Granger Causality

- Reference:

- 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:
    
    $$F(P|\Omega_{t-\Delta t}) \neq F(P|\Omega_{t-\Delta t} - S_{t-\Delta t})$$

    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.
    - $\Omega_{t-\Delta t}$ cannot contain any future information from $t$ or later,
    - $\Omega_{t-\Delta t}$ cannot 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).