# causality, interaction, and feedback and stuff

Allison Goodwell, SITES virtual-Flagstaff, August 2020

Water Resources Research

COMMENTARY

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**Key Points:**

- Information theory provides powerful methods to assess causality and interactions in complex systems
- An understanding of causality is important in Earth sciences for process understanding, modeling, prediction, and decision making
- Information flow, through causality analysis of bivariate to multivariate interactions, opens new windows for Earth system science studies

## Debates—Does Information Theory Provide a New Paradigm for Earth Science? Causality, Interaction, and Feedback

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# most importantly, Wiley formatted my introductory poem so it looks like we are free-styling it

*Come hither, let us lead the way to take a causal view today. Cause and effect are hard to assess, thus we take the risk of making a mess, but present our thoughts on Information Theory, since variance and correlation have grown weary. Couplings, synergy, and the causal path can all be determined with a bit of math. But do they reflect what nature creates? This may be the real debate.*

*A.E.G.*

causality is relevant to many areas of water resources (modeling, decision-making)

a couple perspectives on causality: Pearl (interventional) vs. Granger (statistical conditioning)

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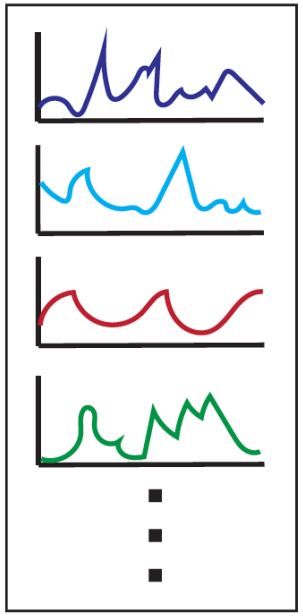
we review some "levels" of analysis, ranging from Transfer Entropy to causal histories

advantages of information theory: non-linear, joint interactions that can be partitioned different ways, directional and weighted relationships

a) time-series variables



consider nodes as a time-series variable
*(measurements or models)*

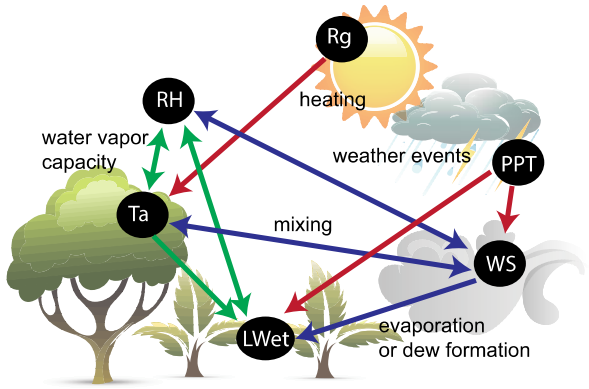
we can think of interactions between pairs of variables *(how does X influence Y?)*

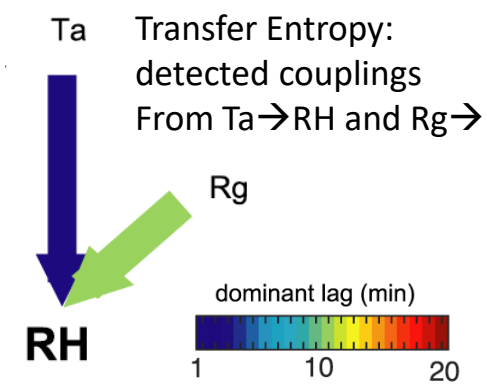
or triplets, quartets, etc of variables
*(how do X and Y drive Z together?)*

or a ”causal history” where causality is measured from the entire historical dynamics
*(how does every experience in my life lead to where I am today?)*

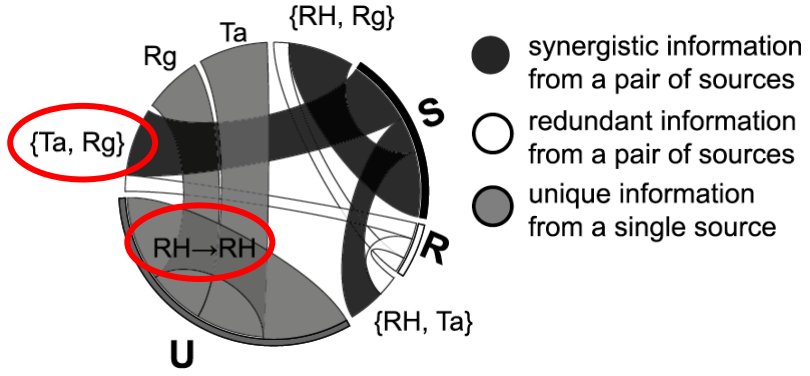
# different IT techniques address these “levels” at which we may consider causal interactions

example: how do variables measured at a weather station (air temperature, relative humidity, solar radiation, wind speed) interact on short timescales (1 minute)?  Let’s just look at sources to RH….



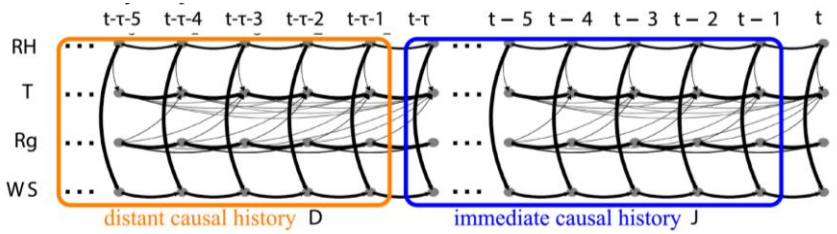



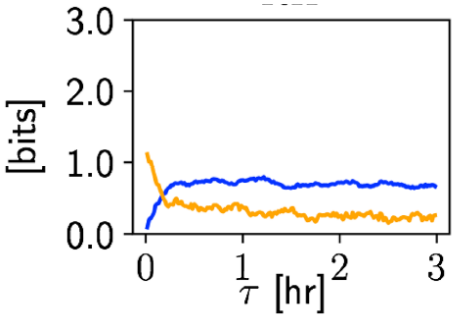

Transfer Entropy:
detected couplings
From Ta→RH and Rg→RH




info decomp: a lot of information is synergistic between {Ta, Rg}, but RH also provides unique info to its own future (a key component in Transfer Entropy)

causal history:  the entire dynamics of all source variables informs RH, with some long-memory (where ”long” is a couple hours here) dependencies



# conclusion: this opens doors for component → system understanding

- behaviors like feedback and synchronization require an expanded view of “cause and effect”
- potential to compare natural and model dynamics
- models provide opportunities to “intervene” in the system
- let us move forth into the “causal revolution” (Pearl 2018)

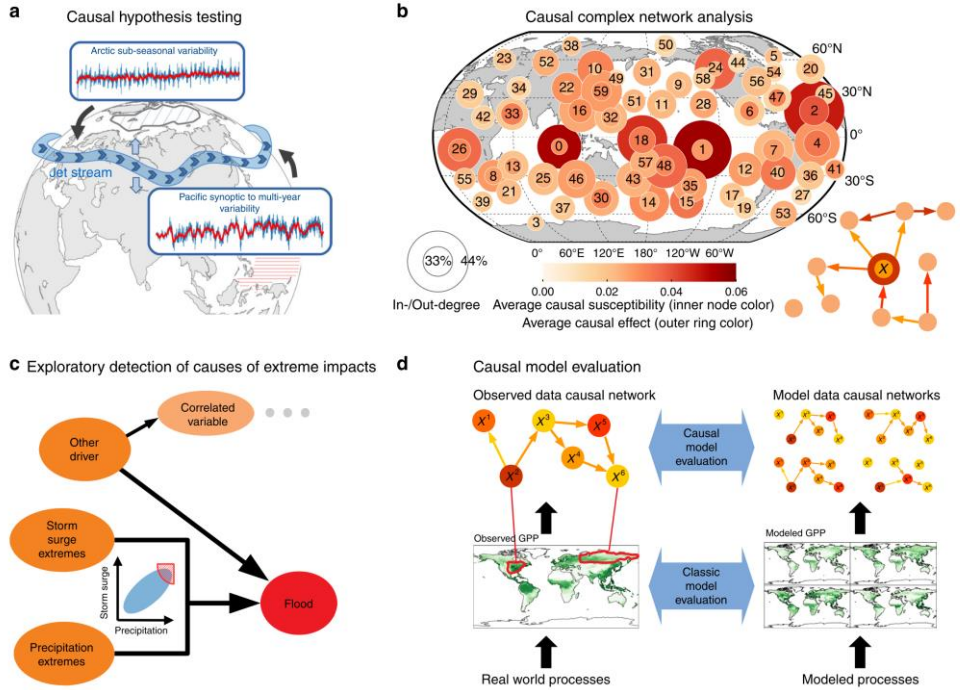



Figure 3 from Runge et al, Nature Communications 2019

# Thanks!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