Parameter estimation for data assimilation with a coupled ocean-atmosphere system

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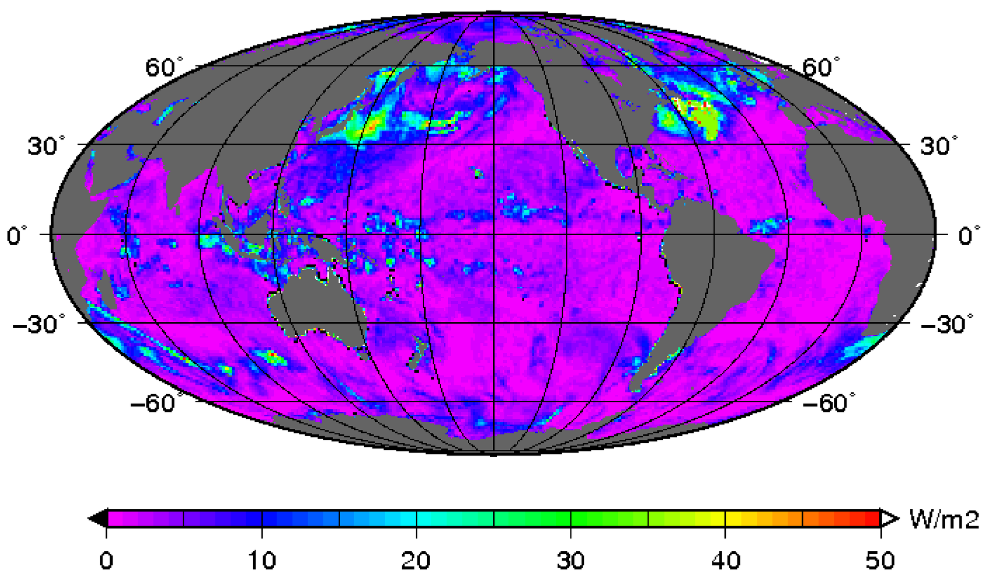
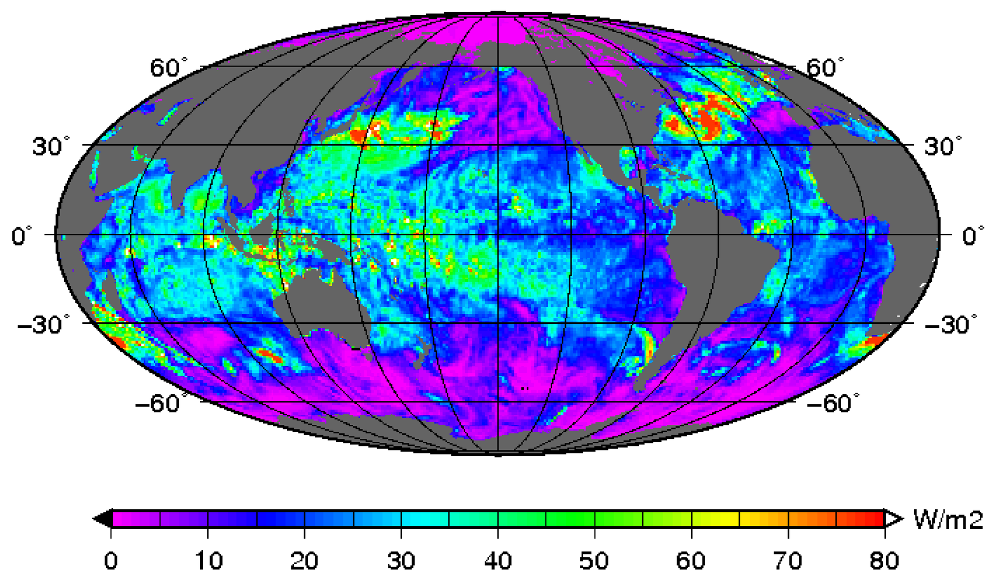
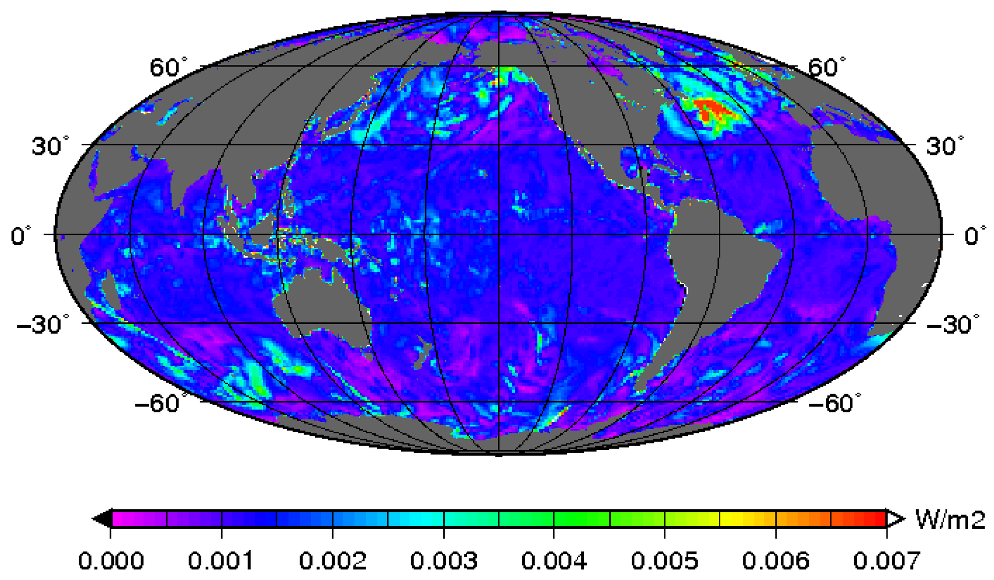
This project is concerned with the accurate estimation of global circulation within a coupled ocean-atmosphere model. The objective is to examine the impact of coupling the ocean to an atmospheric model on the quality of forecasts from the short to seasonal and interannual timescales. The studies of MJO, ENSO phenomenon, sea-ice interaction and even tropical cyclones also could be tackled within a coupled model framework. The application of data assimilation methods to a coupled system may be beneficial with respect to two aspects. First, data assimilation is driven by short-term forecasts from the coupled model and maintains the system trajectory close to the observations by modifying the model state according to the statistical estimation principles underlying the assimilation. As the coupled system introduces unknown parameters to represent heat, moisture and momentum surface flux exchanges between the ocean and the atmosphere, the assimilation can also use observations to estimate unknown parameters used to model these fluxes. This can be useful to improve the processes of ocean-atmosphere interaction and to reduce biases in the coupled model. A coupled ocean-atmosphere data assimilation system is currently being developed within the GOAPP research network. The atmospheric component is the 4D-Var assimilation scheme driven by the Global Environmental Model, used operationally by Environment Canada. This is coupled to the global NEMO model with its own 3D-Var data assimilation component. The coupled system is using a 6-h assimilation window. As a first step to building this system, the atmospheric 4D-Var data assimilation component is forced by ocean SST, and the turbulent transfer coefficients of heat and momentum are estimated and compared to independent estimates such as SURFA high-resolution NWP fluxes. A parameter estimation scheme is added to the 4D-Var by augmenting the state vector of the atmosphere with model parameters used in the parameterization of heat and momentum fluxes. In this presentation, results will be presented regarding the ability of the assimilation system to retrieve correctly the selected parameters from the available observations. The estimated parameters are then used in a fully coupled ocean-atmosphere system to replace traditional bulk formulation of the turbulent transfer coefficients used in the global NEMO ocean model.



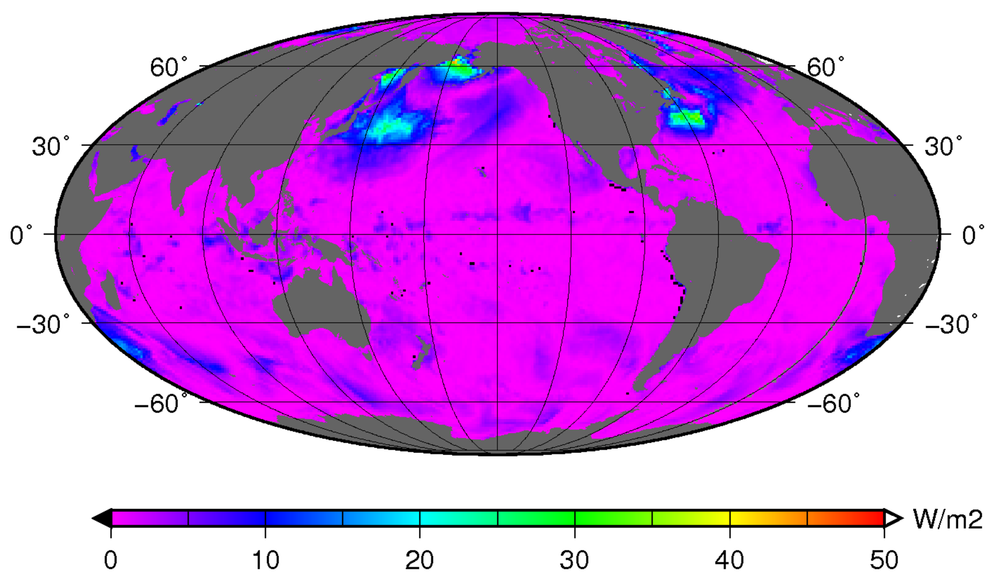
Sensible heat flux 6h variability



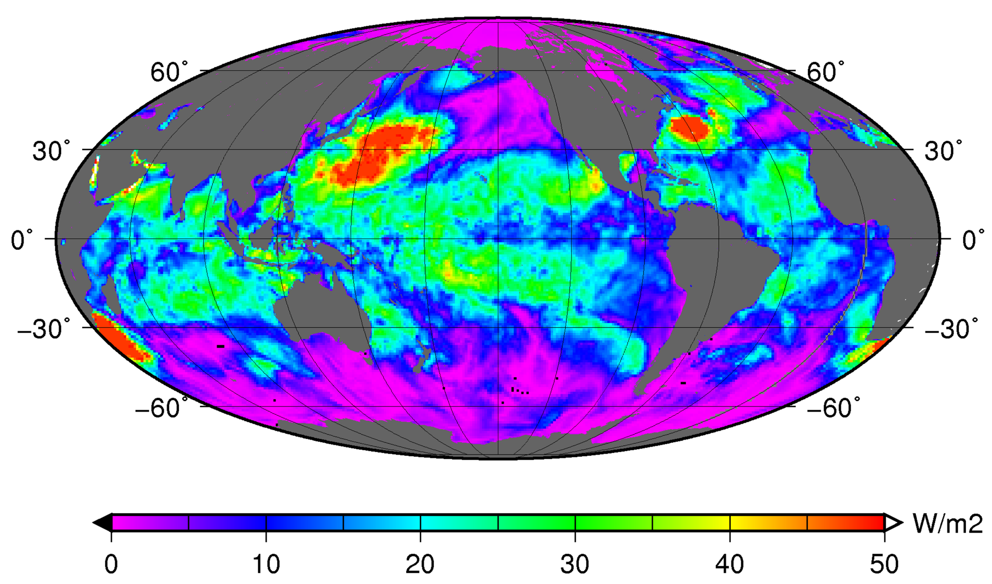
Latent heat flux 6h variability



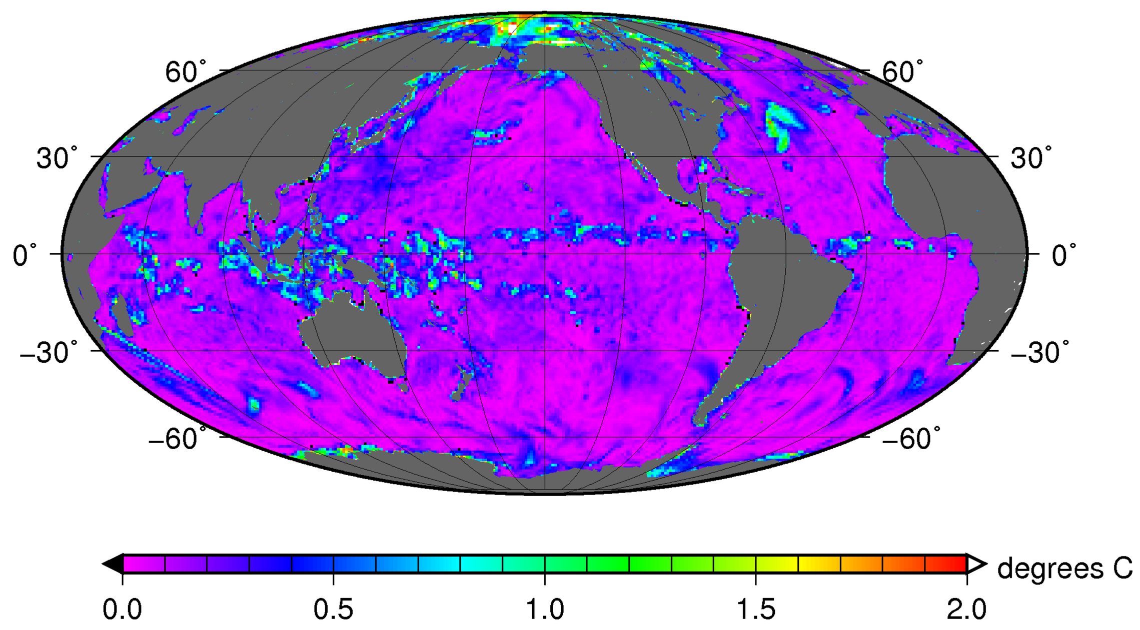
Heat flux transfer coefficient 6h variability



RMS. SURFA – GEM. FC



RMS. SURFA – GEM. FV



CE perturbation impact on T within 6h

Parameter estimation approach

The tendency due to turbulent diffusion is given by

$$\frac{\partial \psi}{\partial t} = -\frac{1}{\rho}\frac{\partial F_\psi}{\partial z}, \qquad (1)$$

where Ψ is the horizontal velocity component, temperature or humidity. F_ψ is the turbulent flux defined as:

$$F_\psi = -\rho K_\psi \left(\frac{\partial \psi}{\partial z} - \gamma_\psi\right), \qquad (2)$$

where K_ψ is the exchange coefficient. The fluxes vanish at the model top, while at the surface, they are consistent with:

$$F_\psi = -\rho C_\psi U (\psi_a - \psi_s) \qquad (3)$$

where C_ψ is the empirical surface exchange coefficient calculated using bulk formulation, U is the friction velocity and s and a indicate the surface and the closest model level respectively.

Let us consider the perturbation of C_ψ. The tangent linear model of (3) is then given by

$$\frac{\partial \delta F_\psi}{\partial t} = -\rho U \bar{C}_\psi \delta \psi_a - \rho U (\bar{\psi_a - \psi_s}) \delta C_\psi,$$

$$\frac{\partial \delta C_\psi}{\partial t} = 0$$

or with the finite-dirrerence approximation:

$$\begin{vmatrix} \delta F_\psi^{\,i+1} \\ \delta C_\psi^{\,i+1} \end{vmatrix} = -\rho U \begin{vmatrix} (1+\bar{C}_\psi^{\,i}) & \Delta t \bar{\Psi}_i \\ 0 & 1 \end{vmatrix} \cdot \begin{vmatrix} \delta F_\psi^{\,i} \\ \delta C_\psi^{\,i} \end{vmatrix}$$

Finally, the adjoint model with the finite-difference approximation is:

$$\begin{vmatrix} \delta' F_\psi^{\,i-1} \\ \delta' C_\psi^{\,i-1} \end{vmatrix} = -\rho U \begin{vmatrix} (1+\bar{C}_\psi^{\,i}) & 0 \\ \Delta t \bar{\Psi}_i & 1 \end{vmatrix} \cdot \begin{vmatrix} \delta' F_\psi^{\,i} \\ \delta' C_\psi^{\,i} \end{vmatrix} + \begin{vmatrix} \mathbf{d}_i \\ 0 \end{vmatrix},$$

where $\mathbf{d}_i = \mathbf{H}_i^T \mathbf{R}_i^{-1} (\mathbf{H}_i \mathbf{X}_i - \mathbf{Y}_i)$ is the observational increment at time t_i.

Conclusions and Perspectives

- Augmented vector approach within 4DVar data assimilation system was implemented into operational GEM-4DVar atmospheric data assimilation system to estimate model parameteres on the atmosphere-ocean interface;
- Preliminary experiments with only one parameter CE, gouverning the calculation of surface heat fluxes were done;
- Data assimilation system involving parameter estimation provides better analysis/forecast quality
- The question of how many parameters could be estimated at the same time should be studied ;

SUGIURA ET AL.: COUPLED DATA ASSIMILATION SYSTEM

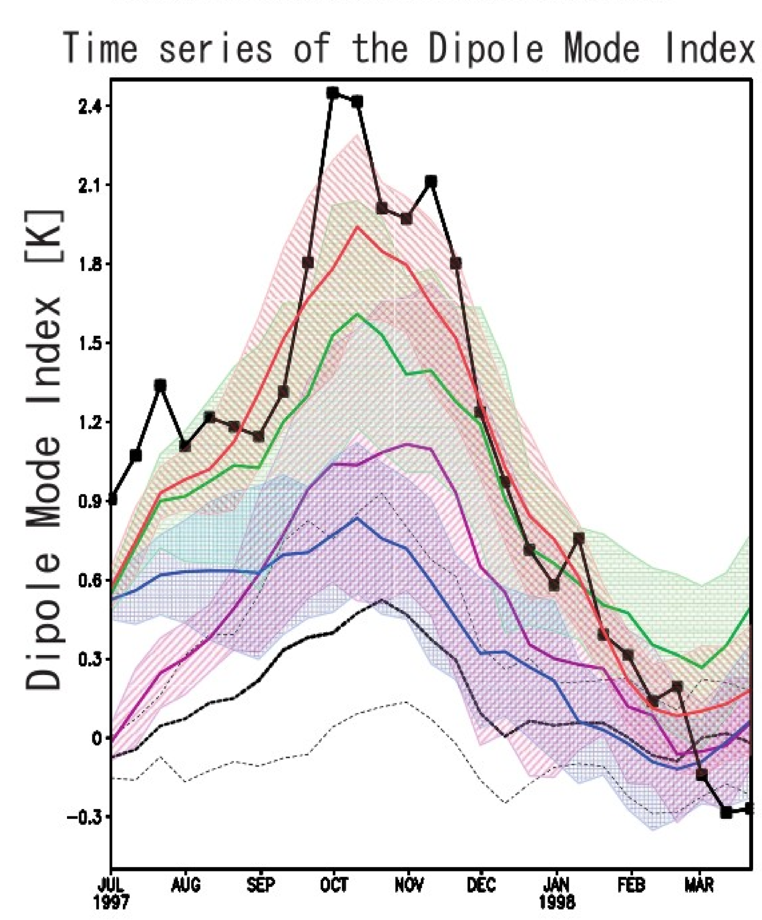


Figure 9. Time series of the Dipole Mode Index of the observation (black solid curve) and the ensemble means of the model runs (black dotted shows the first-guess field, red shows ANL, blue shows IC, purple shows PRM, and green shows IC + PRM). Hatched regions indicate ensemble spreads.