Tropical Pacific Climate and ENSO: Understanding Model Biases through Flux Adjustment

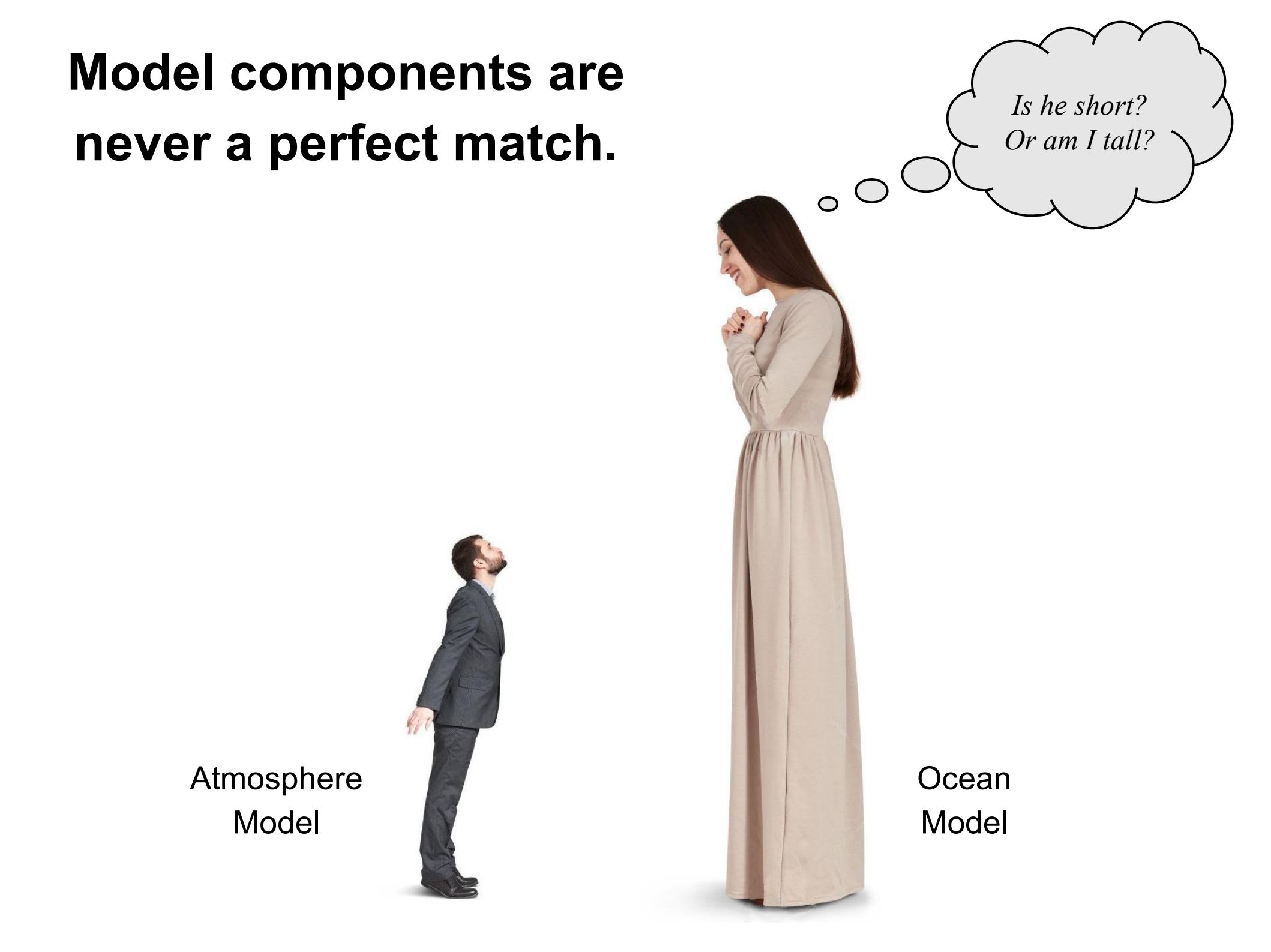
Andrew T. Wittenberg
NOAA GFDL, Princeton, NJ, USA

with G. Vecchi, T. Delworth, A. Rosati, F. Zeng, and S. Ray

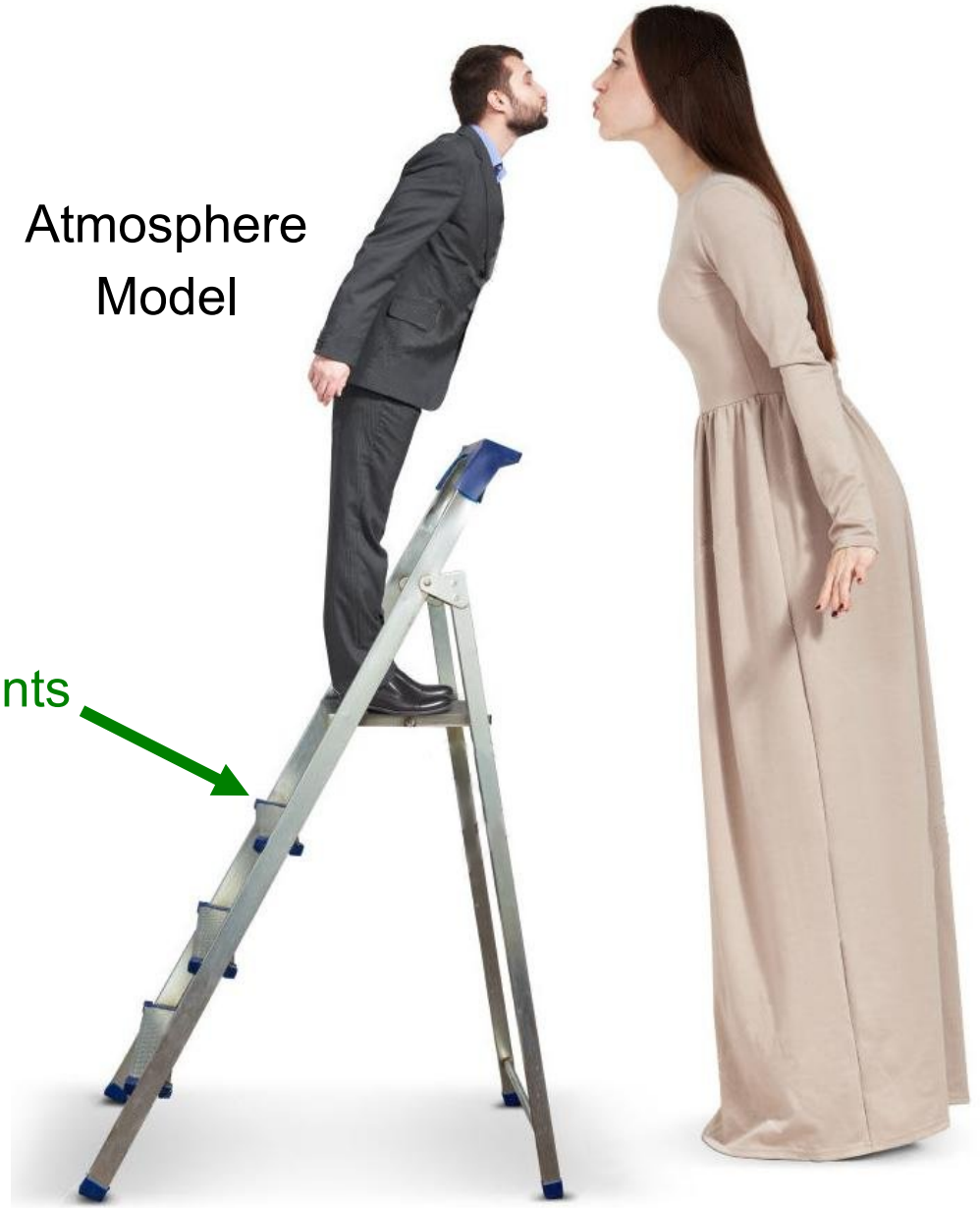
Thanks to: NOAA CPO/CVP

Atmosphere
Model

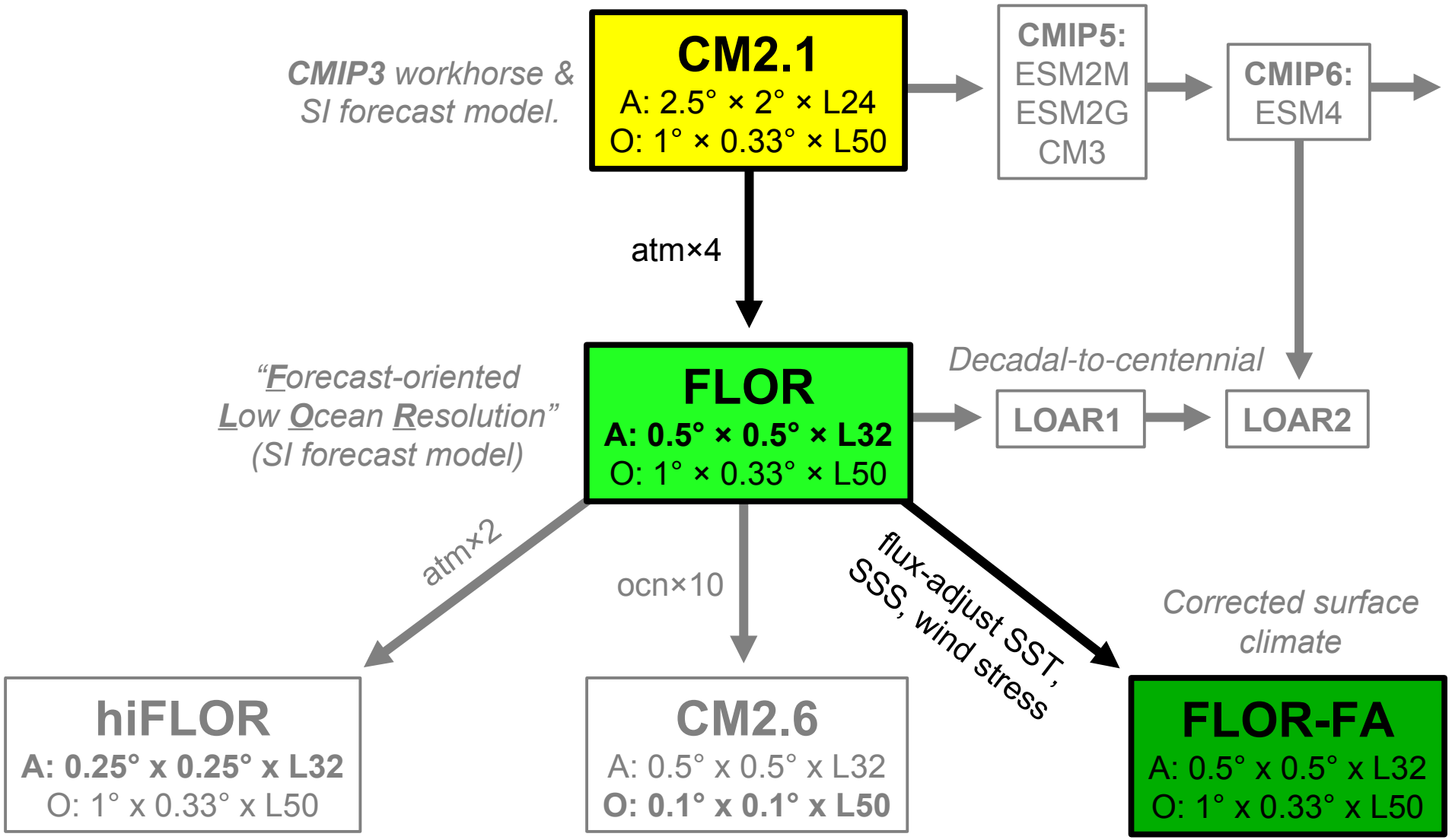
Model components are never a perfect match.



Try an adjustment, to make a better match

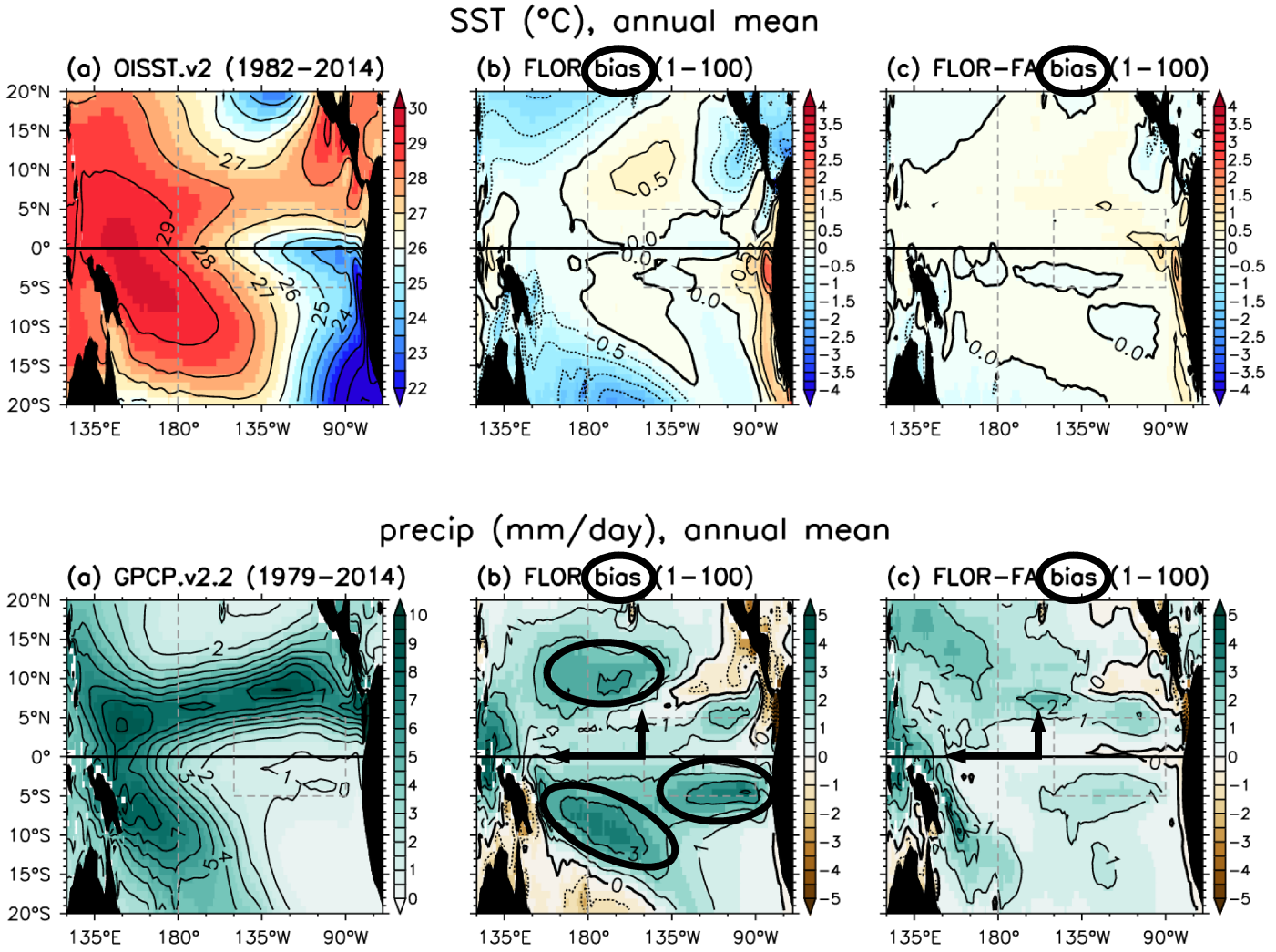


GFDL coupled GCM development



FLOR connects many of GFDL's newest climate models,
and is used extensively for seasonal-to-interannual research and forecasts.

Climatological mean SST & rainfall



FLOR is too warm near South America. dT/dy too strong near the equator. Too cold in NW/SW/NE.

By design, **FA largely corrects these SST biases**.

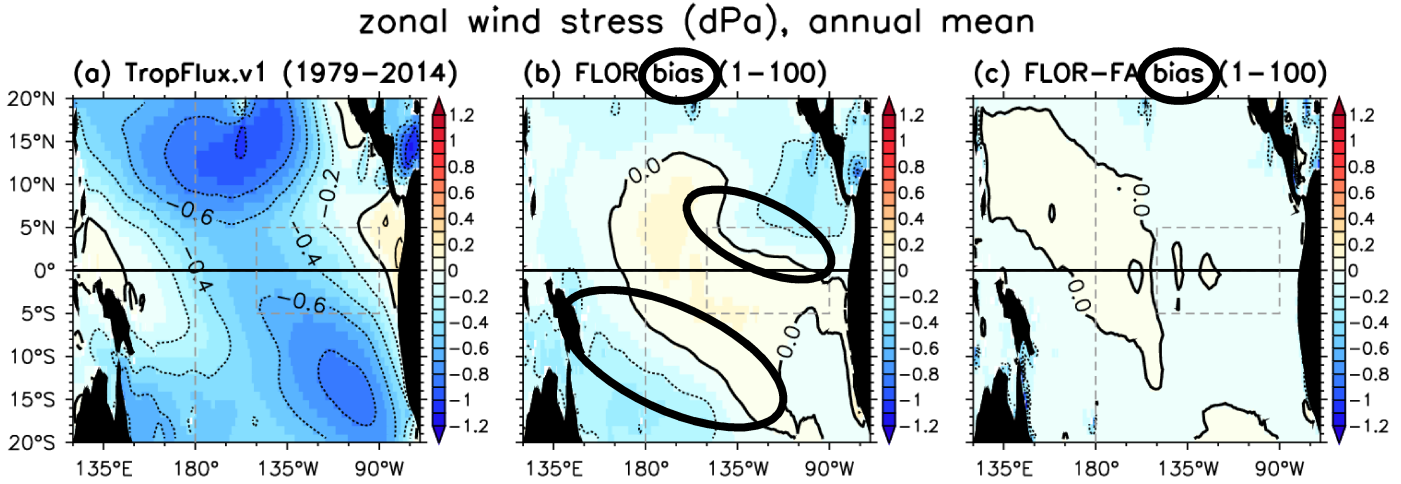
FLOR is too rainy, esp. in convective zones. ITCZ too far north; overly-zonal SPCZ; "double ITCZ".

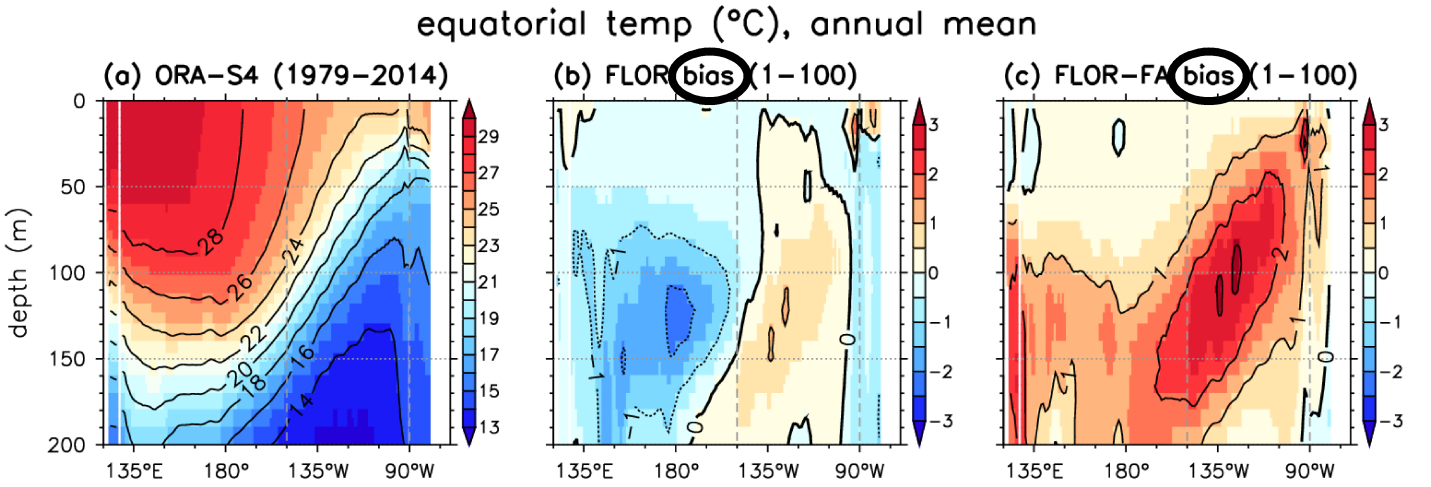
FA reduces these biases, but doesn't eliminate them. Drier equator; **stronger rainfall contrast** between cold tongue & warm pool.

FLOR's atmosphere is too rainy & y-symmetric, even when given the observed SSTs.

FA mostly improves the surface climatology, but not all the rainfall gradients.

Mean zonal wind stress & equatorial thermocline





FLOR's equatorial easterlies are displaced westward.

SW & NE have **too much cyclonic curl**, Ekman suction, and poleward Sverdrup transport.

FA corrects these biases by design.

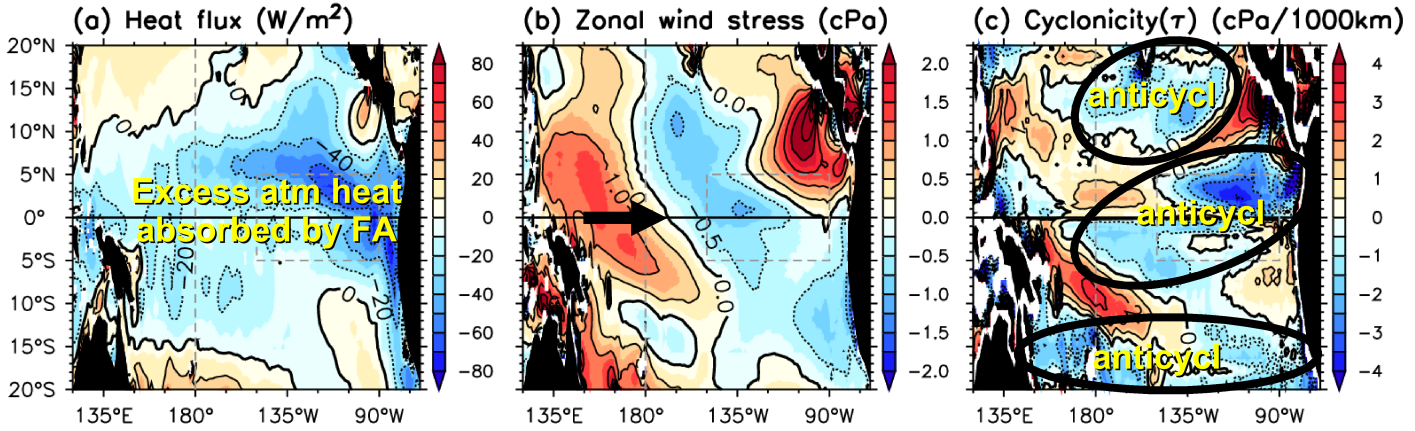
FLOR's equatorial thermocline is a bit flat, but dT/dz looks good over the top 50m.

FA weakens Ekman suction and Sverdrup divergence; deepens thermocline & **weakens dT/dz** at equator.

Surface FA can actually degrade the subsurface. *But it's informative:*
reveals a latent equatorial bias *in the ocean component, when driven by observed winds.*

Surface flux changes due to FA + coupled feedbacks

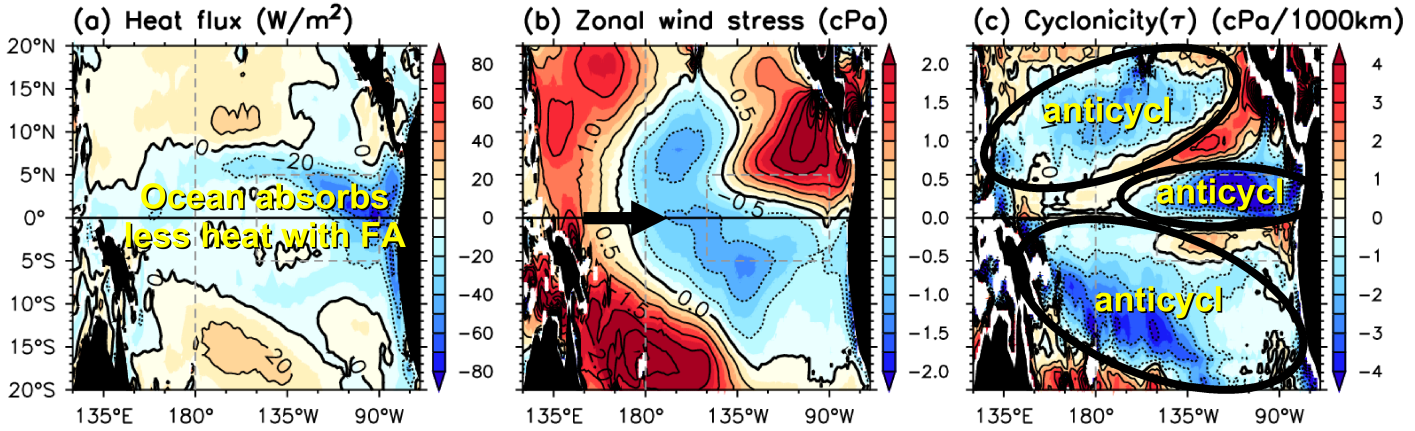
Explicit FA terms only



FA atmosphere provides more heat than the FA ocean can take up. FA absorbs the excess, to maintain realistic SSTs (esp. off-equator & near South America).

FA **weakens cyclonic curl**
→ deeper thermocline
→ weaker cold tongue.

FA + atmos change due to corrected SST



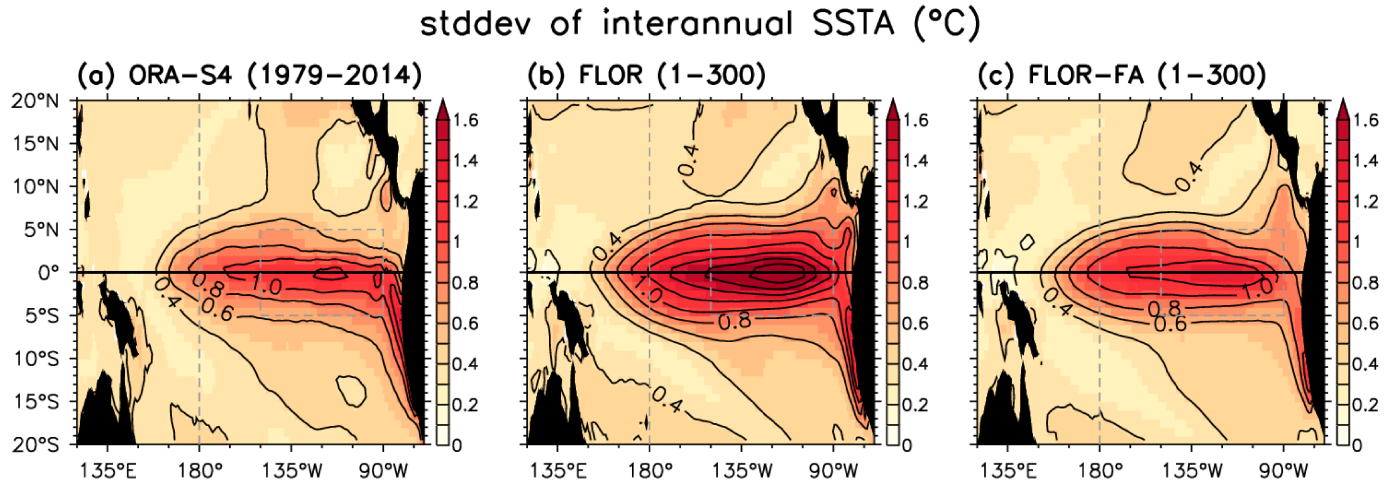
The corrected SSTs make the atmosphere send **more** heat into the ocean.

But the corrected winds make the ocean take up **less** heat.

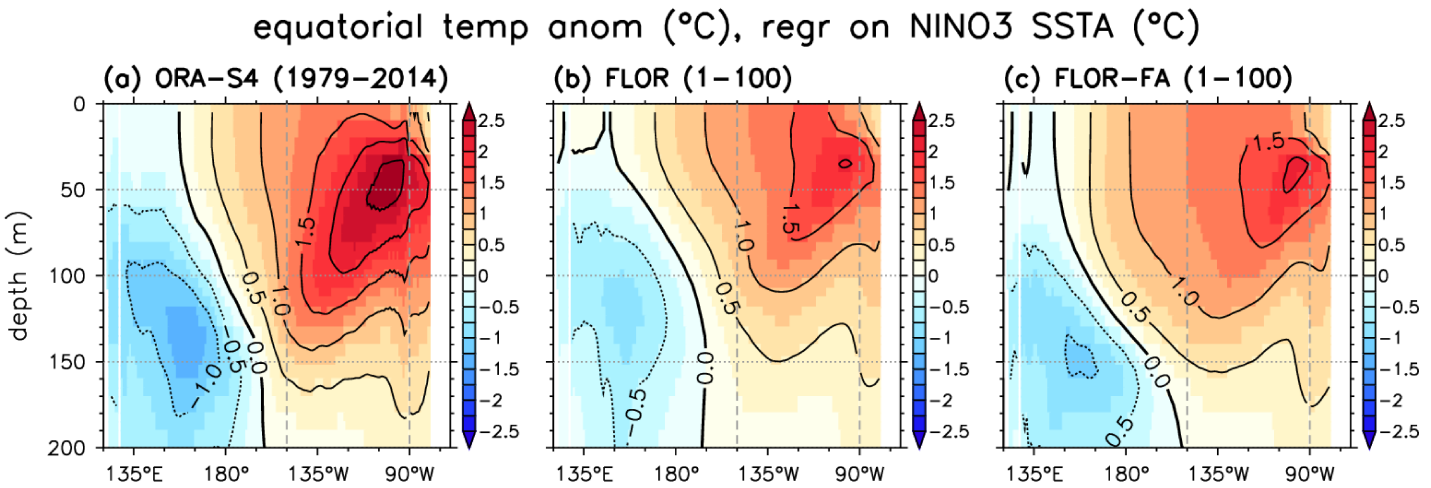
Atmosphere gives too much heat (shortwave), ocean takes too little (TIWs, coastal w).

FA winds are less cyclonic → deeper thermocline → weaker cold tongue → less heat uptake.

ENSO variability of SST and equatorial temperature



FA weakens/improves ENSO amplitude.
SSTA variance still displaced west of obs.

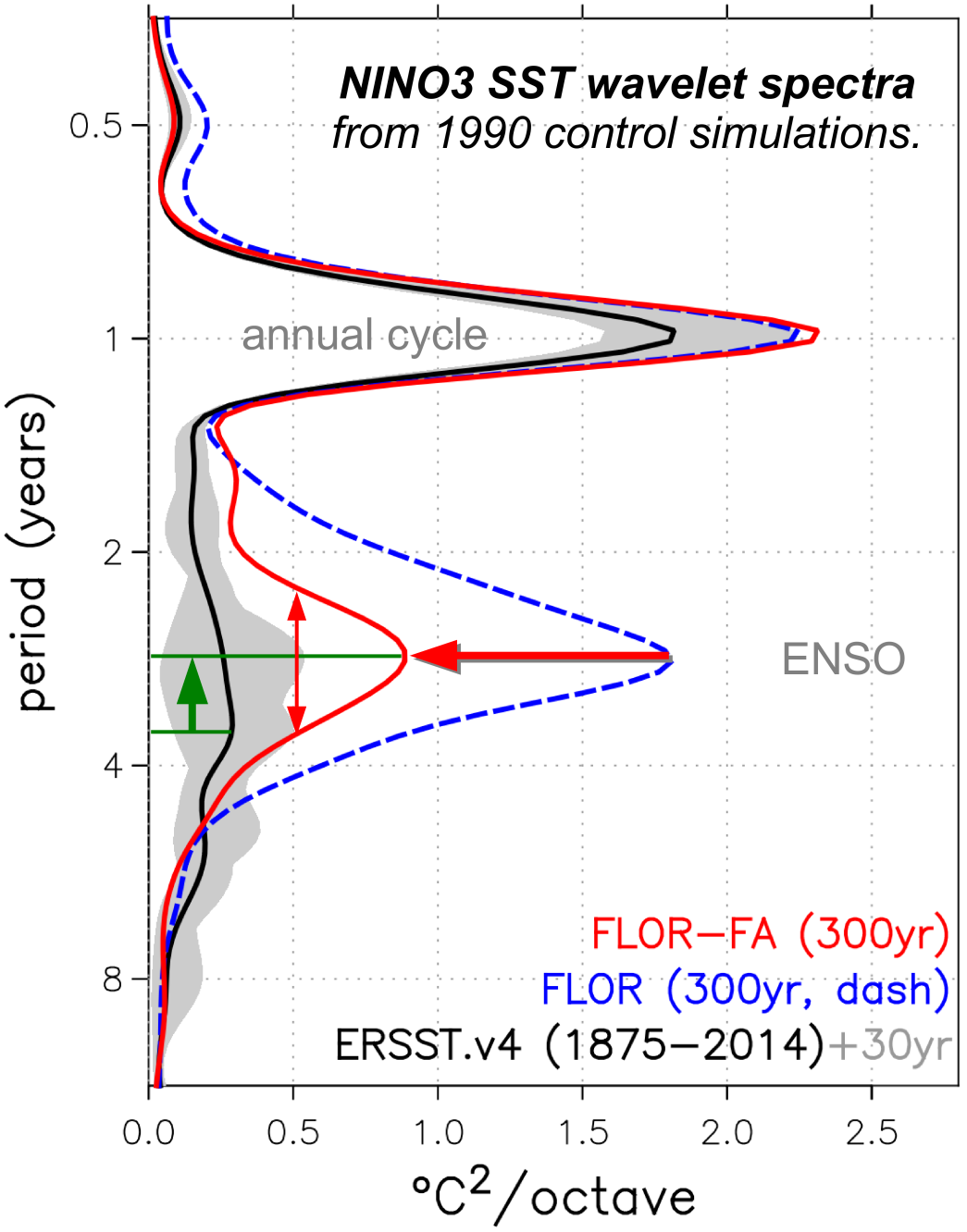


FLOR's equatorial temperature signal peaks near the thermocline, but is too strong near the surface.

FA detaches the signal from the surface, due to the deeper thermocline. But subsurface signature remains too weak.

***The FA helpfully weakens ENSO**, though the equatorial temperature signal remains too weak in the subsurface relative to the surface.*

ENSO spectrum



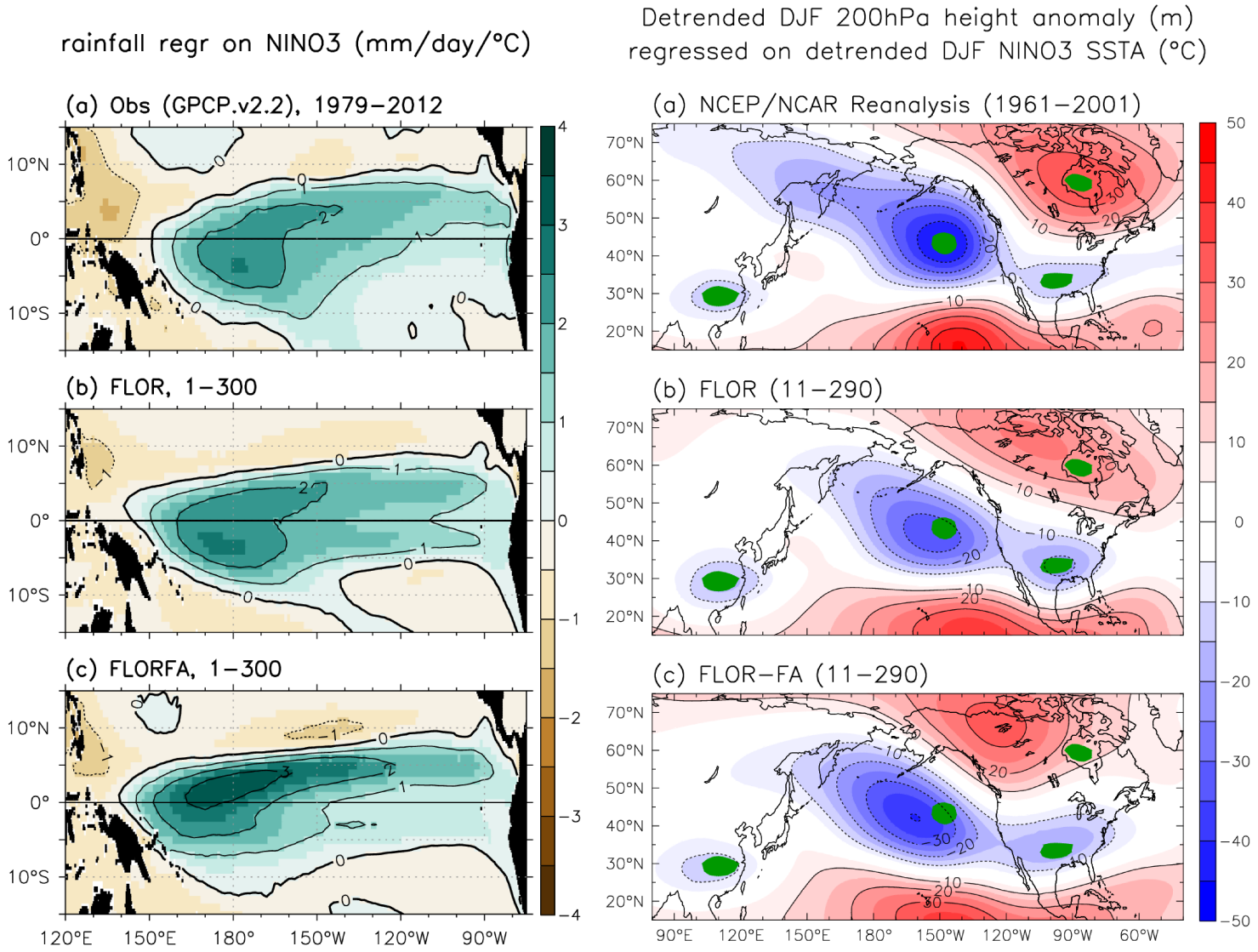
FA cuts the ENSO variance in half.
(Seems great...)

But FA doesn't lengthen
the 2.8yr ENSO period
(obs is ~3.2yr).

And both simulations have
narrower spectral peaks
than observed.

FLOR-FA's spectrum is still
modulated among 30yr chunks --
though less than in hyperactive FLOR.

ENSO teleconnections



FLOR has a good rainfall response; a bit southwest of obs.

FA improves the meridional asymmetry, but also **boosts the sensitivity**, and **shifts the rain response west.**

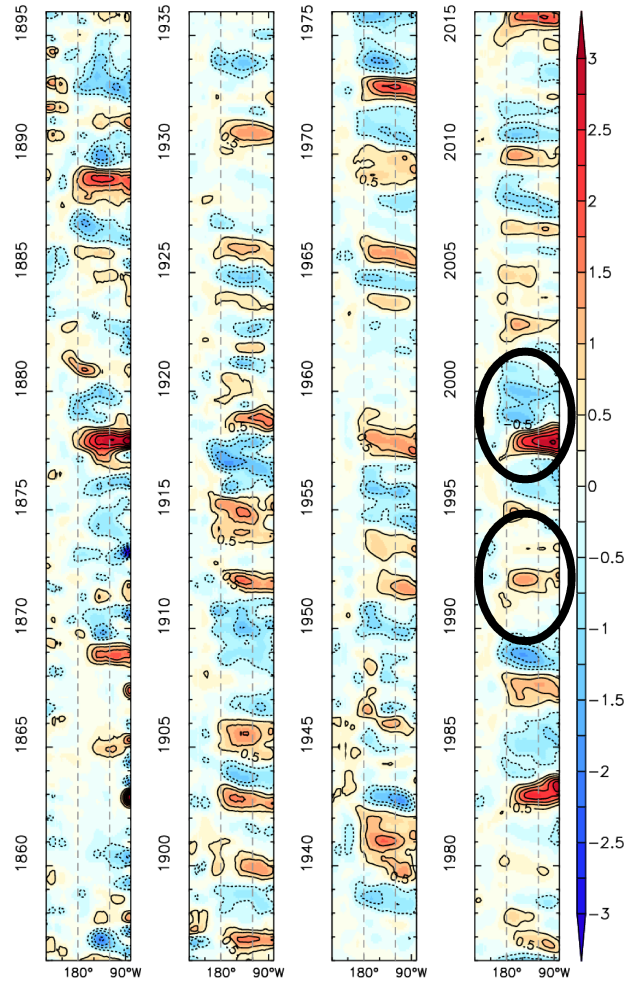
FLOR's extratropical teleconnections are good, but weak in places; some centers of action are west of obs.

FA amplifies the teleconnections, but shifts them further west.

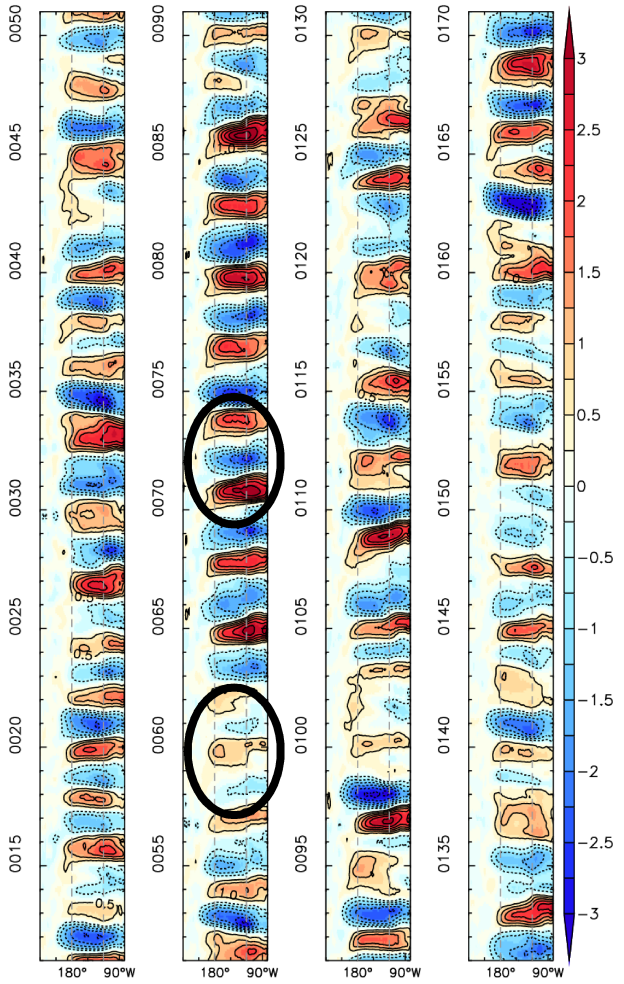
FA improves some teleconnections, but degrades others. *Stronger cold tongue / warm pool convective contrast may inhibit eastward/equatorward shift of rainfall during El Niño.*

Equatorial Pacific SSTAs (°C, 160yr)

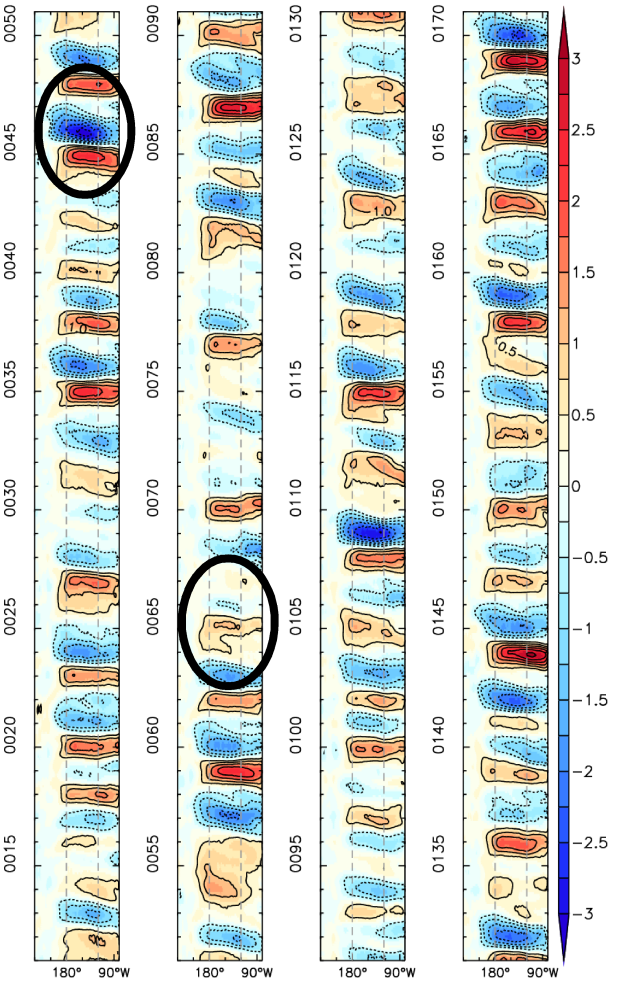
OBS (ERSST.v4)



FLOR

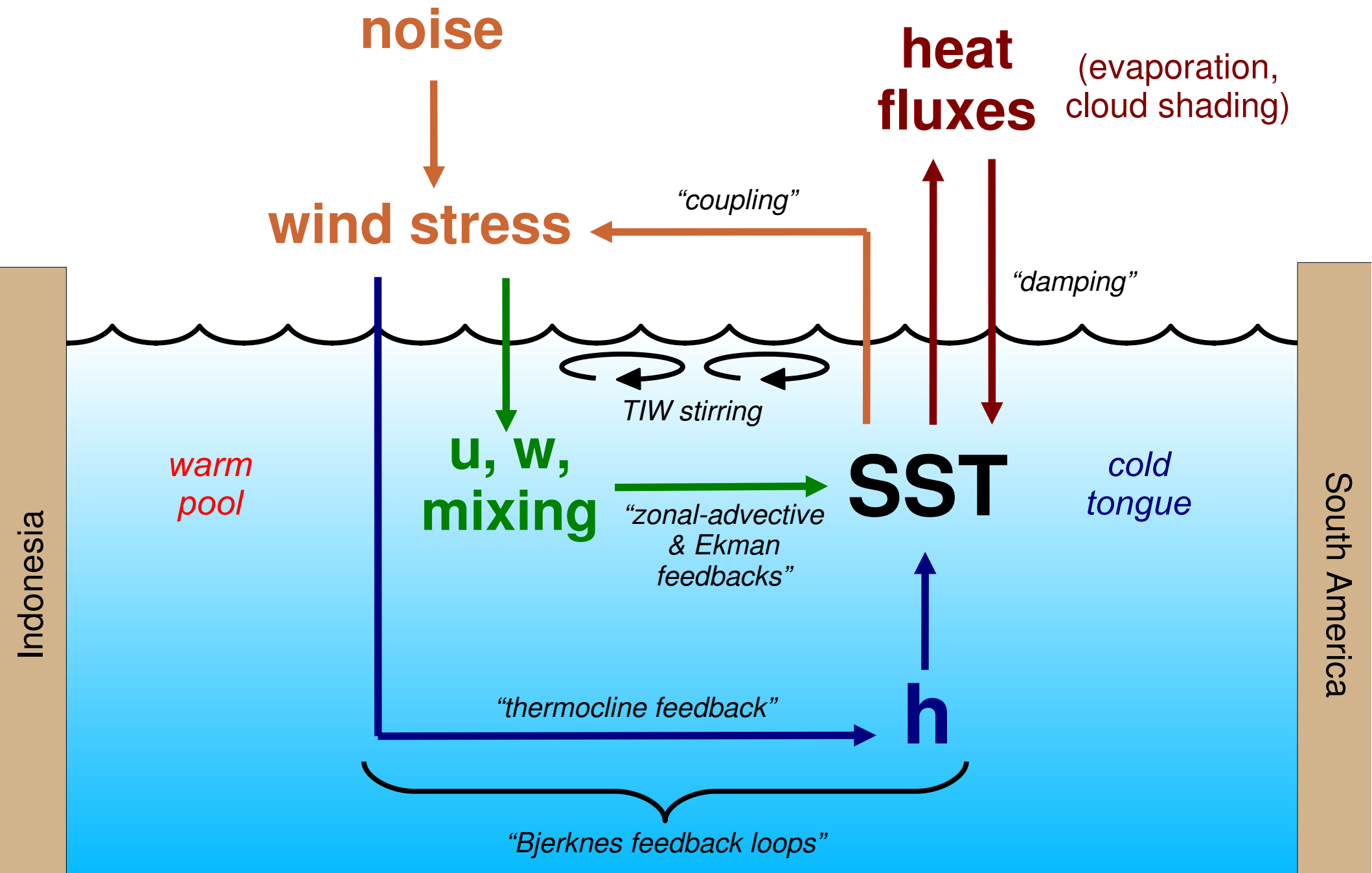


FLOR-FA

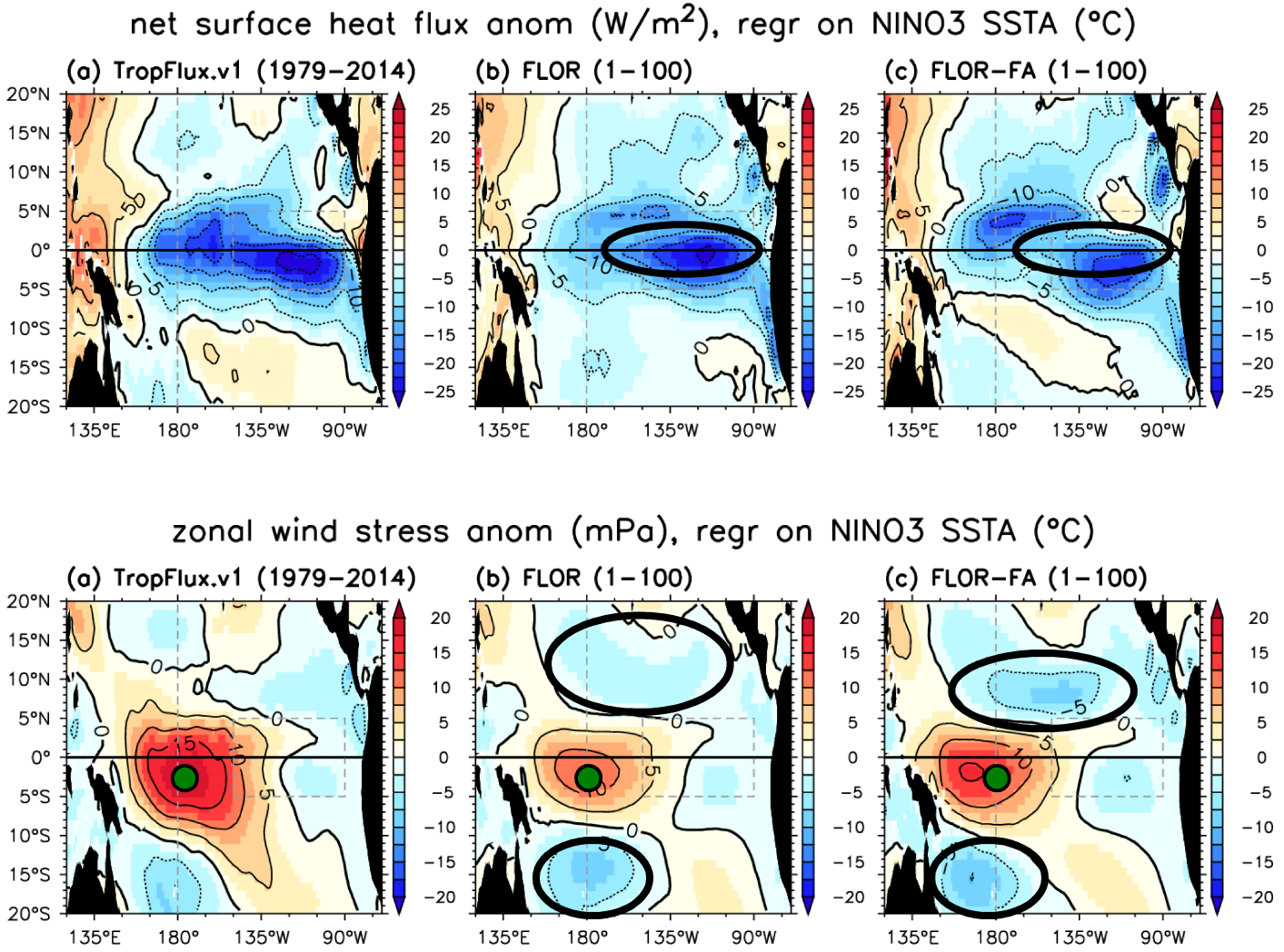


*SSTA amplitude/pattern/propagation **vary from decade to decade** in obs & simulations.*
FLOR SSTAs are too strong, frequent, and eastward-propagating, especially for cold events.
*FA gives weaker ENSO SSTAs, with **more westward propagation and positive skewness**.*

Key ENSO feedbacks



ENSO patterns of surface heat flux and zonal stress



FLOR's damping is too weak, due to a weak cloud shading response.

FA further weakens the damping, by shifting convection north & west.

FLOR's ENSO wind response is meridionally narrower than obs → **excessive cyclonic curl** & Sverdrup divergence.

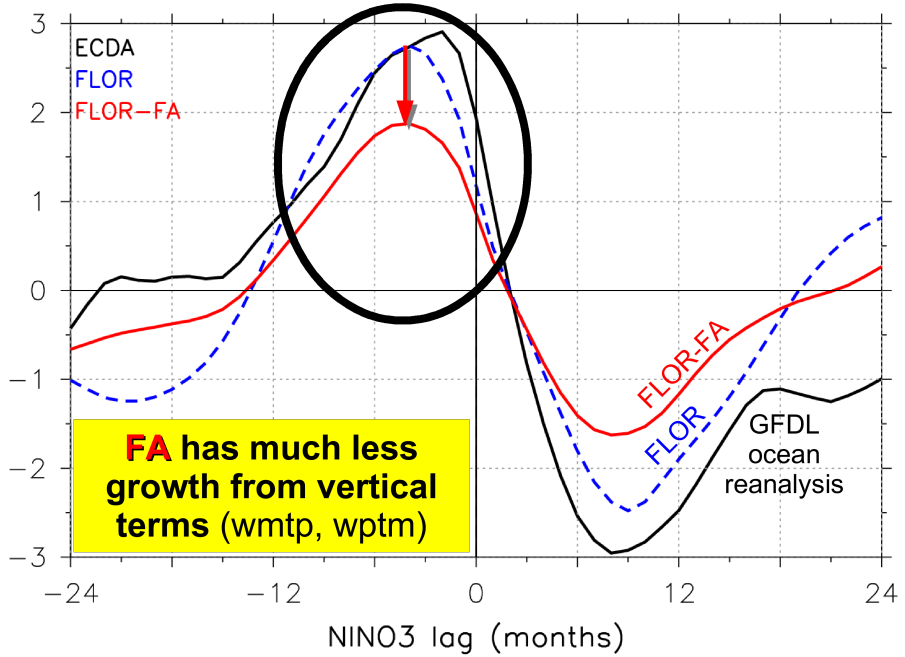
FA boosts strength & y-asymmetry of westerly anomalies, but shifts response west & doesn't improve curl.

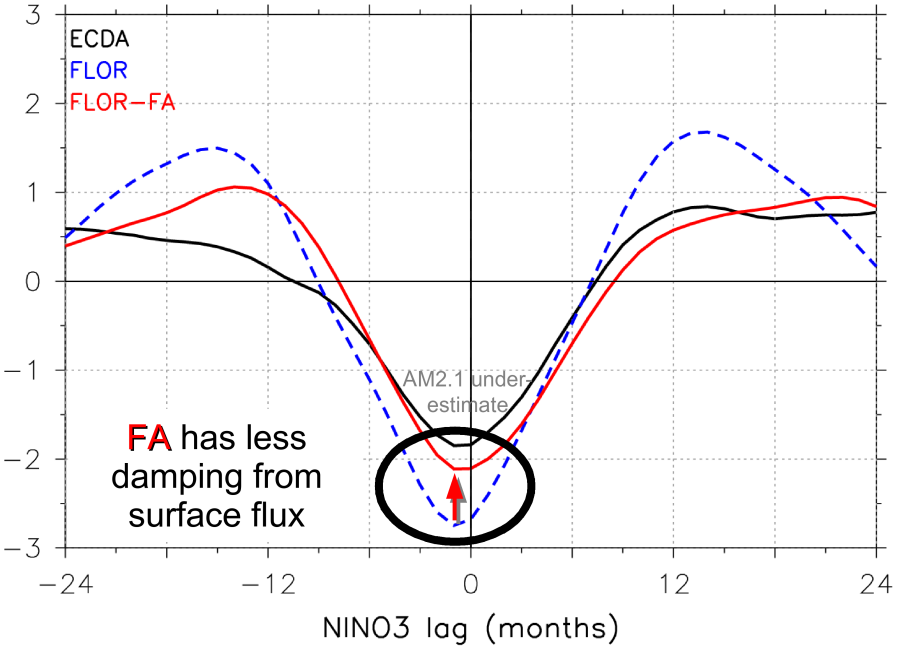
*FA boosts the wind coupling, weakens the damping – **both oppose the weaker ENSO.***

FA doesn't improve the curl-induced delayed negative thermocline feedback.

ENSO heat budget for the equatorial mixed layer

(top-50m anomalies averaged 160°E-90°W; lag-regressed onto NINO3 SSTA; °C/yr/°C)

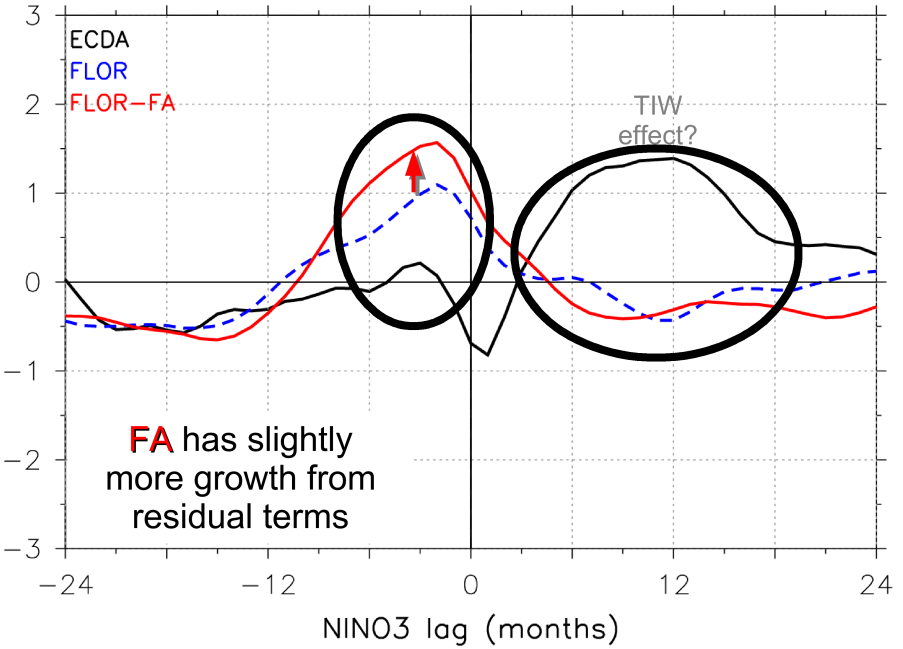




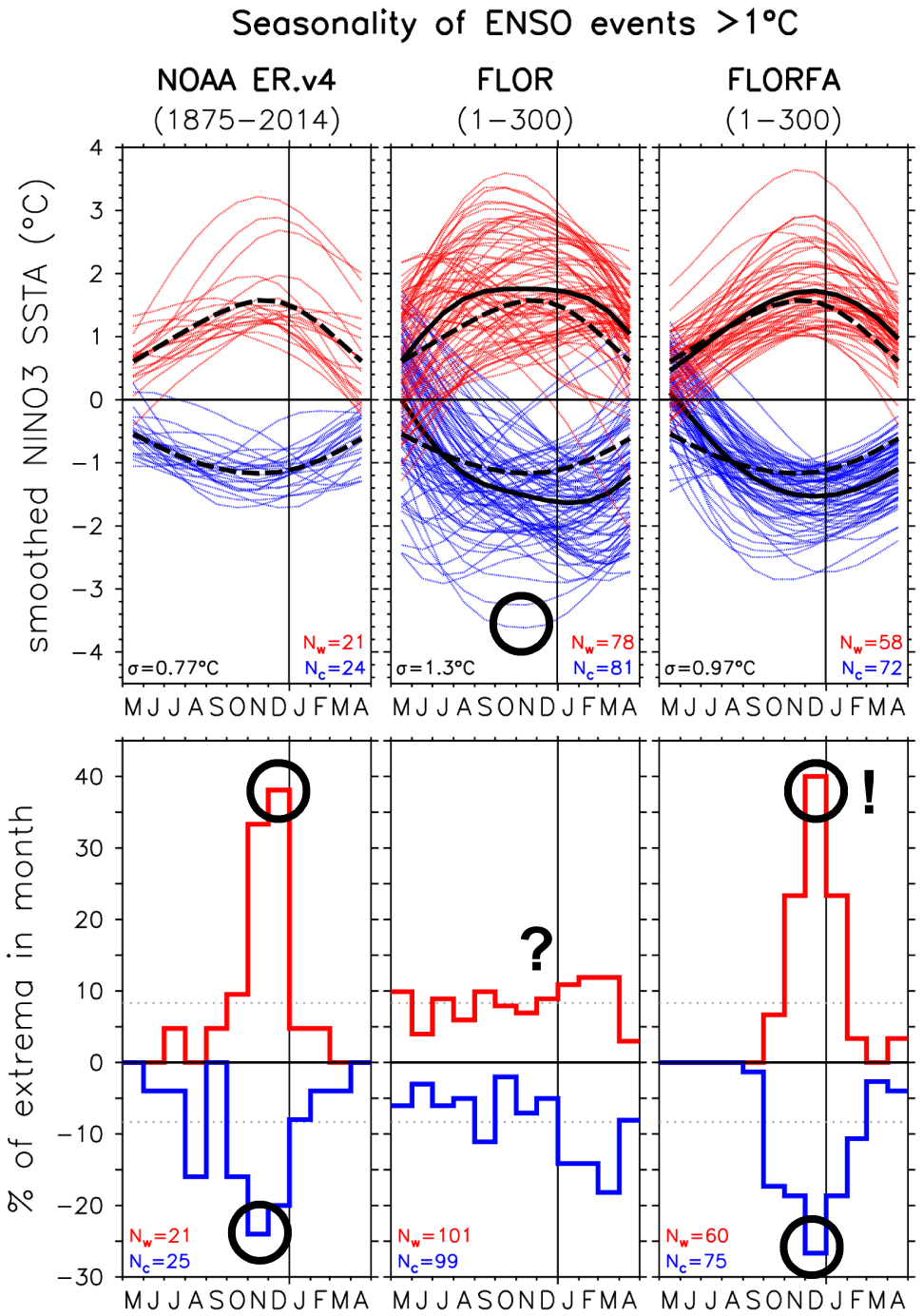
FA weakens ENSO in FLOR, because the deeper thermocline **weakens the vertical advective coupling** between the equatorial thermocline & surface.

(and ENSO would be even weaker, if it weren't for the weaker damping...)

So FA gives us a weaker ENSO for the wrong reasons!



Seasonal synchronization of ENSO



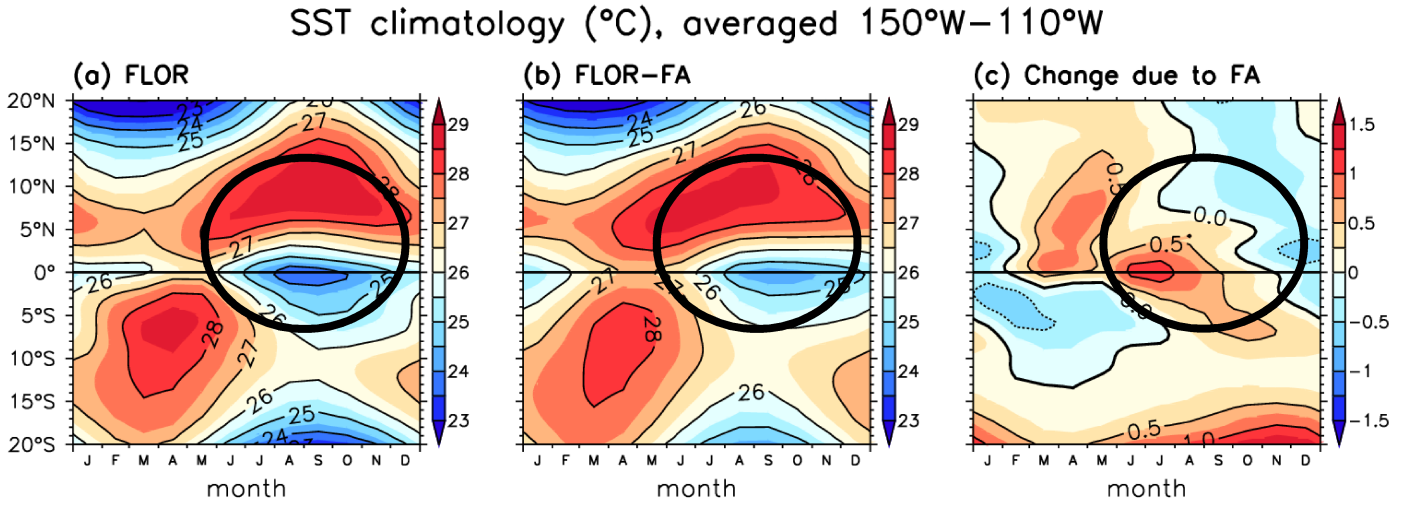
Observed events (especially strong ones) tend to peak during Oct-Dec.

FLOR's events show little seasonal synchrony, except for the strongest events.

And FLOR's cold events are far too strong.

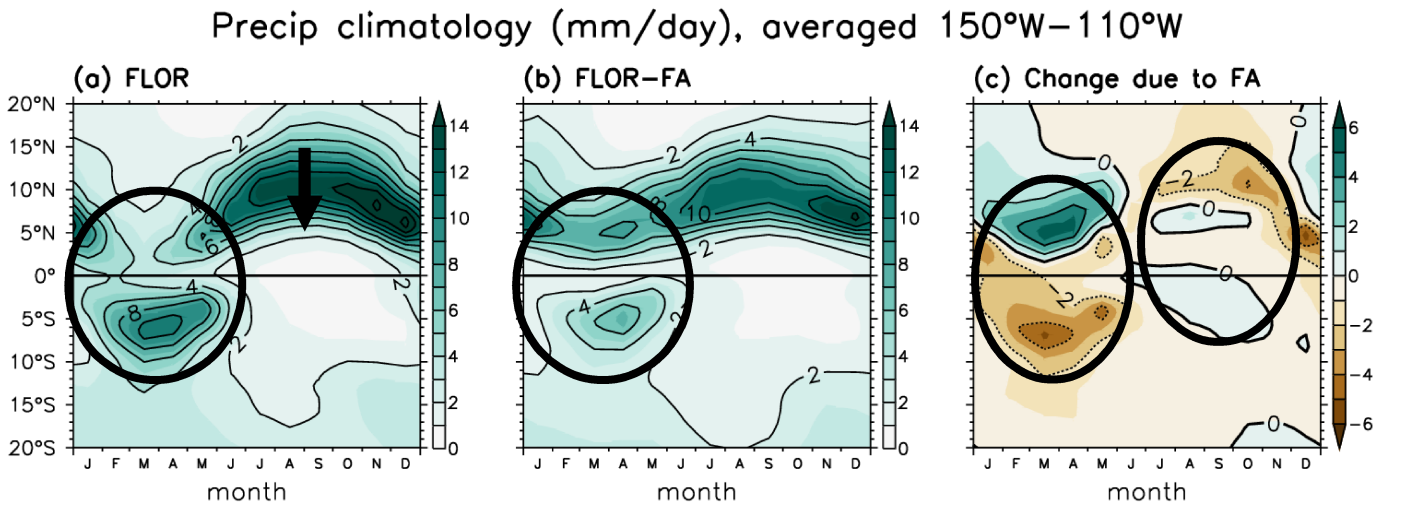
FA synchronizes ENSO events to the end of the calendar year, and **improves the positive skewness** of NINO3 SSTAs.

Seasonal cycle of east Pacific SST & rainfall



FLOR overestimates dT/dy in the eastern equatorial Pacific during Jul-Nov.

FA weakens this dT/dy, aiding equatorial shifts of the ITCZ and extending ENSO through to Dec.



FA weakens equatorial deep convection during Dec-Jun, but shifts the ITCZ equatorward during Jul-Nov.

***FA sensitizes the northeast Pacific ITCZ to equatorial SSTAs in Jul-Nov**, seasonalizing the Bjerknes feedback and **synchronizing ENSO** to the end of the calendar year.*

Summary

1. Flux adjustment (FA) is useful and informative

a. Corrects climatological SST & winds, reduces rainfall biases
b. Can improve aspects of variability (e.g. ENSO strength & synchronization)
c. Helps **attribute** biases to atmosphere or ocean components
d. **Uncovers** ocean biases hidden by atmospheric biases, and vice versa
e. Reveals how **coupled feedbacks modify the biases**
f. Illuminates how **background state affects the variability**

2. But not a magic bullet

a. May actually degrade some parts of the simulation
   - e.g. upper-ocean dT/dz & near-equatorial precip gradients
b. **Overly deepens FLOR's equatorial thermocline**
   - weaker off-equatorial trade winds → less Ekman suction & Sverdrup divergence
   - but uncovers a **latent OGCM bias** → motivates attention to equatorial mixing & TIWs

3. FA strongly affects ENSO in FLOR

a. **ENSO weakens**
   - **weaker thermocline feedback** trumps stronger coupling & weaker damping
   - more westward propagation of SSTAs; less interdecadal modulation of ENSO
b. **Atmospheric teleconnections strengthen & shift west**
   - drier central equatorial Pacific + weaker ENSO → harder to shift convection eastward
c. **ENSO synchronizes to end of calendar year**
   - eastern equatorial Pacific dT/dy barrier weakens in Jul-Nov, relative to Jan-May
   - stronger Bjerknes feedback in Jul-Nov → ENSO peaks near Dec

Moving forward

1. Improve AGCM climatology & ENSO feedbacks

a. **Clouds** & radiative feedbacks (weaken shortwave heating)
b. **Moisture budget:** reduce tropical rain & evap; improve rainfall gradients
c. **Surface fluxes:** bulk formulae, skin temperature, diurnal cycle
d. **Off-equatorial wind stress curl** & response to ENSO (precip pattern, CMT)

2. Improve OGCM climatology & ENSO feedbacks

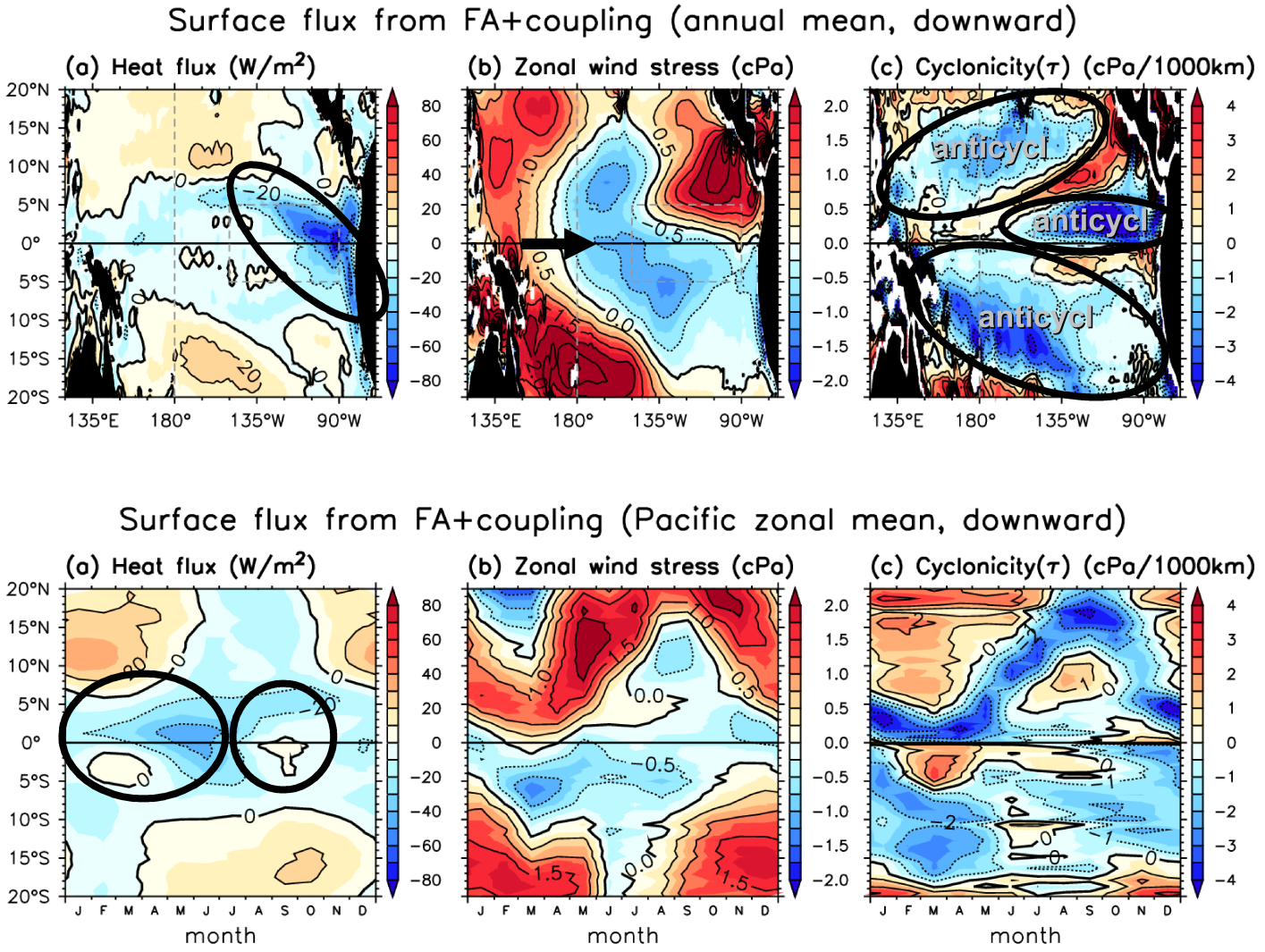
a. **Shoal the equatorial thermocline** (mixing, solar penetration, diurnal cycle)
b. **Resolve or parameterize TIWs** (critical during La Niña)
c. **Mixed layer heat budget** (need obs constraints – TPOS, assimilation)

3. Improve coupled interactions

a. **Seasonal dT/dy** in east Pacific (key for ENSO seasonality)
b. **Coupled feedback** diagnostics (improve obs constraints – winds, heat fluxes)
c. **Subsurface flux adjustments** (3D-FA)
d. **Use FA as a routine diagnostic** for coupled models

Reserve Slides

Surface fluxes: Explicit FA + coupled feedbacks



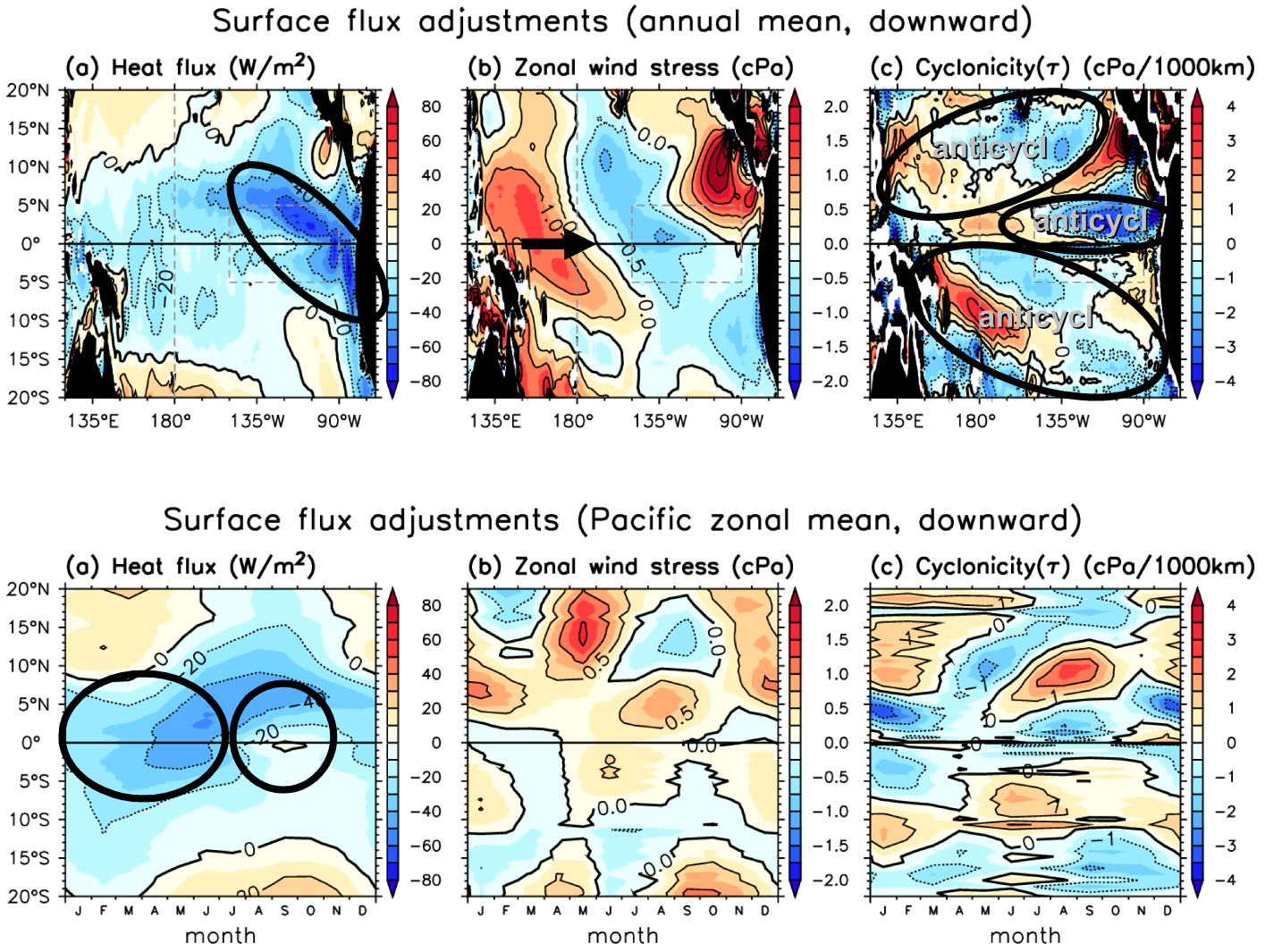
FA pulls heat out of the tropical Pacific, esp. off-equator & near S. America.

FA shifts easterlies eastward, weakens cyclonic curl & Sverdrup divergence near equator. Corrected SST weakens ITCZ/SPCZ → less cyclonic curl & Ekman suction off-equator.

SST gradient (**dT/dy**) between equator & ITCZ is **strengthened Nov-Jun**, but **weakened Jul-Nov**, by the FA.

FA depresses the equatorial thermocline. FA seasonal forcing of dT/dy favors ***equatorward shifts of the ITCZ near the end of the calendar year****.*

Surface fluxes: Explicit FA only



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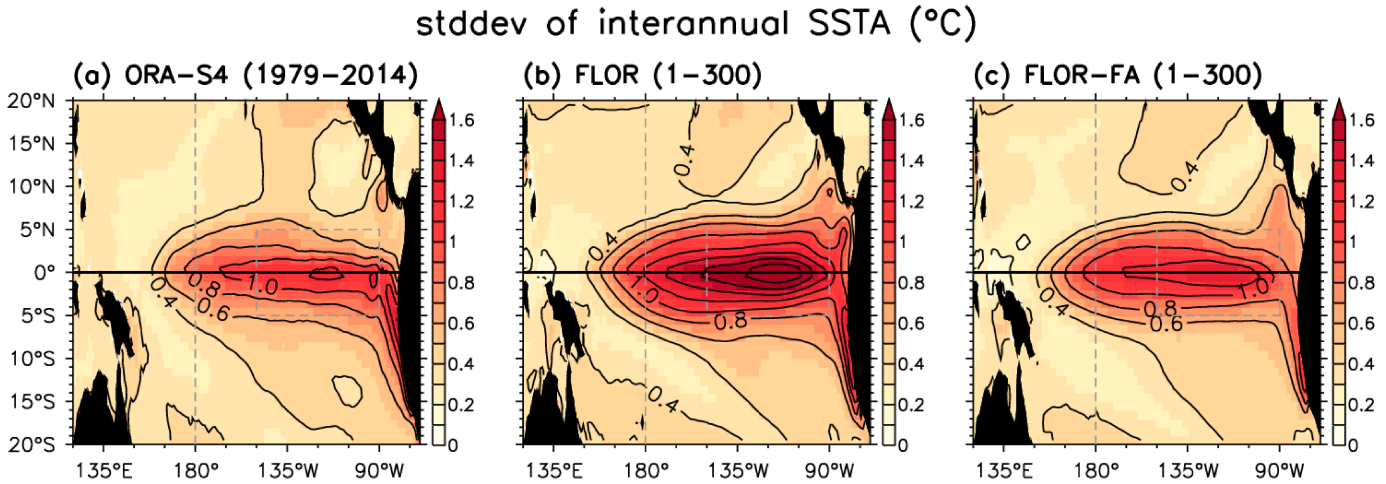
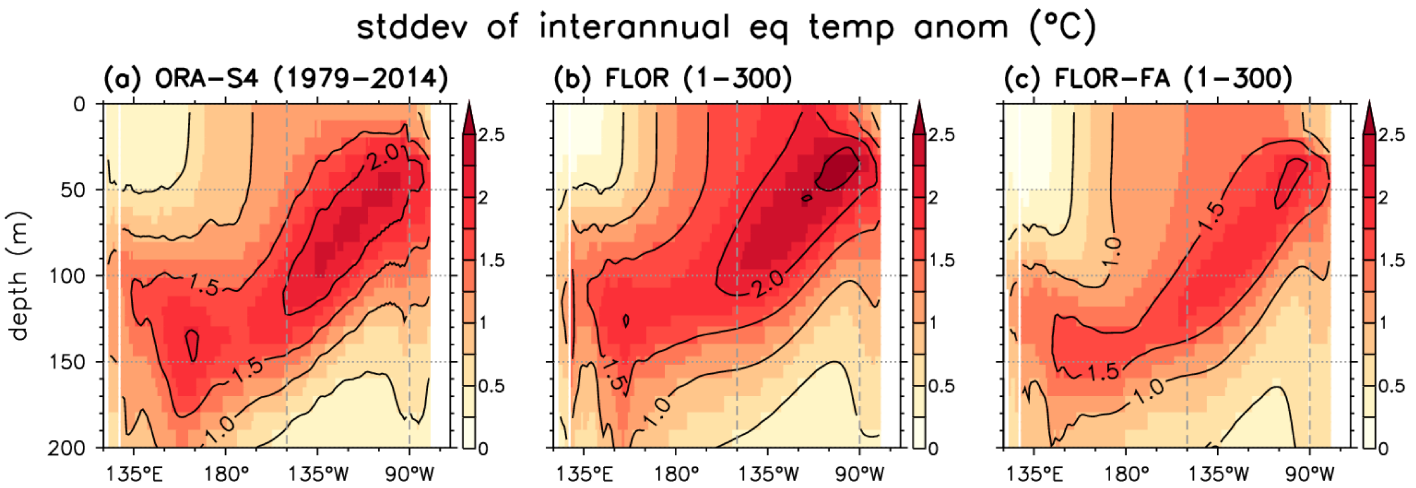
ENSO variability of SST and equatorial temperature





FA weakens/improves ENSO amplitude. SSTA variance still displaced west of obs.

FLOR's equatorial temperature variance peaks at the thermocline, but is too strong near the surface.

FA detaches some variance from the surface, due to deeper thermocline. But surface signature remains too strong.

The FA appropriately weakens ENSO, though the equatorial temperature variance at the surface remains too strong relative to that near the thermocline.