The Conditional Relationship Between Atmospheric River Moisture, Wind, and Precipitation in Satellite Observations

Emilio Yanez[1], *Weiming Ma*[1,2], *Gang Chen*[1]

[1]Department of Atmospheric & Oceanic Sciences, UCLA, Los Angeles, CA; Now at: [2]Pacific Northwest National Laboratory, Richland, WA

Motivations

- ❑ Atmospheric Rivers (ARs) are elongated and narrow filaments of water vapor transport in the atmosphere with **convergence often associated with heavy precipitation events**
- ❑ Previous work on AR "flavors" mainly on the regional scale, but not global **[2]**
- ❑ There is a gap in an understanding of the relationships between AR moisture, wind, integrated vapor transport (IVT), and precipitation

We analyze the AR moisture, wind, IVT-precipitation relationship by…

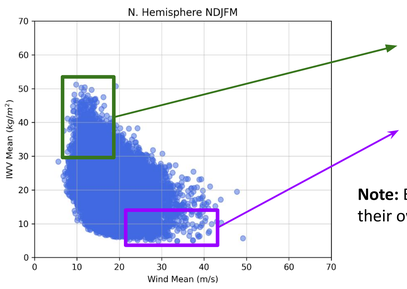
1. Developing a **global, percentile-based classification of AR types** in satellite observations
2. Using a **binned scatter approach** to quantify the sensitivity of mean AR precipitation to changes in other AR metrics
3. Identifying **spatial patterns of precipitation sensitivity** and whether there is a dependence on AR type

Data & Methodology

- ❑ **Satellite-based** data over 2002–2016 case study period
  - ❑ Version 6 of the AIRS/Aqua L3 Daily Standard Physical Retrieval **(AIRS-AMSU)** at a spatial resolution of 1.0° x 1.0° (Teixeira et al., 2013)
  - ❑ Version 6 the GPM IMERG Final Precipitation L3 1 Day **(IMERG)** at a spatial resolution of 0.1° x 0.1° (Huffman et al., 2019)
- ❑ AR detection algorithm based on **GIVT-threshold** developed for satellite data **[3,5]**
- ❑ AR geometry (shape), AR centroids, integrated water vapor (IWV), integrated vapor transport (IVT), geostrophic wind, and precipitation on **daily temporal scale**
- ❑ Binned scatter divides the independent variable (x) into equally sized bins and find the **conditional mean** of the dependent variable (y) within each bin **[1,6]**
- ❑ Precipitation threshold of ≥ 0.01 mm/day to remove non-precipitating ARs
- ❑ Grid point **linear regression** using regular statistics (R, R^2, 95% confidence intervals)

AR Types & Visualization

Relationship Between AR Wind vs AR IWV



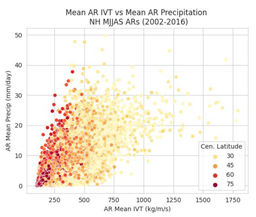
"Wet" Type ARs
- ❑ **≥ 75th percentile of IWV**
- ❑ **≤ 25th percentile of Wind**

"Windy" Type ARs
- ❑ **≤ 25th percentile of IWV**
- ❑ **≥ 75th percentile of Wind**

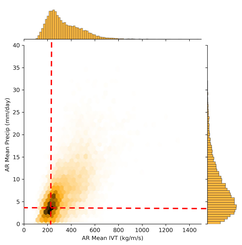
Note: Each season and hemisphere (4 total) consider their own percentiles to classify AR Types

Visualization Types (e.g. NH MJJAS AR IVT-Precipitation)

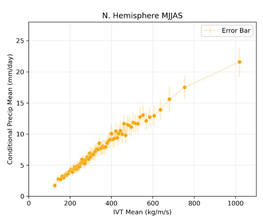
1. Simple Scatterplot



2. Joint Probability Density Function (PDF)

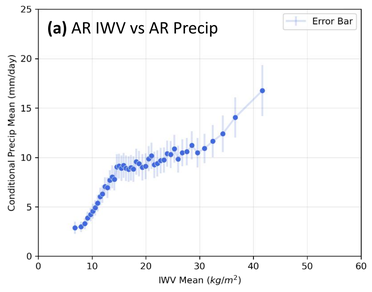


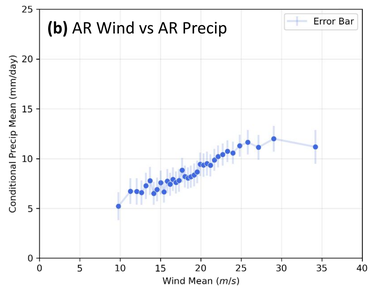
3. Binned Scatterplot (Conditional Means)

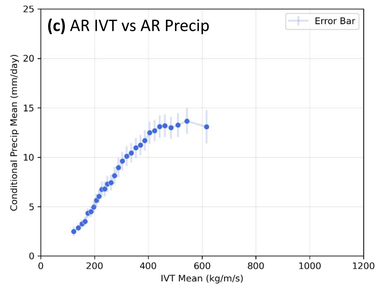


Conditional Relationships

Conditional Means of AR Precipitation, NH NDJFM ARs (2002 – 2016)







What it Means:

With increasing moisture and wind values, AR precipitation also increases (varying sensitivities and small nonlinear deviations)

Figure 1. The satellite-derived conditional relationships between several AR metrics and mean precipitation, shown for Northern Hemisphere (NH) November–March (NDJFM) ARs. **Panels (a–c)** show the relationships for AR moisture (IWV), wind, and IVT, respectively. Error bars represent the 95% CI.

Frequency of Wet and Windy ARs

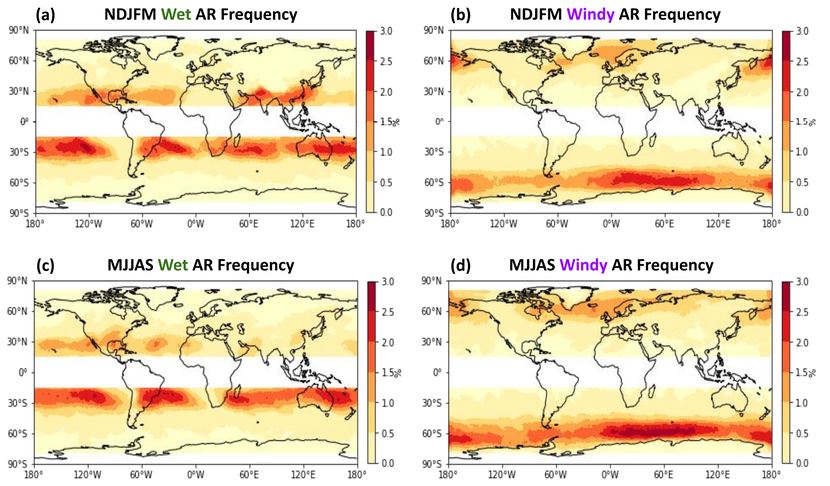


Figure 2. Satellite-derived global frequency of AR types for November–March (NDJFM) and May–September (MJJAS) interannual seasons. We define AR frequency as the fraction of (daily) timesteps a grid point experiences AR conditions, as determined by the GIVT–threshold algorithm. **Panels (a) and (c)** show **Wet** AR frequency. **Panels (b) and (d)** show **Windy** AR frequency.

References

[1] Cattaneo, M. D., Crump, R. K., Farrell, M. H., Feng, Y. (2021). On Binscatter. *arXiv Economics*.

[2] Gonzales, K. R., Swain, D. L., Barnes, E. A., & Diffenbaugh, N. S. (2020). Moisture- versus wind-dominated flavors of atmospheric rivers. Geophysical Research Letters, 47, e2020GL090042.

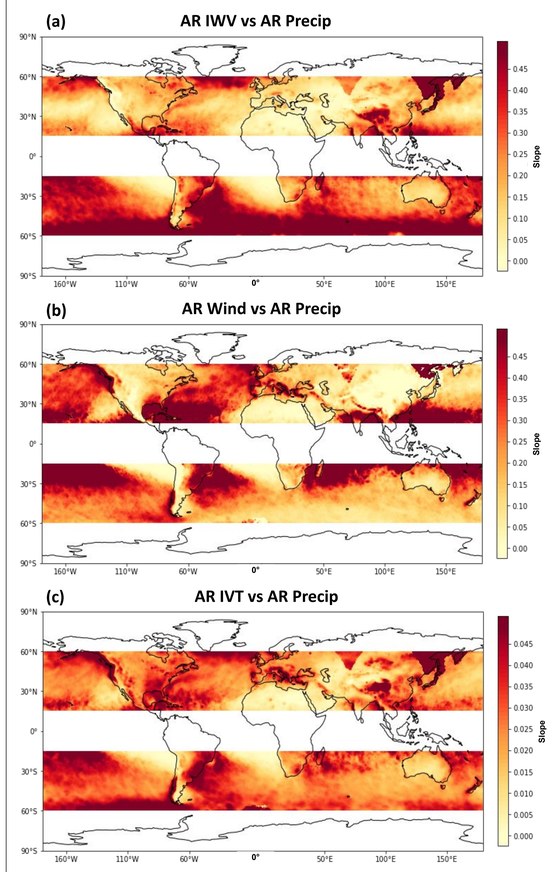
[3] Guan, B., & Waliser, D. E. (2015). Detection of atmospheric rivers: Evaluation and application of an algorithm for global studies. Journal of Geophysical Research: Atmospheres, 120(24), 12514–12535.

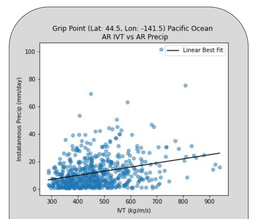
[4] Guan, B., Waliser, D. E., & Ralph, F. M. (2023). Global application of the atmospheric river scale. Journal of Geophysical Research: Atmospheres, 128, e2022JD037180.

[5] Ma, W., Chen, G., Guan, B., Shields, C. A., Tian, B., & Yanez, E. (2023). Evaluating the representations of atmospheric rivers and their associated precipitation in reanalyses with satellite observations. Journal of Geophysical Research: Atmospheres, 128, e2023JD038937.

[6] Peters, O., Neelin, J. (2006). Critical phenomena in atmospheric precipitation. *Nature Phys* 2, 393–396.

Grid Point Linear Regression





For each grid point, derive a scatter plot relationship and take a simple linear regression (example above)

Plots are the precipitation sensitivities (slope values) for each grid point

What It Means:

(a) **Less moisture near poles** → higher sensitivity to IWV

(b) **Less windy near tropics** → higher sensitivity to wind

(c) Mix of both, **convergence over topography** → higher sensitivity to IVT

Figure 3. Global grid point linear regression values for several AR metrics (independent variable) versus mean precipitation (dependent variable). A higher slope value represents a higher precipitation sensitivity to the AR metric and vise versa. **Panels (a–c)** show the relationships for AR moisture (IWV), wind, and IVT, respectively.

Summary

Key points:
- ❑ **Strong, positive conditional AR IVT-precipitation relationship, regardless of ocean basin and season**
- ❑ **High precipitation sensitivity to moisture near poles → Windy AR precipitation is most sensitive to moisture**
- ❑ **High precipitation sensitivity to wind near tropics → Wet AR precipitation is most sensitive to wind**
- ❑ **Wet (Windy)** ARs have a higher frequency near tropics (poles)
- ❑ Mixed regions of precipitation sensitivity to IVT in tropics and near topography
- ❑ (Not shown) AR IVT-precipitation relationship has a small dependence on AR type, associated with nonlinearities

Potential future work:
- ❑ Use the conditional AR IVT-precipitation relationship to define a global ranking scale, expanding on regional case **[4]**
- ❑ Incomporate reanalysis and climate model data to evaluate biases in the AR IVT-precipitation relationship
- ❑ Explore how AR precipitation sensitivities change under global warming

Acknowledgements: Bin Guan & Sudip Chakraborty

Email: emilioy33@g.ucla.edu.

LinkedIn: www.linkedin.com/in/emilio-yanez-3124531b0