The role of air–sea interactions in atmospheric river events: Case studies using the SKRIPS regional coupled model

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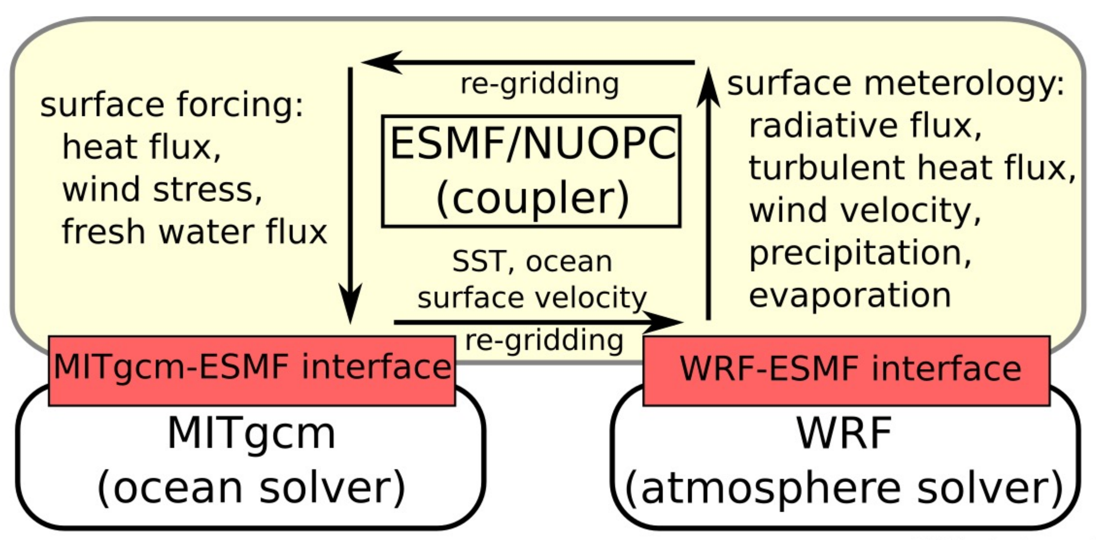
Motivation

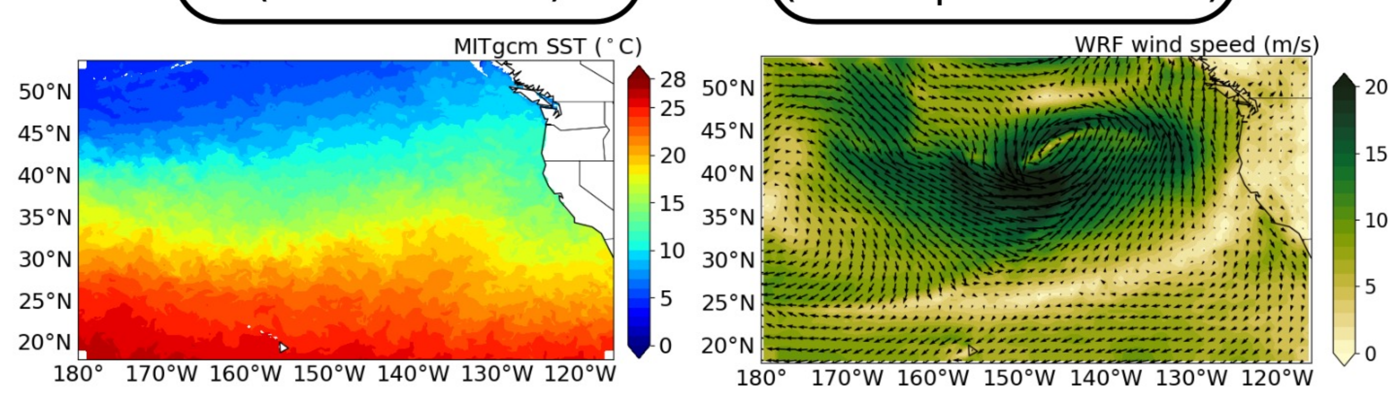
- ARs are responsible for most of the extreme precipitation and flooding events during winter months in California.
- Coupled ocean–atmosphere interactions at mesoscale over the North Pacific region may play an important role in modulating water vapor transport in the ARs.
- We set up a high-resolution (**<9 km grid spacing**) regional coupled ocean–atmosphere model that can resolve the mesoscale features with comprehensive physics, aiming to address the following scientific questions:
  - **How do ARs impact the ocean?**
  - **How does the ocean impact ARs?**
  - **Can a coupled ocean–atmosphere model better simulate AR events?**

Model Implementations

We use the Scripps–KAUST Regional Integrated Prediction System (SKRIPS) modeling framework available at https://github.com/iurnus/scripps_kaust_model

Atmosphere solver WRF; Ocean solver MITgcm; ESMF/NUOPC coupler

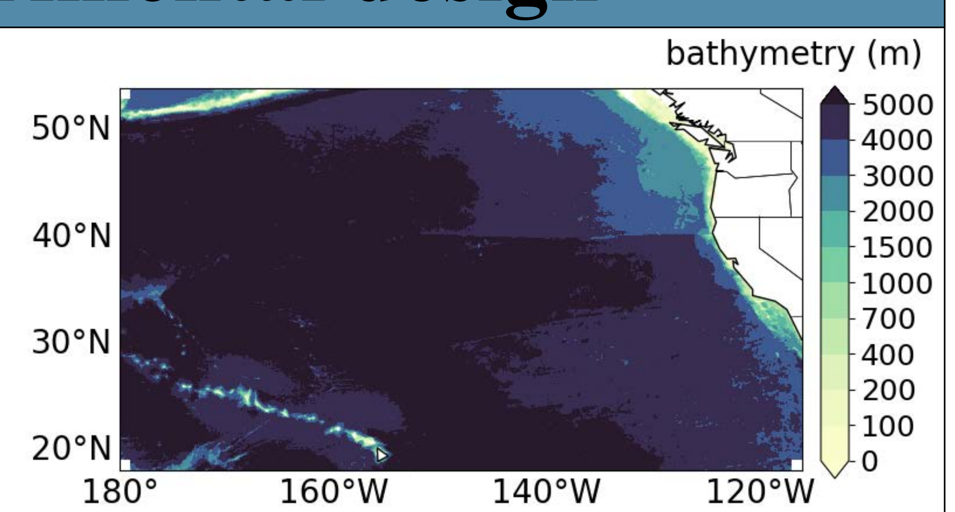




Experimental design

Setups:

- WRF initial/boundary condition from GFS Final Analysis (FNL)
- MITgcm initial/boundary condition: HYCOM analysis
- Both model components have grid-resolution: 0.08° (lon × lat: 800 x 448 points)



Two series of simulations:

- **ATM.STA** (stand-alone atmosphere run): WRF uses persistent SST field as bottom B.C.
- **CPL** (coupled run): WRF uses SST from MITgcm; MITgcm uses atmosphere forcing from WRF

Validation data used for Brier skill scores in Case Study presented

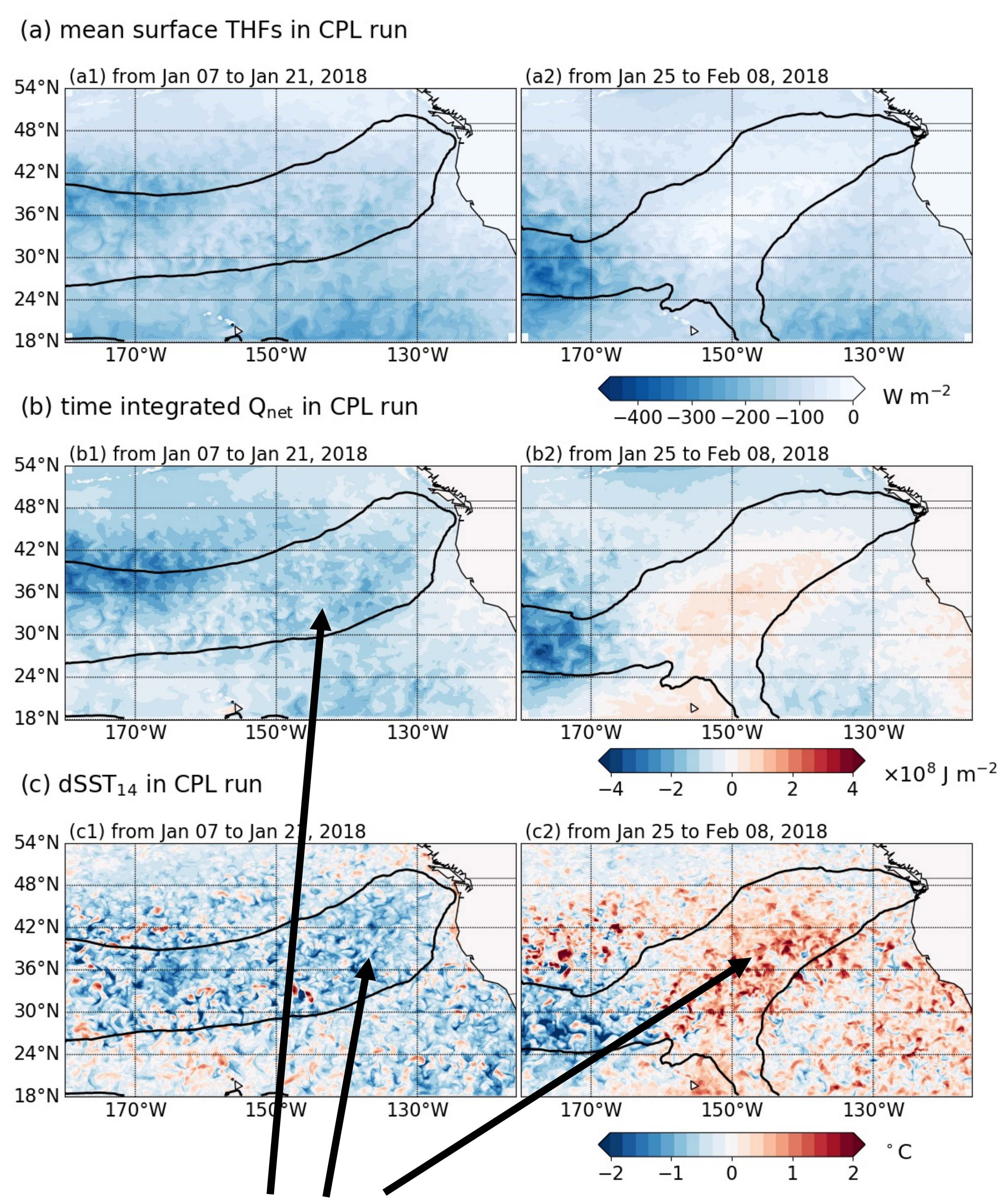
Events: ARs in Jan 2016, 2017, and 2018

- Simulation length: 14 days
- Number of simulations: 3 years x 31 simulations initialized on each day in January

Overview of AR events

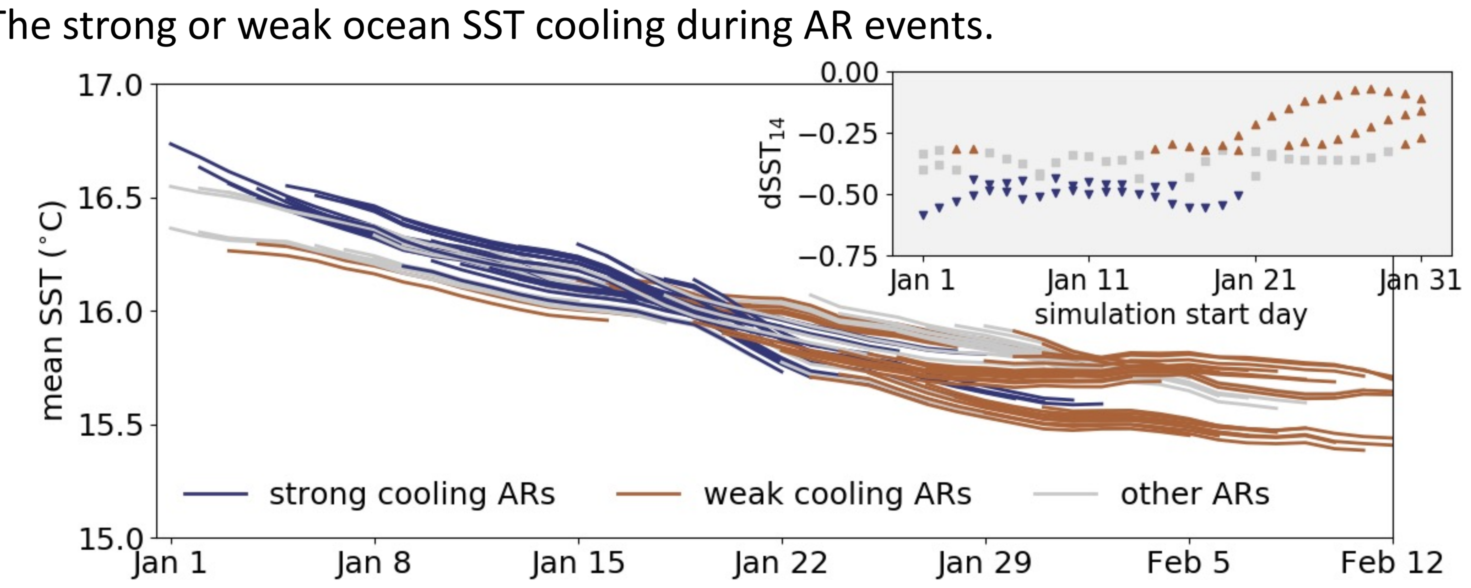
ARs are observed throughout the simulations. These ARs are associated with strong and weak ocean cooling. **We find the skill improvement of the coupled model is a function of the SST cooling (domain-averaged SST), and thus we separate the ensembles into categories based on the changes in SST.**

1. Comparison of turbulent heat flux (THF), net heat flux (Qnet), and SST difference (dSST) in two representative ARs. Left panels: strong cooling ARs; right panels: weak cooling ARs.



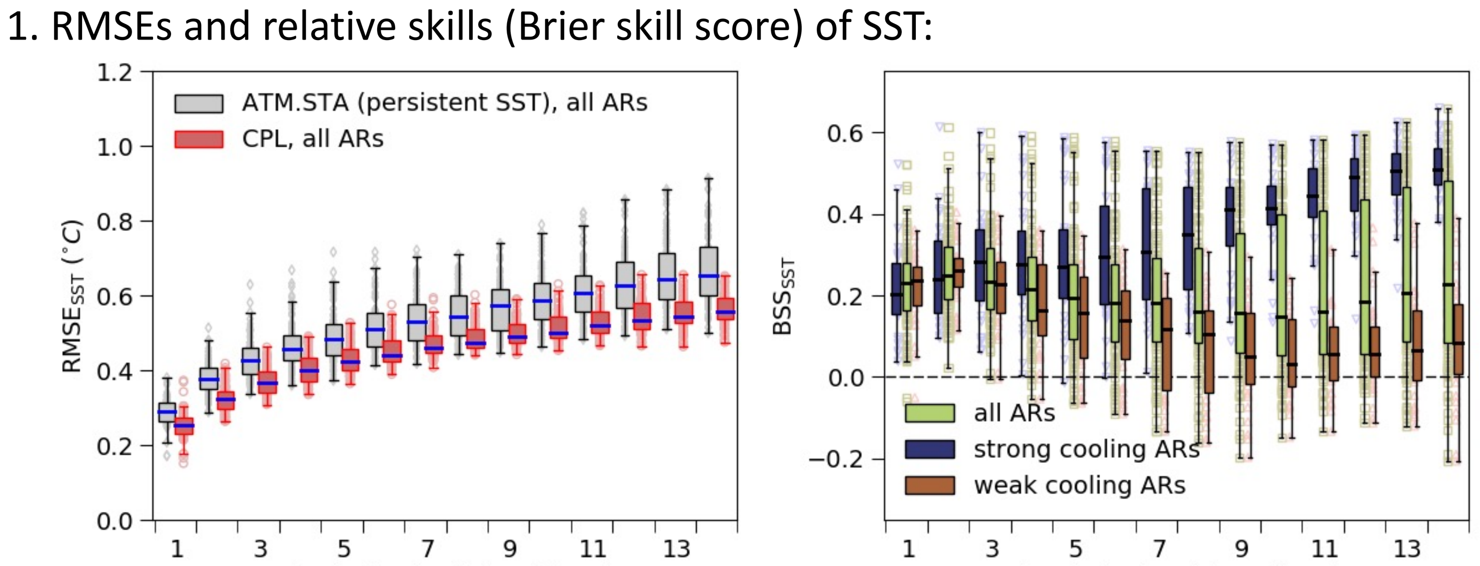
Mesoscale features of the ocean and the atmosphere

2. The strong or weak ocean SST cooling during AR events.



Case study

1. RMSEs and relative skills (Brier skill score) of SST:

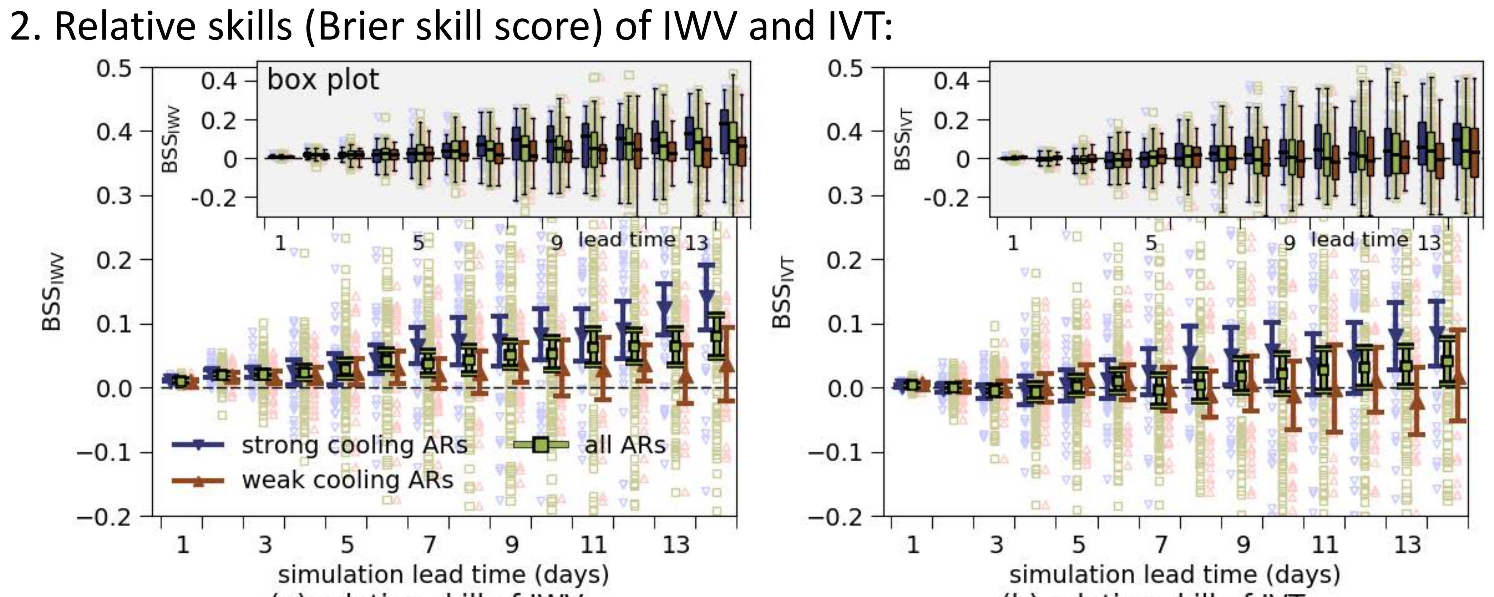


(a) errors of SST at different lead times

(b) relative skill of SST at different lead times

Case study

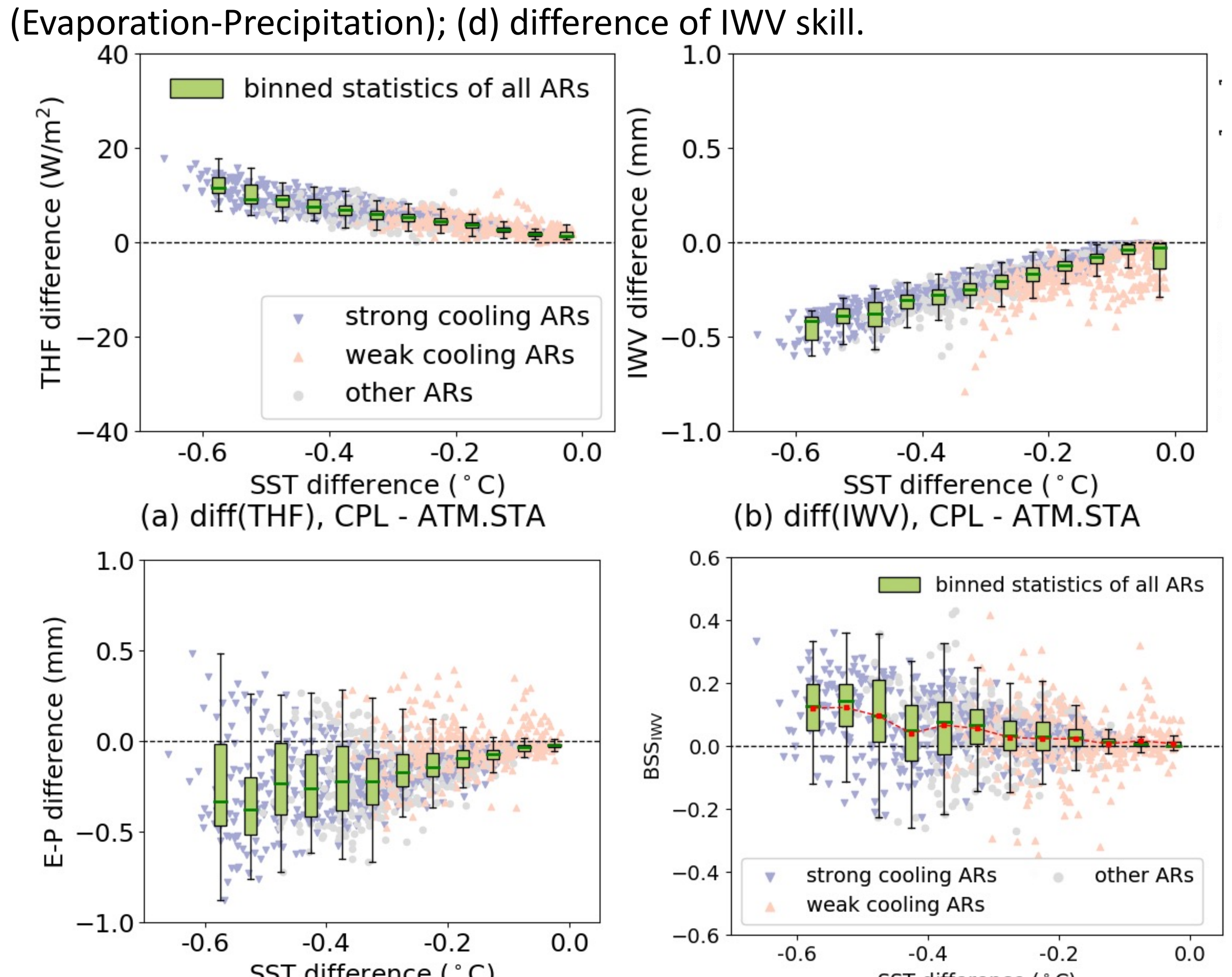
2. Relative skills (Brier skill score) of IWV and IVT:



(a) relative skill of IWV

(b) relative skill of IVT

3. Differences between CPL and ATM.STA runs: (a) THF; (b) IWV; (c) E–P (Evaporation-Precipitation); (d) difference of IWV skill.



(a) diff(THF), CPL - ATM.STA

(b) diff(IWV), CPL - ATM.STA

(c) diff(E-P), CPL - ATM.STA

(d) relative skill of IWV

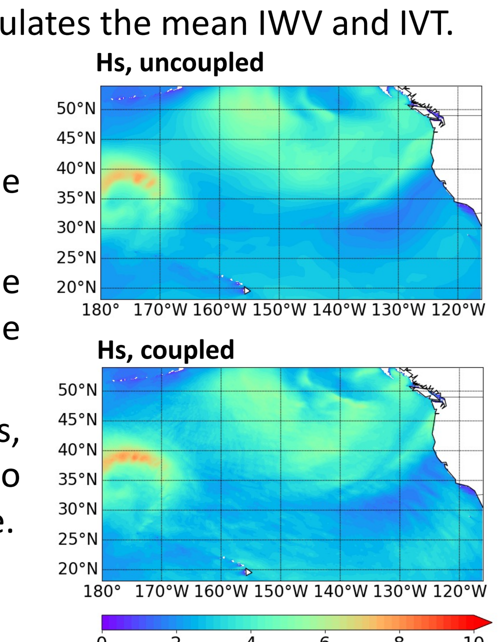
Summary and future work

Summary:

- We performed 93 pairs of coupled and uncoupled simulations of ARs and resolved the mesoscale features.
- In the simulated AR events, both strong and weak SST cooling can be observed. The SST cooling in the AR region can have a magnitude of 2°C in strong cooling cases.
- The SST obtained in coupled runs has better skill than the persistent SST used in uncoupled runs (BSS_{SST} = 0.19). The THF is also better in coupled runs (BSS_{THF} = 0.12).
- Both IWV and IVT in coupled runs are better than uncoupled runs. **The coupled model has better skill improvement in strong cooling AR events. The skill improvement in the second week is more significant (BSS_{IWV} = 0.12; BSS_{IVT} = 0.05) than the first week.**
- The improved skill is because the coupled model better simulates the mean IWV and IVT.

Future work:

- Further investigate the impact of mesoscale features at the air–sea interface on the atmosphere rivers.
- For the SKRIPS model, we have recently implemented the wave model WaveWatch III, and we aim to investigate the mesoscale effects of the ocean and waves on the ARs.
- We aim to study the impact of waves on the ocean and ARs, for example, the feedback of Langmuir turbulence due to extreme sea states or the impact of the sea surface surface.



References

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2. Sun, R., et al., 2021. Journal of Geophysical Research: Atmospheres. 126 (6).
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4. Sun, R., et al,. 2022. Geoscientific Model Development. Under review.