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Global Geodetic Reference System

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Note by the Secretary-General

Summary

The present paper summarizes the report of the Permanent Committee on GIS Infrastructure for Asia and the Pacific, transmitted by the Secretary-General to the Committee of Experts.[1] The report, requested by the Committee of Experts at its first session, describes the development of and growing demand for a global geodetic reference system that underpins all geospatial information. It recognizes that many economic and social activities, including navigation, civil engineering, agriculture, financial transactions and disaster management, are now relying heavily on high-precision positioning technologies and related infrastructure. The report describes the requirements for such geodetic positioning infrastructure as the Continuously Operating Reference Station, the Global Navigation Satellite System and the Global Positioning System. The report considers particular vulnerabilities in the Asia-Pacific region, where the infrastructure is comparatively sparse, inaccurate and difficult to access. Similar problems may exist in other regions. In general, the current networks are not effectively linked to each other or to the global reference frame, while the lack of data sharing has an impact on the accuracy and type of geodetic analysis that can be performed. The Committee of Experts is invited to take note of the report and to express its views on the different options for improved positioning infrastructure to support the Global Geodetic Reference System.

* E/C.20/2012/1.

[1] The full report is available in the language of submission only from http://ggim.un.org/ggim_committee.html.

I. Background – Positioning and Reference Frame

A. Positioning

1. Position is the most fundamental concept in geospatial information management. However, it is generally not well understood what principles and methods are applied and required just to obtain positions. A position of a point on or around the earth is expressed as a set of numbers called coordinates, e.g. Cartesian (x, y, z) or geographical (latitude, longitude, altitude), in some coordinate system. Traditionally, most spatial data were expressed using a geographical coordinate system covering the earth. Although the notion of geographical coordinates is global, available observation methods were locally limited and derived coordinates were usually only valid locally. Consequently each country used its own datum (geodetic reference system), constructed and realized by domestic observations. Technologies for precise positioning were also in the hands of a limited number of professionals like surveyors and scientists, and ordinary people could only use geospatial information as given by authoritative sources.

2. In the latter half of 20th century, the deployment of space geodetic technologies, especially GNSS (Global Satellite Navigation System), changed the paradigm of geodetic positioning. For the first time mankind possessed the tools to globally observe the earth. At present, positioning by new technologies achieves accuracies at the cm-level or better for high-end purposes, orders of magnitudes better than the initially deployed system, accomplishing the realization of truly global reference systems consistent on the whole earth (see Section I.B). With the later advancement of information and communication technologies and mass production of GNSS receiver devices, satellite positioning has become a widely used tool in everyday-life of the general public (see Section II.A).

3. Discrepancies between the satellite positioning and traditional surveys are therefore unavoidable as they are based on the references realized very differently, one by global observations and the other by local surveys. In view of the applications of GNSS today, which includes instantaneous position determination, this situation would lead to confusion and deterioration of positional accuracy of geospatial data if the references would not be unified. It is the task and responsibility of governments or authoritative agencies to provide their nations with a reliable and accurate reference for positioning and geospatial related activities (see Section II.B).

B. Modern Development of Reference Frames for Geodetic Positioning

4. All spatial data must be referred to a coordinate system. As stated above, we have the liberty of choosing a reference system as long as it serves us the best. In case of geospatial position data, geographical coordinates, and their transformations to a local system (e.g., north, east, and height), are appropriate and traditionally used. Throughout this paper, according to the terminology of (5), a reference frame is defined as a realization of a reference (coordinate) system and that the realization is achieved by a set of physical points with precisely determined coordinates. A coordinate system is a set of mathematical rules to assign coordinates to a point.

5. In the case of a local system, the geodetic origin and fundamental directions serve as the origin and axes of the coordinate system and the positions of the control points in the fundamental network establish the national geodetic frame (i.e. the national datum).

6. For the construction of a global reference system, one must deal with the orbit of satellites around the earth and as the rotating earth moves around the sun, rigorous and

systematic treatment of all the phenomena that could possibly affect the kinematics of the earth and the satellites is required. Furthermore, geophysics has revealed the dynamic nature of the planet earth exemplified by plate tectonics and variations in earth rotation, the system must take care of the changes of the surface positions caused by gradual or episodic movement of the earth's crust and rotation axis.

7. In the recent study along with the observations by the improving space geodetic techniques, scientists have successfully developed a series of standard coordinate systems based on a rigorous theory of physics, astronomy and geodesy and the method to realize the system as a physically accessible reference frame. Here only the outline of the construction is presented below. Refer to the reference (5) for technical details.

a) Celestial system

To describe the motion of the earth, we think of a coordinate system with the origin at the barycenter of the solar system and axes should be fixed to the distant matter in the universe. This system is called the Celestial Reference System (CRS). Positions of compact extragalactic radio sources (mostly quasars) are precisely determined by using Very Long Baseline Interferometer (VLBI). Planetary ephemerides supply the positions of celestial bodies, which are continuously improved by accurate astronomical observations from the earth and new modeling for the equation of motion of the celestial bodies.

b) Terrestrial System

A Terrestrial Reference System (TRS) is a spatial reference system co-rotating with the earth's diurnal motion in space. Conventionally we consider geocentric TRSs for which the origin is close to the earth's center of mass (geocenter), the orientation is right-handed equatorial (the Z axis is the direction of the pole). Space geodesy observations determine the necessary parameters to construct the Terrestrial Reference Frame (TRF), i.e. the realization of TRS. The parameters include origin, scale, orientation and their time evolution.

c) Transformation between Celestial and Terrestrial Systems

The TRS is related to CRS through the series of transformations (at the time of observation) arising from the motion of the earth and its orientation in space, specifically motion of the celestial pole (precession-nutation), rotation of the earth around its pole and polar motion. Parameters (Earth Orientation Parameters: EOP) in the transformations are determined mostly by astronomical and space geodetic observations.

II. Global Geodetic Reference System and Society

A. Impact of GNSS Technologies and Applications

8. Today, positioning by GNSS sees its application in virtually every aspect of the management of geospatial information. In addition to the traditional survey, mapping and navigation (including military use) applications are expanding to civil engineering, agriculture, recreation, financial transactions, personal/commodity transportation/tracking, disaster and emergency management/response and scientific research.

9. Precise positioning is required in automated construction, agriculture and mining applications where GNSS is used to guide the machines with a high level of precision. Environmental studies is one of the fields where GNSS technology will be widely used

through the monitoring of animal movements and behaviors as well as the observation and forecasting of meteorological changes. GNSS will play vital role in future intelligent transportation systems.

10. With the spread of smart phones, people have more opportunities to use GNSS technology. Easy-to-use and convenient application programs are increasingly being developed and distributed for free or very cheaply. Location-based services are among the most popular services on phones and are used in business, games, travelling and social-networking.

11. Time synchronization is another function of GNSS that is increasingly used in various circumstances. GNSS can provide very precise time as well as positions (virtually the same as the atomic clocks on the satellite). For example, cellular networks, electrical power grids and financial transactions rely on the precise timing and they use GNSS time for synchronization of their networks and time-stamp recording.

12. An ideal relation of reference frames to positioning would be summarized very simply in a typical application such as on the display of a mobile device, where the GNSS reading and map position must be matched regardless of the scale of the map and everywhere on the earth. There is no need to notice or mind which datum the map or GPS positioning are referred to for economic efficiency, while the accuracy must be assured by an underpinning standard geodetic reference frame.

13. The relation between geodetic positioning and reference frames is, in fact, two-way; without a well realized reference frame, the calculation of position is not accurate, and a reference frame is determined by reliable GNSS and other geodetic observations (see Section III). Especially for GNSS, a global reference frame supports the satellite operation control from the ground.

B. Management of Geospatial Information in Global Perspective

14. Over the years, most national geospatial information authorities have been obtaining, storing and providing fundamental geospatial data of their country. Survey data and fundamental maps were calculated and compiled based on their own local datum. It has been these authorities' responsibility to supply a reliable reference for map making, land transactions, urban development and national security. With the growing use of GNSS positioning and surveying, however, many countries have made the transition from a local national datum to a geocentric datum, referred to a standard reference frame described in Section I.B above, in the last 10-20 years. Their decisions were based on the outlook of taking advantage of GNSS technologies to support societal activities and in the fields of international air and sea navigation. Of course the transition would not come easily, significant volumes of work must be achieved – revision of fundamental maps, re-survey or transformation of legacy data, outreach and education, to name a few.

15. In this century, the advancement of information and communication technologies has forced the inevitable changes in the roles of national geospatial information authorities. Everybody can get their position easily, precisely and instantaneously. The national authority's role in actual surveying and data gathering will be shrinking compared to policy development and management of regulations. Nonetheless, it will be still the responsibility of national authorities to guarantee the quality of the product and provide the means for ensuring the level of the accuracy needed in the geospatial field. As for the geodetic reference, the national datum should be based on a common global standard, and considering the dynamic nature of the earth, continuous monitoring of reference stations must be taken care of by the national authorities irrespective of economical benefits.

III. Current Status of Global Geodetic Reference Frame

A. Global Frames and Network of Geodetic Observations

16. There are two widely accepted global reference frames – ITRF and WGS84. The International Earth Rotation and Reference Systems Service (IERS), which was established in 1987 by the International Union for Geodesy and Geophysics (IUGG) and International Astronomical Union (IAU), constructs and maintains the realizations of the global geodetic system – the International Terrestrial Reference Frame (ITRF). The ITRF is realized by the combination of data from 4 existing space geodetic techniques (GNSS, VLBI, Satellite Laser Ranging/Lunar Laser Ranging (SLR/LLR) and Doppler Orbit determination and Radio-positioning Integrated on Satellite (DORIS)), and has become the standard in the scientific community because of the robust and internationally acknowledged scientific method for its realization and its continuous refinement as the theory improves and new observational data are added. The IERS has established the models and procedures to realize the reference systems based on the resolutions of international scientific unions (5). The General Conference on Weights and Measures (CGPM) also acknowledges the ITRS as the world standard reference system (8).

17. The WGS84 (World Geodetic System 1984) is the datum used by the Global Positioning System (GPS) operated by the U.S. Department of Defense. The datum is defined and maintained by the United States National Geospatial-Intelligence Agency (NGA). WGS84 has been revised several times since its conception and is at present aligned at the one decimeter level to the ITRF, which generally ensures scientific integrity and compatibility with International standards and conventions (3). Consequently, differences between the ITRF and WGS84 are negligible for many users with the notable exception of precise cm-level positioning applications where the use of ITRF is preferred.

18. Space geodetic networks have grown from the experimental networks of few stations in the late 20th century to the current ones covering the whole earth despite some inhomogeneities in the distribution of stations. An international service was established for each technique in the late 1990s under the International Association of Geodesy (IAG) (7) to coordinate and manage the observations and data collection/analysis at the global level. As these services do not have funds to establish or maintain the space geodetic stations and observatories, it depends on the endeavors of each organization to continuously improve the reference frame and provide the quality products to the users.

B. National and Regional Frames referred to the Global Frame

19. As stated in Section II.B a number of countries have adopted a geocentric datum referred to the standard global reference frame. Considering the growing number of Continuously Operating Reference Station (CORS) networks in many countries, this number will be increased in the near future.

20. Following are examples from three countries in the Asia-Pacific region, which have adopted a geocentric system for their national datum.

(a) Australia

Australia was one of the earliest countries to adopt a geocentric frame for the national datum. The Geocentric Datum of Australia 1994 (GDA94) (2) was realized by adopting the coordinates of the Australian Fiducial Network (AFN) geodetic stations referred to ITRF92 at the epoch of 1994.0. The AFN consists of 8 permanent GPS stations included in the IGS network. Australia has now launched an AuScope Geospatial Infrastructure program to contribute to the ITRF. The infrastructure includes 3 new VLBI, 2 SLR and 100 new GNSS sites to enhance the geophysical observing capabilities and serve as the national positioning infrastructure.

(b) China

The China Geodetic Coordinate System 2000 (CGCS2000) has been officially adopted as the new national geodetic coordinate system since July 2008 in China, which is closely related to ITRS. CGCS2000 (1) is referred to ITRF97 (International Terrestrial Reference Frame 1997) at the epoch of 2000.0. The adoption of the new system will allow closer integration with international coordinate frames, global navigation satellite systems, scientific applications and routine spatial data management. The reference frame of CGCS2000 currently consists of the national GPS2000 network, which consists of more than 2500 GPS stations, the accuracy of coordinates of CORS is at the level of millimeter, and the mean accuracy of coordinates is better than ±3cm. In the future, the reference frame of CGCS2000 will be mainly realized by national CORS and a high precision geodetic control network.

(c) Japan

Japan made a transition from its local system (Tokyo Datum, established in late 19th century) to a geocentric one officially in 2002. It refers to ITRF94 at the epoch of 1997.0 and is called the Japanese Geodetic Datum 2000 (JGD2000) (4). The reference to ITRF was through VLBI observations which had a history of more than ten years of observation in the IERS network. A recently established nationwide GPS network served to provide the fundamental coordinates in the new system. A datum change was performed without serious troubles thanks to extensive preparations. As Japan is situated in a very active region in terms of geophysical phenomena, continuous crustal deformation as well as episodic changes due to earthquakes, causes the deterioration of once-accurate coordinates. JGD2000 has now become JGD2011 after a major revision necessitated by the Great East Japan Earthquake in 2011. A major challenge of a national datum in the near future would be how to deal with this dynamic nature of the earth's surface to keep the datum updated and accurate enough at all times for the users.

21. Regional reference frames have been developed by the cooperation of national geospatial information authorities, the International Association of Geodesy (IAG) and academic organizations in the major regions of the world. They are developed as a dense realization of ITRF and serve as the link between national datum and the global frame and introduction of a geocentric reference to the participating nations.

22. In Asia and the Pacific, in particular, development of a regional frame is later than other parts of the world. Development of the European system began almost at the same time as the birth of ITRF in the 1990s. The Asia-Pacific Reference Frame Project (APREF) started in 2010 based on the data from CORS stations in the region. The present network consists of 420 stations in 28 countries, and daily GNSS data and weekly coordinate estimates are available via internet. APREF (and other regional and international geodetic programs as well) is a voluntary, collegial, non-commercial endeavor, and there is no central funding source, and participating organizations contribute their own resources.

IV. Issues for the Future

Outstanding issues in the present and foreseeable future regarding the geodetic reference frame are:

23. Government's responsibilities in ensuring the reliable basis for geospatial information management: Adoption of a geocentric datum based on a global standard reference system is a foregone action to take, but ongoing development of a flexible system to accommodate the inevitable changes in the coordinates should be considered. Continued investment and efforts in infrastructure, hardware, software and systems are required. Regional collaboration could play an important role here through the information exchange and sharing, technology transfer, and support in the decision making of governmental organizations.

24. Maintenance of geodetic infrastructure including international collaboration: As mentioned in Section III.A, geodetic infrastructure is maintained by the efforts of individual organizations and there is no guarantee they could operate it in the long-term. Physical infrastructures are old but budgetary cutbacks do not allow them to be renewed. For example, according to a Global Geodetic Observing System (GGOS) White Paper (6), "In the late 1990s, more than 20 core stations existed, as demonstrated by the larger number of core stations used for the determination of ITRF2000. However, at present there are only 9 stations with permanent GNSS, SLR and VLBI observations."

V. Conclusion

25. Given the growing application areas and markets for the GNSS positioning, the need for a global geodetic reference system is growing. A stable and accurate reference frame is indispensable for spatial data management on the dynamic earth.

26. It is a responsibility of every national government to provide a common frame to facilitate the manipulation of geospatial information for the national benefit that includes the economy and security and scientific development. Many countries have already accomplished it but some who have not should be encouraged to do so.

27. Ongoing regional collaboration is also important as a regional geodetic frame serves as an immediate link between each national frame and the global reference frame. Also regionally focused activity assists developing nations to obtain reference positional data tied to the global reference frame.

28. The maintenance of the fundamental geodetic network needs ongoing investment from all nations as it is only through globally distributed networks of GNSS and space geodetic stations that an accurate and stable global reference frame can be realized.

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