Using sequential DA to identify and fix surface flux bias

- Current approach to flux estimation - the problem
- Temperature increments from SODA ocean reanalysis
- Fluxes that reduce increments + a fitness test
- Different bulk parameterizations and different atmospheric reanalyses affect the results

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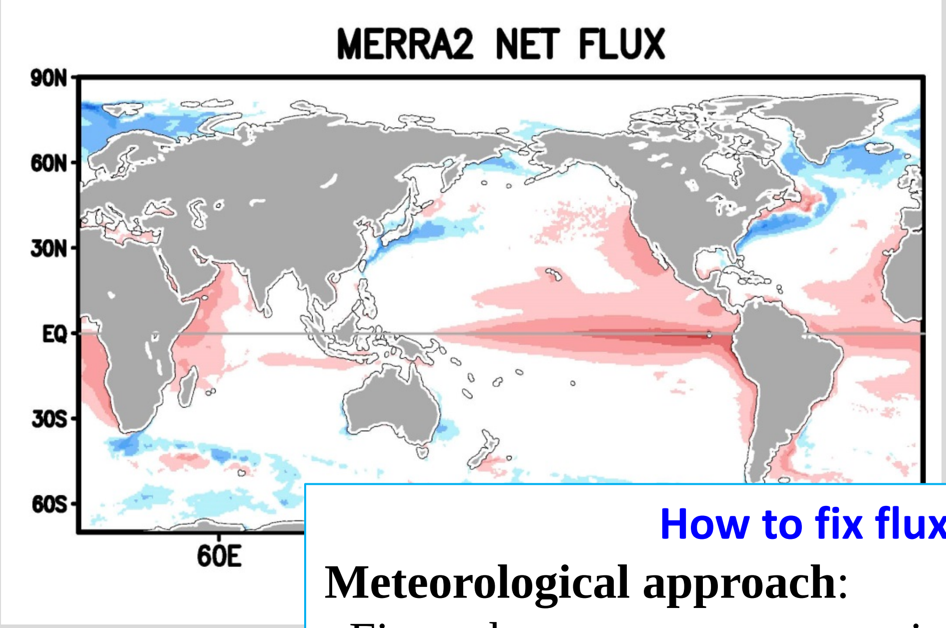
Many thanks to fellow incrementalists: Eugenia Kalnay and Kriti Bhargava

Reanalysis fluxes and their differences



This study examines 3:
- MERRA2
- ERA-I
- JRA55

How to fix fluxes

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)

SODA3

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

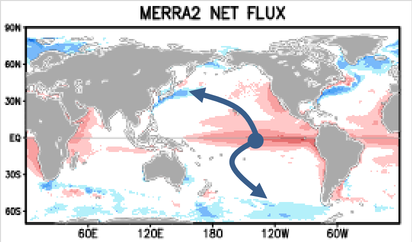
Vertically averaged energy budget

LONG TIME

SHORT TIME

$$h\rho C_p \nabla \cdot \overline{\mathbf{u}\theta} \cong Q$$

$$h\rho C_p \partial\overline{\theta} / \partial t \cong Q$$



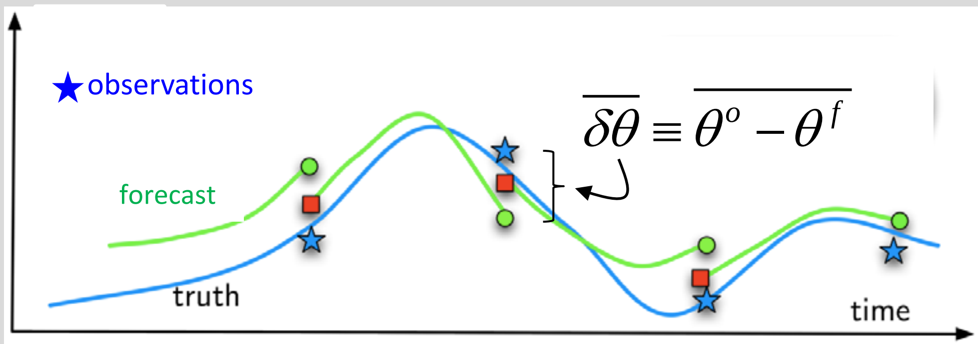
$$h\rho C_p \partial\overline{\theta} / \partial t + L\rho\partial h_i / \partial t \cong Q$$

If you account for sea ice

Sequential data assimilation

Example: vertically averaged temperature

$\overline{\theta}$



time →

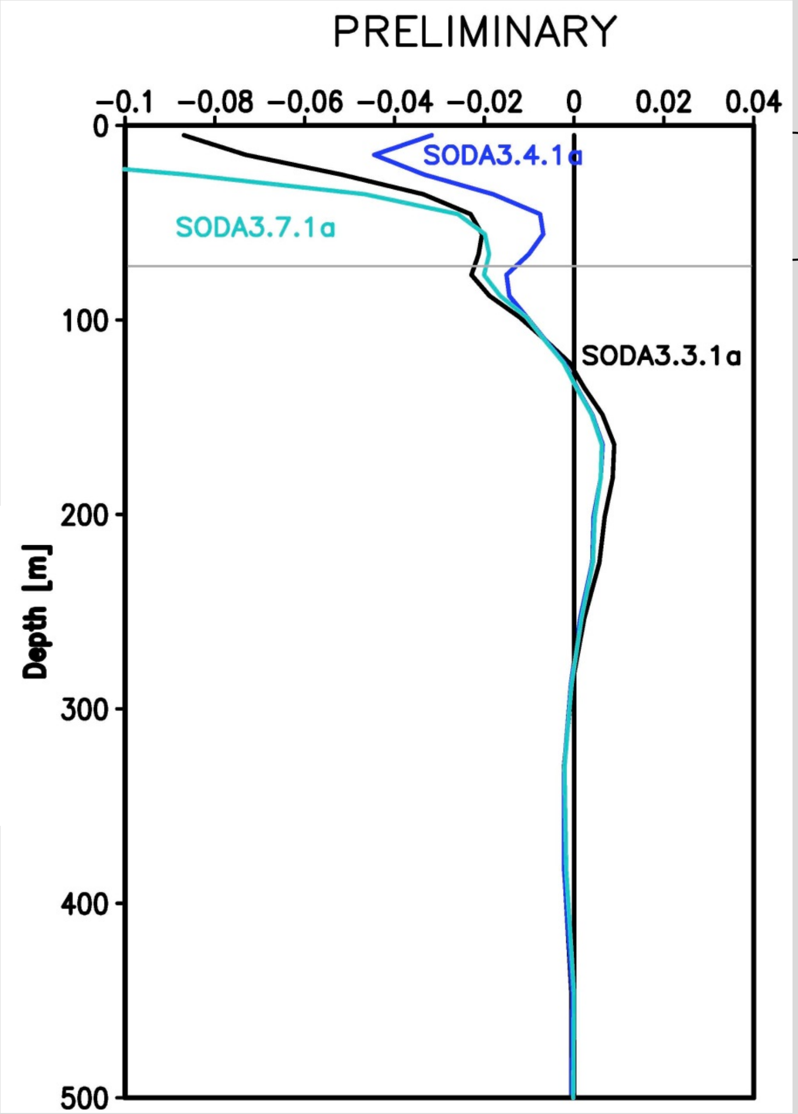
Incremental internal energy equation

(a$\widehat{\text{veragin}}$g over an assimilation cycle)

$$\widehat{\delta\theta} + \widehat{\delta\mathbf{u}\cdot\nabla\theta^f} + \widehat{\mathbf{u}^f\cdot\nabla\delta\theta} \cong [\widehat{Q^o} - \widehat{Q^f}]\frac{\Delta t}{\rho C_p h}$$

$\widehat{\overline{\delta\theta}}$ averaged 60°S-60°N, 2007-2014

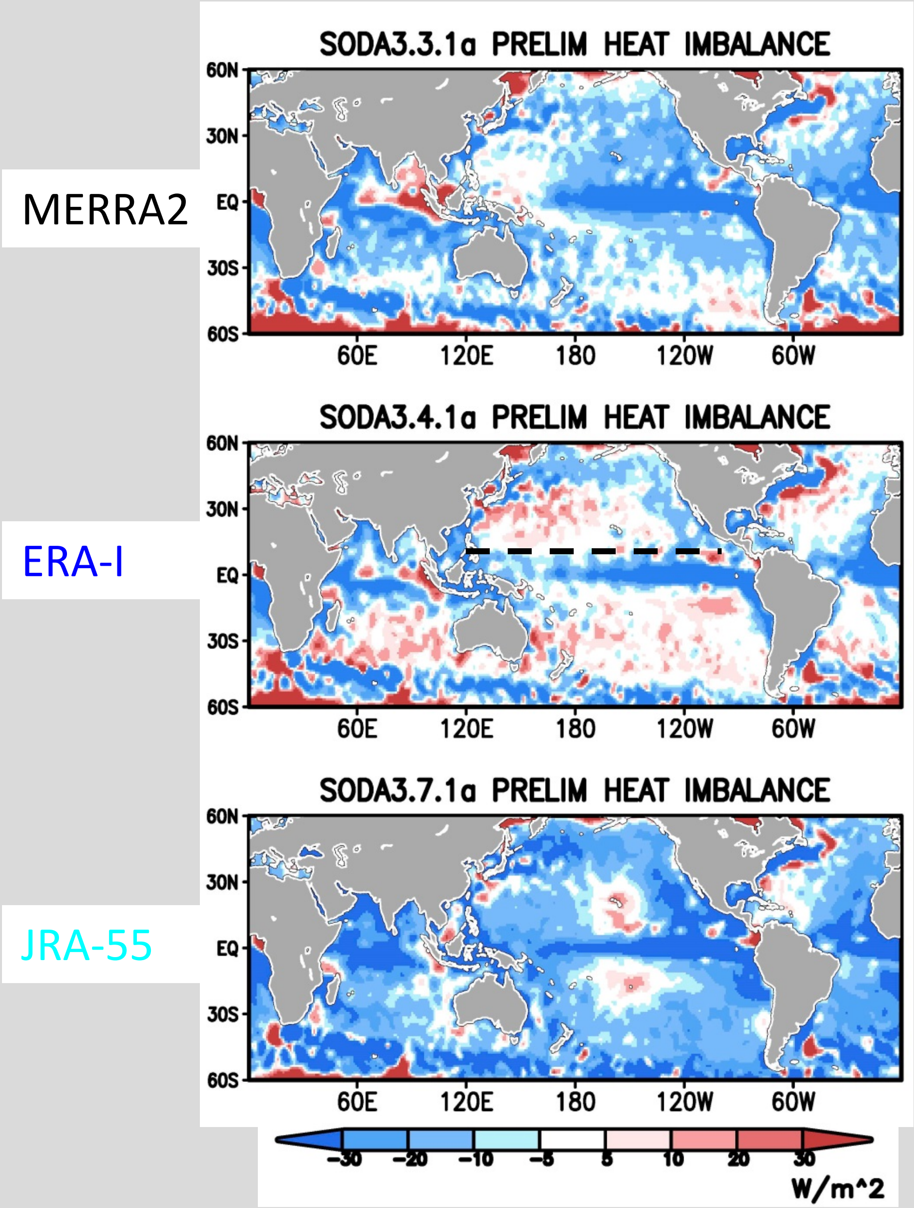
- MERRA2
- ERA-I
- JRA-55



Most of the misfit is in the upper 75m

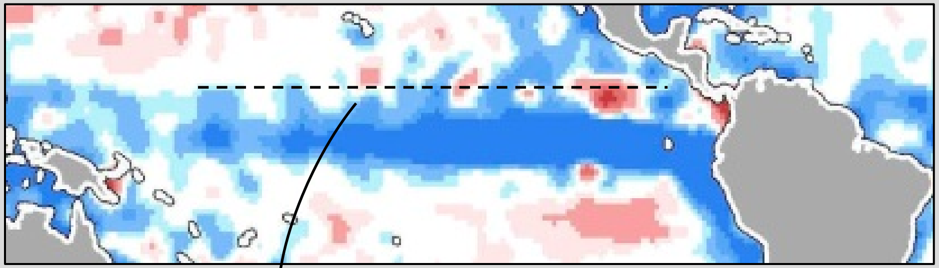
Average heat imbalance (2007-2014)

$$\rho C_p \int_{-75m}^{0} \delta\theta dz$$



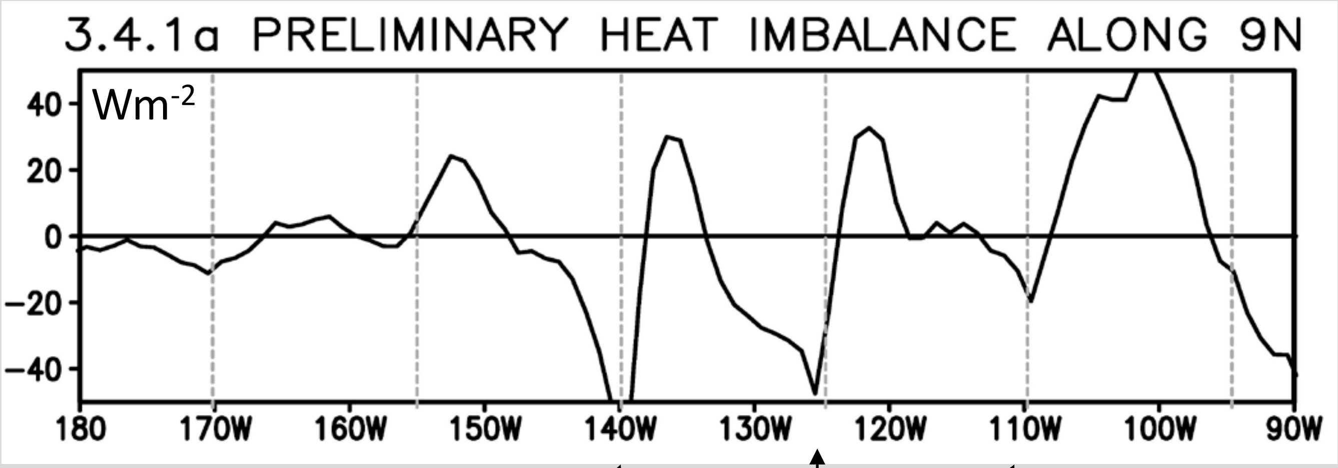
Impact of TAO/Triton moorings on ERA-I fluxes

3.4.1a Equatorial temperature imbalance



Heat out

Heat in

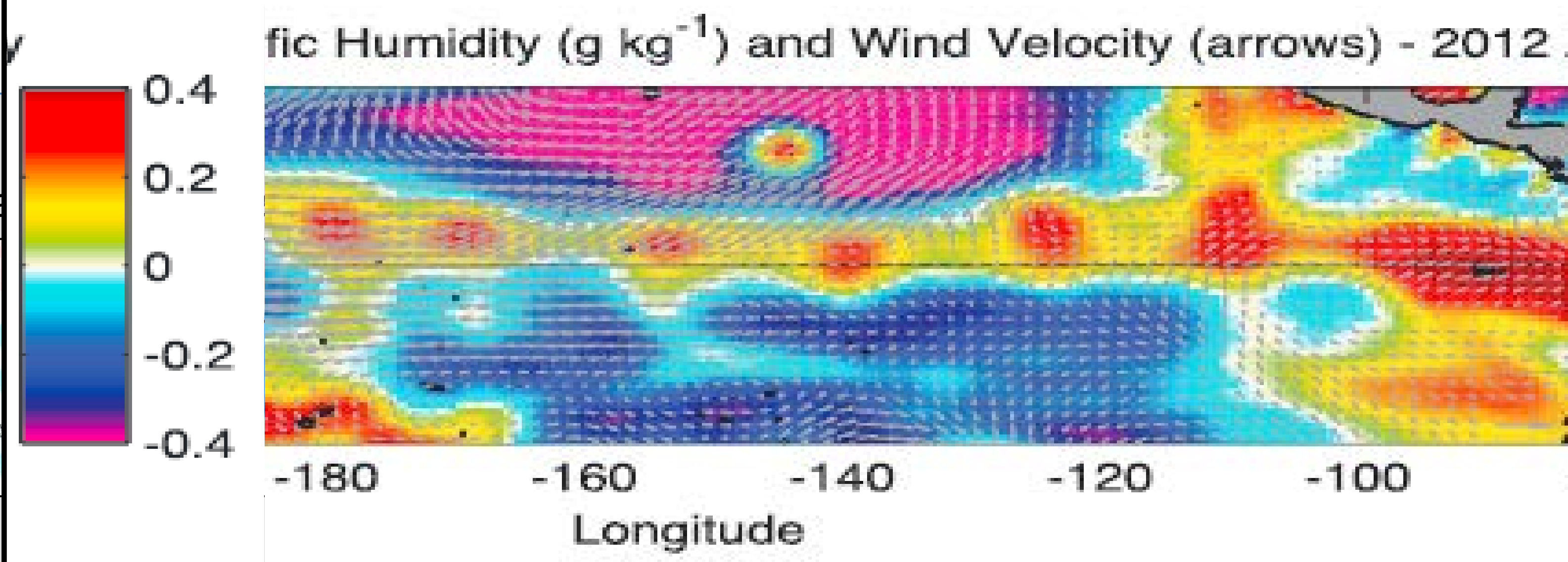


moorings

Impact of TAO/Triton moorings on

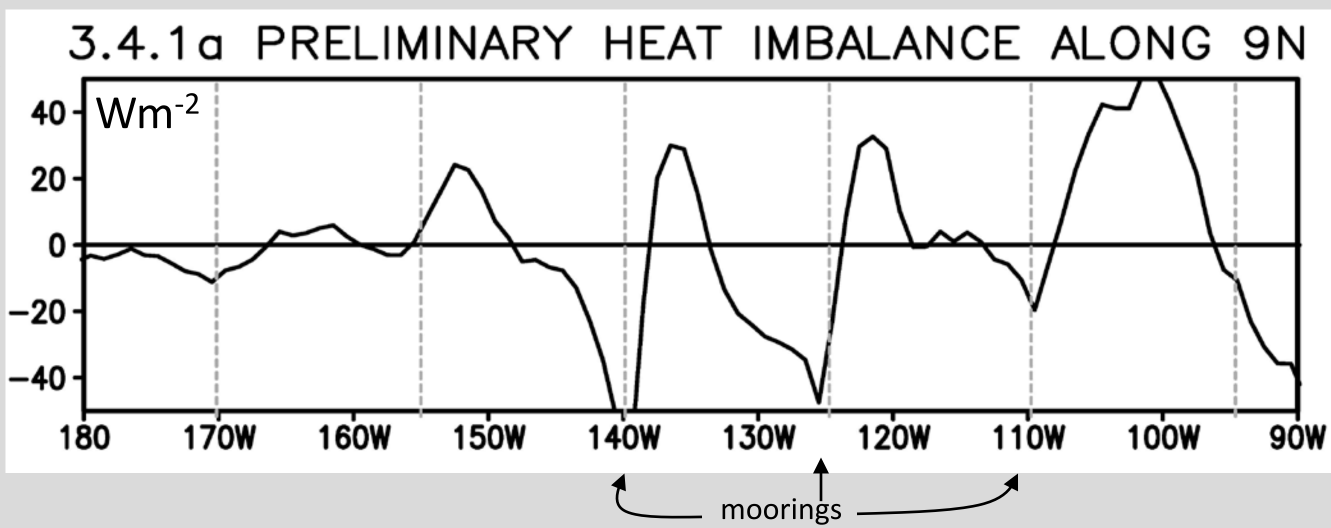
3.4.1a

Josey et al (2014) Fig. 1: ERA-I q'



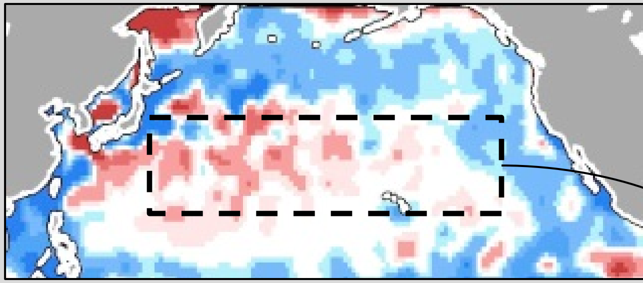
Heat out

Heat in



Impact of seasonal cycle

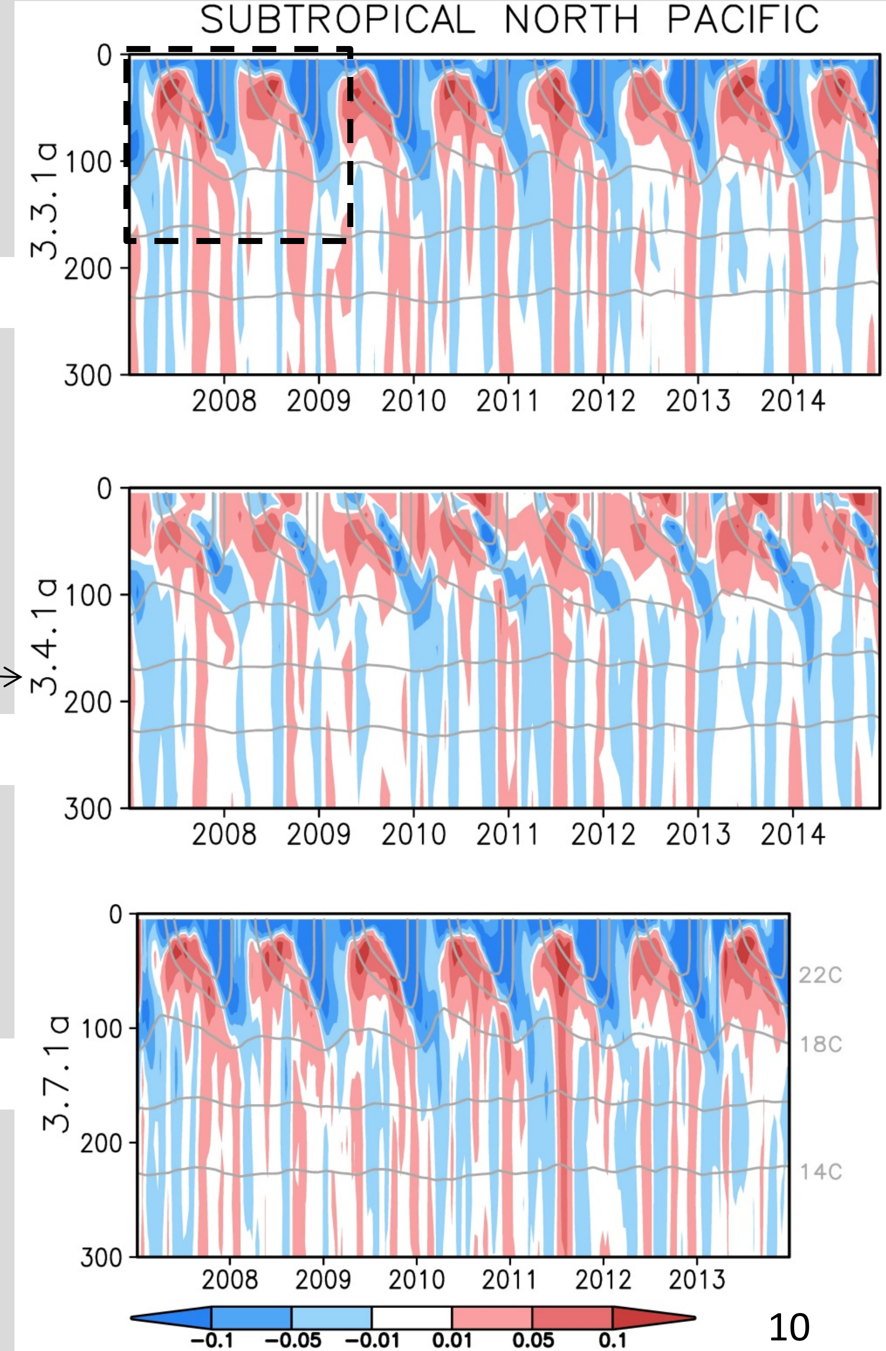
3.4.1a NP temperature imbalance



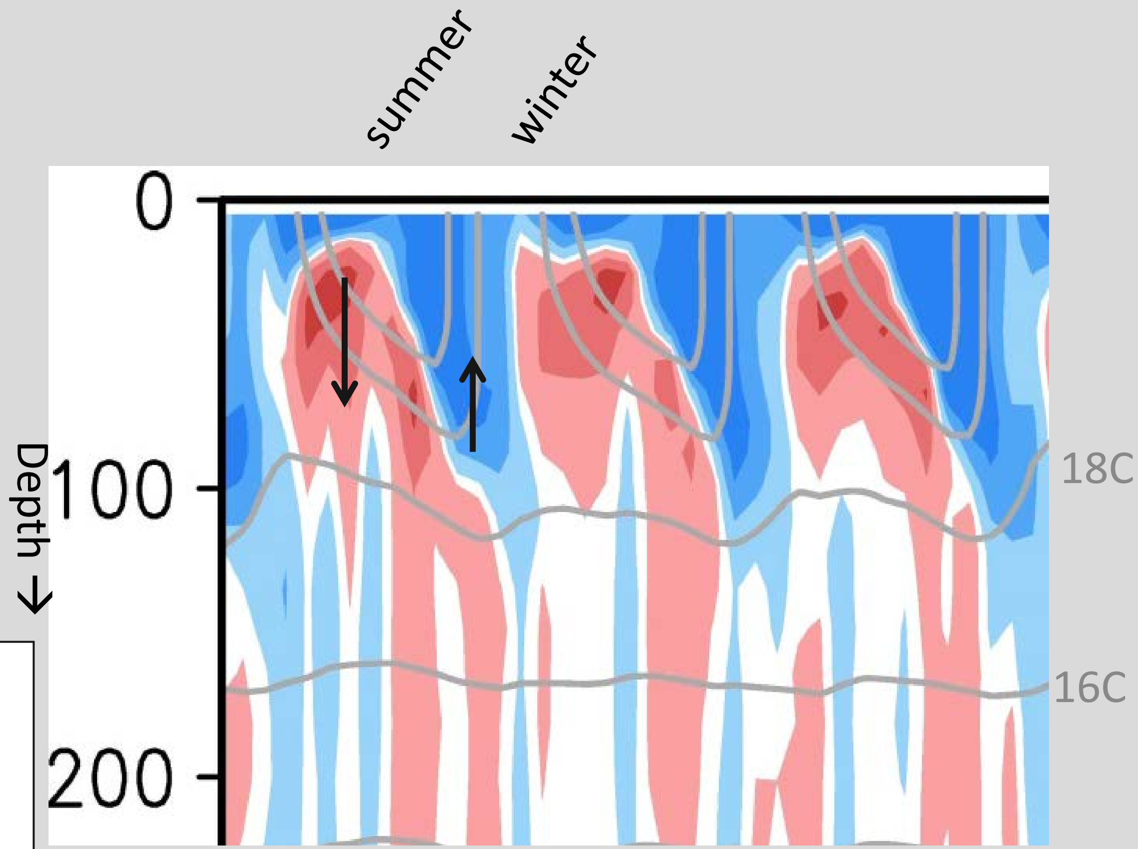
MERRA2

ERA-I

JRA-55



Detail of the 3.3.1a North Pacific temperature imbalance



What impact on mixed layer?

- Deepens summer thermocline,
- Weakens ΔT at the base of the winter thermocline

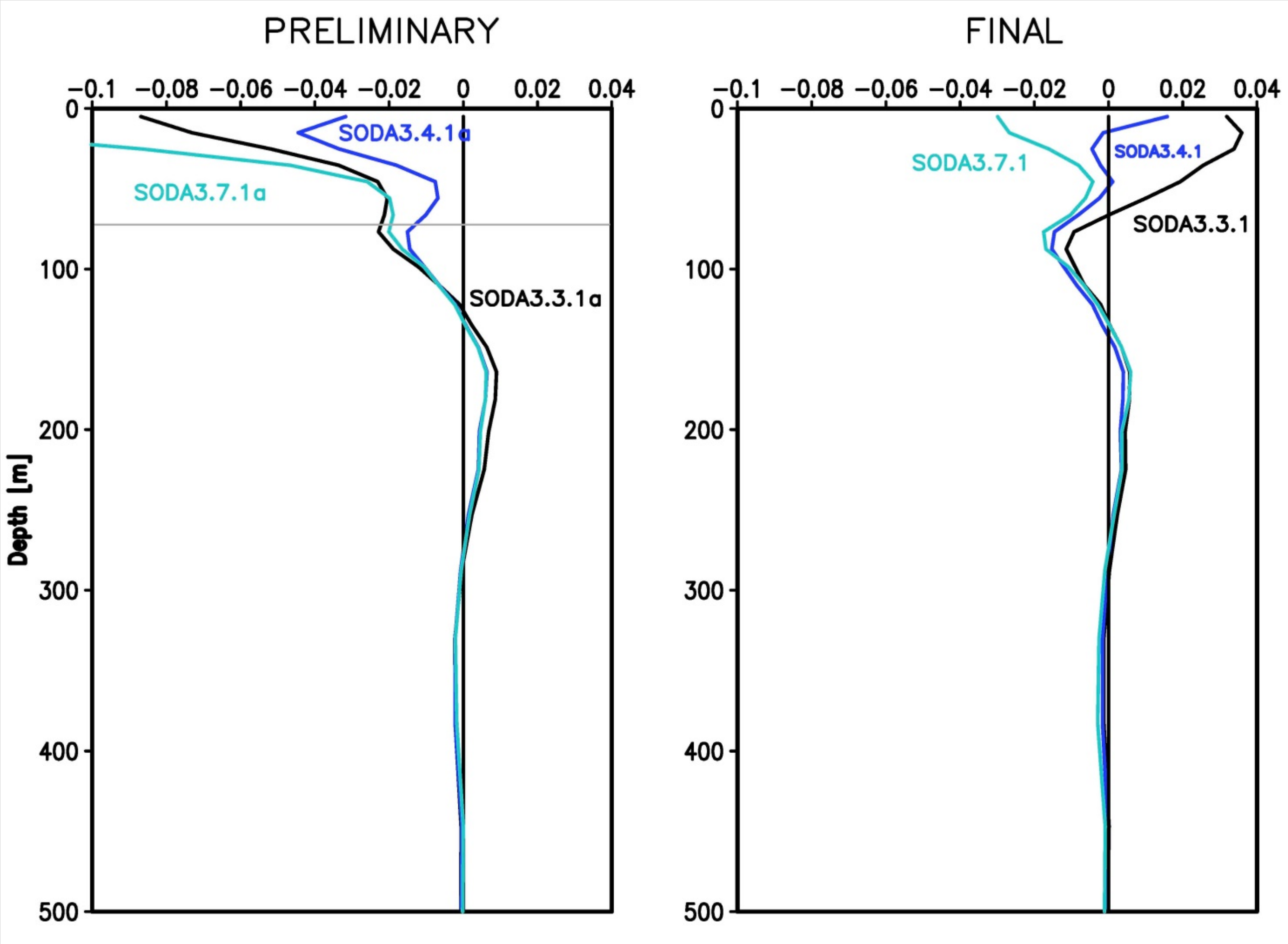
Modify net surface heat flux in the SODA forecast model

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

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

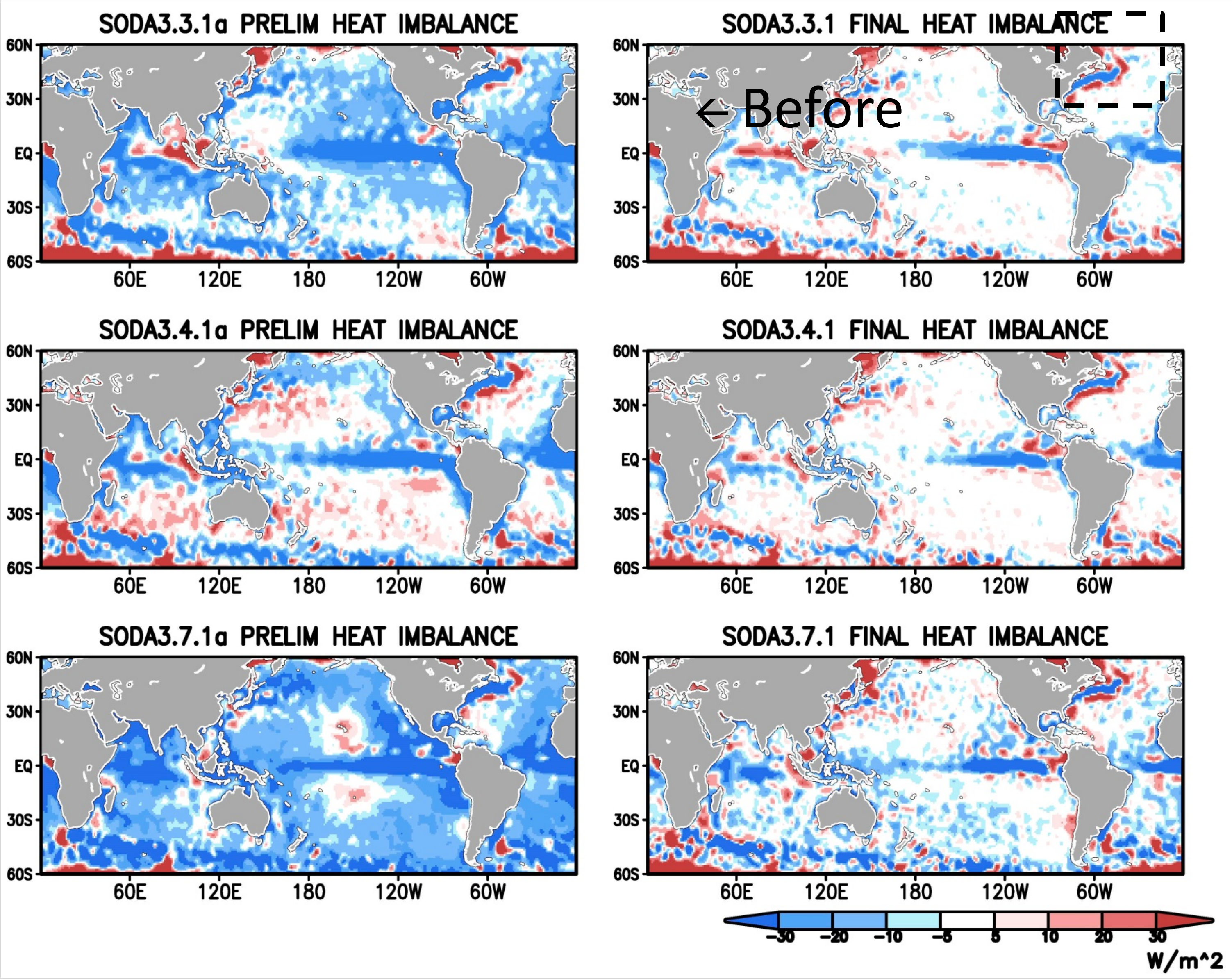
$$\frac{D\theta}{Dt} \cong d(z)\frac{Q + \delta Q}{\rho C_p}$$

$\widehat{\delta\theta}$ averaged 60S-60N, 2007-2014



Average heat imbalance (2007-2014)

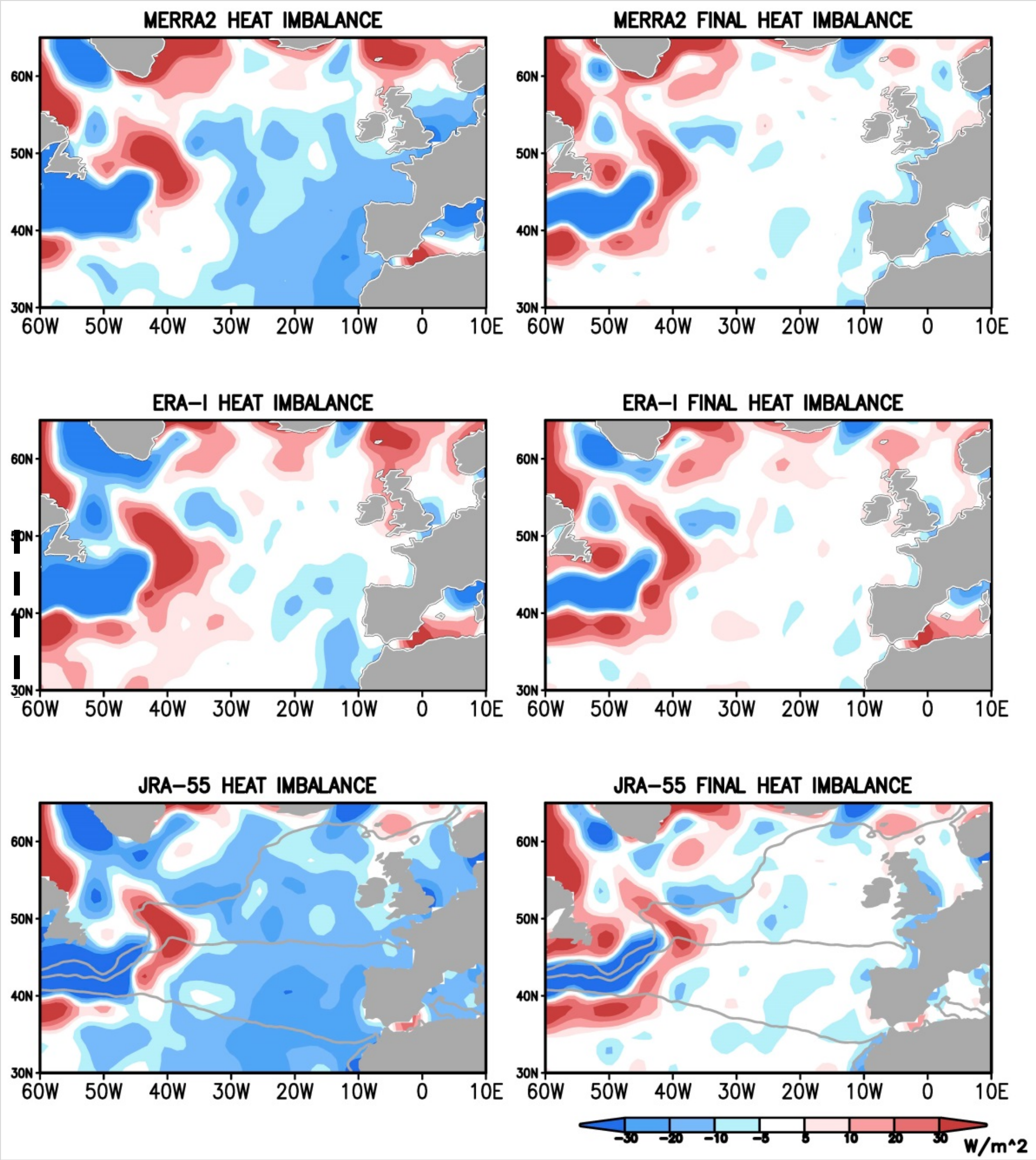
$$\rho C_p \int_{-75m}^{0} \delta\theta dz$$



Model error dominates in western boundary currents

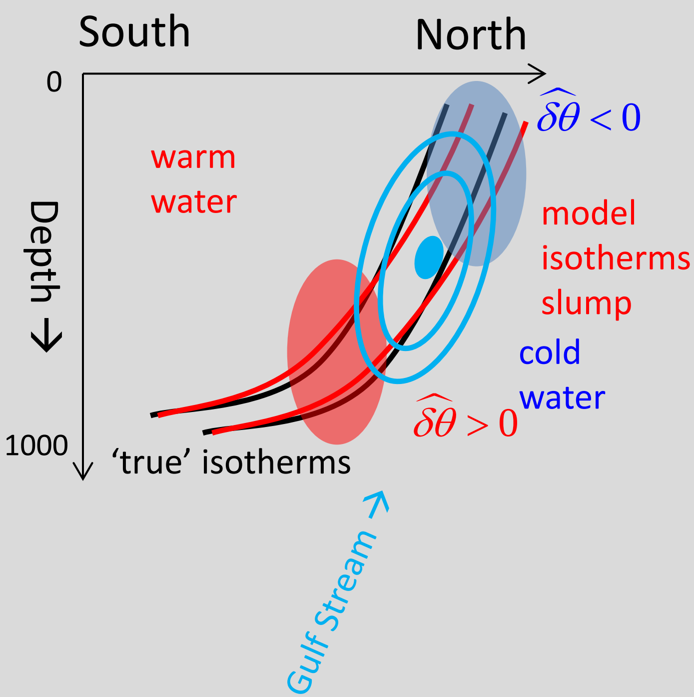
Detail from the North Atlantic

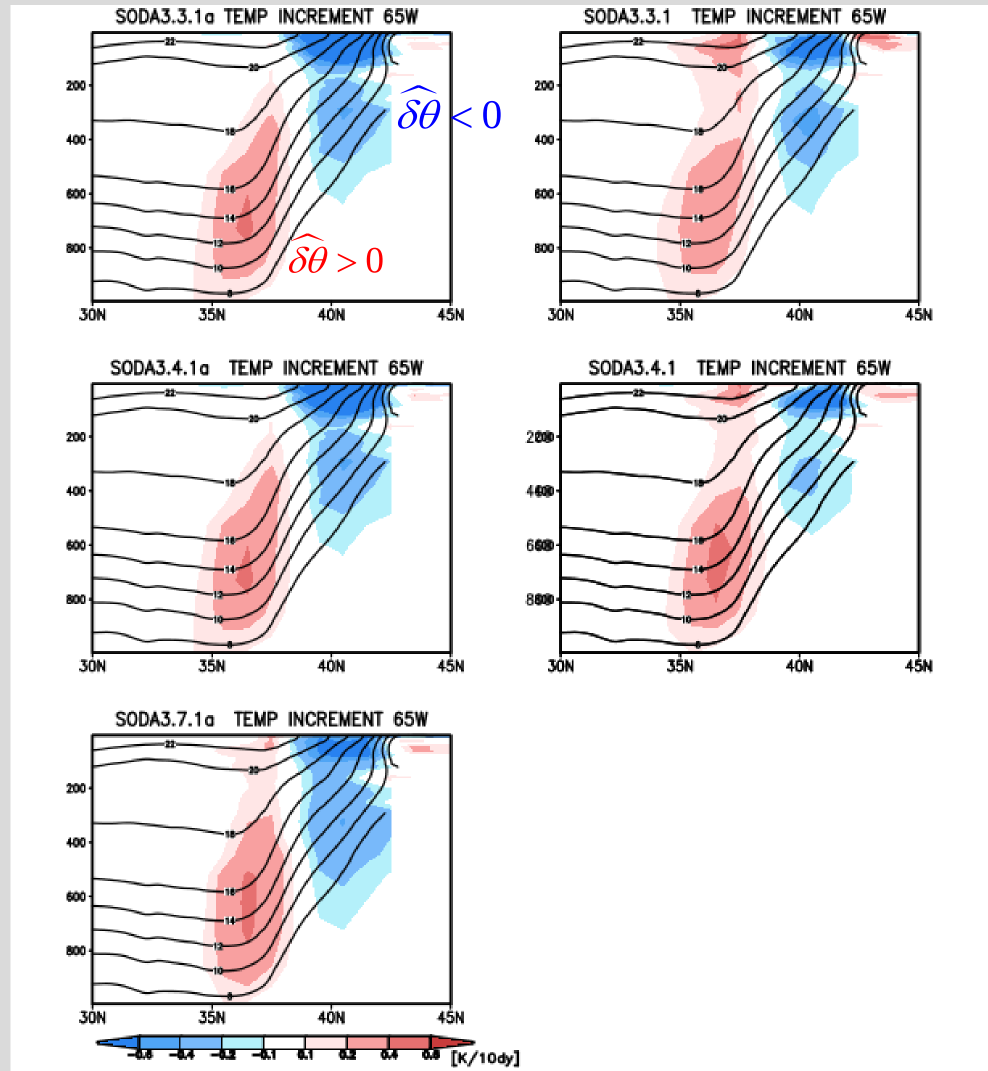
$$\rho C_p \int_{-75m}^{0} \delta\theta dz$$



Cross-section of temperature imbalance $\widehat{\delta\theta}$ across the Gulf Stream

Cross-section along 65°W

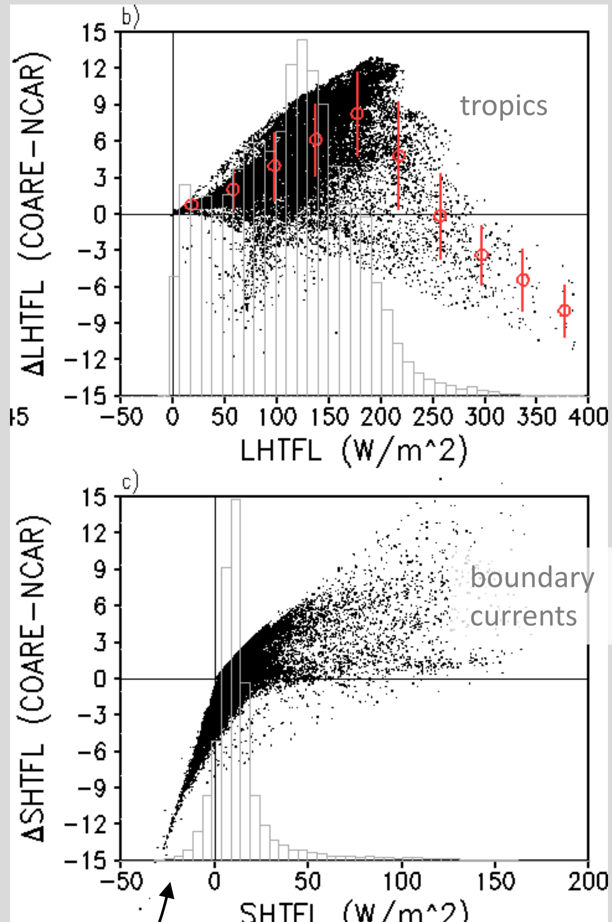




Impact of turbulent flux bulk formula: COARE4 vs NCAR

$$Q_l = C_l L \rho_a \mathbf{U}_a (q_a - q_s)$$

$$Q_s = C_s C_p \rho_a \mathbf{U}_a (T_a - SST)$$

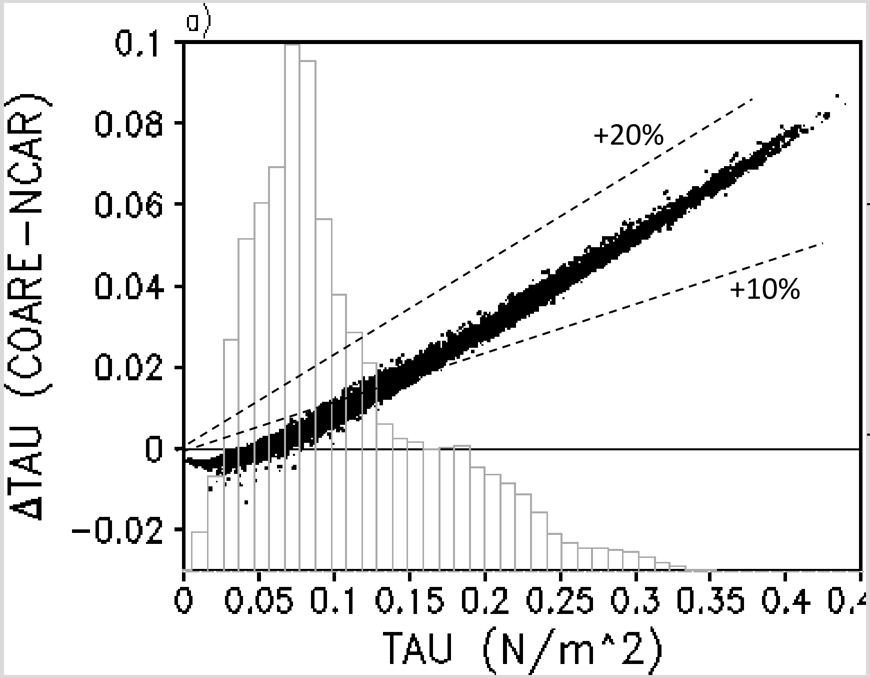


Upwelling zones

Impact of stress bulk formula
NCAR vs COARE4

$$\boldsymbol{\tau} = \rho_a C_D \left|\mathbf{U}_a\right| \mathbf{U}_a$$

Difference in stress



stress

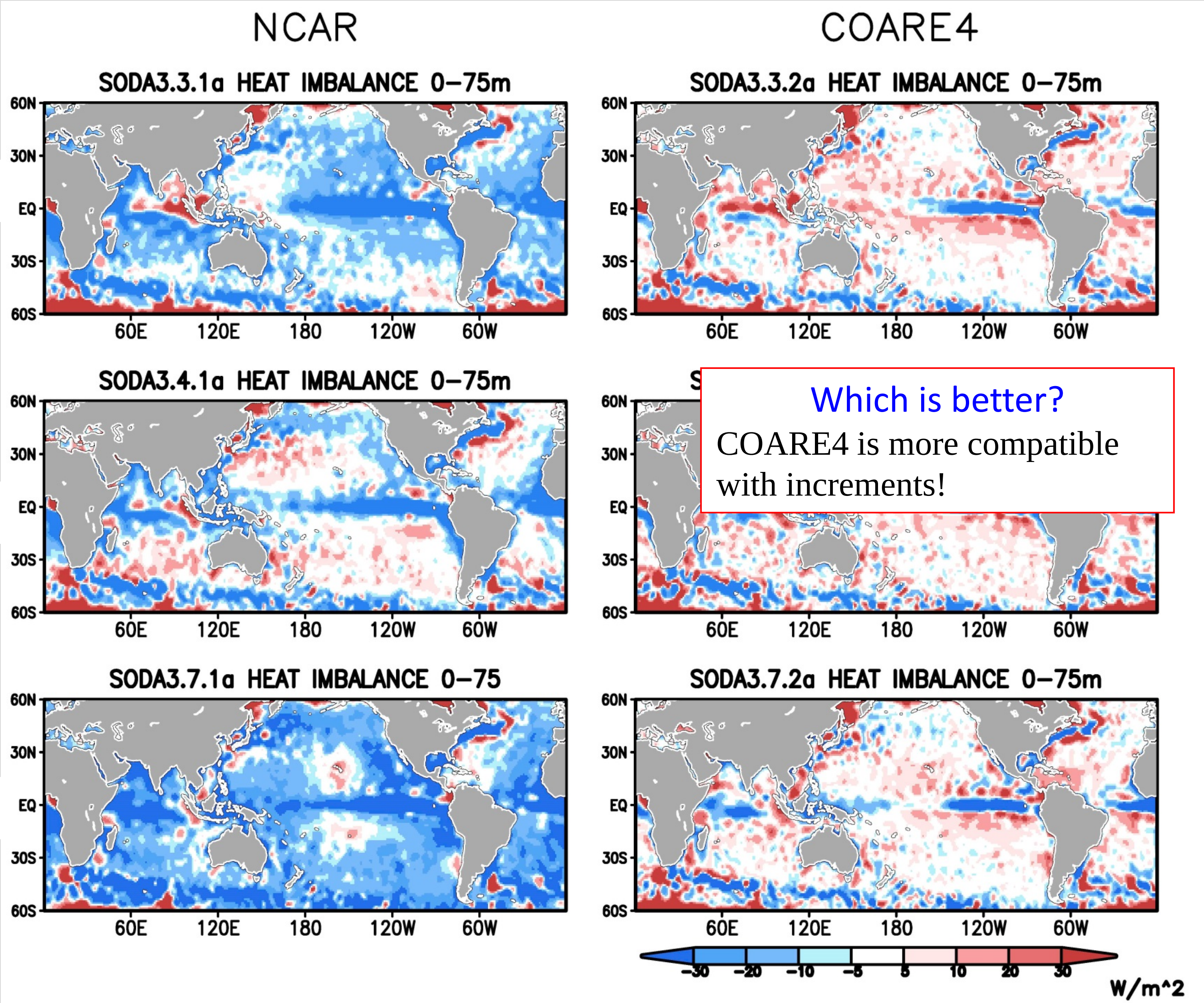
COARE4 stresses are larger under storm conditions

Impact of different flux parameterizations

MERRA2

ERA-I

JRA-55

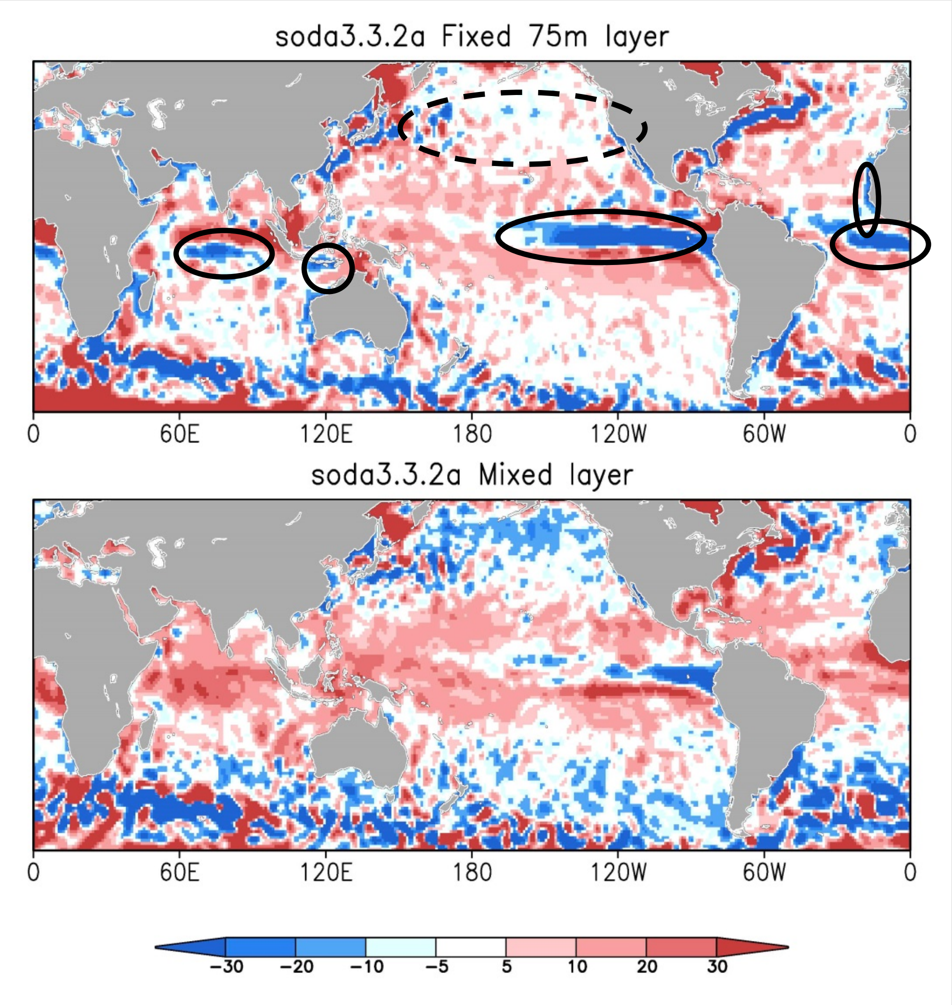


Which is better?

COARE4 is more compatible with increments!

Impact of a more realistic estimate of vertical scale of heat penetration

Fixed 75m layer



Comments

We've applied sequential DA to tackle a problem previously left to inverse methods – using ocean obs. to 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 ±5Wm^{-2} except in regions of strong currents.
  -
- Approach also provides a way to evaluate
  - model error
  - Bulk flux parameterizations
  - Sea ice thickness