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

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LONG-TERM GOALS

Puget Sound, Washington, is both the largest fjord in the lower forty-eight states and closest to the substantial urban centers of Seattle, Tacoma, Everett and surrounding communities. The sound has 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 Sound's circulation and marine ecosystem, and of the sensitivity of the physical and the biological system to natural and human perturbations; and to 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.

OBJECTIVES

Our partnership will develop, maintain and operate a suite of flexibly linked simulation models of 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. Our partnership will 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. Our partnership will function as an estuarine research node within the NOPP Ocean Information Commons.

APPROACH

The partnership consists of five separate organizations: University of Washington (UW, School of Oceanography and College of Education), Department of Natural Resources and Parks, King County, Washington (KC-DNR), Washington State Department of Ecology (WA-DOE), Puget Sound Naval Shipyard (PSNS)/SPAWAR, and Ocean Inquiry Project (OIP). It is administered from School of Oceanography, UW. Collectively we are operating or developing four dynamically based, predictive models of the Sound's aquatic environment, each with a different spatial coverage (and a fifth module for biogeochemistry), and our goal is to integrate these modeling efforts into a coordinated whole. Our tasks are divided as follows:

- Project coordination: Mitsuhiro Kawase (UW)
- Model operation and development:
    - Puget Sound Circulation Model: Kawase, Bruce Nairn (KC-DNR)
    - Sinclair-Dyes Inlet Model: Robert Johnston (SPAWAR), P.F. Wang (SPAWAR)
    - South Puget Sound Model: Jan Newton (WA-DOE), Skip Albertson (WA-DOE)
    - Duwamish Estuary/Elliott Bay Model: Randy Shuman (KC-DNR)
    - Aquatic Biogeochemistry Model (ABC): Allan Devol (UW), Nairn, Newton
- Data management and infrastructure: Miles Logsdon (UW), Mark Warner (UW)
- Education and visualization: William Winn (UW), Fritz Stahr (OIP)

WORK COMPLETED

The current partnership (abbreviated PSMEM for Puget Sound Marine Environmental Modeling) is entering its final year of operation. There is strong regional interest in continuing the activities of the partnership; accordingly, a workshop for regional marine modelers was held on September 20, 2006 in Tacoma, WA. The workshop was 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 re 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 Washington State governor's Puget Sound Initiative, has been written up and presented to the Puget Sound Partnership [1] meeting.

The UW circulation modeling group has published a paper on a simple box model of Puget Sound circulation [2]. Amanda Babson, the principal author of the paper and Ph.D. student supported by this grant, has 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 is due to defend her thesis by the end of the calendar year 2006 [3]. A paper on the modeled circulation in Carr Inlet, southern Puget Sound has been submitted to *Estuaries* [4].

The group has also carried out idealized numerical experiments of a double-silled estuary, using MITgcm numerical model, aimed at understanding processes that control variability of exchange circulation in a fjord-type estuary and in Puget Sound in particular. 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 Physics of Estuaries and Coastal Seas (PECS) conference, September 18-22, in Astoria OR, and a paper is being readied for submission to *Continental Shelf Research.*

A model of sedimentary organic carbon mineralization was developed, parameterized using observations from Puget Sound, documented in a manuscript that will be submitted [5], and incorporated into the Fasham biogeochemical model of the Regional Ocean Modeling System (ROMS).

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. A data extraction tool for the Puget Sound POM, utilizing the OPeNDAP protocol was developed [6] to extract the data needed to simulate currents and mixing for the Fall 2005 sampling period. The current meter data obtained from the ACDPs deployed in the in Inlets during the Fall 2005 [7] are being used to evaluate model performance. Previously, the netCDF (network Common Data Form, Unidata Program Center [8]) 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 [6]. 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.

The modeling framework for Sinclair and Dyes Inlets was also set up 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 [9]. 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 [10]. Ongoing work is continuing to implement sequential runs for one-way forcing of CH3D and refine the tools for processing model output.

The data management team in coordination with the program outreach team released the first two versions of our 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.

The Education and Visualization team had a setback when its principal investigator, Bill Winn, passed away suddenly. 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 [11].

The PSNS/SPAWAR and Department of Ecology partners have successfully completed a joint current meter study for Agate, Port Orchard and Rich Passages, extracted data from the POM output for input as boundary conditions for the Sinclair/Dyes Inlet model, developed a set of analysis tools to process model output, and implemented the linkage between the models. Work is continuing on making the CH3D model output compatible with available model analysis tools and accessible to other PSMEM partners.

RESULTS

At the September 20 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, 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.

One of the most interesting results to come out of the box model study ([2,3]) is that there appears to be considerable amount of oxygen consumption over sill regions of the sound, as opposed to the interior basins. It is speculated that strong mixing over a sill provides a mechanism to directly transfer biomass from surface to deep layers (as an alternative to sinking particulates). Organic matter decomposed in this consumption may come from parts of the sound other than the basin behind the sill, indicating that lateral processes and inter-basin exchanges are significant in the biogeochemical dynamics of Puget Sound.

IMPACT/APPLICATIONS

National Security

An improved modeling capability of the circulation and marine ecosystem of Puget Sound will help local and regional government devise procedures to deal with, for instance, chemical/biological attacks involving harmful agents that may be/need be flushed down into our marine waters, and with terrorism aimed at military and industrial installations that may result in environmental contamination.

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. For instance, forecasting of harmful algal blooms (HABs) and better understanding of hypoxia-induced fish kills in the Sound will help commercial fisheries better deal with this threat to their livelihood. Detailed knowledge of currents and hydrography will help diving operators with their underwater work. Understanding longer term variability in water quality leading to marine ecosystems change will help managers of fisheries resources make decisions.

Quality of Life
The Puget Sound region has always enjoyed a quality of life directly related to the quality of our environment. Our models provide tools for evaluating the impact of regional scale actions on the marine environment by predicting response of the latter to potential stressors. Oceanographic knowledge also has direct uses and benefits for those who work and live at sea. For instance, knowledge of currents will help Coast Guard and regional law-enforcement agencies with search and rescue operations and contaminant spill containment.

Science Education and Communication
With the aid of suitable visualizations, support material, and curriculum modules, the model results will be a valuable tool for learning about Puget Sound's marine environment that can be used in classroom settings as well as by the public at large in museums and through the web.

TRANSITIONS

Quality of Life
We are providing modeling resources in terms of expertise and computational hardware to Hood Canal Dissolved Oxygen Project (HCDOP) [12]. This collaborative project has been developed in response to concerns of residents of communities around the canal about recurrent fish kills in Southern Hood Canal in recent years, which are believed to be due to persistent hypoxia in the marine waters of this region. HCDOP has received congressional funding as well as funding from National Fish and Wildlife Foundation for FY 05 and 06 for a comprehensive study of hypoxia in Hood Canal encompassing observations and modeling of circulation and biogeochemistry of the marine waters and terrestrial inputs of fresh water, nutrients and organic matter. The project's goals are to sort out anthropogenic changes in the oxygen level, if any, from natural variabilities, and to assess the effectiveness of proposed remedial measures. We have provided initial estimates of oxygen consumption rates using a simple box model of Puget Sound circulation [2, 3].

RELATED PROJECTS

The partnership continues a strong cooperative relationship with Puget Sound Regional Synthesis Model (PRISM, www.prism.washington.edu), a University of Washington project to develop and consolidate University-wide expertise in natural and human environment of the Puget Sound region. As described above, partnership scientists also play an active role in the Hood Canal Dissolved Oxygen Project. The partnership's work compliments work being conducted under PSNS & IMF Project ENVVEST [13] 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.

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