ITUNews MAGAZINE

No. 1, 2019

Monitoring our changing planet

Critical spectrum for Earth observation from space

Monitoring our changing planet

Houlin Zhao

ITU Secretary-General

The Earth is a fragile planet with finite resources to sustain the world's growing population. As we work together to build a sustainable global economy, spaceborne remote sensors are poised to play an increasingly important role in achieving the United Nations' Sustainable Development Goals (SDGs).

Indeed, ITU Member States and the global community now see the potential for using Earth observations and geospatial information as fundamental inputs for achieving the SDGs. Remote sensing provides critical information across a wide range of applications, including air quality, disaster management, public health, agriculture, water availability, coastal zone management, and the health of the Earth's ecosystems.

For example, spaceborne sensing data is used to assess the impact of natural disasters and to be better prepared for hazardous events around the globe. Data from spaceborne remote sensors is also increasingly used to guide efforts to minimize the damage that urban growth has on the environment.

These are just a few examples of how remote sensing measurements – and the science they enable – provide a great service to humanity. This edition of the ITU News Magazine provides more such examples and a wealth of insight into how ITU's work helps realize the social and economic benefits of Earth observation from space.

In addition, I am pleased to acknowledge that the ITU News Magazine has turned 150. In this edition you will also discover milestones in the 150-year history of ITU News.

I take this opportunity to wish you all a very healthy and happy New Year!

"Remote sensing measurements — and the science they enable — provide a great service to humanity."

Houlin Zhao

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Cover photo: Shutterstock/NASA

ISSN 1020-4148
itunews.itu.int
Six issues per year

Editor-in-Chief: Matthew Clark
Art Editor: Christine Vanoli
Editorial Assistant: Angela Smith

Editorial office/Advertising information:
Tel.: +41 22 730 5234/6303
Fax: +41 22 730 5935
E-mail: itunews@itu.int

Mailing address:
International Telecommunication Union
Place des Nations
CH-1211 Geneva 20 (Switzerland)

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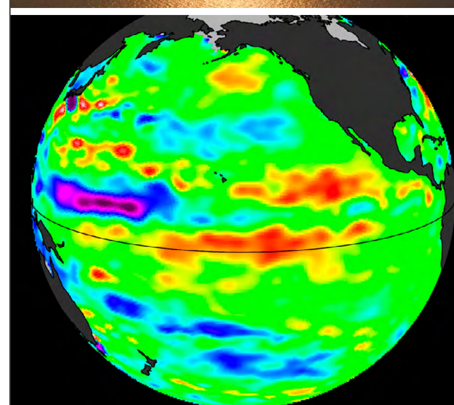
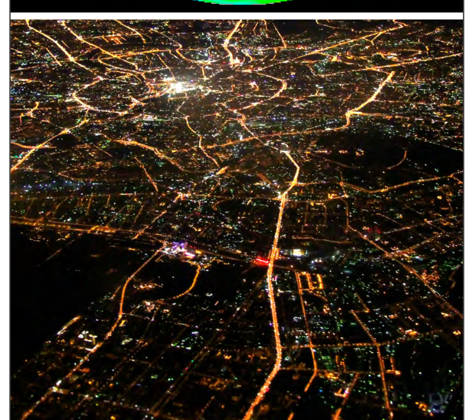




Why we need space sensing observation today

Mario Maniewicz

Director of the ITU Radiocommunication Bureau

Climate change and growing exploitation of the Earth's natural resources is leading to a range of environmental problems that require international action.

If humanity is going to respond effectively, many of the solutions will be informed by global monitoring of the environment, including the use of space assets.

Indeed, space sensing observation is essential to help leaders and citizens make better decisions based on reliable data.

Today, several dozen satellites contribute to the accumulation of critical knowledge about the Earth's system, enabling scientists to describe specific links between a major natural disturbance in the upper atmosphere, and changes in the weather thousands of miles away.

"Today, several dozen satellites contribute to the accumulation of critical knowledge about the Earth's system."

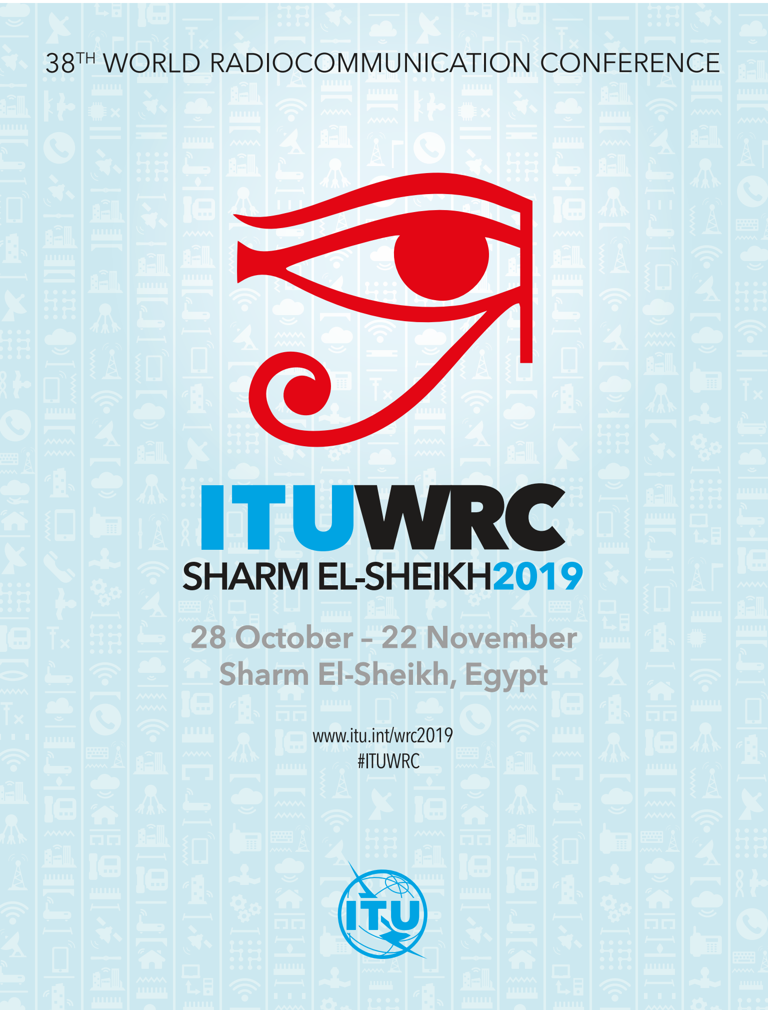
Mario Maniewicz

As accurate weather predictions need to start from the best possible estimate of the current state of the atmosphere, it is crucial that meteorologists have real-time, accurate global observations about what is happening in the Earth's atmosphere over land and oceans. And for this, they rely on space sensing.

Satellite data is today an indispensable input for weather prediction models and forecast systems used to produce safety warnings and other information in support of public and private decision-making.

The Global Climate Observing System – A United Nations Framework

The need for observations is formally addressed through the United Nations (UN) Framework Convention on Climate Change which has charged the Global Climate Observing System with the responsibility for defining requirements for observations relevant to climate change. All concerned UN agencies work together to ensure the sustained provision of reliable physical, chemical and biological observation and data records in order to contribute to the achievement of each one of the 17 Sustainable Development Goals and their associated targets.



The ITU World Radiocommunication Conference 2019 — taking decisions on spectrum

This edition of the ITU News Magazine is published in the context of the preparation of the ITU World Radiocommunication Conference 2019, to be held from 28 October to 22 November 2019 in Sharm El-Sheikh, Egypt.

The conference will take decisions on the use of spectrum by the various radiocommunication services, including space science. It is essential that these decisions provide appropriate protection to space science so that it continues to support the sustainable development of humankind.

> *"It is crucial that meteorologists have real-time, accurate global observations about what is happening in the Earth's atmosphere."*
>
> Mario Maniewicz

Spectrum — crucial for meteorological systems

It is therefore important for the readers of this ITU News Magazine edition to understand why the availability and protection of appropriate spectrum for meteorological systems is crucial for their performance, and why the potential economic and societal value of these systems deserve special attention from the ITU membership to the needs of the space science community. I am very grateful to the authors for sharing their expertise and perspectives.

Types of spaceborne remote sensors for Earth observation

Active sensors are radar systems on spaceborne platforms. They obtain data through the transmission and reception of radiowaves. There are 5 types:

1. **Synthetic aperture radars (SARs)** — Obtain topographical data of the Earth's surface
2. **Altimeters** — Measure the precise height of the ocean's surface
3. **Scatterometers** — Determine wind direction and speed at the ocean's surface
4. **Precipitation radars** — Determine rainfall rates and 3D structure of rainfall
5. **Cloud profile radars** — Measure cloud cover and structure over the Earth's surface

Passive sensors are very sensitive receivers that measure the electromagnetic energy emitted and scattered by the Earth, and the chemical constituents in the Earth's atmosphere. They require protection from radio-frequency interference.

Your source to ITU-R Recommendations

ITU Radiocommunication Sector (ITU-R)
Study Group 7 (Science Services)

Your source to ITU-R Recommendations that describe the technical and operational characteristics, protection criteria, and sharing considerations for remote sensing satellite systems and their associated control and data return links:

- RS Series (for remote sensing)
- SA Series (for space applications and meteorology)
- Handbook on Earth Exploration-Satellite Service
- Joint WMO-ITU Handbook on Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction

Source: ITU Radiocommunication Sector (ITU-R)

Earth observation systems – ITU-R Study Group 7 and World Radiocommunication Conferences

John Zuzek

Chairman of ITU-R Study Group 7, and
National Spectrum Program Manager, NASA

The ITU Radiocommunication Sector (ITU-R) Study Group 7 deals with science services. These include the Earth exploration-satellite and meteorological-satellite services, with systems for passive and active spaceborne remote sensing, which enable us to obtain important data about the Earth and its atmosphere

The systems used for these purposes have far-reaching effects for everyone on the planet. The data are used to study and monitor climate change, to assist meteorologists in predicting the weather, and predicting and monitoring a variety of natural disasters.

It is important to note that while meteorological and Earth observation satellites are operated by only a limited number of countries, the data and data products that result from their operation are distributed and used on a global basis, in particular by national weather services, in both developed and developing countries, and by organizations monitoring and studying climate change.

> *"Data from Earth observation and remote sensing systems are used in applications for disaster prediction, monitoring and mitigation."*
>
> John Zuzek

Furthermore, data from Earth observation and remote sensing systems are used in applications for disaster prediction, monitoring and mitigation. A United Nations report found that approximately 90% of all disasters are weather-related. Due to the global nature of Earth observation and remote sensing systems, protection from harmful interference has to be considered on a global basis.

Spaceborne active sensors

Spaceborne active sensors are instruments that obtain data through the transmission and reception of radiowaves. They are basically radar systems on spaceborne platforms. There are five types of active sensors, each having its own specific purpose. The synthetic aperture radar (SAR) is used to obtain topographical data of the Earth's surface. Altimeters are used to measure the precise height of the ocean surface. Scatterometers are primarily used to determine the wind direction and speed at the ocean surface. Precipitation radars are used to determine rainfall rates and the three-dimensional structure of the rainfall. Cloud profile radars are used to measure cloud cover and structure over the Earth's surface.

Spaceborne passive sensors

Spaceborne passive sensors are very sensitive receivers known as radiometers that measure the electromagnetic energy emitted and scattered by the Earth and the chemical constituents in its atmosphere. These very sensitive receivers require protection from radio-frequency interference in order to be able to make their requisite measurements.

Passive remote sensing instruments operating on Earth observation satellites are looking down at the Earth's surface and atmosphere, and are susceptible to interference from transmitters operating on or near the surface of the Earth. These sensitive receivers can only operate successfully due to the allocation of certain frequency bands to their respective radio services and due to the regulatory protections afforded to them by many special provisions of the Radio Regulations.

In fact, by their very nature, passive sensors are attempting to receive and process very weak, naturally occurring radio signals at specific frequencies determined by molecular physics. Therefore, if such signals are corrupted by interference, it is not possible to simply use another frequency to obtain the information. The information is simply unavailable.

Once scientific data is obtained by Earth observation sensor systems, this data must be transmitted down to the Earth for scientists to process and make use of that data. These data transmission links must also be protected from harmful radio-frequency interference, or the scientific data may be corrupted or lost entirely.

See all ITU-R Study Group 7 recommendations for:

- Remote sensing systems: RS series
- Space applications and meteorology: SA series.

ITU-R Study Group 7

ITU–R Study Group 7 maintains the RS Series (for remote sensing) and the SA Series (for space applications) of the ITU–R Recommendations that describe the technical and operational characteristics, protection criteria, and sharing considerations for remote sensing satellite systems and their associated control and data return links. It also maintains the ITU–R Handbook on Earth Exploration-Satellite Service and the joint WMO-ITU Handbook on Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction as well as many pertinent reports on remote sensing and Earth observation. This documentation contributes to the efforts of the science community in general and the remote sensing community in particular to assist in protecting the use of the radio spectrum for remote-sensing applications.

World Radiocommunication Conferences and remote sensing

The World Radiocommunication Conferences (WRCs) have also had a vital role in remote sensing.

Starting at WARC-79, the first allocations of frequency bands to the Earth exploration-satellite service were made.

At WRC-97, the allocations to the Earth exploration-satellite service (active) were enhanced for active remote sensing of the Earth, the allocations between 50 and 71 GHz were refined and enhanced to provide for important remote sensing applications, and the data downlink frequency bands were globalized.

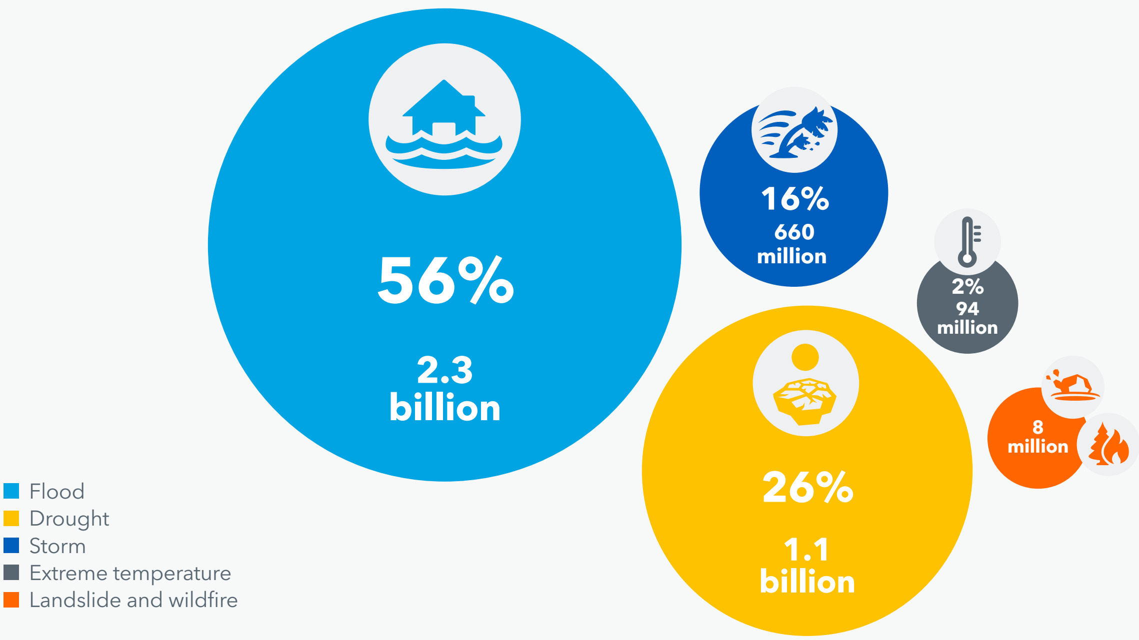
At WRC-2000, further enhancements were made to various remote sensing frequency bands and the allocations from 71 to 275 GHz were rearranged and updated to acknowledge use by remote sensing systems in certain frequency bands.

At WRC-07, protection of certain bands used for passive remote sensing was achieved, including protection of purely passive allocated bands from out-of-band emissions from nearby active service transmitters.

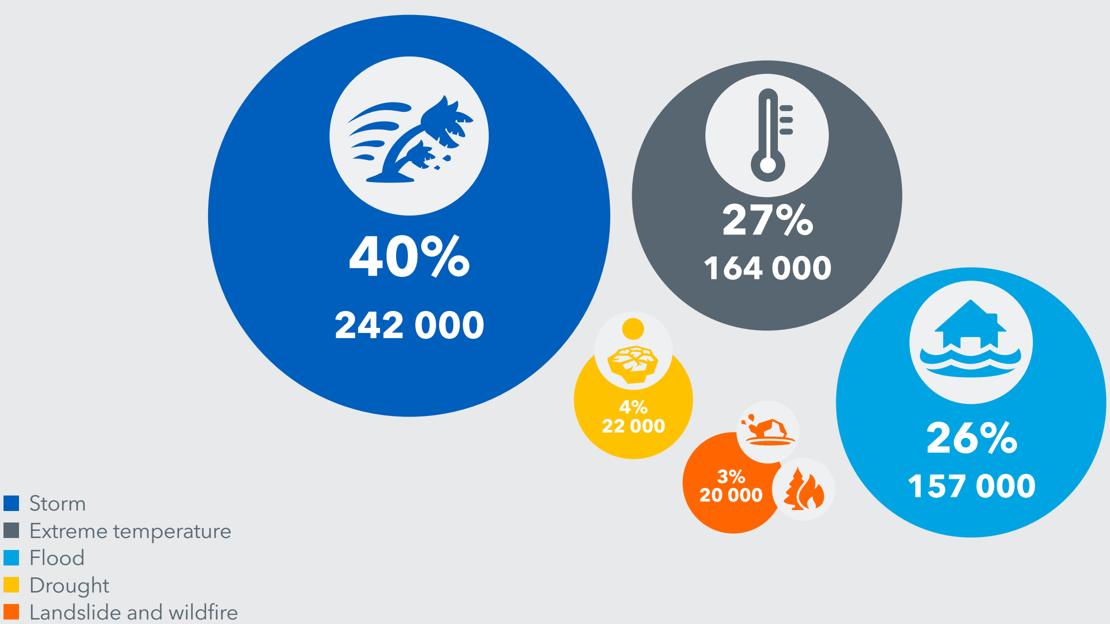
WRC-12 formally recognized the importance of Earth observation Radiocommunication in the Radio Regulations. All of the actions have helped shape the current use of remote sensing systems with their associated societal and economic benefits and point towards the future use of these systems for decades to come.

The human cost of weather-related disasters 1995–2015

Numbers of people affected by weather-related disasters (1995–2015)
(NB: deaths are excluded from the total affected.)



Numbers of people killed by disaster type (1995–2015)



Source: The Human Cost of Weather Related Disasters 1995–2015.
Centre for Research on the Epidemiology of Disasters (CRED)/The United Nations Office for Disaster Risk Reduction (UNISDR)

The space-based component of the WMO Integrated Global Observing System

Petteri Taalas

Secretary-General, World Meteorological Organization (WMO)

The benefits of using Earth-orbiting satellites for the observation of the Earth have been recognized since the early 20th century. They could finally be realized when the first artificial satellite, Sputnik, was launched on 4 October 1957, marking the beginning of the space age.

In 1961, in response to a request made by the newly established Committee on the Peaceful Uses of Outer Space (COPUOS) of the United Nations General Assembly, the World Meteorological Organization (WMO) prepared a ground-breaking report in which it proposed a global programme to advance atmospheric science research and to develop improved weather forecasting capabilities using space technology (see the Global Satellite Observing System: a Success Story).

> *"The World Weather Watch is one of the best examples of the sharing of space benefits among all countries."*
>
> Petteri Taalas

'World Weather Watch' – protecting lives and property

The programme became known as "World Weather Watch." It combined observing systems, telecommunication facilities and data-processing and forecasting centres, operated by WMO Members, to make available meteorological and related environmental information necessary to provide efficient services and protect lives and property in all countries.

The World Weather Watch observing systems component, the Global Observing System (GOS), has grown into a well-planned system of meteorological and environmental satellites, integrated with in-situ based observation networks and supporting a wide range of WMO application programmes. It is composed of numerous satellites in geostationary orbit, low Earth orbit as well as in various other locations in the Earth-Sun system.

The data generated by these satellites provide essential input for a wide range of application programmes. For example, it has improved the accuracy of weather forecasts through numerical weather prediction and provides increasingly reliable and timely warnings of extreme weather events. Products and services making use of space-based data contribute to the implementation of the global development agendas, including the 2030 Agenda for Sustainable Development, the Sendai Framework for Disaster Risk Reduction and the Paris Agreement to combat climate change.

The World Weather Watch is one of the best examples of the sharing of space benefits among all countries. Its data and information are made available to all countries, independent of their social and economic development. This includes the provision of receiving and analysis, equipment and capacity building in the form of training, fellowship programmes and other support.

Ana Ricov/WMO

> *"It is critically important to sustain an observing system capable of detecting and documenting global climate variability and change over long periods of time."*
>
> Petteri Taalas

A new framework for observing global climate variability

In response to the expanding mandates of National Meteorological and Hydrological Services (NMHSs), to the technical and scientific advances and to economic realities, the Global Observing System has become a key element of a framework which is integrating the existing global observing system, with the WMO Integrated Global Observing System (WIGOS). Under this new framework, GOS will be integrated with the observing system components of application areas that had previously been developed independently.

As the Earth's climate enters a new era, in which it is forced by human activities, as well as natural processes, it is critically important to sustain an observing system capable of detecting and documenting global climate variability and change over long periods of time. The research community, policy-makers and the general public require high-quality climate observations to assess the present state of the ocean, cryosphere, atmosphere and land and place them in context with the past. WMO and the Global Climate Observing System (GCOS), together with the Coordination Group for Meteorological Satellites (CGMS) and the Committee on Earth Observation Satellites (CEOS) continue to actively interact to ensure an efficient and optimized space-based component of the climate monitoring system.

WIGOS provides a framework for integration across national, organizational and technological boundaries, and across different levels of performance, utilizing reference and standard networks as well as crowd-sourced data. In a process called Rolling Review of Requirements, observing capabilities are assessed on a regular basis to ensure that the observing systems implemented by WMO members meet user requirements. CGMS and CEOS respond to WMO recommendations to fill gaps in the space-based observing system. WIGOS will be operational from 2020 onwards.

The majority of data is typically shared at no cost among WMO members and disseminated through a variety of communication channels, coordinated under the framework of the WMO Information System (WIS).

The WMO Space Programme, established in 2003, coordinates and supports the development of the space-based component of WIGOS and responds to the growing role that satellites play in WMO application programmes.

The Vision for WIGOS in 2040 outlines how the space-based observing system needs to evolve in the next two decades to keep up with growing user requirements.

New types of sensors, the growing number of satellites, including those deployed in constellations and formations, as well as new fields of applications and mounting bandwidth requirements for transmitting the data are among the factors that lead to a growing demand for frequency spectrum use for space sensing.

The importance of space systems for the direct benefits of citizens all around the world and for providing data and information in support of policy- and decision-making for sustainable development underlines the vital role of ITU for the global management of the radio-frequency spectrum and satellite orbits.

Close cooperation between WMO and ITU therefore remains absolutely essential to guarantee the availability and integrity of WIGOS and to ensure that the global observations of our Planet will continue to contribute to its sustainable development.

Karolin Eichler/Deutscher Wetterdienst/WMO

World Weather Watch (WWW)

To predict the weather, modern meteorology depends upon near instantaneous exchange of weather information across the entire globe. Established in 1963, the World Weather Watch – the core of the World Meteorological Organization (WMO) Programmes – combines observing systems, telecommunication facilities, and data processing and forecasting centres – operated by WMO Members – to make available meteorological and related environmental information needed to provide efficient services in all countries.

Read more here.

The importance of the radio spectrum for Earth observation

Eric Allaix

Chairman, Steering Group on Radio Frequency Coordination

The crucial and scarce resource of the radio-frequency spectrum underpins all Earth-observation activities, such as the collection and measurement of observational data, analyses and forecasts and alerts. These are vital to ensure the protection of people and property, and to monitor and anticipate climate and environmental change.

> *"Worldwide, repetitive and reliable coverage by space-based environmental monitoring systems is essential."*
>
> Eric Allaix

The main systems operated for Earth observation are weather radars (precipitation and wind profiler measurements), meteorological aids (radiosondes, dropsondes, rocketsondes) and satellites.

Active and passive sensors

For the latter, two categories of spaceborne remote sensing are normally used: active and passive sensors. The active sensor transmits and receives on board. It illuminates the target and measures the radiation reflected by it. Emission of a high power signal and detection of a very low level of signal, is therefore often made in the same satellite. The passive sensor is a receiver that targets very low intensity radiation of natural origin from the Earth-atmosphere system.

> *"Earth observation at the global level can only continue to develop through the use of the appropriate frequency bands."*
>
> Eric Allaix

Passive and active sensors use many observation techniques that cover a wide range of wavelengths of the electromagnetic spectrum, from gamma rays to radio waves. Those spectrum bands necessary for Earth observations are determined by the basic laws of physics and radiation. For example, only particular parts of the microwave spectrum are usable for Earth observations because they contain the absorption bands of either oxygen, water vapor or other atmospheric constituents. The radiation received by the satellite is assimilated into numerical weather analyses and prediction models to provide measurements such as temperature, humidity or liquid water content.

Microwaves — reaching through and beyond the clouds

A great advantage with microwaves is that, unlike infrared, it is possible to recover information through and beyond clouds. This is of considerable interest for Earth observation, because generally, almost two-thirds of the globe is covered with clouds. In addition to this possibility to observe the Earth whatever the weather, passive microwave sensor measurements can also be performed at any time of the day or night, because they are not measuring reflected light from the sun or moon. The lower radiation levels of natural microwave signals compared to infrared mean that it is technically much more difficult to perform such measurements from space, so although geostationary provide wider coverage by being further from the Earth, lower Earth orbit satellites are also essential.

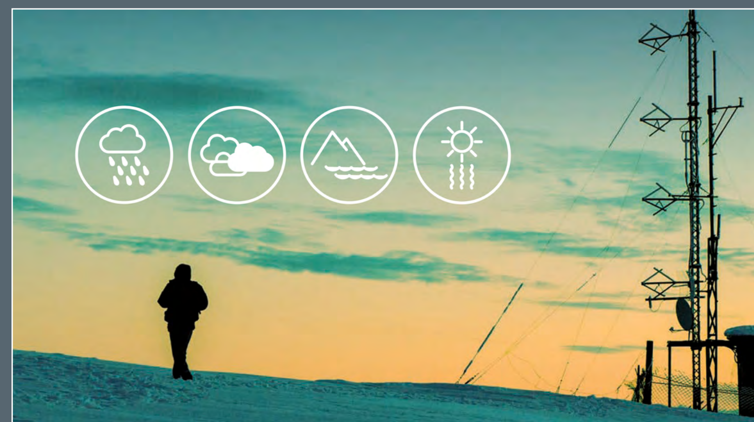
It should also be noted that the technique for measuring certain characteristics of the atmosphere and the surface of the Earth requires a combination of several measurements by diverse sensors at different frequencies. As such, any interference received by one sensor may corrupt multiple measurements.

The dataset collected by space-based Earth observation systems operating in the radio spectrum is playing an increasingly key role in environmental research and operations, in particular to limit the impact of weather- and climate-related disasters and for scientific understanding, monitoring and forecasting of climate change and its effects on our planet.

Ensuring Earth observation at the global level

Worldwide, repetitive and reliable coverage by space-based environmental monitoring systems is essential.

Handbook on Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction



Read more here.

It is of utmost importance to manage the frequency bands assigned to the various scientific and meteorological services in an efficient and informed manner in order to guarantee and improve the quality and precision of the meteorological products and applications resulting from these observations.

Almost all the information collected by Earth observation systems (three-quarters of these data are today provided by satellite) is made available worldwide. Owner or not of satellite networks or receiving stations in its territory, each Administration (ITU Member State), has access to the data necessary for the benefit of weather forecasts and measurements at the ocean's surface (wave height, sea surface temperature, salinity, thickness of sea ice, etc.), on land surface (water vapor, wind speed, rainfall intensity, tree density in forests, etc.) as well as all forms of research related to the impacts of climate change.

Earth observation at the global level can only continue to develop through the use of the appropriate frequency bands, conditioned by precise and unique physical properties that cannot be changed or duplicated in other frequency bands.

Radio spectrum are under increasing pressure from new and growing needs, but also from the high densification of uses, and the high sensitivity of passive sensors, which cannot differentiate the wanted signal from any interference signal received.

This is why the World Meteorological Organization and the International Telecommunication Union have renewed their cooperation agreement for the protection and optimum use of frequencies crucial for the observation of the Earth and its atmosphere, particularly in the context of the preparation of the 2019 World Radiocommunication Conference, which will consider agenda items of major interest to the scientific and meteorological communities.

This close collaboration has also enabled the updating of the Handbook on Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction. The manual is available in the six official languages of the United Nations, and provides comprehensive technical information on the use of radio frequencies by meteorological systems.

Altimetry from space

Jean Pla

Vice Chairman, ITU–R Study Group 7

Altimetry from space is a technique for measuring the altitude of the surface located under the satellite. A radar measures the time taken by a pulse to travel from the satellite antenna to the surface and back to the satellite receiver.

The received signals yield a wide range of information such as accurate measurements of the topography of the oceans in order to extract the precise altitude of the Earth's ocean surface or a better knowledge of the ocean circulation of the currents.

All these operations are made possible through the use of an instrument on board the satellite called "active sensor" which can provide continuous coverage (day and night) under any meteorological condition, irrespective of cloud coverage.

Satellites orbiting around the Earth offer an excellent viewpoint from where to sense the Earth's surface (land and oceans), the components of the Earth's atmosphere, as well as the polar regions.

Geostationary satellites offer continuous monitoring of a large area, while low orbiting polar satellites cover all the Earth at regular intervals.

> *"Measuring mean sea levels reveals vital clues about global warming."*
>
> Jean Pla

Altimetry satellites retrieve topographic maps of the oceans in order to have a precise knowledge of the mean average level of the oceans, to get a better view of the ice, and to get accurate level of land on the Earth and other planets.

Measuring mean sea levels reveals vital clues about global warming.

Table 1 shows the main past and current altimetry missions.

Table 1: Main characteristics of past and current space altimetry missions

Mission	Launch date	Centre frequency	Orbit
GEOSAT	1985, operation ceased in 1986	13.5 GHz	Sun-synchronous polar orbit, inclination 108.1°, altitude 757–814 km
ERS-1 and 2	1991,1995, operation ceased respectively in 2000, 2011	13.8 GHz	Sun-synchronous polar orbit, inclination 98.5°, altitude 780 km
TOPEX-POSEIDON	1992, operation ceased in 2005	13.575 and 5.3 GHz	Non-sun-synchronous circular orbit, inclination 66.039°, 1336 km altitude, 10-day repeat period
JASON-1	2001, operation ceased in 2013	13.575 and 5.3 GHz	Non-sun-synchronous circular orbit, inclination 66°, 1324 km altitude, 10-day repeat period
JASON-2	2008	13.575 and 5.3 GHz	Non-sun-synchronous circular orbit, inclination 66°, 1336 km altitude, 9.9-day repeat period
CRYOSAT-2	2010	13.575 GHz	Non sun-synchronous circular orbit, inclination 92°, 717 km altitude
HY-2A	2011	13.575 and 5.3 GHz	Sun-synchronous circular orbit, inclination 99.3°, 971 km altitude, 14-day repeat period
SARAL	2013	35.75 GHz	Sun-synchronous circular orbit, inclination 98.5°, 800 km altitude, 35-day repeat period
JASON-3	2016	13.575 and 5.3 GHz	Non-sun-synchronous circular orbit, inclination 66°, 1336 km altitude, 9.9-day repeat period
SENTINEL-3A	2016	13.575 and 5.3 GHz	Sun-synchronous circular orbit, inclination 98.6°, 815 km altitude, 27-day repeat period
SENTINEL-3B	2018	13.575 and 5.3 GHz	Sun-synchronous circular orbit, inclination 98.6°, 815 km altitude, 27-day repeat period

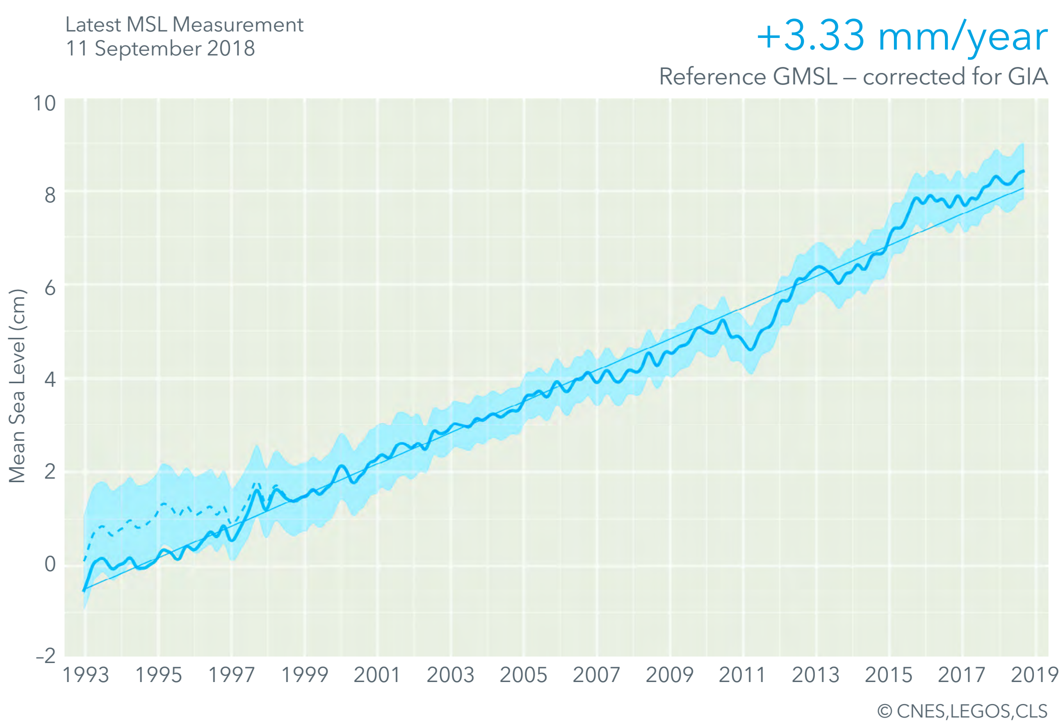
The altimeter is a radar operating at vertical incidence (Altimetry principle), and the signal returning to the satellite is very similar to a reflection off a smooth surface (specular reflection).

The exact position of the satellite is required through the knowledge of a precise orbit. Oceanographers require a relative height of the sea surface to geoid.

The radar altimeter will provide precise measurements of the distance from the satellite to the Earth's surface and also of the power and the shape of the returned echoes from ocean, ice and land surfaces.

The global mean sea level (GMSL) of the oceans is one of the most important indicators of climate change: GMSL is based on data from the TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 missions from January 1993 to present. GMSL is estimated as 3.3 mm/year (see Figure 1).

Figure 1: Mean sea level rise



> *It is now possible to predict El Niño from ocean data obtained by satellite.*
>
> Jean Pla

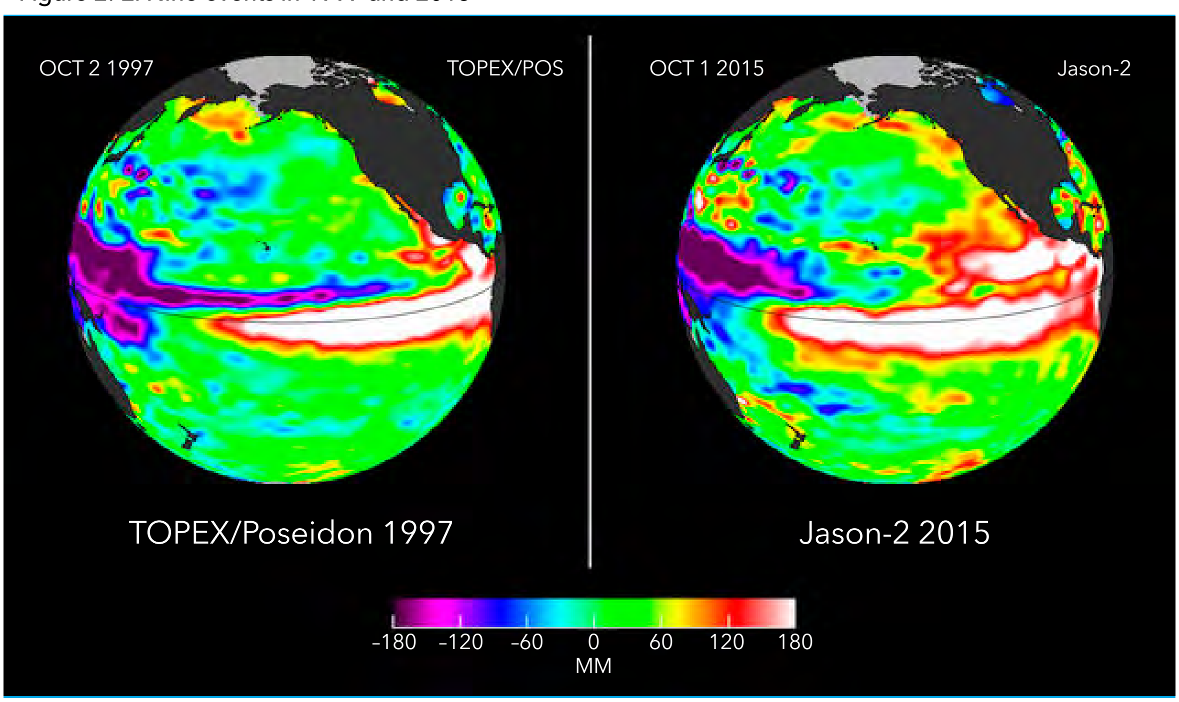
Predicting El Niño – now possible

El Niño represents an example of particular interest to South America. Better knowledge of ocean circulation is enabling us to better understand and predict the climate, especially natural catastrophes (drought, flooding, and cyclones) such as El Niño (an unusually warm pool of water off the west coast of South America, linked with complex, large-scale interactions between the atmosphere and ocean in the Pacific).

Figure 2 shows it is now possible to predict El Niño from ocean data obtained by satellite: a huge anomalous arrival of warm water can be seen on the coast of Peru in 1997 and 2015.

The sea level rise in excess caused by the El Niño phenomenon is widely beyond the mean sea level rise. During 1997, there was a local rise of about 20 cm of the sea level rise in the equatorial Pacific when the phenomenon was at its height (and as much as 30 centimeters off the coast of Peru).

Figure 2: El Niño events in 1997 and 2015



The Indian Ocean earthquake and tsunami disaster destroyed Banda Aceh City, Indonesia, on 26 December, 2004

Table 2: Future space altimetry missions

Name of the mission	Purpose	Orbit
CFOSAT	Direction, amplitude and wavelength of surface waves and measure wind speed	Sun-synchronous, altitude of 520 km, inclination of 97.4°
JASON-CS (Sentinel 6)	Accurate ocean surface topography, continuity with Jason-3	Non sun-synchronous, altitude of 1336 km, inclination of 66°
SWOT	Land hydrology and oceanography	Non sun-synchronous, altitude of 890.6 km, inclination of 77.6°

However, the meteorological effects of El Niño 1997–1998 were felt worldwide, and all these anomalies obviously had an effect on the global mean of sea level: in 1997, there was a global rise of 15 mm.

Altimetry and unexpected tsunami detection

An unexpected application of altimetry is tsunami detection. It was pure coincidence that in the early morning of 26 December 2004, within hours of the big earthquake in the Indian Ocean, two joint NASA/CNES satellites (Topex and Jason-1), ENVISAT an ESA satellite and GFO from NOAA detected, by chance, the tsunami across the Bay of Bengal.

Space agencies are preparing future space altimetry missions (see Table 2).

Passive bands atmospheric sensing and selection

Richard Kelley

Spectrum Manager, Alion Science and Technology, National Oceanic and Atmospheric Association (NOAA), United States Department of Commerce

Background on passive microwave remote sensing frequency bands

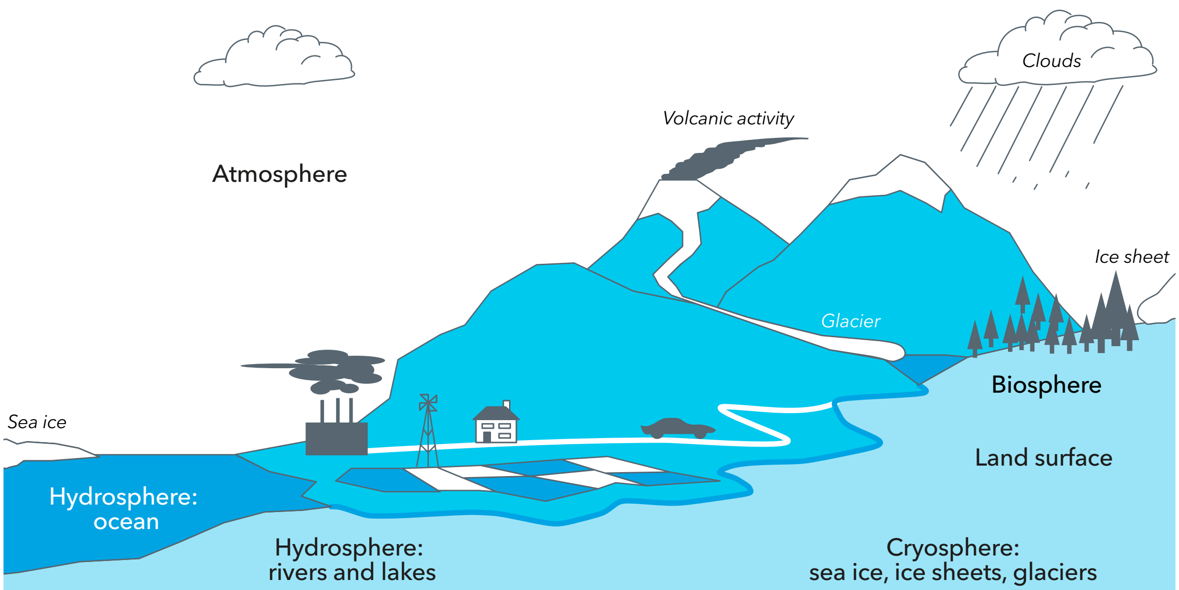
International and national regulatory organizations have set aside certain portions of the microwave spectrum for passive observational purposes. Passive remote sensing in microwave bands is the number one technique used to improve the accuracy of numerical weather prediction (NWP). This type of sensing is also important in determining the state of snow, ice and land surface on Earth.

Satellite-based sensors scan Earth, from the surface up through the air column to space. These sensors scan all of the Earth system components shown in Figure 1.

Countries benefit from passive microwave satellite technology, regardless of whether they own, operate, or launch satellites.

> *"International and national regulatory organizations have set aside certain portions of the microwave spectrum for passive observational purposes."*
>
> Richard Kelley

Figure 1: Earth system components observed by passive sensors



Source: Adapted from "Climate Change 2001: Working Group I: The Scientific Basis – The Climate System" – Intergovernmental Panel on Climate Change (IPCC)

The World Meteorological Organization's Severe Weather Forecasting Demonstration Project is improving the capacity of the National Meteorological and Hydrological Services to deliver improved forecasts and warnings of severe weather to save lives, protect livelihoods, and maintain property and infrastructure in least developed countries (LDCs) and Small Island Developing States (SIDSs) using the products of passive microwave systems.

Over 75 developing countries benefit, including those in Southern Africa, the South Pacific, Eastern Africa, South-East Asia, the Bay of Bengal (South Asia), Central Asia, West Africa and Eastern Caribbean.

This is done with contributions from global and regional meteorological centres and support from donors/partners.

In addition to weather forecasts, other passive microwave information is vital to the world. Much of this data is critical for long-term studies of the Earth's climate. Table 1 gives some examples of the important information provided by passive microwave systems.

Passive sensors continuously collect energy from the Earth within specific radio-frequency bands and transmit the data back to ground stations. These data reports are vital to administrations, providing them with valuable information required for the protection of life and property.

Table 1: Sample remotely sensed information	
1	Determining soil moisture content using active and passive sensors from space
2	Detecting oil spills for marine life and environmental preservation
3	Identifying forest stands and tallying their area to estimate forest supplies
4	Measuring wind speed and director for wind farms, weather forecasting and surfers
5	Forecasting weather to warn about natural disasters
6	Detecting land cover/use types for decision making
7	Observing the flow of ocean currents and circulation
8	Studying glacier melts and effects on sea levels
9	Tracking hazards for better response and recovery. The integration of Earth observation data and geographic information systems (GIS) in hazard situations has become a main tool in disaster management
10	Preventing the degradation and loss of wetland ecosystems
11	Comparing climatic factors from past to present
12	Providing early warning signs for famine over large scales

Source: WMO Severe Weather Forecasting Demonstration Project (SWFDP)

Passive sensor bands cannot move to other frequencies

Passive bands are determined based on the fundamental properties of the Earth and its atmosphere. No amount of engineering and funding can change these properties.

Passive sensors can determine vertical variation and horizontal distribution of temperature and moisture in the atmosphere, which are two key atmospheric variables. Several other physical parameters such as ice, liquid water, and sea state, determine the condition of the planet. Table 2 provides the links between frequency bands and these parameters.

Passive sensors operating in frequency bands

In general, atmospheric opacity is low at low frequencies and increases at higher frequencies, primarily due to water vapour absorption and increased absorption and scattering by clouds and precipitation. In addition, there are bands where absorption caused by different atmospheric gases is much higher, for example oxygen close to 60 GHz and water vapour close to 183 GHz. These characteristic frequencies arise from the rotational modes of these molecules and are fixed by molecular physics. These passive frequency bands are a protected, natural resource.

Table 2: Passive bands selected to monitor Earth system components below 275 GHz	
Frequency band (GHz)	**Physical parameter**
1.37–1.427	Soil moisture, ocean salinity, sea surface temperature, vegetation index
2.64–2.7	Ocean salinity, soil moisture, vegetation index
4.2–4.4	Sea surface temperature
6.425–7.25	Sea surface temperature
10.6–10.7	Rain rate, snow water content, ice morphology, sea state, ocean wind speed
15.2–15.4	Water vapour, rain rate
18.6–18.8	Rain rates, sea state, sea ice, water vapour, ocean wind speed, soil emissivity and humidity
21.2–21.4	Water vapour, liquid water
22.21–22.5	Water vapour, liquid water
23.6–24	Water vapour, liquid water, associated channel for atmospheric sounding
31.3–31.8	Sea ice, water vapour, oil spills, clouds, liquid water, surface temperature, reference window for 50–60 GHz range
36–37	Rain rates, snow, sea ice, clouds
50.2–50.4	Reference window for atmospheric temperature profiling (surface temperature)
52.6–59.3	Atmospheric temperature profiling (O_2 absorption lines)
86–92	Clouds, oil spills, ice, snow, rain, reference window for temperature soundings near 118 GHz
100–102	N_2O, NO
109.5–111.8	O_3
114.25–116	CO
115.25–122.25	Atmospheric temperature profiling (O_2 absorption line)
148.5–151.5	N_2O, Earth surface temperature, cloud parameters, reference window for temperature soundings
155.5–158.5	Earth and cloud parameters
164–167	N_2O, cloud water and ice, rain, CO, ClO
174.8–191.8	N_2O, Water vapour profiling, O_3
200–209	N_2O, ClO, water vapour, O_3
226–231.5	Clouds, humidity, N2O (226.09 GHz), CO (230.54 GHz), O_3 (231.28 GHz), reference window
235–238	O_3
250–252	N_2O

Source: Recommendation ITU-R RS.515 "Frequency bands and bandwidths used for satellite passive remote sensing".

> *"This data is used to create products for the global public such as environmental warnings and watches, coverage of disasters, and long-term studies of the Earth's climate."*
>
> Richard Kelley

Below 10 GHz, the atmosphere is almost completely transparent, even in the presence of clouds. This allows sensors operating below 10 GHz to directly sense the planet's surface.

At 10 GHz clouds and water vapour remain largely transparent, but heavy rain does attenuate, providing unique information about rainfall (other techniques are indirect).

At 18 GHz, the dielectric properties of seawater are such that energy collected by the passive sensors becomes almost independent of the sea surface temperature, but the wind induced ripples and waves change the emissivity, so wind information can be determined.

From 22–24 GHz, there is a weak water absorption line and by measuring this line, the measure total column water vapour can be determined. The 24 GHz band is strongly sensitive to total column water vapour and weakly sensitive to cloud liquid water.

At 31 GHz, liquid water attenuation provides liquid water content of clouds.

Although 24 GHz is referred to as a water vapour channel and 31 GHz as a cloud channel, in reality the loss of data from one channel also diminishes the value of both.

Oxygen absorbs energy between 50 and 60 GHz in several individual narrow bands (lines). Passive sensors operating in these bands provide temperature vertical profile information, showing how temperature changes at different atmospheric heights (vertical temperature profile).

A large number of channels is needed across this oxygen absorption spectral line complex to provide vertical profile information.

Above 60 GHz is the most important water vapour spectral line at 183 GHz. This line is sampled progressively further from the centre frequency to gain profile information. The effects of clouds are even stronger at 183 GHz than at 50 GHz so additional channels are needed to provide cloud information, in particular at 89 GHz, 150 GHz and 229 GHz.

There is also an important 118 GHz oxygen absorption line. The short wavelength allows for narrow sensor fields of view to detect small-scale features of extreme weather events such as hurricanes/typhoons.

The global benefit of environmental satellites

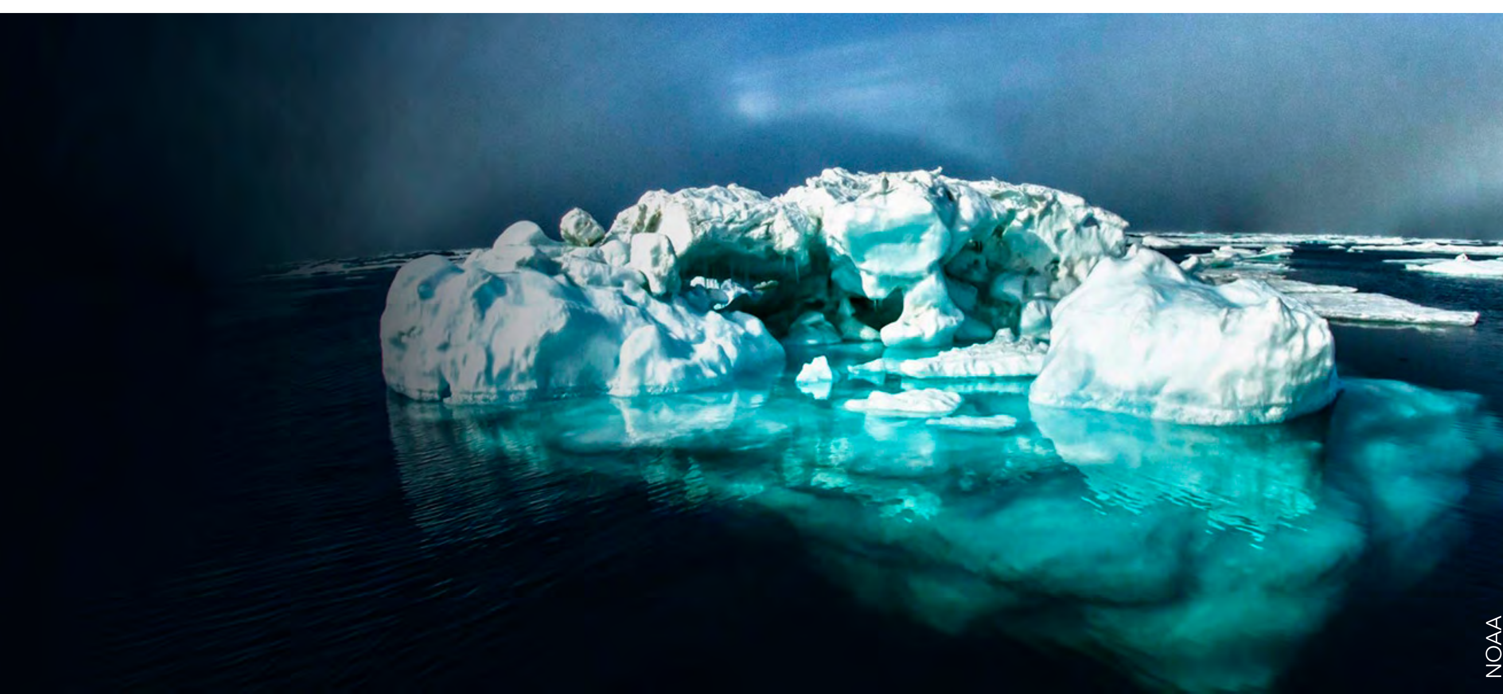
More than 100 national, multinational and international organizations sponsor environmental satellites, which provide satellite passive sensor data to many others. This data is used to create products for the global public such as environmental warnings and watches, coverage of disasters, and long-term studies of the Earth's climate.

The global weather community is the heaviest user of passive microwave data. Computer weather models use passive sensor data and data from other sources to create NWP products. Because the atmosphere changes second by second, the perishable passive data is rapidly downloaded and transmitted to NWP centres where it is ingested into the models. These computer forecasts cover different sized geographic areas from the whole globe down to small areas. The NWP forecasts are passed along to countries that don't yet have this capability.

Summary

On a worldwide basis, administrations have invested heavily in both the environmental satellite enterprise and related infrastructure dependencies. The use of these specific frequencies by passive sensors is critical to understanding the Earth and its atmosphere, and enables critical decisions based on the functions being observed.

The physical measurements of the planet's environment can only be made by using the current suite of passive frequency bands.



NOAA

Monitoring weather and climate from space – indispensable for our modern global society

Markus Dreis

Chairman of ITU-R Working Party 7C,
Frequency Manager, EUMETSAT

Our society is becoming more and more sensitive to the weather, and less tolerant of inaccurate weather observations, forecasts and warnings. Therefore, governments and industries demand continuous improvements in weather forecasts and warnings to be able to manage the growing risks, and the associated effects, from severe weather (e.g. floods, droughts, wildfires, pollution, etc.). Society is also calling for more and reliable weather information in real-time for economical and safety aspects, and even for private use. In this context, EUMETSAT observations are used by National Meteorological and Hydrological Services (NMHS) across the world, and contribute to meeting these requirements.

Weather forecasts also support economic growth, as our highly-developed economies are very weather sensitive in many areas of our modern life, e.g. transport, energy, agriculture, tourism, food, construction, etc. Consequently, the socio-economic benefits of forecasts and their constant improvement are proportional to the GDP of a country or a region.

> *"In our increasingly weather-dependent society, data from meteorological satellites have become vital for National Meteorological Services to forecast the weather at all ranges."*
>
> Markus Dreis

Today's weather forecasts require observations from space

In historical terms, satellite observations of weather and the climate are still very new. Only 20 years ago they had very little impact on Numerical Weather Prediction (NWP) systems. At that point in time, most of the data came from *in situ* measurements.

This has significantly evolved over the last 20 years in which satellite observations have become the most important element in NWP. Today, weather forecasts rely heavily on satellite observations and contribute for more than 70% of the improvement (reduction of errors) in day-1 forecasts (Figure 1).

Figure 1: Improvement of forecast skills due to meteorological satellites

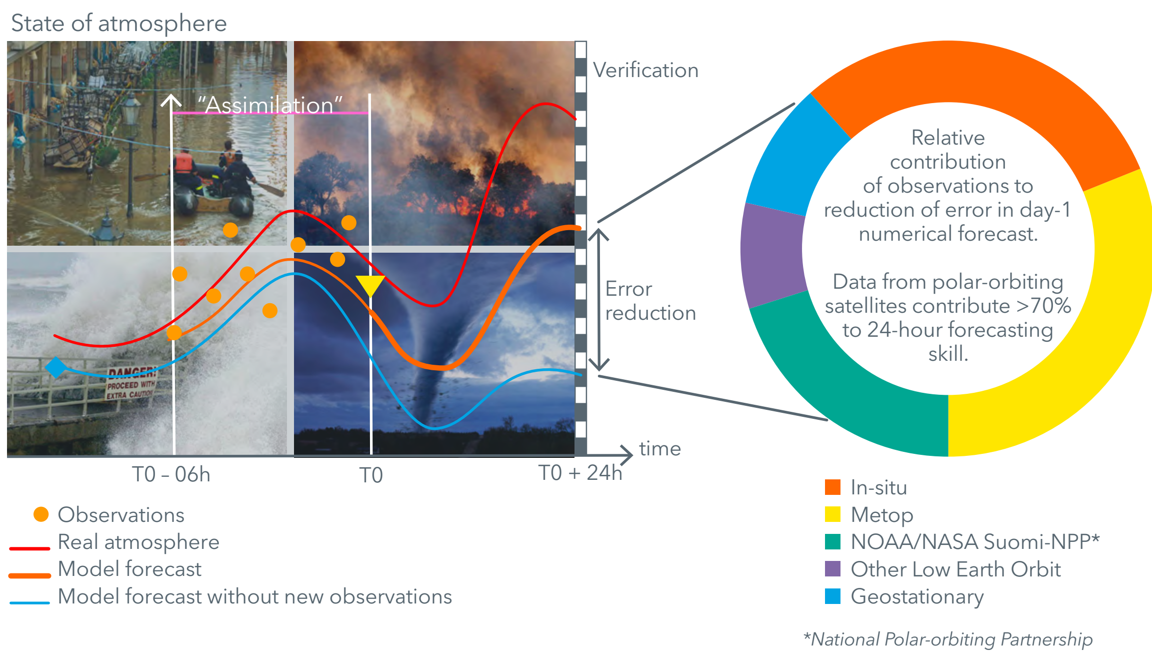


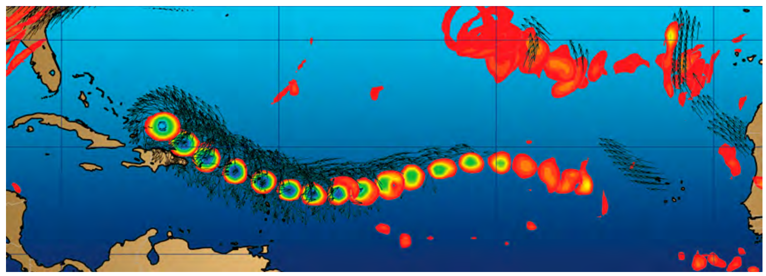
Figure 2 illustrates the contribution of meteorological satellites to forecasting without which valuable time would be lost to prepare for hazardous weather events, with their devastating impacts on society.

Improving Earth observation from space

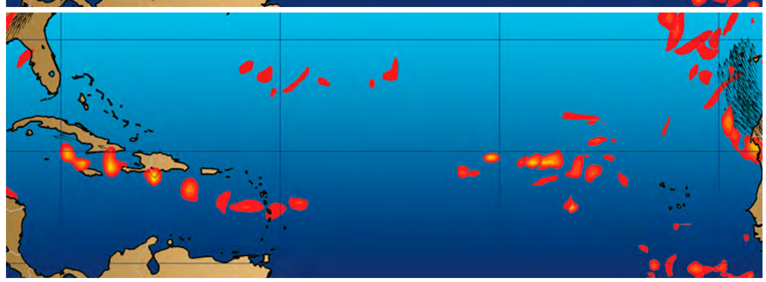
As this trend continues, satellite data will need to fulfil the requirements of innovative, very-high-resolution numerical weather prediction models that will be increasingly used by NMHSs, for very-short-range forecasts, in conjunction with real-time observations.

Figure 2: Contribution of meteorological satellites to forecasting, example: Hurricane Irma

(Example: Initial Joint Polar System (IJPS) of the United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA) and EUMETSAT polar-orbiting satellites)



The initial conditions, largely determined by satellite observations (top right, red), were essential for the ECMWF to forecast the development and trajectory of Hurricane Irma four days in advance. (Source: ECMWF)



Without satellite observations the model would have missed the initial development of Irma. (Source: ECMWF)

Therefore, more and further improved observations from space in terms of timeliness, resolution and volume are expected from organizations operating meteorological satellite systems, such as EUMETSAT, the European Organisation for the Exploitation of Meteorological Satellites.

To feed these prediction systems, EUMETSAT, like the other meteorological satellite operators, has a portfolio of satellites (Figure 3) on the geostationary orbit and non-geostationary low Earth orbits, with dedicated and complementary instruments on board. Based on the data provided by these satellites, there is a sustained, accurate and timely delivery of short to extended-range forecasts of weather, air quality, the ocean and the cryosphere, on regional to global scales. This is achieved with a seamless catalogue of global, regional and local observational products of the atmosphere, ocean, ice and land surfaces, including snow cover.

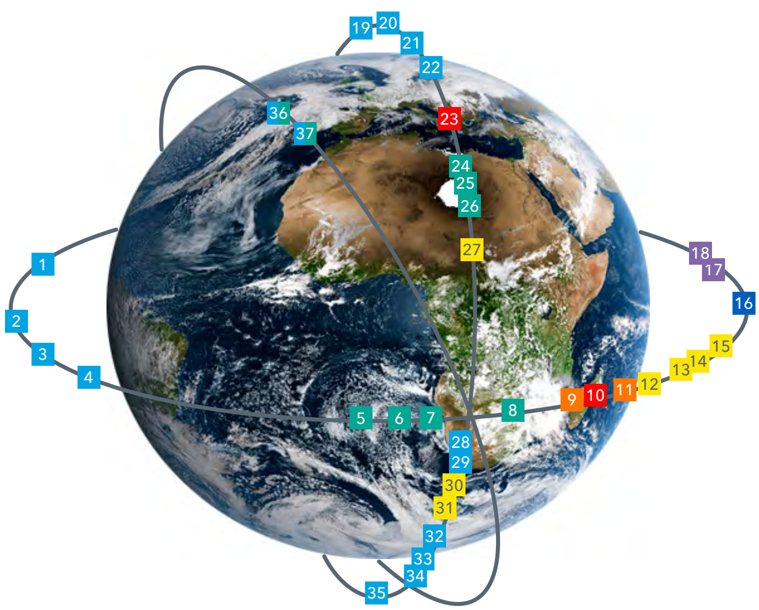
Building the longest climate records

Besides the permanent delivery of weather forecasts, meteorological satellites also build the longest climate records from space, with more than 35 years of meteorological satellite data. Essential climate variables (ECV) of the atmosphere, the ocean, the cryosphere and the land surfaces on a global scale are observed from space. Those climate data records are generated and regularly updated with data gathered from meteorological satellite operators like EUMETSAT. The resulting climate data records are inputs to climate information services in the framework of the World Meteorological Organization (WMO), and are supporting climate change initiatives.

Meteorological satellites feed the space-based component of the WMO Global Observing System

A global network of meteorological satellites on geostationary orbit and non-geostationary low Earth orbits, provide the space-based component of the WMO Global Observing System (GOS) (Figure 3).

Figure 3: Currently operational meteorological satellites



Geostationary meteorological satellites

1 GOES-15 (USA) 135°W
2 GOES-14 (USA) 105°W (stand-by)
3 GOES-17 (USA) 89.5°W (stand-by)
4 GOES-16 (USA) 75.2°W
5 METEOSAT-11 (EUMETSAT) 0°
6 METEOSAT-9 (EUMETSAT) 3.5°E (stand-by)
7 METEOSAT-10 (EUMETSAT) 9.5°E
8 METEOSAT-8 (EUMETSAT) 41.5°E
9 INSAT-3DR (INDIA) 74°E
10 ELECTRO-L N2 (RUSSIA) 76°E
11 INSAT-3D (INDIA) 82°E
12 FY-2E (CHINA) 86.5°E
13 FY-2G (CHINA) 105°E
14 FY-4A (CHINA) 105°E
15 FY-2F (CHINA) 112°E (stand-by)
16 COMS (SOUTH KOREA) 128.2°E
17 HIMAWARI-8 (JAPAN) 140.68°E
18 HIMAWARI-9 (JAPAN) 140.73°E (stand-by)

Non-geostationary meteorological satellites

19 DMSP-F17 (USA) ECT 06:20 descending
20 NOAA-15 (USA) ECT 06:30 descending
21 DMSP-F18 (USA) ECT 07:08 descending
22 NOAA-18 (USA) ECT 07:40 descending
23 METEOR-M N2 (RUSSIA) ECT 09:30 ascending
24 METOP-A (EUMETSAT) ECT 09:30 descending
25 METOP-B (EUMETSAT) ECT 09:30 descending
26 METOP-C (EUMETSAT) ECT 09:30 descending
27 FY-3C (CHINA) ECT 10:15 descending
28 NOAA-20 (USA) ECT 13:25 ascending
29 SNPP (USA) ECT 13:25 ascending
30 FY-3B (CHINA) ECT 13:38 ascending
31 FY-3D (CHINA) ECT 14:00 ascending
32 DMSP-F15 (USA) ECT 14:50 ascending
33 NOAA-19 (USA) ECT 15:44 ascending
34 DMSP-F16 (USA) ECT 15:50 ascending
35 DMSP-F14 (USA) ECT 17:00 ascending
36 JASON-2 (USA, EUROPE) 66° inclination
37 JASON-3 (USA, EUROPE) 66° inclination

(Status: October 2018, information source: CGMS)

Ensuring seamlessly available data from space

To ensure that data from space-based meteorological observations are seamlessly available on a global scale, the operators of meteorological satellites cooperate in providing a global network of meteorological satellites. To provide the necessary continuity of meteorological and climate data over decades, operational satellites have to be replaced by new satellites of the same series of meteorological satellites, or satellites of the next generation of meteorological satellites with increased observation capabilities and resolution (whilst still providing continuity in the observation data). The newer generation of satellites is designed with the latest evolution of instruments with an increasing number of measurement channels and incremented sensitivities and accuracies, necessary to comply with the demands from the meteorological user community. This requires dedicated investments in global infrastructure, in space, and on the ground, in order to optimize the benefits from this joint/coordinated effort with a limited number of meteorological satellite operators.

Meteorological satellites are equipped with visible and infrared imagers and sounders. The data provided by these instruments is used to derive many meteorological parameters. The polar-orbiting satellites are additionally equipped with active and passive microwave sensing instruments that provide, for example, vertical profiles of temperature and humidity of the atmosphere, information on the distribution of clouds, snow and ice cover, and ocean surface temperatures and winds on a global basis. These atmospheric variables are all known to play an important role in long-term climate change monitoring.

In addition to the instruments on board, meteorological satellites also carry data collection systems (DCS) which gather basic meteorological and environmental data for GOS from data collection platforms (DCPs) located anywhere in the world (*in situ* measurements for remote locations or buoys at sea). The information provided is being used in almost near real time for different environmental applications, like hydrology or seismology but also has a civil protection component such as a tsunami warning.

Meteorological satellites and the use of frequencies regulated in the framework of ITU

Meteorological satellites use and have to use many radio frequencies (governed by the ITU Radio Regulations) for the operation of the satellites, for a variety of instruments and for bringing the acquired data down to Earth for further processing and for distribution to the users. These frequency usages comprise:

- telemetry, telecommand and ranging of the spacecraft;
- active and passive microwave sensing;
- transmissions of observation data from meteorological satellites to main reception stations;
- re-transmissions of pre-processed data to meteorological user stations through meteorological satellites;
- direct broadcast transmissions to meteorological user stations from meteorological satellites;
- alternative data dissemination to users (GEONETCast) via other satellite systems than meteorological satellites (not in meteorological satellite (MetSat)/Earth-exploration satellite (EESS) allocated frequency bands);

- transmissions from data collection platforms through meteorological satellites;
- relay of search and rescue messages (COSPAS-SARSAT).

This large portfolio of radio-frequency usage requires that the radio-frequency spectrum resources allocated to the corresponding radiocommunication services in the Radio Regulations are kept available and protected from interference in the long term (in particular for passive sensing), which due to their sensitivity require particular recognition in the Radio Regulations.

Access to measurement data from meteorological satellites

Meteorological satellites deliver time critical data. Therefore, a key objective of a meteorological satellite is to deliver the data to its users with the shortest possible latency, with the highest level of availability and reliability. This requires offering a high level of data services at a minimal cost to users. These data services are provided by different means using radio frequencies. Besides the traditional mechanisms for data distribution directly through meteorological satellites to the users, the processed data are also distributed to users by alternative ways for data dissemination, i.e. GEONETCast, which is using the most efficient digital video broadcasting standards with an optimized management of available bandwidth to provide meteorological and climate data on a global basis through conventional geostationary satellites in the C- and Ku-Band. This service is responsible for the enhancement of the regional data services, achieving a latency of 15–30 minutes from the moment the measurement data are acquired by the instruments, until the data is broadcast to a network of ground stations.

Satellite data — increasingly vital for weather forecasting

In our increasingly weather-dependent society, data from meteorological satellites have become vital for national meteorological services to forecast the weather at all ranges, and to produce timely warnings and other information that support public and private decision making for our social and economic wellbeing.

The exploitation of these meteorological satellites relies on the interference-free availability of the necessary frequency resources (ensured by the appropriate provisions in the Radio Regulations) for the control of the satellites, the operation of a number of microwave instruments for active and passive sensing, and the timely distribution of the data directly from the satellites, or through alternative means of data distribution using other radiocommunication services.

The need for a coordinated long-term response

Weather and climate monitoring are global challenges. They require a coordinated, long-term response based on strategic investments in large infrastructure, in space and on the ground, for the benefit of human society. To achieve this goal, it is also necessary to ensure that the frequency spectrum required for the operation of meteorological satellites and its microwave instruments are kept available, and free of interference. This requires the support of radiocommunication administrations globally.

■

Active spaceborne sensing for Earth study and natural disaster prediction

Bryan Huneycutt

ITU remote sensing delegate,
Jet Propulsion Laboratory, California Institute of Technology, NASA

Space provides an ideal vantage point from which to study the Earth. Spaceborne Earth-orbiting active sensors are used to remotely study the Earth's land, ocean surface and atmosphere. They can be used to detect and monitor natural disasters such as hurricanes, floods, fires, and mudslides, and provide valuable information for response and recovery efforts.

These spaceborne active sensors (see sidebar 1) obtain information by transmitting radio waves and then receiving their reflected (backscattered) energy. Fourteen frequency bands, spanning from 432 MHz to 238 GHz, are allocated to the Earth exploration-satellite service (EESS) (active) for use by spaceborne active sensors. These frequency allocations were obtained by working through the ITU Radiocommunication Sector (ITU–R) and World Radiocommunication Conferences (WRCs).

"Space provides an ideal vantage point from which to study the Earth."

Bryan Huneycutt

1 Active sensors

Active sensors use both a transmitter and a receiver. They transmit a signal in the direction of the target to be investigated. Then they detect and measure the backscatter signal. Passive sensors do not have a transmitter. They are pure receivers that detect naturally occurring radiation (e.g., sunlight) that is reflected from the observed object.

Synthetic aperture

3

Synthetic aperture is created by recording the backscatter signal along the radar flightpath. The data is processed by the SAR algorithm into an image, thereby synthesizing a virtual aperture much longer than the physical antenna length.

The ITU Radiocommunication Sector – protecting frequency bands against harmful interference

The ITU–R performs sharing studies to ensure that proposed new systems will not introduce harmful Radio Frequency Interference (RFI) into frequency bands currently in use. RFI can corrupt the active sensor's backscattered signal, which usually returns at a very low level just above the receiver noise.

For instance, the possible introduction of wireless access systems including radio local area networks (WAS/RLANs) (see side bar 2) into the frequency range 5350–5470 MHz, currently allocated on a primary basis for spaceborne active sensors, is an active area of study within the ITU–R for the World Radiocommunication Conference 2019 (WRC-19).

Five key active spaceborne sensor types

The active spaceborne sensor types studied in the ITU–R as part of the EESS (active) are: synthetic aperture radars (SARs), altimeters, scatterometers, precipitation radars (PR), and cloud profile radars (CPR).

WRC-19 Agenda Item 1.16

2

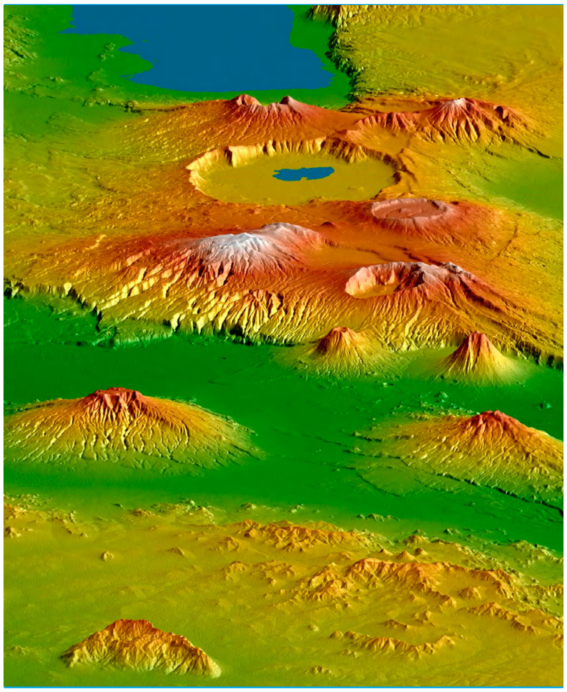
WRC-19 Agenda Item 1.16 concerns, in part, the possible introduction of WAS/RLANs into the frequency range 5350–5470 MHz. As of yet, ITU–R studies have not identified an effective mitigation technique for preventing harmful RFI to spaceborne active sensors from WAS/RLANs.

Synthetic aperture radars provide images and topographical maps

Due to their all weather, day-and-night imaging capability and sensitivity to changes as small as a few centimeters, synthetic (see sidebar 3) aperture radars (SARs) have been successfully used worldwide to respond to disasters including oil spills and earthquakes. The Shuttle Radar Topography Mission (SRTM) used a JPL/NASA 5-GHz SAR to obtain high-resolution digital elevation maps of the Earth's surface.

Figure 1 shows the SRTM SAR image taken in 2000 of the Crater Highlands along the East African Rift in Tanzania.

Figure 1 (SAR): NASA's SRTM image of the Crater Highlands, Tanzania



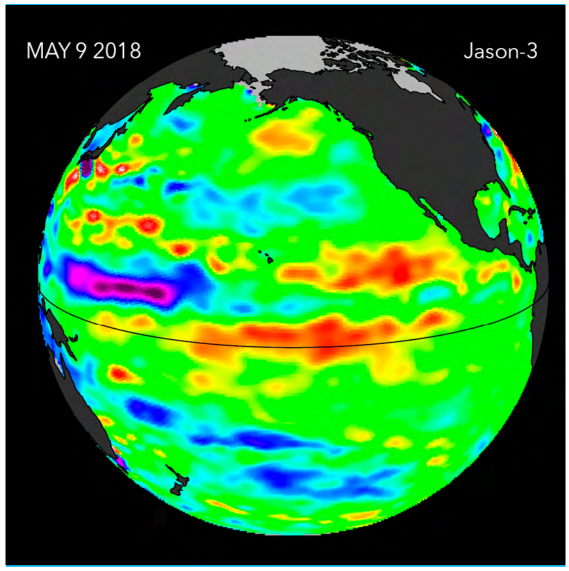
SAR sensors look to one side of the nadir (see sidebar 4) track, collecting a phase and time history of the coherent radar echo. From this information a fine resolution radar image or interferometric topographical map of the Earth's surface is produced.

Altimeters provide altitudes and sea level heights

The Jason-3 altimeter uses dual frequencies in the EESS (active) allocations around 13.6 GHz and 5.3 GHz to image the sea level height. Figure 2 shows a May 2018 image taken as Jason-3 traveled eastward through the tropical Pacific Ocean. The Kelvin wave (red) shown at the equator is often a precursor to an El Niño (see sidebar 5) event. By understanding the patterns and effects of climate cycles such as El Niño, it may be possible to predict and mitigate the disastrous effects of floods and drought.

The altimeter sensors look in the nadir direction, measuring the precise time between a transmit and receive event to extract the precise height of the sea level.

Figure 2 (Altimeter): NASA's JASON-3 image of sea level height



Nadir

4

Nadir is the point on the celestial sphere directly below a given position or observer. It is opposite the zenith.

El Niño

5

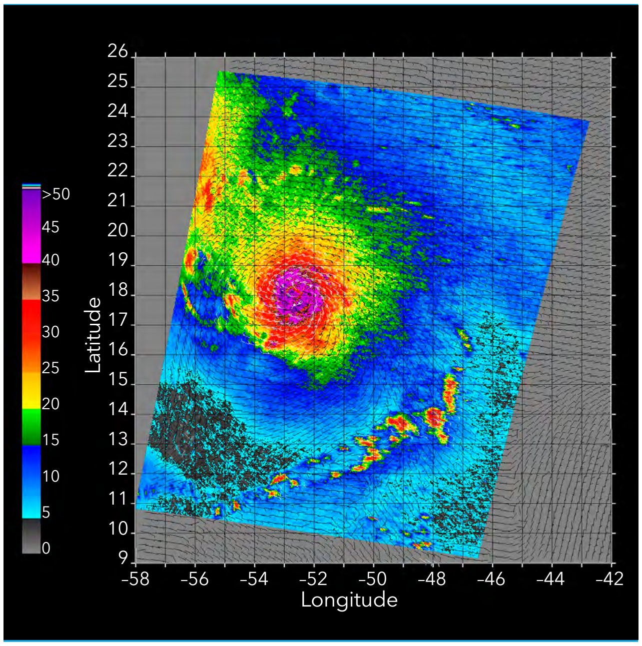
Southern Oscillation (ENSO) refers to the cycle of warm and cold temperatures, as measured by sea surface temperature of the tropical central and eastern Pacific Ocean. El Niño is the warm phase of ENSO and La Niña is the cool phase. Both El Niño and La Niña, cause global changes of both temperatures and rainfall.

Scatterometers provide ocean surface wind speeds and direction

The 13 GHz SeaWinds scatterometer onboard NASA's QuikSCAT satellite collected the data used to create an image of hurricane Frances as it approached Cuba in September 2004. Figure 3 uses pseudo-color to show the near-surface wind speeds and black barbs to indicate wind speed and direction.

Scatterometer sensors look at various aspects to the sides of the nadir track, measuring the return echo power variation with aspect angle to determine the wind direction and speed on the Earth's ocean surface.

Figure 3 (Scatterometer): NASA's SeaWinds image of Hurricane Frances



Precipitation radars provide rainfall rates in the tropics

The Global Precipitation Measurement (GPM) Dual-Frequency Precipitation Radar (DPR) uses the 13.6 GHz and 35.5 GHz frequency bands to create a 3D view of the rainfall rates and structure of the precipitation.

Figure 4 shows a 3D view of the Super Typhoon MANGKHUT structure as it headed towards the Philippines in September 2018. This GPM DPR's 3D cross-section shows the heights of storm tops and the intensity of downpours in MANGKHUT's eye wall and other rain bands.

Figure 4 (Precipitation Radar): NASA's GPM image of Super Typhoon MANGKHUT

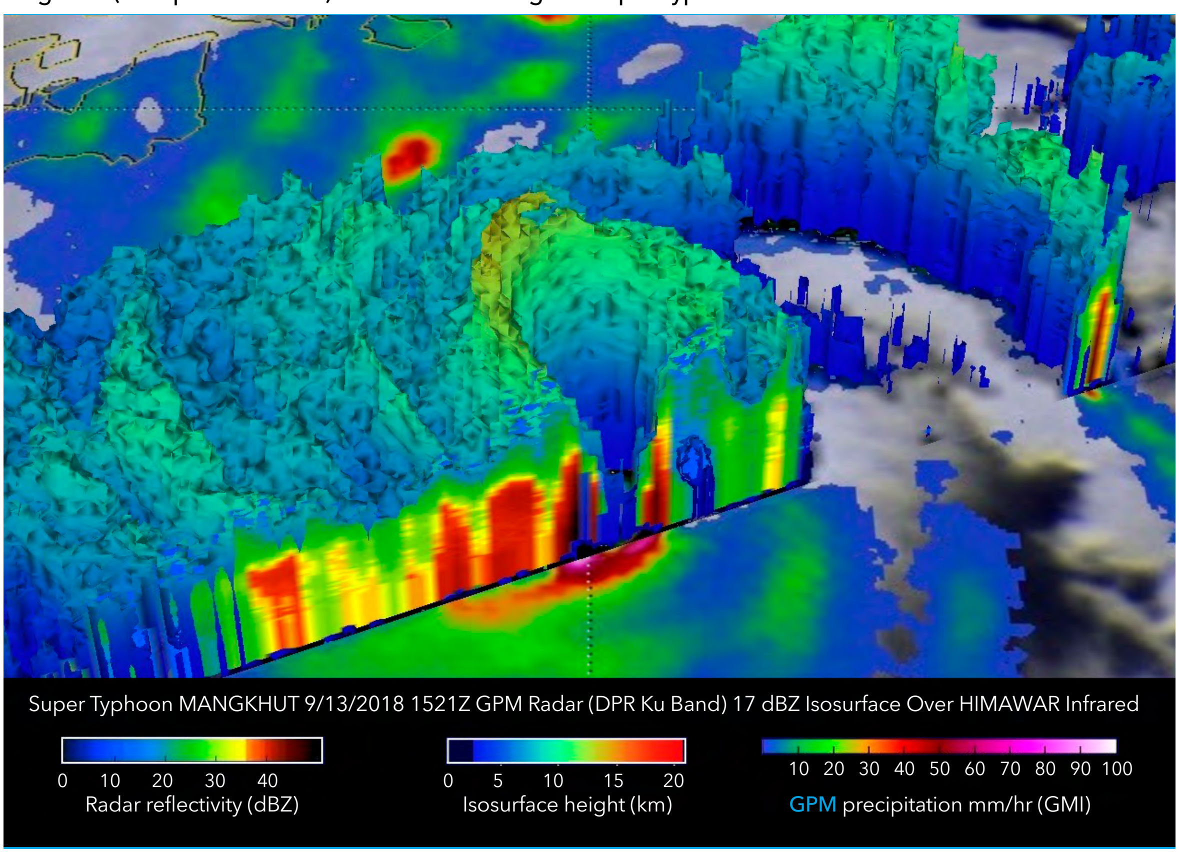
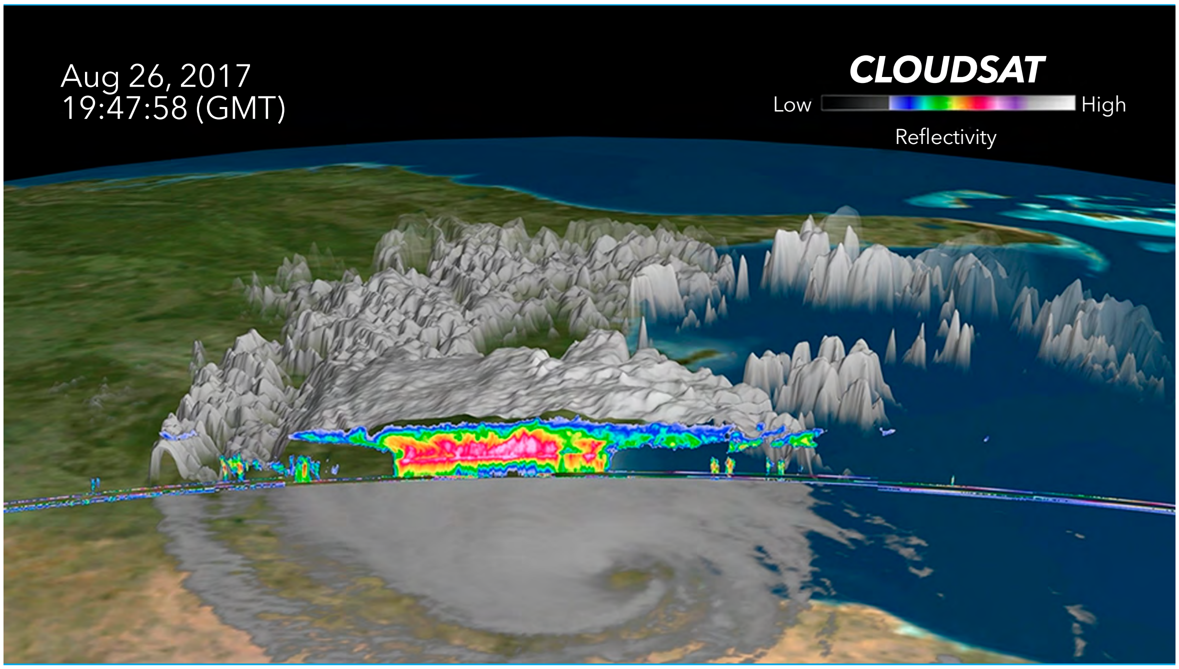


Figure 5 (Cloud profiling radar): Tropical Storm Harvey measured by CloudSat's radar in August 2017



Precipitation radar sensors scan perpendicular to the nadir track, measuring the radar echo from rainfall to determine the rainfall rate over the Earth's surface, typically concentrating on the tropics.

Cloud profile radars provide three-dimensional cloud reflectivity profiles

The JPL/NASA CloudSat satellite supports a 94 GHz radar to profile clouds across the Earth's surface, including profiles of hurricanes and severe storms. Figure 5 shows a vertical profile through the deep clouds of Tropical Storm Harvey measured by CloudSat's radar in August 2017.

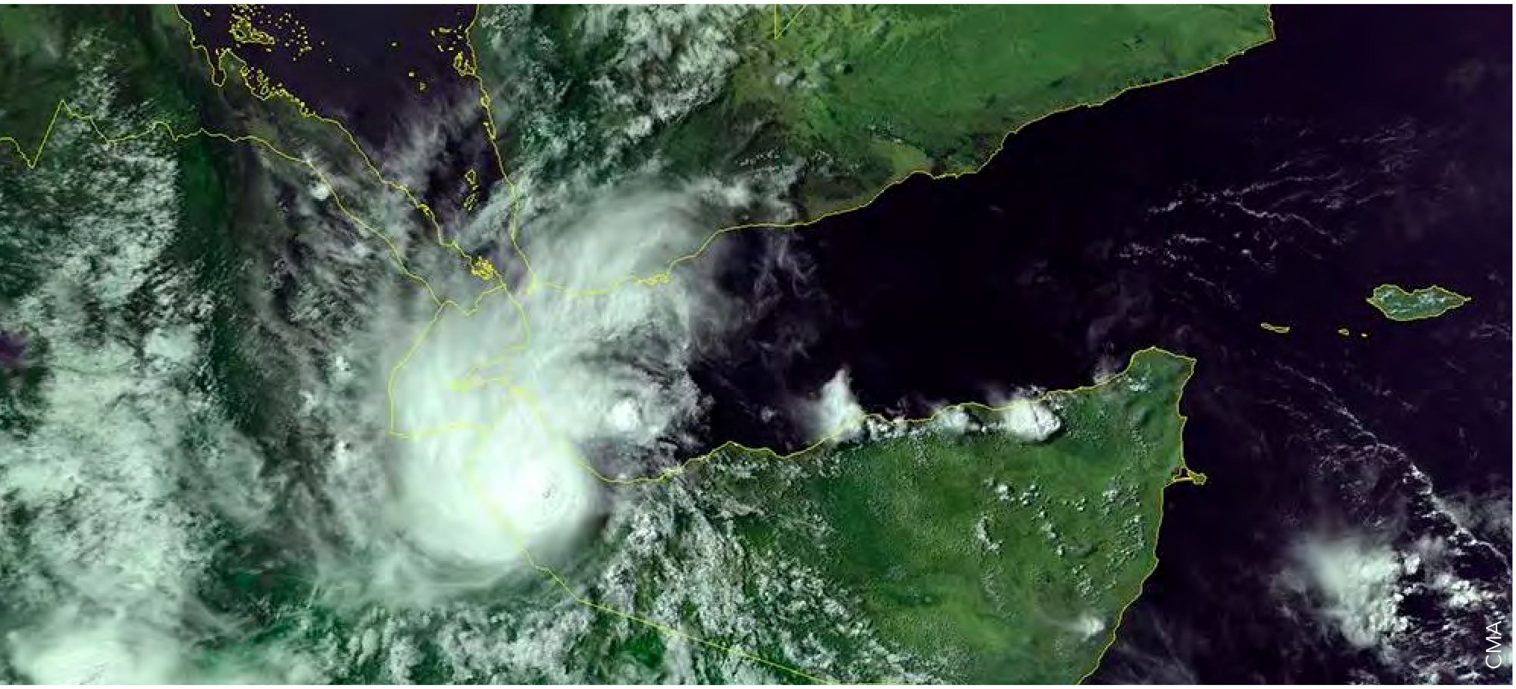
The CloudSat image shows a curtain-view of what the clouds along the red line in the top image from NASA's Aqua satellite looked like.

Cloud profile radar sensors look in the nadir direction, measuring the radar echo return from clouds to determine the three-dimension cloud reflectivity profile over the Earth's surface.

The importance of spaceborne Earth-orbiting active sensors for predicting disaster and improving quality of life

Spaceborne Earth-orbiting active sensors serve an important role in our understanding of our home planet. These sensors have revolutionized our ability to measure and observe the Earth, are enabling a better understanding of the Earth as a complete system, and will help us predict disasters and improve quality of life in the future.

Note: The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.



In May, 2018, the FY-3B satellite monitored the first cyclonic storm Sagar over the North Indian Ocean, National Satellite Meteorological Center

How passive remote sensors are used to predict the weather

Yu Yang

Engineer, National Satellite Meteorological Center,
China Meteorological Administration (CMA)

Remote sensing systems, which measure energy that is naturally available, are called "passive sensing systems". Passive sensing can only be used to detect energy when the naturally occurring energy is available, and the frequency for passive sensing depends on the physical characteristics. That means each frequency band of a passive sensing system can only be used to investigate one physical characteristic, such as temperature, or humidity, for example.

> *"Weather forecasts are made by collecting as much data as possible about the current state of the atmosphere."*
>
> Yu Yang

Many of these physical characteristics provide valuable information for Meteorology and Oceanography, for weather forecasting, climate predicting and environmental monitoring.

There are three main types of passive sensors: imaging sensors, atmospheric sounding sensors and microwave limb sounding sensors.

Imaging sensors

Imaging sensors can obtain environmental data produced using multivariable algorithms to retrieve a set of geophysical parameters simultaneously from calibrated multi-channel microwave radiometric imagery.

Atmospheric sounding sensors

Atmospheric sounding sensors measure the vertical distribution of the atmosphere's physical properties, such as pressure, temperature, wind speed, wind direction, liquid water content, ozone concentration, pollution, and other properties.

Microwave limb sounding sensors

Microwave limb sounding sensors observe the atmosphere in directions tangential to the atmospheric layers, and are used to study the low to upper atmosphere regions, where intense photochemistry activities may have a big impact on the Earth's climate.

Numerical prediction — Today's weather forecasting systems

By using the limited frequency band of a passive sensing system, passive sensors provide a way and the capability to get all-weather, whole day, and global observations of the Earth and its atmosphere. This observation data is the most important part to be assimilated in the Numerical weather prediction (NWP) system, which is the most popular method to make weather forecasts.

Numerical weather prediction predicts the weather using "models" of the atmosphere and computational techniques. Numerical weather prediction models take the data as the starting point to evaluate the state of the atmosphere forward in time, using physics and fluid dynamics equations.

The partial differential equations used in the guidance are supplemented with parameterizations for turbulent diffusion, radiation, moist processes, heat exchange, soil, vegetation, surface water, and the kinematic effects of terrain.

The complicated equations that govern how the state of a fluid changes with time require supercomputers to solve them. Nowadays weather forecasting is the application of current science-based technology on numerical weather prediction, to predict the state of the atmosphere for a future time and a given location.

Data – key to numerical weather prediction (NWP)

Nowadays, weather forecasts are made by collecting as much data as possible about the current state of the atmosphere, particularly the temperature, humidity and wind, and use the understanding of atmospheric processes through meteorology to determine how the atmosphere will evolve in the future. The data from passive sensors therefore provides input for numerical weather prediction equations such as atmospheric pressure, temperature, wind speed, wind direction, humidity, and precipitation. This data is the key to current weather forecasts.

Protecting passive sensing bands at the World Radiocommunication Conference

Passive sensors are designed in a way similar to radio astronomy instruments, which detect emissions having very low power. Interference is a problem for each passive sensing instrument. Fortunately, ITU has already developed a number of recommendations in this regard, and will address the issue of the protection of the use of passive sensing bands at the forthcoming World Radiocommunication Conference 2019.

"ITU has already developed a number of recommendations... and will address the issue of the protection of the use of passive sensing bands at the World Radiocommunication Conference 2019."

Yu Yang

Protect Earth observation sensor spectrum for societal good

Gilberto Câmara

Secretariat Director, Group on Earth Observations (GEO)

Satellite data is essential for a wide range of decision-making processes that protect and preserve our environment and communities. Satellites provide input data for numerical weather prediction, measuring the Earth's radiation budget and ozone depletion, estimating groundwater resources, tracing ocean dynamics, and evaluating terrestrial and marine productivity.

"Satellite data is essential for a wide range of decision-making processes that protect and preserve our environment and communities."

Gilberto Câmara

Sustainable development is a long-term process. To support the production of indicators for the United Nations' Sustainable Development Goals (SDGs), we need multi-satellite, long-term analysis-ready data sets. Long-term data sets are essential for projecting future trends, and big multi-sensor analysis-ready data sets are a major requirement for using Earth observations to support the SDGs.

Radio frequency bands — critical for Earth observation

Radio frequency has been an important issue for Earth observation, in particular when frequency bands are critical to observe the Earth's physical parameters by passive sensors. In the case of conflict of spectrum allocation between Earth observations sensors and commercial services, dedicated spectrum should be protected so information from sensors can be relayed without interruption or corruption. As the work of the Group on Earth Observations (GEO) community shows, there are hundreds of use-cases for satellite data that demonstrate the potential impact that sustained and quality data, enabled by appropriate spectral allocations, can have on environmental and development objectives.

The GEO Global Agricultural Monitoring Initiative (GEOGLAM) uses data from several spaceborne sensors to combat food insecurity and food price volatility. Land use maps are created using optical and radar data (MODIS, Landsat, RADARSAT-2, ALOS-2, TerraSAR). Agricultural information relies on key datasets from precipitation, surface temperature, soil moisture, evapotranspiration, and runoff require non-optical passive and active spaceborne sensors (GPM, SMAP and SMOS) that need spectrum protection.

Contributing to SDG 6: Clean water and sanitation

The Integrated Flood Analysis System of International Centre for Water Hazard and Risk Management (ICHARM) contributes to SDG 6 (Clean water and sanitation) and the Sendai Framework for Disaster Risk Reduction, by enabling better flood forecasting using rainfall data (GSMaP) gathered from satellites and ground stations to estimate runoff conditions. GSMaP is near-real-time global rainfall map produced by microwave radiometer data, thermal infrared data and other meteorological data.

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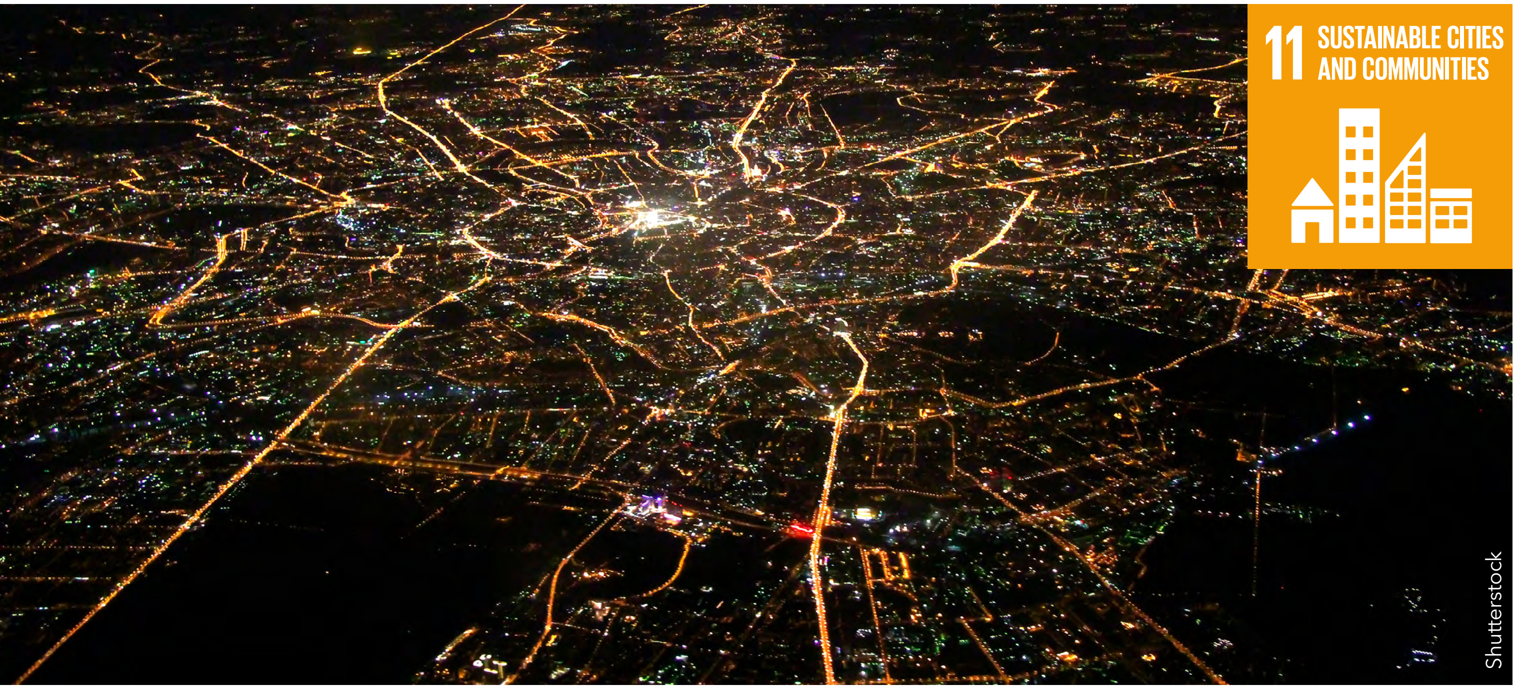


Shutterstock

Monitoring urban growth – SDG 11: Sustainable cities and communities

The Global Human Settlement Layer (GHSL), a product of GEO's Human Planet Initiative, enables decision makers to monitor urban growth in line with SDG 11 (Sustainable cities and communities), by providing global spatial information on human settlements over time, including built up area, population density and settlement maps. This information is produced by radar sensors (Sentinel-1, Envisat) and optical sensors (Landsat and Sentinel-2). Radar sensors provide all-weather monitoring, enabling better analysis in tropical and other areas where cloud cover poses a challenge for optical sensors.

The Global Climate Observing System (GCOS) specifies Essential Climate Variable (ECV) datasets which provide the empirical evidence needed to understand and predict the evolution of climate, to guide mitigation and adaptation measures, to assess risks and enable attribution of climate events to underlying causes, and to underpin climate services. They are required to support the work of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). Currently, more than half of the 55 ECVs benefit substantially from satellite observation.

The importance of protecting Earth observation data

These are just a few of many applications of remotely sensed Earth observation data being employed by the GEO community. As an immensely valuable societal resource, protection of this data should be a key objective of governing bodies. Possible conflicts between required spectrum for Earth observations and requests from commercial services and other users need to be managed to protect continuous and reliable data flows for researchers and decision makers, in order to support better policies for the public good.

The interference problem for passive sensing on a global scale

Josef Aschbacher

Director of Earth Observation Programmes,
European Space Agency (ESA)

This article addresses how interference by other radio-frequency services may impact passive microwave remote sensing and consequently important Earth-observation applications that depend on these measurements. It also addresses the importance of the appropriate provisions in the Radio Regulations (RR) to prevent harmful interference. Other articles in this edition of the ITU News Magazine cover the importance of spectrum, the role of Earth observation, the specificity of passive remote sensing and the international nature of this service.

Passive sensors use a limited numer of bands identified in the RR on the basis of the nature of the emissions from land, atmosphere or ocean, spectrally located in a wide range from ~1 GHz to ~1 THz. They measure the background natural radiative emission floor, therefore any man-made signal (e.g. communications, radars) that rises above this natural emission floor will likely interfere with the measurements. This interference can be tolerated only if its energy is well below the sensor sensitivity.

> *"On the WRC-19 agenda there are four items addressing possible unwanted emissions into passive sensing bands."*
>
> Josef Aschbacher

Given the extremely low levels of the natural emissions, even very low levels of radio-frequency interference (RFI) may degrade the passive sensor measurements.

The market needs are leading to an increasing number of commercial applications with their associated spectrum needs, covering not only the already congested ranges in the radio-frequency (RF) spectrum but also higher frequencies. This situation is becoming a serious concern to ensure protection of critical Earth observation (EO) applications.

Economical and societal impact of harmful interference to passive remote sensing

Operational and research applications in Earth sciences require worldwide measurement areas on a number of frequency bands allocated to the Earth exploration satellite service, EESS (passive). Passive microwave measurements have also emerged as a key contributor to numerical weather prediction (NWP), and are critical to other applications such as climate monitoring and prediction, hydrology, land and agriculture management, natural disaster (e.g. floods, earthquakes, volcanic activity) prediction and management, and many other fields of public and private interest. There are multiple EESS (passive) bands that are critical to operational systems. If passive sensing observations are lost due to interference from man-made sources, there are no alternative bands or techniques that can be employed. Consequently, the corruption of measurements due to interference will underpin the performance of warning systems based on highly strategic numerical prediction systems.

This would set back current and emerging capabilities, with the associated loss in the investments of governments, space agencies and commercial entities.

Special needs of passive remote sensing

If the RFI level is well above the plausible natural emission level, the interference can be detected and the measurements discarded. This will create gaps in the sensor coverage, limiting the capability to understand the complex global phenomena under study as well as any local events. However, if the interference level is lower and the resulting measurements are plausible, the interference may go undetected and then corrupted data will be mistaken for valid data. The analysis of these corrupted data will be seriously flawed.

Most passive sensors cannot discriminate between natural and man-made radiation, and data errors cannot be detected and/or corrected. For example, in meteorology (short- and medium- weather forecast) this would result in a reduction of the quality factor associated with these satellite measurements, representing a step back in the otherwise very successful history of satellite meteorology. Maintaining data integrity therefore depends upon the prevention of harmful interference created by man-made sources by defining, applying and enforcing the appropriate provisions in the Radio Regulations.

The protection of passive remote sensing in the Radio Regulations

In the mid 90's, the first ITU Radiocommunication Sector (ITU–R) Recommendations (technical standards) dealing with the interference protection criteria for space sensors were approved. Since the terrestrial systems were concentrated on low frequency bands, limited attention was given to how active services should be operated to avoid those active services exceeding the protection criteria and causing harmful interference to passive sensors. The first explicit regulatory limitations to protect the sensors came only from 2000 onwards, with protection of the 18.6–18.8 GHz band, for example. It took some time before key concepts in the RFI assessments were accepted and considered in sharing and compatibility analysis. They include the concepts of aggregate effect of multiple interferers, the impact of unwanted emissions of services in adjacent bands, and the apportionment of the RFI budget amongst multiple types of interferers.

Today the performance and interference criteria for passive sensors are contained in Recommendation ITU–R RS.2017.

The increasing problem of harmful interference to passive sensors

Despite regulatory improvements, recent images derived from the operation of passive sensors have shown an increasing number of RFI events. In particular, harmful interference is experienced in bands identified under RR No. 5.340, which prohibits all emissions in multiple passive bands.

This is due to:

- The explosion in the number and types of spectrum active users;
- The capability by active RF devices to operate at ever-higher frequencies (e.g. Ka, Q, V, W band) that used to be occupied only by passive sensors;
- The proliferation of unlicensed low-cost devices whose compliance with the RR is not always guaranteed or enforced.

The RFI experienced by passive sensors typically originates from terrestrial emitters dispersed over the Earth's surface at global level. Most sensors do not allow the localization of the interferers, especially if the RFI comes from the aggregation of multiple small interferers. They only allow identifying large areas affected by harmful interference, often covering multiple countries. Little can be done in this case to protect the sensors. Adjusting the limits on active services in the RR requires time and has effect only after many years from the discovery of the interference problem, hence it is important to define proper limits right from the beginning.

For the few radiometers that allow some form of localization of the interference source, Recommendation ITU–R RS.2106 facilitates the reporting and resolution of RFI cases impacting passive sensors. In comparison with the multiple RFI cases reported by terrestrial and space communication systems, the interference problem for passive sensors is being under-estimated since many RFI cases go unreported to the administration with jurisdiction in the territory where the RFI source is located, and to the ITU Radiocommunication Bureau.

An example of interference: The SMOS experience

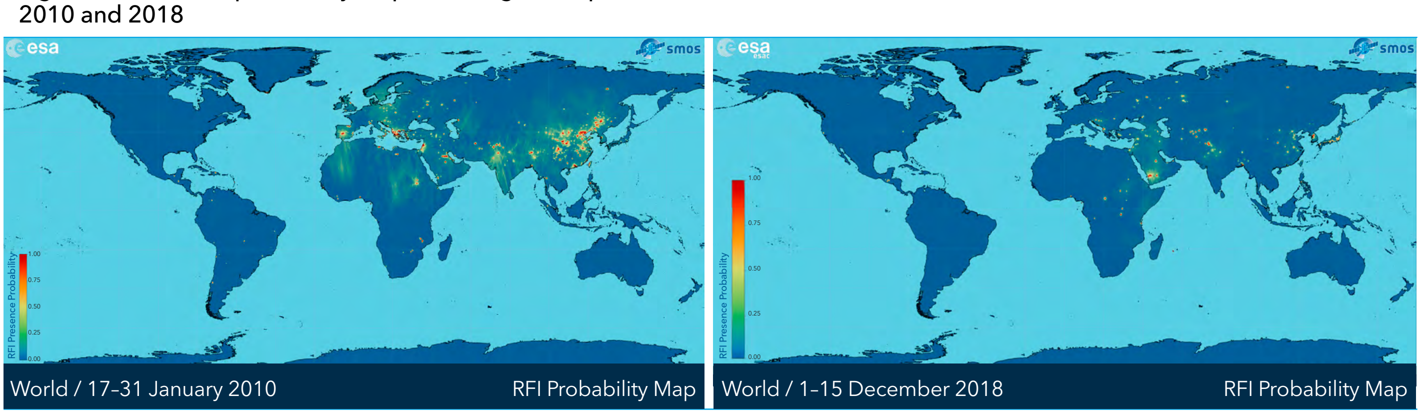
The SMOS satellite, launched in November 2009, is a European Space Agency's (ESA) mission addressing the need for high-quality global observations of soil moisture and ocean salinity from space. Both parameters are key variables describing the Earth's water cycle and have been identified as essential climate variables (ECVs).

SMOS payload consists of a passive microwave imaging interferometric radiometer operating in the 1400–1427 MHz (purely passive) band. From the beginning of its operations, its radiometer has been suffering a large number of RFIs with a large geographical distribution, with the consequent impairment to SMOS measurements. These interferences have also been detected by the radiometers of NASA's missions SMAP and AQUARIUS (see Report ITU–R RS. 2315). Differently from most other radiometers, the SMOS sensor characteristics allow scientists to pinpoint the location of an interferer with high accuracy (0.5–4 km).

Based on this information, ESA started from 2010 a long interaction process with many national administrations worldwide. Location and strength of the RFI sources in their territory have been notified to the relevant administrations according to the guidance in Recommendation ITU–R RS.2106. The global SMOS interference scenario is systematically monitored, and RFI sources catalogued according to their geo-location and strength. A sizeable improvement was noticed over the years thanks to these interactions and the cooperation of many administrations (Figure 1).

The number of very-strong interferers (i.e. with brightness temperature above 5000 Kelvin) has been reduced from 136 RFI sources in 2010 to 60 RFI sources in 2018. However, although a real improvement of the situation has been seen, by the end of 2018 there are still 470 active RFI sources, and the level of data degradation is still of high concern (Figure 2).

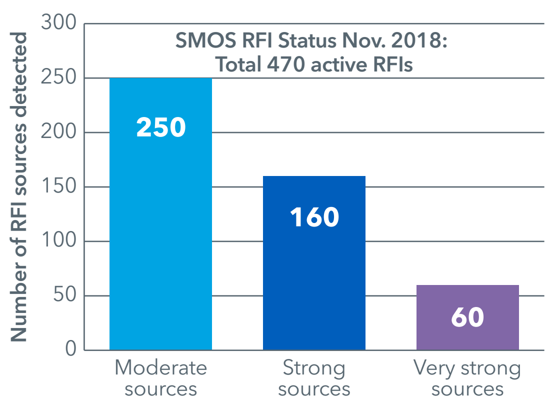
Figure 1: SMOS RFI probability maps showing the improvement in the distribution of interference sources worldwide between 2010 and 2018



Source: European Space Agency

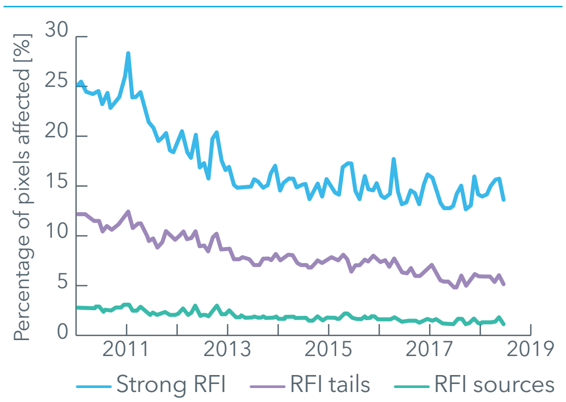
This improvement has allowed for a substantial increase in the amount of data not contaminated by harmful RFI. Figure 3 presents the evolution over time in the percentage of land pixels contaminated by RFI as observed by SMOS.

Figure 2: Global statistics of the number of RFI sources detected by SMOS radiometer in the 1400–1427 MHz passive band



Note: SMOS RFI sources are classified per strength as "very strong" for Brightness Temperature (BT) ≥ 5000 K, "strong" for 5000 K> BT ≥ 1000 K, and "moderate" for 1000 K> BT ≥ 350 K

Figure 3: Evolution in the percentage of the number of SMOS pixels over land affected by RFI from 2010 until 2018



Source: European Space Agency

The interference sources identified are typically radar systems operating in adjacent bands with excessive unwanted emission levels, and also surveillance cameras, malfunctioning radio-links and unauthorized broadcasting systems operating within the passive band. Similar situations should be avoided in the future because of the intense work caused to the satellite operator, the administrations involved and the ITU in trying to identify and eliminate the interference sources. In addition, a serious disruption is caused to the satellite operations and the scientific return of the missions.

WRC-19 agenda items potentially critical for remote sensing

One of the main challenges for the World Radiocommunication Conference 2019 (WRC-19) will be to achieve the right balance between the demand of active services for greater spectrum use and the passive users' right to keep operating without harmful RFI. Experience shows that once the active devices are deployed without the adequate regulatory conditions to protect passive sensors, it becomes extremely difficulty to restore a workable environment for passive sensors. As indicated earlier, this is critical for numerical weather prediction and climate change services with huge economical and societal strategic impact.

On the WRC-19 agenda there are four items addressing possible unwanted emissions into passive sensing bands (AI 1.6, 1.13, 1.14 and 9.1.9), which will require the establishment of appropriate unwanted emission limits:

- Agenda item 1.13: Spectrum for IMT-2020/5G under study in the following bands 24.25–27.5 GHz, 31.8–33.4 GHz, 37–43.5 GHz, 45.5–50.2 GHz, 50.4–52.6 GHz, 66–76 GHz and 81–86 GHz.
- Agenda item 1.14: Identification of additional spectrum for high-altitude platform stations (HAPS) in several bands, in particular in the bands 21.4–22 GHz and 24.25–27.5 GHz, and possible modification of existing footnotes and resolutions, in particular in the bands 6 440–6 520 MHz and 31–31.3 GHz.
- Agenda item 1.6: Development of a regulatory framework for non-GSO fixed-satellite service (FSS) satellite systems that may operate in the bands 37.5–39.5 GHz (space-to-Earth), 39.5–42.5 GHz (space-to-Earth), 47.2–50.2 GHz (Earth-to-space) and 50.4–51.4 GHz (Earth-to-space).
- Agenda item 9.1.9: Possible allocation of the frequency band 51.4–52.4 GHz to the FSS (Earth-to-space).

Figure 4 shows a graphical representation of the frequency bands involved.

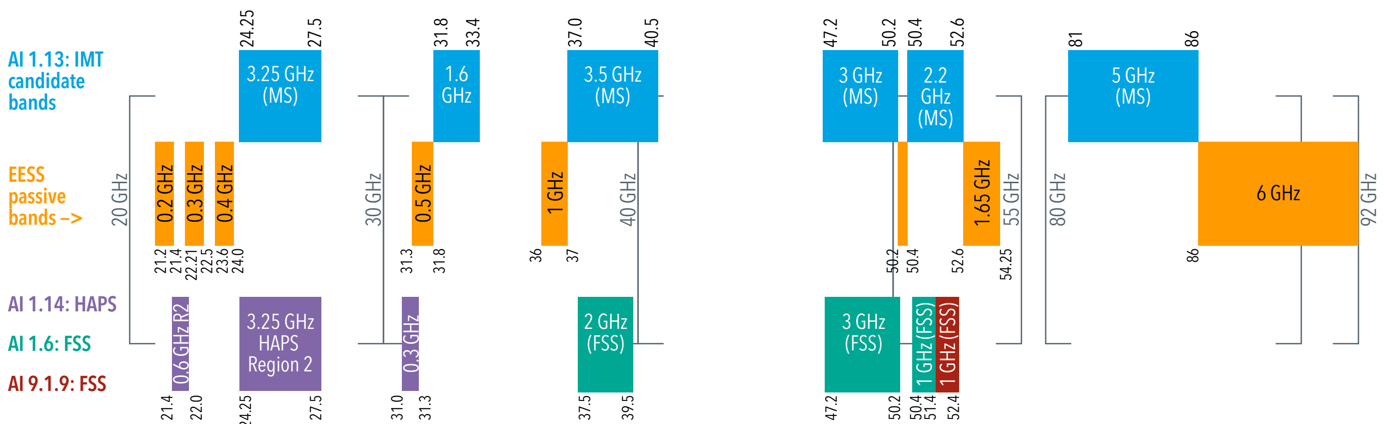
For IMT-2020 devices (AI 1.13) the regulatory limits will have to take into account the huge number of these devices in the long term and not simply the limited number forecasted as initial deployment. Evidently, relaxed limits defined at WRC-19 would create an unrecoverable situation for sensors in the long term.

"Future generations must still be able to enjoy the social and economical benefits brought by remote sensing in meteorology, climatology, land and water management, agriculture, natural disaster prediction, and many other fields of public and private interest."

Josef Aschbacher

Another WRC-19 agenda item with potential impact in passive services is AI 1.15, which is dealing with the identification of bands for land mobile and fixed services in the range 275–450 GHz. Although the RR Table of Frequency Allocations is not established above 275 GHz, in the range 275–450 GHz, there are several important bands for passive service applications, which are identified and protected in RR No. 5.565. Therefore, studies will have to show the compatibility of the new active services with the remote passive sensor operations.

Figure 4: Multiple Earth-exploration satellite service (EESS) (passive) frequency bands that may be impacted by excessive unwanted emissions from IMT-2020/5G mobile service (MS) systems (WRC-19 Agenda item (AI) 1.13); high-altitude platform stations (HAPS) systems (AI 1.14); and/or future fixed-satellite service (FSS) systems (AI 1.6 and 9.1.9)



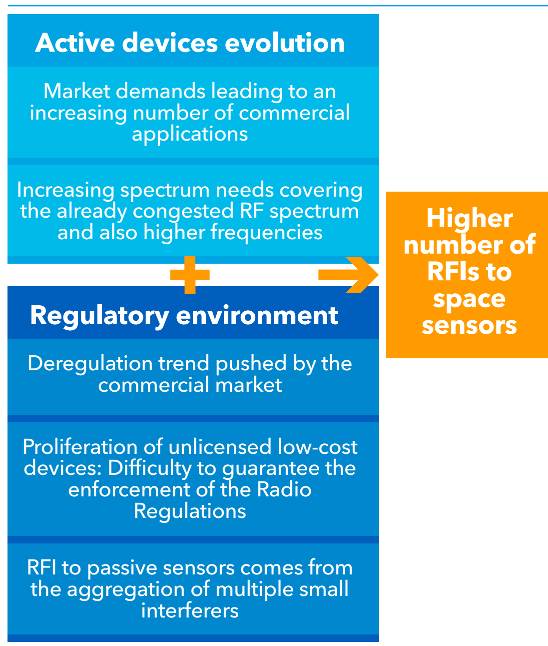
Conclusion

Figure 5 shows graphically the basic reasons for the expected increase in RFIs to passive remote sensing. The only way to mitigate the problem is to define appropriate and enforceable limits in the RR and ITU–R Recommendations for active systems that may impact passive sensor measurements.

Future generations must still be able to enjoy the social and economical benefits brought by remote sensing in meteorology, climatology, land and water management, agriculture, natural disaster prediction, and many other fields of public and private interest. For this to happen, all administrations need to act wisely with a long-term vision.

■

Figure 5: Reasons for the increase in RFIs to passive remote sensing



The importance of passive microwave remote sensing for numerical weather prediction and how WRC-19 can deal with radio-frequency interference

Stephen English

Head of the Earth System Assimilation Section, European Centre for Medium-Range Weather Forecasts (ECMWF)

In adopting the 2030 Agenda for Sustainable Development, world leaders agreed that a global indicator framework was necessary to progress towards the 17 Sustainable Development Goals (SDGs) and 169 associated targets.

Numerical Weather Prediction (NWP) has an essential role to play in relation to most of the SDGs, such as zero hunger, life on land, sustainable cities and communities, etc. NWP is one of the most important cornerstones for achieving substantial reduction of disaster risk and losses in lives, livelihoods and health, and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries as established by the United Nations' Sendai Framework for Disaster Risk Reduction.

> *"For these numerical weather prediction applications, radio-frequency spectrum is crucial for satellite weather observations as well as communications."*
>
> Stephen English

Relying on accurate observations for weather prediction

National early warning systems rely on NWP, as do day-to-day weather forecasts. In turn, NWP relies on accurate observations. NWP can analyse weather systems at an early stage of development, and even predict their genesis, providing advanced warning and time to take necessary action. To achieve this requires a global observing system with a large space-based component to create an estimate of current weather conditions, globally. Mathematical models of the atmosphere and oceans can then predict future weather.

For these NWP applications, radio-frequency spectrum is crucial for satellite weather observations as well as communications. Very high accuracy measurements are needed and even small errors in these observations reduce the effectiveness of NWP. In addition to the critical contribution to public safety, NWP also contributes immensely to the economy ranging from aviation, shipping and traffic, to agriculture and managing electric grid stability for renewable energies.

A recent UK Met Office (the UK's official weather service) study quantitatively assessed (at 2010 prices), based on a number of independent studies, that the socio-economic benefits of weather forecast information in the European Union is 61.4 Billion Euros per year.

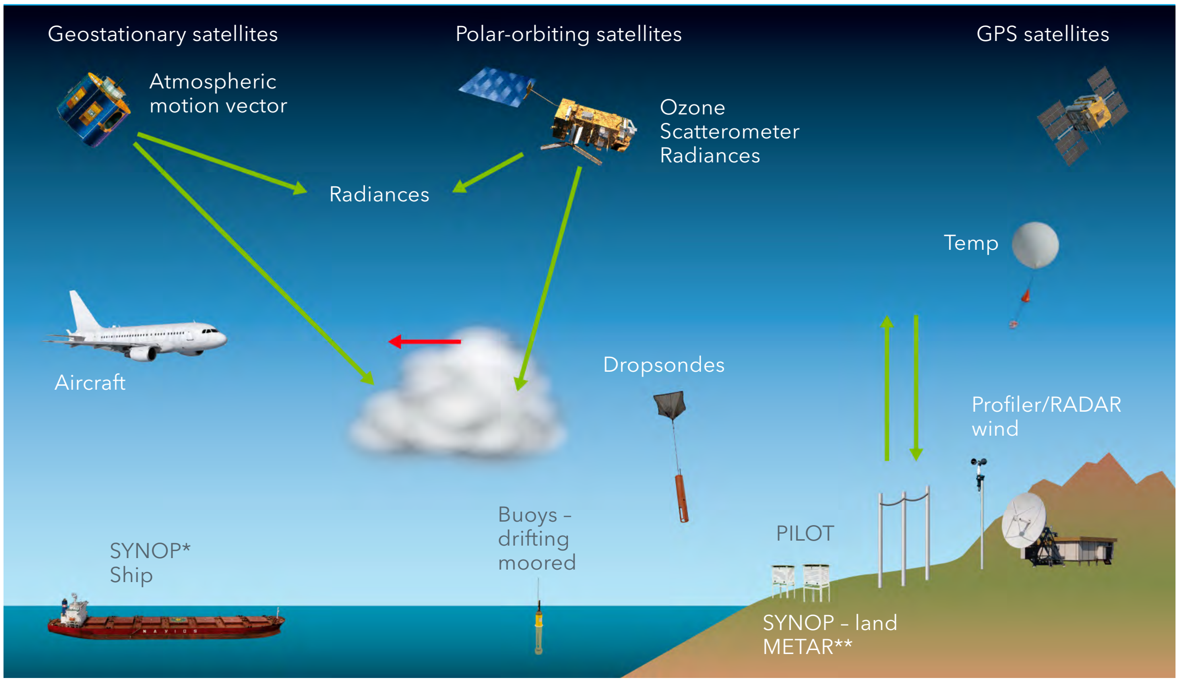
About numerical weather prediction models

NWP models are run by many countries worldwide, using weather observations relayed from Earth-observation satellites, radiosondes, aircraft and other observing systems as inputs (See Figure 1). Some NWP models are global, whereas others cover a local region in more detail.

Many satellite observations for NWP use passive sensing techniques in radio-frequency bands, and therefore rely on Earth Exploration-Satellite Service (EESS) allocations. The absorption characteristics of the atmosphere are characterized by absorption peaks due to the molecular resonance of atmospheric gases, and by the water vapour continuum and cloud absorption and scattering, which increase with frequency.

Below 10 GHz the atmosphere is almost completely transparent, even in the presence of clouds. These low frequencies directly sense the planet's surface. At 18 GHz the dielectric properties of sea water are such that emission becomes almost independent of the sea surface temperature, so the surface emission is primarily sensitive to the sea state and small waves. At 22–24 GHz there is a weak water absorption line and by measuring this line we gain information on total column water vapour. At 31 GHz information on the liquid water content of clouds is obtained.

Figure 1: ECMWF routinely processes data from around 90 satellite data products as part of its operational daily data assimilation and monitoring activities. A total of 40 million observations are processed and used daily; the vast majority of these are satellite measurements, but ECMWF also benefits from all available observations from non-satellite sources, including surface-based and aircraft reports.



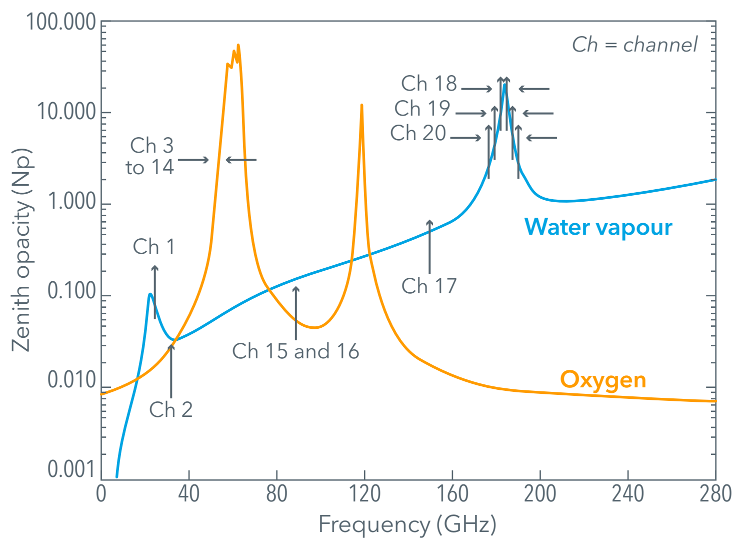
*Surface synoptic observations **Meteorological Terminal Aviation Routine weather report

Source: *https://www.ecmwf.int/en/research/data-assimilation/observations*

There is a strong oxygen absorption band at 50–60 GHz. This is a remarkable spectral feature, enabling us to gain information on the 3D structure of atmospheric temperature with very little impact from clouds and water vapour. Above 60 GHz the most important spectral feature of interest is the water vapour line at 183 GHz, which provides information on the 3D structure of water vapour. Frequencies above 200 GHz provide very detailed information about trace gases and ice clouds.

The frequency of all these spectral features arises from the laws of physics and are therefore determined by nature, and are a unique asset which cannot be substituted by other measurements (see Figure 2). Each EESS band provides information essential to modern state-of-the-art weather prediction.

Figure 2: Atmospheric opacity in the frequency range 0–280 GHz and depicting frequencies used by the channels of the Advanced Microwave Sounding Unit (AMSU-A, channels 1–15, AMSU-B channels 16–20), one of the most important instruments used in NWP, that has been continuously operated since 1998 on a sequence of operational satellites by NOAA and EUMETSAT, as well as new generation instruments such as China's MWTS-2 and MWHS-2, Russia's MTVZA-GY and the USA's ATMS, amongst many others.



Source: English, S. J.; Guillou, C.; Prigent, C.; and Jones, D. C. (1994), Aircraft measurements of water vapour continuum absorption at millimetre wavelengths.

Assessments of the impact of weather observations found that microwave observations are presently the leading satellite observing system for global NWP, contributing around 30–40 % of the overall improvement of short-range forecast skill. The degradation in the forecasts without microwave observations means a loss of average forecast skill of around 3–6 hours for most centres. In other words, without microwave observations, the same level of forecast guidance could only be given 3–6 hours later than it is today.

This means a significant loss of time to issue warnings, for instance, in the case of severe weather events, for all NWP systems worldwide.

A study by ECMWF also illustrated the loss of resilience of the observing system that would result from the loss of microwave data. Indeed, when microwave observations are not present, the degradation from the loss of hyperspectral infrared observations is several times larger than when microwave observations are present.

> *Loss of these and other bands would have a negative impact on national weather warning systems as well as our ability to monitor climate change.*
>
> Stephen English

This scenario would leave many places unprepared and unaware of approaching weather hazards.

The overall impact found for the global NWP systems is also reflected in regional NWP systems. A recent study by the Norwegian meteorological service has shown significant forecast degradation in their regional system without microwave data.

Special attention has to be given to the requirements of operational weather forecasting. However, climate monitoring and prediction also have other, additional requirements, and these are equally dependent on observations by passive microwave remote sensors.

Radio frequency interference and potential band loss

NWP users are already seeing evidence of radio-frequency interference (RFI) in the C, X and K frequency bands, notably on the Japanese Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument. Loss of these and other bands would have a negative impact on national weather warning systems as well as our ability to monitor climate change.

WRC-19's important role of protecting EESS bands from interference

Concerning the agenda items that will be discussed at the next World Radiocommunication Conference 2019 (WRC-19), we must highlight the importance of ensuring the protection of the EESS (passive) bands from the threat of potential interference from unwanted emissions of IMT-2020/5G, in particular into the 24 GHz passive band, and from unwanted emissions from future commercial satellite systems into the passive sensing band at 50/60 GHz.

Given the importance of weather forecasting and the associated economic and societal benefits, appropriate unwanted emission limits in the Radio Regulations need to be decided by WRC-19 to preserve the global measurements in these unique passive sensing bands.

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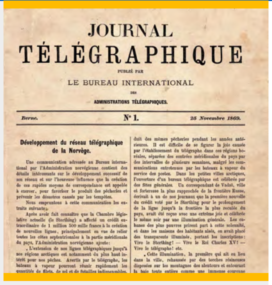
Milestones *in the* **150-year history** *of* **ITU News**

1869

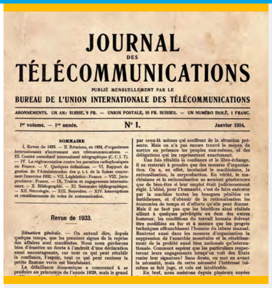
The first issue of the *"Journal télégraphique"* is published


JOURNAL TÉLÉGRAPHIQUE
PUBLIÉ PAR LE BUREAU INTERNATIONAL DES ADMINISTRATIONS TÉLÉGRAPHIQUES.
Berne. N° 1. 25 Novembre 1869.

When the second International Telegraph Conference, held in Vienna in 1868, decided to establish a permanent secretariat for the Union in Bern, Switzerland, among the six tasks assigned to the Bureau was the publication and distribution to members of "a telegraph journal in the French language" (International Telegraph Convention (Vienna, 1868), Article 61). Thus, the publication of the Journal was mandated by the Member States and has been an important part of ITU's role to disseminate information right from the creation of the secretariat. The first issue of the monthly *"Journal télégraphique"* was published on 25 November 1869.

1934

The journal changes its name to: *"Journal des télécommunications"*


JOURNAL DES TÉLÉCOMMUNICATIONS
PUBLIÉ MENSUELLEMENT PAR LE BUREAU DE L'UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS
1er volume. — 1re année. N° 1. Janvier 1934.

In 1932 in Madrid, the International Telegraph Conference and the International Radiotelegraph Conference decided to combine the Telegraph and Radiotelegraph Conventions to form the single International Telecommunication Convention. At the same time, a new name was adopted to reflect the full range of ITU's responsibilities: International Telecommunication Union. The new name came into effect on 1 January 1934. Accompanying the change of name of the Union, the Journal télégraphique became the Journal des télécommunications on 1 January 1934.

1948

The journal is published in three languages: French, English and Spanish


JOURNAL DES TÉLÉCOMMUNICATIONS
TELECOMMUNICATION JOURNAL
BOLETIN DE TELECOMUNICACIONES
N° 1
JANVIER - JANUARY - ENERO 1948

Following the decisions of the International Telecommunication Conference of Atlantic City (1947) related to languages, the Telecommunication Journal became a trilingual publication (English, French and Spanish) starting in January 1948. The three languages were printed side-by-side on the same page. Publishing the Journal in its new form meant a considerable increase in work and in cost of production.

1962

Each language has its own separate edition

Publication of the Journal in three separate English, French and Spanish editions, instead of the old trilingual form, began in January 1962. Throughout the 1960s to 1980s, the journal was increasingly used to spread information about the Union and its work. Part of this strategy consisted of sending copies of the Journal to the United Nations and all its specialized agencies, to the United Nations Information Centres in various parts of the world and to the Union's Technical Cooperation experts in the field. In addition, an increasing number of organs of the general and technical press asked to receive it.

1994

The journal becomes a newsletter

As of 1 January 1994, the Telecommunication Journal was replaced by the "ITU Newsletter". The layout was modified and modernized, and the production schedule was changed to ten times a year. It was announced that, in its new form, the Journal/Newsletter would "concentrate on ITU's activities, on the issues at stake and on the practical results achieved". Opinions, though often conflicting, would also find their place in the new style publication in order to provide readers with not only the basic information about ITU activities, but also "the more hidden aspects, the whys and the wherefores".

1996

ITU News takes the format of a magazine

1999

Electronic version and fee-paying subscribers

As part of the response to a study that showed a need for electronic distribution of information about ITU activities, the first electronic version of ITU News appeared on the ITU website in mid-1999. From then onwards ITU News appeared in both digital and paper copies. In 2003–2006, the ITU News website was a high achiever in terms of average number of visits per month, scoring among the top three most visited ITU sites. From 1999 the printed version became fee paying for non-ITU members. Fee-paying subscribers paid 100 CHF per year, and subscribers included a number of bookshops and private-sector companies.

2009

The ITU News Magazine is published in 6 languages

Since July 2009, at the request of ITU Member States, to enhance the Union's image and the effectiveness of its public-information work, the ITU News Magazine has been published in all six official languages of the Union (Arabic, Chinese, English, Spanish, French and Russian). It continues to provide wide-ranging coverage of ITU activities and events shaping telecommunication/information and communication technologies around the world.

2016

The ITU News Magazine becomes entirely digital

In 2016, the ITU News Magazine became entirely digital, with a new online portal. Digital editions produced around key ITU events and topics throughout the year are now widely distributed by e-mail newsletter. Two sister products were also introduced: ITU News which includes articles on how the latest ICT trends will impact sustainable development worldwide, and also the ITU News weekly newsletter which is widely distributed, to subscribers' inboxes, every Tuesday. Also in 2016, after a long arduous task, the ITU Library and Archives Service made available online a digitized historical collection of ITU News, from 1869–2015. The complete collection is searchable, and researchers, scholars and the general public can explore information about the development of the telecommunication/information and communication technology sector, and ITU's activities over the years. See ITU's journals through the ages 1869–2015.

2019

ITU News celebrates 150 years 1869–2019