[Coupling metrics to diagnose land-atmosphere interactions]

Temporal Information Partitioning / TIPNet

- References:
  - Goodwell, A. E., and P. Kumar, 2017a: Temporal information partitioning: Characterizing synergy, uniqueness, and redundancy in interacting environmental variables. *Water Resour. Res.*, **53**, 5920–5942, doi: 10.1002/2016WR020216.
  - Goodwell, A. E., and P. Kumar, 2017b: Temporal Information Partitioning Networks (TIPNets): A process network approach to infer ecohydrologic shifts. *Water Resour. Res.*, **53**, 5899–5919, doi: 10.1002/2016WR020218.

- Principle:
  - Temporal information partitioning (TIP) detects relationships between multiple source variables that influence target variables. The unique feature is a means to separate the mutual information among the multiple source variables as they affect the target into 3 components: unique, synergistic (greater than the sum of the parts), and redundant.
  - For the case of two sources $S1$ and $S2$ for target T, total information is decomposed as: $I(X_{S1}, X_{S2}; X_T) = U_1(X_T; X_{S1}) + U_2(X_T; X_{S2}) + R(X_T; X_{S1}, X_{S2}) + S(X_T; X_{S1}.X_{S2})$ where U is unique, R is redundant and S is synergistic.
  - The authors propose a method to estimate the terms that is appropriate to environmental variables that does not make blanket assumptions based on the relative strengths and redundancy of the sources. The first paper presents a clear example based on dice, then examples of the impacts of observational noise and degree of correlation between sources, including different time delays / scales.
  - U, S and R provide more information to inform process diagnosis than correlations or other univariate metrics.
  - The linkages can be wired together into *networks* (second paper) where a target for one relationship becomes a source for others, wherein each variable acts as a node.

- Data needs:
  - Binned probability distributions of the individual and combined factors; so that entropy and mutual information can be calculated.
  - The first paper shows examples of how to apply TIP with sparse data, removing harmonic (diurnal, seasonal) effects from data, estimating significance and dealing with mixed distributions.

- Observational data sources:
  - Because of the considerations listed above, this approach is well suited to the vagaries of observational data.

- Caveats:
  - Noise, autocorrelation and nonlinear relationships affect results in various ways – see the first paper for ideal examples and a real data case.
  - As the number of sources (variables) increases, complexity grows quickly – the limitations are not mathematical but involve clear interpretation of results.
  - Hsu & Dirmeyer (2021) show an application to reanalysis data.

Supported by NASA/MAP Grant: NNX13AQ21G

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