EXERCISE 1: Incremental, Strong Constraint 4D-Var

Introduction

During this exercise you will apply the primal form of incremental strong constraint 4D-Var (I4D-Var) to ROMS configured for the U.S. west coast and the California Current System (CCS). This configuration, lovingly referred to as WC13, has 30 km horizontal resolution, and 30 levels in the vertical. While 30 km resolution is inadequate for capturing much of the energetic mesoscale circulation associated with the CCS, WC13 captures the broad scale features of the circulation quite well, and serves as a very useful and efficient illustrative example of I4D-Var.

Model Set-up

The WC13 model domain is shown in Fig. 1 and has open boundaries along the northern, western, and southern edges of the model domain.
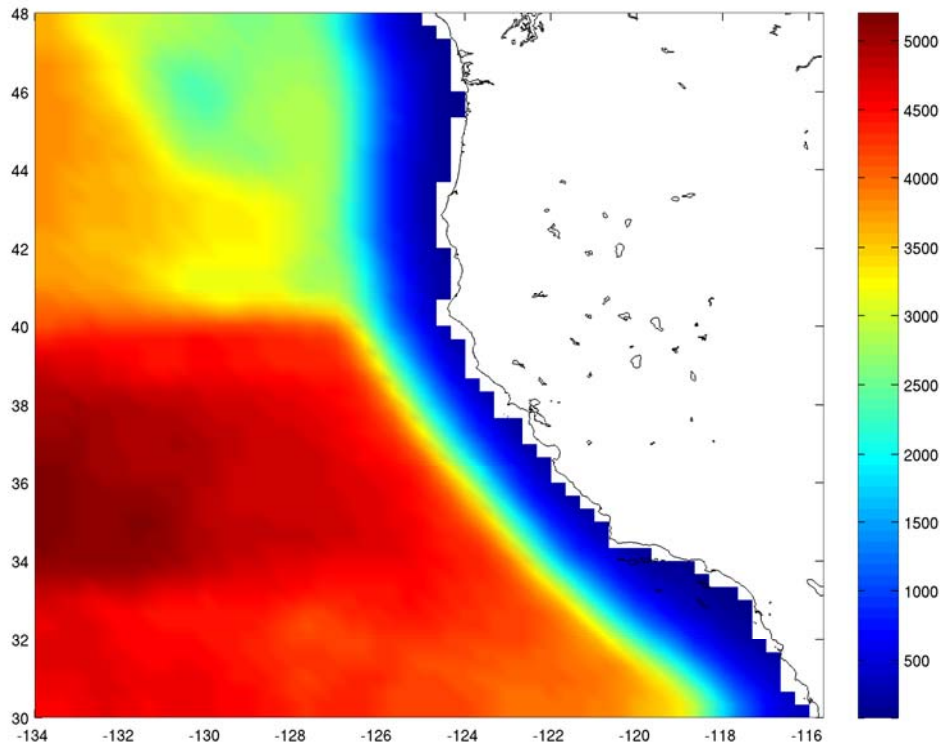

Figure 1: The model domain and bathymetry employed in WC13.

In this first example, you will perform an I4D-Var data assimilation cycle that spans the period 3-6 January, 2004. The I4D-Var control vector $\delta \mathbf{z}$ is comprised of increments to the initial conditions, $\delta \mathbf{x}(t_0)$, surface forcing, $\delta \mathbf{f}(t)$, and open boundary conditions, $\delta \mathbf{b}(t)$. The *prior* initial conditions, $\mathbf{x_b}(t_0)$, are taken from the sequence of I4D-Var experiments described by Moore *et al.* (2010) in which data were assimilated every 7

days during the period July 2002 – Dec. 2004. The *prior* surface forcing, $\mathbf{f_b}(t)$, takes the form of surface wind stress, heat flux, and a freshwater flux computed using the ROMS bulk flux formulation, and using near surface air data from COAMPS (Doyle *et al.*, 2009). Clamped open boundary conditions are imposed on (u,v) and tracers, and the *prior* boundary conditions, $\mathbf{b_b}(t)$, are taken from the global ECCO product (Wunsch and Heimbach, 2007). The free surface height and vertically integrated velocity components are subject to the usual Chapman and Flather radiation conditions at the open boundaries. The *prior* surface forcing and open boundary conditions are provided daily and linearly interpolated in time. Similarly, the increments $\delta\mathbf{f}(t)$ and $\delta\mathbf{b}(t)$ are also computed daily and linearly interpolated in time.
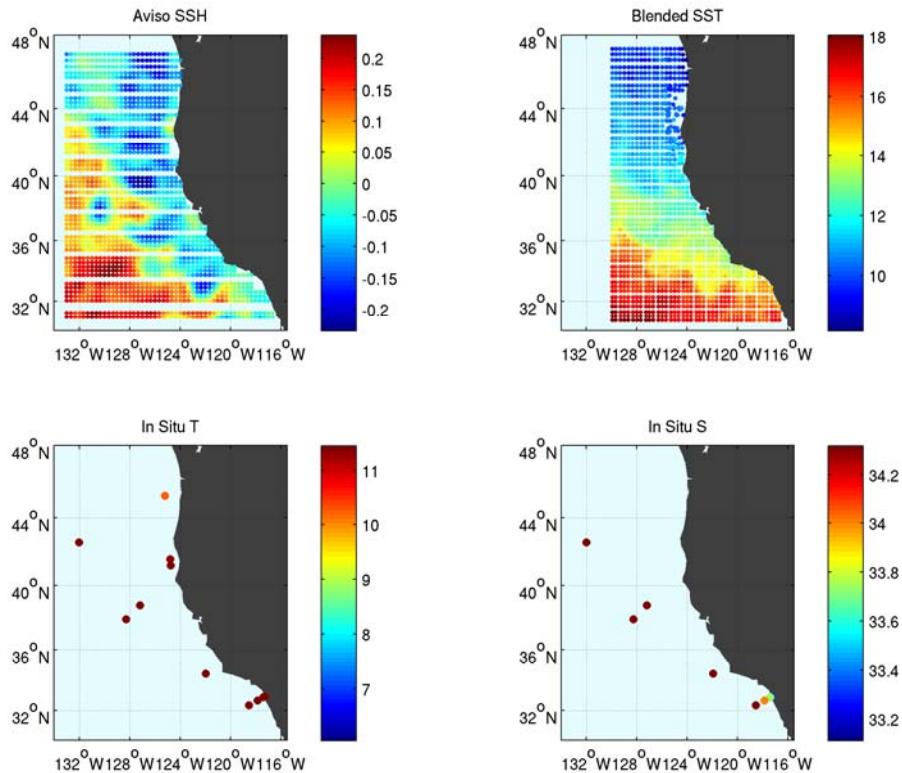

Figure 2: The location of the observations assimilated into the model during the period 3-6 Jan, 2004.

The observations assimilated into the model are satellite SST, satellite SSH in the form of a gridded product from Aviso, and hydrographic observations of temperature salinity collected from Argo floats and during the GLOBEC/LTOP and CalCOFI cruises off the coast of Oregon and southern California respectively. The observation locations are illustrated in Fig. 2.

Running I4D-Var

To run this exercise, go first to the directory **WC13/I4DVAR**. Instructions for compiling and running the model can be found in the **Readme** file.

The recommended configuration for this exercise is one outer-loop and 50 inner-loops, and **ocean_wc13.in** is configured for this default case. However, if you are running on a slow computer or have access to only a few processors, you may use 30 inner-loops instead, although we recommend that you do not use less than this since you will be comparing the I4D-Var solution to other solutions in later exercises. The number of inner-loops is controlled by the parameter *Ninner* in **ocean_wc13.in**.

Go ahead and run I4D-Var as described in the **Readme** file.

Plotting your results

Several Matlab scripts are provided in the directory **WC13/plotting** which will allow you to plot some of the I4D-Var output.

Recall that I4D-Var minimizes the cost function given by:

$$J = \frac{1}{2}\delta\mathbf{z}^{\mathrm{T}}\mathbf{D}^{-1}\delta\mathbf{z} + \frac{1}{2}\left(\mathbf{G}\delta\mathbf{z} - \mathbf{d}\right)^{\mathrm{T}}\mathbf{R}^{-1}\left(\mathbf{G}\delta\mathbf{z} - \mathbf{d}\right) = J_b + J_o$$

Plot first the I4D-Var cost function J and its components J_b, J_o and the theoretical minimum value $J_{min} = N_{obs}/2$ using **plot_i4dvar_cost.m**.

Next, plot the surface initial condition increments $\delta\mathbf{x}(t_0)$ and the surface forcing increments $\delta\mathbf{f}(t)$ at initial time using **plot_i4dvar_increments.m**.

References

Doyle, J.D., Q. Jiang, Y. Chao and J. Farrara, 2009: High-resolution atmospheric modeling over the Monterey Bay during AOSN II. *Deep Sea Res. II*, **56**, 87-99.

Moore, A.M., H.G. Arango, G. Broquet, C.. Edwards, M. Veneziani, B.S. Powell, D. Foley, J. Doyle, D. Costa and P. Robinson, 2010b: The Regional Ocean Modeling System (ROMS) 4-dimensional data assimilation systems: Part II – Performance and application to the California Current System. *Ocean Modelling*, Submitted.

Wunsch, C. and P. Heimbach, 2007: Practical global ocean state estimation. *Physica D*, **230**, 197-208.