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Subject: Brief on recent research on ARs

Some key new recent papers, related to shifts in California precipitation.

Summary of Recent Atmospheric River Research

Introduction

Landfalling atmospheric rivers (ARs) are narrow plumes of enhanced water vapor transport over the Pacific Ocean, more than 2,000 km long, that deliver 20–50% of annual precipitation to the West Coast of North America, including California (Dettinger et al. 2011.)

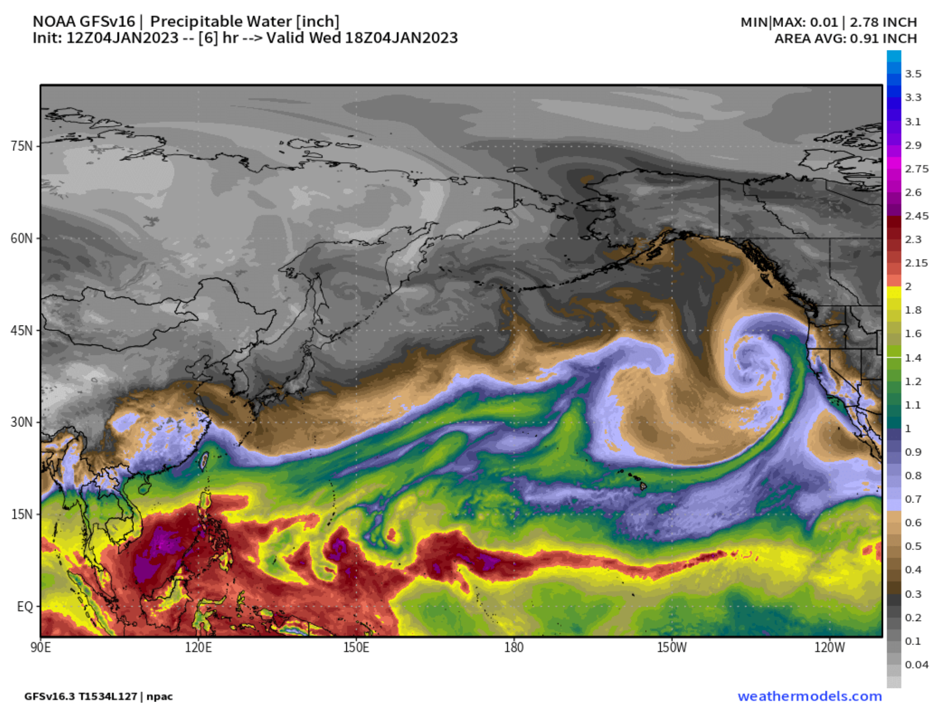

Figure 1 Atmospheric river moisture transport shown by precipitable water, Jan 4, 2023

This report synthesizes findings from key studies published between 2017 and 2025, focusing on observed trends in AR frequency and intensity, their connections to sea surface temperature (SST) patterns, and biases in climate model projections. Emphasis is placed on impacts to western North America, including the 21st Century megadrought in the southwestern United States.

Poleward Shift of Atmospheric Rivers

A study examining global AR trends from 1979 to 2022 identified a poleward shift in AR activity during the Northern Hemisphere winter (December–February) (Li & Ding, 2024). AR frequency has increased at higher latitudes (50°–60°N) in regions like the North Pacific near Alaska and the North Atlantic but decreased in subtropical zones near 30°N. This displacement, approximately 10° poleward, has reduced AR landfalls in subtropical areas, including California and southwestern North America (32°–40°N).

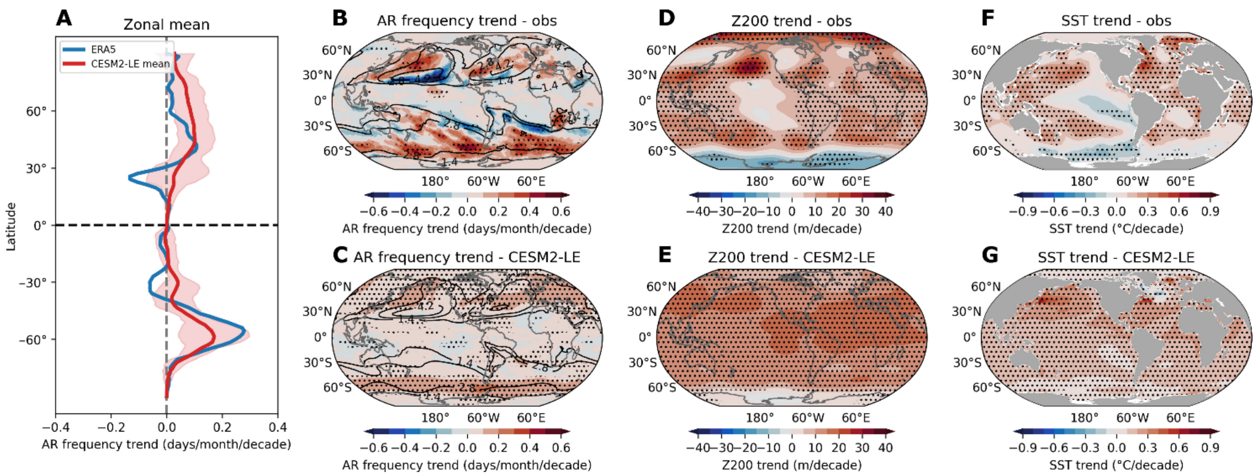

Figure 2 Li and Ding (2024) Fig 1 Observed and simulated historical trends of AR frequency, circulation, and SST.

The study links this shift to La Niña-like Pacific SST trends, characterized by accelerated warming in the western Pacific and muted warming in the eastern Pacific, which strengthens the Walker circulation and alters jet stream dynamics.

Figure 3, below, shows the persistent La-Nina like trends since the 1997-1998 El Nino, as quantified by the Multivariate ENSO Index (MEI). The MEI is calculated by the NOAA Physical Sciences Laboratory. It provides a comprehensive, coupled ocean-atmosphere perspective on state of the El Niño/Southern Oscillation. It combines five key components: sea level pressure, sea surface temperature, zonal and meridional surface winds, and outgoing longwave radiation.

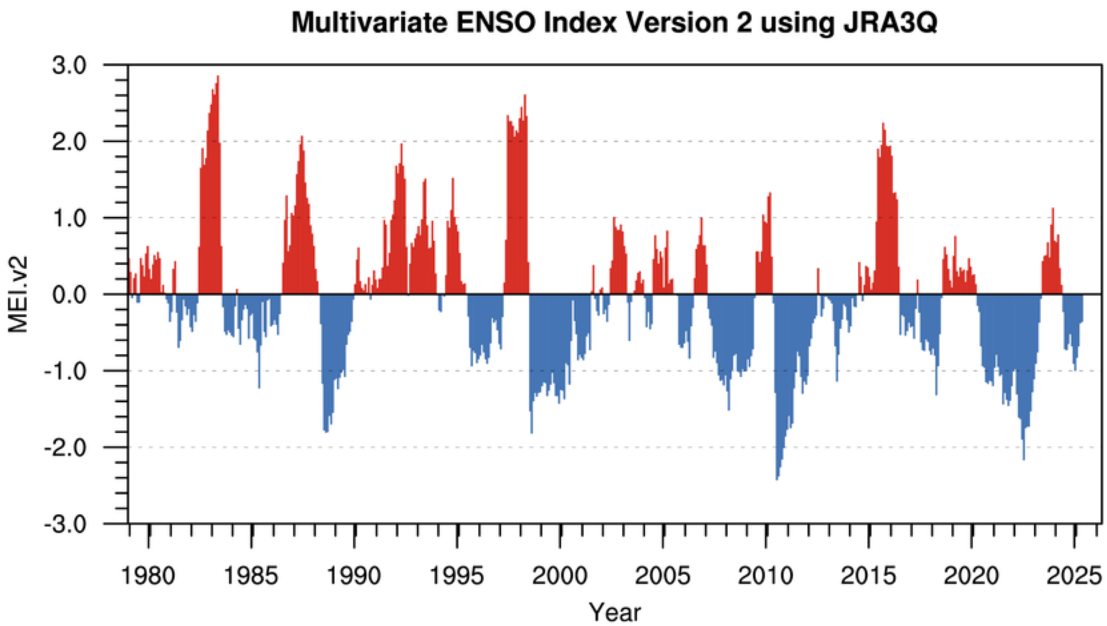

Figure 3 Multivariate Enso Index (NOAA Physical Sciences Laboratory)

The current generation of climate models, including the CMIP 5/6 global climate models and the Community Earth System Model 2 Large Ensemble (CESM2-LE), fail to replicate these observed SST patterns (Seager et. al. 2022, Wills et al. 2022). The visualization below, from the 2023 report of the CLIVAR workshop on the pattern effect, illustrates the discrepancy between observed and modeled tropical Pacific warming patterns.

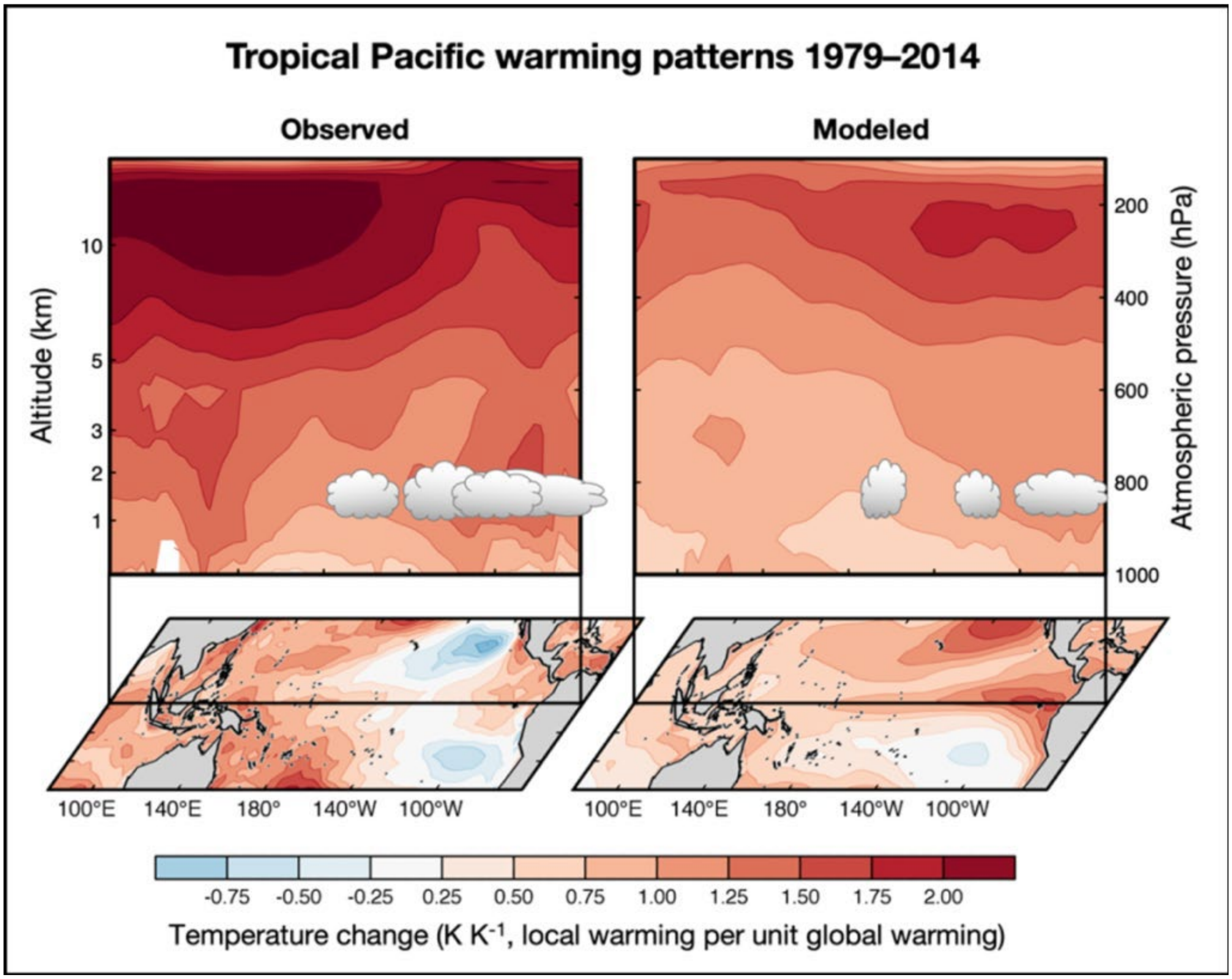

Figure 4 Fig 2 from Rugenstein et al. (2023)

The models thus underestimate associated AR frequency changes, underestimating the decline in subtropical AR activity (Li & Ding, 2024). This model bias also extends to geopotential height trends at 200 hPa, indicating deficiencies in simulating upper-tropospheric circulation responses.

Impacts on Precipitation and the Southwestern Megadrought

The poleward AR shift has contributed to reduced winter precipitation in California and the Southwest, one of the key factors in the 21st-century megadrought (2000–2022) (Li & Ding, 2024, Williams et al. 2022). ARs are a primary moisture source for this region, and their decline aligns with observed declines in precipitation since 1980. Figure 4 from (Cook et. al. 2025) shows observed precipitation anomalies in different seasons in southwest North America during the megapluvials from 1905-1923, and 1978-1999, and in the 21st century. SON is September - November, DJF is December - February, MAM is March-May, and JJA is June-August.

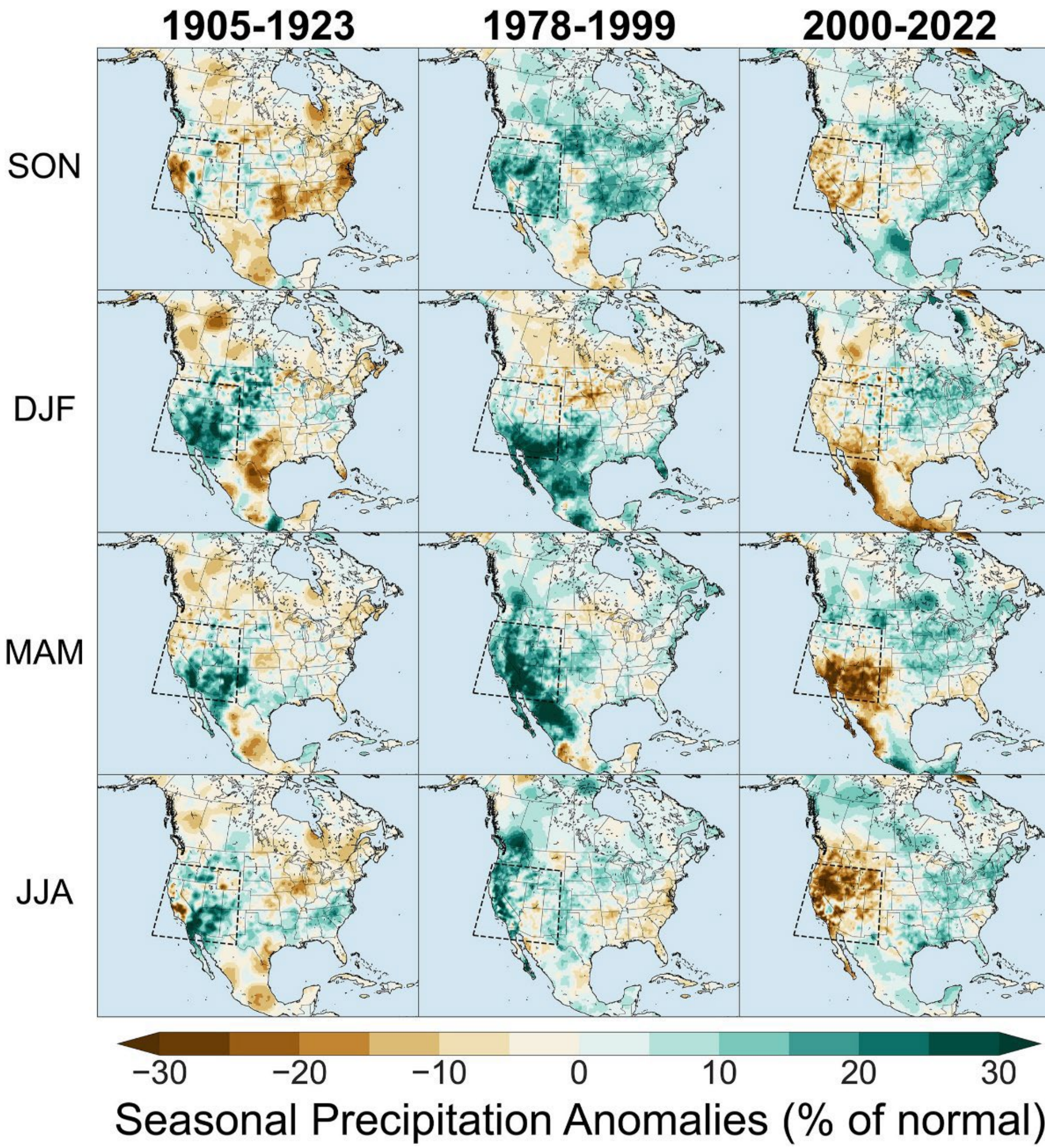

Figure 5 Figure 3 from Cook et. al. 2023 Caption:

Seasonal precipitation anomalies (%) during the early 20th-century megapluvial (1905–1923; left column), late 20th-century megapluvial (1978–1999; center column), and early 21st-century megadrought (2000–2022; right column). Baseline period for the anomaly calculation is 1901–2022. Dashed box represents the Southwestern North America region, the area of focus for our analyses.

Opposing Trends in Winter Atmospheric Rivers Over the United States

Complementing the global perspective, research on U.S.-specific AR trends from 1980 to 2020 reveals divergent patterns across the continent (Dong et al., 2025). In the western U.S., AR frequency and intensity have decreased, particularly along the Pacific Northwest and California coasts, due to a poleward retraction of the North Pacific jet stream and weakened moisture transport. Conversely, the eastern U.S. has seen increased AR activity over the Northeast and Mid-Atlantic, driven by a strengthened subtropical jet over the Atlantic and enhanced moisture from warming Gulf Stream SSTs.

Anthropogenic warming accounts for approximately 60% of these trends, with the Pacific Decadal Oscillation modulating regional outcomes.

Climate Model Biases in North Pacific Jet and SST Trends

Further scrutiny of climate models reveals persistent failures in simulating observed North Pacific jet stream trends from 1979 to 2023 (Patterson & O'Reilly, 2025). The winter jet has shifted poleward, a change not replicated in coupled models, even when accounting for tropical Pacific SST trends. This discrepancy suggests models underestimate either the jet's response to anthropogenic forcing or its sensitivity to multi-decadal natural variability, such as the Pacific Decadal Oscillation (PDO) and Interdecadal Pacific Oscillation (IPO).

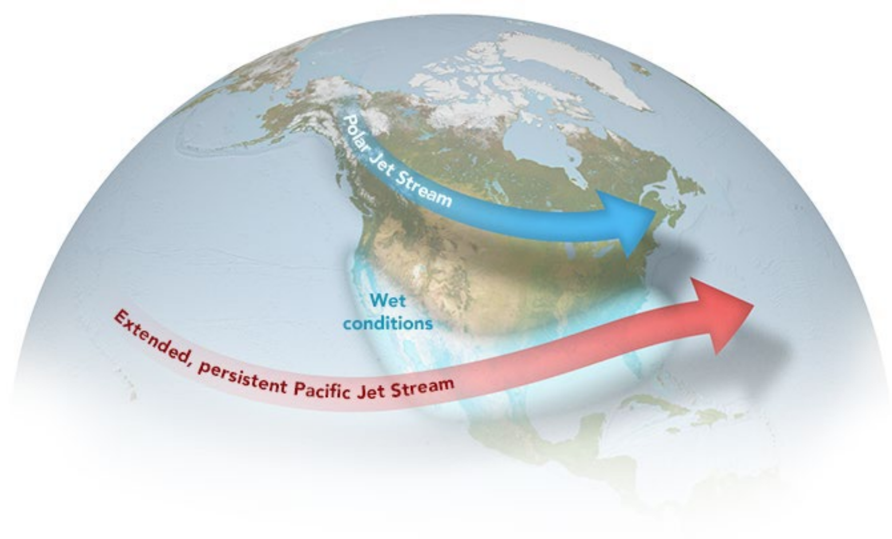

Figure 6 Pacific Jet Stream (Source: NASA Earth Observatory)

These biases align with broader issues in CMIP5/6 models, which project an El Niño-like weakening of the Pacific SST gradient under greenhouse forcing, contrary to observed La Niña-like strengthening (Seager et al., 2019; Seager et al., 2022; Wills et al., 2022). Reduced anthropogenic aerosols may contribute to eastern Pacific cooling, a mechanism poorly captured in models (Hwang et al., 2024). Inadequate representation of cloud-SST feedbacks and ocean-atmosphere interactions further distorts projections of AR dynamics and regional precipitation.

Implications and Recommendations

Recent research indicates that climate-driven atmospheric river redistribution is intensifying droughts in western North America, including California. Global climate model biases in SST trends and Northern Pacific jet dynamics undermine the reliability of model projections.

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