4.11   DIOPS: A PC-BASED WAVE, TIDE AND SURF PREDICTION SYSTEM

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1. INTRODUCTION

The Distributed Integrated Ocean Prediction System (DIOPS) is a PC-based wave, tide and surf prediction system designed to provide DoD accurate and timely surf predictions for essentially any world-wide location. Regional and coastal wave predictions are made by the Simulating Waves Nearshore (SWAN) wave module that is typically initialized by offshore directional wave spectra from the Fleet Numerical Meteorological and Oceanography Center (FNMOC). Tide and storm surge predictions are made by PCTIDES, a relocatable 2-D barotropic ocean model that can assimilate tidal constituent data. A one-dimensional surf model, SURF3.2 generates surf predictions based on wave and tidal information from SWAN and PCTIDES. Wind forcing obtained from FNMOC is used to force all DIOPS models. Water levels from PCTIDES are used to adjust bathymetry in the wave and surf modules. The Dynamic Information Architecture System developed by Argonne National Laboratory provides the object-oriented framework that allows the models to exchange information with each other. DIOPS has been loosely coupled with the Delft3D modeling system for 2-dimenionsal surf predictions to give the U.S. Navy a new capability to predict the location of rip-tides, provided high-resolution (scales of meters) bathymetry is available.

2. DIOPS MODELS

DIOPS consists of a shallow-water wave model, Simulating Waves Nearshore (SWAN), which can receive boundary conditions from either the deep-water wave models WAM or WaveWatch III. WAM is contained within DIOPS, WW3 data is available from FNMOC. DIOPS also includes a globally relocatable tidal-prediction model, PCTIDES, which is used to provide water elevation data to SWAN and the Navy

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Standard Surf Model (NSSM).   Fig. 1 shows the DIOPS model flow. The following discussion provides an overview of these models.
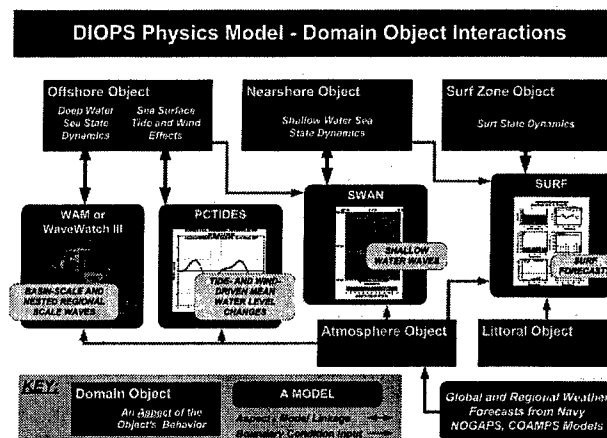

Figure 1.   DIOPS domain object interaction between offshore, nearshore, and the surf zone.

2.1 WAM

The Wave Action Model (WAM) is a spectral wave prediction model developed by the WAMDI Group (1988). WAM is run operationally by the Naval Oceanographic Office (NAVOCEANO) for numerous locations around the globe (Jensen et al., 2002).

In a typical configuration, WAM produces a directional spectrum of energy density in 25 frequency bins ranging from 0.033 to 0.328 hertz and in 24 15-degree wide directional sectors from which significant wave height, average wave period and average wave direction can be computed. Due to its explicit numerical scheme, WAM is rarely run at a higher resolution than 5 minutes or 8 km.

WAM is typically run in a nested fashion, with a basin- scale computation performed at a 1.0° horizontal resolution. If DIOPS is being run to generate a surf prediction, WAM must be run at sufficient resolutions to provide boundary conditions for the shallow-water wave model SWAN. This requires a WAM nest with a typical resolution ranging from 0.20 to 0.25°. Directional wave spectra from this WAM nest will be

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used to provide boundary conditions for a SWAN simulation.

2.2 SWAN

SWAN is a third-generation wave model designed for coastal regions (Booij et al., 1999). DIOPS includes the latest SWAN release (40.11) which incorporates the following physics:

- wave propagation in time and space, shoaling, refraction due to current and depth
- wave generation by wind
- nonlinear three- and four-wave interactions
- whitecapping, bottom friction, and depth-induced breaking
- wave-induced setup.

SWAN can be run in a nested fashion, and similar to WAM, can be initialized with a *restart* file from a prior model run. Bathymetry can be adjusted by time-varying water levels from PCTIDES (Sec. 2.3). SWAN is configured in DIOPS to operate in a spherical coordinate system. Directional wave spectra from SWAN are used to initialize NSSM (Sec. 2.4). Figure 2 depicts a triple-nested SWAN configuration for the Baltic Sea. Figure 3 depicts comparisons of wave height and wave period at a SMHI wave buoy showing excellent agreement for the 15-day period from March 1-15, 2002.

Figure 3. Top: wave height and bottom: peak wave period comparison between SWAN model (red) and SMHI buoy (blue) near Olands, Sweden.
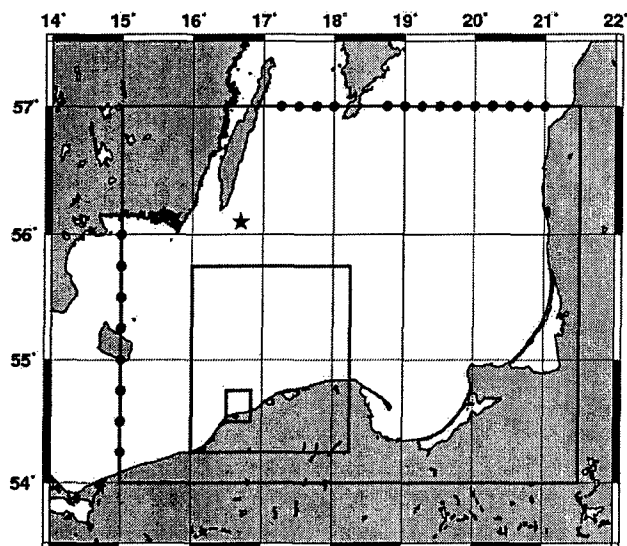

Figure 2. Triple-nested SWAN configuration utilized during NATO Exercise Strong Resolve 2002 in the Baltic Sea. Red circles represent WAM directional wave spectra applied as a lateral boundary condition. Interior blue boxes denote SWAN nests. Star denotes SMHI buoy location.
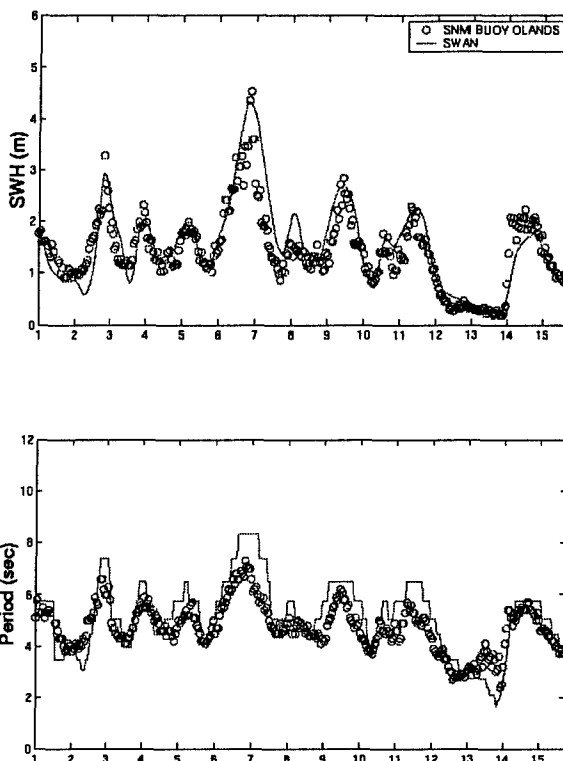
2.3 PCTIDES

PCTIDES (Blain et al., 2002) is a globally relocatable tidal-prediction model, which consists of a 2-D barotropic ocean model. Originally designed for a PC-based environment, PCTIDES has been configured to also run on Unix platforms. Surface winds and pressures and/or astronomical tides are used to force the model. A 0.25° horizontal resolution global tide model, the Finite Element Solutions 99 (FES99, Lefevre et al., 2000), is used to provide tidal conditions on open boundaries. All databases, except for wind and pressure forcing, are internal to PCTIDES. These databases include: (1) bathymetry, a 2-minute interpolated version of the NAVOCEANO Digital Bathymetric Data Base –Variable Resolution (DBDB-V), (2) the FES99 solutions, and (3) a tidal station database consisting of more than 4200 stations from the International Hydrographic Office (IHO) database. The IHO data can be used for model validation or for data assimilation. Additional information on PCTIDES can be found in this proceedings (Preller et al., 2005)

PCTIDES can be configured to run "stand-alone" or in a nested fashion. Generally, a nested region covers an area smaller than the host grid but with a resolution 3 to 4 times higher. PCTIDES is typically forced with

10-m winds and sea level pressure from the highest resolution Navy model available.

2.4 NAVY STANDARD SURF MODEL

The NSSM has been used extensively throughout the U.S. Fleet since it was first introduced in the late 1980's. The model is the primary software for the Navy operational surf forecasting, and it is also used to generate surf climate descriptions. NSSM has gone through several improvements. Earle (1999) provides a model overview and example of its applications.

NSSM produces outputs that meet the operational requirements as described in the Joint Surf Manual (1987). Model outputs include the following:

- A forecast summary which lists the surf zone width, the maximum wave height and longshore current, direction of breakers, breaker type, breaker period, and the Modified Surf Index (MSI), which is a dimensionless number that characterizes overall surf conditions used for operational planning.
- A listing of water depth, wave height, percent of breaking waves, breaker height, breaker angle, and longshore current as a function of distance offshore.

3. DIOPS ARCHITECTURE

In modeling and simulation terms, DIOPS is an object-based virtual maritime environment within which models that represent diverse dynamic ocean processes can interact, to support various analysis and planning functions.

DIOPS provides the capability to set up, run and distribute coupled wave, tide and surf modeling simulations for any location worldwide, using a flexible collection of state-of-the-art physics-based numerical prediction models. Argonne National Laboratory (ANL) employed its Dynamic Information Architecture System (DIAS) to assemble a software object framework (Christiansen, 2000) that allows these models to work together in various context-dependent combinations within the same simulation. DIAS is a flexible, extensible, object-oriented framework for developing and maintaining complex simulations. DIAS supports fully distributed simulations in which the dynamic behaviors of the software "domain objects," representing the diverse entities that populate a simulation, are implemented by an ensemble of simulation models (new models and/or existing "legacy" models) implemented in virtually any programming language.

DIAS has been under development at ANL since 1993 for a series of governmental and private sector sponsors with very diverse needs. DIAS is explicitly designed to be context-neutral; it supports simulations in essentially any domain. DIAS application areas to date, in addition to

The object-based DIOPS framework decomposes the maritime environment from deep ocean to the shore (Fig. 1) into classes of software objects, each with its own spatially distributed sets of attributes, and with dynamic behaviors that are implemented by the appropriate ocean physics models. The DIAS software architecture underlying DIOPS enforces the stricture that models may communicate only with domain objects, and never directly with each other. This makes it relatively easy to add models, and almost trivial to swap alternative models in and out without re-coding. As a result the DIOPS virtual maritime environment can be modified and extended far more easily than can most "model federations".

4. DIOPS Common Graphical User Interface

The DIOPS developers maximized portability by developing the GUI code in the Java Programming Language. The Java Programming Language was chosen because it is supported by all major commercial systems (e.g., Windows 2000, Linux, Sun Microsystems Solaris, Hewlett Packard HPUX, and IBM AIX). In addition, this increased the developers ability to leverage the directions of many vendors in the commercial and government market that are also utilizing Java (e.g., DII COE from the Defense Information System Agency (DISA), NITES II OOR from SPAWAR, DIAS from ANL, and JClass® Graph & Plot software developed by Sitraka Inc.).

The DIOPS developers were able to maximize screen space without covering up the chart by dividing the screen area into 3 major spaces using a "window pane" technology. Although a standard windowing concept, this technology was leveraged from the NITES II OOR effort. The DIOPS display is divided into the Task Area, the Chart Area, and the Analysis Area. There are window pane bars dividing the three areas. The operator can click and drag the window pane bar to make one area larger and another smaller but portions of each area remain visible; no hidden windows. Fig. 4 shows the DIOPS GUI.

The Task Area is in the upper left hand side of the display. It is a visual outline of the operators tasks and is designed to walk the operator through the job (i.e., for DIOPS creating ocean prediction scenarios for an area of interest). The task management software uses colors to identify tasks of priority and the order in which they should be accomplished. For example, the first task the DIOPS operator must complete is creation of a scenario skeleton (i.e. give the scenario a name and choose the ocean models to be used in the scenario). The Create Scenario task is listed in red and is active

and the other tasks are listed in gray and are inactive until the Create Scenario task has been performed.
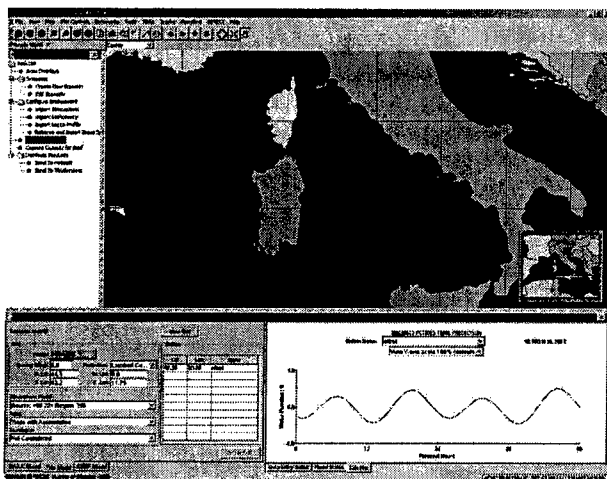

Figure 4. DIOPS GUI featuring a Task Area (left), Chart Area (upper middle), and Analysis Area (Lower right). Lower left shows model configuration for PCTIDES. Graphic depicts PCTIDES water levels in the Ligurian Sea.

The upper right side of the DIOPS display is the Chart Area. The Chart area provides the DIOPS operator some visual cues for the current scenario being worked. If the operator selects the Area Overlays task, overlays for the Chart can be toggled on / off for display. Some of these overlays include offshore model nest boundaries, nearshore model nest boundaries, wave spectra boundary points, and locations of the surf zone beaches and headings. In the future, we hope to add drag and drop interactions with the charts for the creation of model nests and locations. The bottom third of the display is the Analysis Area and contains the screens for the DIOPS application. The screens change within this area depending on the DIOPS task being performed. For example, the screen will change to the model configuration screen when the Configure Models task is chosen. The Analysis Area is completely application dependent. Nevertheless, an attempt has been made to follow some guidelines set by other NITES II OOR applications such as the following.

- Inputs are on the left side of the analysis area and outputs are typically on the right.
- Folder Tabs are used to switch between screens of a task instead of having popup windows with "OK" and "Cancel".
- Folder Tabs are used to switch between different displays of output data.

Data Entry errors are also identified to the operator in the color red and warnings are identified in the color blue. This also helps the novice operator in scenario setup.

The display of model output plots was improved by utilizing a Commercial-Off-The-Shelf (COTS) package, JClass® that provides for development of x-y charts, bar charts, pie charts, etc. For example, the need to modify scripts whenever the area of interest changed; was not very dynamic. The JClass® software provides dynamic flexibility and additional functionality such as dynamic scaling on plots.

5. METCAST

METCAST has been an integral part of the DIOPS system since its inception. Originally, SPAWAR and FNMOC developed the TEDS/METCAST/JMV system to provide model data to forecasters and ship routers in the METOC community. DIOPS utilizes METCAST client to interface with the Tactical Environmental Data Server (TEDS) for 10 m winds and Mean Sea Level Pressure (MSLP) fields from the various atmospheric models run at FNMOC. Furthermore, in 2002, working with FNMOC, wave spectra was delivered into the METCAST Channel technology. METCAST Channels provide the capability for various different types of data to be provided to many different users, using a publish/subscribe data oriented web service. DIOPS users are able to use the METCAST Graphical User Interface (GUI) to subscribe to a channel, and download data (see Fig. 5) published by FNMOC. By updating wave spectra, winds, and MSLP, DIOPS forecasts can be made every 12 hours. METCAST channels have also been used to publish DIOPS data. During exercise, MILLENIUM CHALLENGE 2002, DIOPS data was published into METCAST Channels for use in the Geospatially Enabled METOC (GEM) system at the Naval Pacific METOC Center, San Diego.
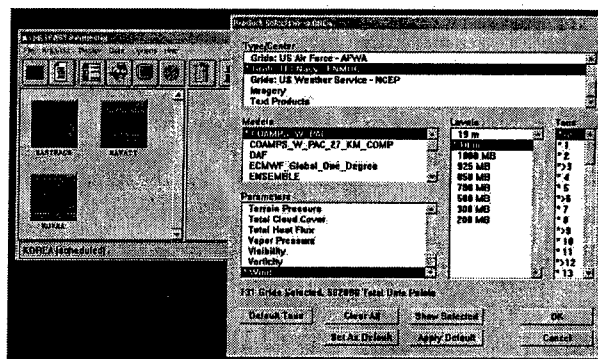

Figure 5. METCAST GUI displaying COAMPS model parameters requested for DIOPS model runs.

6. DELFT3D MODELING SYSTEM

DIOPS has been loosely coupled to the Delft3D modeling system to provide a 2-D surf modeling capability. The Delft3D system, developed by Delft Hydraulics, is a complete coastal hydrodynamic modeling system, capable of simulating hydrodynamic processes due to waves, tides, rivers, winds and coastal currents; the present application of the model is focused on nearshore hydrodynamics forced by breaking waves. The model can be run in Cartesian (equidistant or stretched) or curvilinear coordinates; all necessary grid generation software for creating curvilinear grids is included with the Delft3D package.

The Delft3D system uses two modules for simulating nearshore wave-induced hydrodynamic processes. The WAVE module uses either the SWAN model or the HISWA model (Holthuijsen et al. 1989) for propagation and generation of waves. Hydrodynamics are simulated with the FLOW module, which uses the three-dimensional hydrostatic shallow water Navier Stokes equations with the discretization scheme of Stelling and Van Kester (1994). Forcing for wave-induced flow is provided either with radiation stress gradients or using the wave dissipation (Dingemans et al. 1987) to limit the active current generation to the surf zone. The model can be run with both one-way forcing or with feedback between the two modules.
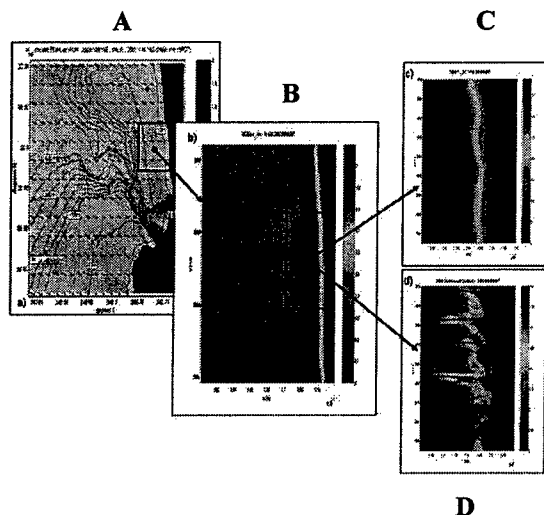

Figure 6: An application of Delft3D to the Nearshore Canyon Experiment site at Scripps Institution of Oceanography. a) Wave heights from DIOPS forcing Delft3D at intermediate nest. b) Wave heights from intermediate nest of Delft3D forcing finest nest of Delft3D. c) Wave heights in finest Delft3D nest, and d) Nearshore current directions and magnitudes in finest Delft3D nest.

The model has been validated with several field data sets (Morris 2001) and has been applied to the 2003

Nearshore Canyon Experiment (NCEX) at Scripps Institution of Oceanography. Figure 6 shows a nested run inside the DIOPS system for the area using typical wave conditions for the time of year (long period swell, propagating from the northwest). The rip current features seen in the finest Delft3D nest have been seen in video and radar data for the area, and are persistent features.

7. SUMMARY

DIOPS is a relocatable wave/tide/surf prediction system capable of operating in a Unix or PC environment. The entire suite of models can be run at a METOC regional center with the ingestion of atmospheric forcing fields such as winds, and sea-level pressure and available bathymetry. The distributed nature of DIOPS will allow production centers at FNMOC and NAVOCEANO to provide deep and shallow-water wave spectra via TEDS, permitting computationally fast surf predictions to be made at almost any location. DIOPS has been designed to be operated by junior enlisted personnel; the redesign of the GUI allows for the streamlining of operator inputs, eliminates duplicative screens, and allows for development of the code to maximize portability of the software. A DIOPS beta-test site established at NPMOC-SD provided DIOPS developers the opportunity to gather feedback from targeted fleet users on model performance and ease-of-use of the GUI. DIOPS and Delft3D are now being run at the Mission Support Center, San Diego.

The Delft3D model system, loosely coupled to DIOPS, provides a capability to generate 2-D surf predictions utilizing very high resolution bathymetry collected from Autonomous Underwater Vehicles (AUV). A prototype system is being tested at the Mission Support Center, San Diego.

ACKNOWLEDGEMENTS

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REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE		3. DATES COVERED *(From - To)*
	Final		

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
DIOPS: A PC-Based Wave, Tide and Surf Prediction System	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
	0603207N

6. AUTHOR(S)	5d. PROJECT NUMBER
Allard, Richard, Dykes, James, Kaihatu, James, Wakeham, Dean	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
	73-7452-03

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004	NRL/PP/7320--04-5013

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
Space & Naval Warfare Systems Command 2451 Crystal Dr. Arlington, VA 22245-5200	SPAWAR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS

surf model, DIOPS, SWAN, tidal-prediciton

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UU	6	Richard Allard
Unclassified	Unclassified	Unclassified			**19b. TELEPHONE NUMBER** *(Include area code)* 228-688-4894