Application of Vertical GPS Positioning on Shipboard

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On 2 May 2000 (04:07, UTC), GPS users in single point positioning mode faced a new era of the system, without the application of S/A (Selective Availability). This was due to the change of the US Government policy on the application of the GPS after the IOC (Initial Operational Capability) declaration on 8 December 1993. Deregulation of GPS was brought forward 6 years ahead the initially planned date of year 2006. Deregulation of S/A has improved the accuracy of single point positioning considerably. Accordingly, the three-days measurement from 21 to 23 July 2000, at the Tokyo site, using a MX9112 GPS receiver, and an elevation mask of 5 degrees, showed a deviation of 10.7 m (2drms, 95 per cent).

The Hydrographic Department could use this GPS single point positioning of 10 m accuracy level to conduct continental shelf survey in the high seas and mobile positioning for ocean observation, even outside the area of DGPS with a medium frequency beacon. As for mobile positioning, GPS single point positioning without S/A, Differential GPS, Kinematic GPS, and Real Time Kinematic GPS are all of interest. Under these favourable circumstances on horizontal positioning accuracy, we also investigated altitude accuracy levels, using the above mentioned GPS approaches and report some results in this article.

GPS single point positioning gives us 3-D co-ordinates in latitude, longitude and ellip-soidal height on the WGS84 reference ellipsoid. The mean Sea Level is almost identical to the gravitational equi-potential surface (called Geoid surface), thus measuring the altitude of sea level accurately is identical to measuring the altitude of the geoid surface.

Utilisation of Altitude

Utilisation of Altitude with GPS Single Point Positioning

Estimated positioning accuracy (2drms,95 per cent) of single point positioning before deregulation of S/A was less than 100m horizontally, 156m vertically, according to the U.S. Federal Radio navigation Plan (1999). Thus, accuracy in altimetry in mobile objects has been the only practical index for on or off of S/A. For example, Figure 1 shows the effect of S/A on 20 April 1997 (02:51~20:00,UTC), using a GPS receiver MX9112 for the research on accuracy improvement of a survey vessel by the Hydrographic Department. Figure 1(a) shows the change in altitude, Fig. 1(b) shows the changes in latitude, longitude, Fig. 1(c) shows the change of hori-

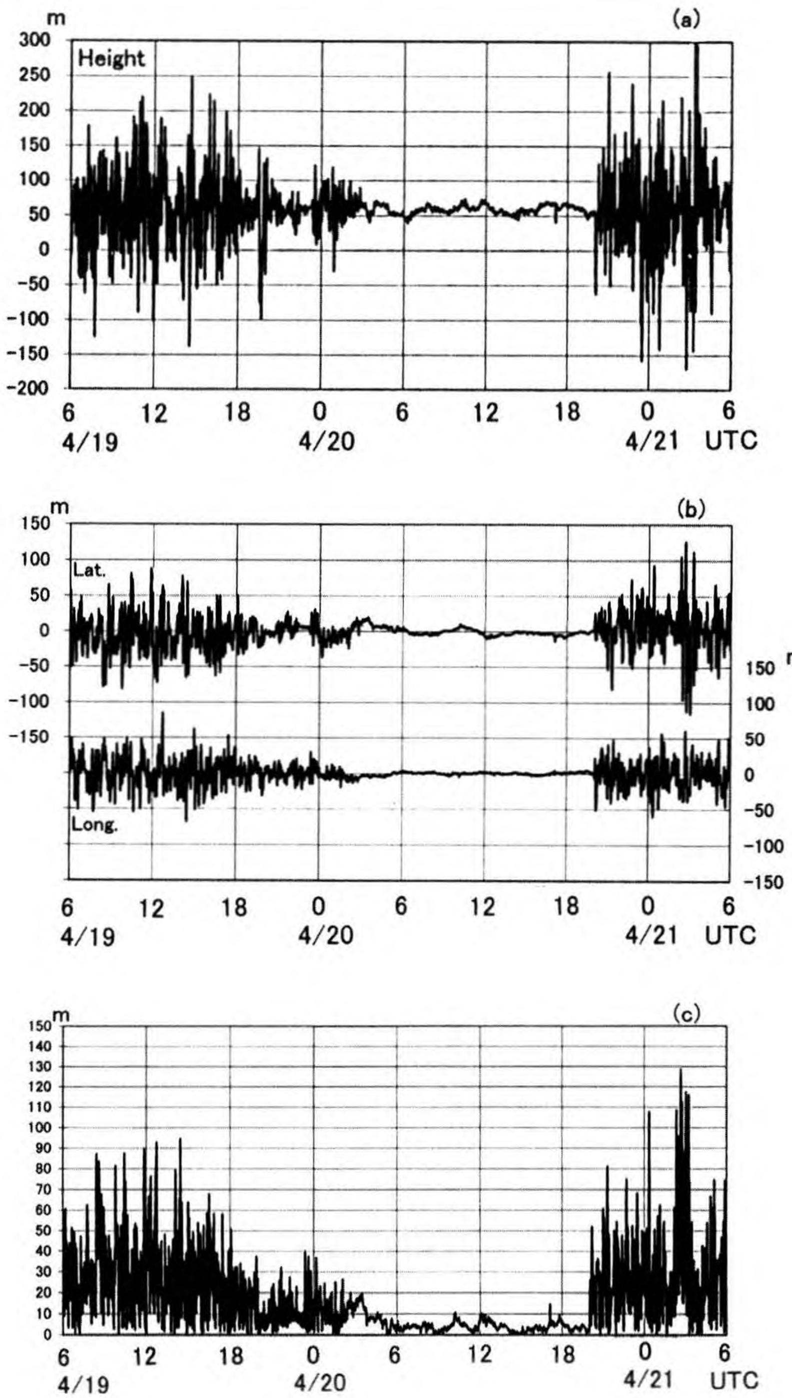

Figure 1: Example of S/A OFF positioning obtained from JHD's DGPS reference station
(a) Height
(b) Lat., Long.
(c) Horizontal deviation (1997/4/20)

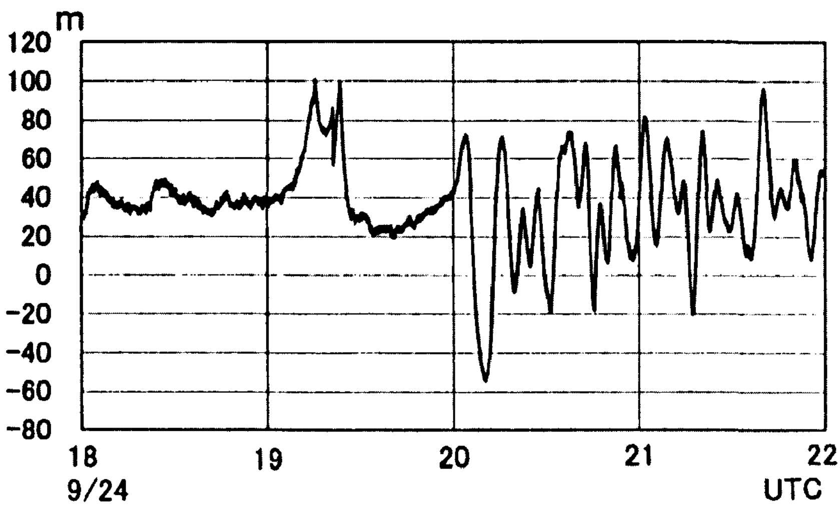

Figure 2: Example of S/A OFF to ON obtained by the survey vessel KAIYO (1994/9/24)

zontal deviation from the average position. These figures show explicitly the effect of deregulation of S/A in a single day. The similar status was also found in the data of the day before. This opportunity was the last deregulation before May 2, 2000. Figure 2 shows the deregulation effect observed by the survey vessel *Kaiyo* on 24 September 1994, using a 6-channel GPS receiver MX4200. During the period of deregulation of S/A, the altitude changed in the range of 30~40m, but after application of S/A at 08:00 (UTC), the altitude changed in the range of -50 to 100m. In the deregulated period, constant change in the range of 80~100 m can be indicated. Since 12-channel GPS receiver MX9112 on the ground station did not have such constant change at the same time interval, this large change might be caused by the change of the vessel heading when only 4~5 satellites were available. The similar observation record on 24 September 1994 for 3 days was also reported by the author (Uchida, 1996). These examples show the apparent change in altitude even on survey vessels, or maritime mobile objects. Table 1 shows the periods when S/A was deregulated. The time is expressed in UTC. Generally, deregulation and application of S/A are not announced, so the columns 2~4 in the table were estimated from the observed results. This table contains some parts, which are not identified or confirmed at the time. After deregulation of S/A, the changing behaviour in vertical directions can be used for monitoring the measuring system itself.

1	10 AUG. 1990 (--:--) ~ 1 JULY 1991 (04:00) standard level re-implemented on 15 NOV. 1991
2	6 SEP. 1992 ~ 22 SEP. 1992 unknown
3	17 SEP. 1994 (--:--) ~ 24 SEP. 1994 (20:00)
4	20 APR. 1997 (02:51) ~ 20 APR. 1997 (20:00)
5	2 MAY 2000 (04:07) , S/A was turned off

Table 1: Periods of S/A OFF

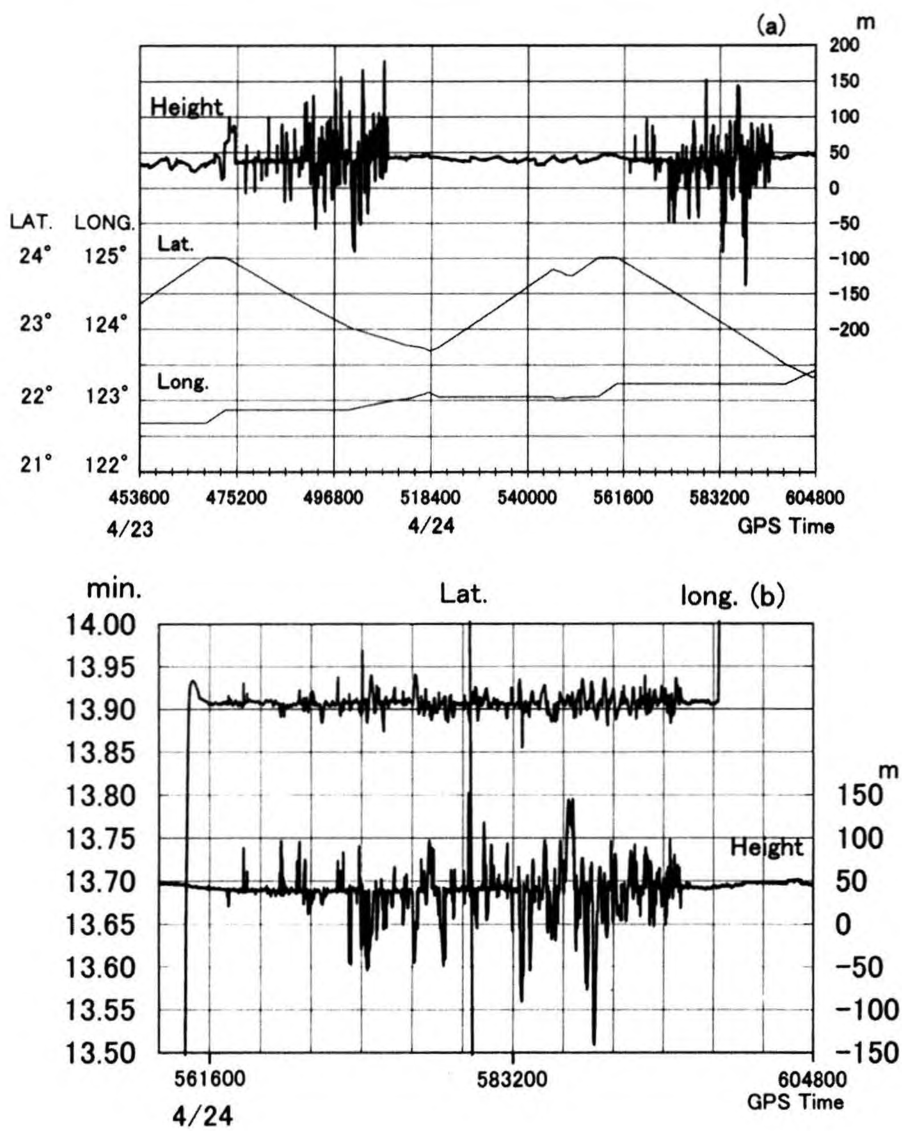

Figure 3a: Example of DGPS height obtained by the survey vessel SHOYO (1999/4/23~24). Lat. and long. coordinates also plotted

Figure 3b: Expansion of Figure 3a, GPS Time: 558000~604800 sec

Utilisation of Altitude with Differential GPS Positioning

A DGPS system with medium frequency beacon, which was officially available from 1 April 1999, has the prime reference station at the Shimosato Hydrographic Observatory (the Shimosato Ocean Geodetic Mainland Control Point), and some DGPS reference stations (GPS antenna phase centres). These are the positioning references around Japanese Islands, for DGPS users. Figure 3 (a) shows DGPS height-lat-long record by the survey vessel *Shoyo*, while continental shelf survey was conducted from 19 April to 14 May 1999 around Ishigaki-jima waters. Figure 3 (b) shows the enlarged part of Figure 3 (a), when correction of DGPS could not be applied properly. Generally, the survey vessel goes along the planned survey lines, so changes in latitude and longitude could not be easily distinguished from corrections by DGPS. However,

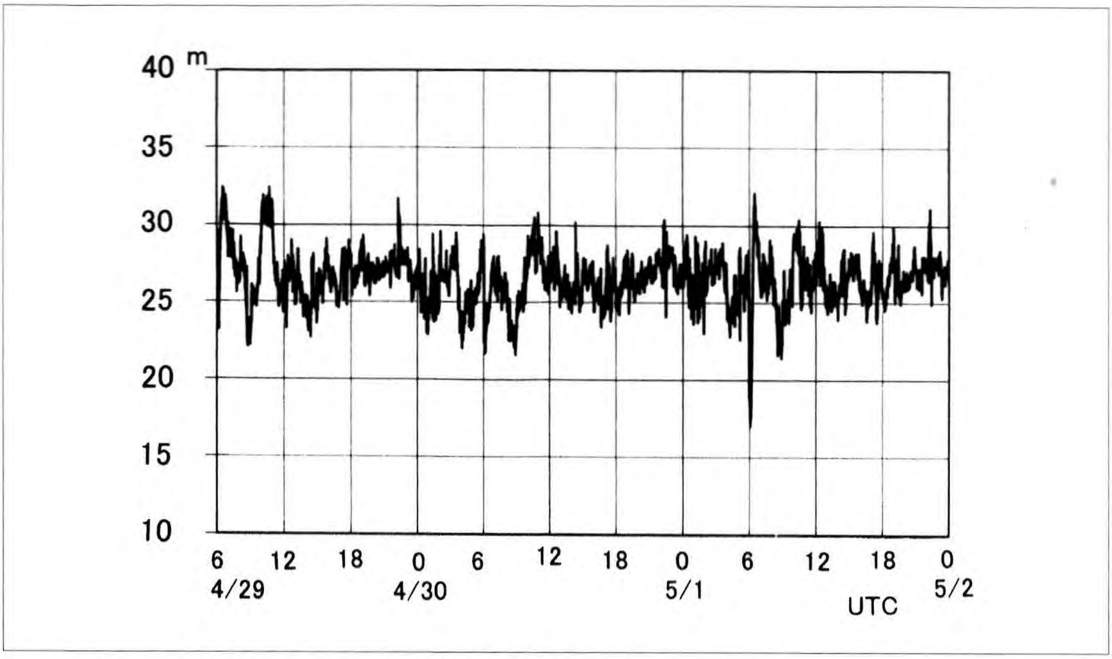

Figure 4: Observed DGPS height at port of Ishigaki (1999/4/29~5/2)

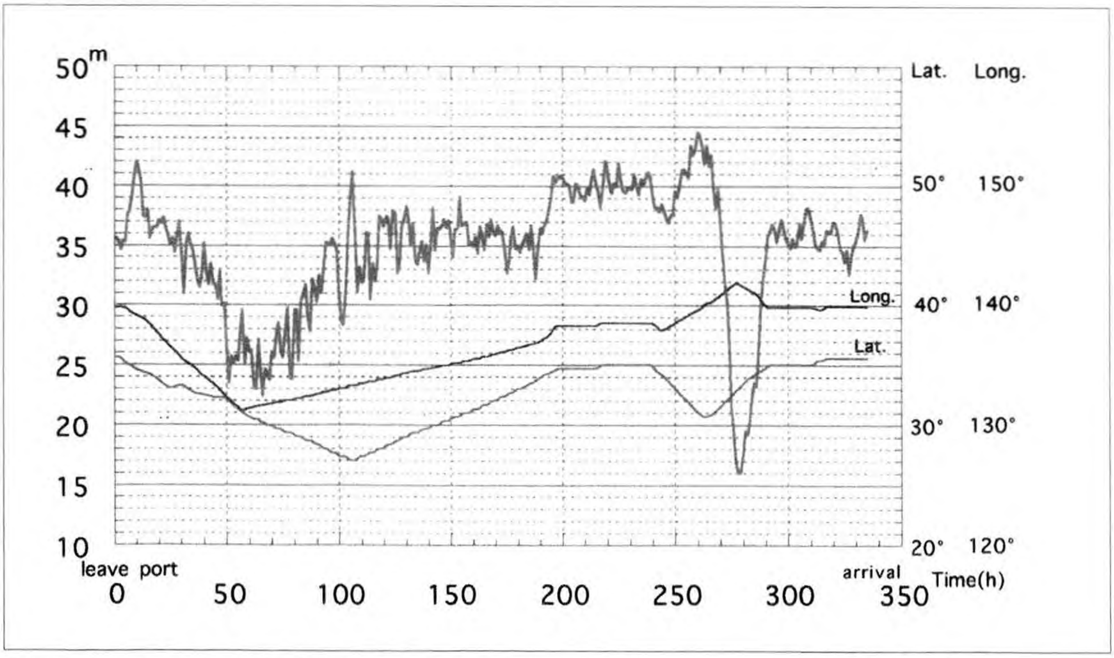

Figure 5: Example of postprocessing DGPS height obtained by the survey vessel SHOYO (1995/11/9~23)

changes in altitude could show the effect of DGPS corrections, considering the magnitude of changes. Figure 4 shows the change of sea surface altitude, when the survey vessel *Shoyo* was at anchor in the Ishigaki harbour. The average sea level from 30 April 00:00 to 2 May 00:00 (UTC) was 26.4 m, and the geoid height of the landing point of the survey vessel *Shoyo* was 25.95 m. These values are almost identical, regarding on the change of water line of the vessel. Figure 5 shows post processing DGPS results showing sea level, latitude and longitude, recorded by the survey vessel *Shoyo*, from when the ship start-

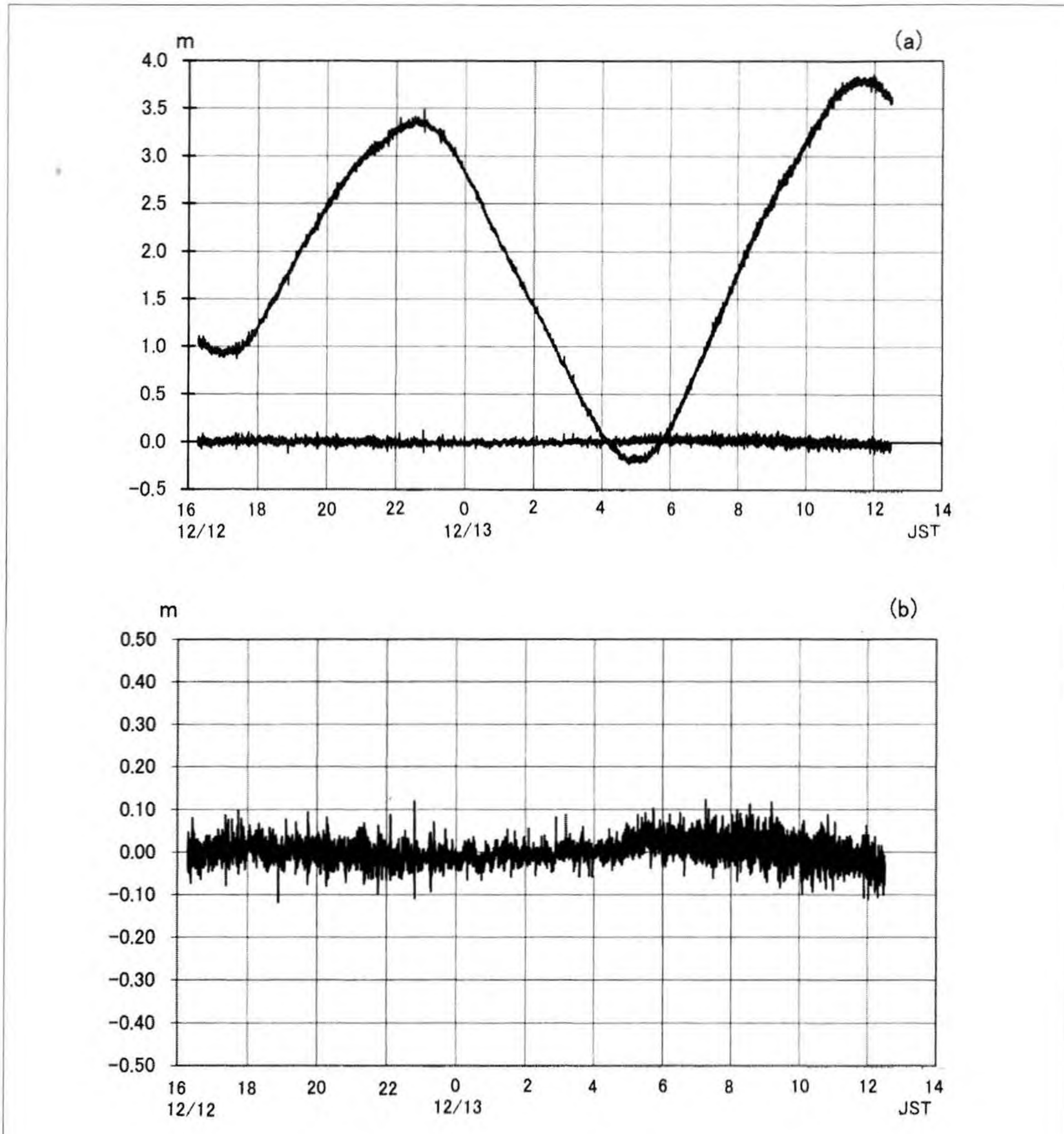

Figure 6a: Observed tide by RTK-OTF at port of Hiroshima (1996/12/12~13)
Figure 6b: Deviation from observed tide

ed and arrived at Tokyo harbour from 9 to 23 November 1995. This figure also shows the changes in sea level while crossing through Izu-Ogasawara trenche. In conclusion, the changes of geoidal height could be observed in DGPS positioning, regardless of inaccuracy of the tidal change.

Utilisation of Altitude with Kinematic GPS and Real Time Kinematic GPS Positioning

Altimetry of a maritime mobile object using GPS single positioning and DGPS is only meaningful when the objects are in dock or anchor. On the contrary, K-GPS and RTK-GPS positioning ensure the accuracy of 2~3 cm+2ppm, thus they could measure the changes in altitude precisely, although there are some limitations by the distance from the reference station. From 12 tO 13 December 1996, we conducted RTK-GPS observation of sea level measurement for about 20 hours, with the ground reference station on the

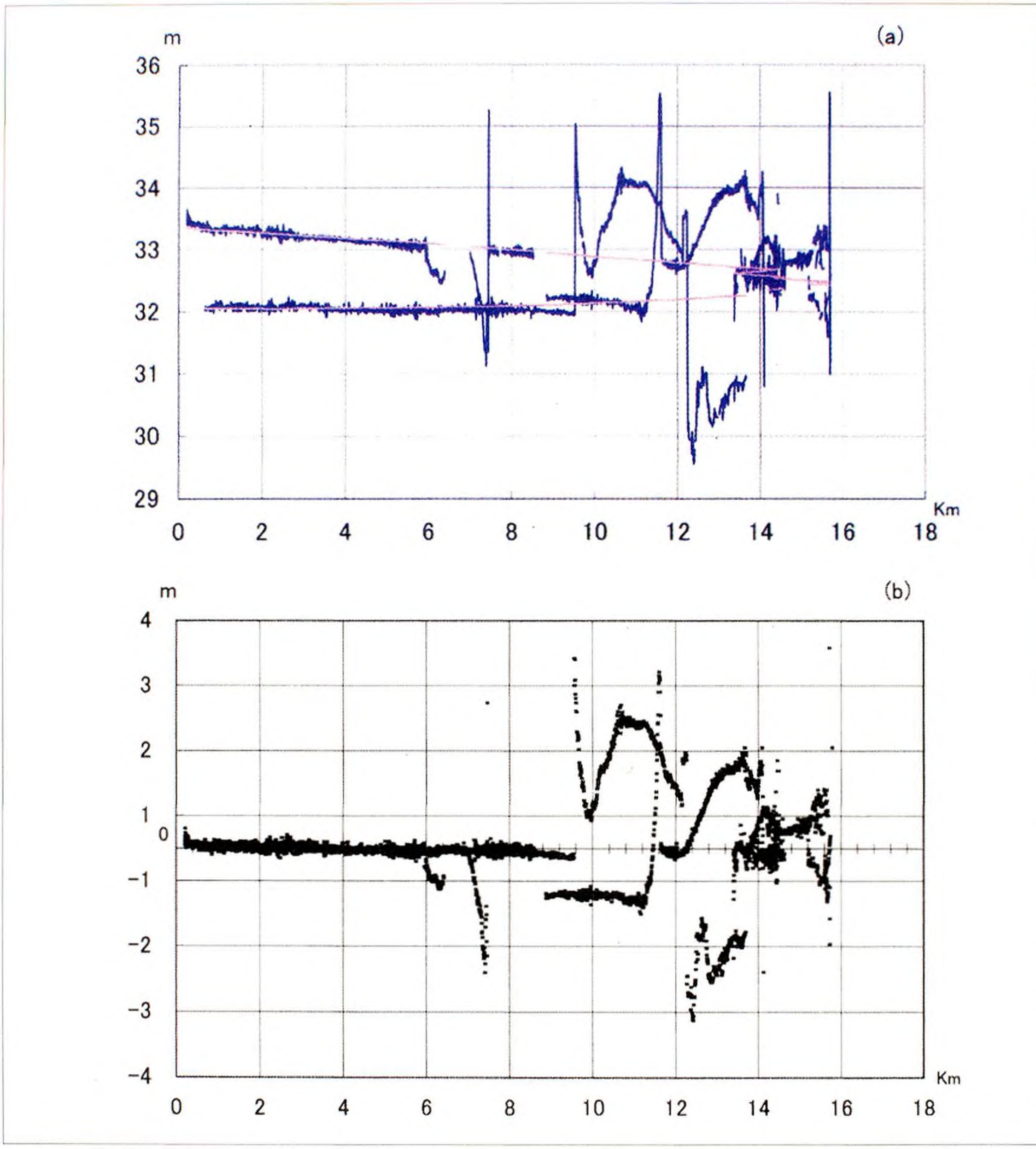

Figure 7a: Observed the ellipsoidal height with RTK-OTF and Air-link during a round trip cruise between port of Hiroshima to Kure

Figure 7b: Deviation from tide observed at port of Hiroshima

roof of the Hiroshima Maritime Governmental building, and the mobile (roving) station on the survey vessel *Kurushima* docked at a floating pier. The GPS receiver was a GP-R1(Topcon) and data transmission was done by digital wireless data transmission device Air-Link. Figure 6 (a) shows tidal change data and the deviation of the difference between average observable RTK data and tidal height. Figure 6 (b) shows the enlarged part of Fig. 6 (a). Because of the accuracy in three-dimensional RTK-GPS positioning, the vertical height was able to obtain accurately. The fine change of the tide and sea surface are also determined accurately. Again from 13 October 13:05 to 16:12, 1997, we conducted reciprocal (to and from) RTK-GPS observation by the survey vessel *Kurushima* from the Hiroshima harbour to the Kure harbour, using digital wireless data transmission device Air-Link, to determine the area covered by RTK-GPS. The Air-Link system covers the area more than 13 km. We thus tested and observed the transmission status up to 16 km, by measuring the change in altitude of the survey vessel and tide at the Hiroshima Tidal Observatory. Figure 7 (a) shows the change in altitude of the vessel and tidal change at the Hiroshima Tidal Observatory. Figure 7 (b) shows the change of the height of RTK-GPS observation subtracted with tidal change and the altitude of the Hiroshima harbour. In these figures, there are some irregular portions, which show the height differences more than the value expected by calculation. This means that RTK-OTF (on the fly) did not work properly at those epochs, and those values might be derived from wrong initial integer bias or cycle slips. At an approximate distance of 6 km, on several occasions, passing ships interrupted our transmission to send correction data, but this did not affect the final results. At an approximate distance of 14 km, stable transmission could not be achieved, even while stopping the vessel or directing the vessel toward the reference station on the ground. Under monitoring the transmission status, RTK-GPS with Air-Link can be used in a stable mode up to 9.5 km. As can be seen in the above case, we could use RTK-GPS successfully to measure sea level change in a real time mode within an operable transmission distance from reference station on the ground. Also K-GPS could be used as a post processing approach to measure not only sea level change but also tidal height change, more than RTK-GPS positioning.

Summary

3-D positioning with GPS single point positioning, Differential GPS, Kinematic GPS and RTK-GPS could be easily applied on the fixed objects on the ground, but it is difficult to apply on mobile, especially maritime, objects in ordinary ways. If we look at only the altitude, by introducing time series observation combining with the accurate altitude data obtained by K-GPS and RTK-GPS positioning, we could find the following utilisation aspects:

1. Monitoring of GPS positioning itself
2. Checking the available area by the transmission and communication devises for DGPS and RTK-GPS
3. Accuracy comparison between DGPS, K-GPS and RTK-GPS
4. Data acquisition of sea level change including tidal change using K-GPS and RTK-GPS
5. Measurement of natural/artificial structures along sea shore to decide shore line, using K-GPS and RTK-GPS

Precise altimetry of a maritime mobile object should be combined with a Gyro-sensor in order to reduce wave effect (pitch, roll, heave of vessel). GPS-antenna calibration should be done in advance in order to know the positioning accuracy and the available area of GPS.

Subjects in the Future

3-D positioning with GPS single point positioning using K-GPS and RTK-GPS is quite innovative with respect to research works in the deep sea area to investigate seafloor in detail. The 3-D For this purpose of deep sea research, the precise 3-D positioning for the AUV (Autonomous Underwater Vehicle) and ROV (Remotely Operated Vehicle), with Gyro sensor in the sea, at more than 100 km far away from reference station on ground, should be investigated.

Biography

Akio Uchida is a principal research officer of the Ocean Research Laboratory at the JHD. He has worked for the JHD since 1968 and served most of the time for the Ocean and Coastal survey. His primary responsibilities include GPS and swath survey systems.