Atmospheric rivers driven precipitation extremes in non-hydrostatic CESM simulations over the Western US

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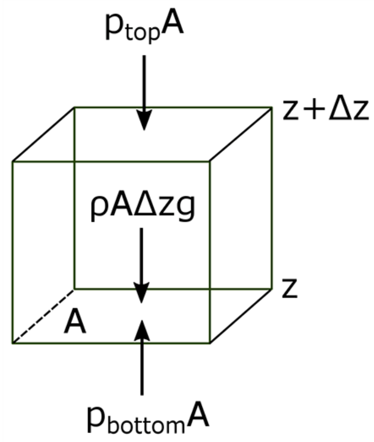
Non-hydrostatic CESM-MPAS simulations

Storm-resolving model → Configuration and experiments

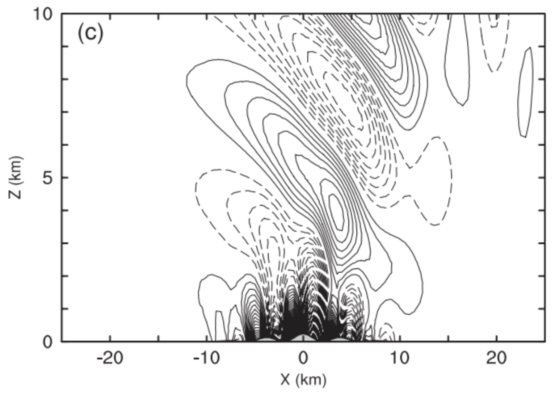
- Hydrostatic to Non-hydrostatic
- Unstructured grids
- Fixed height layers
- Coupling MPAS to CAM physics

- SIMA: System for integrated modeling of the atmosphere
- CESM2 with MPAS nonhydrostatic dynamical core and CAM6 physics
- 60-3km experiments over Western US coupled to CLM5 with prescribed SST and ice

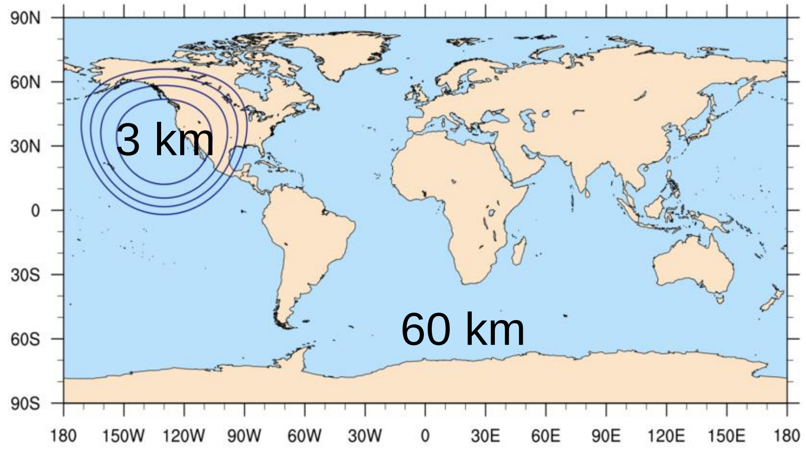


(hydrostatic)

Source: online



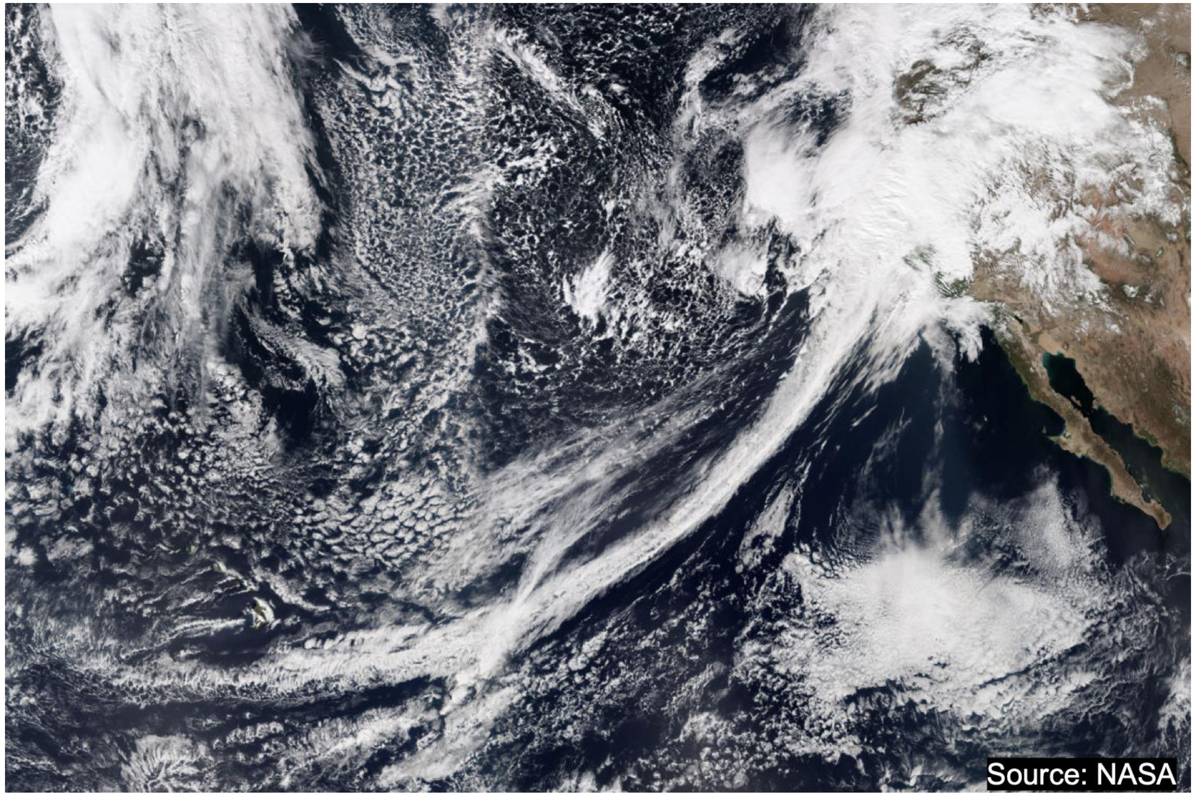
Skamarock et al., 2012
(non-hydrostatic)

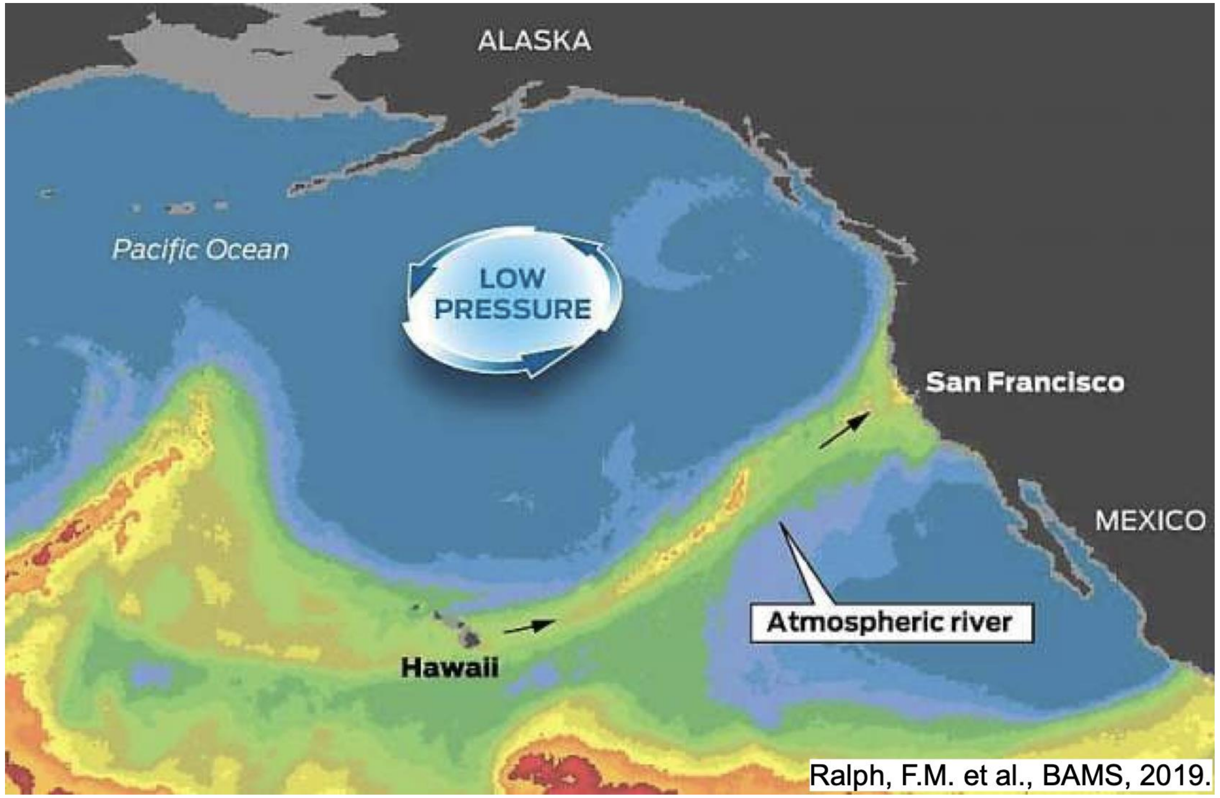


Grid mesh configuration in 60-3km experiments

Huang et al., 2022

Storm events in the form of atmospheric rivers over the western US



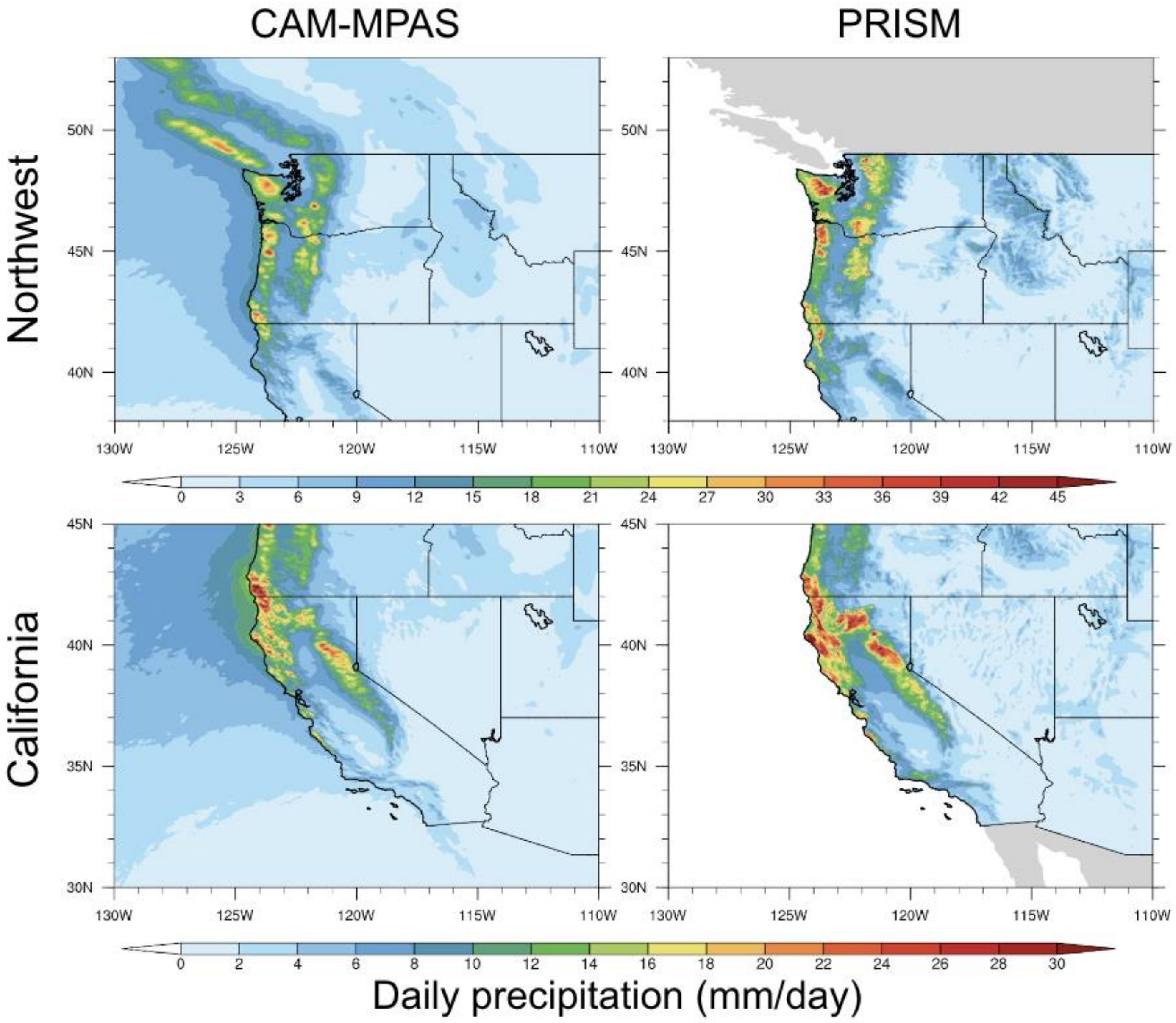


- Above shows how a typical AR event looks like: from satellite observations and the perspective of synoptic features

Atmospheric rivers simulations over the western US using CESM-MPAS

Huang et al., 2025 (in preparation)

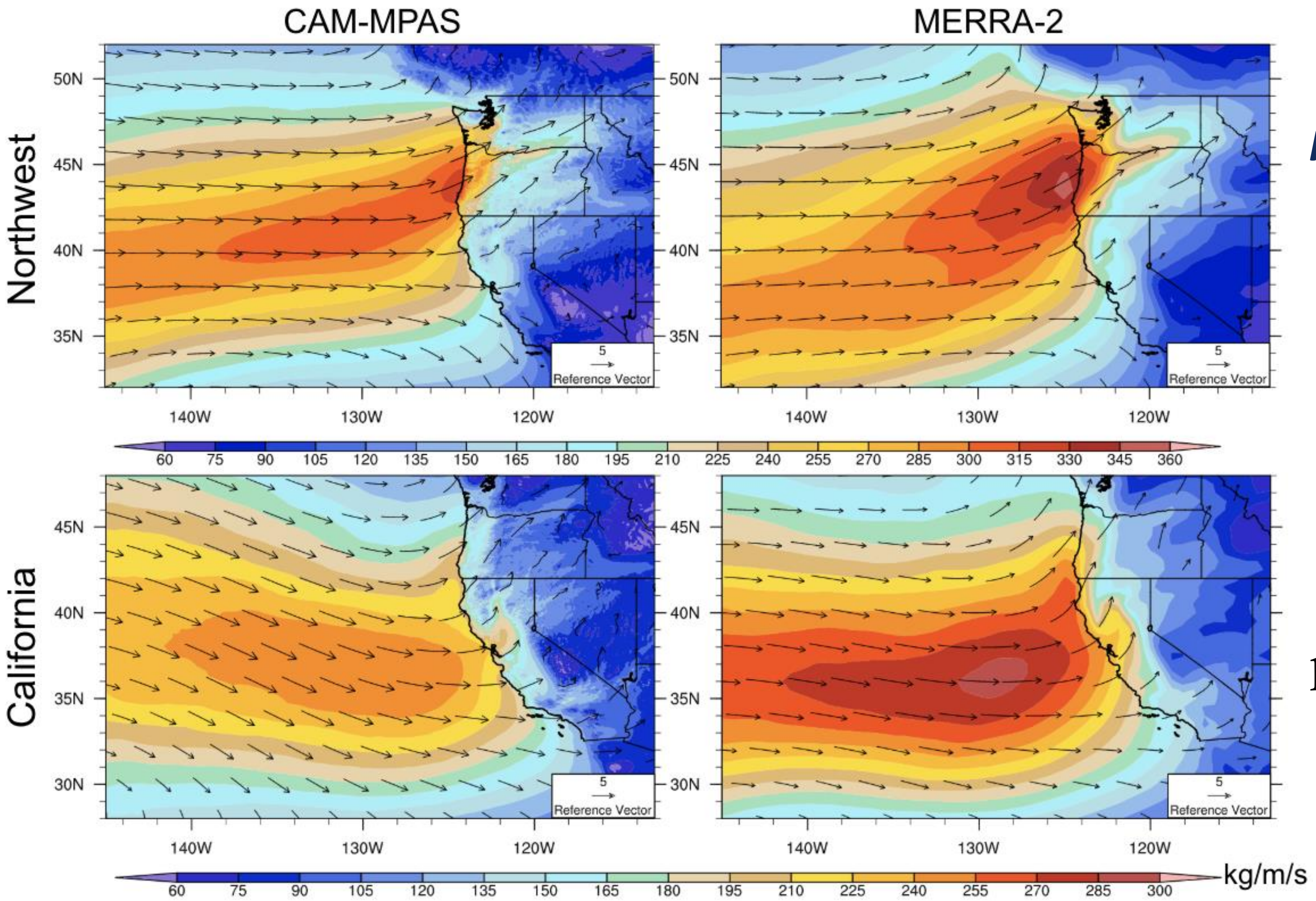
How extreme precipitation is predicted in a global model at convective-permitting scale?



Mean extreme precipitation (P75th) over Wet-season (October-March) precipitation (1999-2004)

A realistic representation of extreme precipitation features over the refined region with complex terrains for heavy precipitation events

Water vapor transport pattern: atmospheric river driven extreme precipitation

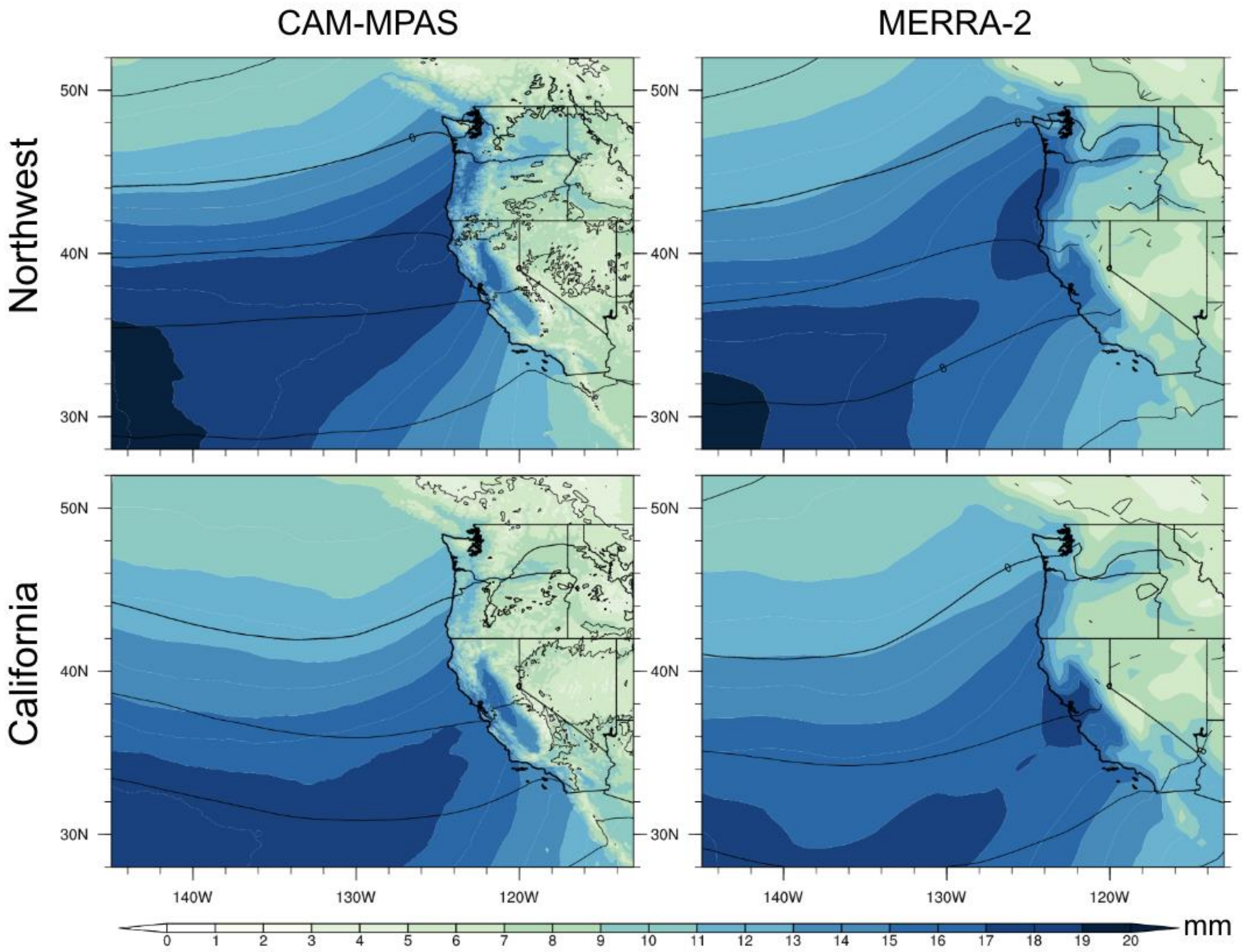


Integrated Water Vapor Transport (IVT)

Mean IVT composite patterns over the heavy precipitation days (1999-2004)

Comparable spatial distribution of the water vapor flux with similar shape, location and winds pattern. The IVT values are underestimated.

Integrated Water Vapor: the thermodynamics component of the IVT

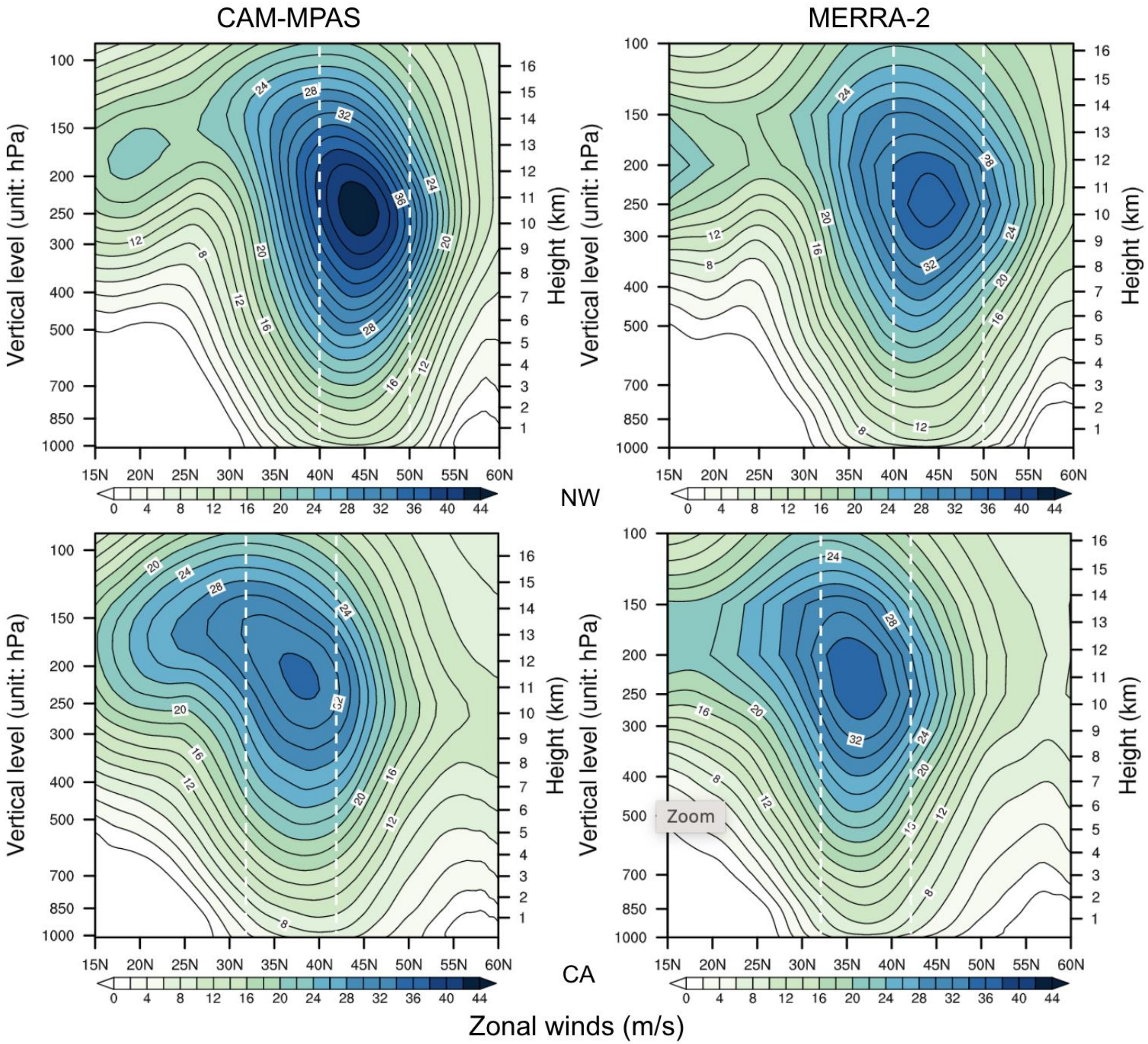


Integrated Water Vapor (IWV)

Mean IWV patterns over the heavy precipitation days (1999-2004)

IWV patterns generally match the reanalysis. The biases in simulated IVT involves both the overestimation of the IWV and the shift of the wind dynamics (discussed next).

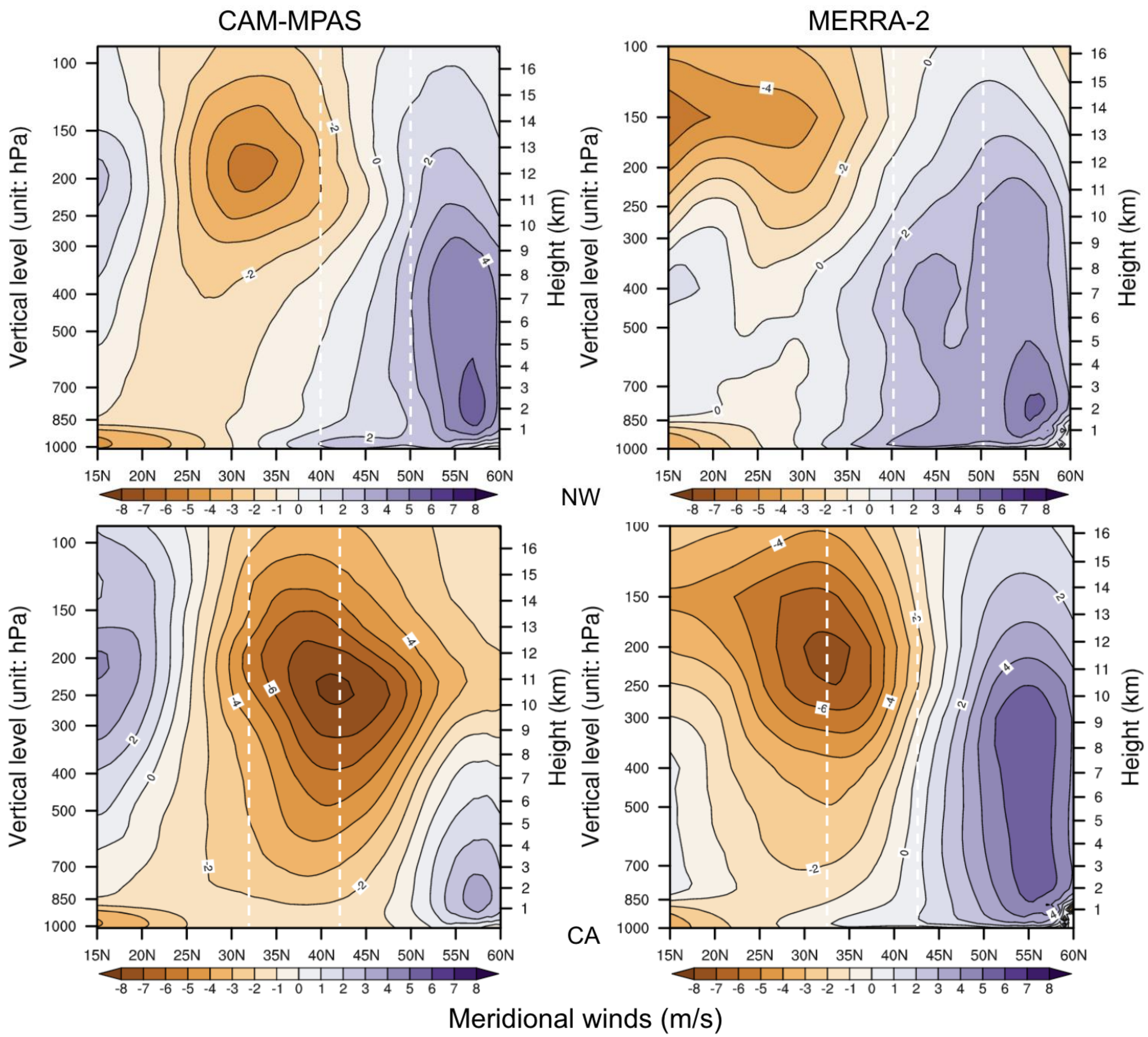
Wind dynamics (zonal winds): the dynamic component of the IVT



Mean latitude-height cross-section of zonal winds (average over 130°W - 140°W)

Overall well-captured wind profile with jet stream location shifted some northward in CAM-MPAS for the California region, and stronger zonal wind over the Northwest region.

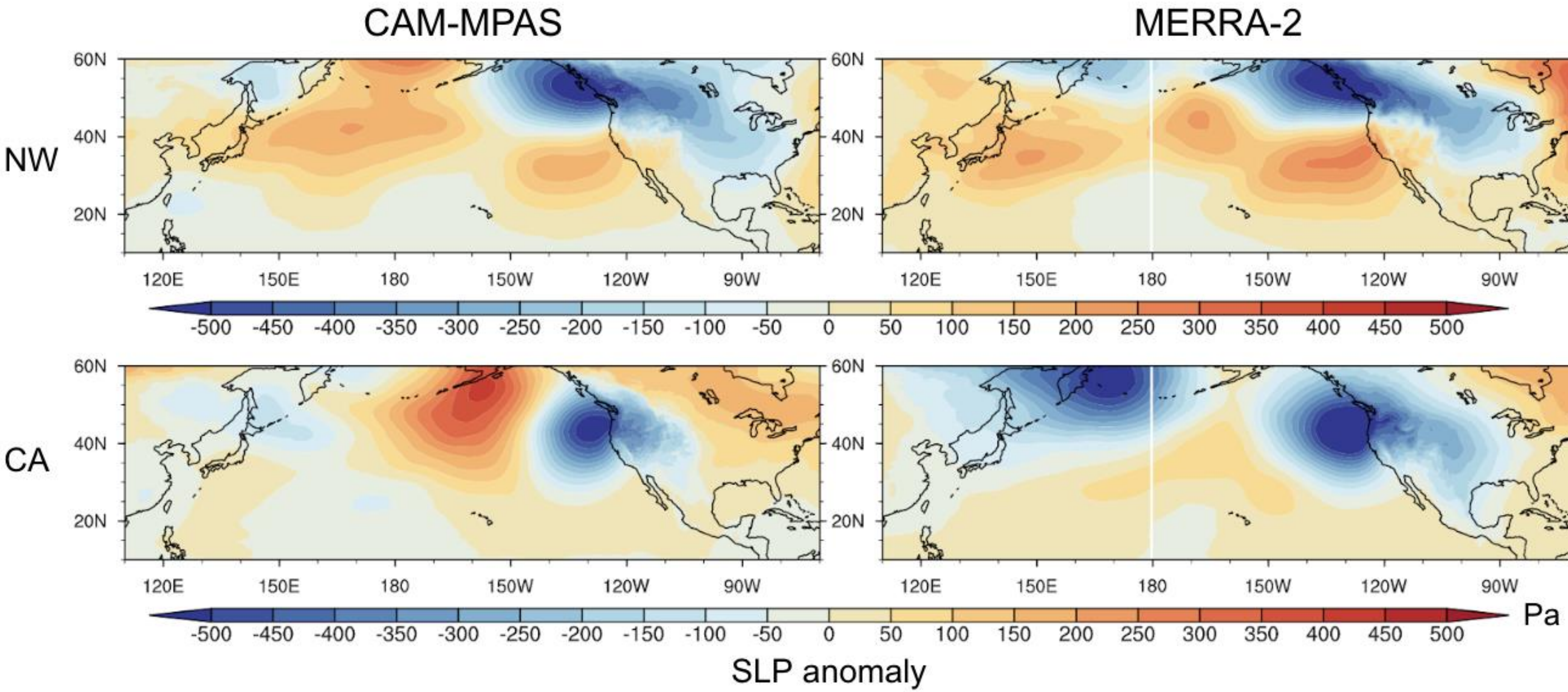
Wind dynamics (meridional winds): the dynamic component of the IVT



Mean latitude-height cross-section of meridional winds (average over 130°W - 140°W)

V-wind component is secondary relative to the dominant U-wind in IVT contribution. However, CAM-MPAS shows stronger southward wind over the California region, which could affect the precipitation spatial distribution directly.

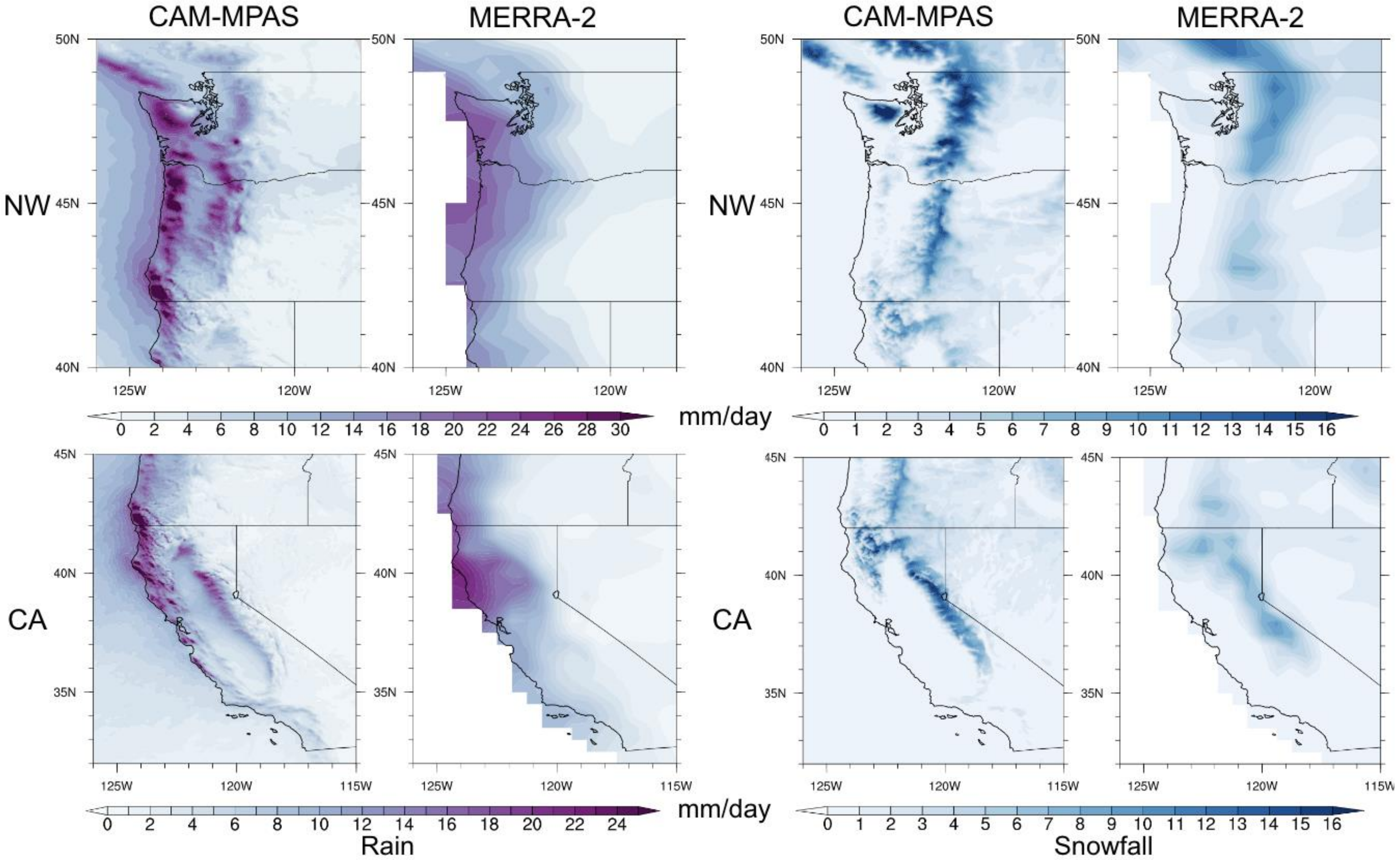
Large-scale anomaly pattern: sea level pressure anomaly



Mean sea level pressure anomaly over the heavy precipitation days

The low pressure associated with the storm is present and the geostrophic wind is in the right position, but the the model fails to capture the surface pressure anomaly of the reanalysis in CA region

Rain vs. Snow: enhanced rainfall and snowpack distributions



Summary

- This work has tested the capabilities and performance of CESM-MPAS in representing atmospheric rivers (ARs) driven heavy precipitation at convection-permitting scale over the western US.
- Investigated the ARs-driven heavy precipitation, large-scale moisture flux transport thermodynamic and dynamics components; and how that links to the landfalling rain vs. snow; compared with MERRA-2 reanalysis and PRISM obs.
- Extreme precipitation features are reasonably captured over the complex terrains including the coastal and the mountainous ranges. The water vapor transport patterns in CAM-MPAS generally match the MERRA-2 reanalysis data with well represented moisture and wind profiles over the western coastal region. Model biases from wind dynamics over the CA region and internal variability.
- Improved representation of spatiotemporal rainfall and snowfall patterns.

Thank you! (xyhuang@ucar.edu; Xingying Huang)