How close is close enough? The role of bulk surface fluxes in regulating tropical clouds and circulations in models

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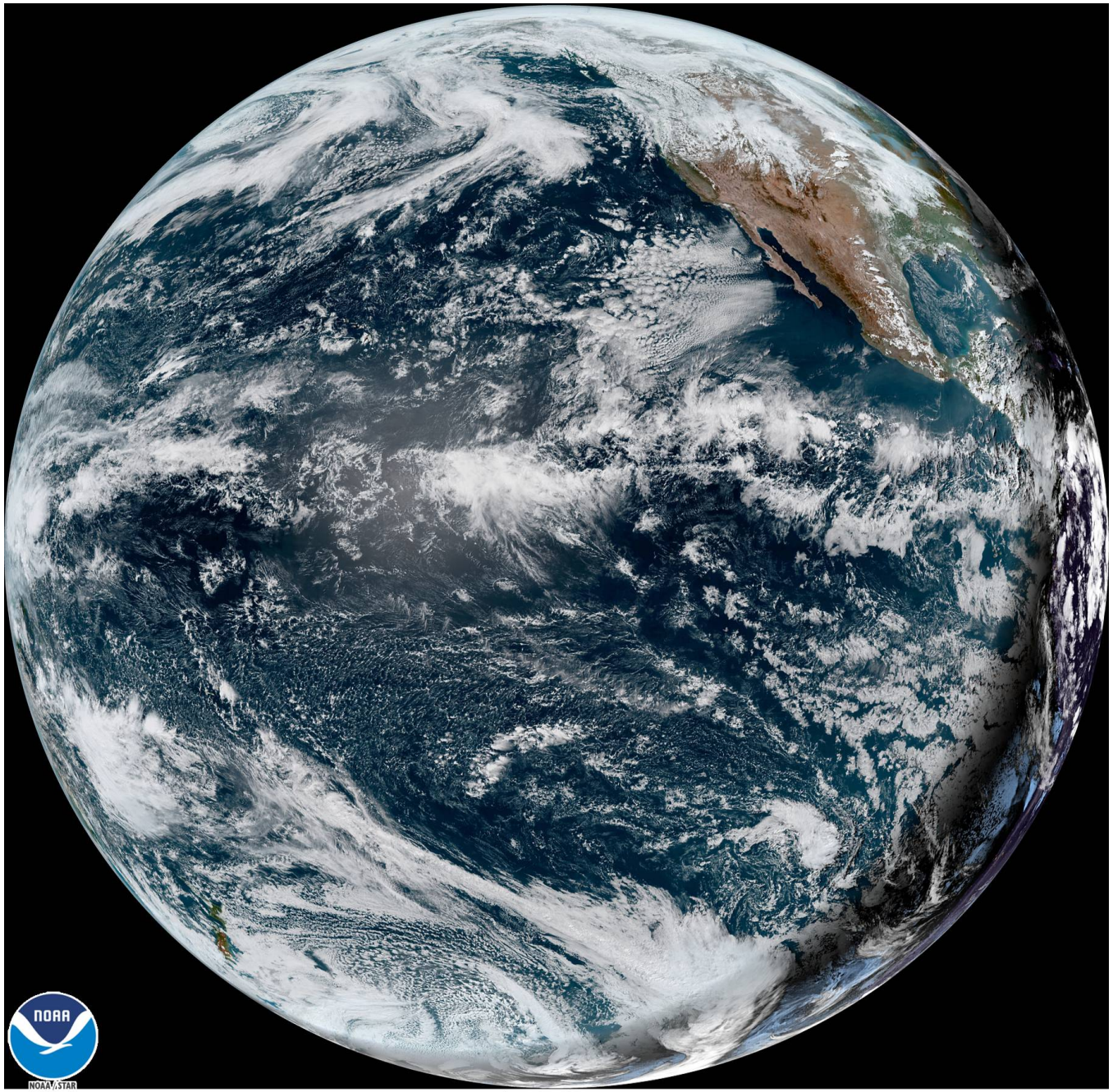
with additional input from Xubin Zeng, Jack Reeves Eyre, Kyle Shackelford, Elizabeth Thompson, Jeremiah Brown

3rd PAN-GASS MEETING: UNDERSTANDING AND MODELING ATMOSPHERIC PROCESSES, 25-29 July 2022

the atmosphere and ocean from above



28 Apr 2022 22:50Z NOAA/NESDIS/STAR GOES-West GEOCOLOR

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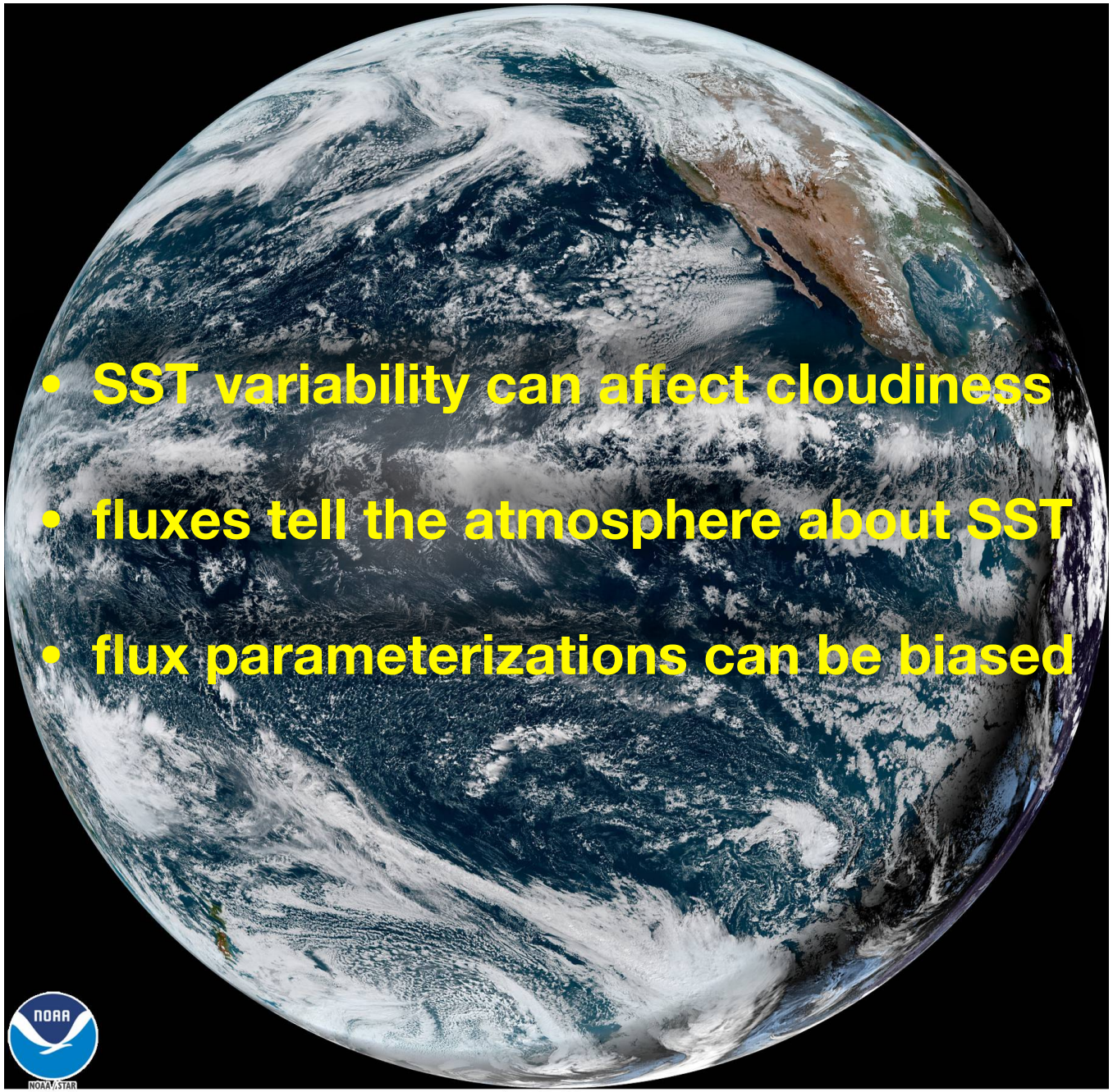
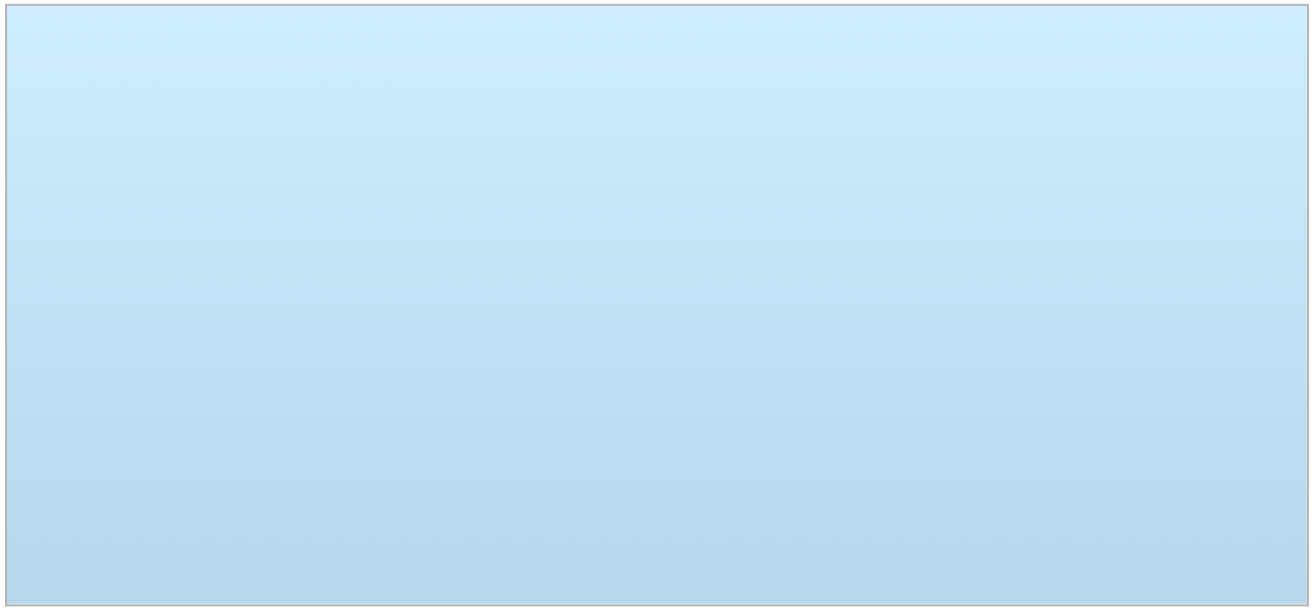


ocean-atmosphere symmetries (similarities)



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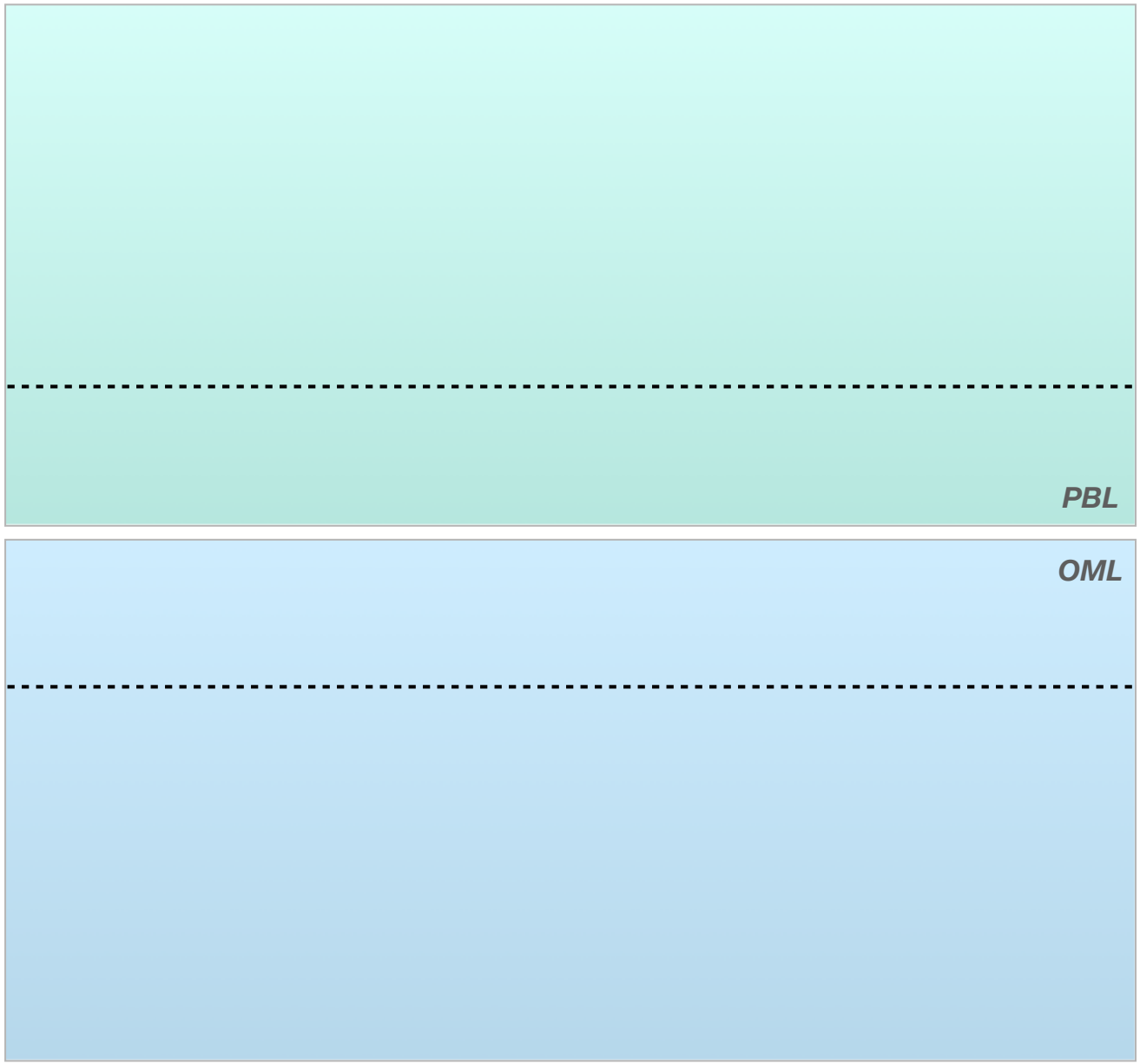

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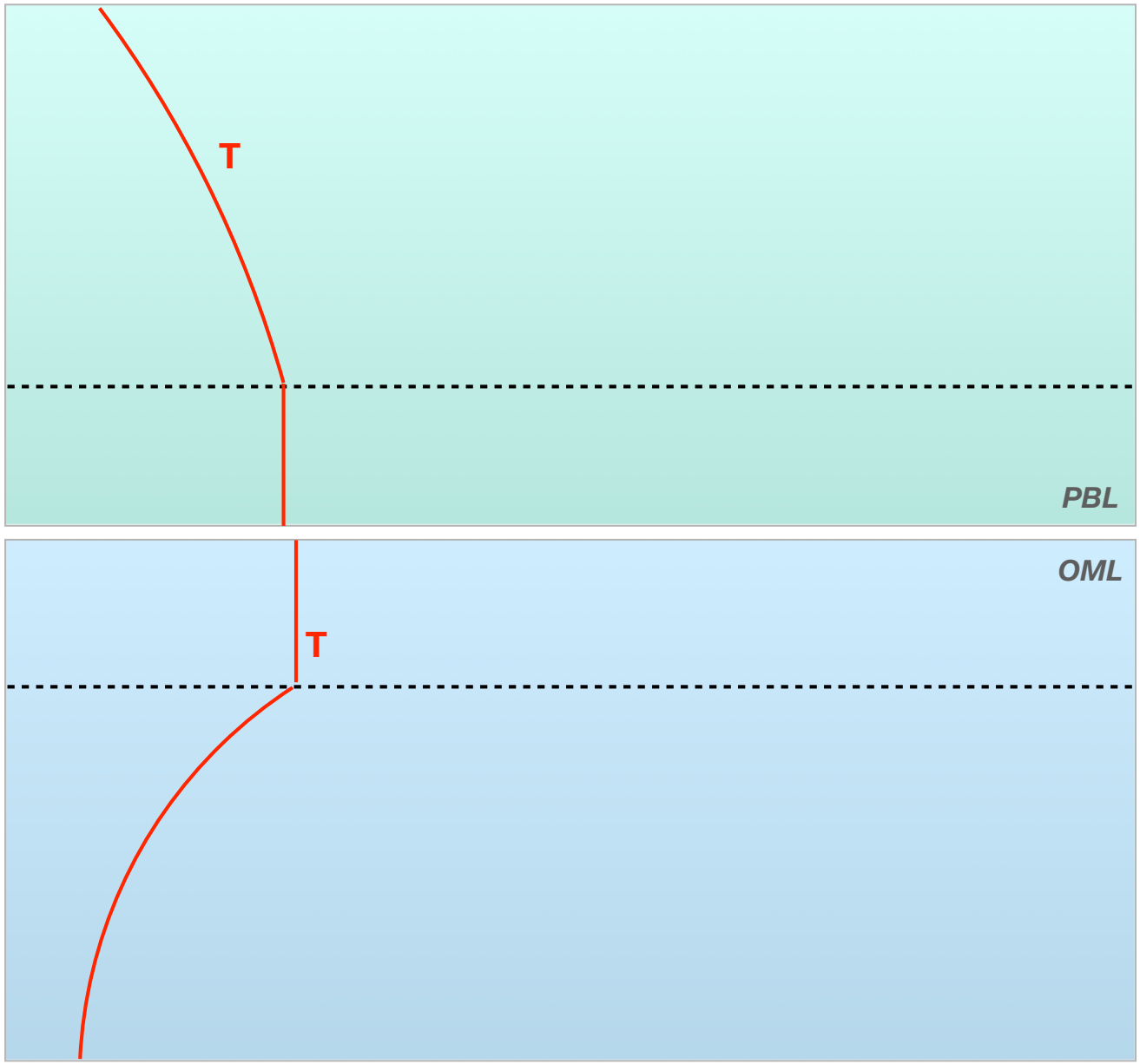

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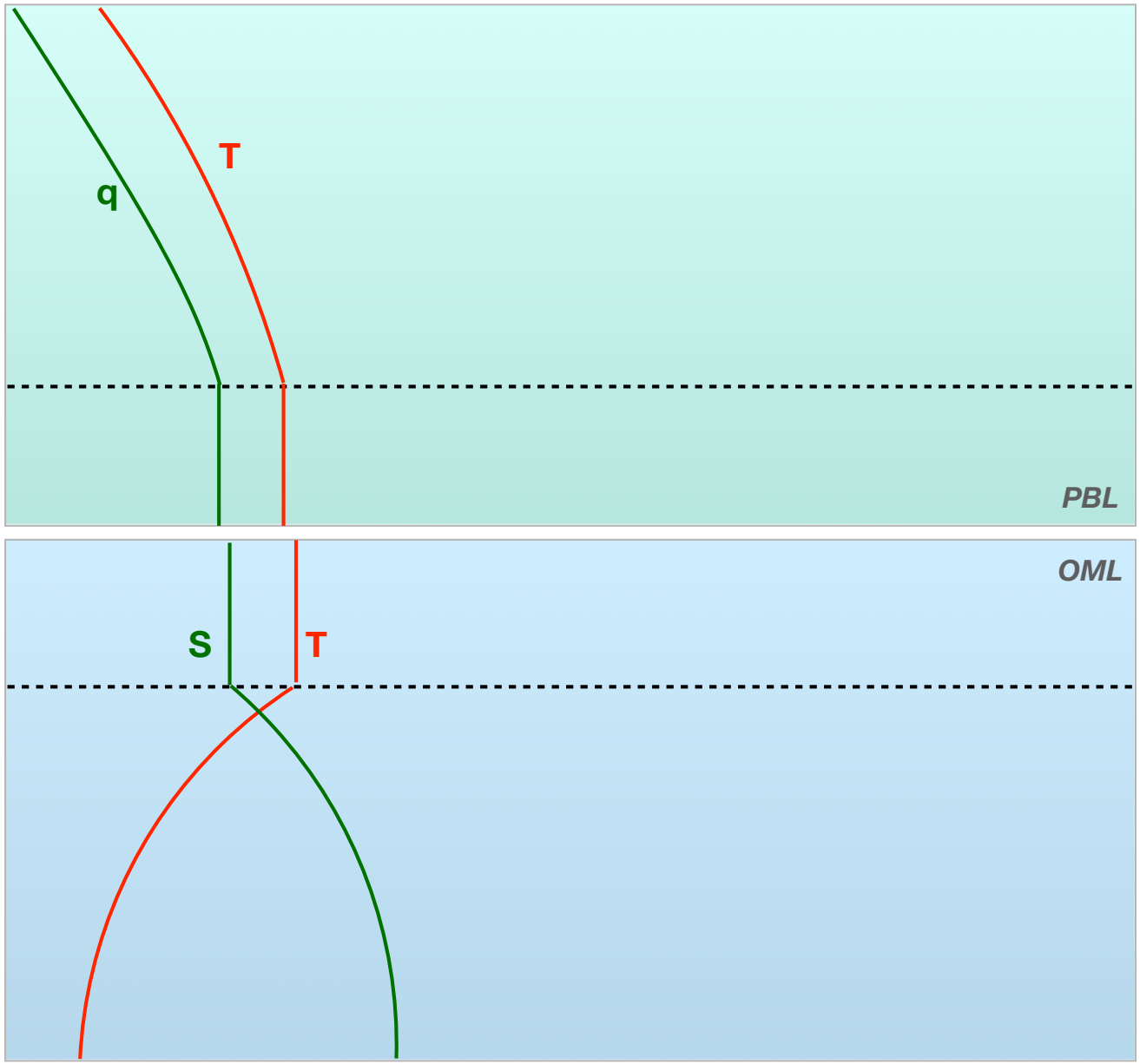

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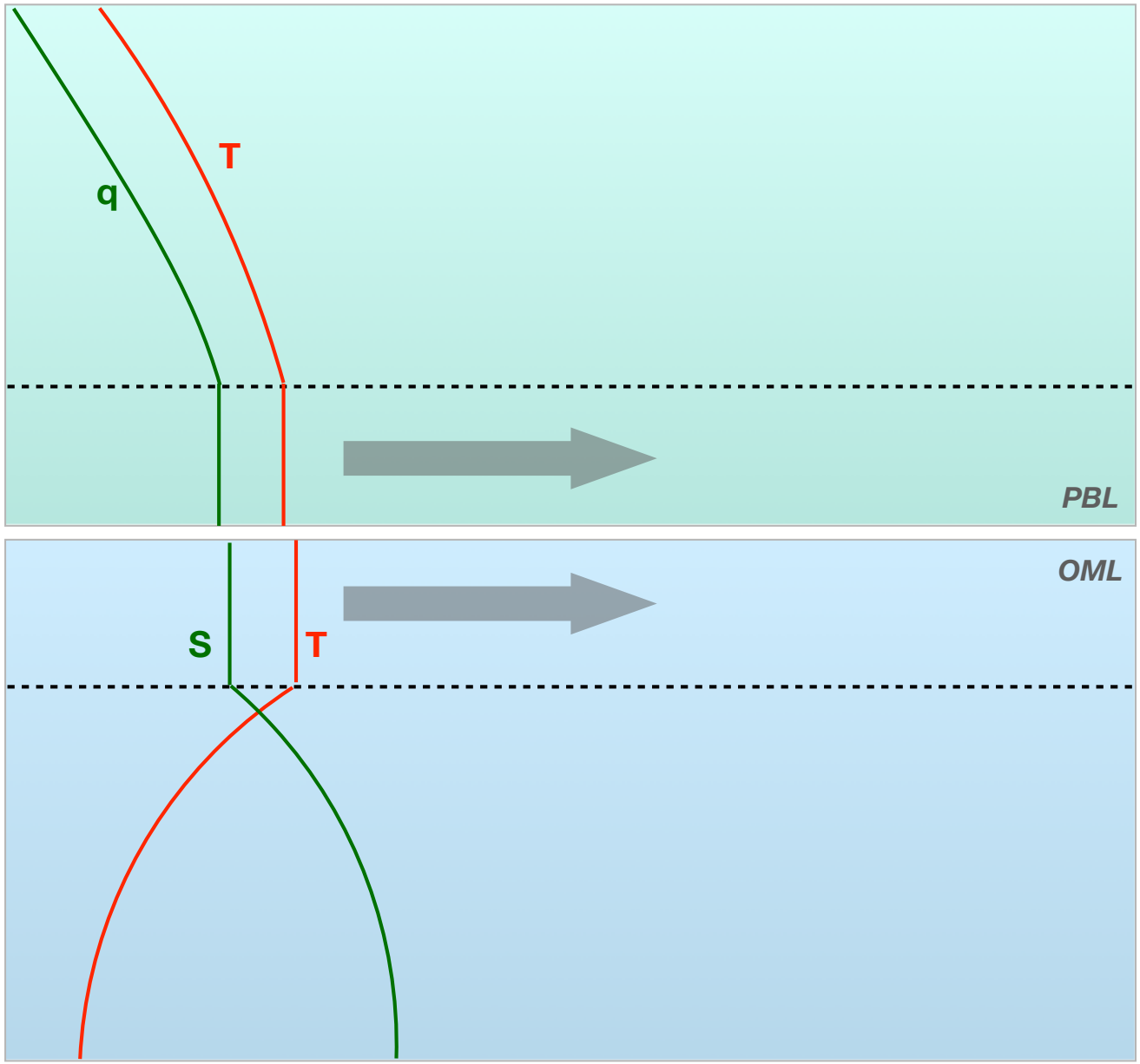

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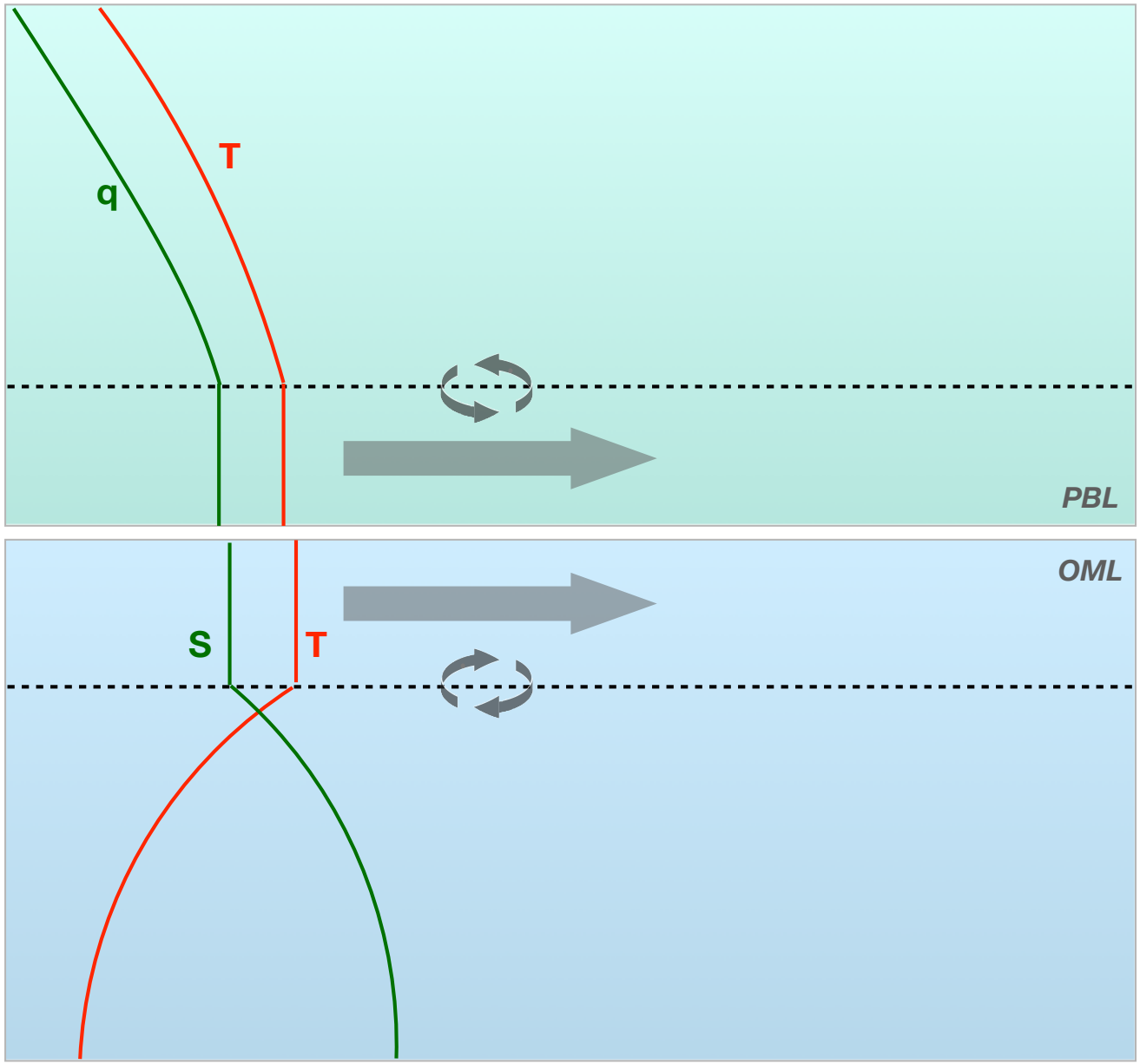

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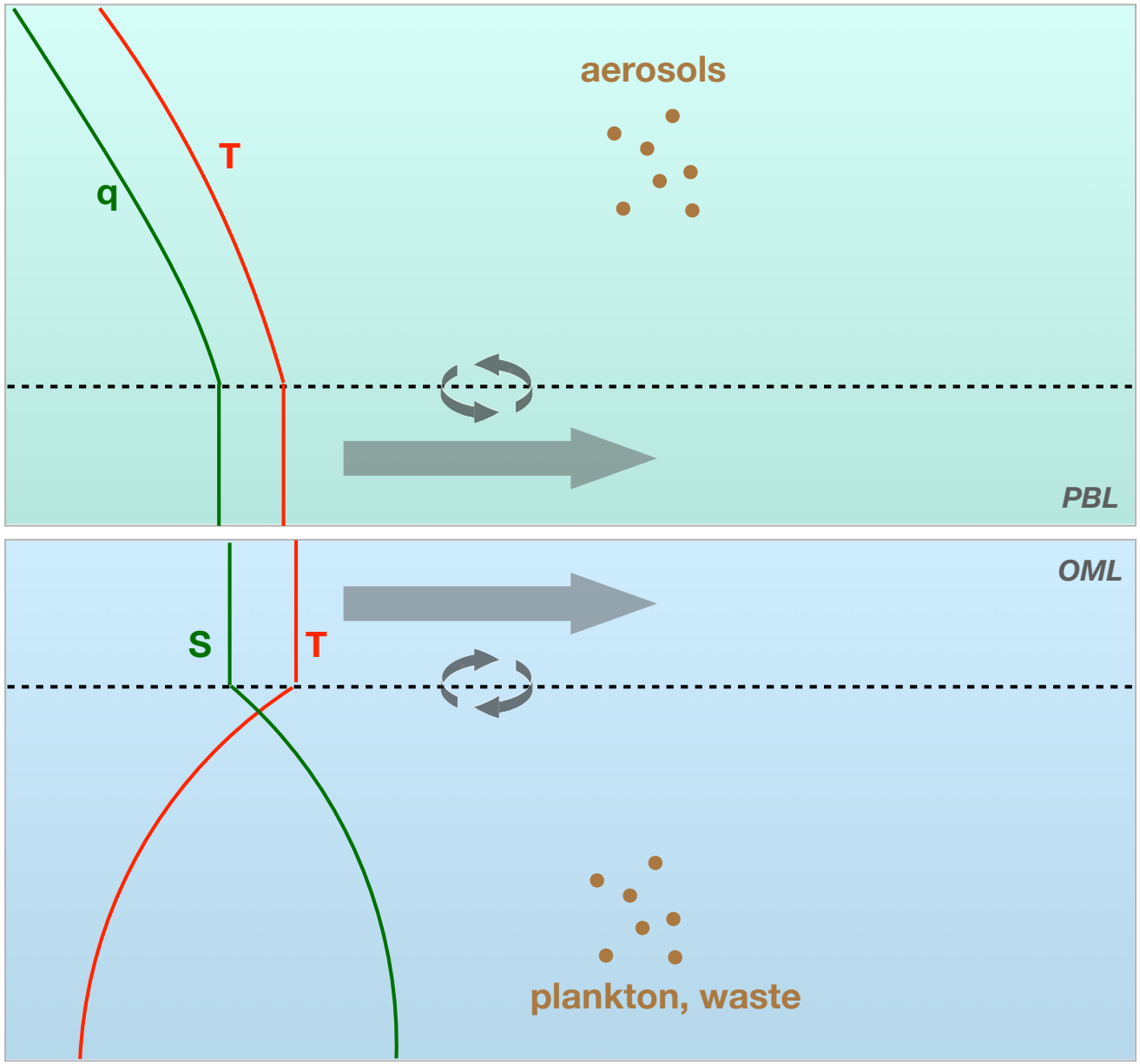

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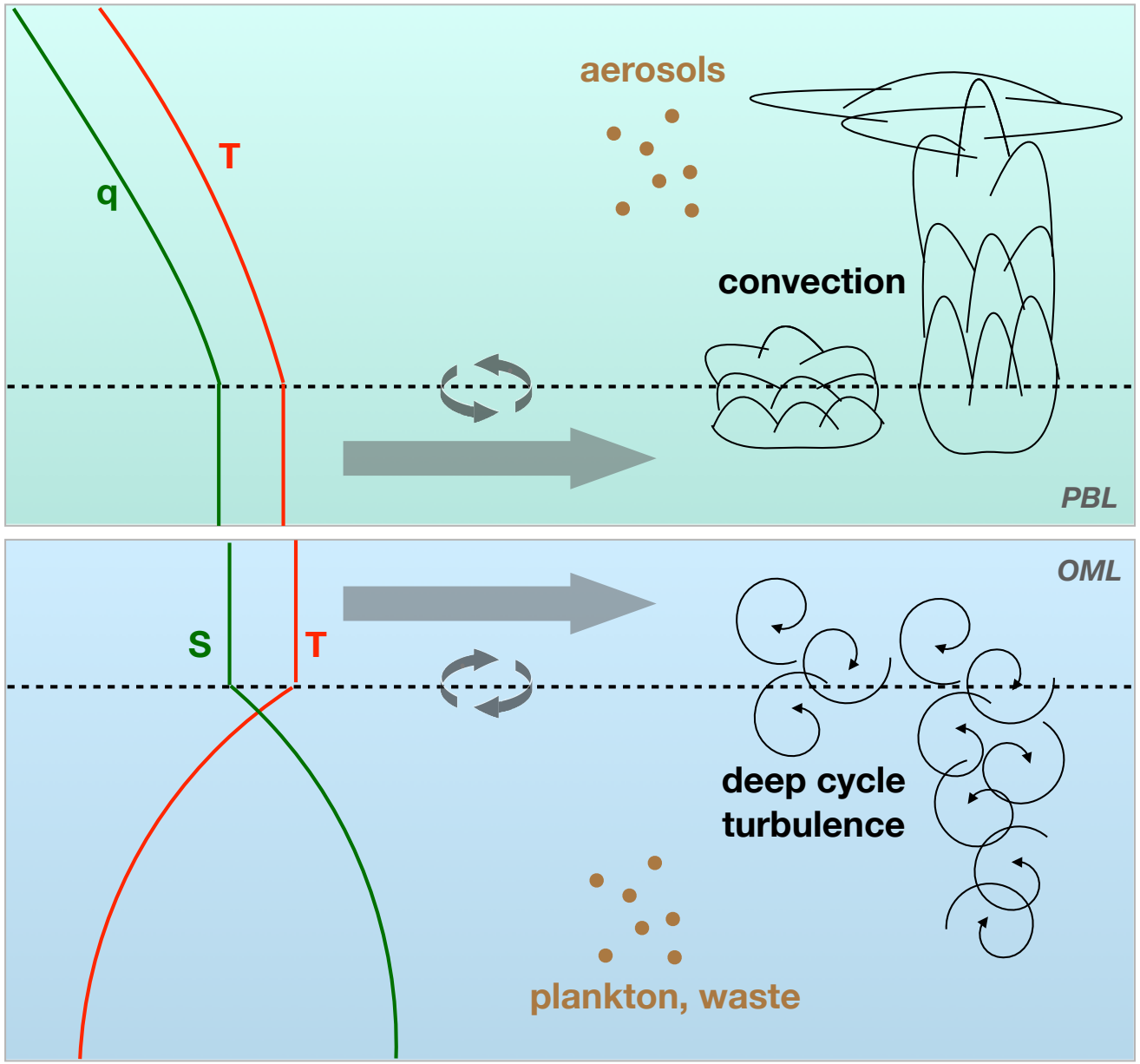

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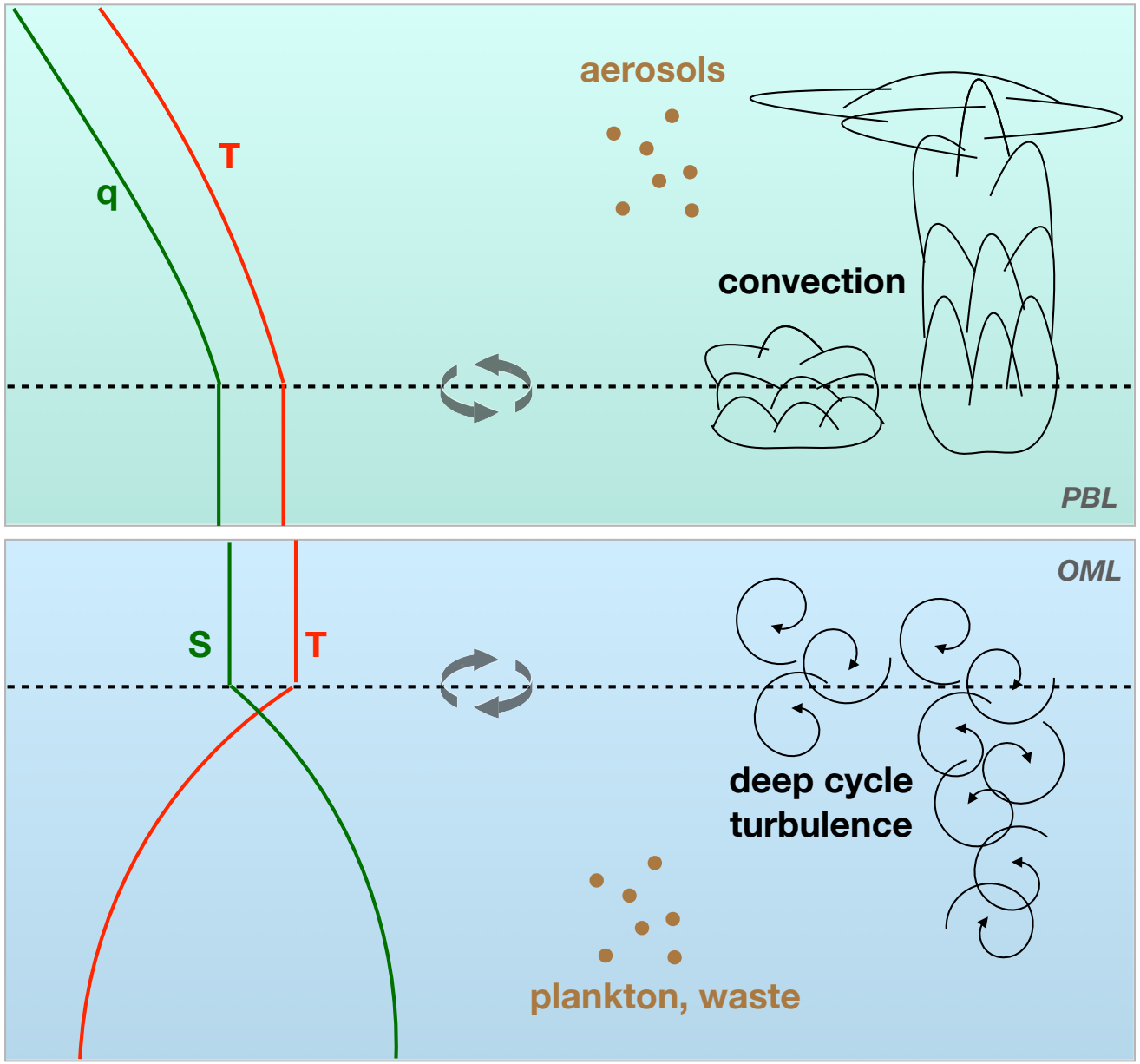

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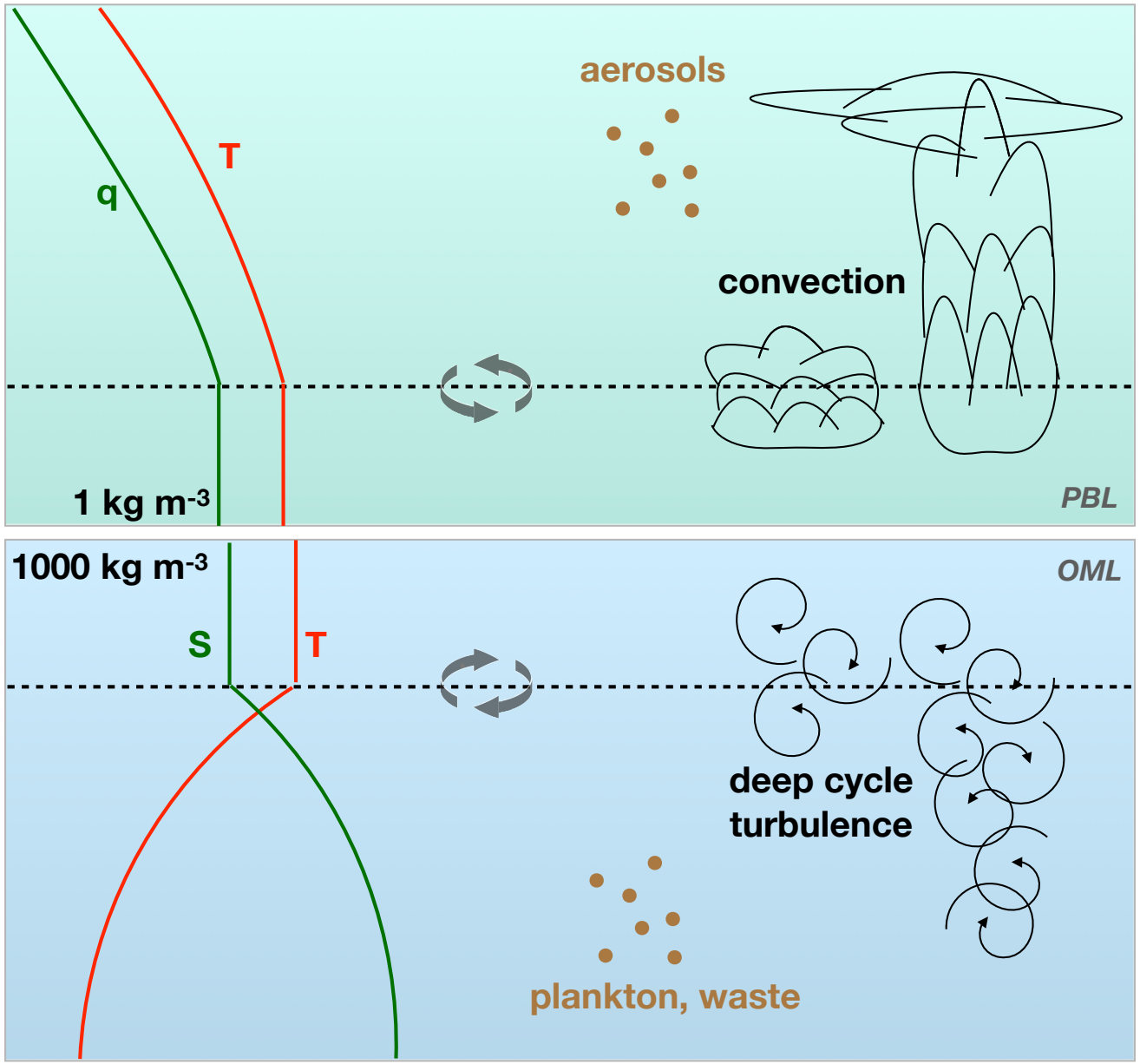
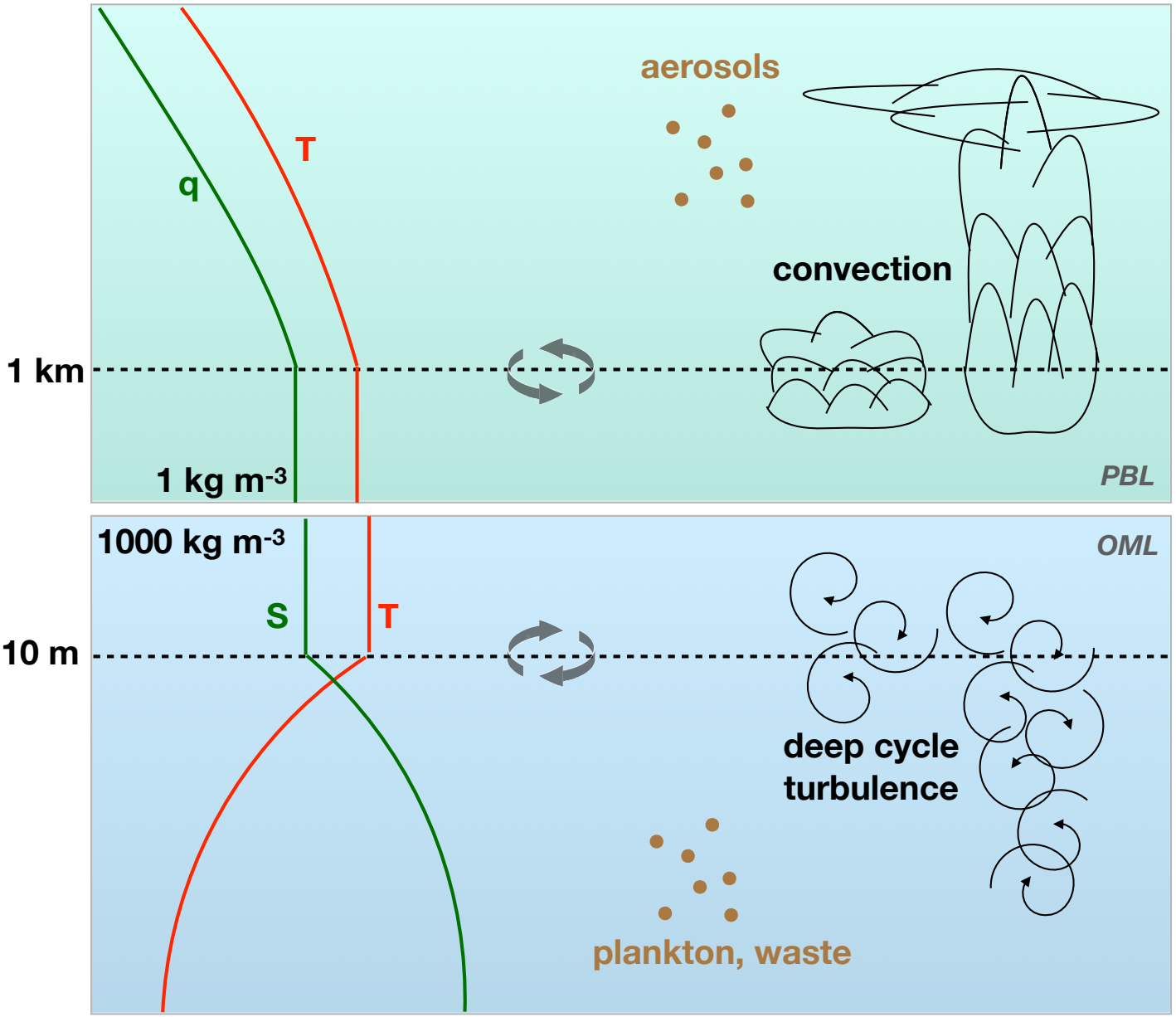


- density: $\delta \sim 10^3$

ocean-atmosphere asymmetries (differences)



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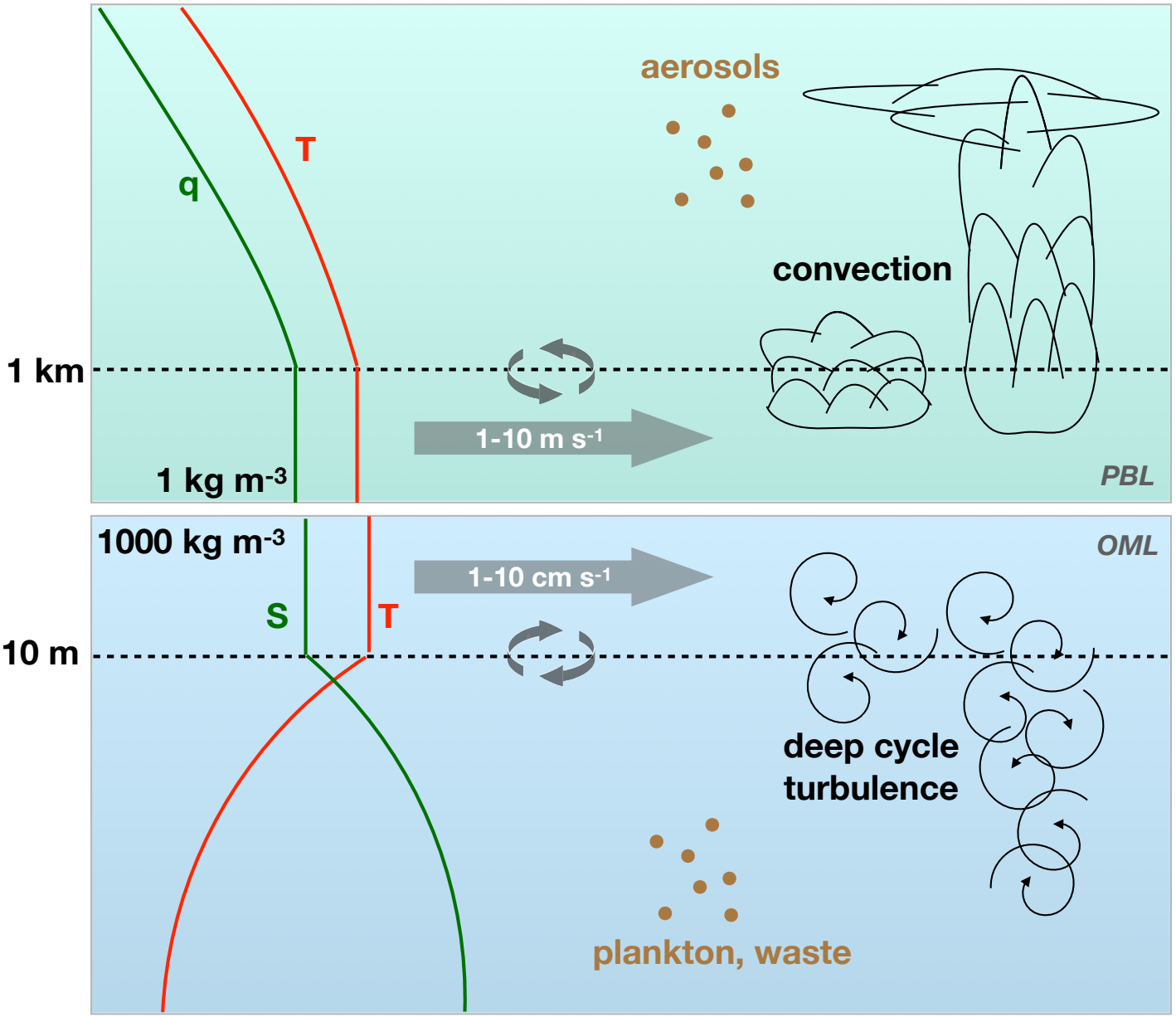
ocean-atmosphere asymmetries (differences)



- density: $\delta \sim 10^3$
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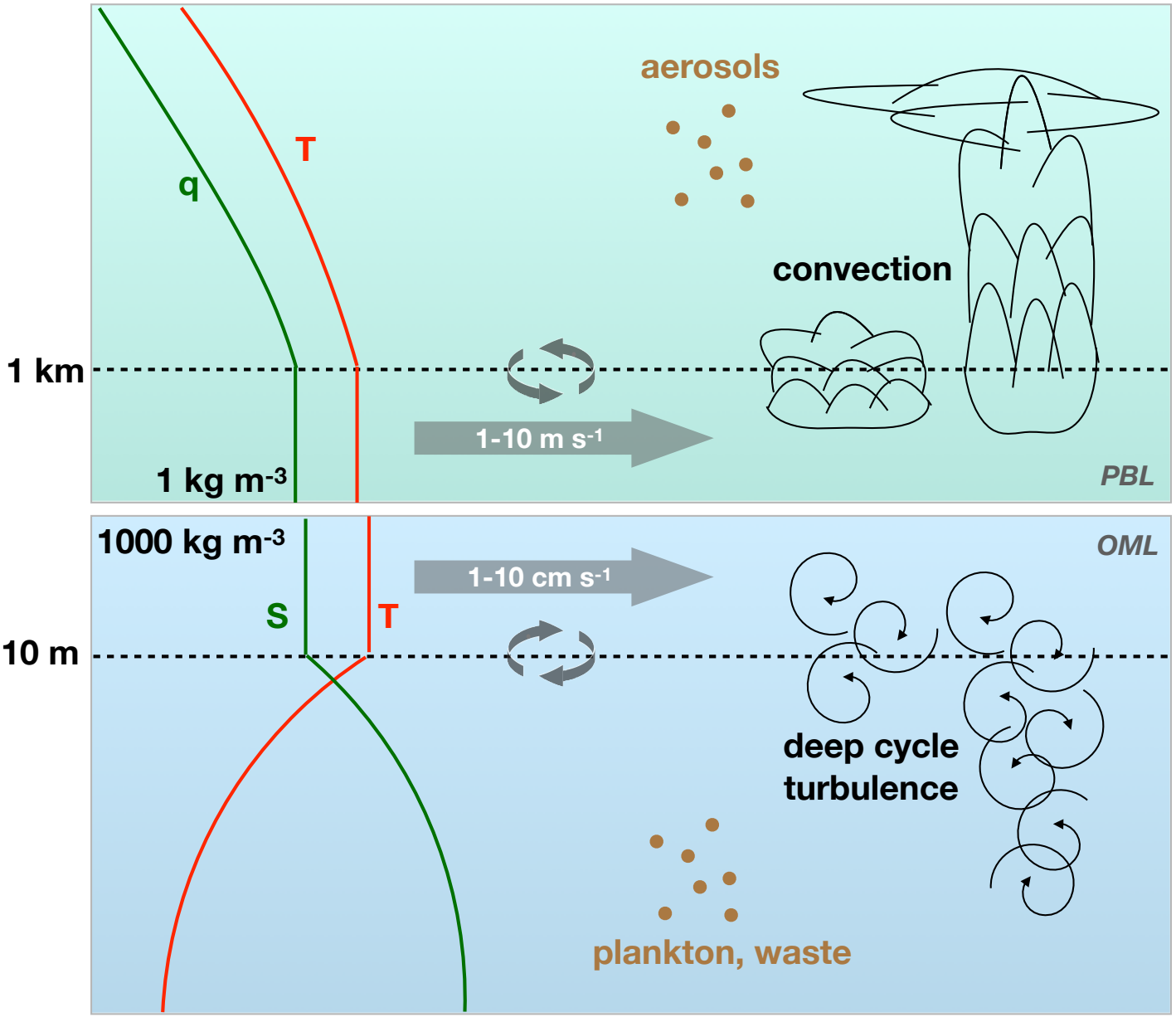

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- clouds are global; DCT mostly on Equator
- clouds regulate radiation; DCT does not

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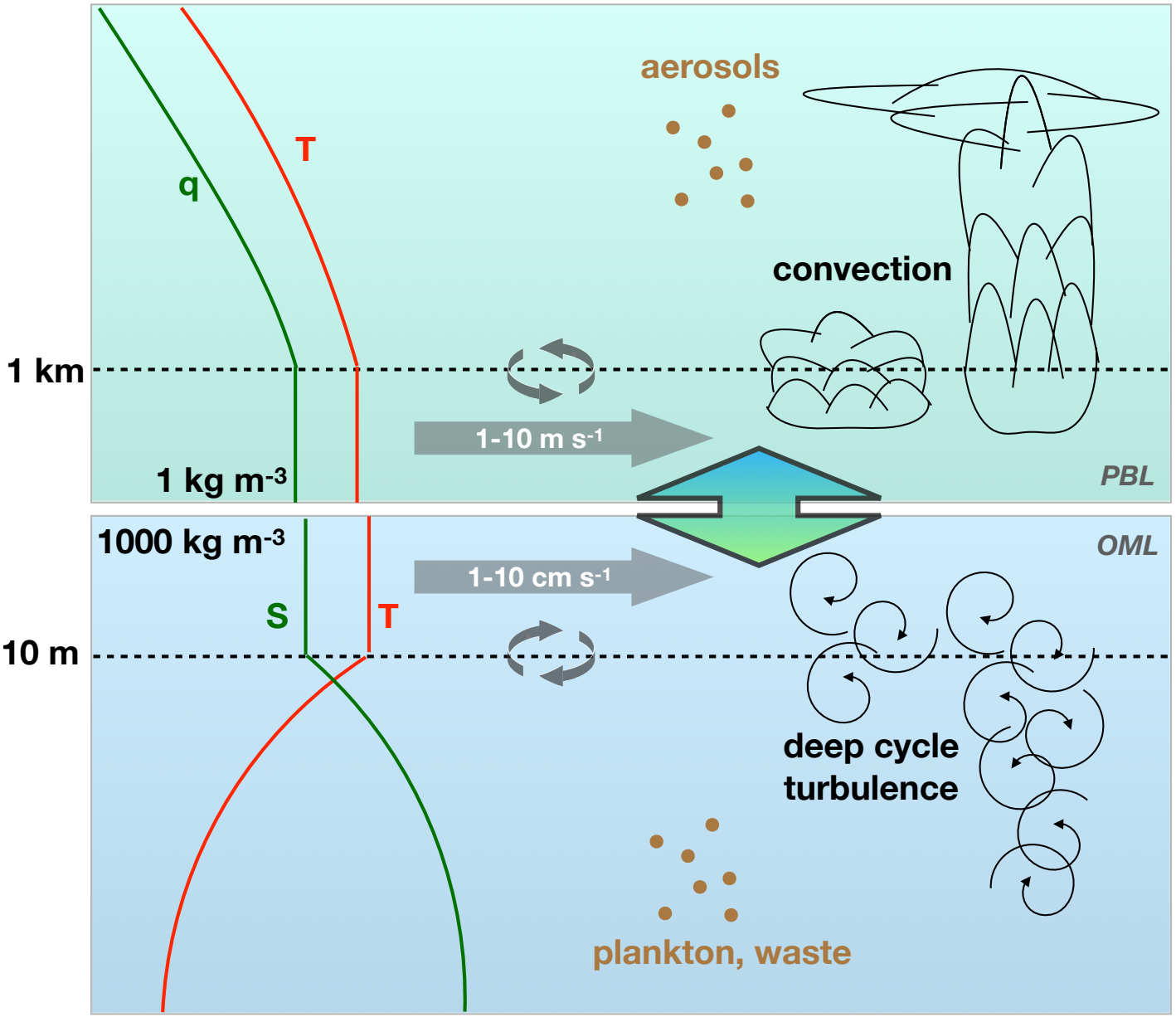

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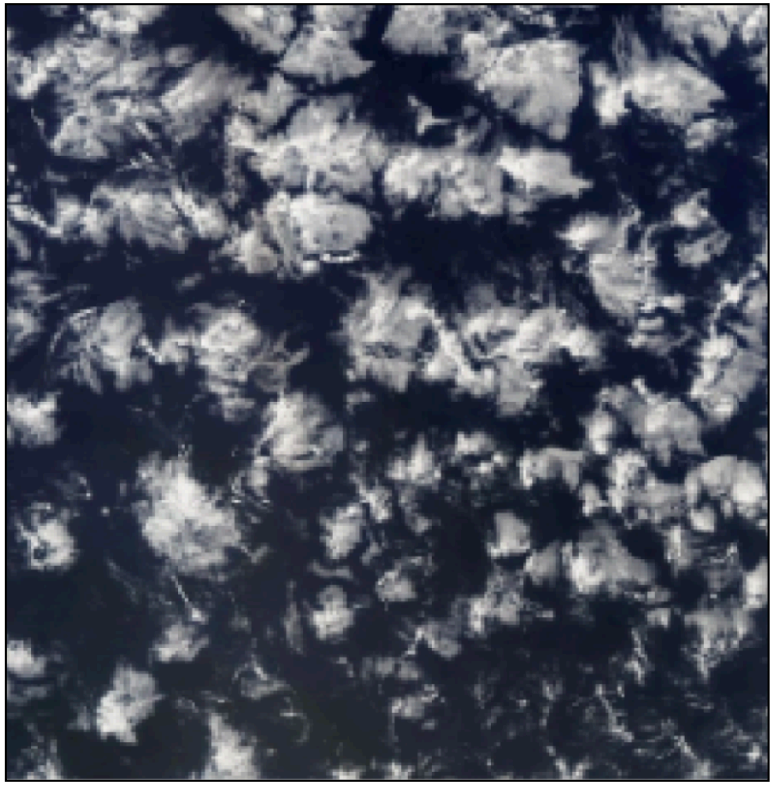
marine surface fluxes across scales



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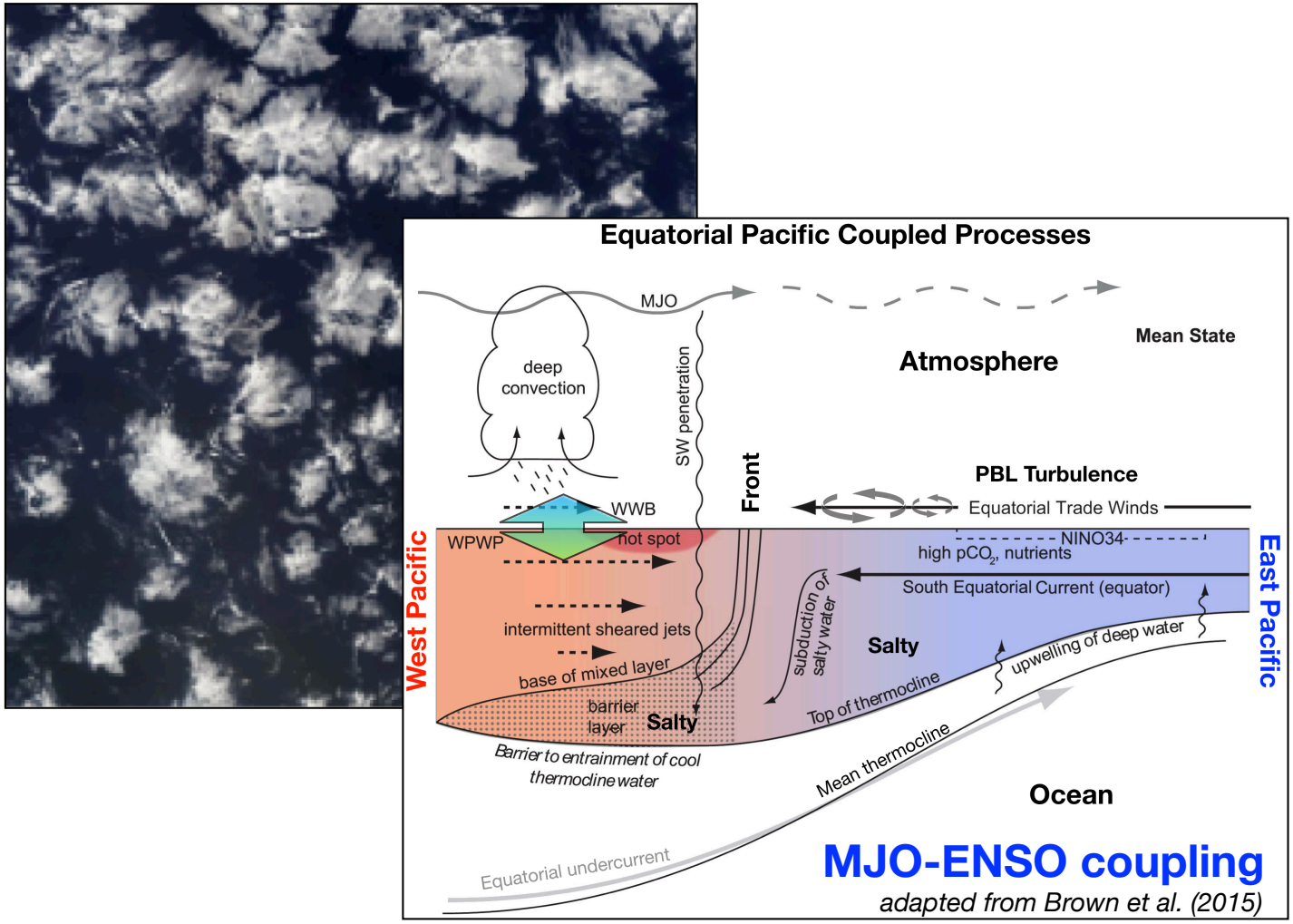

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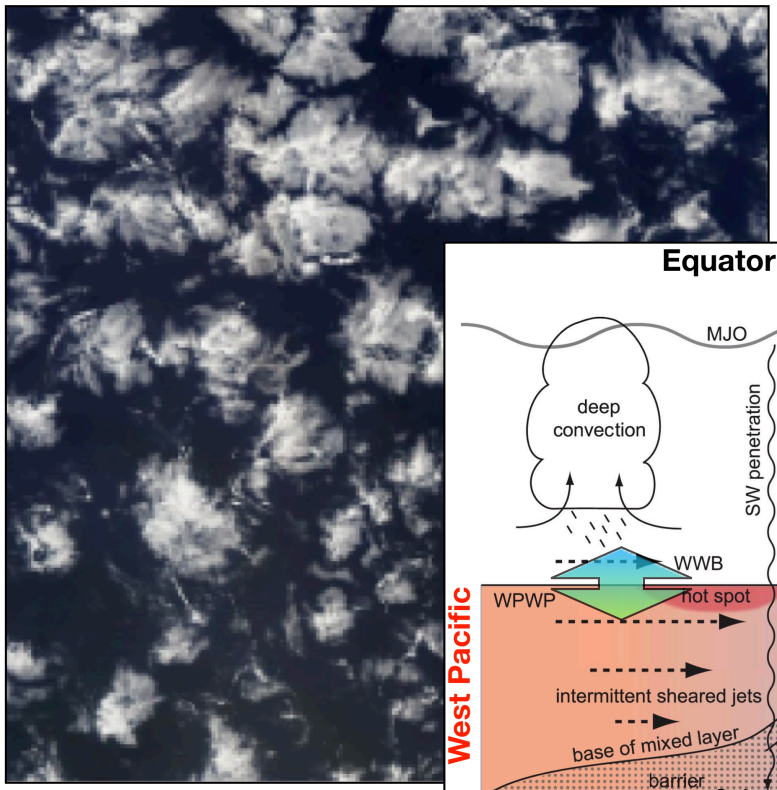
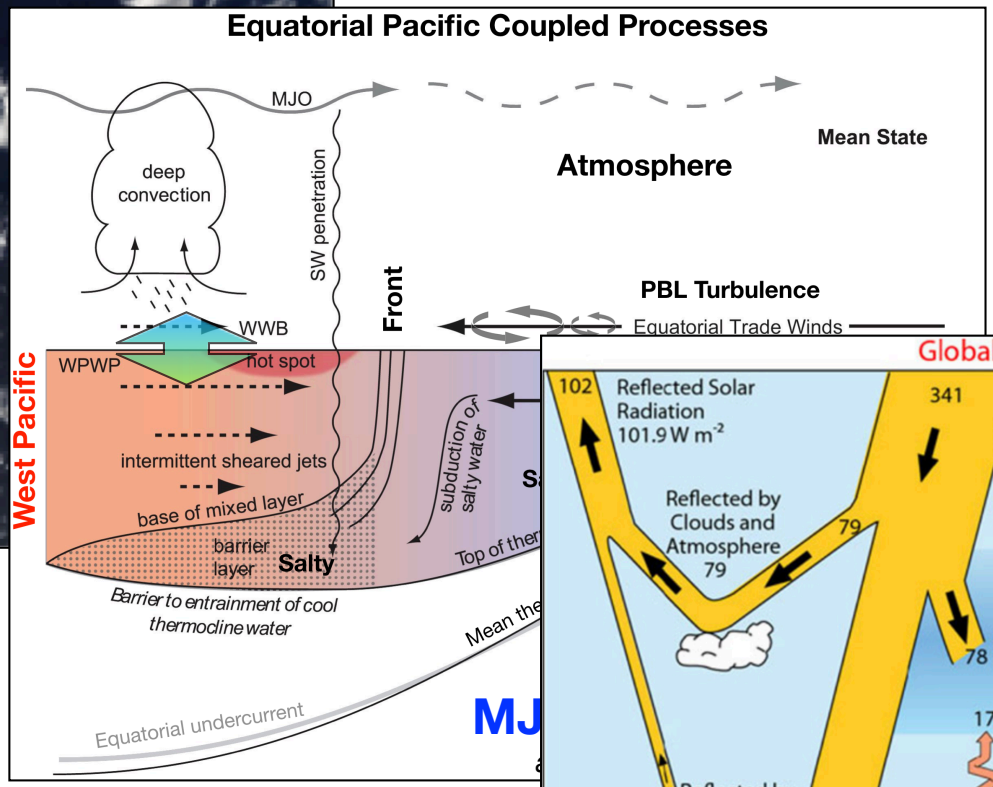
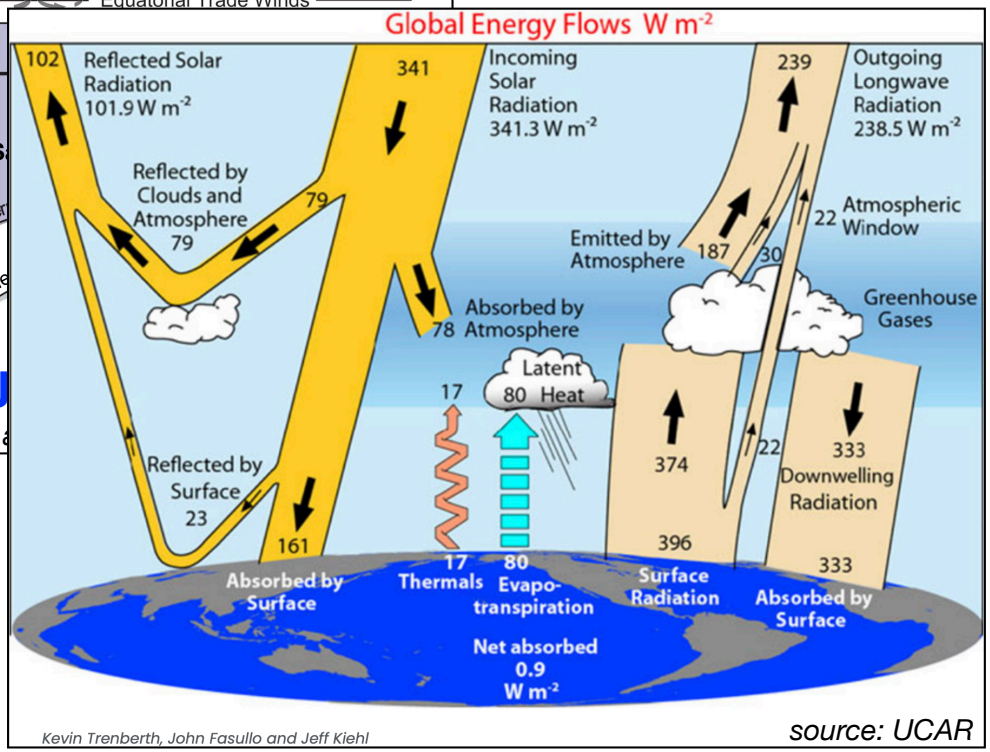
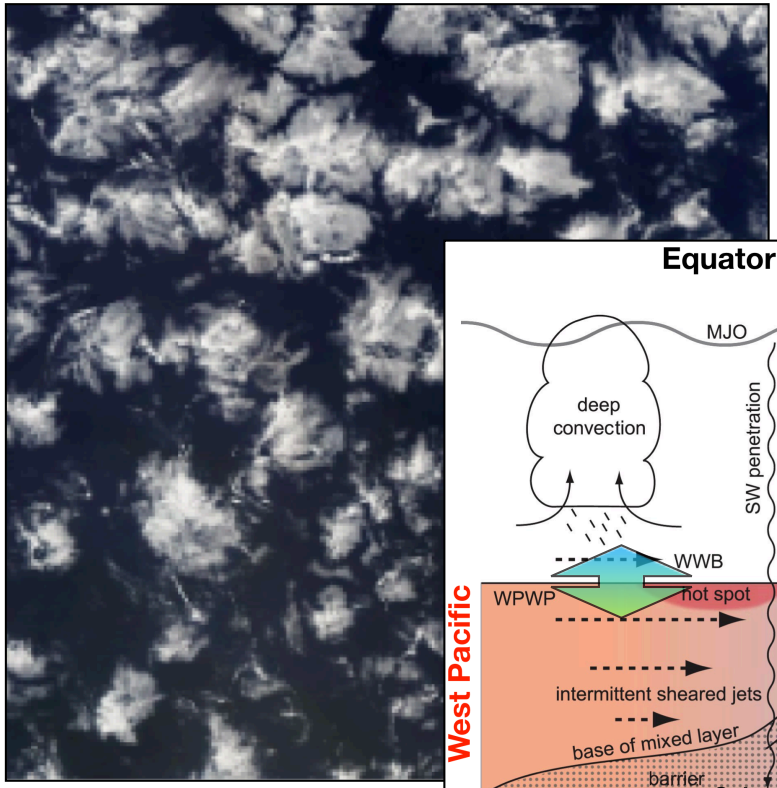


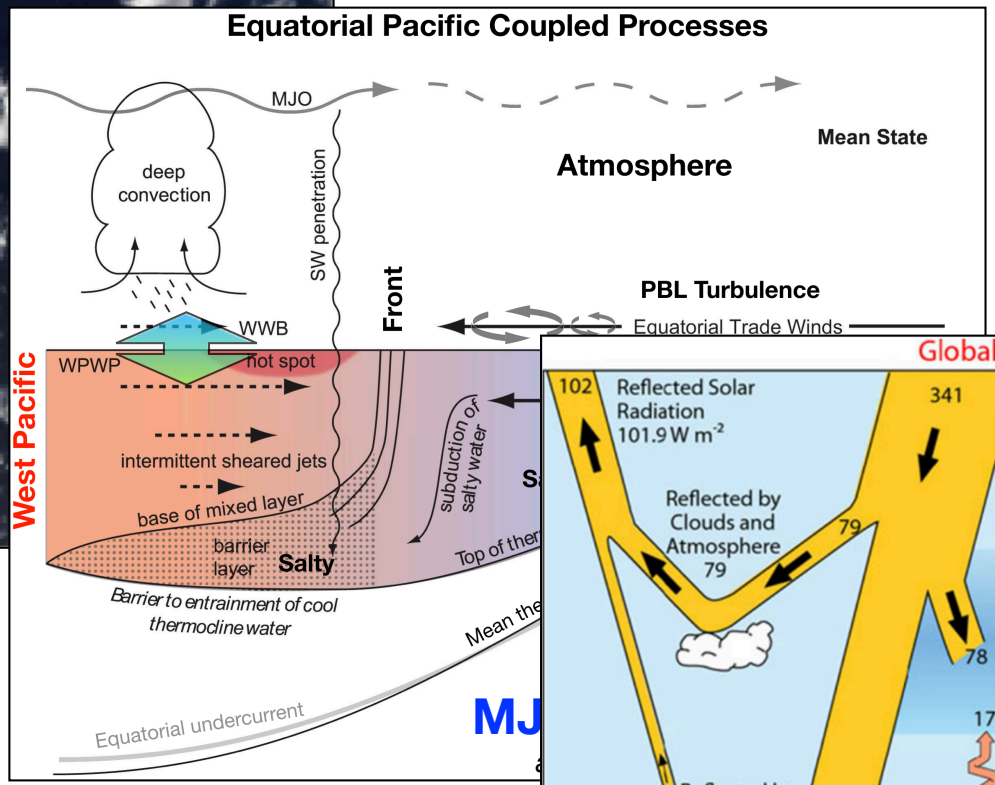


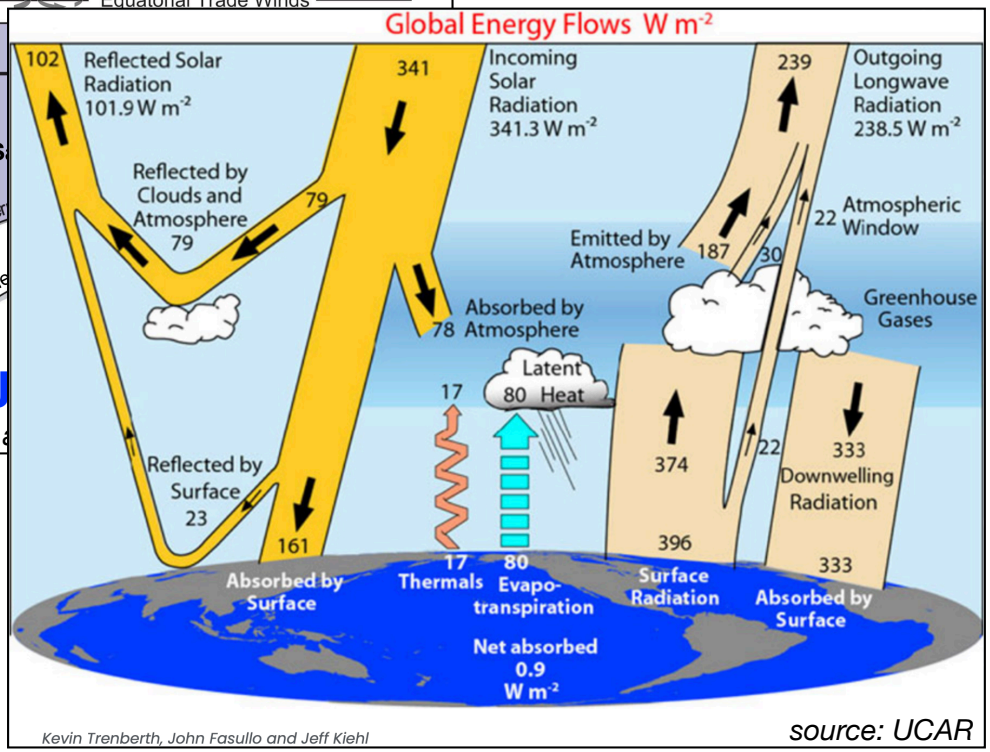


source: UCAR

marine surface fluxes across scales





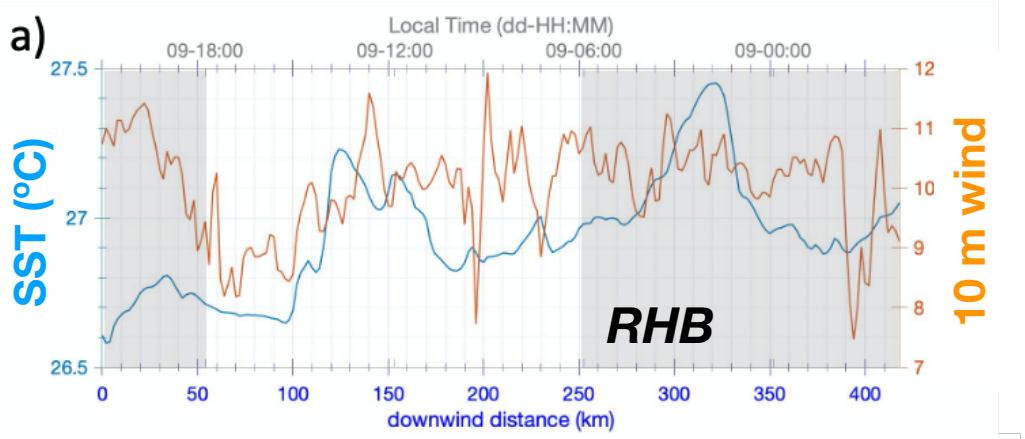


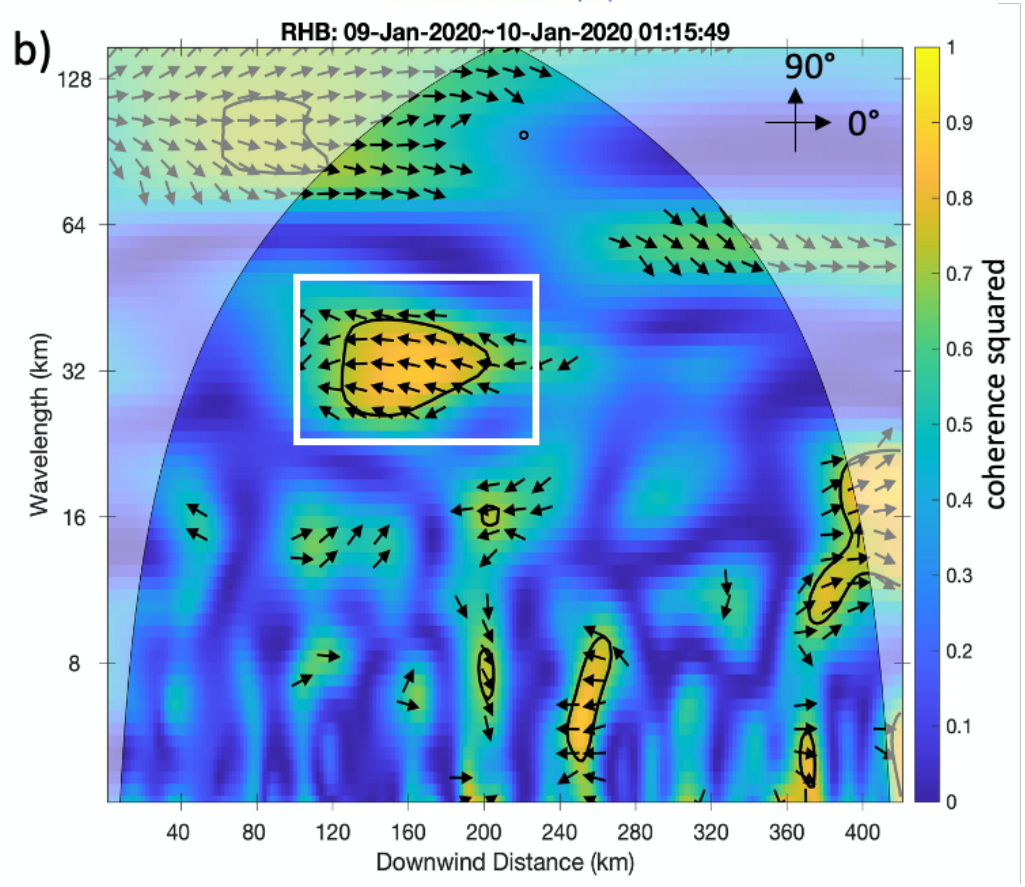
small/fast

large/slow

SST effects during EUREC4A/ATOMIC

Xuanyu Chen (NOAA/CIRES)





- analyzed SST, winds from RHB, wave gliders
- SST, wind vary coherently on 14- and 28-km scales

SST effects during EUREC4A/ATOMIC

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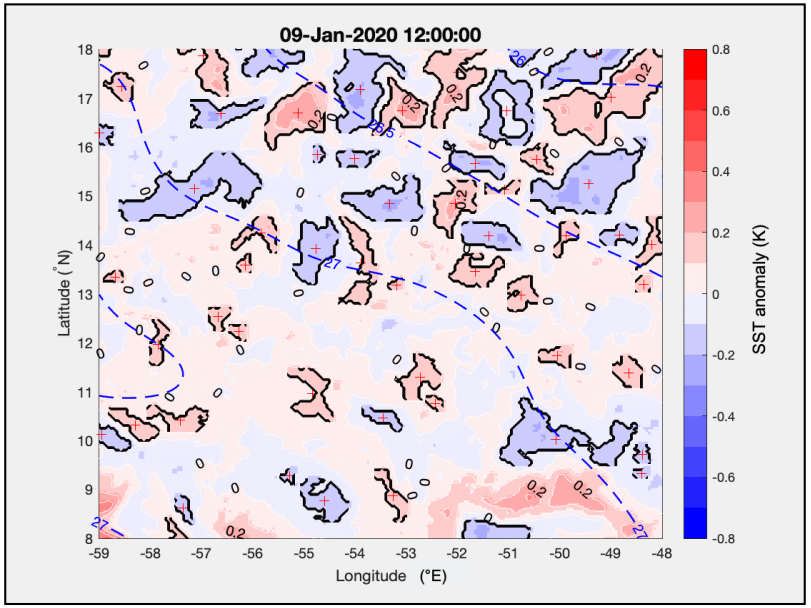

- GHRSST high-pass filtered SST anomalies (~10°x10° lat-lon box)
- ±0.2K warm/cold SST patches 40~140 km dia.

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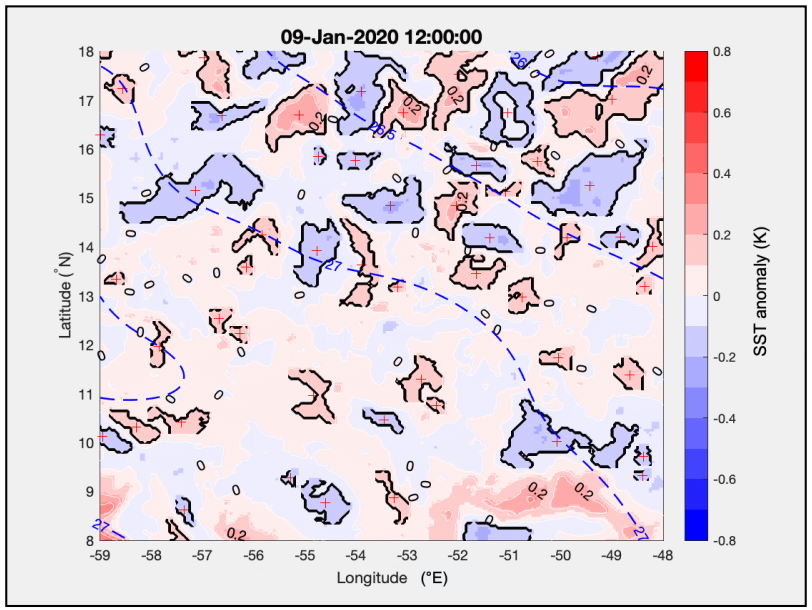

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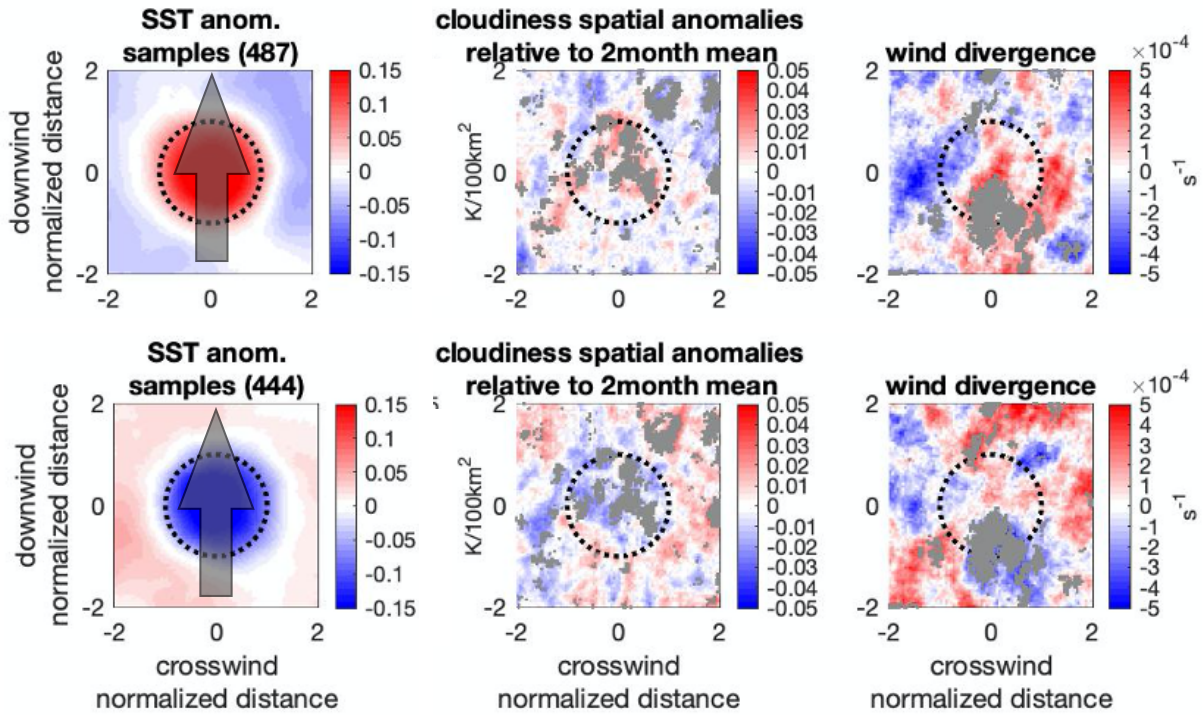

- small, weak SST anomalies regulate surface divergence, cloudiness

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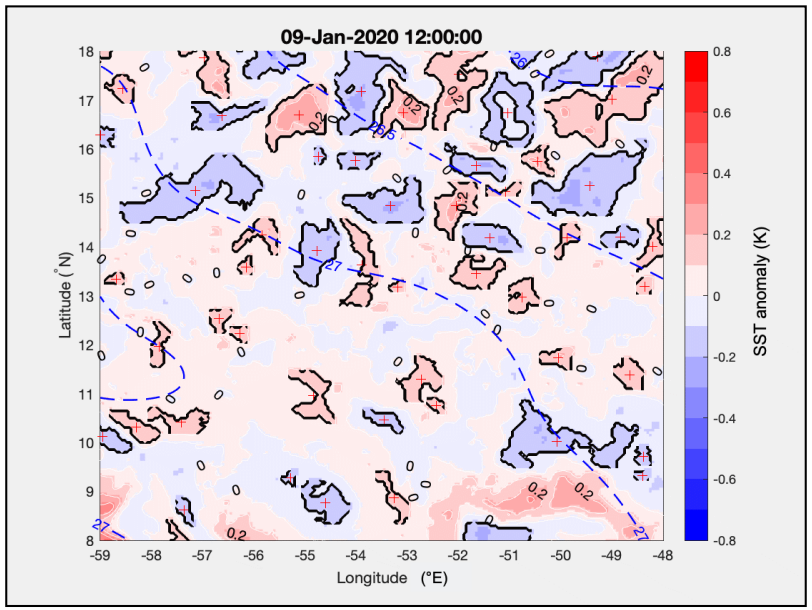

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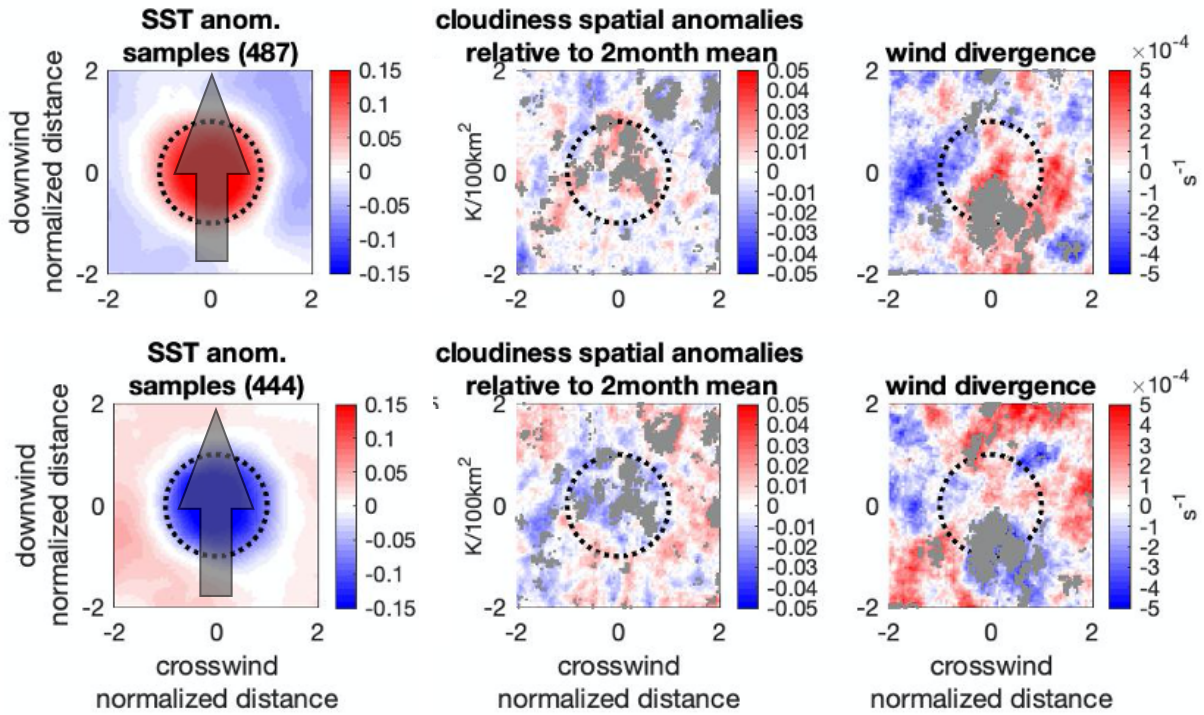

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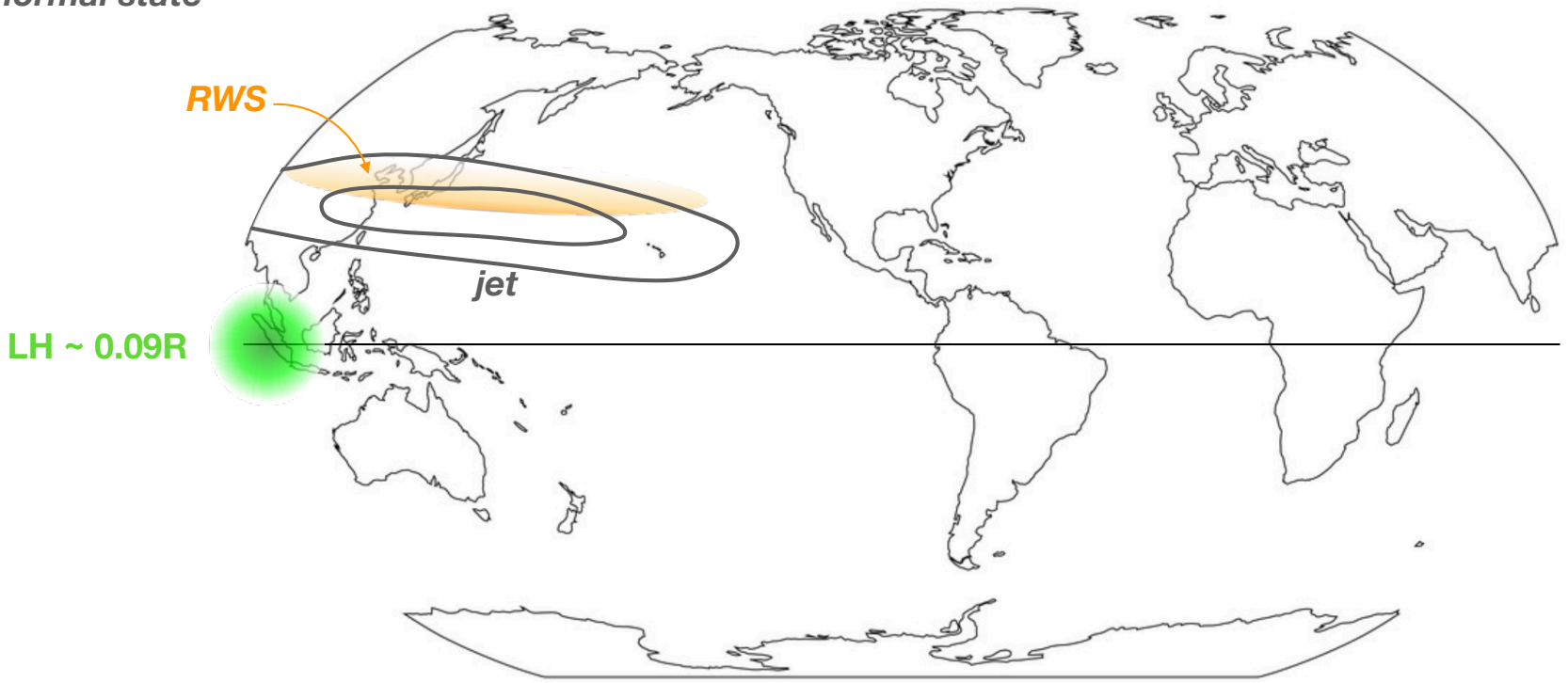
Kyle Shackelford

bulk surface flux effects for weather & climate simulation

Example: MJO teleconnections

normal state



animations adapted from Henderson et al. 2017

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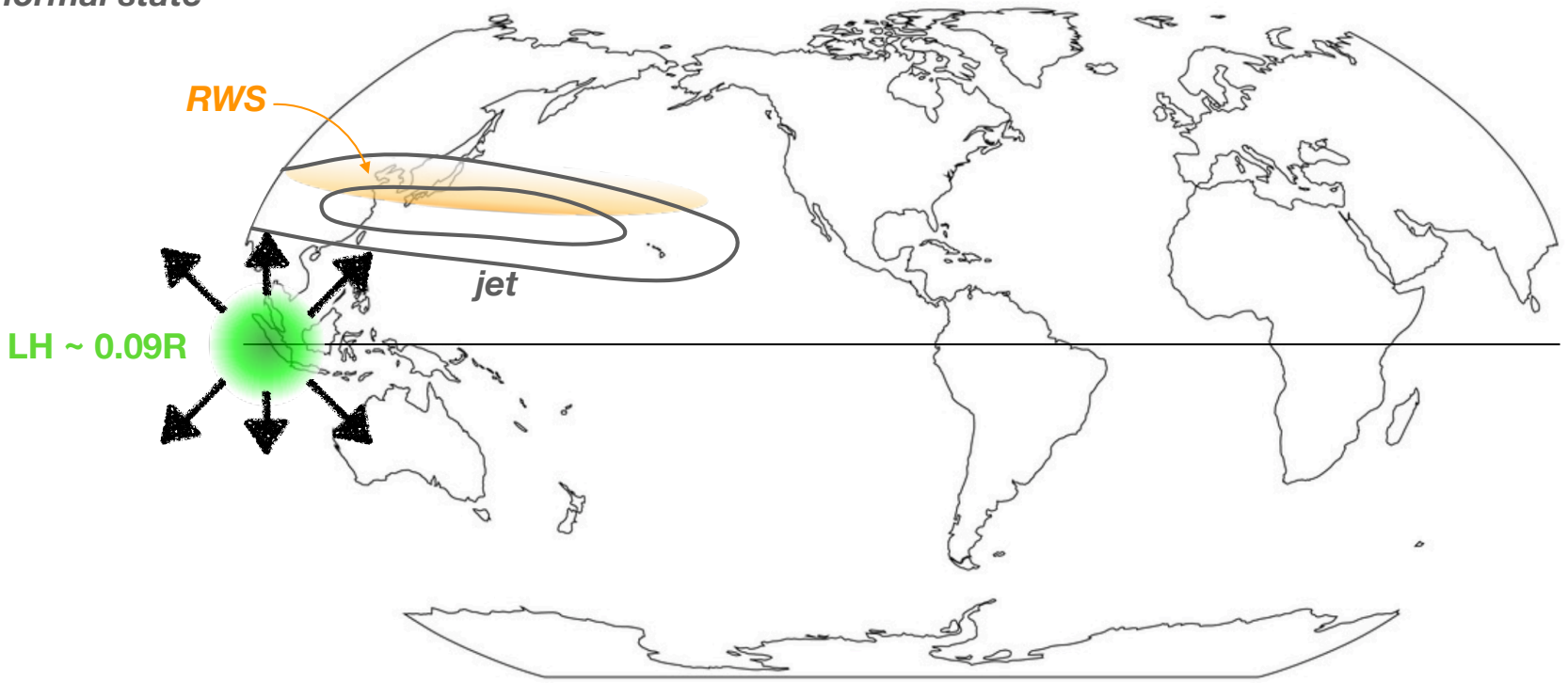

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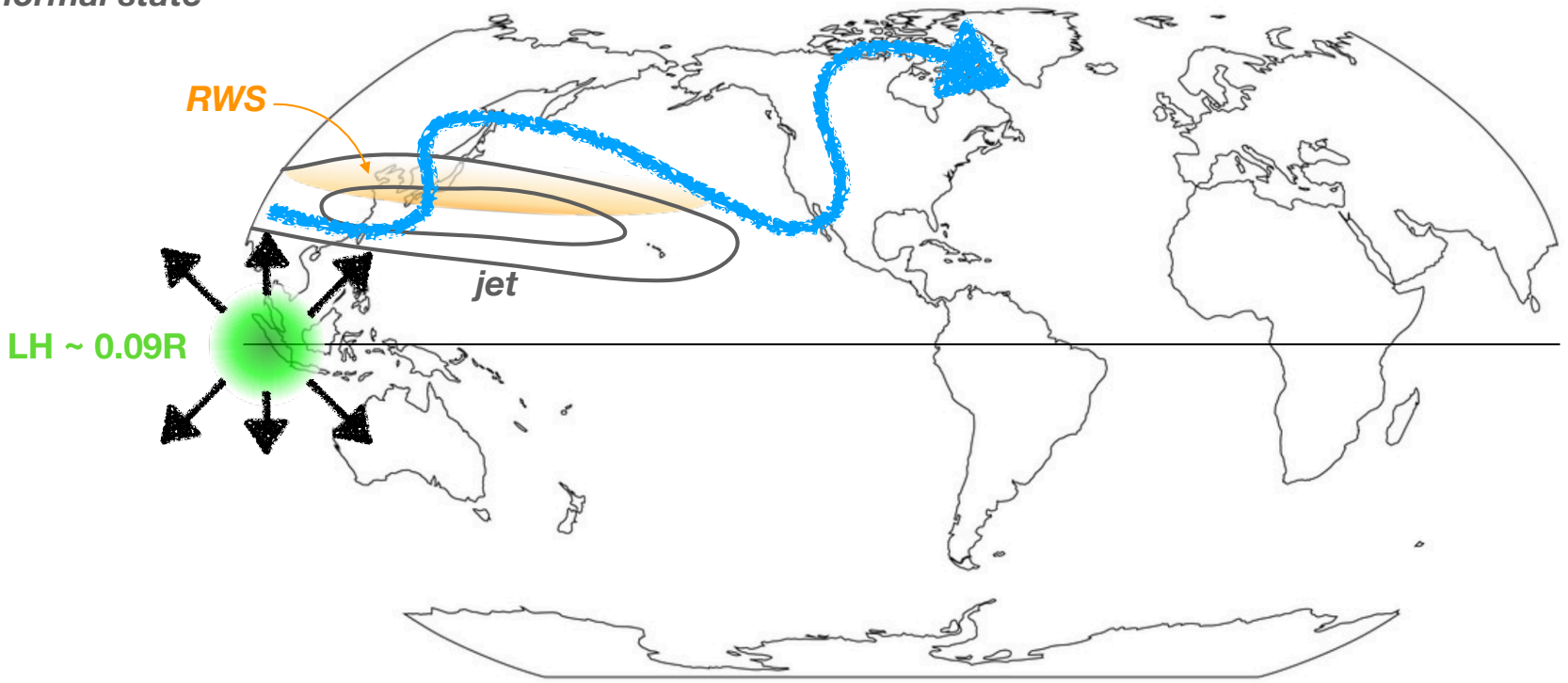

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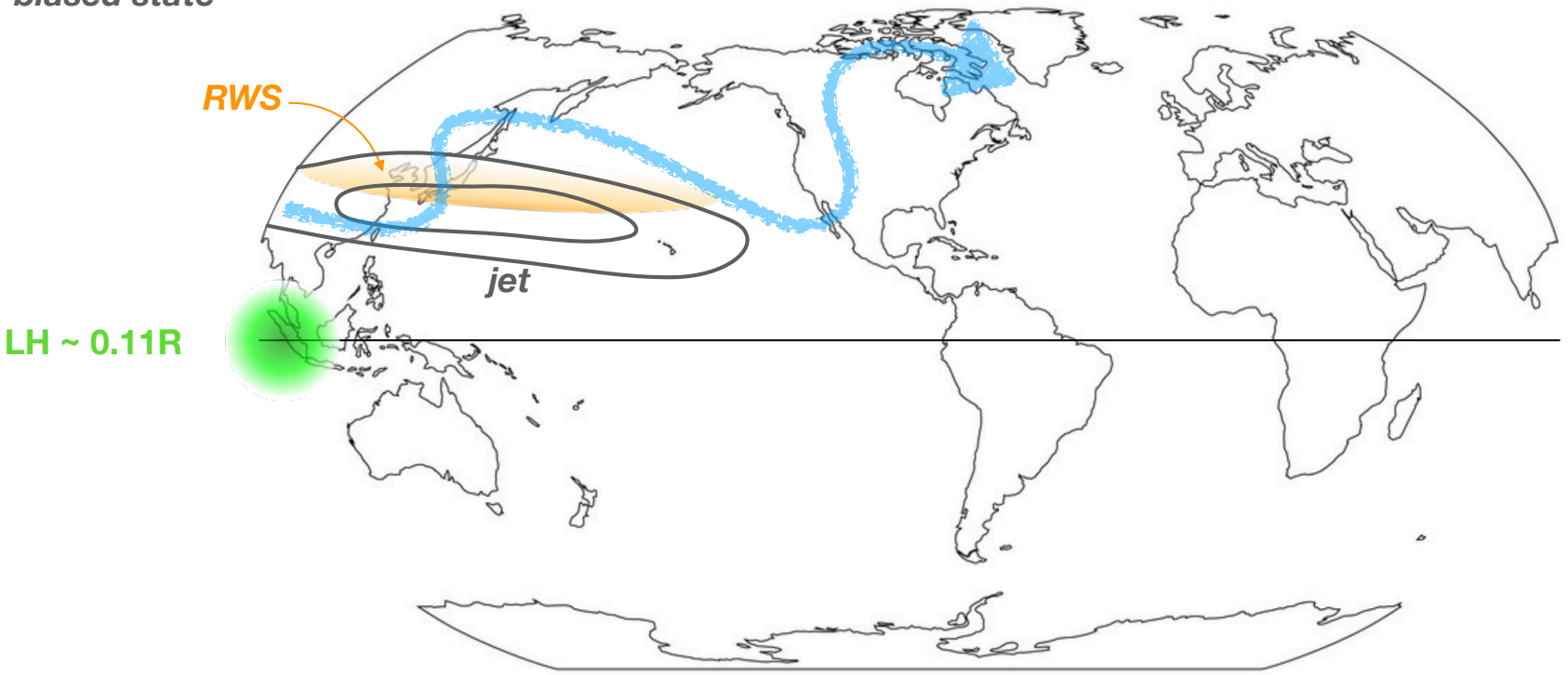
biased state



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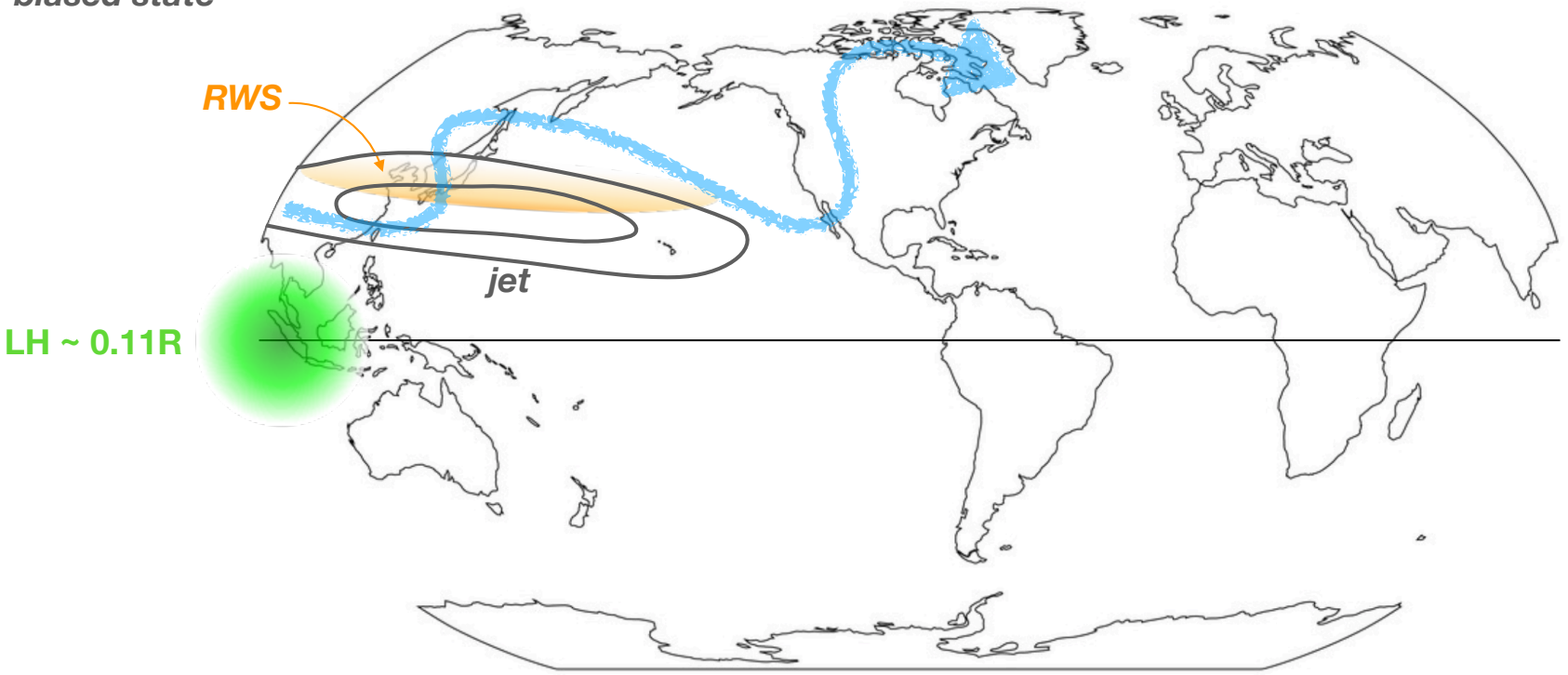

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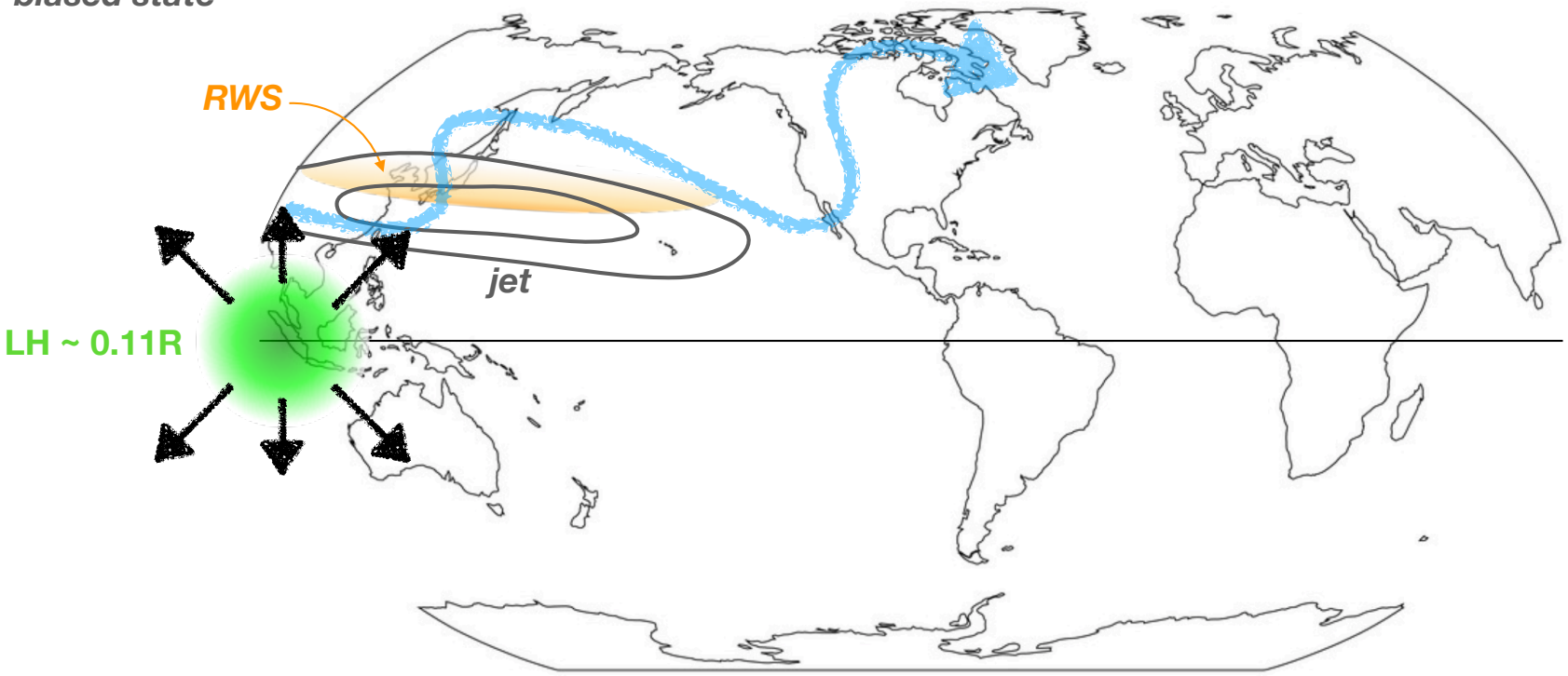

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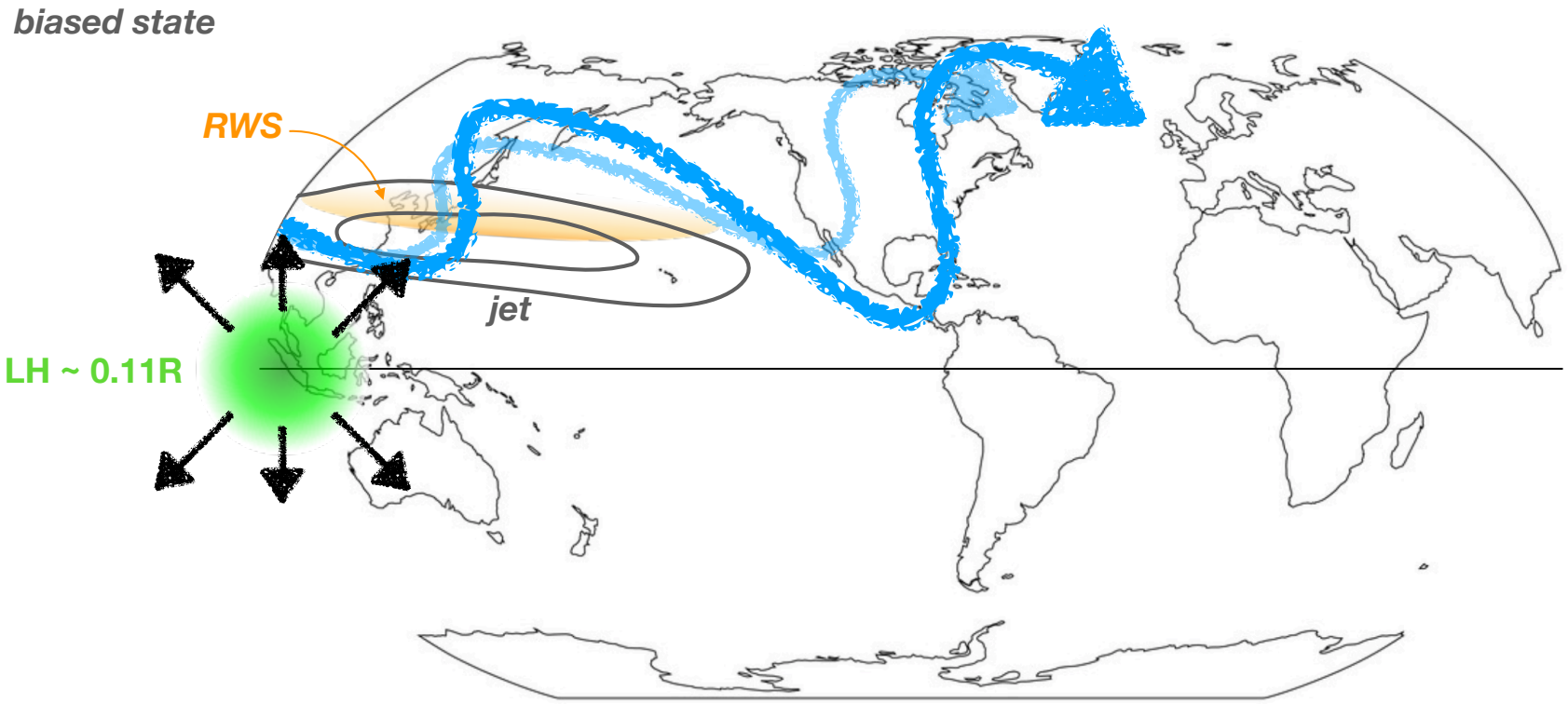

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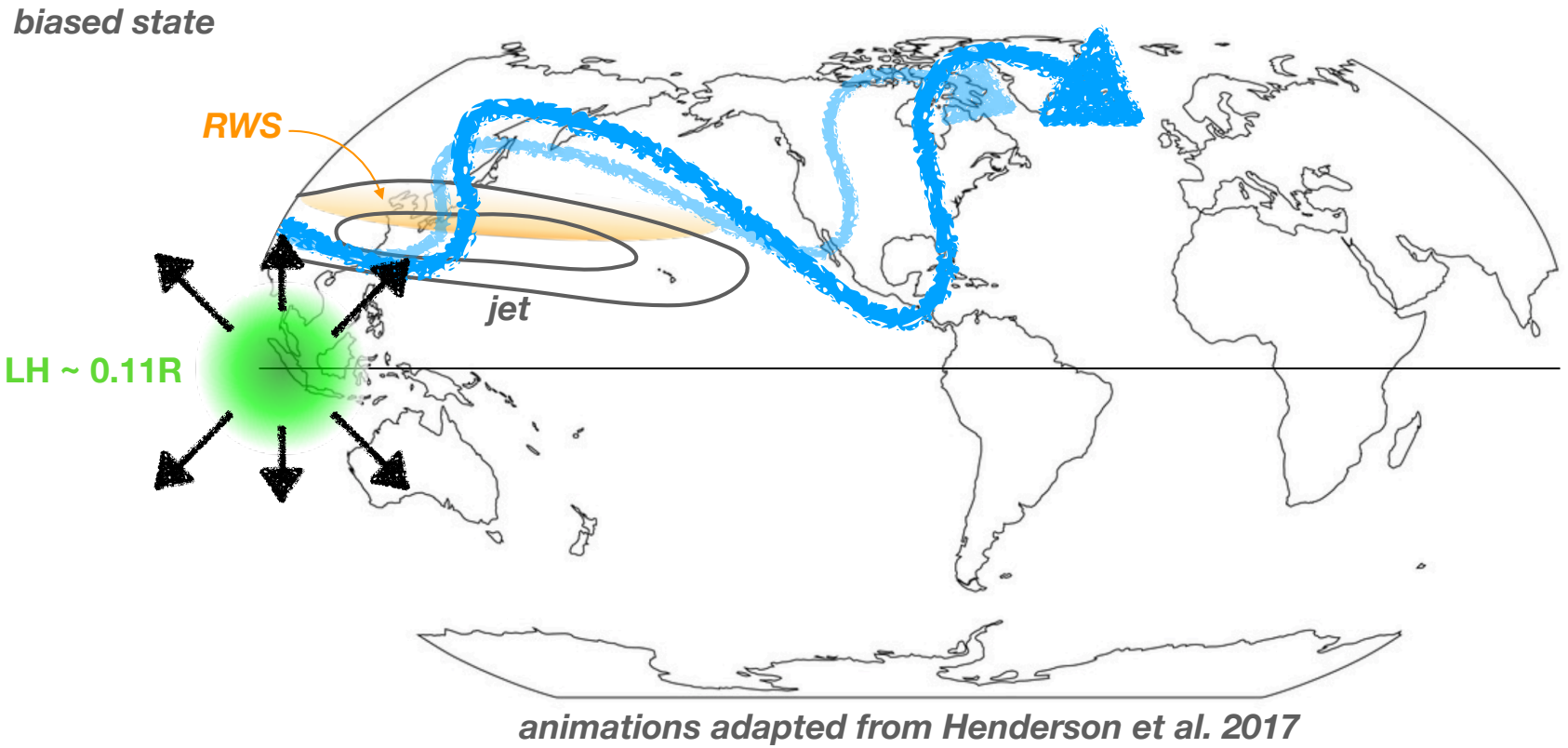

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- MJO amplitude biases -> jet stream biases

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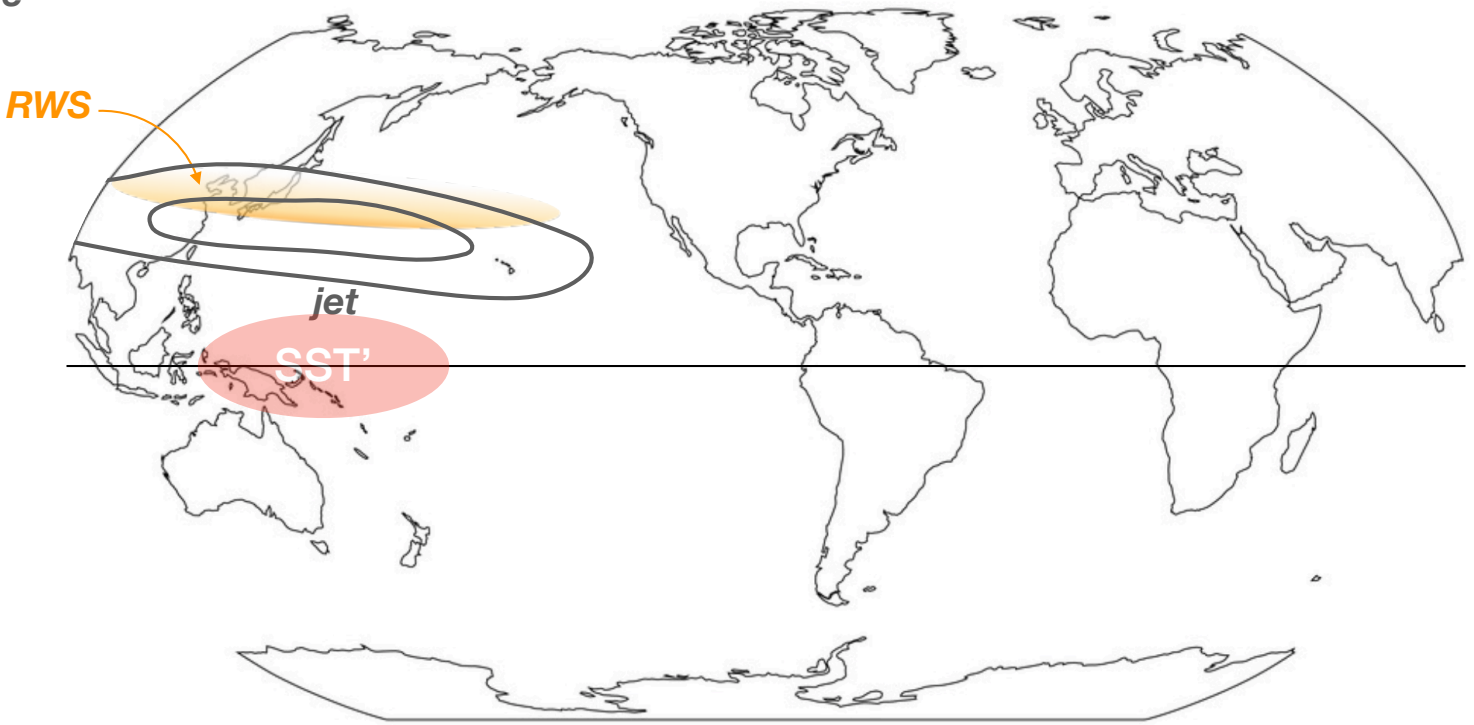

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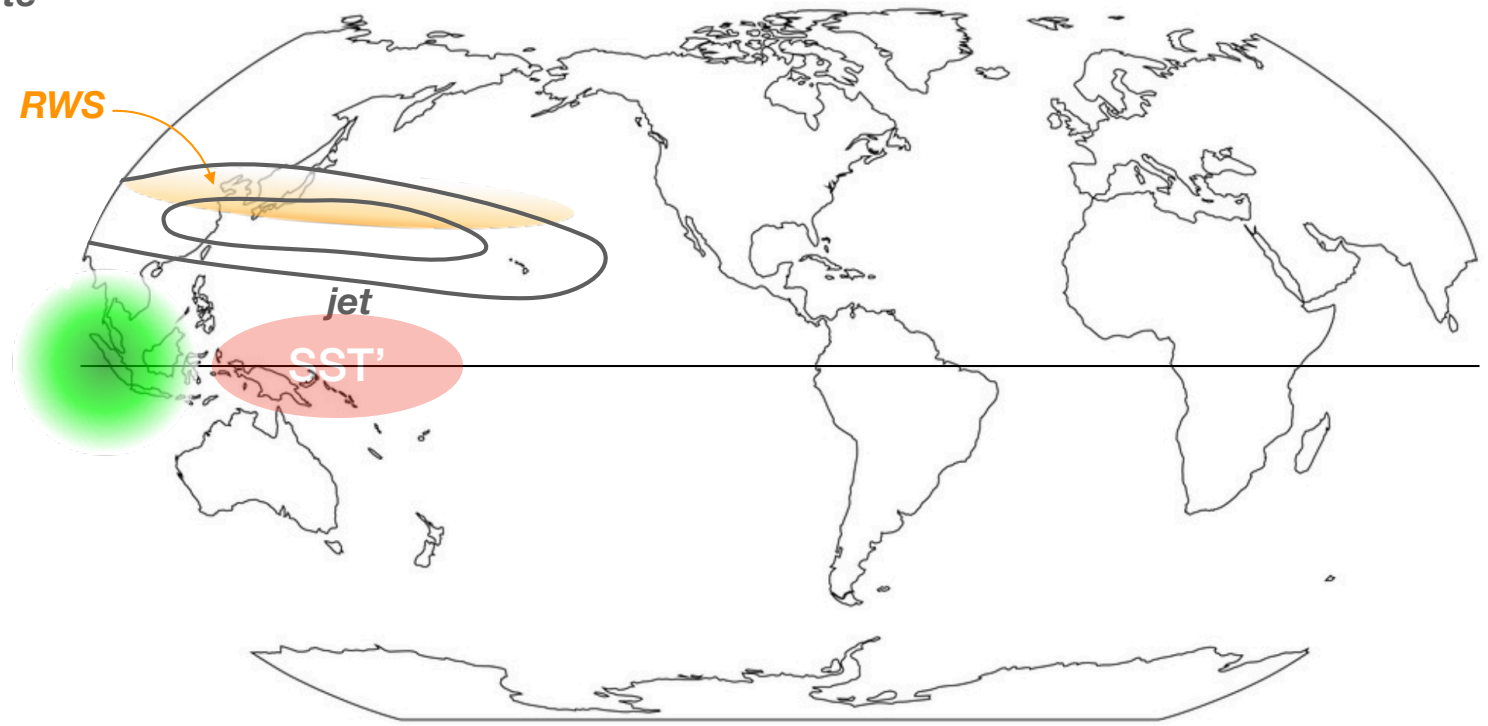

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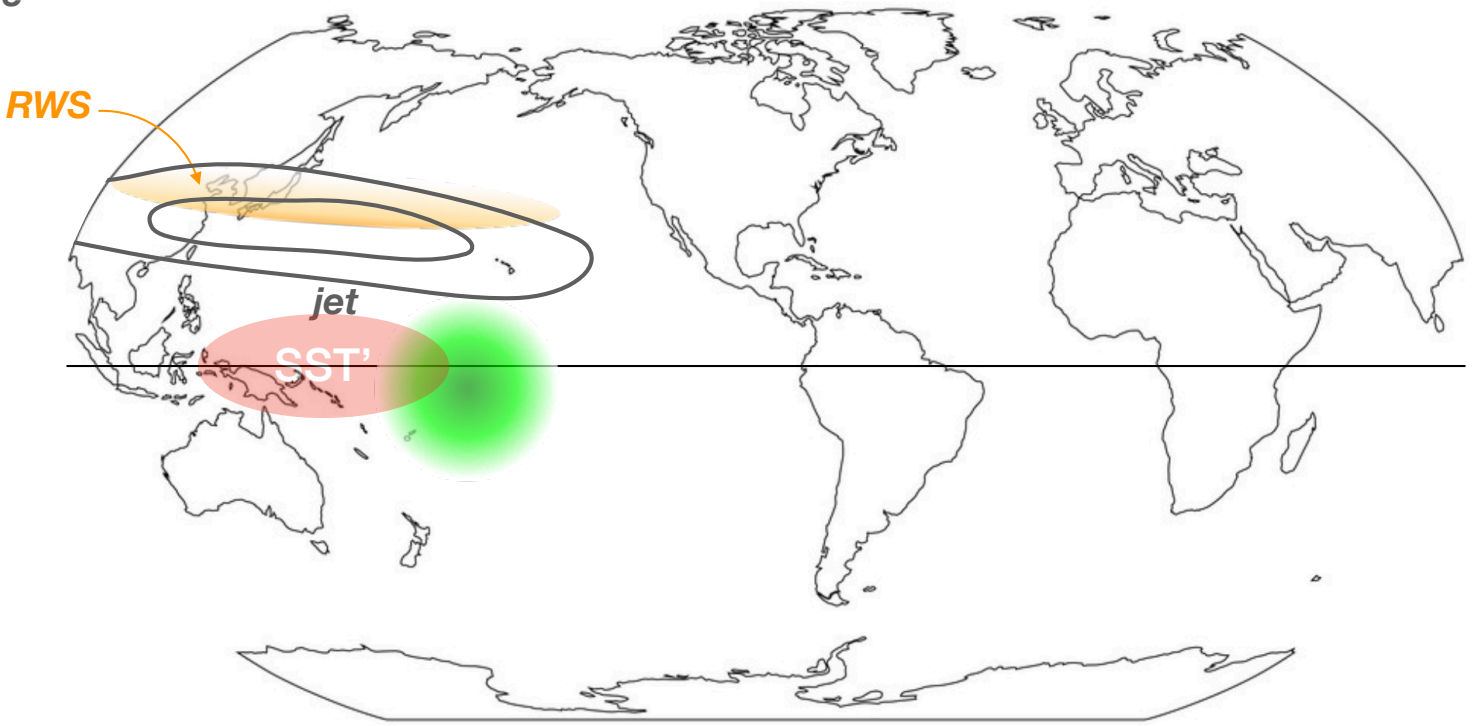

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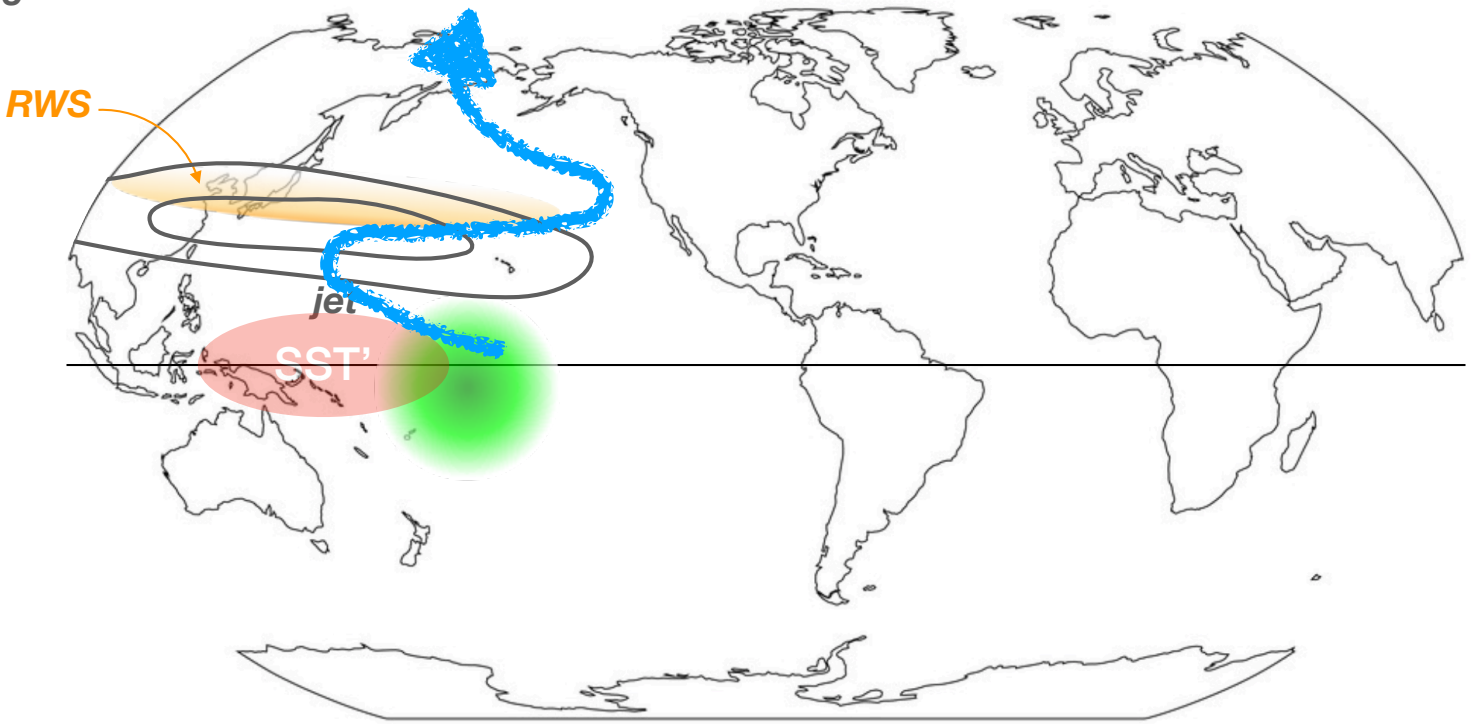

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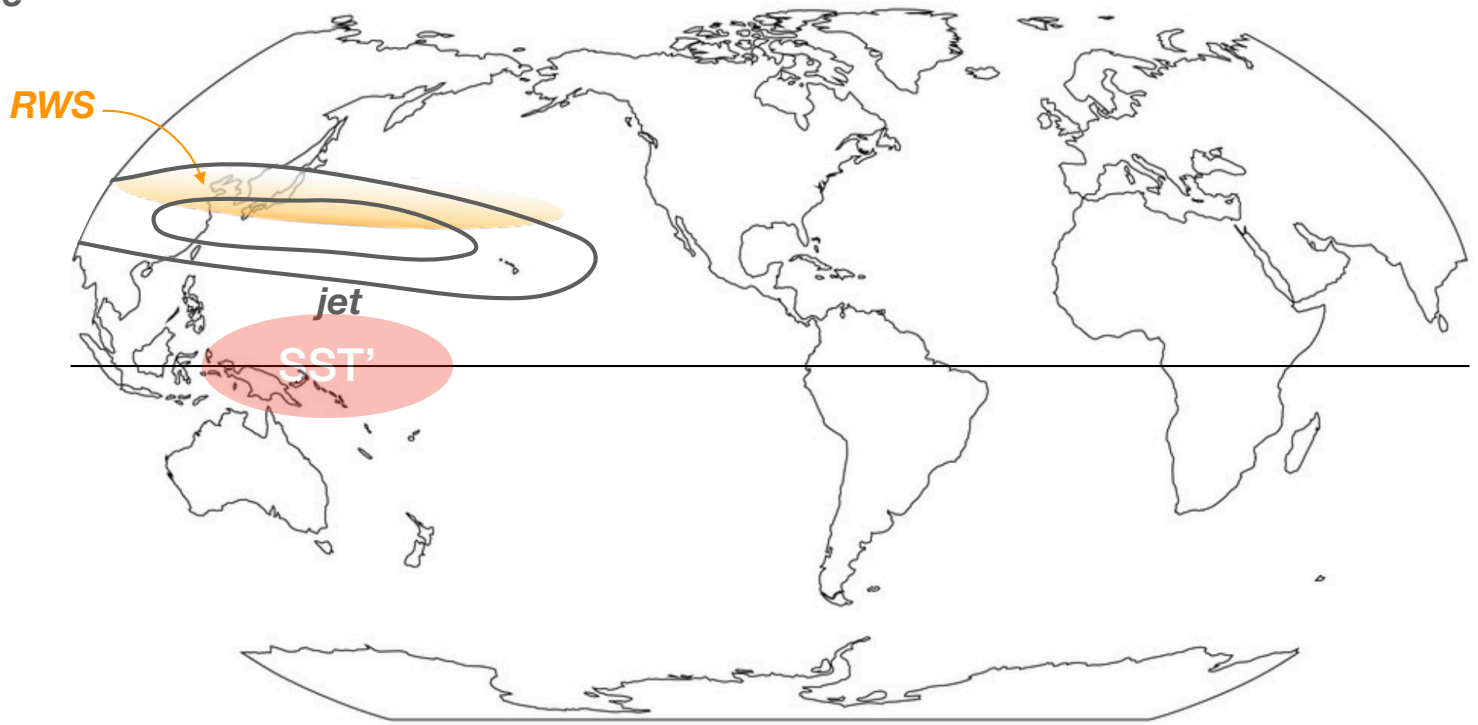

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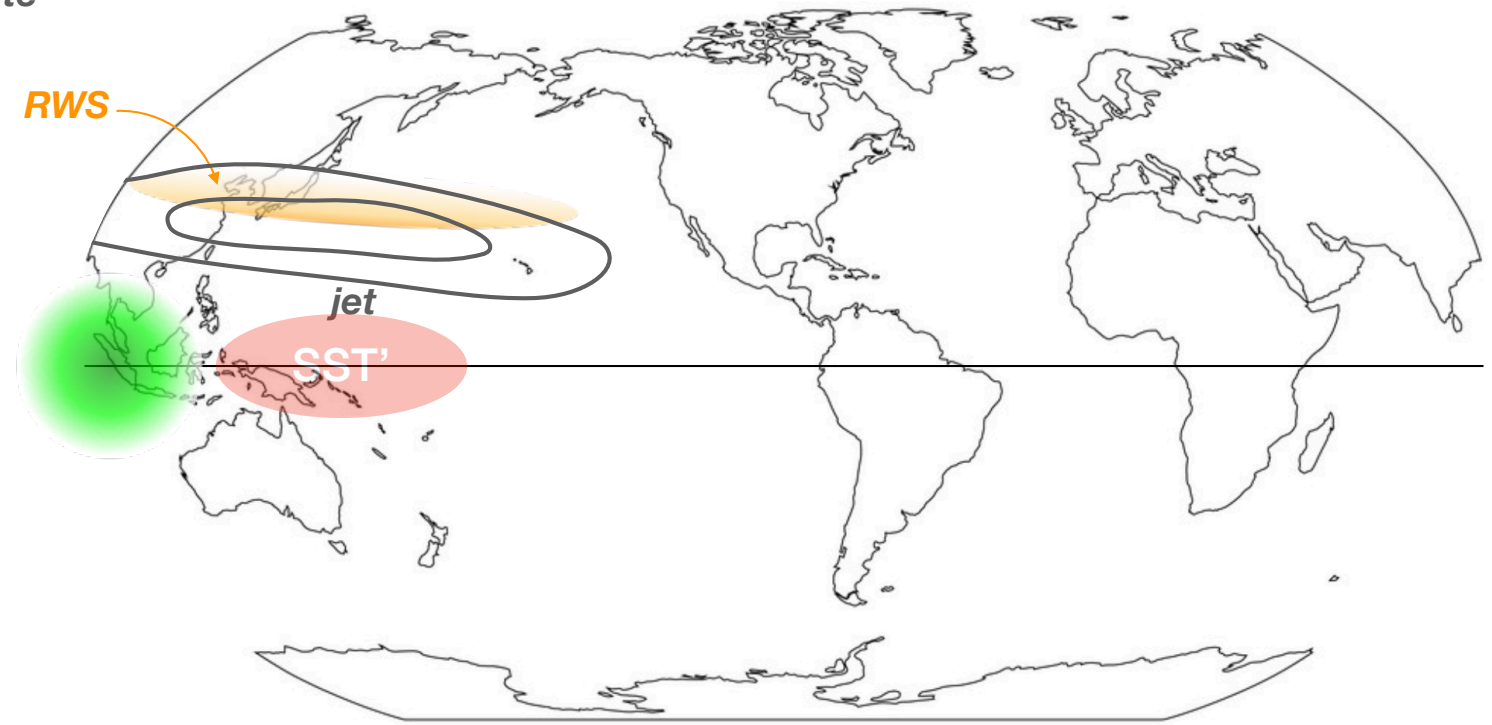

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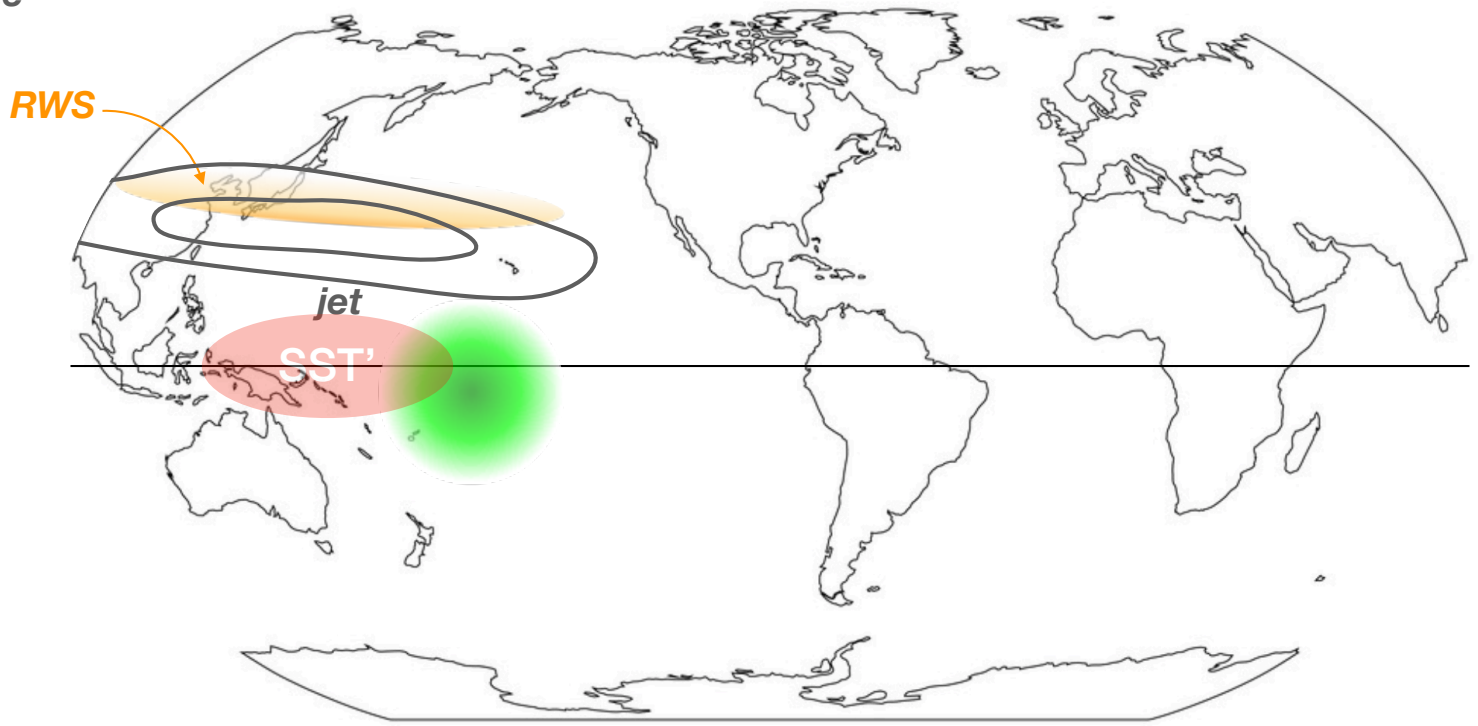

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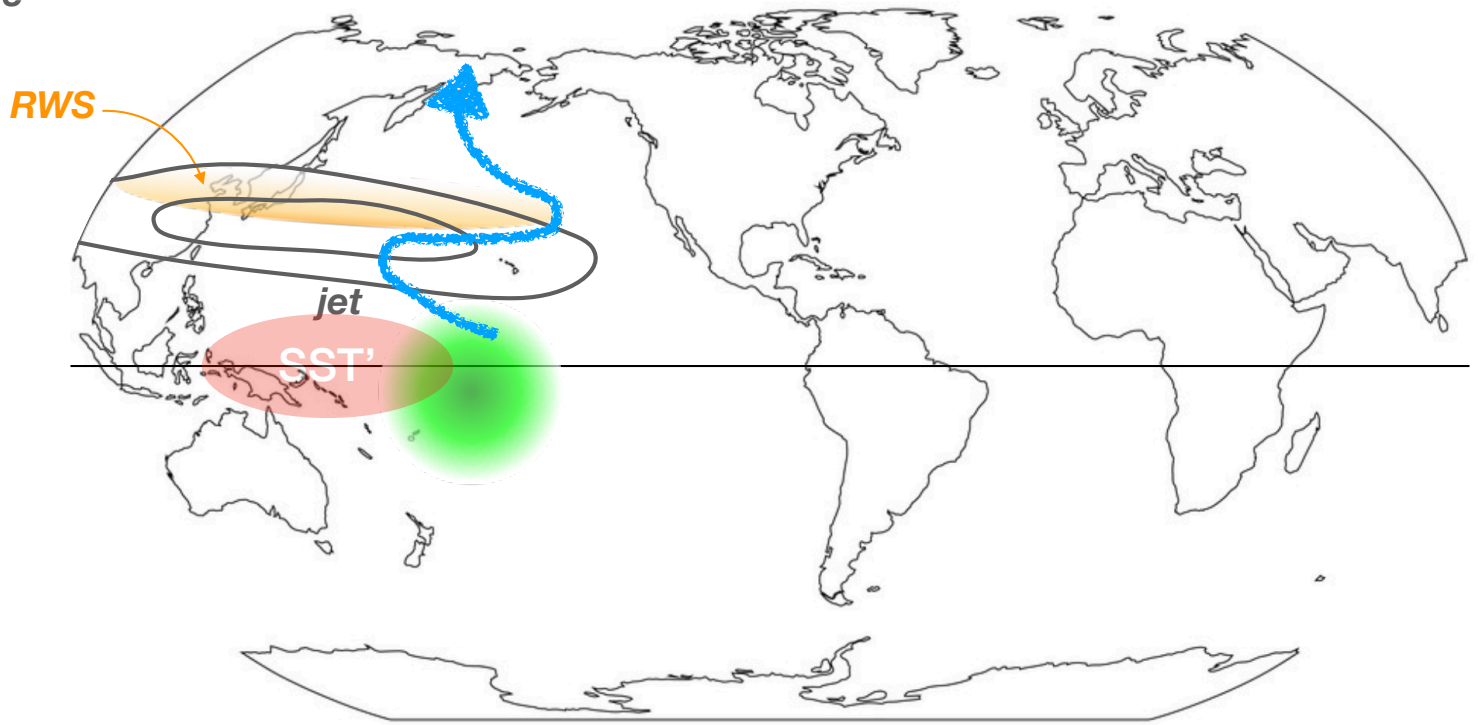

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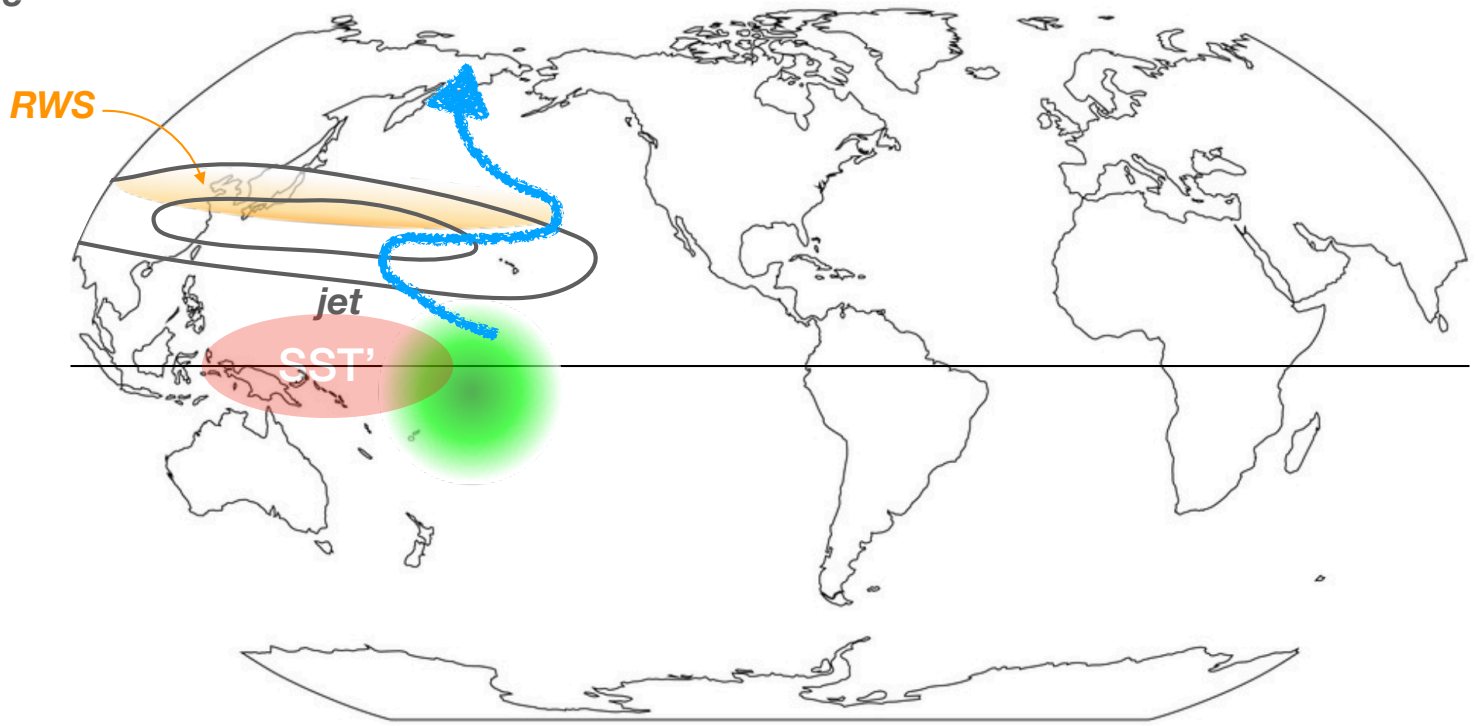

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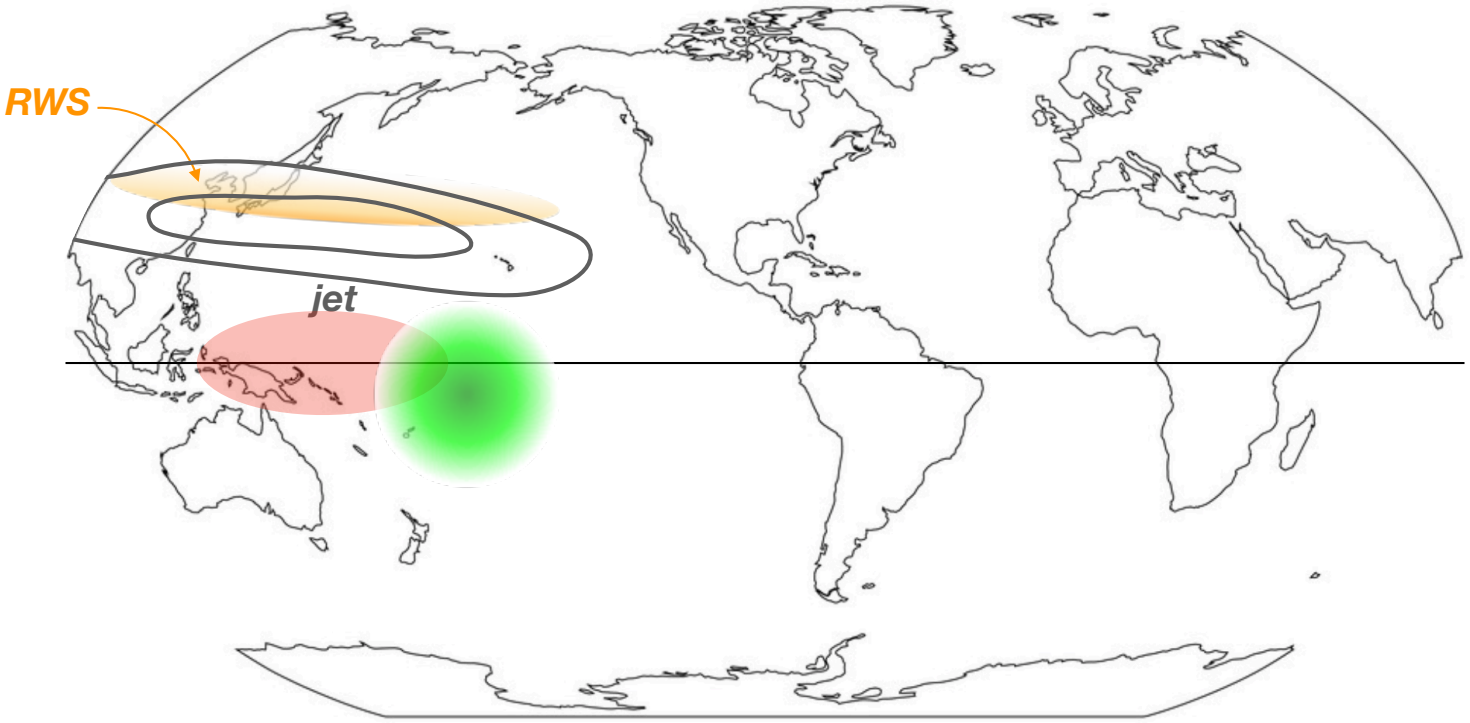
- MJO propagation biases -> jet stream biases

bulk surface flux effects for weather & climate simulation

Example: MJO-ENSO interactions



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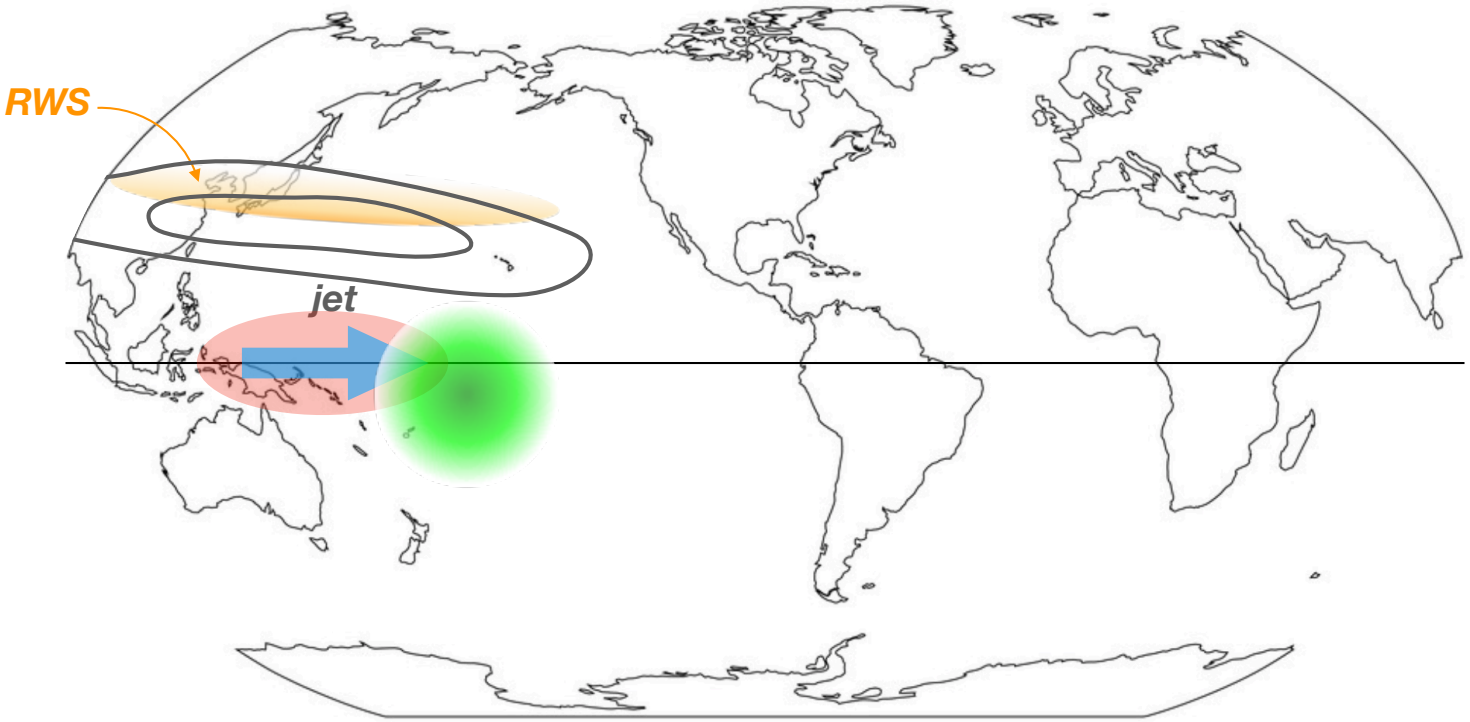
bulk surface flux effects for weather & climate simulation

Example: MJO-ENSO interactions



animations adapted from Henderson et al. 2017

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

bulk surface flux effects for weather & climate simulation

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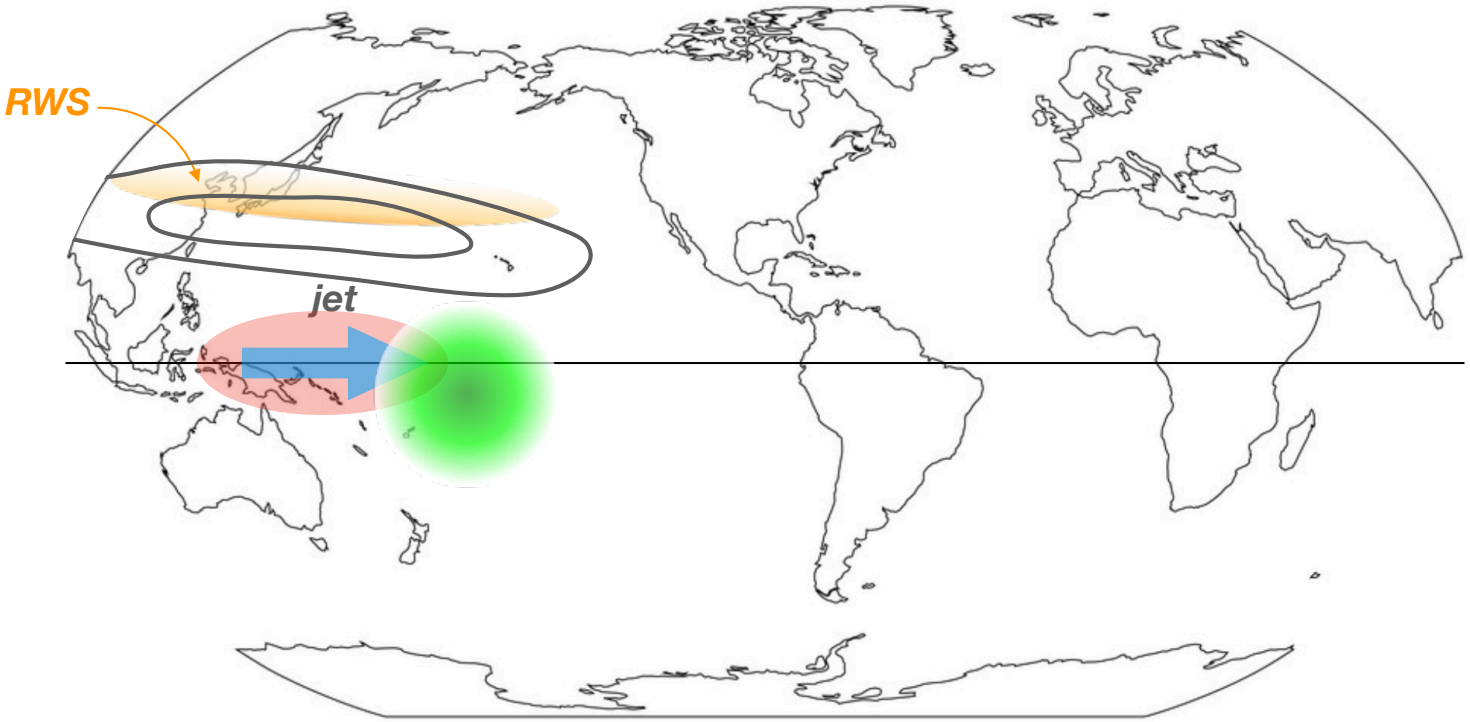

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- MJO amplitude biases -> jet stream biases
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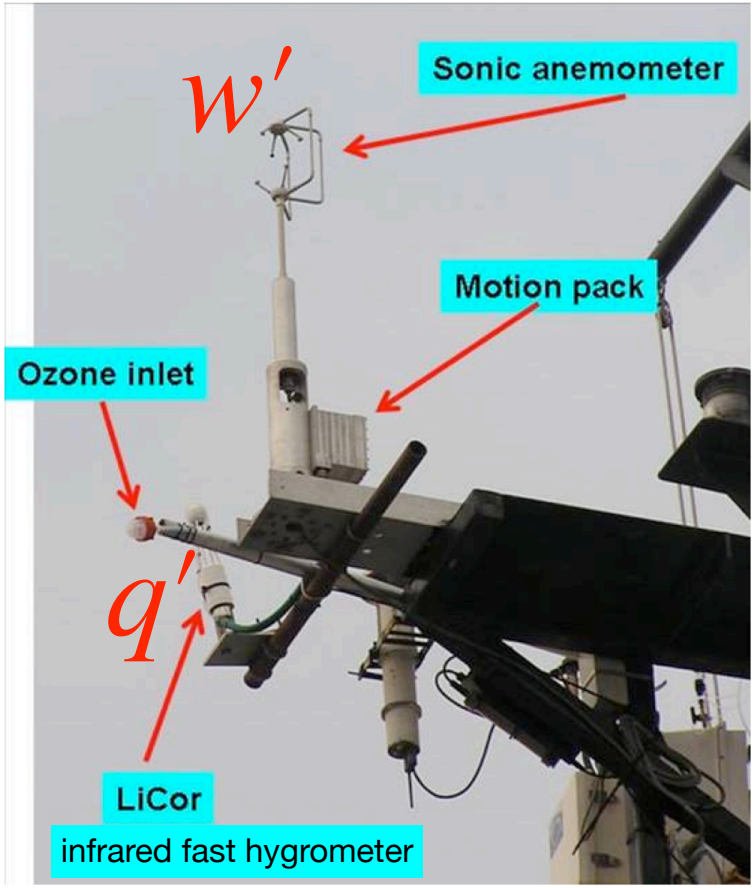
- MJO propagation biases -> ocean Kelvin wave, ENSO biases

surface fluxes: measurement versus estimation

direct covariance measurement

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



Weller et al. 2008

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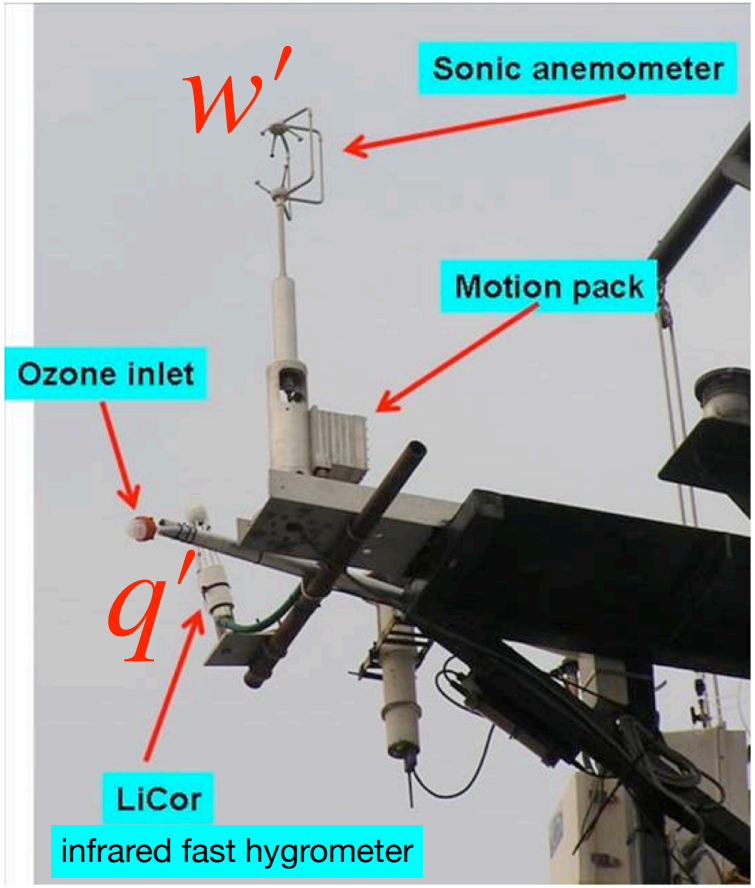

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$$LH = L_v C_e |V| (q^*_{SST} - q_{2m})$$

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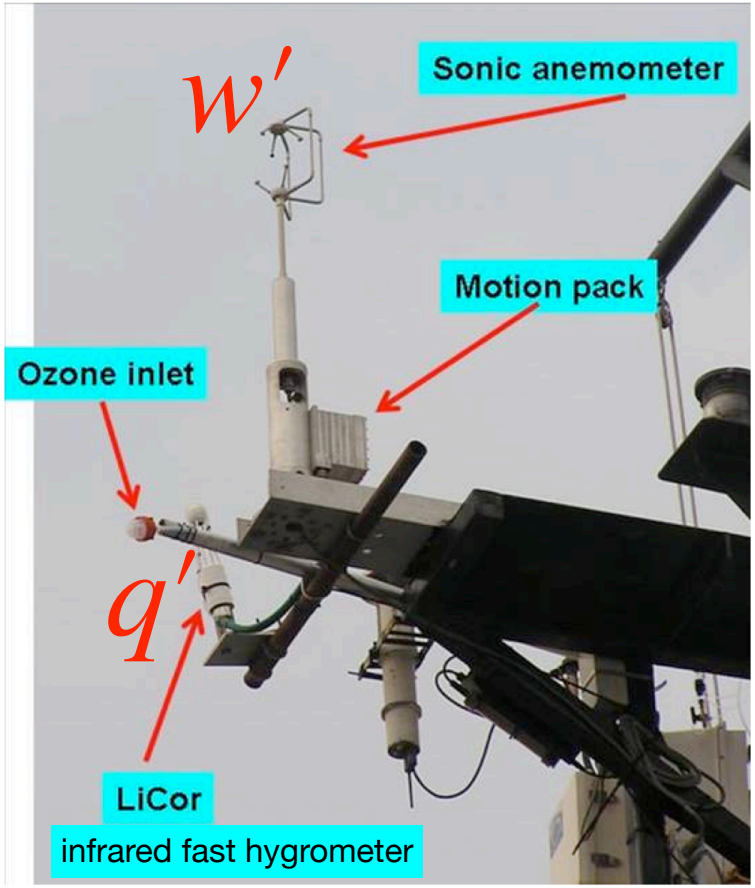

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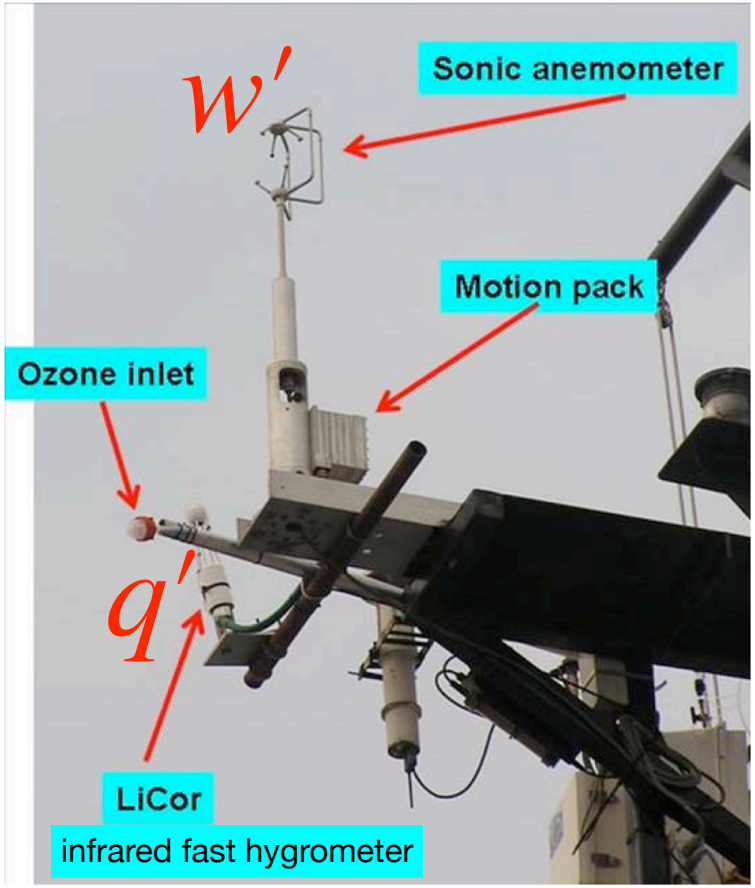

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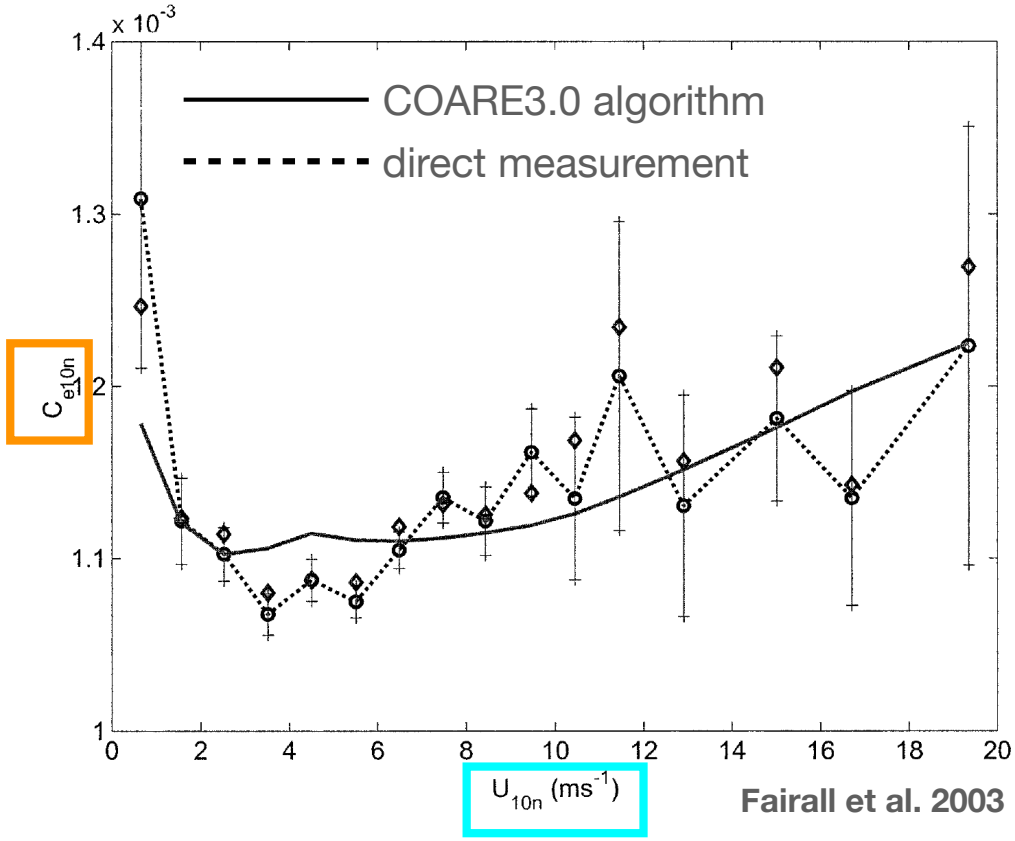
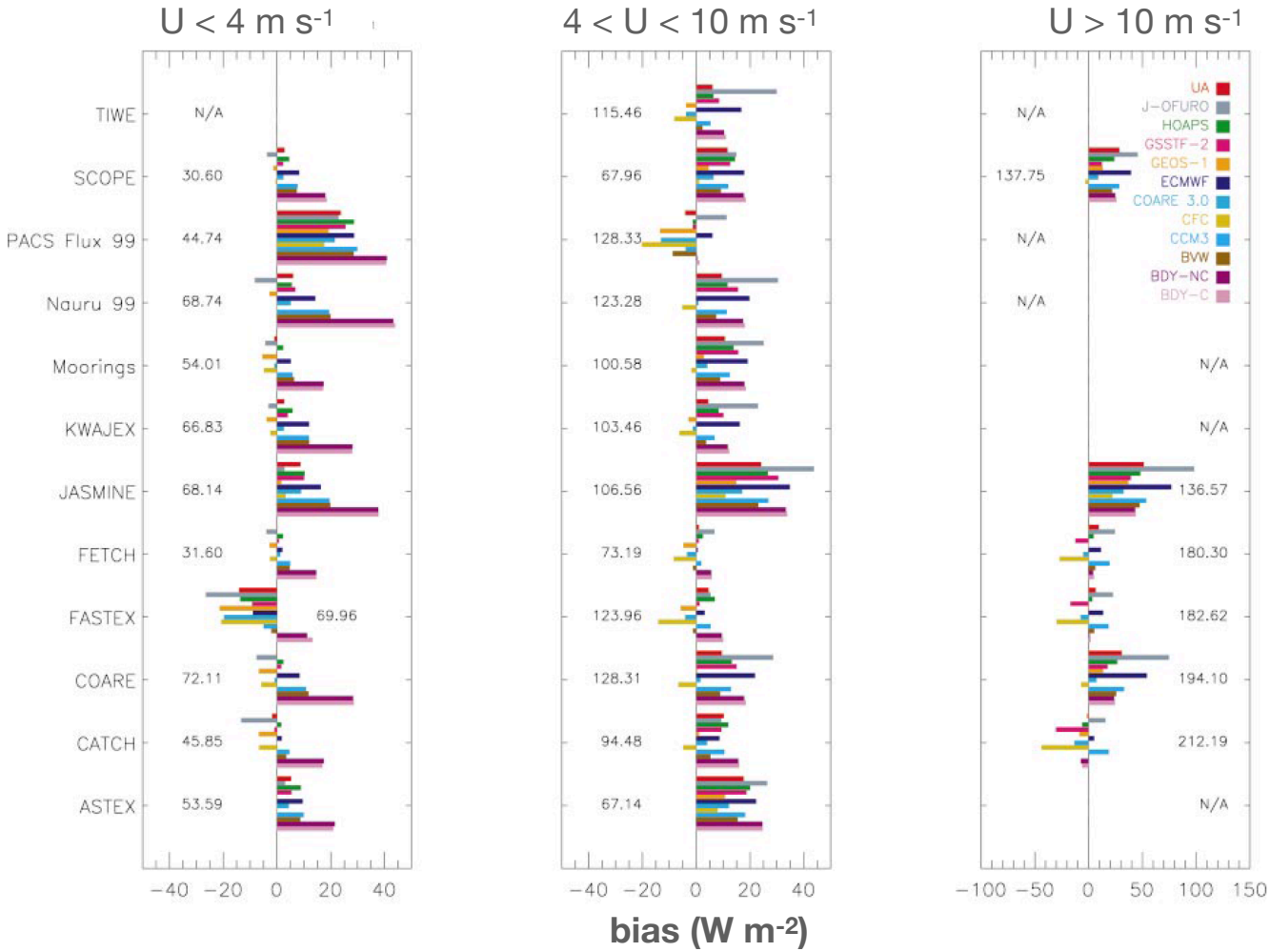


Fairall et al. 2003

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

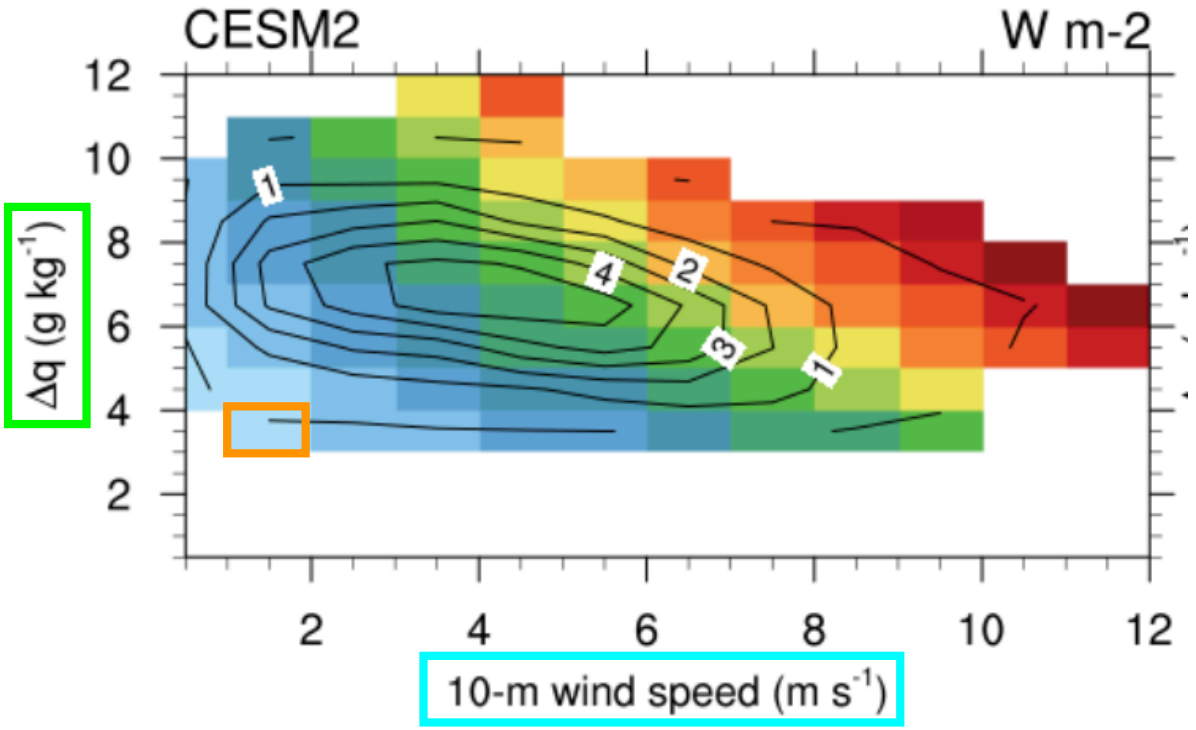
COARE algorithm is among the “least problematic”

Brunke et al. (2003)

surface fluxes: how to diagnose their biases in models?

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

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



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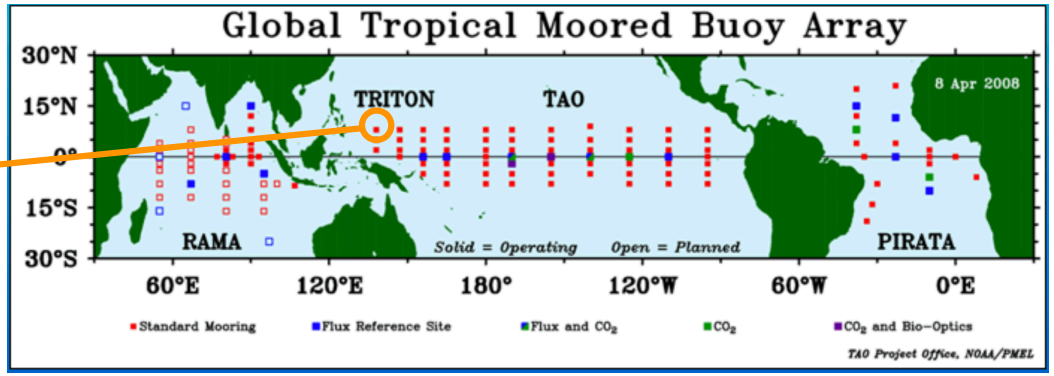

McPhaden (2008)

NOAA

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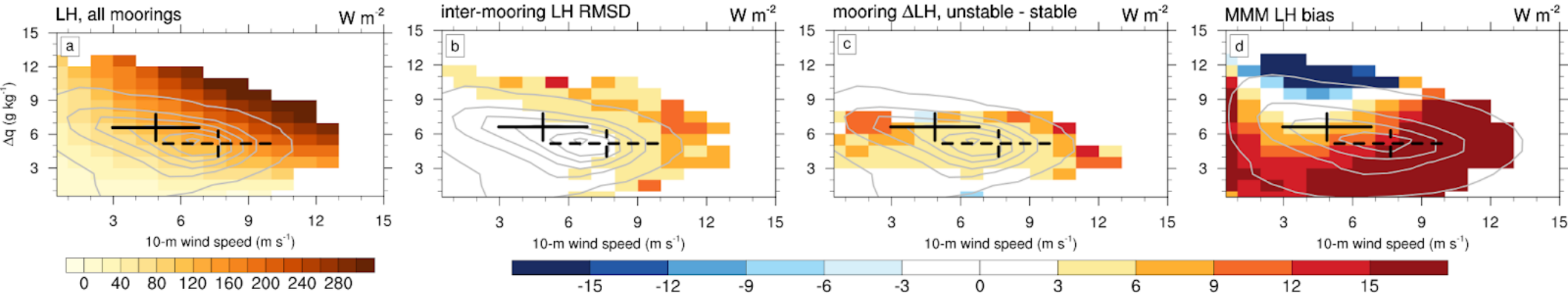

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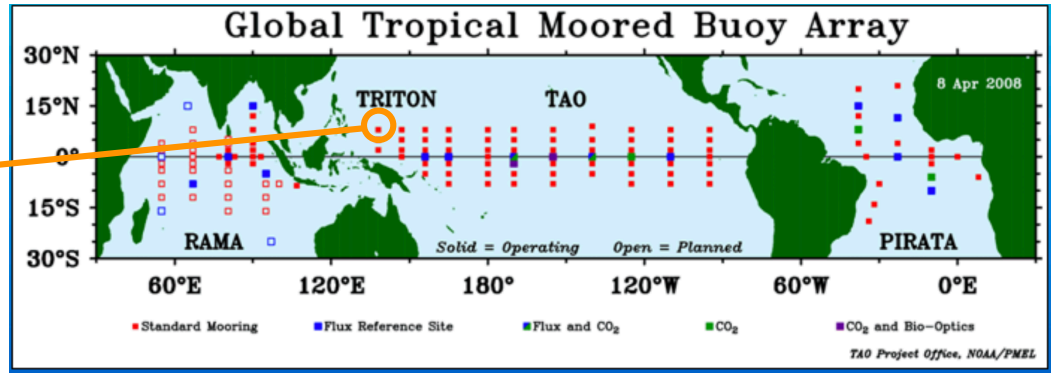

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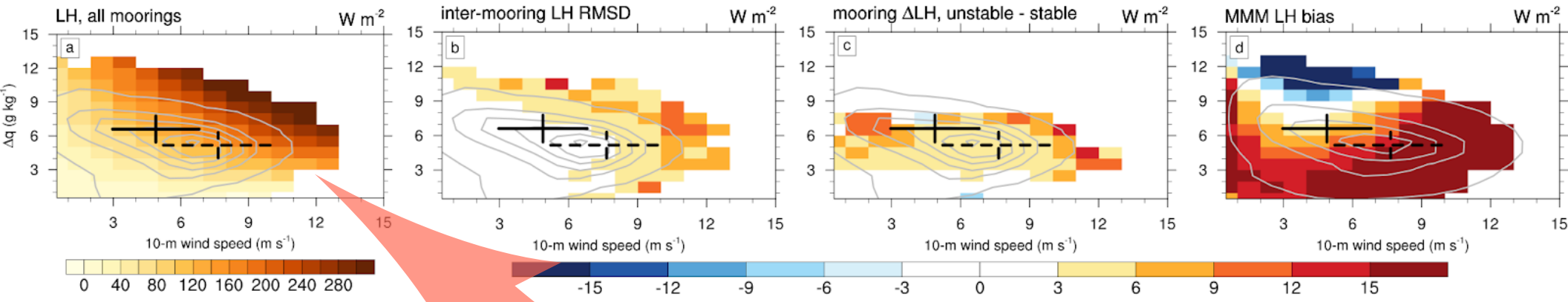

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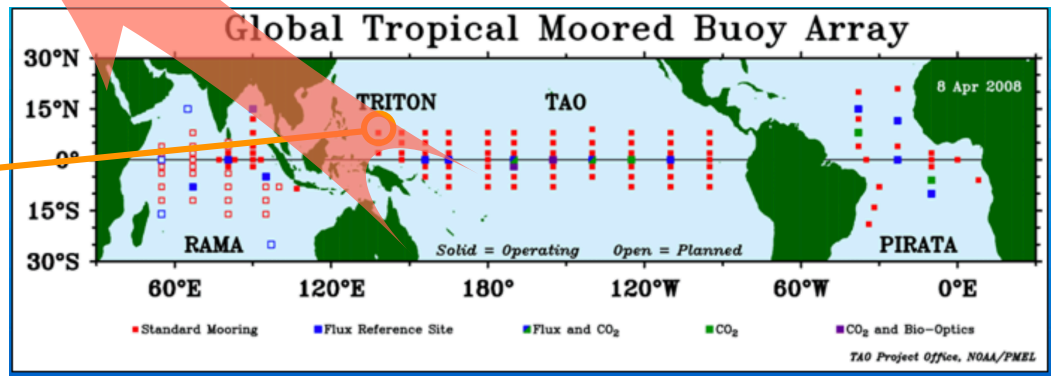

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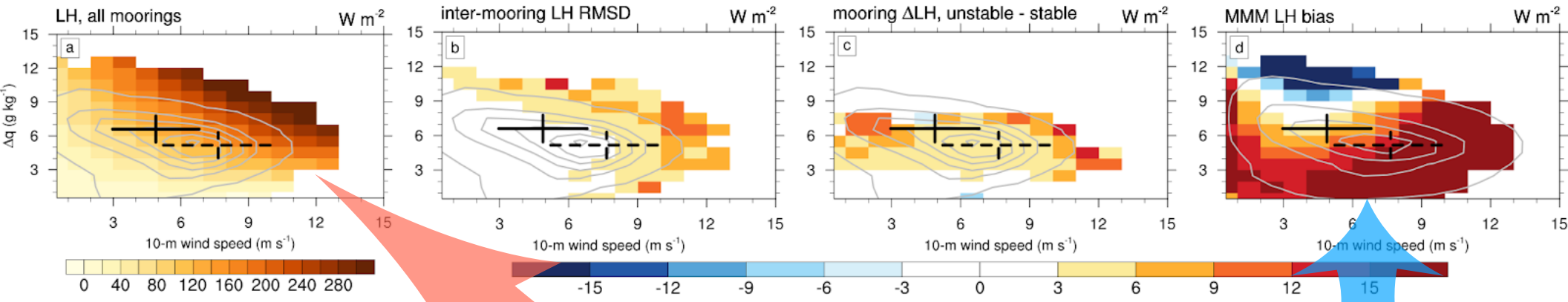

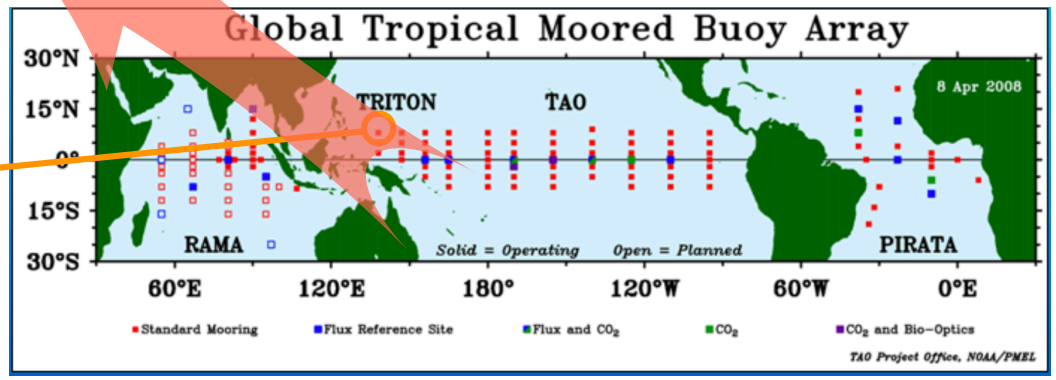

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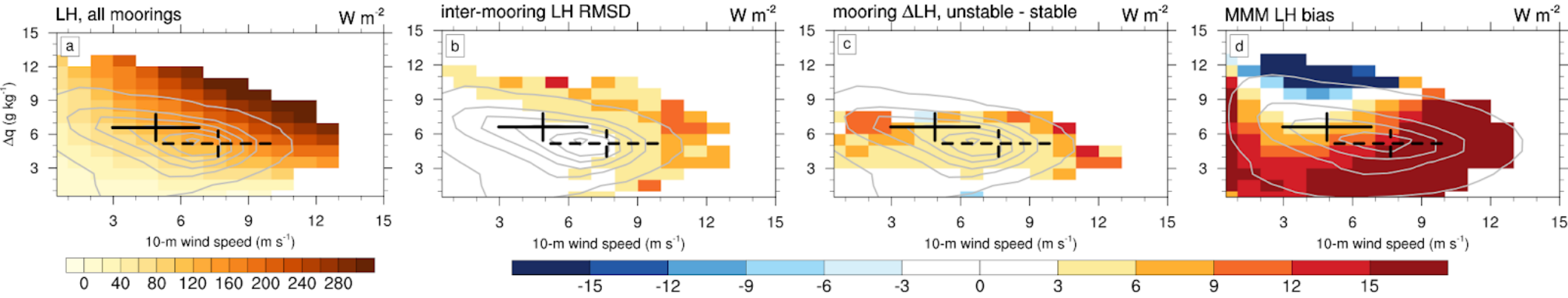

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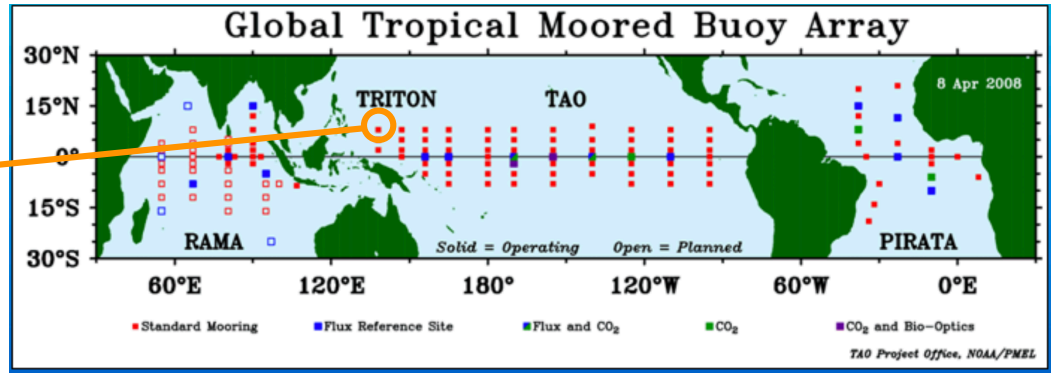

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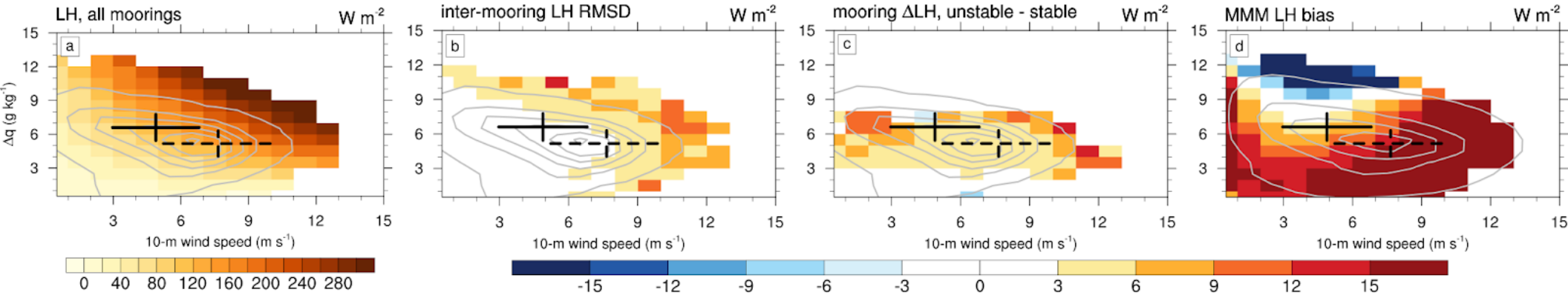
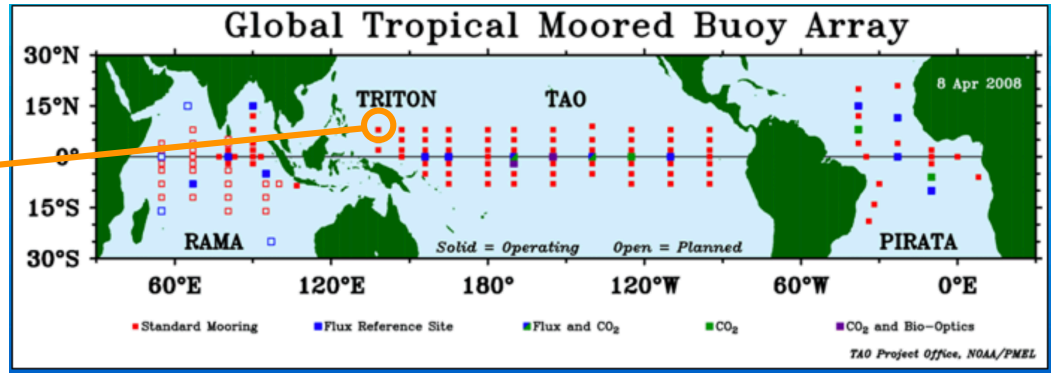


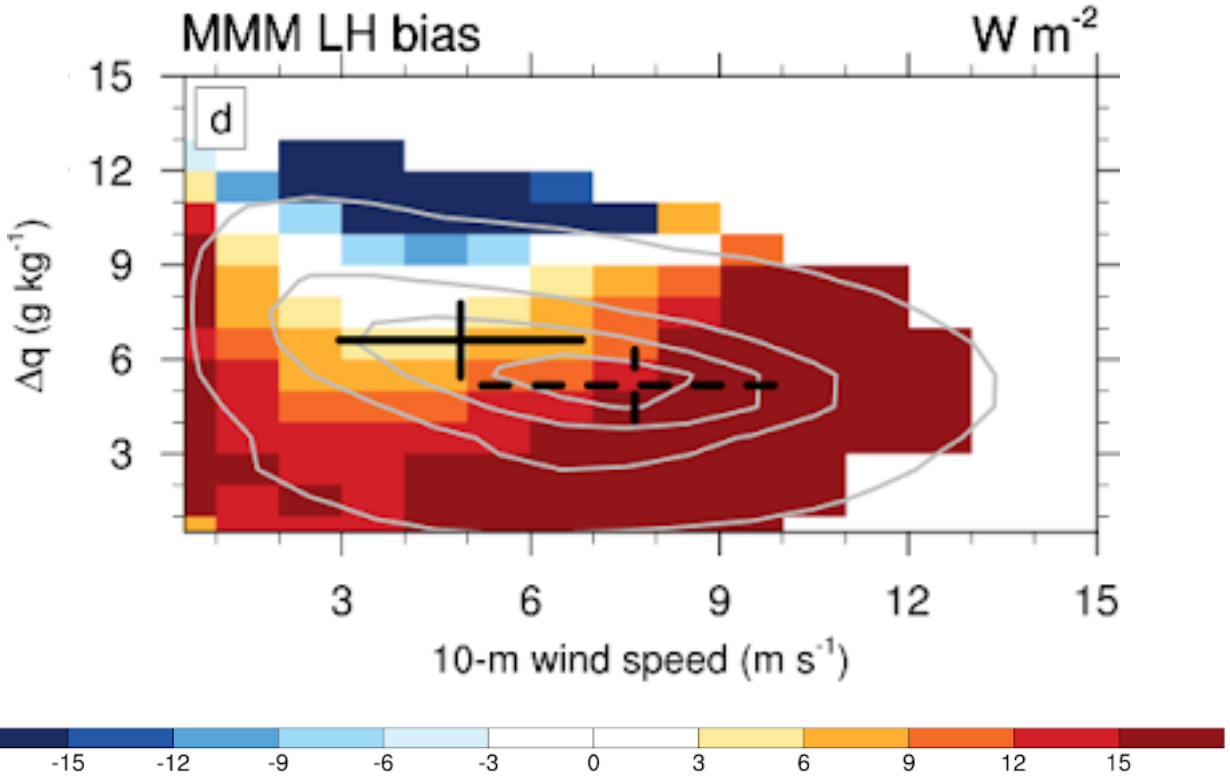


McPhaden (2008)

NOAA

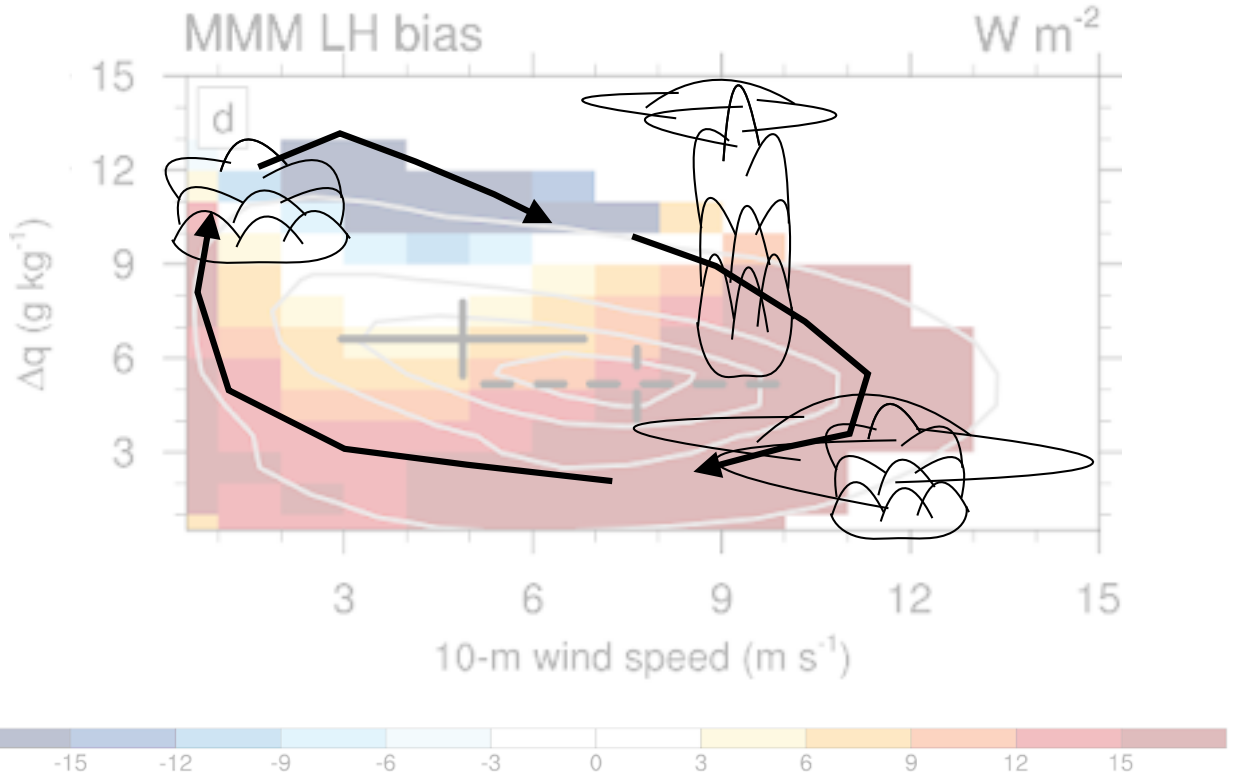
- the “flux matrix” diagnostic illustrates where model fluxes are most biased as a function of wind speed and humidity disequilibrium.

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

surface fluxes diagnostic implications



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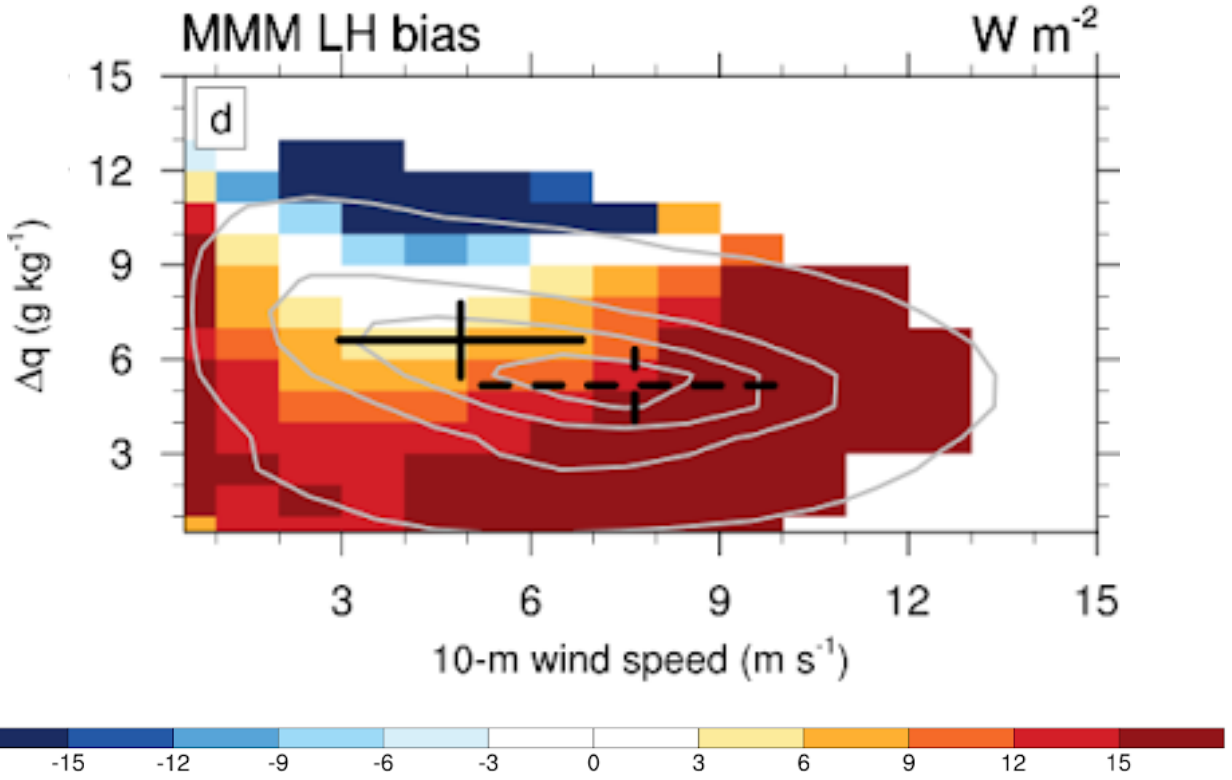
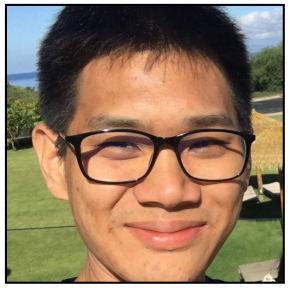
how to assess bulk algorithm impacts



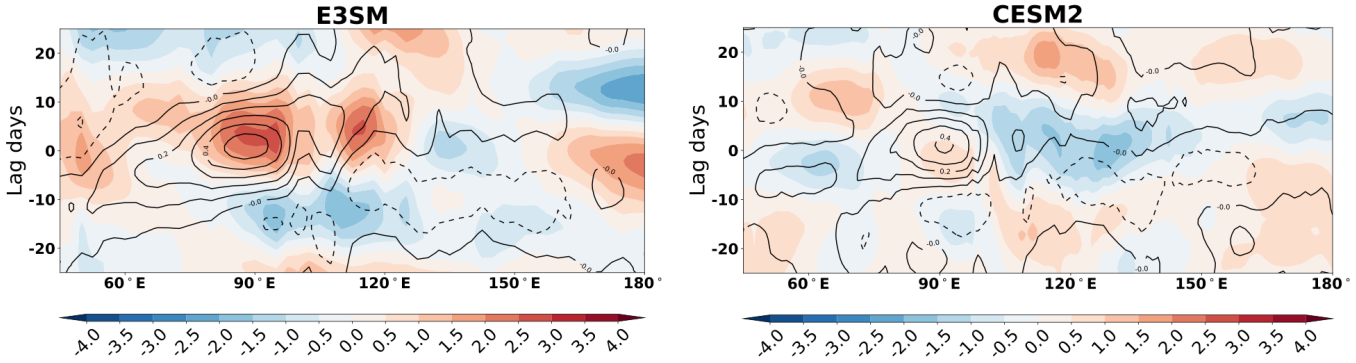
- “offline” correction
  - use flux matrix to generate a “corrected” flux time series
  - no feedbacks to ocean or atmosphere
- “inline correction
  - replace a model’s default flux algorithm with the COARE flux algorithm

flux corrections for the MJO



Chia-Wei Hsu (NOAA/PSL)

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



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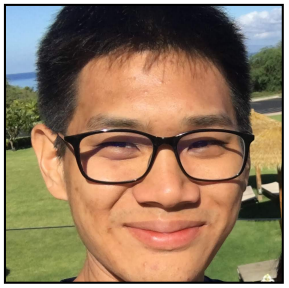

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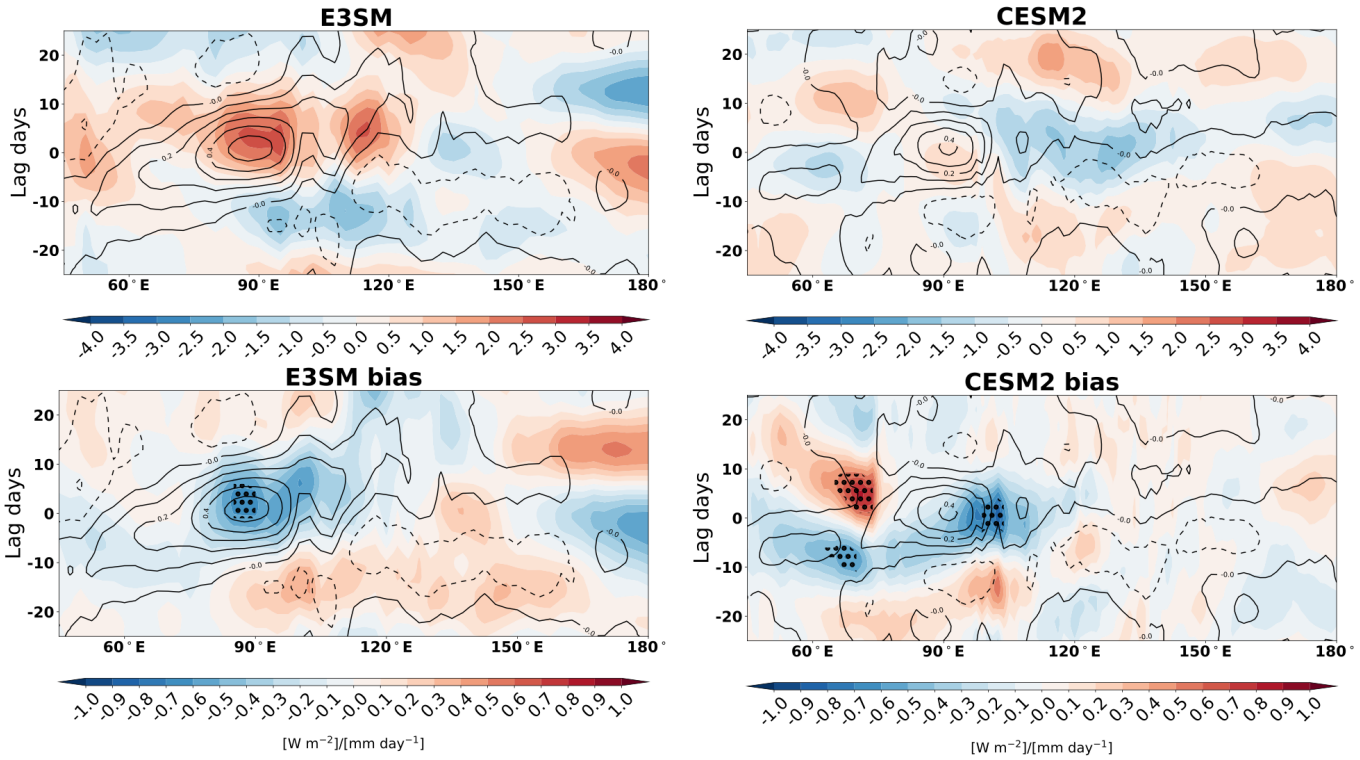

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offline correction: default flux algorithm is overly supportive of MJO convection; too weakly supportive of MJO propagation

Hsu et al. 2022

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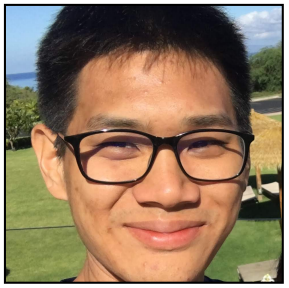

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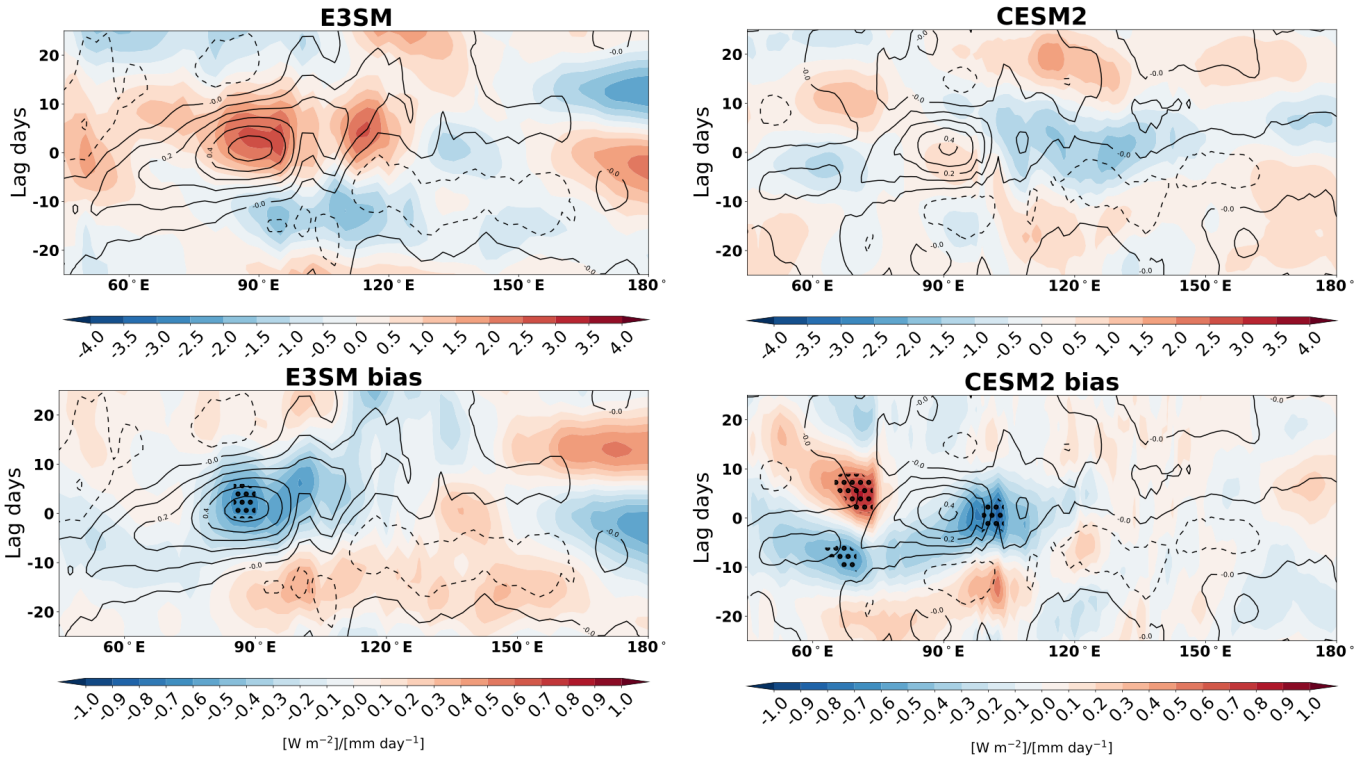

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Model/OBS	CTRL	COARE	COARE-CTRL
E3SM_climo	1.01	1.08	0.07
CESM2_amip	0.95	1.10	0.15
TRMM[a]	2.3		

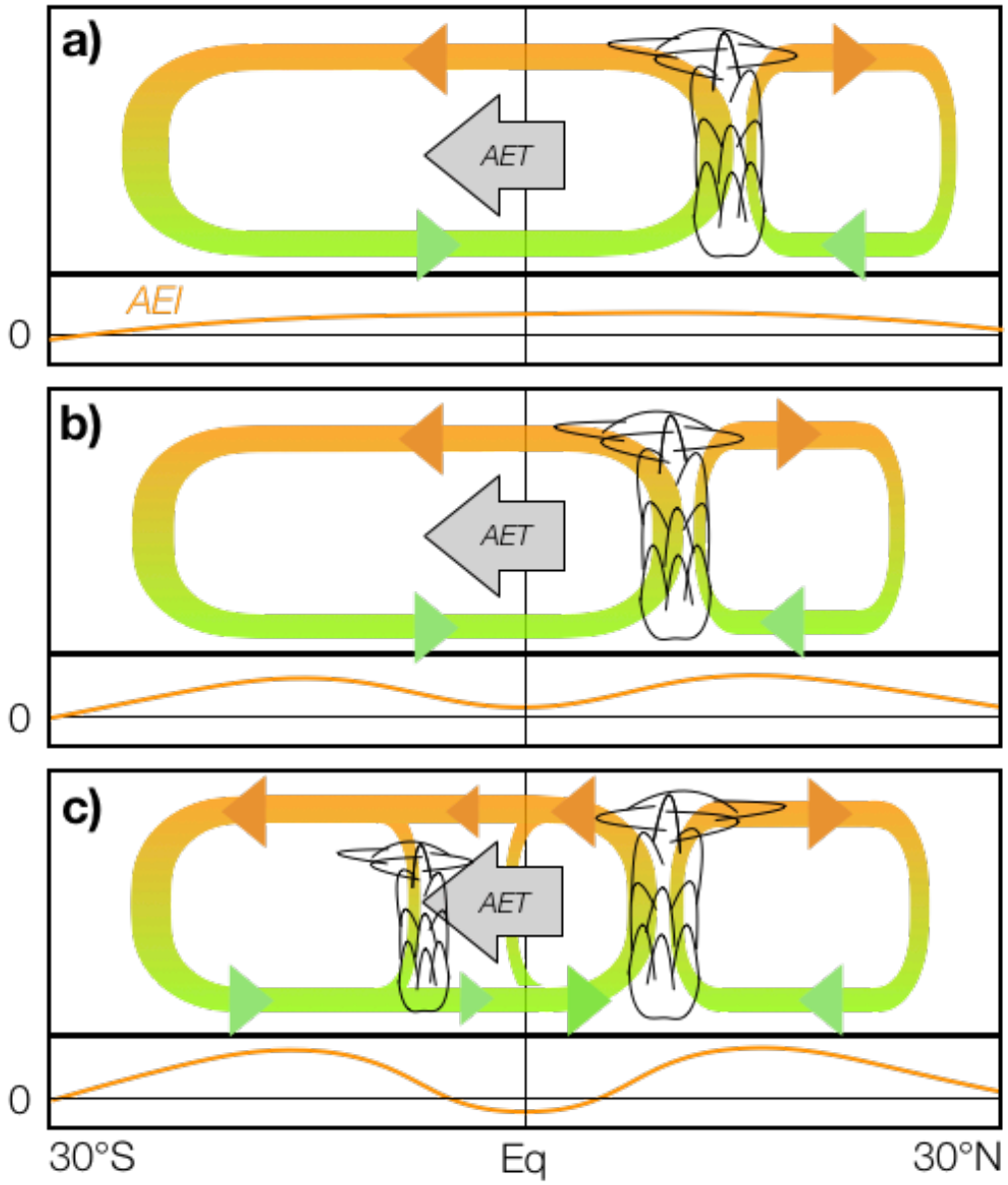
inline correction: COARE fluxes improve MJO eastward propagation

Hsu et al. 2022

bulk surface flux effects for weather & climate simulation

Example: the ITCZ

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



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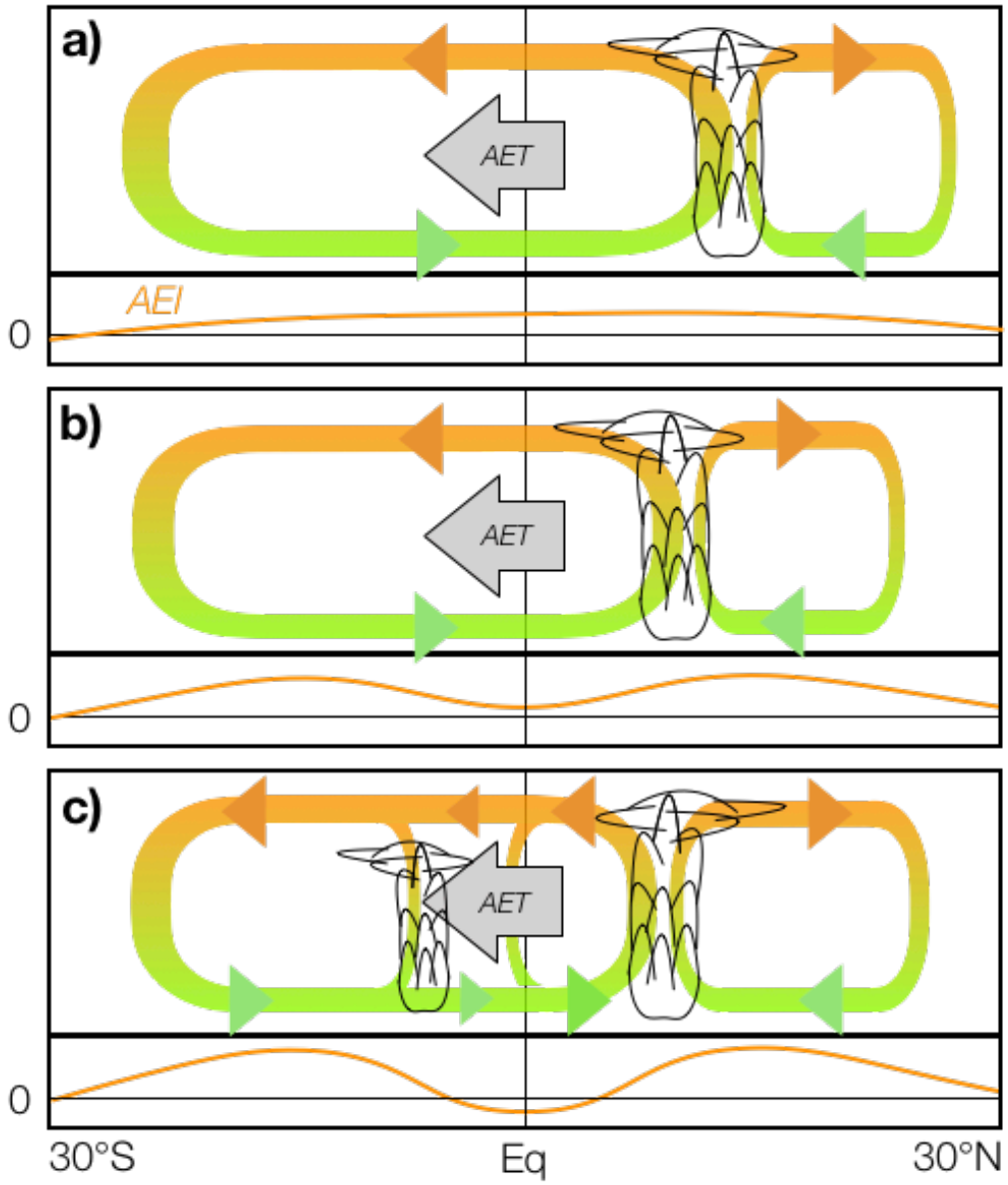

schematic interpretation of Bischoff and Schneider (2014, 2016)

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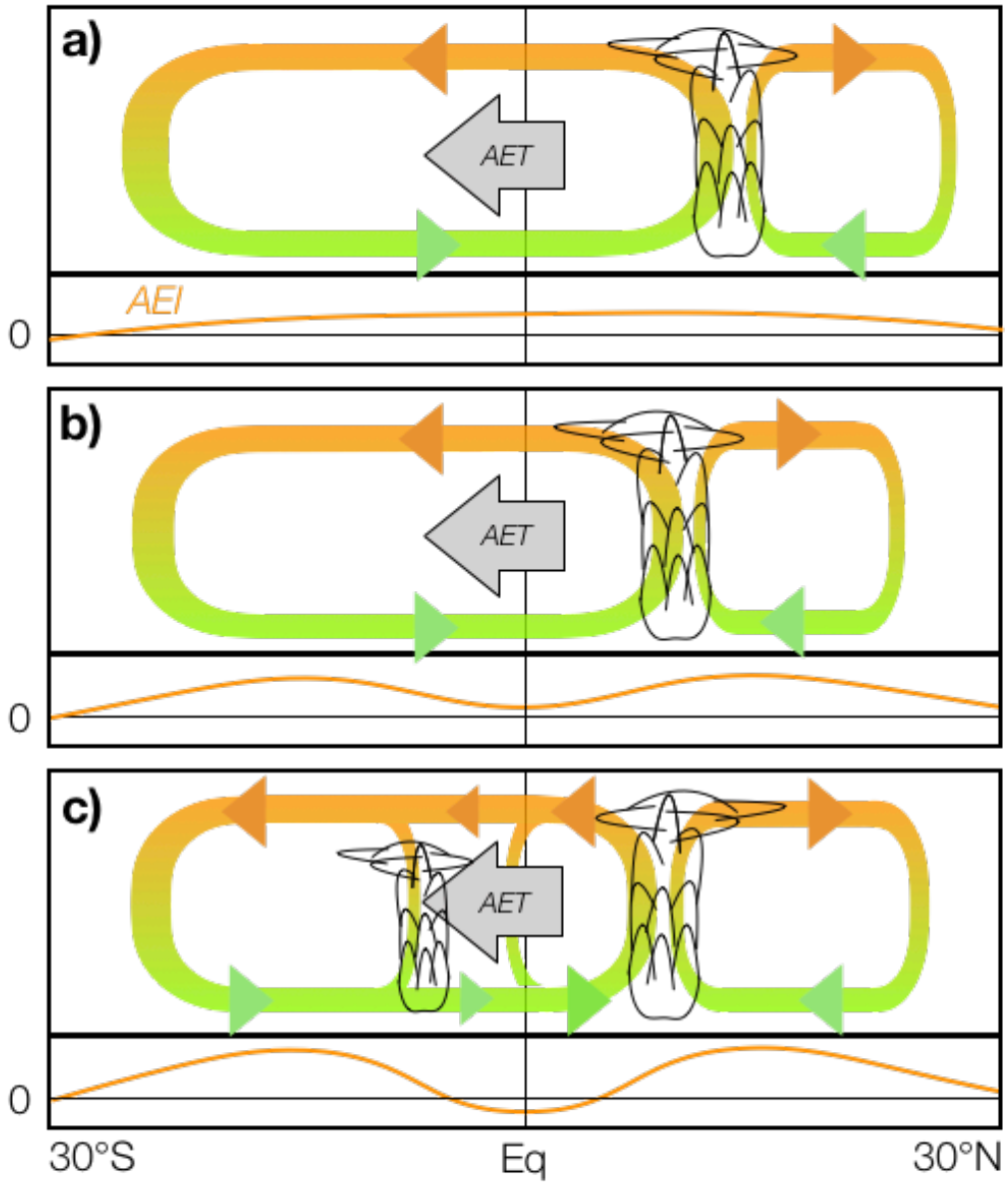
How might biases rooted in surface flux algorithms contribute to model ITCZ biases?



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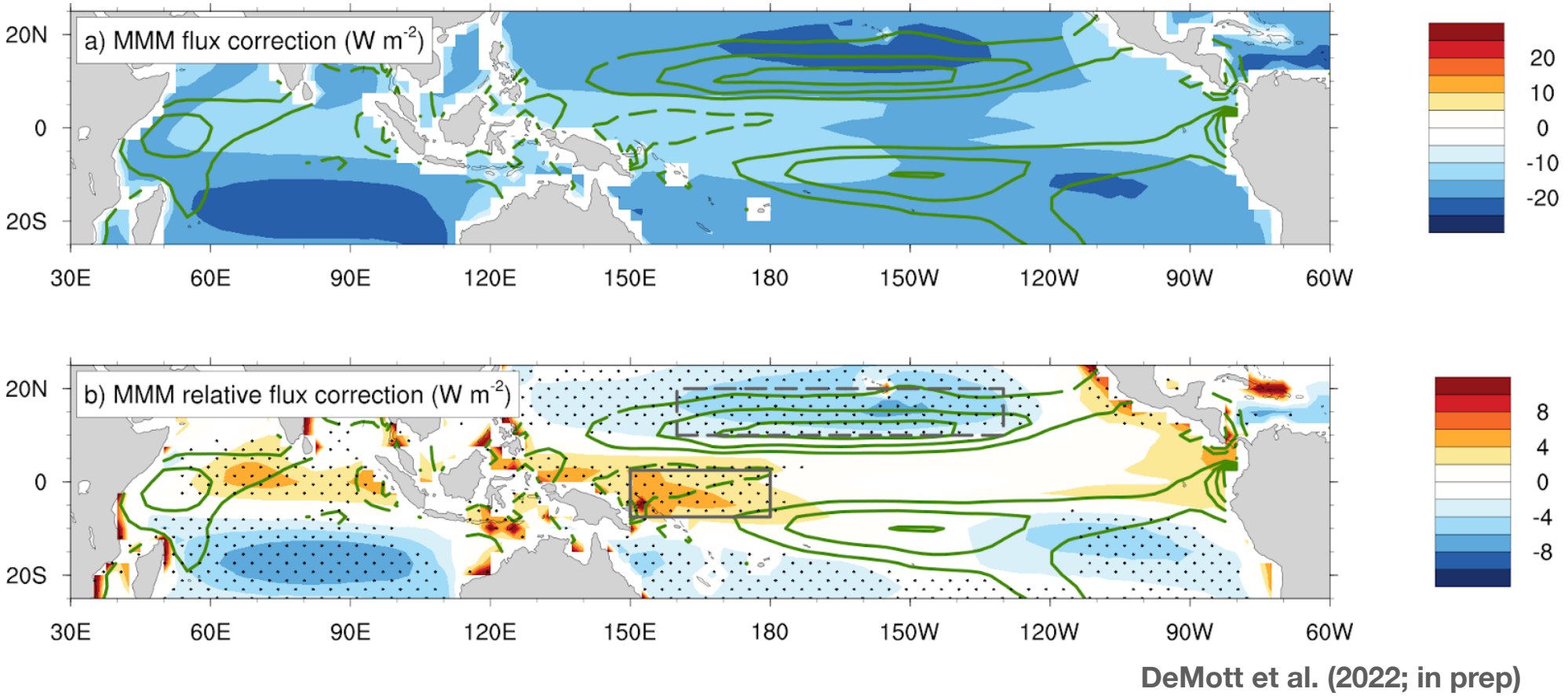
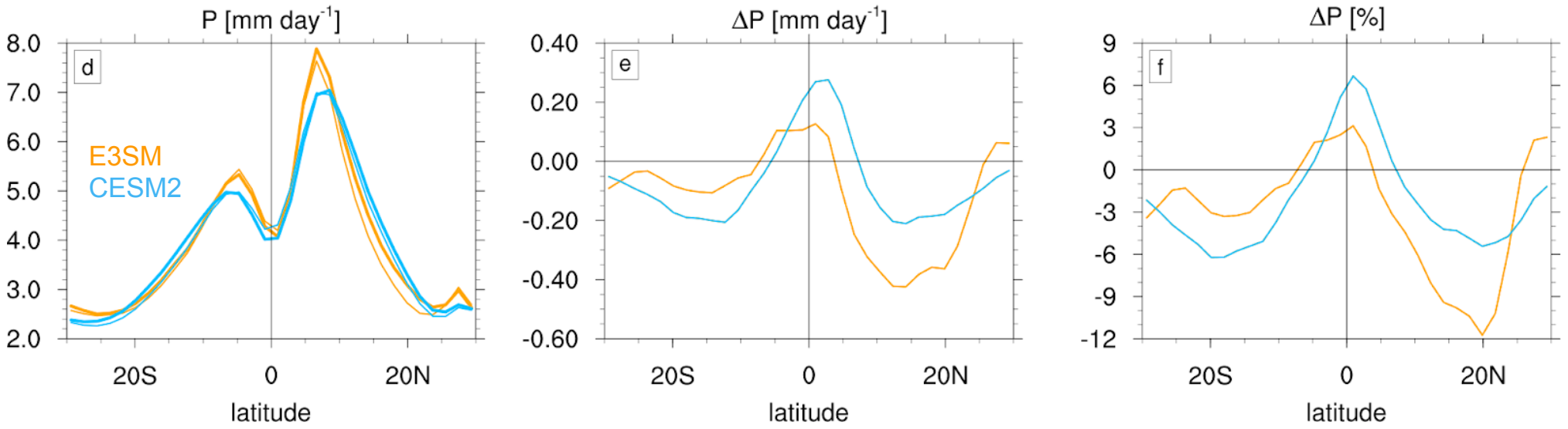


DeMott et al. (2022; in prep)

- "offline" assessment indicates that surface flux algorithm biases may contribute to the double ITCZ bias in climate models
- what about "inline" surface flux corrections?

bulk surface flux effects for weather & climate simulation

Example: the ITCZ

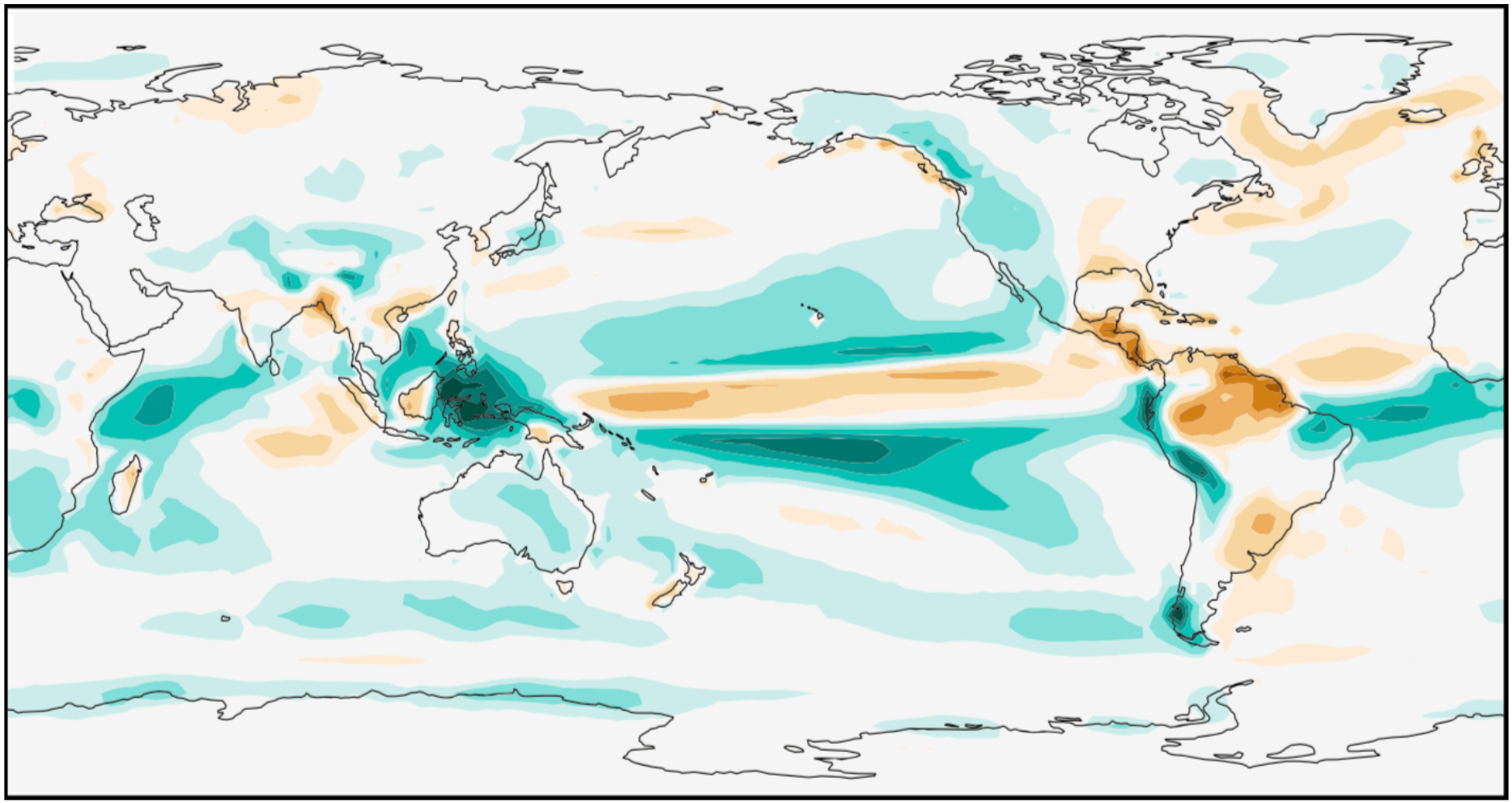


DeMott et al. (2022; in prep)

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

E3SMv1 coupled simulations

Example: the ITCZ



shading = bias

Golaz et al. 2019

E3SMv1 coupled simulations

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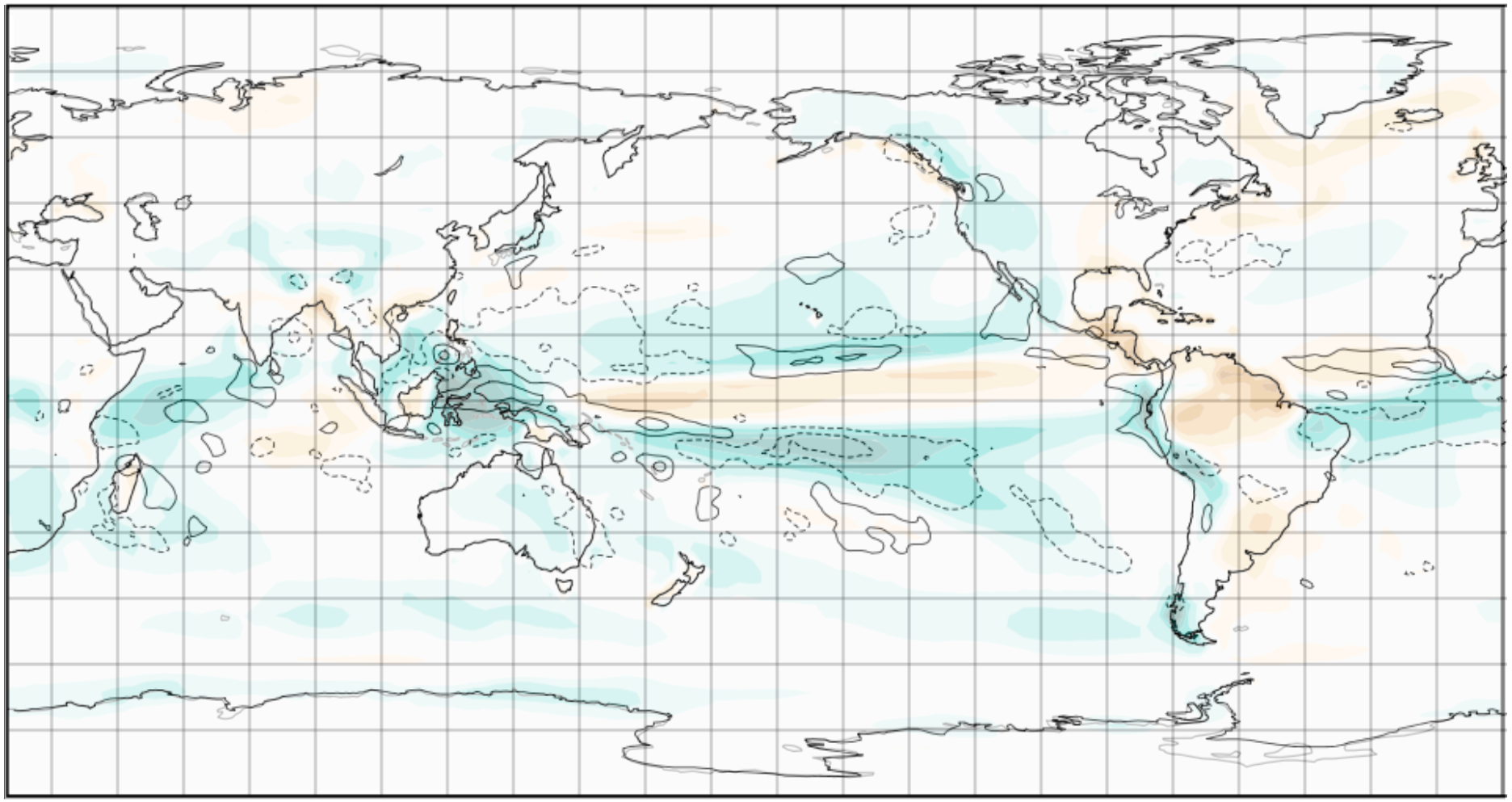
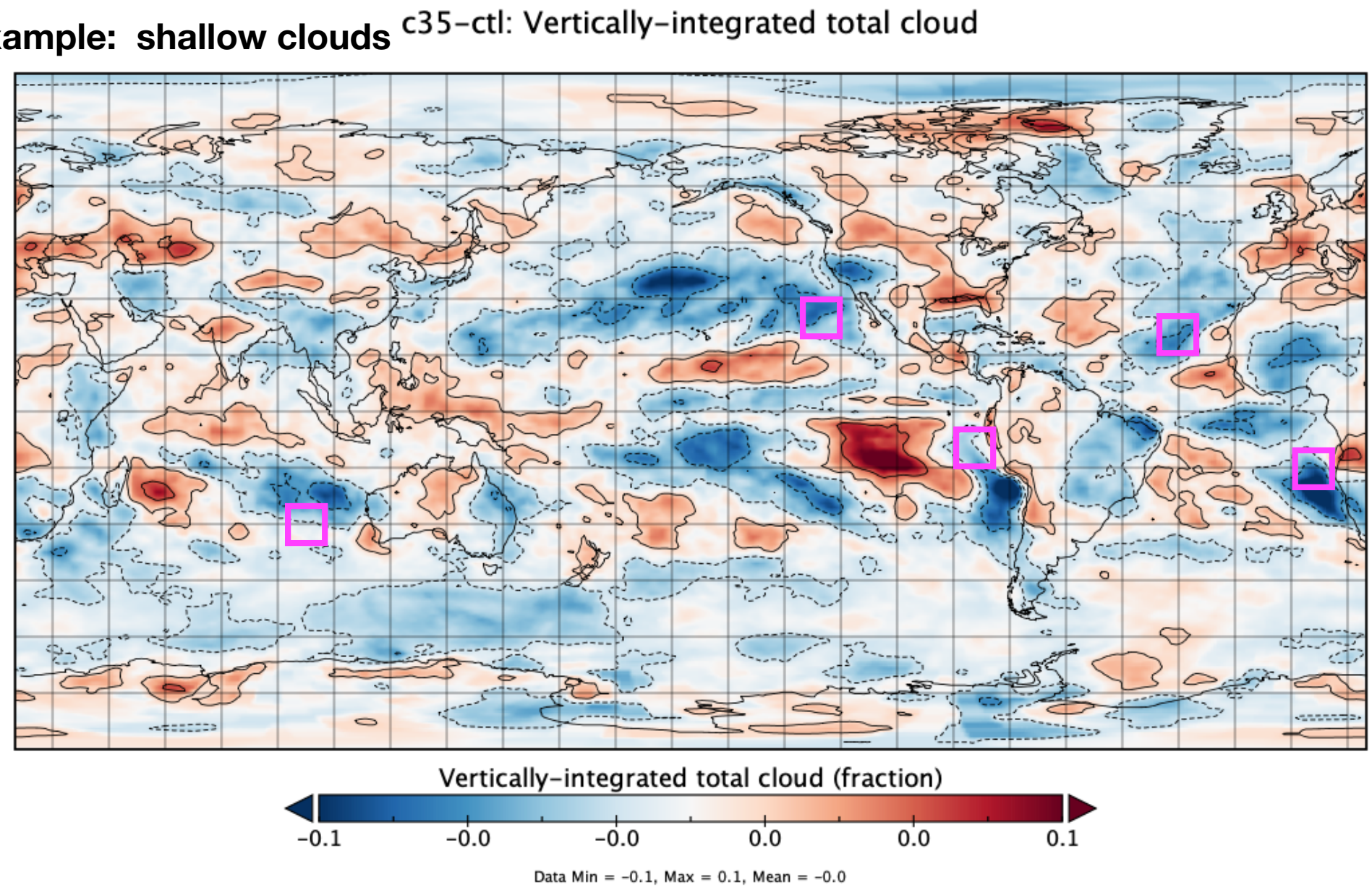


shading = bias **contour = c35-ctl** ***Golaz et al. 2019***

E3SMv1 coupled simulations

Example: shallow clouds



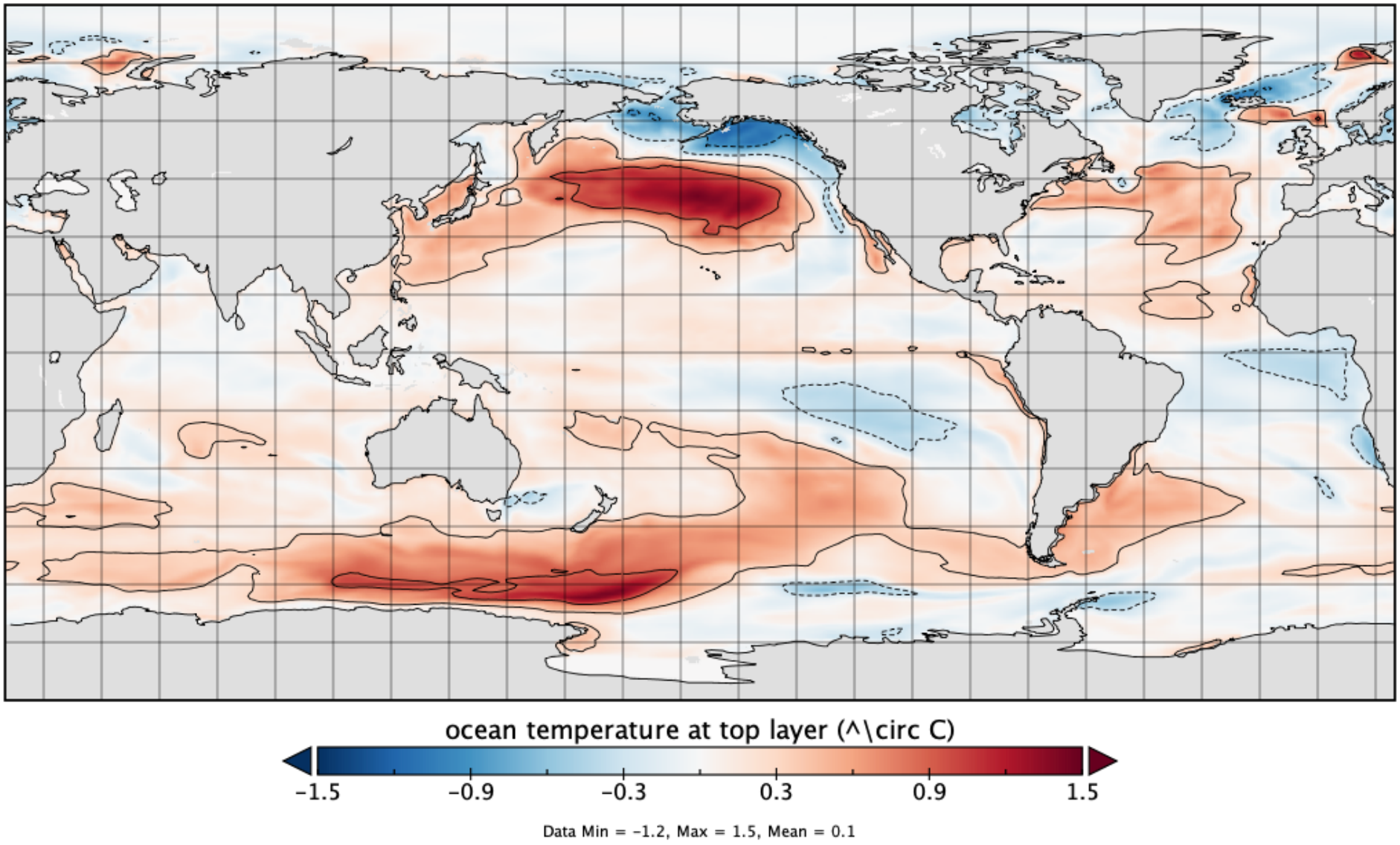
summary

- 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!

extra slides

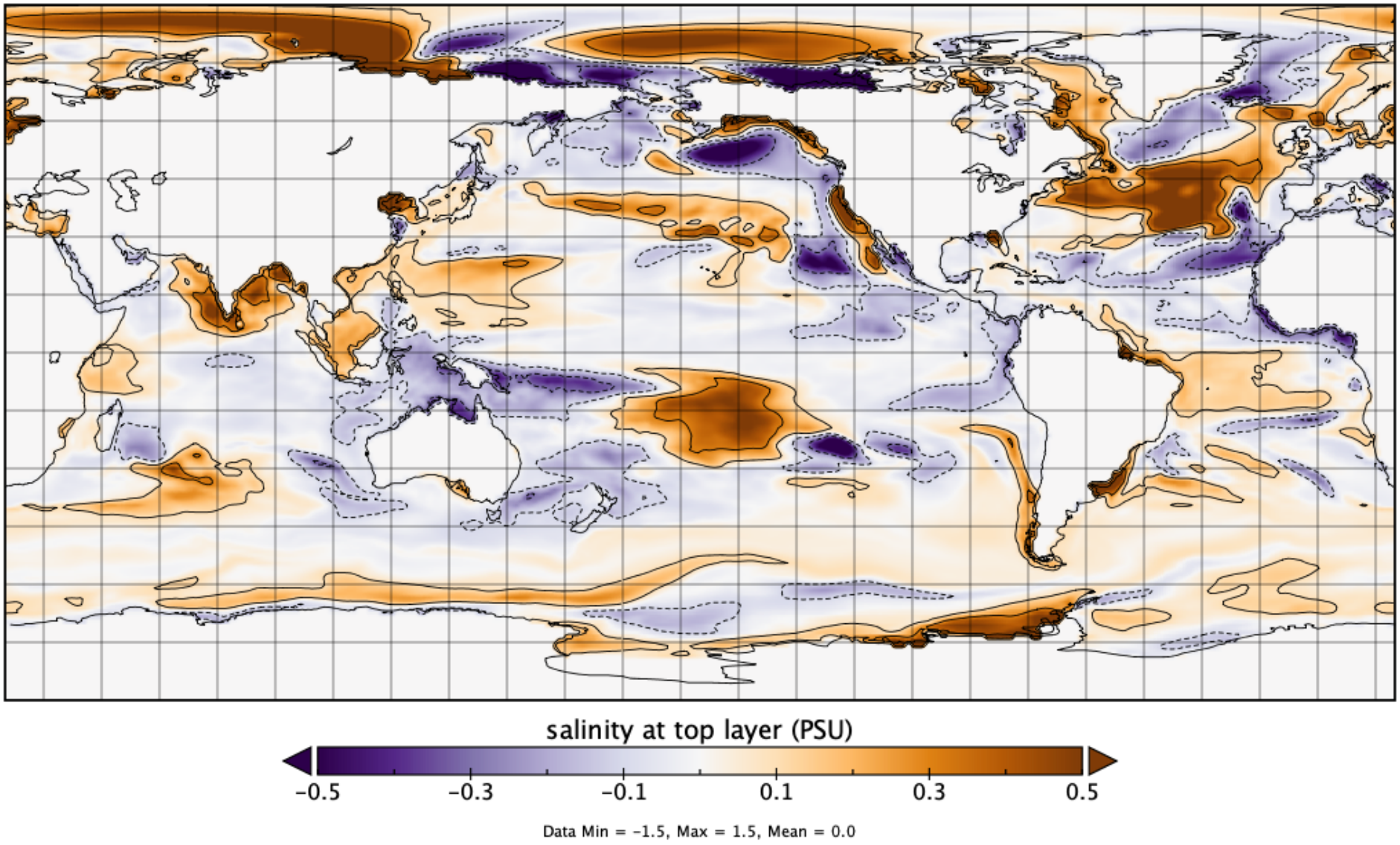
E3SMv1 coupled simulations

c35-ctl: ocean temperature at top layer



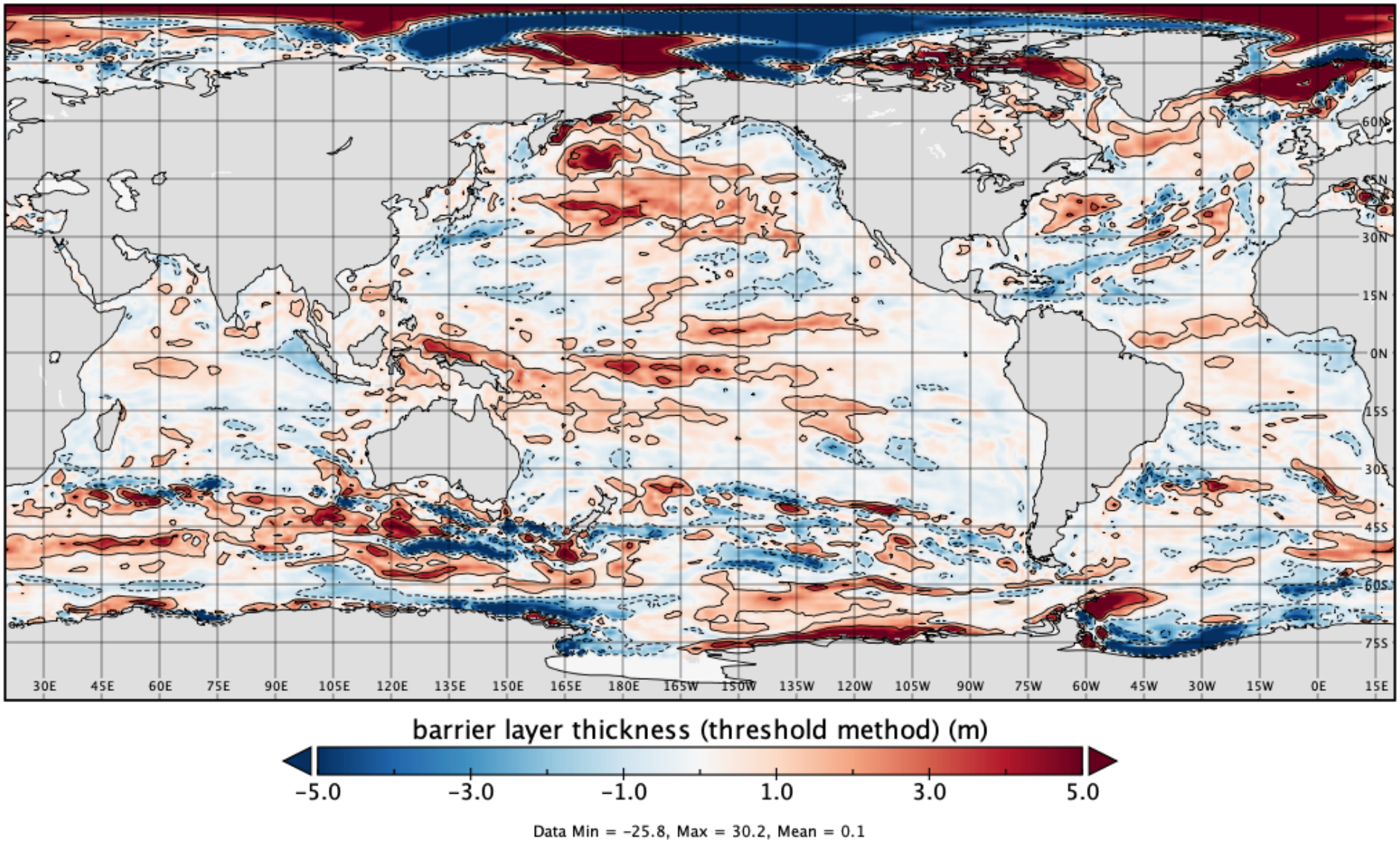
E3SMv1 coupled simulations

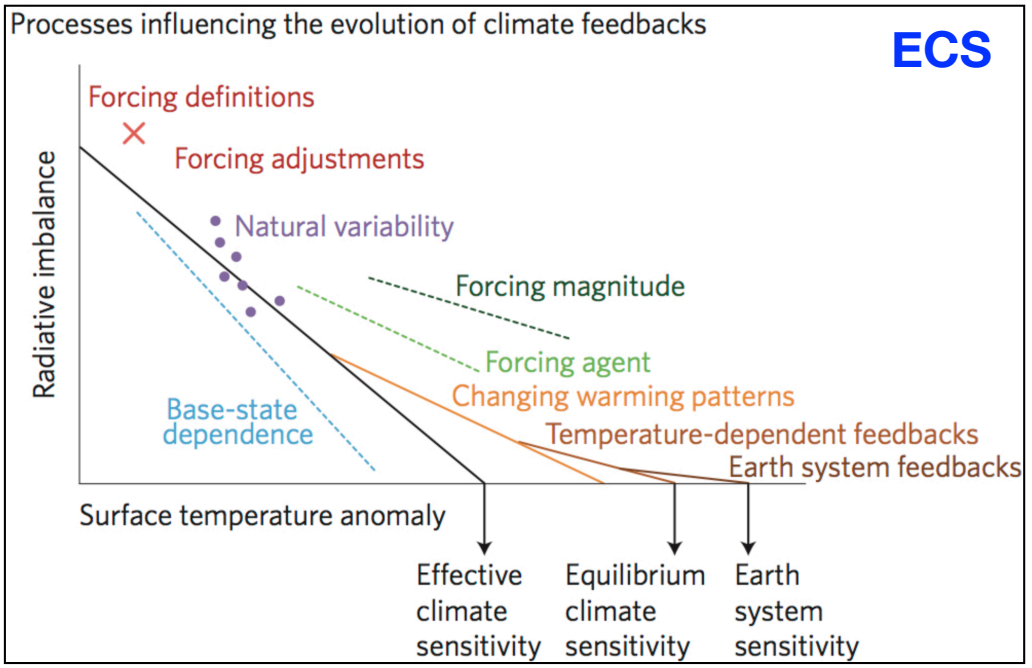
c35-ctl: salinity at top layer



E3SMv1 coupled simulations

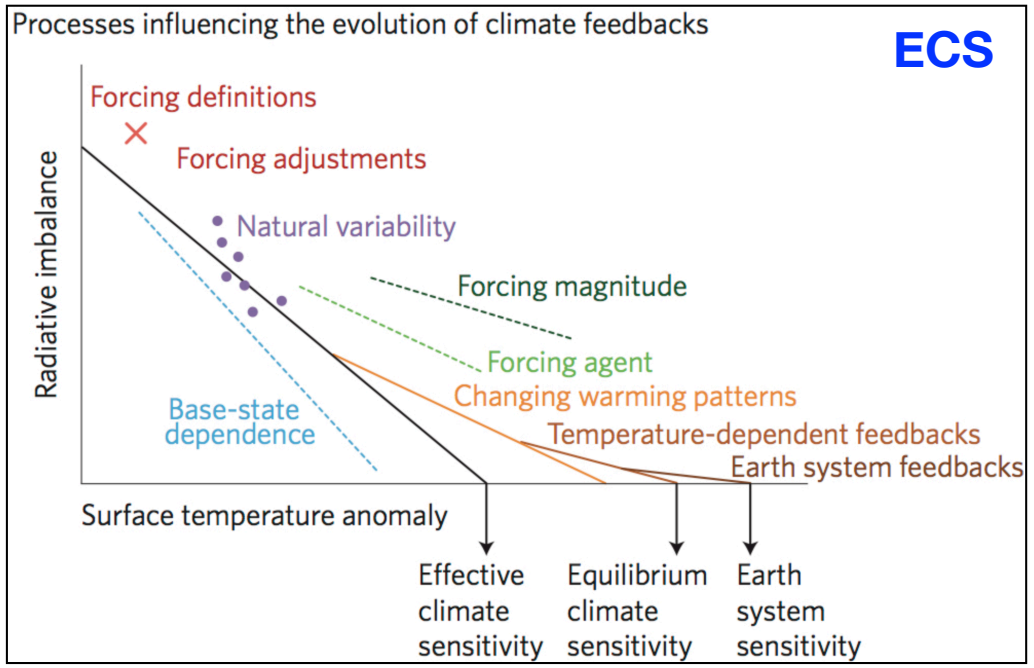
c35-ctl: barrier layer thickness (threshold method)





Knutti et al. (2017)

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



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ongoing work

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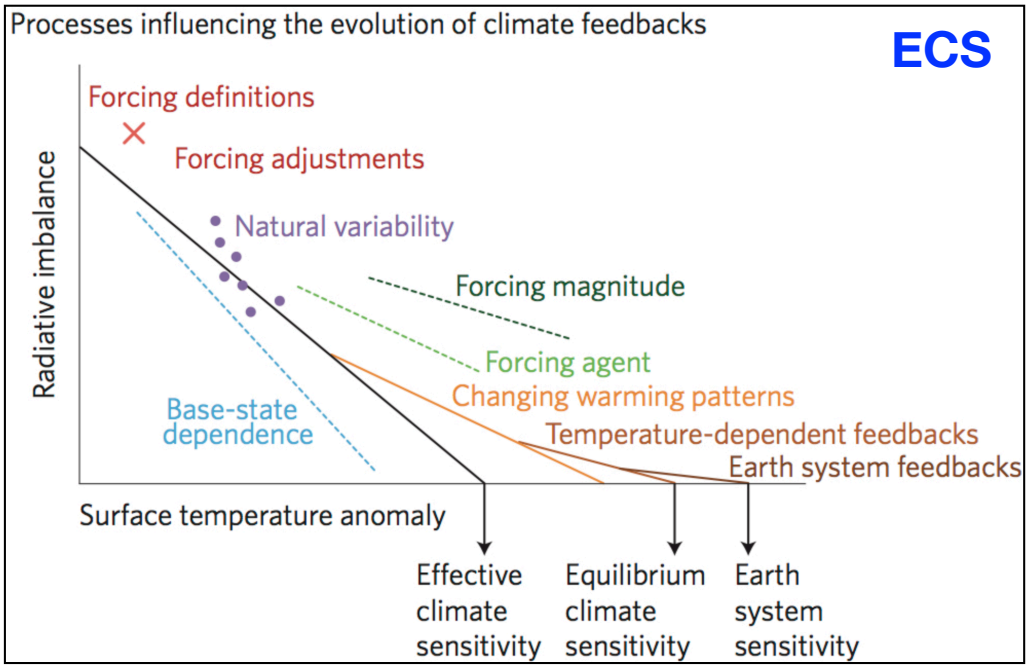

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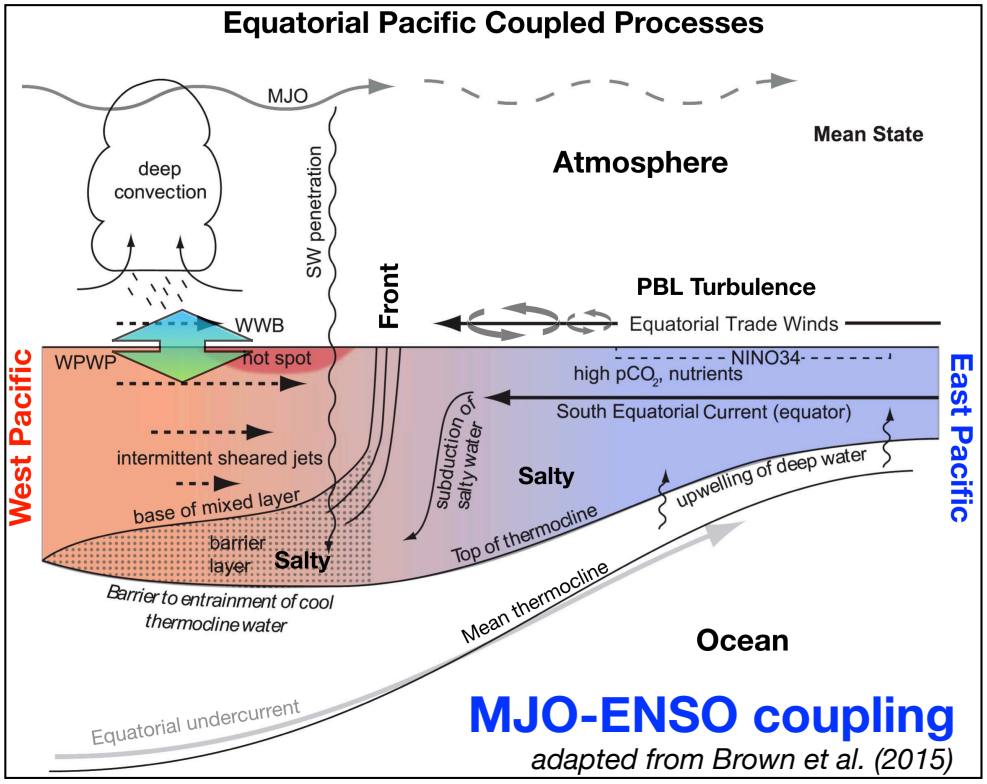

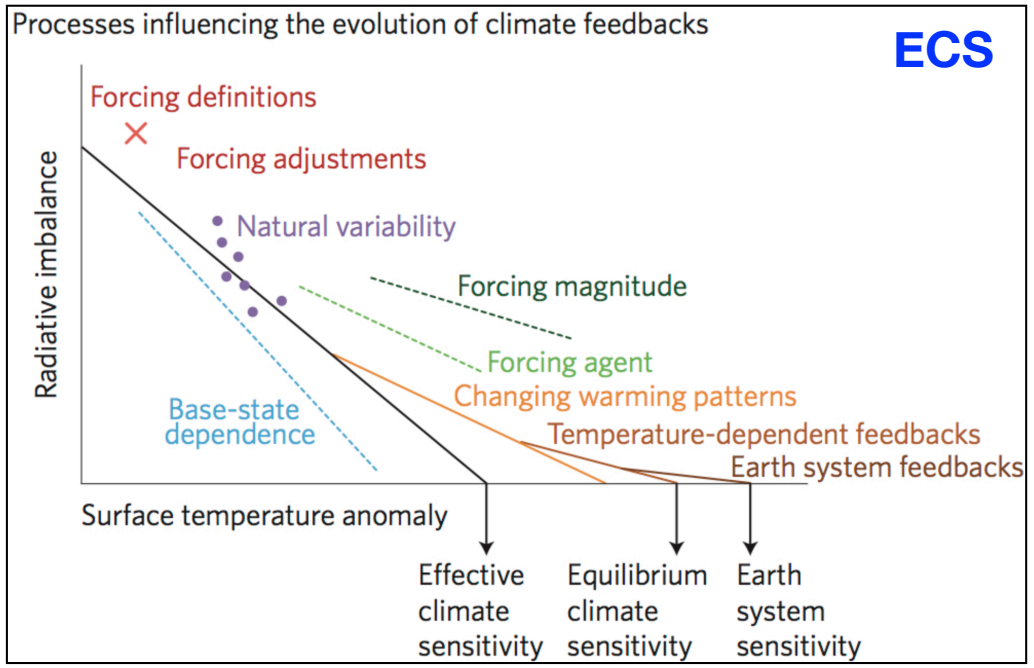

Knutti et al. (2017)

surface fluxes: what can affect their parameterization?

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

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"*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)

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.