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VIEWPOINT

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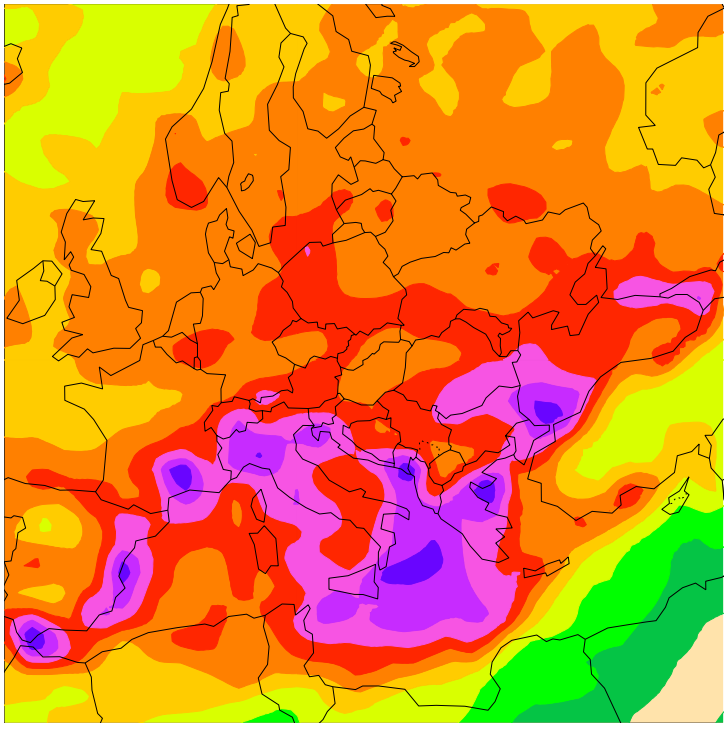

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New group formed to protect spectrum for meteorology and Earth observation

Stephen English

In an initiative led by the European Space Agency (ESA), three European organisations – ECMWF, ESA and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) – and representatives from the European Earth observation, weather and climate science communities have come together to form a new group, ESSEO (European Scientists on Spectrum for Earth Observation), to respond to ever growing concern over Radio Frequency Interference (RFI). This kind of interference affects science services now and is expected to do so even more in the future. Here Stephen English describes the background and the activities of ESSEO, which is chaired by ECMWF.

Sharing of the radio spectrum

In the summer of 2019, an ECMWF Newsletter article provided a viewpoint on the threat and opportunity for meteorology at the World Radiocommunication Conference (WRC) 2019 (*https://www.ecmwf.int/en/newsletter/160/viewpoint/why-we-need-protect-weather-prediction-radio-frequency-interference*). The WRC is the forum that updates the international Radio Regulations, and it is held approximately every four years. These regulations determine the agreed rules under which radio signals can be transmitted. This is of critical importance to the integrity of the global observing system for weather and climate and other Earth observation activities.

As was noted in the 2019 article, a range of global forecast metrics (such as Forecast Sensitivity to Observation Impact, FSOI) show that typically around a third to half of weather forecast error reduction from observations comes from satellite observations that rely on regulatory protection of key spectral bands. This applies both to global numerical weather prediction (NWP) (Bormann et al., 2018) and, mainly via lateral boundary conditions, regional NWP (Randriamampianina et al., 2021). In particular, this is critical for some of the observations which have the highest impact on the skill of NWP, such as microwave temperature and humidity sounders. Up to now, recorded cases of radio frequency interference are mostly below 20 GHz, making it particularly a concern for the Copernicus Imaging Microwave Radiometer, which will be a Sentinel mission under the Copernicus Expansion Missions programme. Other observations also rely on protection, e.g. for downlinks from satellites (there are cases of disruption to the GOES data downlink, for example) and communication of in-situ observations (e.g. radiosondes that use 400–406 MHz transmissions). The radio spectrum, which here can be considered to be frequencies from 1 kHz to 1 THz, is used in many applications. Many of these are expanding, including applications in the fields of weather and climate and other Earth observation activities. The requirements for new generations of mobile phone communications also involve ever increasing swathes of bandwidth. It is important that sharing of the radio spectrum, a unique and valuable resource, is done fairly, taking into account the requirements of diverse application areas.

From WRC-19 to WRC-23

In 2019, the focus was very much on one particular meteorological band: 24 GHz. There had been much controversy in the media concerning a potential threat to this band from 5G. The discussion at WRC-19 was critical to the long-term protection of this band. The outcome from WRC-19 fell short of the position published by the World Meteorological Organization (WMO) in its position paper for WRC-19 (WMO, 2019). However, at least some protection was afforded, and after WRC-19 further discussions were held, notably in Europe, that further improved the situation regionally for 24 GHz. It should be noted that the WMO had 12 agenda items of concern for meteorology, and achieved satisfactory outcomes in 11.

Now, four years on, attention turned to WRC-23. Again there were a number of concerns and opportunities, and once again the WMO published a position paper (WMO, 2023), to inform its negotiating position. Once again, the WMO's team was highly successful, due to the diligence and hard work at the WMO and by spectrum managers from various institutes. Progress was even made in a difficult area concerning C-band. The 5G community was seeking additional spectrum in the 6.425–7.125 GHz band, which overlaps with the bands used by passive sensors near 6.9 GHz. Examples are the AMSR-2 instrument on the Japanese GCOM-W satellite and the future CIMR (Copernicus Imaging Microwave Radiometer) mission, part of the Copernicus Expansion programme, which is currently under development by ESA. The 6.9 GHz band is the only source of sea-surface temperature

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information in persistently cloudy areas, such as underneath a tropical storm that could develop into a damaging hurricane or typhoon. Unfortunately, although this band has been used since the 1970s (it was part of the SMMR channel set first launched in 1978; see *https://space.oscar.wmo.int/instruments/view/smmr*), it has never been afforded protection in the Radio Regulations. The Radio Regulations merely acknowledge its use for ocean measurement without explicitly protecting it: the exact text says that "administrations should bear in mind" the use of this band by Earth observation (EO) sensors. Studies at ANFR (Agence National des Fréquences, France) have predicted that RFI from land-based 5G installations will affect observations 2,000 km out to sea. This could significantly impact weather forecasts, notably for extreme events, such as tropical cyclones.

In addition to this major issue at 6.9 GHz, there were also important discussions concerning a range of microwave frequencies (10.65 GHz, 18.7 GHz and 36.5 GHz, which are important for liquid cloud and terrestrial surface information; and 243 GHz). The lower frequency channels are particularly relevant for the forthcoming Copernicus Imaging Microwave Radiometer.

The need for ESSEO

It is recognised that the science community needs to do more to communicate the importance of all bands used for weather and climate: why they are important, how they are used, and what their impact is. This needs to include passive observations (where we measure natural emissions from the Earth and the atmosphere) and active observations (where we use radar to infer surface or atmospheric information). In the United States, the Committee on Radio Frequencies (CORF) works under the auspices of the National Academies of Science to give a wide-ranging scientific perspective on the value of bands. Until recently, there was no equivalent in Europe. Space agencies (ESA, EUMETSAT) and EUMETNET spectrum managers provided expert contributions to the International Telecommunication Union (ITU), and the WMO and some national meteorological and hydrological services (such as the UK Met Office or Météo-France) have dedicated spectrum managers, who also participate in this process. However, there was no mechanism to ensure review by the wider scientific community of the science case, to ensure it is correct, robust and defendable. Therefore, ESA took the initiative to set up a new group: European Scientists on Spectrum for Earth Observation (ESSEO). From the outset, this has been a collaborative effort between ESA, EUMETSAT and ECMWF. The group is chaired by Stephen English with strong support from ESA and EUMETSAT spectrum managers. It also includes a group of leading scientists from a number of research facilities across Europe, bringing expertise in the understanding and use of passive and active radio spectrum observations. It is narrower in focus than CORF, but gives a voice to science for Earth observations.

Given the timeline, the main focus of ESSEO is towards WRC-27, in about four years' time. However, WRC-23 was critical for ESSEO's work plan because it finalised the agenda items for WRC-27. The way WRC works is to consider proposals for the agenda for the next meeting, in four years' time, at the end of the current meeting, and to then set that agenda. This gives all stakeholders a chance to do the studies needed to establish if there is a concern or not in their application area ahead of the next meeting. Therefore, the work of ESSEO towards WRC-27 really began in earnest with the publication of the WRC-27 agenda. However, there was already a published preliminary agenda for WRC-27 before WRC-23, so ESSEO already had a good idea of the items that might be retained, and it had been doing preliminary work during 2023. Unusually, it is not just meteorology defending its existing bands, but proactively seeking a permanent and properly protected home for C-band marine observation.

The ESSEO team comprises Stephen English (Chair, ECMWF), Catherine Prigent (CNRS, France), Alessandro Battaglia (PoliTo, Italy), Andrea Monti-Guarnieri (PoliMi, Italy), Chawn Harlow (Met Office, UK), Guilia Panegrossi (CNR, Italy), Jesse Andries (WMO), Ken Holmlund (retired, Finland), Markus Dreis (EUMETSAT), Patrick Eriksson (Chalmers University, Sweden), Philippe Chambon (Météo-France), and Yann Kerr (CESBIO, France). They have worked closely with the ESA team, which is made up of Yan Soldo, Bruno Espinosa, Flavio Jorge, and Josep Rosello.

Issues for WRC-27

WRC-27 seems likely to be a very important WRC for weather and climate science, as the Agenda Items (AIs) listed in Table 1 have a potential impact on Earth observations.

In view of the concerns discussed earlier about the future of C-band for passive sensing, the potential for new allocations in C-band for sea-surface temperature (SST) close to 4 and 8 GHz is positive. The concept would be for a future radiometer to operate at the same time at 6.9 GHz, for long-term continuity in RFI-free areas, and in the new bands, to provide SSTs in areas where there is RFI concern at 6.9 GHz. As both new channels would be available in RFI-free areas, it would be straightforward

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to intercalibrate between SSTs using 6.9 GHz and SSTs using the new bands. Also of interest is the consideration of bands above 275 GHz, which will be considered for the first time. This is important for the new Ice Cloud Imager on the EUMETSAT Polar System – Second Generation (EPS-SG), and for the radiometer that will fly on the EPS-Sterna constellation, which will follow ESA's Arctic Weather Satellite Proto Flight Model (AWS PFM).

AI	Topic	Earth Exploration Satellite Service bands
1.1	GSO (geostationary satellite orbit) ESIM (Earth stations in motion) in 37.5–51.4 GHz	36–37 GHz, 50.2–50.4 GHz
1.7	6G in 7–24 and 92–275 GHz	Several passive and active bands
1.8	Radars above 230 GHz	226–231.5 GHz, 235–238 GHz, 239.2–242.2 GHz, 244.2–247.2 GHz, several bands above 275 GHz
1.11	Space-to-space MSS (mobile satellite services) in 1.5–2.5 GHz	1215–1300 MHz 1400–1427 MHz 1525–1535 MHz
1.14	Narrowband MSS in 1.7–3.4 GHz	1.4–1.427 GHz, 2.64–2.7 GHz, 4.2–4.4 GHz 3.1–3.3 GHz 1.525–1.535 GHz
1.17	Space weather sensors	Several passive and active bands
1.18	Protection of RR (Radio Regulations) 5.340 bands > 86 GHz	86–92 GHz, 114.25–116 GHz, 148.5–151.5 GHz, 164–167 GHz, 182–185 GHz, 190–191.8 GHz, 200–209 GHz, 226–231.5 GHz
1.19	New EO (Earth observation) band (mostly for SST (sea-surface temperature)) in 4–10 GHz	4.2–4.4 GHz, 4.95–4.99 GHz, 6.425–7.25 GHz, 8.4–8.5 GHz (last band not allocated)
2.10	EO uplinks in 22.55–23.15 GHz	22.21–22.5 GHz, 23.6–24.0 GHz

Table 1 Topics for the WRC-27 agenda.

There is concern over the future status of bands currently fully protected by footnote 5.340 of the Radio Regulations above 86 GHz. This includes the water vapour band at 183 GHz, which – according to the Forecast Sensitivity Impact Observation metric – contributes most to forecast error reduction at ECMWF. There are new concerns close to 24 GHz, and further concerns in L-band close to the channel used by Soil Moisture and Ocean Salinity (SMOS), Soil Moisture Active Passive (SMAP) and Copernicus Imaging Microwave Radiometer (CIMR) instruments. There are also concerns for the window channel for the temperature sounding band (50 GHz) and the cloud liquid water and surface snow pack band (36.5 GHz). Finally, 6G mobile networks are expected to seek additional spectrum in the 7–30 GHz range, but the exact frequencies are not clear yet. ESSEO is assembling information on the use of all these bands in different application areas. This will lead to a science report available early in 2024, which will both inform and guide spectrum management discussions. It would be of great help if the wider European science community could provide input to the ESSEO Chair or Yan Soldo to ensure this paper is as broad and as accurate as possible.

ESSEO assessment of existing RFI

As well as providing a trusted and consensus science input on WRC issues, the ESSEO group will also monitor the status of RFI and help with the process of reporting. RFI affects sensors in the Earth Exploration Satellite Service (EESS) in many ways. On rare occasions, RFI will be large and easily spotted. Very strong RFI may damage the satellite receiver, in which case the loss of science data would be permanent. More typically, and often of greater concern, is when the level of RFI is small and indistinguishable from real natural variability. However, as this natural variability is the signal for weather and climate, small RFI will lead to unknown errors in the analysis, and therefore errors in prediction and climate monitoring. If there is even a possibility of this, the only safe option is to stop using the observations, because using them is liable to make the analysis worse.

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Even if technology- or software-based mitigation of RFI is possible, RFI has an impact in terms of the cost of designing and operating instruments. For example, modifications would be required to better cope with the RFI environment and, during operations, to process measurements for RFI. Whilst some cases of RFI can be detected and data can be either rejected or corrected, not all RFI can be managed by software or hardware improvements. Therefore, regulatory protection through the WRC is essential, and RFI reporting is of critical importance. However, this implies additional cost and effort for space agencies and for users of these observations.

At the present time, it is known that many EESS sensors are affected by RFI (Draper 2018; SFCG 2023). However, few have taken steps towards reporting the presence of RFI to the proper national regulatory authorities or to the ITU, and it is known that the issue of RFI to EESS sensors is largely under-reported. This is in part due to the challenge of unambiguously identifying RFI, but also because these instruments have a spatial resolution of tens of kilometers, which is too large for practical actions to be taken to pinpoint the source. In recent years, however, algorithms have been developed to locate RFI sources with accuracies much finer than the size of the footprint, typically within a few kilometers. Such accuracy has proven precise enough for national regulatory authorities to identify the RFI sources reported by EESS sensors (e.g. at L-band for SMOS). ECMWF's long-term monitoring of the observation-minus-background differences for SMOS has shown how over the years many RFI sources have been identified and shut down.

Conclusions

The radio frequency spectrum is a valuable and unique resource supporting many critical application areas, including amongst others mobile communications, Earth observation, weather forecasting, climate monitoring, radio astronomy, command and control for satellites, and data downloads from satellites. All have genuine requirements and bring real socio-economic benefits, but at times these requirements will come into conflict. The WRC is the key international forum to resolve these areas of potential conflict, and it is vital that the WRC has the best possible information. To ensure this, those representing weather and climate science and Earth observation in general should have watertight science to back up the position taken on our behalf by the WMO. This is the purpose of ESSEO. RFI contamination is likely to become worse over time, as many terrestrial and spaceborne services plan to rely more heavily on the spectrum. Therefore, this collaboration between ECMWF and space agencies, through ESSEO and also more generally, will become ever more important to weather and climate services.

Further reading

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