The Dynamic Watershed and Coastal Ocean: Predicting Their Biogeochemical Linkages and Variability over Decadal Time Scales

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Introduction

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 northern eastern Pacific Ocean, delivering large loads of sediments, as well as nutrients, organic matter and organisms. The Eel River (Figure 1) discharges into the North Pacific at 40º 38.5', just north of Cape Mendocino in Northern California. Its annual discharge (~200 m^3/s) is about 1% that of the Mississippi, but its sediment yield (15 million tons/yr) is the highest for its drainage area (9500 km^2) in the entire continental US (Lisle 1990; Brown and Ritter, 1971).

This strongly seasonal signal, generated largely by winter storm events that flush sediment and detritus into the river and down to the sea, generates dramatic nutrient pulses that may play a role in the timing and magnitude of offshore phytoplankton blooms. Understanding how the interannual variability of weather, moderated by slower trends in climate, affects these pulses, which in turn may alter offshore nutrient availability, is something we hope to explore through a detailed modeling framework (Figure 2).

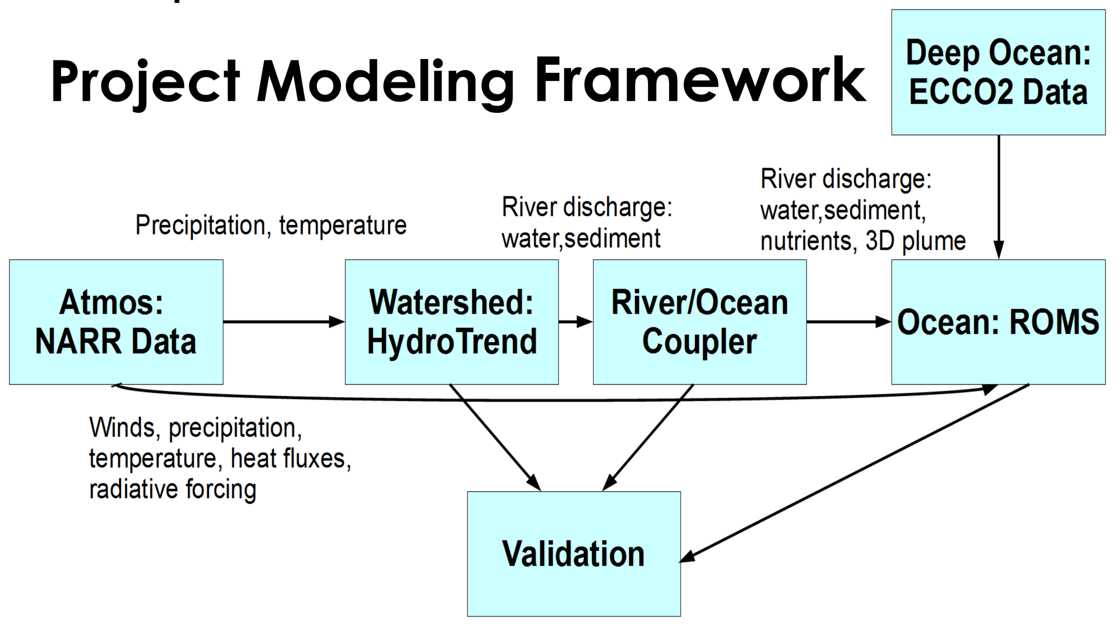
- Does river discharge influence coastal productivity? How? What are the physical and chemical fates of river-borne nutrients in the ocean?

- How and why does a freshwater plume's nutrient load vary from year to year?

- To what extent can our understanding of the dynamics of an air/sea/watershed system be improved using models drawing from all three fields of expertise rather than just one?

Figure 2: A flowchart representing information flow between the components of the framework.

Project Modeling Framework



Methods

In our coupled modeling framework, the watershed is currently represented by the lumped empirical watershed model *HydroTrend* (Kettner and Syvitski 2009), for its ability to generate high-frequency water and sediment time series in relatively unstudied basins. The atmosphere is represented by the NCEP *North American Regional Reanalysis* (Mesinger et al 2006), a model and data assimilation tool. Eventually, we hope to represent the atmosphere with the *Community Earth System Model* (Gent et al 2011), a powerful tool for studying climate change projections, which will let us talk about possible future impacts of climate change on coastal productivity. The ocean is represented with the *Regional Ocean Modeling System* (Shchepetkin and McWilliams 2005), a powerful and very modular, physically distributed model that can efficiently solve fine-scale resolution grids. The coastal biology will be handled by modification of an *iron-limited nutrient-phytoplankton-zooplankton-detritus model* (Fiechter et al 2009). Transforming HydroTrend's output into a form suitable to force the ocean and biology models requires a unique and novel *coupling interface*.

Figure 1: The Eel River, a watershed in the Northern California Coast Range, is driven by a Mediterranean climate.

Ocean Model: Regional Ocean Modeling System

Physically distributed 3D ocean circulation model

- 10 km resolution grid, 40 terrain-following vertical levels
- 1998-2010, 3 minute timesteps, 37-47 N, 132-123 W

Inputs:

- Atmospheric surface forcing: NCEP's NARR temperature, radiation, winds, precipitation, pressure, humidity
- 3D initialization and boundary conditions: NASA's ECCO2 ocean temperature, salinity, velocities

Outputs: 3D temperature, salinity, velocity, desired biological tracers

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).

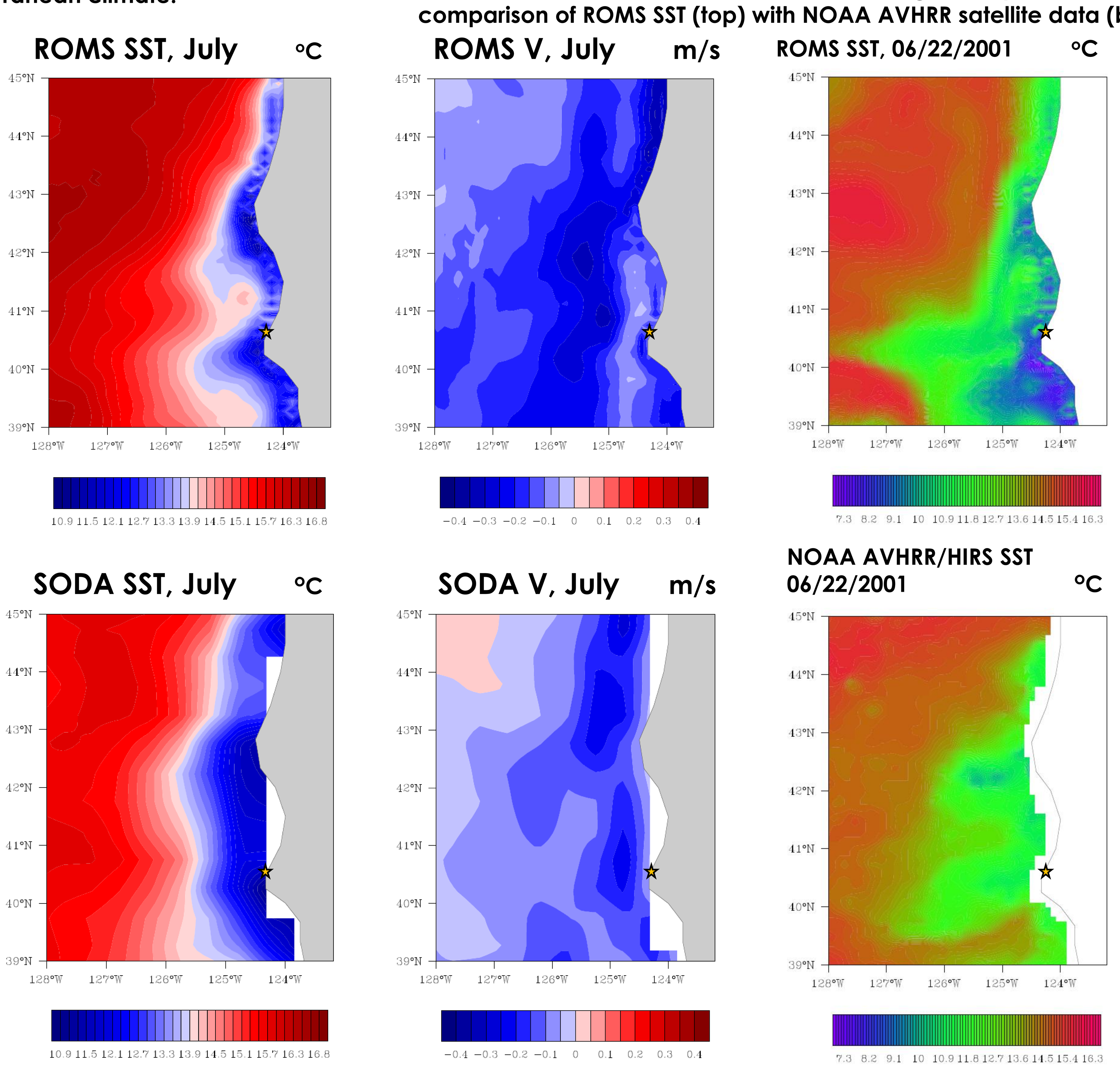


Figure 4: A comparison of daily HydroTrend model results (blue) with USGS Eel River data (red).

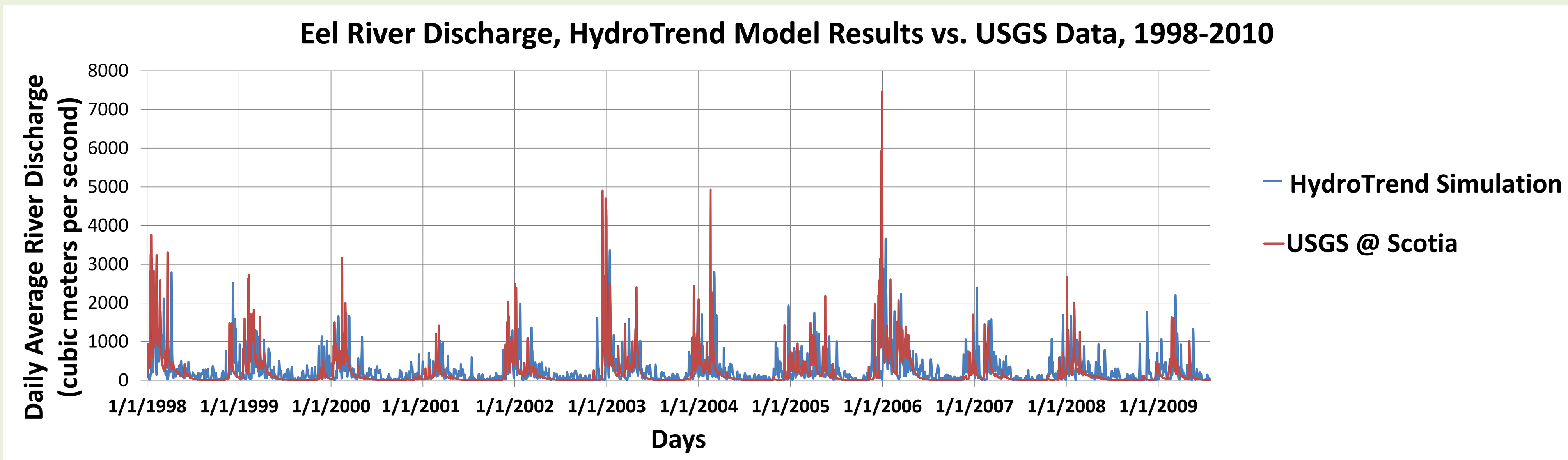


Figure 5: Pathways within HydroTrend that a unit of water can take, from precipitation to outflow into the ocean.

Atmospheric and Deep Ocean Inputs: NARR and ECCO2

NCEP's North American Regional Reanalysis is a long-term, consistent, high-resolution climate dataset for the North American domain, as a major improvement upon the earlier global reanalysis datasets in both resolution and accuracy (Mesinger et al 2006). It has 32x32 km horizontal resolution and 3-hourly temporal resolution.

The NASA Modeling, Analysis, and Prediction (MAP) program has funded a project called Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2): High-Resolution Global-Ocean and Sea-Ice Data Synthesis. ECCO2 aims to produce increasingly accurate syntheses of all available global-scale ocean and sea-ice data at resolutions that start to resolve ocean eddies (Menemenlis et al 2008). Monthly climatologies at quarter-degree resolutions were used for this project.

Results to Date

- 10 km horizontal resolution ROMS runs from 1990-2010
  - Sea surface temperatures within 1 Celsius, generally warmer offshore; upwelling behavior resolved better than SODA; daily timescale eddies (onshore cold water filaments) appear when compared to satellite data (Figure 3)
  - Zonal and meridional velocities within a factor of two of SODA, generally extra circulation; high-velocity regions of squirts and jets well-represented (Figure 3, zonal not shown)
- Daily HydroTrend Eel River runs from 1979-2010
  - Annual behavior (high flow storm events in winter, low flow summers) well-resolved, winter flows slightly less extreme than USGS data (Figure 4)
  - HydroTrend's climatological discharge to sediment yield ratio agrees well with USGS data (not shown)
- Analysis/validation/correction of North American Regional Reanalysis forcing data in our region of interest (not shown)

Validation

- ROMS products compared to the Simple Ocean Data Assimilation (Carton and Giese 2008), satellite data from NOAA's AVHRR/HIRS sensor (NOAA 2012)
- HydroTrend results compared to United States Geologic Survey Eel River data at Scotia, CA (USGS 2010)

Next Steps: River/Coastal Circulation/BGC Coupling

- ROMS: 300m nested grid to better resolve Eel plume
- Hydrotrend-ROMS coupling
- Riverine nutrient input → ocean biology module
- CESM: decadal forecast scenarios

Watershed Model: HydroTrend 3.0

Empirical, highly aggregated watershed model (Figure 5)

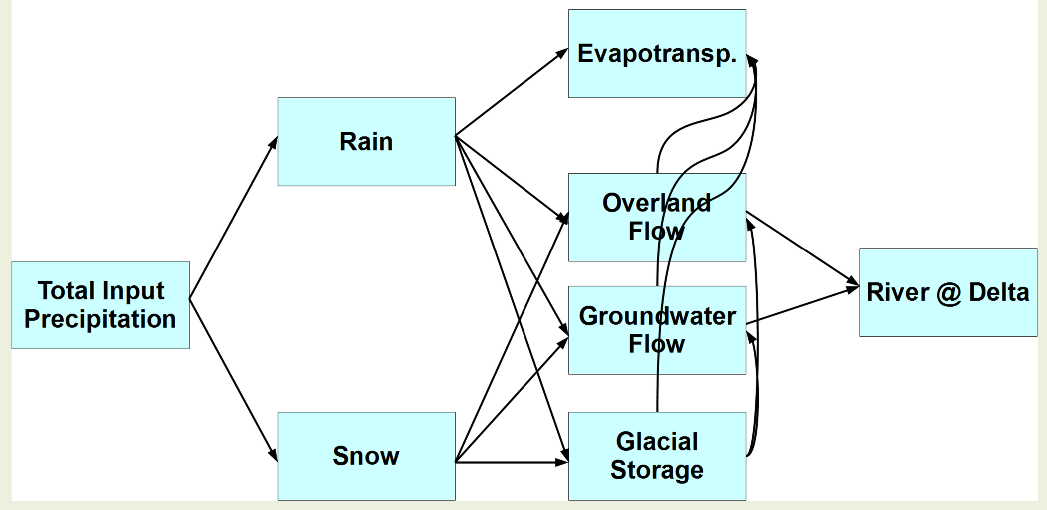
Inputs: Two options

- Stochastic climate simulation, internally generated
- Temperature and precipitation, externally provided by NARR
- 1 day minimum time resolution

Outputs: Daily averaged

- Discharge (width, depth, velocity @ mouth, Figure 4)
- Sediment (multiple size classes, suspended vs. bedload)

Where does the water go in HydroTrend 3.0?



Sediment in HydroTrend 3.0

Three options for empirical sediment models:

ART: based on drainage basin area, max relief, temperature

QRT: based on long term discharge, max relief, temperature

BQART: both, + lithology and human impact

These sediment rating curve models are based on analysis of 340 rivers globally, partitioned into 5 climate zones.

Acknowledgements and References

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