

Procedural Guideline No. 6-1 Positioning using a differential Global Positioning System (GPS) in near-shore tidal waters

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Background

The aim of this document is to provide a set of generic guidelines appropriate for the non-specialist for site location (positioning) and relocation in near-shore tidal waters and lagoons using the Global Positioning System (GPS). All positioning aspects and options discussed relate to the waters surrounding the UK. However, the principles can generally be applied to all GPS systems throughout the world and are also suitable for land-based positioning.

Overview of the Global Positioning System (GPS)

GPS is a space-based positioning system whereby a position can be instantaneously determined anywhere on the surface of the earth by measuring range from a ground-based receiver to at least four satellites from a constellation of 24 which continuously orbit the earth. The system is operated by the US Department of Defense which monitors the satellites and uploads information defining their position and status. This information is then constantly broadcast via a coded signal towards the earth's surface. A ground-based receiver is able to track the satellites via these signals and so calculate ranges to all tracked satellites. In essence this is done by measuring the time of travel of the coded signal. The transmitted signal also provides current satellite orbit information, thereby enabling the ground-based receiver to calculate its current position.

- In general, the user can expect horizontal positional accuracies of around 10–15m (with 95% probability), using a single stand-alone receiver.
- Improved positional accuracies are available by expanding on the basic technique outlined above. This document discusses one of those techniques, differential GPS, which results in possible horizontal positional accuracies of up to 1 metre.
- Other techniques, of which there are many, e.g. RTK (Real Time Kinematic) or rapid static, are beyond the scope of these guidelines. Real Time Kinematic GPS is in the main used for precise surveying where accuracies at 10mm level are required. The technique involves the use of more advanced GPS equipment and local radio transceivers, i.e. user operated. From an operating point of view this technique is similar to user established dGPS systems as outlined later in this document. Commercial RTK correction services are not available at this time

Overview of differential GPS (dGPS)

The accuracy of the basic GPS positioning technique is limited by several factors. One significant factor is that the signals transmitted by the satellite are degraded as they pass through the atmosphere. A

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2 Prior to 1 May 2000 the US used SA to degrade the instantaneous positioning accuracies to 100m 95% of the time. On that date they switched SA off and so now all receivers will yield an instantaneous position of around 10–15m 95% of the time.

second factor is due to the uncertainties of the broadcast satellite position. Errors arising from these factors affect the ranges but can be considered equal between any two points at the same time and in the same locality. In the differential global positioning system technique the errors in the ranges are measured at a predetermined location (base station) in the locality. Corrections to the ranges are then broadcast for use by any local GPS receiver (rover station).

Accuracy achievable with dGPS is typically 1–5m (horizontal position) at the 95% confidence level. The actual accuracy achievable is dependent on factors such as:

- the frequency with which the range correction is received.
- the number of common satellites being tracked by the rover and the base station.
- the number of base stations providing the corrections (several of the commercial operators who provide dGPS corrections improve the quality of their corrections by averaging the corrections from several base stations).
- effects of Multipath; this is the error caused by GPS signals being reflected from local surfaces (sea, buildings, etc.) to give an incorrect, greater range.
- the distance between the base and rover GPS receivers; typically this would be within 500km.
- the dGPS corrections need to be received by any user in (near) real-time – typically within 1–10 seconds.

Several commercial companies broadcast dGPS corrections as a standard service. These corrections can be broadcast via either satellite or ground-based communications. The international standard for the digital format of the correction signal is RTCM SC-104 version 2.1 (Radio Technical Commission for Maritime Services Sub Committee 104).

The dGPS deliverables

The dGPS technique yields a series of point locations, described by co-ordinates, of the rover receiver antenna.

- The horizontal point position so determined will define the location of a site.
- A typical GPS receiver has built in functions allowing real-time navigation along a predetermined route via waypoints. These functions will aid the user to navigate a vessel to relocate a site.
- The basic dGPS technique provides co-ordinates in a worldwide co-ordinate reference system (WGS84) not typically used for near-shore mapping. These co-ordinates can usually be transformed within the receiver into any other co-ordinate reference system. It is essential that the co-ordinate output is compliant with the project requirements. See co-ordinate reference systems section.
- Many receivers have the facility to export the point locations for integration into software packages including attribute mapping devices (geographical information systems (GIS)) and other dedicated marine monitoring systems.

Equipment

Figure 1 shows the basic configuration of a dGPS system that comprises a base station, some form of range correction transmitting equipment and one or more roving GPS receivers. At present there are three main system configurations utilised for dGPS positioning, namely user-established, satellite-based and ground-based systems.

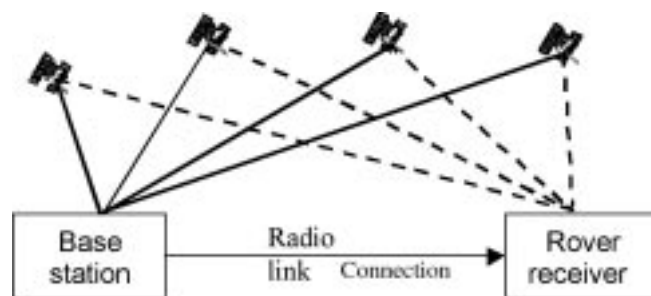


Figure 1 Basic components of a dGPS system

The basic equipment for a roving receiver comprises a GPS positioning receiver and antenna and a dGPS range correction receiver and antenna, power systems and appropriate cables. Other peripheral

devices such as a data logger may be required depending on project specifications. Current trends are for a combined solution with the GPS positioning receiver and dGPS correction receiver situated in the same physical case utilising a combined antenna. A typical terrestrial equipment configuration is shown in Figure 2.



Figure 2 Typical dGPS rover configuration³

Further product information specific to individual manufacturers can be obtained by visiting the websites provided at the end of this document.

User-established systems

The equipment required for the establishment of a base station is a GPS positioning receiver with antenna located at a known, fixed location, dGPS range correction computation software, a correction transmitter, power systems and appropriate cabling. Such equipment is available from all the major GPS receiver manufactures. The following should be taken into consideration with respect to such a system:

Advantages

- flexibility to establish base station at an optimal location for the proposed project
- no dGPS service subscription fees

Disadvantages

- a substantial increase in expense with the need for a second GPS receiver, processing software and corrections transmitter at the base station
- security and monitoring of base station equipment
- possible radio licence costs
- interference of radio signal used to transmit the dGPS corrections; current Department of Trade and Industry (DTI) radio frequency regulations provide very little bandwidth over which dGPS corrections can be transmitted: this may lead to conditions where the correction signal is overpowered by alternative signals and is rendered useless.

A preferable approach is the utilisation of a commercial dGPS service. Such services remove the requirement for the user to establish a base station. This has obvious advantages with respect to the simplicity of system configuration. Depending upon the nature and duration of the project it will be necessary to investigate the suitability of each of these solutions.

As previously stated, commercial dGPS service providers fall into two categories based on the method by which the dGPS correction is transmitted to the user.

Satellite-based systems

- Provide corrections to position with an accuracy of about 1 metre horizontal, due to the use of a network of base stations.
- Coverage available for 95% of the earth.

³ Copyright for this image resides with RACAL Landstar for which no permission has been obtained.

- Correction service is provided on a subscription basis additional to the purchase of rover receiver equipment.
- Correction service charges are often dependent upon duration and coverage required.
- Equipment can often be specific to the project terrain. For instance, a system may be designed for use on land, and at a certain distance out to sea software associated with the equipment will prevent its use. Therefore, an alternative system would be required for offshore work. This is primarily a service supplier's answer to preventing offshore oil and gas companies using the less expensive land systems. The range at which this cut-off occurs is subject to change by each manufacturer

Ground-based systems

- Provided in the UK by the General Lighthouse Authorities and Trinity House under the guise of the Marine Differential GPS Service (MDGPS)
- In general, positions based on these corrections are less accurate (approximately 5m horizontal) as the corrections are calculated and delivered to the rover receiver from a single user-selected radio beacon. Usually this will be the beacon providing the strongest reception.
- There is currently no subscription charged for these corrections, once rover receiver equipment has been purchased.
- The system is designed to maximise coastal and offshore coverage.
- Due to its intended use as a marine navigation aid this system has very limited use on land.

Figure 3 shows the distribution, range and frequency of dGPS stations around the UK and Ireland.

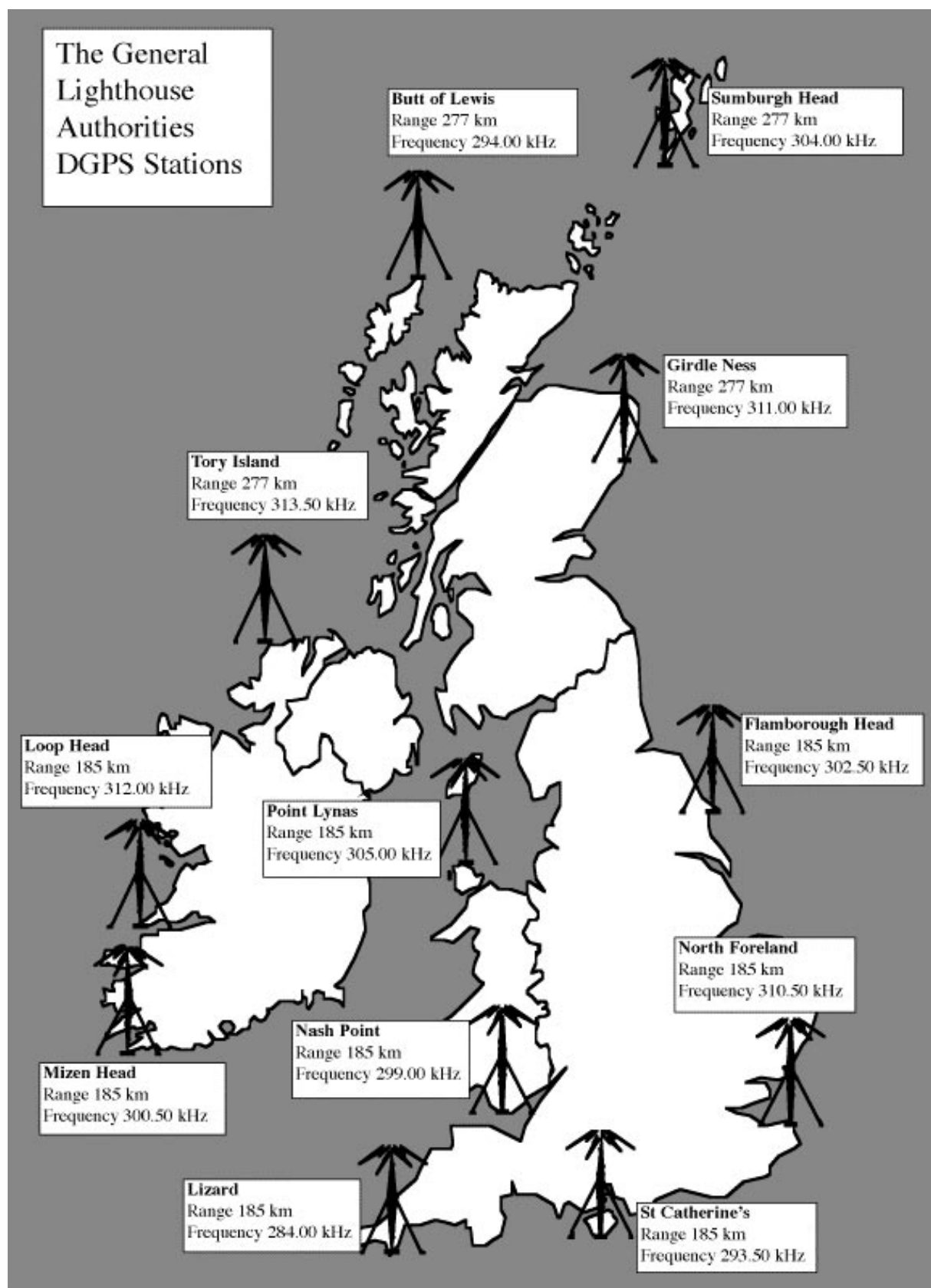


Figure 3 The location and frequency of dGPS beacons around the United Kingdom and Ireland⁴

The table below provides a summary of dGPS options.

⁴ Data on the status of these beacons may be found at <http://www.effective-solutions.co.uk/beacons.html>

<i>Service provider</i>	<i>Type of link</i>	<i>Anticipated accuracy</i>	<i>Approximate cost of correction service</i>
MDGPS	Ground-based	≈3–5m	Equipment ≈ £600–£2000
User system	Ground-based	<3m	Equipment ≈ £5000
Satellite system	Satellite-based (spot beam)	<1m	Equipment – integrated unit ≈ £3000 Correction only ≈£1200–£2500 UK correction service ≈ £800–£1000 pa

Equipment procurement – factors to consider

Assuming a need for dGPS positioning, the specific choice of equipment will be very much dependent upon: (a) the required accuracies for site location/relocation; (b) the location of the project; and (c) the costs involved. For example, a commercial dGPS correction service might not be available in the project area and therefore it may be necessary to implement a user-established dGPS system.

Prior to the procurement of equipment the following additional factors should also be considered:

- Existing equipment availability. It may be possible to upgrade an existing GPS receiver with the addition of a compatible dGPS correction receiver.
- Purchase versus hire of equipment.
- Location and duration of project *vis-à-vis* the costs of using a commercial satellite-based correction service and the service availability within a specific project area. (Areal coverage with respect to commercial dGPS correction availability varies between the different service providers.)
- Financial budget.
- Specific equipment requirements as regards actual dGPS deliverables and extra functionality, e.g. navigation, data collection, site relocation, etc.
- Methods of mounting the equipment on a vessel. Receivers designed for recreational use, e.g. hiking, are not usually ideal for secure mounting on a vessel.
- Backup equipment. When it is vital that data is obtained at a specific time then reliance on a single dGPS system is not ideal. In such situations a multi-system approach is appropriate, whereby a second and ideally independent dGPS system is employed. This provides both a means of monitoring individual system integrity and automatic system swapping should a failure occur in one system. The degree of equipment backup required will vary with specific project requirements. However, it is recommended that wherever possible all equipment should be duplicated.
- Final co-ordinate reference system requirements. The default co-ordinate reference system for all GPS positioning is WGS84 (World Co-ordinate System 1984), see co-ordinate reference system section. This may not be consistent with the project co-ordinate reference system.
- Operator training requirements. Whilst GPS and dGPS positioning is in the main a *black box* technique, users may require specific training in a particular manufacturers equipment, e.g. setting datum and setting co-ordinates.

Technical information of a typical receiver

GPS equipment specifications contain a variety of technical information that is also applicable to dGPS receivers, and the user should be aware of some of the terminology. See also the Glossary of terms (Appendix A).

- Number of receiver channels – this determines the number of satellites that can be tracked at any one time: typically 6 in a lower specification system and 12 in higher order models.
- GPS measurements and frequencies – the coded GPS signal is broadcast on two carrier frequencies called L1 and L2. The L1 frequency carries a modulated code known as the C/A (coarse acquisition) code. Both L1 and L2 frequencies also contain a precise (P) code. In its most basic form a GPS receiver will track only the L1 carrier frequency and use the C/A code to calculate ranges. Advanced GPS receivers are capable of tracking both L1 and L2 and through this gain access to the precise codes, thus improving accuracy by an ability to correct for atmospheric errors.
- Position recording rate (max. per second) – typically this is selectable and might vary from 0.2–60 seconds.

- Latency – particularly important in relation to dGPS, the latency of a system describes the lapsed time since the last dGPS correction was received.

Personnel

Prior to project commencement a number of personnel will be required to rig and test all dGPS equipment on the monitoring vessel. However, once installed, under normal modes of operation only one person is required to operate each GPS receiver. Specifically, it is necessary to monitor only the GPS output (see QC section) values and communication links to other data capture devices and software.

Method

All GPS manufacturers' equipment has variations in set-up functions and user interface. It is therefore essential that the user ensures that the manual for each piece of equipment within the specific system has been read and understood. For example, failure to correctly enable the dGPS correction facility on the rover receiver will result in positioning being performed only at the basic 15m level (horizontal position).

Installation of equipment

Antenna location

The location of the rover receiver antenna on board the monitoring vessel is important. Depending on the nature of the project and required accuracies the following should be taken into consideration:

- Clear view of the sky – the antenna should be located such that it is free from obstructions for 360 degrees above the horizontal plane of the antenna (for example, on top of vessel's mast).
- Interference from other communication sources and electrical fields – GPS and dGPS correction signals are typically weak in comparison to other licensed communication signals, e.g. shipping radio transmissions. It may be necessary to locate the antenna away from other antenna arrays.
- The human/animal interference – this should be minimised. For example, it may be necessary to employ a specialist cover to prevent seabirds sitting on antennae.
- Offset from other measurement devices, e.g. echo-sounding transponder – it should be noted that the movement of the vessel in terms of heading, pitch and roll will have an effect on the position of the GPS antenna with respect to other measurement devices. For example, with an antenna situated 10m up a mast 5 degrees of pitch will introduce ~0.9m of offset.
- Antenna mount – this should be sufficiently robust for the project conditions and the antenna must not move independently of the vessel to which it is attached.

Power supply

GPS receivers from separate manufacturers have differing power requirements. It is therefore essential that attention is paid to the specific requirements of the equipment used. In particular the following key issues should be addressed:

- Most GPS receivers and correction receivers operate on a 12v supply using specialist batteries. The user should check whether alternative voltages are available.
- If it is not possible to replace batteries without powering down the system and the receiver is not operating on an external power supply, e.g. mains adapter, then the user should ensure that recharging facilities are available if project duration is likely to exceed 80% of the stated battery life.
- It may take some time to get a fix after power loss.

Cabling

Depending on configuration individual dGPS systems can require many cables. Moreover the loss of any one cable will generally render the whole system inoperable. Inadequately maintained cables can often be a cause of system failure – avoidable, yet difficult to detect. Implementation of the following recommendations significantly reduces system failure due to cabling problems.

- Ensure each cable is correctly and clearly identified.
- Ensure the complete system is verified before any antennae are fixed in normal operating locations.
- Ensure sufficient coaxial cable is available for proposed antenna location. Maximum antenna cable lengths are dependent upon the thickness of cable and the quality of the end connectors. Thick cable (RG214) has a maximum length of 60m, whilst thin cable (RG58) has a length of 10m. In general antenna cable should not have more than 17db signal loss.
- Ensure cable runs follow paths that are away from areas where personnel or equipment regularly move.

Storage/transportation

All GPS and dGPS equipment designed for use in the field is generally enclosed in rugged waterproof casings. However, the complex electronics housed inside are both sensitive and very expensive to replace and the equipment should be treated with due respect at all times.

When in use, all equipment should be secured and the user should ensure that any mounts used are sufficiently robust for the project conditions.

Ensure that equipment is stored in carrying cases when not being used.

Ensure all cables are carefully stored to prevent damage.

System settings

Once the equipment is correctly installed and prior to the commencement of the project it is necessary to verify that all system components are operating correctly. Specifically **the user must check that all hardware and software parameters have been correctly selected**. The following are identified as the minimum parameters that must be set.

Hardware settings

- Ensure that communication parameters of the rover receiver and the dGPS correction receiver are compatible. Parameters such as baud rate (speed of communication) will be quoted in the manufacturer's manual.
- Ensure that communication parameters of the rover receiver and any other device receiving the output are also compatible.
- Ensure that the correct antenna type is selected. The use of the incorrect antenna type will introduce a bias in the determined position of the rover receiver.

Software settings

- Set the co-ordinate reference system for the position output appropriate for the project. See section on co-ordinate reference systems.
- Ensure rover receiver is set to accept dGPS corrections.
- Set the frequency of position determination – the update rate at which a position is calculated. An appropriate value is 1 second.
- Set the PDOP threshold (Positional Dilution of Precision, a QC measure of the suitability of the current satellite geometry – see QA/QC section). Above the PDOP threshold positions are not calculated. An appropriate value is 5.
- Set elevation mask – a QA measure to improve PDOP value by filtering out signals from low elevation satellites. An appropriate value to set is 15 degrees above the horizon.
- Set the minimum number of satellites to be tracked. The minimum requirement is 4.

QA/QC

For the majority of marine monitoring projects dGPS has now become a cost-effective method of position fixing. However, as with all measurement processes perfect measurements are not possible. No matter how sophisticated the associated technology, errors will still remain in the measured ranges and will have an effect on computed positions. The detailed aspects of how these errors can be quantified and assessed is beyond the scope of this report [3]. However, there are various simple functions available to the user, during dGPS operation, that can be monitored to ensure system integrity.

- DOP (Dilution of Precision) - DOP is a measure of the suitability of the geometry of satellites.

Expressed as a number from 1 to infinity the DOP value represents the geometric contribution to the error in the position fix. A value of 5 and below generally regarded as acceptable. In particular, the PDOP (Positional Dilution of Precision) value is generally used as an indicator of good observing satellite geometry. GPS and dGPS positioning should not be undertaken during periods of high PDOP, i.e. >5. If PDOP rises above 5 the user should consider suspending operations until observing conditions improve, i.e. PDOP value <5. In practice this will entail the user either waiting until the GPS satellite geometry changes or moving the vessel to facilitate such a geometry change.

- Number of satellites to be tracked – both the base and rover receivers need to be tracking at least 4 satellites to maintain accuracy. More importantly for dGPS positioning the base and rover receiver must track, as a minimum, 4 common satellites. If this is not achieved then Positioning in the dGPS mode cannot be performed. This can usually be monitored via an output on the rover receiver. However, with the GPS constellation now complete this should not be a problem for receiver with a clear view of the sky.
- Reception of differential corrections – the loss of dGPS corrections for periods of greater than 10 seconds will lead to degradation in accuracy of position fix. The longer the period without the correction signal the greater the degradation of accuracy. See also technical information section – *latency*.

Accuracy testing

Any position derived from a GPS receiver should only be accepted if it has satisfied the QC factors stated above. Whilst in operation these QC functions provide the only measure of accuracy and it is important that they are monitored. Positions that do not satisfy all of the criteria should be rejected. This can be achieved either automatically or manually depending upon the GPS receiver specification. In order to ensure that QC factors are being met a number of simple accuracy tests can be performed before project commencement. These include:

- Set up the rover receiver according to manufacturer's guidelines and leave the rover antenna stationary for a long period of time (e.g. 1 hour) and monitor the output positions. The average position should not exceed manufacturer's stated system accuracy for 95% of the measured positions. This test should be performed in good operating conditions, i.e. clear view of sky and low multipath. The user should be aware that a hostile environment is likely to reduce system performance.
- Set up the rover receiver according to manufacturer's guidelines and locate the rover antenna over a known co-ordinated point (e.g. Ordnance Survey control point or clearly identifiable point from a local plan). Compare the output positions with the known co-ordinate values. Great care should be taken to **ensure that the co-ordinates of the known point and the dGPS output are in the same co-ordinate reference system** – see co-ordinate reference systems section.
- If a multi-system approach is being used, i.e. two or more independent dGPS systems, then a simple comparison of individual receiver co-ordinate outputs can provide a useful QC test. If this approach is adopted then consideration should be given to the **receiver output co-ordinate reference systems and antenna offsets for each GPS receiver**.

Co-ordinate reference systems

The standard output from a GPS receiver is a single co-ordinated position in the WGS84 (World Geodetic System 1984) co-ordinate reference system. However, many maps and charts used in the monitoring of marine environments are not referred to this system. It is therefore vitally important that all potential users of GPS and dGPS understand the basic concepts and options concerned with transforming GPS positional output into alternative co-ordinate reference systems (Figure 4). In particular:

- The WGS84 co-ordinate datum has been established for common positioning throughout the world.

5 It is not possible to put a general figure on the decrease in accuracy caused by high PDOP as it is totally dependent on the satellite geometry as observed above the user's local horizon. Obviously this will vary from place to place.

- Position output will often be required to comply with the project base mapping, e.g. Admiralty datum (OSGB36 geodetic).
- The principal co-ordinate system in the UK is based on the Ordnance Survey's National Grid, which is a realisation of the Ordnance Survey Great Britain 1936 datum (OSGB36). All points in the UK and within near-shore waters can be expressed in either geodetic co-ordinates (latitude and longitude) or plan co-ordinates (easting and northing).
- There are a number of different transformation methods, e.g. Helmert, available for transforming WGS84 co-ordinates to OSGB36 or another datum. The user should be aware that each method will, in general, yield slightly different values for the same WGS84 position and the specific choice of transformation is important.
- GPS and dGPS receivers can usually be set to output in a local co-ordinate system, e.g. OSGB36. However, the coordinates output are in the main based on a generalised set of transformation parameters and may not always be appropriate. The user should therefore ensure that the transformed positions are to the required accuracy.

Note. There are slight variations to WGS84 that may be referred to in technical documentation, e.g. ETRF89. For this type of project such variations can be regarded as WGS84.

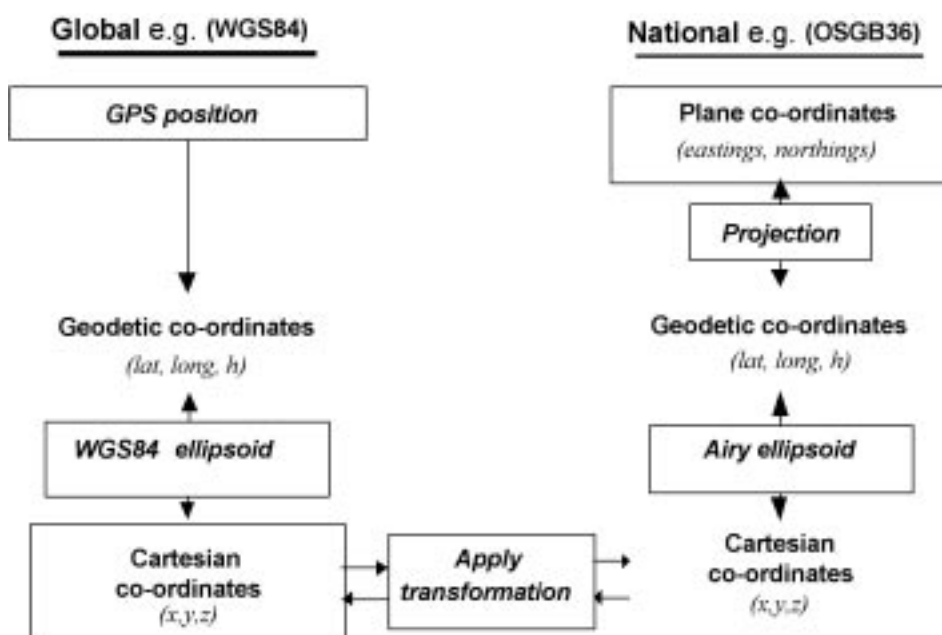


Figure 4 The interrelationship between the WGS84 and OSGB36 co-ordinate reference systems

Data output formats

In the vast majority of marine monitoring projects site location and relocation, whilst fundamental to the task in hand, are not the fundamental objective. The position output from dGPS often forms one of the inputs to another system, e.g. GIS, echo-sounder, etc. It is therefore essential that users understand how data strings can be extracted from a GPS receiver and fed into other scientific applications.

NMEA

The NMEA data format comprises a series of structured messages containing information from the GPS receiver. These messages can be used as an alternative method of interacting with a GPS receiver. The majority of GPS and dGPS receivers use the NMEA format as a communication format allowing interface with other non-proprietary software and data logging devices. The current NMEA standard for interfacing with marine electronic devices is NMEA 0183. The reader may find the following NMEA messages useful:

- GLL
- GGA – GPS position (WGS84 geodetic), time and a measure of quality of that position

- GSA – QC information, such as number of satellites being tracked and PDOP

Export to GIS format

As mentioned above, dGPS positional information is often utilised within a third party software package such as a GIS. This might simply be for navigational purposes or it might comprise other attribute information attached to an information block that can be subsequently recorded and displayed in a GIS. The reader should be aware that export facilities, for GIS formats, are usually only available if the data is processed in proprietary software supplied with the GPS receiver, after the data has been captured. However, some GIS manufacturers now provide add-on modules that allow the direct input of GPS data from many sources. Such packages usually require NMEA output from the GPS receiver, e.g. MapInfo uses Geotracker™ for 'live' GPS input to base maps.

References

- Leick, A (1995) *GPS Satellite Surveying*, 2nd ed. Wiley, New York.
 DGPS http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
 UK Offshore Operators Association (Surveying and Positioning committee) (1994) *Guidelines for the use of Differential GPS in Offshore Surveying*, Issue Number 1.
 Ordnance Survey (1999) *A guide to co-ordinate systems in Great Britain*.
 National Marine Electronics Association (1998) *NMEA 0183 Interface Standard, version 2.30*.

Useful websites

Ashtech	www.ashtech.com
Commissioners of Irish Lights	www.cil.ie/
Fugro OmniSTAR	www.omnistar.nl
Leica	www.leica-geosystems.com
National Marine Electronics Association	www.nmea.org
Northern Lighthouses Board	www.nlb.org.uk/
Ordnance Survey	www.ordsvy.gov.uk/services/gps-co/geo6.htm
Racal LandStar	www.racal-landstar.com
Trinity House Lighthouse Service	www.trinityhouse.co.uk
Trimble	www.trimble.com

Glossary

dGPS	Global Positioning System used in differential mode
DOP	Dilution of Precision of computed position
PDOP	Positional Dilution of Precision
HDOP	Horizontal Dilution of Precision
VDOP	Vertical Dilution of Precision
Ephemeris	Message broadcast from GPS satellite giving the user information on the health and position of the satellite
Rover Station	Term used to describe the moving component of the dGPS system, e.g. the vessel
Base Station	Term used to describe a fixed station at which corrections to ranges are computed and then broadcast to the Rover Station
Multipath	This is caused by GPS signals being reflected from local surfaces (sea, buildings, etc.) onto the GPS receiver's antenna: this can cause errors in the computed range