MEASUREMENT OF ATMOSPHERIC PHASE FLUCTUATION AT 22 GHZ WITH THE NOBEYAMA MILLIMETER-WAVE INTERFEROMETER

T. Kasuga, R. Kawabe[1], M. Ishiguro, K. -I. Morita,
and E. B. Fomalont[2]

Nobeyama Radio Observatory, Tokyo Astronomical Observatory,
University of Tokyo
Nobeyama, Minamisaku, Nagano 384-13, Japan

ABSTRACT

Atmospheric phase fluctuation at 22 GHz was measured by observing a compact radio source with the Nobeyama Millimeter-wave interferometer. The observed interferometer phase are used to derive the Allan variance of phase fluctuations as a function of baseline lengths, L, between 27 m and 413 m and sampling intervals. The results show that the root of the Allan variance, σ_A, has a good correlation to baseline length, L, as $\sigma_A = \beta \times L^{\alpha}$. The mean value of α is 0.72, which value is close to 5/6 as expected from the Kolmogorov turbulence model.The time domain spectra of σ_A imply that atmospheric irreguralities which cause phase fluctuations, have characteristic sizes.

INTRODUCTION

The propagation of radio waves through the troposphere is strongly influenced by the contents of water vapor and oxygen. Hence fluctuations of these contents in the atmosphere disturb the phase of a radio interferometer. The fluctuations increase in proportion to operating frequency and become especially remarkable at millimeter wavelengths (1). This may present serious problems to aperture synthesis interferometers for operating at millimeter wavelengths.

Some studies at longer wavelengths (2) suggest that the magnitude of the fluctuations may have strong dependence on cites, seasons, time ,and weather conditions.

In this letter, we report observations of interferometer phase fluctuations due to the atmosphere at 22 GHz.

This observations are one of steps testing the interferometer which we are preparing to operate at 115 GHz. The results give a measure of the magnitude of the effect at millimeter wavelengths.

OBSERVATIONS

The observations were made on Jan. 11, 30, and Feb. 10, 1985, using the Nobeyama Millimeter-wave Interferometer (3), at an altitude of 1340 m.

---

[1] Department of Astronomy, University of Tokyo,
7-3-1, Hongo, Bunkyo-ku, Tokyo 113, Japan

[2] on leave from National Radio Astronomy Observatory

Five 10 m antennas were located along the E-W baseline, and ten spacings from 27 m to 413 m were obtained at a time and used in the analysis. The frontend was a two-stage parametric amplifier cooled at 20 K and its receiver temperature was typicaly 100 K. The backends were 50 MHz bandwidth analog correlators which outputs every 2 seconds were integrated in 30 seconds.

The observations consisted of measurements of continuum emission at 22.235 GHz from a compact radio source, 3C84 at antenna elevations higher than 60°.

Weather data at 20 m high above the ground monitored during the observations, shows that weather conditions were fairly good.

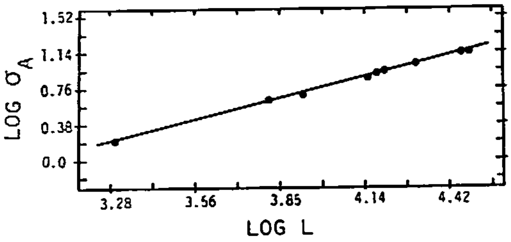

Figure 1

Logarithmic σ_A plotted versus logarithmic baseline length. σ_A is in degree and baseline length, L, in wavelength. σ_A at a sampling interval, 2 minutes, was caluculated for data obtained on Jan. 11. The line in the figure shows the best fit for log $\sigma_A = \alpha \times \log L + \log \beta$. α is equal to 0.78 and residual is 0.27 degree in r.m.s.

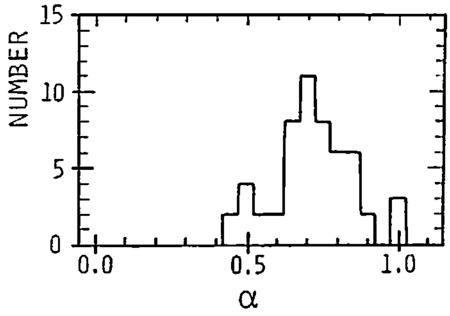

Figure 2

Distribution of α's for observing runs on Jan. 11, 30, and Feb. 10. An average of α's is 0.72, which value is close to 5/6 as expected from the Kolmogorov turbulence model.

RESULTS AND DISCUSSIONS

Observed phase error are mainly caused by, a phase drift in a local oscillator system, a receiver noise, and an atmospheric fluctuation.

Phase fluctuations due to receiver noise have a time scale shorter than the post integration time, 30 seconds and average contribution is estimated to be smaller than 1 degree. The phase drift in local oscillator is expected to be small because highly phase stablilized cables and a round-trip phase stabilization system are used. The other instrumental phase errors which slowly vary with a time scale of hours, can be corrected by repeated observation of calibration sources, the positions of which are well established. Atmospheric phase fluctuations of short time scale can not be removed by such a process, and deteriorate synthesis maps.

The Allan variance (4) which is familiarly used to estimate atomic clock's stability, is insensitive to slow variations and fits for our interests in phase fluctuations due to atmosphere. The root of the Allan variance, σ_A, was caluculated from the interferometer phases which were averaged during the sampling interval, changing the intervals from 30 seconds to 20 minutes.

Figure 1 shows a relation between σ_A, at a sampling interval, 2 minutes and baseline length, L, for the observation on Jan. 11 when we used nine of ten baselines because one correlator did not function. The ordinate indicates log σ_A, and the abscissa logarithmic baseline length, log L. The line in the figure shows the best fit for,

$$\log \sigma_A = \alpha \times \log L + \log \beta,$$

i.e., a power law,

$$\sigma_A = \beta \times L^{\alpha}.$$

Small scatters (r.m.s. of 0.27 degrees) from this line suggests that phase fluctuations were mainly caused by randomly distributed atmospheric irregularities. If fluctuations happened in the system were large, scatters might be large because of independece of these fluctuations on baseline lengths.

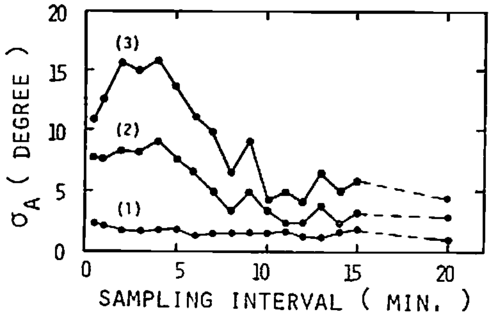

Figure 3

Relations between σ_A and sampling interval are plotted for three baseline lengths, (1) 1978 wavelengths, (2) 13846, and (3) 30658. At the period shorter than 6 min, significant plateaus are seen, which heights depend on baseline lengths. The data used were obtained on Jan. 11.

Figure 2 shows that distribution of α's which were calculated for each run. α's distribute around 0.72, which value is close to 5/6 as expected from the Kolmogorov turbulence model (2). Time domain spectra of σ_A for three baseline lengths are shown in the Fig. 3. Significant plateaus which heights depend on baseline lengths, are seen at the period shorter than 6 minutes. Weaker peaks are also seen in the figure. Figure 4 shows the time domain spectra for three different days, (1) Jan. 11, (2) Jan. 30, and (3) Feb. 10, obtained at the same baseline. The plateaus can be seen in the three spectra. The relation of σ_A to baseline length and sampling interval is clearly seen in the contour map of the Fig. 5, where the ordinate indicates baseline lengths in wavelengths, the abscissa sampling intervals in minutes, and the contour interval is 2 degrees.

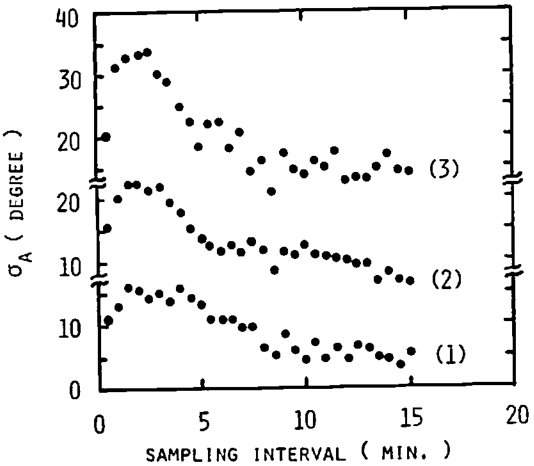

Figure 4

Time domain spectra for varous days, (1) Jan. 11, (2) Jan. 30, and Feb. 10. The data used were obtained at the same baseline, which length is 28680 wavelengths.

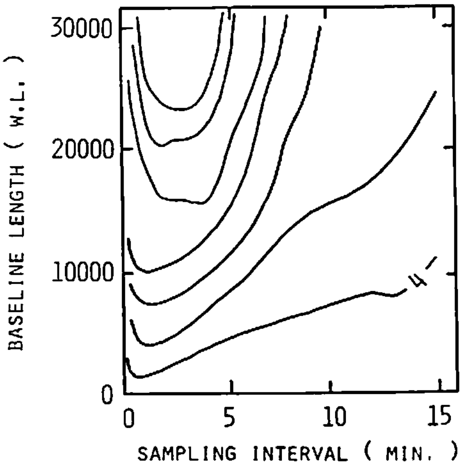

Figure 5

Contours of σ_A as a function of sampling intervals and baseline lengths for the data on Jan. 11. The lowest contour indicates 4 degrees and the contour interval is 2 degrees. The average wind speed of the E-W direction was 1.5 m/s on this day.

In this figure a parabola-like feature is seen where σ_A is greater than 6 degrees. The feature is thought to reflect atmospheric structures, sizes of which have an probability distribution, and also is a function of antenna spacings and wind speeds.

ACKNOWLEDGEMENT

The authors would like to thank T. Kanzawa, H. Iwashita, H. Kobayashi, and S. Okumura of the Nobeyama Radio Observatory for operation of the interferometer and helpful discussions.

REFERENCES

(1) J. H. Bieging et al., Radio Science 19, 1505 (1984).
(2) J. W. Armstrong, and R. A. Sramek, Radio Science 17, 1579 (1982).
(3) M. Ishiguro et al., in the proceedings of the International Symposium on Millimeter and Submillimeter Wave Radio Astronomy, Granada, (1984).
(4) R. Sramek, VLA Test Memo 143, (1983).