State of the Climate in Europe

2021

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

PROGRAMME OF THE EUROPEAN UNION

Copernicus
Europe's eyes on Earth

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WMO-No. 1304

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WMO-No. 1304

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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 978-92-63-11304-7

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Key messages

Temperatures in Europe have warmed significantly over the 1991–2021 period, at an average rate of about +0.5 °C per decade. It is the fastest warming of all the WMO Regions. The annual mean temperature in 2021 ranked between sixth and tenth highest on record, depending on the data set used.

While precipitation in 2021 overall was slightly above normal in Central and Eastern Europe, it still was insufficient to compensate for deficits from the previous three years. In other areas such as the Iberian Peninsula and the Alpine region, it was the second or third consecutive drier-than-normal year.

Average sea-ice extent in the European Arctic sector in September 2021 was the lowest on record for the month (37% below the 1981–2010 average), slightly below the previous record from September 2013 (36% below average). A significant contributor to these low values was the record low sea-ice conditions in the Greenland Sea from July to September.

High-impact weather and climate events led to hundreds of fatalities, directly affected around 510 000 people and caused economic damages exceeding US$ 50 billion. About 84% of the events were floods or storms.

Exceptionally high temperatures and heatwaves occurred in many parts of Europe throughout the summer. On 11 August, a location near Syracuse in Sicily, Italy, reached 48.8 °C, a provisional European record.

Drought and high temperatures fueled significant wildfires in summer, with southern Türkiye, Italy and Greece especially badly affected. Annual burned areas were about three times or more the 2006–2020 average in Cyprus, France, Greece, Israel, Italy, Lebanon, Montenegro and Türkiye.

An unusual spring cold outbreak affected many parts of Europe in early April, resulting in widespread and severe damage to agriculture, with large losses to vineyards, fruit trees and other crops. In France losses exceeded US$ 4.6 billion.

European Union (EU) greenhouse gas emissions decreased 31% between 1990 and 2020 (the net reduction target for 2030 is 55%). While the cut in 2019 was strongly driven by fossil fuel price effects and policy measures, the decline in 2020 was additionally related to the COVID-19 pandemic, and 2021 emissions in the EU are expected to be higher than in 2020. In other countries of the region, reductions targets for 2030 range in general from 35% to 55% compared with 1990.

About 75% of people in Europe are covered by early warning systems (EWSs), and many WMO Members in Europe have an above-average capacity to deliver on all their EWS needs. However, 7 Members (out of the 34 providing data) reported having inadequate end-to-end riverine flood forecasting services, and 13 Members reported inadequate end-to-end flash flood forecasting services. This is a concern, considering that in the last 50 years (1970–2019) 38% of the weather, water and climate disasters were related to floods.

Children are more vulnerable to the impacts of climate change than adults, both physically and psychologically. According to the United Nations Children's Fund (UNICEF) Children's Climate Risk Index (CCRI), nearly 125 million children in Europe live in 'Medium–High' risk countries (the third of five levels of classification used globally).

Comprehensive heat-health action plans have been shown to save lives and strengthen the resilience of communities and people to cope with extreme heat. Several European countries have implemented heat health action plans to prevent ill health and excess mortality from heat.

The European Region is one of the most advanced regions in transboundary cooperation in climate change adaptation. Countries have developed and implemented climate change adaptation strategies and plans and/or integrated climate change adaptation into their planning documents, in particular across several transnational river basins.

Foreword

The WMO *State of the Climate in Europe 2021* is the first edition of a climate report to be published annually by WMO's Regional Association for Europe (WMO RA VI) and the European Union's Earth observation programme, Copernicus. The report provides the status of key climate indicators using WMO and partner organizations' operational monitoring systems and the latest data and information on impacts, risks and policy from United Nations agencies. It addresses specific physical science, socioeconomic and policy aspects that are relevant to the WMO RA VI domain and responds to Members' needs in the fields of climate monitoring, climate change and climate services. The present report also makes use of the latest findings presented in the reports of the Intergovernmental Panel on Climate Change (IPCC) and the Copernicus European State of the Climate report.

Europe has warmed at more than twice the global average over the past 30 years, and it is the fastest warming of the six defined WMO Regions. In 2021, a variety of extreme weather and climate events occurred in various parts of Europe. The exceptional severe floods which led to an unprecedented death toll and damages in parts of Western and Central Europe in July, and the destructive wildfires which devastated South-eastern Europe during the summer, will remain in the memories of the affected nations and in the international climatological records. The year 2021 presented a live picture of a warming world and reminded us that even those societies we consider better prepared are not safe from severe impacts of extreme weather events.

In this regard, WMO is leading international efforts through the United Nations Global Early Warning Initiative to strengthen Earth system observations and monitoring, predictive and warning capabilities. On the mitigation side, the good pace in reducing greenhouse gas emissions in the region should continue and ambition should be further increased. Enhanced ambition would demand from Europe to play a key role towards achieving a carbon neutral society by the middle of the century, a necessary requirement to limit global temperature increase to well below 2 degrees Celsius, while pursuing efforts to limit the increase to 1.5 degrees, as specified in the Paris Agreement.

The present report would not be possible without the invaluable contribution of the National Meteorological and Hydrological Services (NMHSs), the WMO Regional Climate Centre Network for Europe, the Copernicus Climate Change Service (C3S), United Nations agencies, and numerous experts and scientists from the region and worldwide.

I take this opportunity to congratulate the lead authors for the quality of the present report and thank WMO Members, sister United Nations agencies and the contributing experts and scientists for their inestimable support to this publication.

Prof. Petteri Taalas
Secretary-General, WMO

Preface

As the risks and impacts of climate change become increasingly apparent in day-to-day life, the need and the appetite for climate intelligence grow, and rightly so. With this report we aim to bridge the gap between the data and the analysis to provide science-based but accessible information that is 'decision-ready', across sectors and professions.

In this report you will see that 2021 was yet another year of rising greenhouse gas concentrations and record-breaking temperatures, as well as one of severe storms, flooding, heatwaves and drought events in Europe. With the impact that such climate extremes and events have had on life and property, society is more aware than ever of the risks posed by climate change and, I believe, wants action in anticipation that such events will become more common and more intense in the future. At the same time, mitigating and adapting to climate change has introduced a stronger dependency on climate and its variability. The availability of detailed information about climate trends and impacts will become increasingly valuable to enable effective action in economic and societal areas such as energy, transport, agriculture and health – and those working in them – and this report makes an important contribution in this field.

European society is vulnerable to climate variability and change, but Europe is also at the forefront of the international effort to mitigate climate change and to develop innovative solutions to adapt to the new climate Europeans will have to live with. To meet the United Nations Sustainable Development Goals and their targets, to properly support climate policies and planning, and to ensure that our actions are based on facts, European Union (EU) initiatives such as the European Green Deal, the Climate Law, the Mission on climate adaptation and the European Climate Risk Assessment all require good quality information about the present and future climate to be operationally produced, curated and distributed. The EU's Copernicus Climate Change Service, operational since 2018, provides state-of-the-art climate monitoring data and tools for use by governments, public authorities and private entities around the world, and has provided key support to efforts in this direction.

Following the publication of our European State of the Climate report earlier this year, we are pleased to now work with our WMO colleagues in the authoring of this joint report, which summarizes the current understanding of the key climatic events of 2021 and helps put those events and their impact in the context of climate change. The findings are indeed dire, but our hope is that this report, with its evidence, with its insight and coming as it does just before COP27, is a timely and invaluable tool for the continued work to reduce emissions and make progress on our collective commitments under the Paris Agreement.

Dr Carlo Buontempo
Director, Copernicus Climate Change Service
European Centre for Medium-range Weather Forecasts (ECMWF)

Global climate context

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

The latest analysis of observations from the WMO Global Atmosphere Watch (GAW) in situ observational network shows that globally averaged surface mole fractions for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) reached new highs in 2021, with CO_2 at 415.7 ± 0.2 parts per million (ppm), CH_4 at 1 908 ± 2 parts per billion (ppb) and N_2O at 334.5 ± 0.1 ppb.[2] These values constitute, respectively, 149%, 262% and 124% of pre-industrial (before 1750) levels. Increasing greenhouse gas concentrations lead to an accumulation of heat in the climate system, much of which is stored in the ocean.

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

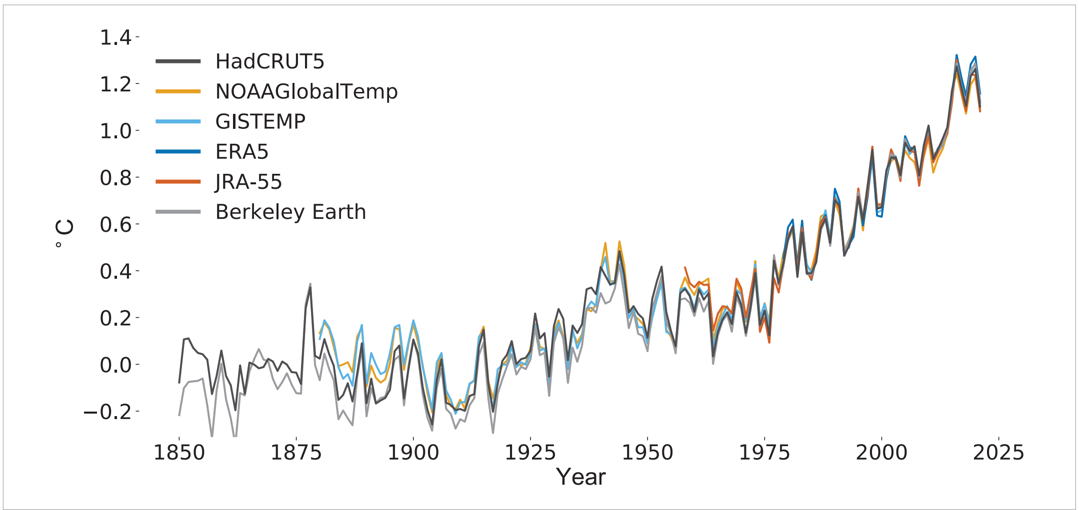

Figure 1. Global annual mean temperature difference from pre-industrial conditions (1850–1900) for six global temperature data sets (in situ datasets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth; reanalysis: ERA5 and JRA55).
Source: Met Office, United Kingdom of Great Britain and Northern Ireland.

Regional climate

The following sections analyse key indicators of the state of the climate in Europe (WMO Region VI – Europe) (see domain map in Region domain section). One important such indicator, temperature, is described in terms of anomalies, or departures from a reference period. For global mean temperature, the reference period used in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), 1850–1900, is used for calculating anomalies in relation to pre-industrial levels. The pre-industrial period cannot be used as a baseline for calculating regional anomalies, however, due to insufficient data for calculating region-specific averages prior to 1900. Regional temperature anomalies are therefore expressed relative to the 30-year 1961–1990 reference period, which is the fixed period recommended by WMO as a consistent and stable reference for assessing long-term climate change, especially for temperature. In order to be consistent throughout this report, the 1981–2010 climatological standard normal period is used for computing anomalies in temperature and other indicators with reference to more recent climate average conditions, as not all WMO Members have finalized the transition to the more recent period. Exceptions to the use of these baseline periods for the calculation of anomalies, where they occur, are explicitly noted.

TEMPERATURE

The temperature close to Earth's surface has large impacts on both human and natural systems. It affects health, agriculture and energy demand, for example, as well as growth cycles in natural environments. Human health is especially affected by extreme temperatures; see the Climate change sensitive health risks section. Temperatures in Europe have warmed significantly during the industrial era, and during the 1991–2021 period Europe has warmed at a rate (+0.5 °C per decade) that is more than twice the global average, making it the fastest warming region of the WMO regions.[5]

The 2021 annual mean temperature for Europe[6] ranked between sixth and tenth highest on record, with an anomaly of 0.90 °C [0.76 °C–1.00 °C] above the 1981–2010 average (Figure 2, left), and 1.44 °C [1.30 °C–1.61 °C] above the 1961–1990 average.[7] The annual temperatures for 2021 were generally above the 1981–2010 average for almost the entire region; only a small area in the north-western Russian Federation saw below-average temperatures. The largest deviations from the 1981–2010 average were recorded over the European part of the Arctic and south-eastern parts of the region, with temperatures more than 2 °C above average over parts of Greenland, primarily the north and the north-west, and Svalbard, as well over eastern Türkiye, the southern Caucasus and parts of the Middle East (Figure 2, right).

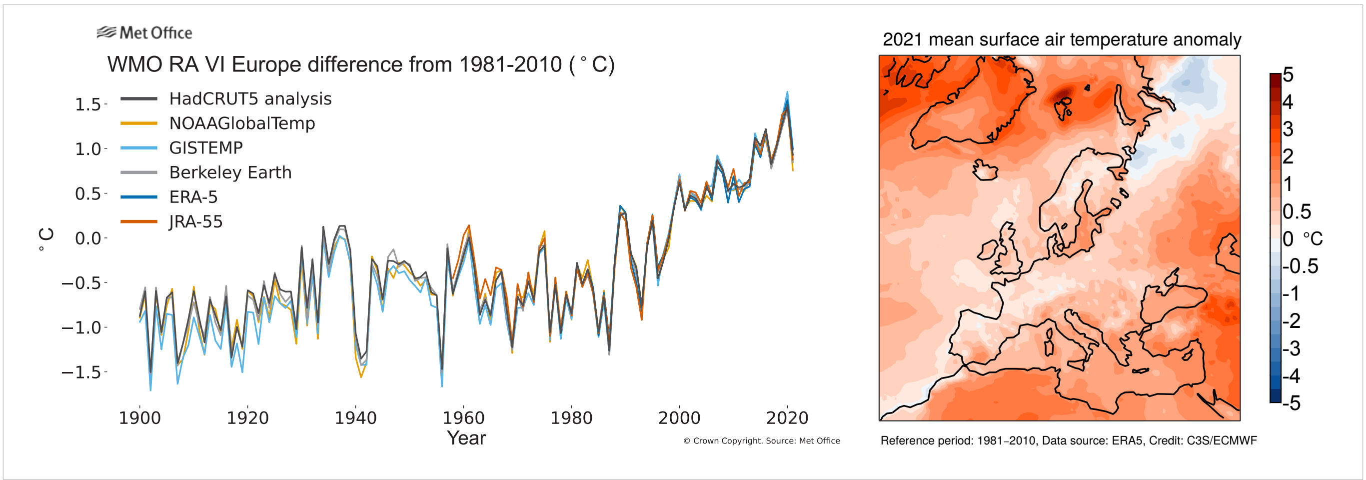

Figure 2. Left: Annual average temperature anomaly for 1900–2021 compared to the 1981–2010 reference period (for land only) over Europe, as defined by the WMO Region VI (see Region domain section). Data: In situ datasets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth; reanalysis: ERA5, JRA-55. Right: Annual average surface air temperature anomaly (°C) for 2021 compared to the 1981–2010 reference period. Data: ERA5 reanalysis. *Source:* Met Office, United Kingdom (left); Copernicus Climate Change Service (C3S)/European Centre for Medium-range Weather Forecasts (ECMWF) (right).

PRECIPITATION

Precipitation is one of the key climate parameters and, compared with temperature, is characterized by a high spatial and temporal variability. Lack of precipitation can lead to droughts, while excess precipitation can cause floods and/or high river discharge and soil moisture. In 2021, the largest annual precipitation totals were observed at the west coasts of Scandinavia and the British Isles, the Alps, the east coasts of the Adriatic and Ionian Seas and Black Sea and the Cantabrian Mountains (north-western Spain). The lowest annual precipitation amounts were detected in the Middle East, the southern Iberian Peninsula, northern Lapland and south of the Gulf of Finland. These patterns of total annual rainfall are similar to those for the 1981–2010 reference period.

In terms of precipitation anomalies compared to this reference period, the highest annual precipitation excesses were measured in South-eastern Europe, north-west Anatolia and the north coast of the Black Sea. Parts of Eastern Europe and east Scandinavia were also wetter than average. Deficits in the region were detected from south-west Scandinavia to the south of the Gulf of Finland, the northern British Isles and South-west Europe. In general, absolute and relative anomalies show quite similar patterns when comparing maps for 2021 (relative anomalies shown in Figure 3).

The year 2021 was the third drier-than-normal year in a row for the Iberian Peninsula.[8] For the Alpine region, it was the second consecutive drier-than-usual year. Across the British Isles as well as in Scandinavia and the Baltic, 2021 precipitation amounts were lower than usual. While rainfall amounts in 2021 were slightly above normal in Central and Eastern Europe after three drier-than-usual years, South-eastern Europe received considerably more precipitation in 2021 after a small excess in 2020.

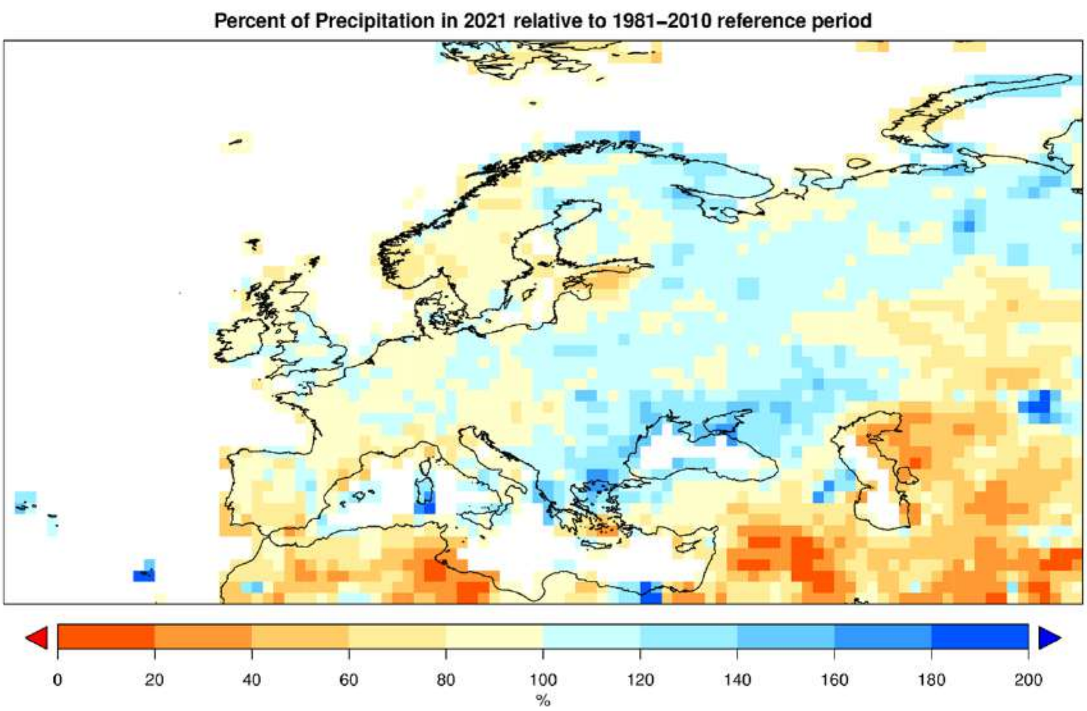

Figure 3. Percent of the annual precipitation total in 2021 with reference to 1981–2010. Yellow, orange and red colours indicate a precipitation deficit, while blue regions experienced a precipitation excess. Iceland is not shown due to known but still unresolved data issues.
Source: Global Precipitation Climatology Centre (GPCC), Deutscher Wetterdienst (DWD), Germany.

CRYOSPHERE

The cryosphere covers all the parts of the Earth system where water is in solid form, including ice sheets, ice shelves, glaciers, snow cover, permafrost (frozen ground), sea ice, and river and lake ice, all of which can be found within the region. The cryosphere is undergoing large changes due to greenhouse-gas-induced warming, and it also plays an important role within the climate system.[9]

GLACIERS AND GREENLAND ICE SHEET

Ice on land, in the form of ice sheets and glaciers, plays an important role in Earth's climate system through its ability to store vast amounts of water away from the oceans for long periods of time. Any change in the ice mass stored on land, such as when ice sheets and glaciers grow or shrink, has a direct impact on global mean sea level. Glaciers and ice sheets gain mass through accumulation of snow and lose mass through surface melting via interactions with the atmosphere or at their frontal regions via interactions with lake or ocean water.

There are more than 215 000 glaciers on Earth outside the polar ice sheets of Greenland and Antarctica. Globally, glaciers have lost a total of 11 500 Gt of ice since 1961, contributing more than 30 mm to global mean sea level, with a third of this contribution occurring during the past decade.[10] In Europe, glaciers have lost a volume of 821 km^3 of ice from 1997 to 2021, with glaciers in the Alps recording the largest ice losses over this period, with a reduction in ice thickness of 30 m (Figure 4).

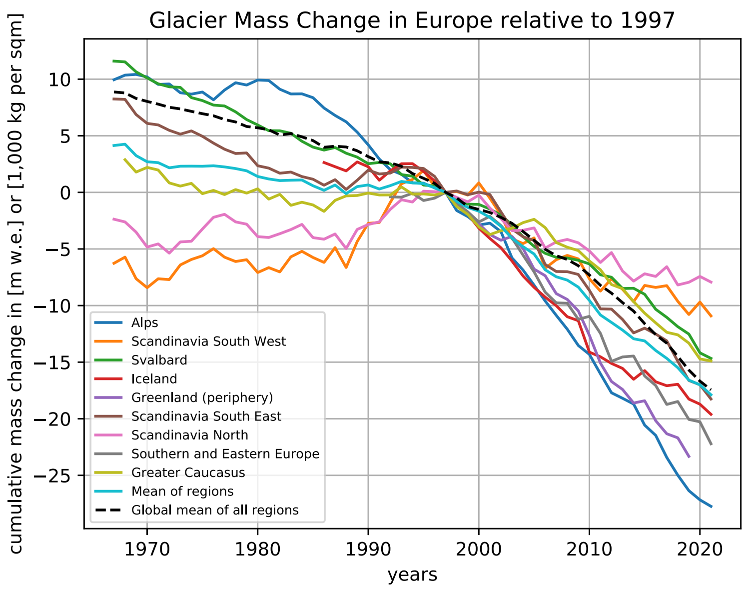

Figure 4. Cumulative mass changes in Europe from 1967 to 2021 for glaciers with long-term records in nine different regions. Mass balance values are given in the unit 'metres of water equivalent (m w.e.)' relative to 1997. Data source: WGMS (2021, updated). Graphic originally published in the C3S European State of the Climate.
Source: C3S/World Glacier Monitoring Service (WGMS).

The Greenland Ice Sheet lost 4 890 ± 460 Gt of ice between 1992 and 2020, contributing 13.6 ± 1.3 mm to global mean sea level rise.[11] In 2020, the latest year for which consolidated data are available (Figure 5), the Greenland Ice Sheet lost 397 ± 121 Gt of ice, which is less than in 2019, during which ice losses in Greenland reached a peak value of 444 ± 93 Gt, due to an intense surface melting event. Independent estimates from different sources indicate that the Greenland Ice Sheet continued to lose mass during the 2021 mass balance year.[12] Further, in summer 2021, Greenland saw an unprecedented melt event, coincident with the first-ever recorded rainfall at Greenland's highest point, Summit station.[13]

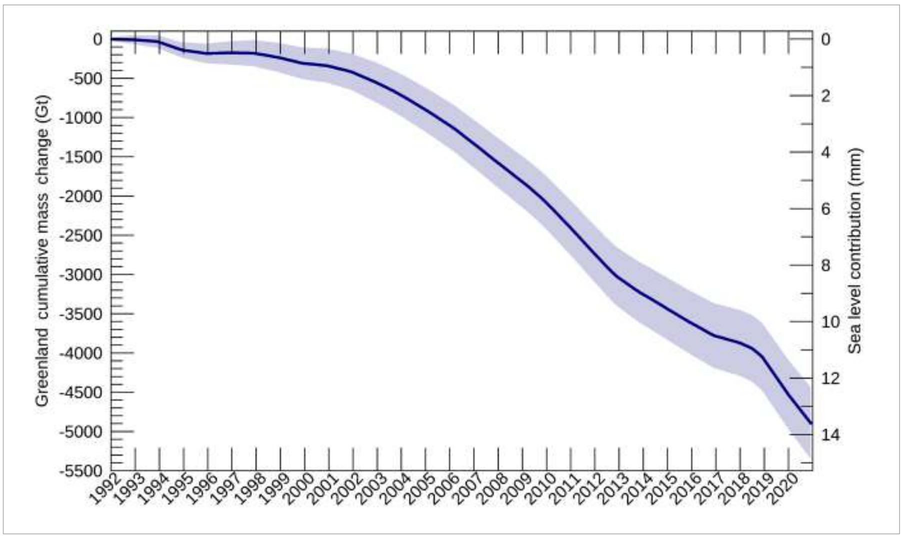

Figure 5. Cumulative mass balance of Greenland Ice Sheet and the corresponding contributions to global mean sea level. The shading represents the cumulative uncertainty.
Source: Data from Ice Sheet Mass Balance Inter-comparison Exercise (IMBIE).

SEA ICE

The European Arctic sector saw contrasting sea-ice conditions over the course of 2021. While the daily sea-ice extent for the region remained below its 1981–2010 average throughout virtually the entire year, it was relatively close to average in February–March, May and December, but well below average during the rest of the year. In September, the daily extent reached record minima for the years covered by the satellite data record. The September average extent was also the lowest for the month (37% below average), though it was only slightly below the previous record of September 2013 (–36%). A significant contributor to these low values was the record low sea-ice extent in the Greenland Sea from July to September, brought about by persistent southerly winds in July and August.

In the winter 2020/2021 the Baltic Sea had a maximum ice extent of around 12 500 km^2, which was the 20th (16th) lowest within the last 60 (30) years. In sheltered areas and along the coast, sea ice was also present in the western Baltic and on the North Sea coast. A large percentage of sea ice at open sea occurred only in the Bay of Bothnia, the Gulf of Finland and the Gulf of Riga. Although the winter 2020/2021 was classified as a normal to weak winter (i.e. slightly less extent than normal), depending on the data set used, and stronger overall than the two winters before, the maximum ice extent in the Baltic Sea continues to decrease along the long-term trend (Figure 6).[14] In the Sea of Azov, sea ice was present in winter 2020/2021, as it has been on average during the past 30 years.

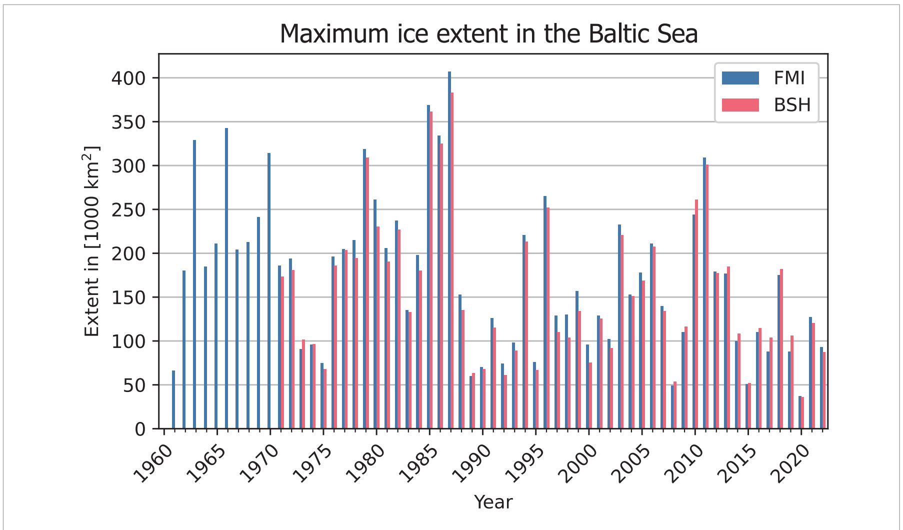

Figure 6. Maximum ice extent in the Baltic for the years 1961–2021, with values in blue from the Finnish Ice Service at the Finnish Meteorological Institute (FMI) and values in red for the Federal Maritime and Hydrographic Agency of Germany (BSH).[15,16]

OCEAN

The region includes several major ocean basins and regions: the eastern Atlantic sector of the Arctic, the North, Baltic, Mediterranean and Black Seas, as well as part of the Caspian Sea. The ocean plays a major role in determining the climate and weather conditions of the region, and it is also highly impacted by the global and regionally changing climate.

SEA-SURFACE TEMPERATURE

The sea surface is the boundary between the ocean and atmosphere. Sea-surface temperature (SST) can be used to understand the flows of energy between the two and hence the role of the oceans in shaping the weather and climate and vice versa. It provides a first indication of warming of the oceans, while ocean heat content provides information about warming at depth. There has been an overall warming of SSTs in all major ocean basins of the region during the industrial era, though the rate of warming differs.

In terms of the average SST across the region,[17] 2021 was between the sixth and eighth warmest year on record, depending on the dataset (Figure 7, left). SSTs across the region were mostly near or warmer than the 1991–2020 reference period.[18] The most above-average temperatures occurred in the central and eastern Mediterranean, the Baltic Sea, off the eastern coast of Greenland (see also Sea ice section), as well as in an area just west of the Iberian Peninsula and North Africa extending across the Atlantic (Figure 7, right). Most of these regions saw the warmest annual SSTs since at least 1993.[19] SSTs were also well above average between Svalbard and Iceland. Temperatures were below the long-term average just off the northern coast of Finland and Norway. Some small areas along the coasts of Spain and Portugal also saw below-average SSTs; here, 2021 was among the five coldest calendar years since at least 1993.[20]

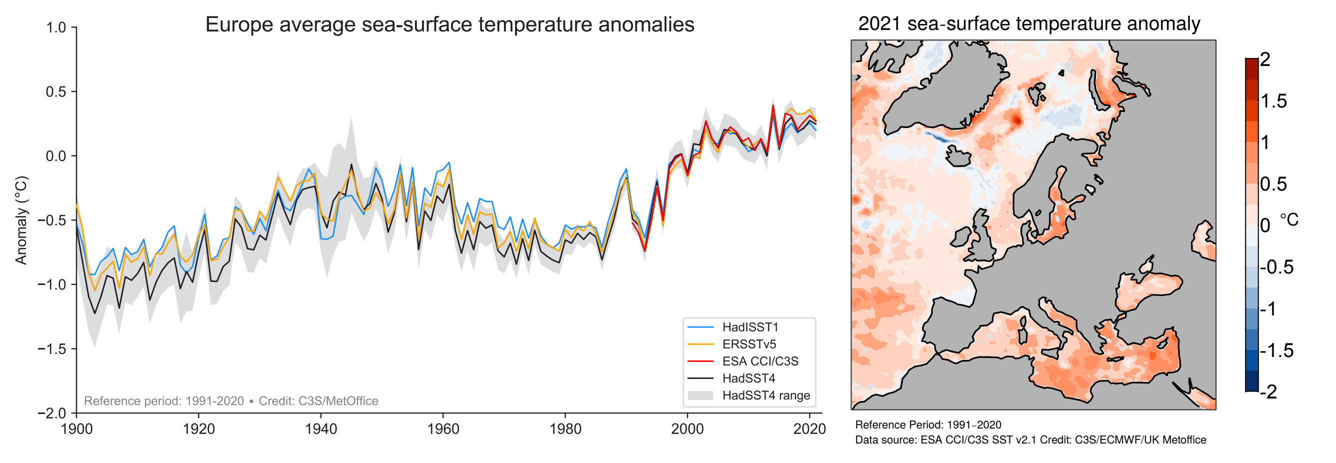

Figure 7. Left: Annual average SST anomalies (°C), from 1900 to 2021, relative to the 1991–2020 reference period, for the European seas. Data source: HadSST.4.0.1.0 (black, grey shading indicates the uncertainty range[21]), ERSSTv5 (orange), HadISST1 (blue), and ESA CCI/C3S SST Climate Data Record v2.1 (red). Right: Annual average SST anomalies (°C) for 2021, relative to the 1991–2020 reference period. Data source: ESA CCI/C3S SST Climate Data Record.
Source: C3S/Met Office, United Kingdom.

OCEAN HEAT CONTENT

Due to emissions of heat-trapping gases resulting from human activities, the global ocean has warmed as it has taken up more than 90% of the excess heat in the climate system, making climate change irreversible on centennial to millennial time scales.[22,23] Ocean warming contributes to about 40% of observed global mean sea level rise,[24,25,26] is altering ocean currents and indirectly altering storm tracks,[27,28,29] increases ocean stratification[30] and can lead to changes in marine ecosystems.[31,32,33,34] In addition, changes in ocean heat content are also affected by climate variability at interannual to longer time periods, and are superimposed on the long-term ocean warming trend.[35]

These natural variations strongly affect the regional trends for the period 2005–2021 (Figure 8), with ocean heat content increasing at rates up to more than 5 W/m^2 in some specific regions, particularly in the Mediterranean Sea – an area which is known to be strongly affected by climate change.[36] There are specific regions where a negative trend is observed at rates up to about –5 W/m^2, such as in the subpolar North Atlantic.

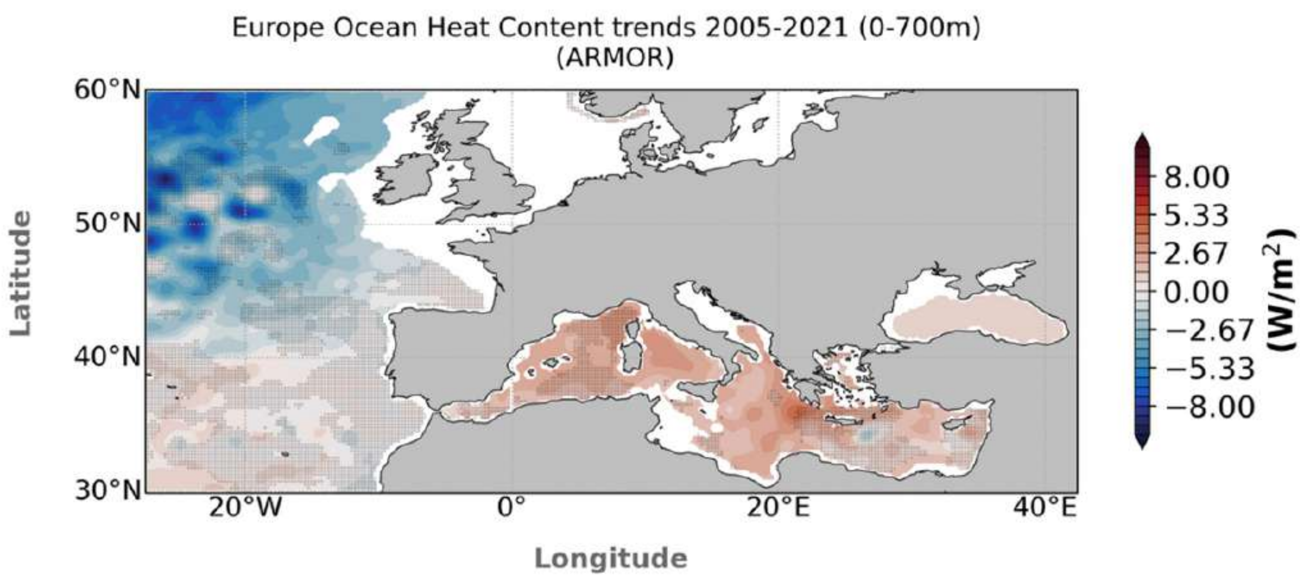

Figure 8. Regional ocean heat content (0–700 m depth) trend over the period 2005–2021 from an observational-based product (ARMOR) distributed by the Copernicus Marine Service (CMEMS). Grey shading indicates areas of most robust signatures[37] based on a multi-product approach.[38] White areas indicate regions where the ocean is shallower than 300 m, which have been excluded for this analysis due to limitations in ocean measurement density.
Source: CMEMS.

SEA LEVEL

Change in mean sea level is an essential indicator of our evolving climate, as it reflects both the thermal expansion effect, due to heat added to the ocean, and the loss of mass from ice sheets and glaciers.[39] Long-term and interannual variations in sea level are observed at both global and regional scales. These variations are related to the changes observed in individual ocean basins and can impact people living in coastal areas, where sea-level variations can be superimposed on the effects of land subsidence and rebound.[40] Since 1993, global mean sea level has increased at an average rate of 3.3 ± 0.4 mm/year.[41] This amounts to a total increase of about 9 cm between 1993 and 2021. On a regional scale for Europe, sea-level trends show spatial variations, with most areas showing increases of 2–4 mm/year[42] (Figure 9).[43] The Baltic Sea exhibits one of the largest rises in sea-level, averaging over 4 mm/year. Only a few areas, such as the central parts of the Mediterranean Sea, show no change or a slight decrease in sea level.

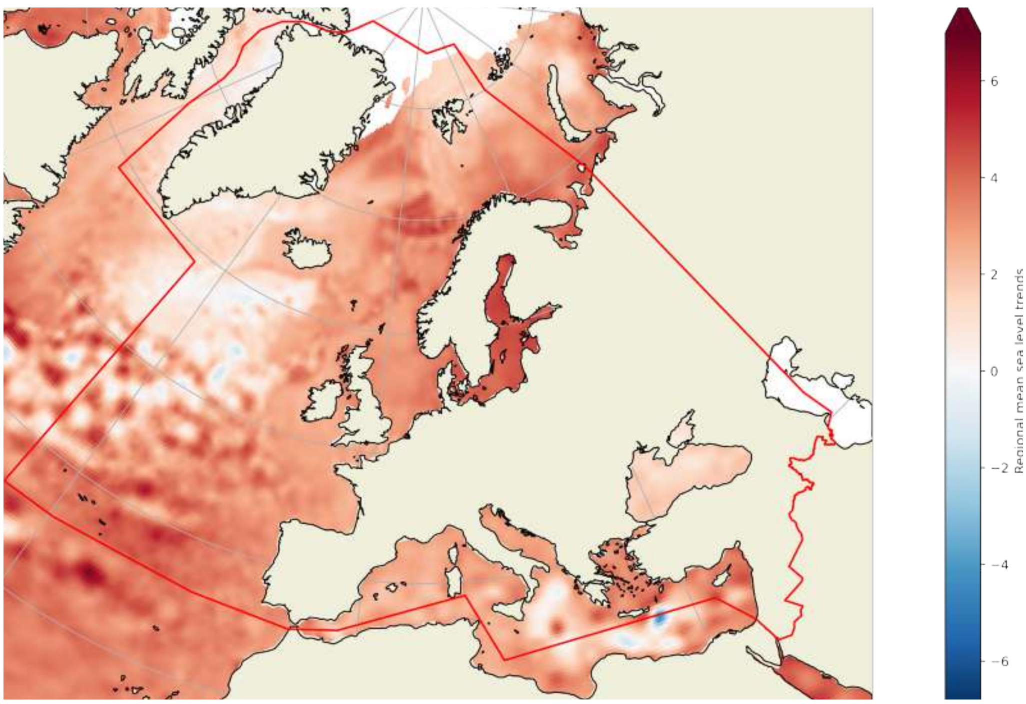

Figure 9. Sea-level trends (mm/year) from January 1993 to December 2021 in shades of blue (from –4 mm) to red (to +7 mm). The data have not been adjusted for glacial isostatic adjustment nor for the TOPEX-A instrumental drift. The red line indicates the WMO Region VI – Europe. Data source: CMEMS Ocean Monitoring Indicator based on the C3S sea-level product.
Source: C3S/ECMWF/CMEMS.

Major climate drivers of the region

Climate drivers are related to slowly varying conditions at the tropospheric boundaries, like SSTs, ice and snow cover, stratospheric temperature, and many others. These slowly varying conditions excite, sustain and interact with the dynamics of the atmosphere to shape weather patterns. All year round, manifestations of extratropical internal dynamics are shown in the position and intensity of subtropical and subpolar jet streams in the upper troposphere and atmospheric circulation patterns in the troposphere.

The weather over the European Region during the cold season is dominated by the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO).[44,45] Typically, a positive AO/NAO pattern gives drier and calmer conditions in Mediterranean Europe and wetter and windier conditions in North-west and Northern Europe. A negative pattern typically gives drier and cooler conditions with fewer storms in mid- and high-latitude Europe and directs these storms, with their moist air, to the Mediterranean region.[46] The winter 2020/2021 and spring 2021 were generally characterized by negative AO/NAO conditions (Figure 10).[47] The negative AO/NAO phase in January 2021 contributed to episodes with severe winter conditions in many parts of Spain, together with sudden stratospheric warming [48] that occurred in the early part of the month and the variations in the stratospheric polar vortex in its aftermath.[49] The same driver also led to negative anomalies in westerly wind speed (weakening of the westerly winds) over North-western Europe, especially in January and April. The strong negative AO/NAO phase in April can be also associated with cold spells in France, Poland, Switzerland, Slovenia, Serbia etc. While AO/NAO influences on European weather patterns are strongest in winter, they may have been instrumental in the enhanced storminess in the Mediterranean in October 2022, which contributed to an extreme flash flood in north-west Italy.

The second mode (weather pattern) of North-Atlantic-European atmospheric variability is the Eastern Atlantic (EA) pattern[50] and its summer manifestation (SEA), the latter being related to spring SST anomalies in the northern tropical Atlantic.[51] The tropical North Atlantic and Caribbean Sea were warmer than normal in spring of 2021 due to the reduction in trade winds caused by the prevailing negative AO/NAO episodes in winter and spring.[52] Between July and September, a negative SEA and slightly positive summer NAO explain the presence of an area of high pressure and exceptionally low winds over North-western Europe and the adjacent Atlantic Ocean.[53] The negative phase of SEA is also consistent, at least partially, with the above-normal precipitation episodes in Western and Central Europe in July.[54] The Baltic SST anomalies during June and July exceeded 5 °C above the average for the 1991–2020 reference period,[55] adding an extra source of water vapour that contributed to abundant precipitation episodes.

The East Atlantic/West Russia (EATL/WRUS) mode is the third prominent weather pattern that affects Europe and Asia throughout the year.[56] The positive phase is associated with above-average temperatures in Eastern Asia and below-average temperatures in large western portions of the Russian Federation. The early summer of 2021 was characterized by a strongly negative EATL/WRUS pattern,[57] which can be associated with the very high June temperatures experienced in Moscow and St. Petersburg.

An anticyclonic circulation in the lower and middle troposphere, affecting much of the Mediterranean and North Africa, contributed to the heatwave in July to August 2021, with record-breaking temperatures in Italy and Spain[58] (see Heatwaves and wildfires section).

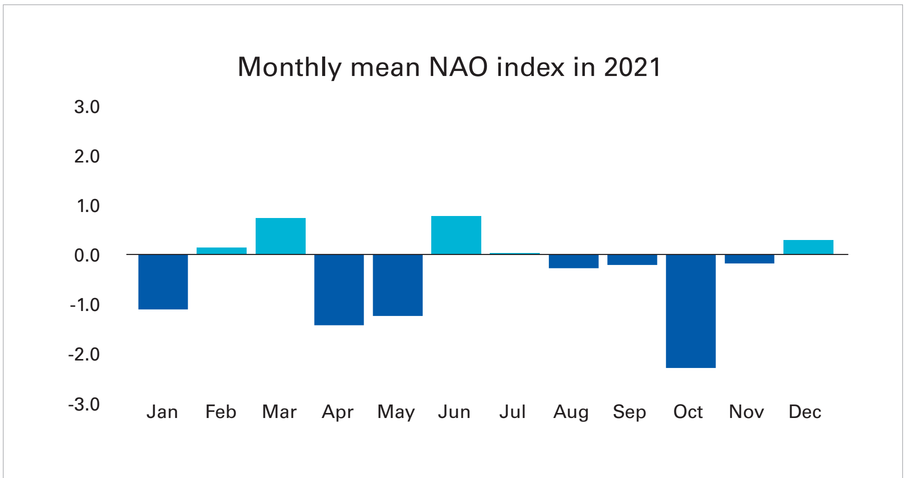

Figure 10. NAO index monthly mean values, in 2021.
Source: Data from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC): http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml.

Extreme and high-impact events

A variety of extreme and high impact events occurred in various parts of Europe in 2021. There were both severe heatwaves with forest fires and severe storms with heavy snowfalls in the North and South of Europe. Exceptional flooding occurred in Central Europe, but there were also drought events in Eastern Europe and in the Middle East region. (For detailed impacts see the Affected population and damage in 2021 section.)

A selection of some outstanding events is shown in Figure 11 and described in the following subsections. For impact of these events see Climate-related impacts and risks section.

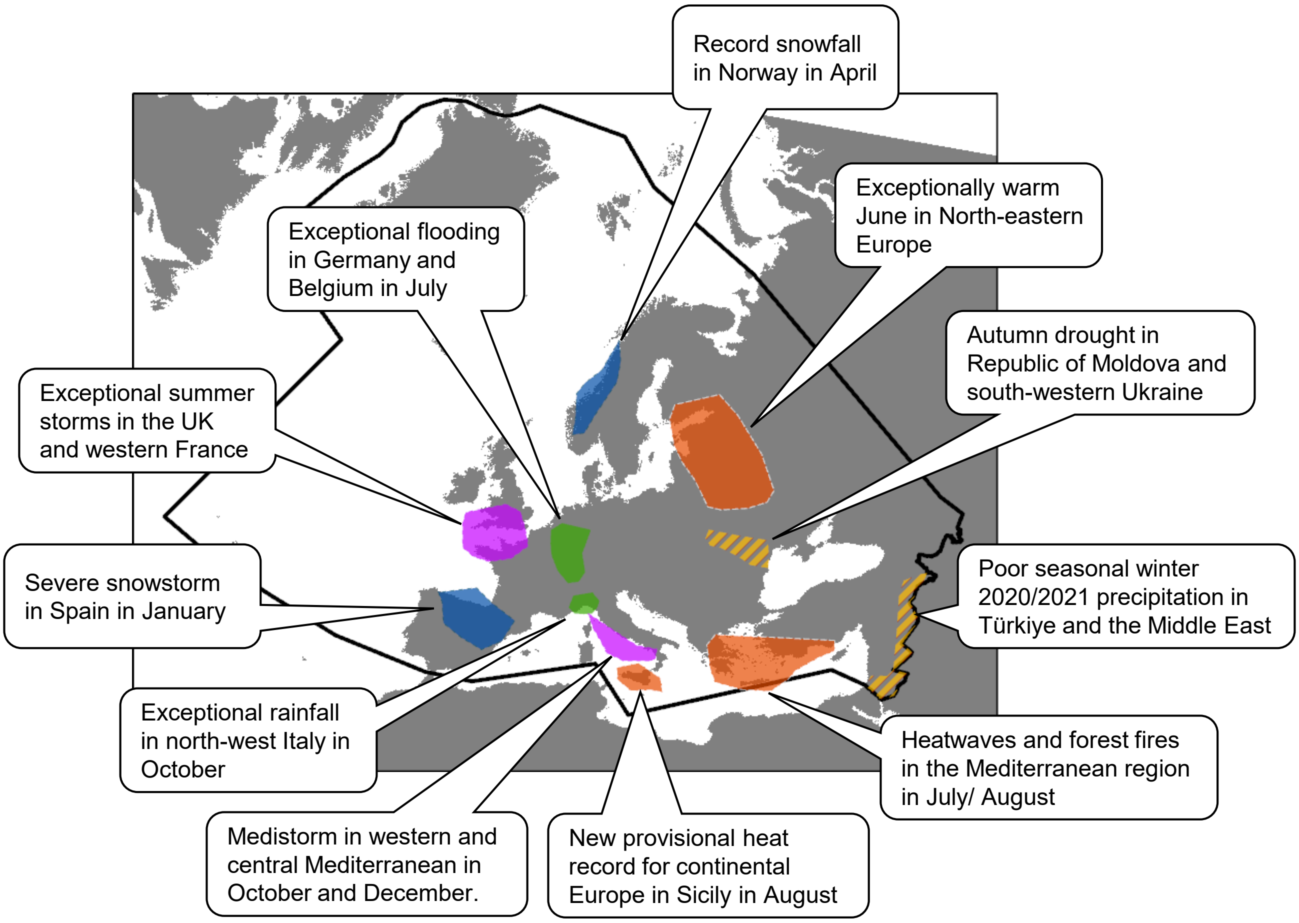

Figure 11. Selected high-impact events in WMO Region VI in 2021.
Source: DWD, Germany.

HEAVY PRECIPITATION AND FLOODS

Central Europe experienced some of its most severe flooding on record in mid-July. The worst-affected areas were western Germany and eastern Belgium, where 100 to 150 mm of rain fell over a wide area on 14–15 July (Figure 12) onto ground which was already unusually wet after high recent rainfall.[59] Hagen (Germany) reported 241 mm of rainfall in 22 hours. The highest daily amount of precipitation in Belgium was 179 mm on 14 July in Hockay (Ardennes region). Numerous rivers experienced extreme flooding, with many towns inundated, and there were also several landslides. Water levels in rivers far exceeded historical records, rising locally to 7–8 m above normal (e.g. the water level of the Rhine River near Maxau was measured at 8.65 m, the third highest water level recorded at this station since measurements started in 1815).[60] France, the Netherlands, Luxembourg and Switzerland also experienced significant flooding. In a rapid extreme weather attribution study,[61] scientists found that for a given location within a larger region (between the north of the Alps and the Netherlands), climate change (assessed comparing today to a 1.2 °C cooler global climate) increased the likelihood of such an event by a factor between 1.2 and 9, and the intensity of the maximum one day rainfall by about 3%–19%.

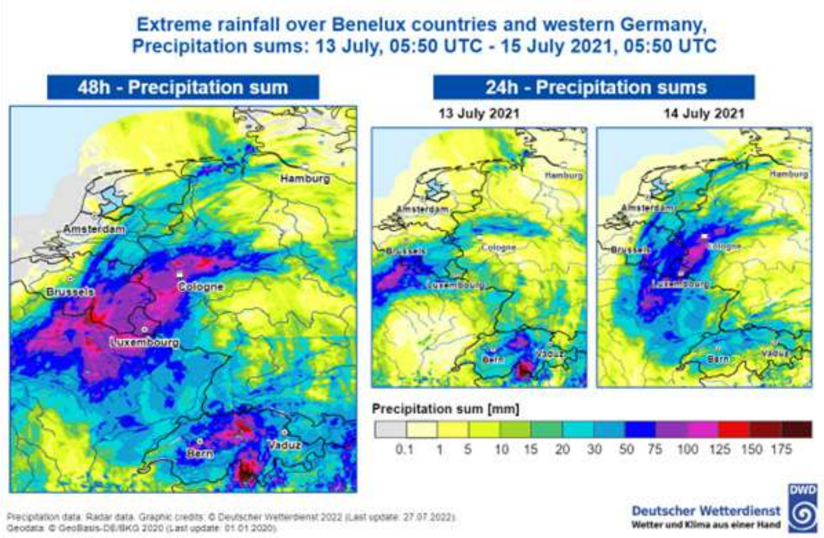

Figure 12. Maps of 24- and 48-hour total precipitation, on 13 and 14 July 2021 using merged radar and in situ data.
Source: DWD, Germany.

In North-western Europe, Storm Christoph brought heavy rain on 18–21 January. Three-day precipitation totals of 50–100 mm, locally 150–200 mm, reached 50% of the average January monthly rainfall in some areas, leading to record-high river levels and flooding that caused damage to bridges, roads and power lines. On 21 January, the Dee River in North Wales reached its highest water level since the water gauge was installed in 1996. Approximately 2 300 homes were evacuated. In February, several Atlantic low-pressure systems brought further heavy precipitation to France, the United Kingdom and the Netherlands. Since soil was already saturated by the rainfall brought by Storm Christoph, the heavy rain in early February caused near-record river levels and widespread flooding in France.

Flash flooding occurred on several occasions around the Mediterranean and Black Sea coasts. The most impactful event was on the Black Sea coast of Türkiye on 10 August. Rainfall of 399.9 mm was recorded at Bozkurt in 24 hours. This event was associated with a storm over the Black Sea. Extreme rainfall and flooding were also reported on the Black Sea coast of the Russian Federation from 12 to 14 August, where the storm made landfall. On 4 October, exceptional rain fell in coastal regions of Liguria (north-west Italy), including 496.0 mm in 6 hours at Montenotte Inferiore and 740.6 mm in 12 hours at Rossiglione, setting a new European 12-hour rainfall record.[62] The rain caused landslides and severe flooding, leading to road and highway closures – with villages cut off, temporary halts to local train services and school closures.

The north-western Syrian Arab Republic experienced flooding on 18 January after a winter storm accompanied by heavy rain. From 12 to 18 January more than 100 mm of rainfall (>400% of the 1981–2010 average) was observed.

DROUGHTS

There were some moderate and severe drought events in various parts of Europe throughout the year.

In winter 2020/2021, moderate drought conditions[63] occurred south of the Gulf of Finland, mainly in Estonia and Latvia (Figure 13). February was the fifth driest on record in Latvia (since 1924). Türkiye and the Middle East were affected by poor seasonal winter precipitation. While parts of Türkiye had some relief in January 2021 due to a period of enhanced precipitation, the south-eastern Anatolia region in Türkiye had an exceptionally dry year in general. Parts of the Middle East (eastern Syrian Arab Republic, southern Israel and southern Jordan) saw moderate to severe drought. In Israel, rainfall amounts in January and February were close to the average (1991–2020), yet the number of rain days was small and most of the rain fell in a limited number of events.

During spring, some regions of the Iberian and Apennine Peninsulas experienced moderate drought. The drought in Portugal occurred with a gradual increase in terms of the concerned area and intensity between April and August, easing in early autumn and worsening again after October. Italy saw its fifth driest spring on record and the driest since 2017.

In summer, much of the western Mediterranean region (part of eastern and southern Spain, southern France, much of Italy) and parts of the central and eastern Mediterranean region (western Balkans, southern Greece, south-western Türkiye) experienced moderate to severe drought conditions in relation with several heatwaves.[64] There was also a dry spell in parts of northern Europe, notably in Estonia in June; 28% of its stations had a monthly total of 25% or less of the month's normal.

The drought situation eased in autumn, but moderate to severe drought conditions developed in the Dniester and Southern Bug catchments (south-western Ukraine and Republic of Moldova). The amount of precipitation per season on the territory of the Republic of Moldova did not exceed 15–45 mm (15%–35% of the normal), which is observed on average once every 15–30 years. In December, severe drought conditions developed in north-eastern Spain and northern Italy.

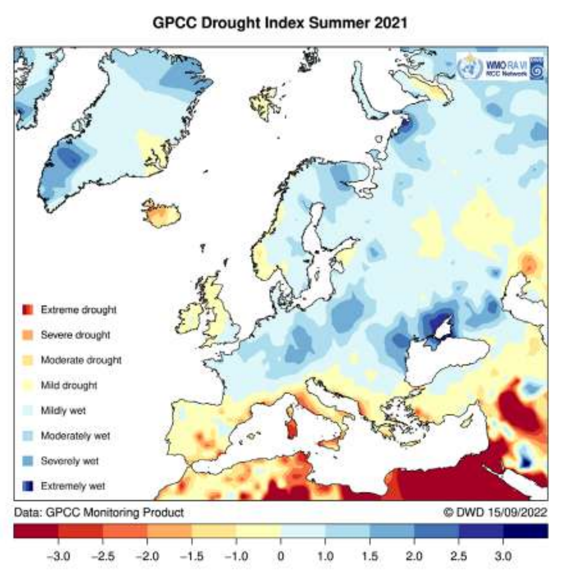

Figure 13. GPCC drought index[65] for summer 2021. Drought areas (including seasonal drought) are shown in red, areas with high summer precipitation in blue.
Source: GPCC, DWD, Germany.

HEATWAVES AND WILDFIRES

The WMO Regional Climate Centre (RCC) Network for Europe compiled information on the heatwaves since 1950 (Figure 14). Out of the the 23 most severe heatwaves, only 7 occurred between 1950 and 2000, while 16 occurred after 2000. This is an indicator that heatwaves have become more frequent and also more severe, with serious impacts, for example, on health and mortality (see Climate change sensitive health risks section). The most severe heatwave occurred from 21 July to 18 August 2010 in Eastern Europe.[66]

Several heatwaves occurred in many parts of Europe in 2021 (Figure 14), and a number of new local and national temperature records were measured.

June was exceptionally warm in many parts of North-eastern Europe and in the South Caucasus. National June records for daily maximum temperatures were set for Estonia (34.6 °C) and Belarus (37.1 °C), while locations which had their hottest June day on record included St. Petersburg (Russian Federation) (35.9 °C) and Moscow (Russian Federation) (34.8 °C), both on 23 June, Yerevan (Armenia) (41.1 °C) on the 24th, and Baku (Azerbaijan) (40.5 °C) on the 26th. Tampere in Finland reported its highest temperature on record (33.2 °C) on 22 June. Latvia had its hottest June and summer on record. Later in the summer, unusual warmth also reached North-west Europe; 31.3 °C was recorded at Castlederg on 21 July – a record for Northern Ireland. Two tropical nights[67] were observed in Ireland in July, with daily minimum temperatures exceeding 20 °C in County Kerry. Unusual warmth also reached Iceland. On 24 August, a station in Hallormsstaour measured 29.4 °C, which was the highest August temperature ever recorded in Iceland.

Extreme heat affected the broader Mediterranean region on several occasions during the second half of the northern hemisphere summer. The most exceptional heat was in the second week of August. On 11 August, an agrometeorological station near Syracuse in Sicily, Italy, reached 48.8 °C, a provisional record for continental Europe.[68] Montoro (47.4 °C) set a national record for Spain on 14 August, while on the same day Madrid (Barajas Airport) had its hottest day on record with 42.7 °C. Earlier, on 20 July, Cizre (49.1 °C) set a national record for Türkiye and Tbilisi (Georgia) had its hottest day on record (40.6 °C).

The drought conditions combined with the high temperatures during the heatwaves were conducive to the major wildfires that occurred across many parts of the Mediterranean region, with southern Türkiye, Italy and Greece especially badly affected.[69] On 13 August, more than 500 wildfires were burning across Italy. During 28 July–3 August, wildfires broke out in southern Türkiye (these were especially notable in the provinces of Antalya and Mugla). Over the balance of the season, burned areas were 3 times or more the 2006–2020 average in Cyprus, France, Greece, Italy, Israel, Lebanon, Montenegro and Türkiye.[70] See more in the Affected population and damage in 2021 section.[71]

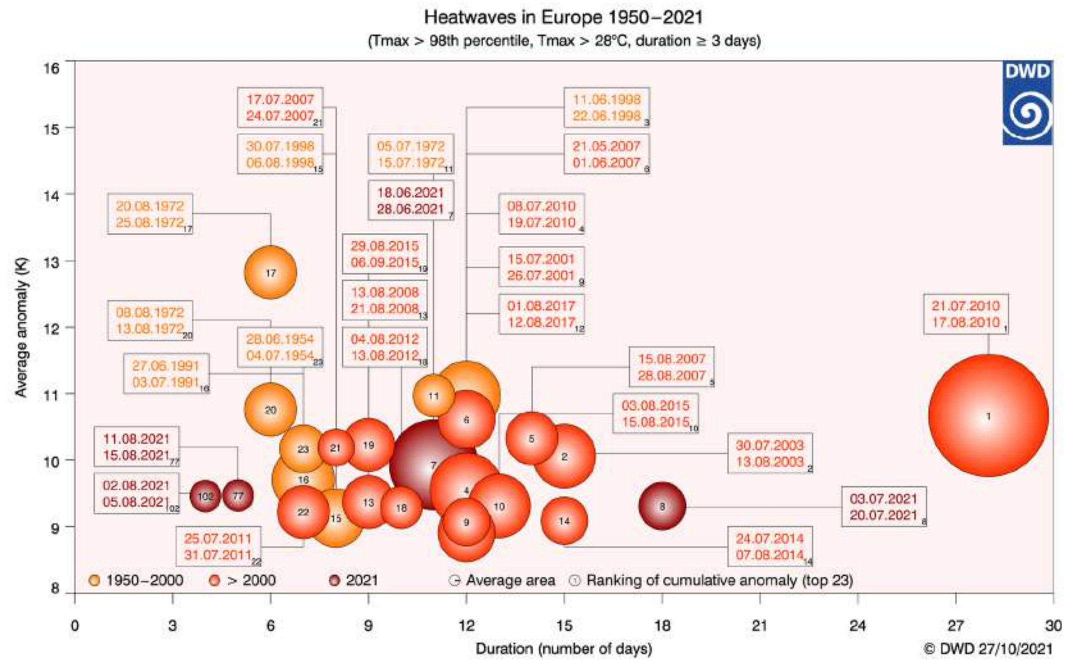

Figure 14. Bubble diagram showing the 23 most severe heatwaves plus the heatwaves in 2021. The heatwave on 18–28 June 2021 ranks seventh in the 1950–2021 period, and the heatwave on 3–20 July 2021 ranks eighth. The figure also shows that most heatwaves occurred after 2000.[71]

COLD SPELLS AND SNOW

A severe snowstorm (Storm Filomena) hit many parts of Spain from 7 to 10 January, followed by a week of freezing air temperatures. A total of 53 cm of snow fell at the central city location of Retiro (Madrid), and heavy snow falls were also reported in many other parts of Spain. The last time a comparable quantity of snow fell in Madrid was in March 1971. Some locations, including Toledo (–13.4 °C) and Teruel (–21.0 °C), had their lowest temperatures on record on 12 January in the wake of the storm. There were major disruptions to land and air transport.

Later in the winter, in the second week of February, the Netherlands experienced its most significant snowstorm since 2010, with heavy snow also falling in Germany, Poland and the United Kingdom. Braemar recorded –23.0 °C on 12 February, the lowest temperature in the United Kingdom since 1995. New local minimum temperature records for February were set in central Germany (Thuringia region), with temperatures as low as –26.7 °C. New all-time snow-depth records were measured at several lowland stations in Germany, with snow depths of 60–70 cm. In South-eastern Europe, Athens (Greece) had its heaviest snow since 2009 on 15 February.

An unusual spring cold outbreak affected many parts of Europe in early April.[72] On 5–6 April, extreme snowfall was measured in parts of southern Norway, with a record 25–41 cm of fresh snow in 24 hours (measurements began in 1896). Record low April temperatures in France included –7.4 °C at Saint-Etienne on the 8th and –6.9 °C at Beauvais on the 6th, while Belgrade (Serbia) had its heaviest April snowfall on record on the 7th, with a record 10 cm snow depth reported. It was the coldest April in Poland in the twenty-first century. At high elevations, national records for April were set for Switzerland (–26.3 °C at Jungfraujoch) and Slovenia (–20.6 °C at Nova vas na Blokah). This followed a very warm end to March, with France having its warmest March day on record on the 31st, favouring early sprouting. Frost damage to agriculture was widespread and severe, with large losses to vineyards and other crops, see Climate-related impacts and risks section. The United Kingdom had its lowest monthly mean temperature for April since 1922.

SEVERE STORMS WITH STRONG WINDS

There were multiple severe thunderstorm outbreaks in Western and Central Europe in the second half of June and in July. An F4 tornado[73] struck several villages in southern Moravia (Czech Republic) on 24 June, with major damage and six deaths reported. This was the strongest tornado on record in the Czech Republic. Tornadoes were also reported during June in Belgium, France and Poland. Large hail (6–8 cm in diameter) was reported in several countries, including the Czech Republic, Slovakia, Switzerland and Germany.

Storm Zyprian passed Brittany in north-western France on 5 July, with gusts reaching 146 km/h at Plougonvelin, located at the west coast of Brittany, setting a new local record for July. The strong gusts were caused by interaction with a jet stream branch in the upper atmosphere. Such an event was last observed more than 50 years ago in July 1969.

On 20–21 October, a powerful storm named Aurore by Météo France brought severe weather to France, Germany, the Netherlands, Belgium, the Czech Republic, Poland, the Channel Islands and parts of southern England. Uprooted trees in France, Germany, the Netherlands and England disrupted rail services. In France, wind gusts up to 175 km/h were recorded in Fécamp (Normandy, at the English Channel), a new October record, and the 150 km/h recorded in Le Havre (Normandy) was a new local all-time record since beginning of measurements in 1994. In Dresden, Germany, the highest October gust in 46 years was recorded (119 km/h).

In the last week of October, a quasi-stationary low developed over the central Mediterranean close to southern Italy and eventually intensified to a medicane[74] named Apollo in Italy or Gloria by the Mediterranean Cyclone Centre. Winds of over 100 km/h blew around its centre. Another storm developed over the western Mediterranean on 6 November, called Blas by the Spanish national meteorological agency AEMET and Helios by the Mediterranean Cyclone Centre. Landfall was several days later on 15 November in north-western Italy (Liguria). More than 13 waterspouts were confirmed off the coast of Italy around this time. One in Sicily killed one person and injured two others, and caused severe damage to infrastructure.

Storm Arwen brought severe winds across the UK overnight on 26 to 27 November 2021, with the Met Office issuing a warning for dangerous winds. The developing storm, tracking south to the north-east of the UK, brought northerly winds gusting widely at over 111 km/h. The highest gust speed was 157 km/h at Brizlee Wood, Northumberland. This was one of the most powerful and damaging winter storms in the latest decade.

In mid-December 2021, Cyclone Carmel developed over the Mediterranean and remained over the eastern part of the basin for some days. It made landfall over Israel on 20 December 2021, bringing record rains and strong winds. The strongest winds were measured in Itamar (Israel) reaching a maximum speed of 83 km/h, with a gust at 110 km/h. The storm left at least one person dead and several injured.

FILLING THE GAPS IN OBSERVATION

According to the Intergovernmental Panel on Climate Change (IPCC), observational capabilities have continued to improve and expand overall since its Fifth Assessment Report (AR5), however there have also been reductions in some observational data coverage or continuity and limited access to data resulting from data policy issues. The current gaps in global surface-based data sharing significantly impact the quality of weather and climate information locally, regionally and globally.

The Global Climate Observing System (GCOS) regularly reviews the state of global climate observations and publishes reports on its findings. The last GCOS Status Report, published in 2021,[1] highlighted recent improvements in global observational capabilities and identified issues and gaps in the observing systems.

Europe is one of regions with better developed observational support for critical global numerical weather prediction (NWP) and climate analysis systems, although there are certain gaps in the observation of some variables over parts of the region. In the ocean large observation gaps still exist. Subsurface measurements are critical to monitor and forecast the climate system. The decision to expand the Argo programme to the full water column and under sea ice, including biogeochemical variables, the deployment of repeated hydrography, the deployment of fixed-point and other autonomous observing platforms and their integration aims to address these gaps.

The new GCOS Implementation Plan (September 2022)[2] provides a set of high-priority actions which if undertaken will improve global observations of the climate system and our understanding of how it is changing. The Global Basic Observing Network (GBON)[3] and the Systematic Observations Financing Facility (SOFF)[4] are key developments to improve observational capabilities.

GBON is a landmark agreement and offers a new approach in which the basic surface-based weather observing network is designed, defined and monitored at the global level. To achieve sustained compliance with the GBON requirements, substantial investments, strengthened capacity and long-term resources for operation and maintenance are needed in many countries. For this purpose, the SOFF was established to provide technical and financial assistance in new – more effective – ways, thereby (i) applying internationally-agreed metrics to guide investments; (ii) using long-term, sustained data sharing as a measure of success; and (iii) creating local benefits while providing a global public good.

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[1] The Global Climate Observation System 2021: The GCOS Status Report (GCOS-240)

[2] The Global Climate Observation System Implementation Plan (GCOS-244)

[3] https://community.wmo.int/activity-areas/wigos/gbon

[4] https://library.wmo.int/doc_num.php?explnum_id=10704

Climate-related impacts and risks

Extreme weather events are affecting countries around the world, including through increases in temperature and changes in the water cycle. In Europe, from 1970 to 2019, 1 672 reported disasters led to 159 438 deaths and economic loss of US$ 476.5 billion (Figure 15). Floods (38%) and storms (32%) were the most-reported cause of disasters, but extreme temperatures led to the highest proportion of disaster-related deaths (93%), with 148 109 lives lost.[75] For example, the heatwaves of 2003 and 2010 led to 127 946 reported deaths. In Europe, extreme heat has been the main weather hazard with respect to excess mortality, while floods caused the highest economic losses (44% of total economic losses).

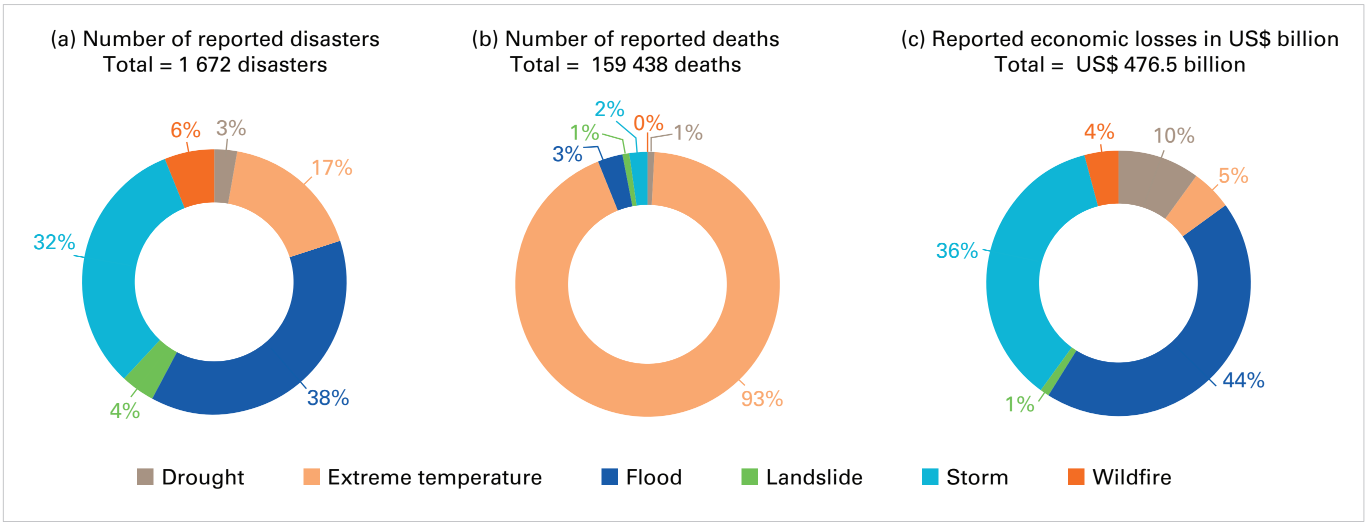

Figure 15. Overview of weather-, water- and climate-related disasters, deaths and US$ economic losses reported in Europe (1970–2019).
Source: Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019) (WMO-No. 1267).

These disasters are projected to increase in the future as assessed in the Working Group I contribution to the IPCC's Sixth Assessment Report (AR6):[76]

(1) Regardless of future levels of global warming, temperatures will rise in all European areas at a rate exceeding global mean temperature changes, similar to past observations (*high confidence*).[77]

(2) The frequency and intensity of hot extremes, including marine heatwaves, have increased in recent decades and are projected to keep increasing regardless of the greenhouse gas emissions scenario. Critical thresholds relevant for ecosystems and humans are projected to be exceeded for global warming of 2 °C and higher (*high confidence*).

(3) Observations have a seasonal and regional pattern consistent with projected increase of precipitation in winter in Northern Europe. A precipitation decrease is projected in summer in the Mediterranean extending to northward regions. Extreme precipitation and pluvial flooding are projected to increase at global warming levels exceeding 1.5°C in all regions except the Mediterranean (*high confidence*).

AFFECTED POPULATION AND DAMAGE IN 2021

In 2021, according to the International Disaster Database (EM-DAT), there were 51 meteorological, hydrological and climate hazard events reported in Europe, 84% of which were flood and storm events.[78] These resulted in 297 fatalities, directly affected approximately 510 000 people and caused total economic damage of over US$ 50 billion[79] (Figure 16). Floods were the hazard event with the highest shares of fatalities (85%), affected population (78%) and economic damage (83%).

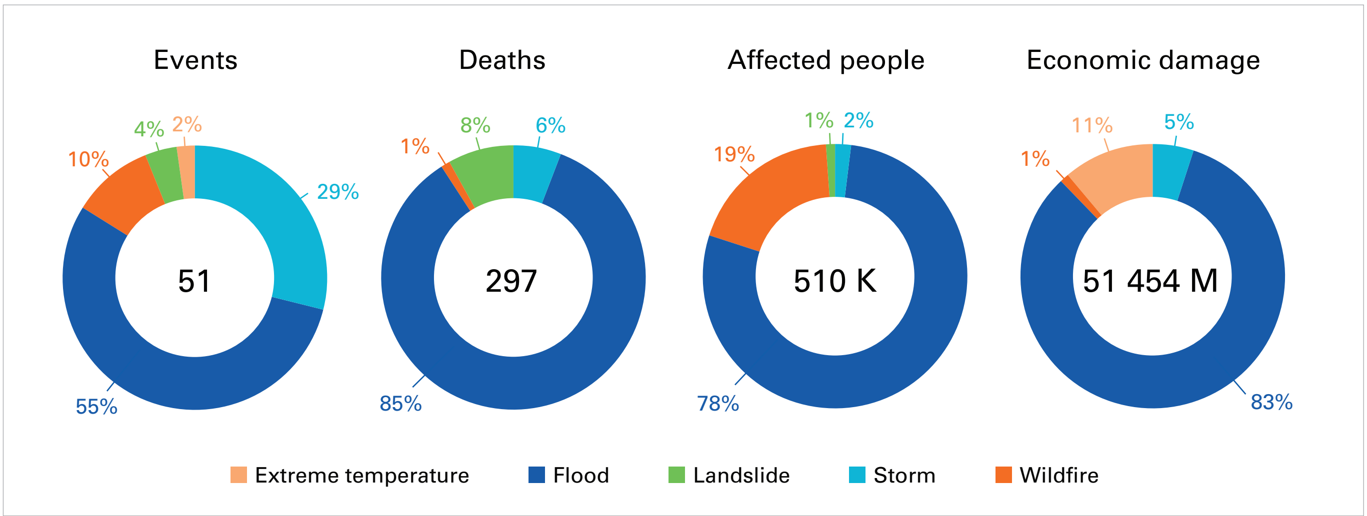

Figure 16. Weather-, climate- and water-related natural disasters in Europe during 2021. Note: impact numbers for some disaster occurrences may be lacking due to data unavailability.
Source: Data from EM/DAT.

Floods: In mid-January heavy precipitation and floods in the north-western Syrian Arab Republic made living conditions difficult for over 140 000 displaced people living in tents, resulted at least in one fatality and damaged or destroyed more than 25 000 tents. Also in mid-January Storm Christoph caused flooding and landslides, blocked roads, and damaged roads, bridges and houses in south-western France. In July 2021, several countries in Western and Central Europe were affected by severe flooding. Heavy rainfall had caused rivers to swell and to overflow their banks. The death toll of over 230 people was unprecedented. In Germany at least 189 people died,[80] and in Belgium at least 42 people died.[81] In addition, there were immense economic losses. In Germany more than 130 km of motorways were closed directly after the event, and 600 km of railway tracks were damaged.[82] On 10 August flash floods on the Black Sea coast of Türkiye killed 77 people (see Heavy precipitation and floods section).

Landslides: In September 2021, heavy rains significantly affected several municipalities in western Georgia, in the Autonomous Republic of Adjara and Guria region. It caused landslides that substantially damaged agricultural areas and fruit orchards and is expected to have long-term effects on food security and the livelihoods of people in the region.[83]

Wildfires: The 2021 wildfire season was the second worst in the European Union (EU) since 2000, when the European Forest Fire Information System (EFFIS) was initiated. Damages in 2021 were only exceeded by those in 2017, when more than 1 million hectares (ha) burned in the EU. In total, fires occurred in 43 countries, with Türkiye being the most affected (206 013 ha), followed by Italy (159 537 ha) (Figure 17). One of the most affected types of land cover was agricultural areas, which accounted for 25% of the burned lands, while various categories of forests totalled about 28% of the area.[84] The fires were fuelled by high temperatures during heatwaves combined with strong winds.[85] Wildfires in Türkiye from 28 July to 3 August displaced more than 10 000 people and killed at least eight people (see Heatwaves and wildfires section).

Droughts: An episode in the main cereal producing areas of the Syrian Arab Republic resulted in a below-average harvest. This was compounded by a difficult socioeconomic situation that reduced access to agricultural inputs,[86] and in the eastern region (particularly the governorate of Al-Hasakah) international tensions worsened the situation due to competing interest in water resources.[87] In Hungary 70% of the country was affected by drought in 2021, resulting in further drying of fertile soils, which hampered agriculture activities and productivity.[88] And in Portugal the percentage of the territory affected by drought reached 94% in December, leading to significant impacts on agriculture[89] (see Droughts section).

Storms: Storm Filomena severely affected the agriculture sector in central Spain (including olive groves, citrus orchards, winter vegetables and livestock farms) in early January 2021, with damages estimated at over € 100 million.[90] On 23 January in Mallorca, Storm Hortense brought damage to buildings and cars, at least 2 people were injured, power outages occurred, and some roads were closed due to landslides and downed trees. On 5 July, Storm Zyprian affected north-western France, downing many trees and cutting power to 4 000 households. In October, a two-day severe weather event (including hailstorms, tornadoes and torrential rains) in Italy destroyed agricultural lands including crops and livestock as well as agriculture infrastructure[91] (see Cold spells and snow, and Severe storms with strong winds sections).

Cold spells: In early April a spring cold outbreak affected many parts of Europe. This resulted in major damage to grapevines and to orchards growing stone fruits across an area stretching from France to northern Greece. Substantial damage to fruit trees was also reported in parts of Central Europe. In France, frost damage to agriculture was widespread and severe, with losses to vineyards and other crops exceeding US$ 4.6 billion (see Cold spells and snow section).

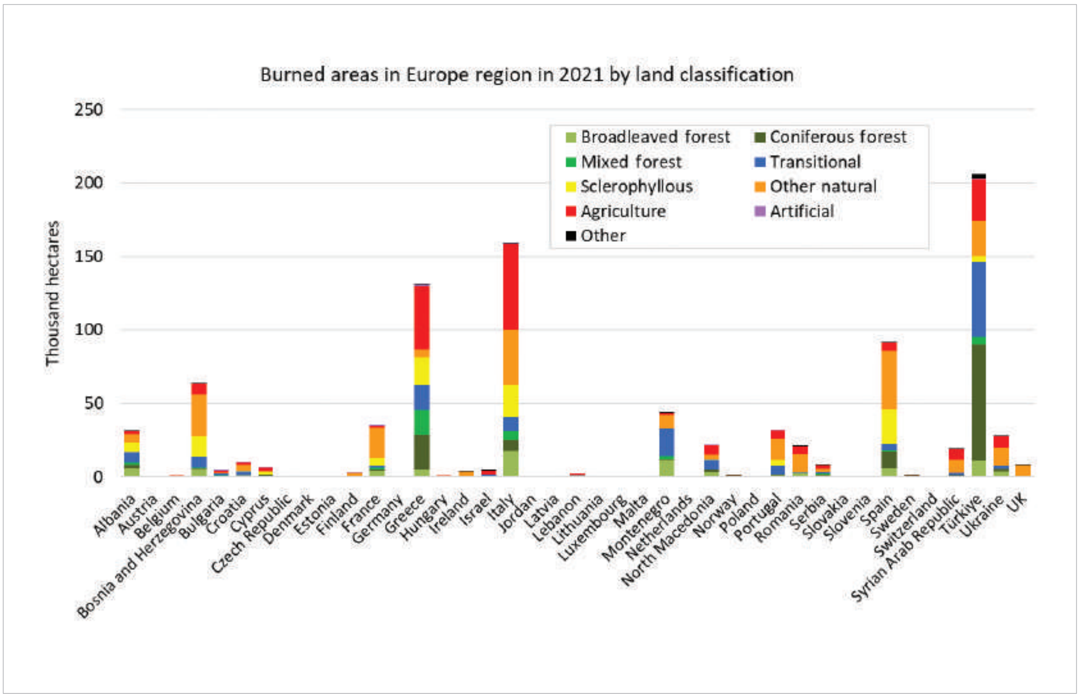

Figure 17. Overview of burned areas in Europe in 2021 by land classification
Source: San-Miguel-Ayanz, J.; Durrant, T.; Boca, R. et al. *Advance Report on Forest Fires in Europe, Middle East and North Africa 2021*; Publications Office of the European Union: Luxembourg, 2022. https://doi.org/10.2760/039729.

CLIMATE CHANGE AND CLIMATE VARIABILITY INDUCED IMPACTS

CLIMATE CHANGE SENSITIVE HEALTH RISKS

This section is based on data for the WHO European Region (please see reference to this domain in Region domain section). People's health in the region is impacted by climate change in a myriad of ways. These include climate change leading to death and illness from increasingly frequent extreme weather events (heatwaves), increases in zoonoses and food-, water- and vector-borne diseases, and mental health issues (Figure 18).

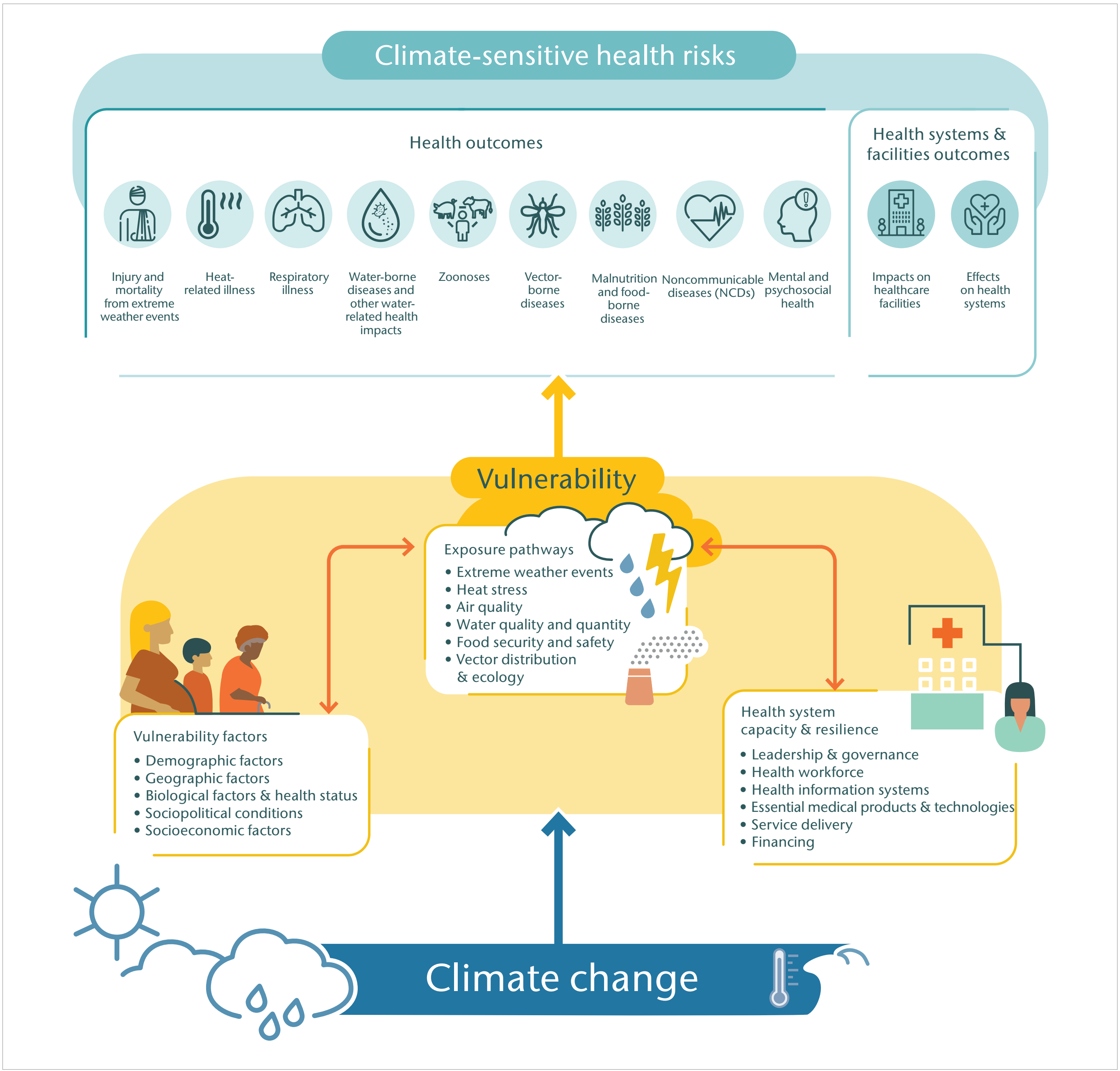

Figure 18. An overview of climate-sensitive health risks, their exposure pathways and vulnerability factors.
Source: World Health Organization (WHO). *COP26 Special Report on Climate Change and Health: The Health Argument for Climate Action*; WHO: Geneva, 2021. https://www.who.int/publications/i/item/9789240036727.

As highlighted at the beginning of this section, the deadliest extreme climate events in Europe are heatwaves, particularly in Western and in Southern Europe. The combination of climate change, urbanization and population ageing in the region creates, and will further exacerbate, vulnerability to heat.[92]

Floods are the most common disaster in Europe. Flooding has widespread and significant health effects over the short term and long term, ranging from drowning and injuries to infectious diseases and mental-health problems. The longer-term health effects result from displacement, physical injuries and psychosocial impact; disruption of access to health and other essential services due to infrastructure damage; and the slow recovery of flood-affected areas.[93]

Climate change-induced alterations in the production and distribution of pollens and spores may lead to increases in allergic disorders. Pollens and spores produced by plants are common allergens. Over 24% of adults living in the European Region suffer from various allergies, including severe asthma, while the proportion among children in the region is 30%–40% and rising.[94] The pollen season in the region has gotten longer due to global warming.[95]

Climate change continues to alter the distribution of vector-borne diseases. Examples include ticks (*Ixodes ricinus*), which can spread Lyme disease and tick-borne encephalitis, the Asian tiger mosquito (*Aedes albopictus*), which can spread Zika, dengue and chikungunya, and the *Phlebotomus* species of sand flies.[96]

WILDFIRES

Wildfire-related pollution and health impacts are recognized by the Sendai Framework for Disaster Risk Reduction as cascading effects that need to be considered in improving risk reduction and sustainable development.[97] Wildfires can have negative impacts on human health across a large range of scales and are likely to contribute to human health impacts across Europe. Fatalities from fires often result from the inhalation of toxic gases, but those directly affected by fire, such as civilians in the immediate vicinity or first responders, can suffer a broad range of physical and mental health impacts related to heat, stress and emissions. Wildfire emissions can also have significant effects on transboundary air quality, and so lead to health impacts regionally and across Europe and beyond.

Most damage from wildfires is due to extreme events that represent less than 2% of the total number of fires.[98] These events, for which neither ecosystems nor communities are adapted, can have significant socioeconomic and ecological consequences. Climate change, human behaviours and other underlying factors are creating the conditions for more frequent, intense and devastating fires in Europe.

AGRICULTURE

Climate variability and change are expected to have a significant impact on global agriculture. Increasing temperatures and changing precipitation patterns can have adverse impacts on the agriculture sector. According to the Food and Agriculture Organization of the United Nations (FAO), negative impacts on crop production including shortening of harvest periods and delays in planting seasons have been experienced in Europe due to adverse weather events.[99] Climate change leads to economic impacts which translate into loss of livelihoods, reduced agricultural production and productivity, adverse effects on food availability and food access, and loss of income, which can contribute to food insecurity as well as leading to hunger and malnutrition, and to food insecurity by extension.

Climate change is changing the distribution, incidence and intensity of animal and plant pests and diseases.[100] In 2021, Italian Locust (CIT) hatching and hopper development continued in Georgia, while CIT breeding continued in the Caucasus and the Russian Federation, and Asian Migratory Locust (LMI) mating and egg-laying continued in the Russian Federation. In total, control operations in 2021 in the Caucasus and Central Asian countries reached around 1.9 million ha by July, which is similar to 2020.[101]

DISPLACEMENTS AND MIGRATIONS

Between 2008 and 2021, the Internal Displacement Monitoring Centre (IDMC) recorded more than 1.23 million displacements triggered by 681 climate, weather and other natural disasters in Europe (Figure 19).[102] Most of them were the result of the impacts of floods (70.8%) and wildfires (20.4%). These figures, however, should be considered underestimates, as there has not been comprehensive monitoring of disaster displacement in the region. In 2021 about 260 000 displacements were recorded, the highest number since start of the data series in 2008 and more than three times the 2008–2020 average.

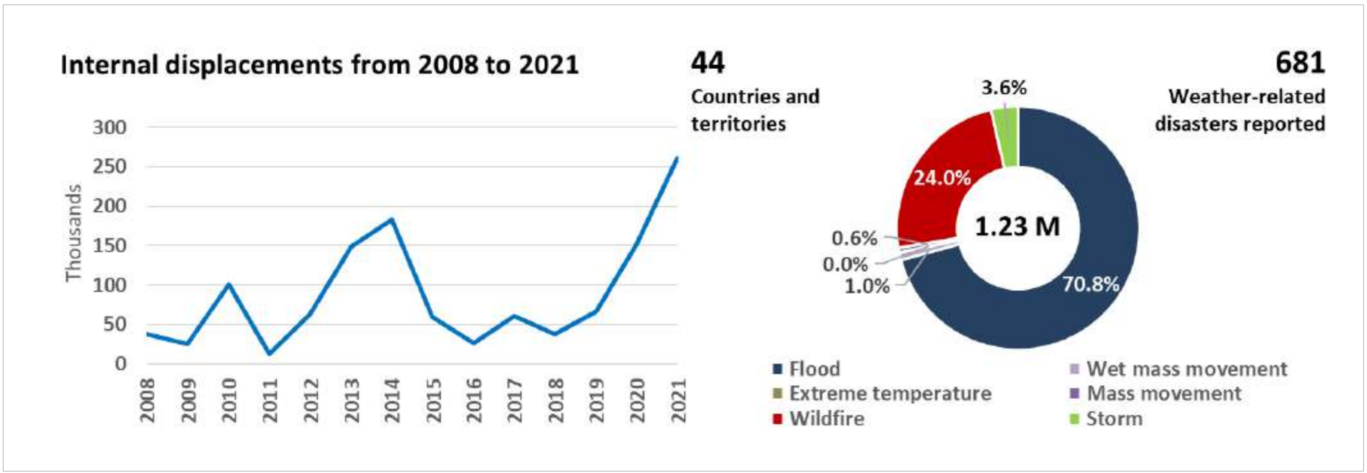

Figure 19. Internal displacements from weather-related disasters, 2008 to 2021, in Europe (WMO Region VI).
Source: Global Internal Displacement Database, IDMC.

Another section of the population which is vulnerable in various aspects, including to hazards, are migrants. European and Central Asian countries are places of transit and destination for diverse, significant international migration flows, originating from within the region, as well as from all other regions in the world. According to estimates by the United Nations Department of Economic and Social Affairs (UNDESA), countries in the region host over 100 million international migrants, or 35% of the world's total. The locations in which many migrants live and transit are often particularly hazardous.

TRANSPORT

Climate variability and change has and will continue to have high impact on transport systems, in terms of both assets (infrastructure) and operations. Transport assets are at risk from both incremental climate change and extreme events (e.g. heatwaves, heavy downpours, high winds and extreme sea levels and waves). Occurrences of extreme events pose a high risk to transport assets, taking into account that these assets were constructed based on historical values for various weather phenomenon thresholds. Figure 20 provides examples of the various possible impacts on transport systems.

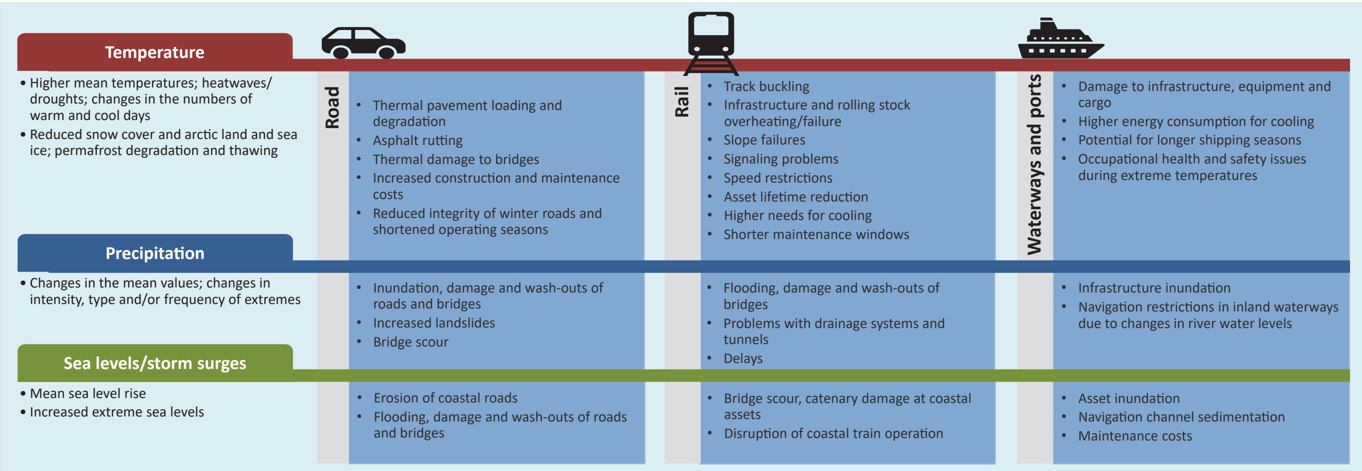

Figure 20. Examples of climate change impacts on transport asserts and operations.
Source: United Nations Economic Commission for Europe (UNECE). *Climate Change Impacts and Adaptation for Transport Networks and Nodes*; United Nations: Geneva, 2020. https://unece.org/sites/default/files/2021-01/ECE-TRANS-283e_web.pdf.

Climate policy and climate action

The Working Group II contribution to IPCC AR6 assessed:

> The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (*very high confidence*).[103]

This statement highlights the interlinkages between mitigation and adaptation. This part of the report gives information about on climate change mitigation and adaptation strategies in Europe.

CLIMATE CHANGE MITIGATION AND ADAPTATION POLICIES

NATIONALLY DETERMINED CONTRIBUTIONS AND CLIMATE LEGISLATION

Nationally determined contributions (NDCs) are at the heart of the Paris Agreement and the achievement of the Agreement's long-term goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. As of March 2022, 194 Parties had submitted an NDC, of which 51 are from Europe, including the EU and its member states. Out of the 51 Parties, 47 have submitted an updated/revised NDC.

In their NDCs, most Parties from the European Region have not prioritized adaptation; only 17 Parties have included an adaptation component in their NDCs, with the majority highlighting agriculture and food security, ecosystems, biodiversity, forestry and health as their top priority areas for adaptation (Figure 21).

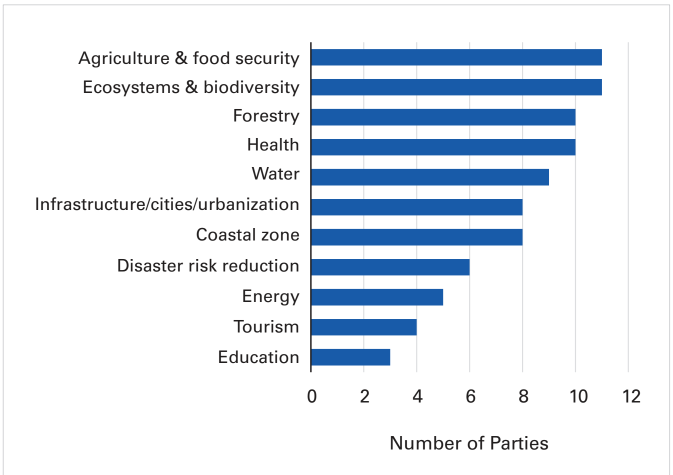

Figure 21. Priority areas for adaptation for the European Region.
Source: WMO analysis of the NDCs of 51 Parties to the Paris Agreement in Europe from 2016 to March 2022 (see also Data sets and methods section).

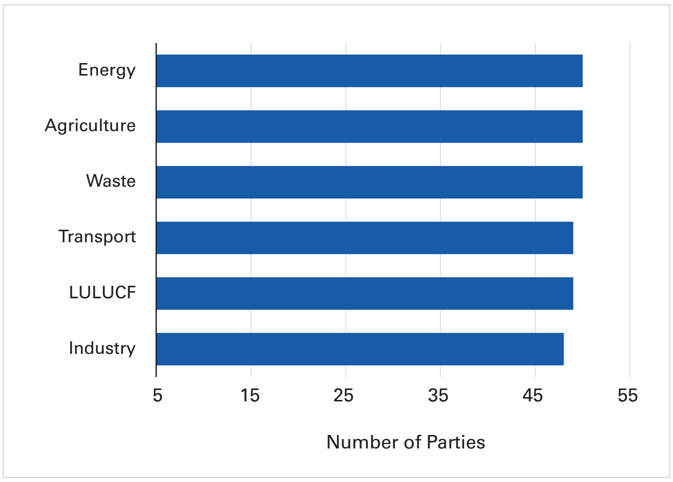

Figure 22. European Parties' priority mitigation sectors. Note: LULUCF – land use, land-use change and forestry.
Source: WMO analysis of the NDCs of 51 Parties to the Paris Agreement in Europe from 2016 to March 2022 (see also Data sets and methods section).

Mitigation of climate change has been a primary focus for many European Parties, as reflected in their NDCs, highlighting the following priority areas: energy supply; agriculture; waste; and land use, land-use change and forestry (LULUCF) as top priorities for mitigation (Figure 22).

In 2021, the EU made climate neutrality (the goal of zero net emissions) by 2050 legally binding in the EU.[104] It set an interim target of reducing emissions by 55% by 2030. The European Green Deal is the roadmap for the EU to become climate neutral by 2050.

The concrete legislation that will allow the EU to reach the Green Deal targets is laid down in the Fit for 55 package that the European Commission presented in July 2021. It will include the revision of existing legislation on emissions reduction and energy. The EU is also working on achieving a circular economy by 2050, creating a sustainable food system and protecting biodiversity and pollinators.

In order to finance the Green Deal, the European Commission presented in January 2020 the Sustainable Europe Investment Plan, which aims to attract at least € 1 trillion of public and private investment over the next decade. Under the investment plan, the Just Transition Fund is designed to support the regions and communities most affected by the green transition, for instance regions that are heavily dependent on coal.

Greenhouse gas emissions in the EU decreased by 31% between 1990 and 2020 – exceeding the EU's 2020 target by 11 percentage points. This overshoot was propelled by steep emissions cuts in 2019 and 2020.[105] While the cut in 2019 was strongly driven by fossil fuel price effects (use of less carbon-intensive fuels) and policy measures, the decline in 2020 was additionally related to the COVID-19 pandemic, and 2021 emissions in the EU are expected to be higher than in 2020. EU greenhouse gas emissions are projected to further decline until 2030. Member States have not yet realigned their ambitions to the new net 55% reduction target for 2030, and the further implementation of impactful policies and measures will be important to bring the new 2030 target within reach (Figure 23).[106] In other countries of the region, reductions targets for 2030 range in general from 35% to 55% compared with 1990.

The table lists examples of NDC mitigation targets (as of 31 December 2021), for each country.

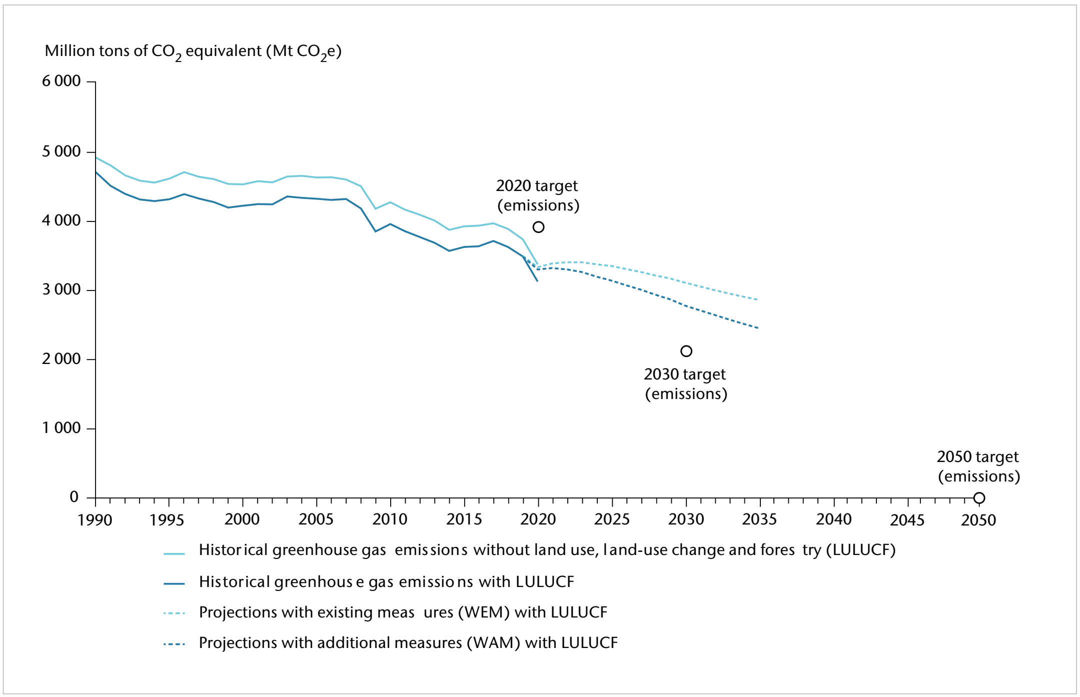

Figure 23. Historical trends and future projections of greenhouse gas emissions in the EU.[107]

Table. NDC mitigation targets

Country (and EU)	Unconditional NDC	Conditional NDC
Albania	11.5% emissions reduction compared with 2016 emissions by 2030	
Armenia	40% reduction from 1990 emission levels by 2030	
Azerbaijan	35% emissions compared with 1990	
Belarus	At least 28% reduction from 1990 levels by 2030	
Bosnia and Herzegovina	12.8% reduction compared with 2014 (or 33.2% reduction compared with 1990) by 2030	17.5% reduction compared with 2014 (or 36.8% compared with 1990) by 2030
European Union (EU)	55% emission reduction by 2030, compared with 1990	
Georgia	35% reduction compared with 1990 by 2030	50%–57% reduction compared with 1990 if global emissions follow the 2 °C or 1.5 °C scenarios respectively, with international support
Iceland	55% reduction by 2030 compared with 1990	
Montenegro	At least 35% emissions reduction by 2030 compared with 1990	
North Macedonia	51% emissions reduction compared with 1990 by 2030	
Norway	Emissions reduction of at least 50% and towards 55% compared with 1990 levels by 2030	
Republic of Moldova	64%–67% to 70% below 1990 level in 2030	78% below its 1990 level
Russian Federation	Limiting GHG emissions to 70% (including LULUCF) of 1990 levels by 2030	
Serbia	Reducing GHG emissions by 9.8% by 2030 compared with 1990 levels	
Switzerland	Emissions reduction of 50% compared with 2010 levels by 2030 and to achieve carbon neutrality by 2050	
Türkiye	Up to 21% reduction in GHG emissions from the BAU level by 2030	
Ukraine	Emissions reduction of 65% compared with 1990 by 2030 (including LULUCF)	

Note: BAU – business as usual; GHG – greenhouse gas.
Source: Van 't Wout, T.; Celikyilmaz, G.; Arguello, C. *Policy Analysis of Nationally Determined Contributions in the Europe and Central Asia Region*; Food and Agriculture Organization of the United Nations (FAO): Budapest, 2021, FAO. https://doi.org/10.4060/cb7745en.

POLICY ACTION ON HEALTH

Over the past 60 years, greenhouse gas emissions have continued to increase, and efforts to address the health risks associated with climate change are progressing slowly and insufficiently. For example, according to the WHO Regional Office for Europe, about 500 000 premature deaths in the WHO European Region (see Region domain section) were caused by anthropogenic fine particle ambient air pollution in

2019 (last available data), of which a large part was directly linked to the burning of fossil fuels. Transition to a zero-carbon economy could bring a range of near- and long-term health gains, which provide a key hook to the policy debate on climate risks, mitigation and adaptation. An analysis of multiple benefits of mitigation action has estimated that about 138 000 premature deaths could be avoided per year through reduced carbon emissions, potentially resulting in savings of US$ 244–US$ 564 billion.[108,109,110]

WHO/Europe guidance supports national and local authorities in essential preparation for extreme heat events. When they are operational, comprehensive heat-health action plans have been shown to save lives and strengthen the resilience of communities and people to cope during extreme heat. Several European countries have implemented heat health action plans to prevent ill health and excess mortality from heat.

POLICY ACTION FOR CHILDREN

Children are more vulnerable to the impacts of climate change than adults, both physically and psychologically. Climate and environmental hazards negatively affect children's access to key essential services, thus reducing their resiliency and adaptive capacity. In 2021, over 99% of children worldwide were exposed to at least one climate hazard.

The United Nations Children's Fund (UNICEF) Children's Climate Risk Index (CCRI)[111] provides a comprehensive overview of children's exposure and vulnerability to the impacts of climate change worldwide. According to the CCRI, nearly 125 million children in WMO Region VI live in 'Medium–High' risk countries, the third of five levels of classification used globally (ranging from Low to Extremely High) (Figure 24).[112] The index also shows that children in the region are exposed in particular to heatwaves, water scarcity, riverine floods and high coastal flooding risk.

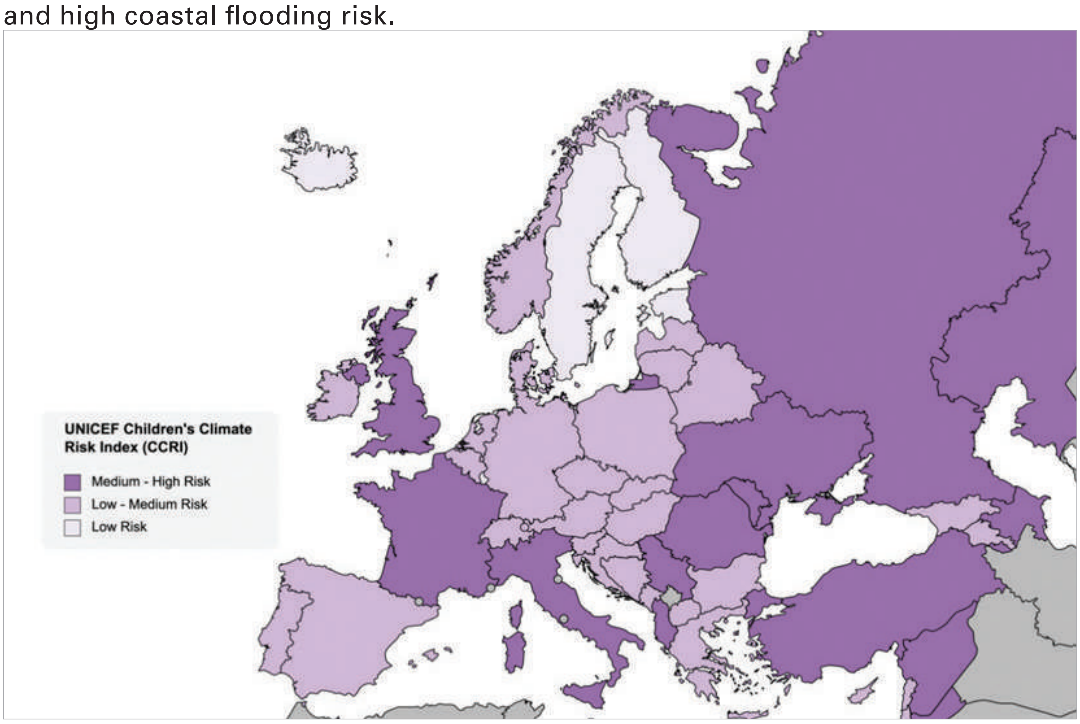

Figure 24. UNICEF Children's Climate Risk Index for countries in WMO Region VI (updated in 2021). *Source:* United Nations Children's Fund (UNICEF). *The Climate Crisis is a Child Rights Crisis: Introducing the Children's Climate Risk Index*; UNICEF: New York, 2021. https://www.unicef.org/reports/climate-crisis-child-rights-crisis.

Access to a safe, clean, healthy and sustainable environment is essential for children's physical, mental and social development. Ambient air pollution is a major cause of disease and premature death in the region, and for children, these risks are magnified. In WMO Region VI, over 157 million children are exposed to ambient air pollution ($PM_{2.5}$) levels above 10 $\mu g/m^3$.[113,114,115,116,117]

Climate change also impacts the mental well-being of children and youth.[118] A 2016 UNICEF poll[119] conducted in 60 countries found that 77% of children and youths believe that climate change is one of the most pressing issues for young people – and 98% want governments to take urgent action to tackle the issue.[120]

As the frequency and intensity of natural hazards increases, the need to build resilience among children and youth to withstand and overcome cumulative stresses and shocks becomes important.

The NDCs are an important mechanism to protect children and youth from the impacts of climate change. A recent UNICEF study analysed 103 NDCs in countries with UNICEF programmes that were submitted by 21 October 2021 to assess whether or not they were child sensitive.[121] The analysis found that out of those countries analysed in WMO Region VI, Georgia and Jordan have child-sensitive NDCs.[122]

The identified impacts on children's well-being call for action on making climate change and environmental policies child and youth sensitive and mainstreaming disaster risk reduction (DRR) and climate change adaptation into primary and secondary school curricula and education legal frameworks.

The Intergovernmental Declaration on Children, Youth and Climate Action is an opportunity to accelerate inclusive, child- and youth-centred climate policies. In WMO Region VI, Bulgaria, Denmark, Hungary, Luxembourg, Malta, Monaco, the Netherlands, North Macedonia, Norway, Sweden, Slovenia and Spain have signed the declaration.[123]

CLIMATE SERVICES, MULTI-HAZARD RISK-INFORMATION SYSTEMS, TRANSBOUNDARY COOPERATION AND OTHER ADAPTATION STRATEGIES

The European Forum for Disaster Risk Reduction (EFDRR) Roadmap 2021–2030,[124] endorsed by the member States of the Council of Europe in 2021, identifies challenges, lessons, opportunities and pathways to support more risk-informed and inclusive regional, national and local DRR policies, strategies, actions and systems for regional collaboration and shared learning.[125]

Within the WMO Region VI, 39 countries have reported having national and local DRR strategies in place, in accordance with Target E of the Sendai Framework for Disaster Risk Reduction.[126] All 39 countries have also reported that their strategies promote policy coherence and compliance, notably with the United Nations Sustainable Development Goals and the Paris Agreement, while 33 have reported that they have made progress on adopting and implementing local DRR strategies in line with national strategies.[127] While these numbers are based on voluntary reporting, and may provide an underestimate of true values, more progress must be made to fulfil the Sendai Framework target on ensuring coherence and integration of national adaptation plans with DRR strategies, as well as ensuring that local strategies are implemented in line with national ones. Examples of successful integration of DRR and climate change adaptation can be found in the United Nations Office for Disaster Risk Reduction (UNDRR) *Recommendations for a Revised EU Strategy on Climate Change Adaptation*.[128]

CLIMATE SERVICES CAPACITIES

Based on WMO data from 43 countries for which data are available (86% of WMO Region VI Members), Europe faces capacity gaps mostly in the monitoring and evaluation component. On average, only 28% of Members monitor and evaluate benefits of climate services (Figure 25).

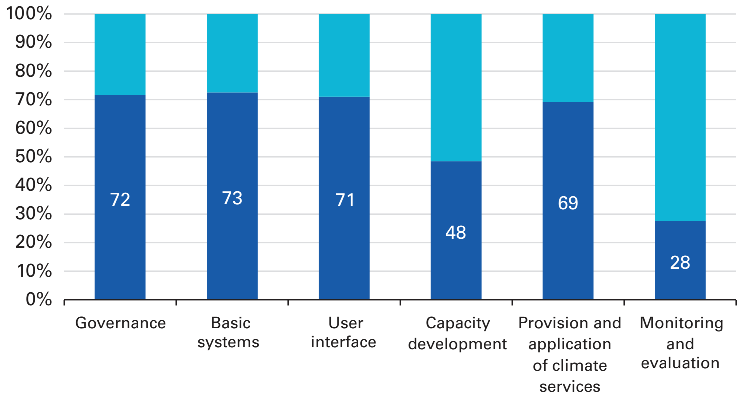

Figure 25. Percentages of functionalities satisfied in value chain components based on data from 43 countries in WMO Region VI. Note: M&E – monitoring and evaluation of socioeconomic benefits of climate services (see also Data sets and methods section).

EARLY WARNING CAPACITY

Based on data from 36 countries (72% of the Members in the region), WMO Members in Europe have an above-average capacity to deliver on all their early warning system (EWS) needs, especially for warning communication and dissemination. Half of Members reported having a multi-hazard early warning system (MHEWS) in place and 75% of people are covered by early warnings in countries where data are available (Figure 26). Monitoring and evaluation of socioeconomic benefits is an area that requires strengthening (Figure 27).

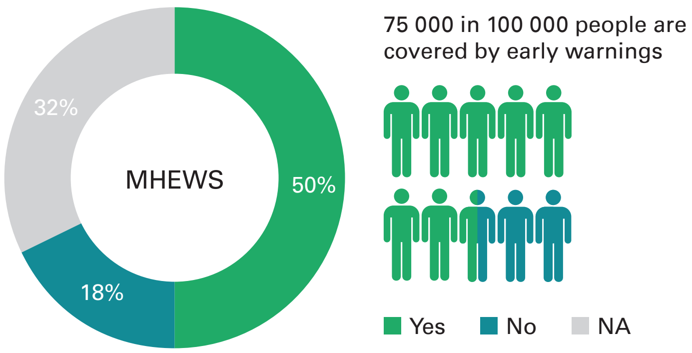

Figure 26. Percentage of the 50 WMO Members in Region VI that reported having a MHEWS in place. *Source: 2020 State of Climate Services: Risk Information and Early Warning Systems* (WMO No. 1252).

Moreover, 44% of countries are using the Common Alerting Protocol (CAP), which is key to supporting standards-based, all-hazards, all-media public alerting (Figure 27).

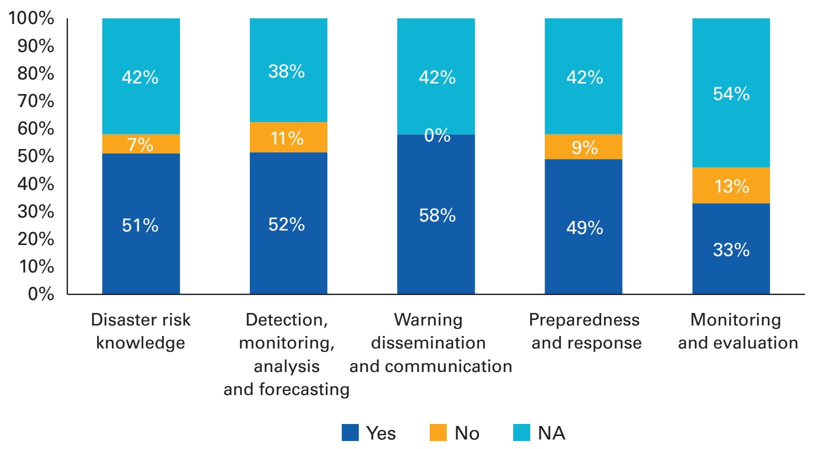

Figure 27. EWS capacities in Europe, by value chain component, calculated as a percentage of functions satisfied in each component area, across the 50 WMO Members in Region VI.
Source: 2020 State of Climate Services: Risk Information and Early Warning Systems (WMO No. 1252).

HYDROLOGICAL CAPACITIES

WMO data from 34 countries (68% of the Members in the region) show that the hydrological capacities of Members in Europe are generally good, though there are some capacities that need improving (Figure 28).

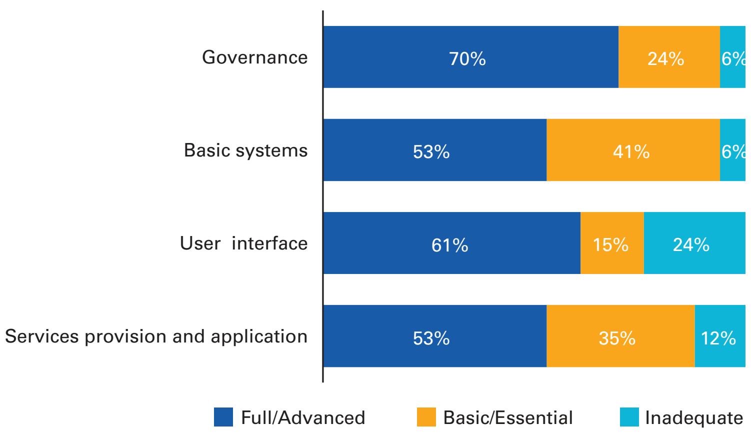

Figure 28. WMO Member capacities across the value chain in Europe, by component, calculated as a percentage of functions satisfied in each component area, across 34 WMO Members providing data, categorized as Inadequate (0%–33%), Basic/Essential (34%–66%), and Full/Advanced categories (67%–100%) of functions satisfied, respectively.
Source: 2021 State of Climate Services: Water (WMO No. 1278).

Seven WMO Members in this region out of the 34 providing data reported having inadequate end-to-end riverine flood forecasting services, whereas 16 Members were providing those services at a Full/Advanced capacity level (Figure 29). Thirteen Members reported having inadequate end-to-end flash flood forecasting services; this is an especially important issue, as in the last 50 years (1970–2019) 38% of the weather, water and climate disasters were flood-related. In addition, 17 Members indicated that they had inadequate end-to-end drought forecasting/warning systems, and only six were providing those services at a Full/Advanced capacity level.

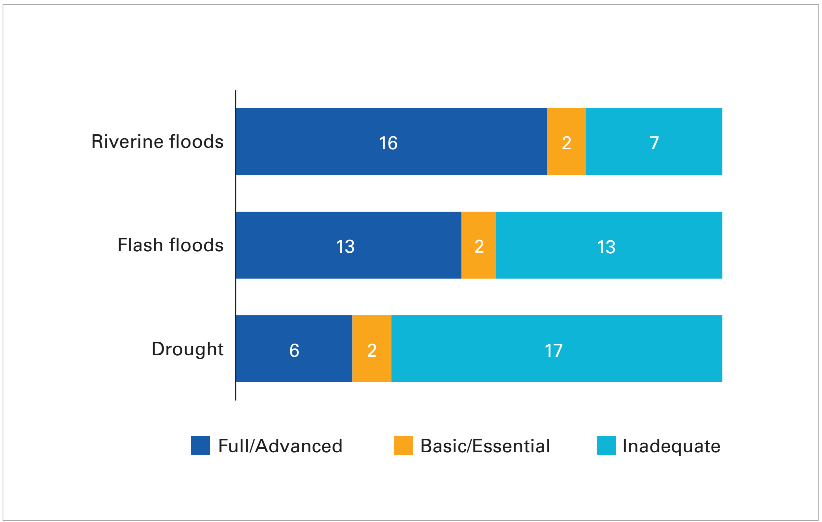

Figure 29. Number of WMO Members in Europe with early warnings available to the population at risk, by hazard type, based on data from WMO Members providing data. For categorization information see Figure 28.
Source: *2021 State of Climate Services: Water* (WMO No. 1278).

TRANSBOUNDARY COOPERATION IN CLIMATE CHANGE ADAPTATION

Climate impacts do not recognize borders, and 60% of global freshwater flow is in transboundary basins shared by 153 countries. Thus, transboundary cooperation is crucial to address climate change more efficiently and to prevent possible negative impacts of unilateral measures.[129]

The European Region is quite advanced in transboundary cooperation in climate change adaptation. For example, such basins as the Danube, the Dniester, the Neman and the Rhine have developed and are implementing transboundary adaptation strategies and plans. Others, such as the Drin, the Meuse and the Sava integrate climate change issues while developing their river basin management and flood risk management plans.[130] The following examples illustrate this cooperation:

- The International Commission for the Protection of the Danube River updated its transboundary adaptation strategy in 2018, and the new Danube River Basin Management Plan incorporated the effects of climate change as a “Significant Water Management Issue” in 2021.

- The International Commission for the Protection of the Rhine integrated climate change adaptation into its third river basin management plan and its second flood risk management plan (adopted in the beginning of 2022 and in December 2021, respectively).

- The Strategic Framework for Climate Change Adaptation and its Implementation Plan were developed for the Dniester basin and endorsed by the riparian countries in 2015 and 2017, respectively. Taking these documents as a reference the Dniester Commission develops and implements activities on climate change and DRR within the relevant working groups and integrates climate change adaptation into the future RBMP.[131]

The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention)[132] supports cooperation in the aforementioned basins and others. Although Europe is one of the most advanced regions in transboundary climate change adaptation, there is still room for improvement. For example, financing climate change adaptation remains a challenge.[133]

Observational basis for climate monitoring

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

In 1992, the Global Climate Observing System (GCOS) was established jointly by WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Science Council (ISC) to coordinate and facilitate the development and improvement of global climate observations. GCOS has identified a set of Essential Climate Variables (ECVs)[134] that together provide the information necessary to understand, model and predict the trajectory of the climate as well as plan mitigation and adaptation strategies.

ECVs are physical, chemical or biological variables or a group of linked variables that critically contribute to the characterization of Earth's climate system and include atmospheric, oceanic and terrestrial components. GCOS currently specifies 54 ECVs (see Figure 30).

ECV data sets provide the empirical evidence needed to understand and predict the evolution of the climate, to guide mitigation and adaptation measures, to assess risks and enable attribution of climate events to underlying causes, and to underpin climate services. They are required to support the work of UNFCCC and IPCC.

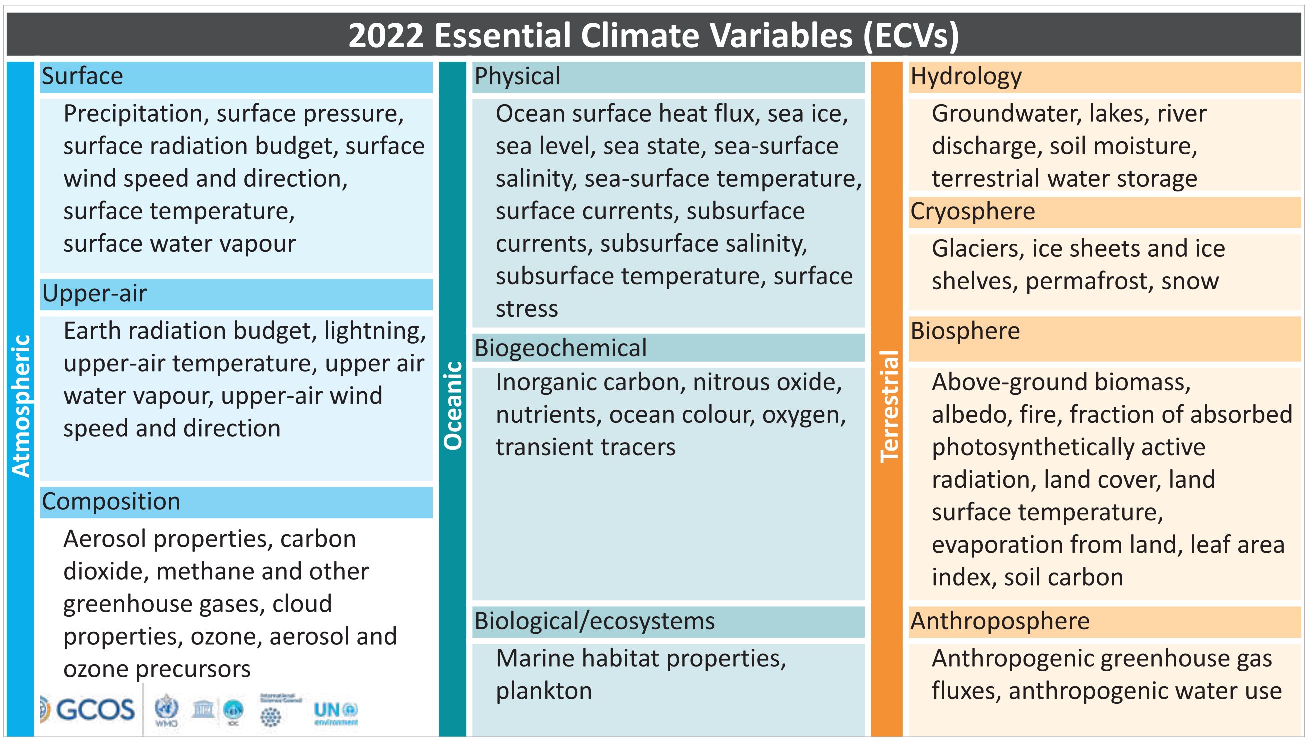

Figure 30. Essential Climate Variables (ECVs) identified by GCOS.
Source: The 2022 GCOS Implementation Plan.

Data sets and methods

REGION DOMAIN

The focus of this report is the WMO Region VI, the extent of which can be seen on the map in Figure 31.

Where possible, numbers for Europe refer to this region; however, in some cases aggregated data refer for other similar but slightly different regions, such as the European Union,[135] WHO European Region[136] or UNECE region.[137] Where this is the case, the region name is explicitly mentioned.

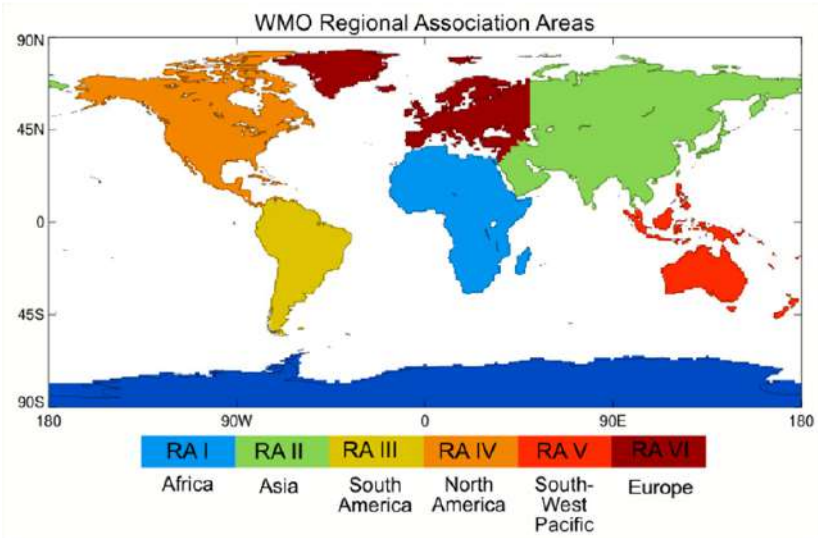

Figure 31. Map of WMO Regional Association (RA) Areas. WMO Region VI is the focus of this report. [138,139]

TEMPERATURE

Six data sets (cited below) were used in the calculation of regional temperature. Regional mean temperature anomalies were calculated relative to 1961–1990 and 1981–2010 baselines using the following steps:

1. Read the gridded data set;

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

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

4. For each year take the mean of the monthly area averages to get 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 to get anomalies relative to that base period.

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 have not been computed for ERA5 as it is currently not used for regular monitoring for data prior to 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*, 3469–3479. https://doi.org/10.5194/essd-12-3469-2020. Data

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. Data

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. Data

HadCRUT.5.0.1.0 – 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* (3), e2019JD032361. https://doi.org/10.1029/2019JD032361. Data

JRA55 – Kobayashi, S.; Ota, Y.; Harada, Y. et al. The JRA55 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, https://www.jstage.jst.go.jp/article/jmsj/93/1/93_2015-001/_article. Data

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: 10.25921/9qth-2p70. 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. Data

Temperature in situ data from National Meteorological and Hydrological Services.

PRECIPITATION

GPCC: see website https://gpcc.dwd.de for description of the GPCC datasets.

Precipitation in situ data from National Meteorological and Hydrological Services.

GLACIERS

The cumulative mass balance estimates considered here are based on long-term in situ observations, which are compiled by the World Glacier Monitoring Service (WGMS) in annual calls for data from a scientific collaboration network across more than 40 countries worldwide. The estimates given here are from a subset of global and European reference glaciers (WGMS 2021, updated and earlier reports).

GREENLAND ICE SHEET

The Greenland Ice Sheet time-series of mass change is compiled from 27 satellite-based estimates of ice sheet mass balance as part of the Ice Sheet Mass Balance Inter-comparison Exercise (IMBIE) (http://imbie.org/) and is freely available at https://data.bas.ac.uk/metadata.php?id=GB/NERC/BAS/PDC/01477.

SEA-SURFACE TEMPERATURE

Four gridded datasets for sea-surface temperature were used:

ERSSTv5: Data and Documentation

ESA CCI/C3S SST Climate Data Record v2.1: Data and Documentation

HadISST1: Data and Documentation

HadSST.4.0.1.0: Data and Documentation

SEA ICE

The sea ice section uses data from the EUMETSAT OSI SAF Sea Ice Index v2.1 (OSI-SAF, based on Lavergne et al. (2019)), as well as Baltic Sea ice data from the Finnish, Swedish and German Baltic ice Services. Sea-ice extent is calculated as the area of ocean grid cells where the sea-ice concentration exceeds 15%.

EUMETSAT OSI SAF Sea Ice Index v2.1: Data and Documentation

Finnish sea-ice winter description: https://en.ilmatieteenlaitos.fi/ice-winter-2020-2021

German sea-ice winter description: https://www.bsis-ice.de/Beschreibung_Eiswinter2021/Eiswinter2021en.html

OCEAN HEAT CONTENT

CMEMS ocean heat content monitoring indicator:

https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/global-ocean-heat-content-trend-map-reanalysis-multi

https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/global-ocean-heat-content-0-2000m-time-series-and-trend

SEA LEVEL

CMEMS sea level monitoring indicator:

https://climate.copernicus.eu/climate-indicators/about-data#Sealevelindicator

https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/global-ocean-mean-sea-level-trend-map-observations

MAJOR CLIMATE DRIVERS OF THE REGION

http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.ERSST/.version5/ anom/dataselection.html

DROUGHT

GPCC data (https://gpcc.dwd.de and https://www.dwd.de/EN/ourservices/rcccm/int/rcccm_int_spi.html), in situ data from National Meteorological and Hydrological Services, information from WMO RA VI RCC-Network

Offenbach Node on Climate Monitoring (RCC Node-CM) (https://www.dwd.de/EN/ourservices/rcccm/int/rcccm_int_sse.html)

WILDFIRES

Information from RA VI RCC Node-CM: https://www.dwd.de/EN/ourservices/rcccm/int/rcccm_int_sse.html

EFFIS burned area index for Europe: https://effis.jrc.ec.europa.eu/apps/effis.statistics/estimates/EU/2021/2006/2020

COLDS SPELLS AND SNOW

In situ data from National Meteorological and Hydrological Services.

SEVERE STORMS WITH STRONG WINDS

Wind in situ data from National Meteorological and Hydrological Services.

EM-DAT DATA

EM-DAT data were used for historical climate impact calculations – (EM-DAT, CRED/UCLouvain, Brussels, Belgium – http://www.emdat.be)

EM-DAT is a global database on natural and technological disasters, containing essential core data on the occurrence and effects of more than 21 000 disasters around the world, from 1900 to 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 are total deaths, number affected and total damages (‘000 US$), respectively.

CLIMATE SERVICES

The WMO RA VI Regional Climate Centre (RCC) Network provides data, climate monitoring and long-range forecasting services to the WMO Members in the region. Access to the services is via https://www.rccra6.org.

The Copernicus Climate Change Service (C3S) provides data and climate monitoring for Europe, the Arctic and the globe. Key monitoring products include the monthly Climate Bulletin and the annual European State of the Climate report.

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

WMO analysis of NDCs (based on the WMO analysis of Parties’ NDCs and further complemented by the UNFCCC synthesis report): UNFCCC, 2021: Nationally Determined Contributions (NDC) under the Paris Agreement.

Checklist for Climate Services Implementation (Members’ climate services capacity, based on responses to this Checklist, can be viewed Here under tab "Services")

WMO Hydrology Survey, 2020

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

List of contributors

MEMBERS' NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES (NMHSS)

Andorra, Armenia, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Ireland, Israel, Italy, Jordan, Kazakhstan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, North Macedonia, Norway, Poland, Portugal, Republic of Moldova, Romania, Russian Federation, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Syrian Arab Republic, Türkiye, Ukraine, United Kingdom

ORGANIZATIONS

Administration des services techniques de l'agriculture, Luxembourg (ASTA); Bundesamt für Seeschifffahrt und Hydrographie (BSH), Germany; Bureau of Meteorology (BoM) Australia; Centre National d'Études Spatiales (CNES) France; Collecte Localisation Satellites (CLS), France; Copernicus Climate Change Service, European Centre for Medium-Range Weather Forecasts (C3S, ECMWF); Food and Agriculture Organization of the United Nations(FAO); Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), France; Mercator Ocean international, France; Deutscher Wetterdienst (DWD), Germany; Met Office Hadley Centre, UK; "Hydrometeorology and Monitoring Center" SNCO of the Ministry of Environment ("HMC" SNCO), Armenia; National Oceanic and Atmospheric Administration (NOAA), USA; United Nations Office for Disaster Risk Reduction (UNDRR); United Nations Economic Commission for Europe (UNECE); United Nations Children's Fund (UNICEF); University of Leeds, UK; University of Reading, UK; World Glacier Monitoring Service (WGMS); World Health Organization (WHO)

INDIVIDUAL CONTRIBUTORS

Andrew Ferrone (coordinating lead author, ASTA), Stefan Rösner (coordinating lead author, DWD) Freja Vamborg (coordinating lead author, ECMWF), Peter Bissolli (lead author, DWD), Vladimir Kendrovski (lead author, WHO), John Kennedy (lead author, UK MetOffice), Benoit Meyssignac (lead author, LEGOS), Inès Otosaka (lead author, University of Leeds), Tania Santivanez (lead author, FAO), Karina von Schuckmann (lead author, Mercator Ocean), Gerard van der Schrier (lead author, KNMI), Michael Zemp (lead author, University of Zurich, WGMS), Markus Ziese (lead author, DWD), Levon Azizyan (HMC), Omar Baddour (WMO), David Baker (UNDRR), Natalia Berghi (WMO), Jessica Blunden (NOAA), Roxana Bojariu (Meteo Romania), Antonio Bombelli (WMO), Roberta Boscolo (WMO), Milan Dacic (WMO), Anny Cazenave (CNES), Sarah Diouf (WMO), Martina Duncan (FAO), Yannice Faugere (CLS), Veronica Grasso (WMO), Atsushi Goto (WMO), Sophie Hearn (UNICEF), Jürgen Holfort (BSH), Flora Gues (Mercator Ocean), Yelena Khalatyan (HMC), Sari Lappi (WMO), Peer Hechler (WMO),Thomas Lavergne (Met.no), David Lavers (ECMWF), Renata Libonati (UFRJ-IGEO), Belén Martín Míguez (WMO), Jens Möller (BSH), Nakiete Msemo (WMO), Virag Nagypal (FAO), Julien Nicolas (ECMWF), Tim Oakley (WMO), Maria Osbeck (UNICEF), Frank Paul (University of Zurich, WGMS), Hanna Plotnykova (UNECE), Claire Ransom (WMO), Nirina Ravalitera (WMO), Anthony Rea (WMO),Reinhard Schiemann (University of Reading), Serhat Sensoy (TSMS), Andrew Shepherd (University of Leeds), Jose Alvaro Silva (WMO), Robert Stefanski (WMO), Tamara VantWout (FAO), Caterina Tassone (WMO), Blair Trewin (BOM), Lukasz Wyrowski (UNECE)

Endnotes

1 Data are from six different data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA55. For details of the data sets and processing see Data sets and methods.

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5 See https://www.metoffice.gov.uk/hadobs/monitoring/regional/wmo_ra_vi.html for graphic showing the trend for the globe and different WMO regions for different 30-year periods. Temperatures for the WMO regions are defined over land only, while global temperatures are defined over all surfaces.

Similar findings, based on slightly different regional definitions can be found for example in Figure 1 and Table 1 of https://wcd.copernicus.org/articles/3/777/2022/.

6 Defined over all land within the WMO Region VI (see map in Data sets and methods section). This region includes Greenland in the west and extends further east by almost 20° longitude compared to the definition of Europe used for the C3S European State of the Climate 2021 and the EEA temperature indicator. Thus some differences in ranking are to be expected.

7 The range and mean of anomalies relative to the two different baselines (1961–1990 and 1981–2010) are based on different sets of data as anomalies relative to 1961–1990 cannot be computed for ERA5. This can lead to apparent inconsistencies.

8 Based on time series analyses of GPCC products.

9 For a brief overview of the cryosphere and its components, see https://climate.copernicus.eu/climate-indicators/cryosphere. For comprehensive overviews on the state of knowledge concerning all components of the cryosphere, see IGOS (2007), Lemke et al. (2007), UNEP (2007), IPCC AR5 (2013), IPCC SROCC (2019) and IPCC AR6 (2021).

10 The estimate of global glacier mass loss used here is based on assessments of international research teams (Zemp et al. 2019, 2020) combining glaciological field observations with geodetic satellite measurements as compiled by the World Glacier Monitoring Service (WGMS 2021, updated and earlier reports).

11 As the Greenland Ice Sheet covers a vast area of 1.7 million km^2 (Morlighem et al., 2017), only satellite observations can provide ice-sheet-wide monitoring of its mass changes. The estimate of Greenland Ice Sheet mass balance used here is the IMBIE estimate updated to 2021, which is the result of the combination of 27 satellite-based ice sheet mass balance estimates, derived from satellite observations of ice sheet volume change from satellite altimetry, changes in the ice sheet's gravitational field from satellite gravimetry, and changes in ice velocity combined with a model estimate of surface mass balance from the input–output method (Shepherd et al., 2020).

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17 Defined as all ocean surfaces in the latitude-longitude box *35°–70°N, 25°W–40°E*. Graphics and information for SST of the European regional seas can be found under https://climate.copernicus.eu/climate-indicators/sea-surface-temperature.

18 The 1981–2010 reference period is not available for this dataset.

19 Based on satellite measurements, which provide the most spatially complete estimate for SST. There are known issues with the dataset prior to 1993, and hence it is not possible to use it for ranking before this date. However, these issues are not substantial enough during 1991/1992 to significantly affect the calculation for the reference period. Therefore, the 1991–2020 reference period is kept in order to provide a full 30-year period.

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WORLD METEOROLOGICAL ORGANIZATION

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

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

Email: cpa@wmo.int

public.wmo.int

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