Dynamic process connectivity for model diagnostics, evaluation, and intercomparison

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Abstract

The hydrologic cycle is a complex and dynamic system of interacting processes. Hydrologists seeking to understand and predict these systems develop models of varying complexity, and compare their output to observations to evaluate their performance or diagnose shortcomings within the models. Often, these analyses take into account only single variables or isolated aspects of the hydrologic system. To explore how process interactions affect model performance we have developed a general framework based on information theory and conditional probabilities. We compare how conditional mutual information and mean square errors are related in a variety of hydrometeorological conditions. By exploring different regions of phase space we can quantify model strengths and weaknesses in terms of both process accuracy as well as classical performance. By considering a range of conditions we can evaluate and compare models outside of their average behavior. We apply this analysis to physically-based models (based on SUMMA), statistical models, and observations from FluxNet towers at a number of hydro-climatically diverse sites. By focusing on how the turbulent heat fluxes are affected by shortwave radiation, air temperature, and relative humidity we go beyond simple error metrics and are able to reason about model behavior in a physically motivated way. We find that the statistically based models, while showing better performance in the mean field, often do not represent the underlying physics as well as the physically based models. The statistically based model's over-reliance on shortwave radiation inputs limits their ability to reproduce more complex phenomena.

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Background

Single-objective model evaluation does not tell the whole story of model performance. It tells us how wrong we are, but not why

Understanding interaction of processes when modeling hydrologic systems can be used to explore the "why" of model performance

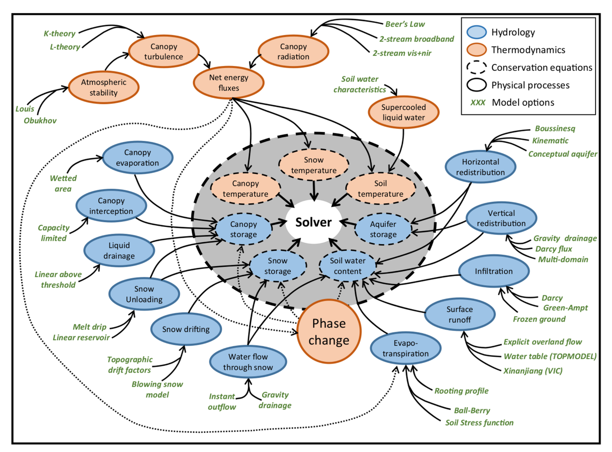
Information theory gives a systematic way to compare various processes across scales and units

SUMMA

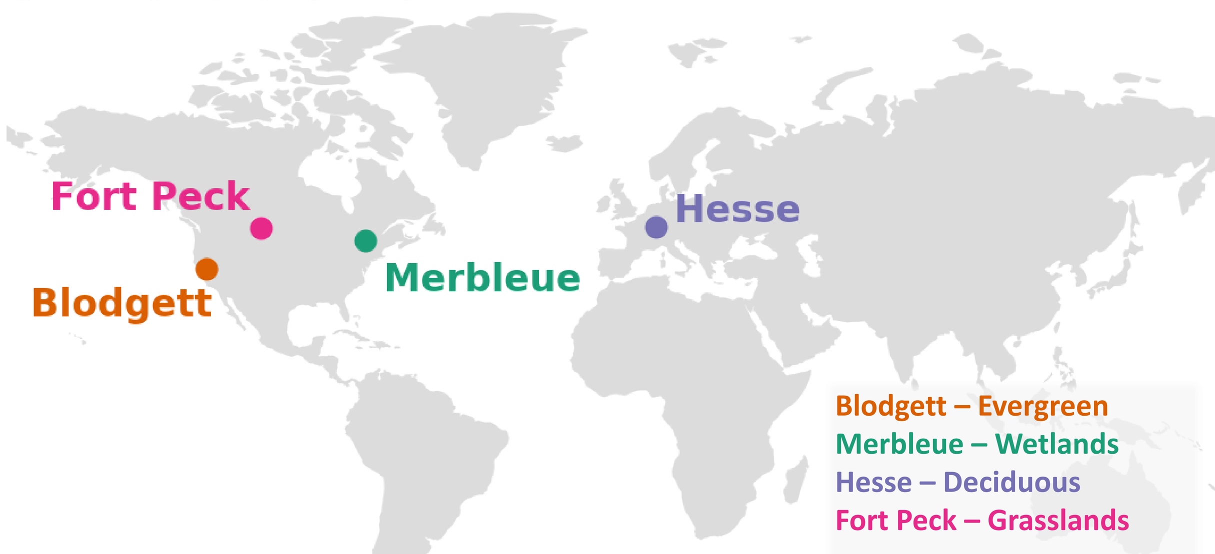
Framework for implementing hydrologic models

User can choose spatial discretization and flux parameterizations

Ensembles can be built in a controlled fashion



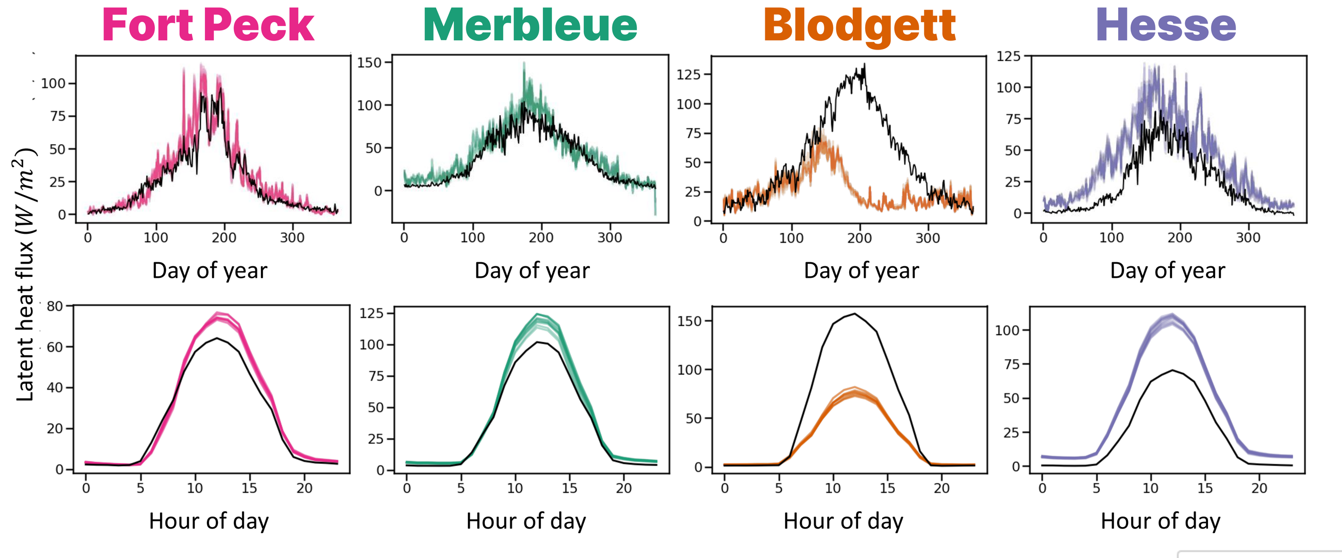
Simulations



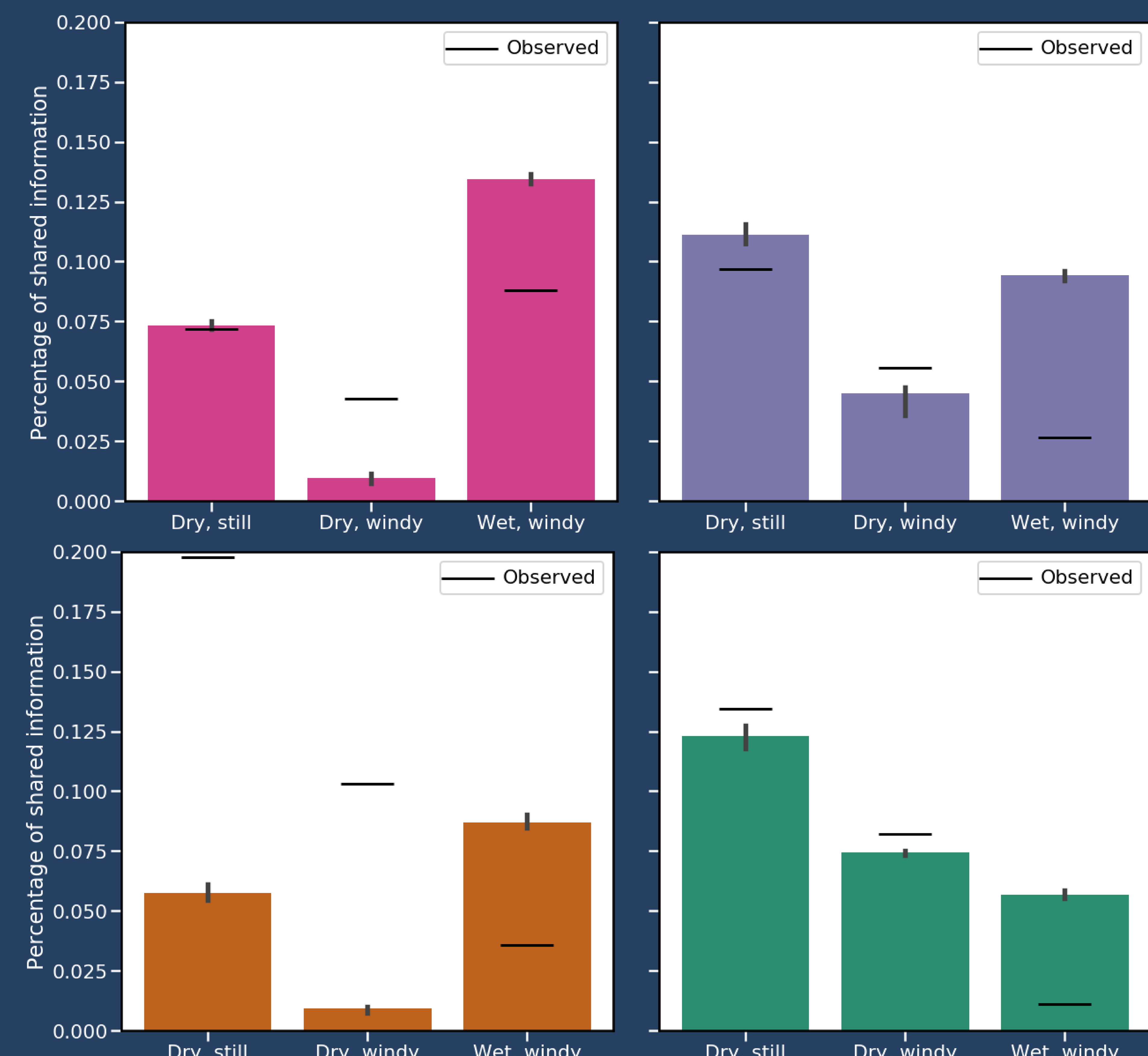
108 Model runs per site:

- 2 parameterizations of vegetation dynamics
- 2 parameterizations of canopy emissivity
- 3 parameterizations of canopy shortwave
- 3 values of soil thermal conductivity
- 3 values of specific heat of vegetation

Latent heat (Q) results



Mismatch in **shared information** between **latent heat** fluxes and **shortwave radiation** indicates poor understanding in **wet, windy conditions**



Computing normalized mutual information between latent heat and shortwave radiation ($NMI(Q;SW)$) for all model instances and the observations we can see whether the modeled interactions are realistic

Evaluation measures

H43J-2157

Normilized mutual information (NMI): How much does measurement of one variable reduce prediction error in another?

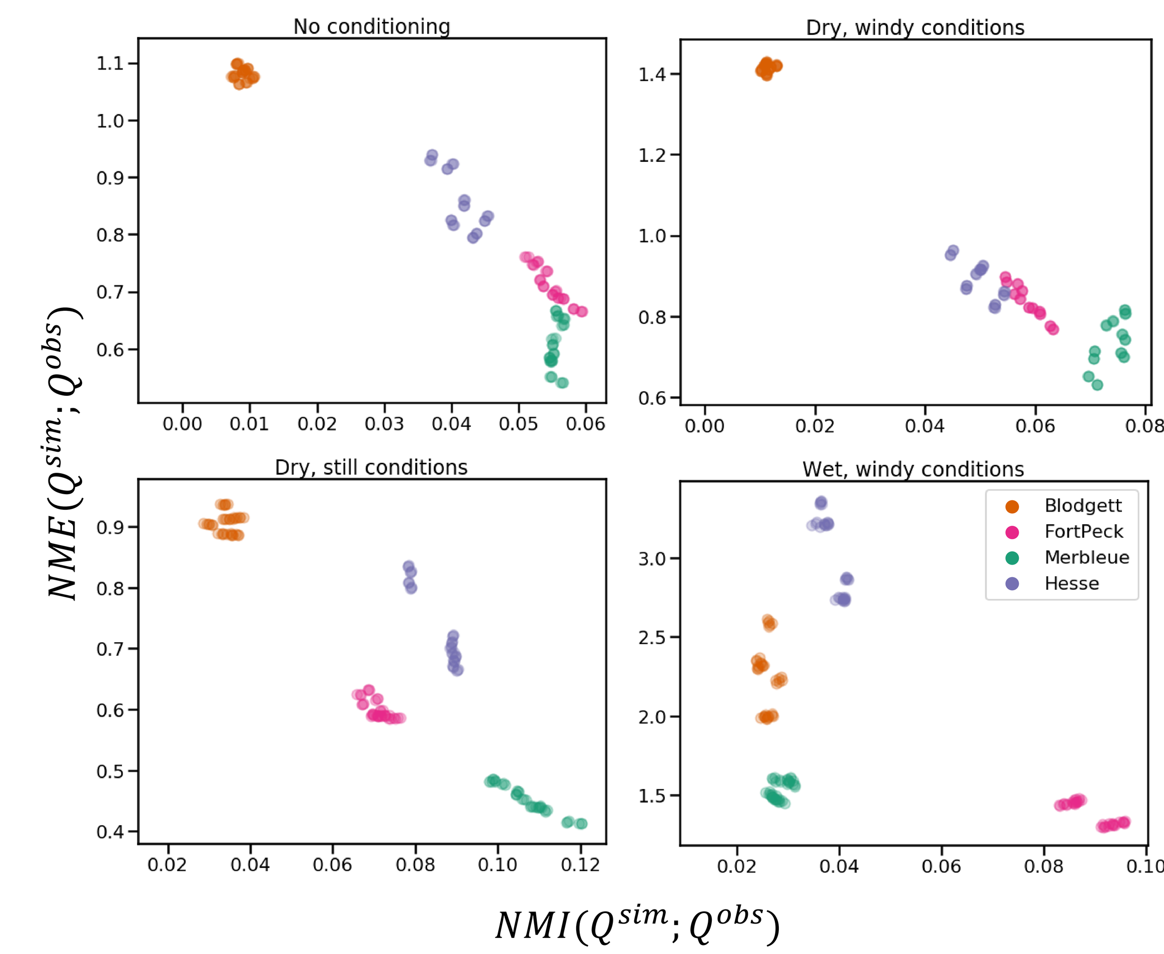
$$NMI = \frac{I(X;Y)}{\min[H(X),H(Y)]}$$

Normalized mean error (NME): How does error in my prediction relate to observation?

$$NME = \frac{\sum|x-y|}{\sum|\bar{y}-y|}$$

NME > 1 indicates that simulation variability is greater than average observed variability

Information versus error



Decreasing error is well correlated with increasing information in all conditions except wet, windy conditions

Departure of trend in wet, windy conditions indicates some process representation deficiency where error is uncorrelated with information

Not enough data to compute wet, still conditions

Discussion

Poor model performance at Blodgett stems from poor usage of both temperature and shortwave information across conditions – most likely bad vegetation parameters

Model performance in wet, windy conditions is poor across sites due to inflated connection with shortwave

Models tend to use shortwave information correctly under dry, still conditions

Further investigation into parameterizations and/or measurements of latent heat in wet, windy conditions should be conducted

Acknowledgements

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