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Establishment of the New Geodetic Reference Frame of Japan (JGD2000)

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Abstract

The Geographical Survey Institute (GSI) has constructed a new geodetic reference frame of Japan. The Survey Act and the related government ordinances were revised to adopt the new geodetic frame as the national reference system. The new frame is a geocentric system based on the observation using space geodetic techniques. The current framework based on Tokyo Datum was established at the beginning of the twentieth century and has been used as a national reference for nearly one hundred years. However, it has a large internal distortion and a shift from a geocentric reference frame, which was revealed by space geodetic techniques. The new framework has been built by referring to ITRF94 (International Terrestrial Reference Frame 1994) at the epoch of 1997.0. The coordinates of the Kashima VLBI station are fixed in ITRF94 using the data from international VLBI observations. Positions of two other domestic VLBI stations (Shintotsugawa and Kainan) were determined referred to Kashima VLBI station. Using these three VLBI stations as anchor points, the coordinates of 950 stations of the nationwide permanent GPS array (GEONET) were determined The coordinates of the first- through third-order triangulation points are calculated by referring to the GPS array. GSI resurveyed 6300 of first- to third-order triangulation points using EDM or GPS. For other 30,000 triangulation points, survey records, which have been obtained by theodolite since 1883, are used. The coordinates newly determined for VLBI stations, GPS stations, and triangulation points are the realization of Japan's new geodetic reference system. GSI named it "Japanese Geodetic Datum 2000" (JGD2000).

1. Introduction

Japanese government decided to adopt new geodetic reference frame as the legal system. The new reference frame is referred as the name of "World Geodetic System" generally. When it is defined as a unique system with certain parameter set, it would be called as "Japanese Geodetic Datum 2000 (JGD2000)".

2. Current Status of Tokyo Datum (horizontal)

"Tokyo Datum" is the name for the present legal geodetic system as defined by Survey Act before this revision. "Horizontal" means Tokyo Datum has vertical reference system also, however the vertical system was not changed this time. Survey Act, the law regulating survey and mapping, has been defining the ellipsoid. The equatorial radius and flattening of the reference ellipsoid were defined in the law (Bessel ellipsoid). Governmental ordinances have been defining geographical longitude, latitude and datum azimuth of the datum. According to these definitions, the whole geodetic network in Japan has been constructed. Those parameters were determined based on the astronomical survey in Meiji era (more than one hundred years ago, in nineteenth century). This geodetic reference system has been referred as "Japanese Geodetic System (Tokyo Datum)" or shortly “Tokyo Datum” However, the space geodetic observations, such as GPS, SLR and VLBI, revealed that Tokyo Datum is not consistent with the newest global frame. Both longitude and latitude are different by 12” at the datum monument. Furthermore, the network is distorted because of the old survey limitation.

3. Process for the Adoption of World Geodetic System

GSI decided that geodetic reference frame should shift to a world geodetic system in 1997. GSI started the computation of coordinates using the observation data obtained by space geodetic techniques, such as the global and domestic VLBI, GPS. GSI started the preparation for the revision of the Survey Act, and relating governmental ordinances, too. GSI decided that reference frame should be International Terrestrial Reference Frame, and ellipsoid should be one defined in Geodetic Reference System 80 by IUGG. The process for the determination of control points were constructed under these definitions. The determination of coordinates was carried out in six steps (Murakami et al, 1999). First, the coordinates of Kashima VLBI station were determined globally by international VLBI observation. Second, domestic VLBI observation data was used for the computation of the coordinates of two other VLBI stations. Third, the coordinates of GPS-based control points (permanent GPS observation stations) were computed using the VLBI stations as the fixed points. Forth, the coordinates of higher order (first or second order) triangulation points, which have been surveyed recently by EDM or GPS, were computed by the network solution fixing GPS-based control points. Fifth, the coordinates of lesser order triangulation points, most of those are third order ones, were computed based on the angular observation data, because they have not been re-surveyed since Meiji era. Finally, the coordinates of fourth order triangulation points were computed by interpolation method with neighboring higher order points coordinates data. While GSI was carrying out these computations of the coordinates of control points, the bill for revising the Survey Act was submitted and the Diet passed it on June 12, 2001. Hydrological Survey Act, which regulates the hydrological survey on the sea, was also revised simultaneously to adopt a world geodetic system. Relating governmental ordinances were also revised in December 28, 2001. Those laws and ordinances come into effect after April 1, 2002. Official survey and mapping in Japan should be carried out based on the world geodetic system defined by laws and ordinances (JGD2000) after this date.

4. VLBI Observation

To replace the conventional datum, a start point that is precisely connected with the geocenter should be settled. GSI has been participating in the international VLBI experiments with Kashima VLBI Station. The ITRF94 coordinates of Kashima VLBI station are precisely determined through more than ten years of observations. The ITRF94 coordinates of Kashima are treated as a practical origin of the JGD2000. During 1986 to 1997, GSI carried out many domestic VLBI observations using mobile VLBI stations and Kashima VLBI station. After an assessment of the effect of crustal movements, two mobile VLBI stations (Shintotsukawa and Kainan) were selected as primary reference points and the three others (Chichijima, Mizusawa, Sagara and Shintomi) were selected as points for comparison. The baseline vectors in ITRF94 between mobile VLBI stations and Kashima VLBI station were used for the computation of coordinates of mobile VLBI stations at epoch 1997.0. From ITRF94 parameters of Kashima and baseline vector, coordinates of mobile VLBI station can be calculated on an epoch of the observation. Using data set from the repeated observation, a regression line can be described on position vs. time chart. Coordinates of the epoch 1997.0 of the mobile VLBI station can be obtained from this regression line.

5. GEONET, the Permanent GPS Array

GEONET (GPS Earth Observation NETwork) is the name of nationwide GPS permanent station array system of GSI. The system includes about one thousand GPS permanent stations covering all over Japanese islands and the analysis center in GSI office. The typical separation between two GPS stations is about 25 km. All stations equip a GPS receiver to obtain carrier phase and code data of GPS satellites with thirty seconds epoch. The data of all station are downloaded once per day to the analysis center (Miyazaki et al, 1998). This GPS array was first established to monitor the crustal deformation continuously. Actually GEONET revealed tectonic movement within Japanese islands as well as the co-seismic movement related to significant earthquakes since 1994. On the other hand, GEONET has been providing continuous GPS observation data usable for field GPS survey. Therefore the permanent stations are referred to as "GPS-based control points". The coordinates of GEONET stations were determined in ITRF94 (epoch 1997.0). We used the data obtained during the period from 27 December 1996 to 5 January 1997 for this computation. At that period the number of GEONET stations was 616 and 595 of them were available. The data was analyzed with GAMIT and adjusted with GLOBK. The three VLBI stations were tied to GEONET and their coordinates were held fixed in the network adjustment. Accuracy assessments have been done with the coordinates at VLBI stations for comparison. They show an agreement of about 3 cm in horizontal components while a formal error of the GPS net adjustment is 2 mm. Baseline analysis of GEONET stations was also carried out with BERNESE to check the results. Because the number of GPS stations has increased since January 1997, coordinates of 350 more stations are being calculated referenced to neighboring existing GPS stations. These VLBI and GPS stations consist of the backbone of JGD2000.

6. Triangulation Points

GSI computed the coordinates of all triangulation points, which are used for survey and mapping, in network adjustment with various observation data. Highly Precise Geodetic Network (HPGN), which consists of 493 first and second order triangulation points, were directly tied to GEONET at 164 points. The computation for HPGN points was carried out using three-dimensional adjustment program. The observation data for this step was totally GPS baseline data. Primary Precise Geodetic Network (PPGN), which consists of the first and second order triangulation points, was directly tied to GEONET at 522 points. Distance measurement data by EDM obtained during 1979-1997 were used for the adjustment by the projection method onto Bessel ellipsoid. Coordinates of 2465 points were derived with the above-mentioned 522 points being fixed. Positional errors relative to neighboring points are estimated to be 3 cm. Secondary Precise Geodetic Network (SPGN), which consists of second and third order triangulation points, was connected to directly GPS stations, HPGN or PPGN points. The coordinates of 3,069 points were computed using distance measurement data on Bessel ellipsoid. The rest of the second and third order triangulation points have not been re-surveyed since the establishment of Tokyo Datum.

We archived survey records of angular observation by theodolite since 1883 for these points. The coordinates of about 30,000 points were computed using archived data referenced to GEONET, HPGN, PPGN, or SPGN. Error of these coordinates was estimated by GPS direct tie survey for the evaluation of the adjustment. We found more than 90% of 856 points have coordinates consistent to the re-survey results within 20 cm. The number of the fourth order triangulation points is more than 60,000. A program that transforms the coordinates from Tokyo Datum to JGD2000 was developed for the determination of those points. This program has a parameter table which holds transformation vector on the grid points (30-second in latitude and 45-second in longitude) covering all over Japanese islands. The parameters were computed from the transformation vectors of superior order triangular points adjusted by the process described formerly. Then transformation vectors for respective fourth order triangulation points will be obtained by bilinear interpolation for this grid data set. This bilinear interpolation program, named "TKY2JGD", and grid data table set can be used for transformation of coordinates of public control points and cartographic products including digital maps in GIS (Geographic Information System) (Tobita, 2000). As GSI uploaded this program and parameter tables on our web site, users can use it freely for their purposes. Though we provide the program and relating documents only in Japanese, the source code by Microsoft Visual Basic, which is also uploaded on the same website, is available. (http://vldb.gsi.go.jp/sokuchi/tky2jgd/download/agreement.html)

7. Effect of New Geodetic Reference System

The shift of the geodetic system would affect not only surveyors but all citizens. For example maps should be changed. GSI is responsible to provide basic maps covering Japan. Therefore we started supply basic maps with the coordinates by JGD2000 from October 2001. GSI also provide a transformation table of the coordinates by JGD2000 for the four corners of the maps those are published by GSI. This table is also uploaded on our web site. (http://www.gsi.go.jp/MAP/NEWOLDBL/New_OldBLindex.html) The coordinates of control points constructed by local governments should be transformed into JGD2000, too. GSI provides "Transformation Manual" to advise them how to transform the coordinates of control points and cartographic products. GSI held seminars to advise how to adopt new geodetic system.

8. Conclusion

GSI has constructed the new geocentric reference frame using space geodetic techniques. The positions of a thousand of GPS stations and a hundred thousand triangulation points have been calculated as a realization of the new datum. GSI is trying hard to ensure that the new system based on revised Survey Act would be accepted smoothly by civil society.

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