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Catchment-scale water-carbon coupling across the contiguous United States: A data-based analysis

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Introduction

- Feedbacks between water, vegetation, biogeochemistry, and soils govern the co-evolution of vegetation with terrestrial hydrology that can alter carbon, water and energy exchanges [Troch et al., 2009]
- Gross primary productivity (GPP) serves as the largest carbon flux between terrestrial ecosystems and the atmosphere. Wetness dynamics is a key link between climate fluctuation and vegetation dynamics in space and time. The interaction between water balance and plant is responsible for some of the fundamental differences among various biomes and developments of their space-time patterns [Porporato and Rodriguez-Iturbe, 2002]
- This co-evolution of vegetation and water balance dynamics as a result of vegetation adaptation to climatic variability can be explored through understanding of the inter-regional and annual/intra-annual variability of their interlink [Troch et al., 2009].

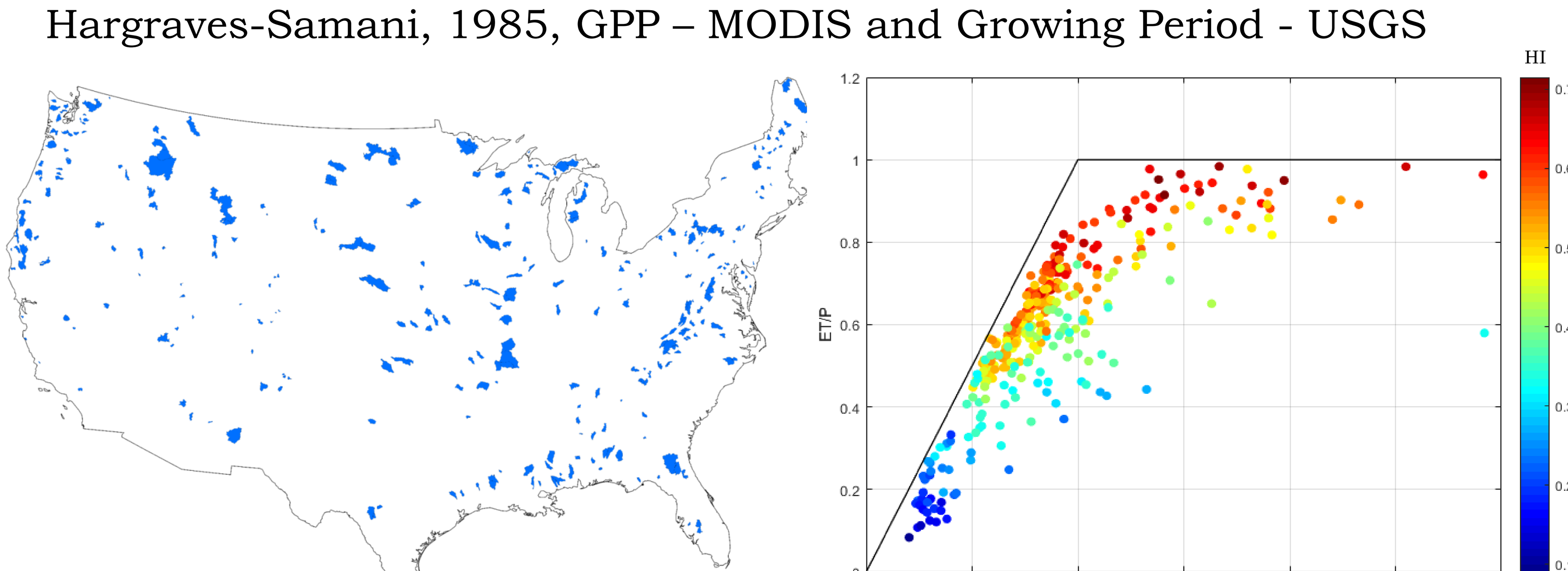
Research Questions

1. How much of the incoming water mass theoretically contribute to GPP at catchment scale?
2. Can we provide a systematic explanation for similarity and dissimilarity of observable spatial and temporal patterns of GPP-catchment wetness interlink and characteristics?

Data and Study Area

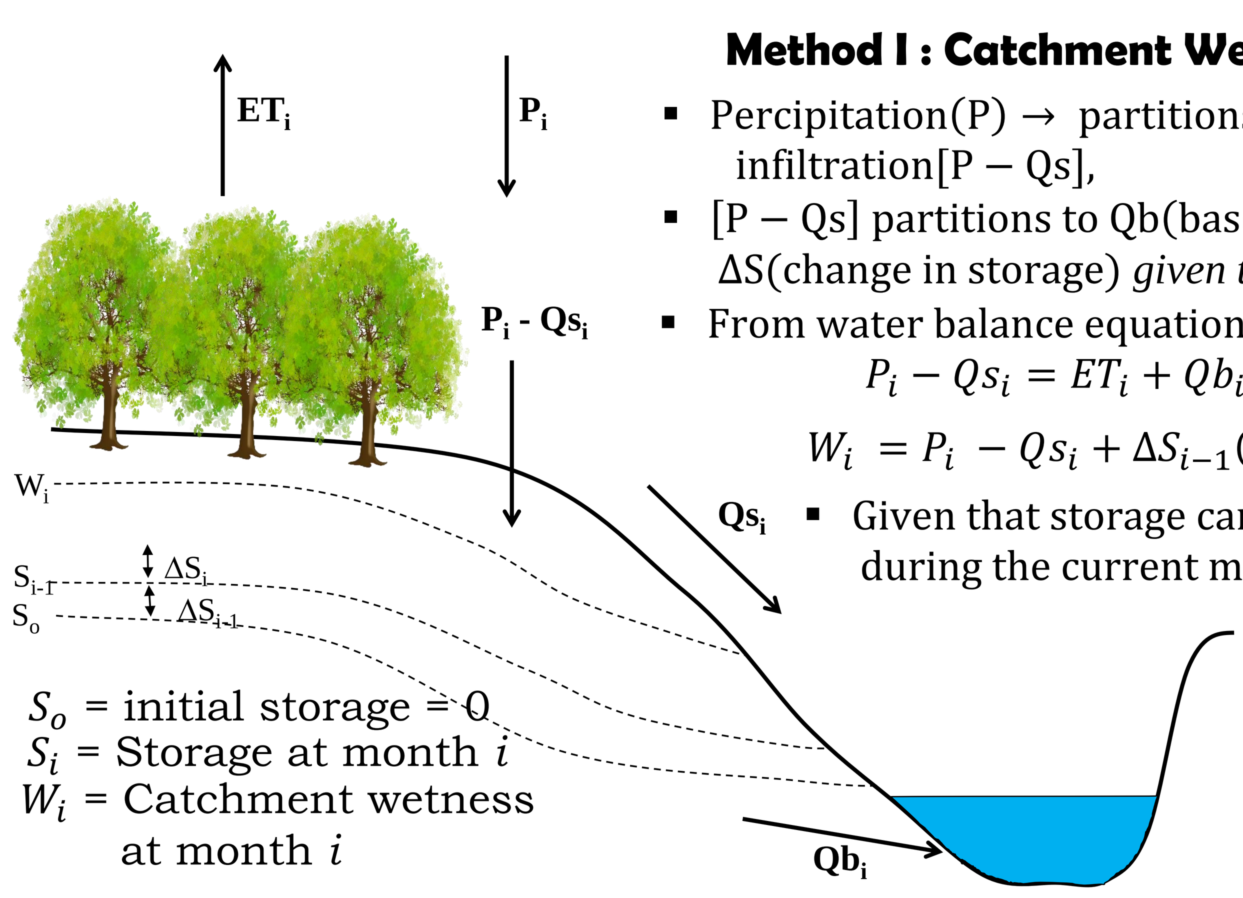
Study Catchments: CAMELS Dataset : 375/671–pristine catchments selected over CONUS–solely based on data availability, Area – ranges between 15.2853 to 14234 Km^2

Data : CAMELS →Rain + Snow, Streamflow, Tmax and Tmin, Actual evapotranspiration (ET) – MODIS, Potential Evapotranspiration (PET) – Hargraves-Samani, 1985, GPP – MODIS and Growing Period - USGS



HI – Horton Index (ET/Catchment Wetness)

Method



S_o = initial storage = 0
S_i = Storage at month i
W_i = Catchment wetness at month i

Method I : Catchment Wetness - By definition

- Percipitation(P) → partitions to surface runoff(Qs)and infiltration[P − Qs],
- [P − Qs] partitions to Qb(base flow), ET and ΔS(change in storage) *given that* ΔS > 0
- From water balance equation

$$P_i - Qs_i = ET_i + Qb_i + \Delta S_i$$

$$W_i = P_i - Qs_i + \Delta S_{i-1} \text{(Storage Carry over)}$$

- Given that storage carry over contributes W during the current month(i) $S_{i-1} > 0$

■ Thus, Wetness at month i can be written as

$$W_i = \begin{cases} ET_i + Qb_i + \Delta S_i + \Delta S_{i-1} & if \ \ \Delta S_i + \Delta S_{i-1} > 0 \\ ET_i + Qb_i & if \ \ \ \ \Delta S_i + \Delta S_{i-1} < 0 \end{cases}$$

Method II : Catchment Wetness - Budyko Framework

- Zhang et al., 2008 , accounts dynamics of catchment storage

$$\frac{ET_i}{P'_i} = F(\emptyset'_i) = 1 + \frac{PET_i}{P'_i} - \left[1 + \left(\frac{PET_i}{P'_i}\right)^{\omega}\right]^{\frac{1}{\omega}} \ where \ P'_i = P - \Delta S_i = ET_i + Q_{si} + Q_{bi}$$

- Water available for vegetation use considering storage carry over

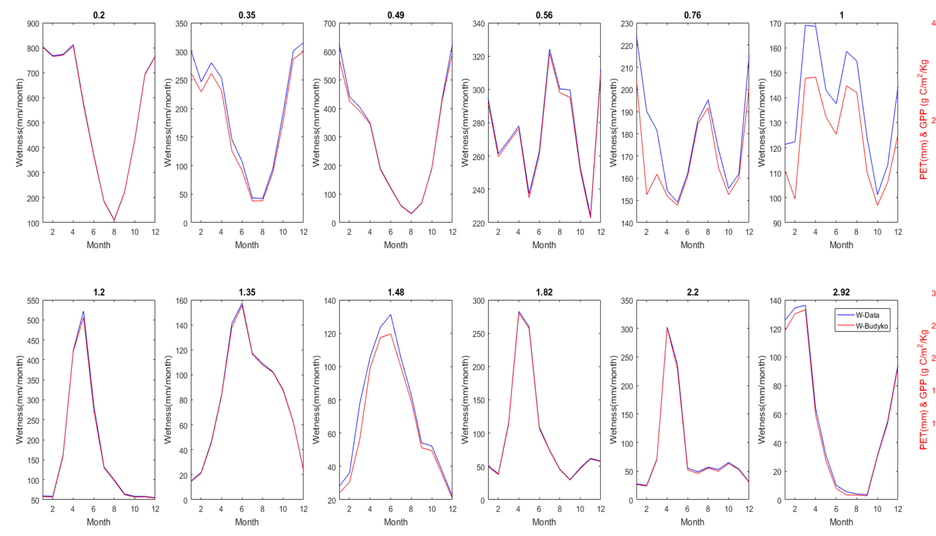
$$W_i = ET_i + Q_{bi} + \Delta S_i + \Delta S_{i-1}$$

$$W_i = ET_i + [(W_i + Q_{si} - \Delta S_i - \Delta S_{i-1})^{\omega} + PET_i^{\omega}]^{1/\omega} - (Q_{si} + PET_i - \Delta S_i - \Delta S_{i-1}),$$
Subjected to $\Delta S \geq 0$

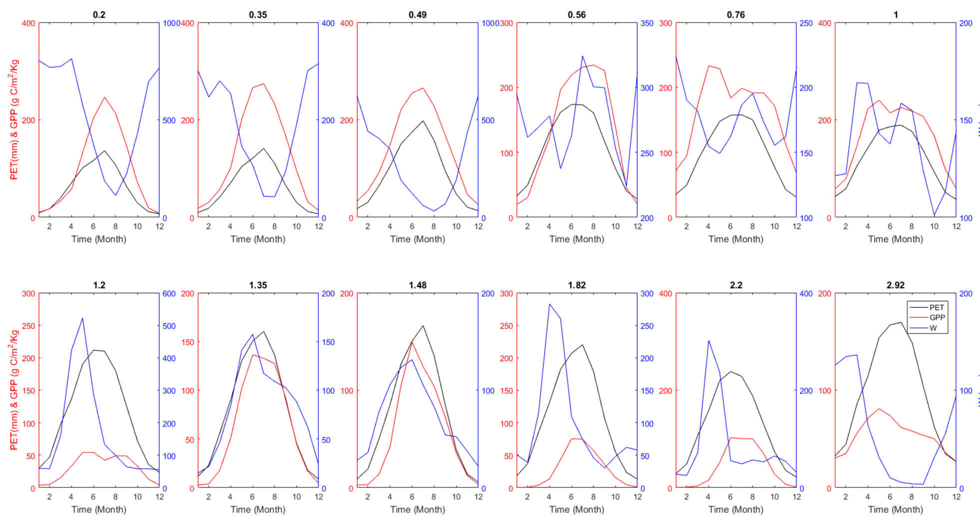
- Catchment Vegetation Water Use Efficiency (CWUE) = GPP/W

Results

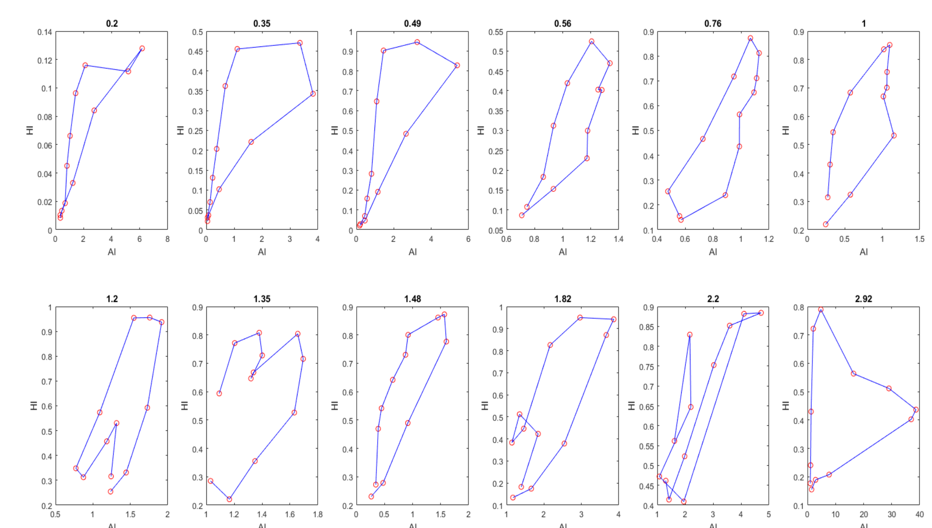
- Method I and Method II comparison for selected catchments *(figure headers = aridity index)*



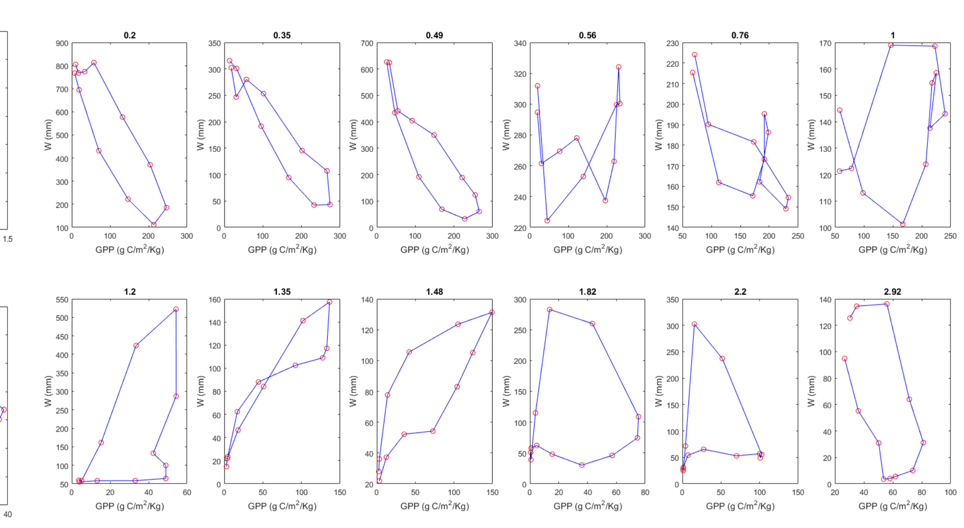
- Intra-annual : Catchment Wetness, GPP and PET *(figure headers = aridity index)*



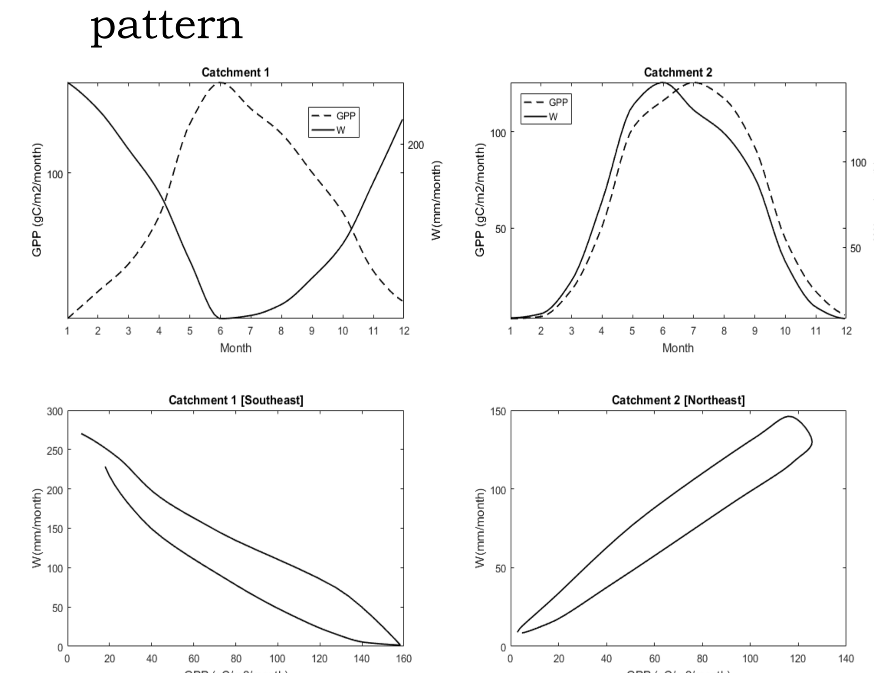
- Intra-annual :Climate dryness (PET/P- ΔS) propagates to Hydrologic dryness (HI) *(figure headers = aridity index)*



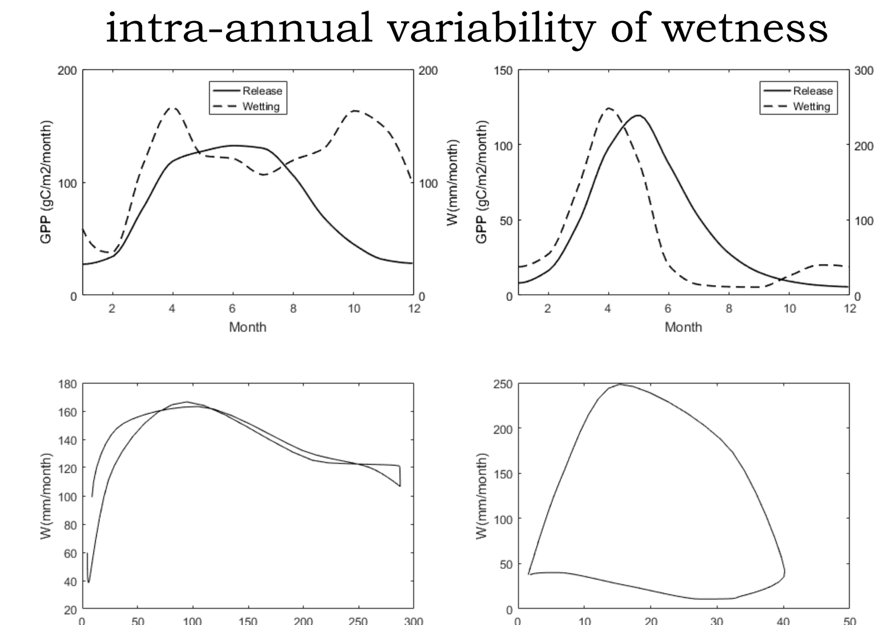
- Catchment W-GPP Hysteresis :Catchment hydrologic state controls on productivity *(figure headers = aridity index)*



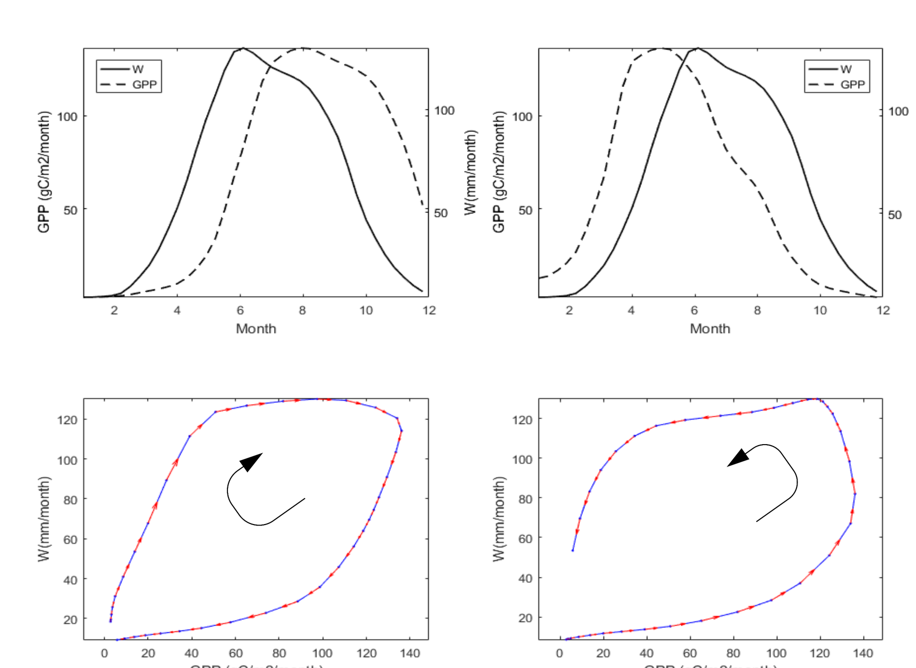
- W-GPP Hysteresis Orientation is linked to variables dominating the wetness pattern



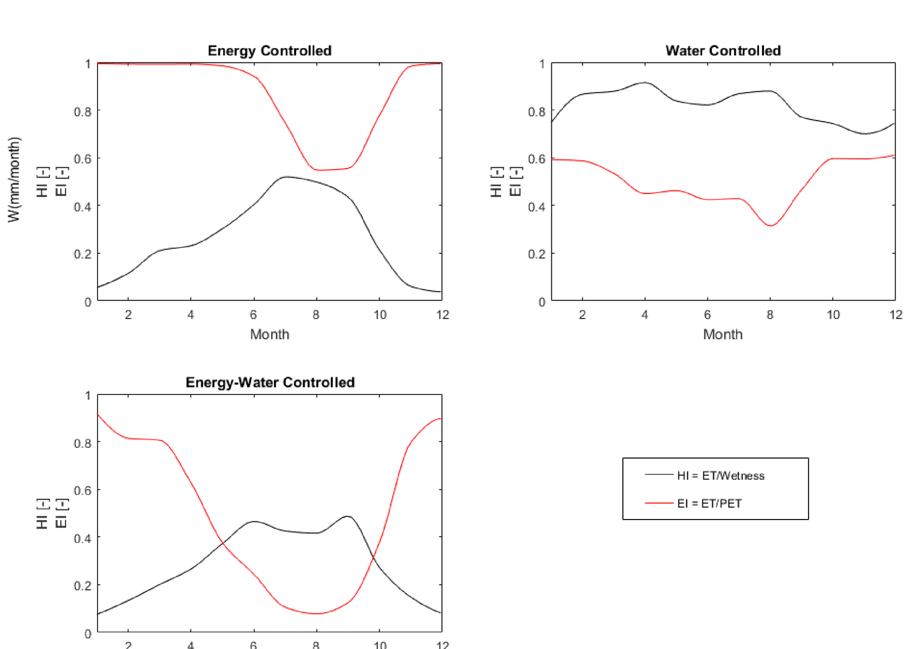
- The slenderness of the W-GPP hysteresis curve depends on the intra-annual variability of wetness



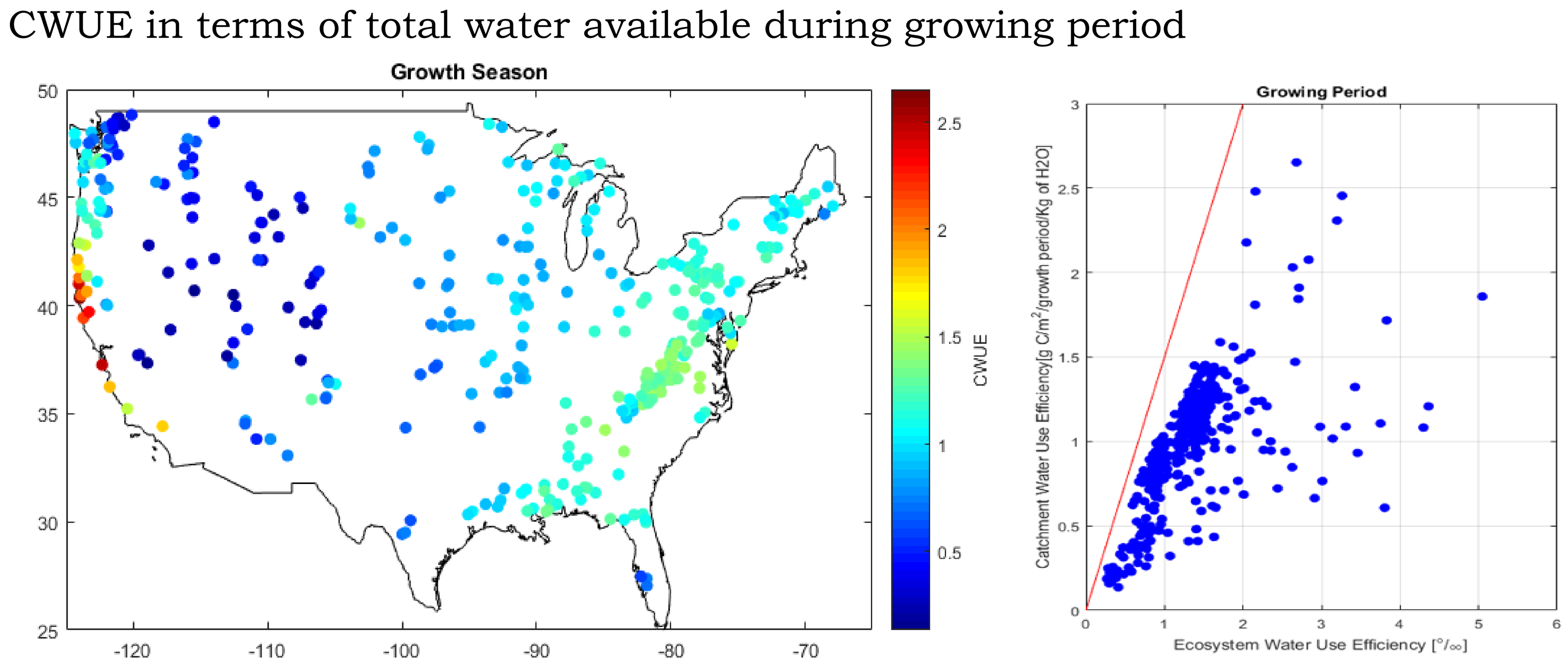
- W-GPP Hysteresis direction: attributed to competition between wetting/release



- Catchment vegetation productivity is drive by controlling factor :energy/water



- CWUE in terms of total water available during growing period



Conclusion

- Intra-annual hysteresis between W and GPP is largely controlled by the competition between the availability of energy and wetness.
- The orientation of W-GPP hysteresis depends on the lag between W and GPP peaks.
- The directions of the hysteresis curves governed by catchment storage characteristics
- The growth period mean CWUE is well correlated with the traditional ecosystem water use efficiency with R^2 of 0.62

References

Porporato, A., and I. Rodriguez-iturbe (2002), Ecohydrology - a challenging multidisciplinary research perspective, *Hydrol. Sci. J.*, *47*(5), 811–821, doi:10.1080/02626660209492985.

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