[Coupling metrics to diagnose land-atmosphere interactions]

## Bulk Recycling

- References:
  - Budyko, M. I., 1974: *Climate and Life.* Academic Press, 508pp.
  - Brubaker, K. L., D. Entekhabi, and P. S. Eagleson, 1993: Estimation of continental precipitation recycling. *J. Climate*, **6**, 1077-1089, doi: 10.1175/1520-0442(1993)006<1077:EOCPR>2.0.CO;2.
  - Trenberth, K. E., 1999: Atmospheric moisture recycling: Role of advection and local evaporation. *J. Climate*, **12**, 1368-1381, doi: 10.1175/1520-0442(1999)012<1368:AMRROA>2.0.CO;2.

- Principle:
  - Over any given area, a certain percentage of the water that falls as precipitation originated as evaporation from the same area. This is a very material notion of land-atmosphere coupling and feedback.
  - The Budyko bulk recycling coefficient: $b = \frac{P}{P_a} = 1 + \frac{EA}{2F^+}$ where $E$ is total evaporation in the reference area $A$, $F^+$ is the flux of atmospheric water vapor into the volume above the area. Total precipitation $P = P_m + P_a$ is the sum of locally evaporated and remotely advected moisture.
  - Trenberth (1999) expressed the recycling ratio directly as: $r = \frac{P_m}{P} = \frac{EL}{PL + 2F^+}$ where $L$ is an assigned length scale.

- Data needs:
  - Typically monthly mean data are used, but this can be applied to shorter time scales.

- Observational data sources:
  - This is well suited to reanalysis or other output, as that simplifies calculation of necessary terms.

- Caveats:
  - The use of time mean data neglects nonlinear advective terms, e.g., in the perturbational expansion of the moisture flux: $F = qV = \bar{q}\bar{V} + q'\bar{V} + \bar{q}V' + q'V'$; Use of time averaged terms to estimate the mean flux neglects the nonlinear contribution of the $\overline{q'V'}$ term, which can be large (e.g., near the Gulf Coast of the Southeast US where southerly winds are usually moist and northerly winds dry).
  - Burde et al. (1996) point out that the one-dimensional assumption of this Budyko approach can lead to errors when flow is variable, and proposed a two-dimensional extension, that was fully developed in Burde and Zangvil (2001).
  - Recycling ratio is highly scale dependent. Dirmeyer and Brubaker (2007) showed the log of recycling ratio scales linearly with the log of area, allowing ratios from different areas to be compared directly by scaling to a reference area.

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