Submillimeter Array Technical Memorandum

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Opacity on Mauna Kea

The 225 GHz radiometer on Mauna Kea has been running now for 3 years. The reliability improved after the first 6 months, and the data from the start of operation in August 1989 to the end of July 1992 are 85% complete. The results show similar overall opacities and diurnal effects to those seen before, but a strong seasonal effect is now evident. The weather during the first 6 months of the year is significantly better than during the second half. This is an important consideration for scheduling of submillimeter and far infrared observations.

Data Analysis

The opacity data were analyzed in a slightly different fashion from the previous studies (Technical Memos 48, and 49), although the results differ insignificantly from Technical Memo 49 as far as the overall opacity is concerned. After the data were retrieved from CSO, using Internet, they were edited using an algorithm based on suggestions by Frazer Owen at NRAO. The opacities derived from tipping scans are more accurate, but less reliable in bad weather than those derived from the zenith opacity. The editing proceeded in three steps: 1) If the zenith opacity was greater than 0.5, then it was used instead of the tipping scan. 2) If the opacity was less than 0.015, the point was rejected. 3) Finally a few points were removed manually. These are listed in Table 1, along with the reason for the editing. A further rejection of bad points occurs during the calculation of the median values, described below.

Table I Opacity Edits

Day number range	Date	Reason
232.000 - 232.149	Aug 1989	Initial setup
261.775 - 267.851	Sep 1989	Zenith and tip disagree; gaps in record
357.004 - 358.150	Dec 1989	gaps in record
365.999 - 366.007	Jan 1990	isolated bad value
383.848 - 419.000	Jan-Feb 1990	Radiometer problems; replaced
558.000 - 570.000	July 1990	Isolated points in long gap
758.000 - 759.000	Jan 1991	Duplicate day (in reconstructed datafile)
759.390 - 759.460	Jan 1991	couple of bad values
775.543 - 775.550	Feb 1991	one bad point

After editing, medians were calculated for 1.5 hour periods. This is long enough to ensure that there should be at least one data point in each period, despite the regular interruptions (every 5 hours) of tipping scans for fluctuation measurements lasting one hour. The use of medians also minimizes the effect of occasional discrepant points not removed by editing. After the processing, there were 14909 median values out of a possible 17521. All medians with opacities less than or equal to 0.025 were inspected and edited individually, to ensure that the overall minimum value is accurate.

Results

Figure 1 shows a histogram of the distribution of measurement times, which run from day number 232 in August 1989 to day number 1308 in July 1992 (day 212 of 1992). The radiometer was replaced after the first six months with a more reliable unit. The overall coverage for the three year period was 85%. Some of the missing points are associated with bad weather, but at other times the radiometer was down during good weather. Since the overall coverage was so high, any correlation between weather and missing data can cause only a small bias. Hogg (1992) has reported results from the NRAO analysis of part of this dataset. Despite slight differences in the

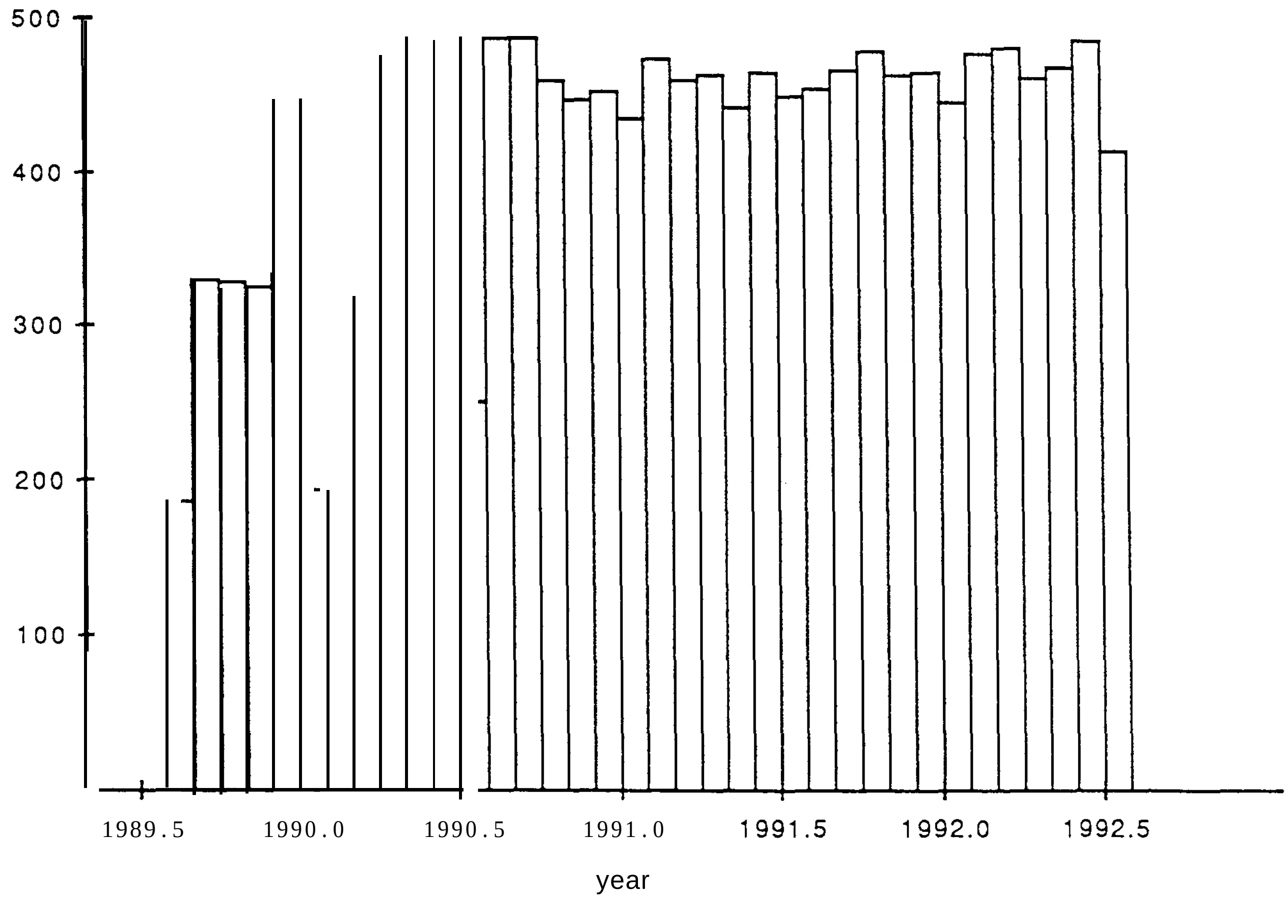

Figure 1 Histogram of time stamps for the 14909 median values measured on Mauna Kea. The first radiometer was not very reliable during the first few months and was replaced after February, 1990.

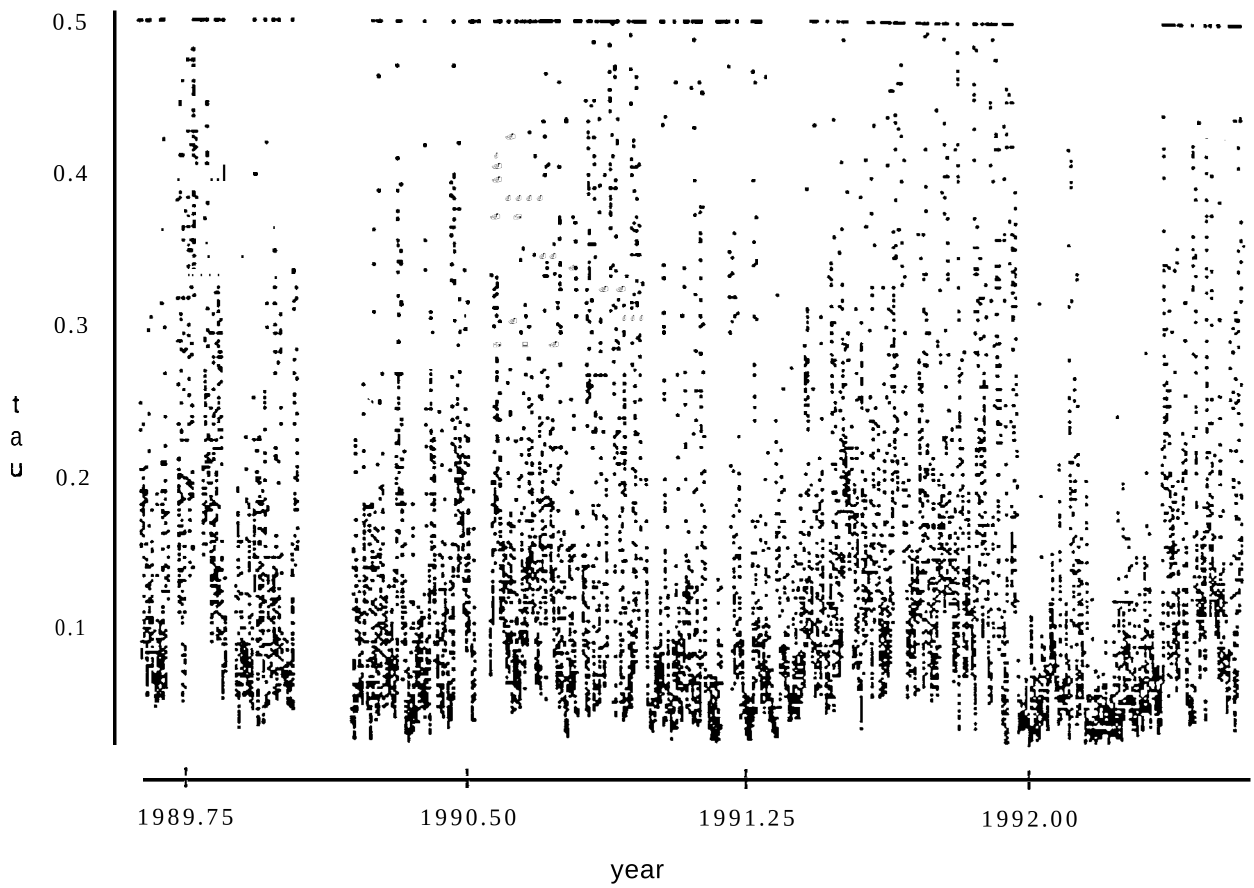

Figure 2 Distribution of all measured median opacities on Mauna Kea over the 3-year period. The values are truncated at 0.5.

editing, the NFL40 results are in good agreement with those presented here.

Figure 2 is a plot of all the 14909 measured median opacities, plotted against date. The values have been truncated at an opacity of 0.5. The gap in January 1990 occurred when the radiometer broke and was replaced. There is an indication of a seasonal effect, with the second half of the year being worse than the first, in each of the three years plotted. The seasonal variation is also evident in the quarterly graphs presented by Hogg (1992).

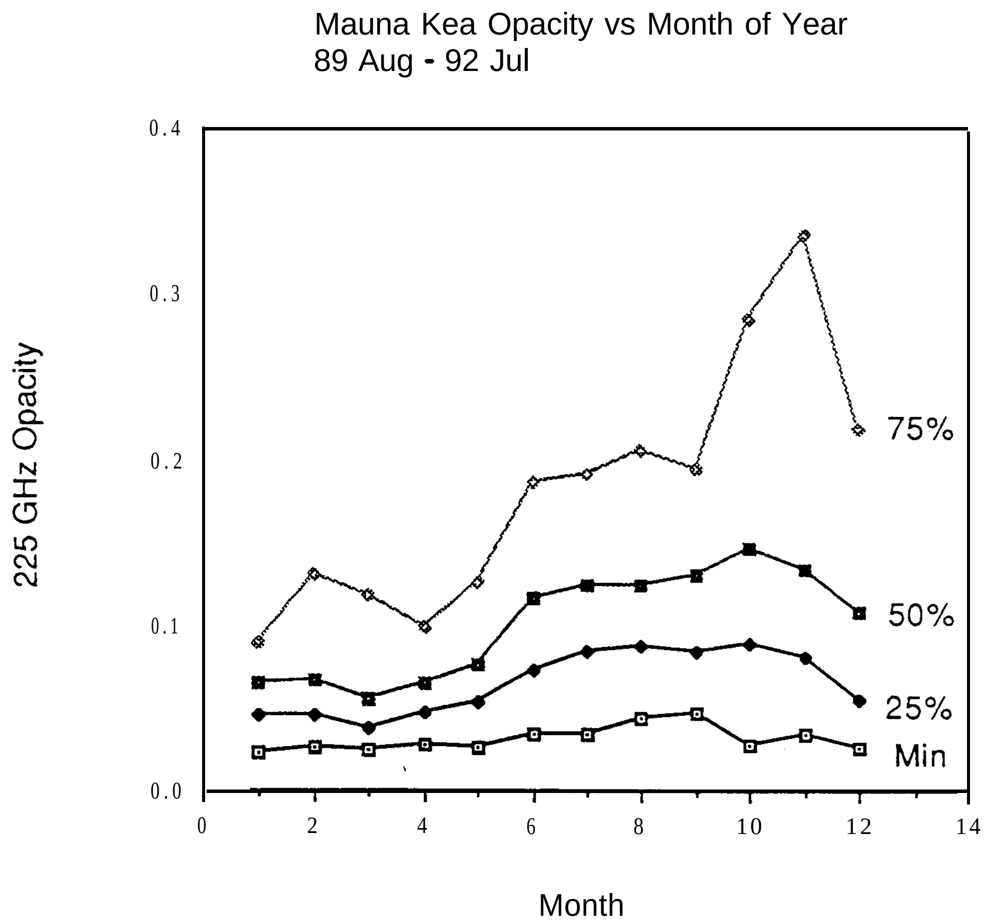

Figure 3 Mauna Kea Opacity plotted versus month of year.

This seasonal effect is shown more clearly in figure 3, where the quartile opacities have been plotted for each month of the year, along with the minimum observed opacity. There is a strong correlation of opacity with season, with the first 6 months of the year showing median opacities approximately half those in the second half. It is interesting to ask whether this correlates with other measured quantities on Mauna Kea The NOAO site survey showed a small seasonal effect in the measured infrared opacities, but the strongest correlation is with the ambient temperature, which is significantly lower during the first half of the year. Although it may be argued that the seasonal effect seen in these data is an anomaly, it is clearly present in each of the three years measured, and the seasonal temperature variation is present in long-term records. Therefore it is almost certain that the seasonal variation is generally present on Mauna Kea, although the strength may well vary from year to year (1992 had a very good spring, for example).

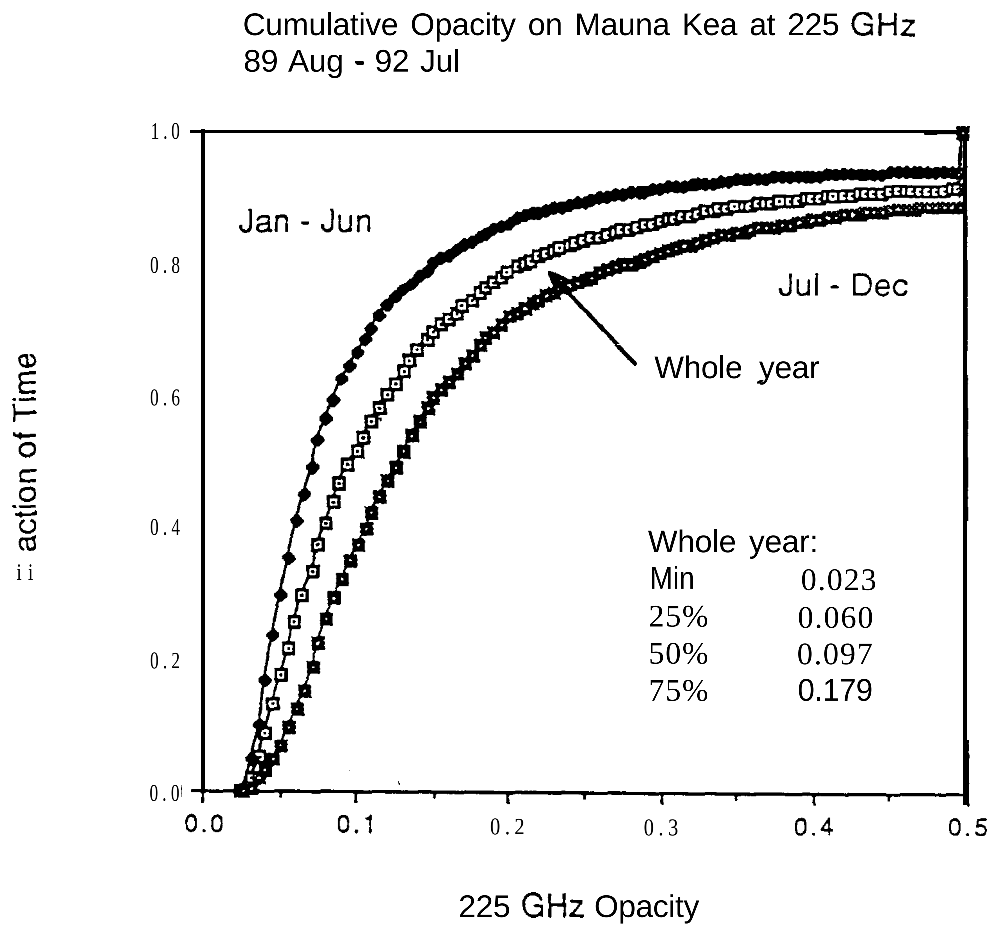

Figure 4 Cumulative distribution of opacity on Mauna Kea, for the whole year, and for the first and second halves separately.

Figure 4 shows the cumulative distribution of measured opacities, both for the whole year and for the two halves. The overall median opacity is 0.097, with quartiles of 0.060 and 0.179. The minimum recorded value was 0.023, and 17% of the points had an opacity less than or equal to 0.05. These statistics apply to the whole dataset, covering 24 hours per day. This figure shows that the probability of low opacity (< 0.05) for a submillimeter observation scheduled in the first half of the year is more than 4 times as great as for one scheduled in the second half.

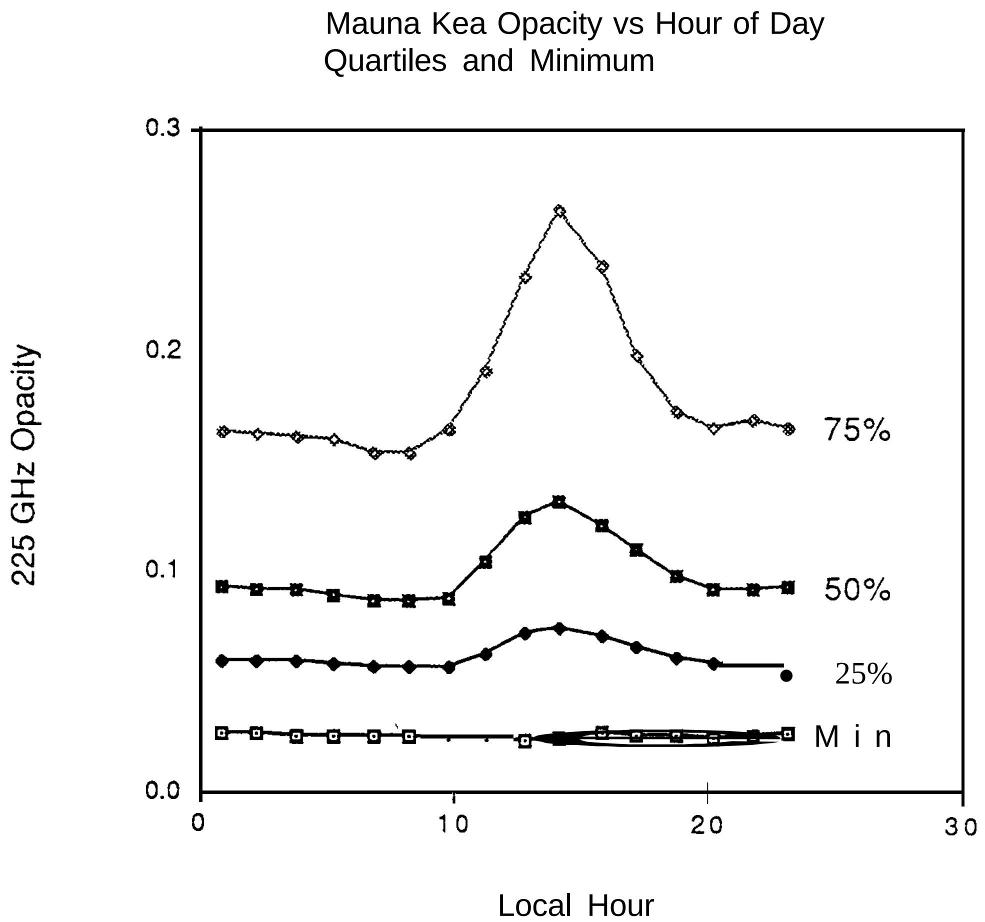

Figure 5 Diurnal variation of opacity on Mauna Kea.

The well-known diurnal effect is shown in figure 5, where the opacity quartiles are plotted against hour of the day. The opacity is better during the night than during the day. However the mornings are still reasonably good until 10 am, and the night-time opacity is not reached until 8 pm, well after sunset. To make best use of the weather, submillimeter telescopes should usually start after sunset, but they should continue in the mornings until well after sunrise. The diurnal effect becomes more pronounced at higher quartiles, and there is almost no effect in the mimimum opacity. This indicates that, when the weather is excellent, there is very little diurnal variation, and observations are possible around the clock.

Discussion

The relation between opacities at high frequency windows and that at *225* GHz has been discussed in Technical Memo 12. Briefly, the precipitable water vapor, PWV, is given roughly by

$$PWV\ (mm) = (\tau_{225} - 0.01) / 0.04,$$

where the offset of 0.01 is due to oxygen opacity. The opacity in the windows at 490, 690, and 820 GHz, is given very roughly by

$$\tau_{490} = \tau_{690} = \tau_{820} = 20 * (\tau_{225} - 0.01).$$

Thus the critical value for high frequency observing is a 225 GHz opacity of 0.05, corresponding to 1 mm of PWV. The very best observed opacity, 0.023, corresponds to about 1/3 mm PWV.

The seasonal effect is very important for telescope scheduling. It is not so important for the SMA, which will use dynamic allocation of time, but for telescopes such as CSO and JCMT, the observing efficiency could be doubled by scheduling critical observations only during the good part of the year. Even for the SMA, the conditions during the first part of the year will probably favor the use of long baselines, and should be taken into account in planning the movement between configurations. The choice of the best strategy will have to await the final analysis of the phase monitor results.

Acknowledgements

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