Earth microwave remote sensing and the electromagnetic spectrum

By Paolo de Matthaeis, Chair, IEEE Geoscience and Remote Sensing Society (GRSS) Frequency Allocations in Remote Sensing (FARS) Technical Committee

Remote sensing is the collection of information on an object or phenomenon from a distance without any physical contact. In the context of Earth science, space- or air-borne sensors are used for data acquisition and the subject of these observations are the atmosphere or the surface of land and the ocean. For microwave remote sensing, measurements are made of electromagnetic radiation ranging from below 45 MHz up to a Terahertz or more.

Microwave remote sensing can be either passive or active. Passive sensors gather radiation originating from the particular objects under observation. This radiation can either be emission by the objects themselves or energy coming from the sun and reflected by these objects. In the case of microwave remote sensing, the signal of interest is predominantly the former and the emitted radiation is collected by instruments called radiometers. Active instruments transmit signals and measure the radiation that is reflected or scattered from an illuminated area.

Operating at specific radio frequencies

The microwave sensors used for Earth science operate at specific radio frequencies chosen according to the electromagnetic radiation emission, reflection, or absorption characteristics of the object under observation. The specific frequencies for these observations are driven by the immutable physical characteristics of the object and other frequencies cannot be used in their place.

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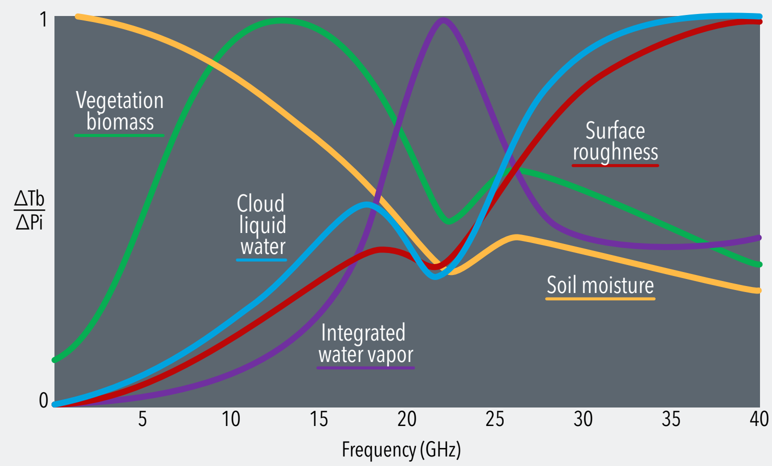
In addition to the need for a specific frequency, it should be noted that, in general, the use of a wider bandwidth during the measurement allows for a higher degree of resolution of the desired characteristic. A narrower bandwidth can be used but this approach then requires a more sensitive receiver to obtain the same desired resolution.

Figures 1 and 2 show over the range of 0–40 GHz, the sensitivity of the electromagnetic emission characteristics of the main subjects of interest to Earth science for ocean and land remote sensing, respectively. For example, soil moisture estimates are most accurate when using measurements at low frequencies, where the sensitivity is very high (Figure 1), and, consequently, 1.4 GHz is the operational frequency of current sensors designed for this purpose.

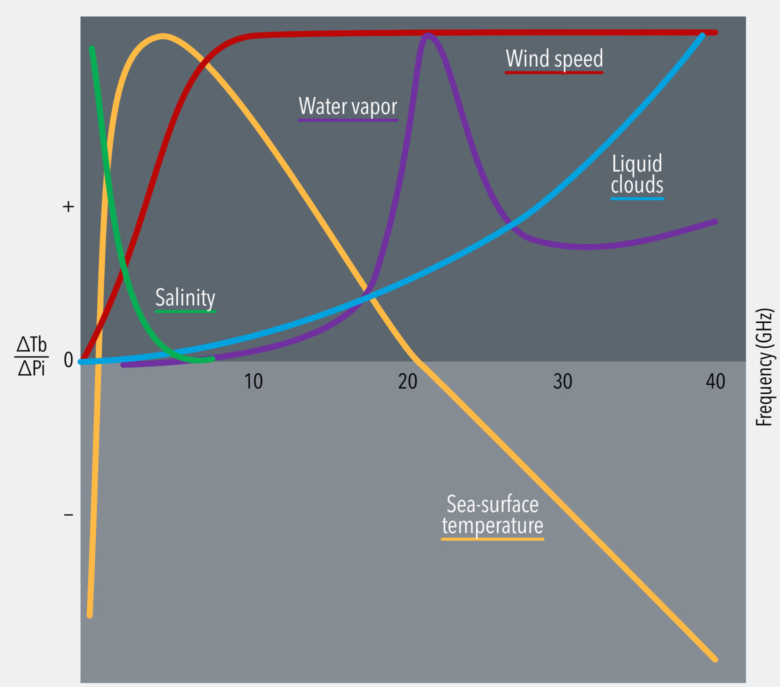
The emission dependence on any one physical parameter is entangled with the dependence on other parameters, thus in order to correctly estimate a physical parameter, it is also often necessary to collect measurements over multiple frequencies to allow for the correction of the undesired emissions.

Figure 1 – Relative sensitivity of brightness temperature to geophysical parameters over land surfaces as a function of frequency.



Source: National Academies of Sciences, Engineering, and Medicine, Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses, Second Edition. Washington, DC, 2015.

Figure 2 – Relative sensitivity of brightness temperature to geophysical parameters over the ocean as a function of frequency.



Source: National Academies of Sciences, Engineering, and Medicine, Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses, Second Edition. Washington, DC, 2015.

For example, observations at two frequencies surrounding the water vapor absorption peak, usually around 18 GHz and 23 GHz, are needed to assess the amount of water vapor in the atmosphere (Figure 2).

Value for society

Space-based remote sensing makes it possible to collect data on a global basis including otherwise dangerous or inaccessible areas. Remote-sensing applications include monitoring deforestation in areas such as the Amazon Basin, glacial features in the Arctic and Antarctic regions, and depth sounding of coastal and ocean depths.

Remote sensing also supplements, or even replaces costly and slow ground-based data collection, ensuring in the process that areas or objects are not disturbed.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides researchers with enough information to monitor trends such as El Niño and other natural long- and short-term phenomena.

Earth science uses include, among others, natural resource management, agricultural fields such as land usage and conservation, oil spill detection and monitoring, and national security and overhead, as well as ground-based and stand-off collection on border areas.

The economic value of these Earth-science observations has been estimated to be easily in the hundreds of billions of dollars, which is far in excess of the cost of the programmes which operate these Earth science data collection systems.

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Frequency bands and interference

Growing demand for electromagnetic spectrum, particularly from commercial applications, has created a situation in which many services have to share or use contiguous frequency bands.

As a result, many radio systems are being affected by unwanted man-made signals, known as radio frequency interference (RFI), that disrupt and degrade performance. Microwave remote sensing is not immune from this problem, with passive remote sensing being particularly harmed due to its reliance on very weak natural electromagnetic emissions, narrow observation bands, and sensitive instruments. Remote sensing operations in frequency bands below 20 GHz have experienced interference for decades from the operation of other services.

However, RFI in remote sensing operations is expected to occur in bands above 20 GHz and, in addition, to become ubiquitous and more severe due to the utilization of these higher frequencies by services such as those supporting 5G and broadband Internet on airplanes and ships or in remote locations.

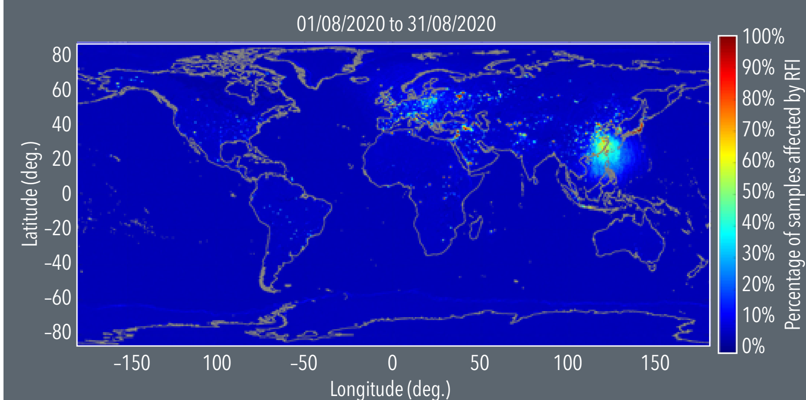
Examples of interference observed by passive sensors operating at 1.4 GHz and 18.7 GHz are given in Figures 3 and 4, respectively, while Figure 5 shows RFI detected by an active instrument at 5.405 GHz.

The IEEE GRSS Frequency Allocations in Remote Sensing Technical Committee

The Frequency Allocations in Remote Sensing (FARS) Technical Committee of the IEEE Geoscience and Remote Sensing Society (GRSS) was formed in 2000 to serve as an interface between the remote-sensing community and the radio-frequency regulatory world.

The technical committee strives to educate all involved parties by providing the remote-sensing perspective and technical input to frequency regulators and also by assisting remote-sensing scientists and engineers on spectrum management matters.

Figure 3 – RFI observed by the soil, moisture, active, passive (SMAP) radiometer in the 1400–1427 MHz band during August 2020.



Source: NASA Goddard Space Flight Center.

Figure 4 – Maximum RFI levels observed by the Global Precipitation Measurement (GPM) Microwave Imager in the 18.6–18.8 GHz band over the United States during 2019.

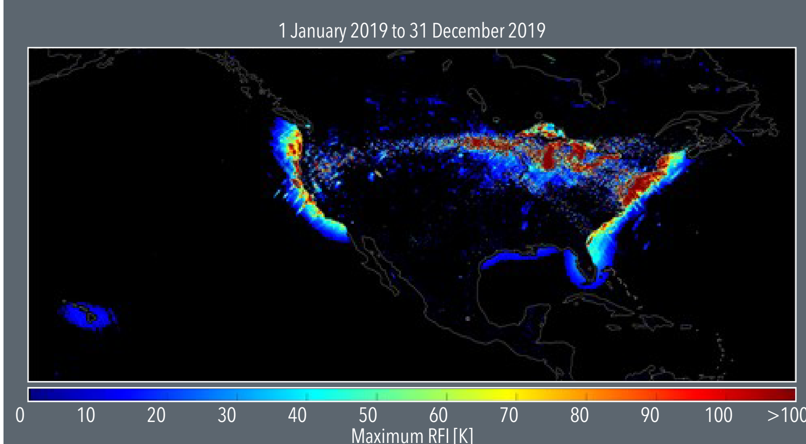
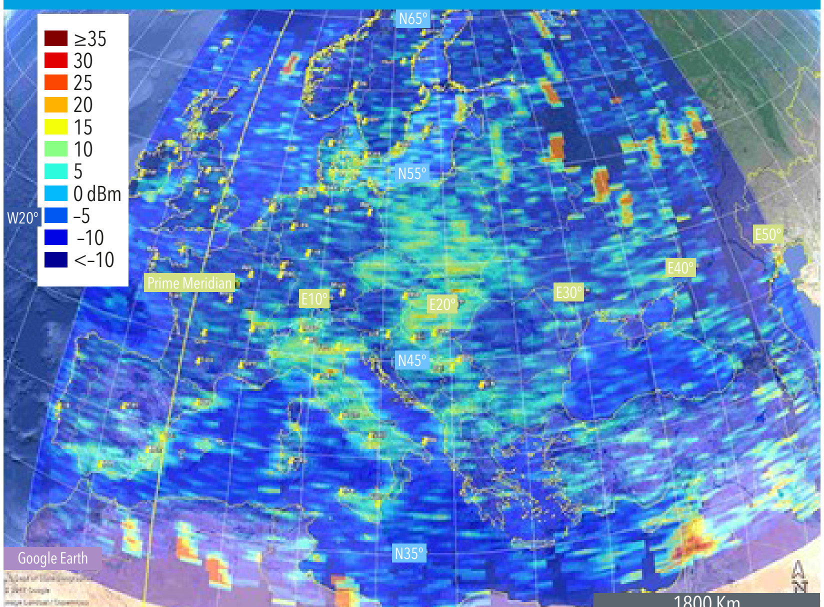


Figure 5 – Map of RFI power at C-band in Sentinel-1 Synthetic Aperture Radar measurements, with locations of weather radars superimposed.



Source: A. Monti-Guarnieri, D. Giudici, and A. Recchia, "Identification of C-Band Radio Frequency Interferences from Sentinel-1 Data," Remote Sensing, vol. 9, no. 11, p. 1183, Nov. 2017.

FARS promotes the development of radio-frequency interference detection and mitigation technology by organizing technical sessions at conferences, workshops, and other relevant venues on the above processes, issues and technologies.

The FARS Technical Committee is also developing an online database of RFI observed by remote sensing sensors. In all these activities, FARS fosters the exchange of information between researchers in different fields, such as remote sensing, radio astronomy, telecommunications, with the unifying goal of minimizing harmful interference between systems.