HICO Data User's Proposal

Coupling Terrestrial Ecosystems and Watershed Hydrology to Coastal Ocean Productivity

Principal Investigator

Dr. Thomas M. Powell

University of California, Berkeley
Department of Integrative Biology
1005 Valley Life Sciences Building # 3140
Berkeley, CA 94720-3140
(510) 642-7455 (phone)
(510) 643-6264 (fax)
zackp@berkeley.edu

Co-Investigator: Elizabeth Olhsson, PhD Candidate, UC Berkeley, lolhsson@berkeley.edu
Co-Investigator: Inez Fung, Professor, UC Berkeley, ifung@berkeley.edu
Co-Investigator: Jim Bishop, Professor, UC Berkeley, jkbishop@berkeley.edu

Abstract/project summary

Using a coupled modeling framework that incorporates watershed, ocean, and atmospheric components, this project seeks to understand the fate and transport of nutrients from the Eel River watershed into the coastal ocean around Cape Mendocino, California (40.64 N, -124.31 E), and how the interannual variability of their delivery creates variability in ocean productivity offshore. Model products include daily time series of Eel River discharge and sediments, while high-resolution physical ocean modeling (nested 10km, 1km, 300m grids, 40 vertical levels) resolves the plume of the Eel River, which in turn drives ocean productivity models. HICO information would provide excellent validation for the behavior of the Eel River freshwater plume, especially post-storm flows that carry heavy sediment loads into the coastal ocean.

1. **Statement of work/project description**

Motivation: The field of earth system modeling seeks to understand and represent the processes of the atmosphere, land, and ocean, as a unified system. It has developed with particular focus on climate change modeling, and in general, due to the computational expense of simulating an entire planet, earth system models run on very large geographical scales. However, in global modeling, we sometimes literally lose the trees for the forest. Thousands of square kilometers are assumed to behave identically to their neighbors, or at least have their differences subsumed within careful model design.

Rivers are an especially under-modeled portion of the earth system.. Most rivers are too small to appear in coarse global grids.. But water systems are vital for wildlife, for agriculture, for urban management, for the transport of sediments and pollutants, and vital for the health of fisheries and other coastal ocean processes. The first question this project seeks to address is: does adding the river inflow to the earth system models improve the product? We can answer this by comparing our regional results to what the field has already produced with global models like the CESM [Community Earth System Model (Gent et al. 2011)] and with regional models driven by extensive and expensive field data studies such as the products of the River Influences on Shelf Ecosystems project (Hickey et al 2010).

The west coast of North America is the setting for one of the world's largest coastal upwelling regions (Smith 1992). Large rivers drain from North America into the northeast Pacific Ocean, delivering large loads of sediments, as well as nutrients, organic matter and organisms. The Eel River discharges into the North Pacific at 40.64 N, -124.31 E, just north of Cape Mendocino in Northern California. Its annual discharge (~200m3/s) is about 1% that of the Mississippi, but its sediment yield (15 million tons/yr) is the highest for its drainage area (9500 km2) in the entire continental US (Lisle 1990; Brown and Ritter 1971).

The Eel River is an advantageous choice for a test case to model because its annual behavior is dramatic and potentially very sensitive to changes in climate. Driven by the Mediterranean climate of northern California, it is characterized by low flow during the long, hot dry season. Then, each winter and spring, storm events flush nutrients down the river to the ocean, in large pulses. The storm flows are out of phase with the other major nutrient input to local coastal biology: late spring and summer upwelling of cold, nutrient-rich ocean water to the photosynthetically active surface. The timing and magnitude of these storm events (and thus the timing and magnitude of Eel riverine nutrient delivery) exhibit much interannual variability and may be altered by climate change.

Furthermore, evidence suggests that the fluxes from the Eel River may contribute to phytoplankton blooms offshore. Ocean color can be used as a surrogate measurement for chlorophyll and therefore primary productivity (Saba et al 2011). Satellite imagery off of Cape Mendocino has demonstrated spatial, seasonal and interannual variability of ocean color, north and south of the Eel River's discharge

(NOAA 2012). This project constructs a detailed modeling framework in order to explore the connections between variability in weather (modulated, slowly, by climate trends), river nutrient delivery to the ocean, and coastal phytoplankton productivity.

The following specific questions guide this research:

- Can the spatial variations in primary productivity around Cape Mendocino be explained solely by variations in upwelling due to weather patterns and near-shore topography? If not, what is the relative impact of upwelling versus nutrient input from the Eel River, and how does that relationship vary from season to season, and year to year?
- If the river is important, how and why is this so? Is its contribution best modeled as particulate or dissolved input? Is the transformation of the nitrogen and iron inputs, from unavailable to bioavailable forms, merely a function of time, or controlled by specific biological or physical conditions?
- How might climate change alter the behavior of the river, the coastal ocean, and the nutrient sources for coastal primary productivity?

The first two points are best studied through hindcast models that, reproduce past conditions under a variety of possible model assumptions, exploring the relative importance of processes within the model. The coupled modeling framework will therefore simulate 2000-2013, with various additions or subtractions (e.g., turning the river on and off; turning iron limitation of phytoplankton on and off; different treatments of nitrogen/iron behavior, etc.) chosen to explore these questions. Once the hindcast demonstrates sufficient ability to reproduce primary productivity data, forecasts will be run under a series of emissions-based climate change scenarios, using forcing data from the CESM.

Physical Modeling/Coupling of the Eel River to the Coastal Northern California Ocean: In the coupled modeling framework (Fig. 1), we represent the watershed with the lumped empirical watershed model HydroTrend (Kettner and Syvitski 2009), which can generate high-frequency water and sediment time series in relatively unstudied basins. The hindcast atmosphere is represented by NARR [NCEP North American Regional Reanalysis (Mesinger et al 2006)], a model and data assimilation tool. The forecast atmosphere will be represented with output from the Community Earth System Model. The ocean is represented with the Regional Ocean Modeling System (ROMS; Shchepetkin and McWilliams 2005, Haidvogel 2008), a powerful, modular, physically distributed model that can efficiently solve fine-scale resolution grids. Transforming HydroTrend's output into a form suitable to force the ocean and biology models required a coupling interface physically driven by a steady, uniform open-channel flow calculation (Yen 1973).

Progress: The Eel River has been modeled in HydroTrend from 1979-2010, and compares well to United States Geological Service gauging station data (Fig 2; USGS 2010). The coastal ocean has been modeled in ROMS from 2000-2010 with 10 km horizontal resolution, with results that improve upon a well-regarded regional-resolution model, SODA [Simple Ocean Data Assimilation (Fig 3; Carton and Giese 2008)]. Nested 1 km and 300 m grids that zoom in around the Eel delta are currently being run with and without the river.

Modeling Eel River Nutrient Fate, Transport and Effect on Coastal Ocean Productivity: The modeling framework will use an Iron-Limited Nitrogen-Phytoplankton-Zooplankton-Detritus biological model (Fiechter et al. 2009) to analyze spatial and temporal variability in coastal ocean productivity. The nutrient load within the Eel River will be estimated from a climatology of USGS Eel River nutrient data (USGS 2010). A variety of Eel River nutrient input behaviors will be explored within the modeling framework: phytoplankton growth limited by nitrogen vs. nitrogen and iron; discrete sinking riverine particles vs. dissolved nutrient concentrations; relative organic vs. inorganic nutrient abundances. In addition, we will investigate two iron-based scenarios for immediately vs. gradually bioavailable nutrients: 1) bioavailability as a function of iron-scavenging ligand production by phytoplankton (Buck et al 2007), and 2) bioavailability as a function of water oxygen content, which implies riverine iron must sink to anoxic depths, transform from ferric to the more soluble ferrous state, and be upwelled before phytoplankton uptake (Chase et al 2007). Progress: The nutrient modeling experiments have been designed and the required data for simulation and validation collected. The results will be computed in 2013.

Decadal Climate Change Regional Forecasting: Sediment and nutrient transport from rivers to the ocean are not currently implemented in comprehensive global climate models. Successful coupling on the regional scale is an important first step in global model development. The hindcast modeling framework will be forced with CESM results to explore decadal-scale variability under a variety of climate change emissions scenarios. The framework will be implemented as an option within CESM for the wider scientific community to use. Progress: the forecast forcing data from CESM has been collected and processed for use in the modeling framework. The results will be computed in 2013-2014.

HICO: HICO already has an EelRiverMouth target at 40.6330 N, -124.3070 E. If images were to again be collected at this site, especially in the week that follows major storm events, this would provide extremely useful validation for the physical modeling of the Eel River freshwater plume. Being able to literally see which direction the plume is being transported, how far offshore significant sediment concentrations are being carried, provides invaluable insight into the plume's behavior, and thus the model's ability to reproduce that behavior. The optional level 2 data products for chlorophyll, suspended sediments, etc., would also be extremely useful for validation of the biological portion of the model, at any time of year.

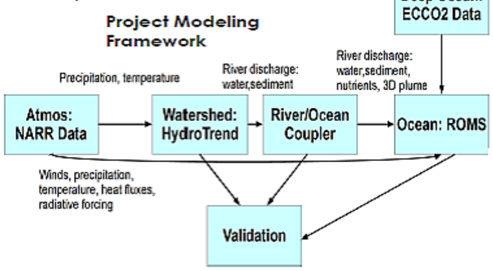
2. Biographical Sketch and available facilities

The PI for the proposed work utilizing HICO data, Thomas M. (Zack) Powell, has worked for more than forty years on physical and biological processes in lakes, estuaries, and the ocean. All have been directed toward the question: how do physical processes, like mixing and turbulence, currents and circulation, or mass and energy transfer at the surface, affect the biological processes in planktonic ecosystems? Since the 1980s a number of Powell's collaborations have utilized remote-sensed/satellite information, most using ocean color. Published accounts include Strub et al. (1984), Strub and Powell (1986, 1987), Powell et al. (2006), Di Lorenzo et al. (2008), and Fiechter et al. (2009). Our computational research is performed at two facilities: a cluster at Lawrence Berkeley National Laboratory, and the National Center for Atmospheric Research-produced Yellowstone Climate Simulation Laboratory (CISL 2012). Our primary Eel River data source is the USGS' discharge, sediment, and nutrient time series at Scotia, CA (USGS 2010), for its proximity to the mouth of the river; USGS data is widely available online. Our ocean productivity results will be compared to MODIS ocean color product, also available online (NASA 2012). Our work is funded by a National Science Foundation Earth Systems Modeling grant (NSF-OCE-1049222).

3. Output and Deliverables

This project will produce modeled daily time series of physical (temperature, salinity, velocity) and biological (phytoplankton, zooplankton, nutrients, detritus) quantities in the coastal ocean, as well as river discharge, sediment and nutrient time series at the mouth of the Eel River itself. Its output will be made available to the public and other scientists who wish to use our results to compare to other models and data sets, or to guide research choices about when and where to pursue more in situ ocean productivity research. An algorithm that quantifies similarity between model results and a HICO image is a potential product as well. Our comparisons of model output and HICO images will demonstrate HICO's potential use in the regional modeling community, and we are committed to sharing them at the HICO annual meeting.

Figure 1: A flowchart representing information flow between the components of the framework.



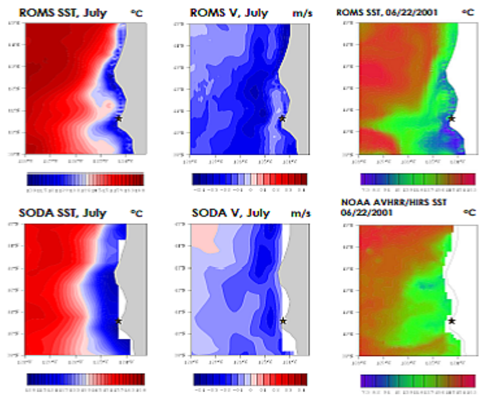
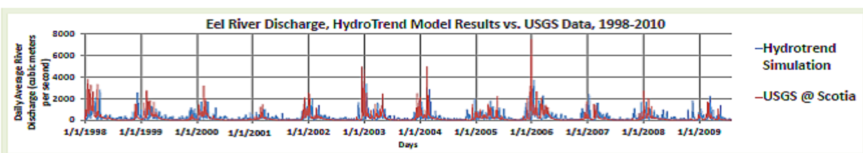


Figure 3: July monthly climatology of our 10-km resolution Regional Ocean Modeling System product (top) compared to the SODA product (bottom). The mouth of the Eel River is starred. On the right: Daily-timescale comparison of ROMS SST (top) with NOAA AVHRR satellite data (bottom).

Figure 2: A comparison of daily HydroTrend model results (blue) with US Geological Survey Eel River data (red).



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