The origins, lifetimes, and terminations of atmospheric rivers: an object-based tracing algorithm

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Atmospheric rivers (ARs)

- Vertically-integrated vapor transport:

\[
\overline{IVT} = -\frac{1}{g} \int_{P_s}^{300} \vec{V} \cdot q \, dP
\]

Ps: surface pressure
V: horizontal wind
q: specific humidity

- ERA-Interim, 1 degree 6hourly
- Nov. – Mar. 1979/80-2016/17

- The detected ARs are time independent

- A strong IVT event can last for a certain period

→ The same IVT event can be detected as ARs during consecutive time steps

(Detection method: Guan and Waliser 2015)
ARs vs. AR Life Cycles (LCs)

ARs:
- 2D objects (LON, LAT),
- time independent

AR LCs:
- Series of spatiotemporally connected ARs (LON, LAT, Time)
Motivation

- To establish a link between the ARs through space and time
- A better understanding of strong moisture transport events

Tracing the AR LCs

Step I: AR detection

Step II: Origin selection

Step III: Recording the LCs

Step I

- ERA-Interim, 1 degree 6hourly
- Focus on North Pacific

(Detection method: Guan and Waliser 2015)
Tracing the AR LCs

Step II: Origin selection

Overlapping ratio at step $t$:

$$\frac{\text{AR}_t' \text{ s overlapping area with AR}_{t-1}}{\text{Total area of AR}_t} \times 100\%$$

- Gray: AR$_{t-1}$
- Orange: Overlapping area at time $t$ with AR$_{t-1}$
- Blue: AR$_t$
Origins & Terminations

Step III: Recording the LCs

- On average 100 LCs over the North Pacific per winter

Climatology: Origins
- Locate over higher latitude
- Packed in the subtropics

Climatology: Terminations
- AR Life Cycle
- Center of IVT
- Lifetime

02/23-02/26 2017

(# of ARs per winter)
Lifetime

- Lifetime = 72 hours
- Long LCs: >72 hours (85th percentile)
- Short LCs: <24 hours (30th percentile)

- Lifetime = (time step-1)×6 hourly
- Explain 40% of total

Long LCs: Origins

Long LCs: Terminations

(# of ARs per winter)
Distance & Propagation Speed

- Long LCs travel seven times longer than short LCs
- Comparable mean propagation speed

Travelled Distance (10^3 km)
- All: 2500 km
  - Long: 6000 km
  - Short: 860 km

Percentage (%)
Accumulated AR Intensity

Accumulated AR Intensity (ARI) index

\[
ARI = \sum_{i=1}^{i=N} \sum_{t=1}^{T_i} [IVT (t)]_i
\]

- Number
- Lifetime
- Intensity

• Unit: \(10^4 \text{ kg m}^{-1} \text{ s}^{-1}\)

The ARI represents the overall AR activities of given period

Year-to-year variability

- \(|IVT (t)|_i\): \(|IVT|\) of the AR at step \(t\) of the \(i^{th}\) LC
- \(T_i\): the total time steps of the \(i^{th}\) LC
- \(N\): the number of LCs of the given season
Model Simulations

➢ ERA-Interim
   • Nov. – Mar., 1979-2016

➢ ECMWF AMIP Runs* (Davini et al. 2017)
   • 1980-2000, 10 ensembles
   • Horizontal resolution: ~60km

➢ CESM1.2 AMIP Runs
   • 1979-2016, 10 ensembles
   • Horizontal resolution: ~100km

*The ECMWF runs are provided by Aneesh Subramanian
Model Simulations

**ERA-I**

**ECMWF (10 ensembles)**

**CESM (5 ensembles)**

(\# of ARs per winter)
Summary

1. The Tracing Algorithm
   • Applies to gridded reanalysis and model output
   • Generate subset of AR life cycles (LCs)
   • Suitable for various time scales

2. Statistical Results
   • The long LCs on average travel 7 times longer than the short LCs.
   • The accumulated AR intensity (ARI) index represents the overall LC activities of given period.

3. Model Simulations
   • The winter climatology patterns of AR frequency, origins and terminations are reproduced.

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Thank you!
Sensitivity Test

(a) 1.5-degree, 6 hourly

(b) 2.5-degree, 6 hourly

(c) 1-degree, daily

(d) 1-degree, 6hrly
Four types of AR Origins

Type II: combination

Type III: division

Type IV: deformation
Four types of AR Origins

<table>
<thead>
<tr>
<th>Type</th>
<th>t-1</th>
<th>t</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td></td>
<td></td>
<td>No overlapping</td>
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<tr>
<td>General</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Type II</td>
<td></td>
<td></td>
<td>Number of overlapping ARs $\geq 2$</td>
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<tr>
<td>Combination</td>
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<tr>
<td>Type III</td>
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<td></td>
<td>$\frac{\text{area}(AR_{t-1})}{\text{area}(AR_t)} &lt; \frac{1}{2}$</td>
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<tr>
<td>Division</td>
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<tr>
<td>Type IV</td>
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<td>$\frac{\text{area}(AR_{t-1})}{\text{area}(AR_t)} &gt; 2$</td>
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<tr>
<td>Deformation</td>
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</tr>
</tbody>
</table>
Origins and Terminations

➢ Short LCs:
  • Origin ARs scatter over the Pacific
  • Termination ARs are close to origins due to short lifetime
  • Terminate over North America (explain up to 20% of total)
Accumulated AR Intensity (ARI) index

Contributors:
- Number of LCs
- Lifetime
- LC Intensity

➢ Lifetime is the relatively stronger contributor to the magnitude of ARI
AR Tracks

- Interpolated into 5°×5° grid