CARMA Memorandum Series #17 [1]

Stability of BIMA antenna positions

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ABSTRACT

This memo discusses temporal changes of up to 3mm in the positions of BIMA antennas observed at HCRO. The motions occur on timescales of days to months, and appear to be related to seasonal temperature changes. Position changes observed over a three month period in the spring of 2001 are shown for illustration, and possible sources of the instability are discussed. Ground stability at the 0.1mm level will be required at Cedar Flat in order to avoid regular monitoring and correction of initial pointing and baseline solutions for CARMA.

Change Record

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[1] This document is also BIMA Memo # 99

1. Introduction

The stability of BIMA baseline solutions, which provide accurate measurements of the antenna positions, has been an issue since careful monitoring began at HCRO in the early 1990s. Temporal changes in antenna positions of several millimeters have been measured which cannot be accounted for by timing or measurement error. While much effort has been expended in an attempt to isolate the antenna stations from environmental effects, instability is still observed - particularly during large seasonal temperature changes. This memo describes the data collection and analysis procedure, and shows an example of the observed instability.

2. Measurement of antenna positions

Antenna positions are measured astronomically by observing a collection of point sources (mostly QSOs) whose sky positions are accurately known. An error in the (assumed) antenna position produces a 24 hour period sinusoid in the measured phase of each QSO. The amplitude of the sinusoid and the HA of the zero crossing gives the direction and magnitude of the error in the equatorial components (B1 and B2 - the local meridian direction and its E-W orthogonal). The error in the polar component (B3) is given by the absolute value of the phase, which is proportional to sin(DEC). Since the antenna-based phases can vary slowly with time due to thermal effects, the QSOs are observed in a semi-random sequence in order to allow smooth time-varying instrumental drifts to be distinguished from the HA & DEC sinusoidal dependence caused by baseline errors.

A typical baseline observation runs for 6-8 hours and includes 10-15 QSOs with a wide range of RAs and DECs. The antenna positions are derived from a least squares solution to the antenna-based phases relative to one of the antennas. Usually four parameters are fit: three geocentric position coordinates (B1, B2, B3) and an instrumental phase. Only the instrumental phase is allowed to vary with time. The uncertainty in the least-squares fit depends on the sampling in HA and DEC and on the quality of the data. At BIMA we routinely achieve an accuracy of 0.2-0.3mm at 3.4 mm wavelength for a 6 hour run in good weather. This is sufficient to keep the phase transfer error in degrees less than about half the sky separation between source and calibrator.

3. Observed position changes

One of the clearest examples of antenna position change occurred during the spring 2001 C-array, which started in late February and ended in early June. During March it became apparent that the position of Ant 10 on station 125E was changing. Four baseline datasets were obtained in order to keep track of the changes. In addition, flux calibration data was used to fill in the gaps between baseline observations. The flux measurements were taken during 2-3 hour periods of unassigned time in varying conditions, and did not use a semi-random sequence. However they generally gave results consistent with the baseline data, although with a larger uncertainty.

Fig. 1 shows the antenna position changes following the original reconfiguration solution obtained at each epoch for which usable data was obtained from either baseline or flux calibration observations. While the antenna positions were updated on-line regularly to keep the phase transfer errors small, the changes plotted are relative to the original antenna positions in order to show the total change clearly. The times at which baseline updates were applied on-line are indicated in the reference antenna panel. The changes plotted in Fig. 1 have been transformed from geocentric coordinates (B1, B2, B3) in nanoseconds to local coordinates (North, East, Elevation) in millimeters. Each directional component change is shown individually, along with the total change in millimeters.

Most of the directional components changed monotonically with time in the 2001 C-array. In the horizontal plane (North and East) this is the case for all antennas. The changes were not all linear with time however. Ant 10 moved southwest by about 2mm in March, and then slowed to about 0.5mm per month in April and May. Almost all of Ant 10’s southern motion occurred in March. Three of the four antennas with significant elevation changes (Ants 1, 7 and 10) dropped in height steadily until mid-May, then began to rise again. Ant 6 on the other hand was fairly stable until mid-May, at which time it began to drop by about 1mm over the next few weeks.

Fig. 2 shows the physical layout of antennas in the 2001 C-array. In this array five antennas are on ”normal” stations, which have independent concrete piers tying the station to bedrock. Two antennas are on ”meadow” stations, which are anchored to large concrete blocks embedded in soil. Three antennas are on ”skin” stations. These sit directly on a concrete slab (the TEE) without any other foundation.

Fig. 2 also shows the total change in position measured between February and June for each antenna, along with a graphical representation of the horizontal and vertical movement. Position changes between 0.2mm (about 2 sigma) and 3mm were observed, with four antennas registering changes greater than 1mm. Ant 2 at normal station 100W was used as the reference antenna for this array.

The following table lists the total change measured for each antenna in millimeters (ordered by amount of change) along with the station name and type.

Antenna:	10	8	1	7	6	9	4	5	3	2
Station:	125E	140N	200N	27N	165W	88NW	53NW	80E	60N	100W
Type:	S	N	N	S	S	M	M	N	N	N
Change:	3.1	1.8	1.6	1.5	0.9	0.7	0.3	0.3	0.2	REF

Three antennas (3,4,5) did not move significantly relative to the reference antenna. Two of these were on normal stations and one was on a meadow station. Of the six antennas that did move by more than 0.3mm, four dropped in elevation by up to 1mm. The three antennas with the largest elevation changes were all located on skin stations. The five antennas with significant horizontal changes moved in a northwest or southwest direction. The two northernmost antennas moved about the same distance west (0.7mm), but Ant 1 moved north and Ant 8 moved south for a total relative position change of 3mm. Both of these antennas were located on normal stations.

4. Discussion

The Hat Creek Radio Observatory is located on a basalt lava flow which was emplaced about 30,000 years ago. The flow originated from a fissure located 15 miles south of the observatory, near the town of Old Station. A young fault scarp along the east side of the valley offsets the flow, indicating that the thickness of the lava is at least 60 feet. The basalt is highly fractured on its surface and laced with lava tubes, potholes and tumulii. Shrinkage cracks tend to be about 1% of the distance between joints in the lava. Since basalt becomes brittle enough to crack at about 760C, a 1% change in length between 760C and 20C implies an expansion coefficient of $\sim$1.4 10^{-5} C^{-1}. This is about the same as the expansion coefficient of concrete.

The C-array stations are located on or near a T-shaped runway which extends 1000 feet EW and 600 ft NS. The Tee is a slab of 8” thick reinforced concrete, with the outer edges 12” thick. It is situated in an area where the lava is partially covered by alluvium. ”Skin” stations simply sit on top of the concrete. ”Normal” stations pierce the Tee and are isolated from it with paper separators, with each of the three telescope legs supported by a pier. The piers reach bedrock at various depths along the Tee, some as deep as 20 feet. ”Meadow” stations are comprised of concrete piers embedded in compacted dirt and gravel to a depth of 4 feet. These piers have 5 ft square by 1.5 ft high concrete footings at the bottom, supporting a 2.5 ft high column 3 ft on a side. None of the meadow stations reach bedrock.

Between February and June, 2001 the median air temperature rose from about 5C to 20C. A few feet below ground the temperature change would be much less, but it might have been as much as 10C between the beginning and end of the 2001 C-array. For a temperature change of 10C and an expansion coefficient of 1.4 10^{-5} C^{-1}, a maximum expansion of 1.3mm would be expected over the full 90m extent of the C-array. This is less than the measured changes, and furthermore most antennas moved closer to the reference antenna rather than farther away. Therefore simple thermal expansion cannot account for the baseline instability.

Nightime lows ranged from -11 to +1 C during January and February, with an average low of about -2 C. It is therefore possible that the ground remained frozen until late February or early March. The fact that the four antennas which moved in elevation all lost height compared to the reference antenna suggests that frost heave may have been a factor. If the ground thawed between February and June, wet soil underlying the Tee would compact, resulting in an elevation drop. The three antennas on skin stations show the largest drops, which is consistent with this explanation. On the other hand, the Tee was designed with extra deep edges in order to mitigate this effect by keeping most of the surface water from seeping under the concrete.

The largest instability previously measured occurred in January 1991. It involved the original 3-element array antennas, all of which were located on normal stations (180E, 0, 100W). The winter 1990-91 temperatures were abnormally low in November and December, but warmed considerably in January. Baseline and pointing changes which indicate physical changes of about 3mm were observed during the first two weeks in January. Systematic weather monitoring at Hat Creek began in 1994 so the air temperatures during that time are not available. However, it seems unlikely that the ground would have thawed in early January, so environmental factors other than frost heave may have been responsible for that instability.

5. Conclusions

Baseline and pointing (tilt) instabilities indicating physical movement of BIMA antennas up to 3mm have been observed at the Hat Creek Radio Observatory. The timescale of these instabilities is weeks to months, implying that the changes are associated with ground movements and not the antenna structure. The largest motions are associated with seasonal temperature changes, but simple thermal expansion cannot account for the motions observed. The terrain on which the telescopes are located is a mixture of sandy soil and lava rock, which probably has a complicated and localized response to changes in temperature, moisture content and the freeze-thaw cycle.

Because the baseline and pointing changes at HCRO are unpredictable, our approach has been to monitor and update the baseline and pointing solutions as necessary. The stability of the ground at the sub-mm level should be evaluated at Cedar Flat in order to determine if such measures are also necessary for CARMA.

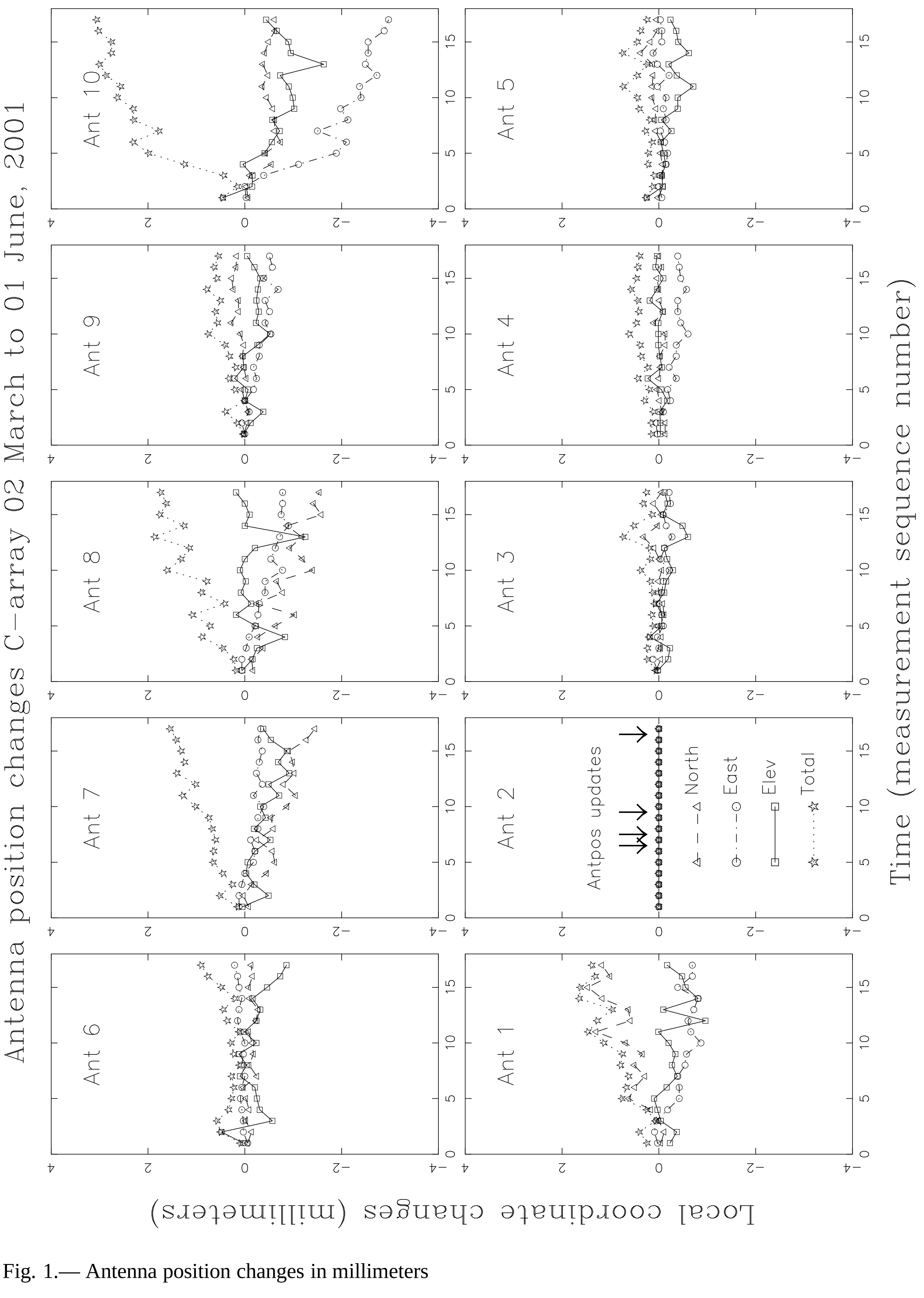

Fig. 1.— Antenna position changes in millimeters

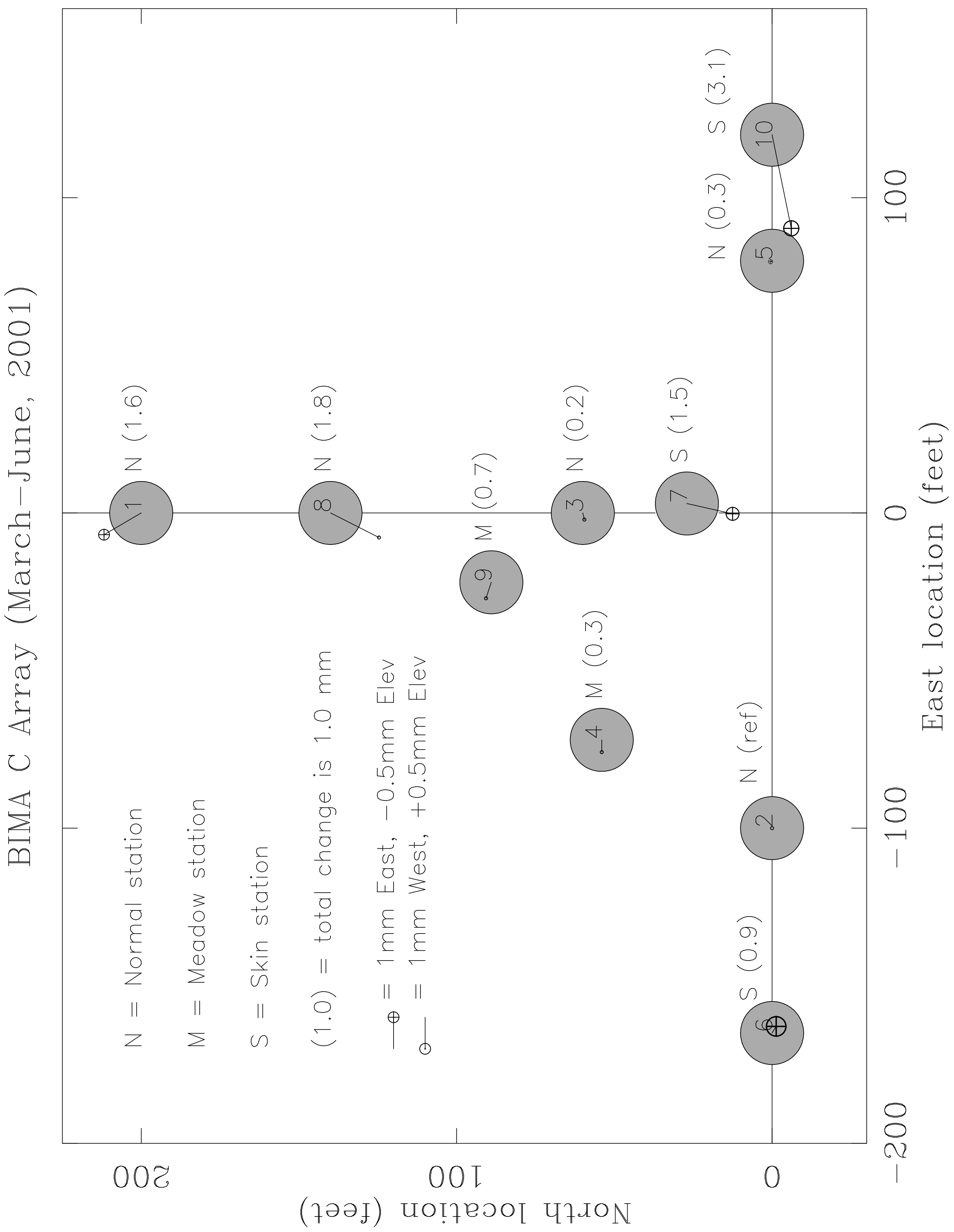

Fig. 2.— Antenna layout and measured motions