Chapter 2
Modernization of GNSS

With four Global Navigation Satellite Systems fully operational by the end of the decade, users on Earth can enjoy signals, at multiple frequencies in the L-band of the Electro-Magnetic (EM) spectrum, from 1.1 to 1.6 GHz, from over 110 satellites. There should then be, on average, about 30 satellites in view above a 10 degrees elevation, anywhere on Earth.

Christian Tiberius [1]

2.1 Introductory Remarks

Throughout history, position (location) determination has been one of the fundamental tasks undertaken by humans on a daily basis. Each day, one deals with positioning, be it going to work, the market, sports, church, mosque, temple, school or college, one has to start from a known location and move towards a known destination. Usually the start and end locations are known, since the surrounding physical features form a reference upon which we navigate ourselves. In the absence of these reference features, for instance in the desert or at sea, one then requires some tool that can provide knowledge of one's position.

To mountaineers, pilots, sailors, etc., knowledge of position is of great importance. The traditional way of locating one's position has been the use of maps or compasses to determine directions. In modern times, however, the entry into the game by Global Navigation Satellite Systems (GNSS) have revolutionized the art of positioning, see e.g., [2]. The use of GNSS satellites can be best illustrated by a case where someone is lost in the middle of the desert or ocean and is seeking to know his or her exact location (Fig. 2.1). In such a case, one requires a GNSS receiver to be able to locate one's own position. Assuming one has access to a hand-held GNSS receiver (Fig. 2.1), a mobile phone or a watch fitted with a GNSS receiver, one needs only to press a button and the position will be displayed in terms of geographical longitude and latitude (ϕ, λ). One then needs to locate these values on a given map or press a

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button to send his/her position as a short message service (sms) on a mobile phone as is the case for search and rescue missions. Other areas where GNSS find use are geodetic surveying (positioning) where accuracies are required to mm level, GIS (Geographical Information System) data capture, car, ship and aircraft navigation, geophysical surveying and recreational uses.

The increase in civilian use has led to the desire of autonomy by different nations who have in turn embarked on designing and developing their own systems. In this regard, the European nations are developing the Galileo system (discussed in Chap. 7), the Russians are modernizing their GLONASS system, while the Chinese are lalready having 21 out of the 30 BeiDou navigation satellite system (abbreviated as BDS) in space. All of these systems form GNSS with desirable positional capability suitable for environmental monitoring. GNSS are:

1. Global: This enables the monitoring of global environmental phenomena, e.g., global warming, sea level rise, etc.
2. All weather: This feature makes GNSS useful during cloudy and rainy periods, which are still stumbling blocks to radar systems and low Earth orbiting satellites.
3. Able to provide 24 h coverage: This enables both day and night observations and can thus enable the continuous monitoring of events such as the spread of oil from a maritime disaster.
4. Cheaper: Although the initial expense and maintenance of the satellites and ground support are very high, from the user's point of view, they are cheaper as compared to other terrestrial observation techniques such as photogrammetry or Very Long Baseline Interferometry (VLBI) [3]. GNSS are economical due to the fact that only a few operators are needed to operate the receivers and process data. Less time is therefore required to undertake a GNSS survey to obtain a solution.
5. Able to use a common global reference frame (e.g., WGS-84 Coordinate System for the GPS system).

2.2 GNSS Family and the Future

Besides GPS, GNSS comprise GLONASS (Russian), Galileo (European Union), and BeiDou (Chinese). GLONASS, first launched in 1982, has been in operation after attaining full operational capability in 1995. The full constellation of GLONASS was designed to have 24 satellites (21 satellites in 3 orbits plus 3 spares) orbiting at 25,000 km above the Earth's surface. By 2001, however, only 6 satellites were in orbit due to funding limitations that led to its near demise [1]. Currently, fewer than originally planned satellites are operating (i.e., 23 satellites as of January, 2017, with a total of 27 in orbit, see.[1]

[1] https://www.glonass-iac.ru/en/GLONASS/.

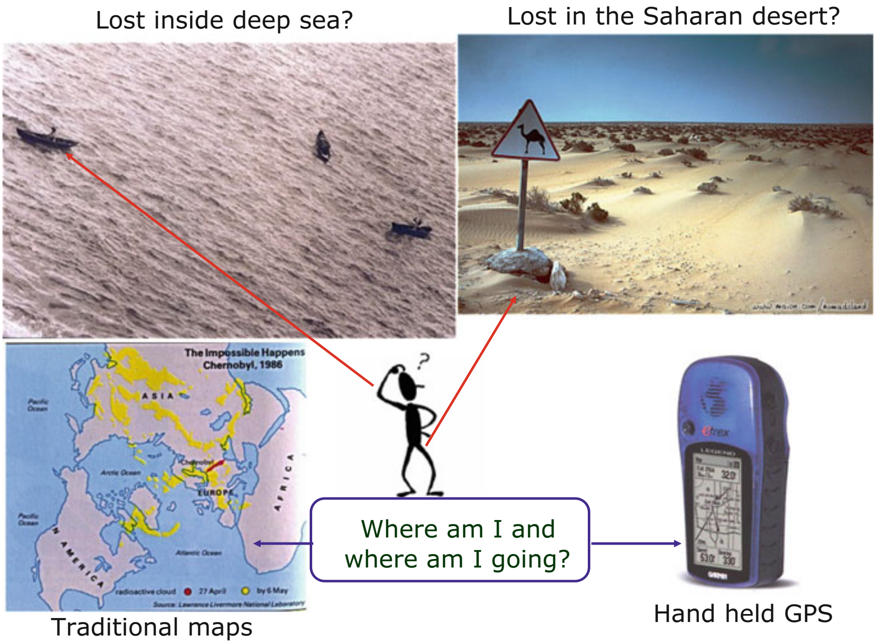

Fig. 2.1 Use of GNSS to position oneself. In case one is in deep sea or desert and wants to know his or her position, pressing a button on a hand-held GNSS receiver will provide the position

The Russian government has, however, embarked on a modernization program which will see the deployment of second generation GLONASS-M and the new third generation GLONASS-K satellites that will have improved features, e.g., reduced weight, more stable clocks, longer lifespan and improved navigation messages, and allow much simpler integration with other GNSS system such as GPS [1]. Table 2.1 provides a comparison between the GLONASS and GPS. On 25th of September 2008, the Space Forces successfully launched three GLONASS-M satellites (launched since 2003) into orbit from the Baykonur launch site in Kazakhstan bringing the number of GLONASS-M satellites to about 18. The launch of the GLONASS-K satellites with three civilian frequencies, which are supposed to have a longer lifetime than the GLONASS-M satellites (i.e., 10 years), and with added integrity components took place on 26th of February 2011, having been delayed from its planned date in December 2010 following the crash of the three GLONASS-M type satellites into the Pacific ocean. From 2025, Russia is planning the launch of GLONASS-KM satellites with comparable frequencies and formats as GPS's L5 and L1C signals, and corresponding to Galileo/BeiDou's E1, E5a and E5b signals (see Chaps. 3 and 7 for more details on the signal structure). GLONASS, like GPS, reserves more highly accurate signals for military use, while providing free standard signals for civilian use.

However, the satellites mentioned in Sect. 2.1 are not the only satellites within the GNSS system where new satellites are continuously being launched. Due to the

Table 2.1 Comparison between GPS and GLONASS as of January 2017

	GPS	GLONASS
Number of satellites	31	27
Number of orbital planes	6	3
Orbital radius	26,000 km	25,000 km
Orbital period	11 h 58 m	11 h 15 m
Geodetic datum	WGS84	SGS84
Time reference	UTC(USNO)	UTC(SU)
Selective availability	Yes	No
Antispoofing	Yes	Possible
Carrier	L1:1575.42 MHz	1602.56–1615.5 MHz
	L2:1227.60 MHz	246.43–1256.5 MHz
C/A code (L1)	1.023 MHz	0.511 MHz
P-code (L1,L2)	10.23 MHz	5.11 MHz

global nature of the GNSS satellites, ensuring sufficient number of a given satellite (e.g., GPS) in other parts of the world or for applications in specific areas (e.g., urban or forested areas) can be challenging. For this reason, other systems have been developed that include satellite based augmentation systems (SBAS) such as US's WAAS (Wide Area Augmentation System), European's EGNOS (European Geostationary Navigation Overlay Service), Japan's MTSAT Space-based Augmentation System (MSAS) and India's GPS-Aided GEO-Augmented Navigation (GAGAN) system.

Local augmentation systems include the Indian Regional Navigation Satellite System (IRNSS) consisting of seven satellites, with the first satellite launched on the 1st of July 2013. As of January 2017, four IRNSS satellites had been launched. IRNSS is an independent regional navigation satellite system being developed by India. It is designed to provide accurate position information service to users in India as well as the region extending up to 1500 km from its boundary, and is expected to provide Standard Positioning Service (SPS) to all the users and Restricted Service (RS) to the authorised users with a positioning accuracy of better than 20 m.[2] The Japanese Quasi-Zenith Satellite System (QZSS) is expected to consists of four satellites by 2018, with 3 satellites visible at all times from locations in Asia-Oceanic regions. The first satellite 'Michibiki' was launched on 11 September 2010, and QZSS is expected to reach full operational capability by 2018 with a total of 7 satellites envisioned by 2024 to improve on stability that will enable positioning in urban and mountainous regions, see.[3]

EGNOS, which is briefly discussed in Chap. 7 is a stand alone system that seeks to augment the existing GPS and GLONASS systems to improve satellite positioning accuracy within Europe. It has its own ground, space, and user segments with

[2] http://www.isro.gov.in/irnss-programme.

[3] http://qzss.go.jp/en/.

support facilities. The ground segment is made up of GNSS (GPS, GLONASS) Geostationary Earth Orbiting satellites-GEO, Ranging and Integrity Monitoring Stations (called RIMS) connected to a set of redundant control, and processing facilities called Mission Control Centre (MCC) that determine the *integrity*, *pseudorange differential corrections* for each monitored satellite, *ionospheric delays* and generates GEO satellite ephemeris [4]. This information is uplinked to the GEO satellites from the Navigation Land Earth Station (NLES). The GEO satellites then send the correction information to individual users (user segment) who use them to correct their positions. For discussions on other GNSS systems, such as DORIS, PRARE, etc., the reader is referred to [2, 5].

China launched the first BeiDou navigation satellite system (BDS) in 2007 and as per January 2017, 21 satellites were in orbit providing regional services for the Asia-Pacific region [1]. BDS constellation is expected to comprise more than 30 satellites orbiting at an altitude of about 21,150 km (i.e., 30 non-geostationary and 5 stationary), see e.g., [2, p. 402] for more details. It will provide positioning (accuracy of 10 m), navigation (velocity accuracy of 0.2 m/s) and timing services (accuracy of 10 nanoseconds) globally based on open and restricted services.[4] BeiDou has already been tested in areas such as communication and transportation, forest fire prevention, disaster forecast, public security and the Wenchuan earthquake, environmental areas where BeiDou will play an important role, see, e.g.[5] By 2020, BeiDou is expected to provide global coverage.

2.3 Benefits of the Expanding GNSS Family

With the receivers undergoing significant improvement to enhance their reliability and the quality of signals tracked, the world is already inundated with various kinds of receivers that are able to track several or all GNSS satellites. The monitoring and management of environmental aspects should therefore benefit enormously from these enhanced and improved GNSS satellites, where the possibilities of combining some of the main GNSS satellite systems is possible. For example, a receiver capable of trucking both GLONASS and GPS satellites such as Sokkia's GSR2700-ISX receiver has the possibility of receiving signals from a total constellation of more than 50 satellites. Similarly, the design of Galileo is being tailored towards an interoperability with other systems, thereby necessitating compatibility with GPS and GLONASS and potentially leading to a constellation of nearly 80 satellites. Adding the Chinese BeiDou puts the number to nearly 110 when all the system will be complete.

This combination of systems will further provide more visible satellites as illustrated by the proposed Australian CORS stations shown in Fig. 5.15, which could be useful in monitoring the future expected rise in sea level, submergence of land due

[4] http://en.beidou.gov.cn/introduction.html.

[5] http://en.beidou.gov.cn/introduction.html.

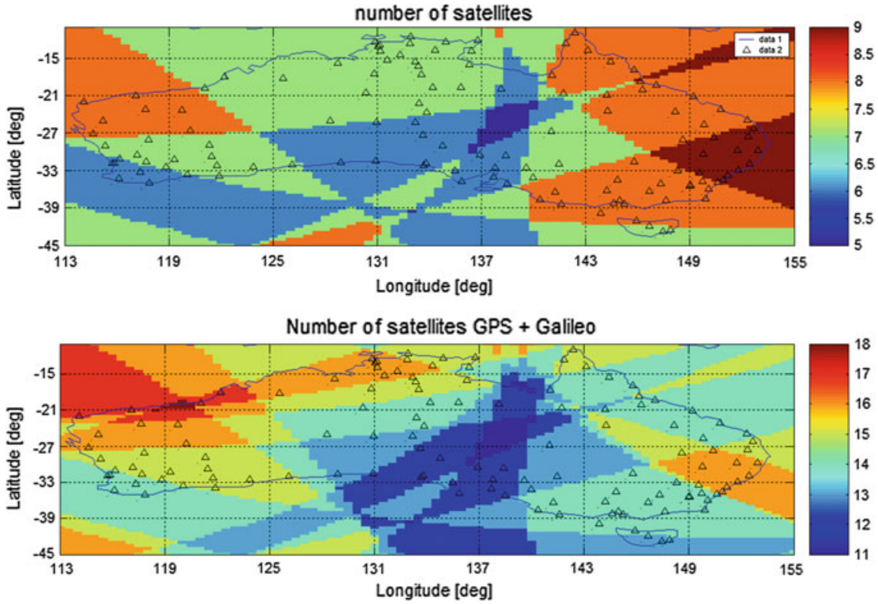

Fig. 2.2 *Top* Number of visible GPS satellites over Australia on 15.03.2007. *Bottom* Number of visible GPS+Galileo satellites over Australia on 15.03.2007. *Source* [6]

to groundwater abstraction and other environmental phenomenon. As an example, Fig. 2.2 presents the number of GPS satellites that were visible on the 15th of March 2007 compared to the situation that would have been if the Galileo system was fully operational on this day. As can be seen, the lowest number of satellites visible at any station on this day was 6. When Galileo satellites are included, the minimum number of visible satellites doubles to 12. Thus, anywhere on the Australian continent at the aforementioned "snapshot" of time, there could have been enough visible satellites for the proposed CORS network since the addition of GALILEO greatly improves satellite visibility. Table 2.2 presents the total number of visible Galileo and GPS satellites as reported by the definition phase of Galileo, see [4].

This increase in the number of visible satellites ensures a better geometry and improved resolution of unknown ambiguity, thereby increasing the positioning accuracies discussed in Sect. 5.3. The advantages of combining GNSS systems listed by the European Union (EU) and European Space Agency (ESA) [4] include:

- Availability: For example, a combination of Galileo, GLONASS and GPS will result in more than 60 operational satellites, resulting in the increased availability of the minimum required number of 4 satellites from 40% to more than 90% in normal urban environments worldwide.
- Position accuracy: Allied to an increased availability in restricted environments (urban) is a better geometry of spacecraft and enhanced positioning performance.

Table 2.2 Maximum number of visible satellites for various masking angles. *Source* [4]

Receiver elevation masking angle	Number of visible Galileo satellites	Number of visible GPS satellites	Total
5°	13	12	25
10°	11	10	21
15°	9	8	17

- Integrity: In addition to generating ranging signals, augmentation of GNSS with SBAS discussed in Sect. 5.4.4.2 will enhance the provision of integrity information.
- Redundancy: The combination of services from separate and fully independent systems will lead to redundant observations.

Increased satellite availability from 40% to more than 90% in urban environments would benefit environmental monitoring measurements undertaken in urban areas, where the effect of multipath and signal reflection from buildings and other features are rampant. Redundant observations will also be beneficial to environmental monitoring projects that may need continuous measurements (e.g., in animal telemetry).

GNSS systems can be combined with non-GNSS systems such as conventional surveying, Long Range Aid to Navigation (LORAN-C) and Inertial Navigation Systems (INS) to assist where GNSS systems fail, such as inside forests and tunnels. Other benefits that would be accrued through the combination of GNSS with conventional methods have been listed, e.g., by the EU and ESA [4] as offering improved signal strength, which provides better indoor penetration and resistance to jamming; offering a limited communication capability, and complementary positioning capability to users in satellite critical environments through mobile communication networks; and the provision of a means for transferring additional GNSS data through communication systems to enable enhanced positioning performances (e.g., accuracy) as well as better communication capabilities (e.g., higher data rates and bi-directional data links).

2.4 Concluding Remarks

With the continuing expansion of the GNSS systems, environmental monitoring tasks requiring space observations will benefit greatly. Some of the advantages arising from the increased number of satellites as opposed to the current regime include additional frequencies which will enable more accurate and better resolved modelling of ionospheric and atmospheric errors, and additional signals that will benefit wider range of environmental monitoring tasks. GNSS will offer much improved accuracy, integrity and efficiency performances for all kinds of user communities over the world. In the Chaps. 3–7, two of the GNSS systems (GPS and Galileo) are discussed in great detail, with the oldest, GPS, given more coverage.

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