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Meeting Summary

The Need for Spectrum and the Impact on Weather Observations

Robert Palmer, David Whelan, David Bodine, Pierre Kirstetter, Matthew Kumjian,
Justin Metcalf, Mark Yeary, Tian-You Yu, Ramesh Rao, John Cho, David Draper,
Stephen Durden, Stephen English, Pavlos Kollias, Karen Kosiba, Masakazu Wada,
Joshua Wurman, William Blackwell, Howard Bluestein, Scott Collis,
Jordan Gerth, Aaron Tuttle, Xuguang Wang, and Dusan Zrnić

Workshop on Spectrum Challenges and Opportunities for Weather Observations

What: Nearly 70 scientists and engineers from across the world with expertise in weather observations and forecasting participated in an in-depth discussion on their growing challenges with radio frequency interference and potential opportunities with the advent of 5G/6G and vital uses of the spectrum for science.

When: 10 November 2020

Where: Virtual

KEYWORDS: Profilers, atmospheric; Radars/Radar observations; Remote sensing; Satellite observations; Numerical weather prediction/forecasting; Data assimilation

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Corresponding author: Dr. Robert D. Palmer, rpalmer@ou.edu

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AFFILIATIONS: **Palmer, Bodine, Kirstetter, Metcalf, Yeary, Yu, Bluestein, and Wang**—University of Oklahoma, Norman, Oklahoma; **Whelan and Rao**—University of California, San Diego, San Diego, California; **Kumjian**—The Pennsylvania State University, University Park, Pennsylvania; **Cho and Blackwell**—MIT Lincoln Laboratory, Lexington, Massachusetts; **Draper**—Ball Aerospace and Technology Corporation, Boulder, Colorado; **Durden**—Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; **English**—European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom; **Kollias**—Stony Brook University, State University of New York, Stony Brook, New York; **Kosiba and Wurman**—University of Illinois at Urbana–Champaign, Urbana, Illinois; **Wada**—Toshiba Corp., Kawasaki, Japan; **Collis**—Argonne National Laboratory, Lemont, Illinois; **Gerth**—University of Wisconsin–Madison, Madison, Wisconsin; **Tuttle**—Federal Aviation Administration, Oklahoma City, Oklahoma; **Zrnić**—National Severe Storms Laboratory, Norman, Oklahoma

One of the most significant challenges—and potential opportunities—for the scientific community is society's insatiable need for the radio spectrum. Wireless communication systems have profoundly impacted the world's economies and its inhabitants. Newer technological uses in telemedicine, Internet of Things, streaming services, intelligent transportation, etc., are driving the rapid development of 5G/6G (and beyond) wireless systems that demand ever-increasing bandwidth and performance. Without question, these wireless technologies provide an important benefit to society with the potential to mitigate the economic divide across the world.

Fundamental science drives the development of future technologies and benefits society through an improved understanding of the world in which we live. Often, these studies require use of the radio spectrum, which can lead to an adversarial relationship between ever-evolving technology commercialization and the quest for scientific understanding. Nowhere is this contention more acute than with atmospheric remote sensing and associated weather forecasts (Saltikoff et al. 2016; Witze 2019), which was the theme for the virtual Workshop on Spectrum Challenges and Opportunities for Weather Observations held in November 2020 and hosted by the University of Oklahoma.

The workshop focused on spectrum challenges for remote sensing observations of the atmosphere, including active (e.g., weather radars, cloud radars) and passive (e.g., microwave imagers, radiometers) systems for both spaceborne and ground-based applications. These systems produce data that are crucial for weather forecasting—we chose to primarily limit the workshop scope to forecasts up to 14 days, although some observations (e.g., satellite) cover a broader range of temporal scales. Nearly 70 participants from the United States, Europe, South America, and Asia took part in a concentrated and intense discussion focused not only on current radio frequency interference (RFI) issues, but potential cooperative uses of the spectrum ("spectrum sharing"). Equally important to the workshop's international makeup, participants also represented different sectors of the community, including academia, industry, and government organizations.

Given the importance of spectrum challenges to the future of scientific endeavor, the U.S. National Science Foundation (NSF) recently began the Spectrum Innovation Initiative (SII) program, which has a goal to synergistically grow 5G/6G technologies with crucial scientific needs for spectrum as an integral part of the design process. The SII program will accomplish this goal in part through establishing the first nationwide institute focused on 5G/6G technologies and science. The University of California, San Diego (UCSD), is leading an effort to compete for NSF SII funding to establish the National Center for Wireless Spectrum Research. As key partners in this effort, the University of Oklahoma (OU) and The Pennsylvania State University (PSU) hosted this workshop to bring together intellectual leaders with a focus on impacts of the spectrum revolution on weather observations and numerical weather prediction.

Lightning round

Given the diversity of workshop participants and the breadth of topics involved, we decided that a primer on the various scientific and technical challenges was needed. After a keynote talk on the overarching goals of the institute, an initial "lightning round" provided a venue for 10 invited speakers from around the world to build a foundation for the workshop participants on the fundamental issues, terminology, and potential solutions relevant to a variety of remote sensing platforms and weather forecast systems. The following is a brief overview of the lightning-round components.

Weather radar. Radar-based observations of high-impact weather (typically in the S, C, and X bands) form the cornerstone of understanding these complex phenomena and serve as a crucial input to data assimilation systems for numerical weather prediction (NWP) models. The weather radar component of the lightning round included a talk by Joshua Wurman and Karen Kosiba on their experience with RFI using the Doppler-on-Wheels mobile research radars. Their extensive field experience gave the audience a unique perspective on adverse RFI effects on research radar data, the importance of frequency coordination among different instrument platforms, and some of the challenges of frequency allocation and potential interference when operating with no fixed base. Representatives from the United States (Terrance Clark), Europe (Philippe Tristant), and Japan (Masakazu Wada) provided provocative presentations about spectrum challenges for operational weather radar networks with specific examples of RFI in their respective countries. The talk from Japan also highlighted a potential mitigation scheme based on Wi-Fi detection by the weather radar with subsequent frequency adjustment to minimize adverse impacts. Finally, John Cho provided a presentation on the challenges associated with "sense-and-avoid" dynamic frequency selection (DFS) techniques that rely on the users' cooperation and proper use of the technology. An important conclusion from Cho was that "regulatory and technical measures have not provided satisfactory solutions," highlighting the challenges ahead for the community.

Cloud radar. Pavlos Kollias provided a talk on the importance of millimeter-wavelength radars for studies of clouds and precipitation processes. The size of these systems allows for ground-based, airborne, and spaceborne implementations. Typically emitting in the Ku, Ka, and W bands, these measurements provide a unique view into cloud processes that are essential for climate studies, among other important applications. Large-scale networks exist with examples including the DOE Atmospheric Radiation Measurement (ARM) facility and the Aerosols, Clouds, and Trace gases Research Infrastructure (ACTRIS) network. From the current systems in existence and based on an extensive survey of users around the world, it was pointed out that RFI was mostly limited to the Ka-band radars. The lack of RFI could partly be due to the typically remote deployments. Nevertheless, concern does exist because of the move to lower peak-power solid-state transmitters, which may be more susceptible to RFI, and the uncertainty of technical specifications for future wireless communication systems.

Spaceborne sensors. Stephen Durden provided an overview of current atmospheric spaceborne radars at Ku, Ka, and W bands and noted that these bands are being considered by NASA for future missions, including those discussed in the Aerosol, Cloud, Convection, and Precipitation (ACCP) study following the National Academies of Sciences, Engineering, and Medicine (NASEM) 2017 decadal survey. He also described development of higher-frequency radars for cloud applications (e.g., humidity profiling). Global coverage, combined with the presence of other services in allocated bands, makes spaceborne radars capable of both generating and receiving RFI. Examples of accommodations for compatibility are *CloudSat*'s publication of orbital information for protection of ground-based radio astronomy and ceasing of TRMM radar transmission over a sensitive ground region. Spaceborne passive microwave imagers were discussed by David Draper from Ball Aerospace which built NASA's Global Precipitation Measurement (GPM) Microwave Imager (GMI). Microwave imagers sense Earth's ambient radiation in C, X, K, and W bands to provide global measurements of soil moisture, sea surface temperature (SST), ocean winds, snow depth, and precipitation. Such sensors are particularly vulnerable to RFI, which contaminates measurements with artificial "hot spots" near interfering sources. C- and X-band channels, used for soil moisture, are severely hampered by RFI over land, albeit Draper's research noted slightly decreasing C-band RFI trends in developed nations such as Japan and the United States with increasing trends in developing countries such as Brazil and Indonesia. Surface reflections of direct broadcast satellite transmissions also interfere at X and K bands around the United States and Europe, impairing measurements of ocean winds and SST near those landmasses (Draper 2018). Other trends were discussed at X and K bands, especially related to direct broadcast satellites. Due to the volume of observational data that must be transmitted to ground receivers, sharing of allocations for high-data-rate direct broadcast with terrestrial transmissions are a secondary challenge, particularly for low-Earth-orbiting satellites. The U.S. government operates a network of receiving antennas for satellite rebroadcast and direct broadcast feeds to reduce the latency of critical weather data entering NWP models.

Operational weather forecasting. Stephen English concluded the lightning round by presenting highlights from an assessment of the value of observations (both passive and active) using spectrum allocated to Earth Exploration Satellite Service (EESS). He drew from a collaborative workshop held at ECMWF 13–14 September 2018.[1] At this event NWP centers from North America, Europe, and Asia presented their assessments of the impact of these observations on the skill of their NWP systems. They also provided evidence on the socioeconomic value of their NWP systems.

In the modern era, global and regional NWP have become critical to WMO member states' national warning systems and many socioeconomic sectors, through what has been referred to as a "quiet revolution of NWP" (Bauer et al. 2015). Satellite observations underpin global NWP, and leading centers have demonstrated that passive microwave observations are the most important. Typically, passive microwave contributes about 40% of the short-range forecast skill improvements from observations, plus a further 10% from active microwave. The most impactful bands are the oxygen band (50–60 GHz) and the water vapor band (176–190 GHz), which drive satellite-derived vertical profiles of stratospheric/tropospheric temperature and humidity, respectively. The impact of 176–190 GHz has increased compared to 10 years ago, and is attributed to improvements in assimilating cloud and precipitation affected observations through an "all-sky" approach (Geer et al. 2018). The sounding bands are also affected by changes in Earth's surface (ocean, land, sea ice, snow), clouds, and precipitation.

Breakout sessions

After the lightning round, workshop participants were organized into four distinct and smaller "breakout sessions." The goal was to have more in-depth discussions focused on four key questions, as summarized below.

Breakout session 1. Moderated by David Bodine, the following key question was discussed: "Of the issues discussed during the lightning round, where do you see the biggest challenges or opportunities and what technological advances and/or policies are needed to seize these opportunities?" One major conclusion was that our organizational structure and policy

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[1] https://events.ecmwf.int/event/96/attachments/958/1675/Workshop_report.pdf

approach remains inadequate to mitigate RFI issues. Policy solutions must consider the application of spectrum among industries and geographic regions, and address inadequate enforcement of RFI regulations. Quantifying economic impacts of RFI on weather forecasts, specific to individual frequency bands, is critical to informing policymakers. Attendees also noted that 5G, due to high bandwidth and low latency, can unleash new modes of operation of complex instrumentation and open up opportunities for AI at the edge.[2]

Breakout session 2. Moderated by Matthew Kumjian, the following key question was discussed: "What are the future spectrum needs for weather observations over the coming decades?" The discussion began with discussing what critical needs there are for weather observations or observational capabilities: vertical or 3D thermodynamic and wind measurements, as well as hazard monitoring were prioritized. Emerging or currently nonoperational technologies including the use of microwave links, gap-filling radars, unmanned aircraft systems (UAS), airborne radars, high-altitude balloons/drones, and phased-array radars were discussed as possible options for obtaining such measurements.

Breakout session 3. Moderated by Pierre Kirstetter, the following key question was discussed: "How do the spectrum opportunities and challenges (e.g., RFI, allocation, change) affect applications such as weather prediction accuracy and the creation of consistent weather/water observations datasets over significant time periods?" The required frequency bands are mostly known but their value is not quantified fully and independently. In addition, not all currently used frequency bands are fully exploited for observational purposes. Some, if not all, bands must be defended from demand by other sectors, yet opportunistic sensing opens prospects. Applications often require a set of specific bands, which increase their vulnerability to RFI. A systematic evaluation of RFI impacts leveraging data assimilation tools such as observing system experiments (OSE), observing system simulation experiments (OSSE), forecast sensitivity observation impact (FSOI), ensemble forecast sensitivity observation impact (EFSOI), and associated mitigation is needed.

Breakout session 4. Moderated by Mark Yeary and Justin Metcalf, the following key question was discussed: "How can radars that are principally used for nonweather applications (e.g., DoD, FAA—aircraft detections) that employ RFI mitigation strategies serve as exemplars to improve weather observations?" Many nonweather radars are moving to software-defined, multichannel architectures to mitigate RFI with techniques such as frequency hopping and adaptive nulling (both via beamforming and signal processing). Creating a challenge dataset for the weather community was recommended to spur development of advanced mitigation techniques.

Concluding remarks

A final wrap-up session began by bringing together all workshop participants for brief reports from the breakout session moderators. The subsequent discussion of the entire group led to several insightful conclusions that are summarized next.

Intangible benefit of science. It was noted that some areas of weather observations/forecasting are quantifiable in terms of economic impact of having access to the spectrum. In contrast, it is more difficult to calculate the "worth" of certain fields of study although often the resulting fundamental discoveries lead to future technologies. This imperative for fundamental science must be considered as we move forward with future 5G/6G systems.

[2] www.orau.gov/5GScience/5G_Workshop_Report_2020-FINAL-print.pdf

International perspective. Radio waves do not respect borders or other artificial boundaries. As a result, international cooperation is essential for the success of the spectrum revolution. This cooperation must be among countries, but also the sometimes-competing sectors of academia, government, and industry.

Policy drivers. It was recognized that the spectrum challenge will only be solved with a seamless blend of technology, science, and policy. Decisions cannot be made solely on economic drivers but must consider the intangible benefits of science, societal needs for a more connected world, underlying physics of radio wave interaction with the atmosphere, and the complexity of proposed engineering solutions.

Interdisciplinary education. Training of a “spectrum-aware” workforce is key to effective collaboration/cooperation. Engineers, scientists, and policymakers must be afforded an interdisciplinary education that instills an appreciation and basic understanding of the other disciplines. Only through education will we truly have thoughtful policies that allow efficient use of the limited spectrum.

The workshop ended with an appreciation of the evolving landscape of spectrum usage/sharing. 5G is nascent, but future needs of the spectrum are, of course, not technically defined. Without question, however, is the demand for more bandwidth that will force cooperation among the various constituents. Therefore, now is the perfect time to bring together the scientific, engineering, and policy communities to find a robust and sustainable solution to the spectrum challenge.

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