WMO
Performance Assessment Report

2020 - 2022

Long-term Goal 3

Advance targeted research: Leveraging leadership in science to improve understanding of the Earth system for enhanced services

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Increased involvement of academia in WMO work

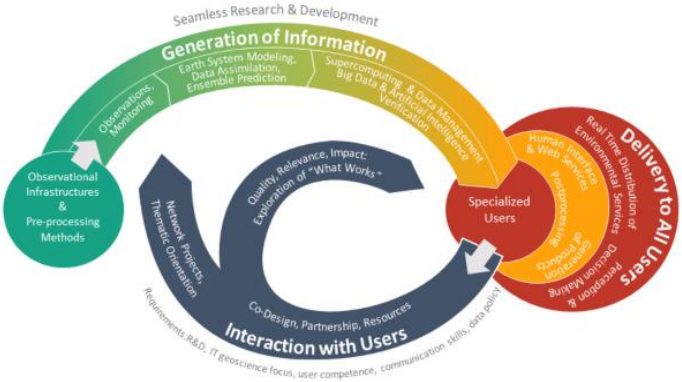
Better engagement of academia was a major objective of the WMO governance reform and was a critical factor in the establishment and composition of the WMO Research Board (RB) and the WMO Scientific Advisory Panel (SAP).

Composed of scientific, technological and innovation experts, RB acts as the WMO interface with the scientific international community. It fosters an integrated and multi-disciplinary research approach to weather, climate, water and the environment, and works on developing all elements of the value cycle, from discovery science to serving society in the context of the Earth System science. Following a virtual inaugural session in April 2020, the RB and experts from the sponsored and co-sponsored research programmes developed a set of concept notes. The motivation was to articulate the high-level scientific priorities and key activities needed in response to the WMO Strategy and other decisions of the WMO Members in a manner that is attractive and accessible to the broad scientific community and to partners who are not familiar with the WMO.

The concept notes provide a holistic view that will facilitate the integration of research activities and the attractiveness for funding agencies and stakeholders in general. **The link and interaction with regions are of paramount importance** to ensure the gathering of needs and to foster a regional development of science needed by meteorological services and citizens living in those regions. The concept notes facilitate interactions within the WMO between the RB, TCs and other bodies, enable the research programmes to work more effectively on cross-cutting aspects, and provide an inclusive framework for partners of the WMO.

To provide forward-looking strategic advice on emerging challenges and opportunities, WMO also created the SAP which makes recommendations on matters concerning research strategies and the optimal scientific directions to support the evolution of the WMO mandate in weather, climate, water and related environmental and social sciences. Many of its members are from academia.

In the reporting period the SAP developed a Vision Paper to inform and make recommendations to WMO Members on game-changing scientific challenges that could guide the development of the Organization's mandate in the coming decades. The paper considers possible future demands and disrupters on existing weather, climate and water services and the emerging or existing capabilities that can help address these forthcoming challenges. The SAP Vision Paper recommendations were further examined by the RB which appraised their feasibility and level of priority. Both the SAP Paper recommendations and the RB appraisal are submitted for consideration to Cg-19.



WMO Hydrological Research Strategy 2022-2030

The RB developed the WMO Hydrological Research Strategy 2022-2030: Operational Hydrology Research Priorities, which was approved by Cg-Ext (2021). The purpose of the Strategy is to provide input to the global research community on the areas of priority research needed to support the provision of improved hydrological services. Its focus is on research that has a direct application to improving operational hydrology and the operations of NMHS in support of the eight ambitions described in WMO's Action Plan on Hydrology. The document provides a framework for research to support National Meteorological Services and National Hydrological Services, a tool for building new research partnerships and collaborations, and a means of effectively communicating the needs and benefits of hydrological research in support of operational hydrology.

Long-term Goal 3

Advance targeted research: Leveraging leadership in science to improve understanding of the Earth system for enhanced services

United in Science Reports

Coordinated by WMO, the United in Science Report is released every year since 2019. The Report is a multi-organization high-level compilation of the latest climate science information, which gives a unified assessment of the state of the Earth system. In practice, the 2022 report provided a holistic assessment of the most recent climate science on:

- Global Greenhouse Gas Emissions and Budgets (Global Carbon Project)
- State of the Global Climate: 2018–2022 (WMO)
- Global Climate Predictions: 2022–2026 (Met Office, UK, WMO, WCRP)
- Emissions Gap (UN Environment Programme)
- Tipping Points in the Climate System (WMO, WCRP)
- Climate Change and Cities (Urban Climate Change Research Network)
- Extreme Weather Events and Socioeconomic Impacts (WMO WWRP)
- Early Warning Systems: Supporting Adaptation and Disaster Risk Reduction (WMO/UN Office for Disaster Risk Reduction)

As summarized by WMO Secretary-General Prof. Petteri Taalas: "Greenhouse gas concentrations are continuing to rise, reaching new record highs. Fossil fuel emissions are now above pre-pandemic levels. The past seven years were the warmest on record. Cities, which contribute 70% of global emissions, are highly vulnerable to climate impacts. Climate science is increasingly able to show that many of the extreme weather events that we are experiencing have become more likely and more intense due to human-induced climate change. It is more important than ever that we scale up action on early warning systems to build resilience to current and future climate risks in vulnerable communities."

The key messages of the 2022 United in Science Report are presented on Figure 3.1. Read more on the United in Science reports' impact under SO 1.2.

Figure 3.1 United in Science 2022 Key Messages

Forward perspective

WMO's expertise in observation and modelling is fostering emerging capabilities for the Organization to provide climate services in relation to GHG mitigation. This would present a crucial opportunity for WMO to position itself as a leader in a critical sector.

Long-term Goal 3 | 2022 Key Performance Indicators (Summary)

Strategic Objective 3.1

KPI 3.1.1

Peer-reviewed publications citing the Coupled Model Intercomparison Program (CMIP)

1'377

▲ 10%*

Strategic Objective 3.2

KPI 3.2.1

Downloads from the Sub-seasonal to Seasonal Prediction (S2S) database, in Terabytes

255

▲31%*

Strategic Objective 3.3

KPI 3.3.1

Members with national greenhouse gas observations

43

▲5%*

KPI 3.3.2a

Members contributing to the WMO Lead Centre for Annual-to-Decadal Climate Prediction

13

▲30%*

KPI 3.3.2b

Centres contributing to the WMO Lead Centre for Annual-to-Decadal Climate Prediction

19

▲19%*

KPI 3.3.3

Decadal prediction products downloaded from the WMO Lead Centre for Annual-to-Decadal Climate Prediction

7'880

▲7%*

**Comparison between 2020 and 2022.*

Strategic Objective 3.1

Advance **scientific knowledge of the Earth system**

Outcome/Focus Area A:

Address overarching challenges in Earth system scientific research, modelling, analysis and observations.

#Current and new integrated research activities respond to the needs of all regions addressing relevant research priorities and fostering the value chain approach
#Integrated research activities implemented across research programmes

Outcome/Focus Area B:

Prioritize research implementation plans and mobilize broad scientific community to help leverage global research potential to generate enhanced knowledge and understanding of the Earth system and related weather, water and climate linkages.

#Implementation Plans of WCRP, WWRP and GAW updated and made available to the research community #Delivery of scientific advances that work towards a WMO open science conference

Outcome/Focus Area C:

Support advancement of WMO-coordinated priority scientific assessments and services.

#Support to early-career scientists

Overview

Strategic Objective 3.1

Advance scientific knowledge of the Earth system

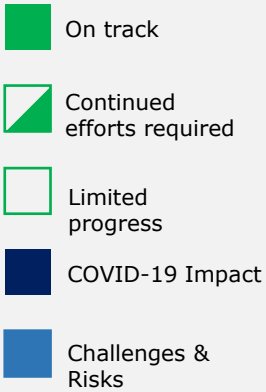
SDG Contribution

ON TRACK

- **New World Climate Research Programme (WCRP)** structure set up, building on the WCRP Strategic Plan and adding 5 new lighthouse activities with science plans approved (see Focus Area A) as well as two new Core Projects on "Earth System Modelling and Observations," including CMIP, and "Regional Information for Society," including CORDEX.
- **New Implementation Plans for WWRP (2024-2027) and GAW (2024-2027)** finalized, taking into account inputs from the WMO technical commissions and research community, and endorsed by EC-76.
- **WCRP Science and Implementation Plan** drafted, to be finalized in 2023.
- **7 Climate Research Forums held regionally** (online) to roll out consultation on WCRP evolution in South America, Europe and Western Asia, Southeast Asia, North and Central America, Eastern Asia, Oceania and Southern Asia.
- **WCRP-WWRP Symposium** on Data Assimilation and Reanalysis held virtually in September 2021, with over 530 registered participants.
- **Quadrennial Global Atmosphere Watch (GAW) Symposium** held virtually in June 2021. It saw 498 registrations from 70 countries and an 81% turnout rate, with over 40% early career scientists. See Focus Area B for more information.
- **Early-career scientists supported** through multiple workshops and webinar series (read more in Focus Area B).
- **Strong connections among the three programmes established**, particularly WCRP and WWRP (e.g., Symposium on Data Assimilation and Reanalysis), but also WCRP, WWRP and GAW (e.g. Digital Earths lighthouse activity).

CONTINUED EFFORTS REQUIRED

- **Continued capacity development** through new cryosphere fellowship schemes, WCRP Academy, dedicated training events and improved engagement with YESS/ECS community.



Overview

Strategic Objective 3.1

Advance scientific knowledge of the Earth system

SDG Contribution

COVID-19 IMPACT

- Programmatic implementation was mildly to moderately affected with a swift adaptation of activities to a virtual mode of delivery.
- The **biggest challenge was to roll out the work of new bodies** that had never met face-to-face (RB, SAP, study groups).
- Launching new initiatives was also difficult, such as the development of a scientific plan for the Aviation Research & Development Project (AvRDP2) Phase II.
- Establishing the needed leadership was also more challenging in the absence of face-to-face meetings. People were **overwhelmed by the large amounts of online meetings as well as family care and health issues** and some members who intended to be involved, had to step down. New leadership was established at the beginning of 2022 only.
- Online trainings, though allowing broader participation than face-to-face meetings, have struggled in keeping participants engaged. **Several workshops were deferred or cancelled**: Symposium on Air Quality Prediction in Africa (postponed to 2023), Regional Climate Information for Societies Implementation workshop, Symposium on Air Quality Forecasting by MAP-AQ.

CHALLENGES & RISKS

- **Knowledge gaps in the Earth system** (processes, drivers of change) need to be addressed through cutting-edge research and included in the implementation plans of the WMO Research Programmes.
- The **engagement of a broader science community** is required to reduce knowledge gaps, as many of those have regional aspects and are cross-cutting in nature.
- **Stronger collaboration between RB and the RAs** is required.

On track

Continued efforts required

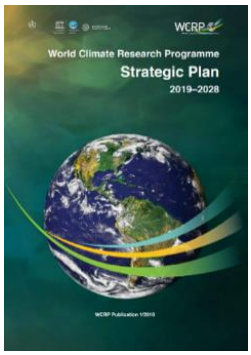
Limited progress

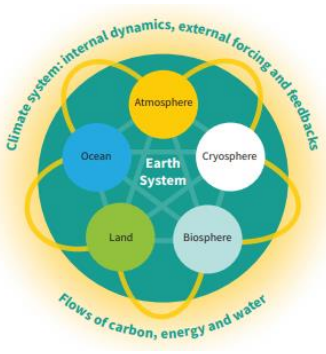
COVID-19 Impact

Challenges & Risks

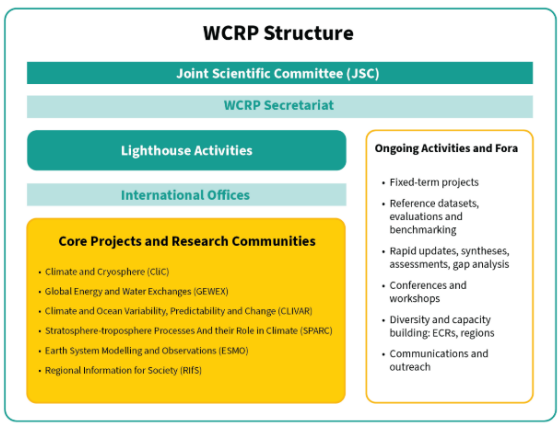
Focus Area A

New WCRP structure for the WCRP Strategic Plan 2019-2028





Having adopted a new **Strategic Plan for 2019-2028**, WCRP focused on reforming its structure in the reporting period to ensure smooth implementation and better alignment with the new WMO governance.



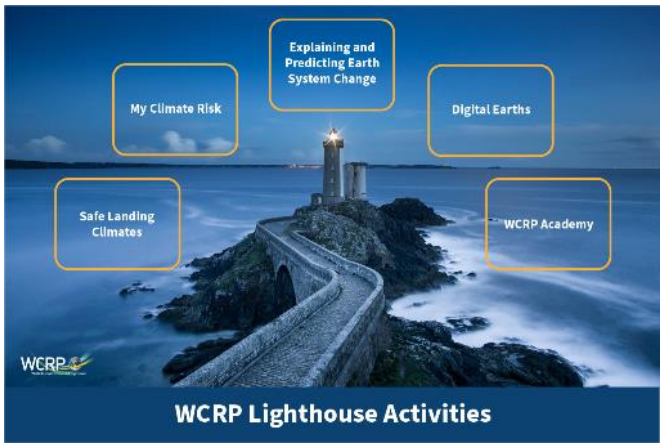
In addition to its four Core Projects (its research communities – each Core Project has an International Project Office) – **CLIC** (cryosphere), **CLIVAR** (oceans), **GEWEX** (water and energy cycles), and **SPARC** (atmosphere) – two new projects were launched:

- The new Core Project on Earth System Modelling and Observations, encompassing all working groups and activities concerned with modelling and data (including the Coupled Model Comparison Project (**CMIP**)).
- The Regional Information for Society Core Project was launched, which includes the Coordinated Regional Climate Downscaling Experiment (**CORDEX**).

WCRP also developed **five ambitious and transdisciplinary Lighthouse Activities** that aim to make critical near-term progress towards meeting its objectives:

1. **Safe Landing Climates**, exploring future pathways that avoid dangerous climate change while at the same time contributing to the SDGs, with strong links to UNFCCC;
2. **My Climate Risk**, developing an approach to regional climate risk rooted in the requirements of decision-makers (several "hubs" around the world in place with others currently being set up);
3. **Explaining and Predicting Earth System Change**, pursuing integrated capability for quantitative observation, explanation, early warning, and prediction of Earth System change (feeds into e.g., WMO annual to decadal outlook and WMO climate statements);
4. **Digital Earths**, pushing the co-development of high-resolution (km-scale) Earth-system modelling;
5. **WCRP Academy**, promoting lifelong learning opportunities and global equity in climate science training by equipping diverse climate scientists with the knowledge, skills and attributes they need for climate research (links closely with WMO Global Campus).

The **science plans of the Lighthouse Activities** were approved at the 42nd Session of the WCRP Joint Scientific Committee in July 2021, and multiple workshops and discussion panels were implemented during 2022.



Many high-level science publications and articles were published, for example major publication on "New high-end estimate of sea-level rise projections in 2100 and 2300."

Publication of "**10 New Insights in Climate Science**" launched at COP27, with Future Earth and the Earth League.

As well as country voluntary contributions, **additional grant approved** from UK Royal Society and the US Global Change Research Programs.

Two WCRP Secretariat staff from outside WMO (in France and in Norway).

GAW Science and Implementation Plan 2024-2027

The new **GAW Science and Implementation Plan 2024-2027** presented for adoption at Cg-19 centres around four objectives formulated to advance the atmospheric composition components needed to support the WMO Strategic Plan 2024–2027.

1. Strengthen the atmospheric composition measurement and data infrastructure and contribute to understanding trends, variability and extremes;
2. Improve monitoring and predictive capabilities and analysis through applied research aimed at advancing the understanding of the roles and fate of aerosols, reactive gases, stratospheric ozone and greenhouse gases and their interactions in the Earth System;
3. Advance the application of atmospheric composition information in support of policies and conventions, and expand societal services related to air quality, human and ecosystem health, climate change, and food production;
4. Enhance capacity throughout the GAW Programme and promote the use of atmospheric composition information and related services.

The activities associated with these objectives will improve the understanding of the atmospheric composition components of the Earth System, advance prediction and analysis capabilities, and enhance the air quality, weather, and climate services needed by WMO Members and regions.

WWRP Implementation Plan 2024-2027

Building on the successes achieved in the **Polar Prediction, S2S and HIWeather projects** and following the guidance of the United Nations, the WMO Strategic Plan 2024-2027 and the Research Board, the new **WWRP Implementation Plan 2024-2027** presented for adoption at Cg-19 is structured around three objectives:

1. Advance research of the Earth system on timescales from minutes to months and, through the science-for-services value cycle approach, enable this research to provide local and regional actionable weather information that is needed for communities to reduce vulnerability to hazards, and advance applications such as renewable energy, agriculture, and health;
2. Revolutionize the warning process to account for compounding and cascading risk, and the evolving nature of weather impacts in a changing climate;
3. Quantify and reduce uncertainty in predictions on timescales from minutes to months, enhance understanding of decision-making under uncertainty, and develop effective communication strategies on uncertainty for informed decision-making.

In the coming financial period, WWRP will continue **scientific threads from major projects** that are ending and expand into new areas, including polar regions, S2S predictions for agriculture, water and energy, integrated hydrology and meteorology to address flooding, and interdisciplinary science to benefit urban communities. WWRP will also work with **early career scientists** to help ensure that the next generation empowered to continue critical weather research work. Furthermore, WWRP will spawn a **new project** aimed at the broad engagement of members of society to better understand user priorities and requirements and improve science communication.

Responding to the Needs of Regions

WWRP held a **WMO Tropical Cyclone-Probabilistic Forecast Products (TC-PFP) Workshop** in June 2021 to coordinate across Regional Specialized Meteorological Centres (RSMCs) and other forecast centres and identify best practice for probabilistic forecasts of tropical cyclones (TC). The workshop convened 100+ participants from 16 countries and 14 time zones. Phase I of TC-PFP, which focuses on TC track and genesis, ended in December 2022 with the presentation of a summary of Phase I at the Tenth International Workshop on Tropical Cyclones (IWCT-10, Bali Indonesia) and the summary report of Phase I. The project will move on to Phase II and focus on the strength and structure of TC.

A **new International Monsoons Project Office** opened at the Indian Institute of Tropical Meteorology, Pune, India, on 30 July 2021 to support global monsoon research activities for an initial period of 5 years. This MoU between WMO and the Indian Institute of Tropical Meteorology is a joint initiative of WWRP and WCRP since monsoon events are related to both weather and climate time scales. The seventh International Workshop on Monsoons (IWM-7) took place online in March 2022 in New Delhi, India. A total of 185 abstracts were received, with 55 participants from outside India. A special issue of the Journal Quarterly MAUSAM (Vol. 74, No 2, 2023) was published after the event.

The **WMO 10th International Workshop on Tropical Cyclones (IWTC-10)** was hosted by Indonesia's Agency for Meteorology, Climatology and Geophysics (BMKG) in Bali from 5–9 December 2022. Overall, there were over 120 in-person attendees and over 300 registered online. The theme "Improved Tropical Cyclone Science and Services for Better Decision-making" aimed to draw attention to the decisions being made at every point along the end-to-end tropical cyclone warning chain to ensure appropriate community action. The workshop yielded 22 recommendations to drive tropical cyclones activities forward.

WCRP held a series of **Regional Climate Forums** which provided a chance to exchange ideas, discuss new activities and opportunities, and explore ways that the WCRP community of scientists, partner programs, funders and end-users of climate science can engage.

The draft Science and Implementation Plan for the **Regional Information for Society project (RifS)** was approved by the WCRP Scientific Steering Committee in June 2022, and by year-end a new International Project Office was set up in Montréal, Canada, hosted by Ouranos, a collaborative innovation hub on regional climatology and climate change adaptation. This new WCRP Core Project aims to address the challenges in reconciling and integrating multiple lines of climate information (distillation) to produce context-relevant knowledge for decision makers, while fostering dialogue with stakeholders to incorporate methods of context-relevant co-design and co-development of climate information, including storylines (narratives).

WCRP Sea Level Conference organized in Singapore on 12-16 July 2022 with a large representation from vulnerable Asian coastal areas, stakeholders, city planners, coastal developers and managers and other relevant stakeholders.

Global observational analysis

Advancements have been made in the improved understanding of atmospheric composition through **peer review papers**. A community analysis on the **impact of COVID-19 lockdown measures on air quality** engaged about 100 co-authors and covered data from 63 cities (540 stations). It demonstrated that in many parts of the world even with the lockdown measurements the WHO guidelines on air quality for health protection cannot be achieved.

The **GAW Scientific Advisory Group on Aerosols** produced a global analysis of the seasonality of the particle number concentration and size distribution.

SAG on Ozone and UV was involved in the development of recommendations for ozone observations and research under the Vienna Convention and the development of the standard operating procedures for the ozone sondes measurement in collaboration with Research Centre-Juelich, NASA, NDACC, GRUAN and International Ozone Commission.

The **greenhouse gas community and community working on ozone** depleting substances supported the production of a comprehensive report on the use of atmospheric observations and inverse modelling as a tool for identification and improvement of emissions estimates of CFC-11.

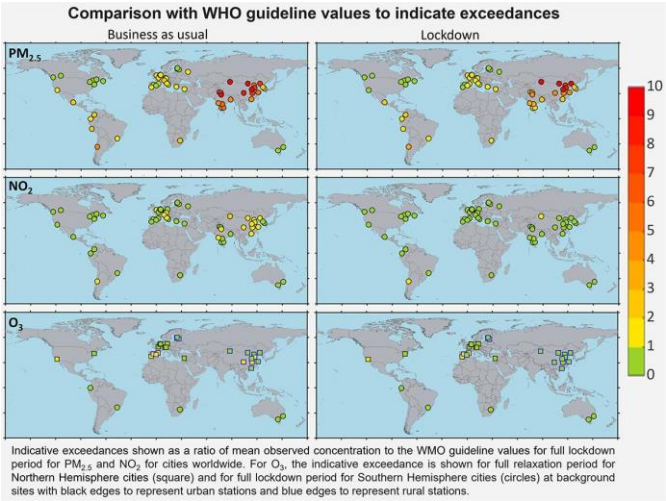


Figure 3.2 global observational analysis to understand changes in air quality during exceptionally low anthropogenic emission conditions, April 2022

Forward perspective

The **next priorities for climate science** will be refined via the coming **WCRP Open Science Conference**, to be held in October 2023 in Kigali, Rwanda. They will then shape the next stages of WCRP implementation. Key publications with outputs of sunsetting **WWRP core projects** will be published by the end of 2023 and lessons learned will be embedded in future projects**. Community papers and data products on the state of science** in relation to observational gaps, air quality forecasting, and use of satellite data in Africa, hydrology, lessons learned from COVID-19, and the future of climate modelling will also be produced by the end of the financial period. **Priorities for addressing model biases and errors** will be established through the WGNE systematic error workshop and subsequent surveys.

Focus Area B

GAW Quadrennial Symposium

The **latest Quadrennial GAW Symposium** took place from 28 June to 2 July 2021. It accrued 498 registrations from participants of 70 countries, with a 81% attendance rate. More than 40% of these registered and actual participants were early career scientists.

The Symposium was comprised of four scientific sessions followed by three panel discussions on capacity building, diversity, and the future strategic planning of GAW. The discussions produced insights on the scientific priorities for the GAW Programme, challenges and possible solutions to training early career researchers in atmospheric composition measurements and research, and developed inputs to WMO Capacity Development Strategy on the role of the scientific community and academia.

Swiss National GAW/GCOS Symposium

The first Symposium took place in September 2021, and included presentations promoting the role of consistent observations for understanding the Earth system across the water, energy and carbon cycles. It further showcased the achievements of the national GAW and GCOS programmes and their associated communities, and sparked ideas for innovative and collaborative approaches among them. A White Paper was developed with the Symposium's outcomes, which would form part of the future national GAW and GCOS programmes.

Support to international science conferences

WMO was also a regular contributor to the scientific sessions of the European Geosciences Union (EGU) General Assemblies conducted annually and the International Global Atmospheric Chemistry Science Conference. WMO-led debates on the role of scientific information in an emerging environmental crisis were attended by over 100 participants at EGU. This session highlighted the importance of early warning systems developed by WMO Members.

Focus Area C

Support to Early Career Scientists

In 2020-2022 WMO placed a special emphasis on supporting the work of early career scientists through capacity building events and facilitating their networking and scientific exchange.

- WWRP supported the session of the **Association for Polar Early Career Scientists, Year of Polar Prediction, Young Earth System Science (YESS)** at the Arctic Science Summit Week in March 2022 by organizing a workshop for early career researchers on "Polar Prediction and Collaboration in the Arctic."
- WWRP recently added a female **Early Career Scientist** to their Scientific Steering Committee, and WWRP encourages the inclusion of early career scientists in all working groups and projects.
- The **GAW Training and Education Centre** organized two webinar series measurements in cooperation with YESS:
    - Webinars on greenhouse gases and atmospheric composition were held between December 2020 and January 2021 and attracted 254 participants from around the world.
    - A second series on reactive gases took place between September and November 2021.The series had over 200 viewers from 45 different countries.
- WCRP held many **online and face-to-face workshops** for early career scientists, with the planning for an Early and Mid Career Symposium associated with the WCRP Open Science Conference in Kigali (October 2023). WCRP, via its CliC Core Project, awarded two fellowships and two grants to early career researchers from Germany, Pakistan, Uzbekistan and Argentina to undertake work related to CliC's strategic goals.

Forward perspective

The next generation of scientists need to be trained and engaged in the work of the three Programmes and ensure their agility and continuity. As such, WMO will pursue and intensify its capacity development activities and support early career scientists through **new fellowship schemes**, the development of the **WCRP academy**, and an **improved engagement with the YESS network** and **early career scientists community**.

Strategic Objective 3.2

Enhance the **science-for service value chain** ensuring scientific and technological advances improve predictive capabilities

Outcome/Focus Area A:
Improve predictive capabilities in high-impact weather forecasting, seasonal to sub-seasonal to decadal prediction, polar prediction, urban and environment prediction and water cycle prediction.

#Seasonal to sub-seasonal prediction #High-performance computing #Exascale world #Integrated Urban Services #End-to-end value chain

Outcome/Focus Area B:
Enhance relevance and utility of products and services through a broader engagement of social science expertise and users including the consideration of local wisdom and local knowledge and closer collaboration between physical and social scientific groups by appropriately addressing sociocultural aspects.

#Stakeholders dialogue #End-users inclusion

Overview

Strategic Objective 3.2

Enhance the science-for service value chain ensuring scientific and technological advances improve predictive capabilities

SDG Contribution

ON TRACK

- **Published**:
  - ✓ Advancing Research for Seamless Earth System Prediction paper;
  - ✓ Report on Concept of Measurement-Model Fusion;
  - ✓ Prolific Lightning and Thunderstorm Initiation over the Lake Victoria Basin in East Africa (2020) article;
  - ✓ Aircraft Observations of the lake land breeze circulation over Lake Victoria from the HyVic pilot flight campaign peer reviewed article;
  - ✓ Guidance on Integrated Urban Hydrometeorological, Climate and Environment Services - Volume II: Demonstration Cities;
  - ✓ Towards the "Perfect" Weather Warning, High-Impact Weather open-access book;
  - ✓ Guidance Measuring, Modelling and Monitoring the Canopy Layer Urban Heat Island (CL-UHI).
  - ✓ Guidelines for Satellite based nowcasting in Africa
- **6 Concept Notes developed by the Research Board**:
  - ✓ Science for Services;
  - ✓ Innovation in Regions;
  - ✓ Advancing Earth System Modelling;
  - ✓ Advancing Earth System Observations;
  - ✓ Exascale Computing and Data;
  - ✓ Data Handling and the Application of Artificial Intelligence in Environmental Modelling.

CONTINUED EFFORTS REQUIRED

- Three stakeholder consultations on industrial methane, urban emissions & land-use emissions held. A total of 233 participants registered for the urban and industrial methane consultations and 178 participants registered for the land use consultations. Regardless of the engagement and interest, the **online format did not allow for proper stakeholder engagement**. As a result of the consultations, several concepts and project proposals were developed. The work on industrial methane is planned in collaboration with UNEP and their International Methane Emissions Observatory. Projects to conduct feasibility studies for utilization of observations-based emission estimates were initiated through Climate and Clean Air Coalition (in relation to the agricultural sector) in **Tajikistan, Albania** and **Armenia**.

On track

Continued efforts required

Limited progress

COVID-19 Impact

Challenges & Risks

Overview

Strategic Objective 3.2

Enhance the science-for service value chain ensuring scientific and technological advances improve predictive capabilities

SDG Contribution

COVID-19 IMPACT

- Implementation was **mildly to moderately affected with a swift adaptation of activities to a virtual mode of delivery**.
- Though virtual meetings allowed for significant cost reductions, they also proved to **require longer time to produce the same outputs as comparatively shorter physical meetings**. It was also noted that the engagement of stakeholders and users on these new topics was insufficient if conducted online.
- Some training events were cancelled (e.g. Sub-seasonal to Seasonal Prediction Project, workshop related to the understanding of the advances in the urban modelling and observations).
- WMO seized the opportunity presented by COVID-19 to investigate the impact of meteorological and air quality factors on the spread of the virus, which led to the **completion of WMO's Review on Meteorological and Air Quality Factors Affecting the COVID-19 Pandemic** by the dedicated Task Team under the Research Board (read more in Focus Area B).

CHALLENGES & RISKS

- The **engagement of the stakeholders in user consultations is a challenging process which requires face-to-face interaction**. It is complex for existing services due to the diversity of the user community. It is even more challenging for the research community in the development of new capabilities in response to user needs.
- User engagement must be approached in a more systematic manner. It also requires the **involvement of representatives from SERCOM** to ensure that services could be developed in the operational phase.
- For many emerging services the provisions under SERCOM do not exist and would require revision of the existing regulatory framework.

On track

Continued efforts required

Limited progress

COVID-19 Impact

Challenges & Risks

Focus Area A

Sub-seasonal to Seasonal (S2S) Prediction

The S2S database is an important tool to assess the current capabilities of state-of-the art models, monitor progress in S2S predictive capabilities and identify gaps. The database, which is constantly maintained and updated, is also a unique tool to evaluate the benefit of multi-model ensemble generation on predictive skill.

It currently contains S2S forecasts from 11 operational centres, of which five models have been upgraded over the past biennium (ECMWF, Meteo-France, KMA, JMA and UKMO), while four centres provide S2S ocean variables. Moreover, S2S reforecast daily climatologies are now available from the IRI data library for several variables.

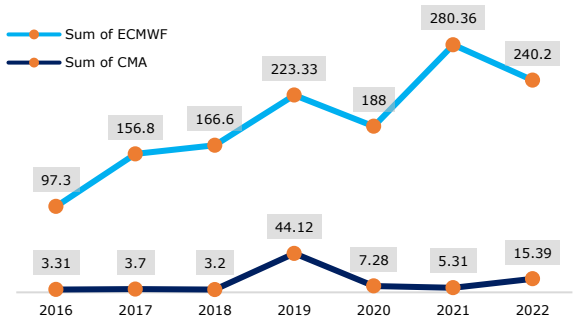


Figure 3.3 Downloads of Sub-seasonal to Seasonal Prediction (S2S) database in Terabytes, December 2022, WMO

Since 2016, **the total volume of data downloaded from the S2S has been in sustained augmentation**, almost entirely from ECMWF (Figure 3.3). Furthermore, the S2S database statistics have shown an increase in the number of active users, now more than 150 unique users per month, out of a community of almost 2,000 active users from 90 countries. This increased usage has been reflected in the number of peer-reviewed publications based on the S2S database, which rose to 300 until 2023.

S2S started a **Real Time Pilot Project** initiative in November 2019 and continued until end-October 2022. It **provided real-time access to the S2S database to 16 co-development application projects**, with the goal to develop an understanding of the S2S forecast value chain and the needs for end-to-end user applications. S2S has advanced the application and utility of subseasonal-to-seasonal predictions.

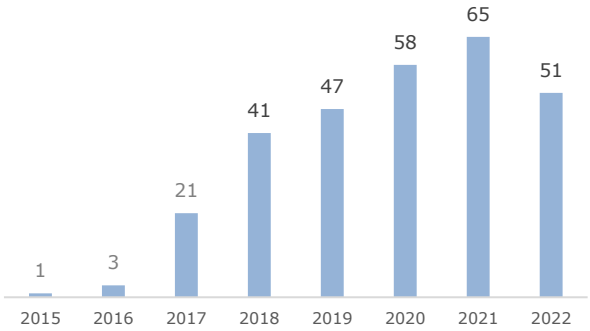


Figure 3.4 Number of peer-reviewed publications citing the S2S database, December 2022, WMO

In 2021-2022, a **prize challenge was organized to assess the potential benefit of artificial intelligence (AI)** methods for S2S prediction through better post-processing of ensemble prediction system outputs. The goal of this competition was to produce the most skillful forecasts of precipitation and 2-m temperature globally averaged over forecast weeks 3 and 4 and over weeks 5 and 6 for the year 2020 using AI techniques. The top three submissions succeeded in producing S2S forecasts significantly more skillful than the bias-corrected ECMWF operational reference forecasts, particularly for precipitation. Their results were published in an article in the Bulletin of the American Meteorological Society in December 2022: Outcomes of the WMO Prize Challenge to Improve Subseasonal to Seasonal Predictions Using Artificial Intelligence.

Forward perspective

The S2S 10-year project will come to an end in December 2023. Beyond that date, it will be important to keep the database and community alive as a key element of the development of usable seamless prediction across time scales. This will need to be developed together with all relevant partners. The maintenance of the current S2S and TIGGE datasets is being discussed with partners such as a Working Group and the TIGGE Panel of WWRP and INFCOM's SC-ESMP. **WWRP envisages a new project on sub-seasonal to seasonal time scales, with specific focus on applications for agriculture and energy.** This will be done in partnership with WCRP as well as representatives from SERCOM.

Sharing data and metadata across WMO research projects

In support of the Next Generation GEOSS for Innovation Business Project, the harmonization of data management and metadata of the GAW-contributing networks started. The goal of the WMO contribution was to facilitate harmonization with WIGOS standard of the metadata used by individual World Data Centres and Data Centres of Contributing Networks for atmospheric composition by creating an inventory of existing reference and guiding documentation and training material. An additional reference guidance was created based on discussions with all 17 Data Centres and Contributing Networks involved.

High-performance computing

The RB Task Team on Exascale Computing, Data Handling and Artificial Intelligence was set up in 2020 with a mandate to inform future directions for WMO programmes in the context of the numerical prediction value chain. The breadth of scientific and technological developments explored in the reporting period includes:

- The need to **reengineer numerical prediction systems for weather, climate, hydrology and atmospheric composition**, as pre-exascale computing and accelerator technology continues to emerge and challenges the current approaches and workflows;
- New approaches to handle the large data volumes within the prediction systems;
- Replacement of time-consuming model components with AI;
- Handling of data volumes as produced by models, including access and exchange;
- Opportunities and challenges in developing countries in AI for meteorological services;
- **Opportunities for AI with observational data records, reanalyses and operational forecasts in government or commercial services, etc.**

As a pragmatic approach to address these themes, two interconnected concept notes were developed: one focusing on numerical models, including their data assimilation systems (**producer perspective**), and one focusing on the data exploitation (**user perspective**).

- The WCRP Digital Earths activity includes WWRP representatives on its steering committee to ensure connections across all time scales. Digital Earths has formed three Working Groups on (1) data assimilation for climate, (2) ultra high-resolution modelling and (3) beyond the traditional Earth System models. A km-scale modelling workshop was held and a report published, including recommendations.

Development of the Earth System modelling

- **Advancing Research for Seamless Earth System Prediction** paper published;
- **Earth System Modelling and Observations Core Project** approved by the WCRP Joint Scientific Committee in November 2020 and formed to coordinate all modelling, data and observations activities across WCRP and key partners, bringing together existing modelling and data elements of the WCRP structure.

- **The Working Group on Numerical Experimentation (WGNE)** has seven active projects on model intercomparison and model evaluation, including on chemistry. Some other activities on forecast verification are developed jointly with the WGNE/WWRP Joint Working Group on Forecast Verification Research.
- **A new project office to support CMIP activities**, based at ESA in the UK, became active; a new organizational structure is in discussion for a more effective planning process and agile delivery of CMIP7 products.
- Several modelling workshops organized, including **Future of Climate Modelling** workshop. Outcomes of these events will feed into and guide the climate modelling activities within WCRP.
- Two workshops on **Data Assimilation Needs for Climate Prediction and Attribution and ultra-high resolution climate modelling** were held in May and October 2022 at the NCAR Mesa Labs in Boulder, CO, USA, in collaboration with NOAA, the University of Colorado Boulder, the University of Texas Austin.

Forward perspective

Looking into the future, emerging techniques in exascale computing and data handling will be required to facilitate km-scale coupled modelling and its societal benefits. Development of a spatially high-resolution, improved model parametrization and data assimilation will further be needed to advance development of targeted/improved services.

Emerging modelling capabilities, including inverse modelling and data assimilation/fusion techniques, will be used for prototyping of new services (e.g. GHG emission quantification, linking ecosystem and human interactions to climate modelling) and should be co-designed and co-implemented with the operational community. Simplified search engines, automated data exchange, targeted data products, improved data discoverability and data utilization through exchange interfaces will therefore be needed.

The Polar Prediction Project and Polar and High-Mountain institutional frameworks

The Polar Prediction Project (PPP), a 10-year (2013–2022) endeavour of WWRP, aimed to promote cooperative international research for the development of improved weather and environmental prediction services for polar regions. In 2020, PPP oversaw the successful deployment of buoys over the Arctic ocean in cooperation with the Russian Federation and the Arctic and Antarctic Research Institute.

In March 2021, the WMO Executive Council Panel of Experts on Polar and High Mountain Observations, Research, and Services (EC-PHORS) held a meeting to link the outcomes of the Project in terms of infrastructure to operations. PPP has notably:

- Improved the existing polar observing system (enhanced coverage, higher quality observations);
- Gathered additional observations through special programmes;
- Improved the representation of key polar processes in (un)coupled models used for prediction;
- Developed improved (coupled) data assimilation systems accounting for challenges in the polar regions such as sparseness of observational data; and
- Improved the understanding of linkages between polar regions and lower latitudes and the verification of polar weather and environmental predictions to obtain better quantitative knowledge on model performance.

In addition, PPP furthered the socio-economic understanding of user interactions with polar forecasts, including assessment of the costs and benefits of using predictive information for a spectrum of users and services and identifying stakeholders of polar forecasts and their unique decision-making needs with respect to weather, climate, ice and related environmental services.

The YOPP Final Summit was held in Montreal, Canada, from 29 August to 1 September 2022, and marked the completion of the Polar Prediction Project. The summit looked to the advancements made in observation and modelling and how these benefit society in the form of information services that contribute to decision making on safe and sustainable economic and civic activities and developments.

A booklet summarizing the achievements of PPP/YOPP was published after the Summit in 2022 and a publication has also been submitted and accepted in BAMS to highlight the outcomes of the Summit. This included lessons learnt and recommendations for future polar research projects.

Forward perspective

WWRP is envisaging a new polar research project in its new Implementation Plan, which will include the Arctic and Antarctic regions as well as applications for the respective local communities.

Science for Integrated Urban Services

- A WMO Study Group on Integrated Urban Services was established in 2020. As an initial priority it looked at the user mapping, development of the implementation plan and development of the guidance on high-resolution urban modelling in support of integrated urban services. **The research community provided substantial support to the drafting of the high-resolution modelling guidelines.**
- GAW Urban Research Meteorology and Environment Scientific Advisory Group continued working on advancing modelling capabilities for urban air quality forecasting through a number of pilot projects. The specific **highlight of 2021 was the finalization of the SURF Project** which addressed observations of the Beijing urban boundary layer and developed urban weather and air quality prediction model with resolution of 1 km.
- The Scientific Steering Committee of the **Paris Olympics 2024 Research Development Project** (shared between WWRP and GAW) had 6 monthly meetings to advance the scientific challenges for the Olympics event in 2024. A Community Advisory Group was established early in 2022 with representatives from users, Olympic village planners, transportation planning, forecasting offices, etc., which will provide input from a user perspective, linking to the social science working group.

  A summer experimental campaign called PANAME2022 was conducted in summer 2022 to establish the impact of additional data on the high-resolution models via an inter-comparison exercise. PANAME brought together 10 research projects to pool resources and measurements to better understand the interactions between the urban environment of the Paris region and the atmospheric boundary layer. The campaign was also aimed at contributing to the improvement of city weather forecast at hectometric scale.

  Three strong heat waves and three thunderstorms occurred during the observation period. Simultaneous meteorological balloon measurements were taken to study the cooling of parks compared to urbanized areas of Paris. The observations showed that parks cool down much faster than urban areas, however, at night, especially after midnight, the differences are reduced. Further measurements were also taken to look at the influence on the ground, specifically on how far the coolness of the parks can be felt. Moreover, PANAME2022 also included air quality studies through a combination of physics, atmospheric chemistry, meteorological, medicine or human and social sciences for some projects.

Forward perspective

A second experimental campaign will take place during the summer of 2023. PANAME2023 will add further measurements to study the effects of parks or vegetated areas on temperature. For this purpose, drones and on-site stations will be set up to increase and improve observations. Furthermore, social sciences studies will be carried out with games attendees and Météo-France forecasters to illustrate the value of inter- and transdisciplinary social-physical science research. Two teams of researchers and practitioners from different institutions will be involved in these initiatives.

Science for Services

- The Steering Committee of the GAW initiative on Global Air Quality Forecasting and Information System (GAFIS) released **a concept note on the provision of globally consistent high-resolution forecasts of air quality** with a focus on the products relevant to the health community. Comparisons of air quality forecasting models was conducted in North America and was initiated in Asia to establish common performance matrices for the forecasting systems.
- The Steering Committee for the **Measurement-Modelling-Fusion for Global Total Atmospheric Deposition** finalized its implementation plan that will guide the development of this initiative towards prototyping and creating the operational services for ecosystems risk evaluation and food security. The work started with the Swedish Environmental Research Institute on initial stakeholder and user mapping and development of the engagement strategy. Preparation of the consistent dataset for the development of the prototype global maps was initiated in the middle of 2021 to cover the year 2010. Further work is being conducted on methods to create global maps of total integrated effect of deposition, which is notably important for evaluating potential crop and ecosystem loss. The group presented its work at the Side-Events to the Science Days for the UN Food Systems Summit 2021 with the highlights presented to the UN Food Summit.
- The **Concept Note on Science for Services** presented to the Research Board in 2020 identified the requirements for decision-making on climate change mitigation and adaptation in the context of growing populations, urbanization and pressure on water and natural resources.
- **First Weather and Society Conference** held by the WWRP Societal and Economic Research Applications (SERA) Working Group in March 2022. The Conference covered various topics across nine sessions ranging from indigenous and local knowledge, citizen science to the use of weather information for humanitarian aid. Over 700 participants registered from 104 countries and more than 40 authors participated in the talks and poster sessions. An article about the gaps and needs identified was published in the Bulletin of the American Meteorological Society.

Forward perspective

The SERA Working Group is organizing the second edition of the Weather and Society Conference, which will take place in March 2024 and will focus on the contribution of social sciences to EWS.

GAW will coordinate the development of prototype products for MMF-GTAD to support the evaluation of deposition impacts on ecosystem and agriculture. GAFIS will conduct and finalize the outputs of Asian models intercomparison and the steps will be made on building connections with related activities under UNEP and WHO auspices.

More generally, the evolution towards impact-based applications is seen as a key priority for the effective translation of science into better services. The fundamental requirement is the ability to overlay weather, climate, water and related environmental information (essentially from the Seamless GDPFS or CMIP model runs) onto spatial information related to risks, vulnerabilities and socioeconomic opportunities.

The WCRP Climate and Cryosphere project (CliC), Antarctic CORDEX and many modelling intercomparison projects feed into the Arctic Science Council and the Antarctic Treaty. Additionally, integrated urban services will be supported through guidance on urban heat island and on high-resolution modelling which will be verified via dedicated pilot projects.

Looking beyond this horizon, harmonization of modelling approaches, including data assimilation, inverse modelling and development of the related standards, will be required for future operationalization of emerging services.

Focus Area B

Meteorological and Air Quality Factors in the COVID-19 Pandemic

In 2020, the Task Team on Meteorological and Air Quality Factors in the COVID-19 Pandemic was set up by the Research Board in consultation with the World Health Organization (WHO) as well as WMO's research programmes and technical commissions. In the reporting period the Task Team:

- Organized the international virtual Symposium on Climatological, Meteorological and Environmental (CME) Factors in the COVID-19 pandemic (4-6 August 2020). The Symposium brought together hundreds of researchers from a wide range of disciplines and organizations to discuss what is known, understood, and can be reliably predicted about CMEs' influence on the trajectory of the pandemic. The Symposium was attended by over 400 participants from 50 countries. The event was supported by 14 organizations, governments and researchers from several international institutions. The outcome statement was used to identify research priorities, further monitor scientific progress, guide good practices for operational informed disease forecasting and information services, and inform authoritative WMO statements on the state of knowledge.
- Published a paper on **"A framework for research linking weather, climate and COVID-19"**[1]. The Task Team found that the current studies provided contradicting results regarding the influence of meteorological factors on COVID-19 and that a lot of uncertainty existed due to the diversity of interventions implemented by national governments.
- Published the First Report on Meteorology and Air Quality (MAQ): Factors and COVID-19 (WMO Report No. 1262). This synthesis thoroughly reviewed the scientific evidence of seasonal effects on COVID-19, as well as other emerging risk factors transmission, such as policy and behavioral change.
- Organized a roundtable series to support in-depth consideration of key issues at the intersection of climate information and COVID-19. Each event featured talks and discussion with leading experts from around the world, with the intention to advance understanding and to generate actionable guidance for researchers, meteorological service providers, users of meteorological services, and health professionals.
- Produced concise fact sheets and best practice documents to support meteorological services in their response to COVID-19 climate services requests.

In addition, a community survey was conducted by the GAW Programme in 2020 to evaluate the engagement of the community in the studies related to the impact of COVID-19 on atmospheric composition.

Forward perspective

As a follow up, the community paper on lessons learned from the COVID-19 studies and evaluation of the open scientific questions will be developed.

Engagement of social science expertise

In 2020, WMO/WWRP signed a Letter of Agreement with Massey University, New Zealand, for the implementation of the WMO Citizen Science Protocol, a WWRP High-Impact Weather Project. The HIWeather Citizen Science Guidance Note was then developed to help groups and agencies increase interest in citizen science and guide project leaders to raise key questions as they start their own citizen science projects, and was released in 2021. WCRP includes social scientists in its Joint Scientific Committee as well.

Forward perspective

By the end of the financial period user consultations will be organized to establish the needs for emission quantification, ecosystem, aeronautical, regional climate, agriculture services. Looking beyond 2023, emerging new products/services will need to be co-designed with the user communities and stakeholders to ensure that they are of importance, relevance and fit for purpose. The development of downscaling techniques is also of high importance for sectoral targeted forecasts/projections.

[1] Zaitchik, B.F., N. Sweijd, J. Shumake-Guillemot, J.Luterbacher et al., 2020: A framework for research linking weather, climate and COVID-19. Nat. Commun. 11, 5730.

Project Highlights:

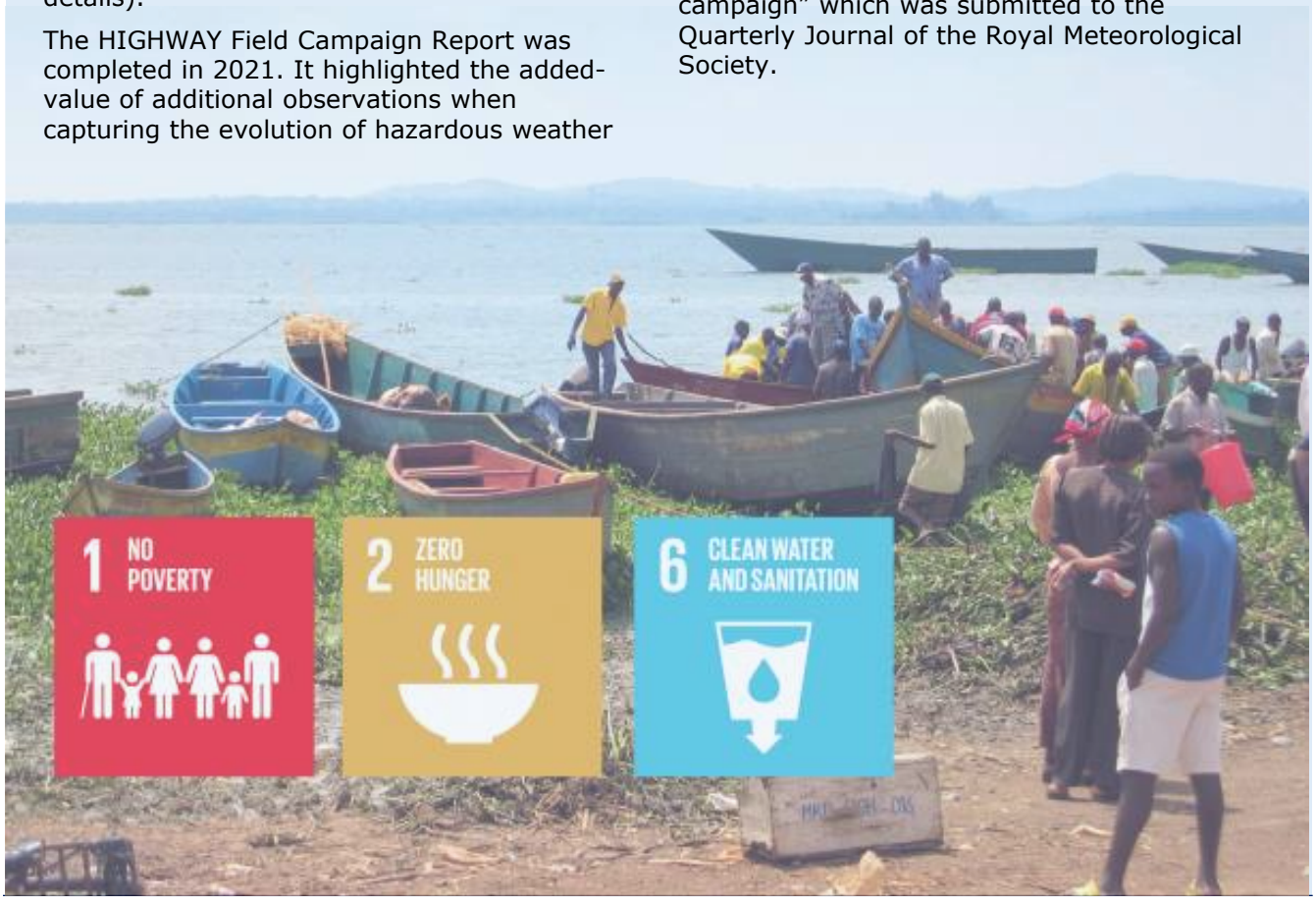
HIGHWAY Project – Research component

Region I – 2017-2020 - for financing information see SO 4.1

The HIGHWAY Project is a WWRP collaboration initiative to strengthen integration between producers and users to develop innovative, accurate and tailor-made early-warning systems products through co-production for the East African region (see SO 1.1 for further details).

The HIGHWAY Field Campaign Report was completed in 2021. It highlighted the added-value of additional observations when capturing the evolution of hazardous weather systems over the lake Victoria Basin and recommended ways to optimize the regional observations network to support the enhancement of early warning systems.

In relation to the project, WWRP published "Prolific Lightning and Thunderstorm Initiation over the Lake Victoria Basin in East Africa" (Virts, K. S., and S. J. Goodman) in 2020, and completed a peer reviewed article "Aircraft Observations of the lake land breeze circulation over Lake Victoria from the HyVic pilot flight campaign" which was submitted to the Quarterly Journal of the Royal Meteorological Society.



Strategic Objective 3.3

Advance policy-relevant science

Outcome/Focus Area A:
Implement an integrated global greenhouse gas information system to enable Members to improve the quality and confidence in national greenhouse gas emission inventories.

#IG3IS #National greenhouse gas observations #GHG Bulletin #Reactive Gases Bulletin #Aerosol Bulletin

Outcome/Focus Area B:
Enhance the body of scientific knowledge assessed by IPCC and other global scientific reports.

#Coupled Model Intercomparison Project (CMIP) #Polar Prediction Project #Annual-to-Decadal Climate Predictions #Antartic Treaty #Arctic Council

Outcome/Focus Area C:
Improve the basis of understanding for water resource management decisions drawing upon improved capabilities, especially in sub-seasonal to seasonal range.

#GESAMP #Ocean pollution

Overview

Strategic Objective 3.3

Advance policy-relevant science

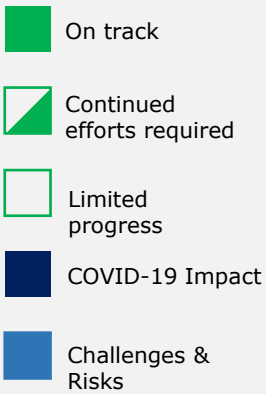
SDG Contribution

ON TRACK

- WMO **assessments, technical reports and policy-relevant datasets** in support of a large number of international conventions and political processes:
  - UN Framework Convention on Climate Change (UNFCCC)
  - Vienna Convention and Montreal Protocol
  - UN Convention to Combat Desertification (UNCCD)
  - Convention on Long-range Transboundary Air Pollution (CLRTAP)
  - Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)
  - Climate and Clean Air Coalition
  - Sendai Framework for Disaster Risk Reduction
  - Arctic Council
  - Antarctic Treaty
- **Published:**
  - ✓ 3 annual GHG Bulletins
  - ✓ 2 WMO Air Quality and Climate Bulletins
  - ✓ 2 WMO Airborne Dust Bulletins
  - ✓ WMO Aerosol Bulletin
  - ✓ IG3IS Best Research Practice Guide on Urban GHG assessment;
  - ✓ "Towards advancing scientific knowledge of climate change impacts on short-duration rainfall extremes" published in Phil. Trans. R. Soc. A.
  - ✓ Desert Dust Outbreak in the Canary Islands report
  - ✓ WMO-UNEP Report on Unexpected Changes in CFC-11
  - ✓ **10 New Insights in Climate Science** (COP26 and 27)
  - ✓ Year of Polar Prediction/PPP papers
  - ✓ YOPP/PPP Achievements booklet

CONTINUED EFFORTS REQUIRED

- New **WCRP Global Extremes Platform** has been established at NUIST in China to support WWRP and Future Earth activities.



Strategic Objective 3.3

Advance policy-relevant science

SDG Contribution

COVID-19 IMPACT

- Implementation was **mildly to moderately affected** with a swift adaptation of activities to a virtual mode of delivery.
- Virtual meetings were difficult to attend for people living in time zones distant from the session's host. In response, **the HIWeather virtual workshop on high-resolution modelling held in December 2020 took place on a 24-hour (non-stop) basis**, starting at noon, New Zealand time, and concluding at noon, US Mountain time, so as to accommodate participation across all time zones. This innovative approach was successful in attracting participants from all WMO regions. The five online seminars gave excellent introductions to the key issues in the areas covered by the task teams of the project, while the three 19-hour workshops enabled broad participation in the three HIWeather highlight activities: citizen science, the warnings value chain, and the HIWeather book. **Over 400 people registered and each webinar recorded an attendance of over 100.**
- Achieving stakeholder engagement also proved challenging through virtual meetings. For example, IG3IS consultations were performed for LULUCF in 2021 but stakeholder engagement was poor due to the novelty of the topic (with only 178 registrations).
- The technical workshop on the connection between deposition to the ocean and management practices was postponed.

CHALLENGES & RISKS

- The operation of the **IG3IS Office was fully dependent on voluntary contributions and led to its closing at the end of 2021** due to the lack of strategic and financial support.
- The degrading global observational network threatens the foundation of data onto which the science basis for climate action is built.
- Lack of resources for the implementation of the innovative tools for the deposition assessment and characterization of atmosphere ocean exchange via GESAMP make the advance of these critical initiatives very slow.

On track

Continued efforts required

Limited progress

COVID-19 Impact

Challenges & Risks

Focus Area A

Integrated Global Greenhouse Gas Information System (IG3IS)

The WMO Integrated Global Greenhouse Gas Information System (IG3IS), a GAW initiative supported by the Swiss Confederation, is an observationally based information system for determining trends and distributions of greenhouse gases (GHG) in the atmosphere and the ways in which they are consistent or not with efforts to reduce GHG emissions. As the benchmarking organization for standards and methodologies for atmospheric inversions, **IG3IS looks to help guide decision-makers' reduction policies and actions.**

IG3IS Integrated Global Greenhouse Gas Information System

In the 2020-2022 WMO:

- Continued working on the **upscale of the IG3IS methodology** uptake through a number of national projects (support to GCF proposal of Morocco, project proposal to the Quadrature Climate Foundation on carbon uptake by bamboo, GCF readiness in Tajikistan, EU Green Deal proposals, Armenia Forestry proposal).
- A new multi-scale IG3IS project was initiated by the Republic of Korea.
- **Partnerships were strengthened** via engagement with the Integrated Carbon Observing System, a NDC partnership.
- Under the **WWF initiative One Planet City Challenge, WWF and WMO designed a 3-part webinar series to showcase success stories** where local governments use the best available scientific information as a basis for decision making aimed at reducing GHG emissions and climate risks and improving urban air quality.
- Contributions were made to the UNFCCC Earth Information Days in 2020 and 2021 and a side event was organized at COP26.
- Contribution was made to the UN Energy compacts.
- IG3IS office organized a workshop on urban GHG assessment in June 2020, which was followed in 2021 by the development of IG3IS Urban Greenhouse Gas Emission Observation and Monitoring Best Research Practices Guide, providing technical guidance on the current state-of-the-art technologies in urban greenhouse gas information systems. A new project under IG3IS was launched in 2022 with the aim to quantify the carbon sequestration capabilities of bamboo in China.

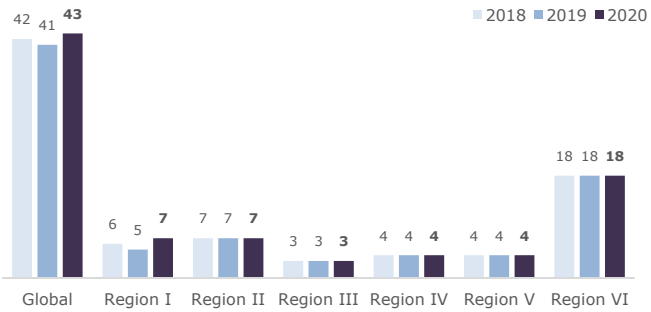


Figure 3.5 Number of Members with national greenhouse gas observations submitting data to the World Data Centre for Greenhouse Gases, WMO

As part of its strategic monitoring, WMO tracks the number of Members with national GHG observations defined as countries/territories with at least one station performing measurements and submitting data to the World Data Centre for Greenhouse Gases (WDCGG). In 2020, only 43 Members met these criteria (N.B. a delay is incurred in the reporting). Notably, several countries have submitted data only prior to 2018 and have subsequently stopped their contribution to WDCGG. Data for the recent years are pending.

Forward perspective

The 76th session of the Executive Council has endorsed plans for a new Global Greenhouse Gas Monitoring Infrastructure to fill information gaps and support action to reduce heat-trapping gases. See more in the highlights of LTG2.

Greenhouse Gases, Aerosol, Airborne Dust and Air Quality Bulletins

As part of its continuous work to monitor the chemical composition and physical properties of the atmosphere, GAW issues periodic thematic bulletins advancing the science critical to support climate and environment policy and services. **Three annual GHG Bulletins were released** in the reporting period. The Bulletins demonstrated that the abundance of heat-trapping greenhouse gases in the atmosphere reached a new record in 2020, with an annual rate of increase above the 2011-2020 average. That trend then continued in 2021, showing that the economic slowdown from COVID-19 did not have any noticeable impact on the rate of increase of GHG concentration.

The Bulletins further described the high risk that the oceans and ecosystems that currently absorb around half of CO2 emissions will become saturated in the future. This would reduce their ability to act as a buffer against larger temperature increase. Part of Amazonia has transitioned from a carbon sink to a carbon source (see complementary information on the Bulletin's outreach in comparison to other WMO climate-related flagship reports under SO 1.2).

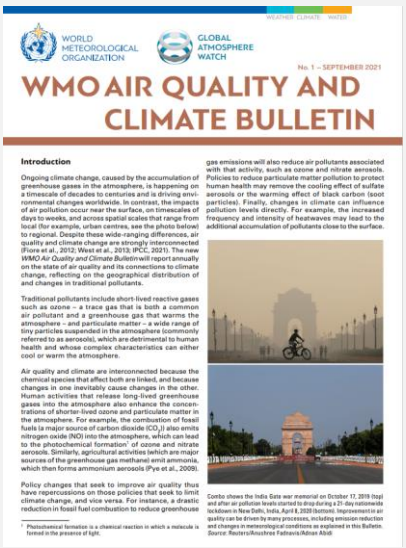
GAW also provided substantive input to the new United in Science Reports (see LTG 3 highlights). Furthermore, in April 2021, WMO published the fourth instalment of its Aerosol Bulletin, which examined the impact of wildfires on climate and air quality through the study of the 2019/2020 Australian bushfires, the 2015 Indonesia peat fires, and smoke transport from boreal forest fires to the Arctic.

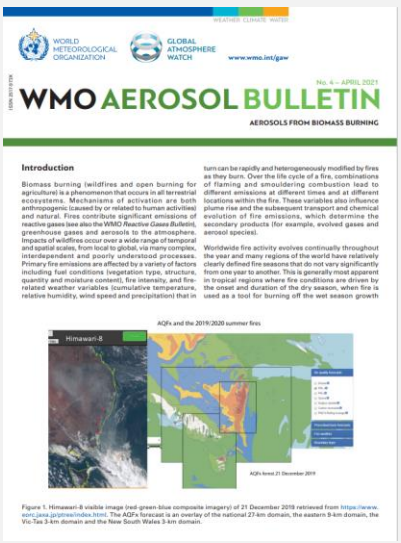
WMO also released its first **Air Quality and Climate Bulletin**, which highlighted the main factors that influenced air quality patterns in 2020 in comparison to other years. It further laid out the intimate connection between air quality and climate change, and demonstrated the critical role that observations play in monitoring the state of the atmosphere.

It was followed by a second report in September 2022, which **provided an update on the global distribution of particulate matter for 2021**, highlighting the contribution of extreme wildfire events. It further presented a range of possible air quality outcomes under high- and low-emissions climate change scenarios, as well as an overview of the implications of atmospheric deposition for air quality, ecosystem health and climate.

Forward perspective

Over the next biennium, WMO will continue to regularly produce publications advancing the science critical to support climate and environment policy and services, including a Guide on the optimal use of MSG and MTG satellite data for nowcasting purposes in Africa, as well as WMO flagship bulletins and reports on GHG, Airborne Dust, Air Quality and Climate, New Insights in Climate Science, and WMO contributions to United in Science and the State of the Global and Regional Climate reports.


WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH
No. 1 – SEPTEMBER 2021
WMO AIR QUALITY AND CLIMATE BULLETIN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WMO AEROSOL BULLETIN
AEROSOLS FROM BIOMASS BURNING


WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH
No. 2 – SEPTEMBER 2022
WMO AIR QUALITY AND CLIMATE BULLETIN

Focus Area B

Annual-to-Decadal Climate Predictions

The release of the **Global Annual to Decadal Climate Update 2021-2025 and 2022-2026** provided an excellent opportunity to establish further connections with stakeholders for the use of that information for policy-making (see SO 1.2). This WMO flagship report was ushered by the WMO-accredited operational decadal predictions provided by 19 centres worldwide (Figure 3.6) and coordinated by the WMO Lead Centre for Annual-to-Decadal Climate Prediction. Combining forecasts from these climate prediction centres enables a higher quality product than what could be obtained from any other single source.

While the number of centres delivering operational decadal prediction products which follow WMO-accredited procedures is good, only one centre is in the Southern Hemisphere (CSIRO in Australia, Region V). Indeed, other centres in southern regions may not produce such forecasts in operational mode or only provide regional predictions. As such, **increasing capacity in developing countries,** both in terms of infrastructure and human resources, remains a critical priority.

Figure 3.6a - World map of 19 centres worldwide

Furthermore, an increased uptake of such information for application in different sectors (agriculture, fisheries, energy, transportation, etc.) is also important for the implementation of climate adaptation strategies. To monitor this process, **WMO introduced a new metric in 2021, tracking the number of decadal prediction products downloaded from the WMO Lead Centre for Annual-to-Decadal Climate Prediction**. This number was 7'384 in 2021 and rose to 7880 in 2022 (Figure 3.7).

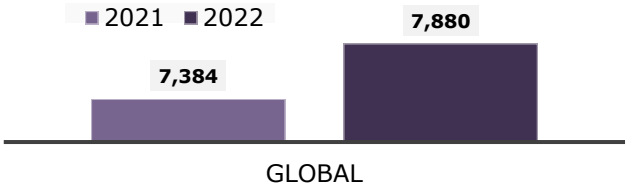


Figure 3.7 Number of decadal prediction products downloaded from the WMO Lead Centre for Annual-to Decadal Climate Prediction

Forward perspective

The success of decadal predictions depends on the accuracy of initial and boundary conditions, which requires long-term records of ocean, land and ice observations. Thus, **funding and institutional frameworks that enable such critical observation should be further increased to foster the science basis for climate adaptation**. Moreover, trainings in the use, analysis and interpretation of the results from decadal predictions should be considered to improve the knowledge base of decisions-makers involved in local and national policy-making processes, particularly in developing countries. WCRP's Explaining and Predicting Earth System Change Lighthouse activity has a focus on improving these annual to decadal outlooks and is working with the Lead Centre (the original concept came from a WCRP Grand Challenge).

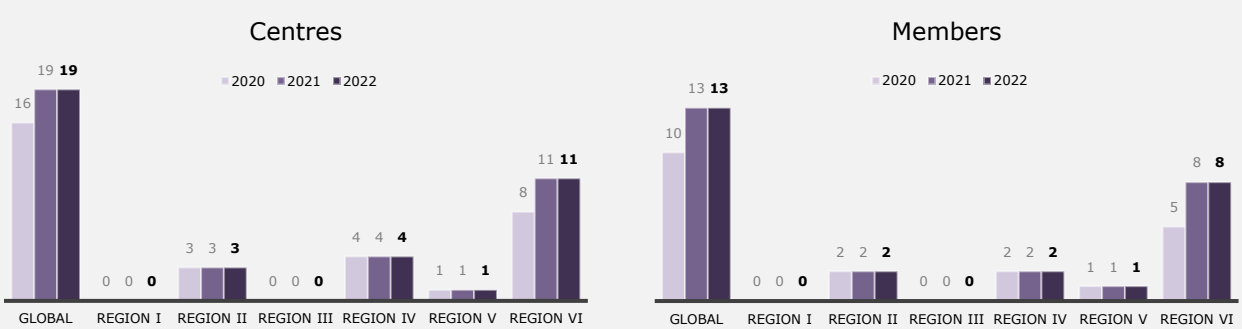


Figure 3.6b Number of Centres and Members contributing to the WMO Lead Centre for Annual-to-Decadal Climate Prediction

10 New Insights in Climate Science at COP26

WCRP released the 10 New Insights in Climate Science at COP 27, **a synthesis of the most robust climate-related research findings produced in collaboration with Future Earth and the Earth League.** Since 2017, the report has been launched annually, based on an assessment made by more than 60 world-leading academic experts.

In 2022, it highlighted the following 10 insights:

1. The potential to adapt to climate change is not limitless: people and ecosystems in different places across the world are already confronted with limits to adaptation, and if the planet warms beyond 1.5°C or even 2°C, more widespread breaching of adaptation limits is expected.
2. Vulnerability hotspots – areas with the highest susceptibility to being adversely affected by climate-driven hazards – are home to 1.6 billion people, a number projected to double by 2050.
3. New threats on the horizon from climate-health interactions
4. Climate mobility - extreme weather events related to climate change will increasingly drive involuntary migration and displacement.
5. Human security requires climate security
6. Sustainable land use is essential to meeting climate targets
7. Private sustainable finance practices are failing to catalyse deep transitions
8. Losses and damages are widespread and will increase significantly on current trajectories, making it imperative to advance a coordinated global policy response.
9. Inclusive decision-making for climate-resilient development.
10. Transformative change towards mitigation is impeded by structural barriers that arise from the current resource-intensive economy and its vested interests in maintaining the status quo.

These insights reinforce WMO's Greenhouse Gas Bulletin and State of the Global Climate reports on the urgent need for much more ambitious climate action. Read more on their impact in SO 1.2.

Forward perspective

In 2023 inputs will be sought from the WCRP community to populate and produce the next annual '10 New Insights in Climate Science' which will – once again – be published to coincide with the November COP in the United Arab Emirates (COP 28).

Coupled Model Intercomparison Project (CMIP)

The Climate Model Intercomparison Project (CMIP) brings together modelling centres from around the world, with the **goal of improving state-of-the-art climate model simulations and future projections.** CMIP is a large activity with 140 models from 52 institutions representing 26 countries. The project provides crucial impetus to climate science, and its outputs provide foundational model datasets used by climate assessments that contribute to global climate negotiations and decision-making. As such, CMIP6 extensively was used in the IPCC Sixth Assessment Report.

WMO is tracking the number of peer-reviewed papers citing the Coupled Model Intercomparison Project (CMIP) published in the Nature, Science, American Meteorological Society (AMS) and American Geophysical Union (AGU) academic journals as a **proxy indicator** for measuring progress on LTG 3. Reflecting the growing global effort spearheaded by WMO to advance the scientific knowledge of the Earth system, the number has steadily been growing since 2016 (see Figure 3.8). The sudden uptick of papers submitted after 2018 is likely to be due to the submission deadline for the IPCC Climate Change 2021 Report, which was extended to December 2020 to account for delays incurred by the COVID-19 pandemic.

Furthermore, in 2021 WMO signed an agreement with the European Space Agency for the establishment of a new CMIP office under the World Climate Research Programme (WCRP), which is a major step forward in ensuring sustainability for the project that used to be a strictly volunteer effort. The office, which has started its work in March 2022, enhances the support for national and international assessments, and coordinates discussions with the scientific and user communities on standardisation protocols, data policy and quality-control of model output and analysis.

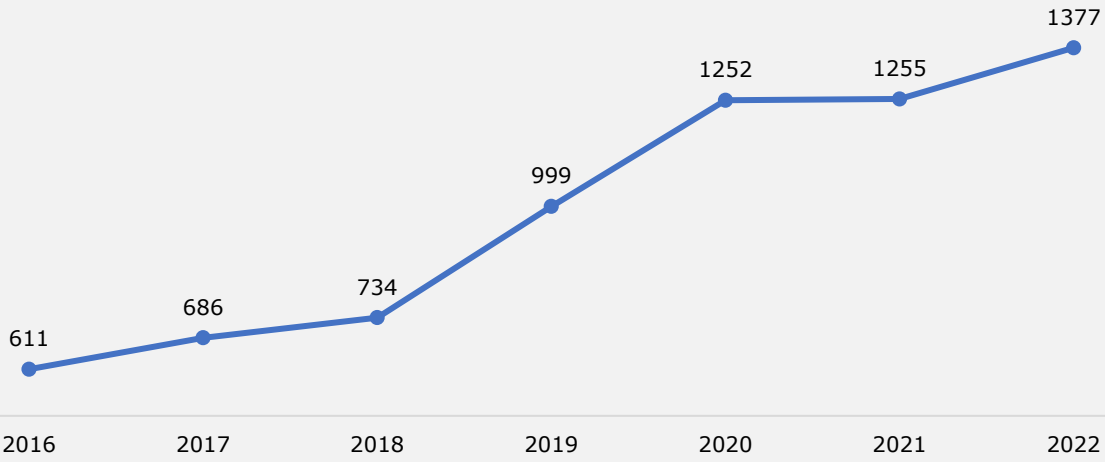


Figure 3.8 Number of peer-reviewed papers citing the Coupled Model Intercomparison Project (CMIP) in the AMS, AGU, Nature, and Science academic journals, 2022.

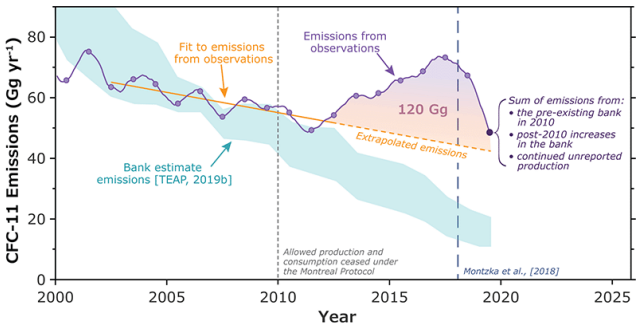
Forward perspective

Good practices for the observation-based emission estimates will also be initiated in consultation with IPCC TFI and UNFCCC.

Stratospheric ozone

In 2021, the **WMO-UNEP Scientific Assessment Panel of the Montreal Protocol on Substances** that **Deplete the Ozone Layer released its report on the Unexpected Emissions of CFC-11**. Indeed, global CFC-11 emissions were expected to decrease steadily after 2010 because of the full phaseout of production and consumption (see Figure 3.9, blue shading). However, CFC-11 emissions began to increase in 2013 and were high from 2014 to 2018 (Figure 3.9, purple line). The report investigated the sources of this increase, and further determined that the emissions observed to date are small enough not to have a major impact on the expected stratospheric ozone recovery.

On the ground, **WMO continues working with UNEP on capacity building** in the countries related to the observations of total ozone under the Vienna Convention. Financial support was provided to Comoros for the implementation of total ozone measurements with an implementation timeline in 2022. Support was provided to **Tajikistan** with setting up the measurement instrument at the **lake Issyk-Kul** (though project implementation and training are delayed due to the COVID-19 travel restrictions). Several instruments from **Brazil** were calibrated in **Canada** and instruments from **Egypt** were calibrated by **Spain**.



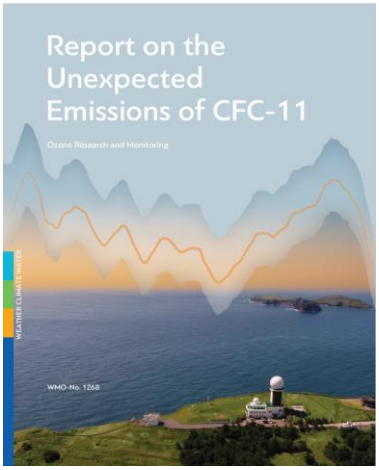


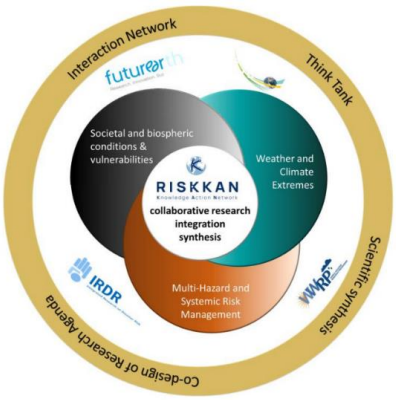
Figure 3.9 CFC-11 Emissions (WMO-No. 1268)

WMO also provided **financial assistance** to 14 scientists from developing countries to attend the 11th Quadrennial Ozone Symposium hosted by the National Institute of Environmental Research of the Republic of Korea in October 2021. The Symposium reviewed the state of science in relation to stratospheric ozone science, ozone-depleting substances, sources, sinks, and budgets; tropospheric ozone science; connection between ozone, climate, and meteorology; advances in ozone monitoring and measurement techniques; and environmental and human health effects of atmospheric ozone and UV.

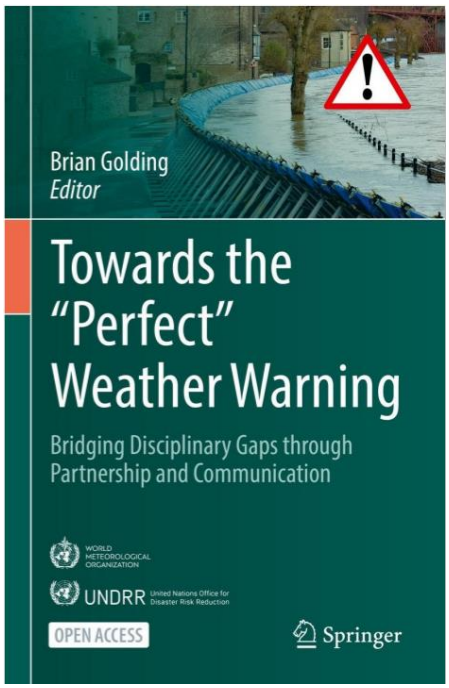
The **Scientific Advisory Group on Ozone and UV** worked with Australia Cancer Council to produce the new SunSmart Global Ultraviolet Radiation mobile telephone application. It provides geo-located 5-day Ultraviolet (UV) and weather forecasts and sun protection times along with tailored notifications. The application is available free of charge at both the Apple App Store and on Google Play for Android versions and an increasing number of Members are requesting further app adaptation for their national circumstances.

Disaster risk reduction research

In 2021, WWRP became a "parent organization" of the **Knowledge Action Network on Emergent Risks and Extreme Events** (Risk-KAN), which builds global leadership on emerging risks and extreme events. This initiative, which is also supported by WCRP, FutureEarth and the Integrated Research on Disaster Risk (IRDR), aims to facilitate a structured integration and synthesis of scientific expertise with professional and local knowledge on emerging and systemic risks in the context of global environmental change.



Moreover, HIWeather contributed to policy-relevant work on compound hazards in the COST DAMOCLES project and to policy-relevant studies of hourly rainfall extremes in the GEWEX extreme events grand challenge. The latter produced a key academic paper: Fowler Hayley J. et al (2021) Towards advancing scientific knowledge of climate change impacts on short-duration rainfall extremes, in *Philosophical Transactions of the Royal Society A.*



In addition, the High Impact Weather book **Towards the "Perfect" Weather Warning** – Bridging Disciplinary Gaps through Partnership and Communication, produced in collaboration with UNDRR, was published in June 2022.

The book, produced by 50 authors, discusses how to make weather warnings more effective through interorganizational communication and partnerships addressing the entire value cycle. It further offers a framework that bridges government, private businesses, civil society and the voluntary sector for HIWeather warnings, and emphasizes the decision makers as the primary paradigm in the HIW warning and forecasting process.

Forward perspective

WWRP is pursuing work on HIWeather through its project on **Value Chain Approaches to Evaluate the End-to-End Warning Chain**. The project aims to review value chain practices used for weather, warning and climate services, assess and provide guidance on how they can be best applied in a weather warning context, generate an easily accessible means to review and assess the efficacy of early-warning systems using value chain approaches, and develop best practice in warning processes. Work on the project is ongoing, and a writing workshop was held in September 2022 towards the completion of a high-level value chain framework tool for decision makers.

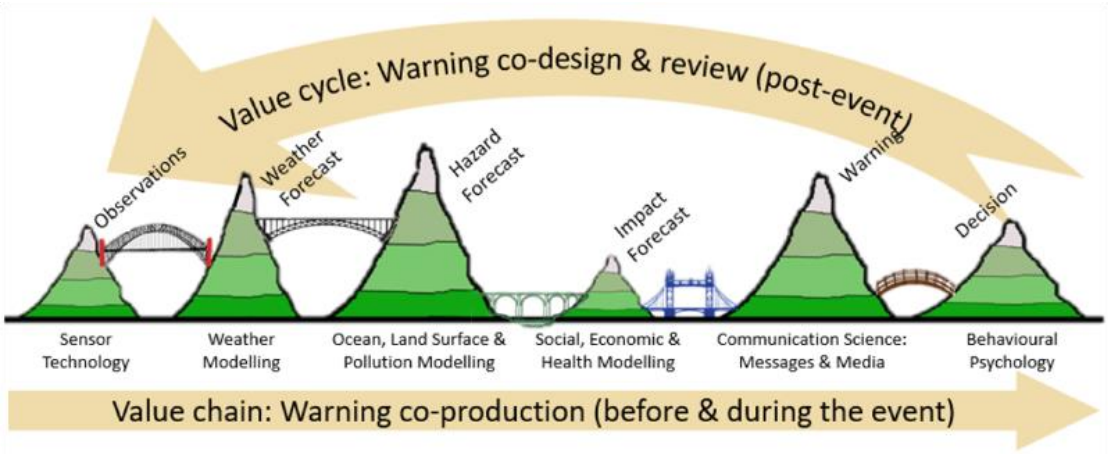
The HIWeather project started a new flagship focused on impact-based warnings and forecasts. The purpose of the **Impact-based Forecasts and Warnings (IBFW) project** is to identify the gaps relating to IBFWs and define a research direction to help fill those gaps going forward. The international project team is conducting a gap analysis based on the literature, available guidance, previous workshops and discussions, and experiences of forecasters and practitioners collected through an open and free virtual workshop series. The output will be a freely-accessible journal article summarizing the findings. The IBFW project is a WMO WWRP HIWeather Flagship Project and is being conducted in collaboration with the WMO Services Commission Expert Team on IBFW. The project runs from early 2022 until late 2023.

Sand and Dust Storms (SDS)

In 2021, WMO released a comprehensive report on the impacts of the desert dust outbreak that took place in the Canary Islands in February 2020. Another report, Sand and Dust Storm Warning Advisory and Assessment System: Science Progress Report, covers general aspects of SDS forecasting and progress made in recent years. Currently, **more than 25 organizations provide daily global or regional dust forecasts in different geographic regions, including 9 global models and more than 15 regional models** contributing to the SDS Warning Advisory and Assessment System (SDS-WAS).

In parallel, WMO is working with AEMET and BSC on the ongoing implementation of SDS-WAS in **7 countries of the Sahel:** Burkina Faso, Cabo Verde, Chad, Mali, Mauritania, Niger, Senegal.

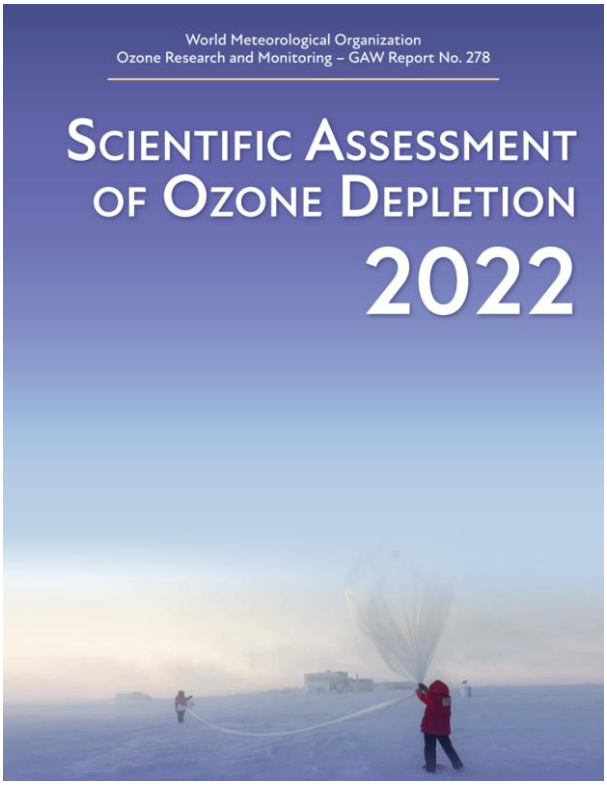
In addition to the regular publication of the Airborne Dust Bulletins mentioned in SO 3.2, WMO also jointly worked with the United Nations Convention to Combat Desertification (UNCCD) to produce the **Sand and Dust Storms (SDS) Compendium: information and guidance on assessing and addressing risks**, which was launched during the SDS Day at UNCCD COP15 in May 2022. The Compendium is an in-depth reference source for SDS management, offering information on SDS modelling and forecasting, as well as on policies and practices to effectively manage SDS and reduce their harmful effects.



Schematic value chain for high impact weather warning showing the capabilities and outputs (green "mountains") and information exchanges (bridges) linking the capabilities and their associated communities (from Golding et al. 2019)

Scientific Assessment of the Ozone Layer Depletion

At the end of 2022, GAW released the latest **Scientific Assessment of the Ozone Layer Depletion** in support of the Montreal Protocol. The report confirmed that actions taken under the Protocol continued to decrease atmospheric abundances of controlled ozone-depleting substances and advance the recovery of the stratospheric ozone layer. Total column ozone (TCO) in the Antarctic continues to recover and is expected to return to 1980 values around 2066 in the Antarctic, around 2045 in the Arctic, and around 2040 for the near-global average (60°N–60°S).



Forward perspective

Key developments expected in 2023-2024 include arrangements for the calibration services of instruments.

Focus Area C

Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)

The **Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection** (GESAMP) advises the United Nations system on the scientific aspects of marine environmental protection. GESAMP is jointly sponsored by ten UN organizations with responsibilities relating to the marine environment, WMO among them.

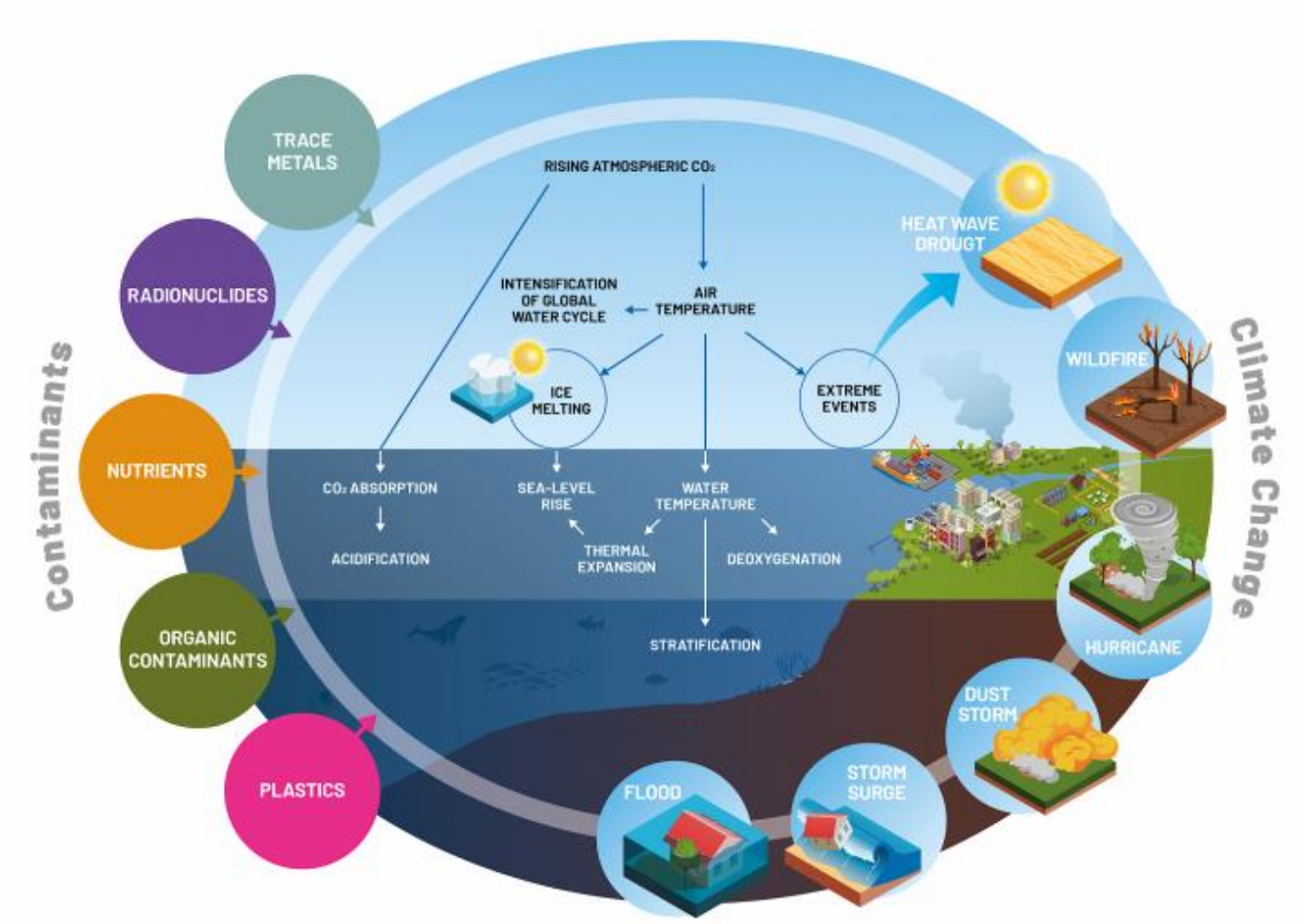
WMO continues co-sponsorship of two Working Groups (WG): **WG 38 on the Atmospheric Input of Chemicals to the Ocean and WG 41 on Ocean Interventions for Climate Change Mitigation.** In 2020 GESAMP WG 38 focused its attention on the organization of a virtual workshop and the production of a publication on the atmospheric transport of microplastics to and from the ocean in collaboration with WG 40. It also worked on the development of a workshop on the ocean management and policy implications of the air/sea exchange of chemicals (postponed to October 2022). In addition, WG 38 produced several peer-reviewed publications and developed a GESAMP Reports and Studies document on the results from the WG 38 workshop on the changing acid/base character of the global atmosphere and ocean and the impact of these changes on certain air/sea chemical exchange processes and on the atmospheric transport of microplastics to and from the ocean.

In February 2021, WMO became the co-sponsor of GESAMP's new WG 45 on Climate Change and Greenhouse Gas Related Impacts on Contaminants in the Ocean. It will critically review existing research on the effects of climate change (ocean physics and chemistry) on the speciation, toxicity, bioaccumulation, mobilization, and transport of pollutants in the ocean and coastal ecosystems identifying knowledge gaps; document the central role and global importance of climate change on the coastal and marine ecosystems' functions and services and make recommendations for future research directions on the effect of climate changes in the speciation, cycling, toxicity, transport, mobility, and bioavailability of diverse pollutants, including trace elements, radionuclides, organic pollutants, and nutrients. It held its first meeting in October 2022 in Monaco, hosted by IAEA.

Forward perspective

The work of GESAMP in the next years will be focused on advancing the comprehensive framework for the assessment of the marine geoengineering proposal and building connections with the stakeholder/ocean managers community in connection to environmental impacts.

WCRP has set up three **Task Teams** to initialize major new foci on **Climate Intervention**, on **Linking Carbon, Energy and Water Cycles** (with GCOS), and on a major new International Experiment the **Global Precipitation Experiment (GPEX)**. All these activities will be presented to the WCRP Joint Scientific Committee meeting in May 2023 and be taken forward as appropriate.



Adapted from Indirect impacts: climate change & contaminant behavior (Gesamp.org, Adapted from Hatje eta., 2022)