

UNITED NATIONS
OFFICE FOR OUTER SPACE AFFAIRS

Education Curriculum

Global Navigation Satellite Systems



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UNITED NATIONS OFFICE AT VIENNA

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Preface

Global Navigation Satellite Systems (GNSS) include constellations of Earth-orbiting satellites that broadcast their locations in space and time, of networks of ground control stations, and of receivers that calculate ground positions by trilateration. GNSS are used in all forms of transportation: space stations, aviation, maritime, rail, road and mass transit. Positioning, navigation and timing play a critical role in telecommunications, land surveying, law enforcement, emergency response, precision agriculture, mining, finance, scientific research and so on. They are used to control computer networks, air traffic, power grids and more. Thus the specific objectives of the implementation of the GNSS education curriculum are the demonstration and understanding of GNSS signals, codes, biases and practical applications, and the implications of prospective modernization.

At present GNSS include two fully operational global systems, the United States' Global Positioning System (GPS) and the Russian Federation's GLObal NAVigation Satellite System (GLONASS), as well as the developing global and regional systems, namely Europe's European Satellite Navigation System (GALILEO) and China's COMPASS/BeiDou, India's Regional Navigation Satellite System (IRNSS) and Japan's Quasi-Zenith Satellite System (QZSS). Once all these global and regional systems become fully operational, the user will have access to positioning, navigation and timing signals from more than 100 satellites.

In addition to these, there are satellite-based augmentation systems, such as the United States' Wide-area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), the Russian System of Differential Correction and Monitoring (SDCM), the Indian GPS Aided Geo Augmented Navigation (GAGAN) and Japanese Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation Systems (MSAS). Combining them with proven terrestrial technologies such as inertial navigation, will open the door to new applications for socio-economic benefits. The latter are applications that require not just accuracy, but in particular reliability or integrity. Safety-critical transportation applications, such as the landing of civilian aircraft, have stringent accuracy and integrity requirements.

For developing countries, GNSS applications offer a cost-effective way of pursuing sustainable economic growth while protecting the environment. Satellite navigation and positioning data are now used in a wide range of areas that include mapping and surveying, monitoring of the environment, precision agriculture and natural resources management, disaster warning and emergency response, aviation, maritime and land transportation and research areas such as climate change and ionospheric studies.

The successful completion of the work of the International Committee on Global Navigation Systems (ICG), particularly in establishing interoperability among the global systems, will allow a GNSS user to utilize one instrument to receive signals from multiple systems of satellites. This will provide additional data, particularly in urban and mountainous

regions, and greater accuracy in timing or position measurements. To benefit from these achievements, GNSS users need to stay abreast of the latest developments in GNSS-related areas and build the capacity to use the GNSS signal.

In conclusion, as we move forward in the 21st century, governments and business in developing and industrialized countries are exploring potential growth areas for their national economies. Almost without exception, the most promising option seems to be outer space, and in particular satellite positioning, navigation and timing, and its potential and future almost universal applications.

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I. Introduction

The Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) adopted a strategy to address global challenges in the future through space activities. The strategy, contained in “The Space Millennium: Vienna Declaration on Space and Human Development”¹, included key actions to use space applications for human security, development and welfare. One such action was to improve the efficiency and security of transport, search and rescue, geodesy and other activities by promoting the enhancement of, universal access to and compatibility of space-based navigation and positioning systems. The use of the signal from global navigation satellite systems (GNSS) constitutes one of the most promising space applications that can be used to implement this action.

In 2001, member States accorded high priority to a limited number of selected recommendations of UNISPACE III. The Committee on the Peaceful Uses of Outer Space established action teams under the voluntary leadership of member States to implement those priority recommendations. The Action Team on GNSS was established under the leadership of the United States of America and Italy to carry out the recommendation relating to GNSS.

The work of the Action Team on GNSS included comprehensive reviews of existing and planned GNSS and augmentations, their applications by system provider and user communities, as well as activities carried out by various entities to promote GNSS. The Action Team also examined the requirements of developing countries and gaps in meeting those requirements, as well as existing education and training opportunities in the field of GNSS.

The Action Team on GNSS, consisting of 38 member States and 15 intergovernmental and non-governmental organizations, recommended, inter alia, that an international committee on GNSS should be established to promote the use of GNSS infrastructure on a global

¹Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 19 – 30 July 1999 (United Nations publication, Sales No. E.00.I.3), chap.I, resolution 1.

basis and to facilitate exchange of information. The Committee on the Peaceful Uses of Outer Space (COPUOS) included this recommendation in the Plan of Action proposed in its report² to the General Assembly on the review of the implementation of the recommendations of UNISPACE III. In resolution 59/2 of 20 October 2004, the Assembly endorsed the Plan of Action. In the same resolution, the Assembly invited GNSS and augmentation system providers to consider establishing an international committee on GNSS (ICG) in order to maximize the benefits of the use and applications of GNSS to support sustainable development.

The work of the Action Team on GNSS serves as a model for how the United Nations can undertake action to follow up on global conferences and yield tangible results within a fixed time frame.

In resolution 61/111 of 14 December 2006, the General Assembly noted with appreciation that the International Committee on Global Navigation Satellite Systems (ICG) had been established on a voluntary basis as an informal body to promote cooperation, as appropriate, on matters of mutual interest related to civil satellite-based positioning, navigation, timing and value-added services, as well as the compatibility and interoperability of GNSS, while increasing their use to support sustainable development, particularly in developing countries.

Globally there is growing interest in better understanding solar-terrestrial interactions, particularly patterns and trends in space weather. This is not only for scientific reasons, but also because the reliable operation of ground-based and space-based assets and infrastructures is increasingly dependent on their robustness against the detrimental effects of space weather. Consequently, in 2009, COPUOS proposed the International Space Weather Initiative (ISWI) as a new agenda item to be dealt with in the Scientific and Technical Subcommittee of COPUOS under a three-year workplan³ from 2010 to 2012.

²A/59/174

³A/AC.105/933, section V, paras 15 and 16.



II. Regional workshops on the applications of global navigation satellite systems and International Space Weather Initiative

Regional workshops on applications of GNSS were held in Zambia and China (2006), Colombia (2008), Azerbaijan (2009), Republic of Moldova (2010), the United Arab Emirates and Austria (2011), and Latvia (2012). These workshops addressed, inter alia, GNSS space technology applications for remote sensing, precision agriculture, aviation, transport and communications, and e-learning. The workshop objectives were focused on initiating pilot projects, and strengthening the networking of GNSS-related institutions in the regions. The workshops also addressed the areas of natural resource management and environmental monitoring by applying GNSS technologies to thematic mapping, forest management and water resources management.

ISWI contributes to the observation of space weather phenomena through the deployment of ground-based worldwide instrument arrays (GPS receivers, magnetometers, solar telescopes, very-low frequency (VLF) monitors, solar particle detectors) and the sharing of recorded data among researchers around the world. It is implemented by the Office for Outer Space Affairs in the framework of the United Nations Basic Space Science Initiative and its series of annual workshops. A first series of workshops dedicated to basic space science was held from 1991 to 2004 in India (1991), Costa Rica and Colombia (1992), Nigeria (1993), Egypt (1994), Sri Lanka (1995), Germany (1996), Honduras (1997), Jordan (1999), France (2000), Mauritius (2001), Argentina (2002), and China (2004) and addressed the status of astronomy in Asia and the Pacific, Latin America and the Caribbean, Africa, and Western Asia.

From 2005 to 2009, the workshops were dedicated to the International Heliophysical Year 2007 and held in the United Arab Emirates (2005), India (2006), Japan (2007), Bulgaria (2008) and the Republic of Korea (2009). These workshops contributed to the deployment of instrument arrays recording data on solar-terrestrial interaction from coronal mass ejections to variations of the total electron content in the ionosphere.

Beginning in 2010, the workshops focused on ISWI and were scheduled for Egypt in 2010 for Western Asia, Nigeria in 2011 for Africa, and Ecuador in 2012 for Latin America and the Caribbean. These workshops reviewed the results of the operation of the instrument arrays and discussed ways and means for the continuation of space weather research and education.

All aspects of the agriculture industry, from basic rural cadastre and surveying to advanced precision agriculture, benefit from the use of GNSS. Agro-climatic and ecological-economic zonings, crop inventory, monitoring and forecasting are examples of agricultural activities where positioning and timing are of paramount importance. In the area of climate change, different factors and mechanisms drive land use and transformation. In many cases, climate, technology and economics appear to be determinants of land use. At the same time, land conversion is an adaptive feedback mechanism that farmers use to smooth the impact of climate variability, especially during extremely wet or dry periods.

Satellites are an indispensable resource for monitoring and observing the Earth and its weather systems. They gather data for global climate models, and efforts continue in developing refined models that can be used in regional and national settings. The use of GNSS has been significant in making detailed observations of key meteorological parameters, whose measurement stability, consistency and accuracy could make it possible to quantify long-term climate change trends.

In the area of transport, studies have shown that civil aviation will significantly benefit from the use of GNSS. These benefits include improved navigation coverage in areas currently lacking conventional tracking aids, accurate and reliable information about aircraft positions and routes that enables safe and efficient management of air traffic, (particularly on airport approaches). Road transport applications can automatically revise a route to account for traffic congestion, changes in weather conditions or road works. Similarly, at sea, GNSS technologies can provide efficient route planning, collision avoidance and increased efficiency in search and rescue situations. For rail transport, GNSS offers enhanced cargo monitoring and assists track surveying. In addition, communication systems, electrical power grids and financial networks all rely on precision timing for synchronization and operational efficiency. For example, wireless telephone and data networks use GPS time to keep all of their base stations in perfect synchronization. This allows mobile handsets to share limited radio spectrum more efficiently.

Since the last solar maximum in 2000, societal dependence on GNSS has increased substantially. Critical applications, such as railway control, highway traffic management, precision agriculture, emergency response, commercial aviation and marine navigation, require and depend on GNSS services. Everyday activities, such as banking, mobile phone operations and even the control of power grids, are facilitated by the accurate timing provided by GNSS. As national, regional and international infrastructure and economy are increasingly dependent on positioning, navigation and timing services, society at large is vulnerable to disruptions that can be caused by space weather or variable conditions on the Sun and in the space environment that can influence space-borne and ground-based technological systems. Just as society takes for granted that electricity, heat and clean

water will be available, it also takes for granted that GNSS will be available, reliable and accurate. GNSS is so entrenched in the daily activities of individuals, businesses and government that any loss of satellite positioning, navigation and timing services would be widely disruptive.

To date, the vulnerabilities of GNSS are well categorized, and it is understood that space weather is the largest contributor to single-frequency GNSS errors. Primary space weather effects on GNSS include range errors and loss of signal reception. The GNSS industry faces several scientific and engineering challenges to keep pace with increasingly complex user needs: developing receivers that are resistant to scintillation and improving the prediction of the state of the ionosphere. With GNSS modernization, the use of additional signals is expected to reduce errors caused by the ionosphere.



III. Regional centres for space science and technology education

The General Assembly, in resolution 45/72 of 11 December 1990, endorsed the recommendation of the Working Group of the Whole of the Scientific and Technical Subcommittee, as endorsed by COPUOS, that the United Nations should lead, with the active support of its specialized agencies and other international organizations, an international effort to establish regional centres for space science and technology education in existing national/regional educational institutions in the developing countries.⁴

The General Assembly, in resolution 50/27 of 6 December 1995, paragraph 30, also endorsed the recommendation of COPUOS that those centres be established on the basis of affiliation to the United Nations as early as possible and that such affiliation would provide the centres with the necessary recognition and would strengthen the possibilities of attracting donors and of establishing academic relationships with national and international space-related institutions.

Regional centres⁵ have been established in India for Asia and the Pacific, in Morocco and Nigeria for Africa, in Brazil and Mexico for Latin America and the Caribbean and in Jordan for Western Asia, under the auspices of the Programme on Space Applications, implemented by the Office for Outer Space Affairs. The objective of the centres is to enhance the capabilities of member States, at the regional and international levels, in various disciplines of space science and technology that can advance their scientific, economic and social development. Each of the centres provides postgraduate education, research and application programmes with emphasis on remote sensing, satellite communications, satellite meteorology, and space science for university educators and research and application scientists.

⁴A/AC.105/456, annex II, para. 4 (n)

⁵A/AC.105/749

Additional GNSS education curriculum will supplement the proven standard model education curricula of the regional centres, developed through the United Nations Programme on Space Applications and comprising the following core disciplines taught at the Centres: (a) remote sensing and geographic information systems, (b) satellite communications, (c) satellite meteorology and global climate, and (d) space and atmospheric sciences.

The activities at each centre are undertaken in two major phases. Phase 1 emphasizes the development and enhancement of the knowledge and skills of university educators and research and application scientists in both the physical and natural sciences as well as in analytical disciplines. This is accomplished over a nine-month period as laid out in the curricula of the education programme of each centre. Phase 2 focuses on ensuring that the participants make use of the skills and knowledge gained in phase 1 in their pilot projects, which are to be conducted over a one-year period in their own countries.

The activities and opportunities provided in the two phases should result in the development and growth of capacities that will enable each country to enhance its knowledge, understanding and practical experience in those aspects of space science and technology that have the potential for a greater impact on its economic and social development, including the preservation of its environment.



IV. Information centres of the International Committee on Global Navigation Satellite Systems

Efforts to build capacity in space science and technology are considered a major focus of the Office for Outer Space Affairs and are of specific interest to ICG with particular reference to GNSS. Such efforts should aim to provide support to the regional centres for space science and technology education affiliated to the United Nations, which would also act as ICG information centres.

Negotiations with the regional centres are ongoing in order to utilize them as “hubs” for training and information dissemination on global applications of GNSS and their benefits for humanity. ICG Information Centres aim to foster a more structured approach to information exchange in order to fulfil the mutual expectations of a network linking ICG and the regional centres; and to connect the institutions involved or interested in GNSS applications with GNSS system providers.

The ICG Executive Secretariat and GNSS providers see two areas where they can assist the process of the development and progress towards the further development of ICG Information Centres: the technical level, which will include various GNSS technologies, and the cooperative level with possible collaboration with industry leaders and linkages with current and planned system and augmentation system providers. Linkages would be facilitated through collaboration with the Providers’ Forum (seminars/trainings and supportive material), as well as communication and outreach to the wider community through the ICG information portal, mailing lists, brochures and newsletter.

From 2008 to 2010, the ICG Executive Secretariat took the lead in organizing training courses on satellite navigation and location-based services in the United Nations-affiliated regional centres for space science and technology education. These training courses addressed GNSS technology and its applications, including hands-on experience in the use of off-the-shelf software for specific applications and GNSS signal processing and facilitated the development of the GNSS education curriculum.



V. Curriculum on global navigation satellite systems

The GNSS education curriculum was developed by taking into account GNSS course outlines as used at the university level in a number of developing and industrialized countries. The incorporation of elements of GNSS science and technology into university-level education curricula served a dual purpose: *(a)* it could enable countries to take advantage of the benefits inherent in the new technologies, which, in many cases, are spin-offs from space science and technology; or *(b)* to introduce the concepts of high technology in a non-esoteric fashion and help create national capacities in science and technology in general. Currently serious efforts are being made worldwide to introduce GNSS, in terms of science, technology and applications, as a stand-alone discipline in university-level curricula.

This GNSS education curriculum differs from most of those available in literature and on the Internet. The GNSS education curriculum was a unique result of the deliberations of the regional workshops on GNSS applications since 2006.

This curriculum will be made available to the regional centres for space science and technology education, affiliated to the United Nations. The regional centres may appropriately tune and structure the actual course by deciding on the depth/content of the topics. Centres may also fine-tune the topics to address issues related to the region. The course prerequisite is a degree in Electronics and Communications Engineering, Geomatics, or Software and Computer Engineering.

The course consists of nine modules covering specific areas of GNSS (theory, technology and applications). The duration of the course is 36 weeks, followed by one year of pilot-project work in the participant's home country.

The following breakdown of time for each module is recommended:

<i>Module</i>	<i>Topic</i>	<i>Duration in hours</i>
Lectures		540
I:	Fundamentals	60
II:	Position determination techniques	60
III:	Technologies: augmented systems	80
IV:	Sensors and embedded system design	60
V:	Receivers	80
VI:	GNSS/INS integrated navigation	80
VII:	GNSS applications	80
VIII:	Space weather and GNSS	40
Practical exercises and thesis		
IX:	Laboratory experiments, field visits, project work	540

The courses take place five days a week, with eight 45-minute sessions per day. The breakdown by module and type of course are as follows:

Module I. Fundamentals

- 1.1 Introduction to GNSS: *Conventional navigation, background, concepts and evolutions of global navigation satellite systems (GPS, GLONASS, Galileo, BeiDou/COMPASS) and regional navigations satellite systems (IRNSS, QZSS). Comparison of GNSS with other navigation systems;*
- 1.2 Reference systems: *Terrestrial, celestial and orbit coordinate reference system. Height Systems. Geoid. Time systems, synchronization and data conversion. Transformations between coordinate reference systems. Contribution of the International GNSS Service (IGS) to providing access to the International Terrestrial Reference Frame (ITRF);*
- 1.3 Satellite orbits: *Orbital parameters. Orbital motion, representation (Keplerian elements, etc) Determination of satellite position, visibility and ground tracks;*
- 1.4 Basic techniques of communications: *Propagation of electromagnetic waves. Antennas and propagation channels. Signal modulation and multiple accesses. Signal processing.*

Module II. Position determination techniques

- 2.1 GNSS measurements: *pseudo-ranges, carrier phase and Doppler*;
- 2.2 Position determination techniques (*general*);
- 2.3 Single point position technique: *models and estimation methods*;
- 2.4 Satellite constellation and dilution of precision: *satellite geometry, bounds and calculations on dilution of precision (DOP)*.

Module III. Technologies: augmented systems

- 3.1 Errors in GNSS measurements: *functional model and fundamental error equation, effect of GDOP, classes of ranging errors and biases*;
- 3.2 Effects of errors: *error budget, user equivalent range error, position accuracy with one sigma and three sigma errors*;
- 3.3 Error mitigation techniques: *real time kinematic (RTK), differential GNSS (DGNSS), local area DGNSS, wide area DGNSS*;
- 3.4 Augmented systems: *Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS), System of Differential Correction and Monitoring (SDCM), Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS), GPS Aided Geo Augmented Navigation (GAGAN), etc.*;
- 3.5 GNSS networks: *Global, regional and local GNSS Permanent Networks and geodetic infrastructure for real positioning services*;
- 3.6 GNSS impact factors and mitigation techniques: *Orbit errors, clock errors, multipath, troposphere, ionosphere including higher order ionospheric refraction effects, vulnerability against space weather, jamming*.

Module IV. Sensors and embedded system design

- 4.1 Sensors and transducers: *Introduction, Sensor classification, characteristics and compensation, classification of transducers. Transducer descriptions, parameters, definitions and terminology*;
- 4.2 Embedded systems: *Cell phones, pagers, PDAs, answering machines, microwave ovens, televisions, VCRs, CD/DVD players, video game consoles, GNSS devices, network routers, fax machines, cameras, music synthesizers, planes, spacecraft, boats, and cars all contain embedded processors*.

Module V. GNSS receivers

- 5.1 Receiver architecture: *Technology, radio-frequency front end, signal processing system hardware and software techniques, software defined radio;*
- 5.2 Signal tracking: *Maximum likelihood estimate of delay and position, delay lock tracking of signal, coherent and non coherent delay lock tracking of pseudo noise sequences, mean square error estimation, vector delay lock loop, receiver noise performance, maximum likelihood estimate, early late gating;*
- 5.3 Navigation algorithm: *Measurement of pseudo range, Doppler, decoding and using of navigation data, single point solution, precise point positioning, dynamics of user, Kalman filter, least-squares adjustment, and other alternatives.*

Module VI. GNSS/INS integrated navigation

- 6.1. Inertial navigation systems. *Accelerometer, Gyroscopes, Inertial platforms, Navigation equation, Integration of modelling equations in e-frame;*
- 6.2. INS error dynamics: *Simplified analysis, Error dynamics equations in e-frame, INS initialization and alignment;*
- 6.3. GNSS/INS integration: *Integration mode, Mathematical model of supported INS navigation, Observation procedures for inertial surveying;*
- 6.4. General sensor fusion concepts.

Module VII. GNSS applications

- 7.1. Geospatial databases: *Geo extensions for Open Source Databases, POSTGRES, MySQL etc.;*
- 7.2. GNSS navigation: *Professional and personal, GIS/mapping, Surveying, Natural Hazards management, Earth sciences, Natural resources, Infrastructure;*
- 7.3. Navigation and communication: *Integrated application;*
- 7.4. Communication, navigation and surveillance: *Integrated application;*
- 7.5. GNSS applications for remote sensing of the atmosphere and space weather: *Radio occultation technique for monitoring terrestrial weather (temperature and water vapour) and monitoring ionospheric weather (electron density and total electron content);*
- 7.6. Revenue model for value added services;

- 7.7. Management, team work, intellectual property, business in GNSS.

Module VIII. Space weather and GNSS

- 8.1. Sources of space weather and related background physics: *Sun, galactic cosmic rays, magnetosphere, thermosphere, ionosphere coupling*;
- 8.2. Impact of space weather events on GNSS;
- 8.3. Satellites, interference with solar radio emission, radio wave propagation;
- 8.4. Different view in precise (geodesy, DGPS) and safety of life (aviation) applications;
- 8.5. Ionospheric scintillations and their impact, monitoring and modeling;
- 8.6. GNSS-based monitoring of the ionosphere by ground and space based measurements;
- 8.7. Ionospheric correction and threat models.

Module IX. Laboratory experiments, field visits, project work

- 9.1. Coordinate and time conversion, and reference system transformations;
- 9.2. GNSS/INS equipment;
- 9.3. GNSS data formats: *Receiver Independent Exchange Format (RINEX), Real-Time GNSS Data Transmission Standard (RTCM), United States National Marine Electronics Association (NMEA)*;
- 9.4. Single point positioning solution;
- 9.5. High precision postprocessed GNSS;
- 9.6. Experiment with DGPS;
- 9.7. Experiment with RTK receivers;
- 9.8. Experiment to demonstrate accuracy improvement using satellite-based augmentation system (SBAS);
- 9.10. Design aspects of software for integrating location-based services with position, for example, Smartphone applications;
- 9.11. Design of application: *Combining satellite navigation with satellite communication (Fleet monitoring)*;

- 9.12. Design of application: *Combining satellite navigation with satellite communication (Disaster management)*;
- 9.13. Design of computer simulated receiver based on software defined radio.

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Available courses, including on GNSS and its applications:

ESA International Summer School on Global Navigation Satellite Systems: http://www.esa.int/esaNA/SEMQWXQVEAG_index_0.html

Galileo Information Center for Latin America: <http://www.galileoic.org/>

Global Positioning System, Serving the World: <http://www.gps.gov/>

Internet Courses on Global Navigation Satellite Systems: University of Maine, USA: <http://www.gnss.umaine.edu>

Master of Science (MSc) in Global Navigation Satellite Systems (GNSS): <http://www.enac.fr/en/menu/training/master-science-degrees/master-gnss>

NAVKIT educational tool: <http://www.navsas.eu/>

NavtechGPS: <http://www.navtechgps.com>

Research group of Astronomy and GEomatics (gAGE), Technical University of Catalonia (UPC), Barcelona, Spain: <http://www.gage.es/>

Regional centres for space science and technology education affiliated to the United Nations www.unoosa.org/oosa/en/SAP/centres/index.html

United Nations/Italy Long-term Fellowship Programme on GNSS and Related Applications, Master in Navigation and Related Applications (MNA): www.unoosa.org/oosa/SAP/gnss/fellowships.html



ANNEX I. Glossary of GNSS terms

The GNSS glossary of terms has been produced as a direct response to the needs of the GNSS user community in the framework of the ICG Providers' Forum workplan. The purpose of this glossary of terms is to provide definitions of terms as they are used in the context of the United Nations General Assembly documentation in the A/AC.105/ series on the meetings of the ICG that had been held since 2005. Some of the definitions were arrived at after considerable debate within the ICG Providers' Forum membership, and some continue to be debated. Therefore, it is intended to be read in conjunction with the ICG documents, which are available in all official languages of the United Nations and can be downloaded from the webpage of the Office for Outer Space Affairs: www.unoosa.org

A

Accuracy A measure of how close an estimate of a satellite position is to the true value of the quantity. Radionavigation system accuracy is usually presented as a statistical measure of system error and is specified as:

- **Predictable:** The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum.
- **Repeatable:** The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
- **Relative:** The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

Acquisition time The time it takes a satellite receiver to acquire satellite signals and determine the initial position.

Air traffic control (ATC) A service operated by an appropriate authority to promote the safe and efficient flow of air traffic.

Almanac Coarse satellite orbital data used to calculate satellite position, rise time, elevation and azimuth.

Ambiguity The unknown integer number of cycles of double differenced carrier phases measured by two receivers from a pair of satellites.

Anti-spoofing Encryption of the authorized code to protect signals from being “spoofed” through the transmission of false signals.

Area navigation (RNAV) A method of navigation that permits aircraft operation on any desired flight path within the coverage of station referenced navigation aids or within the limits of capability of self-contained aids, or a combination of these.

Authorized service A service specifically designed to meet the needs of authorized users in support of governmental functions.

Atomic clock A clock that uses an electronic transition frequency of atoms as a frequency standard for its timekeeping element. Common elements used are cesium or rubidium.

Availability The availability of a navigation system is the percentage of time that the services of the system are usable.

Azimuth A horizontal angle measured clockwise from a direction (such as North).

B

Bandwidth A measure of the width of the spectrum of a signal (frequency domain representation of a signal) expressed in hertz.

Baseline length The length of the three-dimensional vector between a pair of stations for which simultaneous GPS data has been collected and processed with differential techniques. At the level of about one part per billion, which applies to GNSS over global scales, accurate length definition requires considerations of the theory of special and general relativity, implying a dependence on local geopotential fields.

Beacon A stationary transmitter that emits signals in all directions (also called a non-directional beacon).

Bearing Term used in navigation to describe the angle between a reference direction (e.g., geographic north, magnetic north, grid north) and the trajectory.

Beat frequency Either of the two additional frequencies obtained when signals of two frequencies are mixed.

Binary phase shift key (BPSK) modulation using Rectangular Symbols (BPSK_R) A BPSK modulation using a single instantaneous 180° phase transition per symbol.

Binary offset carrier (BOC) An extension of BPSK-R modulation where each symbol is the same portion of a square wave, with each symbols modulated by 180° phase rotation.

BIPM *see* International Bureau of Weights and Measures.

C

C/A code *see* Coarse/Acquisition code.

Cartesian coordinates The coordinates of a point in space given in three mutually perpendicular dimensions (x, y, z) from the origin (Cartesian Coordinate System).

Cartography The art or technique of making maps or charts.

Carrier A radio wave having at least one characteristic (e.g., frequency, amplitude, phase), which may be varied from a known reference value by modulation.

Carrier-aided tracking A signal processing technique that uses the GNSS carrier signal to achieve an exact lock on the pseudo random code generated by the GNSS satellite.

Carrier phase The fraction of a cycle, often expressed in degrees, where 360° equals a complete cycle.

Carrier beat phase The phase of the signal which remains when the incoming Doppler shifted satellite carrier signal is beat (the differential frequency signal is generated) with the nominally constant reference frequency generated in the receiver.

Carrier frequency The frequency of the unmodulated fundamental output of a radio transmitter.

CBOC Composite BOC.

CDMA *see* Code division multiple access.

CELESTE GNSS research laboratory developed and operated by the systems department of the NLR Space Department (The Netherlands).

Channel A channel of a GNSS receiver consists of the circuitry necessary to track the signal from a single GNSS satellite.

Chip Bit in a spreading code.

Chip rate Number of chips per second (e.g., C/A code: 1.023×10^6 cycles per second).

Clock bias The difference compared to the GNSS system time.

Clock offset Constant difference in the time reading of two clocks.

Coarse/Acquisition code (C/A code) The standard positioning signal the GNSS satellite transmits to the civilian user.

Coastal confluence zone (CCZ) Harbour entrance to 50 nautical miles offshore or the edge of the continental shelf (100 fathom curve), whichever is greater.

Code A sequence of binary values.

Code division multiple access (CDMA) A method whereby many signals are transmitted at the same time and same centre frequency but different spreading codes; receivers can distinguish among the signals using their different spreading codes.

Cold start The power-on-sequence where the GNSS receiver has no a priori information, no knowledge of time, position, nor any satellite almanac data, and must download almanac data before establishing a fixed position.

Compacted data Raw data compacted over a specified time interval (compaction time) into one single observable (measurement) for recording.

Common-use systems Systems used by both civil and military sectors.

Compass/BeiDou navigation satellite system The global navigation system of China. The system consists of five geostationary satellites and 30 non-geostationary satellites. The geostationary satellites are located at 58.75° E, 80° E, 110.5° E, 140° E and 160° E.

Compatibility Refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference and/or other harm to an individual system and/or service:

- The International Telecommunication Union (ITU) provides a framework for discussions on radiofrequency compatibility. Radiofrequency compatibility should involve thorough consideration of detailed technical factors, including effects on receiver noise floor and cross-correlation between interfering and desired signals;
- Compatibility should also respect spectral separation between each system's authorized service signals and other systems' signals. Recognizing that some signal overlap may be unavoidable, discussions among providers concerned will establish the framework for determining a mutually acceptable solution;
- Any additional solutions to improve compatibility should be encouraged.

Compliance The act of adhering to, and demonstrating adherence to, a standard or regulation.

Conformal projection A map projection that preserves angles on the ellipsoid after they have been mapped on to the plane.

Constellation A group of satellites working in concert is a satellite constellation.

Conterminous United States (CONUS) Forty-eight adjoining states of the United States on the North American continent and the District of Columbia; specifically not including the states of Alaska and Hawaii.

Continuity The continuity of a system is the ability of the total system (comprising all elements necessary to maintain aircraft position within the defined airspace) to perform its function without interruption during the intended operation. More specifically, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation.

Continuously Operating Reference Stations (CORS) The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service, coordinates a network of continuously operating reference stations.

Control segment Ground-based GNSS equipment operated by the service provider that tracks the satellite signals, determines the orbits of the satellites, and transmits commands and orbit definitions to the satellites.

CONUS *see* Conterminous U.S.

CORS *see* Continuously Operating Reference Stations.

Coordinates A set of numbers that describes the location on or above the Earth. Coordinates are typically based on latitude/longitude lines of reference or a global/regional grid projection (e.g., UTM, Maidenhead).

Coordinated Universal Time (UTC) An atomic time scale derived by the Bureau Internationale des Poids et Mesures (BIPM) based on measurements reported from many contributing national time laboratories, each of which maintains its own local realization of UTC. The scale unit is kept as close as possible to the second of the International System (SI) of units, except that occasional leap seconds are inserted to remain in step with the irregular rotation of the Earth.

COSMIC The Constellation Observing System for Meteorology, Ionosphere and Climate.

Cutoff angle The minimum elevation angle below which no more GNSS satellites are tracked by a GNSS receiver.

Coverage The coverage provided by a radio-navigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy.

Cycle slip A discontinuity of an integer or half integer number of cycles in the measured carrier beat phase.

D

Data message (also known as Navigation Data) Data transmitted by GNSS satellites, which is used to compute a satellite's location and satellite clock corrections.

Datum A mathematical model that depicts a part of the surface of the Earth. Latitude and longitude lines on a paper map are referenced to a specific map datum.

dB Decibel, a logarithmic unit of measurement in acoustics and electronics.

Deflection of the vertical The angle between the normal to the ellipsoid and the vertical (true plumb line).

Delay lock The technique whereby the received code (generated by the satellite clock) is compared with the internal code (generated by the receiver clock) and the latter shifted in time until the two codes match.

DGPS *see* Differential GPS.

Differential A technique used to improve radio-navigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radio-navigation system, operating in the same area.

Differential GPS The term commonly used for a GPS system that utilizes differential corrections to achieve enhanced positioning accuracy.

Differenced measurements Single differences are usually between receivers simultaneously observing the same satellite; double differences are usually single differences between two different simultaneous satellite observations; and triple differences are usually double differences in time.

Differential positioning Determination of relative coordinates between two or more receivers, which are simultaneously tracking the same GNSS signals.

Dilution of Precision (DOP) A statistical measure of the receiver-satellite(s) geometry. Also, *see* Geometric Dilution of Precision (GDOP).

Distance measuring equipment (DME) A transponder-based radio navigation technology that measures distance by timing the propagation delay of VHF or UHF radio signals.

Diurnal Repeating daily as in e.g. diurnal effect.

DOP *see* Dilution of Precision.

DOP holes Space vehicle (SV) configurations (positions in the sky) that lead to high values of GDOP, and therefore to large positioning errors.

Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) A French system that uses Doppler measurements of radio transmissions from ground-based beacons to determine the orbits of satellites installed with special receptors and the positions of the transmitting stations.

Doppler shift The apparent change in frequency of a received signal due to the rate of change of the range between the transmitter and receiver.

DORIS *see* Doppler Orbitography and Radio-positioning Integrated by Satellite.

Dual-Use System System used for civil as well as defence purposes.

Dynamic Positioning The process of determining position and velocity from GNSS signals while the GNSS antenna is in motion.

E

Earth Centered, Earth Fixed (ECEF) A Cartesian coordinate system whose origin is at the Earth's centre of mass and which is fixed to the Earth's surface (i.e., rotating with the Earth). The Z-axis is aligned with the Earth's mean spin (north) axis. The X-axis is aligned

with the zero (Greenwich) meridian. The Y-axis is 90° east of the X-axis, forming a right-handed coordinate system.

Eccentricity The ratio of the distance from the centre of an ellipse to its focus to the semi-major axis: $e = (1 - b^2/a^2)^{1/2}$, where a and b are the semi-major and semi-minor axis of the ellipse, respectively.

ECEF – *see* Earth Centered, Earth Fixed.

EGNOS *see* European Geostationary Navigation Overlay Service.

Ellipsoid In geodesy, unless otherwise specified, a mathematical figure formed by revolving an ellipse about its minor axis (sometimes also referred to as spheroid). Two quantities define an ellipsoid; these are usually given as the length of the semi major axis (a) and the flattening (f). Also, *see* Eccentricity.

Ellipsoid height The vertical distance of a user above the ellipsoid.

En route A phase of navigation covering operations between a point of departure and termination of a mission. For airborne missions, the en route phase of navigation has two subcategories, en route domestic and en route oceanic.

Ephemerides Plural of ephemeris.

Ephemeris Parameters, such as Keplerian coefficients, that can be used to compute a satellite's position at a specified time.

Ephemeris error Difference between the actual satellite location and the location predicted by the satellite orbital data (ephemeris).

Epoch A particular fixed instant of time used as a reference point on a time scale.

Equipotential surface A mathematically defined surface where the gravitational potential is the same at any point on that surface.

ESD Static Electricity and Electrostatic Discharge.

European Geostationary Navigation Overlay Service (EGNOS) EGNOS provides an augmentation signal to the GPS standard positioning service. The EGNOS signal is transmitted on the same signal frequency band and modulation as the GPS L1 (1575.42 MHz) C/A civilian signal function. While the GPS consists of positioning and timing signals generated from spacecraft orbiting the Earth, thus providing a global service, EGNOS provides correction and integrity information intended to improve positioning navigation services over Europe.

European Satellite Navigation System (Galileo) An initiative launched by the European Commission and the European Space Agency, is a global navigation satellite system, owned by the European Union, providing highly accurate, guaranteed global positioning services under civilian control. The nominal Galileo constellation comprises a total of 27 satellites, which are evenly distributed among three orbital planes inclined at 56° relative to the

equator. There are nine operational satellites per orbital plane, occupying evenly distributed orbital slots. Three additional spare satellites (one per orbital plane) complement the nominal constellation configuration. The Galileo satellites are placed in circular Earth orbits with a nominal semi-major axis of about 30,000 km and an approximate revolution period of 14 hours.

F

FDMA Frequency Division Multiple Access.

FEC *see* Forward Error Correction.

Flattening Relating to Ellipsoids: $f = (a-b)/a = 1-(1-e^2)^{1/2}$, where a = semi-major axis, b = semi-minor axis, and e = eccentricity (*see* Eccentricity).

FOC *see* Full operational capability.

Forward Error Correction (FEC) A system of error control for data transmission, whereby the sender adds redundant data to its messages, also known as an error correction code.

Full Operational Capability (FOC) A system dependent state that occurs when the particular system is able to provide all of the services for which it was designed.

G

GAGAN *see* GPS-aided GEO-Augmented Navigation System.

Galileo *see* European Satellite Navigation System.

Galileo In-Orbit-Validation Element (GIOVE) The name for each satellite in a series being built for the European Space Agency (ESA) to test technology in orbit for the Galileo positioning system.

GBAS *see* Ground-based Augmentation System.

GDOP *see* Geometric Dilution of Precision (also, *see* DOP).

GEAS Global Navigation Satellite System (GNSS) Evolutionary Architecture Study.

Geocentric Relating to the centre of the Earth.

Geodesy The study of the Earth's size and shape.

Geodetic coordinates Coordinates defining a point with reference to an ellipsoid using latitude, longitude and ellipsoidal height or using Cartesian coordinates.

Geodetic datum A mathematical model designed to best fit part or all of the geoid defined by an ellipsoid and the relationship between the ellipsoid and a point on the topographic surface established as the origin of datum.

Geographic Information System (GIS) A system, also known as a geographical information system, that captures, stores, analyses, manages and presents data that refers to or is linked to location.

Geoid The particular equipotential surface, which coincides with mean sea level, and which may be imagined to extend through the continents and is everywhere perpendicular to the direction of the force of gravity.

Geoidal height *see* Geoid separation.

Geoid separation The distance from the surface of the reference ellipsoid to the geoid measured outward along the normal to the ellipsoid.

Geometric Dilution of Precision (GDOP) It is composed of Time Dilution of Precision (TDOP) and Position Dilution of Precision (PDOP), which are composed of Horizontal Dilution of Precision (HDOP) and Vertical Dilution of Precision (VDOP). GNSS Accuracy = GDOP x UERE. Also, *see* User Equivalent Range Error (UERE).

Geosynchronous orbit A specific orbit around where a satellite rotates around the Earth at the same rotational speed as the Earth. A satellite rotating in geosynchronous orbit appears to remain stationary when viewed from a point on or near the equator.

GIS *see* Geographic Information System.

GIOVE *see* Galileo In-Orbit-Validation Element.

GLObal NAVigation Satellite System (GLONASS) The global navigation satellite system provided by the Russian Federation. The nominal baseline constellation of GLONASS comprises 24 Glonass-M satellites that are uniformly deployed in three roughly circular orbital planes at an inclination of 64.8° to the equator. The altitude of the orbit is 19,100 km. The orbit period of each satellite is 11 hours, 15 minutes, 45 seconds. The orbital planes are separated by 120° right ascension of the ascending node. Eight satellites are equally spaced in each plane with 45° argument of latitude. Moreover, the orbital planes have an argument of latitude displacement of 15° relative to each other.

Global Positioning System (GPS) The global navigation satellite system provided by the United States of America. The GPS baseline constellation consists of 24 slots in six orbital planes, with four slots per plane. Three of the slots are expandable and can hold no more than two satellites. Satellites that are not occupying a defined slot in the GPS constellation occupy other locations in the six orbital planes. Constellation reference orbit parameters and slot assignments as of the defined epoch are described in the fourth edition of the GPS Standard Positioning Service Performance Specification, dated September 2008. As of that date, the GPS constellation had 30 operational satellites broadcasting healthy navigation signals: 11 in Block IIA, 12 in Block IIR and 7 in Block IIR-M.

GLONASS *see* GLObal NAVigation Satellite System.

GLONASS time An atomic time scale similar to GPS. This time scale is UTC as maintained by the Russian Federation (UTC (SU)). GLONASS time is maintained within 1 ms, and typically better than 1 microsecond (μs), of UTC (SU) by the control segment with the remaining portion of the offset broadcast in the navigation message.

GMS Ground Monitor Station.

GMT *see* Greenwich Mean Time.

GNSS navigation message Data message sent from the satellite which includes satellite ephemeris and clock corrections, constellation health and almanac, etc.

GPB *see* Gravity Probe B.

GPS *see* Global Positioning System.

GPS-aided GEO-Augmented Navigation System (GAGAN) A planned implementation of a regional Satellite-based Augmentation System (SBAS) by India. It is a system to improve the accuracy of a GNSS receiver by providing reference signals. As an operational system, it is planned that the space segment will consist of two geostationary satellites, located at 82° E and 55° E respectively, each of which will carry a bent pipe transponder. An additional on-orbit spare (located at 83° E) will also be added.

GPS time A continuous time system broadcast by GPS satellites, which is traceable to UTC (USNO) as maintained by the United States Naval Observatory but without the insertion of leap seconds. Also, *see* UTC (USNO).

GRACE *see* Gravity Recover and Climate Experiment.

Graticule A plane grid representing the lines of latitude and longitude of an ellipsoid.

Gravitational constant The proportionality constant in Newton's law of gravitation: $G = 6.673\text{E-}11\text{m}^3/\text{s}^2/\text{kg}$.

Gravity Probe B The relativity gyroscope experiment carried out by NASA and Stanford University to test two extraordinary, unverified predictions of Albert Einstein's general theory of relativity.

Gravity Recover and Climate Experiment (GRACE) It consists of two nearly identical satellites launched in March 2002 and flying approximately 220 km apart in a polar orbit 500 km above the Earth whose primary mission is to conduct extraordinarily precise gravity field measurements.

Great circle course Term used in navigation. Shortest connection between two points.

Greenwich Mean Time (GMT) The mean solar time of the meridian of Greenwich. It is used as the prime basis of standard time throughout the world.

Ground-based Augmentation System (GBAS) Localized deployed stations, which support the precision approach and terminal area RNAV operations stages.

H

HDOP Horizontal Dilution of Precision (*see* DOP).

HMI Hazardously Misleading Information.

I

ICG *see* International Committee on Global Navigation Satellite Systems.

ICRS *see* International Celestial Reference System.

IDM Interference Detection and Mitigation.

IERS *see* International Earth Rotation and Reference Systems Service.

IGS *see* International GNSS Service.

IGSO Inclined Geosynchronous Orbit

ILRS International Laser Ranging Service.

Inclination The angle between the orbital plane of a satellite and the equator.

Initial Operational Capability (IOC) A system dependent state that occurs when the particular system is able to provide a predetermined subset of the services for which it was designed.

Integer bias term *see* Ambiguity.

International Bureau of Weights and Measures (BIPM) An international standards organization (Bureau international des poids et mesures, in French), one of three such organizations established to maintain the International System of Units (SI) under the terms of the Convention du Mètre (Metre Convention). The organization is usually referred to by its French abbreviation, BIPM.

International Celestial Reference System The current standard celestial reference system adopted by the International Astronomical Union (IAU) whose origin is at the barycentre of the solar system, with axes that are intended to be “fixed” with respect to space.

International Committee on Global Navigation Satellite Systems The ICG was established on a voluntary basis as an informal body for the purpose of promoting cooperation, as appropriate, on matters of mutual interest related to civil satellite-based positioning, navigation, timing and value-added services, as well as compatibility and interoperability among the GNSS systems, while increasing their use to support sustainable development, particularly in developing countries. The ICG secretariat is provided by the United Nations Office for Outer Space Affairs (UNOOSA).

International Earth Rotation and Reference Systems Service (IERS) The body responsible for maintaining global time and reference frame standards, notably through its Earth Orientation Parameter (EOP), International Celestial Reference System (ICRS),

and International Terrestrial Reference System (ITRS) groups. The organization was formerly known as International Earth Rotation Service until April 2, 2002 when it formally changed its name. The organization chose to retain the acronym IERS.

International GNSS Service, formerly the International GPS Service (IGS) A voluntary federation of more than 200 worldwide agencies that pool resources and permanent GPS and GLONASS station data to generate precise GPS and GLONASS products.

International Laser Ranging Service (ILRS) A global network of observation stations, which measure the round trip time of flight of ultrashort pulses of light to satellites equipped with retroreflectors.

International Terrestrial Reference System (ITRS) Describes procedures for creating reference frames suitable for use with measurements on or near the Earth's surface.

International Union of Geodesy and Geophysics The international organization dedicated to advancing, promoting and communicating knowledge of the Earth system, its space environment and the dynamic processes causing change.

International VLBI Service An international collaboration of organizations that operate or support Very Long Baseline Interferometry (VLBI) components. Also, *see* VLBI.

Interoperability Refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system:

- Interoperability allows navigation with signals from different systems with minimal additional receiver cost or complexity;
- Multiple constellations broadcasting interoperable open signals will result in improved observed geometry, increasing end-user accuracy everywhere and improving service availability in environments where satellite visibility is often obscured;
- Geodetic reference frames realization and system time steerage standards should adhere to existing international standards to the maximum extent practical;
- Any additional solutions to improve interoperability should be encouraged.

IOC *see* Initial Operations Capability.

Ionosphere A region of the earth's atmosphere from about 50 to about 1,000 km above the Earth, where free electrons exist (due to ionization caused by solar radiation, mainly ultraviolet rays), that affects transmission of GNSS signals.

Ionospheric delay The delay wave propagating through the ionosphere (which is a non-homogeneous and dispersive medium) experience. The phase and group delay are of the same magnitude but opposite sign, and are proportionate to the total electronic content (TEC). Also, *see* TEC.

ITRS *see* International Terrestrial Reference System.

IUGG *see* International Union of Geodesy and Geophysics.

J

Jamming (electromagnetic) The deliberate use of unintended radiation, reradiation or reflection of electromagnetic energy for the purpose of preventing or reducing the effective use of a signal.

Jason An oceanography satellite launched in December 2001 and flying in a 66° inclined orbit 1,300 km above the Earth whose mission is to monitor global ocean circulation, study the ties between the oceans and atmosphere, improve global climate forecasts and predictions, and monitor events such as El Niño conditions and ocean eddies.

Jet Propulsion Laboratory (JPL) Operated by Caltech for NASA for unmanned exploration of the solar system.

Julian date The number of days that have elapsed since 1 January 4713 B.C. in the Julian calendar. GPS time zero is defined to be midnight UTC, Saturday/Sunday, 6 January 1980 at Greenwich. The Julian date for GPS time zero is 2,444,244.5.

K

Kinematic positioning Determination of a time series of sets of coordinates for a moving receiver, each set of coordinates being determined from a single data sample, and usually computed in real time.

Keplerian orbital elements Six parameters that describe a satellite's position in space viz:

- a: Semi-major axis
- e: Eccentricity
- ω : Argument of perigee
- Ω : Right ascension of ascending node
- I: Inclination
- n: Mean anomaly

L

LAAS *see* Local Area Augmentation System.

Lambert projection A conformal conic map projection that projects an ellipsoid onto a plane surface by placing a cone over the sphere.

Latitude (Geodetic) The angle between the ellipsoidal normal and the equatorial plane. Latitude is zero on the equator and 90° at the poles.

L-band The radio frequency band extending from 1000-2000 MHz. The frequencies of the L1, L2, and L5 carriers transmitted by GNSS satellites lie within this L-band.

Least squares estimation The process of estimating unknown parameters by minimizing the sum of the squares of measurement residuals.

LEO Low Earth Orbit.

Local Area Augmentation System (LAAS) An all-weather aircraft landing system based on real-time differential correction of the GPS signal. Local reference receivers send data to a central location at the airport. This data is used to formulate a correction message, which is then transmitted to users via a VHF data link. A receiver on an aircraft uses this information to correct GPS signals. The International Civil Aviation Organization (ICAO) calls this type of system a Ground Based Augmentation System (GBAS).

Local ellipsoid An ellipsoid that has been defined for and fits a specific portion of the earth. Local ellipsoids usually fit single or groups of countries such as the Everest ellipsoid for India.

Local time Local time equals to GMT time + time zone.

Localizer performance with vertical guidance (LPV) Provides lateral containment areas comparable to an ILS localizer and decision heights between those of LNAV/VNAV approaches and Cat I ILS approaches.

Longitude The angle between the meridian ellipse, which passes through Greenwich and the meridian ellipse containing the point in question. Thus, longitude is 0° at Greenwich and then measured either eastward through 360° or, eastward and westward by 180°.

Lunar Laser Ranging (LLR) Measures the round-trip travel times of light pulses between stations on the Earth and four retro-reflectors on the surface of the Moon. In April 2010 the Lunokod 1 retroreflector was found; there are now five in use.

M

MADRAS Microwave Analysis and Detection of Rain and Atmosphere.

Maidenhead A coordinate system used in Amateur Radio in which the world is divided into 324 large areas based on latitude and longitude. These areas cover 10° of latitude by 20° of longitude and are called fields. Each field is divided into 100 squares. Each of these 100 squares represent 1° by 2°.

MASER Device that produces coherent electromagnetic waves through amplification due to stimulated emission. Historically the term came from the acronym “Microwave Amplification by Stimulated Emission of Radiation”, although modern masers emit over a broad portion of the electromagnetic spectrum.

Mask angle Minimum acceptable elevation above the horizon that a GNSS satellite has to be to minimize atmospheric distortion.

MBOC Multiplexed Binary Offset Carrier.

M-code GPS military signal.

MCS Master Control Station.

Meridian An imaginary line joining the North to South Pole and passing through the equator at 90°.

MTSAT Satellite-based Augmentation System (MSAS) An air navigation aid developed by Japan Civil Aviation Bureau to augment GPS.

Multipath The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths.

Multipath error A positioning error resulting from interference between radio waves, which have travelled between the transmitter and the receiver by two paths of different electrical lengths.

N

Nanosecond (ns) One billionth of a second.

NASA The National Aeronautics and Space Administration.

NAVCEN Another name for the United States Coast Guard Navigation Centre.

Navigation The process of planning, recording and controlling the movement of a craft or vehicle from one place to another.

Navigation messages/Navigation data Data modulated onto the satellite's signals.

NAVTEX A system designated by the International Maritime Organization (IMO) as the primary means for transmitting urgent coastal marine safety information to ships worldwide.

NDGPS Nationwide Differential Global Positioning System.

NMEA National Marine Electronics Association.

Non-Precision Approach (NPA) An aviation instrument approach procedure based on a lateral path and no vertical guide path.

NOAA The National Oceanic and Atmospheric Administration.

NOCC The National Operations Control.

NPA *see* Non Precision Approach.

O

Observing session A period of time over which GNSS data is collected simultaneously by two or more receivers.

OD&TS Orbit Determination and Timing Synchronization.

Open service Service (using one or more signals) provided to users free of direct user charges.

Orthometric height The distance of a point above the geoid measured along the plumb line through the point (height above mean sea level).

Out-of-band emissions Radio communication emissions, from a transmitter operating in its allocated frequency band, that occur in other frequency bands. Typically, the term refers to those emissions from a transmitter that presents itself in the frequency bands adjacent to the allocated band of the transmitter.

P

P-code The precise GPS code broadcast by GPS.

PDOP Position Dilution of Precision (*see* Dilution of Precision (DOP)).

Phase observable *see* Reconstructed Carrier Phase.

PNT Positioning, Navigation, and Timing.

Point positioning Determination of position (latitude, longitude and height above spheroid), using pseudo-range observations.

Polarization Property of waves that describes the orientation of their oscillations.

Positioning The science of determining location.

Post processing The process of computing positions real-time, using data previously collected by GNSS receivers.

Precise Positioning Service (PPS) The highest level of point positioning accuracy provided by GPS based on dual frequency signals.

Propagation The movement of an electromagnetic (radio) wave through a medium (for example, atmosphere or free space) at the speed of light. Dependent on the medium, the velocity and other characteristics of the wave are altered.

Proprietary Indicates that a party, or proprietor, exercises private ownership, control or use over an item of property; that is, not in the public domain.

Pseudolite (Pseudo-satellite) The ground-based differential GNSS station which transmits DGNSS corrections on a signal with a structure similar to that of an actual GNSS satellite.

Pseudo Random Noise (PRN) code A binary sequence that is finite in length that meets the following three conditions:

- Balance property—In every period, the number of plus ones differs from the number of minus ones by exactly one;

- **Run property**—In every period, half of the runs of the same sign have length 1, one fourth have length 2, one eighth have length 3, and so forth. The number of positive runs equals the number of negative runs.
- **Correlation property**—The auto-correlation of a periodic sequence is two-valued. That is, it can be described by

$$\mathcal{R}(\tau) = \frac{1}{T} \sum_{t=1}^T \rho(t) \rho(t-\tau) = \begin{cases} 1, & \tau = 0, T, 2T, \dots \\ \frac{-1}{\tau}, & \text{otherwise} \end{cases}$$

Pseudo-range A measure of the apparent signal propagation time from the satellite to the receiver antenna, scaled into distance by the speed of light. Pseudo-range differs from the actual range by the influence of satellite and user clock.

Precise time A time requirement accurate to within 10 milliseconds.

Precision approach An instrument approach procedure, based on a lateral path and a vertical glide path, that meets specific requirements established for vertical navigation performance and airport infrastructure.

Q

Quasi-Zenith Satellite System (QZSS) A regional space-based Positioning Navigation and Timing (PNT) system advanced by the Japanese government, which covers the East Asia and Oceania region. It transmits four GPS interoperable signals and two augmentation ones in order to improve current GPS availability and performance.

R

Radio astronomy Radio astronomy is a subfield of astronomy that studies celestial objects at radio frequencies.

Radio-determination The determination of position, or the obtaining of information relating to positions, by means of the propagation properties of radio waves.

Radio location Radio-determination used for purposes other than those of radio navigation.

Radio-navigation The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

Radio occultation A remote sensing technique used for measuring the physical properties of a planetary atmosphere.

RAIM Receiver Autonomous Integrity Monitoring.

RAIM hole Defined to be where at least five GNSS satellites are not in view.

Ranging A technique used to determine a line of position by calculating the distance between a receiver and a known reference point.

Rapid static survey Term used in connection with GNSS for static survey with short observation times.

Raw data Original GNSS data taken and recorded by a receiver.

Real Time Kinematic (RTK) A term used to describe the procedure of resolving the phase ambiguity at the GNSS receiver so that the need for post-processing is removed.

Receiver channel The radio frequency and digital hardware and the software in a GNSS receiver, required to track the signal from one GNSS satellite at one of the GNSS carrier frequencies.

Receiver INdependent EXchange format (RINEX) Asset of standard definitions and formats to promote the free exchange of GNSS data in standard ASCII file.

Reconstructed carrier phase The difference between the phase of the incoming Doppler-shifted GNSS carrier and the phase of a nominally-constant reference frequency generated in the receiver.

Relative positioning *see* Differential positioning.

Reliability The probability of performing a specified function without failure under given conditions for a specified period of time.

Required Navigation Performance (RNP) A statement of the navigation performance accuracy necessary for operation within a defined airspace, including the operating parameters of the navigation systems used within that airspace.

Rhumb line Term used in navigation. Trajectory between two points with constant bearing.

RFI Radio frequency interference.

RINEX *see* Receiver INdependent EXchange format.

RTCM Radio Technical Commission for Maritime Services.

RTK *see* Real Time Kinematic.

S

Safety-of-life Services used by safety critical users, for example maritime, aviation and trains, whose applications or operations require stringent performance levels.

Satellite configuration The satellite constellation at a specific time, relative to a specific user or set of users.

Satellite constellation The arrangement in space of the complete set of satellites of a system like GPS.

Satellite Laser Ranging (SLR) The science of measuring distance to a satellite via laser pulses.

S-band Ranges from 2 to 4 GHz, crossing the (artificial) boundary between UHF and SHF at 3.0 GHz. It is part of the microwave band of the electromagnetic spectrum.

Satellite-based augmentation systems (SBAS) Such as EGNOS, GAGAN, WAAS, complement existing GNSS.

Scintillation (Ionospheric) Variations in received signal amplitude and phase caused by irregularly structured ionospheric regions.

Sidereal day Time interval between two successive upper transits of the vernal equinox.

Sidereal time Defined by the hour angle of the vernal equinox. Taking the mean equinox as the reference yields true or apparent sidereal time.

Site A location where a receiver has been set up to determine coordinates.

SLR *see* Satellite Laser Ranging.

Space segment The part of the whole GNSS system that is in space, i.e. the satellites.

Solar day Time interval between two successive upper transits of the Sun.

Space Service Volume For the United States GPS, the spherical shell extending from the outer surface of the terrestrial service volume up to an altitude of 36,000 km above mean sea level (approximately the geosynchronous orbit altitude) is known as the “space service volume” (SSV-GPS).

SPS *see* Standard positioning service.

Spurious A mathematical relationship in which two occurrences have no causal connection, yet it may be inferred that they do, due to a certain third, unseen factor.

Squared reception mode A method used for tracking GPS signals, which doubles the carrier frequency and does not use the P-code. Also called codeless tracking.

Squaring-type channel A GNSS receiver channel which multiplies the received signal by itself to obtain a second harmonic of the carrier, which does not contain the code modulation.

Standard positioning service (SPS) Level of point positioning accuracy provided by GPS based on the single frequency C/A-code. The SPS also includes the most accurate uses of GPS by those with semi-codeless dual-frequency receivers and various differential correction systems.

Static survey The expression static survey is used in connection with GNSS for all non-kinematic survey applications. This includes the following operation modes: static survey; rapid static survey.

Stochastic A process whose behaviour is non-deterministic in that a state's next state is determined both by the process's predictable actions and by a random element.

Stop and Go survey The term Stop and Go survey is used in connection with GPS for a special kind of kinematic survey. After initialization (determination of ambiguities) on the first site, the roving receiver has to be moved between the other sites without losing lock to the satellite signal.

Surveillance The observation of an area or space for the purpose of determining the position and movements of craft or vehicles in that area or space.

Surveying The act of making observations to determine the size and shape, the absolute and/or relative position of points on, above, or below the Earth's surface, the length and direction of a line, the Earth's gravity field, length of the day, etc.

T

TEC *see* Total Electron Content

Telecommand Command sent to control a remote system or systems not directly connected (e.g. via wires) to the place from which the telecommand is sent.

Telemetry Technology that allows the remote measurement and reporting of information of interest to the system designer or operator.

Terminal A phase of navigation covering operations required to initiate or terminate a planned mission or function at appropriate facilities. For airborne missions, the terminal phase is used to describe airspace in which approach control service or airport traffic control service is provided.

Terminal area A general term used to describe airspace in which approach control service or airport traffic control service is provided.

Terrestrial Service Volume For the United States GPS, the near-Earth region extending from the surface of the Earth up to an altitude of 3,000 km above mean sea level is also known as the "terrestrial service volume" (TSV-GPS).

Time zone Time zone = Local Time, Greenwich Mean Time (GMT). Note that GMT is approximately equal to GPS time.

Tomography Imaging by sections or sectioning.

Topography The form of the land of a particular region.

Total Electron Content (TEC) Defined as the number of free electrons contained in a column which has a 1m by 1m cross section between the receiver and transmitter. The common unit for TEC is 10^{16} e-/m², and causes a delay of 0.54×10^{-9} seconds at 1675.42 MHz.

Transformation The process of transforming coordinates from one system to another.

Transit system The predecessor to GPS. A satellite navigation system that was in service from 1967 to 1996.

Translocation The method of using simultaneous data from separate stations to determine the relative position of one station with respect to another station. Also, *see* differential positioning.

Transverse Mercator Projection A conformal cylindrical map projection, which may be visualized as a cylinder wrapped around the Earth.

Tropospheric propagation delay Time delay affecting satellite signals due to tropospheric layers of the Earth's neutral atmosphere.

TT and C Telemetry, Tracking and Control.

TWSTFT Two-way satellite time and frequency transfer.

TWTA Travelling-wave tube amplifier.

U

Ultra High Frequency (UHF) The frequency range between 300 MHz and 3 GHz (3000 MHz).

Ultra Wide Band (UWB) A radio technology that typically employs relatively low power, extremely short pulse duration transmissions, which reoccur on a relatively low duty cycle. The extremely short pulses have the effect of spreading the transmission over a large frequency range. Typically, hundreds of megahertz in bandwidth are used in the resulting transmission.

USAF United States Air Force.

USCG United States Coast Guard.

USNO United States Naval Observatory.

UTC (NIST) The National Institute for Standards and Time provides UTC (NIST), a local time scale realization of UTC derived from an ensemble of atomic oscillators located in Boulder, Colorado.

UTC (USNO) A local time scale realization of UTC derived from an ensemble of atomic oscillators located at the United States Naval Observatory.

Universal time (UT) Local solar mean time at Greenwich Meridian. More relevant would be UT1, which is a time scale based on the actual rotation of the Earth.

Universal Transverse Mercator Projection (UTM) A form of Transverse Mercator Projection.

User equivalent range error (UERE) Refers to the signal in space (SIS) portion of the GPS error budget:

$$UERE = \sqrt{UEE^2 + URE^2} \text{ where } UEE \text{ user equipment error, } URE \text{ – user range error.}$$

User equipment error (UEE) Error in the GPS position, velocity and timing estimate attributable to user equipment.

User range error (URE) Error in the GPS position, velocity and timing estimate attributable to the GPS Space and Control Segments.

User segment The part of the GNSS system that includes the receivers of GNSS signals.

UTM *see* Universal Transverse Mercator Projection.

UWB *see* Ultra Wide Band.

V

VDOP Vertical Dilution of Precision. Also *see* DOP.

Very High Frequency (VHF) The radio frequency range from 30 MHz to 300 MHz.

Very Long Base Line Interferometry (VLBI) A technique used in radio astronomy and geodesy where several widely separated radio telescopes observe simultaneously the same target and save the observational results with exact time stamps. The data is then combined together so that it is as if the telescopes had been a single instrument with very good resolving power.

W

Wide Area Augmentation System (WAAS) An air navigation aid developed by the Federal Aviation Administration to augment GPS.

World Geodetic System 1984 (WGS 84) An Earth-centered, Earth-fixed terrestrial reference system and geodetic datum. WGS 84 is based on a consistent set of constants and model parameters that describe the Earth's size, shape and gravity, and geomagnetic fields. WGS 84 is the standard United States Department of Defense definition of a global reference system for geospatial information and is the reference system for GPS. It is compatible with ITRS.

World Radiocommunication Conference (WRC) It is organized by International Telecommunications Union, a specialized agency of the United Nations, to review, and, as necessary, revise the international Radio Regulations international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. It is held every two to four years.

Y

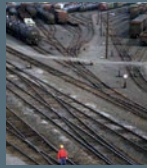
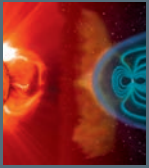
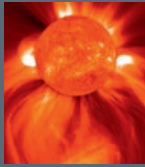
Yaw On moving objects it refers to lateral motion around the vertical (or left-right in the direction of travel).

Y-Code An encrypted version of the P-code that is transmitted by a GPS satellite when in the anti-spoofing mode.

Z

Zenith angle Vertical angle with 00 on the horizon and 90° directly overhead.

■ The United Nations Office for Outer Space Affairs (OOSA) is responsible for promoting international cooperation in the peaceful uses of outer space and assisting developing countries in using space science and technology.



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