ENSO in a Flux-Adjusted Coupled GCM

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No model is perfect . . .

Sometimes the pieces don't quite fit.

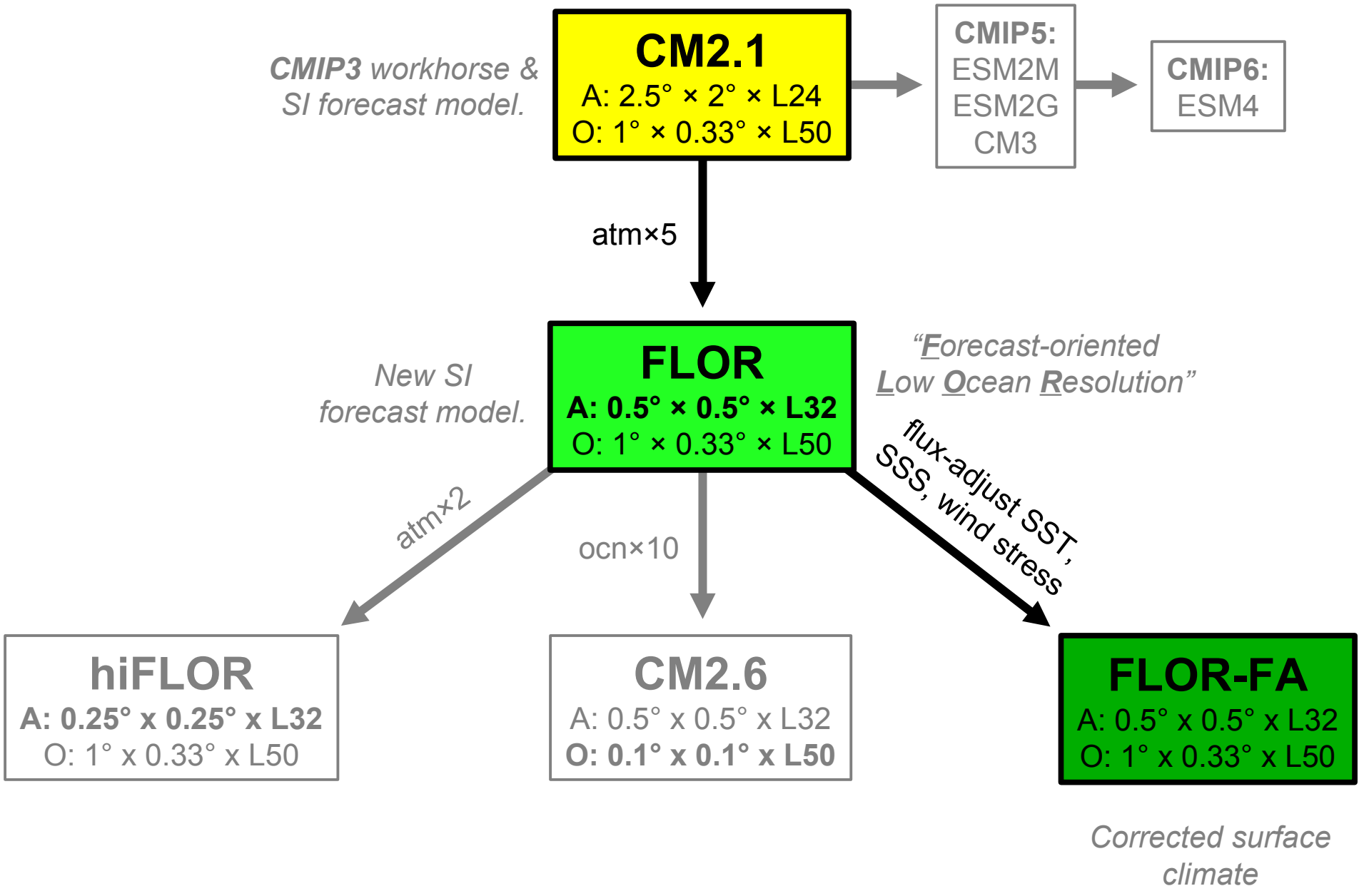
Can **flux adjustments** get us where we want to go?

+

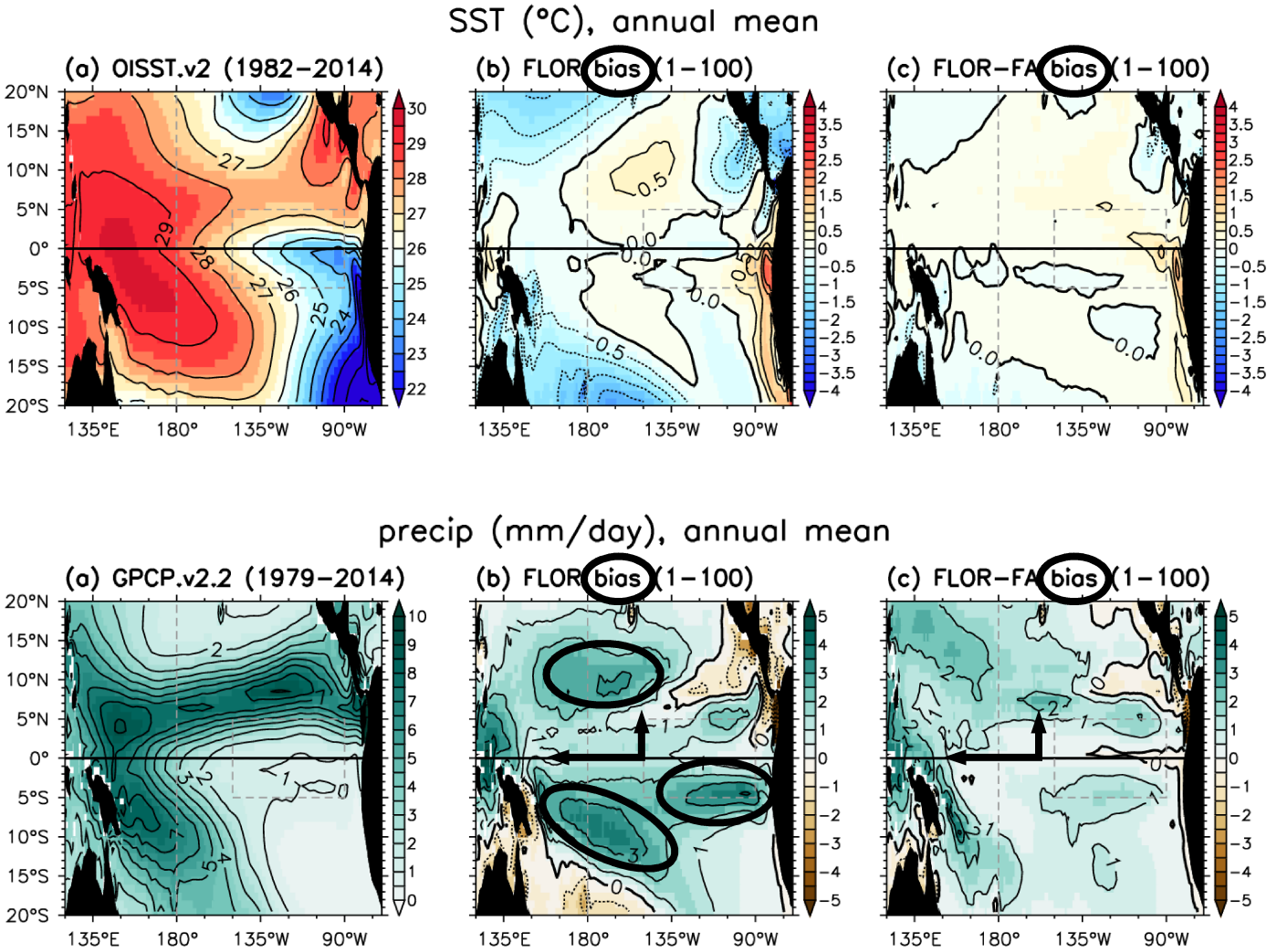
flux adjustment

=

GFDL's high-res model development path



Mean SST & rainfall in the FLOR CGCM



FLOR is too warm along the South American coast, too cold off-equator.

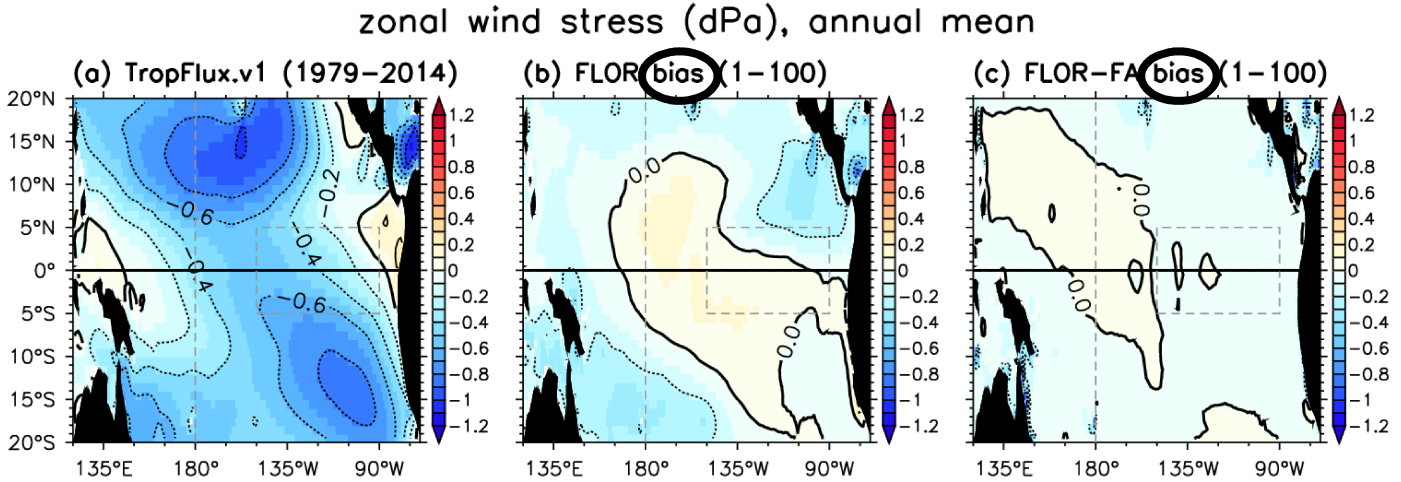
By construction, **FA largely corrects these SST biases**.

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.

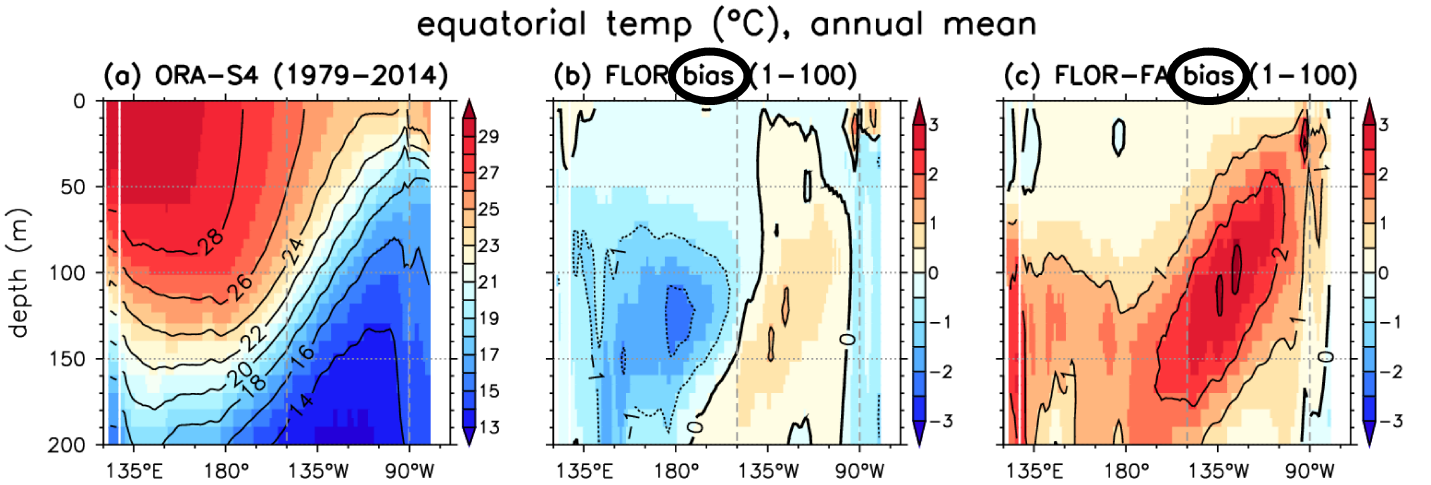
The FLOR atmosphere is too rainy & meridionally symmetric, even when given the observed SSTs. FA improves the spatial means, but not all the rainfall gradients.

Mean zonal wind stress & equatorial thermocline



FLOR's equatorial easterlies are shifted westward. SE & NE have **too much cyclonic curl** & poleward Sverdrup transport.

FA corrects these biases (by construction).

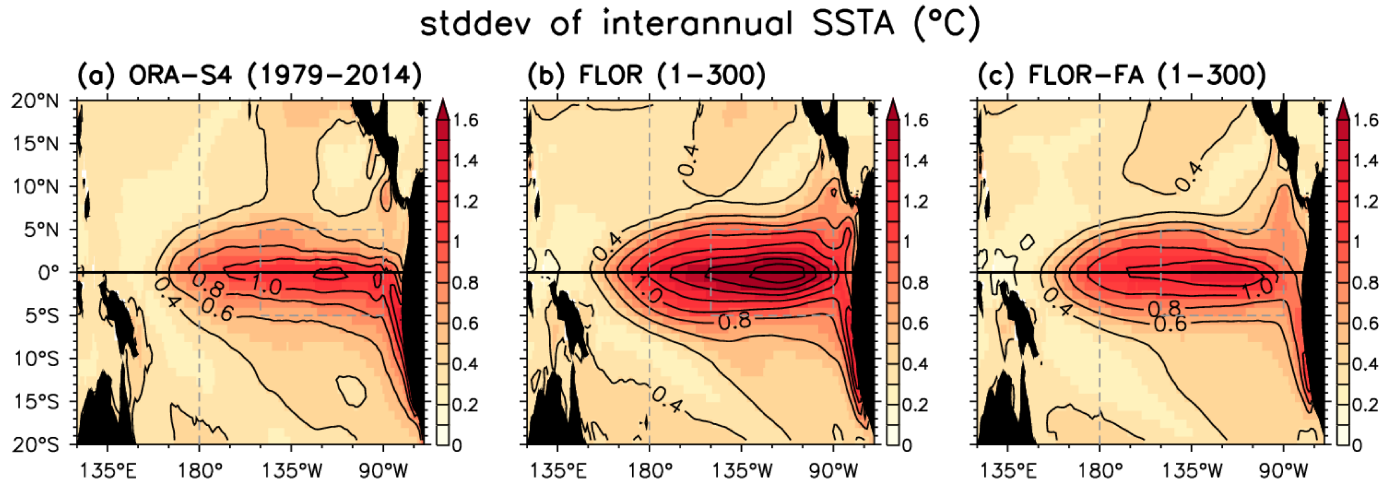


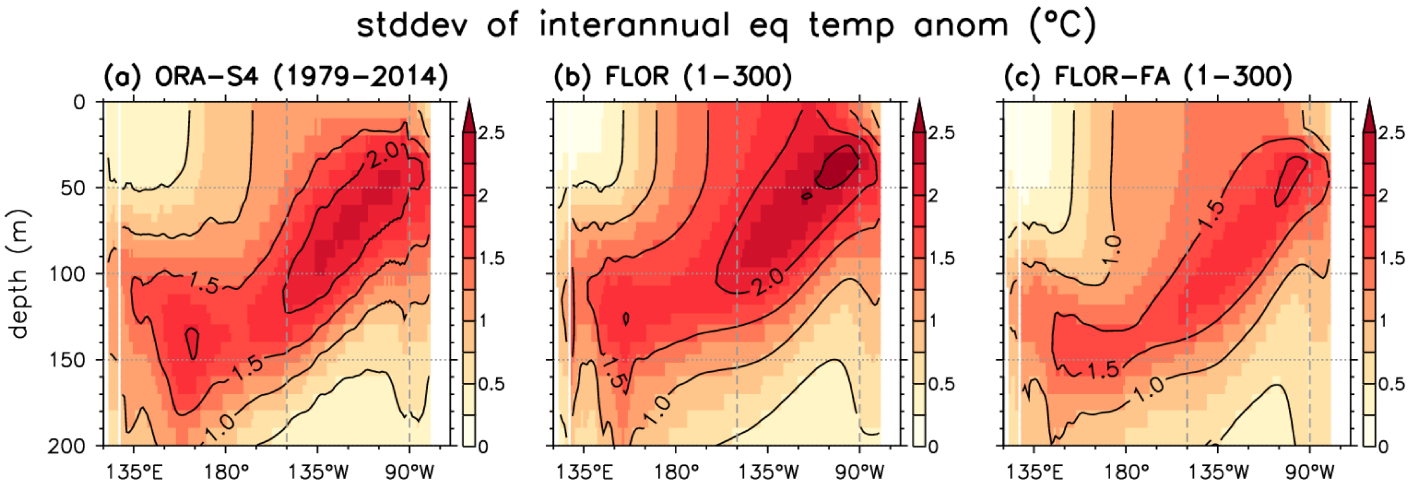
FLOR's equatorial thermocline is a little flat, but dT/dz is mostly ok over the top 50m.

FA reduces the Sverdrup divergence and deepens the thermocline, weakening dT/dz in the upper ocean.

*So **surface-only FA can degrade the subsurface**. But here it's helpful:*
***uncovers a latent bias** in the ocean component, when driven by observed winds.*

ENSO variability of SST and equatorial temperature





FLOR's ENSO is too strong.

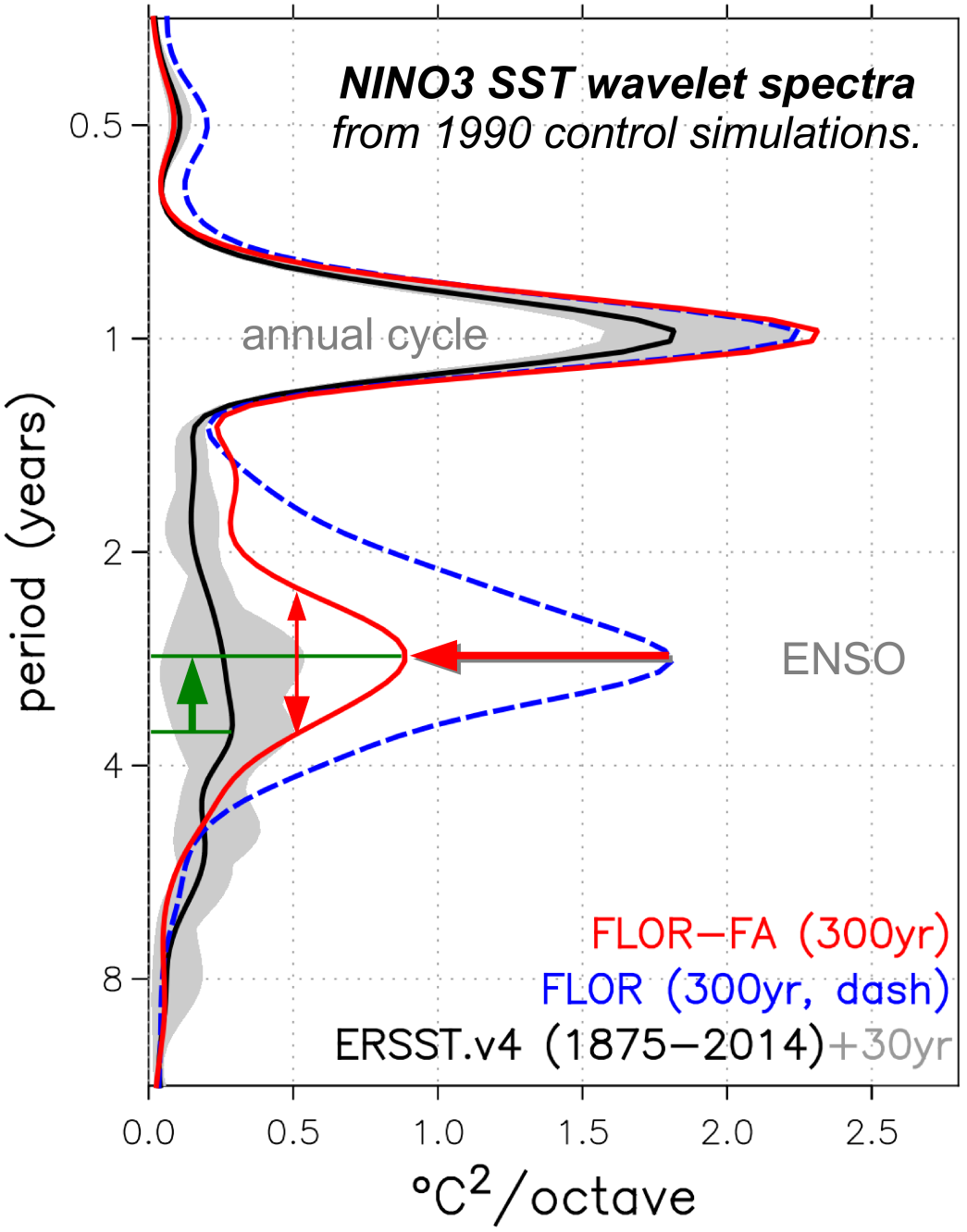
FA weakens/improves the ENSO amplitude. SSTA variance is still displaced west of obs.

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

FA detaches some variance from the surface, in tandem with the 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.

ENSO spectrum



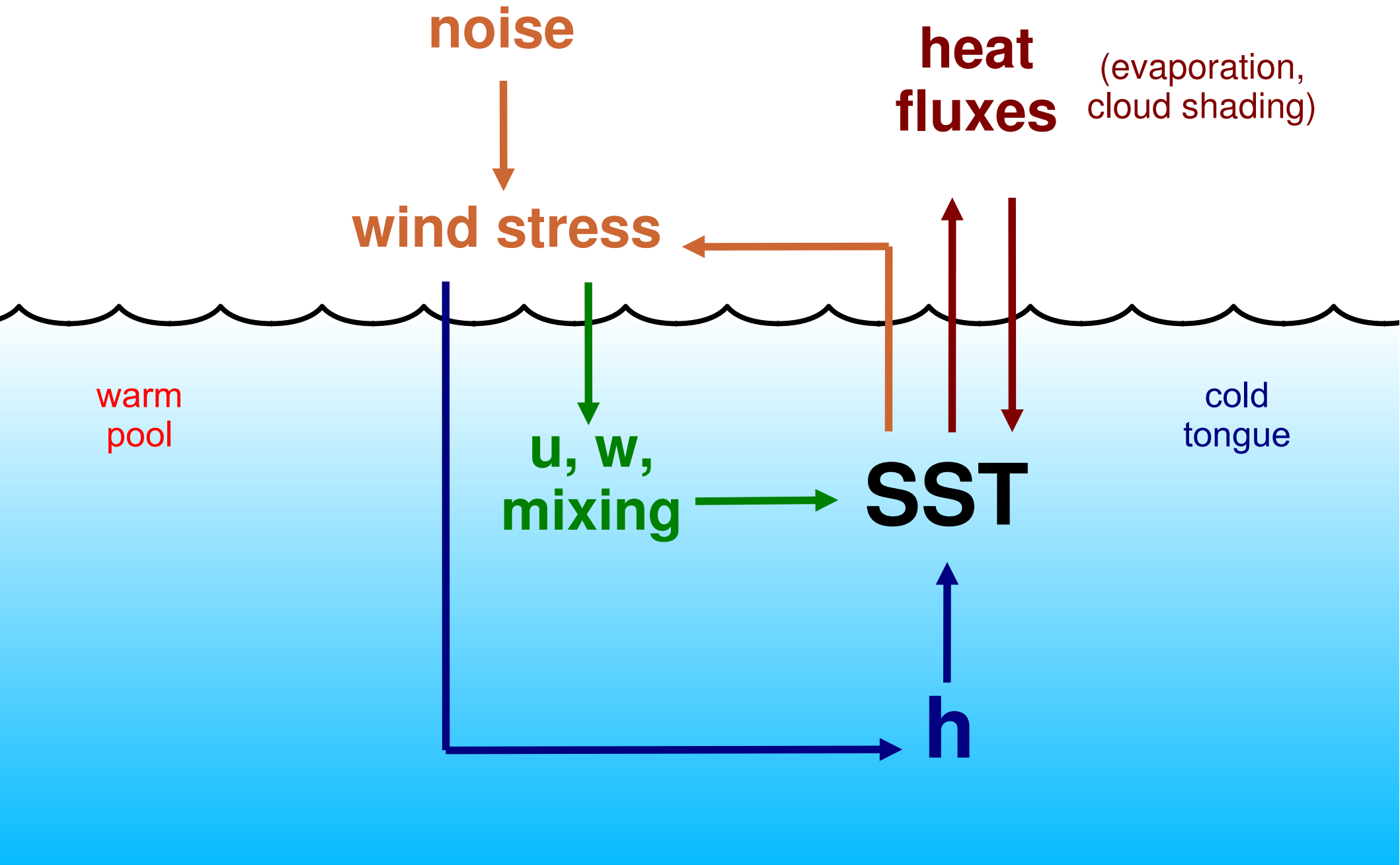
FA cuts the ENSO variance in half.
(Seems great...)

But FA doesn't improve the short ENSO period of 2.8yr (vs. 3.2yr for obs).

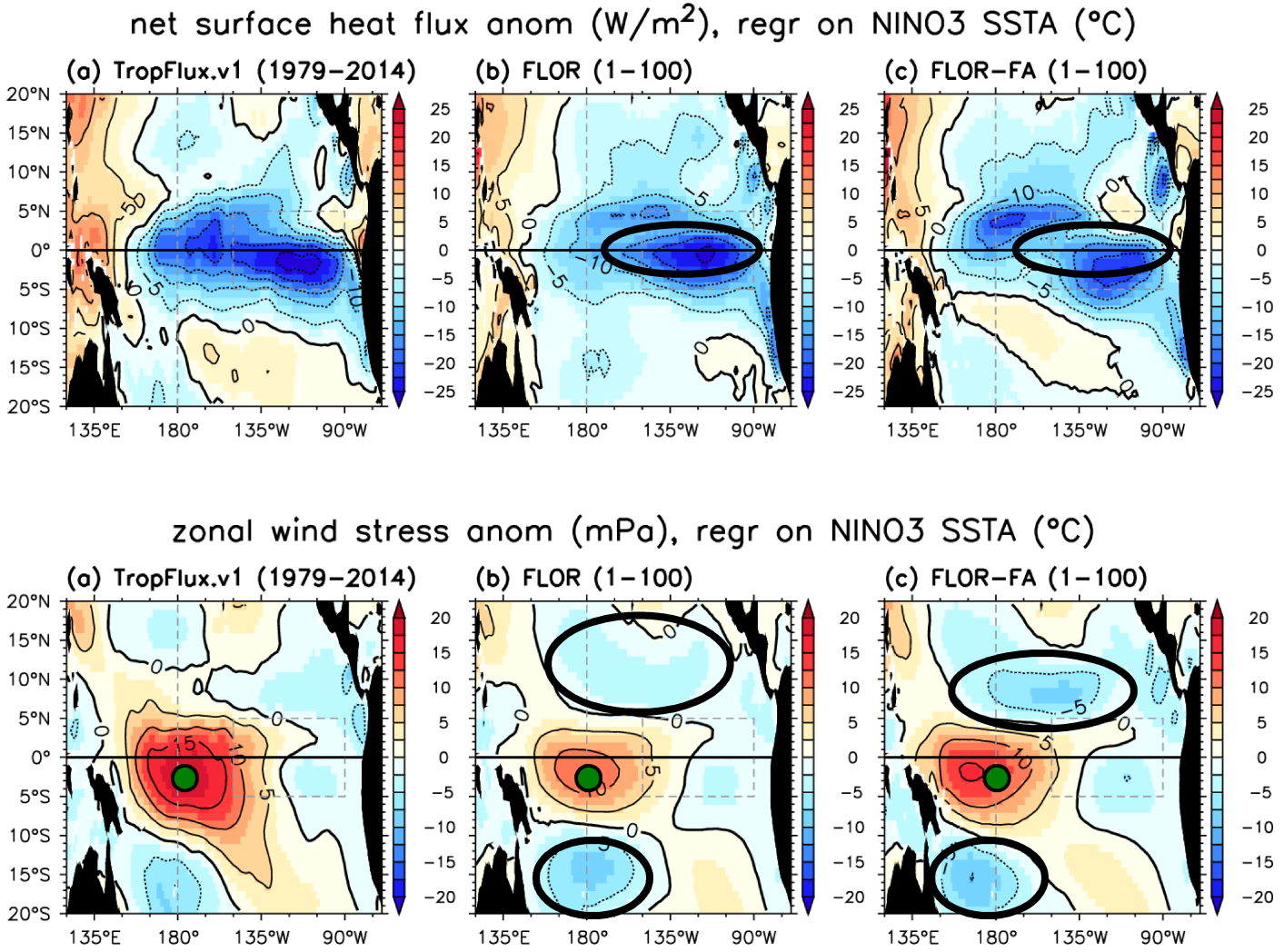
And both simulations have spectral peaks that are narrower than observed.

FLOR-FA's spectrum is still **modulated from decade to decade** -- though less than in hyperactive FLOR.

Key ENSO feedbacks



ENSO response 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 reducing mean high cloud & cloud shading response.

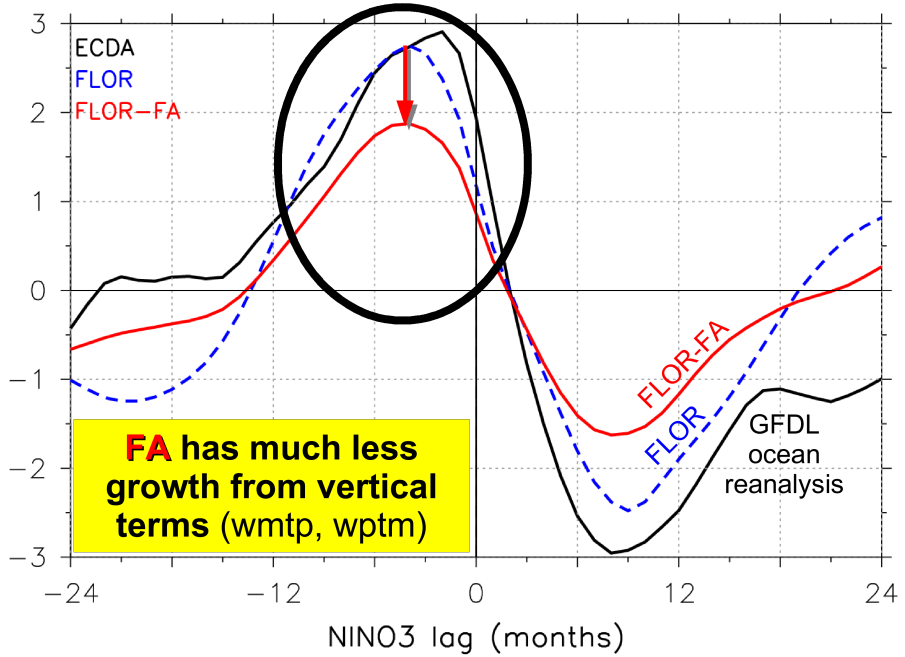
FLOR's ENSO wind stress response is meridionally narrower than obs; **excessive cyclonic curl** & Sverdrup divergence.

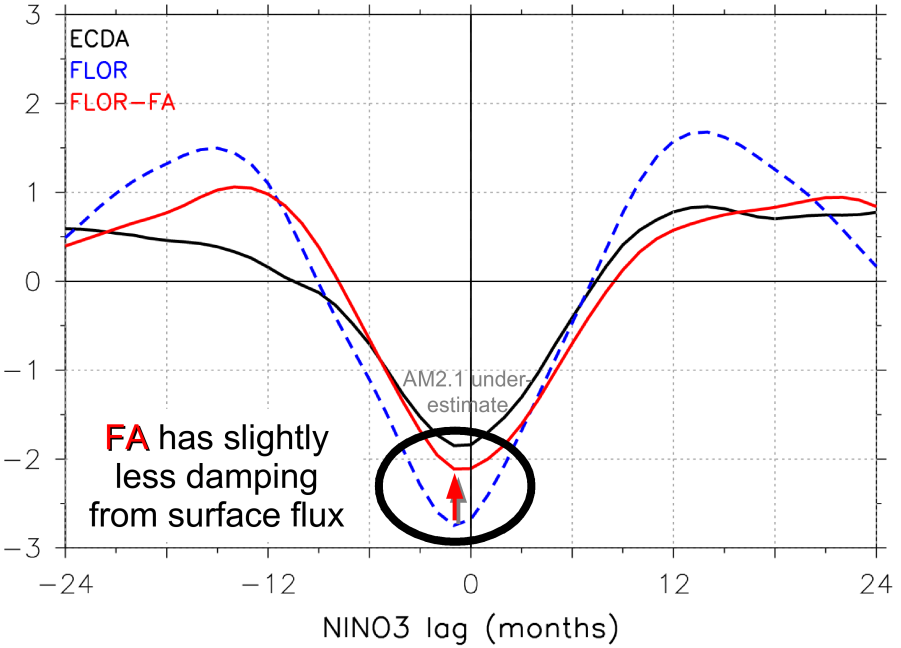
FA boosts strength & y-asymmetry of westerly anomalies, but shifts response west & doesn't improve curl.

*FA boosts equatorial wind stress coupling and weakens damping, both **opposing** 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)

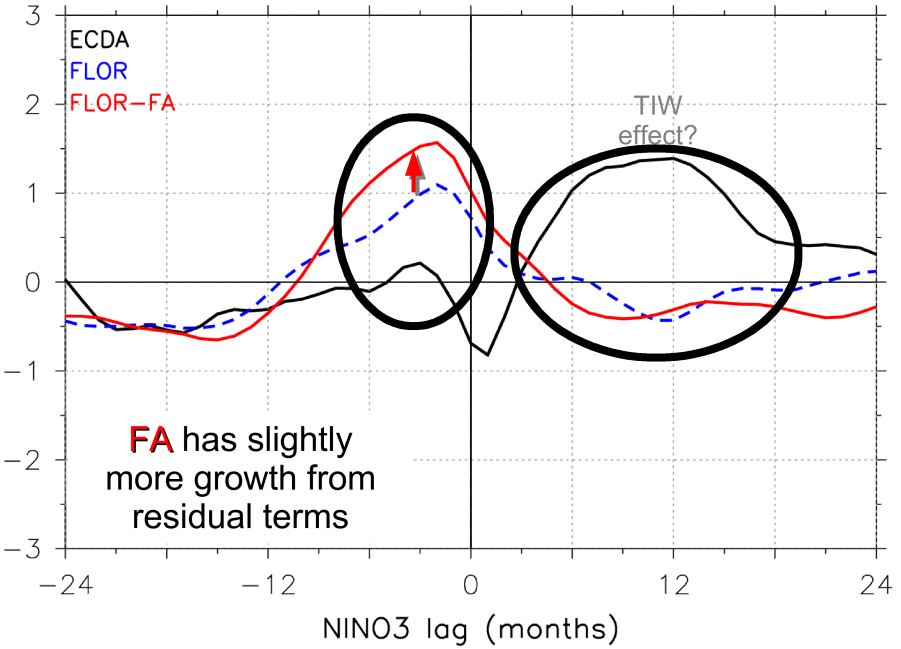




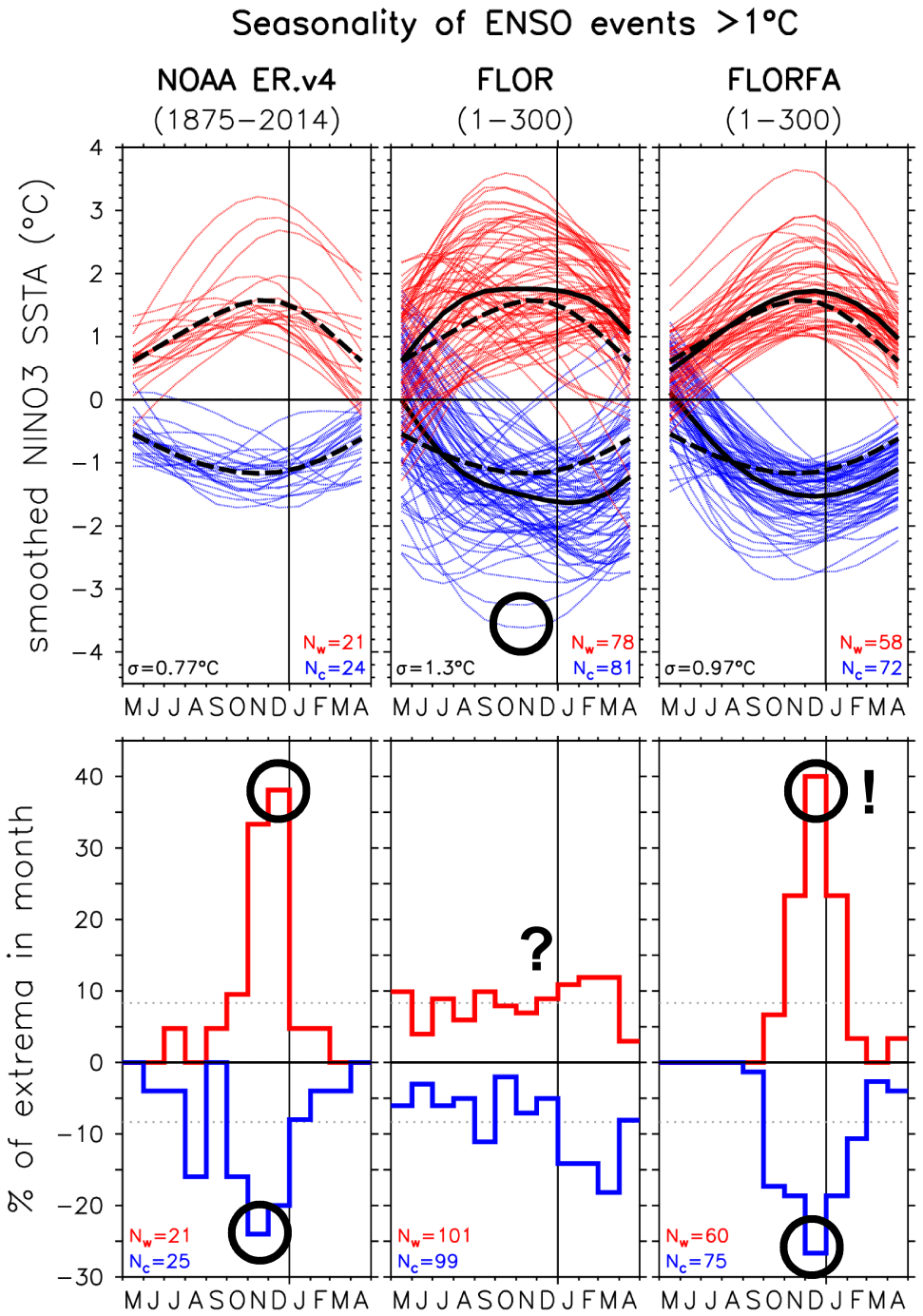
FA weakens ENSO in FLOR, because the deeper thermocline **weakens the vertical advective coupling** between the equatorial thermocline & mixed layer.

(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



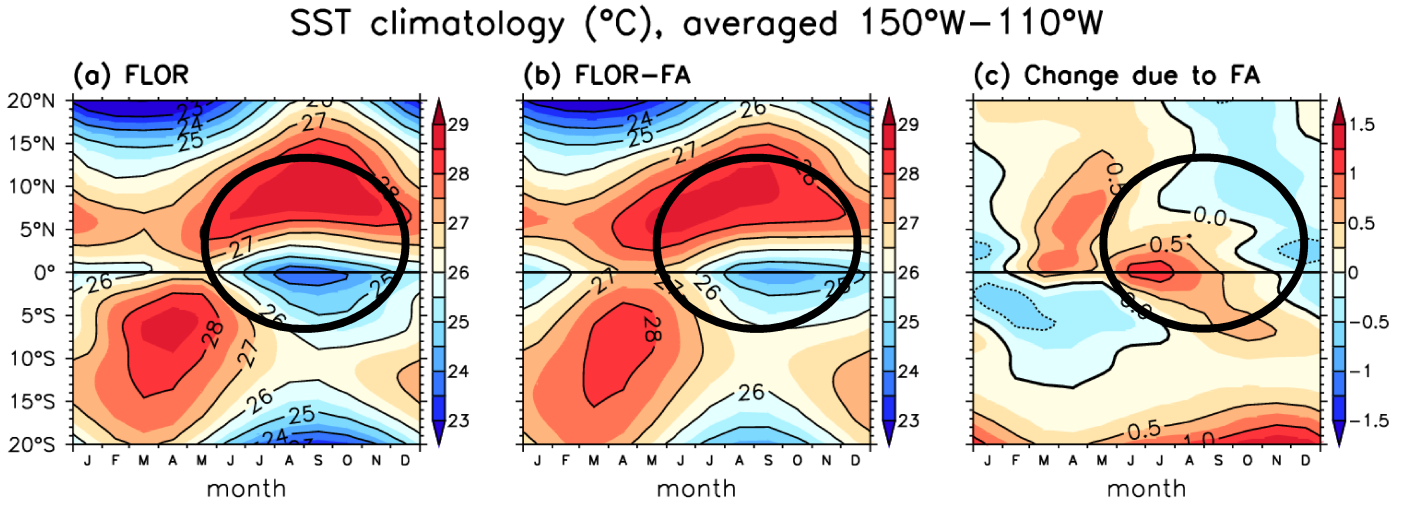
Observed events (especially strong ones) tend to peak during Oct-Dec.

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

And FLOR's cold events are far too strong.

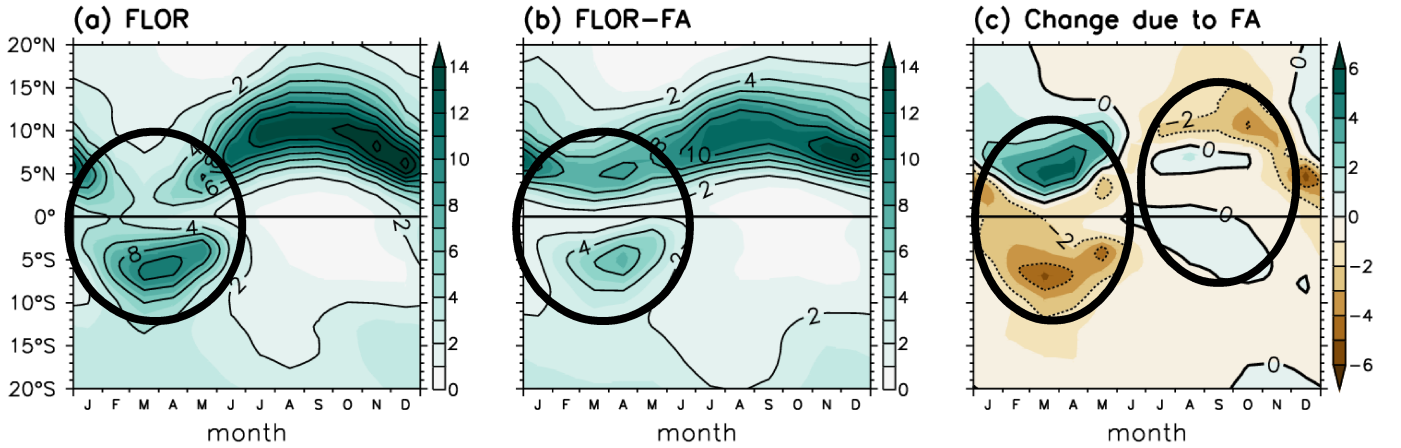
FA synchronizes ENSO events to the end of the calendar year, and slightly improves the positive skewness of NINO3 SSTAs.

East Pacific climatological SST & rainfall



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

FA weakens this dT/dy, facilitating equatorial shifts of ITCZ during ENSO growth season.



FA weakens the spurious Jan-May southern ITCZ.

During Jul-Nov, FA shifts the northern ITCZ slightly closer to the equator.

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.

No model is perfect . . .

. . . but some are useful.

Summary: ENSO in a flux-adjusted CGCM

1. FLOR global coupled GCM

a. **High-res atmosphere** → climate & ENSO forecasts improved over CM2.1
b. But ENSO too strong & frequent, not seasonally synchronized

2. FLOR with flux adjustments (FLOR-FA)

a. **Corrects climatological SST/winds**, greatly improves mean rainfall
b. **Deepens climatological thermocline along equator**
- weaker off-equatorial trade winds → less Sverdrup divergence from equator
- reveals a latent OGCM bias → motivates attention to equatorial mixing & solar penetration

3. FA impacts on ENSO in FLOR

a. **ENSO weakens**
- *despite* weaker SSTA→flux damping and stronger SSTA→wind coupling
- trumped by deeper mean thermocline, weaker h'→Te' coupling
- weaker thermocline feedback → more westward propagation of SSTAs
- less interdecadal modulation of ENSO

b. **ENSO period doesn't change**
- off-equatorial anomalous cyclonic curl still too strong → excessive Sverdrup feedback

c. **Atmospheric responses/teleconnections shift westward**
- drier central equatorial Pacific + weaker ENSO → harder to shift convection eastward

d. **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

Next steps

1. Improve AGCM climatology & ENSO feedbacks

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

2. Improve OGCM climatology & ENSO feedbacks

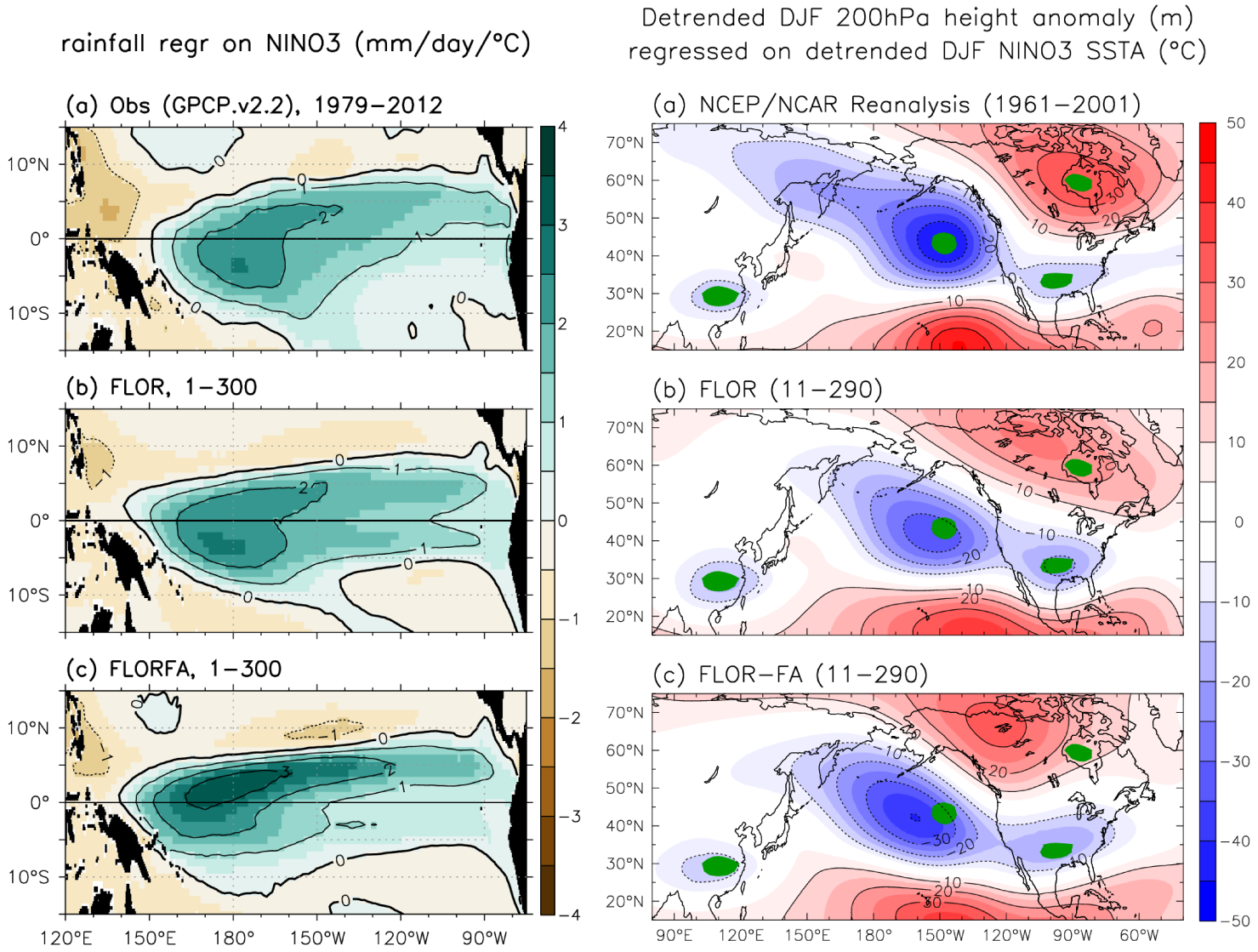
a. **Shoal the equatorial thermocline** (mixing, solar penetration, diurnal cycle)
b. **Resolve TIWs** (critical during La Niña)
c. **Mixed layer heat budget** (need obs constraints!)

3. Improve coupled interactions

a. **Seasonal dT/dy** in east Pacific (ENSO seasonality)
b. **Coupled feedback** diagnostics (need obs constraints!)
c. **Subsurface flux adjustments** (3D-FA)

Reserve Slides

ENSO teleconnections



FLOR has a nice precip response; slightly southwest of obs.

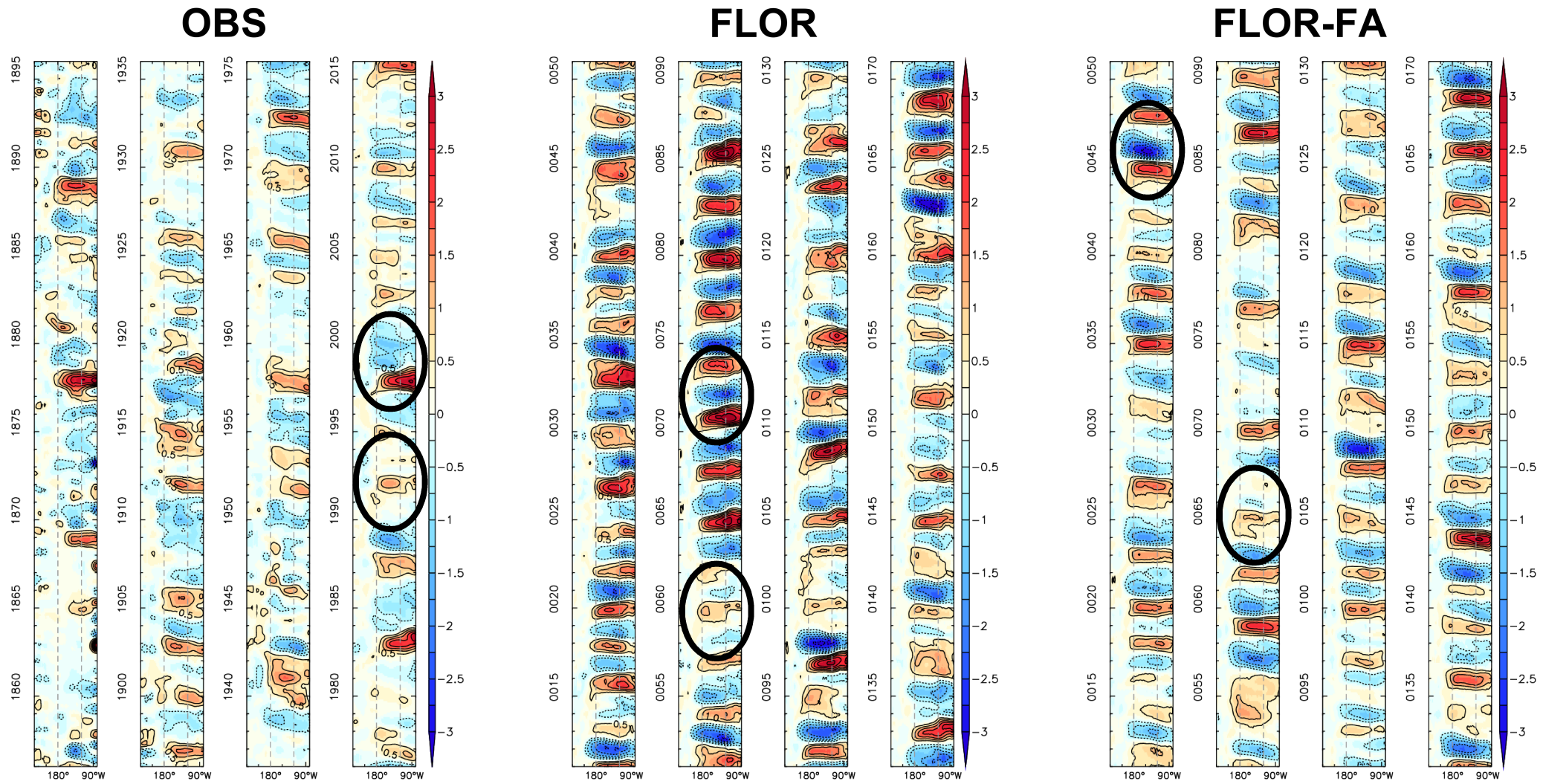
FLOR's teleconnections are also good, but weak in places, and some centers of action are west of obs.

FA boosts the sensitivity to equatorial SSTAs, for both tropical Pacific rainfall and the remote teleconnections.

But FA also shifts the rain response & teleconnections west.

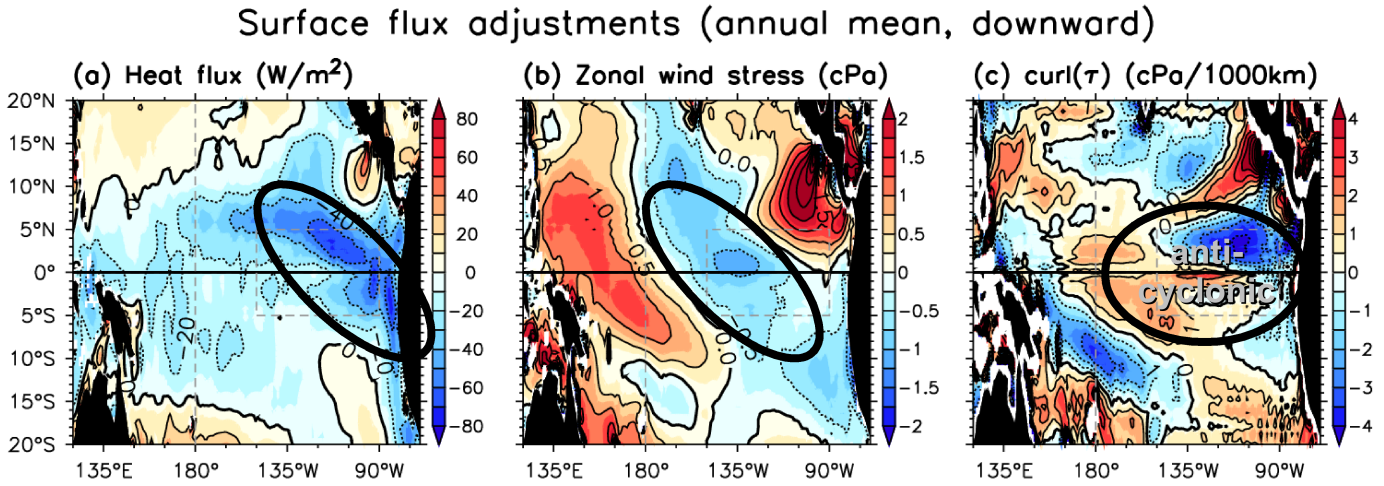
FA improves some teleconnections, but degrades others. Stronger cold tongue / warm pool contrast may inhibit the eastward/equatorward shift of rainfall during El Niño.

Equatorial Pacific SSTAs (°C, 160yr)



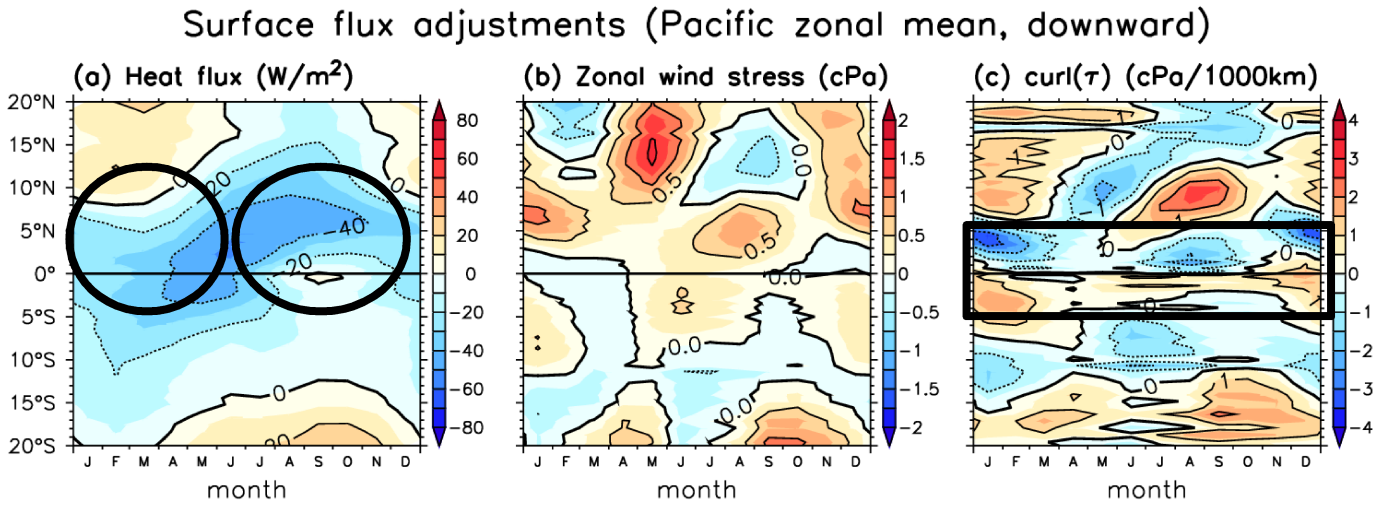
SSTA amplitude, pattern, and propagation vary from decade to decade in obs & simulations.
FLOR SSTAs are too strong, frequent, and eastward-propagating, especially for cold events.
FA leads to a weaker ENSO, with more westward propagation.

Climatological flux adjustments in FLOR-FA



FA cools the tropical Pacific, especially north of equator & near South America.

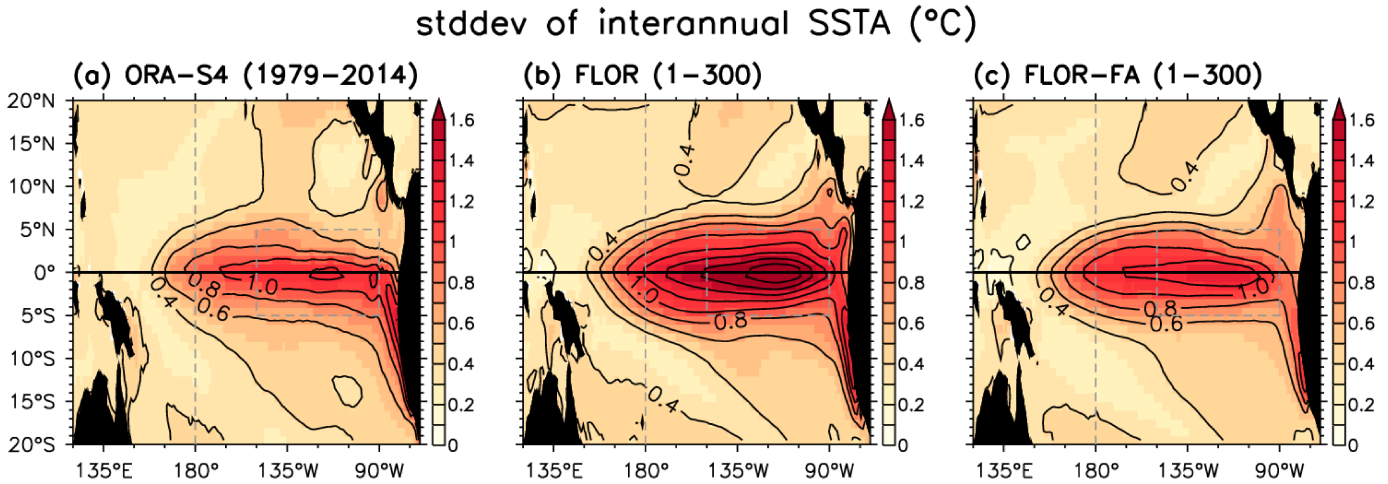
FA shifts easterlies eastward, and weakens the cyclonic curl & Sverdrup divergence in the equatorial band.

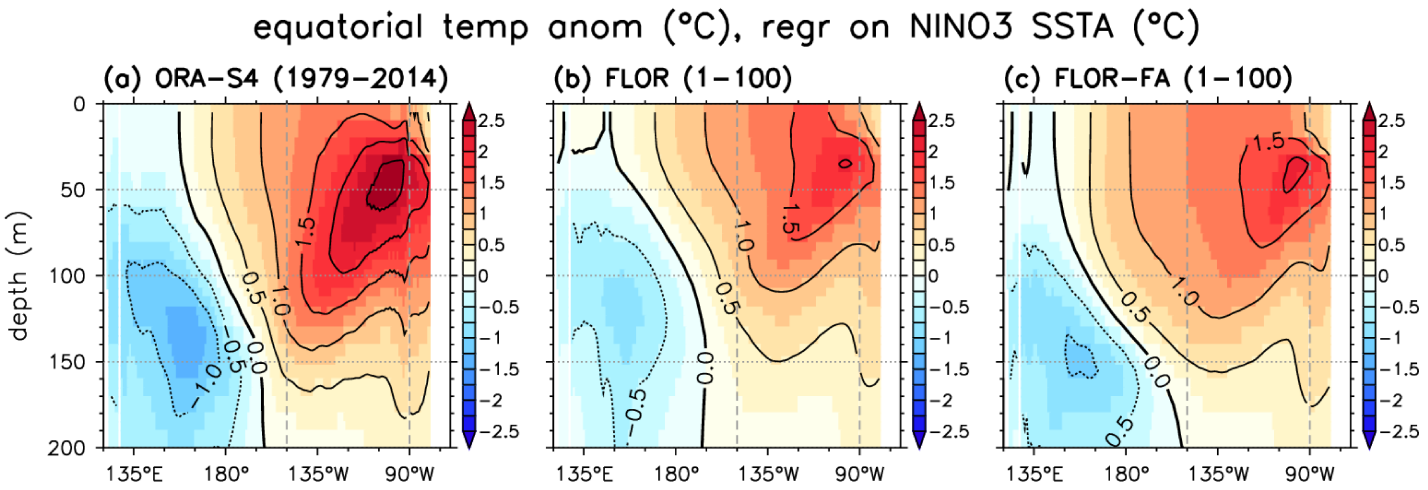


The SST gradient (dT/dy) between equator & ITCZ is weakened Jul-Nov, but strengthened Jan-May, due to the FA heat flux.

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

ENSO variability of SST and equatorial temperature





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