An Origin of North American Monsoon Retreat Biases in Climate Models

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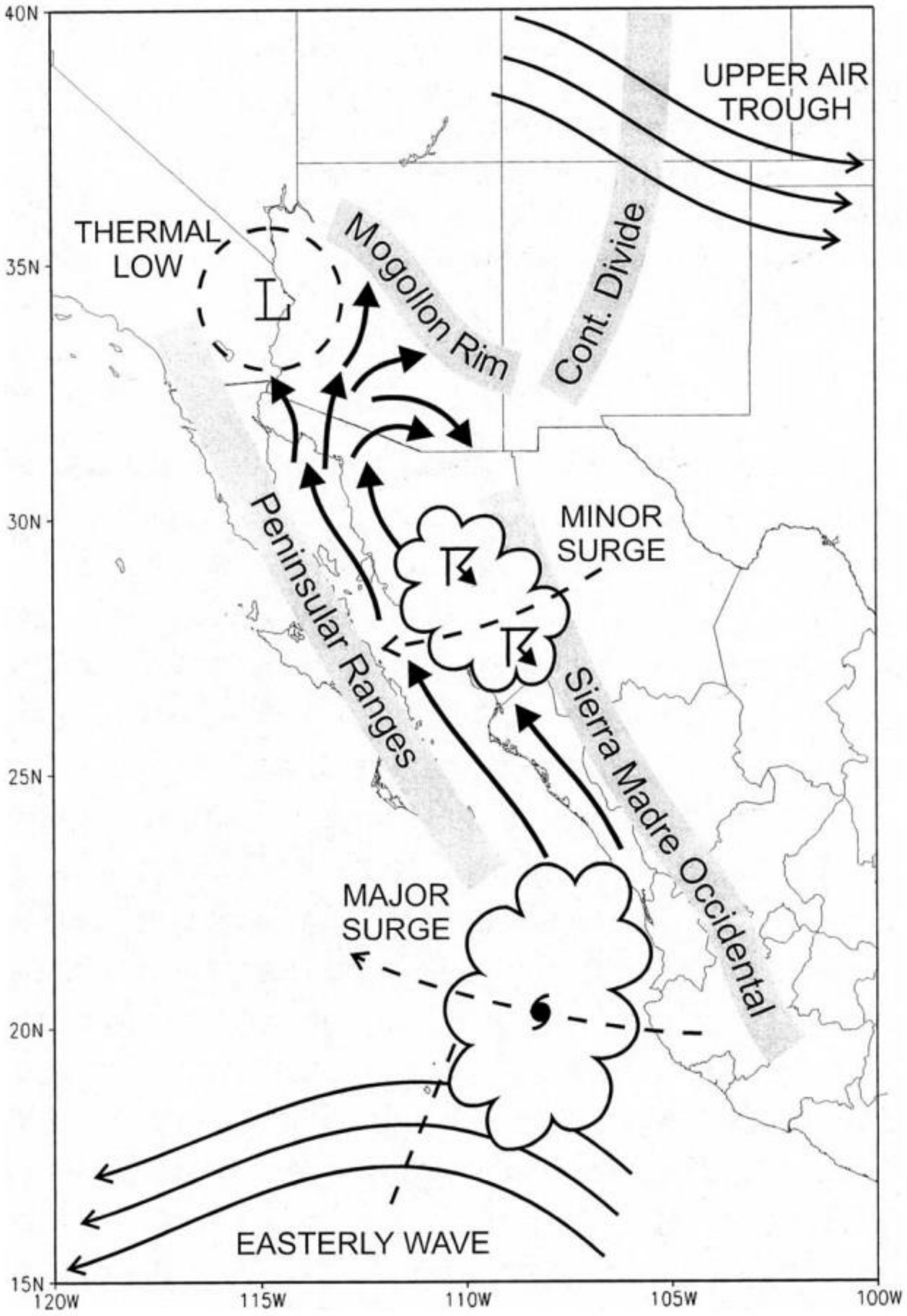
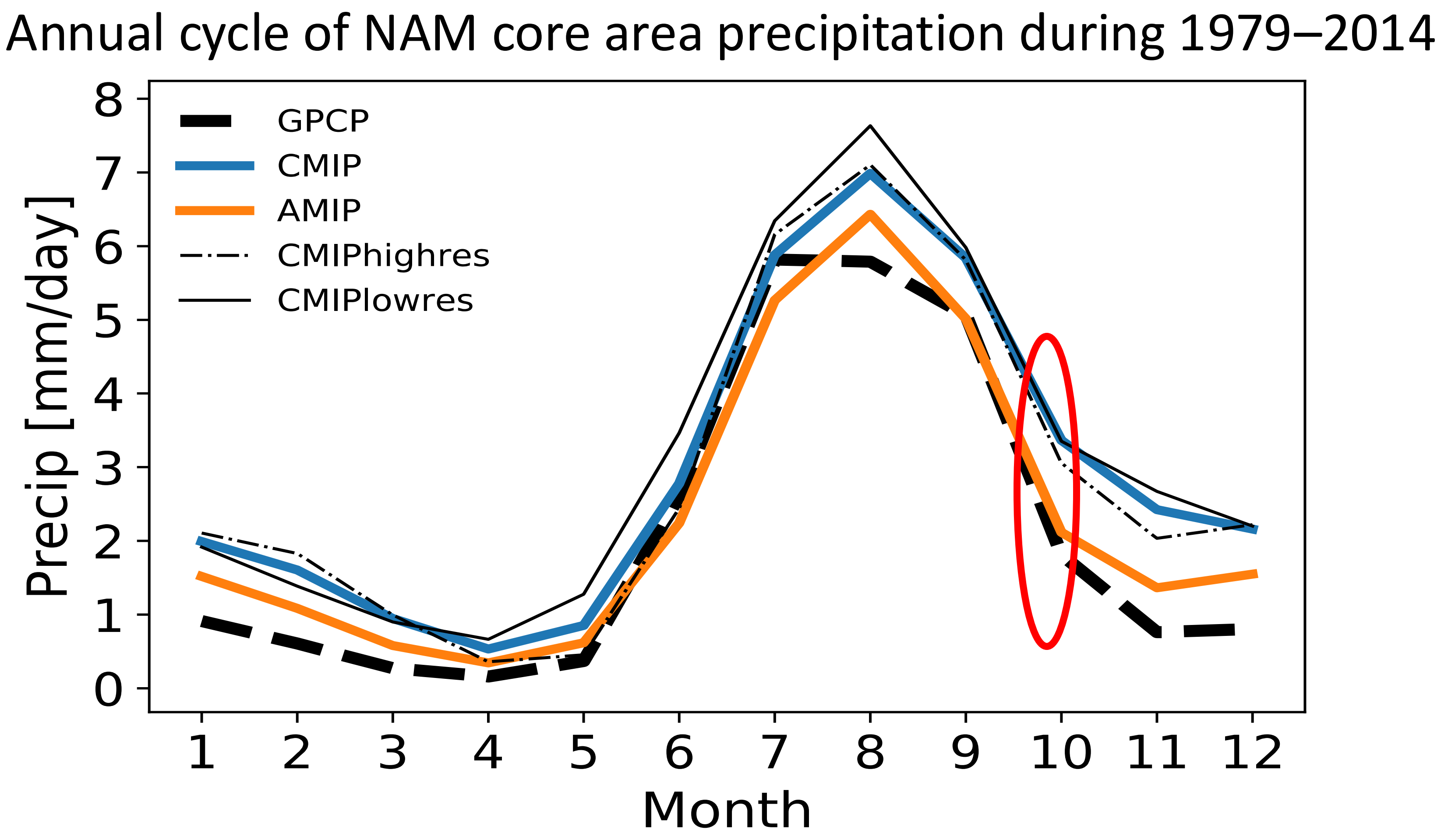


Source: Adams and Comrie (1997)

North American monsoon

- one of the most prominent hydrological features over southwest North America
- Gulf of California (GoC) surges (below 700 hPa);
- Gulf of Mexico (GoM) serves as another moisture source.
- Sierra Madre Occidental (SMO).
- Tropical easterly waves, TCs …

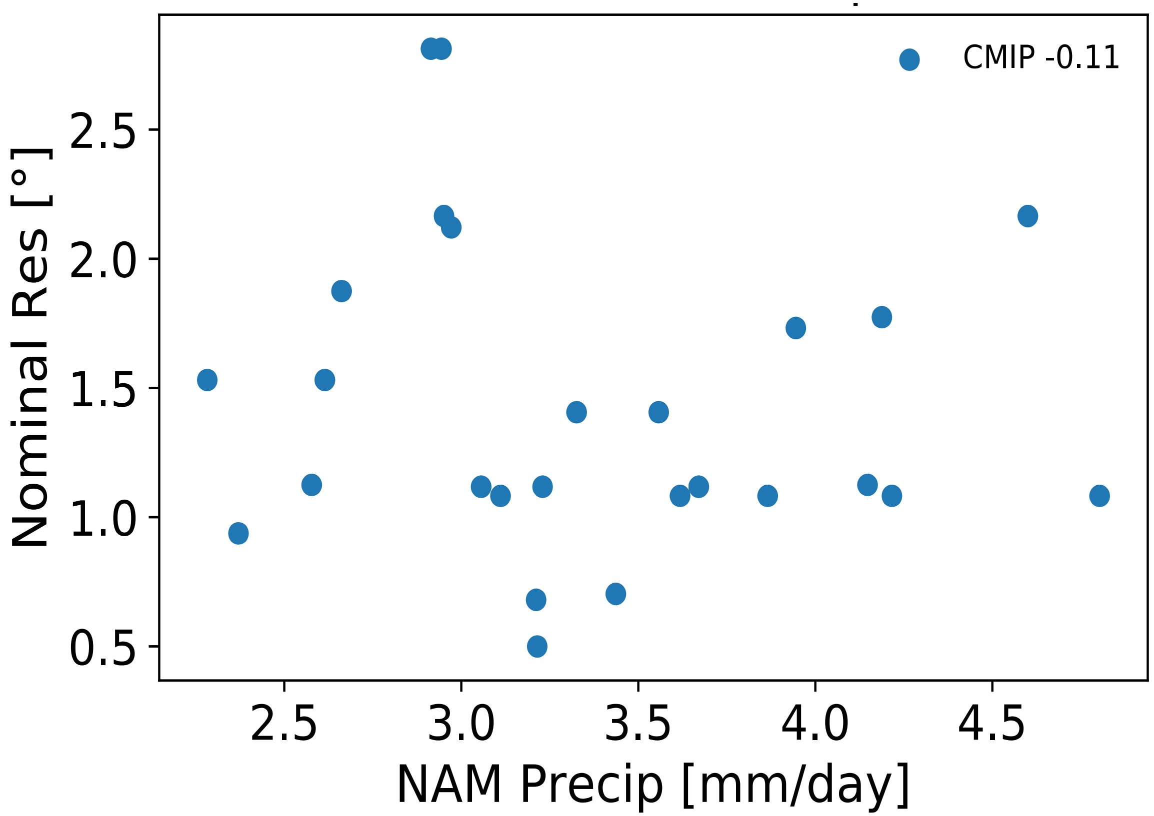
How do the state-of-the-art climate models represent NAM precipitation?



- AMIP models represent the NAM retreat better than the CMIP models.

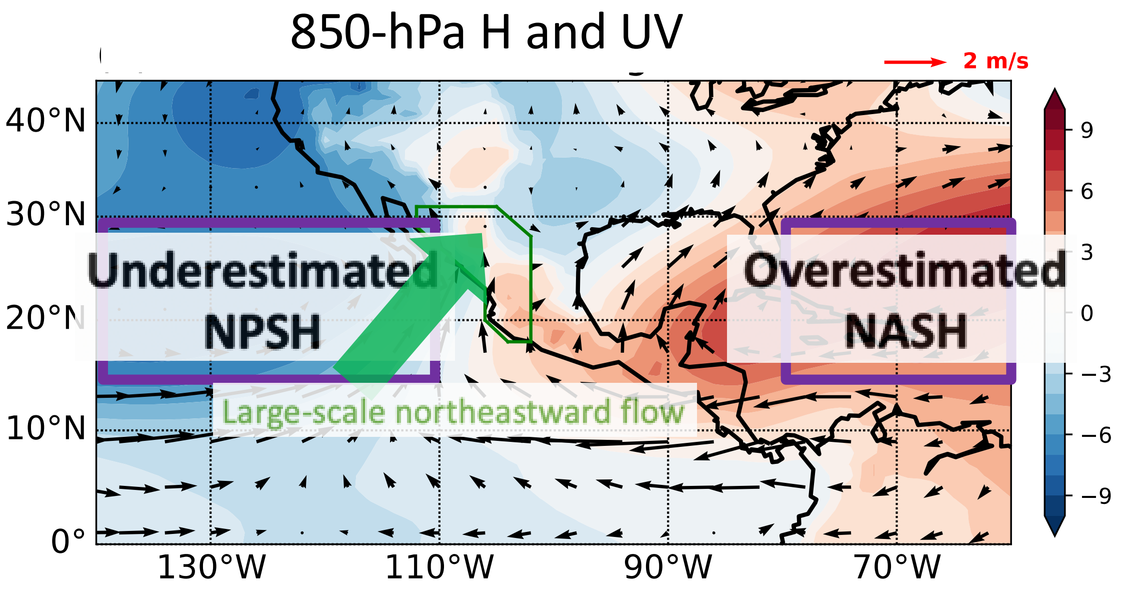
Does higher model resolution help?

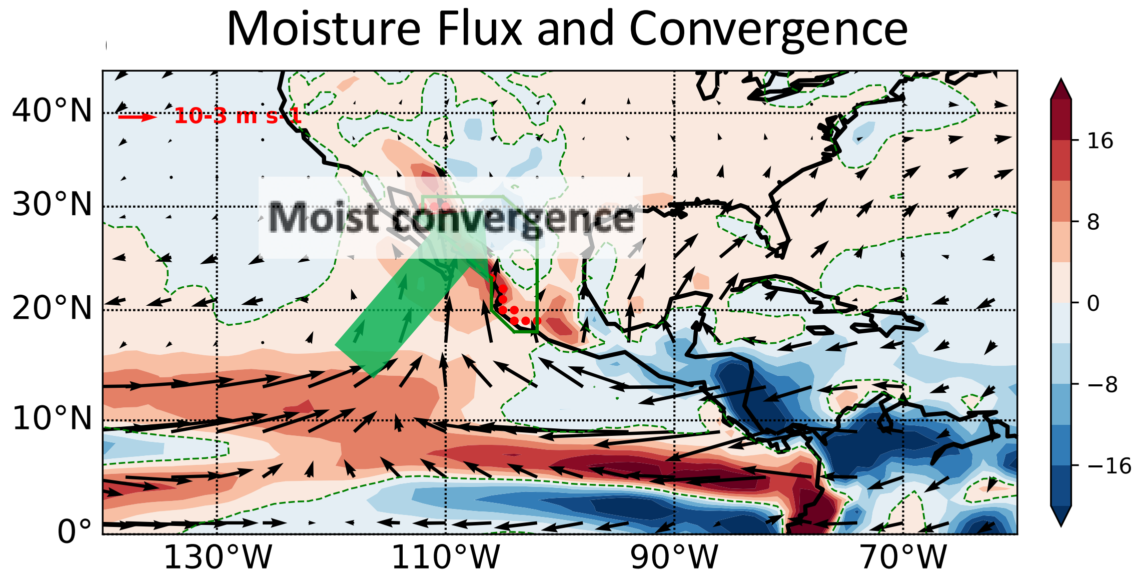
Scatterplot between model resolution and monsoon core precip in October



- Model resolution has limited impacts on the retreat season precipitation.
- ***What causes the NAM retreat biases (October) in CMIP models?***

Differences btw CMIP and AMIP Multi-model Ensemble Mean
CMIP "minus" AMIP



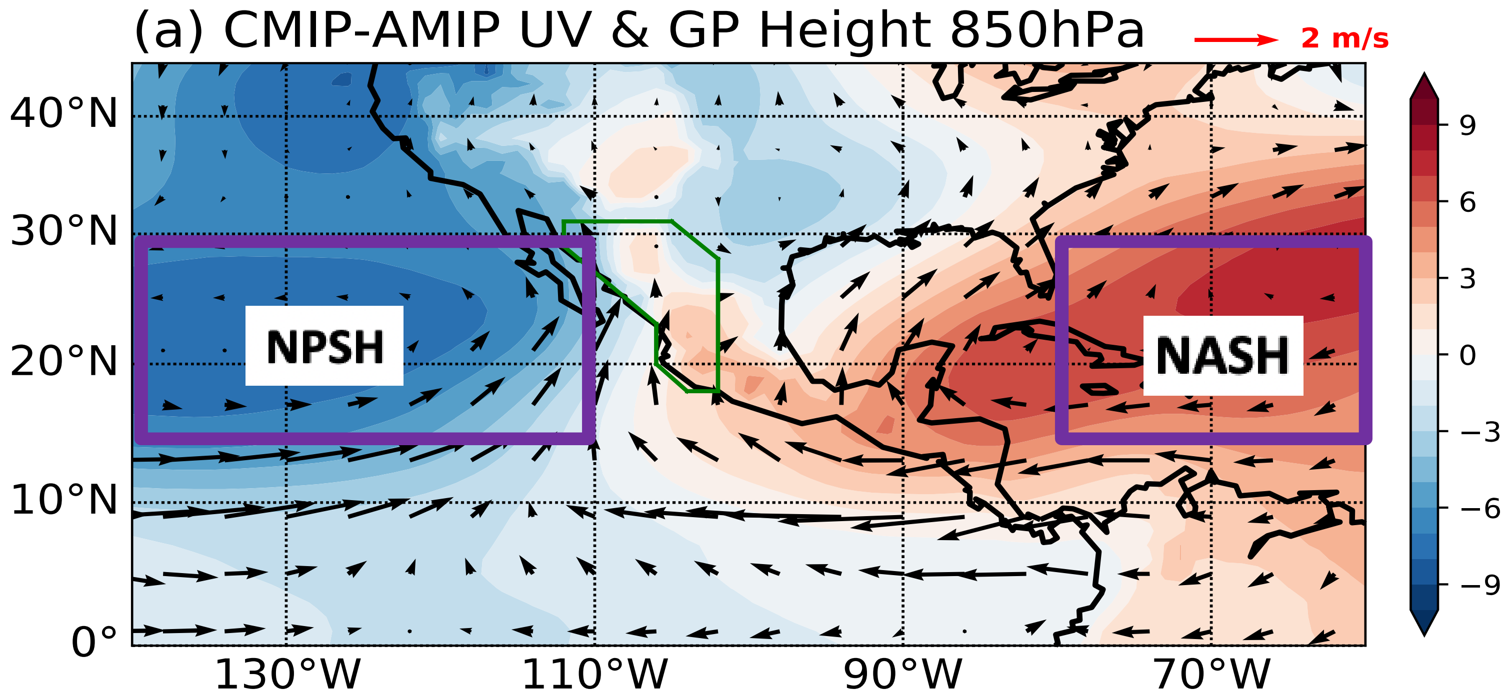


Positive GP height anomaly
→ UV

Moisture flux convergence
→ Moisture flux

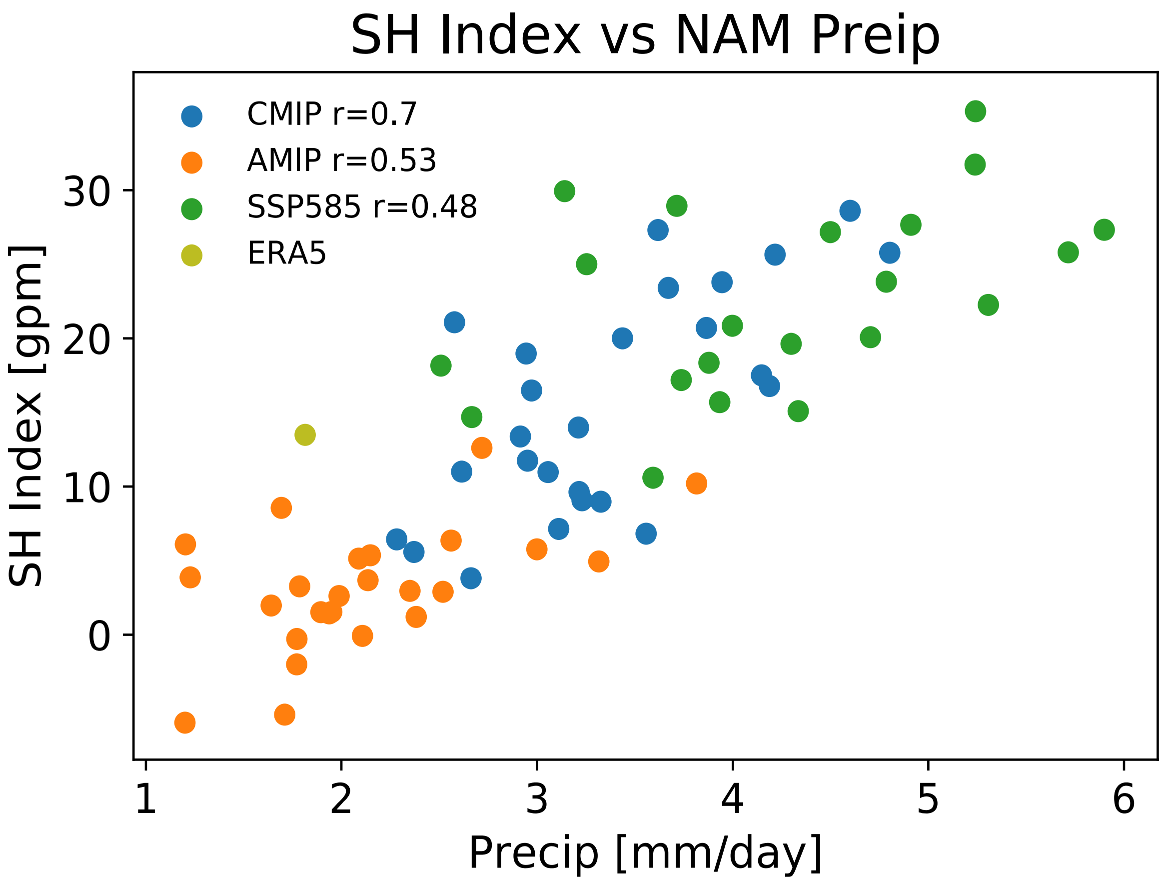
NPSH: North Pacific subtropical high
NASH: North Atlantic subtropical high

Definition of a Subtropical-high (SH) Index



SH = North Atlantic H850 “minus” North Pacific H850

Scatterplot btw the SH index and NAM Precip (Oct)



- ➢ A large SH index (i.e., relatively stronger NASH) leads to higher retreat-season precipitation.

What leads to the subtropical high biases?

- **We adopted a stationary wave model (SWM; Ting and Yu 1998) to diagnose the subtropical high biases.**
- Linearized primitive equations.
- Solves these equations for anomalies relative to a specified three-dimensional basic state.
- **The SWM is forced by three terms, diabatic heating,** topography and transient eddies **(not important).**
- The SWM helps to establish the link of the NAM retreat bias to regional diabatic heating biases.

$$\frac{\partial \zeta}{\partial t} = -\nabla \cdot \{(f+\zeta)\cdot \mathbf{V}\} - \mathbf{k}\cdot\nabla\times\left\{RT\nabla \ln P_s + \dot{\sigma}\frac{\partial \mathbf{V}}{\partial \sigma}\right\} - \varepsilon\zeta - \nu\nabla^4\zeta \tag{A1}$$

$$\frac{\partial D}{\partial t} = \mathbf{k}\cdot\nabla\times\{(f+\zeta)\cdot\mathbf{V}\} - \nabla\cdot\left\{RT\nabla \ln P_s + \dot{\sigma}\frac{\partial \mathbf{V}}{\partial \sigma}\right\} - \nabla^2\left\{\frac{1}{2}(u^2+v^2)+\Phi\right\} - \varepsilon D - \nu\nabla^4 D \tag{A2}$$

$$\frac{\partial T}{\partial t} = -\mathbf{V}\cdot\nabla T - \dot{\sigma}\frac{\partial T}{\partial \sigma} + \frac{\kappa T}{\sigma}\dot{\sigma} + \kappa T\{(\mathbf{V}-\tilde{\mathbf{V}})\cdot\nabla \ln P_s - \tilde{D}\} - \varepsilon T - \nu\nabla^4 T \tag{A3}$$

$$\frac{\partial \ln P_s}{\partial t} = -\tilde{\mathbf{V}}\cdot\nabla \ln P_s - \tilde{D} \tag{A4}$$

$$\frac{\partial \Phi}{\partial \sigma} = -\frac{RT}{\sigma} \tag{A5}$$

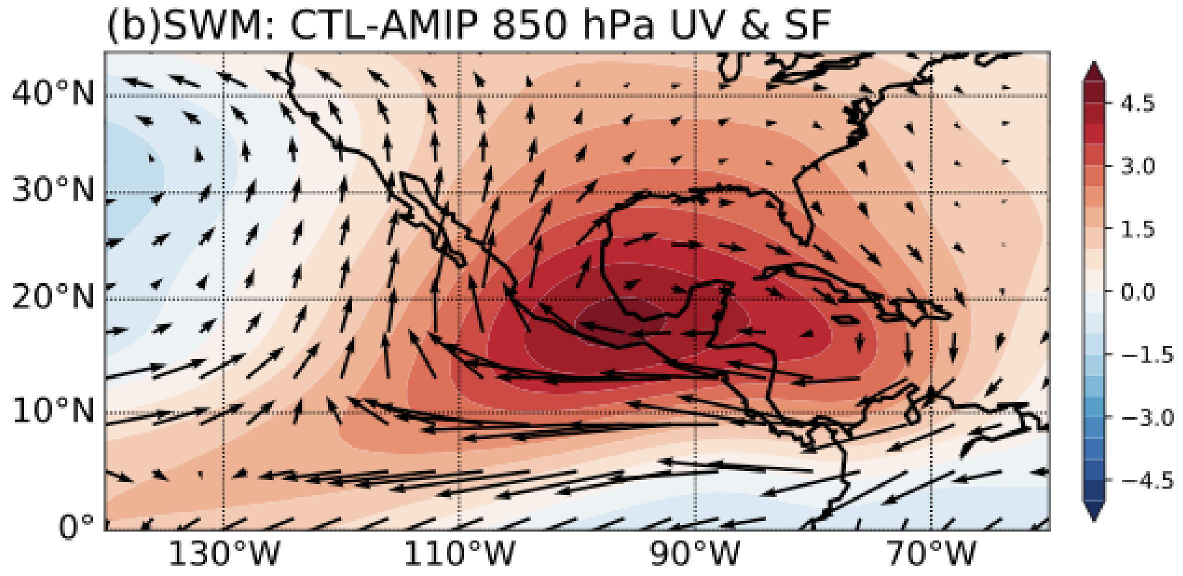
$$\frac{\partial \dot{\sigma}}{\partial \sigma} = -(\mathbf{V}-\tilde{\mathbf{V}})\cdot\nabla \ln P_s - (D-\tilde{D}), \tag{A6}$$

Model Source: Ting and Yu (1998)

CMIP-AMIP vs. SWM Simulation

The SWM is driven by the global diabatic heating diff. between CMIP and AMIP

SWM response



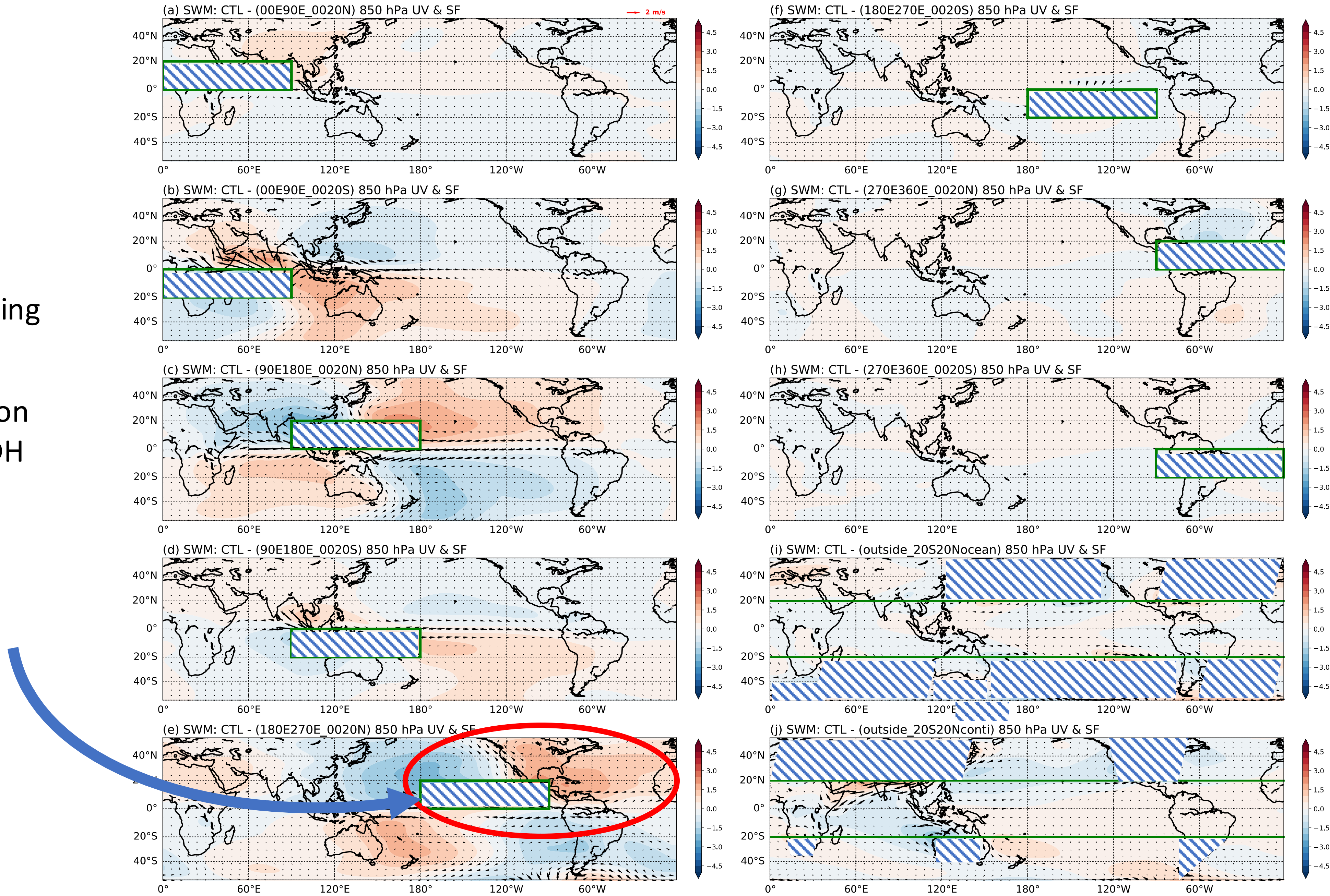
What regional diabatic heating biases contribute to the NAM-related circulation biases?

Question: What regional diabatic heating biases contribute to the NAM-related circulation biases?

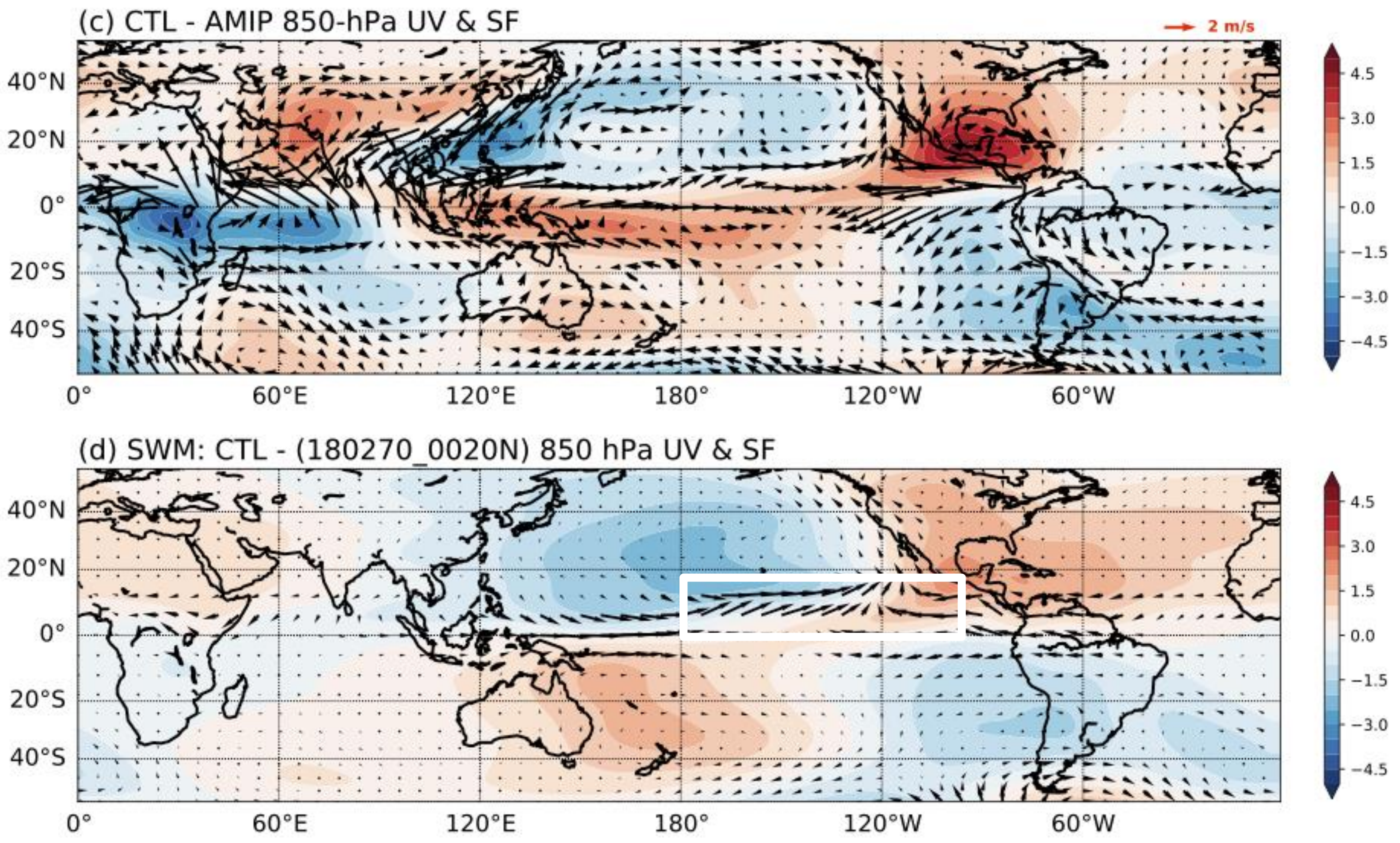
Shadings: Streamfunction (SF, 10^6 kg s^{-1})

CMIP – AMIP diabatic heating

Shading: the streamfunction response to the regional DH



SWM Response: global heating vs. regional heating

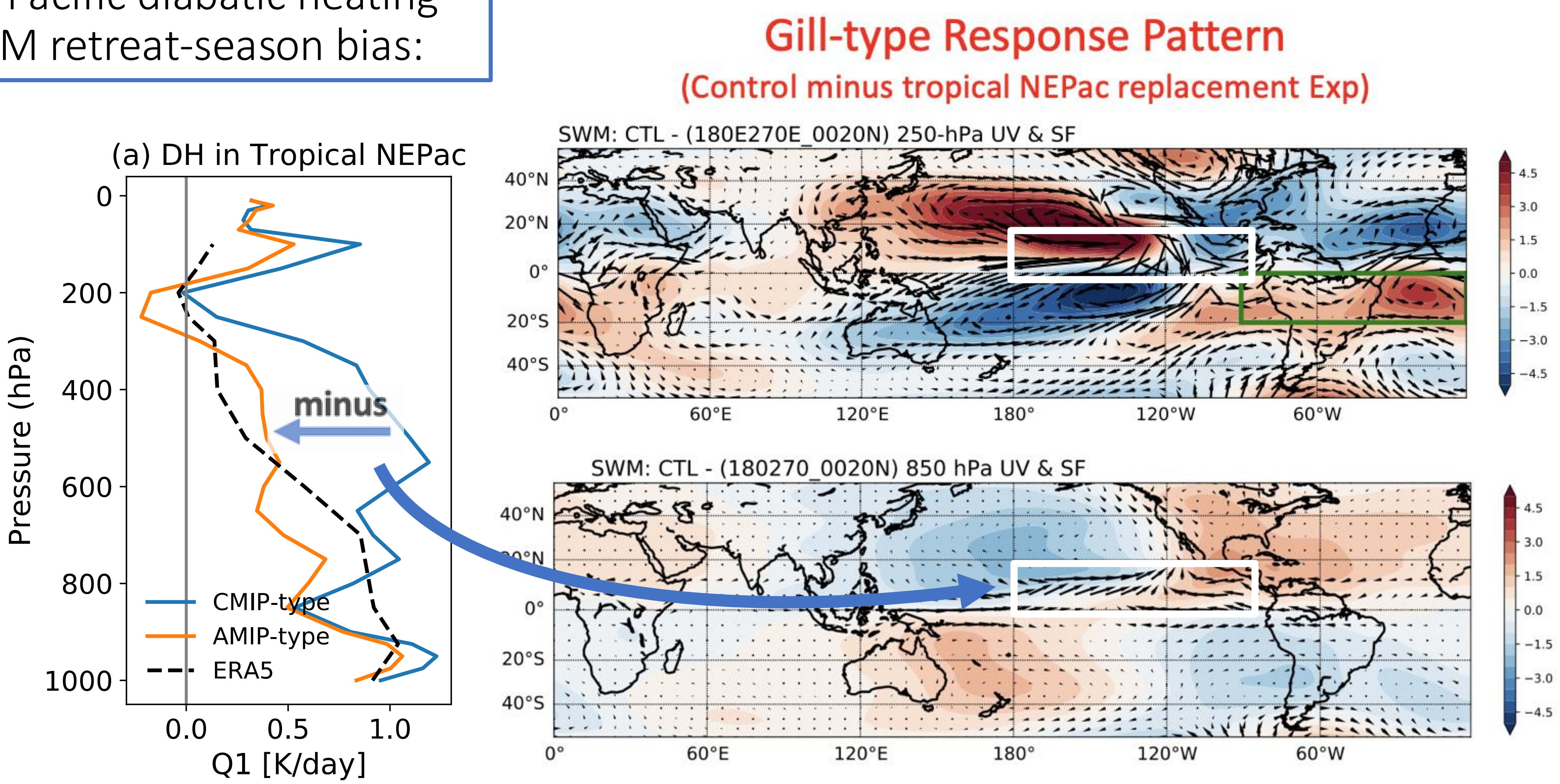


Global heating

NE Pac heating

The diabatic heating over the tropical eastern North Pacific Ocean (0-20N, 180°-90°W) makes the primary contribution.

Linking tropical NE Pacific diabatic heating anomaly to the NAM retreat-season bias:

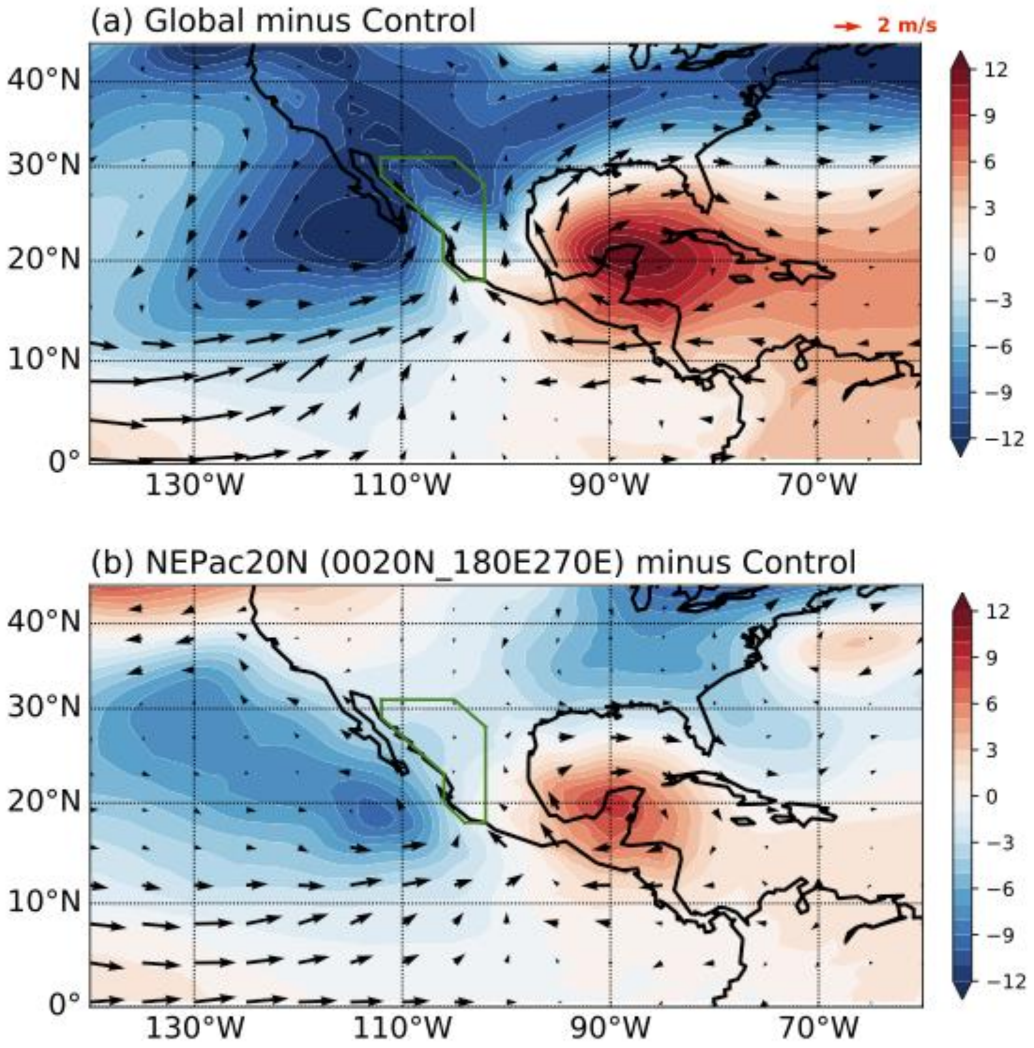


The diabetic heating (DH) over the tropical Northeastern Pacific is largely overestimated;

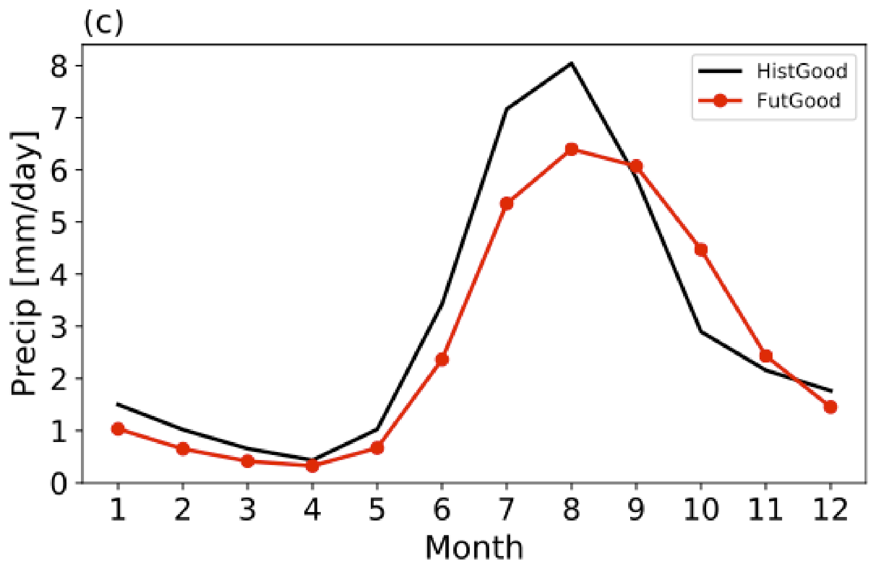
Highly positive correlation between retreat-season precip and vertically integrated DH over the tropical NEPac. **The overestimation of retreat-season precip is mainly contributed by Gill-type response induced by the overestimated DH.**

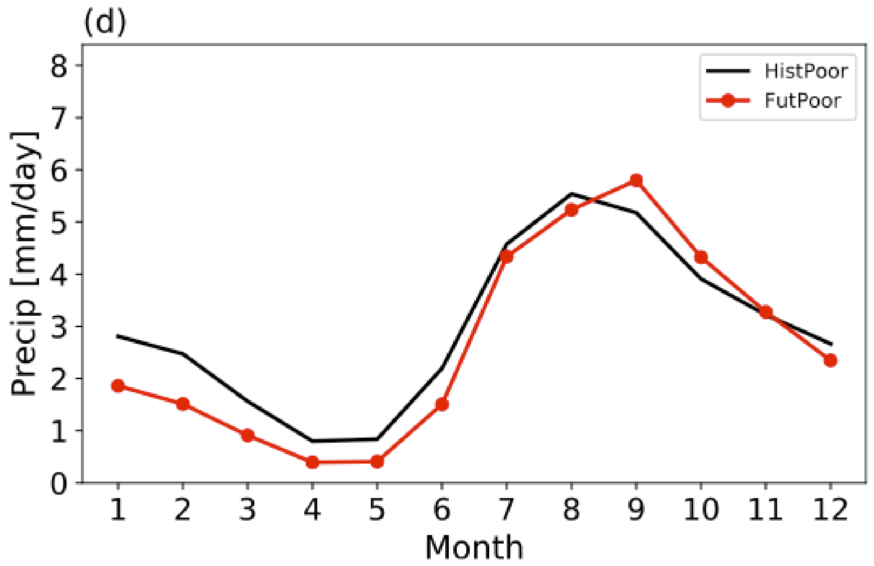
What contributes to the diabatic heating biases over the tropical NE Pacific?

- We forced CESM model with specified SST to explore how SST biases contribute to diabatic heating biases.
- Tropical eastern North Pac SST biases play a dominant role in inducing the retreat-season biases, with SST biases in other ocean basins playing a secondary role



Future changes of the NAM Precip

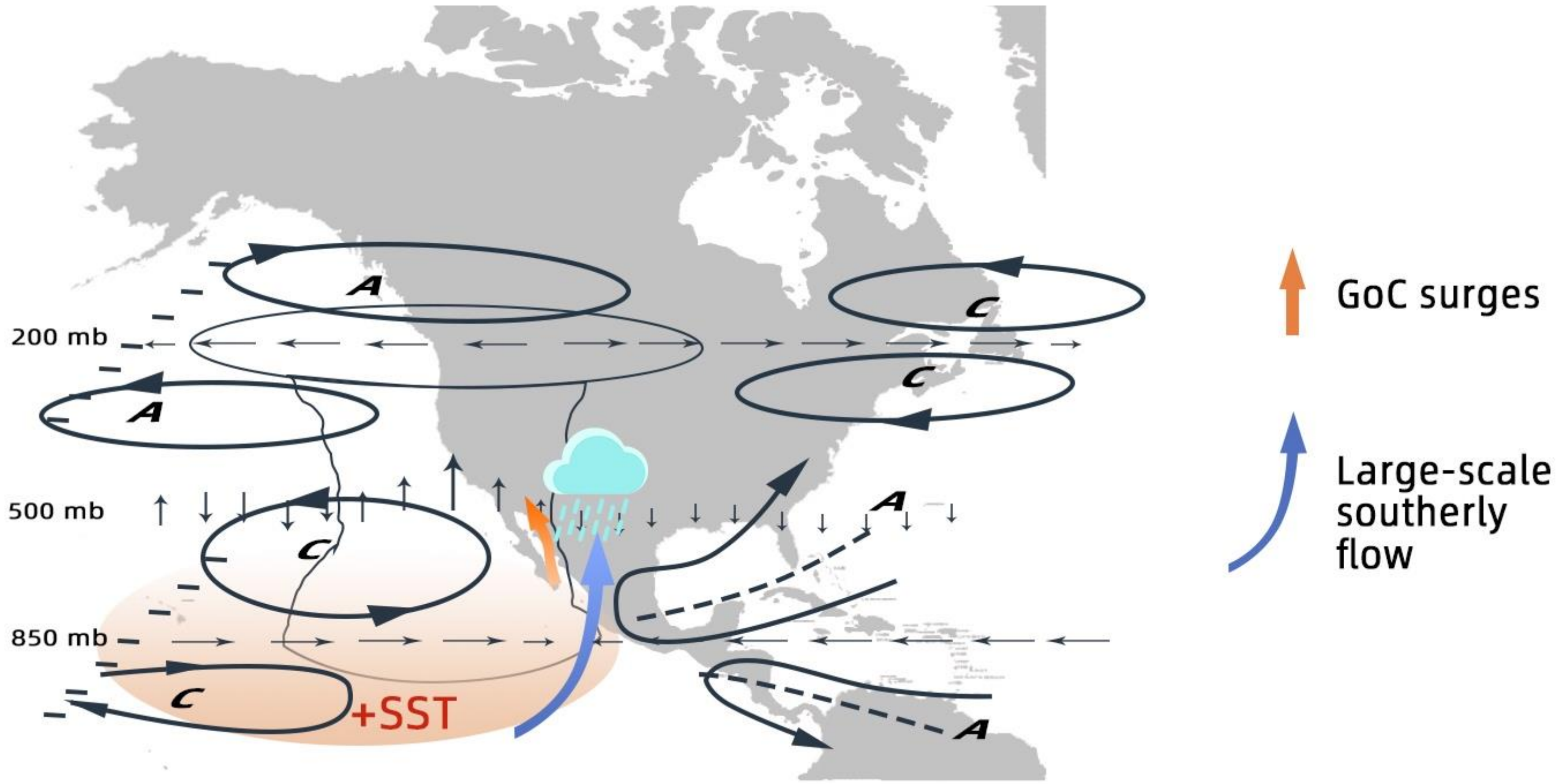




- Relative entropy (Kullback and Leibler 1951) is used to assess how well a model represents the seasonality of NAM precip and select “good” vs. “poor” CMIP6 models.
- The“good” models: the timing of the NAM peak season remains the same, but the peak-season precipitation is reduced and monsoon retreat is delayed.

❖ Black: 1979–2014
❖ Red: 2065-2100

Summary



- CMIP models have a late retreat bias in NAM simulations, which is not correlated with model resolution.
- Using model hierarchies, we found: positive SST biases in the tropical NE Pac → positive diabatic heating biases → a Matsuno–Gill type of response that enhances the moisture transport from to the NAM region.

Thank you!