Robust retrieval of water vapor at NSA using the rotating shadowband spectroradiometer (RSS)

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Abstract

The RSS operated at ARM's NSA from March-August 1999 in conjuction with the water vapor IOP in March 1999. A robust retrieval method using the 940nm water absorption band is presented. The retrieved water column results are presented for clear and partially clear days during the deployment. A sensitivity analysis indicates 0.05mm 1-sigma precision for each 1-minute shadowbanding cycle. The largest source of systematic error is due to air mass uncertainty at very low elevation angles. The results are compared with the CART MWR data

Deployment

Alignment

Shadow Check

Calibration with Licor

Method description

The vertical equivalent water column is obtained from water transmittance T and the air mass m from the formula $h = f(T)/m$. Transmittance-to-water column function $f(T)$ is derived from model were the model irradiance is convolved with RSS slit function. The water transmittance T at $\lambda = 940nm$ is estimated as ratio of iradiances corrected for Rayleigh scattering and extraterrestrial intensity $T = I(\lambda)/I_0(\lambda)$, where $I(\lambda)$ is measured irradiance at λ and $I_0(\lambda)$ is estimate of irradiance at λ when no water is present. This irradiance $I_0(\lambda)$ is obtained from linear interpolation of two neighboring (anchor) wavelengths. Either the irradiance is interpolated

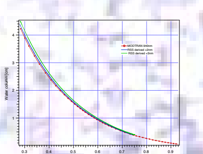
$$I_0(\lambda) = I(\lambda_1) + (I(\lambda_2) - I(\lambda_1))\frac{w(\lambda) - w(\lambda_1)}{w(\lambda_2) - w(\lambda_1)}$$

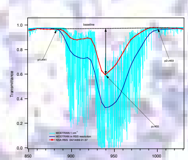
or the optical thickness $\log(I)$ is interpolated

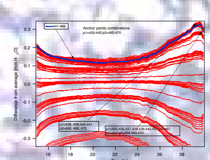
$$I_0(\lambda) = I(\lambda_1)\left(\frac{I(\lambda_2)}{I(\lambda_1)}\right)^{\frac{w(\lambda)-w(\lambda_1)}{w(\lambda_2)-w(\lambda_1)}}$$

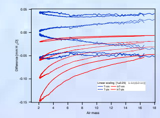
where $w(\lambda)$ is wavelength interpolating function. When interpolation is done in the wavelength space, $w(\lambda) = \lambda$ or when in pixel space, $w(\lambda) = p$ or when in wavenumber space, $w(\lambda) = 1/\lambda$. Ideally the air mass in the equation should be derived from the actual water column profile. Kasten's formula for air mass of water column was used:

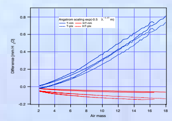
$$m = (\sin(el) + 0.0548(2.650 + el)^{-1.452})^{-1}$$

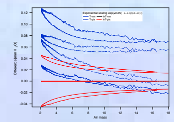






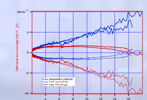


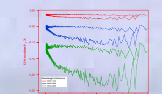


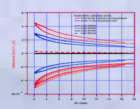


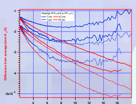
Robustness

Sensitivity with respect to linear, exponential and Angstrom scaling is estimated. Linear scaling that causes ±25% irradiance change between the two anchor points seems to cause the least effect for T-nm method. The errors for lnT-nm method are not bipolar. As expected the lnT-nm method is invariant with respect to exponential scaling and the T-pix method happen to be the least robust. And finally the Angstrom scaling causes the least effect on lnT-pix and lnT-pix methods that are 5-7 times smaller than for the remaining methods at large air masses. One cannot easily decide which one of four interpolation methods is the most robust. The differences between methods are not that large. Any of them could be used. Angstrom scaling has a physical basis thus it might be the most relevant test. If so, lnT-pix and the lnT-nm seem to be the most robust methods. The ratio method is by 1-2 orders of magnitude more sensitive to all three robustness tests than any of baseline removal methods clearly showing its inferiority.









Radiometric calibration: RSS was calibrated four times while at NSA site. The calibration of 03/10/99 was subsequently used to process all data. The four responsivities could differ by as much as 4% in the near IR region however slopes between responsivities differed by less. The change in color temperature of the calibrator was simulated. The difference between calibration change between 03/05/99 and 03/10/99 in terms of effect on the water retrieval could be reproduced by 75K color temperature change.

Detection Noise: It is possible to get good estimate of noise at each pixel for each exposure and subsequently calculate the noise in terms of water column. As could be expected noise increases for larger air masses and is larger when partial obstruction of direct beam occurs.

Stray light: If we believe that filter functions developed from lab measurements are accurate, then the stray light effect is fully correctable. The stray light error was obtained as difference of retrievals performed on stray light corrected and uncorrected spectra. The correction was done with the "intuitive method" that was set to remove stray light from without of [-7,+7] pixels.

Cosine correction error: Two retrievals were compared. One when spectra were cosine corrected and one when no correction was applied. The difference is negligible. One could conclude that no cosine correction is necessary for the accurate water retrieval.

Wavelength shift: Wavelength shift error in principle is correctable as wavelengths shifts can be deduced from the spectrum. However the confidence of these deductions rapidly decreases for large air masses due to reduction of the signal-to-noise ratio. On the day of 04/14/99 the deduced wavelength shifts did not exceed 0.4nm, resulting in errors less than 0.01mm. We may assume that up to 1nm shifts at 940nm may occur chiefly due to air pressure changes.