VLBI geodesy: 2 parts-per-billion precision in length determinations for transcontinental baselines

J.L. Davis, T.A. Herring, and I.I. Shapiro
Harvard-Smithsonian Center for Astrophysics
Cambridge, Massachusetts 02138

ABSTRACT. We have used very-long-baseline interferometry (VLBI) to make twenty-two independent measurements, between September 1984 and December 1986, of the length of the 3900-km baseline between the Mojave site in California and the Haystack/Westford site in Massachusetts. These experiments differ from the typical geodetic VLBI experiments in that a large fraction of observations are obtained at elevation angles between 4° and 10°. Data from these low elevation angles allows the vertical coordinate of site position, and hence the baseline length, to be estimated with greater precision. For the sixteen experiments processed thus far, the weighted root-mean-square scatter of the estimates of the baseline length is 8 mm. We discuss these experiments, the processing of the data, and the resulting baseline length estimates.

1. INTRODUCTION

In recent years, the precision of estimates of baseline length obtained from the analysis of Mk-III very-long-baseline interferometry (VLBI) data has passed below the level of 10 parts-per-billion. The limiting source of error continues to be the atmosphere. The effects of atmospheric errors on estimates of baseline length are discussed in Lanyi [1984], Davis *et al.* [1985], Davis [1986], Herring [1986], and Treuhaft and Lanyi [1987]. The typical treatment of atmospheric propagation delay in the analysis of geodetic VLBI data involves the use of surface meteorological measurements (and possibly radiometric measurements; see Elgered *et al.* [1987]) to determine an *a priori* value for the zenith propagation delay, and the use of a mapping function. (The mapping function describes the elevation-angle dependence of the propagation delay, *i.e.*, the number of air masses traversed.) Corrections to the *a priori* value of the zenith delay are then estimated, along with the relevant geodetic parameters, from the VLBI data.

The unique elevation-angle dependence of the atmospheric propagation delay allows a precise estimate to be made of the zenith-delay corrections. However, the sensitivity of the VLBI group-delay measurement to a change in the zenith delay is highly correlated with the sensitivity of the group delay to a change in the vertical coordinate of site position for small ranges of air mass. By observing sources at low elevation angles, we can decrease the correlation of the estimates of the zenith-delay corrections with those of the vertical coordinate of site positions, and thereby obtain a more precise estimate of those (and other) parameters. Nevertheless, many schedules for geodetic VLBI experiments include no observations below about 10° elevation at any site. This omission is primarily intended to *avoid* the effects of errors in the mapping function used, since such errors are generally worse at lower elevations. (It is harder to predict atmospheric properties at greater horizontal distances from the site.) We therefore pose the question: What is the "optimum" minimum elevation angle to minimize errors in baseline-length estimates?

M. J. Reid and J. M. Moran (eds.), The Impact of VLBI on Astrophysics and Geophysics, 367–368.

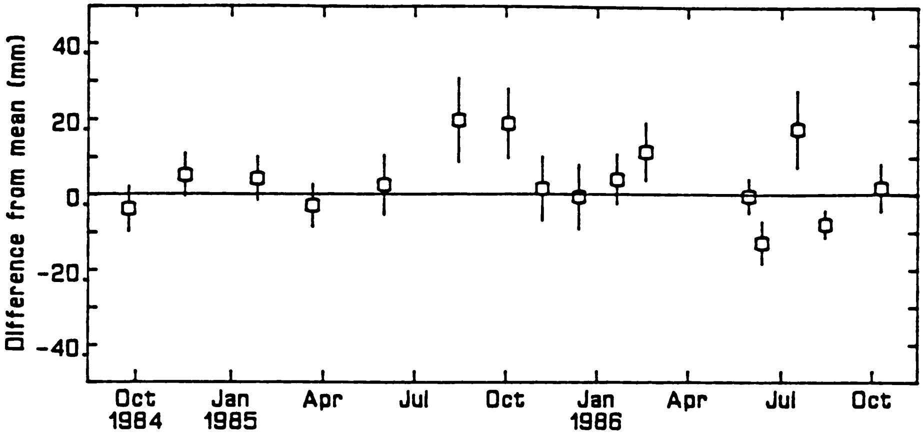

Figure 1. Estimates of the length of the baseline from Haystack/Westford to Mojave (see text). A mean value of 3, 904, 144, 248 mm has been subtracted from the values shown.

2. DESCRIPTION OF EXPERIMENTS and RESULTS

In order to study this question, we designed VLBI experiments known as "low-elevation" experiments in reference to their scheduling strategy: the attempt is made to observe low in the sky as frequently as possible, within the limits of the antennas used. For the standard set of low-elevation experiments, we used the Mojave site ($\epsilon_{min} = 8°$) in California and the Haystack/Westford site ($\epsilon_{min} = 4°$) in Massachusetts.

The processing of the data from these experiments differed in several respects from the processing which we employed several years ago (see, *e.g.*, Clark *et al.* [1985]) for geodetic VLBI data. A new mapping function for the dry atmosphere, developed by Davis *et al.* [1985], and accurate to about 10 mm at 5° elevation for a wide range of atmospheric conditions, was used. Another improvement was the use of a Kalman filter to estimate clock offsets and zenith delay corrections. Each of these corrections is modeled as a time-varying stochastic process, the statistics of which are deduced from other sources; the values of the corrections for the epochs of the VLBI observations are estimated by the Kalman filter. Finally, we used radiometric data to estimate the "wet delay" when these data are available.

In Figure 1, we present the estimates of the Haystack-Mojave baseline lengths as a function of experiment date. The error bars represent the standard deviation of the estimate of the baseline length, deduced from the propagation of the stochastic errors involved. These errors include the the measurement errors of the group-delay observations and the stochastic behavior of the clocks and atmospheres. The weighted root-mean-square scatter of the estimates about their weighted mean is 8 mm, representing a fractional repeatability of 2 parts-per-billion.

This work was supported by Air Force Geophysics Laboratory contract F-19628-86-K-0025; NASA grant NAG5-538; and NSF grants EAR-83-06380 and EAR-86-18989.

Clark, T.A. *et al.*, *IEEE Trans. GARS* **GE-23**, 438–449, 1985.
Davis, J.L., T.A. Herring, I.I. Shapiro, A.E.E. Rogers, G. Elgered, *Radio Science* **20**, 1593, 1985.
Davis, J.L., U.S. Air Force report AFGL-TR-86-0243, 1986.
Elgered, G., J.L. Davis, T.A. Herring, I.I. Shapiro, this volume, 1987.
Herring, T.A., *J. Geophys. Res* **91**, 9177–9182, 1986.
Lanyi, G.E., *Proc. Int. Symp. Space Tech. Geodyn.*, IAG/COSPAR,**2**, 184–195, 1984.
Treuhaft, R.N., G.E. Lanyi, *Radio Science* **22**, 251–265, 1987.