Atmospheric Rivers and Precipitation Augmentation

Todd Flanagan, CCM

North American Weather Consultants, Inc.

Precipitation Augmentation

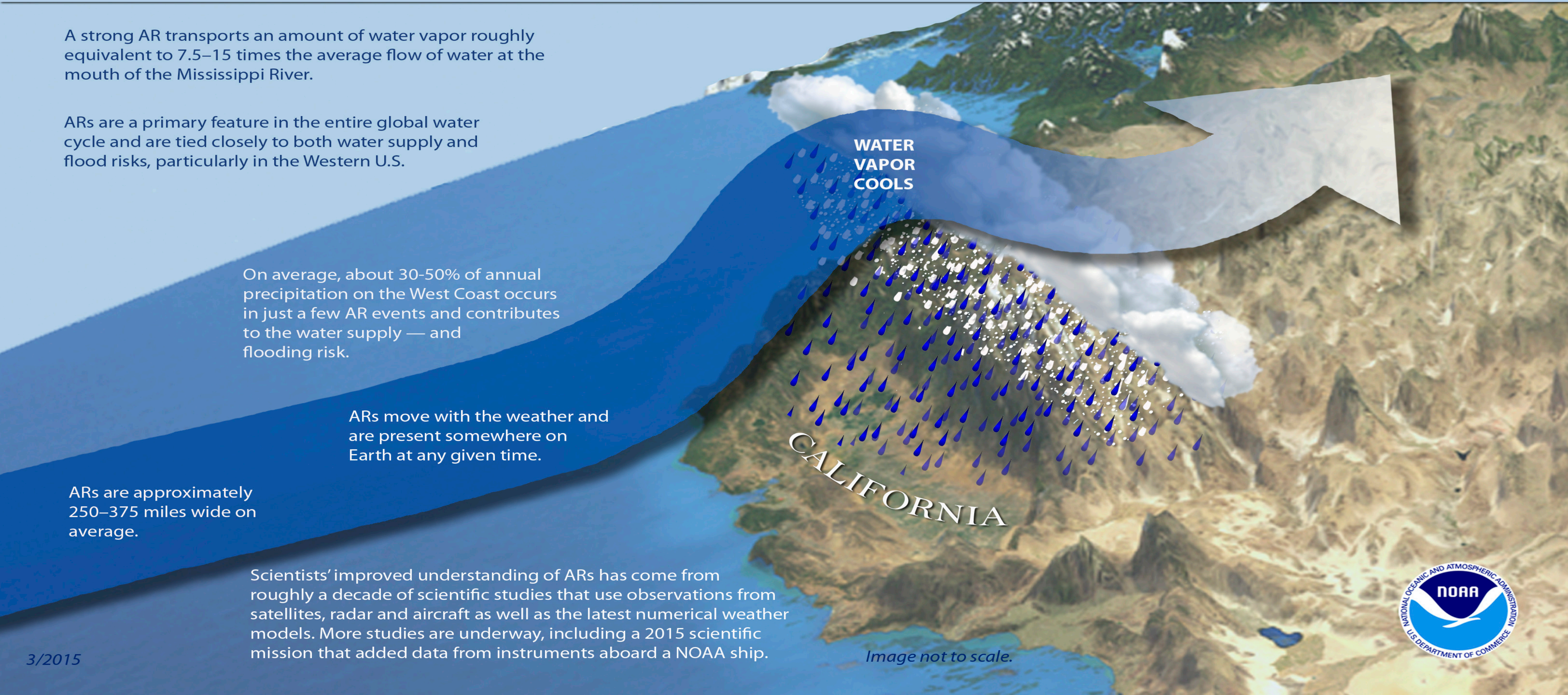
- **Primary goal of wintertime precipitation augmentation/weather modification/cloud seeding is to enhance snowpack several areas of the West**
  - Longer runoff in spring/summer months
  - Help replenish aquifers/reservoirs/lakes
- **Works by targeting supercooled liquid water (SLW) in clouds that may not have enough nuclei to produce (more) precipitation**
- **Also rainfall enhancement for reservoir replenishment SW California**

Seeding Operations

Ground (CNGs/AHOGS); Airborne

The science behind atmospheric rivers

An atmospheric river (AR) is a flowing column of condensed water vapor in the atmosphere responsible for producing significant levels of rain and snow, especially in the Western United States. When ARs move inland and sweep over the mountains, the water vapor rises and cools to create heavy precipitation. Though many ARs are weak systems that simply provide beneficial rain or snow, some of the larger, more powerful ARs can create extreme rainfall and floods capable of disrupting travel, inducing mudslides and causing catastrophic damage to life and property. Visit www.research.noaa.gov to learn more.



A strong AR transports an amount of water vapor roughly equivalent to 7.5–15 times the average flow of water at the mouth of the Mississippi River.

ARs are a primary feature in the entire global water cycle and are tied closely to both water supply and flood risks, particularly in the Western U.S.

On average, about 30-50% of annual precipitation on the West Coast occurs in just a few AR events and contributes to the water supply — and flooding risk.

ARs move with the weather and are present somewhere on Earth at any given time.

ARs are approximately 250–375 miles wide on average.

Scientists' improved understanding of ARs has come from roughly a decade of scientific studies that use observations from satellites, radar and aircraft as well as the latest numerical weather models. More studies are underway, including a 2015 scientific mission that added data from instruments aboard a NOAA ship.

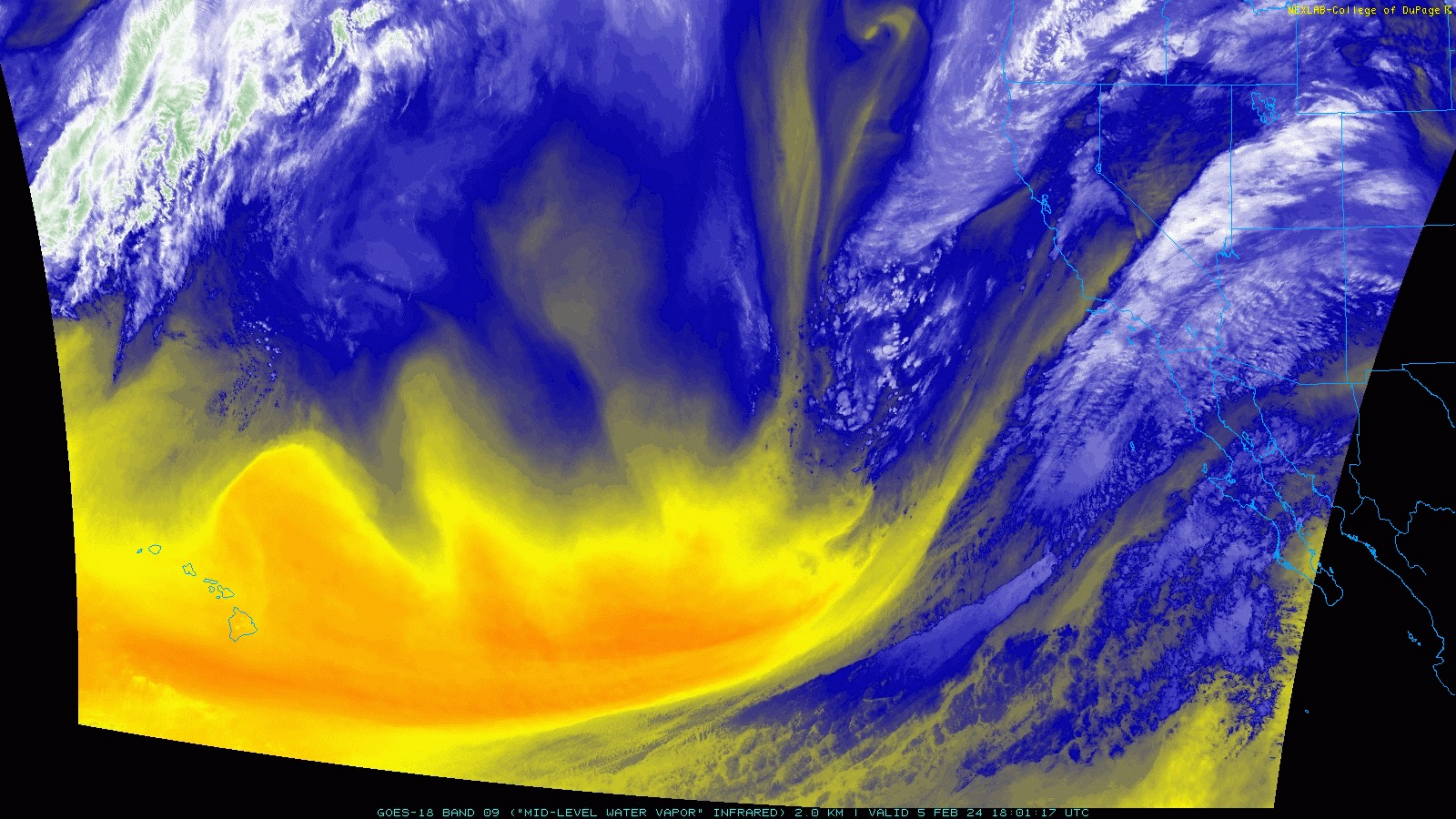
3/2015

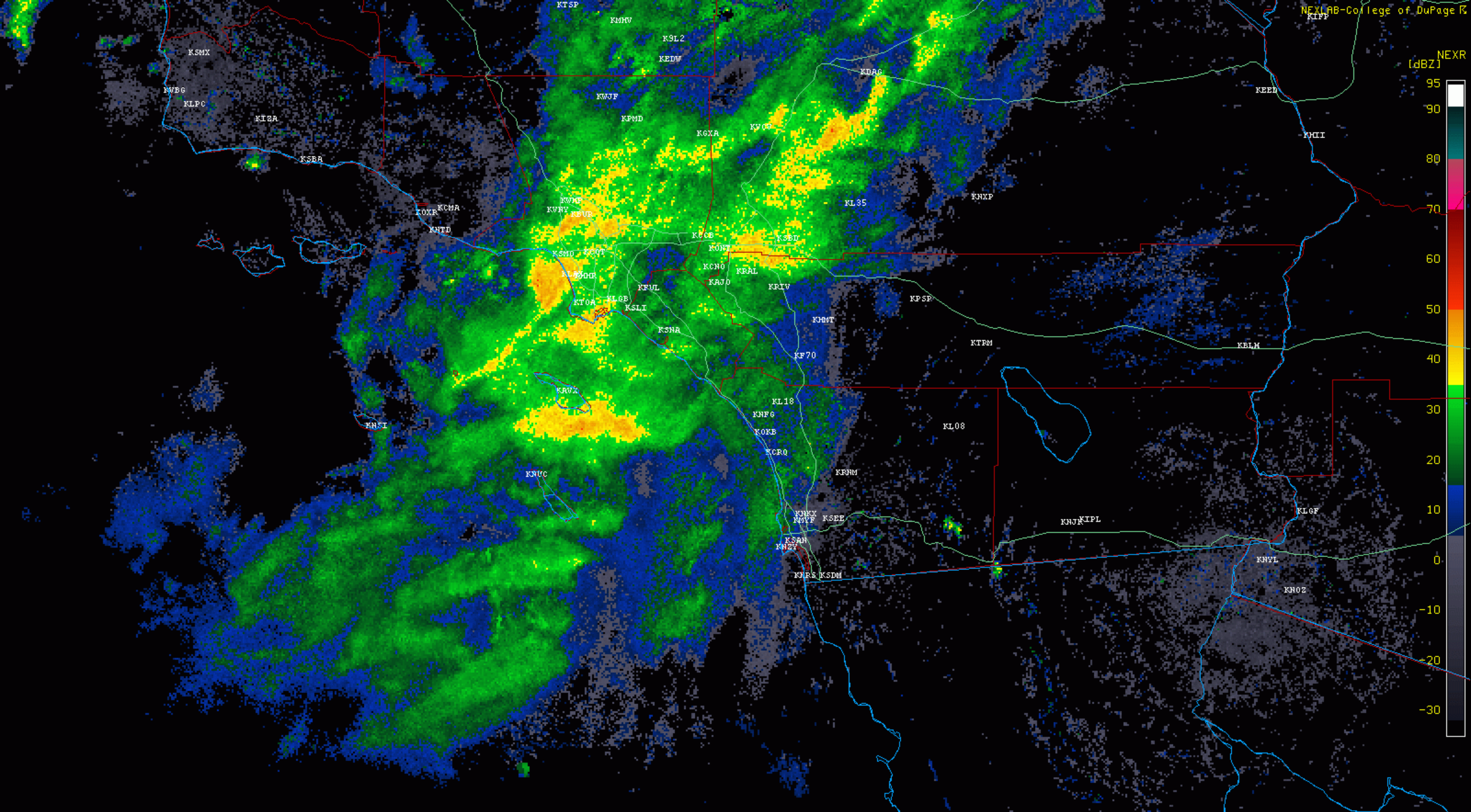
Source:
“A Scale to Characterize the Strength and Impacts of Atmospheric Rivers”, Ralph, F. Martin et. al, *Bull. Amer. Met. Soc.*, Feb 2019

ARs on the West Coast...	Quantitative finding	References
Cause the heaviest rains	92% of West Coast's heaviest 3-day rain events fed by ARs	Ralph and Dettinger (2012)
Bring warmest storms (less snow, more rain)	Average >50% more precipitation and 2.5°C warmer than other storms in Sierra Nevada	Dettinger (2004); Backes et al. (2015); 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); Neiman et al. (2011); Konrad and Dettinger (2017)
Cause storm surges in coastal areas	15%–50% of annual sea level maxima are associated with AR-related cyclones	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)
Cause landslides, debris flows, and avalanches	ARs cause 68% of postfire debris flows in Southern California	Oakley et al. (2017); Young et al. (2017); Hatchett et al. (2017)
Bring cycles of wet and dry years	Account for 85% of multiyear precipitation variance in California	Dettinger and Cayan (2014)
Fill reservoirs and provide water supplies	30%–50% of California rain, snow, and streamflow from ARs	Guan et al. (2010); Dettinger et al. (2011)
End West Coast droughts	40%–75% of droughts on West Coast ended by an AR	Dettinger (2013)
Sustain wetlands, floodplains, and fisheries	77% of ecologically significant inundations of Yolo Bypass floodplain, Sacramento River, initiated by ARs	Florsheim and Dettinger (2015)
Water deserts and forests far inland, modulate wildfire risks	Statistically significant relations found between summer normalized difference vegetation index (greenness) and areas burned in parts of interior Southwest	Albano et al. (2017)
Freshen estuaries but sometimes threaten estuarine fauna	Mar 2011 ARs freshened San Francisco Bay by 60%, resulting in wild oyster kill rate of 97%–100%	Cheng et al. (2016)
Modify banks and bottom sediments, modulating aquatic fauna in mountain streams	More invertebrate densities and diversity after major AR flooding; 10 times more in predisturbed settings	Herbst and Cooper (2010)

AR event – February 3-8, 2024

- Strong (AR3) event (on scale of 1-5)
- More than half of the average annual rainfall fell during this event at several locations, including downtown Los Angeles (Ducommun St. gauge)
- 10-16 inches of rain in some locations in southern California (15.48” Middle Fork Lytle Creek, SB Mountains, Feb 2-9) ; “lake” at Badwater Basin, Death Valley that started with Hilary in August “replenished” with storm rainfall
- Up to NINE FEET of snow at Snow Valley (7800 feet) in SB Mountains west of Big Bear
- Wind gusts to hurricane force Bay Area, Central Coast, SoCal mountains
- Tornadoes SLO County; San Diego County


NEXLAB-College of DuPage
GOES-18 BAND 09 ("MID-LEVEL WATER VAPOR" INFRARED) 2.0 KM | VALID 5 FEB 24 18:01:17 UTC



NEXRAD MOSAIC 5 FEB 24 18:00

AR event – February 3-8, 2024

- **“Seedability” not present most of event (ground)**
  - Warm mid-level temperatures
  - Stable low level layers
  - Storm already was at “maximum efficiency” in producing precipitation

- **Final disturbance in storm series was “ideal” in terms of “seedability”**
  - Mid-level temperatures at/below -5°C (23°F)
  - Stability had mixed out
  - Lower moisture content compared to earlier storms with SLW indicated in models

- **Overall decision: NO SEEDING**
  - Excessive precipitation caused number of problems

CAN we seed Atmospheric Rivers?

- **Strong to Extreme ARs (AR3-AR5)**
  - Typically have abundant subtropical moisture and risk of excessive precipitation
  - Warm
  - Ground-based seeding difficult
  - Precipitation processes are at or near maximum efficiency
- **Weak to Moderate ARs (AR1-AR2)**
  - Moisture content less, with lower risk of excessive precipitation even if they stall over an area
  - Warm, but generally less so compared to stronger ARs
  - Ground-based seeding possible
  - Precipitation processes not at maximum efficiency, can be “helped”

SHOULD we seed Atmospheric Rivers?

- **Upper-end ARs already working at max efficiency**
  - Why seed when storm “doesn’t need help”?
- **Lower-intensity ARs potentially great candidates for seeding ops**
  - less likely to produce flooding/wind damage (antecedent conditions?)
  - Easier to conduct operations by ground and (if available) by air
  - Better potential that clouds not producing precip efficiently, seeding could add desired nuclei to increase production
- **YES, we should conduct seeding ops on SOME ARs, but NOT ALL.**
  - Pre-storm environmental conditions IMPORTANT; can’t adversely impact intended target area

FIN.

tflanagan@nawcinc.com