# A Partnership for Modeling the Marine Environment of Puget Sound, Washington – Puget Sound Naval Shipyard/Space and Naval Warfare Systems Center Report

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Award Number: N00014-02-1-0502
http://www.psmem.org
November 2005

## LONG-TERM GOALS

Estuaries, fjords and sounds are important, major components of marine ecosystems worldwide. Because of this, and their generally poor treatment by man, large estuaries should be the focus of large-scale, multidisciplinary, integrative modeling efforts. We need to both understand how these systems work, and be able to predict how they will respond to changes, whether natural or anthropogenic. Puget Sound, Washington State's largest inland sea, is both the largest fjord in the lower forty-eight states and closest to the substantial urban centers of Seattle, Tacoma, Everett, Bremerton and surrounding communities. Relative to other coastal systems, Pacific Northwest fjords have seasonally high annual phytoplankton standing stock and primary production, and they support several economically valuable fisheries. Our long-term goals are to develop quantitative understanding of the seasonal and longer time-scale variabilities of the Sound's circulation, roles of water column stratification, nutrients, and light (and their interactions) on phytoplankton and zooplankton dynamics, and the sensitivity of the physical and the biological system to natural and human perturbations. We will develop models of Puget Sound that can aid agencies with responsibilities for environmental management in making informed decisions and serve as marine science education tools. A special emphasis for this component of the project is to develop an inlet-scale integrated modeling system that will include the hydrodynamic and contaminant transport within the receiving waters of Sinclair and Dyes Inlets, the surrounding watershed, and the boundaries with the Greater Puget Sound System.

## OBJECTIVES

The Partnership for Modeling the Marine Environment of Puget Sound consists of five separate organizations: University of Washington (School of Oceanography and College

of Education), King County Department of Natural Resources, Washington State Department of Ecology, Puget Sound Naval Shipyard/Space and Naval Warfare Systems Center (PSNS/SPAWAR), and Ocean Inquiry Project. The partnership will develop, maintain and operate a system of flexibly linked simulation models of the Puget Sound's circulation and ecosystem, a data management system for archiving and exchanging oceanographic data and model results that are accessible to all members of the partnership as well as to the regional and oceanographic community, and an effective delivery interface for the model results and observational data for research, education and policy formulation. The partnership engages in research activities aimed at developing fundamental understanding of the Sound's working, as well as addressing practical questions raised by the regional community concerning management of the Sound and its resources. The partnership will function as an estuarine research node within the NOPP Ocean Information Commons.

## APPROACH

The partnership is administered from School of Oceanography, University of Washington. The lead P.I. (Kawase) will be responsible for project oversight and coordination. Under tasking from the Puget Sound Naval Shipyard, the Space and Naval Warfare Systems Center is conducting modeling studies to develop an Inlet-scale integrated modeling capability for the Sinclair and Dyes Inlet watershed [1] to support the development of Total Maximum Daily Load (TMDL) studies [2] and water clean up plans for the Inlets [3]. The modeling framework will be used to conduct specific model applications to support risk analysis, watershed studies, regulatory studies, and respond to stakeholder input. The final modeling product will provide the capability to simulate, on an Inlet-scale basis, various risk management and policy alternatives. Drs. Johnston and Wang will be coordinating with the partnership on aspects of coupling the Inlet-scale model with the larger scale Puget Sound model, sharing data and information, and visualizing model simulations and results. Current work includes modifying the grid for Sinclair and Dyes Inlet to provide for linkage with the sound-scale model, incorporating a common data format (NetCDF-network Common Data Form) to facilitate exchanging model output with other project partners, and initiating a one-way coupling with the sound-scale model to satisfy the boundary conditions of the Inlet-scale model.

## WORK COMPLETED

During the FY2005 reporting period the PSNS/SPAWAR partners have successfully completed integration of netCDF (network common data format) output into the CH3D model code, completed development and testing of the numerical grid for linking with Puget Sound POM model at Agate Pass and Rich Passage facilitating one-way forcing from POM, and developed a technical approach and numerical procedures for implementing two-way coupling between the models. Work is continuing on making the CH3D model output compatible with available model analysis tools and accessible to other PSMEM partners. A collaborative current meter study among the PSMEM partners has also been initiated to obtain current data at selected locations in Port Orchard, Rich, and Agate Passages to support the calibration and verification of the coupled models.

## RESULTS

One-way coupling between the Puget Sound POM and CH3D was implemented using simulation results from selected Puget Sound POM nodes located near the boundaries of the CH3D numerical grid (Figure 1). A data extraction tool for the Puget Sound POM, utilizing the OPeNDAP protocol [2] was implemented by the partners (see http://orchard.ocean.washington.edu/cgi-bin/nph-dods/pom/2004/07/pom-2004-07-10.cdf.html for any example query table). The tool allows selected data sets to be extracted from the POM output to generate fields (Figure 2a) or profiles (Figure 2b) of selected parameters to support model forcing, setting initial conditions, and comparing model output to field data (Figure 2b). Testing of alternative model linking configurations showed that extending the CH3D grid out through Agate Pass and into Port Madison bay (Figure 1b) achieved the best numerical stability in response to dynamic forcing from two simultaneous boundary conditions.

The NetCDF (network Common Data Form) format has been implemented for CH3D to standardize model output (Figure 3). Developed by the Unidata Program Center, NetCDF provides an interface for accessing and displaying array-oriented data [5]. A netCDF algorithm, modified to incorporate curvilinear arrays [6], was incorporated into the CH3D model code allowing netCDF compatible output to be produced. Readily available tools for visualizing netCDF-formatted data can process this output. These tools include

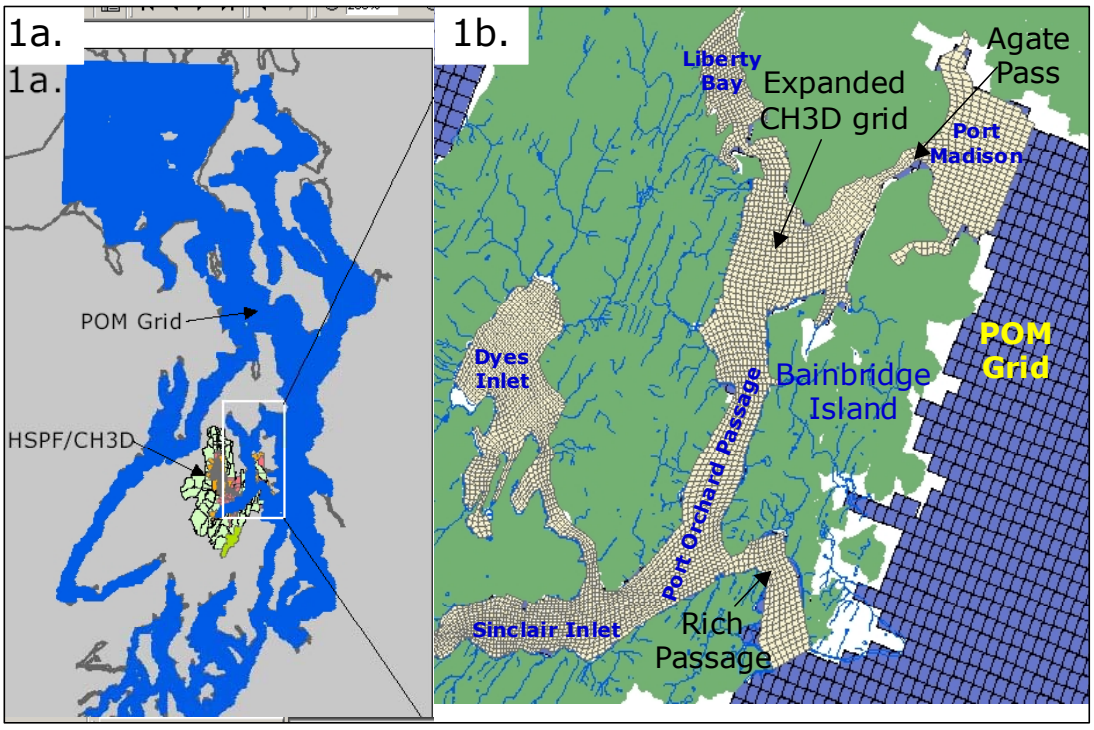


Figure 1. The domains of the Puget Sound POM model (blue) and the CH3D/HSPF models for Sinclair and Dyes Inlet (1a). The nodes of the numerical grid for the Puget Sound POM model (blue grids), the expanded numerical grid for CH3D (polygons), and model boundaries for Agate Pass and Rich Passage around Bainbridge Island (1b).

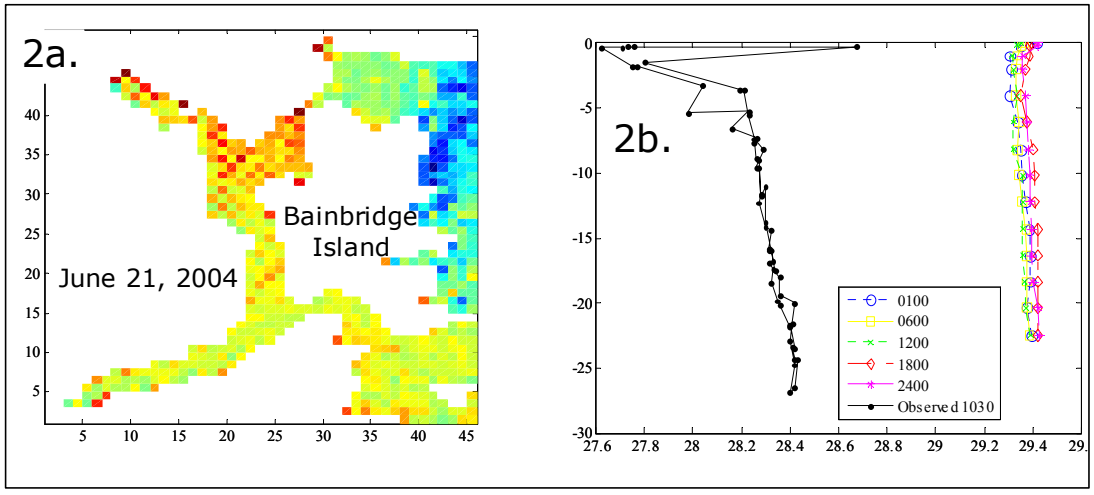


Figure 2. The salinity field (2a) and profile (2b) from the POM run for June 21, 2004.

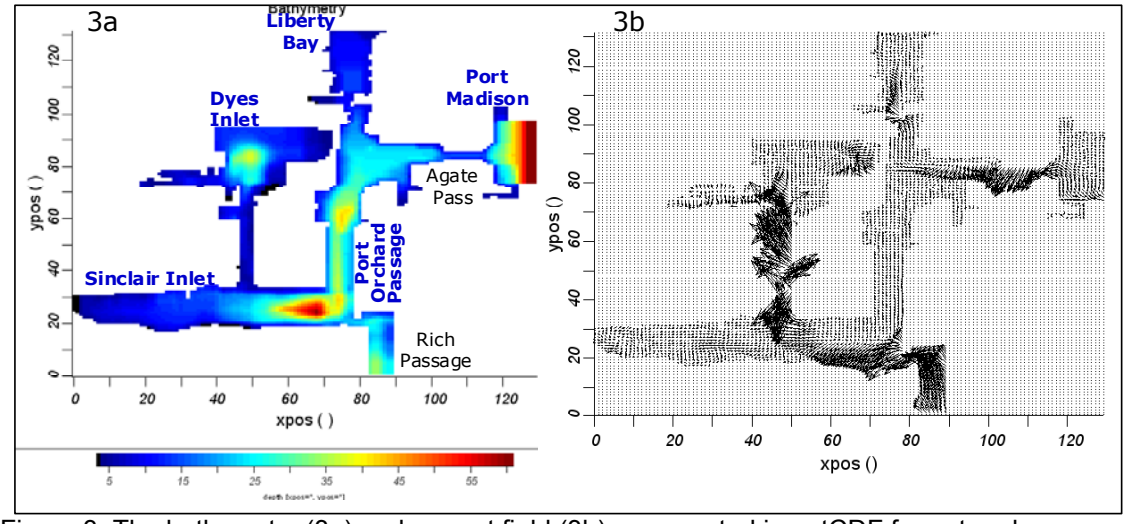


Figure 3. The bathymetry (3a) and current field (3b) represented in netCDF format and displayed using ncBrowse.

ncBrowse, Python, and MatLab). The capability to produce netCDF output has facilitated the development of a library of MatLab m-files that can be used to process and display CH3D output, and generate animations of model results [7]. Examples of netCDF output from the CH3D model and animations of simulation results can be accessed at www.psmem.org/ models/psns-spawar.html. A cooperative current meter study being conducted by the partners [8] will obtain the data needed to calibrate and verify the linked models. Ongoing work is continuing to automate the data extraction tool for momentum and salinity to initialize CH3D runs, implement sequential runs for one-way forcing of CH3D, initiate the two-way transfer protocol, and refine tools for processing model output.

## IMPACT/APPLICATIONS

**National Security.** An improved modeling capability of the circulation and marine ecosystem of Puget Sound at both the sound- and inlet-scale will help local and regional governments develop more effective measures for protecting marine resources

and economic assets of the Puget Sound that are vital to our National Security.

**Economic Development**. Predictive modeling of Puget Sound's circulation and marine ecosystem will have positive impacts on many economic activities taking place in the Sound, including forecasting of harmful algal blooms (HABs), understanding of hypoxia-events, and tracking long term variability in water quality.

**Quality of Life**. The quality of life in the Puget Sound region is directly related to the quality of our environment. Our models, by predicting responses from oceanographic processes and other events will help Coast Guard and regional law-enforcement agencies with search and rescue operations and containment of contaminant spills, and information about tides and currents is of vital interest to boaters and fishermen.

**Science Education and Communication.** Visualizations, support material, and curriculum modules based on the model results will be a valuable tool for learning about Puget Sound's marine environment in classroom, in museums, and through the web.

## TRANSITIONS

The models for Sinclair and Dyes Inlets are being used by the Washington State Department of Ecology to establish TMDLs for the Inlets [3].

## RELATED PROJECTS

This work compliments work being conducted under PSNS & IMF Project ENVVEST [1] to conduct modeling studies of the Sinclair and Dyes Inlet Watershed to assess water quality of the Inlets [3] and support the development of TMDLs for the watershed [2, 3].

## REFERENCES


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## PUBLICATIONS

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## HONORS/AWARDS/PRIZES (none)