UNITED NATIONS

E

Economic and Social Council

Distr.
LIMITED

E/CONF.87/L.22
12 April 1994

ENGLISH ONLY

THIRTEENTH UNITED NATIONS REGIONAL
CARTOGRAPHIC CONFERENCE FOR
ASIA AND THE PACIFIC
Beijing, 9-18 May 1994
Item 5 (a) of the provisional agenda*

NEW TRENDS IN TECHNOLOGY AND THEIR APPLICATIONS: GEODESY

World geodetic system 1984: A three-dimensional reference frame for global mapping, charting and geodetic applications

Submitted by the United States of America**

* E/CONF.87/1.

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94-17588 (E) 150494 19/04/94

INTRODUCTION

Throughout the world, numerous Mapping, Charting, Geodetic (MC&G) and digital products are defined in various local and/or regional geodetic datums. These datums were defined in classical mode with limited area coverage. Some may not even qualify as datums under rigorous geodetic scrutiny. Further, factors, viz., patch adjustments, crustal deformations, and many other natural phenomena have also contributed to affect accuracy and produce large distortions. Simply stated, these datums have "aged."

Another major problem with the currently available local or regional geodetic datums is that the horizontal datums defining horizontal positions (latitude and longitude) were all developed separately from the vertical datums defining elevations. As all these vertical datums were defined using mean sea level (msl), there can be several different msl datums within a horizontal datum covering a large region. For example, though most of the western Europe has been mapped on the European Datum (ED) 1950 under the North Atlantic Treaty Organization (NATO), several of the countries still have their own vertical msl datums.

A global reference frame can simplify this MC&G complexity through common referencing of all MC&G products. With this need in mind, the Defense Mapping Agency (DMA) has been actively involved in the development of World Geodetic Systems since 1960. To date, four such global systems, viz., WGS 60, WGS 66, WGS 72, and WGS 84, each successively more accurate, have been developed. In addition, these WGS's also have been extended in their coverage to link with more and more local and/or regional datums worldwide through improved transformation constants. As the geoid can also provide a unified definition for a globally consistent vertical datum, WGS 84 is truly a three-dimensional Reference System.

The latest WGS represents DMA's state-of-the-art modeling of the earth from a geometric, geodetic, and gravitational standpoint using data, techniques, and technology available through early 1984. Since then, large amount of additional satellite, gravity, and satellite altimeter data have been accumulated and efforts are underway to improve the present WGS 84 geoid. DMA has recently initiated a new effort to utilize these data sets. The intention is to produce a global geoid with an expected accuracy of about ± 50 cm over land and ± 25 cm over oceans by early 1996.

1. THE REFERENCE FRAME

The WGS 84 reference frame (Figure 1) constitutes a mean or standard earth identical to the Conventional Terrestrial System (CTS) as defined by the Bureau International de l'Heure (BIH) for the epoch 1984.0 (BIH, 1984).

For practical realization, the WGS 84 reference frame was defined by suitably modifying the coordinate system of the Navy Navigation Satellite System (NNSS). This modification consisted of the removal of biases in the definitions of the origin, scale and longitude of the NNSS. These corrections ensure the WGS 84 coincides with the BIH-defined CTS [BIH, 1984].

2. THE DEFINING PARAMETERS

In geodetic considerations, three different earth figures or surfaces are normally involved and used, viz., the earth's actual physical surface (the topography), a geometric (or mathematical) reference surface (the ellipsoid), and an equipotential surface (the geoid).

In determining the WGS 84 fundamental parameters and the reference ellipsoid, the International Union of Geodesy and Geophysics (IUGG) defined Geodetic Reference System (GRS) 1980 was adopted as its reference [Moritz, 1980].

3. THE EARTH GRAVITATIONAL MODEL

The WGS 84 Earth Gravitational Model (EGM) is a spherical harmonic expansion of the earth's gravitational potential and is defined complete through degree and order 180. Efforts are underway to develop a new EGM complete through degree and order 360 by early 1996.

4. THE WGS 84 GEOID

In addition to the earth's geometric surface or figure, the WGS 84 Geoid, as the earth's equipotential figure, is defined as so many meters above (+ N) or below (- N) the WGS 84 Ellipsoid, where "N" is known as geoidal height or undulation.

The worldwide geoidal heights were calculated using the full WGS 84 EGM, and are available as a grid of desired density or as a contour chart [DMA, 1991].

The estimated absolute error of WGS 84 geoid ranges from ± 2 to 6 meters (1) and is better than ± 4 meters over approximately 93% of the globe.

With the availability of more accurate satellite, gravity, and satellite altimeter data sets since 1984, DMA's new project is expected to improve the geoid accuracy to ± 50 cm on land and ± 25 cm over oceans by early 1996. This increased accuracy will help in defining elevations with global consistency.

5. WGS 84 AND THE SATELLITE POSITIONING SYSTEMS

Since January 1987, WGS 84 has been used to define the NNSS and the Global Positioning System (GPS) coordinate systems, both for the broadcast and precise ephemerides. The NNSS has been phased out since October 1993, while the GPS constellation of 24 satellites has been completed.

Through point positioning using about four hours of GPS data, the realization of WGS 84 worldwide, on land or over static stations in ocean areas, has become a routine survey task. GPS has now attained worldwide acceptance due to its easy handling, survey time efficiency, cost effectiveness, and high accuracy. As GPS observations provide 3-D coordinates, latitude (ϕ) longitude (λ), and ellipsoidal height (h), subtracting of geoidal height from (h) will facilitate surveying of the orthometric heights (H) or elevations for isolated stations in remote areas and also for differential leveling.

Common referencing to WGS 84 through datum transformation of complex and varying types of data sets and use of GPS survey over islands, regions, countries, and continents will also become more and more popular and useful.

6. WGS 84 AND THE GEOCENTRIC DATUMS

The recent definition of North American Datum (NAD) 1983 as a geocentric datum based on GRS 80 parameters, Indonesia 1974 with NNSS definition, and European Reference (EUREF) 1989 using International Terrestrial Reference Frame (ITRF) have established a new trend. The current indications are that the new continental datums for South America and Africa, Philippines Reference System (PRS), and Korean Reference Frame (KRF) will also be based on the geocentric definition. Australia has also decided to change over its national datum to the WGS 84 from 1 January 2000. In addition Indonesia has recently decided to join Australia and redefine its national datum. The above activities, when completed, will help to extend the global extension of WGS 84.

7. RELATIONSHIP WITH LOCAL GEODETIC DATUMS

Counting islands and other "astro" datums, there are several hundred local and/or regional horizontal and vertical datums, new or old, in use with MC&G products worldwide. There are inherent technical difficulties in dealing with these numerous geodetic datums, each defined with its own specifications and limitations. Daily usage of this myriad of datums paints a picture that is too complex and may even be chaotic.

Because of this bleak scenario, one of the principal tasks and purposes of the World Geodetic System (WGS) is to provide the means whereby these numerous local datums can be referenced to a common system. WGS can facilitate simplification of this global MC&G complexity.

To achieve the referencing of a local datum to WGS 84, one major requirement is to have a well-distributed set of control points common to both the systems. DMA maintains a worldwide data base of control points surveyed by NNSS and GPS. These satellite stations with the local datum coordinates of the area are useful for computing the relationship with the WGS.

As the local/regional geodetic datums are generally defined separately for horizontal positions (Latitude, Longitude) and mean sea level (msl) elevations (H), the geodetic or ellipsoidal height (h) for the local datums are not available. These heights, required to establish datum transformation constants with WGS 84, were computed using the method of geoid transmution to the last datum ellipsoid [Kumar, 1989].

Currently, transformation constants for 115 local horizontal datums are available to tie them to WGS 84 [DMA, 1991].

The availability of a new geoid with 50 cm accuracy for land areas (Section 4.) will allow computation of globally consistent and highly accurate WGS 84 elevations for the satellite surveyed control points of DMA's data base. This information will then be utilized to develop vertical datum transformation constants with WGS 84 and these constants in turn will enable accurate reduction of global gravity data to a common zero.

8. ACCURACY

The accuracy of the WGS 84 coordinates of a site depends on the method used to determine the coordinates. Table 1 lists the four methods generally available to establish the coordinates of a WGS 84 site and the associated accuracies achievable through each of the methods.

It is obvious that Method 1 (where a WGS 84 site is surveyed or established through direct satellite observational data) gives the most accurate positional fix. Method 4 (the least accurate) is entirely dependent on the local/regional distortions and accuracy of the local geodetic datum.

9. SUMMARY

WGS 84 is a state-of-art global geodetic reference system based on the use of data, techniques, and technology available within DMA through early 1984. It replaced its predecessor WGS 72. In the second edition of DMA TR 8350.2 and its INSERT 1, the local datum transformation constants have been updated, improved in quality and coverage, and also expanded with data as available through August 1993.

The latest WGS 84 reference frame, EGM, geoid, and transformation parameters (with the local geodetic datums) are comparatively more accurate and relate more datums (115 compared to 90 in the first edition and 27 for the WGS 72).

The improved WGS 84 EGM and geoid, due for publication in 1996, will enable the realization of WGS 84 as a 3-D worldwide reference system for global mapping, charting, and navigation.

These improvements can be translated into more accurate maps and charts, geodetic positioning, EGM, improved satellite orbits, geoid, and geoidal heights to a unified global system. Moreover, it also facilitates our capability to relate many more local and regional geodetic datums worldwide to simplify the complex MC&G problem.

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Figure 1. World Geodetic System 1984 Reference Frame

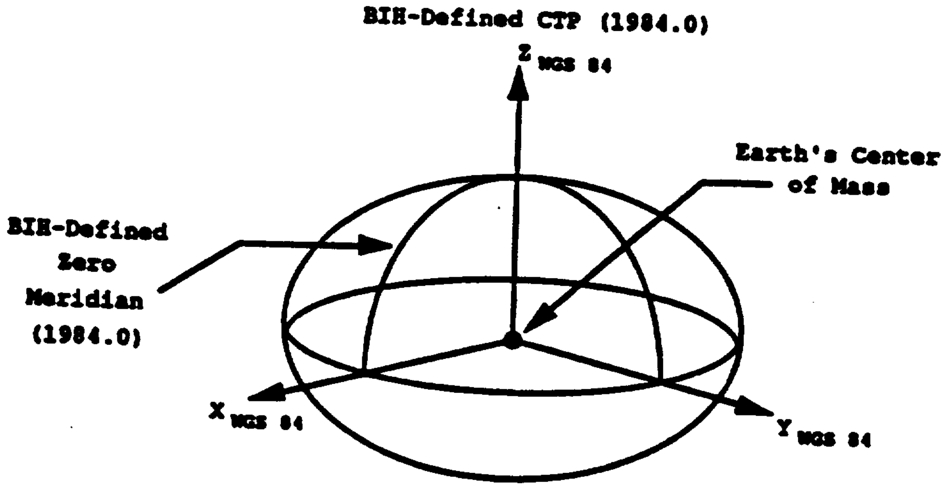

Table 1
Methods of Determining WGS 84 Coordinates

Method of Coordinate Determination	Achievable Accuracy
1. Directly Established in WGS 84 Coordinate System via Using GPS Point Positioning Solution	ϕ and λ - ± 1 m h - ± 1 m
2. By Transformation from Doppler (NSWC 9Z-2) Coordinates (Bias Removal Approach)	ϕ and λ - ± 2 m h - ± 2-3 m
3. By Transformation of WGS 72 Coordinates:	
a. At Doppler Sites	Same as 2. above
b. At Non-Doppler Sites	Dependent on the Originating Local Datum Coordinates and Transformation Errors *
4. By Transformation of Local Datum Coordinates	Same as 3.b. above

* See DMA TR 8350.2, Second Edition, 1 September 1991.
