Session Index

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SENSORS

Surface Positioning for DP Operations

Mark K. Buhrke, PLS

John E. Chance & Associates, Inc. (Houston)

INTRODUCTION

The Gulf of Mexico has experienced a rapid increase in deepwater oil and gas exploration and development in the past decade. Current Gulf of Mexico projects in water depths to 5300' and future projects to 7500' and deeper require more reliance on Dynamic Positioning for drilling vessels, construction barges and ROV/Survey ships. Over the same period, surface positioning technology has changed from land-based to satellite-based positioning systems.

Due to market demands and the implementation of the US Federal Radionavigation Plan several land-based radio positioning systems have been terminated and more consolidation is planned as GPS and GLONASS are fully implemented for land, airborne and marine navigation.

This paper reviews the current status and future plans for several radio positioning systems used in the Gulf of Mexico. A typical redundant DGPS system is discussed and operational requirements and single point failures are addressed.

ABBREVIATIONS AND ACRONYMS

C/A Code	Coarse/Acquisition Code
DGPS	Differential GPS
DOD	US Department of Defense
FAA	Federal Aviation Administration
GDOP	Geometric Dilution of Precision
GIS	Geographic Information System
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
Hz	Hertz (cycles per second)
ICAO	International Civil Aviation Organization
kHz	Kilohertz
L1	GPS Primary Frequency, 1575.42 MHz
L1	GLONASS Frequency, 1602 + 0.5625n MHz (n=0,1,2,...,24)
L2	GPS Secondary Frequency, 1227.6 MHz
L2	GLONASS Frequency, 1246 + 0.4375n MHz (n=0,1,2,...,24)
MHz	Megahertz
MOD	Russian Ministry of Defense
P-Code	Precise Code
PDOP	Position Dilution of Precision
PPS	Precise Positioning Service
PZ-90	formerly Soviet Geodetic System 1985/1990 (GLONASS Reference Spheroid)
QC	Quality Control
RF	Radio Frequency
RTCM	Radio Technical Commission for Maritime Services
SPS	Standard Positioning Service
TDOP	Time Dilution of Precision
UPS	Uninterruptable Power Supply
US	United States of America
USCG	United States Coast Guard
UTC	Universal Time Coordinated
VDOP	Velocity Dilution of Precision
WGS-84	World Geodetic System - 1984 (GPS Reference Spheroid)

LAND-BASED RADIO POSITIONING SYSTEMS

Syledis

Syledis is a privately operated ultra-high frequency (406 - 448 MHz) land-based radio positioning system. This medium range (up to 150 km) system typically uses three or more reference stations located on land or offshore structures to measure pseudo-ranges to a mobile unit. The location of the mobile antenna is calculated by a multi-lateration relative to the known positions of the reference stations. With good network geometry, five meter relative accuracy can be obtained at up to 100 km from the reference stations. This system was terminated in the Gulf of Mexico in 1994.

Omega

Omega is a very low frequency (9 - 14 kHz), land-based radio positioning system developed by the DOD and operated jointly by the United States, Argentina, Australia, France, Japan, Liberia and Norway. This system uses eight reference stations located around the world to provide continuous world-wide positioning with a repeatable accuracy of 2 - 4 nautical miles (nm). This system was primarily used for oceanic aircraft navigation and was terminated on 30 September 1997. [1]

Loran-C

Loran-C is a land-based, pulsed, hyperbolic low frequency (90 - 110 kHz) radio positioning system developed by the DOD. The USCG operates 29 reference stations divided between 12 chains covering most of the coastal waters of the US. The system provides absolute accuracy better than 0.25 nm and repeatable accuracy between 18 and 90 m dependent on the location of the mobile receiver within the coverage area. This system is widely used for airborne and marine navigation and is scheduled for termination in the US by 31 December 2000. [1,3]

SATELLITE-BASED RADIO POSITIONING SYSTEMS

Global Positioning System

The Global Positioning System (GPS) is a satellite-based radio positioning system developed by the DOD to provide world-wide 3-D position, velocity and time information for military and civilian users. GPS provides standard positioning service (SPS) for all users and precise positioning service (PPS) for military and other authorized users.

The DOD is committed to providing a minimum of 24 operational satellites, replaced using an expected failure strategy. There are currently 24 operational satellites and three orbiting spares. The satellites are deployed in six circular orbits at an inclination of 55°. This configuration allows for a minimum of five satellites in view at all times, assuming no local obstructions. Each satellite broadcasts three signals on two L-Band frequencies: L1 (1575.42 MHz) and L2 (1227.6 MHz). L1 carries a Precise (P) Code (PPS) and a Course/Acquisition (C/A) Code (SPS). L2 carries the P-Code only. Civilian users only have access to the L1 C/A Code, although some specialized GPS applications such as Real-Time Kinematic (RTK) make use of the L2 carrier signal. The satellites also broadcast ephemeris data, constellation almanac data, GPS to UTC time offset information and ionospheric propagation delay correction parameters. [1]

The satellites are tracked by a network of five monitoring stations located around the world which report to the master control station in Colorado Springs, Colorado. Three ground antennas are used to uplink commands and update satellite information. [1]

To navigate by GPS, a passive, portable receiver and antenna are used to gather pseudo-range data from each satellite. If four or more satellites are visible, the 3-D position of the antenna and the time can be calculated. The pseudo-range and ephemeris data are used to solve for the antenna position by mutli-lateration.

In order to protect US national security interests, the DOD has implemented Selective Availability (SA). SA is the intentional introduction of rapidly changing, random clock errors in the satellite data. This results in a reduction in accuracy to 100 m (95%) for C/A Code positioning versus 22 m for P-Code users. US GPS policy is to discontinue SA by the year 2006.

Differential GPS

The accuracy of GPS is effected by many factors. SA has the most noticeable impact, but the signal is also degraded by the atmosphere and even sun spot activity. Different parts of the atmosphere act to bend and distort the radio wave, thereby introducing error in the range measurements. For this reason, satellites below 10° above the horizon are typically not used for navigation due to the large atmosphere induced errors. All pseudo-ranges contain errors due to the atmosphere, SA and other factors.

For many tasks, GPS provides adequate accuracy. Applications such as offshore exploration and construction, aircraft navigation, vehicle tracking and GIS mapping require greater accuracy and repeatability. Differential GPS (DGPS) is an efficient means to improve real-time positioning accuracy.

Single-Site DGPS

When pseudo-ranges are observed over a known reference position, a range correction can be calculated by subtracting the “known” range to the satellite from the observed range. This correction can then be transmitted to a second receiver and applied in near real-time to observations at the remote site. To be effective, the range corrections must be transmitted as quickly and as reliably as possible. Due to SA, the rate of change of corrections can be faster than 1m/sec. At a rate of change of 1m/sec, corrections latent by 3 seconds would result in a 3m range error!

A typical single-site DGPS system is comprised of a survey-quality reference GPS receiver and radio transmitter setup on a “known” point and a mobile GPS receiver and radio receiver on the vessel. Using a survey-quality mobile GPS receiver, this system can deliver sub-meter accuracy in the vicinity of the reference site, but accuracy degrades proportionate to distance.

Single-site DGPS works well over short distances (up to 100 km) because pseudo-ranges are observed simultaneously by the reference and mobile receivers through the same portion of the atmosphere. As the mobile receiver moves away from the reference receiver, the transmission path of the satellite signal through the atmosphere changes and the differential corrections are no longer correlated to the remote location. The absolute accuracy typically degrades by 1 m of accuracy per 100 km of distance and fails at about 2000 km due to the lack of common satellites between the reference and mobile receivers. When using radio telemetry for delivery of differential corrections, the reliability of the radio signal also degrades with distance. Radio-based systems typically have a range of less than 200 km.

The USCG Differential GPS Navigation Service is an example of a publicly funded single-site DGPS system. The USCG maintains DGPS reference stations along the US coast primarily to aid the public in harbor and harbor approach navigation. Differential corrections are broadcast using marine radiobeacons (285 - 325 kHz) with a typical range of 150 nm and an average latency of 2 to 5 seconds. This system has a stated accuracy of 10 m over the entire region of operation. In the Gulf of Mexico, reference stations are maintained at Aransas Pass (TX), Galveston (TX), English Turn (LA), Mobile Point (AL), Egmont Key (FL) and Key West (FL). See Figure 1 for the approximate coverage area for the Gulf of Mexico. [2]

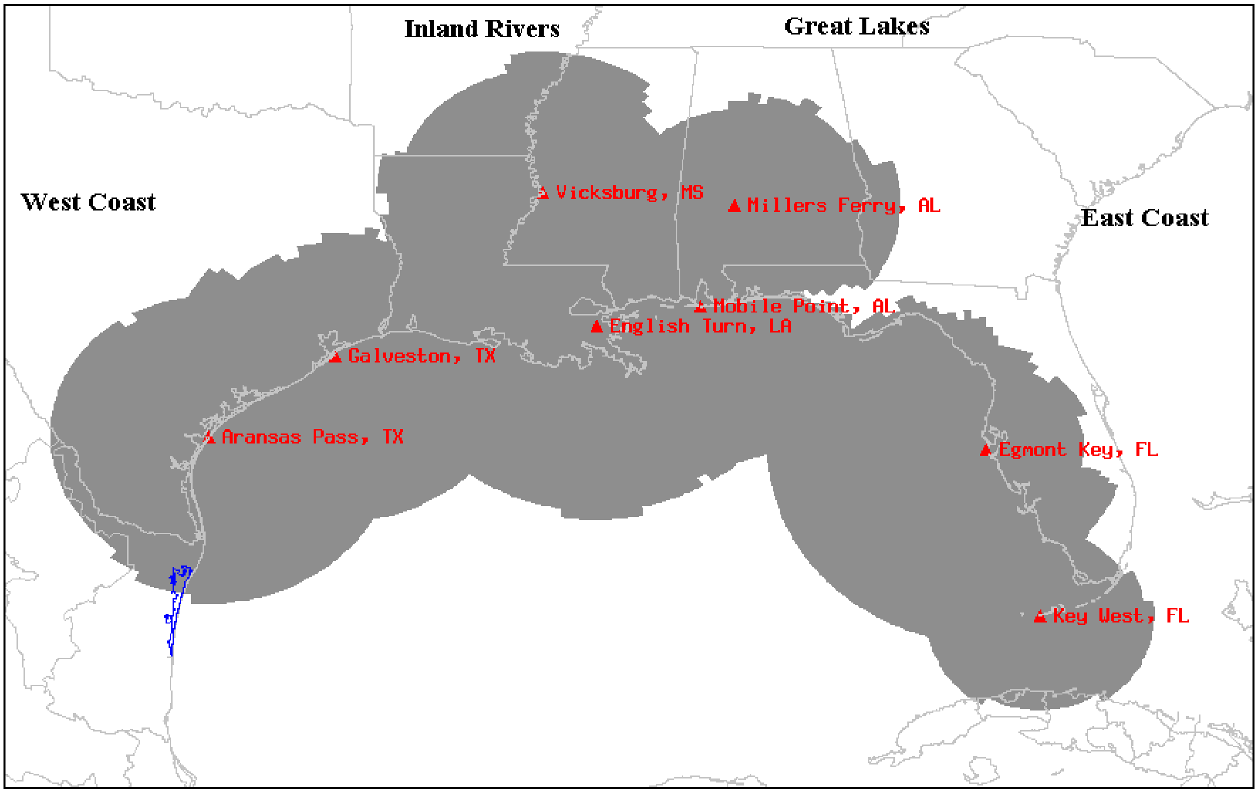

Figure 1 - USCG DGPS Service Coverage Area

Wide-Area DGPS

In order to increase the accuracy of GPS over a larger working area, a wide-area DGPS system must be utilized. A wide-area DGPS system is comprised of several survey-quality reference GPS receivers located throughout the region of operations. Each reference receiver observes pseudo-ranges and transmits the observations to the master control site via dedicated high speed telephone lines or computer network. At master control, range, range rate and atmospheric corrections are calculated for each observed satellite at each reference site. The corrections for each reference site are then transmitted to the mobile receiver via one or more communications satellites. At the mobile location, the range, range rate and atmospheric correction data and approximate user location are used to calculate a single set of differential corrections optimized for the user location.

Wide-area DGPS works over great distances because the effects of the atmosphere can be properly modeled and corrections applied. This system provides increased redundancy and reliability due to multiple reference stations and multiple delivery systems. The satellite communications system typically employed for wide-area DGPS systems deliver more data at a faster rate than radio-based systems so differential corrections are more timely and more accurate.

The Fugro Starfix® DGPS System is an example of a privately developed wide-area DGPS system. The Starfix® system is comprised of over 70 permanent reference stations located throughout the world. In the Gulf of Mexico, differential corrections are supplied via L-band and C-band satellite downlinks for reference stations including Mercedes (TX), Houston (TX), Pensacola (FL), Cocoa Beach (FL) and Ciudad del Carmen (Mexico). Fugro's MRDGPS (Multi-Reference DGPS) software is used to provide optimized differential corrections based on the user's location and for data QC monitoring. See Figure 2 for the approximate coverage area for Starfix® C-band.

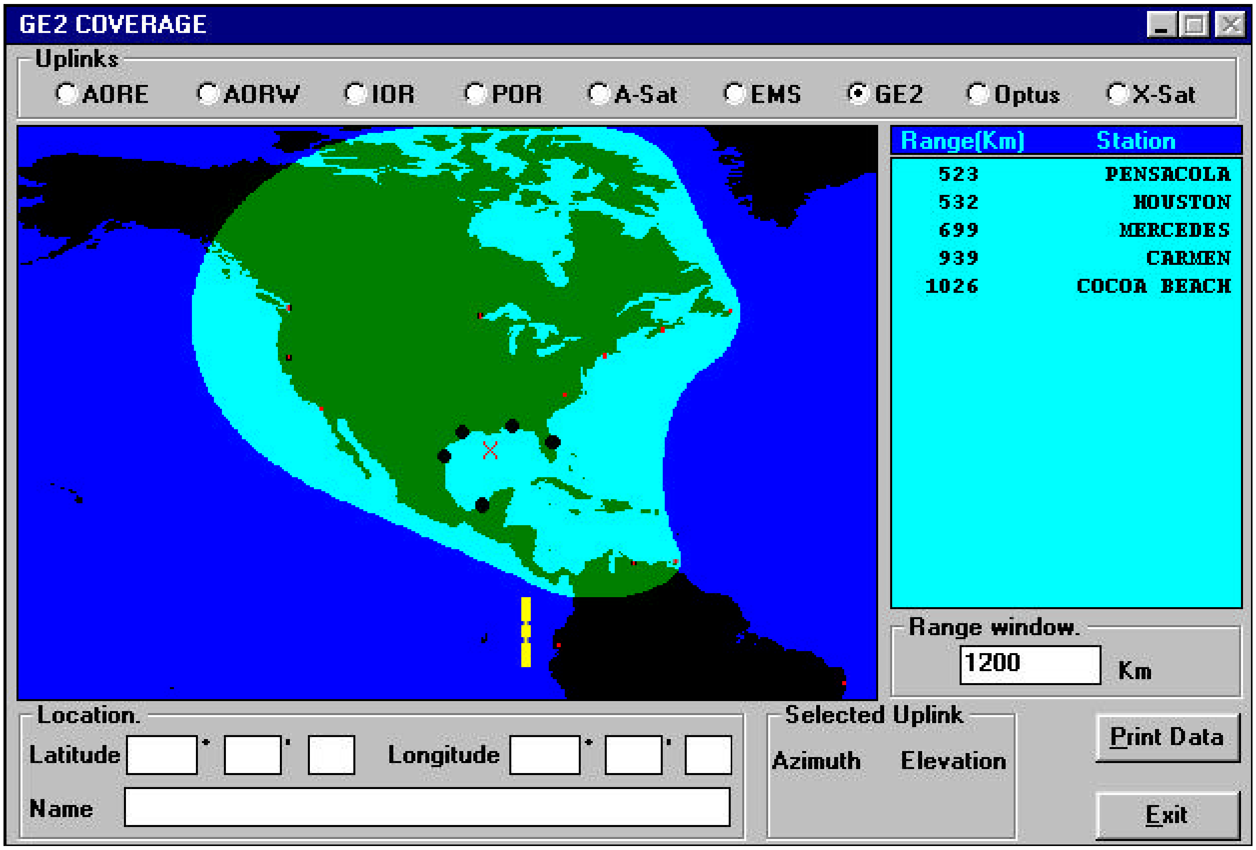

Figure 2 - Starfix® C-Band Coverage Area

Alternately or in conjunction with MRDGPS, Fugro's Starfix® Virtual Base Station (VBS) can be used to provide optimized RTCM corrections. The VBS firmware is incorporated directly into Starfix® receivers to provide a simplified source of optimized differential corrections.

DGPS Delivery Systems

All DGPS systems require the use of a communications system for differential corrections. Differential corrections are typically transmitted via radio or satellite link. The communications system utilized will directly effect the cost and performance of the DGPS system. Table 1 contains a comparison of radio-based and satellite-based DGPS delivery systems.

Feature	**Radio-based**	**Satellite-based**
Equipment cost	Low	High
Portable Reference Site	Yes	No
Central monitoring and control	Maybe	Yes
Redundancy	Low	High
Transmission cost (per bit)	Low	High
Update rate	Slow	Fast
Range	Up to 200 km	Unlimited
Radio Frequency License	Required	Provide by communication company

Table 1 - Comparison of Radio-based and Satellite-based Differential Correction Delivery Systems

GPS Receivers

A wide range of GPS receivers are available for applications such as land surveying, geodesy, GIS, air and marine navigation, vehicle tracking, precision timing and recreation. Each receiver is a compromise between function, cost and accuracy. For DGPS applications such as DP operations, only survey-quality receivers and antennas should be considered. A survey-quality GPS receiver will track up to 12 satellites simultaneously, accept standard RTMC SC-104 Version 2.1 differential corrections and provide sub-meter accuracy. Sub-meter accuracy is defined as a standard deviation in position of less than 1 meter over a 24 hour period. Figure 3 shows a graph of position versus time of a stand-alone (not differentially corrected) GPS receiver setup over a known point. The error in the position is constantly changing and reaches a maximum of ±60 m in latitude (ΔN) and longitude (ΔE) while the average position error over the 24 hour period is -0.1 m in latitude and -1.0 m in longitude.

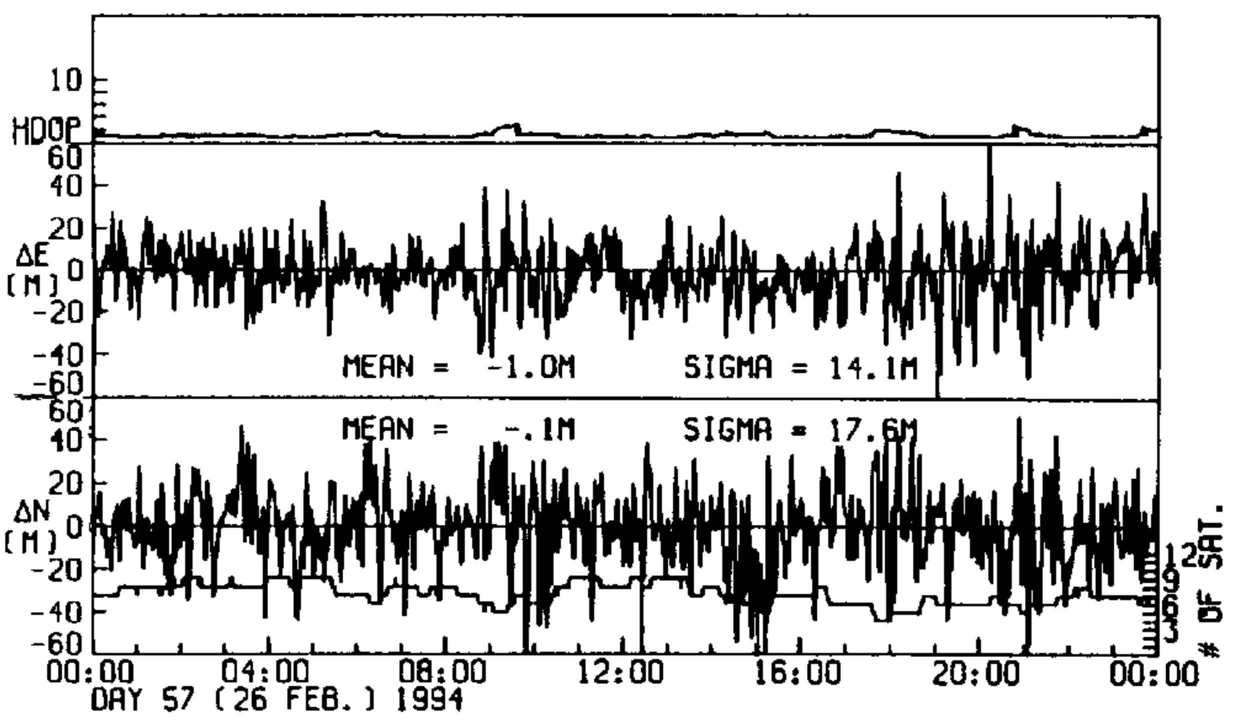

Figure 3 - Uncorrected GPS Position v. Time

Figure 4 is a graph of a differentially corrected GPS receiver advertised to be capable of 1 m accuracy. Although the average position error over the 24 hour period is 0.67 m in latitude and 0.24 m in longitude, the standard deviation (1 σ) of the position is 1.30 m in latitude and 1.57 m in longitude and instantaneous position errors exceeding 5 m frequently occur.

Figure 5 is a graph of a differentially corrected survey-quality GPS receiver. The average position error over the 24 hour period is 0.00 m in latitude and 0.01 m in longitude, the standard deviation of the position is 0.30 m in latitude and 0.23 m in longitude and instantaneous errors never exceed 1 m.

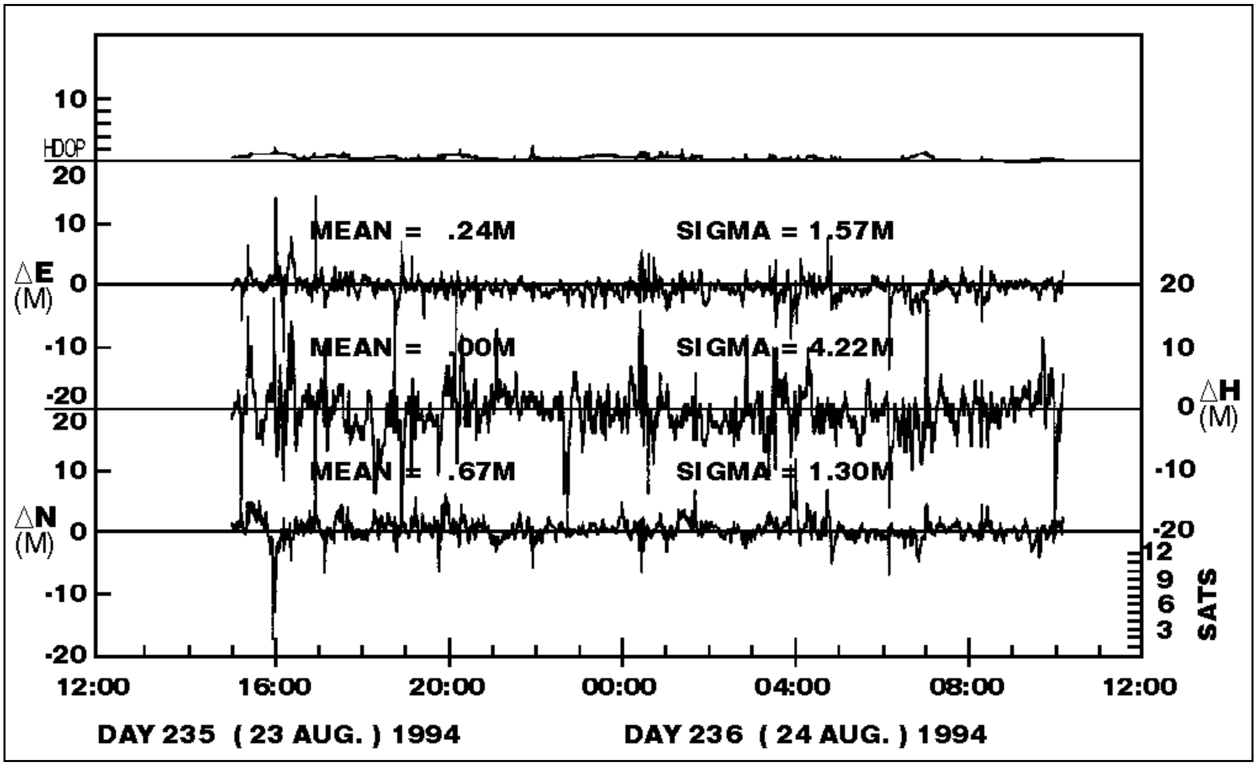

Figure 4 - DGPS Position v. Time

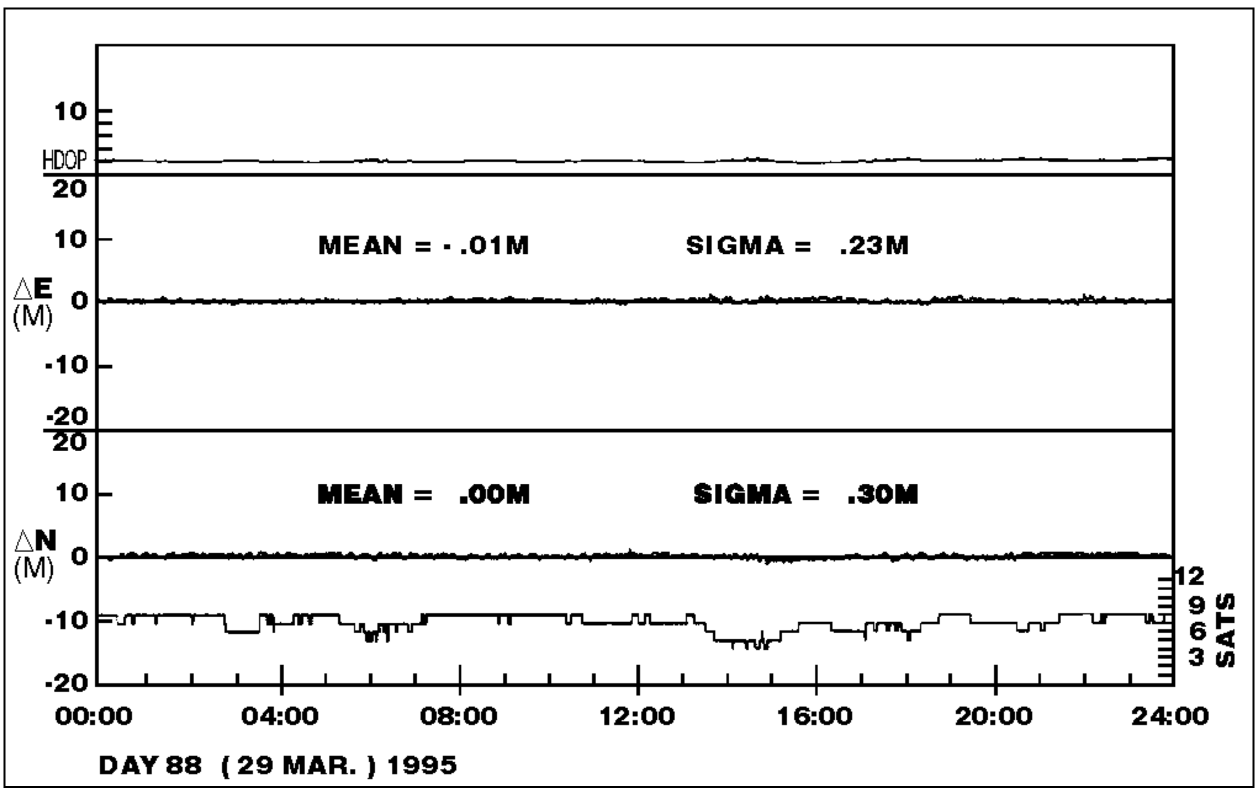

Figure 5 - Survey-quality DGPS Position v. Time

Global Navigation Satellite System

The Global Navigation Satellite System (GLONASS) is a space-based radio positioning system under development by the Russian Ministry of Defense for military and civilian use. Like GPS, this system is designed to provide 24 hour, world-wide position, velocity and time service.

Each GLONASS satellite broadcasts on two frequencies: L1 (1602 + 0.5625n MHz [n=0,1,2,...,24]) and L2 (1246 + 0.4375n MHz [n=0,1,2,...,24]). Due to conflicts with communications satellites, the operating frequencies for GLONASS are expected to change in three stages through the year 2005. [5]

The satellites are monitored by five telemetry and tracking stations in the former Soviet Union and by ground control in Moscow. With a full constellation of satellites, the system delivers 60 m accuracy. Sub-meter accuracy can be achieved using differential techniques similar to DGPS. Currently, there are no plans by the MOD to implement SA. [4]

A full constellation of 24 satellites, operating in three orbiting planes was achieved in January 1996. The same year, the free use of GLONASS for civil aviation was offered for 15 years by the Russian Ministry of Transportation and accepted by the ICAO. Since then, numerous satellites have failed and have not been replaced. The system currently has 14 operational satellites that provide approximately 4 hours of useful positioning daily. Due to the current status of the GLONASS constellation, it is not usable for applications that require 24 hour operations.

Differential GLONASS

Several vendors now offer GPS+GLONASS and Differential GPS+GLONASS receivers which take advantage of the combined constellation of 38 satellites. Differential GLONASS operates in much the same way as DGPS. A receiver is setup on a reference point and pseudo-ranges are observed. Range corrections are calculated by subtracting the “known” range to the satellite from the observed range. The corrections are transmitted to a second receiver and applied in near real-time to observations at the remote site. To be effective, the range corrections must be transmitted quickly and reliably, although, the rate of change of GLONASS corrections should be much slower than DGPS because SA is not used.

With only 14 satellites, GLONASS will only operate as an autonomous system for a few hours per day. For this reason, differential GLONASS is not widely in use, but may gain acceptance when more satellites are available.

DP OPERATIONS

Currently, DGPS is the only readily available precise absolute surface positioning system. Although the principles of DGPS are relatively simple, a safe, reliable and efficient system requires careful planning, installation and operation. The following guidelines are based on experience on various DP vessels and may not be suited to every vessel.

Redundant DGPS

As a minimum, a redundant DGPS system for a DP vessel operating in the Gulf of Mexico should consist of the following equipment:

2	Survey-quality GPS receivers
2	Survey-quality GPS antennas
1	L-Band Differential receiver

1	C-Band Differential receiver
1	USCG Differential receiver
2	MRDGPS Processing and QC Computers
2	UPS systems (separately powered)
2	DP system interfaces

Figure 6 shows the schematic diagram of a typical redundant Starfix® DGPS system. This system will provide at least 100% redundancy on each component.

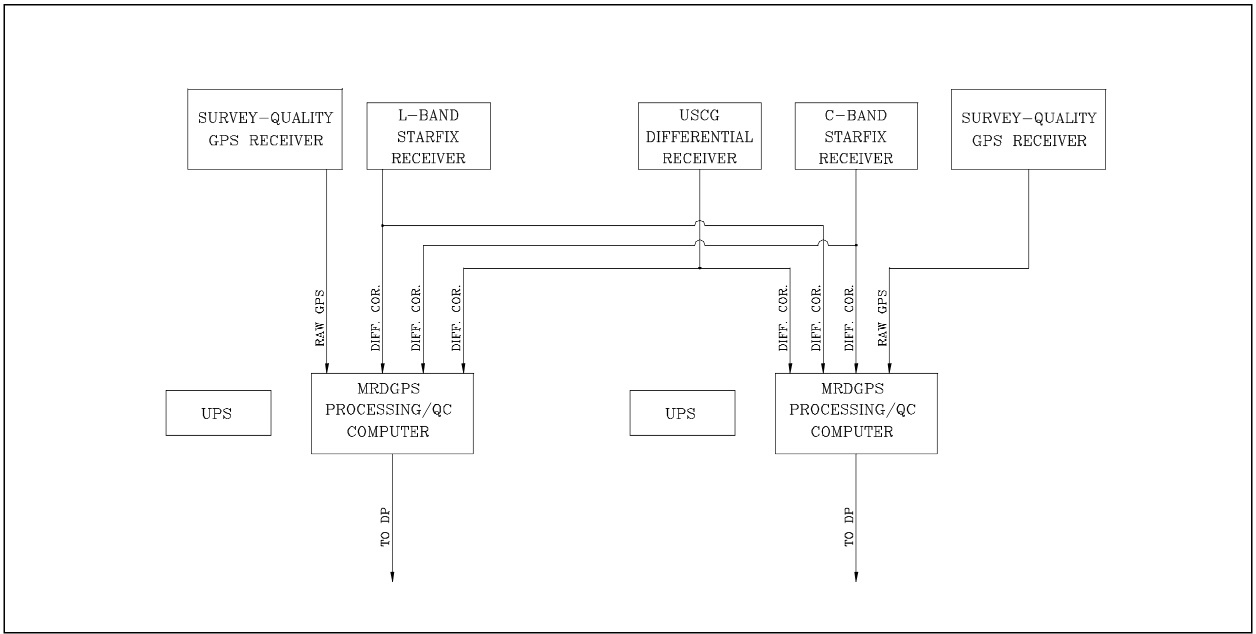

Figure 6 - Redundant Starfix® DGPS System

Antenna placement is crucial for optimal performance. GPS requires a clear view of as much of the sky as possible above 10° above the horizon. Additionally, flat surfaces such as decks and bulkheads reflect the incoming GPS signal and create a multi-path problem. Since most DP vessels have obstructions such as cranes and derricks, the GPS and differential antennas should be mounted as high as possible. To minimize the risk of simultaneous loss of all positioning, the antennas should be separated as much as possible. In practice, one GPS antenna and one differential antenna are mounted in close proximity on the port side of the vessel and a second set are mounted on the starboard side. Antennas must also be protected from strong RF interference. Although GPS operates in the L-Band, the weak signal can be lost in areas of high RF noise.

All cables and connections are subject to corrosion, wear and damage. To prevent a catastrophic failure of all systems, antenna cables must be routed separately to prevent simultaneous interference or damage. Bulkheads are often problematic if all cables enter and exit from DP control using the same penetration.

To prevent simultaneous equipment failure, two UPS systems must be utilized and powered from different sources. The UPS must be sized to carry all devices for a minimum of 45 minutes. If possible, one UPS will be powered on the same circuit as the DP Control system and one UPS will be powered from a second high priority circuit. All electrical and data connections must be secured and grounded.

For DGPS to operate, the GPS receiver and the differential receiver must both continuously receive data. Fugro’s MRDGPS software operates under Windows 95 or NT and is used to process incoming GPS and differential correction data and output one or more positioning strings. MRDGPS accepts one raw GPS string and multiple differential corrections. As long as at least one differential source is active, the software will continue to output differentially corrected position information using the best available source(s).

Single Point Failure Modes

1. Failure of GPS system

DESCRIPTION: A complete failure of the GPS system would require catastrophic failure due to an act of war or an intentional shut-down. An accidental system shutdown is very unlikely due to the safeguards and redundancy implemented by the DOD. An intentional shutdown is equally unlikely due to the US and world-wide dependence on GPS for critical tasks such as civil air navigation [1,6], positive train control [7] and telecommunications timing [8].

ACTION: Corrective action required by DOD to restore system.

2. Loss of GPS signal

DESCRIPTION: GPS operates in the L-band which is not greatly effected by weather events, but can be jammed by (a) strong RF interference or blocked by (b) physical obstructions such as cranes.

ACTION: (a) Move antenna or relocate/redirect RF source (b) move antenna or remove obstruction.

3. Failure of differential system

DESCRIPTION: A complete failure of a redundant wide-area DGPS system such as Starfix® is unlikely. The failure of a single-site temporary DGPS system is more likely due to limited redundancy.

ACTION: Replace failed component at reference station and/or switch to secondary differential source.

4. Loss of differential signal

DESCRIPTION: The differential signal can be lost due to (a) failure of the delivery system, (b) RF interference or (c) a physical obstruction.

ACTION: (a) Switch to secondary delivery system (b) move antenna or relocate/redirect RF source (c) move antenna or remove obstruction.

5. Loss of electrical power

DESCRIPTION: The loss of electrical power is unlikely due to the use of redundant UPS systems. Using a properly sized UPS, operations will continue for a minimum of 45 minutes prior to positioning failure.

ACTION: Restore power from alternate source.

6. Hardware failure

DESCRIPTION: All electrical components have a finite service life and should be periodically serviced and/or replaced according to the manufacturers guidelines. External factors such as voltage spikes, welding and lightning can damage or destroy individual electronic systems. The use of redundant, separately powered UPS systems will minimize the possibility of simultaneous loss of positioning due to equipment failure.

ACTION: Switch to secondary DGPS and replace damaged unit.

7. Software failure

DESCRIPTION: All software programs have potential errors, but a robust system will anticipate potential errors and recover proper operation quickly and automatically. The use of extensive testing and monitoring will reveal errors that can be fixed prior to general software release and use. Although software errors can occur at any time, errors are most likely to occur with the release of new software revisions or when operating parameters are changed. Frequent changes in operating parameters greatly increase the opportunity for human error. Software failures can be caused by (a) incorrect setup parameters, (b) unusual input data or (c) programming errors.

ACTION: (a) Review and correct setup parameters (b) confirm proper input data from GPS and differential receivers (c) continue operations using secondary software.

8. Year 2000 Compliance

DESCRIPTION: Many computer systems were originally developed to recognize only a two digit date field, i.e. 08/18/85 represents August 18, 1985. This was done to save memory in the early days of computing. Unfortunately, under this scheme, 01/01/00 would translate to January 1, 1900 NOT January 1, 2000. This may cause many problems for applications that are date sensitive.

ACTION: Require "Year 2000 Compliance" on all systems: GPS, computers, software, etc. Where possible, test systems in none critical time to confirm proper operation.

9. GPS Week 1024 Rollover

DESCRIPTION: The GPS System Time Cycle began at midnight January 5/6 1980 and is counted in weeks from 0 to 1023 (approximately 20 years). GPS week 1023 ends at midnight 21/22 August 1999 at which time the week count will reset to 0. For most new GPS receivers, this will not be a problem, but older receivers may have serious problems, including complete termination of operations.

ACTION: Obtain firmware upgrade from equipment manufacturer or replace unit.

CONCLUSIONS

Land-based surface positioning systems such as Syledis and Loran-C, have been or will soon be shutdown. Therefore, DGPS currently provides the only reliable, accurate surface positioning reference for DP operations. Even without Selective Availability, differential corrections are required for DP operations due to the large (60 m) uncertainty in positioning using stand-alone GPS.

A second, autonomous surface positioning system, such as GLONASS, would benefit all navigation users by increasing the number of available satellites and/or providing an independent surface positioning system. GLONASS will require time and funding before it can operate as a reliable, 24 hour system.

USEFUL WEB SITES

US Coast Guard Navigation Center	www.navcen.uscg.mil
FAA GPS Team	gps.faa.gov
MIT Lincoln Laboratory	satnav.atc.ll.mit.edu
German Aerospace Center	www.nz.dlr.de
GLONASS Information	www.rssi.ru/SFCSIC/glonass.html

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