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Knowledge Gaps of Atmospheric Rivers

L. Ruby Leung
Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY BATTELLE

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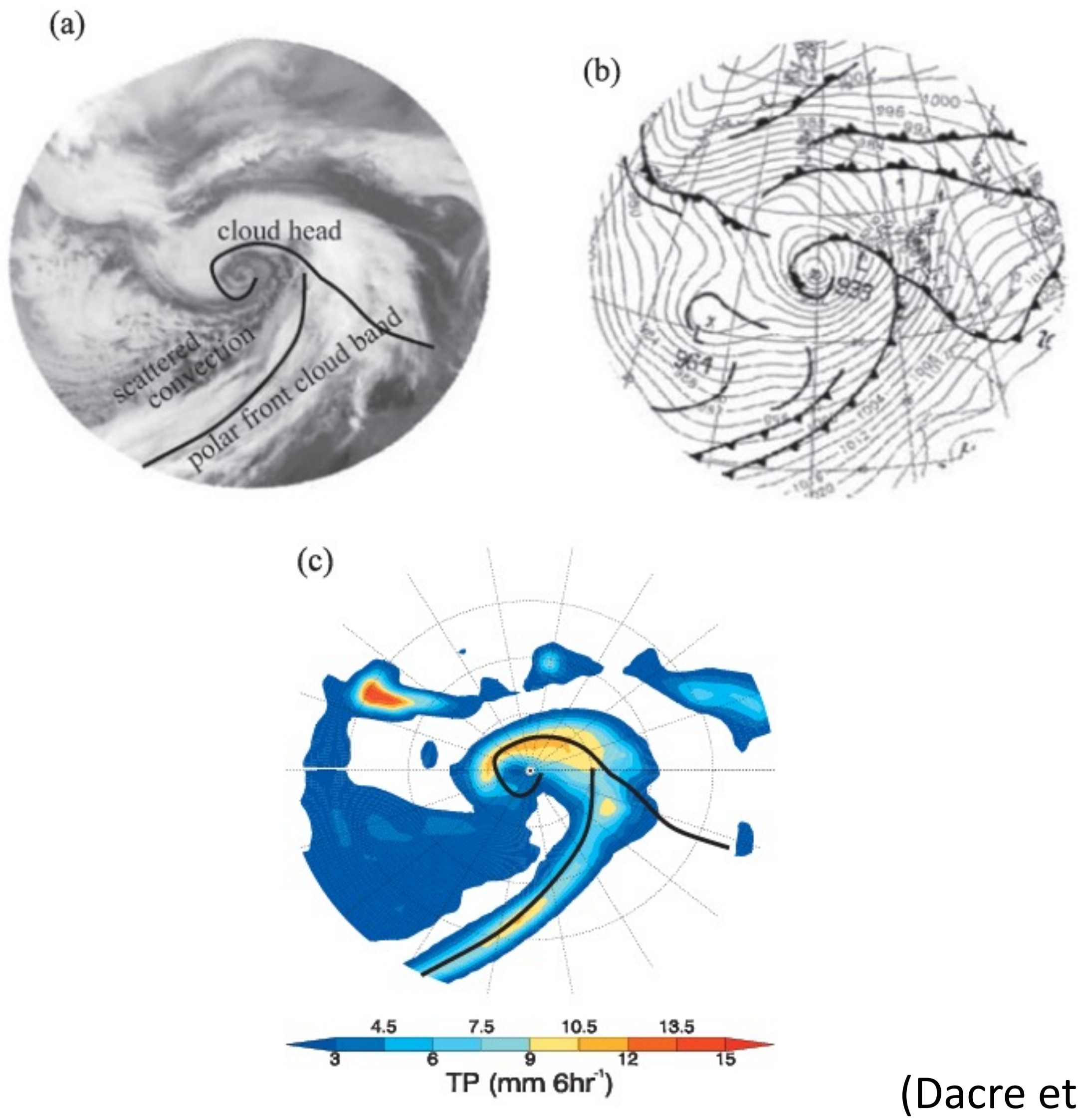
Why might air-sea interactions matter for ARs

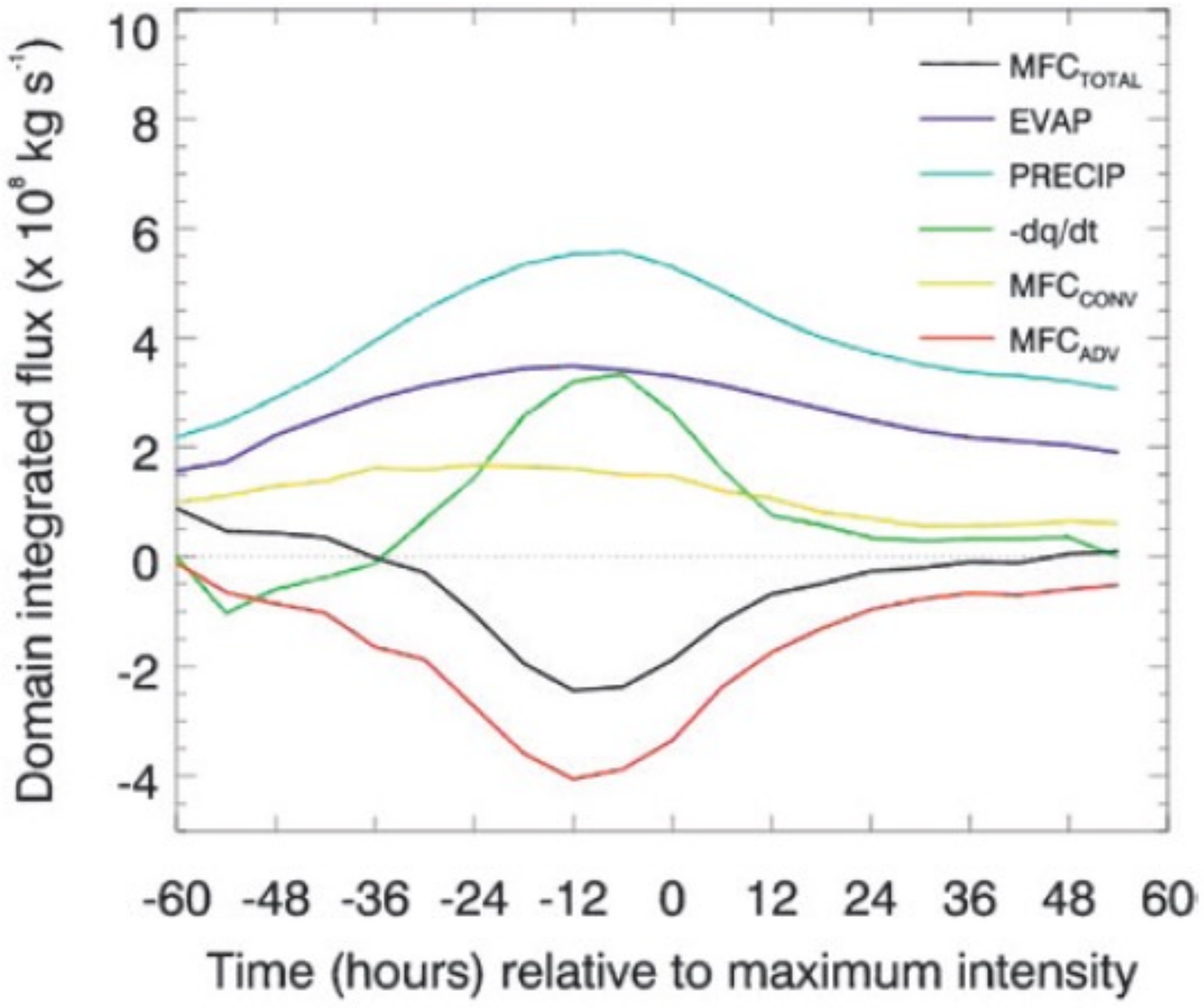
- How much does surface evaporation contribute to AR moisture?
  - What are the impacts of **local** and **remote** SST on landfalling AR moisture and precipitation?
- What are the impacts of ARs in coastal regions and open oceans?
  - Are the impacts different between **coastal** and **open oceans** and among **different ocean basins**?
- How important are air-sea interactions on AR predictions?
- What are the impacts of remote air-sea interactions on ARs through their impacts on various modes of variability?

Why might air-sea interactions matter for ARs

What are the sources of moisture feeding the ARs for their enhanced IVT and IWV?

Moisture budget based on 200 most intense extratropical cyclones in North Atlantic





(Dacre et al. 2015 BAMS)

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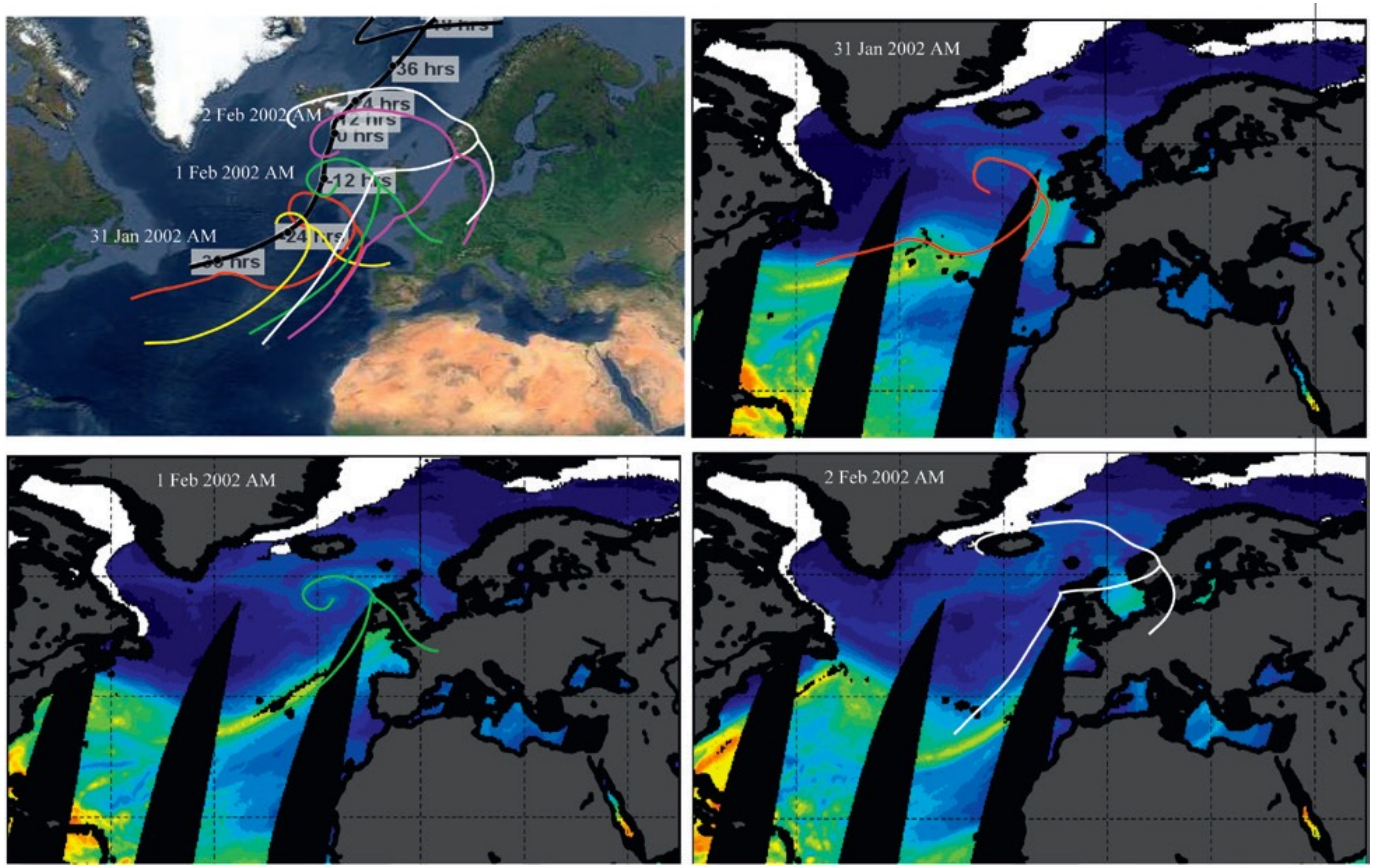
Why might air-sea interactions matter for ARs

What are the sources of moisture feeding the ARs for their enhanced IVT and IWV?

The narrow filament of IWV represents the footprints left behind as the cyclone channels atmospheric moisture into a narrow band as it travels poleward – water vapor is exported from the cyclone rather than transported over long distance from the tropics

… instead of poleward transport occurring because of a direct and continuous feed of moist air from the subtropics to the extratropics (as suggested by the term “atmospheric river”), **poleward transport is the result of a continuous cycling of moisture within the cyclone itself**. **Local convergence of moisture**, occurring ahead of the cold front, **provides a source of moisture at the base of the warm conveyor belt airflow**, which ascends in a slantwise motion, reaches saturation, and forms precipitation.

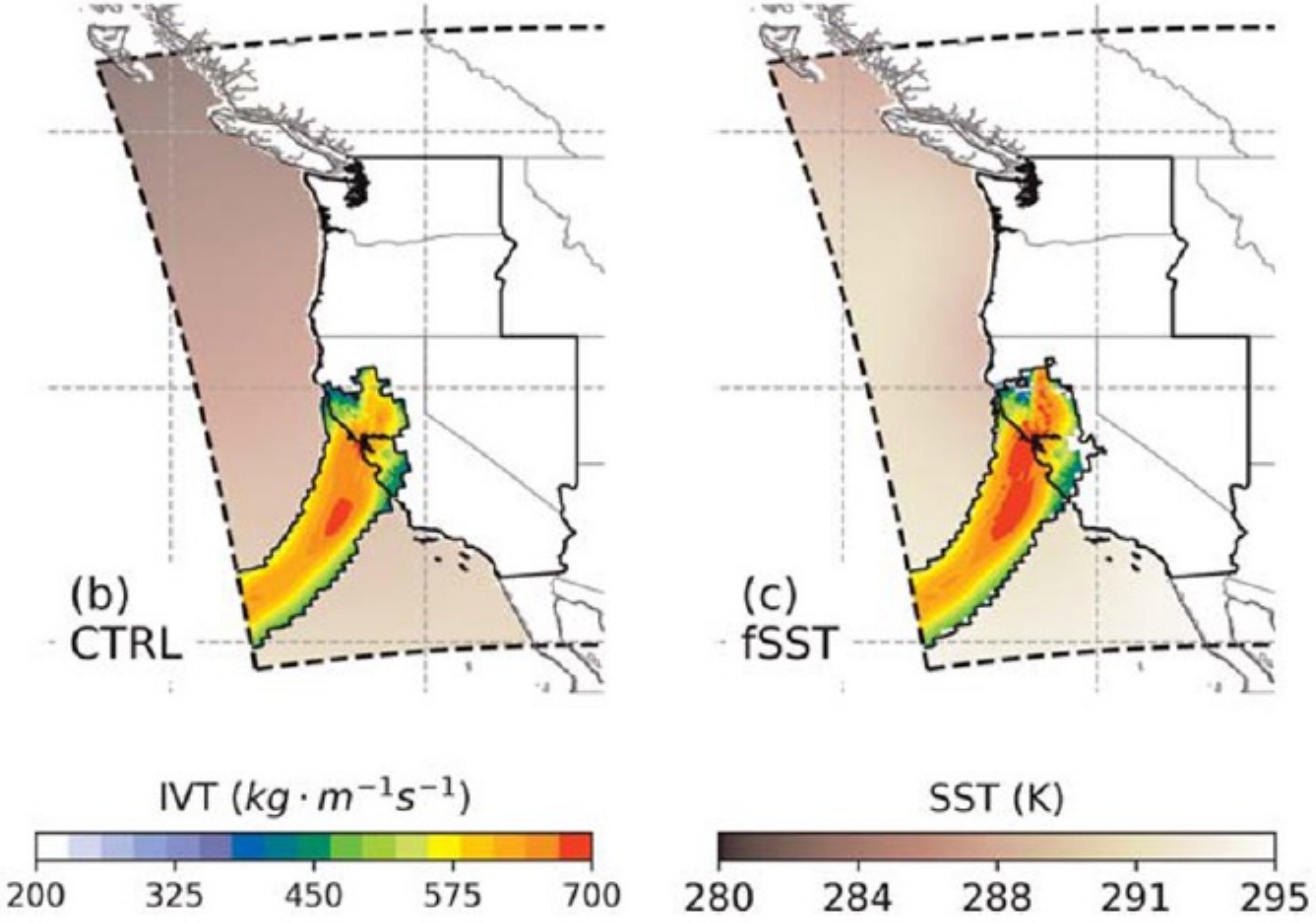


Such analysis has not been done for ARs in the North Pacific!

(Dacre et al. 2015 BAMS)

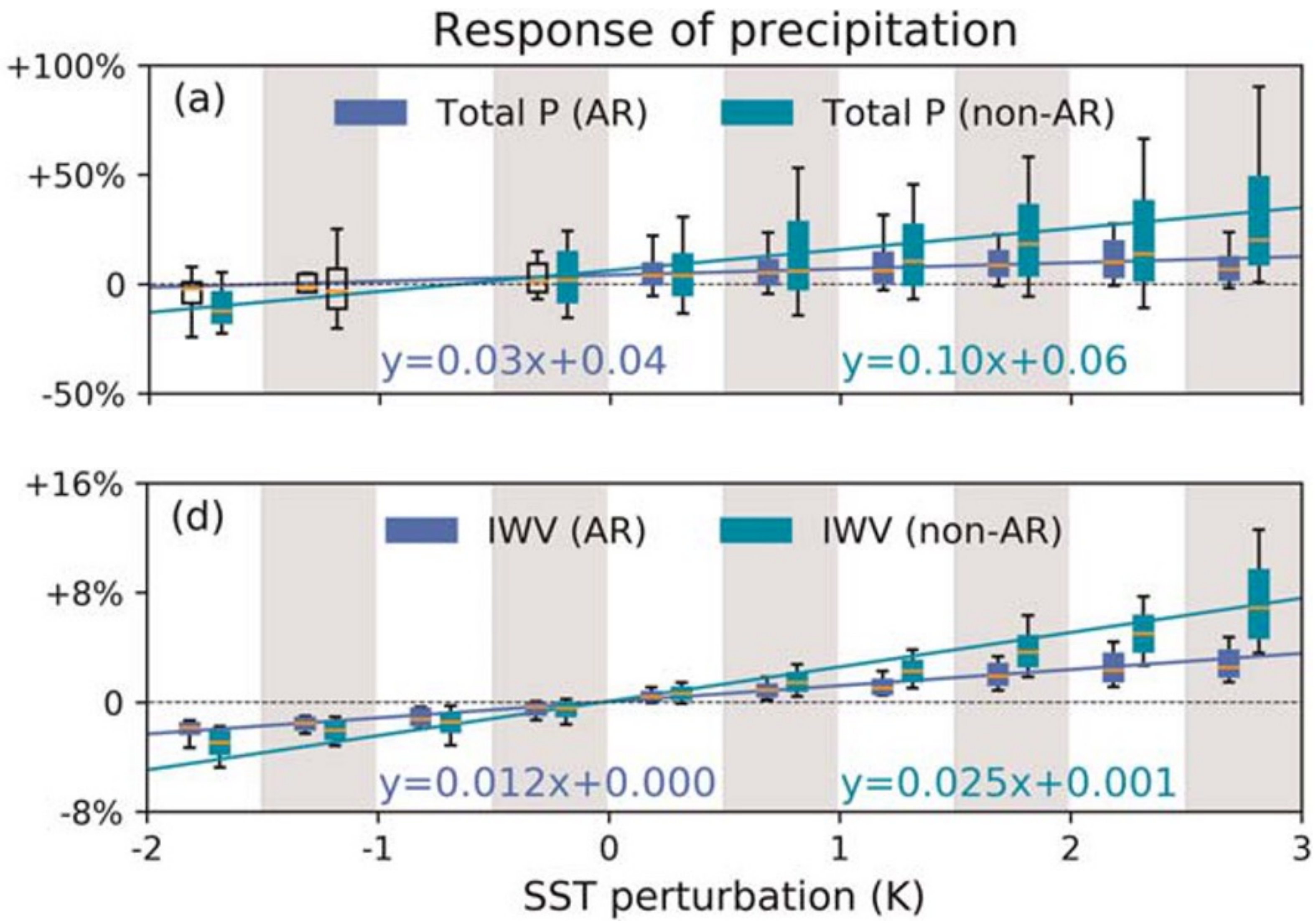
Impacts of local SST on AR moisture and precipitation

What can we learn from two regional climate simulations (6 km resolution) in which the SST in one simulation is on average warmer than that of the other?



(Chen and Leung, 2020 GRL)

Impacts of local SST on AR moisture and precipitation



(Chen and Leung, 2020 GRL)

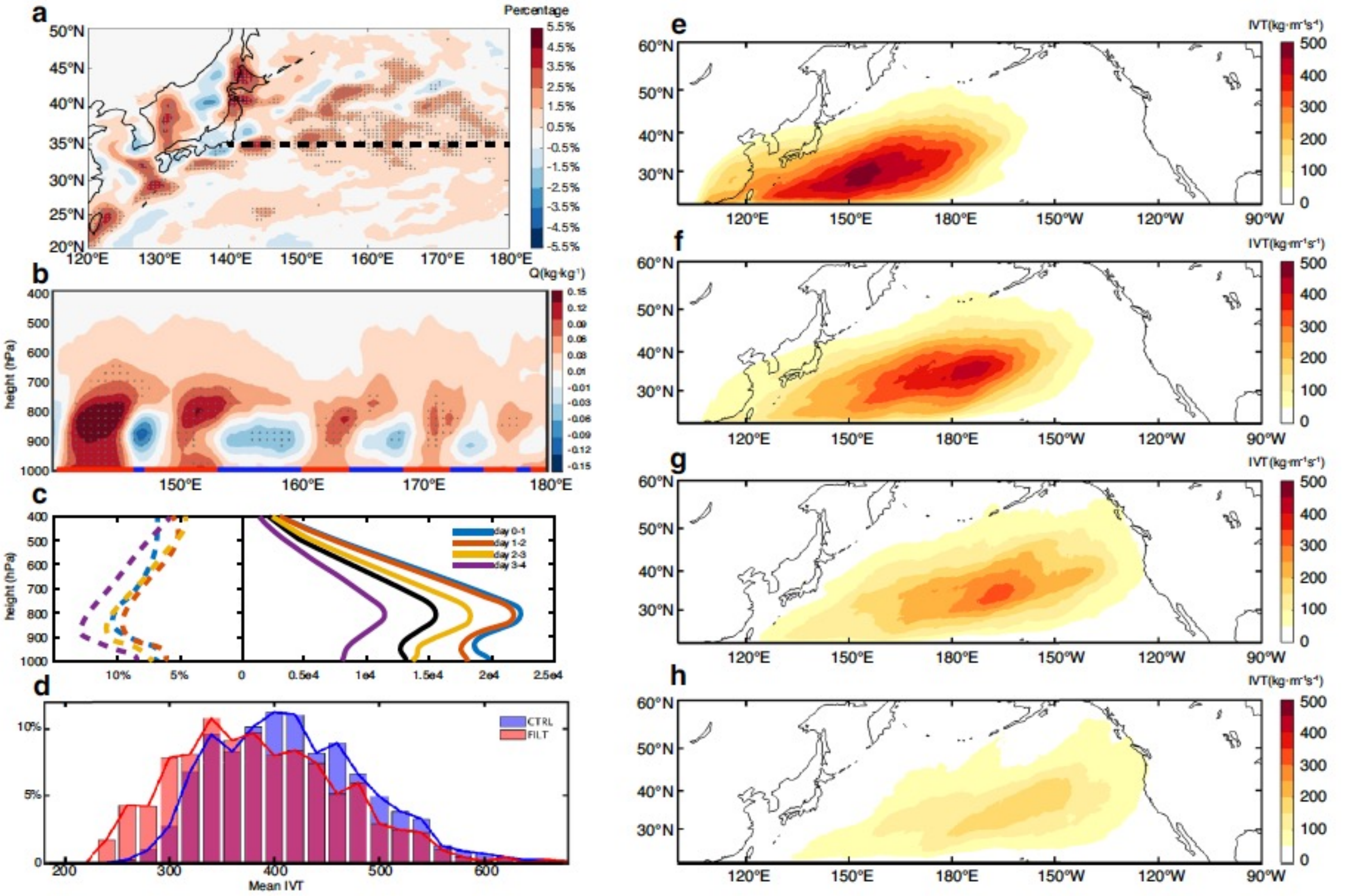
- Evaporation from local ocean contributes 6.5% and 21.0% to the total moisture of AR and non-AR storms
- AR and non-AR precipitation increases by 3%/K and 10%/K of local SST warming
- AR and non-AR IWV increases by 1.2%/K and 2.5%/K of local SST warming
- Precipitation response to SST is 3-4 times that of the IWV
- **Local SST warming amplifies precipitation response by destabilizing storms**

Impact of Kuroshio extension mesoscale eddies on ARs and precipitation in North America

Mesoscale eddies increase landfalling ARs by 40% and extreme precipitation by up to 30%

Comparison of two simulations with prescribed SST with and without filtering of mesoscale features:

- Asymmetric impact of mesoscale warm and cold anomalies on PBL moisture
- Larger fractional impact on AR moisture after 3-4 days of AR evolution

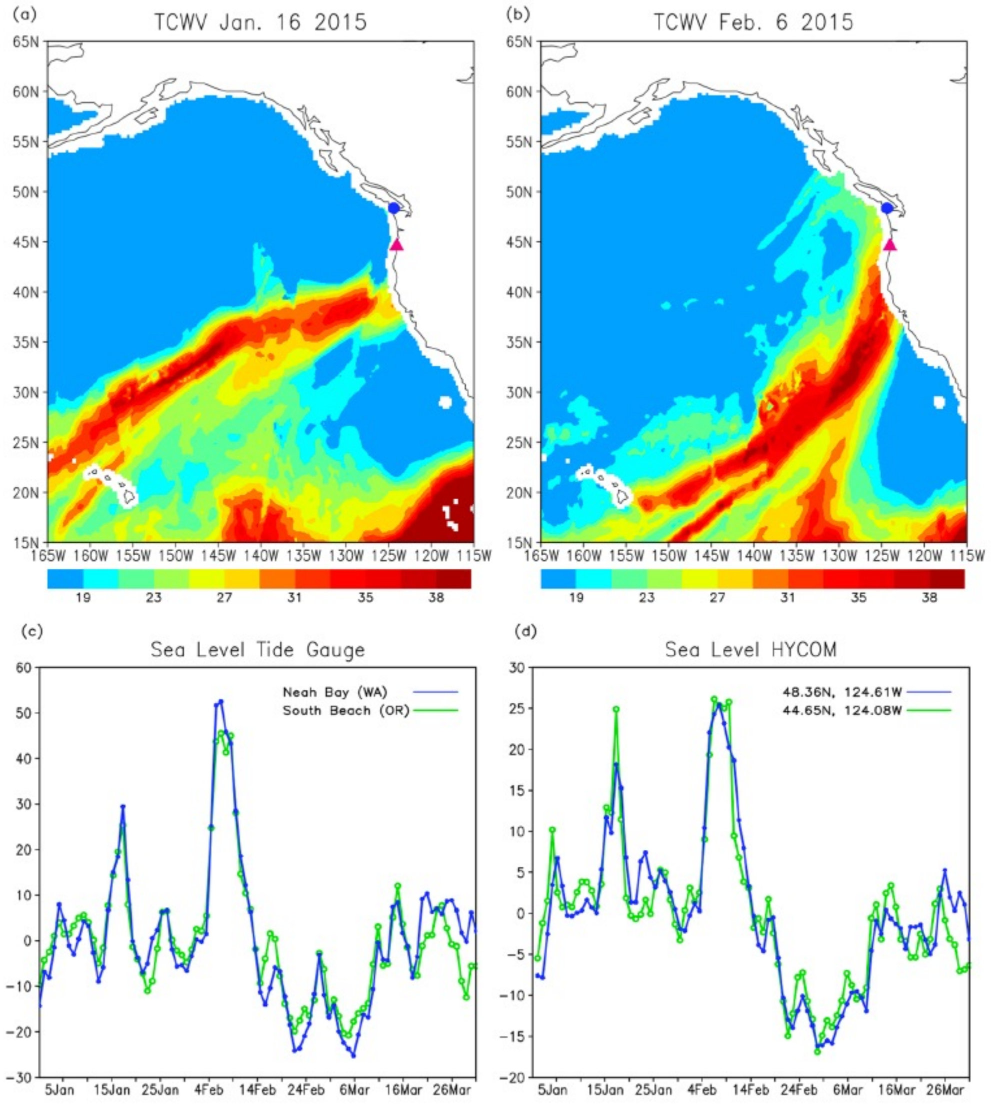


(Liu et al. Nature Communications 2021)

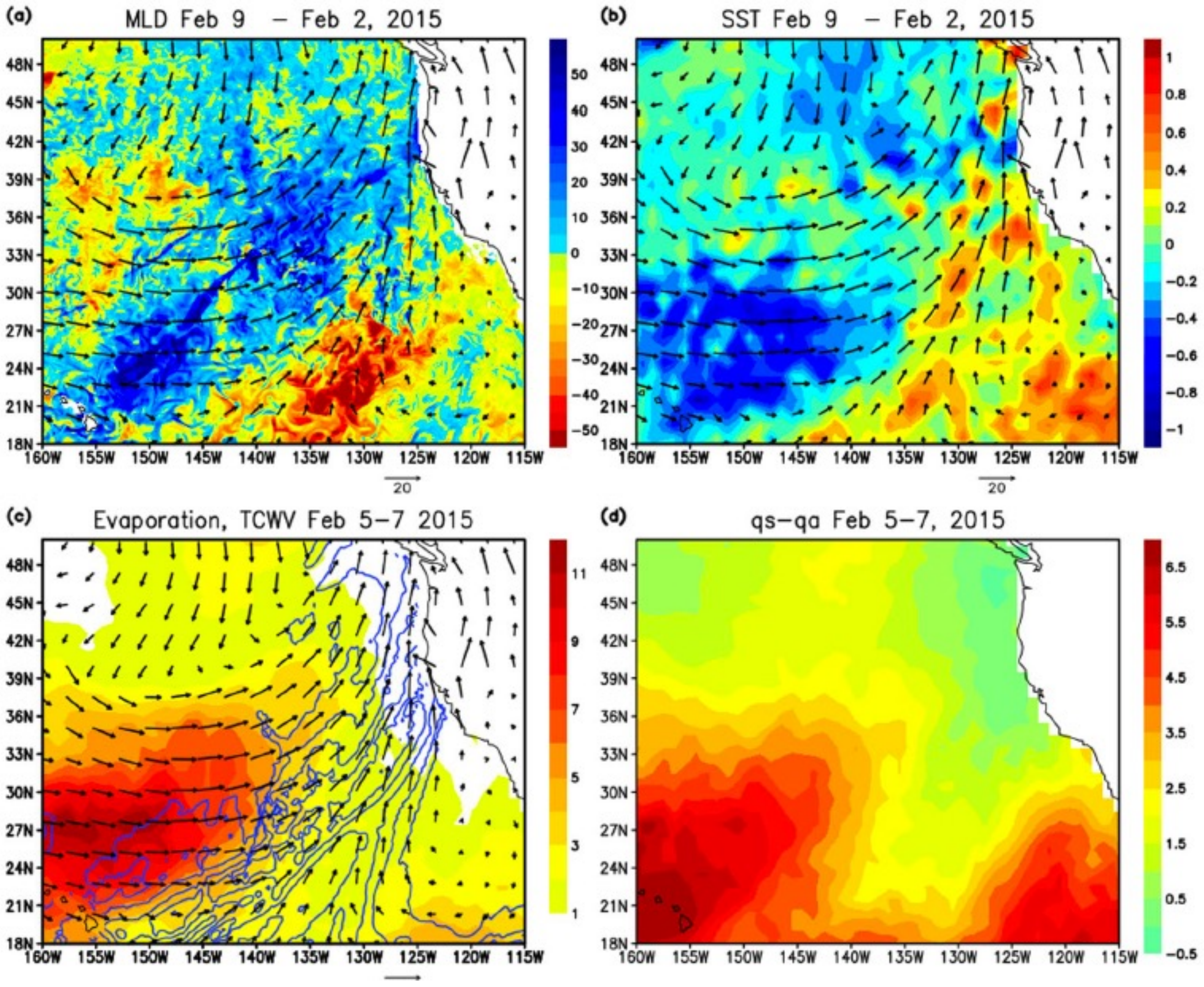
Why might air-sea interactions matter for ARs

What are the impacts of ARs in coastal regions and open oceans?

Strong winds associated with ARs induce sea level changes near the coast

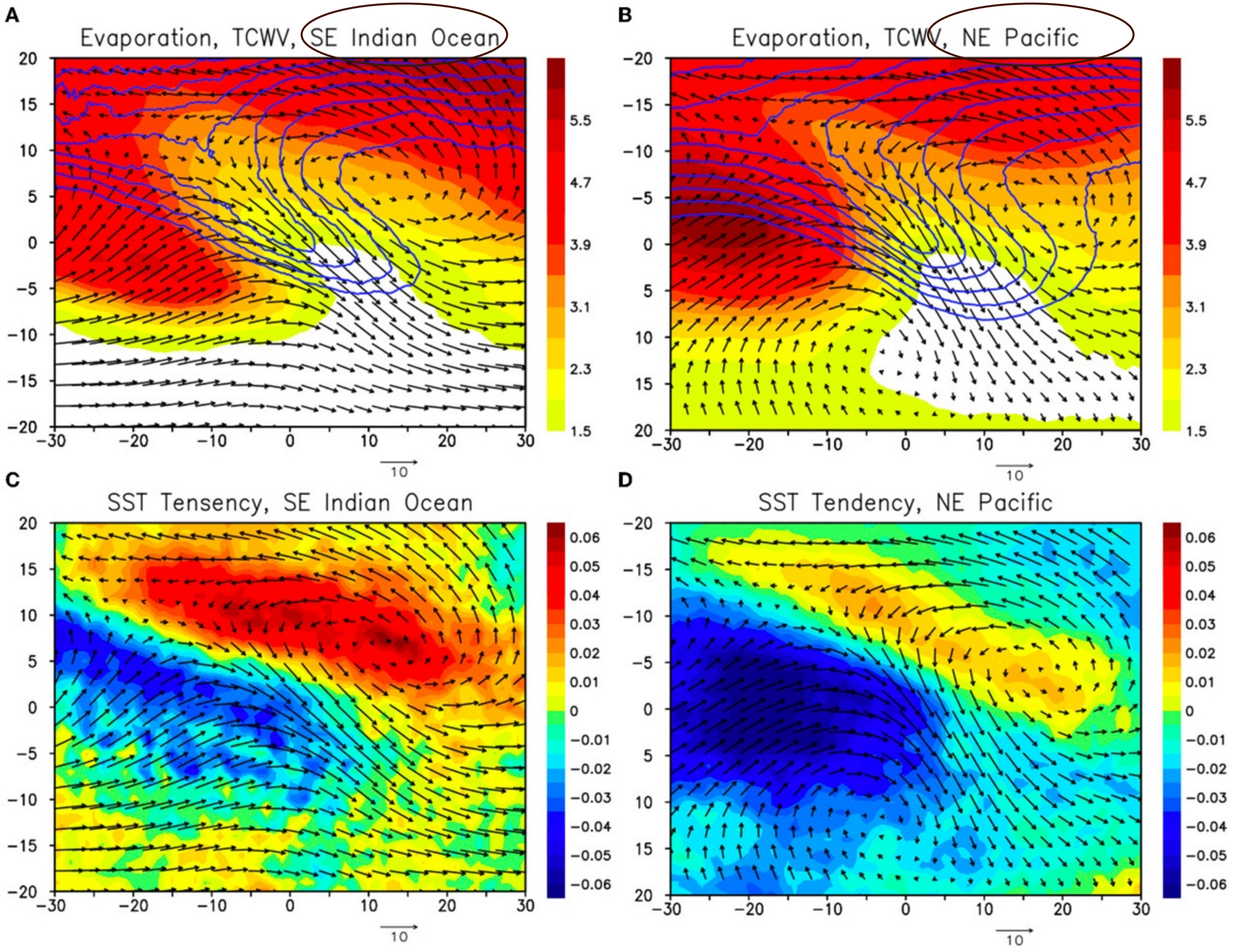


ARs induce SST cooling most prominently within the cold sector of the cyclones by increasing evaporation where air-sea moisture gradient is strongest

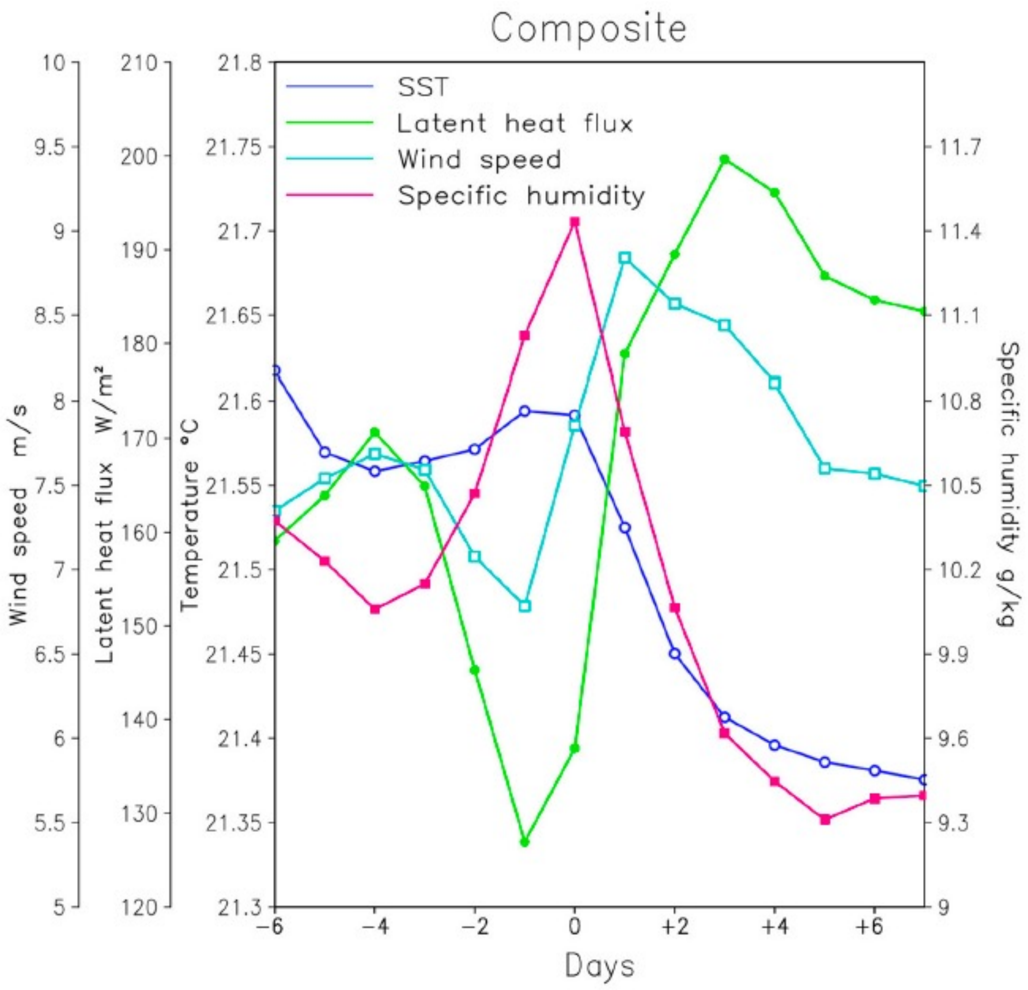


(Shinoda et al. 2019 Sci. Rep.)

Ocean variability and air-sea fluxes produced by ARs



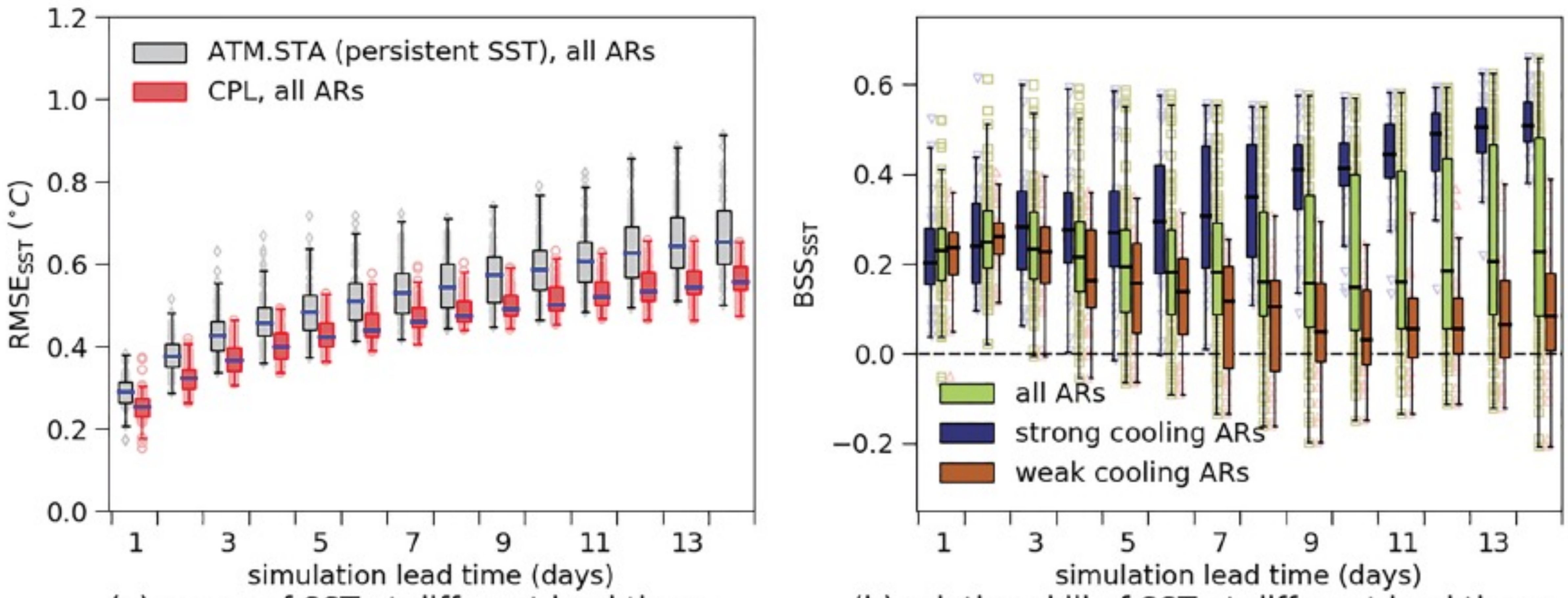
SST cooling lasts for a few days after AR landfall



(Shinoda et al. 2023 Frontiers Clim.)

Does coupled model improve AR forecast?

Larger improvements in SST forecast for ARs that produce stronger SST cooling



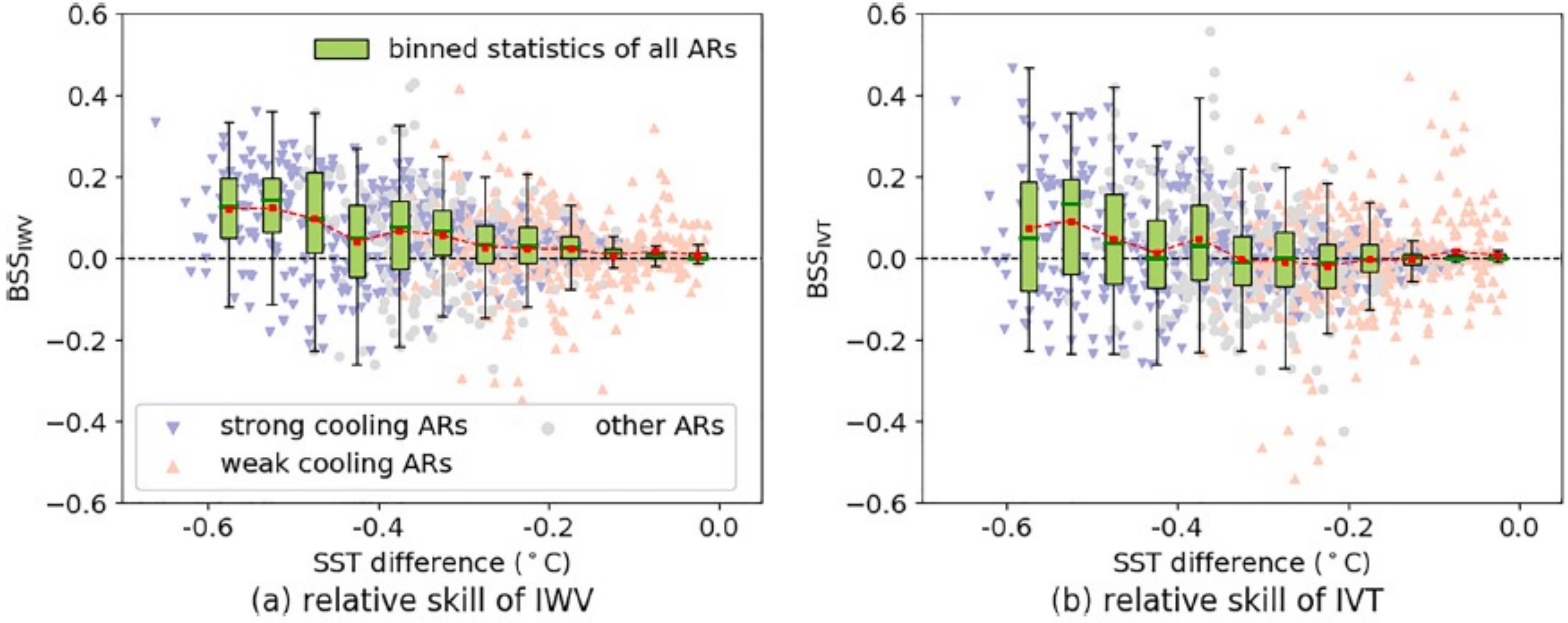
(a) errors of SST at different lead times

(b) relative skill of SST at different lead times

(Sun et al. 2021 JGRA)

Does coupled model improve AR forecast?

Larger improvements in AR IWV and IVT forecast for ARs that produce stronger SST cooling

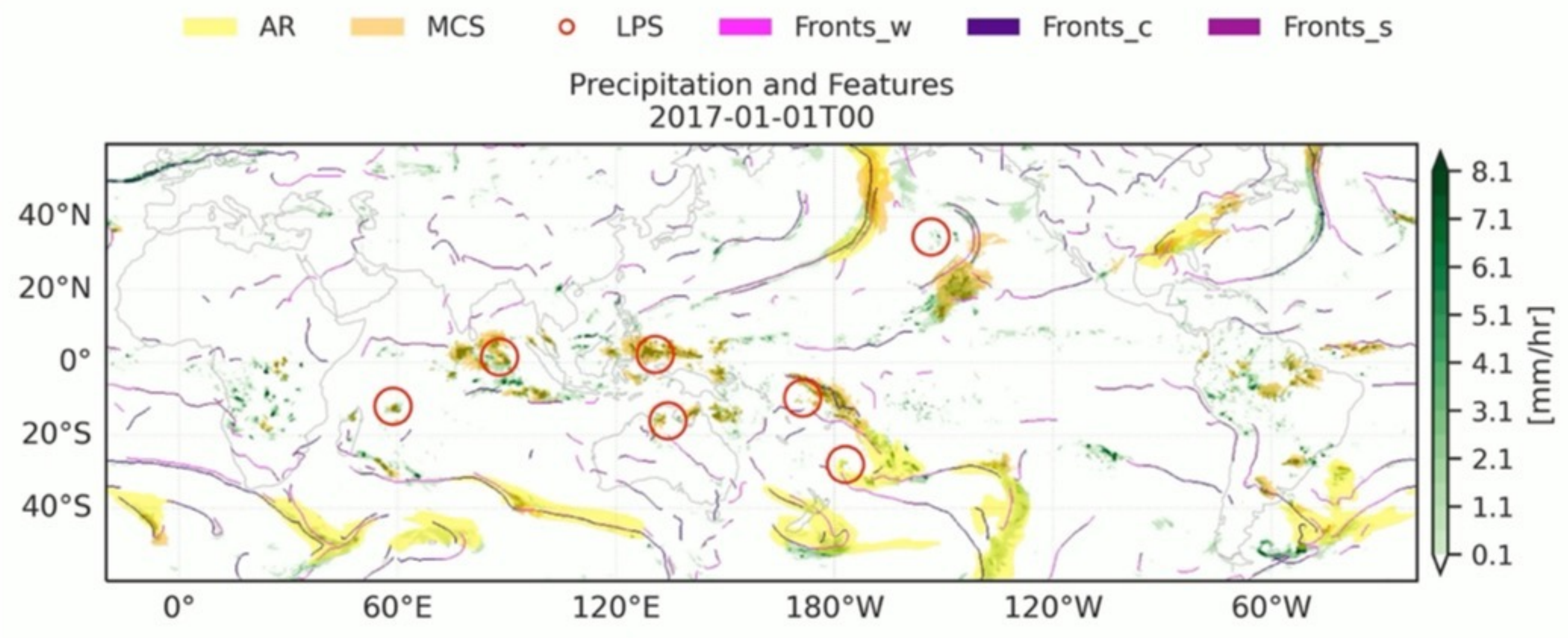


(Sun et al. 2021 JGRA)

Two new DOE funded university-led projects

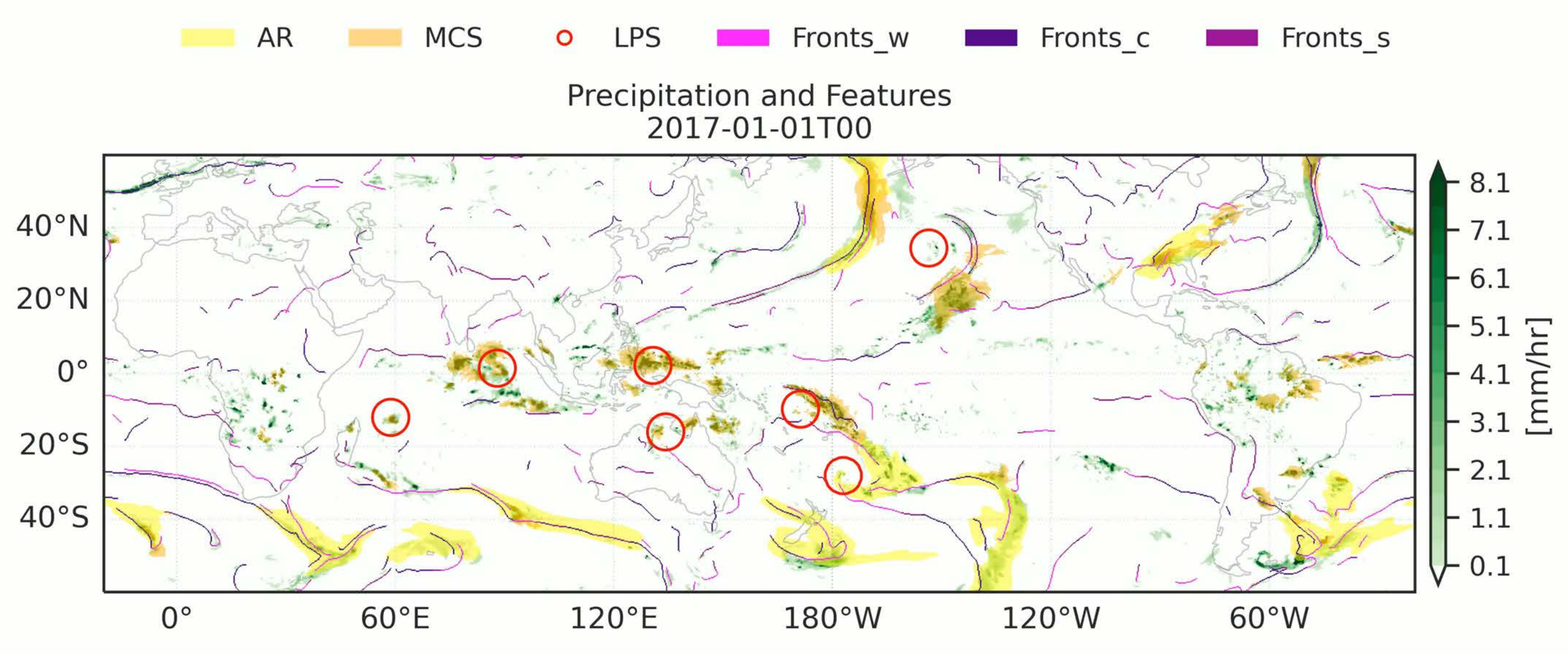
- **Extreme precipitation features and their large-scale environments (PI: David Neelin)**
  - Provide a standardized framework that enables the combination of phenomenon-based diagnostics and spatial-temporal and process-oriented diagnostics
  - Analyze the spatio-temporal characteristics of precipitation in different phenomena, and the contributions of the respective phenomenon to overall precipitation statistics,
  - Create process-oriented diagnostics for the linkages of the phenomena to their large-scale environment.
- **Investigating the effects of co-occurring weather phenomena on extreme precipitation (PI: Travis O'Brien)**
  - How do the meteorological characteristics of weather phenomena vary when they are or are not associated with another weather phenomenon?
  - Does the co-occurrence of phenomena alter the statistical characteristics of precipitation?

Tracking of multiple features and their co-occurrence



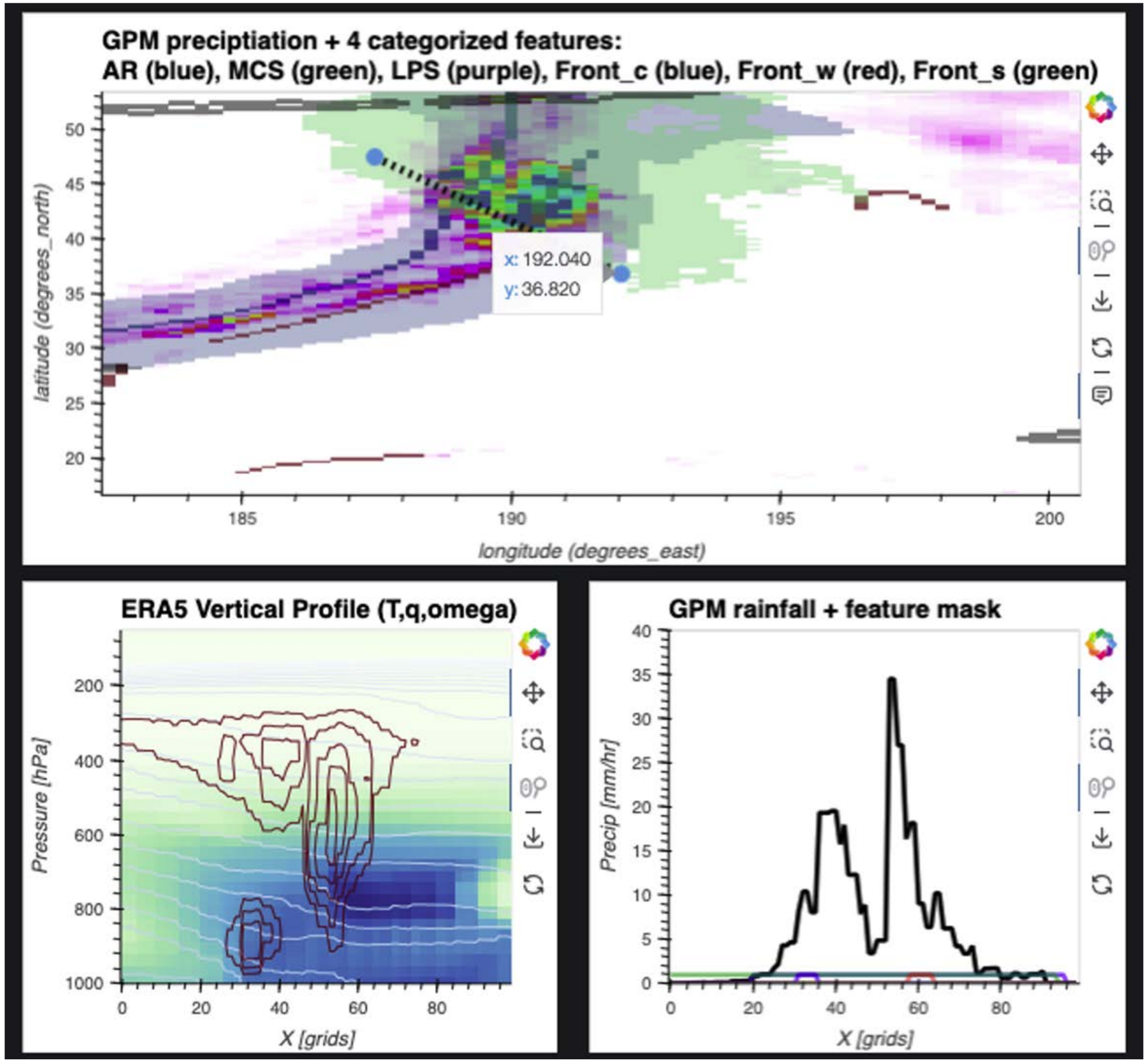
(Source: Wei-Ming Tsai and Suqin Duan of UCLA)

Tracking of multiple features and their co-occurrence



(Source: Wei-Ming Tsai and Suqin Duan of UCLA)

AR heavy precipitation associated with MCS like feature?

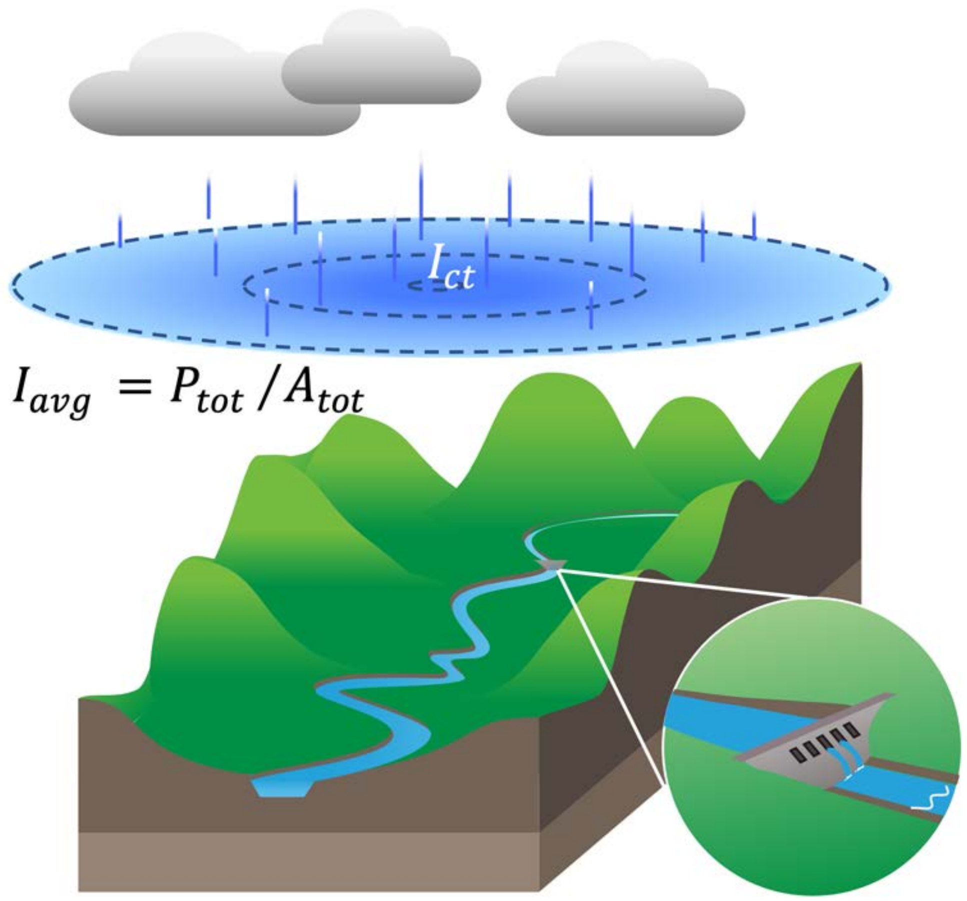


2017-01-01
(lower left):
potential temperature:
(interval = 5K)
moisture (shading)
omega (red contours): from -0.1 pa/s

(lower right):
GPM precip (black)
feature tags (colored)

Storm-resolving simulations and storm metrics

- Storm-resolving simulations performed using WRF for 1981-2010 and 2041-2070 using pseudo-global warming (PGW) over the western US at 6 km grid spacing
- Identified a total of 8843 daily storm events in 1981-2010



$$I_{avg} = P_{tot} / A_{tot}$$

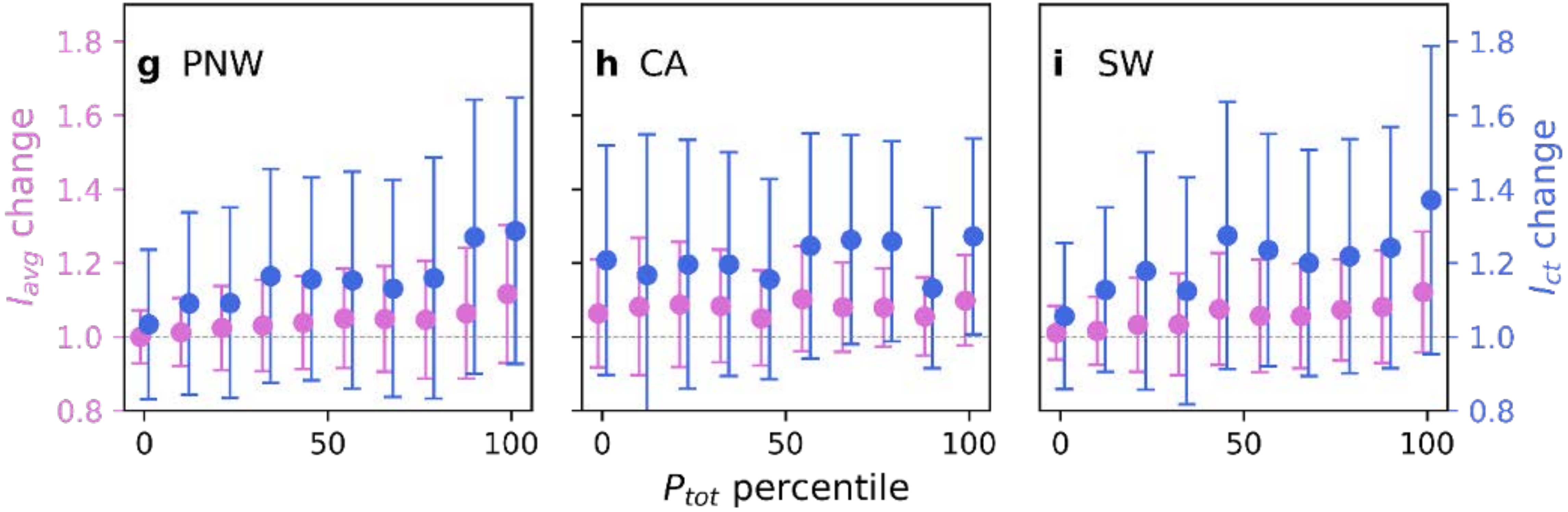
$$P_{tot} = A_{tot} \times I_{ct} \times SC$$

$$SC = I_{avg} / I_{ct}$$

$$SC < 1 \; if \; I_{avg} < I_{ct}$$

Storm-resolving simulations well capture the storm metrics from observations

Larger increases in peak intensity than mean intensity, particularly for storms with higher precipitation percentiles (typically AR storms)



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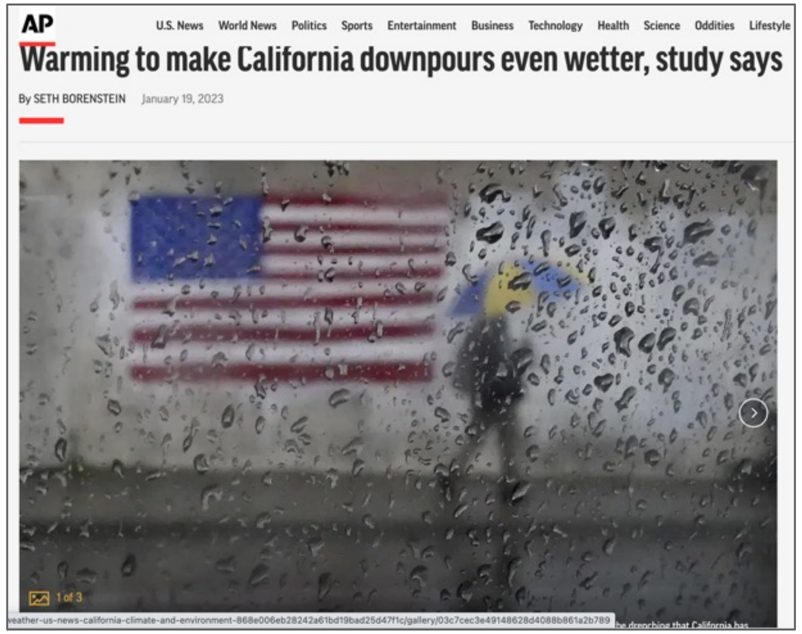
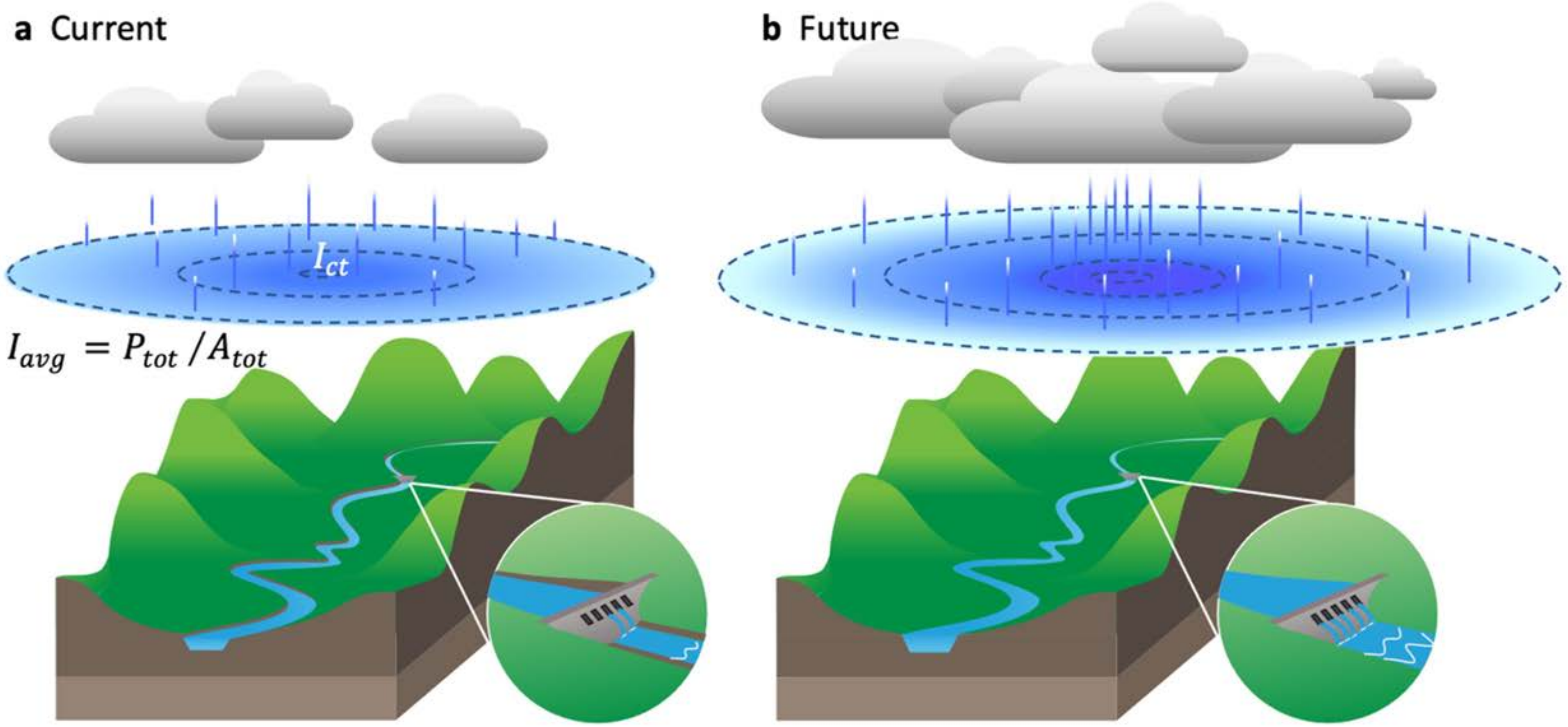
Sharpening of cold season storms in the western US

- Failure to account for climate change significantly underestimates flood risk due to increasing precipitation volume (**slow rising flood**) and increasing peak intensity (**flash flood**).
- Accounting for climate change, grid scale precipitation analysis overestimates flood risk by ignoring storm sharpening or decreasing area reduction factor (spatial concentration).





Chen, X., Leung, L. R., Gao, Y., Liu, Y. & Wigmosta, M. "Sharpening of cold-season storms over the western United States," *Nature Climate Change* **13**, 167–173 (2023). [DOI: 10.1038/s41558-022-01578-0]

Probable maximum precipitation (PMP): how will it change with warming

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Modernizing Probable Maximum Precipitation Estimation

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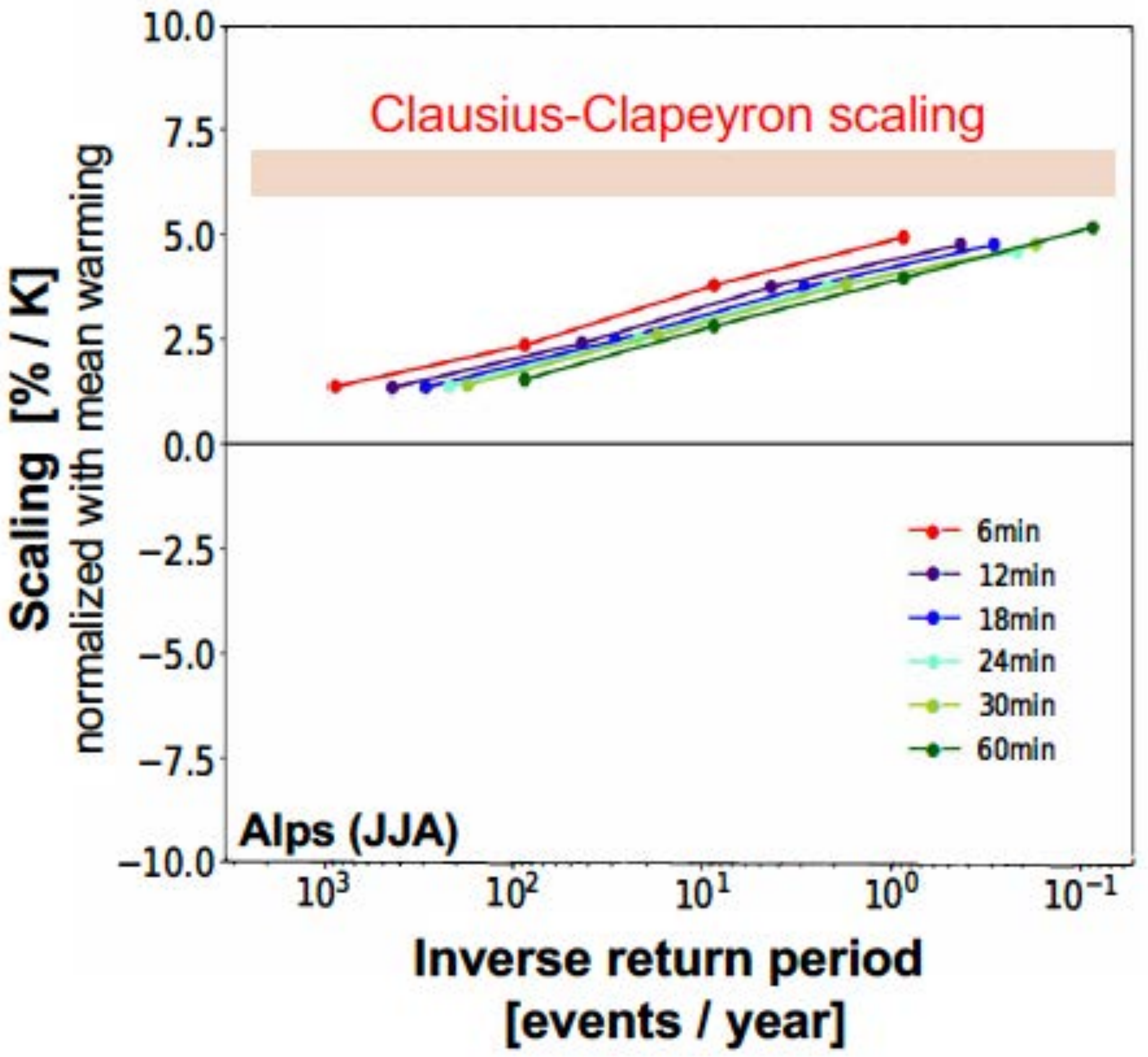
The committee is charged with establishing a common understanding of PMP; **reviewing and assessing existing approaches to PMP estimation and for incorporating the impacts of climate change on those estimates**; assessing PMP data needs and sources; and recommending a preferred approach for PMP estimation that incorporates the impacts of climate change and the characterization of uncertainty.

Probable maximum precipitation (PMP): how will it change with warming

- PMP is traditionally estimated by scaling of precipitation with the ratio of maximum to actual moisture in observed PMP-magnitude storms
- Is linear scaling valid for AR storms, especially if heavy precipitation is produced by convective elements?



(Vergara, Ban and Schär, GRL, 2021, https://doi.org/10.1029/2020GL089506)

Gaps in knowledge

- How much evaporation and local moisture convergence contribute to the moisture supply for AR precipitation? How might that be different between landfalling ARs in different regions?
- What control the spatial/temporal variability of air-sea fluxes under ARs? How well can models simulate such variability?
- What are the impacts of ARs on coastal and open oceans? What are potential implications for subsequent storms?
- How often do ARs co-occur with other weather features? What can we learn from such co-occurrence of ARs?
- What processes control AR heavy precipitation? How might the processes change with warming? What scaling factor should be used (CC, super-CC, or a theoretical maximum exists)?