20.7- and 31.4-GHz Atmospheric Noise Temperature Measurements

S. D. Slobin, M. M. Franco, and C. T. Stelzried
Radio Frequency and Microwave Subsystems Section

The 20.7/31.4-GHz Water Vapor Radiometer (WVR) located on the JPL Mesa in Pasadena was used for atmospheric noise temperature measurements. Tipping curve data and on/off sun data taken on March 24, 1981 are compared. The analysis technique is described in detail. During the time of the data collection (7:00 a.m. to 12:20 p.m.), the sky was clear and the ground temperature and humidity varied from 14°C to 24°C and 65% to 51% respectively. The tipping curve data is felt to be the most accurate. The averaged results of this data for 13 measurements during this time period are:

Frequency, GHz	*1 atmosphere*	
	Noise temperature contribution	*Attenuation, dB*
20.7	*16.3 ± 1.7*	*0.26 ± 0.03*
31.4	*11.6 ± 1.2*	*0.18 ± 0.02*

The indicated errors are 1σ statistical and do not represent overall measurement accuracy. Although this data is consistent with data taken previously at the Goldstone DSS 13 station, it is not necessarily representative of long-term atmospheric noise temperature average.

I. Introduction

The 20.7/31.4-GHz Water Vapor Radiometer (WVR) located on the JPL Mesa in Pasadena was used for atmospheric noise temperature measurements. The data taken on March 24, 1981 is reported. The sky was clear, the ground relative humidity varied from 65% (7:00 a.m.) to 51% (12:20 p.m.) and the ground temperature varied from 14°C to 24°C over the same time period.

Periodically, the antenna was moved in zenith angle between zenith and 60° (30° elevation) for a direct atmospheric noise temperature measurement (tipping curve method). For each calibration, both radiometers were switched between the antenna, hot load and base (ambient load). In addition, the antenna was peaked on the sun and a difference measurement made between on-sun and off- (in azimuth) sun (on/off sun method).

II. Tipping Curve Method

Assuming a flat earth (Fig. 1) with a horizontally stratified nonchanging atmosphere, and a narrow-beam antenna radiometer system, the atmospheric loss factor L is given by

$$L = L_0^{\sec z} \tag{1}$$

or

$$L\ (\mathrm{dB}) = L_0\ (\mathrm{dB}) \sec z$$

where

z = zenith angle

L, L_0 = atmospheric loss at zenith angle z and vertical respectively, ratio $(L, L_0 \geqslant 1)$

The atmospheric loss factor is squared (doubled in dB) for the case of $z = 60^\circ$ with reference to zenith. The noise temperature contribution of the atmosphere is given by

$$T'' = T_p\left(1 - \frac{1}{L}\right) \tag{2}$$

where

T_p = equivalent physical temperature of the atmosphere[1] ($\cong$280 K), K

The increase in system noise temperature at z with reference to zenith is given by

$$\Delta T'' = T_p\left(1 - \frac{1}{L}\right) - T_p\left(1 - \frac{1}{L_0}\right) + \frac{T_c}{L} - \frac{T_c}{L_0}$$

$$= (T_p - T_c)\left(\frac{1}{L_0} - \frac{1}{L_0^{\sec z}}\right) \tag{3}$$

where

T_c = cosmic background noise temperature ($\cong$2.7 K), K

The increase in system noise temperature at $z = 60^\circ$ (looking through two atmospheres) with reference to zenith is given by

[1]Reference 1 indicates a technique for estimating T_p.

$$\Delta T_0'' = (T_p - T_c)\left(\frac{1}{L_0} - \frac{1}{L_0^2}\right)$$

$$= \frac{T_0''}{L_0} - T_c\left(1 - \frac{1}{L_0}\right)$$

$$\cong T_0'' \tag{4}$$

which indicates that for low loss ($L_0 \cong 1$) the increase in noise temperature is approximately equal to the noise temperature contribution at zenith (T_0''), for this type of tipping curve. Tables 1 and 2 [and 3 and 4][2] indicate the results of this type of measurement tabulated under $\Delta T_0''$. Using Eq. (4) gives

$$L_0 = \frac{1}{2x}\left(1 - \sqrt{1 - 4x}\right) \cong 1 + x + 2x^2 + 5x^3 + \ldots \tag{5}$$

where

$$x = \frac{\Delta T_0''}{(T_p - T_c)}$$

and

$$T_0'' = L_0\,\Delta T_0'' + T_c\,(L_0 - 1) \tag{6}$$

The measured values of $\Delta T_0''$ from Tables 1 and 2 [and 3 and 4] are used with Eqs. (5) and (6) to compute averaged L_0 and T_0'':

20.7 GHz

$L_0 \cong (0.26 \pm 0.03)$ dB [(0.26 ± 0.02) dB]

$T_0'' \cong (16.3 \pm 1.7)$ K [(16.1 ± 1.5) K]

31.4 GHz

$L_0 \cong (0.18 \pm 0.02)$ dB [(0.18 ± 0.02) dB]

$T_0'' \cong (11.6 \pm 1.2)$ K [(11.5 ± 1.1) K]

[2]The data were analyzed in two ways for comparison: (1) individual calibrations of the radiometer gain factor (kelvins/volt) and (2) a daily average radiometer gain factor (2nd method shown in brackets).

III. On/Off Sun Method

Again assuming a flat earth (Fig. 1) with a horizontally stratified nonchanging atmosphere

$$\Delta T'_{sun} = \Delta T_{sun} L_0^{-\sec z} \tag{7}$$

where

$\Delta T'_{sun}$, ΔT_{sun} = antenna temperature of the sun with and without atmospheric loss, K

$\Delta T'_{sun}$ is measured using the radiometer with an on/off sun technique. The antenna temperature of the sun is always less than the equivalent black body disk temperature of the sun for wide-beamwidth antennas.

Equation (7) becomes:

$$\log \Delta T'_{sun} = \log \Delta T_{sun} - \sec z \log L_0 \tag{8}$$

This is the equation of a straight line $y = A + Bx$, where

$$y = \log \Delta T'_{sun}$$

$$A = \log \Delta T_{sun}$$

$$B = -\log L_0$$

$$x = \sec z$$

so that with a log $\Delta T'_{sun}$ vs sec z plot, the y intercept A gives log ΔT_{sun} and the slope gives log L_0 (Ref. 2). Figures 2 and 3 [and Figs. 4 and 5] show this type of plot for the data from Tables 1 and 2 [and Tables 3 and 4]. The solid lines are obtained from a computer least squares fit (Ref. 3, using Eq. (4)), which also computes goodness of fit ($\sigma\Delta T_{sun}$ and σL_0, dB). The results are

20.7 GHz

$$\Delta T_{sun} = (35.1 \pm 0.7)\ \text{K} \qquad [(35.9 \pm 0.5)\ \text{K}]$$

$$L_0 = (0.15 \pm 0.05)\ \text{dB} \qquad [(0.19 \pm 0.03)\ \text{dB}]$$

31.4 GHz

$$\Delta T_{sun} = (29.7 \pm 0.8)\ \text{K} \qquad [(29.9 \pm 0.7)\ \text{K}]$$

$$L_0 = (0.086 \pm 0.06)\ \text{dB} \qquad [(0.083 \pm 0.05)\ \text{dB}]$$

For comparison, L_0 can be translated to an equivalent atmospheric noise temperature contribution using Eq. (2). The results are

20.7 GHz

$$T''_0 \cong (9.5 \pm 3)\ \text{K} \qquad [(12.0 \pm 2)\ \text{K}]$$

31.4 GHz

$$T''_0 \cong (5.5 \pm 3)\ \text{K} \qquad [(5.3 \pm 3)\ \text{K}]$$

IV. Conclusion

The errors indicated are all 1σ statistical and do *not* contain the bias errors to indicate overall accuracy. The differences in results between the two methods are slightly greater than the sum of the statistical errors in some cases. This is an indication of the bias error magnitude. It is felt that the tipping curves give the most accurate result. The primary advantage of the tipping curve is the relative ease and fast results. The on/off sun method requires more operator skill in peaking the antenna beam on the sun with subsequent error possibility. Further, the temperature and humidity are changing during the day so that the atmospheric uniformity assumed in the derivation is not strictly true both spatially and temporally.

Further refinement might include more days of data, different weather conditions, correction for antenna size, etc. Although the data presented is consistent with data taken previously on the Mesa and at the Goldstone DSS 13 station, it is not necessarily representative of long-term data average. The WVR output at DSS 13 has been connected to the data collection system (MASDAS), which simultaneously collects data from the X-band atmospheric noise temperature monitoring system.

References

1. Slobin, S. D., and Stelzried, C. T., "Calculation of Atmospheric Loss From Microwave Radiometer Noise Temperature Measurements," *Tracking and Data Acquisition Progress Report 42-62*, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1981.

2. Coates, R. J., "Measurements of Solar Radiation and Atmospheric Attenuation at 4.3-Millimeters Wavelength," *Proceedings of the IRE*, Volume 46, No. 1, pp. 122-126, January 1958.

3. Stelzried, C. T., and Rusch, W. V. T., "Improved Determination of Atmospheric Opacity from Radio Astronomy Measurements," *J. Geophys. Res.*, Vol. 72, No. 9, p. 2445, May 1, 1967.

Table 1. 20.7-GHz WVR data results (data taken on the JPL Mesa, Pasadena, on 3/24/81)

Local time	EL	z	$\Delta T_0''$	$\Delta T_{sun}'$	$\log \Delta T_{sun}'$	sec z	Relative humidity, %
7:00 am	18.5	71.5	15.3	30.5	1.484	3.152	65
7:20	20.8	69.2	16.4	32.5	1.511	2.816	64
7:45	24.0	66.0	16.4	32.8	1.515	2.459	63
8:00	27.0	63.0	15.8	32.9	1.517	2.203	63
8:30	33.0	57.0	16.7	33.9	1.531	1.836	63
8:41	34.9	55.1	16.9	33.2	1.521	1.748	63
9:30	44.0	46.0	12.2	32.8	1.516	1.440	60
9:45	46.0	44.0	14.7	32.7	1.515	1.390	59
10:30	51.6	38.4	13.3	32.3	1.510	1.276	56
10:45	53.0	37.0	13.3	33.8	1.528	1.252	56
11:30	54.0	36.0	15.2	33.2	1.521	1.236	54
11:50	57.2	32.8	16.1	34.4	1.536	1.190	50
12:20 pm	56.9	33.1	15.1	34.6	1.539	1.194	51

Table 2. 31.4-GHz WVR data results (data taken on the JPL Mesa, Pasadena, on 3/24/81)

Local time	EL	z	$\Delta T_0''$	$\Delta T_{sun}'$	$\log \Delta T_{sun}'$	sec z	Relative humidity, %
7:00 am	18.5	71.5	11.2	28.1	1.449	3.152	65
7:20	20.8	69.2	11.7	28.4	1.454	2.816	64
7:45	24.0	66.0	11.6	28.2	1.450	2.459	63
8:00	27.0	63.0	11.9	27.4	1.438	2.203	63
8:30	33.0	57.0	12.6	30.5	1.484	1.836	63
8:41	34.9	55.1	12.5	27.7	1.443	1.748	63
9:30	44.0	46.0	10.4	27.7	1.443	1.440	60
9:45	46.0	44.0	9.9	28.3	1.452	1.390	59
10:30	51.6	38.4	9.6	29.4	1.468	1.276	56
10:45	53.0	37.0	9.1	30.0	1.478	1.252	56
11:30	54.0	36.0	10.7	28.1	1.448	1.236	54
11:50	67.2	32.8	11.9	29.5	1.469	1.190	50
12:20 pm	56.9	33.1	10.3	29.7	1.472	1.194	51

Table 3. 20.7-GHz WVR data results using an average gain K/V = 42.9 (data taken on the JPL Mesa, Pasadena, on 3/24/81)

Local time	$\Delta T_0''$	$\Delta T_{sun}'$	$\log \Delta T_{sun}'$	sec z
7:00 am	15.0	30.9	1.490	3.152
7:20	16.3	32.6	1.513	2.816
7:45	16.3	32.6	1.513	2.459
8:00	15.4	32.6	1.513	2.203
8:30	16.3	33.5	1.525	1.836
8:41	16.3	32.6	1.513	1.748
9:30	12.4	34.3	1.536	1.440
9:45	15.0	33.9	1.530	1.390
10:30	13.3	33.0	1.519	1.276
10:45	13.3	34.7	1.541	1.252
11:30	15.0	33.5	1.525	1.236
11:50	15.9	34.3	1.536	1.190
12:20 pm	15.0	34.7	1.541	1.194

Table 4. 31.4-GHz WVR data results using an average gain K/V = 53.1 (data taken on the JPL Mesa, Pasadena, on 3/24/81)

Local time	$\Delta T_0''$	$\Delta T_{sun}'$	$\log \Delta T_{sun}'$	sec z
7:00 am	11.2	28.1	1.449	3.152
7:20	11.7	28.7	1.457	2.816
7:45	11.7	28.7	1.457	2.459
8:00	11.7	27.6	1.441	2.203
8:30	12.1	30.3	1.481	1.836
8:41	12.2	27.6	1.441	1.748
9:30	10.6	28.7	1.457	1.440
9:45	10.1	29.2	1.465	1.390
10:30	9.6	29.7	1.473	1.276
10:45	9.0	30.3	1.481	1.252
11:30	10.6	28.1	1.449	1.236
11:50	11.7	29.2	1.465	1.190
12:20 pm	10.1	29.2	1.465	1.194

Table 5. Summary of 20.7/31.4-GHz radiometric calibrations for 3/24/81

Frequency, GHz	Method			
	Tipping curve		On/off sun	
	T_0'' (kelvins)	L_0 (dB)	T_0'' (kelvins)	L_0 (dB)
20.7	16.3 ± 1.7 [16.1 ± 1.5]	0.26 ± 0.03 [0.26 ± 0.02]	9.5 ± 3 [12.0 ± 2]	0.15 ± 0.05 [0.19 ± 0.03]
31.4	11.6 ± 1.2 [11.5 ± 1.1]	0.18 ± 0.02 [0.18 ± 0.02]	5.5 ± 3 [5.3 ± 3]	0.086 ± 0.06 [0.083 ± 0.05]

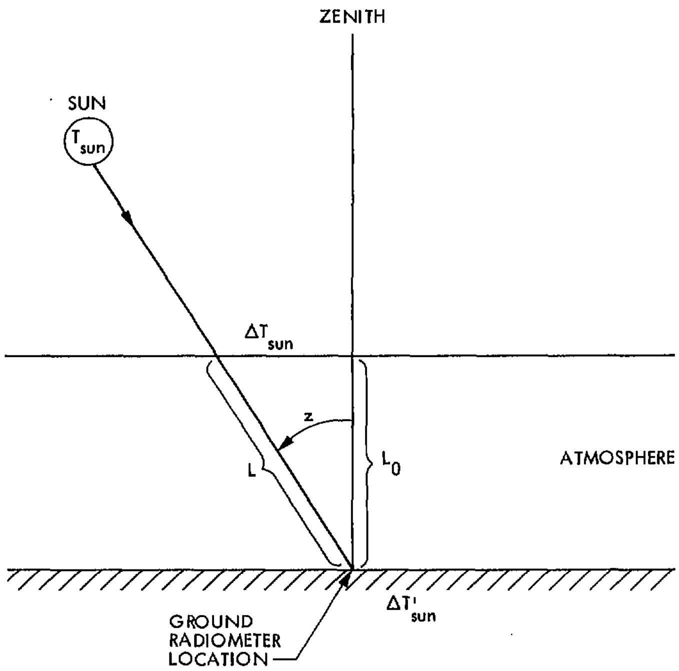

Fig. 1. Representation of radiometer configuration used in atmospheric loss calibrations

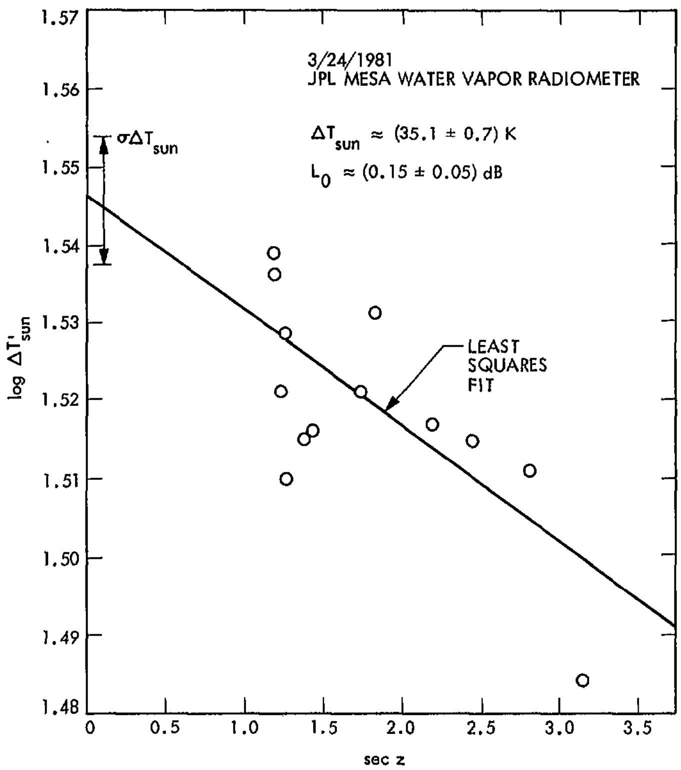

Fig. 2. Plot of log $\Delta T'_{sun}$ vs sec z @ 20.7 GHz using individual radiometer gain calibrations

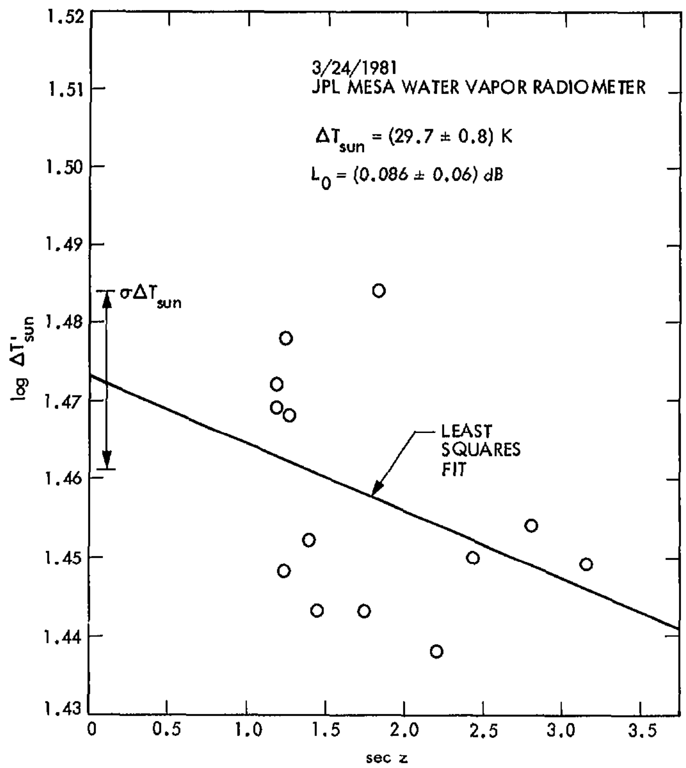

Fig. 3. Plot of log $\Delta T'_{sun}$ vs sec z @ 31.4 GHz using individual radiometer gain calibrations

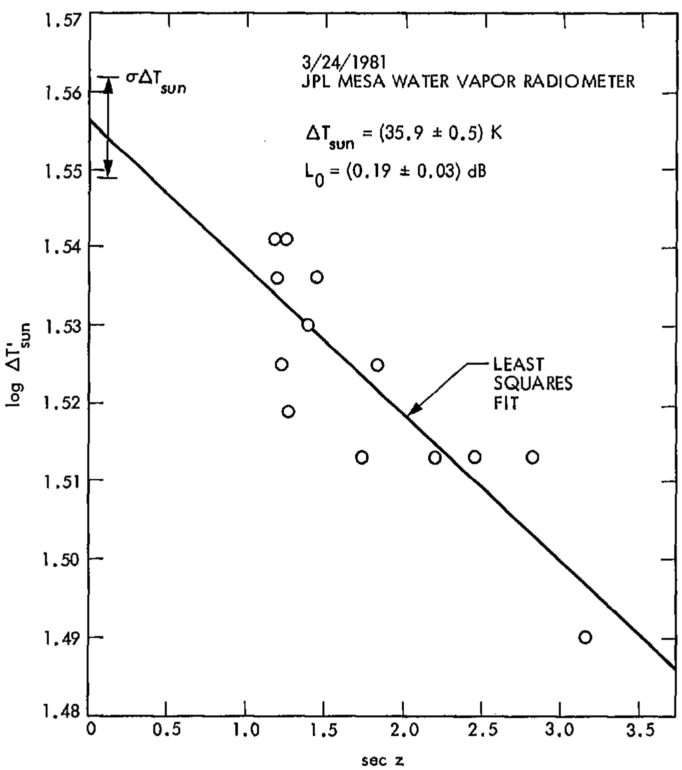

Fig. 4. Plot of log $\Delta T'_{sun}$ vs sec z @ 20.7 GHz using averaged radiometer gain calibrations

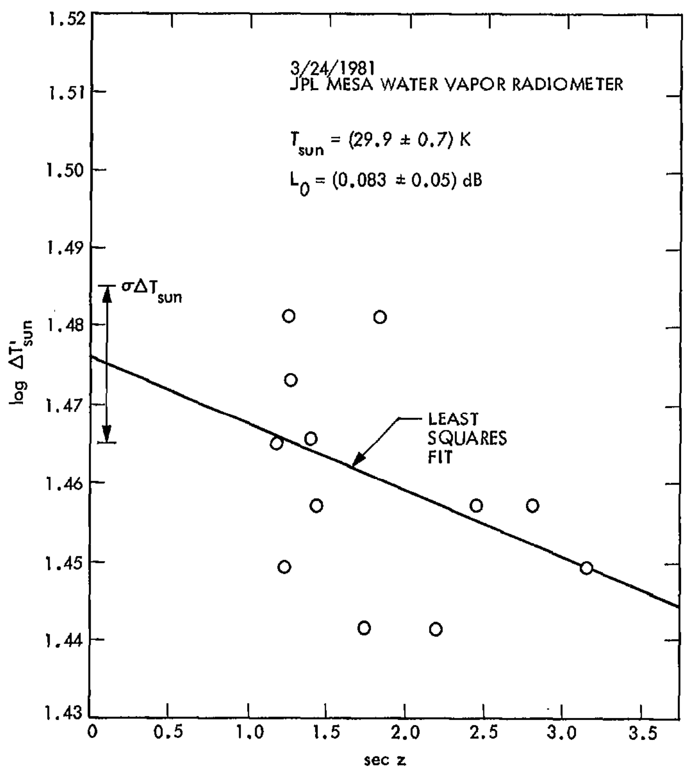

Fig. 5. Plot of log $\Delta T'_{sun}$ vs sec z @ 31.4 GHz using averaged radiometer gain calibrations