Global Analysis of Climate Change Projection Effects on Atmospheric Rivers

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Atmospheric River Impacts

- Global / Extra-tropical Climate & Variability
  
  (Zhu & Newell, 1998; Guan & Waliser, 2015; Nash et al. 2018)

- Global Water Availability & Flood Risk
  
  (e.g. Ralph et al. 2006; Dettinger, 2013; Lavers et al. 2009; Paltan et al. 2017)

Projections of Global Warming Indicate Changes to:

- Global Water & Energy Cycles
- Atmosphere/Ocean Circulation
- Extreme Events
Climate Change & ARs

### Previous Studies

<table>
<thead>
<tr>
<th>Publication</th>
<th>Historical Period</th>
<th>Projection Period</th>
<th>Geogr. Region</th>
<th>AR Freq (± %)</th>
<th>AR IVT (± %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dettinger (2011)</td>
<td>1961-2000</td>
<td>2046-2065; 2081-2100</td>
<td>CA Coast</td>
<td>+ 30</td>
<td>+ 10</td>
</tr>
<tr>
<td>Pierce et al. (2013)</td>
<td>1985-1994</td>
<td>2060s</td>
<td>CA Coast</td>
<td>+ 25 - 100</td>
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</tr>
<tr>
<td>Hagos et al. (2016)</td>
<td>1920 - 2005</td>
<td>2006 - 2099</td>
<td>US West Coast</td>
<td>+ 35</td>
<td>--</td>
</tr>
<tr>
<td>Shields et al. (2016)</td>
<td>1960 - 2005</td>
<td>2055 - 2100</td>
<td>US West Coast</td>
<td>+ 8</td>
<td>--</td>
</tr>
<tr>
<td>Espinoza et al. (2018, current study)</td>
<td>1979 - 2002</td>
<td>2073 - 2096</td>
<td>US West Coast</td>
<td>+ 45</td>
<td>+ 30</td>
</tr>
<tr>
<td>Lavers et al. (2013)</td>
<td>1980 - 2005</td>
<td>2074 - 2099</td>
<td>W. Europe</td>
<td>+ 50 - 100</td>
<td>--</td>
</tr>
<tr>
<td>Ramos et al. (2016)</td>
<td>1980 - 2005</td>
<td>2074 - 2099</td>
<td>Europe</td>
<td>+ 100 - 300</td>
<td>+ 30</td>
</tr>
<tr>
<td>Espinoza et al. (2018, current study)</td>
<td>1979-2002</td>
<td>2073-2096</td>
<td>W. Europe</td>
<td>+ 60</td>
<td>+ 30</td>
</tr>
</tbody>
</table>

- **No Global Studies**
- **No way to compare UK & US, different models, methods and algorithms**
- **What about outside UK & US?**

**CSSR Executive Summary:** The frequency and severity of landfalling “atmospheric rivers” on the U.S. West Coast … will increase as a result of increasing evaporation and resulting higher atmospheric water vapor that occurs with increasing temperature. (*Medium confidence*) (Ch. 9)
Global AR Detection Algorithm

Identifies ARs, frequency, transports and landfalls

Guan & Waliser (2015)

CMIP5 Analysis of IVT Climate Changes for 21 CMIP5 Models

IVT increases by 30–40% in the North Pacific and North Atlantic storm tracks for RCP8.5

Lavers et al. (2015)

Global Evaluation of Climate Change Impacts on ARs

Global AR Detection Algorithm

Identifies ARs, frequency, transports and landfalls

Guan & Waliser (2015)

CMIP5 Analysis of IVT Climate Changes for 21 CMIP5 Models

IVT increases by 30–40% in the North Pacific and North Atlantic storm tracks for RCP8.5

Lavers et al. (2015)
Apply AR detection algorithm* to Historical, RCP4.5, RCP8.5 Simulations

*Use Historical IVT threshold for AR detection on Historical, RCP4.5 and RCP8.5 simulations

Compute Model-Dependent 85\textsuperscript{th} Percentile of IVT from Historical Simulations*

- IVT > 85th percentile
- Look for contiguous areas
- Length > 2000 km
- Length/Width > 2
Climate Change & ARs

AR Frequency, Size & Transport: 21 CMIP5 Models
Climate Change & ARs
AR Frequency, Size & Transport: 21 CMIP5 Models
Climate Change & ARs

AR Frequency, Size & Transport: 21 CMIP5 Models

AR conditions vs AR Events
Climate Change & ARs
AR Frequency, Size & Transport: 21 CMIP5 Models

Typical AR Object
- Length: 4300 km
- Width: 700 km
- Number*: 1.53M

AR Conditions = Number ARs * Length * Width
- Present = \(4.61 \times 10^{12} \text{ km}^2\)
- Future = \(6.46 \times 10^{12} \text{ km}^2\)

* Total Number in 20 Year Period

Changes in ARs
- About 25% longer
- About 25% wider
- About 10% fewer

About 40% Increase in AR Conditions

Occurrence of extreme IVT values within ARs ~double.
CMIP5 Model Biases

AR Frequency

Historical Simulations

ACCESS1-0
ACCESS1-3
IPSLCM5ALR
GFDLESM2G
IPSLCM5AMR
NOR

BCCSM1
BCCSM1M
IPSLCM5BLR
BNUESM
MIROCESM

CANESM2
MIROCESMChem
CNRMCM5
CSIROMK36
MPIESMLR

FGOALSG2
HADGEM2CC
INMCM4
GFDLCM3
MRI CGCM3

ERA-Interim
CMIP5 Model Biases

AR Frequency & IVT
CMIP5 Model Biases

AR Frequency & IVT

[Images of maps and graphs illustrating AR frequency and IVT biases.]
CMIP5 Model Biases

AR Frequency & IVT

[Images of maps and graphs related to AR frequency and IVT]
CMIP5 Model Projections
AR Frequency

RCP8.5 - Historical
CMIP5 Model Projections

AR Frequency & IVT
CMIP5 Model Projections

AR Frequency & IVT

[Map and Graph]
CMIP5 Model Projections

AR Frequency & IVT
### Regional Details: Bias & Projections

#### AR Frequency

<table>
<thead>
<tr>
<th>CMIP5 Model</th>
<th>California Coast</th>
<th>U.S. East Coast</th>
<th>S.W. Australia</th>
<th>UK</th>
<th>S.W. Chile</th>
<th>S.W. Africa</th>
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</thead>
<tbody>
<tr>
<td>ACCESS1-0</td>
<td>H(%) RCP(%) ± %</td>
<td>H(%) RCP(%) ± %</td>
<td>H(%) RCP(%) ± %</td>
<td>H(%) RCP(%) ± %</td>
<td>H(%) RCP(%) ± %</td>
<td>H(%) RCP(%) ± %</td>
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<tr>
<td>ACCESS1-3</td>
<td>6 9 1 45</td>
<td>11 13 1 19</td>
<td>6 7 1 16</td>
<td>10 15 1 52</td>
<td>11 9 -19</td>
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<td>BCCCSM1</td>
<td>8 11 32</td>
<td>11 14 29</td>
<td>7 9 1 30</td>
<td>9 16 85</td>
<td>11 12 17</td>
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<td>12 14 24</td>
<td>7 8 1 16</td>
<td>10 16 51</td>
<td>11 12 2</td>
<td>7 9 23</td>
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<tr>
<td>BNUESM</td>
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<td>11 14 27</td>
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<td>10 11 13</td>
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<td>6 7 14</td>
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<td>MIROCESM</td>
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<td>11 13 27</td>
<td>7 7 1</td>
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<td>7 8 16</td>
<td>11 14 31</td>
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<td>NOR</td>
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<td>5 5 8</td>
<td>9 14 51</td>
<td>10 10 -5</td>
<td>6 8 31</td>
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</table>

#### Average

<table>
<thead>
<tr>
<th>H(%) RCP(%) ± %</th>
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<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
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<tr>
<td>7 10 43</td>
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<td>6 7 18</td>
<td>9 15 61</td>
<td>10 11 6</td>
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</table>

#### Standard Deviation

<table>
<thead>
<tr>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 19</td>
<td>1 1 10</td>
<td>1 1 15</td>
<td>1 1 17</td>
<td>1 2 15</td>
<td>1 1 15</td>
</tr>
</tbody>
</table>

#### ERA-Interim

<table>
<thead>
<tr>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
<th>H(%) RCP(%) ± %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 11</td>
<td>7 10</td>
<td>8</td>
<td>7 11</td>
<td>7 11</td>
<td>7 11</td>
</tr>
</tbody>
</table>
Regional Details: Bias

AR Frequency

AR Frequency Difference (Historical – ERAI) per Geographic Location

AR Frequency Difference (% of time steps)

Geographic Location

AUS  Africa  CA  Chile  UK  US East Coast
Summary

A uniform, global approach is used to quantify how atmospheric rivers (ARs) change between CMIP5 historical simulations and future projections under the RCP4.5 and RCP8.5 warming scenarios.

Key Points:

• Globally, CMIP5 projects that atmospheric rivers (ARs) will be ~10% fewer, ~25% longer, ~25% wider, and with stronger moisture transport under the RCP8.5 scenario.

• In the midlatitudes where ARs are most frequent, AR conditions are ~50–60% more frequent and AR transport is ~20% stronger in the future.

• Systematic low biases exist in the midlatitudes in historical AR frequency (~10%), zonal (~15%), and meridional (~25%) moisture transport.
Illustrative Method Slide

Histogram of GFDL-CM3 IVT in S. Pacific Ocean (61S, 216.25E)

- Total Historical IVT (N=8766)
- Total RCP8.5 IVT (N=8766)
- AR IVT Historical (N=713)
- AR IVT RCP8.5 (N=1838)
- Top N AR IVT RCP8.5 (N=713)
Climate Projection Studies Of Atmospheric Rivers
To Date Mostly Focused On Two Regions

**Western N. America**

- Warner et al. 2015

**Western/Northern Europe**

- Lavers et al. 2013
- Lavers et al. (2013), Gao et al. (2015), Ramos et al. (2016), Shields et al. (2016)

The Impacts Of Climate Change On “Atmospheric Rivers”
Across The Globe Has Yet To Be Examined
Global AR Detection

I. Compute IVT

1. Compute IVT: Gives Long, Narrow Extreme Moisture Transports i.e. Rivers

II. Map IVT timeseries globally

II. Map IVT timeseries globally

III. Apply AR Criteria

1. IVT > 85th percentile
2. Look for contiguous areas
3. Length > 2000 km
4. Length/Width > 2

Gives Long, Narrow Extreme Moisture Transports i.e. Rivers