# A Water Cycle Perspective on the Connection Between Precipitation Extremes and Circulation Anomalies

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We have applied the quasi-isentropic back trajectory scheme of Dirmeyer and Brubaker to the NCEP/DOE (R-2) and MERRA reanalysis data to estimate the evaporative moisture sources that supply water for precipitation over each terrestrial grid box north of 60ºS. This approach produces, for every location, a time series of two-dimensional fields representing the fraction of that place's precipitation that originated as evaporation from each point on the globe; the global integral of this evaporative source map equals the total precipitation at that location. These sources can be aggregated over multiple grid boxes to provide the evaporative source for precipitation over any arbitrary area (e.g., river basins, nations, continents, etc.). The fraction of the evaporative source that comes from the same area as the precipitation sink is, by definition, the "recycling ratio". To reduce the effect of spurious trends and discontinuities in the reanalysis precipitation fields, we use gridded observed precipitation products to correct the reanalysis monthly precipitation totals in our estimates, but otherwise we use only the reanalysis data for three-dimensional fields of atmospheric temperature, humidity, winds, as well as surface pressure and total surface evaporation, at sub-diurnal time resolution (6-hour time steps).

The evaporative source fields are effectively two-dimensional probability density functions (PDFs) indicating the likely origins of water supplying precipitation for any particular location and time period. Their shape and position relative to the location of any precipitation sink are controlled largely by the atmospheric circulation that is advecting the water vapor. Changes or differences in these PDFs are an indication of changes or differences in the circulation. Such differences can be quantified objectively using Relative Entropy (RE; a.k.a. Kullback–Leibler divergence) – a non-parametric measure of the similarity between two PDFs.

We have examined extremes in precipitation as well as the overall correlation of precipitation to RE to show the dependence of precipitation anomalies on circulation pattern changes versus other causes (changes in local humidity, atmospheric stability, soil moisture anomalies, unpredictable random fluctuations, etc.) as a function of season and location. Global maps reveal locations where precipitation extremes are more or less dependent on circulation changes, and whether droughts are more or less dependent on circulation changes than floods. Large-scale patterns and seasonal cycles from the two reanalysis products are similar, but there is a great deal of regional and local structure in each. Correlations and degree of dependence (slope; rainfall anomaly over RE) are calculated for the entire data set, as well as for only dry or wet anomalies (dependencies are rarely symmetric) and statistical significance is assigned to the results.

We find that for both positive and negative precipitation anomalies, circulation changes are more likely to be a cause for extremes in arid (or dry season) regimes than humid (wet season) ones. Surprisingly, floods are less correlated with circulation pattern changes than droughts, considering floods over land need to tap oceanic moisture sources to sustain above-average precipitation rates.

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