Atmospheric Precipitable Water and its Correlation with Clear Sky Infrared Temperature Readings

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Introduction

This project demonstrates the capability to derive precipitable water with low cost tools in higher altitude arid climate zones similar to that found in the desert Southwest

Traditional methods of measuring precipitable water include:

- **Radiosondes**
- Analyzing signal delay from ground-based Global Positioning System networks.
- Microwave-Infrared radiometers
- Sun photometers

We are proposing a new method that utilizes the relationship between the total precipitable water (TPW) and the measured effective temperature (T_{eff}) [1] as,

$$\frac{\mathbf{dT_{eff}}}{\mathbf{dTPW}} = \frac{\partial \mathrm{T_{eff}}}{\partial \mathrm{TPW}} + \frac{\partial \mathrm{T_{eff}}}{\partial \mathrm{T_{air}}}\frac{\partial \mathrm{T_{air}}}{\partial \mathrm{TPW}}, \tag{1}$$

where we define T_{air} as the mean temperature. Existing models show that there are equal contributions from both terms in Equation (1), as seen in Figure 1.

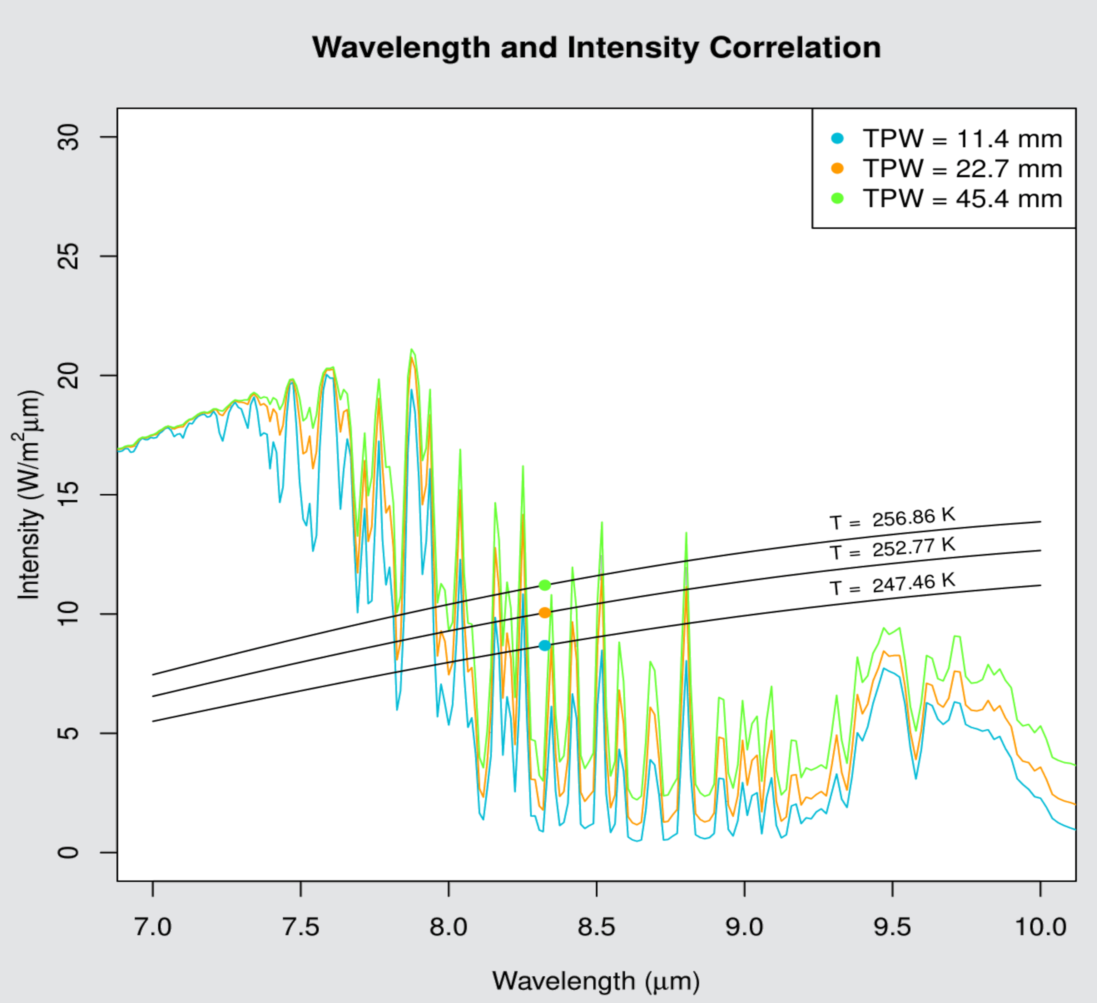

Figure 1: Based on calculations using MODTRAN [2]. Blue, orange, and green curves relate to TPW of 11.4 mm, 22.7 mm, and 45.4 mm, respectively. Corresponding circles represent mean radiance of the spectral band between 7-10 μm. Solid black curves show corresponding black body emission curves at the indicated temperatures.

References

[1] Forrest M. Mims, Lin Hartung Chambers, and David R. Brooks. Measuring total column water vapor by pointing an infrared thermometer at the sky. *Bulletin of the American Meteorological Society*, 92(10):1311 – 1320, Oct 2011.

[2] A. Berk, L. S. Bernstein, and D. C. Robertson. MODTRAN: A moderate resolution model for LOWTRAN. Technical report, July 1987.

Data Collection

Use three different types of infrared thermometers to take daily ground and zenith sky temperature readings

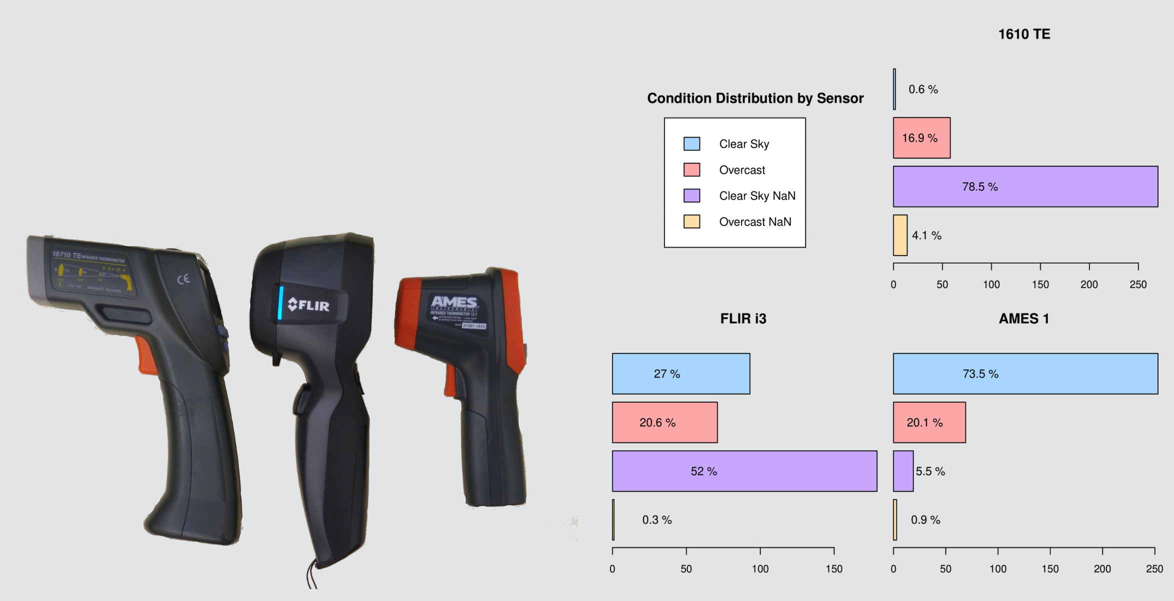

Figure 2: *(Left)* The three infrared thermometers used to collect data: (from left to right) 1610 TE, FLIR i3, and the AMES 12:1 Infrared Thermometer. *(Right)* Distribution of sky condition by sensor

Monitor and record the daily NWS precipitable water measurements taken in **Albuquerque** and **El Paso**.

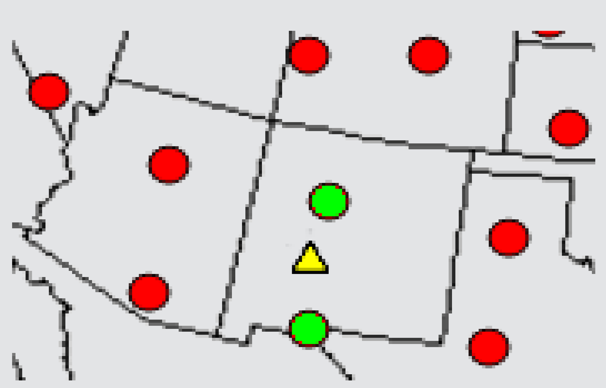

Figure 3: Southwest US Radiosonde Launch Sites, adapted from NWS. Albuquerque and El Paso are denoted in green and Socorro is marked with a yellow triangle.

Show a correlation between zenith air temperature measurements and the amount of TPW over four seasons

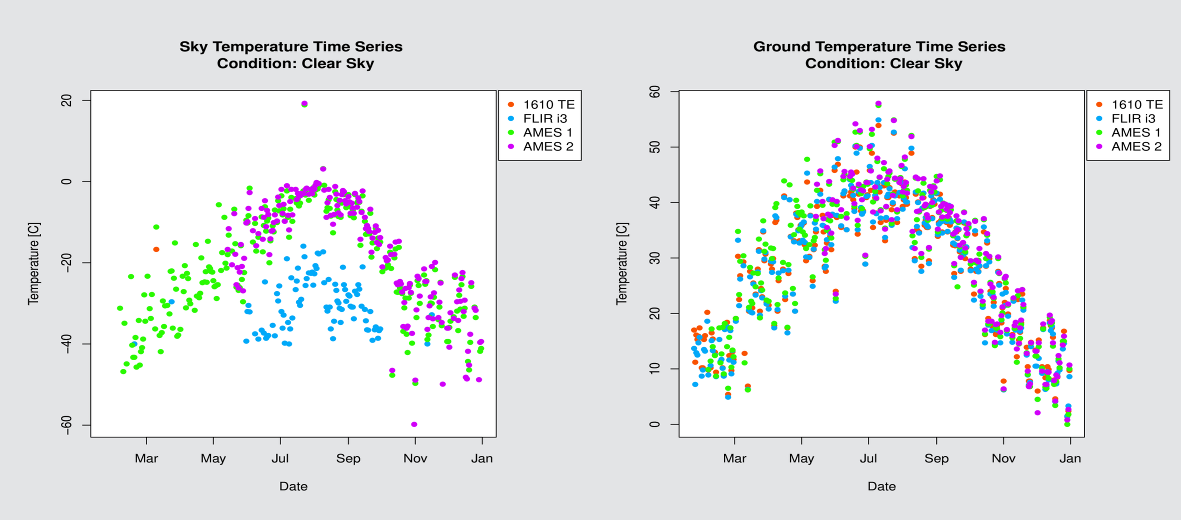

Figure 4: *(Left)* Infrared sky temperature time series. *(Right)* Infrared ground temperature time series.

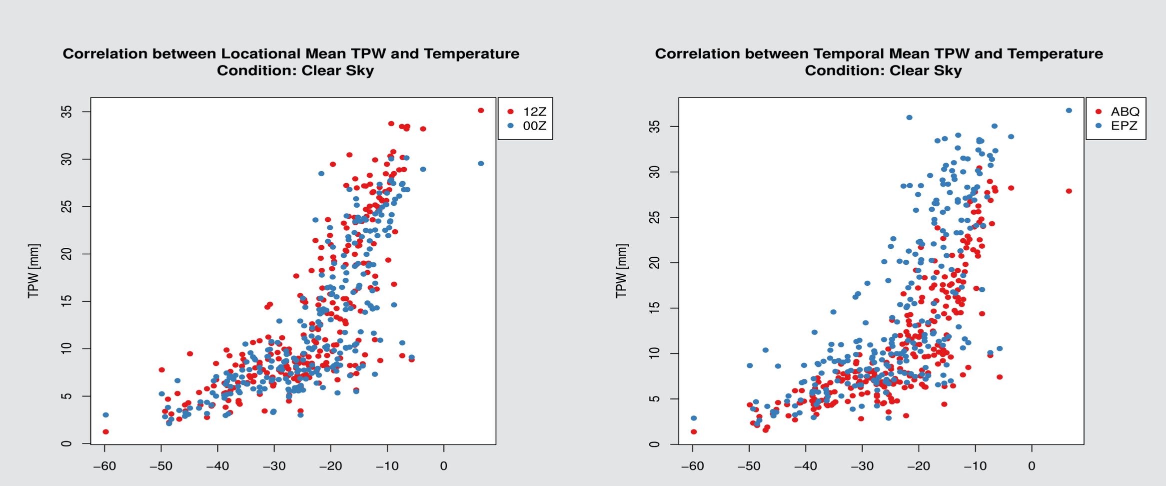

Figure 5: *(Left)*: Temperature and TPW based on averaged ABQ and EPZ radiosondes. *(Right)*: Temperature and TPW based on averaged 12Z and 00Z radiosondes.

Current Analytical Results

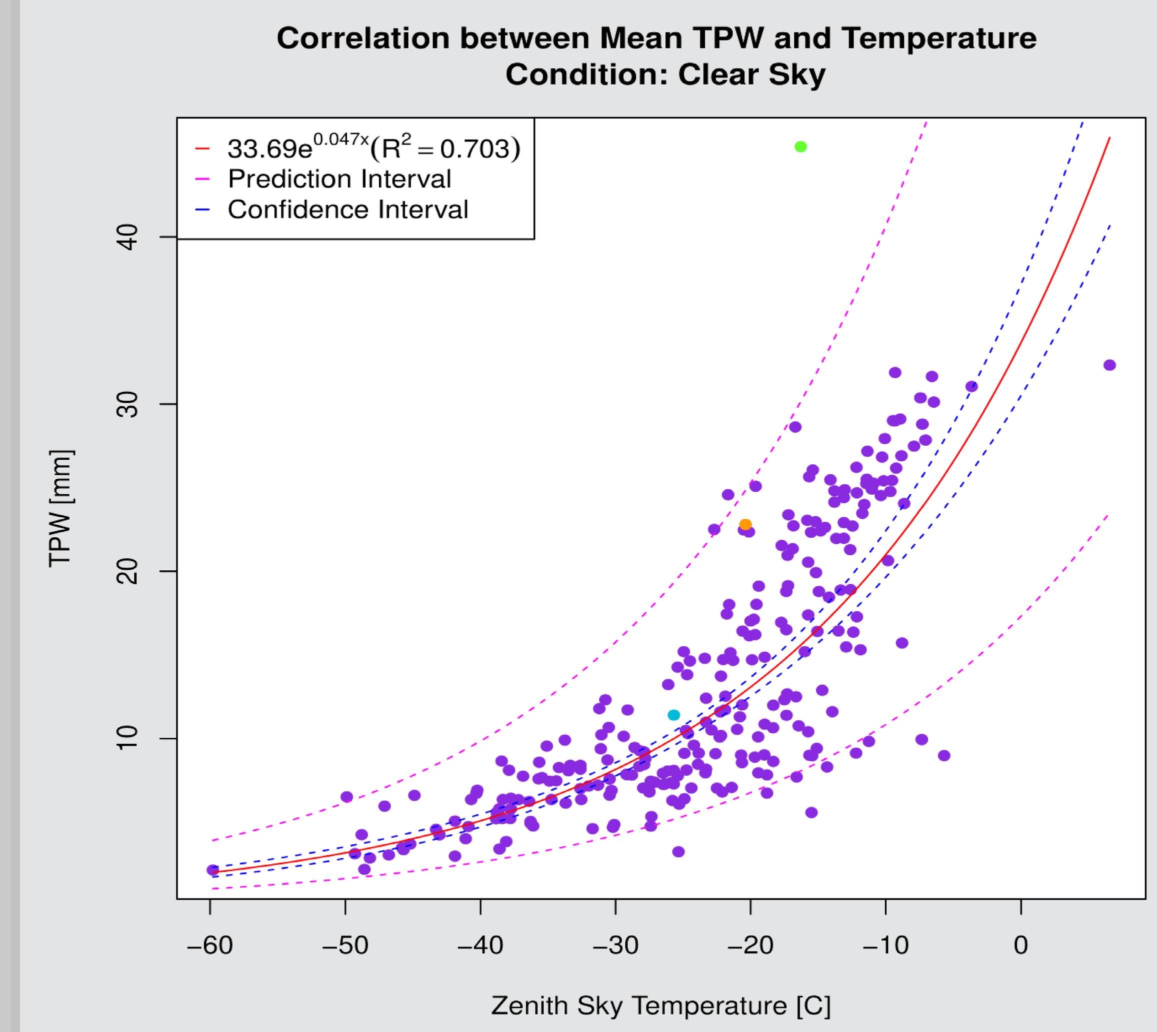

Figure 6: Temperature and TPW based on total mean. The *blue*, *orange*, and *green* circles correspond to results of Figure 1.

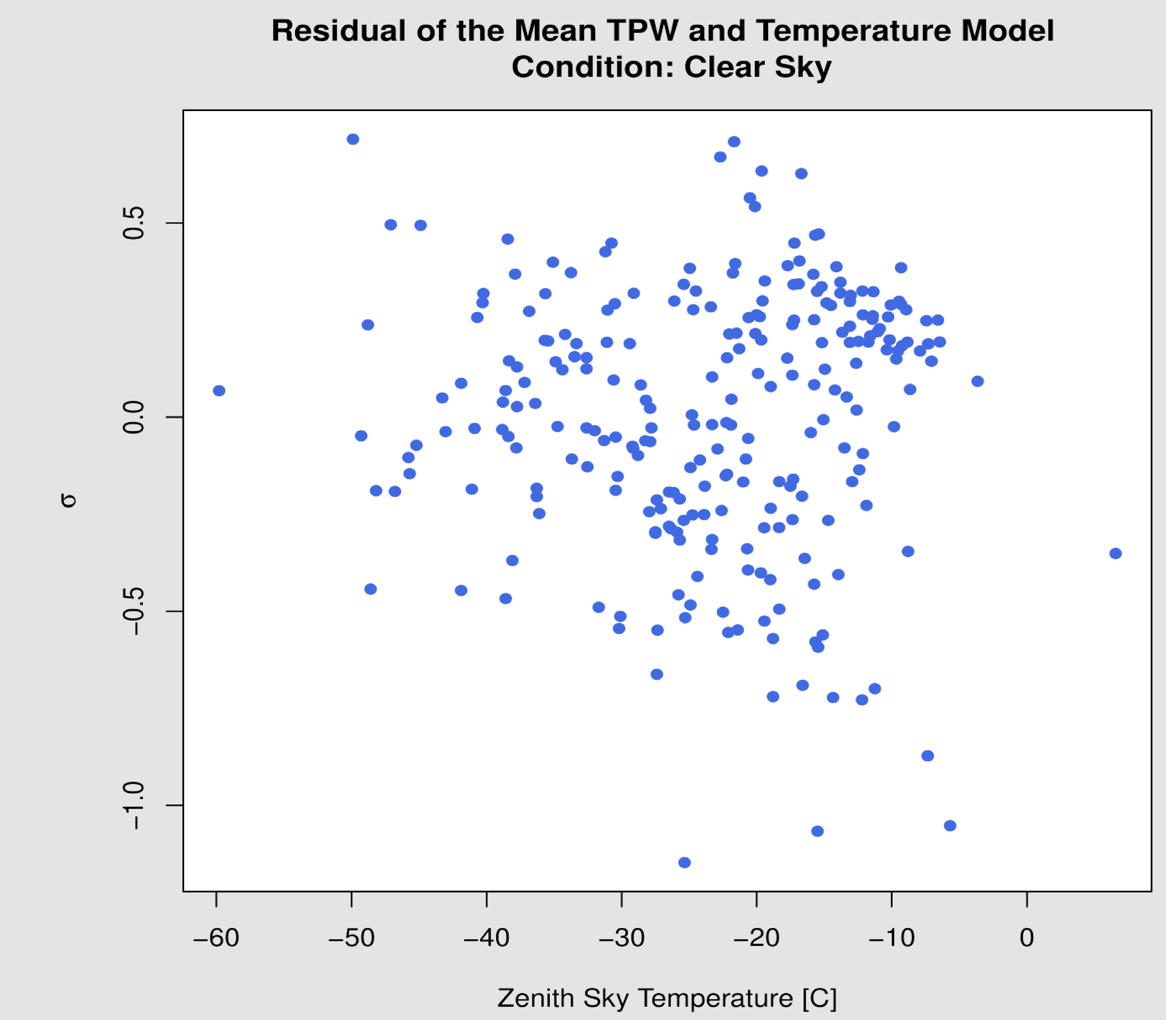

Figure 7: Residual plot.

Computational Methods

We have developed an **open source** tool in R for analyzing the relationship between precipitable water and temperature. The tool utilizes the numerical methods

- Linearization of an exponential relationship
- Linear regression analysis

The computational tool contains four plot sets to visualize the data collected:

- **Time series** of average temperature measurements and precipitable water readings
- **Analytical** plots that show the correlation between temperature and precipitable water
- **Individual sensor** plots that shows the time series of temperature measurements for each of the infrared thermometers.
- **Charts** that show the distribution of observation conditions recorded by each of the infrared thermometers.

Discussion

We have experimentally verified the exponential relationship between TPW and zenith sky temperature.

We also have determined that there is a **moderately strong correlation** between the amount of precipitable water and the temperature at the zenith ($R^2 = 0.703$).

The results of our analysis show that the data **fits within $\sim 1\sigma$**, as seen in Figure 7.

We suspect that the **sources of error** include:

- Temperature measurements do not exactly coincide in time or location with TPW measurements.
- Aerosols, subvisible clouds, and other atmospheric phenomena may have introduced measurement bias
- The instruments are apparently measuring different infrared spectral bands.

The AMES instrument was best suited for measuring zenith clear-sky temperature and deriving precipitable water at this location (see Figures 2 and 4).

Acknowledgements

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Documentation Page: `https://git.io/fj5Xr`