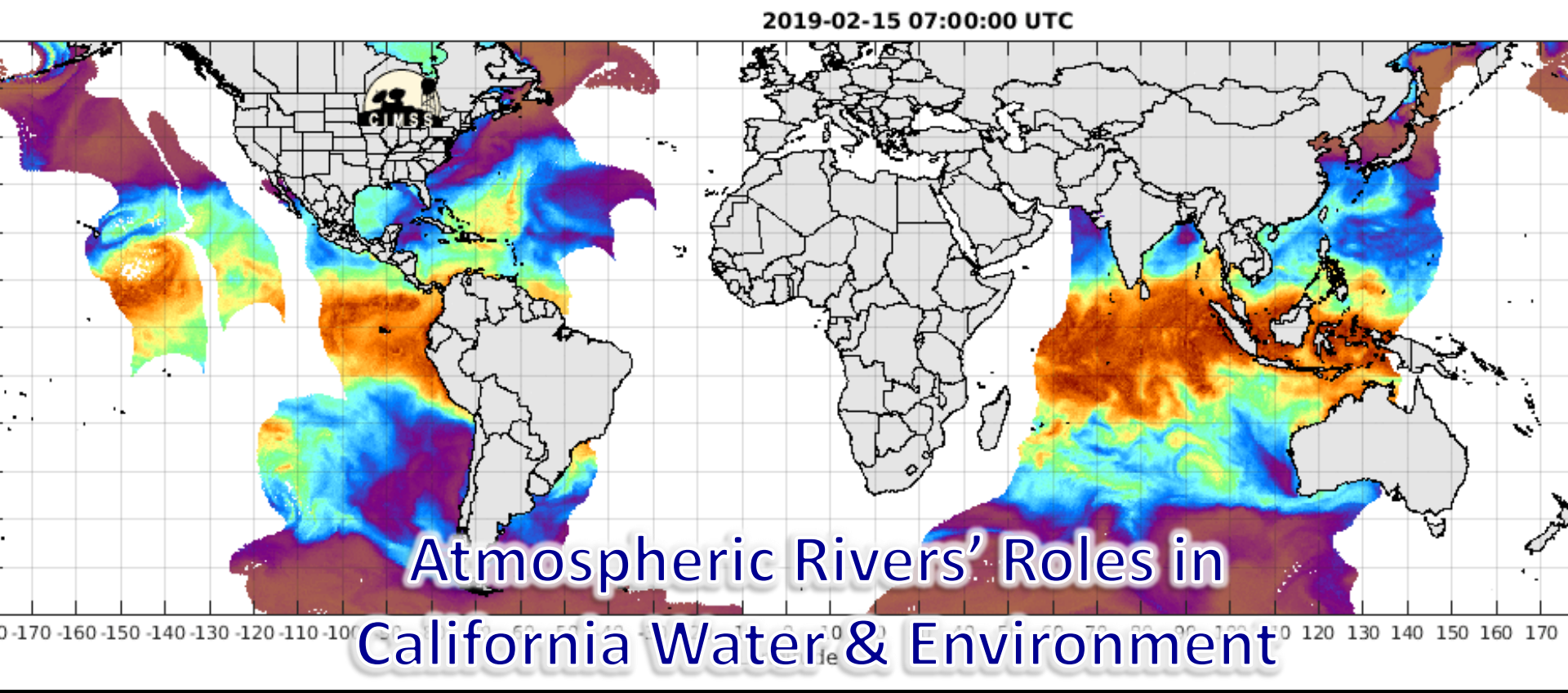

Atmospheric Rivers' Roles in California Water & Environment

Mike Dettinger, SIO, Carson City

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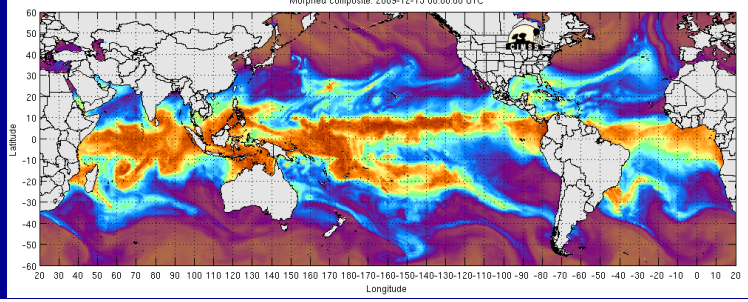
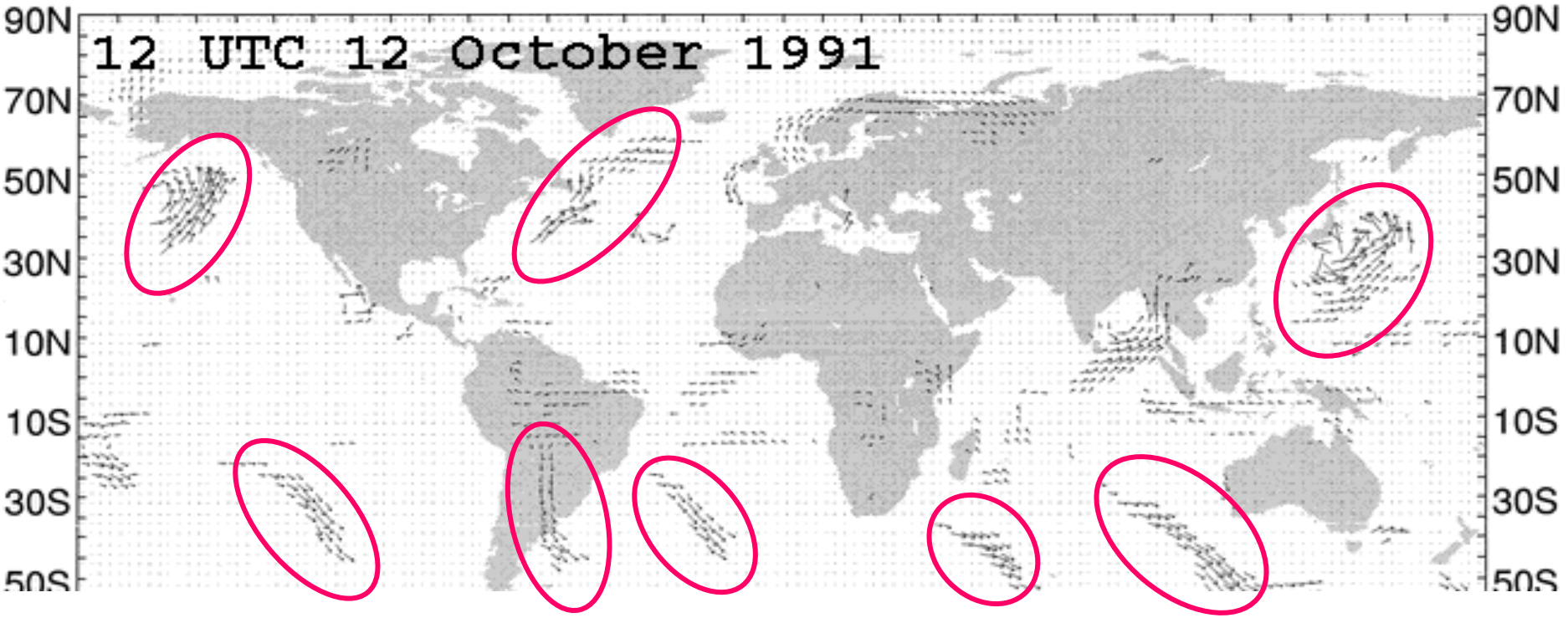
CWEMF 2025 Meeting, Folsom, CA, May 13 2025

Atmospheric Rivers—origins



Zhu & Newell 1998: *Diagnostic study using ECMWF (model-based) forecasts*



Zhu & Newell found **"atmospheric rivers"** that contain 90% of poleward water vapor flux outside the Tropics in <10% of the latitudinal circumference; Guan & Waliser (2024) revisited to update to 85% of vapor flux in ~10% of circumference.

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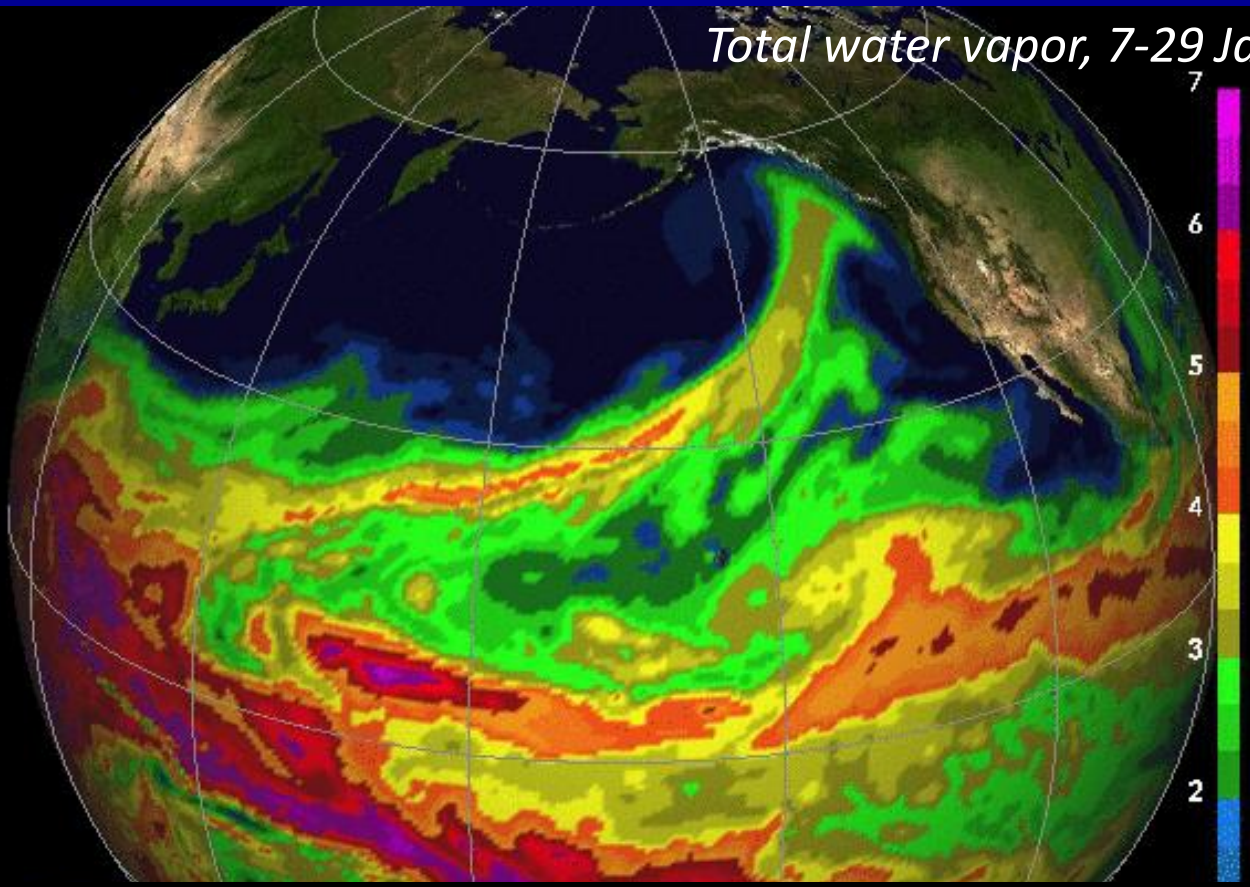
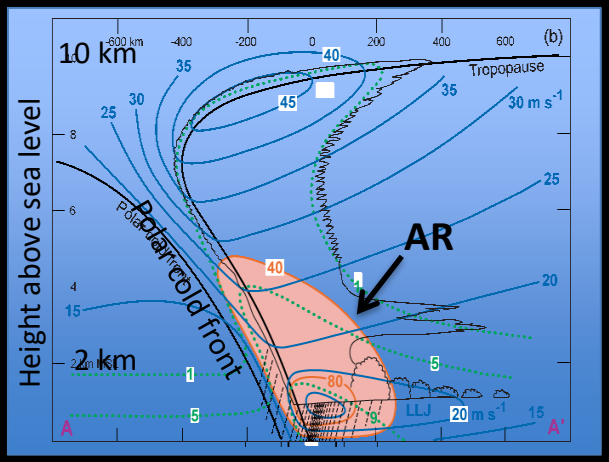
East Pacific Atmospheric Rivers

Total water vapor, 7-29 January 2012



cm of water, if condensed out onto the ground

Side View



Atmospheric river: A long, narrow, and transient corridor of strong horizontal water vapor transport…" Glossary of Meteorology, as of May 2017

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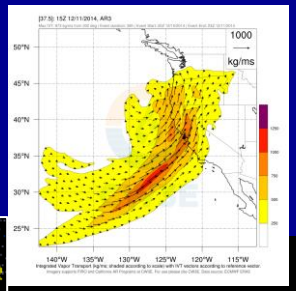
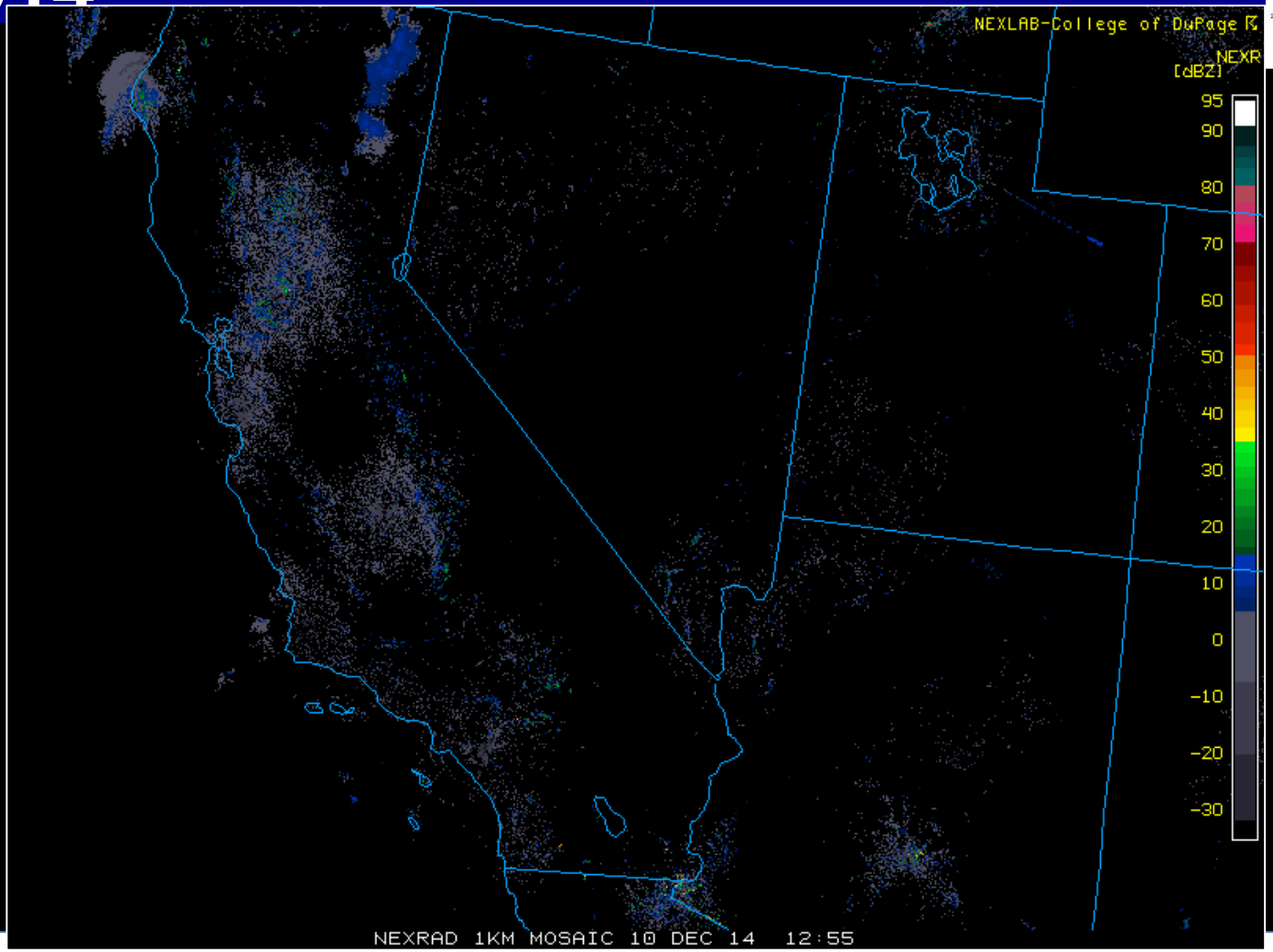
→ Natural jets *(centered ~1.5 km above surface)* of intense water vapor transport that together conduct amount of vapor across 40ºN equivalent to ~40-50% of global terrestrial streamflow, at all times

Radar imagery of precipitation during an AR storm on 10-13 Dec 2014





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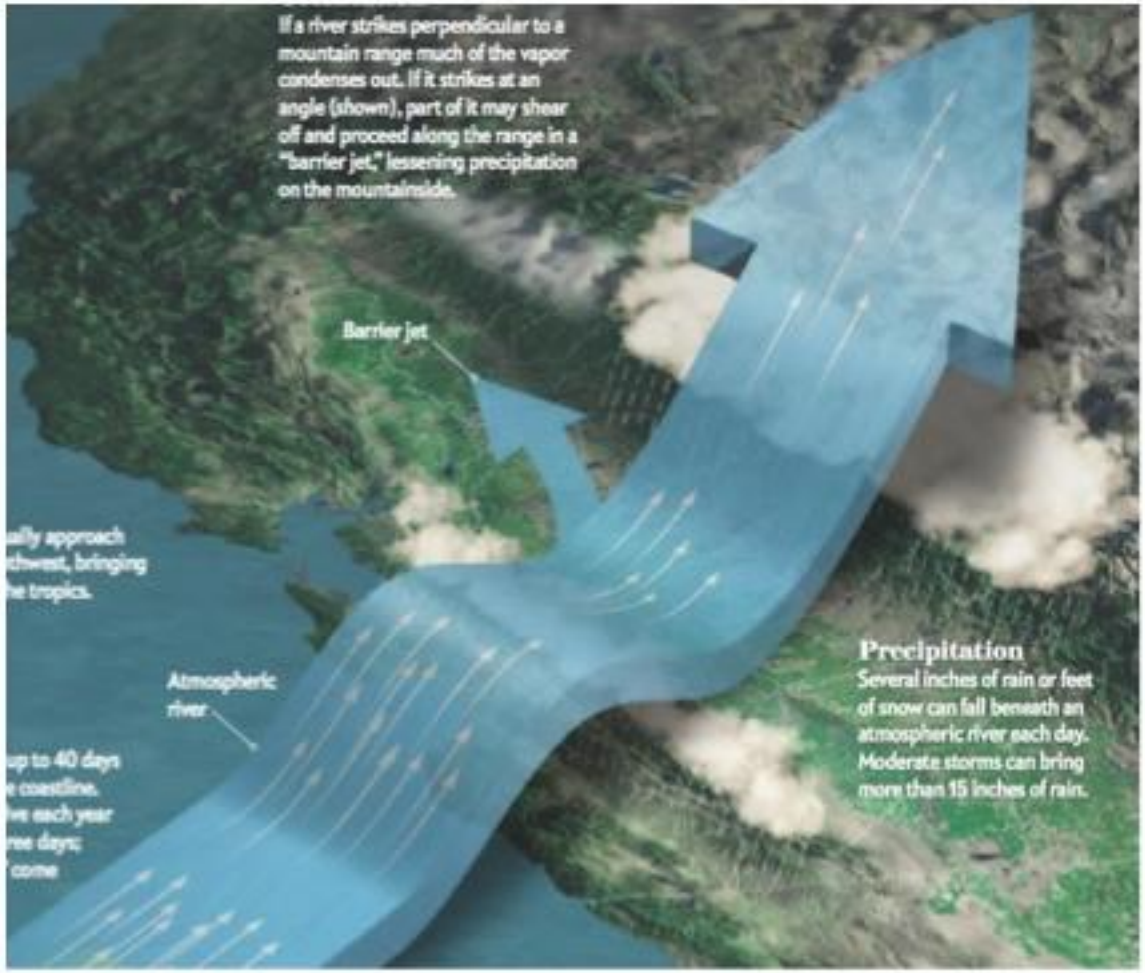
Smith et al (MWR, 2010) found that Northern California orographic precipitation extracted **55-100%** of AR water vapor from two AR storms.

Landfalling Atmospheric Rivers



These atmospheric rivers conduct 5 to 15 Mississippi River's worth of water (as vapor) onto the California coast, and when they lift up and over the coastal mountain ranges, they can yield extremely intense prolonged rain storms.

Dettinger & Ingram, Sci American, 2013

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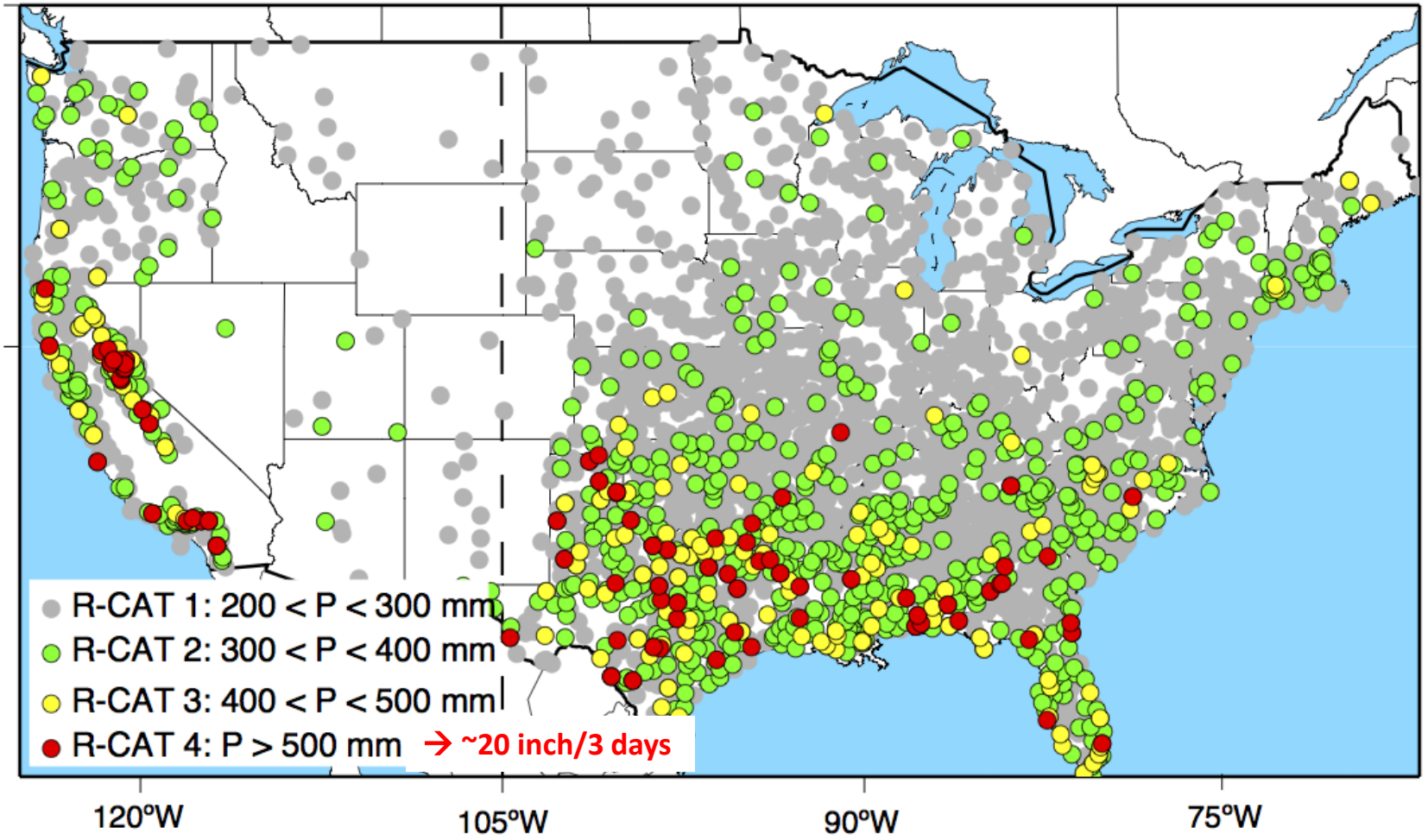
Just how BIG do these storms get to be?



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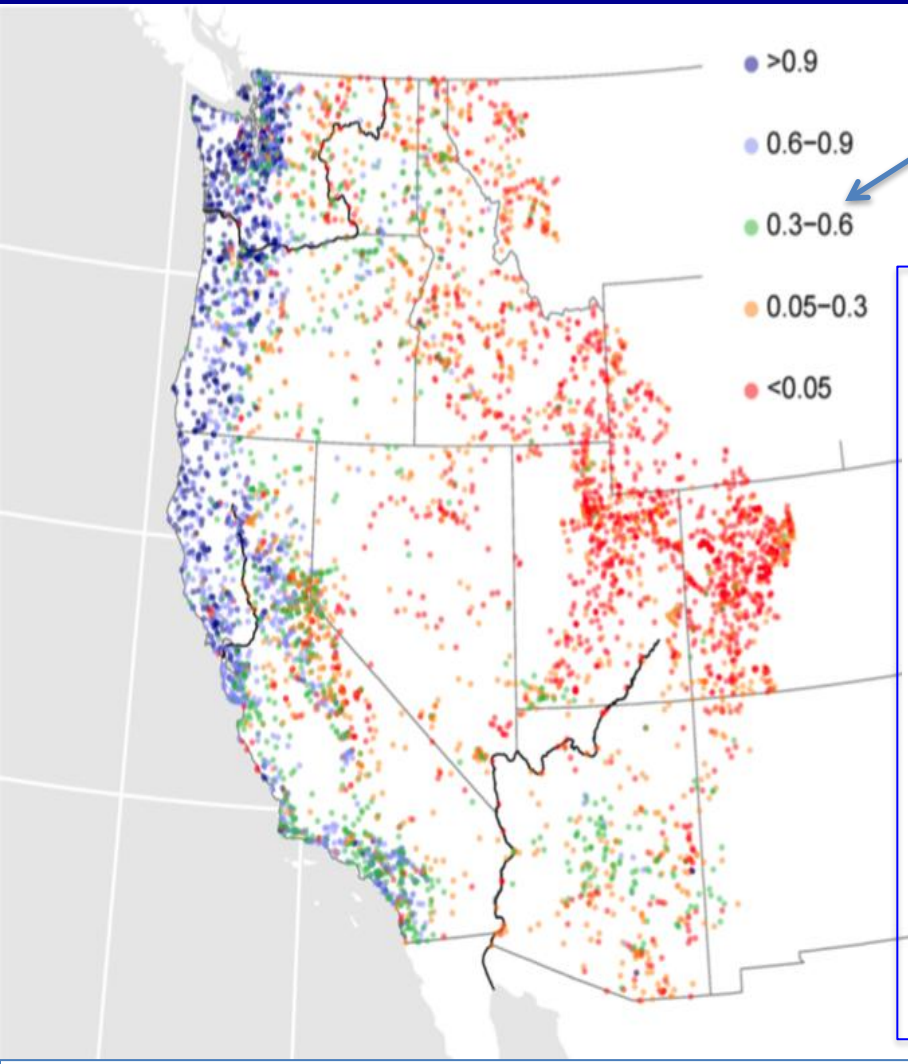
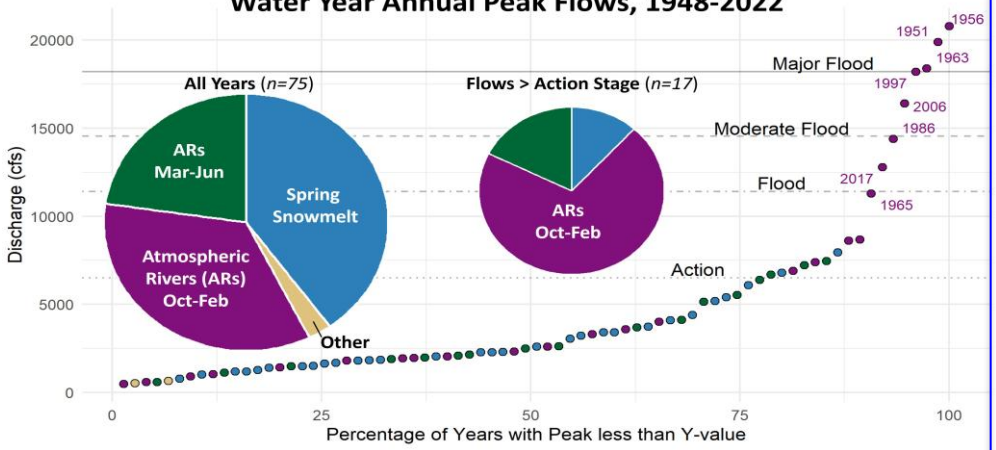
Ralph & Dettinger, BAMS, 2012; updated by Lamjiri et al (JHM), 2020

Atmospheric rivers & Western floods



Fraction of annual-peak flows during atmospheric-river landfalls



- *ARs have caused **88%** of historical ACTION-stage Truckee River flows above action stage*
- ***ALL** flows above FLOOD stage have been.*

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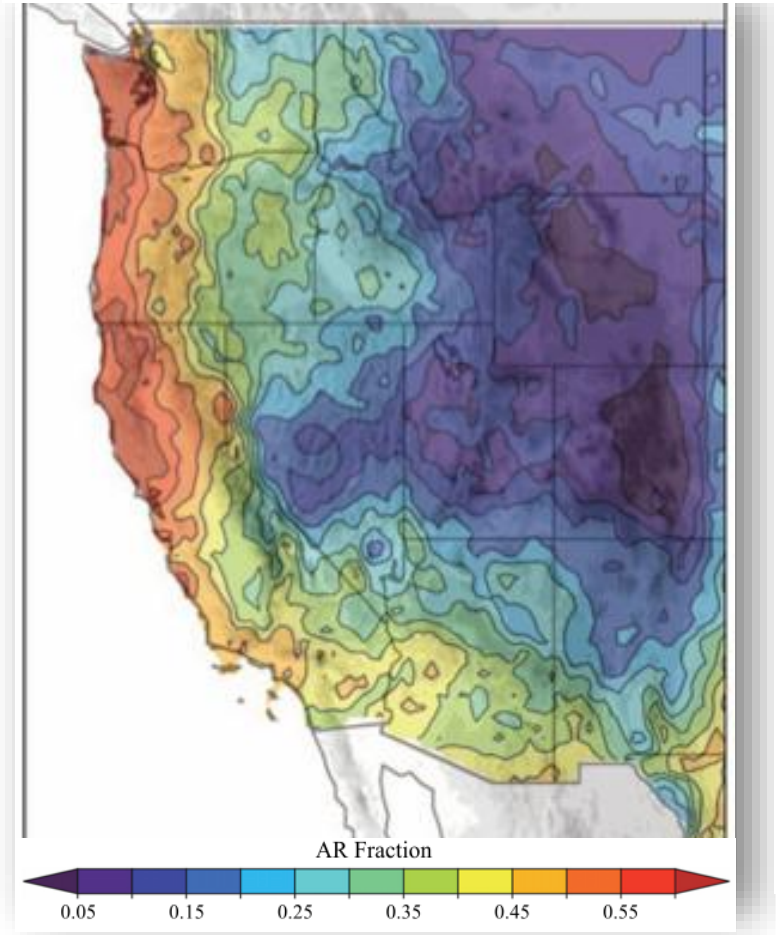
Barth et al., WRR, 2017; Konrad & Dettinger, GRL, 2017; Albano et al., Nat Haz, 2015; Albano et al., DRI, 2023

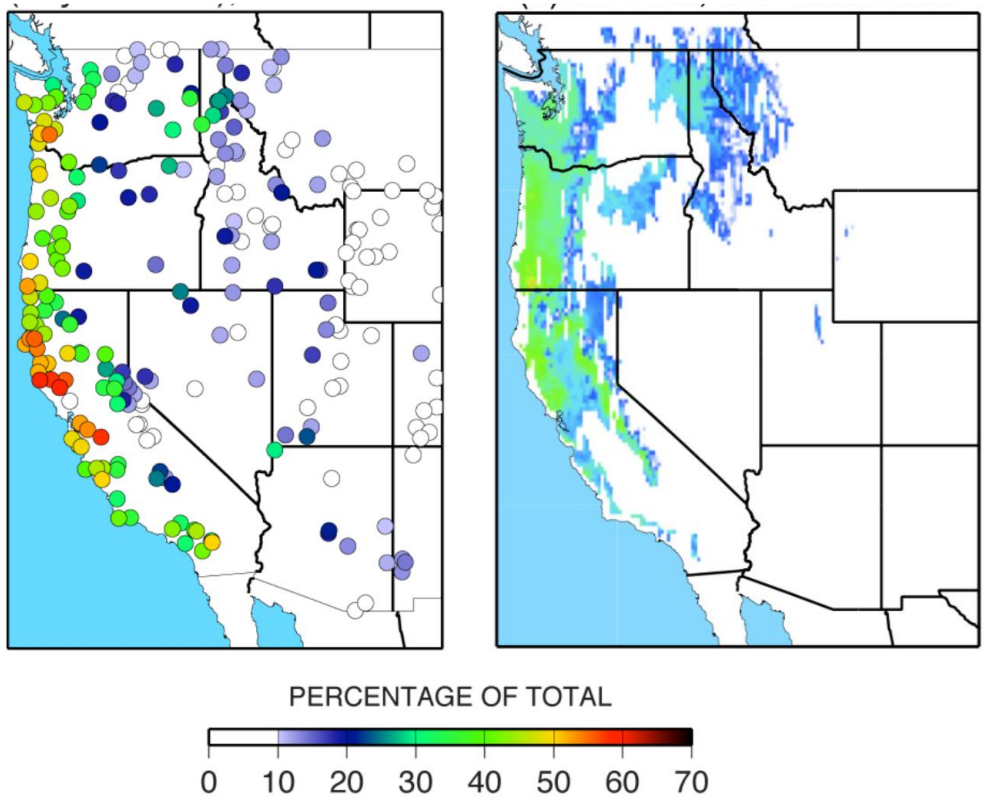
CONTRIBUTIONS FROM ARs TO PRECIPITATION & STREAMFLOW → Water Resources

AR Contributions to Winter Precip



California: 30 to >50% precip

AR Contributions to Storm-Time Streamflow



California: 20 to >50% streamflow

Rutz et al., MWR, 2014;
Dettinger et al., Water, 2011

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West Coast AR Hazards

	ATMOSPHERIC RIVERS (ARs) ON THE US WEST COAST	QUANTITATIVE FINDING	REFERENCES
MOSTLY HAZARDOUS	Cause the heaviest rains	92% of West Coast's heaviest 3-day rain events fed by ARs	*Ralph and Dettinger (2012)* *Vallejo-Bernal et al. (2023)*
	Bring warmest storms (less snow, more rain)	Average >50% more precipitation & 2.5°C warmer than other storms in the Sierra	*Dettinger et al. (2009)* *Backes et al. (2015)* *Ralph et al. (2019)* *Guan et al. (2016)*
	Cause West Coast floods	40–90% of major floods in West Coast rivers have been fed by ARs	*Ralph et al. (2006)* *Corringham et al. (2019)* *Neiman et al. (2011)* *Konrad and Dettinger (2017)*
	Cause storm surges in coastal areas	15–50% of annual sea-level maxima are associated with ARs	*Khouakhi and Villarini (2016)*
	Yield extreme coastal winds	20–50% of extreme coastal-wind episodes associated with ARs	*Waliser and Guan (2017)*
	Breach levees	81% of Central Valley levee breaks happened during ARs	*Florsheim and Dettinger (2015)* *Rittelmeyer et al. (2025)*
	Cause landslides, debris flows, & avalanches	E.g., ARs cause 68% of post-fire debris flows in southern California, *and 82% of landslides in Bay Area*	*Oakley et al. (2017)* *Cordeira et al. (2019)* *Young et al. (2017)* *Guirguis et al. (2023)*

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Updated from Dettinger et al, chapter 5 in AR book, 2020.
See https://tinyurl.com/hbkf2z5z for summary of how this played out in 2023

West Coast AR Benefits

	ATMOSPHERIC RIVERS (ARs) ON THE US WEST COAST	QUANTITATIVE FINDING	REFERENCES
MOSTLY BENEFICIAL	Fill reservoirs & provide water supplies	30–50% of California rain, snow streamflow from ARs	*Guan et al. (2010)* *Jiang et al. (2025)* *Dettinger et al. (2011)*
	End West Coast droughts	40–75% of droughts on West Coast ended by an AR	*Dettinger (2013)* *DeFlorio et al. (2024)*
	Sustain wetlands, floodplains, & fisheries	77% of ecologically significant inundations of Yolo bypass floodplain, Sacramento River, initiated by ARs	*Florsheim and Dettinger (2015)* *Dettinger & Cordeira (2023)*
	Water deserts & forests far inland, modulate wildfire risks	Statistically significant relations found between summer NDVI (greenness) & areas burned in parts of the interior Southwest	*Albano et al. (2017)* *Dettinger & Lavers (2020)* *Hancock & Wlodarczyk, 2025*
	Freshen estuaries but sometimes threaten estuarine fauna	March 2011 ARs freshened San Francisco Bay by 60%, resulting in wild oyster kill rate of 97–100%	*Cheng et al. (2016)* *Chang et al. (2017)*
	Modify banks & bottom sediments, modulating aquatic fauna in mountain streams	More invertabrate densities & diversity after major AR flooding; 10x more in pre-disturbed settings	*Herbst and Cooper (2010)*

Others: LA basin groundwater recharge (Mao et al., 2025)
Coastal-ocean upwelling (Garcia-Santos, 2025)

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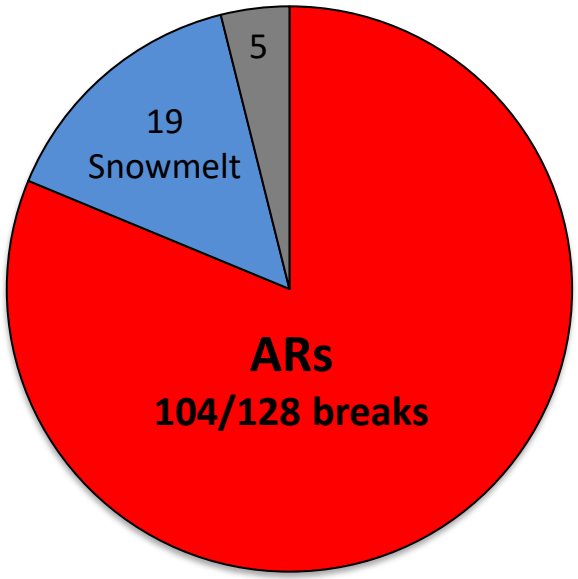
Updated from Dettinger et al, chapter 5 in AR book, 2020.
See https://tinyurl.com/hbkf2z5z for summary of how this played out in 2023

82% of CENTRAL VALLEY & DELTA LEVEE BREAKS occur during AR storms/floods

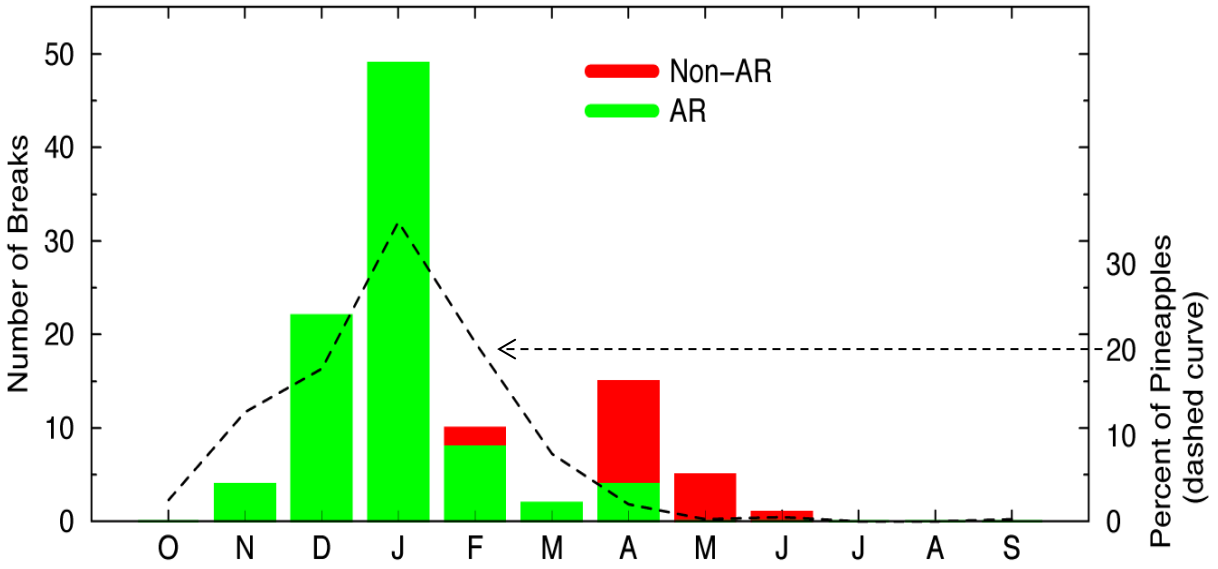
CENTRAL VALLEY LEVEE BREAKS

1951-2006 *(N=128 breaks)*

Total # of Levee Breaks



# of Levee Breaks/month



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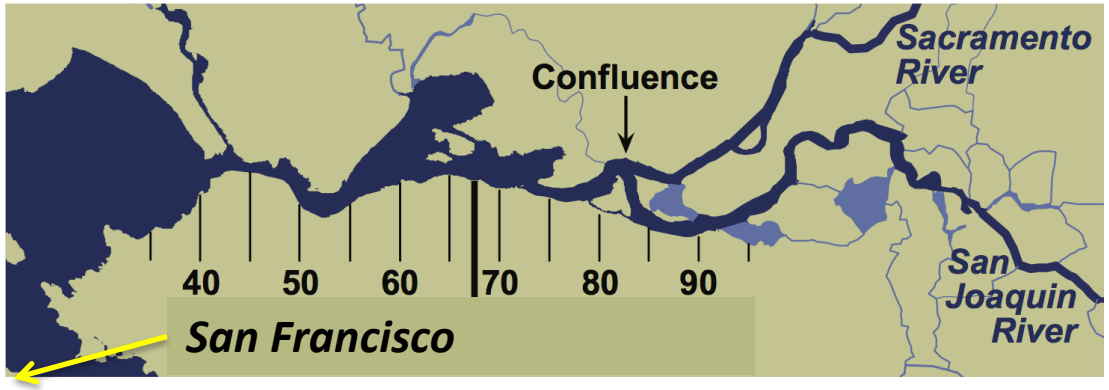
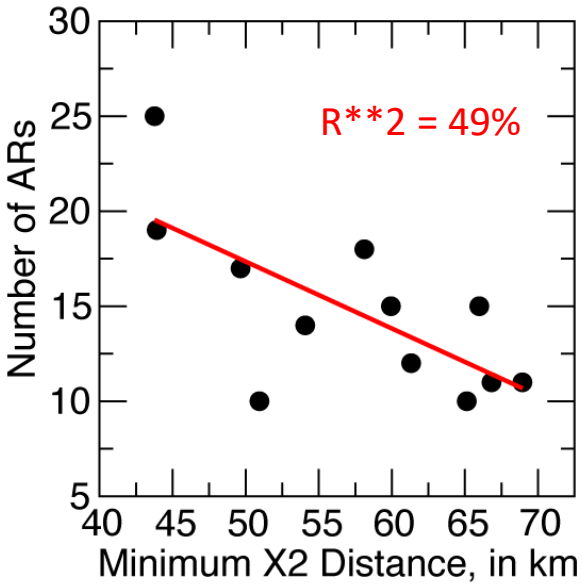
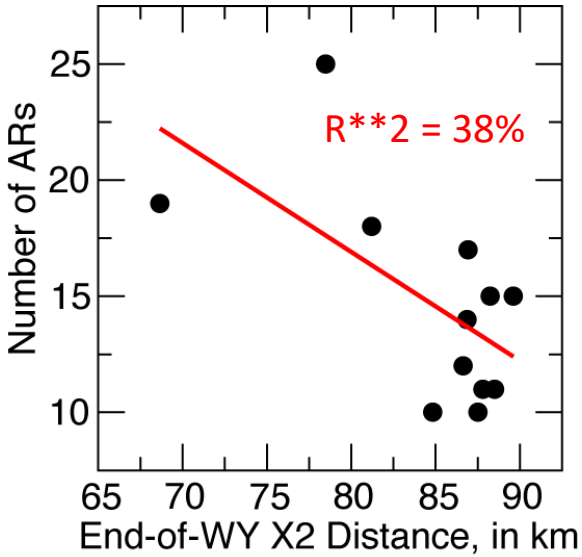
Florsheim & Dettinger, book chapter, 2015; Rittelmeyer et al, 2025

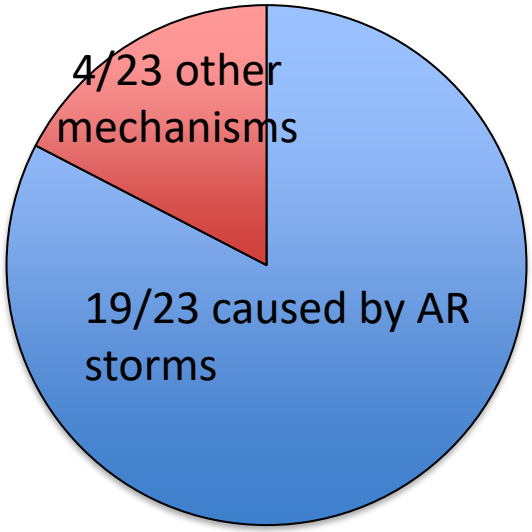
Atmospheric Rivers & X2: Distance from Golden Gate Bridge to where near-bottom salinity drops to 2 ‰



83% of largest (daily-scale, >0.85 km) X2 retreats (freshening estuary), WY1997-2010, have been due to atmospheric-river storms







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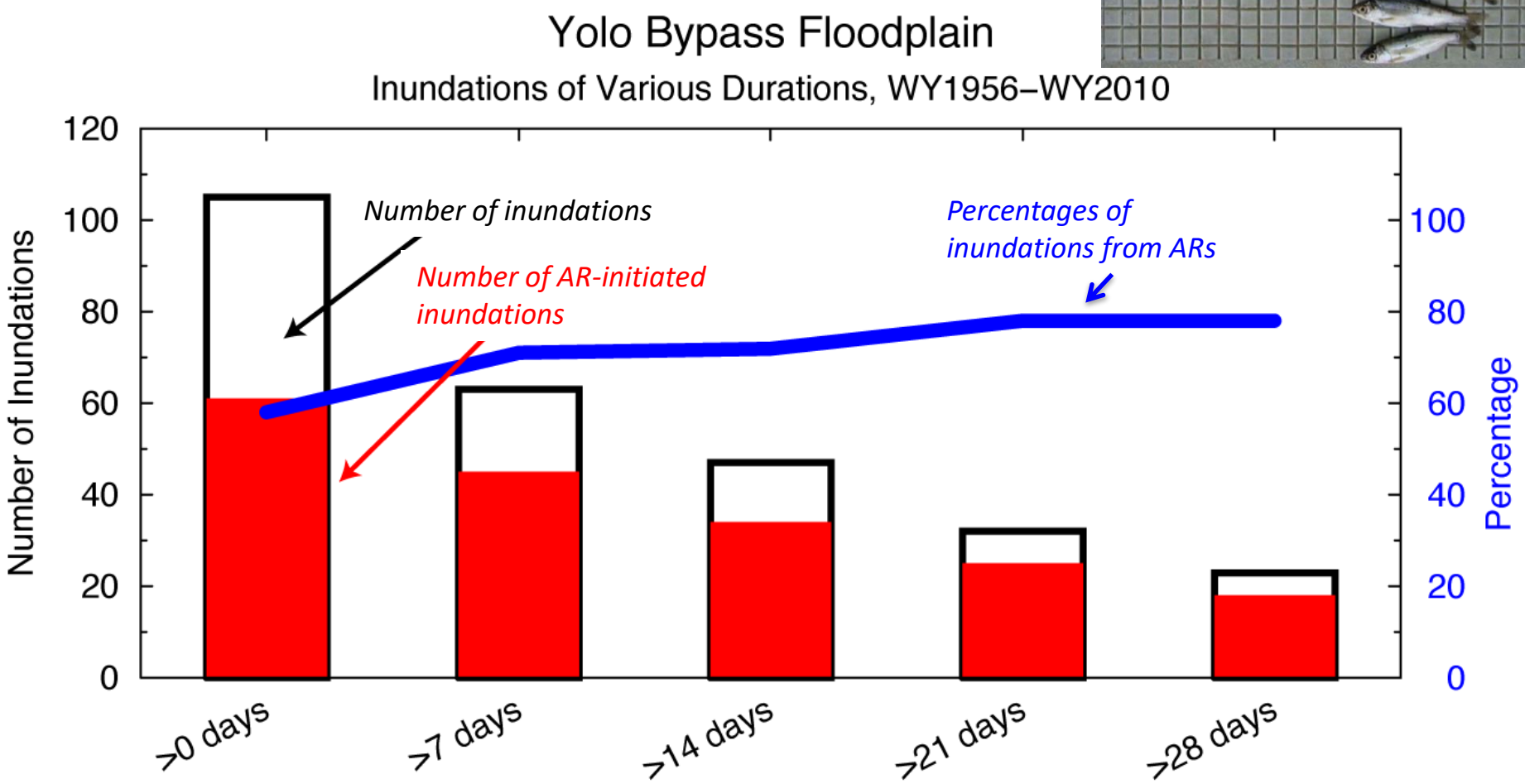
Dettinger & Lavers, AR Book, 2020

Ecologically Valuable Floodplain Inundations, 55 yrs of Yolo Bypass inundation



Florsheim & Dettinger, chapter, 2015

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Summary

- ARs lead to 80% of floods in much of California, for good and ill.
- ARs provide 30->50% of total precipitation and commensurate fractions of streamflow, & cause 85% of year-to-year total-precip variation
- ARs also drive significant variations of estuarine salinity & biology, cold-water reserves & fisheries, sediments & geomorphology, landslides, snow abundance, avalanches & rain-on-snow, vegetation & wildfire, groundwater recharge, drought busting, and more…*Natural & human systems expect & (often) rely on these events.*

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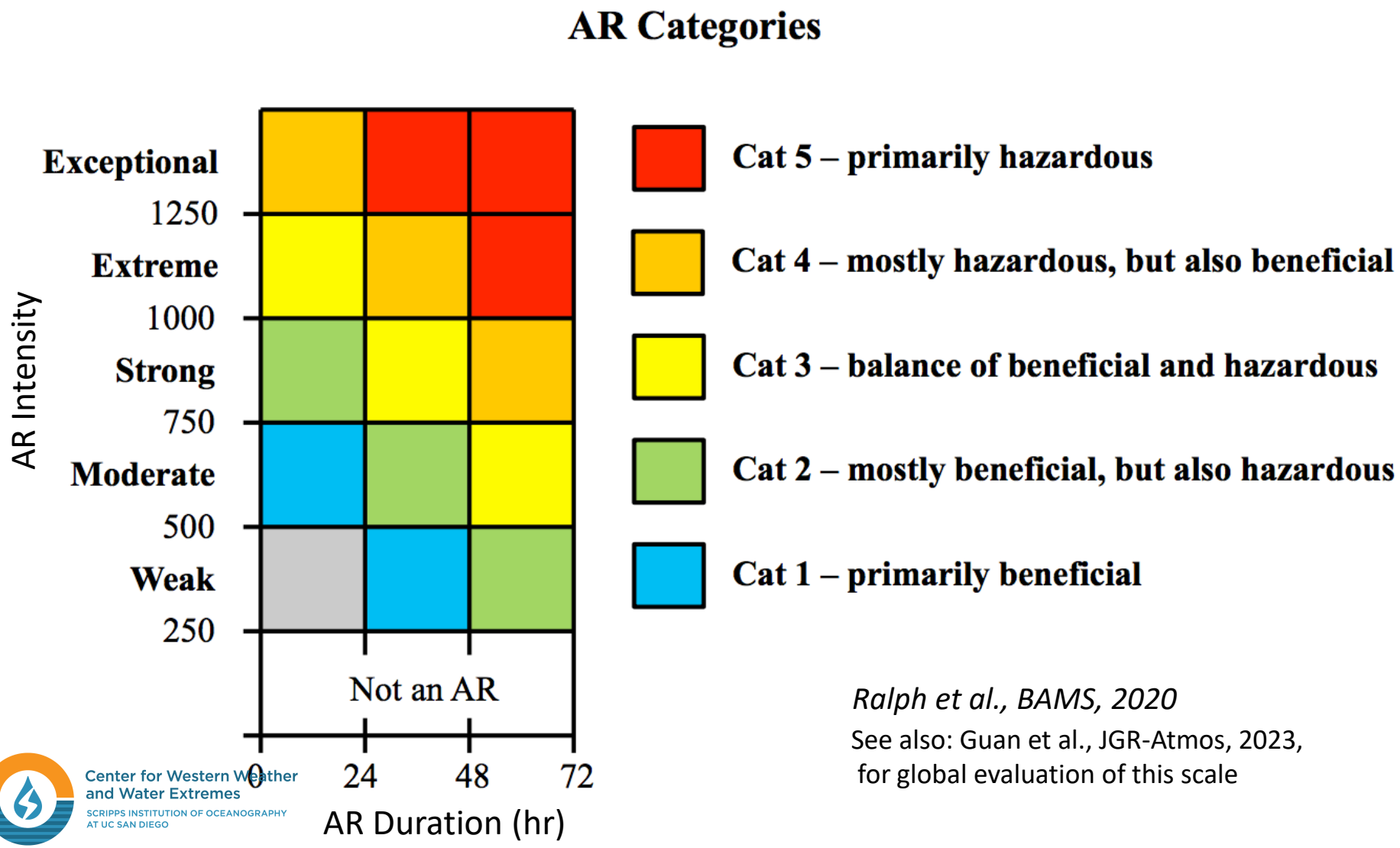
Back up slides

Given this mix of AR benefits & hazards, an AR scale for describing how impactful each atmospheric river is likely to be is now in widespread use.



Ralph et al., BAMS, 2020

See also: Guan et al., JGR-Atmos, 2023, for global evaluation of this scale

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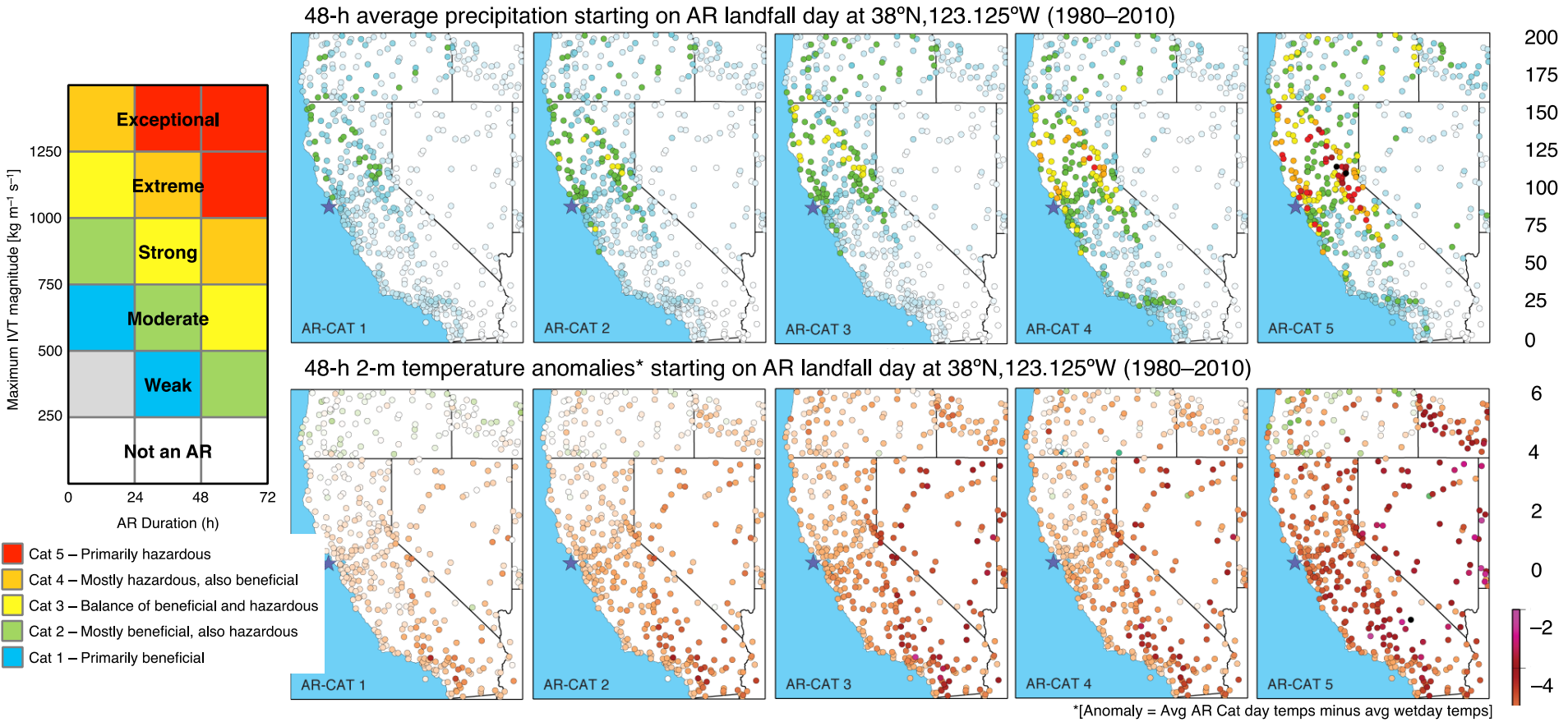
Higher AR-Cats (more intense ARs) are wetter AND WARMER, on average!



Ralph et al., BAMS, 2019