Tap Water Isoscapes revealed ENSO's Impacts on a Drinking Water Distribution System in Southern Africa

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I. Research Question

- How do ENSO-driven climatic variations influence the spatial and seasonal distribution of water sources in Gaborone's urban tap water system, as revealed by isoscapes and mixing model analysis?

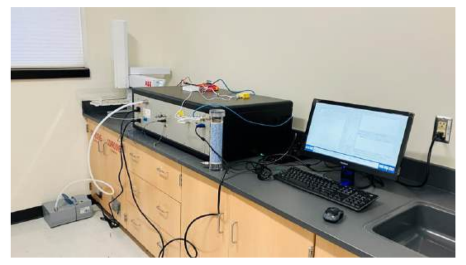
II. Hypothesis

- ENSO-driven climatic variations significantly influence the spatial and seasonal isotopic composition of Gaborone's tap water with greater $\delta^{18}O$ and *d*-excess variability observed during drier periods due to shifts in reservoir contributions.

III. Methods

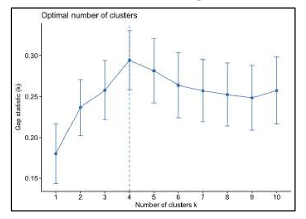
1. Sampling (2022-2024) to capture isotope seasonality. Tap water snapshots = 399, rainfall = 88, weekly tap water = 42 and reservoir water = 48

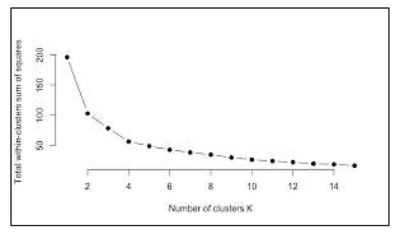
2. Water stable isotopes analysis



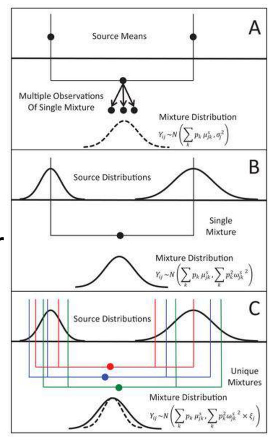
3. Clustering analysis

K-means: partitions data into several clusters (k) by assigning a point to the nearest centroid and updates centroids until convergence (elbow and silhouette methods)



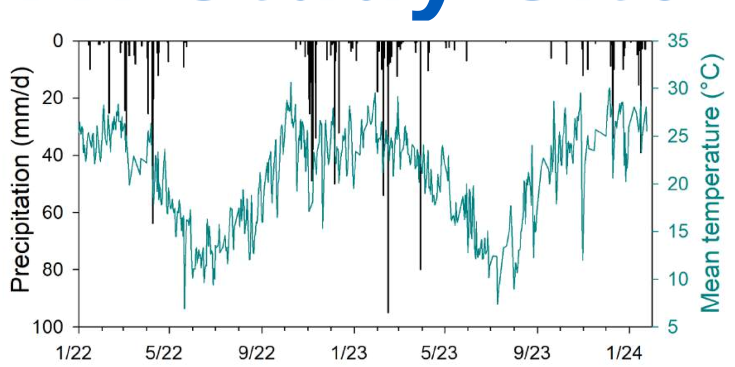


4. Bayesian Mixing model: estimate the relative contributions of different sources to a mixture based on isotope data.
MixSIAR model used
Last two campaigns were combined since the reservoir sampling was started mid-2023.

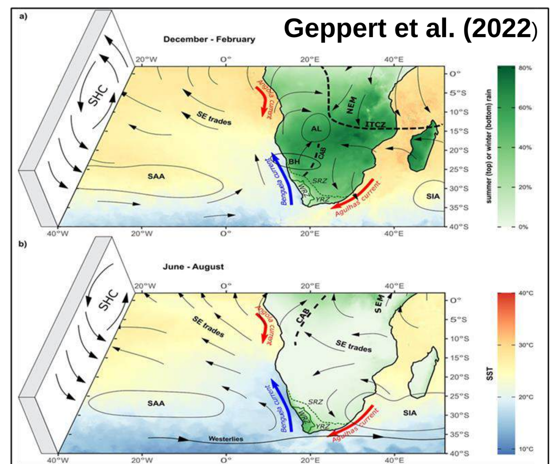


Stock et al. (2018)

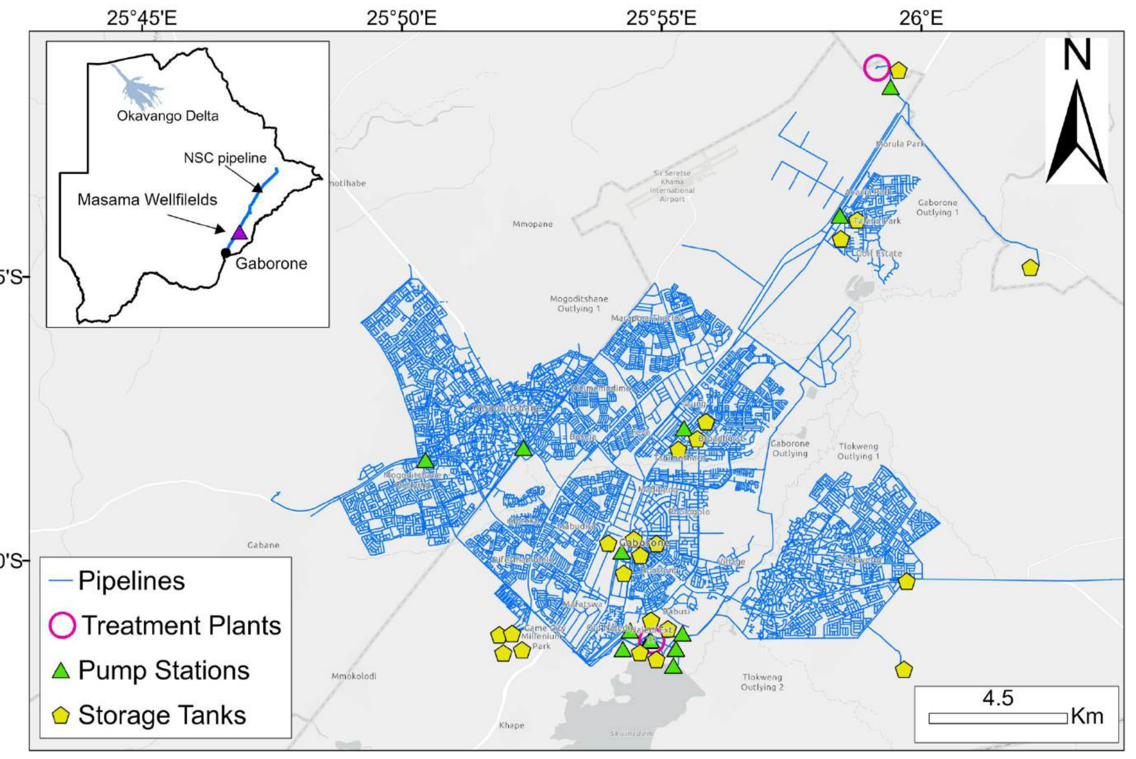
IV. Study Site



Daily precipitation (mm) and mean air temperature (ºC) for Gaborone City

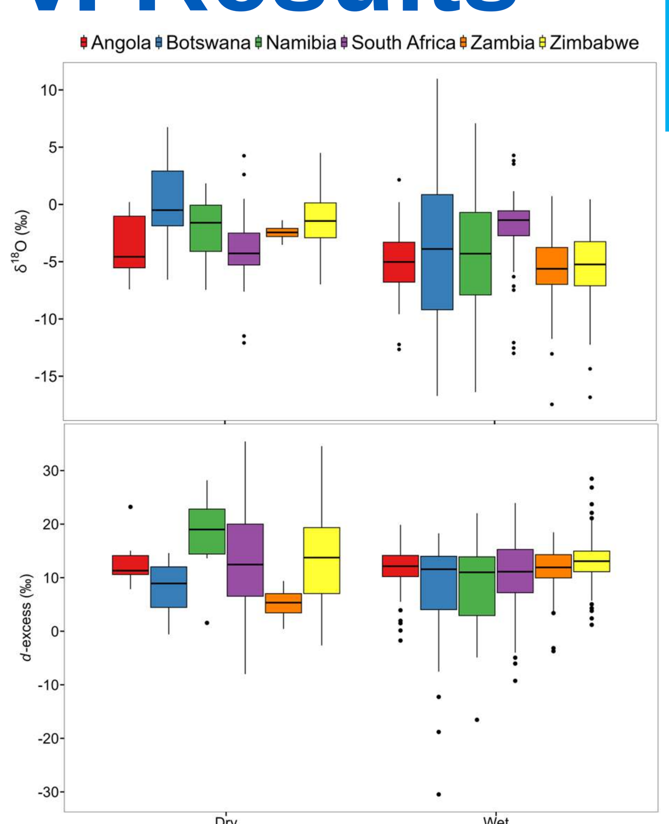


SE trade winds and the seasonal migration of the ITCZ control the isotopic variability of precipitation in southern-central Africa.



Map of the city of Gaborone water infrastructure, showing pipelines, storage tanks, pump stations and drinking water treatment plants

V. Results



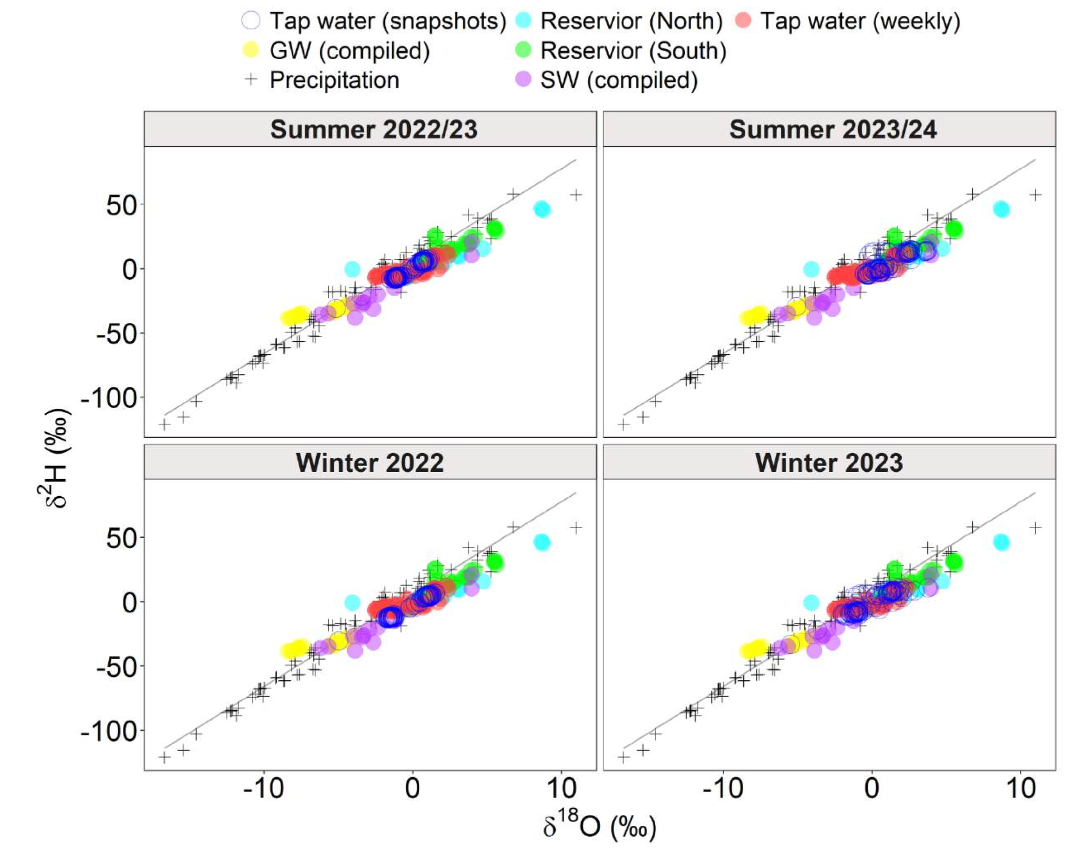
$\delta^{18}O$ and *d*-excess seasonal variation provides insights into climate patterns and hydrological processes

$\delta^{18}O$ values are generally lower in wet season than dry season except South Africa.

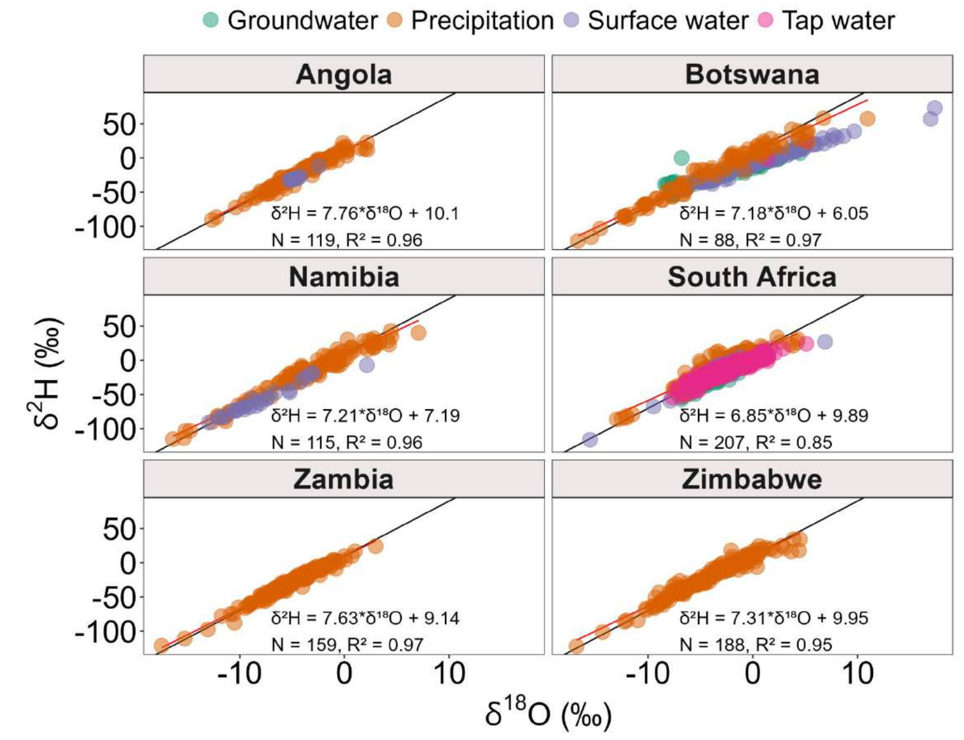
Botswana displays most seasonal shift, with $\delta^{18}O$ decreasing from 0.2‰ in the dry season to -4.1‰ in the wet season

***d*-excess values vary seasonally.**
Botswana displays extreme negative outliers (-30‰) in the wet season.

Regional seasonal isotopic variability $\delta^{18}O$(‰) and *d*-excess (‰)in precipitation across Southern Africa



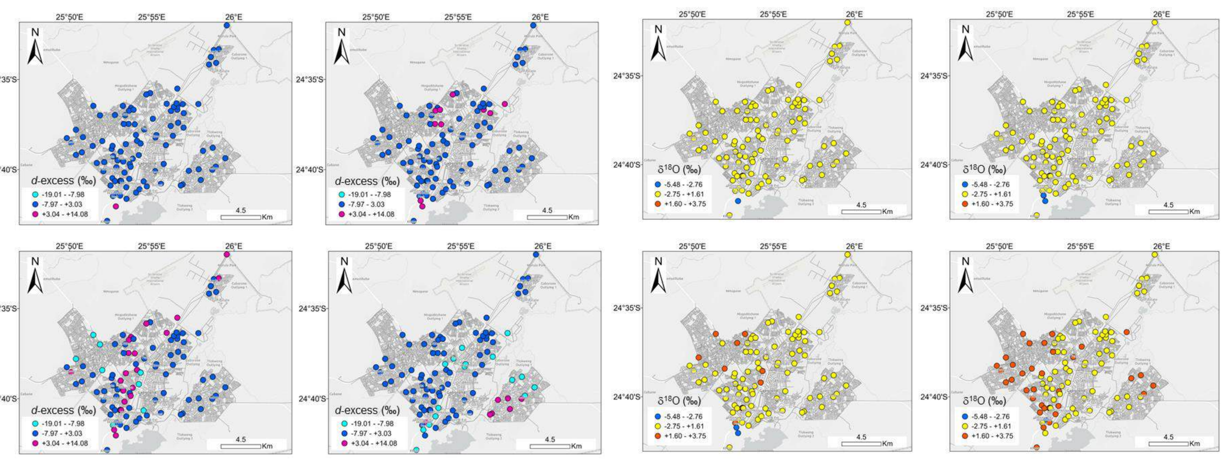
Dual-isotope space showing $\delta^{18}O$ versus δ^2H in tap waters and regional endmembers.



LMWL (Botswana): $\delta^2H = 7.18*\delta^{18}O + 6.05$
Limited data tap water data across Southern Africa except South Africa

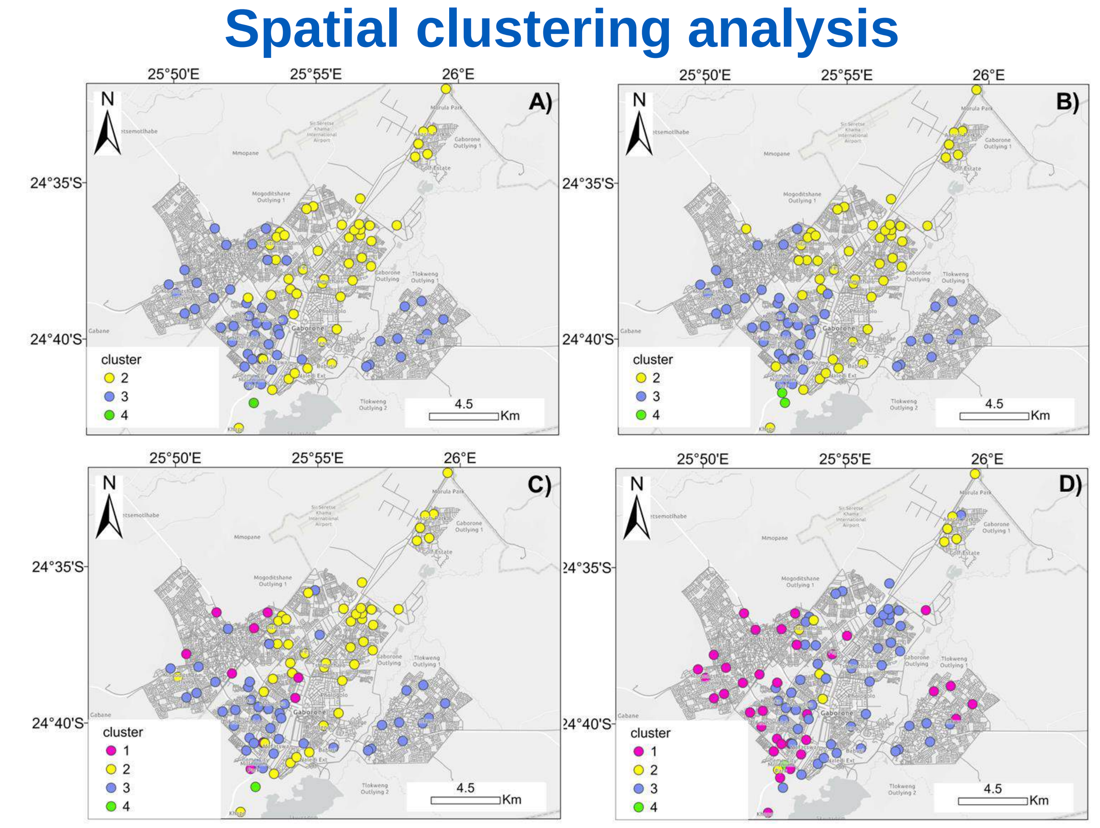
Dual-isotope ($\delta^{18}O$ and δ^2H) plots for Southern African countries with precipitation, surface water, groundwater, and tap water endmembers

Spatial tap water isotopic variability



Tap water $\delta^{18}O$ and *d*-excess isotopic seasonal variations

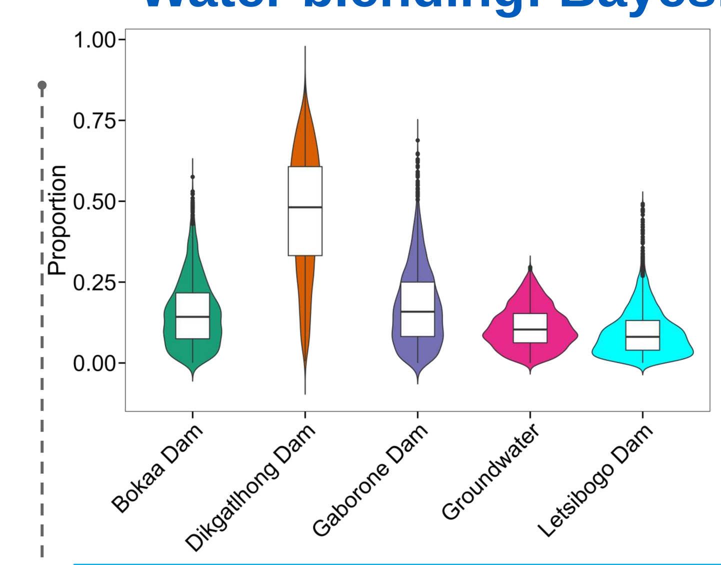
Spatial clustering analysis

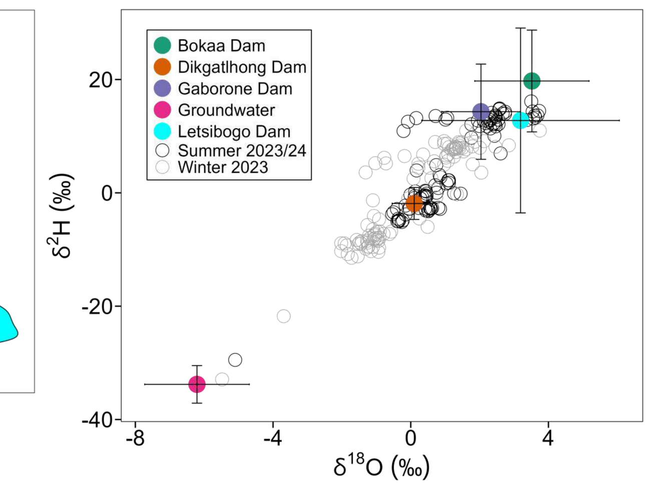


Four clusters, spatial distribution of $\delta^{18}O$(‰) exhibits seasonal variations from winter 2022 to summer 2023/24

$\delta^{18}O$(‰)	*d*-excess (‰)
Cluster 1: +1.76 (‰) to +3.75 (‰)	Cluster 1: -19.01 (‰) to -1.99 (‰)
Cluster 2: -0.21 (‰) to +1.61 (‰)	Cluster 2: -11.75 (‰) to +13.19 (‰)
Cluster 3: -2.02 (‰) to -0.23 (‰)	Cluster 3: -3.16 (‰) to +14.08 (‰)
Cluster 4: -5.48 (‰) to -3.47 (‰)	Cluster 4: +6.48 (‰) to +11.32 (‰)

Water blending: Bayesian mixing analysis





Summer 2023/24 and winter 2023

Dikgatlhong Dam (46.2±18.8%)
Gaborone Dam (17.5±11.9%)
Bokaa Dam (15.6±10.4%)
Letsibogo Dam (9.6±7.6%)
Groundwater (11.1±6.4%)

Proportional contributions for water sources for Gaborone's tap water distribution system estimated by MixSIAR (A) and the dual-isotope ($\delta^{18}O$ vs δ^2H) for reservoirs and tap water snapshots

VI. Conclusions

- ENSO phases significantly impact the isotopic composition ($\delta^{18}O$, δ^2H , *d*-excess) of Gaborone's tap water.
- El Niño periods lead to progressive enrichment in tap water isotopes, indicating increased reliance on surface water reservoirs.
- Bayesian mixing models highlight the adaptability of Gaborone's water supply system in integrating multiple sources to buffer against climatic fluctuations.
- Isotopic techniques combined with Bayesian modeling provide a robust approach for tracking water source contributions in semi-arid urban settings.
- Findings help water managers improve source water identification and management strategies.
- Integrating isotopic and volumetric data can enhance conceptual models of water distribution, and long-term monitoring can provide insights into water use dynamics during stress periods.

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References

- Geppert, M., Hartmann, K., Kirchner, I., Pfahl, S., Struck, U., & Riedel, F. (2022). Precipitation over southern Africa: Moisture sources and isotopic composition. *Journal of Geophysical Research: Atmospheres*, *127*(21)
- Stock, B. C., Jackson, A. L., Ward, E. J., Parnell, A. C., Phillips, D. L., & Semmens, B. X. (2018). Analyzing mixing systems using a new generation of Bayesian tracer mixing models. PeerJ, 6, e5096.