Accurate Weather Forecasting for Radio Astronomy

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The NRAO Green Bank Telescope routinely observes at wavelengths from 3 mm to 1 m. As with all mm-wave telescopes, observing conditions depend upon the variable atmospheric water content. Although the site provides over 100 days when atmospheric opacities are low enough for good observing at 3 mm, winds on the 100-m open-air structure reduces the time suitable for 3-mm observing where pointing accuracy is critical. Thus, to maximum productivity the observing wavelength needs to match weather conditions. For ~6 years the telescope staff has used a dynamical scheduling system (recently upgraded, see http://www.gb.nrao.edu/DSS/) that requires accurate multi-day forecasts for winds and atmospheric opacities. Since opacity forecasts are not provided by the national weather services, I have developed an automated system that takes available forecasts and derives forecasted opacities. The results are deployed on the web in user-friendly graphical overviews.

The system relies on the "North American Mesoscale" models provided by the national weather services. These are updated every 6 hrs, have a 12 km horizontal resolution, 1 hr temporal resolution, run to 84 hrs, and have ~60 vertical layers that extend to ~20 km. Each forecast consists of a time series of ground conditions, cloud coverage, etc, and, most importantly, temperature, pressure, humidity, and cloud coverage as a function of height. I use the MWP model of Liebe (Radio Science, 20, 1069, 1985) to determine the absorption coefficient for each layer for each hour of the forecast for ~30 observing wavelengths. Radiative transfer provides, for each hour and wavelength, the total opacity and the radio brightness of the atmosphere, which contributes substantially at some wavelengths to T_{Sys} and the noise in an observation.

Comparisons of measured and forecasted T_{Sys} at 22.2 and 44 GHz imply that the forecasted opacities are good to about 0.01 Nepers, which is suitable for forecasting as well as for accurate calibration. The reliability of forecasted opacities is high out to about 2 days and becomes slowly less reliable for longer-range forecasts.

Method

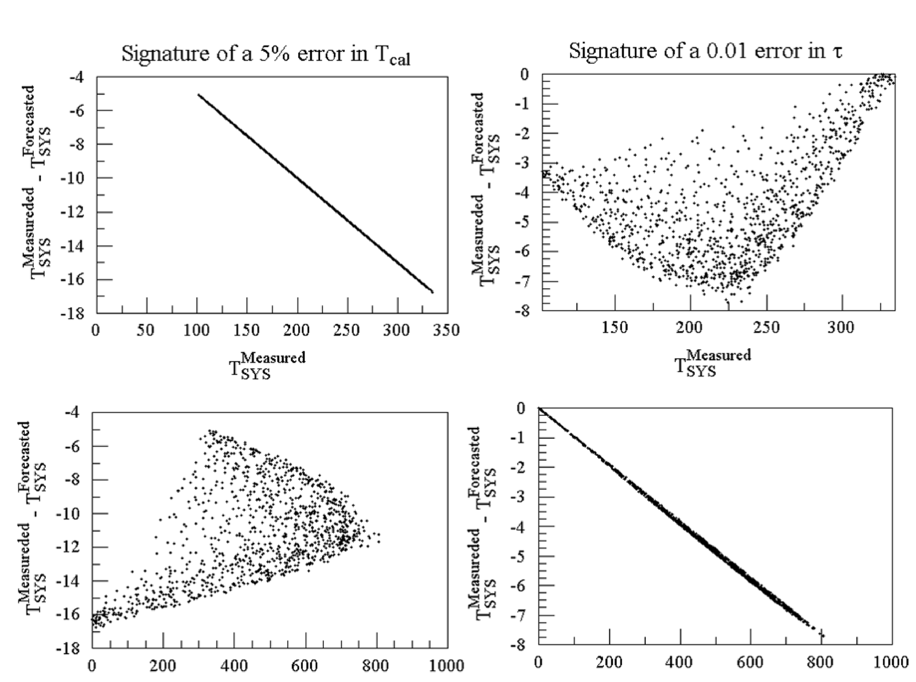
Compare measured and forecasted T_{Sys} to determine errors in Noise Diode (i.e., calibration) and Opacity. One can distinguish a calibration error from an error in forecasted opacity.

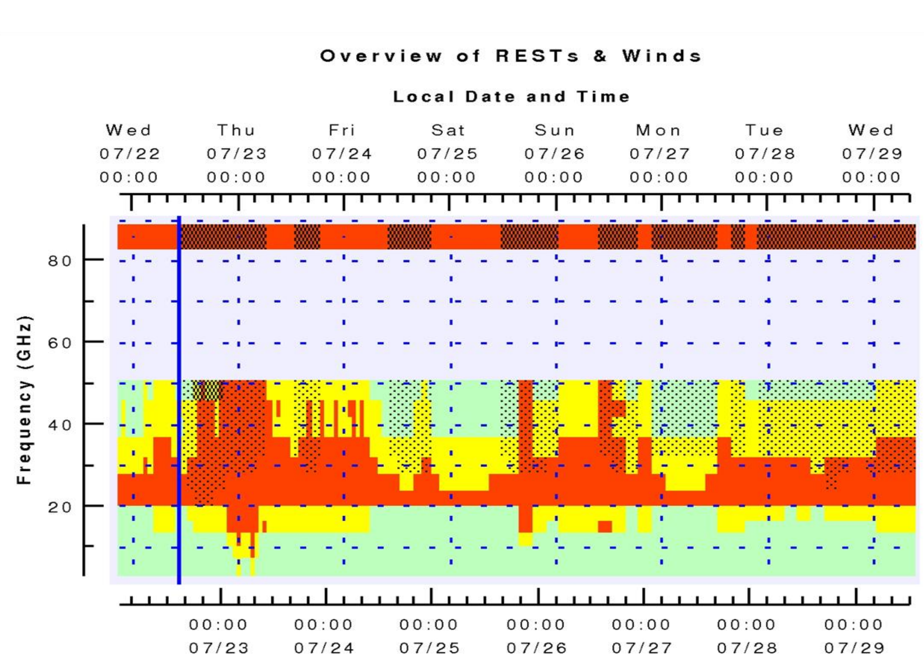
$$T_{SYS}^{Measured} - T_{SYS}^{Forecasted} = \Delta T_{Rcvr} + f \cdot T_{SYS}^{Measured} + \Delta\tau \cdot (T_{ATM} \cdot A \cdot e^{-\tau \cdot A})$$

$$X1 = T_{ATM} \cdot A \cdot e^{-\tau \cdot A}$$

f = fractional error in T_{cal}

A = Airmass

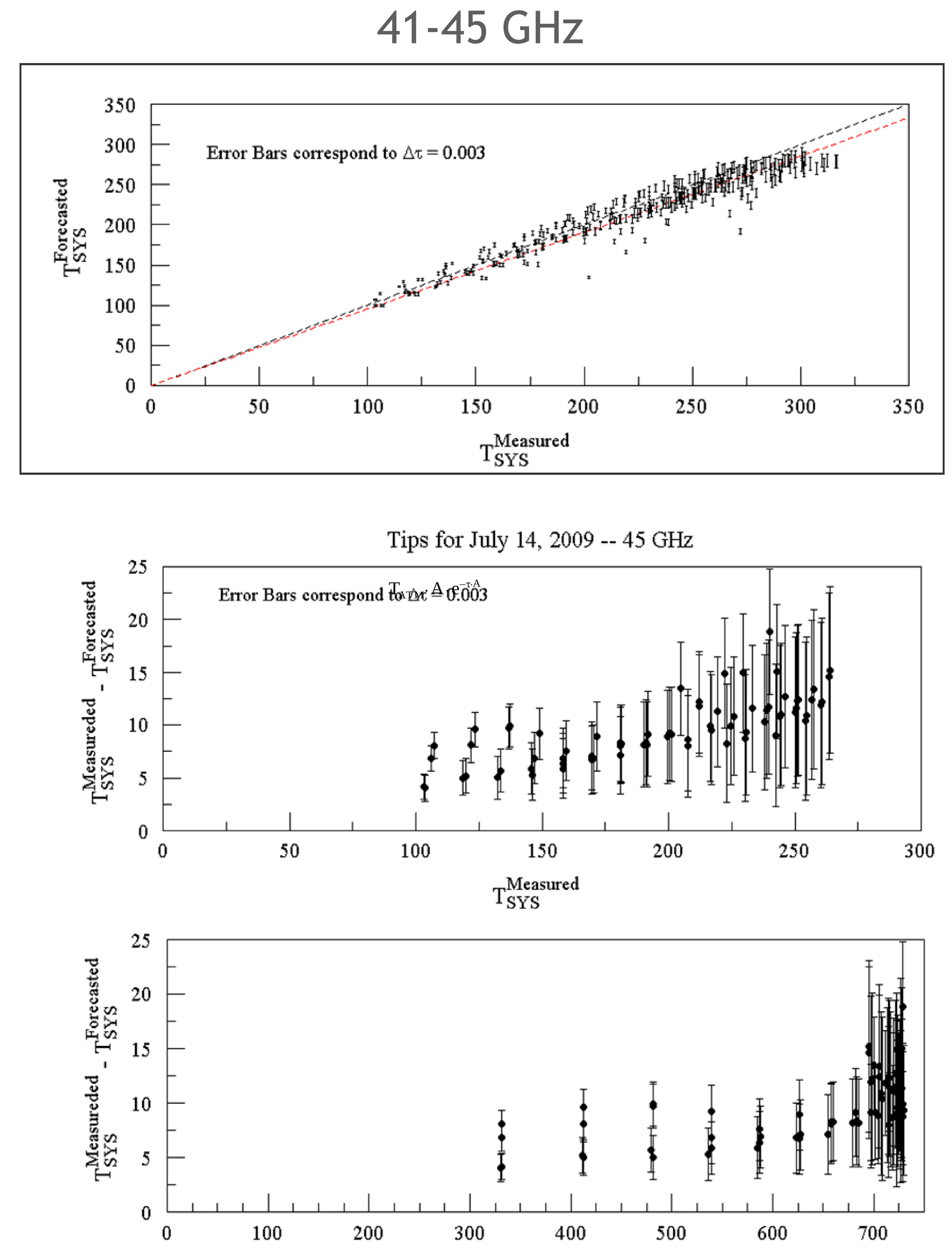




▪http://www.gb.nrao.edu/~rmaddale/Weather/

Accuracy of Forecasts at 22 and 45 GHz

41-45 GHz



Fitting for T_{cal} reduced rms to 1.97 K

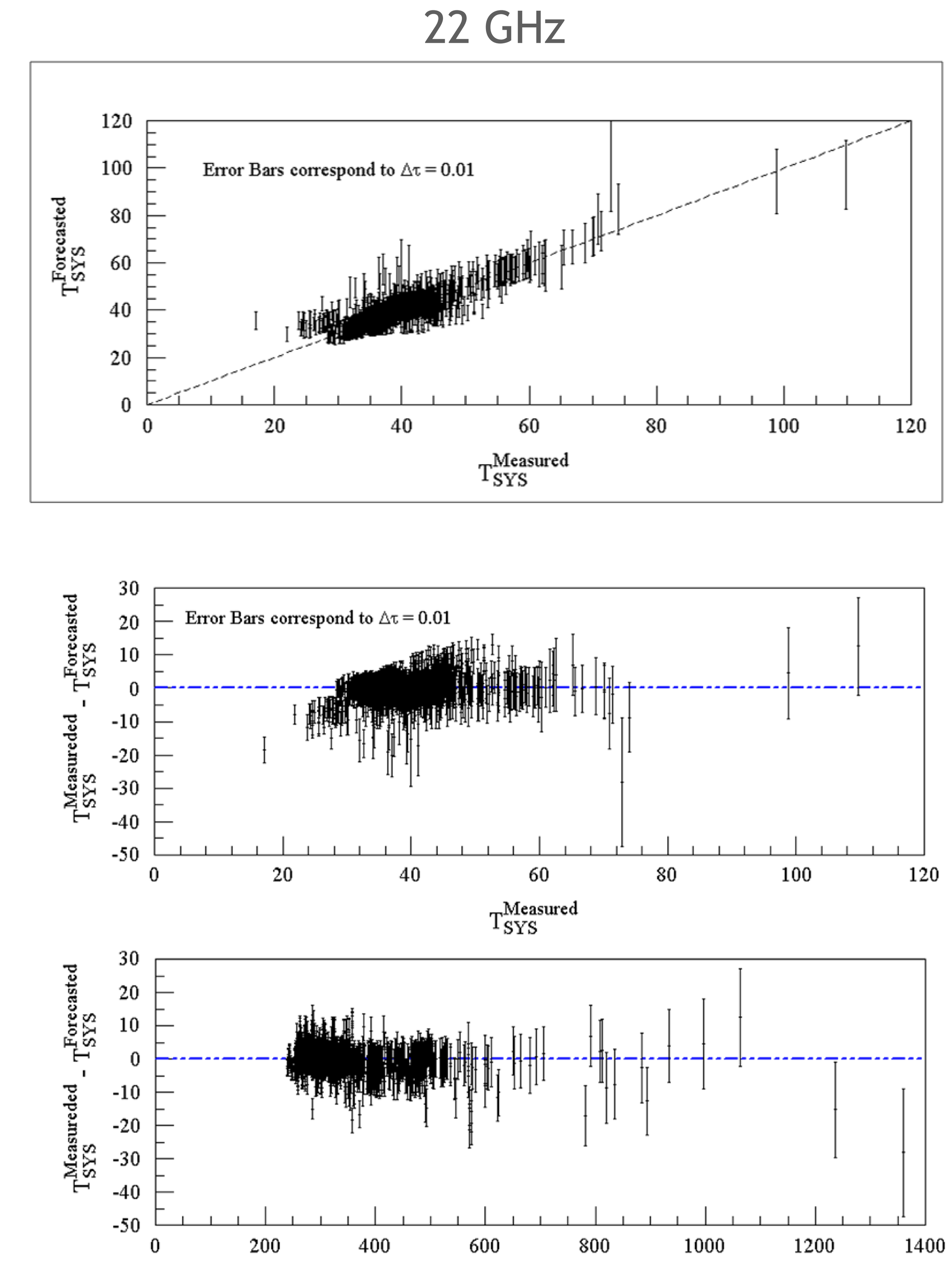
Fitting for T_{cal} and ΔT_{rcvr} reduced rms to 1.98 K

Fitting for T_{cal}, ΔT_{rcvr}, and $\Delta\tau$ reduced rms to 1.97 K

Fitting for $\Delta\tau$ or $\Delta\tau$ and ΔT_{rcvr} reduced rms to 2.36 K and would require $\Delta\tau$ = 0.016

- The likely source of difference is a 5% error in T_{cal}
- The likely upper value of $\Delta\tau$ = 0.006
- The most skeptical upper limit is $\Delta\tau$ = 0.016

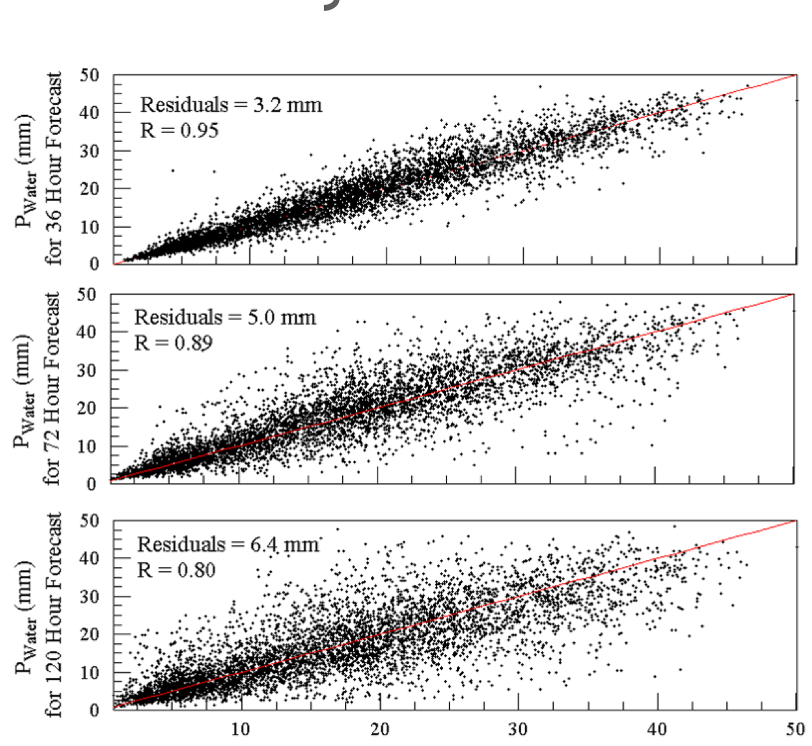
22 GHz



As with 41-45 GHz, fitting for $\Delta\tau$ did not improve rms in a statistically significant way

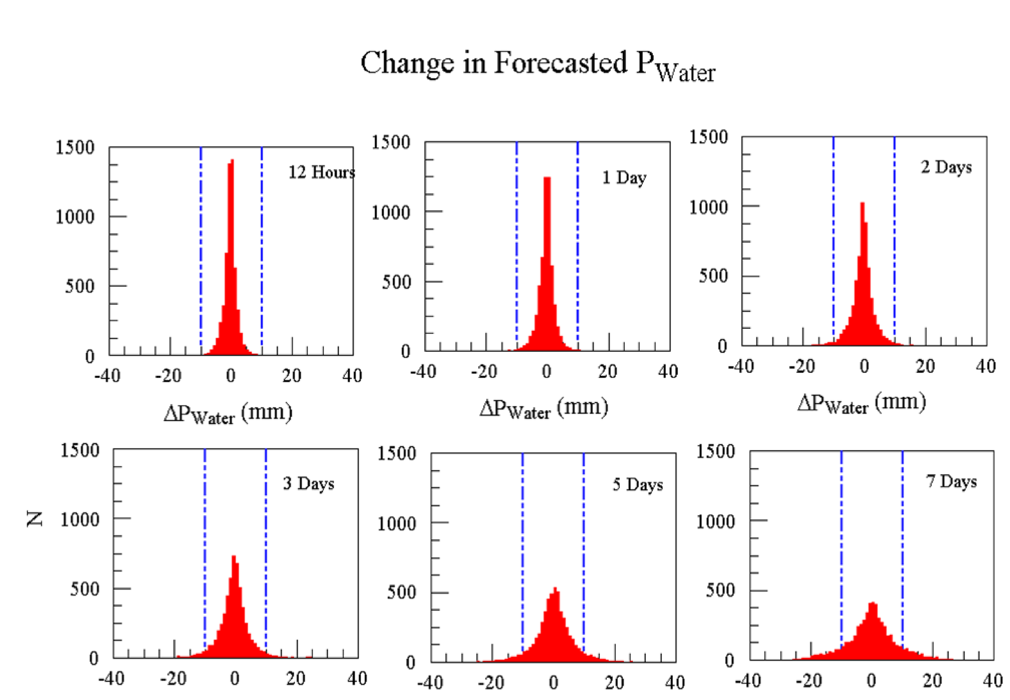
- Most likely upper estimates for $\Delta\tau$ ~0.011.
- Errors in T_{cal} dominate
- For top 50% of data:
  - no fits improved the rms (3.5 K)
  - Most likely upper estimate is $\Delta\tau$ ~0.005.

Reliability of Forecasts



Correlation between Forecasts

Hr	R	rms (mm)
6	0.985	1.76
12	0.978	2.11
18	0.972	2.41
24	0.968	2.58
30	0.960	2.91
36	0.952	3.15
42	0.942	3.46
48	0.932	3.73
54	0.922	4.03
60	0.910	4.35
66	0.898	4.64
72	0.885	4.95
78	0.875	5.19



- Cloud coverage
  - Good for 5 days for spectral line observing
  - But, how do forecasted cloud coverage match with observed?
- Opacity forecasts for spectral line observing are good for:
  - ~2 days for 22 GHz
  - ~3 days for 45 GHz,
  - ~5 days for any other frequencies < 50 GHz
- Wind forecasts are consistent for up to 5 days
  - But, how do forecasted winds match with measured winds?

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