An Experiment for GPS Strain Seismometer

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Abstract

An experiment for GPS strain seismometer, which possibly records large-amplitude near-field seismic motions with flat frequency responses from zero to several 0.1 Hz, has been conducted. Assigning displacement motions with the double amplitude of 15 cm and with periods of 25-300 seconds to a GPS rover antenna, we have made 3-hour GPS observations also at 2 other base sites 160 m and 160 km apart from the rover site, with a sampling interval of 1 second. Post-processing kinematic analyses determine the rover site motion every second from two base sites. Comparison of post-processing results determined from two base sites 60 m and 160 km apart from the rover site show that kinematic GPS can resolve horizontal displacement motions with an accuracy of 1-2 cm every second even from a site 160 km apart, though there exist drift components up to 10 cm during a period of 3 hours. These drift components are, however, mainly due to the use of broadcast ephemerides, and these components will be removed if using precise ephemerides. Thus, our experiment shows a possibility of GPS strain seismometer, which records large-amplitude near-field ground displacement motion with flat frequency responses from zero to several 0.1 Hz.

1. Introduction

GPS can precisely determine baseline vectors between surveying points. Techniques of these precise GPS surveys are generally divided into two; static and kinematic one. Static GPS technique is usually used for precise baseline determination with long baselines up to several 1000 km, and the accuracy has now reached an order of 0.1 to 0.001 ppm from 100 km to a global scale of several 1000 km scale. This technique requires long observation sessions from hours to a day with several 10 seconds interval. In the long session, GPS satellites move long distances in the sky and the geometry of satellites is greatly changed, which make it easy to fix biases. On the other hand, kinematic GPS technique is used for fast baseline determination with relatively short baselines and a sampling interval of seconds. In this kinematic mode, there exist a

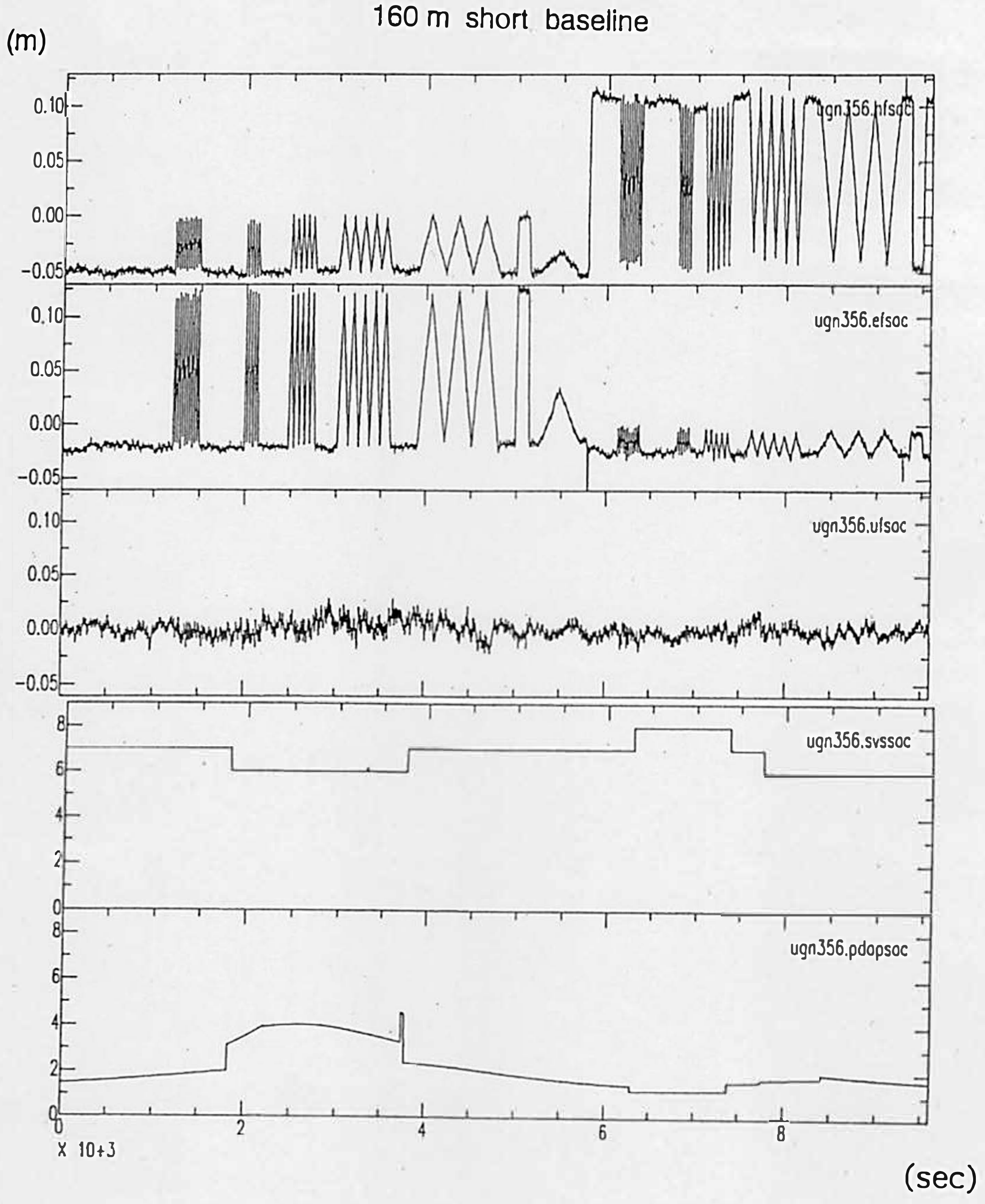


Fig.1 The rover motion determined from the base site 160 m apart.
From the top to the bottom, are shown N-S, E-W and vertical components, and the number of satellites and PDOP.

differential GPS technique, where a moving rover motion is determined relative to a fixed point every seconds. This can be precisely accomplished only with recently developed dual frequency P-code or Y-code GPS receivers. The rover motion generally means the motion where an antenna moves by walking, ship, car or airplane from one point to another.

Here, we examine, however, a possibility that kinematic GPS can detect

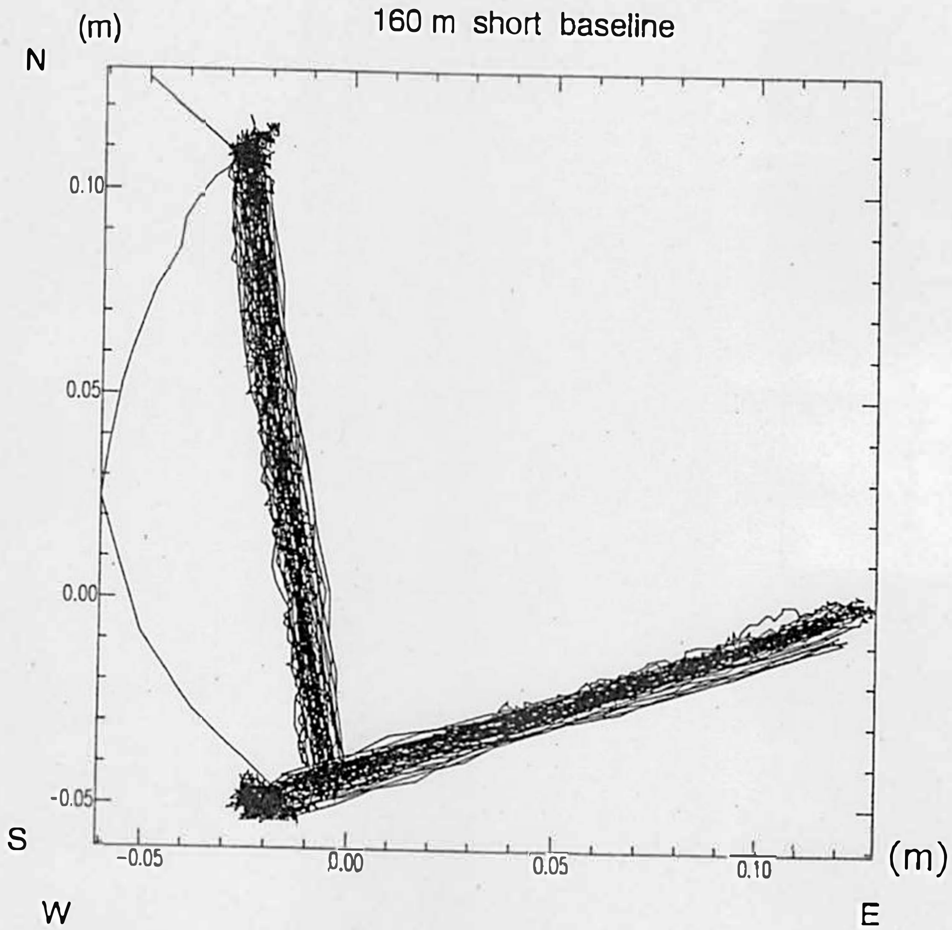


Fig.2 The horizontal motion determined from the base site 160 m apart.

seismic ground motion itself due to an earthquake. If this is the case, GPS can be used as a strain seismometer, which can records large-amplitude ground displacement motion up to several meters with a period of seconds to static. If GPS observation is made just close to a faulting region and at a remote site where no seismic motion appears, a displacement motion in the faulting region, that is, a source time function of the earthquake, can be observed. This would be greatly helpful for understanding source processes.

Here, we made an experiment for GPS strain seismometer, where we gave displacement motions to a rover GPS antenna and made GPS observations also at two other base sites. Our GPS experiment shows that displacement motions given to the rover antenna can be resolved from the base site 160 km apart from the rover site.

2. Kinematic GPS experiment

In the ground of Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan, a rover GPS antenna was put on a slider which was oscillating with a double amplitude of 15 cm and variable velocity controlled by a rotat-

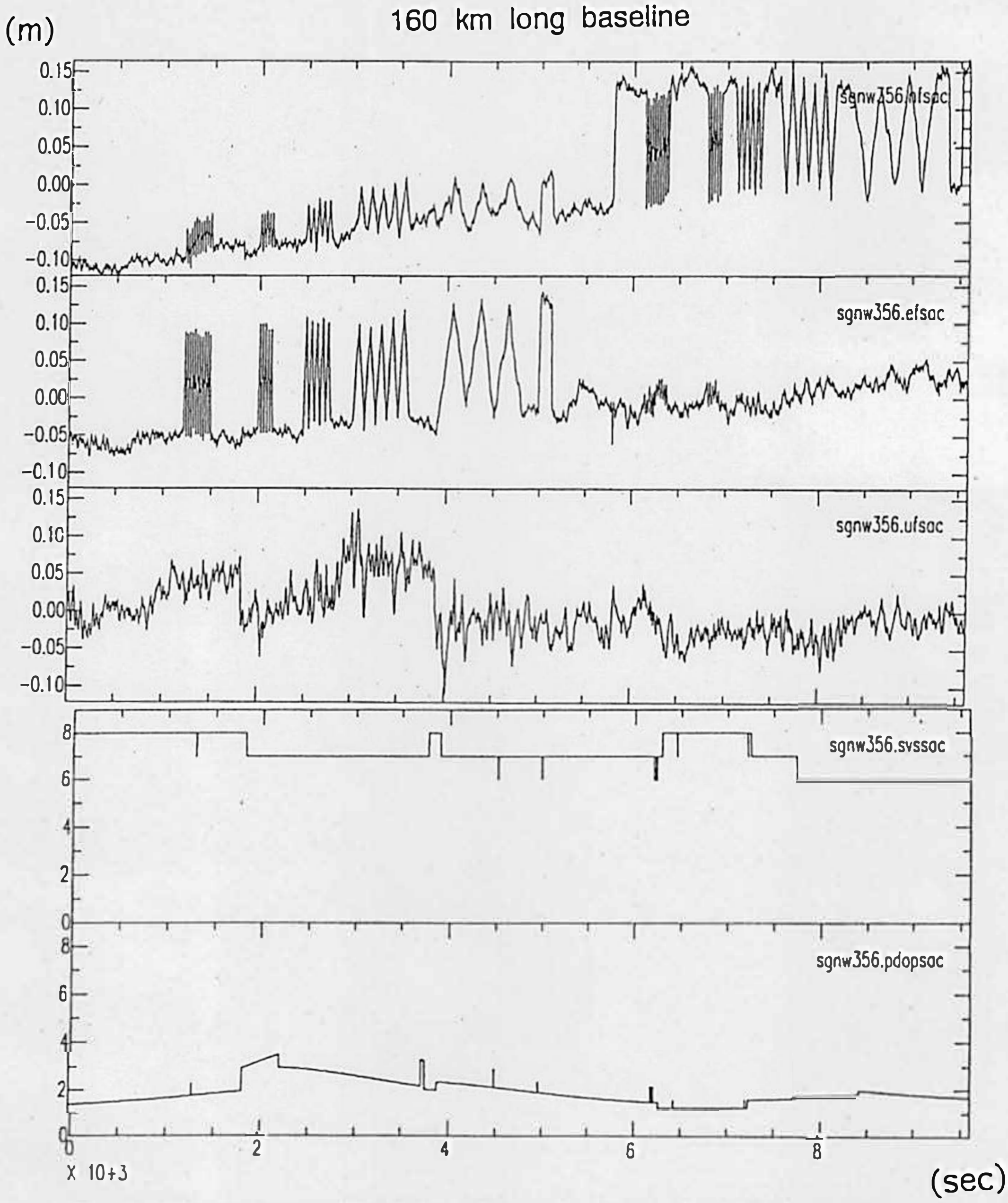


Fig.3 The same as Fig.1 but from the base site 160 km apart.

ing motor in a horizontal direction on December 22, 1994. By changing rotational speed of the motor, it took various times from 25 seconds to 300 seconds for the antenna to move 30 cm distance oscillatly. We employed Ashtech P-code GPS receivers Z-XII.

In the first 1 hour and 36 minutes and the last 1 hour and 3 minutes, we made an attempt to give east-west (E-W) and north-south (N-S) motions to the rover antenna measuring the direction with a compass. We made GPS observations with a sampling interval of 1 second in this rover site and two other base sites which are located 160 m apart in the east and 160 km apart in the south. However, as shown later, the first part of experiment was not aligned in the E-

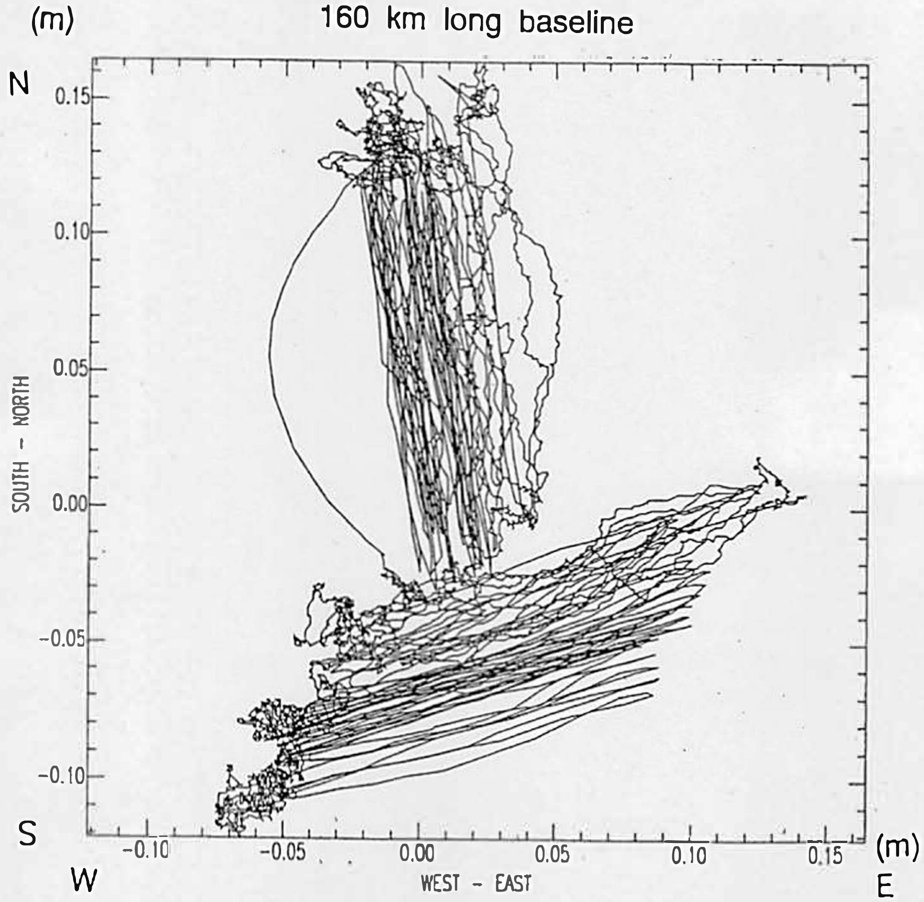
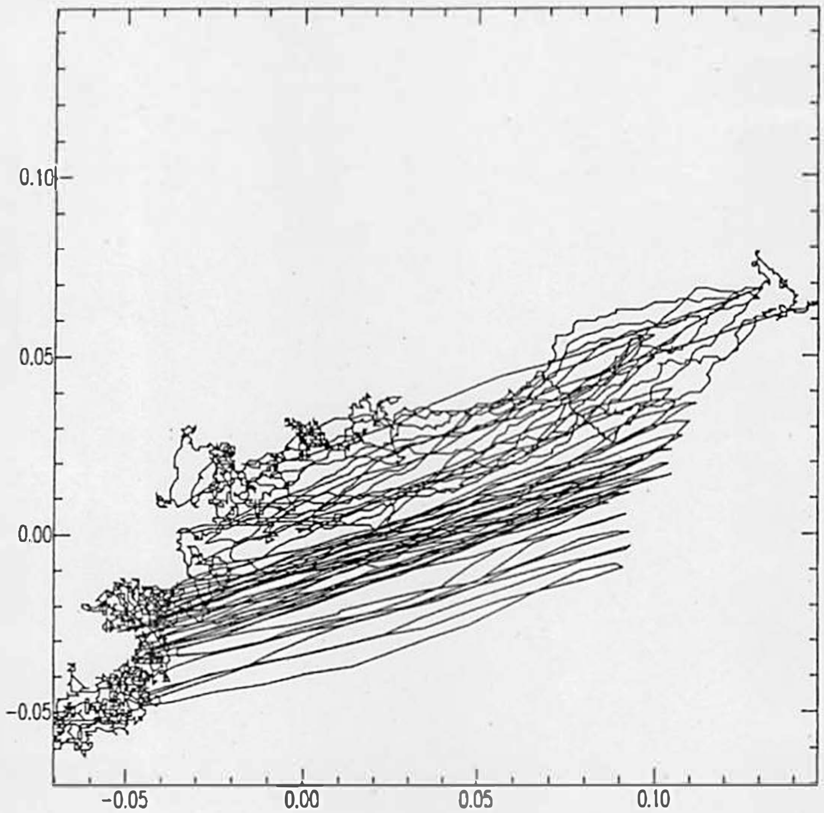


Fig.4 The same as Fig.2 but from the base site 160 km apart.

W direction probably due to mis-setting. In the last of experiment, we set the direction in the north indicated by a compass and the direction is about 6 degrees westwards. In advance, the WGS84 coordinates of two base sites were determined precisely with static GPS observations.

3. Analyses

After the experiment, GPS data are processed for two pairs of GPS data from the base and rover sites. We used a software named PNAV which are developed by Ashtech company for precise kinematic or differential GPS navigation. In this software, backward and forward Kalman filtering is used for obtaining reliable smooth relative positions of rover site, fixing the coordinate of base site. We used the navigation and walking mode for the parameters of Kalman filtering. Unfortunately, in the present version of software, we can not use precise ephemerides but only broadcast ones. Accordingly, orbital errors will affect the accuracy of the determined coordinate in the case of long baseline.



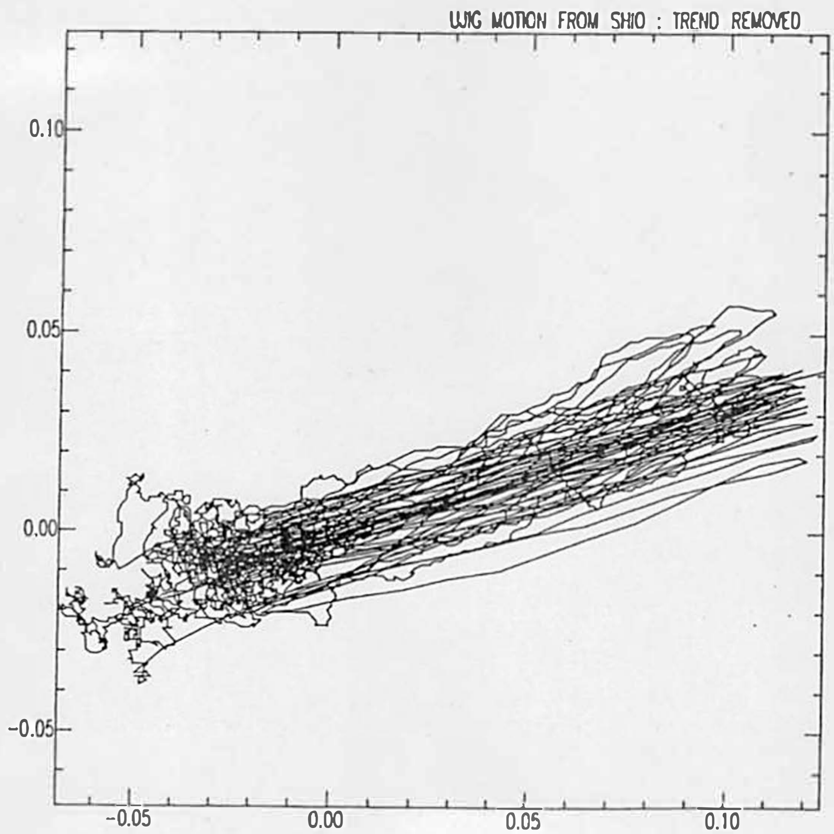


Fig.5 Enlarged plot of the first part of the experiment (uppper) and the one for the linear trend removed (lower).

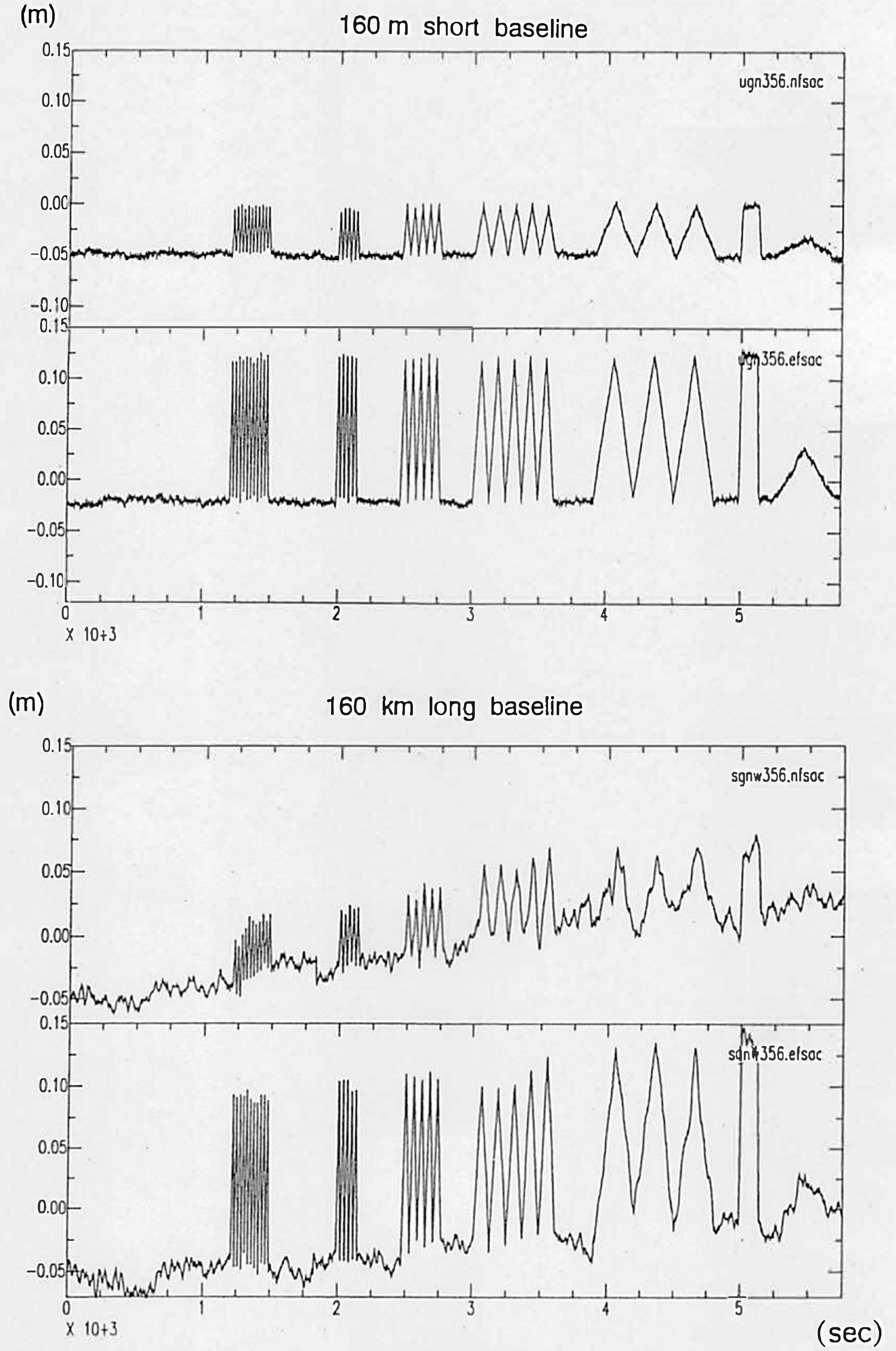


Fig.6 The horizontal motion (N-S and E-W) for the 160 m short baseline in the time window of 0 - 5750 seconds (upper) and for the 160 km long basline (lower).

In the short baseline of 160 m, L1 and L2 data were independently used and biases were completely fixed. But in the long baseline of 160km, ionosphere free linear LC combination was used for correction of ionospheric effects, but biases could not be fixed.

4. Results and discussions

In Fig.1, are plotted the time series of the rover motion determined from the base site 160 m apart. From the top to the bottom, are shown N-S, E-W, and height components, and the number of satellites and PDOP, every 1 second. As shown in the figure, in the first of experiments, a large amount of the north-south component appeared, which is due to mis-setting. In this short baseline, the noise level of horizontal components is less than 1 cm and that of vertical component is 1 cm. Figure 2 plots the horizontal motion which shows the E-W motion was misaligned. And the N-S motion is rotated counter-clockwise by 6 degrees. This is because we set the direction with a compass, and the magnetic north is rotaed counter-clockwise by 6 degrees from the north here. The width of the motions are within 10 mm. The width includes the real fluctuation of the motion of the device. The length of each oscillating swing is 15 cm, which is well resolved in this short baseline experiment. Figures 3 and 4 show the corresponding rover motion determined from the base site 160 km apart. Large drift components appear in two horizontal motions, which amount to 2 cm in the N-S component and 1 cm in the E-W during the period of 3 hours. And larger vertical motion appears in the vertical component. In the horizontal plot of Fig.4, are clearly seen the north-eastward drift. The double amplitude of each cycle is still 15 cm, which means the amplitude of the assigned displacement with periods from 25 to 300 seconds can be resolved even for this long 160 km baseline.

In Fig.5 (uuper), only the first part of the experiment is enlarged. The linear trends of N-S and E-W motion are removed to plot the horizontal motion in Fig.5 (lower). Comparison of these figures shows a simple linear trend reduction thins the apparent width of the motion. The drift components are mostly produced by orbital errors, so that the use of precise ephemerides instead of broadcast ones would reduce the drift components.

In Figs. 6, the N-S and E-W motions are plotted for the time window of 0 - 5750 seconds for 2 baselines. Even in the long 160 km baseline, the assigned motion is well reconstructed, though there are drift components. Figure 7 shows the motion for the time window of 4900 - 5250 seconds. In this time window, we assigned the motion corresponding a source time function with a rise time of 15 seconds and amplitude of 15 cm. Figure 7 indicates that we

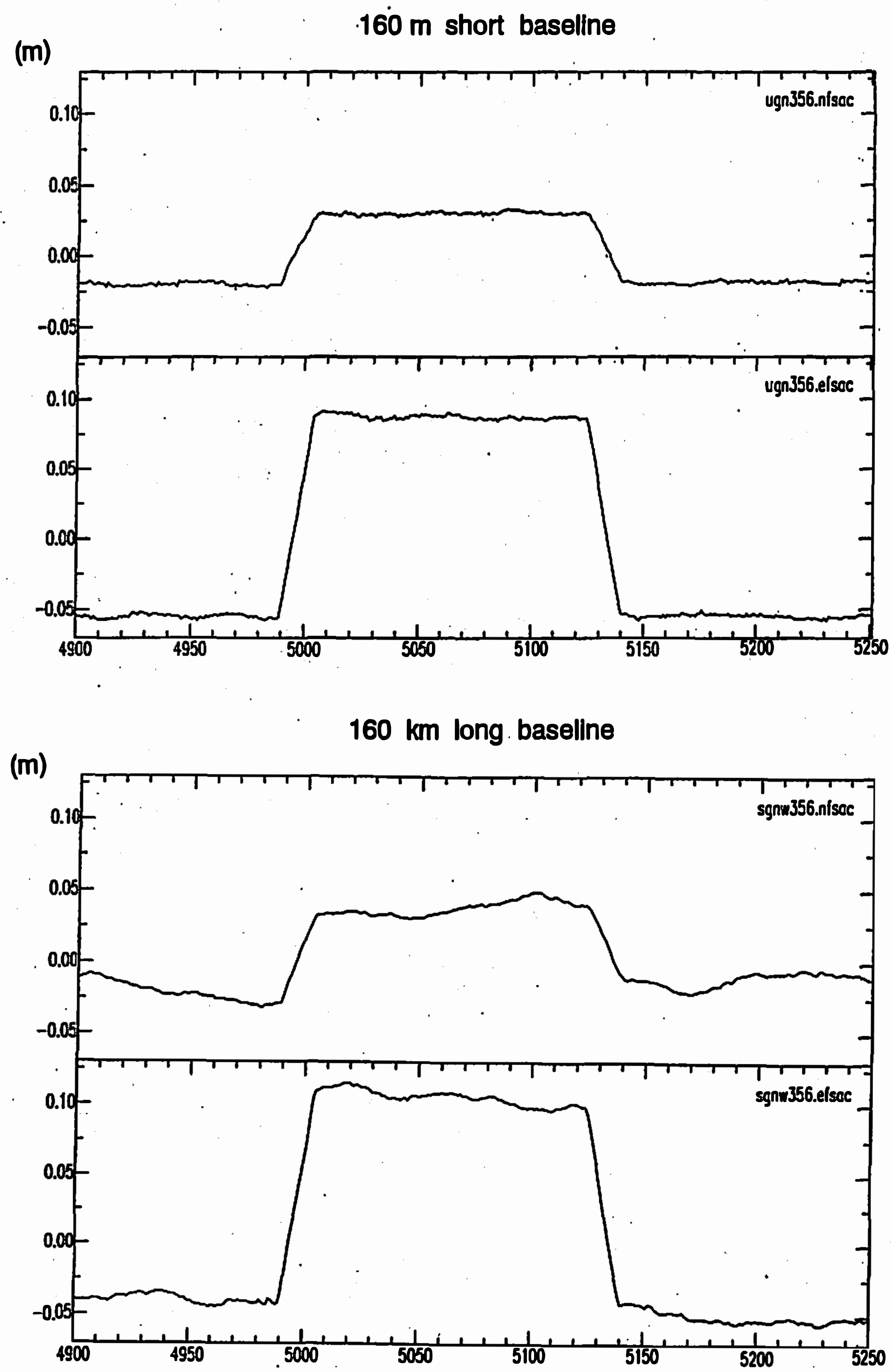


Fig.7 The horizontal motion (N-S and E-W) for the 160 m short baseline in the window of 4900-5250 seconds (upper) and for the 160 km long baseline (lower).

can resolve thé faulting motion even from a site 160 km apart. If a rover GPS site is located close to the faulting region and a base site is located 160 km apart from the faulting region, the travel time of first arrival P wave is larger than 20 seconds, so that at least for 20 seconds the base site will not have any motion and then we can measure the absolute ground displacement in the faulting region. So far, only accelerometer have recorded near-filed ground motion. GPS will give new information on near-filed ground motion in the following two points. One is that the displacement motion, instead of velocity or acceleration, with flat frequency responses from static to several 0.1 Hz can be recorded. And two is that GPS can records in principle large amplitudes up to several meters, which usual seismometers can not record. This is very important for the source study.