Hydrologic insights from NEON stable isotope observations

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Abstract

Water and carbon exchanges between the land and atmosphere reflect key ecohydrologic processes, from global climate change to local watershed dynamics. Environmental stable isotope ratios of H_2O and CO_2 fluxes have been used to study these processes, yet measurement constraints have limited macroscale surface-atmosphere isotope flux evaluations. Across North American biomes within the US National Ecological Observation Network (NEON), we have worked as a team to translate raw measurements of carbon and water stable isotopes into calibrated daily surface-atmosphere flux isotope ratios for precipitation, evapotranspiration, and net ecosystem carbon exchange. Using information theory metrics, we demonstrate that these isotope observations contain meaningful information about the bulk water and carbon fluxes, with isotope measurements carrying about the same amount of information as wind speed measurements. Decomposition of this multivariate mutual information further shows that: (1) this information is unique, i.e. not carried by other traditional ecosystem measurements; and (2) the information added by isotopes is larger in more arid and cool ecosystems. Combining these isotope fluxes with bulk hydrologic fluxes drawn from a suite of land surface models in a first-order mass balance framework also allows for evaluation of hydrologic model structure and estimated uncertainties in partitioning of fluxes into transpiration, evaporation, overland, and subsurface water fluxes. An inter-model comparison suggests distinct patterns in isotope flux composition associated with disparities in the relative contributions of partitioned fluxes. Our results show that conservative isotope tracers provide novel validation metrics for evaluation of land surface model performance across ecosystems at a continental scale. Broadly, this compilation of datasets - combined with both empirical and process-based isotope modeling - suggests NEON stable isotope observations can improve general understanding of land-surface processes influencing the water and carbon cycles from regional to global scales.

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HYDROLOGIC INSIGHTS FROM NEON STABLE ISOTOPE OBSERVATIONS

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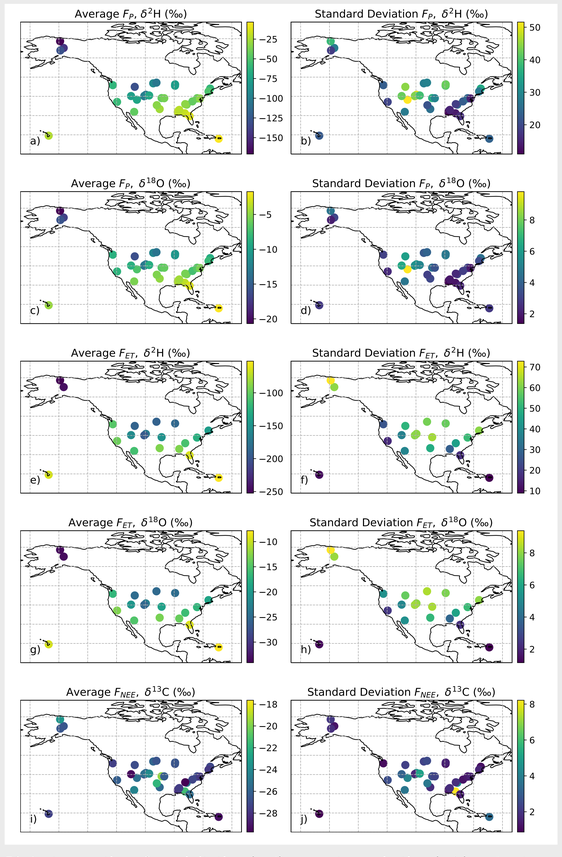
DICEE: THE NEON DAILY ISOTOPES IN ECOSYSTEM EXCHANGE DATASET

The National Ecological Observatory Network (NEON) provides open-access measurements of stable isotope ratios in atmospheric water vapor (δ2H, δ18O) and carbon dioxide (δ13C) at different tower heights, as well as aggregated biweekly precipitation samples (δ2H, δ18O) across the United States. These were used to create the NEON Daily Isotopic Composition of Environmental Exchanges (NEON-DICEE) dataset estimating landscape flux isotope ratios. The NEON-DICEE is now publicly available on Hydro-Share (see QR code) and in press at *Scientific Data*.

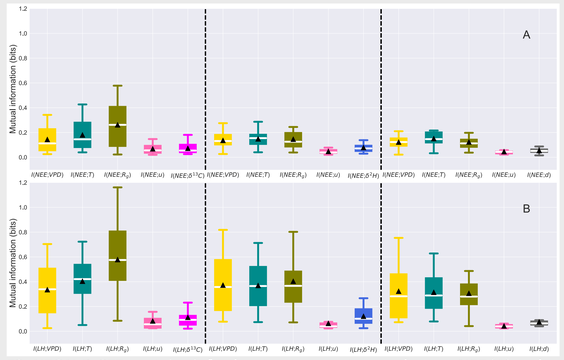
Link to data



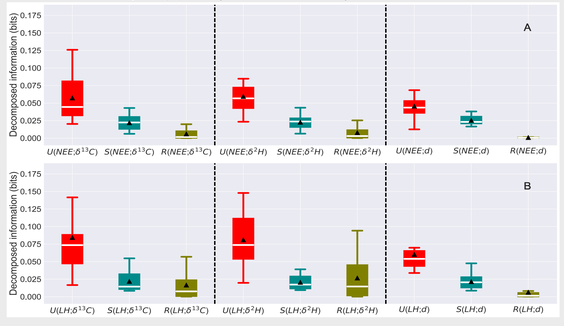
F1: Isotope ratios of precipitation (a-d), evapotranspiration (e-h) and net ecosystem exchange (i-j) at NEON sites.

DICEEE CONTAINS UNIQUE INFORMATION ABOUT FLUXES

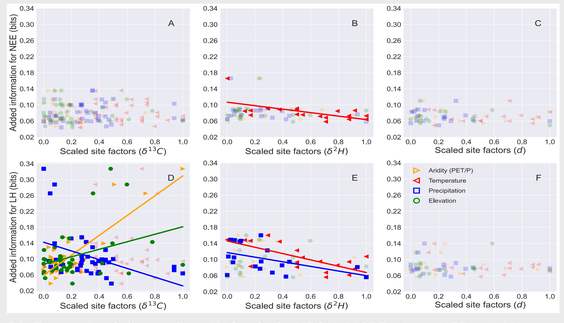
Recently developed techniques from information theory were used to quantify when NEON-DICEE estimates are informative of water and carbon fluxes.



F2: NEON-DICEE contains info about net ecosystem exchange, *NEE* (A) and latent heat fluxes, *LH* (B) comparable to wind speed data.



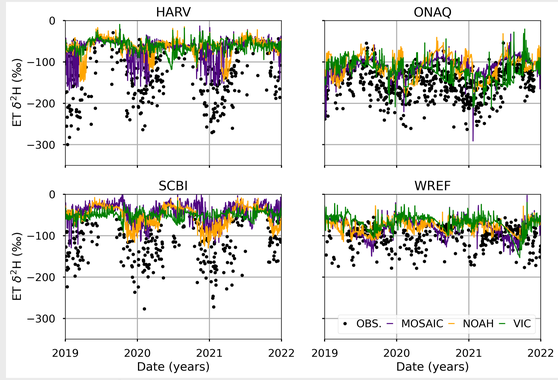
F3: NEON-DICEE data for *NEE* (A) and *LH* (B) fluxes is mostly unique, *U,* but also contains some synergistic, *S,* and redundant, *R,* information with other meteorological observations.



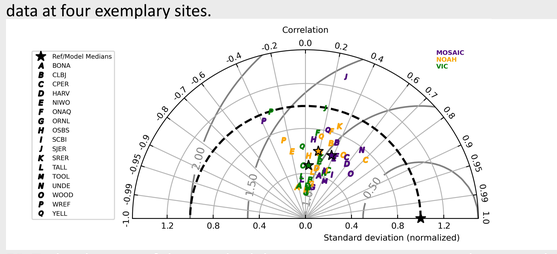
F4: The added information, *U+S,* within NEON-DICEE about *NEE* and *LH* as a function of rescaled site characteristics.

DICEE AND OPERATIONAL HYDROLOGIC MODEL FLUXES

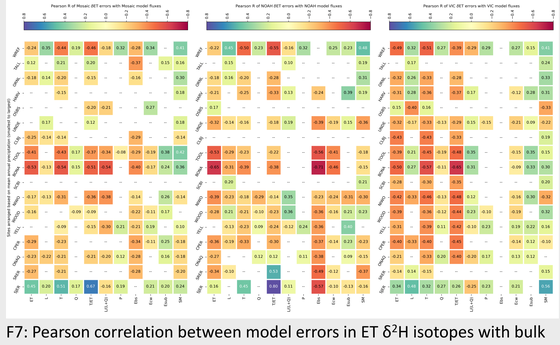
Operational hydrologic models (MOSAIC, NOAH, VIC) estimate different transpiration, canopy interception, overland runoff, and subsurface leakage as well as containing other differences in how soil water is stored and taken up by vegetation. Here, we take estimated partitioned fluxes and estimate the isotope ratio of bulk *ET* using δ2H mass balance and compare with NEON-DICEE.



F5: Estimates of ET flux isotope composition compared with NEON-DICEE data at four exemplary sites.



F6: Taylor diagram of the standard deviation, root mean squared error, and correlation of estimated ET isotope ratios at NEON sites.



F7: Pearson correlation between model errors in ET δ2H isotopes with bulk fluxes and model state variables for each NEON site (e.g. positive correlation is model overestimating ET δ2H at higher flux/pool values).

OVERVIEW (START HERE)

Hydrologic science often determines the accuracy of hydrologic models based on bulk fluxes (river discharge or tower-derived evapotranspiration), however different components of bulk flows are associated with varied timescales, mixing volumes, and ecohydrologic processes. Stable isotope tracers help identify these processes, however prior macro-scale inferences have been limited by data availability. Here we derive a new continental scale isotope dataset (left column), evaluate the conditions where this new data set is informative of water and carbon fluxes (middle column), and then evaluate how well hydrologic model fluxes are able to match the observed isotope mass balance (right column)

KEY FINDINGS

- Based on NEON observations a new dataset (NEON-DICEE) was created with daily estimates of the isotope ratio of precipitation and evapotranspiration at sites across the United States (F1).
- NEON-DICEE contains about as much information about surface-to-atmosphere water and carbon exchange as wind speed measurements, but less than radiation, temperature, and VPD data (F2).
- This information is *newly added* information that is distinct from other meteorological observations (F3).
- δ13C observations are more informative of latent heat fluxes under arid, higher-elevation sites, and at sites with lower rainfall (F4).
- δ2H observations are more informative of net ecosystem exchange at cooler sites, and more informative of latent heat fluxes at cooler sites with lower rainfall (F4).
- Using different hydrologic models for estimates of fluxes for a δ2H isotope mass balance provides different estimates of evapotranspiration isotopes(F5).
- Relative to NEON-DICEE isotope mass balance estimates, MOSAIC has lower RMSE and highest correlation while VIC has a closer match to observed NEON-DICEE standard deviations (F6).
- Hydrologic model fluxes and pools are both positively and negatively correlated with errors in ET δ2H isotope ratios, suggesting site-specific biases for model component fluxes and states (F7).

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