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 (UW), 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

During the FY 2005 reporting period, the University of Washington has implemented an OpenDAP server to start dissemination of results from POM daily hindcasts in a numerical format. A system for on-demand, on-the-fly generation of section and plane plots and animations, to replace the current pre-generated animations, is under development. The Aquatic Biogeochemistry Model has been implemented for the entire Puget Sound. A sediment biogeochemistry model has been developed by post-doc Steve Colbert, and has been applied to Dabob Bay. A post-doc has been hired (Dmitri Leonov, Ph.D. Florida State University July 2005) to work on a coast-sound linkage model. The data management system can now serve metadata listing from the website. It has been populated with POM model results metadata and hydrography metadata from PRISM cruises. Listings will be made available to the public soon. The partnership is at a stage to start soliciting data from agencies and scientific institutions in the region. Our data system will service Hood Canal Dissolved Oxygen Program (HCDOP). We have started discussion with Northwest Association of Networked Ocean Observing Systems (NANOOS). The partnership may also be in a position to service data management needs of Puget Sound Ambient Monitoring Program (PSAMP) and will initiate discussions with them.

PSNS/SPAWAR partners have successfully completed integration of netCDF (network common data format) output into CH3D model code, completed development and testing of the numerical grid for linking with Puget Sound POM model at Agate Passage and Rich Passages facilitating one-way forcing from POM, and developed a technical approach and numerical procedures for implementing two-way coupling between the models. Working is continuing on making 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.

King County DNRP has configured the Aquatic BiogeoChemical (ABC) model to simulate the entire Puget Sound region. Several factors hindering model performance were identified and corrected, and work is continuing on evaluating model performance. King County also contributed expertise to the partnership's development of a data infrastructure strategy.

Ocean Inquiry Project (OIP) and the UW School of Education (UW-SOE) partners finished and published a paper regarding our 2003 comparison of introductory oceanography classes using Virtual Puget Sound (VPS) – a 3D immersive model visualization - and field experiences. This research was also presented at one national and two international meetings on educational research. A separate study was completed on how oceanography faculty and science teachers can use VPS in their classrooms, and based on this templates for lesson plans are being developed. We put a number of our reports and other content on the Partnership website (www.psmem.org) and further improved VPS for both the Partners and educational researchers working with language-learning disabled students. OIP operated four research cruises on Puget Sound engaging approximated 80 students in collecting data for validating partnership models.

Washington State Department of Ecology (Ecology) has continued to collect current meter data from select parts of Puget Sound in support of modeling efforts. We collected bottom-mounted ADCP data coupled with surface S4 time series in Hammersley Inlet and Oakland Bay during the first 90 days of 2005. In March we asked the partnership at which locations we should focus future efforts to collect essential ADCP data in support of modeling and they responded with Central Sound, in the area of greatest overlap of the greatest number of models. Consequently we are planning a collaborative current meter study beginning in mid-September. Ecology will work closely with other PSMEM partners to obtain current data at selected locations in Port Orchard, Rich, and Agate Passages to support the calibration and verification of the coupled models in that region.

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 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 or profiles of selected parameters to support model forcing, setting initial conditions, and comparing model output to field. 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. A netCDF algorithm, modified to incorporate curvilinear arrays, 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

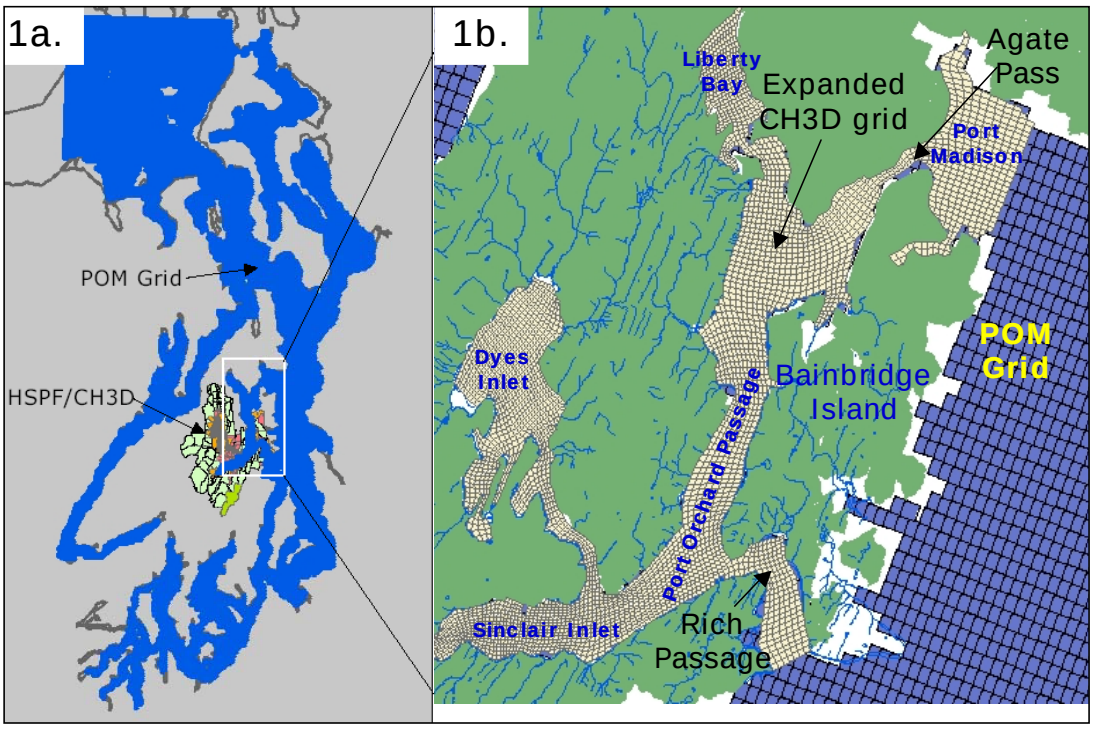

Figure 1. The domains of the Puget Sound POM model (blue) and the CH3D/HSPF models for Sinclair and Dyes Inlet (1a). The nodes of the numerical grid for the Puget Sound POM model (blue grids), the expanded numerical grid for CH3D (polygons), and model boundaries for Agate Pass and Rich Passage around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

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. 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 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.

As part of our support for the Hood Canal Dissolved Oxygen Program, we did a study of the model circulation in Hood Canal. We found a three-layer circulation consisting of a thin, outgoing surface layer, a mid-depth inflow layer, and a bottom layer moving towards the exit. The outgoing surface layer corresponds to a layer of relatively fresh water deriving from river inflow on top of a shallow pycnocline. The circulation is sensitive to the local wind, and patterns of wind-driven upwelling similar to the observed distribution of fish kills due to upwelling of subsurface hypoxic waters can be seen in the model during periods of southerly wind over the Canal (Figure 2). This result was reported at the Puget Sound – Georgia Basin Conference in Seattle WA in April 2005.

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

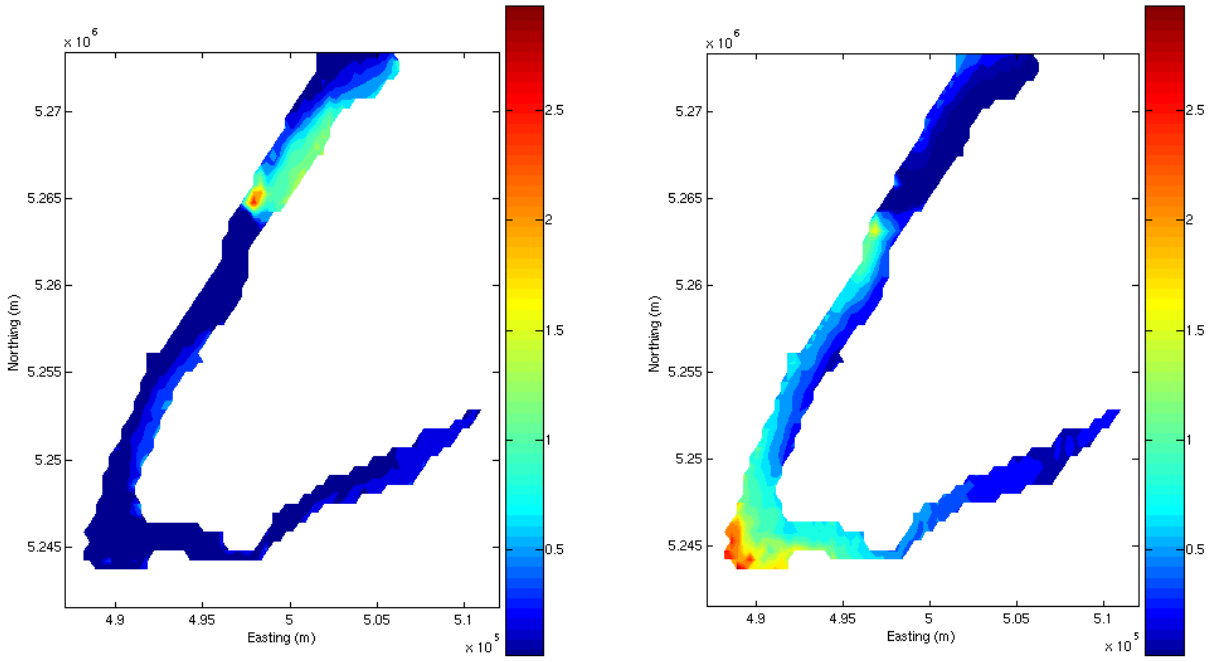

Figure 2. Patterns of anomalously high surface salinity in Hood Canal (indicative of regions of upwelling) during northerly (left) and southerly (right) winds. POM circulation model.

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

Economic Development
The results of the Inlet-scale model of fecal coliform (FC) in Sinclair and Dyes Inlets are already being used by the Washington State Department of Health to reclassify shellfish beds in Dyes Inlet.

Quality of Life
We are providing modeling resources in terms of expertise and computational hardware to Hood Canal Dissolved Oxygen Project (HCDOP). 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. As described above, we are providing HCDOP with results from the POM circulation model in order to aid design of the observational program and development of a detailed model of Hood Canal.

Science Education and Communication

Version 3.0 of VPS is now relatively stable and has been installed in the Spatial Analysis Lab. in the School of Oceanography, University of Washington. Eighteen lesson plans for instructors wishing to use VPS in classes have been developed. These are available and can be downloaded from the project web page (www.psmem.org). Three papers were presented during the year at international education research conferences that describe our recent work.

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.

The partnership’s work compliments work being conducted under PSNS & IMF 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 Ocean Inquiry Project ran a workshop in March entitled “Coordinating and Advancing Field-based Marine Science Education in Puget Sound” which was funded by the Russell Family Foundation. It gathered over 80 participants together to discuss what could help further the exposure of students to marine science. The basic result was to suggest the creation (and staffing) of a coordinator position to help link providers and users of field based marine science education. A copy of the final report is available at http://www.oceaninquiry.org/workshop.

As described above, partnership scientists will play an active role in the Hood Canal Dissolved Oxygen Project.

PUBLICATIONS

Babson, A., M. Kawase and P. M. MacCready, Seasonal and Interannual Variability in the Circulation of Puget Sound, Washington: A Box Model Study, *Atmosphere-Ocean*, in press.

Winn, W., F. Stahr, C.Sarason, R. Fruland, P.Oppenheimer, Y.L. Lee: Learning Oceanography from a Computer Simulation Compared with Direct Experience at Sea; *Journal of Research in Science Teaching*, in press.