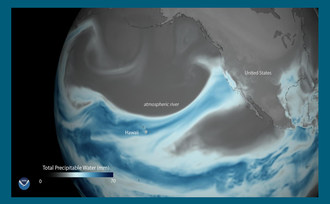
A Stable Isotopic Comparison of Atmospheric River and non-Atmospheric River Precipitation Impacting Northern California

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Stable isotope** analysis of **precipitation** can help inform **climate research** and **water resource management.

1. Introduction

Understanding atmospheric river dynamics and patterns of behavior is crucial for the well-being of California and its citizens. These powerful weather events are responsible for 40–60% of the state's rainfall, with the potential to cause both beneficial precipitation and devastating flooding. Accurate prediction and management of atmospheric rivers can help mitigate the risks of extreme weather while ensuring adequate water supply. However, AR activity can be erratic and known for producing extremes of either too much or not enough precipitation. A whopping 84% of floods occurring in California in the lat 70 years have been linked to AR storms, whereas successive years of reduced AR activity can lead to prolonged drought. The urgent need to understand the behavior of AR storm systems, the physical processes that drive them, and the potential effects of climate change on their future activity has made them a top research priority for the state. Stable isotope analysis is promising yet thus far underutilized tool that can add greatly to the AR research toolbox.

Isotopes are variants of the same element that differ in their number of neutrons and, thus, in mass. Different isotopes of oxygen and hydrogen atoms that combine to form water molecules have slightly different thermodynamic properties that result in the non-random partitioning of lighter and heavier isotopes during phase changes of water (Craig 1961). By comparing the ratio of "heavy" (^{2}H, ^{18}O) to "light" (H, ^{16}O) isotopes in a water sample, the relative abundance of these isotopes can be used to trace water's movement through the hydrologic cycle and understand the climatic and environmental conditions through which it has traveled.



As water evaporates from the ocean, molecules with lighter isotopes tend to preferentially rise, forming clouds with specific isotopic signatures (Figure 2). The water molecules with heavier isotopes tend to precipitate out first (Dansgaard 1964), progressively changing the proportion of isotopes in the clouds as they move inland. The degree of fractionation that occurs can be influenced by **temperature**, **distance** from moisture source, **altitude**, **latitude**, and **amount** of rainout (Craig 1961).

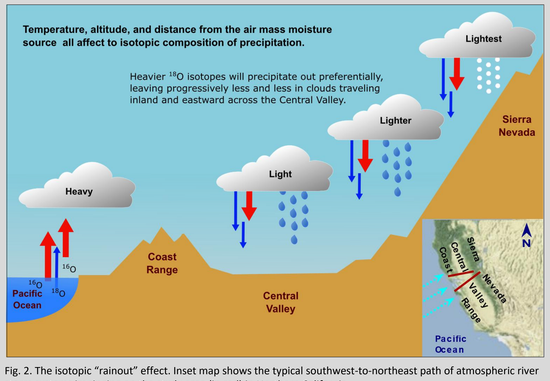


Fig. 2. The isotopic "rainout" effect. Inset map shows the typical southwest-to-northeast path of atmospheric river storm systems impinging on the study area (in red) in Northern California.

Because atmospheric river storms that impact California form over warm tropical waters near Hawai'i and often follow a more direct route than the high-latitude winter storms which more commonly affect the state, it would be reasonable to hypothesize that the isotopic values of these two storm types would also differ. This study sought to create an isotopic profile of AR storms impacting Northern California for potential use in local hydrologic monitoring, ecological research, and regional paleoclimate reconstruction applications. Its objectives were to:

1) Determine if a significant difference exists between the isotopic composition of AR and non-AR storms.

2) Evaluate the influence of regional topography on the isotopic value of rainout by defining a local isotopic lapse rate for $\delta^{18}O$ values per storm type, relative to shifts in elevation and distance from the Pacific Ocean.

3. Study Area & Methods

The study area consists of ~ 245 km transects running roughly parallel to the typical northeastward trajectory of AR storms across Northern California (Fig. 3). A total of twelve collection sites along northern Transect 'A' (elevation 187–1174 m) and fourteen sites along southern Transect 'B' (elevation 2–2359 m) were selected to represent a variety of terrains, including coastal plain and range, valley, foothill, and high-elevation mountains. Shoreline positions at Bodega Bay (38.319ºN, 123.072ºW) and the Half Moon Bay State Lifeguard Headquarters (37.466ºN, 122.446ºW) were chosen as points of origin for calculating the distance from the ocean.

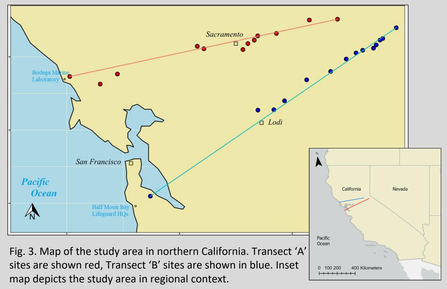


Fig. 3. Map of the study area in northern California. Transect 'A' sites are shown red, Transect 'B' sites are shown in blue. Inset map depicts the study area in regional context.

- Samples were collected daily, per site, for each storm event from October 2018–March 2019 with the help of citizen science volunteers of the CoCoRaHS (Community Collaborative Rain, Hail, and Snow) Network, friends, family, and one amazing human who collected 87.6% of Transect 'B' samples all by himself (the main author's husband).
- Storm events were categorized as either AR or non-AR using satellite imagery, integrated water vapor (IWV)/wind speed thresholds (Ralph et al. 2004; Neiman et al. 2008), and integrated vapor transport (IVT) data (Rutz et al. 2019).
- Samples were analyzed at the LSU PAST Laboratory using a Picarro L-2130i Isotopic Water Analyzer and at the CSU Sacramento WAGS Laboratory using a Los Gatos Research IWA-45EP Liquid Water Isotope Analyzer.
- Analysis results of the AR (n = 42) and non-AR (n = 68) groups were compared first for Transect 'B' as a whole, then per individual site. Weighted least squares regression was then used to determine isotopic lapse rates for distance and elevation.
- Finally, Local Meteoric Water Lines of Transect 'B' were produced for both storm types (not presented here.)

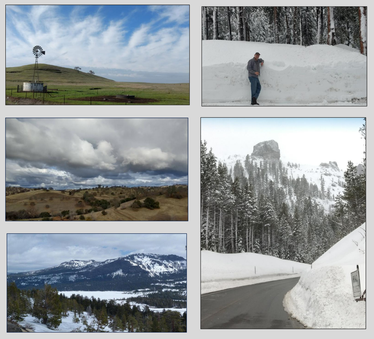


Fig. 4. Sites B4 (top left), B5 (center left), B10 (bottom left), B11 (top right), and B14 (bottom right).

4. Results & Discussion

Comparison of means tests performed for Transect 'B' considered as a whole (Fig. 5) and for eight of the twelve sites tested showed a statistically significant difference in the isotopic composition of the AR and non-AR precipitation at a 95% confidence level (Table 1). Four sites showed a statistically significant difference at a 90% confidence level. Sites B11 and B13 were excluded from means testing due to an insufficient number of samples.

Kendall's tau ranked-correlation tests analyzed at the 95% confidence level showed distance from the ocean (AR: τ = -0.61, p < 0.001; non-AR: τ = -0.53, p < 0.001) and elevation (AR: τ = -0.66, p < 0.001; non-AR: τ = -0.55, p < 0.001) each shared a negatively correlated relationship with $\delta^{18}O$ values. Results of the WLS regressions for distance are shown in Fig. 8 for both storm types.

Table 1. Results of two-independent sample comparison of $\delta^{18}O$ mean values between AR and non-AR storm precipitation.

Site	AR mean $\delta^{18}O$ (‰)	Non-AR mean $\delta^{18}O$ (‰)	t-statistic	Degrees of freedom	p-value
B1	-2.43	-6.87	4.31	8.39	<0.01
B2	-4.51	-6.60	2.10	11.93	0.06
B3	-3.34	-6.83	3.95	17.18	<0.01
B4	-4.48	-7.82	2.22	4.33	0.09
B5	-4.78	-8.48	4.71	18.94	<0.01
B6	-6.09	-10.27	7.08	25.00	<0.01
B7	-6.03	-10.74	5.53	7.66	<0.01
B8	-6.93	-11.09	3.97	12.26	<0.01
B9	-6.59	-10.99	W = 28	n/a	0.02
B10	-6.76	-12.21	7.60	6.92	<0.01
B12	-8.26	-14.32	W = 12	n/a	0.07
B14	-10.12	-16.17	3.32	2.80	0.05
Overall	-5.55	-10.10	10.66	115.92	<0.01

Notes: Significance was evaluated using the parametric Welch's t-test (sites B1–B8, B10, B14) and non-parametric Mann-Whitney U test (sites B9, B12).

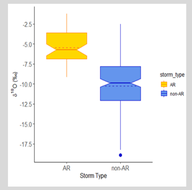


Fig. 5. Comparison of precipitation $\delta^{18}O$ values between storm types for Transect 'B' considered as a whole.

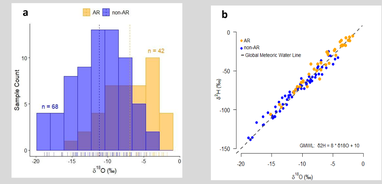


Fig. 6. Overall distribution of quality-controlled water isotopic values for Transect 'B'. (a) Histogram showing the frequency distribution of $\delta^{18}O$ values per storm type. (b) Scatterplot showing water isotope value distribution of samples plotted against the Global Meteoric Water Line (Craig, 1961).

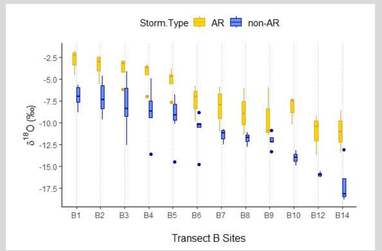


Fig. 7. Box and whiskers plots comparing δ^{18} values per storm type, per individual site.

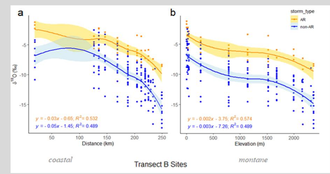


Fig. 8. Single-predictor weighted least squares regression for (a) distance and (b) elevation for precipitation $\delta^{18}O$ per storm type, shown with loess-smoothing. Dots represent individual datapoints.

5. Conclusions

There is a statistically significant difference AR and non-AR precipitation $\delta^{18}O$ and $\delta^{2}H$ values. A fair amount of overlap exists between the values of the two storm types (Figure 6a), but it can be seen in Figure 6b that AR values predominately cluster at the more positive end of the Global Meteoric Water Line than non-AR values, indicating that AR precipitation is more enriched in the heavier oxygen and hydrogen isotopes than non-AR high-latitude winter storms. The difference, while not distinct enough to definitively identify storm source per se, does provide an expected isotopic range for local AR precipitation.

The AR storms investigated here showed less isotopic variability in the precipitation isotopes than non-AR storms (Fig. 6.a.) and a less steep regression slope than non-AR storms for both distance from the ocean and changes in elevation. Elevation was found to more strongly influence fractionation than distance for both storm types. The most interesting and unexpected finding was that the relative depletion rate for both storm types tracks fairly closely up to about 200 km inland and 1000 m elevation, at which point the AR values plateau and hold fairly steady, but the non-AR storms continue to become more depleted in the heavier isotopes. This finding bears further investigation, as it would have implications for future planned high-elevation isotope-based hydrological research.

References

Craig, H., 1961: Isotopic Variations in Meteoric Waters. *Science*, **133**, 1702–1703.

Dansgaard, W., 2012: Stable isotopes in precipitation. *Tellus Dyn. Meteorol. Oceanogr.*, **16**, 436.

Dee, S., A. Bailey, J. L. Conroy, A. Atwood, S. Stevenson, J. Nusbaumer, and D. Noone, 2023: Water isotopes, climate variability, and the hydrological cycle: recent advances and new frontiers. *Environ. Res. Clim.*, **2**, 022002

Neiman, P. J., F. M. Ralph, G. A. Wick, J. D. Lundquist, and M. D. Dettinger, 2008: Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West Coast of North America based on eight years of SSM/I satellite observations. *J. Hydrometeorol.*, **9**, 22–47.

Ralph, F. M., P. J. Neiman, and G. A. Wick, 2004: Satellite and CALJET aircraft observations of atmospheric rivers over the eastern North Pacific Ocean during the winter of 1997/98. *Mon. Weather Rev.*, **132**, 1721–1745.

Rutz, J. J., and Coauthors, 2019: The Atmospheric River Tracking Method Intercomparison Project (ARTMIP): Quantifying Uncertainties in Atmospheric River Climatology. *J. Geophys. Res. Atmospheres*, **124**, 13777–13802.

Zhu, Y., and R. E. Newell, 1998: A proposed algorithm for moisture fluxes from atmospheric rivers. *Mon. Weather Rev.*, **126**, 725–735.

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