[Coupling metrics to diagnose land-atmosphere interactions]

Soil Moisture Breakpoint / Threshold

- References:
  - Benson, D. O., and P. A. Dirmeyer, 2021: Characterizing the relationship between temperature and soil moisture extremes and their role in the exacerbation of heatwaves over the contiguous United States. *J. Climate*, **34**, 2175–2187, doi: 10.1175/JCLI-D-20-0440.1.
  - Dirmeyer, P. A., G. Balsamo, E. M. Blyth, R. Morrison, and H. M. Cooper, 2021: Land-atmosphere interactions may have exacerbated the drought and heatwave over northern Europe during summer 2018. *AGU Advances*, (in press), doi: 10.1029/2020AV000283.
- Principle:
  - There is a threshold or breakpoint value of soil moisture W below which there is a marked change in surface heat and moisture fluxes, resulting in a change in sensitivity of maximum 2m air temperature T_{Max} such that $-dT_{Max}/dW$ becomes much greater. This *hypersensitive* regime at low soil moisture plays a role in the severity of heat waves and can exacerbate drought.
  - This soil moisture breakpoint can be found from daily observational or model data in moisture-limited regimes (per the Budyko framework) by an optimization of piecewise linear regression. Optimization minimizes the error on a pair of linear regressions, selecting 4 parameters:
    1. Soil moisture value at the breakpoint
    2. Maximum daily temperature value at the breakpoint
    3&4. Slope of the best-fit linear regressions on each side of the breakpoint, intersecting at the breakpoint
  - Metrics include the breakpoint soil moisture value, the dry-side sensitivity $-dT_{Max}/dW$, change in sensitivity across the breakpoint, and fraction of days on dry side of breakpoint. These can be used to validate model behavior.
- Data needs:
  - Time series of daily soil moisture, and maximum temperature at the same location(s).
  - Soil moisture can also be paired against daily surface sensible and/or latent heat flux as part of a process chain investigation.
- Observational data sources:
  - Most soil moisture measurement sites also record temperature. If hourly (or finer) data are available, maximum temperature can be estimated.
- Caveats:
  - Works better with surface soil moisture, as that is most closely associated with sensible heat flux. Column soil moisture (e.g., from model output) correlates less well as vertical moisture gradients in the column can obscure the impact on surface fluxes.
  - Optimization will almost always find a breakpoint. Physically-based constrains can limit spurious results, e.g. reject cases where dry-side slope is positive, where change in sensitivity across breakpoint is of the wrong sign, or where there are too few cases on one side of the estimated breakpoint.
  - Similar in concept to the *critical soil moisture* of Denissen et al. (2020) but can be derived without flux data.

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