United in Science 2023

SUSTAINABLE DEVELOPMENT EDITION

A multi-organization high-level compilation of the latest weather-, climate- and water-related sciences and services for sustainable development

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This report was compiled by the World Meteorological Organization (WMO) under the direction of the United Nations Secretary-General to bring together the latest climate science-related updates from key global partner organizations with a focus on weather-, climate- and water-related sciences and services for sustainable development. The content of each chapter is attributable to each respective organization.

The report is available electronically at: https://library.wmo.int/idurl/4/68235

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Foreword by António Guterres, Secretary-General of the United Nations

2023 has shown all too clearly that climate change is here. Record temperatures are scorching the land and heating the sea, as extreme weather causes havoc around the globe. While we know this is just the beginning, the global response is falling far short. Meanwhile, halfway to the 2030 deadline for the Sustainable Development Goals (SDGs), the world is woefully off track.

Science is central to solutions.

It is widely understood that weather-, climate- and water-related sciences provide the underpinnings for climate action. But it is less recognized how these sciences can supercharge progress on the SDGs across the board.

This report aims to change that – illustrating how weather-, climate- and water-related sciences can advance aims such as food and water security, clean energy, better health, sustainable oceans and resilient cities.

As the report shows, for example, weather predictions help boost food production and move us closer to zero hunger. Integrating epidemiology and climate information helps us to understand and anticipate those diseases sensitive to climate. And early warning systems help to reduce poverty by giving people the chance to prepare and limit the impact of extreme weather on their livelihoods.

The evidence is clear: uniting in science helps ignite progress for people and planet. Let us heed the lessons of this report and harness the power of science to build a cleaner, safer, more sustainable future for us all.

A. Guterres
Secretary-General,
United Nations

Foreword by Prof. Petteri Taalas, Secretary-General of the World Meteorological Organization

The science is clear – the planet is far off track from reaching global climate goals and the 2030 Agenda.

July 2023 was the hottest month ever recorded, and it is likely 2023 will be one of the warmest years on record. This has been a year of extremes with exceptional heatwaves, scorching wildfires, torrential rains and devastating tropical cyclones.

Observed global surface temperature in 2013–2022 reached 1.15 °C above pre-industrial levels (1850–1900), yet greenhouse gas emissions continue to rise. Urgent and ambitious action is needed to mitigate global warming and adapt to the adverse impacts of climate change and extreme weather events, which disproportionately impact vulnerable communities and threaten achievement of the Sustainable Development Goals (SDGs).

However, weather-, climate- and water-related sciences and services are an underutilized tool that can help accelerate progress towards achieving the SDGs. Groundbreaking scientific and technological advances, such as high-resolution climate modelling, artificial intelligence and nowcasting, can catalyse transformation in support of the SDGs. And achieving Early Warnings for All by 2027 will not only save lives and livelihoods but also help safeguard sustainable development.

At this pivotal moment in history, the halfway mark to achieving the SDGs, the science community stands united in the effort to achieve prosperity for people and the planet. I thank the many multidisciplinary expert teams involved in creating this report to highlight the crucial role of weather-, climate- and water-related science and services for sustainable development.

Prof. P. Taalas
Secretary-General, WMO

EXECUTIVE SUMMARY

We stand at a pivotal point in history – the halfway mark for achieving the 2030 Agenda for Sustainable Development. With only 15% of the Sustainable Development Goals (SDGs) on track, we are down at half-time and far from meeting global climate goals. The most recent *Sustainable Development Goals Report 2022* highlights the increasing impacts of climate change and extreme weather events, along with other interlinking global challenges, which are setting back development gains and threatening the full achievement of the SDGs by 2030.

At the half-time point of the 2030 Agenda, the science is clear – the planet is far off track from meeting its climate goals

Anthropogenic climate change has resulted in widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere, affecting many weather and climate extremes, with adverse impacts and related losses and damages to nature and people (IPCC, 2023). The years from 2015 to 2022 were the eight warmest years on record, and the chance of at least one year exceeding the warmest year on record (2016) in the next five years is 98%. With a warm start to 2023 and the emergence of the El Niño phenomenon, there is an increased likelihood that 2023 will be among the warmest years on record. In addition, the chance of the annual mean global near-surface temperature temporarily exceeding 1.5 °C above pre-industrial levels for at least one of the next five years is 66% and is increasing with time.

There has been very limited progress in reducing the emissions gap for 2030 – the gap between the emissions reductions promised by countries and the emissions reductions needed to achieve the temperature goal of the Paris Agreement. To get on track to meet the Paris Agreement goals of limiting warming to well below 2 °C and preferably 1.5 °C, global greenhouse gas emissions must be reduced by 30% and 45%, respectively, by 2030, with carbon dioxide (CO_2) emissions getting close to net zero by 2050, compared with current policy projections.

Urgent and ambitious mitigation and adaptation action is needed. Limiting global warming will require large-scale, rapid and systemic transformations to reach net zero anthropogenic CO_2 emissions, and adaptation is crucial to reduce the adverse impacts of climate change and prevent loss and damage. Some future changes in climate are unavoidable, and potentially irreversible, but every fraction of a degree and ton of CO_2 matters to limit global warming and achieve the SDGs.

The impacts of extreme weather and climate change are undermining progress towards achieving all of the SDGs

Changes in the global climate system affect efforts to achieve the SDGs, and the increasing impacts of extreme events, in particular, are disproportionately affecting vulnerable communities. Between 1970 and 2021, there were 11 778 reported disasters attributed to weather, climate and water extremes, causing over 2 million deaths and US$ 4.3 trillion in economic losses. Over 90% of these reported deaths and 60% of economic losses occurred in developing economies. The impacts of these extreme events lead to losses of lives and livelihoods, exacerbate poverty and inequality, amplify food and water insecurity, trigger economic instability and, ultimately, undermine sustainable development.

2023 has already seen record-breaking extreme weather-, climate- and water-related events across the world. Cyclone *Freddy*, the longest-lived tropical cyclone in recorded history, impacted vulnerable communities across southern Africa. In Asia, Typhoon *Doksuri* triggered record-breaking rainfall in Beijing – the heaviest rainfall recorded since records began 140 years ago. July was the hottest month on record, with scorching temperatures across Europe, North America and China that have become increasingly common but would have been extremely rare without human-induced climate change. In eastern Canada, climate change more than doubled the likelihood of extreme fire weather conditions, and record-breaking sea-surface temperatures led to serious marine heatwaves in the Mediterranean and off the coast of the United States of America. These extreme events had significant impacts on human health, ecosystems, economies, energy, agriculture and water supplies, threatening sustainable development globally.

Advances in weather-, climate- and water-related sciences can boost our game to achieve the SDGs

The world is equipped with science, technology and knowledge that are unprecedented in history. Weather-, climate- and water-related sciences and services, in particular, have undergone revolutionary advancements over the past few decades. Scientific advancements, satellites and supercomputers, as well as an increase in observational data, have improved our ability to forecast hydrometeorological events with remarkable accuracy and project future changes in climate with reduced uncertainty. Advances in early warning systems have decreased mortality rates, and new technologies, such as nowcasting, artificial intelligence and high-resolution modelling, are revolutionizing the way we predict high-impact weather and water hazards. Although often under-recognized,

Figure 1. Weather-, climate- and water-related sciences support the achievement of many of the SDGs

weather-, climate- and water-related sciences and services play a crucial role in achieving the SDGs, as highlighted in Figure 1.

However, barriers prevent the full, effective and equitable use of weather-, climate- and water-related sciences for sustainable development, which limits progress towards achieving the SDGs. Gaps in global surface-based data remain due to insufficient observations in parts of the world and restricted data exchange and access, which significantly impact the quality of weather-, climate- and water-related services locally, regionally and globally. Insufficient data, particularly in lower-income countries, results in knowledge gaps and ineffective policymaking, limiting progress towards achieving the SDGs. Additionally, reaching local communities with understandable, affordable, applicable and real-time weather, climate and water information remains a significant challenge, as does effectively integrating local, contextual and Indigenous knowledge. Failure to fully engage local stakeholders and integrate their knowledge limits the effectiveness of science. And finally, a lack of scientific capacity has prevented many countries from using weather-, climate- and water-related sciences effectively in support of ambitious action to achieve the SDGs.

As the final whistle draws near, investing in and mobilizing the scientific community will super-charge the achievement of the SDGs

In August 2023, the United Nations General Assembly adopted a resolution that designates 2024 to 2033 the International Decade of Sciences for Sustainable Development. Moving forward, the scientific community will be a game-changing player as we enter the second half of the game. Unprecedented advances in weather-, climate- and water-related sciences and services remain underutilized in support of sustainable development but must be enhanced, accelerated and scaled up to support achievement of the SDGs. We have the solutions to achieve the SDGs by 2030 – now is the time to mobilize the scientific community to supercharge SDG implementation.

Recommendations

- **Close the gaps in weather, climate and hydrological observations and data.** Investing in systematic observations and promoting the free and unrestricted exchange of data is crucial to enhancing our understanding of the Earth system and strengthening weather-, climate- and water-related sciences and services in support of achieving the SDGs.

- **Advance research and expand access to science, technology and innovation.** Scaling up integrated weather-, climate- and water-related research will close existing knowledge gaps and advance emerging technologies, such as high-resolution modelling, artificial intelligence and nowcasting, that can support the SDGs when made accessible.

- **Strengthen scientific capacity and skills through education and training.** Enhancing scientific capacity, especially in lower-income countries, will support innovation and improve the use of weather-, climate- and water-related sciences to ensure national sustainable development policies, plans and actions are grounded in best-available science.

- **Embrace local, contextual and Indigenous knowledge.** Enhancing participatory, user-driven approaches, such as citizen science and co-production, supports integration and legitimization of local, contextual and Indigenous knowledge to translate weather-, climate- and water-related sciences into on-the ground impact for the SDGs.

- **Unite diverse stakeholders to boost the impact of science.** Mobilizing multidisciplinary collaboration with diverse stakeholders – including scientists, the private sector, civil society, youth, local communities, governments and others – is essential to improve the effectiveness of weather-, climate- and water-related science across society and accelerate progress towards achieving the SDGs.

Links between weather-, climate- and water-related sciences and services and the Sustainable Development Goals

Building on the Global Sustainable Development Report 2023, which emphasizes the role of science in accelerating transformation to achieve the SDGs, *United in Science 2023* provides a high-level compilation of the latest weather-, climate- and water-related sciences and services for sustainable development. These sciences and services underpin the achievement of all the SDGs; however, a complete analysis of all the ways in which weather-, climate- and water-related sciences and services support sustainable development is beyond the scope of this report. As a result, eight SDGs were selected to review in this report based on their direct linkages to these sciences: SDG 2 – Zero Hunger, SDG 3 – Good Health and Well-being, SDG 6 – Clean Water and Sanitation, SDG 7 – Affordable and Clean Energy, SDG 11 – Sustainable Cities and Communities, SDG 13 – Climate Action, SDG 14 – Life Below Water, and SDG 17 – Partnerships for the Goals.

While the remaining SDGs are no less important, their links to weather-, climate- and water-related sciences and services are more indirect and often linked to one of the eight SDGs covered in this report. For example, weather forecasting and climate projections support agricultural decision-making and production, thereby improving food security outcomes (SDG 2 – Zero Hunger), which in turn, improves livelihoods and reduces poverty (SDG 1 – No Poverty). Additionally, in some cases, limited knowledge and understanding of the role these sciences play in enabling sustainable development presented barriers to more in-depth analysis of particular SDGs. The SDGs that are not covered in depth in this report are briefly highlighted in this section.

SDG 1: No Poverty

SDG 1 aims to end poverty in all its forms everywhere. Climate change intensifies poverty by disrupting livelihoods, amplifying food and water scarcity, and fostering economic instability, presenting a significant challenge to achieving SDG 1. However, weather-, climate- and water-related sciences and services, particularly early warning systems, provide tangible benefits in poverty reduction by reducing the impacts of climate change on people's livelihoods and helping them to avoid damaging events and economic losses. For example, seasonal and long-term forecasts can assist farmers in reducing their exposure to climate-related impacts, which increases agricultural productivity, improves livelihoods and reduces poverty (Griggs et al., 2021). Additionally, climate projections help us understand future development and appropriate adaptation measures under changing climatic conditions that promote socioeconomic well-being in vulnerable populations.

SDG 4: Quality Education

Extreme weather events and climate change impact communities worldwide, making it imperative to equip learners with the knowledge and skills to understand, adapt to and mitigate these challenges. Integrating weather-, climate- and water-related science education into curricula enhances students' scientific literacy, critical thinking, social empathy and evidence-based problem-solving abilities. Additionally, a robust weather and climate science education may also serve as a catalyst for innovation and technological advances. Addressing the complex challenges posed by climate change will require upskilling and re-skilling existing professionals, such as meteorologists, hydrologists, climate scientists and policy experts. It will also require promoting education to prepare people for professions such as energy storage specialists, green building architects, smart city planners and decarbonization strategists. Fostering a deeper understanding of weather and climate dynamics, water management and environmental sciences helps students become informed and proactive global citizens. As a result, they will be well prepared to address current and future challenges, develop solutions and contribute to sustainable development efforts.

Photo: Ab Rashid, UNDP Climate

SDG 5: Gender Equality

Weather and climate impacts are not gender neutral – they are experienced differently by women and men at the intersection of other social determinants, such as economic status, location, age, disability and marital status (Azcona et al., 2023). Gender discrimination heightens climate-associated risks for women and girls, including the risk of food insecurity, poverty, gender-based violence, and early and forced marriage. Despite their vulnerability to the impacts of extreme weather and climate change, women also hold knowledge that can play a transformative role in addressing local challenges when effectively integrated into the scientific process. For example, FemLINKPacific's Women's Weather Watch initiative engages women to ensure weather information reaches communities in remote areas and that disaster preparedness, management and response involves local women (*Gendered Impacts of Weather and Climate: Evidence from Asia, Pacific and Africa*). Integrating the knowledge of women and engaging them in the scientific process ensures that weather-, climate- and water-related sciences and services are better suited to meet their needs.

Photo: Ade Bayu Indra

SDG 8: Decent Work and Economic Growth

SDG 8 promotes sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. According to the World Economic Forum (2023), the top three risks to global economic development over the next 10 years are the failure to mitigate climate change, the failure to adapt to climate change, and natural disasters and extreme weather events. However, weather-, climate- and water-related sciences and services deliver economic, environmental and social benefits across a range of timescales, from early warnings regarding imminent danger to life and property to long-term projections of climate change that are essential for adaptation activities (Kull et al., 2021). Additionally, early warning systems play an important role in enabling anticipatory action and response from workers, employers and authorities at the national and local levels, thereby preventing human and economic losses in the workplace (ILO, 2022). Early warning systems also promote decent work as part of occupational health and safety standards in the workplace.

SDG 9: Industry, Innovation and Infrastructure

SDG 9 aims to build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. Industry and innovation are highly vulnerable to the impacts of climate change and extreme weather events. Extreme weather events can damage or destroy critical infrastructure, resulting in human and economic losses, and climate change impacts, such as rising sea-levels, threaten coastal industries and infrastructure. However, weather-climate- and water-related sciences and services play an important role in enabling action to achieve SDG 9. For example, advances in weather forecasting and early warnings protect infrastructure and industry from natural hazards, while climate change scenarios enhance the resilience of infrastructure by providing guidance on the placement and climate-proofing of structures in coastal and other vulnerable areas. Additionally, enhancing scientific research is central to achieving SDG 9, and weather-, climate- and water-related research in particular can foster innovation that will deliver benefits across society and contribute to the achievement of all SDGs.

SDG 10: Reduced Inequalities

SDG 10 strives to reduce inequality within and among countries. Existing inequalities related to age, sex, disability, race, ethnicity, origin, religion, and economic or other status increase vulnerability to the impacts of climate change and extreme weather events. At the same time, these impacts also exacerbate existing inequalities – leading to a vicious cycle (Islam and Winkle, 2017). Additionally, SDG 10, target 10.7 aims to facilitate orderly, safe, regular and responsible migration and mobility of people. According to IPCC (2023), climate and weather extremes are increasingly driving displacement in Africa, Asia, the Americas and small island States in the Caribbean and South Pacific. However, weather-, climate- and water-related sciences and services can help minimize forced climate-related displacement. For example, early warning of hazardous events not only saves lives and livelihoods but can also reduce losses and damages that may trigger forced displacement. These sciences can also inform adaptation strategies, allowing people to stay where they are if they choose to do so, or informing planned relocation to ensure they can move safely and with dignity to areas that do not put them at an increased risk to weather-, climate- and water-related hazards.

SDG 12: Responsible Consumption and Production

SDG 12 aims to ensure sustainable consumption and production patterns. Weather-, climate- and water-related sciences and services play an indirect role in supporting the achievement of SDG 12 through other SDGs. For example, access to timely, reliable and actionable data and information enhances agricultural productivity, thereby reducing food losses related to the adverse effects of extreme weather and climate change (SDG 2 – Zero Hunger). Additionally, weather-, climate- and water-related sciences are essential for supporting sustainable energy consumption and production, including planning and development of renewable energy and operation and management of energy systems

Photo: Vladimir Tadić

(SDG 7 – Affordable and Clean Energy). Climate models support the development of scenarios about the future use and conservation of marine areas (SDG 14 – Life Below Water), and data on land, weather, climate and water are crucial to support the observation, monitoring, modelling, forecasting and early warning of droughts, floods, wildfires and sand and dust storms to support the sustainable management of natural resources on land (SDG 15 – Life on Land).

SDG 15: Life on Land

SDG 15 seeks to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss. Extreme weather-related events, such as droughts, floods and wildfires, and the impacts of climate change degrade land and impact achievement of SDG 15. The interaction of climate change and land degradation, deforestation and biodiversity loss lead to significant impacts on the environment, food and water security and human health, and consequently impact sustainable development. Data on land, weather, climate and water are crucial to support the observation, monitoring, modelling, forecasting and early warning of droughts, floods, wildfires and sand and dust storms to reduce impacts across society. Global cooperation on drought, floods, and sand and dust storms leads to the provision of warnings and advisories to guide preparedness, and the development of guidance for building resilience and accelerating adaptation and mitigation action to minimize impacts and support sustainable development.

SDG 16: Peace, Justice and Strong Institutions

SDG 16 aims to promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels. Ongoing conflicts across the world threaten the achievement of SDG 16. While climate change and extreme weather events do not directly cause conflict, their impacts intersect with compounding social, economic and political pressures that increase the risk of conflict (ICRC, 2020). For example, the impacts of climate change and extreme weather events threaten the food, water and economic security of vulnerable communities, particularly in areas already enduring protracted conflict and fragility. As a result, people may diversify their livelihoods and ways of life or move to seek greater opportunities and protection, which may increase pressure on natural resources, leading to tensions between communities. The intersection between climate change and conflict is complex; however, weather-, climate- and water-related sciences and services support the achievement of food, water, energy and health security, reducing the risk of conflict triggered by insecurity.

Key messages

- **Total carbon dioxide (CO_2) emissions from fossil fuels and land use change remained high in 2022 and the first half of 2023. Fossil fuel CO_2 emissions increased 1% globally in 2022 compared to 2021, and global average concentrations continued rising through 2022 and the first half of 2023.**
- **The years from 2015 to 2022 were the eight warmest on record, and the chance of at least one year exceeding the warmest year on record in the next five years is 98%.**
- **It is estimated that current mitigation policies will lead to global warming of around 2.8 °C over this century compared to pre-industrial levels. Immediate and unprecedented reductions in greenhouse gas (GHG) emissions are needed to achieve the goals of the Paris Agreement.**

Greenhouse gas (GHG) emissions and concentrations

Human activities associated with the emissions of GHGs have unequivocally caused global warming, with observed global surface temperature in 2013–2022 reaching 1.15 °C above pre-industrial levels (1850–1900), of which 1.14 °C can be attributed to human influence (IPCC, 2023, updated in Forster et al., 2023). GHG emissions have continued to increase, with unequal historical and ongoing contributions arising from the use of fossil fuels, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals.

According to the Global Carbon Project, total CO_2 emissions from human activities remained high in 2022, with an estimated 40.6 billion tons of carbon dioxide ($GtCO_2$) emitted.[1] Fossil CO_2 emissions are estimated to have risen 1% (uncertainty range 0.1% to 1.9%) in 2022 relative to 2021, primarily driven by growth in oil use as the aviation sector rebounded following the COVID-19 pandemic (Friedlingstein et al., 2022). Coal emissions increased globally by about 1% (uncertainty range 0.2% to 1.8%) in 2022, while emissions from natural gas declined.

The remaining carbon budget compatible with a 50% of chance of limiting global warming to 1.5 °C continues to be depleted and has now been reduced to around 250 $GtCO_2$ based on a recent update of the IPCC estimate (Forster et al., 2023). If total CO_2 emissions stay at current levels, then this remaining budget would be exhausted before 2030, inexorably leading to overshoot of 1.5 °C global warming.

Preliminary estimates shows that global fossil CO_2 emissions in January to June 2023 were 0.3% above the same period in 2022 (Figure 1), with declines in emissions from power generation and domestic use but increased emissions from industry and all transport modes (ground, domestic and international aviation) compared the same period last year (Carbon Monitor).

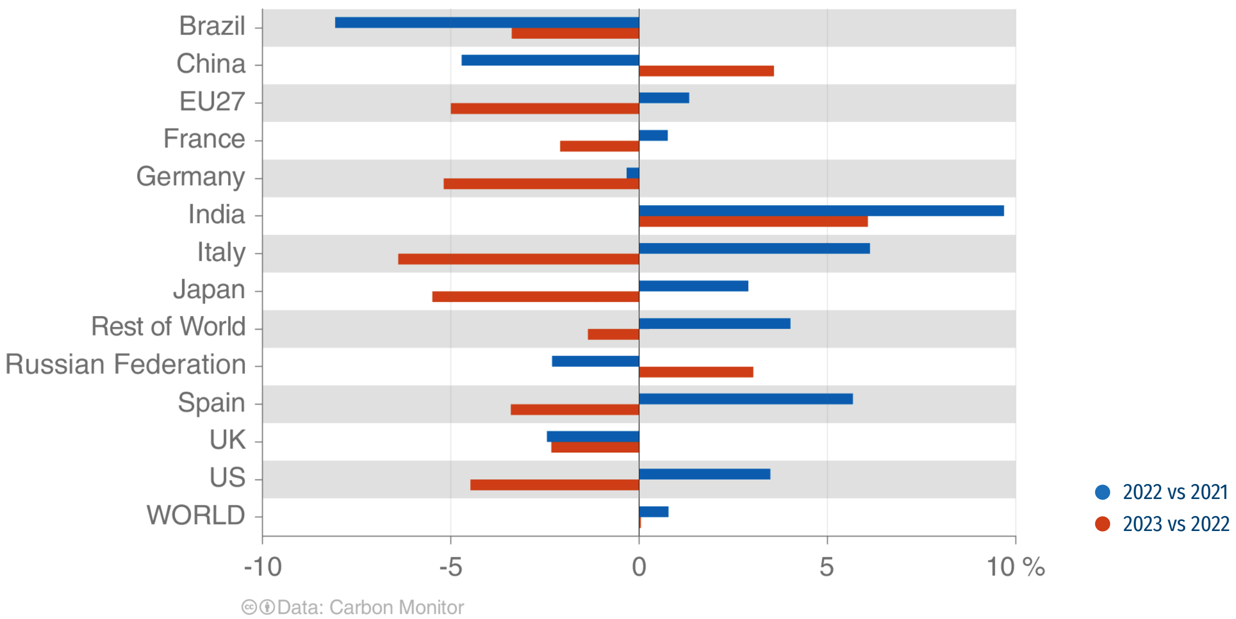

Figure 1. Preliminary estimates of the percentage change in fossil CO_2 emissions for January to June of 2023 compared with the same period for 2022, and the same comparison for 2022 versus 2021. Source: **Data from Carbon Monitor**

1. GHG emissions calculated as CO_2-equivalent using the global warming potential over 100 years.

As emissions continue to rise, so do atmospheric concentrations of GHGs, including CO_2, methane (CH_4) and nitrous oxide (N_2O), which are closely linked to anthropogenic activities and interact strongly with the biosphere and oceans (***WMO Greenhouse Gas Bulletin, No. 18***). To predict the evolution of atmospheric GHG concentrations, a quantitative understanding of sources, sinks and chemical transformations is required. The latest analysis of observations from the WMO Global Atmosphere Watch (GAW) in situ observational network shows that globally averaged surface mole fractions[2] for CO_2, CH_4 and N_2O reached new highs in 2021, with CO_2 at 415.7 ± 0.2 parts per million (ppm),[3] CH_4 at 1 908 ± 2 parts per billion (ppb) and N_2O at 334.5 ± 0.1 ppb. These values constitute, respectively, 149%, 262% and 124% of pre-industrial (before 1750) levels. CO_2 levels continued increasing through 2022 and the beginning of 2023 as documented through the observations at the GAW network of stations.[4]

Global climate indicators

Anthropogenic climate change has resulted in widespread, rapid and intensifying changes in the atmosphere, ocean, cryosphere and biosphere, affecting many weather and climate extremes (assessed up to 2020 in IPCC, 2023, some updated to 2022 in Forster et al., 2023). The WMO State of the Global Climate reports provide an annual summary of the state of global climate indicators, including global temperature, ocean heat and cryosphere indicators, such as sea-ice extent and glacier mass, among others (Trewin et al., 2021).

Global mean temperature

The years from 2015 to 2022 were the eight warmest years on record (Figure 2). A warm start to 2023 and the emergence of the El Niño phenomenon increase the likelihood that 2023 will be among the warmest years on record. Global mean temperature for the last decade, 2013–2022, was 1.15 °C above the 1850–1900 average (Forster et al., 2023), with preliminary estimates for 2023 (to June) indicating a continued increase to 1.18 ± 0.12 °C. The human-induced component of the warming for the decade 2013–2022 has been estimated to be 1.14 ± 0.1 °C (Forster et al., 2023), very similar to the total observed warming.

La Niña conditions were persistent from late 2020 to early 2023, with global temperatures falling below the long-term trend. With the cessation of La Niña in early 2023, global temperatures have risen to record levels. For the period 2019 to June 2023, most areas of the world were warmer than the recent average (1991–2020), with only a few regions – parts of North America, India, the Southern Ocean and an area of eastern Australia – cooler than the recent average (Figure 3).

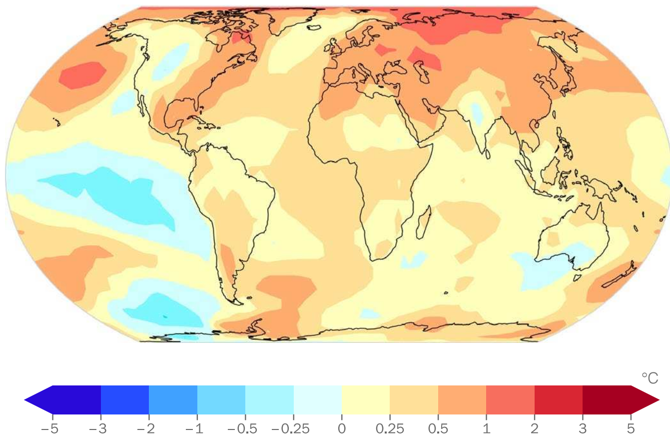

Figure 3. Five-year mean near-surface temperature difference (°C) from the 1991–2020 average for the period 2019–2023 (data to June 2023). Each map grid cell value is the median calculated from five data sets: HadCRUT5, GISTEMP, NOAAGlobalTemp, JRA-55 and ERA5.

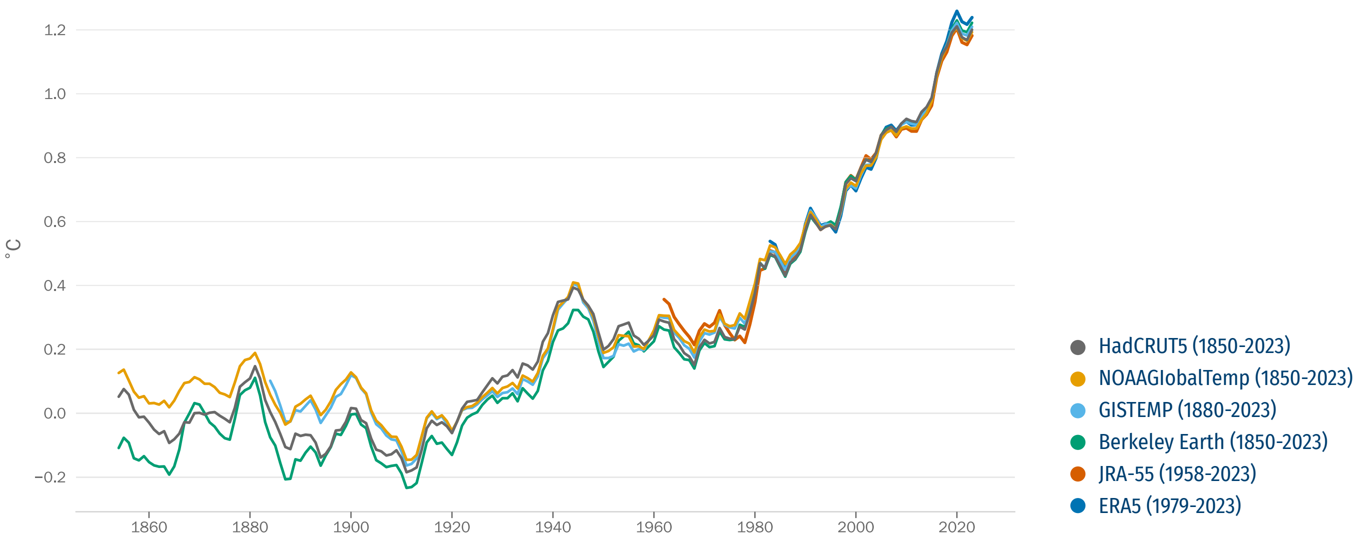

Figure 2. Five-year running average of global temperature anomalies (°C relative to 1850–1900) from 1850–1854 to 2019–2023 (data to June 2023) shown as a difference from the 1850–1900 average. Six data sets are shown as indicated in the legend.

2. Mole fraction = The preferred expression for the abundance (concentration) of a mixture of gases or fluids. In atmospheric chemistry, the mole fraction is used to express the concentration as the number of moles of a compound per mole of dry air.
3. ppm = The number of molecules of a gas per million (10^6) molecules of dry air.
4. Updated globally averaged mole fractions for three mentioned gases will be made available in November 2023.

Ocean heat content

Around 90% of the excess energy that accumulates in the Earth system due to increasing concentrations of GHGs is taken up by oceans. This added energy warms the ocean, and the consequent thermal expansion of the water leads to sea-level rise – to which melting land ice also contributes. The surface layers of the ocean have warmed more rapidly than the deeper waters, resulting in a rise in the global mean sea-surface temperature and an increase in the incidences of marine heatwaves. Preliminary data show global sea-surface temperatures were at record highs for the time of the year in May and June 2023, and temperatures in the North Atlantic in particular have been unprecedented (**Preliminary Data Shows Hottest Week on Record – Unprecedented Sea Surface Temperatures and Antarctic Sea Ice Loss**).

Ocean heat content is a measure of the heat that has accumulated in the ocean. Figure 4 shows the global ocean heat content 0–2 000 m from 1960 to 2022. The upper 2 000 m depth of the ocean continued to warm in 2022 and reached the highest heat content on record. It is expected that it will continue to rise – a change which is irreversible on centennial to millennial timescales (Riser et al., 2016; Roemmich et al., 2019). All data sets agree that ocean warming rates were particularly high in the past two decades: the rate of ocean warming for 0–2 000 m was 0.7 ± 0.1 W m^{-2} from 1971 to 2022, but 1.2 ± 0.2 W m^{-2} from 2006 to 2022.

The Earth energy imbalance (EEI) includes changes in energy associated with warming not just of the ocean but of the land and air, as well as melting of ice. The most recent IPCC report estimated that the EEI was 0.79 W m^{-2} for the period 2006–2018 (IPCC, 2021). A more recent update estimates the EEI to be 0.89 W m^{-2} for the period 2010–2022 (Forster et al., 2023).

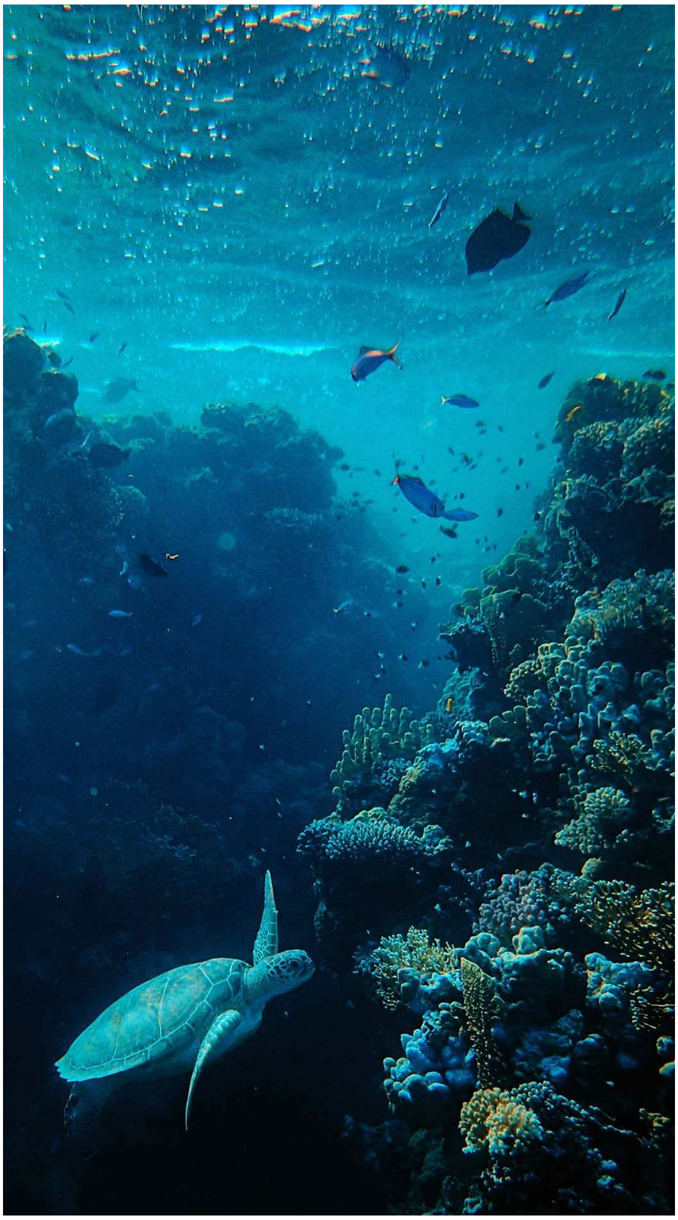

Photo: Francesco Ungaro - Pexels

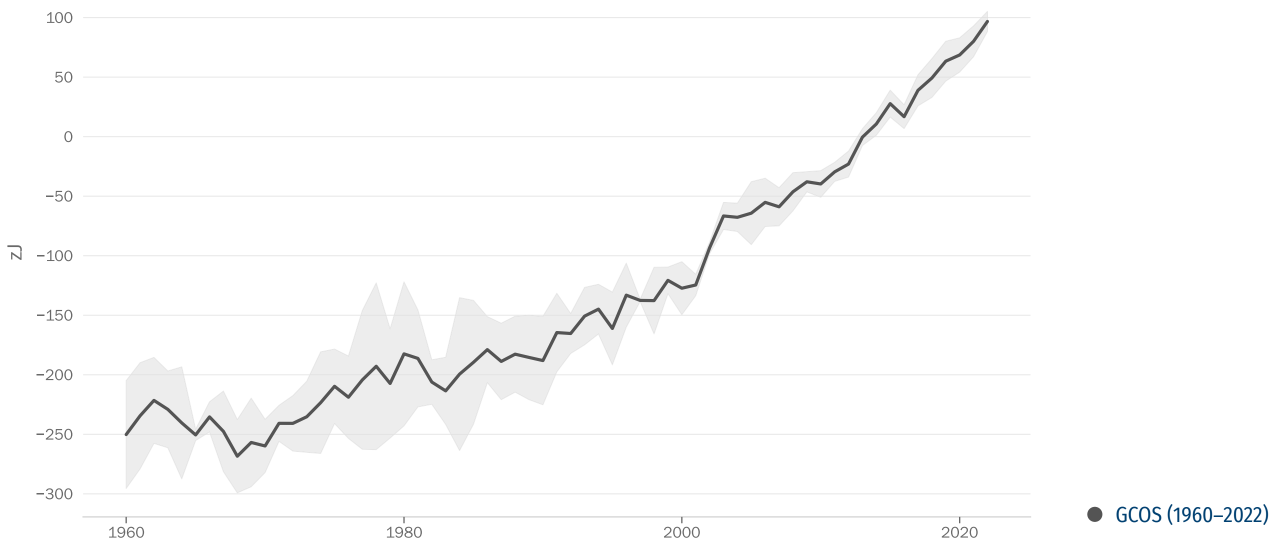

Figure 4. Global ocean heat content 0–2 000 m from 1960 to 2022. Data are based on a combination of data sets (see Appendix).

Cryosphere

Human influence is very likely the main driver of the decrease in Arctic sea-ice area between 1979–1988 and 2010–2019 (IPCC, 2023). The current Arctic sea-ice cover (both annual and late summer) is at its lowest level since at least 1850, and the Arctic is likely to reach practically ice-free conditions at its summer minimum at least once before 2050. During the period 2018–2022, September Arctic sea-ice extent was on average nearly 1 million km^2 below the 1991–2020 average (Figure 5).

There has been no significant trend in Antarctic sea-ice extent from 1979 to 2020 due to regionally opposing trends and large internal variability (IPCC, 2021). Antarctic sea-ice extent increased slowly from the start of the satellite era to around 2015 (Figure 6), dropped rapidly between 2015 and 2017, and returned to close to the long-term average between 2017 and 2021, before reaching its lowest minimum on record in February 2022 and then again in February 2023. Low growth of the ice through the autumn and early winter led to daily extents that were far below the previous record lows in June and July. According to preliminary data, in June 2023, Antarctic sea ice reached its lowest extent for June since satellite observations began, at 17% below average, breaking the previous June record by a substantial margin (**Preliminary Data Shows Hottest Week on Record – Unprecedented Sea Surface Temperatures and Antarctic Sea Ice Loss**).

Glaciers are also highly sensitive to anthropogenic climate change. For the glaciological year 2021/2022, data available for 37 reference glaciers indicate an average global mass balance of –1.18 m water equivalent (m w.e.), which is a larger mass loss than the average for the last decade (–0.92 m w.e. from 2012 to 2021) (WGMS, 2021). Glacier losses were particularly extreme in the European Alps, high-mountain Asia, western North America, South America and parts of the Arctic.

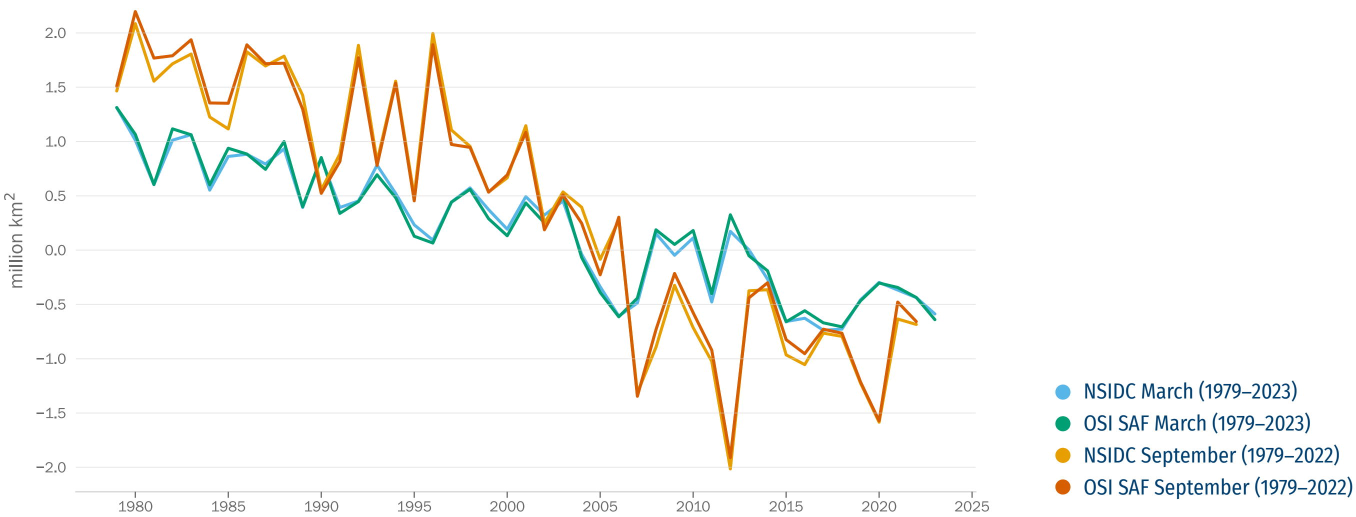

Figure 5. Sea-ice extent differences from the 1991–2020 average in the Arctic for the months with maximum ice cover (March) and minimum ice cover (September) from 1979 to March 2023. ***Source:*** **United States National Snow and Ice Data Center (NSIDC) and European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Ocean and Sea Ice Satellite Application Facility (OSI SAF)**

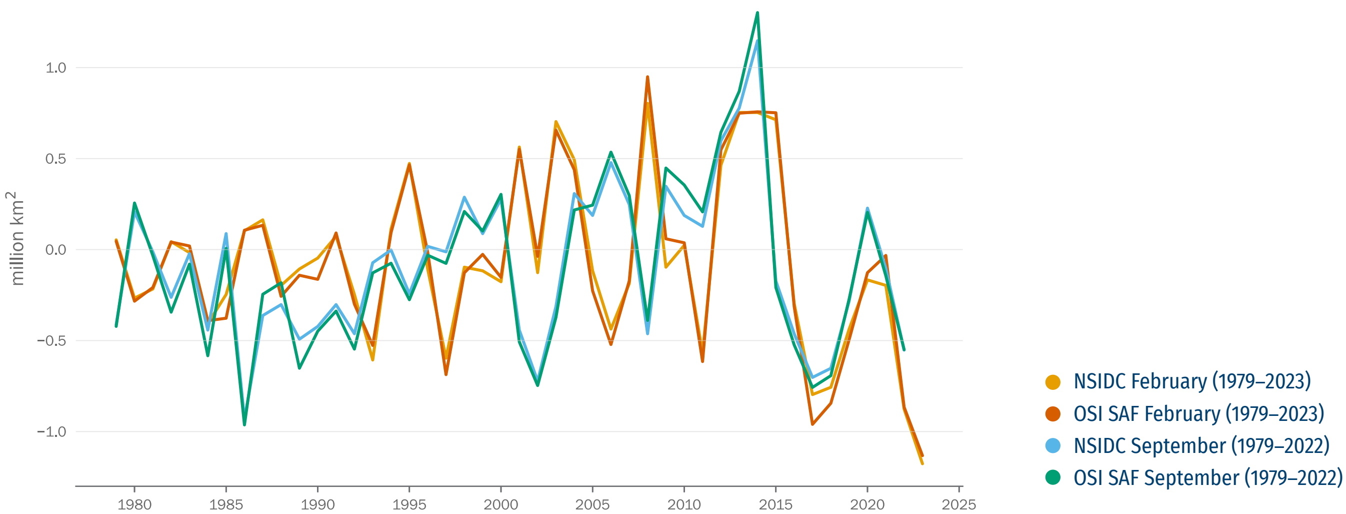

Figure 6. Sea-ice extent differences from the 1991–2020 average in the Antarctic for the months with maximum ice cover (September) and minimum ice cover (February) from 1979 to March 2023. ***Source:*** **NSIDC and EUMETSAT OSI SAF**

2023 extreme events

Extreme weather has become an increasingly frequent occurrence in our warming climate and has had devastating socioeconomic consequences. Between 1970 and 2021, 11 778 reported disasters attributed to weather, climate and water extremes caused 2 087 229 deaths and US$ 4.3 trillion in economic losses. Over 90% of reported deaths and 60% of economic losses due to weather-, climate- and water-related disasters worldwide were reported in developing economies (*WMO Press release No. 22052023*).

A year of extremes, 2023 has already seen record-breaking extreme weather-, climate- and water-related events across the world. Cyclone *Freddy*, which made landfall in Mozambique in March 2023, was the longest-lived tropical cyclone in recorded history, lasting over five weeks and causing widespread destruction across Mozambique, Madagascar and Malawi (*NASA Tracks Freddy, Longest-lived Tropical Cyclone on Record*). Tropical cyclones also impacted parts of Asia, including Typhoon *Doksuri*, which brought extreme rainfall to parts of China in July and August 2023. Beijing recorded 744.8 mm of rain between the night of 29 July and the morning of 2 August 2023 – the heaviest rainfall recorded since records began 140 years ago (*Typhoons Trigger Destruction and Record-breaking Rainfall in China*). In parts of eastern Canada, climate change more than doubled the likelihood of extreme fire weather conditions, including record warm temperatures and drought, that fuelled intense and extensive wildfires (Barnes et al., 2023).

July 2023 saw record heat affecting the south-west United States and Mexico, southern Europe and North Africa, and parts of China, which reported breaking the national record, with 52.2 °C measured on 16 July 2023 at Turpan City. An analysis by the World Weather Attribution network concluded that, without human-induced climate change, this intense heat (which has become increasingly common) would have been extremely rare (Zachariah et al., 2023). Additionally, record-breaking sea-surface temperatures led to marine heatwaves in the Mediterranean and off the coast of the United States, impacting marine ecosystems and coastal communities (*Preliminary Data Shows Hottest Week on Record – Unprecedented Sea Surface Temperatures and Antarctic Sea Ice Loss*).

Looking ahead: future climate

According to the WMO Lead Centre for Annual to Decadal Climate Prediction, global mean near-surface temperatures are likely to increase in the five-year period 2023–2027 and stay well above the 1991–2020 reference. Annual mean global near-surface temperature for each year in this five-year period is predicted to be between 1.1 °C and 1.8 °C higher than the average over the period 1850–1900. Additionally, warming from continued GHG emissions and the emergence of the El Niño phenomenon will lead to a high chance of new temperature records. The chance of at least one year exceeding the warmest year on record, 2016, in the next five years is 98%, and the chance of the five-year mean for 2023–2027 being higher than the mean for the previous five years is also 98% (*Global Annual to Decadal Climate Update – Target Years: 2023 and 2023–2027*).

Continued emissions of greenhouse gases will lead to increased global warming. The best estimate from scenario-based projections[5] has the long-term warming (averaged over 20 years) reaching the Paris Agreement level of 1.5 °C in the early 2030s (IPCC, 2023). Temporary exceedances are expected to occur before this date due to natural climate variability, and with increasing frequency as global temperatures approach this level (Trewin, 2022). The chance of the annual mean global near-surface temperature temporarily exceeding 1.5 °C above pre-industrial levels for at least one of the next five years is 66% and is increasing with time. However, it is unlikely (32%) that the five-year mean exceeds this level (*Global Annual to Decadal Climate Update – Target Years: 2023 and 2023–2027*).

The predicted temperature patterns for 2023–2027 relative to the 1991–2020 average are presented in Figure 7 for two extended seasons: May to September and November to March. For both extended seasons, temperatures are predicted to be above the 1991–2020 average almost everywhere, with land temperatures

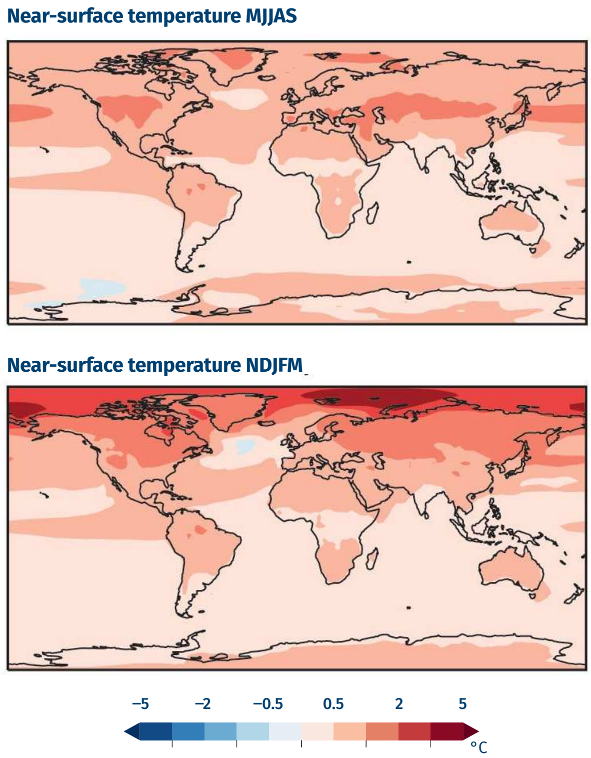

Figure 7. The WMO Lead Centre for Annual to Decadal Climate Prediction's multi-model forecast for the next five extended seasons of near-surface temperature anomalies relative to 1991–2020. Ensemble mean prediction for May to September (MJJAS) 2023–2027 (top) and ensemble mean prediction for November to March (NDJFM) 2023/2024–2027/2028 (bottom).

5. A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of GHGs and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized (IPCC, 2023).

showing larger anomalies than those over the oceans. The warming over the Arctic in November–March is particularly pronounced and is three times larger than the global mean anomaly. Most of the North Atlantic is predicted to be warmer than average, but a small region in the northern North Atlantic shows negative anomalies in November–March averaged over the five years, which is likely related to a slow-down of northward transport in the Atlantic due to climate change (***Global Annual to Decadal Climate Update – Target Years: 2023 and 2023–2027***). However, it is important to note that future warming will depend on future emissions, emphasizing the importance of ambitious climate action.

Science for climate action

Climate change is a threat to human well-being and planetary health. While some future changes in climate are unavoidable, and potentially irreversible, urgent and ambitious mitigation and adaptation action will reduce losses and damages and deliver many co-benefits, especially for air quality and health (IPCC, 2023).

According to the United Nations Environment Programme's Emissions Gap Report (UNEP, 2022), the world is on a path towards global warming far above the Paris Agreement goal. As of September 2022, 166 countries, representing more than 90% of global GHG emissions, submitted new or updated mitigation pledges, known as nationally determined contributions (NDCs). However, there has been very limited progress in reducing the emissions gap for 2030 – the gap between the emissions reductions promised by countries and the emissions reductions needed to achieve the temperature goal of the Paris Agreement, and new submissions by countries in the last nine months have not changed the situation visibly. Without additional action, current policies are estimated to result in global warming of 2.8 °C (uncertainty range: 1.9–3.3 °C, 66% chance) over this century. Full implementation of unconditional and conditional NDC scenarios reduces this to 2.6 °C (uncertainty range: 1.9–3.1 °C) and 2.4 °C (uncertainty range: 1.8–3.0 °C), respectively.

The emissions gap in 2030 remains immense (Figure 8). Current commitments by countries as expressed in their unconditional and conditional NDCs for 2030 are estimated to reduce global emissions by 5% and 10%, respectively, compared with current policies and assuming that they are fully implemented. To get on track to meet the Paris agreement goals of well below 2 °C and preferably 1.5 °C, global GHG emissions must be reduced by 30% and 45%, respectively, by 2030 and approximately 65% and 87% by 2050, with CO_2 emissions getting close to net zero by 2050, compared with current policy projections (UNEP, 2022).

Moving forward, limiting global warming will require large-scale, rapid and systemic transformation to reach net zero anthropogenic CO_2 emissions (UNEP, 2022). Implementation of all NDCs plus net-zero commitments made by countries points to a 1.8 °C (range: 1.8–2.1 °C, 66% chance) increase. However, currently this scenario is not credible, based on the discrepancy between current emissions, near-term NDC targets and long-term net-zero targets (UNEP, 2022).

In addition to mitigating emissions, adaptation is crucial to reducing the adverse impacts of climate change and preventing loss and damage. Vulnerable communities that have historically contributed the least to climate change are disproportionately affected. While adaptation has progressed across all sectors and regions, gaps remain, and today's adaptation options will become less effective with increasing global warming. Human and natural systems will reach adaptation limits, with some limits already reached in some ecosystems and regions. However, current global financial flows for mitigation, and particularly adaptation, are insufficient to adequately respond to climate change (IPCC, 2023).

Climate action is imperative in all countries and must be achieved simultaneously with the SDGs. Prioritizing equity, social justice, inclusion and transition processes can enable adaptation and mitigation while also contributing to sustainable development. Regulatory and economic instruments, and behavioural and lifestyle changes can support emissions reductions, while scaled-up finance, new technologies and innovations, and enhanced international cooperation are critical enablers for accelerated climate action (IPCC, 2023). Every fraction of a degree, ton of CO_2 and choice matters. A global transformation is necessary to move towards a carbon-neutral future that will allow us to limit global warming and deliver other social and environmental benefits, including achievement of the SDGs.

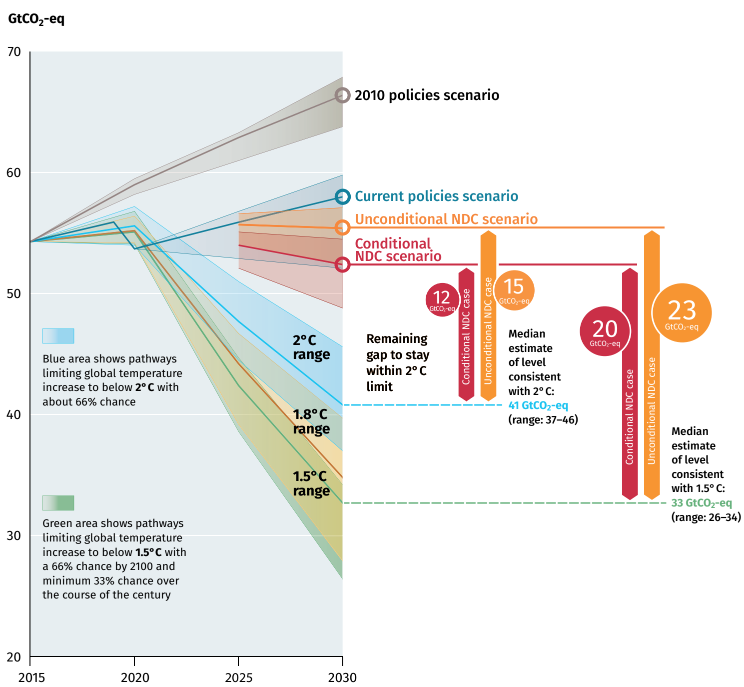

Figure 8. Global GHG emissions under different scenarios and the emissions gap in 2030 (median estimate and 10th to 90th percentile range). Note: $GtCO_2$-eq – billion tons of carbon dioxide equivalent. Source: **UNEP (2022)**

SDG 2
ZERO HUNGER

Food and Agriculture Organization of the United Nations

Key messages

- **Projections estimate that nearly 670 million people may still face hunger in 2030, in part due to more frequent and intense extreme weather events that are disrupting each pillar of food security (availability, access, utilization and stability).**
- **Weather-, climate- and water-related sciences underpin services that enable farmers to make climate-informed decisions that enhance food and nutrition security.**
- **To effectively support the achievement of SDG 2, global investments are needed in weather-, climate- and water-related sciences and services along agrifood value chains.**

Introduction

SDG 2 seeks to end hunger, achieve food security, improve nutrition and promote sustainable agriculture. However, according to the latest report on *The State of Food Security and Nutrition in the World*, the gap to achieving SDG 2 is growing wider every year (Figure 1). Both global and national efforts are proving insufficient in the face of compounded uncertainties and protracted challenges. Projections estimate that nearly 670 million people may still face hunger in 2030 (FAO et al., 2022).

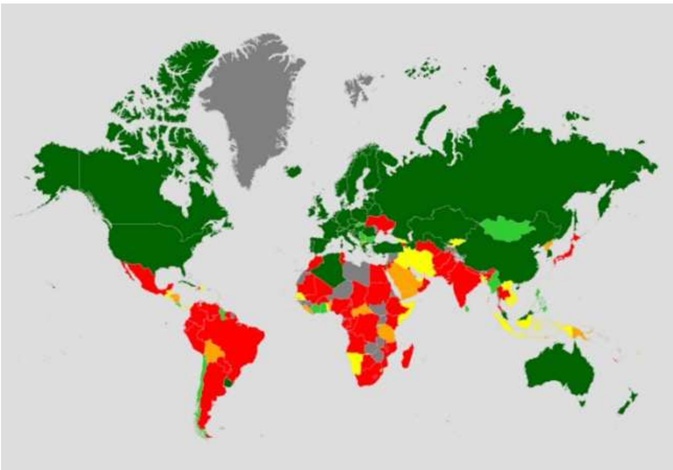

Figure 1. Progress towards eradicating hunger across the world (2015–2020)[6]. Source: FAO, 2022a

Climate change has reduced food security, hindering efforts to meet the SDGs (IPCC, 2023). In particular, more frequent and intense extreme weather events are disrupting each pillar of food security (availability, access, utilization and stability), threatening the achievement of SDG 2. Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally (IPCC, 2023). Additionally, climate change poses an increasingly significant threat to rural small-scale producers, who are the backbone of global food security and key actors in the transformation to sustainable food systems. Therefore, the achievement of SDG 2 is strongly connected to climate risk management, particularly along the agrifood value chain, which is highly exposed and vulnerable to extreme weather events as well as slow-onset changes, such as droughts, rising sea levels, ocean warming and ocean acidification. For example, ocean warming and ocean acidification have adversely affected food production from fisheries and aquaculture in some regions (IPCC, 2023; FAO, 2022b). Additionally, heat and water stress conditions may result in food losses at the production stage, while excess rainfall may cause losses during the harvest and storage stages. Other hazards such as landslides caused by heavy rainfall may affect road infrastructure, hindering transportation and access to markets. As a result, food spoilage and waste may pose risks to food safety and consequently threaten food security.

Weather-, climate- and water-related sciences underpin robust services that have numerous social, economic and environmental benefits and enable farmers to make climate-informed decisions to improve food and nutrition security. For example, access to timely, reliable and actionable data and information allows farmers to better manage agricultural inputs like fertilizer and pesticides, enhance productivity by optimizing crop variety selection and timing of planting, and reduce food losses related to the adverse effects of extreme weather and climate change (FAO, 2022c). Therefore, weather-, climate- and water-related sciences help to significantly strengthen adaptive capacity and increase resilience in the agriculture sector, thereby reducing climate risks, supporting agricultural livelihoods and assets and, ultimately, improving food and nutrition security in line with SDG 2.

6. Due to the probabilistic nature of the indicator and the margins of uncertainty associated with the estimates of each parameter in the model, FAO does not publish estimates of the prevalence of undernourishment (PoU) lower than 2.5%. This prevents assessing whether a country has or has not already met the SDG target. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between Sudan and South Sudan has not yet been determined.

Weather-, climate- and water-related sciences for food security

Weather and climate services include relevant and timely information for agriculture, such as impact-based forecasts focusing on livestock, fisheries, forestry and crops to manage climate risks through better planning. Additionally, weather-informed agricultural advisories help reduce the impacts of weather extremes during the agricultural season (Kim et al., 2023). The development of these climate services relies on robust weather-, climate- and water-related sciences. It also requires a consistent flow of timely and reliable climate and weather data and information tailored to users' needs and socioeconomic characteristics to enhance the resilience of local communities and build the adaptive capacity of agrifood value chains.

Box 1. Early warnings for food security

Communities and countries alike need adequate warning to respond ahead of extreme weather events, such as floods and droughts, and to changes in climate patterns, which disrupt and threaten food security. Early warning systems are an effective adaptation measure that can minimize losses and damages in the agriculture sector, safeguard food security and support the achievement of SDG 2.

Multi-hazard early warning systems are integrated systems that enable communities, governments and others to take timely action to reduce disaster risk before a hazardous event occurs. In the context of food security, early warning is crucial to enabling anticipatory action to protect agricultural livelihoods and assets as well as identify potential areas of crop failure that may lead to emergencies. For example, drought early warning systems can inform governments and humanitarian organizations of potential food security crises to support timely action before the situation develops into famine (***Agriculture and Food Security Exemplar to the User Interface Platform of the Global Framework for Climate Services***).

However, major challenges remain to ensure all countries and people have access to multi-hazard early warning systems. The Early Warnings for All initiative seeks to address these challenges. It recommends co-designing these systems with farmers and local communities, incorporating feedback mechanisms, implementing the Principles for Locally Led Adaptation and building a robust understanding of climate risk and uncertainty at both national and local levels (***Early Warnings for All Executive Action Plan 2023–2027***).

For example, real-time weather information is essential for day-to-day farm management operations, including fertilizer application and irrigation. Additionally, this information supports early warning and weather-informed decision-making to protect crops, livestock and livelihoods ahead of extreme hydrometeorological events, as highlighted in Box 1. When extreme weather strikes, index-based weather insurance based on climate-related indices (such as rainfall, temperature and wind speed) issues instant payments to farmers to compensate them for losses. This type of insurance requires robust science, high-quality weather data and effective monitoring instruments and methods to downscale weather information and produce real-time crop yield estimates at local scales. As a result, it can be an effective weather and climate risk management tool to improve food security outcomes.

On sub-seasonal to seasonal timescales, forecasts are utilized for agricultural planning and decision-making, such as determining dates for land preparation, timing of planting and selection of crops based on the predicted duration of season and harvesting time. Forecasts that extend beyond a planting season help to identify the likelihood of drought, for example, based on large-scale climate phenomena such as El Niño Southern Oscillation (ENSO). Additionally, climate projections support long-term planning (for example, allocation of water resources) at the institutional level, and can provide important data about potential climate risks (FAO, 2021c). For example, the combination, or coupling, of climate and crop models is important for understanding the impacts of climate change on the suitability and the production of different crops. These projections also inform risk assessments that encompass weather hazards, exposure and impacts, socioeconomic vulnerability and the feasibility of adaptation interventions to inform long-term evidence-based planning for agricultural investments, policy strategies and the climate-proofing of agricultural infrastructure to ensure it is resilient in the face of a changing climate.

Weather-, climate- and water-related sciences play an important role in improving agricultural decision-making to enhance food security when they are trusted, robust and used appropriately. The integration of science with participatory processes has also shown a huge potential to enhance trust in and the use of climate services in the agriculture sector. The Participatory Integrated Climate Services for Agriculture (PICSA) methodology mixes scientifically analysed historical data visualized in a simple manner with Indigenous and local knowledge through participatory approaches to engage farmers in identifying appropriate adaptation actions on a seasonal and longer-term basis. Another example is the Food and Agriculture Organization of the United Nations (FAO) Farmer Field Schools (highlighted in Box 2) and WMO Roving Seminars, where farmers are engaged in the co-production, co-design and co-development of weather and climate advisory services, which increases ownership and trust and, thus, enhances the use of weather and climate information. By integrating two-way communication between National Meteorological and Hydrological Services (NMHSs) and farmers, such approaches enhance and simplify access to information, allowing farmers to be an integral part of surveillance, while also communicating and receiving information (FAO, 2015). As a result, science is used in an effective way to enhance food security.

Looking ahead: challenges and opportunities

The world is currently not on track to achieve SDG 2. Challenges around data collection and exchange, and monitoring of weather, climate and agronomic information remain. Examples include insufficient weather and agrometeorologial stations to collect ground data, interrupted monitoring, variable quality of data from agricultural fields, and insufficient long-term and high-quality climate forecasts for agricultural decision-making (***Guidelines for the Assessment of Competencies for Provision of Climate Services*** (WMO-No. 1285)). However, climate services, underpinned by robust weather-, climate- and water-related sciences, can play a key role in addressing these challenges.

Investments should be directed towards infrastructure development and monitoring, strengthening institutional arrangements between NMHSs and agricultural extension, as well as creating public–private partnerships to enhance delivery and uptake of information. Further, gaps around reaching local communities with understandable, affordable, applicable and real-time weather, climate and water information remain large. Climate services need to be user-driven, which means participatory approaches and feedback mechanisms are paramount. Therefore, co-production of climate services is crucial to ensuring they are tailored to users' needs and preferences.

Closing these gaps is vital to ensuring equitable use and provision, leaving no one behind. Moving forward, continued operational observations, particularly in lower-income countries where observational gaps remain, are urgently needed to improve weather forecasting and climate projections to support agricultural decision-making (FAO, 2015). Additionally, investment in research and development as well as agro-innovation need to be strengthened, as they are essential drivers for agricultural transformation (Kim et al., 2023). Enhancing weather and climate science as well as scaling up efforts to build effective climate services that reach vulnerable smallholder farmers is essential to achieving SDG 2 and ensuring global food security by 2030 (FAO, 2021b).

Box 2. **Farmer Field Schools and Participatory Integrated Climate Services for Agriculture**

Farmer Field Schools (FFSs) enhance farmer engagement in climate-informed decision-making for agriculture by ensuring that farmers provide feedback on the effectiveness of climate services (Figure 2). Mainstreaming climate change adaptation into FFSs is fundamental to monitor the exposure and vulnerability of targeted agricultural systems to climate hazards and identify adaptive and context-specific strategies to modulate the identified risks.

During the preparatory stage, exercises, including a baseline vulnerability assessment and a community resource mapping exercise, are carried out by FFS facilitators, community members and farmers. These involve the assessment of the exposure of key farming systems and activities to climate- and weather-related hazards, as well as the identification of adaptation strategies and options that farmers and the community have already implemented and which could be scaled up through community-based adaptation plans. In order to ensure farmers' participation in the collection, access to and use of detailed weather information as part of the FFS activities, it is essential to evaluate the performance of the adaptation practices and technologies. Information gained from FFS activities is subsequently shared by FFS participants with the community through systematic approaches (FAO, 2021a).

Photo: Jorge Alvar-Beltrán, FAO

Figure 2. Women participate at a Farmer Field School in Pakistan.

SDG 3
GOOD HEALTH AND WELL-BEING

Key messages

- **Transdisciplinary research is fundamental to analysing, monitoring and addressing climate-sensitive health risks and climate impacts on the health sector.**
- **Climate change and extreme events are projected to significantly increase ill health and premature deaths, as well as population exposure to heatwaves and heat-related morbidity and mortality.**
- **Scaling up investments in climate-resilient and low-carbon health systems, and progress towards universal health coverage (UHC) are critical for the achievement of SDG 3.**

Introduction

SDG 3 seeks to ensure healthy lives and promote well-being for all at all ages. The pathway to achieving many of the SDG 3 targets is influenced by various climatic and environmental conditions. As a result, overall progress towards SDG 3 might be hindered if health impacts from climate change are not sufficiently addressed. This section reviews progress towards achieving SDG 3 through a climate science lens, including the connection to climate services, and articulates how these play a critical role in achieving the SDG 3 targets.

The Intergovernmental Panel on Climate Change (IPCC) reports that climate-related illnesses, premature deaths, malnutrition in all its forms, and threats to mental health and well-being are increasing (Cissé et al., 2022). The IPCC further states that climate change and extreme events are projected to significantly increase ill health and premature deaths, as well as population exposure to heatwaves and heat-related morbidity and mortality. In addition, the global trend of rapid urbanization puts more people at risk of adverse health outcomes, as existing vulnerabilities to climate change may be aggravated in urban contexts. For example, air pollution is a major urban threat to health and is associated with nearly seven million premature deaths annually (**Air Pollution**). Additionally, climate change is further threatening progress towards global universal health coverage (UHC) through adverse health outcomes and healthcare system disruptions (Salas and Jha, 2019; WHO, 2022). Progress towards UHC and climate-resilient health systems are strongly linked, highlighting the importance of striving for UHC to safeguard health and address structural inequalities (Cissé et al., 2022).

Transdisciplinary research, data and tools that can help us to understand, monitor and even predict health risks can be critical contributions to achieving SDG 3 targets such as improving early warning systems for global health risks, fighting communicable and non-communicable diseases, and reducing illnesses from hazardous chemicals and pollution. Other SDG 3 targets, including achieving UHC and increasing health financing, are also fundamental to improving the climate resilience of health systems.

Weather-, climate- and water-related sciences for health and well-being

The integration of health and epidemiological data with weather-, climate- and water-related information underpins robust services for the health sector. These services can inform health policy and prevention to understand, anticipate and monitor climate-sensitive communicable diseases (such as malaria and dengue) and non-communicable diseases (such as cardiovascular diseases and mental health), supporting the corresponding SDG 3 targets.

Using seasonal climate outlooks and extreme weather forecasts, risk assessments and customized tools can help to identify communities at greatest risk, and where interventions can be targeted. Analytical diagnostics can improve evidence about how, when and where climate can affect human exposure to hazardous or beneficial conditions, who is likely to be affected, and what the magnitude, pattern and duration of the exposure and vulnerability are likely to be. Future climate scenarios can be explored to hypothesize how service delivery may perform under diverse climatic conditions and evaluate which health interventions are most likely to be effective at different times of the year (Shumake-Guillemot and Fernandez-Montoya, 2019).

Heat health warning systems (HHWSs) are also an important climate service grounded in weather and climate science (WHO–WMO Joint Office, 2022). An alarming number of preventable deaths and illnesses from extreme heat are occurring as global temperatures continue to rise. For example, a recent epidemiological modelling study found that an additional 60 000 people died across Europe due to extreme heat during the summer of 2022 (Ballester et al., 2023). HHWSs use weather and climate forecasts and predetermined trigger levels of heat stress to provide public advisories and initiate public health interventions. These early warnings reduce health risks before, during and after periods of extreme heat, and contribute to achieving progress towards ensuring healthy lives and well-being for all.

Additionally, while the heath sector is increasingly vulnerable to the impacts of climate change, it is also a major contributor to global GHG emissions. In 2022, the health sector was responsible

Photo: Ali Karim Alsari

for 5.2% of global GHG emissions – a 5% increase compared to the previous year (Romanello et al., 2022). GHG emissions from the production and burning of fossil fuels threaten health, particularly among vulnerable communities which are disproportionately affected by air pollution. Hence, there is a clear need to systematically build resilience as well as to reduce GHG emissions across the health system using the best available climate science and services, which will contribute to wider health co-benefits (Health Care Without Harm, 2023).

Climate science and services provide evidence on past, present and future climate risks and health vulnerabilities to identify the most effective options for climate-resilient and low-carbon transitions and investments in health systems. For example, a key tool for increasing the resilience of health systems in the context of climate change is vulnerability and adaptation assessments (VAAs). These studies incorporate historical climate information to establish links with health outcomes and model potential future health burdens using climate projections. The VAAs directly inform national policy and help health authorities to identify climate risks across timescales and the resources needed to prepare their health systems for the impacts of climate change and variability (WHO, 2021).

Looking ahead: challenges and opportunities

Weather-, climate- and water-related sciences play a crucial role in supporting good health and well-being and achieving SDG 3, as well as other SDGs, through enhancing climate services and supporting climate-resilient and low-emission health facilities. However, while 74% of WMO Members provide climate data to the health sector, only 48% of National Meteorological and Hydrological Services provided tailored climate products and services to the health sector.[7] This gap between the provision and use of tailored services indicates an opportunity to better translate science into tailored services to support the health sector and achieve SDG 3.

To close this gap, enhancing transdisciplinary collaboration between the weather, climate, water and health science communities will be crucial in development of climate services for the health sector. Effective climate and health adaptation and mitigation strategies require a strong evidence base and tailored climate products and services can enhance the evidence and information available to detect, monitor, predict and manage climate-related health risks. As a result, governments can devise policy options that minimize the effects of weather, climate and water variability and change on public health as well as implement effective mitigation strategies across the health sector. Additionally, health systems need to be strengthened through integrated approaches, including UHC planning that incorporates climate-sensitive considerations, particularly in regions of the world that experience the highest levels of vulnerability to the health impacts of climate change and low levels of UHC (Salas and Jha, 2019).

Overall, safeguarding health and well-being will also depend on the progress towards achieving other SDGs given the strong interdependence between a sustainable and healthy future. The weather, climate and water communities, in partnership with the health community and other stakeholders, can contribute to achieving SDG 3 and achieving good health and well-being for all.

7. The WMO-led high-level State of Climate Services for Health Report will reveal a more in-depth analysis of the global state of health-tailored climate science and services. It will be published in late 2023, ahead of COP 28.

SDG 6
CLEAN WATER AND SANITATION

United Nations | UN WATER

Key messages

- Climate change is exacerbating water-related hazards and altering the Earth's water cycle, making it increasingly difficult to achieve SDG 6.
- More than 60% of countries face challenges due to inadequate and declining hydrological monitoring capabilities.
- More scientific collaboration, financial investments and data and information exchange will be key for policymakers to make informed decisions to accelerate implementation of SDG 6.

Introduction

In 2023 the United Nations (UN) convened the first UN Water Conference in a generation. This conference provided the international community with a platform to share experiences related to water and sanitation and present game-changing solutions to achieve SDG 6, which aims to ensure availability and sustainable management of water and sanitation for all. SDG 6 encompasses targets such as achieving universal and equitable access to safe and affordable drinking water, promoting adequate sanitation and hygiene practices, improving water quality, enhancing water-use efficiency, implementing integrated water resources management, and protecting and restoring water-related ecosystems. The SDG 6 Synthesis Report on Water and Sanitation provides the most recent information on progress, summarized in Figure 1, which remains alarmingly off track and, in some regions and countries, is even backsliding (UN-Water, 2023).

Water security is critical for meeting all SDGs and for the systems transitions needed for climate-resilient development (Caretta et al., 2022). However, according to the Intergovernmental Panel on Climate Change (IPCC), global warming will exacerbate water-related hazards and threats to water availability and quality, making it increasingly difficult to achieve SDG 6 (IPCC, 2022). Floods can disrupt water supply systems, cause damage to sanitation infrastructure, and lead to the contamination of water sources. In addition, more frequent droughts can lead to water scarcity, affecting water availability for people and ecosystems. The latest scientific evidence also indicates that the Earth's water cycle is changing (Van Dijk et al., 2022). As a result, changes in precipitation patterns, evaporation rates and water storage pose significant challenges for managing water resources sustainably and impact water availability.

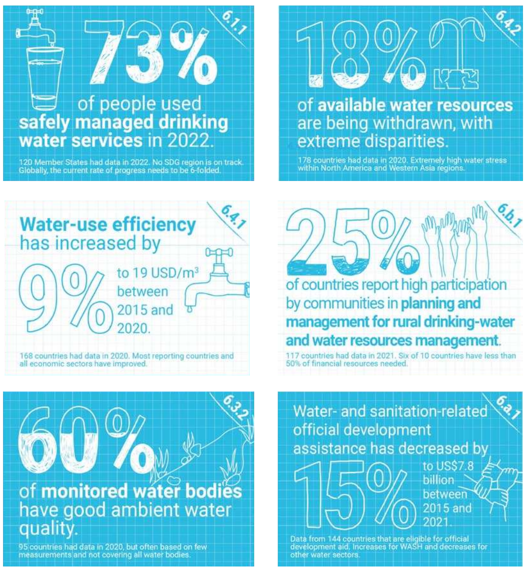

Figure 1. Progress against SDG 6 indicators according to the SDG 6 Synthesis Report on Water and Sanitation. *Source:* Adapted from UN-Water (2023)

Understanding the effects of extreme weather and climate change is crucial to achieving SDG 6. Scientific data provide valuable insights into water availability and quality, making it possible to obtain a comprehensive understanding of water resources and their management. Scientific advancements, particularly related to climate modelling and the understanding of hydrological processes, allow researchers to assess how climate change affects water availability and demand, influences extreme events and alters the distribution of water resources globally and regionally. Additionally, the implementation of new technologies enables the development of data-driven integrated water management practices and policies to support sustainable development. By leveraging scientific research, data and innovation, decision makers and practitioners can develop effective strategies to address water-related issues and achieve SDG 6.

Weather-, climate- and water-related sciences and services for sustainable water management

Weather-, climate- and water-related sciences and services provide essential insights into hydrological conditions and inform decision-making processes to advance progress towards achieving SDG 6. Science allows us to collect and analyse data on various aspects of water resources, including rainfall patterns, river flow, groundwater levels, water quality and aquatic ecosystems. For example, researchers analyse water samples to identify pollutants, assess contamination levels and determine potential risks to human health and the environment. As a result, protective measures and restoration plans can be developed to safeguard water resources. Additionally, hydrological data are fundamental for effective water resources management, as they allow us to identify factors influencing water availability.

A comparison of average annual streamflows in 2022 with those of the previous 30 reference years shows that more than 50% of basins experienced anomalous (either wetter- or dryer-than-normal) conditions (WMO, in press). Similarly, other components of the hydrological cycle can be monitored by analysing variables such as reservoir levels, groundwater levels, soil moisture and evapotranspiration levels (WMO, in press). Box 1 highlights how hydrological data were used to analyse hydrological conditions at local/national scale with an example from Paraguay.

Scientific and technological advances, such as drones, artificial intelligence (AI) and satellite technology, provide opportunities to enable the development of data-driven integrated water management practices and policies (UNCTAD, 2023). Drones equipped with specialized sensors and cameras enable efficient environmental monitoring, infrastructure inspections and flood assessments. Additionally, real-time satellite data support the monitoring of water consumption, and AI-driven data analytics process vast amounts of hydrological data, identifying patterns

Box 1. Analysing river discharge status and streamflow conditions in Paraguay to support sustainable development

In recent years, Paraguay has experienced economic growth; however, drought, combined with high inflation and the impacts of the COVID-19 pandemic, has led to an increase in extreme poverty (***The World Bank in Paraguay***). In 2021, the Paraguay River experienced an extremely dry year (Naumann et al., 2021, 2023). Its annual exceedance curve dropped below the range of historical data for most of its course and broke the record for the all-time lowest daily discharge value (compared to values in the last 30 years). Modelled and observed discharge data provided by the Paraguay Dirección de Meteorologia e Hidrología and Global Runoff Data Centre database, as well as streamflow observation data were used to analyse hydrological conditions.

Figure 2 presents the mean December–January–February (DJF) 2021 discharge ranking with reference to the historical period (1991–2020) for the Paraguay River (Asunción station). The mean DJF discharge was ranked as normal with reference to the historical period, whereas the June–July–August (JJA) discharge was well below normal. Simulations obtained from global hydrological models (GHMs) also rank JJA discharge as well below normal and DJF discharge as below normal.

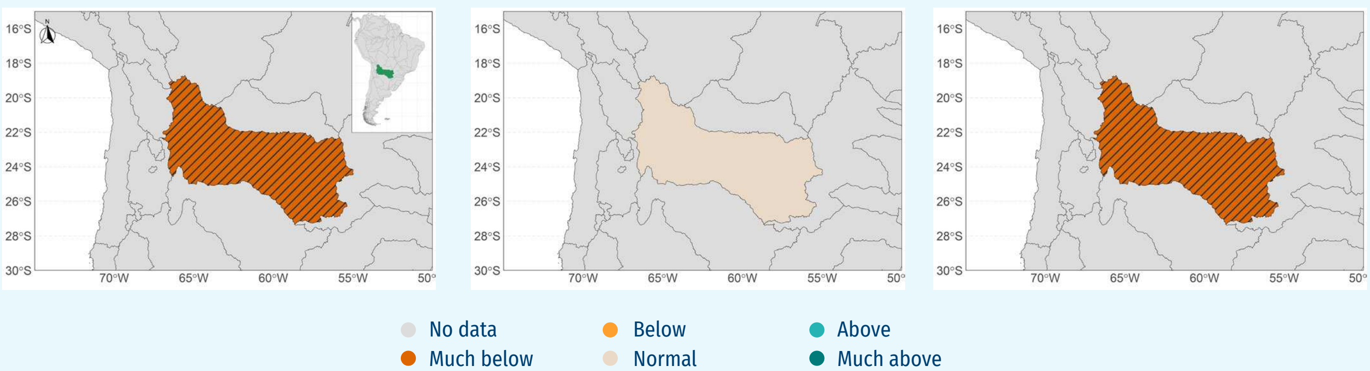

Figure 2. Discharge ranking for 2021 with reference to the historical period (1991–2020) for Paraguay River: (a) mean annual normal; (b) December– January–February; (c) June–July–August. Hatching indicates agreement between the discharge characteristics obtained from observed flow data and GHM simulations. *Source:* WMO, 2022

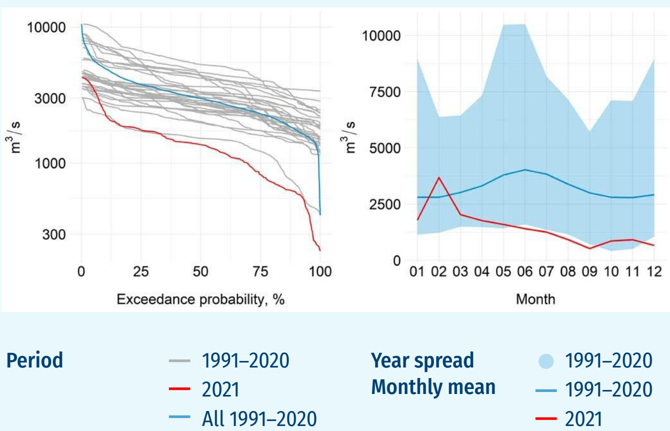

Figure 3 presents exceedance probability curves based on observations for historical years and the year 2021 and mean monthly discharge in 2021 against years of the selected historical period. This hydrological assessment is used by water resource planners and decision makers to support progress towards achieving SDG 6 as well as other SDGs related to the agricultural, environmental, energy and industrial sectors.

Figure 3. Comparison of 2021 streamflow observation data with respect to the reference period 1991–2020 for the Paraguay River, Paraguay: exceedance probability (left); mean monthly discharge (right). *Source:* WMO, 2022

and anomalies for informed decision-making and improved forecasting. Precision agriculture benefits from drones and AI by optimizing irrigation and fertilizer application. Water quality assessment, pollution detection and leakage management are made more effective with AI-enabled drone technologies. These advancements empower scientists and policymakers to detect trends and identify potential challenges and opportunities, contributing to a more sustainable use of water resources.

Science is also instrumental in studying the links between climate change and water resources. Researchers analyse historical climate information in tandem with models to project future climate change, including changes in the hydrological conditions. This information helps assess how these changes might affect water availability and uses, increase the frequency of extreme hydrological events, such as floods and droughts, and alter the distribution of water resources globally and regionally. By running multiple simulations under different scenarios, researchers explore different management strategies and assess their effectiveness before implementation. Decision makers can use this information to implement water-dependent climate change adaptation and mitigation measures, develop climate-resilient water management strategies, prepare for extreme weather events and optimize water allocation during periods of water scarcity. However, this scientific evidence must also integrate local and traditional knowledge, including local weather conditions, water availability and culture, which improve water resources management, as highlighted in Box 2.

Looking ahead: challenges and opportunities

The UN 2023 Water Conference reiterated the importance of science and innovation for strengthening the water sector and called for more scientific collaboration and financial investments, and unrestricted data and information exchange to achieve SDG 6. Moving forward, it will be crucial to address the gaps and challenges in how weather-, climate- and water-related sciences support informed decision-making and the implementation of effective policies. For example, the lack of timely, accessible, available and verified hydrological data is a significant challenge, with more than 60% of countries facing inadequate and declining hydrological monitoring capabilities (***2021 State of Climate Services: Water*** (WMO-No. 1278)). This lack of data results in knowledge gaps and ineffective policymaking, and limits progress towards achieving SDG 6. Efforts to enhance Earth system observations, monitoring and research efforts are vital for better forecasting of extreme hydrological events. Reliable and high-resolution weather, climate and water data must be collected, analysed and freely shared globally. Developing early warning systems for hydrological hazards will also be crucial for minimizing the impact of climate change on communities.

Addressing these gaps and challenges will require a holistic and collaborative effort involving governments, international organizations, academia, research institutions and the private sector. Investing in research, education, technology and capacity-building presents an opportunity to overcome these challenges in support of achieving SDG 6. Advancements across the science–policy–society interface are needed to maximize positive outcomes. Taking a holistic approach that considers not only science but also the local context in which it is implemented could be catalytic in delivering on-the-ground impact and achieving SDG 6.

Photo: Ab Rashid, UNDP Climate

Box 2. Harnessing the traditional knowledge of women for water security

The impacts of a changing climate set back progress towards achieving SDG 6 and disproportionately impact women and girls. An estimated 380 million women and girls in 26 countries are living with high or critical water stress, and by 2030 the number is projected to rise to 471 million in 29 countries. Efforts to provide communities with the latest information on weather and climate science can be crucial in supporting achievement of SDG 6 as well as women's empowerment, but only if women are fully included in such processes (Azcona et al., 2023).

Indigenous, rural and coastal women, in particular, are highly vulnerable to water stress. In the Pyanj river basin of Tajikistan, for example, women and girls find it increasingly difficult to collect water due to higher temperatures and reduced rainfall and glacier snow. However, the knowledge of women also plays a transformative role in addressing both the water crisis and food insecurity. In many Indigenous communities, women hold traditional knowledge related to local culture, water availability and forecasting weather conditions, which improves management of drinking water supplies, food production and energy security and enhances climate resilience. Therefore, it is crucial for the scientific evidence to integrate the traditional knowledge of women to support achievement of SDG 6 (Azcona et al., 2023).

SDG 7
AFFORDABLE AND CLEAN ENERGY

SUSTAINABLE ENERGY FOR ALL

Key messages

- **Extreme weather events and anthropogenic climate change threaten the achievement of SDG 7 by changing energy supply capability and demand profiles, making the clean energy transition more unpredictable and potentially more expensive.**
- **More timely and accurate weather-, climate- and water-related data, science and services support SDG 7 achievement by improving energy planning and operations.**
- **Challenges remain in data quality, limited availability of data types and tools, restricted data access, and low affordability of data and services.**

Introduction

SDG 7 aims to provide access to clean and affordable energy to all, ensuring universal access to affordable, reliable and modern energy services in electricity and clean cooking, increasing the share of renewable energy in the global energy mix, and improving energy efficiency (**Ensure Access to Affordable, Reliable, Sustainable and Modern Energy**). Clean and affordable energy is vital for the achievement of many SDGs, both directly and indirectly, as shown in Box 1.

Achieving SDG 7 relies on affordable, renewable, clean and efficient energy, which requires accurate and timely weather, climate and water data to lower costs and risks for decision makers. Climate change makes renewable energy outputs more unpredictable, increasing risks for investment decisions and energy system management/operation. Energy demand characteristics are also significantly impacted by weather and climate through, for example, changing temperature patterns which can accelerate the needs for affordable and efficient cooling.

Box 1. Role of SDG 7 in achieving the SDGs

SDG 7 is crucial for the achievement of many SDGs (Figure 1). Clean and affordable energy enables productive and sustainable agriculture and food production (SDG 2: Zero Hunger), provides electricity to social infrastructure such as healthcare, educational and water/sanitation facilities (SDG 3: Good Health and Well-being, SDG 4: Quality Education, SDG 6: Clean Water and Sanitation) and supports responsible industrial and service production (SDG 12: Responsible Consumption and Production). SDG 7 also supports diverse economic activities, leading to economic growth, and provides decent jobs in the clean energy sector (SDG 8: Decent Work and Economic Growth).

Additionally, sustainable industrialization requires reliable energy systems with limited environmental impacts (SDG 9: Industry, Innovation and Infrastructure) and growing cities need large amounts of affordable and clean energy (SDG 11: Sustainable Cities and Communities). Clean energy is also essential for reducing GHG emissions (SDG 13: Climate Action) and provides substantial environmental benefits by reducing energy-related environmental hazards and pollution (SDG 14: Life Below Water, SDG 15: Life on Land). Indirectly, SDG 7 also supports the reduction of poverty and gender equality (SDG 1: No Poverty, SDG 5: Gender Equality) by increasing productivity and substituting for labour-intensive, time-consuming tasks, especially those borne by women and children.

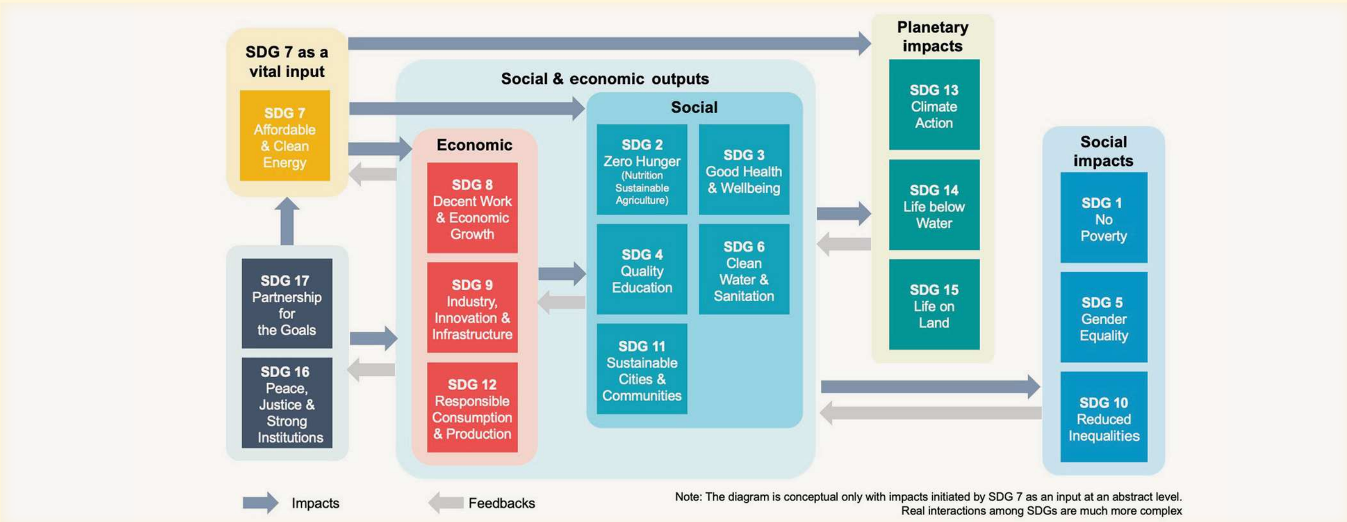

Figure 1. A conceptual diagram of impacts and feedbacks between SDG 7 and other SDGs. *Source:* SEforALL

Weather-, climate- and water-related sciences for sustainable energy

Weather-, climate- and water-related sciences are essential for supporting sustainable energy, including planning and development of renewable energy and operation and management of energy systems.

Planning and development

Climate change-induced changes in weather, climate, water and feedstock availability, including predicted changes in long-term wind speeds and patterns (IPCC, 2021) and wave energy outputs (Reguero et al., 2019), impact energy generation by renewable resources (solar, wind, marine, hydroelectric, geothermal and bioenergy) (Bloomfield et al., 2016). Therefore, weather, climate and water data are essential to inform renewable energy infrastructure and project planning and development. Information on renewable energy resources, such as solar radiation, wind speed and biofuel resources, can be built into national and international atlas tools and support investment decisions by identifying strategic locations for renewable power and grid development (some examples can be found in Global Atlas; Technical Assessment Services; IRENA and FAO's Collaboration Drives Better Decision-making for Sustainable Bioenergy Development; Delivering a Low Carbon Future; Round 4 Project Map; ENTSO-E, 2010, 2020). More site-specific local weather and climate data and geospatial mapping tools have been used to analyse project feasibility and investment decisions (Bioenergy Simulator and SolarCity Simulator). Such information and data tools are also vital for independent small-scale energy systems (such as mini-grids and solar home systems) to provide affordable energy access where large infrastructure cannot reach.

Weather and climate also impact energy demand, which influences planning and development (Figure 2). Hot/humid climate and weather lead to summer energy peaks as demand for cooling increases, while dry and temperate/continental climates experience peak heating demand in winter. High-resolution weather and climate data and forecasts can help inform energy planning based on projected demand. As global temperatures continue to rise, information on temperature and humidity is crucial to provide insights into energy demand for cooling (SEforALL, 2020a, 2021), which has significant implications for human health (IPCC, 2021, 2023a, 2023b).

Ambitious and credible energy planning, using geographical data, supports energy transitions and adaptation, and effective allocation of resources. Integrated Energy Planning identifies priority geographic areas for energy access with the least-cost technology by using geospatial tools. Renewable energy resource data are considered for efficient integration of diverse supply solutions, together with demand-side factors like affordability, in order to provide a national central framework for stakeholders to coordinate all SDG 7 activities cost effectively (SEforALL, 2020b; Universal Integrated Energy Planning). Such a planning tool can be expanded to coordinate other SDG activities with those relating to SDG 7. Energy system transition and climate change adaptation have strong synergies with few trade-offs (IPCC, 2023a, 2023b), and robust weather-, climate- and water-related sciences and data can support these synergies by enabling adjustment of plans, more resilient energy system development and better risk management.

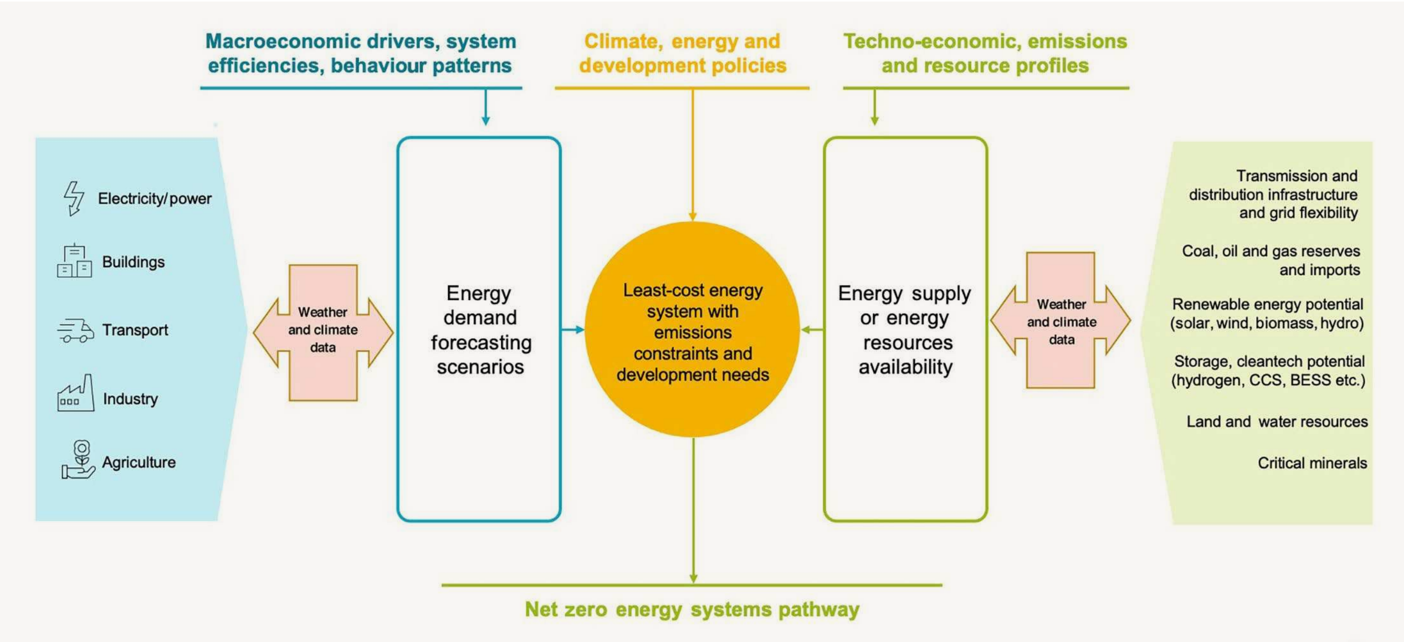

Figure 2. Role of weather/climate data in long-term energy transition planning. Note: BESS – battery energy storage systems, CCS – carbon capture and storage. *Source:* SEforALL

Operations and management

The day-to-day operation of energy systems is heavily dependent on weather and climate data across timescales, from minutes to years, to manage supply and demand. This is particularly true for variable renewable energy (VRE), or energy supply that is variable due to fluctuating weather conditions (for example, wind and solar energy), as well as thermal power plants, performance of which can be negatively impacted by high temperatures. Thermal power plants also require cooling, which often uses large amounts of water, the availability of which is strongly affected by climate change. Energy demand and operational optimization are similarly dependent on weather and climate data and information. For example, many industrial processes require stable temperatures and humidities under varying weather conditions, and therefore there are alterations in the energy demand to regulate these variables.

The potential of demand-side management (DSM) can be optimized by artificial intelligence (AI) with higher-resolution weather forecasts and big data (see Box 2) on building occupancy, usage, energy prices and consumer patterns (IRENA, 2019). DSM reduces daily energy consumption, monthly energy bills and long-term energy investment needs, making sustainable energy more viable for suppliers and more affordable for consumers.

Precise supply–demand forecasts enhance the operations and management and increase the profitability of electricity supply businesses by reducing excess or shortage of supply, while contributing to grid stability by informing grid operators accurately about flexibility needs to compensate for fluctuating VRE inputs. Figure 3 shows how weather data (the first stage of power generation forecast) and renewable resource data (the second stage) are crucial for accurate supply forecast and system operation. Improved weather forecasting abilities and more robust data will lead to enhanced energy supply–demand forecasts, reducing risks and costs across the energy sector and optimizing the operation of VRE.

Looking ahead: challenges and opportunities

Weather-, climate- and water-related sciences are crucial to achieving SDG 7 by 2030 and will become increasingly important in the context of climate change with intensifying extreme weather and compound events, which disproportionately impact low-income populations (IPCC, 2021, 2023a, 2023b; **World Weather & Climate Extremes Archive**). However, challenges remain, particularly related to data quality, accessibility, transmission, resolution and affordability. For example, more granular geospatial and temporal data enable enhanced modelling and analysis for sustainable energy systems in low-income regions and at subnational levels. However, the availability of analytical tools, expertise and large processing capabilities for generating and using higher-resolution data remains a significant challenge (***Integrated Weather and Climate Services in Support of Net Zero Energy Transition*** (WMO-No. 1312)). Additionally, data quality needs (for example, reliability, transparency, consistency, granularity, accuracy and usability) vary based on the intended use of the planning or modelling exercises. Access to data also remains a challenge, particularly in lower-income regions. Where open data sources do exist, they often lack higher resolutions and desired coverage, and commercial dataset access is frequently limited due to licensing and confidentiality requirements.

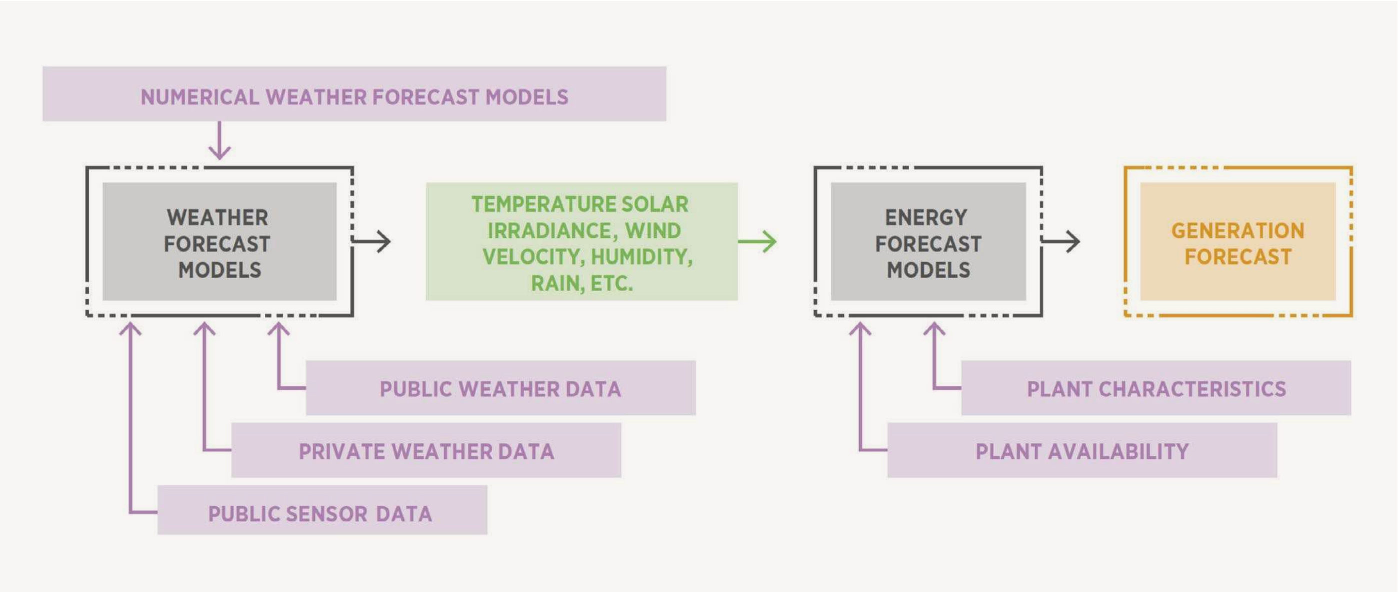

Figure 3. From weather to power generation forecast. *Source:* IRENA, 2020

To address these challenges, collaboration is essential, as clean energy transition requires a new paradigm for more effective information exchange between weather, climate and water specialists and energy-sector stakeholders. Such interaction can ensure more reliable and fit-for-purpose data and information (**State of Climate Services Report**). Additionally, fortifying open data sources and attempting to make commercial data more accessible to a broader community, especially for public planning purposes, are important (SEforALL, 2020b; ***Integrated Weather and Climate Services in Support of Net Zero Energy Transition*** (WMO-No. 1312)). Advancing scientific research and innovation, such as the application of AI to support weather forecasting for renewable energy (Box 2), will also be crucial to achieving clean and affordable energy for all.

Box 2. Enhanced energy system operation and decision-making with big data and artificial intelligence

Advanced weather forecasting and predictive maintenance (averting unexpected costly failure or downtime by predicting problems and implementing maintenance in advance) are examples of AI applications. These applications improve VRE operation by utilizing supercomputers and big data (very large data sets containing patterns that can be revealed through computer analysis) to blend multiple sources of local, real-time and/or historical weather information. Such data include high-resolution numerical weather prediction, nowcasting based on meteorological observations (in situ measurements and remotely sensed data) and integration of real-time generation information (***Integrated Weather and Climate Services in Support of Net Zero Energy Transition*** (WMO-No. 1312)).

The operational, economic and social benefits of combining weather and climate big data with AI are clear. Emerging examples (IRENA, 2020; ***Integrated Weather and Climate Services in Support of Net Zero Energy Transition*** (WMO-No. 1312)) include improved wind and solar generation, demand forecast and DSM forecast. Besides maintaining grid stability/reliability and improving DSM and efficiency, this approach supports optimizing energy storage and market operation (for example, optimizing economic load dispatch) and market design improvement (IRENA, 2019).

Advancements in remote sensing and AI-supported analytics such as machine learning are increasingly contributing to enhancement of data, increasing the levels of granularity across a wider set of geographies (SEforALL, 2020b). With more technological advancement, AI and big data are expected to further enhance decision-making, planning, condition monitoring, inspections, certifications and supply chain optimization, which will generally increase the efficiency of energy systems (IRENA, 2019).

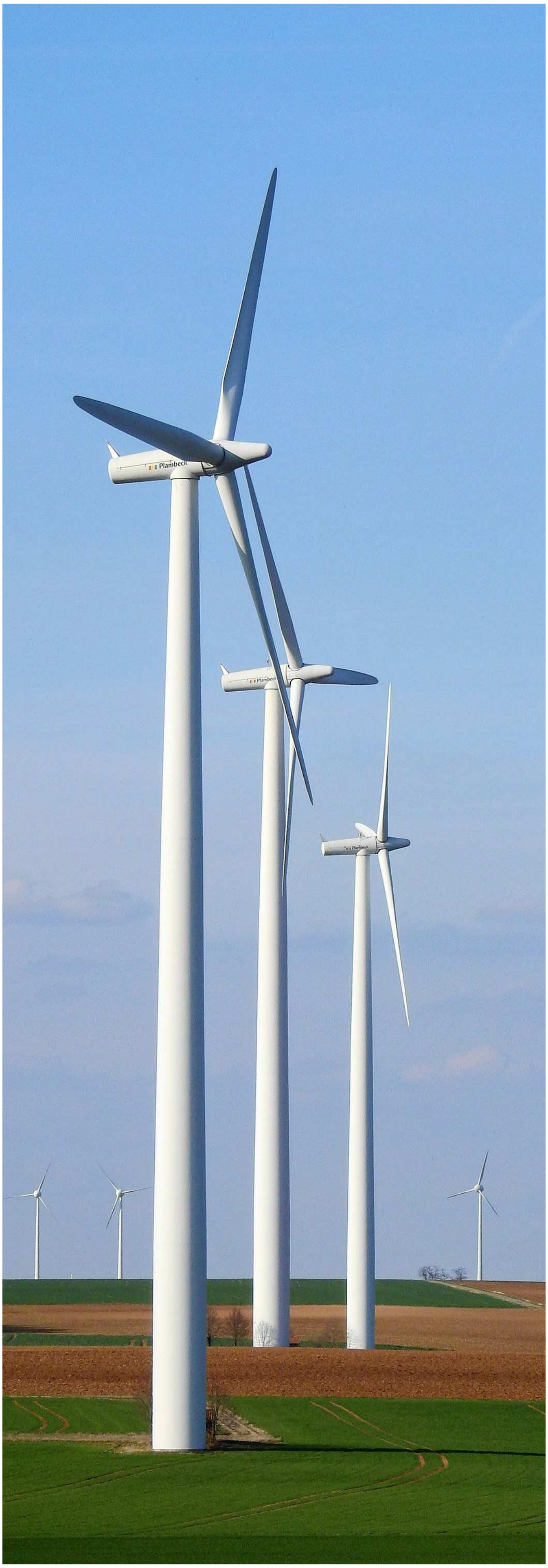

Photo: Pixabay

SDG 11
SUSTAINABLE CITIES AND COMMUNITIES

WORLD METEOROLOGICAL ORGANIZATION

UN-HABITAT

Key messages

- **Cities are responsible for a high proportion of global greenhouse gas (GHG) emissions and are highly vulnerable to the impacts of climate change and extreme weather events, which threaten the achievement of SDG 11.**
- **Integrated urban weather, climate, water and environmental services, grounded in best-available science, are helping cities to achieve SDG 11.**
- **Observations, high-resolution forecasting models and multi-hazard early warning systems are the fundamental basis for integrated urban services.**

Introduction

SDG 11 strives to make cities and human settlements inclusive, safe, resilient and sustainable. Today, more than half of the global population lives in cities, and by 2050, this number is expected to grow by 2.2 billion people, raising the urban share to 68% of the global population (UN Habitat, 2022). Cities are hubs of innovation and economic growth, contributing more than 80% of global gross domestic product. However, urban-based activities also generate a high proportion of global GHG emissions, with cities responsible for around 70% of global emissions in 2020 (IPCC, 2023a, 2023b). In addition, due to their high concentration of people and infrastructure, cities are highly vulnerable to the impacts of climate change and extreme weather events, including, for example, rising sea levels and storm surges, heat waves, extreme precipitation and flooding, drought and water scarcity, and air pollution (IPCC, 2023a, 2023b). These risks are amplified for the approximately one billion urban dwellers who live in informal settlements, lack essential infrastructure and services, and are at high risk from extreme weather events (UNSD, 2019).

To achieve SDG 11 and support the implementation of the New Urban Agenda, the Sendai Framework for Disaster Risk Reduction and other international agreements, it is crucial to integrate urban weather, climate, water and environmental sciences and services. Integrated urban services improve the sustainability and resiliency of cities and provide benefits to multiple users, city stakeholders and inhabitants. They can also assist cities in making good use of dense observation networks, high-resolution forecasts across timescales, multi-hazard early warning systems and climate services for risk management and adaptation strategies as well as improve understanding of public perception within a framework that promotes achievement of SDG 11 (*WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150); *Guidance on Integrated Urban Hydrometeorological, Climate and Environmental Services*, *Volume I: Concept and Methodology* and *Volume II: Demonstration Cities* (WMO-No. 1234)).

Weather-, climate- and water-related sciences for urban activities

The core principle of integrated urban services is to maximize the value of scientific knowledge for cities to become resilient and sustainable. Weather-, climate- and water-related sciences are the fundamental basis for integrated urban services, which support cities in responding to extreme weather events, increasing resilience to climate change and monitoring environmental conditions, such as air quality.

Responding to extreme weather

Urban areas are highly vulnerable to extreme weather events, such as strong wind and heavy rainfall, hail and snowfall. These high-impact weather events are difficult to predict accurately because small- and medium-scale weather systems are influenced by many factors that are difficult to resolve in models. Therefore, integrated urban observation networks designed with high-resolution observations and measurements from satellites, radars, ground stations, low-cost sensors and citizen observations (connected cars, mobile phones and other sources) are essential. In addition, urban data, including geomorphological, environmental and socioeconomic data, are also vital to support urban analyses and model applications, such as high-resolution meteorological and hydrological models, which are crucial for integrated urban services (*Guidance on Integrated Urban Hydrometeorological, Climate and Environmental Services, Volume I: Concept and Methodology* (WMO-No. 1234)). These models can produce high-resolution forecasting products for various urban applications and significantly enhance impact-based forecasting and multi-hazard early warning services (Box 1) (Good Practices on High-resolution Modeling for Integrated Urban Services).

Climate responsive design and planning

Climate change has led to increasing heatwaves and more frequent and intense droughts and floods that disproportionately impact the urban poor and threaten public health and well-being as well as the supply of water and energy. However, properly integrating climate science into urban planning and evaluating the impact of climate change on cities' infrastructures helps cities become more resilient and sustainable in a changing environment.

For example, rapidly developing numerical modelling, remote sensing and geographical information system (GIS) technologies have been applied to develop urban climate maps, known as UCMaps (Ng, 2009a, 2009b; Ng and Ren, 2015; He et al., 2015; Liu et al., 2016). UCMaps are developed at various scales to guide local urban planning and design practices ranging from urban master planning to regional planning, as well as at the scale of detailed district and building site design (Ren et al., 2010, 2018). The urban climate services from the rapidly growing cities, especially in lower-income regions, are in great demand, so the rapid transfer of technology and knowledge to make these cities more resilient is imperative.

Box 1. Early warnings for safe and resilient cities

Shenzhen, China is implementing a pilot project that demonstrates how public–private engagement can improve early warning services in megacities (**Pilot Project on Public-Private Engagement for Smart Meteorological Service in Mega-Cities in Regional Association II**). Low-cost, multifunctional smart poles increase the density of weather observations in urban built-up areas, and high-resolution models, combined with artificial intelligence (AI) technologies, provide rainfall nowcasting (resolution 1 km, updated every 6 minutes). To offer effective early warnings and emergency responses to urban stakeholders throughout extreme weather events, a progressive meteorological forecasting mechanism called "31631" was established (Figure 1). Through an effective public–private partnership with telecommunication companies, targeted early warning messages can be sent to people in warning-affected areas very quickly. For example, warning messages can be delivered to mobile phone users in a disaster-stricken area in 5–10 minutes.

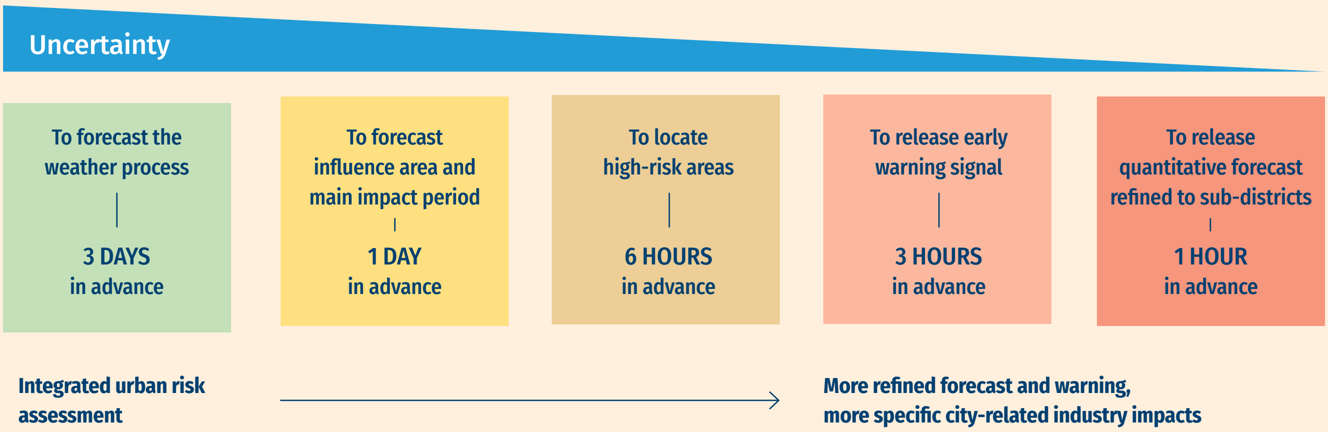

Figure 1. "31631" progressive meteorological forecasting and meteorological service mechanism applied to extreme weather events (typhoon, heavy rainstorm, etc.). *Source:* Xiaolin Wei, Meteorological Bureau of Shenzhen Municipality, China Meteorological Administration (CMA)

Environmental monitoring

Scientific advances in meteorology and in monitoring atmospheric composition and air quality on an urban scale are important for the environment and human health. However, challenges remain, including connecting various physical scales in air quality modelling, the need for ground-based and remote sensing instruments, the lack of effective mitigation and adaptation strategies to cope with the impacts of air pollution on urban areas, and uncertainties in emissions from diffuse sources and particulate matter chemical components.

To address these challenges, a multiscale coupled modelling system has recently been developed to predict street-, urban- and regional-scale air quality across Delhi, India (Figure 2) as part of a joint India–United Kingdom project called PROMOTE (funded by the UK Natural Environment Research Council and Ministry of Earth Sciences, India). These detailed high-resolution model predictions aid the development of mitigation strategies for reducing population exposure to air pollutants such as fine particulate matter (PM2.5). The project has emphasized that both local and regional contributions to air quality need to be understood and quantified to arrive at more robust and effective mitigation options to improve air quality in Delhi.

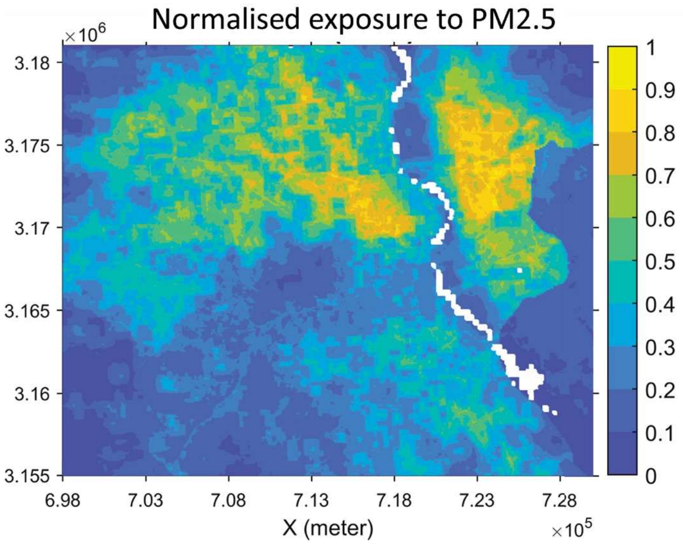

Figure 2. Example of normalized population exposure to PM2.5 predicted with the coupled WRF-Chem-OSCAR modelling system for Delhi, India. *Source:* PROMOTE project

Looking ahead: challenges and opportunities

Rapid urban sprawl, urbanization and population growth, extreme weather events, climate change, environmental and water pollution, and anthropogenic factors will continue to threaten urban safety, resilience and sustainability. Additionally, data gaps and a lack of effective multi-stakeholder (transport, energy, health, tourism, etc.) partnership and user engagement render cities vulnerable.

Weather-, climate- and water-related sciences and technology, as well as effective governance and planning at the local level and more cross-discipline collaborations between public and private sectors, can help address these challenges to achieve SDG 11. To better understand the complexity, diversity and risks in cities, it is important to promote the science-based methodologies of integrated urban services, exchange urban data freely and without restriction, expand observation networks and conduct further research on an urban scale. Impact-based environmental and hydrometeorological forecasting and climate change projections are crucial and there is a need for innovative modelling approaches at the urban level (Box 2). Combined with results-based city planning, infrastructure construction and management, tailor-made weather services can enhance human settlements by improving cities' resilience and delivering co-benefits for sustainable urban development, including improved public health, safety and well-being in cities.

Box 2. **Emerging urban-related weather and climate research in Paris**

The Paris region has been chosen as an area of interest for emerging weather and climate research. For example, the **Paris 2024 Olympic Games Research Demonstration Project** of the World Weather Research Programme, supported by the Global Atmosphere Watch Urban Research Meteorology and Environment project, focuses on improving weather forecasting at a 100-metre (or finer) resolution in urban areas to enhance urban planning and decision-making. Observational data from the experimental campaign PANAME (Figure 3) are complemented by data from numerical atmospheric models to analsye physical processes in the atmosphere and assess the impacts of weather events, such as thunderstorms, on cities. This information will be used by weather forecasters to help Olympic planners for scheduling and planning purposes and by city administrators to facilitate climate change adaptation planning.

Additionally, the World Climate Research Programme's **CORDEX Urban Environments and Regional Climate Change flagship pilot study** aims to understand the effects of urban areas on the regional climate and the impact of regional climate change on cities. Cities play a fundamental role in climate at local scales through modification of heat and moisture fluxes and local atmospheric chemistry and composition. CORDEX's work coordinating multidecadal experiments with urbanized regional climate models at kilometric scale will improve our understanding of climate change impacts on cities such as Paris and inform adaptation and mitigation action.

These two projects open complementary approaches for weather and climate studies, contributing to seamless and integrated urban weather, environmental and climate services that strengthen city planning and management.

Photo: Cyril Frésillon, French National Centre for Scientific Research (CNRS)

Figure 3. Launch of meteorological balloon in Paris during PANAME experimental campaign.

SDG 13
CLIMATE ACTION

WORLD METEOROLOGICAL ORGANIZATION

GREEN CLIMATE FUND

United Nations Climate Change

Key messages

- **The accumulation of heat in the climate system resulting from human emissions of greenhouse gases (GHGs) has caused widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere, which threaten to reverse progress towards achieving all the SDGs.**
- **Weather-, climate- and water-related science underpin ambitious climate action and the mobilization of climate finance, particularly in lower-income countries.**
- **Stakeholder engagement, through means such as citizen science, provides an opportunity to strengthen weather-, climate- and water-related sciences to advance progress towards achieving SDG 13.**

Introduction

SDG 13 urges ambitious action to combat climate change and its impacts, including mitigating GHG emissions, adapting to climate impacts and mobilizing climate finance. Climate change has resulted in widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere, affecting many weather and climate extremes and leading to adverse impacts across the world (IPCC, 2023a, 2023b). These impacts increasingly threaten sustainable development and achievement of all the SDGs. At the same time, development activities that are not sustainable may contribute to an increase in GHG emissions, jeopardizing progress towards achieving the goals of the Paris Agreement.

From the outset, the Paris Agreement recognizes the crucial role of science, stating that Parties to the Agreement recognize "the

Box 1. Supporting mitigation action through the Global Greenhouse Gas Watch (GGGW)

The GGGW is a new initiative endorsed by the Nineteenth World Meteorological Congress in May 2023 that will provide near-real-time information about greenhouse gas fluxes over the entire globe in support of climate change mitigation action (*WMO Global Greenhouse Gas Watch*). This initiative builds on and expands WMO's long-standing activities in GHG monitoring, implemented as part of the Global Atmosphere Watch, and via its Integrated Global Greenhouse Gas Information System. The spatially-resolved flux estimates are generated by combining Earth observations, prior information about the fluxes from the terrestrial biosphere, oceans and anthropogenic emissions, and advanced modelling (Figure 1). The GGGW will establish an internationally coordinated approach to observing network design, and to acquisition, international exchange and use of the resulting observations. It will engage and closely collaborate with both the broader scientific community and other United Nations agencies and international coordination entities. This systematic monitoring is crucial to improving our understanding of GHG budgets, reducing uncertainties, and enhancing the design and assessment of mitigation action. As a result, this initiative will contribute to enhanced transparency and accountability and provide input to the Paris Agreement's global stocktake.

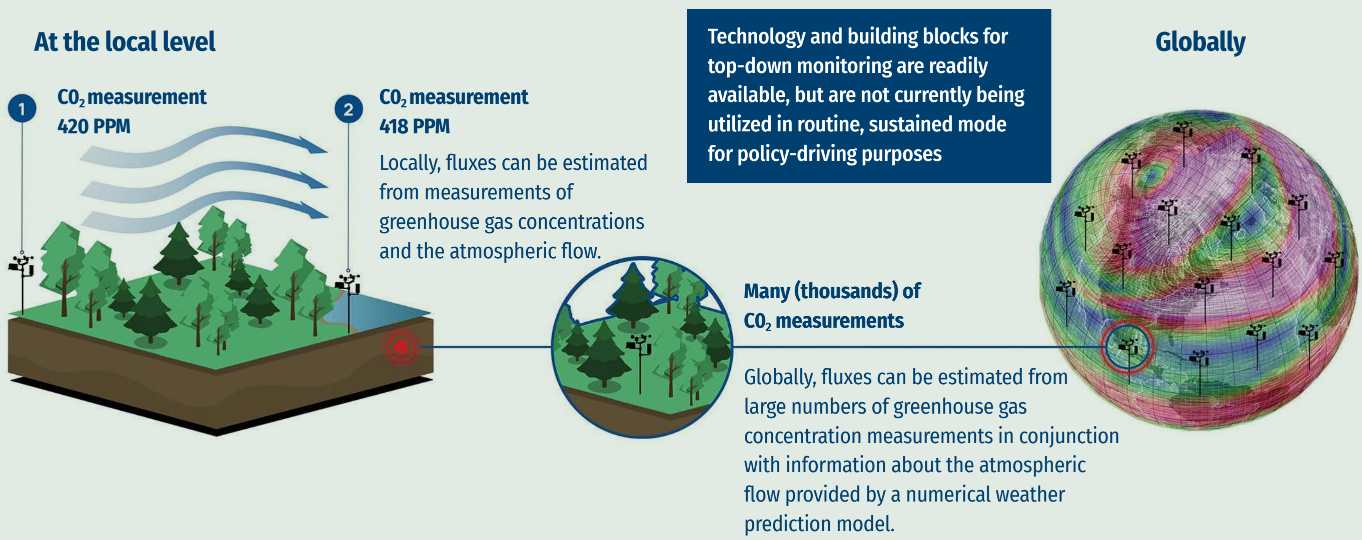

Figure 1. Estimation of greenhouse gas fluxes via the systematic comparison between model-predicted and observed GHG concentrations. The quality of the flux estimates will depend on the quality of the atmospheric transport fields and the observational data coverage. Note: PPM – parts per million.

need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge". Past, present and projected future climate information is necessary to understand how climate change affects a region, sector or community. Therefore, this information must be taken into consideration when planning and designing investments that reduce GHG emissions, increase adaptive capacity and resilience of vulnerable communities and address losses and damages. While challenges remain, as climate science continues to advance, there are opportunities to enhance climate action in support of achieving the SDGs.

Weather-, climate- and water-related sciences for climate action

Weather, climate and water science is fundamental in understanding how to reduce anthropogenic emissions of GHGs to limit global temperature rise to well below 2 °C above preindustrial levels and to pursue efforts to limit temperature rise to 1.5 °C. Under the Paris Agreement, countries are required to submit nationally determined contributions that outline mitigation action in line with this goal and regularly report on progress. Yet, the rise in global CO_2 concentrations has been steadily accelerating over the last 60 years, and there has been very limited progress in reducing the emissions gap for 2030 (**WMO Global Greenhouse Gas Watch**; UNEP, 2022). However, advances in systematic monitoring of atmospheric GHG concentrations and fluxes (Box 1) can provide actionable information to enhance mitigation action and help us get on track to meet the Paris Agreement's goals.

Weather-, climate- and water-related sciences also contribute to climate change adaptation, helping to minimize impacts, losses and damages associated with climate-related hazards or exploit opportunities arising from changing climate conditions. The Global Goal on Adaptation, established under the Paris Agreement and in the process of being defined by the Parties, aims to enhance adaptation and contribute to sustainable development based on the best available science through the implementation of national adaptation plans. However, effective adaptation is highly localized, which requires reliable, high-resolution and timely weather, climate and water information to support adaptation decision-making. Context-specific climate data, such as soil moisture data for adaptation in the agricultural sector, as well as data on high-impact hydrometeorological events, such as droughts, floods, tropical cyclones and heatwaves, help identify potential climate action options (***Developing the Climate Science Information for Climate Action*** (WMO-No. 1287)). Additionally, global and regional climate models are important tools that help us understand how the climate may change in the future and identify appropriate adaptation actions.

Weather-, climate- and water-related sciences also provide an evidence-based approach to mobilize finance for ambitious

Box 2. Climate science information for climate action

The Green Climate Fund (GCF) and WMO have joined together to provide the international community with new climate information and tools for interpreting the latest climate science data (Figure 2). The Climate Science Information for Climate Action initiative includes resources that provide technical guidance, case studies and two online platforms: the **Climate Information Platform**, which provides access to global climate projections, and **Climpact**, which calculates over 70 indices associated with climate impacts, such as historical daily temperature and precipitation (**Climate Science Information for Climate Action**). These tools and resources help translate science into technical guidance to inform policymaking and climate finance investments, particularly for adaptation, including early warning.

For example, the scientific information these tools provide is crucial for developing a robust climate rationale that underpins GCF projects and demonstrates clear climate impact. A project titled "Enhancing Early Warning Systems to Build Greater Resilience to Hydro-Meteorological Hazards in Timor-Leste" is analysing historical climate information on temperature, rainfall, sea-level rise and extreme events and considering how these variables may change in the future based on climate projections (GCF, 2021). With a strong scientific foundation, this project will transform Timor-Leste's climate information capabilities and early warning systems. Additionally, it will provide essential high-resolution data and information needed to underpin science-based adaptation action and contribute to achieving Early Warnings for All.

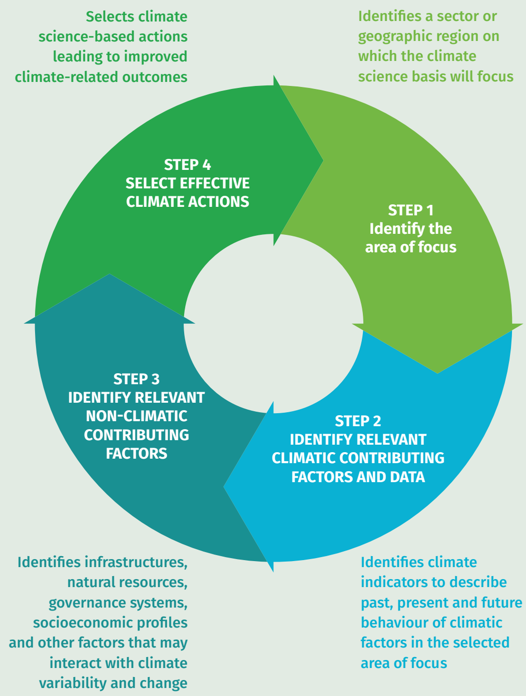

Figure 2. A four-step methodology for developing climate science information for climate action

climate action, particularly in lower-income countries that lack financial resources. For example, climate science data and information help increase certainty, enhance planning, and mitigate potential risks to ensure adaptation and mitigation projects are cost-effective, generate benefits for vulnerable populations and contribute to sustainable development (***Developing the Climate Science Information for Climate Action*** (WMO-No. 1287)). As a result, these investments are more attractive to funders, including multilateral financing institutions such as the Green Climate Fund (GCF), and the private sector (Box 2). Climate science also ensures that climate finance supports climate action as opposed to other non-climate-related development needs or priorities. However, most climate-related projects have co-benefits that contribute to sustainable development, disaster risk reduction and other national priorities (***Developing the Climate Science Information for Climate Action*** (WMO-No. 1287)).

Looking ahead: challenges and opportunities

The science is clear – we are far off track from meeting the goals of the Paris Agreement, undermining progress towards achieving SDG 13 and all the other SDGs. Urgent and ambitious climate action is needed to mitigate GHG emissions and adapt to the impacts of climate change. Weather-, climate- and water-related sciences play an important role in underpinning ambitious climate action, including enhancing mitigation efforts, enabling adaptation and supporting the mobilization of climate finance. However, adaptation at local scales is hindered by insufficient climate models that lack the spatial resolution necessary for local-level decision-making. Additionally, lower-income countries often lack adequate climate information and the scientific capacity to use it effectively, limiting progress towards achieving SDG 13 (***Developing the Climate Science Information for Climate Action*** (WMO-No. 1287)).

Thanks to scientific research initiatives, enormous progress has been made in advancing global and regional climate modelling to better understand and predict how a warming world will affect society. However, there is an opportunity to scale up efforts to improve climate modelling to deliver robust, reliable and actionable information through enhanced observations and understanding of climate processes. Advances in high-resolution climate modelling, in particular, can better predict future climate changes at the local level and contribute to achieving SDG 13 by supporting ambitious adaptation action and reducing the risk of maladaptation. Additionally, as climate science advances, training, education and stakeholder engagement will be increasingly important to ensure new data, knowledge and technologies can be used effectively. One way to enhance stakeholder engagement is to involve the general public in scientific research through citizen science (Box 3), which is used to select the most relevant data for local contexts and integrates local, Indigenous and contextual information. In turn, this engagement enhances trust and builds capacity to effectively use weather, climate and water science, data and information in a local context.

The Paris Agreement goals are in danger of slipping out of reach. As a result, urgent and ambitious mitigation action is essential to achieve not only SDG 13 but all SDGs, which are greatly impacted by climate change. When acted upon, weather-, climate- and water-related sciences can underpin climate action and help to safeguard economic and human development in support of achieving the SDGs.

Box 3. **Engaging local communities in Ghana through citizen science**

A lack of weather stations in Ghana limits data observations, resulting in inaccurate weather forecasts. Furthermore, delays in media reports and warnings have degraded public faith in designated organizations, creating a significant communication gap. A citizen science project was launched by the World Weather Research Programme, through its HIWeather flagship activity, to explore the impact of users' feedback on weather forecast evaluation in Ghana (Figure 3). This project used a WhatsApp platform called "Let's Talk Weather", open to those interested in weather forecasting and verification (**Let's Talk Weather in Ghana**). Citizen scientists' feedback data were collected to evaluate and verify the weather forecasts. People sent their observations with photos to this platform, after which they were analysed to compare information regarding the occurrence, distribution and intensity of the rainfall. The project not only improved forecast evaluation and verification but also encouraged the public's willingness to learn and engage with the platform. Therefore, through engagement and education, the project bridged the gap between scientists and the public, strengthening people's trust in meteorological agencies.

Photo: WMO

Figure 3. A group of farmers participating in a citizen science activity in Ghana.

Key messages

- **Climate- and human-related impacts are threatening our oceans, affecting marine ecosystems and the communities that rely on them for food and livelihood security.**
- **Climate-related ocean science enhances our understanding of climate impacts on the ocean and contributes to strategies for sustainably managing and protecting marine ecosystems.**
- **The United Nations Decade of Ocean Science for Sustainable Development provides an unprecedented opportunity to mobilize the scientific community and accelerate ocean-related science.**

Introduction

SDG 14 calls for the conservation and sustainable use of the ocean, seas and marine resources for sustainable development. The ocean represents the largest biome on the globe, contributing essential resources and services in support of human health and nutrition as well as cultural and spiritual connection to nature. Inclusion of SDG 14 in the 2030 Agenda for Sustainable Development demonstrates recognition of the ocean's critical role in human well-being and its contribution to achievement of all the SDGs.

The ocean, with its diverse ecosystems and prosperous marine life, and the key services it provides are under heightened pressure from diverse threats, including the impacts of climate change. Climate-related impacts on the global ocean and its coastal waters include events that occur incrementally over a long duration, such as ocean warming, acidification, deoxygenation, sea-level rise, loss of sea ice and glacial retreat as well as extreme events, such as marine heatwaves and weather-driven storm surges and waves. These impacts are exacerbated by human-induced stressors, such as pollution, eutrophication, habitat destruction, invasive species and unsustainable use of marine resources. Climate- and human-related impacts profoundly affect marine ecosystems and the communities that rely on them for food and livelihood security. Therefore these impacts threaten progress towards achieving not only SDG 14, but also other SDGs.

Climate-related ocean science enhances our understanding of climate impacts on the ocean and contributes to strategies for sustainably managing and protecting marine ecosystems. Challenges, such as limited data access and exchange and insufficient capacity in lower-income countries, have resulted in significant gaps in ocean observation and knowledge. However, initiatives such as the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), known as the Ocean Decade, is accelerating ocean science by transforming how diverse stakeholders collaborate to generate, finance and use ocean science in support of sustainable development.

Climate-related science for a sustainable ocean

The impacts of climate change, including ocean acidification and warming, are already being observed. The ocean absorbs around one quarter of the annual emissions of anthropogenic CO_2 to the atmosphere and around 90% of the energy trapped in the climate system (***State of the Global Climate 2022*** (WMO-No. 1316)). As a result, the ocean helps alleviate the impacts of climate change on the planet (Friedlingstein et al., 2022). However, as the CO_2 reacts with seawater, it changes the acidity of the ocean, leading to ocean acidification. Additionally, the uptake of energy in the climate system leads to ocean warming, which can exacerbate sea level rise due to thermal expansion and lead to more frequent and intense marine heatwaves. According to IPCC (2023), ocean acidification and warming will continue to increase in the twenty-first century, at rates dependent on future emissions.

Ocean acidification

Ocean acidification impacts marine organisms and ecosystem services, endangering fisheries and aquaculture, which impacts food security. It also weakens the coral reefs that protect the coastline, provide food and nutrition and also drive tourism, which many coastal communities rely on for their livelihood. As a result, ocean acidification poses a serious threat to sustainable development.

As a key global climate indicator, monitoring of ocean acidification is crucial to enhancing understanding of our climate system. To detect ocean acidification, observations must be made with a frequency that is adequate for describing variability and trends in carbonate chemistry, as well as its impacts on marine life. Over the past ten years, monitoring of surface ocean pH has become a focus of many international science initiatives, mainly thanks to the Global Ocean Acidification Observing Network (GOA-ON) (Newton et al., 2015). GOA-ON is a collaborative international network that enhances the detection and understanding of ocean acidification through several initiatives, including the SDG 14.3.1 Data Portal (Box 1) and the Ocean Acidification Research for Sustainability programme, a United Nations-endorsed Ocean Decade programme (Global Ocean Acidification Observing Network).

As a result of these initiatives, human and technological capabilities to obtain ocean acidification data of sufficient quality are increasing.

Box 1. Guidance on conducting ocean acidification observations

With the support of the scientific community, a methodology and data portal were developed to deliver the necessary guidance on how to conduct ocean acidification observations, using different types of technology and measuring different variables, including pH, carbon dioxide partial pressure [pCO_2], total dissolved inorganic carbon [CT/DIC], and total alkalinity [AT/TA], as well as pressure, salinity and temperature. The methodology further provides assistance on what kinds of data sets to submit, and how to ensure the production of quality-controlled global and possibly regional products.

Since the launch of the **SDG 14.3.1 Data Portal** in December 2019, an increasing number of ocean acidification observations have been reported to the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) and are included in the annual 14.3.1 assessment (rising from 308 stations in 35 countries reported in 2022 to 539 stations in 41 countries in 2023) (Figure 1). However, the current global coverage of ocean acidification monitoring remains inadequate, with gaps in observations and data in all areas of the ocean. The rate of change in ocean acidification, its pattern and its scale show great regional variability and therefore require observations with high spatial and temporal resolution.

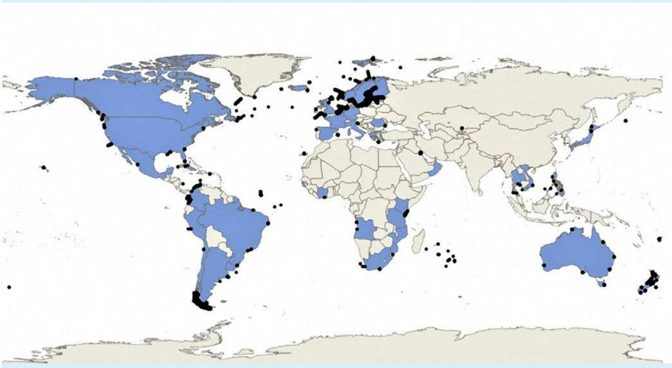

Figure 1. Map of 539 stations (black circles) for which data on ocean acidification were provided in 2023 by 41 countries towards the SDG indicator data collection. *Source:* IOC-UNESCO

Marine heatwaves

Marine heatwaves are periods of extreme warm sea-surface temperatures that persist for days to months and can extend up to thousands of kilometres (IPCC, 2019). Since the 1980s, marine heatwaves have approximately doubled in frequency, and human influence has very likely contributed to most of them since at least 2006 (Cooley et al., 2022). These heatwaves are associated with devastating and long-lasting impacts on marine ecosystems, including biodiversity loss and ecosystem degradation, threatening the food security and livelihoods of coastal communities. Additionally, marine heatwaves can exacerbate other extreme events, such as droughts and tropical cyclones, and may influence monsoon variations (Rodrigues et al., 2019; Saranya et al. 2022; Mawren et al., 2022).

To minimize the impacts of marine heatwaves on achievement of the SDGs, climate science can play a crucial role in enhancing our understanding of the characteristics, mechanisms and future projections of these events. For example, the World Climate Research Programme's Climate and Ocean – Variability, Predictability and Change (CLIVAR) core project has established a Research Focus on Marine Heatwaves in the Global Ocean (**Marine Heatwaves in the Global Ocean**). The aim of this initiative is to enhance understanding of marine heatwaves globally, including detection, surface and subsurface characteristics, mechanisms, connection with climate change and biogeochemical extremes. As the science continues to advance, global climate forecasts and seasonal sea-surface temperature forecasts are enabling prediction of marine heatwaves from 1 to 12 months in advance, depending on the region, season and state of large-scale climate drivers, such as El Niño (Jacox et al., 2022). These predictions support effective policy- and decision-making for adaptation planning and sustainable development.

Strategies to sustainably manage and protect marine ecosystems

Marine spatial planning (MSP) presents a way of developing strategies to balance conservation and sustainable use of the ocean through spatial and temporal allocation of areas for various uses, while ensuring they retain their ecosystems. A data-driven and knowledge-based approach grounded in best available science is crucial to the further development and implementation of MSP, particularly in the context of climate change. Climate-smart MSP refers to the use of climate-related ocean science, data and knowledge to integrate adaptation and mitigation measures in ocean planning with a goal of increasing resilience of marine ecosystems and reducing exposure and vulnerability of coastal communities to climate change (IOC-UNESCO/European Commission, 2021). For example, analysis of cumulative impacts and incorporation of climate change modelling in the development of scenarios about the future use

Photo: Muhammad Amdad Hossain

and conservation of marine areas helps support assessments needed during the MSP process. For such analyses, it is crucial that data be available at appropriate spatial scales and that uncertainties in the planning scenarios be recognized and properly addressed (IOC-UNESCO, 2021).

At the global level there is an increased awareness of the need to manage and protect marine and coastal habitats and ecosystems. Sustainable management of marine and coastal ecosystems is enshrined in MSP Global, which is a multi-sectoral policy that has been adopted by 38 countries and is being implemented in several additional countries (IOC-UNESCO, 2022a).

Looking ahead: challenges and opportunities

Sustainable development and the need to protect the ocean are becoming even more urgent with climate change. Climate-related ocean science plays an important role in enhancing our understanding of climate impacts on the ocean and contributes to strategies for sustainably managing and protecting marine ecosystems. However, challenges remain, such as limited data access and exchange and insufficient human and technological capacity in many parts of the world, particularly small island developing States and least developed countries, which often have limited capacity to meet the demand for scientific support (IOC-UNESCO, 2020). As a result, there are significant gaps in ocean observations and research in the Global South. Additionally, ocean-related research remains significantly underfunded, limiting our understanding of the ocean and how it may be impacted by a changing climate (IOC-UNESCO, 2022a). There is also a need for improved ocean models and an increase in cross-disciplinary scientific collaboration to facilitate the co-design of science, bridge existing knowledge gaps and enhance capacity to achieve SDG 14.

The United Nations Ocean Decade was launched to address these challenges, and provides an unprecedented opportunity to mobilize the scientific community to accelerate ocean-related science (IOC-UNESCO, 2022b). Through a common framework that engages a wide range of stakeholders, the Ocean Decade aims to ensure all countries can generate and support the ocean science needed to achieve the ocean we want.

WORLD METEOROLOGICAL ORGANIZATION

Key messages

- **Half of countries report not having multi-hazard early warning systems (MHEWSs) in place and, where they do exist, there are significant gaps in coverage.**
- **Weather-, climate- and water-related sciences underpin effective MHEWSs by enhancing the physical understanding of hazards, growing the understanding of the associated risks and impacts, and enabling the detection, monitoring and forecasting of hazards.**
- **Partnerships across diverse stakeholders, including the weather-, climate- and water-related science communities, are essential to deliver Early Warnings for All and achieve the SDGs.**

Introduction

SDG 17 focuses on partnerships for the goals, including enhancing international cooperation on access to science, technology and innovation to support the achievement of the SDGs. Effective partnerships across diverse stakeholders, including the weather-, climate- and water-related science communities, are crucial for achieving the SDGs by 2030. One example of a partnership that is contributing to achieving the SDGs, as well as the targets of other global frameworks such as the Paris Agreement and Sendai Framework for Disaster Risk Reduction, is the United Nations Secretary-General's Early Warnings for All (EW4All) Initiative. This initiative aims to ensure that everyone on Earth is protected from hazardous weather, climate and hydrological events through life-saving early warning systems by the end of 2027.

With human-induced climate change leading to more extreme weather conditions, the need for multi-hazard early warning systems (MHEWSs) is more crucial than ever. Advances in MHEWSs have decreased mortality rates, and data show that just 24 hours' notice of an impending hazardous event can reduce damage by 30% (WMO Press release No. 22052023). Additionally, MHEWSs support climate change adaptation, disaster risk reduction and sustainable development, providing cross-cutting benefits towards nearly all of the SDGs (*Early Warnings for All Executive Action Plan 2023–2027*). However, major gaps exist, with half of countries not protected by MHEWSs, especially lower-income countries and small island developing States, where vulnerable communities are hit hardest by extreme weather events and the impacts of climate change (Figure 1).

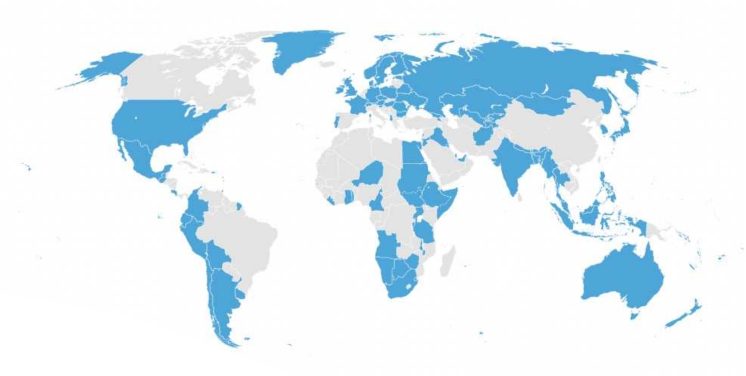

Figure 1. Countries reporting early warning system coverage through the Sendai Framework Monitor. MHEWS coverage is increasing globally; only 95 countries reported having MHEWSs in place in 2021 (Early Warnings for All Executive Action Plan 2023–2027)

EW4All is an example of SDG 17 in action, requiring global collaboration and partnerships across United Nations entities, the scientific community, the private sector, financing institutions, governments, academia and others. The initiative is co-led by WMO and the United Nations Office for Disaster Risk Reduction (UNDRR), in partnership with the International Telecommunication Union (ITU) and the International Federation of Red Cross and Red Crescent Societies (IFRC). Other partners include the Food and Agriculture Organization of the United Nations (FAO), Risk-Informed Early Action Partnership (REAP), United Nations Development Programme (UNDP), United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Environment Programme (UNEP), United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and World Food Programme (WFP), among others.

Weather-, climate- and water-related sciences in support of EW4All

A MHEWS is an integrated system which allows people to know that hazardous weather or climate events are on their way and informs how governments, communities and individuals can act to minimize impacts. An end-to-end MHEWS is people-centred and includes four key components as highlighted in Box 1. The EW4All Executive Action Plan is structured around these core components, known as pillars, to deliver inclusive and people-centred MHEWSs that empower those threatened by hazards to act in sufficient time and in an appropriate manner (*Early Warnings for All Executive Action Plan 2023–2027*).

Weather-, climate- and water-related sciences underpin all four pillars of action. For example, global surface and space-based observation data are the foundation of a MHEWS. This information is essential for the detection, observation, monitoring, analysis and forecasting of hazards as well as providing reliable, understandable and relevant risk information. Additionally, numerical weather models, which replicate the physical interactions of the Earth system (weather, hydrology, ocean and cryosphere) depend on observational data to create predictions, enabling National Meteorological and Hydrological Services (NMHSs) to provide forecasts and early warnings to citizens. These observational data are also important for the prediction of high-impact weather and water hazards on timescales up to six hours, known as nowcasting (Box 2), which is crucial for early warning (*Early Warnings for All Executive Action Plan 2023–2027*).

Box 1. The four pillars of EW4All

The EW4All Initiative is structured around four pillars described below, each led by a United Nations agency with support from partner organizations.

Disaster risk knowledge and management (led by UNDRR with support from WMO): ensuring all countries have access to reliable, understandable and relevant risk information, science and expertise.

Detection, observation, monitoring, analysis and forecasting (led by WMO with support from UNDP, UNESCO and UNEP): ensuring all countries have robust forecasting, observation and monitoring systems (both soft and hardware infrastructure) and enabling policies to support optimization and sustainability of hazard monitoring and early warning.

Warning dissemination and communication (led by ITU with support from IFRC, UNDP, REAP and WMO): using a people-centred approach to ensure that early warnings are disseminated effectively and in a timely manner to reach everyone, especially those most at risk.

Preparedness and response capabilities (led by IFRC with support from REAP, OCHA, FAO and WFP): ensuring local governments, communities and individuals at risk have the knowledge and means to take pre-emptive early actions to prepare for and respond to incoming disasters upon receiving warnings.

As weather forecasting skill improves, a paradigm shift from providing information on "what the weather will be" to "what the weather will do" is transforming how NMHSs provide early warnings to citizens. Known as impact-based forecasting, this approach integrates traditional forecasting of physical hydrometeorological hazards and understanding of societal exposure and vulnerability to those hazards to inform decision-making and enable action to reduce impacts to society and ensure sustainable development (Golding, 2022). Partnership, collaboration and co-design are essential to integrate diverse sources of knowledge, including physical and social science and local and indigenous knowledge, to ensure impact-based early warnings are actionable, timely and effective.

Advances in climate modelling are also improving our understanding of changes in the Earth system due to climate variability and change and how those changes may influence hazards. Quantitative explanation of observed changes, through process-based detection and attribution, enhances confidence in climate assessments, predictions and projections. Additionally, climate models enable climate predictions on multi-annual to decadal timescales, which improves our knowledge of hazards and how MHEWSs may need to evolve in the future. While models have undergone unprecedented advances in recent years, there is still much research to be done to improve our observational and modelling capabilities, particularly for annual to decadal timescales. The World Climate Research Programme's Lighthouse Activity on Explaining and Predicting Earth System Change is one example of research that is advancing our understanding of the Earth system in support of EW4All. This activity is advancing the ability to understand, attribute and predict multi-annual to decadal changes in the Earth system, including for early warning of potential high-impact changes and events (Findell et al., 2023).

Technological advances in the modelling of natural hazards have led to better tools to respond to extreme weather events (Kuglitsch et al., 2022a, 2022b). For example, artificial intelligence (AI) can enhance MHEWSs by using geospatial data to strengthen our understanding of hazards, improve the accuracy and timeliness of detection and warnings, and support effective emergency communications (Kuglitsch, et al., 2022b). However, more research is still needed to effectively integrate this emerging technology into MHEWSs and disaster management. Interdisciplinary, multi-stakeholder and international scientific collaboration and partnership, such as the joint WMO, ITU and UNEP Focus Group on Artificial Intelligence for Natural Disaster Management, are crucial for laying the groundwork for standards in the use of AI to support natural disaster management (Kuglitsch et al., 2022b).

Box 2. **Reducing risk from thunderstorm events in cities across southern Africa using satellite-based nowcasting science**

Severe thunderstorms threaten lives and cause significant damage to property and livelihoods, particularly in urban areas in southern Africa. Advances in nowcasting technology allow weather forecasters to observe thunderstorms as they form and assess how severe they will be. As a result, forecasters can provide early warnings that enable members of the public to take early action to minimize impacts.

The Weather and Climate Information Services (WISER) Early Warnings for Southern Africa (**EWSA**) project aims to reduce disaster risk through the co-production of new weather information services and early warnings. This is done through partnership and engagement, which is essential to ensure that the science and technology translates into useful and actionable information for local urban communities, particularly disadvantaged groups, including women and those with disabilities. By fostering strong partnerships and bringing together a multidisciplinary team of meteorologists, economists, social scientists and user engagement specialists to work with disaster risk management agencies and local non-governmental agencies, the WISER EWSA project will improve early warnings across the region (Symonds, 2023).

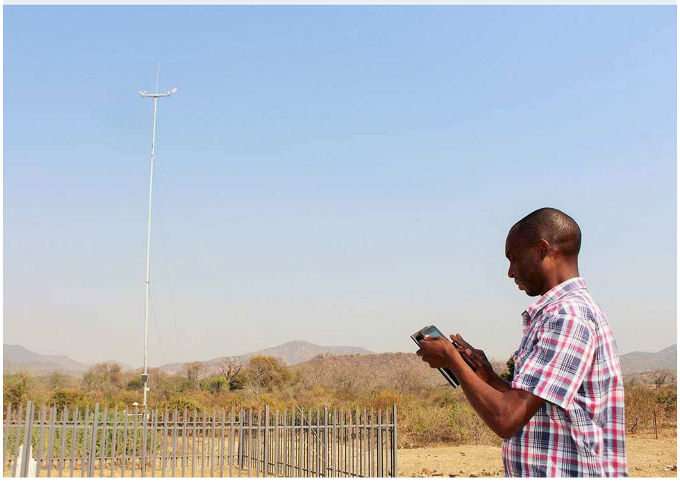

Photo: UNDP Zambia

Looking ahead: challenges and opportunities

Despite advances in weather-, climate- and water-related science, there are still scientific and technological challenges that must be addressed to improve the prediction and forecasting of extreme hydrometeorological events and expand the provision of accurate and effective early warnings. Gaps in global surface-based data, particularly hydrological data, significantly impact the quality of weather, climate and water services and early warnings (***Early Warnings for All Executive Action Plan 2023–2027***). Limitations in climate modelling, especially at annual to decadal timescales, present challenges in understanding how hazards may change in the context of climate change and how to design effective MHEWSs. Additionally, gaps between the physical and social sciences are a barrier to improving forecasting of extreme events and expanding impact-based, people-centred early warnings.

Moving forward, it is crucial to enhance capacity to detect, monitor and forecast hazards. This can be done by closing the observations gaps, promoting the unrestricted exchange of data, enhancing human capacities and competencies, and ensuring access to satellite observations and advanced technologies, including radar, nowcasting, high-resolution modelling and AI. It is also important to enhance the research-to-operations process to ensure the latest scientific and technological advances are being applied in operational settings and, ultimately, inform decision makers. Input and feedback from users also enhance the effectiveness of scientific information, and greater efforts are needed to integrate local and Indigenous knowledge through the co-development of impact-based early warnings. And finally, partnerships between the physical and social science research communities and other stakeholders must be strengthened to better understand how to communicate science and early warnings effectively to support decision-making and ultimately encourage early action to minimize impacts on society and sustainable development (***Early Warnings for All Executive Action Plan 2023–2027***).

Early warning systems can only save lives and protect livelihoods if all the MHEWS components work together, bridging the gaps between areas of expertise. EW4All emphasizes the importance of SDG 17 and effective partnerships across the United Nations system, international organizations, civil society, scientists, the private sector, financial institutions, local communities, governments, academia and other stakeholders. Together we can deliver EW4All and the SDGs.

APPENDIX
DATA SETS

Global temperature data sets

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