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)

- 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 retaining 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).

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

- Model states
- Perturbation in model states
- Background error covariance
- Observation error covariance
- Observation operator
- Observation time step
- Observation error time step
- Total # of observation time steps
- Observation time steps
- Background states
- Analysis states
- Forecast states
- Observations
- Assimilation window

Adjoint Sensitivity

- Consider a model state vector described as \( \Phi = (u, v, T, S, c)^T \).
- A cost function \( J(\Phi) \) is defined as a function of the state vector \( \Phi \).
- Small changes \( \delta \Phi \) in 4DVAR (\( \delta \Phi = \delta u, \delta v, \delta T, \delta S, \delta c \)) will reflect as changes \( \delta J \) in the function:
  \[
  \delta J = \left( \frac{\partial J}{\partial u} \right) \delta u + \left( \frac{\partial J}{\partial v} \right) \delta v + \left( \frac{\partial J}{\partial T} \right) \delta T + \left( \frac{\partial J}{\partial S} \right) \delta S + \left( \frac{\partial J}{\partial c} \right) \delta c
  \]
- Adjoint sensitivity can be defined as:
  \[
  s^* = \left( \frac{\partial J}{\partial u} \right)^T, \quad v^* = \left( \frac{\partial J}{\partial v} \right)^T, \quad T^* = \left( \frac{\partial J}{\partial T} \right)^T, \quad S^* = \left( \frac{\partial J}{\partial S} \right)^T, \quad c^* = \left( \frac{\partial J}{\partial c} \right)^T
  \]
- Hence it can be shown that the solution of the adjoint system also represents the system’s sensitivity
  \[
  \Phi^* = (u^*, v^*, T^*, S^*, c^*)
  \]

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-Flex Study Region (135-275, 90W-60W)
- Wind forcing – QuikSCAT climatology and QuikSCAT annual wind stress data.
- Heat flux – COADS climatology or NCEP annual data.
- Freshwater flux – COADS climatology.
- 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.

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 evaluate the predictability of the model.

\[ J(\Phi) = \frac{1}{2} \sum \left( \mathbf{b}(t) - \mathbf{S} \Phi(t) \right)^T Q^{-1} \left( \mathbf{b}(t) - \mathbf{S} \Phi(t) \right) \]

\[ \Phi^* = \left( \frac{\partial J}{\partial \Phi} \right)^T = \left( \frac{\partial J}{\partial \mathbf{b}} \right) \left( \frac{\partial \mathbf{b}}{\partial \Phi} \right)^T = \mathbf{S}^T Q^{-1} \left( \mathbf{b} - \mathbf{S} \Phi \right) \]

\[ \frac{\partial \mathbf{b}}{\partial \Phi} = \mathbf{S} \]

\[ \frac{\partial J}{\partial \mathbf{b}} = \left( \mathbf{b} - \mathbf{S} \Phi(t) \right) \]

Observations

- Surface Geostrophic Velocities in coastal summer from observations [1]
- Sea Surface Temperature (SST) and Surface velocities in coastal summer from observations [1]
- Wind forcing – QuikSCAT climatology
- QuikSCAT climatology
- COADS climatology or NCEP annual data.
- Heat flux – COADS climatology or NCEP annual data.
- Freshwater flux – COADS climatology.
- 1-15’ resolution for zonal and meridional directions (about 7.5 km)
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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.