PREDICTING THE CALIFORNIA CURRENT SYSTEM: SYMPOSIUM OF THE 2014 CALCOFI CONFERENCE

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The California Current system (CCS) extends from British Columbia to Baja California. The southern end of the CCS has been observed by CalCOFI[1] for more than 66 years. What will the CCS be like in the coming decades and beyond? How well can the CCS, or parts of it, be forecast on the scale of days to seasons and predicted on the scale of climate change? How will warming, stratification, acidification, and deoxygenation affect the CCS? Our ability to inform management and policy decisions depends on answers to such questions. The Symposium of the 2014 CalCOFI Conference was planned to address these issues. Presentations included hindcasting and prediction of the California Current using statistical and dynamical models, ranging from physics to fishers, and including the atmosphere and ocean. Model types included general circulation models, regional models, Atlantis-type models, and hybrid models including fish and humans.

Dunne et al. used the GFDL's Earth System Model[2] (ESM). A key question was how to bridge scales, from global, which is coarse in resolution but inclusive in processes, to regional, which has the desired resolution but excludes interactions with other regions and the earth. Both have inherent biases with regard to Eastern Boundary Currents. Dunne et al. presented results for a 0.1˚ (~10 km) ocean and 50 km atmosphere ESM that includes lower trophic levels. This spatial resolution is necessary to resolve currents in the EBCs, whose lateral dimensions scale with the Rossby radius. Comparsion of EBC temperature and chlorophyll with observations improved markedly from the 1˚ to 0.1˚ models, though challenges remain. The value of ESMs in predicting EBC dynamics was demonstrated by the unexpected result of the predicted influence of distant processes in the NW Pacific on the nitrate concentration of water upwelled in the California Current under a future climate (Rykaczewski and Dunne 2010).

Curchitser et al. addressed this scale issue by combining model types. A multi-scale ocean was incorporated as part of the NCAR CESM[3]. Scales ranged from a 7 km ocean model in the 1˚ CESM (ocean, atmosphere) and from months to 150 years. Not only was the fidelity of the model to observations enhanced in the multiscale model but feedbacks between regional and global models, particularly large-scale perturbations by regional upwelling, were discovered.

Rose et al. focused on End-to-End modeling—from physics to fishers in the California Current and with anchovy and sardine. The Regional Ocean Modeling System (ROMS) was used with ~10 km and daily resolution and ~1000 km and 50 y domain. A distinguishing feature of this effort is the inclusion of an "individual-based, full life cycle anchovy and sardine submodel" and characterizations of predators, including fishing fleets (Rose et al. in press). This model recreates the decadal-scale variation in anchovy and sardine dynamics, giving hope to our ability to predict such dynamics under a future, changed climate.

Edwards et al. hindcast and nowcast the state of the California Current system using the UCSC ROMS 4D-Var model[4]. A key element of this work is the use of data assimilation, i.e., the continuous incorporation of observational data into the model. Resolution is ~10 km and 8d/cycle and domain being waters off California, Oregon, and Washington and 31 years. This model has enabled the evaluation of fundamental physical processes, such as wind-induced upwelling and stratification, to characterize the habitat of rockfish.

Seo et al. focused on the effects of mesoscale SST and surface currents on eddy kinetic energy (EKE) and Ekman pumping. A 7 km regional coupled model showed a 25%–30% dissipation of EKE due to primarily to eddy-wind interactions, showing the need to include high-resolution air-sea coupling in both directions.

Siedlecki et al. focused on seasonal forecasts of ocean conditions that are "testable and relevant to annual management decisions" in the CCS using J-SCOPE[5].

[1]CalCOFI (California Cooperative Oceanic Fisheries Investigations) http://www.calcofi.org/

[2]GFDL ESM (Geophysical Fluid Dynamics Laboratory's Earth System Model) http://www.gfdl.noaa.gov/earth-system-model

[3]UCAR CESM (University Corporation for Atmospheric Research Community Earth System Model) http://www.cesm.ucar.edu/models/ccsm4.0/

[4]UCSC Ocean Modeling and Data Assimilation http://oceanmodeling.ucsc.edu/

[5]J-SCOPE (JISAO Seasonal Coastal Ocean Prediction of the Ecosystem) http://www.nanoos.org/products/j-scope/

Seasonal forecasts are needed for management decisions yet have been largely neglected due to their being between short-term forecasts and long-term predictions. J-SCOPE combines a ROMS model with the NOAA Climate Forecast System (3-dimensional with data assimilation) and a detailed model of dissolved oxygen to hindcast and forecast SST, O_2, and pH locally and regionally. Forecast skill is good to several months. This model is of particular value to inform management decisions in a region with significant climate-related changes in biogeochemistry and ecology, including fisheries and aquaculture.

Kaplan describes the use of the Atlantis[6] End-to-End model in the California Current system. Atlantis is a ROMS-based model with differential equations defining interactions between physical, chemical, and biological, including human, components of a system. It is a highly parameterized model that can be tuned with observations. Resolution is 12-h time steps and domain is the coastal waters of California, Oregon, and Washington.

Ye et al. describe how nonlinear systems do not lend themselves to analysis and prediction using linear models. They show that nonlinear properties of systems, derived from the analysis of time series of system variables, can be used for short-term forecasting, hence management, using equation-free models.

Themes derived from the combined presentations in the Symposium include:

- Scale is important. As Levin (1992) wrote, we perceive "only a low-dimensional slice through a high-dimensional cake" (p. 1945). In general, populations (e.g., of fish) affected by management decisions are at a scale currently resolved poorly in global-scale models. Yet the latter are useful, if not necessary, to inform higher-resolution models, e.g., with boundary conditions. Increasing computing power and new modeling schemes give promise here.
- Two-way coupling is often important.
- Trade-offs and limits exist. Resolution and domain vary inversely. Forecasting and prediction of nonlinear systems may be inherently limited by their chaotic behavior.
- Long-term, continuous observing programs, such as CalCOFI, are necessary to support all modeling efforts to understand and forecast the CCS. Observations are needed to create models and evaluate their predictive skill. Environmental intelligence requires environmental knowledge.
- Communication and collaboration are important, within both the modeling community writ large and between it, those who observe and those who rely on models, particularly to make decisions in management and policy.

Highest priority should be given to enhancing collaboration among governmental agencies and academic institutions. CalCOFI's success is due in large part to the federal (National Oceanic and Atmospheric Administration[7]), state (California Department of Fish and Wildlife[8]) and university (University of California, San Diego's Scripps Institution of Oceanography[9]) partnership of 66 years. The Symposium papers demonstrate the strengths of individual NOAA and academic entities in state-of-the-art prediction of the California Current system. An investment in an enhanced partnership among NOAA line offices, centers and labs and cooperative institutes working on the California Current system would have a high return in regard to informing decisions on management and policy. Such entities include Geophysical Fluid Dynamics Laboratory[10], the Northwest and Southwest Fisheries Science Centers[11,12], the Pacific Marine Environmental Laboratory[13], the Joint Institute for the Study of the Atmosphere and Ocean[14], the Cooperative Institute for Marine Resources Studies[15], and the Cooperative Institute for Marine Ecosystems and Climate[16].

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[6]Atlantis Ecosystem Model http://www.nwfsc.noaa.gov/research/divisions/cb/documents/atlantis_ecosystem_model.pdf

[7]NOAA http://www.noaa.gov/

[8]CDFW https://www.wildlife.ca.gov/

[9]UCSD/SIO https://scripps.ucsd.edu/

[10]GFDL http://www.gfdl.noaa.gov/

[11]NWFSC http://www.nwfsc.noaa.gov/

[12]SWFSC https://swfsc.noaa.gov/

[13]PMEL http://www.pmel.noaa.gov/

[14]JISAO http://www.jisao.washington.edu/

[15]CIMRS http://hmsc.oregonstate.edu/cimrs

[16]CIMEC https://scripps.ucsd.edu/cimec