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VERTICAL COLUMN PRECIPITABLE WATER  
DETERMINATIONS OVER TERRESTRIAL SURFACES  
FROM AVHRR THERMAL CHANNELS

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#### ABSTRACT

Knowledge of the total vertical column water vapor (precipitable water) is important to meteorological analyses, as a dynamic component of the atmosphere, and for remote sensing investigations due to broad and narrow water vapor absorption bands in the Near-IR and thermal bands. Recent work using NOAA-9 daylight overpass AVHRR thermal band temperature differences (split window) over areas of known aerosol optical thickness and precipitable water in the African Sahel have shown a very high correlation ( $r^2 \sim .9$  between precipitable water and the split window temperature difference) for aerosol optical thicknesses less than 0.4 in the visible band. Using this relationship, an approach is described which can possibly be applied for operational retrieval of precipitable water for the Sahel.

**KEYWORDS:** Precipitable Water, Remote Sensing, AVHRR.

#### INTRODUCTION

Simulations of the difference in radiative temperature (T4-T5) from AVHRR channels 4 (10.7 mm) and 5 (11.8 mm) exhibit a linear relationship between precipitable water (Pw) and T4-T5 for a wide range of atmospheric temperature and humidity profile representative of tropical and mid latitude atmosphere (Dalu, 1986). Based on this relationship, Dalu (1986) developed a formula to complete Pw from T4-T5 and applied it to simulations of AVHRR signals for a set of oceanic radiosonde profiler, yielding an error of 0.4 cm in estimated Pw. Similarly, Schluessel (1989) has shown from radiative transfer calculations, using tropical and mid latitude profiles, that Pw may be estimated from AVHRR T4-T5 with a standard error ranging from 0.48 cm at nadir to 0.59 cm at 50 degrees scan angle, for a single pixel. It is noted that Schluessel (1989) has considered only clear atmospheric conditions in his simulations, with aerosol optical depth at 550 nm of 0.2.

#### METHODOLOGY AND DATA

In order to test these relationships under real atmospheric conditions we have analyzed measurements of the radiative temperature in AVHRR channels 4 and 5 of NOAA-9 and nearly simultaneous values of Pw inferred from sunphotometer. The sunphotometer measurements were made at Gao, Mali (16.25°N, 0.0°) at 1430 LST with a 4 band instrument. The four

wavelength bands are each 10 nm wide and are centered at 500, 640, 875, and 940 nm. The calibration technique of Reagan et al (1987) was used to calibrate the 940 nm channel and to infer precipitable water. Holben and Eck (1990) have applied this calibration technique to an identical sunphotometer and compared the retrieved Pw from sunphotometer to radiosonde derived Pw. They found that the root mean square (rms) error of the sunphotometer Pw was 15% of the mean value of the radiosonde derived Pw. However, the sunphotometer and radiosonde were 60 km apart and the observations were typically 1-3 hours apart, thus contributing somewhat to the rms error. It was therefore concluded that the sunphotometer calibrated by this method provided fairly accurate measurements of Pw. In addition, Holben and Eck (1990) have shown that there was good agreement between radiosonde derived Pw at Timbuktu and Pw from sunphotometer at Gao for a few selected days in different seasons even though these stations are 325 km apart.

The AVHRR data utilized in this study was GAC data of about 4 km resolution. The AVHRR channel 4 and 5 GAC data were averaged for a 12 km square area, thus resulting in the averaging of about 9 GAC pixels for each day. The area for which the AVHRR data were selected was located about 30 km west-northwest of GAO in a region which is uniform in topography and soil/vegetation type. This area was selected in order to avoid the possible effects of human modification of the land surface and its spatial variability in the immediate area of Gao. We analyzed AVHRR measurements for all satellite view angles.

#### RESULTS

The comparison of the AVHRR T4-T5 difference and the sunphotometer derived Pw was made for the period of June through October, 1986 which spans the growing season in the Sahel of July-September. Although sunphotometer measurements were only taken when the sun was unobscured by clouds, this does not exclude the possibility of scattered clouds being present. In order to filter out this type of cloud contamination a cloud screen was applied which consisted of a low threshold value of the standard deviation of the AVHRR channel 4 and 5 radiative temperatures. If the value of the standard deviation of the radiative temperature in the 3X3 pixel (AVHRR) area was below the threshold then the average value of the temperature was computed for each channel and the T4-T5

difference computed from these average temperatures.

Figure 1 shows a plot of the AVHRR T4-T5 difference in degrees Kelvin versus the sunphotometer derived precipitable water in cm for Gao. Data for the complete range of aerosol optical thickness at 500 nm ( $\tau_{500}$ ) from a minimum of 0.19 to a maximum of 2.49 were included. There is considerable scatter in this relationship with  $r^2 = 0.32$ , however, there is a trend of increasing T4-T5 with increasing Pw. In order to separate the effects of aerosols and Pw on the AVHRR T4-T5 difference, we stratified the data set for various ranges of  $\tau_{500}$ . Figure 2 shows T4-T5 versus Pw for only the days where  $\tau_{500}$  was less than 0.4. For these clear days with low optical depth the AVHRR T4-T5 is highly correlated with the precipitable water inferred from sunphotometer, with  $r^2 = 0.94$ . Fitting a regression equation to these data and applying this equation to estimate Pw from T4-T5,

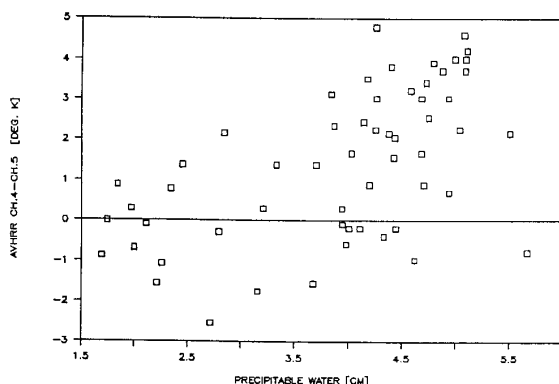


Figure 1. Radiative temperature difference between AVHRR channels 4-5 versus precipitable water derived from sunphotometer for Gao, Mali.

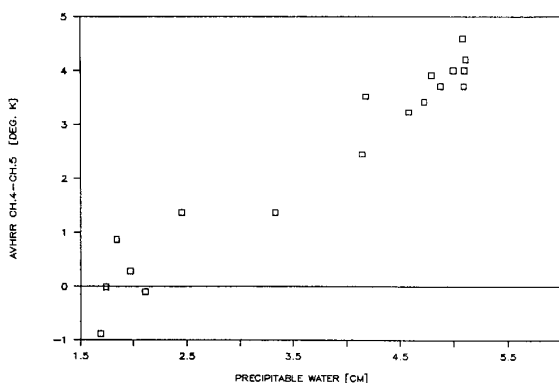


Figure 2. Same as Figure 1 but only for days where aerosol optical depth at 500 nm was less than 0.4.

it was found that the rms error of the estimated Pw compared to the sunphotometer derived Pw was 0.32 cm. It is noted that the simulations of Dalu (1986) show a water vapor amount of zero

for a T4-T5 difference of zero while our observations for the Sahel show Pw of about 1.9 cm for T4-T5 of zero. These differences are possibly due to a combination of the following factors which could modify the retrieval of Pw: surface emissivity, vertical distribution of water vapor, temperature profile, and surface temperature. It is possible therefore, that the observed relationship between T4-T5 and Pw for Gao may be representative for only Sahelian atmospheric and surface conditions. For extremely hazy conditions with  $\tau_{500}$  greater than 1.2 the relationship between T4-T5 and Pw is shown in Figure 3. There is virtually no correlation with  $r^2 = 0.13$ , and 9 of the 13 observations having a value of T4-T5 ranging from +1K degree to -1K over a wide range of Pw. Both theoretical computations by D'Almeida (1989) and observations by Levin and Lindberg (1979) have shown that desert aerosols have high absorption in thermal infrared window of 8-12 micron. Therefore, conditions in the Sahel with high aerosol optical depth result in a masking of the surface and lower atmosphere in the thermal infrared window since the altitude of the Saharan dust layer often exceeds 3km, below which the majority of the water vapor is located (Aro, 1976).

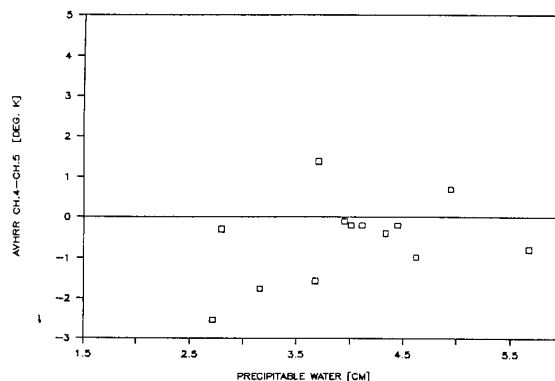


Figure 3 Same as Figure 1 but only for days when aerosol optical depth at 500nm was greater than 1.2.

In order to operationally correct for the effects of water vapor absorption on remote sensing in the Sahel region, a relationship between T4-T5 and Pw for the majority of atmospheric conditions which occur is required. Figure 4 shows the variation in T4-T5 versus Pw for all days with  $\tau_{500}$  less than 0.7. This range of aerosol optical depth values occurred on 55% of the days of our sunphotometer observations at Gao for the entire time period of July - October, 1986. Thus if cases of high  $\tau_{500}$  (greater than 0.7) can be filtered out, possibly by maximum value composite of the Normalized Difference Vegetation Index (NDVI) (Holben, 1986), then an empirical relationship based on these observations can be applied for the Sahel region. Using a regression equation fit to the data in Figure 4, the estimated Pw from T4-T5 difference compared to the sunphotometer derived Pw results in an rms error of 0.55 cm, which is similar to the errors obtained in the simulations of Dalu (1986) and Schluessel (1989) for AVHRR T4-T5.

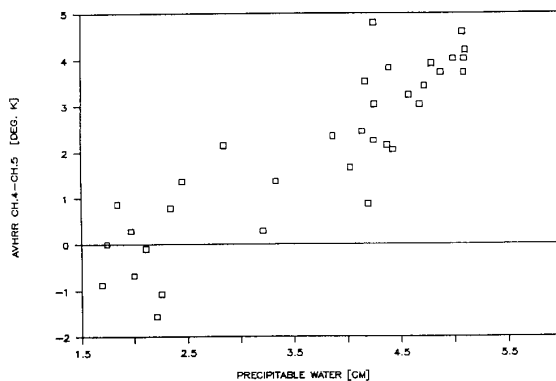


Figure 4 Same as Figure 1, but only for days when aerosol optical depth at 500nm was less than 0.7.

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