Budgets in ECCO - Basics, Pitfalls, and some Examples

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Full Practical Guide and Tutorials

- Christopher Piecuch has written a technical budgeting tutorial with MATLAB examples
- Three tutorials for Python budget closure in ECCOv4 for mass, salt, heat are online
- Momentum budget in MATLAB from Helen Pillar
- Vorticity budgets are described by Le Bras et. al 2019
- **Broad goal**:
    - Attribute instantaneous changes in the ocean to specific processes (ie SST change due to shortwave radiation, SSS change due to sea ice melt)
    - Double check that added diagnostics or changes to the model setup are reflected in the results

Model Setup

Parameter choice	Explanation
`implicitDiffusion`=.TRUE.,	Implicit vertical diffusion
`useRealFreshWaterFlux`=.TRUE.,	Real surface freshwater exchange
`select_rStar`=2,	Choice of rescaled vertical coordinate
`nonlinFreeSurf`=4,	Choice of nonlinear free surface
`implicitFreeSurface`=.TRUE.,	Implicit free surface
`exactConserv`=.TRUE.,	Exact conservation of global ocean volume
`tempAdvScheme`=30,	Multidimensional temperature advection
`saltAdvScheme`=30,	Multidimensional salt advection
`tempVertAdvScheme`=3,	Third-order vertical temperature advection
`saltVertAdvScheme`=3,	Third-order vertical salt advection
`tempImplVertAdv`=.TRUE.,	Implicit vertical temperature advection
`saltImplVertAdv`=.TRUE.,	Implicit vertical salt advection
`staggerTimeStep`=.TRUE.,	Staggered time step
`vectorInvariantMomentum`=.TRUE.,	Vector invariant momentum equations

Table 1: Model parameters (`PARM01`) in `MITgcm` configuration `data` file. See the `MITgcm` user manual for more general details.

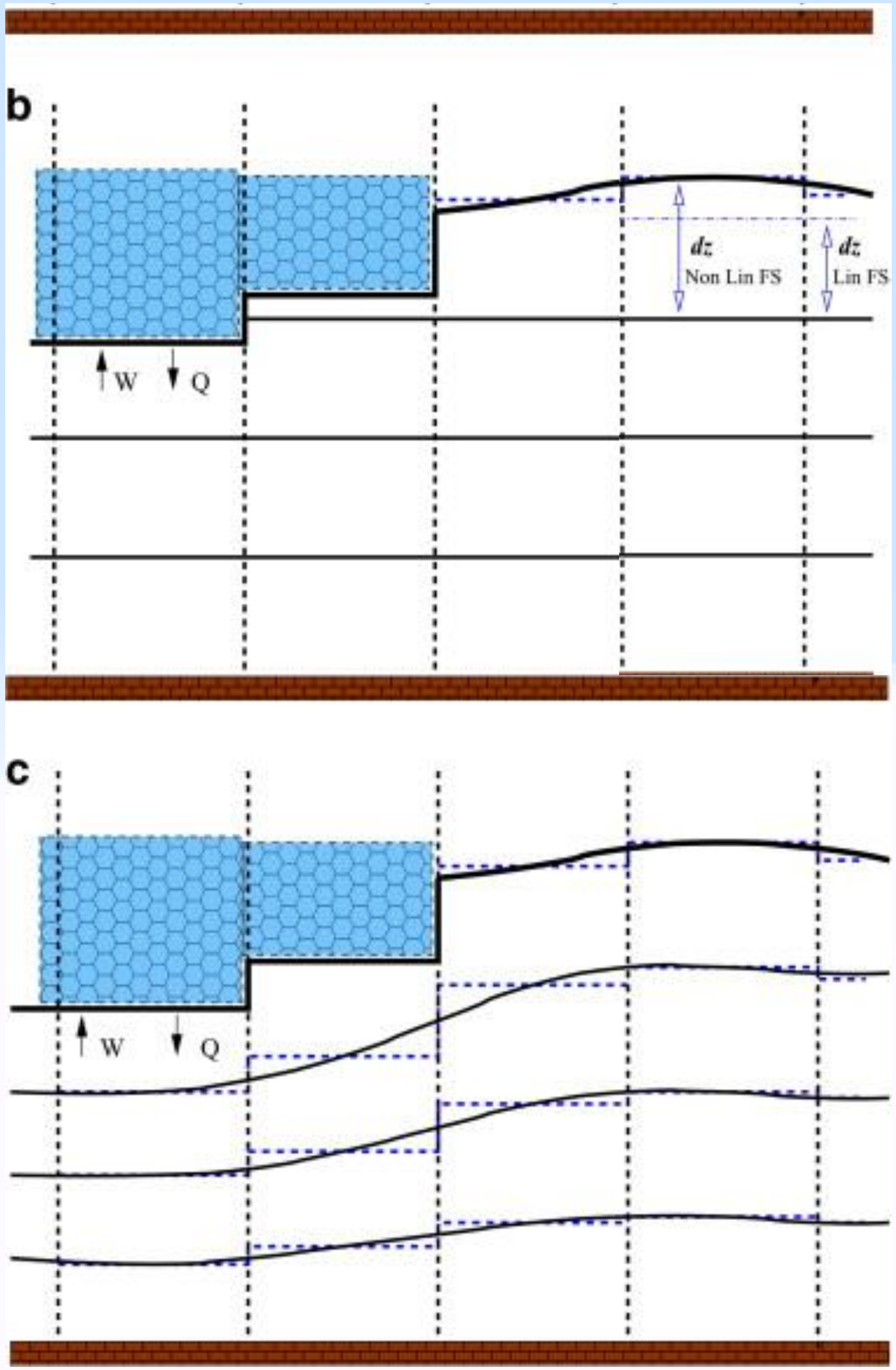
z* coordinate system

$$z^* = \frac{z - \eta(x,y,t)}{H(x,y) + \eta(x,y,t)} H(x,y) \,.$$

Right: Schematic for
`useRealFreshWaterFlux=.TRUE.`

Top: W and Q show heat and salt flux exchange in z-coordinates

Bottom: W and Q show heat and salt exchange using z*-coordinates



Source: [Campin et. al 2008]

Mass Budget Fundamentals

η from snapshot

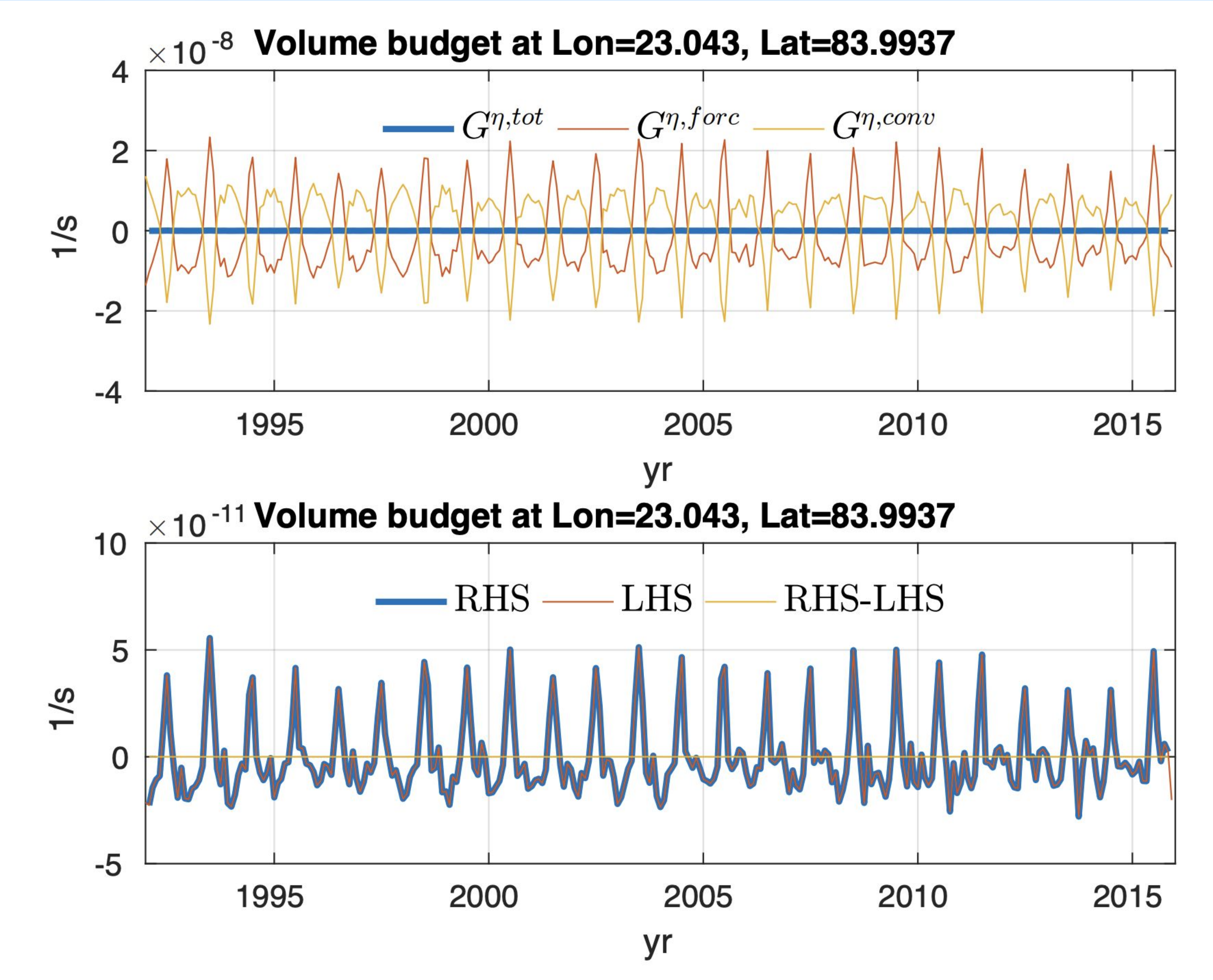
from time-averaged diagnostics

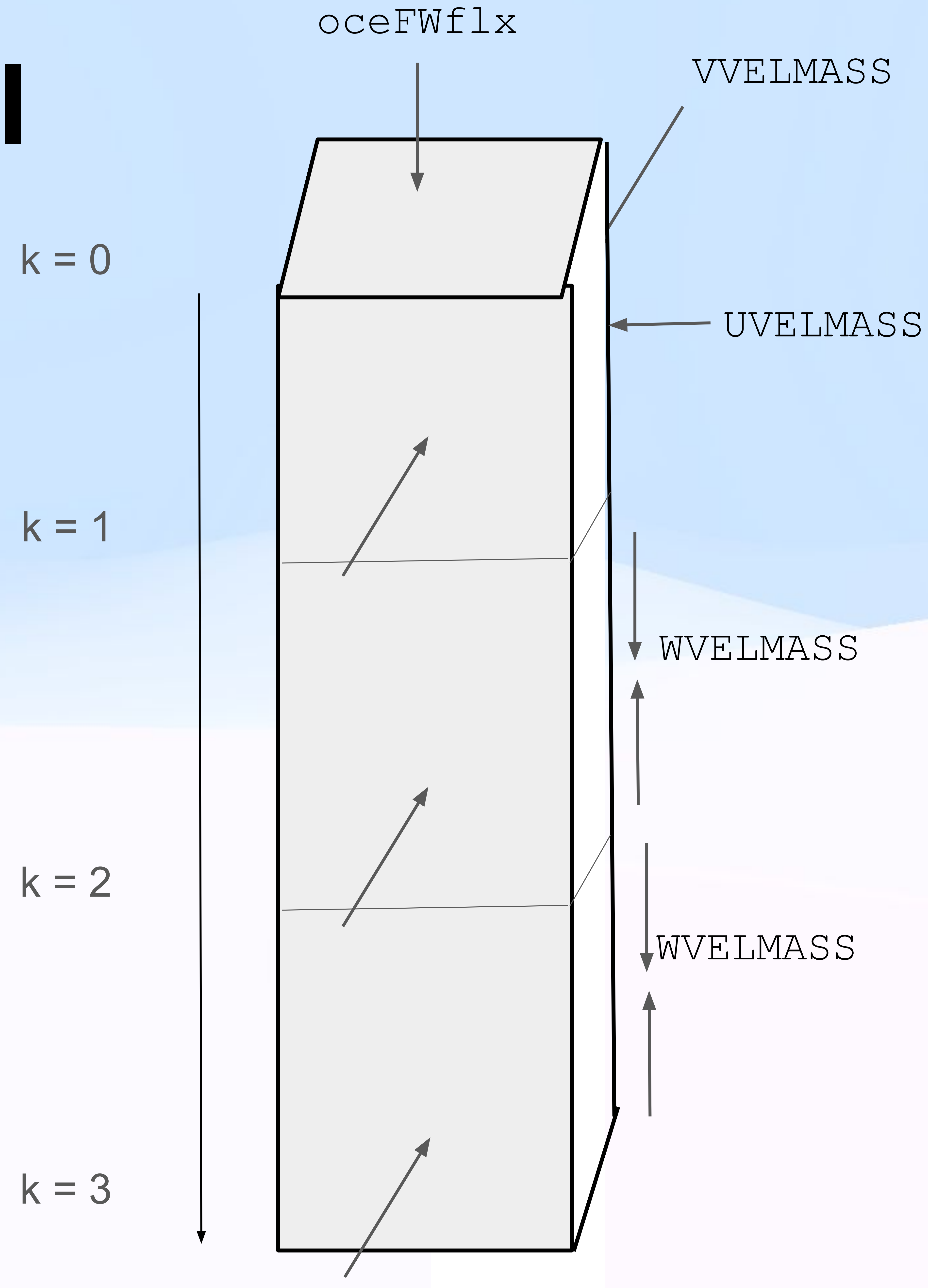
$$\underbrace{\frac{1}{H}\frac{\partial \eta}{\partial t}}_{G^{\eta,tot}} = \underbrace{-\nabla_{z^*}\left(s^*\mathbf{v}\right) - \frac{\partial w}{\partial z^*}}_{G^{\eta,conv}} + \underbrace{s^*\mathcal{F}}_{G^{\eta,forc}},$$

Diagnostic	Temporal	Description (Units)
ETAN	Snapshot	Surface height anomaly (m)
oceFWflx	Average	Net surface freshwater flux into the ocean (kg m^{-2} s^{-1})
UVELMASS	Average	Zonal mass-weighted component of velocity (m s^{-1})
VVELMASS	Average	Meridional mass-weighted component of velocity (m s^{-1})
WVELMASS	Average	Vertical mass-weighted component of velocity (m s^{-1})

Table 2: MITgcm diagnostics required to evaluate the vertically integrated volume budget.

Mass Budget for One Cell





Heat Budget Fundamentals

Diagnostic	Time	Description (Units)
`ETAN`	Snapshot	Surface height anomaly (m)
`THETA`	Snapshot	Potential temperature (°C)
`TFLUX`	Average	Total heat flux (W m^{-2})
`oceQsw`	Average	Net shortwave radiation (W m^{-2})
`ADVr_TH`	Average	Vertical advective flux of pot. temp. (°C m^3 s^{-1})
`ADVx_TH`	Average	Zonal advective flux of pot. temp. (°C m^3 s^{-1})
`ADVy_TH`	Average	Meridional advective flux of pot. temp. (°C m^3 s^{-1})
`DFrI_TH`	Average	Implicit vertical diffusive flux of pot. temp. (°C m^3 s^{-1})
`DFrE_TH`	Average	Explicit vertical diffusive flux of pot. temp. (°C m^3 s^{-1})
`DFxE_TH`	Average	Explicit zonal diffusive flux of pot. temp. (°C m^3 s^{-1})
`DFyE_TH`	Average	Explicit meridional diffusive flux of pot. temp. (°C m^3 s^{-1})

Table 3: `MITgcm` diagnostics required to evaluate the grid cell heat budget. In addition, to evaluate the globally averaged or deep ocean heat budget, the user needs the geothermal flux forcing file, as described below in section 4.2.1.

Heat Budget Fundamentals

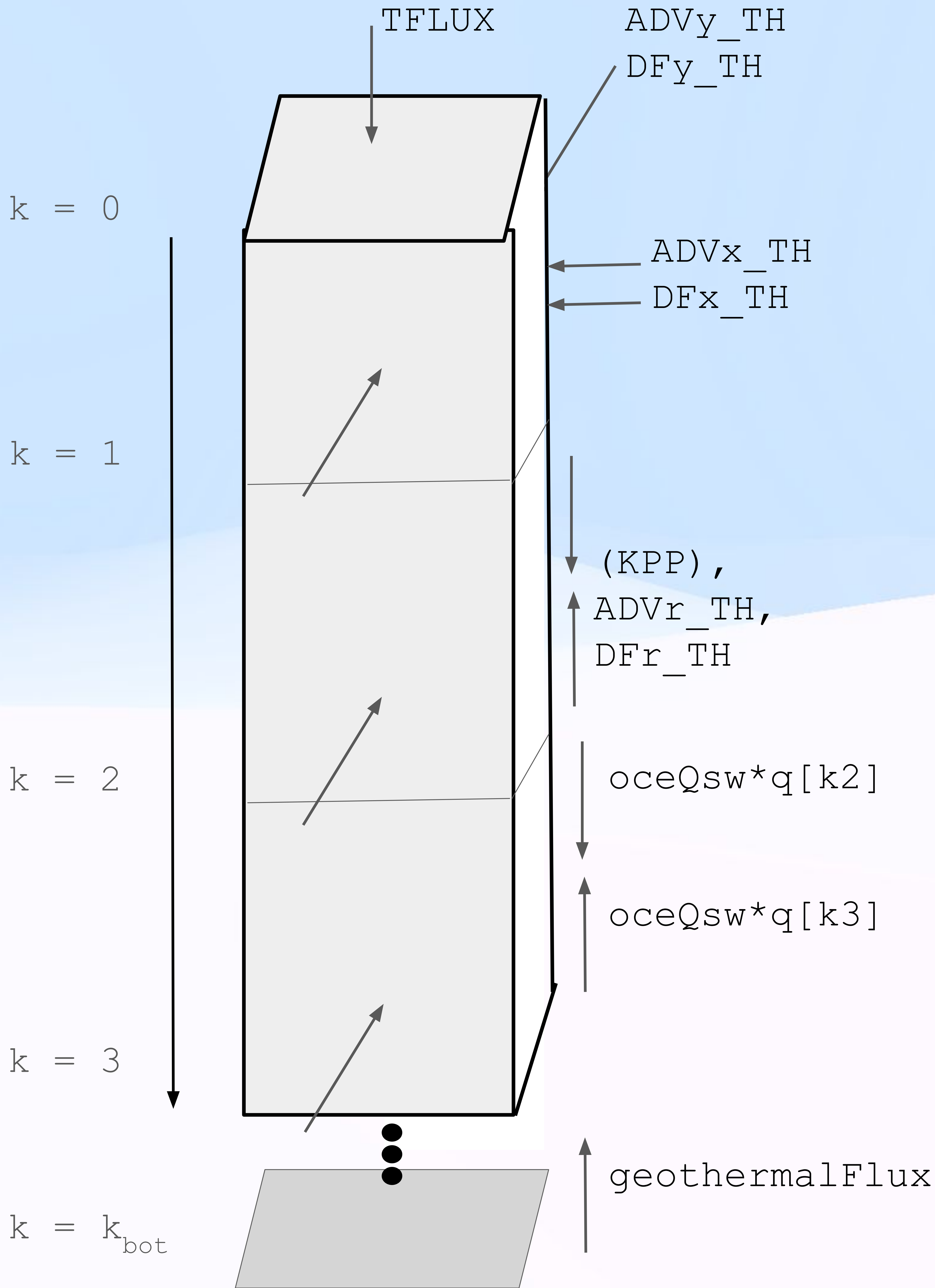
Heat Budget

$$\underbrace{\frac{\partial (s^*\theta)}{\partial t}}_{G^{\theta,tot}} = \underbrace{-\nabla_{z^*}(s^*\theta\mathbf{v}_{res}) - \frac{\partial(\theta w_{res})}{\partial z^*}}_{G^{\theta,adv}} + \underbrace{s^*\mathcal{F}_\theta}_{G^{\theta,forc}} + \underbrace{s^* D_\theta}_{G^{\theta,diff}} .$$

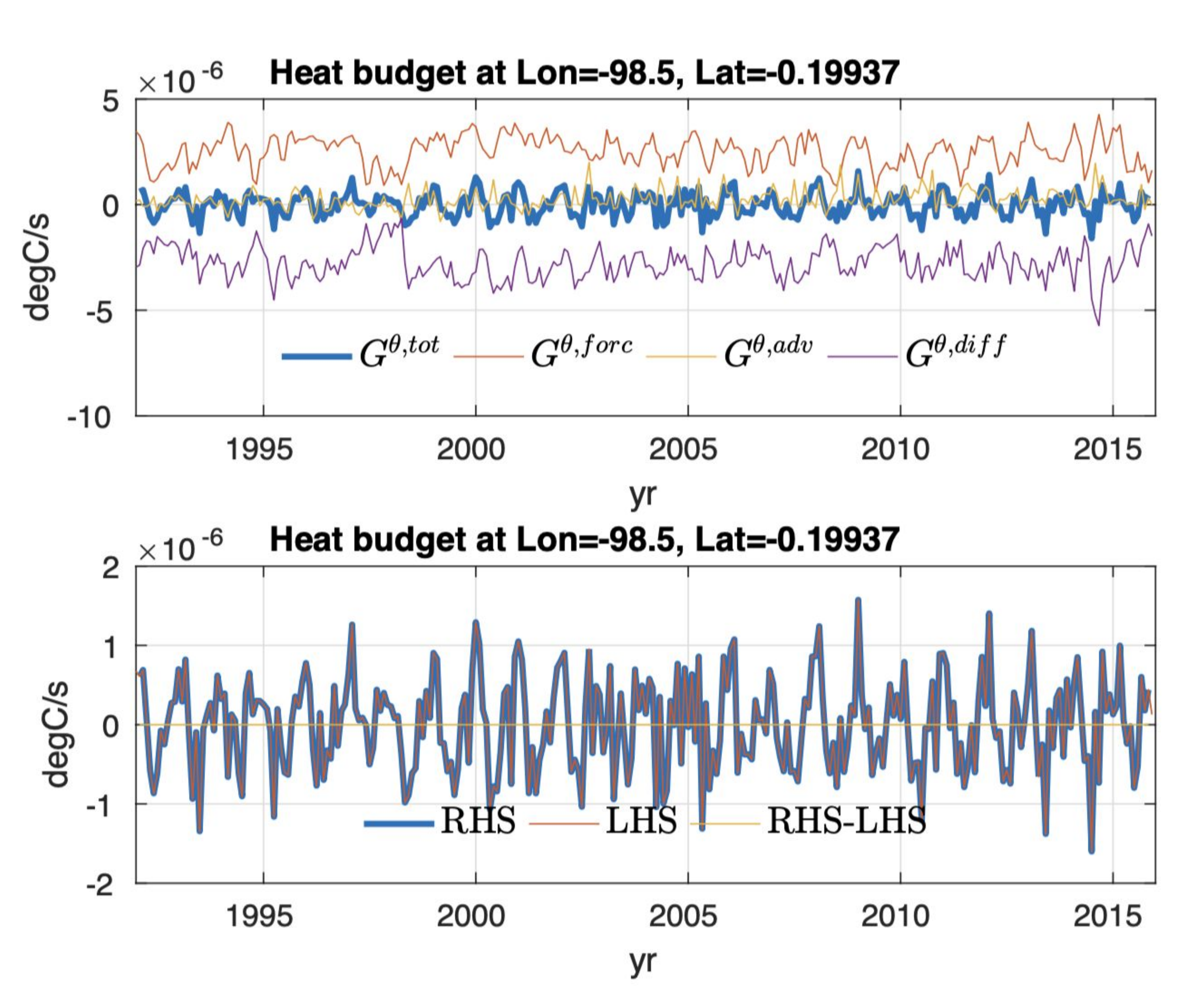
Shortwave penetration (top 200 m)

$$Q^{sw}(z) = Q^{sw}(0)\frac{q_1 - q_2}{\Delta z}.$$

$$q_i = 0.62\exp\left(\frac{z_i}{0.6}\right) + (1-0.62)\exp\left(\frac{z_i}{20}\right) \ , \ i \in \{1,2\}\, , \ z_i < 0$$



How do we ascertain heat budget closure?



Salt Budget Fundamentals

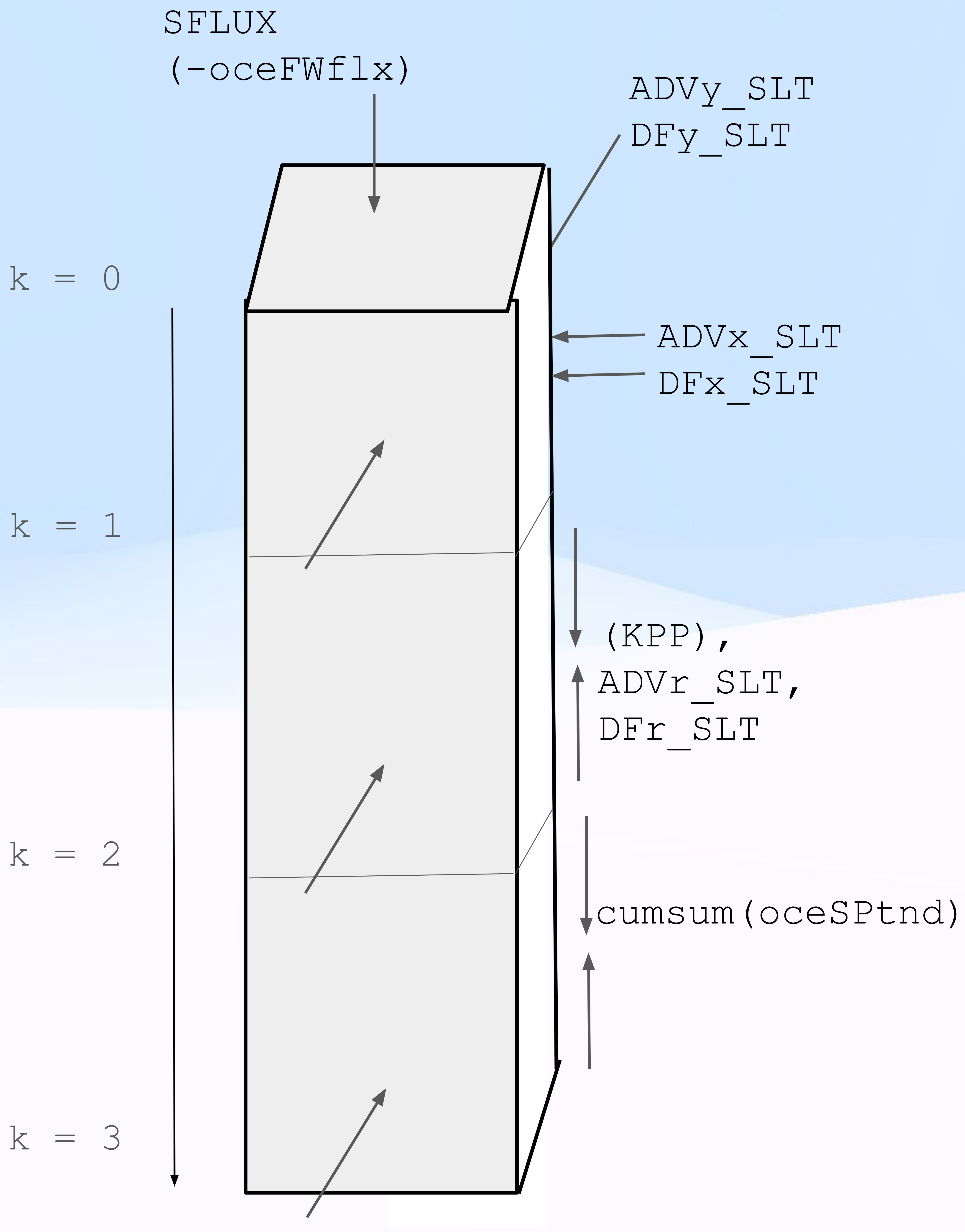
Diagnostic	Time	Description (Units)
`ETAN`	Snapshot	Surface height anomaly (m)
`SALT`	Snapshot	Salinity (psu)
`SFLUX`	Average	Total salt flux (g m^{-2} s^{-1})
`oceSPtnd`	Average	Salt tendency due to salt plume flux (g m^{-2} s^{-1})
`ADVr_SLT`	Average	Vertical advective flux of salinity (psu m^3 s^{-1})
`ADVx_SLT`	Average	Zonal advective flux of salinity (psu m^3 s^{-1})
`ADVy_SLT`	Average	Meridional advective flux of salinity (psu m^3 s^{-1})
`DFrI_SLT`	Average	Implicit vertical diffusive flux of salinity (psu m^3 s^{-1})
`DFrE_SLT`	Average	Explicit vertical diffusive flux of salinity (psu m^3 s^{-1})
`DFxE_SLT`	Average	Explicit zonal diffusive flux of salinity (psu m^3 s^{-1})
`DFyE_SLT`	Average	Explicit meridional diffusive flux of salinity (psu m^3 s^{-1})

Table 4: `MITgcm` diagnostics required to evaluate the grid cell salt budget.

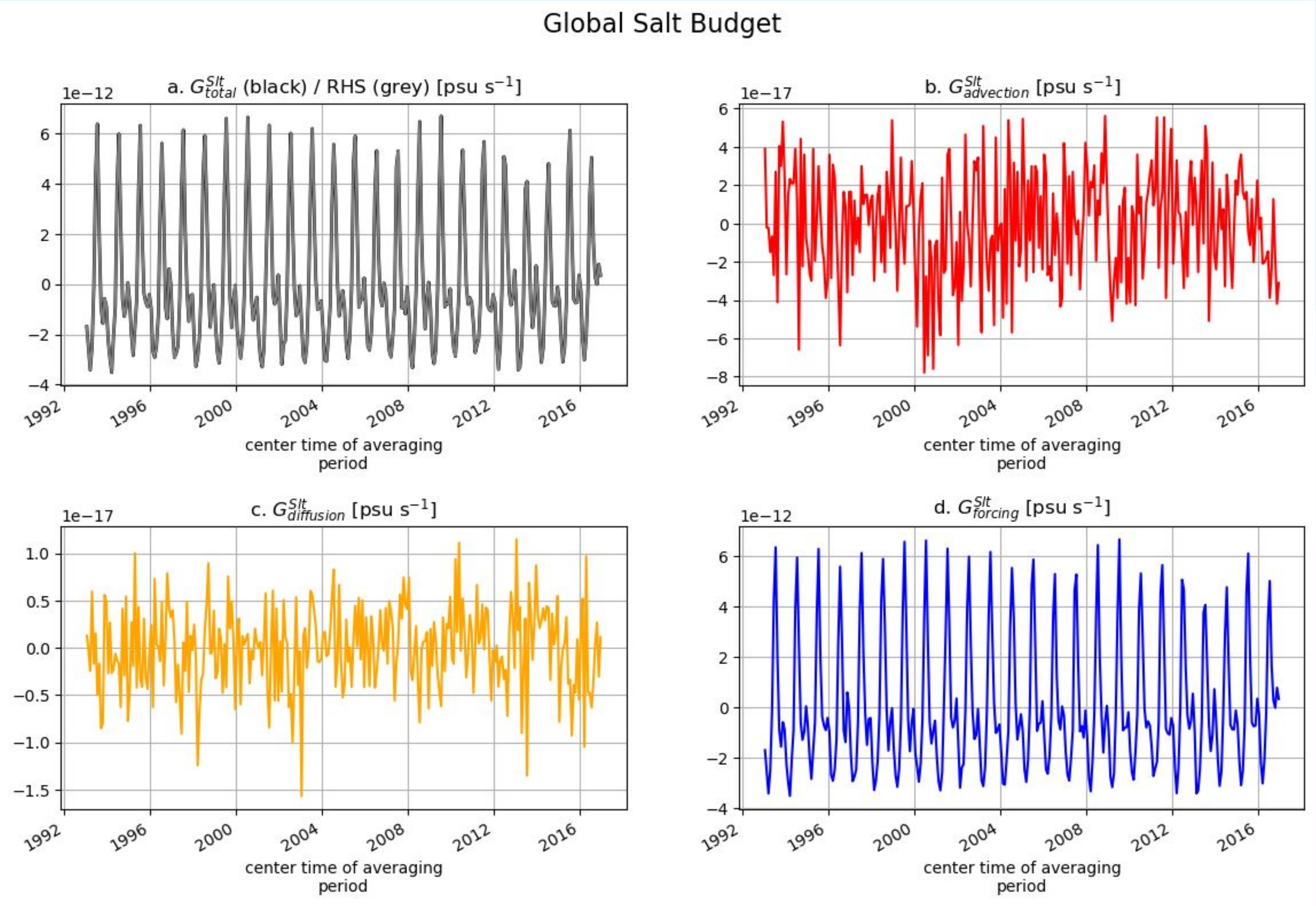
Salt Budget Fundamentals

Salt Budget

$$\underbrace{\frac{\partial\left(s^{*}S\right)}{\partial t}}_{G^{S,tot}}=\underbrace{-\nabla_{z^{*}}\left(s^{*}S\mathbf{v}_{res}\right)-\frac{\partial\left(Sw_{res}\right)}{\partial z^{*}}}_{G^{S,adv}}+\underbrace{s^{*}\mathcal{F}_{S}}_{G^{S,forc}}+\underbrace{s^{*}D_{S}}_{G^{S,diff}},$$



Global Budgeting

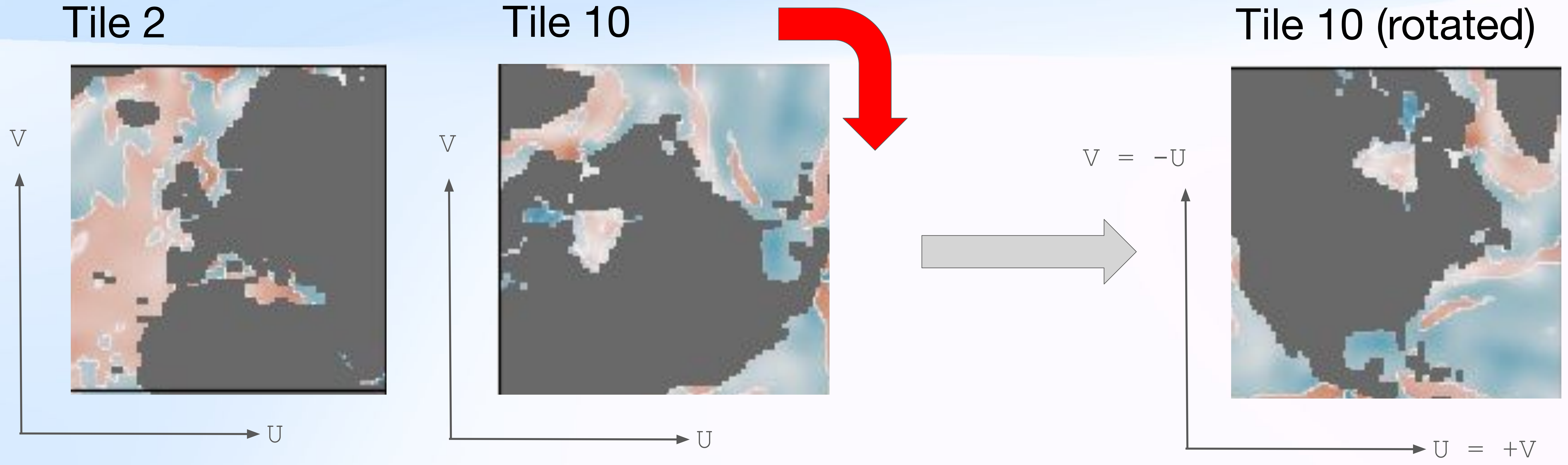


Common pitfalls

- **The bottom**
  - Must take into account the hFacC term, especially at bottom where this may be a fraction
- **The top**
  - Shortwave penetration is dependent on depth (see q fraction)
  - Salt plume penetration affects the top cells; be careful
- **Units!**

Common pitfalls

- **Tiles**
  - Existing functions work take divergences on the llc 90 grid
  - Always double check the edges!



Thank you!