

Heat and salt budget in MITgcm

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Foreword: This document discusses the prescriptions for analyzing heat and salt budgets for a particular configuration of MITgcm. The details of the model configurations are presented below. Also, this document provides instructions on the model diagnostics parameters required to close the tracer budgets. Finally there are few illustrations in the document showing the time series of various tendency terms leading to tracer balance.

Model configuration: The configuration of MITgcm used in this study is very similar to the one used in Estimating the Circulation and Climate of the Ocean (ECCO-1) project. The model domain is pseudo-global, extending from 80°S to 80°N. The horizontal resolution of the model is 1°x1°. There are 50 vertical levels with a thickness of 10 m in the upper 180 m, gradually increasing to 450 m at the bottom. Thus the mode has $n_x = 360$ grid points along the longitudes, $n_y = 160$ points along the latitudes and $n_z = 50$ levels along vertical. In this study, GM-Redi eddy parameterization as well as non-local K-Profile Parameterization has been used. The details of the configurations can be found in *Chakraborty et al., 2014a, Chakraborty et al., 2014b*.

The following parameters (*PARM01* in "data") are of utter importance for the particularity of this configuration pertaining to tracer budget:

- (1) implicitFreeSurface=.TRUE., (default configuration)
- (2) nonlinFreeSurf=0, (default)
- (3) useRealFreshWaterFlux=.FALSE., (default)
- (4) linFSConserveTr = .TRUE.,

Model spin up and experiments: The model has been spun up for a period of 500 years using climatological data. Once it was ensured that the model has attained a practical steady state (through the temporal evolution of kinetic energy), further model runs were carried out. For the inter-annual runs, which spans from 2000 to 2013, the model was forced by daily NCEP reanalysis datasets. The estimation of the tracer (heat and salt) budget is carried out during a period from April - December, 2013. A weak (6 months) relaxation towards climatology has been applied to the surface temperature and salinity.

Model diagnostics: The diagnostic parameters (“data.diagnostics”) required for the analysis of *heat budget* are:

TOTTEND, TFLUX, ADVr_TH, ADVx_TH, ADVy_TH, DFrE_TH, DFxE_TH, DFyE_TH, DFrI_TH, KPPg_TH (if using KPP), oceQsw, WTHMASS.

The same for the analysis of *salt budget* are:

TOTSTEND, SFLUX, ADVr_SLT, ADVx_SLT, ADVy_SLT, DFrE_SLT, DFxE_SLT, DFyE_SLT, DFrI_SLT, KPPg_SLT (if using KPP), oceFWflx, WSLTMASS.

The diagnostic parameters were written (output) *daily* for “timePhase=0.” in data.diagnostics.

Grid parameters: The grid parameters required for the budget analysis are:

RAC, DRF, RF, hFacC, globalArea ("STDOUT.0000").

The details of the diagnostics as well grid parameters can be found in the manual (http://mitgcm.org/public/r2_manual/latest/online_documents/manual.html).

By using the above mentioned diagnostics and grid parameters, tracer balance can be obtained for any horizontal grid point and for any vertical level within the model domain. The details of such balance are provided below in a step by step manner.

Heat budget at a particular point (ix,iy,iz):

$$\text{CellVol} = \text{RAC}(\text{ix},\text{iy}) * \text{DRF}(\text{iz}) * \text{hFacC}(\text{ix},\text{iy},\text{iz})$$

Tendency due to advection:

$$\begin{aligned} \mathbf{Adv_tend} = - [& \{ \text{ADVr_TH}(\text{ix},\text{iy},\text{iz}) - \text{ADVr_TH}(\text{ix},\text{iy},\text{iz}+1) \} / \text{CellVol} + \\ & \{ \text{ADVx_TH}(\text{ix}+1,\text{iy},\text{iz}) - \text{ADVx_TH}(\text{ix},\text{iy},\text{iz}) \} / \text{CellVol} + \\ & \{ \text{ADVy_TH}(\text{ix},\text{iy}+1,\text{iz}) - \text{ADVy_TH}(\text{ix},\text{iy},\text{iz}) \} / \text{CellVol}] \end{aligned}$$

Tendency due to diffusion:

$$\begin{aligned} \mathbf{Dif_tend} = - [& \{ \text{DFrE_TH}(\text{ix},\text{iy},\text{iz}) - \text{DFrE_TH}(\text{ix},\text{iy},\text{iz}+1) \} / \text{CellVol} + \\ & \{ \text{DFrI_TH}(\text{ix},\text{iy},\text{iz}) - \text{DFrI_TH}(\text{ix},\text{iy},\text{iz}+1) \} / \text{CellVol} + \\ & \{ \text{DFxE_TH}(\text{ix}+1,\text{iy},\text{iz}) - \text{DFxE_TH}(\text{ix},\text{iy},\text{iz}) \} / \text{CellVol} + \\ & \{ \text{DFyE_TH}(\text{ix},\text{iy}+1,\text{iz}) - \text{DFyE_TH}(\text{ix},\text{iy},\text{iz}) \} / \text{CellVol}] \end{aligned}$$

If using KPP, add tendency due to KPP non-local term to the above diffusion tendency

$$\mathbf{Kpp_tend} = - [\{ \text{KPPg_TH}(\text{ix},\text{iy},\text{iz}) - \text{KPPg_TH}(\text{ix},\text{iy},\text{iz}+1) \} / \text{CellVol}]$$

Tendency due to shortwave penetration:

In MITgcm, the effect of shortwave forcing term is treated in the following manner so as to compute the tendency due to shortwave forcing at each level:

$$\text{depth} = \text{RF}(\text{iz})$$

$$\text{depth1} = \text{RF}(\text{iz}+1)$$

$$\text{swfrac} = 0.62 * \exp(\text{depth}/0.6) + (1.0 - 0.62) * \exp(\text{depth}/20.0)$$

$$\text{swfrac1} = 0.62 * \exp(\text{depth1}/0.6) + (1.0 - 0.62) * \exp(\text{depth1}/20.0)$$

$$\mathbf{Qsw_tend} = \text{oceQsw}(\text{ix},\text{iy}) / (\text{rhoConst} * \text{Cp}) / (\text{DRF}(\text{iz}) * \text{hFacC}(\text{ix},\text{iy},\text{iz})) * (\text{swfrac} - \text{swfrac1})$$

Tendency at surface due to incident heat flux:

$$\mathbf{Tflx_tend} = (\text{TFLUX}(\text{ix},\text{iy}) - \text{oceQsw}(\text{ix},\text{iy})) / (\text{rhoConst} * \text{Cp} * \text{DRF}(1) * \text{hfacC}(\text{ix},\text{iy},\text{iz}))$$

Tendency of mass correction at the surface (due to *Linear Free Surface approximation*):

$$\text{Surf_corr_tend} = (\text{tsurfcor} - \text{WTHMASS}(\text{ix}, \text{iy})) / (\text{DRF}(1) * \text{hFacC}(\text{ix}, \text{iy}, 1))$$

Where $\text{tsurfcor} = \text{SUM}(\text{WTHMASS} * \text{RAC}) / \text{globalArea}$ (if using $\text{linFSConserveTr} = \text{True}$, and $= 0$ otherwise.)

Thus heat budget at surface ($\text{iz} = 1$):

$$\text{surf_heat_tend} = \text{Adv_tend} + \text{Dif_tend} + \text{Kpp_tend} + \text{Qsw_tend} + \text{Tflx_tend} + \text{Surf_corr_tend}$$

Heat budget at subsurface ($\text{iz} > 1$):

$$\text{sub_surf_heat_tend} = \text{Adv_tend} + \text{Dif_tend} + \text{Kpp_tend} + \text{Qsw_tend}$$

These heat budget tendencies should be equal to $\text{TOTTEND}(\text{ix}, \text{iy}, \text{iz}) / 86400.0$ (for linear *free surface*).

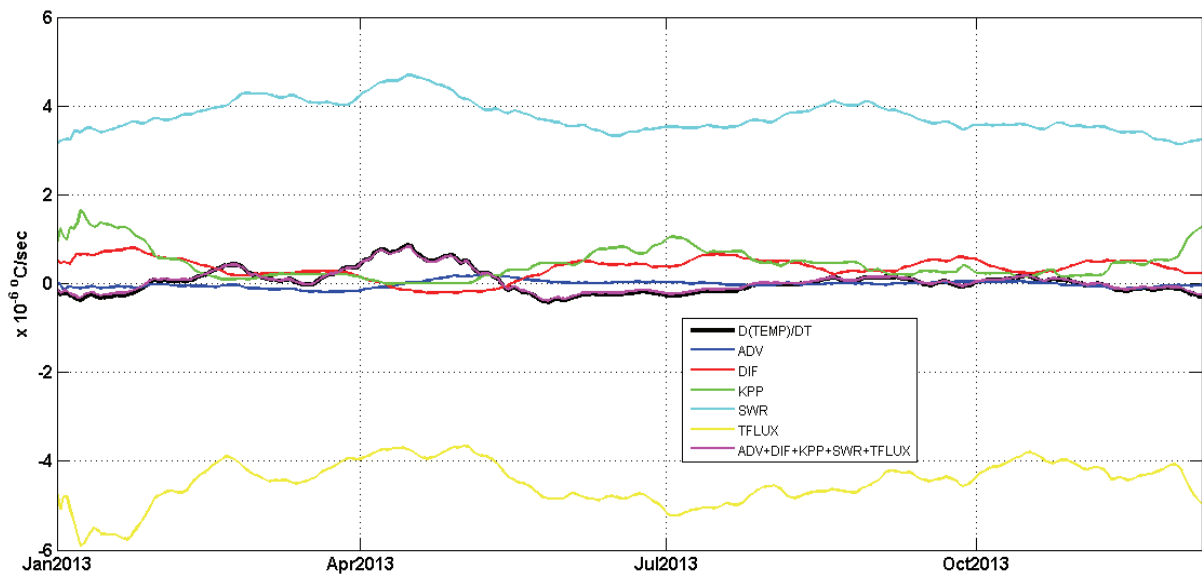


Figure 1: Surface temperature balance at 90°E 12°N. Here "D(TEMP)/DT" represents "surf_heat_tend". "ADV", "DIF", "KPP" and "SWR" represent "Adv_tend", "Dif_tend", "Kpp_tend" and "Qsw_tend" respectively. The term "TFLUX" represents "Tflx_tend + Surf_corr_tend".

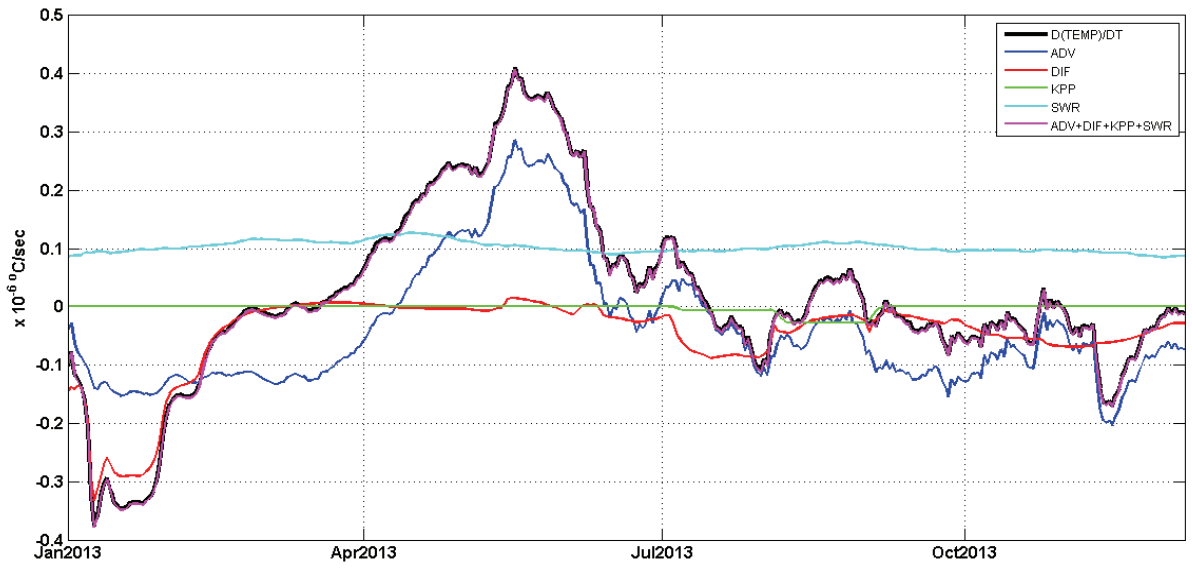


Figure 2: Sub-surface (at 50m) temperature balance at 90°E 12°N. Legends are explained in Figure 1.

Salt budget analysis at a particular point (ix,iy,iz):

Tendency due to advection:

$$\mathbf{Adv_tend_slt} = - [\{ADV_r_SLT(ix,iy,iz) - ADV_r_SLT(ix,iy,iz+1)\}/CellVol + \\ \{ADV_x_SLT(ix+1,iy,iz) - ADV_x_SLT(ix,iy,iz)\}/CellVol + \\ \{ADV_y_SLT(ix,iy+1,iz) - ADV_y_SLT(ix,iy,iz)\}/CellVol]$$

Tendency due to diffusion:

$$\mathbf{Dif_tend_slt} = - [\{DFrE_SLT(ix,iy,iz) - DFrE_SLT(ix,iy,iz+1)\}/CellVol + \\ \{DFrI_SLT(ix,iy,iz) - DFrI_SLT(ix,iy,iz+1)\}/CellVol + \\ \{DFxE_SLT(ix+1,iy,iz) - DFxE_SLT(ix,iy,iz)\}/CellVol + \\ \{DFyE_SLT(ix,iy+1,iz) - DFyE_SLT(ix,iy,iz)\}/CellVol]$$

If using KPP, add tendency due to KPP non-local term to the above diffusion tendency

$$\mathbf{Kpp_tend_slt} = - [\{KPPg_SLT(ix,iy,iz) - KPPg_SLT(ix,iy,iz+1)\}/CellVol]$$

Tendency at surface due to salt flux:

$$\mathbf{Sflx_tend} = SFLUX(ix,iy) / (\rho_{const} * DRF(1) * hfacC(ix,iy,iz))$$

Tendency of mass correction at the surface (due to *Linear Free Surface approximation*):

$$\mathbf{Surf_corr_tend_slt} = (ssurfcor - WSLTMASS(ix,iy)) / (DRF(1) * hFacC(ix,iy,1))$$

Where $ssurfcor = \text{SUM}(WSLTMASS * RAC) / \text{globalArea}$ (if using `linFSConserveTr = True`, and = 0 otherwise.)

Thus salt budget at surface ($iz = 1$):

$$\mathbf{surf_salt_tend} = \mathbf{Adv_tend_slt} + \mathbf{Dif_tend_slt} + \mathbf{Kpp_tend_slt} + \mathbf{Sflx_tend} + \mathbf{Surf_corr_tend_slt}$$

Salt budget at subsurface ($iz > 1$):

$$\mathbf{sub_surf_salt_tend} = \mathbf{Adv_tend_slt} + \mathbf{Dif_tend_slt} + \mathbf{Kpp_tend_slt}$$

These salt budget tendencies should be equal to $TOTSTEND(ix,iy,iz)/86400.0$ (for linear free surface).

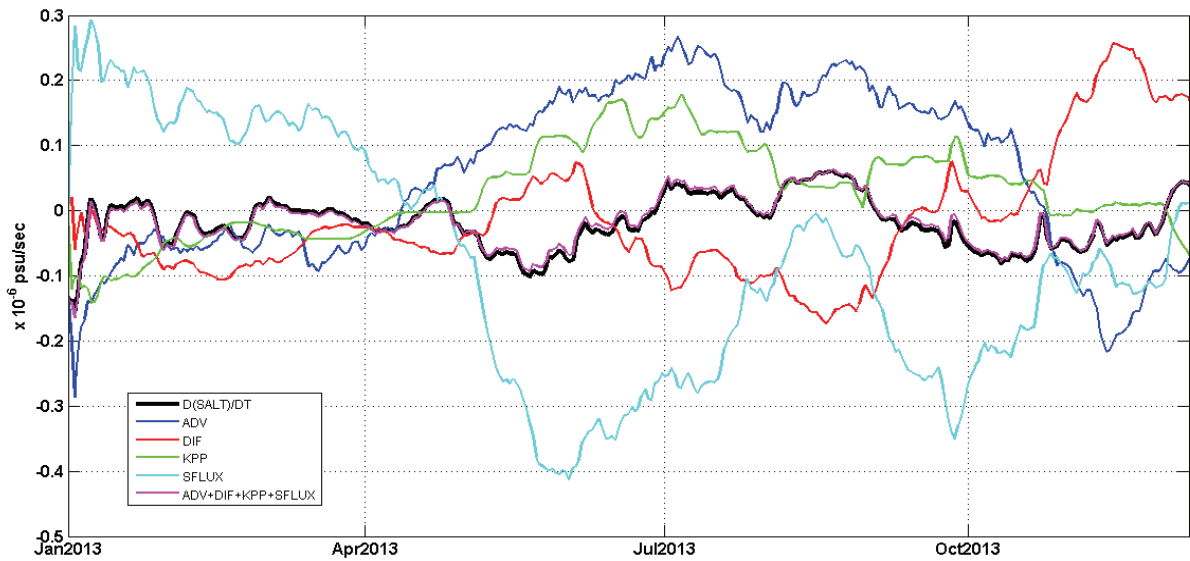


Figure 3: Surface salinity balance at 90°E 12°N. Here "D(SALT)/DT" represents "surf_salt_tend". "ADV", "DIF", "KPP" represent "Adv_tend_sl", "Dif_tend_sl", "Kpp_tend_sl" respectively. The term "SFLUX" represents "Sflx_tend + Surf_corr_tend_sl".

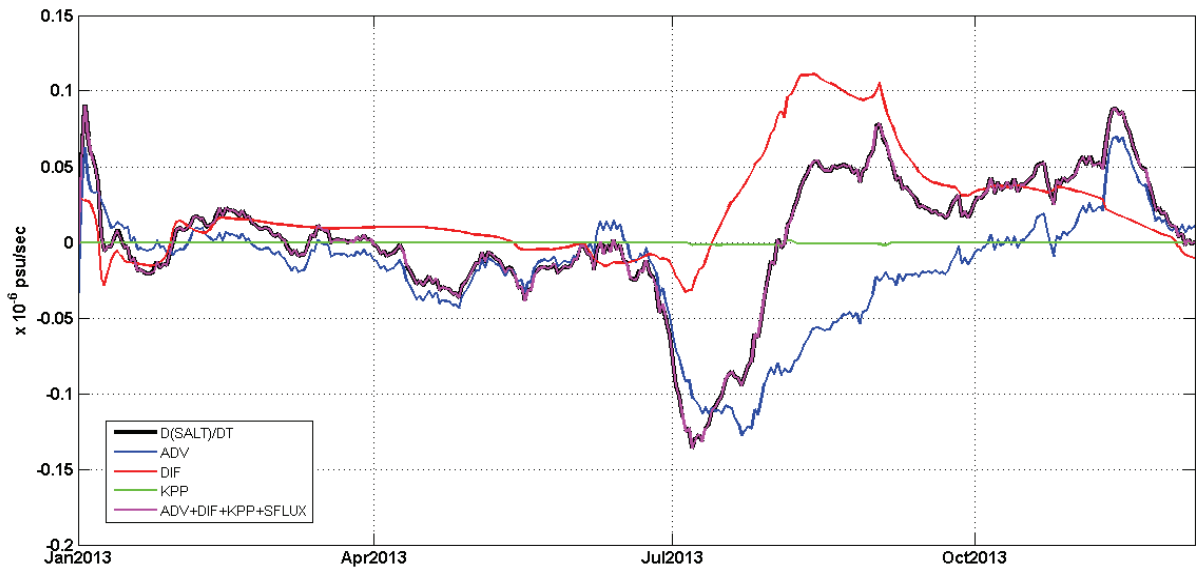


Figure 4: Sub-surface (at 50m) salinity balance at 90°E 12°N. Legends are explained in Figure 3.

References (for details of model configuration used in this study)

Chakraborty, A., R. Sharma, R. Kumar, and S. Basu (2014a), An OGCM assessment of blended OSCAT winds, *J. Geophys. Res. Oceans*, 119, 173–186, doi:10.1002/2013JC009406.

Chakraborty, A., R. Sharma, R. Kumar, and S. Basu (2014b), A SEEK filter assimilation of sea surface salinity from Aquarius in an OGCM: Implication for surface dynamics and thermohaline structure, *J. Geophys. Res. Oceans*, 119, 4777–4796, doi:10.1002/2014JC009984.