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220 GHz tipping radiometer for monitoring sky opacity at Hanle

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Abstract. A 220 GHz tipping radiometer is in operation at the Indian Astronomical Observatory, Mt Saraswati, Digpa-ratsa Ri, Hanle (Latitude 32° 46′ 46.″3 N, Longitude 78° 57′ 51.″1 E, Altitude 4500 m above msl) for continuous monitoring of sky opacity at this frequency. We describe here the working principle, data acquisition method and data reduction scheme of the radiometer. We also present some preliminary results on the 220 GHz zenith optical depth at Mt. Saraswati which shows that optical depths less than 0.10 can be achieved for nearly 75% of the time during the six colder months (October to March).

1. Introduction

The identification and development of the high altitude cold desert site, Hanle, in the trans-Himalayan region of Ladakh, for the Indian Astronomical Observatory (IAO) by the Indian Institute of Astrophysics (IIA), Bangalore (Anupama 2000; HIROT Team 1996), opens up the possibilities of future observing facilities in the sub-mm and lower wavelength bands. As the low relative humidities (annual median $\sim$ 30%, and minimum $\lesssim$ 10%), and low ambient temperatures (annual median of $-1.4°$ C, minimum $-24°$ C) suggest that the atmospheric content of precipitable water vapour is low above this site, it was natural to undertake site characterization experiments towards sub-mm and mm-wave astronomy. A collaborative program was hence undertaken to measure directly and continuously the 220 GHz transparency / opacity of the sky. The atmospheric transparency at higher frequencies can be extrapolated from the zenith opacity values at 220 GHz (see Sekimoto et al. 1996).

Currently, atomospheric transparency at sub-mm wavelengths is available at the existing facilities such as Mauna Kea in Hawaii islands, Gornergrat in Switzerland, and Mt. Fuji in Japan. Surveys are being conducted in potential sub-mm sites such as the South Pole and Atacama desert in northern Chile, and also at a few proposed sites for mm-wave telescopes (e.g., Cerro la Negra

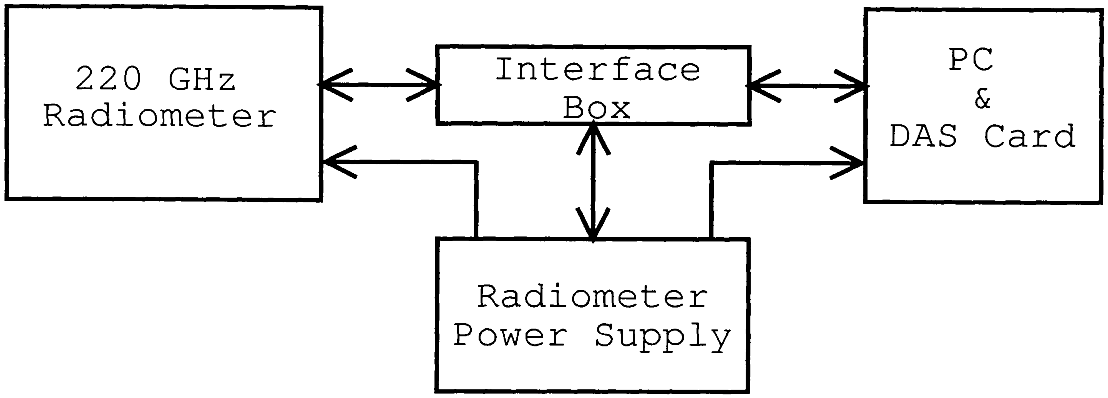

Figure 1. Block diagram of the radiometer system showing all the four units. The basic radiometer is installed outdoors and the other three components inside the seeing monitor building.

in Mexico), at a variety of frequencies, the 220 and 225 GHz being the most common (cf., Radford & Chamberlain, 2000; Chamberlain, Lane & Stark 1997; Holdaway et al. 1996a). We describe here the instrument we have deployed at Hanle, Ladakh, for continuous monitoring of 220 GHz opacity, and also some preliminary results.

2. The radiometer

The tipping radiometer deployed in Hanle is essentially the same as the one used at the top of Mt. Fuji during 1994–95 (Sekimoto et al. 1996), but with some minor modifications. Especially, the heating of the radome enclosure was not found necessary at Hanle due to negligible snowfall. It was installed at the site on December 23, 1999. The early data were noisy due to slightly variable gain and the instrument developed more serious problems in May 2000. The software was upgraded and the instrument overhauled in October 2000 after which it has been performing satisfactorily. The block diagram of different units is shown in Fig. 1 and the schematic of the basic radiometer unit is shown in Fig. 2.

This personal computer (PC) controlled instrument consists of an off-axis parabolic mirror of focal length 150 mm, with a projected aperture of 80 mm, mounted at 45° to the rotation axis, and a 220 GHz prime-focus receiver also located on the rotation axis. With this simple arrangement, the system can look at the sky at all elevations or zenith angles (z) at a fixed azimuth position, with just one axis of rotation and with no blockage. The mirror with about 1° beam, driven by a step motor under PC control is rotated to look at every 0.72° on the sky for 90 ms, covering a zenith angle range of nearly $-90°$ to $+90°$. The sky coverage through the radome window is limited to about 90°, i.e., from $-75°$ to $+15°$ in zenith angle. The window is covered with a low loss woven teflon membrane. A forward scan and a reverse scan are taken in about a minute. A reference load (blackbody termination at ambient temperature) is fixed towards the $+90°$ zenith angle position. The averaged signal corresponding to mirror positions pointing to the blackbody is the reference for temperature calibration

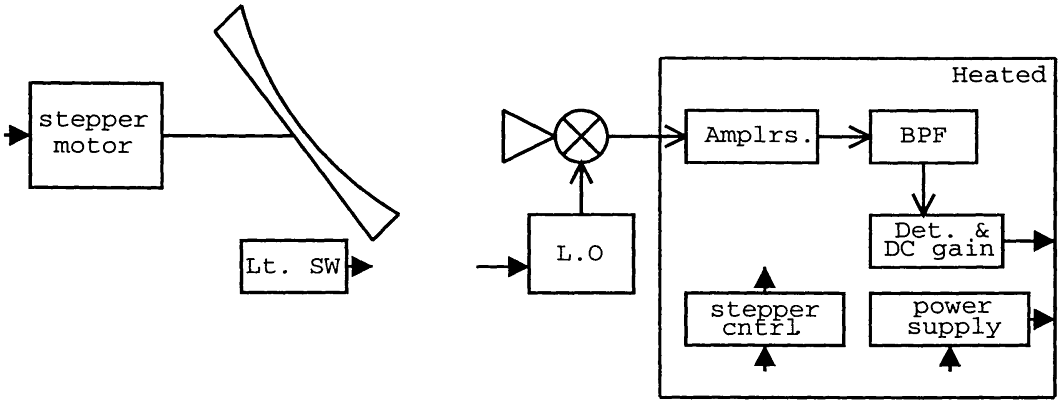

Figure 2. A schematic diagram of the 220 GHz radiometer, Hanle

of the signal received from the sky. The signal received from each sky position is down-converted to 1450 MHz with 500 MHz bandwidth, detected, digitized and stored in the PC's hard disc. Scans are taken once every 10 min. The system sensitivity or minimum detectable signal T_{rms} is 2 K.

3. Data analysis

The basic equations relating the detected voltage and temperature are:

$$V_{\rm sky} = K[T_{\rm rx} + T_{\rm medium}(1 - e^{-\tau_0 \sec(z)}) + T_b e^{-\tau_0 \sec(z)}] \tag{1}$$

$$V_{\rm ref} = K(T_{\rm rx} + T_{\rm ref}) \tag{2}$$

where, K is a proportionality constant or conversion factor, $T_{\rm rx}$ is the receiver noise temperature and T_b is background source temperature. With the assumptions that the system gain is constant or variation is corrected, system sensitivity is the same at all zenith angles, sky is stable during the scans, no background source in the beam and $T_{\rm medium} = T_{\rm ambient} = T_{\rm ref}$, the above equations can be reduced to a single linear equation and zenith optical depth can be determined by a least-squares fit routine using the sec(z) dependency of the sky emission. Data up to air mass 2.4 is used in the fit to derive the zenith opacity.

4. Results and discussion

The opacities derived for the month October 2000 are shown in the top panel of Fig. 3. Only the hourly average values (average of results from 7 scans each including both the beginning and end of the hour) are shown for convenience and for comparison of weather derived value of precipitable water vapour (lower panel) which is available at hourly intervals. The weather station data on surface temperature and relative humidity was used to derive the surface water vapour pressure which was then converted to precipitable water vapour (pwv) above the site assuming a scale height of 1.5 km for the vertical distribution of water vapour (cf., Butler 1998; Holdaway et al 1996b). The opacity was then estimated

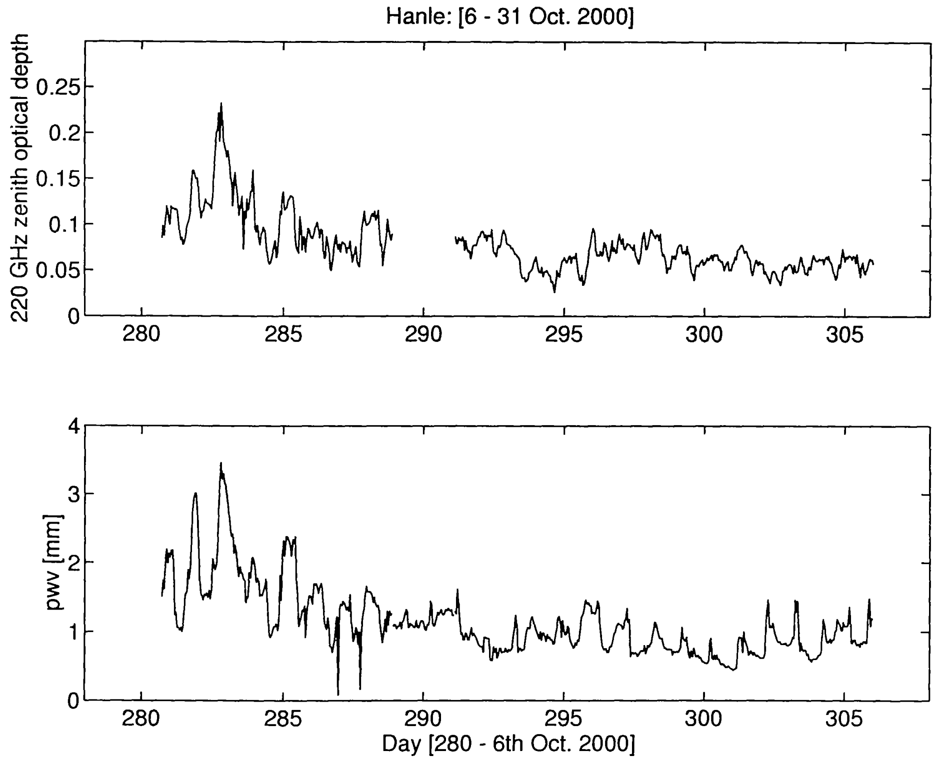

Figure 3. Hourly average values of 220 GHz opacities at Hanle for the month of October 2000 (top panel); the precipitable water vapour above the site estimated from weather station data is shown in the lower panel.

tentatively following the empirical relation (14) of Delgado et al. (1999) which was derived for Llano de Chajñantor site at 225 GHz. The relationship between the opacity at 220 GHz and pwv will be estimated for Hanle site in future when reliable data is available over a larger range of surface water vapour pressure. Fig. 3 shows that there is a good correlation between 220 GHz opacity and pwv which are compared more directly in Fig. 4.

Another important quality of a good site is the number of hours one can observe continuously. Fig. 5 shows diurnal variation of opacity for 5 consecutive days in October 2000. The variations over day and night are low and thus a sub-mm telescope can function 24 hours a day at the site.

The 220 GHz opacities at Hanle have quartiles of 0.060, 0.076 and 0.095 during the month of October 2000. The opacities are expected to decrease further during the months of November to March when the ambient temperatures decrease and the amount of water vapour the atmosphere can hold will reduce further. We show in Fig. 6 the quartiles of the distribution of opacities for the months of December 1999 to May 2000 together with October 2000. As mentioned before, the opacity values from December 1999 to May 2000 have large errors due to imperfect gain cancellation between the two scans in a 10 min run. While the early data is noisy, the quartiles of the opacity distributions over each

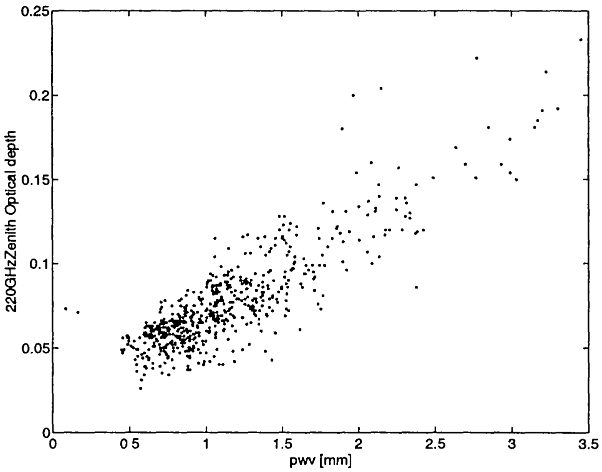

Figure 4. Correlation between 220 GHz opacity and weather-derived precipitable water vapour for data from 6–31 October 2000.

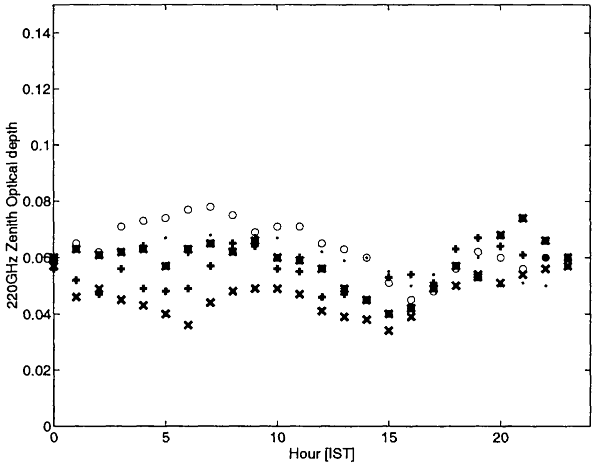

Figure 5. Diurnal variation of opacity for 5 days in October 2000: '.' – 26th,'o' – 27th, 'x' – 28th,'+' – 29th and '*' – 30th.

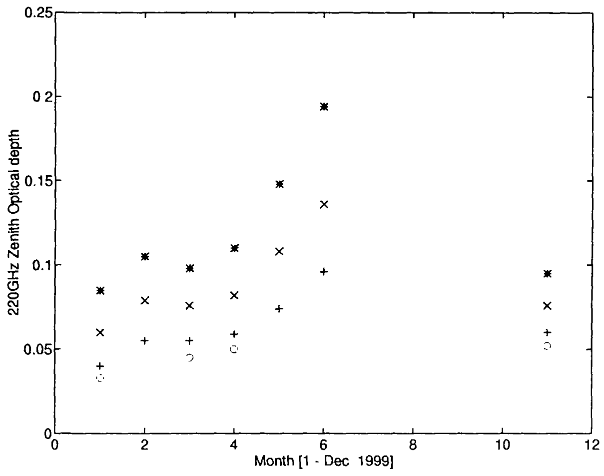

Figure 6. Monthly quartiles of opacity (error ±0.03): '+' – 0.25q, 'x' – 0.5q, '*' – 0.75q and 'o' – 0.5q expected from weather-derived pwv.

month appear reasonable. Thus, it appears that the opacities are below 0.10 for 75% of the time in the winter months October – March.

5. Conclusions

A 220 GHz tipping radiometer has been installed at Hanle, Changthang Ladakh, at 4500 m above msl. It has provided near-continuous data between December 1999 and May 2000. The quality of data has improved after a major overhaul of the system beginning October 2000. The data collected so far indicates that the opacity values are $\lesssim 0.10$ for over 75% of the time during the colder six months (October – March). Further data being accumulated will soon provide better estimates.

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