Using radio frequencies to observe Earth

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Abstract:
Radio frequencies are heavily used to observe the earth, in particular from satellites. This Earth watch, the measurements made and their impact are described with regard to weather predictions. The decision to assign 5G a bandwidth close to that of the absorption of water vapor (crucial for measurements) could endanger observations of the earth.

A very unusual event marked the end of the World Radiocommunication Conference (WRC-19) held in Sharm El Sheikh, Egypt, in November 2019.[1] The allocation of new radio-frequency bands for 5G was expected. What came unexpected was that the secretary-general of the World Meteorological Organization (WMO) addressed to his counterpart at the International Telecommunication Union (ITU) a very negative message that was circulated during the plenary session and supported by many delegations, including France's. With reference to the conditions set for allocating to 5G service the 24.25-27.5 GHz band, which lies close to the 23.6-24 GHz band allocated to Earth observation, this message stated, "*This WRC-19 decision has the potential to significantly degrade the accuracy of data collected in this frequency band which would jeopardize the operation of existing Earth observation satellite systems essential for all weather forecasting and warning activities of the national weather services. […] Potential effects of this could be felt across multiple impact areas including aviation, shipping, agricultural meteorology and warning of extreme events as well as our common ability to monitor climate change in the future.*"[2]

What led up to this unusual event? How would the Earth observation system be endangered? To answer these questions, it is necessary to describe how this system operates and how the radio frequencies for this service have been allocated and are protected. This article mostly refers to the systems of meteorological observation that, owing to their age and operations, have been decisive in shaping the Earth observation system. So we might also ask: what are the previous cases of conflict about the allocation of frequencies for Earth observation?

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[1] The author warmly thanks Stephen English (ECMWF) and Philippe Tristant (expert on radio frequencies) for the information they conveyed for the writing of this article. This article has been translated from French by Noal Mellott (Omaha Beach, France). The translation into English has, with the editor's approval, completed a few bibliographical references. All websites were consulted in October 2020.

[2] WMO press release of 27 November 2019 available at
https://public.wmo.int/en/media/news/wmo-expresses-concern-about-radio-frequency-decision.

arth observations

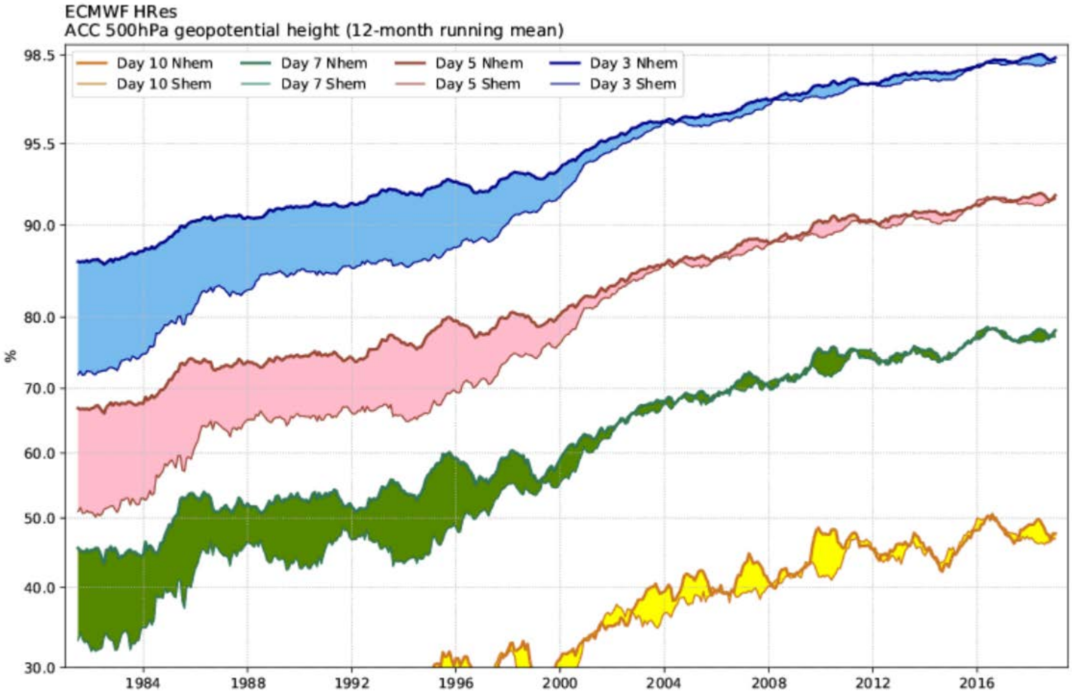
"Earth observation" refers to a very large range of activities for monitoring the atmosphere (at all levels: troposphere, stratosphere, etc.), oceans, continental land surfaces (plant cover, geology, watercourses, constructions, etc.), the cryosphere (polar caps, glaciers), biodiversity, and so forth. The first systematic records, dating back to Ancient Times, mostly reported on winds and clouds. As of the 17th century, such records became more frequent as instruments for measurements (thermometers, barometers) were designed and the idea of "network measurements" was worked out. In the second half of the 19th century, this idea gained ground and led, in 1873, to the first meeting of the International Meteorological Organization in Vienna. The IMO would later become the existing World Meteorological Organization (WMO).

Measurements at ground level were gradually supplemented with a few made in the air using kites, balloons, aeroplanes and, in 1959, the first weather satellite Vanguard-2. Although this first attempt failed, Tiros-1 would, as of 1960, provide a long series of observations from space that helped develop a full range of Earth observations.

Numerical weather prediction

Weather forecasting has made strides during the past fifty years thanks to a combination of two major developments: systems of observation from space and numerical weather prediction (*i.e.*, the ability to build models of the atmosphere and make calculations using computers). The success of numerical weather predictions can be set down: on the one hand, to this model-building for forecasting and, too, for handling the data reported; and, on the other hand, to the increase in computing power from 100,000 additions per second on the first mainframe computer used to predict the weather (ENIAC in the early 1950s) to a number of operations now measured in petaFLOPS (10^{15} operations per second).

Figure 1: The quality of forecasts from 1981 to 2019 made by the European Center for Medium-Range Weather Forecasts (ECMWF).
The score is the correlation of anomalies at 500 hPa. A perfect score is 100%, and the minimum for useable predictions is taken to be 60%. The trend is presented for four predictions: three days ahead (blue), five days ahead (red), seven days ahead (green) and ten days ahead (yellow). For each, the bold-faced upper curve corresponds to the score in the northern hemisphere; and the lower curve, to that in the southern hemisphere.
Source: ©ECMWF.



These advances can be illustrated with the trend in weather prediction scores in the northern and southern hemispheres since the early 1980s. In Figure 1, we notice that the quality of forecasts has improved by 3-4 days over this period. For instance, the score of seven days at the end of the period is higher than for three days at the start. Note too the strong improvement of the score in the southern hemisphere compared with that in the northern. At the start of the period, the difference between the two can be set down to the low density of the means of observations (radiosondes and ground stations). However the southern hemisphere has gradually caught up thanks to weather observations from space, especially since the application of the data assimilation method in 1996-1997.

Figure 2: Number of satellite data products monitored at the European Center for Medium-Range Weather Forecasts (ECMWF) from 1996 to 2019, and projections up till 2023.
Source: ©ECMWF.

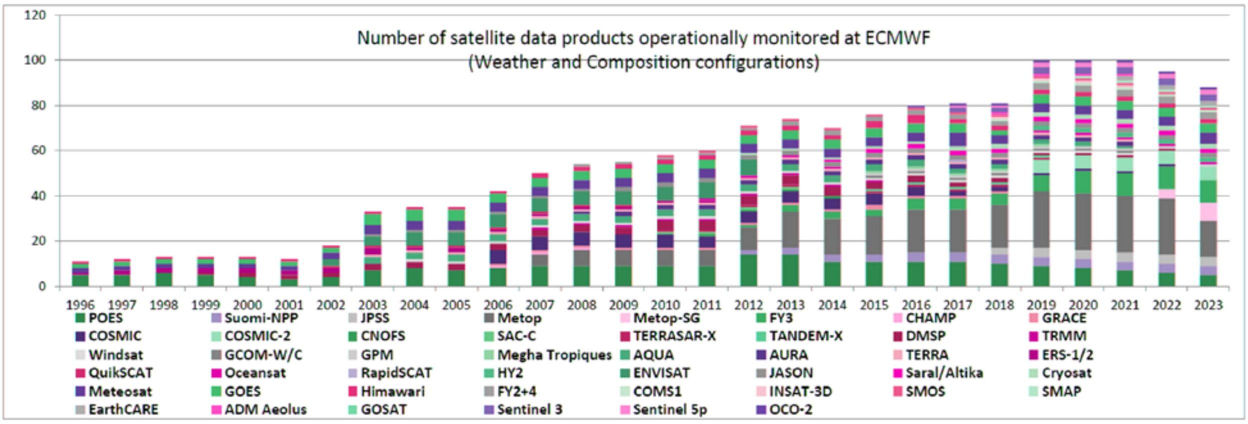


Figure 2 simply, which provides evidence of the increase in the number of satellites since 1996, helps us gauge the growing importance of space observations for numerical weather predictions. About a hundred satellites are currently in operation or being tested; and the data from satellites amounts to more than 70% of assimilated data. What has reinforced this trend is that numerical weather prediction models — which used to be (25 years ago) models of the atmosphere — have become models of the Earth system, inclusive of the oceans, ice fields, chemistry of the atmosphere, plant cover, etc. These models rely on a number of Earth observation systems, all of which use radio waves. These systems are of two sorts: passive or active.

Passive observation systems

Passive systems measure natural electromagnetic emissions from Earth's surface. Instruments using radio frequencies have been invented to measure the results of these emissions observed from a point in the atmosphere, thus after the emissions have crossed the layers of the atmosphere between the satellite and the ground. Since these measurements are made in narrow frequency bands (corresponding to the absorption bands of particles or molecules in the atmosphere), it is necessary to detect extremely weak signals. The natural emissions from Earth are weak, and measurements are made of what is left after crossing layers of the atmosphere. The frequency bands are determined by the molecular structure of what is to be measured. These bands are irreplaceable natural resources governed by the laws of physics. Let me cite two important examples. First of all, the oxygen absorption band 50-60 GHz is used to collect information that is not affected by clouds and water vapor about the temperature profile. Secondly, 24 GHz, the peak for water vapor absorption, serves to measure the column of vapor while not being very sensitive to water in its liquid form.

Despite the simplicity of the principle guiding these measurements, it is extremely complicated to make them for the following raisons:

● Since the signals to be measured are so weak, the least interference on the frequency band used to measure them will easily drown them out. Besides, the method of measurement cannot tell the difference between natural and parasitic emissions.

● Measurements are a result tied to the cumulative effects of all layers of the atmosphere below the satellite. The objective is to reconstitute 3D fields of the atmosphere's parameters, such as temperature, moisture or water vapor. This requires several simultaneous channels; and the loss of a channel is detrimental to all measurements.

Radiometric measurements in microwaves have made considerable advances over the past twenty years. Providing information day and night (even through cloud cover) about the globe, they are now the primary source of data for numerical weather predictions.

Other passive systems, in particular infrared weather sounds, are also important sources of information, not to mention imaging devices (mainly in the ranges of visible light and infrared).

Active observation systems

Active systems are radars that beam toward a target and then measure the signal broadcast back or returned by reflection. Several instruments have been designed and tested to provide new Earth observations by using all frequencies possible. One example is the Atmospheric Dynamics Mission Aeolus, an Earth observation satellite launched in 2018 that returns information about high-altitude winds by measuring the movement of particles and molecules in the atmosphere and using the Doppler effect.

The main types of active radio systems are:

● Synthetic-aperture radar (SAR), which provides a topographic image of Earth's surface. A good example is the series Sentinel-1 of the EU's Copernicus Program.

● Altimeters, for measuring the ocean's surface below the satellite. The French-American mission Topex/Poseidon produced the first precise maps (down to a few centimeters) of these surfaces.

● Scatterometers (or diffusionmeters), which measure the waves and, thereby, winds on the ocean's surface, and provides information about plant cover.

● Weather radars for measuring the intensity of precipitations on Earth.

● Cloud radars for information about cloud layers.

Physics and metrology are the grounds for selecting the frequencies to be used for these measurements. This selection depends on the nature of the target, the method whereby a radio wave is returned from this target, and the passage of transmissions across the layers of the atmosphere between the target and transmitting station. Given the importance of these measurements, radio frequencies have to be reserved for these services and protected against interference.

Radio frequencies for Earth observation

As just pointed out, several radio frequencies are indispensable for Earth observation from space, regardless of whether the system uses active or passive sensors. Besides the frequencies needed for measurements, bands are necessary for transmitting data and images to devices on the ground. In turn, these devices have similar needs, including the devices used in active observation systems (radars for detecting precipitation, wind profilers, cloud telemeters, or systems for measuring visibility). In particular radiosondes (for measuring pressure, temperature, humidity and the wind with balloons) have to be able to transmit data.

Managing and protecting all the frequencies to be used is the main issue addressed by the International Telecommunication Union (ITU), where decisions are made during word radio conferences (WRCs). The principal frequency bands for passive observation systems have been strictly reserved for this service, whereas the bands used by active systems are managed following the ITU's usual procedures (RANCY 2019). For observations from space, an ITU handbook (2011) describes the "*Earth exploration-satellite service*" (EESS), its systems of observation and transmissions, along with the management of the corresponding frequencies. The fact that the ITU allocates and protects frequencies for EESS has advantages but also a few worrisome weak points.

A major advantage is that space activities and meteorology are both tightly coordinated on the planetary scale. The ITU and WMO are both installed in Geneva, a few hundred meters from each other. Furthermore, they are used to working together, as shown by their joint publication of a handbook on the radio spectrum for meteorology (WMO & ITU 2017). Another advantage is that requests for allocating frequency bands to services have long been handled in this way and with satisfaction — but at a time when there was much less competition for bands than nowadays.

Among the weak points, the most important one is that major or controversial decisions are made by the ITU's world conferences on international telecommunications (WCITs), where representatives from member states are specialists on radio frequencies — but for these specialists, a radio frequency is for transmitting a signal, not for making measurements. Besides, the ITU's slogan "Committed to connecting the world" is not, I might mention, "Committed to connecting and observing the world". Another weak point is that more and more requests for new frequency allocations are coming from entities that, active in growing sectors with a significant economic impact, have strong backing from their governments. Recently, several attempts have been made on the frequencies allocated for Earth observation, in particularly the water vapor absorption band, 23.6-24 GHz.

The coveted absorption band

A first attempt on the water vapor absorption band, 24 GHz, was made at the turn of the century by the automobile industry. This extremely powerful lobby wanted to use a wide band of 5 GHz (covering the "water vapor frequency") for radar detection systems that would help vehicles park. After laborious discussions and the enormous work accomplished by scientific organizations (ESA, Eumetsat and Eumetnet, among others), the European Commission took up this question in 2005. The Commission authorized the automobile industry to use this band; but the authorization was limited in time (2013); and the number of vehicles to be equipped, restricted (7%). Furthermore, the vehicles equipped with these radar detection systems were to gradually move toward another frequency (79 GHz). These conditions were effectively monitored and enforced. The switch toward 79 GHz has been made; and now only 0.1% of vehicles are still equipped with 24 GHz radar — too few to cause problems.

In the case decided by WRC-2019 mentioned at the start of this article, the problem was somewhat different. First of all, the allocation of new frequency bands for 5G did not concern the band in question but a very close band, 24.25-27.5 GHz. The point at issue was not about the use of an already allocated band for 5G but, instead, about the level of protection of the water vapor band against interference from this neighboring band. To ward off problems, those who used instruments to measure water vapor (specialists from the WMO and space agencies) claimed a protection of -50 dBW/200 MHz[3] so that their instruments could operate normally. Prior to the WRC, Europe had set the level of protection at -42 dBW, a reasonable compromise. However the WRC set a level of -33 dBW for eight years and -39 dBW thereafter. This solution — far from the level demanded by the parties interested in Earth observations — provoked the WMO's reaction.

There is a very high risk that the quality of measurements and, as a consequence, of weather forecasts will deteriorate. Several agencies have announced that this decision will set us back decades, especially if 5G is rolled out fast during an eight-year period — what now seems to be in the works.

Unfortunately, this decision is typical of what we usually observe in cases related to environmental issues: the huge difficulty that various national and world governing bodies encounter when balancing the choice to protect natural resources with chances for economic growth. Nevertheless, weakening our capacity to protect ourselves from extreme phenomena could cost society more than the extra costs for 5G and the slower rollout that would result from a better protection of the water vapor absorption band.

References

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[3] This figure in decibel watts (dBW) corresponds to the maximum power allowed of pollution of the air waves. The lower this figure, the stronger pollution. For instance, a pollution of -30 dBW is ten times more detrimental than -40 dBW and a hundred times more than -50 dBW.