# Understanding future ENSO risks

presented by

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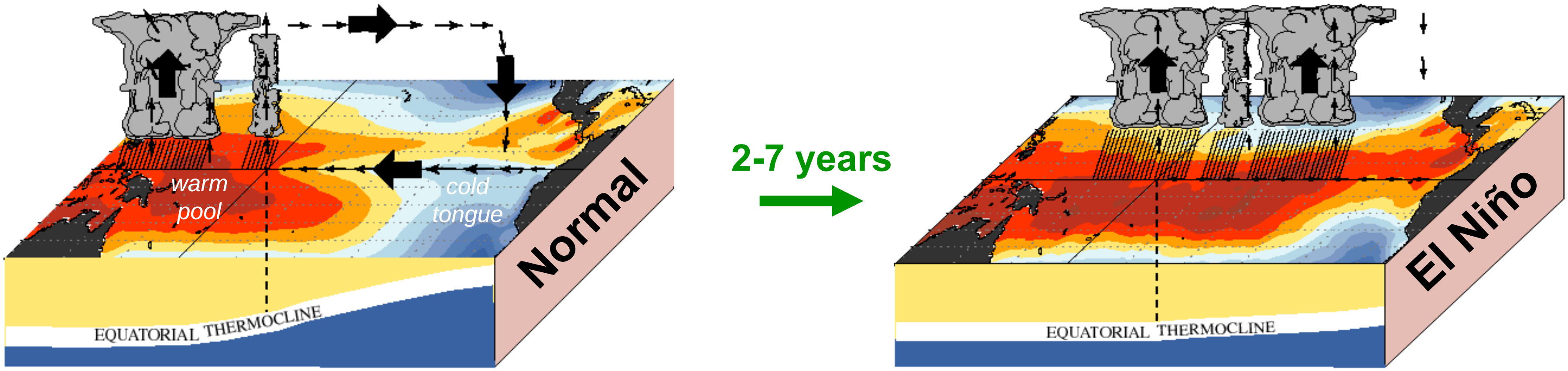
# ENSO: Earth's dominant year-to-year climate signal




## Global impacts:

- **weather & climate**, extremes, natural disasters
- **ecosystems**, fisheries, agriculture, forests
- **economies:** commerce, transportation, energy, water, food, health

## How vulnerable are we to ENSO?

- sources & limits of seasonal-to-decadal **predictability**
- **natural vs. anthropogenic risks**
- changes in **dynamics** vs. **impacts**
- short, gappy, nonstationary observing system → **models crucial**
- coupling & scale interactions → **key test** for models

# GFDL: Strongly positioned in the ENSO community

## ENSO simulations among the best in the world

- **realistic** ENSO behavior: patterns, spectra, mechanisms, teleconnections
- **stable** multi-millennial control runs, large ensembles
- **diverse** model tools, complementary **assimilation & forecast** systems

*Wittenberg et al. (JC 2014; JAMES 2018); Vecchi et al. (JC 2014); Wittenberg (CV 2015); Choi et al. (JC 2015); Delworth et al. (JC 2015); Krishnamurthy et al. (JC 2015, 2016; CD 2019); Griffies et al. (JC 2015); Jia et al. (JC 2015); Yang et al. (JC 2015; CD 2018); Ward et al. (ERL 2016); Zhang et al. (JC 2016); Ray et al. (JC 2018ab); Zhao et al. (JAMES 2018a); He et al. (JC 2018); Park et al. (GRL 2018); Held et al. (JAMES 2020); Johnson et al. (JC 2020); Delworth et al. (JAMES subm); Dunne et al. (in prep)*

## Groundbreaking ENSO research & collaborations

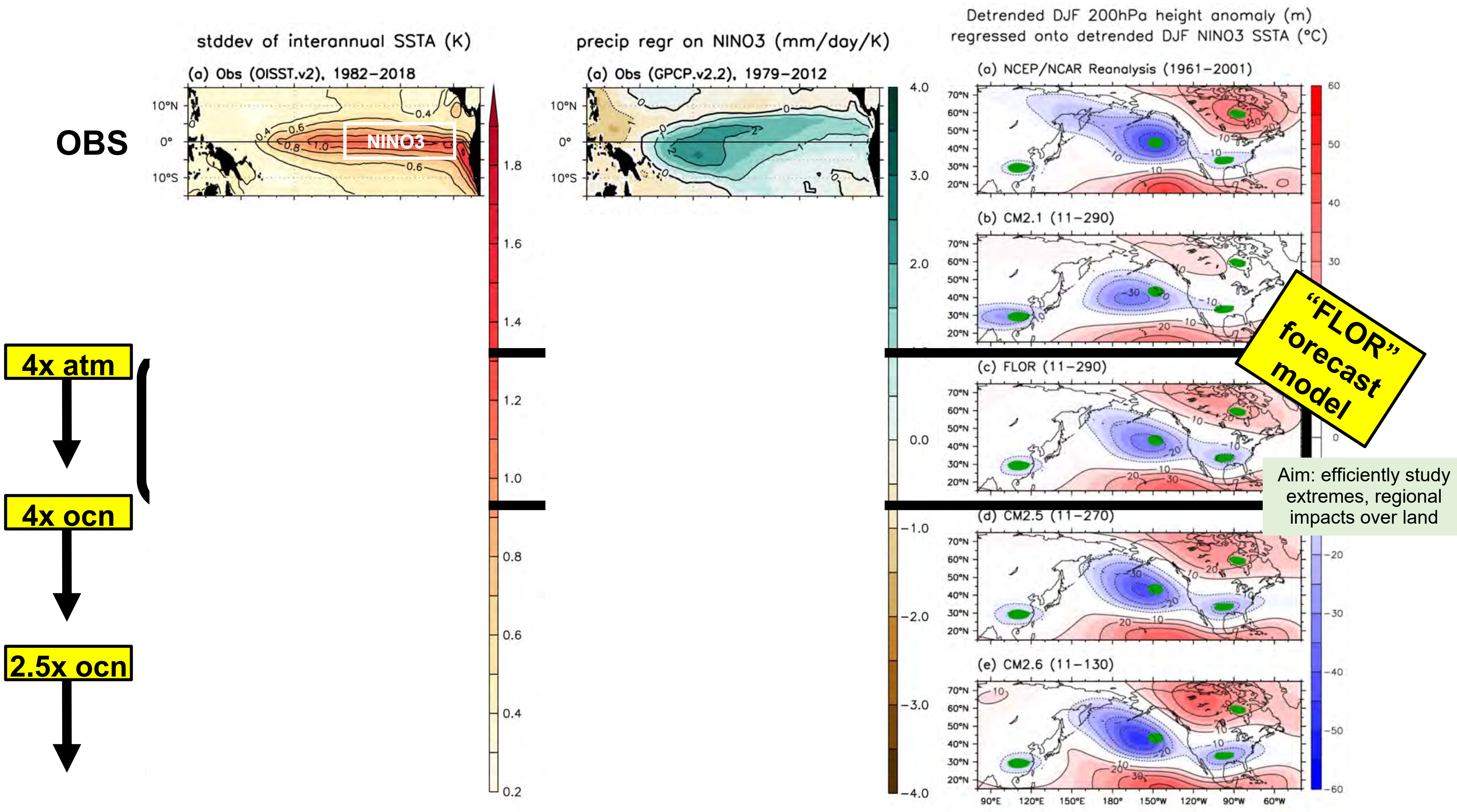
- **Diversity, sensitivities & trends,** mechanisms
- **Predictability**, forecasts, observing system design
- **Impacts** on hydroclimate, storms, extremes, ecosystems
- **Community metrics, emergent constraints**, model hierarchy

**60+ peer-reviewed papers** related to ENSO during 2014-19, with 2300+ citations (Google Scholar, Sept. 2019)

*NOAA & U.S. collaborations:* ***ESRL, AOML, PMEL, NCEP, NDBC, CPO; U.S. CLIVAR Working Group on ENSO Diversity****.*
*International:* ***CLIVAR (Research Focus on ENSO; Working Group on ENSO Metrics; Pacific Region Panel); CMIP; IPCC; NMME; TPOS2020.***

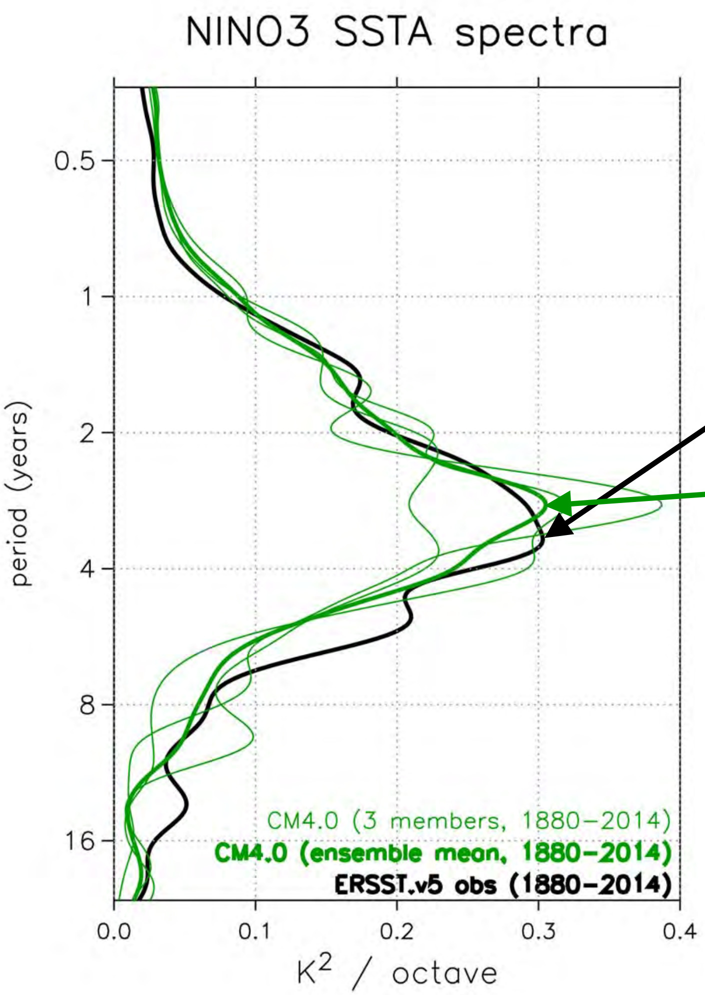
*Collaborative studies: Lee et al. (GRL 2014, 2018; ERL 2016); Capotondi et al. (BAMS 2015; CV 2015); Erb et al. (JC 2015); Cravatte et al. (TPOS 2016); Guilyardi et al. (BAMS 2016); Zhang et al. (GRL 2016) Atwood et al. (CD 2017); Chen et al. (JC 2017); Graham et al. (CD 2014, 2017; JC 2015); L'Heureux et al. (BAMS 2017; WF 2019); Naiman et al. (JC 2017); Stuecker et al. (GRL 2017); Predybaylo et al. (JGRA 2017); Newman et al. (BAMS 2018); Ding et al. (JC 2018; GRL 2019); Timmermann et al. (Nature 2018); Chiodi et al. (GBC 2019); Kessler et al. (TPOS 2019); Vecchi et al. (CD 2019); Capotondi et al. (AGU 2020); Fedorov et al. (AGU 2020); Guilyardi et al. (AGU 2020); Predybaylo et al. (SA subm); Santidrian et al. (CC subm); Lee et al. (in prep); McGregor et al. (in prep); Power et al. (in prep); Stevenson et al. (in prep)*

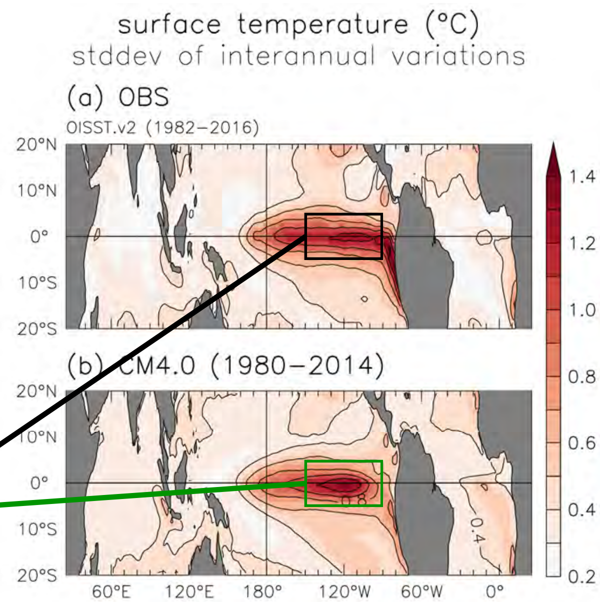
# ENSO improvements with increasing resolution

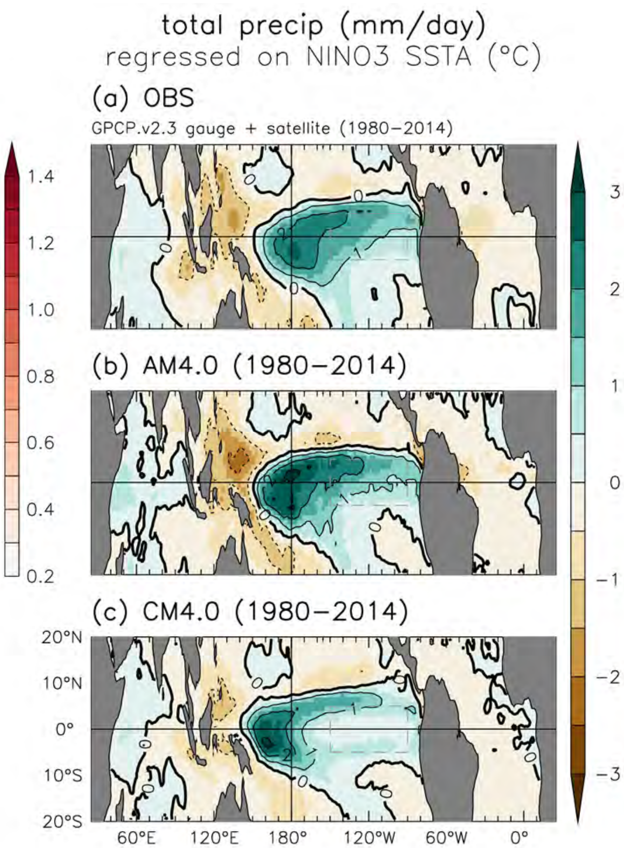



*Vecchi et al. (JC 2014; CD 2019); Jia et al. (JC 2015); Yang et al. (JC 2015); Wittenberg et al. (JAMES 2018); Ray et al. (JC 2018ab)*

# Improved ENSO patterns & spectra in CM4



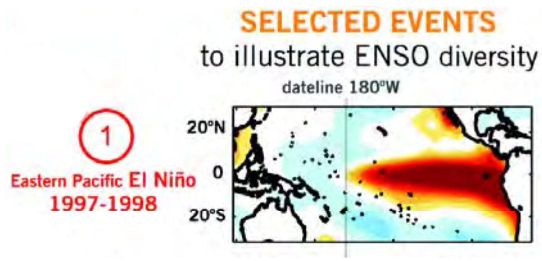

Better **resolution**
**& comprehensiveness**

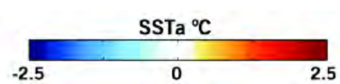
→ New avenues for
research & applications

*Zhao et al. (JAMES 2018a)*
*Held et al. (JAMES, in press)*

# ENSO diversity in observations

ENSO flavors have different dynamics & impacts



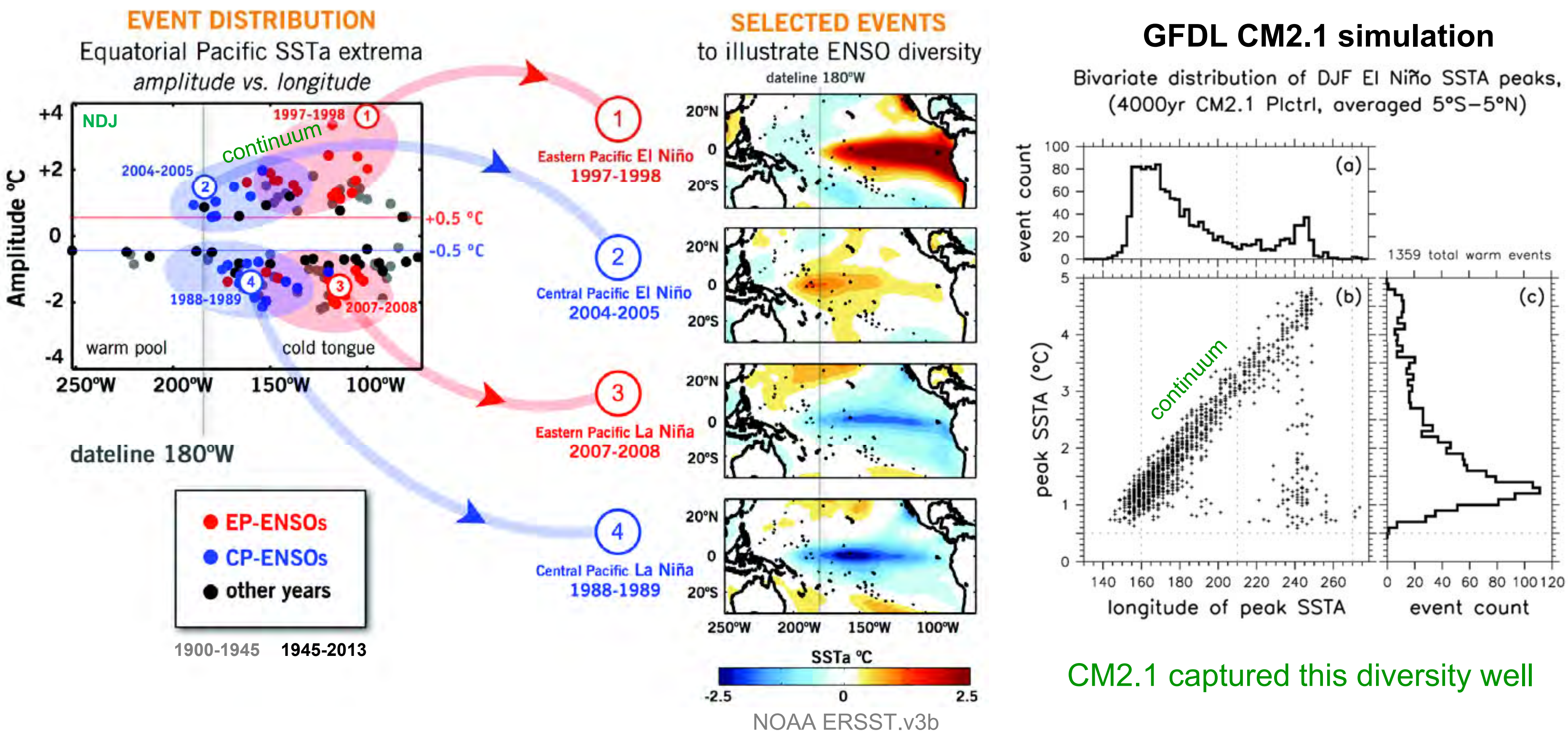




NOAA ERSST.v3b

**U.S. CLIVAR Working Group on ENSO Diversity**: *Capotondi, Wittenberg, et al. (BAMS 2015; AGU 2020)*

# ENSO diversity in observations & models

ENSO flavors have different dynamics & impacts

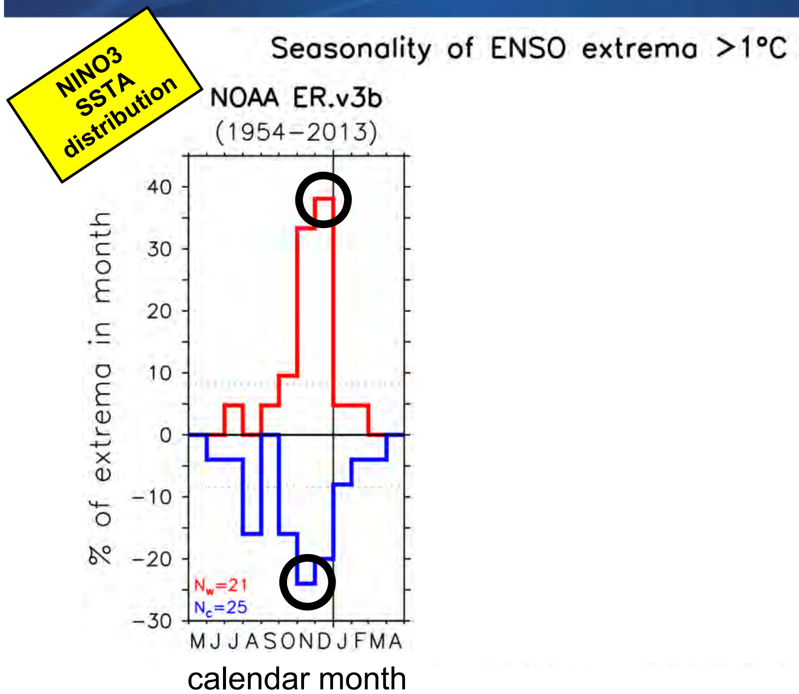



CM2.1 captured this diversity well

**U.S. CLIVAR Working Group on ENSO Diversity**: *Capotondi, Wittenberg, et al. (BAMS 2015; AGU 2020)*

Sources, impacts, predictability: Wittenberg et al. (JC 2014); *Graham et al. (CD 2017); Chen et al. (JC 2017); Atwood et al. (CD 2017); L'Heureux et al. (BAMS 2017); Yang et al. (CD 2018); Timmermann et al. (Nature 2018); Johnson et al. (GRL 2019); Santidrian et al. (CC subm)*

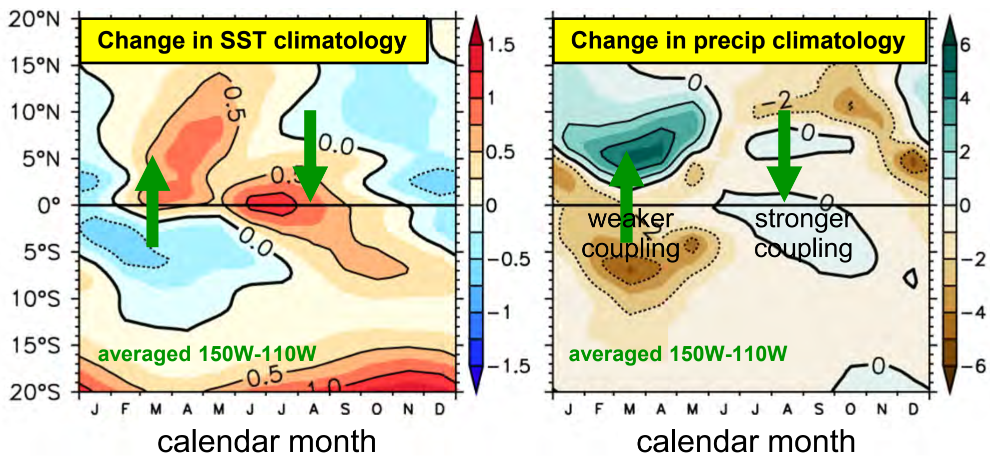
# Improved seasonal synchronization of ENSO




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

**GFDL-FLOR** (like many models) didn't capture this.

Correct climatological SST & wind stress using **flux adjustments (FA)** → ENSO **synchronizes** to end of calendar year.



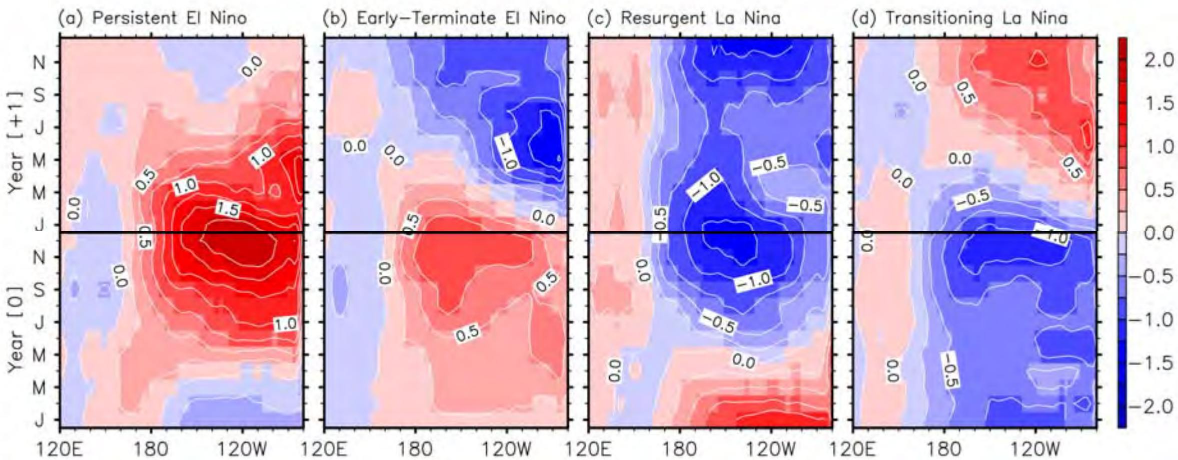

FA corrects east Pacific seasonality of **dT/dy** and **ITCZ latitude**.

Boosts SST→wind coupling during the key Jun-Nov season of ENSO growth.

*Wittenberg et al. (in prep)*

# ENSO diversity & seasonality affect remote impacts

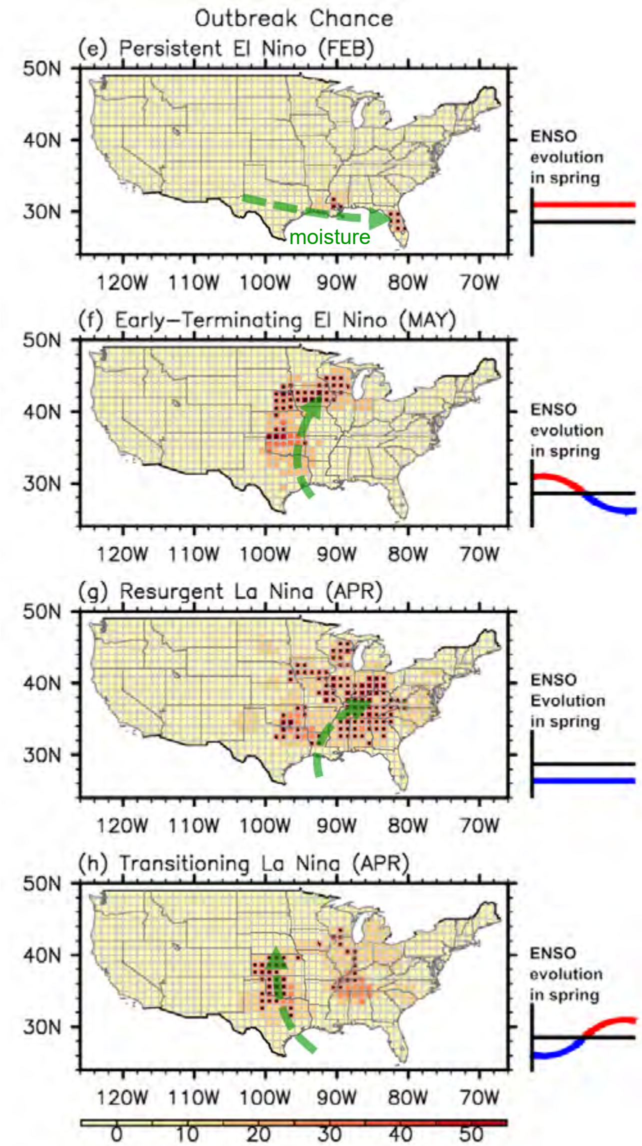
*Key flavors of observed ENSO evolution*




ENSO events show diverse temporal behavior in boreal spring: **persisting, terminating early, resurging,** or **transitioning**.

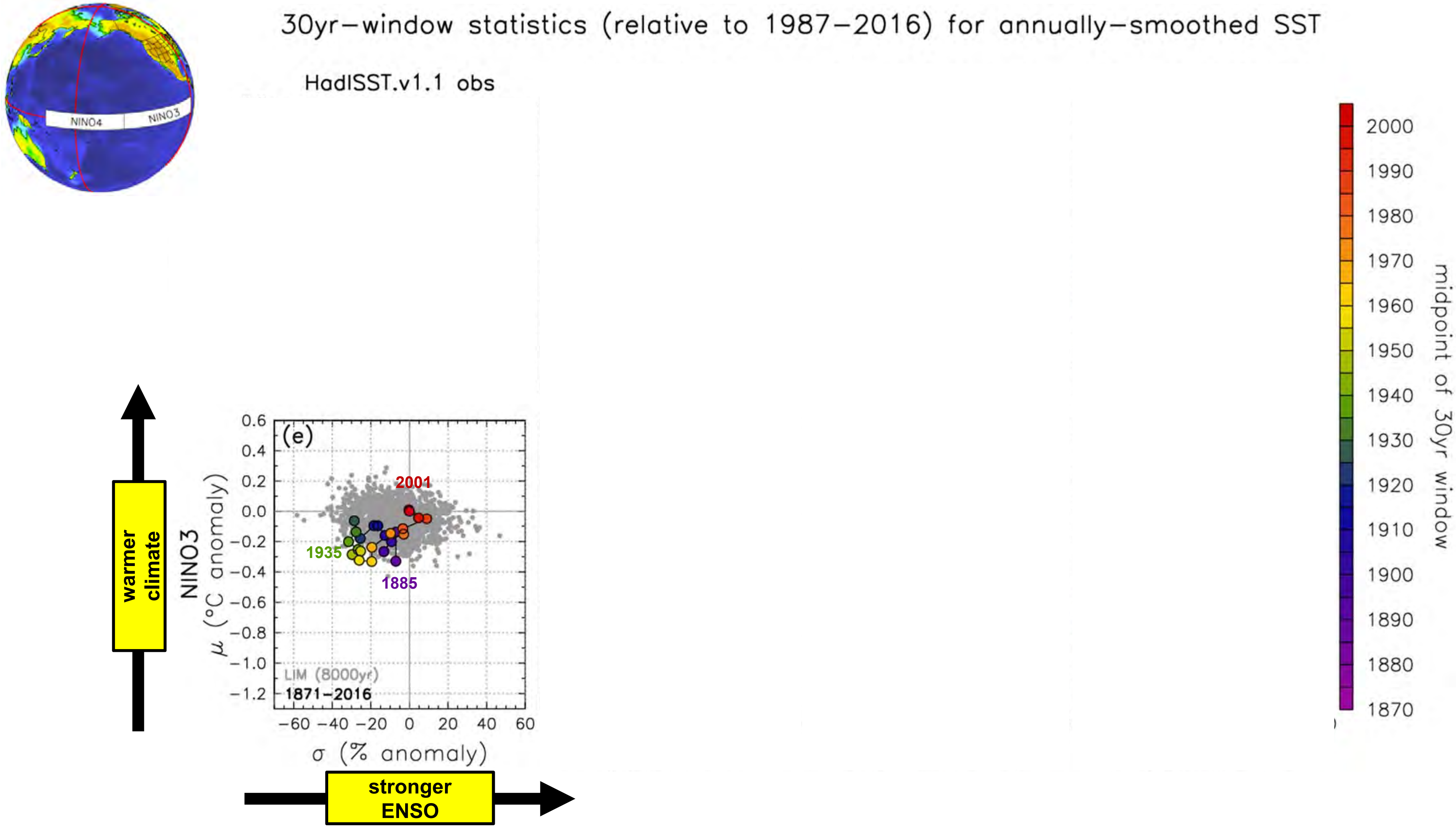
This significantly affects ENSO impacts, e.g. on U.S. **tornado outbreak frequency** & California rainfall.

large-scale seasonal wind shear, moisture advection (GPLLJ)



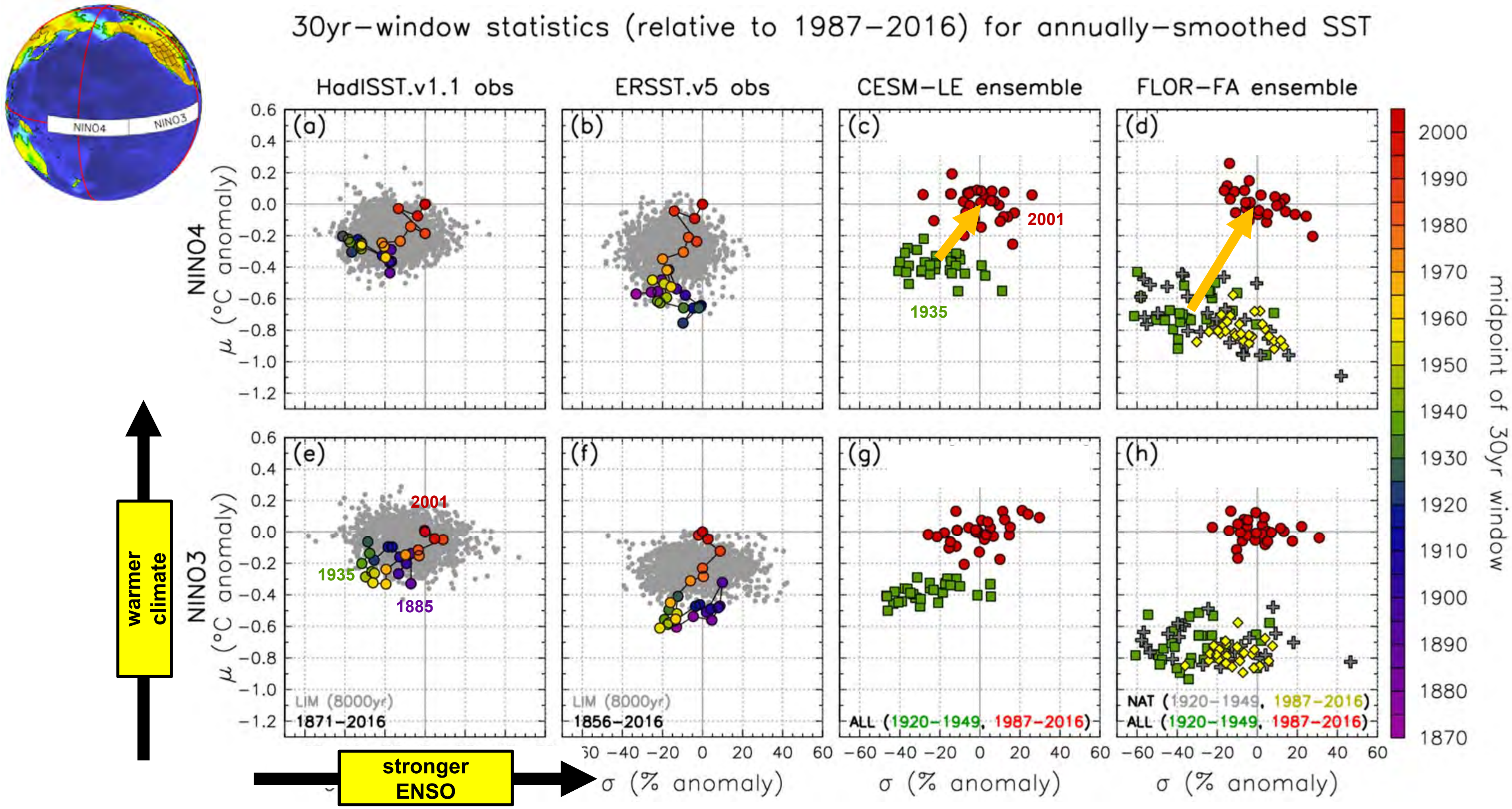

*Lee et al. (GRL 2014, 2018; ERL 2016)*
*Krishnamurthy et al. (JC 2015)*

# Historical changes in ENSO & mean eq. Pacific SST




*Newman, Wittenberg, et al. (BAMS 2017)*

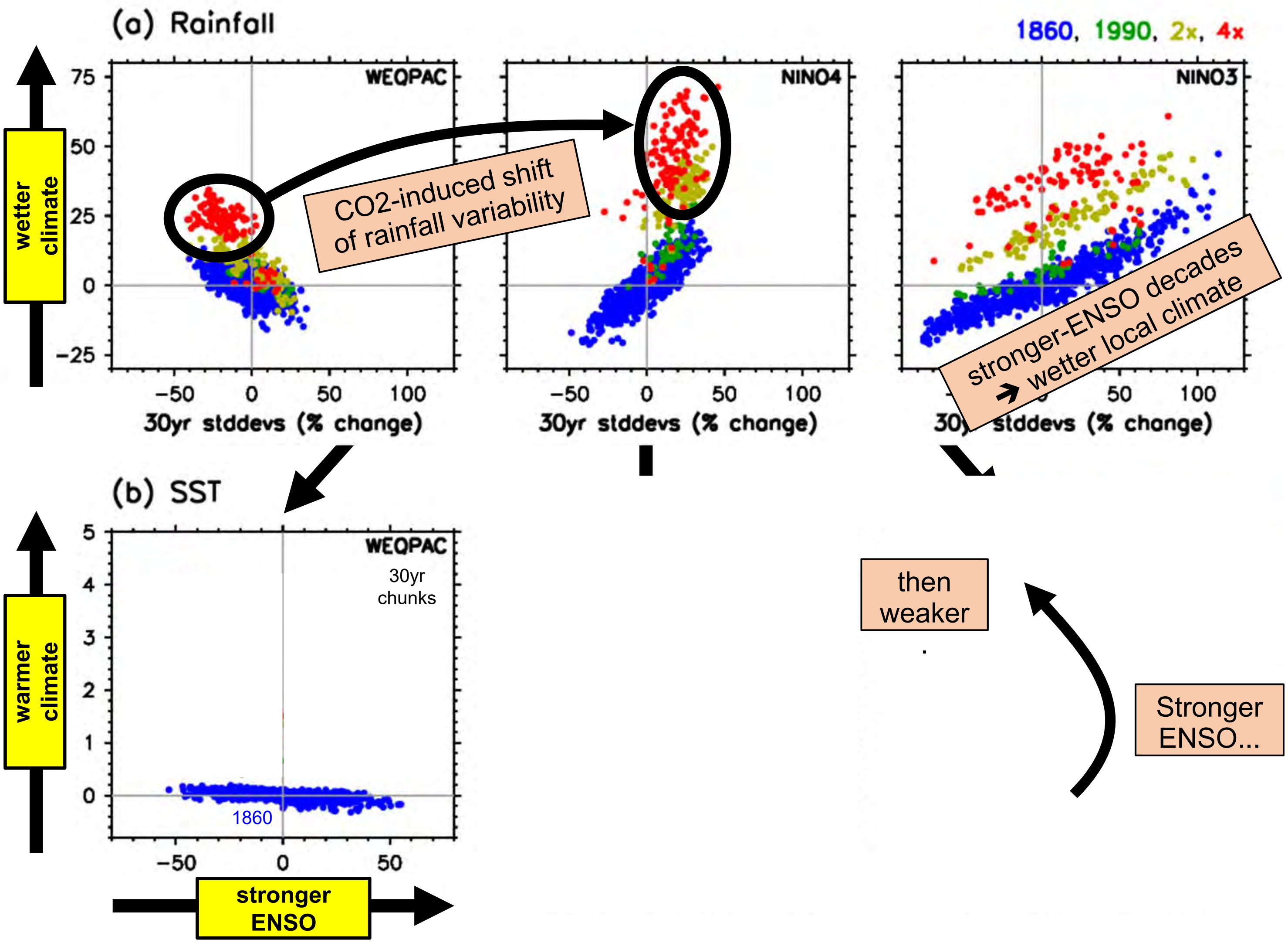
# Historical changes in ENSO & mean eq. Pacific SST




Mean SST change marginally detectable. ENSO change, less so.

*Newman, Wittenberg, et al. (BAMS 2017)*

# ENSO responses to increasing $CO_2$



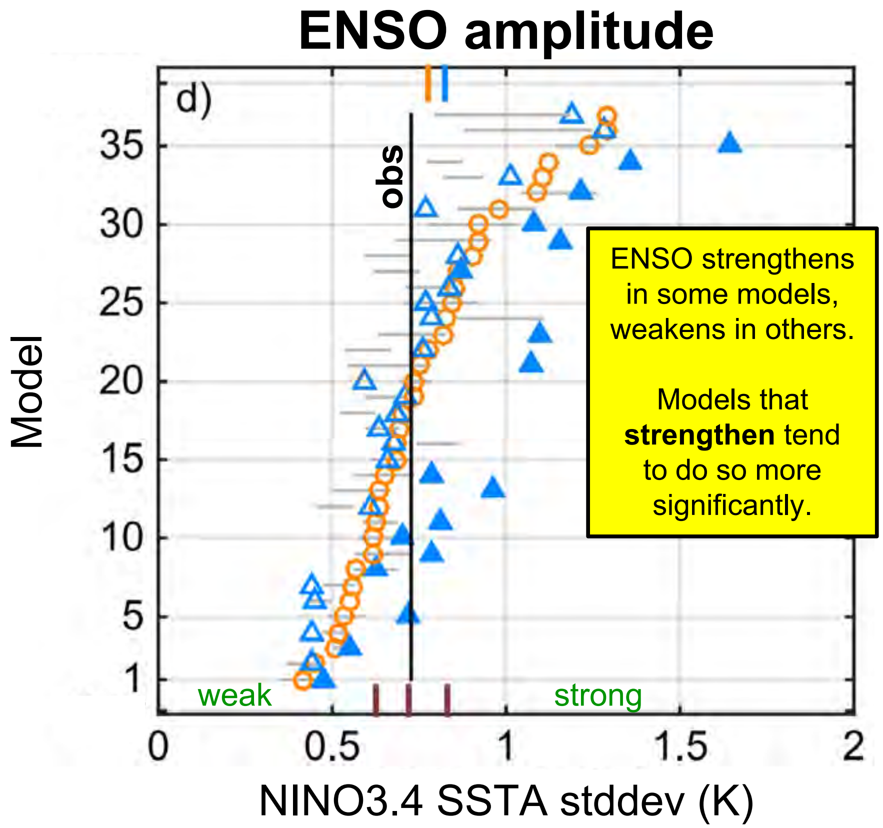

*Wittenberg (U.S. CLIVAR Variations, 2015)*

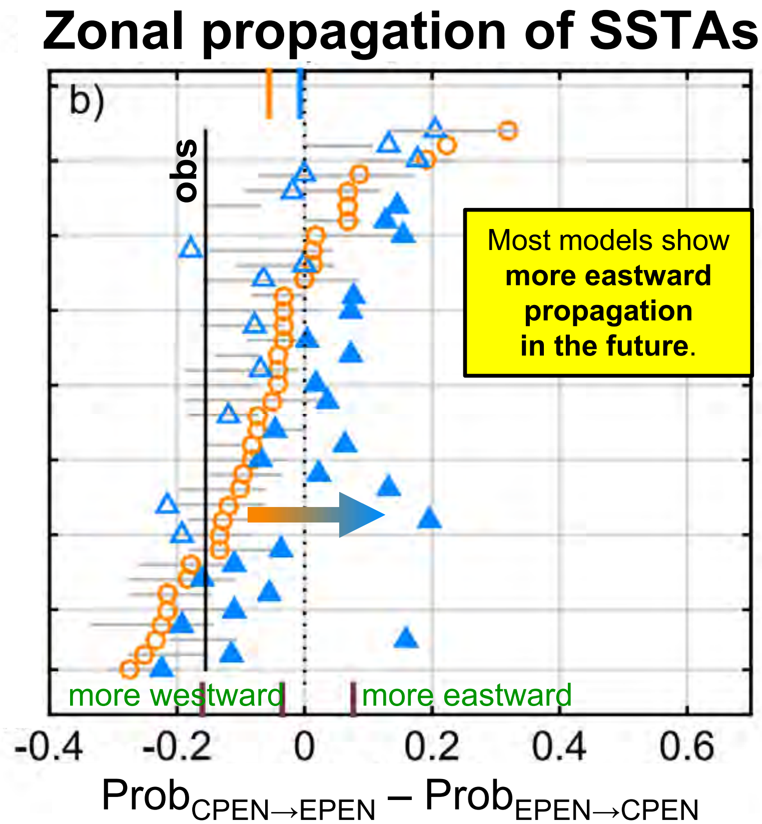
CM2.1 simulations show interplay of intrinsic ENSO modulation, multidecadal climate, nonlinear sensitivity, and regional responses to increasing $CO_2$.

Further work:

*Knutson et al. (BAMS 2014)*
*Cai et al. (NCC 2014)*
*Delworth et al. (JC 2015)*
*Choi et al. (JC 2015)*
*Kam et al. (BAMS 2016)*
*Chen et al. (JC 2017)*
*Graham et al. (CD 2017)*
*Atwood et al. (CD 2017)*
*Timmermann et al. (Nature 2018)*
*Fedorov et al. (AGU 2020)*
*Stevenson et al. (in prep)*

# CMIP5 projections (PI, 1900-99, 2000-99)

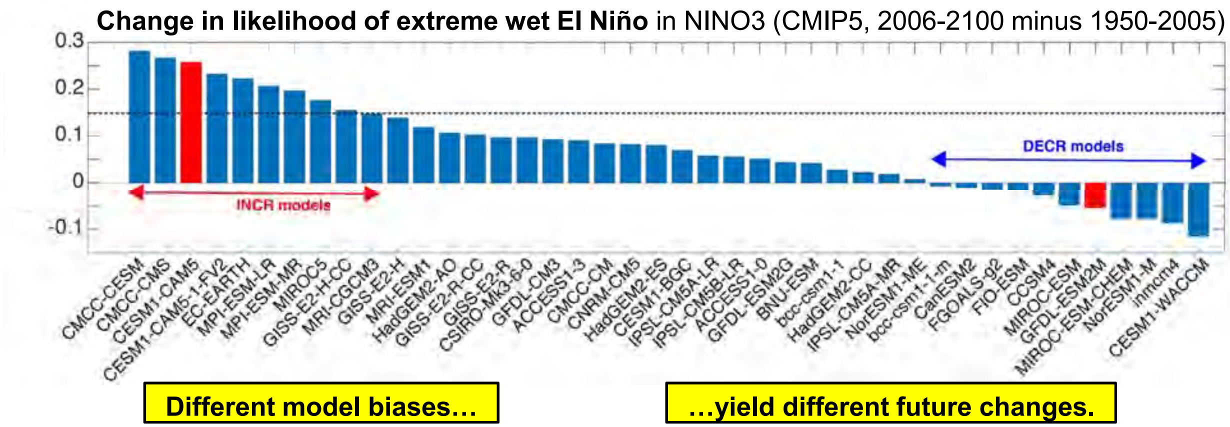


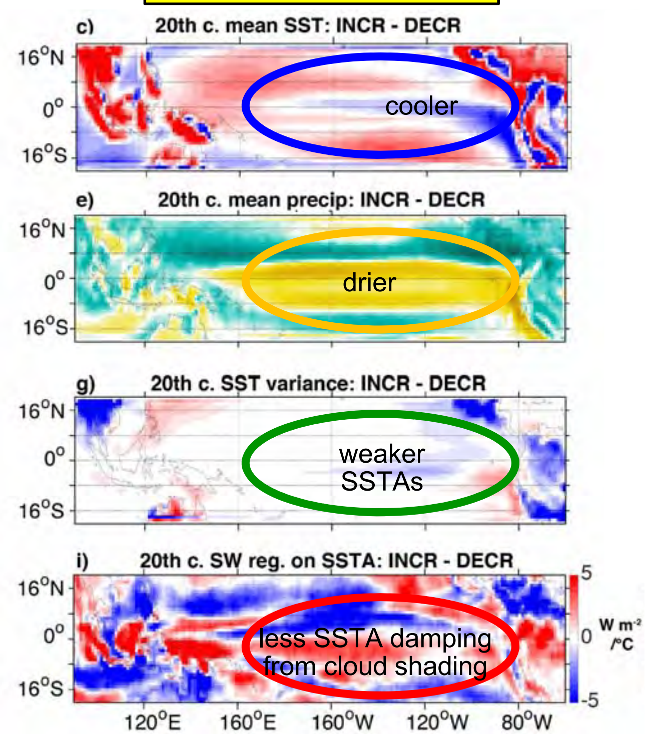




No CMIP5-model consensus on future ENSO SSTA amplitude.
But they do suggest **changes in ENSO's dynamics & evolution**.

*Chen et al. (JC 2017)*

# Emergent constraints for future ENSO extremes




*Stevenson et al. (in prep)*

Models project a wide range of changes in **El Niño rainfall extremes**: some **strongly increase**, others **decrease**.

**"Increasers"** start with common biases: **cooler** & **drier** cold tongue, **weaker ENSO**, and **weaker heat flux damping** of SST changes. → More room to amplify ENSO extremes.

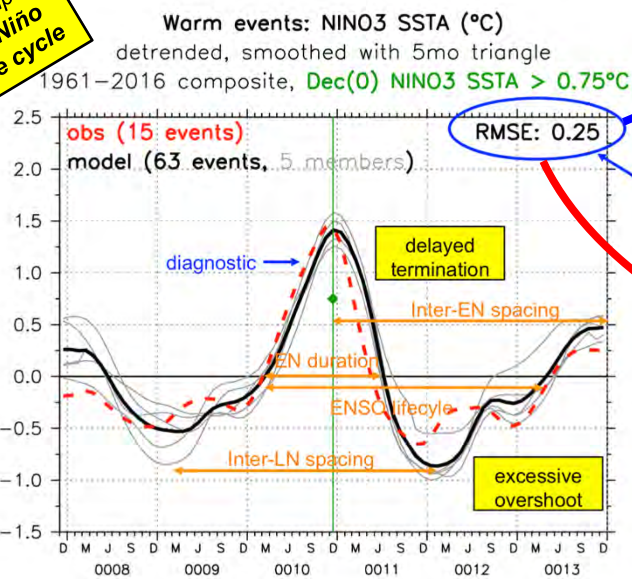
Increasers also project **more future warming, wetting, and ENSO SSTA amplification** in the cold tongue.

Can use these **emergent constraints** to leverage model diversity and inform future projections.

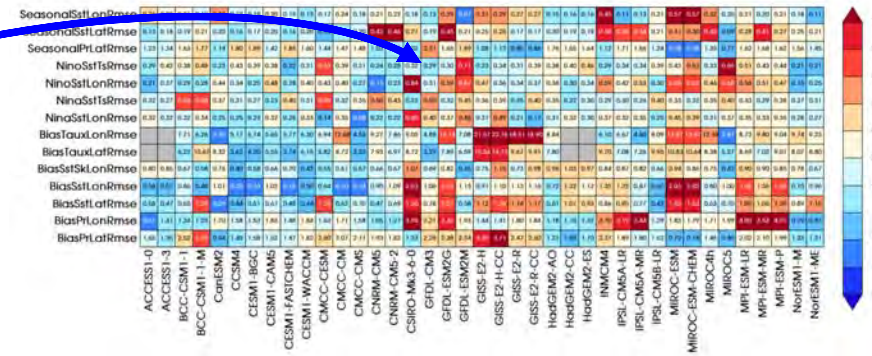
# Community metrics for ENSO simulations

**CLIVAR Research Focus on ENSO** – *Guilyardi et al. (AGU 2020); Planton et al. (in prep)*

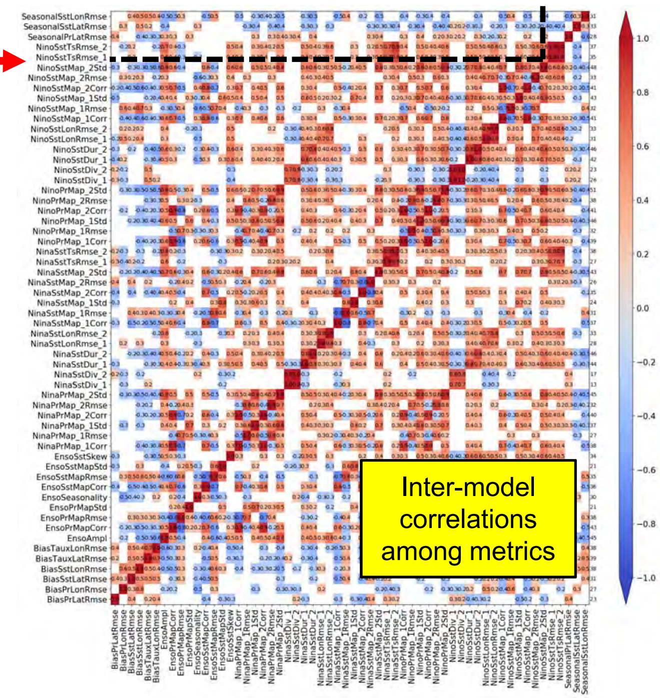
Example: El Niño life cycle



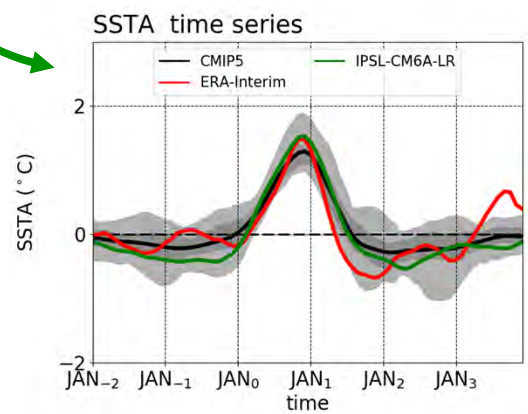

Compare to other models & metrics



Discover connections among metrics, find emergent constraints



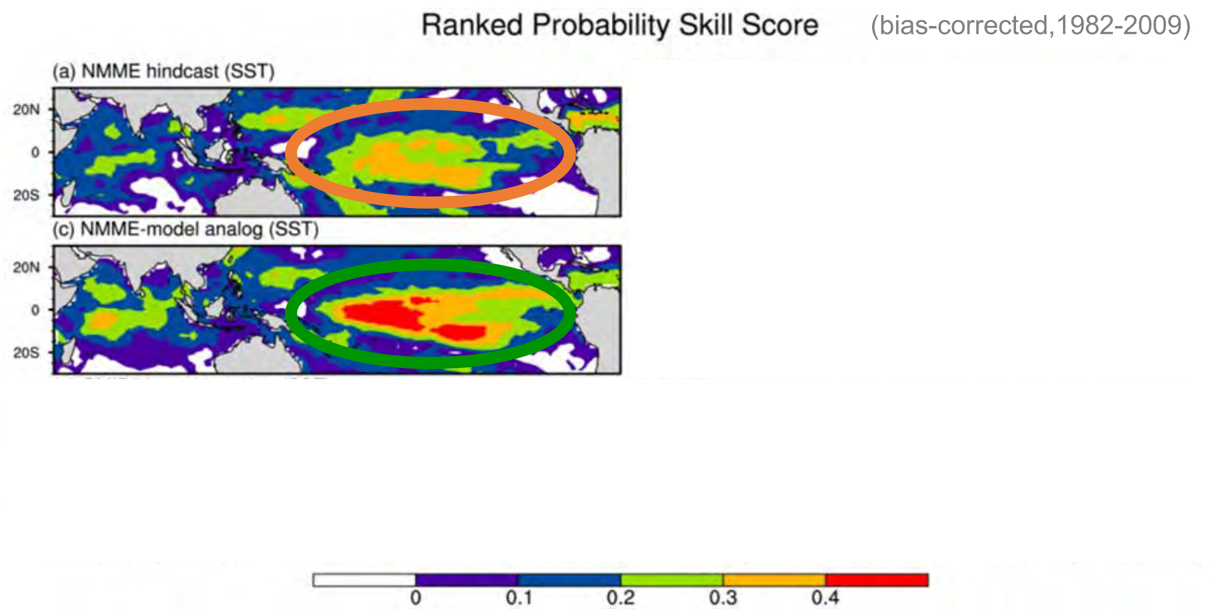

Provide multi-model context




python → CMIP, PMP (PCMDI Metrics Package), ESMValTool (Earth System Model eValuation Tool)

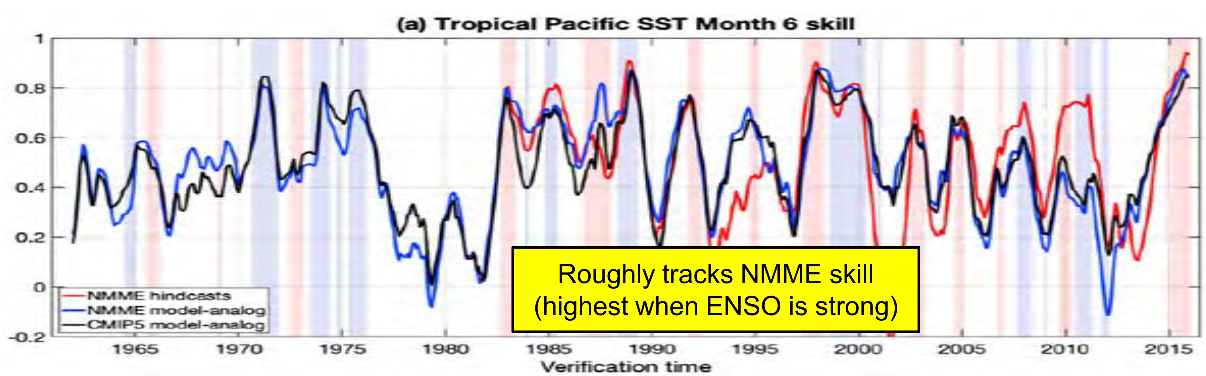
# ENSO forecasts using model-analogs

*Existing **long model control runs** are like "libraries" of ENSO behavior.*
*Find **analogs** of obs SST & SSH → trace how those states evolved in control runs.*




*→ Like a forecast with*
***no initialization shock.***

At 6-month leads in the tropics, **analogs** from the NMME control runs beat the same models' **initialized forecasts**!




Suggests that even models **without assimilation** (e.g. CMIP5) could offer useful forecast guidance.

Also permits rapid assessment of secular variations in **predictability**.

*Ding et al. (JC 2018; GRL 2019)*

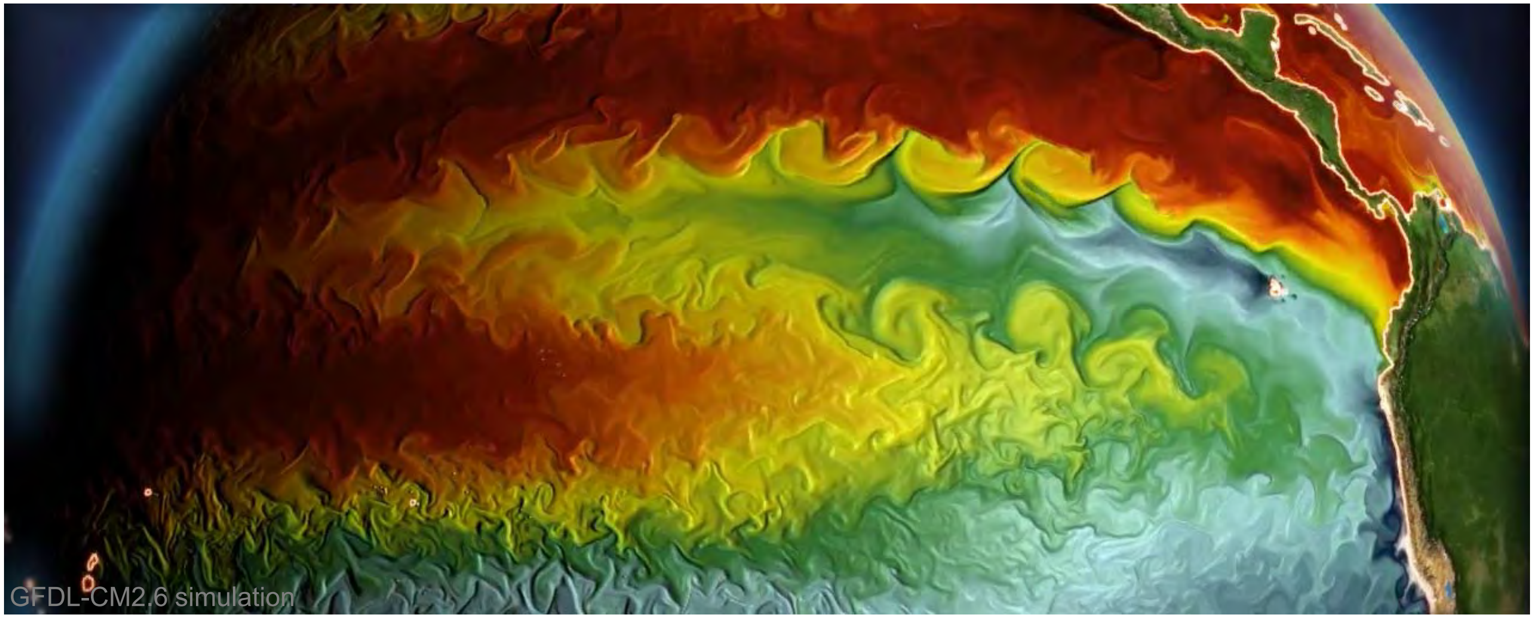
# Future plans and challenges

## 1. Better understand ENSO & improve models

a. **Background climate** is key (flux adjustments, heat/momentum budgets)
b. Community metrics & obs **constraints** (TPOS2020, LES, reanalyses, paleo)
c. Enhance model **resolution & physics**
- *clouds & convection, surface winds & fluxes, ocean mixing (TIWs), diurnal cycle*

## 2. Improve predictions & projections

a. Clarify ENSO connections to **extremes & regional** impacts
b. Understand sources & limits of **predictability** (model analogs)
c. **Emergent constraints** to improve future projections



# Summary

1. ENSO understanding & predictions are **critical to NOAA's mission**.

2. GFDL's ENSO simulations, forecasts, and projections are **among the world's best**. They are widely used, and improving.

3. GFDL is rapidly **advancing community understanding** of ENSO's diversity, dynamics, sensitivities, impacts, and predictability.

# 2014-2019 ENSO Publications (1 of 2)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Graham, F. S., et al., 2014: Effectiveness of the Bjerknes stability index in representing ocean dynamics. *Climate Dyn.*, **43**, 2399-2414. doi: 10.1007/s00382-014-2062-3

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