Impact of atmospheric water vapor on VLBI measurements

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VLBI and geodesy

- The distance between radio telescopes is calculated from the time delay for a signal to reach each telescope

- Atmospheric wet delay is one of the main error sources for VLBI and satellite measurements

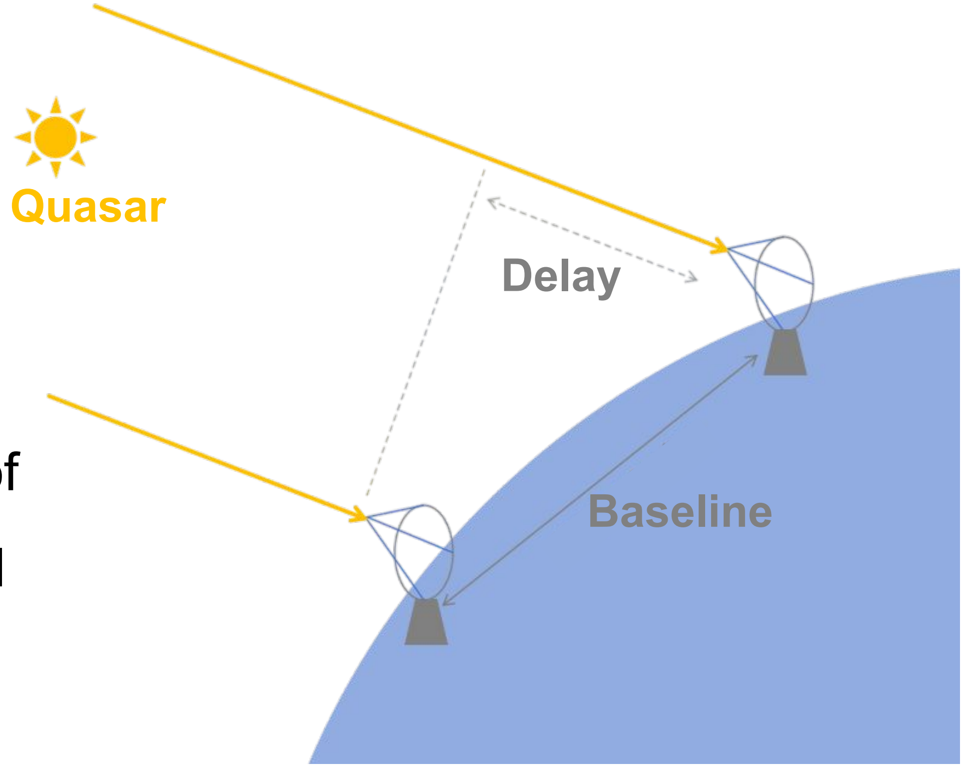

Image from TERSUS GNSS: https://tersus-gnss.com/tech_blog/What-is-SLR-and-VLBI

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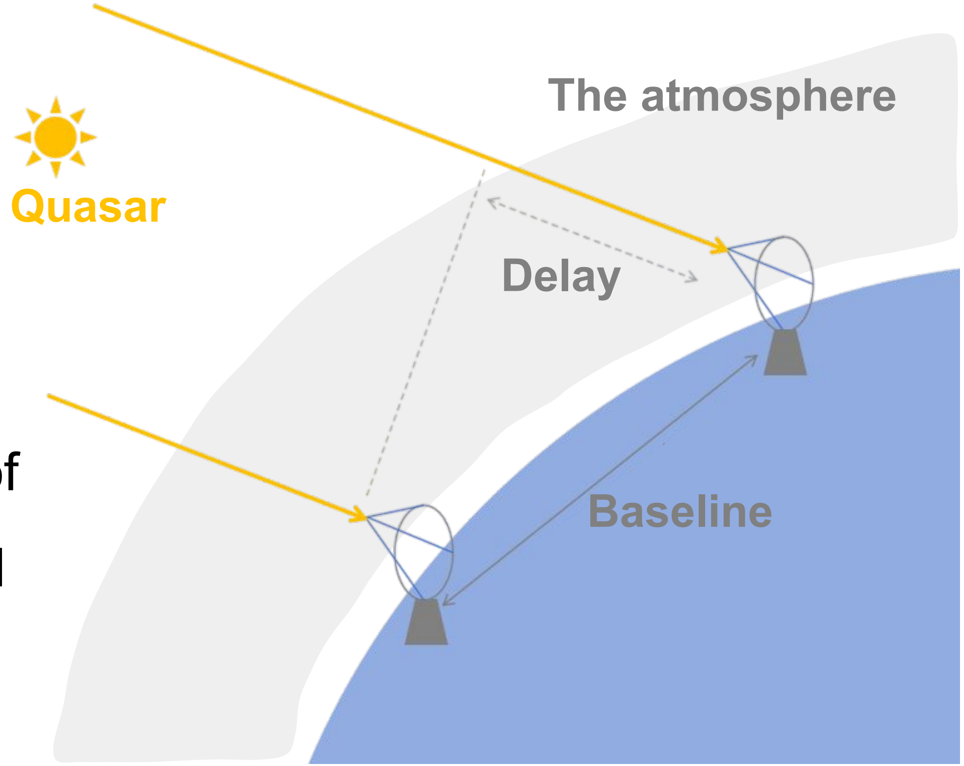

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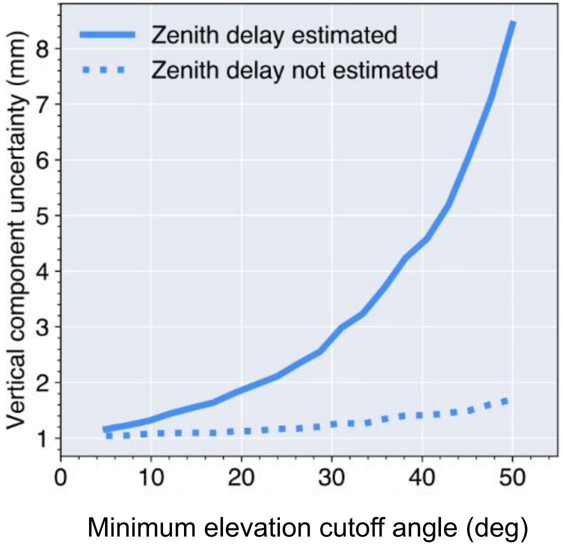
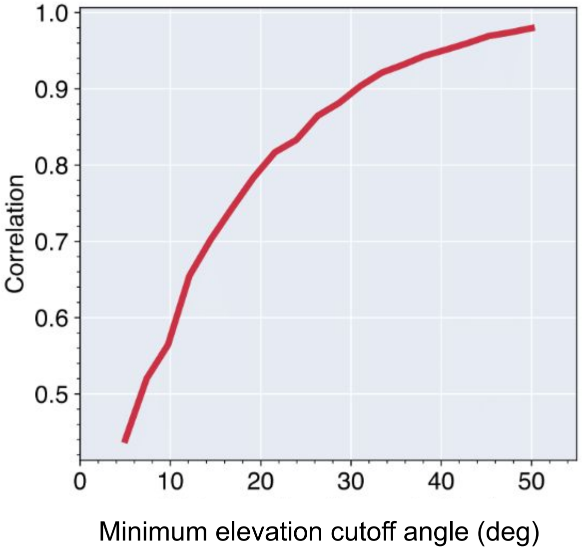
Estimating wet atmospheric delay

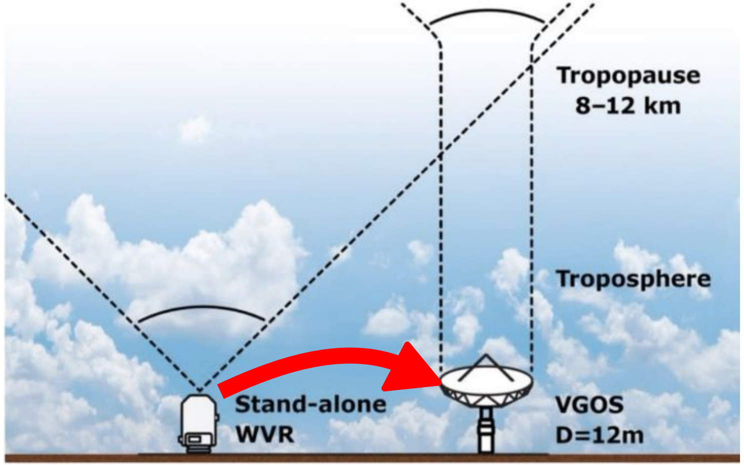




The vertical component uncertainty increases when the delay is estimated

The correlation between the site position vertical component and wet delay increases for higher cutoff elevation angles

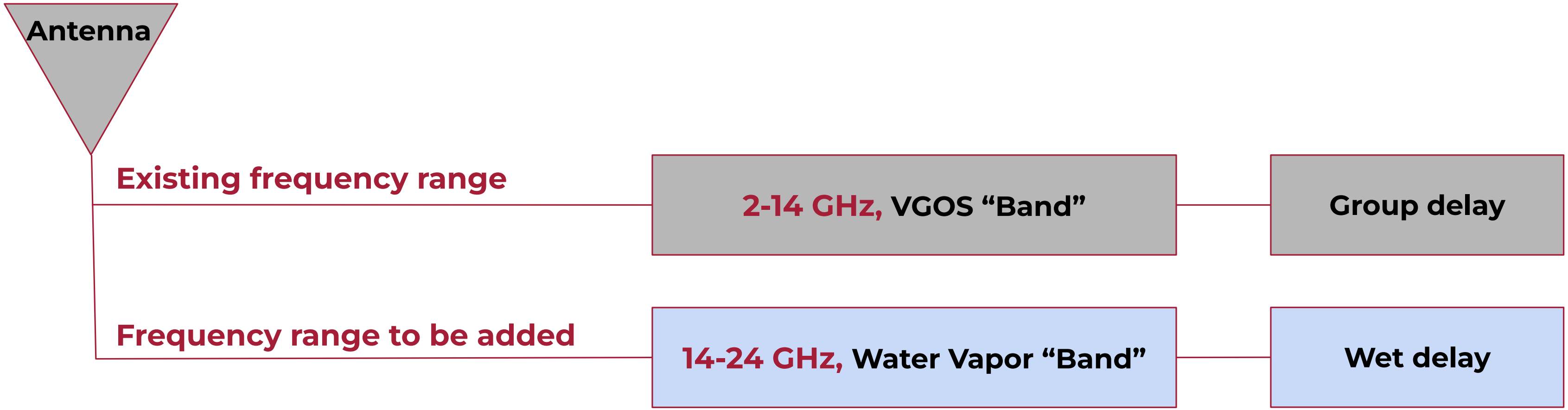
Measuring wet atmospheric delay



- Water vapor radiometer (WVR) to measure thermal emissions from the rotational transition of water vapor around 22.235 GHz [1]

- Simulating combined system [2]
  - Observed intensity is related to the sky brightness temperature

Objectives



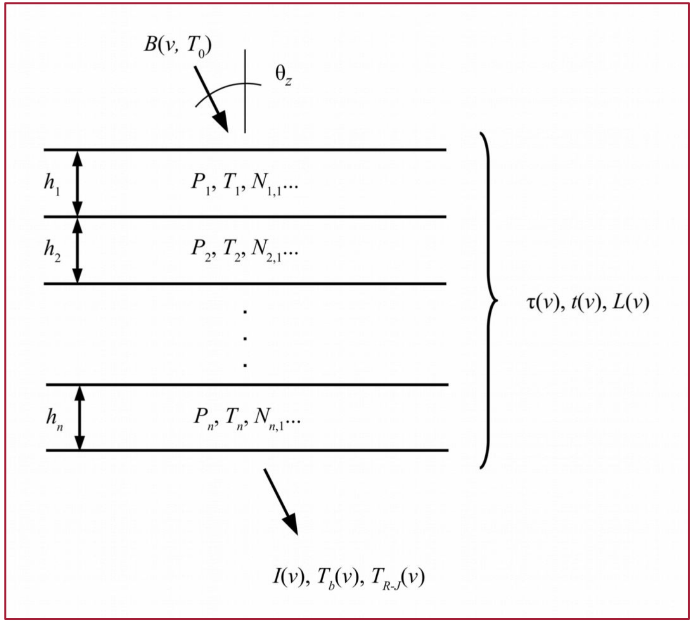
How well do we need to know the brightness temperature to determine the wet delay for that observation?

- Determine how sensitive the sky brightness temperature spectra is to atmospheric conditions

Methods

Calculating wet delay from the brightness temperature

- am atmospheric model [3]
  - Flexible and well validated software for atmospheric modeling
  - Models propagation paths where each layer contains a mixture of absorbing species
- Monte Carlo simulations to generate distributions
- NASA Modern-Era Retrospective analysis for Research and Applications (MERRA-2) reanalysis data model

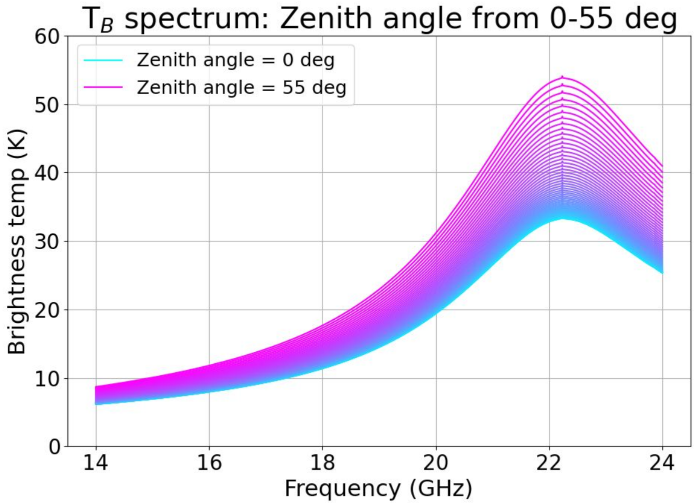


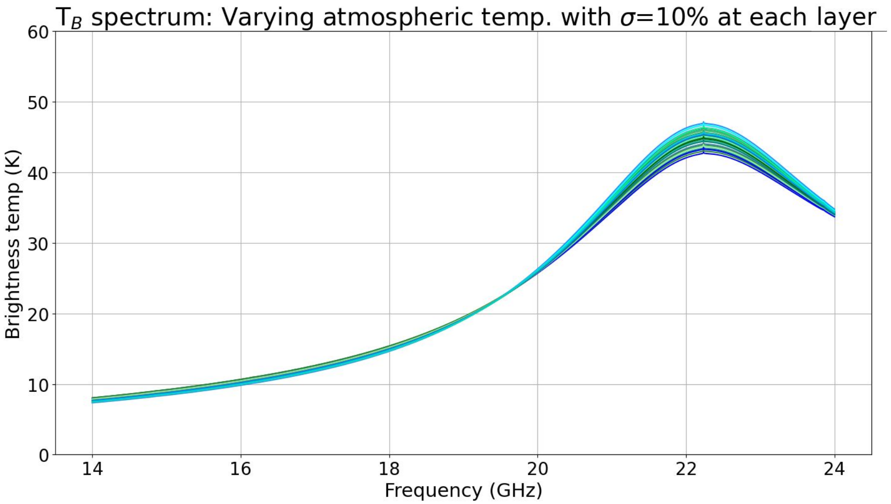
The am layer model [3]

“*am*” atmospheric model

Changing one input parameter at a time:

- Temperature, relative humidity, liquid water, and zenith angle change the brightness temperature spectrum
- The ozone mixing ratio has a negligible impact





Calculating wet delay from the brightness temperature

- Least squares fit to the brightness spectrum: $T_{\text{sky}}(\nu) = a + b\nu^2 + ch_\nu,$

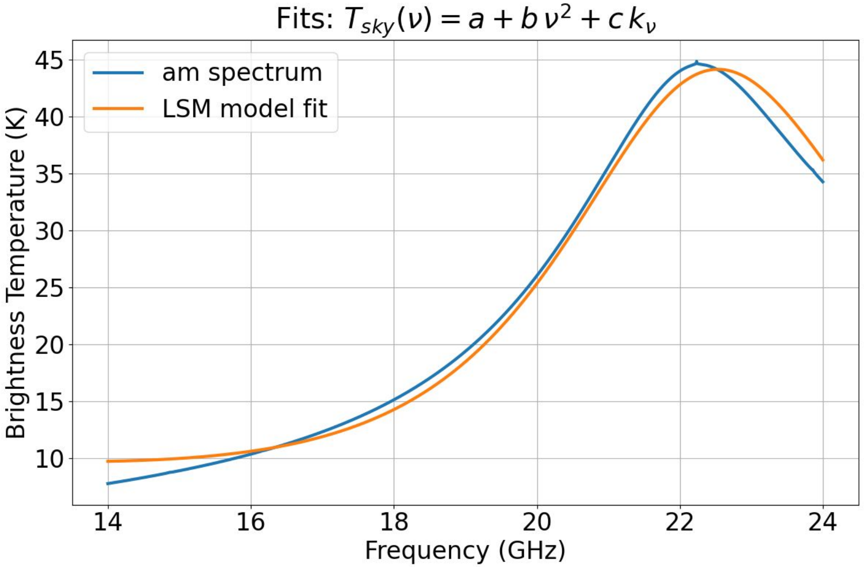
attenuation spectrum normalized to 1 at 22.2 GHz

frequency

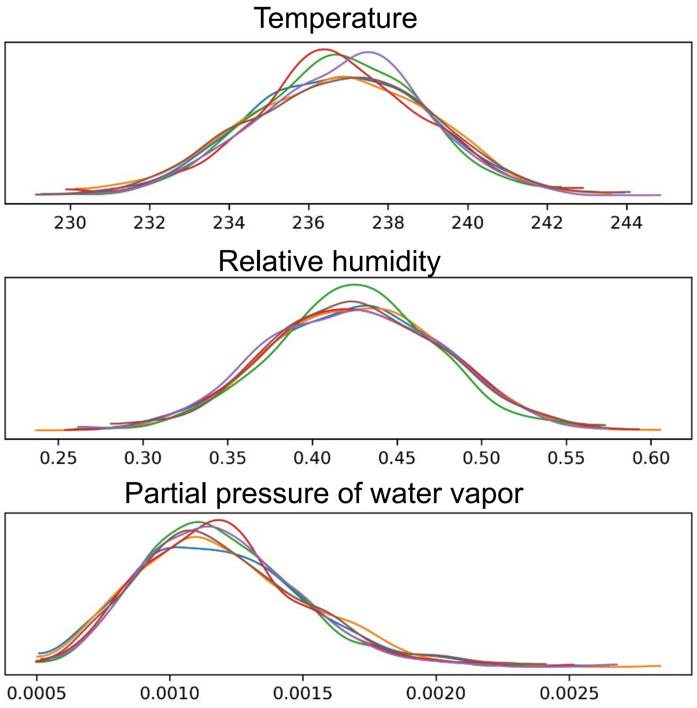
- Calculated from the brightness temperature value at 22.235 GHz
  - Delay function:

    $$d(T_B, k_v, p_v, T)$$

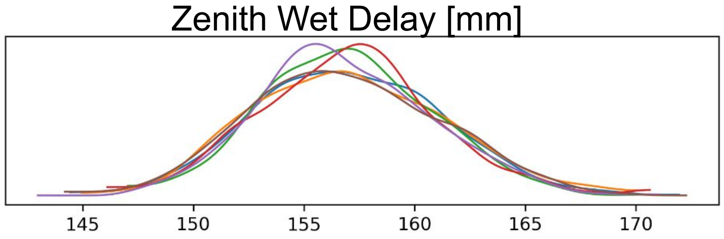
  - Attenuation spectrum function: $k_v(T, p_v, p, \nu)$



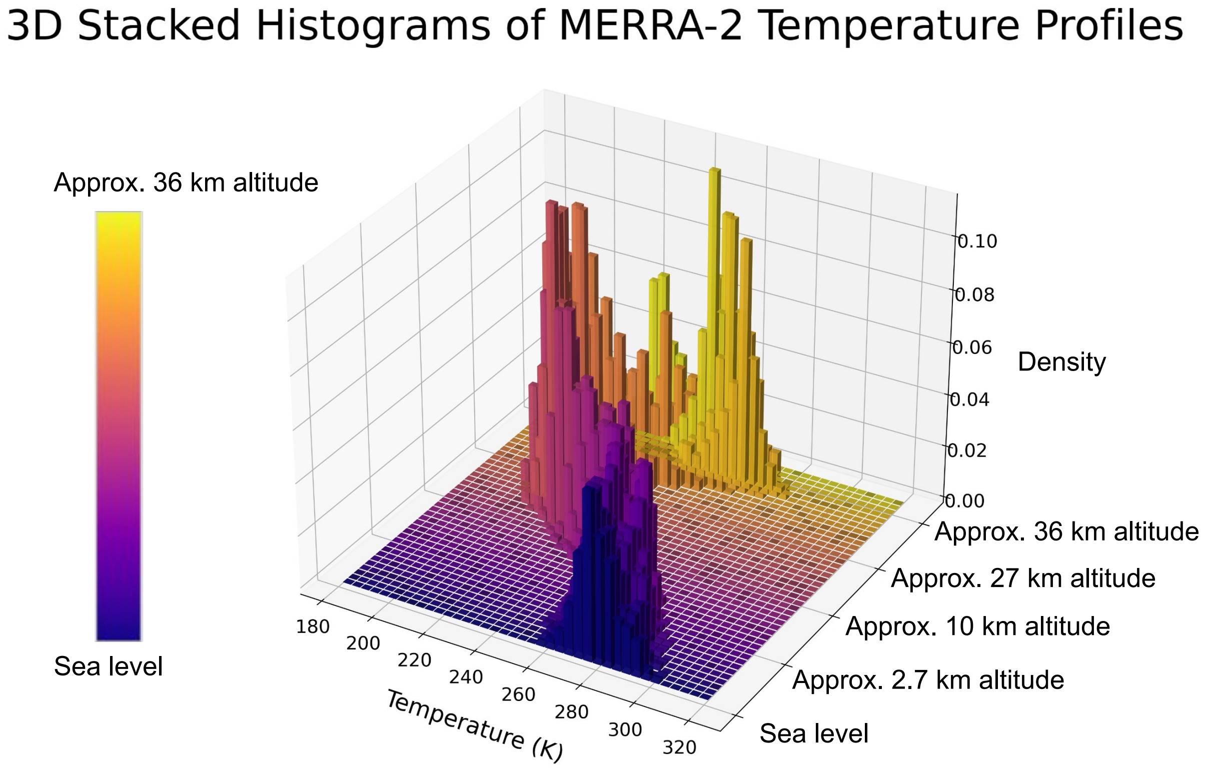
Monte Carlo simulations with normal distributions



- Examine how changing the variation in each input changes the variation in the output
- Currently assuming everything is Gaussian

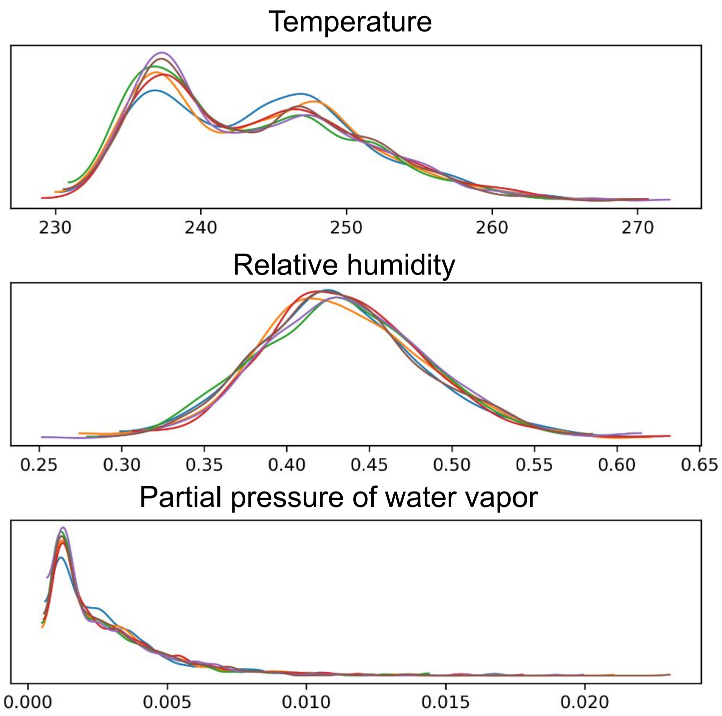


Using MERRA-2 reanalysis data

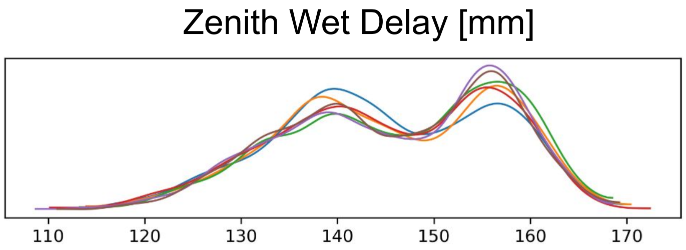


Extracted MERRA-2 data for temperature, relative humidity, and liquid water to understand realistic data distributions for Westford, MA

Monte Carlo simulations with realistic distributions



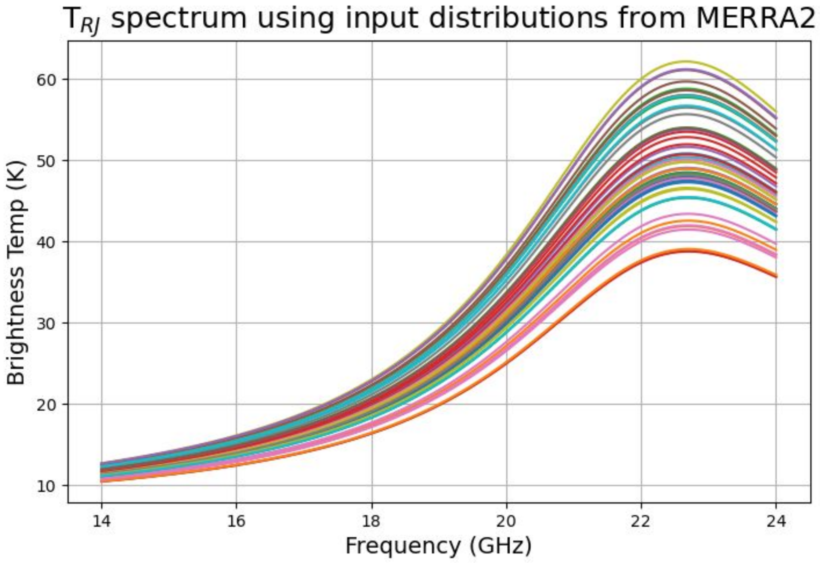
- Temperature is appears inversely correlated with the wet delay
- Relative humidity appears to have a smaller impact



Combining *am* and MERRA-2 and LSM

Using MERRA-2 data for realistic input values for the am model:

- LSM fit to the spectrum using MERRA-2 data
- For Westford, MA the annual expected variation in T_{RJ} is 25 K
- 0.2K resolution in brightness temperature corresponds to 0.1 mm resolution in zenith wet delay



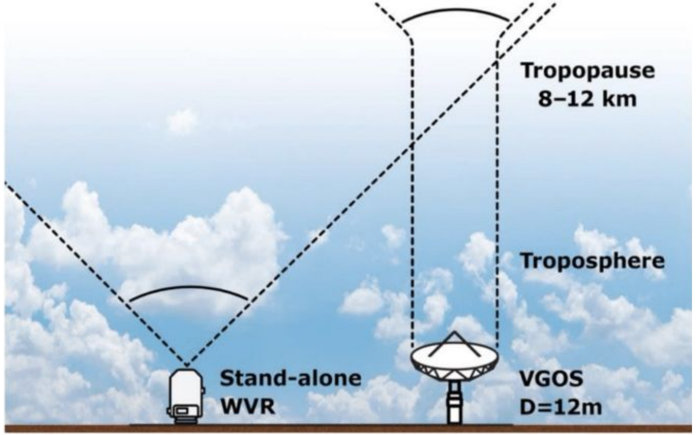
Each line represents a sample brightness temperature spectrum in Westford using MERRA-2 data

Summary

- The ozone mixing ratio has very little impact on the spectrum
- Temperature is appears inversely correlated with the wet delay
- For a 0.1 mm resolution in zenith wet delay the brightness temperature should be known with 0.2 K resolution

Future Work

- Compare with other methods of determining the delay from the brightness temperature
- Use the expected variations/necessary resolution to inform system design and calibration requirements
- Design and build the combined system



Acknowledgments & References

Acknowledgments

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References

[1] Tahmoush, D, and Rogers, A. "*Correcting atmospheric path variations in millimeter wavelength very long baseline interferometry using a scanning water vapor spectrometer.*" Radio Science, Vol 35, pg. 1241-1251, Sept-Oct 2000.

[2] Forkman, P, Flygare, J, and Elgered, G. "*Water vapour radiometry in geodetic very long baseline interferometry telescopes: assessed through simulations.*" Journal of Geodesy (2021)

[3] Paine, Scott. The *am* atmospheric model. SMA technical memo #152, version 9.2, March 2017