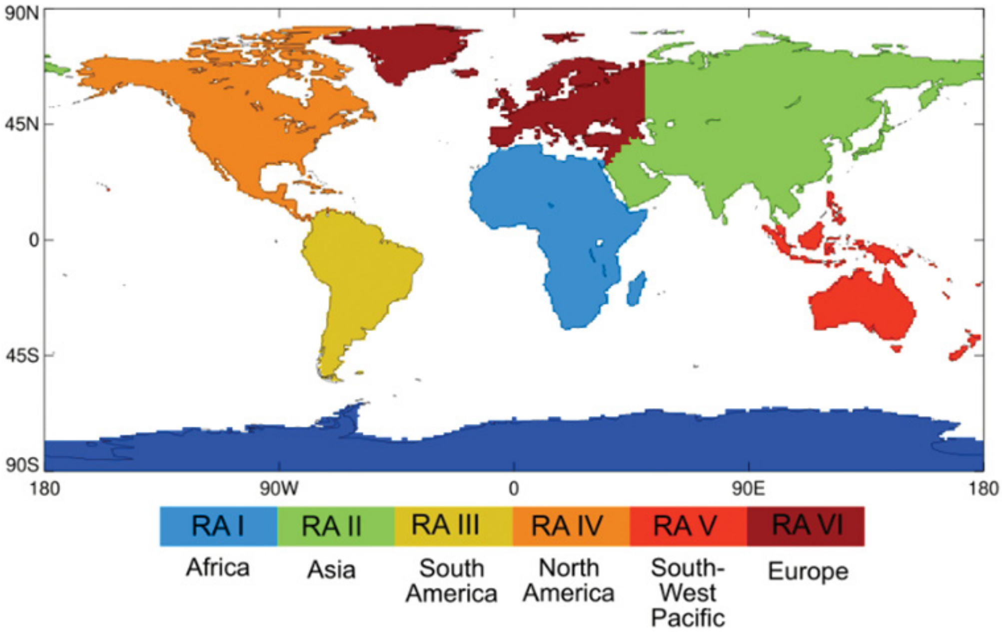


Figure 25. Map of WMO Regional Association (RA) areas. WMO Region II is the focus of the present report.

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 1991–2020 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, 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 over land 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:

Berkeley Earth – Rohde, R. A.; Hausfather, Z. The Berkeley Earth Land/Ocean Temperature Record. *Earth System Science Data* **2020**, *12* (4), 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. The ERA5 Global Reanalysis. *Quarterly Journal of the Royal Meteorological Society* **2020**, *146* (730), 1999–2049. https://doi.org/10.1002/qj.3803. The data are available here.

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* (1), 5–48. https://doi.org/10.2151/jmsj.2015-001. The data are available here.

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* (12), 6307–6326. https://doi.org/10.1029/2018JD029522. The data are available here.

HadCRUT.5.0.1.0 – Morice, C. P., Kennedy, J. J., Rayner, N. A., Winn, J. P., Hogan, E., Killick, R. E., et al. (2021). An Updated Assessment of Near-Surface Temperature Change From 1850: The HadCRUT5 Data Set. *Journal of Geophysical Research: Atmospheres* **2021**, *126* (3), e2019JD032361. https://doi.org/10.1029/2019JD032361. HadCRUT.5.0.1.0 data were obtained from http://www.metoffice.gov.uk/hadobs/hadcrut5 on 9 March 2023 and are © British Crown Copyright, Met Office 2023, provided under an Open Government License, http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.

NOAAGlobalTemp v5 – Zhang, H.-M.; Huang, B.; Lawrimore, J.et al. NOAA Global Surface Temperature Dataset (NOAAGlobalTemp), Version 5.0. *NOAA National Centers for Environmental Information*. doi:10.7289/V5FN144H. Huang, B.; Menne, M. J.; Boyer, T. et al. Uncertainty Estimates for Sea Surface Temperature and Land Surface Air Temperature in NOAAGlobalTemp Version 5. *Journal of Climate* **2020**, *33* (4), 1351–1379. https://journals.ametsoc.org/view/journals/clim/33/4/jcli-d-19-0395.1.xml. The data are available here.

PRECIPITATION

Regional time series analyses of the area-mean annual precipitation totals are from the Global Precipitation Climatology Centre (GPCC). Regional precipitation anomalies are expressed relative to the 1991–2020 average. Schneider, U.; Becker, A.; Finger, P. et al. GPCC Monitoring Product: Near Real-Time Monthly Land-Surface Precipitation from Rain-Gauges Based on SYNOP and CLIMAT Data; Global Precipitation Climatology Centre (GPCC), 2020. https://opendata.dwd.de/climate_environment/GPCC/html/gpcc_monitoring_v2022_doi_download.html.

SEA ICE

In the present report, the estimation of sea-ice extent is based on an analysis of blended Arctic ice charts from the Arctic and Antarctic Research Institute (Russian Federation), the Canadian Ice Service (Canada) and the U.S. National Ice Center (United States of America), using passive microwave estimates (SMMR, SSM/I and SSMIS) from the National Snow and Ice Data Center.

GLACIERS

Data are from the World Glacier Monitoring Service (WGMS) and the Chinese Academy of Sciences (CAS).

PERMAFROST

Data are from measurements from the Russian Federal Service for Hydrometeorology (Roshydromet) within the Circumpolar Active Layer Monitoring Program.

SNOW COVER

The Interactive Multisensor Snow and Ice Mapping System and data from the National Snow and Ice Data Center are used. To derive the monthly snow cover extent (SCE) anomalies for each grid, the number of monthly snow cover days is divided by the total number of days in that month and then multiplied by the area of the grid. Spatially, the mean SCE in spring for each grid is the average of the SCE in March, April and May for the grid in question. The area-averaged SCE over Asia is obtained by averaging the SCE of all the grids within the area bounded by the red line in Figure 10.

SEA-SURFACE TEMPERATURE

Data are from the remote sensing product 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.

OCEAN HEAT CONTENT

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 LEVEL

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

Meteorological characteristics and statistics are based on reports from WMO Members in Regional Association II (Asia), Regional Climate Centres and Regional Specialized Meteorological Centres in the region. 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 NDCs;

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).

WMO Climate services dashboard

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FAO, LEGOS, Mercator Ocean International, ESCAP, ESCWA, UNHCR, UN Migration, WFP, WMO

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Endnotes

1 Data are from the following data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, JRA-55 and ERA5. For details regarding these data sets see Data sets and methods in *State of the Global Climate 2022* (WMO-No. 1316).

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