Progress Towards ECCO2 Project: A First Optimization

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1. Introduction

A robust and comprehensive set of ocean state synthesis is important for ocean and climate study, such as mean and variability of Antarctic Circumpolar Current (ACC), meridional overturning circulation (MOC), and sea surface height (SSH). Previous ocean state estimates exist but they are not sufficient for such study. For example, some are configured on coarse resolution while others are not global. ECCO2 project aims to produce increasingly accurate, physically consistent synthesis of all available global-scale ocean and sea-ice data at resolutions fine enough to resolve ocean eddies and narrow current systems. At current stage, we calibrate a small number of control variables using Green's function approach. By combining different perturbation experiments we minimize the overall misfits between model and observation and generate a preliminary synthesis of ocean state estimates which are consistent with both the model physics and the global data.

2. Methodology

Generally the ocean state estimates are obtained by combining all the diverse ocean observations (including satellite observation of SSH and in-situ measurements of hydrography of temperature and salinity) with theoretical knowledge of ocean circulation (embodied in numerical ocean circulation model). Rigorous global ocean state estimation methods are required to produce time-varying model/data synthesis. Here we use Green's function to calibrate a small number of key model parameters. The key machinery is:

GCM: $$\mathbf{x}(t_i+1) = M[\mathbf{x}(t_i), \boldsymbol{\eta}] \quad (1)$$

Data: $$y^o = H[\mathbf{x}] + \boldsymbol{\varepsilon} = G[\boldsymbol{\eta}] + \boldsymbol{\varepsilon} \quad (2)$$

Cost function: $$J = (\boldsymbol{\eta} - \boldsymbol{\eta}^b)^T \mathbf{Q}^{-1} (\boldsymbol{\eta} - \boldsymbol{\eta}^b) + \boldsymbol{\varepsilon}^T \mathbf{R}^{-1} \boldsymbol{\varepsilon} \quad (3)$$

Linearization: $$y^o - G[\boldsymbol{\eta}^b] = \mathbf{G}(\boldsymbol{\eta} - \boldsymbol{\eta}^b) + \boldsymbol{\varepsilon} \quad (4)$$

The detail can be referred to Wunsch (1996) and Menemenlis et al. (2005a). Here we only give a brief introduction of each term in the above equations. A general circulation model (GCM) can be written as Equation (1) where $\mathbf{x}(t_i)$ is the state vector. M represents the full non-linear operator stepping the model forward from a prescribed initial condition $\mathbf{x}(t_0)$ and $\boldsymbol{\eta}$ represents the model parameters that can be used as "controls" to bring the GCM simulation closer to observations. For ocean GCM, vector $\boldsymbol{\eta}$ includes initial conditions, boundary conditions, and internal model parameters such as mixing coefficient. On the other hand, most oceanography measurements y^o are approximately a linear combination of the model state vector $\mathbf{x}(t_i)$ but are contaminated by noise $\boldsymbol{\varepsilon}$, which is the first part of Equation (2) where H relates the model state vector $\mathbf{x}(t)$ to observations y^o. An estimated $\boldsymbol{\eta}$ is obtained by minimizing the model/data misfits (Equation 3), where $\mathbf{R}$ is the observational error covariance and $\mathbf{Q}$ is the error covariance in parameter space. For the Green's function approach, $\boldsymbol{\eta}$ is related to measurement by G, the convolution of M and H (the second part of Equation 2). By minimizing the cost function (Equation 3) and assuming linearity of the model (Equation 4, where $\mathbf{G}$ is the Green's function computed using a GCM sensitivity experiment for each parameter in vector $\boldsymbol{\eta}$), we obtain the optimal parameter $\boldsymbol{\eta}$. Then we could put this set of parameters into the model to generate an optimized ocean state.

3. Results

3.1 Model and Experiments

The model is based on the MITgcm (see http://mitgcm.org). It is configured on cubed-sphere (see Menemenlis et al 2005b) with horizontal resolution of 18km and vertical resolution raging from 10 m near surface to 500 m near bottom (50 levels). There are 48 forward sensitivity experiments performed, of which 26 are chosen to generate this optimized solution. They are classsified into 3 groups:

- internal model parameters
  - horizontal viscosity, vertical viscosity, vertical diffusivity, albedo, critical Richardson number, sea-ice model parameters
- initial conditions
  - initial conditions of temperature/salinity from WOA01/WGHC/spin-ups
- boundary conditions
  - surface forcing from NCEP/ERA40/CORE
  - Sea Surface Salinity (SSS) relaxation timescale

The current optimization only covers WOCE Global Hydrography Climatology (WGHC) and only integrates from 1992 to 2002. In future we will incorporate more data sets and extend the integration time span to decadal time scale.

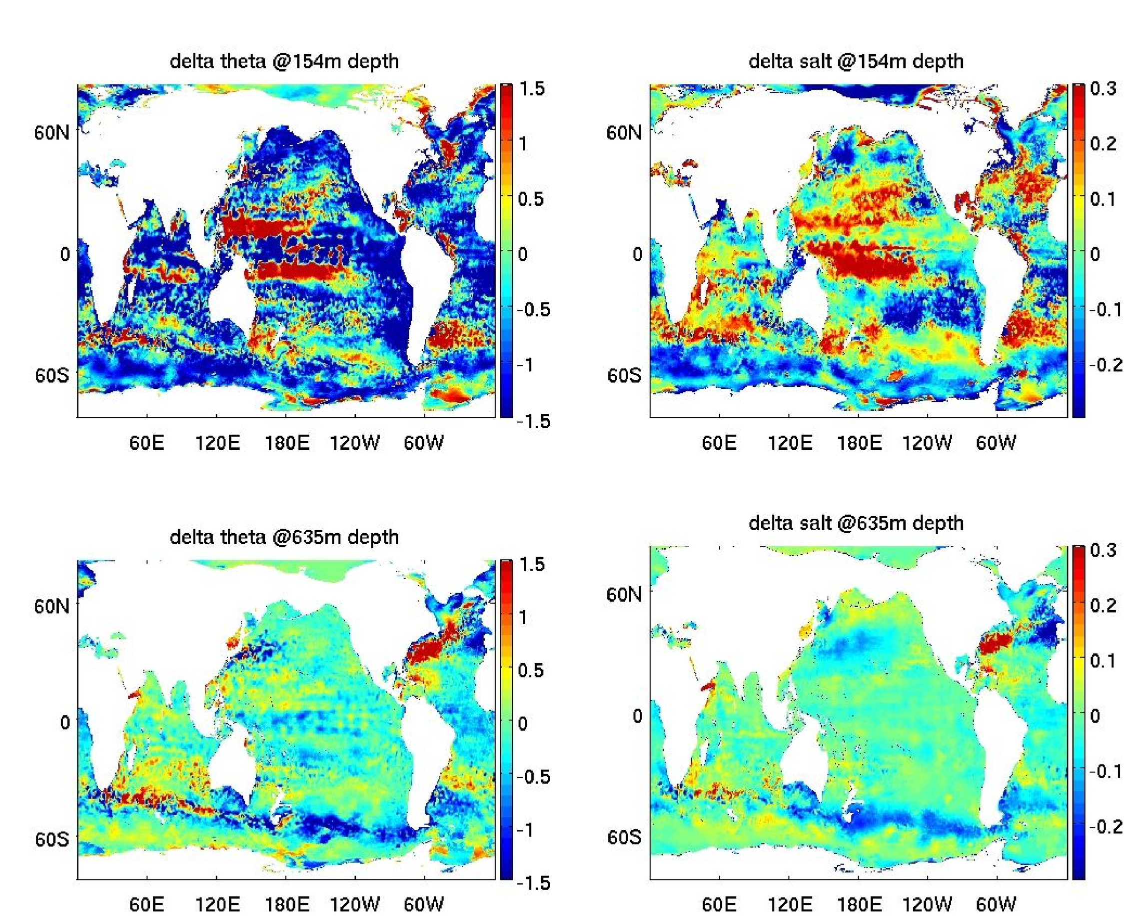

Fig 1. Adjustments in initial temperature (°C) and salinity (psu) at depth of 154 m and 635 m, respectively. Left column for temperature and right column for salinity.

3.2 Corrections in Initial Conditions and Boundary Conditions

Based on Green's function approach, an optimal set of parameters is obtained, including the initial conditions and boundary conditions. The initial conditions are the optimal linear combination of WOA01, WGHC and several spin-ups. Fig 1 shows the difference of optimal initial temperature and salinity with respect to the baseline. The adjustment is more significant at shallower depth. It becomes smaller with depth. At about 600 m depth, it is mainly distributed in Gulf Stream and ACC region. Fig 2 compares several boundary conditions for optimized and baseline integrations. It shows the mean difference (over 12 years) for the boundary conditions of surface air temperature, longwave radiation, and near-surface winds. Compared with the baseline, the optimal surface air temperature is warmer at high latitudes, the longwave radiation is more intense at high latitude and weaker at low latitude, the zonal wind is stronger in Southern ocean and weaker near equator, and the meridional wind is stronger in Southern ocean and near

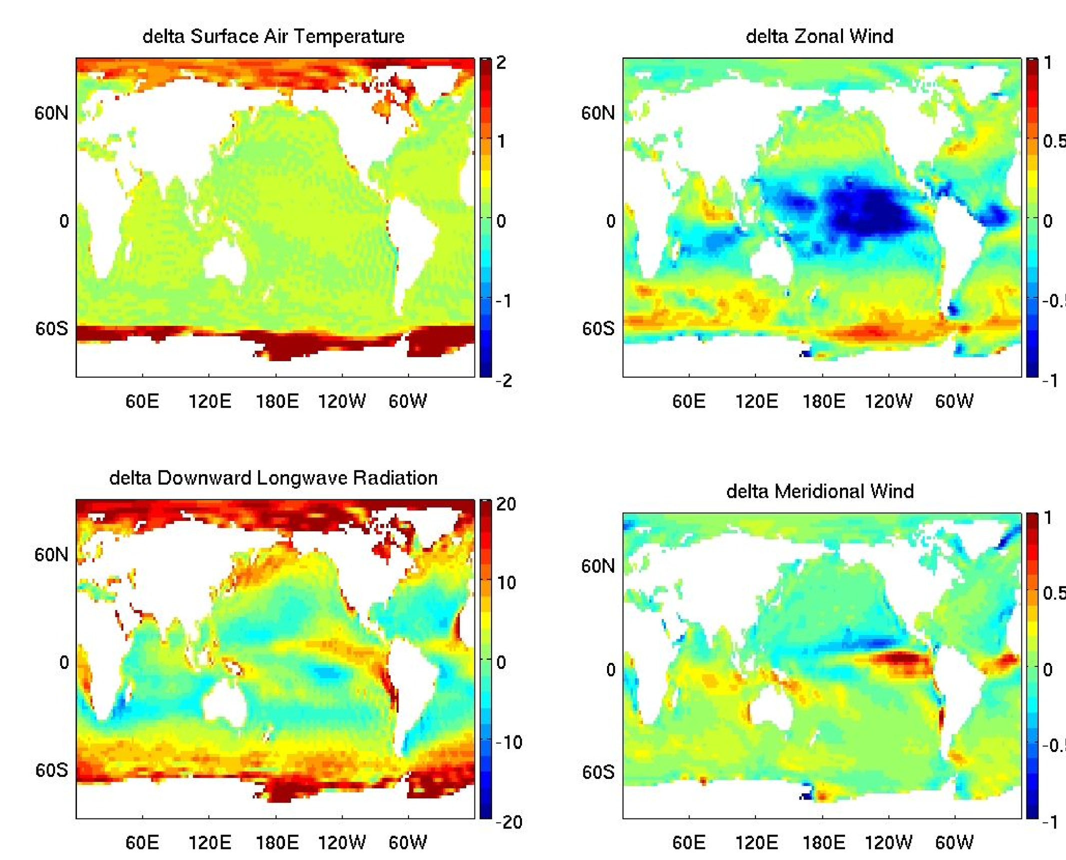

Fig 2. Mean adjustments in Surface Air Temperature (°C), zonal wind (m/s), downward longwave radiation (W/m^2), and meridional wind (m/s).

3.3 Mean state of hydrography

The optimized solution has significant improvement in temperature and salinity fields. Fig 3 shows that for the baseline the top 700 m is too warm everywhere and too salty in the Arctic and southern ocean with respect to WGHC climatology while the optimized solution is much closer to the WGHC climatology data. The overall cost function which measures the misfit between model and observation has reduced 64%. Fig 4 and Fig 5 further illustrate that the optimized solution is much better, especially for the temperature field.. Fig 4 compares the vertical hydrography profile along equator and Fig 5 for the Atlantic ocean along 40W. However, the salinity field in North Atlantic has little improvement in comparison to the baseline.

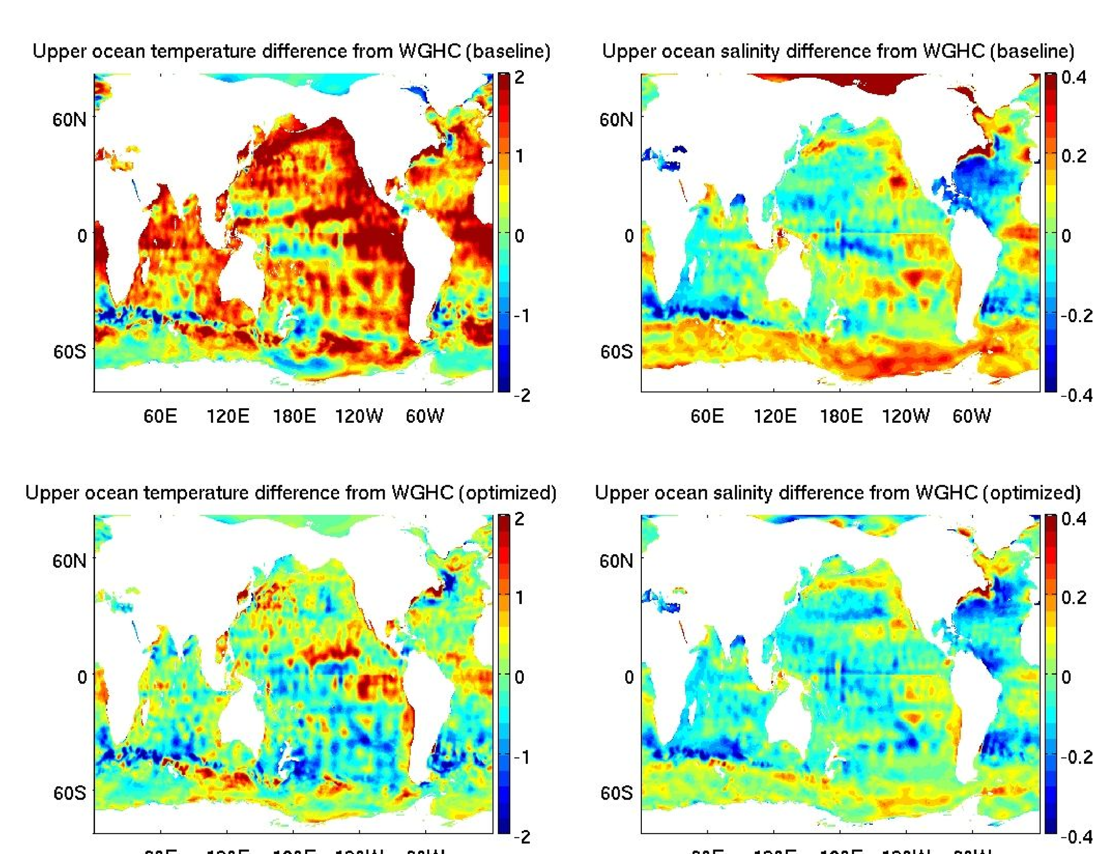

Fig 3. Difference of climatology temperature (°C) and salinity (psu) with respect to WGHC data. Left column for temperature and right column for salinity. Upper row for baseline integration and bottom row for optimized solution.

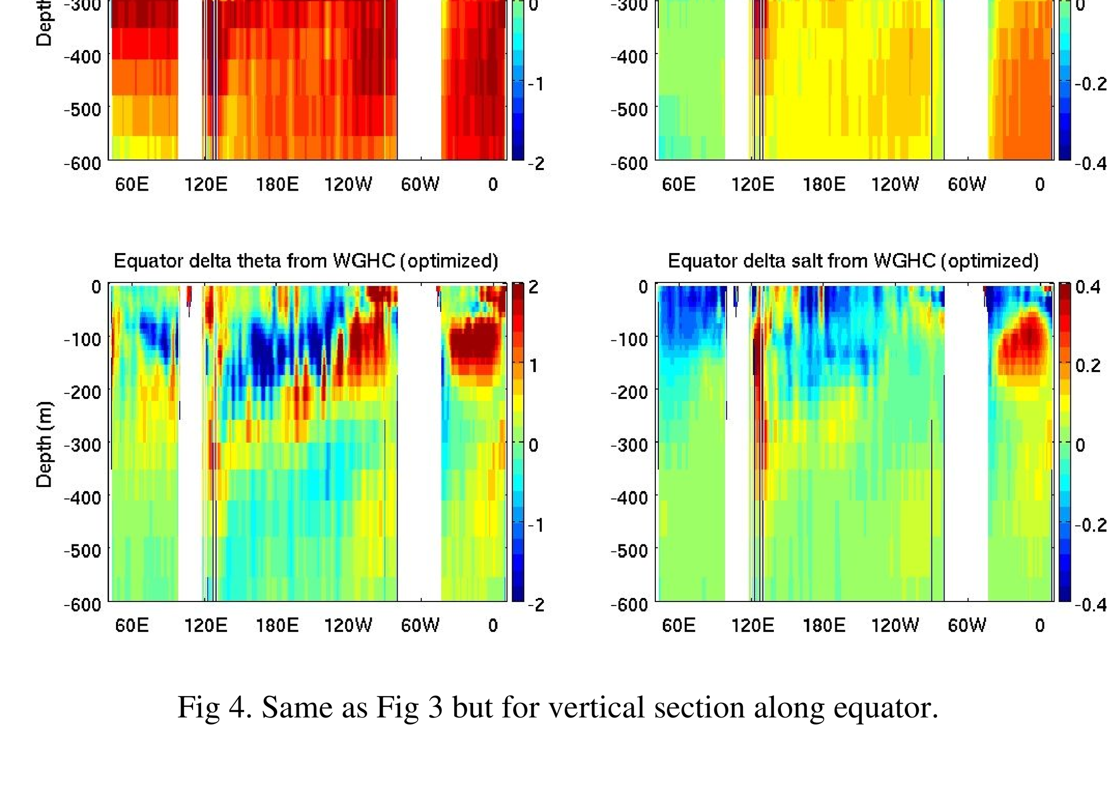

Fig 4. Same as Fig 3 but for vertical section along equator.

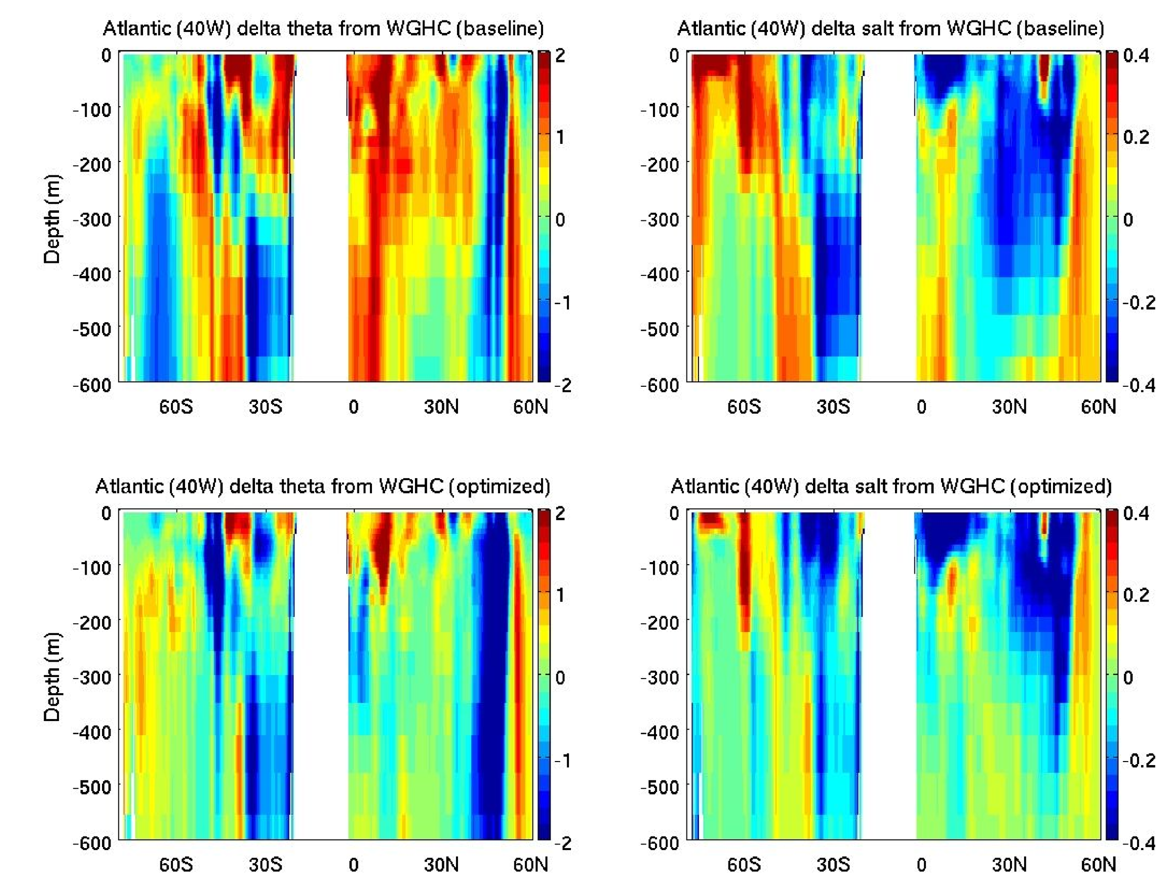

Fig 5. Same as Fig 3 but for vertical section of North Atlantic along 40W.

3.4 Mean and variability of SSH

Fig 5 shows on global scale the mean SSH and its variability and associated difference from the baseline. The ACC circulation becomes weak in comparison to the baseline

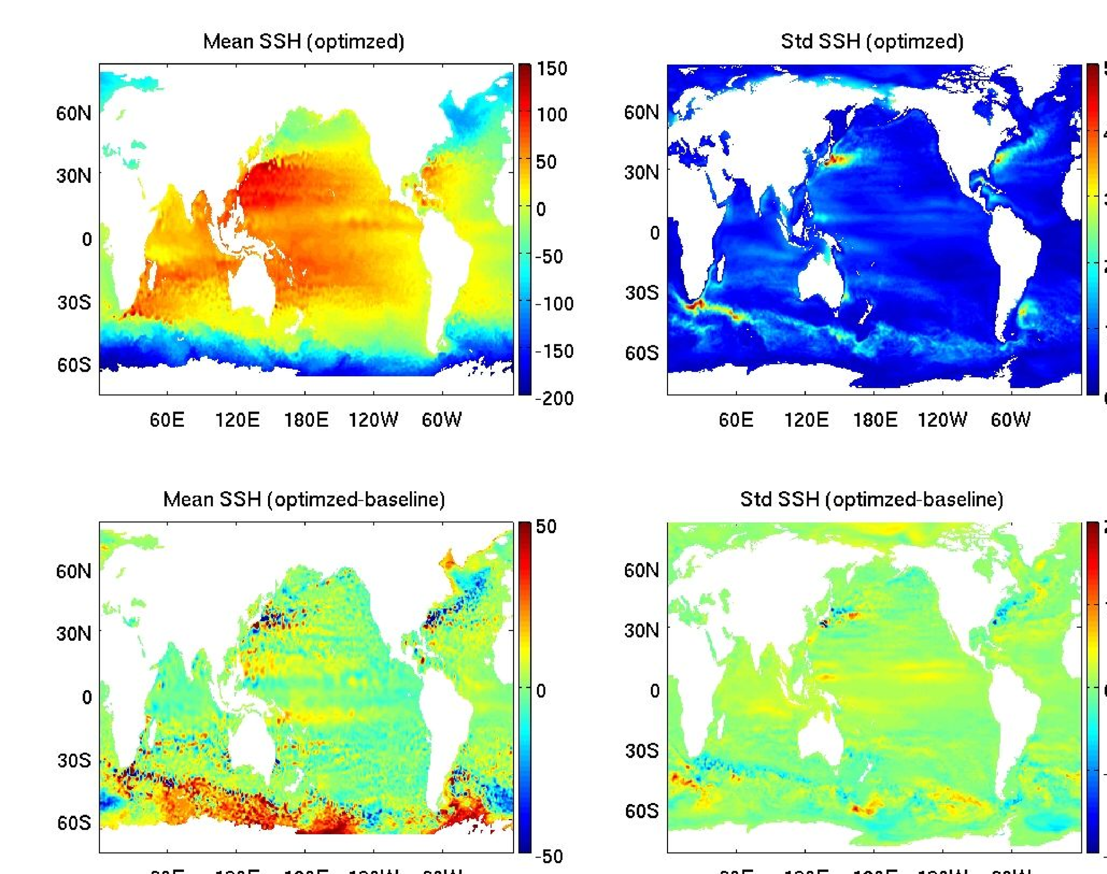

Fig 6. Upper row: mean and std of SSH (cm); bottom row: difference between optimized and baseline solutions.

3.5 Mean current

Fig 5 shows one particular current from the global ocean circulation: the Gulf Stream and North Atlantic current (top 200m) and the deep western boundary current (about 2000m depth). The adjustments in the upper ocean lead to a colder subtropical gyre, while in

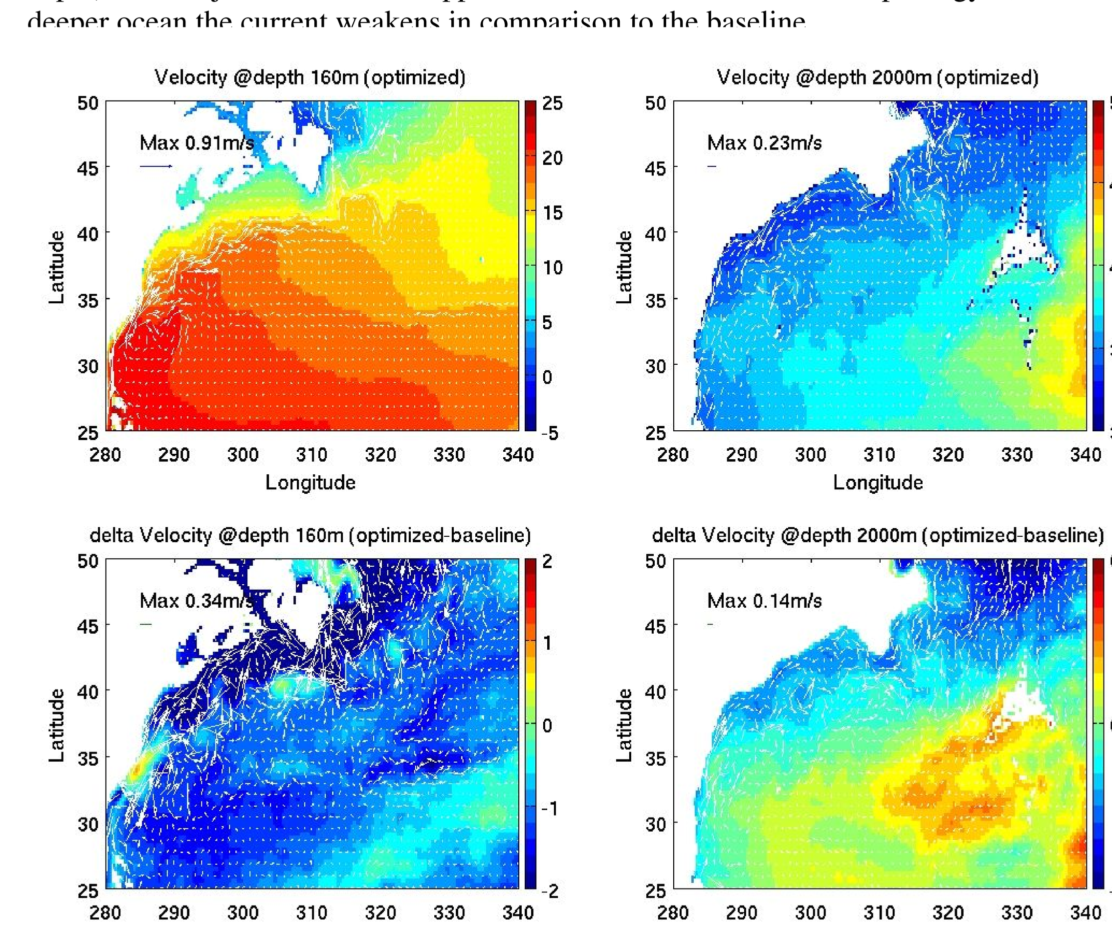

Fig 7. Velocity at 160 m and 2000 m depth over temperature fields (°C) from optimized solution (upper row) and changes with respect to the baseline (bottom row).

4. Concluding Remarks

- The preliminary optimization based on Green's function approach brings the model closer to the WGHC climatology. The overall cost function reduction reaches 64%;
- However, there are many deficiencies in this news solution, as shown in the above figures. Based on this optimization, 20 more sensitivity experiments have been carried out. For the next optimization, we will include these new integrations, incorporate more data constraints (like satellite altimetry data), and extend integration period to cover decadal timescales.

References

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