MMA Memo. No. 238

Precipitable Water at KP — 1993–1998

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Introduction

This memo is essentially a clone of MMA Memo No. 237 (also VLA Scientific Memo No. 176) (Butler 1998), but done for the 12-m site at Kitt Peak. See Butler (1998) for the details of the precipitable water estimation from surface measurements. In the following section, I outline only those things which are different about the retrieval for KP.

Deriving the precipitable water

Assuming that the water vapor is exponentially distributed in the atmosphere above a given location, the amount of precipitable water is given by (Butler 1998):

$$h = \frac{m_w \; P_0 \; H}{\rho_l \; k \; T_0} \quad ,$$

where m_w is the mass of each water molecule ($m_w = 18$ amu), P_0 is the water vapor partial pressure at the surface, H is the scale height of water vapor (assumed to be 1.5 km, for consistency with the VLA analysis), ρ_l is the mass density of liquid water ($\rho_l = 1000$ kg/m^3), k is the Boltzmann constant, and T_0 is the surface temperature. Putting in these constants gives:

$$h \sim \frac{P_0}{3 \; T_0} \quad ,$$

where h is in mm, P_0 is in μbar, and T_0 is in K. Note that if you have a surface water vapor partial pressure measurement in hPa (a common meterological unit), multiply by 1000 to get μbar. In this case, to first order, the precipitable water in mm is equal to the surface water vapor partial pressure in hPa (because T_0 is always $\sim$ 250-310 K).

The surface temperature, T_0 is measured and recorded regularly in the 12-m electronic weather logs. The relative humidity (RH) is also measured and recorded in these logs. The surface water vapor partial pressure can be derived from the surface relative humidity via (Liebe 1989):

$$P_0 = 2.409 \times 10^{12} \; RH \; \theta^4 \; e^{-22.64\,\theta} \quad ,$$

where the value of RH is in percent, θ is inverse temperature ($\theta = 300/T_0$, T_0 in K), and the resultant water vapor partial pressure is in μbar.

Results

Electronic weather records from November 1992 to September 1998 for the 12-m site were parsed for values of T_0 and RH (4 months were missing - Dec92, Apr93, Jul94, and Aug94). Oddball values were excluded (often, for example, it was apparent that one or the other of the measurement instruments was not functioning properly). The remaining values were used to calculate the precipitable water (h) according to the above formula, and 1 hour averages of RH, T_0, and resultant estimated precipitable water were formed. If the hourly average of RH was $> 90\%$, that particular sample was thrown out, on the assumption that there was possibly liquid water somewhere in the column above the site, and hence the estimate of precipitable water may be wrong. The remaining hourly averages of RH, T_0, and h (40022 of them in total), along with date and time were recorded for analysis. Figure 1 shows a plot of all of the recorded values of h. The seasonal variation is readily apparent in the data. Figure 2 shows the data for 1997 only. The effects of weather systems can be seen clearly at this higher time resolution (variations on the scales of a few to 10's of days).

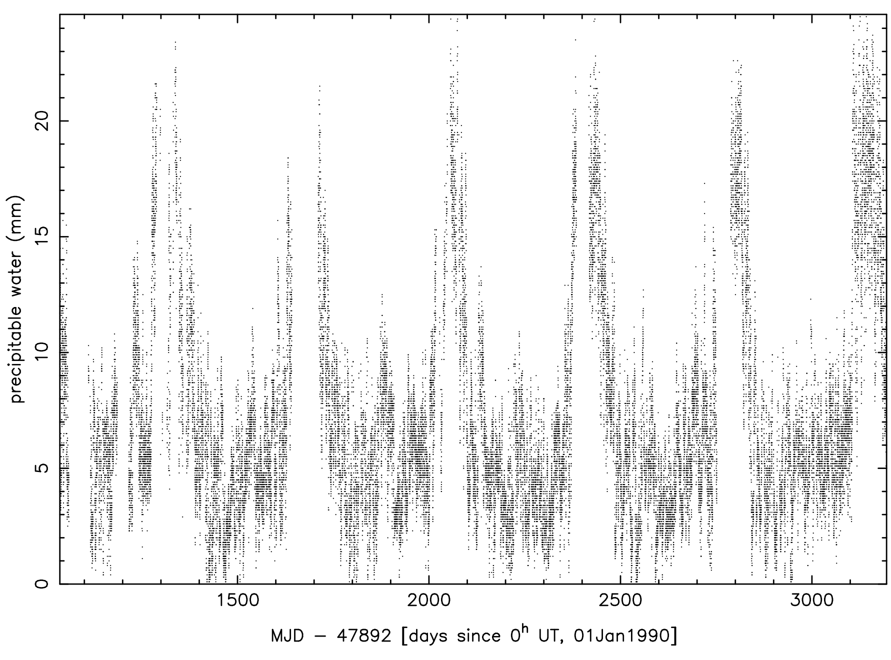

Figure 1: All precipitable water data from November 1, 1992 to September 30, 1998.

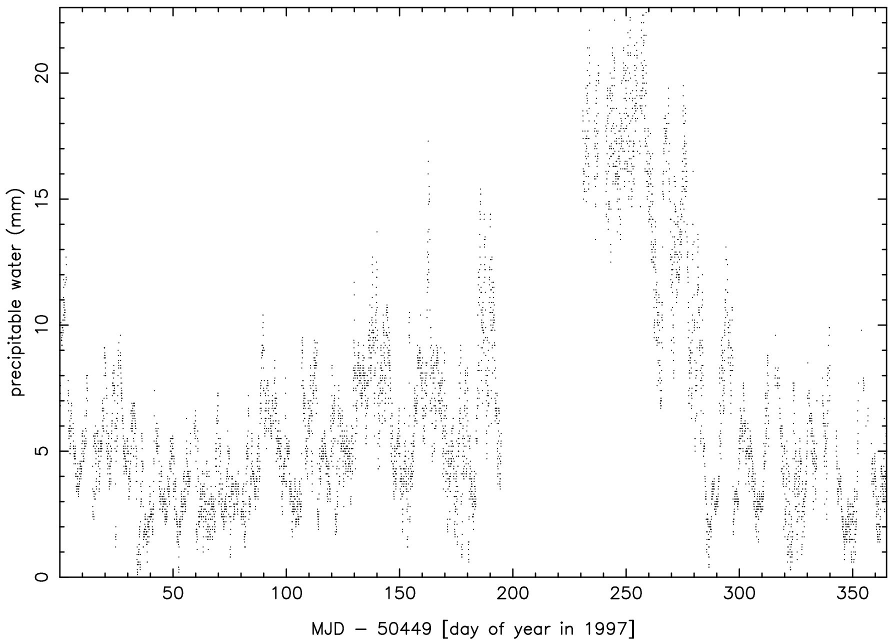

Figure 2: Precipitable water data for 1997.

Monthly values

Figure 3 shows the monthly mean and minimum value (the absolute lowest value in all of the data for that month) for all of the data. Again, the seasonal variation is clearly evident. The wet summer months have a mean precipitable water which is more than twice what it is in the winter months. The typical mean precipitable water in the "winter" months (November - April) is about 5 mm, while in the "monsoon" season (July, August and September), the typical mean precipitable water is of order 15 mm. The absolute very best conditions are 0.1 mm of precipitable water in the months from November to February, 0.2 to 0.5 mm in October, March, April, May, and June, and 2 to 4 mm in July, August, and September.

Hourly values

Figure 4 shows the hourly mean values for all of the data. There is a clear diurnal trend. Note that sunrise is roughly UT 12h in summer, and UT 14h in winter (local time is $\sim$ UT - 7.5h).

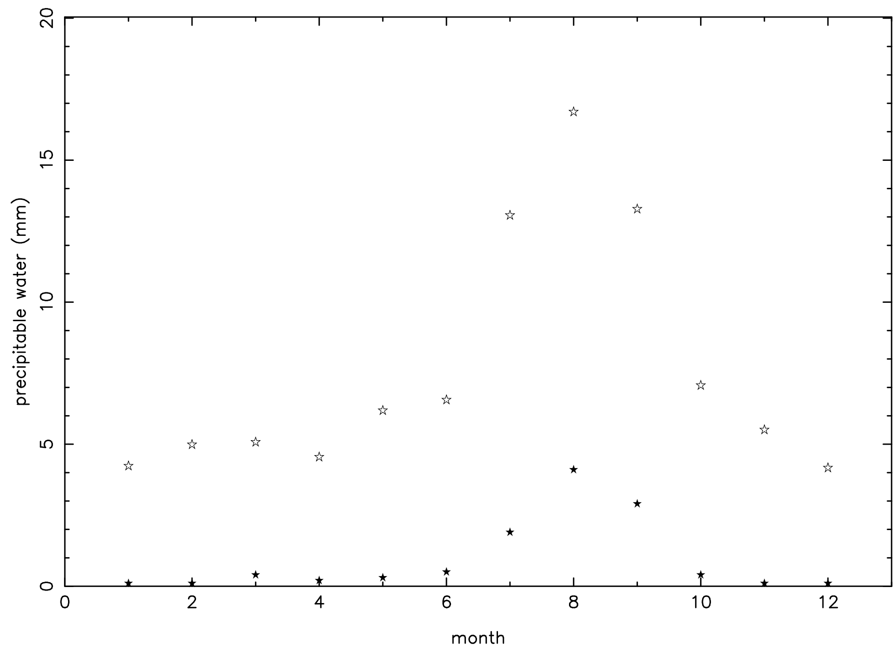

Figure 3: Monthly mean (open stars) and absolute minimum (filled stars) values of precipitable water.

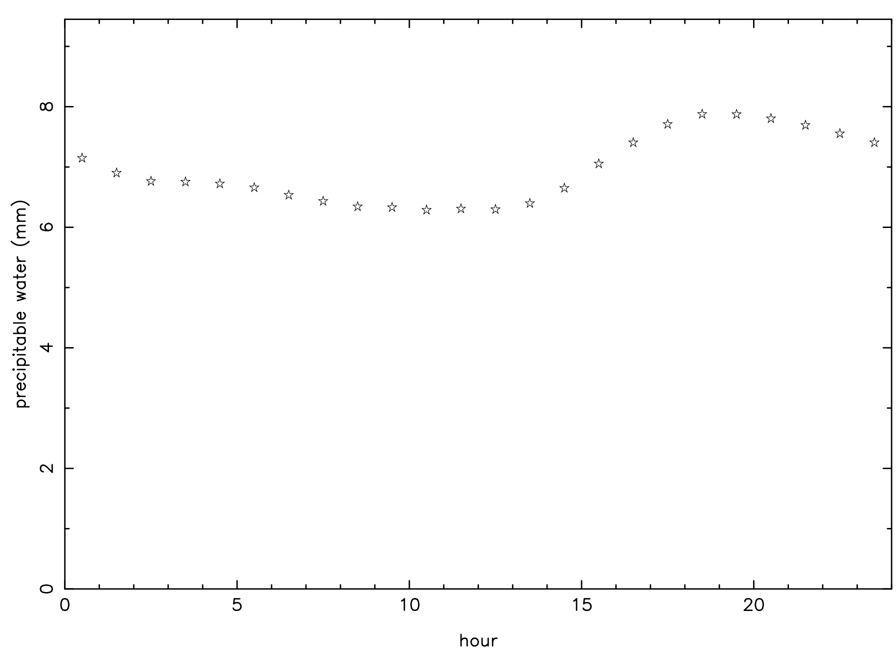

Figure 4: Hourly mean values of precipitable water.

Comparison with measured opacity

Since water vapor is one of the primary contributors to the opacity at radio wavelengths, the opacity is expected to correlate very well with the amount of precipitable water. However, there is some disagreement about whether surface measurements can yield any reasonable estimate of the precipitable water (e.g. Reber & Swope 1972). In order to test whether the precipitable water derived via the technique outlined above has a good correlation with true opacity, I took the data from the 225 GHz tipper over the last 2 years (November 1996 to September 1998) which are also recorded in the weather logs, and plotted the measured opacity against the estimated precipitable water.

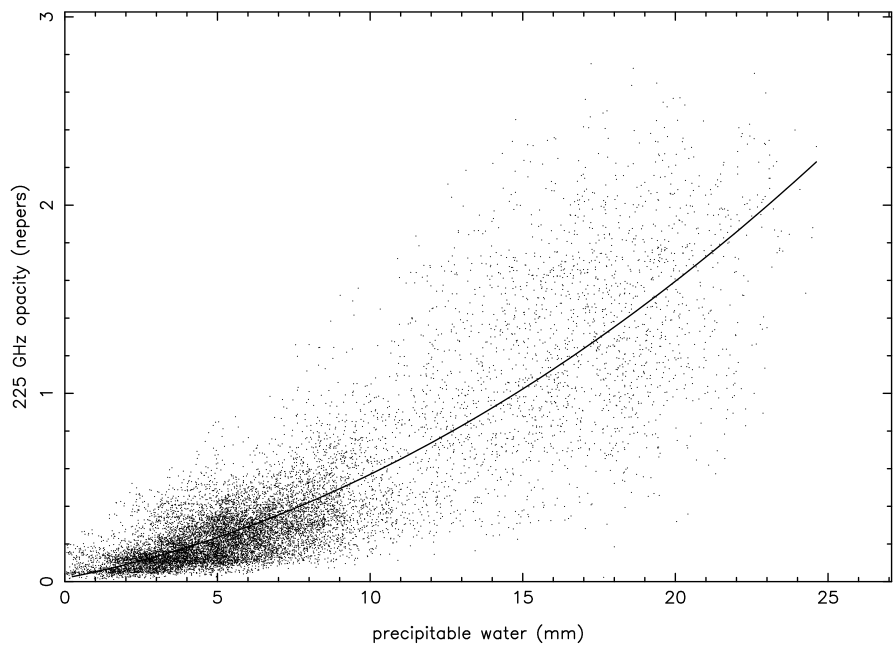

Figure 5: Measured opacity at 225 GHz at KP compared with estimated precipitable water over the past 2 years.

The result is shown in Figure 6. A good correlation is seen, and a fit with a second order polynomial is also shown in Figure 6. This fit is of the type:

$$\tau = a_0 + a_1\,h + a_2\,h^2 \quad ,$$

where the three coefficients are: $a_0 = 1.8\%$, $a_1 = 3.1\%$, $a_2 = 0.24\%$. If only the data with estimated water column less than 8 mm is used in the fit, the coefficients are: $a_0 = 6.8\%$, $a_1 = 2.1\%$, $a_2 = 0.21\%$. While individual data points can be significantly different from the fit, for the purposes of statistical analysis it seems quite valid to use the surface measurements to predict precipitable water (and hence opacity). Of course, at KP this is not necessary, since a measurement of opacity is provided independently by the tipping radiometer.

Comparison to VLA values

It seems reasonable to compare the numbers from KP to those from the VLA. Figure 7 shows the 50th percentile (the median value) and 10th percentile numbers for each of the months for all of the data for the two sites. This data is also reproduced in Table 1. Note that in this memo, the KP data had values with relative humidity > 90% excluded, while the VLA data had no such filter applied (Butler 1998). For the values shown in Figure 7 and Table 1, this additional filter was applied to the VLA data, to make it consistent with the KP data.

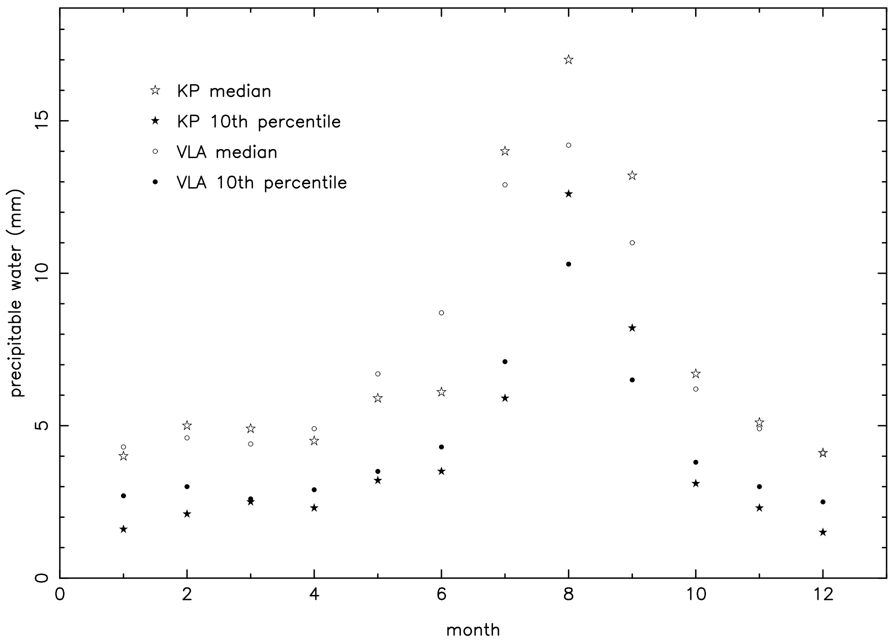

Figure 6: Monthly median (open stars=KP; open circles=VLA) and 10th percentile (filled stars=KP; filled circles=VLA) values of precipitable water.

Acknowledgements

Thanks to Jeff Mangum for providing the 12-m weather logs.

References

Butler, B., Precipitable Water at the VLA — 1990–1998, MMA Memo No. 237, 1998

Liebe, H.J., MPM – an atmospheric millimeter-wave propagation model, *Int. J. Infr. Mill. Waves, 10*, 631–650, 1989

Reber, E.E., and J.R. Swope, On the Correlation of the Total Precipitable Water in a Vertical Column and Absolute Humidity at the Surface, *J. Appl. Met., 11*, 1322–1325, 1972

Table 1: Precipitable Water at the KP and VLA Sites

Month	KP		VLA	
	50th percentile	10th percentile	50th percentile	10th percentile
Jan	4.0	1.6	4.3	2.7
Feb	5.0	2.1	4.6	3.0
Mar	4.9	2.5	4.4	2.6
Apr	4.5	2.3	4.9	2.9
May	5.9	3.2	6.7	3.5
Jun	6.1	3.5	8.7	4.3
Jul	14.0	5.9	12.9	7.1
Aug	17.0	12.6	14.2	10.3
Sep	13.2	8.2	11.0	6.5
Oct	6.7	3.1	6.2	3.8
Nov	5.1	2.3	4.9	3.0
Dec	4.1	1.5	4.1	2.5