HYDROGRAPHIC SURVEYS TO IHO STANDARDS WITHOUT SHORE STATIONS USING THE REAL-TIME GIPSY (RTG) GLOBAL POSITIONING SYSTEM (GPS)

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ABSTRACT

The Naval Oceanographic Office (NAVOCEANO) conducts hydrographic surveys in accordance with International Hydrographic Organization (IHO) S-44 hydrographic survey standards. Presently, under most circumstances, shore stations must be established for collecting tide information that is used to define the local vertical chart datum, derive tidal correctors to reduce soundings to the chart datum, and derive harmonic constituents for future tide predictions. In addition, in many cases a shore station must be established that provides differential corrections to the GPS pseudo-ranges used by the survey vessel for accurate horizontal positioning. This current concept of operations requires clearances and permissions from national/local authorities and landowners to access and establish these shore stations. It also requires substantial efforts to establish or maintain security for both shore parties and equipment left behind at the shore stations. Recently, NAVOCEANO acquired 13 GPS receivers from NavCom Technology, Inc. with Real-Time Kinematic (RTK) and Real-Time GIPSY (RTG) capabilities and associated StarFire™ Wide Area Differential GPS (WADGPS) services from C&C Technologies in partnership with NavCom. NAVOCEANO has integrated these RTK/RTG receivers into its Mission Survey Systems on its fleet of survey ships and Hydrographic Survey Launches (HSLs). The RTG software produces globally uniform precise GPS orbit and clock corrections. Using StarFire's satellite-based RTG signal with corrections for solid earth tide, NAVOCEANO conducted tests that indicated horizontal accuracies of 20 cm (2 sigma) and vertical accuracies of 24 cm (2 sigma) wherever the INMARSAT-C signals can be reached. These accuracies in the horizontal and vertical along with techniques to acquire the ellipsoid-chart datum separation using GPS buoys indicate a capability to survey anywhere in the littorals (outside territorial waters) to IHO standards without establishing shore stations. This paper will discuss a new concept of operations under development at NAVOCEANO using the NavCom GPS technology, GPS buoys, and bottom-mounted tide gages to support the Navy's need for navigational charting and near-real-time battlespace characterization.

INTRODUCTION

The Naval Oceanographic Office (NAVOCEANO), located at Stennis Space Center, Mississippi, has 175 years of hydrographic and navigation experience. In the last few years, NAVOCEANO has focused on the goal to provide the warfighter with high-resolution, near-real-time depiction of the battlespace environment that requires collecting and fusing sensor data with historic data to produce the best possible area charts and model and simulation forecasts. To achieve this goal NAVOCEANO employs or has access to:

- Seven multipurpose survey ships, of which six are the new T-AGS 60 class. Of the seven ships, three are equipped with Hydrographic Survey Launches (HSL).

- Highly mobile data collection assets capable of supporting immediate Fleet needs. These include the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system equipped with airborne hydrographic and topographic lasers and the Fleet Survey Team (FST) soon to be equipped with Unmanned Surface Vehicles (USV).

- The International Surveys Program, an international program that combines foreign platforms with NAVOCEANO technical assistance and equipment in the foreign countries' home waters in exchange for full data sharing.

- Remote sensors, such as Unmanned Underwater Vehicles (UUV), buoys, and ocean gliders, deployed by Fleet delivery systems.

- Classified and commercial satellite collection systems that employ high-resolution imagery and multi-spectral and hyper-spectral sensors.

- The Survey Operations Center (SOC) at Stennis Space Center, MS, which is capable of downloading survey data directly from survey ships around the world using C Band (1 megabit/sec) satellite links from ship to shore.

NAVOCEANO conducts hydrographic surveys in accordance with International Hydrographic Organization (IHO) S-44 hydrographic survey standards. Presently, under most circumstances, shore stations must be established for collecting tide information that is used to define the local vertical chart datum, derive tidal correctors to reduce soundings to the chart datum, and derive harmonic constituents for future tide predictions. In addition, in many cases a shore station must be established that provides differential corrections to the GPS pseudo-ranges used by the survey platforms for accurate horizontal positioning. This current concept of operations (CONOPS) requires clearances and permissions from national/local authorities and landowners to access and establish these shore stations. It also requires substantial efforts to establish or maintain security for both shore parties and equipment left behind at the shore stations.

NAVOCEANO recently acquired GPS receivers from NavCom Technology, Inc. with RTK and RTG capabilities and associated StarFire™ Wide Area Differential GPS (WADGPS) services from C&C Technologies in partnership with NavCom. StarFire is a commercial implementation of the RTG technique developed by the Jet Propulsion Laboratory and NavCom Technologies, Inc. The award was made under the I.T.S. Corporation's ANSWER Contract with the General Services Administration (GSA). The initial task order under the GSA ANSWER contract was for 13 systems with options for 16 additional systems in the years following. These GPS systems are being integrated with the Position and Orientation System for Marine Vessels (POS/MV) and Integrated Survey System (ISS-60) aboard NAVOCEANO survey platforms. The NavCom GPS systems are also employed by the CHARTS, FST, and International Surveys Program survey teams with their unique survey systems.

The RTG method, also referred to as Globally corrected GPS (GcGPS), produces globally uniform precise GPS orbit and clock corrections. Using StarFire's satellite-based RTG signal with corrections for solid earth tide, NAVOCEANO tests indicate that IHO horizontal and vertical accuracy standards can be achieved without establishing shore stations. These accuracies in the horizontal and vertical along with techniques to acquire the ellipsoid-chart datum separation using GPS buoys indicate a capability to survey anywhere in the littorals to IHO standards. This paper will discuss a new CONOPS under development at NAVOCEANO using the NavCom GPS technology, GPS buoys, and bottom-mounted tide gages to support the Navy's need for high-accuracy navigational charting and battlespace characterization anywhere in the littorals (outside territorial waters). Furthermore, the intention of this CONOPS is to employ NAVOCEANO assets to impact operational and tactical time scales.

U.S. NAVY DOCTRINE AND MILITARY SURVEYS

"Sea Power 21" is the new U.S. Navy vision for a Naval strategy that will fully integrate U.S. Naval forces into joint operations against regional and transnational threats. ForceNet provides the architectural framework for Sea Power 21 that implements the concepts of network-centric warfare. This framework for Naval warfare in the information age integrates warriors, sensors, command and control, platforms, and weapons into a networked, distributed combat force.

To provide ForceNet with a common geospatial reference frame, the Oceanographer/Navigator of the Navy has articulated the concept of "4D Cube." 4D Cube encompasses the complete set of knowledge, information, and data required to characterize the battlespace, spatially referenced to World Geodetic System 1984 (WGS-84) and temporally referenced to Universal Time Coordinated (UTC). The portion of the 4D Cube battlespace that requires environmental characterization is called the Recognized Environmental Picture (REP). The aim is to add value and knowledge to the information used by the commander and his decision making cycle to execute the military operation (Oceanographer of the Navy, 2002).

Traditional hydrographic surveys for safety of navigation provide the information required to produce standard nautical charts and the static bathymetry layers of the REP. NAVOCEANO hydrographic data are usually acquired with the cooperation or active participation of the host nation. In general, the host nation provides the clearances and permissions for all the shore station sites needed for tide gage stations and GPS differential correction stations. But in many areas of the world, recent hydrographic data do not exist or may not be available to U.S. planners for political or military reasons. Rapid Environmental Assessments that include hydrographic operations are required to develop the data requirements and associated processes for populating the REP with the necessary environmental information. The goal, therefore, is to provide the warfighter with a high-resolution, near-real-time depiction of the battlespace environment. This will require collecting and fusing on-scene sensor data with historic data to produce the best possible nautical and bathymetric charts and oceanographic forecast models (Van Norden, Harrison, and Kosbab, 2003).

In many of these cases it will not be possible to establish shore stations or the security risk is too high to justify deploying survey teams ashore for geodetic or tidal data collection.

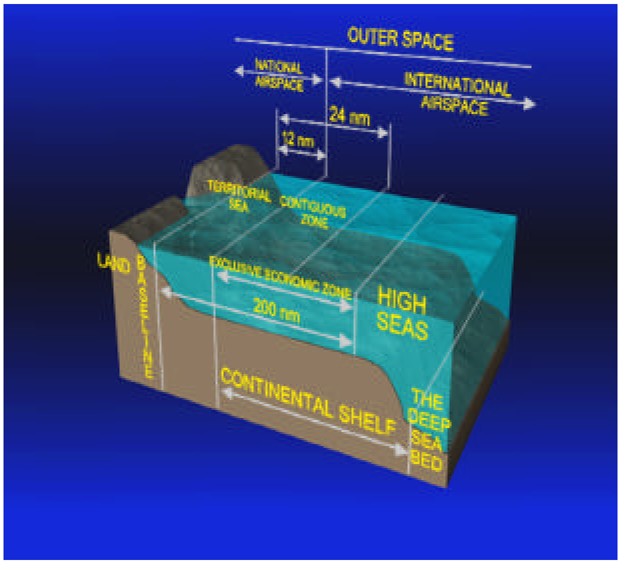

Figure 1. Sea Zone areas defined by UNCLOS.

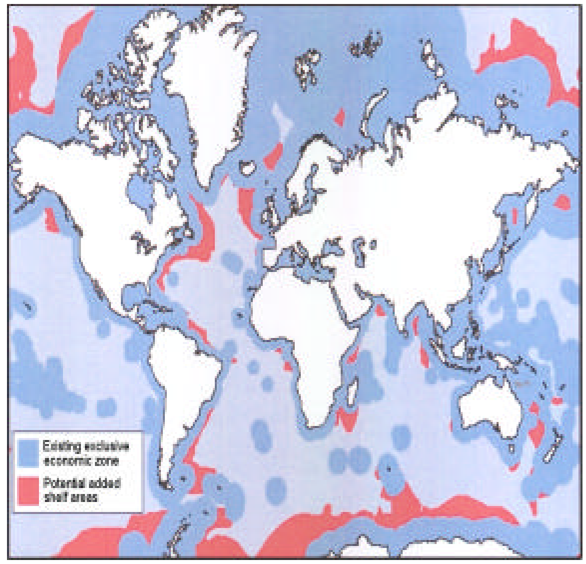

Figure 2. Approximate EEZ areas of the world.

Figure 1 graphically depicts sea zone areas as defined by the United Nations Convention on Law of the Sea (UNCLOS). Figure 2 approximately depicts the Exclusive Economic Zone (EEZ) areas of the world and the possible expanded areas. While UNCLOS gives the Coastal State jurisdiction over Marine Scientific Research (MSR) in the EEZ, it is the U.S. Government view that UNCLOS MSR provisions do not apply to hydrographic and military survey activities in the EEZ. But in all cases, the Coastal State has complete sovereignty in its Territorial Sea and adjacent coastland. Permission must be obtained prior to conducting a hydrographic survey there or accessing locations ashore (Young, 2004). This permission cannot always be obtained for a variety of political reasons. Offshore surveys, using present standard procedures, cannot meet IHO accuracy standards for hydrographic surveys without access to shore stations.

Another factor to consider prior to establishing shore stations is security of personnel and equipment. Figures 3 and 4 are photographs taken during last year's hydrographic survey in Iraq in support of Operation Iraqi Freedom. It indicates the extraordinary Force Protection (FP) efforts that had to be in place to conduct geodetic and tide surveys to support nautical charting requirements.

Figure 3. NAVOCEANO tide gage installation in Iraq.

Figure 4. NAVOCEANO geodetic survey operations in Iraq.

Since the NavCom-integrated RTG-StarFire solution provides for the first time decimeter accuracy offshore in both the horizontal and vertical, requirements for access and FP are greatly reduced.

CURRENT METHODS TO ACHIEVE IHO STANDARDS FOR HORIZONTAL AND VERTICAL ACCURACIES

ORDER	Special	1	2	3
Examples of Typical Areas	Harbours, berthing areas, and associated critical channels with minimum underkeel clearances	Harbours, harbour approach channels, recommended tracks and some coastal areas with depths up to 100 m	Areas not described in Special Order and Order 1, or areas up to 200 m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy (95% Confidence Level)	2 m	5 m + 5% of depth	20 m + 5% of depth	150 m + 5% of depth
Depth Accuracy for Reduced Depths (95% Confidence Level) (1)	a = 0.25 m b = 0.0075	a = 0.5 m b = 0.013	a = 1.0 m b = 0.023	Same as Order 2

Figure 5. Table 1, International Hydrographic Organization Standards for Hydrographic Surveys, Special Publication 44, Fourth Ed., April 1998.

Currently, the following methods are used in trying to achieve the IHO horizontal accuracy requirements indicated by Figure 5:

- U.S. Coast Guard or host nation Differential GPS beacons. This is a free local waters service.

- WADGPS. This is a worldwide subscription service that employs a network of ground stations whose pseudo-range correctors are relayed through the IMARSAT system. NAVOCEANO has observed horizontal errors of 14 meters (95% confidence) in Equatorial regions.

- NAVOCEANO-established DGPS pseudo-range corrector station at a geodetically established point. This option is employed only if the first two options do not meet the accuracy standards. This option has access and security requirements.

The disadvantages for establishing shore stations whether the station is a DGPS corrector station or a tide station are:

- The need to break survey, go ashore, and establish or maintain the station(s).
- The need for logistics – power, frequency clearance.

- The limits of DGPS transmitter ranges.
- The need for access and security at shore stations.
- The need for FP for personnel ashore.

Under current nonkinematic methods in hydrography, soundings are referenced to chart datum using tide corrections referenced to local long-term mean sea level. ("Local" refers to the mean sea level at the sounding, and "tide" actually refers to the low-frequency change in the water level due to tide, weather, and oceanographic effects.) If a permanent benchmark along the coast were tied into each sounding, one would find that the mean sea level at each sounding is at a different elevation with respect to the benchmark. Of course, under current methods, these elevations would be impossible to measure with respect to each sounding, but the illustration points out that there is a slope to the mean sea level. Fortunately, under current methods, the local mean sea level slope is not a concern as long as it is used as the reference point for each sounding. Unfortunately, it also means that since there is no fixed reference plane (such as WGS-84) for the charted area, the hydrographer must model the tide phase, tide amplitude, and the chart datum distance to local mean sea level (Zoo). This collective model must attain an accuracy that does not permit a vertical error to exceed IHO standards for the reduced depths. Table 1 of the IHO standards for Hydrographic Surveys (SP 44) (Figure 5) shows the allowable error for "depth accuracy for reduced depths (95% confidence level)."

The allowable errors for typical depths for each survey order are:

Special	0.25 to 0.39 m allowable in 1 to 40 m of water
Order 1	0.50 to 1.39 m allowable in 1 to 100 m of water
Orders 2 & 3	2.50 to 4.71 m allowable in 100 to 200 m of water

Typically, tide errors are the largest error components because of modeling errors. The typical total tide errors are:

Special	0.10 m (25 to 40% of total allowable error)
Order 1	0.20 to 0.30 m (14 to 60% of total allowable error)
Order 2 & 3	0.50 to 1.00 m (20 to 40% of total allowable error)

To obtain tide corrections for nonkinematic surveys, the tide phases and tide amplitudes above short-term mean sea level are determined by constructing co-tidal or co-range charts or by using numerical models such as ADCIRC, FES-99, and CU-Tides.

Co-tidal chart construction. The co-tidal charts are tide constituent models that are determined by locating known constituents (phase lag and amplitude) from several known tide stations. Often, areas of unknown constituents may be filled in with virtual tide stations using constituents from numerical models. Each constituent is then gridded for phase lag and amplitude throughout the survey area. Then the Zoo value is determined at each station by datum transfer from the known tide stations. The datum transfer is determined by calculating the ratio of the tide range at the unknown station to the known station and then multiplying this ratio by the Zoo at the known station, being careful to transfer the datum only between stations with the same tide characteristic. The Zoo is then gridded. Finally, the area is divided into tide zones, with each zone having a set tolerance, usually +/- 10 to +/- 20 cm, from the average set of constituents and Zoo value for each zone. The tide height and phase are determined by a predicted tide program, and the Zoo value is algebraically added to obtain the tide correction.

Co-range chart construction. The co-range chart is a means of determining tide height by knowing the tide series for the same time period at several tide stations throughout a survey area and comparing these tide series to a tide series for the same time period at a base tide gage. At least three benchmarks are installed and leveled to the base gage. After collecting data for preferably at least one lunar cycle, a chart datum is computed at the gage referenced from tide gage zero. The chart datum computation is usually done by simultaneous comparison with a nearby established primary gage. Range ratios and average time differences are then determined at each station with respect to the base station. The ratios and time differences are then gridded, and the area zoned with a set tolerance. The tide heights and phases at any location are then determined by multiplying the base station heights by the ratio and algebraically adding the time difference from the base station. This technique has the advantage of incorporating weather effects into the tide correction since the base station is an actual tide gage.

Numerical models. This is a constituent model and determined using the best available bathymetry, coastline, known tide stations, possibly weather information, and boundary conditions into a model that uses equations of motion to determine tide height. Once the model is generated, it is used the same way as a co-tidal model.

Current Kinematic Methods to Achieve IHO Standards for Vertical Accuracy. Currently, NAVOCEANO conducts Kinematic GPS (KGPS) hydrographic surveys using a KGPS base station established at a nearby coastal location. The distance from the WGS-84 reference ellipsoid to the chart datum is determined by placing a tide gage alongside a GPS base station. The tide gage data and a level line run are used to determine the chart datum and the height of chart datum to a benchmark. The GPS receiver is used to determine the height of the benchmark to the WGS-84 ellipsoid. The algebraic addition of the two provides the WGS-84 to chart datum relationship at the tide gage. This results in a chart datum referenced to the seamless Earth Centered Earth Fixed (ECEF) WGS-84 reference system.

Sanders (2003) provided an excellent primer on the basic principles of KGPS surveys. The following equation explains how Chart Depths (CD) are determined:

$$CD = RD - A + H + SEP$$

RD = Raw Depth from Echosounder calibrated to the transducer or other reference line
A = Height of the KGPS Antenna with respect to the WGS-84 Ellipsoid
H = Height of the KGPS Antenna Measured Above the transducer or other reference line
SEP = Separation Between the Chart Datum and the WGS-84 Ellipsoid

All the terms in the above equation are measured values with the exception of SEP. Thus the key to KGPS surveying is the determination of SEP.

There are three drawbacks to this current method:

- The practical distance from the base station to the vessel for RTK surveys is approximately 10 km due to radio transmission limitations and difficulties associated with maintaining accurate carrier cycle count by the RTK software. This distance can be increased by conducting the survey in post-processing kinematic (PPK) mode.

- The WGS-84 to chart datum distance varies throughout the survey area. The variation is a function of the mean sea level slope and the tide range. In other words, the local long-term mean sea level is at different elevations in the survey area, and the Zoo value varies with the tide range. Therefore, a local model of this distance is required. This distance is modeled by placing GPS stations and tide gages at a number of well-distributed stations around and in the survey area using land-based GPS stations and/or GPS buoys. Or as options, (1) a tide model may be used in place of the tide gages, or (2) an accurate geoid model and modeled Zoo values may be used. If a geoid is used, the local long-term mean sea level to geoid distance must also be determined.

- A base station must be established and tied in with GPS. This is often a problem overseas, where permissions must be obtained from the country to occupy the station. The station may also need to be manned around-the-clock, and guards may be required for protection of the equipment and personnel.

PERFORMANCE TESTING OF THE C-NAV RTG GPS SYSTEM

In 2002, NAVOCEANO began evaluating state-of-the-art GPS technologies and in particular the implementation of technologies and techniques to derive water level corrections to bathymetric soundings utilizing RTK GPS systems. We began by evaluating the specifications of several GPS RTK systems. In addition to the RTK positioning techniques, NAVOCEANO began evaluating the theoretical aspects of the RTG and its Internet-based Global Differential GPS (IGDG) infrastructure. Hydrographers were particularly aware of the limitations of the current WADGPS system. Soon after evaluating the current technologies, we realized the possibilities of acquiring a system that can derive positions in both RTK and in RTG mode. The RTG method produces globally-uniform precise GPS orbit and clock corrections. Ionospheric and multipath corrected range measurements are performed at the receiver site by processing the L1 and L2 code and carrier measurements. In addition, a constrained estimate of the tropospheric refraction is made using the data from all the satellites (Hatch et al., 2002). The GPS system would be utilized in RTK mode whenever the mission requires centimeter-level accuracy and secure access to land can be obtained. RTG mode would be used for all other missions. The capability of storing GPS RAW observables was also an essential requirement in cases where centimeter-level positions were needed. Since the RTK solutions are limited in range from a land-based RTK base station, a Post-Processed Kinematic (PPK) position will be computed in such a case.

Evaluating RTG and RTK Performance

Soon after narrowing down the search for GPS systems, NAVOCEANO performed an independent test at Ascension Island, far from any reference site. For the test, the following equipment was tested:

- C-NAV Dual-Frequency GPS Unit, constructed with the NavCom 2000D GPS engine and L-Band demodulator,
- NavCom SF-2050R Dual-Frequency GPS receiver, which utilizes the NavCom 2000D GPS engine and the SF-2045 L-band demodulator,
- JAVAD HiPER Dual-Frequency GPS receiver, and
- FUGRO SeaStar 3000LR Demodulator.

The FUGRO SeaStar 3000LR—the equipment currently in use by the NAVOCEANO Survey Fleet—was configured with the JAVAD HiPER to obtain Radio Technical Commission for Maritime Services (RTCM) WADGPS corrections. The C-NAV and the NavCom SF-2050R GPS receivers operated utilizing their own L-Band demodulator, which received the RTG clock and orbit corrections. The vertical accuracy of the FUGRO SeaStar WADGPS service differenced over a geodetic benchmark was found to be > 15m @ 95% Confidence Level. The vertical accuracy of the C-NAV and NavCom RTG receivers differenced over a Geodetic Benchmark was found to be ~ 40cm @ 95% Confidence Level. (See Arroyo-Suarez and Hsiao, 2004, for detailed testing information.)

An additional feature noticed was the systematic fluctuation of the heights over time. Further investigations of the observed phenomena indicated that the NavCom GPS receivers when operating in RTG mode were not applying the International Earth Rotation and Reference Systems Service (IERS) Note 21 convention to correct the time-variable displacements in station coordinates due to solid earth tide (SET), ocean loading, and solar motion.

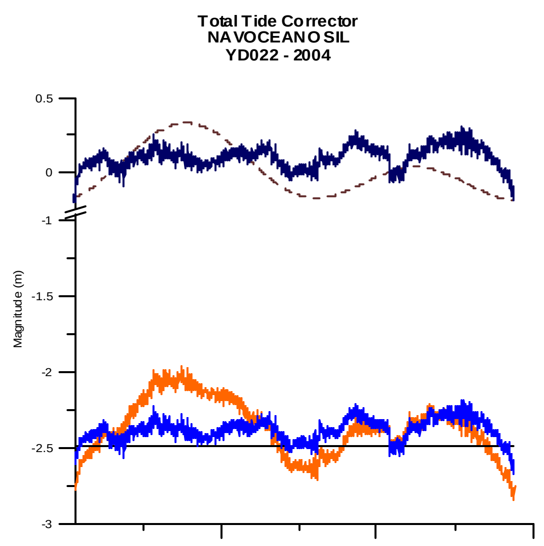

Figure 6. NavCom RTG solutions corrected with IERS Note 21 SET model. Vertical Accuracy ~ 24cm @ 95% Confidence Level.

Figure 6 shows that by applying the SET corrector to the NavCom RTG solutions, the actual vertical accuracy of the NavCom Receiver operating in RTG mode became ~ 24cm @ 95% Confidence Level. This finding was so encouraging that it led to this new paradigm of conducting hydrographic surveys.

Selected System

NAVOCEANO selected SF-2050R GPS receivers from NavCom Technology, Inc. with RTK and RTG capabilities and associated StarFire™ WADGPS services from C&C Technologies in partnership with NavCom (Figure 7). This is an integrated RTG and RTK solution capable of providing seamless high-accuracy navigation in real time, anywhere and at any time. The elected system is comprised of two subsystems. One of the subsystems is a multi-mode shipboard system capable of operating in DGPS, RTG, RTK, and PPK. This subsystem is required to generate seamless decimeter positions in real time within the areas where the RTG corrections can be received via the INMARSAT-C coverage.

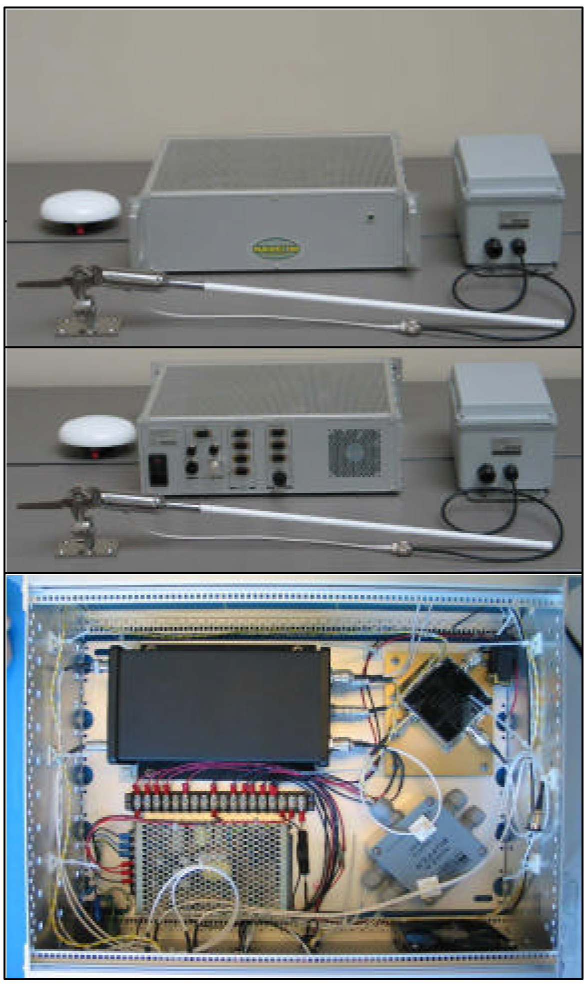

Figure 7. Multi-Function shipboard GPS System. SF-2050R on a 2U Rack Chassis.

In addition, the system includes a transportable RTK land-based station, capable of transmitting carrier phase differential GPS (CPDGPS) corrections to the shipboard system in real time and to collect dual-frequency GPS observables to generate primary control position benchmarks. The transportable RTK station can be deployed ashore and left unattended for up to or beyond 30 days by operating off solar cells.

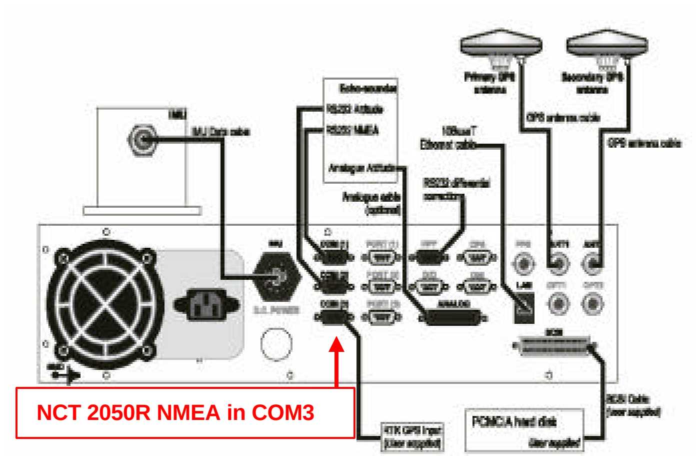

Figure 8. RTG/RTK NMEA Position Solution into POS/MV Auxiliary GPS Input (comm port #3).

The Shipboard RTG/RTK contains multiple data communication ports (Figure 8). Among them there are four serial National Marine Electronics Association (NMEA) DB9 connectors. RTK or RTG antenna phase center position solutions are output as $GPGGA, into the Applanix POS/MV GPS/Inertial system. The POS/MV generates heading, attitude, heave, and navigation. It is delivered commercially with a specific differential port for code DGPS and a serial port (port #3) for higher-accuracy auxiliary position inputs such as RTK and RTG. NMEA GST, GSA and GSV supporting messages are input to the same POS/MV port. The antenna phase centered positions generated by the NavCom 2050R GPS are lever-arm corrected and translated to the vessel common reference point by the POS/MV. The SIMRAD sonar EM3002 console utilizes the attitude and navigation solution generated by the POS/MV to generate attitude corrected depths. A product of this integrated system can be expressed as absolute three-dimensional depth solution tied to the WGS-84 Earth Centered Earth Fixed (ECEF) coordinate system.

For the first time in NAVOCEANO, a single shipboard unit delivers centimeter positioning inshore using RTK and can seamlessly transition to decimeter accuracy offshore using RTG. The NavCom SF-2050R RTG system (corrected for solid earth tide) provides the ship ~ 20cm horizontal accuracies and ~ 24cm vertical accuracies anywhere the INMARSAT-C signals can be reached. Within range of the RTK station, 1 to 2 centimeter accuracy in the horizontal and vertical can be achieved.

FUTURE CONCEPT OF OPERATIONS FOR MILITARY SURVEYS

With the recently acquired GPS receivers from NavCom Technology, Inc. and their 20 cm (2 sigma) horizontal accuracies, meeting IHO horizontal accuracy standards worldwide is nearly a trivial problem. Meeting the vertical accuracy standards, however, without the use of tide gages ashore requires a coherent CONOPS. Similar to KGPS surveys, soundings in RTG surveys are related in three dimensions (horizontally and vertically) to the WGS-84 Ellipsoid. The survey platform is a moving tide gage, and charted depths are derived by subtracting the WGS-84 to Chart Datum distance (SEP).

When creating nautical charts, bathymetric measurements tied to the WGS-84 ECEF coordinate system are reduced to a Chart Datum. The measurements of water levels tied to an ECEF coordinate system and the derivation of chart datum from RTK GPS-based buoys have been proved feasible by a number of studies (Shannon and Martin, 1996; Chang, Lee, and Tsui, 2000; Bisnath et al., 2004). Research had shown that the utilization of high-accuracy GPS buoys to derive water levels increases the accuracy of the bathymetric solution by eliminating the uncertainty inherent by tide modeling in complex surveys areas far from land-based tide gages (Riley, Milbert, and Mader, 2003).

In addition to RTK solutions, accuracies obtained by GPS operating in RTG mode offer a level of certainty to warrant the reference of each global acoustic measurement to a true three-dimensional ECEF reference frame. Traditionally, horizontal and vertical positioning of bathymetric measurements is treated separately. This new level of three-dimensional absolute positional accuracy should prompt a review of how bathymetric measurements are processed, archived, and presented.

To reduce the bathymetric measurements to chart datum utilizing GPS height, the chart datum-ellipsoid separation must be defined. Chart datum-ellipsoid separation may already be determined by the national authorities. In the United States, the majority of primary tide gage benchmarks (TGBM) are tied to the International Terrestrial Reference Frame (ITRF) 2000 reference frame. The UNESCO International Oceanographic Commission (IOC) recommends the connection of TGBM to the ECEF reference frame by leveling. Countries like Australia are going beyond the IOC's recommendation by building chart datum ellipsoid surface (AUSHYDROID) around the major maritime ports (Martin and Broadbent, 2004).

The proposed concept of tying hydrographic measurements to an ECEF reference frame is depicted in Figure 9. By applying such concepts, the capability exists to avoid the whole issue of tides. To the hydrographer, tides are a nuisance parameter and are not required to be explicitly solved for (Wert, Dare, and Clarke, 2004). The major problems are the determination of local chart datum throughout the survey area and the relationship of chart datum to WGS-84 throughout the survey area. Three techniques will be employed in combination using the datum transfer methods discussed earlier in this paper:

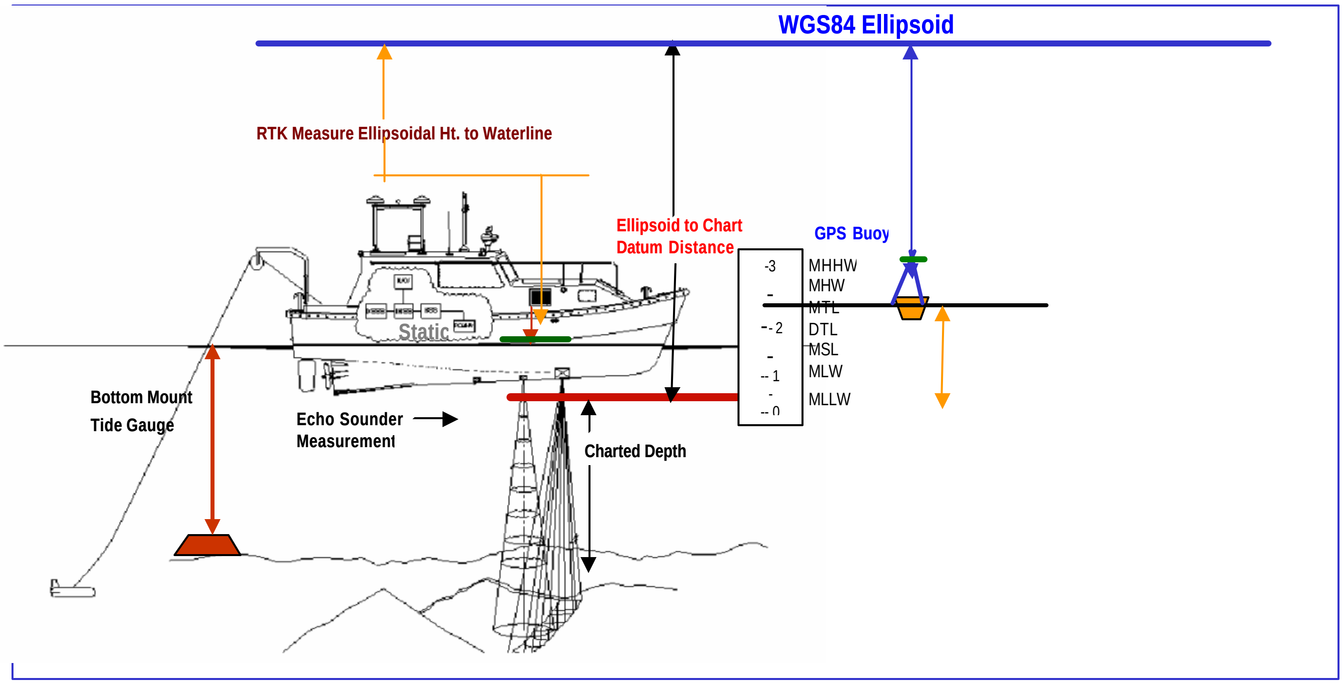

Figure 9. Proposed concept for tying hydrographic measurements to an ECEF.

- Bottom-mounted tide gages from which local chart datum can be determined. Datum transfers from a 19-year station will be employed to refine the long-term Mean Sea Level. Sounding over the top with a launch will provide a vertical reference to the WGS-84 Ellipsoid. The disadvantages of this technique are the difficulty in installation and retrieval and the delay in obtaining needed data until the end of the observation period. Bottom gages are also expensive and susceptible to bottom trawls by fishing vessels. But bottom gages, if corrected for barometric pressure and properly installed, provide very reliable data.

- RTG GPS-equipped buoys from which local chart datum referenced to WGS-84 can be directly determined. Datum transfers from a 19-year station will be employed to refine the Chart Datum relationship to long-term Mean Sea Level. The advantages of buoys are that they are easy to install and data can be easily retrieved. The disadvantage of this technique is, like all small buoys, they are susceptible to tampering and severe weather. Initially, the buoys are similar in cost to bottom gages, although prices are expected to decrease. Figure 10 depicts the NAVOCEANO buoy under construction.

- Using numerical models to determine Mean Sea Level, Chart Datum, and the WGS-84 Ellipsoid relationships.

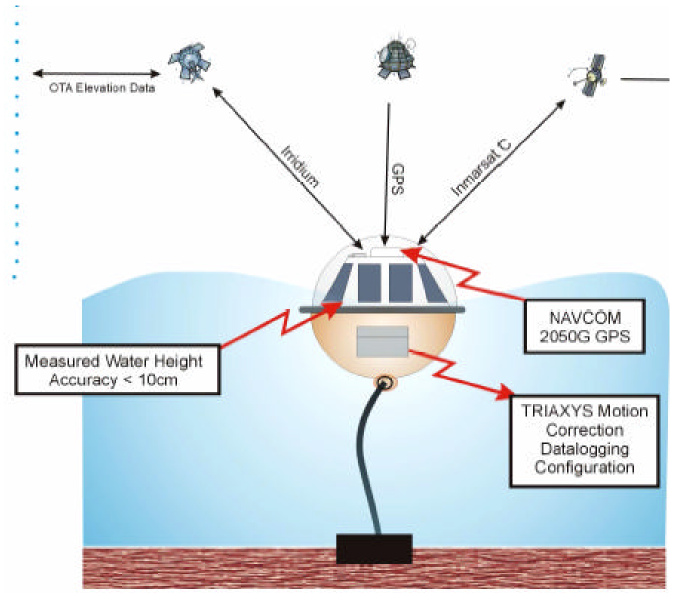

Figure 10. NAVOCEANO buoy under construction.

This CONOPS is still in the developmental stage and requires more analyses and testing to determine the necessary detailed procedures. Initially, all three of the above techniques will be used to determine the Chart Datum to WGS-84 Ellipsoid relationship (SEP). Ideally, the modeling technique will be used to define the general characteristics of the Chart Datum/WGS-84 model and determine any steep slopes in the area. Two to three GPS buoys will be used to refine the modeled relationships throughout the immediate survey area. One technique will be to use one buoy to determine the SEP for each 10 nmi by 10 nmi area and survey in that box. Survey operations can commence immediately, and soundings can be adjusted to Chart Datum as soon as the SEP is determined. A second technique would be to install at least three buoys around the survey area to determine the SEPs and interpolate SEP values in between. As few as two days of observations are needed at Spring Tides for Semi-diurnal tide regimes. More complex tide regimes will require at least 15 days of observations to resolve the four primary tide constituents. Initially, at least one bottom gage will be installed as a backup measure to ensure that critical data will be available until the reliability of the GPS buoys are proven.

CONCLUSIONS

NAVOCEANO can no longer rely on the traditional methods for conducting hydrographic surveys. The terrorism threat and nations unwilling to provide access to shore sites have severely decreased traditional NAVOCEANO hydrographic survey operations. Furthermore, hydrographic information is essential to meeting the goals of the Sea Power 21 strategy, particularly Sea Basing. In the last few years, NAVOCEANO has focused on the goal to provide the warfighter with high-resolution, near-real-time depiction of the battlespace environment, which requires collecting and fusing sensor data with historic data to produce the best possible area charts and model and simulation forecasts for the Recognized Environmental Picture. The CONOPS under development at NAVOCEANO, which uses NavCom RTG technology and GPS buoys, provides a capability to obtain hydrographic information anywhere outside territorial waters without a permission slip. The new NavCom GPS receivers with the associated RTG correction service provide this capability.

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