[Coupling metrics to diagnose land-atmosphere interactions]

Two-Legged Coupling Metrics

- References:
  - Guo, Z., et al., 2006: GLACE: The Global Land-Atmosphere Coupling Experiment. 2. Analysis. *J. Hydrometeor.*, **7**, 611-625, doi: 10.1175/JHM511.1.
  - Dirmeyer, P. A., 2011: The terrestrial segment of soil moisture-climate coupling. *Geophys. Res. Lett.*, **38**, L16702, doi: 10.1029/2011GL048268.
  - Dirmeyer, P.A., et al., 2014: Intensified land surface control on boundary layer growth in a changing climate. *Geophys. Res. Lett.*, 41, doi: 10.1002/2013GL058826.

- Principle:
  - Correlations between land surface state variables and surface fluxes (terrestrial leg) and between land surface fluxes and atmospheric states or properties (atmospheric leg) may be indicative of feedbacks.
  - Positive (negative) correlation between soil moisture and latent (sensible) heat flux implies soil moisture control of fluxes (moisture limited) as opposed to energy (net radiation) limited situations where atmosphere controls the fluxes.
  - Variability of the response (upper) aspect to the lower one – high correlation without variability means little real impact from the land.
    - $I = \sigma(b)r(a,b) = \sigma(a)\frac{db}{da}$, where the linear regression slope of b on a is a measure of sensitivity of b to a.
    - By chain rule, we can connect soil moisture directly to atmosphere variable c as: $I = \sigma(c)r(b,c)r(a,b) = \sigma(a)\frac{dc}{da}$, if both relationships a: b and b: c are linear.
    - If non-linearities are present: $I = \sigma(c)r(b,c)r(a,b) = \sigma(a)\frac{dc}{db}\frac{db}{da}$ (using $r(a,b) = \frac{\sigma(a)}{\sigma(b)}\frac{db}{da}$ and the same for $r(b,c)$, $\sigma(b)$ and $\sigma(c)$ cancel out)
  - Note the correlation chain can be used to differentiate different paths, e.g., heat versus moisture).
- Data needs:
  - Means from daily to longer can be used; meaning may change with averaging period.
  - Only 2-D fields needed, unless 3-D needed to estimate a variable (e.g., PBL depth)
    - For terrestrial leg, a soil moisture or other land state variable to a surface flux variable (water, energy or carbon)
    - For atmospheric leg, surface flux to atmospheric state or derived variable.
- Observational data sources:
  - Terrestrial: co-located soil moisture and surface flux measurements.
  - Atmospheric: co-located surface flux and meteorological or profile measurements.
- Caveats:
  - Usually a seasonal dependence – want to calculate correlations or sensitivities by month or season – increases number of years of data (or ensemble members) needed for stable statistics.
  - This is a local coupling metric, but it could be applied across two different locations for the atmospheric part to determine remote impacts.
  - Can use Kendall's τ for correlations (cf. Ferguson et al. 2012; 10.1175/JHM-D-11-0119.1)

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