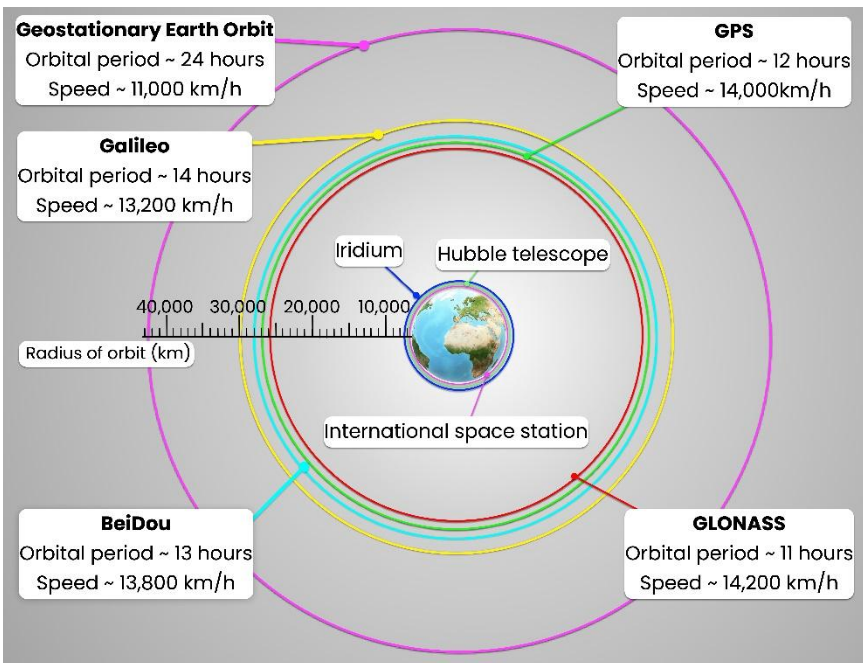
# GNSS derived positions

For our onboard Electronic Chart Systems (ECS) to locate our position, speed over the ground, and course over the ground they rely upon a number of Global Navigation Satellite Systems (GNSS). In this article we aim to explain how these work and give examples of how we, the humans, ensure we use them appropriately with sufficient safeguards in place, particularly with regards to over confidence in the precision of the information on our ECS screens.

## Satellite Overview

To date there are nearly 10,000 satellites in space, with this number changing regularly as new constellations are launched and others reach the end of their life. We use satellites for a huge number of applications, from communications, location services and safety systems as well as providing us with certain television channels.
In the maritime domain, alongside position fixing, satellites are used for long range communications, receiving distress messages from EPIRBs & PLBs and in more recent times long range internet connections.

The varying constellations are divided into three main categories according to their altitude:




**GEO (Geostationary Earth Orbit)**
As the name suggests, satellites in this area are stationary. Technically they are orbiting the earth but at a great altitude (around 36,000km) their orbital speed is the same as the earths. This results in them having the same footprint on the earth's surface. Geostationary satellites cover most of the earth's surface 24 hours a day, their permanent blind spots being the polar regions. These become useful for applications such as satellite television as it allows the users satellite dish to point in one fixed direction. We also use GEO Stationary Constellations to receive distress messages sent via EPIRBs and PLBs, and for GNSS Satellite Based Augmentation Systems (SBAS).

**MEO (Medium Earth Orbit)**
These constellations are at around 19-23,000km above the earth's surface and have an orbit time of around 12 hours, that means the satellites speed is around 14,000 km/h! It's at this altitude we find our GNSS Satellites. In recent years the COSPAS SARSAT system (the system that receives and delivers distress messages from EPIRBs and PLBs) is also transitioning to utilise more MEO satellites as once fully functional it will allow for fully global coverage and near real time beacon detection.

**LEO (Low Earth Orbit)**
These satellites are the closest to the earth's surface with an altitude of around 300-500km. The main uses of these satellites are for communication. At this altitude we also find the International Space Station. These constellations have the smallest footprint on the earth's surface at any one time.

## GNSS Satellites

The GNSS network of satellite's comprises of four main constellations. Historically we would be required to purchase a GNSS receiver that was suited to just one of these systems. Meaning that there was limited visibility of satellites. However, in recent years it has become common to have the ability to use multiple GNSS constellations to obtain a position. This increases the likelihood of having enough satellites in view to create an accurate position.

| System | Operated by | Altitude | Number of Satellites |
|---|---|---|---|
| GPS – (Global Positioning System) | USA | 20,200km | 24 |
| Glonass – (Globalnaya Navigazionnaya Sputnikovaya Sistema) | Russia | 19,310km | 24 |
| Galileo | European | 23,222km | 30 |
| BeiDou | China | 21,528km | 27 |

**How does it work?**

Each GNSS system uses its own constellation of satellites to transmit a signal that allows a GNSS receiver to calculate the distance from the satellite. This gives a large circle of possible locations of where we are on the earth. With more satellites we can increase this accuracy.

Let's explain. If we think of the satellite transmission as a sound transmission, then we can also think of the satellite as being a lighthouse with a sound signal (other than a lighthouse isn't moving but the satellites are). We could calculate a distance from a lighthouse if we knew the time it made the sound, and the time we heard the sound. Let's build this up working on the assumption that sound travels approximately one mile every five seconds.

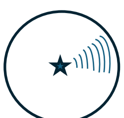


Fig.1

At 1200 a sound is made from the blue lighthouse (the star in Fig.1). We hear the sound 15 seconds later. This means we could be anywhere three miles away from the lighthouse. i.e. on the blue circle. In the maritime context we would say that the lighthouse has a range of three miles.

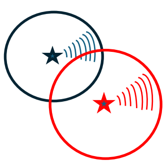


Fig.2

In Fig. 2 the red lighthouse also makes a sound, which takes 20 seconds to reach us. This gives us a range of four miles from the red lighthouse and is indicated by the red circle. The two points where the blue and red circles cross are our two possible locations.

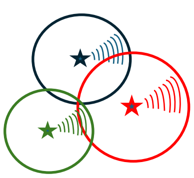


Fig.3

The green lighthouse in Fig. 3 makes a sound that takes 10 seconds to arrive, this puts you two miles away from the green lighthouse. Where all three circles cross is where we are. GNSS systems use this general principal, using transmissions around 1.6GHz in the electromagnetic spectrum, to identify circles of where we could be one the earth's surface and establishing our position by identifying the location with multiple circle intersections, albeit using much more complicated technology that our simple explanation.

We need at least four 'in view' satellites in clear view of your receiver to create a horizontal position, i.e. Latitude and Longitude. The more widely spread these satellites are, the more accurate the position fix will likely be. A calculated value we can find in most GNSS receivers is Horizontal Dilution of Precision (HDoP), which is an indication of accuracy based on the geometry of the satellites being used.

Fig.4 shows four satellites with good geometry leading to a relatively small area where all four circles intersect. This would give a low HDoP and therefore higher accuracy.

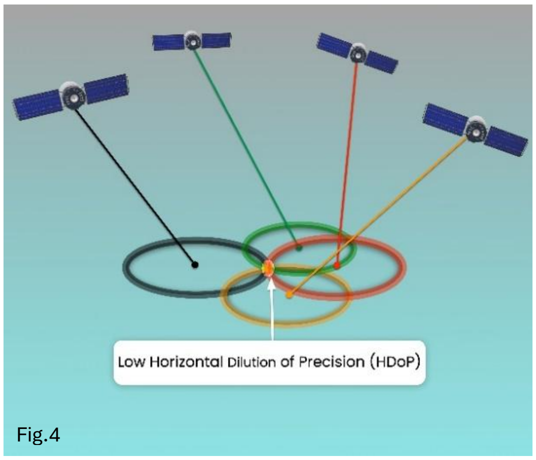



Fig.4

Fig.5 shows four satellites that are bunched together leading to a large area where all four circles intersect. This would give a high HDoP and therefore, a lower level of accuracy.

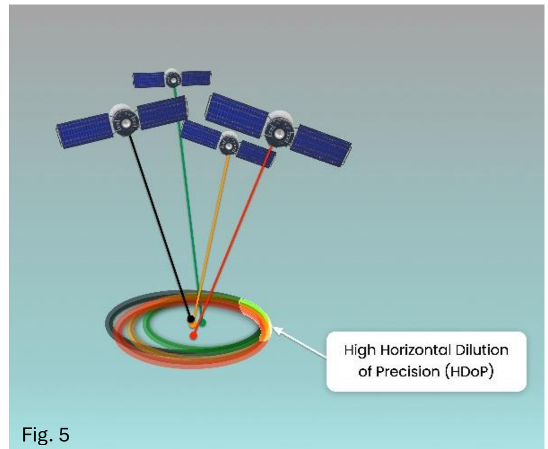



Fig. 5

With a HDoP number around 1, we can expect GNSS positions to be accurate to a few metres, numbers above 2 should increasingly prompt extra caution and increased use of non-GMDSS techniques to verify position.

HDoP is an inbuilt system-monitoring function based on the availability of satellites in clear view and the geometry of those satellites. A high HDoP value means increased risk of inaccurate positioning but doesn't automatically mean a low value guarantees good positioning. As with most systems there are vulnerabilities external to the system itself that can affect the accuracy of position or fail the system entirely.

Whilst at sea, the most common interference comes from atmospheric conditions which affect the speed and/or direction of the satellite signals on their way to GNSS receivers, leading to errors in position. See Fig.6

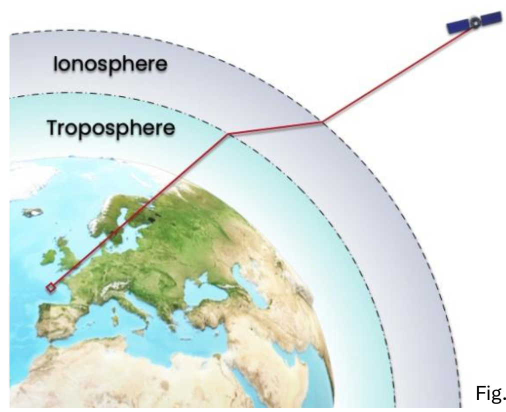



Fig.6

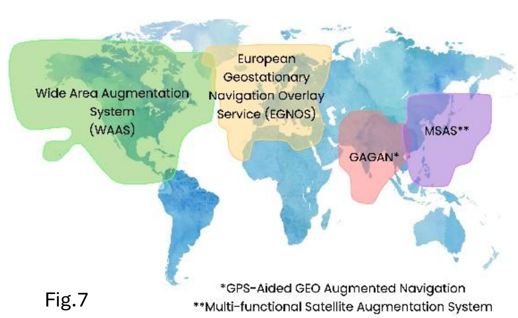



Fig.7

To combat this problem modern GNSS receivers can enable Satellite Based Augmentation Systems (SBAS). SBAS systems have dedicated ground stations which compare their GNSS position against their actual position to provide corrections to GNSS signals. These corrections are distributed via geostationary satellites covering the geographic area of the specific SBAS. There are four existing SBAS systems as detailed in Fig.7. It is worth noting that whilst SBAS systems continue to be developed they are a long way from being globally available.

A similar cause of error, but not quite as technical, is multi-path signals, as seen in Fig.8, where a signal reflects off objects on its way to a GNSS receiver's antenna, leading to the impression the satellite is further away than it actually is, and therefore an error is introduced. In the boating world these errors are likely to be in areas with high cliffs or in high-sided waterways. Luckily for us, these areas are typically where radar and non-satellite-based navigation is already a priority for the navigator. The multi-path error is also the reason we should mount our antennae low down and with a clear view of the sky rather than the top of a mast.

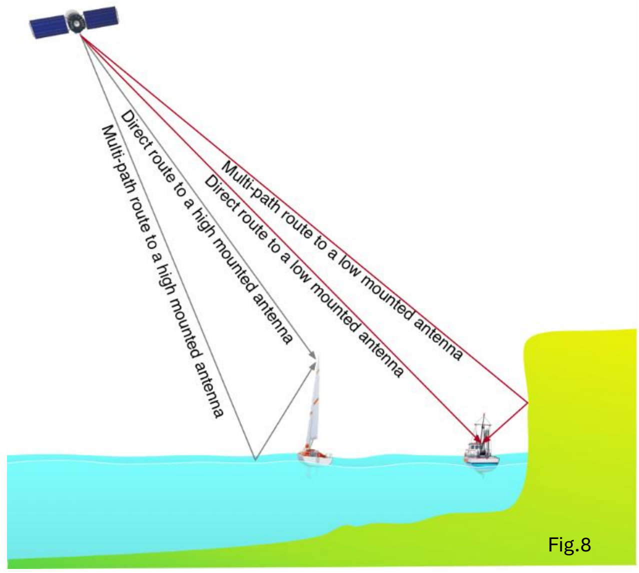


Fig.8

An extreme version of the atmospheric interference is the impact of solar flares or storms. These can change the behaviour of satellite signals such that a receiver will not be able to lock on to a sufficient number of satellites. In recent years warning of interruption has made mainstream news headlines. Unfortunately, SBAS cannot produce corrections for these types of events.

## Human interference

Unfortunately, there is deliberate disruption of GNSS signals for malicious purposes. GNSS signals are quite weak and therefore can be disrupted by stronger radio signals. Jamming and Spoofing are two forms of disruption that utilise devices in the proximity of the GNSS receiver.

- Jamming is where deliberate radio interference in a proximity prevents a GNSS receiver locking on to satellite signals leading to a poor, or no, position being available. Jamming is relatively easy to do on a small scale but is more difficult to do on a larger scale.

- Spoofing is a more sophisticated type of interference that fools the receiver into locking on to a false GNSS signal, meaning the GNSS receiver can present incorrect positions, SOG, and COG and course.

If the general principals of good navigation are followed, then you will identify when the GNSS position and information isn't making sense and will be able to continue using the secondary means of positioning you have identified in your passage plan.

## Mobile devices with in built GNSS positioning

It is estimated that 70% of the world's population own a smart device. In recent years it has become common to use smart devices for a large amount of daily life, including maps and traffic direction. The maritime sector has also embraced the smart device market with onboard Electronic Chart Systems being able to sync to smart devices to share vessel data or act as an independent monitor of the main ECS. There are also a huge number of navigation apps aimed at the leisure market. This article cannot compare and contrast them all, but we do want to address the GNSS status in smart devices.

The chip set in smart devices is usually designed to be very power efficient. Therefore, the system is often referred to as assisted GNSS as the device uses techniques to help find your position such as wi-fi connections, Bluetooth, Near Field Technology (NFC), phone cell towers and in some mapping apps camera augmentation. For example, identifying the profile of a mountain range in combination of the inbuilt compass heading to help refine the position. Many of these augmentations are not available when at sea, meaning that in many cases the position becomes less accurate, and power usage will increase for the receiver. Where a smart device can be linked to a power supply and gain inputs from external systems to provide a more robust GNSS receiver and other data then there is no real reason for it not to be used as part of a navigational approach. However, if it is entirely dependent on its own battery life, internal GNSS, and cell towers or an internet connection to be fully functional it risks being a single point of failure. It is for this reason the RYA does not recommend a smart device used in isolation as a primary part of safe navigation. A key part of safe navigation is to **not** rely upon one source of information. Whilst a smart device can offer a lot of information, particularly in the appraisal and planning phases taking place before a passage, we need to ensure that the information remains available and reliable throughout a passage at sea.

## The bigger picture

To be able to pin-point your position on the globe to within 50m with no effort would have been unbelievable for the famous navigators, such as Columbus or Magellan. Today, we have free access to multiple global satellite systems that provide positioning accuracy to within a few meters, requiring no training or understanding of how they work. However, to ensure safety at sea, it's crucial to have a better understanding of these systems to make informed decisions.

Whilst GNSS positions are remarkably good most of the time, there are, as described in this article, scenarios that give poor or no position and sufficient independent monitoring is the way that we mitigate for these relatively rare scenarios. We also need to remember that even if a GNSS position is accurate to within 20cm on their model of the world, it can still show at an incorrect position on your chart display. Why? Because there are errors that exist within chart surveys due to the age or type of survey used to create the chart. There are also changes to navigable channels due to erosion, silting or dredging that may not yet have made its way to the chart, digital or paper.

As navigators we need to do understand when an absolute position – such as a latitude and longitude calculated by a GNSS receiver against the World Geodetic System (WGS 84[1]), is sufficient with a light touch on monitoring, and when a relative position such as, I am 25metres from the isolated rocky outcrop becomes much more useful. The proximity of dangers will inform this and the provision of aids to navigation such as transits, buoyage systems and racons will prompt us to make good use of the aids to relative positioning rather than the position on a mathematical global model.

[1] WGS 84 is a model of the Earth that is used by the GPS system and most commercial GNSS receivers. Each GNSS system uses its own model against which their latitude and longitude positions are calculated.