Completion Report

Bond, Nicholas

Period: 2/1/2012 - 1/31/2013
Project: R/COCC-1 - Projections of Ocean Properties along the Washington Coast Related to Environmental Health

:: STUDENTS SUPPORTED

Negron-Rivera, Dennis, dennis.negron-rivera@noaa.gov, University of Puerto Rico, Electrical and Computer Engineering, status:cont, field of study:Meteorology, no advisor, degree type:BS, degree date:2012-06-01, degree completed this period:Yes

Student Project Title: none

Involvement with Sea Grant This Period: none

Post-Graduation Plans: none

Negron-Rivera, Dennis, dennis.negron-rivera@noaa.gov, University of Puerto Rico, Electrical and Computer Engineering, status:cont, field of study:Meteorology, no advisor, degree type:BS, degree date:2012-06-01, degree completed this period:Yes

Student Project Title: none

Involvement with Sea Grant This Period: none

Post-Graduation Plans: none

:: CONFERENCES / PRESENTATIONS

Cheng, W., N. Bond and A. Hermann: “Projections of Ocean Properties along the Washington Coast Related to Environmental Health”. 93rd Annual Meeting American Meteorological Society, Austin, TX, public/profession presentation, 80 attendees, 2013-01-07

Bond, N: “Which Climate Change Signals in the North Pacific are Liable to Emerge Sooner and Stronger?”. 2nd International Symposium on the Effects of Climate Change on the World’s Oceans, Yeosu, Korea, public/profession presentation, 60 attendees, 2012-05-16

:: ADDITIONAL METRICS

K-12 Students Reached:	**Acres of degraded ecosystems restored as a result of Sea Grant activities:**
Curricula Developed:	**Resource Managers who use Ecosystem-Based Approaches to Management:**
Volunteer Hours:	**HACCP - Number of people with new**

	certifications:
Cumulative Clean Marina Program - certifications:	

:: PATENTS AND ECONOMIC BENEFITS

No Benefits Reported This Period

:: TOOLS, TECH, AND INFORMATION SERVICES

		Developed	Used	Names of Managers	Number of Managers
Application of local adaptations of the Regional Ocean Modeling System to projections from NOAA's Coupled Forecast System model to provide seasonal forecasts of oceanographic conditions along West Coast. R/COCC-1	**Actual** (2/1/2012 - 1/31/2013) :	1	1	Phil Levin, William Peterson (NWFSC/NOAA)	2
	Anticipated (2/1/2013 - 1/31/2014) :	0	1		

		Developed	Used	Names of Managers	Number of Managers
A Scripts, protocols developed for researchers to run the Regional Ocean Modeling System on user-specified grids using IPCC global climate model output for boundary, initial conditions. R/COCC-1	**Actual** (2/1/2012 - 1/31/2013) :	1	1		0
	Anticipated (2/1/2013 - 1/31/2014) :	0	0		

:: HAZARD RESILIENCE IN COASTAL COMMUNITIES

No Communities Reported This Period

:: ADDITIONAL MEASURES

Safe and sustainable seafood

Number of stakeholders modifying practices
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

Number of fishers using new techniques
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

Sustainable Coastal Development
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

Coastal Ecosystems
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

:: PARTNERS

Partner Name: Bering Ecosystem Study, National Science Foundation
Partner Name: North Pacific Research Board
Partner Name: University of Washington, Joint Institute for the Study of the Atmosphere and Ocean, College of the Environment
Partner Name: Washington State Department of Fish and Wildlife
Partner Name: Washington State University Extension, Island County Beach Watchers

:: IMPACTS AND ACCOMPLISHMENTS

Title: Washington Sea Grant research develops a high-resolution modeling system for forecasting climate-driven changes in ocean processes, coastal environment, and seasonal weather

Type: impact
Relevance, Response, Results:
Relevance: Climate change will likely affect many physical and ecological processes on Washington's coast. Will it promote harmful algal blooms, hypoxia (low dissolved oxygen), invasive species migrations, or other threats to coastal environmental health? An accurate, high-resolution modeling system, heretofore lacking, could predict such climate-associated impacts.
Response: Washington Sea Grant-funded researchers combined various global climate models with the finer-grain Regional Ocean Modeling System, to forecast future upwelling, circulation, wind, temperature and ecological conditions in Washington waters. They tested their models by "predicting" past conditions and comparing the results to known outcomes. And they adapted NOAA projections to devise what may be the first system for forecasting ocean biochemistry, in detail, on seasonal time scales.
Results: The simulations yielded a wealth of insights: Decadal fluctuations will mask the effects of changing climate until mid-century. Stronger summer winds will increase offshore upwelling. The water column will become more stratified, and water arriving inshore will likely contain more nutrients and carbon dioxide, promoting acidification. The changes anticipated in oceanic circulation in the next few decades will not favor species invasions or harmful algal blooms. Subtropical invasives may nevertheless thrive as waters warm. NOAA's Northwest Fisheries Science Center is using the new biochemistry-forecasting system in integrated ecosystem assessments. Other researchers have expressed interest in using it for seasonal ocean predictions, possibly in the Bering Sea. It may provide early warning of harmful algal blooms and hypoxia, which agencies can now only monitor once they appear. The research has also informed the principal investigator's service as Washington State Climatologist, and as mentor to a local tribal member investigating prospective climate impacts on his community.
Recap: A Washington Sea Grant-supported project has developed a new modeling system that forecasts cyclical and climate-driven changes in regional ocean conditions, with many other potential applications.

Comments: Primary Focus Area – COCC (HRCC) Secondary Focus Area – OCEH (HCE) Associated goals: Improve understanding of coastal hazards and environmental change and develop tools and approaches for observation, prediction, planning and adaptation (HRCC Risks). Improve understanding and management of emerging and cumulative threats to ocean and coastal health (HCE Science).

Related Partners:

Bering Ecosystem Study, National Science Foundation (NSF)
North Pacific Research Board
Rutgers University
University of Washington, Joint Institute for the Study of the Atmosphere and Ocean (JISAO), College of the

Environment (UW)
Washington State Department of Fish and Wildlife
Washington State University Extension, Island County Beach Watchers (WSU)

:: PUBLICATIONS

No Publications Reported This Period

:: OTHER DOCUMENTS

No Documents Reported This Period

:: LEVERAGED FUNDS

No Leveraged Funds Reported This Period

WASHINGTON SEA GRANT SUMMARY REPORT

WSG Project Number: R/COCC-1
Project Title: Projections of ocean properties along the Washington coast related to environmental health

Principal Investigator and Affiliation:
Nicholas Bond University of Washington, Joint Institute for the Study of the Atmosphere and Ocean

Project Objectives

The objective of this project has been to determine likely changes in the climate forcing, and mesoscale ocean response, of the coastal waters of Washington in association with climate change.

Methodology

Our research has proceeded along two lines: (1) direct analysis of the output for the region from global climate model (GCM) simulations carried out by a number of centers in support of the Intergovernmental Panel on Climate Change (IPCC), and (2) dynamical downscaling using a sub-set of this global model output as input for high-resolution numerical ocean model simulations for the Washington coast using the Regional Ocean Modeling System (ROMS). The ROMS model is driven via one-way nesting and has a grid spacing that allows resolution of key oceanographic features in the region of interest.

Rationale

The marine ecosystem of the Pacific Northwest has experiences a variety of episodic events of significance to environmental health. Notable examples here include the particularly large harmful algal boom (HAB) observed off the Washington state coast in early fall 2004, the delayed upwelling of the summer of 2005, and record-setting low concentrations of dissolved oxygen (hypoxia) in 2006. It has been speculated that the latter type of event is likely to become more frequent and severe in association with global warming (due to a trend towards increased summertime upwelling), but this issue is far from settled. The projection of these changes, and ultimately phenomena such as hypoxia events, requires proper accounting of the mesoscale dynamics of the coastal zone. There are complex interactions between the processes important to the mesoscale oceans, and these interactions can best be deduced through dynamical downscaling using a state-of-the-art numerical ocean model such as ROMS.

Major Findings

a. Analysis of IPCC models

Through consideration of multiple runs by a variety of GCMs, this component of our project provides context for the component involving regional ocean model simulations. The focus here is on broad measures of the climate forcing and ocean response that can be deduced using GCM output directly.

The composite changes in air-sea interaction parameters for a strip along the Washington coast (46-49° N, 126-124° W) from 1950-2000 to 2040-2060 are summarized in Tables 1 and 2. The models are unanimous in their indication of warming from the last half of the 20th century to the middle of the 21st century during both winter and summer, with greater increases in surface air temperature (SAT) than in sea surface temperature (SST). The standard deviations in these changes are about 0.6 C and 0.4 C for SAT and SST, respectively. The composite changes in the winter winds were essentially zero. On the other hand, the models indicate a tendency for slightly greater upwelling-favorable winds from the north during the summer.

Sub-surface physical ocean properties from the GCM simulations were also examined. The region considered was the entire North Pacific basin. This examination reveals that the models are suggesting a poleward shift in the mean upper-ocean circulation west of the dateline but little in the way of systematic changes in the mean upper ocean flow in the eastern Pacific by the middle of the 21st century. The models indicate a shoaling of the mixed layer of about 10 m throughout the year, in a composite model sense (not shown). The latter result is highly tentative because of the inability of present-generation GCMs to resolve key ocean processes in the near-coastal zone, which is why it was important to carry out the dynamical downscaling with ROMS as described below.

Table 1 Changes in Winter (Dec-Mar) Air-Sea Interaction Parameters

Parameter	SAT (C)	SST (C)	U (m/s)	V (m/s)
Mean Change	1.9	1.4	~0	~0
Count	36/36	26/26	12/25	11/25

Table 2 Changes in Summer (Jun-Sep) Air-Sea Interaction Parameters

Parameter	SAT (C)	SST (C)	U (m/s)	V (m/s)
Mean Change	2.0	1.4	~0	-0.2
Count	36/36	26/26	16/25	19/25

Note: The count refers to the number of individual model runs with changes of the same sign as that of the ensemble mean change, relative to the total number of runs considered.

b. ROMS Simulations for the Washington coast

High-resolution ocean model simulations for the near-coastal waters of the Pacific Northwest were carried out using the output from 3 different global climate models for initial and boundary conditions, specifically the MIROC, CCCMA and ECHOG models. These models were chosen because they have been found to be able to replicate the observed nature of the Pacific Decadal Oscillation (PDO) in hindcast simulations for the 20th century, and because they represent decidedly different scenarios for the regional climate forcing over the next few decades. The projections focus on the decade of 2030-2040. This time period was chosen under the assumptions that it was far enough into the future to include meaningful changes but within an interval for which plans are being made and information is needed. Projections for later in the 21st century are less reliable because of much greater uncertainty in greenhouse gas concentrations, and other human-caused factors. Results from our dynamical downscaling using the ROMS ocean model, and the three different sets of climate model forcing are illustrated below.

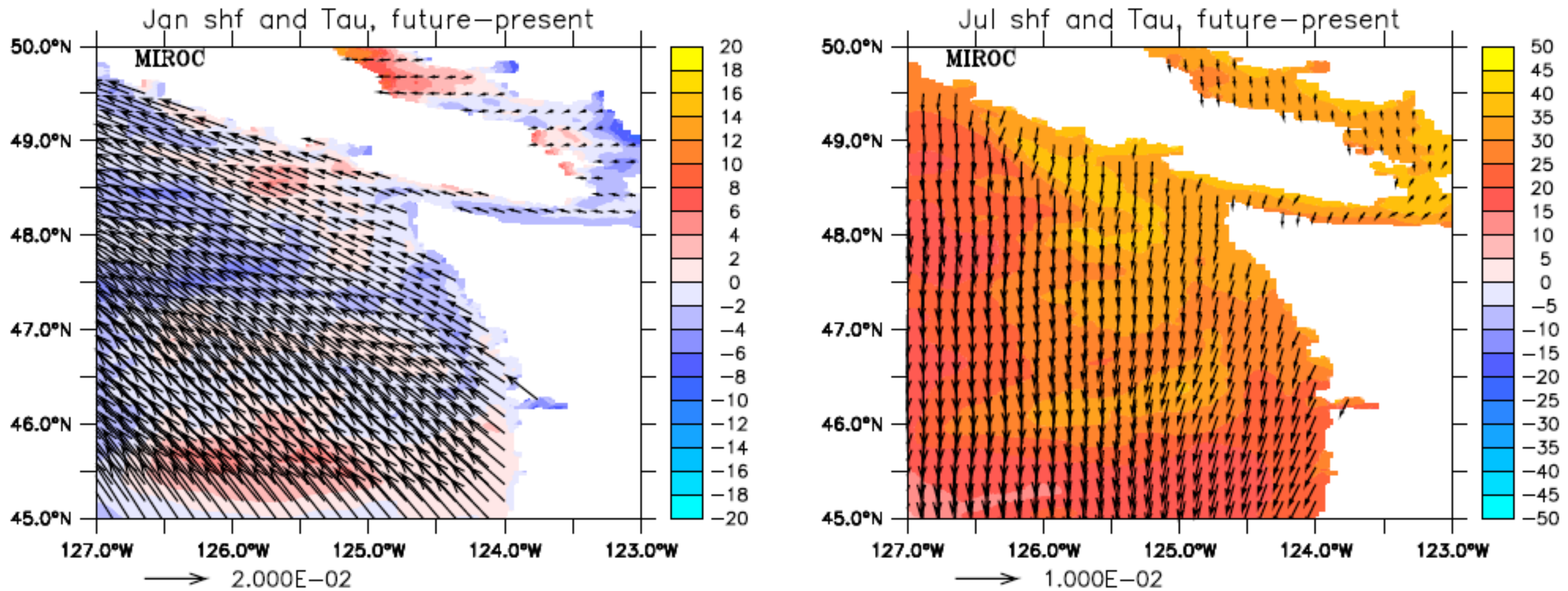

Figure 1 Changes in surface stress (vectors) and net surface heat fluxes (color fill) in January (left panel) and July (right panel) from 2000-2010 to 2030-2040 based on ROMS simulations using the MIROC climate model. Positive changes (orange-red colors) mean greater atmospheric heating of the ocean in the latter period.

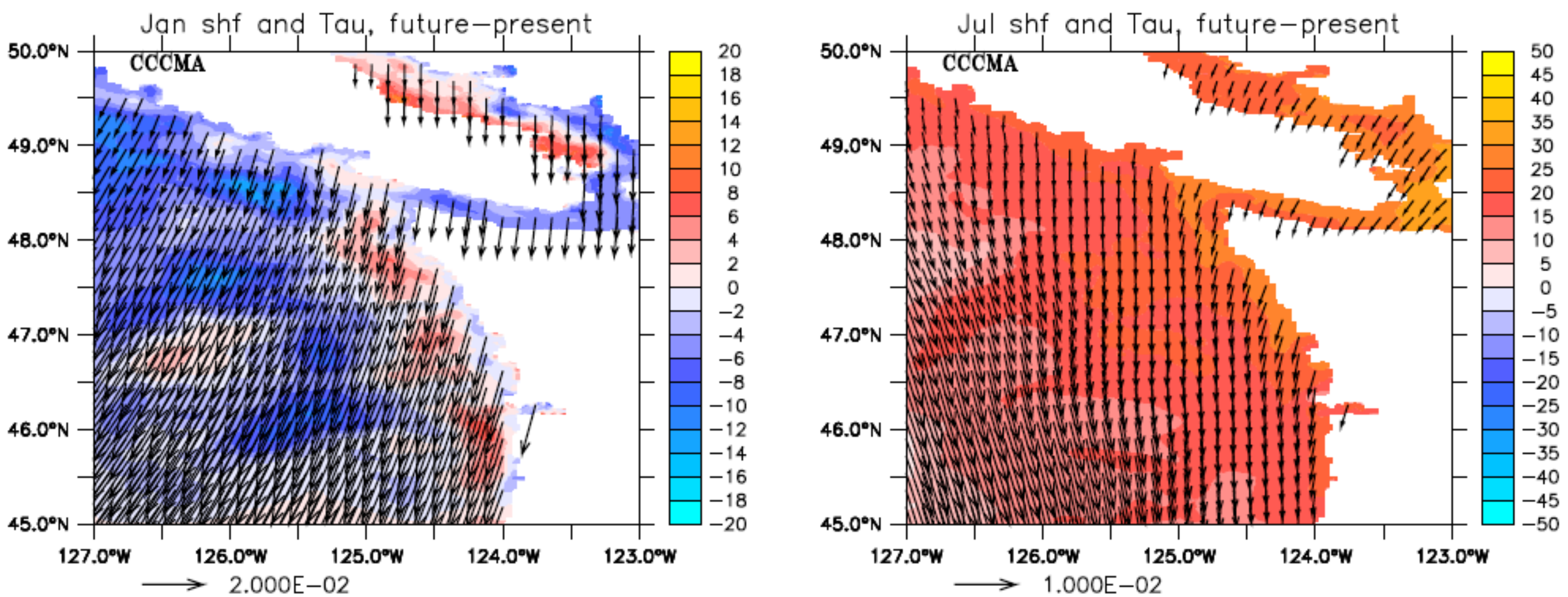

Figure 2 As in Fig.1, but for the CCCMA climate model.

The changes in the climate forcing vary amongst the climate models that have been used. Note that especially during the winter month of January that the MIROC model indicates a change to more wind from the south (downwelling favorable), the CCCMA indicates a change of the opposite sign, and that ECHOG model indicates a change to greater winds from the west. There is more consistency towards greater upwelling in summer, but as shown in Table 2 above and the results shown in Figure 3 here, not complete agreement among the climate models used for our ROMS experiments.

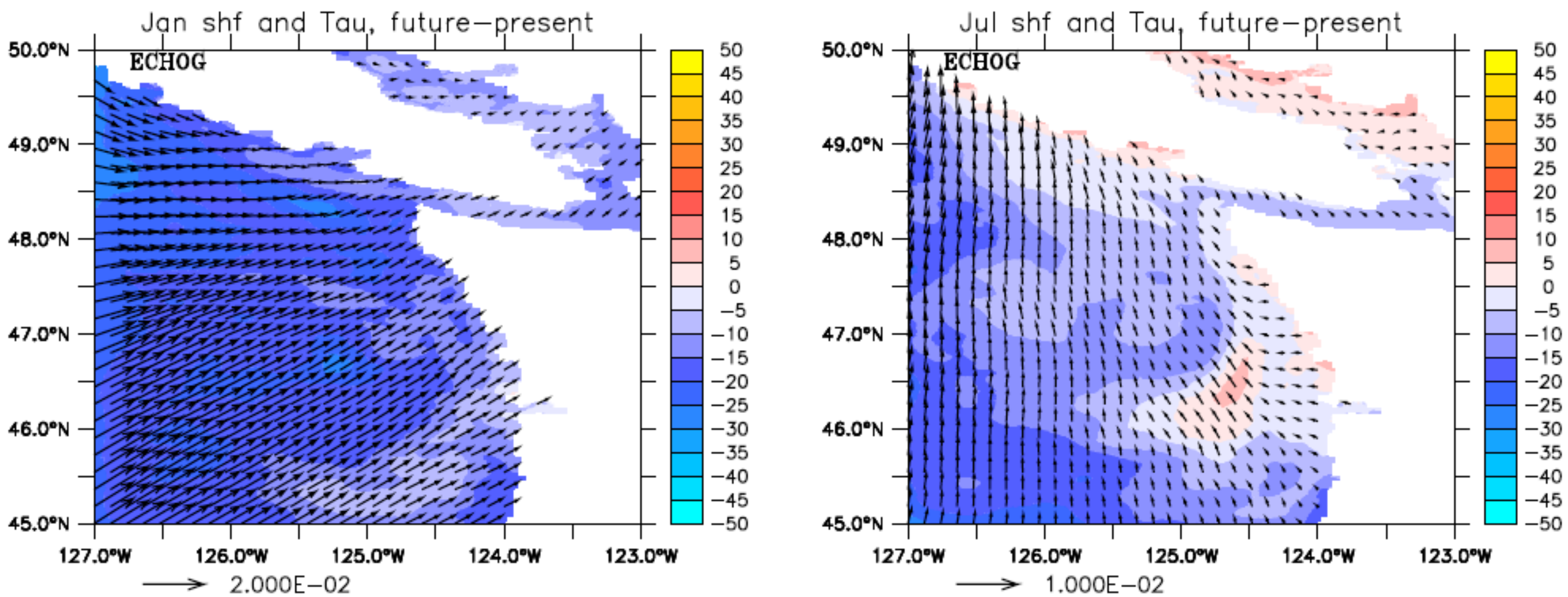

Figure 3 As in Fig. 1, but for the ECHOG climate model.

An example of an important consequence of the difference in climate forcing is shown in Figure 4. The upper ocean stratification in the immediate vicinity of the Washington coast generally increases in the ROMS simulations using MIROC and ECHOG and decreases in its counterpart using CCCMA. The differences in these changes can be attributed in large part to greater increases in freshwater runoff from the MIROC and ECHOG versus the CCCMA-based simulation. The reduced runoff with the CCCMA is associated with the relatively cold and dry winter weather for the decade of 2030-2040 from this particular climate projection.

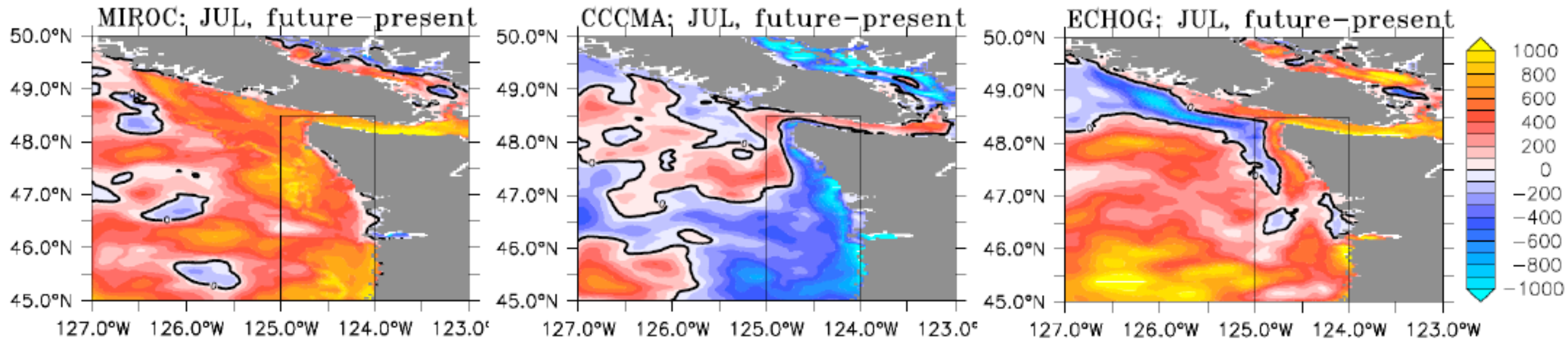

Figure 4 Changes in upper ocean stratification from the surface to 50 meters (in terms of potential energy J/m2) from 2000-2010 to 2030-2040 during July based on ROMS simulations using large-scale forcing from the MIROC (left), CCCMA (middle) and ECHOG (right) climate models. Positive values (red colors) imply greater stratification.

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c. Summary and Implications

This project has investigated likely changes in the physical oceanographic conditions in the near-coastal waters of Washington state. The results from our research, along with related work carried out as part of other projects, can be used to make the following general statements.

1. Decadal-scale variability in the climate forcing will dominate the climate change signal during the next 10-20 years; the latter will become dominant by roughly the 2040-2050s.

2. Systematic changes in upper-ocean temperature are much more certain than those in salinity over the next few decades due to uncertainty/decadal variability in the future weather during winter and hence the amount and seasonality of freshwater runoff.

3. A tendency towards slightly greater upwelling-favorable winds in summer is more likely than not, but it is unclear whether there will be an increase in the vertical flux of nutrient-rich waters from depth in the coastal zone.

4. There is little evidence of meaningful change in the basin-scale gyre circulation in the eastern Pacific by the middle of the 21st century.

The projected changes summarized above should have ramifications for the marine ecosystem of the region. The increases in upper-ocean temperatures, and probably upper-ocean static stability, may favor sub-tropical versus sub-arctic species. This kind of change in preferred habitat may occur prior to any noticeable shift poleward in the transition zone between the sub-tropic and sub-arctic gyres. Increases in summertime upwelling favorable winds are expected to bring more frequent and intense periods of hypoxia and lower pH water from depth into shallow regions near the coast. These events may tend to be exacerbated during dry periods when the stratification is reduced. The Juan de Fuca eddy is a recurring feature of the local oceanography and has been associated with harmful algal blooms (HABs), but the ROMS simulations provide little indication of whether it is liable to become more prevalent or not.

Students Supported

This project benefitted greatly from the participation of Mr. Dennis Negron-Rivera, an undergraduate student in the Department of Electrical and Computer Engineering, University of Puerto Rico. Mr. Negron-Rivera's participation was during June-August 2011 through the Summer Undergraduate Internship Program of the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) of the University of Washington. His role was to examine the output from IPCC-class GCMs in terms of their climate forcing of the region of interest. This work culminated in a poster that he presented at the annual meeting of the American Meteorological Society in New Orleans, LA in January 2012. The results of his research have been critical towards providing a context for the ROMS-based part of the project through analysis of multiple runs by a large variety of GCMs.

Outreach

Under the auspices of this project, a variety of outreach activities have been carried out. In particular, lead investigator Nicholas Bond has provided 7 public lectures on the implications of climate change for the Pacific Northwest over the duration of the project. He has also given three guest lectures at the University of Washington that have drawn from the present project, and has served as a contributing author and reviewer on a report "Climate Change and Olympic Coast: Interpreting Potential Futures" for the Marine Sanctuaries Conservation Series.