



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** Since 1965

Atmospheric Rivers in a Hierarchy of Climate Simulations: Resolution Sensitivity and Impacts of Global Warming

L. Ruby Leung, Samson Hagos, Jian Lu, Yang Gao, and Chun Zhao
Atmospheric Sciences and Global Change Division
Pacific Northwest National Laboratory

2016 International Atmospheric Rivers Conference
August 8 - 11, 2016, La Jolla, CA

A hierarchy of modeling experiments



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** Since 1965

Aquaplanet simulations

AMIP experiments

Forecast experiments

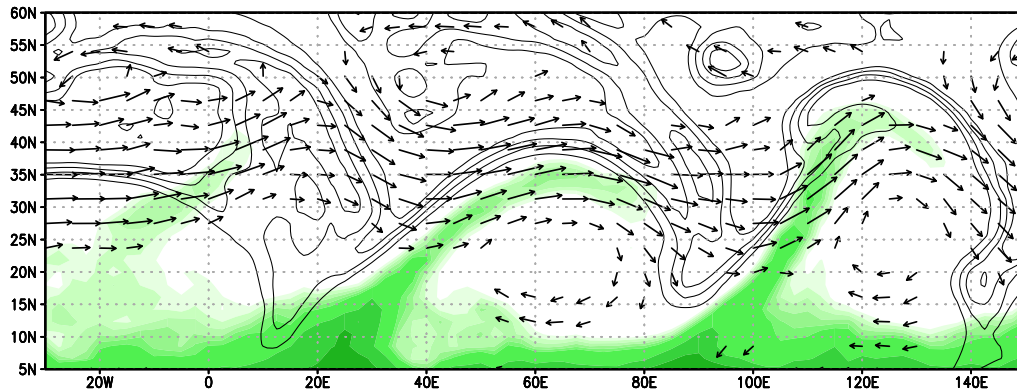
CMIP experiments

Large ensemble experiments

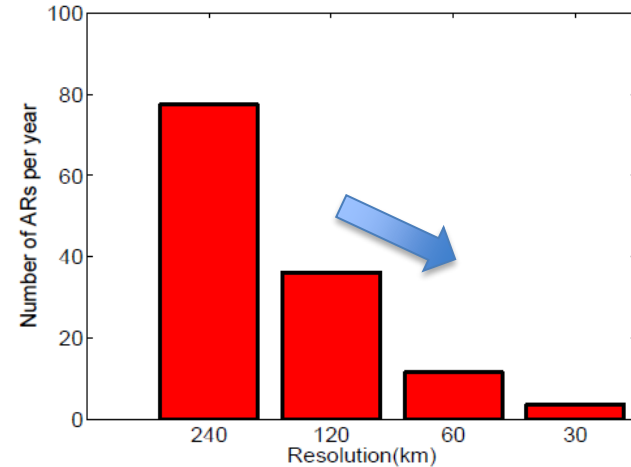
- ▶ How well are ARs simulated by climate models?
- ▶ What are the sensitivities of ARs to model resolution? Is there a critical resolution for convergence and why?
- ▶ What are the implications to model projections of AR changes in a warmer climate?

Poleward shift of subtropical jet with increasing resolution reduces AR frequency

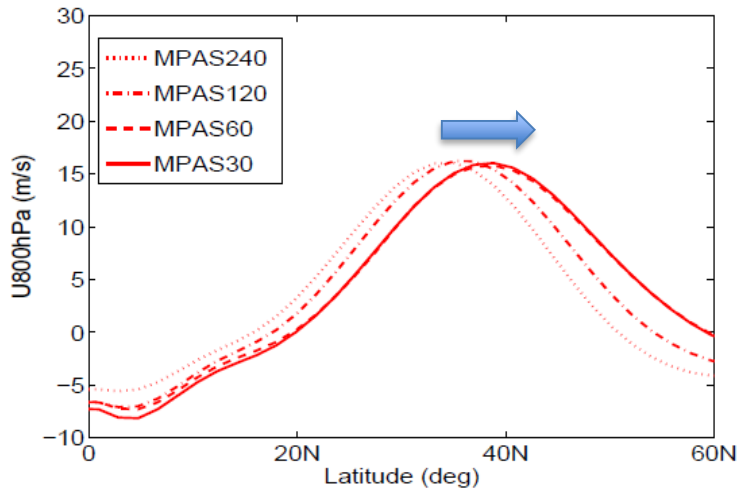
ARs in an aquaplanet simulation



AR frequency in aquaplanet simulations

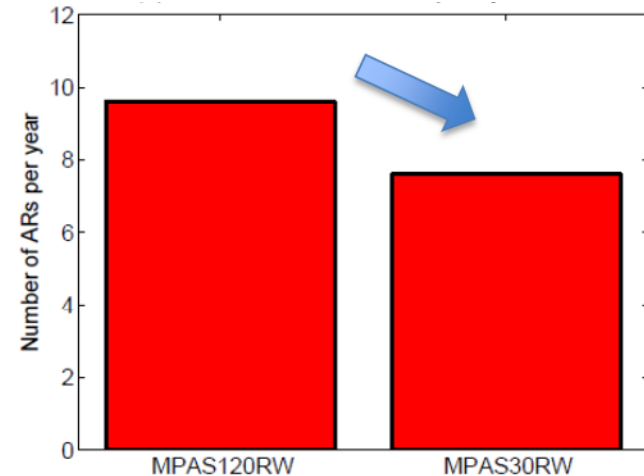


Zonal mean U-wind at 800 hPa



(Hagos et al. 2015, JCLIM)

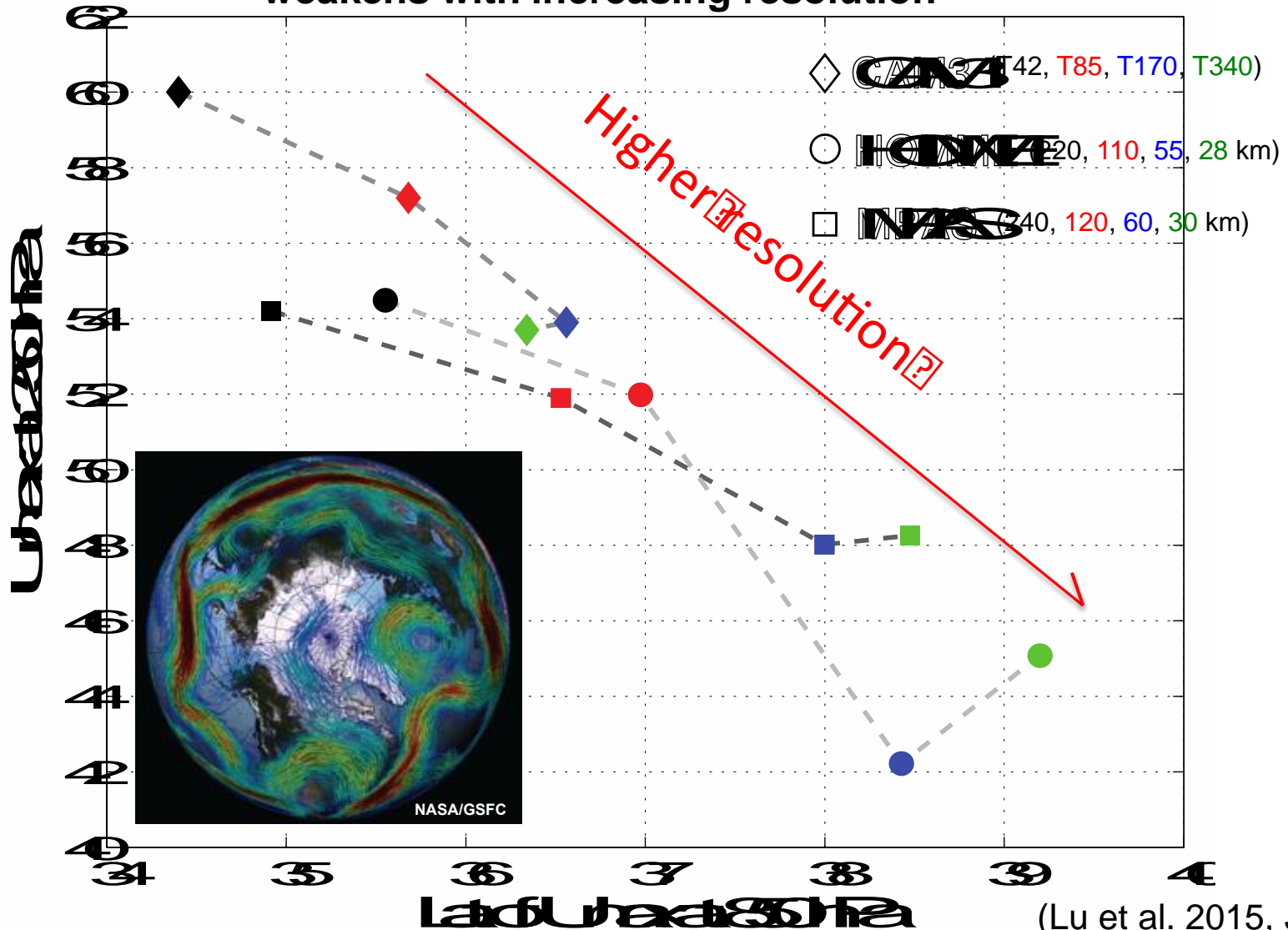
Southeast Pacific AR frequency in AMIP simulations



Dependence of jet stream on resolution

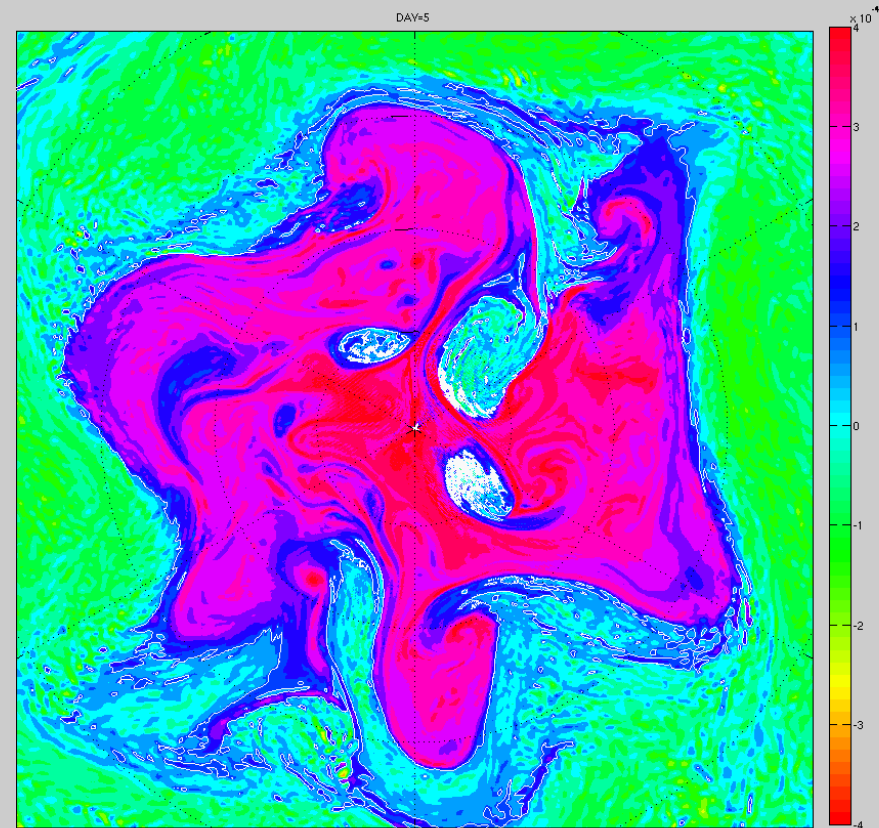
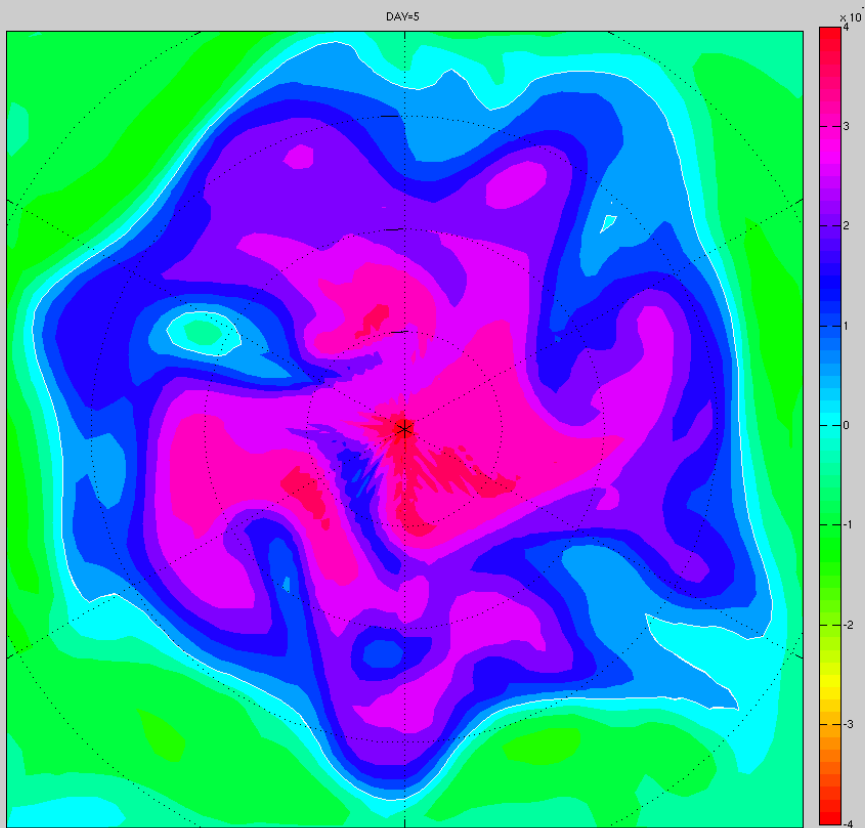


Jet location shifts poleward and jet strength weakens with increasing resolution



Wave Breakings at Two Model Resolutions

250hPa QG PV



Model diffusivity approaches the asymptotic effective diffusivity of the Batchelor turbulence

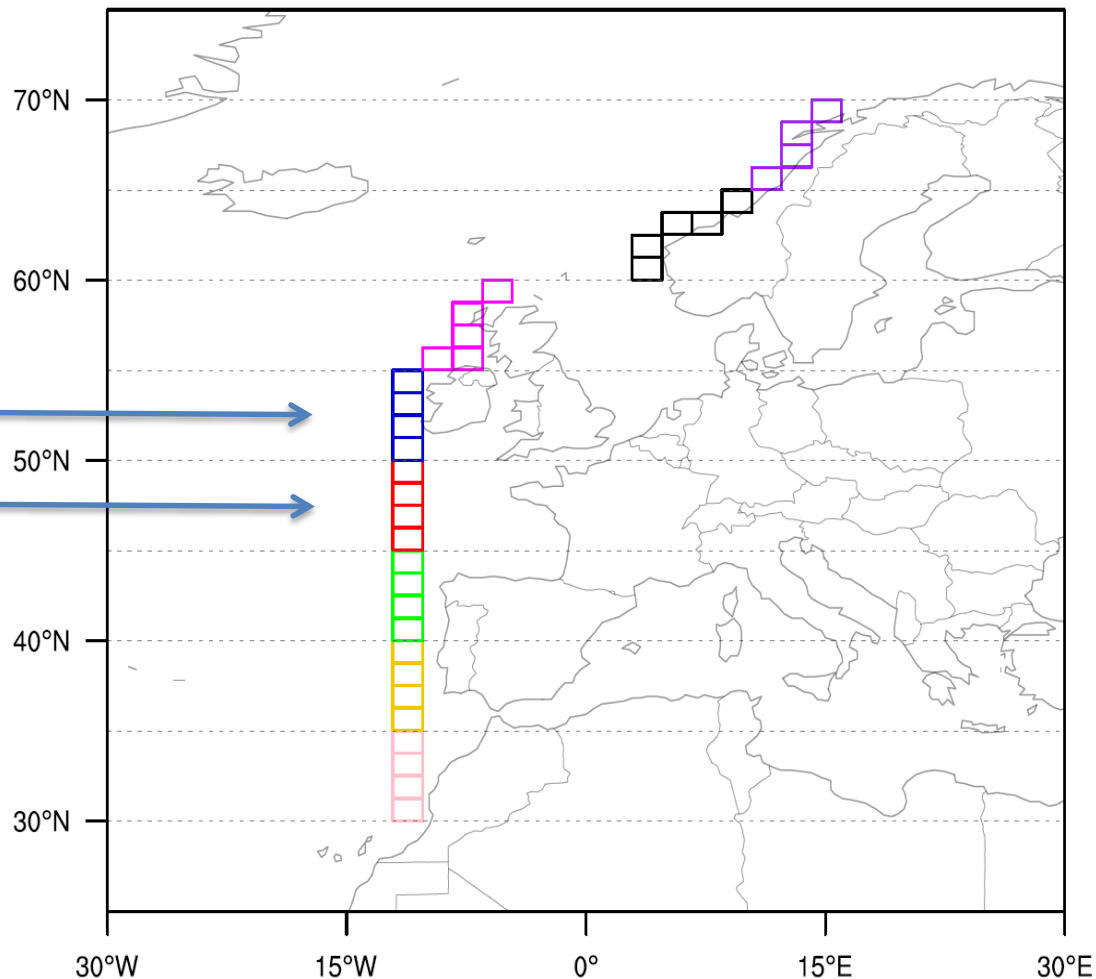
ARs in N. Atlantic-Europe in CMIP5

- ▶ IVT > 85th-percentile
- ▶ Elongated >2000km
- ▶ Averaged IWV > = 2 cm

Observed jet position



Simulated jet position

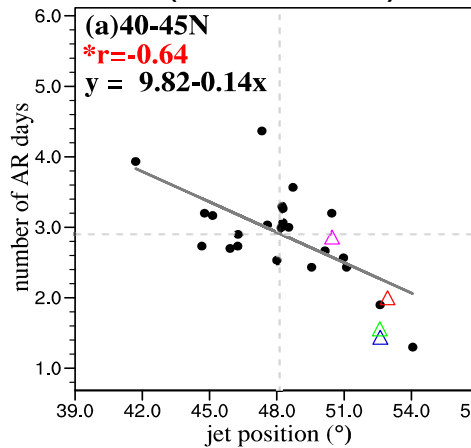


(Gao et al. 2016, JCLIM)

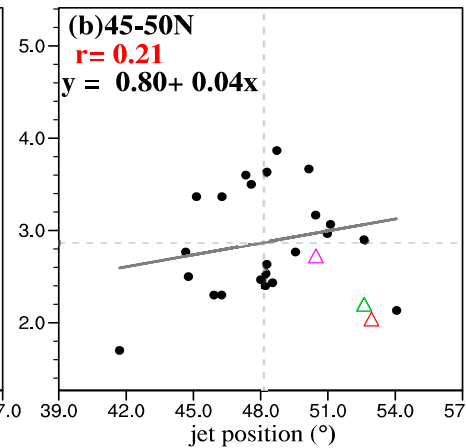
Simulated AR frequency linked to jet location and speed

Number of AR days

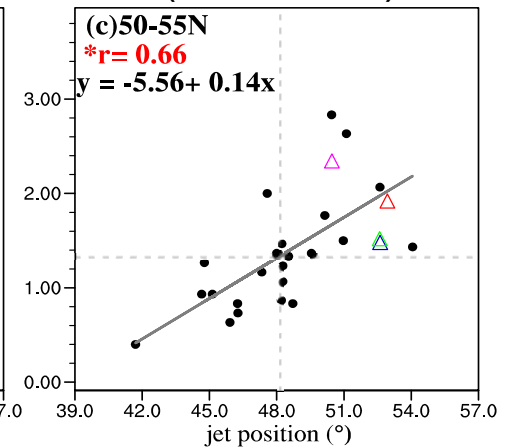
Equatorward of jet
(40 – 45 N)



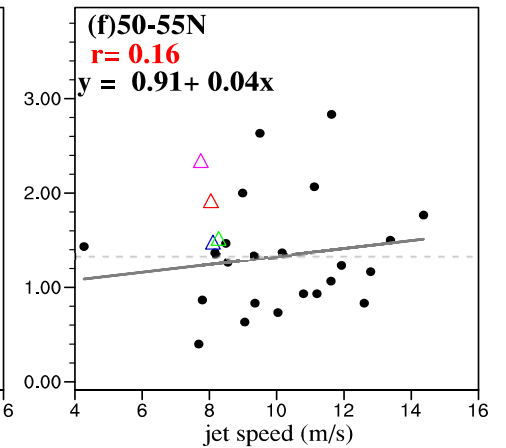
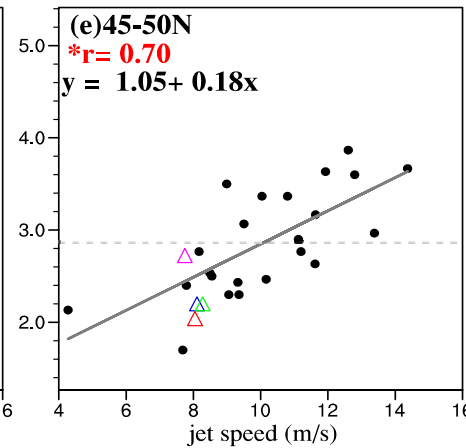
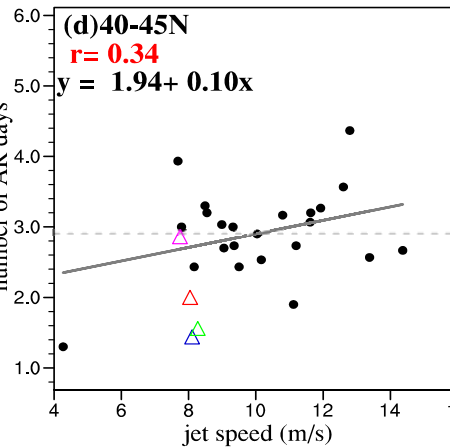
Center of jet
(45 – 50 N)



Poleward of jet
(50 – 55 N)



Relationship
with jet latitude



Relationship
with jet speed

● CMIP5

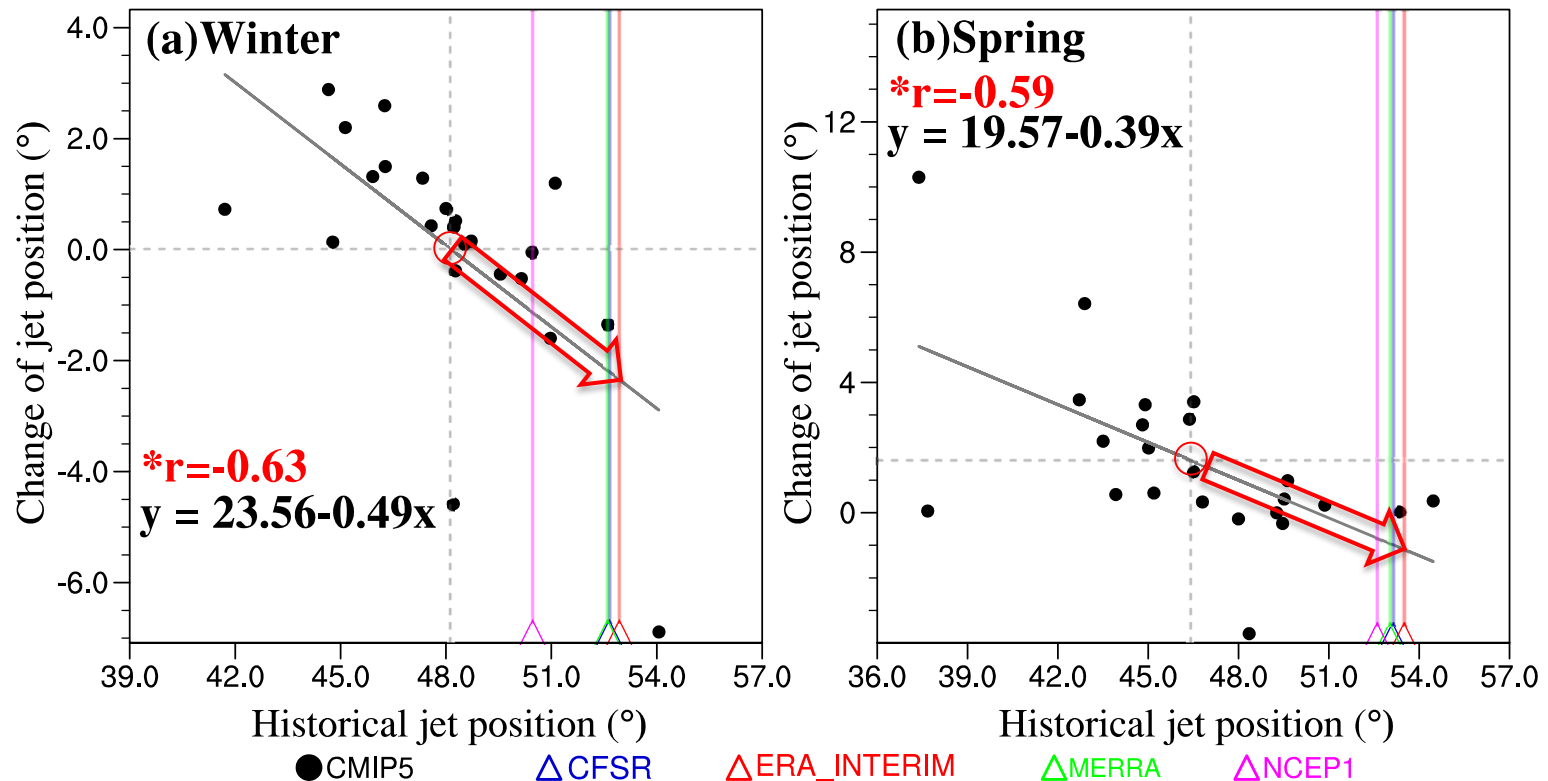
△ CFSR

△ ERA_INTERIM

△ MERRA

△ NCEP1

Emergent constraint on the shift of the Atlantic jet stream under warming

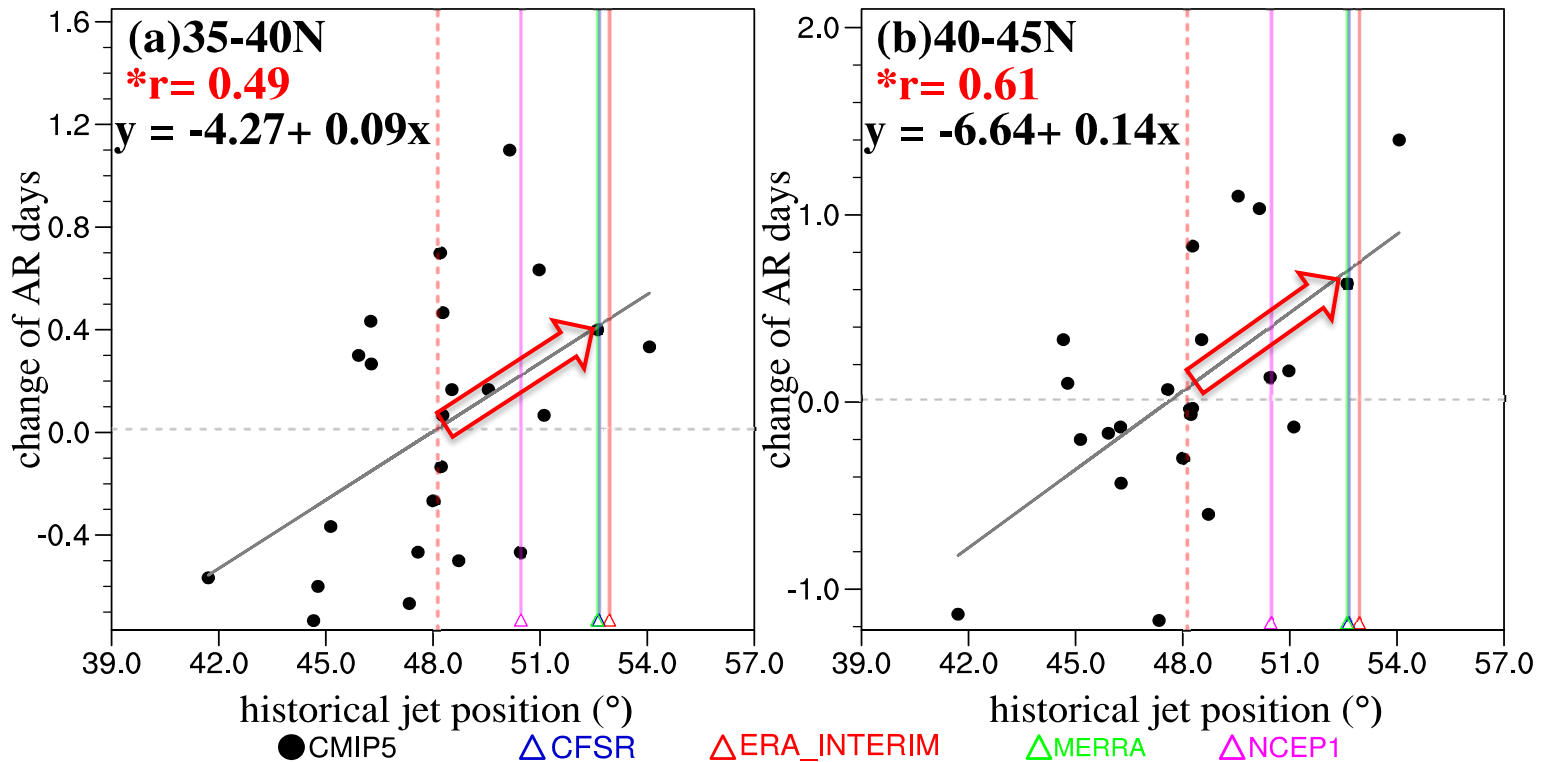


- ▶ Systematic equatorward bias of CMIP5 model in jet position
- ▶ More equatorward-biased jet has a greater shift poleward (Barnes and Hartmann 2010; Kidston and Gerber 2010)

Manifestation in the projection of ARs

Winter

Spring

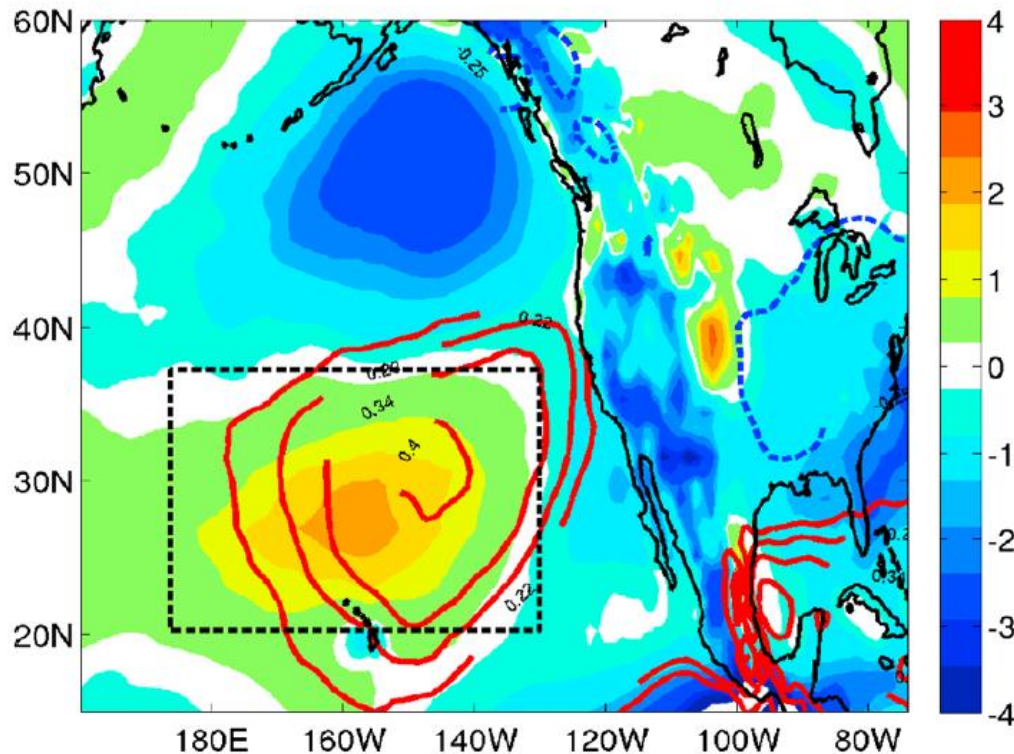


- The projected dynamical change in ARs at the equatorward flank of the mean jet ought to be calibrated upward according to the emergent constraint

ARs in N. Pacific-US in CESM-LE

- ▶ CESM-LE wind biases show a dipole pattern corresponding to a equatorward bias in the subtropical jet
- ▶ Biases in AR frequency in 29 members of CESM-LE simulations correlate with the positive wind biases

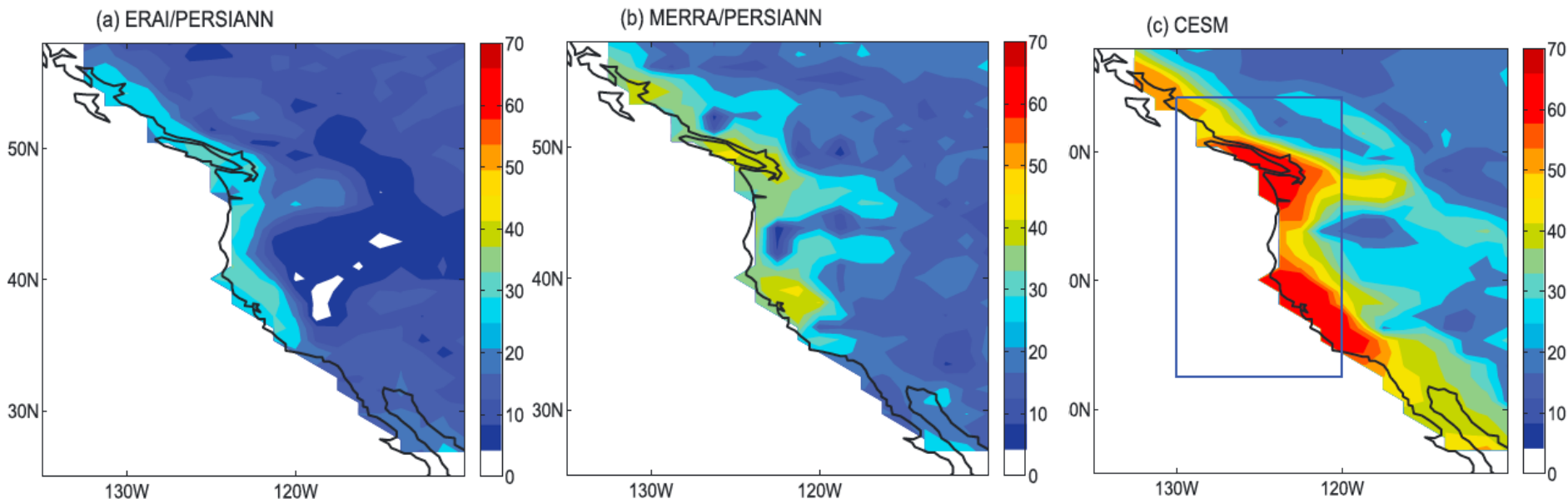
Bias in 800 hPa winds



(Hagos et al. 2016, GRL)

Extreme precipitation associated with ARs

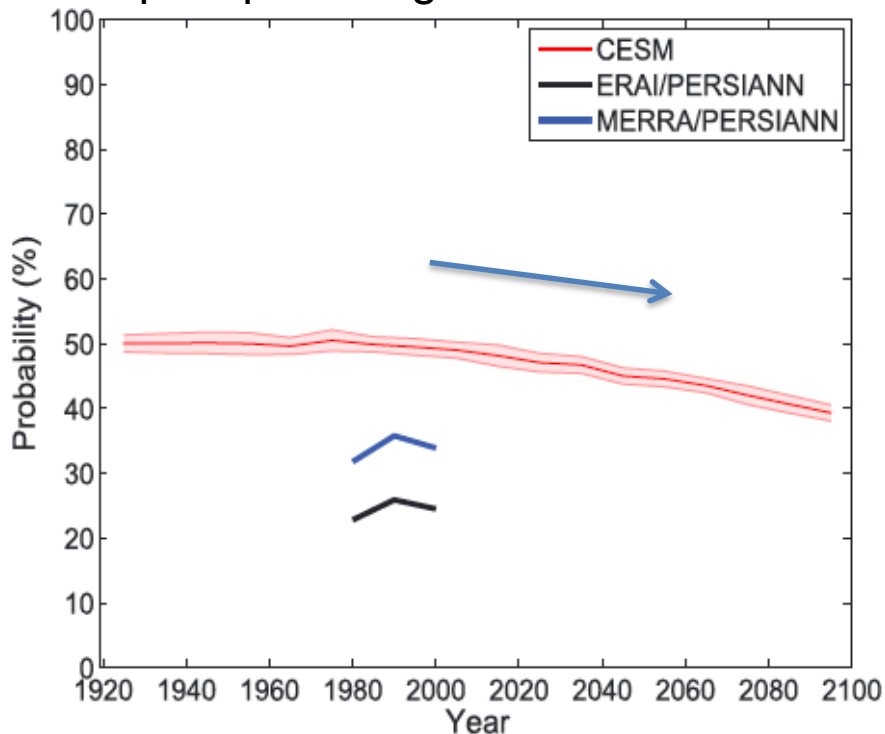
- ▶ Probability of extreme precipitation (95%) given extreme IVT is much higher in CESM than observations
- ▶ CESM has a colder middle and upper troposphere compared to reanalysis – orographic uplift leads to saturation more easily



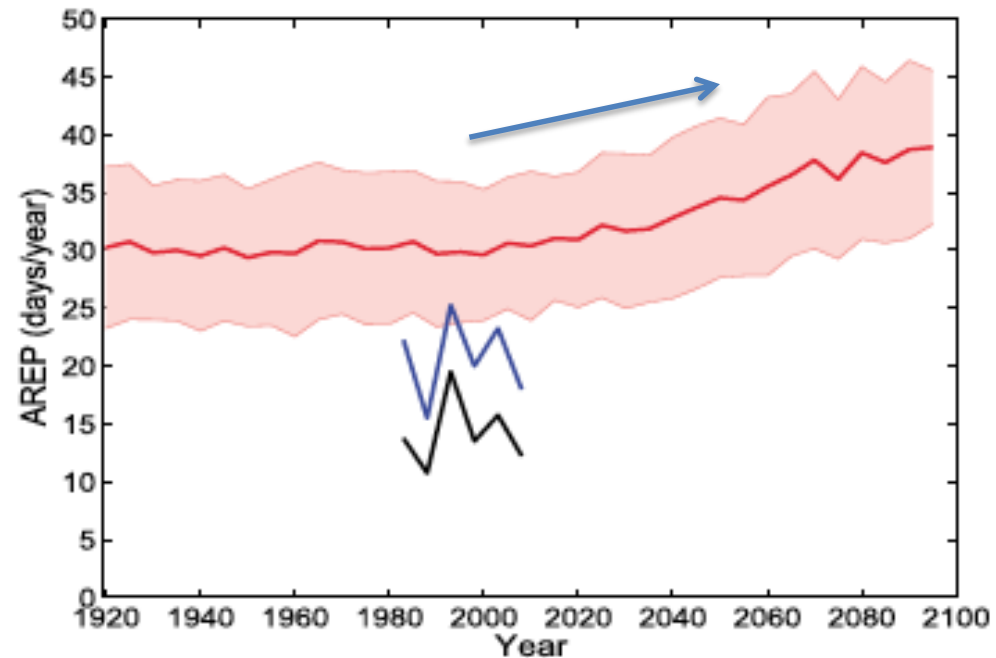
Projected changes in extreme precipitation

- ▶ Probability of extreme precipitation given extreme IVT is projected to decrease in the future as the warming in the upper troposphere outpaces that in the lower troposphere to increase static stability

Probability of extreme precipitation given extreme IVT



AR days with extreme precipitation

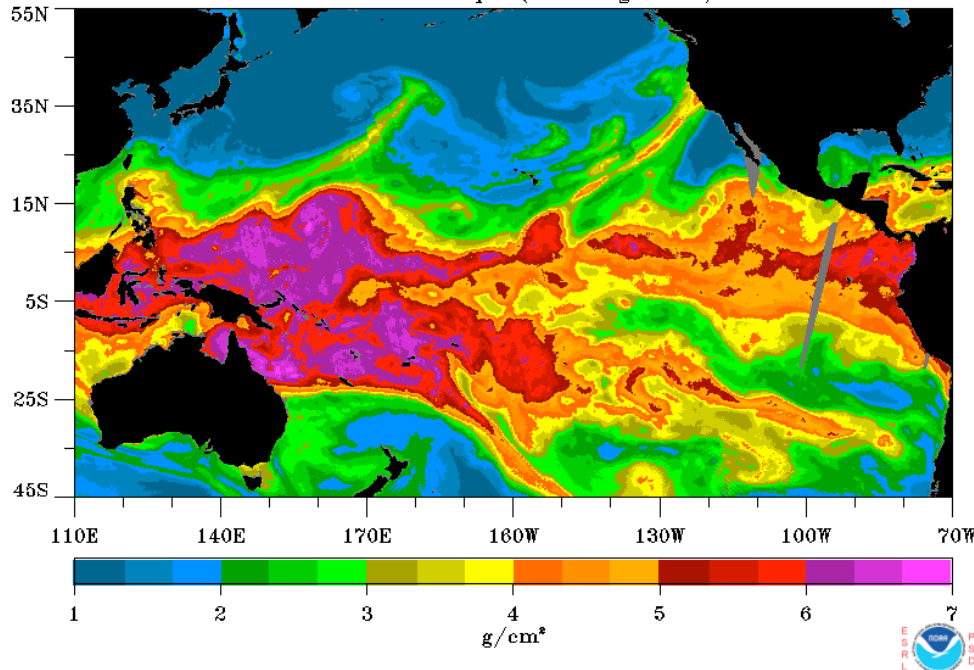


Effects of resolution in short term forecasts

- ▶ AR forecast using a global variable resolution model – Model for Prediction Across Scales (MPAS)

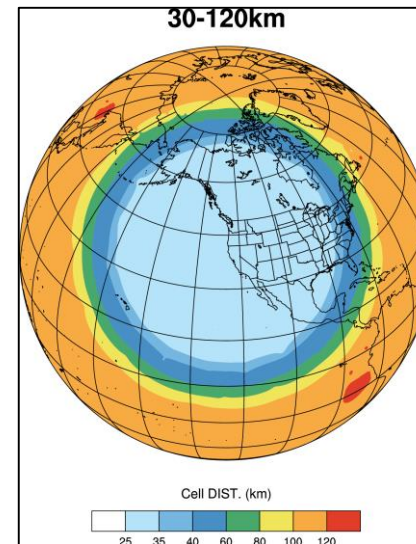
An AR observed during CalWater 2015

February 07, 2015 0-12Z
SSMIS Water Vapor (Wentz algorithm)

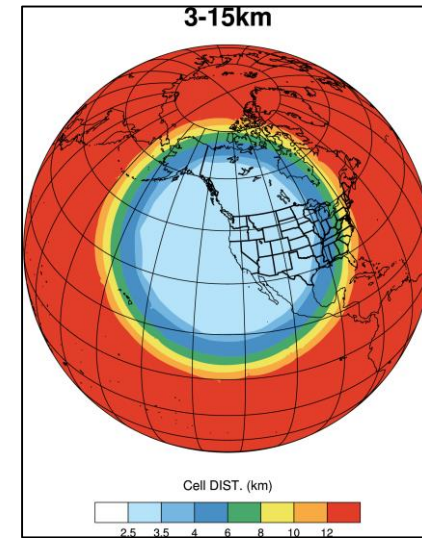


Variable resolution model configurations

VR-30km

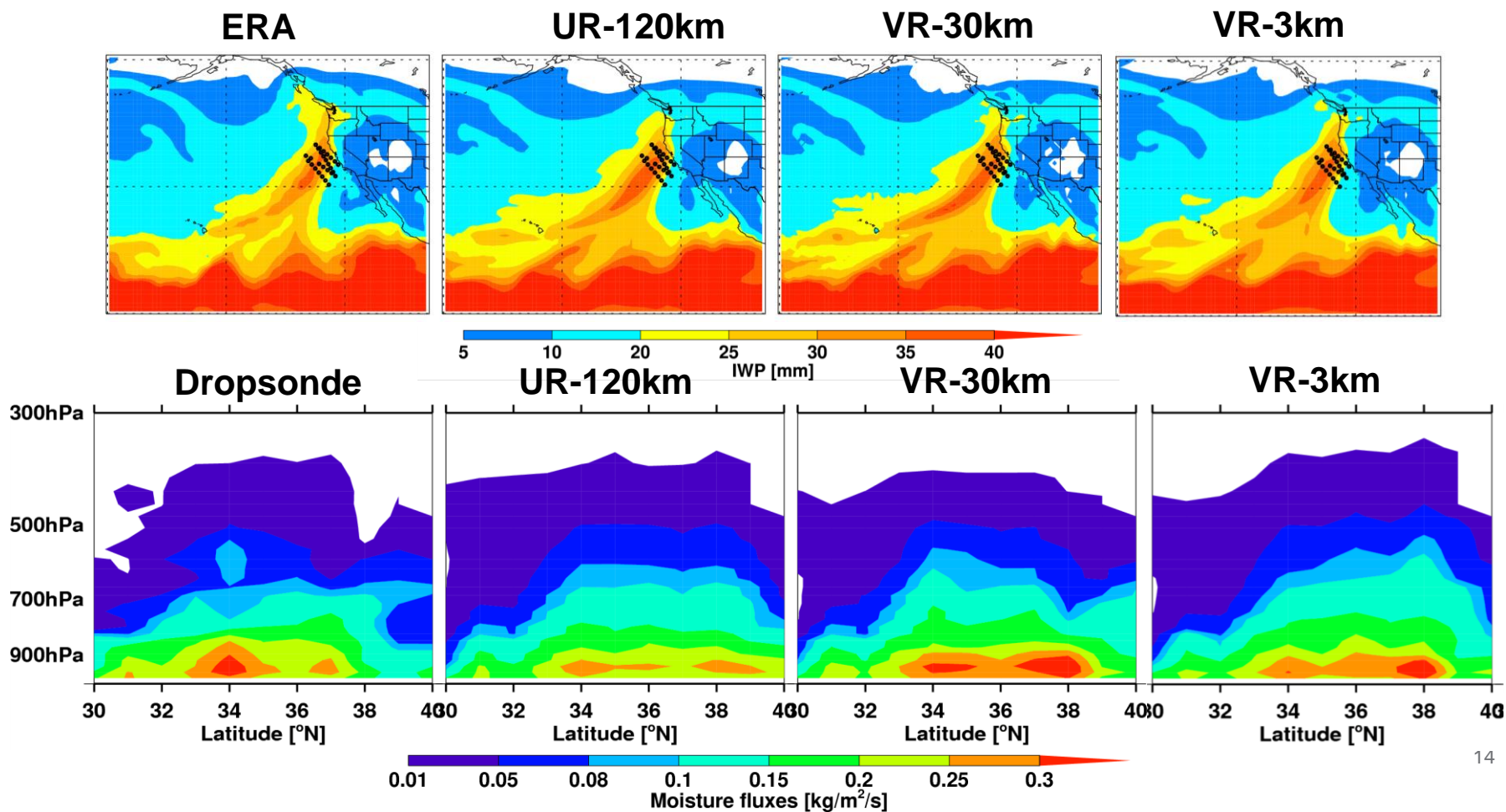


VR-3km

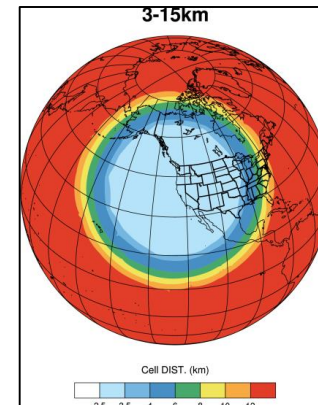
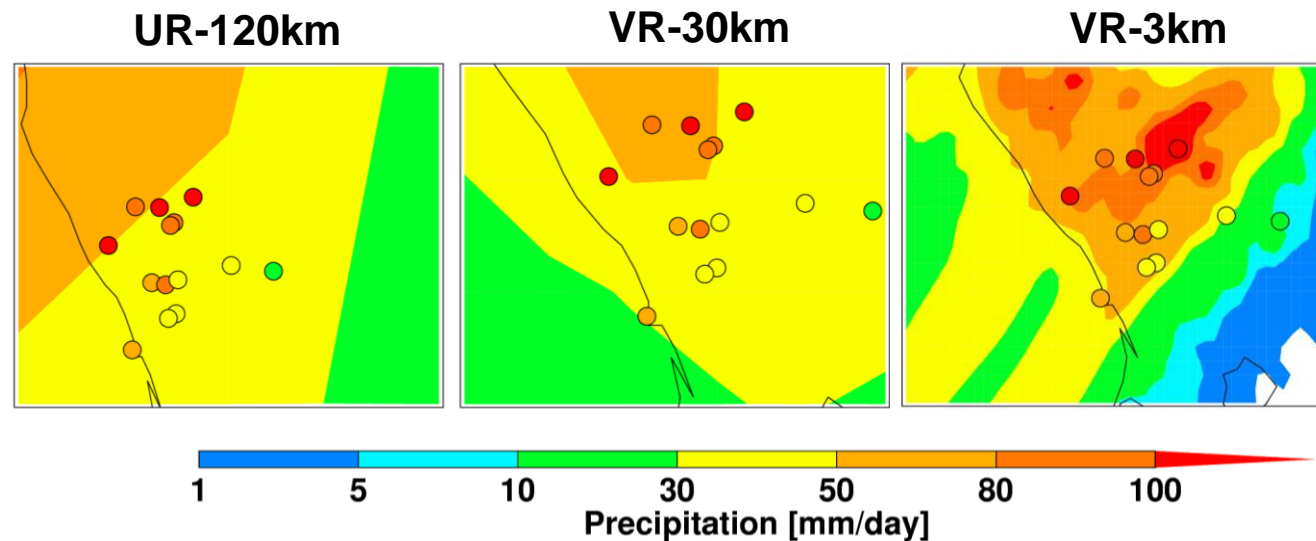
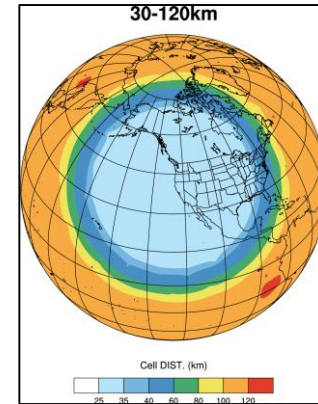
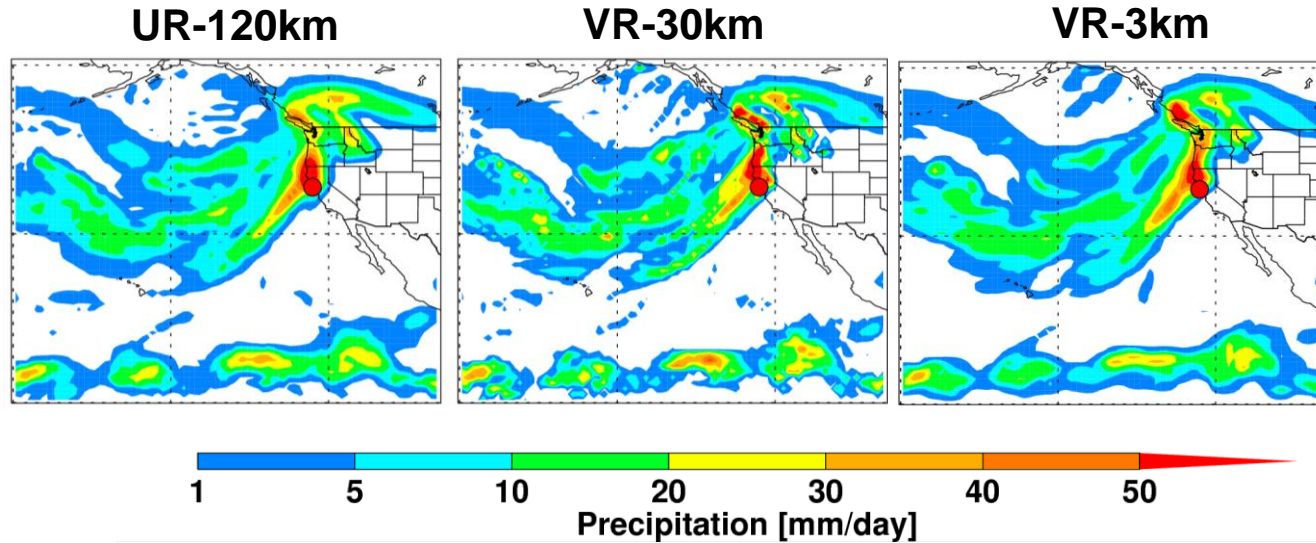


Forecast of water vapor fluxes

- Some sensitivity to model resolution, but no noticeable improvement with increasing resolution



Forecast of precipitation noticeably improved at high resolution



Insights from the modeling hierarchy



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** Since 1965

APE

Resolution dependence of
effective diffusivity

APE

Resolution dependence of eddy-driven
jet and dynamical convergence

APE, AMIP

Resolution sensitivity of AR
frequency

CMIP5, CESM-LE

Relationships between AR
frequency and jet

CMIP5

Emergent constraints on AR frequency
changes using historical jet position

CESM-LE

AR extreme precipitation bias related
to CESM cold upper troposphere

Bias correct projections of AR
frequency and extreme precipitation

A global variable resolution modeling framework
represents the multiscale AR processes

MPAS forecast