**Slab Ocean Model Forcing**

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This document is intended as a brief scientific description or white paper on the Slab Ocean Model formulation in CCSM4.

**1. CAM-SOM** (i.e. the "old" way)

The method for performing a SOM simulation in the CAM-SOM framework involved calculating the ocean heat transport, or Q-fluxes from an existing CAM simulation with prescribed SST, sea ice extent, and thickness. As with a CAM simulation the intention was to reproduce the *observed* climate, but with the timescale damping effect of a mixed-layer ocean. So-called Q-fluxes were created and used in a SOM simulation in order to recreate the surface flux imbalances seen in the CAM simulation such that the annual cycle of surface temperatures followed that of the prescribed conditions from a CAM simulation. The Q-fluxes were generated from an assumption about the mixed layer depth of the form:

$$Q_{flx} = F_{net} - \rho c_p h_{mix} \frac{dSST}{dt}. \qquad (1)$$

In this case $h_{mix}$ was an estimate of the observed annual mean mixed layer ocean depth, $dSST/dt$ was the change in the sea surface temperature (SST) and $F_{net}$ was the surface net energy balance obtained from a control CAM simulation ($F_{net} = SW - LW - LH - SH$). This method has been the standard procedure for running a SOM and performing climate sensitivity experiments for many years. However, there were a number of drawbacks to this methodology that lead us toward a new approach as we transition the sea-ice model from CSIM to CICE. The greatest difficulty in the above equation was the absence of model information as to the magnitude of fluxes between the ice and ocean. Given the best estimate of the observed monthly variability in ice-fraction an extra flux was added to $F_{net}$ in order to provide a stable ice simulation. This difficulty arose due to the absence of any such information from the CAM run which uses prescribed SST, ice-thickness and ice areal coverage. These additional fluxes were somewhat arbitrary, non-conservative and heavily dependent on the sea-ice model used to determine the thermodynamic evolution of the ice in CAM. The sea-ice model typically used in the CAM-SOM runs was thermodynamic-only and of limited use for polar studies. For these reasons we are opting to switch to a different SOM paradigm.

**2. CCSM-SOM** (i.e. the "new way")

Although the above method aims to reproduce the observed climate mixed layer ocean the Q-fluxes are clearly dominated by the model climate biases. Using the CCSM-SOM method is arguably a more valid approach. Performing a SOM simulation in the CCSM-SOM framework differs from the above methodology in three significant ways: Firstly, the aim is to reproduce the coupled climate of the model as opposed to the observed climate. Secondly, the SOM integrations are designed to use the full sea ice model (CICE). Thirdly, the fully-conservative information about ice-ocean fluxes necessary to obtain the Q-flux (and if desired ice tilt terms and ocean currents) is obtained from a coupled experiment. In this case the equation solved for the mixed-layer temperature in the model is:

$$\rho c_p h_{mix} \frac{dT_{mix}}{dt} = F_{net} - Q_{flx} \ , \qquad (2)$$

where $h_{mix}$ is the depth of the mixed-layer, $T_{mix}$ is the mixed-layer temperature, $F_{net}$ is the net surface heat flux including the ice-ocean heat exchange, and $Q_{flx}$ is the implied horizontal and vertical flux of heat into/out of the local mixed-layer column. This is essentially the same equation solved in the CAM-SOM formulation, but the Q-flux is calculated using $h_{mix}$, $T_{mix}$, and $F_{net}$ from a fully-coupled simulation instead of being based on an estimated mixed-layer depth from observations. This equation is technically only valid for an annual average or a time-constant mixed-layer depth. The assumption is that the ocean temperature is "well-mixed" and that the SST is the same as $T_{mix}$. It is highly recommended that $h_{mix}$ and $T_{mix}$ are consistent. That is, they both represent an assumed well-mixed layer in the vertical. An annual mean (but still spatially variable) mixed-layer thickness is desirable as it is much easier to balance the annual cycle of heat in a fixed layer.

From ocean model output we are able to compute the term on the left-hand side of (2) as well as $F_{net}$. We can then use these to solve for $Q_{flx}$ similar to equation (1). Generally the ocean model output is saved in monthly-mean history files and so this equation is solved for monthly-mean values, ignoring the sub-monthly variability. Also, to represent a climatological period of an equilibrated simulation, a monthly-mean climatology is often created over a twenty-year or longer period. For more information on the CAM-SOM method and using a SOM for equilibrium climate sensitivity studies, see Kiehl et al. 2006 and Danabasoglu and Gent, 2009.

**References**

Danabasoglu, G., and P. R. Gent, 2009: Equilibrium Climate Sensitivity: Is It Accurate to Use a Slab Ocean Model? *J. Climate*, **22**, 2494-2499.

Kiehl, J. T., C. A. Shields, J. J. Hack, and W. D. Collins, 2006: The Climate Sensitivity of the Community Climate System Model Version 3 (CCSM3). *J. Climate*, **19**, 2584-2596.