Congressional Testimony

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before the

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"Spectrum Needs for Observations in Earth and Space Sciences"

Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, thank you for the opportunity to testify today. My name is William Mahoney, and I currently serve as an Associate Director of the National Center for Atmospheric Research. The National Center for Atmospheric Research (NCAR) is a Federally Funded Research and Development Center (FFRDC) of the National Science Foundation (NSF) and it is operated by the University Corporation for Atmospheric Research, which is a nonprofit consortium of more than 120 North American colleges and universities focused on research and training in the Earth system sciences. I have also had the privilege of previously serving at the Commissioner of the American Meteorological Society's (AMS) Commission on the Weather, Water, and Climate Enterprise, which is charged with ensuring the needs and concerns of the public, private and academic sectors of the United States weather, water and climate enterprise.

The Nation's economy and the public depend on accurate weather information. Remote observations of the Earth that utilize radio frequency channels, such as those operating in the 23.8 GHz spectrum, provide critical datasets required for weather prediction and the provision of warnings to save lives and protect property. This is why the public, private, and academic sectors of the meteorological community are deeply concerned over increasing encroachment on weather-related radio frequency bands and are urging the FCC and other bodies to recognize the need for adequate protection and mitigation efforts against the loss and shared use of this critical spectrum for observing the Earth system[1]. Earth monitoring is required for weather forecasts, studies of climate change, for the protection of the environment, for economic development (transport, energy, food security, urban development, deployment of utilities, supply chain management and security) and for safety of life and property protection. This threat is coming during a period when our country is facing a significant increase in billion-dollar weather disaster events. The 1980–2020 average of billion-dollar disasters is 7.1 events per year (CPI-adjusted) while the annual average for the most recent 5 years (2016–2020) is 16.2 events (CPI-adjusted)[2]. The U.S. economy is also sensitive to weather. The U.S. economic output varies by up to $601 billion per year (CPI-adjusted) of gross domestic product (GDP) or about 3.4% of GDP owing to weather variability[3]. In addition, a nationwide survey indicated that weather forecasts generated $41.1 billion (CPI-adjusted) in economic benefits to U.S. households[4].

Radio-based observations such as remote sensing instruments operating on-board satellites and on the ground provide the main source of information about the Earth's atmosphere and surface. Measurement of the natural emission of microwave radiation of the Earth has been recognized as a priority of Earth observation for many decades and it expanded with the satellite microwave

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[1] Radio Frequency Allocations for Meteorological Operations and Research: A Policy Statement of the American Meteorological Society. Adopted by the AMS Council on 1 October 2009.

[2] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73.

[3] Lazo, J.K., M. Lawson, P.H. Larsen, and D.M. Waldman. June 2011 "United States Economic Sensitivity to Weather Variability." Bulletin of the American Meteorological Society. 92: 709-720.

[4] Lazo, J.K., R.E. Morss, and J.L. Demuth. 2009. "300 Billion Served: Sources, Perceptions, Uses, and Values of Weather Forecasts." Bulletin of the American Meteorological Society. 90(6):785-798.

sounding instruments launched first in the 1970's[5]. These sensors exploit the oxygen absorption band between 50 to 60 GHz to provide global coverage of atmospheric temperature measurements of the troposphere and stratosphere[6]. While global remotely sensed temperature improves forecast skill, it is well recognized that atmospheric water vapor sensing is critical to improve the prediction of precipitation processes, severe weather, and drought. Advanced microwave sounding units operating at 23.6 – 24.0 GHz were developed and implemented on satellites to address this need and are considered part of the backbone of the global observing system[7]. Increased utilization of satellite-based water vapor sounding data is now recognized as a key reason behind increases in weather model prediction skill in recent years[8]. Some of the most advanced satellite-based microwave sounding systems utilized in the U.S. and internationally operate at 23.8 GHz, which is within the International Telecommunications Unions (ITU)[9] Earth Exploration Satellite Service (EESS) spectrum.

Protecting the Nation's ability to provide high-quality operational weather data and accurate weather forecasts requires limiting interference in the L-Band and in the passive microwave spectrum bands. The science is very clear on the positive impact on weather prediction skill from

[5] Njoku, E. G. (1982). Passive microwave remote sensing of the Earth from space—A review. Proc. IEEE, 70(7), 728–750, doi:10.1109/PROC.1982.12380.
[6] Rodgers, C. D. (1976). Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. Rev. Geophys., 14(4), 609–624, doi:10.1029/RG014i004p00609.
[7] English, S., McNally, A., Bormann, N., Salonen, K., Matricardi, M., Hor´anyi, A., Rennie, M., Janiskova, M., Michele, S. D., Geer, A. J., di Tomaso, E., Cardinali, C., de Rosnay, P., Sabater, J., Bonavita, M., Albergel, C., Engelen, R. and Th´epaut, J.-N. (2013). Impact of satellite data. Technical Report 711, ECMWF Tech. Memo., doi:10.21957/b6596ot1s, URL https://www.ecmwf.int/node/9301.
[8] Geer, A., Baordo, F., Bormann, N., Chambon, P., English, S., Kazumori, M., Lawrence, H., Lean, P., Lonitz, K. and Lupu, C. (2017). The growing impact of satellite observations sensitive to humidity, cloud and precipitation. Quart. J. Roy. Meteor. Soc., 143(709), 3189–3206, doi:10.1002/qj.3172.
[9] The International Telecommunication Union (ITU) is the United Nations specialized agency for information and communication technologies. Founded in 1865 to facilitate international connectivity in communications networks, ITU allocates global radio spectrum and satellite orbit and develops the technical standards that ensure networks and technologies seamlessly interconnect.

utilizing remotely sensed temperature and water vapor data from the passive absorption bands. In general, it is critical that the scientific community be at the table to inform policy makers on issues such as this that have a major impact on science and critical operational public safety services. Spectrum allocation policy must be informed by science, particularly on issues where the science is so clear.

Background. The meteorological community increasingly relies on remote-sensing technologies for both routine and experimental Earth observations. These activities require global access to radio frequency spectrum for radars, wind profilers, microwave radiometers, and data telemetry systems, as well as for satellite-based passive and active sensors[10]. Radio spectrum is used for meteorology in three primary ways:

- Passive remote sensing, in which scientists measure the natural radio frequency emissions from the environment and space. This requires the use of a receiver only. These are generally located on space-based platforms.
- Active remote sensing, in which systems emit radio waves into the atmosphere and measure their transmission (e.g., Doppler weather radar and wind profilers). This requires the use of both a transmitter and a receiver.
- Data transmission, in which radio waves are used to distribute data. For environmental data, this may include broadcasting information directly from a satellite to users throughout the country (e.g., 1685.7 – 1686.6 MHz Geostationary Operational Environmental Satellite (GOES) downlink channel).

[10] The Radio Frequency Spectrum and Weather, Water, and Climate: Uses and Challenges By AMS Policy Program, April 2017.

Radio waves are reflected, absorbed, scattered, refracted, and diffracted by the atmospheric conditions that they encounter, such as clouds and precipitation. Critically, different atmospheric conditions affect radio waves differently. This allows scientists to use radio frequencies directly or indirectly to detect tornadoes, track hurricanes, and to determine a wide range of meteorological conditions from the ground upward such as atmospheric humidity, cloud types and amounts, wind speed and direction, and precipitation types and amount. Furthermore, and critically, determining atmospheric conditions using passive remote sensing requires the use of specific radio frequencies for which substitution is not possible. For example, only certain wavelengths pass through clouds unimpeded. Often, the same wavelengths are valuable for telecommunications because they can pass through weather, buildings and other obstacles. Some examples of passive radio frequency bands that are critical for Earth system sensing are shown below.

Passive Band (GHz)	Frequency Range (GHz)	Principle Use
18.6	18.6 - 18.8	Sea Surface Wind Speed and Direction; Snow Coverage, Sea Ice, Precipitation
23.8	23.6 - 24.0	Integrated Atmospheric Water Vapor
36.5	36.0 - 37.0	Tropical Cyclone Monitoring; Sea Surface Wind Speed and Direction
50 - 60	50.2 - 50.4	Atmospheric Vertical Temperature Profile (multiple bands)

The significant progress that has been made in recent years in weather forecasting skill is largely attributable to these observing technologies and the use of Earth observations in weather prediction models, by forecasters, and the atmospheric science research community. To predict the weather accurately, the current state of the atmosphere must be known in detail across the globe from the surface of the Earth to the top of the atmosphere. In situ and remote sensing technologies are critical to the forecasting process. This is not an issue of academics or researchers losing access to a data set, this is about not having the necessary information to protect life and property. Weather data and forecasts are important for the public and are required for large segments of our Nation's economy. Examples of how Earth system data and weather forecasts are used to support decision making include, but not limited to:

Agriculture: Daily and seasonal decisions are made regarding seed selection, pest mitigation, irrigation, fertilization, and harvesting. Soil moisture and soil temperature, whose remotely sensed measurements are also sensitive to out of band interference, are important parameters for agriculture planning and decision making and contribute to forecast skill. Weather information is used to analyze global and regional supply chain risks and market conditions related to extreme weather such as flooding and droughts.

Aviation: Daily decisions are made by airlines, general aviation pilots, and air traffic controllers on route selection to maximize flight efficiency and minimize fuel consumption, and for the avoidance of thunderstorms, wind shear, turbulence, low ceiling and visibilities, and icing to maximize flight safety.

Surface Transportation: Daily decisions are made by departments of transportation to optimize snow and ice control and pavement maintenance operations, anticipate extreme weather conditions and position emergency response assets such as tow vehicles to clear roadways when weather related incidents occur. Railroad operators utilize daily weather information to assess the risk of track washouts, buckling due to heat, track pull-aparts due to extreme cold, and strong crosswinds that could lead to railcar blowover events. Commercial freight operators use weather information for optimal routing to ensure the Nations' goods and services are delivered on schedule and are not impacted by poor road and weather conditions.

Water Management: Daily to seasonal decisions are made for reservoir management, hydro-power operations, river and stream flow rates for fish protection, recreation, to meet regulatory requirements, assess flooding potential, and predict water consumption.

Emergency Management: Weather information is used daily to support risk assessment, manage emergencies and evacuation planning, and support warning and recovery activities associated with tornadoes, hurricanes, flooding, snow and ice storms, derechos, landslides, severe thunderstorms and lightning, and high winds.

Wildfire: Weather information is used daily to determine the risk of wildfire ignition from lightning and human activities, fire rate of spread, intensity, air quality, and to manage ground based and airborne fire mitigation operations.

Energy: Energy production, generation, demand, and transmission are very sensitive to weather. Wind, solar, and hydroelectric power require accurate information on wind speed and direction, clouds, incoming solar radiation, and precipitation. Reductions in prediction accuracy due to the loss of remotely sensed weather data from frequency interference will increase the uncertainty in wind and solar energy prediction and therefore make the integration of variable generation energy into the electric grid more challenging and risky.

National Security and Defense: Accurate weather information and forecasts are critical for our armed services conducting land, sea and air operations around the world including humanitarian missions. Precise information is needed on ceiling, visibility, severe weather, wind shear, turbulence, and marine conditions.

At a time of increasing weather hazard vulnerability due to climate change and demographic shifts, it is imperative that critical Earth observations be protected from interference. The radio frequency allocation process must adopt a "do no harm" posture that requires evidence that commercial activities would not interfere with critical Earth observations.

Spectrum Inference Concerns. Spectrum sharing can create significant challenges because receivers and transmitters must be able to distinguish among meaningful signals, background noise, and unwanted signals. In some cases, protective zones placed around critical satellite downlink receiving stations (i.e., areas where commercial telecom users are prohibited from interfering with scientific and operational uses) can accommodate commercial uses of the radio spectrum while maintaining critical Federal operations. However, protected zones are not always adequate to protect all Federal users and do not help the large population of non-Federal users that are distributed throughout the country and sit outside the protected zones. There are Federal agencies that utilize GOES downlink receiver stations that may not be considered for protection zones in a similar manner as NOAA, the primary stakeholder. Non-Federal users include the Nation's private sector weather industry that provides critical user-tailored weather and warning information to state and local emergency management, utilities, water managers, commercial freight operators, trucking industry, transportation officials, and many more end-users. There is a significant concern that the downlink of GOES data will be contaminated by interference if the 1675-1680 MHz band is not safeguarded. Interference could have a disastrous impact on both the government and the commercial weather industry and its stakeholders.

A major concern of the U.S. weather, water, and climate communities is the potential for interference in the specific radio frequencies for which substitution is not possible. While imperfect, there may be ways to mitigate interference in other frequencies, but the laws of physics make it impossible to find substitutes for specific atmospheric absorption frequencies such as the 23.6-24 GHZ spectrum band. The 23.6-24 GHz spectrum band is used for microwave sensor-based remote sensing of atmospheric levels of water vapor, which is the single most impactful data type for accurately forecasting weather and weather hazards and it is critical for atmospheric science research aimed at improving understanding and predictability of the Earth system. These passive instruments are, by necessity, sensitive to extremely weak signals naturally emitted by the Earth's atmosphere, including signals emitted at 23.8 GHz. The sensors are even more vulnerable to radio frequency interference as they have a much bigger footprint and use wider bandwidth.

Atmospheric microwave emissions in the Earth Exploration-Satellite Service spectrum are a unique natural resource of the Earth. The Earth's natural microwave emissions can be contaminated by even slight noise into the band. A total combined power in excess of 0.1 Watts from all terrestrial sources will contaminate the measurements. 5G wireless technology encompasses a broad spectrum. It is projected that more than 50% of data transfer in 5G will take advantage of Wi-fi[11]. Wi-fi signal strength (Pico Watt) is ten times stronger than the weakest signal detected by radar and satellite receivers. Therefore, radio frequency interference will significantly degrade or make the satellite and radar signals useless. Unwanted byproducts from a 5G signal that falls within the frequency range detected by the weather satellite would raise the noise floor or confuse the sensor. There is no method to separate the unwanted 5G signal from the desired natural signal, which simply measures the total power detected, meaning it would not be possible to know that the environmental data had been contaminated. Preliminary studies have indicated that the proliferation of terrestrial 5G systems using 24 GHz frequencies will make

[11] Emerging Technologies and Their Expected Impact on Non-Federal Spectrum Demand. Office of Science and Technology Policy, May 2019.

current and future data less accurate, or even unusable, unless 5G is rigorously implemented in a manner that protects the adjacent Earth Exploration Satellite Service spectrum.

Summary. The meteorological community (public, private, and academic sectors) relies on high quality, real-time and archived Earth system data for weather, climate, and water monitoring, prediction and warnings, natural disaster risk reduction, support of disaster-relief operations, homeland security and defense, and for planning preventive measures for adapting to and mitigating the negative effects of climate change. The socioeconomic benefits associated with the meteorological use of radio frequency spectrum are central to the success of society and must be accounted for in optimal spectrum management. Critically, virtually every sector of the Nation's economy is weather-sensitive and any degradation of Earth observation data for scientific and operational uses can be expected to have significant negative financial and safety impacts. If forecasts of hurricanes, floods, and other natural disasters were degraded, lives and property would be at risk. The profitability of United States industries, ranging from agriculture and energy to manufacturing and transportation, would also be adversely affected if forecasts become less accurate.

It is in the Nations' best interest to protect radio frequencies essential for meteorological activities that are critical for the accurate forecasting of adverse weather, climate-change research and assessment, and to ensure the Nation's leadership in future wireless technologies and in science and engineering. Advancements in environmental forecasting and hazard prediction can only occur if existing spectrum assets in the key passive bands such as 23.6-24 GHz are protected from interference. The laws of physics dictate these frequency bands; therefore, there is no alternative other than protection.

In order to have both accurate weather forecasts and 5G technologies, prudent restrictions on the use of spectrum near the weather data bands are required for maintaining and enhancing the quality and accuracy of Earth system observations and weather predictions.

Collaborative studies involving science agencies and non-Federal stakeholders should be funded to assess the impact of terrestrial interference in the atmospheric absorption bands and their cascading effects on numerical weather prediction skill and Earth system science. Research programs such as or similar to the National Science Foundation's (NSF) Spectrum Innovation Initiative, which is designed to develop innovations that can circumvent the challenges of radio spectrum scarcity and interference, need to be expanded.

The concerns of the weather enterprise and Earth sciences community need to be heard and taken seriously as the impact of lost Earth observing data could be catastrophic for the Nation.

Thank you for giving me the opportunity to testify before this committee.