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

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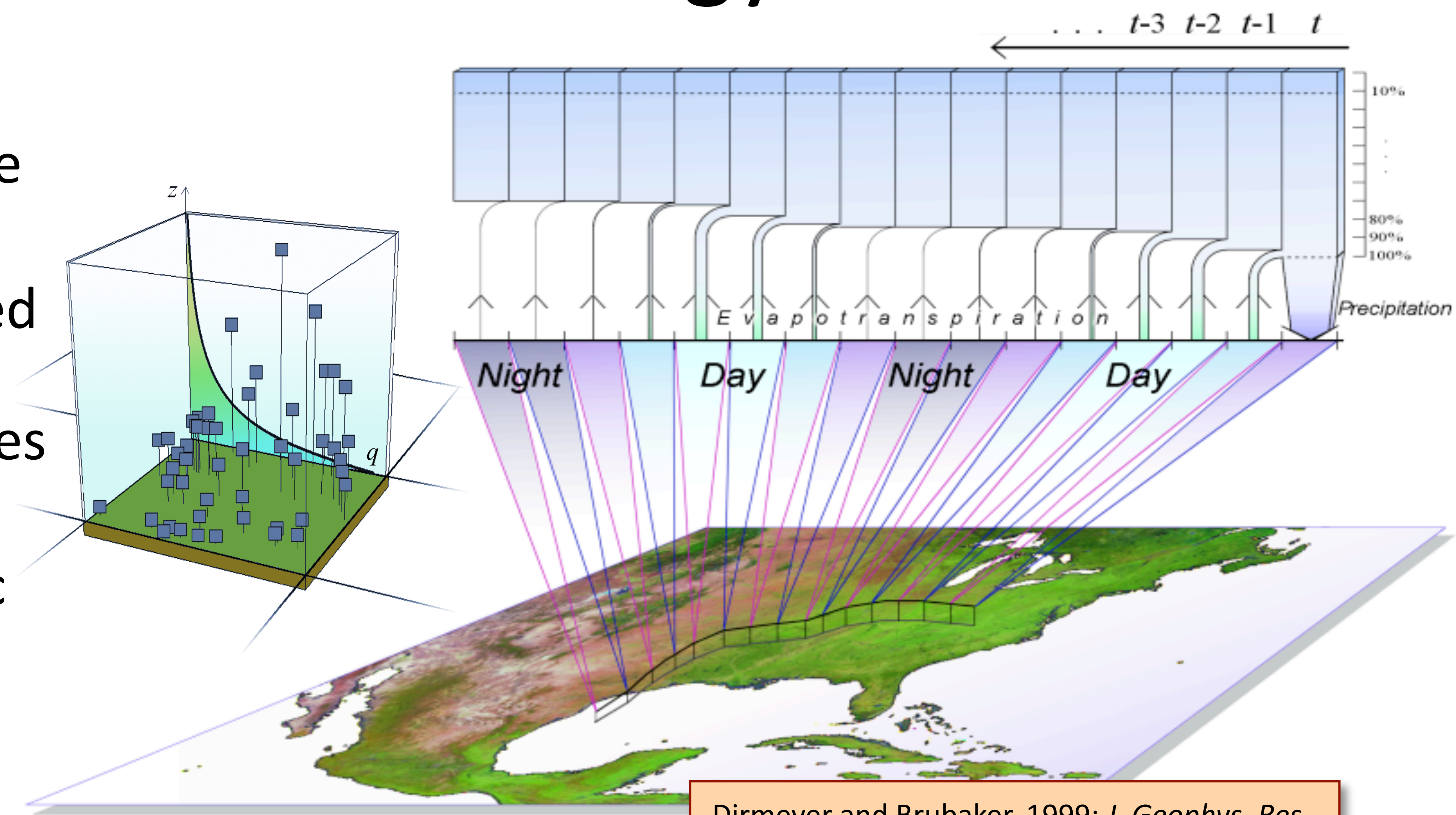
Acks: *Rolf Reichle, Qing Liu, Tim DelSole, Jennifer Adams*

Quasi-Isentropic Back Trajectories

- The idea for the technique is borrowed from air pollution meteorology (e.g., Merrill et al. 1986 *Mon. Wea. Rev.*).
- Water vapor is treated as a passive tracer between time of evaporation from surface and time of condensation/precipitation.
- The key to the technique is treatment of the endpoints.
  - Traces begin at precipitation events, go backwards in time.
  - Each trace generates a PDF of evaporative sources; these are aggregated over many traces for each grid point, pentad.
  - Further aggregation can be performed in space or time to estimate sources for regions, months, seasons, etc.

QIBT Methodology

- Lagrangian “parcels” are used to estimate moisture transport *a posteriori*.
- Many parcels are launched at random humidity-weighted altitudes at times of precipitation.
- 6-hourly 3-D atmospheric data are used to trace parcels backward in time (45-minute time steps).
- Evaporative contribution during each time step is proportional to ET/PW.



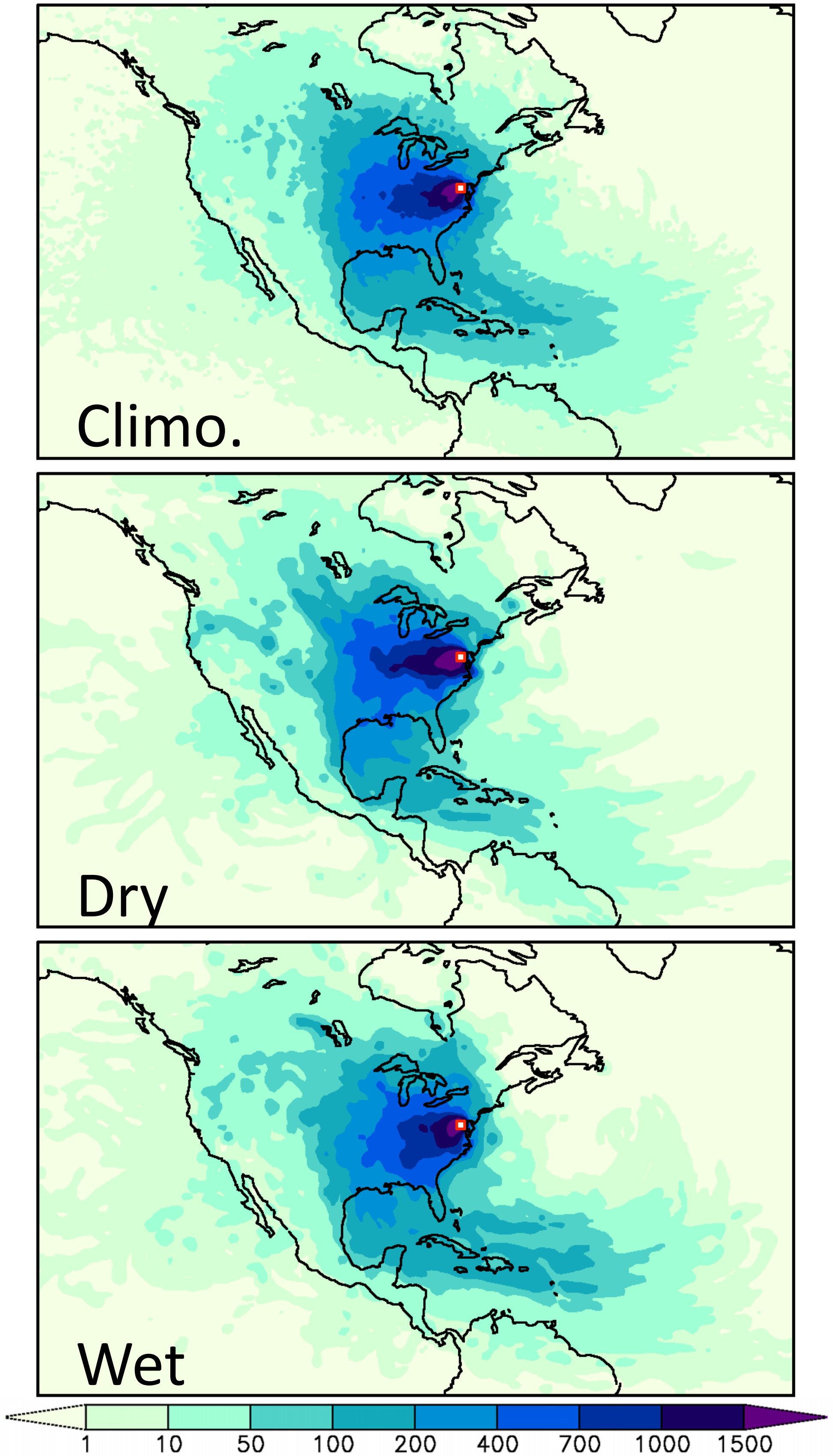
Period: 1979-2005

Dirmeyer and Brubaker, 1999: *J. Geophys. Res.*
Brubaker et al., 2001: *J. Hydrometeor.*
Sudradjat et al., 2003: *J. Geophys. Res.*
Dirmeyer and Brubaker, 2007: *J. Hydrometeor.*
Dirmeyer and Kinter, 2009: *EOS.*
Dirmeyer and Kinter 2010: *J. Hydrometeor.*
Dirmeyer et al., 2011: *J. Hydrometeor.*

Data Sets Used

- NASA MERRA Reanalysis:
  - Precipitation (corrected by CPC Unified precipitation at pentad timescale)
  - ET (corrected by MERRA-Land* at pentad timescale)
  - 3-D fields of Temperature, Humidity, Wind (U and V)
- 6-hourly data, Jan 1979 – Dec 2005
- 1/2° x 2/3° resolution

* Reichle et al., 2011: *J. Climate*.



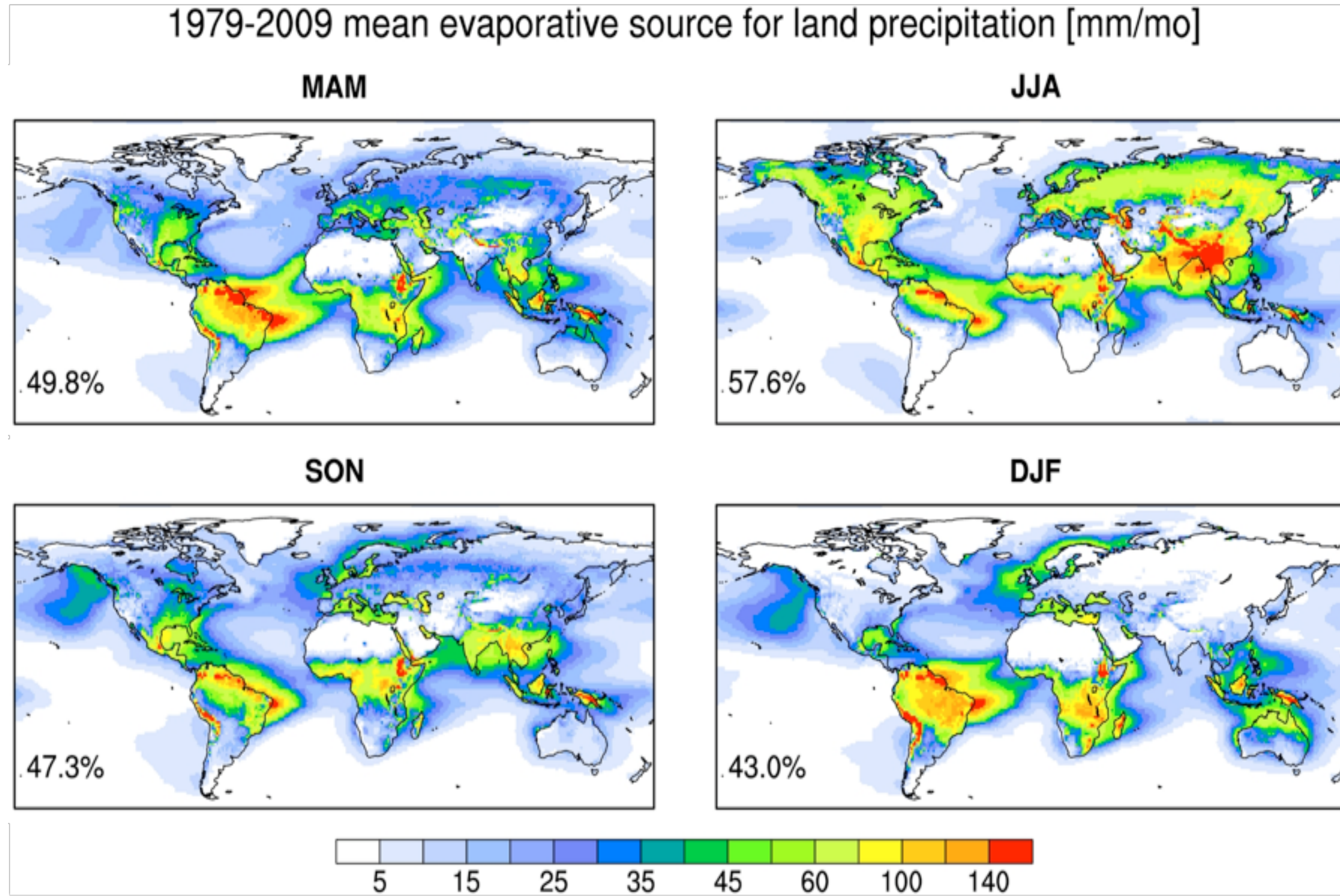
ppm – normalized so global integral = 10^6

Evaporative Source

- Example (left) of 1979-2005 JJA moisture source for rainfall over the DC area (single MERRA grid box), the 3 driest years [middle panel], and the 3 wettest years [bottom].

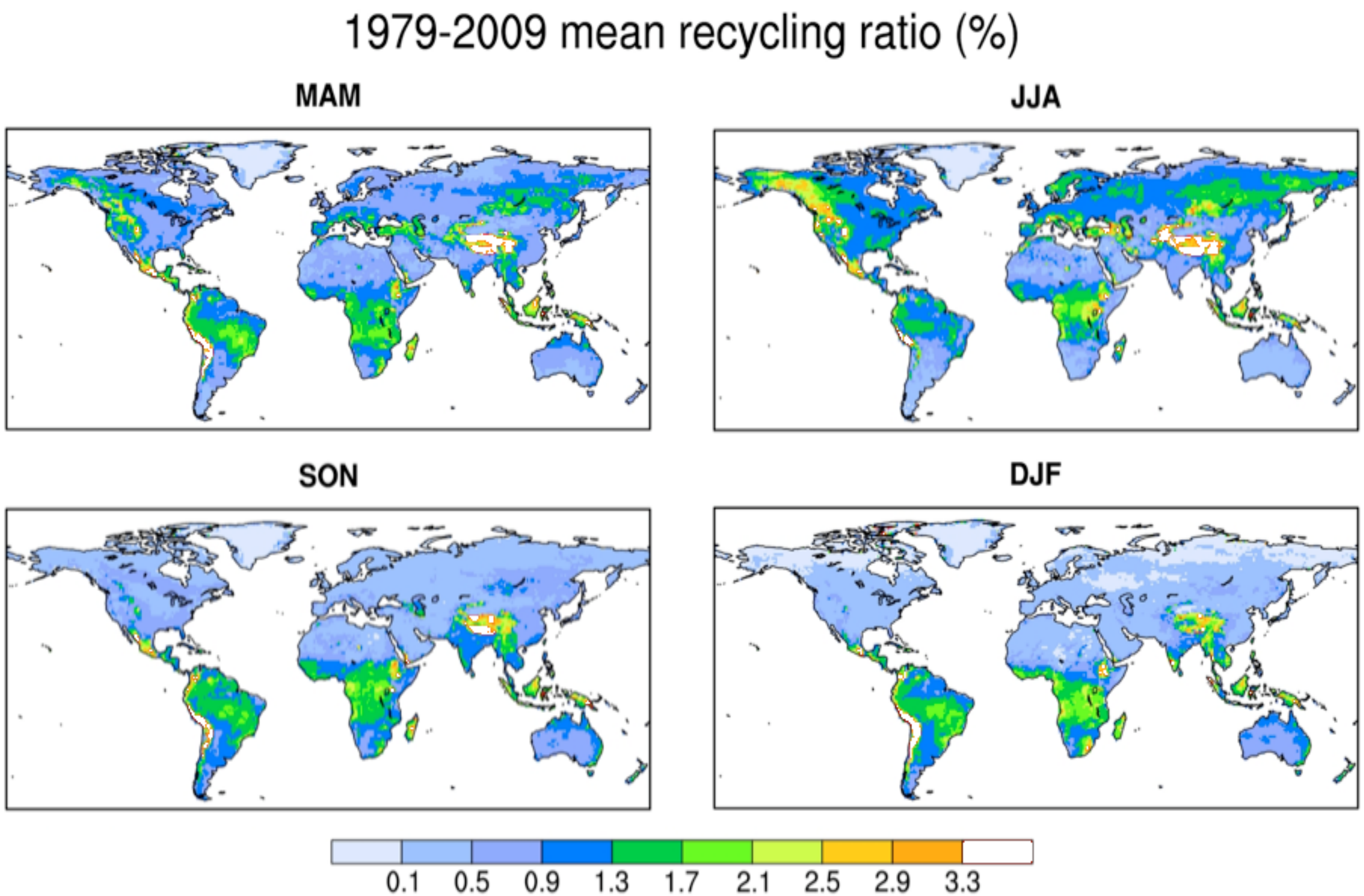
Global Source for Continental Precipitation

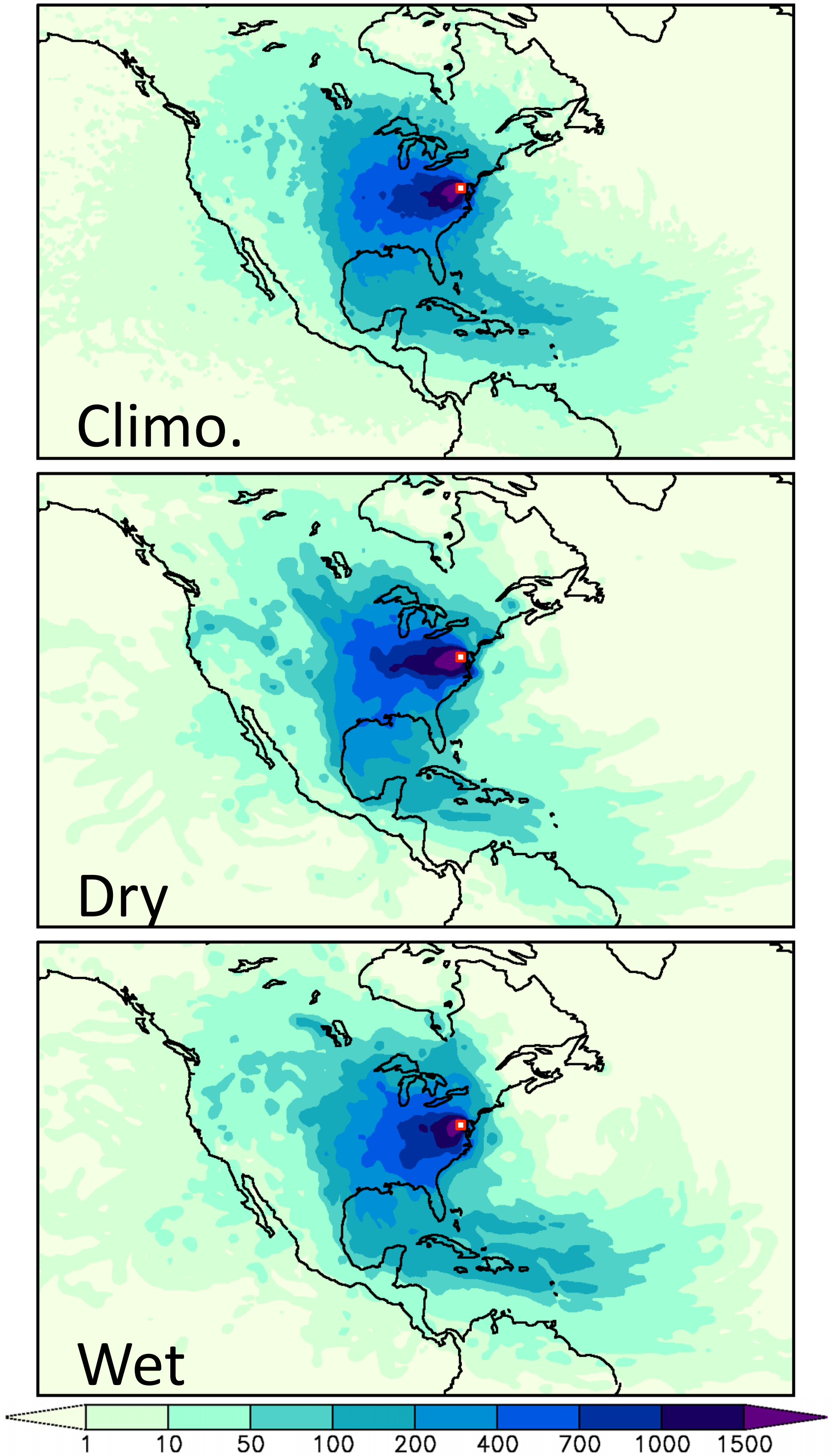
- Globally, about half of the moisture supplying precip over land evaporates from land.
- Maximum land source in JJA, minimum in SON.
- Tropical and subtropical oceans are the main oceanic sources.



Recycling Ratio

- Unscaled ratio for ½°x⅔° grid boxes is shown.
- Strong seasonal cycle in most locations.
- Two main controls:
  - Local evaporation rate
  - Moisture transport (winds)
- Agrees well with previous distributions.





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Evaporative Source

- Example (left) of 1979-2005 JJA moisture source for rainfall over the DC area (single MERRA grid box), the 3 driest years [middle panel], and the 3 wettest years [bottom].
- The “blobs” are effectively PDFs – and there exists a tool to compare them objectively….

Tool: Relative Entropy (RE)

- Relative entropy (also called Kullback-Leibler Divergence or Information Divergence) measures the difference between two probability distributions p and q:

$$RE(x) = \int p(y \mid x) \log \frac{p(y \mid x)}{q(y)} dy$$

- This measure from information theory is often applied in statistics, communications, finance.

- x can be multidimensional – for data on a finite grid:

$$RE_{p,q} = \sum_i p(i) \log \frac{p(i)}{q(i)}$$

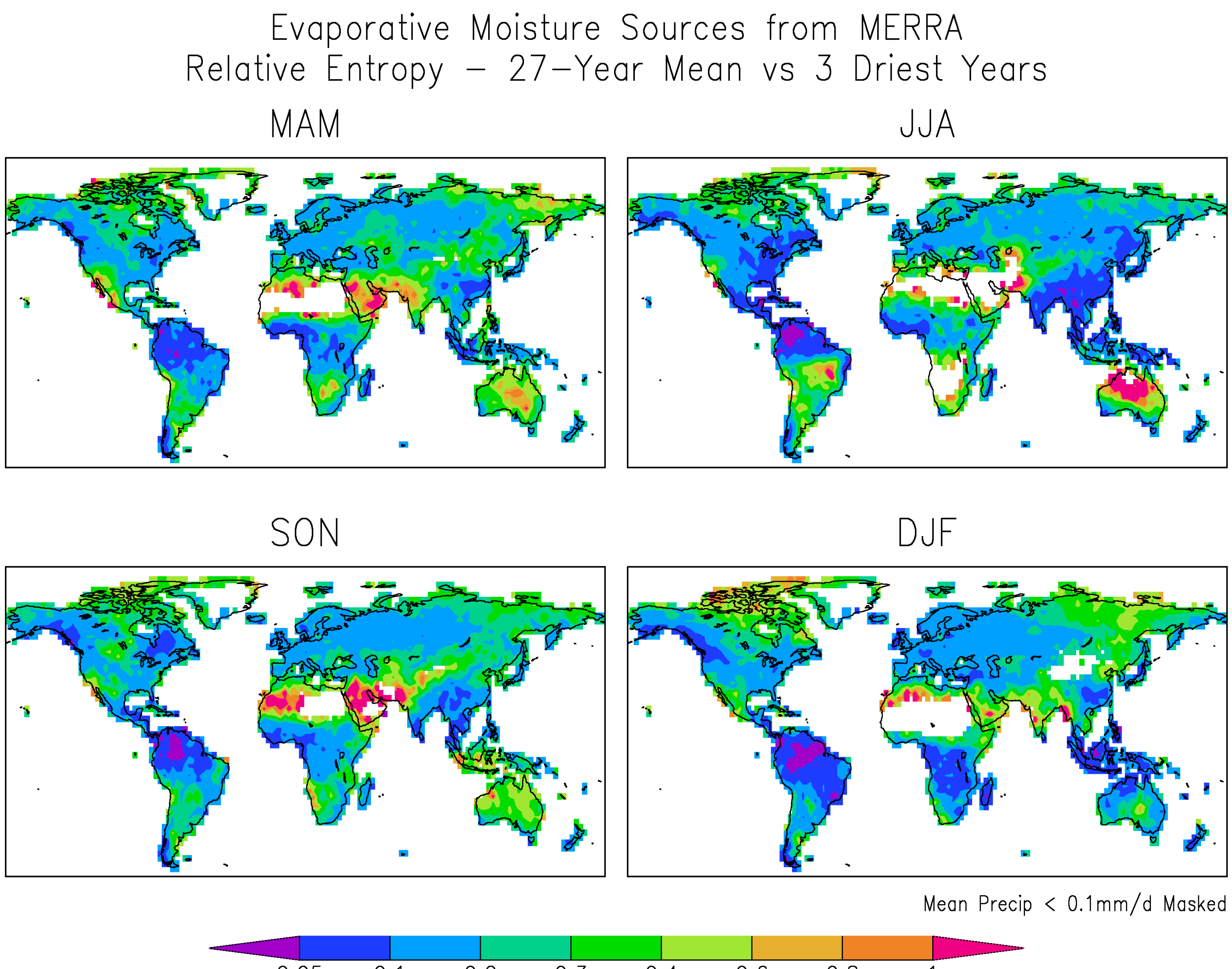
Properties of RE

$$RE_{p,q} = \sum_i p(i) \log \frac{p(i)}{q(i)}$$

- $RE \geq 0$
- $RE = 0$ only if the two distributions p and q are identical.
- $RE_{p,q} \neq RE_{q,p}$, but ranking is preserved, and RE is invariant to nonlinear transformations.
- Here, p is the climatological evaporative source for rainfall over a given area, and q is the source conditioned on extremes in precipitation ("drought" and "flood" deciles).
- At every land grid box we calculate RE based on its evaporative sources – plot maps of RE.

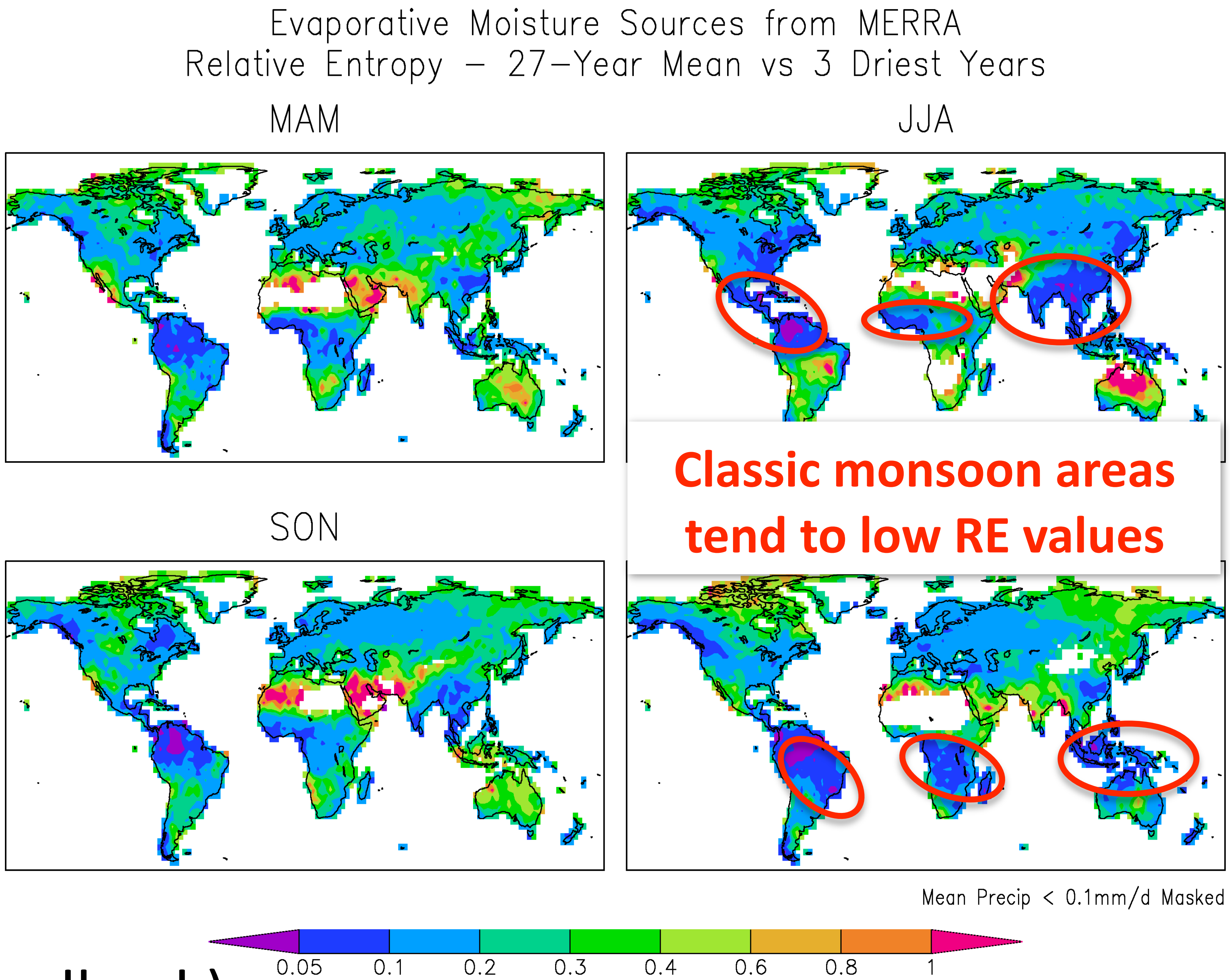
Drought Years vs. Climatology

- Maps show RE between <u>monthly</u> climatological evaporative moisture sources calculated at each point and the sources for the 3 driest years.



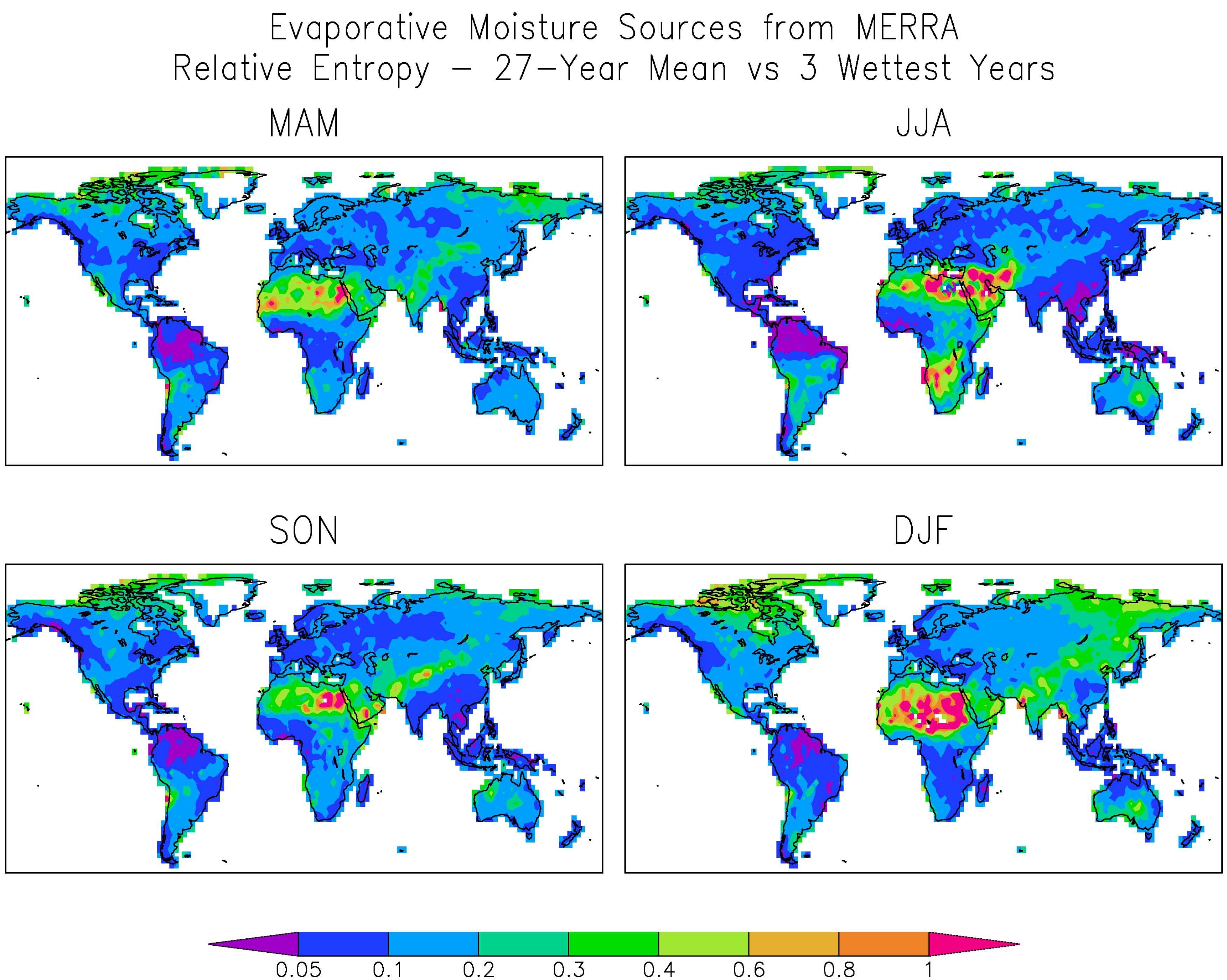
Drought Years vs. Climatology

- Maps show RE between <u>monthly</u> climatological evaporative moisture sources calculated at each point and the sources for the 3 driest years.
- Small values ≈ circulation (moisture source) changes are <u>not</u> associated with drought. Must be another cause (stability, subsidence, L-A feedback).



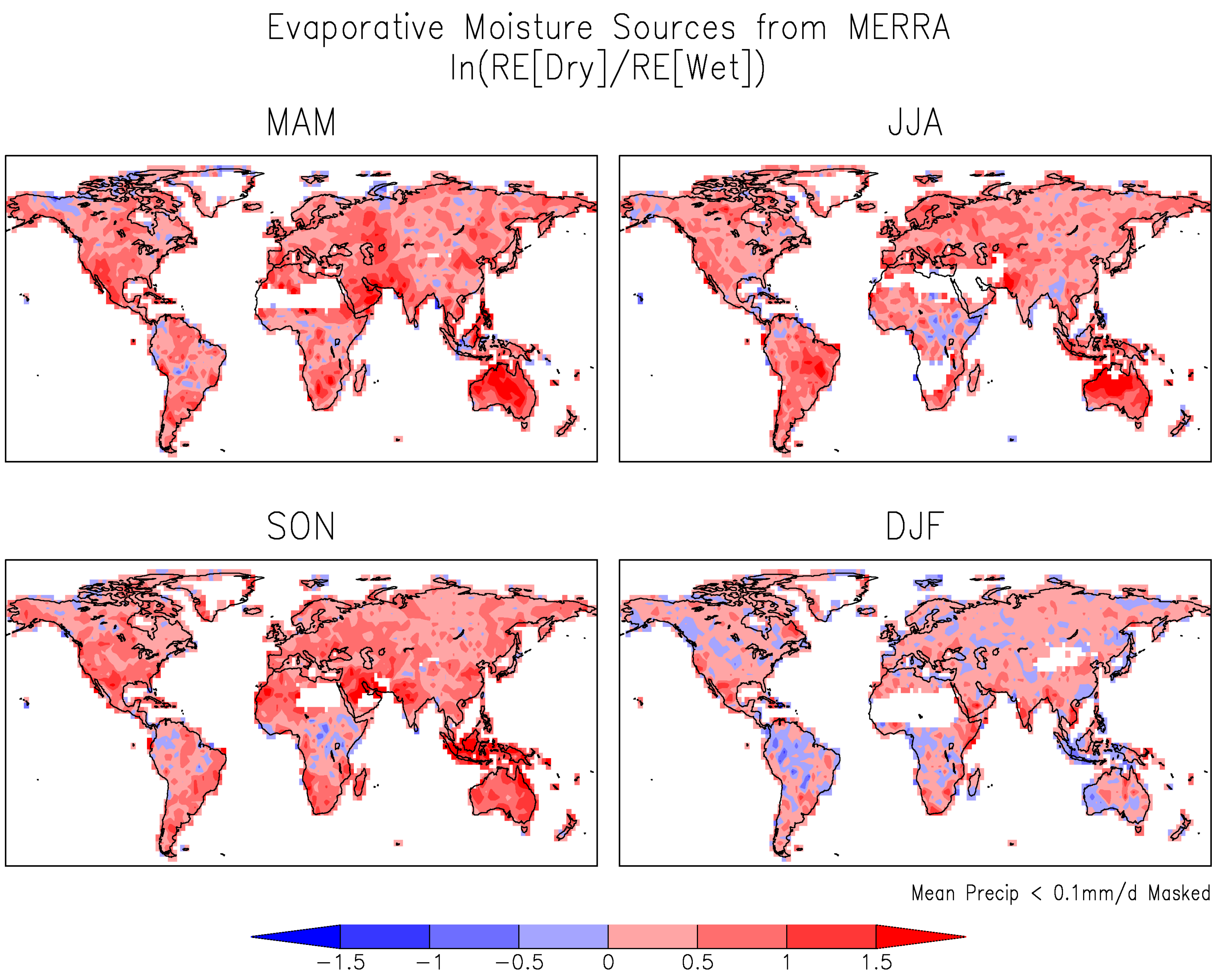
Wet Years Signal

- Wet years show similar large-scale patterns.
- Note that the highest RE values are usually over arid regions – require a circulation change to bring in moisture.



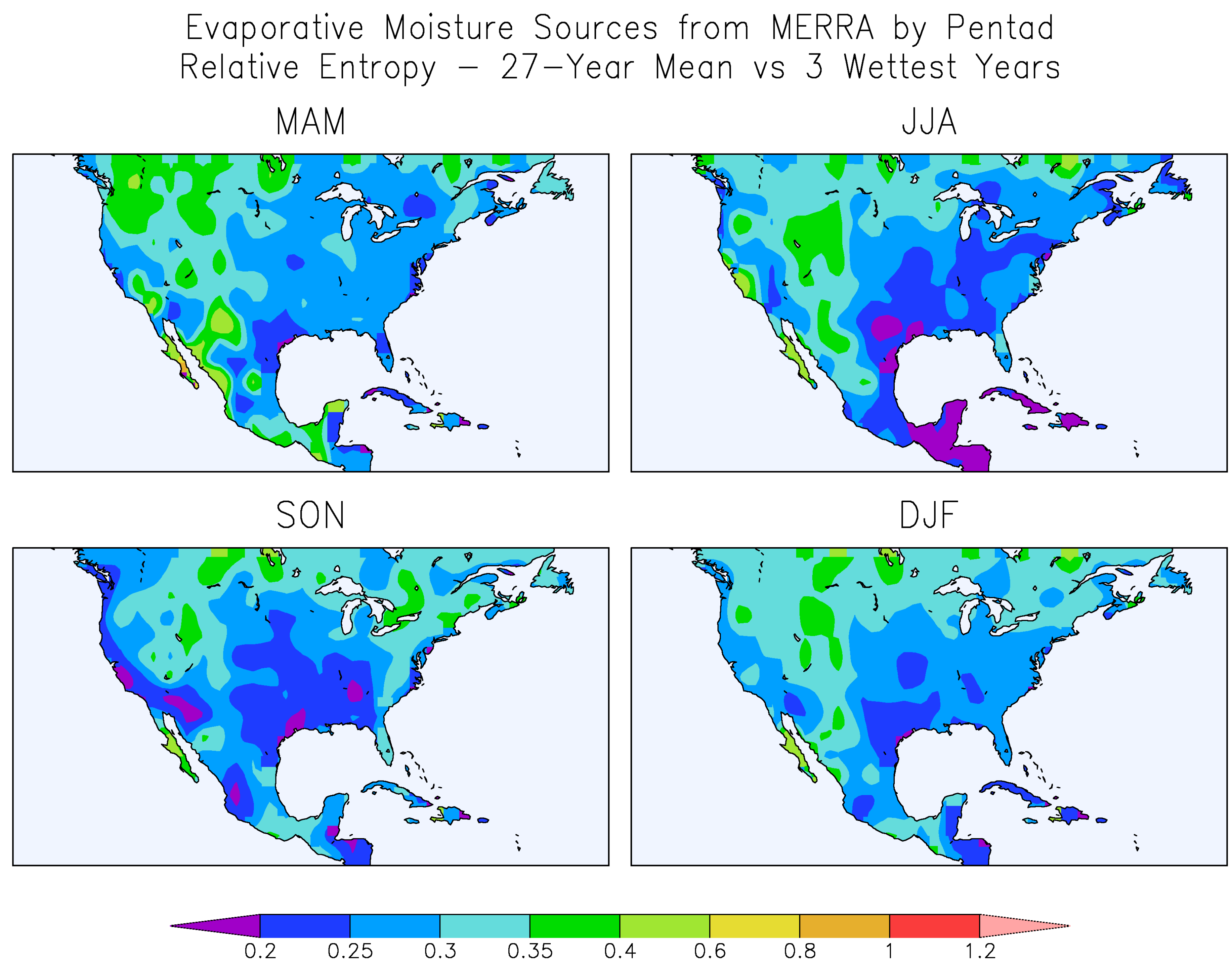
Extremes Associated with Circulation

- The ratio of the REs (log of ratio shown) indicates "droughts" are more likely than "floods" to be associated with circulation changes.
- Implies wet spells are either more locally driven or more random in nature.
- But droughts have longer time scale than floods – Is this a fair comparison?



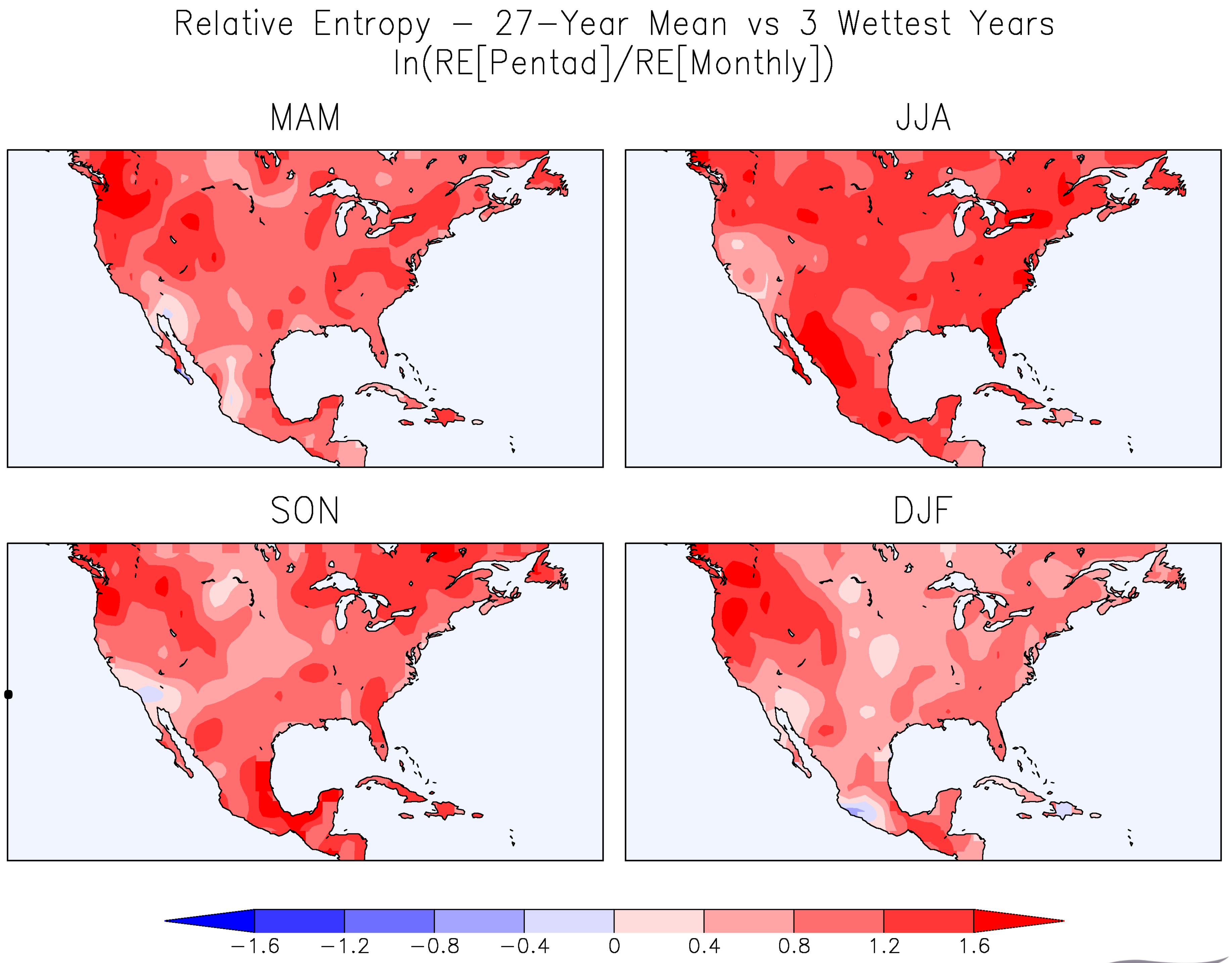
RE Based on Pentads

- Seasonal averages based on wettest of <u>pentads</u> show generally higher values than monthly.
- Gulf Coast / South floods are <u>not</u> associated with changing moisture sources during "hurricane season". East Coast <u>is</u>.



Seasonal RE Based on Pentad vs. Monthly Data

- Comparison shows for many places, summer is most likely to have a wet season caused by brief anomalous fetches of moisture (atmospheric rivers).
- For DJF it's N. Cal. and Pacific NW.



Summary

- Back trajectories of water vapor from precipitation (sinks) to evaporation (sources) reveal a new perspective on the atmospheric water cycle (mean and variability).
- We can quantitatively compare variations in source regions during dry/wet periods to elucidate causes.
- To do: Compare to MERRA model (GEOS5) with WV tracers.

J. Wei et al., **Poster UA-48**: "Where Does the Irrigation Water Go? An Estimate of the Contribution of Irrigation to Precipitation Using MERRA."

D. Mocko et al., **Poster AT-39**: "Water Vapor Tracers in MERRA Replay Mode Using the NASA/GSFC GEOS-5 GCM."

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Only changed one word…