Spectrum Allocation Opportunities and Regulatory Challenges
for
Earth Remote Sensing Systems at the World Radiocommunication Conference 2027

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Key Takeaways

The radio spectrum is an essential and irreplaceable tool to study Earth's environment, predict weather events, and save lives and property from catastrophic losses.

The demand for spectrum continues to grow – as does the risk of RF interference.

WRCs and national regulatory proceedings present both risks and opportunities for the scientist who depends upon access to RF spectrum for his research.

Active participation of interested parties in spectrum management activities is essential to ensure that risks to scientific RF dependencies are minimized and mitigated.

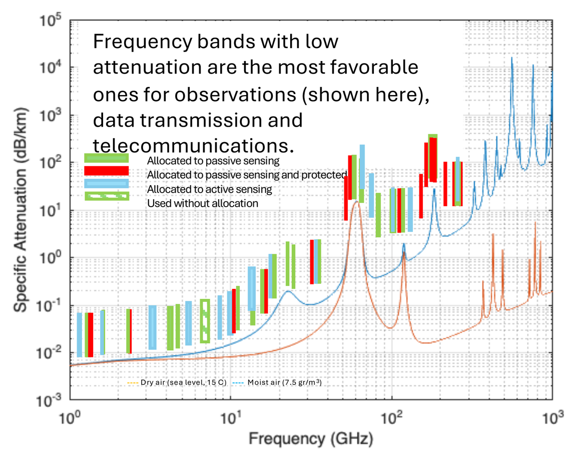
Participation is needed at domestic, regional and global levels.

The Radio Spectrum is a Limited Resource

At the low-frequency end (below ~30 MHz) use of the radio spectrum for communication and remote sensing is limited by the absorption and reflection of radio waves caused by free electrons in the ionosphere.

At the high-frequency end (above ~700 GHz) use of the radio spectrum for communication and remote sensing is limited by the attenuation caused by gasses and aerosols (O_2 and H_2O) in the atmosphere.

The spectral regions where the attenuation is smallest are the most desirable (and sought) for both long-range communication and remote sensing of the environment.



Use of the radio spectrum is specified by an international treaty supervised by a branch of the United Nations, the ITU (International Telecommunication Union).

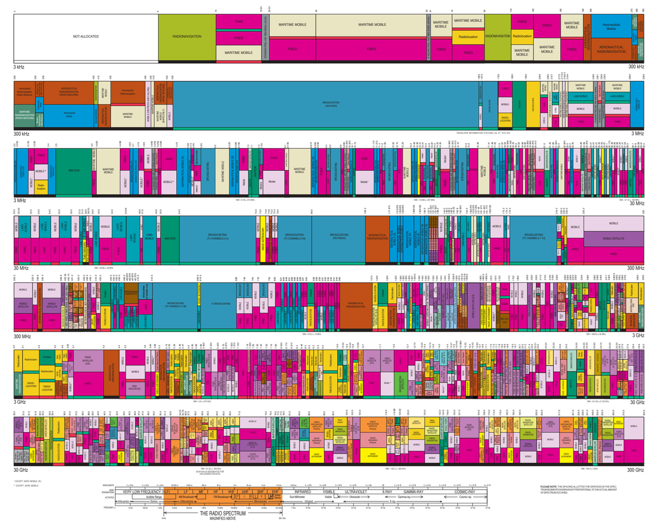
Goal of the ITU is the harmonization of the use of the radio spectrum between the world's countries. The RR (Radio Regulations) is a comprehensive document accepted by all member states. It covers the range from 9 KHz to 300 GHz and is the fundamental legal framework for the deployment of radio-related infrastructures both on Earth and in space.

The world is divided into three regions (Americas, Europe and Africa and Middle East and Siberia, Asia and Australia and Pacific Ocean). In each region the radio spectrum is divided in 'bands' and each band is allocated to a specific service as 'primary' or 'secondary' user. Primary users have the right to not-be-interfered by any other user; secondary users must accept any interference that might arise from primary users.

Primary users may demand that any interfering user be shut down.

The radio frequencies are allocated by international treaty and domestic regulations to multiple applications.

There are no 'empty' spaces for new unique 'primary' users.



Why is the RF spectrum important to the Earth-studying scientific community?

In order to study the Earth (its weather, water and carbon cycles, and climate), scientists depend upon the radio spectrum for two vital functions:

to observe the Earth (e.g., with satellites, weather radars, and wind profilers), and

(1) to transmit data about the Earth system to meteorologists, hydrologists, emergency managers, and other scientists

Why should a scientist be concerned about radio spectrum management?

- Access to the radio spectrum is **critical** to the operation of all remote sensing networks.
- The radio-frequency spectrum is a physically limited and increasingly **contested** resource, with emerging technologies continually raising demand.
- Revision of Radio Regulations to meet new requirements is a **long process.**
- Expertise in radiocommunications regulatory work develops slowly.

Acronyms
CITEL – Comision Interamericana de Telecomunicaciones
CPM – Conference Preparatory Meeting
EESS – Earth Exploration Satellite System
FARC – Frequency Allocation in Remote Sensing
FCC – Federal Communication Commission
IRAC – Interdepartmental Radio Advisory Committee
ITU – International Telecommunication Union
NTIA – National Telecommunication and Information Administration
RCS – Radio Conference Subcommittee
RFI – Radio Frequency Interference
RR – Radio Regulations
SG – Study Group
SW – Space Weather
SMOS – Soil Moisture and Ocean Salinity satellite
WAC – Washington Administrative Code
WP – Working Party
WRC – World Radio Conference
WTDC – World Telecommunication Development Conference
WTSA – World Telecommunication Standardization Assembly

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WHAT'S NEXT FOR SCIENCE

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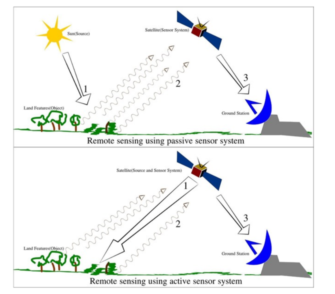
Spectrum makes Science and Science saves Lives but Spectrum needs Protection

The World Radiocommunication Conference in 2027 will decide whether radio frequencies currently used for remote sensing shall remain available to science or become contaminated by radio frequency interference from telecommunication transmitters.

The time to be active and reach out to regulators to protect the interests of the scientific community (and the world population at large) is NOW.

Why is remote sensing important?

- Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object.
- It can be classified into two categories: passive and/or active.
  - **Passive Remote Sensing**: the sensor gets information from radiation emitted or reflected by the object or environment.
    - E.g., photography, radiometers, sondes
  - **Active Remote Sensing**: the sensor emits its own energy to the target object, which then reflects or backscatters some of this energy back to the sensor.
    - E.g., RADAR, LiDAR



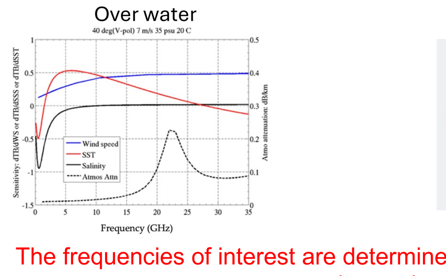
A global, continuous network to monitor the Earth cannot be implemented using local, pinpointed sensors, but instead ...

must rely on a system of remote sensing devices interconnected in real (or almost-real) time.

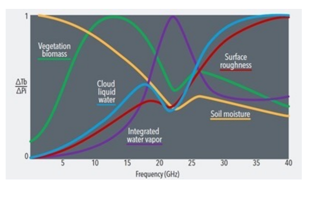
These sensors depend on RF technology to measure the environment and share information.

Sounders (and to some extent imagers) are limited to well-defined frequency bands, where the response is optimal.

Over water



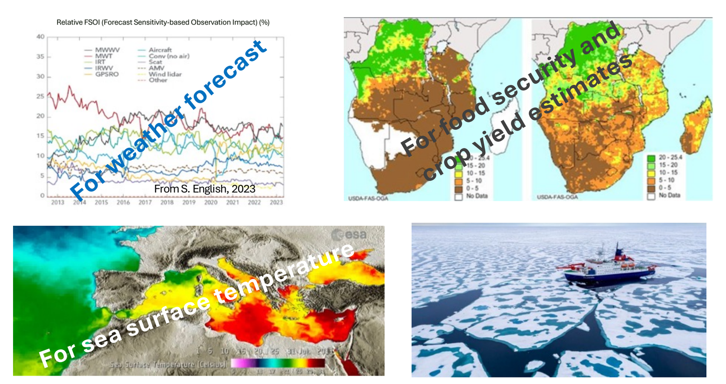
Over land



The frequencies of interest are determined by physics and cannot be changed.

At any given frequency, the intensity of the natural signal depends upon the geophysical characteristics of the surface and of the atmosphere. These characteristics are dictated by physical laws, and are therefore immutable. Every portion of the RF spectrum is unique. Measurements at different frequencies provide complementary information about different geophysical parameters.

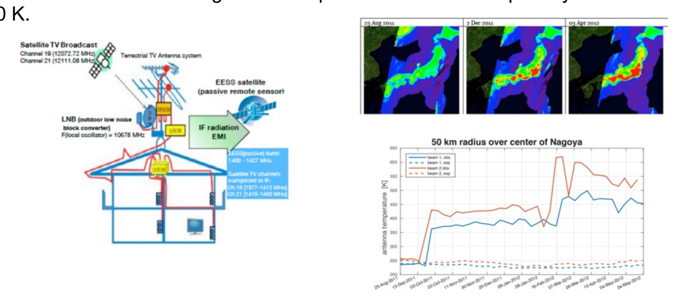
Passive sensing



Passive sensors are used for a variety of applications, including weather forecast, climate change monitoring, and crop yield estimation.

Because they measure very weak signals, passive sensors are easily affected by Radio-Frequency Interference (RFI) which can 'pop up' unannounced at any time.

Example: unintended X-band pollution in Japan when Japanese broadcasting satellite home TV receiver added low noise block converter (1.415 – 1.450 GHz for channel 21) in October 2011. The band partially overlaps SMOS passive band 1.400 – 1.427 GHz. The RFI-affected SMOS brightness temperatures in these maps vary between 500 and 700 K.



Space weather (SW)

SW is the collective noun for all the physical processes occurring in the space environment that ultimately **affects human activities on Earth and in space**.

SW is mainly influenced by the solar wind and the interplanetary magnetic field (IMF) carried by the solar wind plasma.

SW cannot be measured in situ; it can only be monitored remotely via perturbations in the radio flux from the sun or in the Earth's ionosphere.

A variety of physical phenomena are associated with SW and they affect many aspects of everyday's life.

SW sensors operate at the low end of the radio spectrum: from a fraction of a MHz (ionospheric monitors) to 2.8 GHz (solar flux monitors)

Industry	Impact	How forecasting can help
Energy	Power blackouts Damage to grid infrastructure	Energy companies can use space weather services to help minimise the impact of geomagnetic storms, improve the design and modelling of future, more resilient, systems and increased monitoring of impacted systems.
Satellite	Damage to satellites Impacts on performance	Satellite operators can use space weather forecasts to advise of potential degradation or failures in the services they provide.
Communications	Loss of long distance radio communication	Advance notice of heightened solar activity can help flag the risk of blackouts.
Aviation	Disruption to HF comms and high latitude routes Additional radiation doses at high altitude	Advance notice of space weather events is critical to rerouting of high latitude flights, and to alert aircraft in flight of possible loss of communications.
Marine	Disruption to critical navigation systems	Mariners can benefit from space weather forecasts to advise of potential degradation or failures in the GNSS service.
Road transport	Disruption of GNSS	Space weather forecasts help road users understand when Sat Navs may be unreliable.
Rail transport	Disruption of GNSS	Space weather forecasts help rail network operators understand when rail systems may be at risk.

Meteorological Radars

Meteorological Radars are specific and essential since they allow for in-situ and real time detection, quantification and monitoring of rain and wind conditions.

These information are input to Numerical Weather Prediction models for nowcasting, short-term and medium-range forecasting.

The forecasts are important in aiding aeronautical and maritime navigation, and essential in monitoring Chemical or Nuclear disasters.

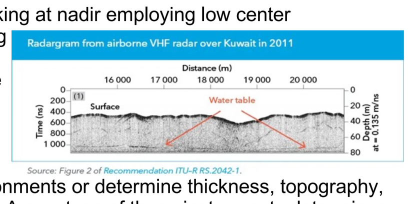
And finally they are critical in hydrological rain and alert processes.

Meteorological radar networks represent the last line of defence against loss of life in flash floods or severe storms events.

Active Sensing

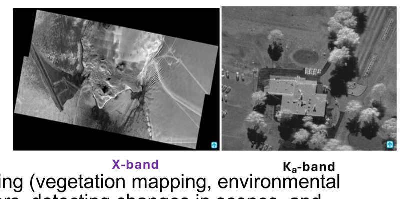
- The amount of reflection and backscattering from the target object(s) is a function of the material and shape of the object(s) and of the frequencies used to illuminate the scene.
- Active sensors (radars) operate from 40 MHz to 200 GHz with bandwidths ranging from 5 KHz to 500 MHz.
- Lower center frequencies can penetrate denser mediums to reflect and backscatter from objects beneath (e.g. foliage or ground penetration), while higher frequencies tend to have shallow penetration depth and are used for thin media (clouds and aerosols).

Radar Sounder: Sensors looking at nadir employing low center frequencies for ground penetrating radar (GPR) applications. They measure the radar return from the Earth's surface and subsurface to identify and characterize underground features such as depth and spatial distribution of shallow aquifers in desertic environments or determine thickness, topography, and discharge rates of ice sheets. A new type of these instruments determines the equivalent water content of snow fields.

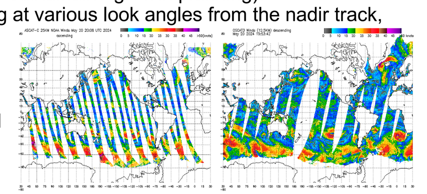


Source: Figure 2 of Recommendation ITU-R RS.2042-1.

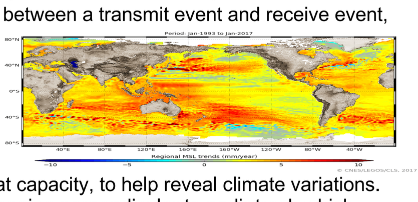
Synthetic Aperture Radar (SAR) Imager: Sensors looking to one side of the nadir track, collecting a phase and time history of the coherent radar echo from which a high-resolution 3-D radar image of the Earth's surface can be produced. Depending upon the center frequency of the radar they are used for geophysical monitoring, global mapping and urban monitoring (vegetation mapping, environmental changes, deforestation and disasters, detecting changes in scenes, and monitoring areas with low to moderate penetration, development and infrastructure changes, useful for sustainable growth planning).



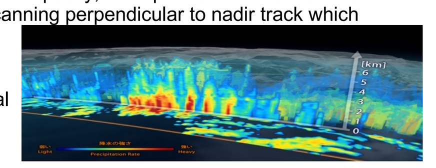
Scatterometer: Sensors pointing at various look angles from the nadir track, using the measurement of the return echo power variation with aspect angle to determine the roughness of land surface or to determine the wind direction and speed on the Earth's ocean surface.



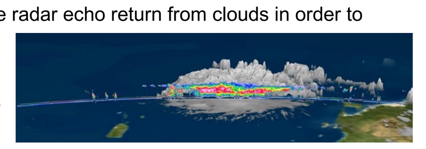
Altimeter: Sensors looking at nadir, measuring the precise time between a transmit event and receive event, to extract the precise altitude of the Earth's surface (sea, ice, land). They are used for ocean-surface topography to study ocean dynamics and effects on climatology and meteorology, and in ocean models to calculate velocity of ocean currents and heat capacity, to help reveal climate variations.



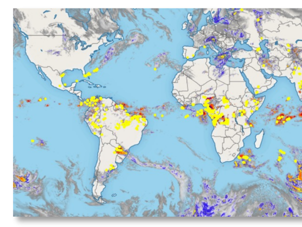
Precipitation Radar: Sensors scanning perpendicular to nadir track which measure the radar echo from rainfall in order to determine the rainfall rate over the Earth's surface and the three-dimensional structure of rainfall.



Cloud Profile Radar: Sensors looking at nadir which measure the radar echo return from clouds in order to determine the cloud reflectivity profile over the Earth's surface and from that the cloud's altitude and properties.



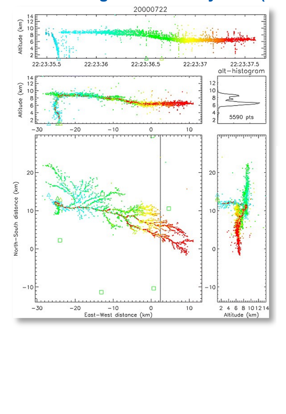
Lightning



Two Minutes of global lightning detection data measured by the GLD360 system for long range lightning detection network superimposed on satellite data showing cloud and precipitation.

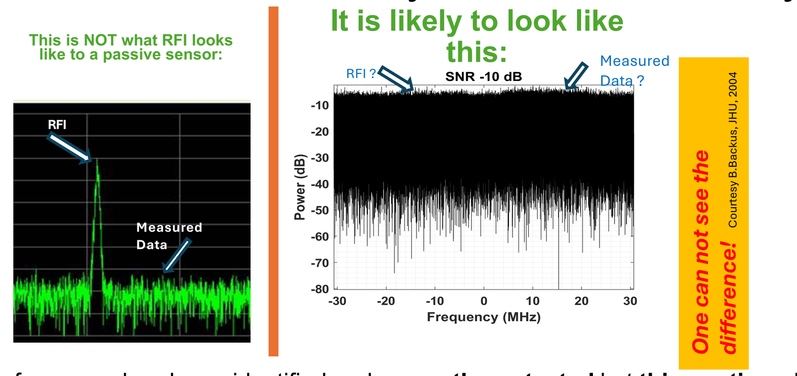
Courtesy K. McBeath, 2024

Short-range detection system (60-66 MHz)



Radiation sources for a negative polarity cloud-to-ground discharge observed by the New Mexico Tech LMA that illustrates the spatial resolution the LMA system can obtain

RFI is insidious and very difficult to identify



Some frequency bands are identified and **currently protected** but **this continued protection can't be taken for granted.**
Some bands have **never been afforded any protection**, but are used because there is no alternative.
Some bands are in areas of spectrum, where **protection has not been considered necessary** but is now needed.

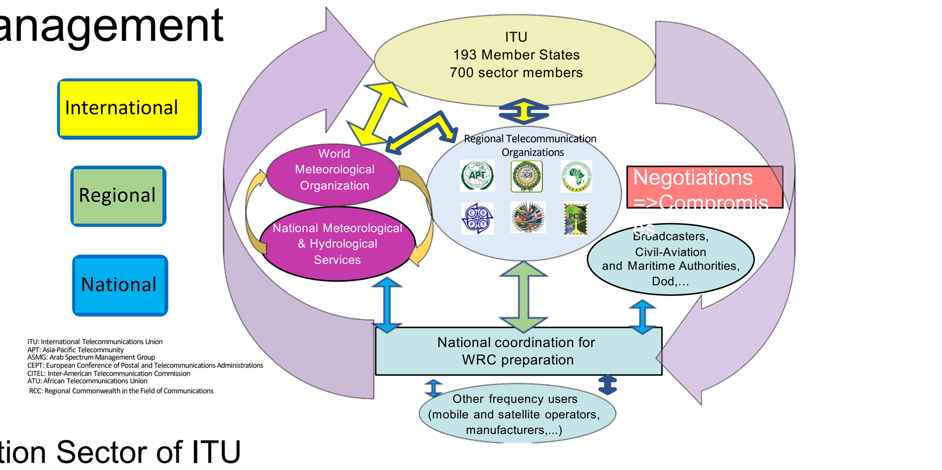
Bands being actively used for weather forecasts:
green = protected by RR 5.340, blue = EESS in Radio Regulations, Red = No protection

Frequency GHz	Instruments	Application area
1.4-1.427	SMOS (ESA), SMAP (NASA), Aquarius (NASA) , CIMR (ESA)	Soil moisture, salinity, thin sea ice
6.425-7.25	AMSR-2 (JAXA) , CIMR (ESA)	SST
10.6-10.68 10.68-10.7	AMSR-2 (JAXA), GMI (NASA), MWRI (CMA) , CIMR (ESA)	Heavy Precipitation
18.6-18.8	AMSR-2 (JAXA), GMI (NASA), AMR (NOAA), MWRI (CMA) , CIMR (ESA) , MWI (EUMETSAT)	Ocean near surface wind,
23.6-24	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), SSMIS (DOD), GMI (NASA), AMR (NOAA), MTVZA-GY (Roscosmos), MWRI (CMA), MWS+I (EUMETSAT), AMSR-2 (JAXA)	Total column water vapour
31.3-31.8	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), GMI (NASA), MTVZA-GY (Roscosmos), MWS+I (EUMETSAT)	Total column cloud liquid
36-37	SSMIS (DOD), GMI (NASA), AMSR-2 (JAXA), MWRI (CMA), CIMR (ESA)	Liquid water path and cloud detection on GMI
50.2-50.4 52.6-54.25 54.25-59.3 59.3-59.5 60.40-61.15 63-63.5	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), SSMIS (DOD), MWTS-2 (CMA), MTVZA-GY (Roscosmos), MWS (EUMETSAT)	Temperature profile
86-92	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), SSMIS (DOD), MWHS-2 (CMA), MTVZA-GY (Roscosmos), MWRI (CMA), MWS (EUMETSAT), AMSR-2 (JAXA)	Precipitation
100-102 109.5-111.8 114.25-116 116-122.25	MWHS-2 (CMA), TROPICS (NASA), MWI (EUMETSAT)	Temperature profile, cloud
148.5-151.5 155.5-158.5 164-167	ATMS (NOAA), GMI (NASA), MHS (EUMETSAT), MWHS-2 (CMA), MTVZA-GY (Roscosmos), SSMIS (DOD) , MWS+I (EUMETSAT)	Precipitation, water vapour
174.8-182.0 182-185 185.0-190.0 190.0- 191.8	AMSU-B (NOAA), MHS (EUMETSAT), ATMS (NOAA), SSMIS (DOD), MWHS-2 (CMA), GMI (NASA), SAPHIR (CNES-ISRO), TROPICS (NASA), MTVZA-GY (Roscosmos), MWS+I (EUMETSAT)	Water vapour
200-209 226-231.5	TROPICS (NASA), MWS (EUMETSAT)	Ice cloud

- Telecommunications engineers and regulators do not understand the operations and sensitivity of EESS passive sensors and constantly question the protection criteria used
- Protection criteria for these passive services are often labeled as "overly protective" (they are not !)
- The accelerated growth in mobile broadband use since the turn of the century has fueled a seemingly insatiable desire for the occupation of more spectrum
- Communications (either mobile broadband or satellite-to-user) are expanding into areas of the radio spectrum that were previously used predominantly by the science services (i.e., ~20-100 GHz)
- Even the millimeter-wave spectrum (~> 100 GHz) is seeing growing demands, which include the request to operate in bands subject to RR 5.340 where no emissions are allowed
- The radio spectrum is considered a revenue-generating commodity by governmental regulatory agencies and it is being auctioned to telecommunication companies for their exclusive use

Spectrum for Science, Science for Humanity

Spectrum Management is a complex and multi-layered process



The Radiocommunication Sector of ITU

Establishes and updates international regulations governing use of the spectrum, through world and regional radiocommunication conferences.

Applies the international regulations governing use of the spectrum, to ensure the most efficient use of the orbit/spectrum resource for operation of radiocommunication services free from harmful interference.

Produces global Standards, Recommendations, Reports and Handbooks for wireless radiocommunication systems.

Informs and assists administrations on radiocommunication matters.

Within the ITU-R, Study Group 7 addresses the needs of scientific services, remote sensing and radioastronomy.
SG7 develops ITU-R Recommendations, Reports and Handbooks and prepares for WRC agenda items, either as responsible or contributing group, related to:
- Dissemination, reception and coordination of standard-frequency and time-signal services on a worldwide basis, including the application of satellite techniques; time signals and frequency standard emissions → Working Party 7A
- Space radiocommunication applications: systems for transmission/reception of telecommand, Tracking and telemetry data for space operation, space research, Earth exploration-satellite, and meteorological satellite services, including the related use of links in the inter-satellite service → Working Party 7B
- Systems for passive and active remote sensing applications in the Earth exploration-satellite service operating on both ground-based and space-based platforms; systems of the MetAids service, including space weather sensors as well as space research sensors, including planetary sensors → Working Party 7C
- Radio astronomy (RAS) and radar astronomy sensors, both Earth-based and space-based, including space very long baseline interferometry (VLBI) → Working Party 7D

Items affecting the Remote Sensing Community and studied by WP7C (partial list)

1.1 Facilitate the use of the frequency bands 47.2-50.2 GHz and 50.4-51.4 GHz (Earth-to-space) by aeronautical and maritime earth stations in motion
1.3 Enable gateway stations transmitting to non-geostationary-satellite orbit systems in the fixed-satellite service (Earth-to-space) to use the 51.4-52.4 GHz band
1.8 Spectrum allocations to the radiolocation service on a primary basis in the frequency range 231.5-275 GHz and possible new identifications for radiolocation service applications in the frequency bands within the frequency range 275-700 GHz for millimetric and sub-millimetric wave imaging systems
1.12 Allocations to the mobile-satellite service in the bands 1 427-1 432 MHz (space-to-Earth), 1 645.5-1 646.5 MHz (space-to-Earth) (Earth-to-space), 1 880-1 920 MHz (space-to-Earth) (Earth-to-space) and 2 010-2 025 MHz (space-to-Earth) (Earth-to-space) for non-geostationary mobile-satellite systems
1.13 and 1.14 Possible additional allocations of spectrum to the mobile-satellite service.
1.15 Allocations to space research service (space-to-space) for development of communications on the lunar surface and between lunar orbit and the lunar surface.
1.16 Protection of radio astronomy operating in specific Radio Quiet Zones and, in frequency bands allocated to the radio astronomy service on a primary basis globally, from aggregate radio-frequency interference caused by non-geostationary satellite orbit systems.
1.17 Allocations to the meteorological aids service (space weather) to accommodate receive-only space weather sensor applications in the RR.
1.18 Protection of the Earth exploration-satellite service (passive) and the radio astronomy service in certain frequency bands above 76 GHz from unwanted emissions of active services
1.19 New primary allocations to exploration-satellite service (passive) in the frequency bands 4 200-4 400 MHz and 8 400-8 500 MHz

How to get involved

➢Record and report any instance of RFI; what is not known cannot be regulated. https://www.fcc.gov/reports-research/guides/interference-complaints

➢Document and quantify how RFI affects your data and your work. Publish in your preferred scientific journal.

➢Reach out to the NASA Spectrum Management Office; it develops policies and provides planning, coordination and representation to secure and protect necessary radio spectrum in support of NASA's programmatic goals supporting all NASA program areas. It provides spectrum analysis expertise and support across the whole NASA. https://www1.grc.nasa.gov/space/scan/spectrum/

➢Reach out to NOAA's Office of Radio Frequency Management Division; its mandate is to ensure the availability and usability of Radio Frequency spectrum to radio users in the Department of Commerce (DOC) by coordinating the NOAA satellite systems with domestic and foreign space networks to prevent and resolve any interference involving DOC and other systems. It negotiates with other government agencies, the private sector, and foreign and international entities on behalf of Commerce and/or the U.S.A. to ensure the future availability of spectrum and the absence of interference. https://www.noaa.gov/information-technology/ocio-programs/radio-frequency-management

➢Join the IEEE-FARS; it is a Technical Committee whose goal is to interface between IEEE-GRSS and the radio-frequency regulatory world. It provides spectrum managers and regulators with technical input and perspective from remote sensing scientists and engineers while advocating for protection of the scientific-sensitive frequency bands. https://www.grss-ieee.org/technical-committees/frequency-allocations-in-remote-sensing/

If you're not at the table, you're on the menu!
[anonymous, first documented circa 1990]