Pinpointing sources of equatorial Pacific SST biases in a coupled GCM via surface flux adjustments

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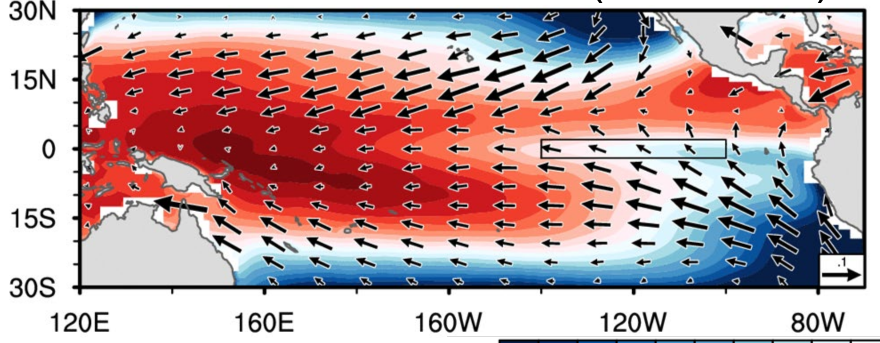
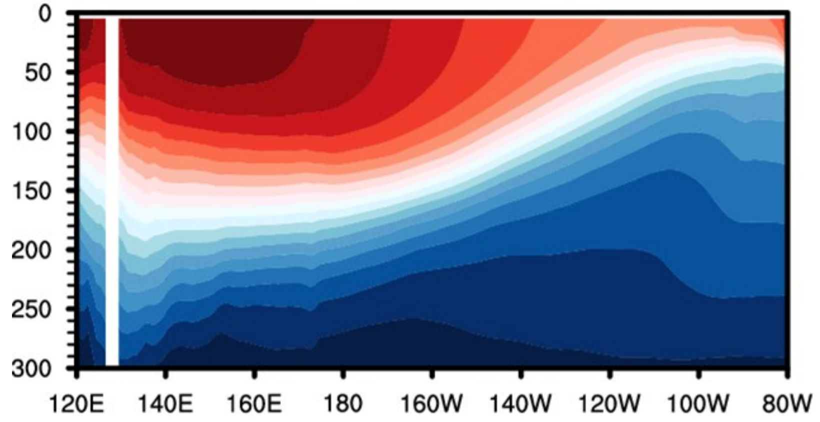
Equatorial Pacific biases in the GFDL SPEAR coupled model (1°)

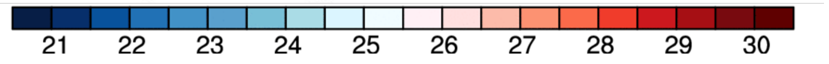
Annual mean 1979–2018

SST (°C; HadISST)
& surface wind stress (Pa; ERA5)

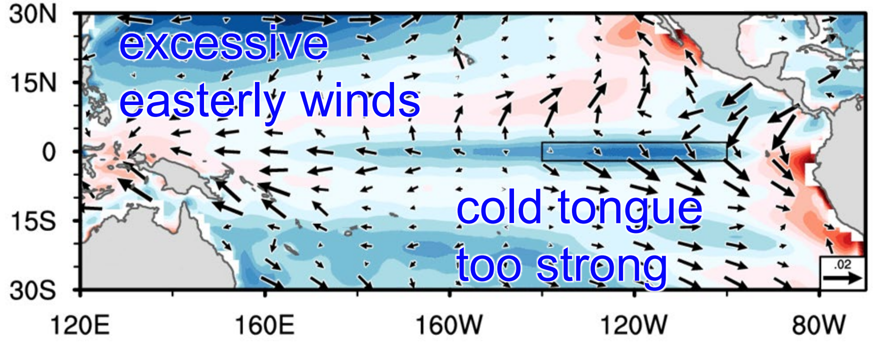


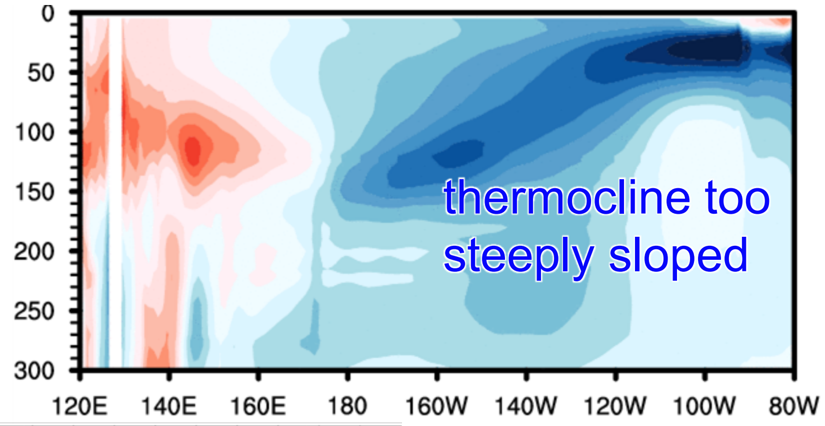
Ocean temperature (°C; ORAS5), 2°S–2°N

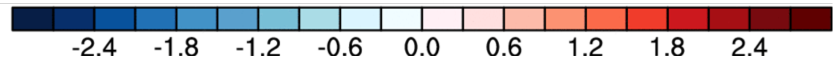




SPEAR_LO bias







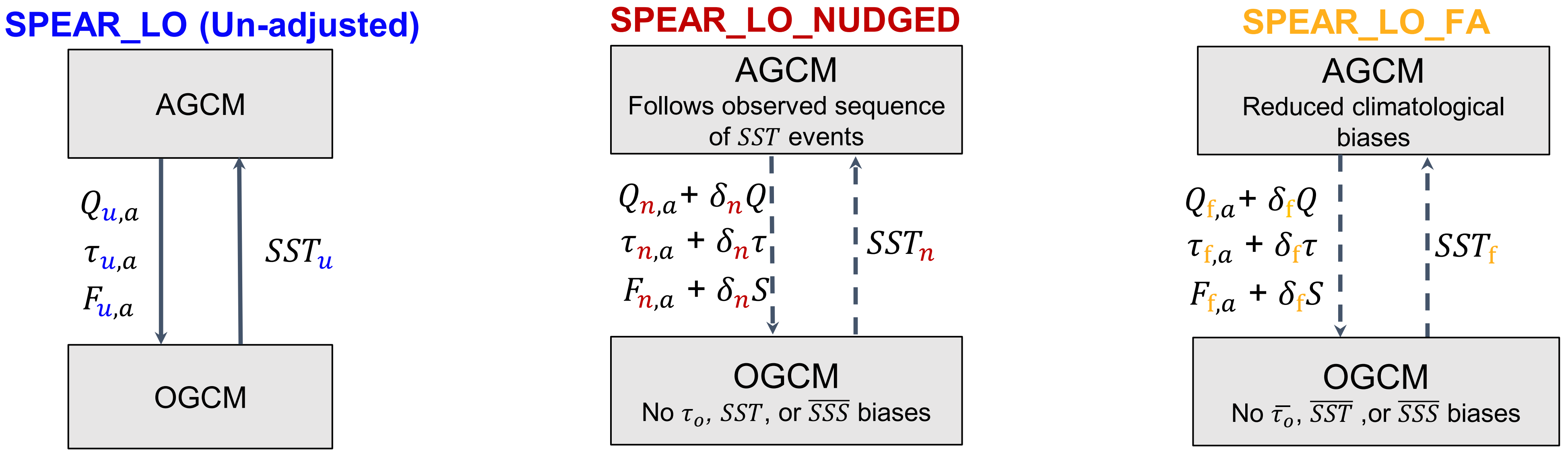
SPEAR_LO: *Low-resolution (**1°**) of GFDL **S**eamless System for **P**rediction and **EA**rth System **R**esearch (Delworth et al. 2020)*

Do biases originate from AGCM (AM4), OGCM (MOM6), or coupled feedbacks?

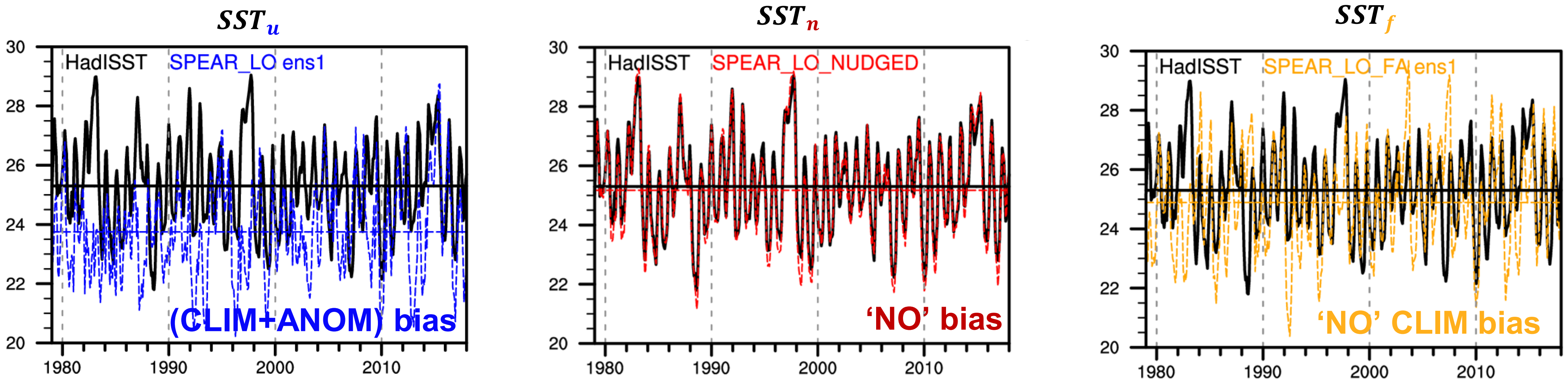
SPEAR surface nudged and flux-adjusted coupled experiments

Nudge to obs monthly SST & τ, and climatological SSS

Prescribe climatological surface flux adjustments of heat, τ, salt



Monthly Equatorial Pacific SST (°C) (2°S–2°N, 140°–100°W) 1979–2018

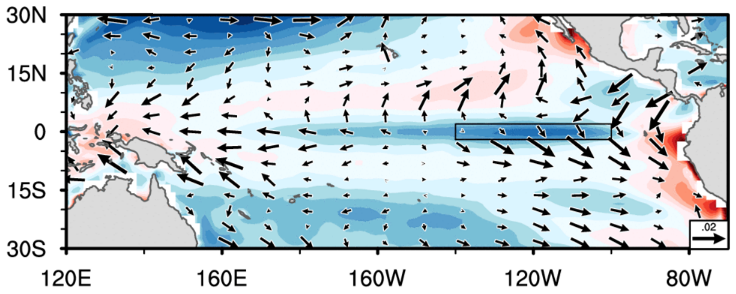


The effect of flux adjustments (FA) on climatological biases

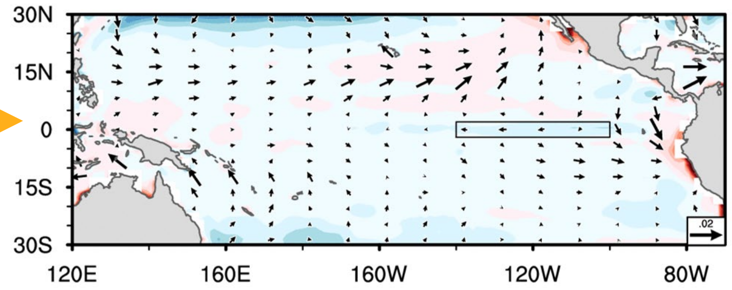
Annual mean 1979–2018

SPEAR_LO Bias | **SPEAR_LO_FA Remaining Bias**

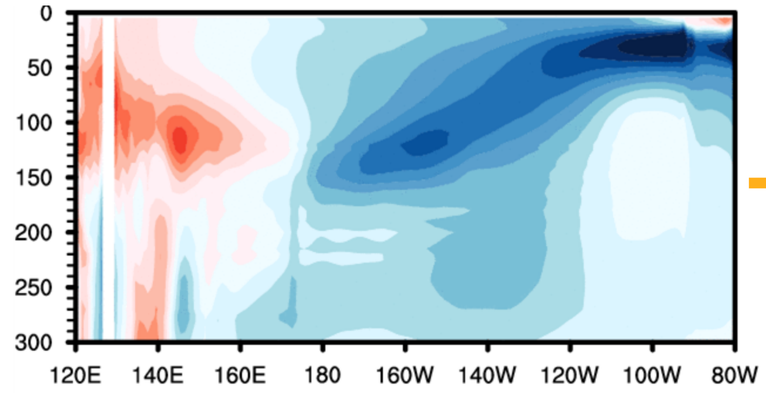
SST (°C) & surface wind stress (Pa)

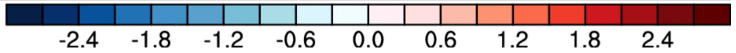


FA (or nudging) remove *surface* OGCM biases

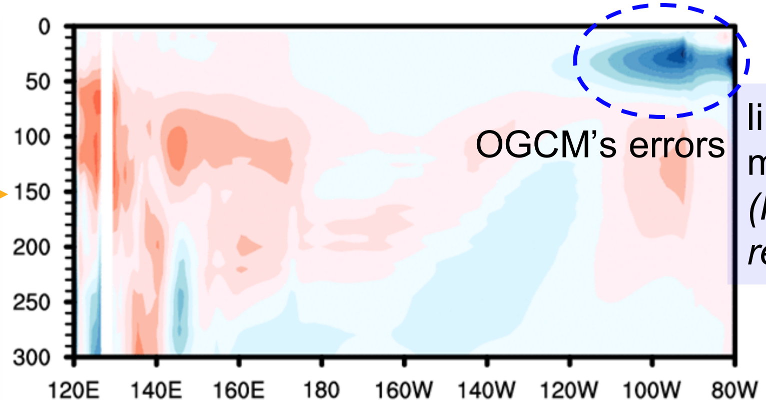


2°S–2°N ocean temperature (°C)





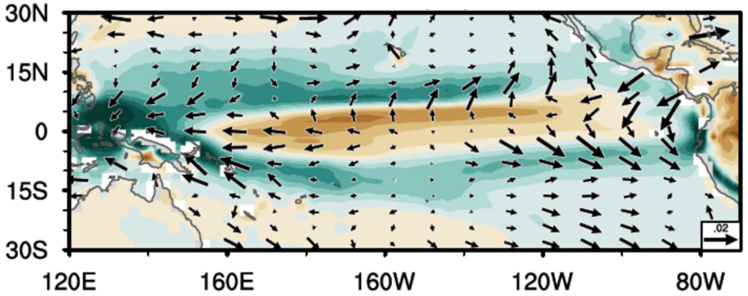
wind stress correction reduces *interior* OGCM biases

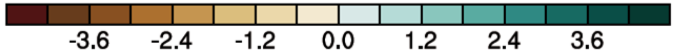


OGCM's errors

linked to ocean mixing schemes *(Reichl et al. revised)*

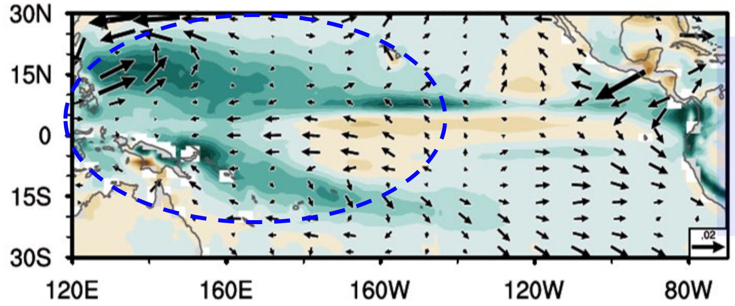
rainfall (mm/day; relative to GPCP)





SST correction reduces AGCM errors

AGCM's errors

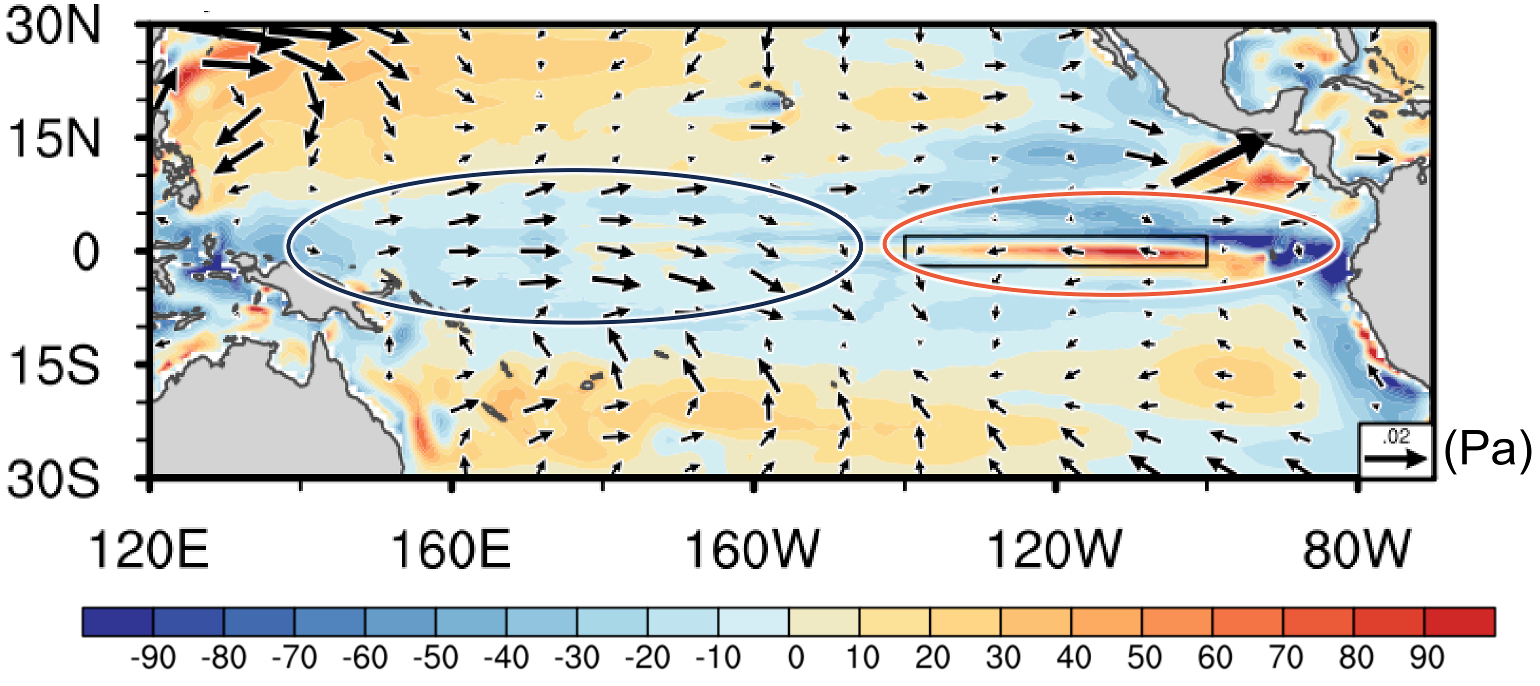


too strong convective rainfall & trade winds

Do surface flux adjustments compensate for AGCM or OGCM errors?

Annual mean

Explicit correction $\delta_f Q$, $\delta_f \tau$ added to OGCM



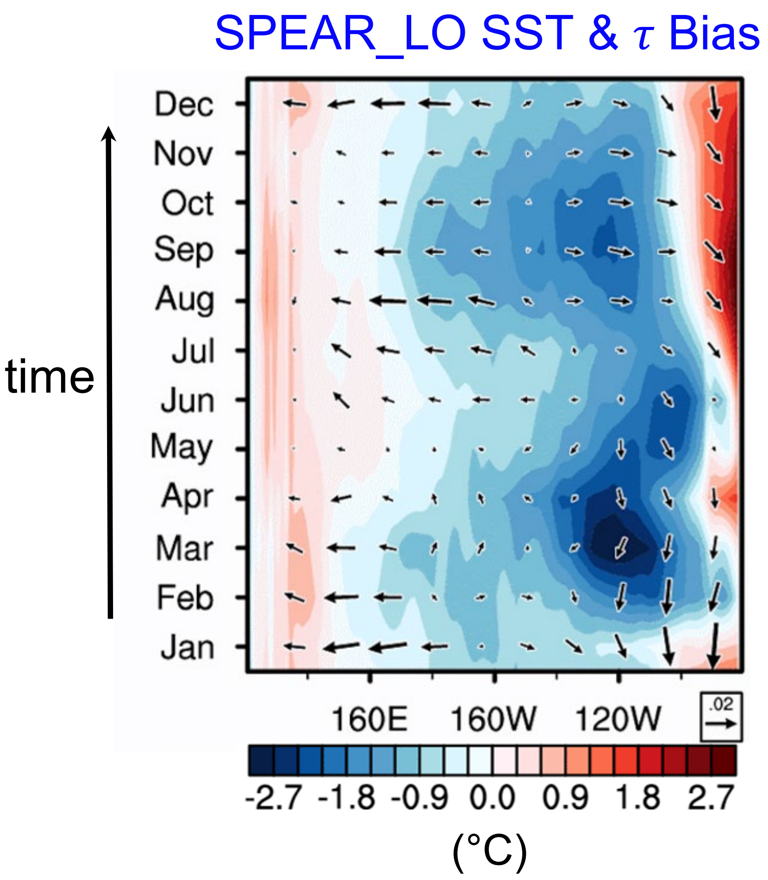
Shading: positive = downward (W/m^2)

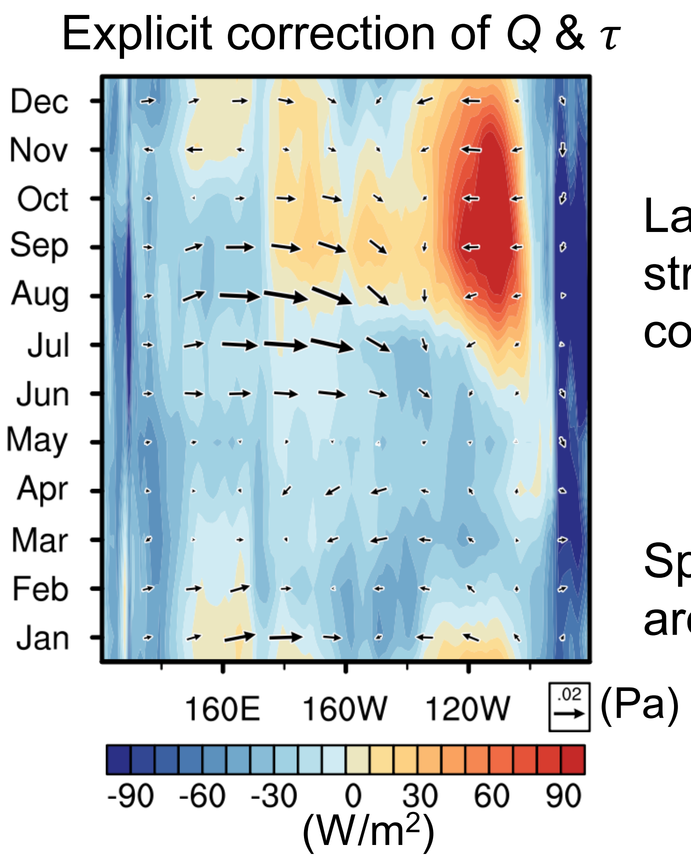
wind stress correction compensating for AGCM biases in excessive easterly trade winds

Heat flux correction compensating for OGCM biases in weak tropical Instability waves (TIWs)

Strong seasonality in climatological biases and surface corrections

Equatorial Pacific (2°S–2°N)

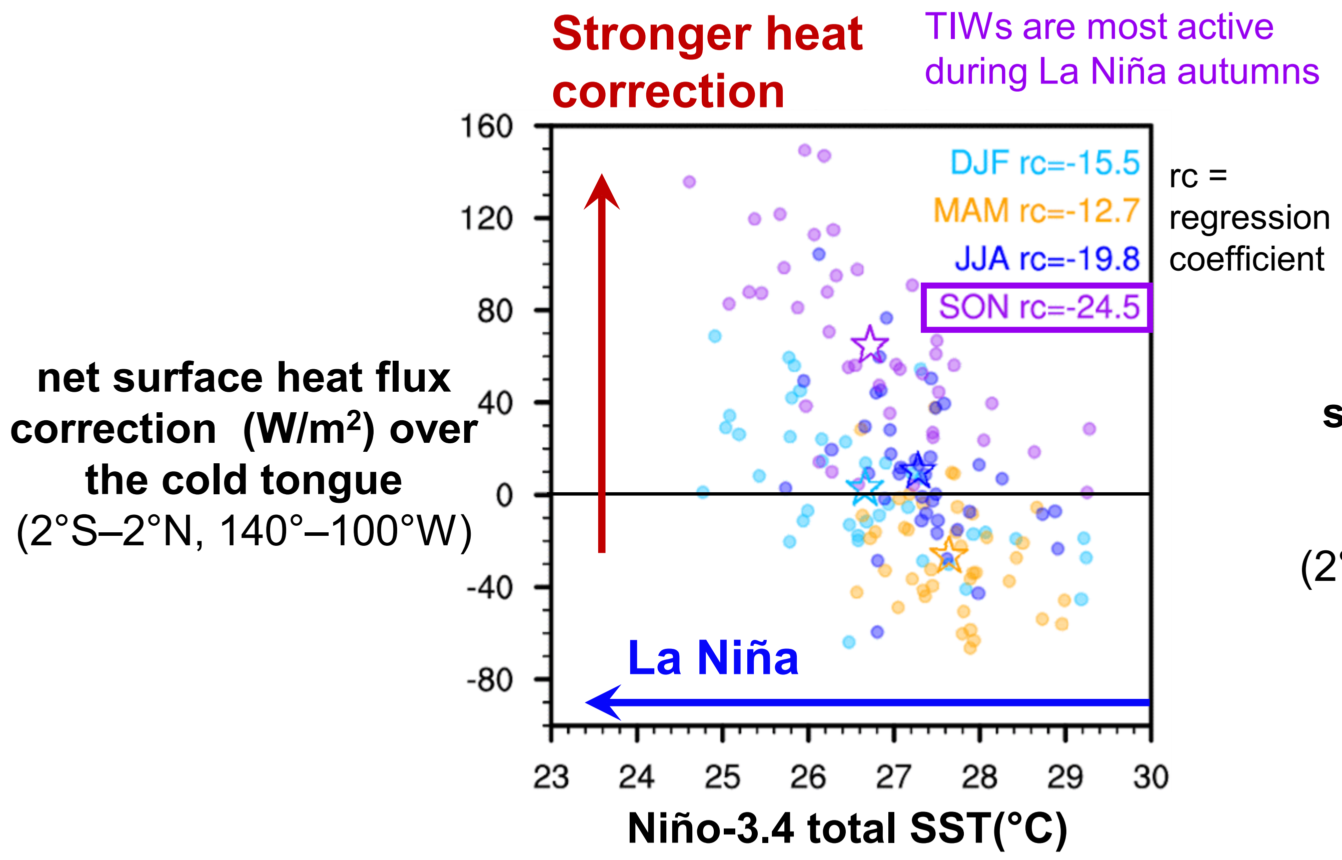


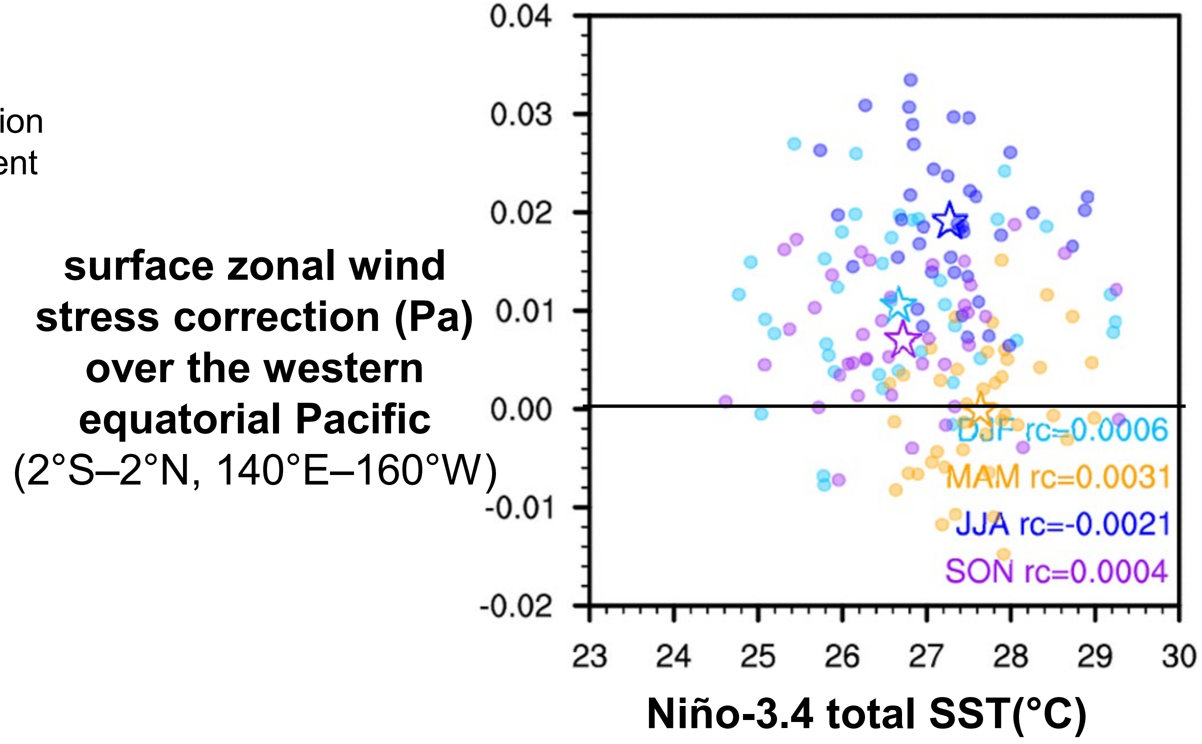


Late summer–autumn:
strong Q & τ correction
compensates for OGCM & AGCM biases

Spring: weak explicit τ corrections
are amplified by air-sea coupling

Strong added heating compensates for OGCM errors during La Niña autumns

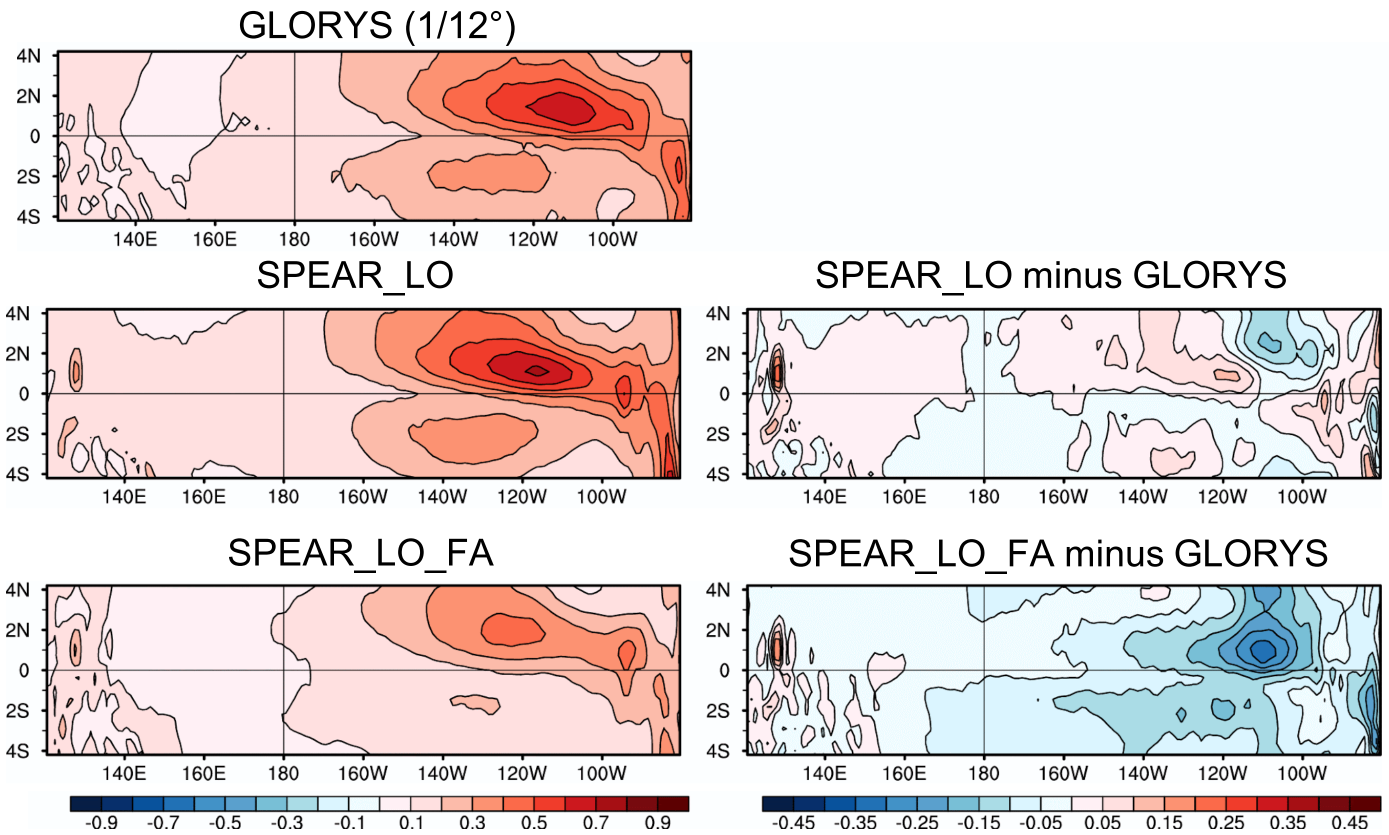




Wind stress correction is less dependent on ENSO states than heat correction, indicating that AGCM can well capture the ENSO related wind variability.

Tropical Instability Wave (TIW) Activity (1993–2010)

Standard deviation of TIW SST anomalies (°C)



TIW SST is strongly affected by its meridional heat transport ($v'\frac{\partial \bar{T}}{\partial y}$).

$\frac{\partial \bar{T}}{\partial y}$ is overestimated in SPEAR_LO with climatological cold tongue SST bias.

FA reduces $\frac{\partial \bar{T}}{\partial y}$ by removing SST climatological bias.

Band-pass filter used to isolate TIW subseasonal variability: 7-90 day, zonal wavelengths 5–25°, and meridional wavelengths >2°

Summary and implications

- Surface nudging and flux adjustments are effective to isolate sources of coupled SST biases.
- By comparing the multi-scale diagnostics and heat budgets in SPEAR_LO vs SPEAR_LO_FA, we **identify the sources of mean-state cold tongue SST bias** in different seasons and ENSO conditions:
  - *Spring:* Surface wind stress biases in the AGCM generate excessive dynamical cooling, which is amplified by air-sea coupling.
  - *Autumn:* In addition to the wind-driven bias, the coarse-resolution OGCM likely underestimates TIW-induced warming, particularly during La Niña autumns.
- **Improving observations (TPOS/TEPEX),** reanalysis, and data assimilations in the tropical Pacific is important for understanding heat budgets and constraining climate models.
- Improving climatological biases in the equatorial Pacific is key to improving the forecast skill of climate variability and change.

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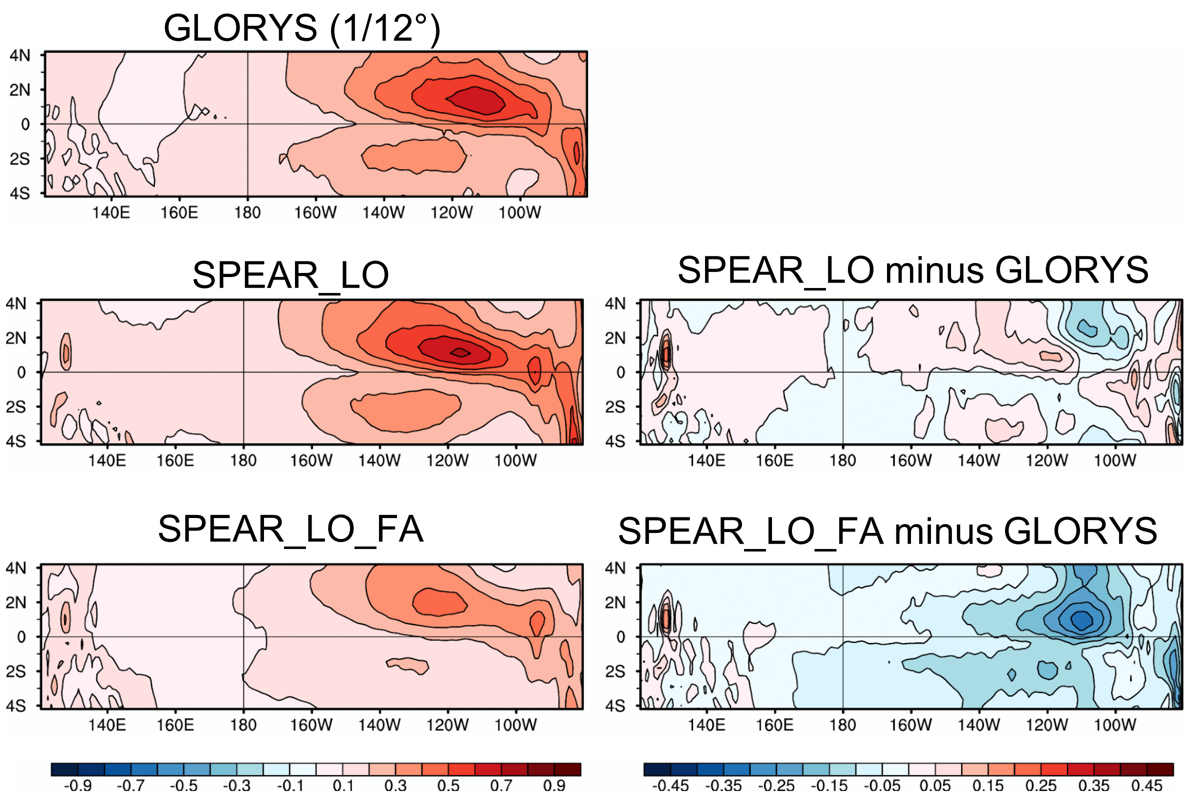
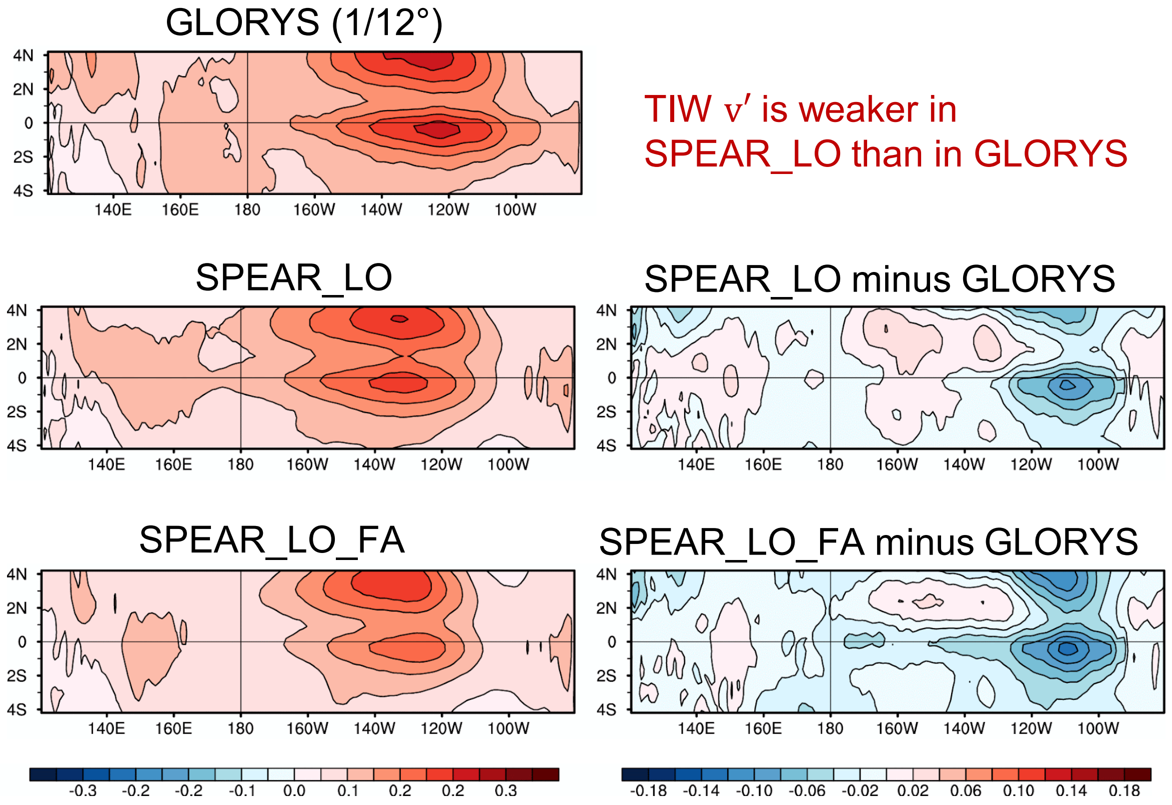
Tropical Instability Wave (TIW) Activity 1993–2010

Standard deviation of TIW SST anomalies (°C)



Standard deviation of TIW sea surface meridional velocity v′ anomalies (m/s)

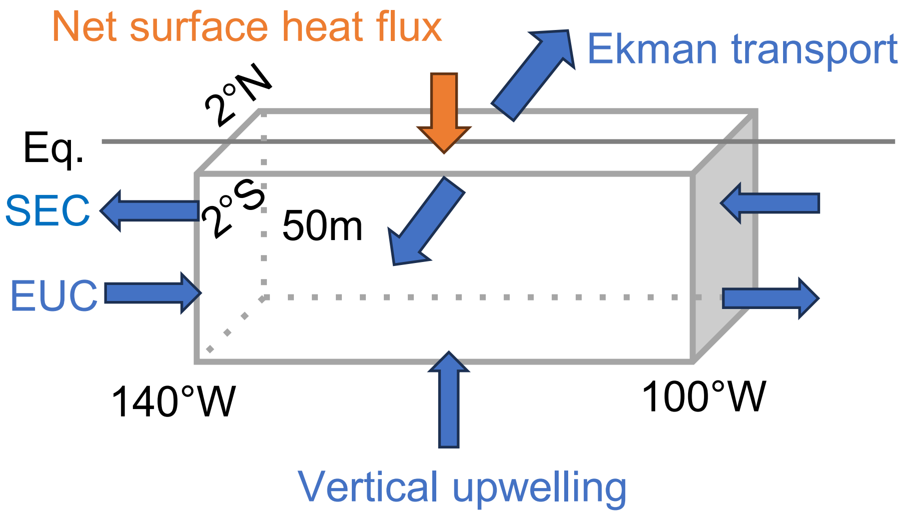


TIW v′ is weaker in SPEAR_LO than in GLORYS

Band-pass filter used to isolate TIW subseasonal variability: 7-90 day, zonal wavelengths 5–25°, and meridional wavelengths >2°

Mixed layer heat budget analysis

Equatorial Cold tongue mixed layer
(2°S–2°N, 140°W–100°W; 0–50m)



Calculate temperature flux into the domain at each face

$$\iint_{Sw} u(T - T_m)\, dy\, dz / V_D - \iint_{Se} u(T - T_m)\, dy\, dz / V_D$$

u,T: zonal velocity and temperature along each face
T_m: average temperature of the cold tongue box
V_d: volume average of the cold tongue box

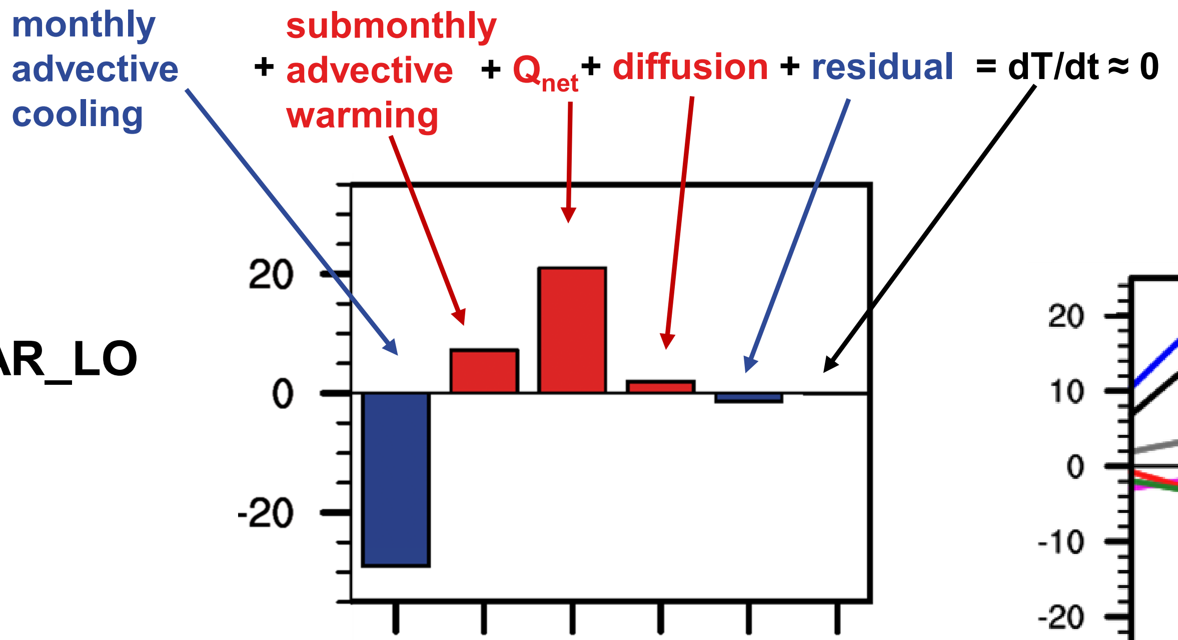
Time average of daily heat budgets, 1979–2010

monthly temperature advection + submonthly temperature advection + Q_{net} + diffusion + residual = dT/dt ≈ 0

Flux adjustments affect the time-mean heat budget

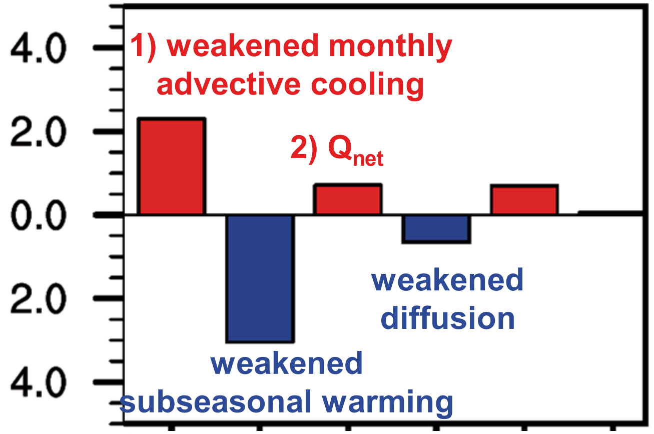
Annual averages of daily heat budgets (K/year),1979–2010

SPEAR_LO

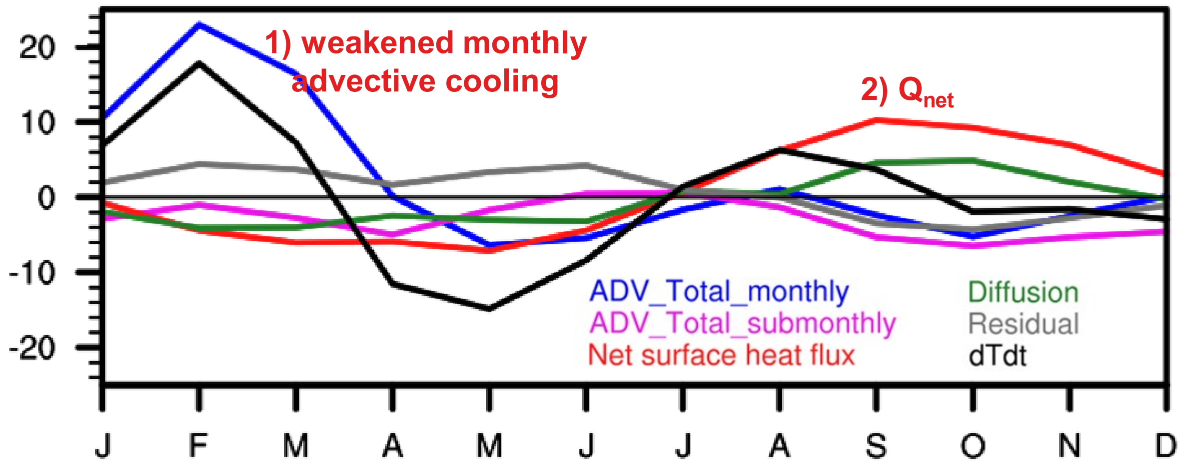


Effect of flux adjustments

SPEAR_LO_FA minus SPEAR_LO



Seasonality in effect of flux adjustments on heat budgets



- FA corrects cold tongue bias due to 1) explicit heating correction and 2) weakened advective cooling driven by surface wind stress correction. 1) is important in summer-fall, and 2) is pronounced in spring.

- FA reduces subseasonal advective warming by changing temperature gradients and shear. However, the actual effect of TIWs-induced stirring and mixing lacks observations.