National Aeronautics and Space Administration

Maximize Europa Clipper Data Return by Accurate Prediction of Atmospheric Noise Temperature Using Machine Learning

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Program: FY22 R&TD Topics

Strategic Focus Area: RF and Optical Communications

Background

- Ka-band (32 GHz) communications links are far more sensitive to weather degradation than X-band (8.4 GHz).
- Current models for the Ka-band downlink data rates are quite conservative, usually accounting for 90% weather availability. The Europa Clipper mission is using a 3 dB margin. This approach can result in inefficient downlink capacity.
- Recent studies showed that using real-time weather forecasting can increase data return and the reliability of the communication links.

Objectives

- The objective of this project is to develop a customized real-time prediction system for atmospheric noise temperature (T_{atm}), which is the input to the telecommunication link model, for Deep Space Network (DSN) tracking sites using machine learning (ML).
- We focus on Ka-band (32 GHz) communication links that will be demonstrated for possible use by the Europa Clipper mission.
- The prediction system of zenith T_{atm} with uncertainty quantification (UQ) will be developed, with forecast lead time of 1-16 days.
- In FY21, we have focused on developing the ML-based forecast system at Goldstone, CA.
- In FY22, we adopt the ML-based forecast system to the DSN tracking sites at Madrid, Spain and Canberra, Australia, and assess the benefit of using real-time forecasts for data downlink from Europa Clipper in a telecommunication link model.

Approach

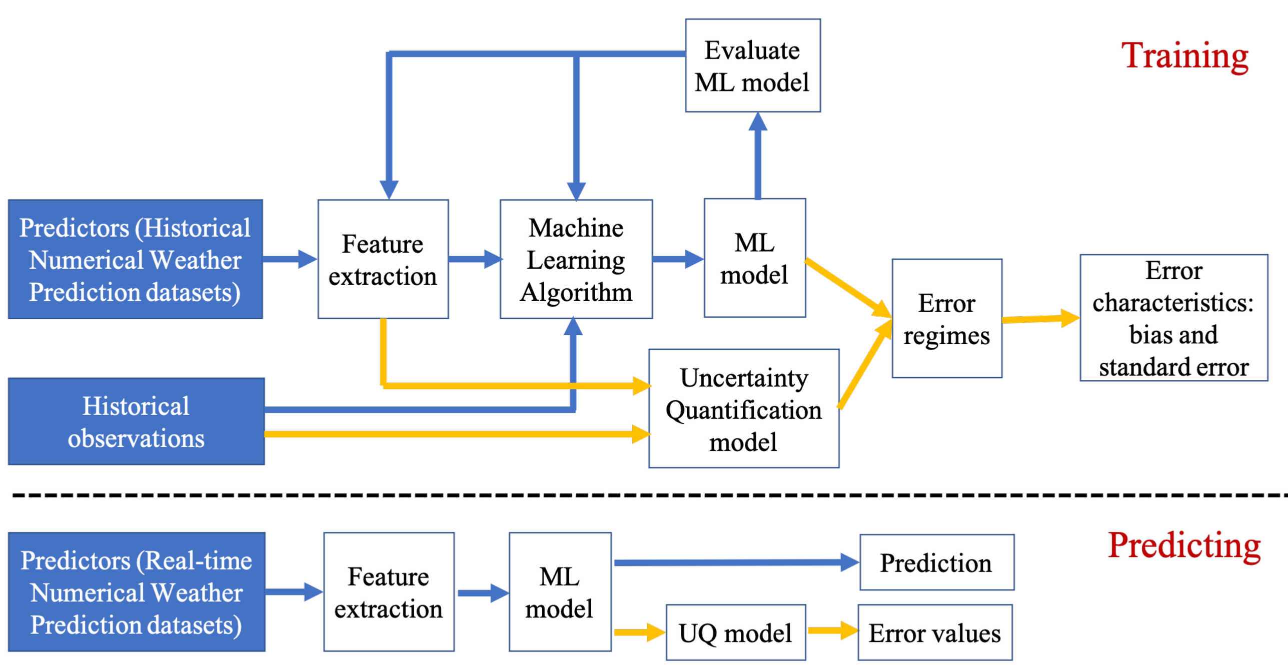

Figure 1. Workflow of the ML-based forecast system.

Significance/Benefits to JPL and NASA

- This project proposes to provide direct support to the operation of the Europa Clipper mission and other flight projects using the DSN.
- This project is aligned with JPL's strategic goals to achieve "seamless, higher rate, larger volume data and information delivery" and enable more productive and impactful space missions for the ultimate quest of life beyond Earth and other scientific investigations.
- The ML model for predicting T_{atm} can be generalized to many other missions in which data communications are essential. It could serve as a universal component of future onboard data prioritization protocol.

Results

- Because the AWVR/WVR equipment hasn't been operational at Madrid and Canberra in recent years and GFS archive is only available starting from 2015, we develop a RF model to derive T_{atm} from the ERA-5 reanalysis.
- The simulated T_{atm} has good agreement with the observations at the three DSN sites (Fig. 2). Then the simulated T_{atm} is used to train the ML-forecast system.
- 90% of the 1-day (7-day) forecasts has a RMSE<25% (35%) relative to the mean T_{atm} (Fig. 3).
- The real-time error analysis from the UQ model (Fig. 4) is consistent with the error analysis comparing to the observations in Fig. 3.
- During most of the time, higher data return can be realized when weather forecasting is used in telecommunication operations in place of using 90% weather availability in the link assumptions (Fig. 5).

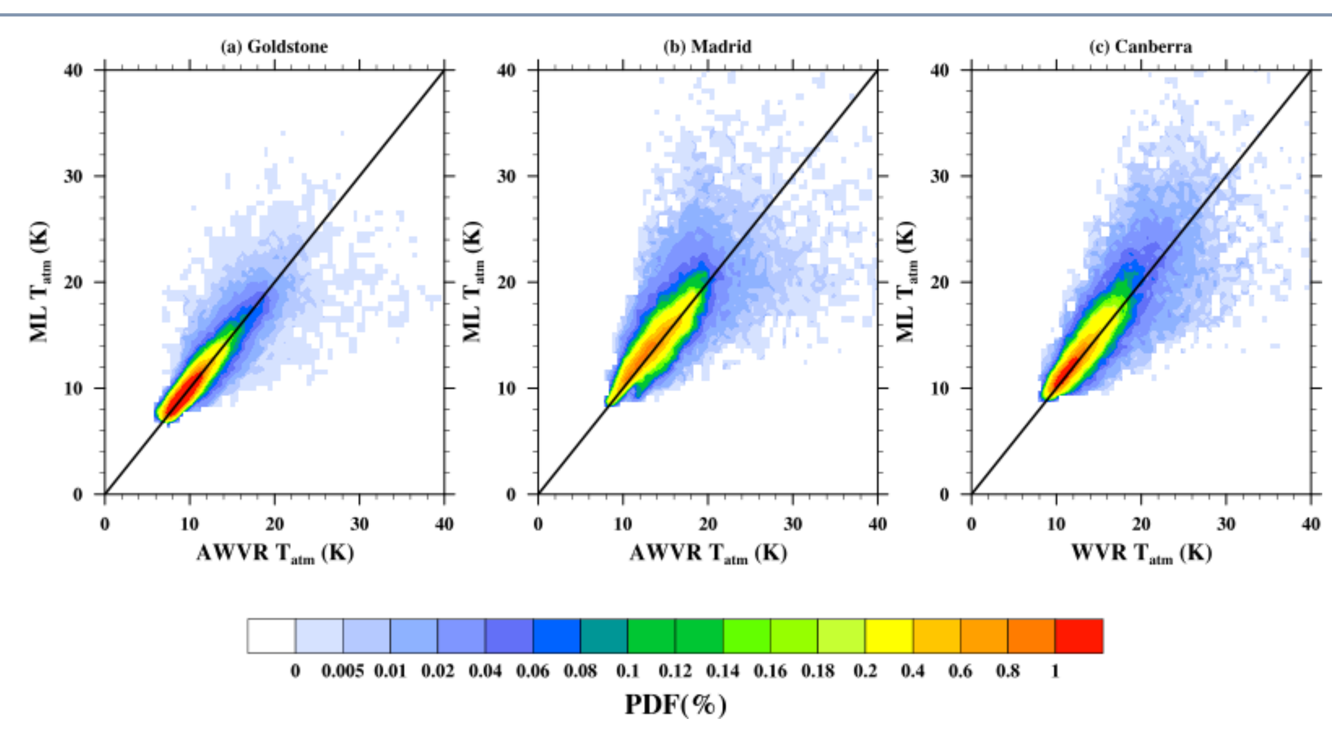

Figure 2. Joint distribution of AWVR/WVR observed and ML-simulated T_{atm} from the ERA-5.

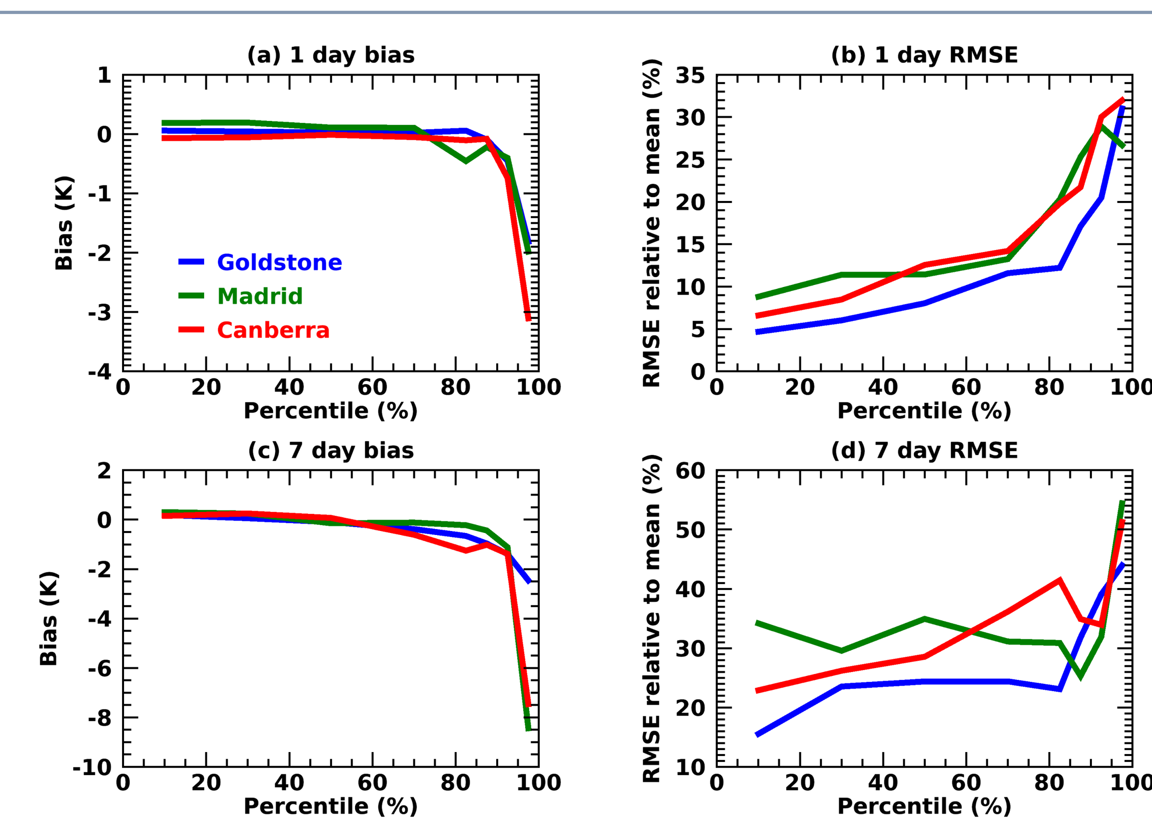

Figure 3. ML forecast results. X-axis is the percentile range (%) of the forecasted T_{atm}.

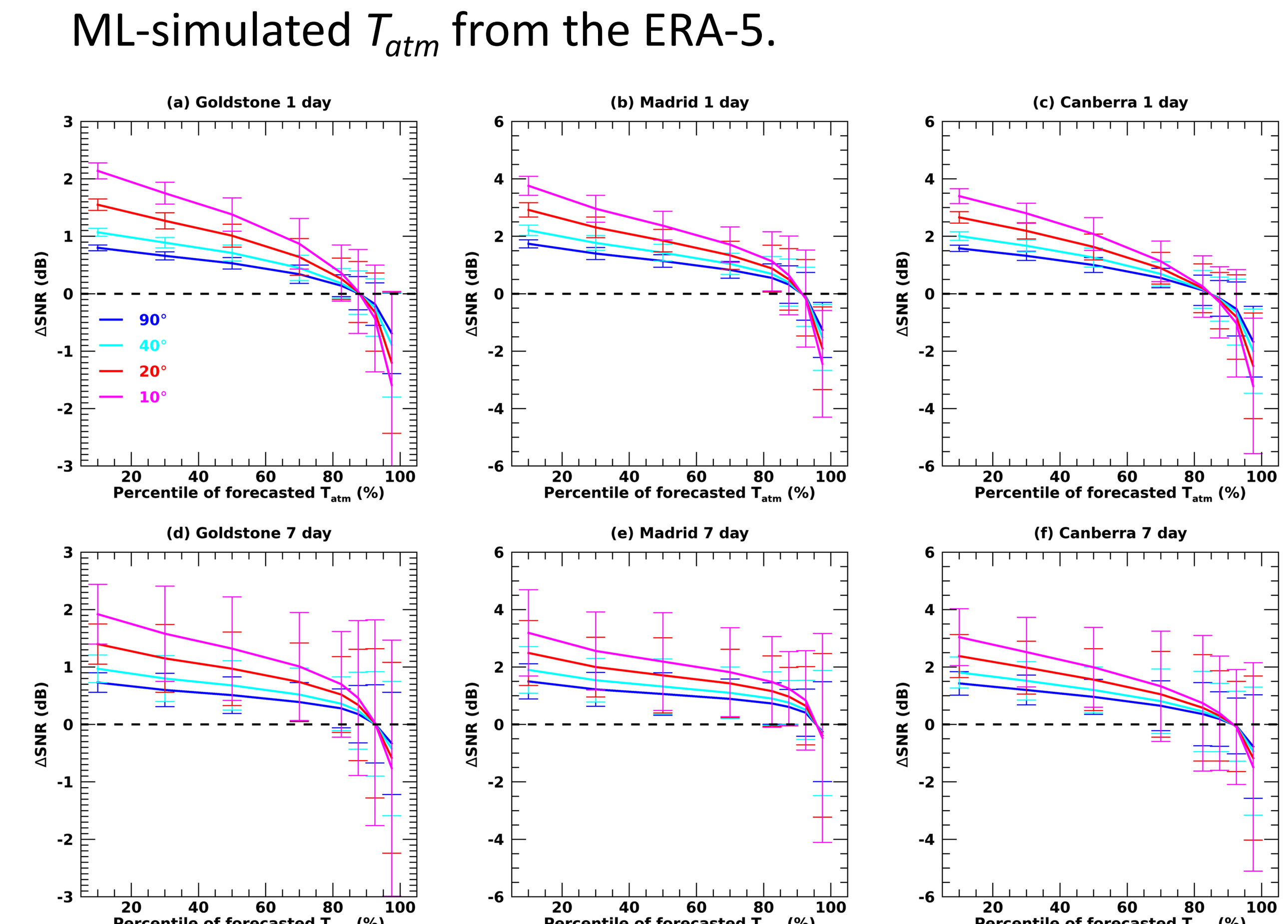

Figure 5. Forecast Gain (ΔSNR, dB) relative to the 90% weather availability VS. mean T_{atm} for different elevation angle cases (90°, 40°, 20° and 10°).

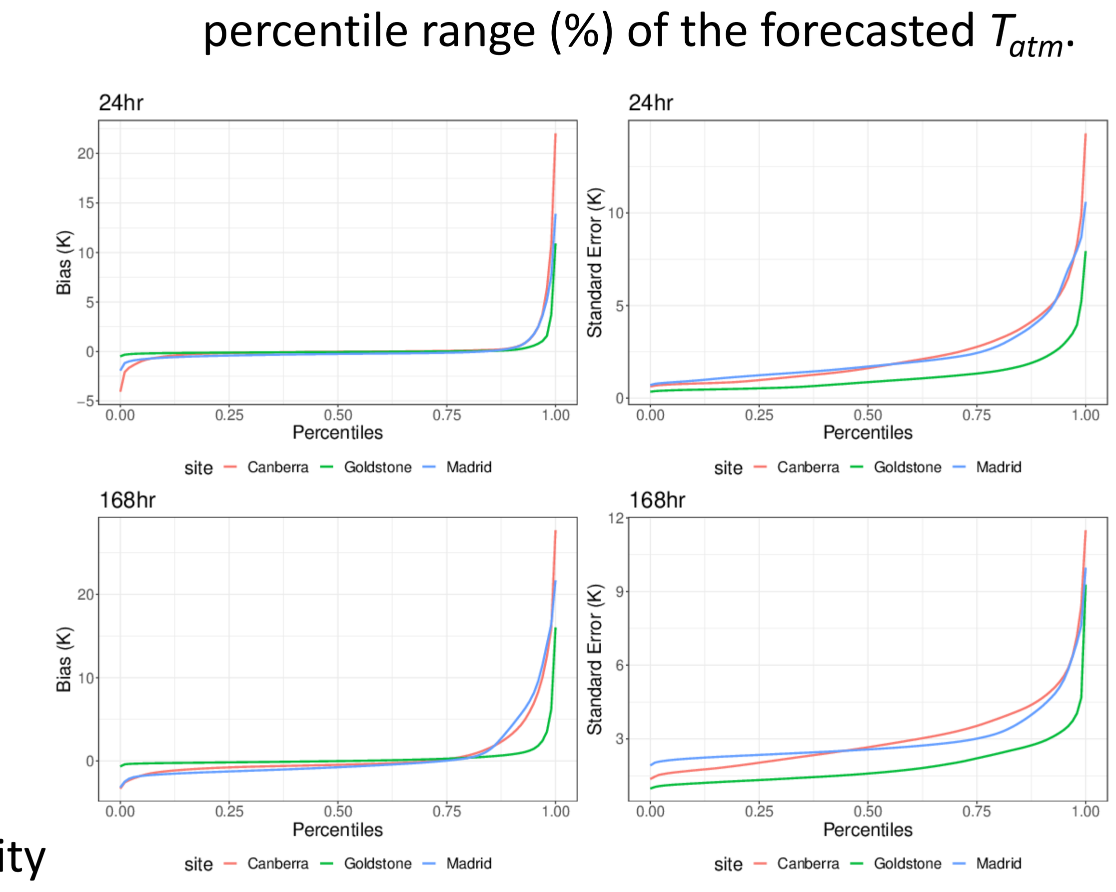

Figure 4. Quantile plot of UQ results.

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Publications:

[A] Wu, L., D. D. Morabito, J. P. Teixeira, L. Huang, H. M. Nguyen, H. Su, M. A. Soriano, L. Pan, and D. S. Kahan, "Prediction of Atmospheric Noise Temperature at the Deep Space Network with Machine Learning", Radio Science, in review.

[B] Morabito, D.D., D. S. Kahan, M. Paik, L. Wu, E. Barbinis, D. Buccino, and M. Parisi, "A Study of Twenty Years of Advanced Water Vapor Radiometer Data at Goldstone, California", The Interplanetary Network Progress Report, vol. 42-226, Jet Propulsion Laboratory, Pasadena, California, pp. 1–18, February 15, 2022.

[C] Morabito, D.D., L. Wu, and J. Teixeira, "An Assessment of Weather Analysis Data from the DSN Sites", in preparation.

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