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PHASE MEASUREMENTS WITH INTERFEROMETER BASELINES OF UP TO 35 KM

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INTRODUCTION

One of the few remaining questions that need to be answered before proceeding with the construction of the VLA is whether or not there is any fundamental difficulty inherent in extending the synthesis technique to an angular resolution of one second of arc. In 1966 with the aim of investigating this problem, it was decided to construct a phase stable interferometer whose length would be comparable to that of the proposed VLA. In previous interferometers with baselines larger than 3 km, absolute phase had not been preserved for longer than a few minutes and it was not possible to compare the phase of a radio source with that of a calibrator. By using a two-way phase stablized microwave link it was hoped to investigate the problems of phase stable long baseline interferometry. This interim report describes the phase observations to date. Amplitude studies with this interferometer have been discussed elsewhere [1].

Description of the Telescope System

A portable 42-foot telescope was constructed to be used at a remote site with one of the 85-foot telescopes at Green Bank as a long baseline interferometer. For economic reasons the sky coverage of this telescope was limited to declinations between 0° and 66°. Above 15° declination the hour angle range was $\pm\ 2^h\ 40^m$, but below 15° sources could only be tracked between $\pm\ 1^h\ 30^m$.

The telescope surface consists of removable panels covered with 1/2 cm mesh. The errors in the positioning of the mesh prevent operation at frequencies much higher than 2695 MHz. An aperture efficiency of approximately 30% at this frequency was measured by comparing the well-known strong radio sources Cas A, Cyg A, and Tau A with the signal from an argon noise tube, which in turn had been calibrated against a cooled resistor.

The local oscillator signal was sent to the antenna by the microwave link at 1347.5 MHz, one-half of the eventual local oscillator frequency. The signal radiated from the base location was used to phase lock the local oscciallator at the remote telescope. This local oscillator signal was also radiated back to the base location and by comparing the phases of the radiated and returned signals, the phase delay of the air path could be determined. This information was used to control the phase of the local oscillator at the portable antenna so that its phase was independent of the phase delay of the air path.

The receiver was a dual parametric amplifier, followed by a double sideband mixer. The feeds could receive either right or left circular polarization, selected by a switch at the antenna. The two to twelve MHz IF signal was then sent to the base location over a 2.6 GHz frequency modulated microwave link. The receiver noise temperature was measured to be about 140°K.

The signals from the two elements of the interferometer were correlated in an analog multiplier (correlator). The two path lengths from the radio source to the multipliers must be equalized. This was accomplished by a delay system employing three types of delays--pieces of cable for the short delays, lumped constant delay lines for the intermediate delay lengths, and glass ultrasonic delay lines for the long delays. The selection of the appropriate delay lines to be switched into the signal path was controlled by the DDP-116 on-line computer which also performed the initial reduction of the data.

The output of the correlator was sampled at 20 ms intervals. These samples were accumulated for 15 seconds and then fitted to a sine wave by the method of least squares. The amplitude and phase of the fitted sine wave were written on magnetic tape for further processing in the computer at Charlottesville. The rms noise was approximately 0.3 flux units in each 15 second data point.

Observations

The portable antenna was first located on Spencer's Ridge, a mountain 11.3 km northeast of the 85-1 antenna and 384 meters above Green Bank. This gave a baseline of length 101,797 wavelengths at 2695 MHz. It was operated at this site for five days on each of eight months between December 1967 and July 1968. Then it was moved to a new location near Huntersville, West Virginia, a distance of 35.2 km from Green Bank. The difference in elevation was 274 meters. This provided a second baseline whose length of 317,100 wavelengths at 2695 MHz is directly comparable to the longest baseline in the proposed VLA. During each of the observing periods eight unresolved radio sources were observed. These were 3C48, CTA21, 3C147, PKS1055+01, 3C286, 3C345, CTA102, and 3C454.3 and were chosen to provide information over a wide range of declination and right ascension. Each source was smaller than 0.2" and stronger than 3 flux units at 2695 MHz. Therefore, fluctuations in the amplitude and phase of the fringes due to both finite source size and system noise were negligible. Remaining changes in phase were caused by system changes, inaccurate knowledge of the baseline parameters and source positions, and atmospheric effects.

To study the effect of the atmosphere on the phase, one must account for the other causes of phase drift. Changes in phase due to the equipment are difficult to separate from those caused by the atmosphere. A known timing error in the equipment occasionally caused phase jumps typically of 10°, but sometimes reaching 30° on the 11.3 km baseline. Furthermore, observing time was lost due to various other instrumental difficulties and in particular it has not yet been possible to gather much reliable data with the 35.2 km baseline. The remaining trouble has been traced to the delay system. This is now being overhauled and during the next few months it is hoped we can make further observations over this baseline.

The accuracy with which the baseline parameters can be determined depends upon the precision with which the source positions are known and vice versa. To reduce phase drifts due to baseline and source position errors to less than 10°, it is necessary to know the position of the sources to better than 1/36 of a fringe spacing. However, the positions of the eight calibrator sources were not known to better than 0.5" and this has complicated the subsequent analysis. Because of the long baseline, hour-to-hour variations in source positions due to precession and nutation were important. Many other effects which could be neglected for the 3-element interferometer needed to be taken into account in the analysis of the present interferometric data and a new set of computer programs were required [2]. These programs are now nearly complete and will eventually be used to solve for both the baseline parameters and the source positions. Even though some baseline and position errors remain they should not interfere greatly with an analysis of atmospheric phase fluctuations because the day-to-day phase behavior should be consistent.

Results

Examples of typical phase behavior are shown in Figs. 1 to 3. The observed phase fluctuations can be divided into three types:

(1) Short term minute-to-minute phase noise. This has an rms value typically $\sim 5°$.

(2) Phase drifts with a time scale of 10 - 45 minutes. These are usually very regular and symmetric in appearance and often resemble an 'S'. The peak-to-peak excursions can exceed 90° but are more typically $\sim 30°$.

(3) Long term day-to-day variations which may be caused by changes in the equipment.

Fig. 4 shows histograms of the distribution of fringe phase over 30 minute intervals for January 1968, April 1968 and July 1968 (11.3 km baseline). Similar histograms for the 3 element interferometer in January 1968 are shown for comparison in Fig. 5. The abscissa represents the rms of a 30 minute segment of phase and the ordinate is the number of times a particular value of rms has occurred. The secondary maxima in the distribution are caused by the S curves previously described. These present a more severe problem in the summer (when the atmosphere water content is high) than in the winter, and are probably caused by some meteorological phenomenon in which a cell of water vapor moves along the baseline.

The variation of short term phase stability with baseline and time is illustrated in Table I. Two thirds of the area of the histograms are to the left of the values in the phase columns. Two interesting points emerge from this table regarding the short term phase stability. Firstly, the behavior over the 11.3 km baseline is at worst a factor of 3 different from that over the 2 km baseline. Secondly, the phase stability appears more dependent on seasonal changes for the long baseline than for the short baselines. This is probably due to an increase in the frequency of S curves during the summer months. During January 11% of the data contained S curves with peak-to-peak phase drifts greater than 20°. In April the corresponding percentage rose to 54%.

TABLE I

SHORT TERM PHASE STABILITY

BASELINE IN m	rms Phase Deviation January	April	July
200	3°		
300		2°	
1,800		4°	
1,900	4°		
2,100	5°	5°	6°
11,300	6°	10°	13°

Next we shall investigate the long term phase stability of the system. As has already been pointed out, this can be studied despite the fact that the baseline parameters and source positions have not yet been exactly determined. To eliminate systematic errors, each calibrator source was observed at the same time each day. The differences between these daily measurements and their average are shown in Figs. 6 to 8. For every 24 hour period, the rms of these phases were calculated. The results are shown in Table II. Overall, the system behavior is quite consistent. The increase in the atmospheric water vapor content between January and April is reflected more in the short term than in the long term phase stability of the interferometer.

TABLE II

LONG TERM PHASE STABILITY

BASELINE IN m	MONTH	rms Phase Deviation over 24 Hrs.
11,300	January 1968	15° ± 5°
11,300	April 1968	16° ± 2°
35,100	December 1968	25° ± 5° (?)

One can see from a comparison of Figs. 6 and 8 that the phase scatter between 2^h and 12^h LST is much worse for the 35.2 km baseline than for the 11.3 km baseline. During the remainder of the day there is little difference between them. There is not yet enough information to decide whether the increased scatter was caused by the atmosphere or by the equipment. The period of poor phase stability occurred at night, when one might expect a more stable atmosphere. Therefore, it is felt that the frequent trouble which arose in the equipment, especially during the precipitation of dew on the microwave link antenna, contributed largely to the increased scatter.

We have shown here that for baselines longer than 2 km the phase instabilities appear to be much more sensitive to the weather than to further increases in baseline length. Specifically, during the winter when the water vapor content of the atmosphere was relatively low, there was not much difference in phase behavior between the 11.3 km baseline and the shorter baselines. Therefore the quality of maps synthesized with 2 seconds of arc resolution should be comparable to those already produced with the three-element interferometer.

It is clear that peak-to-peak atmospheric phase variations are less than 150° on the 35.2 km baseline, and that the rms variations are not much more than 25°. This is equivalent to a $\lambda/20$ filled aperture and means that for one second of arc synthesis atmospheric problems would cause negligible loss of efficiency in the main beam. However the possibility does exist that an object will have to be observed on several days to reduce the side lobes generated by the atmospheric phase fluctuations. This cannot be ascertained until the remaining equipmental phase effects have been removed and more information is obtained about the size and statistical behavior of the atmospheric fluctuations.

REFERENCES

[1] Basart, J. P., B. G. Clark, and J. S. Kramer, "A phase stable interferometer of 100,000 wavelengths baseline", Publication of the Astronomical Society of the Pacific, Vol. 80, pp 273-280, June 1968.

[2] Basart, J. P., and J. S. Kramer, "Description of 4-element interferometer programs", NRAO Internal Report.

Fig. 1. Typical examples of good and bad short term phase behavior on 11.3 km baseline, January 1968.

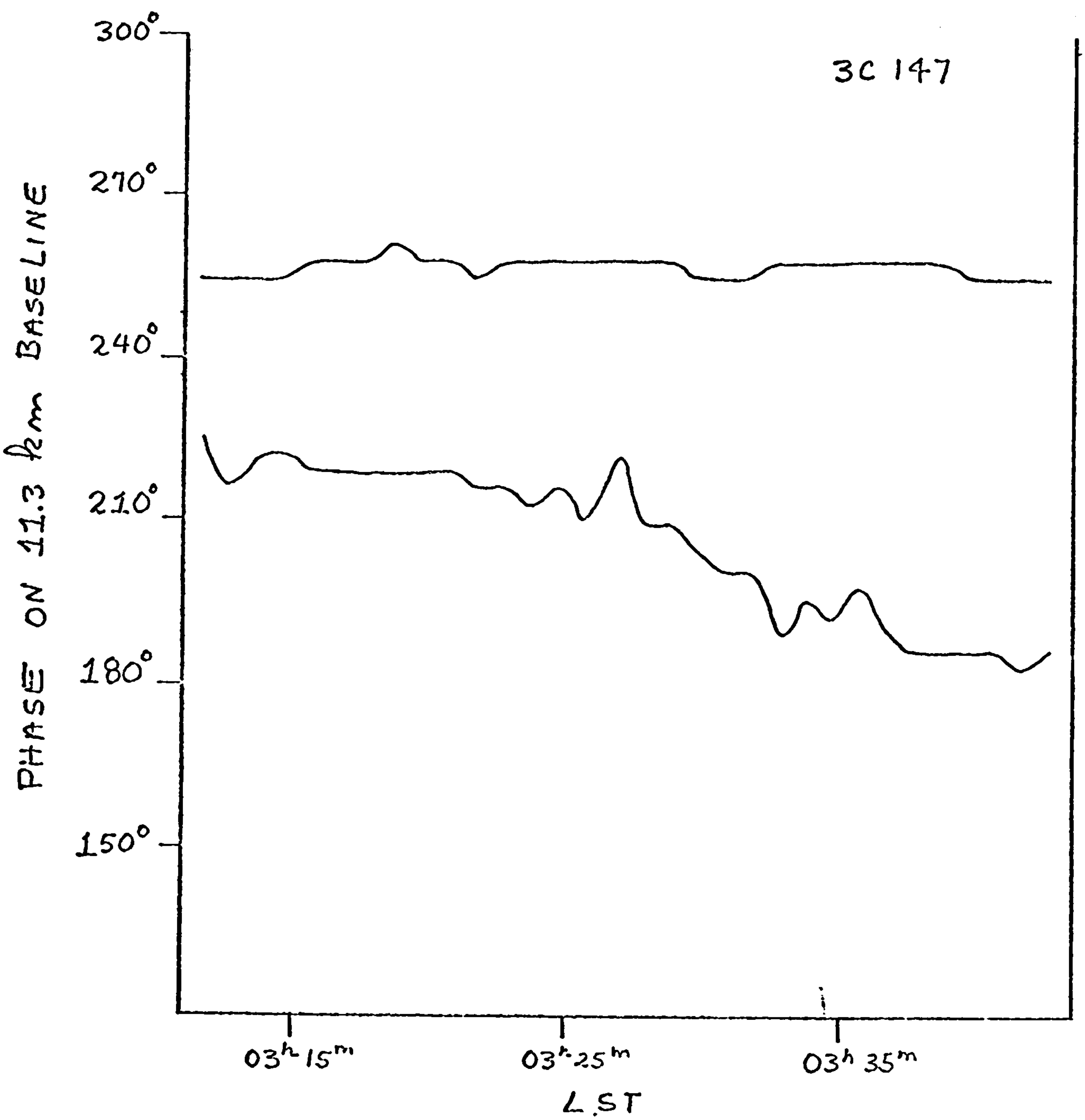
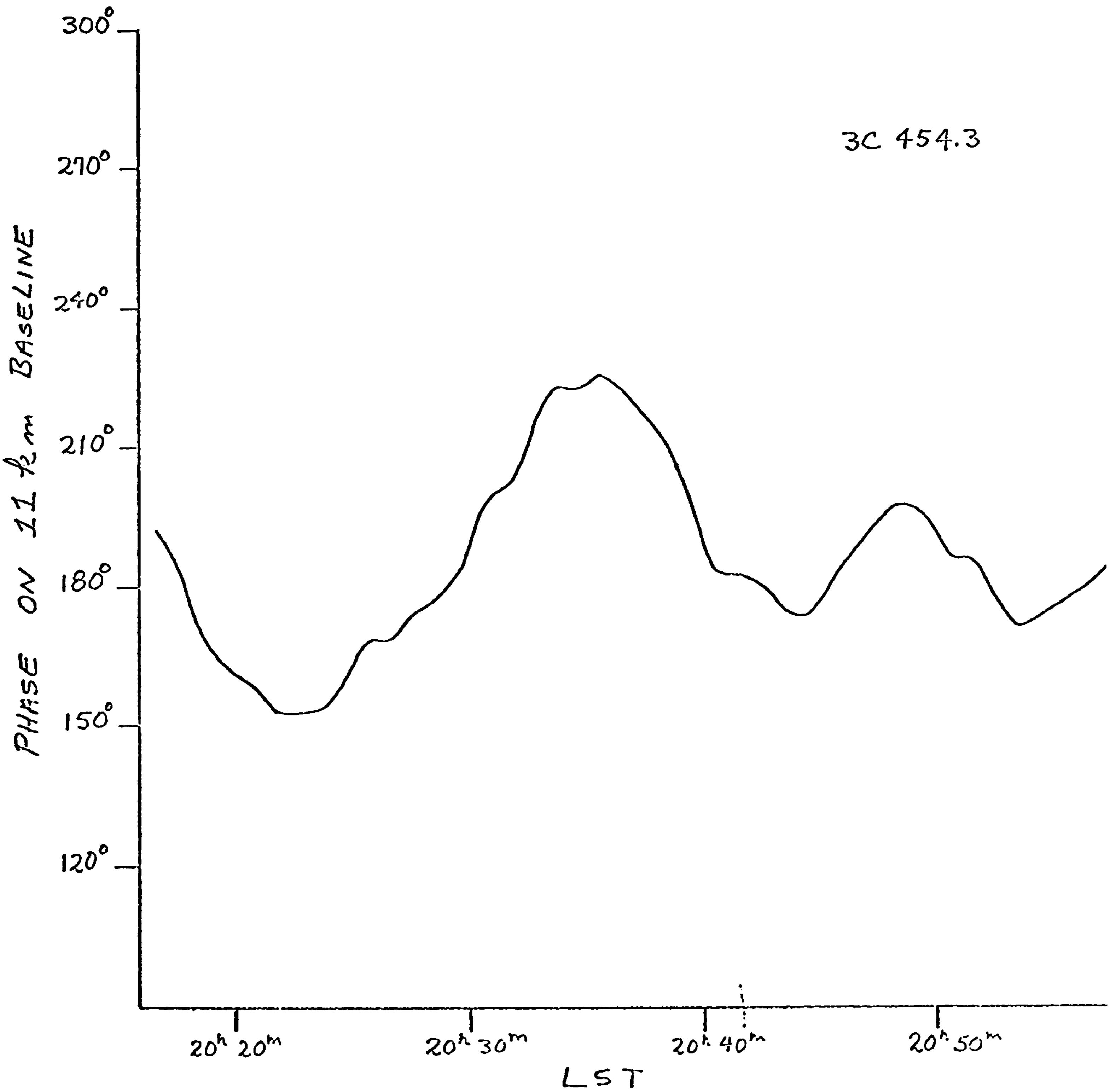


Fig. 2. Example of "S" curve in July 1968 on 11 km baseline. For uncontaminated data the phase curve would be a horizontal line since the source is much smaller than the fringe spacing.



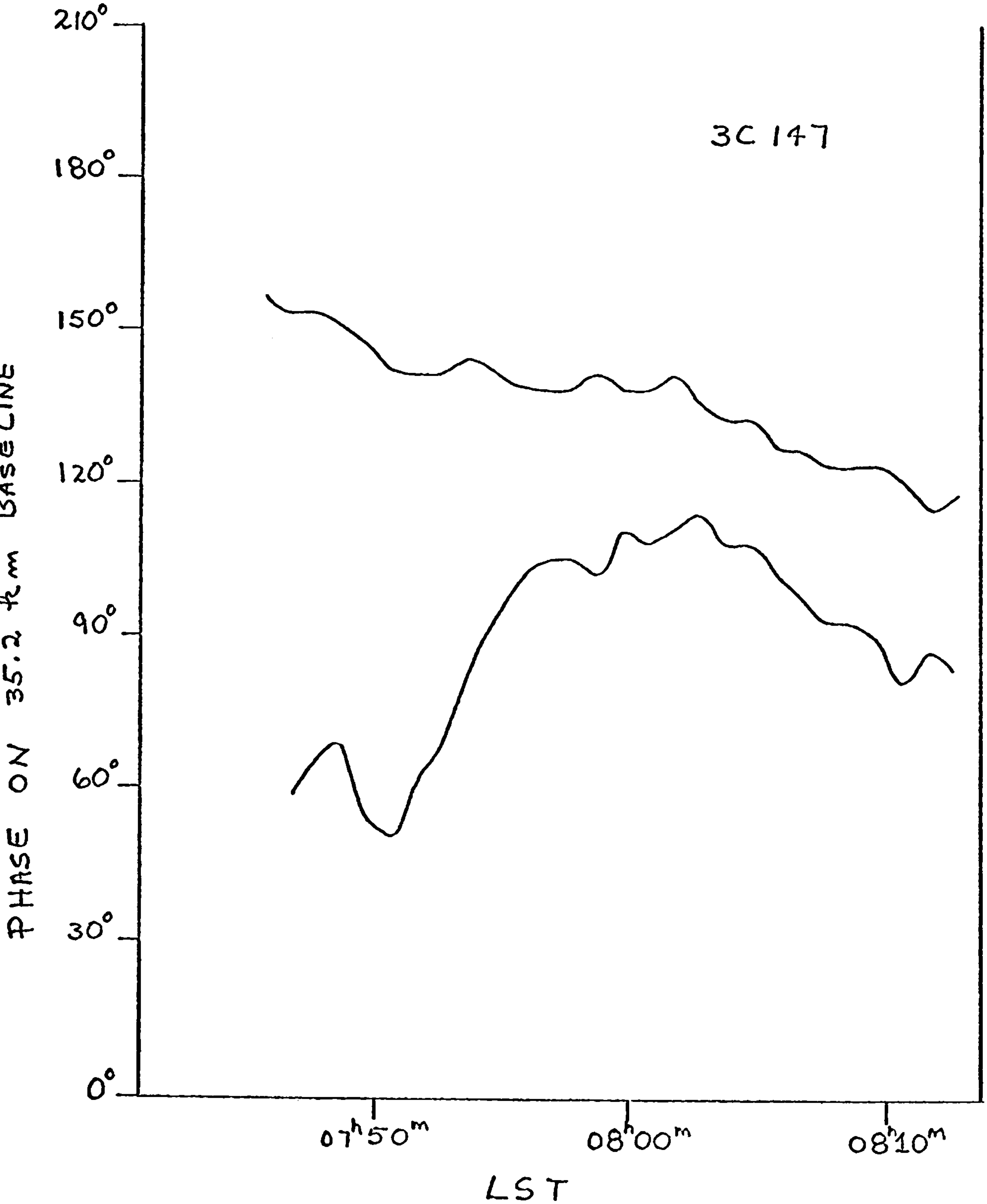


Fig. 3. Good and bad phase behavior on two different days. 35.2 km baseline, December 1968.

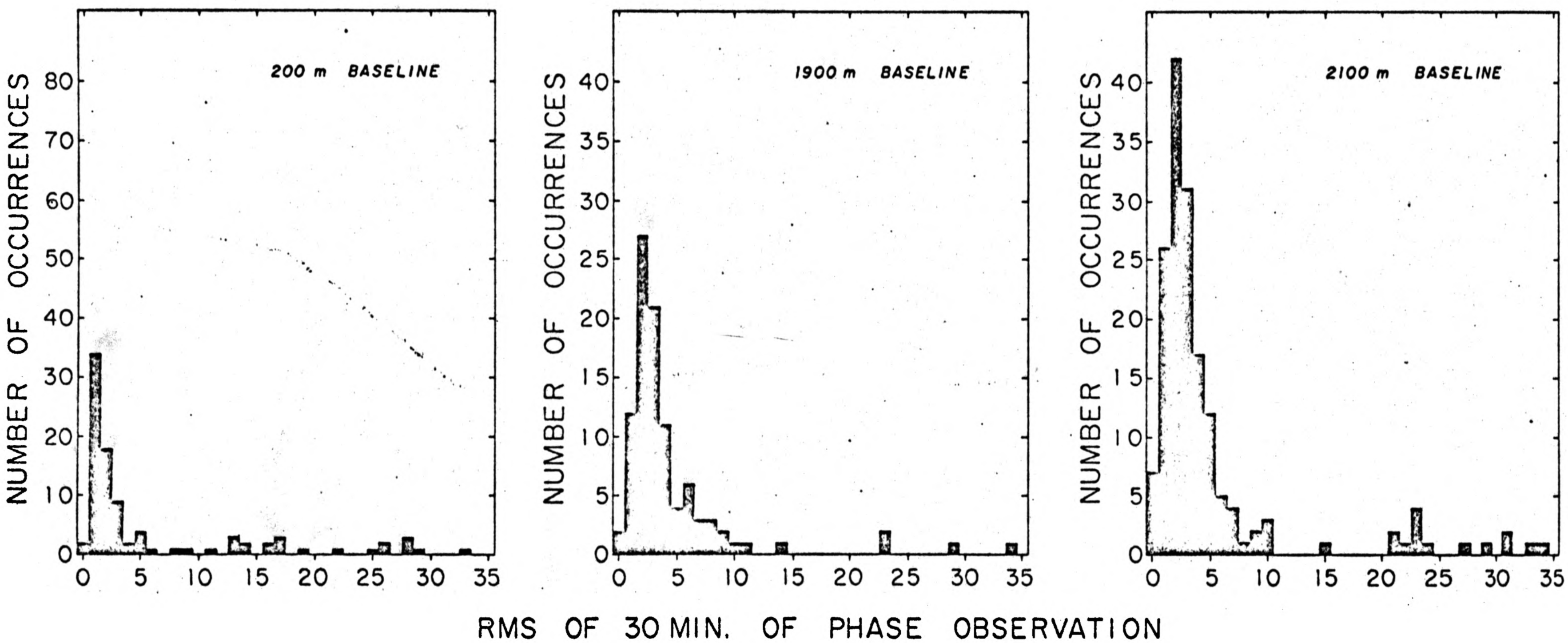


Fig. 4. Short-term phase behaviour -- three-element interferometer, January 1958.

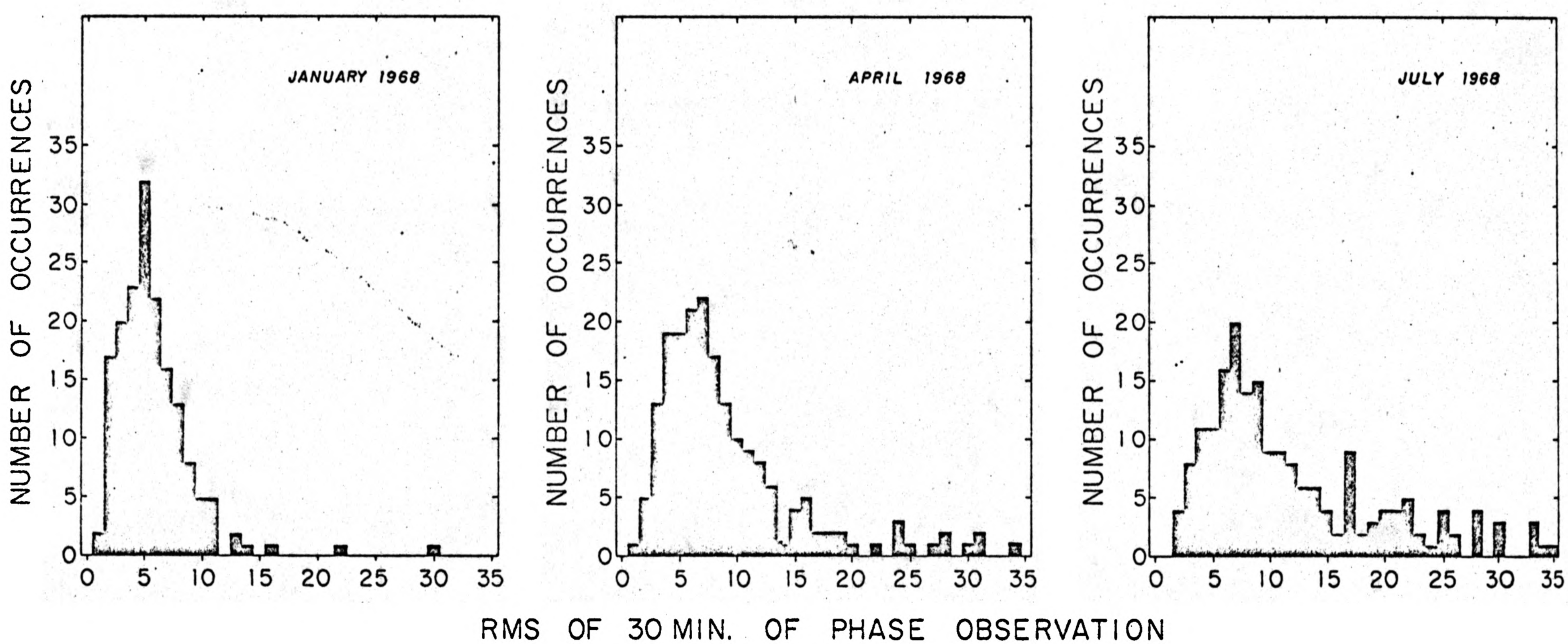


Fig. 5. Short-term phase behaviour -- 11.3 km baseline.

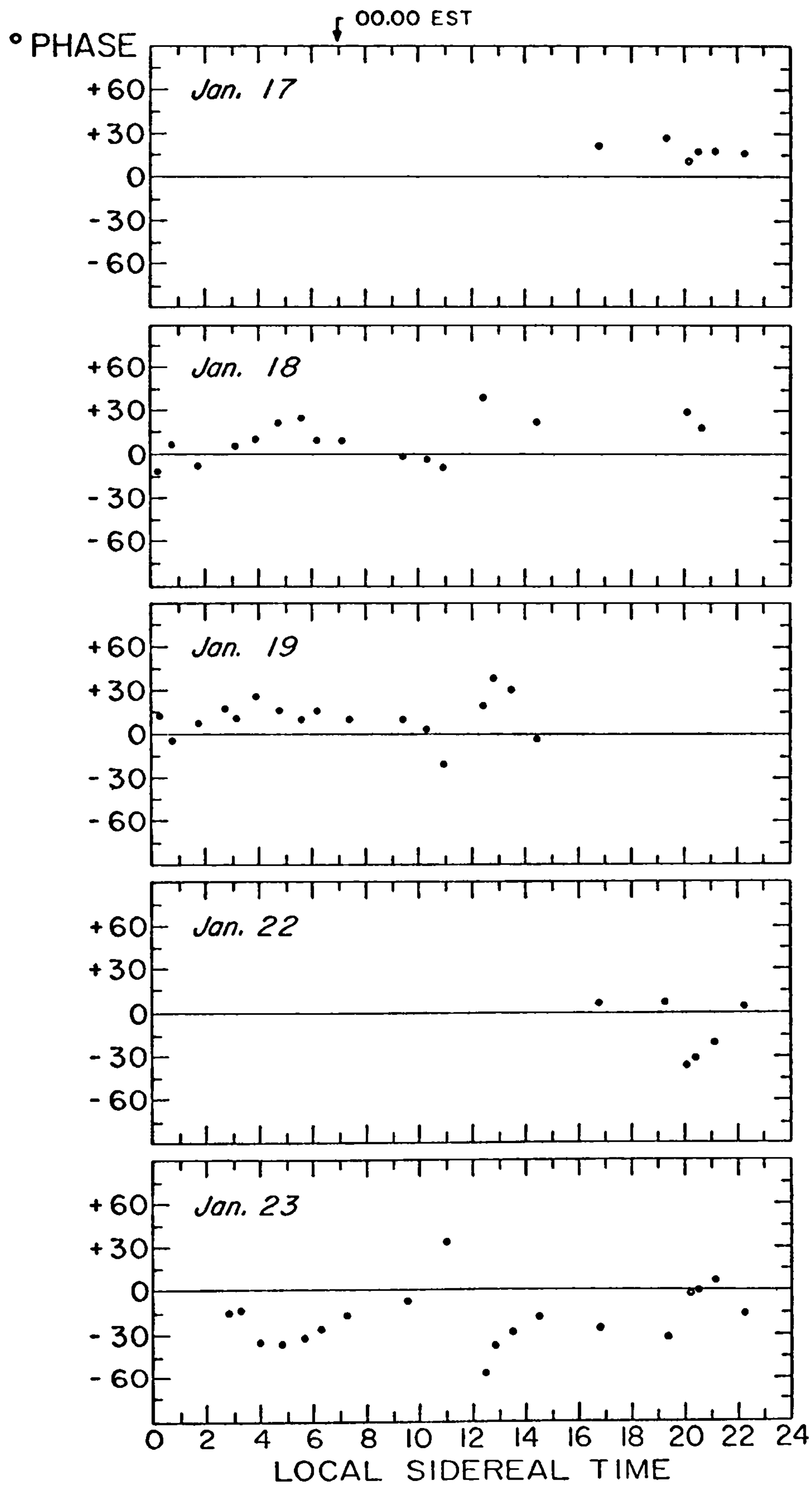


Fig. 6. Long-term phase behaviour -- 11.3 km baseline, January 1968.

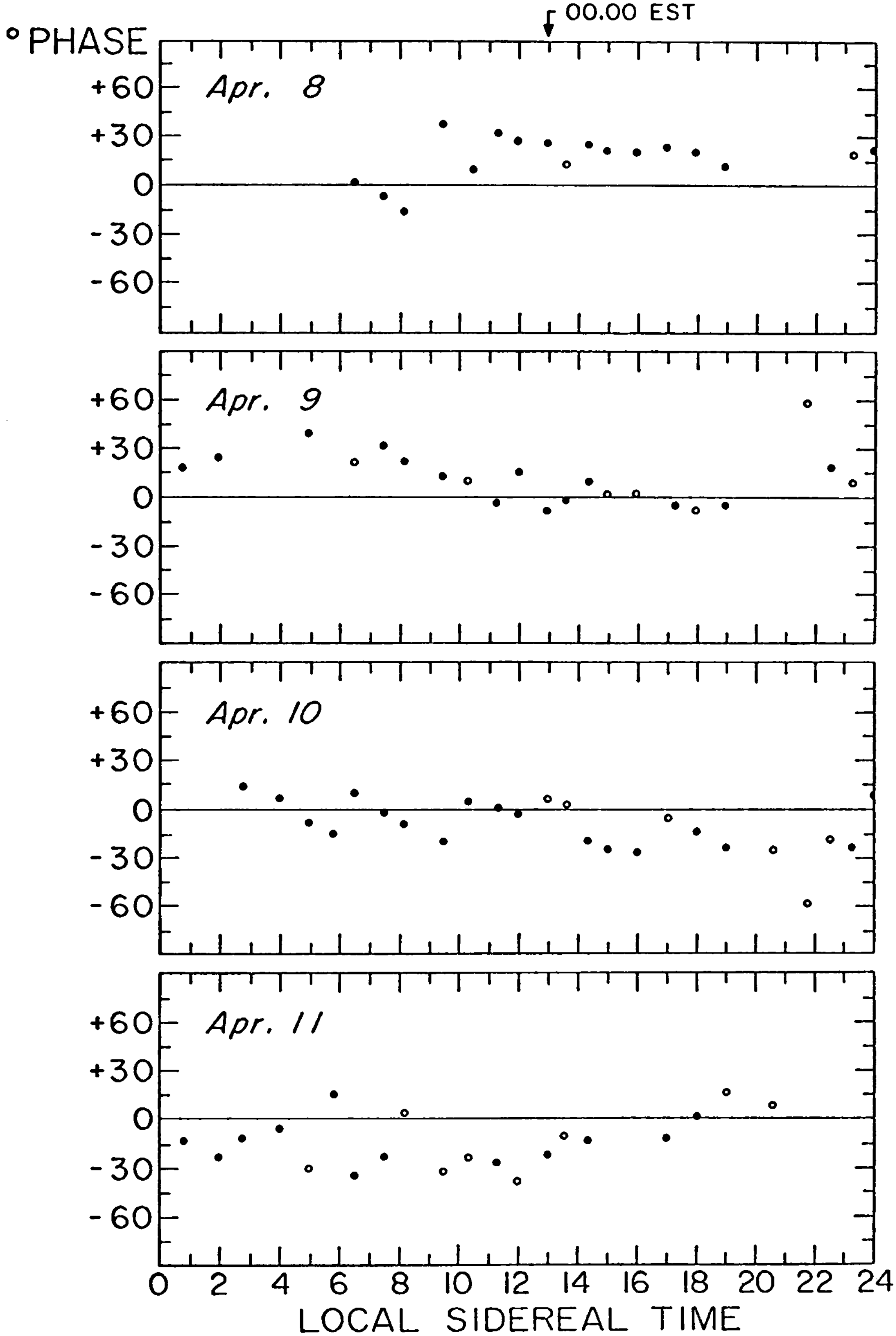


Fig. 7. Long-term phase behaviour -- 11.3 km baseline, April 1968.

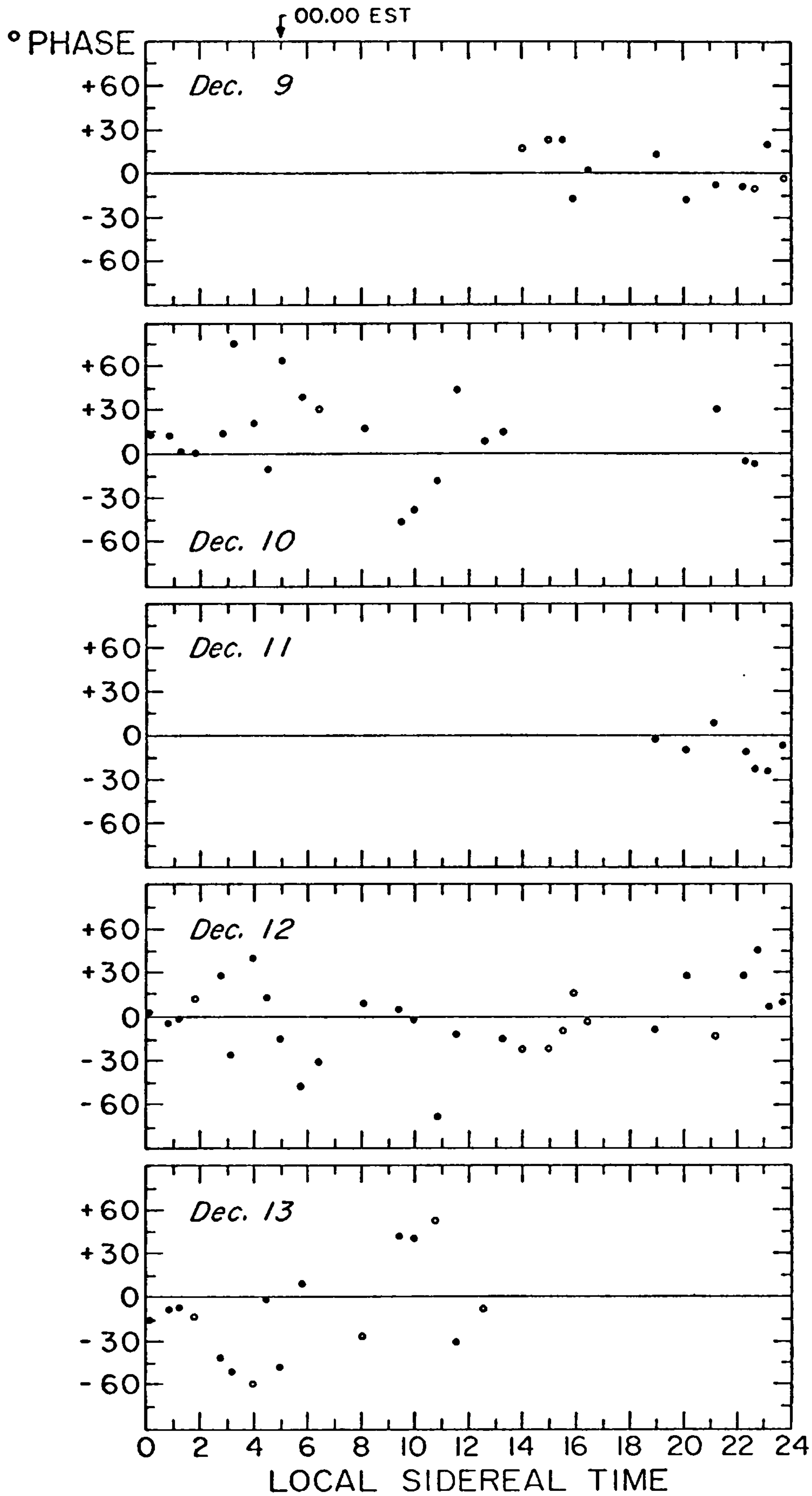


Fig. 8. Long-term phase behaviour -- 35.2 km baseline, December 1968.