

RAPID DIGITAL NAUTICAL CHARTING FOR MILITARY NAVIGATION

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ABSTRACT

The United States Navy stands at the brink of transition from traditional navigation with paper charts to computer-based electronic charting. The Naval Oceanographic Office (NAVOCEANO), collector of worldwide hydrographic data for 171 years, is posturing to support this transition with upgrades to state-of-the-art survey ships, instrumentation, and processing equipment. Recently, the Navy's Fleet Battle Experiment - Hotel (FBE-H) provided an opportunity to demonstrate the Office's ability to rapidly update existing Digital Nautical Chart (DNC®) products with hydrographic survey data and produce an updated field DNC®, a prototype Electronic Navigational Chart (ENC), and four static and three dynamic Additional Military Layers (AMLs). Input data included information from other GIS software, multibeam data, side-scan sonar-detected targets, aerial photos, airborne lidar data, and other oceanographic information. The updated field DNC®, prototype ENC, and AMLs were built for a Naval exercise area near Panama City, Florida, from data contained in National Imagery and Mapping Agency DNC® 15, Edition 10, Library A1508750. Another very important objective of FBE-H was to promote awareness of electronic charting issues and current commercial navigation technology. Digital navigation information was provided to the Commander, Second Fleet's flagship, USS MOUNT WHITNEY, USS HARRY S. TRUMAN, two U.S. Navy submarines, and mine warfare participants, both ashore and afloat. The results of this demonstration were quite successful; NAVOCEANO final navigation information was delivered to exercise participants within 60 days of the hydrographic survey.

INTRODUCTION

The Naval Oceanographic Office (NAVOCEANO), located at Stennis Space Center, Mississippi, has 171 years of hydrographic and navigation experience with a focused investment in state-of-the-art hydrographic ships, services, and products. NAVOCEANO operates eight multipurpose survey ships, of which six are of the new T-AGS 60 class, arguably the world's finest oceanographic ships afloat. Furthermore, NAVOCEANO has maintained high standards in the hydrographic community by implementing state-of-the-art oceanographic sensor developments, GIS utilization, data visualization, and high-speed data processing facilities and by building technical expertise with International Hydrographic Organization (IHO) certified Category A and Category B programs in hydrographic science. The Category A course is a one-year master's degree program jointly conducted with the University of Southern Mississippi. In addition, NAVOCEANO has maintained a commitment to the international hydrographic community through its international Hydrographic Cooperation

(HYCOOP) Program, which assists foreign nations in conducting hydrographic surveys and producing nautical charts. NAVOCEANO also participates in IHO working groups and other international activities to further advance hydrographic science.

Producing nautical charts and navigational products at sea to directly support naval operations has been a fundamental U.S. Navy capability since World War II. It was recognized early on that the normally conservative procedures for processing and validating survey data and for shore-based chart production were too lengthy for supporting the rapid pace of military operations. During World War II, the Vietnam War, and the Gulf War, nautical charts, called field charts, were produced aboard hydrographic survey ships as soon as processed hydrographic data were available to shorten the normal chart production process. Survey ships up to and including the USNS CHAUVENET (T-AGS 29) and USNS HARKNESS (T-AGS 32), which served from 1970-1991, used a photolithographic process that included a multicolor offset press for onboard production. More recent efforts by USNS JOHN MCDONNELL (T-AGS 51) and USNS LITTLEHALES (T-AGS 52) have used Intergraph MGE software and work-stations with Hewlett-Packard 750C plotters to produce onboard field charts. In August 1999, NAVOCEANO personnel aboard USNS LITTLEHALES surveyed the entire coastline of Jordan, processed the data, and produced two field charts (scales at 1:5,000 and 1:10,000) of the port of Aqaba and approaches within a span of 30 days. An important caveat, however, is that field charts, due to time constraints, are compiled from survey data which has not necessarily completed the full validation process, and therefore, distribution is limited to ships and military units with immediate needs. Once the survey data have been completely validated, the data are forwarded to the National Imagery and Mapping Agency (NIMA) for incorporation into standard chart products in accordance with the programmed chart revision or update cycle.

As navigation technology has changed from paper nautical charts to digital electronic charts, NAVOCEANO has implemented changes to support naval operations in the digital age and has established the following capabilities as part of its mandate to support the Fleet:

- ❑ Highly mobile data collection assets capable of supporting immediate Fleet needs. These include the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system and the Fleet Survey Team (FST).
- ❑ Significant speedup in the processing, editing, and validation of multibeam sonar and side-scan sonar data using a suite of NAVOCEANO and contractor-developed processing software capable of achieving a 4:1 collection time to processing time ratio.
- ❑ Construction in FY2001 of a Survey Operations Center capable of downloading survey data directly from survey ships anywhere in the world using C/Ku Band satellite links capable of 2 megabit/second transmission rates from ship to shore.

- ❑ A Digital Nautical Chart (DNC®) co-production program with NIMA for rapid turnaround of digital navigation information from survey to chart delivery for use by the Navy version of the Electronic Chart Display and Information System (ECDIS-N), other ECDIS, and Electronic Charting Systems (ECS).
- ❑ The means to rapidly produce and disseminate battlefield visualization of digital hydrographic and other tactically significant data layers to support ECDIS-N and shipboard Command and Control systems.

This paper will focus on discussing the last two objectives.

ELECTRONIC NAVIGATION IN THE U.S. NAVY

The Chief of Naval Operations (CNO) has mandated that all U.S. Navy ships will navigate strictly through electronic means by FY07. However, affected by several highly publicized groundings and collisions of its ships, such as, the USS LA MOURE COUNTY (LST 1194) grounding in Chile last year (Figure 1), the Navy is considering speeding up the full implementation of electronic navigation to FY04. In an effort to focus navigation issues for the U.S. Navy and to facilitate this acceleration of electronic navigation into its Fleet, the CNO has recently added the title and responsibilities of “Navigator of the Navy” to the Oceanographer of the Navy, RADM Richard West.



Figure 1. USS LA MOURE COUNTY aground in Caleta Cifuncho Bay, Chile after navigating with GPS (WGS-84 datum) on a local chart on local datum. The Navy has decided to write off the 29-year-old, 561-foot vessel and sink it.

The system being defined to display electronic charts for the U.S. Navy is called Electronic Chart Display and Information System-Navy (ECDIS-N). In addition to using electronic chart data, ECDIS-N will integrate a variety of other navigational sensors including GPS/DGPS, surface-search radar, gyrocompass, fathometer, and other pertinent navigational information on one display. The functional requirements and performance standards are closely modeled after the International Maritime Organization (IMO) standards for ECDIS. Recent NAVOCEANO initiatives have resulted in ECDIS-N performance standards being modified for a “multifuel” capability that displays not only the DNC® but also the Electronic Navigational Chart (ENC) and the Raster Nautical Chart (RNC). This will enable U.S. Navy ships to employ the best navigational charts available, particularly when operating in overseas areas of emerging interest. In addition,

based on a NATO Standardization Agreement (STANAG) for Warship ECDIS (WECDIS), there will be Additional Military Layers (AMLs) to supplement the core electronic chart data with tactically significant data layers. This fusion of information will greatly improve the situational awareness of the ship's crew, particularly in support of littoral warfare missions, such as mine and amphibious warfare.

The primary source for navigational data displays will be the NIMA DNC®. Interoperability between the maps and charts of air, land, and sea forces, is essential for joint military operations; therefore, NIMA decided to use the NATO Digital Geographic Information Exchange Standard (DIGEST) instead of the IHO S-57 data exchange standard. The DNC® is an unclassified, vector-based, relational, digital database containing significant maritime features essential for safe marine navigation and is distributed on 29 CD-ROMs. The DNC® portfolio was initially produced by digitizing approximately 5000 paper charts and consists of over 2400 digital chart libraries. The database is structured using the NIMA Vector Product Format (VPF), which distributes the data into 12 thematic layers and uses the Feature Attribute Coding Catalog (FACC) to encode chart features and associated attributes. Currently the DNC® cannot be used for navigation because it has not been brought into routine updating. The current technique under development for updating the DNC® is the "patch" method. This is a binary difference file, estimated to be 2KB to 1MB in size, that is created by differencing an updated DNC®, called the "Gold Copy" with the base DNC®. Patch files will be "pushed" to the end user or "pulled" from the NIMA Navigational Safety System website for application to the ships' ECDIS-N systems. Additional information is available at the NIMA website (www.nima.mil/dncpublic).

PROVING RAPID CHARTING CONCEPTS - FLEET BATTLE EXPERIMENT - HOTEL (FBE-H)

Survey Operations and Survey Data

In order to prototype the concepts of the above objectives, NAVOCEANO participated in the preparatory phase of Fleet Battle Experiment - Hotel (FBE-H). FBE-H was a Naval Warfare Development Command experiment conducted by the Commander, Second Fleet that experimented with the operational and tactical level of war in the 2005 to 2010 time frame. It was part of a larger all-service experiment held in the southeastern United States from mid-August to September 2000. The Commanding Officer of NAVOCEANO, Captain Tim McGee, initiated a program to demonstrate NAVOCEANO capabilities and expertise to support rapid Fleet navigation requirements via FBE-H. The major NAVOCEANO objectives to support FBE-H were:

- ❑ Demonstrate an ability to rapidly update a NIMA DNC® library with NAVOCEANO survey data. The ambitious time goal from survey to product was set at one month.
- ❑ Demonstrate an ability to rapidly produce other digital navigation and tactical products, i.e., ENC and AMLs.

- Promote WECDIS performance concepts on existing commercial ECDISs, including the capability for “multifuel” chart sources and to display AMLs.

From 30 May to 12 June 2000, NAVOCEANO conducted hydrographic surveys near Panama City, Florida in a Mine Warfare (MIW) exercise area. An inshore area was first surveyed for three days using the SHOALS system, which is mounted on a Twin Otter aircraft. Then USNS HEEZEN (T-AGS 64) and its two embarked hydrographic survey launches (HSL) surveyed for five days, 8 to 12 June, in adjacent areas. HEEZEN collected soundings, acoustic backscatter, bottom objects, water column properties (CTD, XBT, SST/SV), tidal, currents, 3.5-kHz sub-bottom profiles, and bottom sediments data.

SHOALS is a U.S. Army Corps of Engineers (USACE) owned, contractor-operated survey system managed by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) of which NAVOCEANO is a member. The SHOALS lidar collects 2.5 nmi² of depth data per hour in a 4-m horizontal grid, flying at 110 kn and 300-m altitude. Data density can be adjusted by flying higher or lower, at different speeds, or by selecting different scan widths. Additional information is available at the JALBTCX website (www.SHOALS.sam.usace.army.mil). The SHOALS System had just returned in April from supporting the NATO exercise LINKED SEAS 2000 in Portugal. This exercise aimed at accelerating military reaction strategies for crisis response, peace support, and humanitarian operations, possibly conducted beyond the normal NATO area of responsibility.

USNS HEEZEN is 329 ft long with a displacement of 4700 L.T. and has diesel electric propulsion with twin props, retractable bow thruster, and Z-drive. A contract crew of about 25 personnel operated the ship, supplemented with a NAVOCEANO scientific party of about 13 personnel for conducting surveys. The HEEZEN is equipped with the Science Applications International Corporation (SAIC) Integrated Survey System (ISS-60) for data collection. The major survey sensors used for producing the chart products were the Simrad EM 1002 multibeam sonar and the Klein 5000 side-scan sonar (SSS). HEEZEN carried two 34-ft HSLs each equipped with its own SAIC ISS-60 acquisition system that integrated a Simrad EM 3000 multibeam sonar, Data Sonics side-scan sonar, SeaBird CTD, and Tasman GPS. These highly capable launches collected 3 million soundings per hour.

During the FBE-H survey operation, HEEZEN, which was brand new and still in its sea trial period, was not an operational survey ship. However, because all of NAVOCEANO’s operational survey ships were forward deployed, HEEZEN was the only platform available. Consequently, the crew had never conducted HSL launch and recovery operations, nor steered survey lines. A greater impact, however, was that the EM 1002 multibeam sonar system, due to a lack of time, had not been thoroughly tested prior to the survey. Unfortunately, the POS MV attitude sensor was not operating properly and even after extreme attempts to adjust the data, the survey team had to reject the outer beams. Also, a beta version of the NAVOCEANO Bathy-Hydro Post Processing Area Based Editor (ABE) was used to process the multibeam and lidar data for the first time. It worked quite well but required our surveyors to learn new skills.

And finally, the survey was plagued with both shipboard and in-office data network management and memory systems that gridlocked on the avalanche of multibeam depth and backscatter data and side-scan sonar imagery. These problems contributed to missing the ambitious timeline of survey to chart product in 30 days. However, quality products were delivered by 30 July, 60 days, prior to the FBE-H exercise, considerably beating the normal two-year production process.

Digital Chart Compilation

NAVOCEANO contracted for CARIS software engineering services and purchased several CARIS modules for producing the DNC®, ENC, and AML products, including CARIS HOM, DOM, DTM, GIS, and Suppress Soundings. The CARIS tools were also used to produce a variety of other products such as a sun-illuminated shaded relief image of high-resolution bathymetry and Raster Nautical Charts in National Oceanic and Atmospheric Administration (NOAA) BSB and unencrypted British Admiralty HCRF formats. These tools were mainly used in compiling the soundings, creating and editing bathymetric contours, and re-arranging the geometry of linear features to achieve proper topology. Presentation rules for most of the AML features were derived using the GEOSYM 4.0 symbol set. The S-52 presentation rules were used in other cases. The survey data collected onboard were combined with a variety of other source data that had previously been collected and processed from other government sources. Figure 2 is a screen portion of NAVOCEANO Field DNC® Library A1508750 (Panama City, FL).



Figure 2. Field DNC® Library A1508750 displayed using NIMA FUND software.

To the best of our knowledge, this was the first time a mapping from DNC® to ENC has been implemented in an operational environment. The DNC® approach tile scheme was used, which suits charts of scale between the range of 1:25,000 to 1:100,000. The geometry and layer schemes of DNC® coverages were suitable for use with the ENC. Also, some of the DNC® polygons were re-grouped into a single layer to form the

“Skin of the Earth” layer, or Group One feature objects. The requirements for ENC are very strict with regard to co-linear geometry and prohibit the duplication of vectors. Some of the CARIS HOM/DOM filters were applied to correct this, while the remaining co-linear lines were corrected interactively. Figure 3 is a screen portion of the NAVOCEANO Field ENC for Panama City FL. Appendix A describes the chart compilation and data processing workflow in more detail. The reader is advised to consult with the CARIS web pages (www.caris.com) to obtain more detailed description of the ENC and DNC® production work through various on-line technical papers. With the availability of worldwide coverage of the NIMA DNC®, foreign hydrographic offices may find that ENC production may be much easier if starting from the DNC® rather than producing an ENC from “scratch.” Interested hydrographic offices are advised to contact NIMA.

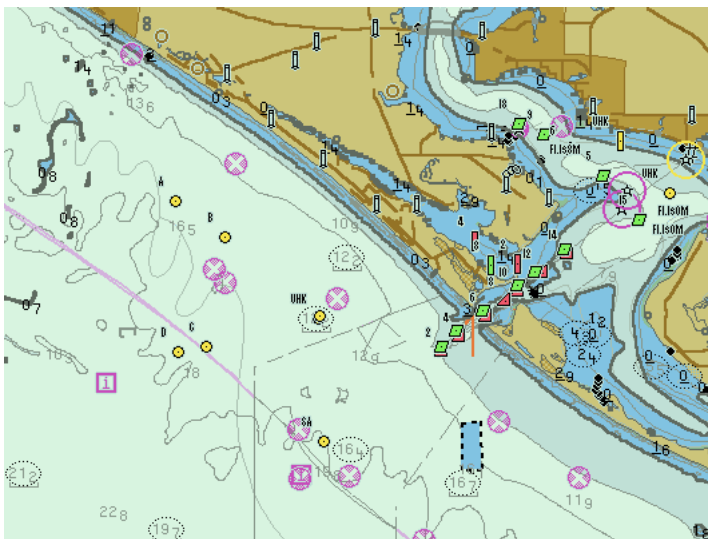


Figure 3. Field ENC for Panama City FL displayed on Seven Seas See My ENC software.

Finally, both static and dynamic AMLs were developed. The static layers consisted of MIW operating area boundaries and geometry, high-resolution hydrographic soundings at 50-m spacing, bottom objects discovered by the Klein 5000 and Data Sonics side-scan sonars, and sediment type provinces (Figure 4). The computer display of the high-density soundings AML in vector format was quite cluttered, incomprehensible due to the enormous number of soundings displayed on the screen, and made a very large-sized file. It is recommended that a raster format be used to represent the high-density soundings AML. The raster image provides a more comprehensible display of bottom relief and tactically significant features (Figure 5). Time-varying AMLs originated from NAVOCEANO’s Warfighting Support Center and consisted of satellite-observed sea surface temperature (updated daily), wave height predictions from a shallow-water wave model (updated twice daily), and tide current direction and speed from a tide model (updated every 3 hours). The time-varying AMLs were electronically sent using file transfer protocol (FTP) aboard ship, and then transferred using a computer disk to the ECDIS and ECS processing and display (Figure 6).



Figure 4. Static AMLs overlain on a Field DNC® of Panama City, FL displayed on Offshore Systems Ltd. (OSL) ECPINS. Shown are operational areas, bottom targets, and sediment contours.

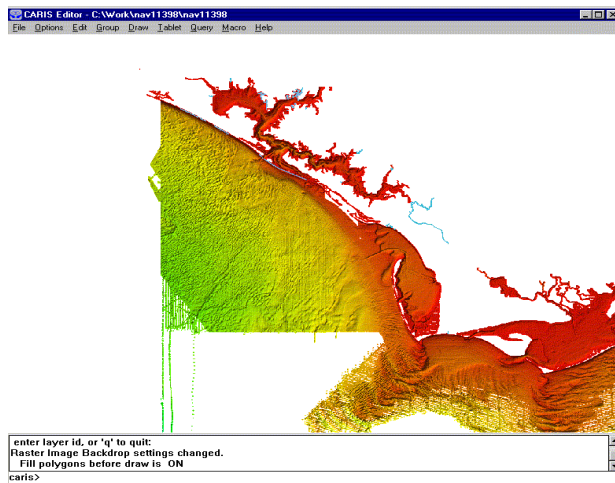


Figure 5. Raster image of high-resolution bottom bathymetry displayed on CARIS GIS software.



Figure 6. Dynamic AMLs overlain on a Field DNC® of Panama City, FL displayed on OSL ECPINS. Displayed using text are sea surface temperature, wave heights, and current speed and direction. Also shown are several static AMLs.

FBE-H: Active Phase

NAVOCEANO delivered the final CD-ROMs containing the updated DNC®, the ENC. and the static AMLs to Experiment participants on 30 July 2000 within 60 days of the commencement of survey operations. During the exercise phase of FBE-H, the NAVOCEANO chart products were used on navigation display systems on the Second Fleet flagship, USS MOUNT WHITNEY, aircraft carrier USS HARRY S. TRUMAN, two submarines, and Mine Countermeasure ships (MCM) USS CHIEF, USS SCOUT, and USS DEVASTATOR. Aboard the USS MOUNT WHITNEY, a variety of commercial systems were used to display the information. These included Offshore Systems Limited Electronic Chart Precision Integrated Navigation System (*ECPINS*®), Kelvin Hughes' Navigation Chart Display (NCD), TRANSAS Marine *NaviSailor 2400*® and the Litton Marine's Voyage Management System software on a laptop system. Additionally, NIMA's Full Utility Navigation Demonstration (FUND) software version 2.5.4 was aboard for chart display. Even though the USS MOUNT WHITNEY did not get underway for this Experiment, a GPS-simulated track run through the electronic chart data was shown on all four COTS electronic chart systems. This team of commercial and government systems provided a clear indication of state-of-the-art navigation technology for a host of FBE-H visitors and VIPs. In a post-experiment message, VADM Fallon, Commander of the U.S. Navy's Second Fleet, highlighted NAVOCEANO's FBE-H electronic charting initiative, *"using advanced hydrographic data processing techniques, the Naval Oceanographic Office (NAVOCEANO) performed hydrographic surveys of the MIW OPAREA (Mine Warfare Operating Area) and accelerated chart production in support of MIW operations. An updated Digital Nautical Chart (DNC) and additional layers of environmental information for display on Electronic Chart Display and Information Systems (ECDIS) onboard MCM ships and USS MT WHITNEY were provided for use."*

PARTNERSHIP IN DNC® CO-PRODUCTION

On 15 November 2000, a Memorandum of Agreement was signed between NIMA and NAVOCEANO under which NAVOCEANO would assume the responsibility to compile specific DNC® libraries. An objective for co-production is to provide quality DNC® products to the Warfighter that meets their high-priority navigational and operational requirements in the shortest possible time. These libraries would consist of those directly affected by NAVOCEANO surveys, either with Navy survey platforms or with survey vessels cooperating under the HYCOOP Program. Upon completion of the compilation and after rigorous quality control, the libraries would be sent to NIMA for general dissemination as part of the NIMA chart maintenance and update program. To support immediate military operations, NAVOCEANO may also provide an onboard field version of the DNC® and provide it directly to affected military units. Also, the DNC® Field Chart compilation may be used to produce an ENC in partnership with HYCOOP and foreign host nation hydrographic offices. Such production/co-production would be subject to the terms of separate bilateral international agreements.

Initial production efforts have been modest due to a start-up process that involved learning many new skills and because of the small number of available personnel allocated to the NAVOCEANO DNC® chart production program. In late February 2001, NAVOCEANO delivered an updated, larger-scale DNC® Library H509300 (Figure 7) for Ingleside, TX to support MCM ships based there. The Jewell Fulton, La Quinta, and parts of Corpus Christi Channels were resurveyed by the NAVOCEANO FST in November – December 2000, and this new data was used in the new DNC® revision. As of this writing, two new DNC® libraries are under production for Saipan with a due date of end-March to address immediate Pacific Fleet requirements. SHOALS and USNS SUMNER conducted survey operations there in January through mid-February 2001 with tidal support provided by NOAA. With the existing level of resources, eight NAVOCEANO-compiled DNC® libraries are planned this fiscal year.

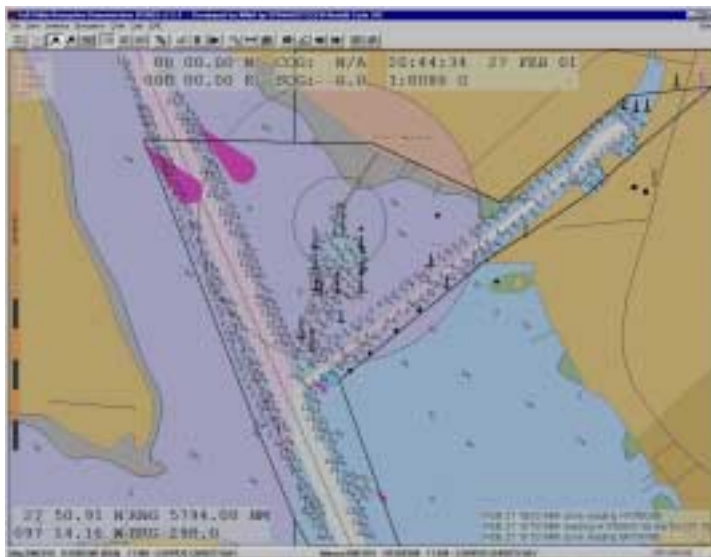


Figure 7.
Co-produced revision
of DNC® Library
H509300 of Ingleside
TX displayed using
NIMA FUND
software.

ECDIS-N DATA PRODUCTS DEVELOPMENT LABORATORY

In FY00 and FY01, resources were used to develop capabilities to rapidly collect and process hydrographic survey data and quickly build new electronic nautical charts critical for safe navigation and tactical digital overlays for battlespace awareness. Plans exist to continue and expand these capabilities in a joint effort with University of Southern Mississippi's Hydrographic Sciences Research Program by constructing an ECDIS development laboratory and navigation technology demonstration center. This laboratory will be used to conduct quality control and testing of electronic chart products from NAVOCEANO and other providers and assist Navy ship personnel with understanding and correctly using these products to safely navigate and operate in the shallow littoral areas of the world. Furthermore, the laboratory is envisioned to become an information clearinghouse and demonstration center on available electronic chart products and technological advances in electronic navigation techniques and commercial-off-the-shelf ECDIS. The demonstration center would showcase the use of electronic charts and the resulting capabilities commonly used today to avoid groundings and

collisions at sea. It would demonstrate the use of tactical digital overlays to provide bridge crews with critical military information affecting safe navigation. Finally, it would focus on understanding the limitations of using the vast majority of very impressively colorful electronic charts, produced by both the government and private sector, that are seriously flawed with hidden dangers due to the use of century-old hydrographic source data.

CONCLUSION

As the U.S. Navy migrates into the digital navigation era, NAVOCEANO has taken the initiative to provide essential navigation and tactical data products to support Fleet operations. FBE–Hotel provided the venue for NAVOCEANO to showcase the modernization of its hydrographic and oceanographic collection capability, its ability to accelerate the processing, editing, and validation of collected data, its Digital Nautical Chart production program, and its ability to produce both static and time-varying additional layers of environmental information. FBE-H tested the Office’s ability to rapidly survey, process, and produce digital navigation information for display on commercial and existing fleet electronic charting systems. In responding to this challenge, NAVOCEANO has clearly postured itself to meet the demand by operational Navy ships and submarines for current, accurate digital navigation information.

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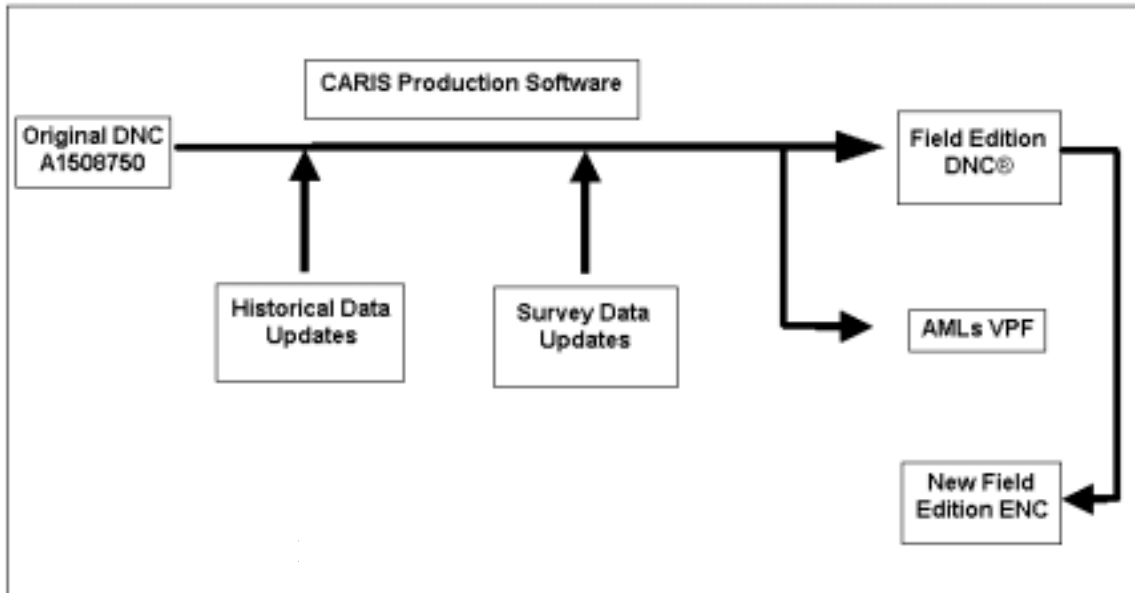
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APPENDIX A CHART COMPILATION AND DATA PROCESSING WORKFLOW



A summary of the processing steps for Figure A-1 follows (van Norden et al, 2000):

- Step 1: Import Original DNC® into CARIS mapping environment.
- Step 2: Import historical and new survey data for compilation. GSF, Lidar XYZ, ArcView E00, etc. data were imported using various batch utility tools. User defined parameters were set to map the various features to necessary layers within the CARIS environment in preparation for chart compilation.
- Step 3: Cut compilation map into DNC® tile scheme and update tiles. Once compilation was completed the data were merged with the original DNC® tiles and the objects were restored using new geometry. New features, including AMLs, were turned into new DNC® objects. Old tiles were replaced using an automated process. Finally, the DNC® Library was updated.
- Step 4: Change VPF tables so that new AMLs and FACC enhancements are effective. A new FACC was created through an interactive editor. VPF tables were edited for structure and content and then rebuilt.
- Step 5: Conversion of DNC® tiles to ENC cells. A combined DNC® / ENC object dictionary was generated. A lookup table was set up to automatically convert DNC® features to ENC objects. Objects were assigned to the necessary layers for ENC production. Once completed and the topology checked, the objects were written to the S-57 exchange dataset.