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OPACITY AT THE OWENS VALLEY MILLIMETER ARRAY

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ABSTRACT We have measured the opacity at the Owens Valley Millimeter Array with tip curves at frequencies from 95 to 248GHz. These measurements have been interpreted using a model and then scaled to a standard frequency of 100GHz. The unique aspect of this data is the wide range of frequencies covered and the use of receivers with different sideband gain ratios.

THE OBSERVATIONS

The OVRO Millimeter Array (Padin, Scott and Woody 1990) is located in the rain shadow of the Sierra Nevada mountains at an elevation of 1.2km. Average annual precipitation is 14cm. The interferometer is composed of three 10.4 meter telescopes equipped with SIS receivers. The receiver sidebands are separated by 2.9GHz and have independent gains that are a function of the receiver tuning.

Tip curves were obtained over 3 years as part of the regular observing sequence, usually once or twice per day. The frequency coverage was thus determined by the various molecular transitions of astronomical interest. The frequency coverage was broken into two bands; the 100GHz band extended from 95 to 115GHz while the 200GHz band extended from 220 to 248GHz. The changes between the 100GHz and 200GHz bands occurred once per observing season. Because the tips were done as a part of regular observing, data was not collected approximately 3% of the time when observing was suspended during the most severe weather conditions.

The resulting data set is comprised of 679 sets of tip curves beginning in October of 1987 through September of 1990. A tip sequence resulted in the recording of the received total power both on the sky and on an ambient temperature absorber as a function of elevation angle.

MODELS

In our frequency bands the clear sky opacity is caused almost entirely by water vapor and oxygen. The interpretation of the opacity measured from a tip curve requires a model based on the opacity contributions of oxygen and water vapor in the atmosphere above the telescope. From the models

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that have been proposed (Waters 1975, Liebe 1985 and Liebe 1989), we have used the more recent of the Liebe models with a 2km scale height for the water vapor. This model has given good agreement with tip curves at 20.6, 31.65 and 90GHz (Westwater, Snider and Falls 1990) and with ground level attenuation measurements at 337GHz (Galm, Merat and Claspy 1990), but has not been extensively tested over the frequency range of our data. While the interpretation of opacity in terms of precipitable water vapor is useful for local studies, using the model to convert the opacities to a standard frequency removes some of the model dependence and presents the quantity of interest for intersite comparisons. In particular, note that the model opacity is proportional to precipitable water vapor and pressure which introduces a site altitude dependence (Masson 1990). There is also a contribution that is proportional to precipitable water vapor squared that can be significant in comparison to the linear term.

DATA REDUCTION

The formalism used to reduce the observations to estimated opacities is based on standard treatments, but differs in its use of a full double sideband system. This introduces two new factors, the gain ratio of the two sidebands and the opacity difference between the two sidebands. The gain ratio is a function of receiver tuning and may be significantly different on the three telescopes. The gain ratios are measured astronomically by using all three baselines of the interferometer. Differences in opacity between the two sidebands are confined to observations near the strong oxygen line at 118.8GHz. We have used a simple model for the oxygen and temperature distributions with height and parameters for the oxygen transition measured by Read, Hillig, Cohen and Pickett (1988) to derive a model opacity difference for the two sidebands based on the local temperature and pressure.

The first step in the data analysis was to use the sideband ratios given with the data and the oxygen model opacity difference for the sidebands to obtain a least squares fit to the opacity at the center frequency of the sidebands under the assumption that the atmospheric temperature is equal to the ambient temperature. The second step was a correction for the fact that the atmospheric temperature is not equal to the ambient temperature. We used the Liebe model to estimate the atmospheric temperature as a function of water vapor opacity and then used this new temperature to again solve for the total opacity. Repeating this step we found that convergence was rapid, typically in 4 to 5 iterations, and that the correction can be as large as 20% for small opacities. The last step was to convert the estimated opacities to a standard frequency of 100GHz using the Liebe model to invert the estimated opacity to precipitable water vapor which was then used in the model at 100GHz.

The resulting set of derived opacities was then edited to remove data that were redundant or that were of poor quality. Redundant data, defined as data taken less than 8 hours apart with a frequency difference less than 0.1GHz, caused the removal of 237 points. Poor quality data, defined as data with opacity estimates with errors greater than 10% and greater than 0.01 nepers when scaled to 100GHz caused 17 more points to be removed. The

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remaining set is comprised of 425 points. The resulting scaled opacities for the two observing seasons with the most complete coverage are shown in Figure 1.

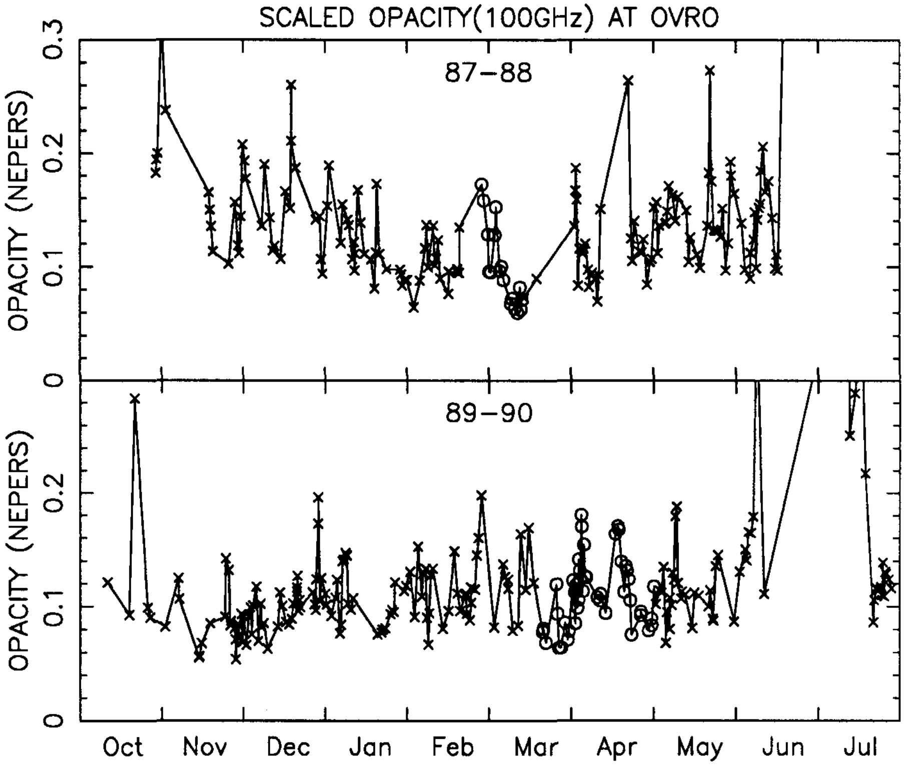

Fig. 1. Opacity scaled to equivalent opacity at 100GHz for two observing seasons. X is 100GHz band and O is 200GHz band data.

The formal error in the opacities from the tip curve fits was very small. We have estimated the errors from the model conversion by comparing measurements that are close in time but at frequencies differing by at least 0.2GHz. From this we inferred an opacity error of about 0.01 nepers in a single estimate scaled to 100GHz. There were two instances with measurements taken at frequencies more than 100GHz apart but very close in time. These differed in scaled opacities by less than 0.01 nepers, giving confidence in the model scaling between the bands. The opacity scale factor from 100GHz to 225GHz for average conditions at OVRO is approximately 4.3.

RESULTS

The scaled opacities show a seasonal variation, with the five month period from November through March having significantly lower opacity than the rest

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of the year. Figure 2 shows the cumulative distribution of the scaled opacity during the November through March period for all years. We see that 50% of the scaled opacities are less than 0.1 nepers. The data were also analyzed to look for day/night differences with the result that day/night differences (if any) are below the 10% level.

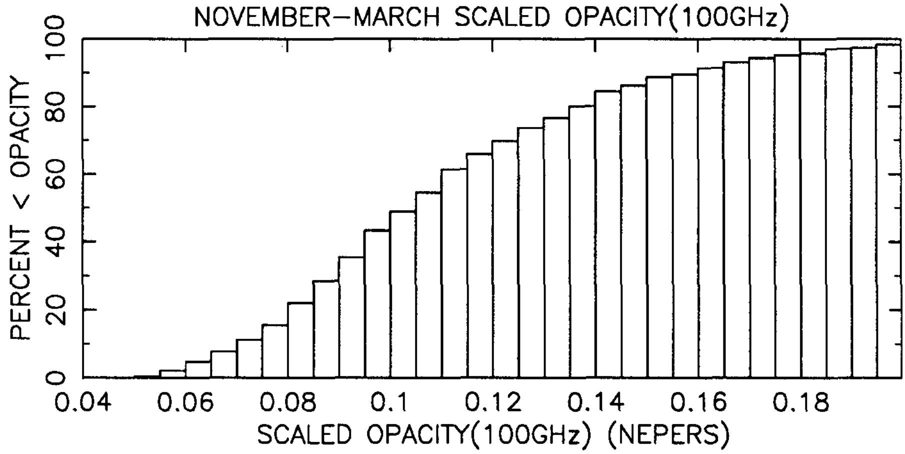

Fig. 2. Cumulative distribution for all measured opacities in November through March period, scaled to 100GHz.

SUMMARY

Tip curves at frequencies from 95 to 248GHz have been analyzed and the resulting opacities has been scaled to 100GHZ to provide a frequency invariant measure of the opacity. The scaled opacities have been used to derive seasonal and fractional distribution of opacity at the Owens Valley Millimeter Array.

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David Shaffer: Do you have any information on day/night variations or azimuthal variations?
Steve Scott: No.

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