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Littoral Environmental Sensing Architecture (LESA) Report—The Current State of Sensing Capability for Naval Special Warfare METOC Support

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14. ABSTRACT

This study describes the Naval Special Warfare littoral sensing gaps and requirements, both in-situ and remotely sensed, and the environmental impacts affecting the warfighter. Topics include a review of warfighter requirements, concept of operations, available commercial off-the-shelf sensors, communications and capability development.

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1.0 INTRODUCTION

"Almost everything that could go wrong did go wrong during this operation. A Navy SEAL reconnaissance mission floundered in heavy seas and four of the SEALs drowned after a night combat equipment water jump in the ocean about 40 kilometers off the north-northwest tip of Port Salinas, Grenada. They were dropped into the teeth of a squall along with a "Boston Whaler" from an Air Force C-130 and immediately went under."[1]

Naval Special Warfare (NSW) encompasses some of the most unique and arduous challenges confronting naval personnel in combat situations, due in part to the dynamic nature of the littoral environment in which Sea, Air, and Land (SEALs) forces perform their work. Environmental data and *in situ* information play a pivotal role in properly assessing the viability, safety, and hazards of each mission. This knowledge is an integral part of the pre-deployment planning process and is crucial to real-time operations.

Accurate measurements of wind, seas, swell, tides, and nearshore currents are just a few of the critical meteorological and oceanographic (METOC) elements needed by the warfighter to properly determine whether to proceed with an operation. Transit through riverine environments requires thorough knowledge of the environmental conditions, particularly water depth and current velocity, and the probable ranges of these elements based on rainfall rates and tides.

Currently, environmental parameters are only estimated during the mission planning process using available remote-sensing capabilities and techniques. There is no maritime METOC sensing architecture, either at the operational or tactical level. This report defines the sensing architecture as a well defined plan for setting up specified instruments to measure the littoral environment and maximize information output. Forecasters embedded within NSW units are responsible for providing tactical METOC support for the SEAL teams. When data are lacking, embedded forecasters resort to 'filling in the blanks' by employing rudimentary manual methods and/or using coarse-scale, synoptic models to predict microscale, littoral processes.

NSW operations typically occur in demanding environments, forcing the Navy to discover new and unconventional METOC support methods. Further, communications are severely hampered due to unreliable and fickle bandwidth information transfers, preventing timely reachback support. These are major obstacles with no immediate solution.

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[1] United States Pysop in Grenada, SGM Herbert A. Friedman (Ret.)

Manuscript approved October 7, 2009.

Though the Navy is rapidly developing networked capabilities and service-oriented architectures, NSW support is essentially in a bandwidth-constrained environment, especially on submarines.

Future METOC decisions at the tactical level will be focused on rapid environmental assessment of *in situ* METOC sensing and tactical decision aids (TDA) by the embedded Navy forecaster. Techniques must be developed for combining numerical model prediction with environmental observations and tailoring that product for transfer in bandwidth-constrained environments. This entails deciding what information is needed, prioritizing it, and then sending it to the on-scene METOC support.

1.1 Statement of Purpose

NSW requires sensing, fusion and integration capabilities to increase mission effectiveness and safety for naval expeditionary war fighters in Overseas Contingency Operations (OCO). This document stresses NSW's littoral oceanographic sensing gaps and requirements, both *in situ* and remotely sensed, and the environmental impacts affecting the warfighter.

1.2 Executive Summary

Representatives from the QinetiQ North America (QNA) Technology Solutions Group have met extensively with NSW commanders, planners, and METOC support personnel to assess the current and future needs of the NSW community with respect to meteorological and oceanographic sensing in the nearshore zone. The nature of NSW operations in littoral and riverine environments requires microscale forecasting techniques. Reliable environmental battlespace characterization is necessary for determining route planning, platform selection, execution timeline, sensor placement, objective action, and gear selection. Currently, Navy forecasters stationed within SEAL teams do not possess an 'on-scene' capability to measure METOC elements such as currents and wave spectra.

The following five points summarize the overall littoral environmental sensing requirements of NSW:

1) Deployment of wave/current sensing capabilities through METOC Theatre Sensing Plans. This is contingent upon the classification of the mission.

2) Development of *in situ* wave/current sensing capabilities for the embedded forecaster serving deployed SEALs.

3) Sensors must be very small, with minimal or disguised surface signature, un-attributable[2], generally expendable, and easily deployed.

4) Improved high-resolution remote sensing, such as satellite and Unmanned Vehicle (UV) technology, in the coastal and riverine environments. There must be capabilities to:
   a. decipher wave and current patterns qualitatively and quantitatively;
   b. resolve bathymetry to force high-resolution models; and
   c. determine accurate water levels and depths and provide accurate estimates of river current flow.

5) Further development of *in situ* sensing. These data are necessary for calibration and validation of hydrodynamic models and remote sensing technologies.

[2] This is meant to infer that if the sensor is found it cannot be traced to the US Military, and any data found cannot be destroyed or copied.

2.0 REQUIREMENTS

NSW "requires an expeditionary sensing, fusion, and integration capability to increase mission effectiveness and safety for Naval expeditionary war fighters…" [1]. It is widely known that inaccurate environmental knowledge or a lack thereof will result in mission failure. The Naval Oceanography Operations Command (NOOC) supports NSW through the Naval Oceanography Special Warfare Center (NOSWC), who, in turn, provides meteorological and oceanographic data for tactical, operational, and strategic advantage during mission planning and execution [2].

Table 1 outlines several of NSW's Mission Critical METOC Parameters. Knowledge of these parameters (hydrography, tides, currents, waves and surf, visibility, wind, and temperature) prior to mission execution provides a decisive advantage for all operations in the littoral environment. Ideally, climatological ranges of each parameter are analyzed during the feasibility and mission-planning process. Operational support is derived and briefed to NSW operators by an on-scene METOC expert using available tools to forecast METOC environmental conditions on short-range time scales. For example, the organic METOC expert will utilize available model data and pre-loaded guidance and operational TDAs to directly support operators on-scene. Appendix A details the instrumentation available to meet these required parameters.

Table 1: Mission Critical METOC Sensing Requirements.

Parameter	Details	Rationale
Hydrography/Bathymetry	Very shallow water, harbors, and inland waterways (rivers, estuaries, lakes, etc.) to include natural and manmade obstructions and bottom type	Affects boat, platform, and swimmer route planning and influences modeling of other parameters.
Tides	Currents, heights, and times	Affects route planning, detection, and navigation.
Currents	Littoral, surf zone, and open ocean to include all depths	Affects navigation, swimmer capabilities, and overall mission execution.
Waves and Surf	Height, direction, and periodicity	Affects route planning, launch and recovery, sea keeping, and overall mission execution.
Visibility	Atmospheric: slant range, cloud cover, and ceiling heights; Oceanographic: diver, combat swimmer	Affects detection, counter-detection, and target acquisition.
Winds	Surface and aloft	Affects personnel safety and overall mission planning considerations.
Temperature	Atmospheric to include surface temperature	Affects personnel safety and equipment.
Bioluminescence	Bioluminescent potential	Affects counter detection.

Parameter	Details	Rationale
Light and Illumination	Daily solar and lunar illumination	Affects diver visibility and counter detection.
Electro-Magnetic/Electro-Optical Performance	Inherent optical properties (IOPs); magnetic properties	Affects environmental sensor performance.
Precipitation	Amount of rainfall and frozen precipitation	Affects water clarity, river flow rates, and depth.

2.1 Warfighter/Operator

Kenneth H. Brink, a former Chair of the Ocean Studies Board of the National Research Council (from 1996-2001), appropriately states: "…SEAL teams, more than any other special warfare unit, depend on environmental information to obtain a tactical advantage in the field. Consequently, oceanographic and meteorological information can be as important to a SEAL team as any single piece of equipment in its arsenal."[3]. For example, strong winds blowing over the ocean can develop high/steep seas too large for operations in a small craft. High seas have orbital currents below the sea surface, often to the point where offloading a SEAL Delivery Vehicle (SDV) from a submarine or a rigid hull inflatable boat (RHIB) from a surface ship (Figure 1) is either too dangerous or impossible. High seas or swell may prohibit grounding a SDV in nearshore waters due to excessive motions or cause seasickness to transiting SDV personnel, requiring alternative dive plans. When swells enter the surf zone and become breakers, water is forced around the littoral area, inciting rip and longshore currents with speeds of several knots. Tidal currents must also be considered, especially when they exceed speeds of one knot, a critical threshold value for a combat swimmer. Tidally induced currents in tight reef gaps can also reach speeds exceeding critical threshold values, which will halt SDV and combat swimmer operations. In one exercise, tidal currents were flowing at roughly one knot over a particular area, but between a reef pass where a seafloor sensor was to be secured, currents were estimated at 3-4 knots, requiring a new sensor location. In this case, having prior knowledge of areas where strong currents can hamper sensor installation saves both time and money.

Figure 1: SEALs leaving a RHIB, U.S. Navy photo

The riverine environment is highly dynamic due to precipitation from a large geographic area being concentrated into a relatively narrow channel. Rainfall occurring well inland can have major effects on the watershed downstream. Depending on the tidal cycle, currents can accelerate or slow through an area in response to river flow. Additionally, when cold, fresh water runs out of a river mouth, density-driven eddies can form and spread down coast. Model simulations of snowmelt and short, fast bursts of fresh water entering the ocean can vividly illustrate the often complicated anomalies to normal flow.

Convective weather conditions can rapidly change the riverine environment, leading to flash floods and radically stronger currents over a short time span. Fluctuating river levels and water depths must be determined to insure vessel safety of navigation. The recent drowning of a SEAL tragically swept downriver in Afghanistan during a combat operation underscores the critical need for a firm situational awareness (SA) of the riverine battlespace. Riverine forecasting, therefore, must take into consideration the magnitude of the entire watershed system and the vast amounts of water collecting and moving downstream. These characteristics make accurate prediction of conditions in rivers, river mouths, and nearshore environments complex and challenging, and as a result they must be anticipated and planned for well in advance.

The warfighter/operator requires accurate METOC predictions prior to disembarking the platform to ensure mission success and safety. Equipping the organic forecaster with real-time METOC sensing capabilities significantly improves his ability to provide the best recommendations for ensuring the safety and success of the SEAL team and their missions in riverine areas and the open sea. Table 2 gives some examples of basic mission critical environmental parameters of select NSW assets.

Table 2: Mission Critical Environmental Parameters.

	Winds (KT)	Currents (KT)	Waves (FT)	Bathymetry
SDV	N/A	> 2.5	>3 Combined	Significant
Combat Swimmer	N/A	> 1	> 5	Significant
CRRC	N/A	Minimal	> 4	Significant
RHIBS, MK V	> 35	Minimal	> 10	Significant

Note that the wave threshold values from Navy standards listed in Table 2 are vague and non-specific for properly delineating NSW impacts. Not only must wave height be specified, but also wave steepness, period, and type. For example, wave steepness is a primary concern for threshold wave heights in deep water. According to Table 2, a wave height greater than four feet is considered critical for a Combat Rubber Raiding Craft (CRRC) (See also Figure 2). But in reality, only a short-period, steep wave reaching this threshold in deep water makes CRRC transit uncomfortable and potentially unsafe. Conversely, four feet of long-period swell with a low steepness has minimal impact in deep water, rolling gently underneath the boat’s hull. The balancing act of communicating when a projected wave height exceeding the textbook critical value will or will not affect a mission is a great challenge for embedded METOC personnel. To make this call, the forecaster must spectrally analyze the sea state, either by visual means, a wave gauge, or from Fleet Numerical Meteorology and Oceanography Center (FNMOC) Spectral Wave Bulletins (SWB). Also, the environmental characteristics of the area of interest (AOI) must be specified as open ocean, littoral, or riverine, because mission critical values may vary for different locations. As a result, many NSW units have developed internal thresholds that deviate slightly from the official mission critical parameters in Table 2. A more comprehensive chart is needed that includes wave period and wavelength.

Bathymetry is a critical parameter for supporting NSW forces, especially in riverine and littoral environments, but it is often challenging to acquire. Because wave and current activity are largely driven by the bathymetry in the littoral zone, bathymetric and hydrographic soundings are particularly important to littoral operations. Unfortunately, without a good bathymetric database for a given area, accurate forecasting of any oceanographic parameters is extremely challenging, if not impossible.

Navigational planning for NSW teams is also highly dependent on water depth (Fig. 2). Accurate bathymetry is critical for preventing contact with unknown obstacles, which cause delays to operator timelines, prevent access to necessary locations, or cause safety hazards. For some operating areas, hydrographic charts still in use are almost 80 years old.

Figure 2: SEALs in a CRRC, U.S. Navy photo.

2.2 Mission Planning

The mission planning process is crucial for METOC personnel supporting NSW. The warfighter/operator requires accurate knowledge of the particular environmental parameters that will affect an operation during mission planning, prior to disembarking, and throughout the actual mission. Intensive study by Naval METOC and Intelligence (INTEL) groups yields a report called the Target Intelligence Package (TIP). The METOC portion of the TIP provides an accurate and comprehensive picture of the anticipated battlespace environment. Under most conditions, METOC support does not have direct and detailed environmental measurements from which to characterize the AOI, but relies on available background information/climatology for a particular area provided by reachback centers. This includes estimations of ranges for numerous METOC parameters along with detailed annotated aerial imagery.

Figure 3 displays some variables that aid in Mission Planning. Improving remote sensing capabilities, including increasing resolution and enhancing algorithms to extract pertinent littoral zone information, is extremely desirable. The ability to remotely estimate various environmental parameters, such as waves, currents, turbidity, and visibility from satellite or low-flying aircraft and comparing to model forecasts provides an opportunity to validate the sensor data and verify and tune the numerical models. This, in turn, allows the forecaster to adjust his predictions based on new data to be incorporated into the model boundary and initial conditions.

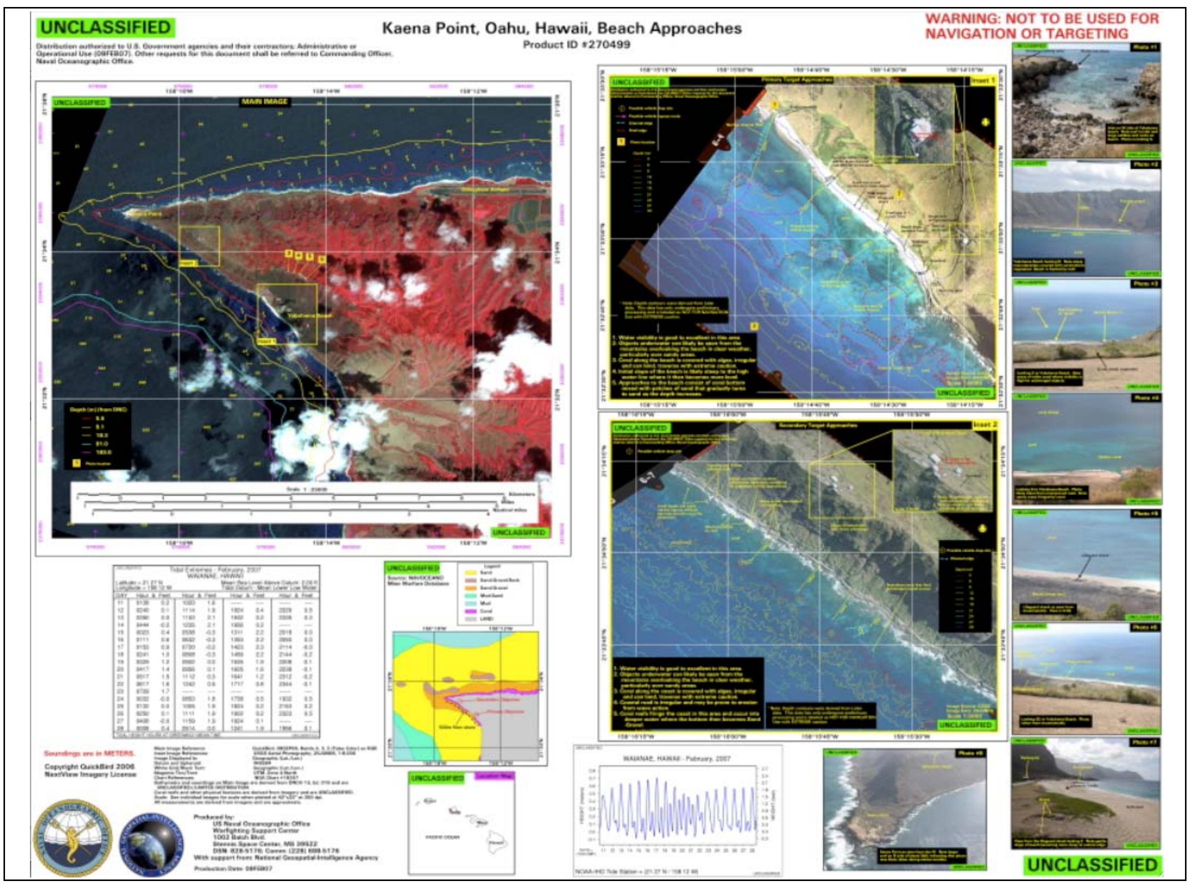


Figure 3: NAVOCEANO frontloaded annotated aerial imagery is an invaluable tool for not only pre-assessment but also on-scene operational forecasting support. Improvements in remote sensing that enable better extraction of waves, currents, and other METOC elements are highly desired.

Placing METOC sensors strategically throughout a Theatre has several advantages. First, these oceanographic observations may be used directly by forecasters on-scene. Secondly, global and regional models can assimilate the data for initialization, boundary conditions and model comparison. Thirdly, the data provides a better understanding of the region's climatology for present and future use.

2.3 Mission Execution

A SEAL's decision-making process is critically affected by the ability to receive a factual environmental report during the course of his mission. Within a typical operation, there is only a periodic delivery of pertinent METOC information to the platoon. Communication frequency between the forward SEAL platoon and embedded METOC forecaster (EM) varies, but is principally determined by the importance of the METOC information with respect to the mission and Communications (COMMS) availability by the platoon. In other words, there are certain times that communications are scheduled between forward and rear parties for updated Intelligence (INTEL), and that is the time when METOC updates are transmitted.

METOC assessment of present conditions is an ongoing, highly subjective, information-gathering process. From a submarine, this is normally a peek through the periscope to assess sea state. When divers/SEALs enter the Dry Dock Shelter (DDS), they get a taste of motions they will soon experience when they exit the door. From a small boat, similar last minute checks of waves and currents are performed by combat swimmers before slipping overboard for operations. Operators will usually toss a floating object into the water, noting its drift and deviation. Before swimming through a surf zone, breakers are observed, with respect to their consistency and areas of concentration. There is an ongoing effort to gain understanding of real-time environmental conditions. If adaptations are necessary, operations will remain on schedule. If real-time METOC elements differ significantly from projections, mission safety and success will be severely compromised. This ongoing verification and understanding of mission-impacting METOC parameters is essential for operators.

2.4 Modeling

Numerical models are important forecasting tools in the littoral environment. They can provide an estimate of expected wave and flow conditions for a defined AOI. The Simulating WAves Nearshore (SWAN) model [5] has proven to be a valuable wave forecasting tool in the littoral environment as well as on regional scales. It predicts wave conditions in spectral space, delineating between seas and swell. SWAN simulates wave propagation, shoaling and refraction due to current and depth, nonlinear wave-wave interactions, whitecapping, wave generation by wind, bottom friction and depth-induced breaking. Furthermore, SWAN is used to compute wave conditions in the Delft3D model [6]. Delft3D (D3D) predicts two- and three-dimensional flow and transport for tidal and riverine environments. It can evaluate salt intrusion, river flow simulations, fresh water river discharges into bays, tide and wind driven flows, stratified and density driven flows, and wave driven flows. It can also estimate bathymetry. D3D is an integrated modeling capability for hydrodynamics, waves, sediment transport, morphology, water quality, and ecology. In addition to SWAN, Delft3D is coupled to a hydrodynamic model to capture the wave-current interactions, giving a more accurate description of wave and current conditions in the AOI (See Figure 4).

Observations serve to both validate models and provide the data necessary to parameterize modeled processes. Integrating observational data over maritime areas where sensing does not already exist improves model forecasts. Exploitation of the satellite's optical products from electro-optical (EO) sensors, cloud imagery, and aerosols extends the 1D sea-surface fields to a 3D profile, greatly enhancing knowledge of the ocean. All data may be cataloged into a database for future use as climatology.

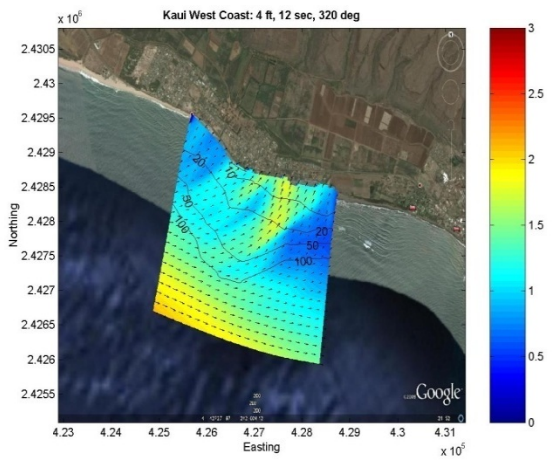
2.4.1 Assimilation and Boundary Conditions

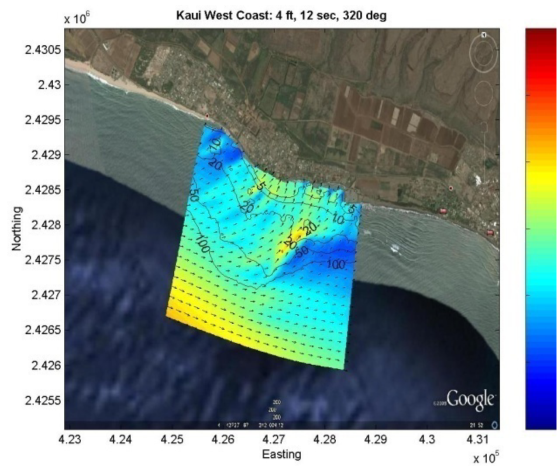
Numerical models of the littoral environment depend on input conditions from larger, more regional models, which, in turn, rely on global models. Alternatively, the detailed, littoral models acquire information from *in situ* devices like wave buoys, tide gages, and current profilers. If using a regional model for boundary conditions (which allows for 24-72 hour forecasting), the littoral model will only be as good as those boundary conditions. *In situ* data, while providing more reliable conditions at or near a detailed model's boundaries, are only available in real time under the best circumstances. Ideally, in locations where Operations Security (OPSEC) permits data transfers and bandwidth is sufficient for sensor device communication, real-time sensor data is transmitted back to production centers for processing and use in numerical modeling. Assimilation of real-time data into models usually improves the forecast. Real-time observations may also be incorporated into TDAs. Data sent back to production centers from a Theatre Sensing Architecture improves the mesoscale models in a region through the assimilation process. The Navy Coupled Ocean Data Assimilation system (NCODA; [7]), will be employed to assist with assimilation of observational data into the operational models.

Another possible option is to employ assimilation of *in situ* measurements to improve model boundary conditions. Such techniques are being developed for many regional models, including SWAN. More accurate regional models will lead to more accurate boundary conditions for the detailed, littoral models and result in a more reliable depiction of wave and current conditions in the AOI.

As mentioned previously, bathymetry/hydrography is the most important parameter for oceanographic/riverine modeling. Without accurate bathymetry for a given area, the uncertainty of the models can become very high. The inability to collect bathymetric/hydrographic data in a riverine or littoral region is a critical capability gap. In order to trust model results and minimize uncertainty in the model predictions, bathymetry data is required for the AOI.

Since nearshore bathymetry is so difficult to obtain in areas where NSW operates, forecasters must rely on other analytical methods to tune the model. Sophisticated nearshore modeling can be employed when bathymetry is sufficient to drive basic wave and current patterns, allowing for visualization and comparison, when discernable, from overhead imagery (Fig. 4). In other words, during the pre-deployment process, forecasters will compare the high-resolution model results to any discernable littoral wave patterns or available imagery provided to them by the Naval Oceanographic Office (NAVOCEANO).





Parameterized pre-forced D3D model runs with coarse bathymetry to resolve wave interactions in various conditions.	*D3D model now run with LIDAR based high-resolution bathymetry. Wave features are enhanced with a finer bathymetry in the near shore region.*

Figure 4: Delft3D (D3D) Wave Model Results, O'omanu, Point Kauai, Hawaii.

2.4.2 Validation and Verification

Sensor data serves to ground truth hydrodynamic modeling efforts through validation and verification. Statistics are calculated on real-time data and model forecasts, revealing model biases and generally, the robustness and accuracy of the model predictions. Models are typically put through a battery of verification and validation scenarios, but these provide only a limited data set for all the possible scenarios where a model is utilized. Therefore, ongoing validation efforts from exercises help the Navy understand the capabilities and limitations of these models. The D3D model will be used in the validation process.

3.0 CONCEPT OF OPERATIONS

3.1 NSWG1-2 (Groups 1 and 2)

3.1.1 SEAL Teams

Since the outset of the Global War on Terror (GWOT), many SEAL teams have shifted their focus from a nearshore/coastal battleground to a heavily land based terrain. Their operating areas include various environments, from the mountains of Afghanistan to Iraqi deserts to the tropical climes of the Horn of Africa. However, as illustrated by the recent elimination of three pirates by SEAL snipers aboard the USS Bainbridge off the Somali coast, access to accurate sea state and other maritime environmental forecasts is still relevant to the current war effort.

For the SEAL teams involved in terrestrial operations, timely and accurate collection of observational data over land is a new goal for mission success. METOC research and operations are experimenting with various types of weather observing systems, such as small footprint surface sensors that measure a large spectrum of meteorological observations. These sensors can be incorporated into other joint forces observational networks. Remote sensing via polar and geostationary satellites is employed in conjunction with surface and available upper-air sounding information to produce traditional meteorological forecasts for NSW.

Correctly forecasting the formation, intensity, and longevity of dust storms is an important goal for desert operations. An upwind network of surface sensors is required for monitoring potential dust storm formation and verifying them once they have begun. Missions over mountainous regions necessitate good wind data for helicopters, aircraft, and paratroopers. In areas such as Afghanistan that have huge variations in wind direction and speed surrounding the rocky topography, surface observational networks never cover enough area to give meaningful data. High-resolution atmospheric modeling coupled with available surface weather sensors greatly improves forecasts over mountainous regions. The Hindu Kush Mountains in northeast Afghanistan and western Pakistan are another AOI that presents difficult challenges, where extreme winters shape the fighting season. The capacity to monitor snow fall and snow pack extends the fighting season and gives operators a strategic advantage of taking the fight to the enemy when they least expect it. Additionally, improved remote-sensing capabilities for global lightning detection layered over satellite imagery permits identification of thunderstorm formation and tracking.

3.2 NSWG3 (Group 3)

3.2.1 SDV Teams

SEAL Delivery Vehicle (SDV) operations represent an excellent case study for SEAL missions in the littoral environment (Figure 5). The SDV is unique in that it requires a complete multi-dimensional forecast both above and beneath the ocean (from the surface down to about 60 feet) through distance and time. SDVs are highly sensitive to changing currents and subsurface motions caused by both short period wind waves and longer period swells, especially approaching the shore. Tidally-induced currents can also pose a problem in areas where they exceed critical threshold values (1 kt combat swimmer / 2.5 kt SDV). Navigating an SDV effectively, even with weak currents, can be extremely challenging.

SDV team at work just outside a Dry Dock Shelter (DDS), U.S. Navy photo	*SEALs wrestle swaying SDV just outside DDS under moderate seas atop SSGN submarine, U.S. Navy photo*

Figure 5: SDV operations.

The SDV requirements contain two major gaps. The first is the inability to sense real-time waves and currents from the submarine and the SDV. The second is the impaired capacity to accurately assess, during both pre-deployment operational planning and on-board mission planning, the METOC parameters contributing to ocean motion and the detection of NSW forces. Some of these elements include waves, currents, water clarity, bioluminescence, and turbidity.

According to the leadership at SEAL Delivery Vehicle Team ONE (SDVT1), owing to their clandestine approach, they are not interested in deploying METOC sensors for purely METOC's sake prior to, or in advance of a mission in a given area. Rather, the best possible METOC information is provided prior to the SEALs' arrival at the AOI, both by an EM's climatological research during the mission planning process and from real-time forecasting on-scene. Another option is to include METOC sensors in other Battlespace Awareness (BA) sensing platforms. This requires insight into the development of the BA platform as well as the conditions under which it is to be deployed. METOC sensing packages in this case must not interfere with other collection capabilities on the platform. These platforms are either mobile, such as on an unmanned vehicle, or stationary, as on a fixed sensor platform.

It is highly desirable to have current and wave information available to the forecaster onboard the submarine. The NSW and the Navy submarine community have begun development of a small sensing unit capable of measuring current velocity and sea height affixed to the Ship Submersible Guided missile, Nuclear powered (SSGN). Augmenting this capability with spectral wave information provides assessment of station wind waves and verification of passing swells to the EM in a cost-effective way. This is practical for refining a nearshore forecast by exploiting known conditions.

The SDV team can benefit tremendously from a small, expendable, current and wave device capable of being deployed outside of the surf zone. Additionally, instrumentation attached to the SDV to log location, along with *in situ* wave and current meters, is also greatly needed. Ocean temperature, salinity and other water properties can be measured and sent directly to the SDV or to ground stations via wireless telemetry. This data is interpreted either by the submarine's forecaster or at a modeling center, providing ground truthing for the following night's operations. These capabilities must not interfere with SEAL operations, either in the deployment stage or from an OPSEC perspective.

3.3 NSWG4 (Group 4)

3.3.1 Special Boat Teams

As part of a Theatre Sensing Strategy, wave and current sensors attached to existing navigational buoys will fill an enormous observational gap for NSW forecasters. The data can be transmitted back to NAVOCEANO for assimilation into predictive models. Not only does this data assist Special Boat Team (SBT) units (e.g., as shown in Figure 6), it supports other NSW operators conducting missions in the area. Therefore, a fine sensing capability at the Theatre level will contribute significantly to many facets of NSW and joint expeditionary units. This type of shared maritime-sensing architecture does not currently exist.

Figure 6: Special Boat Team (MK V special operations craft, U.S. Navy photo)

An ideal deployment location of wave and current sensors is in the AOI where the gauge yields an adequate sampling of the incoming swell/wave energy. However, the sensors do not require close proximity to a beach of interest if the buoy is placed in a location of comparable wave conditions. A good example of this is the success of a few wind and wave buoys deployed around the Hawaiian Islands. During swell and wind-induced wave events, measurements taken from buoys hundreds of miles away effectively characterized the region of interest. As a result, these data allowed for finer-scale, near-shore predictions through model validation and forecaster adjustments. Conversely, coastal currents must be measured as close as possible to the AOI, as these currents are highly variable in space and time.

In the event that a mission requires data at a particular location, small, disguised, expendable wave/current sensors can be either dropped overboard as drifters, mounted to an existing buoy/structure, or anchored to the seafloor. Real-time information is then reported back to the unit base station for monitoring by the embedded Aerographer's Mate (AG). Varying security and threat levels dictate the type of communication package permissible. Most importantly, having the means to measure these physical parameters with small, expendable, clandestine sensors gives the Navy one more piece of information to bolster mission success.

When SBTs transit into a riverine environment, they require accurate river depths, currents, tides and rainfall measurements. Forecasting these details with accuracy sufficient to send a boat upstream requires correct hydrography and river flow rates. Sensing river levels remotely and covertly is of high priority. Small drifting sensors measuring depth and current velocity can be dropped by helicopter, aircraft, or scout teams upriver. However, the information must be adequately annotated and forwarded to the SBT prior to the mission. Satellite rain estimates positively correlate to watershed outflow, so remote sensing algorithms also must be refined in order to improve watershed predictions based on upstream meteorological events.

4.0 SENSORS

Based on NSW's *Mission Critical METOC Parameter Requirements* (Section 2.0), environmental sensors must: 1) measure specific environmental parameters; 2) provide data in real time, and 3) supply data in a format that is readable by independent parties, i.e., the sensor data format must be compatible with NSW and Naval Expeditionary Combat Command (NECC) mission planning systems, production/reachback centers, and NAVOCEANO databases. Spiral upgrades include the capability to exfiltrate data via satellite communications (SATCOM) for reachback processing.

Environmental collection requirements by NSW often vary with mission, customer, and operational scenario. Building modular sensors that can easily be modified into multiple mission plans is advantageous. For example, newer weather PODS have the ability to include particular sensors while omitting unnecessary components. This type of foresight allows for a more affordable and streamlined system, both in size, weight, and overall footprint.

4.1 Commercial, Off-the-Shelf Sensors

Table 3 lists many available, commercial, off-the-shelf (COTS) oceanographic sensors which collect valuable information but require some degree of modification in order to support NSW operations. Appendix A lists the sensors that can successfully address NSW-required METOC parameters. Installing an ADCP on a submarine is an example of how a COTS product fits into a CONOPS to provide a valuable capability to NSW forecasters and operators.

Table 3: COTS Multi-Sensors

Potential Multi-sensor Platforms /Instruments	Add-on Sensors (not limited)	Parameters Measured	Comments
Underwater Vehicles (UUV, SAHRV, GLIDERS, AUV) crawl, swim, glide and drift	ADCPs, c-profiler, CTD, optical sensors, SAR, side scan sonar	Ocean/river visibility, bathymetry, T_w, bioluminescence, currents	Limited to nearshore but not surf zone; some are depth limited
Aerial Vehicles (UAV)	SAR, Video/Imagery analysis from satellite, optical, biological, chemical sensors, rawinsonde	Surf zone characteristics*, bioluminescence, atmospheric/ocean visibility, currents, hydrography, winds, EM/EO propagation, T_{air}, water/land structures	Launch on land or aboard boat, but not from USV.

ADCP surface, bottom, towed	Pressure gauge sensor, CTD's, optical, chem, bio sensors, Microwave laser range finder	Water levels, wave parameters, vertical and horizontal current profile, turbidity, T_w	Launch w/ diver, boat
All in one Buoy- wave + current profiler/current meter	AWOS, ADCPs, current profiler/meter, pressure sensors	Bioluminescence, atmospheric/ocean/night-time visibility, nearshore/inland currents, tides, winds, waves, T_a, T_w.	Radio buoy, acoustic modems, telesonar surface buoy, gateway sonar buoy
Wave Buoy + current meters/profilers	AWAC, current meters, pressure sensors, optical sensors, current-meter, mini buoys, littoral dye	Waves, currents/depth, T_w,	Used in shallow water
Small weather station	Hand held radar and weather sensor, weather PODS, AWOS, rawinsonde	Night/daytime atmospheric visibility, winds, T_a, EM/EO propagation, precipitation	Portable and sturdy. Setup in adverse conditions

4.1.1 Sensing Platforms

Robotic systems, or unmanned underwater vehicles (UUV's), are applicable to NSW sensing. As the technology advances, commercial products (such as the IVER-2 UUV and REMUS 100) are becoming available. The NSW Semi-autonomous Hydrographic Reconnaissance Vehicle (SAHRV) is one such adaptation of the REMUS 100, which is outfitted with side scan sonar and ADCPs. The SAHRV was developed by NSW programs to collect hydrographic data. Unmanned Aerial Vehicles (UAVs) are also used to collect environmental data and through-the-sensor (TTS) capabilities.

5.0 COMMUNICATIONS

It will be difficult to convince NSW forces to agree to deploy METOC-specific sensors if the systems do not possess the technology to communicate data effectively. Sensor communications must be addressed on a case-by-case basis when a system is selected, taking into consideration the leveraging of any available NSW or SOF communications architectures. Appropriate solutions for transferring data must be incorporated into the specific sensing capability. Some potential communication methods include Satellite Communication (SATCOM) (such as Iridium, Globalstar, and Inmarsat), UV mules, high speed acoustic modems, cellular transmission, and blue-green lasers. Figure 7 depicts the CONOPS for sensors, platforms, and communications paths for data dissemination.

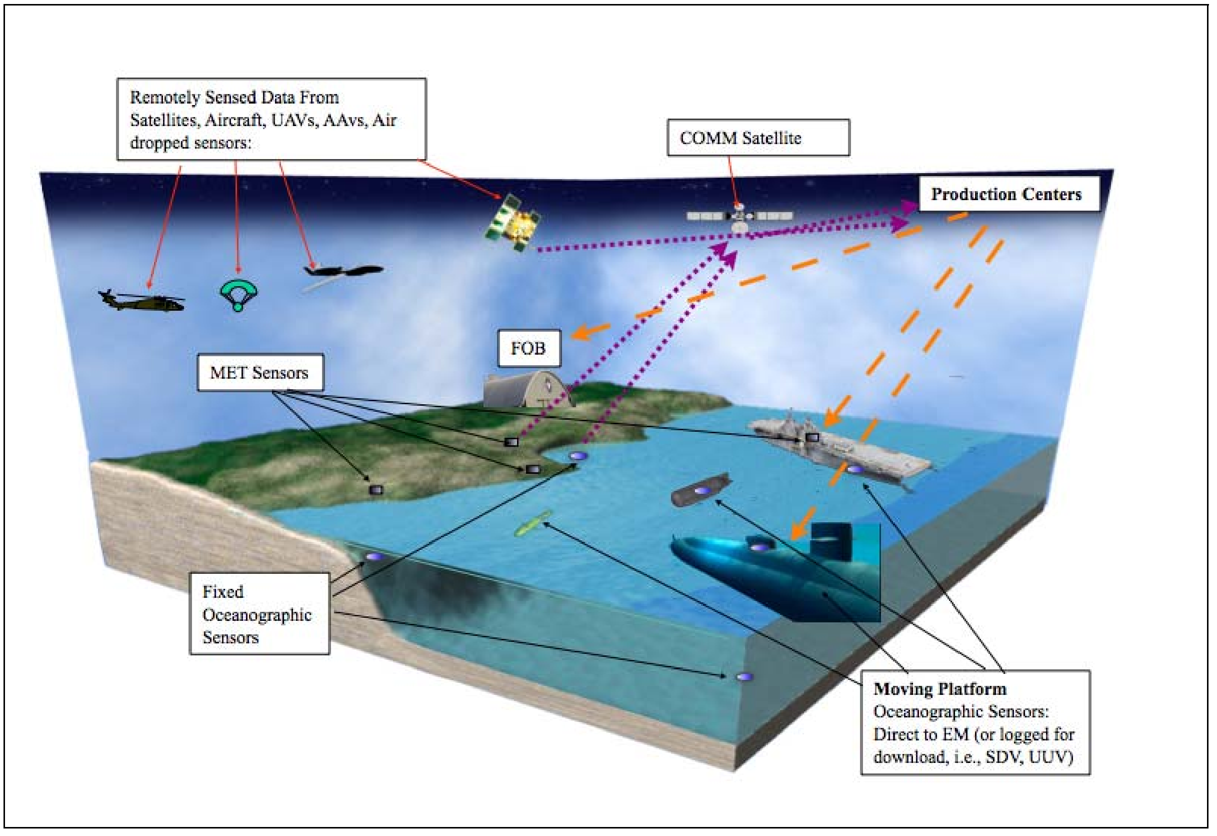


Figure 7: Schematic of CONOPS for various METOC sensors and their idealized communication paths.

5.1 NSW Forecaster Support: Background, Model Products and Aids

A recurring communication problem for NSW operations is bandwidth. The majority of littoral observations are being collected by SDV Teams on SSGN submarines. Bandwidth on submarines is typically constrained and unreliable. Bandwidth limitations restrict METOC data flow and reachback communications, thus isolating the mission's forecaster, requiring him to make onboard predictions unaided [4].

Currently, embedded METOC personnel use TDAs combined with the operational FNMOC Spectral Wave Bulletins (SWB) [3] and Mobile Meteorology and Oceanography Support (MMOS). SWBs are small, pre-requested text files that display partitioned wave events for a chosen point in the ocean forecast out to 144 hours for a global run (Figs. 8 and 9). Assessment of wave steepness for small crafts and prediction of swells heading to shallower water are easily deciphered and can be considered separately in the execution timeline forecast. The location of the point can be masked and given a customized name, as is the case in Figure 8. MMOS is a small binary file sent through message traffic or email that, when opened in the Joint METOC Viewer (JMV) program, displays graphical synoptic weather charts (Fig. 10). Both of these model capabilities are an invaluable source of information for the limited bandwidth forecaster.

Location : WKAUAI
Model : global_720x361
Cycle : 2009050312

day & hour	Hst (ft)	Wsp kts	Wdr (d)	Hs (ft)	Tp (s)	dir (d)	Hs (ft)	Tp (s)	dir (d)	Hs (ft)	Tp (s)	dir (d)	Hs (ft)	Tp (s)	dir (d)	Hs (ft)	Tp (s)	dir (d)	Hs (ft)	Tp (s)	dir (d)
03 12	4.2	5.4	85	3.7	11.1	327	1.5	12.2	185	1.3	7.4	91	0.2	7.5	142						
03 15	4.2	3.2	85	3.7	11.0	326	1.4	12.2	185	1.2	7.4	90	0.8	7.5	141						
03 18	4.2	1.8	67	3.7	10.9	324	1.3	12.1	184	1.4	7.4	88				0.2	13.6	327			
03 21	4.1	1.4	72	3.5	10.8	324	1.2	12.1	184	1.4	7.4	90	0.7	7.4	141	1.0	13.5	330			
04 00	4.2	1.5	8	3.5	10.6	324	1.1	12.1	184	1.2	7.4	90	0.7	7.3	141	1.4	13.7	332			
04 03	4.3	3.5	11	3.4	10.1	325	1.3	12.1	184	1.2	7.4	92	0.7	7.3	141	2.0	13.3	329			
04 06	4.6	5.5	31				2.7	11.5	184	1.4	7.4	93	1.2	7.0	141	3.3	13.4	329	0.2	0.0	0
04 09	4.9	5.9	52	0.8	0.0	0	1.4	11.3	184	2.9	7.3	95	1.0	7.0	141	3.5	13.4	331			
04 12	5.1	5.4	48				1.0	11.3	183	1.6	7.3	94	0.7	6.9	141	4.6	13.3	331			
04 15	5.2	5.7	43				1.2	11.3	183	1.6	7.3	94	0.2	6.9	141	4.8	13.1	332			
04 18	5.4	5.5	43				1.2	11.3	184	1.5	7.2	93				5.0	12.7	332			
04 21	5.4	5.3	42	0.2	4.5	90	1.6	11.4	182	1.2	7.2	95				5.0	12.3	332			
05 00	5.4	5.9	36	0.5	4.5	92	1.6	11.6	184	1.1	7.1	95				5.0	12.2	333			
05 03	5.3	6.5	32	0.5	4.5	93	1.6	11.7	184	1.1	7.1	96				4.9	12.2	333			

Figure 8: Sample FNMOC SWB used by EMs to assess the types and trends of deep-water wave trains passing a chosen point as much as 144 hrs out. The wind speed (Wsp) is in kts, wind direction (Wdr) is in degrees, significant wave height (H_s) is in ft, wave period (T_p) is in seconds, and wave direction (dir) is in degrees.

TROF OVR ISLANDS WEAKENING TRADES. MODERATE TRADES RETURN OVRNGHT THUR. SWELLS CONTINUE FROM S THRU NEXT WEEK. NO SIG WXR BESIDES S SWELL.

10/12	3.5	5.4	32	2.4	13.2	196	2.0	17.8	189	1.4	7.6	314	0.7	8.7	95	0.3	12.1	148
10/18	3.6	8.4	53	2.3	13.0	195	2.2	16.6	190	1.4	7.5	310	0.4	11.7	147	0.7	8.9	101
11/00	3.5	10.2	70	2.1	12.3	195	2.3	16.3	191	0.8	7.6	44	1.2	11.2	147			
11/06	3.9	11.5	69	1.9	12.0	195	2.5	15.9	192	2.1	6.0	56	0.5	8.3	146	0.3	11.1	148
11/12	3.8	10.1	97	1.9	12.1	195	2.4	15.0	192	1.8	5.8	66	0.4	11.0	148	1.1	7.1	286
11/18	3.6	12.2	94				2.7	14.7	193	0.4	8.3	146	0.4	10.8	147	0.9	7.2	286
12/00	3.7	13.1	93	2.3	3.3	79	2.9	14.5	193	0.5	8.1	146	0.2	10.3	148	0.4	7.3	287
12/06	4.1	17.6	87	2.9	3.7	78	2.8	13.8	193	0.2	12.4	148	0.5	10.1	148	0.4	7.4	288
12/12	4.5	15.8	90	3.6	4.1	81	2.6	13.5	194	0.2	12.3	147	0.4	7.7	148	0.5	10.1	147
12/18	4.4	15.6	81	3.6	3.9	76	2.4	13.4	194	0.6	17.6	195	0.3	7.5	149	0.4	10.1	147

Figure 9: Sample FNMOC SWB with accompanying synoptic discussion. Along with frontloaded resource center carry-on, this represents the totality a forecaster can currently utilize in clandestine operations.

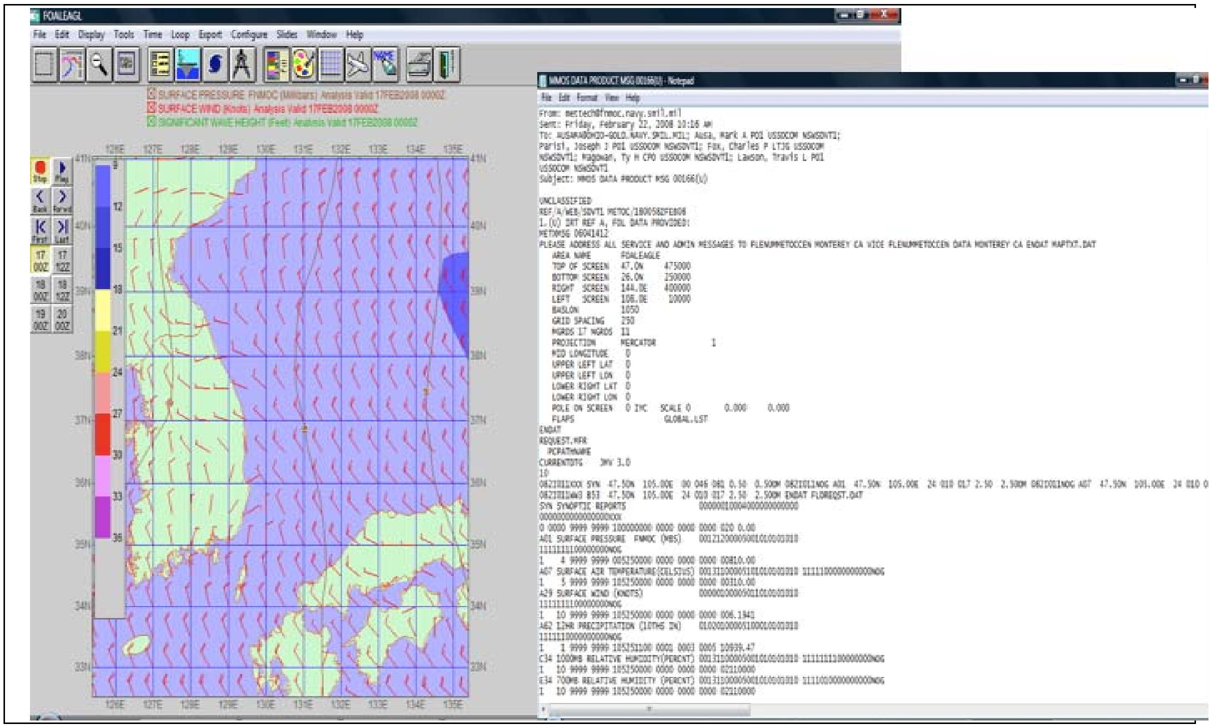


Figure 10: A sample FNMOC MMOS binary text file viewed in JMV. This serves as the synoptic model data for the EM in limited bandwidth environments.

Additionally, NSW forecasters are now using a pre-forced, parameterized, high-resolution Delft3D nearshore model [6] available through NAVOCEANO (Figure 11). The model functions as a pre-downloaded suite of visual look-up tables. A forecaster chooses the closest anticipated swell height, direction, and period of waves expected to move into a region from hundreds of combinations stored on disk. In a higher-bandwidth environment, forecasters can request the dynamically-run model predictions.

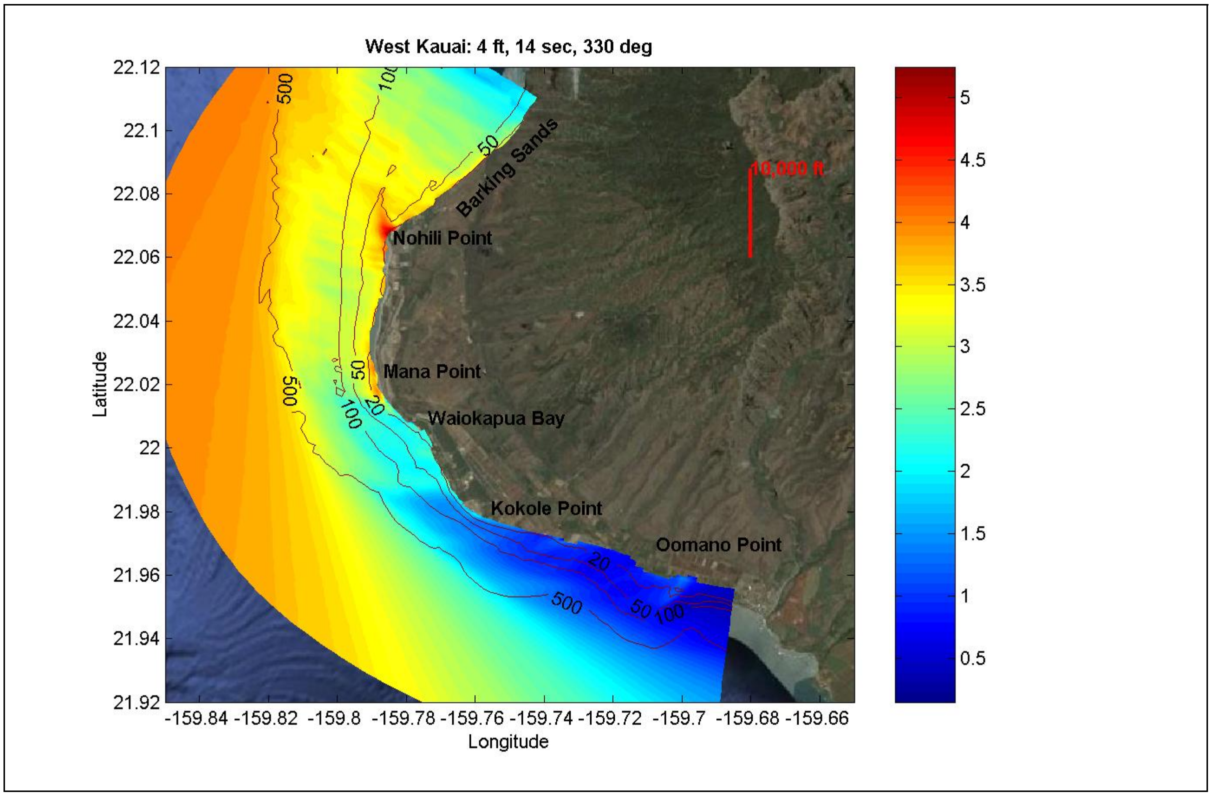


Figure 11: NAVOCEANO DELFT3D model output of the western Kauai coastline, with visualization of nearshore swell characteristics. Wave-forced longshore currents and riptides are easily estimated through wave focusing and spreading illuminated by the model. A nested view of the same area is shown in Section 2.2.

NAVOCEANO's METOC Model Viewer (MMV) is used for on-scene display and manipulation of tidal current files, D3D files, climatological layers, and geo-rectified, annotated imagery. METOC thresholds from all NSW platforms also can be plotted from a drop-down menu for each model layer. This allows for quick identification of areas of opportunity or increased risk (Figure 12).

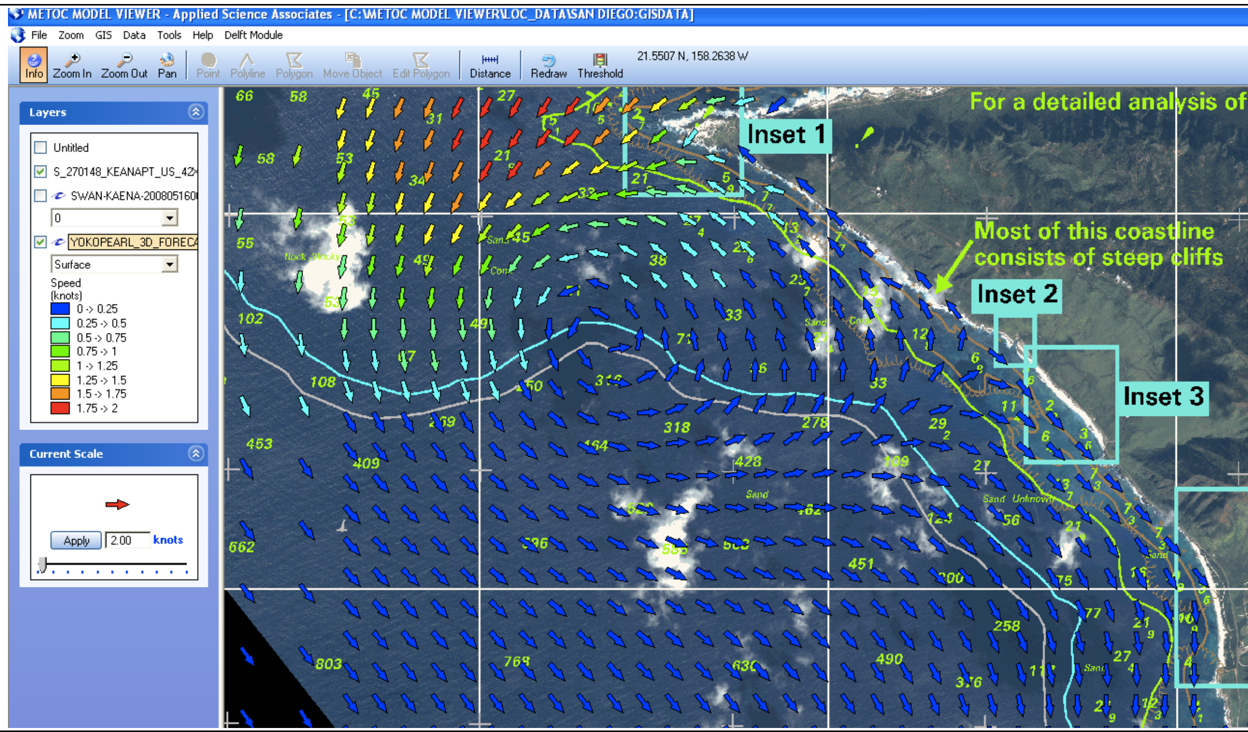


Figure 12: MMV with tidal model vectors displayed over NAVOCEANO-annotated geotiff. Like the pre-forced D3D runs, data is downloaded prior to deployment.

The integration of real time, *in situ* METOC sensing capabilities (not yet developed) will drastically improve the accuracy of predictions. Currently there is no sensing available for NSW forecasters. All forecasts are based on model predictions. With high-resolution, real time METOC sensing data, a forecaster could assimilate, validate, and ultimately fine-tune a forecast for a specific littoral zone.

6.0 CAPABILITY DEVELOPMENT

The Process Flow Chart shown in Figure 13 demonstrates how to incorporate capable environmental sensors and tools into the operational arena. To ensure that these sensors are shaped into the correct solution the following issues must be considered:

- A process for collecting, documenting and prioritizing requirements;
- An engaged, informed, and coordinated developer community (The Naval Research Laboratory (NRL), Industry, NAVOCEANO, FNMOC) to ensure that requirements are being addressed and limited resources are being managed;
- Ability to respond to emergent requirements (Combat Development); and the
- Ability to sustain developed capabilities through the Acquisition Process.

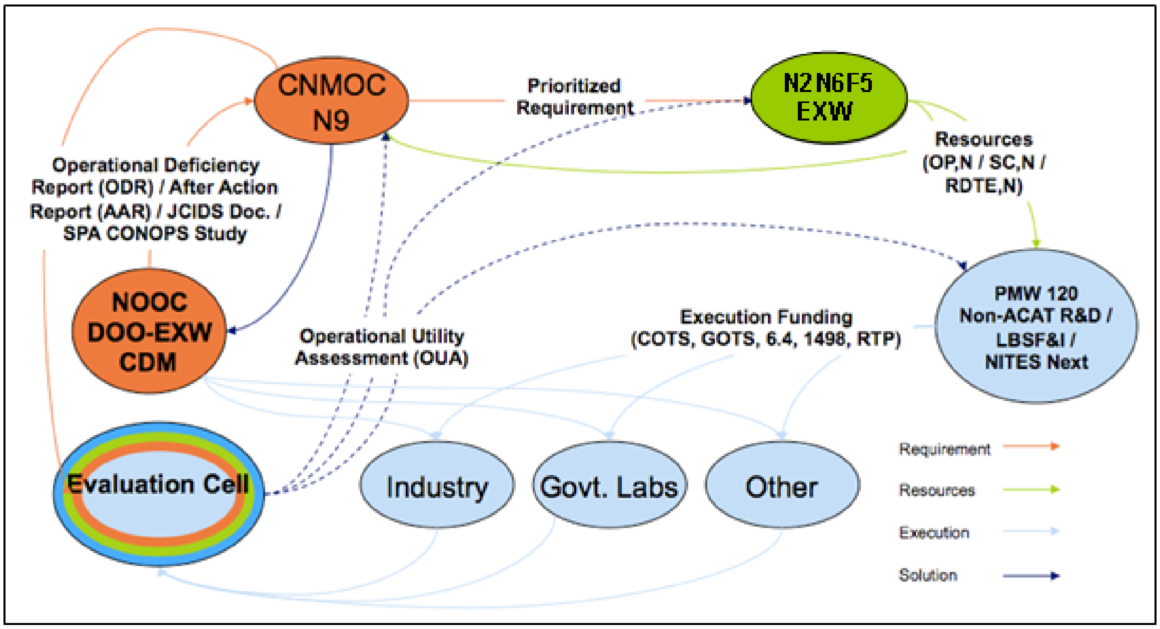


Figure 13: Process flowchart for incorporating capable environmental sensors into the operational environment.

7.0 CONCLUSIONS

Due to the covert nature of NSW operations, along with temporal and spatial demands and scale and environmental intricacies, METOC support faces complex challenges for developing and employing the correct observational sensors and environmental models. Furthermore, bandwidth constraints prevent timely reachback information flow to forward units. Mission planning demands that environmental parameters are provided as much as a week in advance, due to infiltration and exfiltration route planning and platforms that cannot be changed hours or even days before deployment. Long lead times require that sensor data be assimilated into models and a forecast returned in a timely manner.

Forward deploying Navy forecasters with NSW units need improved on-scene environmental support. However, without access to METOC sensors, forecasters are often unable to ground truth environmental models. Local forecasters can integrate on-scene environmental sensor data into their models and validate model performance. Additionally, data sent to reachback centers may be assimilated into various high-resolution models, potentially improving their products.

Remote sensing is an excellent option since there is no risk of detection and data collection can begin well in advance of operations. Developing a reliable unmanned vehicle capability is another valid option, especially for sensitive areas where bathymetry and environmental information are lacking.

The need for a more developed METOC sensor application for the NSW program is underscored by accidents and mishaps that may have been prevented had accurate METOC support been available. The Vietnam War's Operation Thunderhead (June 3, 1972) exemplifies how navigation errors took two SDV's off course, and strong, unforeseen currents overpowered them, leading to their scuttling. In October 1983, the successful mission of rescuing US citizens on the island of Grenada was marred by the loss of four Navy SEALs involved in a nighttime jump into rough coastal waters and poor visibility during a squall. There were, once again, navigational errors, and the topographical information being used was poor and outdated. Had there been a better assessment and understanding of the evolving environmental conditions, these tragedies may have been averted.

We have a clear understanding of the NSW requirements to operate in and through the littoral environment. However, the intricacies of developing small, stealthy environmental sensors that can communicate data to all involved operations in a timely fashion require considerable creativity. Developing these capabilities necessitates a coordinated effort between the acquisition program office (PMW120), the resource sponsor (N2N6F5), and the operational commands (CNMOC, NOOC, DOO, EXW, and NOSWC).

8.0 TECHNICAL REFERENCES

8.1 General Technical References

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[2] Naval Special Warfare (NSW) METOC Sensing Requirements for POM-10 Consideration, dated 22 June, 2007.

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[4] Requirement for Low Bandwidth Support for Naval Special Warfare (NSW) Operations, dated 30 September, 2008 – Operational 30 April, 2009.

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9.0 NOTES

9.1 Acronyms and Abbreviations

Acronym	Description
AAR	After Action Report
AAVs	Assault Amphibious Vehicles
ADCP	Acoustic Doppler Current Profiler
AG	Aerographer’s Mate
AOI	Area Of Interest
AUV	Autonomous Underwater Vehicle
AWAC	Acoustic Wave and Current profiler
AWOS	Automated Weather Observing System
BA	Battlespace Awareness
COMMS	Communications
CONOPS	Concept of Operations
COTS	Commercial, Off-the-Shelf
CRRC	Combat Rubber Raiding Craft
CTD	Conductivity Temperature Depth
D3D	Delft 3D model
DDS	Dry Dock Shelter
DOO-EXW	Director of Oceanographic Operations - Expeditionary Warfare
EM	Embedded METOC forecaster
EM/EO	Electro-Magnetic/Electro-Optical
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GOTS	Government Off-the-Shelf
GWOT	Global War on Terror
INTEL	Intelligence
JCIDS	Joint Capabilities Integration and Development System
JMV	Joint METOC Viewer
LBSF&I	Littoral Battlespace Sensing, Fusion, and Integration
METOC	Meteorology and Oceanography
MK V	Mark V special operations craft
MMOS	Mobile Meteorology and Oceanography Support
MMV	METOC Model Viewer
NAVOCEANO	Naval Oceanographic Office
NECC	Naval Expeditionary Combat Command
NITES	Navy Integrated Environmental Support Subsystem
NOOC	Naval Oceanography Operations Command
NOSWC	Naval Oceanography Special Warfare Center

Acronym	Description
NRL	Naval Research Laboratory
NSW	Naval Special Warfare
OCO	Overseas Contingency Operations
ODR	Operational Deficiency Report
OPN	Other Procurement, Navy
OPSEC	Operations Security
OUA	Operational Utility Assessment
PODS	Portable on Demand weather sensors
QNA	QinetiQ, North America
R&D	Research and Development
RDT&E, N	Research, Development, Test and Evaluation, Navy
RHIB or RIB	Rigid Hull Inflatable Boat, Rigid Inflatable Boat
SA	Situational Awareness
SAHRV	Semi-Autonomous Hydrographic Reconnaissance Vehicle
SAR	Search and Rescue
SATCOM	Satellite Communications
SBT	Special Boat Teams
SCN	Shipbuilding and Conversion, Navy
SDV	SEAL Delivery Vehicle
SDVT1	SEAL Delivery Vehicle Team ONE
SEAL	Sea, Air, and Land
SOF	Special Operations Forces
SPA	Systems Planning and Analysis
SSGN	Ship Submersible Guided missile Nuclear powered
SWAN	Simulating Waves Nearshore
SWB	Spectral Wave Bulletins
TDA	Tactical Decision Aid
TIP	Target Intelligence Packet
TTS	Through-The-Sensor
UAV	Unmanned Aerial Vehicle
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
UV	Unmanned Vehicle

APPENDIX A: Recommended Instrumentation to Fill NSW Sensing Requirements

	HYDRO/ BATHY	TIDES	CURRENTS	WAVES & SURF	BIOLUM.	ATM VIS.	OCN VIS.	TEMP.	LIGHT & ILLUM.	WINDS	EM/ EO	PRECIP.
UUV	X		X		X		X	X				
HAND HELD CURRENT METER			X									
NITES SUITES						X		X	X	X	X	X
HES								X	X	X	X	X
RAWINSONDE								X		X	X	
GPS UNIT												
AWOS						X		X	X	X	X	X
LITTORAL FLOW ASSESS. DYE			X	X								
HORIZ. MOUNT ADCP		X	X	X				X				
SMALL LITTORAL TOWED ADCP		X	X					X				

	HYDRO/ BATHY	TIDES	CURRENTS	WAVES & SURF	BIOLUM.	ATM VIS.	OCN VIS.	TEMP.	LIGHT & ILLUM.	WINDS	EM/ EO	PRECIP.
CRAFT MOUNTABLE SONAR	X											
PORT. WEATHER RADAR								X		X	X	X
SMALL WAVE BUOY				X								
UAV	X		X	X	X	X						
DOWN-LOOKING BUOY MOUNTED ADCP		X	X					X				
GLIDERS	X		X		X		X	X				
VERT. MOUNT. ADCP		X	X	X				X				
SMALL, PORTABLE SIDE SCAN SONAR	X						X					
RADIOMETER									X			
SECCI DISK							X					
REMOTE MINI WEATHER STA.						X		X	X	X	X	X