Uncertainties in climate projections of EXTREMES:
Forced trends in the tropical Pacific and global tropical cyclones

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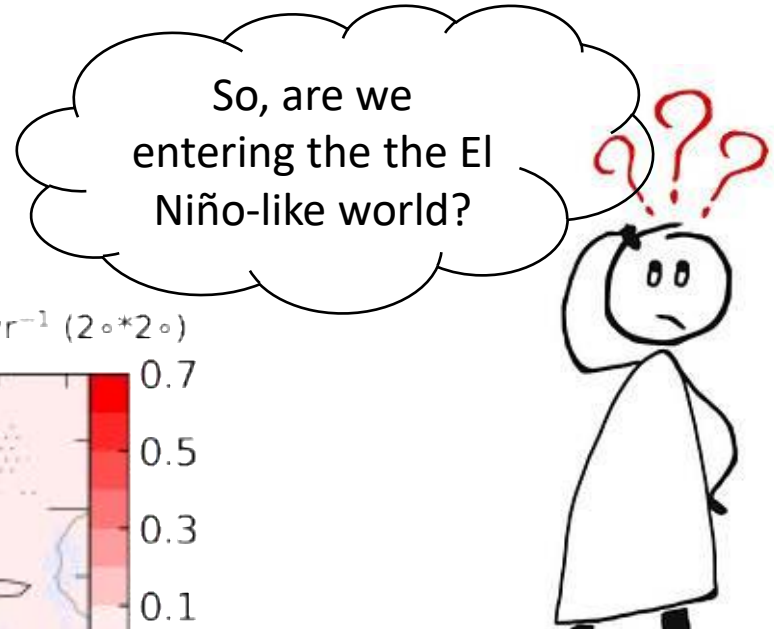
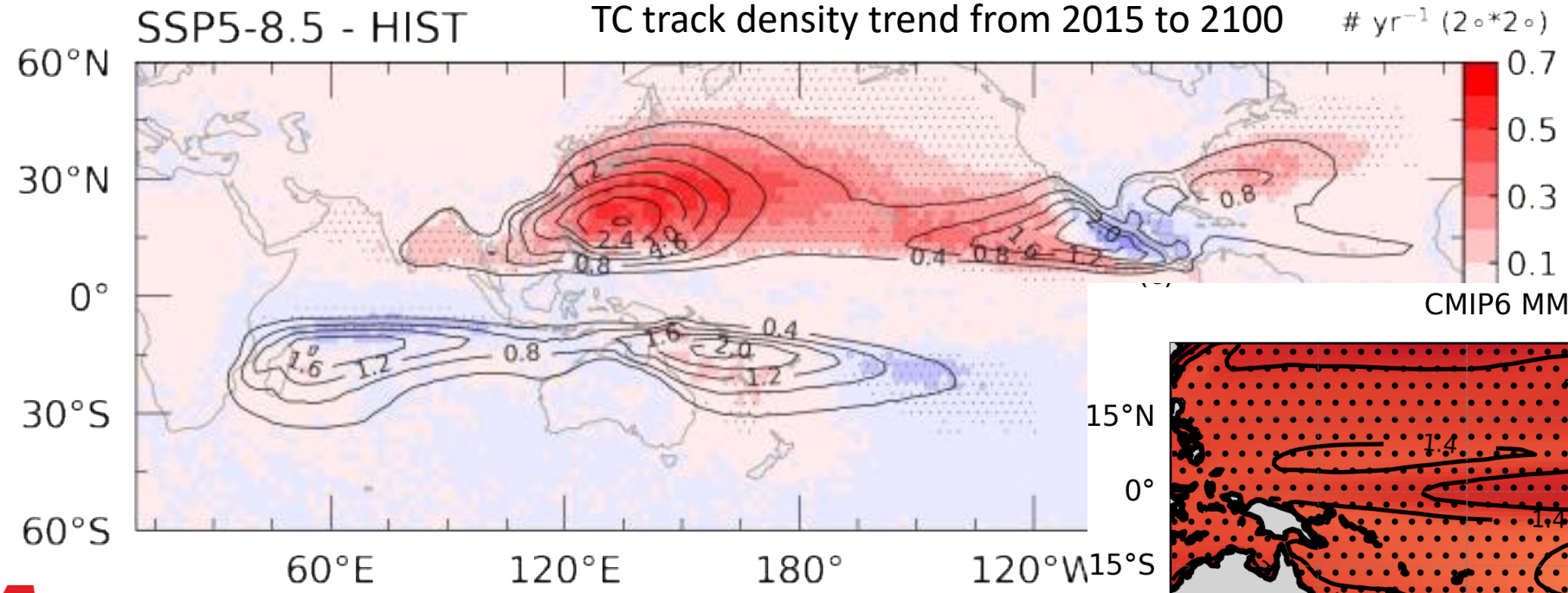
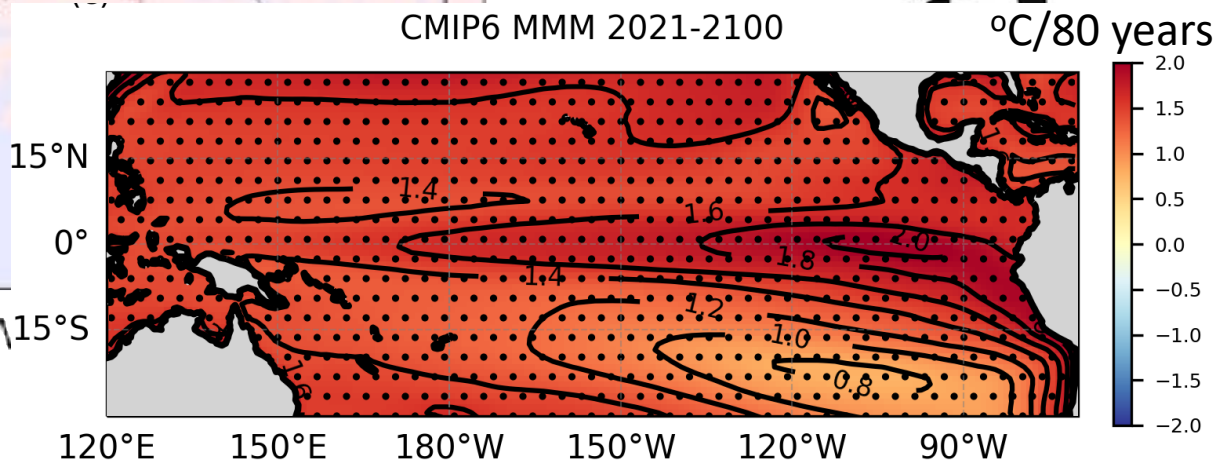
U.S. Department of Energy

El Niño-like projections of TC risk

Increased TC activity in Pacific is enhanced than in North Atlantic, similar to El Niño modulations of TC activity

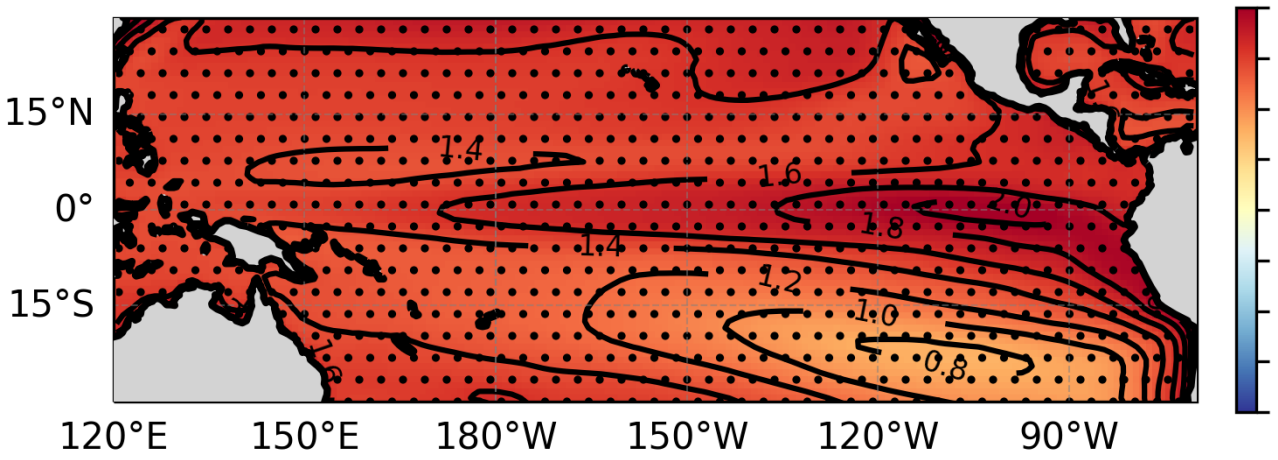


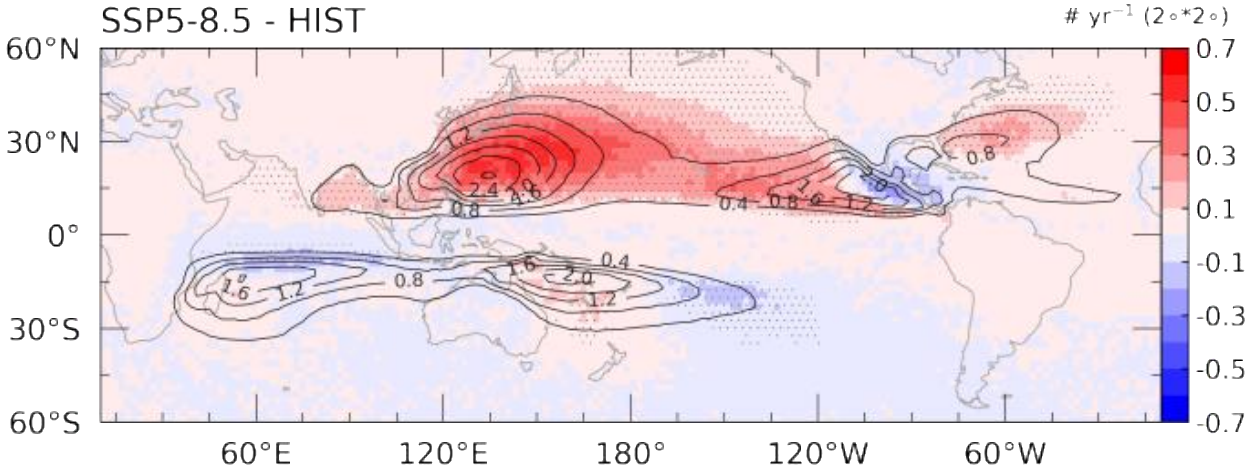




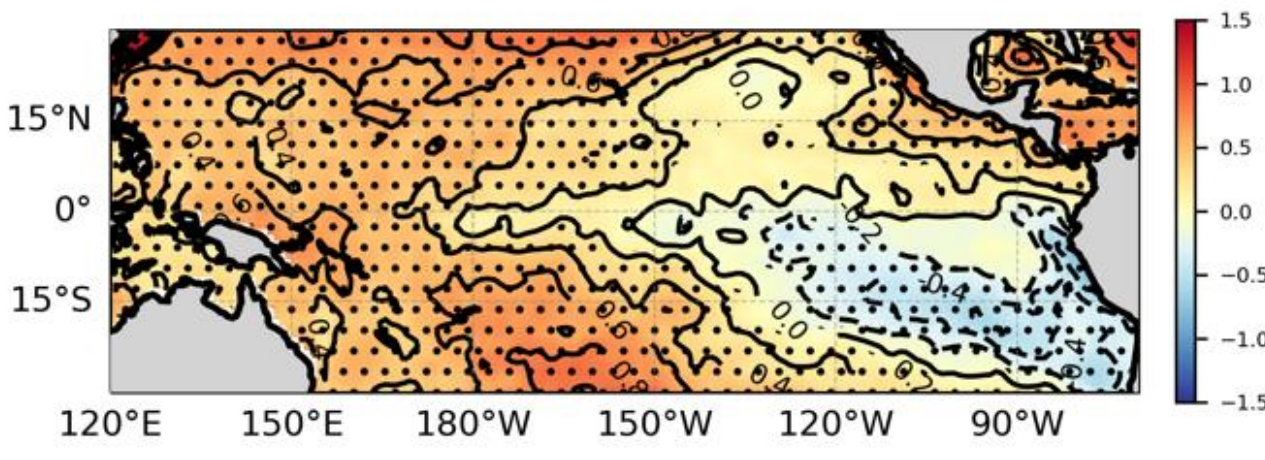
GCM's projections (or even historical simulations) of El Niño-like tropical Pacific have been **INCONSISTENT** with recent observations
So are their TC projections/simulations

El Niño-like CMIP6 MMM 2021-2100 °C/80 years





La Niña-like HadISST 1981-2020 °C/40 years



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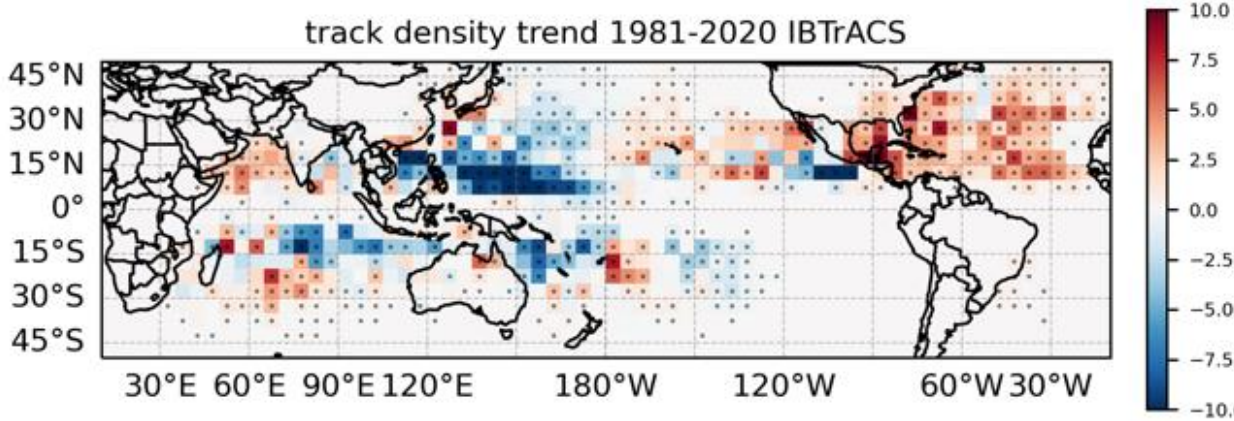


(g)

Sobel, Lee, et al. (2023 PNAS)

Observational error? Internal variability? OR Trends are real, and models are wrong?

More stable atmosphere and thus weaker circulation…

Damping in evaporative cooling in the east …

Aerosol….

Deeper convections in Western Pacific …

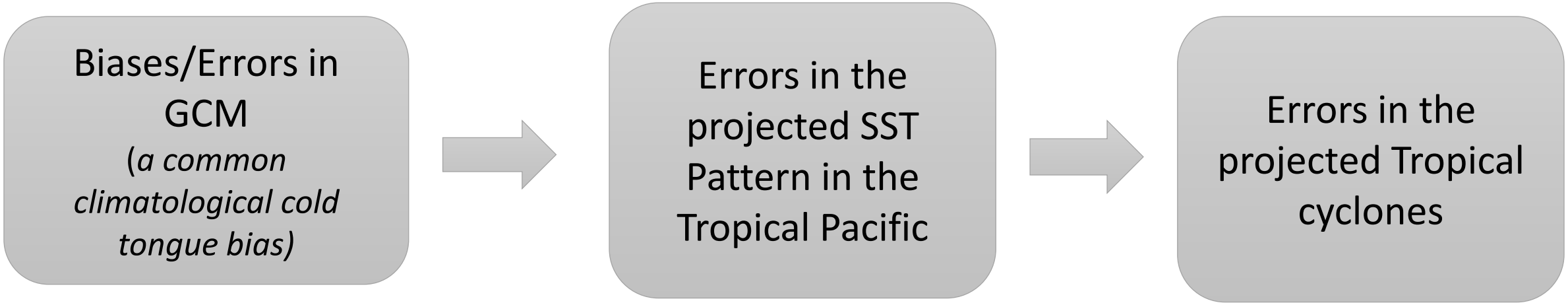
Ocean thermostat effect …

Southern Ocean heat uptake …

Seager et al. (2019): The El Niño-like trend is an erroneous consequence of a common climatological cold tongue bias that has persisted in a few generations of global climate models

e.g., Jiang, Seager, Cane (2024, Science Advance, in review). Huang et al. (2024), Kang et al. (2023), Lee et al. (2023), Heede and Fedorov (2022), Seger et al. (2022, JC);

Scientific questions



Q1: What would the **alternative projection** looks like if we force GCM to have trends similar to observations by removing biases in the cold tongue region? Why?

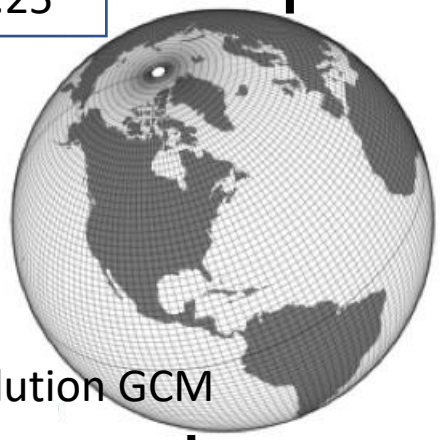
Q2: How would global TCs respond to these two different mean-state tropical Pacific changes? Through processes **similar to TC responses to ENSO** on the interannual timescale?

Hierarchical modeling approaches

Apply flux adjustment to remove mean state SST biases in tropics in **CESM2** and E3SM
(Zhuo et al. 2024, JC, submitted)

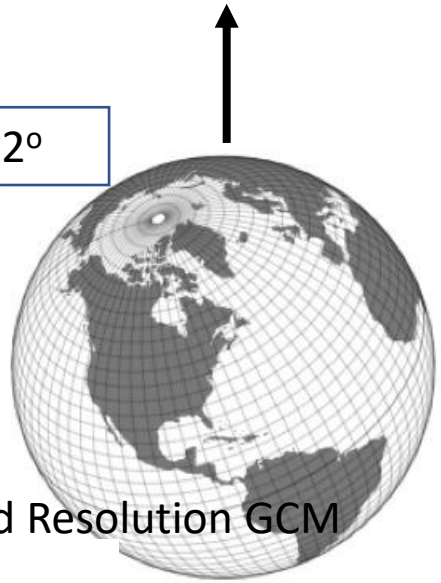
Responses of directly simulated TCs

~0.25°



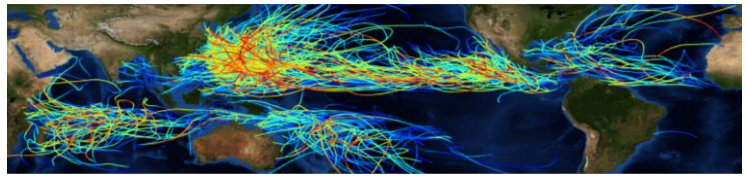
High Resolution GCM

~2°



Standard Resolution GCM

Noel Brizuela: Equatorial Pacific upwelling
Gutierrez-Brizuela et al. (2024, to be submitted, JPO)



Statistical-Dynamical Downscaling models

ENSO analogies for the forced trends of global TCs
(Lee et al. 2024, in pre.)

Dependence of global TCs on the tropical Pacific mean state in HighResMIP
Xia et al. (2024, in pre.)

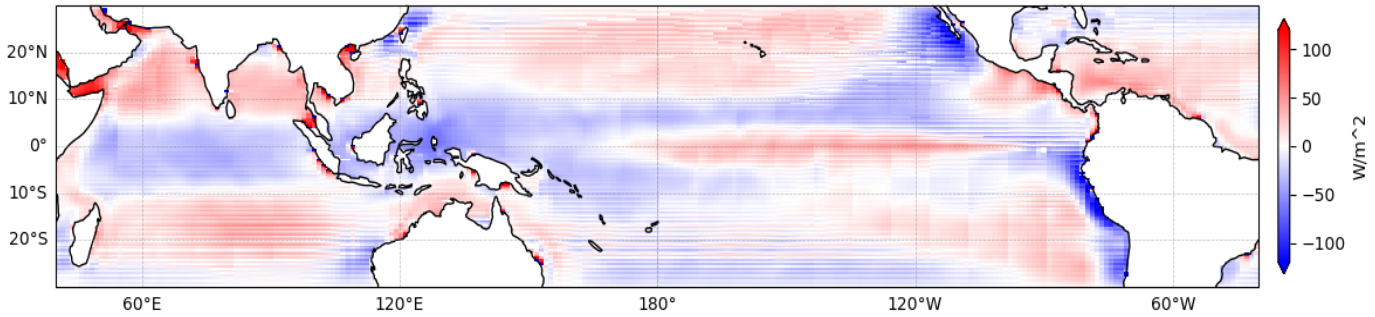
The response of TC hazard to natural & forced SST patterns
(Lin et al. 2024, Nat. Clim. Chang., submitted)

Boniface Fosu (MSU): Roles of anthropogenic GHGs and aerosols

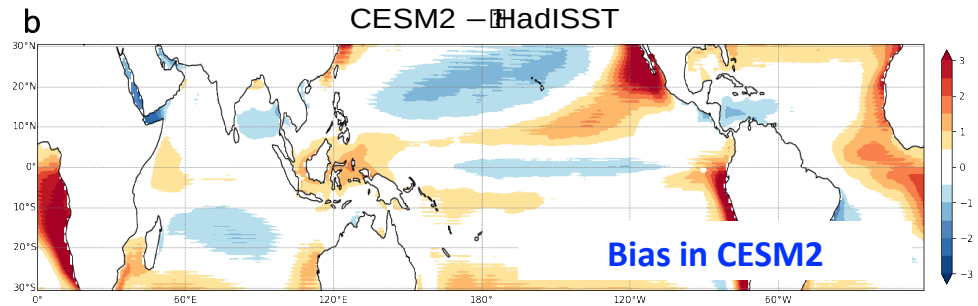
Alternative La Niña-like Projections of tropical Pacific

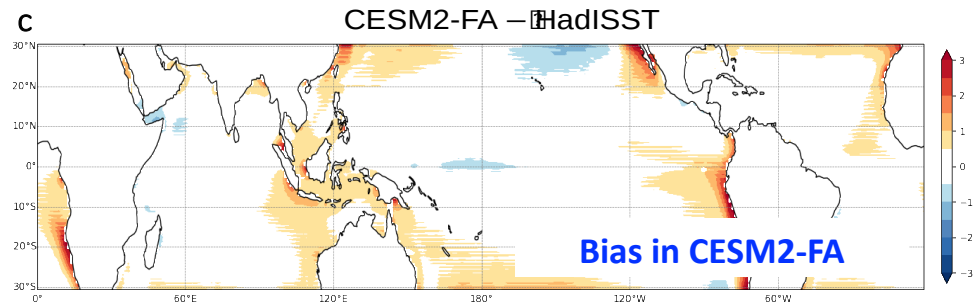
Standard CESM2 *vs.* Flux-adjusted CESM2 (CESM2-FA)

Annual Mean Heat flux adjustment terms (W/m^2)



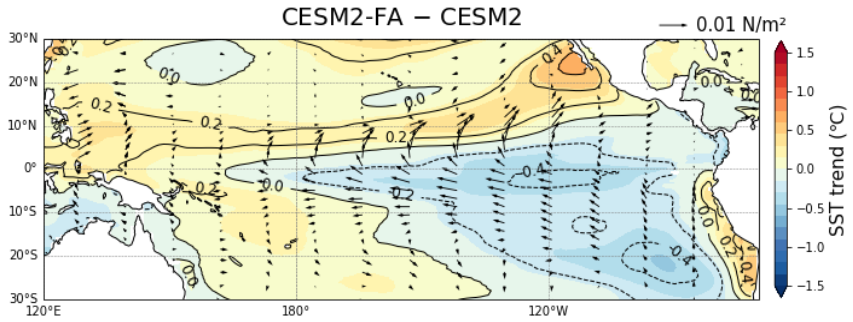
- **Same model setting:** fully-coupled CESM2 at ~ 2° for atmospheric, ~1° for oceanic resolution (f19_g17)
- **Same Forcing:** all are subjected to identical historical forcing (1950-2014) + SSP-585 (2015-2049)
- **Flux adjustment approach:** climatological monthly heat & momentum flux corrections added to the ocean component of CESM2; 30°S~ 30°N （Vecchi et al. 2014)
- **Ensemble:** 15 members initial condition perturbation

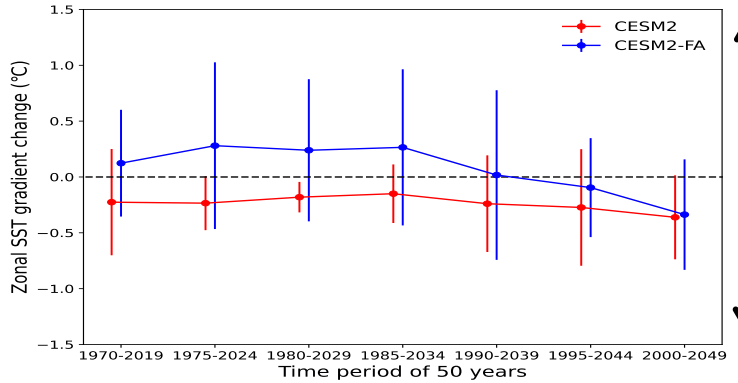




Zhuo, Lee, et al. 2024 *(submitted to JCL)*

Alternative La Niña-like Projections of tropical Pacific

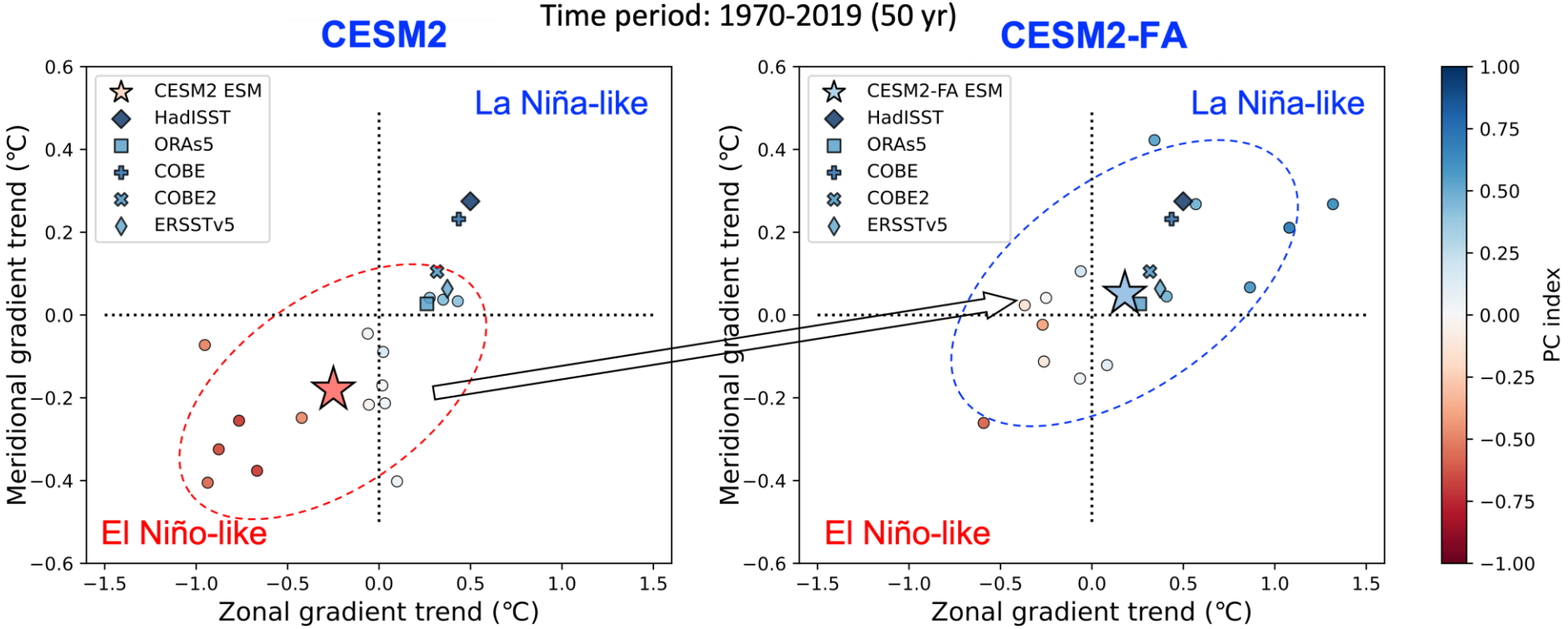




La Niña-like warming

El Niño-like warming

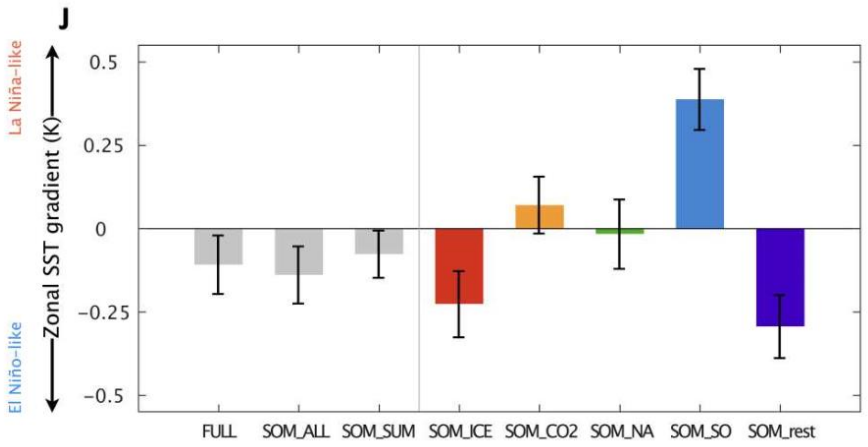
Time period: 1970-2019 (50 yr)



Zhuo, Lee, et al. 2024 *(submitted to JCL)*

Problem solved? Not so fast…

- physical mechanisms behind the patterns
- model sensitivity
- resolution matters



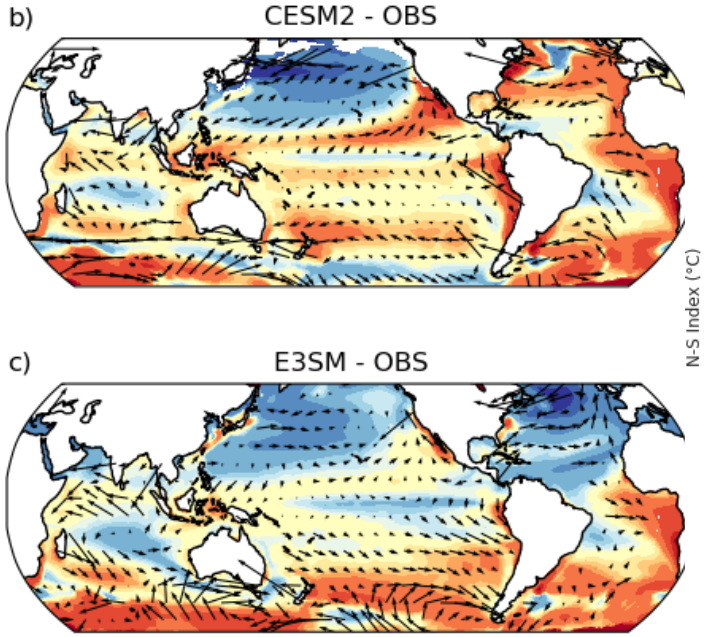
Sea ice melting

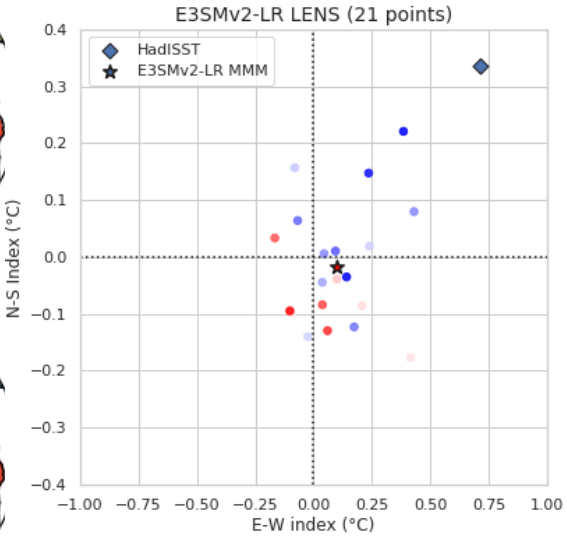
Double CO2

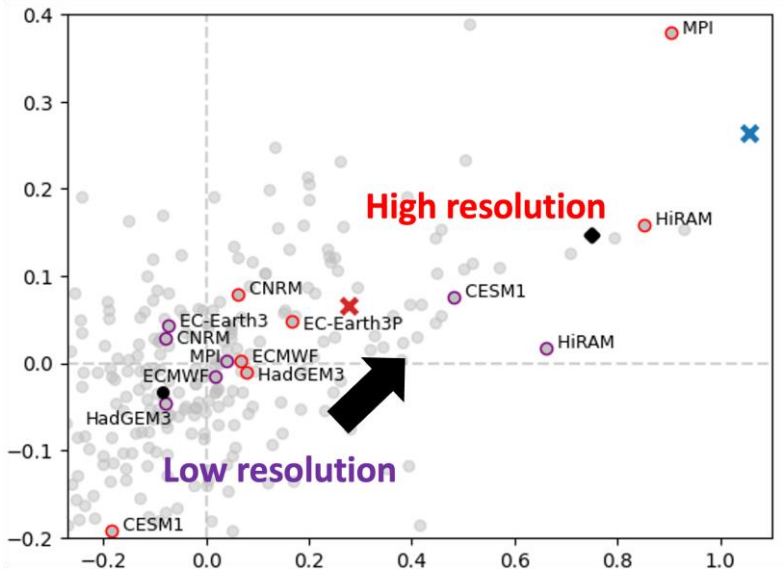
Southern Ocean heat uptake

Ocean heat uptake for the rest ocean

Kang et al. (2023, Science)

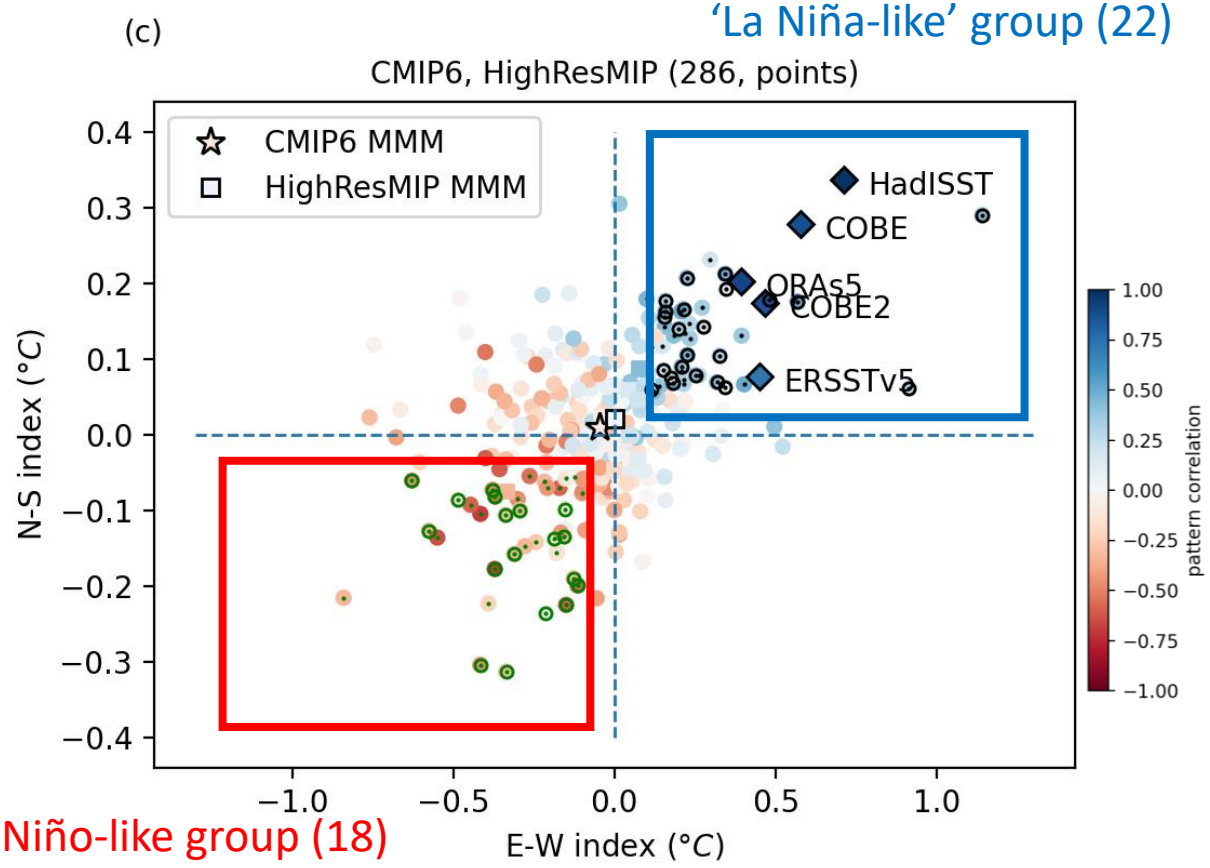






Global TC responses to ENSO-like mean state changes are ***different*** from their responses to ENSO at the interannual timescale

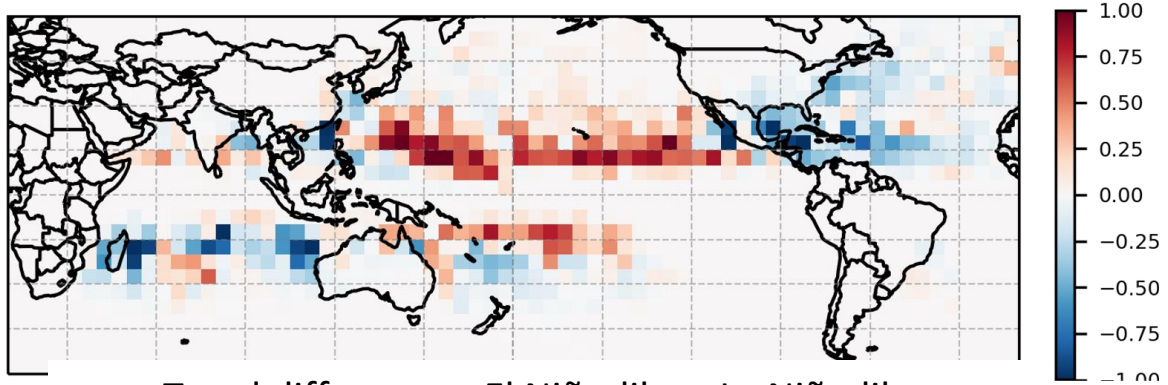
We need to be cautious when using ENSO (especially La Niña-like) analogies to communicate future trends of extreme events like TCs!



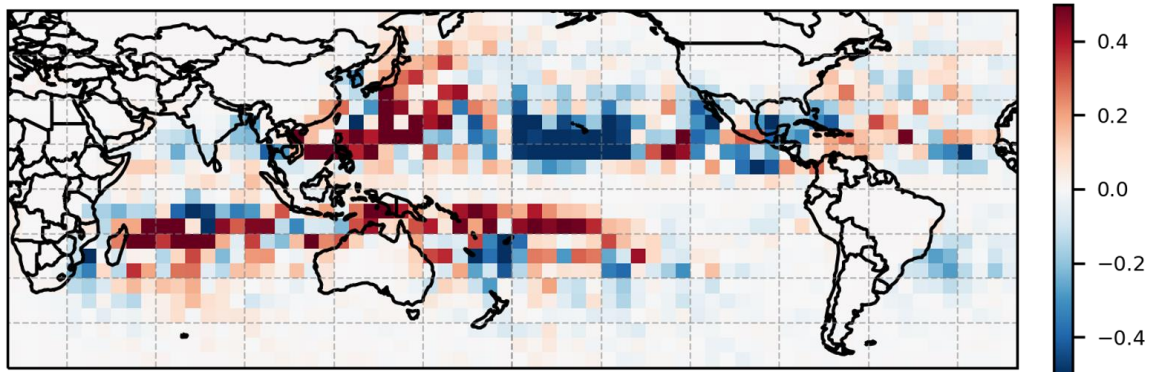
'La Niña-like' group (22)

El Niño-like group (18)

ENSO TC composite; El Niño– La Niña



Trend differences; El Niño-like – La Niña-like



Lee et al. 2024 *(in pre.)*

Uncertainties in climate projections of EXTREMES

- **How can we characterize uncertainties that are difficult to quantify, e.g., distributions on the multi-model ensembles don't capture them?**
  - from a scientific perspective
  - from a pragmatic perspective (for estimate risk of extremes in which the information is actually be used….)
- **On the forced trends in tropical Pacific: what is the real world doing, what are models doing, why do they differ?**
  - physical mechanisms behind the patterns
  - model sensitivity
  - resolutions
- **On the climate informed TC risk assessment – Gaps between physics-based downscaling TC hazard model and real world**
  - freedom to capture climate change impacts vs. observational constraints

These problems are generic

– not just specific to TC risk or to the Tropical Pacific, though both have their own special issues –

and are worth researching as an opportunity for coordinated efforts

Summary

Q1: What would the **alternative projection** looks like if we force GCM to have trends similar to observations by removing biases in the cold tongue region? Why?

Based on CESM2, the alternative projection is more La Niña-like

Q2: How would global TCs respond to these two different mean-state tropical Pacific changes? Through processes **similar to TC responses to ENSO** on the interannual timescale?

Not really, We need to be cautious when using ENSO (especially La Niña-like) analogies to communicate future trends of extreme events like TCs!

U.S. DEPARTMENT OF ENERGY

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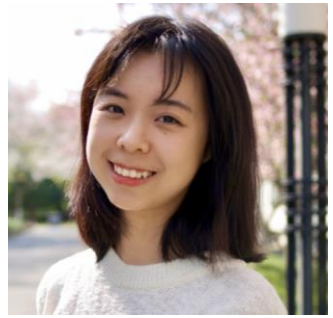
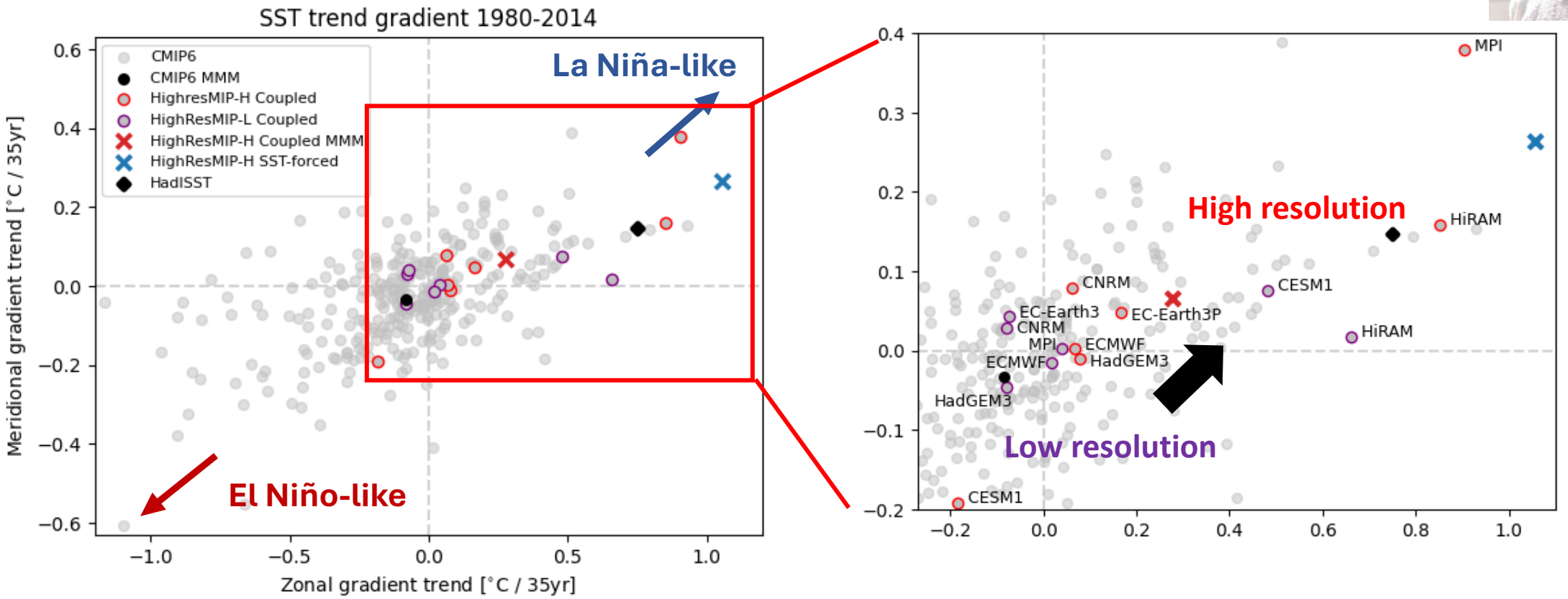
Can the models be improved with increasing horizonal grid spacing??

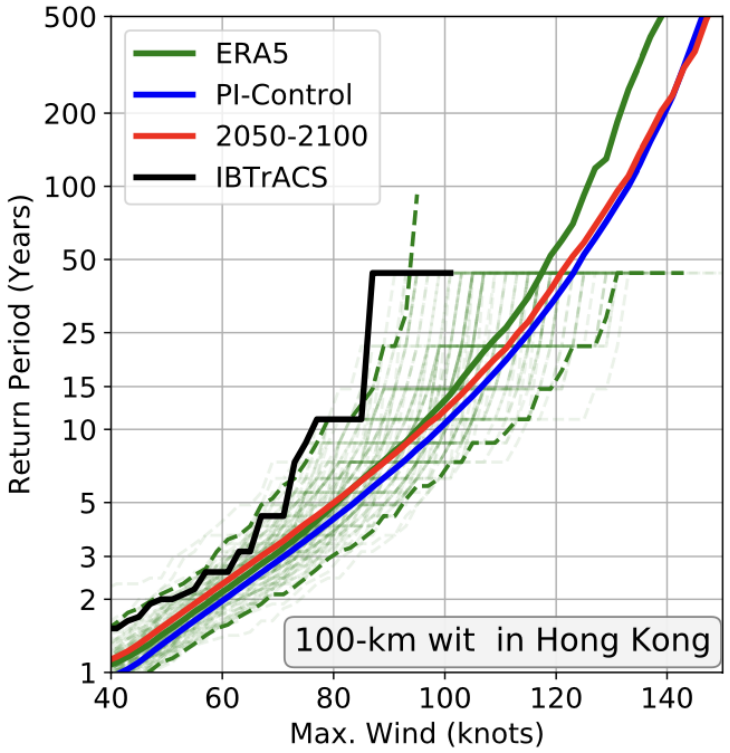




by Yi Xia (Xia et al. 2024, in pre.)

El Niño-like projection mutes the signal of increasing TC risk in Hong-Kong

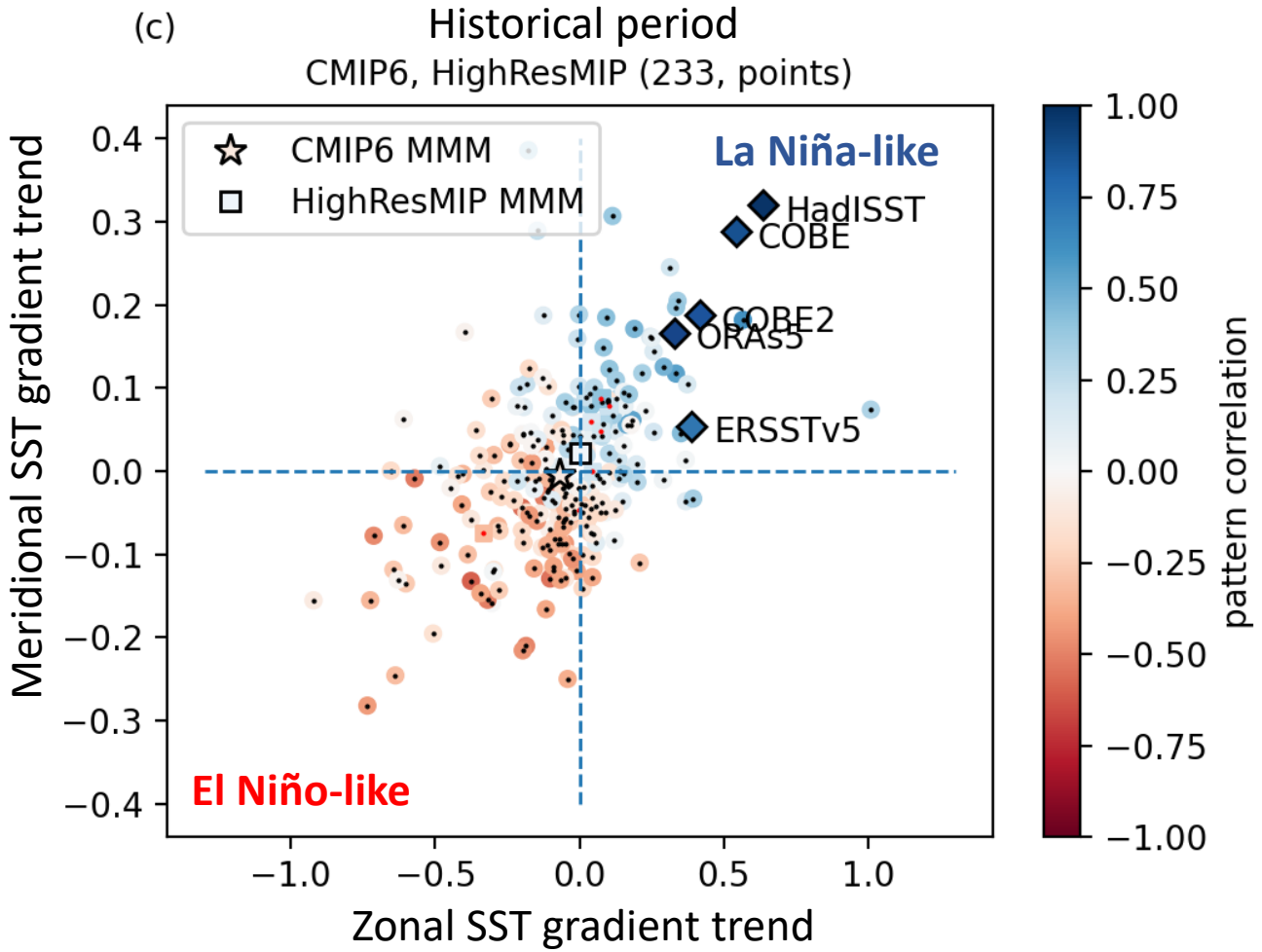
Lower Risk



Higher Risk

Lin, Lee, et al. (2024, in prep.)

Observational error? Internal variability?



Jiang, Seager, Cane (2024, Science Advance, in review)

Seger et al. (2022, JC); Sobel, Lee, et al. (2023 PNAS)