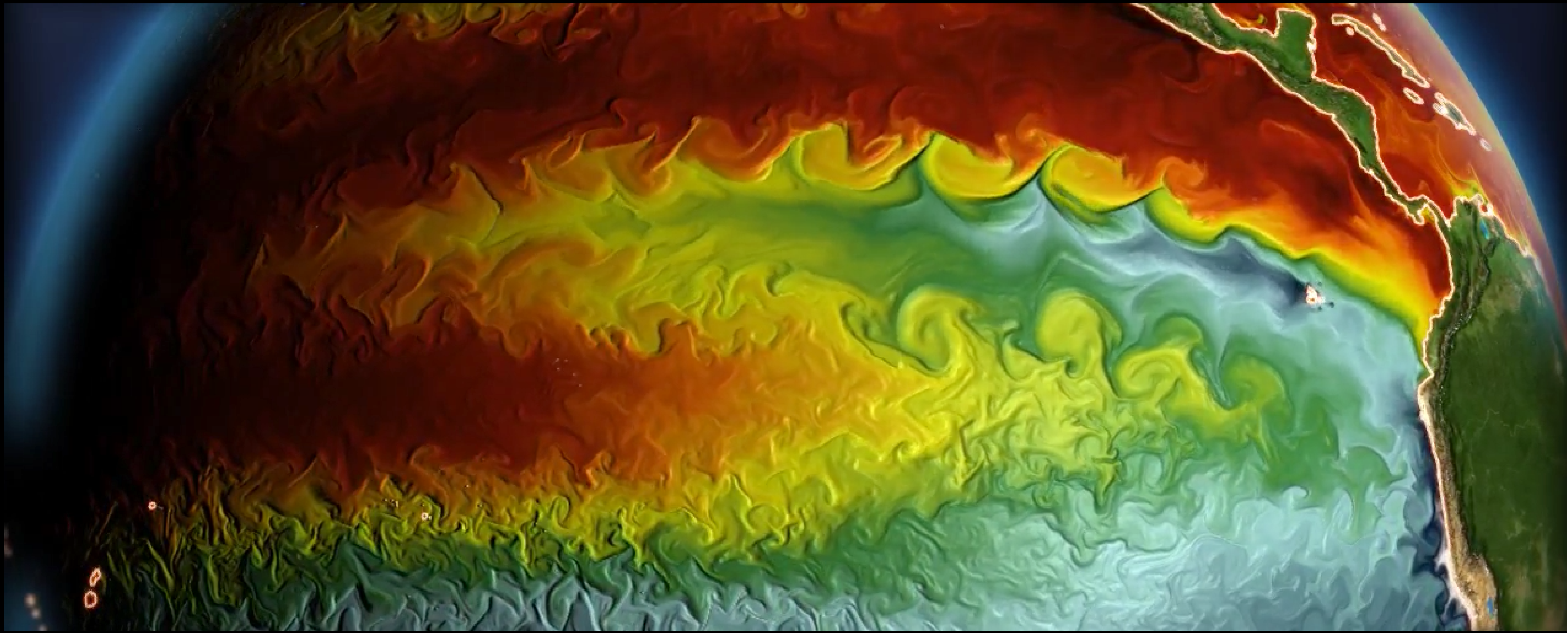
ENSO in GFDL's Next-Generation Global Models



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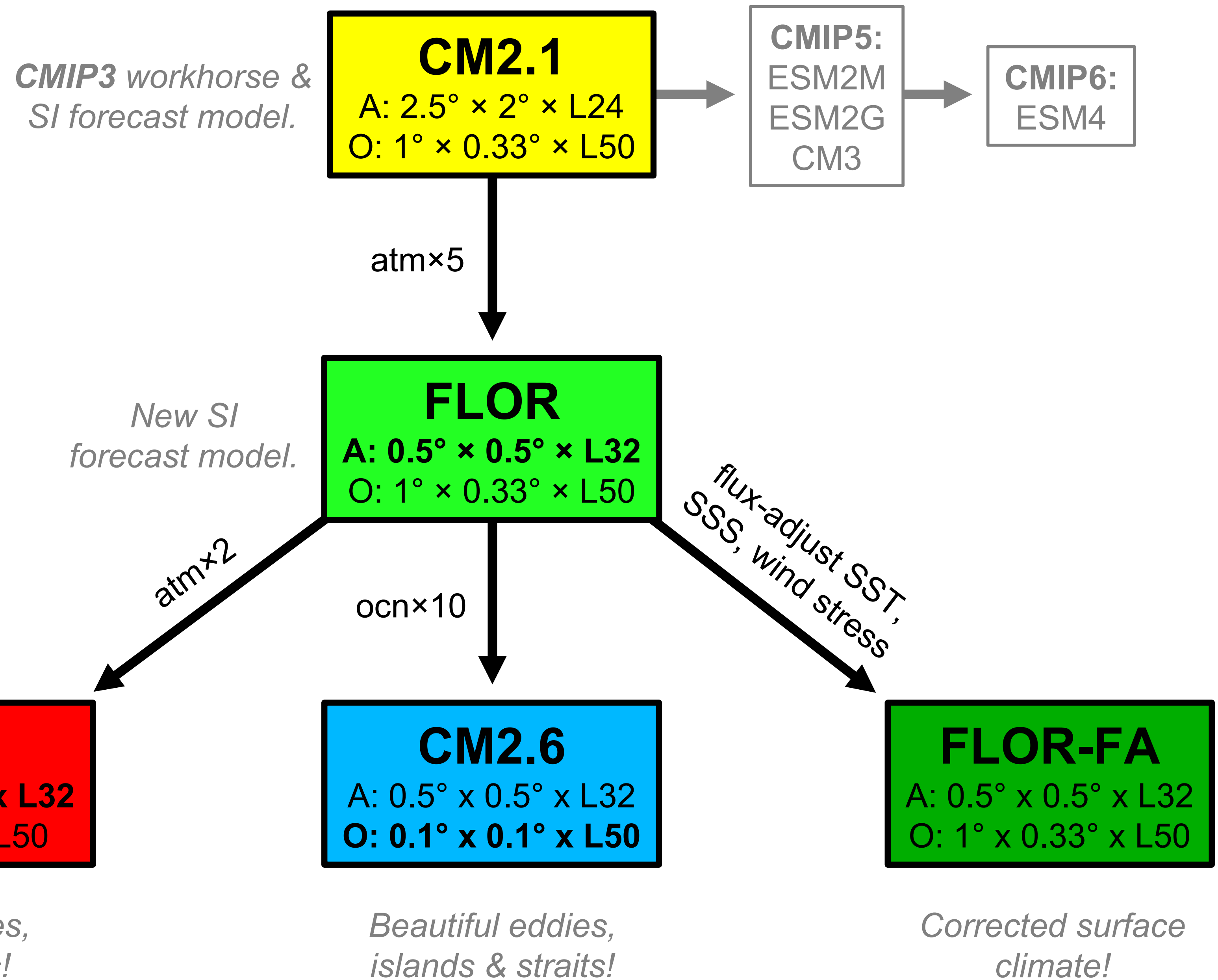
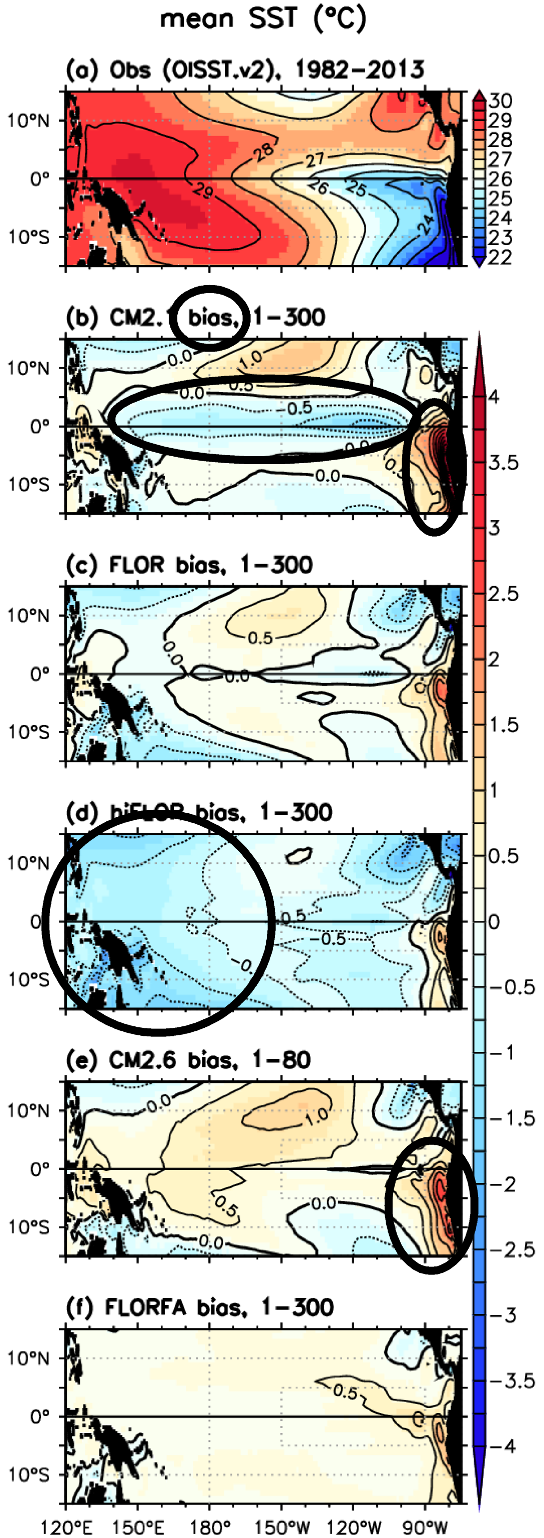
with G. Vecchi, T. Delworth, A. Rosati, W. Anderson, K. Dixon, F. Zeng, S. Underwood

GFDL's high-res model development path



Annual mean climate:
SST & rainfall



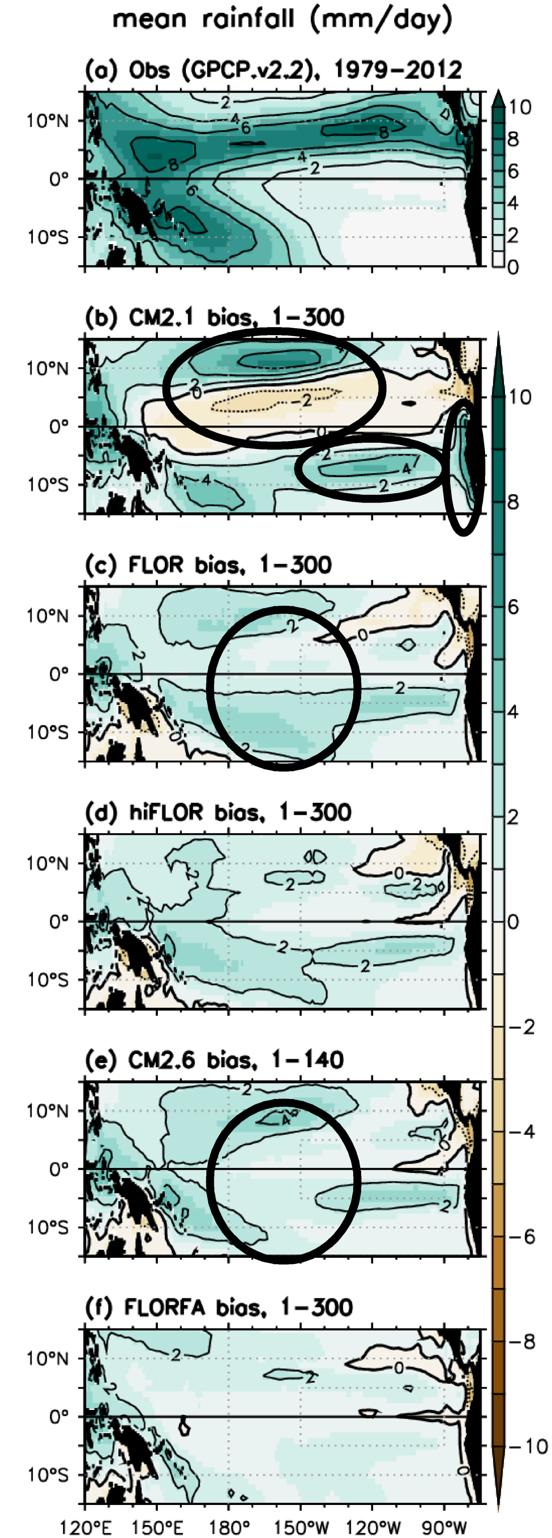
CM2.1 had equatorial cold/dry bias, seasonally-alternating ITCZ, and warm/wet bias along South America.

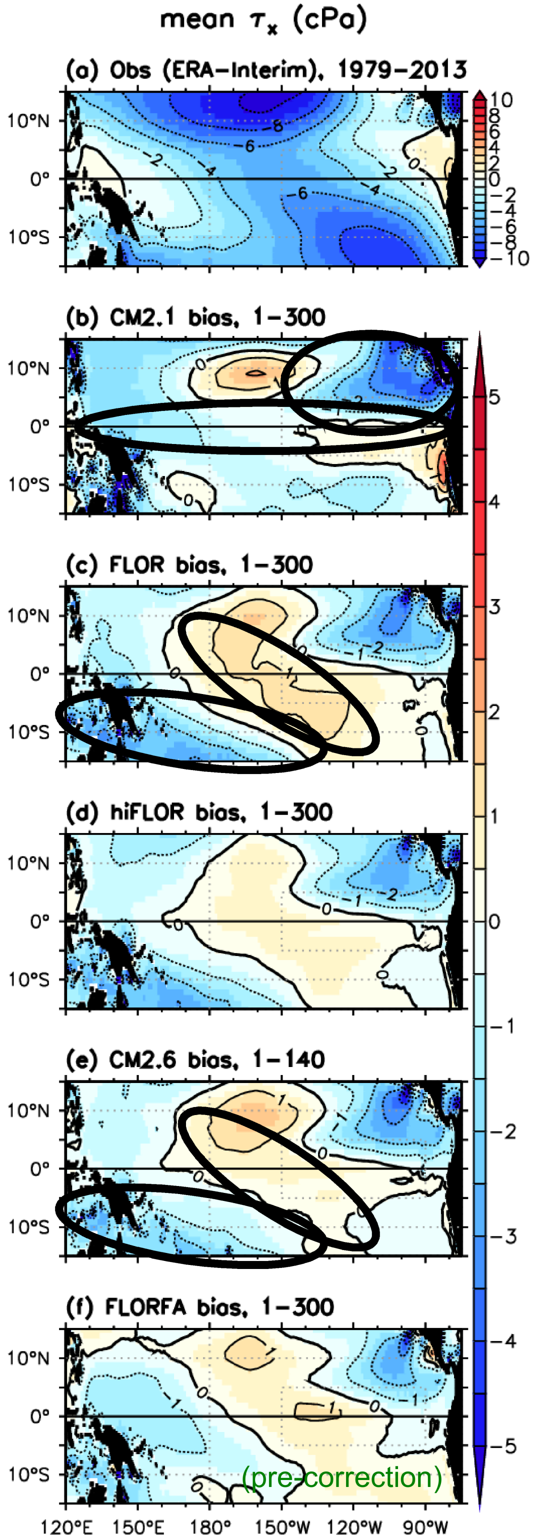
Atmospheric refinement (**FLOR**) **greatly improves the simulation.** Strengthens evap damping of SSTAs.

Further atmospheric refinement (**hiFLOR**) yields a few improvements, but warrants radiative re-tuning. Even stronger evap/cloud damping of SSTAs.

Oceanic refinement (**CM2.6**) slightly improves y-asymmetry, but brings back the coastal warm SST bias.

As intended, flux adjustment (**FLOR-FA**) corrects the the surface climatology.





Annual mean climate:

τ_x & equatorial ocean dT/dz

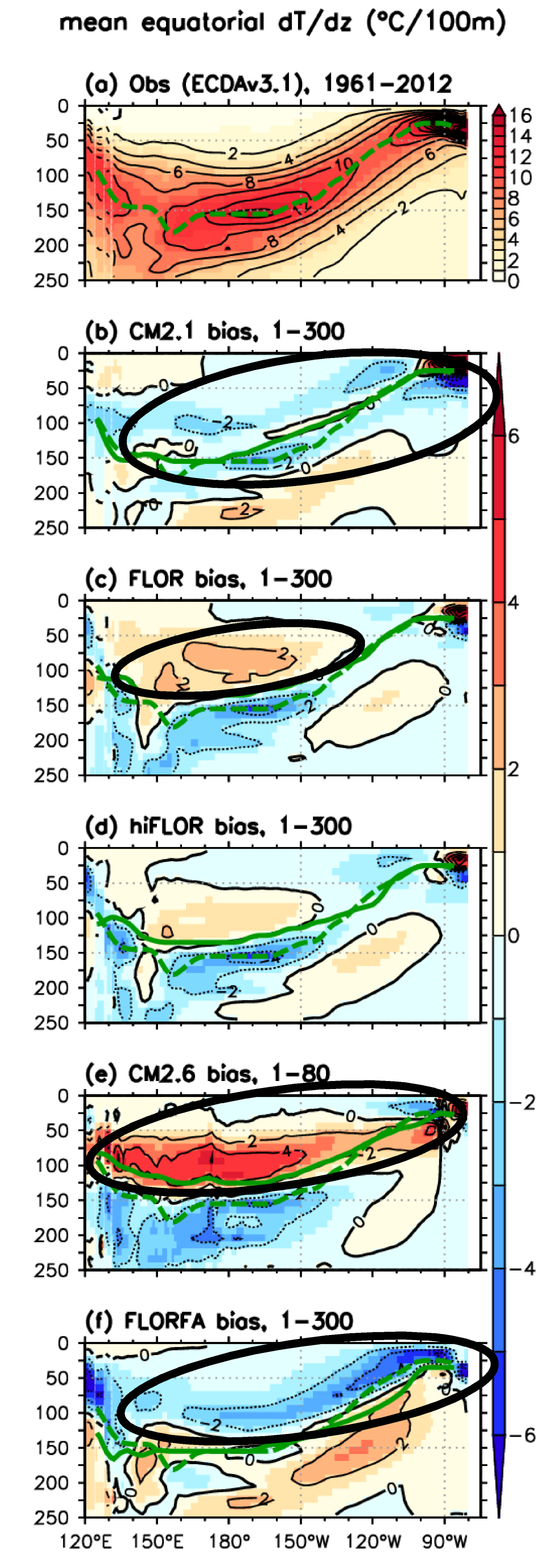
CM2.1: west-shifted equatorial trades, cyclonic curl in NE. Diffuse thermocline, but strong dT/dz along South America.

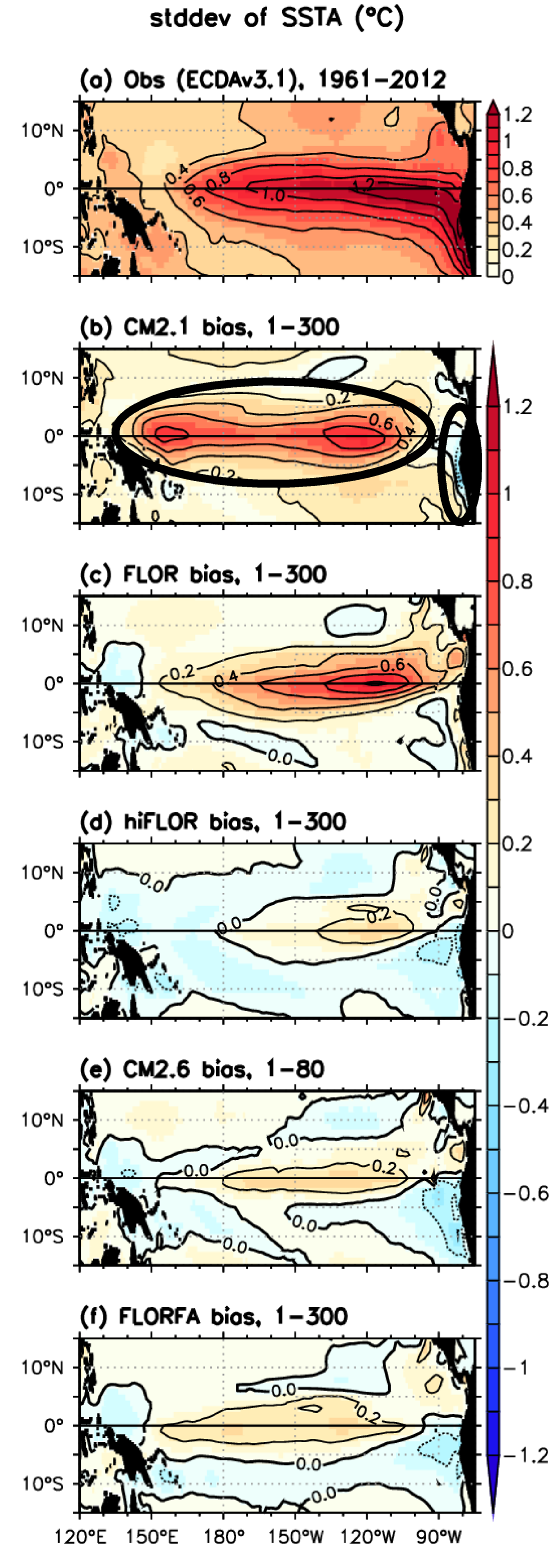
Atmos refinement (FLOR) weakens equatorial trades & NE curl; boosts SW curl & boosts dT/dz in central Pacific.

Further atmos refinement (hiFLOR) improves the simulation; weaker dT/dz.

Oceanic refinement (CM2.6) improves winds, but overly intensifies dT/dz. Vertical mixing needs attention.

Flux adjustment (FLOR-FA) deepens thermocline, degrades (weakens) dT/dz.





ENSO temperature anomalies:

Stddev at surface & equator

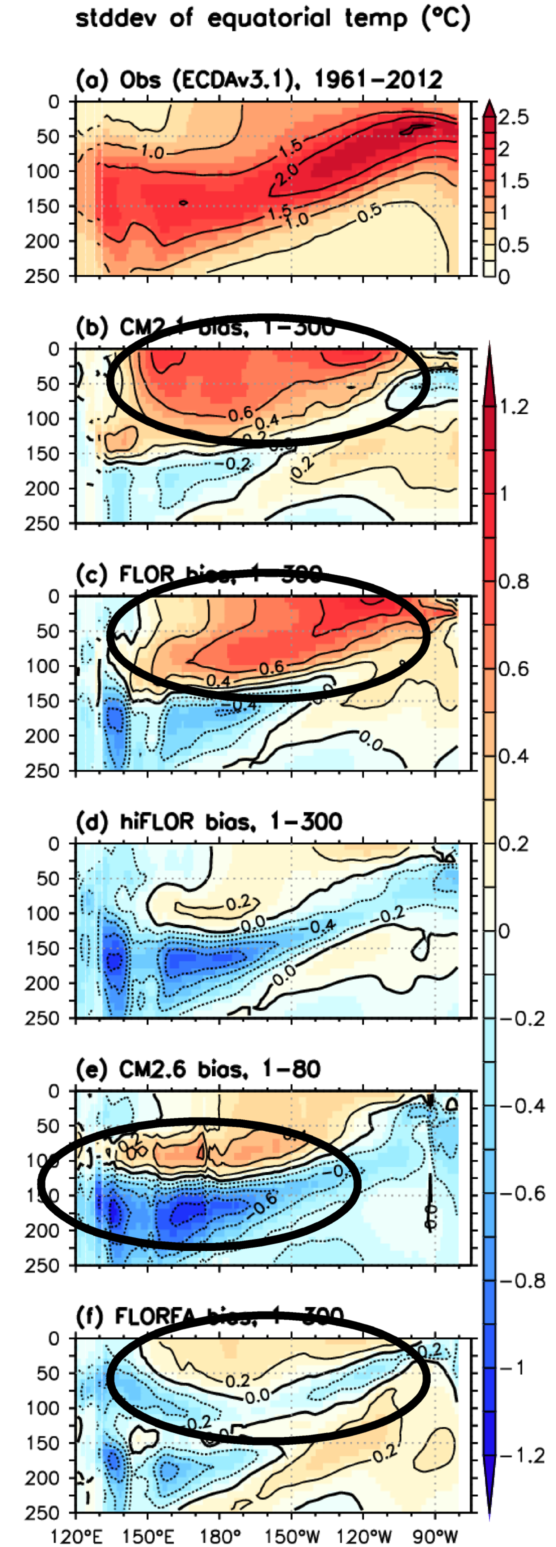
CM2.1: ENSO too strong & surface-intensified in west/central Pacific; too weak along South America.

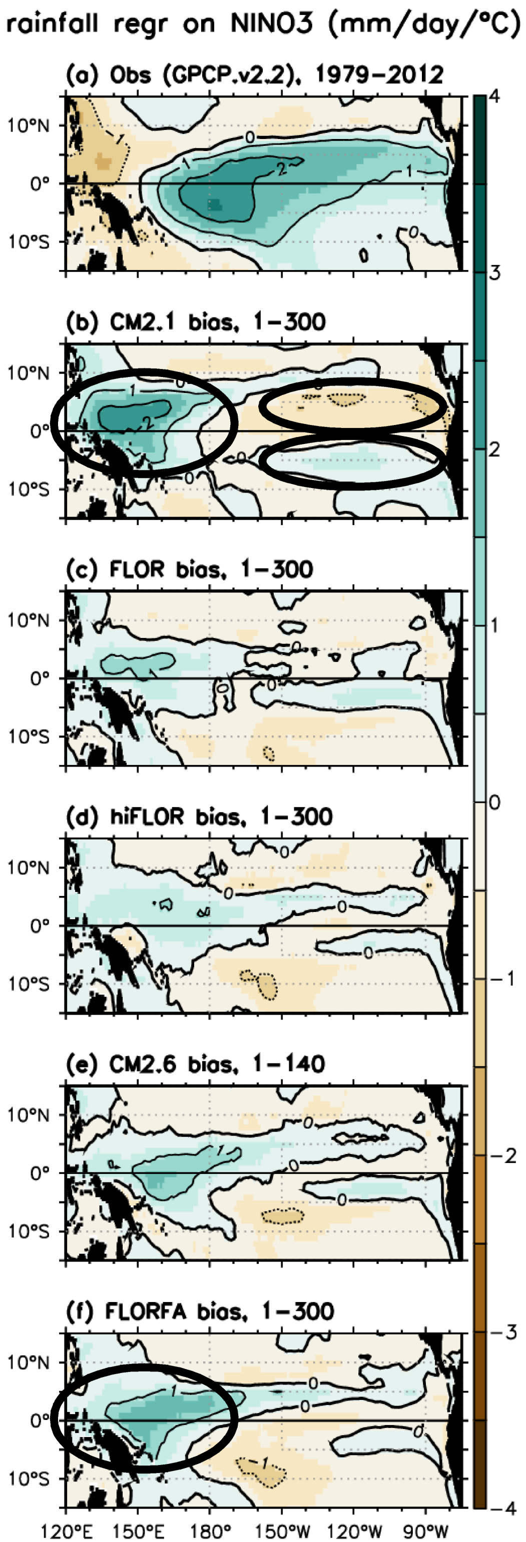
Atmos refinement (FLOR) reduces both biases. ENSO still too strong at surface; too weak in WEqPac subsurface.

Further atmos refinement (hiFLOR) **greatly improves surface simulation;** slightly degrades subsurface.

Oceanic refinement (CM2.6) likewise shifts biases from surface to subsurface.

Flux adjustment (FLOR-FA) also improves the ENSO simulation, especially subsurface.





ENSO anomaly patterns:

Rainfall and τ_x

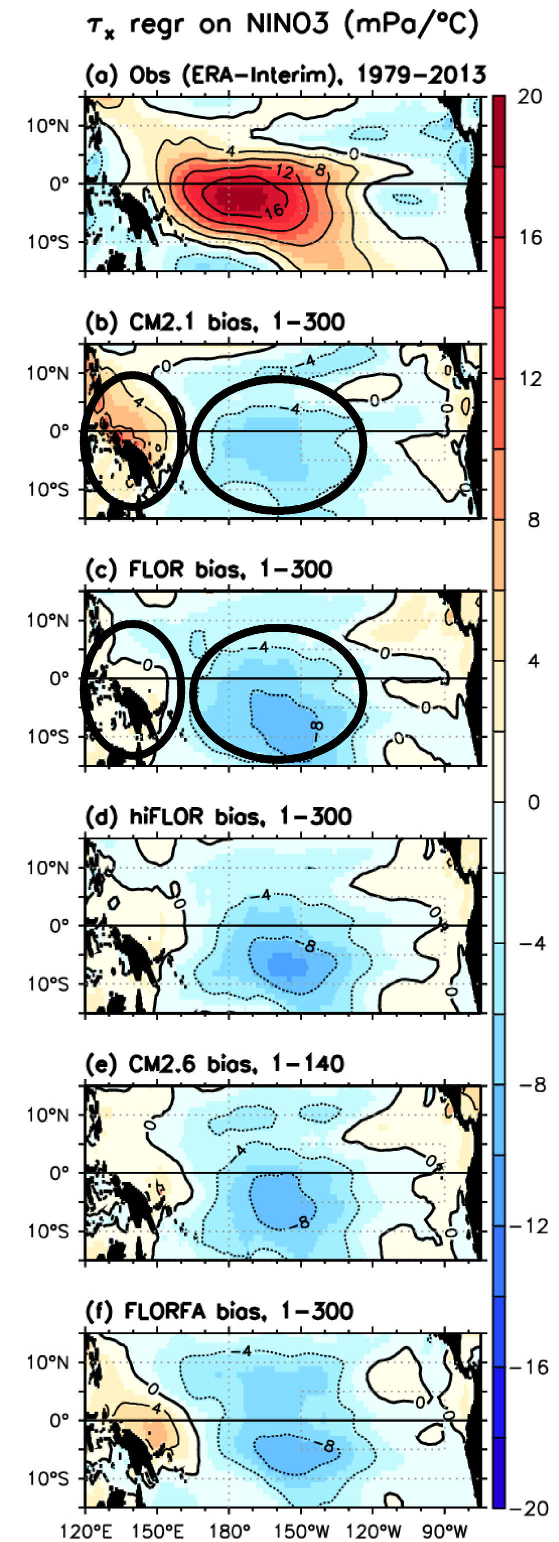
CM2.1: too little rain moves east, and what does is south of equator. Westerly wind anomalies are too far west, too weak, too narrow.

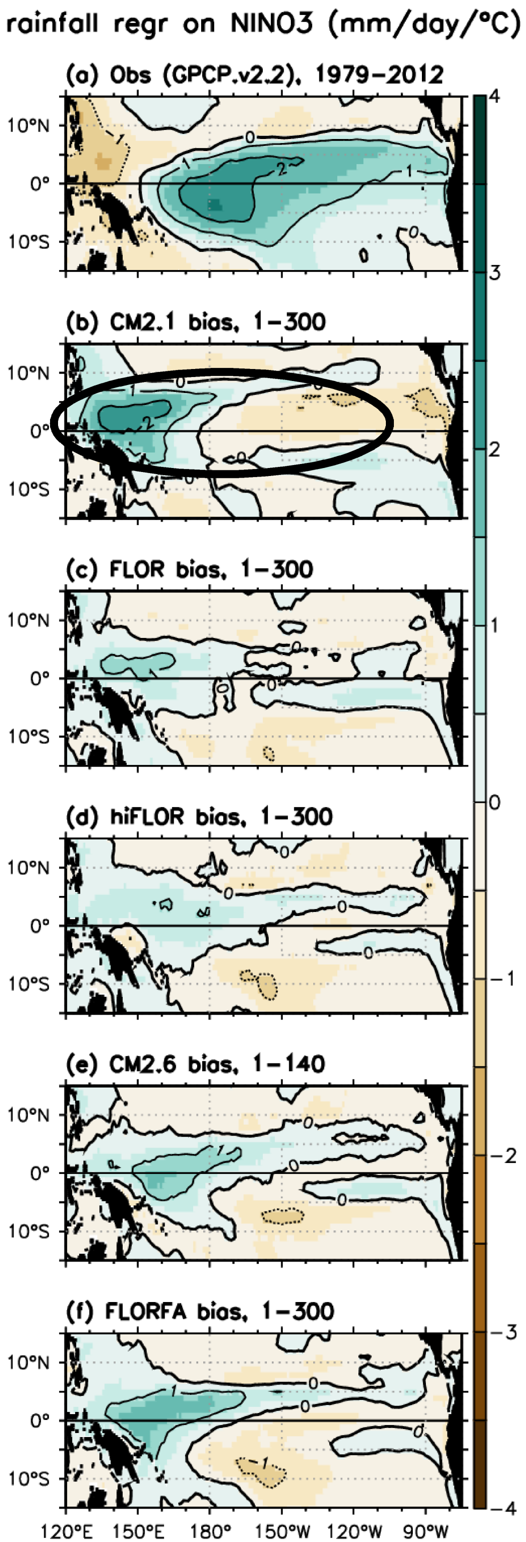
Atmos refinement (**FLOR**) **greatly improves rainfall anomalies**, but westerlies narrow further.

Further atmos refinement (**hiFLOR**) yields similar improvements.

Oceanic refinement (**CM2.6**) also improves the simulation, but less than atmos refinement.

Flux adjustment (**FLOR-FA**) aids the east, degrades the west.





ENSO teleconnections:

PNA response for DJF

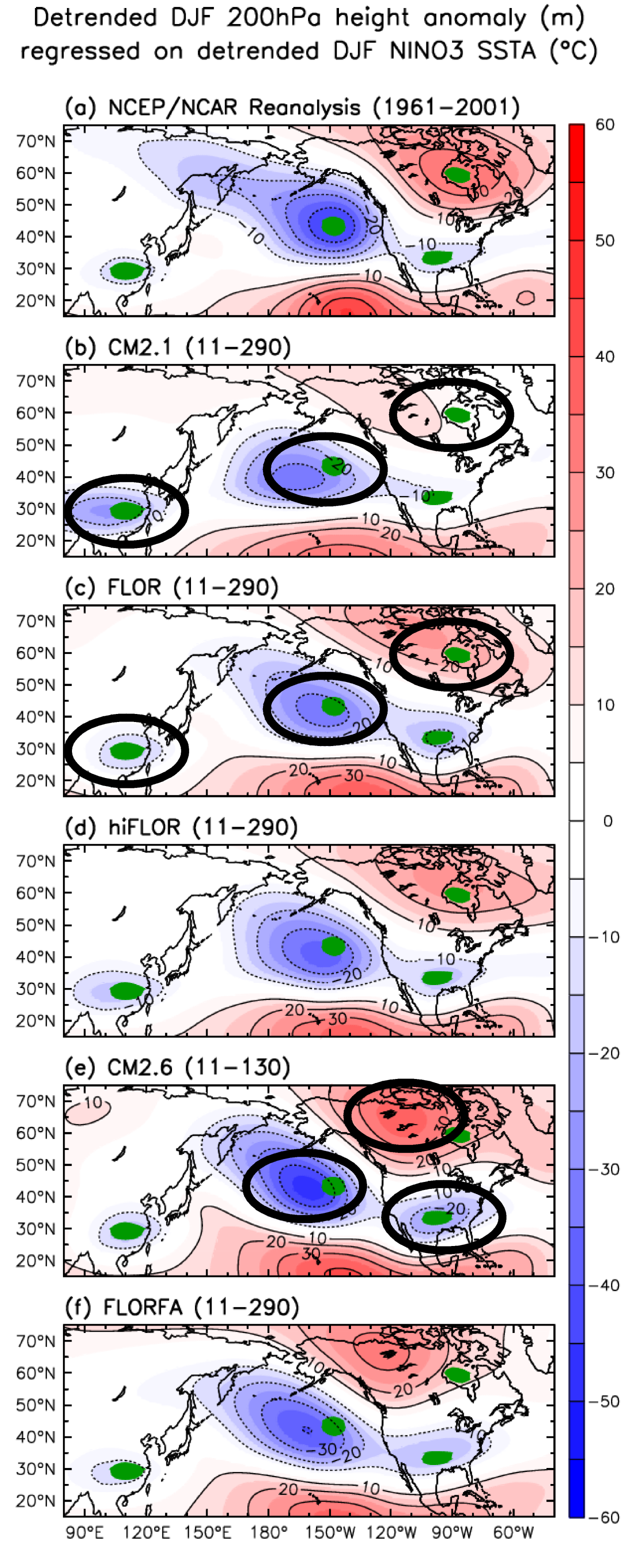
CM2.1: remote sensitivity is too weak and shifted west of obs, reflecting the biases in anomalous convective heating at the equator.

Atmos refinement (**FLOR**) improves the **alignment** of the remote response.

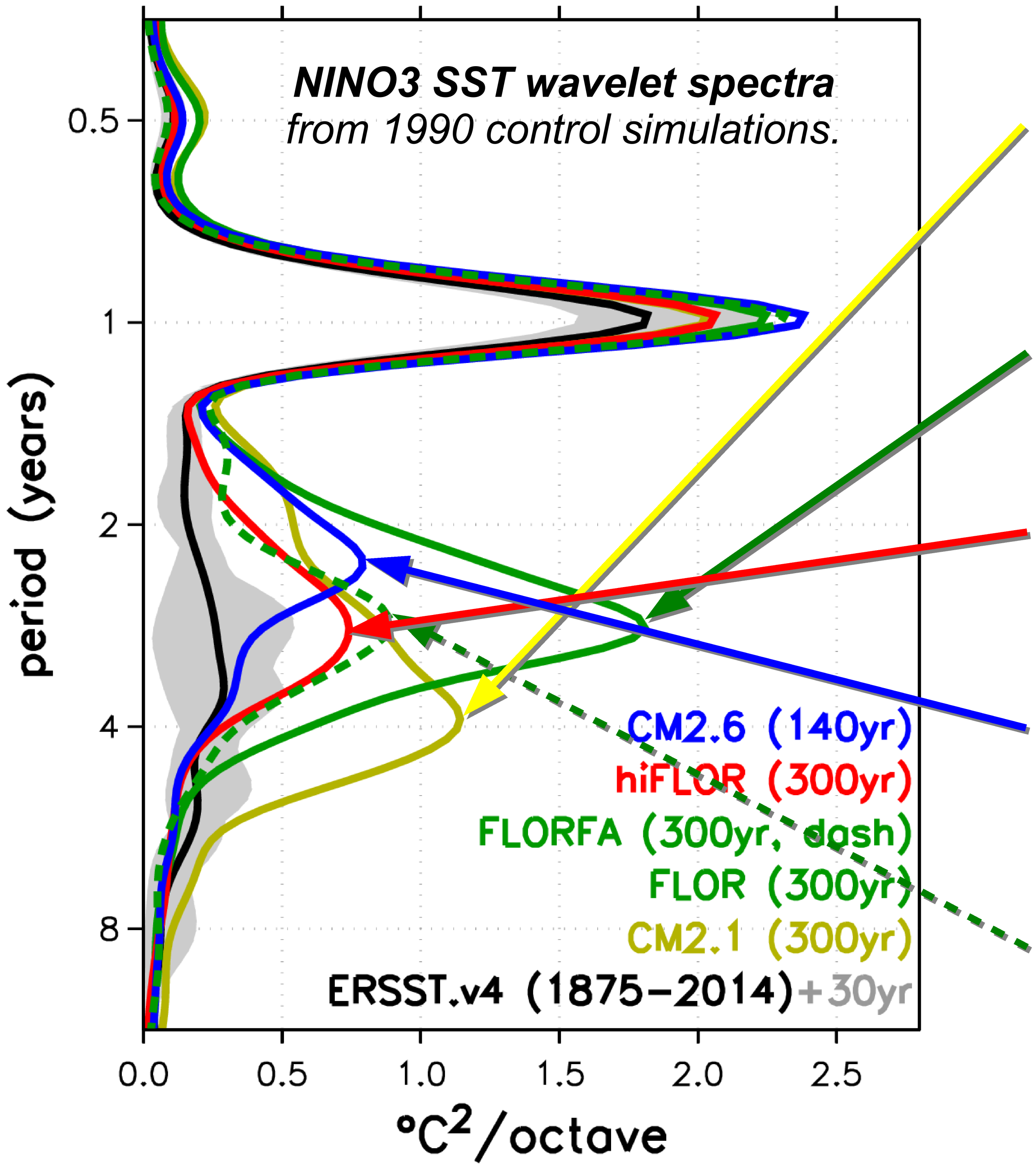
Further atmos refinement (**hiFLOR**) yields further improvements.

Oceanic refinement (**CM2.6**) **amplifies** the PNA response.

Flux adjustment (**FLOR-FA**) aids strength, degrades alignment of PNA.



ENSO amplitude & period



CM2.1 ENSO was too strong, but time scale looked good.

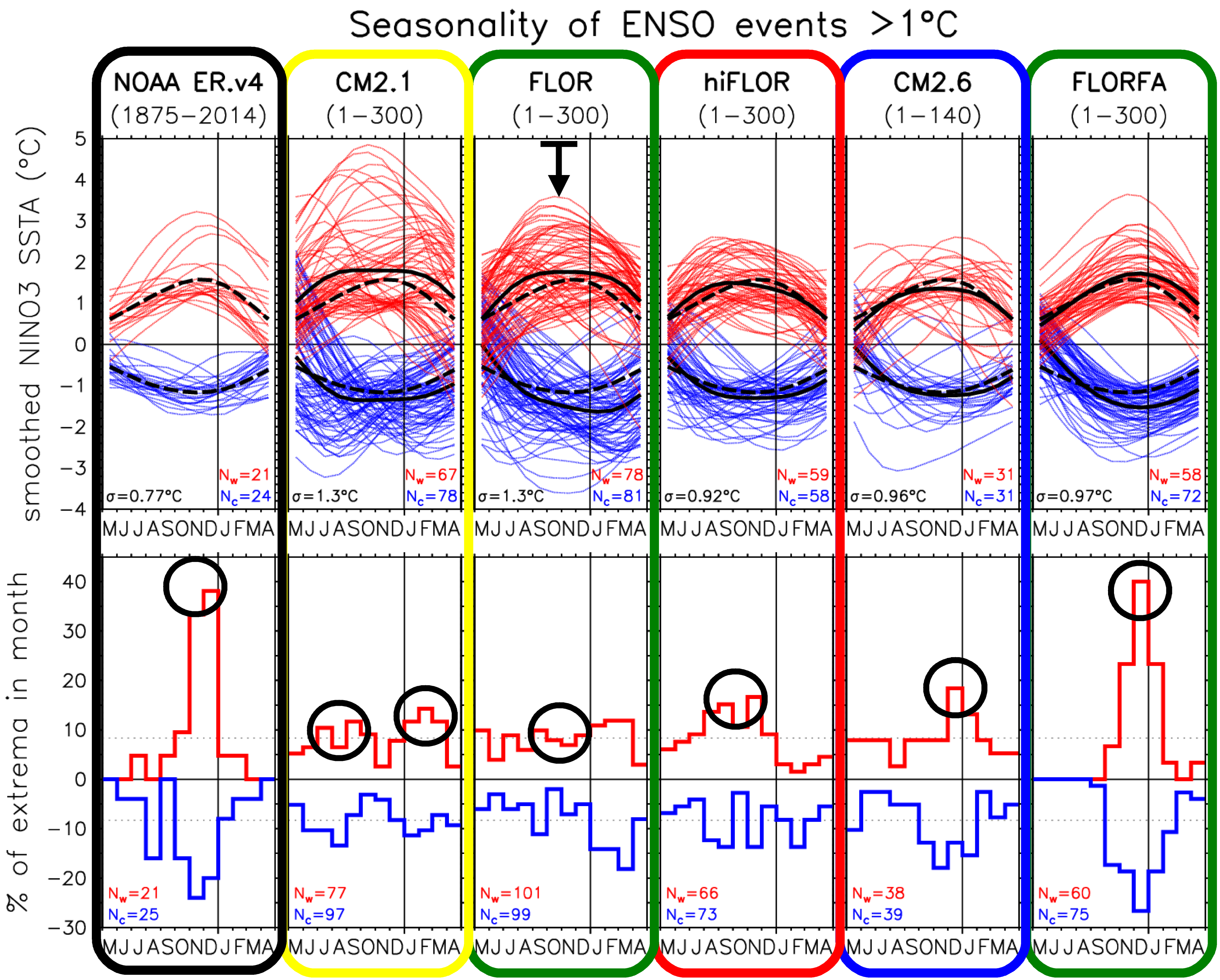
FLOR's atmos refinement shortens period, narrows spectrum.

HiFLOR's atmos refinement weakens ENSO.

CM2.6's oceanic refinement weakens ENSO, shortens period.

Surface flux adjustment weakens ENSO.

Seasonality & diversity of ENSO events



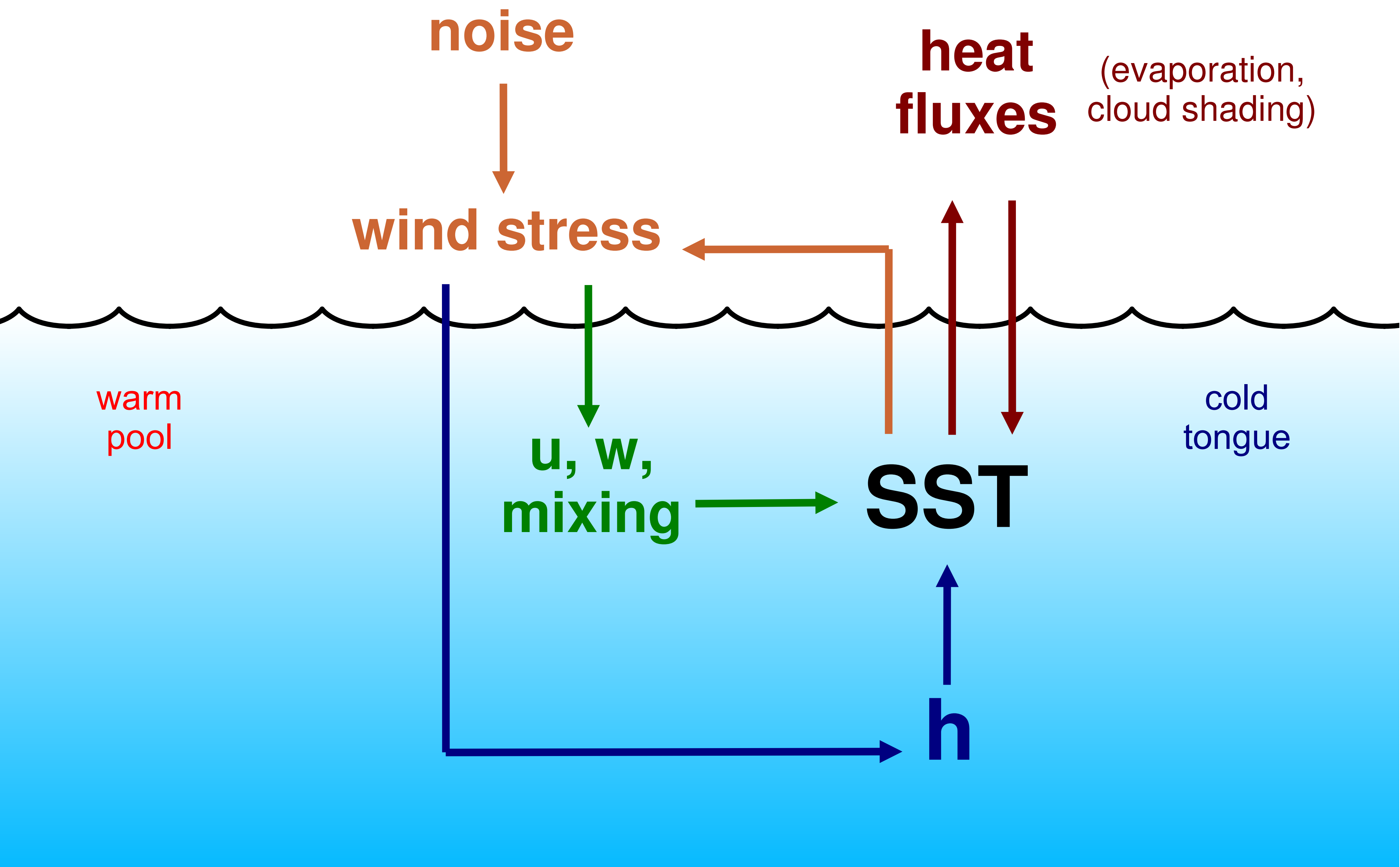
Obs events peak in Nov/Dec.

CM2.1 was *semiannually* synchronized!

Atmos/ocean refinement *slightly* improves seasonality, but weakens skewness.

Flux adjustment nails the seasonality, due to improved SST/rain/wind, climatologies.

Key ENSO feedbacks



ENSO heat budget

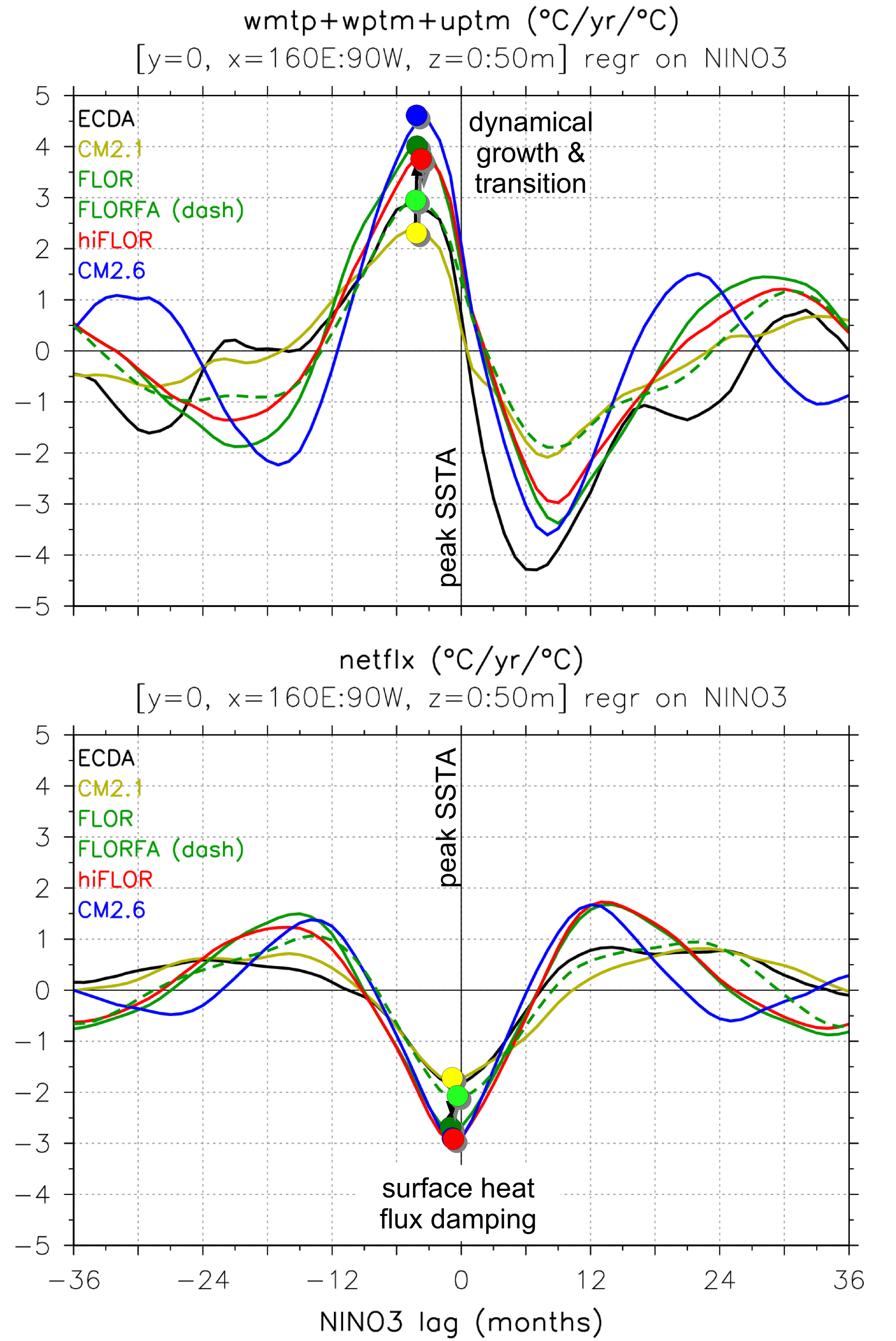
SSTAs are generated & transitioned by **dT'/dz, w', u'**; damped by **surface fluxes**.

Relative to CM2.1, atmos refinement (**FLOR**) boosts the damping, but boosts vertical & horiz dynamics even more. → Faster ENSO, farther east.

Further atmos refinement (**hiFLOR**) further boosts the damping, and slightly weakens vertical dynamics. → Weaker ENSO.

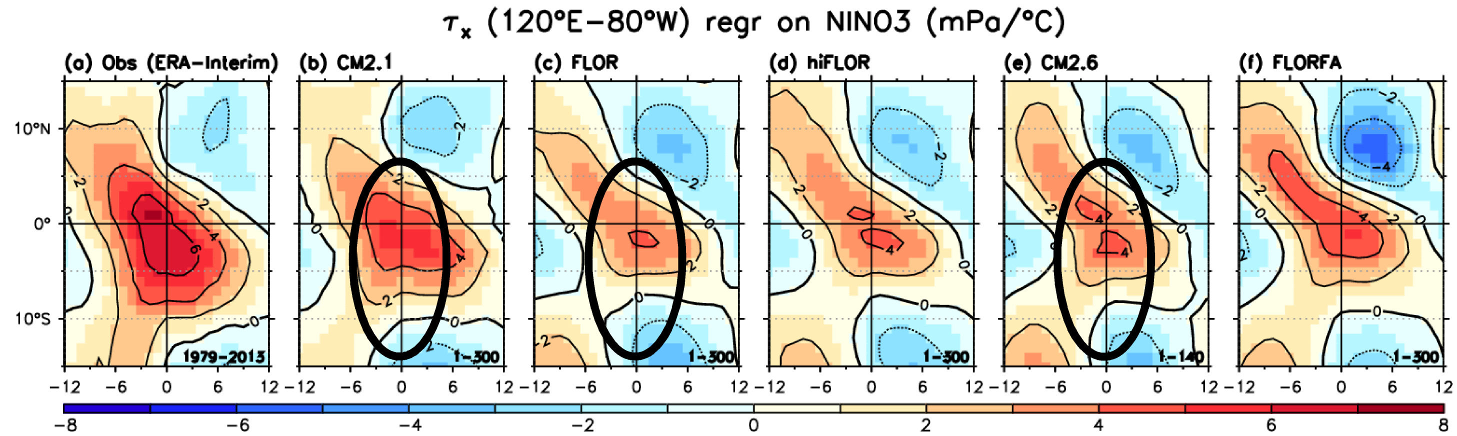
Oceanic refinement (**CM2.6**) boosts the vertical dynamics, but also boosts damping from TIWs & surface fluxes. → Weaker, faster ENSO.

Flux adjustment (**FLOR-FA**) weakens damping, but weakens vertical dynamics even more. → Weaker, slower, westward-propagating ENSO.

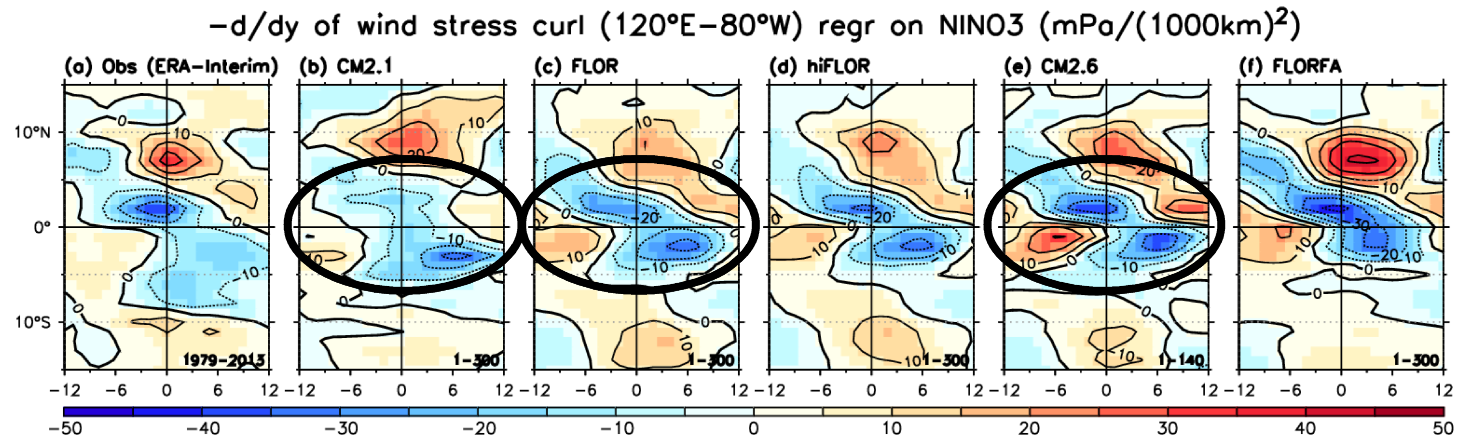


ENSO recharge/discharge (zonal mean)

CM2.1 had meridionally-broad westerly stress anomalies, much like obs. Other models are narrower.

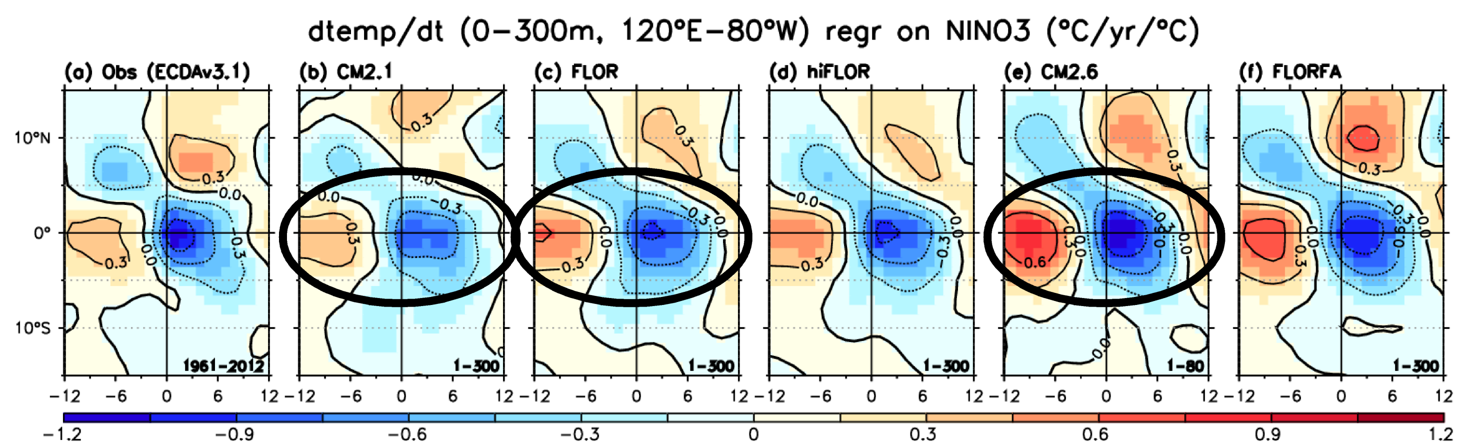


Both atmos (FLOR) & ocean (CM2.6) refinement boost the equatorial Sverdrup divergence.



Larger zonal-mean h' speeds transitions.
→ **Shorter period.**

FLOR-FA avoids this via deeper mean thermocline & weaker upwelling.



Summary: ENSO in GFDL's Next-Gen Models

1. Tropical Pacific climatology

a. **Atmospheric grid refinement** greatly improves mean SST/rain/winds

b. **Ocean refinement** helps too, but ocean mixing needs revisiting

c. **Flux adjustment** has pros & cons
- greatly improves surface climate (by construction)
- but deepens thermocline, weakens upper-ocean dT/dz

2. ENSO patterns

a. **Both atmos & ocean refinement improve ENSO's anomaly patterns**
- SSTAs, rainfall anomalies, PNA teleconnection, seasonal synchronization

b. **Flux adjustment strongly improves ENSO seasonality**
- but doesn't improve spatial patterns

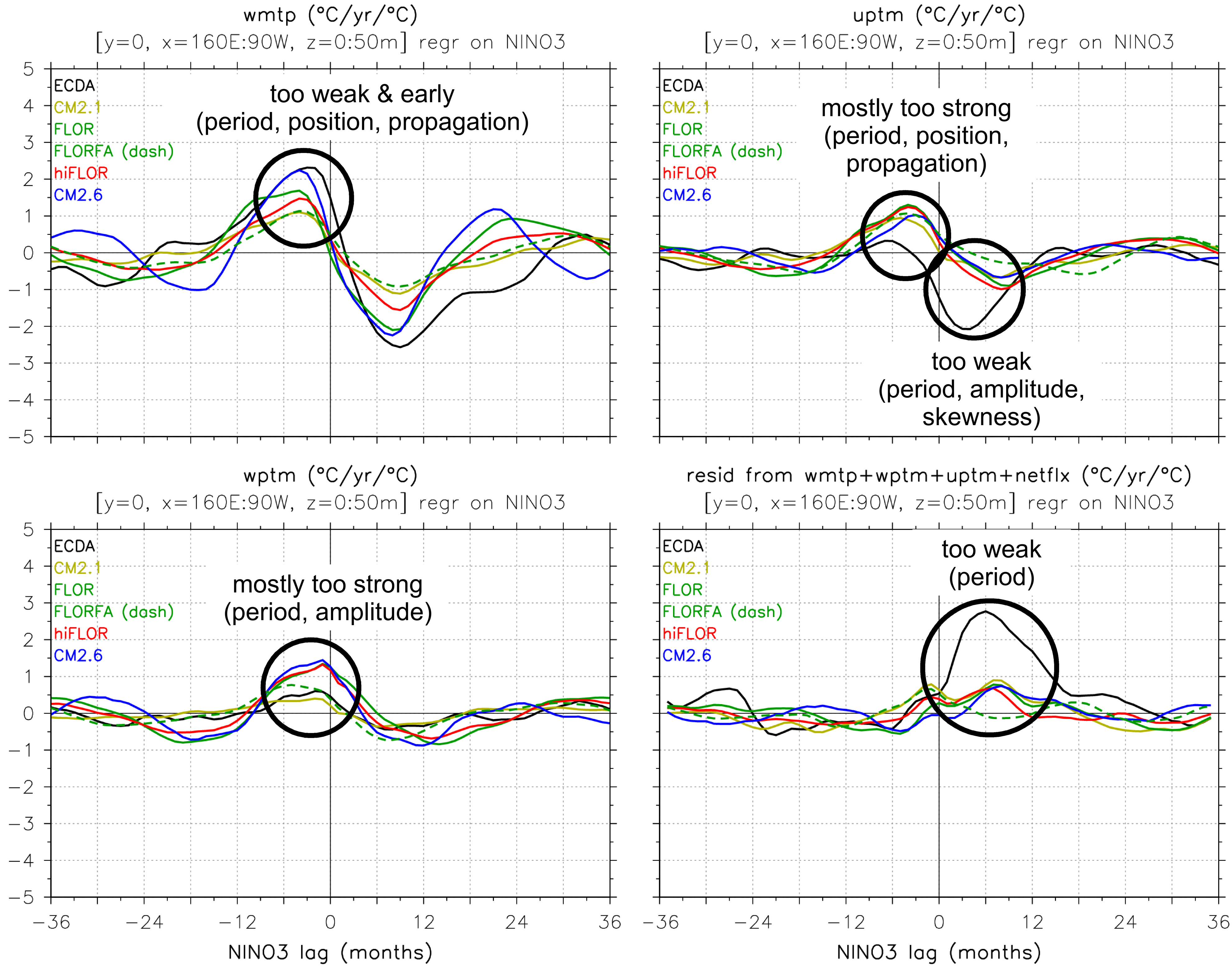
3. ENSO feedbacks

a. **As surface climate improves, thermodynamic damping increases**
- warmer cold tongue, stronger EEqPac winds, nearer ITCZs → stronger evap & cloud shading
- ocean refinement gives stronger TIWs → more damping during La Niña

b. **Stronger ocean dynamical feedbacks**
- amplifying aspect can be offset by stronger surface flux damping, TIWs
- transitioning aspect serves to accelerate ENSO transitions, shorten ENSO period
- largely controlled by mean thermocline depth

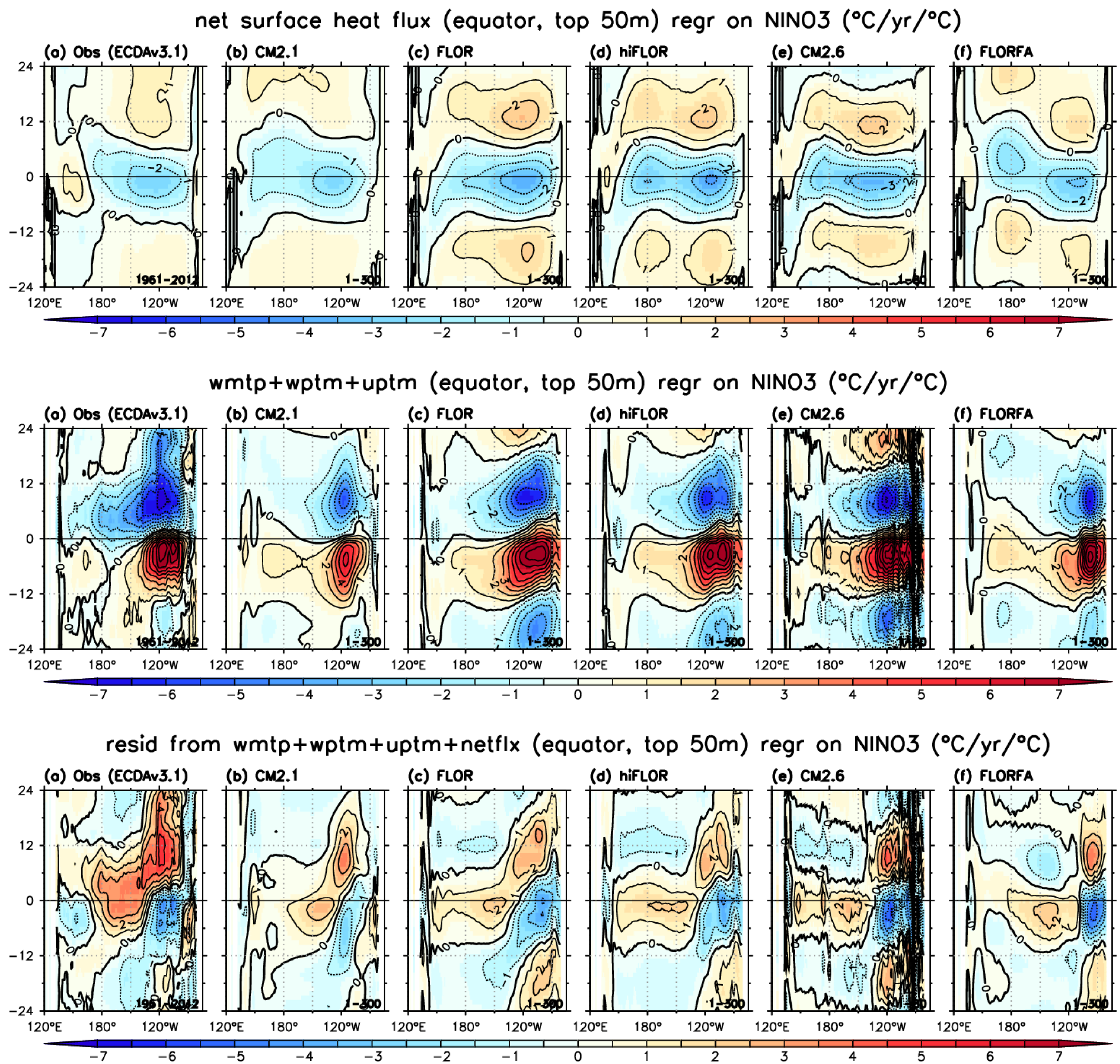
c. **Meridional narrowing of westerly wind anomalies during El Niño**
- produces too much Sverdrup divergence of heat content from equator
- rapidly shoals thermocline, shortens ENSO period

Reserve Slides

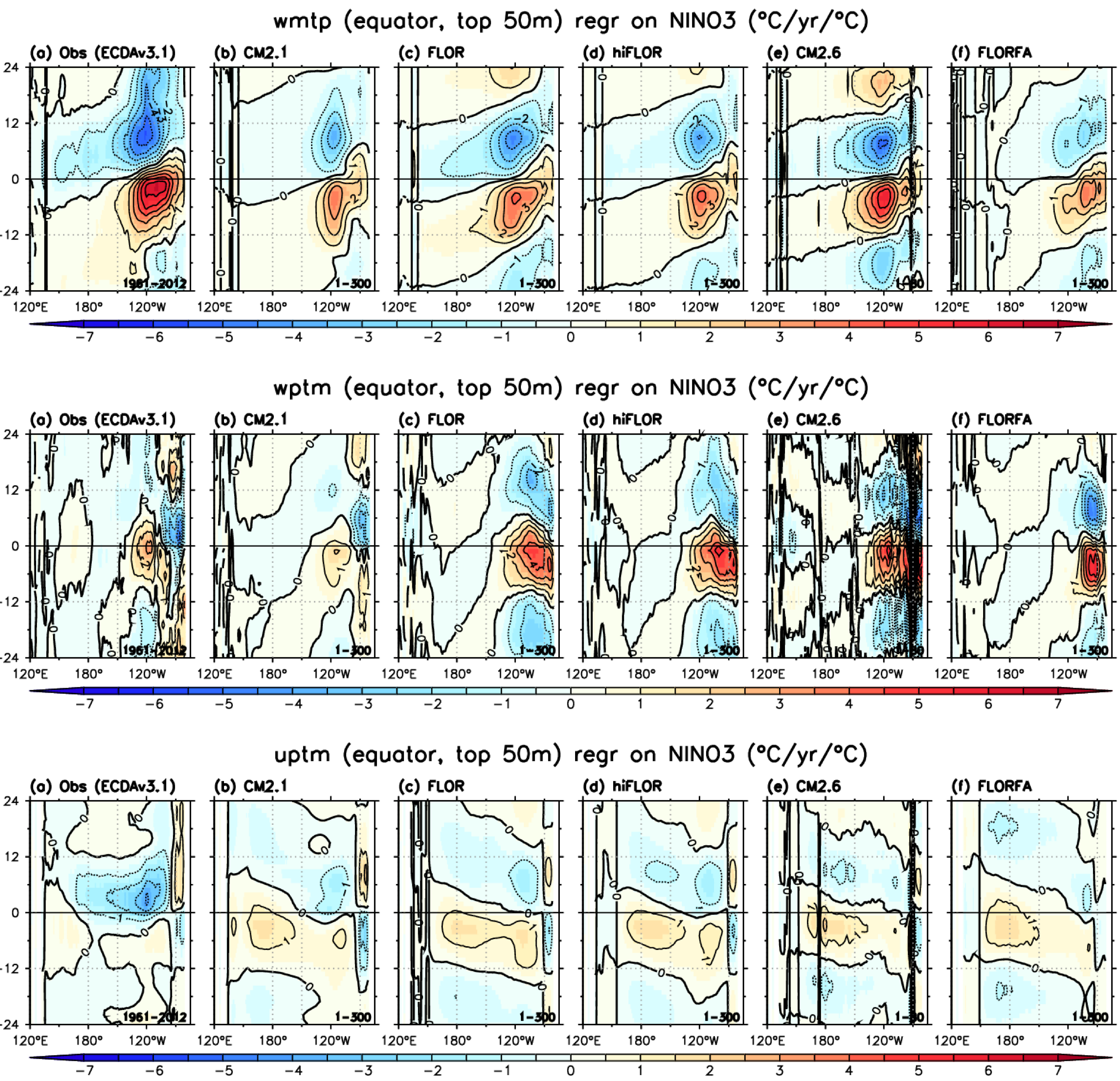


wmtp (°C/yr/°C)
[y=0, x=160E:90W, z=0:50m] regr on NINO3
ECDA
CM2.1
FLOR
FLORFA (dash)
hiFLOR
CM2.6
too weak & early
(period, position, propagation)
uptm (°C/yr/°C)
[y=0, x=160E:90W, z=0:50m] regr on NINO3
mostly too strong
(period, position,
propagation)
too weak
(period, amplitude,
skewness)
wptm (°C/yr/°C)
[y=0, x=160E:90W, z=0:50m] regr on NINO3
mostly too strong
(period, amplitude)
resid from wmtp+wptm+uptm+netflx (°C/yr/°C)
[y=0, x=160E:90W, z=0:50m] regr on NINO3
too weak
(period)
NINO3 lag (months)
NINO3 lag (months)

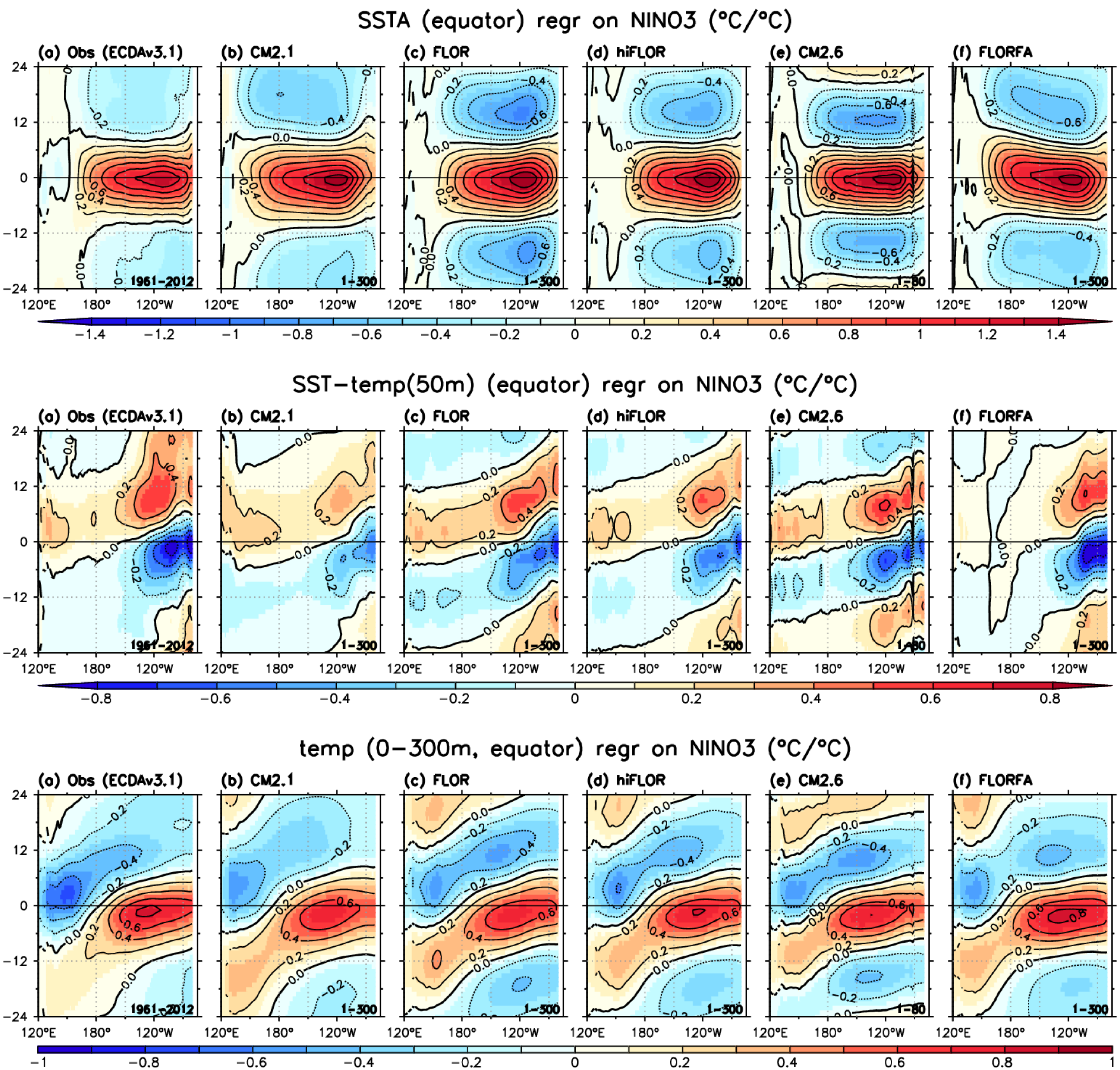
ENSO heat budget (equator, top 50m)



ENSO feedbacks: Dynamical heating



ENSO temperature evolution (equator)



Global ENSO teleconnections