# The Impact of Emerging 5G Technology on U.S. Weather Prediction

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**Executive Summary:** Fifth generation (5G) wireless networks promise to provide faster and more expansive data connectivity, exceeding thresholds from previous fourth generation (4G) technology. The deployment of 5G infrastructure requires allocating additional frequencies in radio bands at 24 gigahertz (GHz), potentially contaminating neighboring remote sensing bands used for weather forecasting and prediction. The current U.S. out-of-band emissions limit at 24 GHz of -20 dBW per 200 MHz is projected to degrade meteorological forecast accuracy by up to 30%, reducing the hurricane forecast lead time by 2 to 3 days, and endangering thousands of additional lives. Under the Weather Research and Forecasting Innovation Act of 2017 (Pub.L 115-25), the National Oceanic and Atmospheric Administration (NOAA) must develop more accurate and timely severe weather forecasts in order to protect life and property and reduce economic risk; however, the potential out-of-band interference from the roll out of 5G threatens this aim. Given U.S. economic reliance on accurate weather prediction (estimated to be in the trillions of dollars), we propose that Congress mandate stricter noise restrictions to adequately meet requirements of the Pub.L 115-25, while minimizing disruption to 5G deployment.

## I. Statement of the issue

Weather forecasting accuracy has significantly improved over the past 40 years. For example, a modern 5-day forecast is as accurate as a 1-day forecast was in 1980, and useful forecasts now can project 9 to 10 days into the future (Bauer et al. 2015). To achieve this accuracy, weather prediction models require satellite measurements of microwave signals radiated by atmospheric water vapor in the 23.6–24.0 GHz passive band (see Figure 1). While little is known about the out-of-band emissions from developing 5G technology at 24.24-27.5 GHz, there is significant concern that current Federal Communications Commission (FCC) limits on out-of-band noise from 5G are insufficient to ensure accurate water vapor measurements in the 23.6–24.0 GHz passive band. In particular, the faint water vapor signal at 23.8 GHz is likely masked by 5G noise, making it nearly impossible for scientists to discern the natural water vapor signal from 5G interference. Likewise, the 37.0–43.5 GHz 5G band could impact data collected in the 36–37 GHz range, which is used for liquid water path and cloud detection (ECMWF 2018).

According to both the National Aeronautics and Space Administration (NASA) and the leading European weather prediction institute, microwave observations provide the largest positive forecasting impact of satellite-based data (Bormann, Lawrence, and Farnan 2019). Microwave observations are estimated to improve short term forecasts by 30–

40%, the loss of which would reduce forecast accuracy by 3–6 hours compared to current forecasts (ECMWF 2018). Because current technology cannot filter noise from 5G operations or remove it through post-processing while maintaining current levels of data precision (Lubar et al. 2020), pollution of these bands would significantly degrade data and potentially reduce the reliability of forecasts.

To illustrate the enhancement in hurricane prediction afforded by microwave sensing, consider the microwave image of Hurricane Lorenzo from September 28 2019 in Figure 2. The image from the Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument utilizes parts of the spectra proposed for 5G. While infrared and visible imagery provide useful information on the structure, intensity, and temperature of a storm (NOAA NESDIS 2019), these tools cannot be used when there is cloud cover. Microwave sensors are particularly useful because of the ability to penetrate the atmosphere, allowing a view inside the hurricane when it is obscured by clouds. This microwave data allows for a more accurate characterization of the intensity and location of precipitation as well as an exact location of the eye, which together provide valuable information about whether the hurricane is intensifying, and thus can enhance our ability to track and forecast the hurricane's future evolution (Lubar et al. 2020). In particular, AMSR2 images from Hurricane Lorenzo were critical to understanding the differences in wind patterns at different levels of the atmosphere, which were not possible with other instruments (JPSS SDOC 2019).

The FCC has proposed an out-of-band emission limit for the 24.25-24.75 GHz band of -20 dBW/200MHz, while the International Telecommunication Union World Radiocommunication Conference agreed to a more stringent level of -33 dBW/200MHz. Neil Jacobs, the acting head of NOAA, testified before the House Committee on Science, Space, and Technology that the proposed FCC limit is predicted to cause a 77% loss of passive microwave data (US Congress 2019). The study concluded that a stricter out-of-band emission restriction between -45.2 and -52.4 dBW/200MHz would maintain the integrity of satellite data in the 23.6-24 GHz passive bands (NASA and NOAA 2020).

The periodic nature of satellite orbits may allow 5G systems to temporarily switch to a different frequency, called time-division multiple access (commonly referred to as "time sharing") (Miao et al. 2016). While already in use by cellular carriers (Lubar et al. 2020), time sharing could affect the accuracy of weather predictions and warnings by causing gaps in NOAA's satellite coverage. Existing proposals to purchase commercial weather data may potentially fill identified data gaps, but there is some concern that tying accurate national weather prediction to non-governmental sources presents risks to national security (Freedman 2019; White House OMB 2020).

## II. Regulatory and Economic Considerations
The regulatory responsibility of radio bands in the United States is divided between the National Telecommunications and Information Administration (NTIA), which administers federal band use, and the FCC, which oversees private and commercial use (FCC 2020). The FCC has the authority to reallocate bands from government to commercial users through the Commercial Spectrum Enhancement Act (Pub. L. 108-494). Given current White House priorities, (White House 2018; White House 2020), the FCC's strategy to "Facilitate America's Superiority in 5G Technology" (the 5G FAST Plan) is pushing even more bands into the 5G marketplace, raising $2 billion in revenue from leasing shared by T-Mobile and AT&T after auctioning began in May 2019 (FCC 2016). Despite these efforts, portions of the 5G roll out directly conflict with the 2017 Weather Research and Forecasting Innovation Act, which mandates prioritizing the development of more accurate and timely warnings of high impact weather events that endanger life and property. Furthermore, the National Integrated Drought Information System Reauthorization Act of 2018 instructs NOAA to establish the Earth Prediction Innovation Centre (EPIC) to accelerate improvements in weather prediction (Pub.L. 115-423).

The rollout of 5G is expected to enable significant improvements in economic and social goals. The World Economic Forum presents five key drivers of 5G technology: improvements in mobility, reliability, security, band efficiency and power efficiency (World Economic Forum 2020). The successful deployment of these five drivers is estimated to create $13.2

trillion in global economic value by 2035, generating 22.3 million jobs in the 5G global value chain alone (Campbell et al. 2019), but will require vast new infrastructure costing at least $2.7 trillion by the end of 2020 (Greensill 2019).

Even with the large economic benefits of 5G deployment, the importance of passive remote sensing on the U.S. economy, particularly for predicting extreme weather events, should not be overlooked. The average estimated cost of $1 billion for severe weather events between 2008-2015 doubled over the past 35 years, increasing global demand for accurate and timely weather services (NOAA NCEI 2020). In the U.S. alone, it is estimated that as much as 30% of the economy, or $1.3 trillion using 2011-2014 growth domestic product (GDP) estimates, is impacted by weather (Dutton 2002), with 3–6% of the variability in U.S. GDP attributable to weather (Lazo et al. 2011). Revenue from the U.S. forecasting service itself is estimated to be $500 million, with the total value of weather data captured across all industries to be in the range of $13 billion (NWS 2017).

Acting NOAA Administrator Neil Jacobs testified to Congress that the FCC auction has the potential to degrade meteorological forecasting ability by ~30% and decrease the hurricane forecast lead time by 2 to 3 days (US Congress 2019), potentially resulting in significant loss of life and property, which NOAA is mandated to protect. Other international research institutions have tested the impact of excluding microwave water vapor data from forecasts, finding that their models would have inaccurately predicted the path of 2012 Superstorm Sandy (McNally, Bonavita, and Thépaut 2014). As the deadliest windstorm in over 40 years, the total economic losses from Superstorm Sandy is estimated to exceed $70 billion, making it the second costliest storm in U.S. history after Hurricane Katrina (Allianz Global Corporate & Speciality 2013).

## III. Policy options

*i. Policy option A: Do not prohibit 5G Plan from moving forward, but require report*
Let the FCC continue implementation of the 5G FAST Plan and associated band auctioning, without interruption. Within three years of band auctions,

require a joint report by relevant federal agencies to evaluate the effects of 5G use on weather forecasting.

*Advantages*

- Likely to gain support from industry given existing financial and technological investments.
- Provides future protection of other bands as necessary based on further scientific assessment.
- Multi-agency reporting increases the likelihood of acceptable recommendations moving forward.

*Disadvantages*

- Wait-and-see approach may result in inaccurate prediction of extreme weather events.
- Joint agency research and reporting can be costly and time intensive.
- Proposed recommendations for noise mitigation may apply to 5G bands not yet auctioned, leaving interference from the 24 GHz unaddressed.

*ii. Policy option B: Create new limits on frequency window allocation*
Pass new legislation mandating that the out-of-band noise stay below -50 dBW in the 23.6-24.0 GHz band (superseding current FCC guidelines of -20 dBW). Encourage future research on maximum noise levels in other bands with potential effects on weather forecasting performance.

*Advantages*

- Proposed limit is strict enough to reduce unwanted interference on weather predictions to near zero.
- Does not prevent the commercial adoption and widespread deployment of 5G.
- Noise level limits may spur innovation in the area of telecommunications; specifically, engineering solutions to maintain frequency integrity, such as changes to modulation schemes, that could have broader use and position the U.S. as a world leader in technical innovation.

- Research on potential interference on other bands would inform future allocation of frequency bands with respect to current weather prediction capabilities.

*Disadvantages*

- Low-noise 5G technology would have to be developed for the already-auctioned 24 GHz band, potentially delaying progress and increasing costs.
- Proposed limits could reduce the usefulness of the 24 GHz band for 5G and would require new engineering to reduce out-of-band emissions.

*iii. Policy option C: Require frequency window time sharing between federal agencies and commercial entities*

Mandate time sharing between federal agencies and commercial entities of frequencies from 24.24 GHz to 27.5 GHz and 36.0 GHz to 40.5 GHz. Specifically, amend Title 47 CFR § 25.259 to expand the range of frequencies protected for NOAA satellites. Such an amendment could be proposed within H.R. 5000 SHARE Act, which was introduced in the House of Representatives in November 2019. Additional commercial data may be purchased to supplement potential data loss via timesharing.

*Advantages*

- The deployment and roll-out of 5G as planned avoids the need for reduced out-of-band noise emissions, which could delay the deployment of 5G.
- No known adverse effects on the accuracy of weather data.

- Reduced costs since time sharing protocols already exist in industry.

*Disadvantages*

- Presents risks to national security due to reliance on commercial data to fill gaps.
- Only protects bands from satellites operated by U.S. federal entities.
- 5G applications that rely on constant high-speed link between two parties might suffer performance loss.

**IV. Policy recommendation**

We recommend that Congress implement option B, creating new limits on frequency window allocation. This recommendation has the advantage of allowing the 5G rollout to continue while still limiting out-of-band emission interference with water vapor measurements critical for accurate weather forecasting. While the direct economic costs of emissions interference are not known, the indirect costs of interference for economies dependent on accurate weather prediction are estimated to be in the trillions of dollars, especially given the increase in unpredictable and extreme weather events due to climate change. Stricter noise restrictions are appropriately precautionary given the enormous risk of adverse impacts. While there are certainly some potential impacts on 5G planning for commercial entities, this option does not prevent or unduly delay 5G implementation. Further, it provides an avenue for future band allocation through continued research. Congress should write legislation to protect accurate weather prediction services to adequately meet requirements of Pub.L 115-25, while ensuring 5G deployment is not critically hindered.
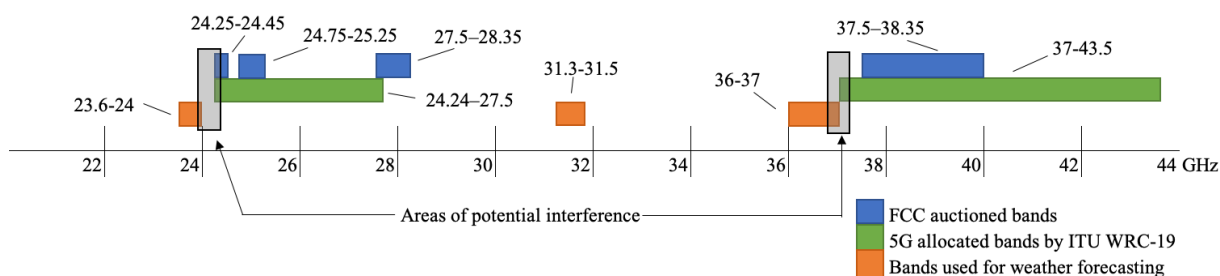
# Appendix

**Figure 1.** 5G band allocations of the FCC and 2019 International Telecommunication Union (ITU) World Radiocommunication Conference (WRC-19) compared to existing spectra used for weather prediction. Image credit: Shantam Ravan.
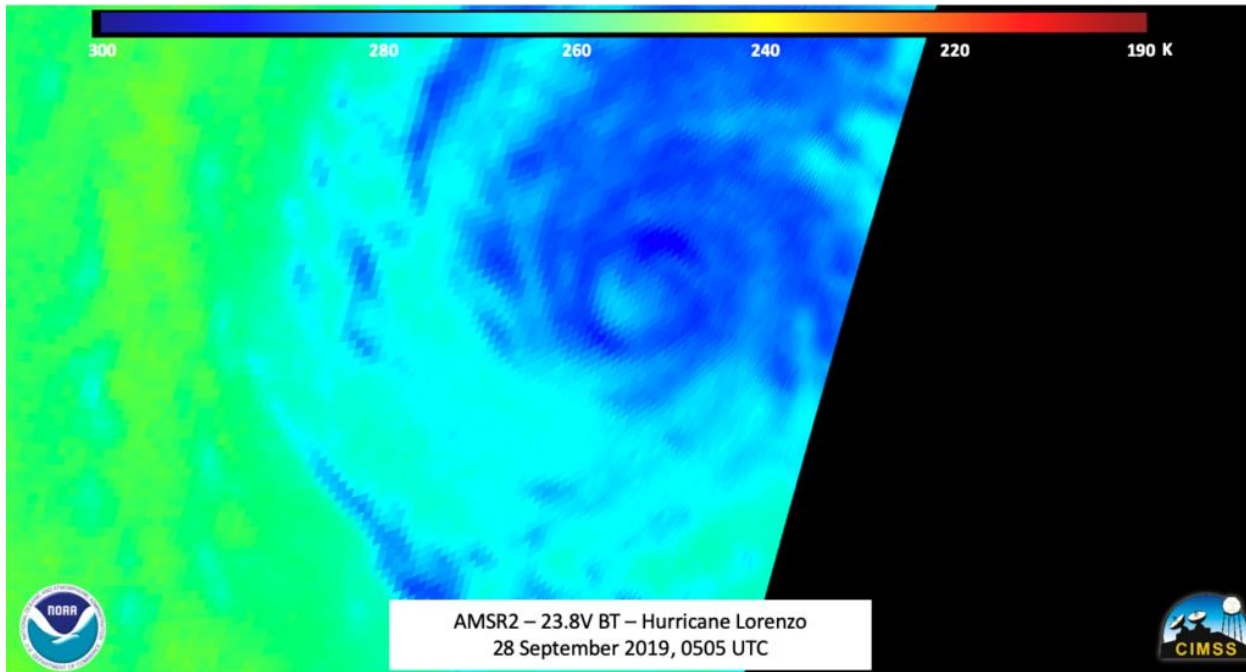


**Figure 2.** Microwave sensed image from the Advanced Microwave Scanning Radiometer 2 (AMSR2) of Hurricane Lorenzo from September 28, 2019. This image utilizes parts of the spectra proposed for 5G and allows a view of the hurricane from different levels of the atmosphere. When the eye of a hurricane is obscured by clouds, microwave imagery like AMSR2 is used to capture the eye location, providing valuable information about the storm necessary for ensuring the safety of life and property. Images used by permission from William Straka/CIMSS.

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