UNITED NATIONS
OFFICE FOR OUTER SPACE AFFAIRS

International Committee on Global Navigation Satellite Systems

The Way Forward

10 YEARS OF ACHIEVEMENT 2005-2015

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FOREWORD FOR THE INTERNATIONAL COMMITTEE ON GLOBAL NAVIGATION SATELLITE SYSTEMS (ICG): 10 YEARS OF ACHIEVEMENT 2005 – 2015

The establishment of the International Committee on Global Navigation Satellite Systems (ICG) in 2005 ushered in an unprecedented era of cooperation for the United Nations. First proposed in General Assembly resolution 59/2, ICG promotes coordination among leading satellite operators and strives to maximize the benefits of global navigation satellite systems (GNSS) for sustainable development. ICG also serves as a platform for discussion and the exchange of information on general trends in user needs, applications and technology development. Over the past decade, ICG has achieved tangible and wide-ranging progress.

Satellite technology has the potential to contribute enormously to environmental protection, disaster risk reduction, food security and making agriculture more sustainable and productive. It also has a vital role to play in responding to emergencies, improving the efficiency of surveying and mapping, and enhancing the safety of transportation by land, sea and air. Space technology truly complements our global efforts to achieve sustainable development, and has important contributions to make in implementing the recently adopted Sustainable Development Goals.

The United Nations Office for Outer Space Affairs, as the Executive Secretariat of the ICG, promotes the use of GNSS technology for national development and poverty alleviation in a sustainable manner. One main challenge is to provide assistance and information for those countries seeking to integrate GNSS into their basic infrastructure, including at governmental, scientific and commercial levels.

The present publication highlights how Member States benefit from space activities and the use of satellite systems. I hope that it will inspire even deeper cooperation in sharing outer space peacefully, for the benefit of all.

BAN Ki-moon

Foreword by the Director of the Office for Outer Space Affairs

The tenth anniversary of ICG brings with it the opportunity to recognize and acknowledge the vital role that satellite technology has played as an innovative tool for sustainable development. The Office for Outer Space Affairs, as the executive secretariat of ICG, has worked with Member States to enhance the compatibility and interoperability of constellations of GNSS, so that satellite technologies remain equally accessible for all.

ICG has encouraged tangible international cooperation, and leading global satellite operators have coordinated their GNSS services to provide global coverage in satellite-based positioning, navigation and timing, for the benefit of all. The ICG acts as a platform for open discussions and the exchange of information under the umbrella of the United Nations, and as such promotes the use of GNSS technology for environmental management and protection, disaster risk reduction, agriculture and food security, emergency response, more efficient surveying and mapping, and safer and more effective transportation by land, sea and air.

The Office for Outer Space Affairs continues to support progress towards achieving compatibility and interoperability among global and regional space-based navigation systems. As new systems emerge, signal compatibility and interoperability among GNSS on one hand, and transparency in the provision of open civil services on the other, will be key factors in ensuring that civil users around the world receive the maximum benefit from GNSS applications. It is my hope that collaboration among the representatives of GNSS providers and GNSS user communities will continue to grow and deepen in the future. We must also use that vital collaboration to address the protection of the GNSS spectrum, orbital debris and orbit de-confliction among current and future global and regional satellite-based systems. First and foremost we support the broader objective of integrating GNSS and their augmentations into the basic infrastructure, i.e. governmental, scientific and commercial, of developing nations.

The remarkable work ICG and the Office for Outer Space Affairs are doing to promote international cooperation in the peaceful uses and exploration of space is important in helping to build a multi-GNSS environment for sustainable development.

The tenth anniversary of ICG represents a milestone in the cooperation between Member States in the use of outer space for peaceful purposes. I am proud of the role that the Office for Outer Space Affairs has played and look forward to working with all Member States to confront the challenges ahead.

Ms Simonetta Di Pippo
Director, Office for Outer Space Affairs

Introductory remarks by the Co-Chairs of the Action Team on Global Navigation Satellite Systems

In 1999, at the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space, known as UNISPACE III, the participating States outlined the social and economic benefits of GNSS. Since then, GNSS have rapidly become an integral component of the emerging global information infrastructure, with applications including aviation, maritime and land transportation, mapping and surveying, agriculture, power and telecommunications networks, and disaster warning and emergency response, to name only a few. Particularly for developing countries, GNSS applications offer cost-effective solutions that make it possible to pursue economic growth without compromising on the need to preserve the environment, now and in the future, thus promoting sustainable development.

As co-chairs we would like to recall that the Action Team on GNSS is made up of more than 30 countries and more than 10 international organizations. It has presented detailed reviews of existing and planned GNSS, augmentations to existing GNSS, and GNSS applications. It has also promoted the use of GNSS in the implementation of the recommendation relating to GNSS made by UNISPACE III.

In 2004, the Action Team concluded that it was important to create an international framework to support operational coordination and an exchange of information among system operators and national and international user communities. The assumption was that current and future system operators would soon move from a competitive to a collaborative model, as they had a shared interest in the universal use of GNSS services regardless of the system used.

That is why, taking stock of what has been achieved to date, we are pleased to note that ICG has played its role as an important platform for international cooperation and coordination in achieving compatibility and interoperability among GNSS providers, and that it greatly contributes to the overall aim of achieving efficient interaction in one of the most important fields of space applications. Of particular note have been the productive discussions in ICG, in which providers of space and ground-based navigation systems work together to address their differences, including protection of the GNSS spectrum, addressing orbital debris and orbit de-confliction. We are also pleased to note that the leadership of the Office for Outer Space Affairs has contributed significantly to the organization of and planning for the meetings of ICG and the activities undertaken in its capacity as executive secretariat of ICG.

Looking ahead, as co-chairs of the Action Team on GNSS, we believe that ICG will continue to strengthen its role as a major player in the multilateral arena, given that satellite positioning becomes more and more a multinational cooperative venture.

Mr Mario Caporale

Mr Kenneth Hodgkins

Acknowledgements

This publication was produced by the United Nations Office for Outer Space Affairs in its capacity as executive secretariat of ICG and its Providers' Forum on the basis of reports submitted by the ICG members, associate members and observers.

The purpose of this publication is to provide the GNSS user community and manufacturers of GNSS receivers with a clear and consistent description of the global and regional navigation satellite systems and satellite-based augmentation systems that are currently operating and that will operate in the future. This publication also provides key facts about international and regional organizations and associations dealing with GNSS services and applications, including the United Nations Office for Outer Space Affairs, and the role of those organizations and associations in ICG as associate members and observers.

The executive secretariat of ICG and the Providers' Forum gratefully acknowledge the support of the ICG participants for their advice throughout the whole process of preparation of the publication. The executive secretariat is also grateful to the Office for Outer Space Affairs for its communication support, advice, cooperation and proofreading assistance.

List of acronyms

APV	approach procedure with vertical guidance
BOC	binary offset carrier
BPSK	binary phase shift keying
C/A	coarse/acquisition
CDMA	code division multiple access
CEPT	European Conference of Postal and Telecommunications Administrations
CGSIC	Civil Global Positioning System (GPS) Service Interface Committee
EGNOS	European Geostationary Navigation Overlay Service (European Union)
EPN	EUREF Permanent Network
ESPI	European Space Policy Institute
EUPOS	European Position Determination System
EUREF	IAG Reference Frame Sub-Commission for Europe
FAI	World Airsports Federation
FDMA	frequency division multiple access
GAGAN	GPS-aided GEO-augmented Navigation System (India)
GBAS	Ground-based Augmentation System (United States)
GDGPS	Global Differential GPS System
GEO	geosynchronous
GLONASS	Global Navigation Satellite System (Russian Federation)
GNSS	global navigation satellite systems
GPS	Global Positioning System (United States)
IAG	International Association of Geodesy
IAIN	International Association of Institutes of Navigation
ICAO	International Civil Aviation Organization
ICG	International Committee on Global Navigation Satellite Systems
iGMAS	International GNSS Monitoring and Assessment Service
IGS	International GNSS System
IOAG	Interagency Operations Advisory Group
IRNSS	Indian Regional Navigation Satellite System (India)
ISRO	Indian Space Research Organization
ITU	International Telecommunication Union
ITU-R	ITU radiocommunication sector
MBOC	multiplexed binary offset carrier
MSAS	MTSAT-based Augmentation System (Japan)
MTSAT	Multi-functional Transport Satellite
NASA	National Aeronautics and Space Administration (United States)

QZSS	Quasi-Zenith Satellite System (Japan)
RNSS	radio navigation satellite services
Roscosmos	Federal Space Agency (Russian Federation)
Roskomnadzor	Federal Service for the Supervision of Communications, Information Technology and Mass Media (Russian Federation)
SDCM	System of Differential Correction and Monitoring (United States)
SPS	standard positioning service
UNISPACE III	Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space
UTC	Coordinated Universal Time
WAAS	wide-area augmentation system
WGS-84	World Geodetic System 1984
ETRS89	European Terrestrial Reference System 1989

Contents

Introduction

The Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space, held in 1999, adopted the resolution entitled "The Space Millennium: Vienna Declaration on Space and Human Development", subsequently endorsed by the United Nations General Assembly. The Vienna Declaration called for action 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 among space-based navigation and positioning systems. In response to that call, in 2001, the Committee on the Peaceful Uses of Outer Space established the Action Team on Global Navigation Satellite Systems (GNSS) to carry out those actions under the chairmanship of the United States of America and Italy.

The Action Team on GNSS consisted of 38 member States and 15 intergovernmental and non-governmental organizations and recommended that an international committee on GNSS be established to promote the use of GNSS infrastructure on a global basis and to facilitate the exchange of information.

Following workshops for Africa, Asia and the Pacific, West Asia, Latin America and the Caribbean, and Europe, international preparatory meetings and intergovernmental actions, Global Navigation Satellite Systems (ICG) was established in December 2005 under the umbrella of the United Nations. ICG is an informal, voluntary forum where Governments and interested non-governmental entities can discuss all matters regarding GNSS on a worldwide basis. ICG promotes international cooperation on issues of mutual interest related to civil satellite-based positioning, navigation and timing, and value added services.

The ultimate goal of ICG is to achieve compatibility and interoperability of GNSS systems, thereby saving costs through international cooperation and making positioning, navigation and timing available globally. The societal benefits will include the capability to monitor all aspects of the environment and security. Another significant issue before ICG is the integration of GNSS services into national infrastructure, particularly in developing nations.

In compliance with its workplan, as adopted at its first meeting in 2006, the work of ICG has been organized into four working groups. The working groups focus on compatibility and interoperability, performance enhancement of GNSS services, information dissemination and capacity-building, and reference frames, timing and applications.

The ICG Providers' Forum, established in 2007, provides ways and means of promoting communication among system providers on key technical issues and operational concepts such as protection of the GNSS spectrum, orbital debris mitigation, and orbit de-confliction.

Government members of ICG currently include China, India, Italy, Japan, Malaysia, Nigeria, the Russian Federation, the United Arab Emirates, and the United States, as well as the European Union. Associate members drawn from international organizations representing users or specific application areas include the Civil Global Positioning System Service Interface Committee, the European Position Determination System (EUPOS), the World Airsports Federation (FAI), the International Federation of Surveyors, the International Association of Geodesy (IAG), the Reference Frame Sub-Commission for Europe (EUREF) of the International Association of Geodesy, the International Cartographic Association, the International GNSS Service (IGS) (formerly the International Global Positioning System Service), the International Earth Rotation and Reference Systems Service, the International Society for Photogrammetry and Remote Sensing, and the Office for Outer Space Affairs of the Secretariat. Additional observer organizations include the Asia-Pacific Space Cooperation Organization, the Arab Institute of Navigation, the Committee on Space Research, the International Bureau of Weights and Measures, the European Space Policy Institute (ESPI), the International Association of Institutes of Navigation (IAIN), the International Telecommunication Union (ITU), the Interagency Operations Advisory Group (IOAG) and the Union radio-scientifique internationale.

The Office for Outer Space Affairs, as the executive secretariat of ICG and its Providers' Forum, implements a programme on GNSS applications and maintains a comprehensive information portal for ICG and users of GNSS services entitled "International Committee on Global Navigation Satellite Systems (ICG)" at www.unoosa.org.

The current and planned global and regional navigation satellite systems and satellite-based augmentation systems

United States: the Global Positioning System and the Wide-area Augmentation System

History of the Global Positioning System as a dual-use system

The Global Positioning System (GPS) was the second navigation satellite system developed by the United States. The world's first such system was the Navy Navigation Satellite System, popularly called Transit. The inspiration for Transit came from Doppler measurements on the first human-made Earth satellite, Sputnik I, which was launched on 4 October 1957. Transit became operational in January 1964 and was decommissioned at the end of 1996, after 32 years of continuous service. Transit initially began as a military system, but was released for public use on 29 July 1967. This policy of making the system available to both military and civilian users is known as the dual-use policy and was applied to GPS from the beginning. Detailed descriptions of GPS were first published in *Navigation: Journal of the Institute of Navigation* (United States), volume 25, number 2, summer 1978. That publication coincided with the first official release of GPS interface control document ICD-GPS-200, leading to the availability of commercial GPS receivers in the early 1980s. The announcement by the President of the United States in 1983 that GPS would be available for civilian use, while not establishing a new policy, did make it explicit that GPS was, is, and will continue to be a dual-use system.

System description: space segment

Global Positioning System constellation

The GPS baseline constellation consists of 24 satellite slots in six orbital planes, with four slots per plane. Three of the 24 slots are expandable with the capability of holding two satellites each rather than just one when there are more than 24 satellites in orbit. As of October 2014, those three slots are expanded, resulting in a routine configuration of 27 GPS 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 Standard, dated September 2008. The GPS constellation consists of up to 31 operational satellites broadcasting healthy navigation signals made up of Block IIA, Block IIR, Block IIR-M, and Block IIF satellites.

Wide-Area Augmentation System

The Wide-Area Augmentation System (WAAS) currently relies on the service of three leased geostationary satellites, a Satellite-Based Augmentation System that conforms to the standards of the International Civil Aviation Organization (ICAO). Its objective is to augment the performance of GPS by increasing integrity and improving accuracy to meet the demanding operational performance requirements of civil aviation for all navigation operations, from en route use through localizer performance with vertical approach.

System description: ground segment

Operational control segment of the Global Positioning System

The GPS operational control segment consists of three major subsystems: a master control station, a network of four ground antennas, and a network of globally distributed monitor stations. The master control station is located at Schriever Air Force Base in Colorado, United States, with an alternate at Vandenberg Air Force Base in California, United States, and is the central control node for the GPS constellation. Operations are maintained 24 hours a day, 7 days a week, 365 days a year.

The master control station is responsible for all aspects of constellation command and control, including the following:

- Routine satellite bus and payload status monitoring
- Satellite maintenance, payload uploading, and anomaly resolution
- Management of signal-in-space accuracy, integrity, continuity, and availability performance in support of the GPS Standard Positioning Service Performance Standard and the GPS Precise Positioning Service Performance Standard
- Detecting and responding to GPS signal-in-space failures

Ground segment of the Wide-Area Augmentation System

There are 38 wide-area reference stations throughout North America (in Canada, Mexico, and the United States, including in Alaska, Hawaii, and Puerto Rico). The Federal Aviation Administration of the United States plans to upgrade the wide-area reference stations with receivers capable of processing the new GPS L5 signal.

Ground-Based Augmentation System

The Ground-Based Augmentation System (GBAS) was developed to provide precision approach capability for categories I, II and III approach procedures. It is designed to provide multiple runway coverage at an airport for three-dimensional required navigation performance procedures, navigation for parallel runways with little space between them, and super-density operations. Newark Liberty International Airport, and Houston George Bush Intercontinental Airport, both in the United States, have non-federal GBASs in operation providing category I service in a joint effort with participating airlines. Additional contributions to GBAS, as a technology enabling the use of the Next Generation Air Transportation System, are being explored in areas such as closely spaced parallel runway operations and wake turbulence avoidance.

Nationwide Differential Global Positioning System

The Nationwide Differential Global Positioning System is a national positioning, navigation and timing utility operated and managed by the United States Coast Guard for surface and maritime transportation, agriculture, environmental and natural resource management, weather forecasting, and precise positioning applications. After 15 January 2016, the System will consist of at least 21 sites for single-station near-shore coverage, and one inland site operated by the United States Army Corps of Engineers.

Continuously operating reference stations

The network of continuously operating reference stations, coordinated by the National Geodetic Survey of the United States and tied to its National Spatial Reference System consists of more than 1,900 sites operated by over 230 public and private entities, including academic institutions. Each site provides GPS carrier phase and code range measurements in support of three-dimensional centimetre-level positioning activities throughout the United States and its territories.

Global Geodetic Observing System and International GNSS Service

The Global Geodetic Observing System works with IAG to coordinate the collection and analysis of geodetic data necessary for monitoring the Earth system and for global change research. United States agencies, including the National Aeronautics and Space Administration (NASA), contribute approximately 40 per cent of Service, including geodetic observatories for very long baseline interferometry, satellite laser ranging, and GNSS/GPS geodetic networks. The overall support the United States gives to IGS is approximately 60 per cent of the total. Post-processed data from these networks are used to generate the International Terrestrial Reference Frame, which is the fundamental reference frame for most geodetic applications, including some of the GNSS constellations.

Global Differential GPS System

The Global Differential GPS System (GDGPS) is a high-accuracy GPS augmentation system, developed by the Jet Propulsion Laboratory (United States) to support the real-time positioning, timing, and orbit determination requirements of NASA science missions. The GDGPS network consists of dual-frequency, real-time GPS reference stations and has been operational since 2000. Its real-time products are also used for GPS civil signal monitoring, situational assessment, natural hazard monitoring, emergency geolocation and other applications.

Current and planned signals

The L1 frequency, transmitted by all GPS satellites, contains a coarse/acquisition (C/A) code ranging signal and a navigation data message available for civilian, commercial, and scientific use, and a precision P(Y) code ranging signal and navigation data message available to users with valid cryptographic keys. GPS satellites also transmit a second P(Y) code ranging signal and message on the L2 frequency.

The central focus of the GPS modernization programme is the addition of a new type of navigation signal. That signal is being phased in as new GPS satellites are launched to replace older ones. The second civil signal, L2C, is designed to enable dual frequency L1/L2 receivers to transition from using the more fragile semi-codeless method of accessing L2 carrier and code measurements to directly tracking the more robust L2C signal, which in addition provides a civil navigation message. This transition can occur one satellite launch at a time, since receivers can use the more robust L2C signal rather than having to use the semi-codeless L2 signal for that satellite. L2C enhances performance, especially in challenging conditions, such as under tree cover, during signal scintillation events, or near radar stations or other sources of interference. The L2C signal became available with the first launch of a Block IIR-M satellite in 2005. Every GPS satellite fielded since then has included the L2C signal. The L2C signal is defined in GPS interface specification IS-GPS-200, which is available at www.gps.gov/technical.

The third civil signal, L5, is broadcast in a radio band allocated for aeronautical radio navigation services and radio navigation satellite services (RNSS). With its higher power, greater bandwidth, and other features, the L5 signal is designed to support safety-of-life transportation and other high-performance applications. Aircraft will use L5 signals in combination with L1 signals (also in a band for aeronautical radio navigation services) to improve accuracy via ionospheric correction, and robustness via signal redundancy. It also will enhance the coverage and performance of WAAS. The benefits of using the L5 signal on aircraft include increased capacity, fuel efficiency, and safety in United States airspace. L5 signals became available with the first launch of a Block IIF satellite, and has been included in every satellite since. The L5 signal is defined in GPS interface specification IS-GPS-705, which can be found at www.gps.gov/technical.

The fourth civil signal, L1C, was designed to improve performance in many ways and enhance interoperability between GPS and other satellite navigation systems. The United States and the European Union have cooperated to make the L1C and Galileo E1 open service signals as interoperable as possible. Other satellite navigation systems, such as the Quasi-Zenith Satellite System (QZSS) of Japan and BeiDou of China, broadcast or plan to broadcast signals similar to L1C to enhance overall GNSS interoperability. The L1C signal features a strong pilot carrier, increased signal strength, reduced time to first fix, and enhanced message assurance, all of which provide better performance, especially in challenging environments. The GPS III satellite includes the L1C signal, and all satellites launched after it will include the signal. The L1C signal is defined in GPS interface specification IS-GPS-800, which can be found at www.gps.gov/technical.

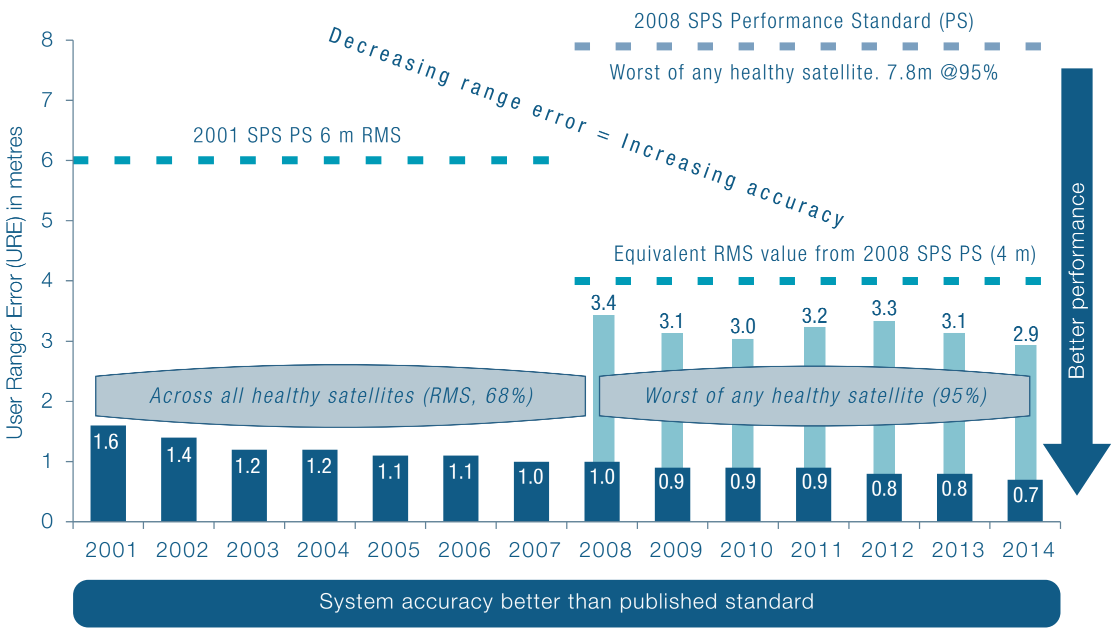
System time and geodetic reference frame standards

The signal-in-space navigation message of the GPS standard positioning service (SPS) contains offset data for relating GPS time to Coordinated Universal Time (UTC) as maintained at the United States Naval Observatory. During normal operations, the accuracy of this offset data during the transmission interval is such that the UTC offset error is within 40 nanoseconds 95 per cent (20 nanoseconds 1 sigma). The geodetic reference system used by unaugmented GPS is the World Geodetic System 1984 (WGS-84). The most recent WGS-84 reference frame and the International Terrestrial Reference Frame are in agreement to within 1 cm.

Performance standards and actual performance

Since GPS initial operational capability was declared in 1993, actual GPS performance has continuously met or exceeded minimum performance levels specified in the standard positioning service and precise positioning service performance standards. In general, users can expect better performance than the minimum specified. For example, with the signal-in-space accuracy available in 2008, well-designed GPS receivers were achieving a horizontal positioning accuracy of 3 metres (m) or better and a vertical accuracy of 5 m or better, 95 per cent of the time. Improvements in user range error over time, compared with the published performance standard, are shown in figure I.

Figure I. GPS signal-in-space accuracy exceeds the published performance standard



Services provided and provision policies

GPS provides two levels of service: a standard positioning service, which uses the C/A code on the L1 frequency, and a precise positioning service, which uses the C/A code on the L1 frequency and the P(Y) code on both the L1 and L2 frequencies. Authorized access to the precise positioning service is restricted to the armed forces and federal agencies of the United States, and the armed forces and Governments of certain of its allies. The standard positioning service is available to all users worldwide on a continuous basis and without any direct user charge. The specific capabilities provided by the GPS open service are published in the GPS Standard Positioning Service Performance Standard. The United States Government has undertaken a commitment to maintaining the existing GPS L1 C/A, L1 P(Y), L2C, and L2 P(Y) signal characteristics that enable codeless and semi-codeless GPS access until at least two years after there are 24 operational satellites broadcasting L5.

To provide for information and civil interface services outlined in interface control documents ICD-GPS-240 and ICD-GPS-870, GPS data files, operational and technical information, and policy guidance documents are published for public use through the United States Coast Guard Navigation Center website (www.navcen.uscg.gov) and the website of the National Coordination Office for Space-based Positioning, Navigation and Timing (www.gps.gov).

Space-based positioning, navigation and timing policy of the United States

The current space-based positioning, navigation and timing policy of the United States, signed by the President in December 2004, ensures that the United States maintains space-based positioning, navigation and timing services, as well as augmentation and back-up capabilities by:

- Providing uninterrupted availability of positioning, navigation and timing services
- Meeting growing national, homeland security, economic security, and civil, scientific, and commercial demands
- Remaining essential components of internationally accepted positioning, navigation and timing services
- Promoting the technological leadership of the United States in applications involving space-based positioning, navigation and timing services

The President's national space policy of 2010 continues to promote the global use of GPS by:

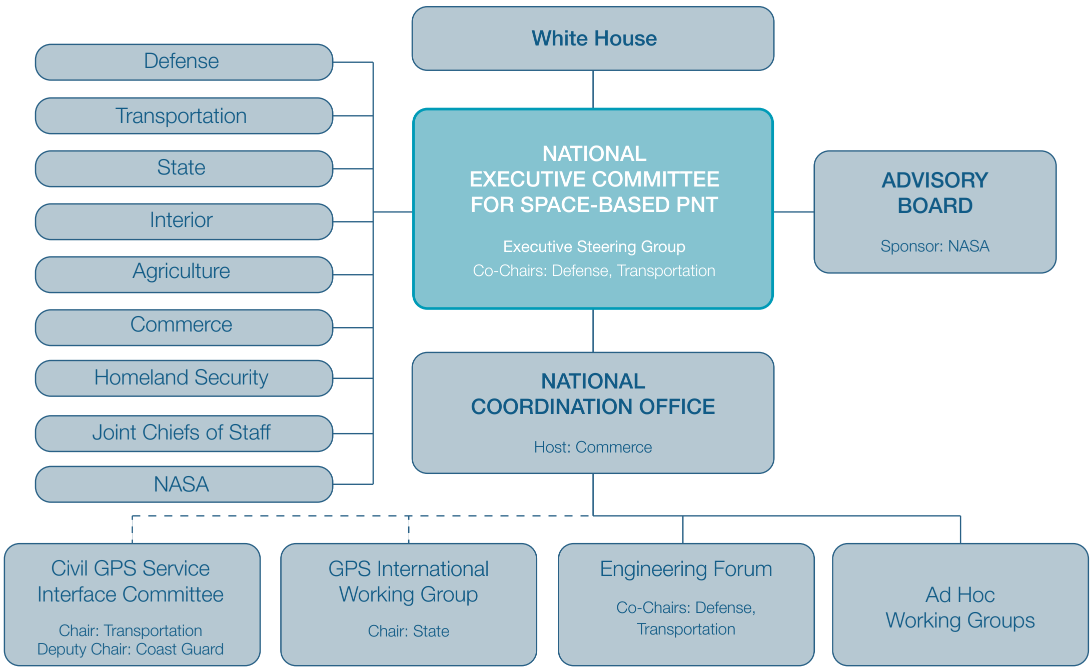
- Providing continuous worldwide access for peaceful civil uses, free of direct user charges
- Maintaining the GPS constellation consistent with published performance standards and interface specifications
- Allowing foreign positioning, navigation and timing services to be used to augment and strengthen the resiliency of GPS

- Encouraging GNSS compatibility and interoperability with GPS
- Promoting transparency in civil service provision
- Supporting international activities to detect and mitigate harmful interference

The National Executive Committee for Space-based Positioning, Navigation and Timing continues to coordinate federal implementation of the space-based positioning, navigation and timing policies of the United States. The National Executive Committee is an inter-agency advisory body co-chaired by the Deputy Secretary of Defense and the Deputy Secretary of Transportation.

The United States national space-based positioning, navigation and timing management structure is shown in figure II.

Figure II. United States national space-based positioning, navigation and timing management structure



Perspective on compatibility, interoperability, and transparency

The United States pursues compatibility and interoperability by bilateral and multilateral means. Its objectives in working with other GNSS service providers include:

- Ensuring compatibility, defined as the ability of space-based positioning, navigation and timing services based both inside and outside the United States to be used separately or together without interfering with each individual service or signal, involving both radiofrequency compatibility and spectral separation between M code and other signals

- Achieving interoperability, defined as the ability of civil space-based positioning, navigation and timing services based both inside and outside the United States to be used together to provide the user with better capabilities than would be achieved by relying solely on one service or signal, with primary focus on the common L1C and L5 signals
- Ensuring fair, market-driven competition in the global marketplace
- Promoting transparency for users in the international provision of civil GNSS services

International cooperation

In addition to participating in ICG, the Asia-Pacific Economic Cooperation, ITU, standard-setting bodies such as ICAO, and the International Maritime Organization, the United States pursues its international GNSS objectives through bilateral cooperation with other system providers.

- *With China:* in 2014, the United States and China held a meeting about bilateral space-based position, navigation and timing to discuss civil cooperation topics. A joint statement was signed, and a working group on civil satellite navigation cooperation was established for continuing discussions on topics of mutual interest.
- *With the European Union:* in 2004, the United States on one hand, and the European Union and its member States on the other, completed the Agreement on the Promotion, Provision and Use of Galileo and GPS Satellite-based Navigation Systems and Related Applications. The Agreement provided the foundation for cooperation and established several working groups, which meet regularly.
- *With India:* policy and technical consultations on GPS-related cooperation have taken place since 2005, and a joint statement on GNSS-related cooperation was issued in February 2007 in Washington, D.C.
- *With Japan:* policy consultations and technical meetings on GPS began in 1996, leading to the 1998 Clinton-Obuchi joint statement, with a technical working group and annual dialogue under its auspices. Both countries have benefited from that close relationship, and the regional QZSS and the Multi-functional Transport Satellite (MTSAT)-based Augmentation System (MSAS) are designed to be compatible and highly interoperable with GPS.
- *With the Russian Federation:* a joint statement was issued in December 2004, and technical discussions on compatibility and interoperability are taking place in working groups, and GPS and Global Navigation Satellite System (GLONASS)-based search and rescue services.

Global navigation satellite system spectrum protection

In order to minimize domestic service disruptions and prevent situations threatening the safe and efficient use of GPS, any transmission on the GPS frequencies is strictly regulated through federal provisions. Within the United States, two regulatory bodies oversee the use of the radiofrequency spectrum. The Federal Communications Commission is responsible for all non-federal use of the airwaves, while the National Telecommunications and Information Administration manages spectrum use for the federal Government. In that capacity, the Administration hosts the Interdepartment Radio Advisory Committee, a forum consisting of executive branch agencies that act as service providers and users of the Government spectrum, including safety-of-life frequency bands. Because radio navigation systems broadcast radio signals, United States regulators also need to coordinate, through the Department of State, with other States through forums such as that provided by ITU.

Plans and procedures for radio navigation satellite service interference detection and mitigation

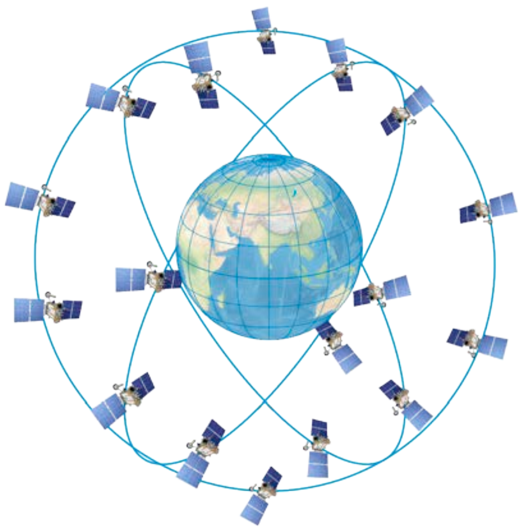
In August 2007, the United States Department of Homeland Security developed and published the National Positioning, Navigation and Timing Interference Detection and Mitigation Plan, and, in January 2008, a national interference detection and mitigation plan implementation strategy. These documents establish procedures and techniques to identify interference and provide guidance for mitigating and resolving interference incidents in a timely manner, in order to quickly restore positioning, navigation and timing services to users.

Russian Federation: the Global Navigation Satellite System and System of Differential Correction and Monitoring

System description: space segment

The nominal baseline constellation of the Global Navigation Satellite System (GLONASS) of the Russian Federation comprises 24 satellites equally distributed in three orbital planes inclined at 64.8 ± 0.3 degrees to the equator. The GLONASS satellites are placed in roughly circular orbits with an altitude ranging from 18,840 kilometres (km) to 19,440 km (the nominal orbit altitude is 19,100 km) and an orbital period of 11 hours, 15 minutes, 44 seconds ± 5 seconds. The orbital planes are separated by the 120-degree right ascension of the ascending node. Eight navigation satellites are equally spaced in each plane with the 45-degree argument of latitude. The orbital planes have an argument of latitude displacement of 15-degree relative to each other (see figure III).

Figure III. GLONASS orbital constellation



This constellation configuration provides for continuous global coverage of the Earth's surface and near-Earth space, while minimizing the effect of disturbances on deformation of the orbital constellation.

As of the date of compiling this brochure, the GLONASS constellation had 29 satellites: 27 GLONASS-M and 2 GLONASS-K satellites, of which 24 were operational and used for navigation, 2 were orbital spares, 1 had undergone technical inspection by the prime-contractor, and 2 (GLONASS-K) had been flight-tested.

System description: ground segment

The GLONASS ground control segment consists of the following components:

- A system control centre

- A central synchronizer
- Telemetry, tracking and control stations and monitoring stations

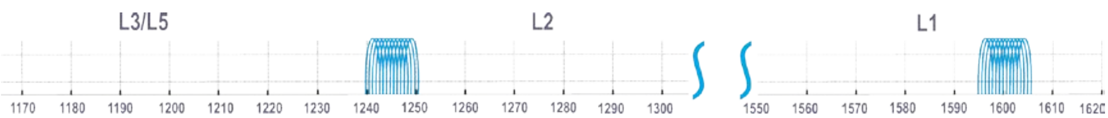
The system components operate 24 hours a day, 7 days a week, and are responsible for:

- Operating satellites in the orbital constellation and monitoring satellite functions
- Maintaining the constellation structure
- Processing measurements for calculating the input data, and uploading the data to the satellites for generating the navigation message
- Managing signal-in-space performance in terms of accuracy and integrity

Current and planned signals

GLONASS satellites transmit navigation signals in three sub-bands of the L-band (see figures IV and V). All GLONASS satellites transmit open-access civil signals and authorized-access frequency division multiple access (FDMA) signals in both the L1 and L2 sub-bands.

Figure IV. Spectral characteristics of GLONASS FDMA signals



The main characteristics of the L1 and L2 FDMA signals are provided below:

L1 and L2 signal polarization:	Right-handed circular
L1 carrier frequencies:	1,598.0625~1,605.3750 megahertz (MHz)
L2 carrier frequencies:	1,242.9375~1,248.6250 MHz
Superframe capacity:	6.375 bits
Superframe duration:	2.5 minutes
Data rate:	50 bits per second (bps)
Iteration period time tag:	2 seconds

A new L3 code division multiple access (CDMA) navigation signal has been implemented on the first GLONASS-K series satellite, launched in 2011.

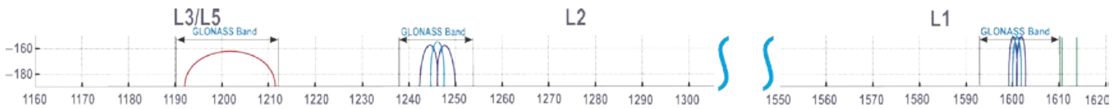
The modernized GLONASS-K satellites will transmit both the full set of traditional FDMA signals and new CDMA signals (see table 1).

Table 1. GLONASS navigation signals implementation plan

Satellite	*FDMA signals*		*CDMA signals*		
	L1	*L2*	*L1*	*L2*	*L3*
GLONASS-M	L1OF* L1SF**	L2OF L2SF			L3OC*** (2014+)
GLONASS-K	L1OF L1OF	L2OF L2SF			L3OC
GLONASS-K (advanced performance)	L1OF L1OF	L2OF L2SF	L1OC L1SC	L2OC L2SC	L3OC

* OF — open FDMA. ** SF — secured FDMA. *** OC — open CDMA.

Figure V. Spectral characteristics of future GLONASS CDMA signals



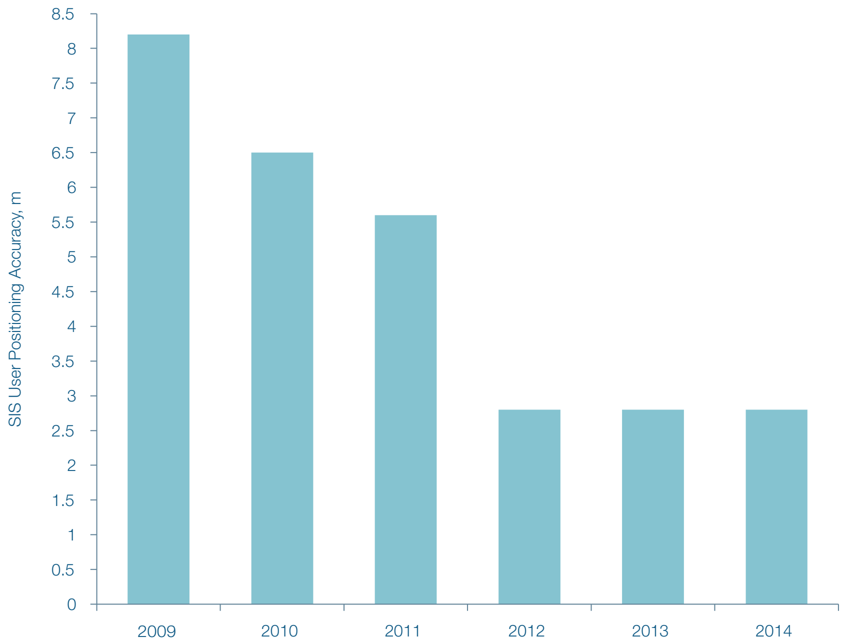
The main characteristics of the L1, L2 and L3 CDMA signals are provided below:

L1 carrier frequency:	1,600.995 MHz
L2 carrier frequency:	1,248.06 MHz
L3 carrier frequency:	1,202.025 MHz
Data rate:	L1 — 125 bps L2 — 250 bps L3 — 100 bps
Navigation data transmission time:	L1 — 8 milliseconds L2 — 4 milliseconds L3 — 10 milliseconds
Pulse rate:	L1 — 0.5115 MHz L2 — 0.5115 MHz L3 — 10.23 MHz

Performance standards and actual performance

Actual GLONASS performance has improved significantly over the five-year period 2010-2015. Currently, the GLONASS signal-in-space positioning accuracy is 2.8 m on average (see figure VI).

Figure VI. GLONASS signal-in-space positioning accuracy



The Russian Federation has been developing the open access service performance standard recommended by ICG. The document will be issued as soon as it is officially approved.

Timetable for system deployment and operation

The baseline 24-satellite constellation was deployed in 2010. It has been and will be sustained at that level through single or multiple launches, in accordance with the launch schedule.

Currently the operational GLONASS orbital constellation consists of 24 GLONASS-M satellites transmitting civil signals in two frequency bands. In the period 2015-2017, 9 GLONASS-M satellites featuring the L3 CDMA signal, in addition to the traditional GLONASS FDMA signals, are scheduled to be launched.

After that, the GLONASS orbital constellation will be sustained with the advanced performance GLONASS-K launches.

Services provided and provision policies

GLONASS provides two types of services in the L1 and L2 sub-bands: an open service with open access and a secured service with authorized access. It also provides an open service in the L3 sub-band.

An open service using standard positioning signals on the L1, L2 and L3 frequencies is provided for all users without restriction. A secure service, which uses precise positioning signals on the L1 and L2 frequencies modulated with a special code, is provided for authorized users only.

The fundamental principles of the Russian Federation Government policy on satellite navigation are set out in presidential decree 638 of 17 May 2007 on utilization of the GLONASS Global Satellite Navigation System for the benefit of social and economic development of the Russian Federation. The decree states the following:

- National and international users have free and unlimited access to GLONASS standard positioning signals.
- The federal authorities of the Russian Federation and organizations within their jurisdictions are to use GLONASS-based user equipment.
- The recommendation for regional administrative authorities of the Russian Federation, its local authorities and its Government organizations, irrespective of organizational and legal status, is to use navigation equipment utilizing GLONASS.
- The Russian Federal Space Agency (Roscosmos) acts as a coordinator of activities on GLONASS sustainment, development and use for the benefit of civil, including commercial, users and on promoting international cooperation.

The fundamental principles of Government policy on satellite navigation are also documented in the official declaration of the Russian Government issued in October 2012, which extends that Government's commitment to provide GLONASS open service signals on a non-discriminatory basis and free of charge, with no intentional signal degradation for at least the next 15 years.

Perspective on compatibility and interoperability

The Russian Federation adheres to the definitions of compatibility and interoperability adopted by ICG. It interacts with GNSS service providers through bilateral cooperation and multilateral forums and other mechanisms to pursue compatibility and interoperability.

The position of the Russian Federation is as follows:

With respect to compatibility:

- GNSS compatibility is defined by the radiofrequency compatibility of navigation signals.
- ITU sets out procedures for radiofrequency compatibility coordination.

With respect to interoperability:

- Interoperability of global, regional navigation satellite systems, their augmentations and the services they provide stem from interoperability of navigation signals, coordinate systems and time scales used.
- To provide better signal interoperability, it is equally beneficial to have signals with widely used centre frequencies and signals in centre frequency bands not widely used, depending on the user market segment for which a signal is intended.
- Having signals with a common centre frequency results in a number of benefits: receivers are less complex, weigh less, are smaller, use less power, and cost less.
- Signals in uncommon centre frequency bands provide for intersystem interference reduction, better interference and jamming resistance, service diversity, and better service quality.
- The balance of costs and benefits should be provided when choosing a signal structure.

International cooperation to ensure compatibility and interoperability

In addition to participating in ICG, the Russian Federation is involved in the activities of regulating organizations and organizations formulating the principles and standards of GNSS development and use, namely ICAO, ITU, the Radio Technical Commission Aeronautics, and the European Organization for Civil Aviation Equipment. Activities are under way to include GLONASS in the standards being developed by those organizations.

Following the recommendations of ICG, the Russian Federation is developing a GLONASS open service performance standard.

Bilateral consultations with system providers have been ongoing to ensure compatibility of GLONASS with existing and emerging systems.

With China: on 13 October 2014, a memorandum of understanding was signed between Roscosmos and the Chinese Committee on the BeiDou Navigation Satellite System. Cooperation is ongoing through the Committee on Strategic Navigation Satellite Projects of the Russia-China Commission on the Preparation of Regular Meetings of Heads of Government.

With the European Union: meetings to discuss a future agreement on cooperation in the field of satellite navigation for peaceful purposes are ongoing.

With the United States: in 2012 the statement of cooperation between the United States Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS) was renewed. It reaffirms the parties' intention to cooperate on matters of mutual interests.

Global Navigation Satellite System Spectrum protection activities

National Radio-Navigation Satellite Service (RNSS) spectrum regulation and management procedures

Spectrum regulation and management procedures in the Russian Federation, including the RNSS spectrum regulation and management procedures, are established by the Federal Law on Communications, other Government documents and are specified in departmental documents.

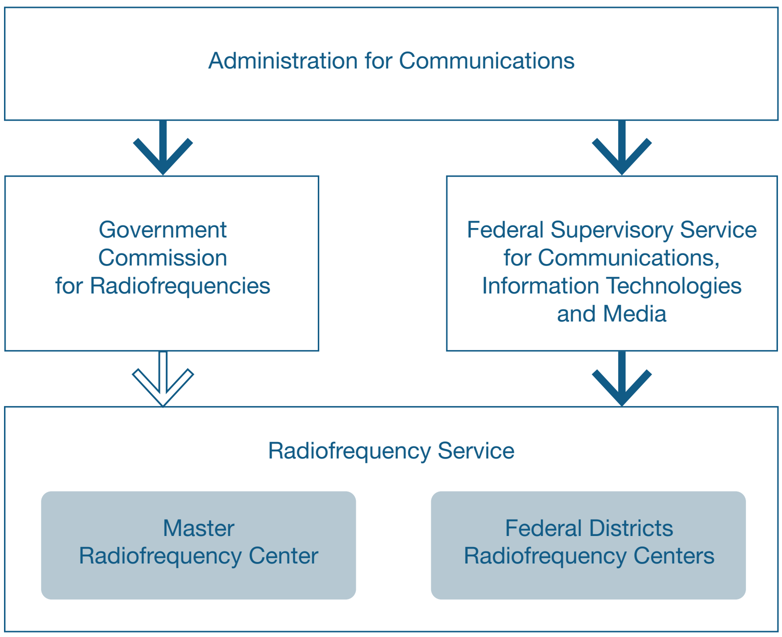
The Federal Law on Communications and the Government of the Russian Federation determine authorities responsible for radiofrequency spectrum regulation and management (see figure VII).

The Government of the Russian Federation determines the general policy on spectrum and satellite orbit use.

The State Commission for Radiofrequencies, which is the inter-agency collegiate authority hosted by the Administration of Communications, is responsible for regulating the radiofrequency spectrum use in the Russian Federation.

According to the frequency allocation chart of the Russian Federation, GLONASS frequency bands fall into the category of frequencies for governmental and combined governmental and civil use. Therefore they are treated as frequencies under special protection.

Figure VII. Organizations and Services of the National Regulator of radiofrequency spectrum use



The Federal Service for the Supervision of Communications, Information Technology and Mass Media (Roskomnadzor) and its radiofrequency service are responsible for the electromagnetic compatibility and interference-free operation of RNSS equipment through frequency planning of transmitter use; the issuing of permits to access radiofrequency spectrums; the centralized registration of operational transmitters, their users and the spectrum use permits issued; the monitoring of spectrum and transmitter emissions; the supervision of compliance with the rules of spectrum and transmitter use; and the tracking and mitigation of interference with legally operating radio equipment.

The General Radiofrequency Centre is responsible for the initial assessment of the potential impact associated with the future operation of radio equipment so that adjacent and shared band electromagnetic compatibility requirements can be met.

Spectrum use permits are granted to users only by Roskomnadzor, based on a positive assessment report. Any radio equipment operating in the Russian Federation is subject to registration.

The Roskomnadzor radiofrequency service is responsible for monitoring compliance with the existing rules and standards of spectrum use, using the technical facilities of an automated radio monitoring system. According to the decisions in force adopted by the State Commission for Radiofrequencies, it is not permitted to use jammers, electromagnetic noise generators or GNSS spoofers in the Russian Federation. The development, manufacture, import, purchase, domestic sale and operation of any technical means creating radio interference in GNSS frequency bands, including noise generators, is also illegal.

Radio navigation satellite service interference detection and mitigation plans

Taking into account the level of social penetration and relevance of GNSS technologies, changes to the regulatory documents on spectrum use and spectrum protection are being considered. Specific regulations are to be introduced to enable the reporting of GNSS interference and jamming in the Russian Federation.

Taking into account the nature of GNSS signals, their propagation and their reception characteristics, additional studies on the dynamics and the impact on the quality of GLONASS-based services of electromagnetic noise and interference limits from various technical sources have been planned within the federal programme for GLONASS sustainment, development and use for 2012-2020. In addition, development, manufacture and implementation have been budgeted under the programme of the technical facilities for radio monitoring in all GNSS bands to detect interference sources, assess their impact on GNSS operation and maintain the register of the identified interference events.

System description: System of differential correction and monitoring

The System of Differential Correction and Monitoring (SDCM) has been operational since 2012. SDCM provides high-precision differential corrections using geostationary relay satellites and ground communication links.

SDCM consists of four main elements:

- A network of measuring stations
- The SDCM master centre
- Data delivery facilities comprised of data up-link station network and transponders on board geosynchronous satellites
- SDCM data assessment facilities

Space segment

The SDCM space segment broadcasts corrections and integrity information using a navigation-like augmentation signal in the L1 frequency band (1,575.42 MHz).

As at the moment of compiling the present brochure, the following geostationary satellites were used by SDCM:

Satellite name	*Orbital slot*
Luch-5A	16 degrees West
Luch-5B	167 degrees East
Luch-5V	95 degrees East

Ground segment

The SDCM ground segment is responsible for monitoring satellite signals in real time, generating corrections and integrity information for GLONASS and GPS signals, delivering SDCM data to users via ground communication links, analysing SDCM performance a posteriori, and monitoring the quality of SDCM information.

The principle of SDCM operation is as follows: the measurement stations receive current navigation parameters and data from the open GLONASS and GPS signals in the L1 and L2 frequency bands and, based on those, generate a real-time and a post-processed assessment of orbit and clock data, together with a vertical ionospheric delay map. The resulting data are used by the SDCM master centre to generate corrections and integrity information. The corrections and integrity information are then delivered to users via the geosynchronous Luch satellites and/or an Internet server, in the form of standardized messages. The facilities for SDCM data assessment monitor the efficiency of correction and integrity data usage, closing the feedback loop between the SDCM master centre and data delivery facilities.

System performance

Multifrequency receivers: for fully deployed GLONASS and GPS constellations, the signal-in-space user positioning accuracy (root mean square (rms)) should not exceed 0.1 m (in real time) and 0.03 m (in post-processing), in the Parametry Zemli 1990 (PZ-90) coordinate system (and later versions) for GLONASS, and in corresponding coordinate systems for other GNSS.

Single-frequency receivers: in the nodes of the ionospheric delay map built by SDCM, and using carrier phase measurements, signal-in-space user positioning accuracy (rms) should not exceed 0.5 m (in real time mode).

Integrity: 1×10^{-7} in any 150 seconds

Time to alarm: 6 seconds

System development

The main strands of SDCM development are the following:

- Providing corrections and integrity information for users throughout the Russian Federation.
- Expanding the zone of consistent reception from SDCM transponders on board Luch geostationary satellites.
- Introducing an additional signal or signals to deliver corrections and integrity information.
- Deploying additional SDCM measuring stations in the Russian Federation and neighbouring countries.
- Certifying SDCM in accordance with ICAO standards.

System description: Global system of real-time precise orbit and clock determination for civil users

A global system of real-time precise orbit and clock determination is being designed to assist real-time high-precision GLONASS/GNSS orbit and clock data, together with post-processed orbit and clock data for civil users.

Precise point positioning has been selected as the baseline technology for the system. It offers a larger service area and improved accuracy and efficiency as a result of using real-time measurements of the global network, implementing precise models of satellite motion, and enhancing the methods for processing information from heterogeneous sources.

Decimetre-level accuracy is achieved by means of processing assisted information based on high-precision orbit and clock data delivered through communication links in real time, together with the use of GNSS signals in specific user receivers. Centimetre-level accuracy in any daily interval is achieved by means of post-processed GNSS orbit and clock data, and tropospheric model parameters.

System architecture

The system includes the following components:

- A master centre and an alternate system control centre

- A network of GNSS monitoring stations deployed in the Russian Federation and abroad, based on international agreements (60 stations in total, with at least 25 outside the Russian Federation)
- User receivers capable of processing data from the system for high-precision navigation solutions
- A data transmission subsystem, which uses ground and space communication links

The monitoring stations in the Russian Federation are deployed at even intervals to provide coverage of the whole country. The SDCM stations are also included.

Each station is assumed to collect no less than one complete set of measurements per satellite per second. Based on the results of those measurements, stations generate data files once every 15 or 60 minutes containing measurements for every 30 second-period, and navigation messages received via open signals, including ephemeris and almanac validity indications. The data generated are synchronized with the IGS station measurements. File generation delay does not exceed one minute from the latest measurement. The measurement and navigation data are delivered to the system control centre using protocols accepted for real-time networks.

System-enabled user receivers determine their position using advanced algorithms, including real-time algorithms, based on the combined processing of GNSS signals and assisted information. The receivers should be capable of conducting code and phase measurements for all GNSS satellites within their minimum visibility zone in two frequency bands. They should also be able to store measurements and to output the stored measurements onto external devices for post-processing.

The main means of delivering high-precision orbit and clock data are satellites in geostationary orbit, inclined geostationary orbit, highly elliptical orbit and low-Earth orbit on one hand, and generally available ground communication links (Internet, mobile networks) on the other. The technology for networked transport of Radio Technical Commission for Maritime Services data via Internet protocol will be used to transmit data through ground links. The system will provide updated corrections and deliver post-processed GNSS orbit and clock data to users with a delay of no more than one day, and real-time assisted information with a delay of no more than 10 seconds from the moment the latest measurement has been obtained for processing by the system control centre.

Current and planned signals

The monitoring stations continuously monitor civil GLONASS L1, L2 and L3, FDMA and CDMA signals; GPS L1 C/A signals, L1C, L2C and L5 signals; Galileo E1 and E5 signals; BeiDou B1 and B2 signals within their visibility zone. The stations provide code pseudorange measurements and carrier phase measurements.

System performance

Signal-in-space positioning accuracy in the State geocentric coordinate system is the following:

- Phase 1 (2016): 0.3 m in real time; 0.1 m in real time (initial data initialized); and 0.05 m in post-processing
- Phase 2 (2020): 0.1 m in real time; 0.05 m in real time (initial data initialized); 0.03 m in post-processing

Timetable for system deployment

The system will be deployed in two phases. It is expected that phase 1 will be completed in 2016 and it will comprise a partial network of about 40 monitoring stations, of which 7 stations will be located outside the Russian Federation.

The system will be deployed in full by 2020.

European Union: Galileo and the European Geostationary Navigation Overlay Service

System description: Galileo

Space segment

The space segment of Galileo comprises its satellites, which transmit precise, time-encoded navigation signals from space. The nominal Galileo constellation consists of 24 satellites, plus 6 active in-orbit spares, spaced evenly in three circular medium-Earth orbit planes inclined at 56 degrees relative to the equator. Their orbits have a nominal altitude of about 23,000 km and an orbital period of approximately 14 hours.

Ground segment

The Galileo ground segment controls the Galileo satellite constellation, monitors the health of the satellites, provides core functions of the navigation mission (satellite orbit determination, clock synchronization), performs the statistical analysis of the signal-in-space ranging error, determines the navigation messages, and uploads the navigation data for subsequent broadcast to users. The key elements of the transmitted data (such as satellite orbit ephemeris, clock synchronization, signal-in-space accuracy and the parameters for the NeQuick ionospheric model) are calculated from measurements made by a global network of reference sensor stations.

Currently, the Galileo ground segment comprises two control centres, a global network of 16 sensor stations, 6 satellite tracking and command facilities and 5 mission uplink stations.

Current and planned signals

Galileo will transmit radio-navigation signals in four different operating frequency bands: E1 (1,559-1,594 MHz), E6 (1,260-1,300 MHz), E5a (1,164-1,188 MHz) and E5b (1,195-1,219 MHz).

Galileo E1

The Galileo E1 band is centred at 1,575.42 MHz and is composed of a carrier modulated with two types of binary offset carrier (BOC) signal that can be used alone or in combination with signals in other frequency bands, depending on required performance. The signals are provided as an open service and a public regulated service, both of which include a navigation message. The open service uses a multiplexed BOC (MBOC) signal known as composite binary offset carrier signal CBOC(6,1,1/11), while a BOC_{cos}(15,2,5) is used under the public regulated service for governmental applications. The open service signal was originally designed in cooperation with the United States to aid interoperability with the GPS L1C signal, and since then, MBOC signals with similar spectral shapes have also been adopted by BeiDou and QZSS, further aiding interoperability between all those systems.

Galileo E6

The Galileo E6 signal is transmitted on a centre frequency of 1,278.75 MHz and includes commercial service and public regulated service signals, which are modulated with a binary phase shift keying (BPSK(5)) signal and a BOCcos(10,5), respectively. Both include navigation messages and encrypted ranging codes.

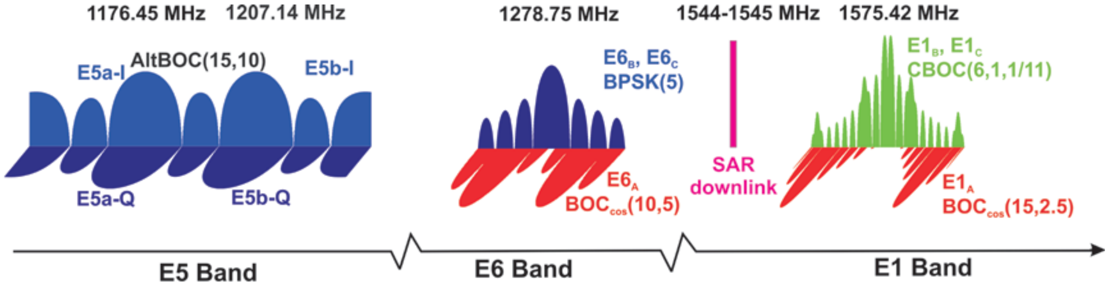
Galileo E5

The wideband Galileo E5 signal is centred on a frequency of 1,191.795 MHz and is generated with AltBOC, a novel BOC modulation with a side-band subcarrier rate of 15.345 MHz. This scheme provides two side lobes, which look like separate BPSK(5) signals that can be demodulated either independently, if required, or as a whole, to maximize the benefits of the wideband AltBOC signal. The lower E5 side lobe is called the Galileo E5a signal, which is centred on a frequency of 1,176.45 MHz and provides a second signal (dual frequency reception) for the open service. The upper E5 side lobe, centred on a frequency of 1,207.14 MHz, is called the Galileo E5b signal and can also be used for dual frequency reception for the open service. Both signals include a navigation message.

Search and rescue

Galileo satellites are fitted with a search-and-rescue payload that can receive emergency distress beacon transmissions in the internationally harmonized 406 MHz band. The distress beacon data is then transmitted to rescue centres using the 1544-1545 MHz search-and-rescue downlink band dedicated to distress and safety communications. Figure VIII shows the frequency ranges of the Galileo signals.

Figure VIII. Frequency ranges of the Galileo signals



Performance standards versus actual performance

Galileo open service

The open service of Galileo will make positioning, navigation and timing services widely available to all users free of charge.

The target accuracy performance of Galileo's open-service positioning, navigation and timing is specified as the ninety-fifth percentile of the positioning, navigation and timing error distribution for different user types, and takes into account all sources of error, including those external to the Galileo system. Hence, the target performance specifications positioning, navigation and timing are subject to several assumptions regarding the user terminal and local environment: clear sky visibility, absence of radiofrequency interference, reduced multipath environment, mild local ionospheric conditions, absence of scintillations and fault-free user receiver. Table 2 provides an overview of the Galileo open-service target performance specifications for positioning, navigation and timing.

Table 2. Galileo open-service target performance specifications for positioning, navigation and timing

Performance specification	*Single-frequency open-service user (E1)*	*Dual frequency open-service user (E1-E5b)*
Horizontal accuracy (95 per cent)	15 m	4 m
Vertical accuracy (95 per cent)	35 m	8 m
Timing accuracy (95 per cent)	..	30 nanoseconds (with respect to UTC)
Galileo open-service availability (averaged over the lifetime of the system)	99.5 per cent	99.5 per cent

Galileo search-and-rescue service

The Galileo search-and-rescue service complements the current International Satellite System for Search and Rescue (COSPAS-SARSAT) service by performing detection and localization of COSPAS-SARSAT distress beacons and by providing a return link capability for distress beacons fitted with Galileo open-service receivers. The Galileo search-and-rescue service will be provided free of charge.

The localization accuracy performance of the Galileo search-and-rescue service is expected to be better than 100 m (95 per cent) for COSPAS-SARSAT beacons fitted with Galileo receivers and better than 5 km (95 per cent) for legacy COSPAS-SARSAT beacons.

In stand-alone mode, Galileo provides search-and-rescue service coverage in Europe and associated search-and-rescue areas of responsibility of all of the European Union and European Space Agency member countries.

Timetable for system deployment and operation

The Galileo in-orbit validation phase was completed in 2013. It was conducted with four satellites and an appropriate in-orbit validation ground segment. Procurement for Galileo's full operational capability is under way and the overall timing aims to achieve full system deployment with 30 Galileo satellites (including the 6 in-orbit active spares), an upgraded ground segment. Galileo is to be in full operation by 2020.

A phased approach to the introduction of services will be adopted as the Galileo space and ground segments are deployed. With the currently planned launch schedule, it is expected that initial services will be offered in the course of 2016.

System description: European Geostationary Navigation Overlay Service

The European Geostationary Navigation Overlay Service (EGNOS) provides an augmentation signal to the GPS standard positioning service. EGNOS signals are transmitted with the same signal frequency and modulation as the GPS L1 (1,575.42 MHz) C/A signal. While GPS provides global positioning, navigation and timing signals and service from medium Earth orbit satellites, EGNOS uses geostationary satellites to provide additional correction and integrity information that allows improved positioning navigation services over Europe.

Space segment

The EGNOS space segment consists of two operational navigation transponders on board geostationary satellites, which broadcast corrections and integrity information for GPS satellites in the L1 frequency band (1,575.42 MHz). Additional navigation transponders, used for testing or for back-up purposes, may also be integrated into EGNOS. As of October 2015, the following geostationary satellites were part of the EGNOS space segment:

Geostationary satellite	*Pseudo-random noise number*	*Orbital slot*
INMARSAT AOR-E (3F2)—operational	PRN 120	15.5 degrees West
SES 5 — operational	PRN 136	5.0 degrees East
INMARSAT IOR-W (4F2)—test	PRN 126	25.0 degrees East
ASTRA 5B—commissioning phase	PRN 123	31.5 degrees East

Ground segment

The EGNOS ground segment includes a network of ranging integrity monitoring stations, four mission control centres, six navigation land Earth stations, the EGNOS wide area network (which provides the communication network for all ground segment components), the performance assessment and system checkout facility, and the application-specific qualification facility, support system operations and service provision.

Current and planned signals

The EGNOS signal-space format complies with ICAO standards and recommended practices for satellite-based augmentation systems.

Performance standards versus actual performance

Open service

The main objective of the EGNOS open service is to improve the positioning accuracy achievable by correcting several error sources that can affect raw GPS signals in a particular geographical region.

The accuracy achievable with the EGNOS open service corrections is specified as the ninety-fifth percentile of the error distribution. The performance specifications indicated below assume a user terminal compliant with the specifications of minimum operational performance standard DO229 class 3 of the Radio Technical Commission for Aeronautics and clear-sky visibility of 5 degrees above the local horizontal plane:

Horizontal accuracy (95 per cent)	3 m
Vertical accuracy (95 per cent)	4 m

The EGNOS open service area is defined as the region where the EGNOS open service positioning performance (defined above) is available at least 99 per cent of the time. It is shown in figure IX.

The typical measured positioning accuracy in the middle of the EGNOS open service area is significantly better than specified (around 1 m (95 per cent) vertical accuracy).

EGNOS also provides support to timing applications by transmitting specific corrections that make it possible to trace EGNOS network time to the physical realization of coordinated UTC by the Observatoire de Paris.

EGNOS safety-of-life service

The main objective for the EGNOS safety-of-life service is to support civil aviation applications up to localizer performance with vertical guidance operations.

EGNOS safety-of-life service provides two different levels of integrity service compliant with ICAO definitions for non-precision approach and vertical guidance approach. Figures X and XI show the qualified EGNOS safety-of-life service areas for several levels of availability.

Figure IX. EGNOS open-service area

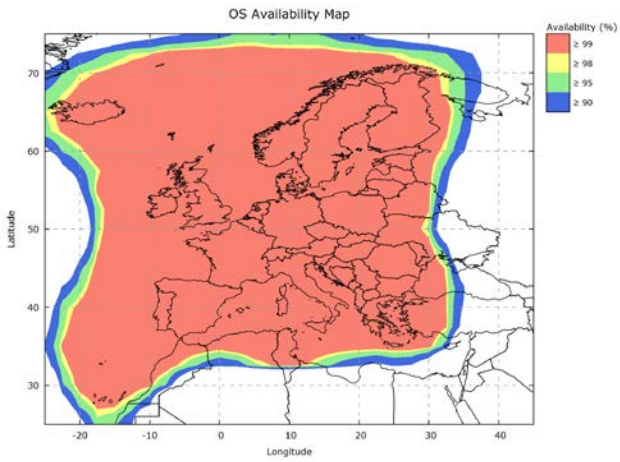


Figure X. EGNOS safety-of-life service: service coverage for non-precision approach (availability)

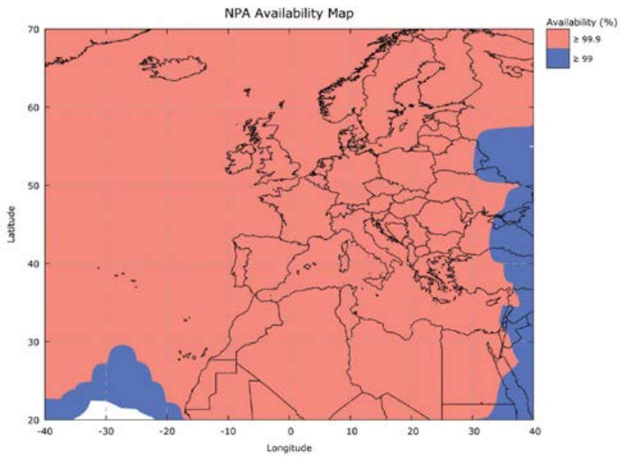
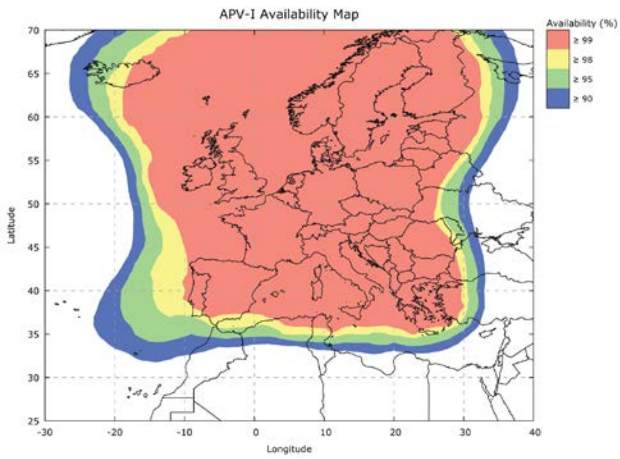


Figure XI. EGNOS safety-of-life service: service coverage for approach procedures with vertical guidance (APV-I)



Services provided and provision policies

Galileo

The specific objective of the Galileo programme is to ensure that the signals emitted by the satellites can be used to provide the following services:

- An open service that is available to all, free of charge, and provides positioning and synchronization information. The positioning accuracy achievable with single-frequency (open-service) receivers, without augmentation, will be better than 15 m in the horizontal dimension and better than 35 m in the vertical dimension. Moreover, the positioning accuracy achievable with dual-frequency receivers will be increased to better than 4 m (horizontal) and 8 m (vertical).
- A commercial service for commercial and professional users, including centimetre-level accuracy and spreading code-level authentication (subject to formal confirmation by the programme).
- A publicly regulated service for Government-approved use in sensitive applications that require a high level of robustness, especially where the delivery of other services is denied. The publicly regulated service uses encrypted signals.
- A search-and-rescue service, provided in close connection and collaboration with COSPAS-SARSAT. This service will allow the detection and localization of emergency signals emitted by COSPAS-SARSAT distress beacons in less than 10 minutes, relaying them to rescue coordination centres through the COSPAS-SARSAT network. The service will also allow a response to be sent back to the beacon in less than 15 minutes, anywhere in the world, via the Galileo satellites, informing the user that their distress signal has been received and position determined.

European Geostationary Navigation Overlay Service

EGNOS delivers three services: an open service, a safety-of-life service and a commercial service.

- *Open service.* In October 2009, EGNOS reached a milestone as the European Union declared the EGNOS open service to be ready, demonstrating the maturity of EGNOS development and qualification. The EGNOS signal transmitted over Europe allows GPS augmentation to reach accuracies of between 1 m and 2 m, with availability greater than 99 per cent. The 2009 announcement marked the start of the valuable service that will remain for the long term.

  The EGNOS open service is accessible to any user within the EGNOS open service area who is equipped with a receiver compatible with GPS satellite-based augmentation systems. No authorization or receiver-specific certification is required to access and use the EGNOS open service. This allows GNSS receiver manufacturers and application developers to tailor EGNOS signal use to need, and to benefit from EGNOS performance improvements at no additional cost.
- *Safety-of-life service.* The second milestone was achieved in March 2011, when the EGNOS service provider was certified and the European Union declared the

safety-of-life service to be ready. The EGNOS safety-of-life service was certified in compliance with the Single European Sky initiative, and was therefore available for use in civil aviation applications, in particular for en route to non-precision approach and vertical guidance approach operations. The European Union intends to keep improving EGNOS performance and to extend the geographic coverage of EGNOS services for all modes of transport, including maritime and land-based vehicles that might require more stringent augmentation requirements.

- *Commercial service.* The third milestone was achieved in July 2012 when the EGNOS commercial data distribution service was declared operational, providing authorized customers (e.g. added-value application providers) the following EGNOS products for their commercial distribution: *(a)* all EGNOS augmentation messages in real time (including satellite clocks and ephemeris corrections, propagation corrections and integrity information in the format of satellite-based augmentation systems); and *(b)* raw data from the network of ranging integrity monitoring stations in real time (including high-precision satellite pseudorange measurements). Those products are accessible via the EGNOS data access service. The EGNOS commercial data distribution service makes it possible to generate EGNOS post-processed products (to be provided through specific service providers connected to the EGNOS data server) in real time. Those products include, but are not limited to, high-rate propagation corrections, EGNOS availability warnings, internal monitoring data and performance information.

Perspective on compatibility and interoperability

Compatibility is the ability of GNSS and regional systems to be used separately or together without causing interference with each other's individual service or signals, and without adversely affecting national security.

- ITU defines a framework that facilitates radiofrequency compatibility coordination between systems.
- To respect national security requirements, systems should keep encrypted authorized signals spectrally separated from all other signals.

Ensuring radiofrequency compatibility

Galileo has actively coordinated with other GNSS and regional systems to ensure both radiofrequency and national security compatibility. Galileo and EGNOS have now completed L-band frequency coordination with GPS III/WAAS, the GPS-aided GEO-augmented Navigation System (GAGAN) of the Indian Regional Navigation Satellite System (IRNSS), QZSS, and BeiDou. Galileo and GLONASS have limited frequency overlaps, but any new signals would be coordinated as required.

Interoperability is the ability of global and regional satellite navigation systems, augmentations and services, to be used together seamlessly to provide better capabilities at user level than would be achieved by individual systems. Interoperability can be at the system or receiver level.

Interoperability can be enabled by:

- Using common centre frequencies, common modulations and common maximum power levels
- Specifying the highest minimum power levels
- Providing details of open signal characteristics (such as public signal-in-space interface control documents)
- Steering geodetic reference frames and system time references to international standards
- Publishing performance standards and system architecture descriptions

Towards interoperability

When interoperability was first considered many years ago, only one system was effectively available: GPS. At that time it was highly desirable for new systems to aim for interoperability with GPS to improve satellite availability, for example in urban canyons. Only system-level interoperability was considered feasible, as receiver designs could not accommodate additional complexity.

Since then receiver designers have overcome those technical obstacles. They have produced chip sets able to process signals from multiple systems and integrated them into positioning, navigation and timing solutions. Today, even inexpensive smartphones can combine GPS and GLONASS signals, even in the absence of a common spectrum. Now that BeiDou and Galileo are well on their way to providing global coverage, tomorrow's multi-system receivers are likely to use the many interoperability enablers already present in current systems to combine signals from all available satellites. The common MBOC modulation in L1/E1 is a good example of one such enabler. It is already used by various systems, which will reduce the need for system-level interoperability. When considering the burden on each system in terms of cost and complexity, the case for system-level interoperability becomes even less compelling.

For these reasons, and to minimize impacts on deployment, the focus for Galileo in the next few years will be on facilitating interoperability of its open signals with the signals of other systems. Building on MBOC modulation, in future it may also be feasible to consider a common open signal design to be used by later versions of all systems.

Global navigation satellite system spectrum protection activities

Without interference-free access to frequencies, satellite-based positioning, navigation and timing would not be possible. Thus, protection of the GNSS spectrum is critical to operations.

Under the international Radio Regulations, GNSS frequency bands are allocated as part of the frequency bands reserved for RNSS, but non-exclusively. However, the allocation process determined by World Radiocommunication Conferences ensures that radio systems sharing bands, or using adjacent bands, are compatible as far as possible in order to minimize interference between them. Fundamentally, the received signal power characteristics of terrestrial services and satellite services are very different. Therefore, frequency regulators recognize that they should be kept apart, primarily to protect the satellite services. For RNSS, with received signal levels below the noise floor, this is even more important.

ITU and World Radiocommunication Conferences spectrum activities

ITU provides a forum for member States to discuss technical issues related to the RNSS spectrum, and it develops guidelines and recommendations to aid compatibility. Together with the other GNSS operators, the European Union has been actively involved in that process, so as to refine and enhance the applicability of the Radio Regulations to RNSS. With spectrum becoming an increasingly valuable commodity for commercial interests, threats to the RNSS spectrum will only increase. It is crucial that GNSS operators work together to ensure that the latent economic value of GNSS to the global economy is fully recognized and factored into any World Radiocommunication Conferences decisions on the Radio Regulations that may affect the RNSS spectrum.

The cooperation between GNSS operators at ITU and the World Radiocommunication Conferences has been extremely beneficial, and the European Union firmly believes that it should continue in the form of preparatory action at both the national and the regional levels.

National-level radio navigation satellite services spectrum regulation and management procedures

The Radio Regulations were established to minimize interference between systems at the international level. Nevertheless, the regulations recognize that within national boundaries, ITU member States have the right to use frequencies as they choose, provided that other member States' application of the regulations is not impacted.

Within Europe the same applies, with spectrum activities generally harmonized within the European Conference of Postal and Telecommunications Administrations (CEPT), with the assistance of the European Telecommunications Standards Institute and other international standards bodies.

European Union member States have given the European Union's executive arm, the European Commission, the authority to negotiate Galileo and EGNOS frequency matters and compatibility and interoperability agreements with relevant international partners.

Radio navigation satellite service interference detection and mitigation plans and procedures

Interference to RNSS typically occurs locally and often goes unnoticed or is attributed to the individual GNSS being tracked. Currently interference cases in the European Union are resolved only if users report problems to their national regulator, which then investigates the interference source. This can take hours or days to resolve, and with the growing economic importance of GNSS and the increased use of illegal GNSS jammers, this is not an ideal situation.

A faster, and ideally automatic means to detect interference is likely to be required in future, and there are European studies investigating various techniques.

In parallel, the European Union has banned the sale of GNSS jammers, but preventing their sale on the Internet remains a challenge. For enforcement to be effective, international cooperation is essential. CEPT has established a project team named FM22, which is dedicated to monitoring and enforcement. Its work has resulted in some harmonization of such activities. CEPT also has a shared satellite monitoring facility in Leeheim, Germany, that can check for space-based interference sources.

All electrical equipment sold within the European Union is already subject to certification and standardization, but it needs to be determined whether the existing certification standards (defined before GNSS became as important as it is today) are sufficient to prevent unwanted frequency emissions impacting RNSS receivers. In addition, all equipment intentionally transmitting or receiving radio waves and sold within the European Union has to comply with European Union directive 2014/53/EU of 16 April 2014, known as the radio equipment directive. That includes GNSS receivers.

Participation in the International Committee on Global Navigation Satellite Systems

The European Union, the European Space Agency and experts from European Union member States are actively involved in all of the working groups and task forces associated with the workplan of ICG.

China: the BeiDou Navigation Satellite System

System description

As a global navigation satellite system compatible with other navigation satellite systems worldwide, the BeiDou Navigation Satellite System is being independently established by China.

In connection with BeiDou, China upholds the principles of openness, cooperation, and resource sharing. It adheres to the concept that BeiDou belongs to China, and also to the world. China has already held extensive exchanges and consultations with countries that possess navigation satellite systems, so as to promote mutual compatibility and interoperability between GNSS.

Openness means that BeiDou will provide open services for direct users free of charge, and will welcome applications worldwide. Independence means that BeiDou will be developed and operated by China independently. Compatibility means that BeiDou is devoted to pursuing compatibility and interoperability with other satellite navigation systems so as to provide better services for users. Gradual deployment means that BeiDou is deployed step by step in accordance with current national technical and economic development.

Space segment

The BeiDou baseline constellation will consist of 35 satellites that provide open services to users worldwide. BeiDou has been in full service, providing open services to most of the Asia-Pacific region since 27 December 2012. As of that date, the BeiDou constellation had 14 operational satellites, as shown in figure XII: 5 geostationary satellites, 5 satellites in inclined geostationary orbit and 4 satellites in medium-Earth orbit.

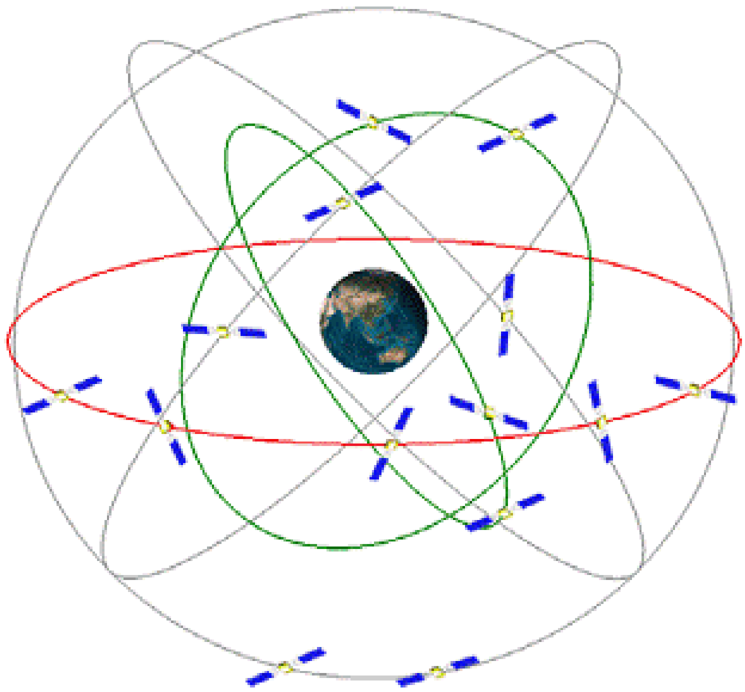
Constellation reference orbit parameters and slot assignments as of the defined epoch are described in the first edition of the BeiDou Navigation Satellite System open service performance standard, issued in December 2013.

The geostationary satellites are operating in orbit with an altitude of 35,786 km. They are positioned at 58.75 degrees East, 80 degrees East, 110.5 degrees East, 140 degrees East and 160 degrees East respectively.

The satellites in inclined geostationary orbit are operating at an altitude of 35,786 km and an inclination of 55 degrees relative to the equatorial plane. The phase difference of the right ascensions of the ascending nodes of the orbital planes is 120 degrees. The sub-satellite tracks for three of those satellites in inclined geostationary orbit coincide. The longitude of the intersection point is 118 degrees East. The sub-satellite tracks for the other two satellites in inclined geostationary orbit also coincide. The longitude of the intersection point is at 95 degrees East.

The satellites in medium-Earth orbit are operating at an altitude of 21,528 km and an inclination of 55 degrees relative to the equatorial plane. The satellite recursion period is 13 rotations within 7 days. The phase is selected from the Walker 24/3/1 constellation, and the right ascension of the ascending node of the satellites in the first orbital plane is 0 degrees. The current 4 satellites in medium-Earth orbit are in the seventh and eighth phases of the first orbital plane, and in the third and fourth phases of the second orbital plane respectively.

Figure XII. Current space constellation of BeiDou



Ground segment

The ground segment of the BeiDou system consists of the master control station, time synchronization and upload stations and monitoring stations.

The master control station is the operation and control centre of BeiDou. Its main tasks include the collection of observation data about navigation signals from each time synchronization and upload station and monitoring station; processing data; generating satellite navigation messages; performing mission planning and scheduling; conducting system operations, management and control; observing and calculating the satellite clock bias; uploading satellite navigation messages; monitoring the satellite payload; and analysing anomalies.

The main tasks of the time synchronization and upload stations are to measure satellite clock biases and to upload satellite navigation messages.

The main tasks of the monitoring stations are to continuously observe satellite navigation signals, and to provide real-time data to the master control station.

The current basic parameters of BeiDou civil signals are shown in table 3.

Current and planned signals

Table 3. Current basic parameters of BeiDou civil signals

Component	*Carrier frequency (MHz)*	*Chip rate (MHz)*	*Data rate (bps)*	*Modulation*	*Service type*
B1I	1,561.098	2.046	50 (MEO/IGSO) 500 (GEO)	QPSK	Open
B2I	1,207.140	2.046	50 (MEO/IGSO) 500 (GEO)	QPSK	Open

The planned BeiDou frequency bands include:

B1: 1,559.052–1,591.788 MHz

B2: 1,166.22–1,217.37 MHz

B3: 1,250.618–1,286.423 MHz

The planned basic parameters of BeiDou civil signals are shown in table 4.

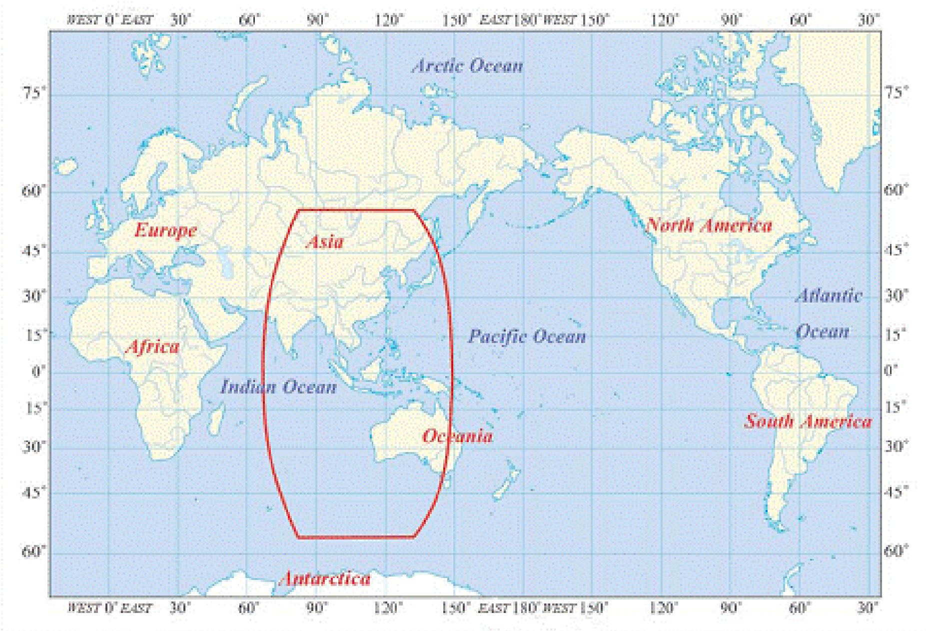
Table 4. The planned basic parameters of BeiDou civil signals

Component	*Carrier frequency (MHz)*	*Chip rate (MHz)*	*Data/Symbol rate (bps/symbols per second (sps))*	*Modulation*	*Service type*
B1-C_D	1,575.42	1.023	50/100	MBOC(6,1,1/11)	Open
B1-C_P			No		
B2-a_D	1,191.795	10.23	25/50	ALTBOC(15,10)	Open
B2-a_P			No		
B2-b_D			50/100		
B2-b_P			No		

Performance standards versus actual performance

The BeiDou open-service volume is defined as the open-service signal-in-space coverage of the BeiDou satellites where both the BeiDou open-service horizontal and vertical position accuracy are better than 10 m (with a probability of 95 per cent). At the current stage, the BeiDou regional service capability has been achieved, which can provide continuous open service to the area as shown in figure XIII, including most of the region from 55 degrees South to 55 degrees North, 70 degrees East to 150 degrees East.

Figure XIII. The current BeiDou open-service volume



The BeiDou standards for open-service position, velocity and time accuracy within its service volume are shown in table 5.

Table 5. The BeiDou standards for open-service position, velocity and time accuracy within its service volume

Positioning accuracy		*Reference standard (95 % probability)*	*Constraints*
Position accuracy	Horizontal	≤10 metres	Calculate the statistical position/velocity/time error for any point in the service volume over any 24-hour interval.
	Vertical	≤10 metres	
Velocity accuracy		≤0.2 metres per second	
Time accuracy (multi-signals-in-space)	≤50 nanoseconds		

At present, in addition to the specified open-service volume, in most of the area between 55 degrees South, 55 degrees North, 55 degrees East and 160 degrees East, BeiDou could provide open services with a horizontal and vertical position accuracy better than 20 m. In most of the area between 55 degrees South, 55 degrees North, 40 degrees East and 180 degrees East, BeiDou could provide open services with a horizontal and vertical position accuracy better than 30 m. As a user moves away from the nominal service volume, the service accuracy and availability will decrease accordingly.

Timetable for system deployment and operation

The BeiDou system was constructed in three steps.

Step 1: the BeiDou Navigation Satellite Demonstration System

In 1994, China initiated the construction of BeiDou Navigation Satellite Demonstration System. In 2000, the first two BeiDou experimental navigation satellites were launched, and the system was established. In 2003, the third BeiDou experimental navigation satellite was launched, which further enhanced the system's performance.

Step 2: the regional version of the BeiDou Navigation Satellite System

In 2004, China initiated the construction of the BeiDou Navigation Satellite System. By the end of 2012, the BeiDou system possessed full operational capability for China and the surrounding areas.

Step 3: the global version of the BeiDou Navigation Satellite System

From 2014, additional satellites have been launched, while BeiDou service performance will be enhanced and expanded worldwide. Approximately 40 BeiDou navigation satellites will be launched by 2020, and the system with global coverage will be fully established, to provide all time, all weather and high accuracy positioning, navigation and timing services to users. The BeiDou system will achieve full global coverage by 2020.

Services provided and provision policies

Since BeiDou was officially brought into service, China has achieved remarkable progress in the field of theoretical study, technology research and development, receiver production, and application and service development.

Along with the construction of the BeiDou system and the development of service capabilities, a complete application industry chain has been formed, which consists of fundamental products, user terminals, system applications and operating services. All-round breakthroughs have been made in some key technical areas, such as BeiDou core chips and modules. The performance of domestic products is comparable to that of international products in the same class.

The related products have gradually been introduced in transportation, marine fisheries, hydrological monitoring, weather forecasting, forest fire prevention, power grid synchronization, timing for telecommunication systems, disaster relief and reduction, national security, and many other fields. This has resulted in significant social and economic benefits. In particular, BeiDou played an important role in the South China severe cold surge, earthquake relief in Wenchuan and Lushan, Sichuan province and Yushu, Qinghai province, the Beijing Olympic Games, and the Shanghai World Expo.

The BeiDou system has brought the navigation satellite and location-based services industry in China into a new era, and will further provide more high-performance positioning, navigation timing and short-message communication services for the civil aviation, shipping, railway, finance, postal, land resource, agriculture, tourism and other industries.

The main functions and performance specifications of the BeiDou Navigation Satellite Demonstration System were as follows:

- Main functions: positioning, one-way and two-way timing, short message communications
- Position accuracy: better than 20 m
- Time accuracy: one-way 100 nanoseconds, two-way 20 nanoseconds
- Short message communications: 120 Chinese characters per message

The functions and performance parameters of BeiDou in the full operational capability phase are as follows:

- Main functions: positioning, velocity measurement, one-way and two-way timing, short message communications
- Position accuracy: better than 10 m
- Velocity accuracy: better than 0.2 metres per second
- Time accuracy: 50 nanoseconds
- Short message communications: 120 Chinese characters per message

At the global level, the BeiDou system can provide two types of service: open service and restricted service. Through its open service, it provides free positioning, velocity and timing services. Through its restricted service, such as wide-area differential service and the short-message communication service, it provides safer positioning, velocity and timing services, as well as system integrity information, for authorized users in China and the surrounding areas.

Perspective on compatibility and interoperability

Compatibility refers to the ability of multiple satellite navigation systems to be used separately or together, without interfering with the navigation performance of each system.

Interoperability refers to the ability of the open services of multiple satellite navigation systems to be used together to provide better capabilities at the user level than would be achieved by relying solely on one service, without significantly increasing the complexity of receivers.

Efforts to ensure radiofrequency compatibility through bilateral and multilateral venues

China's international exchanges and cooperation in the field of satellite navigation started in the 1990s. Over the 20 years preceding 2015, various activities have been carried out with great impact. China always upholds and adheres to the concept that BeiDou belongs to China, and also to the world. It advocates compatibility and interoperability among navigation satellite systems, and is endeavouring to stimulate the widespread use of navigation satellite systems throughout the world.

The BeiDou system will achieve frequency compatibility with other satellite navigation systems within the ITU framework through bilateral or multilateral coordination. So far, the BeiDou system has facilitated meetings to coordinate radiofrequency compatibility with GPS, Galileo, GLONASS and QZSS.

Efforts to pursue interoperability through bilateral and multilateral venues

The BeiDou system will achieve interoperability with other navigation satellite systems by coordinating through bilateral or multilateral platforms, including ICG. So far, the BeiDou system has facilitated coordination meetings with GPS, Galileo and GLONASS concerning interoperability.

Global navigation satellite system spectrum protection activities

National-level radio-navigation satellite system spectrum regulation and management procedures

Many governmental departments in China have been involved in the construction, operation and application management of the BeiDou system. The China Satellite Navigation Office, a joint office established by related governmental departments, is in charge of managing the construction, application promotion and industrialization of the BeiDou system, as well as the international cooperation related to it.

The Radio Regulatory Bureau of the Ministry of Industry and Information Technology of China is responsible for managing radiofrequency resources in China.

Views on International Telecommunication Union radio navigation satellite service spectrum issues or agenda items of the World Radiocommunication Conferences

BeiDou international frequency coordination activities have been conducted in a phased, step-by-step, focus-centred approach.

In 1994, within the framework of the International Telecommunication Union, China started BeiDou frequency coordination activities. Satellite network information was submitted in accordance with the BeiDou construction plan and progress.

China has been actively participating in the ITU radiocommunication sector study groups and working groups 8D and 4C, as well as those on efficient orbit and spectrum utilization for mobile-satellite services and the radiodetermination satellite service. China has also been actively involved in the consultation meeting on World Radiocommunication

Conferences resolution 609 and participated in the RNSS aggregate equivalent power flux-density calculation in the 1,164-1,215 MHz frequency band.

A Chinese delegation participated in the ITU World Radiocommunication Conference of 2012, and argued for an extension of the radiodetermination satellite service (space-to-Earth) allocations in the S-band, and strive to designate a new band for navigation satellite systems. Together with other countries, China successfully sponsored the use of the S-band (2,483.5-2,500 MHz) for this purpose.

Radio navigation satellite system interference detection and mitigation plans and procedures

China has been conducting research on the evaluation of interference between non-RNSS services and RNSS services, interference among RNSS systems, and the technical characteristics of RNSS receivers and associated protection requirements, techniques and regulations for RNSS interference detection and mitigation.

Participation in the International Committee on Global Navigation Satellite Systems

China, as a founding member of ICG, has participated in all ICG annual meetings and the ICG Providers' Forum. In 2007, China became one of the four core providers designated by the organization.

During the sixth meeting of ICG, held in 2011, China proposed the creation of the International GNSS Monitoring and Assessment Service (iGMAS), for open services, and the BeiDou/GNSS Application Demonstration and Experience Campaign. It also sponsored the establishment of an iGMAS working subgroup and application working subgroup and became co-chair of both. The purpose was to offer users more reliable satellite navigation services by cooperating in the field of international GNSS monitoring and assessment, making use of global monitoring stations, sharing international monitoring statistics, implementing joint assessment studies, and offering users reliable monitoring and assessment data and products. At the eighth meeting of ICG, China sponsored the establishment of an interference detection and mitigation task force and an interoperability task force, and became co-chair of both.

To enable countries in the coverage area to benefit from BeiDou's creation sooner, the BeiDou team visited a great number of countries to promote the use of navigation satellite systems as part of two events entitled "BeiDou's tour to the Asia-Pacific region" and "BeiDou's tour of the Association of Southeast Asian Nations".

In November 2012, the seventh meeting of ICG was hosted by China. More than 200 representatives from 16 countries and 18 international organizations joined the meeting. The meeting considered 20 proposals, and the Providers' Forum adopted a statement concerning ICG, making it a landmark meeting in ICG history.

The Government of China has been attaching great importance to cultivating talents in the field of GNSS, and has been keen to promote international GNSS education and training. With the support of the United Nations Office for Outer Space Affairs, China has established the Regional Centre for Space Science and Technology Education for Asia and the Pacific, located at Beihang University in Beijing, which also serves as one of the information centres for ICG.

Views on future areas of focus and activities of the Committee as appropriate

With the participation of States Members of the United Nations, intergovernmental bodies and non-governmental organizations, ICG has become an important platform for communication and cooperation in the field of global satellite navigation.

As a country with an independent navigation satellite system, China will continue to sponsor international exchanges and cooperation, promote the development of GNSS, encourage the use of new technologies, and promote the popularization of and knowledge about satellite navigation technologies, especially those that enhance recognition and application capacities of satellite navigation in developing countries.

India: the Indian Regional Navigation Satellite System Global Positioning System-aided GEO-augmented Navigation System

System description: space segment

Indian Regional Navigation Satellite System

The nominal baseline of the IRNSS constellation will comprise seven satellites. Three satellites will be placed in geostationary orbit, at 32.5 degrees East, 83 degrees East and 131.5 degrees East, respectively, and four satellites will be placed in inclined geosynchronous orbits with an equator crossing at 55 degrees East and 111.75 degrees East, respectively, with an inclination of 29 degrees (two in each plane). The constellation provides continuous regional coverage for positioning, navigation and timing services.

Global Positioning System-aided GEO-augmented Navigation System

The space segment of the GPS-aided GEO-augmented Navigation System (GAGAN) consists of two geostationary satellites, located at 83 degrees East and 55 degrees East respectively, each of which carries a bent pipe transponder. An additional on-orbit spare (located at 93.5 degrees East) will be added in the near future.

System description: ground segment

Indian Regional Navigation Satellite System

The ground segment is responsible for the maintenance and operation of the IRNSS constellation. It consists of 2 spacecraft control centres with 7 IRNSS telemetry, tracking, and command stations in total, 2 IRNSS navigation centres, 17 IRNSS range and integrity monitoring stations, 2 IRNSS timing centres, 4 code division multiple access (CDMA) ranging stations and 2 data communication links. In addition, support from stations in international laser ranging stations is utilized for laser ranging.

GPS-aided GEO-augmented Navigation System

As part of the ground segment, 15 Indian reference stations for monitoring and collecting data, 2 master control centres and 3 uplink stations are in operation using dual communication links.

Current and planned signals

The IRNSS constellation transmits navigation signals in the L5 and S bands. Standard positioning service and restricted services that use encryption technologies are the basic services offered by IRNSS. The IRNSS standard positioning and restricted services are transmitted in the L5 band (1,164-1,215 MHz) and the S band (2,483.5-2,500.0 MHz).

The IRNSS carrier frequencies and the bandwidths of transmission for the services are shown in table 6. It is planned to have additional signals in the L1 band.

Table 6. IRNSS carrier frequencies and bandwidths

Signal	*Carrier frequency*	*Bandwidth*
SPS — L5	1,176.45 MHz	24 MHz
RS — L5	1,176.45 MHz	24 MHz
SPS — S	2,492.028 MHz	16.5 MHz
RS — S	2,492.028 MHz	16.5 MHz

The standard positioning service (SPS) signal is modulated with a BPSK (1) in the L5 and S bands. The navigation data are transmitted at a rate of 25 bps and is modulo-2 added to a pseudo-random noise code chipped at 1.023 megachips per second (Mcps), identified for the standard positioning service. The CDMA-modulated code modulates the L5 and S carriers at 1,176.45 MHz and 2,492.028 MHz, respectively.

The restricted service is for authorized users only. Its signal is transmitted in the L5 and S bands using binary offset coding. It has two channels: a data channel and a pilot, or data-less, channel. The navigation data at 25 bps is modulo-2 added with designated pseudo-random noise code chipped at 2.046 Mcps in the data channel. The CDMA bit stream modulates the L5 and S carriers using BOC (5,2). The pilot channel is transmitted using primary and secondary codes without data modulation. The primary codes are chipped at 2.046 Mcps. The pilot carrier is in phase quadrature with the data channel.

The GAGAN signal-in-space format complies with ICAO standards and recommended practices for satellite-based augmentation systems. The GAGAN carrier frequencies of transmission are shown in table 7.

Table 7. GPS-aided GEO-augmented Navigation System centre frequency

Description	*Signals*
Satellite-based augmentation system signal	L1 — 1,575.42 MHz
	L5 — 1,176.45 MHz

Performance standards versus actual performance

Indian Regional Navigation Satellite System

IRNSS would primarily provide services to India and an area covering 1,500 km around its land mass. IRNSS would provide dual frequency users with targeted position accuracy of less than 20 m in the service area.

GPS-aided GEO-augmented Navigation System

The GAGAN system has been provisionally certified by the Directorate General of Civil Aviation of India to provide non-precision approach services with required navigation performance 0.1 over the Indian flight information region. GAGAN will be certified for precision approach service using approach procedures with vertical guidance (APV) 1.0/1.5 in 2015.

Timetable for system deployment and operation

Indian Regional Navigation Satellite System

The first IRNSS satellite was launched on 1 July 2013, the second on 4 April 2014 and the third on 16 October 2014. The fourth IRNSS satellite is scheduled for launch in March 2015. The remaining satellites are planned to be launched by the first quarter of 2016.

GPS-aided GEO-augmented Navigation System

The certification and commissioning was completed for required navigation performance 0.1 service over the Indian flight information region in February 2014. GAGAN will be certified for precision approach service of APV 1.0/1.5 in 2015.

Services provided and provision policies

Indian Regional Navigation Satellite System

Standard positioning services and restricted service are the basic services offered by IRNSS. The standard positioning service is free for all users. The restricted service is encrypted and available only to authorized users. The signal-in-space interface control document for the standard positioning service was released in October 2014 on the website of the Indian Space Research Organization (ISRO) of the Department of Space.

GPS-aided GEO-augmented Navigation System

GAGAN will provide a safety-of-life service that meets all the requirements of accuracy, integrity, continuity and availability imposed by ICAO for utilization by civil aviation en route, and for non-precision and precision approaches.

Perspective on compatibility and interoperability

IRNSS plans to achieve compatibility and interoperability of GAGAN with other GNSS operators and service providers through bilateral and multilateral meetings.

Definition of compatibility and interoperability

Compatibility refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference or other harm to an individual system or service. To achieve this, ITU provides a framework for discussions on radiofrequency compatibility. The frequency spectrums used for the authorized service signals of different systems must be kept separate, but some signal overlap may be unavoidable. The providers concerned will hold discussions to find a mutually acceptable solution.

Interoperability refers to the ability of global and regional navigation satellite systems and augmentations to be used together so as to provide users better capabilities than would be achieved by relying solely on the open signals of one system.

Interoperability is achieved by using a common centre frequency, common modulation, compatible signal and power levels, as well as geodetic reference frames and system time steerage standards that adhere to international standards.

Efforts to ensure radiofrequency compatibility through bilateral and multilateral venues

Efforts to establish compatibility between IRNSS and other GNSS and augmentation systems on one hand, and between GAGAN and other GNSS and augmentation systems on the other, have been pursued for many years. IRNSS has completed radiofrequency compatibility with GPS and Galileo in the L5 and S bands. IRNSS is approaching radio frequency compatibility with QZSS, MSAS and Compass/BeiDou. IRNSS is pursuing coordination in the L1 band with all GNSS operators.

GAGAN has completed coordination with GPS, Galileo and Compass/BeiDou. GAGAN is completing the coordination process with QZSS and MSAS.

Efforts to pursue interoperability through bilateral and multilateral venues

Interoperability is considered desirable, but has yet to be established. IRNSS intends to achieve interoperability by interacting with other GNSS agencies through bilateral and multilateral talks.

IRNSS is interoperable in the L5 frequency band and the WGS-84 geodetic reference frame, and has signal power levels and system time that are compatible with other GNSS operators.

GAGAN is compatible and interoperable with other satellite-based augmentation systems.

Global navigation satellite system spectrum protection activities

Radio navigation satellite service spectrum regulation and management procedures

National RNSS spectrum regulation is managed by the Wireless Planning Commission of the Government of India, in close coordination with ISRO.

Over the years, the national regulatory process has ensured the availability and protection of the RNSS spectrum.

Views on International Telecommunication Union radio navigation satellite service spectrum issues or items on the agenda of the World Radiocommunication Conferences, as appropriate or necessary

Recognizing that navigation signal frequency bands need protection, India has actively participated in the World Radiocommunication Conferences and the meetings of the ITU radiocommunication sector (ITU-R), and contributed to ensuring availability and protection of RNSS spectrum resources.

Participation in the International Committee on Global Navigation Satellite Systems

All service providers are involved in the working groups pursuant to their respective work-plans, agreed within ICG. ISRO is also actively involved in the activities of ICG.

Japan: the Multifunctional Transport Satellite-based Augmentation System and the Quasi-Zenith Satellite System

Description of the Multifunctional Transport Satellite-based Augmentation System

MSAS provides GPS augmentation information for the satellite navigation systems on board civil aircraft within the Fukuoka flight information region. It is one of the satellite-based augmentation systems that comply with ICAO standards and recommended practices.

Space segment

MSAS provides navigation services for all aircraft within Japanese airspace via two geostationary satellites: MTSAT-1R at 140 degrees East, and MTSAT-2, at 145 degrees East. MTSAT-1R is scheduled to retire in December 2015, after which, MTSAT-2 will provide two pseudo-random noise codes (PRN 129 and PRN 137) simultaneously.

Ground segment

MSAS consists of two geostationary satellites and a ground network made up of two master control stations (one at Kobe and one at Hitachiota), and six ground monitoring stations (at Sapporo, Hitachiota, Tokyo, Kobe, Fukuoka and Naha).

The master control stations generate augmentation information based on the GPS and MTSAT signals received at the ground-monitoring stations. The ground-monitoring stations monitor GPS satellite signals.

Current and planned signals

MSAS navigation signals transmit from the L1 C/A satellites at a centre frequency of 1,575.42 MHz.

The signal is modulated by a BPSK technique with PRN spreading codes having a clock rate of 1.023 MHz, which is contained in the 250 bps/500 symbols per second (sps) binary navigation data stream. The parameters of the MSAS signal are summarized in table 8.

Table 8. SAS transmission parameters

Parameter (units)	L1 C/A
Carrier frequency (MHz)	1,575.42
PRN code chip rate (Mcps)	1.023
Navigation data bit/symbol rates (bps/sps)	250/500
Signal modulation method	BPSK(1)

Table 8. (*continued*)

Polarization	RHCP
Minimum received power level at input of antenna (dBW)	-161.0
Frequency bandwidth (MHz)	2.2

Performance standards versus actual performance

MSAS provides horizontal guidance for navigation, which is used in non-precision approaches.

In order to satisfy ICAO standards and recommended practices, horizontal accuracy is less than 220 m, observed value is less than 2.2 m (95 per cent), integrity (probability of hazardous, misleading information) is less than 1×10^{-7}/hour, fault tree analysis leads 0.903×10^{-7}/hour, availability is more than 99.9 per cent, observed 99.97 per cent.

Timetable for system deployment and operation

MTSAT-1R was launched in February 2005 and entered orbit at 140 degrees East. MTSAT-2 was launched in February 2006 and entered orbit at 145 degrees East. MSAS has been operating since September 2007.

Services provided and provision policies

MSAS is used for aircraft navigation. MSAS offers three advanced functions. In the event of a GPS failure, the health status of the GPS signal is transmitted via the integrity function of MSAS, while the differential correction function provides ranging error data. MSAS also employs a ranging function to generate GPS-like signals and enable aircraft to use MTSAT as an additional GPS satellite.

In order to ensure the reliability of this function, MSAS monitors MTSAT/GPS signals, ranging the determinate MTSAT satellite orbit and estimating ionospheric delay 24 hours a day, seven days a week.

Perspective on compatibility and interoperability

MSAS is compatible and can interoperate with other satellite-based augmentation systems.

Participation in the International Committee on Global Navigation Satellite Systems

MSAS has participated in the ICAO interoperability working group and navigation system panel meetings.

Description of the Quasi-Zenith Satellite System

QZSS is a regional space-based, all-weather, continuous system for positioning, navigation and timing that provides interoperable signals for GPS (L1, L2 and L5), a sub-metre level augmentation signal (L1S, previously L1-SAIF), a centimetre-level augmentation signal (L6, previously LEX), and one channel for technology verification (L5S). QZSS provides navigation services for East Asia, including Japan, and the Oceania region.

Space segment

The space segment comprises the QZSS satellites, which function as celestial reference points, emitting precise time-encoded navigation signals from space. QZSS consists of three quasi-zenith orbit satellites and one geostationary orbit satellite. The operational constellation of QZSS operates in orbit as shown in tables 9 and 10. The satellites are phased so that there is always one satellite visible at a high elevation angle from Japan.

The satellite is a three-axis stabilized vehicle whose mass, without propellant, is approximately 2 tons, including a 400 kg-navigation payload. The major elements of its principal navigation payload are the atomic frequency standard for accurate timing, the onboard navigation computer to store navigation data, generate the ranging code and stream navigation messages, and the 1.1/1.6 GHz band transmitting antenna whose shaped-beam gain pattern radiates near-uniform power of signals at the four 1.1/1.6 GHz band frequencies to users on or near the surface of the Earth.

Table 9. Quasi-zenith orbit parameters and operational ranges

Orbit parameter	*Nominal value*	*Operational range*
Semi-major axis	42,164 km (Average)	– —
Eccentricity	0.075	0.075 ± 0.015
Argument of perigee	270 degrees	270 ± 2.5 degrees

Table 10. Geostationary orbit parameters and operational ranges

Orbit parameter	*Nominal value*	*Operational range*
Longitude	127 degrees East	127 ± 0.1 degrees East
Latitude	0 degrees	0 ± 0.1 degrees

Ground segment

The control segment performs the tracking, computation, updating and monitoring functions needed to control all of the satellites in the system on a daily basis. It consists of master control stations, monitoring stations, and tracking and control stations.

The master control station controls the satellite system and ground system and creates data for each service.

The tracking and control stations handle the communications for controlling the satellite system and uploading data.

The monitor stations receive the positioning signals transmitted from QZSS, GPS, and other GNSS. They transmit the data to the master control station. The data are processed at the master control station so that the satellite's ephemerides, clock offsets, clock drifts and propagation delay can be calculated, and are then used to generate messages for uploading. This updated information is transmitted to the satellites via tracking and control station for memory storage and subsequent transmission by the satellites as part of the navigation messages to the users.

Current and planned signals

The QZSS navigation signals transmitted from the satellites consist of five modulated carriers: two L1 carriers at centre frequency 1,575.42 MHz ($154f_0$), one L2 carrier at centre frequency 1,227.6 MHz ($120f_0$), one L5 carrier at centre frequency 1,176.45 MHz ($115f_0$) and one L6 at carrier at centre frequency 1,278.75 MHz ($125f_0$), where f_0 = 10.23 MHz. The symbol f_0 stands for the output of the on-board frequency reference unit to which all signals generated are coherently related.

The L1 signal consists of four BPSK modulation signals. Two of those, the L1C/A and L1S signals, are modulated with two different PRN spreading codes that are modulo-2 add sequences of the outputs of two 10-bit linear feedback shift registers having a clock rate of 1.023 MHz and a period of 1 millisecond. Each of those is modulo-2 added to a 50 bps/50 sps or 250 bps/500 sps binary navigation data stream prior to BPSK modulation. The other two signals, L1Cp and L1Cd, are modulated with two different spreading codes having a clock rate of 1.023 MHz and with two identical square waves having a clock rate of 0.5115 MHz. The data stream is modulo-2 added to the L1Cd signal. Only the L1S signal is transmitted through a separate horn antenna using a different L1 carrier wave.

The L2 signal is BPSK-modulated with an L2C spreading code. The L2C code has a clock rate of 1.023 MHz, with alternating spreading codes having a clock rate of 0.5115 MHz: the L2CM signal with a period of 20 milliseconds, and the L2CL signal, with a period of 1.5 seconds. A 25 bps/50 sps data stream is modulo-2 added to the code prior to phase modulation.

The L5 signal consists of two BPSK signals (L5I and L5Q) multiplexed in quadrature, and one BPSK signal, L5S. The two BPSK signals in both the I and the Q channels are modulated with two different L5 spreading codes. Both of the L5 spreading codes have a clock rate of 10.23 MHz and a period of 1 millisecond. A 50 bps/100 sps binary navigation data stream is transmitted on the I channel and no data (i.e. a data-less pilot signal) on the Q channel. The L5S signal has a clock rate of 10.23 MHz and a period of 1 millisecond.

A 250 bps/500 sps binary navigation data stream is transmitted. Only the L5S signal is transmitted through a separate horn antenna using a different L5 carrier wave.

The L6 signal is also BPSK-modulated. A set of small Kasami code sequences is employed for the spreading code having a clock rate of 5.115 MHz.

The main characteristics of QZSS signals are summarized in table 11.

Table 11. QZSS transmission parameters

Parameter (units)	*L1 C/A*	*L1S*	*L1C*	*L2C*	*L5*	*L5S*	*L6*
Carrier frequency (MHz)	1575.42	1575.42	1575.42	1227.6	1176.45	1176.45	1278.75
PRN code chip rate (Mcps)	1.023	1.023	1.023	1.023	10.23	10.23	5.115
Navigation data bit/ symbol rates (bps/sps)	50/50	250/500	25/50	25/50	50/100	50/100	2000/250
Signal modulation method	BPSK(1)	BPSK(1)	BOC(1,1)	BPSK(1)	BPSK(10)	BPSK(10)	BPSK(5)
Polarization	RHCP	RHCP	RHCP	RHCP	RHCP	RHCP	RHCP
Minimum received power level at input of antenna (dBW)[a]	-158.5	-158.5	-163 (pilot), -158.25 (data-less)	-158.5	-157(I) -157(Q)	-157	-155
Frequency bandwidth (MHz)	30.69	30.69	30.69	30.69	24.9	24.9	42

[a] The QZSS minimum received power assumes the minimum receiver-antenna gain is at angles of 10 degrees or more above the Earth's horizon viewed from the Earth's surface.

Performance standards versus actual performance

The specification of signal-in-space user range error is less than 2.6 m (95 per cent), including time and coordination offset error to GPS. These specifications have already been verified by simulation using the actual system design. The design result shows a signal-in-space user range error of 1.0 m (95 per cent) in the quasi-zenith orbit satellites, and 1.5 m (95 per cent) in the geostationary satellite.

The L1S signal provides ionospheric error correction data and wide-area differential GPS correction data. The positioning accuracy is estimated to be 1 m (1 sigma rms) in the Japan area.

Timetable for system deployment and operation

Michibiki, the system's first satellite, was launched in 2010. It is undergoing technical verification, and many applications are in operation. The development of the three additional satellites and many ground system components will be completed by the end of the 2016 Japanese fiscal year. Ground system manufacturing and testing will be completed by the end of September 2016, and preliminary operation will be started up by the end of the 2017 Japanese fiscal year. QZSS service with four satellites will start operating from the beginning of the 2018 Japanese fiscal year.

Services provided and provision policies

All QZSS signals (L1C/A, L2C, L5 and L1C) and augmentation signals (such as L1S and L6) are to be provided free of charge to direct users. In order to support the design of a QZSS receiver by manufacturers and enable providers of positioning, navigation and timing services to use QZSS signals, interface specifications will be released. The document describes radiofrequency properties, message structure and definition, system characteristics, service performance properties and the concept of operation. The document can be downloaded free of charge from the QZSS website.

The role of international organizations and the value added by the International Committee on Global Navigation Satellite Systems

Civil Global Positioning System Service Interface Committee

The Civil Global Positioning System (GPS) Service Interface Committee (CGSIC) is recognized as the worldwide forum for effective interaction between all civil GPS users and the United States GPS authorities. CGSIC is chaired by the United States Department of Transportation. The United States Coast Guard Navigation Center coordinates and manages the administration of the committee as deputy chair and executive secretariat.

The United States Department of Transportation established CGSIC to exchange information about GPS with the worldwide civil user community, respond to the needs of civil GPS users, and integrate GPS into civil sector applications.

Information from CGSIC members and meetings is provided to United States GPS authorities for consideration in GPS policy development and GPS service operation.

CGSIC acts as a representative for the world's civil GPS users and advocates for the civil use of GPS in a number of United States and international forums. Also, under the auspices of CGSIC, the United States Coast Guard Navigation Centre publishes information about operations related to the GPS programme and acts as an operational civil liaison between the world's civil users of GPS and the GPS authorities. It is in this capacity that CGSIC attends meetings of the ICG as an associate member.

European Position Determination System

The European Position Determination System (EUPOS) is an international organization of European public institutions related to the development and maintenance of real-time

GNSS services. The contributing national GNSS networks—mostly covering Central and Eastern Europe—are providing correction data for real-time positioning and navigation, and observation data for geodetic post-processing, fulfilling all positioning requirements. EUPOS acts to determine real-time positioning standards so as to harmonize the national positioning services to support seamless cross-border applications. EUPOS also acts on behalf of GNSS service providers in international bodies to represent their needs and proposals.

The most important task of EUPOS is to support the realization and maintenance of precise national positioning services based on dense national active GNSS networks. EUPOS members have defined common standards, and given those to the national positioning services for implementation. Those standards are necessary to maintain harmonized high-quality services and seamless cross-border applications. EUPOS promotes those standards in countries where the establishment of GNSS production networks is planned or is under way. Another important task of EUPOS is to represent its members in international bodies and to act for the common interests in those bodies.

The international steering committee of EUPOS is an ICG associate member. It is represented at ICG meetings and participates in the working groups on differential GNSS topics and regional reference systems. The most important decisions and issues discussed in ICG plenary meetings are reported and discussed in the main decision-making body of EUPOS, the international steering committee.

World Airsports Federation

The World Airsports Federation (FAI) was founded on 14 October 1905. Its principal aims are to "methodically catalogue the best aviation performances achieved, so that they be known to everybody; to identify their distinguishing features so as to permit comparisons to be made; and to verify evidence and thus ensure that record-holders have undisputed claims to their titles."

FAI is an international, non-governmental organization whose main aim is the development throughout the world of sport aviation and astronautical activities.

Just over 20 years ago, the FAI gliding section adopted a new concept for flight verification: secure GPS flight recorders. That concept has spread throughout much of FAI, with complete reliance on the availability, continuity, integrity and accuracy of GPS. The proliferation of other satellite navigation systems is looked upon favourably, as long as there is no reduction in the viability of GPS. ICG is the obvious international forum where more than one million FAI members worldwide can express their views on GNSS compatibility, interoperability and interchangeability.

International Federation of Surveyors

The International Federation of Surveyors is an international, non-governmental organization recognized by the United Nations whose purpose is to support international collaboration for the progress of surveying in all fields and applications.

The Federation was founded in 1878 in Paris as the Fédération Internationale des Géomètres. It represents more than 120 countries throughout the world. Its aim is to ensure that surveying and those who practise it meet the needs of the markets and communities that they serve.

The Federation's activities are governed by a workplan, which is approved by its general assembly and reviewed by its council as its tenure progresses. The current workplan, titled "Ensuring the rapid response to change, ensuring the surveyor of tomorrow", guides the activities of the Federation's council, commissions, networks and task forces, focuses surveyors' response to the challenges currently faced by humanity. The Federation recognizes that the science and technology of surveying, and the knowledge and practices of the surveying community pursue the common good. The present council of the Federation continues to build on past efforts and to work on extending the progress, achievements and global standing for the betterment of society, the environment and the world economy, and thus enhance the significance, role and relevance of the profession.

The Federation has been an associate member of ICG since its formation and has been represented at every ICG meeting. It has also held one of the co-chairs of the ICG working group on reference frames, timing and applications since it was established. The following are areas where the Federation sees value in participation in ICG:

- Keeping up-to-date with the latest GNSS developments through direct contact with system providers
- Explaining to system providers the requirements of the Federation's members concerning precise positioning applications, given the current state of GNSS, and discussing how those requirements may evolve with future system developments
- Encouraging system providers to publish system information that is important to users, such as templates describing geodetic and timing references
- Influencing certain aspects of system design, such as inclusion of retro-reflectors on future satellites
- Contributing to discussions about the role of ground infrastructure operated by various organizations, including not only system providers but also organizations aligned with the surveying industry in both the public and private sectors that provide GNSS augmentation services
- Networking with other associate members on GNSS issues of mutual interest
- Working with the United Nations Office for Outer Space Affairs on specialized workshops of interest to the Federation and the Office, such as the technical seminars on reference frame held in developing countries

International Association of Geodesy

The International Association of Geodesy (IAG) is the scientific organization responsible for geodesy. It has been a member association of the International Union of Geodesy and Geophysics since that organization's inception in 1919. In 1862, its predecessor, the Mitteleuropäische Gradmessung was established. The work of IAG is performed within a structure consisting of commissions, inter-commission committees, services, the IAG communication and outreach branch, and the Global Geodetic Observing System. The GNSS-related IAG service is the International GNSS Service (IGS), the reference-frame IAG service is the International Earth Rotation and Reference Systems Service, and the time-reference service is the time department of the International Bureau of Weights and Measures. Those services lend IAG its unique and highly valued expertise.

IAG is an associate member of ICG. IAG is co-chair of the ICG working group on reference frames, timing and applications and has been working with its sister organization, the International Federation of Surveyors, to promote the use of the single International Terrestrial Reference Frame for the precise alignment of individual GNSS data, and to document geodetic and time reference frames. In addition, IAG and IGS are the precise GNSS positioning experts responsible for the development of a range of GNSS techniques and data products and services to support high-precision GNSS users. In particular, IGS has operated a globally distributed network of several hundred GNSS ground tracking stations since 1994. Initially the International GPS Service (as IGS was then known) generated a series of GPS data products, principally raw tracking data, and computed satellite orbit and satellite clock error states. Over a decade ago that was expanded to include GLONASS tracking and products, and most recently (since 2012) IGS has been running its Multi-GNSS Experiment (M-GEX). In 2013, the real-time service commenced. IAG and IGS are cooperating with the ICG working group on compatibility and interoperability to define the scope and nature of international GNSS monitoring and assessment activity. It is envisaged that IAG/IGS would provide some components of a future international GNSS monitoring and assessment service.

ICG has considerable visibility within IAG; the IAG president attends many of the annual ICG meetings. The primary focus is the International Terrestrial Reference Frame and the contribution of IGS to multi-constellation GNSS performance monitoring.

Reference Frame Sub-Commission for Europe of the International Association of Geodesy

IAG created the Reference Frame Sub-Commission for Europe (EUREF) at the general assembly of the International Union of Geodesy and Geophysics held in Vancouver, Canada, in 1987. Since then, EUREF has been developing activities related to the establishment and maintenance of the European Terrestrial Reference System 1989 (ETRS89) and the European Vertical Reference System.

ETRS89 is ideally suited, and commonly used, as the backbone for modern mapping and Earth science applications in Europe. A key instrument in maintaining ETRS89 is the EUREF Permanent Network (EPN), which covers the European continent with numerous well-distributed sites. The stations that make up EPN observe continuously and with high accuracy GPS, GLONASS and, in the future, Galileo receivers. They operate under well-defined standards and guidelines that guarantee the efficiency of EPN and the long-term quality of its products. In addition, EPN constitutes the European contribution to, and densification of, IGS, and contributes to the realization of the International Terrestrial Reference System, to the monitoring of tectonic deformations in Europe, to long-term climate monitoring and to the development of the standards and the operational means needed to disseminate GNSS data over the Internet.

EUREF is an associated member of ICG. Its main focus is the ICG working groups on reference frames, timing, applications and the enhancement of the performance of GNSS services, so that satellite navigation services can be used to further develop ETRS89, and services can be established that provide information and data for precise positioning tasks with centimetre-level accuracy.

ICG is important for strategic considerations and planning of EUREF, since at the annual meetings fundamental decisions are taken for the further development and homogenization of the satellite navigation services.

Arab Institute of Navigation

The Arab Institute of Navigation is a non-governmental organization established in 1978 in Egypt. It is an active member of a number of national and international organizations.

The Arab Institute of Navigation organizes conferences and seminars featuring the best academic research in navigation. It publishes a semi-annual scientific journal focusing on the developments in navigation and its related technologies.

European Space Policy Institute

The European Space Policy Institute provides decision makers with an informed view on mid- to long-term issues relevant to Europe's space activities. In that context, ESPI acts as an independent platform for developing positions and strategies.

ESPI was established following a decision by the council of the European Space Agency. Based in Vienna, it is structured as an association under Austrian law. It incorporates a number of member institutions drawn from European agencies, operators and companies.

ESPI recognizes that, as of today, ICG is the most relevant platform for an open exchange of views on compatibility, interoperability, integrity, and interference detection and mitigation, which are paramount factors for ensuring a smooth development for the global governance to come.

Attendance at the ICG meetings is also an opportunity to get exposed to some pending issues and gain a better sense of the general problems facing GNSS providers. Thus, ESPI is better able to produce and publish more relevant and reliable information on the future governance of GNSS.

Finally, the information gained through ICG is also of interest for the continuous involvement of ESPI in terrestrial applications embedding space content.

International Association of Institutes of Navigation

IAIN is a non-governmental organization whose objective is to unite national and multinational institutes and organizations that aim to foster activities at sea, in the air, in space and on land, and that may benefit from the development of the science and practice of navigation and related information techniques.

The aims of IAIN are achieved by, among other things:

- Fostering cooperation and assistance between members
- Establishing technical committees or working groups to study specific problems, and producing appropriate recommendations and standards
- Organizing congresses and seminars relevant to its work
- Collecting and evaluating information about the activities of its members, as well as encouraging, supporting and making known recent developments on its website
- Providing assistance to organizations requesting help either technical or organizational, or in training
- Maintaining liaison with relevant intergovernmental and other organizations and offering specialized advice where appropriate

IAIN has observer status at ICG. An IAIN representative attends ICG meetings, contributes to different general navigational activities and addresses recent developments in its organization and upcoming IAIN events.

International Telecommunication Union

ITU allocates global radio spectrum and satellite orbits, develops the technical standards that ensure networks and technologies to interconnect seamlessly, and strives to improve access to information and communication technologies to underserved communities worldwide.

ITU protects and supports every person's fundamental right to communicate. Today, information and communication technologies underpin everything we do. They help manage and control emergency services, water supplies, power networks and food distribution chains. They support health care, education, government services, financial markets, transportation systems and environmental management. They also allow people to communicate with colleagues, friends and family anytime, and almost anywhere.

Following the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (known as UNISPACE III), held in 1999, ITU became one of the founders of the Action Team on GNSS and has observer status within it. Since 2005, ITU has been an observer to the ICG, regularly participating in ICG meetings and activities, in particular the working group on compatibility and interoperability. Useful information concerning the ITU radiocommunication sector and GNSS-related activities can be found on the ITU website, in particular information on:

- Working party 4C of the ITU radiocommunication sector on efficient orbit and spectrum utilization for the mobile satellite service and the radiodetermination satellite service conducts studies aimed at a more efficient use of the orbit and spectrum resources by mobile satellite service systems and radiodetermination satellite service systems. That includes analysing various interference situations between such systems and with systems operating as part of other radiocommunication services, developing coordination methodologies, describing the potential use of mobile satellite service systems and radiodetermination satellite service systems for specific purposes, such as in emergency situations, for maritime or aeronautical telecommunications, and for time distribution;
- Resolution 609 consultation meeting;
- The recommendations of the ITU radiocommunication sector related to RNSS, available at http://www.itu.int/rec/R-REC-M/en;
- The space network list: a list of basic information concerning planned or existing space stations, Earth stations and radio astronomy stations.

Interagency Operations Advisory Group

IOAG is comprised of national space agencies from around the world established to proactively address strategic issues related to inter-agency interoperability and other space communications and navigation matters. A key goal of IOAG is to achieve full international interoperability of systems and services to enable seamless space operations among its members. This is done through the development and implementation of technical standards and operating procedures that allow for cross-utilization of space agency assets and services. IOAG reports to its interoperability plenary, a senior-level body comprised of top leaders of space agencies. It works in a collaborative manner to seek consensus solutions.

As part of its strategic role overseeing the development of space agency standards for inter-agency mission operations, IOAG contributes as a recognized observer of the ICG and is focused on ensuring that all emerging GNSS constellations are fully interoperable for space operations and science missions. This is done through the continued refinement of a fully interoperable GNSS space service volume, which would enable all constellation services to have some level of performance guarantee up to geosynchronous altitudes.

To facilitate this work and related activities, IOAG has established a permanent link with ICG to assist the IOAG chair in documenting and updating inter-agency mission models in the space domain that will rely on GNSS services. The IOAG chair uses the permanent link for communication and coordination between IOAG member space agencies and ICG representatives.

Executive secretariat of the International Committee on Global Navigation Satellite Systems at the Office for Outer Space Affairs

The Office for Outer Space Affairs works to promote international cooperation in the peaceful uses and exploration of outer space, and in the utilization of space science and technology for sustainable economic and social development. The Office assists United Nations Member States in establishing legal and regulatory frameworks to govern space activities, and strengthens the capacity of developing countries to use space science, technology and applications for development by helping to integrate space capabilities into national development programmes.

Pursuant to the ICG workplan, the coordination of future programmes among current and future GNSS operators, including those operating augmentation systems, will enhance the utility of GNSS services and should result in a number of new international and national programmes that support a broad range of interdisciplinary and international activities. Such activities will need a strong outreach campaign on the benefits of the use of GNSS, particularly in developing nations.

The Office for Outer Space Affairs is organizing regional workshops, training courses and international meetings focusing on capacity-building in the use of GNSS-related technologies in various rapidly growing fields of science and industry. Those activities bring together a large number of experts every year, including experts from developing countries, to discuss and act on issues that are also of great relevance to ICG.

Information centres of the International Committee on Global Navigation Satellite Systems hosted by the regional centres for space science and technology education, affiliated to the United Nations

The ICG information centres are hosted by the regional centres for space science and technology education, affiliated to the United Nations. The regional centres are located in India and China 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 West Asia.

The objective of the ICG information centres is to enhance the capabilities of member States in the use of GNSS and related applications at the regional and international levels, so as to advance their scientific, economic and social development. The ICG information centres are working towards the establishment of a network of institutions involved or interested in GNSS, as well as towards identifying new applications that could be developed in the regions in question on the basis of global navigation satellite systems and their services.

The centres closely coordinate their activities with the ICG executive secretariat and GNSS providers, which provide support for the development of GNSS services and applications in the regions.

Promoting the use of global navigation satellite system technologies as tools for scientific applications

Reference frames and timing

In recognition of a number of ongoing projects and initiatives to establish regional reference frame networks that meet the growing needs of industries, science programmes and the general public using positioning applications, such as the African Geodetic Reference Frame project, EUPOS, EUREF, the Asia-Pacific Reference Frame and the Geocentric Reference System for the Americas, cooperation between GNSS providers and the regional reference frames has been established. This cooperation should enhance applications in fields such as geodesy, mapping, surveying, geoinformation, natural hazard mitigation, and Earth sciences. Facilitated through the regional centres for space science and technology education, affiliated to the United Nations, this cooperation would also be a major springboard for the transfer and enhancement of skills and knowledge in GNSS and its applications.

Space weather

At its forty-first session, in 2004, the Scientific and Technical Subcommittee agreed that, as society became increasingly dependent on space-based systems, it was vital to understand how space weather, caused by solar variability, could affect, among other things, space systems and human space flight, electric power transmission, high-frequency radio communications, GNSS signals and long-range radar.

Since 2004, worldwide ground-based instrument arrays for exploring atmospheric phenomena related to space weather and climate change have been established. Within the framework of the ICG workplan, GNSS applications in low-cost worldwide ground-based instrument arrays have been considered in the ICG working group information dissemination and capacity-building.

Long-term fellowship programme on global navigation satellite systems and related applications

The Office for Outer Space Affairs and the Government of Italy, through the Politecnico di Torino (Turin, Italy) and the Istituto Superiore Mario Boella (Turin, Italy), and with the collaboration of the Istituto Nazionale di Ricerca Metrologica (Turin, Italy), have established a 12-month fellowship programme for postgraduate study on GNSS and related applications for specialists from developing countries. As a master's programme in navigation and related applications it provides extensive background knowledge in navigation/localization systems as well as a detailed analysis on navigation/localization integration and environmental monitoring applications.

Annual meetings of the International Committee on Global Navigation Satellite Systems

The leadership of the Office for Outer Space Affairs, in its capacity as the executive secretariat of ICG and its Providers' Forum, has contributed significantly to the organization of and planning for ICG and its Providers' Forum annual meetings. The Office also coordinates the informal meetings of ICG and the Providers' Forum in conjunction with sessions of the Committee on the Peaceful Uses of Outer Space and its subsidiary bodies. Further, in cooperation with the international GNSS community, the Office contributes to international and regional conferences to introduce the work of ICG.

Annex

Mission Statement of the International Committee on Global Navigation Satellite Systems

The International Committee on Global Navigation Satellite Systems (ICG), established in 2005 under the umbrella of the United Nations, promotes voluntary cooperation on matters of mutual interest related to civil satellite-based positioning, navigation, timing and value-added services. ICG contributes to the sustainable development of the world. Among the core missions of ICG are to encourage coordination among providers of global navigation satellite systems (GNSS), regional systems and augmentations in order to ensure greater compatibility, interoperability and transparency, and to promote the introduction and utilization of those services and their future enhancements, including in developing countries, through assistance, if necessary, with the integration into their infrastructures. ICG also serves to assist GNSS users with their development plans and applications by encouraging coordination and serving as a focal point for international information exchange.

Vision Statement of the International Committee on Global Navigation Satellite Systems

The International Committee on Global Navigation Satellite Systems strives to encourage and facilitate compatibility, interoperability and transparency between all the satellite navigation systems, to promote and protect the use of their open service applications and thereby to benefit the global community. Our vision is to ensure the best satellite-based positioning, navigation and timing for peaceful uses for everybody, anywhere, any time.

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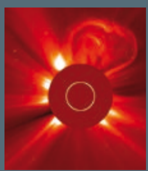
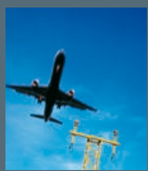
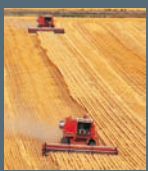
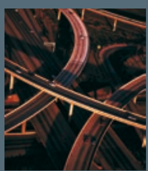
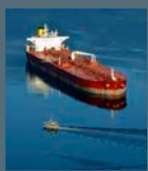

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