CORIE: the first decade of a coastal margin collaborative observatory

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Abstract—CORIE, a pioneering coastal margin observatory for the Columbia River, has over the last decade advanced the state of the art in coastal margin observation and prediction. Concepts and capabilities developed and demonstrated in CORIE are informing US-wide ocean observing initiatives.

I. INTRODUCTION

Originally conceived as a nowcast-forecast system for the Columbia River estuary and plume, CORIE [1–3] was initiated in June 1996, with the deployment of a single telemetered conductivity-temperature-depth sensor (CTD). Since then, CORIE has progressively fulfilled the vision of an integrated cross-scale ocean observing system with observation, modeling and information delivery components (Fig. 1).

Although to date there has been a deliberate focus on observation and modeling of physical properties, CORIE products and analyses have had a broader impact. CORIE is (a) enabling innovative thinking in both coastal oceanography and ecosystem science, and (b) contributing to address management and operational issues such as salmon survival, navigation improvements, and flow regulation.

CORIE infrastructure and tools are currently being extended in diverse ways, including: (a) a geographically flexible rapid-deployment forecasting system for estuarine and coastal circulation; (b) an observation network for Pacific Northwest estuaries; and (c) a next-generation river-to-ocean observation and prediction system. Each extension addresses an identified need in the creation of an integrated US ocean observing system.

II. THE COLUMBIA RIVER AT A GLANCE

Second in annual discharge in the US, the Columbia River provides 70% of freshwater inflow to the Eastern North Pacific Ocean between San Francisco Bay and the Strait of Juan de Fuca. Highly coupled, the Columbia River estuary and plume respond dramatically to changes in tide, discharge, ocean conditions, and shelf winds (Fig. 2). The plume [4] extends north to British Columbia and south to California, and is a major feature in the upwelling-dominated Oregon–Washington shelf. In the estuary, tides are strong; wetting and drying is extensive; and channel circulation is highly stratified, leading to formation of estuarine turbidity maxima [5, 6].

III. CORIE OBSERVATIONS AND SIMULATIONS

Our objectives in developing CORIE were: (a) to create a multi-purpose regional infrastructure for science and management in the Columbia River estuary and plume; and (b) to develop portable technologies to advance observation and prediction of coastal margins. To meet these objectives, CORIE includes both an observation network and a modeling...
system, integrated by an information management infrastructure, and focused on 3D baroclinic circulation processes and features. Only the observation network and the modeling system are explicitly described in this paper.

A. Observation Network

The observation network has 18 fixed stations in the estuary and two in the plume/shelf. Sensors vary from station to station, with temperature taken at all stations, and water level, salinity, and velocity profiles measured selectively. All but the most off-shore station have real-time telemetry; all are deployed continuously, except the near-plume station (deployed only from late Spring to early Fall). A vessel operated by a local community college has been equipped with automated oceanographic instrumentation (salinity, temperature, turbidity, dissolved oxygen and velocity profiles) and telemetry, thus constituting a frequently deployed mobile station. The telemetry network is occasionally used in support of other vessels, including vessels from the UNOLS fleet.

Data from the CORIE stations is displayed in real time on the web, albeit with limited quality control, and is then subjected to extensive off-line quality control on a monthly basis. All quality-controlled data is available through the web, for either download or visualization, as are common data statistics.

Figure 3. Location of the fixed CORIE stations. Colors represent sources of funding, illustrating the multiplicity of uses of the CORIE data.

B. Modeling System

The modeling system is designed for systematic generation of quality-controlled simulations of cross-scale 3D baroclinic circulation in the form of: daily forecasts; multi-year databases; and process/scenario simulations. “Cross-scale” means estuary, plume, and shelf/slope between northern California and southern British Columbia. Numerical grids are unstructured in the horizontal, with highest resolution in the estuary (~100 m) and near-plume (~250 m). Time steps are 60–90 s. Integral to the design is automated access to all external forcings (tides, ocean conditions, atmospheric conditions, river inputs) and to a core set of observations from CORIE and other regional in-situ networks.

Two unstructured-grid numerical models (ELCIRC [7] and SELFIE [8]) are used interchangeably as computational engines. Both use semi-implicit Eulerian-Lagrangian numerical methods to solve shallow water equations. Their differences lie in specific underlying methods (e.g., finite volumes with finite difference approximation of derivatives [7] versus finite elements with finite volumes for the vertical momentum equation [8]) and in vertical representation of the domain (Z-coordinates [7] versus Z-coordinates over grids designed locally with S- or hybrid SZ constructs [8]).

Three 3D circulation forecasts are produced daily, inter-compared, and compared against observations. Each represents a different choice in model, domain (full domain versus estuary only), and model parameterization (e.g., turbulence closure). Since 1999, several multi-year simulation databases have been constructed, with the most recent being DB11 (ELCIRC, full-domain [9]), DB12 (SELFIE, estuary only), and DB14 (SELFIE, full-domain). All forecasts and databases are generated without data assimilation. Results show useful predictive skill, even under such challenging conditions as high river discharge and fast-changing winds. Simulation databases (e.g., DB12–DB14) predict well the spatial, tidal, seasonal, and inter-annual variations of water level (Fig. 5), currents and salinity (Fig. 6); locations of estuary and plume fronts; and responses of the plume to wind and September. It also illustrates the cooling (warming) effect of the tidally induced penetration of ocean waters during Summer (Winter).
shifts. Limitations persist, including variability of errors in time (Fig. 5) and tendency of ELCIRC-based simulations to under-predict salinity in the near-plume. Although some are associated with numerical algorithms, remaining limitations often relate to errors in external forcings.

![Figure 6: Trends in maximum/minimum daily salinities (model is black; data red) at this complex channel station were first captured using SELFE (CORIE DB12).](image)

**IV. SELECTED CORIE APPLICATIONS**

The observational and modeling products of CORIE have been extensively used for science and management of the Columbia River. Selected applications are described below.

**A. Near Real-Time Support of Scientific Cruises**

CORIE daily forecasts routinely provide near real-time support for oceanographic and fisheries cruises, in particular by enabling vessels to have direct access to products that identify the location and/or frontal characteristics of the plume 24 h in advance. These forecasts are used to guide cruise planning and daily adjustments of sampling strategies.

![Figure 7. Vessels contribute through on-board sensors to the near real-time quality control of the CORIE forecasts that they receive at an on-board web server.](image)

NOAA Fisheries cruise in 2004, while Fig. 7 is representative of routine graphic displays. Model forecasts are quality-controlled in near real-time with data collected at the vessel, at other collaborating vessels, and at fixed CORIE stations. Enabling technologies include CORIE forecasts, observations, and information technology; a real-time telemetry network; on-vessel instrumentation, typically in the form of flow-through and/or hull-mounted sensors such as CTDs and ADCPs; and an on-board web server.

**B. Role of the Plume on Ocean Salmon Survival**

CORIE databases provide a uniquely refined description of the context of physical variability in the Columbia River plume. Fig. 8 shows the 1999-2004 monthly climatology for plume surface salinities as described by DB11. General seasonal trends identified in the early 70’s by [10] are recognizable, with the winter plume oriented northward and closely attached to the coast, and the summer plume oriented southward and much more detached from the coast. However, the Columbia River plume is remarkable in its variability at multiple temporal and spatial scales. We have shown earlier that the summer plume may change direction radically in the course of a few days (Fig. 2) in response to changes in shelf winds, a behavior independently described by a recent observationally based publication [11].

![Figure 8: 1999-2004 monthly climatology for plume surface salinities as described by DB11.](image)

Although CORIE databases are purely physical, their analysis in contrast with biological data creates a powerful instrument for development and/or testing of hypotheses relating salmon behavior with plume characteristics and management strategies (Burla, personal communication). As an example, strong correlations were found between smolt-to-adult ratios (SARs) for steelhead and plume size generated from CORIE simulation databases; however, spring Chinook smolt-to-adult ratios were much less sensitive to plume conditions. The implication is that controlling time-of-ocean entry might be an effective management strategy for some salmon species, although not for all.

**C. Changes in Estuarine Habitat Opportunity For Salmon**

Strategies to characterize physical habitat opportunity from multi-year simulation databases of circulation were introduced by [12], who defined favorable habitat for juvenile Columbia River salmon, based on water depth (D) and depth-averaged velocity ($U$), as habitat where:

$$0.1 m \leq \eta \leq 2 m$$

$$|U| \leq 0.3 m/s$$

These metrics where extended to local (rather than depth-averaged) velocity and to salinity by [13]; metrics were also
more recently extended to temperature. Favorable habitat is defined as:

\[
\begin{align*}
|u| & \leq 0.3 \text{ m/s} \\
0 & \leq S \leq 5 \text{ psu} \\
0 & \leq T \leq 19^\circ \text{C}
\end{align*}
\]  

(2)

Filtering the CORIE circulation databases with the above criteria enables the development of annual climatologies of habitat opportunity (Fig. 9) and even the exploration of the seasonal and inter-annual variability (Fig. 10) of this potentially important ecological metric.

This methodology is useful to evaluate, prior to implementation, the impact of anthropogenic actions, whether those actions have the potential for negative impact or are intended for estuarine restoration. A high-profile example was the application of the methodology to build consensus among participating agencies (US Army Corps of Engineers, US Fish and Wildlife Service, and NOAA Fisheries) on specific issues related to the proposed deepening of the Columbia River navigation channel [13].

V. SCALING UP CORIE

Integrated ocean observation and prediction evolved over the last decade from remote abstraction into feasible concept, in part because of identifiable implementation opportunities including the Ocean Observation Initiative (OOI) and the Integrated Ocean Observing System (IOOS). In this context, pilot systems like CORIE offer “lessons learned” as well as capabilities and tools that are potentially upward scalable. Examples of scalability are presented below.

A. Scaling Up Observation Networks

In the spirit of the US Integrated Ocean Observing Systems and under the umbrella of the Northwest Association of Ocean Observing Systems, the CORIE data management infrastructure was extended to support near real-time data acquisition in various Pacific Northwest estuaries (Fig. 11). In most cases, collaborations were established with a local entity (typically a state agency or a university) that assumed responsibility for the deployment and maintenance of the field and telemetry instrumentation. When these collaborators had data acquisition and distribution capabilities in place, appropriate interfaces with CORIE protocols were established; otherwise, CORIE tools, protocols and training were provided to minimize the learning curve of local technicians. Off-line quality control is typically a local responsibility, while standardized displays (with customized identifiers such as institutional logos) are provided centrally.

B. Scaling Up Modeling Systems

The CORIE modeling system has been developed and systematically improved and validated over a decade. This has been possible because of the nature of the Columbia River—a system that raises a variety of fundable scientific questions and that is an economic regional driver. For most other US estuaries, the opportunities for funding sophisticated modeling systems are much more limited.
To address the reality of those many other estuaries and coastal margins, we developed a geographically flexible rapid-deployment forecasting system that directly leverages the CORIE modeling and information management capabilities. This system was designed and is currently used to create daily circulation forecasts for multiple estuaries and coastal margins that are drastically different in size, freshwater inputs, economic importance and development stages (Fig. 12). At the core of each forecast are (a) numerical models of 3D baroclinic circulation, such as [7] or [8], (b) an information system that provides access to multiple global and regional ocean and atmospheric forecasts and to river discharge and oceanographic observations (where available), (c) visual and automated quality controls, and (d) an interactive, geo-referenced, web-based display interface.

The system allows for a 24-h cycle between the availability of an appropriate numerical grid and the routine production of daily 3D circulation forecasts, with quality automatically controlled against existing field observations (where those are available). The intent is to minimize the effort of initial deployment. Model expertise is required to improve the forecasts over time.

C. Scaling Up the Impact of Ocean Science and Technology

As a multi-purpose regional infrastructure, CORIE has influenced science, management and education in the Columbia River basin and the Pacific Northwest. Yet, it lacks the critical mass for truly transformative impact.

A recently funded NSF Science and Technology Center for Coastal Margin Observation and Prediction (CMOP, www.stccmop.org) is undertaking the challenge of scaling up such impact. Motivated by the CORIE experience, CMOP is a multi-institutional center with complementary responsibilities in research, education, knowledge transfer and diversity.

CMOP will address major science questions on the impact of climate on coastal margins, the role of coastal margins on global elemental cycles, and the seaward propagation of anthropogenic impacts. Integral to CMOP activities is a new river-to-ocean testbed observatory for the Pacific Northwest, which will leverage extensive resources from partner institutions into configurable integrations of modeling systems, heterogeneous observation networks, and information systems—all aimed at fundamental advancements in science and at the delivery of more reliable information to scientists, educators, resource managers, and interested citizens.

ACKNOWLEDGMENT

CORIE has had contributions from innumerable individuals, over many years. The core OHSU team (Charles Seaton, Paul Turner, Ethan vanMart, Michael Wilkin, and Dr. Joseph Zhang) has provided an outstanding blend of dedication and multi-faceted skill, augmented at times by the talent of others (such as Dr. Arun Chawla, Dr. Mike Zulauf, Phil Barrett and Cole McCandlish). OHSU students and alumni (among others, Ed Myers, Cynthia Archer, Michela Burla, Sergey Frolov, Nick Hagerty, Bill Howe, Nate Hyde, Ryan Kilgren, Aaron Racicot, among others) have kept the CORIE vision fresh and evolutionary. Colleagues from different disciplines and affiliations (Drs. Ed Casillas, Todd Leen, Jan Newton, George Priest, David Maier, Barbara Hickey, Dan Bottom, Si Simenstad, Mike Foreman, Claudio Silva, Curtis Roegner, David Martin, Jack Barth, among others) generously provided the incentive and expertise to explore new ideas and concepts. Funding for CORIE and extensions thereof, as well as for CORIE-based science, has been provided in part by various programs within the National Science Foundation, National Oceanic and Atmospheric Administration, US Army Corps of Engineers, Bonneville Power Administration, US Fish and Wildlife Service, Office of Naval Research, Oregon Department of Geology and Mineral Industries, and the City of Astoria.

REFERENCES


1 The CMOP lead partners are Oregon Health & Science University, Oregon State University and the University of Washington. CMOP is, however, designed as a national resource and involves the participation of many other institutions in academia, industry and government.


