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In 2002 National Oceanographic Partnership Program funded a partnership of a university, federal, state and local government agencies, and a private non-profit corporation who share a common interest and concern about a body of water – Puget Sound, Washington. Designated as the Puget Sound Marine Environmental Modeling (PSMEM) partnership, the objectives of the partnership were to conduct scientific research 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 is a new kind of collaborative effort between academia, government and a private nonprofit organization - one that capitalizes on existing strength of each and respects the different mandate that each organization carries.

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A Partnership for Modeling the Marine Environment of Puget Sound, Washington

FINAL REPORT

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Introduction

Computer simulation models of the marine environment have been in research use since 1960s, and are increasingly in routine use for marine forecasting, environmental policy and decision making, and other practical applications. Communities that rely heavily on maritime resources, such as the region surrounding Puget Sound, Washington, are starting to develop modeling cabilities as an element of their scientific and resource management infrastructure. In the Puget Sound region, several institutions now operate simulation models of Puget Sound or its sub-basins in a more-or-less routine manner. All of these models perform simulation of currents and salinity; some include thermodynamics (temperature), marine biogeochemistry, and fate-and-transport modules for, for example, fecal coliform from combined sewer outflow events. In addition, models have been implemented for specific regions within Puget Sound in support of specific projects.

In order to facilitate sharing of information and expertise, in 2002 National Oceanographic Partnership Program funded a partnership of a university, federal, state and local government agencies, and a private non-profit corporation who share a common interest and concern about a body of water – Puget Sound, Washington. Designated as the Puget Sound Marine Environmental Modeling (PSMEM) partnership, the objectives of the partnership were to conduct scientific research 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 membership consisted of: University of Washington (UW), School of Oceanography and College of Education; Department of Natural Resources, King County, Washington (KC-DNR); Department of Ecology, State of Washington (WA-DOE); Puget Sound Naval Shipyard, Bremerton, Washington (PSNS); and Ocean Inquiries Project, Seattle, Washington (OIP). Federal funding supported the partnership for the period of April 2002 to December 2007, with a no-cost extension to the end of December 2008.

Overall achievements

The partnership has been playing a very active role in fostering oceanographic modeling in the Puget Sound region. Scientists from member institutions have been holding monthly meetings at the University of Washington and other venues to brief one another of modeling developments, plan collaborative activities, and hold strategic discussions.

The partnership organized a well-attended public workshop on April 23, 2004 at the University of Washington, School of Oceanography. The goal of this workshop was to present the current status of marine modeling capabilities in the Puget Sound region as well as develop and refine a subsequent research agenda. It was our desire to collaborate with as many individuals or institutions as possible to formulate regional research priorities and achieve our goals for an integrated modeling framework. An invitation went out to scientists at regional academic institutions, federal and local government agencies. The morning session included a description of the current PSMEM status including anticipated goals and then focused on participant activities involving current, planned or envisioned modeling projects. The afternoon session broke out into working groups focusing on water quality, aquatic / fisheries resources, atmospheric – terrestrial – marine interaction, and hazardous materials response. A brief, concluding session by the whole group was held at the end of the meeting, and the meeting agenda and summaries of the breakout group discussions were posted on our web site.

With the inception of Puget Sound Partnership through the leadership of the Washington State Governor, Christine Gregoire, there was strong regional interest in the activities of the partnership; accordingly, a second workshop for regional marine modelers was held on September 20, 2006 in Tacoma, WA, co-hosted by Washington State Department of Ecology and University of Washington PRISM project. It was attended by all PSMEM partners as well as Pacific Northwest National Laboratory and U.S. Geological Survey. The goals of the workshop was to introduce and be better informed on what technical modeling expertise exists in the region as well as the motivation, to discuss how to and/or what to continue on PSMEM has been providing, and to identify where regional synergies or challenges may exist. The workshop considered a continued forum of Puget Sound marine modeling partners, similar to PSMEM, but expanded to include more partners and focused on information exchange. A white paper on Puget Sound marine modeling, based on the

discussions at the workshop and making recommendations to the governor's Puget Sound Initiative, was written up and presented to the Puget Sound Partnership.

Expected and actual outcomes

Three broad classes of products were initially envisioned of this partnership and described in the original proposal. These were: (1) A suite of simulation models for the marine environment of Puget Sound, including several newly designed models, linked in a flexible hierarchy; (2) A data management system for archiving and sharing model results and observational data among the partners and with the outside community; and (3) A delivery interface that enables a user to interact with model results and oceanographic data according to his or her purpose and level of expertise, and that can be used as a curricular resource in schools.

1. *A suite of simulation models for the marine environment of Puget Sound, including several newly designed models, linked in a flexible hierarchy;*

    a. With support from NOPP, the University of Washington Puget Sound Circulation Model, based on the Princeton Ocean Model and initially set up by the University's Puget Sound Regional Synthesis Model (PRISM) initiative, has been set up to produce routine one-day hindcasting of the Sound's circulation with surface atmospheric conditions from an MM5 regional weather forecasting model. The hindcasting system now resides at Applied Physics Laboratory, and has been incorporated into the nascent Northwest Association of Networked Ocean Observing Systems (NANOOS) project. The results are made publically available via an OPeNDAP server. King County Department of Natural Resources and Parks performed model runs with different resolutions for the year 2000, during which year they performed an intensive physical oceanographic survey in the northern Main Basin of Puget Sound as part of a Marine Outfall Siting Study for the new Brightwater Waste Water Treatment Plant. Results of these comparisons were presented at the American Geophysical Union Ocean Sciences Meeting 2004 (Nairn and Kawase, 2004). The model was used as a part of a study of circulation and biological productivity in Carr Inlet in the southern Puget Sound in the spring of 2003. The model results compared favorably and the comparison study has been published (Edwards, et al, 2006). Finally, the model was used in a study of fate and transport of wastewater discharges from cruise ships in Puget Sound sponsored by the Washington State Department of Health. This work was reported at the American Geophysical Union Ocean Sciences Meeting 2006 (Sarason, et al., 2006).

    b. A simple box model of Puget Sound circulation was developed by Amanda Babson as a part of her Ph.D. thesis study. This model was used to study variability of the exchange circulation in Puget Sound over seasonal and longer time scales. The model and the results were

presented in Babson et al. (2006). Babson continued her doctoral thesis research, focusing on oxygen production and consumption in Puget Sound and three-dimensional processes governing circulation in an estuarine fjord. She defended her thesis in 2006 (Babson, 2006).

c. The partnership has developed an aquatic biogeochemistry (ABC) model and implemented it, together with a POM-based circulation model, for Budd Inlet in South Sound. The combined POM-ABC model has been run for the year 1996-97 for verification against hydrographic and biogeochemical data collected during an intensive survey of the inlet during these years. To aid collaborative development of the ABC model, we have developed a collaborative environment in which two off-the-shelf software products, one a Java-based visualizer of netCDF files, the other a threaded discussion, are combined into a forum where people can post quick visualization of model output and make comments.

d. Development of models for regions of steep bathymetry was led by post-doc Dmitri Leonov. A non-hydrostatic model (MITgcm) was implemented for Admiralty Inlet, which forms the connection between Puget Sound and the Strait of Juan de Fuca, with an idealized vertical two-dimensional (x-z) geometry. The model was first validated by simulating the fortnightly cycle of deep water intrusions as the external conditions were kept constant in time, and then used to simulate adjustments to abrupt changes in external salinity and river discharge. Results of the study were presented at the 2007 Physics of Estuaries and Coastal Seas (PECS) conference and reported in Leonov and Kawase (2008). There is considerable interest in the regional community for modeling this waterway, in particular coming from interest in tidal power generation as an alternative energy source. A three-dimensional non-hydrostatic model of Puget Sound tidal currents using Stanford University's SUNTANS code was developed and used in a study exploring tidal energy potential in collaboration with the Snohomish Public Utility District. Development of this model contiunues, and is now taken over by the new Northwest National Marine Renewable Energy Center, a joint University of Washington – Oregon State project funded by the U.S. Department of Energy.

e. A model of sedimentary organic carbon mineralization was developed by post-doc Stephen Colbert. The model processes are parameterized using observations from Puget Sound and was reported at the American Geophysical Union Ocean Sciences Meeting 2006 (Colbert and Devol, 2006). A sediment diagenesis module based on this model for the Regional Ocean Modeling System (ROMS), to be incorporated into the Fasham biogeochemical model, has been developed.

f. A CH3D model of Sinclair and Dyes Inlets was set up by Puget Sound Naval Shipyard and SPAWAR as a part of the ENVVEST project to simulate the hydrological and tidal conditions present during the release of hatchery-reared, juvenile Chinook salmon from the Gorst Creek Hatchery (May 19 - Jun 30, 2002) during a catch and release out migration sampling study conducted in Sinclair Inlet. The model simulated the release of a conservative "tracer" that corresponded to when the majority of the marked fish were released into Gorst Creek. The model results were compared to fish recapture rates to evaluate differences between fish density and the tracer concentrations predicted by the model, and were reported at the 2007 Georgia Basin – Puget Sound Research Conference (Johnston et al., 2007).

2. *A data management system for archiving and sharing model results and observational data among the partners and with the outside community;*

   a. The data management team, in coordination with the program outreach team, released two versions of metadata management desktop software (the Investigator's Toolkit), which includes network services for creating, editing, registering, and searching the metadata records associated with the project.

   b. As the first entry into the partnership data stream system, all hydrographic, chemical and biological data collected during the semi-annual PRISM cruise since 1998 in Puget Sound have been calibrated and made available online via the partnership web site.

   c. As an example of the data stream being used as a model coupling system, a one-way coupling between the Puget Sound POM and CH3D model of Sinclair-Dyes Inlets was implemented using simulation results from selected Puget Sound POM nodes located near the boundaries of the CH3D numerical grid. A data extraction tool for the Puget Sound POM, utilizing the OPeNDAP protocol was developed to extract the data needed to simulate currents and mixing for the Fall 2005 sampling period.

3. *A delivery interface that enables a user to interact with model results and oceanographic data according to his or her purpose and level of expertise, and that can be used as a curricular resource in schools.*

   a. A project web site (http://www.psmem.org) was designed and launched in early October 2003. The web site serves as a portal for disseminating results of our model runs and data collected by member institutions, for collaborative interactions among the partners, and for general outreach.

b. The Partnership's Education and Visualization Team, which consists of members of the UW School of Education, UW Human Interface Technology Lab and Ocean Inquiry Project, has developed a "Virtual Puget Sound" (VPS), a 3-D navigable learning environment based on the UW POM Puget Sound model. Originally developed for an SGI computer, it has been migrated to a PC-based platform for portability and easy deployment in classrooms. Along with the VPS, the team developed K-12 and community college curricula on circulation and oceanographic properties of Puget Sound incorporating model output and VPS together with observational data. Finally the team developed assessment techniques that can measure learning in virtual reality environments. The team had a setback when its principal investigator, Bill Winn, passed away suddenly in 2006. The group has nevertheless developed and released version 3.0 of Virtual Puget Sound (VPS) visualization software featuring custom configurability, extended dataset library, enhanced user interface and navigation, and new data visualization approaches. VPS 3.0 was deployed, configured and supported for use in student lab exercises both in-house and for visiting university groups. It has been to some of our collaborative partners, for their use and evaluation. The group's comparative study of how students learn science from computer simulations verses how they learn from direct experience has been published (Winn, et al., 2006).

c. The netCDF (network Common Data Form, Unidata Program Center) format was implemented for CH3D to standardize model output. The capability to produce netCDF output has facilitated the development of a General User Interface (GUI) tool for processing and displaying CH3D model results using Matlab. The tool makes it possible to evaluate model results at each node and depth and generate time series and animations of model results. The tool includes features that allow the user to zoom, view tidal elevations at selected nodes, and generate time series of model results. Examples of netCDF output from the CH3D model and animations of simulation results can be accessed at http://www.psmem.org/models/psns-spawar.html.

d. Finally, the team has also experimented with using Google Earth as a visualization interface for Puget Sound models. While this project could not be completed within the duration of the NOPP funding, we believe that Google Earth's increasingly widespread use and easy navigation could make it an ideal platform to disseminate and visualize geospatially explicit model results in future.

Other projects with which the Partnership has collaborated

The partnership has actively collaborated with various projects conducted by the

member institutions including: University of Washington's Puget Sound Regional Synthesis Model (PRISM) Initiative to create a suite of prognostic models that simulate the Puget Sound region's natural and human environment; Puget Sound Naval Shipyard's Project ENVVEST to conduct modeling studies of the Sinclair and Dyes Inlet Watershed to assess the impact of CSO discharges on water quality of the Inlets; and support the development of TMDLs for the watershed; the Hood Canal Dissolved Oxygen Program (HCDOP) to investigate low-oxygen conditions in Hood Canal, a major branch estuary of Puget Sound; and the most recently the Northwest National Marine Renewable Energy Center (NNMREC), a joint Washington – Oregon State project to investigate extraction of wave and tidal energy sponsored by the U.S. Department of Energy.

Conclusion and Future Prospects

This partnership represents a new kind of collaborative effort between academia, government and a private nonprofit organization - one that capitalizes on existing strength of each and respects the different mandate that each organization carries. Experience of such collaboration was itself of value and be of interest to other regions and the nation as a whole.

We expect this modeling partnership to continue and grow beyond the initial five years and the initial members of five institutions. At the September 20, 2006 workshop, there was a strong sense of need and desire among regional partners to continue the partnership and extend its membership to other institutions involved in Puget Sound marine modeling. The white paper recommends that the partnership continue as the Puget Sound Marine Environmental Modeling Consortium (PSMEM-C), to serves as the umbrella organization providing leadership and coordination for Puget Sound marine environmental modeling. It also recommends that the Consortium be funded adequately to realize its vision as described above, and be closely linked to the emerging Puget Sound Partnership governance, serving to inform policy and direct research.

It is fair to say that our experience with models in any of these applications in Puget Sound is still limited, and lags behind those around other large inlets and inland waters such as Chesapeake Bay, San Francisco Bay and Great Lakes. Accurate modeling of Puget Sound's environment is perhaps most hampered by lack of observational data needed to force or verify the model; this is especially true of meteorological data, such as wind and solar radiation, which tends to be shore-based and concentrated around population centers. Further, research indicates that Puget Sound's marine environment is greatly influenced by conditions in the outlying marine regions, including Straits of Georgia and Juan de Fuca, coastal oceans of Washington, Oregon and British Columbia, and the northeast Pacific Ocean. Data coverage of these regions is sparse in space and spotty in time, and a clear understanding of the nature of the influence is lacking. Lack of up-to-date information on the hydrography of the eastern Strait of Juan de Fuca, for example, is a limiting factor in real-time forecasting of Puget Sound circulation. Projects such as Northwest Association of Networked Ocean Observing Systems (NANOOS) are

spinning up to address the data needs of region's scientists and agencies; PSMEM-C can actively partner with NANOOS and other routine observational activities, communicate modelers' data needs to those designing these systems, and share support for the needed operation, so that our needs can be met effectively.

Publications acknowledging support by this project

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