Projecting Regional Climate Change: Approaches, Uncertainties, and Extreme Events

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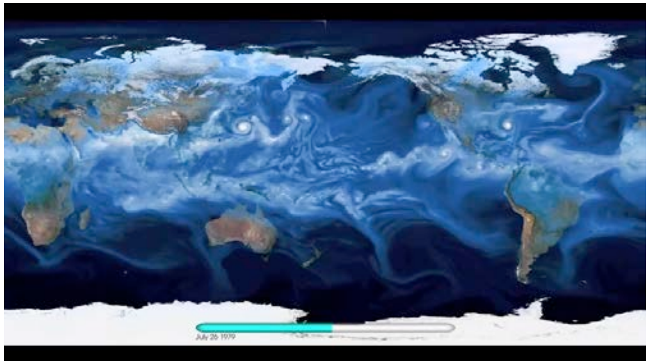
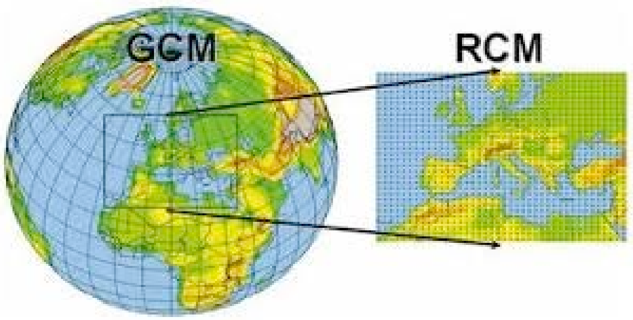
Approaches for projecting regional climate change

Global high resolution models



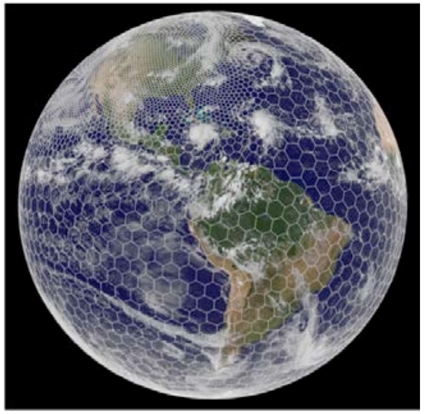
- CMIP6 HighResMIP: a multi-model ensemble of simulations at resolution ~ 25 – 50 km
- US GFDL, CESM, E3SM: simulations at resolutions ~ 25 – 50 km

Nested regional climate models



- NA-CORDEX: multi-RCM ensemble of North America simulations at 25 km and 50 km
- WRF: simulations at 4 km, 6 km, 12 km, and 20 km over CONUS, WUS and EUS

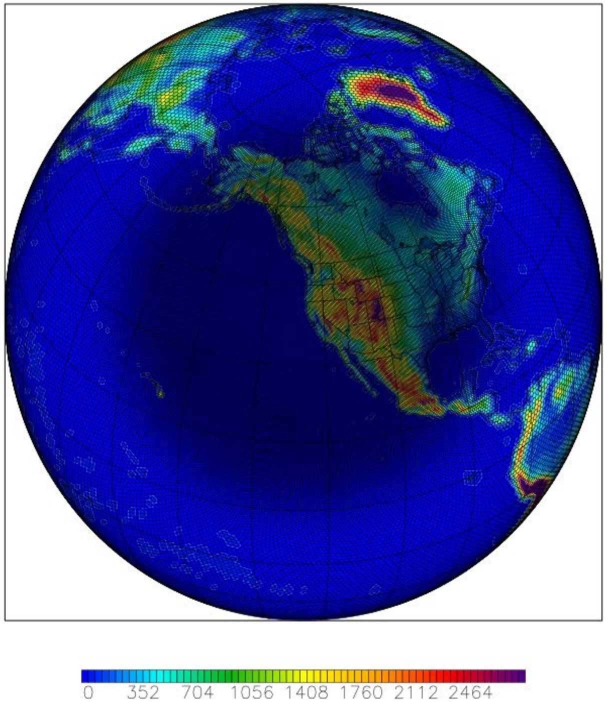
Global variable resolution models



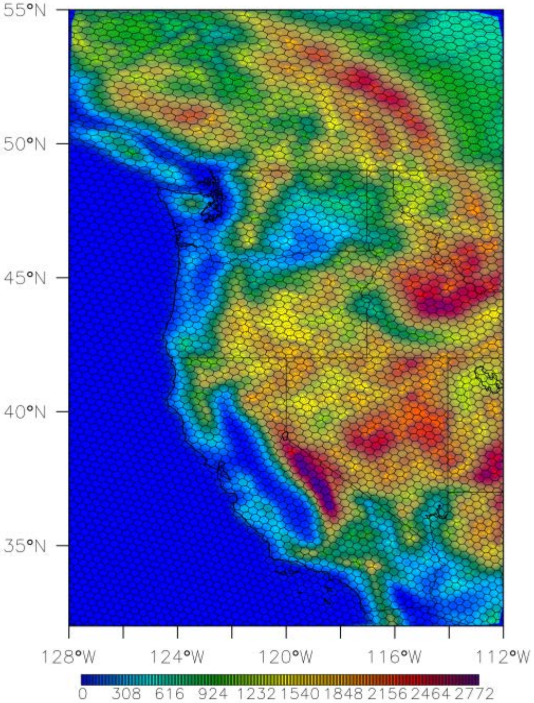
- MPAS and CAM-SE simulations with regional refinement over CONUS at 12 km, 25 km, and 50 km

Global variable resolution simulations for WNA

30-120 km: ~ 1/6 of the computing resources of global 30 km simulations

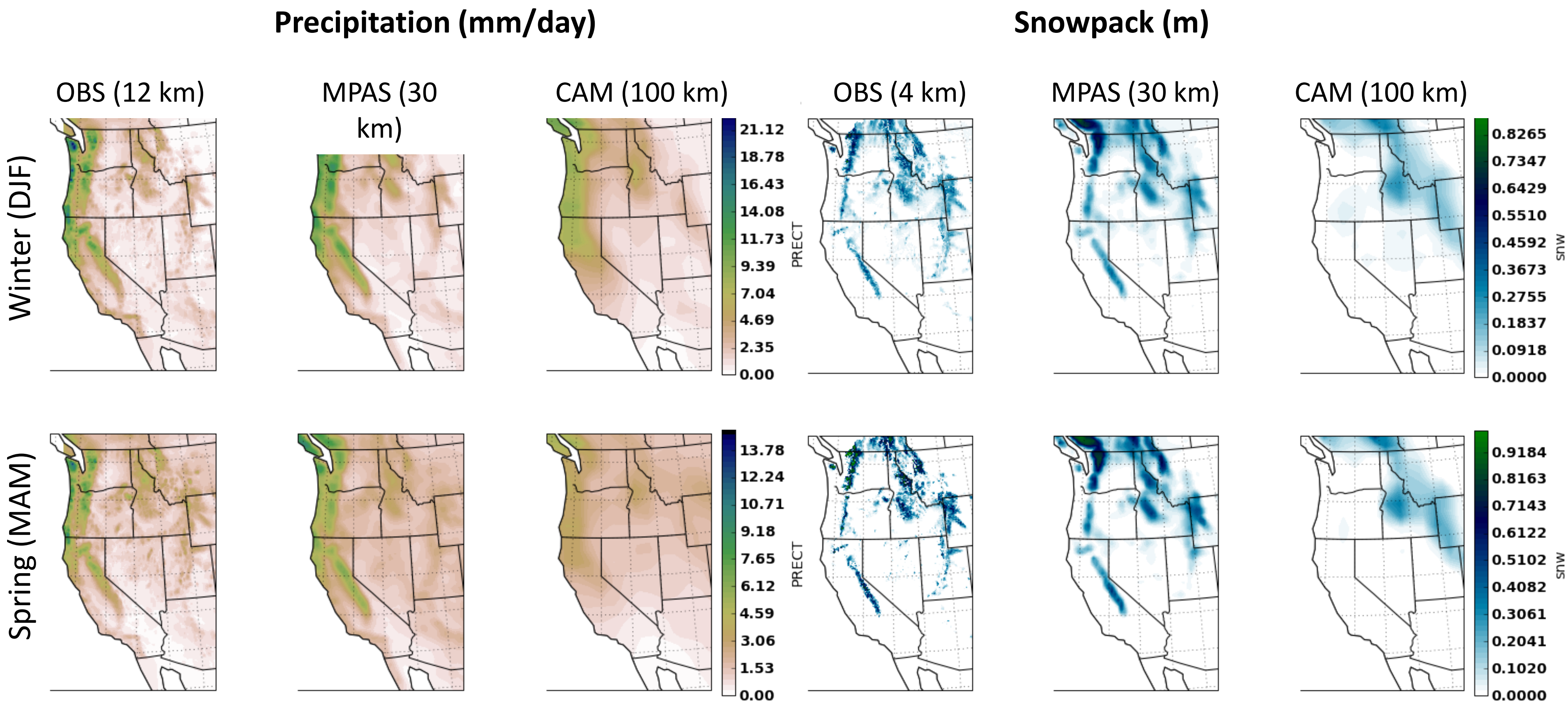


Topography of the western North America at 30 km resolution



(Source: Naomi Goldenson, UW)

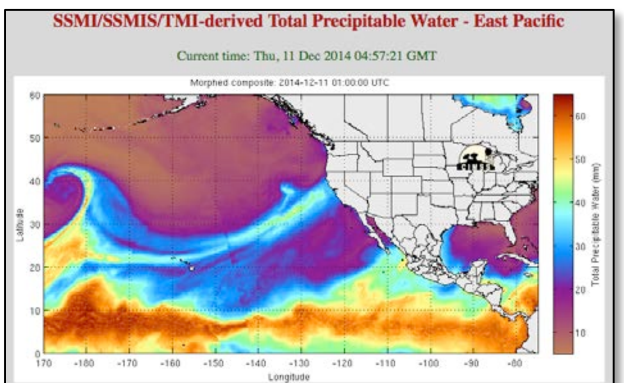
Three ensemble members (1982-2012)



Atmospheric river is a leading cause of floods

- Globally, atmospheric rivers (ARs) are responsible for over 90% of moisture transport in the extra-tropics
- Regionally, they are key contributors to floods, but also provide water resources in western North America and Europe

A landfalling AR on December 11 – 12, 2014 caused flooding in San Francisco

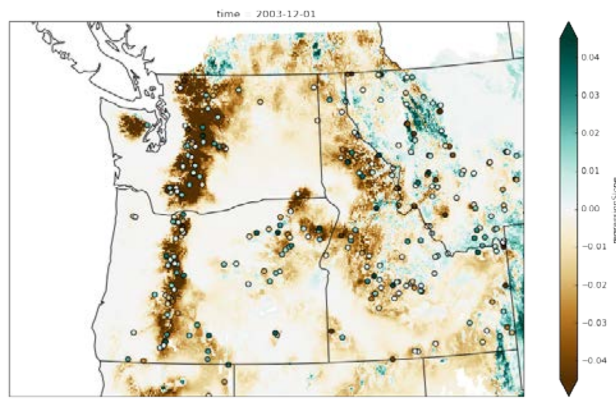


ARs produce significant snowfall in mountains and fill reservoirs

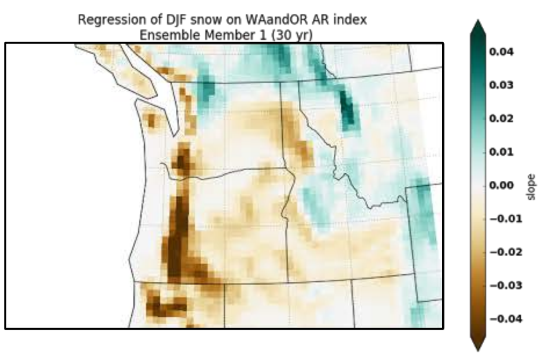
Atmospheric rivers and snowpack

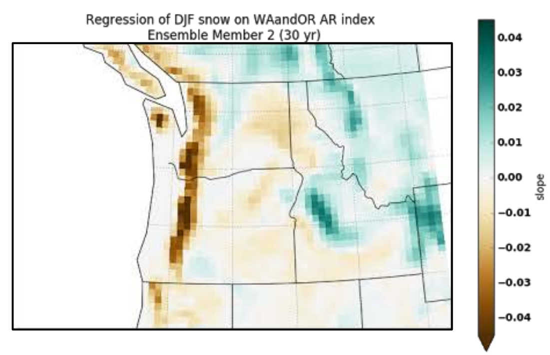
Regression of winter snowpack on the AR frequency along the WA/OR coast

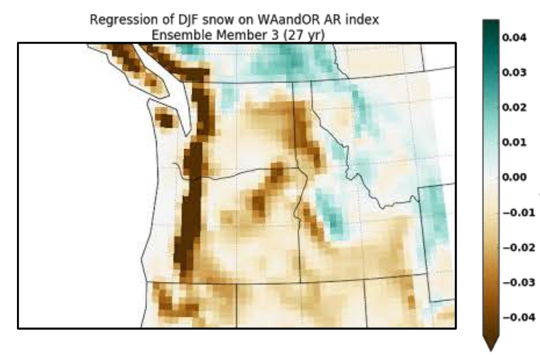
- More ARs, less snowpack in the Cascades and vice versa in the northern Rocky Mountain
- In the Cascades, ARs cause snowpack to melt during and days after AR arrivals



- MPAS captured the general pattern, but ensemble variability is noticeable



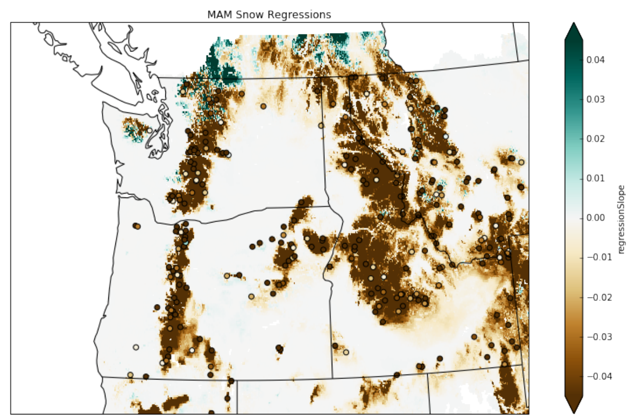




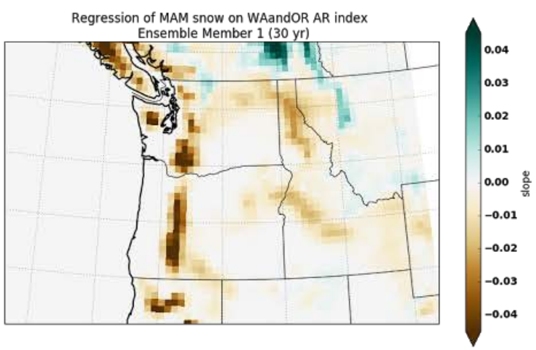
Atmospheric rivers and snowpack

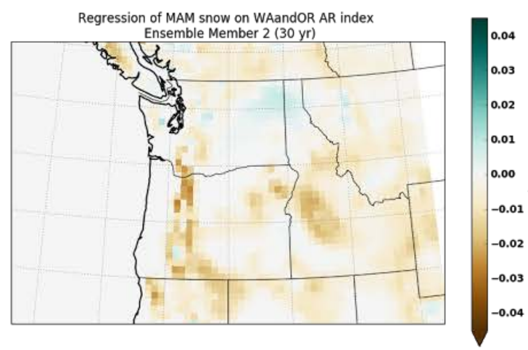
Regression of spring snowpack on the AR frequency along the WA/OR coast

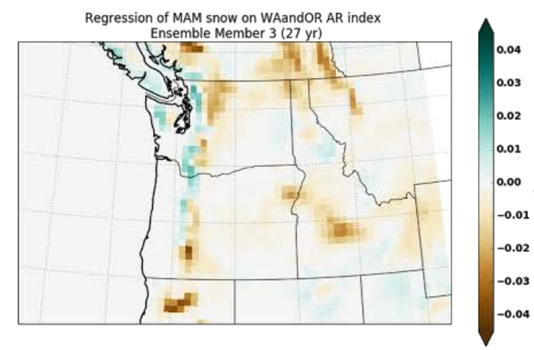
- Spring snowpack is reduced in years with more ARs



- Comparable relationship in MPAS, but larger variability among ensemble members in spring than winter

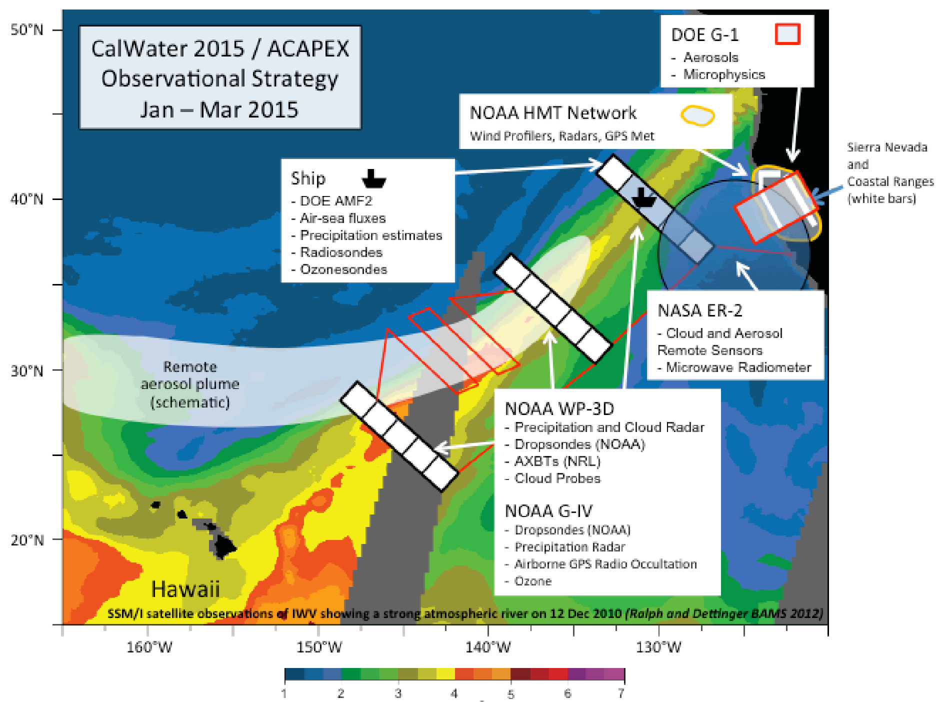






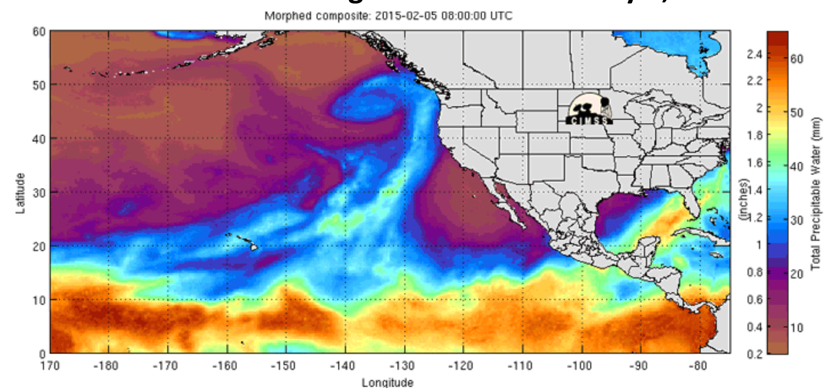
AR measurement and modeling

- CalWater-2015 observing platforms: NOAA G-IV, P-3, RHB and HMT, DOE G-1 and AMF, NASA ER-2, NSF aerosol and cloud measurements

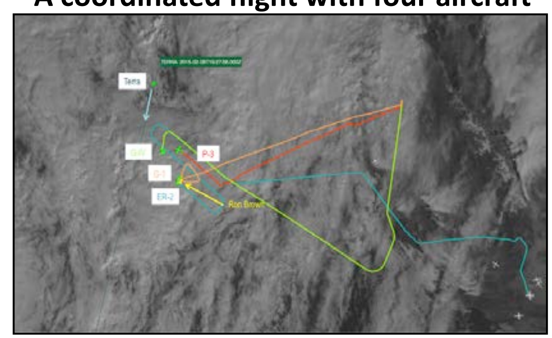


Courtesy of F. M. Ralph, NOAA Earth System Research Laboratory

An AR making landfall on February 6, 2015

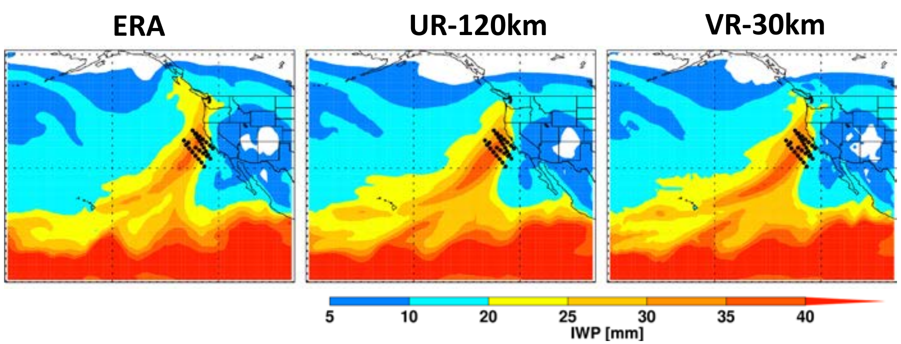


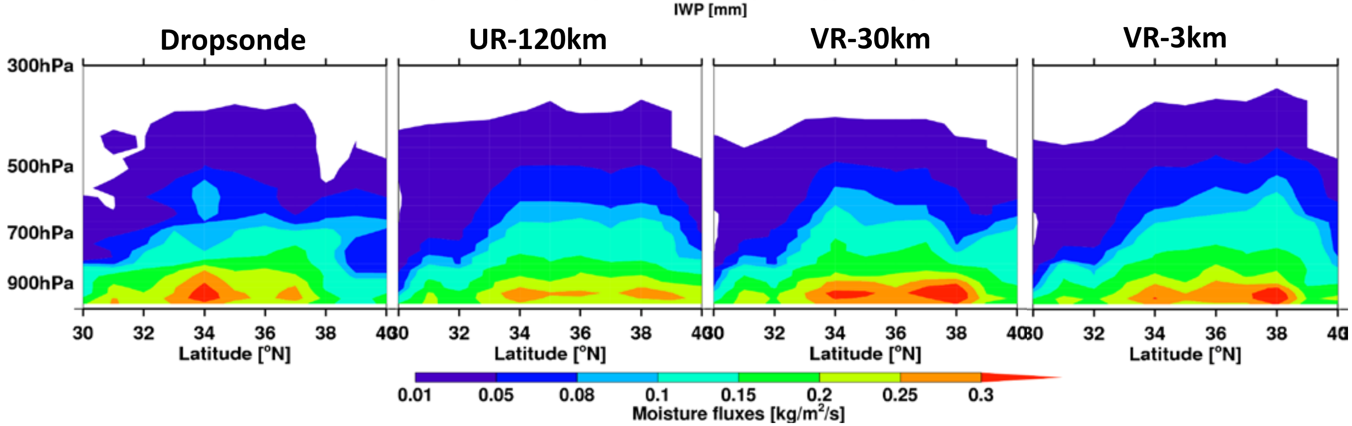
A coordinated flight with four aircraft

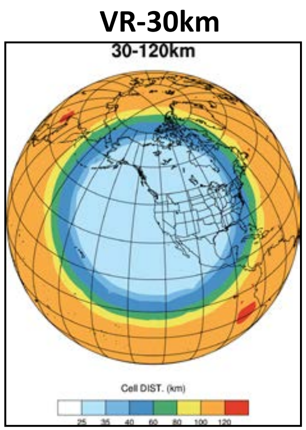


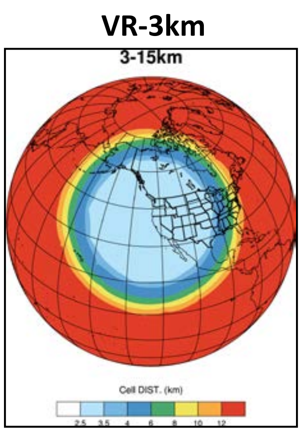
Resolution effects: AR moisture fluxes

- MPAS simulations: UR-120km, VR-30km, VR-3km
- Compare with ERA and dropsonde measured moisture fluxes



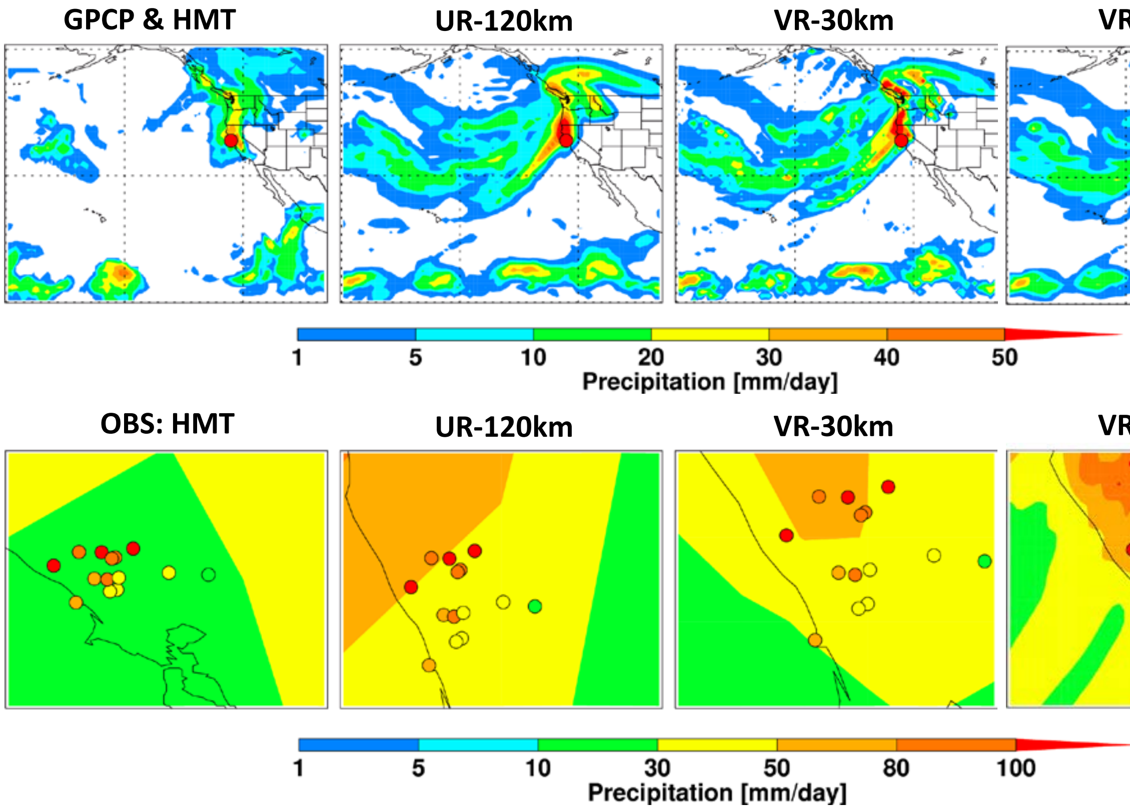






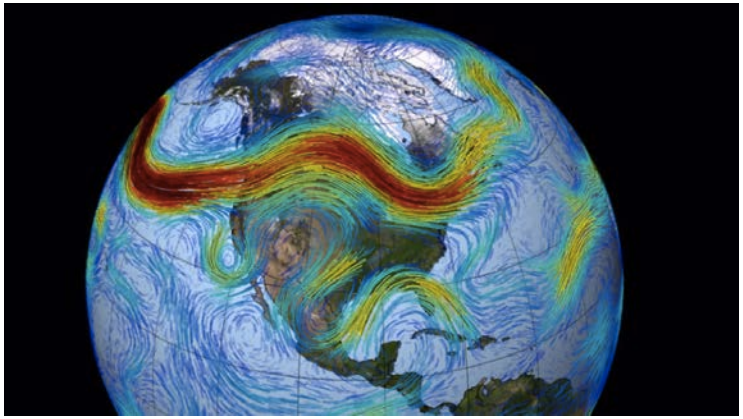
Resolution effects: AR precipitation

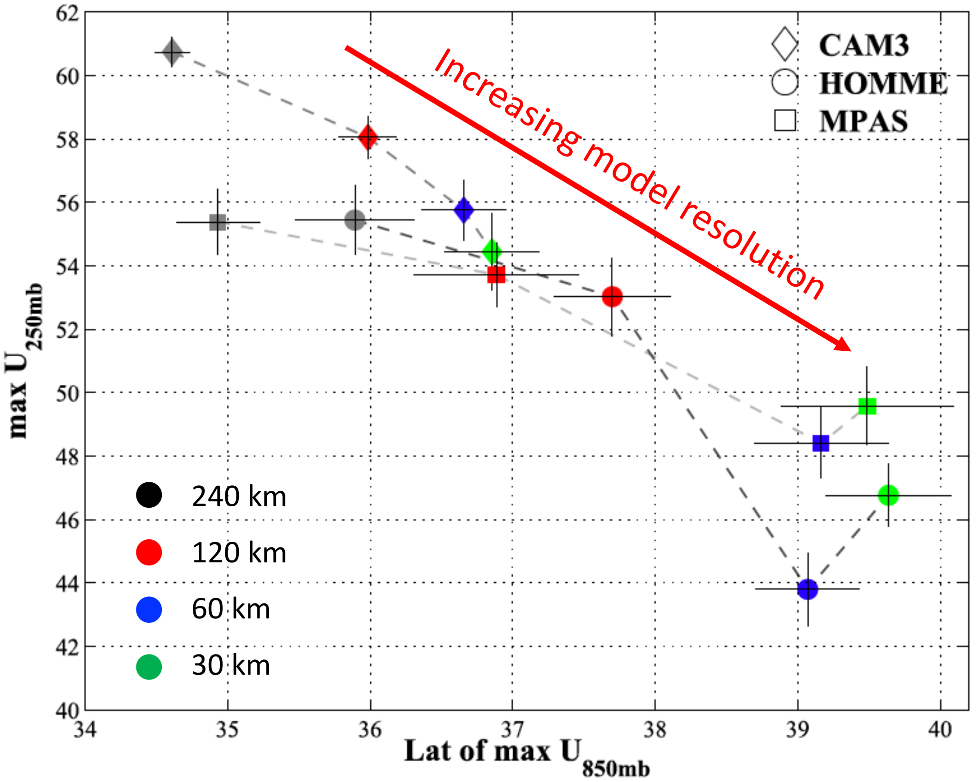
- Resolution has more positive effects on precipitation



Resolution effects: Jet stream strength/position

- Jet location shifts poleward and jet strength weakens with increasing resolution



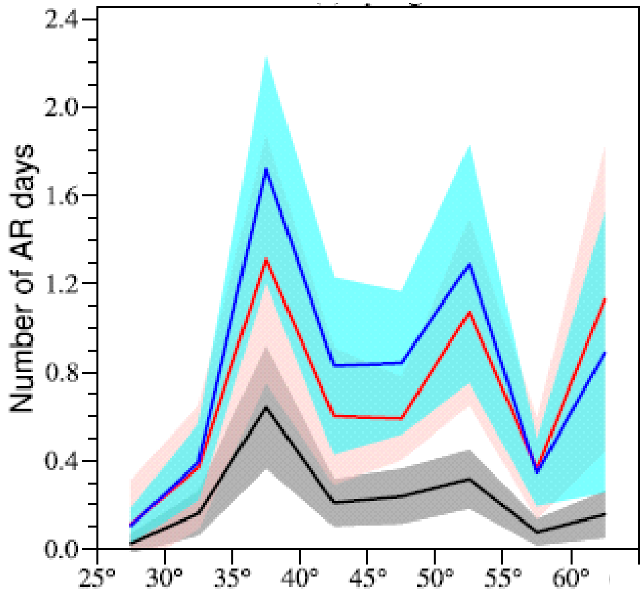


(Lu et al. 2015 JCLIM)

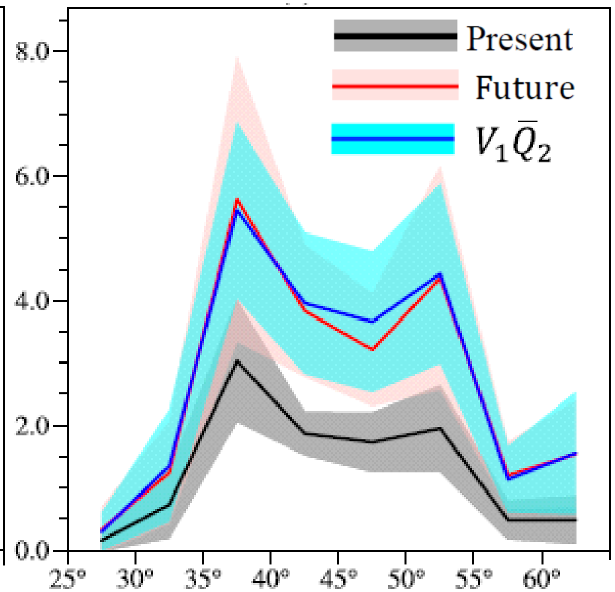
Jet stream and AR frequency

- Climate models projected significant increases in AR frequency in the future
- Uncertainty in projecting AR frequency change is partly explained by uncertainty in projecting jet position shift

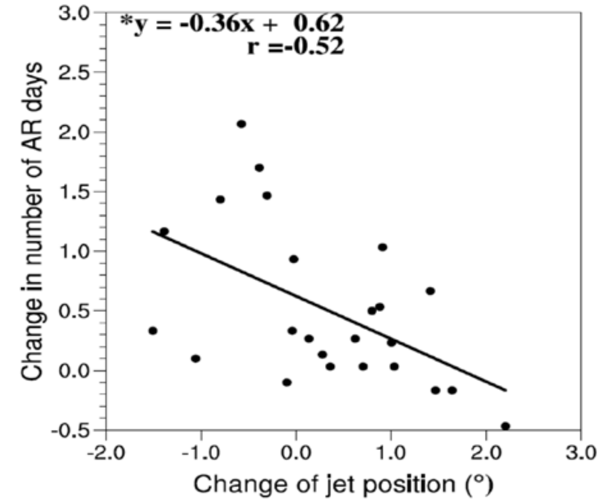
AR frequency in spring



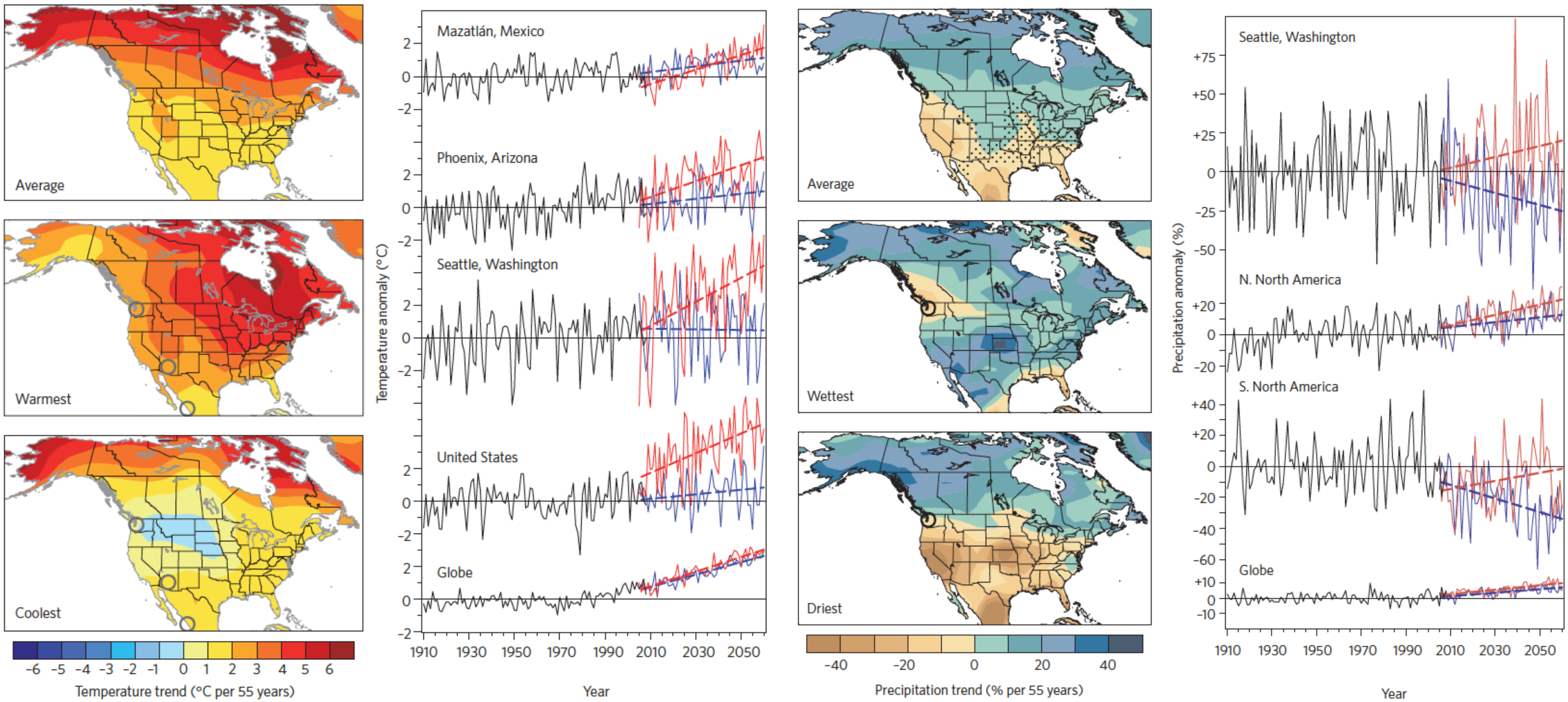
AR frequency in winter



AR frequency change vs. change in jet position



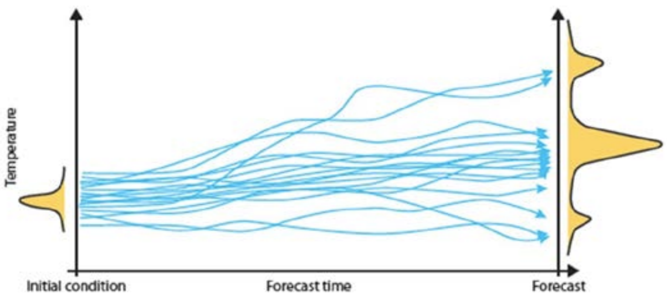
Large internal variability in future projections



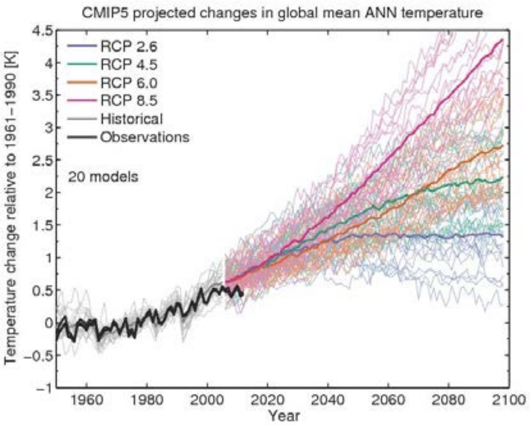
(Deser et al. 2012 Nat. Clim. Change)

Ensemble approach to estimate uncertainty

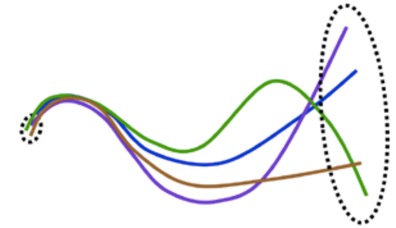
Internal variability:
Single model initial condition ensemble

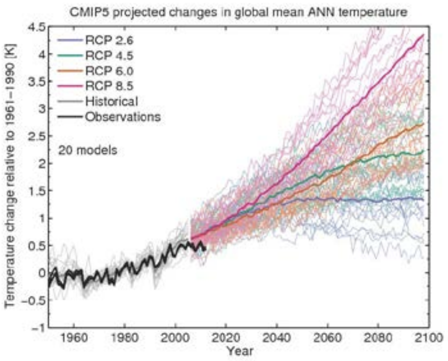


Model uncertainty:
Multi-model ensemble



Combination: Small initial condition ensemble + Multi-model ensemble





Estimating uncertainty from internal variability

- An ensemble of opportunity including a small initial condition ensemble in a multi-model ensemble provides an estimate of internal variability comparable to that of the large initial condition ensemble

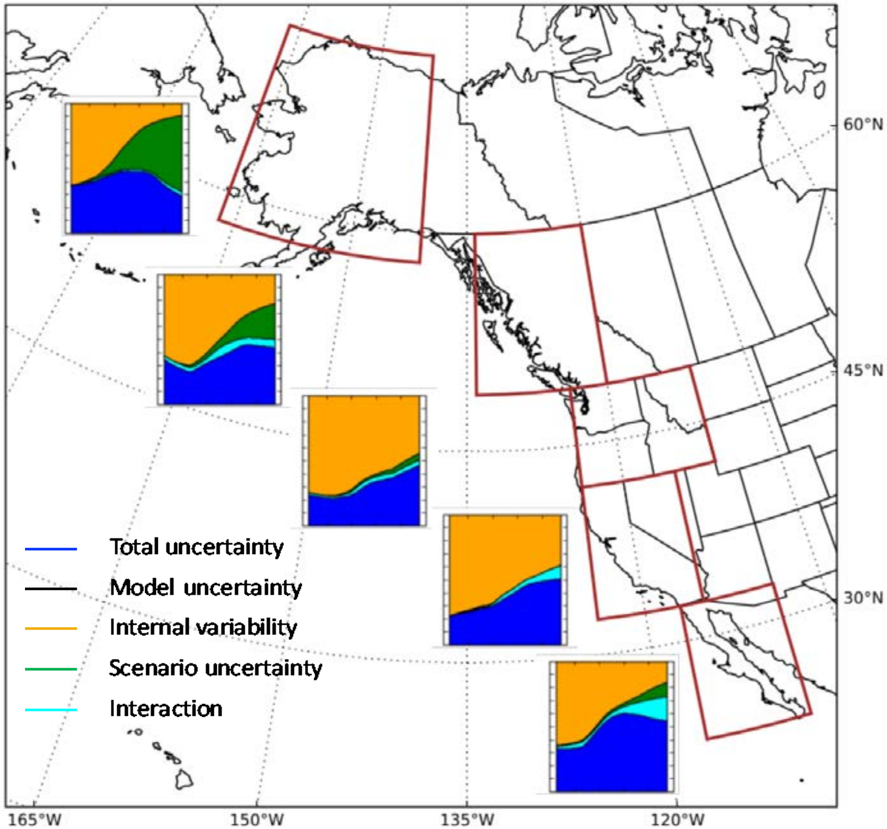
Estimates of internal variance of temperature

Method	Dataset	N[a]	Global	Northwest
σ^2	CESM LE	40	0.0036	$\boxed{0.053}$
HS09	CMIP5[b]	68	0.0044	0.064
NC14	CMIP5	278	0.0034 (0.0027-0.0042)	$\boxed{0.050}$ (0.039-0.060)
NC14	Combined Ens.	318	0.0038 (0.0031-0.0045)	0.050 (0.041-0.059)
NC14	Reduced Combined Ens.[b]	159	0.0049 (0.0029-0.0070)	0.048 (0.028-0.066)

[a]The total number of simulations across all models and scenarios.
[b]Only one simulation from CMIP5 is included per model for each scenario.

Regional variations in relative contributions to precipitation projection uncertainty

- Internal variability contributes importantly to the overall uncertainty across western North America
- High latitude: larger warming – larger contributions from scenario uncertainty
- In PNW and CA, internal variability contributes more to the overall uncertainty



Summary

- With advances in computing and modeling, several high resolution modeling approaches are now viable for projecting regional climate change
- High resolution (a few km) has obvious impacts on modeling precipitation and snowpack in the western US
- High resolution (25-50 km) is also important for improving modeling of large-scale circulation features (e.g., jet stream and atmospheric rivers)
- Uncertainty arising from internal variability is irreducible and must be quantified
- An ensemble of opportunity including a small initial condition ensemble in the context of a multi-model-scenario ensemble is best for estimating multiple sources of uncertainty
- Need to explore strategies for combining low and high resolution projections