

# The Distributed Integrated Ocean Prediction System (DIOPS)

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**Abstract-The Distributed Integrated Ocean Prediction System is a complete wave, tide and surf prediction system that can be run on a Unix platform or personal computer. Operational Navy meteorological numerical modeled winds and sea level pressure are used to initialize and force the system. An improved Graphical User Interface allows for efficient model setup, configuration, and visualization. DIOPS is being designed to be operated by junior enlisted personnel.**

## I. INTRODUCTION

The Distributed Integrated Ocean Prediction System (DIOPS) is a complete wave, tide, and surf prediction system that allows a trained user to generate surf predictions at essentially any world-wide location, provided adequate bathymetry is available. Atmospheric forcing (10-m winds, sea level pressure) is provided through the U.S. Navy's Tactical Environmental Data Server (TEDS).

DIOPS utilizes an object-oriented framework called the Dynamic Information Architecture System (DIAS) in which models communicate with domain objects. Distribution to the warfighter (via TEDS) and visualization on the Defense Information Infrastructure-Common Operating Environment (DII-COE) command and control viewer called the Common Operating Picture (COP) have also been a keystone of DIOPS development.

A DIOPS beta-test site was established at the Naval Pacific Meteorology and Oceanography Center (NPMOC-SD), San Diego, CA in April 2001. A full-time scientist runs DIOPS and gathers feedback between NPMOC-SD personnel and DIOPS developers. The development of DIOPS is geared toward operation by junior enlisted Meteorology and Oceanography (METOC) personnel. The scientist provides recommendations for improvements and provides training

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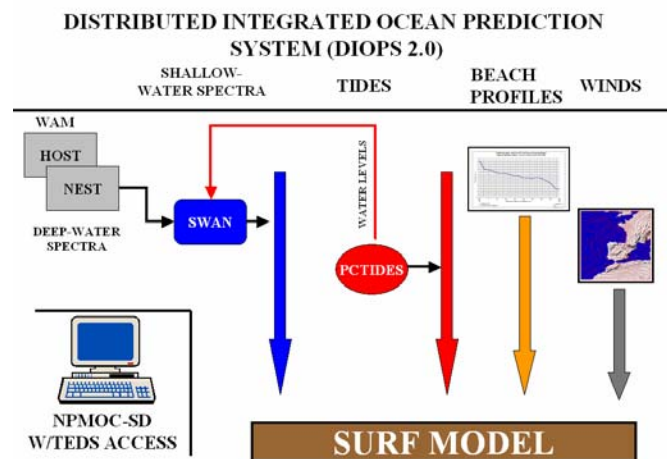
and documentation. It is anticipated that DIOPS will be deployed to U.S. Navy Regional METOC Centers beginning in 2004.

## II. DIOPS MODELS

DIOPS consists of a deep-water wave model WAM, which provides boundary conditions to the Simulating Waves Nearshore (SWAN) shallow-water wave model. A globally relocatable tidal-prediction model, PCTIDES, is used to provide water elevation data to SWAN and the Navy Standard Surf Model (NSSM). Fig. 1 shows the DIOPS model flow. The following discussion provides an overview of these models.

### A. WAM

The Wave Action Model (WAM) is a spectral wave



**Fig. 1. DIOPS model components. The Navy Standard Surf Model requires four inputs: directional wave spectra from a shallow-water wave model, water elevation from a tidal prediction model, beach profiles, and wind speed and direction.**

prediction model developed by the WAMDI Group [1]. WAM is run operationally by the Naval Oceanographic Office (NAVOCEANO) for numerous locations around the globe (Jensen et al., [2]).

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 used to provide boundary conditions for a SWAN simulation.

### B. SWAN

SWAN is a third-generation wave model designed for coastal regions (Booij et al., [3]). 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.

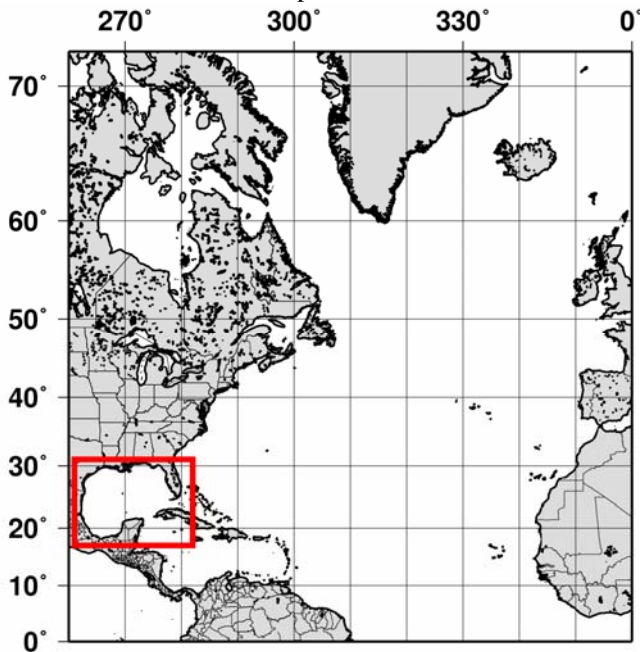


Fig. 2. Portion of WAM Atlantic Basin shown with embedded Gulf of Mexico Regional WAM.

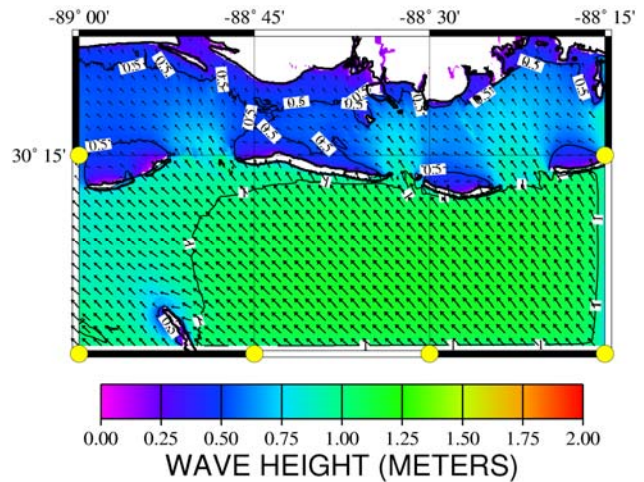


Fig. 3. SWAN wave heights for Mississippi Bight. Note the sheltering effects of the barrier islands. Circles on model boundary denote locations where WAM directional wave spectra were applied.

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. C). SWAN is configured in DIOPS to operate in a spherical coordinate system. Directional wave spectra from SWAN are used to initialize NSSM (Sec. D).

### C. PCTIDES

PCTIDES (Blain et al., [4]) 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 global tide model, the Finite Element Solutions 95.1/2.1 (FES95.1)/2.1, 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 3-minute interpolated version of the NAVOCEANO Digital Bathymetric Data Base –Variable Resolution (DBDB-V), (2) the FES95.1/2/1 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.

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.

### D. NSSM

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[5] provides a model overview and example of its applications.

NSSM produces outputs that meet the operational requirements as described in the Joint Surf Manual [6]. 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.

### III. 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, [7]) to assemble a software object framework 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

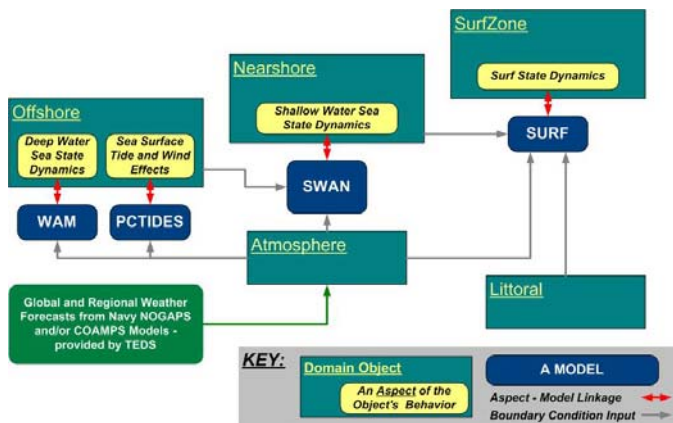


Fig. 4. Relationship between offshore, nearshore, and surf zone objects in DIAS.

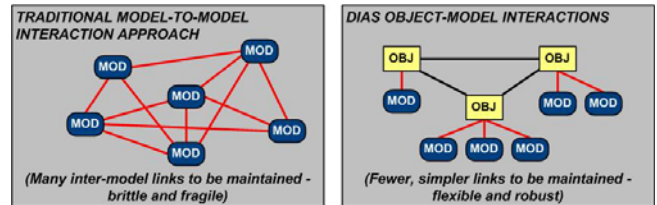


Fig. 5. Flow diagram showing model linkages using a) traditional stovepipe approach and b) object-oriented design found in DIAS.

DIOPS, include dynamic terrain- and weather-influenced military unit mobility assessment; integrated land management at military bases; clinical, physiological and logistical aspects of health care delivery; avian social behavior and population dynamics; and a multidisciplinary simulation software system to aid drug interdiction analysts in deriving and justifying force structure and operational planning recommendations for combating the South American cocaine trade.

The object-based DIOPS framework decomposes the maritime environment from deep ocean to the shore (Fig. 4) 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 (Fig. 5), 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".

### IV. TACTICAL ENVIRONMENTAL DATA SERVER (TEDS)

DIOPS is able to obtain and publish data via TEDS, a METOC information storage and management system. TEDS allows tactical applications and customers to access environmental information in historical databases and commercial relational database management systems (RDBMS) using network and Internet protocols. With the METOC Broadcast Service (METCAST) automated delivery software, users with Internet access can monitor information updates on demand, continuously or on schedule. Ten-meter winds and mean sea level pressure binary gridded files are extracted twice daily from TEDS via METCAST. DIOPS utilizes operational Navy Operational Global Atmospheric Prediction System (NOGAPS) and Coupled Ocean Atmosphere Prediction System (COAMPS) field data for its inputs. The NOGAPS forecasts are used primarily for basin scale WAM predictions, or in areas where COAMPS fields are not available. The COAMPS is a higher resolution mesoscale model, and its fields are used for higher resolution model runs, such as regional WAM areas, SWAN, PCTIDES and NSSM/SURF models. TEDS also contains a static bathymetry database, which DIOPS can access for wave model runs.

## V. DIOPS Common Graphical User Interface (GUI)

The original (DIOPS 1.0/2.0) software GUI (Fig. 6) contained duplicate windows and similar windows of information for defining grids that extracted data from the TEDS database and set up grids for ocean model runs. This created the need for the Common GUI task for DIOPS software. The goal for the DIOPS Common GUI was to streamline the operator inputs, eliminate duplicative screens, and develop the code to maximize portability of the software. During the design of the DIOPS Common GUI, the developers leveraged Fleet Feedback on the GUI design for Navy Integrated Tactical Environmental Subsystem (NITES) II Object Oriented Redesign (OOR). The major points of feedback on NITES II OOR GUIs from the fleet were the following:

- Don't put up windows that can cover the Chart or get lost behind the Chart.
- Eliminate Pop Up boxes with "OK" and "Cancel".
- Minimize the number of button pushes for the operator.
- Make the GUI more intuitive to use.

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 HP-UX, 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<sup>®</sup> 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. 7 shows the new redesigned 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

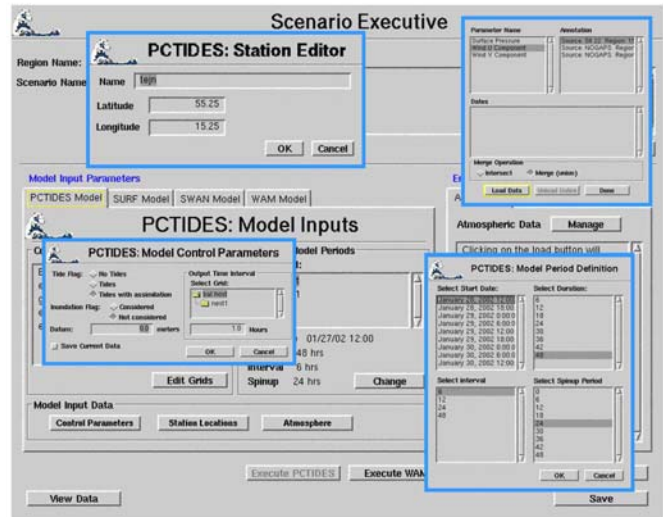


Fig. 6. Example of original DIOPS GUI used in setting up the relocatable tide model PCTIDES. Note the many "pop-up" windows that can appear.

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.

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

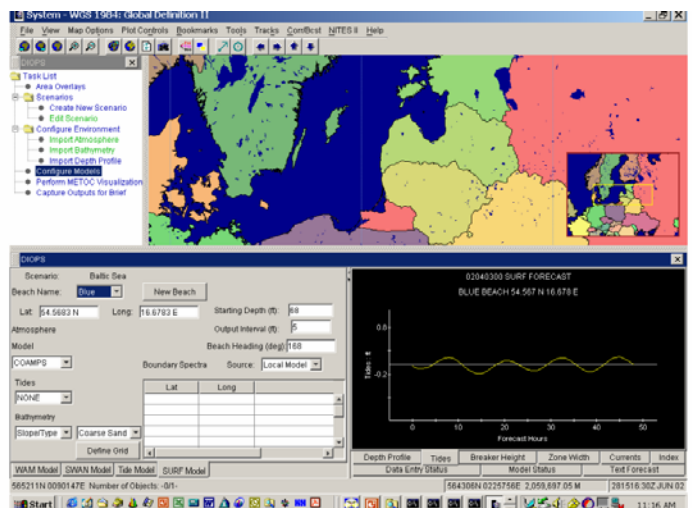


Fig. 7. Redesigned DIOPS GUI featuring a Task Area (left), Chart Area (upper middle), and Analysis Area (Lower right). Lower left shows model configuration for NSSM. Graphic depicts PCTIDES water levels in the Southern Baltic Sea.

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.

The DIOPS 2.0 GUI had many screens for configuring an ocean model. For example, the WAM model configuration had approximately 20 popup screens to accomplish the model setup. By selecting appropriate defaults for the model configuration, for many parameters, the WAM model configuration can now be accomplished via one screen. In addition, default information was added for nested grid sizes and spacing. This aids the novice operator in quickly setting up a scenario. 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<sup>®</sup> that provides for development of x-y charts, bar charts, pie charts, etc. The DIOPS 2.0 software utilized a set of scripts that controlled plots generated using freeware graphics packages. The freeware package contained in DIOPS1.0/2.0 was robust but its script oriented nature caused it to be less flexible. For example, the need to modify scripts whenever the area of interest changed; was not very dynamic. The JClass<sup>®</sup> software provides dynamic flexibility and additional functionality such as dynamic scaling on plots.

## VI. 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. The DIOPS beta-test site established at NPMOC-SD provides DIOPS developers the opportunity to gather feedback from targeted fleet users on model performance and ease-of-use of the GUI.

Future plans call for the addition of the Delft3D model to DIOPS, which will provide a capability to generate 2-D surf predictions utilizing very high resolution bathymetry collected from Autonomous Underwater Vehicles (AUV).

## REFERENCES

- [1] WAMDI Group, “The WAM model --- a third generation ocean wave prediction model”, *J. Phys. Ocean.*, vol. 18, 1988, pp 1775-1810
- [2] R.E. Jensen, P.A. Wittmann, and J.D. Dykes, “Global and regional wave modeling activities”, *Oceanography*, Vol. 15 (1), 2002, pp. 57-66.
- [3] N. Booij, R.C. Ris, and L.H. Houlthuijsen, “A third-generation wave model for coastal regions, part 1, model description and validation,” *J. Geoph. Res.*, Vol. C4 (104), 1999, pp. 7649-7666.
- [4] C.A. Blain, R.H. Preller, and A.P. Rivera, “Tidal prediction using the advanced circulation model (ADCIRC) and a relocatable PC-based system”, *Oceanography*, Vol. 15 (1), 2002, pp. 77-87.
- [5] Earle, “Applied and operational surf modeling,” *Shore and Beach*, vol. 67, 1999, pp. 70-75.
- [6] Commander, Naval Surface Force, Pacific and Commander, Naval Surface Force, Pacific, “*Joint surf manual*”, COMNAVSURFPAC/COMNAVSURFLANTINST 3840.10B, 02 January 1987, 13 chap.
- [7] J.H. Christiansen, “A flexible object-based software framework for modeling complex systems with interacting natural and societal processes,” *Proceedings of the 4<sup>th</sup> International Conference on Integrating GIS and Environmental Modeling*, Model Integration Framework Workshop Session, 2000, (Banff, Alberta, Canada, Sept. 2-8).