Boundary Conditions, Data Assimilation and Predictability in Coastal Ocean Models

(NOPP-CODAE/ONR)

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Off Oregon and California, CTZ includes shelf, slope, adjacent ocean interior.

Complex flows in CTZ govern shelf/ocean exchange.

CTZ flow strongly influenced by continental slope—not well resolved in basin scale models.

Natural coastal domain includes CTZ and extends 200-300 km offshore and alongshore 41°-47°N.
Coastal ocean response to large-scale winds

Lagged correlations indicate wave propagation  (Halliwell and Allen, 1984)
Coastal sea-level response to large-scale winds

Forced and damped first-order wave equation

Fig. 18. Time series of measured and predicted $\zeta$ at SBC.

(Halliwell and Allen, 1984)
Numerical modeling - instabilities of coastal upwelling jet

(see Durski and Allen, JPO, 2005)
Nesting: Large-scale influence + local fine-resolution

Best of all possible models?
Project Objectives

• Determine the impact of open ocean boundary conditions from large-scale models on numerical model simulations of Oregon coastal ocean circulation.

• Compare model results to observations from coastal HF radar arrays and in-situ data sets (2000-2003).

• Assess impact of the boundary conditions quantitatively through data assimilation, using a variational generalized inverse method.

• Address also the impact of directly assimilating satellite remote sensing observations, including sea-surface heights and temperatures, and of using scatterometer wind stress fields.

• Address closely related issues of uncertainty and predictability, using empirical and theoretical methods to study disturbance growth mechanisms and to develop uncertainty budgets for these models.
Model Configuration - BC/DA

(Springer, Kurapov, Egbert, Allen; Choi)

Model SST June 29, 2001

Oregon CTZ ROMS
Oregon CTZ ROMS

- ROMS, 3-km horizontal resolution, 40 vertical levels (terrain-following)
- Surface forcing from NRL COAMPS regional product
- Boundary and initial conditions from NRL NCOM-CCS
- Various open boundary condition formulations

(see poster by Springer et al.)
Comparison with HF radar - speeds
Comparison with HF radar - correlations
Comparison with COAST mooring data

Depth-integrated velocity
(complex correlation amplitude)

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Cape Blanco: Jet separation and eddy formation

- Quasi-deterministic feature formed during July-August 2001, verified by satellite SSH
- Coastal jet deflected by topography; meanders separate during relaxations
- CB eddy originates from separated meander; enlarged by additional eddies
Cape Blanco: Jet separation and eddy formation

Four simulations, initialized on days 105, 110, 115, 120

Day 130 SSH mean

Day 130 SSH variance
Cape Blanco: Jet separation and eddy formation

Four simulations, initialized on days 105, 110, 115, 120

Day 231 SSH mean
Day 231 SSH variance

Day 231 SSH mean

Day 231 SSH variance
Cape Blanco: Jet separation and eddy formation

Four simulations, initialized on days 105, 110, 115, 120

Satellite verification - alongtrack SSH comparison

T/P Track 206 (day 229) T/P Track 247 (day 231)
Sensitivity to barotropic velocity BCs: direct estimate

Depth-integrated alongshore velocity (45 N)

BCs: clim. hydrogr. (green), NCOM w/ assim. (red), NCOM w/o assim (blue)
Sensitivity to barotropic velocity BCs: direct estimate

SSH (45 N)

BCs: clim. hydrogr. (green), NCOM w/ assim. (red), NCOM w/o assim (blue)
Sensitivity to barotropic velocity BCs: direct estimate

- BCs have significant impact over central Oregon shelf and upper slope; regional forcing (wind) often dominates
- Impact of BCs increases toward deeper water
- BC source more important than implementation
- Climatological hydrography yields “most different” result
- Southern BC has strong influence on path of jet
Data Assimilation

- Representer-based variational DA on finite time intervals (alternate form of 4DVAR)
- Strong-constraint (correct initial conditions) and weak-constraint (correct ICs plus forcing and dynamical errors)
- DA and dynamics: instabilities and CTZ-eddy/shelf-current interactions
- Test TL & Adj ROMS + Inverse Ocean Modeling (IOM) System (Chua & Bennett)

Previous work:
Optimal Interpolation w/ POM
(Oke et al. JGR 2002; Kurapov et al. 2005abc)
DA: Representer method for nonlinear flows

Shallow-water model of nearshore circulation
(Kurapov et al. JGR, submitted)

Irregular, nonlinear flow; limited memory of initial conditions; steady true forcing

DA corrects both ICs and forcing

Success over time intervals substantially exceeding eddy time scales and limit of validity of tangent linearization

Convergence and accuracy depend on the choice of the forcing error covariance

(further details: see poster by Kurapov et al.)

Kurapov et al. JGR, submitted
Oregon CTZ ROMS implementation

(Erofeeva, Kurapov)

- Assimilate long-range HF radar data (summer 2002)
- Verify vs. shelf moorings, satellite SST
- Test ROMS + IOM

CTZ-eddy/shelf-current interaction

Dynamically consistent error covariance, based on multivariate model EOFs

**Mode 1, 34% total var**
- SSH, depth-ave current
- surf T

**Mode 2, 20% total var**
- SSH, depth-ave current
- surf T

SST

ROMS (prior)

8/2/2002
Predictability and ensembles for a coastal ocean model
(with S. Kim, C. Snyder)

25-member ensemble of 60-day simulations, forced with spatially uniform mean + oscillatory (5-day period) wind
Regions of large ensemble variance downstream of major topographic features
(see poster by Kim et al.)
Quantifying predictability: relative entropy

Relative entropy $R_E$ (univariate, Gaussian; forecast ensemble $f$, climatology $c$):

$$R_E = \frac{1}{2} \left[ \frac{(\mu_f - \mu_c)^2}{\sigma_c^2} \right] + \ln \left( \frac{\sigma_c^2}{\sigma_f^2} \right) + \frac{\sigma_f^2}{\sigma_c^2} - 1$$

$R_E$ large if:

1. **Signal** (difference in means relative to climatological variance) large; or
2. **Dispersion** (ratio of climatological to forecast ensemble variance) large.

Thus, $R_E$ large indicates predictive information content is large.

(see, e.g., Kleeman)
Ensemble statistics - Oregon coastal ocean simulations

25-member ensembles of 60-day simulations, forced with spatially uniform mean + oscillatory (5-day period) wind

Regions of large ensemble variance are associated with topographic features
Relative entropy - Oregon coastal ocean model (day 25)

\[
R_E = \frac{1}{2} \left[ \frac{(\mu_f - \mu_c)^2}{\sigma_c^2} + \ln \left( \frac{\sigma_c^2}{\sigma_f^2} \right) + \frac{\sigma_f^2}{\sigma_c^2} - 1 \right]
\]
Relative entropy - Oregon coastal ocean model (day 45)

Relative entropy $R_E$

$$R_E = \frac{1}{2} \left[ \frac{(\mu_f - \mu_c)^2}{\sigma^2_c} + \ln \left( \frac{\sigma^2_c}{\sigma^2_f} \right) + \frac{\sigma^2_f}{\sigma^2_c} - 1 \right]$$
Summary

• Oregon CTZ ROMS nested in NCOM-CCS
• Verification vs. moorings, HF radar, satellite SSH
• Wind-driven shelf currents; Cape Blanco CTZ eddy
• Direct (nonlinear) estimates of sensitivity to barotropic velocity BC
• Data assimilation: 4DVAR for Oregon CTZ ROMS in progress
• Ensembles - central OR ensemble variance associated topographic interactions
• Relative entropy: measure of predictive information content