A Data-Assimilative, Physical-Biological Model for the Coastal Gulf of Alaska

Jerome Fiechter\textsuperscript{1}, G. Broquet\textsuperscript{2}, A. Moore\textsuperscript{1}, H. Arango\textsuperscript{3}

\textsuperscript{1}University of California, Santa Cruz
\textsuperscript{2}CEA-Orme des Merisiers, \textsuperscript{3}Rutgers University

PICES Meeting, Portland, 28 October 2010
Motivation

“Coastal Ocean Observing and Forecasting Systems”

Data assimilation of physical observations

- Do more reliable ocean circulation estimates lead to more reliable ecosystem predictions?

Observation impact calculations

- Which observational datasets contribute most to corrections made to physics and biology?

Control vector impact calculations

- Which model corrections contribute most to corrections made to physics and biology?
CGOA: Physical and Biological Properties

Physical Variability
- Downwelling-favorable winds (Stabeno et al., 2004)
- AS intrinsic mesoscale variability (Combes and Di Lorenzo, 2007)
- Anticyclonic (Yakutat) eddies (Okkonen et al., 2003)

Biological Variability
- CGOA shelf: highly productive
- Subarctic Gyre: HNLC region (Lam et al., 2006)
- Iron limitation on phytoplankton (Strom et al., 2006)
CGOA: Coupled Physical-Biological Model

- ROMS ocean model
  ~10 km horizontal resolution
  42 terrain-following vertical levels

- Boundary/initial conditions
  Northeast Pacific (NEP) ROMS
  (Curchitser et al., 2005)

- Surface and river forcing
  CORE2 (Large and Yeager, 2008)
  Freshwater line source (Royer, 1982)

- Ecosystem model
  4-Comp. NPZD (Powell et al., 2006)
  Iron limitation (Fiechter et al., 2009)

Taylor diagrams with respect to SeaWiFS Chlorophyll
(No data assimilation)

CGOA Shelf (<500m depth)

NEMURO+Fe (16 components)

CGOA Basin (>500m depth)

NPZD+Fe (6 components)
CGOA: GAK Line Sea Surface Height (1995-2004)
Model solution depends on:

- Initial condition: $x(0)$
- Surface forcing: $f_b(t)$
- Boundary conditions: $b_b(t)$

(• Model error if weak constraint)
**Strong Constraint Variational Data Assimilation**

The objective of the strong constraint incremental 4-dimensional variational (I4DVAR) approach is to find the increments to the initial condition ($\delta x$), boundary conditions ($\varepsilon_b$), and surface forcing ($\varepsilon_f$), that minimize the cost function ($J$) given by:

$$J = \frac{1}{2} z^T D^{-1} z + \frac{1}{2} (Gz-d)^T R^{-1} (Gz-d) = J_b + J_o$$

**Definitions:**
- **$D$** = Background error covariance matrix
- **$G$** = Tangent linear model sampled by $H$
- **$R$** = Observation error covariance matrix
- **$d$** = $y-H(x_b)$ = Innovation vector
- **$z$** = $(\delta x(0), \varepsilon_b(t), \varepsilon_f(t))^T$ = Increments vector
I4D-VAR Data Assimilation for CGOA

• ROMS with NPZDFe, 7-day assimilation cycle

• Univariate background error covariances (D)
  - Isotropic, homogeneous correlations (50 km horiz., 30 m vert.)
  - Surface forcing: 300 km for wind stress, 100 km for T/S fluxes
  - Standard deviations based on non-assimilated 5-year run

• Observations sources and standard deviations (R)
  - AVISO 7-Day ADT, Pathfinder 7-Day SST, GLOBEC in situ T/S
  - MDT = 2 cm; T = 0.25 C (sat), 0.1 C (in situ); S = 0.1

• Cases
  - “Free”: no data assimilation
  - “Analysis”: data assimilation up to and during current cycle
  - “Forecast”: data assimilation up to previous cycle
CGOA Sea Surface Height, 1998-2002

Model-Data correlations and RMS differences (ROMS-AVISO)
(Assimilated datasets: AVISO ADT, Pathfinder SST, GLOBEC T/S)

Free Analysis Forecast

Correlation RMSD
CGOA Surface Chlorophyll, 1998-2002

Model-Data correlations and RMS differences (NPZDFe-SeaWiFS)
(Assimilated datasets: AVISO ADT, Pathfinder SST, GLOBEC T/S)
CGOA Ecosystem Response to Mesoscale Variability

Model Analysis (EKE, Chl)  Observations (EKE, Chl)

NORTH

CENTRAL

SOUTH

NORTH

CENTRAL

SOUTH

COR = 0.4

COR = 0.5

COR = -0.2

COR = 0.2

COR = 0.3

COR = -0.05
CGOA Ecosystem Response to Mesoscale Variability

Timing of Yakutat/Sitka anticyclonic eddies in Northern CGOA

SSH Analysis

Chl Analysis

Chl Observations

SEP 2000

MAY 2002
Observation Impact in Northern CGOA

Assimilation of satellite SSH and SST, and *in situ* T and S

SSH (38%) SST (31%) T (16%) S (15%)

SSH (38%) SST (23%) T (27%) S (12%)
Adjustments to initial conditions, surface forcing, and boundaries

Control Vector Impact in Northern CGOA

Eddy Kinetic Energy

INI(87%) FRC(2%) BC(12%)

Surface chlorophyll

INI(78%) FRC(17%) BC(6%)
Summary (1)

Data assimilation of physical observations

- Data assimilation yields more reliable ocean circulation estimates, leading to improved ecosystem predictions

Observation impact calculations

- Corrections to physical and biological processes occurs primarily from assimilation of satellite SSH observations

Control vector impact calculations

- Correction to physical and biological processes occurs primarily from adjustments to model initial conditions
Summary (2)

Data assimilation of physical observations

- Ecosystem forecasting ability on weekly timescales without assimilation of biological observations

Observation impact calculations

- Assessment and optimization of ocean observing system design (data redundancy, in situ vs. satellite)

Control vector impact calculations

- Errors in ocean circulation initial conditions are primary source of uncertainties in ecosystem model forecasts