[Coupling metrics to diagnose land-atmosphere interactions]

Granger Causality

- References:
  - Salvucci, G. D., J. A. Saleem, and R. Kaufmann, 2002: Investigating soil moisture feedbacks on precipitation with tests of Granger causality. *Adv. Water Resour.*, **25**, 1305-1312, doi: 10.1016/S0309-1708(02)00057-X.
  - Granger, C. W. J., 1969: Investigating causal relations by econometric models and cross-spectral methods. *Econometrica*, **37**(3), 424, doi: 10.2307/1912791.

- Principle:
  - This is a general statistical principal not specific to land-atmosphere coupling. It comes from the field of econometrics –models are formed with and without an input S (e.g., soil moisture) and a significant difference in response indicates the causality of S.
  - For the potential dependence of precipitation P on soil moisture S, the conditional distributions tested are:
    $$F(P_t|\Omega_{t-\Delta t}) \neq F(P_t|\Omega_{t-\Delta t} - S_{t-\Delta t})$$
    within some range of confidence, where $\Omega_{t-\Delta t}$ is all knowledge available up to time $t - \Delta t$ (which includes previous precipitation, soil moisture and potentially other variables as well) and $\Omega_{t-\Delta t} - S_{t-\Delta t}$ means all knowledge except that of soil moisture.
    - $\Omega_{t-\Delta t}$ must not contain any future information from t or later,
    - $\Omega_{t-\Delta t}$ must not contain redundant information (e.g., multiple functionally-related variables)

- Data needs:
  - Observational or model data can be used – multiple linear regression or other models are common. The method is non-restrictive, however, as long as two conditional distributions can be constructed and statistically tested.

- Observational data sources:
  - Observed soil moisture and precipitation (or any data pertinent to the causality test).

- Caveats:
  - Care must be taken to avoid detection of false causal relationships (e.g., effect-effect relationships or apparent causation due to persistence).

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