Regional Ocean Modeling of the South East Pacific - A data assimilation framework

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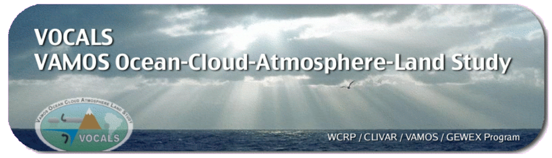
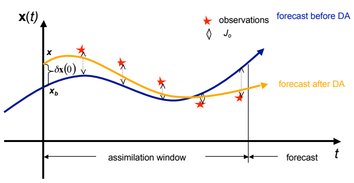


Motivation

To diagnose the dynamics and sensitivities of the ocean circulation fields using data assimilation experiments with observed mesoscale oceanic surveys of the VOCALS observations and a regional ocean modeling system.

Data assimilation, IS4DVAR

Incremental Strong Four-Dimensional Variational Analysis (IS4DVAR)



- We want to estimate a new state which is close to the observations, yet dynamically consistent.
- IS4DVAR corrects initial states only. However it is still able to estimate ocean states better.
- We use the cost function which is the combination of two terms – changes in the initial model states and residuals from observations. It is defined below.

$$J(\delta\mathbf{x}(0)) = \underbrace{\frac{1}{2}\delta\mathbf{x}(0)^T\mathbf{B}^{-1}\delta\mathbf{x}(0)}_{J_b} + \underbrace{\frac{1}{2}\sum_{i=1}^{N}\{\mathbf{H}_i(\mathbf{x}_i+\delta\mathbf{x}_i)-\mathbf{y}_i\}^T\mathbf{O}_i^{-1}\{\mathbf{H}_i(\mathbf{x}_i+\delta\mathbf{x}_i)-\mathbf{y}_i\}}_{J_o}$$

$\mathbf{x}$	Model states	i	Observation time step	N	Total # of observation time steps
$\delta\mathbf{x}$	Perturbation in model states	$\mathbf{y}$	Observations	$\mathbf{O}$	Observation error covariance
$\mathbf{B}$	Background error covariance	$\mathbf{H}$	Observation operator		

- The solution will minimize the cost function. This means that it will make both the residuals and the changes in the initial states small.
- Therefore, the solution for $\delta\mathbf{x}(0)$ satisfies $\nabla_{\delta\mathbf{x}}J = \mathbf{B}^{-1}\delta\mathbf{x}(0) + \sum_{i=1}^{N}\mathbf{H}_i^T\mathbf{O}_i^{-1}(\mathbf{H}_i(\mathbf{x}_i+\delta\mathbf{x}_i)-\mathbf{y}_i) = 0$

ROMS IS4DVAR (Regional Ocean Modeling System Incremental Strong Constraint 4DVAR)

- Free-surface, hydrostatic, primitive equation ocean model. [1]
- Terrain-following vertical coordinates. [1]
- Orthogonal curvilinear horizontal coordinates. [1]
- It corrects initial ocean state to minimize the cost function while remaining physically balanced.
- It assumes that the model dynamics are good so that no artificial terms disrupt physically balanced model.
- Therefore it does not include model errors (Strong constraint).

[1] Haidvogel, D. B., H. G. Arango, K. Hedstrom, A. Beckmann, P. Malanotte-Rizzoli, and A. F. Shchepetkin (2000), Model evaluation experiments in the North Atlantic basin: Simulations in nonlinear terrain-following coordinates, *Dyn. Atmos. Oceans*, 32, 239– 281

Adjoint Sensitivity

- Consider a model state vector described as $\Phi = (u, v, T, S, \varsigma)^T$.
- A cost function $J(\Phi)$ is defined as a function of the state vector Φ.
- Small changes $\delta\Phi$ in Φ will reflect as changes δJ in J.

$$\delta J = \left(\frac{\partial J}{\partial u}\right)\delta u + \left(\frac{\partial J}{\partial v}\right)\delta v + \left(\frac{\partial J}{\partial T}\right)\delta T + \left(\frac{\partial J}{\partial S}\right)\delta S + \left(\frac{\partial J}{\partial \varsigma}\right)\delta\varsigma$$

- Adjoint sensitivity can be defined as:

$$u^\dagger = \left(\frac{\partial J}{\partial u}\right),\ v^\dagger = \left(\frac{\partial J}{\partial v}\right),\ T^\dagger = \left(\frac{\partial J}{\partial T}\right),\ \text{etc}$$

- Hence it can be shown that the solution of the adjoint system also represents the system's sensitivity

$$\Phi^\dagger = (u^\dagger, v^\dagger, T^\dagger, S^\dagger, \varsigma^\dagger)^T$$

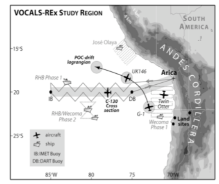
Surface adjoint sensitivity of the South East Pacific ocean domain in an adjoint sensitivity test case was run for 90 days to test the sensitivity of the coastal region to surrounding coastal flows. Sensitivity to strong coastal upwelling and the Humboldt current was evident from the simulations.

Model settings and Observations

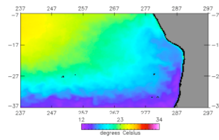
Model grid and settings

- VOCALS-Rex Study Region (13S~27S, 69W~90W)
- Wind forcing – QuikSCAT climatology and QuikSCAT annual wind stress data.
- Heat flux – COADS climatology or NCEP annual data.
- Freshwater flux – COADS climatology.
- Boundary condition – Radiation condition [2] with 3 degree sponge layer and nudging to the climatology for open boundary [2]
- 1/15° resolution for zonal and meridional directions (about 7.5 km)
- 32 vertical levels
- 7 years climatological spin-up and then annual forcing with 2005-06 winds from QuikSCAT.

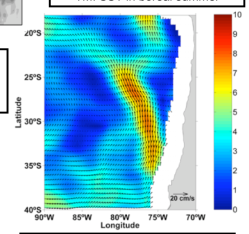
Observations



VOCALS-Rex study region and key platforms/components. Proposed ship cruise track of Nov 2008 is shown here.



TMI SST in boreal summer



Surface Geostrophic Velocities in austral summer from observations [3].

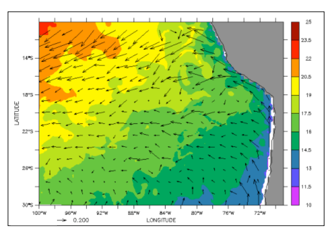
Data assimilation experiments

- Data assimilation of VOCALS cruise time intervals can be achieved using the inverse ROMS, a 4D variational data assimilation system for high-resolution basin-wide and coastal oceanic flows [2]
- Assimilation can be performed either under the perfect model assumption (strong constraint) or by also allowing errors in the model dynamics (weak constraint).
- Sensitivity of the South East Pacific ocean circulation is studied using adjoint tracer calculations.
- Sensitivity studies also imply the possible impacts of the various datasets will have in data assimilation experiments and also significantly indicate the predictability of the model.

[2] Di Lorenzo, E., Moore, A., H. Arango, Chua, B. D. Cornuelle, A. J. Miller, B. Powell and Bennett A., 2007: Weak and strong constraint data assimilation in the inverse Regional Ocean Modeling System (ROMS): development and application for a baroclinic coastal upwelling system. *Ocean Modeling*, 16 (3-4): 160-187.
[3] Fuenzalida, R., Schneider, W.,Vargas,J. G., and Bravo, L., 2008: Satellite altimetry data reveal jet-like dynamics of the Humboldt Current. *Journal Of Geophysical Research*, Vol. 113

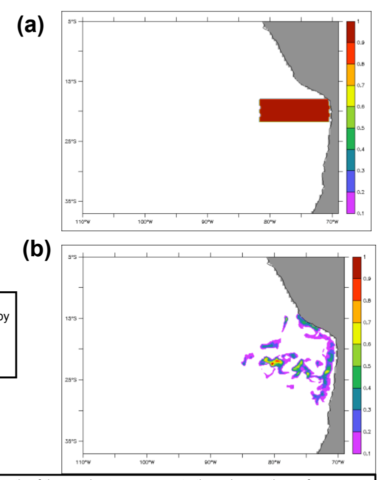
Model Results

20 km resolution Model



Sea Surface Temperature (SST) and Surface velocities in May simulated in a coarse resolution ROMS model forced by monthly winds of 2006.

The mesoscale eddy fields are simulated although not at a high resolution.



(a) Initial state and (b) 90 day prior to the initial state percent ratio of the passive tracer concentrations close to the surface indicating a bifurcation in the jet-like structure of the Humboldt current.

Goals

- Data assimilation "fits" of the VOCALS hydrographic surveys (and concomitant data) will provide crucial dynamically consistent diagnostics of the circulation for interpreting the relation between physical variables, atmospheric variables and biology.
- Associated with the data assimilation platform of Inverse ROMS is a suite of Generalized Stability Analysis tools which will allow the quantitative assessment of sensitivities of model solutions to various parameters, such as upstream ocean forcing, topography, winds, heat fluxes.

Summary

ROMS eddy resolving high resolution coastal ocean model in the Peruvian Current system was setup forced by satellite derived winds and estimated heat fluxes. This high resolution ROMS coastal model is nested in a coarser resolution model to have a more consistent boundary condition. Further tests in adjoint sensitivity of this region needs to be performed to understand the regional dynamics better of the VOCALS region, before data assimilation is embarked upon.