# Developing an Operational Wave, Surf, and Tide Forecasting System for the United States Navy Meteorology and Oceanography Community

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**Abstract - The Distributed Integrated Ocean Prediction System (DIOPS) has been designed for US Navy Meteorology and Oceanography (METOC) forecasters to provide worldwide wave forecasts from basin to beach scale. Current beta-testing of DIOPS is being concluded at the Naval Pacific METOC Center, San Diego (NPMOC-SD). Through cooperation of NRL and NPMOC-SD, the DIOPS Project was developed and utilized in multiple operations and exercises to support littoral and beach crossing mission of the US Navy. An innovative development plan delivered an initial build and integration scientist to NPMOC-SD to develop training and integration of the DIOPS system, while providing feedback to the software developers in order to deliver a user friendly littoral wave, surf, and tide forecasting system. This paper will discuss an overview of the DIOPS (Graphical User Interface) GUI, some of the recent operational support provided by DIOPS, and a summary of future advances of DIOPS Project, including the integration plan for the DELFT 3D Hydrodynamic model.**

## 1. INTRODUCTION

United States Navy and Marine Corps operations often involve moving people and equipment from the sea ashore. Special warfare and special operations, mine warfare, amphibious operations, all may have to take place within the littoral environment, as well as require movement through the surf zone. In 2000, the Office of Naval Research and the Space and Naval Warfare Command (SPAWAR) Meteorology and Oceanography (METOC) code commissioned the Naval Research Laboratory, Stennis Space Center (NRL-SSC), Ocean Dynamics and Prediction Branch to develop the Distributed Integrated Ocean Prediction System (DIOPS). DIOPS is a suite of ocean prediction models including a deep water wave model, the Wave Model (WAM); a shallow water wave model, the Simulating Waves Nearshore (SWAN) Model; a surf zone model, the Navy Standard Surf Model (SURF or NSSM); and the Navy Relocatable Tide and Surge Prediction Model (PCTIDES). [1]

DIOPS allows these models to communicate with each other by using the Dynamic Information Architecture System (DIAS) developed by Argonne National Laboratory (ANL) [2], an object oriented architecture that allows the models to communicate with specific environmental "domain objects" rather than with the models themselves. This architecture allow for ease of adding/swapping models in and out of the architecture without recoding

The DIOPS project is a 3 year effort to demonstrate the capability or running regional ocean prediction models at regional METOC centers. The DIOPS beta-testing is ongoing at the Naval Pacific METOC Center, San Diego (NPMOC-SD), located at North Island Naval Air Station. This paper will discuss specific operational support DIOPS has provided for naval operations and exercises, changes to the DIOPS suite over the course of the demonstration, and future work for the DIOPS project.

# DIOPS 1.0 Data Flow

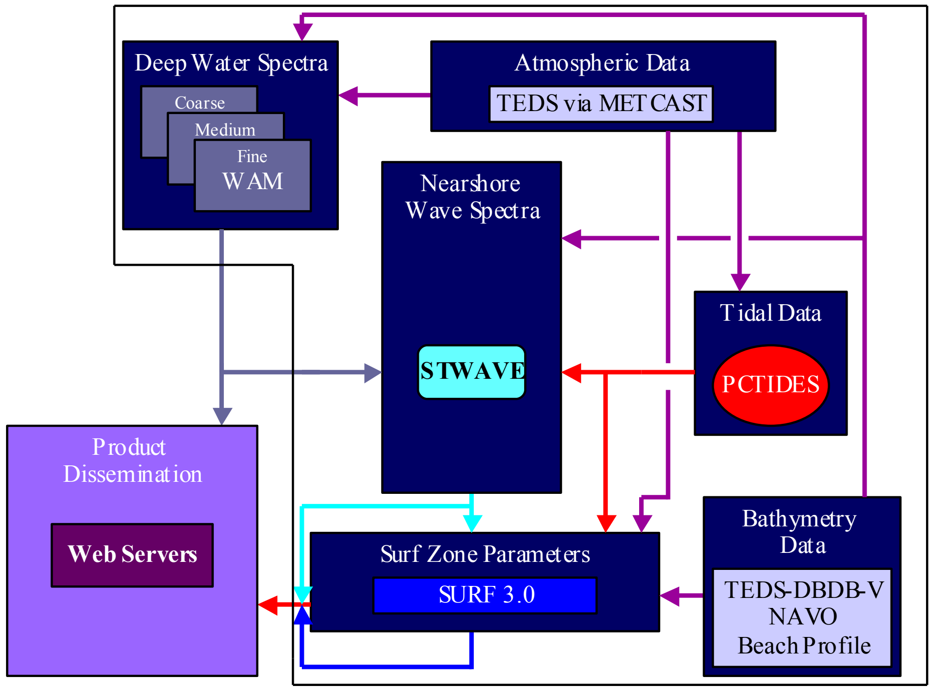


Figure 1. DIOPS 1.0 Data Flow. Atmospheric Data is obtained from METCAST for all of the models. Bathymetry can come from various sources including the TEDS DBDB-V database, from NAVO databases, or from model contained databases. The WAM model provides deepwater wave spectra which is used with tidal data and atmospheric data to force STWAVE, which in turn provides wave spectra to SURF. Products from each of the models are able to be displayed graphically or as text documents on web pages.

## 2. DIOPS 1.0

DIOPS 1.0 was installed at NPMOC-SD in April 2001, on a Sun Ultra80 computer system. The initial version of DIOPS ran by obtaining 10 meter winds and mean sea level pressure data from numerical weather prediction models run at the Fleet Numerical METOC Center (FNMOC) in Monterey, CA. This data was accessed via the FNMOC-SPAWAR designed METCAST data server access to the Tactical Environmental Data Server (TEDS), an operational, relational database of METOC data produced at FNMOC.

DIOPS also requires bathymetry for the various models. For the WAM model, this bathymetry is obtained via the DBDB-V bathymetry database, via the TEDS API's. Initially the nearshore model in DIOPS was the steady state wave model, STWAVE. This model was a half plane model, and required the offshore boundary to be perpendicular to the beach. Bathymetry for this model was provided by the Naval Oceanographic Office. Bathymetry for PCTIDES was obtained from self contained 2 arc-minute data base within the software system itself. For NSSM, the bathymetry or beach profiles can be input from Navy Hydrographic Reconnaissance Charts, or can be estimated from generic approximations based on the sediment size within the surf zone.

The data flow for DIOPS 1.0 is demonstrated in Figure 1.

## 3. DIOPS 2.0

In February 2002, the SWAN model was introduced into DIOPS (Version 2.0), as was the Refraction-Diffraction model REF-DIF. The REF-DIF model was found to be unsuitable for rapid response to naval operations, due to the long initialization of the model coefficients. The SWAN model, was found to be easier to set up than STWAVE, as it is a full-plane model, where all boundaries of the model can be initialized with boundary spectra, preventing the need for rotating the grid, and providing a more complex boundary condition for wave spectra, if necessary. Furthermore, SWAN is able to be nested, and can run in a steady state mode similar to STWAVE if needed. SWAN has become the nearshore wave model of choice, although, the other models are still available to be used. Figure 2, depicts some of the changes incorporated into DIOPS 2.0.

DIOPS 2.0 was showcased in multiple exercises and operations through 2002 and into 2003. The first exercise, a NATO exercise called, STRONG RESOLVE 2002 (SR02) occurred in March 2003, in the Baltic Sea. The DIOPS 2.0 was installed on a Sun Blade 100, which was shipped to the Navy European METOC Center (NEMOC) in Rota, Spain. The DIOPS team was able to make forecasts for the landing forces involved in the exercise. Accuracy of the DIOPS 2.0 model was compared against a Swedish buoy (Figure 2) as well as altimetry data, and shown to be good in both cases. Feedback from the embarked METOC staff onboard the USS MOUNT WHITNEY was excellent, as they were unable to use their normal TDA product for surf zone forecasts, and found the DIOPS products invaluable. Unfortunately, the amphibious landing ended up an administrative landing and no observations of the surf conditions were able to be obtained.

Also during SR02, DIOPS was first integrated with a Geospatial Information Service (GIS) tool. Applied Coherent Technologies (ACT) was also demonstrating a technology during SR02, called the WWW Information Processing Environment (WIPE) server. WIPE provides access to geospatially referenced METOC data through a web browser. Further information about WIPE can be found at www.actgate.com.

In Summer 2002, MILLENIUM CHALLENGE 2002 (MC02) took place in Southern California. MC02 was the largest US Joint exercise ever conducted. Along with MC02, the Naval Warfare Development Center (NWDC) also held its Fleet Battle Experiment – JULIET (FBE-J). As a part of FBE-J, NPMOC-SD worked an initiative to move METOC data into the warfighter decision making system, by integrating it into the mission planning cell, and specifically into the Naval Fires Network (NFN). As a part of this effort, Polexis was funded to enhance their Viewpoint application to create a tool which would allow forecasters to create products which could be displayed in NFN. FNMOC was also instrumental in the effort, as their METCAST Channels were developed to handle the data delivery to the METOC forecasters, for use in Viewpoint. From Viewpoint, the products could be converted into shape files and geotiff format for use in the ESRI product ArcView 3.2.

To this end, DIOPS products were uploaded into a METCAST channel in their native format. At FNMOC, they were converted to into NetCDF GIEF format, then published in a different channel, where they could be downloaded for ingestion into the Viewpoint software. In this software, they are then able to be transformed into shape files and viewed in different ESRI software products, as well as other products with the capability of reading shape files.

DIOPS products were also made available to to METOC forecasters supporting amphibious and Naval Special Warfare (NSW) operations, via the NPMOC-SD webpage. Qualitatively, the results of DIOPS SWAN forecasts compared well with buoy results in the area. Also, the DIOPS SURF results were able to be compared to a surf observation taken by a Navy SEAL Team during a beach reconnaissance exercise, and also compared to the Video Imaging System Surf Zone Environmental Reconnaissance (VISSER) camera at Camp Pendleton. Although ground truth data within the surf zone was not collected, the observations, VISSER, and DIOPS results all provided reasonable answers of surf zone characteristics, and were accurate enough for the forecasters to make recommendations to the warfighters to proceed or not to proceed with operations and specific missions. Qualitative feedback from the USS BOXER METOC Division and the NSW Mission Support Center (MSC) METOC Cell was very positive.

In October 2002, DIOPS was again supporting NATO force in Europe. This time, for the NATO exercise DESTINED GLORY 2002 (DG02). Although for DG02, DIOPS was able to produce forecasts, bandwidth and lack of technology prevented any GIS or other advanced display of the DIOPS products. The products were hosted on the NEMOC website, and were available to all of the NATO forces. However, advancement was made in DIOPS development, specifically in the “outsourcing” of the deep water wave modeling resource.

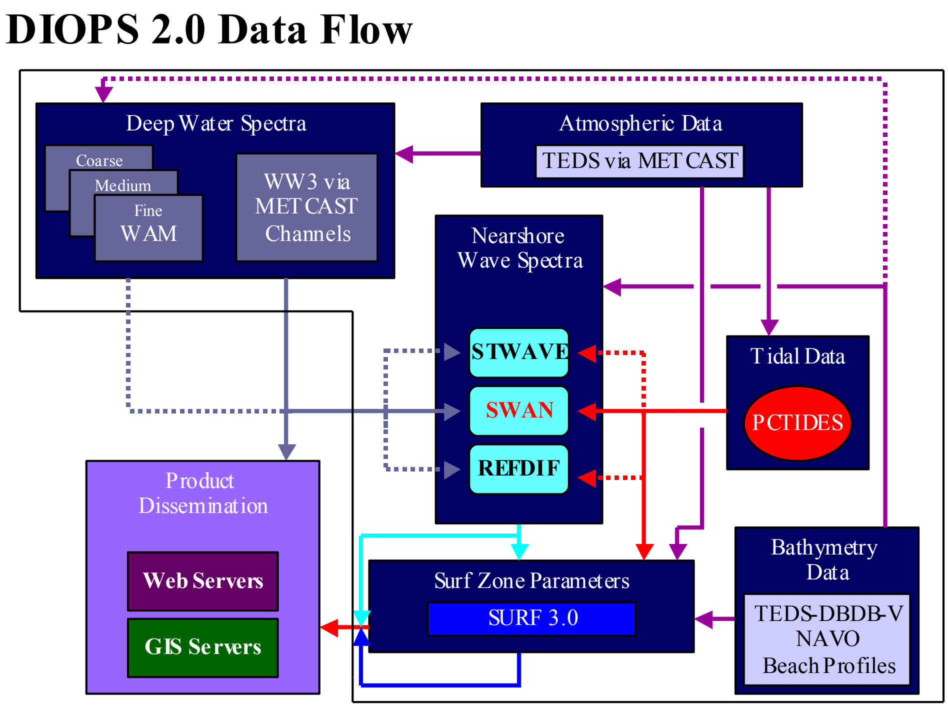


Figure 2. DIOPS 2.0 Data Flow. DIOPS 2.0 included the addition of SWAN and REFDIF as additional Nearshore wave models, the capability to obtain deep water wave spectra from FNMOC's WaveWatch3 runs, and the delivery of DIOPS products to GIS Serves such as WIPE and the METCAST Channels for use in Polexis Viewpoint.

Deep Water wave models are operationally run at two Navy Production centers. At FNMOC, the WaveWatch3 model is run at 1.0 degree resolution over the world as well as 0.2 degree resolution for most areas where the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) models are run. At the Naval Oceanographic Office, the same deep water wave model that is in DIOPS, the WAM model, is run in various locations around the globe. The DIOPS Project leveraged these resources to save computer time, as well as to maintain consistency with the METOC community answer to the deep water wave question.

For DG02, FNMOC converted wave spectra at user-requested locations into a format which was able to be ingested into SWAN. These files were then pushed into a METCAST channel, where the DIOPS system could access them and use them as boundary conditions for the DIOPS model. By delivering this data, FNMOC was able to save DIOPS having to run WAM, which depending upon the size of the area, was taking up to 4 hours of computer time (with nests) for regions such as the Pacific Ocean.

In February 2003, DIOPS began publishing products to support the NPMOC-SD focus on supporting the Inter Deployment Training Cycle (IDTC). Littoral training areas throughout Southern California were published on the NPMOC-SD Secret webpage. The USS PELELIU Expeditionary Strike Group, as well as the NSW MSC are able to access these products daily as they prepare for deployment of forces. Again qualitative feedback has been excellent.

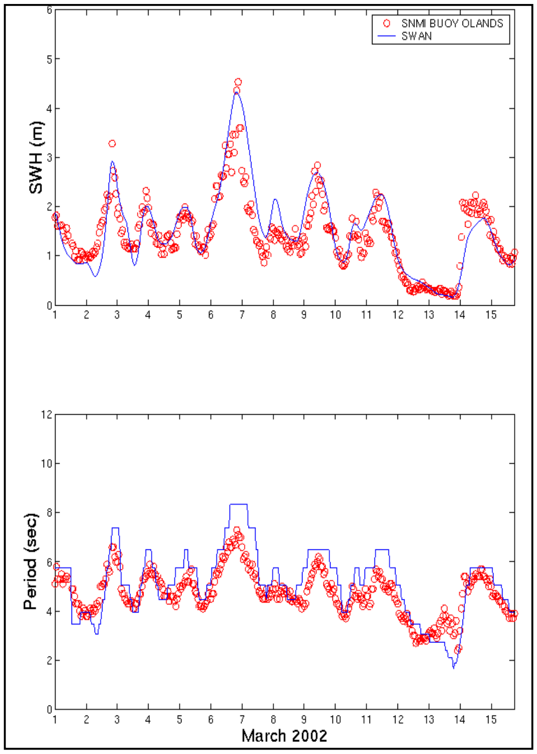


Figure 3. DIOPS SWAN Forecasts compared with observations from Swedish Buoy located near 56º N 17º E.

During March 2003, Operation Iraqi Freedom took place, and a special request was received from the MSC. The Global wave models were not handling the wave prediction in the North Arabian Gulf, and the DIOPS SWAN model was requested to provide a high resolution solution for the Area of Interest. Figure 4 depicts the 24 hour prediction of significant wave height and direction from the 25 March 2003 0000Z SWAN run. Due to the refraction effects the shallow water area had on the waves, much more dissipation was seen in the Kwhar `Abd Allah than was predicted with the deep water wave models running near 0.2 degree resolution. Because of the limits of the platforms the Navy SEALS were operating on, this product allowed them to see where they would be safe, and where conditions might prove more dangerous.

## 4.0 DIOPS 3.0

The changes made to DIOPS 3.0 are for the most part Graphical User Interface (GUI) changes. The original DIOPS GUI was designed to have the most robust options available for the user. The end DIOPS system however is to be designed for a non-forecaster qualified Aerographer's Mate Petty Officer Second Class (AG2) to use. In order to simplify the GUI, Anteon Corporation leveraged separate work that they were doing on the Naval Integrated Tactical Environmental Sub-System II Object Oriented Redesign (NITESII OOR), a means of integrating METOC data and Tactical Decision Aids with Command and Control Systems. Incorporating fleet feedback on GUI design for the NITESII OOR design, Anteon developed a task oriented GUI which provides for a logical method of setting up and executing the DIOPS models. The GUI also allows the user to set up automatic data retrieval, and automatic running of the models as data becomes available. The DIOPS 3.0 architecture will also allow data to be stored and retrieved directly from TEDS, and allow the importing of high resolution bathymetry and beach profiles which can be obtained from outside sources, such as NAVO, METOC divisions afloat, or from the MSC. DIOPS 3.0 will incorporate NSSM 3.2. This version of the SURF model has improved physics and streamlined data input

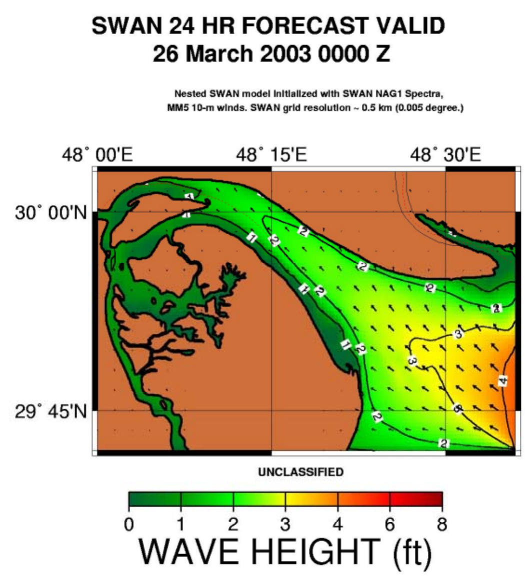


Figure 4. 25 March 2003 24 Hour forecast of significant wave height and direction in the Northern Arabian Gulf.

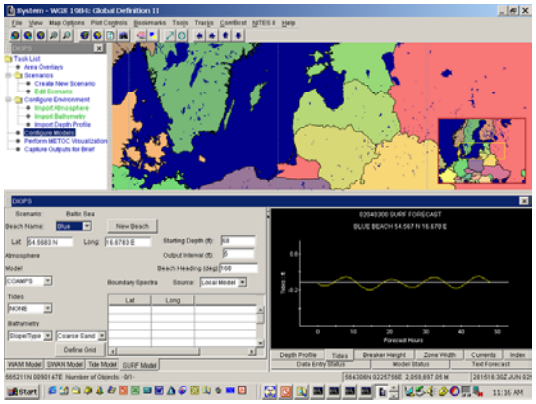

Figure 5. DIOPS 3.0 Graphical User Interface. Upper left area shows the task list for setting up the models. Upper right area is the command and control chart area. The lower section has model setup, product, and status windows.

DIOPS 3.0 saw its debut during a SACLANT Centre Maritime Rapid Environmental Assessment, in June 2003. The system was deployed on board the R/V Alliance and forecasts were made for Biodola Beach on the north coast of Elba.

DIOPS 3.0 was delivered to NPMOC-SD in July 2003. Training of the operational watchstanders is ongoing at NPMOC-SD, with the DIOPS scientist providing feedback on last minute development ideas from the fleet. DIOPS 3.0 will maintain the same computational hardware as the 2.0 system, but the GUI will be run on a Defense Information Infrastructure – Common Operating Environment (DII-COE) Windows platform. As the development of DII-COE and the NITES II OOR progresses, the GUI will also be able to run on the same hardware platform as where the computational models will run, but with the same look and feel as the Windows based version.

## 5.0 Delft 3D

In 2001, the DIOPS project was funded for an additional year as a part of an AUV Nowcasting project. The task for the DIOPS Project is to incorporate the Delft 3D Hydrodynamic modeling suite into DIOPS. Delft 3D was developed for engineers to use in analyzing the coastal environment to develop solutions along the coast. Recently work has been done to adapt Delft 3D to the surf zone, and the DIOPS project will look to make it an operational forecast tool.

There are 4 modules in the Delft 3D hydrodynamic modeling suite. These include the WAVE, FLOW, SEDIMENT (SED), and MORPHOLOGY (MOR) Modules, The DIOPS project will look at the integration of 2 of these modules, WAVE and FLOW.

The WAVE module has 2 different wave models which can be used, SWAN and HISWA. As the DIOPS project is already familiar with SWAN, it will continue to be the default wave module for the DIOPS Delft 3D integration. However, as Delft 3D runs from its own GUI, the SWAN model can only be used in stationary mode. DIOPS will be able to leverage off of its existing hardware, by running the DIOPS SWAN model in a non-stationary mode, to provide boundary conditions for Delft 3D WAVE module, stationary SWAN runs, which will in turn provide boundary conditions for the Delft 3D FLOW module (see Figure 6).

The Delft 3D FLOW module will allow for quasi-3D modeling of the surf zone, and will provide more realistic information on the currents in the surfzone, by maintaining the along shore physics as well as the cross shore physics of the surf zone. Currents will be driven by winds, tides, and waves.

Integration of Delft 3D will include the use of the TEDS/METCAST system as a data source, as well as using PCTIDES data as boundary conditions for the FLOW module. Further advancement may also look to tie in a GIS system to DIOPS-D3D. In 2002, NIMA awarded the Commercial Joint Mapping Tool Kit (C/JMTK) contract, which is undergoing development for integration into NITES II OOR. If this capability is realized, it would encourage DIOPS products to be output into the C/JMTK formats, such as shape files, which could then be used in mission planning and command and control systems. In any event, by providing 2 dimensional surf zone characteristics, including depth averaged currents, the addition of Delft 3D should allow an increased presence of METOC in the mission planning phase of naval operations within and through the surf zone.

# DIOPS/Delft-3D Data Flow

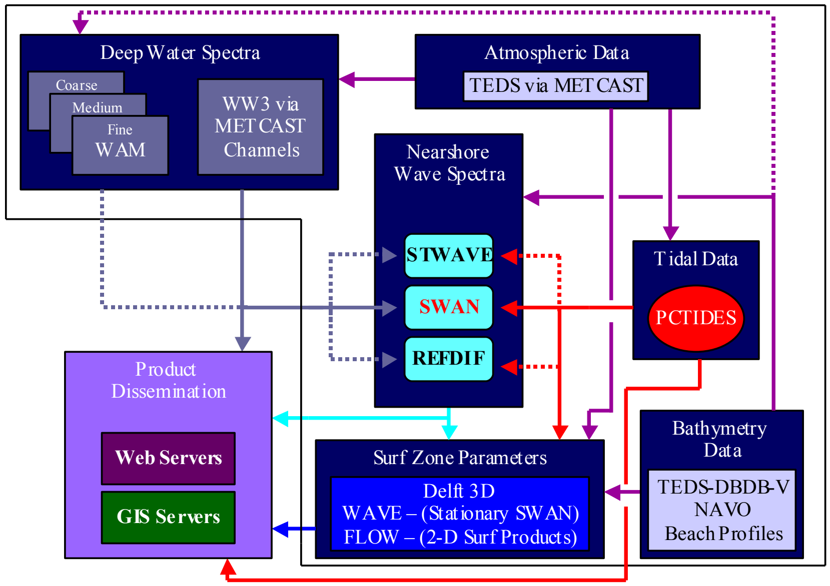


Figure 6. DIOPS/Delft3D Data flow. Similar to the DIOPS 2.0/3.0 data flow, but SURF is replaced with the Delft 3D, where the original SWAN model will run non-stationary parent nests for stationary higher resolution nests around the surf zone, to be used as input into the FLOW module.

**Refrences:**


[1] R. Allard, J.. Christiansen, T. Taxon, D. Wakeham, S. Williams, "The Distributed Integrated Ocean Prediction System," *Ptoceedings of the Marine Technical Society Oceans 2002 Conference,* (Biloxi, MS, 2002)

[2] J.H. Christiansen, "A flexible object-based software framework for modeling complex systems with interacting natural and societal processes," *Proceedings of the 4th International Conference on Integrating GIS and Environmental Modeling*, Model Integration Framework Workshop Session, 2000, (Banff, Alberta, Canada, Sept. 2-8).



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