All-Sky Infrared Cloud Imager

Precipitable Water Vapor Retrieval Algorithm Accuracy

Overview

The All-Sky Infrared Cloud Imager (ICI) autonomously detects and characterizes clouds over the full sky using a calibrated long-wave infrared (LWIR) thermal imaging camera providing real-time cloud data products. The ICI produces consistent cloud products day and night unlike visible band systems.

Cloud detection in the infrared requires accurate estimation of the emission from the atmospheric column beneath the cloud. This emission is a substantial portion of the total radiance observed. The ICI's residual radiance algorithm uses proprietary global atmospheric radiance models to first estimate this radiance. Then, it is subtracted from the total to calculate the residual radiance, while is used in the cloud product derivation. The primary atmospheric radiance model requires precipitable water vapor (PWV) as a key input. PWV along with surface temperature are critically important to the accuracy of the atmospheric radiance model.

To address the need for accurate PWV data, the ICI incorporates a global navigation satellite system (GNSS) receiver and antenna. The GNSS observations are fed to a proprietary algorithm (similar to that of Xu et al. 2023) which derives the PWV. (Live streamed precise point position (PPP) correction data from the internet are also required.) The result is an onboard real-time measurement of the PWV. External PWV observations can also be provided to the instrument as desired, but this system makes them unnecessary.

In 2023, an ICI system was deployed to the Atmospheric Radiation Measurement (ARM) Southern Great Plains user facility. The purpose of the field campaign was to compare the data products generated by the ICI to ARM instruments in the following ways:

- Observed zenith radiance data from the ICI were compared to band-integrated spectral radiance data from the Atmospheric Emitted Radiance Interferometer (AERI).
- Atmospheric radiance models were compared to those generated from sondes.
- PWV from the microwave radiometer (MWR) was compared to that derived by the ICI's GNSS receiver system.

The results from this last comparison are reported in this white paper. The ARM MWR (Cadeddu et al.) is generally regarded as the most accurate measurement of columnar integrated precipitable water vapor. It measures microwave emission at two frequencies and derives both the liquid and vapor in the atmospheric path from these data. Radiosondes are launched from each ARM site multiple times per day (Keeler et al.). The data from these can also be processed into PWV. The following figures compare the PWV observations measured by the ICI, the MWR, and the sonde. In addition, they are compared to the PWV included in the ERA5 weather reanalysis (Hersbach, 2020).

Results

Figure 1 shows a time series comparison between the different PWV sources. Figure 2 shows a histogram of the same data. Since the MWR shows high errors during cloudy periods, observations with large errors were removed from the histogram statistics.

As shown in Figure 1Figure 2, the GNSS-based PWV retrieval is accurate to ~2.3 mm (1-σ). This is better than the ERA5, but significantly worse than the sonde. Both the ICI and the ERA5 are slightly biased negative from the MWR while the sonde is biased slightly positive. In all cases, the bias is small compared to the standard deviation. Considering the relative simplicity of the GNSS receiver system, the precision achieved is remarkable. For reference, the ICI radiance error associated with this level of PWV error is approximately 1.0 W/(m^2Sr) (1-σ) at zenith. Natural variation in the temperature and vapor profiles result in radiance errors at a similar level, so a more accurate PWV measurement would not radically improve the atmospheric model radiance anyway.

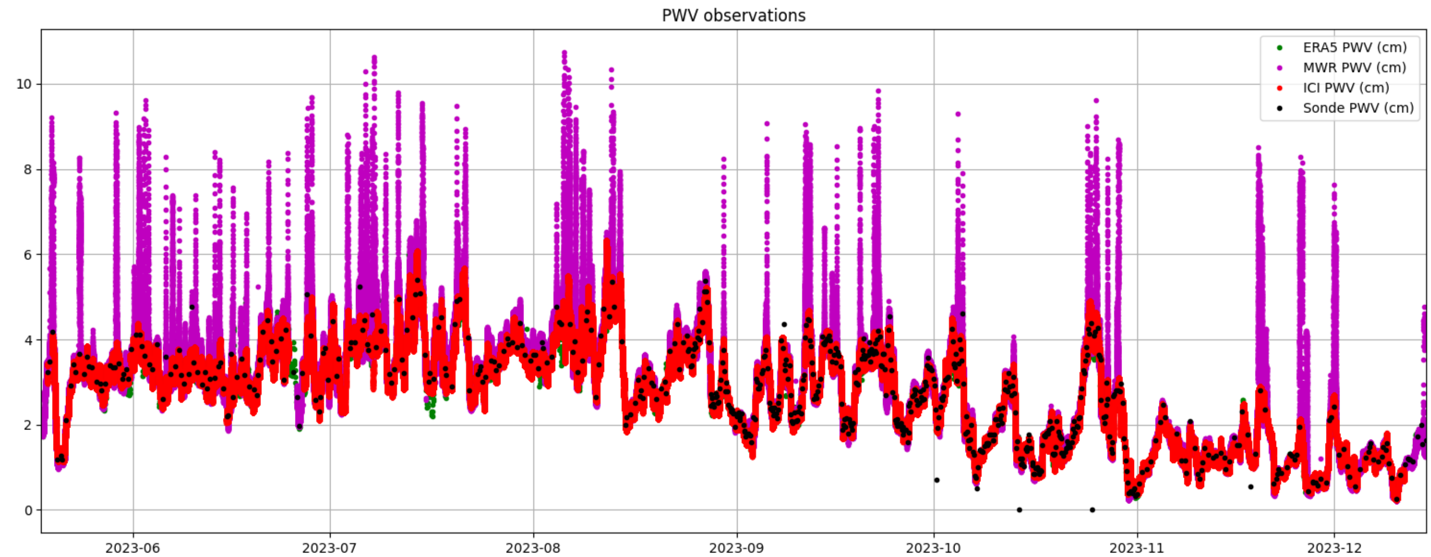

Figure 1. Time series comparison of various PWV observation methods

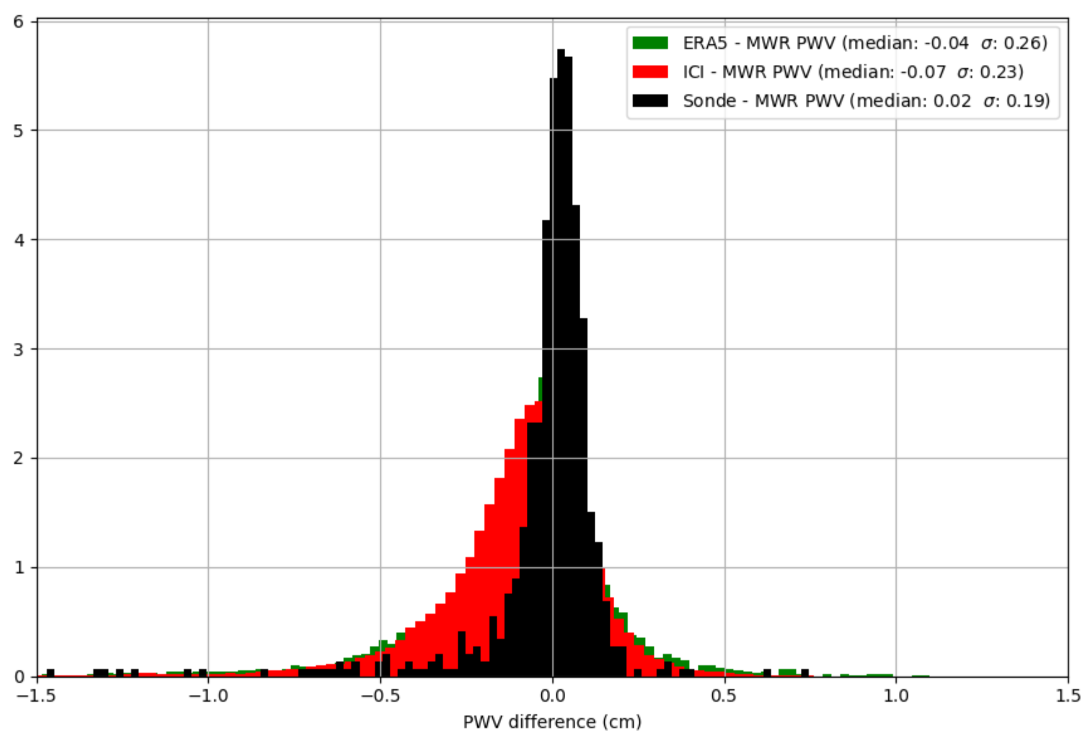

Figure 2. Histogram of PWV errors compared to the MWR

References

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