The Distributed Integrated Ocean Prediction System (DIOPS)

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1. INTRODUCTION

The Distributed Integrated Ocean Prediction System (DIOPS) is designed to provide relocatable wave, tide, and surf predictions for US Navy forces operating in the littoral environment. The current version of DIOPS includes 4 numerical prediction models: the Wave Action Model (WAM), the Simulating Waves Nearshore (SWAN) model, the US Navy Relocateable Tide and Surge Model (PCTIDES), and the Navy Standard Surf Model (NSSM). DIOPS is currently undergoing beta-testing at the Naval Pacific Meteorology and Oceanography Center (NPMOC), San Diego, CA, where complete forecasts are made on a daily basis, and fleet user feedback is channeled to the developers for improvements. In the past year, DIOPS has been involved with 2 major exercises, including the NATO exercise STRONG RESOLVE 2002 (SR02), and Joint US Military Exercise MILLENIUM CHALLENGE 2002 (MC02). During the course of these exercises, DIOPS products were distributed to operational forecasters and decision makers, as graphical and text products on webpages as well as via innovative geospatial information systems (GIS). This paper will present a brief summary of the components of the DIOPS system, and discuss results of the model forecasts compared with observed environmental data collected during SR02.

2. DIOPS COMPONENTS

The DIOPS components are briefly outlined below. Please refer to the DIOPS website http://diops.spawar.navy.mil or see Allard et al. (2002) for a more detailed description of the DIOPS components and the evolution of DIOPS. Fig. 1 provides an overview of the system.

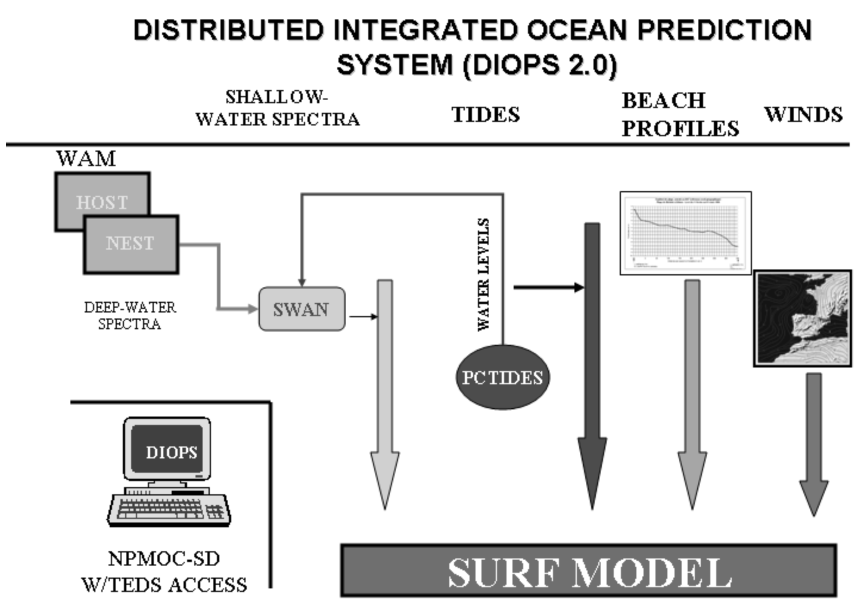

Figure 1. Schematic detailing data inputs and data flow through DIOPS, to produce a surf zone forecast.

2.1 Wave Action Model (WAM)

WAM is a deep water wave model that utilizes numerical weather prediction model, 10 m wind fields to develop deep water wave characteristics. DIOPS uses forcing winds for WAM, obtained from the Navy's Tactical Environmental Data Server (TEDS). The METOC Broadcast (METCAST) interface allows the DIOPS computer to access TEDS to obtain 10 m winds from the Navy's operational numerical weather prediction models, the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The TEDS/METCAST interface also allows DIOPS access to static databases for bathymetry for WAM runs. WAM has the capability for nesting, and is run to provide wave spectra to the SWAN nearshore model.

2.2 Navy Relocatable Tide/Surge Modeling System (PCTIDES)

PCTIDES is a relocatable tide and surge prediction system, which incorporates atmospheric as well as astronomic effects on sea level elevation. A bathymetry database is contained within PCTIDES, and the model assimilates data from worldwide International Hydrographic Office (IHO) tide stations. The model is also able to be nested, to provide high resolution 2-dimensional gridded water level elevation fields, which can be used in the SWAN or other nearshore models. Point output can also be generated for use with NSSM. PCTIDES receives mean sea level pressure (MSLP) and 10 m wind data from TEDS also.

2.3 Simulating Waves Nearshore (SWAN)

SWAN is a nearshore wave model that is initialized with wave spectra from a deep water wave model and wind forcing. SWAN can also be run with tides and currents to activate a wave-current interaction option. Bathymetry for SWAN is typically provided from the Naval Oceanographic Office (NAVO), and can be supplemented with on-scene data. SWAN can be run in a nested mode and is used to propagate wave spectra through the nearshore to the surf zone.

2.4 Navy Standard Surf Model (NSSM)

NSSM was initially developed in the 1980's and has been used in continuous operation since. Multiple improvements have been made to the original version of NSSM, and its operational history and employment are found in Earle (1999). The operational version of DIOPS will include NSSM version 3.2. NSSM is a one-dimensional surf prediction model, which utilizes wave spectral output from SWAN, 10 m winds, and a beach profile, to provide information on the surf zone. Data from NSSM is formatted into coded surf forecasts, in the format delineated by the Joint Surf Manual, COMNAVSURFPACINST/ COMNAVLANTPACINST 3840.1B, (1987). The contents and format of the coded surf forecast provide an efficient and effective means of relaying data of interest to amphibious forces about the surf zone, including, significant and maximum breaker height, angle of incidence, longshore current, surf zone width, number of surf lines within the surf zone, and

2.5 Dynamic Information Architecture System (DIAS)

DIOPS incorporates a middleware developed at Argonne National Laboratory. The middleware is based upon the Dynamic Information Architecture System (DIAS), and allows the models to share data through the use of an object oriented communication scheme. Models do not actually communicate with each other, but obtain data and provide data to classes of software objects. This architecture allows for ease of use in adding or removing more models into the DIOPS system. More information on DIAS is available at http://www.dis.anl.gov/DIAS.

3. OPERATIONAL DIOPS SUPPORT

DIOPS developed wave, tide, and surf forecasts are designed to be utilized by NATO forces operating in a littoral environment. DIOPS forecasts for SR02 were produced by the DIOPS scientist, at the Navy European Meteorology and Oceanography Center (NEMOC) in Rota, Spain. Table 1 shows the setup parameters for the SR02 scenario.

STRONG RESOLVE 2002 (SR02)
WAM: 1 Grid 10-30°E, 53-60°N 0.25° res.
PCTIDES: 2 Grids: Coarse: 54-57°N, 11-21.5°E, 9 km res. Fine: 54.25-55.25°N, 16.0-17.5°E, 3 km res.
SWAN: 3 Grids: coarse: 54-57°N, 15-21.5°E, 0.10° res. nest 1: 54.25-55.75°N, 16-18.25°E, 0.025° res. nest 2: 44.5-54.75°N, 16.6-16.85°E , 0.005° res.
NSSM: 4 locations along the Polish Coast.
NEMOC Webpage: 48 hr SWAN Coarse and Fine Nest forecast @ 6 hrly intervals 48 hr NSSM graphical and text forecasts for 4 beaches @ 6 hrly intervals. 48 hr PCTIDES forecast graphic for 4 beaches
GIS: **Products provided to WIPE Server** SWAN Medium and Fine Nest 48 hr. forecast At 6 hrly intervals. NSSM Forecast graphics for 4 beaches

Table 1. Model specifics for SR02 exercise.

Complete 48 hour forecasts, including WAM, SWAN, PCTIDES, and NSSM were performed once per day, with a 12 hour continuity run of WAM performed using the NOGAPS and COAMPS model runs from the previous 12-hr watch cycle. PCTIDES forecasts were performed every 24 hours. Point tide forecasts for beaches of interest were provided to the warfighters, in a graphical format via the NEMOC webpage. SWAN runs were provided to the operational users for sea state, as well as run for generating wave spectra for the NSSM model runs. Significant wave height and direction forecasts were provided at 6 hourly intervals in a graphical format on the NEMOC webpage. NSSM forecasts were provided in graphical and text format via the NEMOC webpage.

With the recent advances in Geospatial Information Systems (GIS), point and gridded datasets are able to be viewed and/or overlaid on other datasets, such as charts and imagery. This overlay capability, allows military command and control display systems to present operational decision makers an integrated picture of the battlespace, including, intelligence and METOC data, as well as location of forces. During SR02, data was imported into GIS capable systems to allow operational decision makers the capability of overlaying the data on their command and control pictures. DIOPS products were also able to be viewed on the Applied Coherent Technologies WWW Image Processing Environment (WIPE) server using an internet browser and the WIPE applet (http://www.actgate.com).

4. MODEL RESULTS

Overall, the modeled ocean parameter matched reasonably with the observed parameters that were available. Only one wave buoy was available (Ölands s. grund – WaveRider) located near 56.1°N 16.7°E. Four altimetry passes over the area of interest were obtained for the exercise period. Photographs taken as press coverage during the exercise were available from the SR02 webpage. Fig. 2 shows the seas encountered by USS BRISCOE in the Baltic during the exercise.

Figure 2. USS BRISCOE endures heavy seas while cruising in the Baltic Sea, March 7, 2002, during STRONG RESOLVE. U.S. Navy photo by journalist Mate 1st Class Kevin Elliott.

4.1 STRONG RESOLVE 2002 Results

DIOPS was run in support of NATO Exercise Strong Resolve 2002 at the Navy European Meteorological Oceanography Center (NEMOC) March 1-15, 2002 on a Sun Blade 500 MHz workstation. NEMOC's role was to provide support products for a planned amphibious landing off the Polish Coast. High-resolution bathymetry was collected in mid-February, off the Polish Coast, during a Rapid Environmental Assessment (REA) of the area of interest. Tides were removed based on a tide gauge located near Ustka, Poland. High resolution REA bathymetry was merged with hydrographic data obtained from the Naval Oceanographic Office using the Surface Modeling System grid generation software. Information about SMS can be found at http://www.emrl.byu/edu/sms.html .

A regional WAM model for the Baltic Sea was run twice daily, forced with the Navy Operational Global Atmospheric Prediction System (NOGAPS) wind fields. Directional wave spectra from WAM were specified as boundary conditions to a 0.1° resolution host SWAN domain for the Southern Baltic Sea. Fig. 3 shows the 22 locations in which WAM spectra were applied on the SWAN western and northern boundaries. Two SWAN nests with resolutions of 0.025° and 0.005° were embedded within the host SWAN depicted in Fig. 3. High-resolution bathymetry was applied to the inner-most SWAN nest only. All three SWAN domains were forced with 10-m winds from the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) Europe grid.

During the time SWAN was run at NEMOC, a software bug did not allow SWAN to be run in a RESTART (*hotfile*) mode. As a short-term workaround, each WAM model run was started 6 hours before the analysis time, providing directional wave spectra at t-3 hours. Subsequently, SWAN was initialized from a cold start, from $t=-3$ hours and run for a total of 51 hours to $t=+48$ hours.

Fig. 4 depicts SWAN wave height and peak period versus a buoy located near the Swedish Island of Olands. The buoy data was obtained through the Swedish Meteorological and Hydrological Institute. Fig. 4a (top) shows SWAN results when using a 3-hr initialization. Clearly, this short spin-up time does not provide adequate time to resolve these features. Fig. 4a(middle) shows results of an identical model run, but using a 6-hr spin-up period. Improvement is shown versus the 3-hr spin-up. Fig. 4a (bottom) depicts a SWAN simulation in which a *RESTART* file is saved every 12-hours. In this case, SWAN does a very good job resolving the wave height during the 15-day period. SWAN peak wave period, shown in Fig. 4b exhibits good agreement in the *RESTART* case, with a one-second over-prediction on the major event on March 6, 2002.

The amphibious assault during SR02 consisted of a Swedish Combat Boat 90H's launched from the USS TORTUGA. These craft did not assault a beach through the surf zone, but rather landed their troops at a quay wall in Hel, Poland. Predicted and observed waves exceeded 4 m and had some impact on at sea operations, as seen in Fig. 2. Feedback from the afloat METOC division was that DIOPS provided a beneficial service for the Amphibious Forces, especially when their own version of NSSM was found to be inoperable.

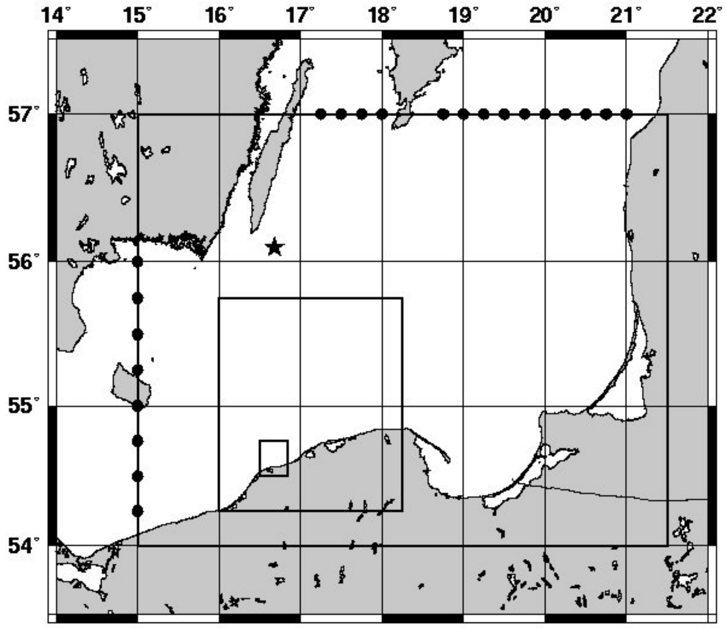

Figure 3. DIOPS SWAN areas run during NATO Exercise STRONG RESOLVE 2002. A triple nested SWAN run was performed, using data from a 0.25° Baltic Sea WAM. WAM wave spectra were applied at the points indicated by filled circles, to initialize the outer nest of a coarse resolution SWAN model. The star indicates the location of the SMHI wave buoy.

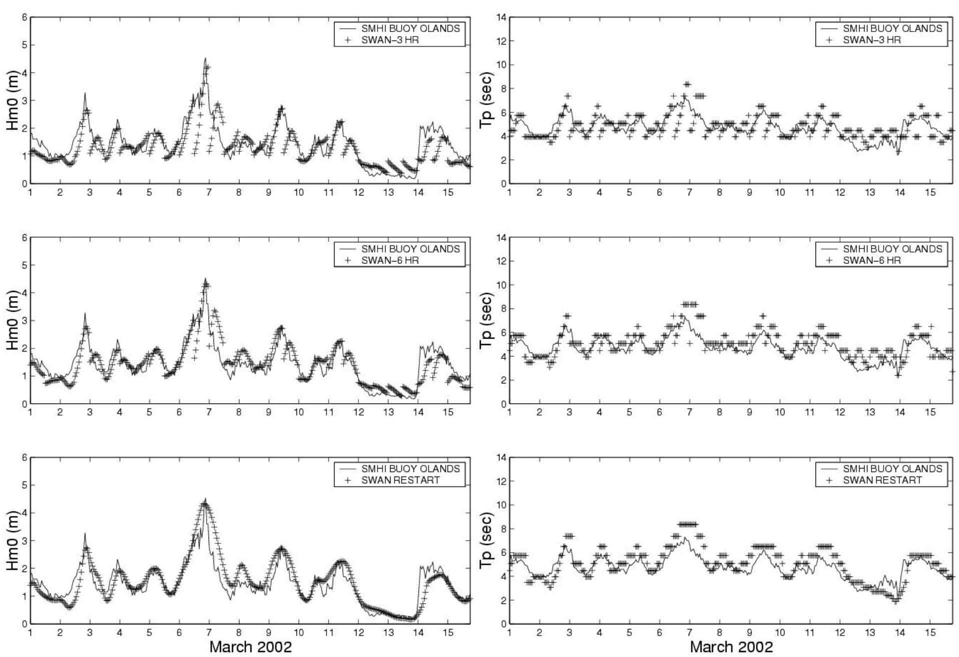

Figure 4. Comparison of SWAN a) wave height and b) peak period for three test cases. The first uses a 3-hr spin-up from rest, the second uses a 6-hr spin-up from rest, the last cases is initialized with a RESTART file.

Fig. 5 depicts the 4 separate over-flight paths for altimeters within the area of the medium resolution SWAN nest. The comparison between altimeter-derived wave heights and SWAN (Fig.6) shows a reasonable agreement. Hwang et al. (1998) showed that when spatial lags were less than 10 km, RMS errors between TOPEX and buoy observations were on the order of 0.1m in the Gulf of Mexico. Gower (1996) examined TOPEX altimeter-derived wave heights with 14 buoys along the west coast of Canada and reported RMS differences in the range of 0.3-0.35m. Fig. 7 depicts a comparison of SWAN model predictions at locations and times when the altimeters were over-flying the area. The ERS-2 and TOPEX on March 11 show very good agreement, while SWAN shows an under-prediction of wave height as the altimeter gets closer to land on March 4. SWAN shows an under-prediction of about 0.5 m for the March 8 comparison with TOPEX.

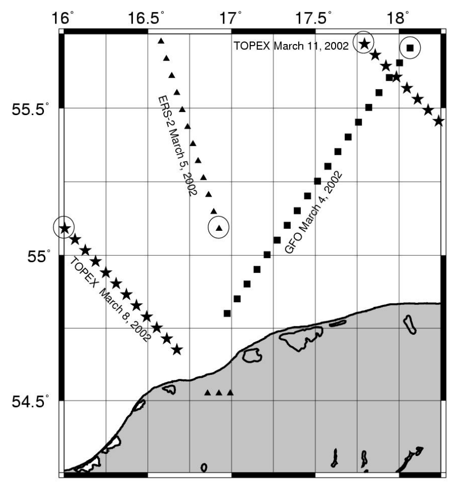

Figure 5. Tracks of ERS-2, TOPEX and GFO altimeters contained within the first SWAN nest (0.025 deg resolution) during the period March 4-11, 2002. Open circles for each track denote the first point for that track, denoting direction altimeter is moving.

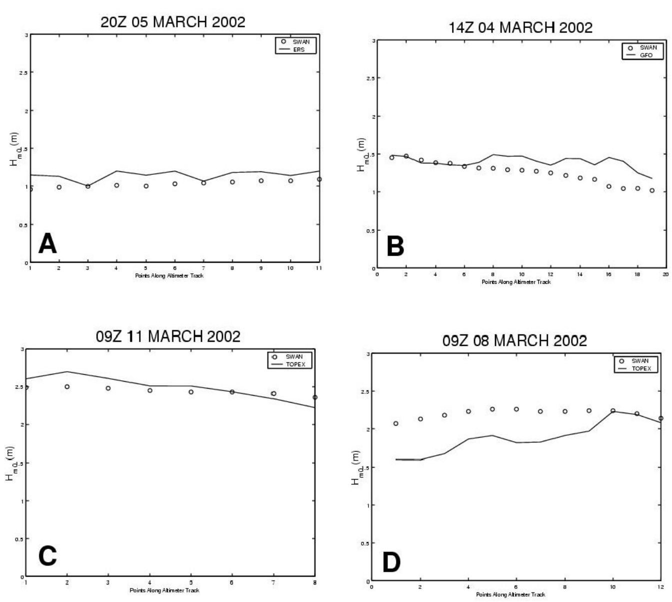

Figure 6. Comparison between SWAN wave heights and a) ERS-2 on March 5, 20GMT, b) GFO on March 4 14Z GMT, c) TOPEX on March 11 9Z and d) TOPEX on March 8, 09Z. The first point in each plot corresponds to the open circle represented in Fig. 5.

5. FUTURE OF DIOPS

The DIOPS project has been working with Fleet Numerical METOC Center (FNMOC) in developing a method of distributing the computational resources of running DIOPS. To enable this capability, DIOPS will leverage off of FNMOC's WaveWatch3 (WW3) global wave model runs, reducing the run time required for performing a forecast. FNMOC will liaison with NPMOC-SD to add necessary locations to the WW3 output, and deliver wave spectra for these points via METCAST channels. The DIOPS operator at NPMOC-SD will then be able to subscribe to the channel and use the WW3 wave spectra to initialize the nearshore and surf zone models. A similar process may be developed to allow regional METOC centers, such as NPMOC-SD, to provide SWAN output spectra to forward deployed forces that will then use the spectra in surf models for their areas of interest.

Recently work has been completed on a streamlined DIOPS Graphical User Interface (GUI). This new GUI will allow for setup of DIOPS scenarios and visualization of DIOPS data via 2-D X-Y plots using JClass software, as well as gridded products visualized on the Defense Information Infrastructure-Common Operating Environment (DII-COE) Common Operating Picture (COP), using the Joint Mapping Tool Kit (JMTK). DIOPS developers have utilized the NITES 2 Joint Mapping Plot (N2JMP) technology to develop the streamlined GUI. DIOPS will begin integration into operational watch forecasting beginning January 2003, using the streamlined GUI and personnel from NPMOC-SD. Delivery to the Navy of the DIOPS system is scheduled for October 2003.

6. ACKNOWLEDGEMENTS

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