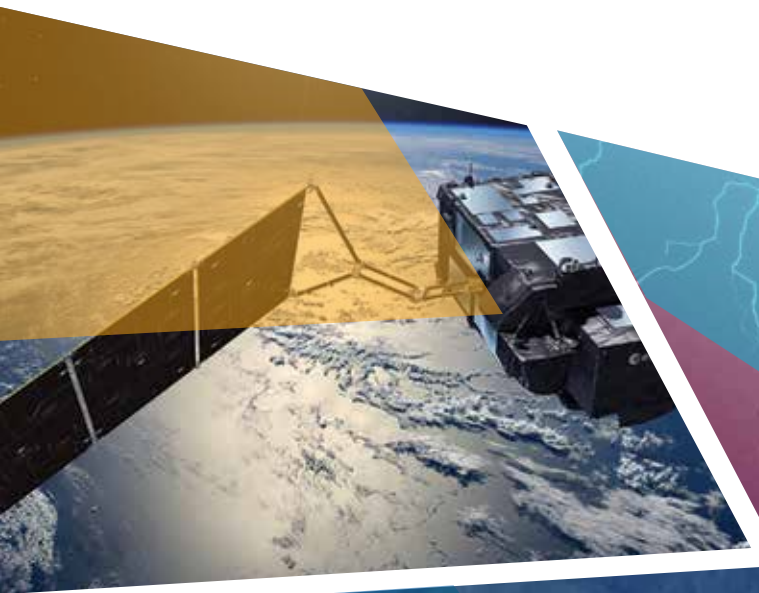
WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

2016 Highlights

Annual Report



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

Tel.: +41 (0) 22 730 84 03
Fax: +41 (0) 22 730 81 17
E-mail: publications@wmo.int

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FOREWORD

The weather and climate of 2016 were extraordinary. During the year, many new regional and global records were observed. After the 2015 record warming of one degree Celsius compared with pre-industrial levels, 2016 saw the global average temperature rise exceed 1.1 degrees. Severe droughts and floods affected many regions of the world, in part due to the 2015/2016 El Niño. Devastating tropical storms struck both the Caribbean and the Pacific, including Hurricane *Matthew*, which caused widespread loss of life in Haiti.

The concentrations of three important greenhouse gases – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – also broke records, with the annual global average level of CO_2 reaching new highs after exceeding 400 parts per million for the first time in 2015. Over 90 per cent of the excess heat trapped by rising levels of greenhouse gases is being stored in the oceans, where it contributes to rising sea levels, acidification and coral bleaching. The impact of climate change has been particularly strong in the Arctic, which in the final months of the year saw unusually low levels of sea-ice extent and unusually high temperatures.

These events and trends make the work of the World Meteorological Organization (WMO) and its 191 Members ever more relevant for meeting the challenges of today. The weather, climate and water enterprise coordinated by WMO mobilizes billions of dollars in technology and equipment and hundreds of thousands of professionals and support staff every year. This makes it possible to protect lives and property and to inform major business and policy decisions. Weather, climate and hydrology forecasts and services permeate our lives and support virtually every economic and social sector. They leverage trillions of dollars of investments in infrastructure, industry and public services by enhancing their impact and effectiveness.

There is evidence that one dollar spent on weather science and services generates at least ten dollars of value. Too often, however, these services are taken for granted, as the advanced expertise and intense work that goes into producing daily forecasts and other services is often invisible to the user. In fact, weather, climate and hydrological services are an essential public good that, like roads and schools, require continued upkeep and investment. I hope that WMO *2016 Highlights* helps to shed some light on the impressive accomplishments and added value that our community consistently provides year after year.

WMO and its Members will continue to contribute to the global agenda, in particular to the Paris Agreement on climate change, the Sendai Framework for Disaster Risk Reduction 2015–2030, and the United Nations Sustainable Development Goals. We will also develop new products and services to assist vulnerable communities and decision-makers in a wide range of social and economic sectors. People expect continuously improved services for ensuring safety, supporting diverse economic sectors and providing guidance to governments, the general public and diverse customers with very specific needs. I am confident that, together with all of our Members and partners, we will satisfy those demands in the years ahead.

(P. Taalas)
Secretary-General

INTRODUCTION: THE WMO MISSION

WMO strategies, policies, programmes and partnerships provide an international framework for cooperation among National Meteorological and Hydrological Services (NMHSs) and the companies, associations and research institutions that contribute to the WMO mission. The priorities and work programme of WMO are established every four years by the World Meteorological Congress, most recently for the 2016–2019 period.

All of these activities are driven by the WMO mission statement, which is presented here to provide the reader with context for this report:

WMO provides world leadership and expertise in international cooperation in the delivery and use of high-quality, authoritative weather, climate, hydrological and related environmental services by its Members, for the improvement of the well-being of societies of all nations.

The mission of WMO, as defined in its Convention, is:

- To facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations as well as hydrological and other geophysical observations related to meteorology, and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;
- To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close cooperation between Meteorological and Hydrological Services;
- To encourage research and training in meteorology and, as appropriate, in related fields, and to assist in coordinating the international aspects of such research and training.

As the name suggests, WMO *2016 Highlights* does not aim to provide a comprehensive review of all that WMO has achieved in 2016 – such details are available in the official documents posted on the WMO website. Instead, it provides a snapshot of progress on selected activities that have recently made a significant impact on people's lives and well-being.

A 21ST CENTURY SYSTEM FOR EARTH OBSERVATION

Without observations there would be no meteorology: no forecasts, no warnings, no progress. But thanks to investments made over the past decades, millions of atmospheric and oceanic observations are gathered, stored and distributed every day. Huge quantities of data from weather stations, raingauges, satellites, ocean buoys, ships, airplanes, balloons and other traditional and high-tech instruments are distributed daily to meteorological centres. WMO is currently upgrading this massive and complex system to meet the rapidly expanding needs of governments and stakeholders.

The WMO Integrated Global Observing System (WIGOS) has been conceived as the future hub for global weather, climate and water observations. It will provide an all-encompassing framework for bringing all WMO global observing systems into the twenty-first century. The present systems, in particular the Global Observing System, the Global Atmosphere Watch, the WMO Hydrological Observing System and the Global Cryosphere Watch, are evolving to form an integrated, comprehensive and coordinated WIGOS. The four-year WIGOS pre-operational phase got under way in 2016. The focus today is on finalizing the necessary technical procedures and regulations, establishing WIGOS Regional Centres and assisting all countries to build capacity to contribute to, and make full use of, this emerging system.

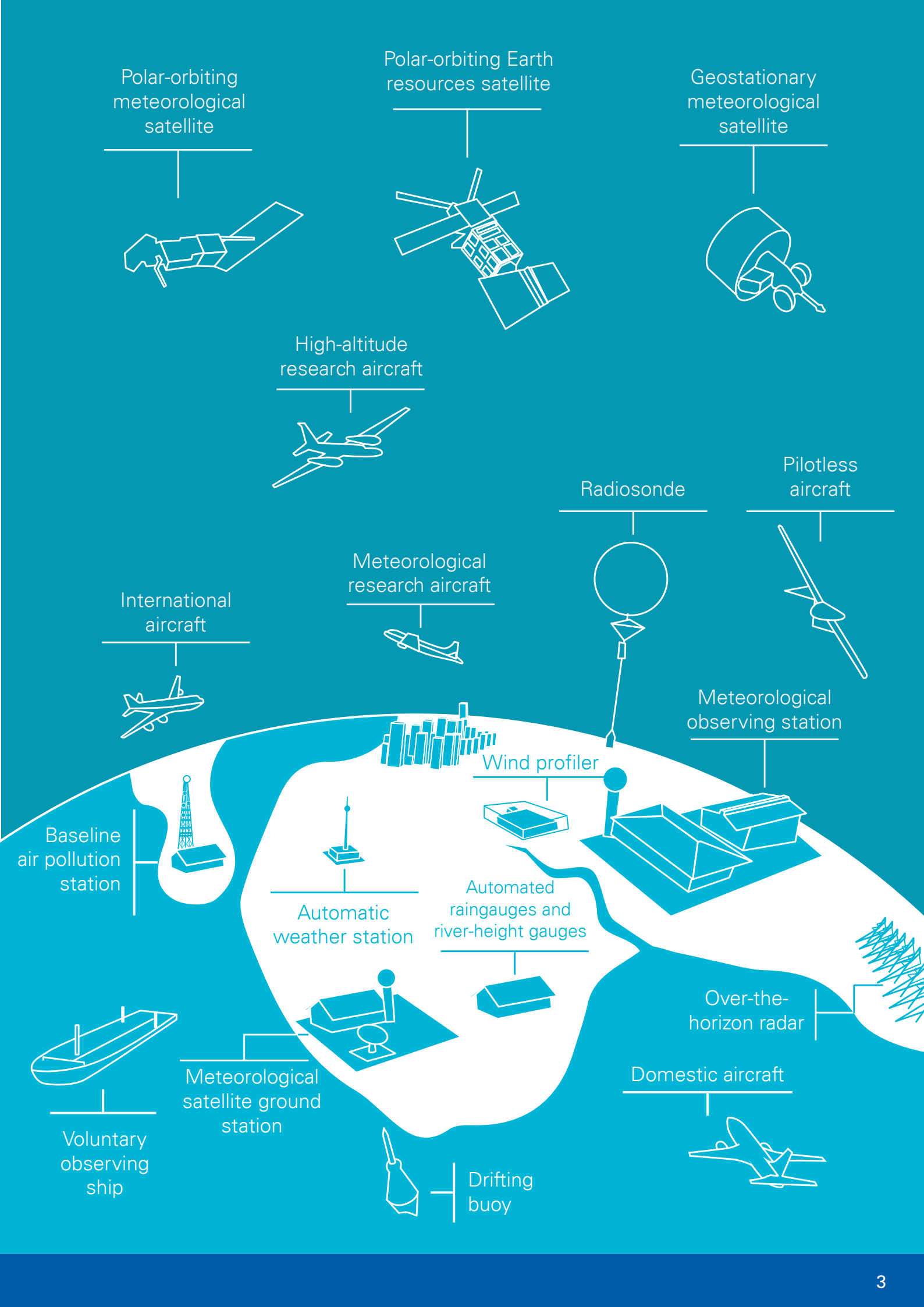
Important progress has also been made on the WMO Information System (WIS), which provides a major upgrade to the way weather services and their partners manage and transmit weather, climate, water, marine and related environmental information. It exploits the most recent advances in communications technology and reduces the costs of exchanging information. For the first time, and unlike the closed and private Global Telecommunication System that it replaces, WIS gives users outside the meteorological community free access to an expanded range of information. As a result, WMO can now collaborate more fully with United Nations and other international partners on implementing common programmes and activities, such as the Global Framework for Climate Services.

The backbone of WIS is a network of 15 Global Information System Centres (GISCs). The last GISC to be certified as WIS-compliant was established in Casablanca, Morocco in 2015. These Centres collectively serve as a library for the data, information, products and services that are delivered by 132 Data Collection or Production Centres, most of which are international organizations or specialized centres. The primary users of WIS are some 224 National Centres, most of which are National Meteorological and Hydrological Services.

In October 2016, WMO conducted a survey of the National Centres to assess their progress on transitioning into WIS. The survey found that about 70 per cent had already implemented at least some of the new functionality of WIS. Meanwhile, the set of technical regulations and manuals needed for guiding the system and assisting users has now been completed. With the global and regional infrastructure in place, WMO and its Members are now focusing on building national capacity for using WIS. Training is being provided by GISCs and WMO Regional Training Centres.

A new version of the WMO space-based Observing Systems Capability Analysis and Review tool (OSCAR/Space v2.0), which will constitute an important part of WIGOS, became available in 2016. OSCAR now provides a wider range of information on satellite programmes, instruments and the variables they can observe in the areas of weather, water, climate, the marine environment, land processes and space weather. It features powerful search functions and gap analyses, by variables and mission types, for users in NMHSs and satellite agencies.

WMO developed OSCAR as a resource to support Earth observation applications, studies and global coordination. It contains quantitative user-defined requirements for the observation of physical variables in the areas of weather, climate and water. OSCAR also provides detailed information on all Earth observation satellites and instruments, and expert analyses of space-based capabilities. It constitutes a building block of WIGOS and, more specifically, the so-called WMO Rolling Requirements Review process. OSCAR targets all users interested in the status and the planning of global observing systems as well as data users looking for instrument specifications.


Polar-orbiting meteorological satellite
Polar-orbiting Earth resources satellite
Geostationary meteorological satellite
High-altitude research aircraft
Radiosonde
Pilotless aircraft
Meteorological research aircraft
International aircraft
Meteorological observing station
Wind profiler
Baseline air pollution station
Automatic weather station
Automated raingauges and river-height gauges
Over-the-horizon radar
Meteorological satellite ground station
Domestic aircraft
Voluntary observing ship
Drifting buoy

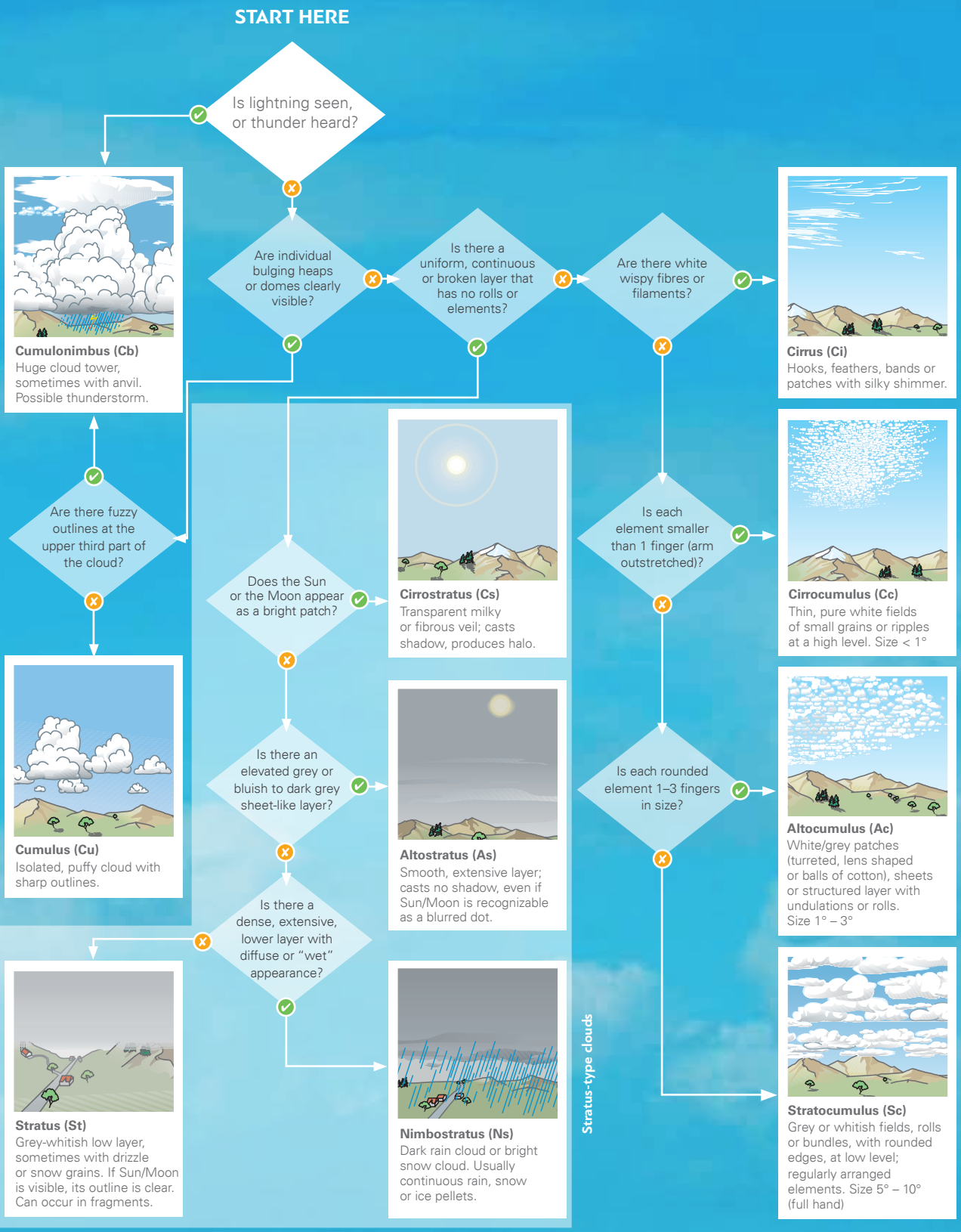
Clouds

The WMO **International Cloud Atlas** is the standard reference document for operational observation systems. It supports weather forecasting, hydrology and climate research (clouds are one of the key uncertainties in the study of climate change). The first Atlas, containing 28 coloured pictures, was published by the International Meteorological Organization in 1896. The current version of the Atlas, containing two volumes, was originally published in 1956 and was last updated in 1987 – 30 years ago.

WMO therefore decided to launch a major project to fully update and revise the Atlas, initially as a web-based product. This authoritative, comprehensive and accessible product will serve as an important training tool for meteorologists and will be of great service to WMO Members. The bulk of the work, which was led by the WMO Commission for Instruments and Methods of Observations with special support from the Hong Kong Observatory, was carried out in 2016. The new version was released on 23 March 2017 to mark World Meteorological Day and its theme, Understanding Clouds.

Cloud identification guide

Learn how to identify cloud types by using this flow chart from the International Cloud Atlas. Clouds are divided into 10 fundamental types known as genera, depending on their general form. The genera are then further subdivided based on a cloud's particular shape, structure and transparency; the arrangement of its elements; the presence of any accessory or dependent clouds; and how it was formed.



BETTER FORECASTS

Scientific news on climate change grabbed the headlines in 2016. Meanwhile, a quiet revolution has been under way in the tightly linked field of meteorology. Thanks to major investments in research and observations, today's five-day forecast is as reliable as the two-day forecast of 20 years ago. Now, with the support of WMO, meteorologists and climate scientists are moving towards an Earth system approach and developing "seamless weather and climate predictions" that further blur the boundaries between weather and climate science.

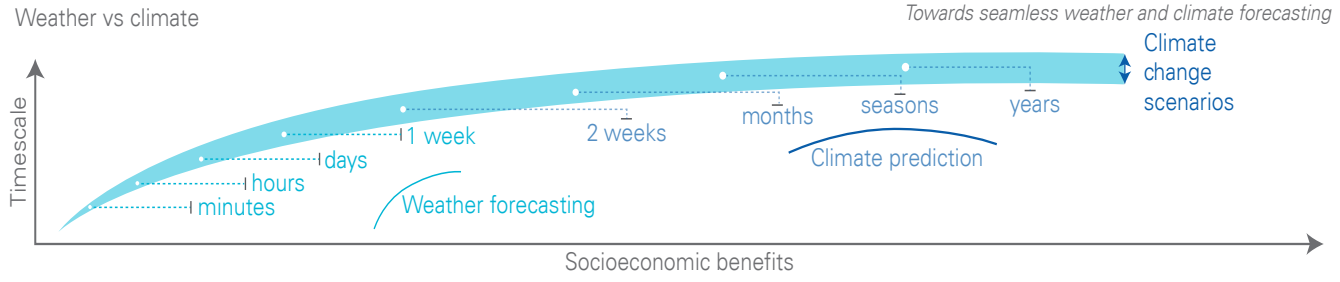
Benefitting from continuing research, improved observations and growing computer processing power, modern weather science is rapidly leading to better forecasts of storms, heatwaves, droughts and other high-impact weather events. Perhaps one of the most exciting ongoing developments in weather forecasting is the development of ensemble forecasts by numerical weather prediction centres around the world. These ensembles combine results from as many as 50 numerical weather prediction models to explore hazards such as a storm's potential path. Based on these predictions, probabilities can be assigned to the various possible tracks a storm might follow and to its future intensity.

Another promising area of research draws on improved observations and computing power to detect and understand broader patterns and cycles in the weather and climate system. The best known and most important of these patterns is the El Niño/Southern Oscillation. While the arrival of the massive 1982/1983 El Niño was an unpleasant surprise, and the powerful 1997/1998 El Niño was forecast several months in advance, the 2015/2016 event was predicted at least six months before its impact started to be felt. As a result, the affected countries had much more time to prepare their defences for protecting life and property. Farmers around the world were able to make planting and harvesting decisions that anticipated the wetter or drier conditions expected in their region.

The WMO Global Data-processing and Forecasting System and its 25 Regional Specialized Meteorological Centres, 12 Global Producing Centres for Long-range Forecasts and five Regional Climate Centres are key drivers of this progress. These Centres, which are typically hosted and operated by NMHSs, have advanced expertise and prediction products that they share freely with all National Weather Services in their respective regions and beyond.

Thanks to WMO efforts in knowledge-sharing and capacity-building among all its Members, in recent years many more NMHSs and related institutions have gained the necessary capacity to also be designated as WMO specialized centres. WMO therefore has updated the requirements that an institution must meet to be designated and to retain that designation, thus ensuring the high standard of WMO specialized centres. These new requirements are expected to receive final approval by the WMO Executive Council in May 2017. This will open the door for national and regional institutions – a dozen of which have already expressed interest – to apply for designation as specialized centres. An expanding network of highly qualified centres will accelerate improvements in forecasts, their delivery to end users, and the trend toward seamless weather and climate forecasting.

The advanced WMO centres support NMHSs in least developed countries and small island developing States.



Seamless weather and climate prediction is becoming a reality as scientific advances erase the traditional boundaries between these once-separate disciplines. Longer forecasting timescales are associated with greater socioeconomic benefits.

They transmit high-value information to them through a cascading forecasting process under the Severe Weather Forecasting Demonstration Project being implemented in most WMO Regions. This information is contributing to improvements in forecast accuracy and to lead times for warnings. As a result, the probability of detecting severe rainfall events during the last three months of 2016 in eastern Africa, for example, was 66.7 per cent, while for severe strong winds it was 96.1 per cent. This contributes to public safety, sustainable water management and agricultural productivity.

2 ZERO HUNGER

WMO contributes to Sustainable Development Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture

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New records reached or announced in 2016

19 m
New world record wave height, recorded by an automated buoy at 0600 UTC on 4 February 2013 in the North Atlantic Ocean between Iceland and the United Kingdom

+1.1 °C
Above pre-industrial levels, setting average yearly global temperature record

30 inches (76.2 cm)
Amount of rain in one week in Louisiana, United States, a 1-in-1 000-year flood

400 ppm
Globally averaged concentration of carbon dioxide in the atmosphere reached the symbolic and significant milestone of 400 parts per million for the first time in 2015 and surged again to new records in 2016.

51 °C
New heat record for India, recorded in May in Rajasthan

54 °C
New heat record for the eastern hemisphere and Asia – possibly. A WMO committee is examining the measurement, taken at Mitribah, Kuwait on 21 July 2016.

7.74 seconds
Longest continuous lightening event, over southern France

4.14 million km²
Arctic minimum sea-ice extent on 10 September 2016 ties second lowest extent in satellite record

9.08 million km²
Arctic sea-ice extent is the lowest November in the satellite record for that month.

321 km
Longest horizontal distance of lightning flash, over Oklahoma, United States, in 2007

14.52 km²
On 24 March 2016, Arctic sea-ice maximum extent was the lowest in the satellite record.

Mobilizing resources

In June, WMO became the first United Nations specialized agency to formalize its relationship with the **Green Climate Fund (GCF)**. By signing its accreditation master agreement with GCF, WMO can now receive financial resources for climate action programmes and projects. WMO proposals will focus on GCF investment priorities. These include:

- Transforming energy generation and access
- Creating climate-smart cities
- Encouraging low-emission and climate-resilient agriculture
- Enhancing resilience in small island developing States

WMO is developing a series of proposals that address these broad priorities. They include projects and programmes to enhance early warning systems in Pacific Ocean small island developing States, to link climate knowledge to action for resilience in countries of the Sahel, to enhance urban services and transform Jakarta into a "climate-smart" city, and to prepare global climate services for energy in Colombia, the United Republic of Tanzania and the Republic of Moldova.

TARGETED WEATHER SERVICES

With observations and forecasts in hand, the providers of weather services can take the next step: packaging the information and delivering it in the form of impact-based warnings, weather updates and so forth. The general public may want easy-to-read daily reports to plan their activities and to avoid or minimize risks. Farmers may require detailed analyses on how precipitation will affect soil moisture, while shipping companies will request forecasts of wind speeds and storm conditions at sea. Many other sectors also need specialized weather information in well-defined formats.

The role of National Weather Services in ensuring the safety of air traffic has become more important than ever. Increasingly crowded air routes and a rising incidence of extreme weather events linked to a changing climate are raising the stakes. In response, WMO and the International Civil Aviation Organization (ICAO) continue to enhance their international standards for the provision of aeronautical meteorological services.

Many countries are in the process of enhancing their compliance with these standards by establishing a quality management system (QMS). Establishing a QMS gives the aviation industry confidence that national authorities are exercising strong oversight over the meteorological information being provided for international air navigation and that the meteorological personnel possess the required level of competence and qualification. WMO is working with ICAO and regional partners to build national capacity for implementing a QMS by providing guidance materials, training aids, seminars and workshops.

Today, approximately 80 per cent of NMHSs providing meteorological services for international air navigation have established a QMS or are progressing towards full QMS implementation. Of those with a QMS in place, three out of every four have had their QMS certified to the International Organization for Standardization (ISO) standard. While great progress continues to be made, quite a few NMHSs still need to further improve their QMS implementation. The bar was raised even higher in 2015 when ISO enhanced its quality assurance standards, with a compliance deadline of September 2018. WMO is assisting its Members to transition to the new ISO 9001:2015 standard through the publication of an update to the *Guide to the Implementation of a Quality Management System for National Meteorological and Hydrological Services* (WMO-No. 1100).

Weather forecasts are also a powerful tool for addressing many of today's most tragic situations. For example, WMO is increasingly able to support the humanitarian assistance activities of the United Nations by facilitating access to weather services. Refugees are particularly vulnerable to adverse weather conditions during their perilous journeys to safety. During the winter of 2015/2016, refugees from parts of Africa and the Middle East faced stormy conditions in the Mediterranean Sea and snow-blocked or flooded land routes as they travelled to and through Europe.

WMO, in partnership with the Met Office, United Kingdom, assisted the United Nations High Commissioner for Refugees (UNHCR) by coordinating the provision of weather forecasts and information from National Weather Services in south-east Europe. This was essential because the information was being produced with different languages, formats and approaches and was not always easily accessible to decision-makers in aid agencies. Consolidated and timely forecasts made it possible for UNHCR to better prepare for arrivals and reduce the impacts of weather on these vulnerable people.

WMO is contributing to the New Urban Agenda adopted last year at HABITAT III, the third United Nations Conference on Housing and Sustainable Urban Development, by promoting safe, healthy and resilient cities through the development of Integrated Urban Weather, Environment and Climate Services. Crowded cities are centres of creativity and economic progress but, from polluted air to flooding and other climate impacts, they also face major weather, climate, water and environment-related challenges. Increasingly dense, complex and interdependent urban systems leave cities vulnerable. Fortunately, meteorological and related services provide essential information and forecasts that can assist urban decision-makers to face these challenges.

The aim of these new activities is to build urban services that meet the special needs of cities through a combination of dense observation networks, high-resolution forecasts, multi-hazard early warning systems, disaster-management

plans and climate services. This approach gives cities the tools they need to reduce emissions, build thriving and resilient communities, and implement the United Nations Sustainable Development Goals. One of the first cities to successfully implement elements of the Integrated Urban Weather, Environment and Climate Services is Shanghai.

Mexico City has also been working on improving air quality through comprehensive air-quality management programmes based on scientific, technical, social and political considerations and on taking actions to mitigate greenhouse gas (GHG) emissions. In 2016, WMO and Mexico City launched a pilot project to support the government's efforts to use air-quality forecasting and modelling to further develop policies for reducing pollutants emissions and protecting public health. In 2015, Canada hosted the Pan and Parapan American Games, both international regional sporting events; it supported the Games by developing a high-resolution spatial and temporal dataset for the Greater Toronto Area urban environment. This required the installation of new automated land- and marine-based weather stations, additional experimental monitoring platforms, air quality stations and other sophisticated equipment.

Wind, precipitation and temperature interact in complicated ways in heavily built city landscapes. Urban weather is best monitored through a combination of different monitoring platforms including satellites, aircraft and dense networks of high-resolution instruments.

11 SUSTAINABLE CITIES AND COMMUNITIES

WMO contributes to Sustainable Development Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable

SUSTAINING CLIMATE OBSERVATIONS

In 2016 – the hottest year in the modern record – WMO and its Members continued to advance the entire climate value chain linking observations to research to services. As with weather, observations underpin the entire enterprise. A key challenge is that climate observations come from across the entire Earth system – the atmosphere, ocean, biosphere, geosphere and cryosphere. They must also be sustained over time and be comparable from year to year and place to place.

Observations from all parts of the world underpin both climate science and climate services. To promote awareness of climate observations and the invaluable information they provide us, WMO publishes annual Greenhouse Gas Bulletins and Statements on the State of the Global Climate. The great value of these reports is that they incorporate contributions from the global network of National Meteorological and Hydrological Services.

The 2016 release of these reports, which confirmed that levels of GHGs continue to rise and that the global atmosphere is breaking new temperature records, received major press coverage around the world. What is more, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) formally recognized the WMO climate reports and GHG bulletins for the first time last November in Marrakech. They requested that WMO regularly submit these authoritative reports to future sessions of the Conference of the Parties to complement the assessment reports of the WMO/United Nations Environment Programme (UNEP) Intergovernmental Panel on Climate Change, which are produced only every six to seven years. WMO has clearly become widely recognized as a highly credible source of climate information.

The United Nations Climate Change Conference in Marrakech further recognized the value of climate observations by giving, for the first time, high-level political backing to the WMO co-sponsored Global Climate Observing System (GCOS). GCOS defines Essential Climate Variables and seeks to guide and coordinate national investments in improved climate observations from space, on land, in the ocean and in the atmosphere.

Anniversaries

The **Izaña Atmospheric Observatory**, located on Tenerife in Spain's Canary Islands, marked 100 years on 8 April 2016. To promote awareness of the importance to climate science of digitizing and sustaining uninterrupted long-term datasets, WMO is inviting governments to nominate candidates for recognition as WMO Centennial Observing Stations. The Spanish State Meteorological Agency nominated Izaña Observatory (and other stations) for recognition as Centennial Observing Stations..

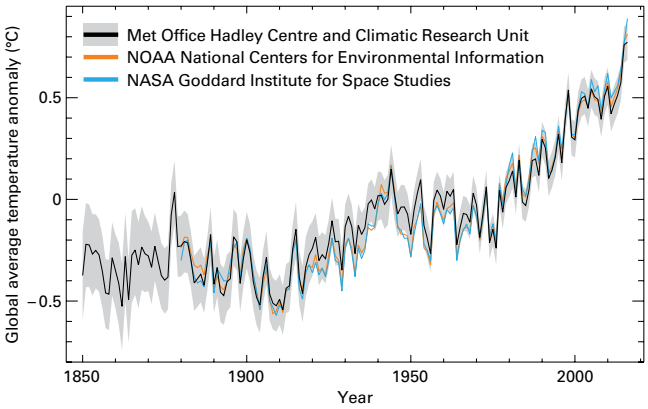
Izaña started making meteorological measurements on 1 January 1916. Its records include temperature, relative humidity, wind direction and speed, pressure, rainfall, cloud classification/amount, sea cloud, visibility range, present weather and sunshine-duration observations. The Izaña Atmospheric Observatory is a major contributor to the Global Atmosphere Watch (GAW) Programme, which was set up in 1989. It monitors concentrations of carbon dioxide, which increased from an annual average of 346.0 parts per million in 1985 to 398.6 parts per million in 2014.

The **Cape Grim GAW Global Station** in Tasmania, Australia marked 40 years of monitoring the composition of the Earth's atmosphere. The station, established in 1976 and operated by the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organization, is Australia's principal contribution to the GAW observing network. The first set of instruments lived in an ex-NASA caravan. Today the station is housed in a permanent building that features state-of-the-art infrastructure, including a tower fitted with important monitoring equipment. Cape Grim's data records of atmospheric constituents, such as greenhouse gases, ozone, black carbon and similar aerosols, mercury and acids in precipitation, improve our scientific understanding of atmospheric, environmental and climate change and the impact of human activity.

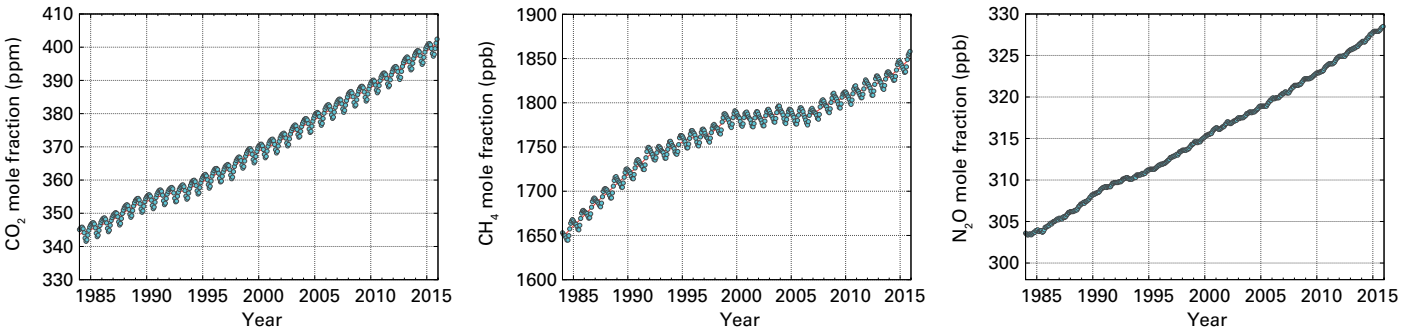
These enhanced observations will support research and the operational climate services to support climate mitigation and adaptation actions under the United Nations Framework Convention on Climate Change.

To be truly useful, climate observations need to be long-term and sustained. Without continuous observations from thermometers, raingauges and other traditional instruments, it would not be possible to know that the atmosphere has warmed by about one degree Celsius since the mid-1800s. Unfortunately, many long-term historical records are at risk due to changed conditions and budget cuts. To encourage governments to reverse this trend and protect long-operating stations, WMO launched a programme inviting governments to nominate such stations for formal recognition as Centennial Observing Stations.

Several other accomplishments deserve mention. WMO issued consensus reports tracking the progress of and outlook for the powerful 2015/2016 El Niño event; these reports were used by decision-makers and were highly visible in the press. In October, a meeting of the Montreal Protocol on Substances that Deplete the Ozone Layer agreed to reduce the emissions of ozone-friendly but climate-warming hydrofluorocarbons; this decision was based on a 2014 ozone assessment report by WMO and UNEP. In December, the United Nations General Assembly adopted its annual resolution on oceans, which includes a reference to "the latest findings by the World Meteorological Organization." In March, the World Climate Research Programme (WCRP) and the Prince Albert II of Monaco Foundation launched a new Polar Challenge to develop an Autonomous Underwater Vehicle capable of a 2 000-km mission under the sea ice in the Arctic or Antarctic.



Rising global temperatures. Global average temperature anomalies (1961–1990 reference period) for the three major datasets used in the *WMO Statement on the State of the Global Climate in 2016* (WMO-No. 1189). The grey shading indicates the uncertainty in the HadCRU dataset. (Source: Met Office Hadley Centre, United Kingdom)



Rising levels of greenhouse gases. Globally averaged mole fractions (a measure of concentration) of CO_2 in parts per million (left), CH_4 in parts per billion (middle) and N_2O in parts per billion (right). Global annual-average levels of these gases continued to rise to record heights during the period 1984–2015. (Source: WMO Greenhouse Gas Bulletin No. 12)

Selected satellite launches in 2016

Sustaining and expanding satellite observations are essential to modern meteorology and climatology. Launched in January, Jason-3, a United States of America–European oceanography satellite mission with the participation of the National Aeronautics and Space Administration (NASA), will continue the time series of mean sea-level measurements that started in 1992 with the launch of the Topex-Poseidon satellite and continued with Jason-1 and -2. Within a month of its launch it had produced its first complete science map of global sea-surface height, capturing the current signal of the 2015/2016 El Niño. The map was generated from the first 10 days of data collected once Jason-3 reached its operational orbit of 1 336 kilometres on 12 February. It shows the continuing evolution of the ongoing El Niño event that began in early 2015.

In February, the European Space Agency launched its third satellite supporting Europe's Copernicus environment programme. Sentinel-3 carries four Earth-observing instruments with cutting-edge sensors. Copernicus relies on the Sentinels and contributing missions to provide data for monitoring the environment and supporting civil security activities. Over the oceans, it measures the temperature, colour and height of the sea surface as well as the thickness of sea ice. Over land, the satellite will monitor wildfires, map the way land is used, check vegetation health and measure the height of rivers and lakes. Data from all the Sentinels are used worldwide and are free of charge for all users.

In March, WMO facilitated the use of Japan's new Himawari-8 satellite data by providing satellite data receiving and processing systems to nine countries in East Asia and the Western Pacific region in cooperation with the Japan Meteorological Agency. The aim is to spread the benefits of advanced satellite technology with developing countries to improve early warning systems and monitor and detect hazards such as tropical cyclones, for example, severe Tropical Cyclone *Winston* that hit Fiji in February. The system can detect various severe events including volcanic ash, which is detrimental for aircraft.

In November, the United States launched the GOES-16 satellite, the first of a new generation of National Oceanic and Atmospheric Administration (NOAA) geostationary environmental satellites. Part of the GOES-R satellite series, it will provide atmospheric and surface measurements of the Earth's western hemisphere to support weather forecasting, severe storm tracking, space-weather monitoring and meteorological research. In December, China launched FengYun-4A as part of its Fengyun-4 (Wind and Cloud) series of second-generation geostationary meteorological satellites. These satellites are designed with an enhanced imagery scanning capability for monitoring small- and medium-scale weather systems. FengYun-4A is equipped with vertical atmospheric sounding and microwave detection capabilities to address 3D remote-sensing at high altitudes.

RESEARCH FOR ENHANCING SAFETY AND RESILIENCE

Researchers are gaining a growing understanding of the Earth system, the interactions among its key components, and the resulting impacts on weather and climate. WMO supports the international programmes that promote and coordinate research activities that generate this knowledge. Continuing advances in research are vital to national and global efforts to promote safety and to build greater resilience to weather extremes and climate impacts.

The WMO weather and climate research programmes seek to strengthen and align the efforts of the world's leading researchers and modellers in order to accelerate progress. The World Weather Research Programme (WWRP) works in partnership with other international initiatives to support seamless prediction of the Earth system – from minutes to months – which can contribute to the management of weather-related risks to life and property. The World Climate Research Programme (WCRP) addresses the predictability of the climate and how human activity contributes to climate change.

WWRP promotes international interdisciplinary research aimed at improving the accuracy and reliability of weather forecasts on all timescales. It is advancing sub-seasonal to seasonal prediction through a collaboration with WCRP. The two programmes have established the S2S database that now contains 11 models. The number of registered users has increased to over 700 from about 60 countries. About 12 terabytes of data are downloaded every month from the S2S data servers maintained by the European Centre for Medium-Range Weather Forecasts and the China Meteorological Administration.

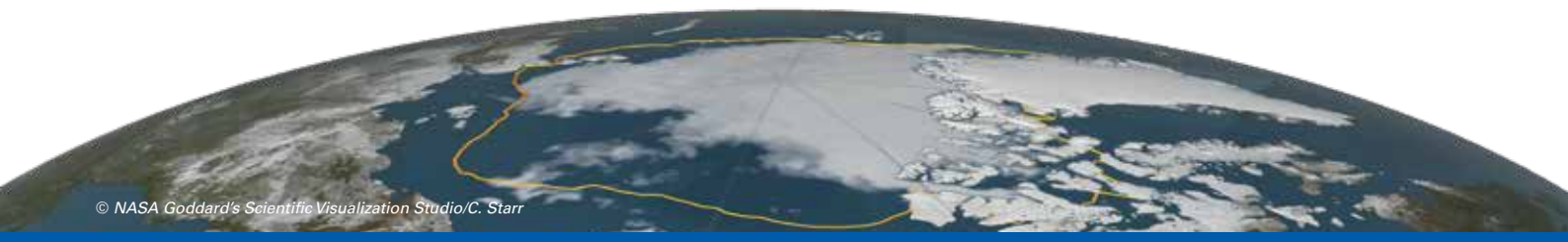
While significant advances have been made in improving short-term or seasonal prediction and long-term or multi-decadal prediction, less progress has been made on the near-term period of two, five and ten years. The WCRP Grand Challenge on Near-term Climate Prediction seeks to fill this gap and make possible the seamless climate prediction service required for the Global Framework for Climate Services. It aims to start producing annual Global Decadal Climate Outlooks using the template currently used for Global Seasonal Climate Updates. The first research Outlook is expected in 2017.

Throughout 2016 WMO continued its preparatory activities for the launch of the Year of Polar Prediction, which will run from mid-2017 to mid-2019, and will involve intensive observing, modelling, verification, user-engagement and educational activities. It will focus on achieving a significant improvement in environmental prediction capabilities for both polar regions on a wide range of timescales. It will include a field campaign that will provide new observations.

Research into atmospheric chemistry is supported by the WMO Global Atmosphere Watch (GAW) Programme, a partnership involving WMO Members, contributing networks and collaborating organizations and bodies. GAW provides reliable scientific data and information on the chemical composition of the atmosphere and on how it is affected by natural and human-induced change. It seeks to improve the understanding of interactions between the atmosphere, the oceans and the biosphere and to inform decision-making on how to improve air quality and public health.

In 2016, GAW advanced its work on the Regional Vegetation Fire and Smoke Pollution Warning and Advisory System. GAW continued its collaboration with the World Health Organization (WHO) on the impacts of air quality on health and initiated discussions on a potential coalition of WMO, WHO and UNEP. In particular, WMO supported the WHO-led establishment of an air quality and health assessment system in Accra. Other areas of work included improving the use of low-cost sensors and of crowd-sourced data for monitoring atmospheric chemistry.

The 2016 Arctic sea-ice summertime minimum, reached on 10 September, was 2.36 million square kilometres (911 000 square miles) below the 1981–2010 average minimum sea-ice extent, shown here as a gold line.



SERVICES FOR CLIMATE ACTION AND RESILIENCE

Scientific progress on understanding why and how the climate is changing is empowering policymakers and communities to build greater resilience in the face of climate and weather extremes and trends. It also supports national action on climate change under the United Nations Framework Convention on Climate Change and its Paris Agreement. WMO assists decision-makers to use climate knowledge to address today's major challenges.

WMO is spearheading the Global Framework for Climate Services (GFCS) in partnership with other United Nations agencies, such as the World Health Organization, the World Food Programme and the Food and Agriculture Organization of the United Nations, as well as with other national and international organizations. The Framework is assisting countries to improve their climate services, starting with the most vulnerable developing countries, and the priority sectors of agriculture, health, water management, disaster risk reduction and clean energy production.

In 2016, GFCS projects made good progress. During the 2015/2016 El Niño event, Norway-funded projects in Malawi and the United Republic of Tanzania assisted farmers to intervene early and make the right choices about when and what to plant. Thanks to GFCS support, the United Republic of Tanzania now also hosts three Climate Outlook Forums per year that issue seasonal forecasts and engage both stakeholders and the media.

The Climate Services for Increased Resilience in the Sahel project, funded by the United States Agency for International Development (USAID), was launched in 2016. It seeks to enable countries to mitigate the risks and take advantage of the opportunities brought about by climate variability and change. The project will develop the capabilities of the African Centre of Meteorological Applications for Development (ACMAD) as a WMO Regional Climate Centre so that it can help to strengthen meteorological services in the Sahel.

Elsewhere in 2016, Vanuatu established its Framework for Climate Services, making it the first Pacific Island nation to do so. Prepared by the National Institute of Water and Atmospheric Research Ltd, the Framework will engage stakeholders, assess existing data and services, and improve the delivery of information to the most remote and rural island communities. Similarly, the mountainous Hindu Kush-Himalayan region, known as the Third Pole, which covers an area of more than 4.3 million square kilometres and supplies water for about 45 per cent of the world's population, has launched a regional consultation with the aim of developing climate services.

The growing uptake of climate services is reflected in the national submissions to the UNFCCC of Intended Nationally Determined Contributions (INDCs). In total, 66 Parties out of 189 (or 35 per cent) have included climate services terminology in their INDCs. Sub-Saharan Africa invoked climate services the most, followed by Latin America and the Caribbean.

Climate services receive valuable inputs from a growing number of Regional Climate Centres and Regional Climate Outlook Forums. The Pacific Islands Climate Outlook Forum, the Greater Horn of Africa Climate Outlook Forum, the North Eurasia Climate Outlook Forum, and the Southern Africa Regional Climate Outlook Forum all produced regular seasonal climate forecasts.

Good progress was also made on developing the Integrated Global Greenhouse Gas Information System. While global levels of GHGs have been tracked for many years, advances in science and technology now make it possible to connect these observations with emission estimates made through the traditional inventory process at the national and subnational levels. This can be achieved by combining networks of high-resolution monitoring instruments with advanced models that simulate how winds and rain dispersed the gases after they were emitted. This system can reduce uncertainties in national emission inventories, identify additional emission sources for mitigation opportunities and provide a timely update of national GHG emissions. Switzerland, the United Kingdom and a number of cities in the United States are now implementing this approach, while other countries are developing pilot and demonstration projects.

13 CLIMATE ACTION

WMO contributes to Sustainable Development Goal 13: Take urgent action to combat climate change and its impacts

A NEW PARADIGM FOR HYDROLOGY

Obtaining freshwater for drinking, sanitation, farming and other uses has been a top priority for humanity since time immemorial. Today, rapidly growing populations and economies, combined with the impacts of climate change, are putting greater stress than ever on this essential resource. In response, the United Nations has adopted Sustainable Development Goal 6, which aims to ensure access to water and sanitation for all by the year 2030. WMO is taking action to support this Goal as well as other national, regional and global needs by establishing the Global Hydrometry Support Facility.

The new WMO Global Hydrometry Support Facility, also known as WMO HydroHub, will provide the data and analyses that policymakers and managers need for making evidence-based decisions about water management. The WMO HydroHub was endorsed in December by the WMO Commission for Hydrology, setting the stage for its rapid development.

The WMO HydroHub will transform how hydrological observations and information are gathered and distributed. Recognizing the challenges that many countries face in sustaining hydrological measurements, it will assist National Hydrological Services to broaden the sources of hydrological information and adopt innovative technologies, from exploiting geographical information systems to empowering citizens to make useful observations to obtaining supplementary information from satellites. A four-year grant from the Swiss Agency for Development and Cooperation is supporting a dedicated HydroHub team at the WMO Secretariat and assisting it to leverage additional funding for projects.

Within the next several years, the WMO HydroHub will lead to dramatic improvements in the quality and availability of information on the hydrological cycle, including observations from rivers, groundwater, lakes, reservoirs and rainfall. It will encourage the production and maintenance of new water monitoring systems and the spread of best practices. It will deliver technical assistance and foster international cooperation. In this way, it will assist policymakers and managers to keep drinking water safe and to find solutions for urbanization, climate change, poverty reduction, and drought and desertification.

The WMO HydroHub will comprise the existing World Hydrological Cycle Observing System, which promotes and provides hydrological data; the WMO Hydrological Observing System, which provides access to the hydrological data held by National Hydrological Services; a new hydrological information platform providing information on organizations that monitor water; a help desk offering technical support to National Hydrological Services; and an Innovation Hub for generating new approaches and technical solutions in the field of water monitoring.

The WMO HydroHub will also contribute to other actions launched by WMO in 2016. Proposed Communities of Practice on Flood Forecasting and Drought Management are expected to support the development of products and services for managing water resources. A new Global Hydrological Status and Outlook project will produce local, regional and global hydrological status reports; these outlooks would provide more timely and actionable information on the near-term risk of floods, droughts and water shortages. Already established initiatives, such as the Flash Flood Guidance System with global coverage, which is already operational in more than 50 countries thanks to support from USAID, will also benefit from the implementation of the WMO HydroHub. Finally, the WMO HydroHub will make an essential contribution to strengthening the WMO Integrated Global Observing System.

6 CLEAN WATER AND SANITATION

WMO contributes to Sustainable Development Goal 6: Ensure availability and sustainable management of water and sanitation for all

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REDUCING DISASTER RISK

Together with the United Nations Sustainable Development Goals and the Paris Agreement, the Sendai Framework for Disaster Risk Reduction 2015–2030 is a key pillar of the global agenda. The Framework seeks to substantially reduce global disaster mortality by 2030. WMO is contributing to this goal by promoting the development of Multi-hazard Early Warning Systems. By engaging all relevant actors – including health, emergency and weather services – and addressing all major hazards – from storms to floods to earthquakes – these end-to-end systems greatly strengthen cooperation at the national level and help to save lives and reduce property damage through more effective early warnings.

WMO and its partners are contributing to the Sendai Framework through the newly established International Network for Multi-hazard Early Warning Systems. The Network brings together agencies that play a role in producing and delivering warnings in order to share the best available scientific, technological and social knowledge and techniques for delivering early warnings and building climate resilience. The Network was formalized in 2016 and is now leading the organization of the Multi-hazard Early Warning Conference, to be held in Cancun, Mexico, in May 2017, in conjunction with the Global Platform for Disaster Risk Reduction, which is led by the United Nations Office for Disaster Risk Reduction (UNISDR).

According to the insurer Munich Re, in 2015 (the most recent year for which data are available), 97 per cent of natural disasters were caused by weather, climate or water, resulting in some US$ 97 billion in overall losses. Nevertheless, despite recent progress, WMO has confirmed that over 80 per cent of the world's 48 least developed countries as well as many small island developing States have only a basic early warning system. Weather observation networks, the foundation of early warning systems, are inadequate in many African countries. To respond to this challenge, a coalition led by France, with support from Australia, Germany, Luxembourg, the Netherlands, Japan and Canada, launched the Climate Risk and Early Warning Systems (CREWS) initiative at the United Nations Climate Change Conference in Paris in 2015.

CREWS is being implemented by WMO, UNISDR and the World Bank Group and its Global Facility for Disaster Reduction and Recovery. It builds on existing WMO initiatives, including the Global Framework for Climate Services and the Severe Weather Forecasting Demonstration Project.

In November 2016, the United Nations Climate Change Conference in Marrakech followed up the CREWS launch by outlining an action plan to assist African least developed countries and Pacific islands to upgrade their early warning systems for weather and climate-related shocks. Mali, Burkina Faso, the Democratic Republic of the Congo and small island developing States in the Pacific will be supported to improve their early warning systems and forecast services with an initial US$ 12 million in funding allocated by the CREWS initiative. Additional projects are under development.

In addition to strengthening risk information and warning systems in vulnerable countries, the international partnership seeks to leverage financing from the Green Climate Fund and other sources to protect populations exposed to extreme climate events. CREWS aims to mobilize more than US$ 30 million by July 2017 and US$ 100 million by 2020.

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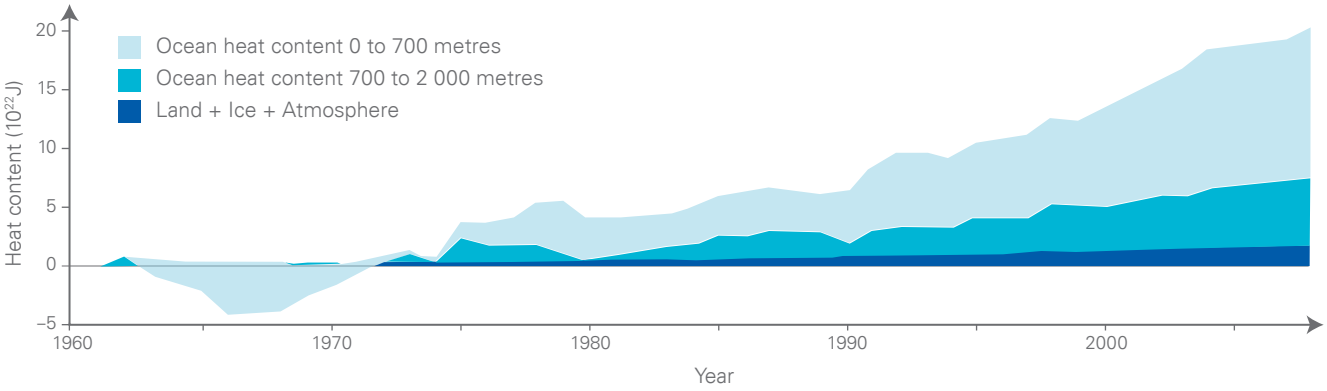
OCEANS, WEATHER AND CLIMATE

Covering some 70 per cent of the Earth's surface, the ocean is a major driver of the world's weather and climate. It is also a major driver of the global economy, carrying more than 90 per cent of world trade and sustaining the 40 per cent of humanity that lives within 100 km of the coast. Recognizing this, WMO collaborates with the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and supports agencies and programmes that regularly monitor the ocean, model how it affects the atmosphere and deliver marine services to support coastal management and safety at sea. Today, the growing impact of climate change and the risks faced by small island developing States and coastal areas are making ocean observations, research and services more critical than ever before.

WMO contributes to progress on monitoring the ocean and its interactions with weather and climate by advocating for enhanced ocean observations through IOC-UNESCO, the Global Ocean Observing System (a component of GCOS), and the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). For example, recognizing the enormous impact that the Pacific has on the global climate and on the El Niño/Southern Oscillation, WMO is supporting efforts to develop and improve ocean observations, such as through the Tropical Pacific Observing System 2020 project to enhance and redesign the observing system in this vital region.

The WCRP Grand Challenge on Regional Sea-level Change and Coastal Impacts is engaging research institutes in an effort to quantify natural and anthropogenic mechanisms of regional to local sea-level variability, promote advances in observation systems required for integrated sea-level monitoring and foster the development of sea-level predictions and projections to benefit coastal zone management. The WMO Coastal Inundation Forecasting Demonstration Project, led by JCOMM and the WMO Commission for Hydrology, seeks to promote the safety and socioeconomic sustainability of coastal communities through the development of coastal inundation forecasting and warning systems at the regional scale.

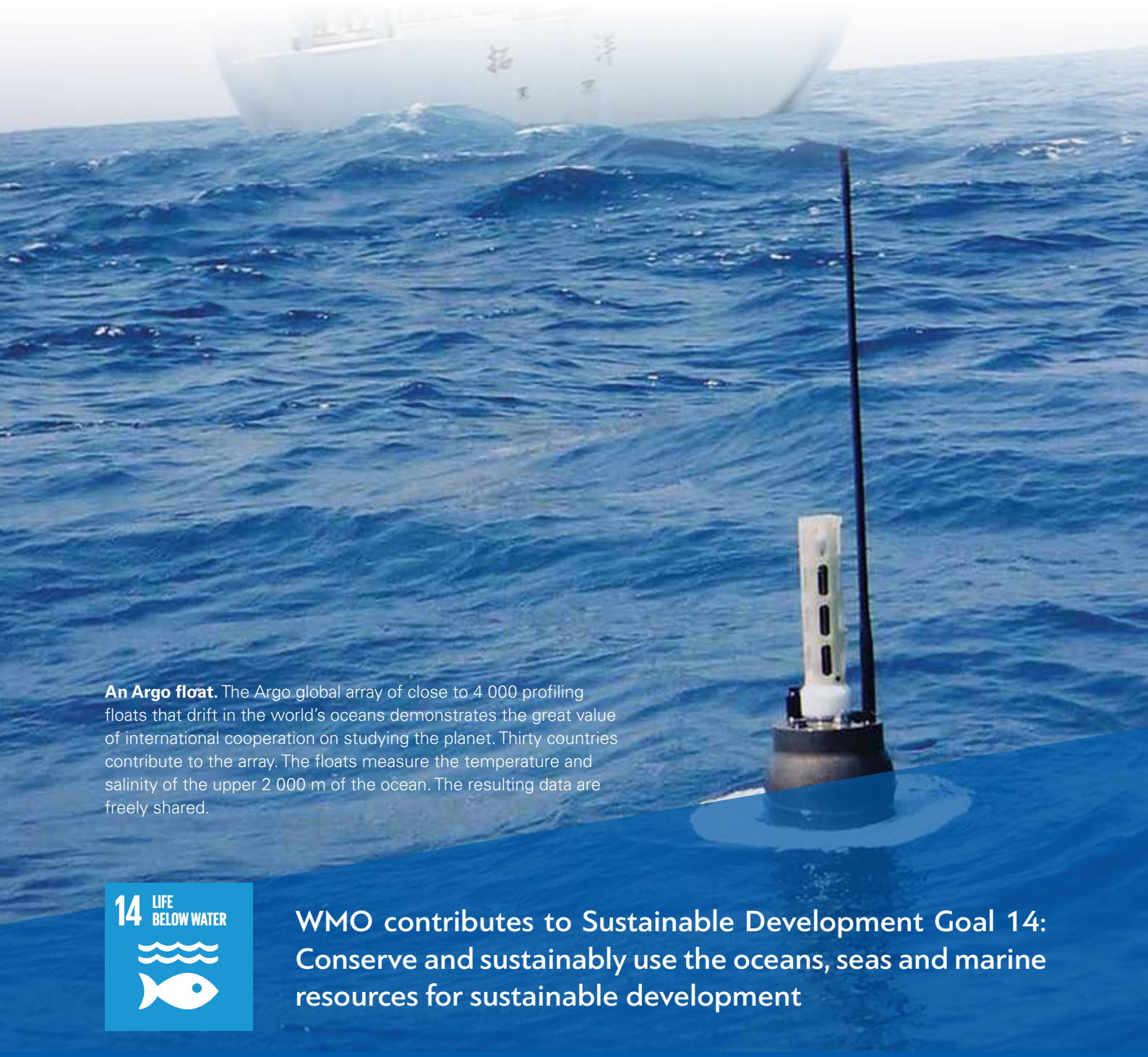
Forecasts and alerts about tropical cyclones, also known as typhoons and hurricanes, are the most important kind of warnings provided for coastal areas and marine activities. WMO has established six tropical cyclone Regional Specialized Meteorological Centres together with six Tropical Cyclone Warning Centres. They provide advisories and bulletins with up-to-date, first-level basic



The oceans are rapidly warming. Over 90 per cent of the extra heat trapped by the greenhouse gases produced by humanity goes into the ocean. As a result, the heat content in the upper and lower levels of the ocean continues to rise steadily. This heat will affect the climate for many centuries to come.

meteorological information on tropical cyclones in all tropical regions that experience these powerful storms.

For example, in 2016 severe Tropical Cyclone *Winston* caused widespread damage and destruction as it hit the Fiji islands on 20–21 February as a Category 5 intensity storm, the highest category of cyclone, with winds averaging 220 km per hour and gusts of 315 km per hour. The Fiji National Disaster Management Office coordinated the response and has activated the National Emergency Operation Center. On the other side of the world, Hurricane *Matthew* caused massive destruction as the first Category 5 Atlantic hurricane since Hurricane *Felix* in 2007. *Matthew* wrought widespread destruction and catastrophic loss of life during its journey across the Western Atlantic, including parts of Haiti, Cuba, the Dominican Republic and the Lucayan Archipelago, the south-eastern United States and the Canadian Maritimes.



An Argo float. The Argo global array of close to 4 000 profiling floats that drift in the world's oceans demonstrates the great value of international cooperation on studying the planet. Thirty countries contribute to the array. The floats measure the temperature and salinity of the upper 2 000 m of the ocean. The resulting data are freely shared.

14 LIFE BELOW WATER

WMO contributes to Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

MEETING THE CHALLENGES OF DEVELOPMENT

WMO recognizes the vital contribution that weather, climate and hydrological services can make to supporting the most vulnerable communities. It addresses issues of special concern to developing countries, small island developing States and others at risk around the world. It assists National Meteorological and Hydrological Services in strengthening their capacity to provide high-quality weather, climate and hydrological services in a changing and increasingly competitive marketplace.

Weather, climate and water can either disrupt sustainable development or advance it. The providers of weather, climate, hydrological, marine and related environmental services therefore have a critical role to play in assisting countries to implement the United Nations 2030 Agenda for Sustainable Development and the Sustainable Development Goals. High-quality meteorological services empower decision-makers to better manage agriculture, public health, water resources, energy production, transportation and other sectors that are critical for national development. In this way, WMO and NMHSs contribute directly to most of the Goals and indirectly to others.

Drought and desertification are priority development issues for many countries in Africa and elsewhere. WMO promotes proactive policies for addressing these issues through the Integrated Drought Management Programme, which it co-sponsors together with the Global Water Partnership and some 30 other partners. In August, the Programme officially released the *Handbook of Drought Indicators and Indices* (WMO-No. 1173) during the African Drought Conference to promote monitoring, early-warning and information-delivery systems in support of risk-based drought management policies and preparedness plans.

A related challenge is the health effects and other damaging impacts of sand and dust storms. WMO has responded to growing concern about this phenomenon by establishing the Sand and Dust Storm Warning Advisory and Assessment System. The System provides timely and high-quality forecasts and knowledge to users through an international partnership of research and operational communities. In April, the Barcelona Dust Forecast Center, which serves as a WMO Regional Specialized Meteorological Centre, reached an agreement with ACMAD to share the numerical output of its dust prediction models. The agreement will spread the benefits of the Center's expertise and models to more sub-Saharan African countries. It will allow ACMAD to develop dust forecast products adapted for African National Meteorological Services and for decision-makers from socioeconomic sectors affected by the high incidence of heavy dust events, such as transport and agriculture.

WMO, together with UNEP and the United Nations Convention to Combat Desertification, published a *Global Assessment of Sand and Dust Storms*. The report, with a foreword by former United Nations Secretary-General Ban Ki-moon, was included in the documentation of the 71st session of the United Nations General Assembly in late 2016. It synthesizes the latest scientific information on the causes of sand and dust storms and their consequences for human well-being and the environment. The report also summarizes the latest knowledge about predicting sand and dust storms, reducing their impact and taking action to mitigate them.

Because skilled staff is the key to success for every National Meteorological and Hydrological Service, WMO facilitates a wide range of education and training programmes and activities. The world's NMHSs employ some 200 000 staff, many of whom are meteorologists, hydrologists or other highly skilled professionals. Thousands of weather, water and climate professionals also work in other public institutions, the private sector and academia. Newly trained experts are in constant demand due to natural staff turnover, while accelerating change in both science and society makes retraining and continuing education absolutely essential.

WMO focuses on ensuring that this occurs through a variety of mechanisms. It works in close collaboration with development partners to provide resources and training opportunities for many least developed and developing countries. Every year, the 27 designated WMO Regional Training Centres ensure that thousands of professionals receive training in meteorology, operational hydrology and climatology. National Training Centres, universities, Centres of Excellence and WMO partner organizations also provide training and continuing education through short-term attachments, fellowships, seminars, workshops and short training courses. In all, the WMO Regional Training Centres alone offered over

150 degree-level courses of study and 160 short courses, which have served nearly 10 000 national and approximately 2 000 international students.

In 2016, the WMO Fellowship programme supported 78 long-term fellowships to study in various institutions, ranging from one-month, short-term training to BSc, MSc and PhD degree programmes as long as five years. WMO also developed new "competency frameworks" to support training on climate services, marine weather forecasters, and public weather services, and it produced a *Guide to the Management and Operation of WMO Regional Training Centres and other Training Institutions* (WMO-No. 1169) and a Guide to Competencies, both of which are to be published in 2017.

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How WMO promotes gender equality

Reflecting the emphasis placed on gender equality by the United Nations Sustainable Development Goals and by United Nations Secretary-General António Guterres, WMO fully recognizes the value and importance of engaging women in all aspects of its work. To encourage women to enter the fields of meteorology, climatology and hydrology and to move into senior positions, the WMO Executive Council at its annual meeting in June endorsed the newly developed WMO Gender Action Plan. The Plan seeks to put the WMO Gender Equality Policy into action within the WMO Secretariat, the various governance bodies that guide the work of WMO and at the national level within the NMHSs.

The representation of women in decision-making roles at WMO has already started to improve. For example, female representation at the last meeting of the WMO Commission for Hydrology was 10 per cent higher than at its previous meeting. WMO Secretary-General Petteri Taalas is an International Geneva Gender Champion and has declared that gender equality and the empowerment of women are among his objectives. WMO Deputy Secretary-General Elena Manaenkova was selected as one of 20 inspirational women in Geneva working in the area of the environment.

5 GENDER EQUALITY

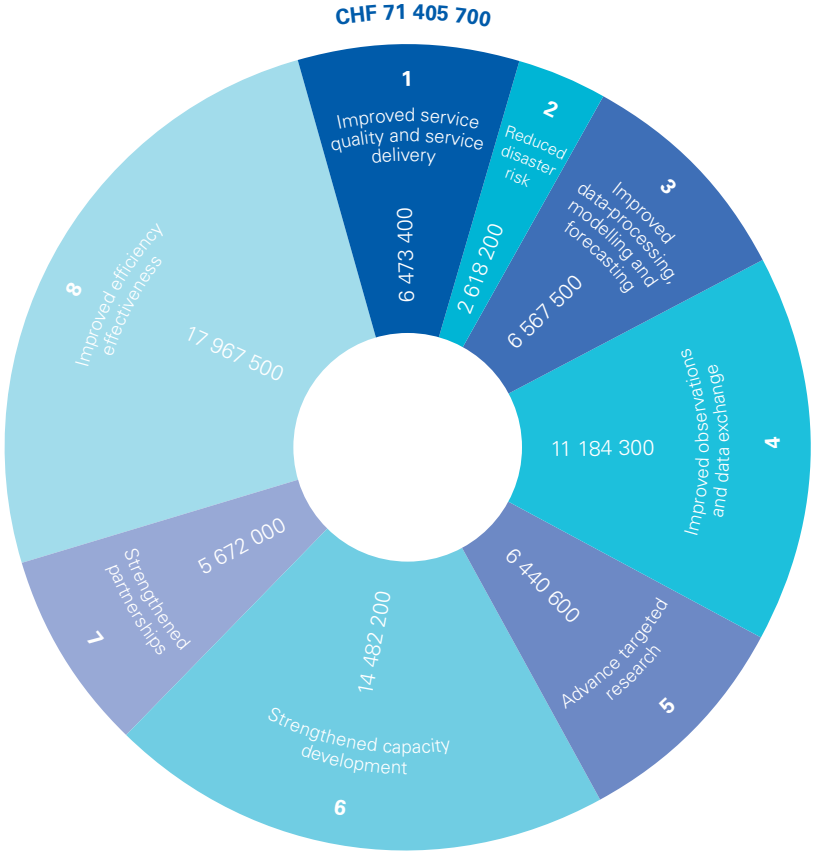
WMO contributes to Sustainable Development Goal 5: Achieve gender equality and empower all women and girls

WMO IN THE NEWS

The activities, reports and meetings of WMO are widely covered in the news media around the world.

WMO BUDGET, STAFFING AND STRUCTURE

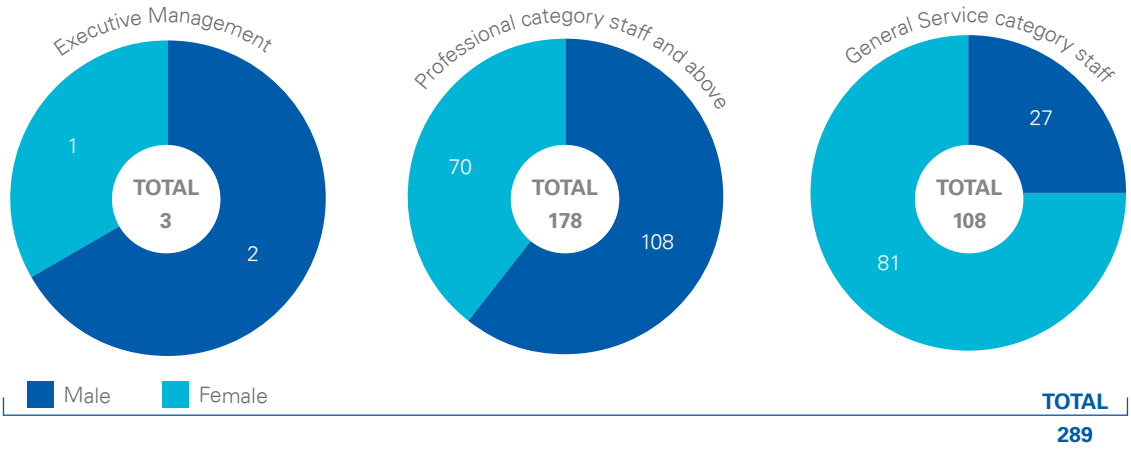
WMO regular budget for the year 2016 by Expected Result (in Swiss francs)



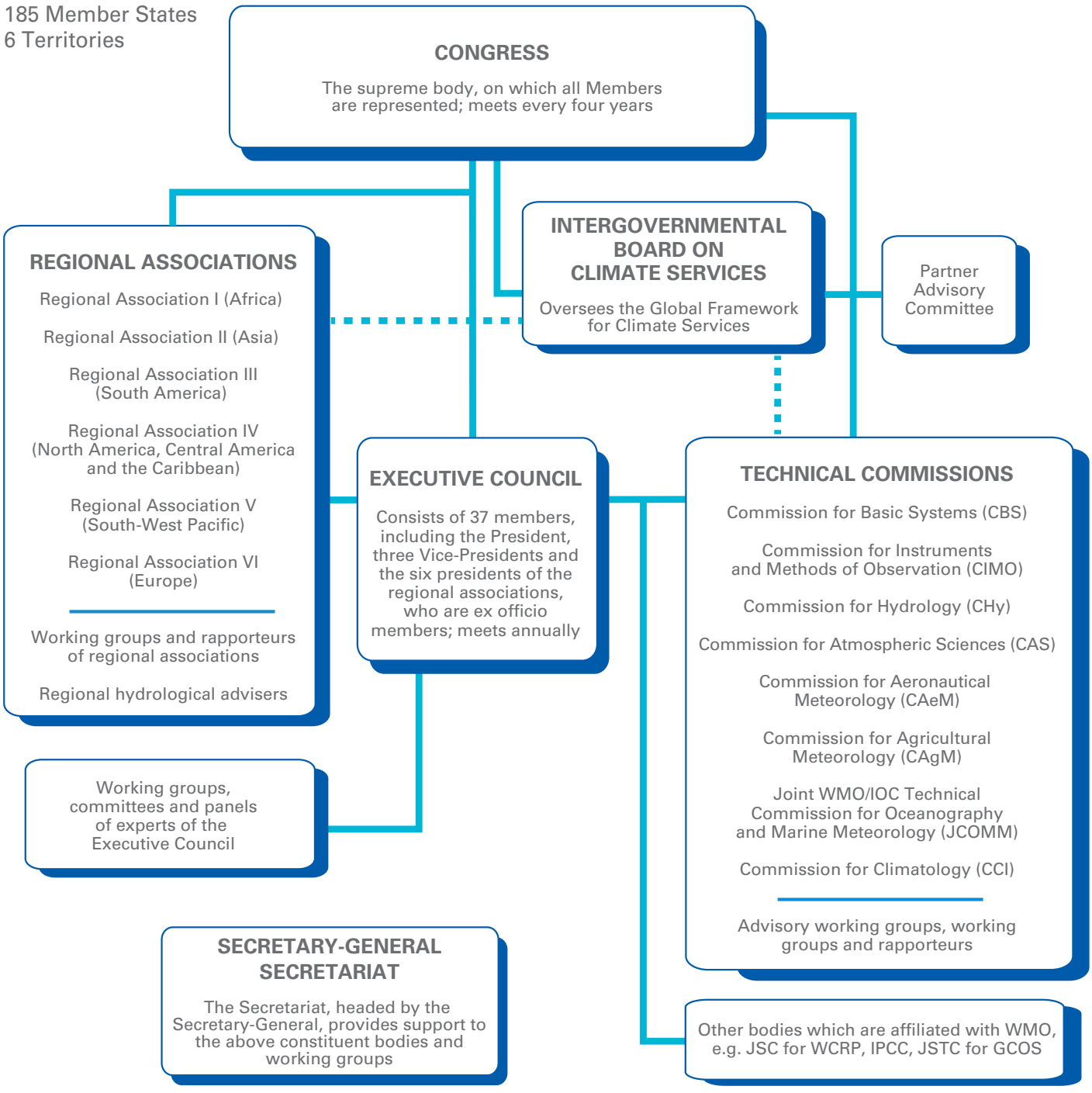
Note. These eight expected results are set out in the *WMO Strategic Plan 2016–2019* (WMO-No. 1161) approved by the Seventeenth World Meteorological Congress in May 2015. The Plan also defines seven strategic priorities: disaster risk reduction, the Global Framework for Climate Services, the WMO Integrated Global Observing System, aviation meteorological services, polar and high-mountain regions, capacity development, and improved WMO governance.

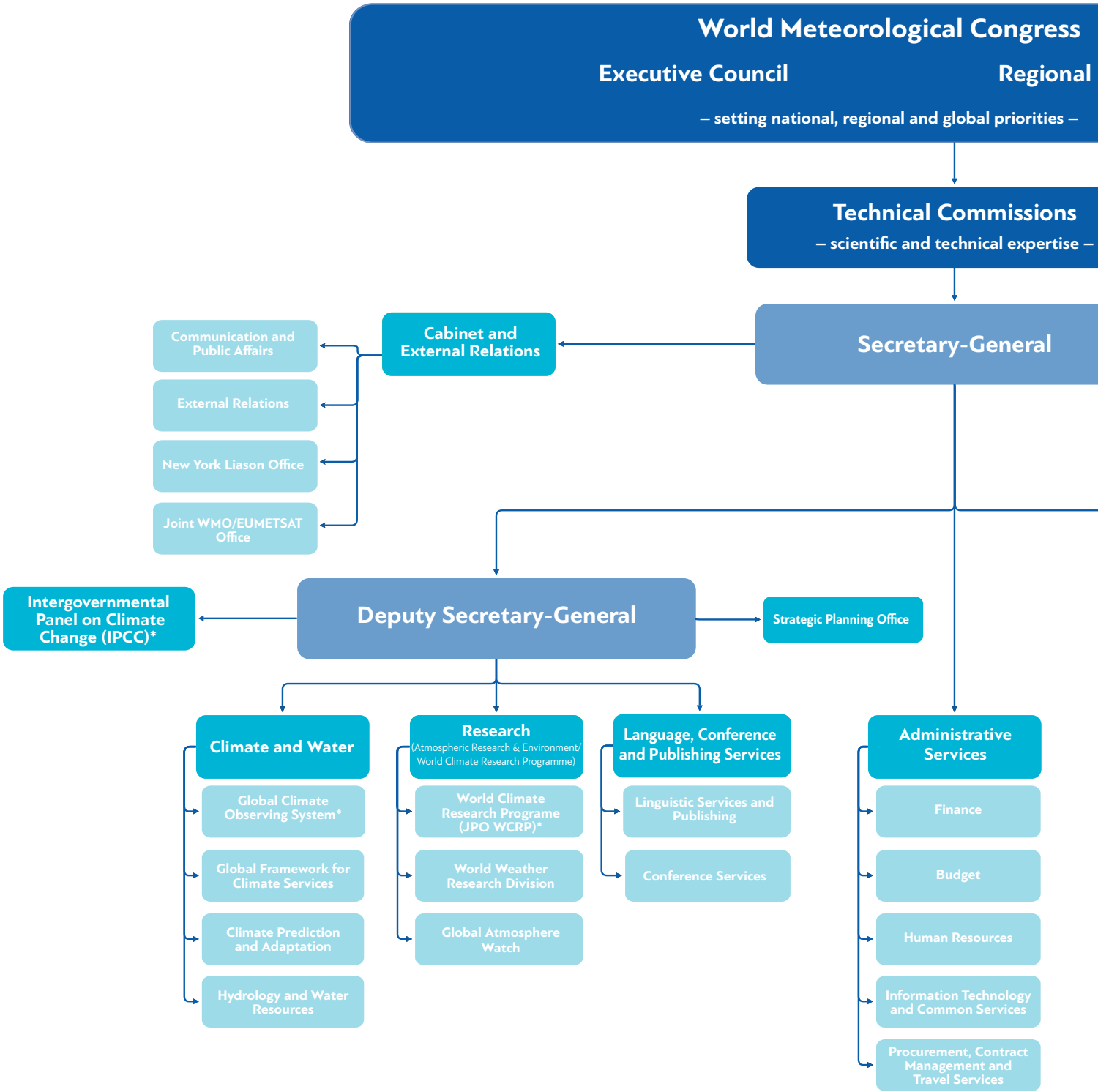
The enhanced implementation of WMO Expected Results and strategic priorities is made possible by additional support in the form of in-kind and voluntary contributions from Members and partners. In 2016, these contributions totalled CHF 7 278 000.

Secretariat staffing table (as at 31 December 2016)



Structure of the World Meterological Organization




World Meteorological Congress
Executive Council
Regional
– setting national, regional and global priorities –
Technical Commissions
– scientific and technical expertise –
Secretary-General
Cabinet and External Relations
Communication and Public Affairs
External Relations
New York Liason Office
Joint WMO/EUMETSAT Office
Intergovernmental Panel on Climate Change (IPCC)*
Deputy Secretary-General
Strategic Planning Office
Climate and Water
Global Climate Observing System*
Global Framework for Climate Services
Climate Prediction and Adaptation
Hydrology and Water Resources
Research
(Atmospheric Research & Environment/ World Climate Research Programme)
World Climate Research Programe (JPO WCRP)*
World Weather Research Division
Global Atmosphere Watch
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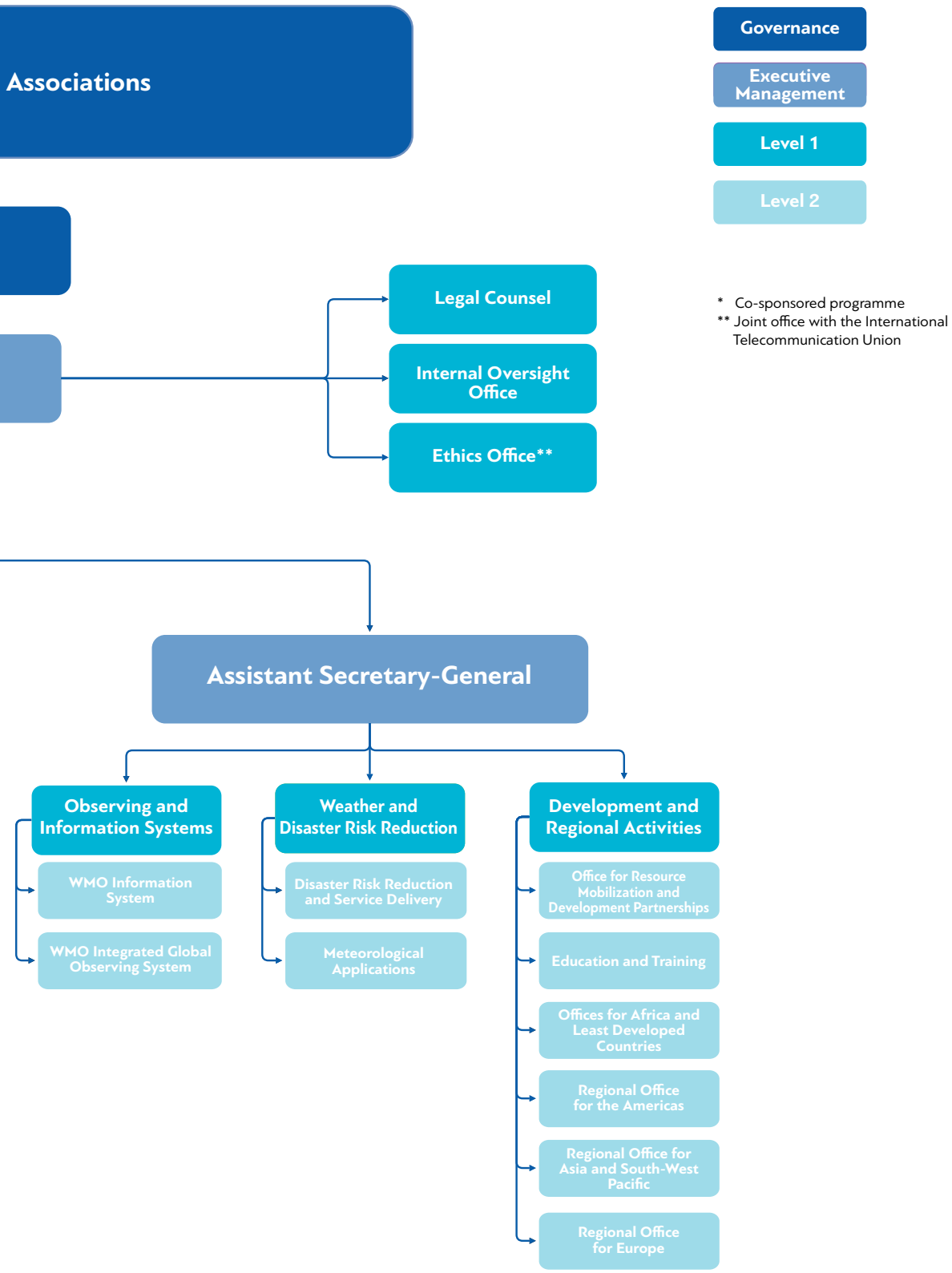
Conference Services
Administrative Services
Finance
Budget
Human Resources
Information Technology and Common Services
Procurement, Contract Management and Travel Services



* Co-sponsored programme
** Joint office with the International Telecommunication Union

For more information, please contact:

World Meteorological Organization

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

Communication and Public Affairs Office

Tel.: +41 (0) 22 730 83 14/15 – Fax: +41 (0) 22 730 80 27

E-mail: cpa@wmo.int

public.wmo.int

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