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ATMOSPHERIC PHASE PREDICTION FROM TOTAL POWER MEASUREMENTS

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ABSTRACT

We have analysed data obtained with the Hat Creek 9-antenna array with antenna spacings between 80 and 1045m. In clear weather we find a correlation between the atmospheric phase fluctuations and the total power measurements. This memo provides a recipe for correcting the phase, and an analysis of some recent data.

1. Introduction

At millimeter wavelengths both atmospheric emission, and pathlength variations are dominated by water vapor. Since the real and imaginary parts of the water vapor refractivity are related through the Kramers-Kronig relation, we might be able to correct for the atmospheric path length variations by measuring the atmospheric brightness fluctuations in the direction of the radio source. At an observing frequency away from the water lines, the emission from atmospheric water vapor is optically thin. In clear weather, assuming that all the water is in the form of water vapour, a measurement of the brightness temperature fluctuations gives a direct measurement of the integral, or column density, of water vapor in the direction of the radio source. The corresponding path length variation is about 1.6mm/K at 100 GHz, and 0.3mm/K at 250 GHz (Welch, 1994). Although the same receiver can be used for both observations and water vapor measurements, the brightness temperature of the atmosphere must be measured to an accuracy of 0.01 K in order to measure 2 degrees of atmospheric phase shift at 100 GHz. For a typical (current) system temperature of 200 K, and a bandwidth of 1 GHz, the thermal noise allows this accuracy in an integration time 0.2 s, i.e. fast enough to follow the atmospheric fluctuations. However, the gain stability needed, 10^{-4}, requires careful attention to the thermal and mechanical stability of the receiver components, and the total powers on each antenna must be accurately calibrated .

2. A Recipe for Atmospheric Phase Correction

1) If the weather was clear during the observations, then look for a correlation between phase and total power on the calibrator. Choose a stable reference antenna, and look at plots of phase versus tpower, both relative to the same reference antenna.

```
selfcal vis=$cal line=wide,1 interval=.2 refant=2
varfit  vis=$cal device=/xs xaxis=tpower yaxis=phase options=wrap
```

Most likely the slopes and correlation coefficients printed by **varfit** are dominated by instrumental drifts, but look at the correlation plots. Atmospheric phase variation with tpower appears as stripes with a gradient around -280 degrees/Kelvin.

2) If you see some correlation, then correct the calibrator using the measured total power difference. Then compare the corrected and uncorrected phase fluctuations.

```
tpgains vis=$cal refant=2 tgain=-280.
uvplt   vis=$cal device=/xs axis=time,phase line=wide,1
uvplt   vis=$cal device=/xs axis=time,phase line=wide,1 options=nocal
```

3) If the phase coherence is improved, then correct the calibrator and source data and proceed with the corrected data.

```
uvcal   vis=$cal out=$cal.tpcal
tpgains vis=$source refant=2 tgain=-280.
uvcal   vis=$source out=$source.tpcal
```

3. Analysis and Discussion

In this memo we analyse data obtained on 14 march 1996 in clear weather. First we inspect the total power versus time and pick a stable reference antenna. Figure 1 shows the phase plotted versus the total power differences w.r.t. antenna 9. A good correlation is evident for antenna 3 and similar gradients around -280 degrees/Kelvin can be seen for antennas 1 4 5 6 and 7. Antenna 8 appears quite discrepant. The correlation coeficients, slopes, and rms phase, printed by **varfit** confirm this.

Figure 2 and 3 show the phase plotted versus time before and after correcting the phase for total power fluctuations using a slope -280 degrees/Kelvin. The fluctuations are reduced on all antennas except for antenna 2 and 8. In order to compare the rms phase, we used **varfit** to fit a phase slope versus time. The rms phase before and after the total power correction is listed in Table 1 (rms1 and rms2). The rms phase fluctuations are reduced by a factor between 0.5 and 0.8, except for antennas 2 and 8 where the rms phase is increased.

There are several possible reasons why the correlation between phase and total power is not better. Instrumental phase or total power fluctuations or calibration can spoil the correlation. The total power correction for antenna 8 is clearly wrong. One possibility is that the total power calibration into Kelvin units is wrong. We can fit the overall variation of total power to be the same on all antennas, and adjust the calibration scale. **varfit** provides a convenient way to make a quadratic fit. The fitted scale factor, listed in Table 1, is within a few percent, for all except antenna 8, where the total power calibration is evidently wrong by a factor 1.7. The quadratic coeficients are all very small. The fitted coeficients are written into the log file which can be edited and used in **tpgains** to correct the Tsys calibration of the total powers.

```
varfit vis=3c111.14mar96 xaxis=tpower yaxis=tpower refant2=9 options=quad log=tpfile
tpgains vis=3c111.14mar96 tgain=-280 tsys=@tpfile
```

Using the re-calibrated total powers to correct the phase results in an improved rms phase for antenna 8 (Table 1 - rms3). Correction of the phase for variations in the cable lengths on time scales of 0.5 – 5 min. results in a modest improvement in the correlation with total power and a slight reduction in the rms phase after correcting for both cable length and total power fluctuations (Table 1 - rms4).

The correlation between phase and total power fluctuations varies greatly with atmospheric conditions. Liquid water droplets in clouds emit strongly, but cause little path length change so the weather must be clear for a total power calibration to succeed. If the water vapour is close to saturation the transition of vapour into liquid water may be important. Aggregates of water vapor, dimers, and polymers up to $n = 10^6$ may cause variations in absorption up to $50 percent$ (Gebbie, 1980). Since the slope (degrees/Kelvin) varies with the height of the water vapor, multiple layers of turbulence at different altitudes will reduce the correlation between path length (phase) and emission. In particular, water vapor close to the ground, and close to the inversion layer may account for most of the turbulence. The time scale of the fluctuations may also vary with the height of the turbulence.

The phase structure function (PSF), $D\phi(T)$, is often used to measure the phase fluctuations as a function of the time interval between samples, T.

$$D\phi(T) = < (\phi(t) - \phi(t+T))^2 > \tag{1}$$

Figures 4 and 5 show the PSF before and after correcting for total power fluctuations. The best reduction of phase fluctuations occurs on time scales of 30 – 200 seconds. At shorter or longer times the total powers do not correlate so well with the phase fluctuations. Fast total power variations may be dominated by phase transitions in the water, or by fluctuations in the dry component of the atmosphere. Instrumental drifts may reduce the correlation over longer time intervals.

4. CONCLUSIONS

Atmospheric phase correction using the measured total power at each antenna can reduce the phase fluctuations in clear weather.

The correlation between the phase and total power fluctuation varies considerably with atmospheric conditions. The technique can not be used in cloudy weather, and multiple turbulent layers at different heights may spoil the correlation.

Good gain stability and accurate calibration of the total powers is required, and the correction must be applied with care.

REFERENCES

Welch, W.J., 1994. Astronomy with Millimeter and Submillimeter Wave interferometry, M.Ishiguro and Wm.J.Welch (eds), ASP conference series 59, 1

Gebbie,H.A., 1980, in Atmospheric water vapor, A.Deepak, T.D.Wilkerson, and L.H.Ruhnke (eds), Academic Press, New York. p. 133.

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Table 1: Rms phase (degrees) versus physical baseline

ant	rms1	rms2	scale	rms3	rms4
1	74	34	1.007	34	33
2	33	50	1.013	51	42
3	102	47	0.938	48	41
4	111	90	0.991	89	87
5	90	56	0.964	55	52
6	93	67	1.051	69	67
7	108	72	1.066	70	63
8	131	255	1.702	130	129

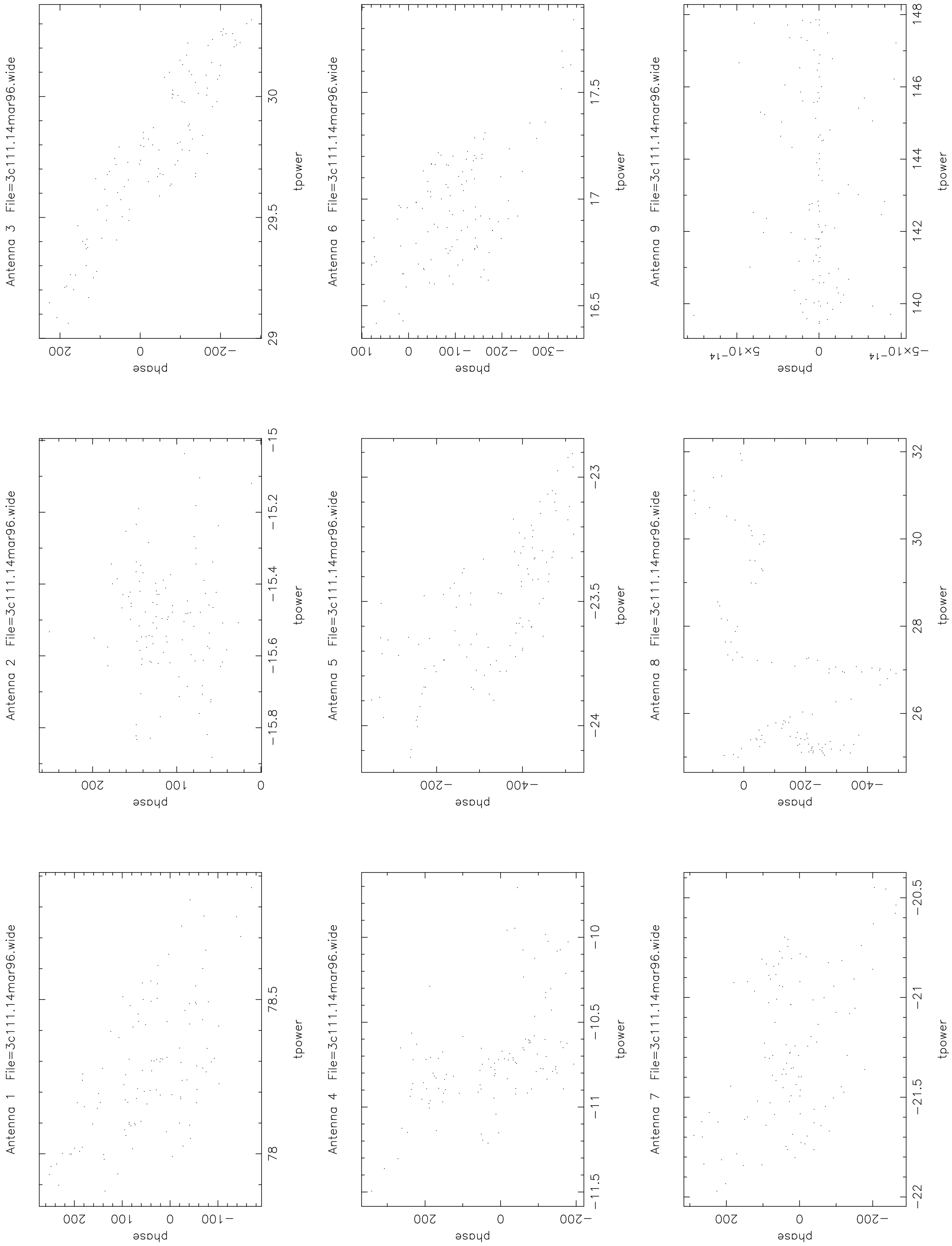

Fig. 1.— phase versus total power

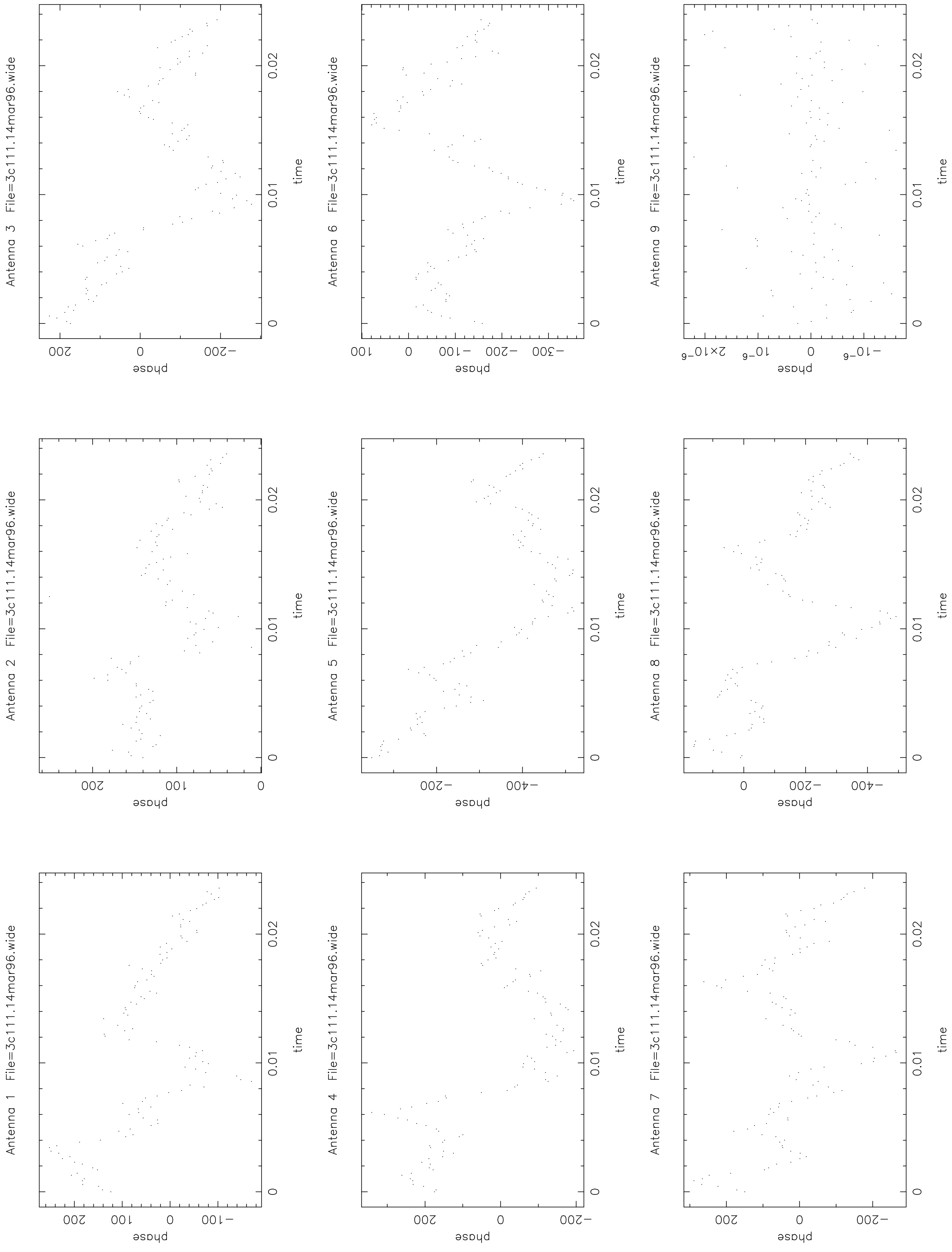

Fig. 2.— measured phase versus time

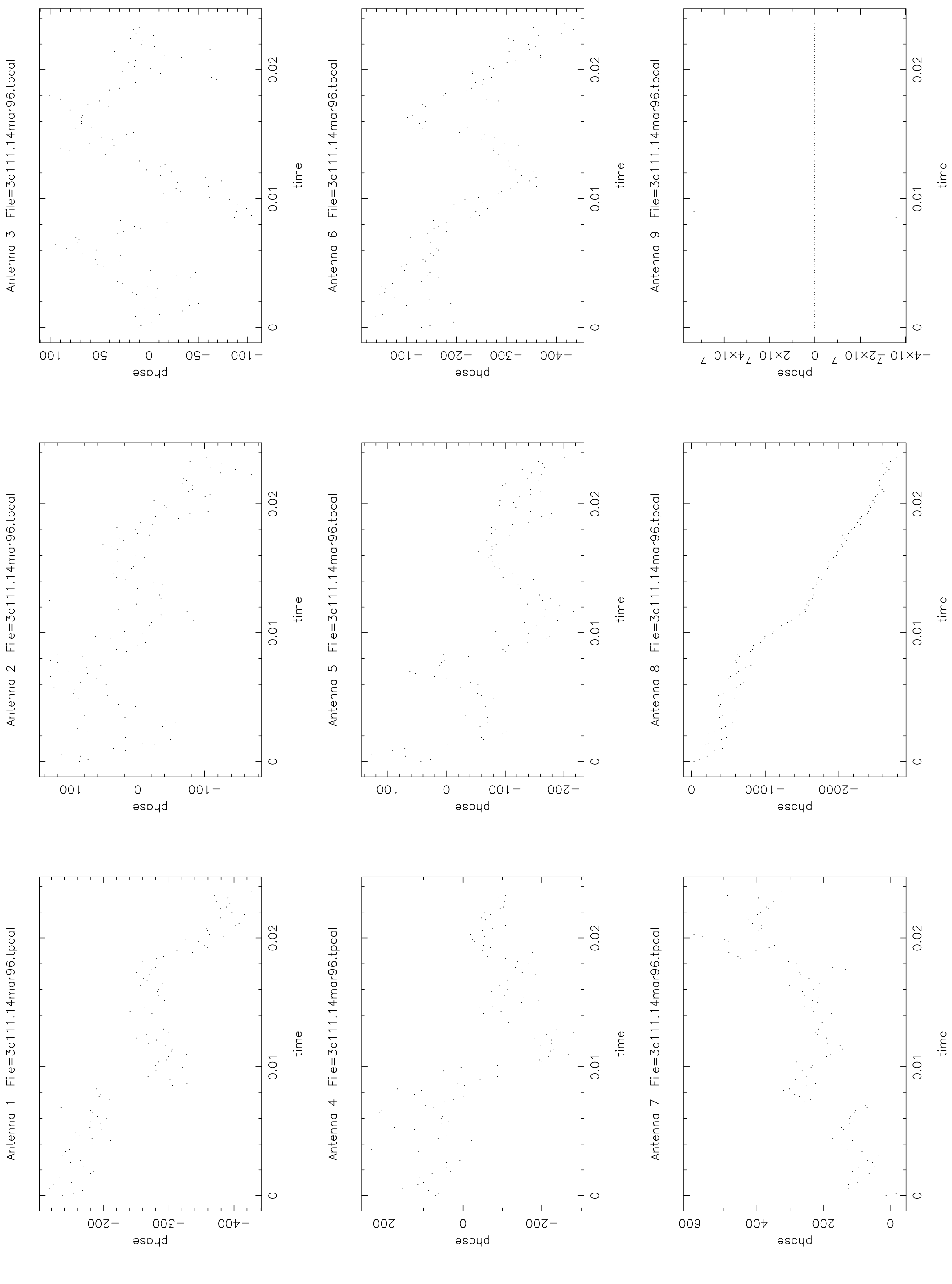

Fig. 3.— phase after total power correction

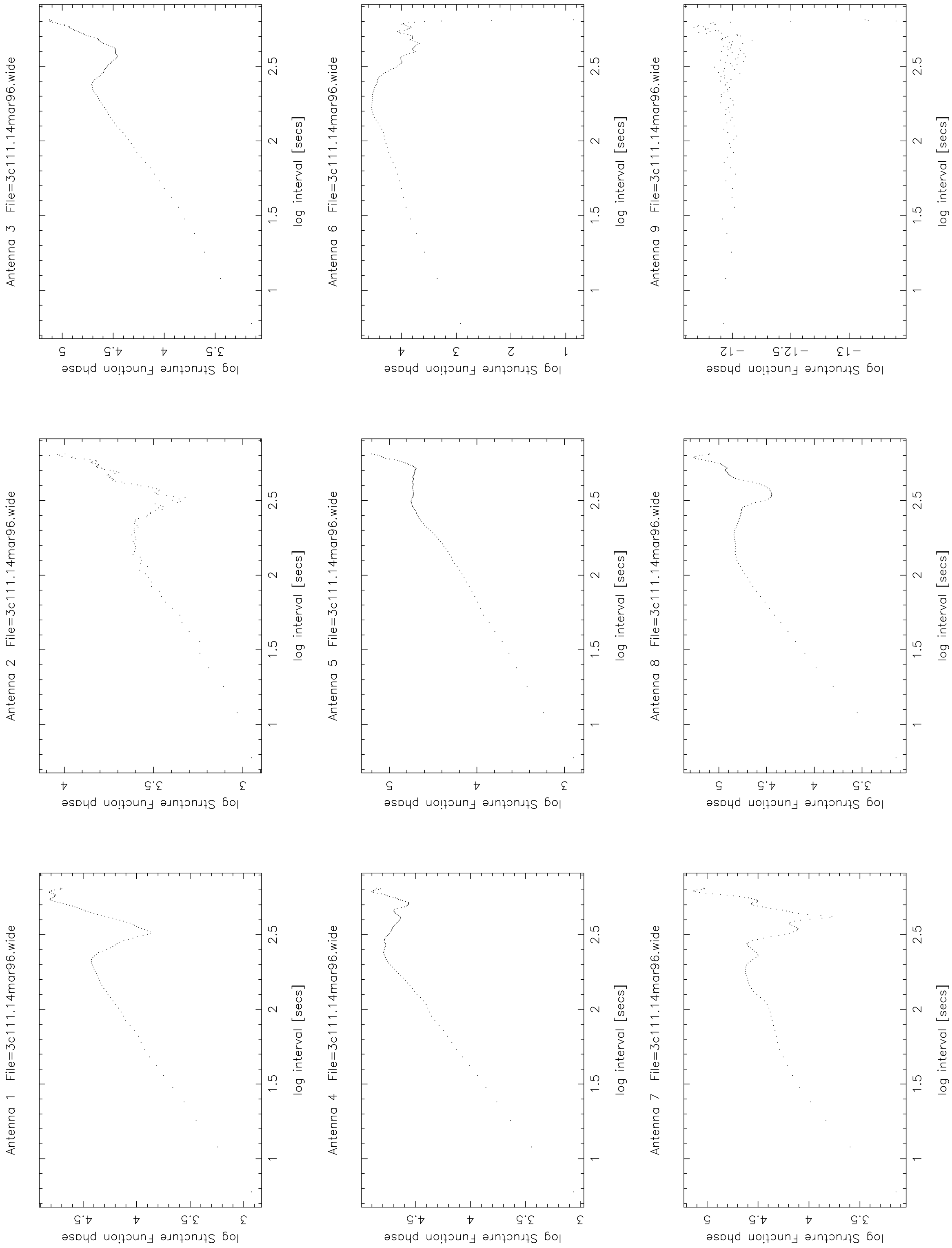

Fig. 4.— phase structure function before total power correction

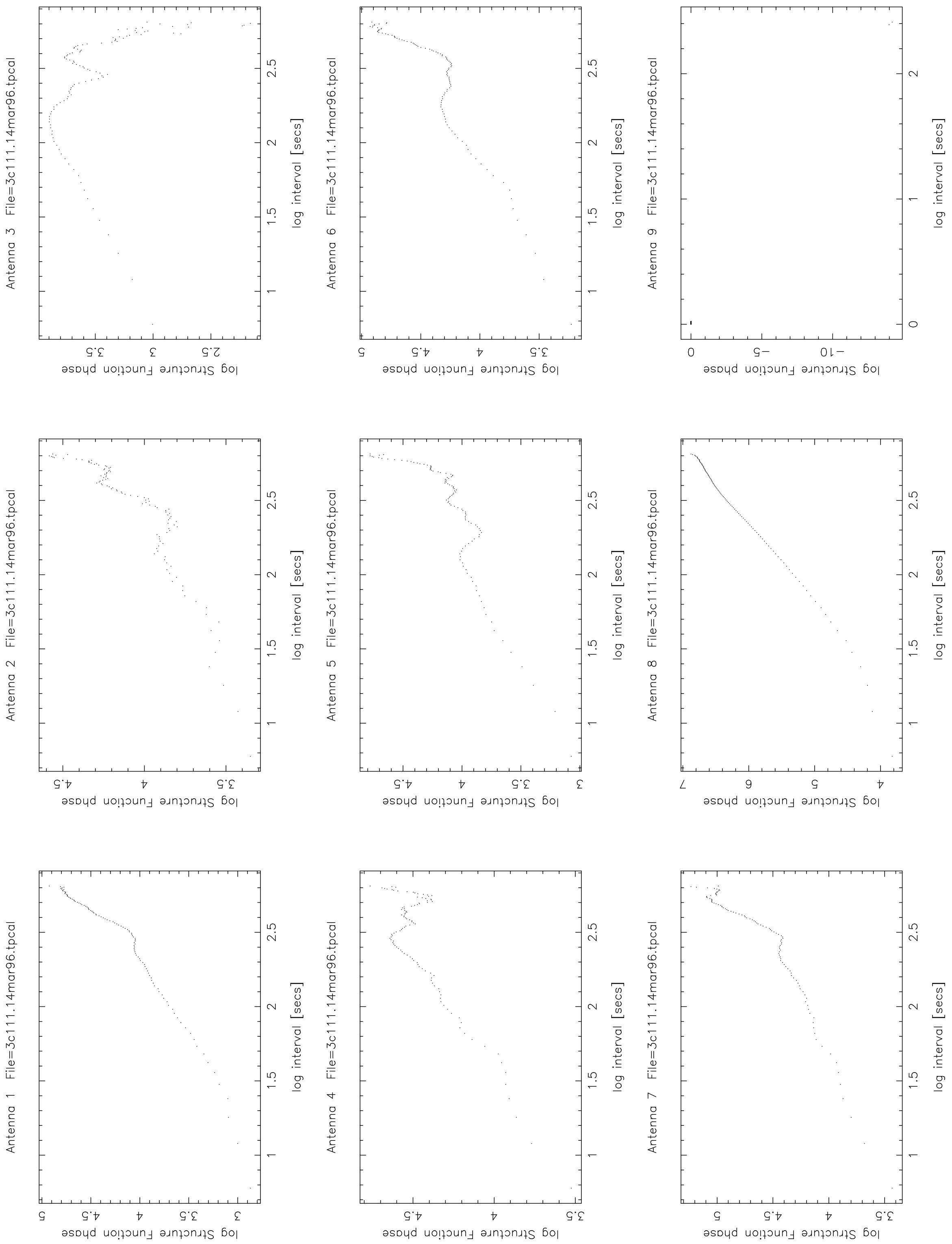

Fig. 5.— phase structure function after total power correction