Correlating NEXRAD Data with Electromagnetic Propagation Data

AJ Cuddeback,*† Chris Anderson,* Scott Palo†
* Institute for Telecommunication Sciences, Boulder, CO 80305; https://its.ntia.gov/; (acuddeback@ntia.gov)
† The University of Colorado Boulder, Boulder, CO 80309; https://www.colorado.edu/

***Abstract*—This paper describes a first step toward correlating publicly available data from the Next Generation Weather Radar (NEXRAD) system with electromagnetic propagation measurements. We demonstrate the successful extraction of data from a specified volume to generate a time series and contextualize our results alongside transmission loss, humidity, and temperature measurements taken during a snowstorm. We propose future development of the toolchain to enable widespread adoption.**

I. Introduction

Predictive electromagnetic propagation models such as the Irregular Terrain Model (ITM) [1] rely on the U.S. Standard Reference Atmosphere [2] for atmospheric refractivity to estimate basic transmission loss (BTL). This model of refractivity doesn't account for localized atmospheric conditions, largely because at the time of its development there was no way to continuously monitor widespread meteorological activity at spatial resolution fine enough to capture localized variations.

Since the development of the ITM in the 1960s, the National Oceanographic and Atmospheric Administration (NOAA) has deployed its Next Generation Weather Radar (NEXRAD) system that provides measurements of meteorological activity up to 10 times per hour from each station [3]. The NEXRAD network consists of 160 S-band Doppler radars providing coverage over most of the continental United States, Alaska, Hawaii, Puerto Rico, Guam, and South Korea [3]. NEXRAD Level 2 (L2) data files are generated every 6–10 minutes and cover the area within 460 km of the radar. We anticipate future electromagnetic propagation models are likely to incorporate high spatiotemporal resolution atmospheric data products due to the proliferation of high-resolution NEXRAD data and predictive weather models.

To make L2 NEXRAD data available for developing predictive propagation models or evaluating anomalous localized propagation events, we developed a toolchain to create radar reflectivity time series for specific spatial volumes. Using this tool chain, we compare NEXRAD weather data including humidity, temperature, and reflectivity with synchronized propagation loss measurements. We then discuss the potential relationship between the propagation loss and the weather data.

II. Volume Selection Process

Generating a time series of NEXRAD data requires collecting L2 data files from the desired time window and a definition of the desired volume in latitude, longitude, and altitude. Each data file is referenced by the timestamp at which it was generated and processed individually using the Python ARM Radar Toolkit (pyart) [4] to obtain the radar measurements and metadata. Valid measurements are retrieved based on the defined selection criteria and stored with the timestamp of the file from which they were obtained. Selected NEXRAD data products in the volume of interest can then be plotted against their corresponding timestamp to show the behavior of the volume as a function of time. Fig. 1 illustrates this process.

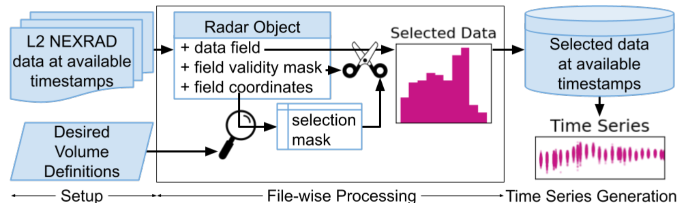

Fig. 1: NEXRAD data selection flow from volume definition and input of L2 data files to the generation of a time series plot of the extracted radar measurements. The resulting time series plot can be compared to longitudinal propagation measurements.

III. Volume Selection Times Series Output

To demonstrate the utility of our tool chain, we examined the volume ranging from 1700 m to 2700 m altitude above mean sea level (MSL) along the line-of-sight path of a 3.995 GHz propagation experiment. The experiment setup describes a 3.4 GHz link [5], but the frequency was changed to 3.995 GHz in early 2024. We chose to study the time period between 14:00:00 MDT on 03/13/2023 and 02:00:00 MDT on 03/14/2023, corresponding to the presence of a snow storm covering most of Eastern Colorado. Fig. 2 shows reflectivity data taken by the KTFG NEXRAD station near Denver, CO at 14:06:55 MDT on 03/14/2023 (left) and the data within the selected volume (right). The L2 reflectivity is range corrected

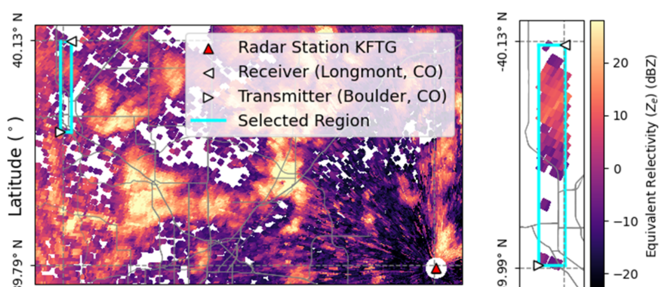

Fig. 2: Radar reflectivity for 0.483° elevation sweep at the beginning of our time window under scrutiny, rendered using [4]. Left plot shows location for the selected volume bounds and radar station, and transmitter and receiver placement from [5]. Right plot shows data extracted for time series generation. Background lines signifying major surrounding roadways are added for visual landmarking.

U.S. Government work not protected by copyright in the United States. This paper was presented at and published in the 2025 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM). USNC-URSI NRSM Proceedings are copyright © IEEE.

to account for free space path loss. During this time period we observed a sharp, approximately 10 dB increase in BTL that slowly returned to the nominal measured value over a period of about 3 hours. This sharp increase in BTL from its nominal value of 133 dB was accompanied by a sharp decrease in temperature and preceded by a more gradual increase in humidity and radar reflectivity, as shown in Fig. 3. The humidity and temperature readings were taken by a weather stations along the link, described in the experiment setup [5].

We are currently unaware of a model that would completely attribute the additional attenuation to snowfall over the 14.5 km path. Increases in reflectivity are consistent with storm activity, which signify an increase in hydrometeor abundance. The sharp decrease in temperature to $0°$ C corresponds to a change from rain to snow. Thus, the increased BTL could be at least partially attributed to hydrometeor composition during this time.

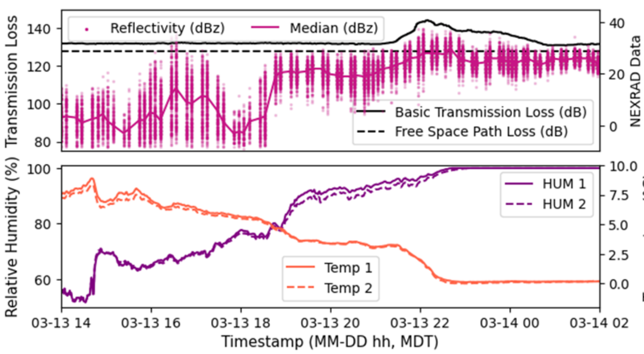

Fig. 3: NEXRAD time series plotted alongside link transmission loss and humidity. The heights of humidity sensors 1 and 2 differ from those reported in the experiment setup [5], and are $72.5''$ and $139''$ above ground level, respectively. This provides clear visualization as basis for discussion of the relationship between radar reflectivity and path loss.

IV. Discussion

The results in Fig. 3 illustrate the ability of this tool to provide data from a widely available weather radar data source that could contribute to future propagation variability analysis. However, further analysis is required to refine the data product to enable meaningful correlation results, particularly where meteorological activity does not result in radar returns in the volume of interest. For example, a median statistic for the selected volume shown in Fig. 2 does not account for the fraction of the volume that yields no radar return, nor does it account for the decreasing spread in values over time.

In the future, we intend to expand the tool's capabilities to account for data scarcity in the selected volume. We also hope to make improvements such as matching / mirroring RF link geometries as determined by real-life antenna parameters and automating unique volumes for a wider variety of links. We also hope to make this toolchain compatible with data from NOAA's High Resolution Rapid Refresh (HRRR) dataset [6] to enable the use of predictive data. These changes would improve the tool's functionality, increase the range of experiments to which it could be applied, and facilitate its use by a broad audience.

The outcome of this study has the potential to significantly improve studies of the impact of atmospheric variability on propagation. While more sophisticated means of weather monitoring exist, our tool provides a straightforward way of gathering meteorological data from a publicly available dataset. NEXRAD data is widely available and this toolchain could facilitate weather variability studies in both tropic regions and near-arctic regions using the same meteorological data product. Moreover, because models such as HRRR [6] predict radar reflectivity, results of these variability studies would have a direct tie-in to use in updating predictive models.

V. Summary

This paper describes a method to correlate publicly available L2 NEXRAD data with measured electromagnetic propagation data using a purpose-developed toolchain, with the goal of analyzing the effect of atmospheric conditions on electromagnetic propagation. The toolchain was applied to visualize and analyze weather radar data alongside measured BTL, humidity, and temperature data. Future improvements include refining the data product for more meaningful correlation results and expanding the tool's capabilities to handle multiple volumes and automate volume selection based on antenna parameters.

Acknowledgment

We thank Dr. Chris Anderson of the Institute for Telecommunication Sciences for providing the data used to contextualize our toolchain.

References

[1] P. L. Rice, A. G. Longley, K. A. Norton, and A. P. Barsis, "Transmission loss predictions for tropospheric communication circuits: Volumes I and II," U.S. Department of Commerce, Environmental Science Services Administration, Institute for Telecommunication Sciences and Aeronomy, Technical Note TN-101 Vols. I and II, Jan. 1967.

[2] United States Committee on Extension to the Standard Atmosphere, *U.S. Standard Atmosphere, 1976*, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Oct 1976, https://www.ngdc.noaa.gov/stp/space-weather/online-publications/miscellaneous/us-standard-atmosphere-1976/us-standard-atmosphere_st76-1562_noaa.pdf.

[3] National Oceanic and Atmospheric Administration, "Next generation weather radar (NEXRAD)," https://www.ncei.noaa.gov/products/radar/next-generation-weather-radar.

[4] J. J. Helmus and S. M. Collis, "The python arm radar toolkit (py-art), a library for working with weather radar data in the python programming language," *Journal of Open Research Software*. [Online]. Available: https://www.osti.gov/biblio/1339572

[5] A. Vanleer and C. R. Anderson, "Characterization of atmospheric variability on long range 3.4 GHz propagation," in *2023 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, 2023, pp. 120–121.

[6] D. C. Dowell, C. R. Alexander, E. P. James, S. S. Weygandt, S. G. Benjamin, G. S. Manikin, B. T. Blake, J. M. Brown, J. B. Olson, M. Hu, T. G. Smirnova, T. Ladwig, J. S. Kenyon, R. Ahmadov, D. D. Turner, J. D. Duda, and T. I. Alcott, "The high-resolution rapid refresh (HRRR): An hourly updating convection-allowing forecast model. part I: Motivation and system description," *Weather and Forecasting*, vol. 37, no. 8, pp. 1371 – 1395, 2022. [Online]. Available: https://journals.ametsoc.org/view/journals/wefo/37/8/WAF-D-21-0151.1.xml

U.S. Government work not protected by copyright in the United States. This paper was presented at and published in the
2025 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM). USNC-URSI NRSM Proceedings are copyright © IEEE.