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

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Modeling Hierarchies Workshop
November 2 – 4, 2016, Princeton, NJ
Atmospheric rivers: the weather-climate nexus

- Atmospheric rivers (ARs) are responsible for over 90% of moisture transport across the subtropical zone (Zhu and Newell 1998)
- Comparable water flux to that of the Amazon (~8x Mississippi)
- A few ARs/year account for over 30% of annual precipitation in CA
- Contribute to most flooding events in CA and PNW, but are also drought busters (Dettinger 2014)

A landfalling AR on December 11 – 12, 2015 caused flooding in San Francisco.
A hierarchy of modeling experiments

- Aquaplanet simulations
- AMIP experiments
- CMIP experiments
- Forecast experiments
- Large ensemble experiments

- How well are ARs simulated by climate models?
- What are the sensitivities of ARs to model resolution and what dominates the sensitivities?
- 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

Zonal mean U-wind at 800 hPa

AR frequency in aquaplanet simulations

Southeast Pacific AR frequency in AMIP simulations

(Hagos et al. 2015, JCLIM)
Dependence of jet stream on resolution

Jet location shifts poleward and jet strength weakens with increasing resolution

(Lu et al. 2015, JCLIM)

Higher resolution
ARs in N. Atlantic-Europe in CMIP5

- IVT > 85\textsuperscript{th}-percentile
- Elongated >2000km
- Averaged IWV ≥ 2 cm

(Gao et al. 2016, JCLIM)
Simulated AR frequency linked to jet location and speed

**Number of AR days**

**Equatorward of jet**
(40 – 45 N)

(a) 40-45N  
\*r = -0.64  
y = 9.82 - 0.14x

**Center of jet**
(45 – 50 N)

(b) 45-50N  
r = 0.21  
y = 0.80 + 0.04x

**Poleward of jet**
(50 – 55 N)

(c) 50-55N  
\*r = 0.66  
y = -5.56 + 0.14x

**Relationship with jet latitude**

**Relationship with jet speed**

- **CMIP5**
- **CFSR**
- **ERA_INTERIM**
- **MERRA**
- **NCEPI**
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)
Using the emergent constraint on the jet shift, the projected dynamical change in ARs at the equatorward flank of the mean jet may be calibrated upward.
ARs in N. Pacific-US in CESM-LE

- CESM-LE wind biases show a dipole pattern corresponding to an 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.
Insights from the modeling hierarchy

APE
- Resolution dependence of effective diffusivity

APE, AMIP
- Resolution sensitivity of AR frequency

CMIP5, CESM-LE
- Relationships between AR frequency and jet
- Emergent constraints on AR frequency changes using historical jet position

CMIP5
- Account for biases in projecting AR frequency and extreme precipitation

CESM-LE
- AR extreme precipitation bias related to CESM cold upper troposphere