Views of the U.S. NAS and NAE on Agenda Items at the World Radiocommunications Conference 2015

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. The committee wishes to thank the following individuals for their review of this report:

Paul Feldman, Esq., Fletcher, Heald and Hildreth,
William Howard, Universities Space Research Association (retired),
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John Osepchuk, Full Spectrum Consulting,
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Frank Drake (NAS), SETI Institute. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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1

Introduction

The World Radiocommunication Conference (WRC), a gathering of official delegations from over 140 nations, is organized by the International Telecommunication Union (ITU). These delegates come together every few years to negotiate proposals to change international radio spectrum regulations, which, if approved, would then be in force internationally through the auspices of the ITU. These proposals, called agenda items, are not brought to the WRC spontaneously; they must have been agreed on at a previous WRC in order to be considered at the subsequent WRC. In the interim between the two conferences, national governments work internally and with their regional counterparts to develop a consensus position on each proposal to the extent possible given varying national priorities and interests. The national delegates then bring their positions to the WRC and negotiate with other delegations before a final vote on each proposal in carried out.

Agenda items are typically very specific in nature and propose narrow but potentially substantial changes to the use of the spectrum that can have a significant impact on users. Since the vast majority of spectrum allocations are for the active use of the spectrum, it is

NOTE: Portions of this text are taken from National Research Council, *Views of the NAS and NAE on Agenda Items at Issue at the World Radiocommunication Conference 2012*, The National Academies Press, 2013.

critical for vulnerable passive (or, receive-only) services to voice their concerns about potentially adverse effects on their operations.[1]

The passive Radio Astronomy Service (RAS) and the Earth Exploration-Satellite Service (EESS) provide scientific observations of the universe and Earth through the use of advanced receiver technology with extreme sensitivity and complex noise reduction algorithms. Even with such technology, RAS and EESS are seriously adversely affected by what most active services would consider extremely low noise levels.[2]

EARTH EXPLORATION-SATELLITE SERVICE

Satellite remote sensing is a uniquely valuable resource for monitoring the global atmosphere, land, and oceans. Passive instruments are particularly vulnerable to man-made emissions within the EESS bands because they rely on very small signals emitted naturally from Earth's surface and its atmosphere and because they look everywhere (i.e., they monitor globally). Passive remote sensing from satellites provides information that is critical to human welfare and security. This includes information to predict weather and climate and to understand climate change. Examples are parameters such as ocean temperature, salinity, and surface wind speed, needed to understand ocean circulation and the associated global distribution of heat. Passive remote sensing is also important for monitoring soil moisture, a parameter needed for monitoring and predicting agricultural productivity for food security; for land use; for the assessment, adaptation, and risk management of hydrological extremes such as drought and floods; for weather prediction (heat exchange with the atmosphere); and even for defense (planning military deployment). Passive sensors also provide temperature and humidity profiles of the atmosphere, used for weather forecasting, and gather information to monitor changes in the polar

[1] In the United States, the Radio Astronomy Service (RAS) and the Earth Exploration-Satellite Service (EESS) are allocated 2.07 percent of the spectrum on a primary basis and 4.08 percent of the spectrum below 3 GHz on a secondary basis. Allocations for RAS and EESS are comparable in the ITU's international allocation tables. From National Research Council, *Spectrum Management for Science in the 21st Century*, Washington, D.C.: The National Academies Press 2010, pp. 137 and 138.

[2] Spectrum management in the context of the scientific services is discussed in National Research Council, *Spectrum Management for Science in the 21st Century*, Washington, D.C.: The National Academies Press, 2010; National Research Council, *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses*, Washington, D.C.: The National Academies Press, 2007; and "Radio Frequencies: Policy and Management" (2013), to appear in *IEEE Transactions in Geoscience and Remote Sensing* (TGARS).

ice cover and information needed in assessing hazards such as hurricanes, wildfires, and drought.

For many applications, satellite-based microwave remote sensing represents the only practical method of obtaining atmospheric and surface data for the entire planet. Major U.S. governmental users of EESS data include the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Department of Defense (especially the U.S. Navy), the Department of Agriculture, the U.S. Geological Survey, the Agency for International Development, the Federal Emergency Management Agency (FEMA), and the U.S. Forest Service. Much of this data is available free to anyone anywhere in the world.

It is evident that some of these valuable measurements are being corrupted by radiofrequency interference (RFI). For instance, the Soil Moisture and Ocean Salinity (SMOS) mission and the Aquarius mission, operating at 1.413 GHz in a band protected for passive use only, and the Advanced Microwave Scanning Radiometer (AMSR-E), operating at 10.7 GHz, cannot retrieve soil moisture in some areas of the globe because of RFI. Figure 1.1 shows the impact of RFI as observed by the Aquarius satellite. In addition to the RFI effects on passive instruments, recent measurements from active remote sensing instruments[3] have also been found to be affected by RFI.

RADIO ASTRONOMY SERVICE

Radio astronomy is a vital tool used by scientists to study our universe. For example, it is the most promising way of mapping out the Epoch of Reionization (EoR), which refers to the period in the history of the universe shortly after the big bang when the first luminous sources emerged. Radio astronomy also provides valuable data for the benefit of society, such as the monitoring of solar flares and sunspots. Such monitoring allows for 1-4 day forecasts of geomagnetic disturbances that can affect the operation of satellite communications, Global Positioning System (GPS) navigation systems, and terrestrial power grids, as well as the safety of astronauts engaged in space walks. It was through the use of radio astronomy that scientists discovered the first planets outside the solar system, circling a distant pulsar. Subsequent observations of pulsars have revolutionized our understanding of the physics of neutron stars

[3] Active remote sensing involves sending a signal, receiving the reflected signals, and analyzing them. Radar is the prime example of active remote sensing.

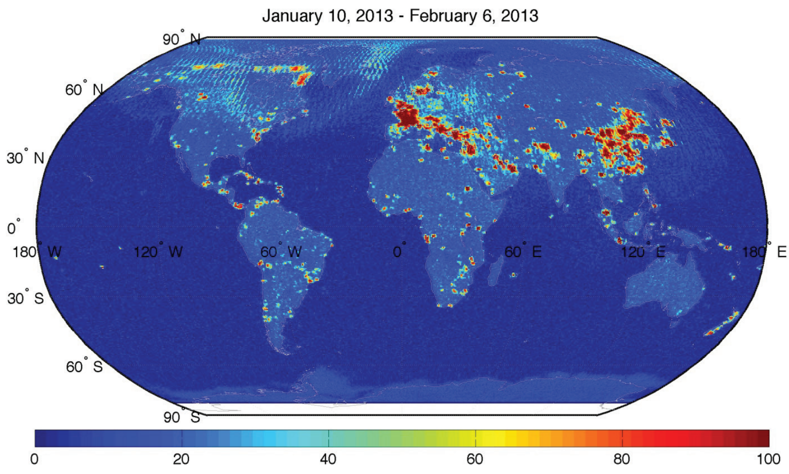

FIGURE 1.1 Percentage of samples flagged as RFI. This is data from the Aquarius radiometer, which operates in the band at 1.413 GHz protected for passive use only (Le Vine et al., *IEEE TGARS* 45, 2007). The radiometer observes the Earth with a footprint diameter of about 100 km. Each observation is tested for RFI, and the map shows the percentage of samples identified as RFI and therefore removed from data processing. The map illustrates the magnitude of the problem even in a band protected for passive use. The map is similar to observations by the SMOS L-band radiometer (Oliva et al., *IEEE TGARS* 50, 2012). RFI is much more prevalent over the land than over the ocean, but it is also a problem over the ocean. For example, the figure shows RFI over the North Atlantic and along the coasts of Greenland and North America. SOURCE: David Le Vine, NASA Goddard Space Flight Center.

and have resulted in the only experimental evidence so far for gravitational radiation.

Radio astronomy has also enabled the discovery of organic matter and prebiotic molecules outside our solar system, leading to new insights into the potential existence of life elsewhere in our galaxy. Measurements of radio spectral line emission have identified and characterized the birth sites of stars in the galaxy, the processes by which stars slowly die, and the complex distribution and evolution of galaxies in the universe.

Radio astronomy measurements have discovered the cosmic microwave background (CMB), the radiation left over from the original big bang after it cooled to only 2.7 K. Later observations discovered the weak fluctuations in the cosmic microwave background (CMB) of only one-thousandth of a percent, generated in the early universe. These later formed the stars and galaxies we know today. Radio observations uncovered the first evidence for the existence of a black hole in our galactic center, a phenomenon that may be crucial to the creation of galaxies. Observations of supernovas have allowed astronomers to witness the distribution of heavy elements essential to the formation of planets like Earth, and of life itself.

Spectrum Sharing and the Scientific Services

The critical science undertaken by Earth remote sensing scientists and radio astronomers cannot be performed without access to interference-free spectrum. Notably, the emissions that radio astronomers receive are extremely weak—a radio telescope receives less than one hundredth of a percent of one-billionth of one-billionth of a watt (10^{-20} W) from a typical cosmic object. Because radio astronomy receivers are designed to pick up such remarkably weak signals, they are particularly vulnerable to interference from in-band emissions, spurious[4] and out-of-band[5] emissions from licensed and unlicensed users of neighboring bands and from emissions that produce harmonic signals in the RAS bands. Out-of-band emissions can exist anywhere in the spectrum. Even weak, distant, man-made signals can preclude scientific use of the spectrum. Similarly, since remote sensing scientists observe the noise floor generated by natural (thermal) radiation and the extremely weak variations therein, their observations are also very vulnerable to interference from man-made transmissions. ITU Recommendations RA.769, RS.1029 and RS.2017 provide technical recommendations on levels that allow reasonable shared use of the spectrum in the context of the passive scientific services.

Moving to other bands is not always a viable option. To fulfill

[4] *Out-of-band emission*: emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions (definition taken from Rec. ITU-R SM.1541-4). *Necessary bandwidth* is defined in Rec. ITU-R SM.1541-4 as "the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions [for a given class of emission]."

[5] *Spurious emission:* emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products, and frequency conversion products but exclude out-of-band emissions (definition from Rec. ITU-R SM.1541-4).

their scientific missions, radio astronomers and remote-sensing scientists must often observe at the specific frequencies characteristic of elements, ions, or molecules, which are established by the laws of physics and chemistry.

To ensure their ability to use the radio spectrum for scientific purposes, scientists must participate in the discussion in the lead-up to the WRC-15, which will next be held in November 2015 in Geneva, Switzerland. At the request of NSF and NASA, the U.S. National Research Council (NRC) convened a committee to provide guidance to U.S. spectrum managers and policy makers as they prepare for the WRC-15 to protect the scientific exploration of the Earth and universe using the radio spectrum (see Appendix for the committee's Statement of Task). While the resulting document (the present report) is targeted at U.S. agencies, representatives of foreign governments and foreign scientific users may find its contents useful as they plan their own WRC positions.

This report identifies the agenda items of relevance to and potentially impacting U.S. radio astronomy and Earth remote sensing observations. The sections are laid out serially in numerical order to facilitate locating a specific agenda item. The committee has determined that the agenda items given in Table 1.1 could, if agreed on as proposed, impact RAS and EESS operations. This report discusses only those agenda items that the committee believes most important and most deserving of comment at the current time. The committee does not comment on the communication of scientific data (i.e., space-to-Earth, Earth-to-space, and space-to-space), because this topic is not within its purview and as such the membership was not composed to address it. It is noted that impact is assessed on criteria related to in-band, out-of-band, and spurious emission as appropriate. For purposes of providing information, it is also noted where a proposed change would impact common practice.

The committee advocates for effective use of the electromagnetic spectrum across all services. This shared use of the spectrum is coupled with a shared responsibility to ensure continued availability of this critical resource for effective use by all.

TABLE 1.1 WRC-15 Agenda Items With Potential Impact on RAS and EESS

Agenda Item	Title
1	On the basis of proposals from administrations, taking account of the results of WRC-12 and the Report of the Conference Preparatory Meeting, and with due regard to the requirements of existing and future services in the bands under consideration, to consider and take appropriate action in respect of the following items:
1.1	To consider additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for International Mobile Telecommunications (IMT) and related regulatory provisions, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution **233 (WRC-12)**;
1.3	To review and revise Resolution **646 (Rev.WRC-12)** for broadband public protection and disaster relief (PPDR), in accordance with Resolution **648 (WRC-12)**;
1.6	To consider possible additional primary allocations:
1.6.1	To the fixed-satellite service (Earth-to-space and space-to-Earth) of 250 MHz in the range between 10 GHz and 17 GHz in Region 1;
1.6.2	To the fixed-satellite service (Earth-to-space) of 250 MHz in Region 2 and 300 MHz in Region 3 within the range 13-17 GHz;
	And review the regulatory provisions on the current allocations to the fixed-satellite service within each range, taking into account the results of ITU-R studies, in accordance with Resolutions **151 (WRC-12)** and **152 (WRC-12)**, respectively;
1.9	To consider, in accordance with Resolution **758 (WRC-12)**:
1.9.1	Possible new allocations to the fixed-satellite service in the frequency bands 7 150-7 250 MHz (space-to-Earth) and 8 400-8 500 MHz (Earth-to-space), subject to appropriate sharing conditions;
1.9.2	The possibility of allocating the bands 7 375-7 750 MHz and 8 025-8 400 MHz to the maritime-mobile satellite service and additional regulatory measures, depending on the results of appropriate studies;
1.10	To consider spectrum requirements and possible additional spectrum allocations for the mobile-satellite service in the Earth-to-space and space-to-Earth directions, including the satellite component for broadband applications, including International Mobile Telecommunications (IMT), within the frequency range from 22 GHz to 26 GHz, in accordance with Resolution **234 (WRC-12)**;
1.11	To consider a primary allocation for the Earth exploration-satellite service (Earth-to-space) in the 7-8 GHz range, in accordance with Resolution **650 (WRC-12)**;

continued

TABLE 1.1 Continued

Agenda Item	Title
1.12	To consider an extension of the current worldwide allocation to the Earth exploration-satellite (active) service in the frequency band 9 300-9 900 MHz by up to 600 MHz within the frequency bands 8 700-9 300 MHz and/or 9 900-10 500 MHz, in accordance with Resolution **651 (WRC-12)**;
1.16	To consider regulatory provisions and spectrum allocations to enable possible new Automatic Identification System (AIS) technology applications and possible new applications to improve maritime radiocommunication in accordance with Resolution **360 (WRC-12)**;
1.17	To consider possible spectrum requirements and regulatory actions, including appropriate aeronautical allocations, to support wireless avionics intra-communications (WAIC), in accordance with Resolution **423 (WRC-12)**;
1.18	To consider a primary allocation to the radiolocation service for automotive applications in the 77.5-78.0 GHz frequency band in accordance with Resolution **654 (WRC-12)**;
2	To examine the revised ITU-R Recommendations incorporated by reference in the Radio Regulations communicated by the Radiocommunication Assembly, in accordance with Resolution 28 (Rev.WRC-03), and to decide whether or not to update the corresponding references in the Radio Regulations, in accordance with the principles contained in Annex 1 to **Resolution 27 (Rev.WRC-12)**

2

Views on WRC-15 Agenda Items

The following pages discuss the committee's consensus on the potential impact and relevance of certain agenda items at issue at the upcoming World Radiocommunication Conference (WRC) in 2015.

AGENDA ITEM 1.1: TERRESTRIAL MOBILE BROADBAND APPLICATIONS

Agenda Item 1.1 considers "additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for International Mobile Telecommunications (IMT) and related regulatory provisions, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution 233 (WRC-12)."

This agenda item is asking administrations to study ways of making additional bandwidth available for IMT, preferably worldwide, and to make submissions to the International Telecommunications Union-Radiocommunication Sector (ITU-R) for consideration prior to WRC-15. It appears to be addressing the broad and generic frequency range from 400 MHz to 6 GHz; however, higher frequencies may also be under consideration. The committee urges administrations to consider the needs of Radio Astronomy Service (RAS) and Earth Exploration-Satellite Service (EESS) services, both passive and active, when making any new allocations to IMT. Care is required in deciding new allocations to prevent interference from in-band, out-of-band, and spurious emissions, given the technological limitations of mobile applications. Furthermore, the proposed application (broadband telecommunications) is often spread-spectrum in nature. As such, it may be problematic for passive (receive-only) applications since its signals may resemble thermal noise for EESS and RAS instruments, interfering with the types of signals detected. It is important to note that ITU footnote 5.340 says "all emissions are prohibited in the bands 1400-1427 MHz and 2690-2700 MHz"[1] among many other bands at frequencies above 6 GHz.

Radio Astronomy Service

Several bands in the subject frequency range are allocated on a primary basis to RAS, including 406-410 MHz, 1400-1427 MHz, 1610.6-1613.8 MHz, 2690-2700 MHz and 4990-5000 MHz. These bands are widely used in RAS applications and care must be taken not to interfere with established observatories using these frequencies. Several other bands are secondarily allocated to RAS and are also widely used and require protection (see listing in Table 2.1). The committee notes that several major RAS facilities operate in this frequency range, including the Robert C. Byrd Green Bank Telescope

[1] Except those provided for by Footnote 5.422 in the case of 2690-2700 MHz.

TABLE 2.1 Current RAS and EESS (Active and Passive) Frequency Allocations in 400 MHz to 6 GHz

Frequency (MHz)	Primary (P) or Secondary (S) Service	Allocated Service and Its Research Application
406.1-410	P	RAS: the Sun, interstellar medium, pulsars, cosmology
432-438	S[a]	EESS (active): biomass, soil moisture
608-614	P	RAS: the Sun, interstellar medium, pulsars
1215-1300	P	EESS (active): soil moisture and sea surface salinity
1330-1400	Footnote protection[b]	RAS: extragalactic neutral hydrogen (HI), recombination lines
1370-1400	S[c]	EESS (passive): sea surface salinity, soil moisture, sea surface temperature, vegetation index
1400-1427	P	RAS: galactic and extragalactic HI, source spectra, interstellar medium, recombination lines, galactic continuum EESS (passive): soil moisture, sea surface salinity, sea surface winds
1525-1535	S	EESS RAS: extragalactic hydroxyl (OH)
1610.6-1613.8	P	RAS: OH
1660-1670	P	RAS: OH
1718.8-1722.2	S[d]	RAS: OH
2640-2655	S[c]	EESS (passive): ocean salinity, soil moisture, vegetation index
2655-2690	S	RAS: continuum observations EESS: ocean salinity, soil moisture
2690-2700	P	RAS: continuum observations EESS: ocean salinity, soil moisture
3100-3300	S	EESS (active): radar altimetry: snow and sea ice; winds; land and ocean topography/mapping; waves and currents
3260-3267	Footnote protection[e]	RAS: CH line
3332-3339	Footnote protection[e]	RAS: galactic continuum

continued

TABLE 2.1 Continued

Frequency (MHz)	Primary (P) or Secondary (S) Service	Allocated Service and Its Research Application
3345.8-3352.5	Footnote protection [e]	RAS: galactic continuum
4200-4400	S [f]	EESS (passive): sea surface temperature
4800-4990	S	RAS: formaldehyde, galactic continuum
4950-4990	S [c]	EESS (passive): estuarine temperature
4990-5000	P	RAS: continuum, very long baseline interferometry
5250-5570	P	EESS (active): synthetic aperture radars, such as RadarSat-2, RISAT-1, Sentinel-1

[a] EESS (active) is secondary in this band in the international table and gains secondary status through Footnote US 397 in the U.S. table.
[b] Per 5.149 and US 342.
[c] Per 5.339.
[d] Per 5.385.
[e] Per 5.149 and US 342.
[f] Per 5.438.

(GBT), the Karl G. Jansky Very Large Array (VLA), the Very Long Baseline Array (VLBA, an instrument with 10 discrete receiving stations spread over North America), and the Arecibo Observatory, for studies of galactic synchrotron continuum emission, neutral hydrogen (HI), pulsars, and active galactic nuclei.

Earth Exploration-Satellite Service

EESS passive applications will often use frequencies in bands protected for RAS passive use since the two services are completely compatible. In fact, EESS shares primary allocations with RAS at 1400-1427 MHz and 2690-2700 MHz and secondary allocations at 2655-2670 MHz. This practical solution results in multiple shared bands. Passive EESS users below 6 GHz include several satellite facilities, which deliver science and operational data for climate science and weather forecasting. These include the European Soil Moisture and Ocean Salinity (SMOS) mission, NASA's Aquarius Mission, and the soon-to-be-launched Soil Moisture Active/Passive

(SMAP) mission, each providing a record of soil moisture and/or ocean salinity, with passive sensors operating in the band at 1400-1427 MHz.

In addition to the protected bands shared with RAS, EESS uses several active bands in the subject frequency range. The 1215-1300 MHz band is used for Earth surface characterization by the Aquarius and SMAP missions. The 5250-5570 MHz radar band has been extensively used for synthetic aperture radar (SAR) missions and experiments to characterize Earth's surface. The active instruments are also subject to radiofrequency interference (RFI), and careful management is needed for successful science applications. Figure 2.1 is an example of the potential for problems with RFI when various uses are shared within a band. These data are from the radar scatterometer that is part of the Aquarius/SAC-D satellite. It operates at 1260 MHz and the primary application is over ocean (although future sensors such as that planned for SMAP will have a primary mission over land). The sensor helps correct for the effect of waves on the retrieval of sea surface salinity. Figure 2.1 provides the per-

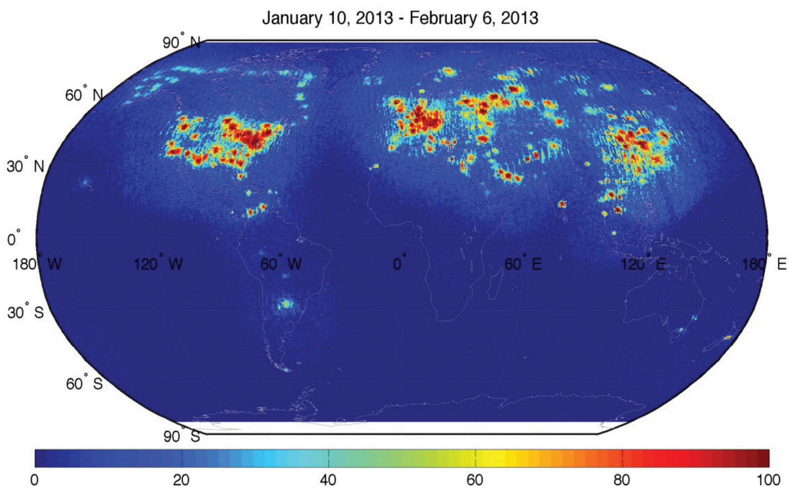

FIGURE 2.1 The distribution of RFI in the active band as detected by the scatterometer (radar) aboard the Aquarius/SAC-D satellite. The map shows the percentage of radar observations contaminated by RFI. The radar operates in the band 1215-1300 MHz and the figure is an illustration of the potential for RFI problems in the active EESS services. SOURCE: David Le Vine, NASA Goddard Space Flight Center.

centage of samples corrupted by RFI, showing the impact of RFI on potential applications over land.

Recommendation: The committee urges administrations to consider the needs of the Radio Astronomy Service and the Earth Exploration-Satellite Service (both passive and active) when making any new allocations to International Mobile Telecommunications (IMT). The committee supports the shared use of the spectrum for this purpose but recommends that rigorous compatibility studies be carried out to determine how services may effectively share the spectrum before any such allocations are made to IMT.

AGENDA ITEM 1.3: BROADBAND PUBLIC PROTECTION AND DISASTER RELIEF

Agenda Item 1.3 is "to review and revise Resolution 646 (Rev. WRC-12) for broadband public protection and disaster relief (PPDR), in accordance with Resolution 648 (WRC-12)."

The committee expresses support for exploring the use of technologies to facilitate emergency response in the immediate aftermath of a catastrophic event and for public protection. The committee notes, however, that in evaluating frequency planning and minimizing the potential for harmful interference, consideration must be given to passive scientific use of the spectrum. Indeed, some passive and active scientific uses of the spectrum may help to predict and mitigate the effects of natural disasters. While deploying PPDR systems in the event of a disaster is not an issue and is indeed endorsed by the committee, the testing of such systems, as well as their use in less urgent situations, could adversely impact scientific services. In particular, it is noted that PPDR systems are often aerially deployed, which results in a strong potential for interference to radio astronomy facilities when such systems are being tested.

Radio Astronomy Service

The 380-470 MHz band mentioned in the resolution contains a primary allocation for radio astronomy at 406.1-410 MHz, which is an important band for interstellar medium studies, pulsars, and baryonic acoustic oscillations.

The mentioned band 4940-4990 MHz is adjacent to the RAS primary allocation at 4990-5000 MHz, which is an important allocation for very long baseline interferometry.

Recommendation: The committee supports studying radio systems for public protection and disaster relief to increase the efficiency and application of such systems. These studies should take into consideration the potential impact on spectrum use by passive services of testing and deploying PPDR systems.

AGENDA ITEM 1.6: ALLOCATION OF 250-300 MHZ IN THE 10-17 GHZ RANGE

Agenda Item 1.6 considers "possible additional primary allocations: to the fixed-satellite service (Earth-to-space and space-to-Earth) of 250 MHz in the range between 10 GHz and 17 GHz in Region 1 [Agenda Item 1.6.1]; and to the fixed-satellite service (Earth-to-space) of 250 MHz in Region 2 and 300 MHz in Region 3 within the range 13-17 GHz [Agenda Item 1.6.2]."

There are a number of existing allocations for scientific services in this frequency range, including passive use by RAS and both passive and active allocations to EESS. Passive use by EESS/RAS is compatible with all other passive users of the electromagnetic spectrum. When considering the impact of frequency allocations on other users, it is also important to note that certain scientific uses cannot be shifted to other frequencies due to the natural origin of the emission features.

Radio Astronomy Service

Primary considerations for RAS are unwanted out-of-band emission from fixed-satellite service (FSS) in neighboring bands. Spurious and out-of-band emission can potentially exist anywhere in the spectrum, and new allocations to FSS at these frequencies could be particularly deleterious to RAS because satellites are difficult to avoid: They appear at high elevations and therefore enter into the line-of-sight of radio telescopes conducting astronomical observations. Almost all major U.S. radio observatories have versatile receivers capable of observing within the specified frequency range. While RAS has limited allocations within this band, common practice is to observe throughout this range. These receivers are used to observe continuum emission from nonthermal synchrotron sources, which reveal the high-energy jets driven by black holes in the centers of galaxies and spinning dust within our own galaxy. Spectral line observations in this frequency range include the formaldehyde transition at 14.4885 GHz (rest frequency) and Doppler shifted carbon monoxide from distant galaxies.[1]

Of significant concern for RAS would be modifications of the current allocations for FSS at 14.47-14.5 GHz, which are currently Earth-to-space. RAS has a secondary allocation at 14.47-14.5 GHz

[1] The Doppler shift associated with the expansion of the universe is characterized by the parameter z (known as redshift), such that the observed frequency is lower than the emitted frequency by a factor of $1 + z$.

(Footnote 5.149) associated with observations of the formaldehyde transition at 14.4885 GHz (rest frequency). If the FSS allocation is revised to include space-to-Earth at these frequencies in Region 1 (Agenda Item 1.6.1), radio observatories in Europe may be adversely impacted.

Earth Exploration-Satellite Service

The primary concern for EESS is out-of-band emissions interfering with reception in the allocated bands of 10.6-10.7 GHz (Footnote 5.149) and 15.35-15.40 GHz (Footnote 5.340). In addition, EESS (active) has an allocation at 13.25-13.75 GHz. Altimeters and scatterometers on satellite observatories such as Cryosat, Jason-2, Jason-3, Jason-CS, Sentinel-3, HY-2, WindSat, GCOM, and GMI use this band. Observations in both the passive and active bands are used for a number of applications including observations of soil moisture, sea surface temperatures, sea surface height, ocean winds, sea ice, snow, and precipitation. These observations are critically important to predict weather, monitor climate, quantify changes in global water cycle, monitor and predict agricultural productivity and to better understand linkages and feedback in ocean circulation and climate change.

The proposed modification to spectrum usage as given in the agenda item includes bands that are allocated to EESS (both passive and active). In addition, allocation of bands adjacent to these EESS bands may severely impact Earth remote sensing through out-of-band emissions. EESS sensors are particularly sensitive to out-of-band emission from space-to-Earth transmissions since the satellite-based transmitter is visible to virtually all EESS users. Even downward-looking sensors are sensitive to RFI from satellites due to reflections from the surface.

Recommendation: The committee recommends that any new fixed-satellite service (FSS) allocations strictly adhere to all current regulation requirements for unwanted emission and out-of-band emission in the protected scientific service bands.

AGENDA ITEM 1.9: POSSIBLE NEW ALLOCATIONS AT 7150-7250 MHZ, 8400-8500 MHZ, 7375-7750 MHZ, AND 8025-8400 MHZ

Agenda Item 1.9 considers "in accordance with Resolution 758 (WRC-12): possible new allocations to the fixed-satellite service in the frequency bands 7150-7250 MHz (space-to-Earth) and 8400-8500 MHz (Earth-to-space), subject to appropriate sharing conditions [Agenda Item 1.9.1]; and the possibility of allocating the bands 7375-7750 MHz and 8025-8400 MHz to the maritime-mobile satellite service and additional regulatory measures, depending on the results of appropriate studies [Agenda Item 1.9.2]."

The 7000-8500 MHz band includes primary allocations to Fixed Service (FS) and Mobile Service (MS). In addition, Space Research Service (SRS) has primary allocations to support deep space missions at 7145-7190 MHz and 8400-8450 MHz; SRS also has primary allocations at 7190-7235 MHz and 8450-8500 MHz to support near-Earth missions, Earth to space (E-s) and space to Earth (s-E), respectively. Furthermore, EESS has a primary allocation for s-E between 8025-8400 MHz. In the United States, subject to Footnote 5.461, Mobile-satellite Service (MSS) has been allocated 7250-7300 MHz (s-E) and 7900-8025 MHz (E-s) on a primary basis. Worldwide, 7250-7750 MHz and 7900-8400 MHz have been allocated to FSS on a primary basis, for downlink (s-E) and uplink (E-s), respectively.

Agenda Item 1.9.1 aims to add an additional 100 MHz above and below the current range for FSS. As listed above, both of these bands are currently allocated to FS, MS, and SRS.

Agenda Item 1.9.2 aims to extend the allocation of Maritime Mobile-Satellite Service (MMSS) to regions of the spectrum within the FSS allocation, specifically 7375-7750 MHz and 8025-8400 MHz.

Radio Astronomy Service

In the United States, the Very Large Array (VLA), the Very Long Baseline Array (VLBA), the Green Bank Telescope (GBT), and Arecibo Observatory all use the 7-9 GHz band for continuum studies of astrophysical objects ranging from planets to stars to galaxies. Radio spectroscopy and broad band continuum observations have identified and characterized the birth sites of stars in the galaxy, the processes by which stars slowly die, and the complex distribution and evolution of galaxies in the universe. The enormous energies contained in the enigmatic quasars and radio galaxies discovered by radio astronomers has led to the recognition that most galaxies, including our own Milky Way, contain a super massive black hole at their center, a phenomenon that appears to be crucial to the creation and evolution of galaxies. Synchronized observations using widely spaced radio telescopes around the world give extraordinary angular resolution far superior to that which can be obtained using the largest optical telescopes on the ground or in space.

Agenda Item 1.9.1

The addition of new allocations 7150-7250 (s-E) and 8400-8500 MHz (E-s) to FSS would have some impact on VLA, GBT, and other radio observatories that currently make use of this band. Specifically, the current allocation of 8400-8500 MHz to SRS has allowed RAS to use this band, without formal protection, since there are relatively few deep space missions, and the signals they send back to Earth are very faint compared to typical satellite downlinks. New allocations to FSS at these frequencies would be particularly deleterious to RAS because satellites are difficult to avoid: They appear at high elevations, can cross much of the sky, and therefore enter into the line of sight of radio telescopes conducting astronomical observations. The committee notes that SRS receivers will experience similar adverse effects from satellites as well.

Agenda Item 1.9.2

New allocations for maritime-mobile satellite service from 7375-7750 MHz (s-E) and 8025-8400 MHz (E-s) are likely to have some impact on VLA and other radio telescopes using this band. However, the Earth-to-space uplinks are much less likely to affect radio telescopes since radio observatories are generally distant from shorelines (with two exceptions: the VLBA_SC antenna in Saint Croix and the VLBA_MK antenna in Hawaii).

Earth Exploration-Satellite Service

The 7-9 GHz band is currently used by meteorological satellites (MetSat) with applications to the measurements of Earth variables necessary for operational meteorology, forecasts, numerical weather prediction (NWP), climate monitoring, and climate change studies. Currently, 7450-7550 MHz is used for geostationary orbit (GSO) downlinks (s-E) and 8175-8215 MHz is used for uplinks (E-s) by MetSat. However, some EESS downlink Earth stations are located near the coast and therefore could suffer interference from new proposed maritime transmissions within 8025-8400 MHz near these regions unless acceptable sharing criteria or exclusion zones are established.

Conclusion: The committee is not in favor of the proposed FSS allocations of 7150-7250 MHz (s-E) and 8400-8500 MHz (E-s) due to their potential conflicts with radio astronomy observations at these frequencies. The committee does not oppose the proposed Maritime Mobile-Satellite Service allocations 7375-7750 MHz (s-E) and 8025-8400 MHz (E-s) if ITU-R studies demonstrate compatibility with existing services.

AGENDA ITEM 1.10: MOBILE-SATELLITE SERVICE IN THE EARTH-TO-SPACE AND SPACE-TO-EARTH DIRECTIONS

Agenda Item 1.10 is "to consider spectrum requirements and possible additional spectrum allocations for the mobile-satellite service in the Earth-to-space and space-to-Earth directions, including the satellite component for broadband applications, including International Mobile Telecommunications (IMT), within the frequency range from 22 GHz to 26 GHz, in accordance with Resolution 234 (WRC-12)."

A principal concern is the 22.21-22.5 GHz band, which has a co-primary allocation between the EESS and RAS passive services and the fixed and mobile services, except for aeronautical and mobile services, and the 23.6-24 GHz band, which has primary allocation for EESS passive services. In the frequency range 22-26 GHz, there are primary allocations for RAS at 22.21-22.5 GHz and 23.6-24 GHz and footnote protection at 22.01-22.5 GHz, 22.81-22.86 GHz, and 23.07-23.12 GHz (Footnotes 5.149 and US 342). There are primary allocations for EESS at 22.21-22.5 GHz (passive), 23.6-24 GHz (passive), and 25.5-27 GHz, and a secondary allocation at 24.05-24.25 (active). In the 22.21-22.5 GHz band, ITU Radio Regulations Footnote 5.149 states that, "administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service." The proximity of communication uplinks to the allocated 22.21-22.5 GHz band increases the risk that out-of-band emissions will interfere with EESS and RAS passive services. Furthermore, ITU Footnote 5.340 says "all emissions are prohibited" in the 23.6-24.0 GHz band.

Radio Astronomy Service

The RAS passive service in the primary and secondary allocation bands has several key molecular transitions, which are used to study the structure of dense interstellar clouds. Understanding molecular clouds is an important goal of galactic astronomy. All star formation in our galaxy proceeds from molecular clouds and understanding the role they play in how stars form is fundamental to fully understanding the life cycle of stars. The most important transitions for the study of molecular clouds in these bands are the NH_3 1(1)-1(1) and 2(2)-2(2) lines at 23.7 GHz, the CH_3OH line at 24.9 GHz, and H_2O at 22.2 GHz. Other species are also present, but the ones specifically mentioned are key probes of the physical conditions in molecular cloud cores. Molecular clouds can be studied both in the Milky Way Galaxy and in external galaxies, where the relevant molecular transitions will be shifted toward lower frequencies by the expansion of the universe.[1] In external galaxies, water maser emission at 22 GHz, particularly from 22.2 GHz down to the red-shifted frequency of 21.2 GHz, is extremely useful in determining distances to distant galaxies. Given that the determination of distances in astronomy is one of the most fundamental problems, the importance of observations at this frequency cannot be overstated.

Earth Exploration-Satellite Service

For EESS, the 23.6-24.0 GHz band is currently used extensively in operational environmental satellite systems to provide measurements of total integrated water vapor and cloud liquid water. These are key measurements for many current models of climate and environmental impact. Uses of this frequency include hurricane tracking, ocean topography, oil spill monitoring, and ship routing.

In addition, passive measurements from EESS satellites near the water vapor absorption line at 22.2 GHz are essential not only for measuring atmospheric water vapor but also for reducing error in other geophysical parameters due to the presence of water vapor, especially in moist atmospheres. For example, the accuracy in measuring sea surface wind speed, sea surface temperature, liquid cloud water or precipitation would significantly degrade if the 22 GHz water vapor channel was not present or was unusable due to RFI contamination.[2]

Recommendation: The committee recommends that any new Mobile-Satellite Service allocations strictly adhere to all current regulation requirements for unwanted emission and out-of-band emission in the protected scientific service bands, which includes a critical tracer of water vapor in the atmosphere.

[1] The Doppler shift associated with the expansion of the universe is characterized by the parameter z (known as redshift), such that the observed frequency is lower than the emitted frequency by a factor of $1+z$.

[2] As found in National Research Council, *Views of the NAS and NAE on Agenda Items at Issue at the World Radiocommunication Conference 2012*, The National Academies Press, 2013, p. 26.

AGENDA ITEM 1.11: A PRIMARY ALLOCATION FOR THE EARTH EXPLORATION-SATELLITE SERVICE (EARTH-TO-SPACE) IN THE 7-8 GHZ RANGE

Agenda Item 1.11 considers "a primary allocation for the Earth exploration-satellite service (Earth-to-space) in the 7-8 GHz range, in accordance with Resolution 650 (WRC-12)."

Radio Astronomy Service

The impact of this agenda item on RAS is expected to be minimal. Existing EESS Earth-to-space terminals are few in number relative to other services and are in fixed locations that have negligible impact on RAS. Furthermore, the potential impact on RAS of Earth-to-space communications is much less severe than space-to-Earth.

Earth Exploration-Satellite Service

Given that the associated terminals are few in number and are in fixed locations, the impact on EESS would be minimal.[1] Furthermore, this agenda item will have a positive impact on EESS scientific programs by supporting uplink operations.

Conclusion: Given the fact that the proposed frequency allocation will support Earth Exploration-Satellite Service (EESS) scientific programs with little deleterious impact on Radio Astronomy Service or EESS (passive), the committee supports Agenda Item 1.11.

[1] However, it should be noted that the NASA Deep Space Network uses 7.145-7.190 GHz for communication with deep space missions (e.g., planetary and outer solar system science). These missions provide invaluable information on the nature of our solar system, so an allocation outside this band is preferred.

AGENDA ITEM 1.12: EXTENSION OF WORLDWIDE ALLOCATION TO EESS (ACTIVE) TO 8700-9300 MHZ AND/OR 9900-10500 MHZ

Agenda Item 1.12 considers "an extension of the current worldwide allocation to the Earth exploration-satellite (active) service in the frequency band 9 300-9 900 MHz by up to 600 MHz within the frequency bands 8700-9300 MHz and/or 9900-10500 MHz, in accordance with Resolution 651 (WRC-12)."

Radio Astronomy Service

Observations with radio telescopes at these frequencies measure the continuum emission from astrophysical sources, such as quasars, which can reveal the physical processes dominating the energetic cores of many galaxies. Existing instrumentation on U.S. radio astronomy facilities includes receivers that are optimal within 8000-10000 MHz (X band). These receivers are compatible with all other passive users of the radio spectrum and with active users that are geographically shielded from the fixed locations of the radio observatories. Allocation of additional active services for EESS above 9300 MHz is unlikely to impact RAS significantly.

Earth Exploration-Satellite Service

The proposed extension of the 9300-9900 MHz band allocated for EESS active services will further enhance Earth remote sensing applications. However, allocation of the additional EESS (active) services in the band at 9900-10500 MHz is a concern for EESS passive services conducted in the protected 10600-10700 MHz band because of the potential for unwanted out-of-band emissions. ITU Footnote 5.340 says "All emissions are prohibited in the 10.68-10.7 GHz band except those provided for by No. 5.483." This protected band is critical for measurement of parameters such as sea surface winds, soil moisture, and precipitation.

Recommendation: Additional allocations to Earth Exploration-Satellite Service active services should follow existing regulatory requirements and recommendations for demonstration studies (*Resolution 651*) to ensure that unwanted out-of-band emissions will not impact the passive scientific services in the neighboring 10600-10700 MHz band.

AGENDA ITEM 1.16: AUTOMATIC IDENTIFICATION SYSTEM TECHNOLOGY APPLICATIONS AND MARITIME RADIOCOMMUNICATION

Agenda Item 1.16 considers "regulatory provisions and spectrum allocations to enable possible new Automatic Identification System (AIS) technology applications and possible new applications to improve maritime radio communication in accordance with Resolution 360 (WRC-12)."

Radio Astronomy Service

Radio astronomy observations of the 21 cm hydrogen line redshifted[1] to the 150.05-153 MHz band are used to study the Epoch of Reionization (EoR) in the early universe. RAS has primary status in this band in ITU Region 1. Current programs to study the EoR include observations with the Long Wavelength Array (LWA) in New Mexico, the Low Frequency Array (LOFAR) in Europe, the Murchison Widefield Array (MWA) in Western Australia, the Giant Metrewave Radio Telescope (GMRT) in India, and the Precision Array for Probing the Epoch of Reionization (PAPER) in South Africa. New frequency allocations should avoid regions of the spectrum allocated to the passive scientific services.

Recommendation: The committee recommends that any new Automatic Identification System (AIS) allocations avoid the bands allocated to the passive scientific services and strictly adhere to all current regulation requirements for unwanted emission and out-of-band emission in the protected scientific service bands. In particular, new channels assigned to enhance the AIS service should avoid the 150.05-153 MHz band, which is allocated on a primary basis in Region 1 to Radio Astronomy Service.

[1] The Doppler shift associated with the expansion of the universe is characterized by the parameter z (known as "redshift"), such that the observed frequency is lower than the emitted frequency by a factor of $1 + z$.

AGENDA ITEM 1.17: WIRELESS AVIONICS INTRA-COMMUNICATIONS

Agenda 1.17 considers "possible spectrum requirements and regulatory actions, including appropriate aeronautical allocations, to support wireless avionics intra-communications (WAIC), in accordance with Resolution 423 (WRC-12)."

This agenda item does not indicate the specific frequency range of interest, but the desired allocation would come from existing Aeronautical Mobile Service (AeMS), Aeronautical Mobile (R) Service (AM(R)S), and Aeronautical Radionavigation Service (AeRNS). Additional frequency bands above 15.7 GHz would be considered if the requirements cannot be met in the existing aeronautical allocations.

In this context, current allocations of concern for the scientific services below 15.7 GHz are 117.975-137 MHz MetSat under Radio Regulation No. 5.203; 5350-5460 MHz EESS (active); and 13.25-13.4 GHz EESS (active) and Space Research Service (active) (SRS). In addition, if radio navigation bands are considered for WAIC, this could affect usage of 74.8-75.2 MHz, which is in close proximity to the 73-74.6 MHz allocation to RAS, and of 15.4-15.43 GHz, which is adjacent to the 15.35-15.4 GHz RAS allocation.[1]

Radio Astronomy Service

In common practice, radio observatories operate in all of these bands. The 117.975-137 MHz and 73-74.6 MHz bands are of particular interest to EoR studies because they encompass the 21 cm line at redshifts from 11 to 9 which are very close to the predicted trough and peak in the spectrum of the EoR of the early universe.[2] Aircraft travel at high elevations, so they can enter into the line of sight of radio telescopes, with very adverse impact.

Earth Exploration-Satellite Service

Space-borne active sensors have been used to study Earth's surface and atmosphere using sensors such as synthetic aperture radars (SAR), altimeters, scatterometers, and precipitation and

[1] ITU Footnote 5.340 says, "All emissions are prohibited in 15.35-15.4 GHz, except those provided for by No. 5.511."

[2] The Doppler shift associated with the expansion of the universe is characterized by the parameter z (known as redshift), such that the observed frequency is lower than the emitted frequency by a factor of $1 + z$.

cloud radars. These sensors provide multiple geophysical parameters used for weather forecasting and climate monitoring, including the altitude of Earth's ocean surface, ocean surface wind speed and direction, cloud water amount, and precipitation rate. Examples of EESS active sensors are RADARSAT-2, Jason-1 and Jason-2, Jason-3 (upcoming), QuikSCAT/SeaWinds, the Tropical Rainfall Measuring Mission (TRMM), and OceanSat-2/OSCAT. As an example of frequency selection, the TOPEX/Poseidon follow-on missions Jason-1 and Jason-2 use a dual-frequency radar altimeter that measures in the K_u (13.575 GHz) and C (5.3 GHz) bands. The choice of frequency depends on the Earth/ocean surface interaction with the electromagnetic field and therefore cannot be chosen arbitrarily. Dual frequency operation allows ionospheric delay compensation for adequate accuracy of measurements. The bandwidth is selected according to necessary accuracy and resolution of the measurements and can vary from 300 kHz to 300 MHz.

Interference from direct path signals and signals reflected off Earth's surface can affect measurements made by EESS sensors over large areas. The higher the originating transmitter, the larger the area affected. The airborne application is global and when combined with the emitter altitude, it becomes impossible to achieve geographic isolation of the signals.

Recommendation: No new allocations to wireless avionics intra-communications (WAIC) should be made unless acceptable criteria are developed to avoid interference with Radio Astronomy Service (RAS) and Earth Exploration-Satellite Service (both active and passive). Particular care should be taken to limit out-of-band emissions if WAIC allocations are made in the 74.8-75.2 MHz band (in close proximity to the 73-74.6 MHz RAS allocation) or the 15.4-15.43 GHz band (adjacent to the 15.35-15.4 GHz RAS allocation).

AGENDA ITEM 1.18: PRIMARY ALLOCATION TO THE RADIOLOCATION SERVICE FOR AUTOMOTIVE APPLICATIONS IN THE 77.5-78.0 GHZ BAND

Agenda Item 1.18 considers "a primary allocation to the radiolocation service for automotive applications in the 77.5-78.0 GHz frequency band in accordance with Resolution 654 (WRC-12)."

Industry is seeking to include 77.5-78 GHz, which is currently allocated to Amateur, Amateur-Satellite, Radio Astronomy and Space Research (space-to-Earth), in a wider band, 77-81 GHz, for Short Range Radar (SRR) for automobiles. This wider frequency band in which Radio Astronomy has primary allocations[1] contains several molecular spectral lines, including that of semi-heavy water (HDO), methanol (CH_3OH), and the ion N_2D^+, that are very important to studies of the interstellar medium. These spectral lines provide unique information about star formation, including the formation of planets in other solar systems, the building blocks of biological molecules, the physics and chemistry of the interstellar medium, and the history of the early universe.

Radio Astronomy Service

The primary concern for radio astronomy is the operation of radars close to millimeter-wave radio observatories. Based on tests of a SRR conducted at the University of Arizona's 12 meter mm-wave telescope located at Kitt Peak, Arizona, an exclusion zone in the ~30-40 km range around a mm-wave observatory would be required to keep interference from a single vehicle below the Recommendation ITU-R RA.769-2 level of -148 dBW/m^2/MHz.[2] While smaller radii might suffice in areas without direct line of sight to the radio telescope, aggregate effects should be taken into account as more vehicles are outfitted with SRR in the coming years. ITU-R RA.1272-1 specifically recommends that such zones be established

[1] In 77-81 GHz, RAS has primary allocations at 76.0-77.5 GHz (ITU and U.S tables); 78-79 GHz (U.S. table); and 79-81 GHz (ITU and U.S tables). In this range RAS has secondary allocations at 77.5-78 GHz (ITU and U.S tables) and 78-79 GHz (ITU table).

[2] National Radio Astronomy Observatory, "Measurements of Automotive Radar Emissions Received by a Radio Astronomy Observatory," Electronics Division Technical Note No. 219, December 8, 2011.

around mm-wave astronomical observatories, following the procedure outlined in Recommendation ITU-R RA.1031-2.[3]

The committee is concerned about the further erosion of this important RAS band to accommodate automotive radar but appreciates the safety aspect of SRR. Compatibility studies would help ascertain whether provisions could be made to protect radio astronomy observatories and other sensitive facilities from emissions from the SRRs. The committee feels strongly that, at a minimum, the driver of a vehicle should be allowed to take personal responsibility for turning off the radar, with appropriate warnings to ensure safety, within an exclusion zone around a mm-wave observatory in the same manner as a switch allows vehicle headlights to be turned off when approaching an optical observatory at night. Alternatively, the radar could be automatically disabled by a geolocation device.

Recommendation: Comprehensive compatibility studies should be undertaken prior to allocating spectrum to the radiolocation service for automotive applications to ensure that provisions can be made to protect radio astronomy observatories and other sensitive facilities. Furthermore, the driver should be able to turn off the radar, with appropriate warning to ensure safety, within an exclusion zone around a millimeter-wave observatory. Alternatively, a geolocation device in the vehicle could automatically disable the radar and alert the driver of this action. Such protections should be applied to the whole 77-81 GHz band.

[3] Ibid. In addition it is noted that the automobile radars in close proximity to an optical telescope can interfere with sensitive charge coupled device (CCD) detectors. Automobiles within 20 m of an optical telescope could also exceed the limit of 2 μW/m^2 in Recommendation 3 of the International Astronomical Union (IAU) Commission 50 (Appendix 4.1, Section 6.3, published in 1978) required to avoid radiofrequency power interfering with sensitive CCD detectors.

AGENDA ITEM 2: UPDATING THE REFERENCES IN THE RADIO REGULATIONS IN ACCORDANCE WITH PRINCIPLES CONTAINED IN THE ANNEX 1 TO RESOLUTION 27 (REV. WRC-12)

Agenda Item 2 reads as follows: "to examine the revised ITU-R Recommendations incorporated by reference in the Radio Regulations communicated by the Radiocommunication Assembly, in accordance with Resolution 28 (Rev.WRC-03), and to decide whether or not to update the corresponding references in the Radio Regulations, in accordance with the principles contained in Annex 1 to Resolution 27 (Rev.WRC-12)."

To clarify which Recommendations are incorporated into the Radio Regulations, a list of Recommendations incorporated by reference is published in the Radio Regulations. Recommendation ITU-R RA.769, which includes interference levels as a function of radio telescope parameters, has been in effect since the early 1970s, and until recently ITU-R RA.769-1 was referenced in the Radio Regulations. The updated Recommendation ITU-R RA.769-2 has been dropped from the list, which diminishes the ability of groups to draft and implement recommendations and regulations based on this important Recommendation. Similarly, RS.2017 provides important information on interference levels for EESS passive and should also be included.

Recommendation: The committee recommends that ITU-R RA.769-2 and RS.2017 be added to the list of recommendations incorporated by reference.

3

Concluding Remarks

Radio frequency interference is a substantial concern to the passive scientific services, the Radio Astronomy Service (RAS) and the Earth Exploration-Satellite Service (EESS). The 2010 National Research Council report *Spectrum Management for Science in the 21st Century*[1] found that "[i]mportant scientific inquiry and applications enabled by the Earth Exploration-Satellite Service (EESS) and the Radio Astronomy Service (RAS) are significantly impeded or precluded by radio frequency interference (RFI). Such RFI has reduced the societal and scientific return of EESS and RAS observatories and necessitates costly interference mitigation, which is often insufficient to prevent RFI damage." In particular, even when false measurements due to RFI are detected and eliminated, scientific measurements and their use are degraded by the loss of data. Of particular concern to both RAS and EESS are spurious and out-of-band transmitter emissions from commercial devices. Such emissions are typically neither precisely controlled during device manufacturing nor essential to the devices' intended purposes.

Strategies to minimize RFI for RAS and EESS include cooperative agreements, respecting primary and secondary spectrum allo-

NOTE: Portions of this text are adapted from National Research Council, *Views of the NAS and NAE on Agenda Items at Issue at the World Radiocommunication Conference 2012,* The National Academies Press, Washington, D.C., 2013.

[1]National Research Council, *Spectrum Management for Science in the 21st Century*, The National Academies Press, Washington, D.C., 2010.

cations, placement of facilities in remote locations, establishment of radio quiet zones, and application of sophisticated RFI excision algorithms. In concert, these mitigation techniques allow continued scientific advancement in some areas, but not all are applicable to all scientific services. For example, many EESS programs include observations of the entire globe and thus cannot rely on local shielding or remote locations to reduce RFI. Conversely, many RAS programs require observations at frequencies not allocated specifically to the passive services and thus rely on local shielding to minimize RFI at these frequencies. It is important to note that, by their very nature, passive services do not interfere with other users of the spectrum. In consideration of these varied approaches to RFI mitigation for the passive services, comments on agenda items include discussion of spectral regions not allocated specifically to RAS or EESS and to geographic regions outside the United States.

RADIO ASTRONOMY SERVICE

For context, it is important to understand the exceedingly weak nature of the typical signals detected by radio telescopes. They can be a million times smaller than the internal receiver noise, and their measurement, or even just their detection, can require bandwidths of many gigahertz and integration times of a day or more. This requirement puts a premium on operating in a very low noise environment. It should be emphasized that serious interference can result from weak transmitters even when they are situated in the sidelobes of a radio astronomy antenna. This state of affairs has been recognized by the International Telecommunications Union (ITU) internationally and by the Federal Communications Commission (FCC) in the United States, and various spectral bands have been allocated to the RAS for "exclusive" or "shared" use of these bands. However, "exclusive" does not mean that there is zero emission in the protected bands. It is a fundamental fact that any information-carrying signal can contain out-of-band emission, which spreads across a wide radio spectrum. Regulation of this out-of-band emission from a licensed transmitter involves controlling the intensity of the emission, but the allowable level of out-of-band emission may still cause harmful interference to radio astronomy observations. It is likely that spurious and out-of-band emissions will be an even greater problem in the future as the active services continue to proliferate and scientific advances drive radio astronomers to observe weaker and weaker sources. Recommendation ITU-R RA.769 discusses interference protection criteria for the RAS and defines threshold levels of emissions that cause interference detrimental to radio astronomy. Interference protection is often specified separately for spectroscopic observations and continuum observations.

Radio spectroscopic observations require observations at frequencies determined by the physical and chemical properties of individual atoms and molecules. In particular, our knowledge of the chemical makeup of the universe comes through measurement of spectral lines arising from quantum mechanical transitions, so it is important to protect the frequencies characteristic of the most important atomic and molecular cosmic constituents. However, the necessary parameters are not yet known for all possible species of interest. Moreover, due to the expansion of the universe, even known spectroscopic lines may be Doppler shifted by more than a factor of five. For reference, the apparent Doppler shift associated with the expansion of the universe is characterized by the parameter z, such that the observed frequency is lower than the emitted frequency by a factor of $1 + z$. Therefore, detection of molecules in distant sources may require observations at frequencies well below the characteristic frequency measured in the laboratory. Thus, observations at spectral frequencies well outside the bands allocated to RAS on a primary or secondary basis are often conducted in order to search for new molecular species and to detect Doppler shifted spectroscopic lines from both nearby and distant sources and the early universe.

The situation with continuum observations of radio emission from cosmic thermal and nonthermal sources, however, is different from that of spectral lines. There are no preferred frequencies, but observations at multiple frequencies are required to define the properties of stars, galaxies, quasars, pulsars, and other cosmic radio sources. Historically, narrow bands spaced throughout the spectrum have been given various levels of protection to enable these important studies. However, improvements in antenna and receiver design now permit instantaneous bandwidths of 50 percent or more to be used in the latest generations of radio telescopes. This results in an improvement in sensitivity over earlier narrow band systems by up to an order of magnitude; furthermore, broad bandwidths are also employed to study many spectral lines simultaneously. Unfortunately, receivers can become nonlinear as a result of RFI at neighboring frequencies, and intrinsically weak emission can be easily overwhelmed by RFI. Thus, the advent of routine observations over broad bandwidths by radio telescopes will require even more vigilance in RFI mitigation to enable further advances in radio astronomy. In particular, while improved RFI mitigation and excision techniques have expanded the scientific return of many facilities, they are an inferior option relative to a clean, interference-free spectrum. This relies on the shared responsibility of users to make sure all are making effective use of the electromagnetic spectrum.

Emissions from satellites and aircraft for the purposes of communications and operations are a prime concern for RAS because satellites and aircraft have no geographical boundaries and are in the direction in which radio telescopes observe. Thus, the remote locations chosen for telescope sites provide no protection from such sources when they are in direct line of sight above the horizon. Future progress in radio astronomy may largely depend on national and regional protection of large frequency bands in the vicinity of major radio telescopes, along with the global regulation of transmissions from satellites and aircraft.

EARTH EXPLORATION-SATELLITE SERVICE

Satellite remote sensing is a uniquely valuable resource for monitoring the global atmosphere, land, and oceans. Passive instruments are particularly vulnerable to man-made emissions within the EESS bands because they rely on very small signals emitted naturally from Earth's surface and atmosphere and because they monitor globally. In many cases having global coverage is essential to the application (e.g., soil moisture as a parameter for understanding the global water, energy. and carbon cycles). This means worldwide controls are necessary.

Passive remote sensing from satellites provides information that is critical to understanding Earth's environment. This includes information to predict weather and climate and to understand climate change. Examples are parameters such as ocean temperature and salinity, needed to understand ocean circulation and the associated global distribution of heat. Passive remote sensing is also important for monitoring soil moisture, a parameter needed for monitoring and predicting agricultural productivity for food security; land use; for the assessment, adaptation and risk management of hydrological extremes such as drought and floods; for weather prediction (heat exchange with the atmosphere); and even for defense (planning military deployment). Passive sensors also provide temperature and humidity profiles of the atmosphere, used for weather forecasting, and gather information to monitor changes in the polar ice cover and information needed in assessing hazards such as hurricanes, wildfires, and drought. For many applications, satellite-based microwave remote sensing represents the only practical method of obtaining atmospheric and surface data for the entire planet.

Recommendations ITU-R RS.1029 and RS.2017 provide criteria for protecting applications of the EESS. The high radiometric accuracy and sensitivity needed to accomplish the measurements of modern EESS systems results in commensurately high sensitivity to RFI that can cause errors in the retrieval of geophysical parameters. A description of the impact of such emissions on a specific EESS geophysical measurement is discussed in §2.2 of *Spectrum Management for Science in the 21st Century*.[2] The maximum signal-power contamination that can exist without impacting the information contained in the EESS measurement has been derived by scientists for each of the EESS allocated bands and is documented in Recommendations RS.1029 and RS.2017. However, as technology improves and is more able to meet the requirements of science for better resolution, these limitations also become more restrictive. Hence, more protection will likely be needed in the future.

Furthermore, over the last decade, the rate of occurrence of harmful interference in EESS allocations between 1.4 GHz and 18.7 GHz has increased. When compared with historical data, the level and the rate of interference appear to be on the rise. Specifically, satellites observing within the allocations at 1400 MHz, 10.65 GHz, and 18.7 GHz receive harmful interference on a daily to weekly basis. Thus, interference both from unwanted emissions and from transmission in shared allocations by ground- and space-based sources are of concern to the EESS.

The committee advocates for effective use of the electromagnetic spectrum across all services. This shared use of the spectrum is coupled with a shared responsibility to ensure continued availability of this critical resource for effective use by all.

[2]National Research Council, *Spectrum Management for Science in the 21st Century*, The National Academies Press, Washington, D.C., 2010.

A

Statement of Task

The National Academies will convene a committee to prepare a short report which will articulate the views of the U.S. science community on specific agenda items at issue at the 2015 World Radiocommunication Conference (WRC) with potential impact on scientific observations, particularly future radio astronomy and Earth remote sensing observations. The committee will:

- Identify the agenda items at issue at the 2015 WRC that are potentially relevant to the scientific use of the radio and microwave spectrum, namely for, but not limited to, radio astronomy and Earth remote sensing;
- Assess each of the identified agenda items for their potential impact—positive, negative, or none—on radio frequency science applications;
- Describe the scientific justification for protecting radio astronomy and Earth remote sensing observations in agenda items with potential impact, where appropriate;
- Solicit and consider input from the broad international science community relevant to the committee's task; and
- Establish a position, where needed and within the scope of the identified agenda items, to ensure that radio astronomy and Earth remote sensing and other related radio frequency science applications will continue to be able to make needed observations.

In preparing its report, the committee will take into account the anticipated future spectrum requirements of the scientific communities, and will ensure that the needs of multiple communities are appropriately considered.

B

Acronyms

AeMS	Aeronautical Mobile Service
AeRNS	Aeronautical Radionavigation Service
AIS	Automatic Identification System
AMSR-E	Advanced Microwave Scanning Radiometer-Earth
CCD	charge-coupled device
CMB	cosmic microwave background
EESS	Earth Exploration-Satellite Service
EoR	Epoch of Reionization
FCC	Federal Communications Commission (U.S.)
FEMA	Federal Emergency Management Agency (U.S.)
FS	Fixed Service
FSS	Fixed-Satellite Service
GBT	Green Bank Telescope
GCOM	Global Change Observation Mission
GMI	GPM Microwave Imager
GMRT	Giant Metrewave Radio Telescope
GPM	Global Precipitation Measurement (NASA)
GSO	geostationary orbit
HY-2	HaiYang mission

IAU International Astronomical Union
IMT International Mobile Telecommunications
ITU International Telecommunication Union

LOFAR Low-Frequency Array
LWA Long Wavelength Array

MetSat meteorological satellites
MMSS Maritime Mobile-Satellite Service
MS Mobile Service
MSS Mobile-Satellite Service
MWA Murchison Widefield Array

NAE National Academy of Engineering (U.S.)
NAS National Academy of Sciences (U.S.)
NASA National Aeronautics and Space Administration (U.S.)
NOAA National Oceanic and Atmospheric Administration (U.S.)
NRC National Research Council (U.S.)
NSF National Science Foundation (U.S.)
NWP numerical weather prediction

PAPER Precision Array for Probing the Epoch of Reionization
PPDR broadband public protection and disaster relief

RAS Radio Astronomy Service
RFI radio frequency interference

SAR synthetic aperture radar
SMAP Soil Moisture Active/Passive mission
SMOS Soil Moisture and Ocean Salinity mission
SRR short-range radar
SRS Space Research Service
TRMM Tropical Rainfall Measuring Mission

VLA Very Large Array
VLBA Very Long Baseline Array

WAIC wireless avionics intra-communications
WRC World Radiocommunication Conference