Atmospheric Rivers Drive Flood Damages in the Western United States

Cary Talbot, PhD, PE
Coastal & Hydraulics Laboratory
US Army Engineer Research & Development Center (ERDC), Vicksburg, MS

2020 Interagency Flood Risk Management Training Seminars
St. Louis, MO - February 26, 2020

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Acknowledgements

Tom Corringham, Marty Ralph, Alexander Gershunov, Daniel Cayan - Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California San Diego
Forecast Informed Reservoir Operations (FIRO)

Begun in 2014, an on-going collaborative research & development activity between federal, state and local agencies, academia and stakeholders to explore simultaneous improvements to flood risk management, water supply and ecosystem benefits through the use of weather forecast information in water management decisions.
May 2016 Update to Engineer Regulation (ER) 1110-2-240
Water Control Management

Section 3.3 Evacuation of Impounded Water.
Consistent with the authorized purposes of a project and affected interests in the project area, any water impounded in the flood control space defined by the plan of regulation shall be evacuated as rapidly as can be accomplished without causing downstream flows to exceed the controlling rates and not releasing more than peak inflow or in accordance with reservoir regulation schedules. That is, releases from reservoirs shall be restricted insofar as practicable to quantities that, in conjunction with uncontrolled runoff downstream of the dam, will not cause water levels to exceed the controlling maximum non-damaging stages currently in effect. This implies making decisions based on the principle of water on the ground which is observed precipitation or observed snowpack.

Emphasis added
Lake Mendocino FIRO Hybrid Operations Scenario

Zone of “flexible” operational storage

Hybrid Operations Scenario Modified Guide Curve

- Existing Guide Curve
- Modified Guide Curve

80,050 acre-feet
68,400 acre-feet

Date

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

Storage (ac-ft)

60,000 70,000 80,000 90,000 100,000 110,000

732.35 738.45 744.33 750.07 755.72 761.27 766.70

Elevation (ft)
What is an Atmospheric River (AR)?

“A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone.”

- Typically low in the atmosphere (5-10k feet), supplied by warm, tropical moisture, AKA: “Pineapple Express” storms
- Provide ~50% of CA rainfall, >85% flood damages across West
January 1995, Central California

Precipitable water (kg/m²) January 4, 1995

Russian River at Guerneville

Sonoma County

IVT

Precipitation

Stream Flow

Insured Losses

FLOOD STAGE
January 1995, Guerneville, CA
Quantifying AR Flood Damages in the Western US

- National Flood Insurance Program (NFIP) daily claims of insured losses, by community, 1978 – 2017 for 11 western conterminous states
- 40-year catalog of AR activity meeting minimum AR threshold (IVT > 250 kg/m/s) as defined in Gershunov et al. 2017

• 84% of insured losses in the 11 western states were caused by ARs

• Over 99% of insured losses were caused by ARs in the many of the most highly affected areas

• Lower but still significant proportions of insured losses in southern California and Arizona were caused by ARs
<table>
<thead>
<tr>
<th>County</th>
<th>AR Proportion of Insured Losses</th>
<th>Claims</th>
<th>Insured Losses ($m)</th>
<th>Total Damages ($b)</th>
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</thead>
<tbody>
<tr>
<td>Sonoma, CA</td>
<td>0.998</td>
<td>6650</td>
<td>172.0</td>
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<td>Los Angeles, CA</td>
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<td>Marin, CA</td>
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<td>Snohomish, WA</td>
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<td>33.7</td>
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<td>1557</td>
<td>33.4</td>
<td>1.0</td>
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<td>730</td>
<td>31.5</td>
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<tr>
<td>San Diego, CA</td>
<td>0.912</td>
<td>1945</td>
<td>30.7</td>
<td>0.9</td>
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<tr>
<td>Orange, CA</td>
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<td>3619</td>
<td>29.3</td>
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<td>Pierce, WA</td>
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<td>Riverside, CA</td>
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<td>Cowlitz, WA</td>
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<td>26.6</td>
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<td>Placer, CA</td>
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<td>Columbia, OR</td>
<td>0.998</td>
<td>414</td>
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</tbody>
</table>
AR Scale and Flood Damages

- AR Scale (Ralph et al. 2019)
- Depends on intensity IVT and duration
- AR 1 and AR 2 are mostly beneficial, replenishing water supply
- AR 3 mix of beneficial and harmful
- AR 4 and AR 5 are mostly harmful causing significant flood damages

AR Scale and Flood Damages

<table>
<thead>
<tr>
<th>AR CAT (1-5) (Denoted by color)</th>
<th>AR Intensity Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Exceptional</td>
</tr>
<tr>
<td>3</td>
<td>Extreme</td>
</tr>
<tr>
<td>5</td>
<td>Strong</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
</tr>
<tr>
<td>2</td>
<td>Weak</td>
</tr>
<tr>
<td>Not an AR</td>
<td></td>
</tr>
</tbody>
</table>

Flood Damages by AR CAT

- $10b
- $1b
- $100m
- $1m
- $100k
- < $10k

AR Duration (IVT > 250) (h)

0 24 48 72

Maximum IVT (kg m$^{-1}$ s$^{-1}$)

AR Scale and Flood Damages

AR CAT (1-5) (Denoted by color)

<table>
<thead>
<tr>
<th>AR CAT</th>
<th>AR Intensity</th>
<th>AR Duration (IVT &gt; 250) (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weak</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>Strong</td>
<td>72</td>
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<td>4</td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>Extreme</td>
<td></td>
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</tbody>
</table>

Flood Damages by AR CAT

- $0.1m (130,000) for Weak
- $1m for Moderate
- $10m for Strong
- $100m for Extreme
- $10b for Exceptional
AR Scale and Flood Damages

AR CAT (1-5)
(Denoted by color)

4 5 5
3 4 5
2 3 4
1 2 3

AR Intensity Name
Exceptional
Extensive
Strong
Moderate
Weak
Not an AR

AR Duration (IVT > 250) (h)
0 24 48 72

1250
1000
750
500
250

Flood Damages by AR CAT

- Weak
  - $0.1m
  - (130)

- Moderate
  - $0.4m
  - (168)

- Strong
- Extreme
- Exceptional
AR Scale and Flood Damages

AR CAT (1-5)
(Denoted by color)

AR Intensity
- Exceptional
- Extreme
- Strong
- Moderate
- Weak
- Not an AR

Maximum IVT (kg m⁻¹ s⁻¹)

AR Duration (IVT > 250) (h)

1250
1000
750
500
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0
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Flood Damages by AR CAT

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<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>$3m (201)</td>
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AR Scale and Flood Damages

AR CAT (1-5) (Denoted by color)

AR Intensity Name
Exceptional
Extreme
Strong
Moderate
Weak
Not an AR

Maximum IVT (kg m$^{-1}$ s$^{-1}$)

0 24 48 72 AR Duration (IVT > 250) (h)

Flood Damages by AR CAT

- 1 Weak: $0.1m (130)
- 2 Moderate: $0.4m (168)
- 3 Strong: $3m (201)
- 4 Extreme: $20m (99)

< $10k

$100k

$1m

$10m

$100m

$1b

$10b
AR Scale and Flood Damages

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</tr>
<tr>
<td>Not an AR</td>
<td>1</td>
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Maximum IVT (kg m⁻¹ s⁻¹)

AR Duration (IVT > 250) (h)

Flood Damages by AR CAT

- CAT 1: Weak, $0.1m (130)
- CAT 2: Moderate, $0.4m (168)
- CAT 3: Strong, $3m (201)
- CAT 4: Extreme, $20m (99)
- CAT 5: Exceptional, $260m (11)
AR Scale and Flood Damages

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<td>Weak</td>
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<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
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</tr>
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</table>

AR Duration (IVT > 250) (h)

- 0
- 24
- 48
- 72
- 1250
- 1000
- 750
- 500
- 250

Flood Damages by AR CAT

- 1 Weak: $0.1m (130)
- 2 Moderate: $0.4m (168)
- 3 Strong: $3m (201)
- 4 Extreme: $20m (99)
- 5 Exceptional: $260m (99)

$10b
$1b
$100m
$1m
$100k
<$10k
AR Scale and Flood Damages

AR Intensity Name
- Exceptional
- Extreme
- Strong
- Moderate
- Weak
- Not an AR

AR CAT (1-5) (Denoted by color)

Max IVT (kg m^{-1} s^{-1})
- 1250
- 1000
- 750
- 500
- 250

AR Duration (IVT > 250) (h)
- 72
- 48
- 24
- 0

Flood Damages by AR CAT

- $10^b$
- $1b$
- $100m$
- $10m$
- $1m$
- $100k$
- < $10k

- Weak
- Moderate
- Strong
- Extreme
- Exceptional

- $0.1m$ (130)
- $0.4m$ (168)
- $3m$ (201)
- $20m$ (99)
- $260m$ (11)

US Army Corps of Engineers • Engineer Research and Development Center
AR Reconnaissance Missions

- AF Reserve & NOAA Hurricane Hunter aircraft fly missions over northeast Pacific Ocean to collect data that feeds and tunes global weather models
- FY18: 9 missions; FY19: 12 missions; FY20: 12 missions (projected); FY21: 20 missions (planned)
- Analysis indicates impact from AR Recon data has greater impact on forecast skill than all US-based weather balloon observations combined
- Now part of National Winter Season Operations Plan
Atmospheric Rivers: Not Just a West Coast Issue
Integrated Water Vapor (IWV) Perspective

Integrated Water Vapor Transport (IVT) Perspective

Pac NW AR
Nov 2006
Record rain

Nashville Flood
May 2010
>$2B damage

“Snowmageddon”
Feb 2010
East Coast
Paralyzed

Slide courtesy Marty Ralph
Up to 19.4 in rainfall in 2 days caused major flooding

Physical Processes Associated with Heavy Flooding Rainfall in Nashville, Tennessee, and Vicinity during 1–2 May 2010: The Role of an Atmospheric River and Mesoscale Convective Systems
Ben Moore, Paul Neiman, Marty Ralph, Faye Barthold
Conclusions

- Understanding atmospheric rivers is key to understanding potential flood damages in the western US as well as in many other locations across the US.
- AR intensity scale provides context to the strength and potential for damage for approaching storms.
- AR recon missions are significantly improving forecast skill for global weather models during the winter storm season.