Comparison of PWV measurements determined from co-located water vapour monitors used in the Thirty Meter Telescope site testing campaign

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***Abstract*—The 20 μm (15 THz) Infrared Radiometer for Millimetre Astronomy (IRMA) monitors a narrow spectral band containing only water vapour molecular transitions. When used in conjunction with an accurate atmospheric model (BTRAM), it is possible to determine absolute precipitable water vapour (PWV) in a column of atmosphere to high accuracy. Flux calibration of IRMA is accomplished by using a calibrated blackbody source. The resulting PWV measurements can be used to determine atmospheric opacity and thus the potential to conduct infrared astronomical observations at the site.**

Since January 2007, three calibrated IRMA units have been deployed in the Americas as part of a site selection effort for the Thirty Meter Telescope (TMT) project. The three units were operated in parallel while co-located and viewing the same atmosphere. We present the parallel observation data, model sensitivity studies, and error analysis.

I. Introduction

We have developed an Infrared Radiometer for Millimetre Astronomy (IRMA) which employs a novel technique for measuring atmospheric precipitable water vapour columnar abundance (PWV). The IRMA device is a simple infrared radiometer that observes a narrow spectral region around 20 μm (15 THz), which contains only rotational transitions of water vapour.[1] We have previously demonstrated that the optical depth measured at 20 μm correlates directly with the optical depth at the operating wavelengths of telescopes such as the JCMT, APEX and ALMA (∼200 GHz—1.2 THz).[2] Moreover, the 20 μm opacity is of direct interest to infrared telescopes that can operate at these wavelengths when the weather is of sufficiently high quality, making IRMA an important tool for site selection of new telescopes.

II. Determining PWV

There are two steps to determing PWV with an IRMA unit. First, the radiometer measures IR flux. Then an atmospheric model is used to convert the flux to PWV. The overall accuracy of the measured PWV is dependant on errors associated with each of these steps.

In order to measure the rotational transitions of water vapour at 20 μm, IRMA uses a single pixel Mercury Cadmium Telluride (MCT) photodetector cooled to 70 K. The spectral band is limited to the desired ∼2 μm window by a bandpass filter.[3] To convert the measured output voltage to emitted flux the IRMA units must first be calibrated. Each IRMA unit

Fig. 1. Greg Tompkins with the three TMT IRMA units during the calibration verification on site.

is equipped with an internal blackbody (BB) mounted on the underside of the weather protection shutter. Two temperature sensors embedded in the BB are used to determine its effective temperature. When the shutter is closed a calibration is performed by observing the internal BB at ambient temperature and then heating the BB to ∼25 K above ambient. To first order there exists a linear relationship between emitted flux and measured voltage so that the calibration measurements can be used to determine the radiant flux received by IRMA. This technique works well for relative measurements of atmospheric water vapour as measured with a single unit. However, when two radiometers operated side-by-side they produced different absolute values that were traced to errors in the assumed effective temperatures of the BB calibration sources.

For a site testing role, relative measurements are insufficient, as it must be possible to trust the absolute measurements of PWV when they are on different sites. To accomplish this, a procedure has been developed whereby the individual IRMAs are calibrated with respect to a standard BB; the internal BBs then act as secondary calibration sources. This external reference BB is sufficiently larger than IRMA's viewing port to minimize edge effects and temperature gradients across its surface. To characterize the surface it is mapped by sixteen embedded temperature sensors. Knowing the temperature gradients across the surface allows us to determine the absolute flux emitted from the surface. This procedure not only allows

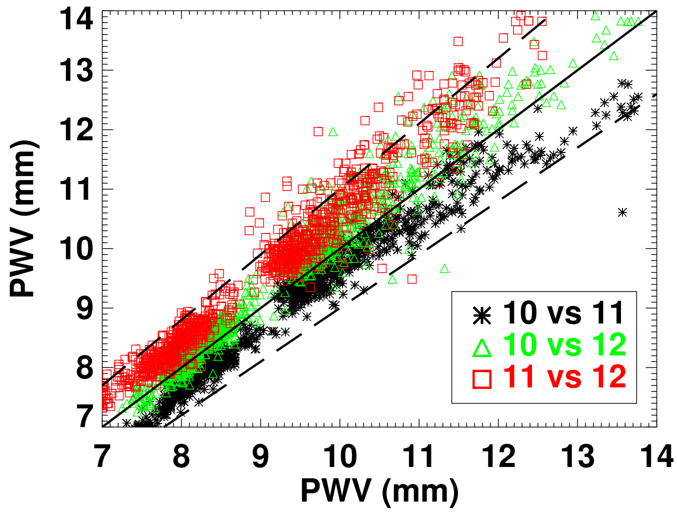

Fig. 2. Box versus box comparisons of the three TMT IRMA units while on the roof at the University of Lethbridge. Expected unity relationship (solid) and 10% difference relationship (dashed) are also shown.

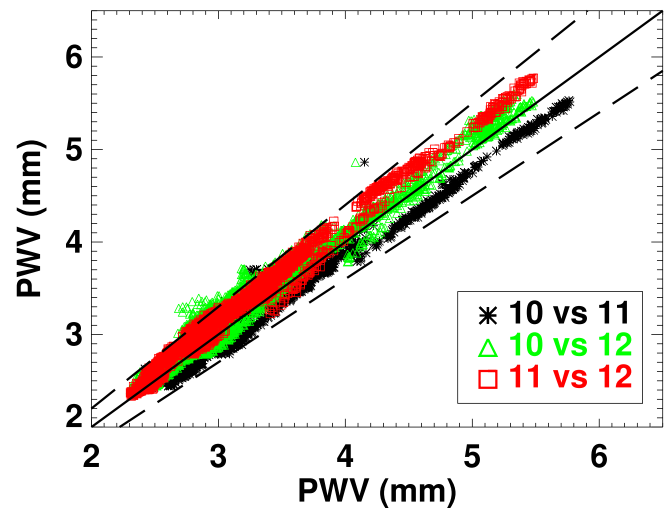

Fig. 3. Box versus box comparisons of the three TMT IRMA units while co-located on site. Expected unity relationship (solid) and 10% difference relationship (dashed) are also shown.

the individual IRMA BBs to be cross calibrated not only correlates the IRMA BB to the external reference BB, but also helps determine the systematic effects due to asymmetrical heating within the optical cavity on the measured signal. Once the units are calibrated, and the absolute IR flux can be determined, an atmospheric model is used to convert the values to PWV.

The atmospheric model BTRAM converts IR flux to PWV for any geographical location.[4] Its accuracy is dependant on many parameters including temperature, pressure and water vapour profile. These parameters are determined through statistical analysis of nearby radiosonde data if available. Otherwise, a standard model for the geographic region is used. The temperature and water vapour profile have the greatest effect on the accuracy of the model.

III. Results

Three IRMA units (labeled Box 10, 11 and 12) were built for TMT to assist with site selection. The three units were calibrated to the external BB in our laboratory in Lethbridge. The calibration of the units was verified by placing the three units on the roof at the University of Lethbridge. These results showed a good correlation (Fig. 2). However, due to the low altitude, and wet atmosphere, the sensitivity of the IRMA units at low PWV values could not be tested. In order to verify the calibration at lower PWV values, all three IRMA units were initially shipped to the same site in Chile. Here, the IRMA units ran co-located for nearly two weeks. The data from these observations are shown in Fig. 3 where correlation between the three units at lower PWV abundances is maintained. The data for each of the IRMA units are processed with the same model so any differences in the above plots are due to the IR flux measurements. However, when the IRMA units are moved to different sites, the relative errors in the models generated for each location will have to be taken into account when comparing the data.

IV. Future Work

While the measurements obtained from the units show a high degree of correlated (Fig. 2 and Fig. 3), efforts are still being made to improve the calibrations. This involves reprocessing the data from the calibrations obtained in the laboratory and applying the new parameters to the data measured while on site. Efforts are also continuing in analysing how errors in the various inputs to the atmospheric model affect to accuracy of the model. Knowing the errors contributed by each step of the PWV measurement will give an overall accuracy of the IRMA units.

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