Does choice of bulk surface flux algorithm contribute to systematic errors in climate and forecast models?

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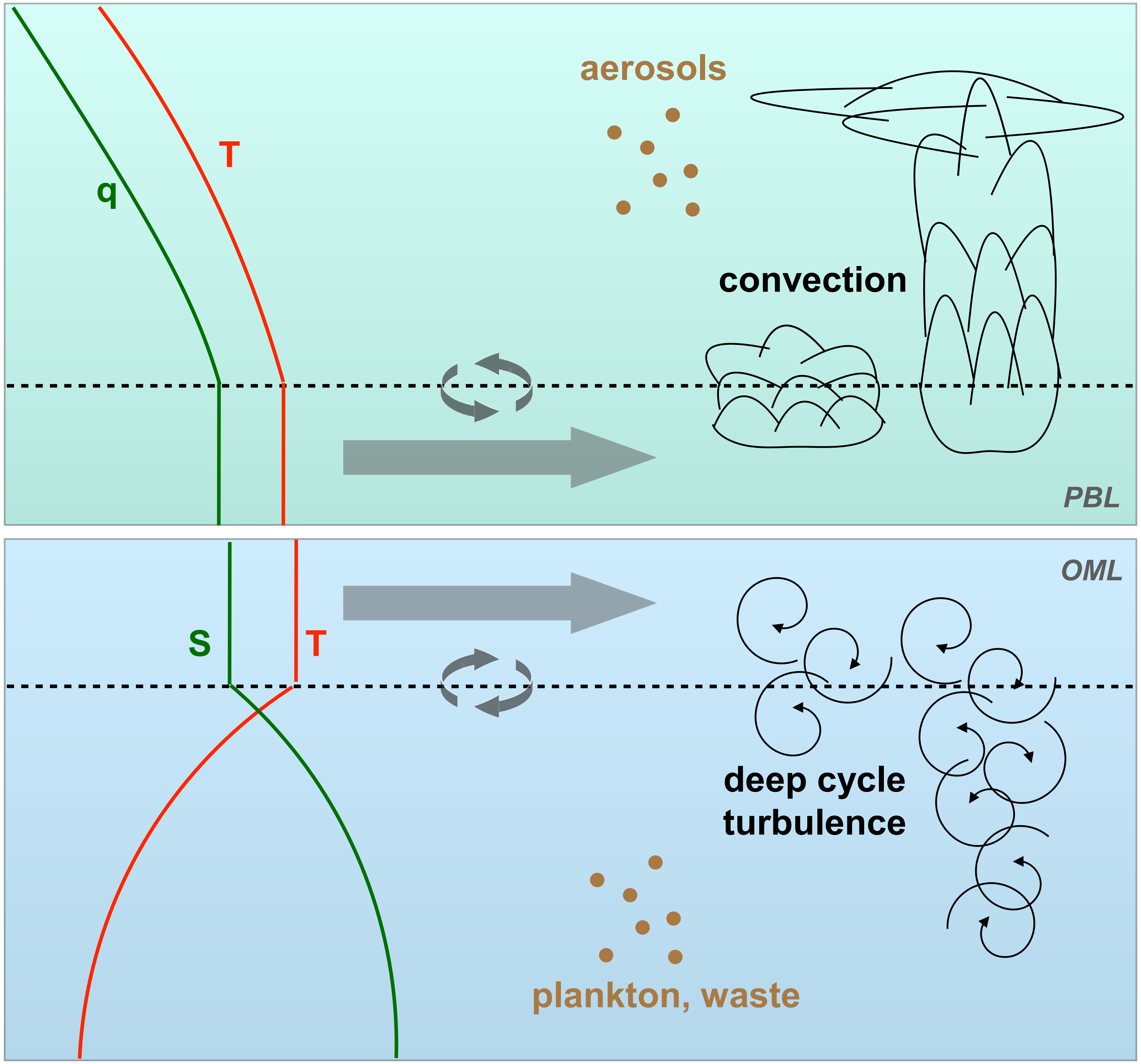
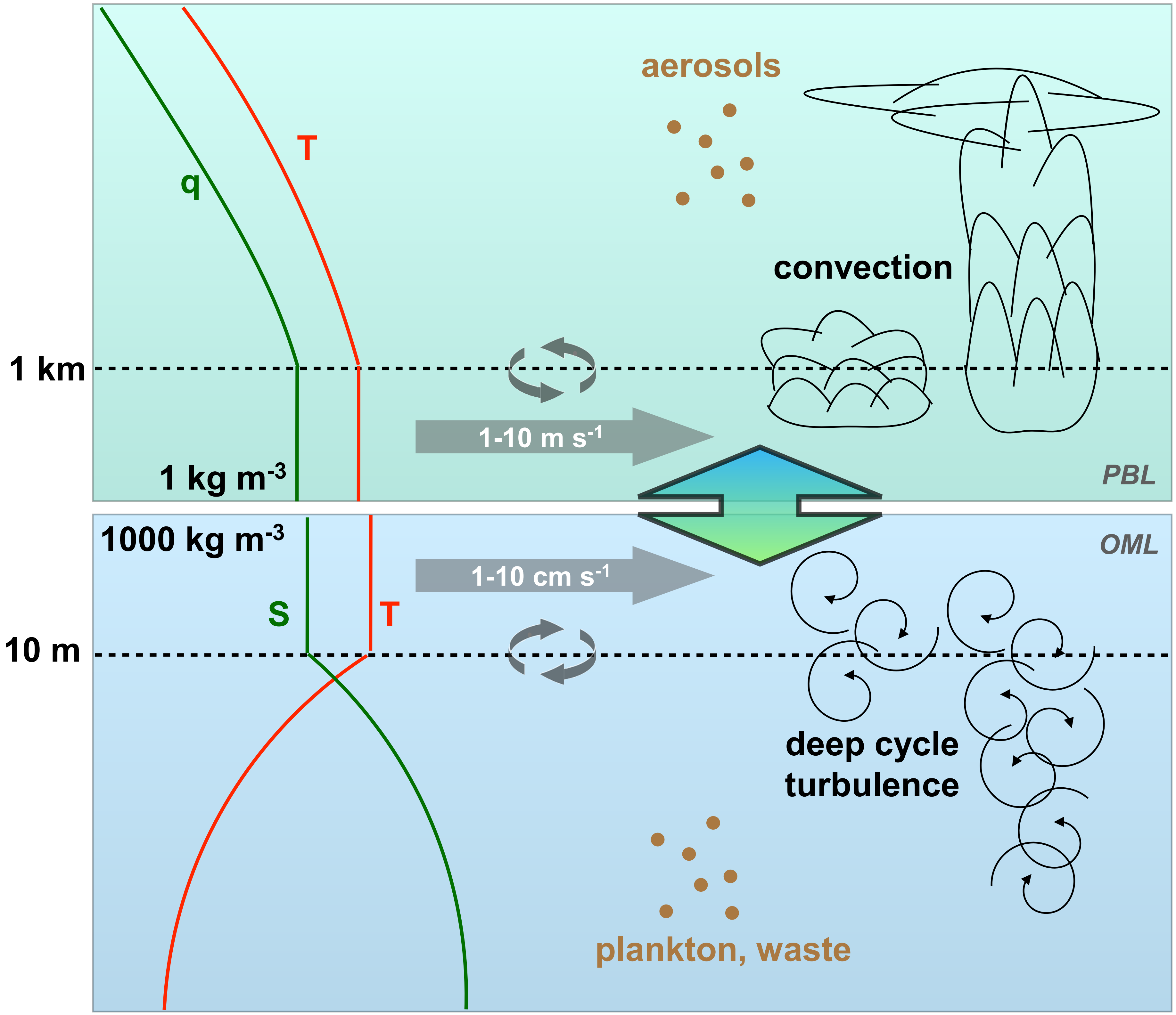
6th WGNE workshop on systematic errors in weather and climate models, 31 October - 4 November 2022
ECMWF, Reading UK

ocean-atmosphere symmetries (similarities)

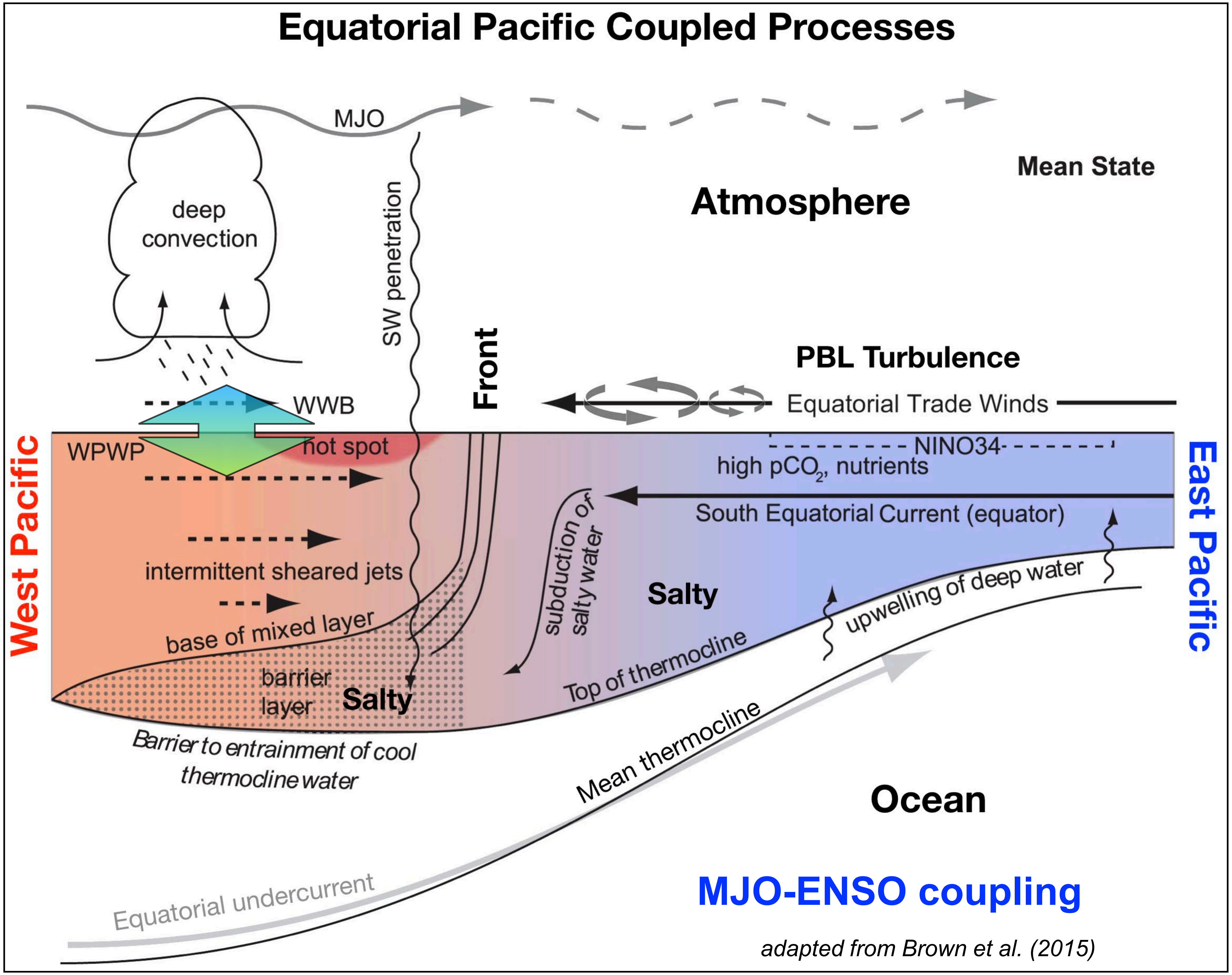


ocean-atmosphere asymmetries (differences)



- density: $\delta \sim 10^3$
- ML depth: $\delta \sim 10^2$
- *u,v*: $\delta \sim 10^2$
- clouds are global; DCT mostly on Equator
- clouds regulate radiation; DCT does not

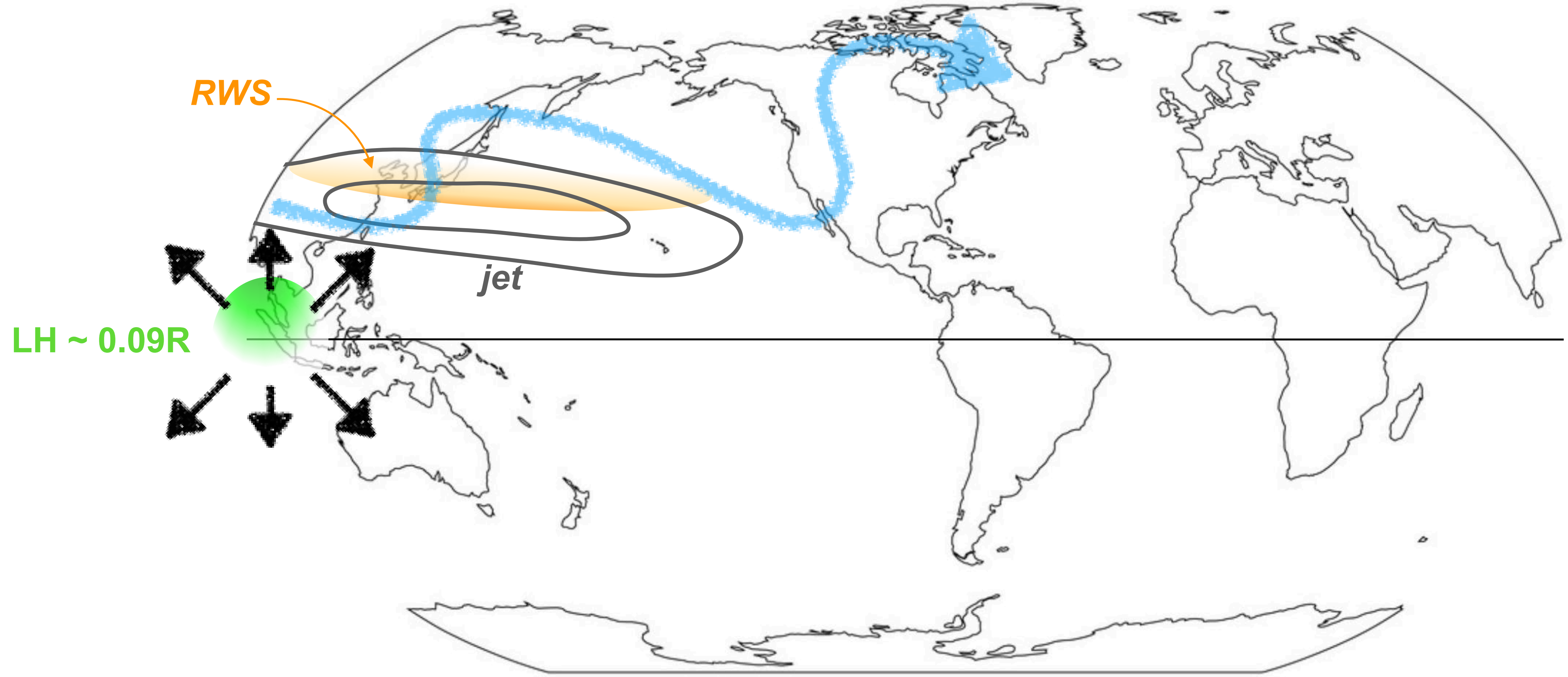
marine surface fluxes couple ocean & atmosphere across scales



bulk surface flux effects for weather & climate simulation

Example: MJO teleconnections

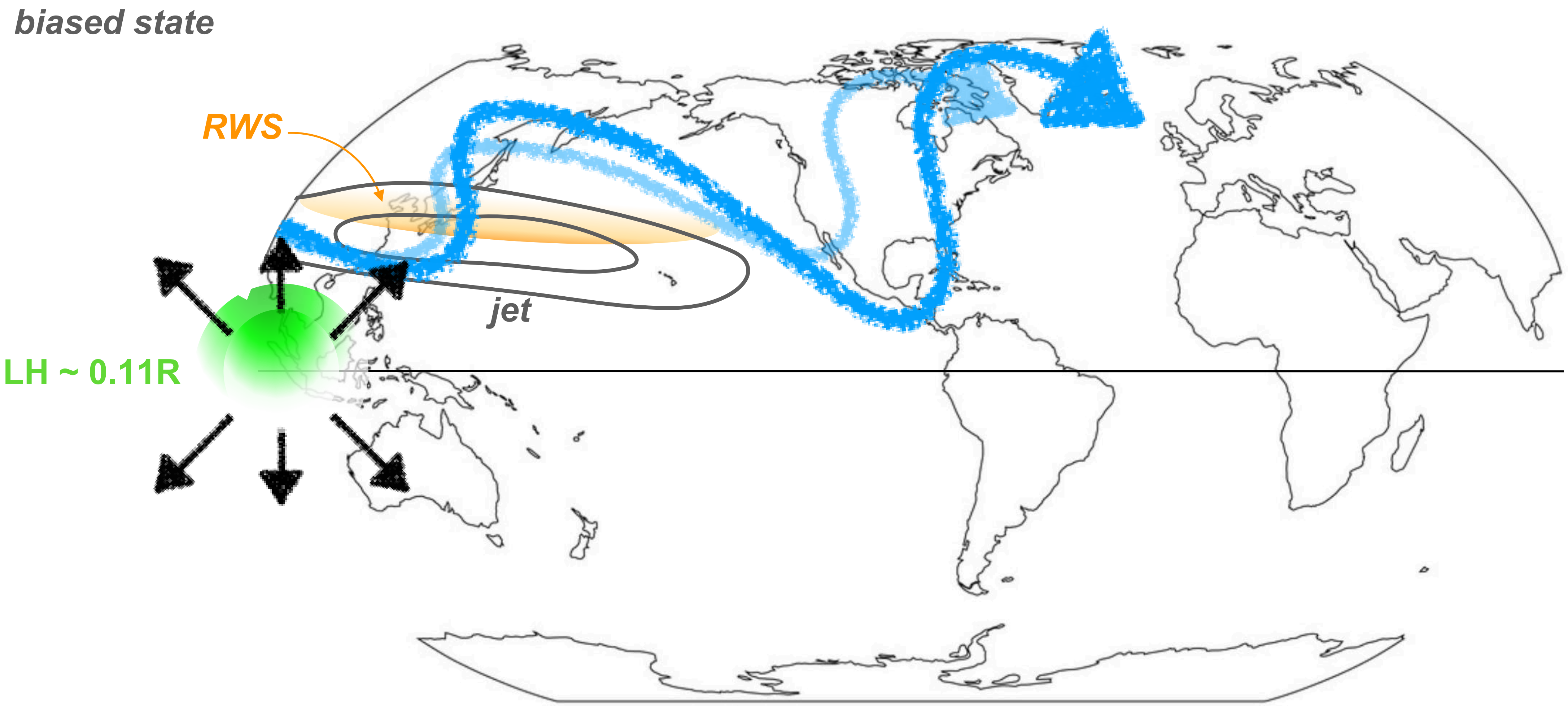
normal state



animations based on Henderson et al. 2017

bulk surface flux effects for weather & climate simulation

Example: MJO teleconnections



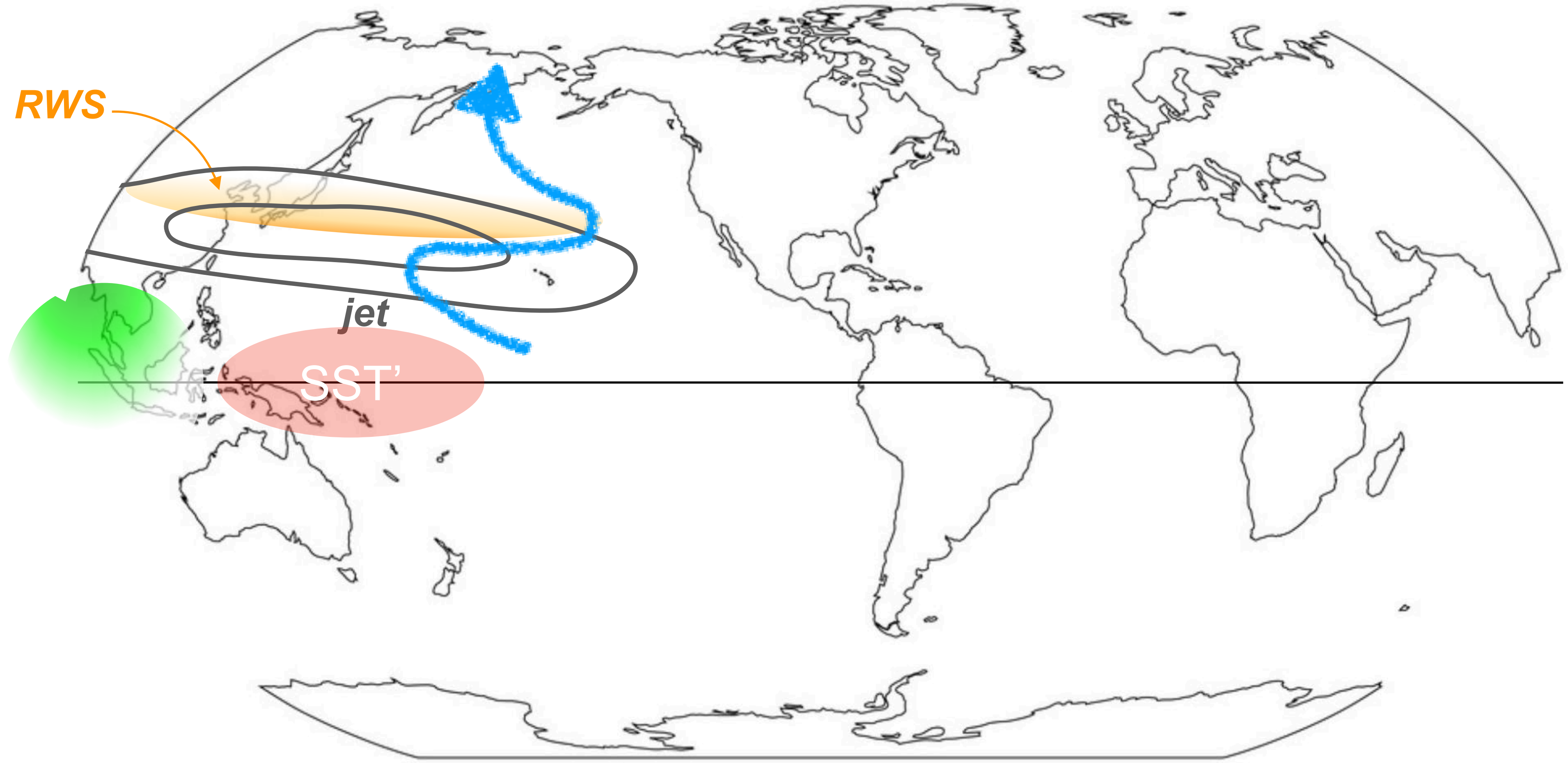
animations based on Henderson et al. 2017

- MJO amplitude biases -> jet stream biases

bulk surface flux effects for weather & climate simulation

Example: MJO teleconnections

biased state

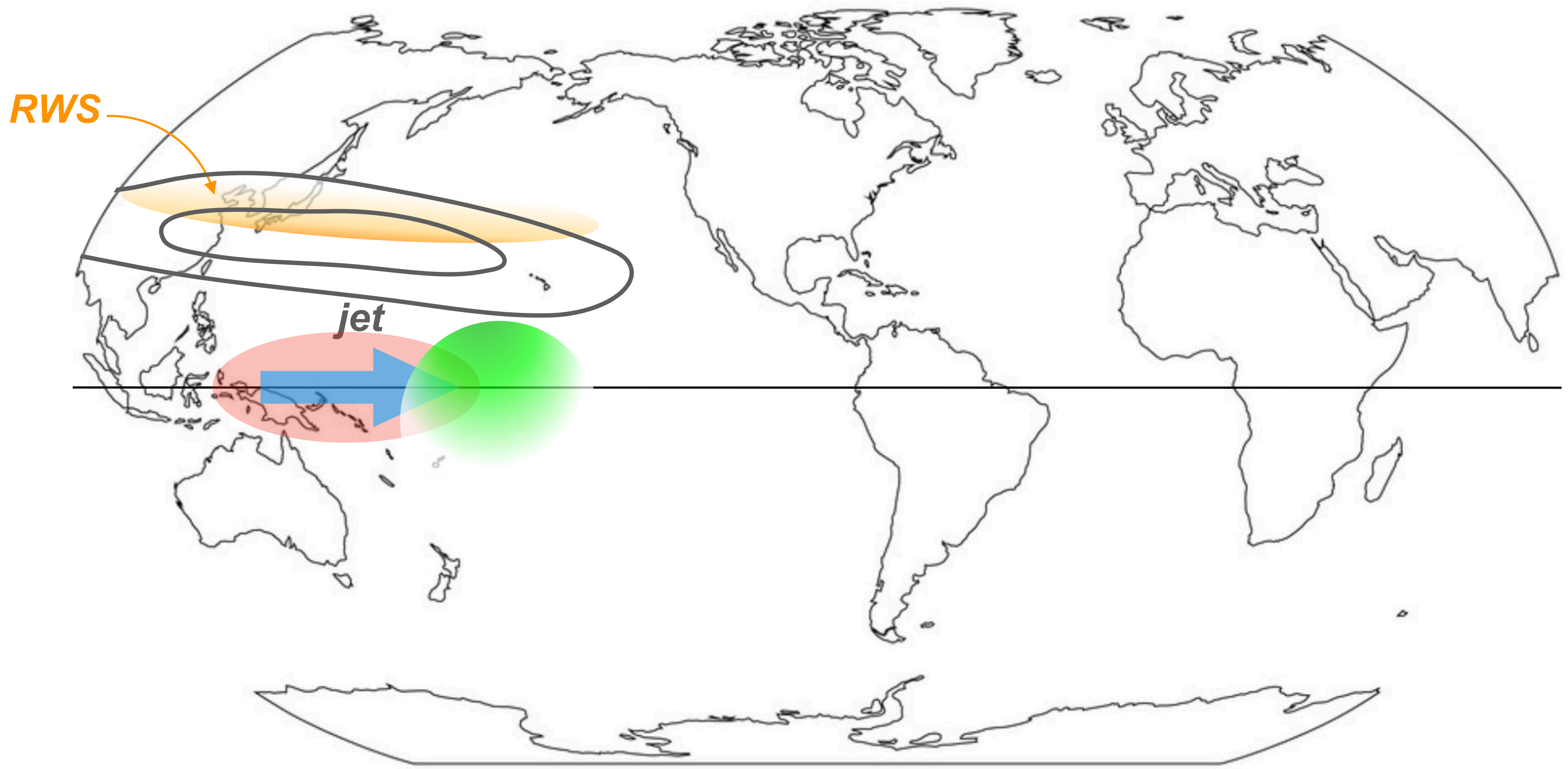


animations based on Henderson et al. 2017

- MJO amplitude biases -> jet stream biases
- MJO propagation biases -> jet stream biases

bulk surface flux effects for weather & climate simulation

Example: MJO-ENSO interactions



animations based on Henderson et al. 2017

- MJO amplitude biases -> jet stream biases
- MJO propagation biases -> jet stream biases
- MJO propagation biases -> ocean Kelvin wave, ENSO biases

in this talk…

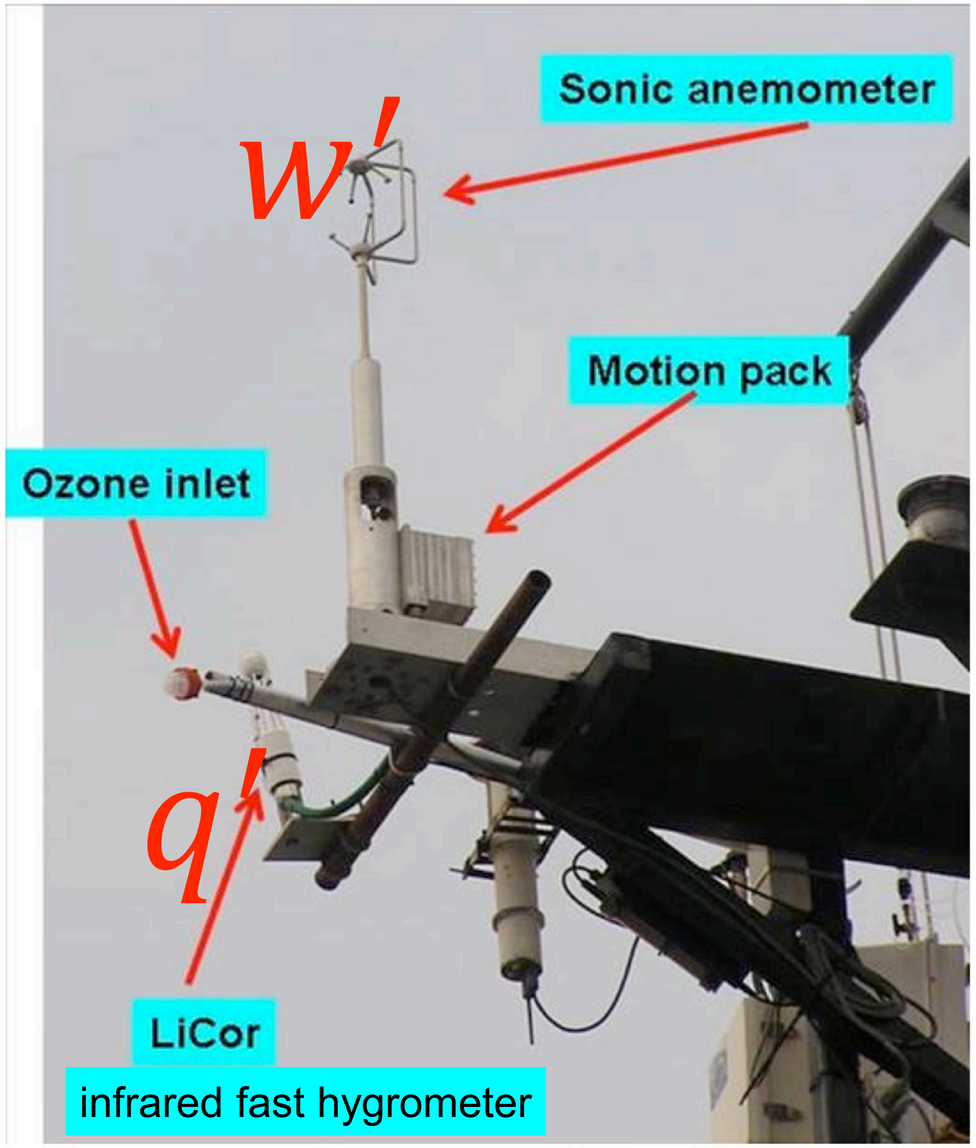
- how to diagnose surface flux biases
- surface flux biases and the MJO
- surface flux biases and the ITCZ

how to diagnose surface flux biases

surface fluxes: measurement versus estimation

direct covariance measurement

$$LH = L_e \overline{w'q'}$$



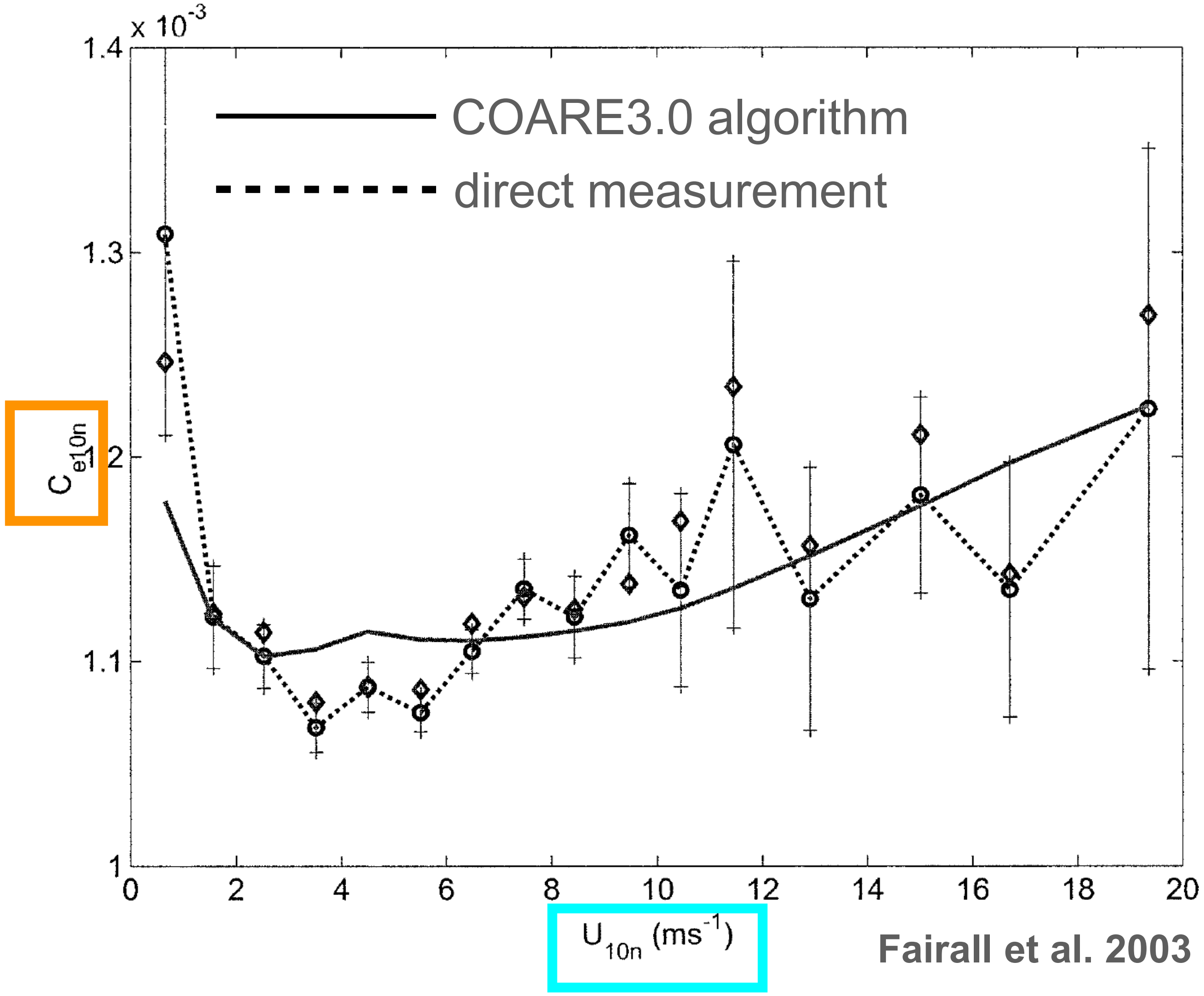
Weller et al. 2008

bulk estimation

$$LH = L_v C_e |V| (q_{SST}^* - q_{2m})$$

parameterization

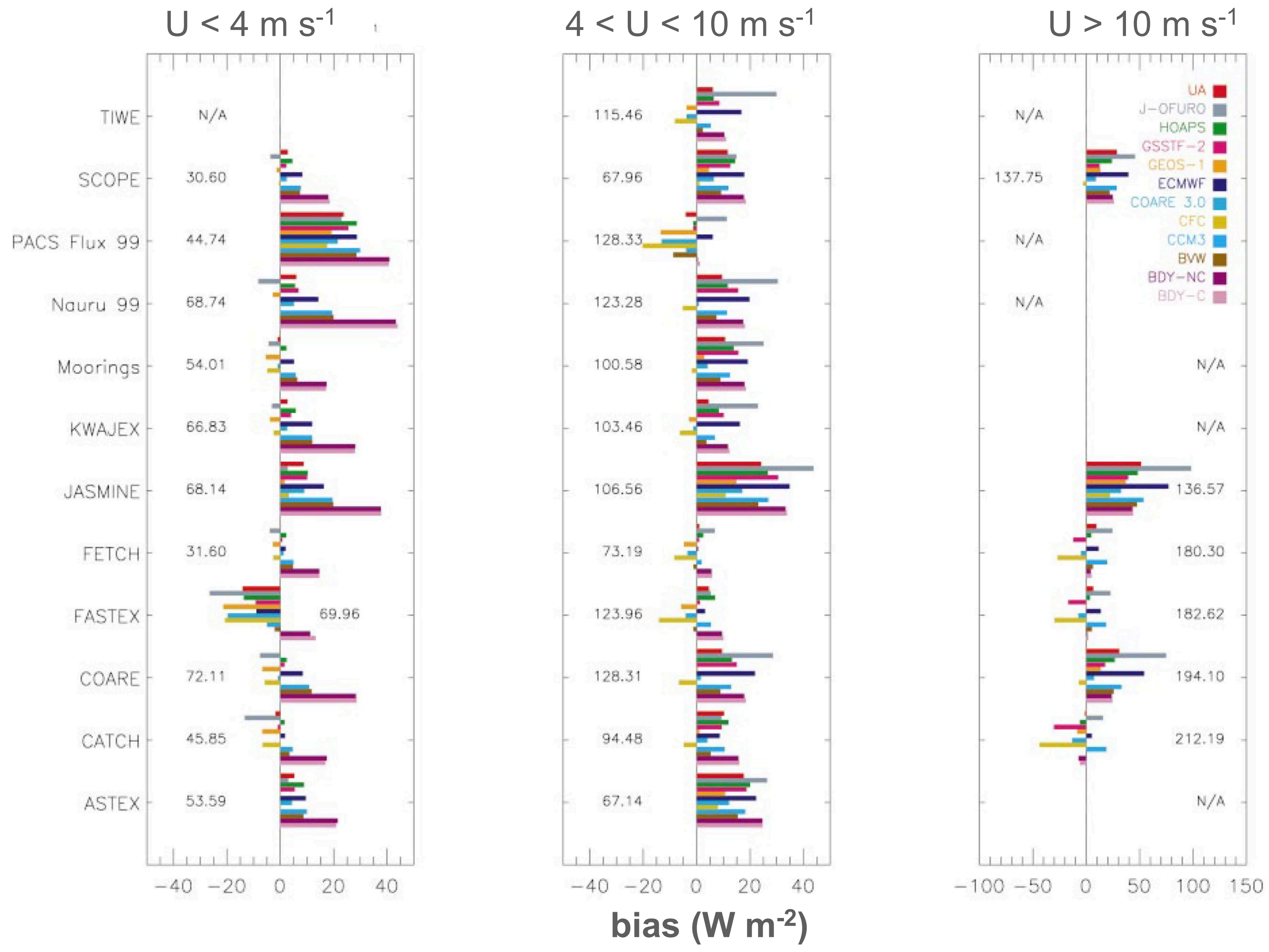
bulk inputs



Fairall et al. 2003

surface flux biases among bulk algorithms

- climate and forecast models compute surface fluxes using a variety of bulk surface flux algorithms
- most algorithms overestimate surface fluxes



10-20% biases on average

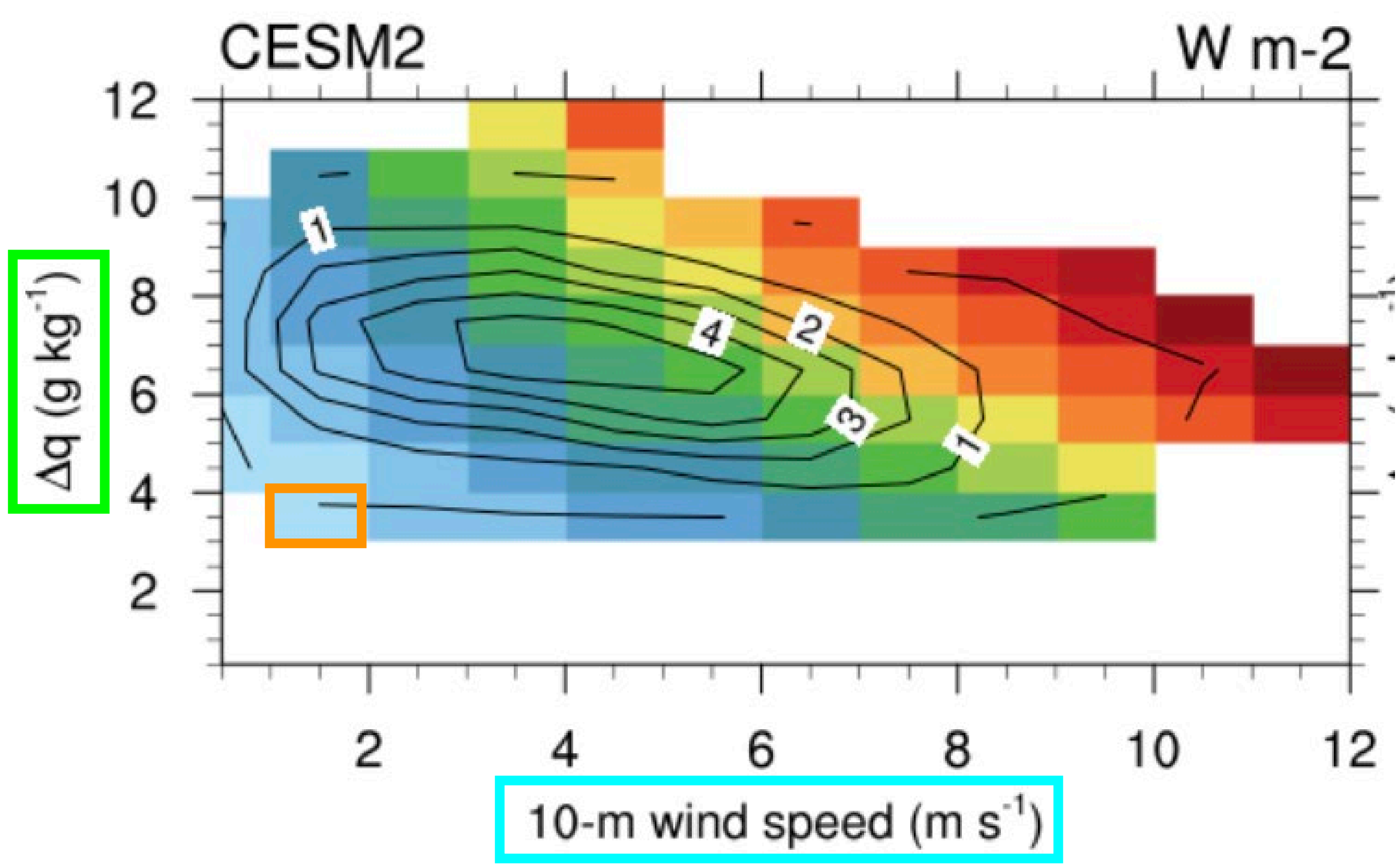
COARE algorithm is among the “least problematic”

Brunke et al. (2003)

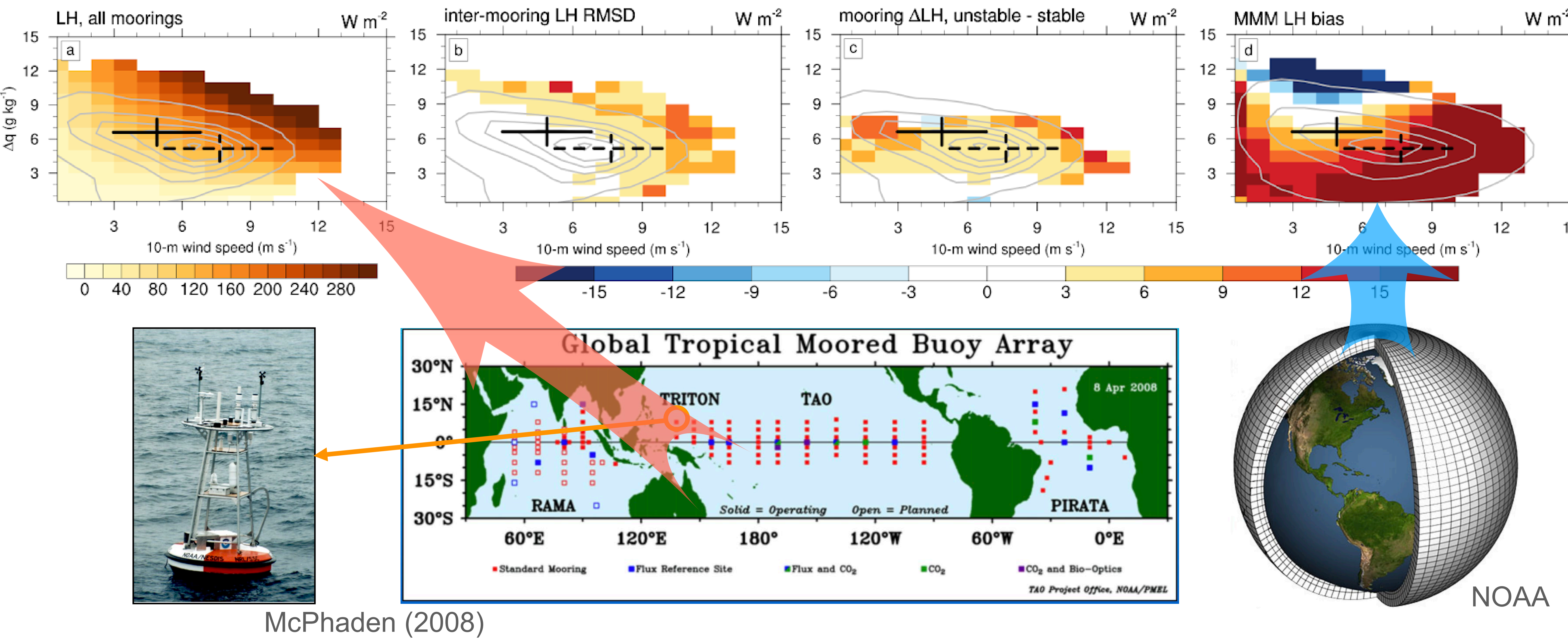
surface fluxes: how to diagnose their biases in models?

$$LH = L_v C_e |V| (q^*_{SST} - q_{2m})$$

$$LH = L_v C_e |V| \Delta q$$

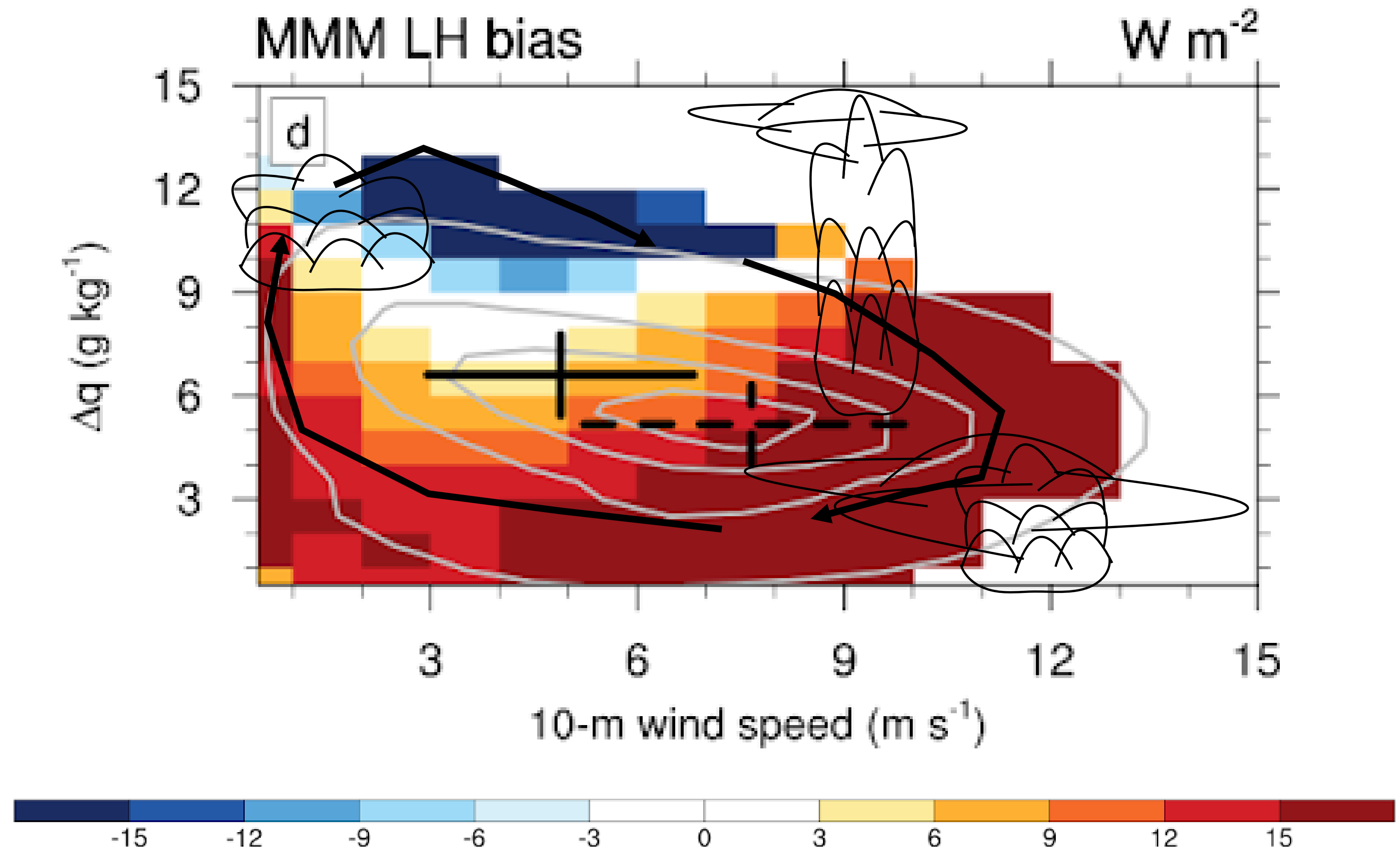


surface fluxes: how to diagnose their biases in models?



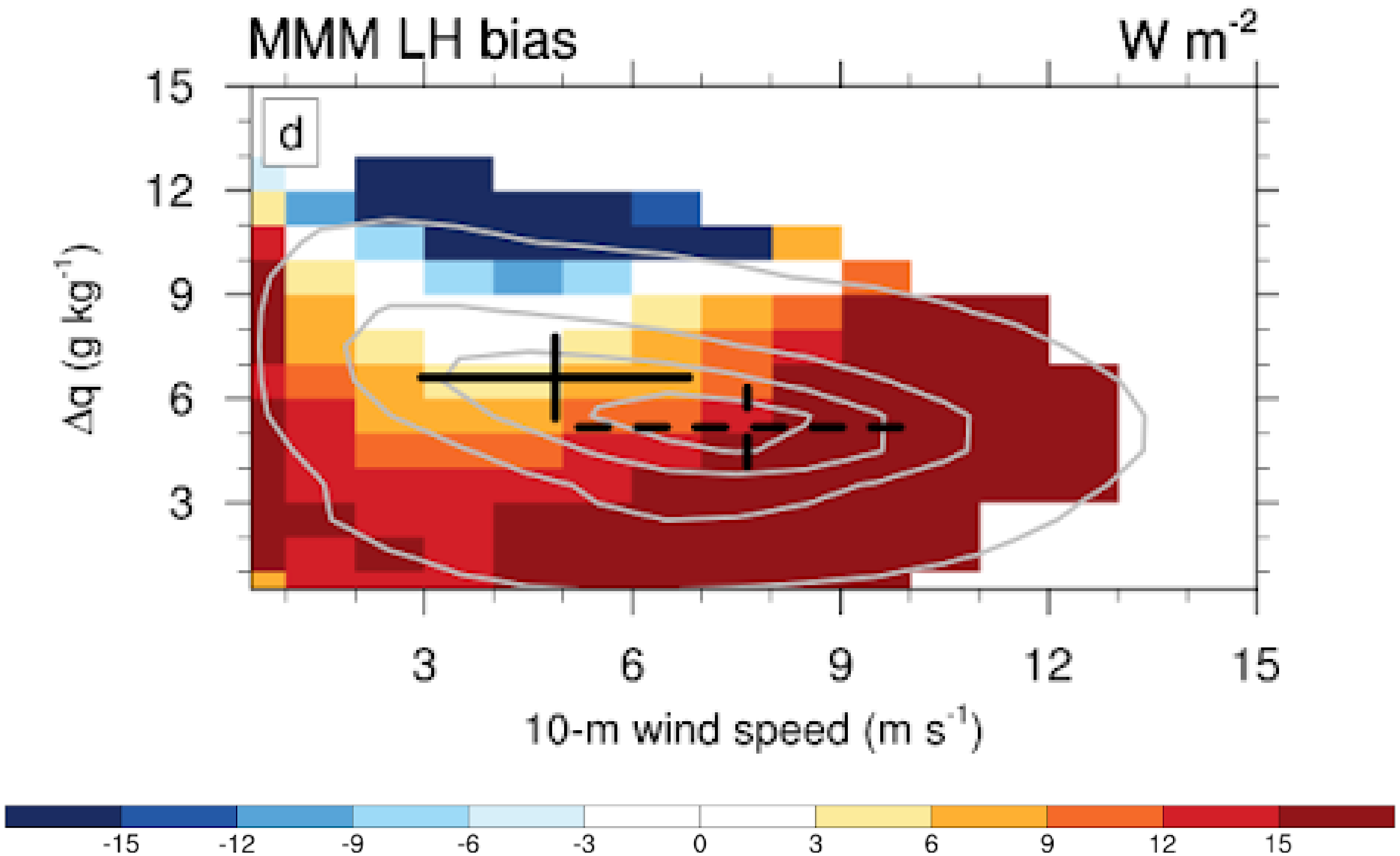
- the “flux matrix” diagnostic illustrates where model fluxes are most biased as a function of wind speed and humidity disequilibrium.

surface fluxes diagnostic implications



- flux biases are not uniform throughout the convective lifecycle!
  - fluxes too large for mature convection
  - fluxes too small for shallow and transitioning convection

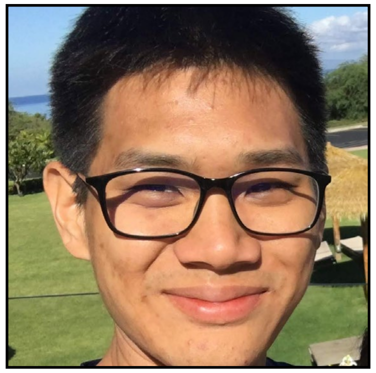
how to assess bulk algorithm impacts



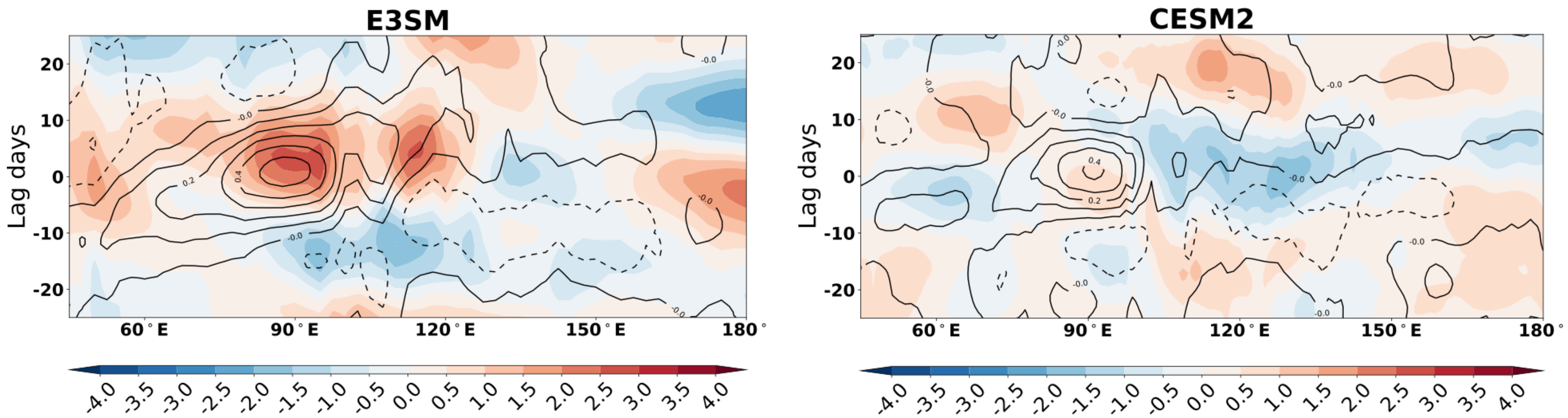
- “offline” correction
  - use flux matrix to generate a “corrected” flux time series
  - no feedbacks to ocean or atmosphere
- “inline correction
  - replace a model’s default flux algorithm with the COARE flux algorithm

surface flux biases and the MJO

flux corrections for the MJO



Chia-Wei Hsu (NOAA/PSL)



MJO rainfall (contour) and surface latent heat flux (shading)

offline correction: default flux algorithm is overly supportive of MJO convection; too weakly supportive of MJO propagation

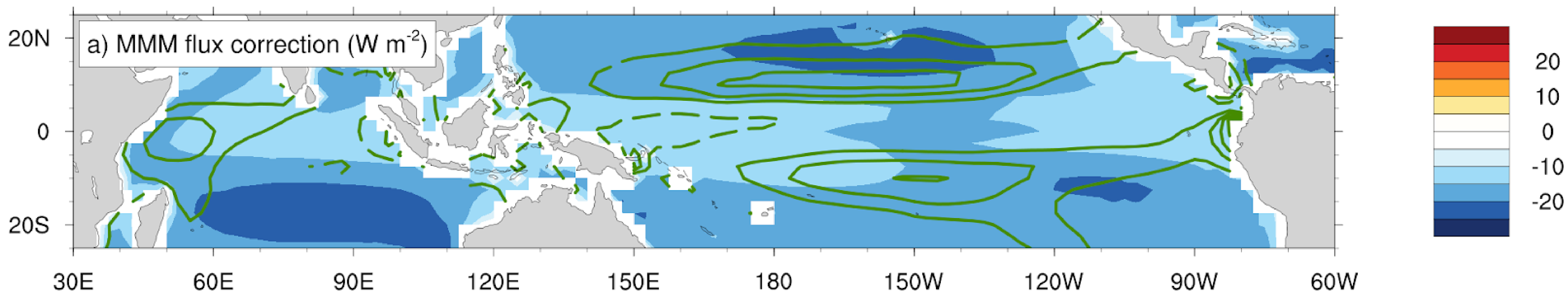
Model/OBS	CTRL	COARE	COARE-CTRL
E3SM_climo	1.01	1.08	0.07
CESM2_amip	0.95	1.10	0.15
TRMM[a]	2.3		

Hsu et al. 2022

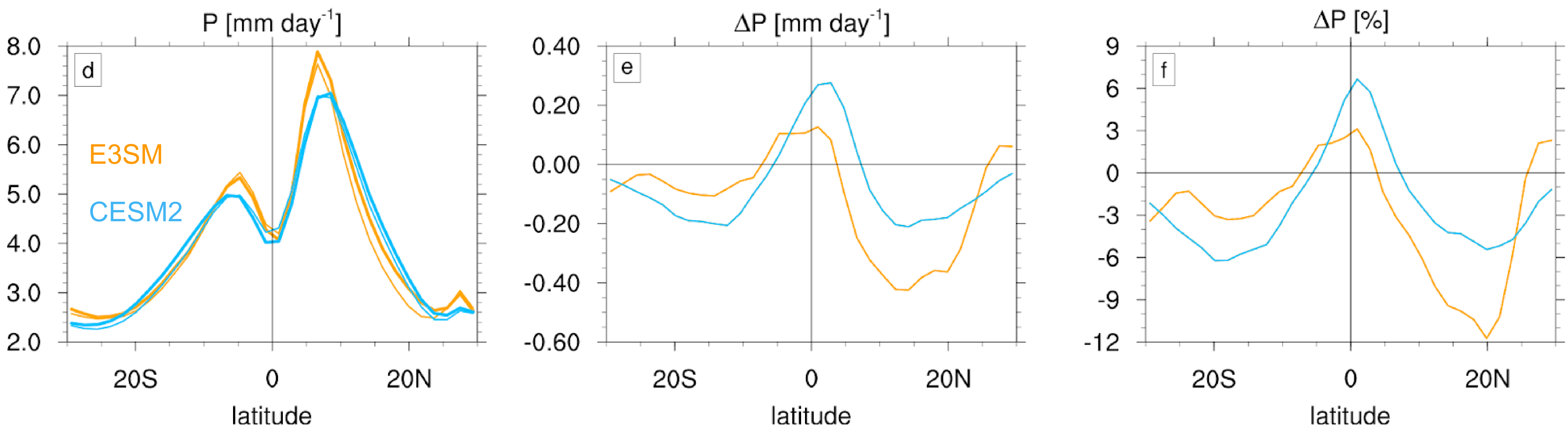
inline correction: COARE fluxes improve MJO eastward propagation

surface flux biases and the double ITCZ bias

bulk surface flux effects for weather & climate simulation



bulk surface flux effects for weather & climate simulation



DeMott et al. (2022; in prep)

- “inline” correction in atmosphere-only simulations of two models reduce the double ITCZ bias

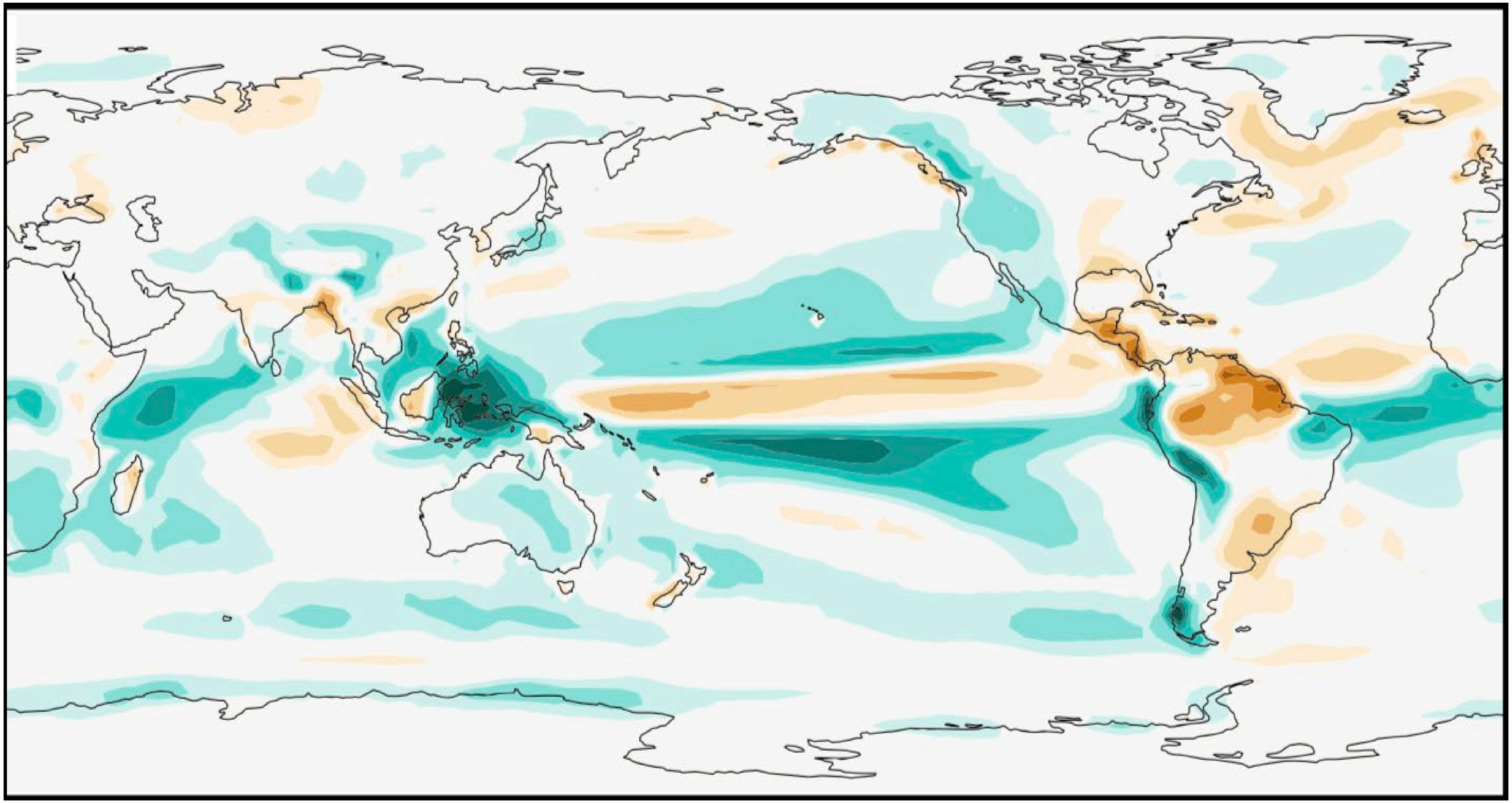
summary

- ocean processes modulate SST
- surface fluxes communicate SST to the atmosphere
- bulk flux algorithms in most climate models overestimate surface fluxes
- surface flux biases are not uniform across convective lifecycles
    - erroneous ocean feedbacks to convective development, teleconnections
- offline and inline corrections to bulk fluxes indicate
    - improved MJO
    - reduced double ITCZ bias
    - more analysis is needed!
- ongoing work
    - MJO-ENSO feedbacks in the E3SM with different bulk flux algorithms

extra slides

E3SMv1 coupled simulations

Example: the ITCZ

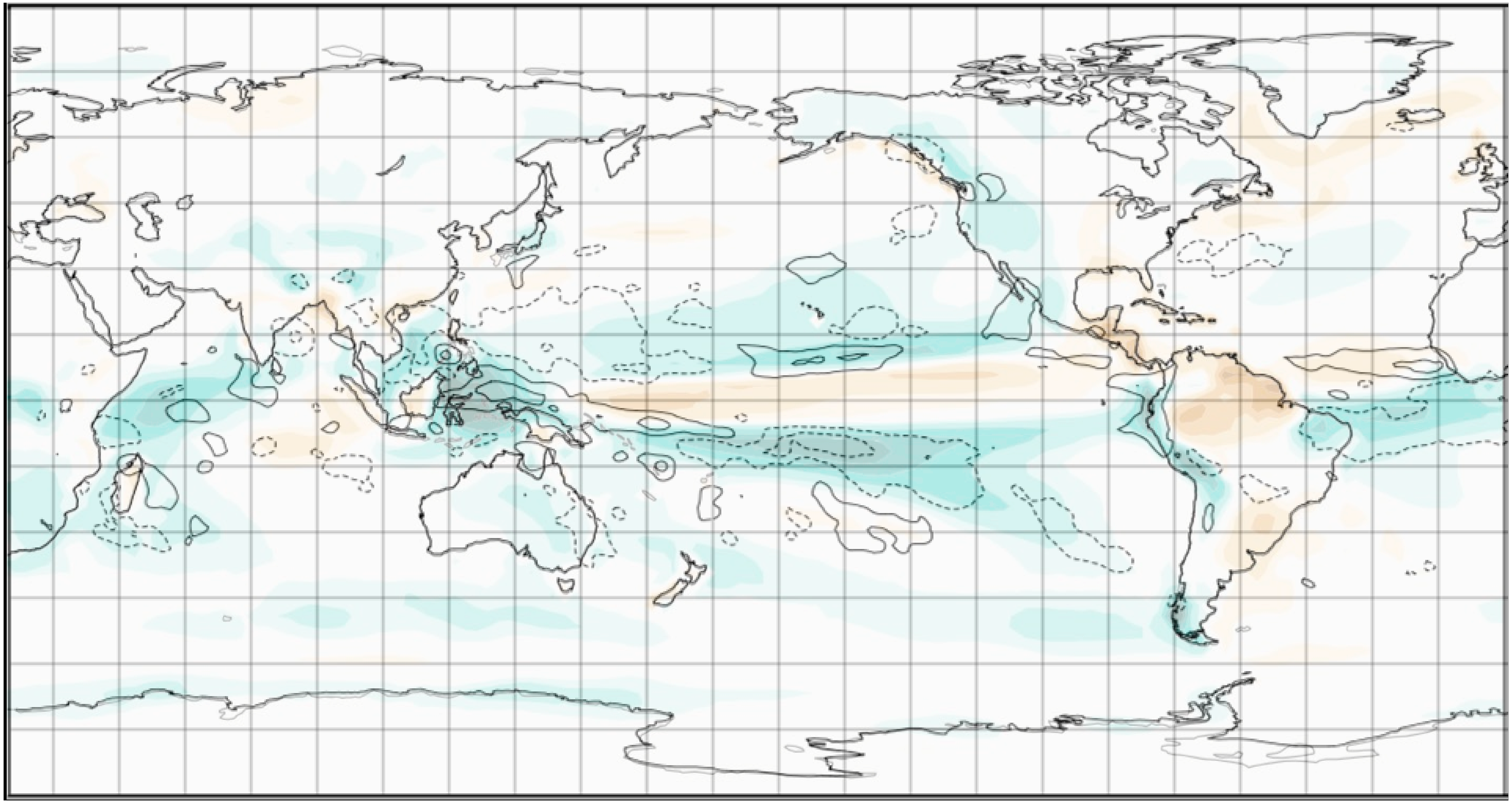


shading = bias

Golaz et al. 2019

E3SMv1 coupled simulations

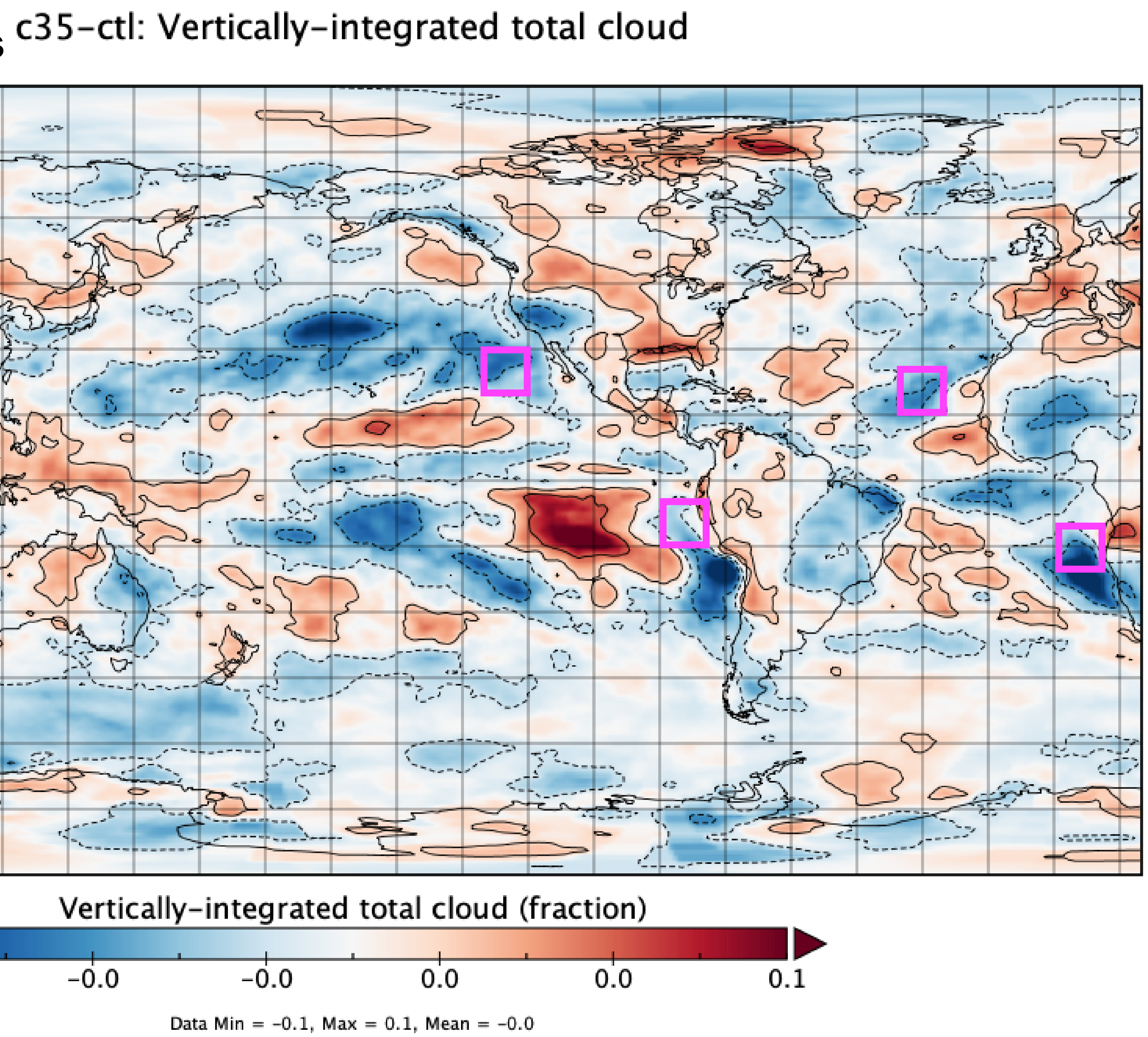
Example: the ITCZ



shading = bias contour = c35-ctl *Golaz et al. 2019*

E3SMv1 coupled simulations

Example: shallow clouds



surface fluxes: what can affect their parameterization?

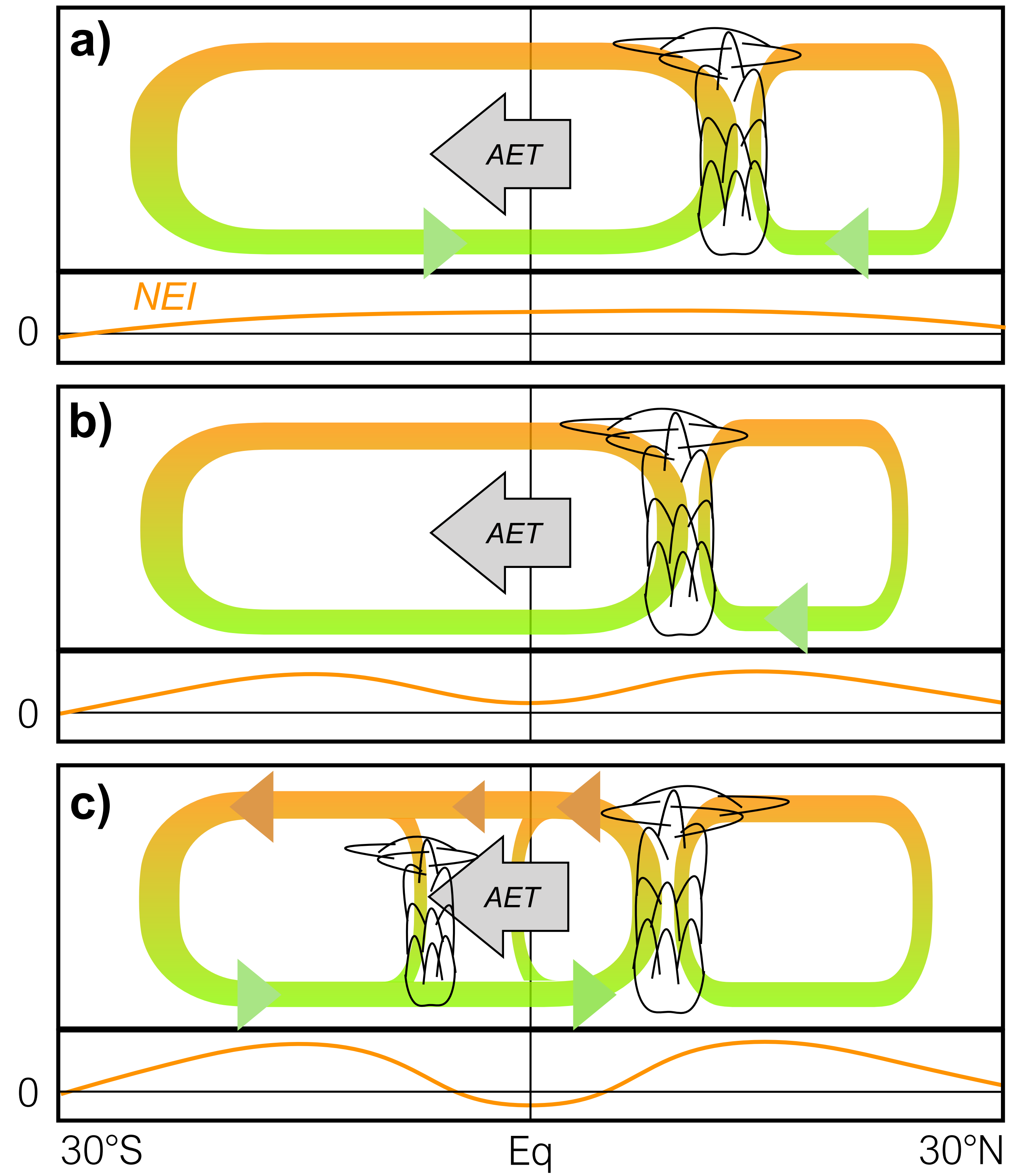
- absolute or relative wind speed
- wind gustiness
- stability of the boundary layer
- surface roughness
- surface salinity

“*many aspects of the algorithms are empirical, relying on constants and functional forms estimated from (a relatively small number of) ship- and buoy-based observational campaigns*”
—Reeves Eyre et al. (2021)

bulk surface flux effects for weather & climate simulation

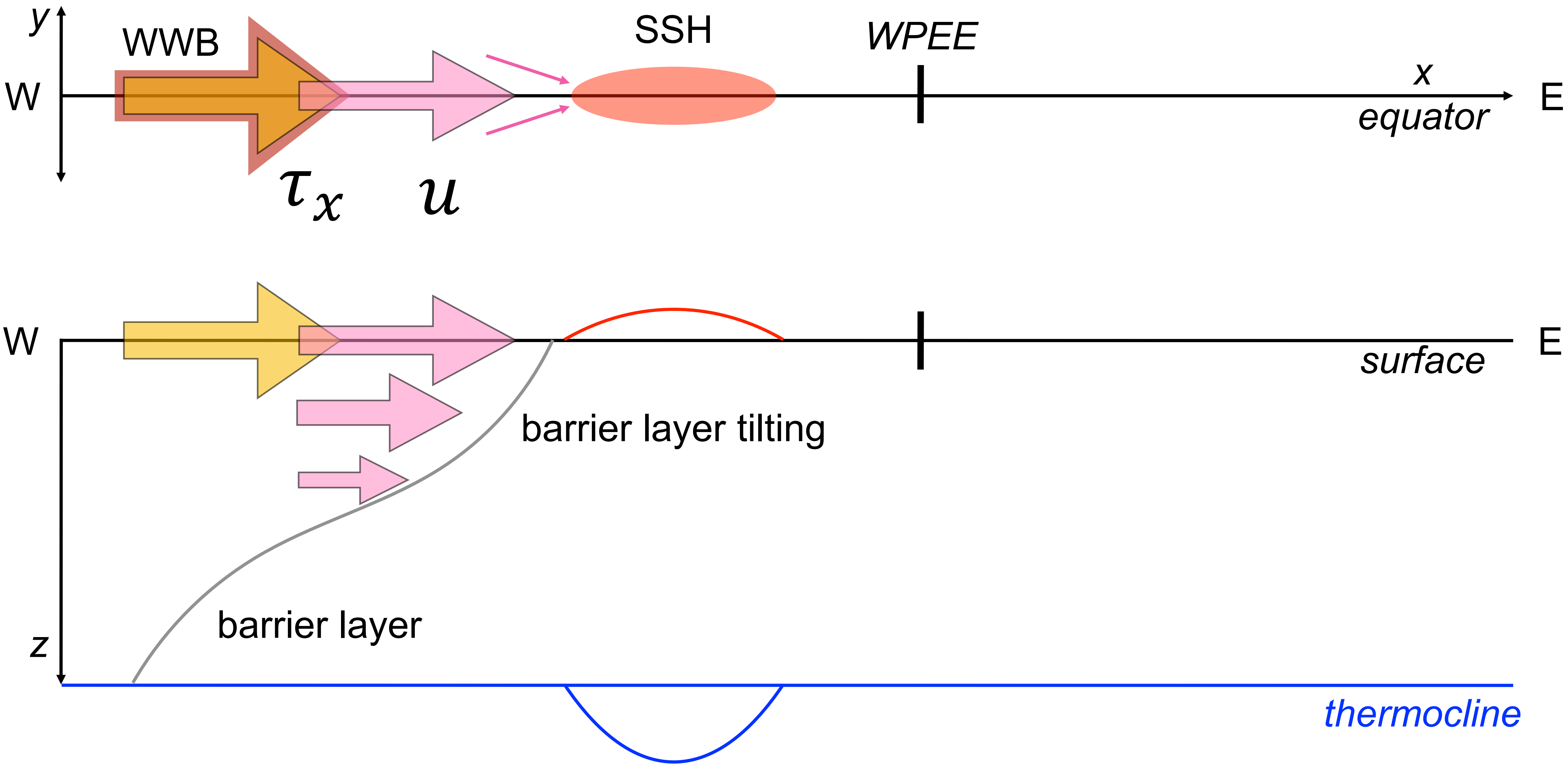
- ITCZ position set by
  - **AET** (Atmospheric Energy Transport) zonal mean across Equator
  - **NEI** (Net Energy Input to atmosphere) meridional structure
- $NEI = \langle SW \rangle + \langle LW \rangle - OHU$
  - the residual of net shortwave heating, net longwave cooling, and ocean heat uptake (**OHU**)
- **OHU** depends in part on **surface fluxes**

How might biases rooted in surface flux algorithms contribute to model ITCZ biases?

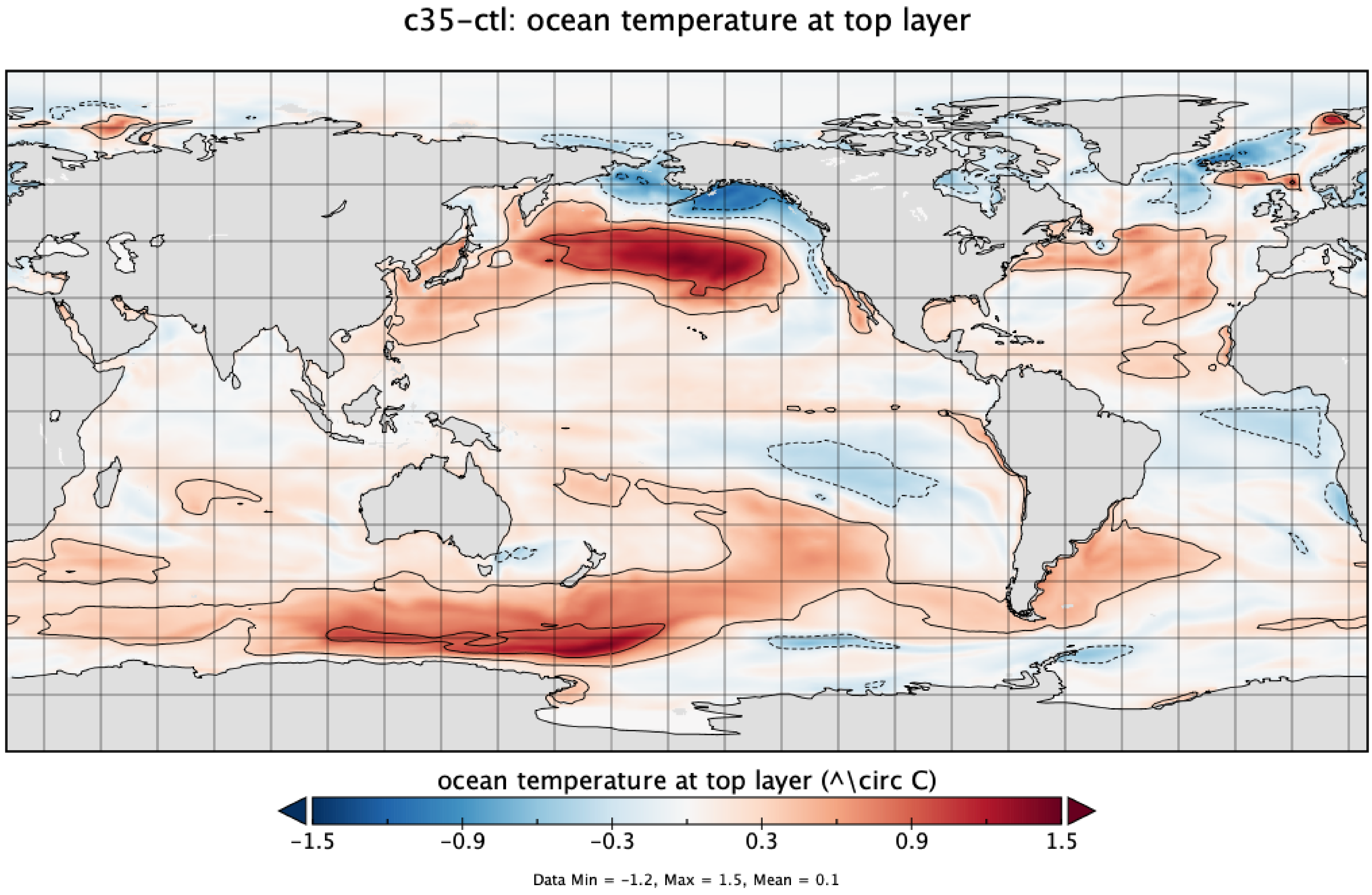


schematic interpretation of Bischoff and Schneider (2014, 2016)

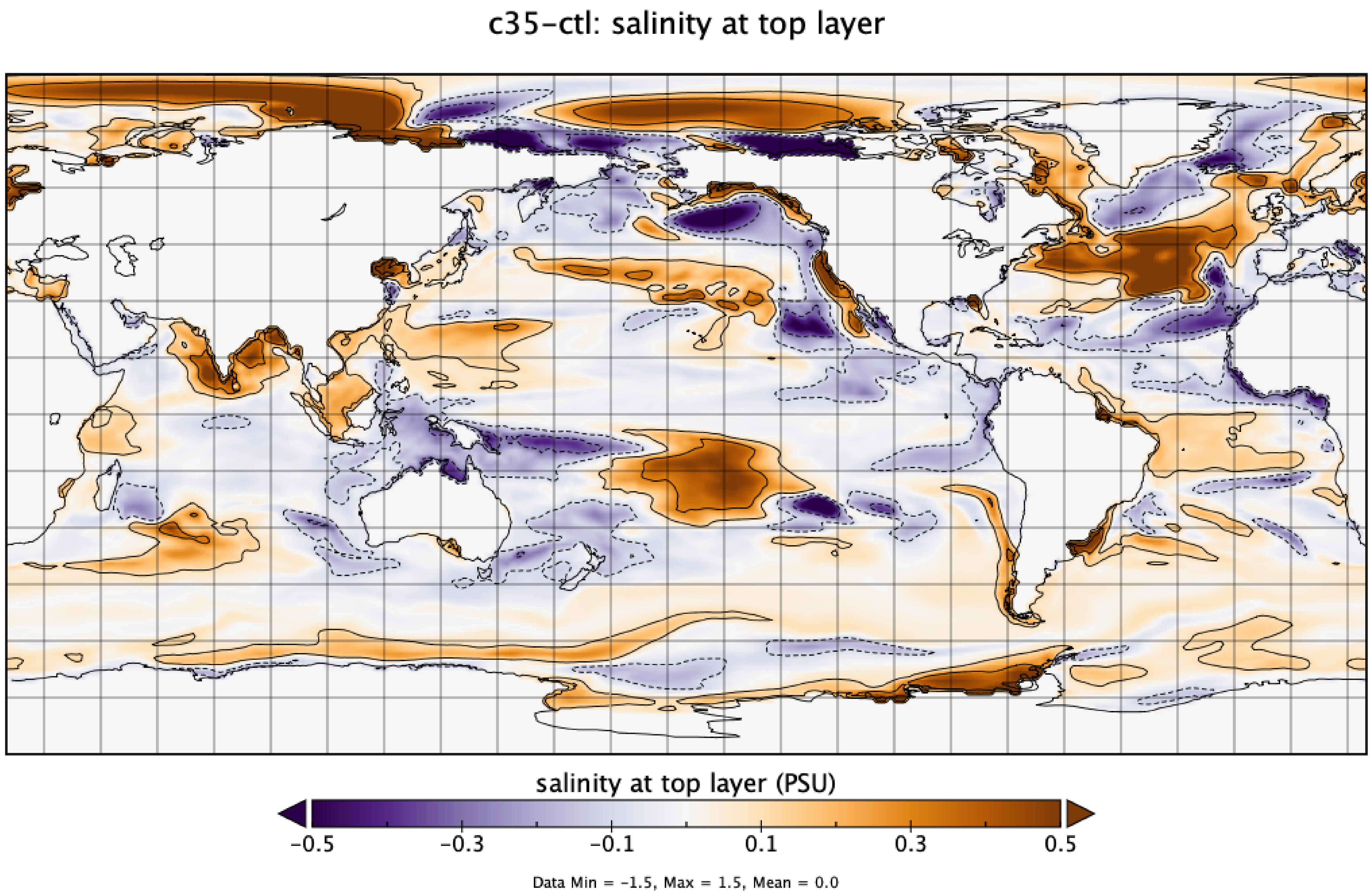
WWBs, oceanic Kelvin waves, and barrier layers



E3SMv1 coupled simulations

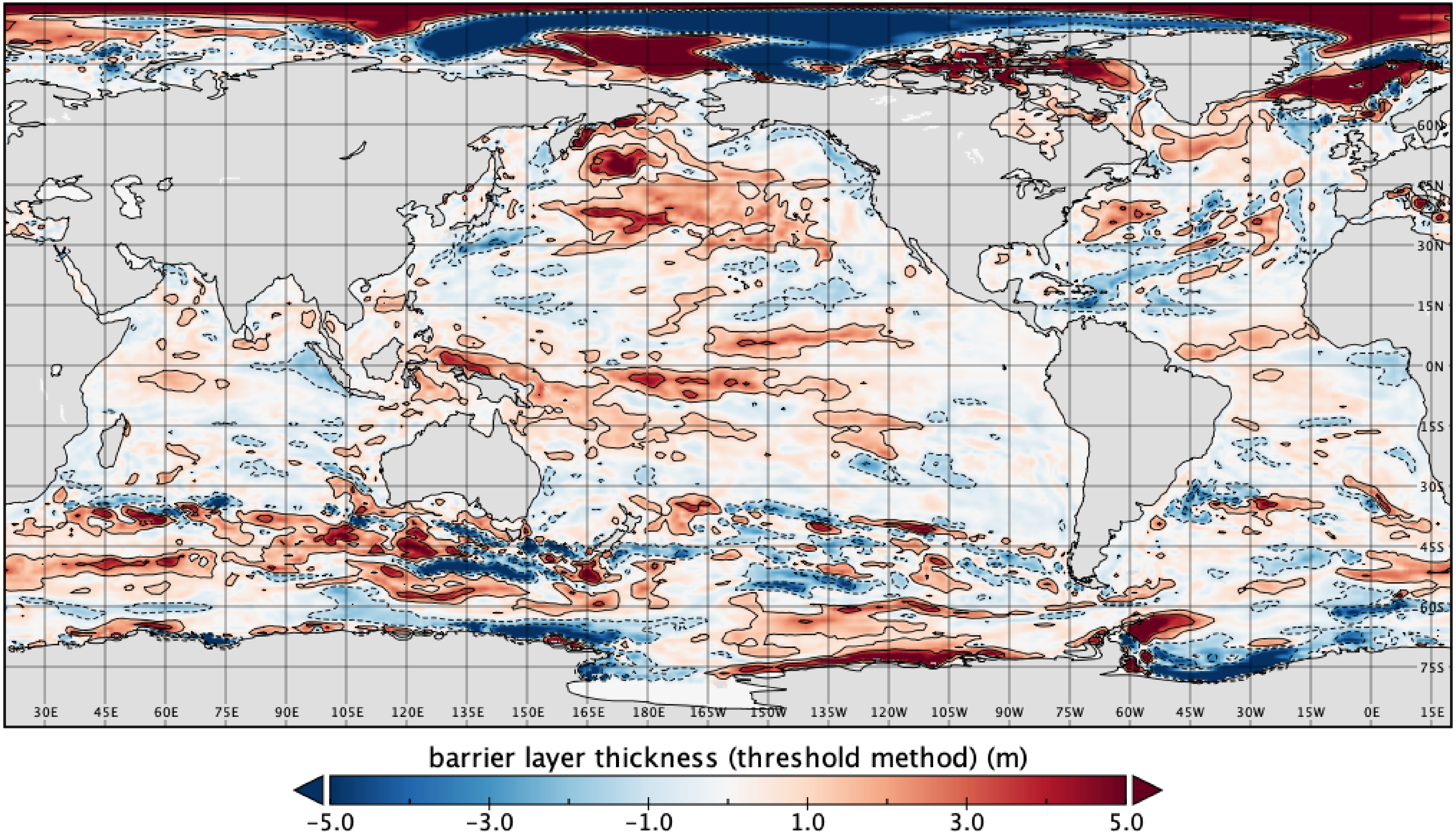


E3SMv1 coupled simulations



E3SMv1 coupled simulations

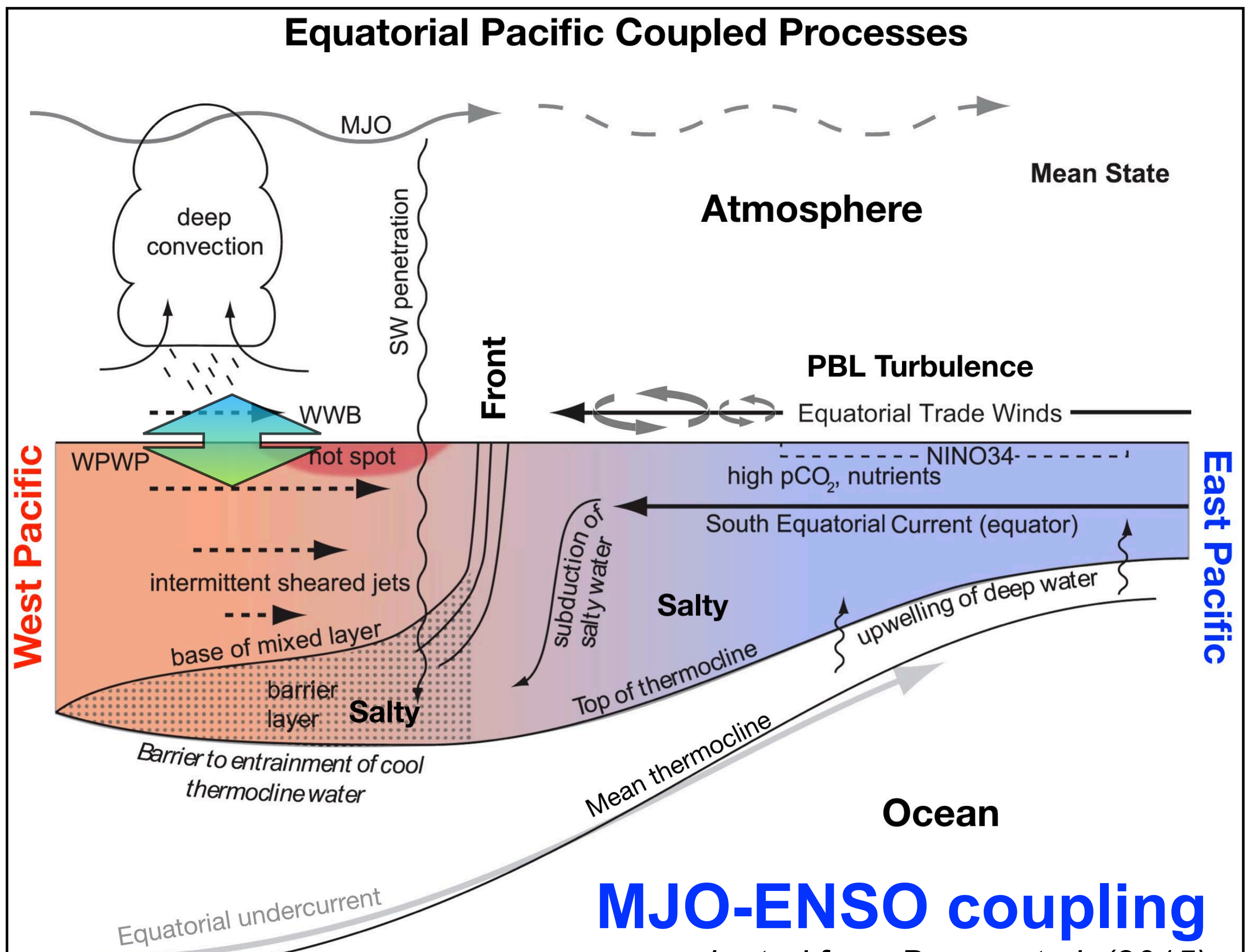
c35-ctl: barrier layer thickness (threshold method)



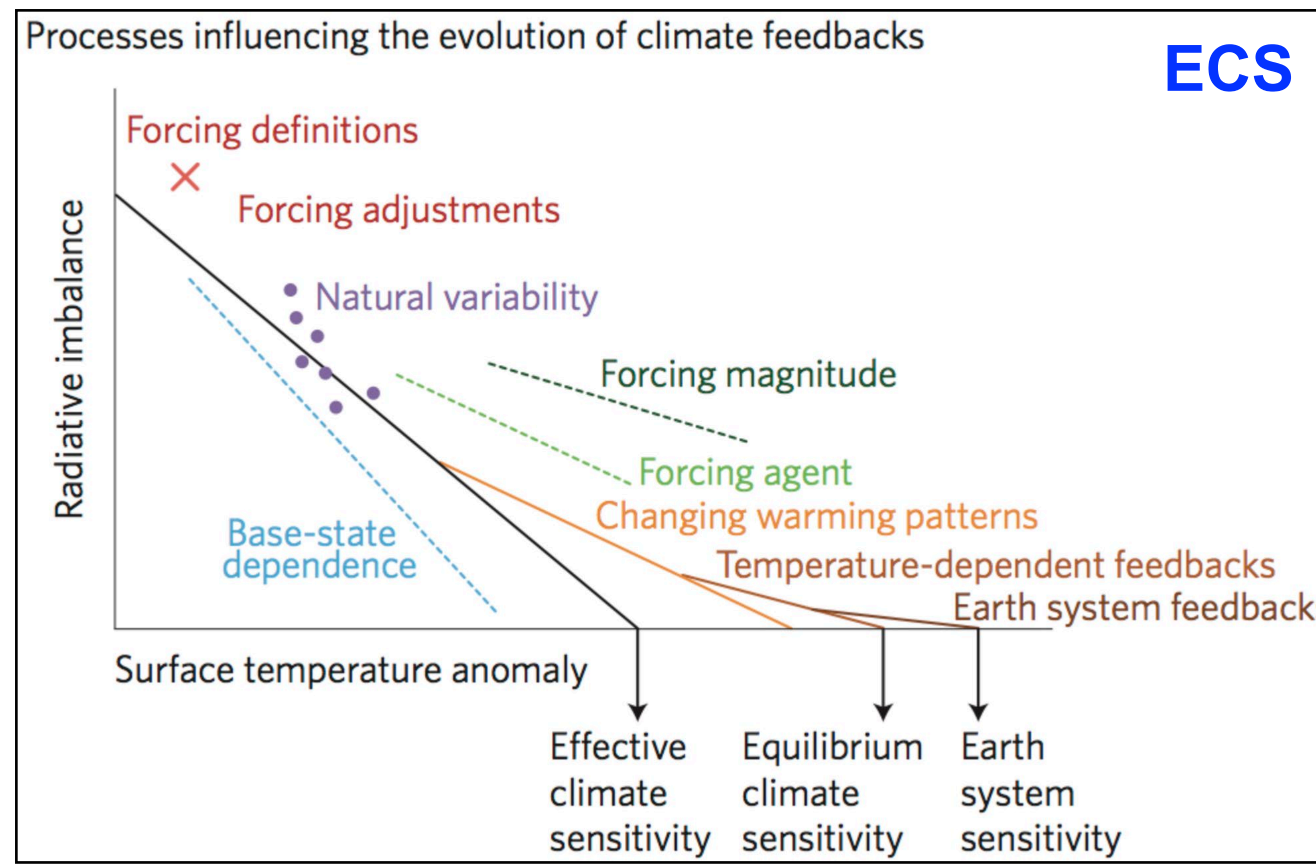
Data Min = -25.8, Max = 30.2, Mean = 0.1

ongoing work

- how does the inline correction affect MJO-ENSO coupling?
- how does the inline correction affect ECS?



adapted from Brown et al. (2015)



Knutti et al. (2017)

pathways for future progress

- Needs:
  - Improving CONUS precipitation forecasts on S2S+ timescales relies (in part) on improving the representation of tropical O-A coupling
  - Coupled forecast models need to be initialized with atmospheric and oceanic states that are well-constrained by observations
  - An increasing recognition that the OML and AML must be thought of and observed as a single entity: the Air Sea Transition Zone (ASTZ).

- Needed observations
  - Important, but hard-to-observe ASTZ processes require targeted field programs.
  - Improving understanding and model representation of coupled cross-scale interactions requires sustained, detailed measurements of the ASTZ at multiple locations.