GPS Measurements of the Baseline between Quincy and Platform Harvest

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Abstract *As part of Topex altimeter verification, the Global Positioning System has been used to measure the baseline between the verification site at oil platform Harvest and a GPS antenna collocated with the satellite laser ranging site at Quincy, California. Data from Harvest, Quincy, and a global network of stations, collected between September 25, 1992, and December 17, 1993, have been analyzed to obtain 272 single-day estimates of the baseline. These daily estimates have in turn been fitted with a linear model, yielding a single estimate of the baseline and its rate of change. Changes in the horizontal components of the baseline reflect the relative tectonic motion of the Pacific plate and the Sierra Nevadan microplate, along with local motion at Harvest and Quincy. The vertical component, crucial to verification, is determined with millimeter-level accuracy and shows no significant variation during the measurement interval.*

Keywords GPS measurements, geodesy, tectonic plate motion.

Introduction

Measurements made with the Global Positioning System (GPS) provide an estimate of the baseline (vector separation) between a monument at the Topex verification site, on oil platform Harvest, and a second monument collocated with the satellite laser ranging (SLR) tracking station near Quincy, California. This measurement can then be combined with measurements of the offset of the GPS monument with respect to the SLR monument at Quincy, and the offset of the GPS monument at Harvest with respect to the surface of the ocean below, to specify the location of the ocean surface in the SLR reference frame. When further combined with orbital measurements of the Topex/Poseidon satellite, this knowledge furnishes an independent calibration of the measurement made by the satellite's altimeter as it overflies the platform.

GPS data were collected more or less continuously at both Quincy and Harvest throughout the verification period (from September 22, 1992, to about February 25, 1993) and thereafter. These data were divided into day-long segments for analysis and yielded an independent estimate of the Quincy–Harvest baseline for each day analyzed. Since Harvest lies on the Pacific plate and Quincy is on the Sierra Nevadan microplate, the time series of these daily estimates is expected to reveal a slow variation, on the order of a few cm per year, caused by tectonic motion and possibly by subsidence of the oil platform. Accompanying this slow drift, there may also be more rapid variations arising from various unmodeled effects.

The following section describes the GPS instrumentation and how it was set up and operated at the two stations. The third section discusses the processing of the baseline data, and the fourth examines the results of this analysis. The last section presents conclusions.

Instrumentation and Data Collection

Both Harvest and Quincy are equipped with TurboRogue SNR–8000 GPS receivers. Connected to each receiver is a crossed-dipole-type antenna mounted on a cylindrical choke ring. This ring reduces the effect of multipath, the dominant error source in the GPS measurements, by suppressing signals that approach the antenna from low elevation angles. A low-noise preamplifier attached beneath the choke ring boosts the signal before sending it to the receiver.

The receiver installation at Quincy is fairly typical. This laser tracking site is located in the Plumas National Forest about 4 km north of Quincy, California, and about 611 km north of Harvest. Since 1982, the laser tracking station has been located over monument #7109. On September 6, 1992, the TurboRogue antenna was installed on a leveling plate directly over monument #7221, about 55 m south of #7109. The leveling plate allows the antenna structure to be centered and leveled precisely over the monument. A 95–m length of RG–214 cable connects the antenna to the receiver, frequency standard, and modem, which are installed in the station's office trailer.

A disadvantage of the ground mount is its vulnerability to snow, which covered the antenna to a depth of several feet beginning on January 5, 1993. As a result, the data from Quincy were unusable from January 5 until heavy rain melted the snow down to ground level on February 19. At that time the entire receiver system was replaced, and the station resumed routine operation on March 26.

At the oil platform, the unique site required a special installation. It was necessary to place the antenna as high as possible in a location with an unobstructed view of the sky, in order to minimize multipath and maximize the visibility of the satellites. The mount also had to be exceptionally rugged and provide a sturdy cover, in order to protect the antenna from the harsh environment. It was decided to place a custom-designed monument on the sloping roof of the heliport stairwell, virtually at the highest point on the platform. From the antenna, a cable carries the GPS signals to the receiver in the control shed.

In operation, the GPS receivers are programmed to track all visible satellites, up to a maximum of eight. The range and phase data are written to a 4-megabyte internal memory card at 30-second intervals and stored for later retrieval. Once a day, an auto-dialer calls each receiver and collects the previous 24 hours of data. After retrieval the data files are transferred from the auto-dialer to archival storage, logged, and converted to a standard format in preparation for analysis.

Processing of GPS Baselines

For each day, the GPS baseline from Quincy to Harvest is determined by combining the data collected from those two receivers with the data from a global network of GPS tracking stations and performing a multiparameter fit to all the data simultaneously. These daily fits are performed regularly as part of a long-term program of global geodetic monitoring (Zumberge *et al.*, 1993). Consistency with the ITRF91 reference frame (International Earth Rotation Service, 1992) is assured by holding as many as eight "fiducial" stations at their ITRF91 coordinates. The GIPSY (GPS Inferred Positioning SYstem) software package, developed at JPL, has been used throughout the analysis described here.

When the first verification data became available in September, 1992, Harvest and Quincy were not yet part of the global network, and the verification data were analyzed separately, but in parallel with, the standard daily reductions. Since January 18, 1993, however, the verification results have simply been extracted from the standard daily reductions.

In general, the processing of each day of data proceeded in the following steps:

1) Monitor the archive for adequate data from the global network. Occasionally data from Harvest or Quincy were unavailable, and no baseline could be estimated. At other times, part or all of the GPS constellation was undergoing tests, and the estimated baselines proved to be unreliable during those intervals. The affected days have therefore been removed from the baseline time series.

2) Edit the processing control parameters to reflect known anomalies (stations having problems, satellites undergoing maneuvers, and so on) in the current day's data.

3) Perform the standard analysis, including the following steps: generate a priori orbits, edit the data, model the observations, and estimate the parameters. Each day's reduction actually used 30 hours of data from each station, including the last three hours of the previous UT day and the first three hours of the following day. Although the input data were generally sampled at 30-second intervals, the standard reduction thinned the data to $7^1/_2$-minute intervals (10 minutes between February 4 and October 31, 1993, and 5 minutes before that) in order to reduce the processing time and storage requirements. Table 1 lists the parameters that are estimated in the standard reduction. Solid Earth tides were modeled but not estimated, and ocean loading was modeled (but not estimated) only after November 3, 1994.

4) Review the run logs and examine the residuals of the measurements with respect to the fitted model, in order to identify problems with the input data. Edit the data further, if necessary, and rerun the estimation step. Repeat this examine-edit-estimate loop as often as necessary.

5) Extract from the final solution the results relevant to verification, format those results appropriately, and transfer them to the verification database.

GPS Baseline Results

The GPS baseline between Quincy and the verification site at oil platform Harvest has been estimated for 272 days between September 25, 1992 and December 17, 1993. Although this interval extends well beyond the end of the verification period, the additional data contribute significantly to the accuracy of the final estimate of the baseline, and particularly to the estimate of the linear rate of change of the baseline. Estimates have not been made for all days in the interval, for the various reasons discussed above. The longest single outage, which lasted from

Christmas day, 1992, until March 26, 1993, resulted from a combination of receiver outages and snow cover at Quincy.

Despite the gaps, the remaining measurements easily suffice to determine the Quincy-Harvest baseline with the required uncertainty of 2 cm in the vertical component (Topex/Poseidon Joint Verification Team, 1992, p. III–9). Figures 1–3 show the time series of the three components of the baseline in the local (east, north, vertical) coordinate frame. The coordinate axes are aligned with the corresponding directions at the platform, and the vertical component increases upward. In each figure an approximate mean value, indicated in the label for the vertical axis, has been subtracted from the plotted values. Although the east and north components (Figures 1 and 2, respectively) are less significant for verification than the vertical (Figure 3), they do reflect the general quality of the daily solutions; and like the vertical they can be tested for consistency with comparable measurements, as discussed below.

Three different plotting symbols indicate the use of three slightly different analysis strategies, as indicated in the legends. Generally speaking, the evolution of the strategy parallels that of the standard daily global analysis, as described in the previous section and in Table 1. On December 8, 1992, the original strategy was modified slightly in two ways: by introducing an improved gravity model into the GPS orbit analysis, and by updating the locations of the fiducial stations monthly rather than holding them fixed at their locations on July 1, 1992. After the long gap in the data, the verification analysis and the standard analysis are identical.

In all three figures, the error bars represent the formal uncertainties (1-σ) ascribed to the estimates by the GIPSY analysis software. Weighted linear fits to the time series, indicated by the dashed lines, indicate that the actual scatter of the points is somewhat higher than one would predict from the formal errors. This discrepancy is largest for the north component, where the scatter of the daily points suggests that the true uncertainties are about twice the formal errors.

The averaged values of the baseline components, and their estimated rates of change, are shown in Table 2. Note that the epoch to which the values in Table 2 refer is approximately June 9, 1993. For all components, the uncertainties have been scaled up to conform to the actual variance of the time series, rather than the nominal a priori uncertainties. As expected, the vertical is less well determined than the horizontal components. However, its fitted rate of change is only –0.17 mm per year, and in fact the data are consistent with a vertical velocity of zero. Figure 3 also shows no convincing evidence for unmodeled systematic variations on time scales of days to weeks.

Ryan *et al.* (1993, p. 7.195) have used very long baseline interferometry to measure the rate of change of the baseline from Quincy to Vandenberg Air Force Base for the Crustal Dynamics Project (CDP). Vandenberg is an onshore site about 11 km from Harvest, and so its tectonic motion with respect to Quincy is expected to be nearly the same as that of the platform. Table 3 reproduces the CDP data along with the current measurements. Note that for comparison, the verification measurements have been converted to the local (length, transverse, vertical) coordinate frame used by the CDP, and that the "vertical" directions in the verification and CDP frames are defined differently. The table shows satisfactory agreement between the two sets of measurements in the length and vertical components, although the CDP determination of the vertical rate is relatively poor. In the transverse direction the results are less consistent, differing by about 2.1 times their root-sum-square uncertainty.

Conclusions

The time series of 272 single-day measurements of the baseline between the GPS antennas at Quincy and platform Harvest conforms well to a linear model. Both the a priori errors and the post-fit residuals of the measurements imply that at any time during the interval spanned by the data, the components of the baseline are known with a uncertainty on the order of a millimeter. In particular, the vertical component was constant, at the level of its uncertainty, during the measurement period. These results are supported by VLBI measurements of the similar baseline from Quincy to Vandenberg Air Force Base, which shows a comparable rate of change. Continuing GPS measurements will further refine these results.

The research in this article was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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ESTIMATED PARAMETERS	COMMENTS
All satellite orbits	Epoch state includes 3 components of position and velocity, 6 parameters for each satellite.
Solar radiation pressure parameters	G_X, G_Y, and G_Z each estimated as a constant plus a stochastic component modeled as a first-order Gauss-Markov process with a time constant of 4 hours. G_X and G_Z constants are constrained to be identical (Bierman, 1977).
All estimated station locations	3 constant components for each station.
Polar motion (X and Y components)	Each modeled as a constant and a fixed rate that change every 24 hours.
UT1 – UTC	Modeled as a constant and a fixed rate that change every 24 hours.
GPS carrier phase constants	On the order of 1000 parameters of this type, for a 30-hour solution.
All satellite and receiver clocks	Stochastic "white noise" parameters (independent values estimated for each measurement epoch.)
Wet zenith troposphere at each station	Stochastic "random walk" parameters constrained to 1 cm/$\sqrt{\text{hour}}$

Table 1. Summary of Parameters Estimated in Standard GIPSY Estimation for Verification

COMP.	VALUE (meters)	RATE (mm/year)
x	-168,838.2612 ± 0.00040	-10.9 ± 1.1
y	–328,489.2613 ± 0.00046	+26.0 ± 1.2
z	–487,029.0082 ± 0.00040	+23.9 ± 1.1
e	+22,416.4722 ± 0.00031	–22.6 ± 0.8
n	–610,168.7844 ± 0.00022	+29.0 ± 0.6
v	+28,290.7136 ± 0.00063	–0.17 ± 1.7

Table 2. Estimated Baseline from Quincy to Harvest

in Global (x,y,z) and Local (e,n,v) Coordinates

COMPONENT	VERIFICATION RATE (mm/year)	CDP RATE (mm/year)
Length	–29.8 ± 0.56	–29.9 ± 1.8
Transverse	+21.6 ± 0.82	+18.5 ± 1.2
Vertical	–1.0 ± 1.72	+9.7 ± 9.6

Table 3. Comparison of Measured Baseline Rates for

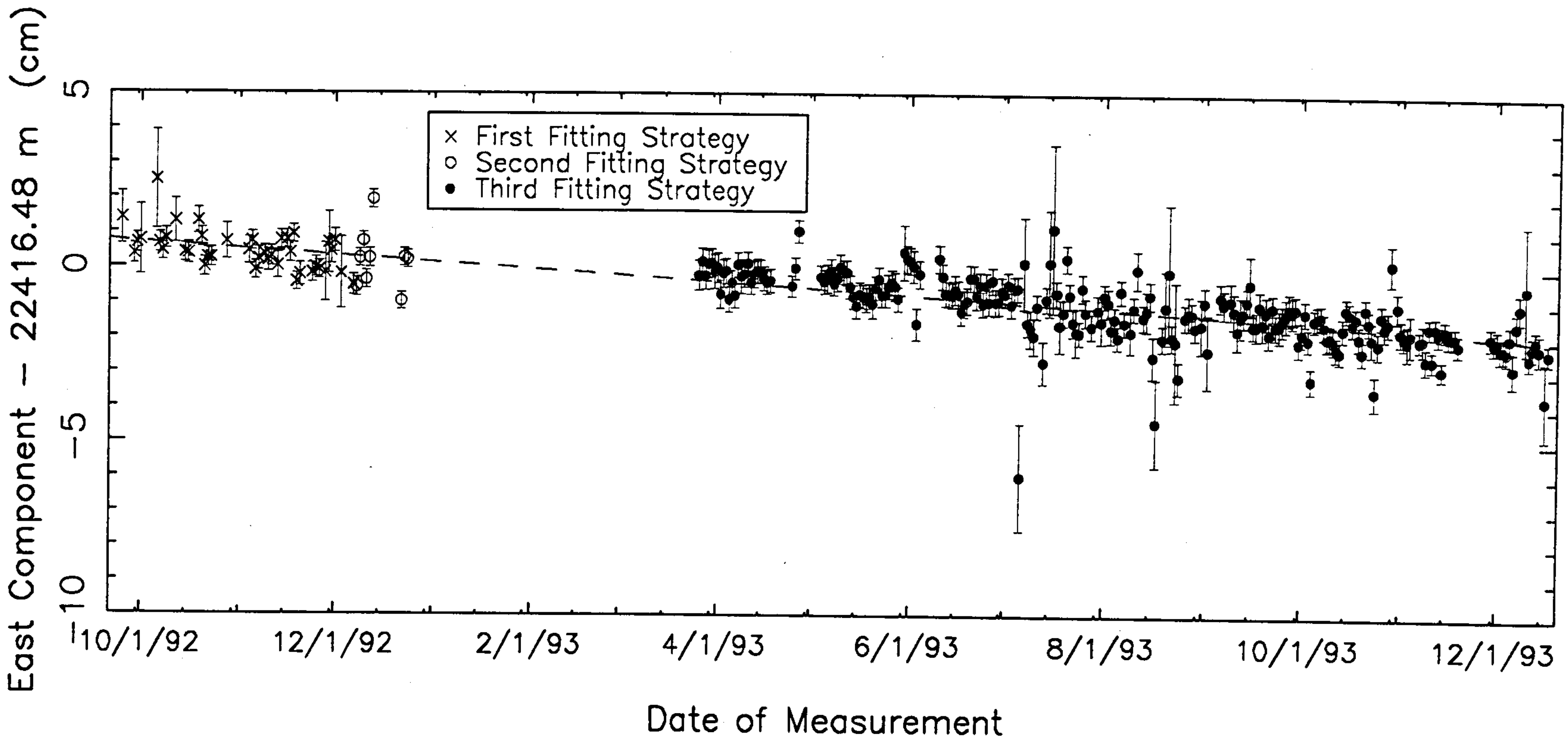
Quincy–Harvest (Verification) and Quincy–Vandenberg (CDP)

Figure Captions

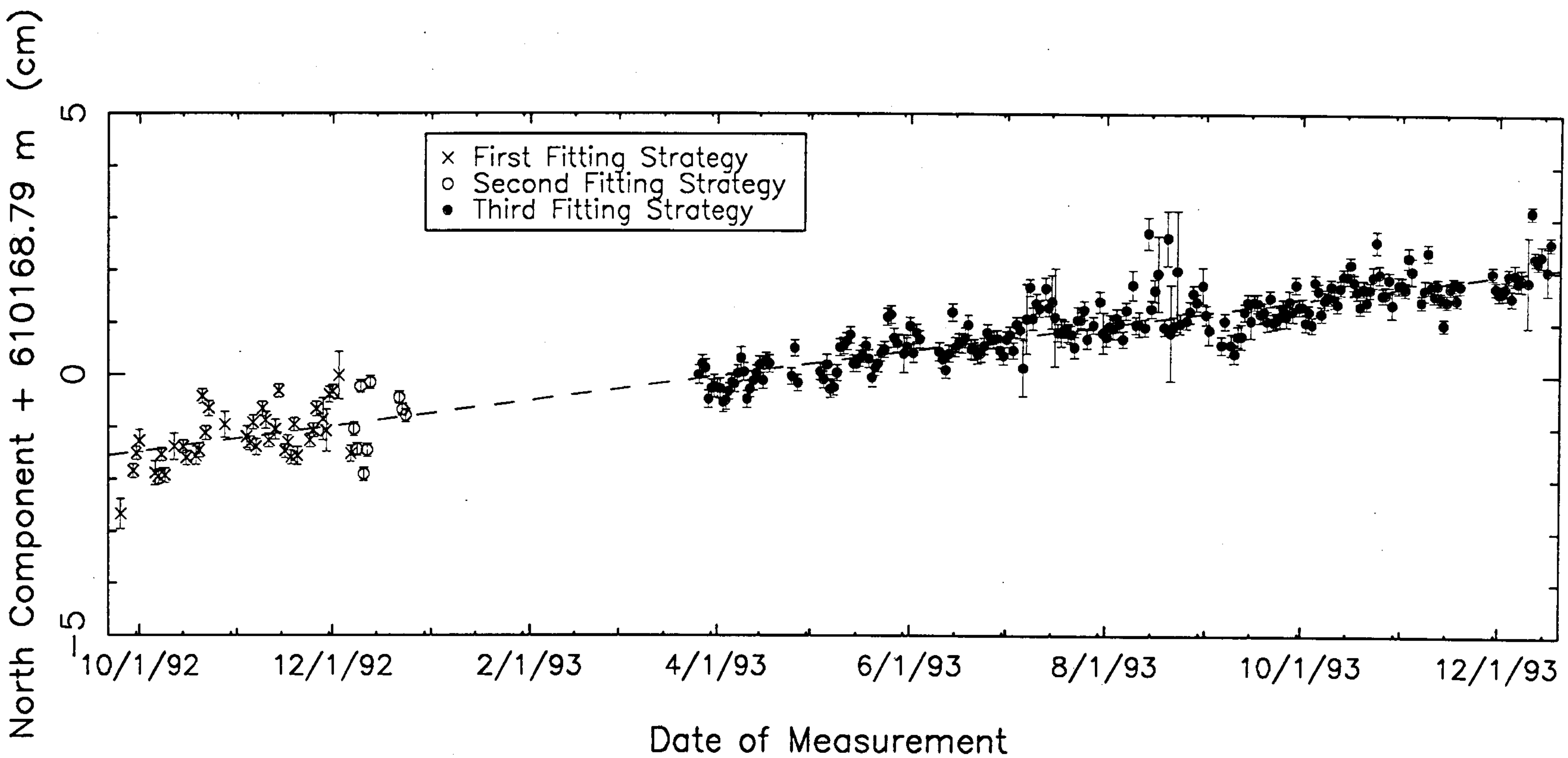
Figure 1: East Component of the Baseline from Quincy to Harvest

Figure 2: North Component of the Baseline from Quincy to Harvest

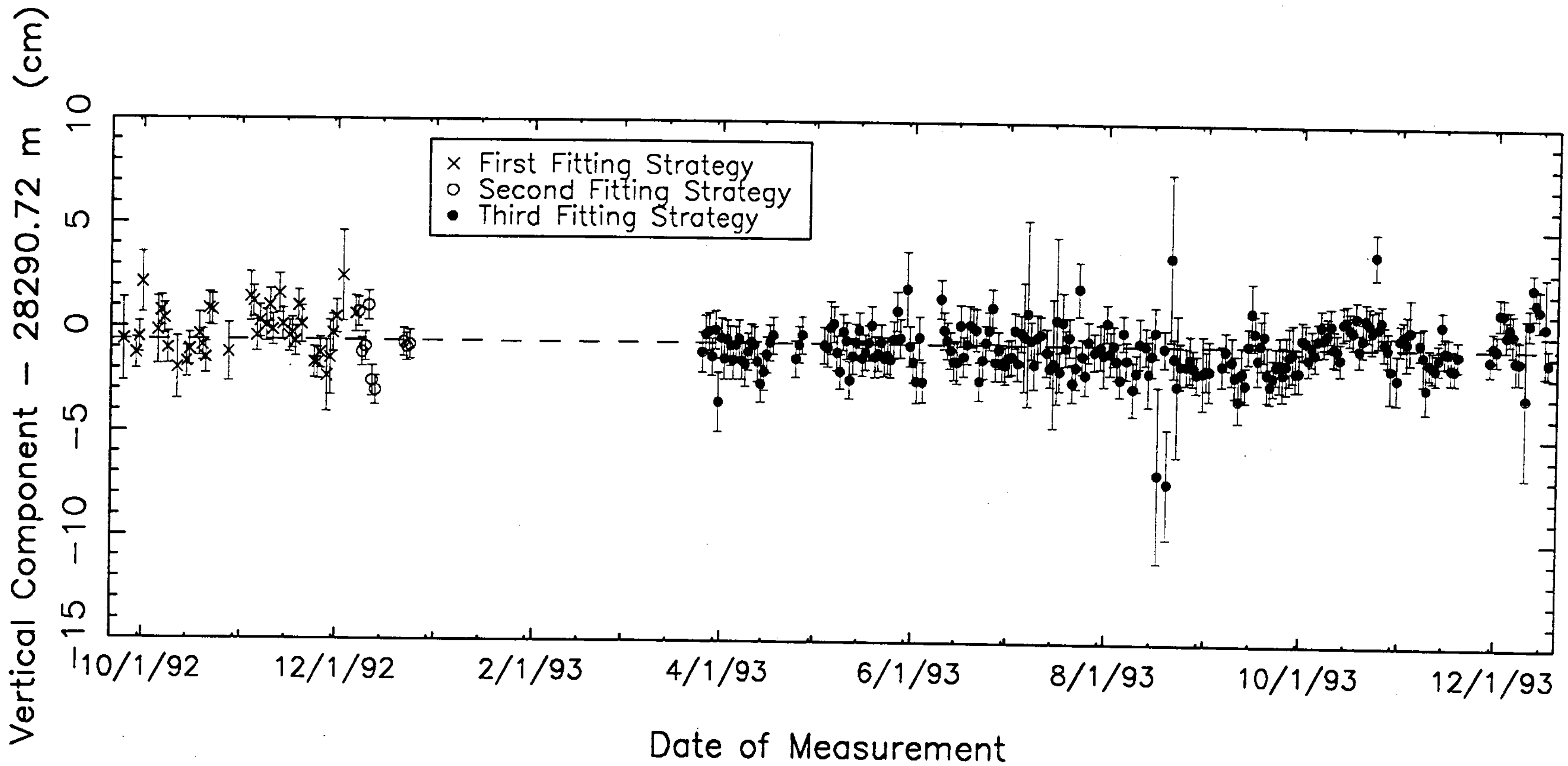
Figure 3: Vertical Component of the Baseline from Quincy to Harvest



East Component − 22416.48 m (cm)
5
0
−5
−10
× First Fitting Strategy
○ Second Fitting Strategy
• Third Fitting Strategy
10/1/92
12/1/92
2/1/93
4/1/93
6/1/93
8/1/93
10/1/93
12/1/93
Date of Measurement



First Fitting Strategy
Second Fitting Strategy
Third Fitting Strategy
North Component + 610168.79 m (cm)
5
0
−5
10/1/92
12/1/92
2/1/93
4/1/93
6/1/93
8/1/93
10/1/93
12/1/93
Date of Measurement


× First Fitting Strategy
○ Second Fitting Strategy
● Third Fitting Strategy
Vertical Component − 28290.72 m (cm)
10
5
0
−5
−10
−15
10/1/92
12/1/92
2/1/93
4/1/93
6/1/93
8/1/93
10/1/93
12/1/93
Date of Measurement