Water vapor measurement and compensation in the near- and mid-infrared with the Keck interferometer nuller.

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Motivation: Why measure H_2O?

* “Dry air” (molecules other than H2O) contributes most of the overall refractive index across visible and infrared wavelengths

* H2O density can vary somewhat independently of the overall air density, on short timescales (“H2O Seeing”)

* H2O is highly dispersive and often dominates the overall dispersion

=> Fringe phase delay at 10 um differs significantly from phase delay at 2 um (“inter-band dispersion”)

=> Phase delay varies significantly across the Nuller bandpass (“intra-band dispersion”)

* These effects can substantially increase the leakage through the null

=> For typical Mauna Kea conditions, the inter-band dispersion between the K and N bands is of the order of 1 um. This corresponds to a V^2 loss of 28%, or a null leakage of 7%.

=> Intra-band dispersion in the Keck Nuller is comparable

Method: How do we measure H_2O?

* For a typical Nuller target, the N-band SNR is not adequate to measure the broadband fringe phase or the dispersion across the band quickly enough.

* The K-band SNR is much higher.

* However, there will be differences between N-band and K-band values due to non-common paths. These are expected to introduce slow relative drifts.

=> Use the K-band data to measure the differential H_2O column on short timescales. Feed this information forward to the N-band system.

=> Use the N-band data itself to make measurements on long timescales.

* H_2O differential column is proportional to the difference between the group delay (GD) and the unwrapped phase delay (PD)

=> Measure GD-PD in the K-band data

=> Compute N-band fringe position and GD (linear transformation)

=> Compute the optimal delay-line OPD and dispersion controller setting for N

Data: Phase and Group Delays for the K and N Bands

Measurements on Epsilon Eri

m_K= 1.7 (134 Jy)

F_ν(N)= 9 Jy

θ = 2.1 mas

5 minutes of data taken on UT 19 Oct 2005, during a period of strong H_2O seeing

Simultaneous fringe measurements with

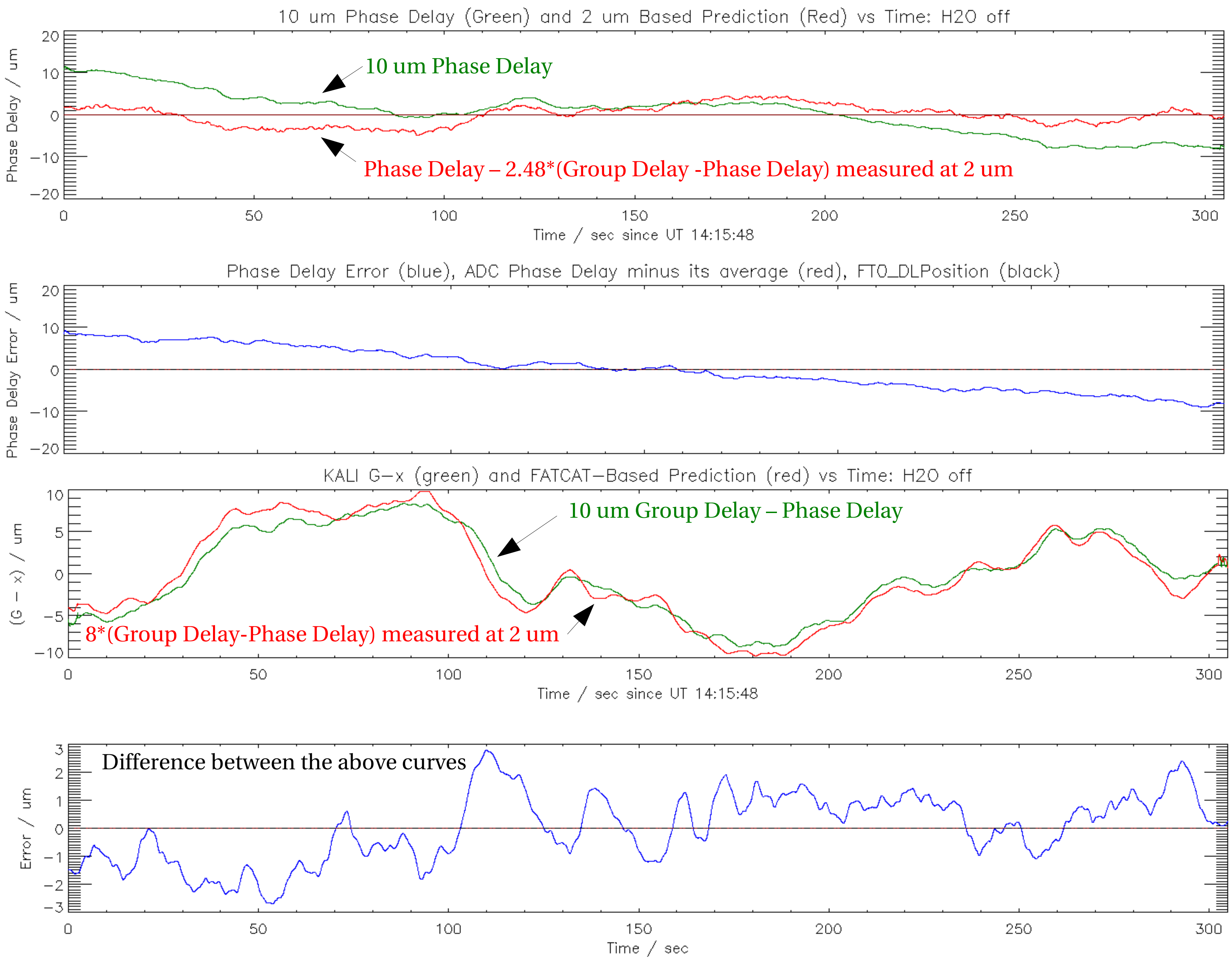
Primary MMZ (N-band beam combiner; 16 spectral channels, 8.0-12.5 um)
Primary FATCAT (K-band beam combiners; 4 spectral channels, 2.0-2.4 um)

Phase and group delays were derived from the spectral data, and filtered to improve SNR

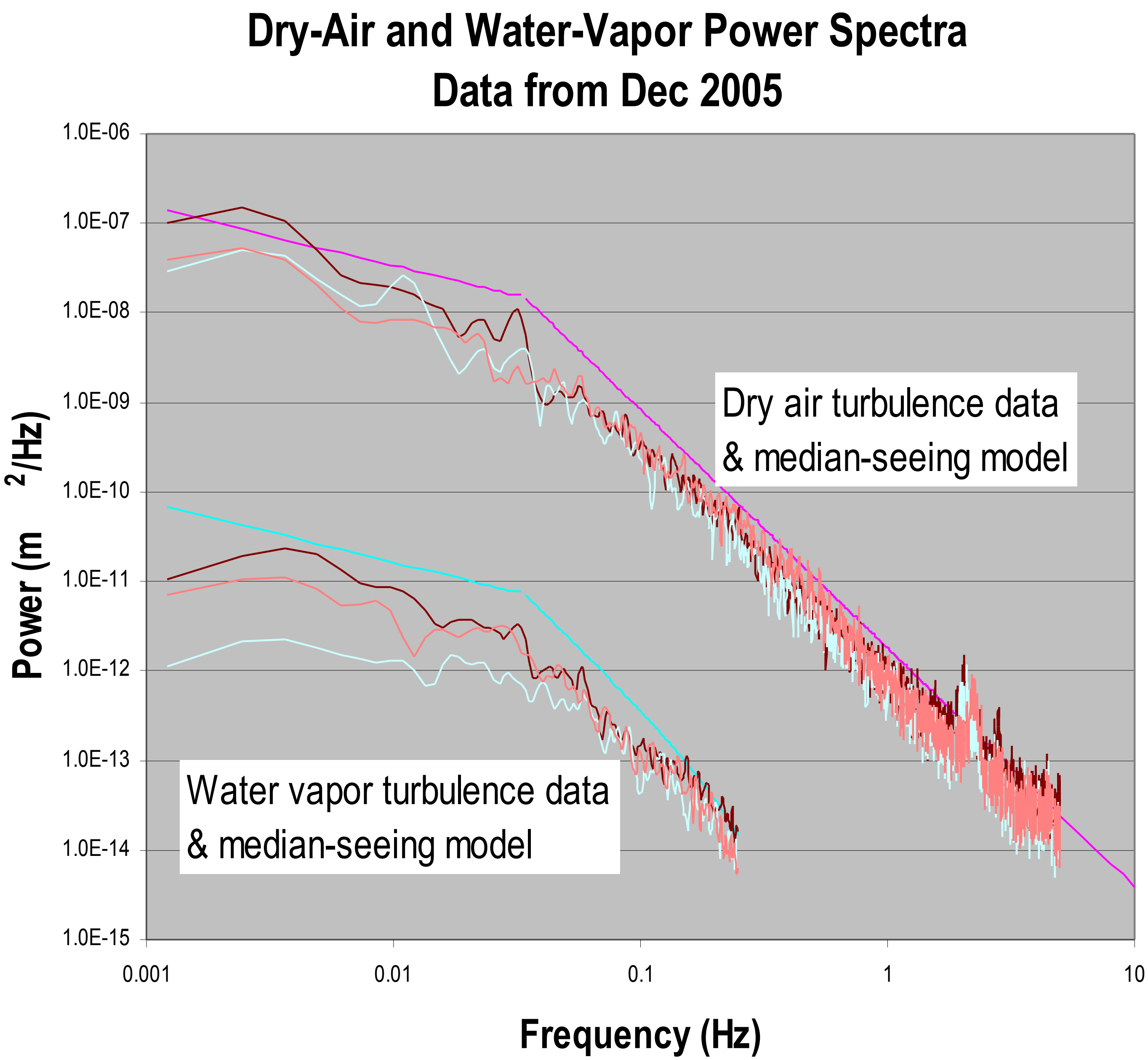
Phase was unwrapped using a "circular average filter" to avoid jumps due to unwrapping errors

Phase and group delay in the N band were computed from their values in the K band, and the results were compared to the measured N-band values to validate the model

Predicted and Actual N-band Phase and Dispersion



Validation of Atmospheric Turbulence Models with KI Data



Colavita et al. (2004) estimated that the amplitude of the dispersion fluctuations due to H_2O is a small, roughly constant fraction of the "dry-air" phase fluctuations.

The top traces are the measured and model power spectra for the dry-air phase fluctuations.

The bottom traces are the corresponding observed and model power spectra for the dispersion (GD-PD) due to H_2O.

We conclude that the model is essentially consistent with the observations.

Conclusions

The dispersion in the K and N bands is due primarily to H_2O vapor.

=> Use the known refractivity of H_2O to relate the dispersion measured in the K band to the difference between the K-band and N-band OPDs, and to the N-band dispersion

=> Feedforward from the K-band (where SNR is high) to the N-band (where SNR is low) can improve the phase and group-delay tracking in the N-band

Simultaneous observations of K-band and N-band fringes demonstrate this

Still have a mysterious linear drift between the predicted and actual N-band phase