DEVELOPING A CONCEPT OF OPERATIONS FOR MILITARY SURVEYS TO IHO STANDARDS WITHOUT SHORE–BASED STATIONS

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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. The new draft standards for Order 1a/1b for waters shallower than 100 meters limit the Total Vertical Uncertainty (TVU) to a maximum of 0.5 meters plus a depth-dependent factor. Presently, to meet this standard, shore stations must be established for collecting tide information that is used to define the local vertical chart datum and derive tidal correctors to reduce soundings to the chart datum. 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 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. The new CONOPS under development at NAVOCEANO, which uses Real-Time GIPSY (RTG), Post-Processed Point Positioning (PPP) technology, and GPS buoys, provides a capability to conduct military surveys meeting IHO Order 1 requirements. It also uses improved survey procedures to map the seabed tied to the WGS-84/ITRF00 reference frame. Modeling and other techniques are utilized to determine the WGS-84 Ellipsoid/chart datum separation to produce depths referenced to the local chart datum. This paper will discuss the status of the efforts to develop the NAVOCEANO CONOPS to date.

Introduction

The Naval Oceanographic Office (NAVOCEANO), located at Stennis Space Center, Mississippi, has 178 years of hydrographic surveying experience to support the production of navigation charts and to support military operations with tactical products. 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 require 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:

- The six multipurpose survey ships of the T-AGS 60 class and one coastal survey ship of the T-AGS 50 class. Of the seven ships, three are equipped with hydrographic survey launches.

- The Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system. This is a highly mobile, airborne coastal mapping system equipped with hydrographic and topographic lasers, a hyperspectral sensor, and a camera.
- The Fleet Survey Team (FST). This expeditionary unit specializes in quick response surveys with deployable Rigid Hull Inflatable Boats (RHIBs) boats and hydrographic surveys that support theater security cooperation goals of U.S. military commands.

NAVOCEANO conducts hydrographic surveys in accordance with International Hydrographic Organization (IHO) S-44 hydrographic survey standards (International Hydrographic Bureau, 2008). 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. 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. Figures 1 and 2 indicate the extraordinary Force Protection efforts that had to be in place to conduct hydrographic, geodetic, and tide surveys to support charting requirements in Iraq in support of Operation Iraqi Freedom.

Figure 1. NAVOCEANO hydrographic operations in Iraq.

Figure 2. NAVOCEANO geodetic surveys in Iraq.

NAVOCEANO tests indicate that IHO Order 1 horizontal and vertical accuracy standards can be achieved without establishing shore stations using the Real-Time GPS Inferred Positioning System (GIPSY) (RTG) capabilities of its NavCom GPS receivers. With the associated StarFire™ Wide Area Differential GPS (WADGPS) services from C&C Technologies, the RTG method, also referred to as Globally corrected GPS (GcGPS), produces globally uniform precise GPS orbit and clock corrections (Hatch, Sharpe, and Galyean, 2002). Using StarFire's satellite-based RTG signal with corrections for solid earth tide, 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 tidal models to support the Navy's need for high-accuracy navigational charting and battlespace characterization anywhere in the littorals.

Background

U.S. Navy Doctrine and Military Surveys

The environmental characterization of the battlespace is called Intelligence Preparation of the Environment (IPE). The aim is to add value and knowledge to the information used by an operational commander and do it within his decision-making cycle to execute the military operation. Traditional hydrographic surveys for safety of navigation provide the information required to produce standard nautical charts and the static bathymetry layers of the battlespace. NAVOCEANO hydrographic data are usually acquired with the cooperation or active participation of the host nation. 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. 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. Rapid Environmental Assessments that include hydrographic operations are required to develop the data requirements and associated processes for populating the battlespace with the necessary environmental information. 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).

NAVOCEANO conducts hydrographic surveys in conformance with the IHO S-44 hydrographic survey standards listed in Table 1. Under traditional methods in hydrography, soundings are referenced to chart datum using tide corrections referenced to local long-term mean sea level. 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. This slope in mean sea level points out 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 indicates the maximum allowable Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU) for various orders at the 95% confidence level. The allowable uncertainties for typical depths for each survey order are:

Special	0.25 to 0.39 m allowable in 1 to 40 m of water
Order 1a/1b	0.50 to 1.39 m allowable in 1 to 100 m of water
Order 2	2.50 to 4.71 m allowable in 100 to 200 m of water

Traditional Methods to Achieve IHO Standards for Vertical Accuracies

Typically, tide uncertainties are the largest components of TVU because of modeling uncertainties. The typical total tide uncertainties are:

Special	0.10 m (25 to 40% of TVU)
Order 1a/1b	0.20 to 0.30 m (14 to 60% of TVU)
Order 2	0.50 to 1.00 m (20 to 40% of TVU)

It is important to note that the fifth edition of S-44 (International Hydrographic Bureau, 2008) is more explicit in the depth ranges for applying IHO Order 1 survey standards. Achieving the Order 1 TVU in offshore areas in depths to 100 meters is not a trivial matter, and it requires careful construction of co-tidal or co-range charts.

Table 1. Excerpt from Table 1, International Hydrographic Organization Standards for Hydrographic Surveys, Special Publication No. 44, Fifth Ed., 2008.

ORDER	Special	1a	1b	2
Description of areas.	Areas where under-keel clearance is critical	Areas where the seabed is less than 100 metres and under-keel clearance is less critical but where features of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of vessel expected to transit the area.	Areas generally deeper than 100 metres where a general description of the seafloor is considered adequate.
Maximum allowable THU 95% Confidence Level	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Maximum allowable TVU 95% Confidence Level	a = 0.25 metres b = 0.0075	a = 0.5 metres b = 0.013	a = 0.5 metres b = 0.013	a = 1.0 metre b = 0.023

Table 1 Note: Recognising that there are both constant and depth-dependent uncertainties that affect the uncertainty of the depths, the formula below is to be used to compute, at the 95% confidence level, the maximum allowable TVU. The parameters "a" and "b" for each Order, as given in the Table, together with the depth "d" have to be introduced into the formula in order to calculate the maximum allowable TVU for a specific depth:

$$\pm\sqrt{a^2 + (b \times d)^2}$$

Where:

a	represents that portion of the uncertainty that does not vary with depth
b	is a coefficient which represents that portion of the uncertainty that varies with depth
d	is the depth
b x d	represents that portion of the uncertainty that varies with depth

Co-tidal Chart Construction

Co-tidal charts are tide constituent models that are determined by inferring the major tide constituents (phase lag and amplitude) or tide ranges from neighboring established tide stations. Often, areas with 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 a known primary tide station, being careful to transfer the datum only between stations with the same tide characteristic (see equation (1)). 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 (see Figures 3 and 4).

From Admiralty Tidal Handbook No. 2 (U.K. Hydrographic Office, 1975), chart datum (cd) above gage zero for the local (temporary) station is given by:

$$cd = m - (S.C.) - (r/R)\, Z_{oo} \qquad \text{Equation (1)}$$

m = height of observed mean sea level (MSL) above gage zero at local station
r/R = ratio of local station/primary station tide ranges for semi-diurnal type tides, or the ratio of the sum of the M2+S2+K1+O1 constituents at each station (local station/primary station) for diurnal type tides
Z_{oo} = height of long-term MSL above chart datum at the primary station
S.C. = Seasonal Change correction is the difference between long-term MSL and observed MSL at the primary tide station.

Basically the hydrographer needs to know MSL at the local (temporary) gage or virtual gage and the tide range. As little as 50 hours of data for semidiurnal tides if taken during spring tides can give sufficient results. Diurnal tides require 15 days of observation to resolve the four primary constituents. If "m" is the height of observed MSL above the WGS-84 Ellipsoid or, in other words, if gage zero is the WGS-84 Ellipsoid, then "cd" is the distance chart datum is above the WGS-84 Ellipsoid at the local station.

The distance from the WGS-84 reference ellipsoid to the chart datum at a tide reference station is determined by placing a GPS receiver at the tide gage station. This results in a chart datum referenced to the seamless Earth Centered Earth Fixed (ECEF) geocentric WGS-84 reference system. Note, as the tidal effects decrease with increasing depth, the chart datum merges to mean sea level (geoid); so that for all practical purposes, in depths greater than 200 meters, the separation between the chart datum and the WGS-84 Ellipsoid, SEP, is the ellipsoid-geoid separation.

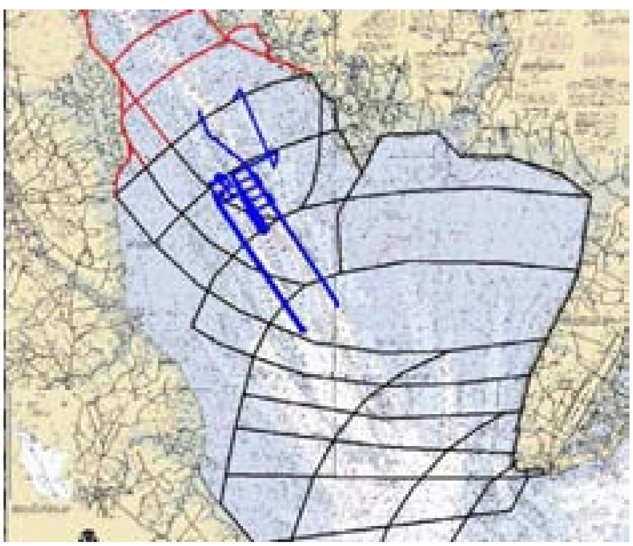

Figure 3. NOAA tide zoning for Delaware Bay. Blue lines depict NOAA survey lines crossing multiple zones.

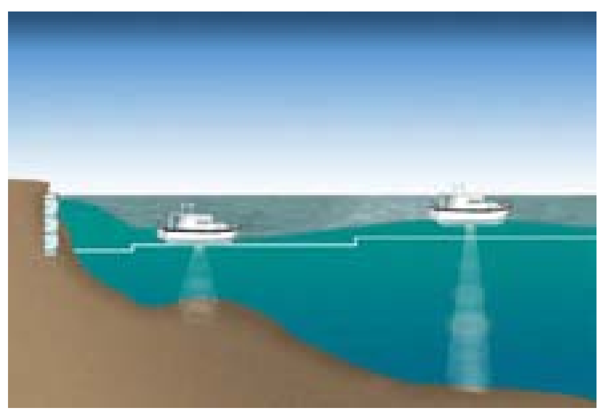

Figure 4. Cross section of tidal zoning.

Current Kinematic Methods to Achieve IHO Standards for Vertical Accuracy

Currently, NAVOCEANO routinely conducts Post-Processing Kinematic GPS (PPKGPS) hydrographic surveys with the CHARTS system. A KGPS base station is usually located as close to the survey operating area as possible, and existing or temporary tide gage stations in the vicinity are surveyed to the WGS-84 reference ellipsoid. Co-tidal modeling techniques are then used to establish tide zones for the survey area referenced to the WGS-84 Ellipsoid. These result in a chart datum referenced to the seamless ECEF WGS-84 reference system for each tidal zone.

Equations (2) through (8) explain how chart depths (CD) are determined (see Figure 5):

D = Echosounder depths (corrected for sound velocity) at the transducer or boat reference
d = Draft of the survey platform
T = Tide height above (or below) chart datum
h = Instantaneous height of the GPS antenna with respect to the WGS-84 Ellipsoid
H = Fixed height of the GPS antenna above the transducer or boat reference
SEP = Separation between the chart datum and the WGS-84 Ellipsoid

CD = D + d – T (traditional hydrographic equation)	Equation (2)
h_Nav = h + H (transducer elevation w.r.t. ellipsoid)	Equation (3)
T = SEP – h_Nav + d (tide height w.r.t. chart datum)	Equation (4)
CD = D + d – (4) (substituting eq. (4) into eq. (2))	Equation (5)
CD = D + h_Nav – SEP (tide and draft no longer required)	Equation (6)
ED = h_Nav +D (summation of both time varying measured values)	Equation (7)
CD = ED – SEP (new hydrographic equation)	Equation (8)

Equation (6) shows that the tide and draft are no longer required. All the terms in equation (6) are measured values with the exception of SEP. Thus the key to KGPS surveying is determining SEP, which ideally is determined a priori. Another important point is that while “h” is known to centimeter accuracy in KGPS surveys, it is only known to decimeter accuracy in RTG surveys. But numerous tests have shown that the vertical accuracies in RTG surveys are good enough to conduct hydrographic surveys to IHO Category 1 standards (Arroyo-Suarez and Hsiao, 2004; van Norden, Arroyo-Suarez, and Najjar, 2005; Arroyo-Suarez, Glang, Riley, and Mabey, 2005).

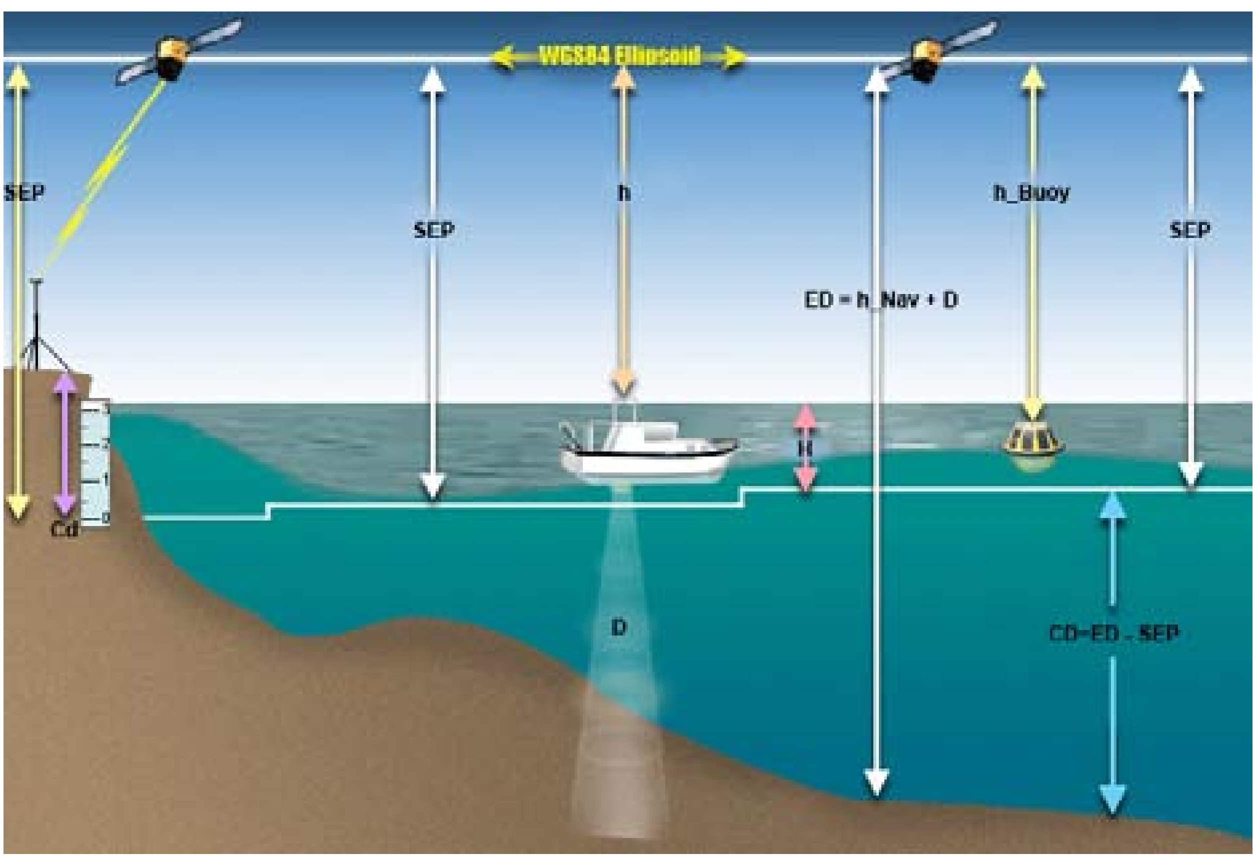

Figure 5. Surveying on the ellipsoid.

Status of Implementation of PPKGPS and RTG Survey Methods Aboard NAVOCEANO T-AGS Survey Ships

In 2005, NAVOCEANO selected the SF-2050R GPS receivers from NavCom Technology, Inc. NavCom uses a commercial implementation of the RTG technique developed by the NASA Jet Propulsion Laboratory in association with the StarFire™ WADGPS services from C&C Technologies and INMARSAT-C to forward the RTG corrections. This is an integrated multi-mode shipboard system capable of operating in DGPS, RTG, RTK, and PPK providing seamless high-accuracy navigation in real time, anywhere and at any time. 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, Sharp, and Galyean, 2002). The GPS system could be utilized in RTK mode whenever the mission requires centimeter-level accuracy and secure access to land can be obtained. PPK or 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.

NAVOCEANO has integrated these RTK/RTG receivers into its mission survey systems on its fleet of survey ships and their hydrographic survey launches, the CHARTS system, and Fleet Survey Team survey assets. For the T-AGS survey ships, 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. For the first time, 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 ~ 25cm 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.

The RTG/RTK capability is being integrated into the ISS-60 mission software in a four-phased approach. Those phases are:

1. Real-time data logging in ISS-60. This includes GPS raw observables from both the POS/MV and the NavCom. Surveys in real time will continue to use predicted tides and chart datums for vertical reference.
2. Use the POS/MV data (with L1 and L2 enabled) to provide the vertical control in post processing. Lever arm corrections are done within the POS/MV.
3. Use the POS/MV data (with L1 and L2 enabled) to provide vertical control in real time. Positions can be refined in post time with NavCom GPS observables.
4. Develop capability to obtain vertical control directly from the NavCom. Positions can be refined in post time. Lever arm corrections are done within ISS-60.

Phases one and two are both under implementation at this time. Phase one will be tested in April 2008 with completion scheduled for September 2008. Phase two involves updates to the Sonar Analysis and Area Based EditoR (SABER) software NAVOCEANO employs for post-processing multibeam data collected via ISS-60. Enhancements are also scheduled to be completed in September 2008.

The real-time integration requires that ISS-60 be modified to properly populate the $GPGGK message sent to the Kongsberg Seafloor Imaging System, so the quality indicator indicates

GIPSY and the ellipsoidal height field is populated. Additionally the POS/MV controller in ISS-60 has been enhanced to log raw GPS observables at 5 Hz for ship operations and 10 Hz for launch operations. Likewise, the NavCom controller in ISS-60 has been modified in the same fashion. Note that in this phase, real-time surveying will not change. Depths will still be referenced to a predicted tidal datum with heave, squat/settlement, and draft updates being applied in real time.

The post-processing modifications for phase two involve enhancements to SABER and the potential use of third-party Post-Processing Positioning (PPP) software. First, the NavCom and/or POS/MV raw observables can be post-processed giving a PPP solution. SABER will use the output from this process or the logged POS/MV GPS observables to create water level corrector files. The water level corrector files are time series providing ellipsoid to chart datum separation, observed height (reference point to ellipsoid), and uncertainty. It must be noted that heave, squat/settlement, and the waterline offset are removed from the GPS height at this time. These are then merged into the GSF files logged in ISS-60 in real time.

Also of interest is the tracking of uncertainty. The SABER Total Propagated Error function will also be updated to track the vertical component appropriately. The uncertainty associated with heave and draft will be removed from the Heave Vertical Navigation (HV Nav) Error records in the appropriate GSF files, while uncertainty associated with the GPS Z measurement and the ellipsoid to chart datum separation model will be added.

The third and fourth phases of this approach, planned for completion by September 2009, will totally eliminate the need for tide zoning. ISS-60 will be enhanced to apply the ellipsoid-chart datum separation in real time with the appropriate data being recorded in the GSF files. Pre-survey, a separation model will be created and used during acquisition in lieu of predicted tides. Draft components will continue to be recorded so that conventional tide correction can be applied if necessary.

Concept of Operations Under Development for Military Surveys

The FIG Commission 4 Working Group made a strong case for using the ellipsoid as the vertical reference surface for hydrographic surveys (FIG, Pub. No. 37, 2006) and for the development of a global separation model. They also outlined a procedure for obtaining accurate SEP values offshore that requires the installation of temporary tide stations. Chart datum-ellipsoid separation values are already being 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, and the National Oceanic and Atmospheric Administration (NOAA) has developed a SEP model for Tampa Bay, Florida. Countries like Australia are building SEP models (AUSHYDROID) around the major maritime ports (Martin and Broadbent, 2004). The United Kingdom Hydrographic Office is developing a SEP model for U.K./North Sea waters referenced to ETRF89 to achieve 20cm accuracy, 1 sigma (Ruth Adams, U.K. Hydrographic Office, 2007, pers. comm.).

Although, in some cases, the chart datum-ellipsoid separation may already be determined by national authorities, the major problem for the military surveyor will be the determination of the relationship of chart datum to WGS-84 throughout the survey area without establishing temporary tide stations ashore. This requires the careful development of a coherent CONOPS.

Three techniques will be employed in combination using the datum transfer methods discussed earlier in this paper.

Bottom-Mounted Tide Gages

Tide ranges and local mean sea level (with respect to the gage) can be determined by observing the water elevations. With at least 15 days of data, the four major constituents can be derived from the tidal signal. Chart datum transfers from a 19-year station will be employed using the datum transfer methods discussed earlier in this paper. 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

By observing the water elevations, tide ranges and local mean sea level (with respect to the WGS-84 Ellipsoid) can be determined. With at least 15 days of data, the four major constituents can be derived from the tidal signal. Chart datum transfers from a primary station will be employed using the datum transfer methods discussed earlier in this paper. The advantages of buoys are that they are easy to install, data can be easily retrieved, and tide levels can be directly related to WGS-84. 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.

Numerical Tide Models

Numerical models to determine mean sea level, chart datum, and the WGS-84 Ellipsoid relationships can also be used. Tide models are built using the best available bathymetry, coastline, known tide stations, possibly weather information, and boundary conditions and using the equations of motion, determine tide heights at any time at any place within the modeled area. Examples of numerical models are ADCIRC, FES-99, GOT-99, and TPXO. Once the model is generated, it is used the same way as a co-tidal model to determine MSL and chart datums throughout the survey area. NAVOCEANO is developing the capability to reference numerical model results (now referenced to the geoid) to the WGS-84 Ellipsoid.

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 preceding 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 semidiurnal 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. Whatever the difficulties in obtaining SEP values throughout the survey area, once these are known, they can be assumed to be constant at least over a tidal epoch, and re-surveys will no longer have to deal with tidal corrections.

Description and Status of GPS Buoy Developments

NAVOCEANO acquired two Positioning and Telemetry Buoy (P&TB) from AXYS Technologies Inc. in 2005 (Figure 6). The P&TB uses the NavCom NCT-2050G GPS receiver to provide real-time accurate three-dimensional positions that include solid earth tide corrections. Synchronously, position along with tilt (pitch, roll) and heading data is supplied to the buoy processors, which perform the necessary tilt corrections, averaging, and filtering. GPS data observation intervals, logging, filtering, and averaging are user-configurable via a secure Blue Tooth®, allowing for an optimum water-level position solution in real time. Processed data are provided to the user over an Iridium satellite link. All data are also logged internally for the duration of any data collection period, allowing post-processing of the GPS and motion data for further analysis and to increase the position accuracy. In addition, a power-saving scheme was implemented, optimizing the life cycle of each deployment. The P&TB provides the ability to measure the water elevation for a period of at least 240 hours (no solar recharge) continuously and for a lifetime of at least 5 years. Power is supplied with rechargeable lead acid batteries and solar cells. The complete buoy system is 0.9 m in diameter and weighs less than 216 kg. Tests conducted from 21 June to 10 July 2005, in Patricia Bay, B.C., Canada indicated very good comparisons with a Canadian Hydrographic Service (CHS) tide gage 500 m away. Table 2 lists the results achieved (Arroyo-Suarez, Mabey, Hsiao, and Phillips, 2005) and tide levels computed from simultaneous observations for Vancouver (#7735), the standard station, from the CHS website. Using equation (1) to transfer the chart datum at the buoy from Vancouver (the primary reference station) and using: m = -18.79, r = 3.02, R = 3.88, Z_{oo} = 3.1, and S.C. = 0, results in a chart datum of 21.20 m below the ellipsoid. This value is 0.12 m below the established chart datum at the nearby CHS tide gage. Although this is only one example, the results are within the expected uncertainty range for short term tide observations and confirm the viability of the CONOPS. More tests are planned and a sensitivity analysis will be conducted to determine the limits of this methodology.

Table 2. 19-day comparison of CHS tide gage data and P&TB (Arroyo-Suarez, Mabey, Hsiao, and Phillips, 2005).

diff to ellipsoid	CHS Tide Gage (m)	P&TB (m)	Difference (m)	Vancouver observed
MHHW (m)	-17.64	-17.57	0.07	4.65
MLLW (m)	-20.55	-20.59	-0.04	0.77
Range	2.91	3.02	0.11	3.88
MSL (m)	-18.78	-18.79	-0.01	3.1
Chart Datum (m)	-21.076	-21.20	-0.12	N.A.

In 2007, NAVOCEANO acquired three more buoys from AXYS Technologies Inc., with a reduced size of 0.6 m diameter and a weight of only 58 kg (Figure 7). These buoys are much easier to deploy from any vessel, including a survey launch. These buoys are similar to their larger predecessor but instead use non-rechargeable lithium thionyl chloride batteries. Power consumption is still expected to allow for 20-day deployments. The P&TB can be moored in waters as deep as 150 m. An added feature of these buoys is the capability to monitor their moored locations through the use of the NCT-2050 GPS receiver coupled with the AXYS buoy mooring WatchCircle® Alarm. Further testing of these buoys is scheduled for this summer.

Figure 6. The 0.9-meter buoy with Tri-band Antenna (GPS L1/L2 and INMARSAT L-band) and solar panels.

Figure 7. The 0.6-meter buoy, only 58 kg.

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 shore-dependent hydrographic survey operations. Furthermore, hydrographic information is essential to meeting the goals of the IPE. 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/simulation forecasts for battlespace awareness. 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 to IHO accuracy standards. Although the accuracy limitations of the Range-Ratio Datum transfer methodology with short-term tidal observations require more sensitivity analyses, the method appears sufficiently accurate in coastal areas. 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. This new level of three-dimensional absolute positional accuracy should prompt a review of how bathymetric measurements are processed, archived, and presented.

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