Establishment of Land-atmosphere Feedback Regimes using Flux Site Observations

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Abstract

The land surface water and energy balances are important factors in understanding the Earth's climate system related to the coupling between land and atmosphere. This study employs principal component analysis (PCA) combined with Granger causality and Pearson's correlation to investigate more accurate land-atmosphere (LA) interactions using soil water content (SWC), surface latent heat flux (LE), surface sensible heat flux (H), and surface net radiation (RAD). The analysis focuses on identifying the most influential components in flux observation sites across four seasons. Our findings indicate that H is a crucial factor in LA interactions for all seasons, and LE becomes more an important driver in summer than in other seasons. In contrast, SWC, despite its link to the surface water budget, is less influential compared to energy balance terms. Effects of RAD vary seasonally, being more significant in energy-limited regimes during spring and summer. The 2-dimensional LA coupling matrix, delineated into four quadrants based on the correlation signs between SWC/LE and SWC/H, facilitates the classification of distinct LA feedback regimes. The LA matrix provides a clearer understanding of both water- and energy-limited regimes. This result suggests that H and LE are key drivers in both water- and energy-limited regimes. Detailed analyses reveal that different regimes exhibit unique characteristics depending on factors like temperature, humidity, and energy availability. Spatial analysis of observation sites shows significant LA interactions mainly in middle latitudes, influenced by solar radiation. The global distribution of LA feedback regimes underlines the complexity of defining LA coupling regimes, which vary according to geographic location, local climate, and land/vegetation types. These insights will be vital for enhancing the predictability of climate models and comprehending the intricate interplay between different surface conditions in LA interactions.

1. Introduction

- Land-atmosphere (LA) interactions are one of the important processes for the energy and water cycle on the globe. This study seeks a better understanding of energy and water cycle characteristics and LA interactions on the globe across all seasons using data from *in situ* flux observation sites (FLUXNET; Pastorello et al. 2020).
- The first scientific objective is to find the major impacting components of surface budgets among SWC, LE, H, and RAD through principal component analysis (PCA) with Granger causality applied to determine significant contributors to observed PCs.
- The second is to establish a more accurate depiction of the terrestrial leg of LA feedback regimes using FLUXNET to fill the missing definition of LA feedback regimes. We focus on the terrestrial coupling leg of LA interactions to find water- and energy-limited regimes, defined by a temporal correlation between SWC and surface fluxes (Dirmeyer 2011).

2. Method

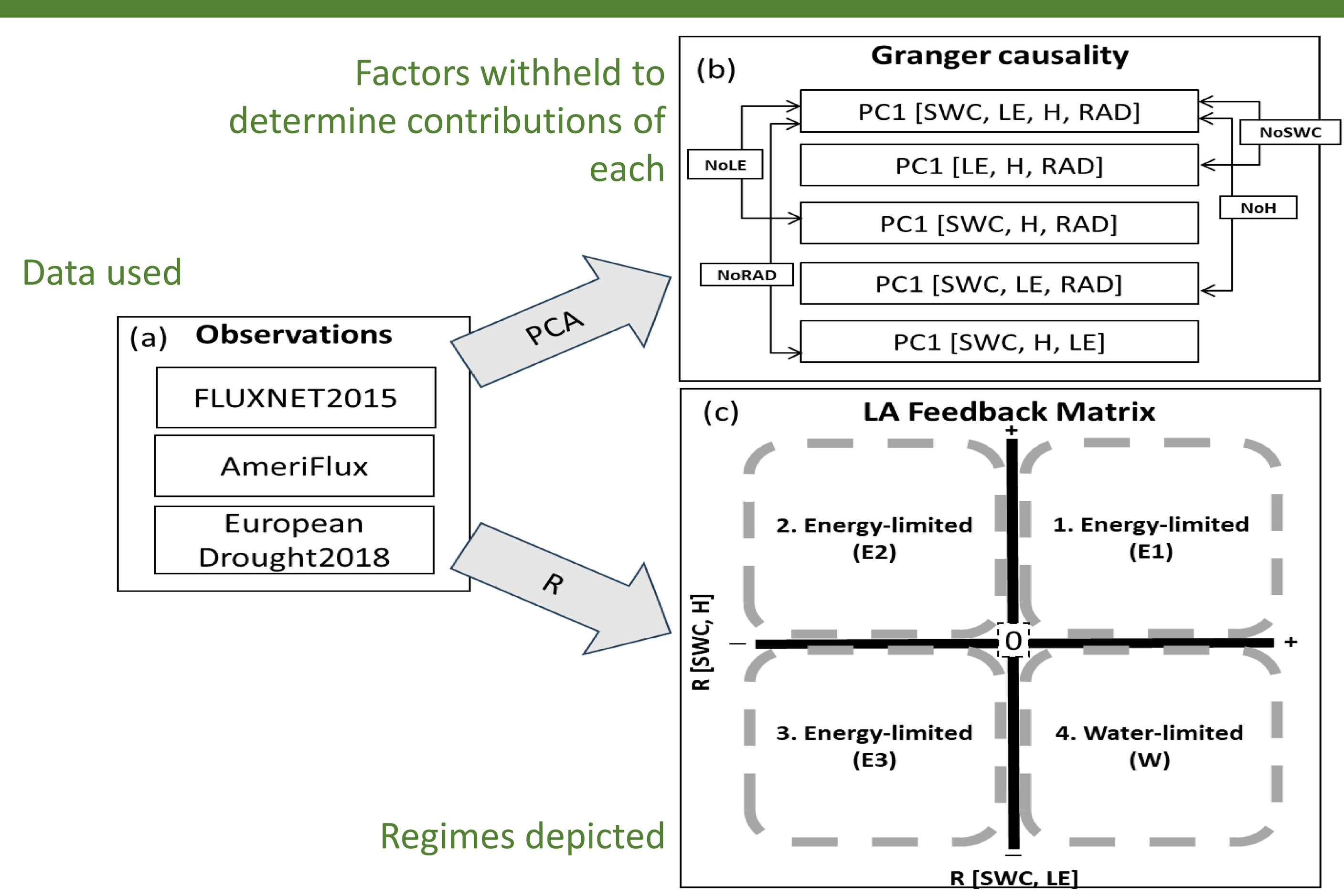


Fig. 1 *Schematic of comparison of the land-atmosphere relationship between Granger causality through principal component analysis (PCA) and matrix of land-atmosphere feedback regime using Pearson correlation coefficient (R)*

3.1. Principal Characteristics & Land-atmosphere Matrix

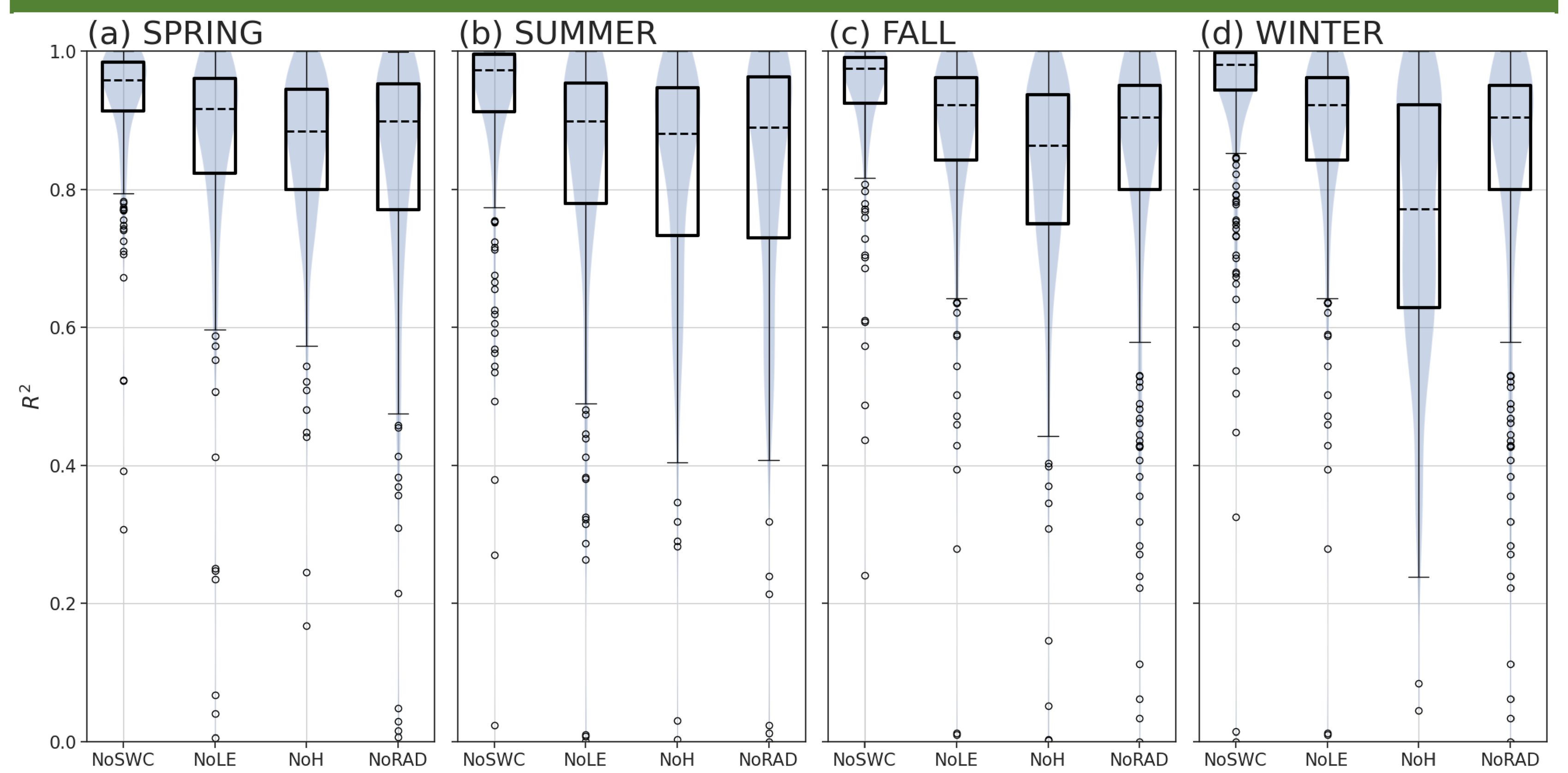


Fig. 2 *Boxplots of R-squared values (y-axis) from Granger causality for surface terms (x-axis) in PC1 from (a) spring, (b) summer, (c) fall, and (d) winter. Dash lines, dots, and shading are median values, outliers, and probability density functions. The outliers are above the absolute values of 3σ (standard deviations) of data.*

- Each season has a set of four box plots corresponding to different surface variables from which a specific factor has been excluded to measure the importance of a variable by the decrease in R-squared value: NoSWC (soil water content), NoLE (surface latent heat flux), NoH (surface sensible heat flux), and NoRAD (net radiation on the surface).
- H is the most important driver and SWC is the least likely to be the major contributor to the major principal component (PC1) of surface conditions.

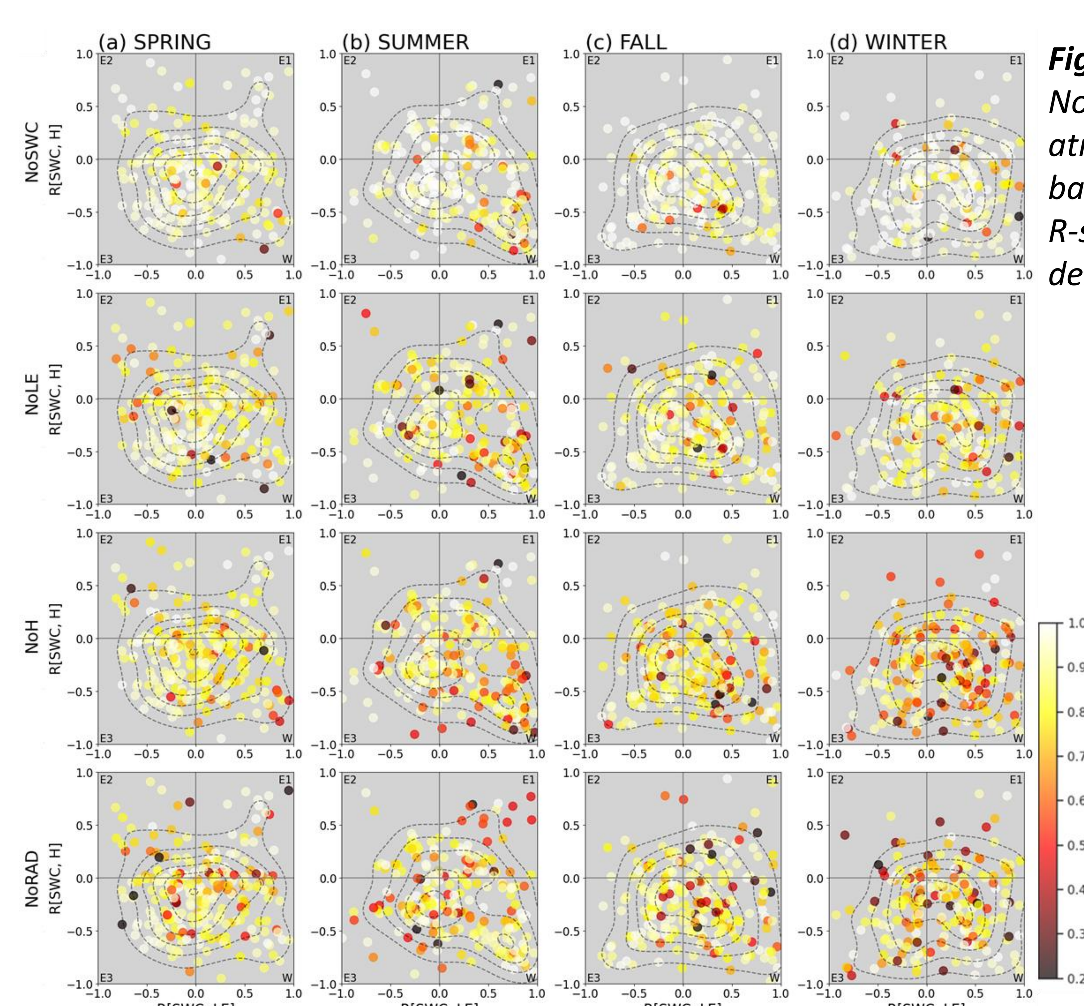
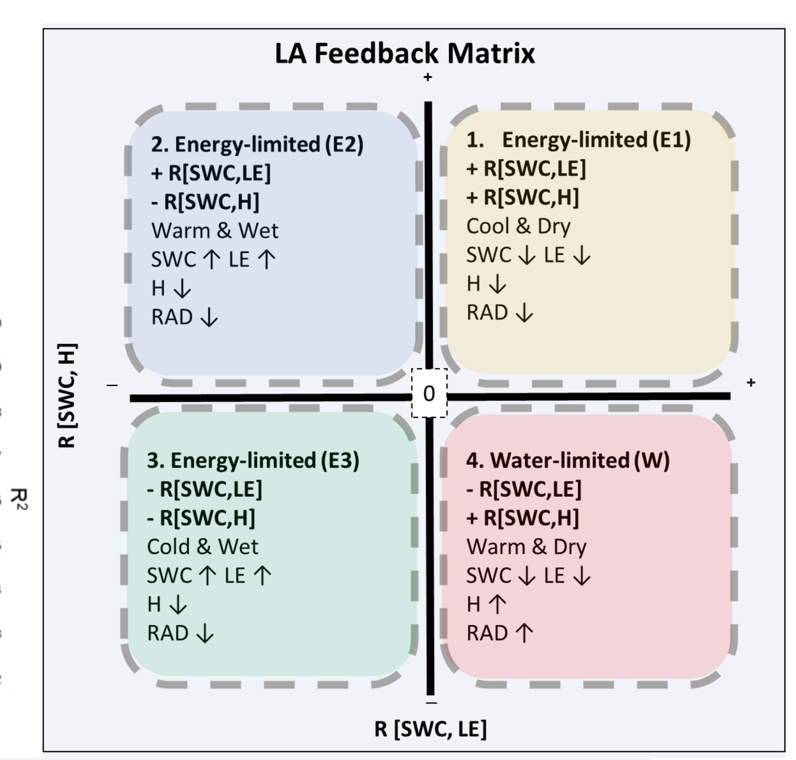


Fig. 3 *Scatter plots for Granger causality of NoSWC, NoLE, NoH, and NoRAD and the land-atmosphere matrix using Pearson correlation based on Fig1 (c). Color and dash lines indicate R-squared values from Granger causality and density of scatter plot, respectively*



- **W:** warm and dry land conditions; there is enough radiation energy to make it possible that SWC is an important driver of the partitioning of heat fluxes.
- **E1:** cold regions and thus less RAD, resulting in less H thus implying energy-limited regimes. As SWC increases, there is more water available for evapotranspiration like plant transpiration.
- **E2:** a wet soil moisture regime where available energy goes to terrestrial evaporation. Thus, even though **E2** is hotter than other energy-limited quadrants, **E2** is still wetter and has more SWC and LE but less H than quadrant **W**.
- **E3:** SWC is still an available moisture source as an energy-limited regime such as **E2** despite the cold status. Cooler and wetter conditions do not lead to a significant change in either surface flux, depending on SWC, because radiation energy is limited.

3.2. Principal Characteristics & Land-atmosphere Matrix

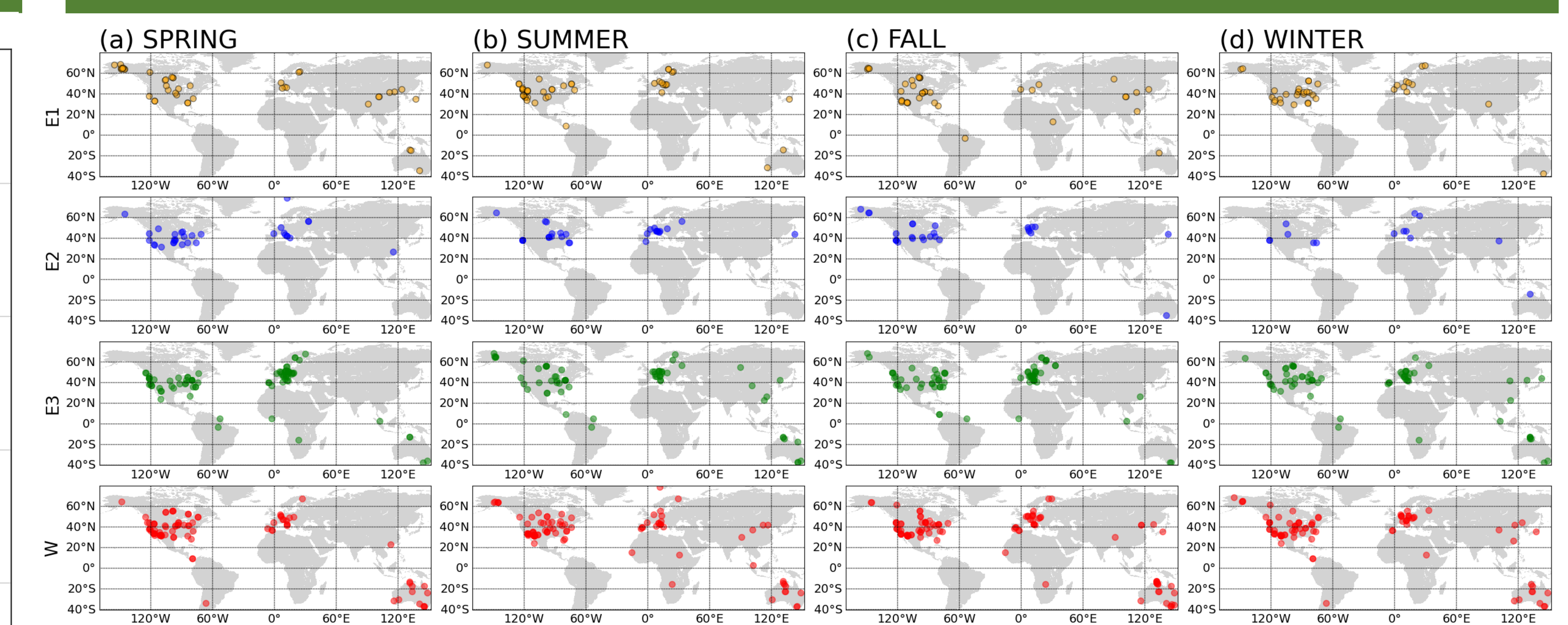


Fig. 4 *Global distribution for LA interaction regimes: **E1**, **E2**, **E3**, and **W** across seasons.*

- Major components are mainly located in the middle latitudes, meaning that surface variables are interactive where solar radiation plays a role for all seasons.
- Land-atmosphere (LA) interaction regimes are changeable across seasons in the sites, depending on different mechanisms of land/vegetation type from different local climates and weather systems.
- **E1** needs to be separately considered for LA matrix, not including **W**, because this regime is globally distributed.
- There is the spatial coverage limitation of observations to generalize the global characteristics. Despite this limitation, the results suggest the establishment of more accurate LA feedback regimes across seasons

4. Discussion & Concluding Remarks

- Granger causality analysis examines that NoH (excluding surface heat flux (H)) consistently shows the lowest median R-squared values across all seasons, indicating its significant role in driving LA interactions.
- Despite its inherent link to the surface water budget, SWC appears less influential component compared to the energy balance terms in driving LA interactions.
- This study reveals that H significantly influences water-limited regimes and LE has a crucial role in energy-limited regimes through the 2-dimension LA matrix.
- RAD is more important in spring and summer in the energy-limited than in fall and winter, highlighting the seasonality of RAD.
- Major components of LA interaction are concentrated in middle latitudes, where solar radiation significantly influences surface variables in all seasons.
- This study acknowledges limitations from methodology, sample dependency, and the predominance of certain vegetation types in in-situ measurements.
- Surface heat has significantly played roles in the hydrological cycle contributing to precipitation in global climate models (Myhre et al. 2018). This study reveals the year-round importance of H to LA interaction through flux observation sites.

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