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Atmospheric phase conditions for the Hat Creek 1997-98 observing season

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ABSTRACT

This memo analyzes data collected at Hat Creek on the atmospheric phase conditions during the 1997-98 observing season. The data come from observations of quasars during normal observing and from the dedicated phase monitor. Percentiles of rms phase are calculated as a function of time of year and time of day. The length of time over which the phase remains below a given threshold is measured and discussed with regards to dynamic scheduling. The effect of phase noise on observations in different arrays is briefly discussed.

1. Atmospheric phase measurements

Fluctuations in atmospheric water vapor cause variations in the phase measured by an interferometer. On long baselines, such as in the A array at Hat Creek, this phase noise is generally the limiting factor on the seeing. Real-time measurement of the rms phase can be used in making scheduling decisions, particularly when choosing between the 1 and 3mm bands. In this memo, I analyze the data taken during the 1997-98 observing season at Hat Creek.

There are 2 sets of data on the atmospheric phase rms for Hat Creek. Since October 1997, M. Wright has been running a program called *atmos* which analyzes array observations for quasars above a give signal-to-noise limit. These data are analyzed to calculate the rms phase as a function of baseline, then fit with a power law slope. The rms path at 100 m scaled to the zenith is recorded, along with several other quantities.

The second set of data come from the dedicated phase monitor (Lay 1998). This instrument measures the rms phase at 12 GHz on a 100 m baseline by monitoring signals from a digital TV satellite at an elevation of $\sim 45°$. The phase monitor data record begins in April 1998 and records a value for the rms phase every 10 minutes. The values for the last 3 days can be displayed by running the program *pmn* on the hat or bima2 machines.

Data from the two measurements were compared by scaling the quasar data to an elevation of 45°. The quasar data were also filtered to include only points with power law slopes consistent with values previously measured for the array and as expected from theory (see Wright 1996). Figure 1 shows a time series of rms path variation in microns for both the phase monitor (dots) and the array data (closed squares). With a few exceptions, the phase monitor is a very good predictor of the array phase, as expected. As the rms phase scales linearly with frequency, I will use the rms path in microns for the following plots and calculations. For reference, 1 radian of phase at 100 GHz is equal to 950 μm and 1 radian at 230 GHz is equal to 415 μm.

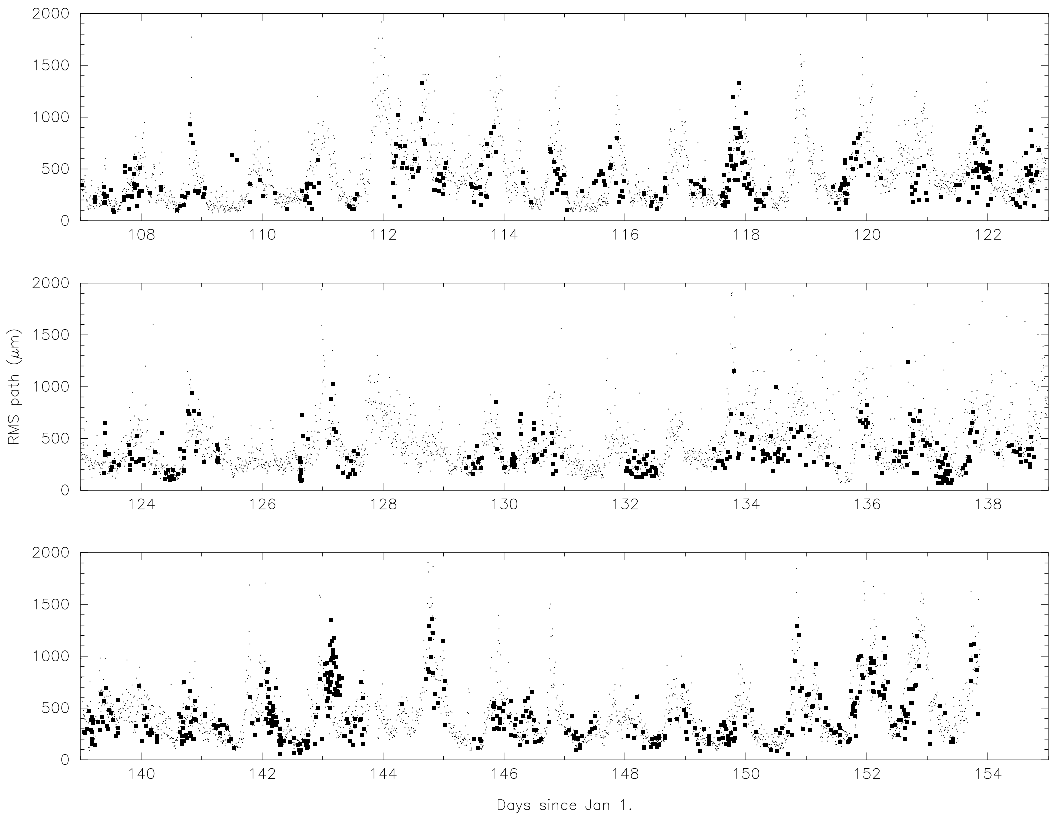

Fig. 1.— Comparison of the rms path as measured by the phase monitor at 12 GHz (dots) and by the array (filled squares) for the months of April and May 1998.

2. Phase percentiles

2.1. Seasonal variations

To calculate the percentage of observing time with good phase stability, the quasar data were divided by month for the 1997-98 observing season, beginning in October. The rms path in microns was scaled to an elevation of 45°. The percentage of time below a given rms path are shown in Figure 2. As the quasar data are only recorded when the array is observing, weather sufficiently bad to stop the observing is *not* included in these statistics. Using the schedule files for each array, I estimated that out of 187 observing days covered by the data used (Oct 9 to Jun 1), 9 days had weather too bad to observe. Also plotted is the coherence at λ=3mm for a 100m baseline as a function of rms path. On baselines much shorter than the scale height of the

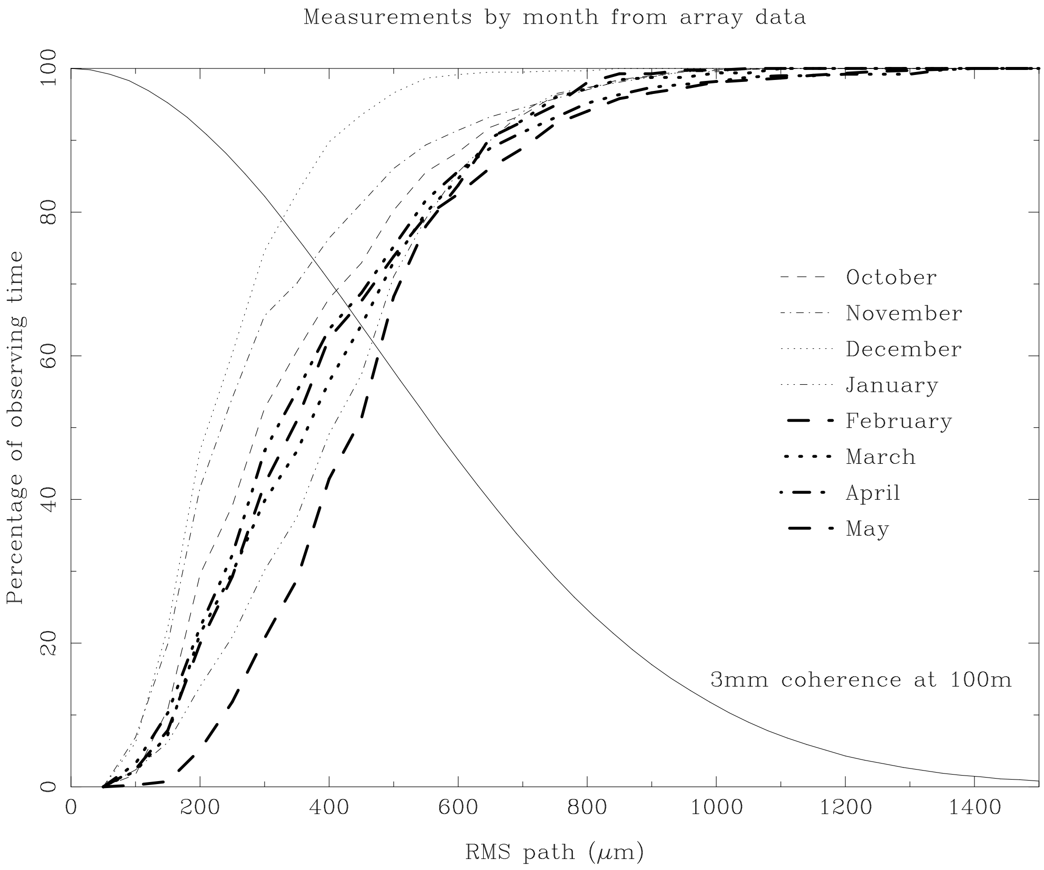

Fig. 2.— Percentiles of rms path divided by month from the atmos data. Also plotted is the coherence as a function of rms path for a 100m baseline at 100 GHz.

turbulence, the phase should scale as baseline$^{5/6}$, while on baselines longer than the scale height, the phase should scale as baseline$^{1/3}$. At Hat Creek, the scale height of the turbulence has been estimated at 100–500m (Wright 1996, Lay 1998).

For the 1997-98 observing season, the best phase stability was in December, followed by November and October. In December, 28% of the time used for observing had phase stability below 200 μm rms path (which corresponds to 65% coherence at 1mm on a 100m baseline), while in January, which was severely impacted by winter storms, only 7% of the time was below 200 μm rms path. A comparison of the seasonal rms path quartiles is given in Table 1. To avoid possible rms path differences due to different baseline coverage, only data from the C array is compared. Observations in the C array were obtained in late Nov/early Dec and in April/May.

	C array Nov/Dec			C array Apr/May		
Quartile	rms (μm)	3mm coh	1mm coh	rms (μm)	3mm coh	1mm coh
25	160	99	60	230	89	35
50	225	89	36	330	79	12
75	335	76	10	510	57	2

Table 1: Phase quartiles for winter vs. spring during C array from rms measurements taken from quasar data. The coherence values given are for a 100m baseline.

2.2. Diurnal variations

To examine the diurnal variation in the rms path, I used the phase monitor data from April and May, as these data provide a complete, unbiased record of the phase. Figure 3 shows the rms path percentiles for day (6am – 6pm) vs night (6pm – 6am). The coherence on a 100 m baseline is also plotted for both 100 and 230 GHz. Table 2 lists the rms path quartiles divided into day and night. The path rms quartiles for April/May for the quasar data (Table 1) are somewhat better than the average of day and night for the phase monitor data (Table 2) because the quasar data do not include the worst weather days.

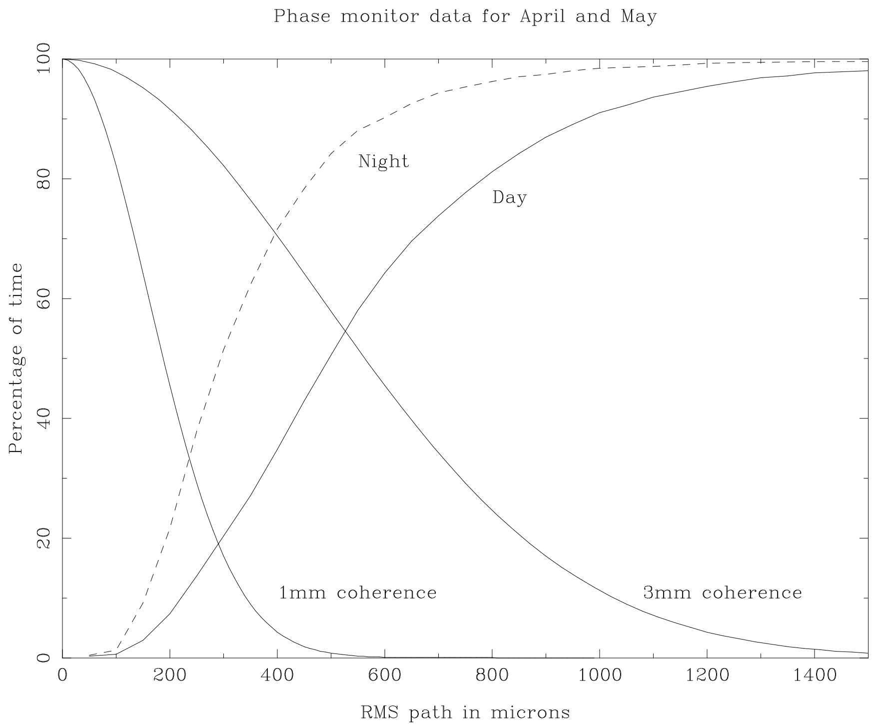

Fig. 3.— Percentiles of rms path as measured by the phase monitor divided into day and night. Also plotted is the coherence as a function of rms path for a 100m baseline at 100 GHz and 230 GHz.

	Day			Night		
Quartile	rms (μm)	3mm coh	1mm coh	rms (μm)	3mm coh	1mm coh
25	340	78	10	210	91	42
50	500	58	1	295	83	19
75	720	32	0	425	68	3

Table 2: Phase quartiles for day vs. night during the spring taken from phase monitor data.

3. Interval lengths

One important aspect of the phase stability is how long the phase remains below a given level. If the intervals of good phase stability are generally long, then projects can be scheduled after the phase decreases with a reasonable chance of several hours of good observing. However, if these intervals are generally less than the length of an average project, dynamic scheduling on shorter time scales is necessary to utilize the available good weather.

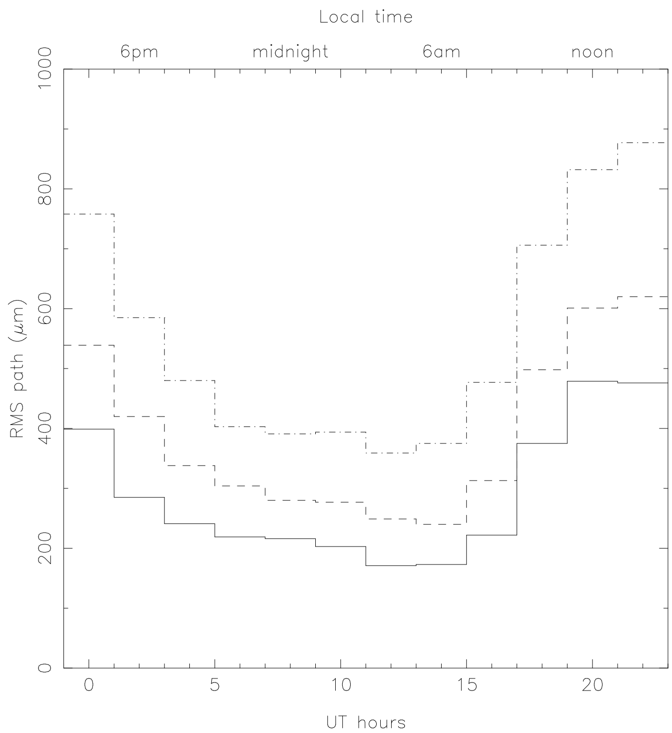

Fig. 4.— RMS path quartiles from the phase monitor data as a function of UT. The 25% (solid), 50% (dash) and 75% (dot-dash) quartiles are shown.

Figure 4 shows the rms path as a function of UT for the phase monitor data. The three lines are for the 25% (solid), 50% (dash), and 75% (dot-dash) phase quartiles. On average, the atmosphere phase noise slowly decreases starting at 6pm, reaches a minimum near 2–4am and increases rapidly after 8am. Close examination of Figure 1 shows that the rms path profile can vary greatly from day to day, with some nights having several hours of low rms path (ex. Day 109–110), while on other nights, the phase never improves (ex. Day 128–129).

Both the quasar data and the phase monitor data were examined to quantify the intervals of good phase stability. The quasar data were filtered as described above. The interval lengths were calculated for different smoothing times for a path rms of 200 μm. Smoothing intervals of 1, 2, 4, and 8 hours were tried. The results for the 4 and 8 hour intervals are averages of several runs when the intervals were set to start at different times of the day.

For the phase monitor data, which has complete time coverage for two months (April and May), the total time below the threshold (200 μm) decreases for longer smoothing times and the number of intervals of a given length also decreases (Table 3). For example, when using a 2 hour interval, there were 4 periods of 6–8 hours of good weather. However, when smoothing over 4 hours, only one 6–8 hour interval was found. And when using 8 hour intervals, equivalent to checking the phase only after each track finishes, only 32 hours of good weather would be used, out of a total of 119 hours when the rms path was below 200 μm. This suggests that the weather should be checked at least every 2 hours to effectively utilize the periods of stable phase. Also, the last 1–2 hours of phase data should be averaged to avoid periods of good phase which only last for one or two 10 minute samples.

			# of intervals with length in hours					
t_{smth}	phase limit	total hrs	0-2	2-4	4-6	6-8	8-10	>10
1	200	119	25	15	4	4	1	0
2	200	104	7	7	5	4	1	1
4	200	86	–	4	6	1	1	2
8	200	32	–	–	–	2	1	1

Table 3: Intervals for phase monitor data. The total time range covered by the data is 47 days or 1126 hours.

The quasar data contain many gaps in the time coverage. Times with no measurements are considered to have phase above the threshold. The data are intially binned into 1 hour slots, then the intervals were measured using the same smoothing time as for the phase monitor data. Because of the uneven time coverage the total number of hours below the threshold path rms is a lower limit for smoothing times of 4 or 8 hours. However, shorter time intervals are still much more efficient at utilizing the long periods of good phase stability (Table 4).

			# of intervals with length in hours					
t_{smth}	phase limit	total hrs	0–2	2–4	4–6	6–8	8–10	> 10
1	200	465	167	58	5	9	4	1
2	200	300	20	48	9	8	4	2
4	200	172	–	16	9	3	5	1
8	200	40	–	–	–	3	2	0

Table 4: Intervals for array data. There are 1776 total hours of data out of 5871 total hours in the time span covered.

4. Effect on observing

Atmospheric phase fluctuations on timescales of twice the calibration cycle time are removed from the data by the normal calibration procedure. However, phase fluctuations on shorter time scales remain, as well as phase errors introduced by imperfect measurement of the slower fluctuations (Lay 1996). For weak sources which can not be self-calibrated, these phase errors will cause flux in the image to be scattered away from the true position of the source, decreasing the amplitude and increasing the apparent size. To quantify this effect for a few cases, I used a model atmosphere from Lay (1996b) with a scale height of 500 m and a wind speed of 5 m/s. Using the rms on a 100m baseline as the reference value, I scaled the phase power in the fluctuations for each baseline, corrected for phase power removed by the gain calibration, and then calculated the rms phase for that baseline from the remaining phase power. These rms phases were added to a 1 Jy point source, which was then imaged (Table 5). The size was measured by fitting an elliptical Gaussian to the image. In the A array at λ=3mm, an rms phase of 200 μm on a 100m baseline results in a 17% loss in amplitude and a 25% increase in the apparent size, while a 400 μm rms path results in a 44% loss in amplitude and a source size of two times the beam. These results emphasize the need for A array observers to use a second, nearby calibration source to test the quality of the calibration. In the C array, an rms path of 800μm only causes a 5% loss in amplitude and a 10% increase in source size at λ=3mm.

5. Conclusions

- Measurements of the rms path variations in the atmosphere as measured with the 12 GHz phase monitor agree well with values calculated from array observations of quasars.

- During the 1997-98 observing season, the best phase stability occurred during the months of October–December. In December, 28% of the observing time had an rms path below 200 μm (which corresponds to 65% coherence at 1mm on a 100m baseline). In January, which was affected by many winter storms, this percentage dropped to 7%.

A array	Path rms on 100m (μm)	0	200	300	400
	Peak flux (Jy/bm)	1.0	0.33	0.14	0.09
	Total flux (Jy)	1.0	0.83	0.73	0.56
	Size (arcsec)	0.53×0.32	0.72×0.58	1.07×0.76	1.17×0.92
C array	**Path rms on 100m (μm)**	**0**	**200**	**400**	**800**
	Peak flux (Jy/bm)	1.0	0.99	0.94	0.79
	Total flux (Jy)	1.0	1.0	0.99	0.95
	Size (arcsec)	7.7×7.1	7.9×7.2	8.0×7.3	8.5×7.9

Table 5: Effect of residual phase rms on different array. A calibration cycle time of 4 minutes was used for the A array and a time of 25 minutes was used for the C array.

- The quasar data and the phase monitor data were analyzed to determine how often to check the phase conditions during dynamic scheduling to best utilize the available good weather. Using a 2 hour interval, the majority of the stable phase conditions are utilized, while using 8 hour intervals would miss most of the good weather.
- Observations in the A array are extremely sensitive to phase noise; even an rms of 200 μm results in a smearing of the source size by 25%. This emphasizes the need to use a second, nearby calibrator as a check.

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