ENSO Changes With Increasing Resolution in the GFDL Models

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1. Introduction

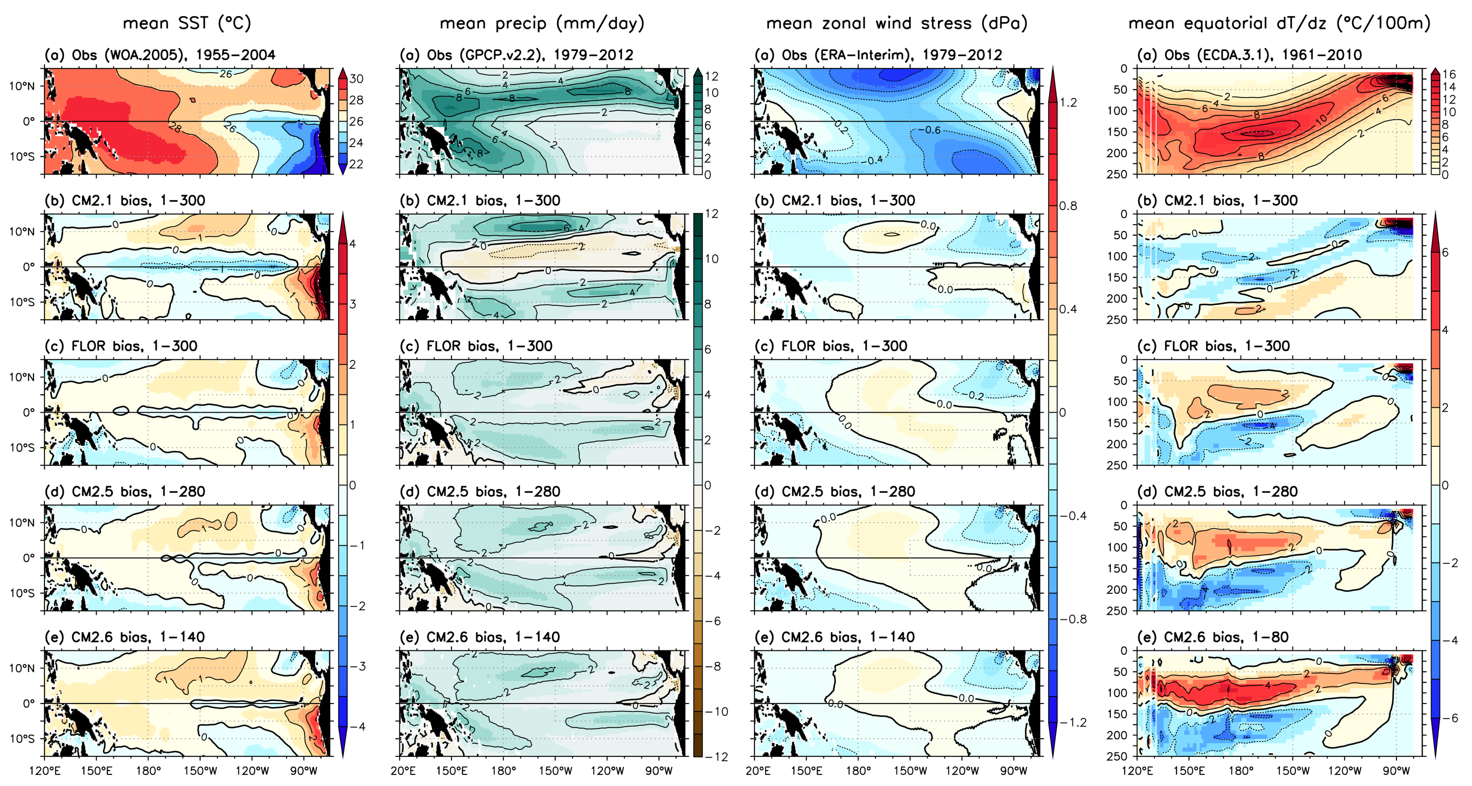
We examine the El Niño / Southern Oscillation (ENSO) in 1990-control simulations from GFDL's global coupled GCMs, in which horizontal resolution has been progressively refined in the ocean & atmosphere.

	Grid spacing (°): $\Delta x \times \Delta y$	
	Atmosphere	Ocean
CM2.1	2.5 × 2	1 × (1–0.33)*
FLOR	0.5 × 0.5	1 × (1–0.33)*
CM2.5	0.5 × 0.5	0.25 × 0.25
CM2.6	0.5 × 0.5	0.1 × 0.1

*Δy telescopes from 1° at 30°N/S, to 0.33° at the equator.

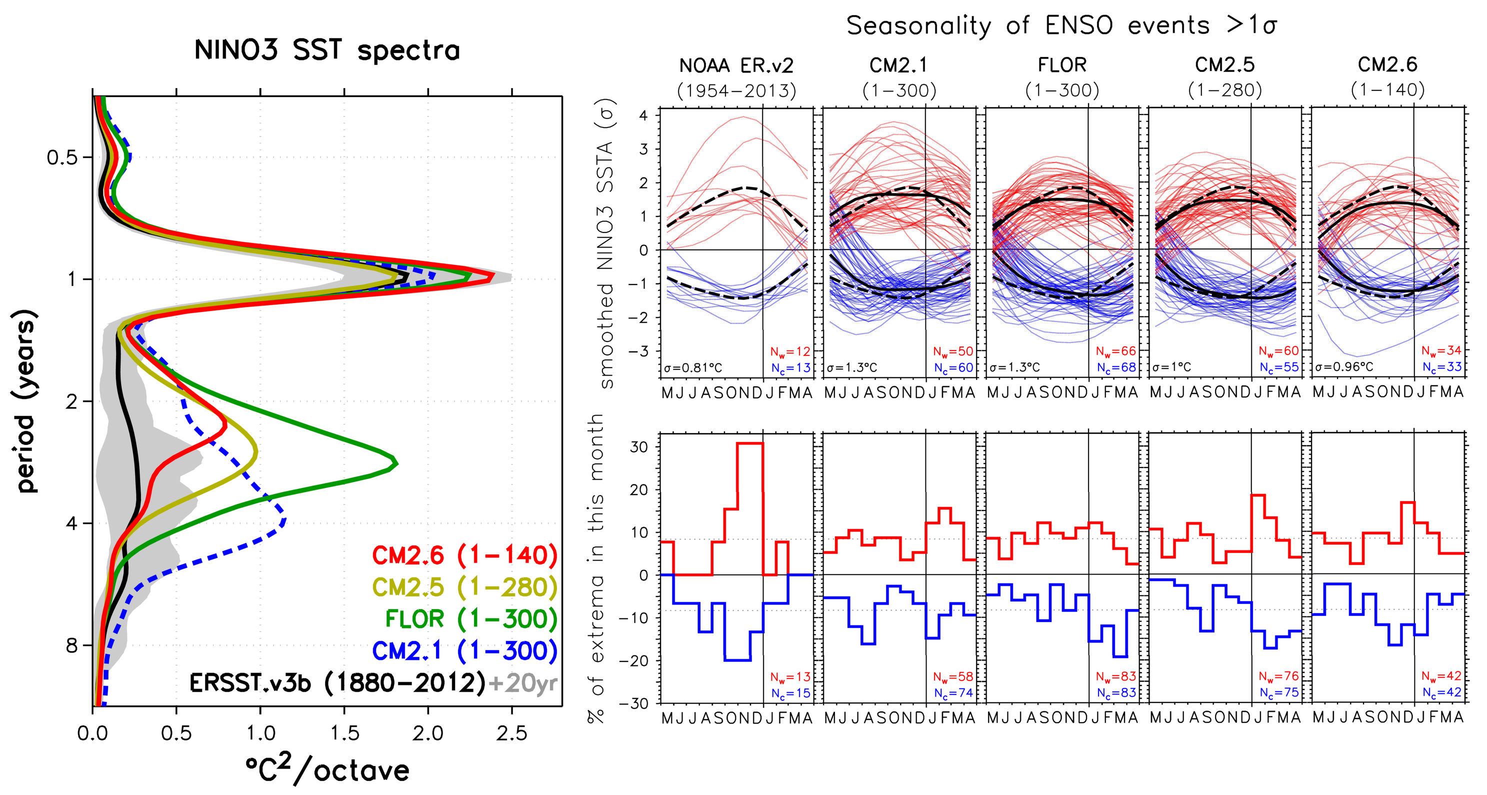
2. Climatological Context

The atmospheric grid refinement (CM2.1→FLOR) improves the annual-mean tropical Pacific climatology, dramatically reducing the equatorial cold/dry bias, Peru coastal warm bias, double-ITCZ bias, and the overly strong equatorial trade winds in the west, as well as boosting the upper-ocean thermal stratification in the central equatorial Pacific. The oceanic grid refinement (FLOR→CM2.6) slightly reduces the equatorial cold bias and double-ITCZ, but worsens the warm SST biases and overly shoals & intensifies the equatorial thermocline. Further attention to the ocean formulation may be warranted for these high ocean resolutions.



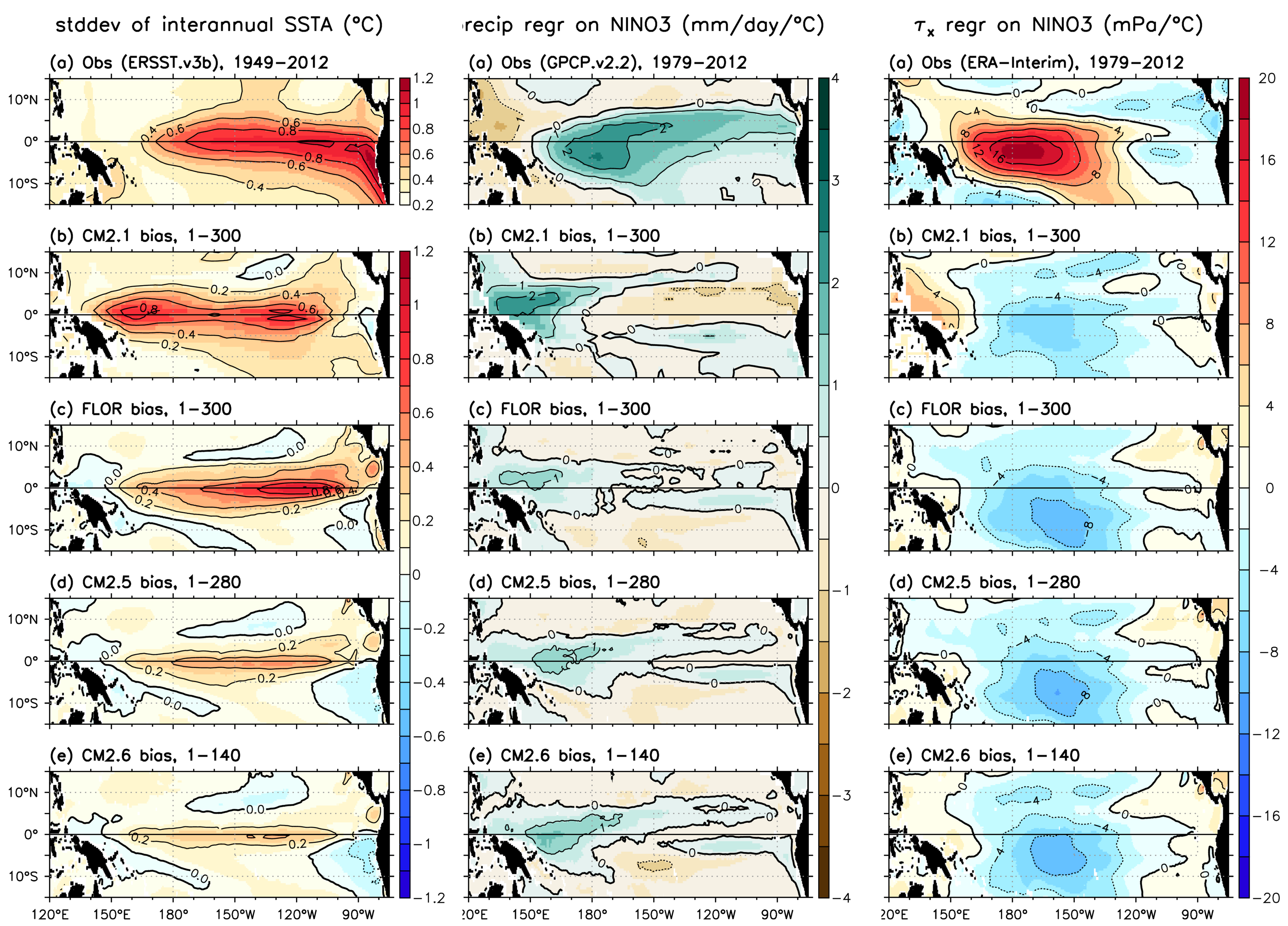
3. ENSO Spectrum, Seasonality, and Diversity

CM2.1's ENSO spectrum is fairly realistic, except for its very strong variance. The NINO3 region (150°W-90°W, 5°S-5°N) SST anomaly (SSTA) variance is even stronger in FLOR, but weakens in CM2.5 & CM2.6. Atmosphere/ocean grid refinement leads to a sharper spectral peak & shorter period for ENSO, less positive skewness of NINO3 SSTAs, and less diversity of event amplitudes. All four models show too little tendency for ENSO events to peak near the end of the calendar year, but CM2.1 & CM2.5 show a distinct semiannual synchronization, while CM2.6 shows improved annual synchronization. Such differences may be linked to the strength of the double-ITCZ in each simulation.



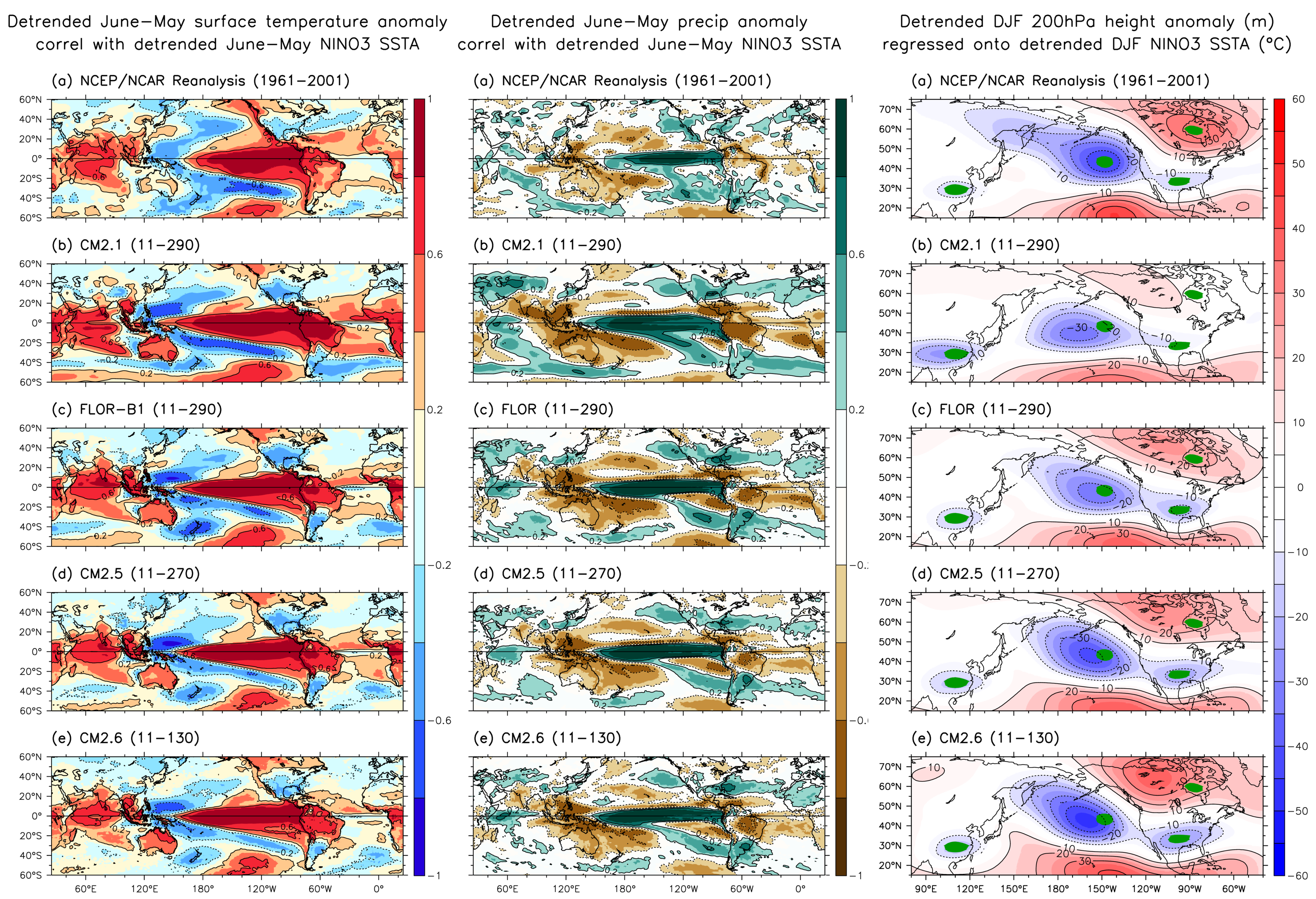
4. Tropical Pacific Patterns of ENSO

Relative to observations, CM2.1 shows a westward shift of its patterns of tropical Pacific SST, rainfall, and wind stress during ENSO. The SSTA pattern benefits from both atmospheric & oceanic refinement, while the rainfall & wind responses benefit mostly from atmospheric refinement. Compared to CM2.1 or observations, the high-res models show a weaker and meridionally-narrower westerly wind response to El Niño, particularly on the southern flank of the equatorial westerly anomalies.



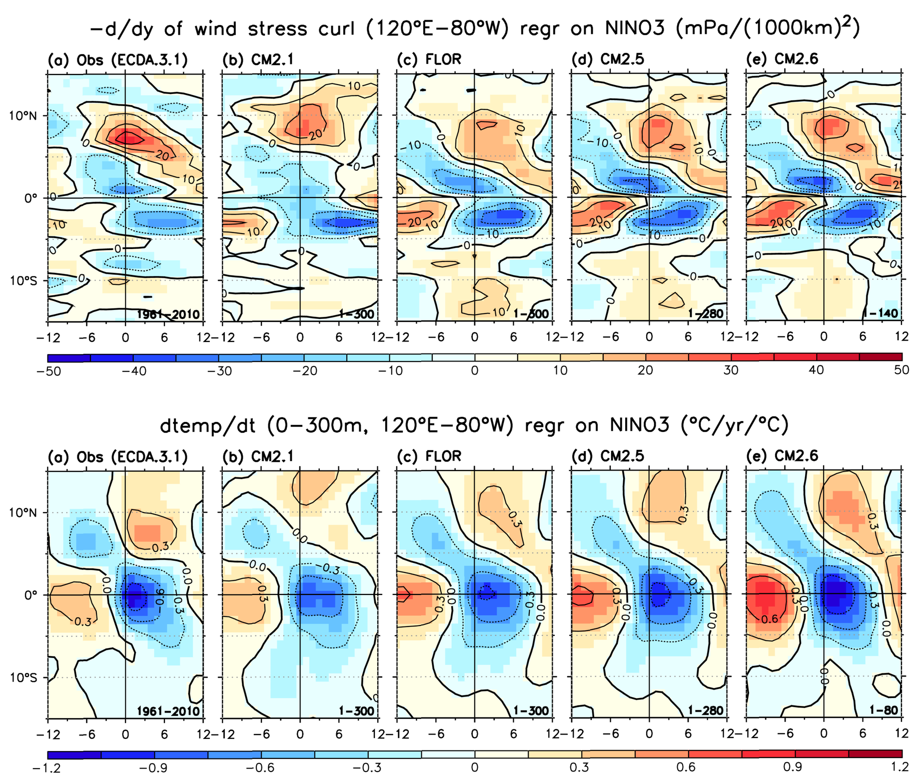
5. Global Teleconnections of ENSO

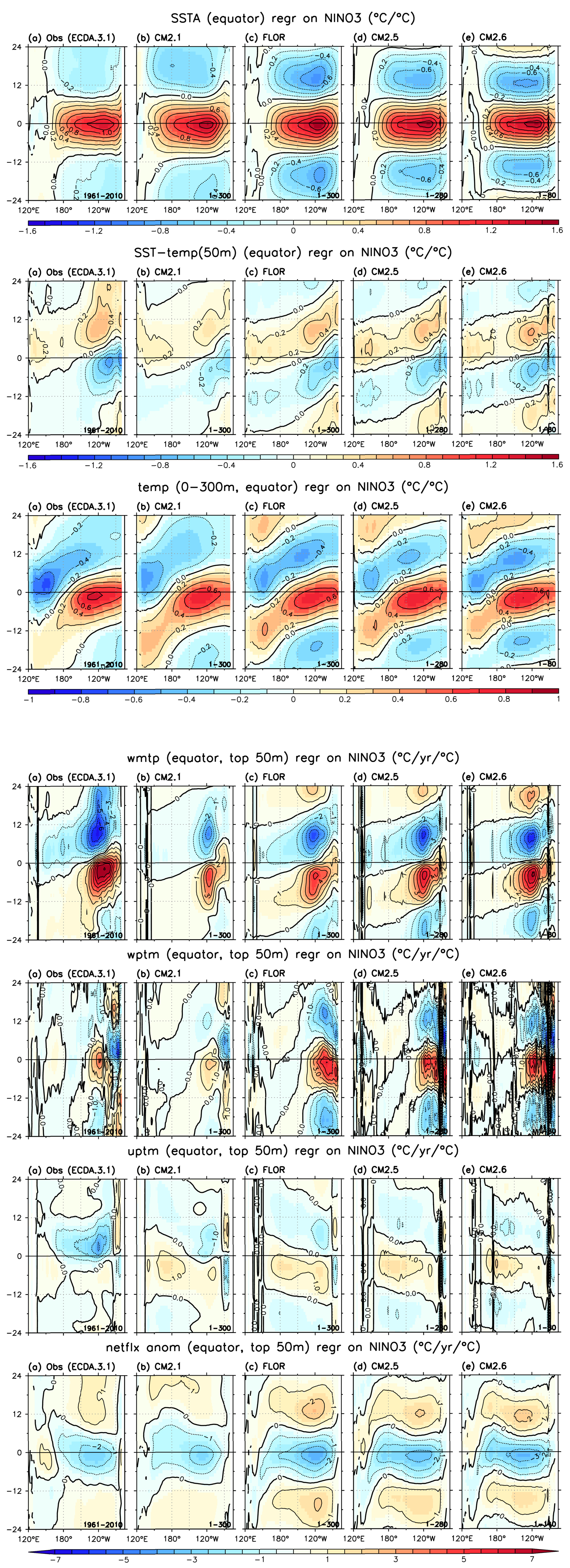
Many of ENSO's global teleconnections improve as the model resolution increases – in particular for **surface temperature** over North America, Africa, India, northern Asia, the Amazon basin, and the tropical Atlantic and Indian Oceans; **rainfall** over North America, Africa, the Amazon, and the west Pacific; and **200hPa geopotential heights** over North America, northern Asia, and the North Pacific. The teleconnections benefit from an eastward shift of the response of tropical atmospheric deep convection to ENSO, as well as improved storm tracks & global topography/bathymetry at high resolution.



6. ENSO Mechanisms

The above changes in ENSO emerge from a complex interplay of processes that drive equatorial SSTAs. In FLOR, a stronger thermal damping of equatorial SSTAs (primarily from an enhanced east Pacific evaporative feedback) is trumped by stronger subsurface feedbacks which amplify ENSO and pull its SSTAs eastward. The thermocline feedback (**wmtp**) is boosted by stronger subsurface temperature fluctuations – which are driven by stronger east Pacific thermocline depth anomalies (h), and by increased sensitivity of the SSTAs to h due to the intensified thermocline. The stronger h is caused not by the *equatorial* wind anomalies (which hardly change) but by enhanced *off-equatorial* surface wind stress curl, which generates a stronger delayed meridional recharge/discharge of equatorial heat content. Enhanced upwelling feedbacks (**wptm**) further amplify ENSO in FLOR, due to both stronger upwelling fluctuations and stronger upper-ocean thermal stratification. Enhanced zonal advective feedbacks (**uptm**) play a transitioning (period-shortening) role in the central Pacific, augmenting a similar role for the thermocline feedback in the east Pacific as the thermocline intensifies at high-res.





Related Work

Capotondi, A., A. Wittenberg, and S. Masina, 2006: Spatial and temporal structure of tropical Pacific interannual variability in 20th century coupled simulations. *Ocean Modelling*, **15**, 274-298. doi: 10.1016/j.ocemod.2006.02.004.
Capotondi, A., and A. Wittenberg, 2013: ENSO diversity in climate models. *U.S. CLIVAR Variations*, 11, 10-14.
Capotondi, A., A. Wittenberg, et al., 2014: Understanding ENSO diversity. Subm. to *Bull. Amer. Meteor. Soc.*, February 2014.
Choi, K.-Y., G. A. Vecchi, and A. T. Wittenberg, 2013: ENSO transition, duration and amplitude asymmetries: Role of the nonlinear wind stress coupling in a conceptual model. *J. Climate*, **26**, 9462-9476. doi: 10.1175/JCLI-D-13-00045.1.
Collins, M., et al., 2010: The impact of global warming on the tropical Pacific and El Niño. *Nature Geoscience*, **3**, 391-397. doi: 10.1038/ngeo868
Delworth, T. L., et al., 2006: GFDL's CM2 global coupled climate models, Part I: Formulation and simulation characteristics. *J. Climate*, **19**, 643-674. doi: 10.1175/JCLI3629.1
Delworth, T. L., et al., 2012: Simulated climate and climate change in the GFDL CM2.5 high-resolution coupled climate model. *J. Climate*, **25**, 2755-2781. doi: 10.1175/JCLI-D-11-00316.1
DiNezio, P. N., et al., 2012: Mean climate controls on the simulated response of ENSO to increasing greenhouse gases. *J. Climate*, **25**, 7399-7420. doi: 10.1175/JCLI-D-11-00494.1
Graham, F. S., et al., 2014: Effectiveness of the Bjerknes stability index in representing ocean dynamics. *Climate Dyn.*, in press. doi: 10.1007/s00382-014-2062-3.
Guilyardi, E., A. Wittenberg, et al., 2009: Understanding El Niño in ocean-atmosphere general circulation models: Progress and challenges. *Bull. Amer. Meteor. Soc.*, **90**, 325-340. doi:10.1175/2008BAMS2387.1
Jia, L., et al., 2014: Improved seasonal prediction of temperature and precipitation over land in a high-resolution GFDL climate model. Subm. to *J. Climate*, February 2014.
Karamperidou, C., et al., 2014: Intrinsic modulation of ENSO predictability viewed through a local Lyapunov lens. *Climate Dyn.*, **42**, 253-270. doi: 10.1007/s00382-013-1759-z.
Kug, J.-S., et al., 2010: Warm pool and cold tongue El Niño events as simulated by the GFDL CM2.1 coupled GCM. *J. Climate*, **23**, 1226-1239. doi: 10.1175/2009JCLI3293.1.
McGregor, S., et al., 2013: Inferred changes in El Niño-Southern Oscillation variance over the past six centuries. *Clim. Past*, **9**, 2269-2284. doi: 10.5194/cp-9-2269-2013.
Ogata, T., S.-P. Xie, A. Wittenberg, and D.-Z. Sun, 2013: Interdecadal amplitude modulation of El Niño/Southern Oscillation and its impacts on tropical Pacific decadal variability. *J. Climate*, **26**, 7280-7297. doi: 10.1175/JCLI-D-12-00415.1.
Vecchi, G. A., and A. T. Wittenberg, 2010: El Niño and our future climate: Where do we stand? *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 260-270. doi: 10.1002/wcc.33
Vecchi, G. A., et al., 2014: On the seasonal forecasting of regional tropical cyclone activity. Subm. to *J. Climate*, February 2014.
Watanabe, M., and A. T. Wittenberg, 2012: A method for disentangling El Niño-mean state interaction. *Geophys. Res. Lett.*, **39**, L14702. doi: 10.1029/2012GL052013.
Watanabe, M., et al., 2012: Uncertainty in the ENSO amplitude change from the past to the future. *Geophys. Res. Lett.*, **39**, L20703. doi: 10.1029/2012GL053305
Wittenberg, A. T., 2002: ENSO response to altered climates. Ph.D. thesis, Princeton University. 475pp. Available from http://www.gfdl.noaa.gov/~atw/research/thesis.
Wittenberg, A. T., 2004: Extended wind stress analyses for ENSO. *J. Climate*, **17**, 2526-2540. doi: 10.1175/1520-0442(2004)017%3C2526:EWSAFE%3E2.0.CO;2
Wittenberg, A. T., et al., 2006: GFDL's CM2 global coupled climate models. Part III: Tropical Pacific climate and ENSO. *J. Climate*, **19**, 698-722. doi: 10.1175/JCLI3631.1
Wittenberg, A. T., 2009: Are historical records sufficient to constrain ENSO simulations? *Geophys. Res. Lett.*, **36**, L12702. doi: 10.1029/2009GL038710
Wittenberg, A. T., et al., 2014: ENSO modulation: Is it decadally predictable? *J. Climate*, in press. doi: 10.1175/JCLI-D-13-00577.1.
Zhang, S., M. J. Harrison, A. Rosati, and A. Wittenberg, 2007: System design and evaluation of coupled ensemble data assimilation for global oceanic climate studies. *Mon. Wea. Rev.*, **135**, 3541-3564. doi: 10.1175/MWR3466.1.

Poster:

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