An incremental approach to fixing surface fluxes

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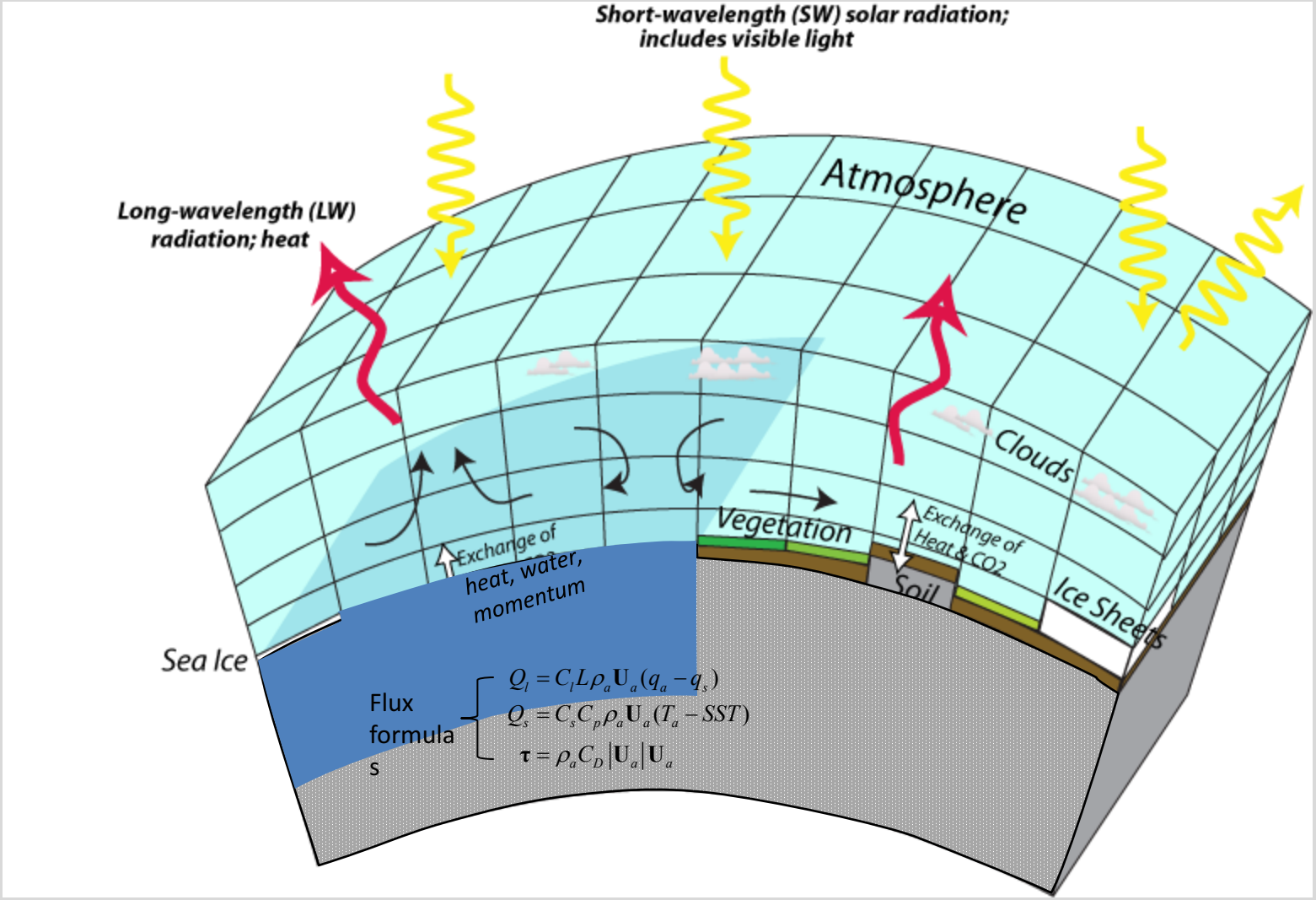
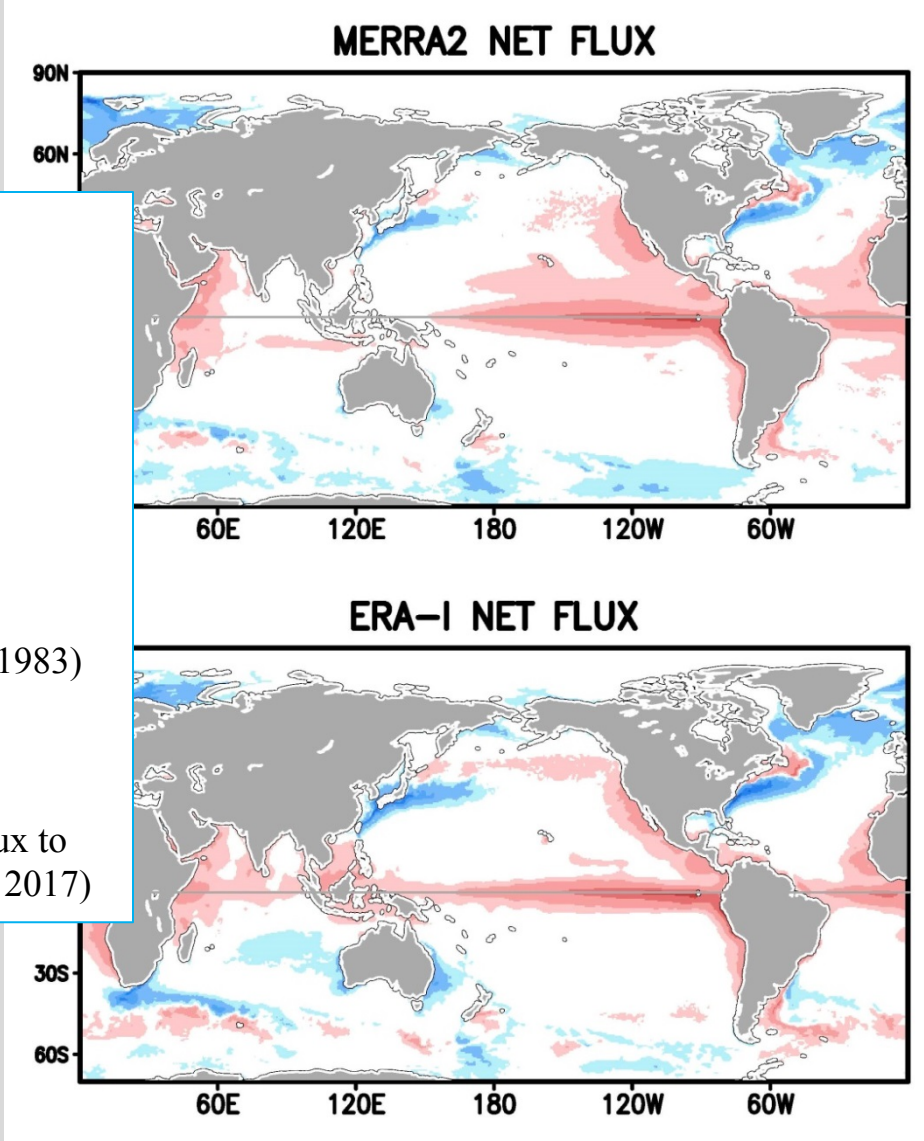
Surface heat/water fluxes are the residual of the atmospheric heat/freshwater budgets!



Different reanalyses have mean estimates that differ by 10-30Wm^{-2}!



How to reduce HF errors

Meteorological approach:

Fix each component *a posteriori*:

Large and Yeager (2009); *Brodeau et al.* (2010)

Parameter estimation:

Kang and Kalnay (2013); *Bateni and Entekhabi* (2012)

Oceanographic approach:

Profiles as a constraint:

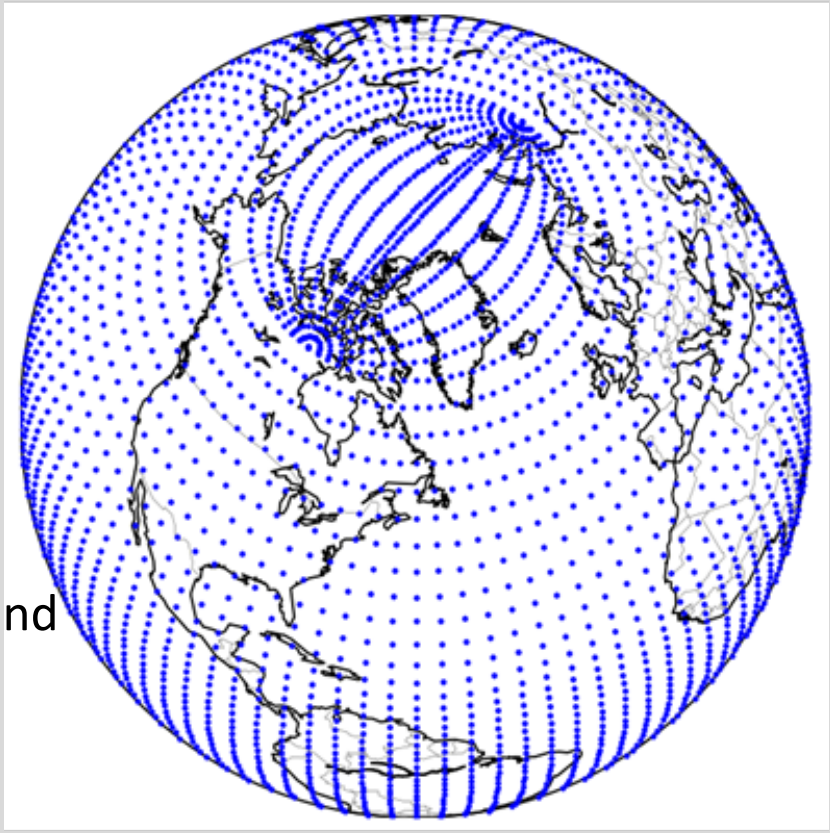
0) DaSilva (1994); Lamb (1981); Hastenrath & Merle (1983)

1) Isemer et al. (1989); *Grist & Josey* (2003)

2) Stammer et al. (2004)

(there is a related issue of trying to adjust momentum flux to balance horizontal pressure gradients, e.g. *Waters et al.,* 2017)

SODA3



Ocean/ice Model

- MOM v5.1, tripolar 0.25°×0.25° x 50 lev
- SIS 5 layer sea ice
- Coastal tide & internal tide mixing
- *Dai and et al.* rivers, *Bamber* et al. Greenland
- Restoring of temperature and salinity (WOA13) below 2 km depth.
- Multiple forcings

Data Assimilation

- OI-like sequential assimilation $\omega^a = \omega^f + \mathbf{K}[\omega^o - \mathbf{H}(\omega^f)]$
- Data: WDB13 profiles, SST (ICOADS2.5, PATHFINDER AVHRR, VIIRS/MODIS
- We also have a 'static' LETKF

Bias Correction

- Surface flux bias correction based on examination of analysis increments:

$$\overline{\mathbf{K}[\omega^o - \mathbf{H}(\omega^f)]}$$

Ongoing SODA3 experiments*

(1980-2016)

Name	Forcing	Bulk Formula	Fluxes modified?	Completed?
Soda3.3.1	MERRA2	Large & Yeager	no	yes
Soda3.3.2	MERRA2	COARE4 (& 10% speedup of u10m)	yes	Just started
Soda3.4.1	ERA-Int	Large & Yeager	no	yes
Soda3.4.2	ERA-Int	COARE4	yes	mostly
Soda3.5.2	ERA20C	COARE4	yes	no
Soda3.6.2	NOAA 20CRv2	?	yes	no
Soda3.7.1	JMA55	Large & Yeager	no	yes
Soda3.7.2	JMA55	COARE4	yes	mostly
Soda3.8.2	CORE2	Large & Yeager	no	mostly

*we're using www.soda.umd.edu as our distribution port

Liquid ocean heat budget

$$h\rho C_p \frac{\overline{D\theta}^z}{Dt} \cong Q$$

Following incremental 4DVar: approximate vertically averaged increment heat budget

$$h\rho C_p \frac{\partial \delta\theta}{\partial t} + L\rho \frac{\partial \delta h_i}{\partial t} = Q^a - Q^f$$

ocean ice

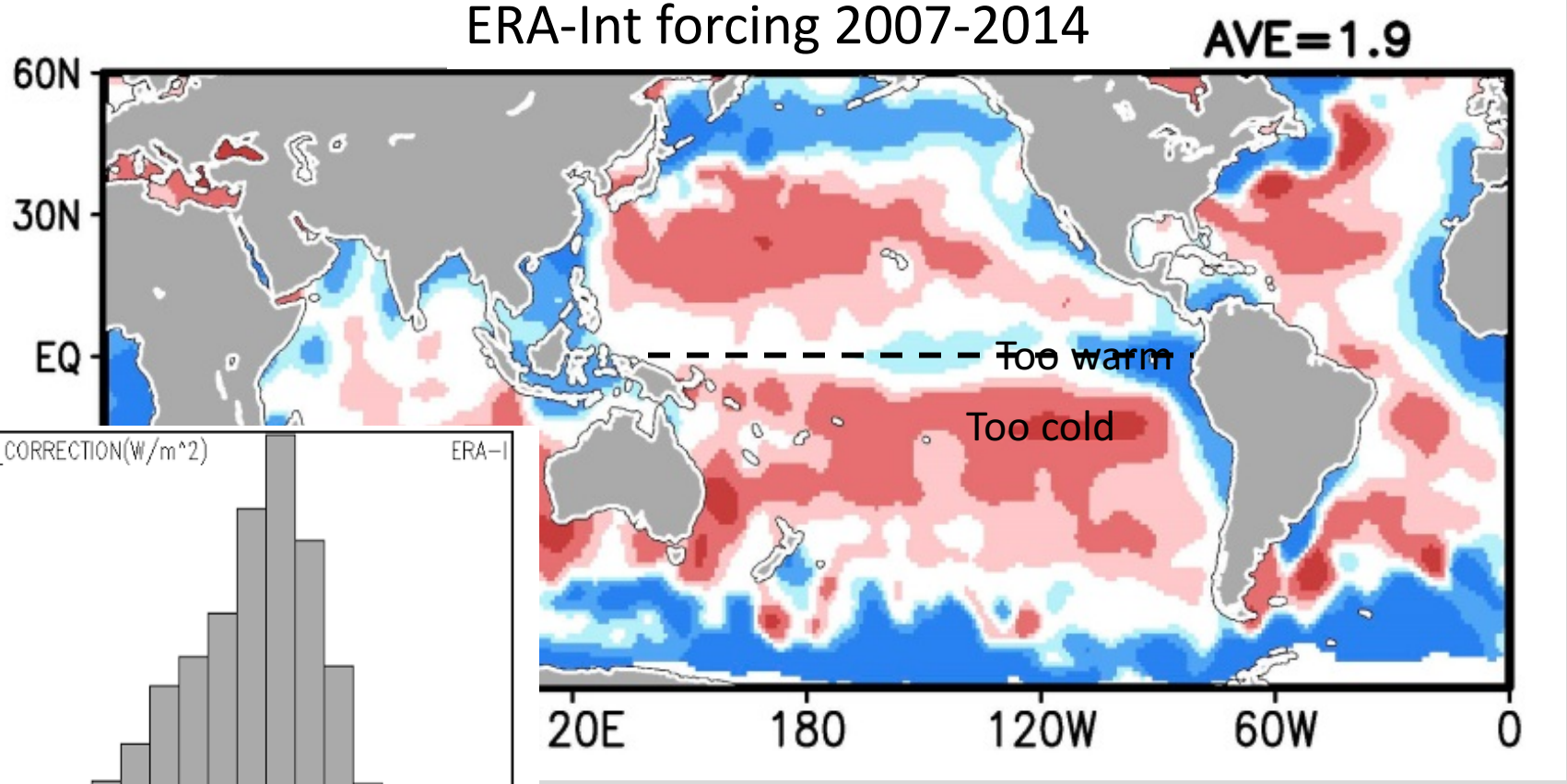
A formula for improving net surface heat flux:

$$Q^{improved} \cong Q^f + \delta\theta \frac{\rho C_p h}{\Delta t} + \delta h_i \frac{L\rho}{\Delta t}$$

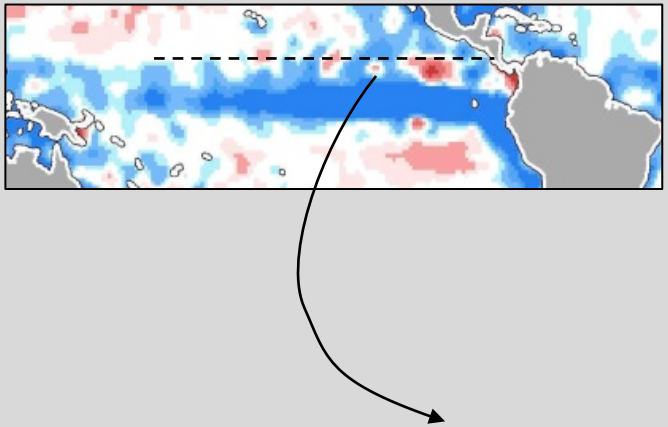
SODA3: $\partial\theta \frac{\rho C_p h}{\Delta t}$

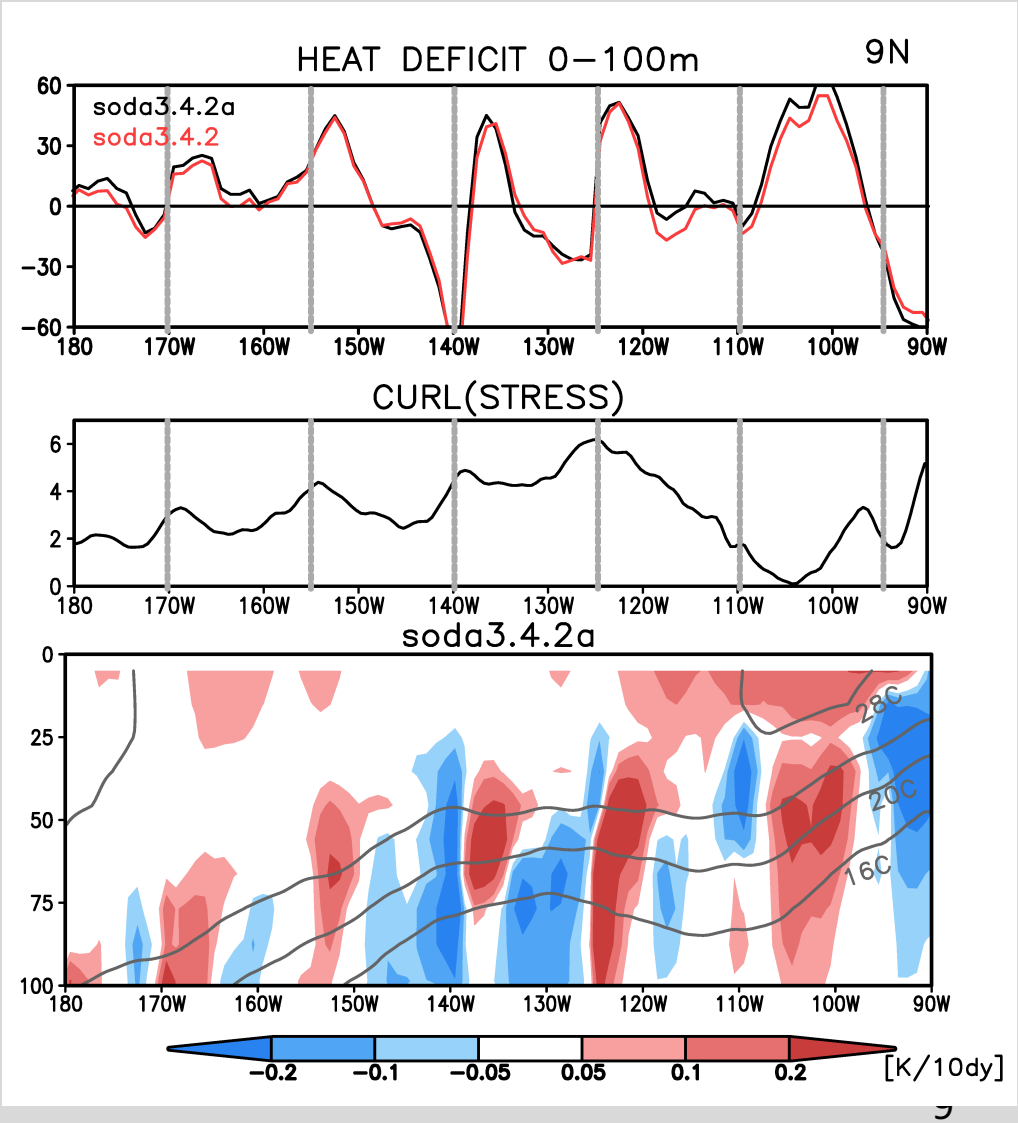
$h = mld$

ERA-Int forcing 2007-2014

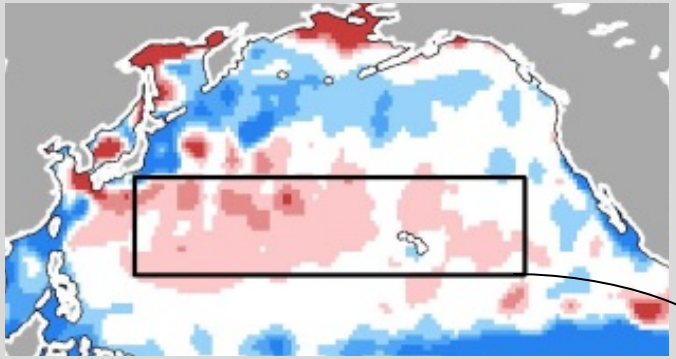


TAO/Triton moorings and $\frac{\partial}{\delta\theta}\frac{\rho C_p h}{\Delta t}$



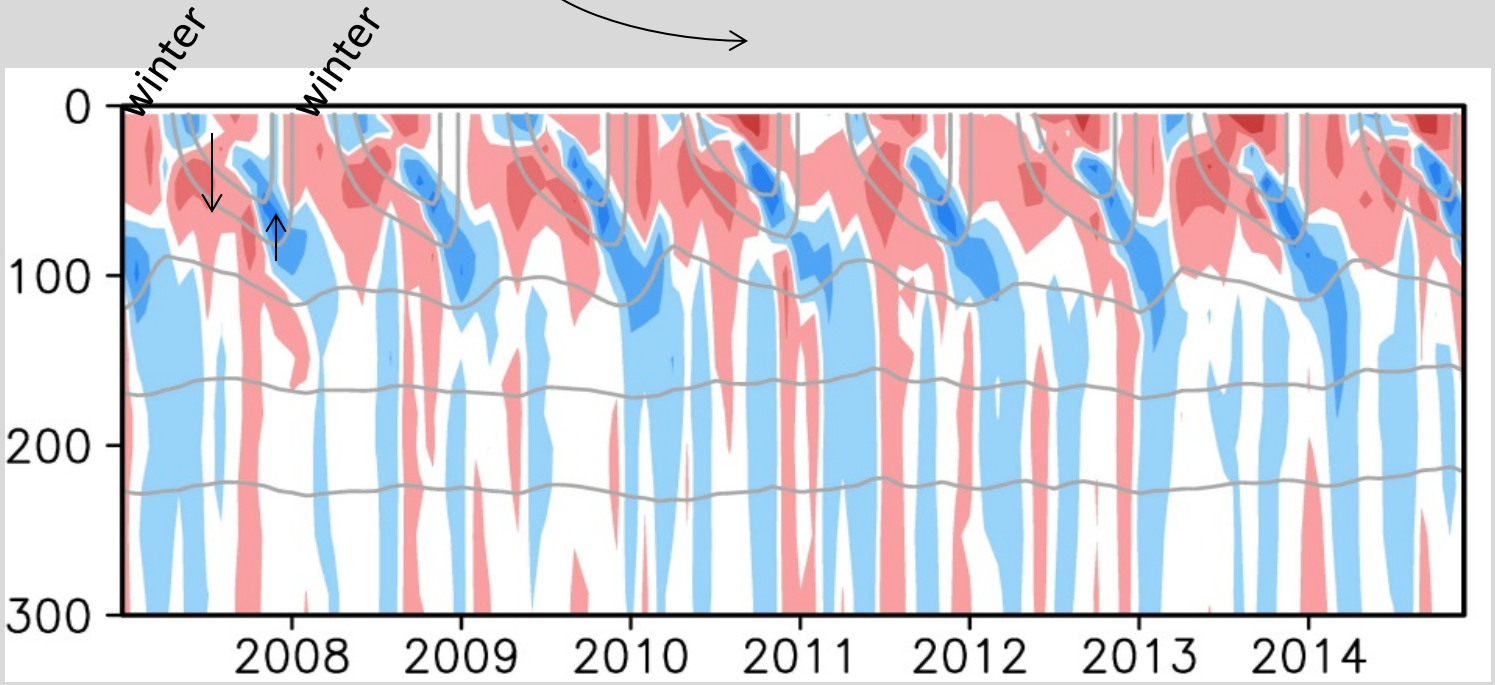


Seasonal cycle of $\partial\theta$

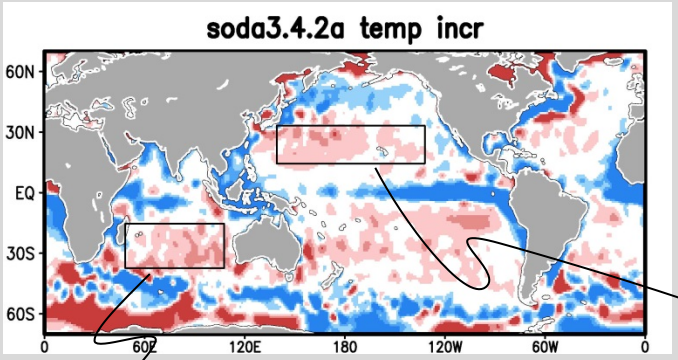


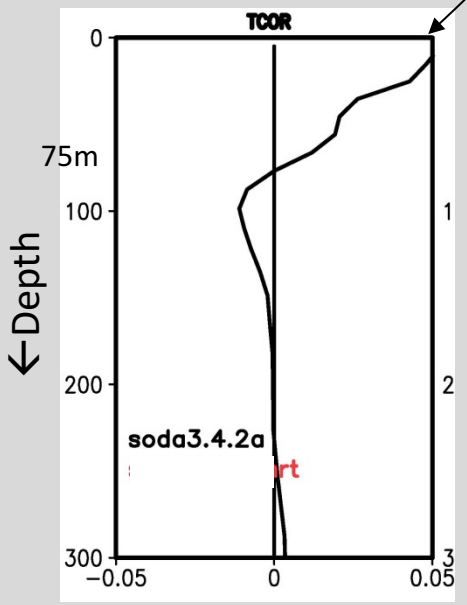
Impact of increments

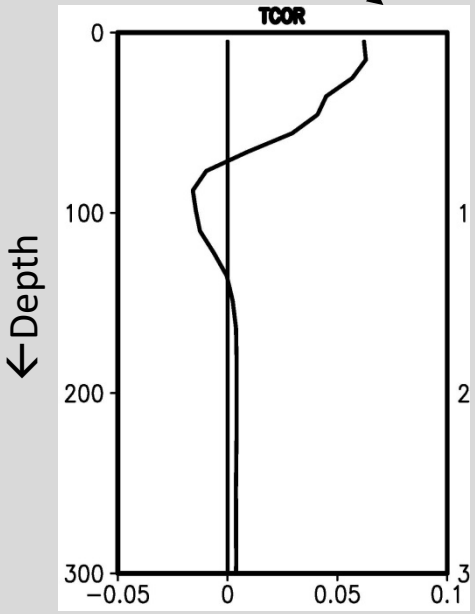
- Deepens summer mixed layer,
- Weakens ΔT at the base of the winter mixed layer



Mean $\partial\theta(z)$







Modify net surface heat flux and repeat SODA3 during 2007-2014

$$\frac{D\mathbf{u}}{Dt} = \ldots$$

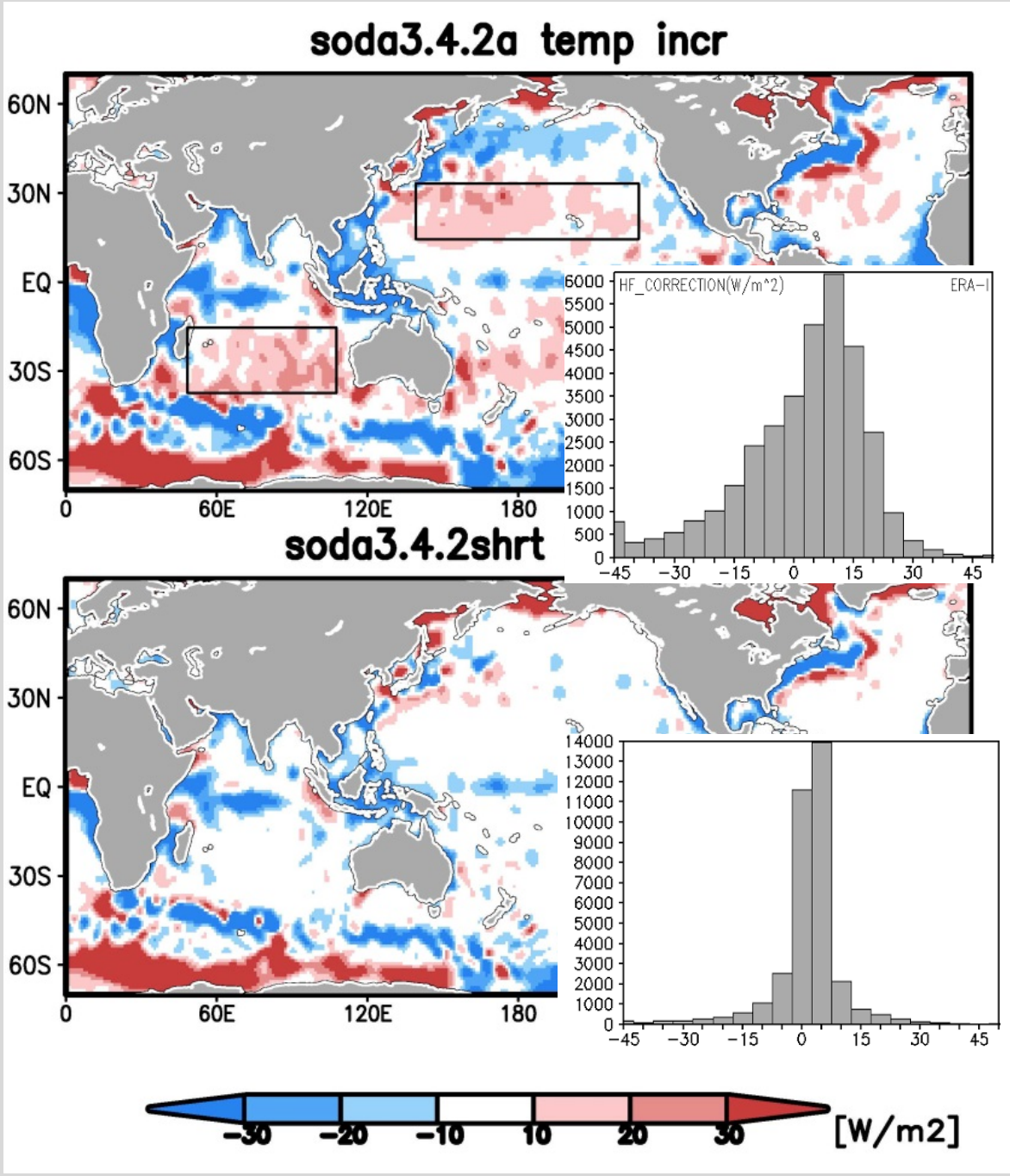
$$\frac{DS}{Dt} = \ldots$$

$$\frac{D\theta}{Dt} \cong d(z)\frac{Q + \delta Q}{\rho C_p}$$

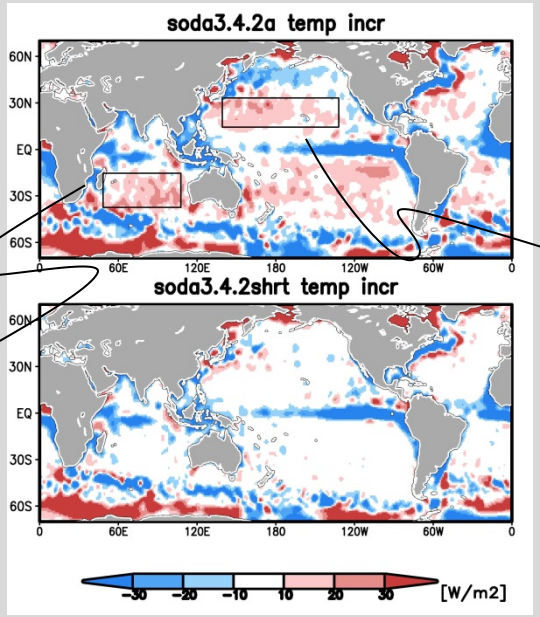
$$\frac{\partial}{\partial\theta}\frac{\rho C_p h}{\Delta t}$$

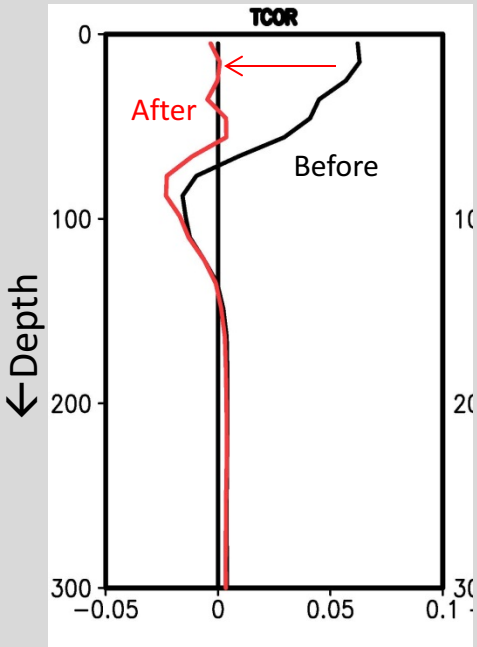
Before

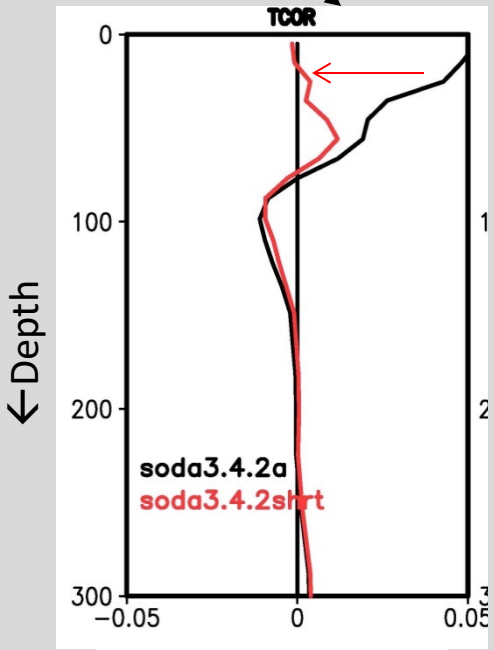
After



Recalculate $\delta\theta(z)$



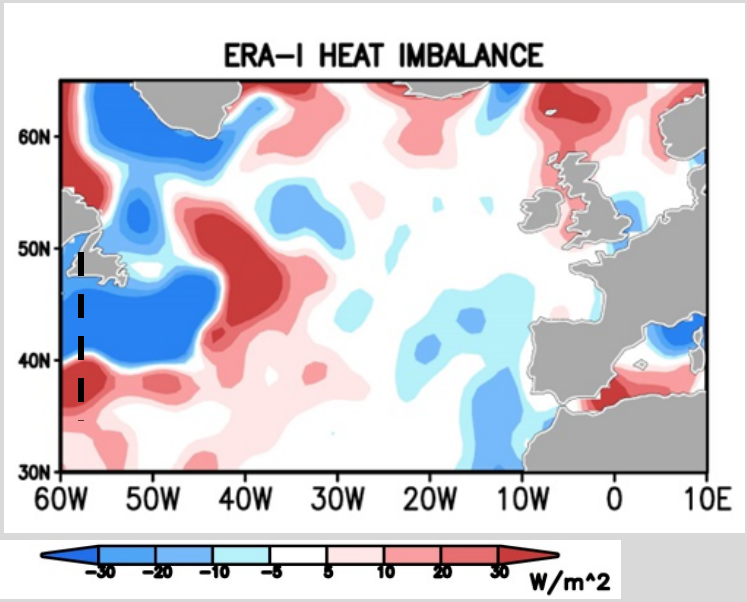




North Atlantic $\frac{\partial}{\delta\theta}\frac{\rho C_p h}{\Delta t}$

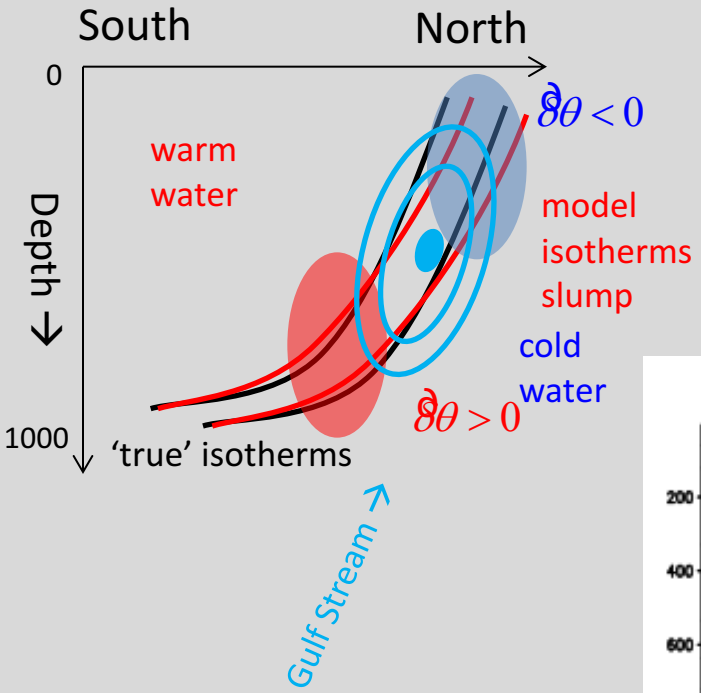
$h = 75m$

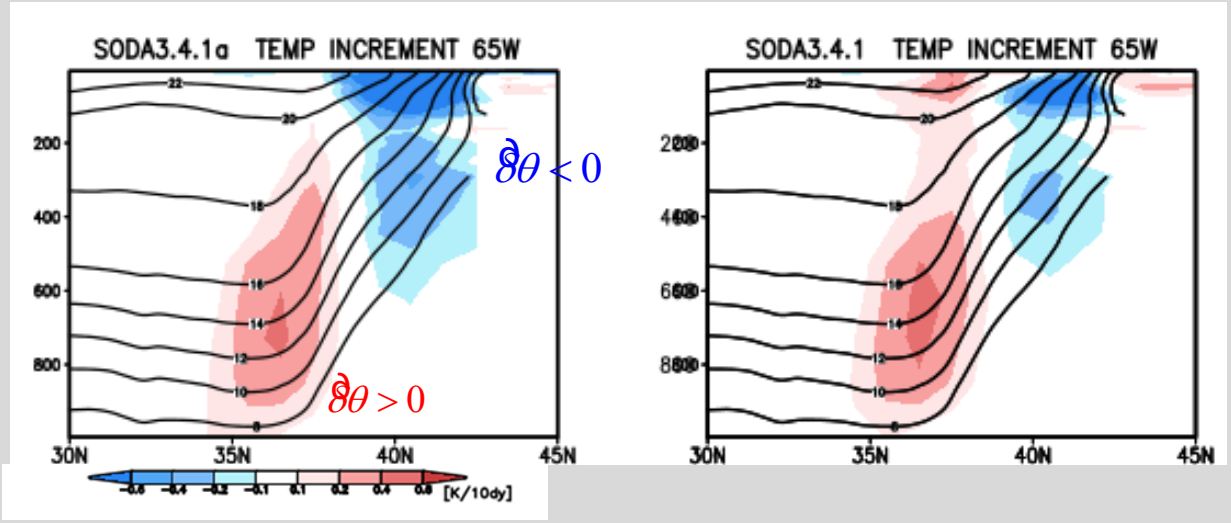
Before



Cross-section of temperature imbalance $\partial\theta$ across the Gulf Stream

Cross-section along 65°W

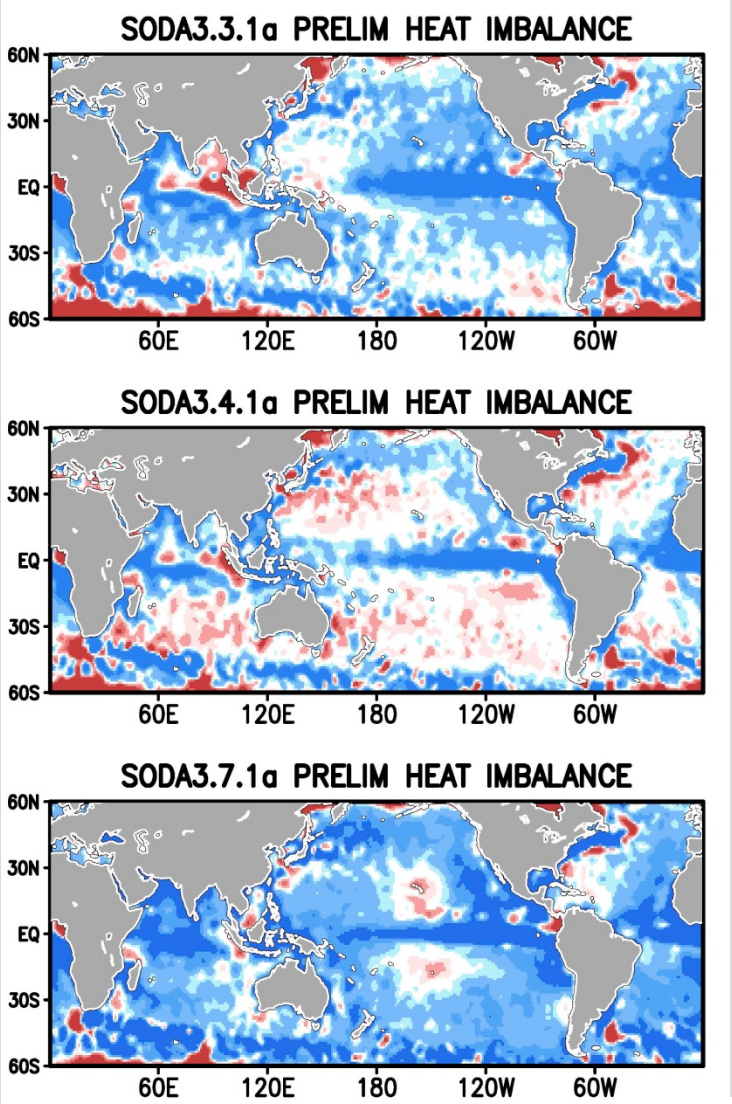




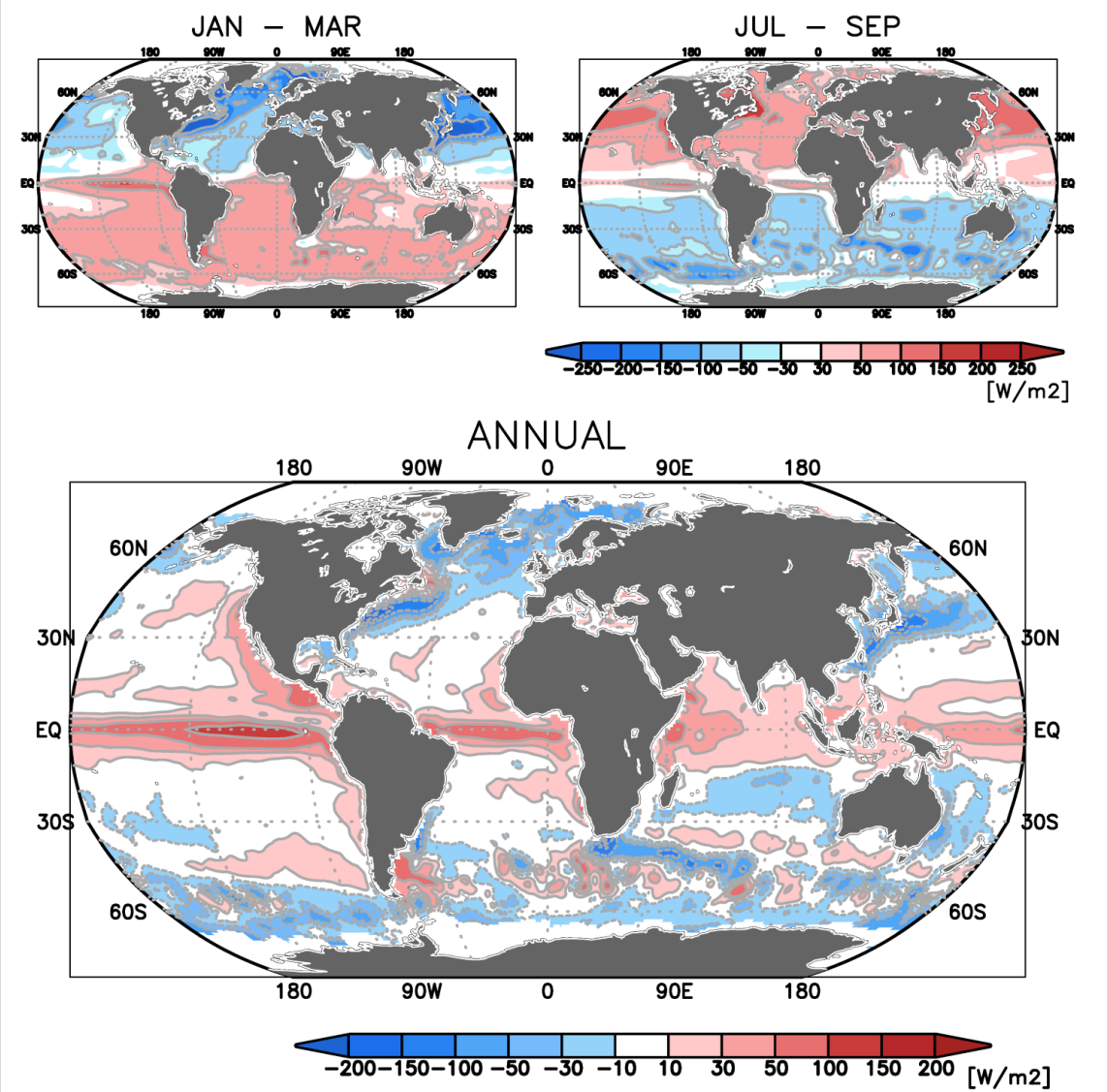
Three reanalyses

$$\frac{\partial}{\delta\theta}\frac{\rho C_p h}{\Delta t}$$

Before



Improved estimate of seasonal heat flux



Global imbalance: ~3Wm^{-2}

∞ Comments ∞

We argue in favor of using increments correct surface fluxes. It works great: it's cheap and iterative.

In playing with this approach we find:

- Most surface net heat flux misfit (error) is stored locally in the mixed layer – and it is mainly seasonal.
- Approach corrects seasonal heat fluxes to within $\pm 5 Wm^{-2}$ except in regions of strong currents.
- Approach also provides a way to evaluate
  - model error
  - Bulk flux parameterizations
  - Sea ice thickness

Results are from: Carton et al., JGR, 2017
https://drive.google.com/drive/folders/0BwoSvidgOLDMZG43LWV6SkpRTnc?usp=sharing