Ecosystem responses to favorable weather conditions modulates decadal water use efficiency trends

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Plant Water Use Efficiency (WUE)

Leaf-scale

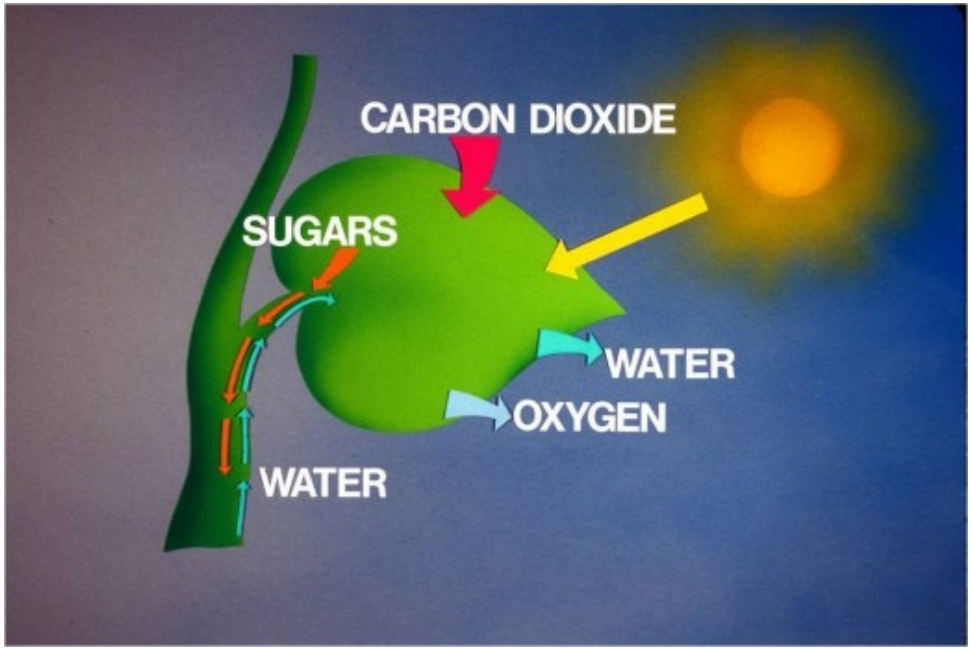
$$A = g_s(c_a - c_i)$$
$$E = g_s(v_i - v_a)$$

- water-use efficiency

$$WUE_i = \frac{A}{E} = \frac{A}{g_s(v_i - v_a)}$$

Intrinsic water-use efficiency

$$WUE_i = WUE * (v_i - v_a) = \frac{A}{g_s}$$



Ecosystem-scale

$$A \rightarrow GPP$$
$$E \rightarrow ET$$

water-use efficiency

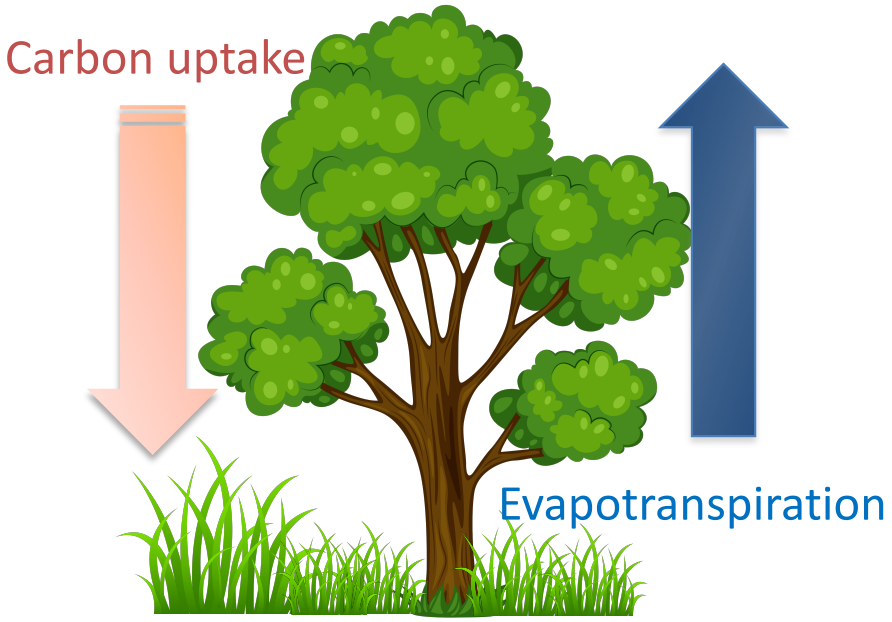
$$WUE^* = \frac{GPP}{ET}$$

Inherent water-use efficiency

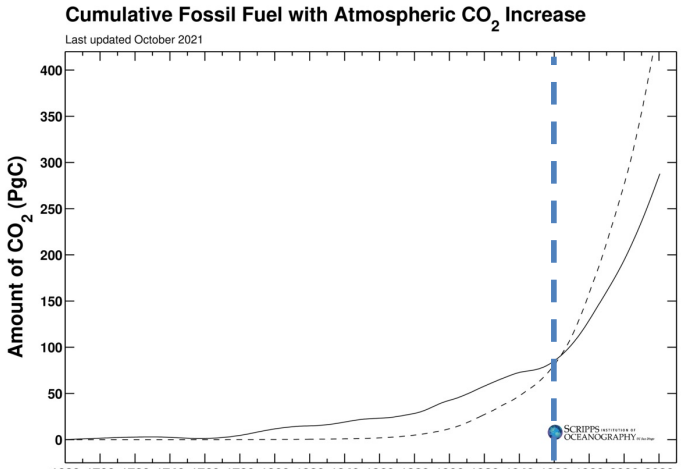
$$WUE_{ei} = \frac{GPP}{ET} * VPD$$

Underlying water-use efficiency

$$WUE_u = \frac{GPP}{ET} * \sqrt{VPD}$$

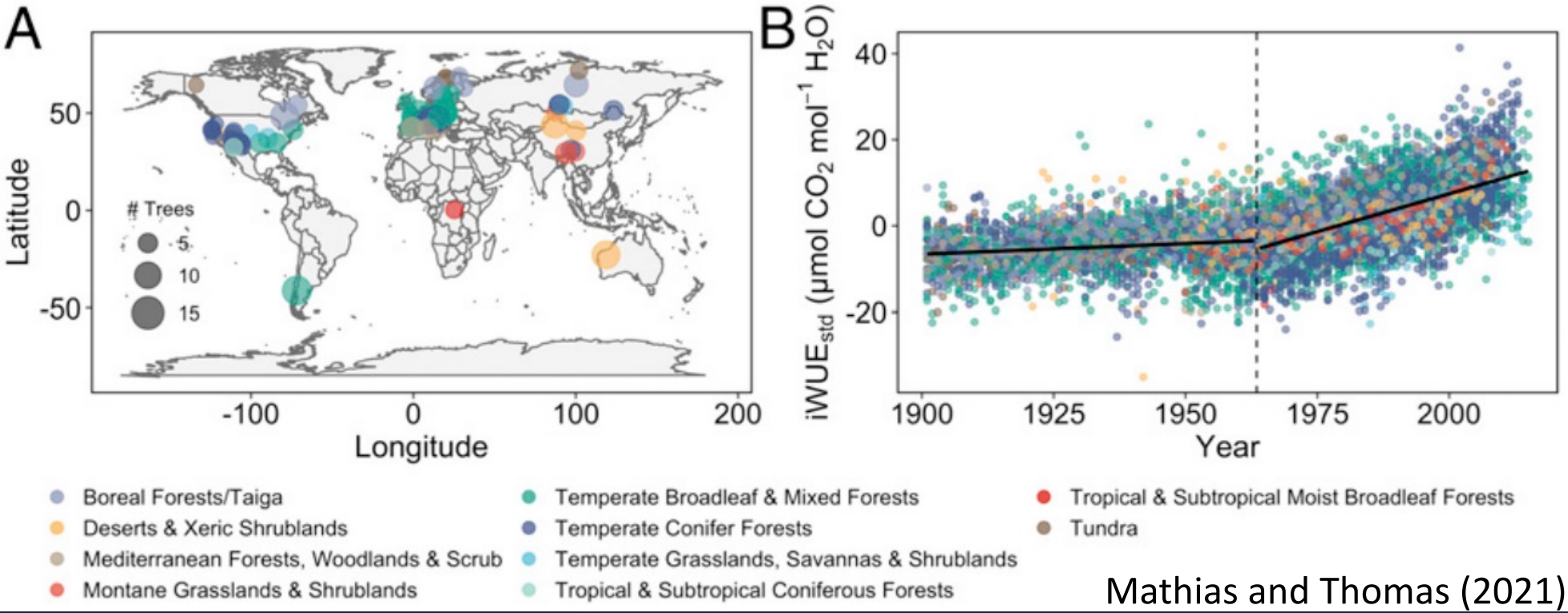


WUE changes over the past decades



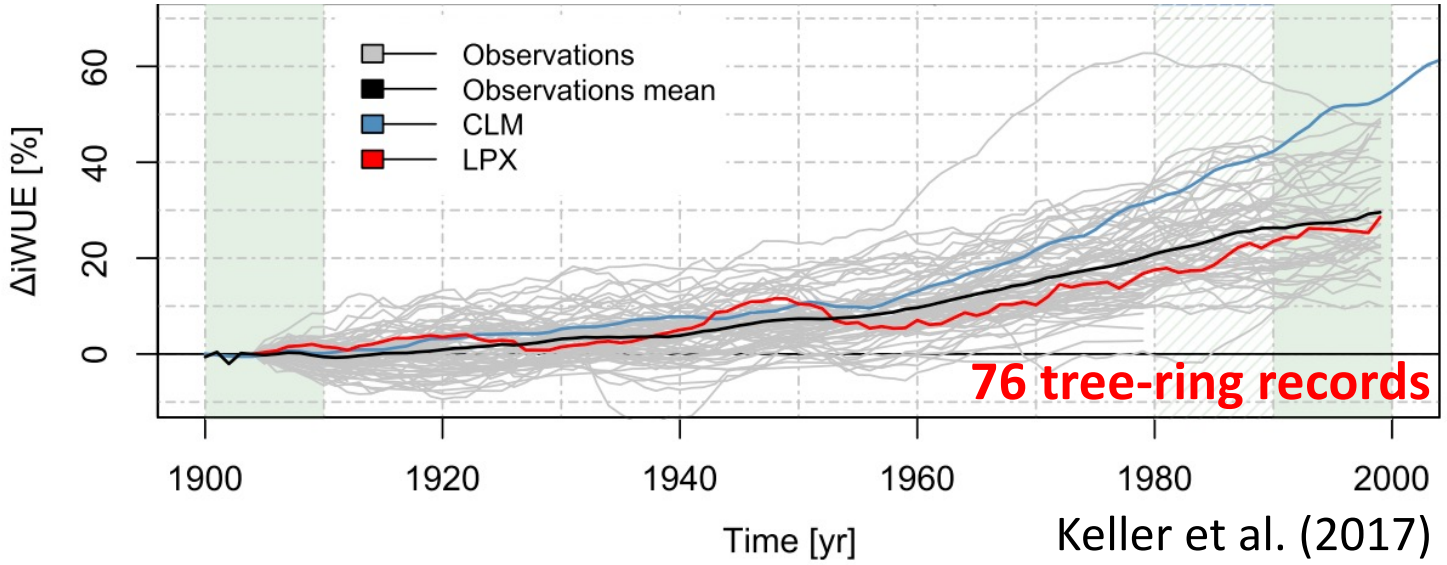
$$WUE \propto \left[\frac{A}{g_s} \quad \frac{GPP}{ET} \right]$$

~40% increase in *iWUE* globally over the 20th century, coinciding with a **~34%** increase in atmospheric CO_2 (36 species, 84 sites, 113 trees)



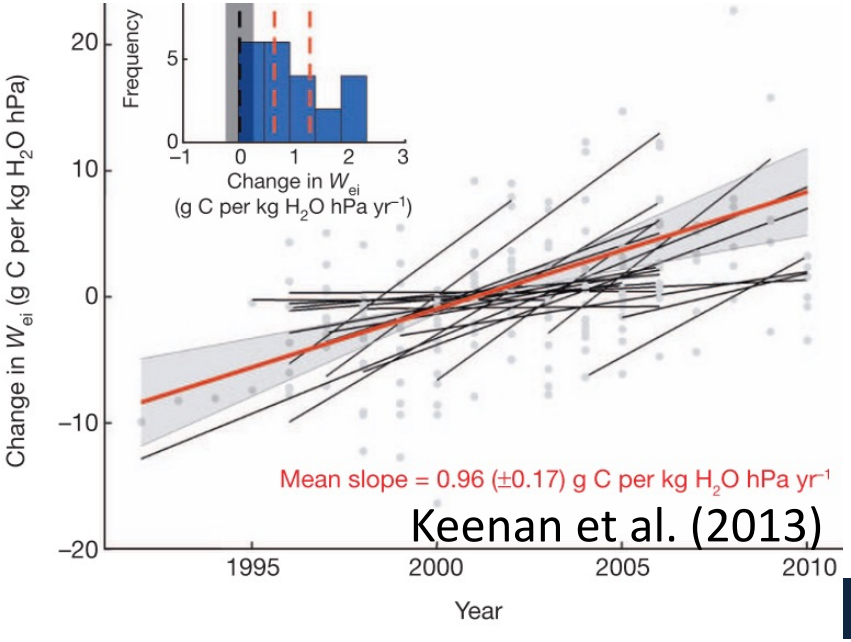
Mathias and Thomas (2021)

WUE changes over the past decades



Keller et al. (2017)

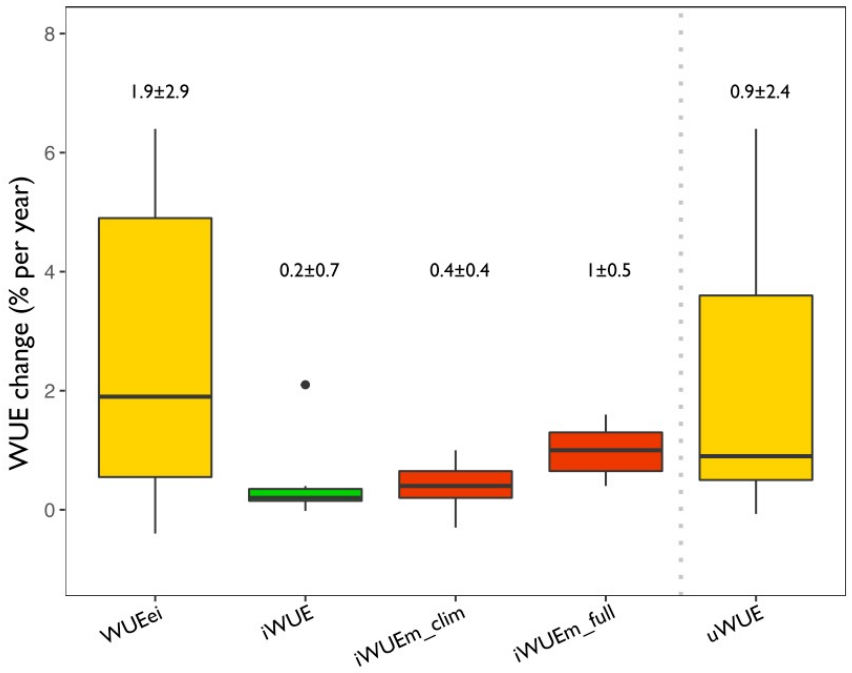
~0.3% yr^{-1} increase in **tree-ring** *iWUE*



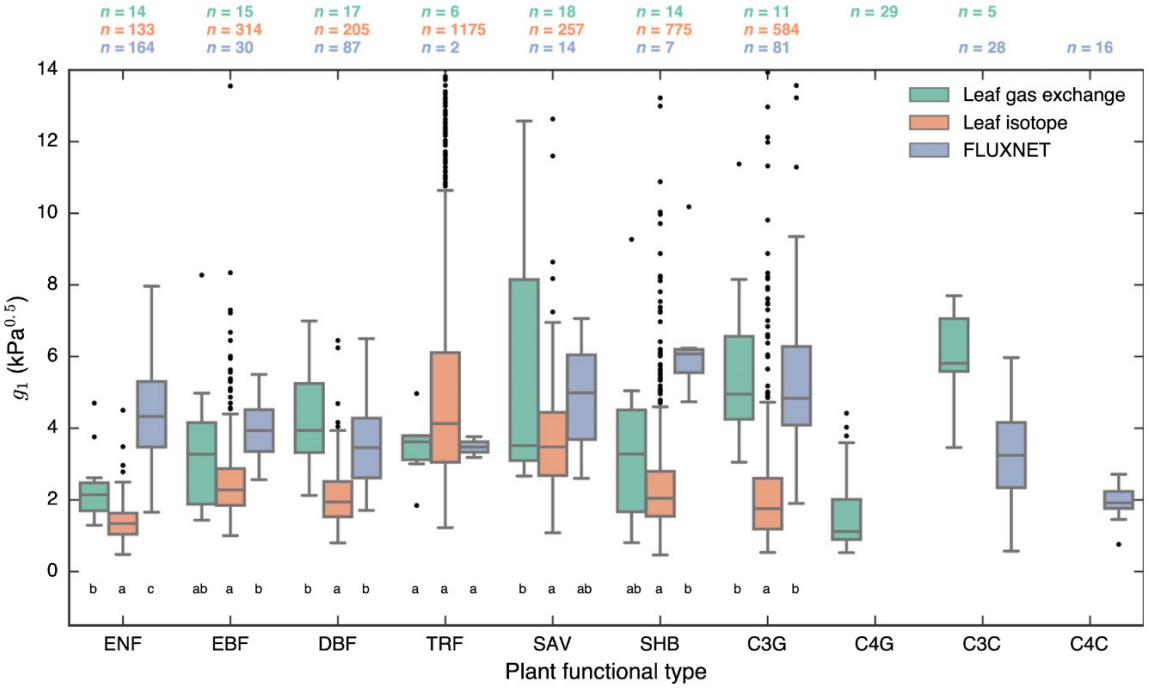
Keenan et al. (2013)

~2.3% yr^{-1} increase in **ecosystem-scale** *WUE_{ei}*

The mismatch is not just about spatial heterogeneity

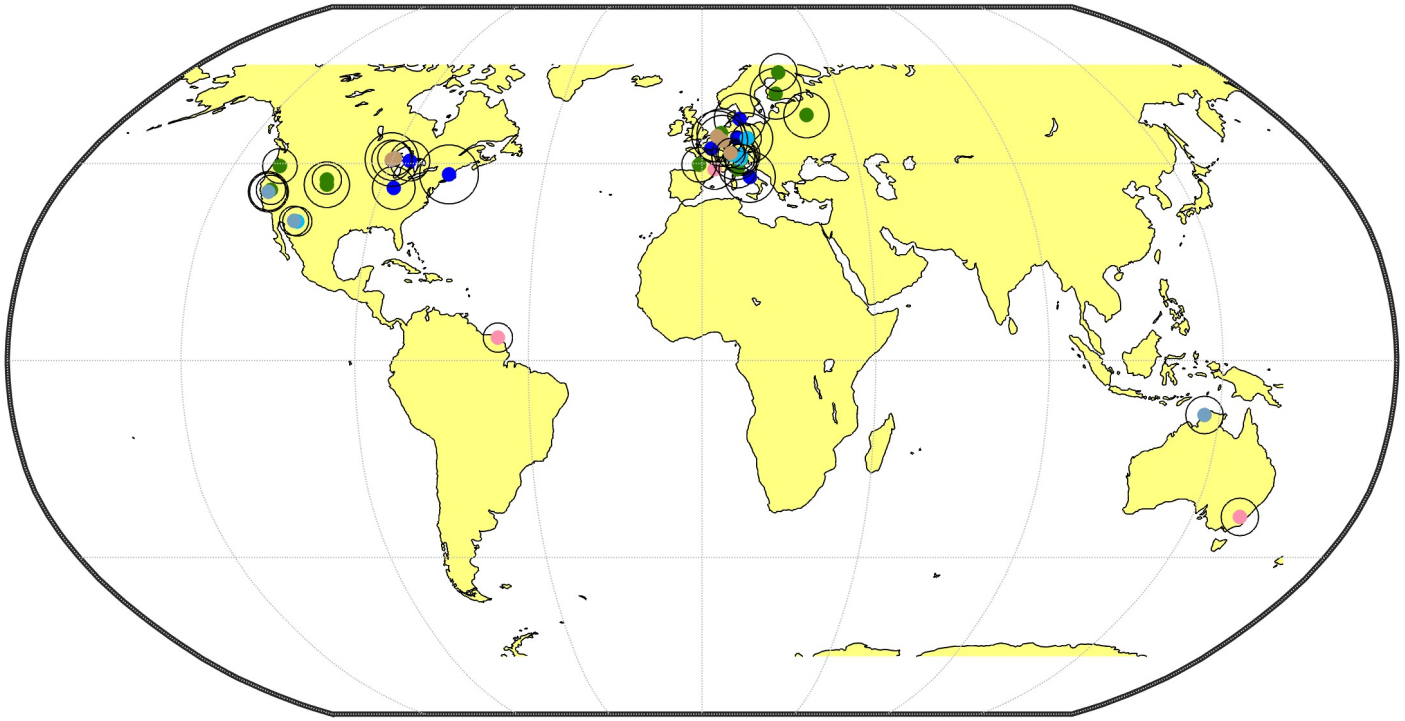


Guerrieri et al. (2019)



Medlyn et al. (2017)

WUE calculation



DBF EBF ENF GRA MF WSA

Underlying water-use efficiency

$$uWUE = \frac{GPP}{ET} * \sqrt{VPD}$$

Each **hour** $$uWUE_{hour} = \frac{GPP_{hour}}{ET_{hour}} * \sqrt{VPD_{hour}}$$

Each **season**

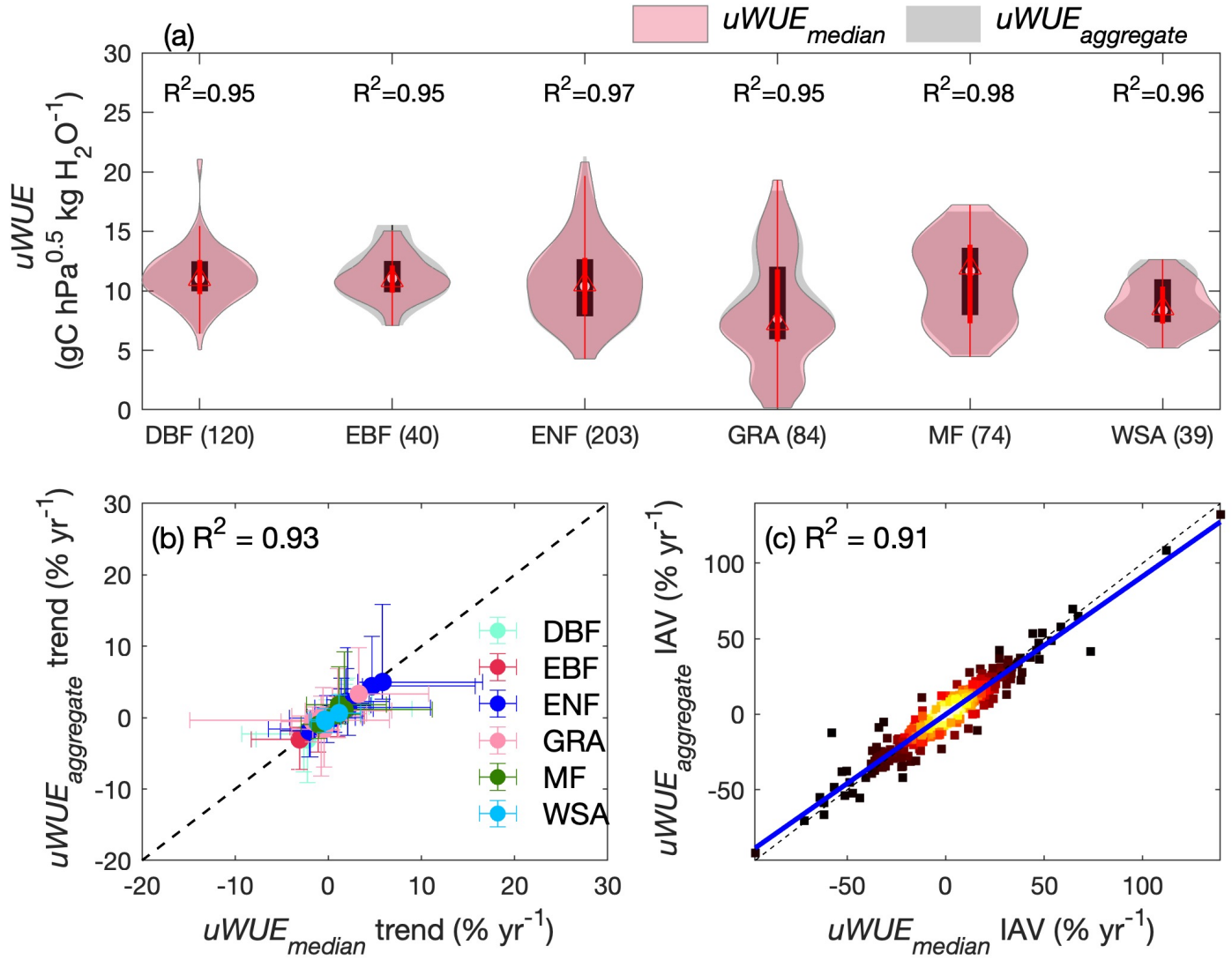
$$uWUE_{median} = median(uWUE_{hour})$$

$$uWUE_{aggregate} = \frac{\Sigma GPP_{hour}}{\Sigma ET_{hour}} * mean(\sqrt{VPD_{hour}})$$

uWUE sensitivity to temporal resolution

Underlying water-use efficiency

$$uWUE = \frac{GPP}{ET} * \sqrt{VPD}$$



Consistent results with summer only measurements

Underlying water-use efficiency

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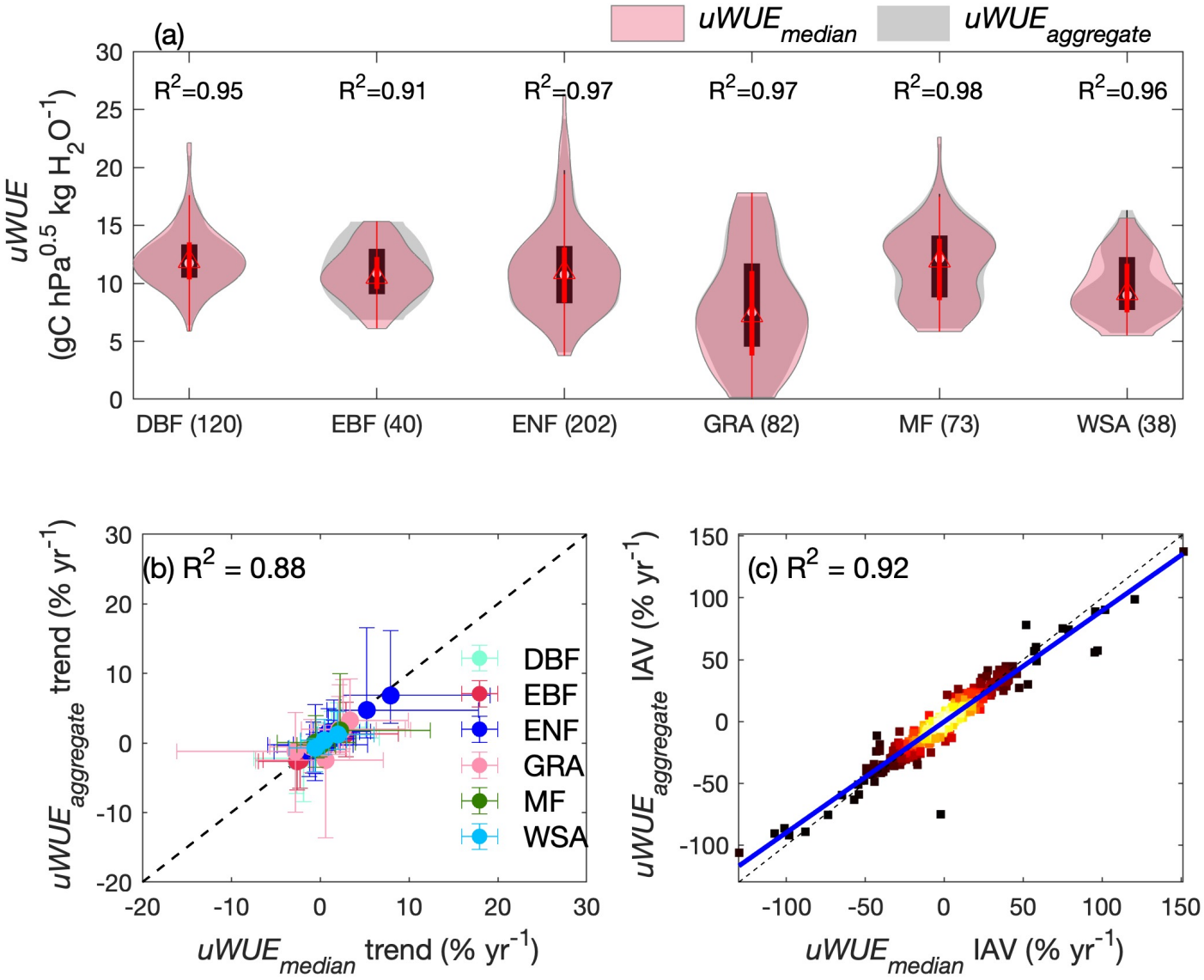
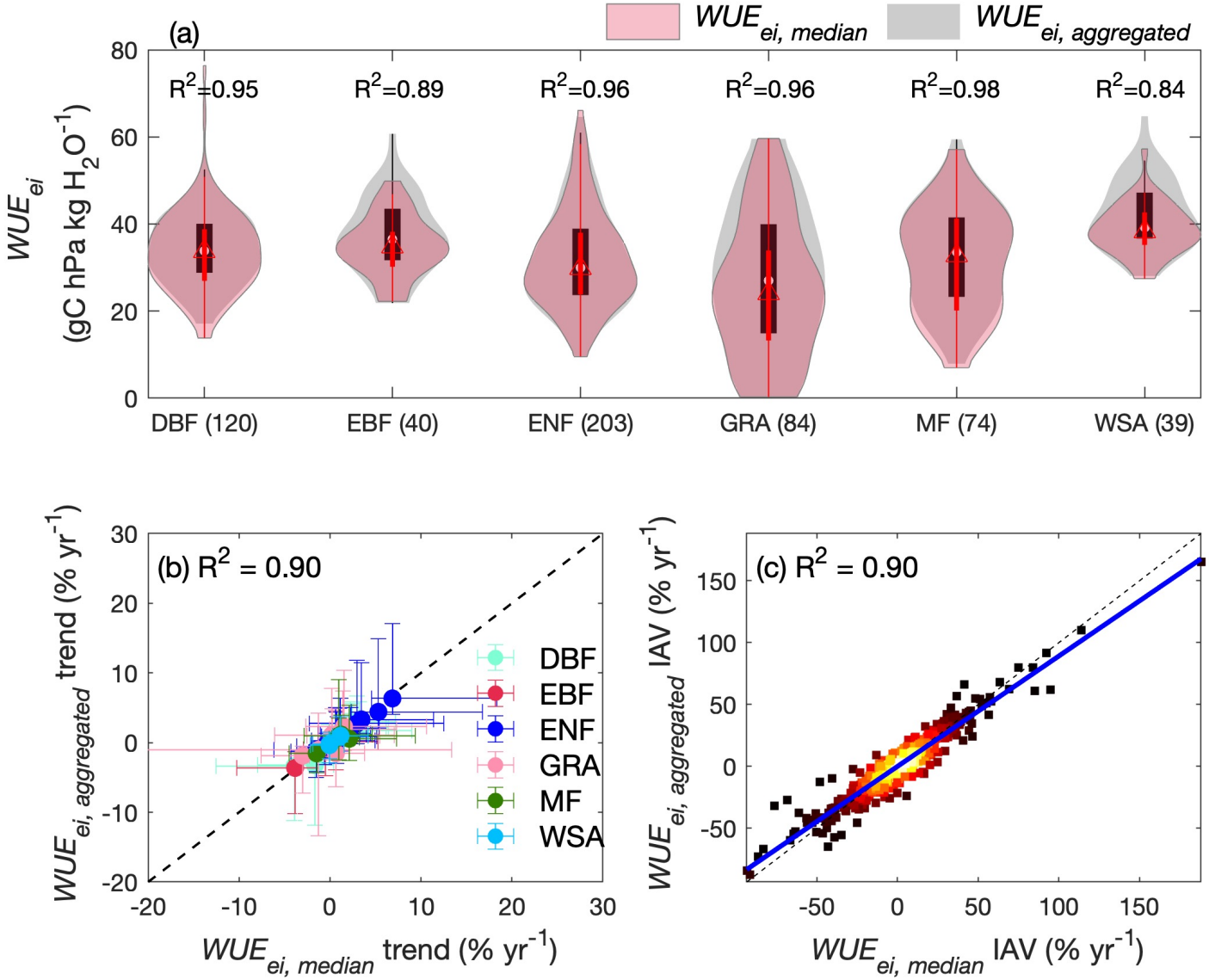


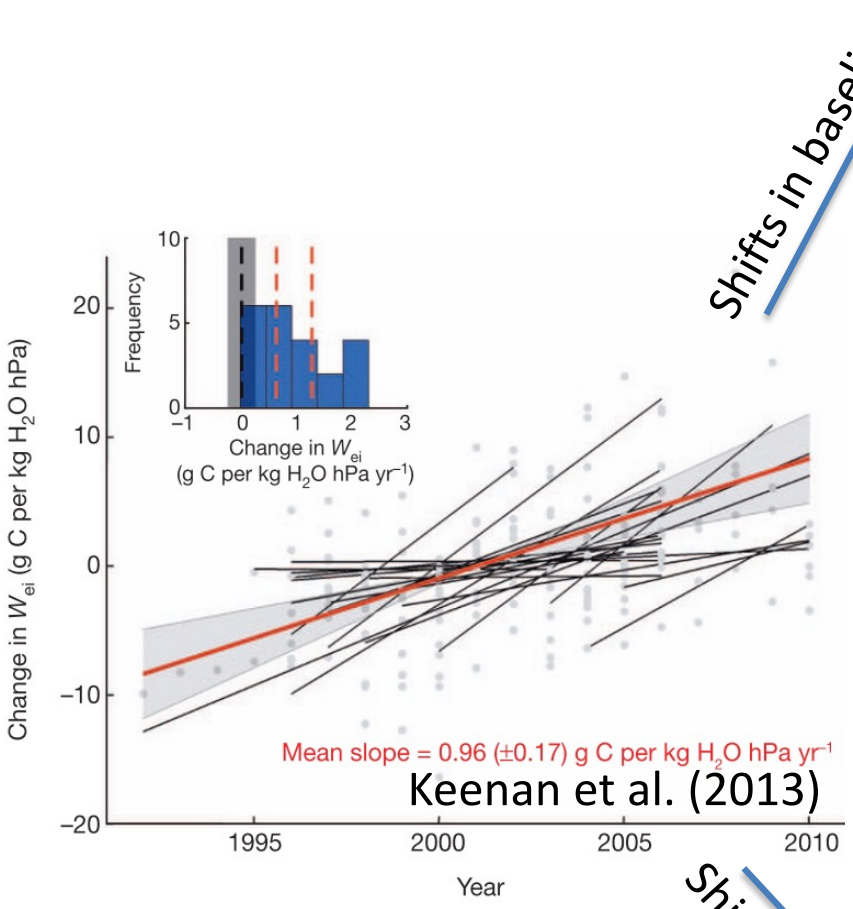
Consistent results with WUE_{ei}

Inherent water-use efficiency

$$WUE_{ei} = \frac{GPP}{ET} * VPD$$

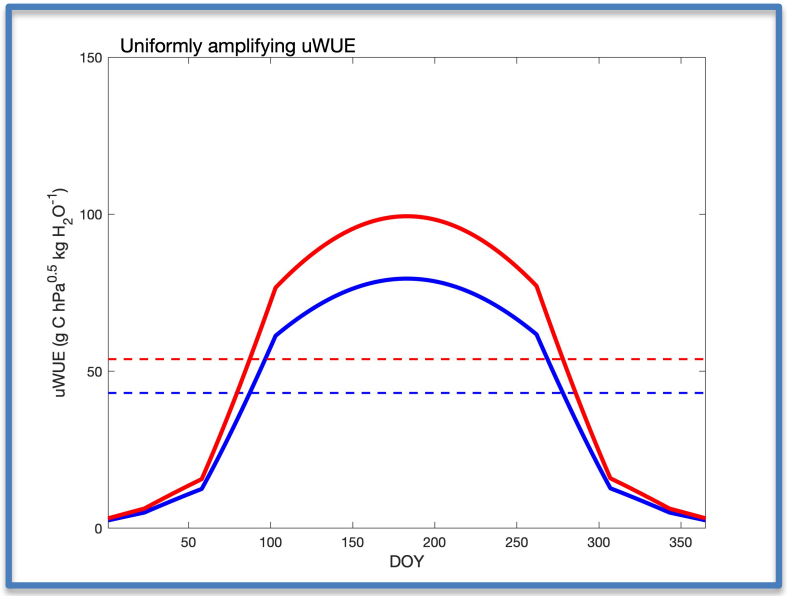


What leads to recent increases in uWUE?

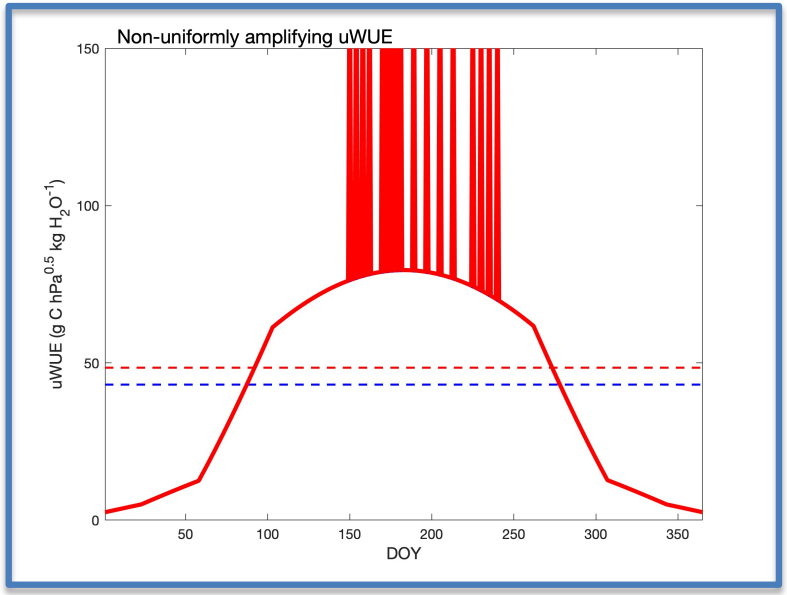


Keenan et al. (2013)

Shifts in baseline



Shifts in extreme

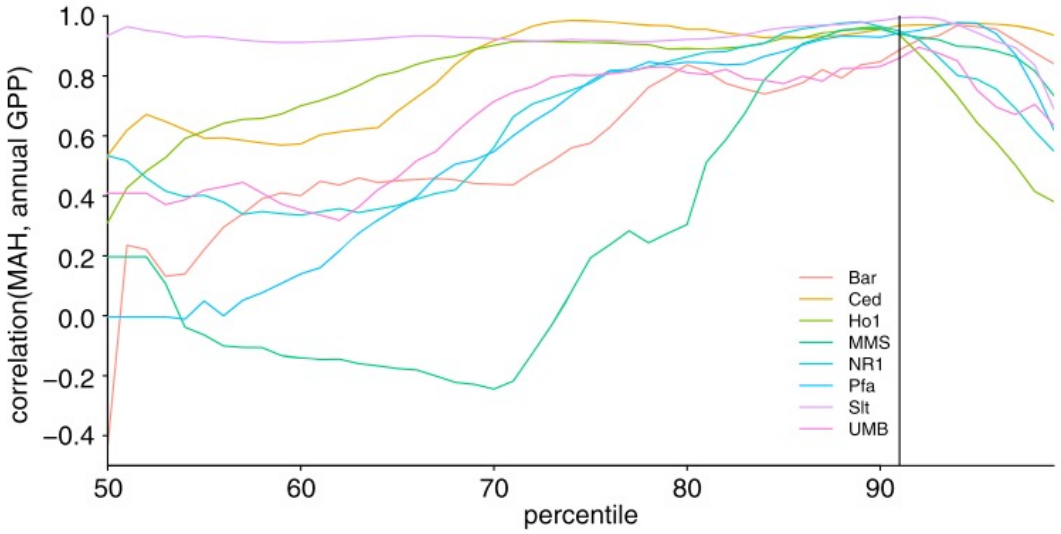


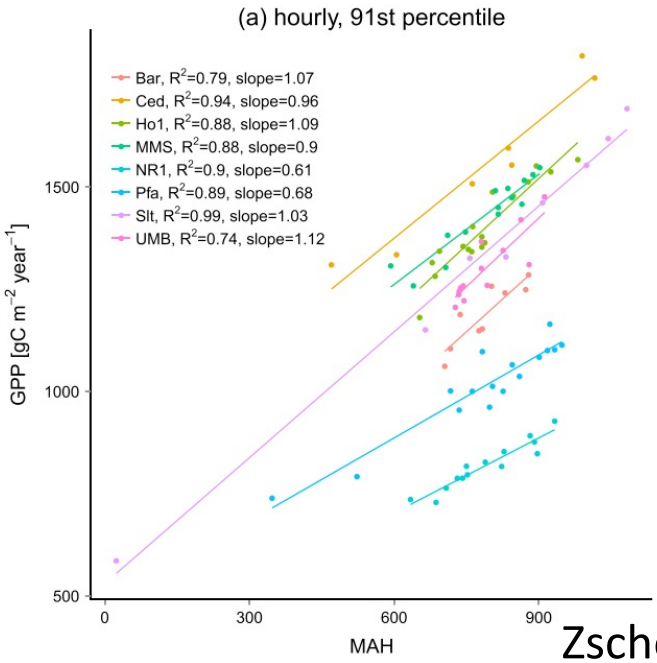
Most Active Hours (*MAH*)

GPP, RE, NEP, and ET

$$\mathrm{MAH}^{x}(y) = \sum_{i=1}^{n} 1_{\{x(y,i) > p\}}$$

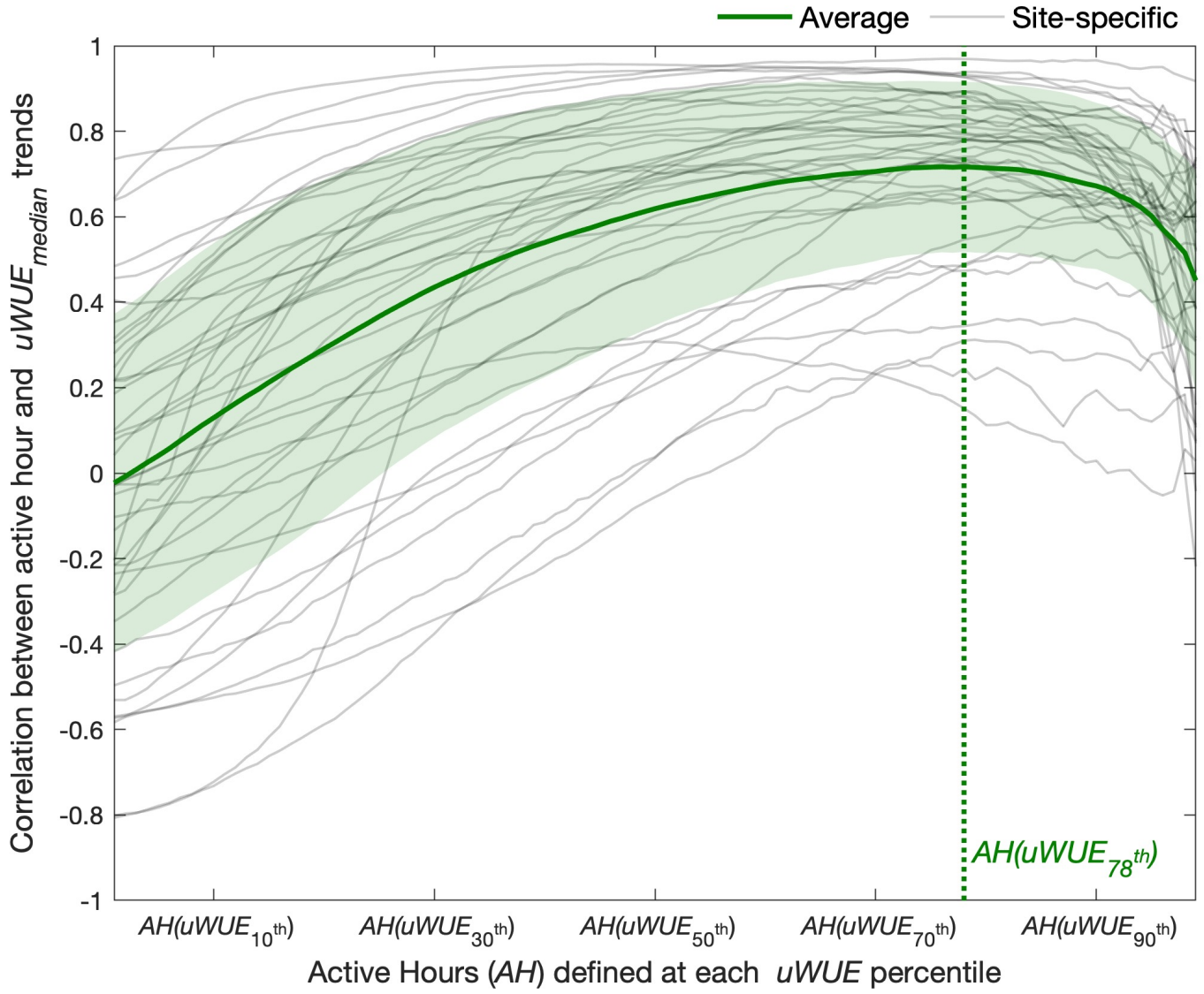
The percentile of the respective flux over the entire site-years



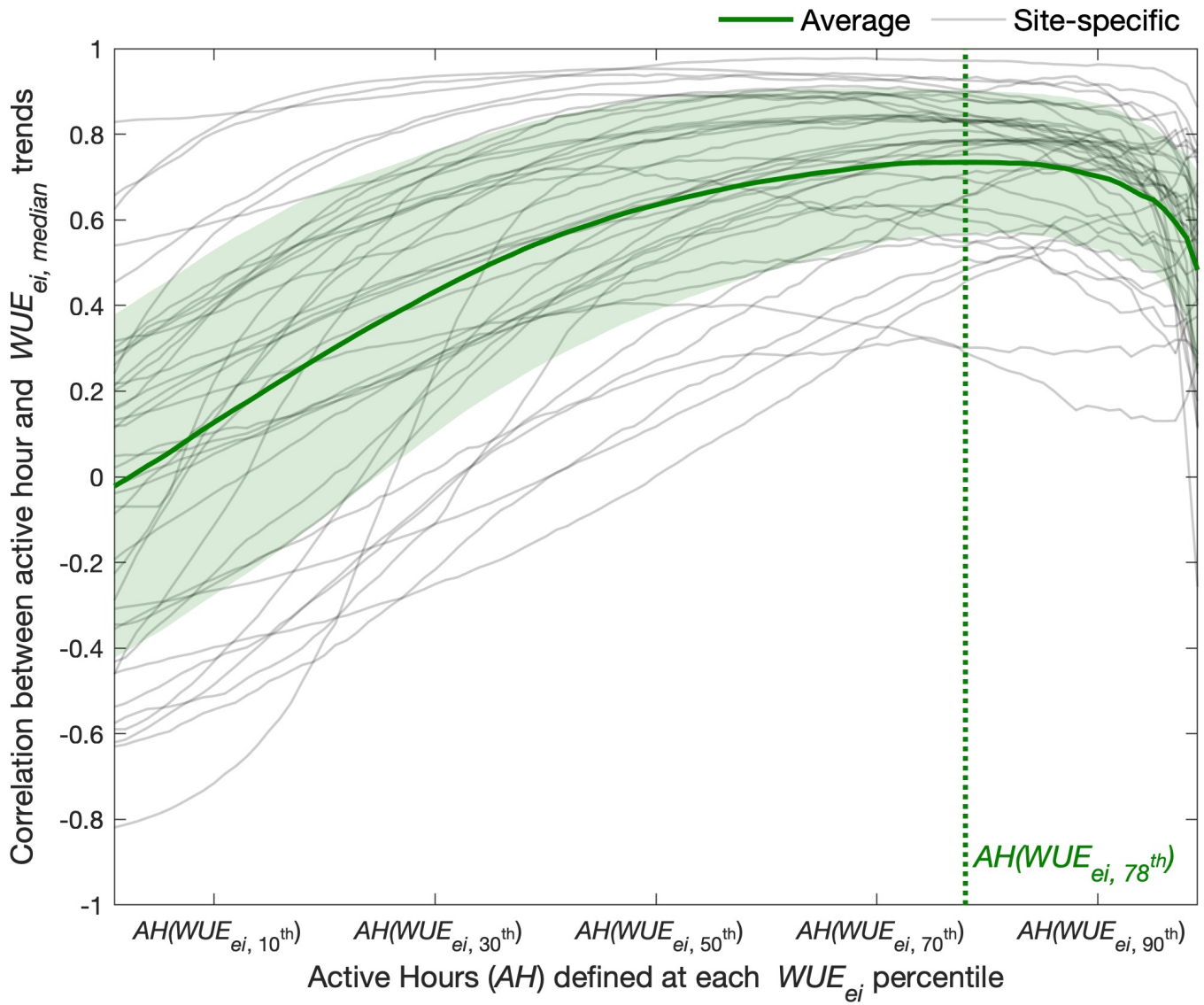


Zscheischler et al. (2016)

Correlation between *AH* and *uWUE* increases with higher *uWUE* percentiles



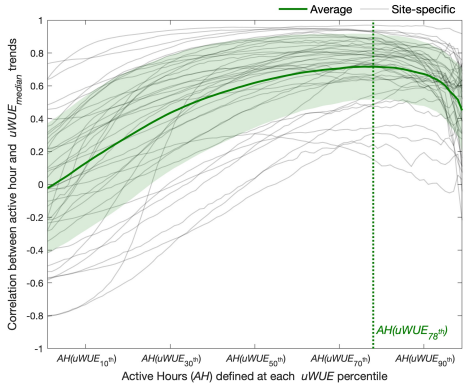
Consistent results with WUE_{ei}

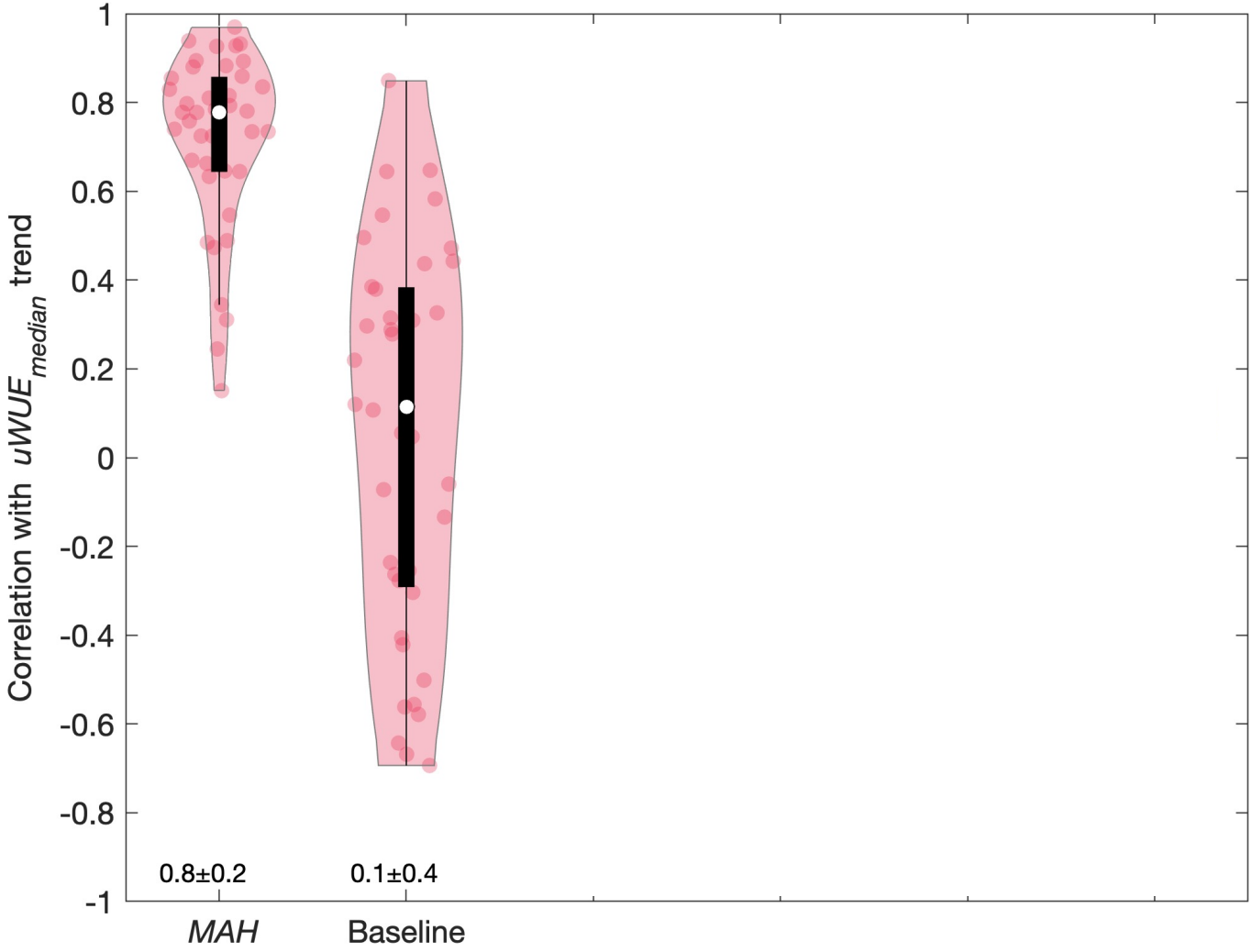


Factors controlling decadal trends in *uWUE*

***MAH* -> WUE ≥ WUE^{78th}**

***Baseline* ->WUE^{60th} ≥ WUE ≥ WUE^{40th}**





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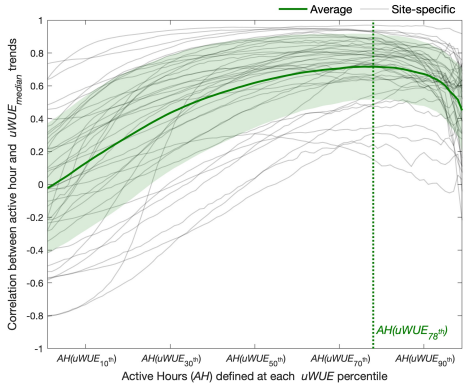

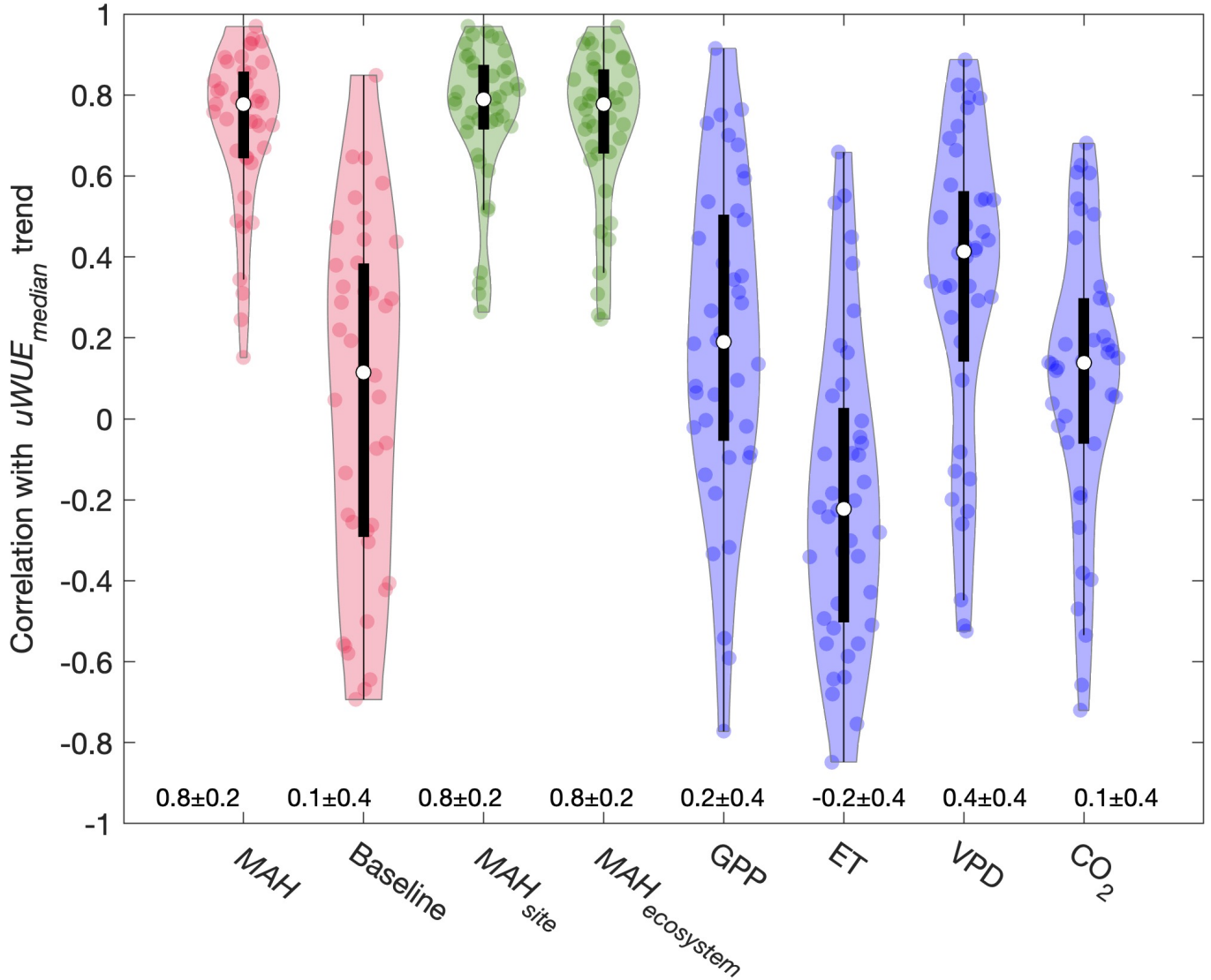

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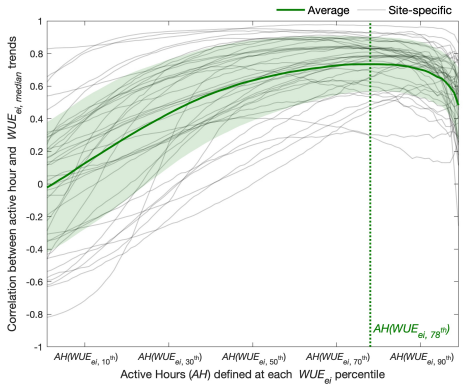
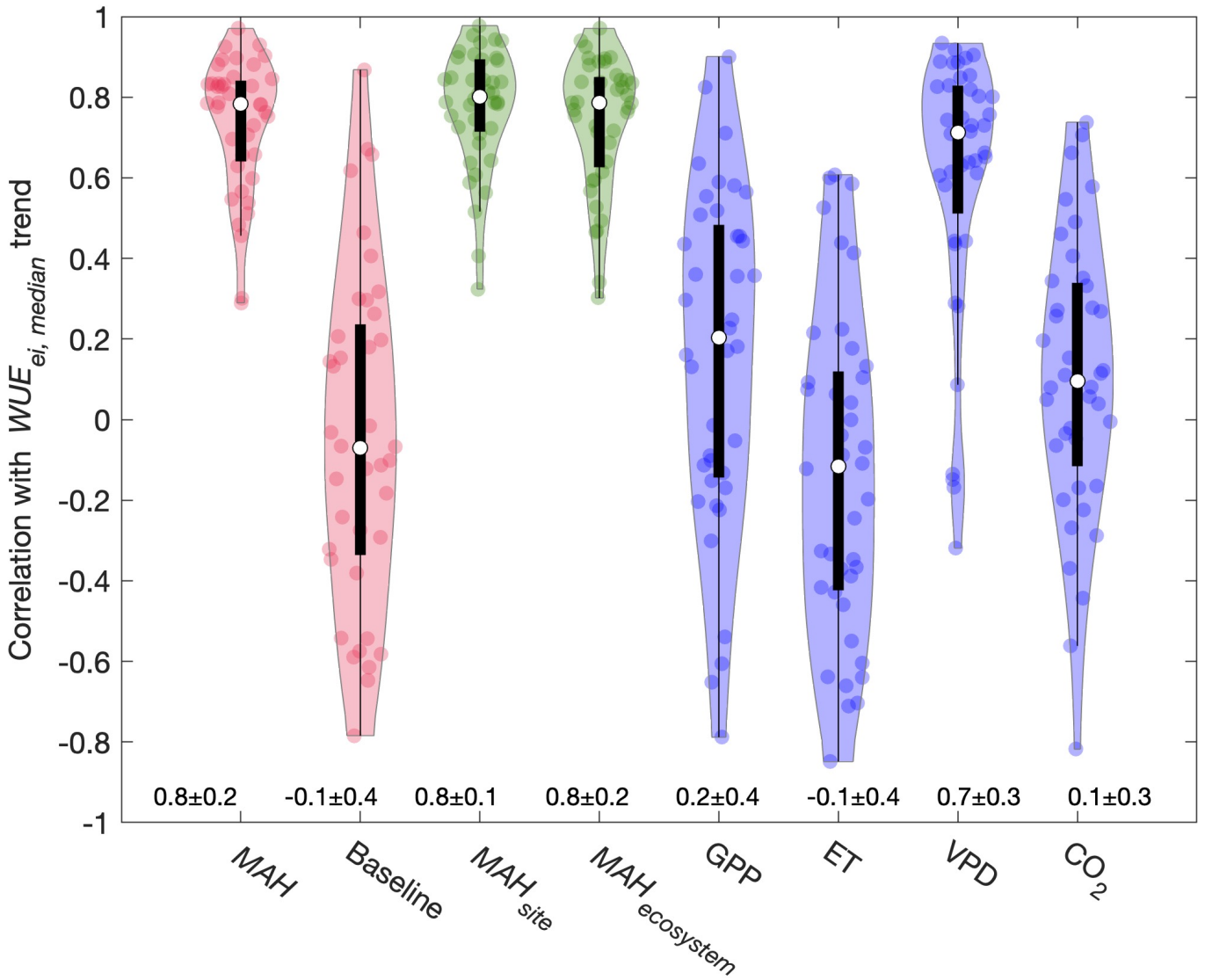
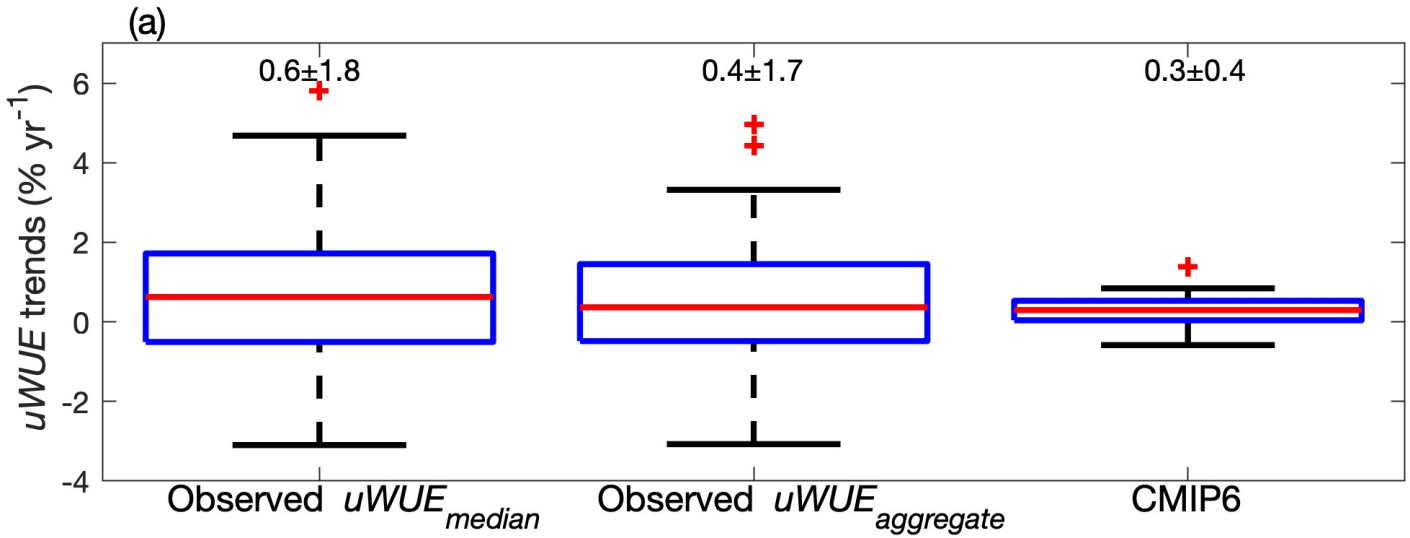
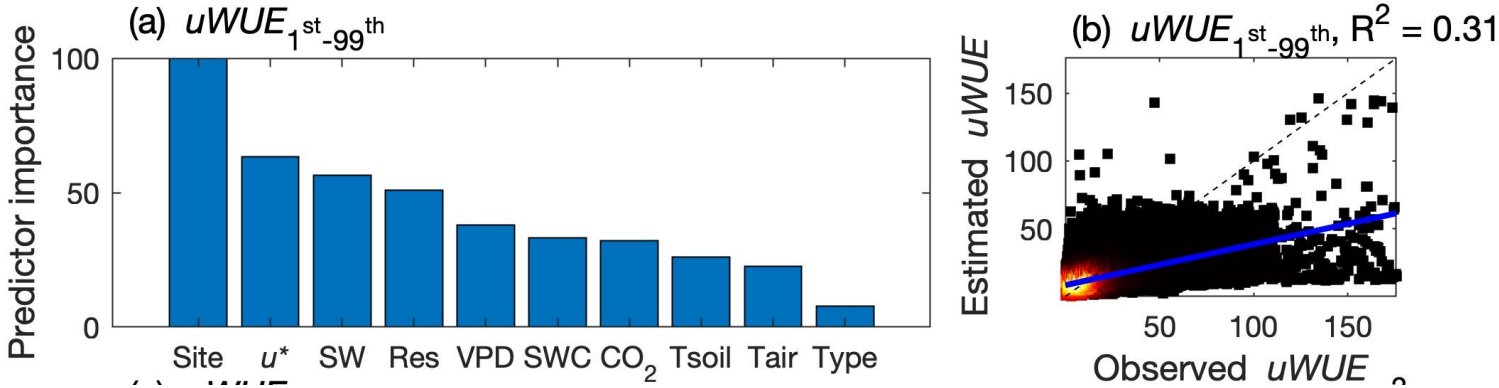




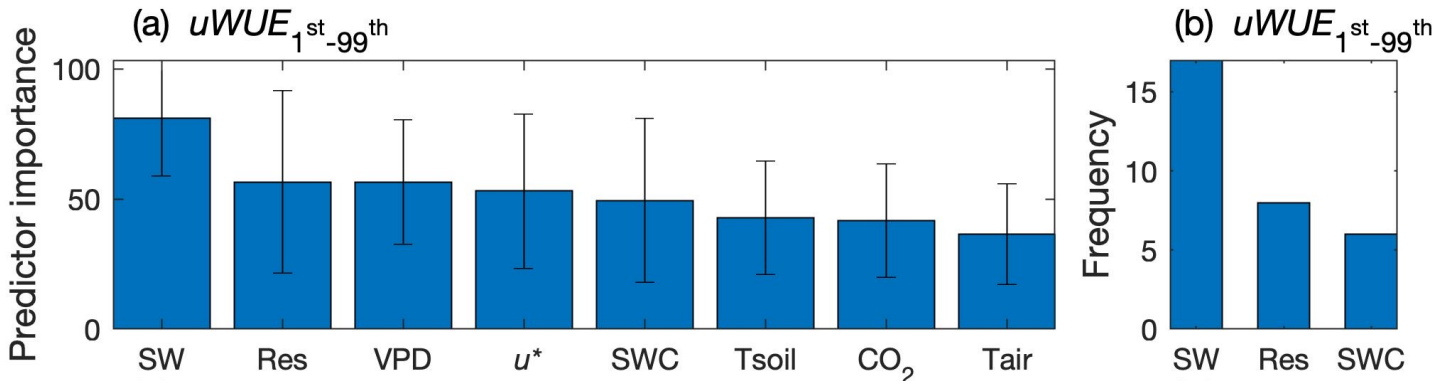
Favorable weather conditions modulate *uWUE* trends



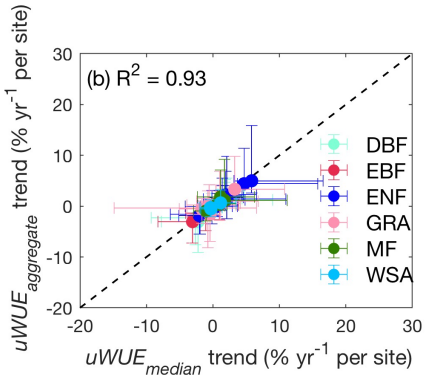
Large inter-site variability in WUE



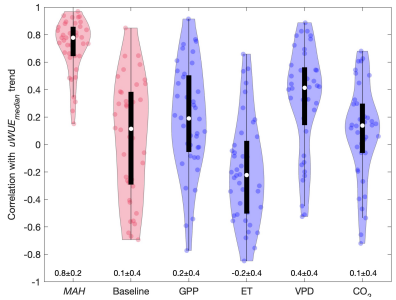
Variations in solar radiation affect water-carbon interactions



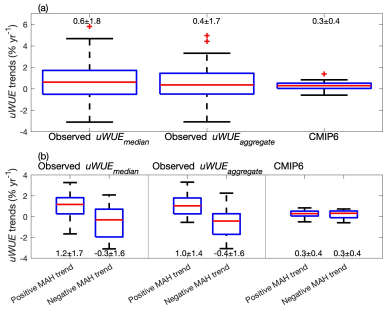
Summary



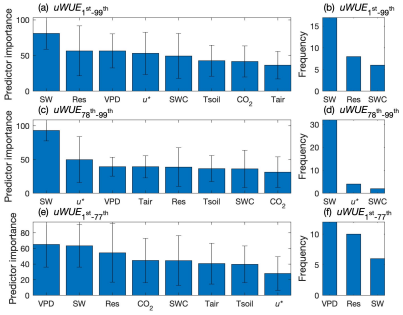
WUE trends inferred from the median of hourly *WUE* values are comparable with those from seasonal aggregated GPP, ET and VPD.



WUE trends correlate well with temporal changes in the number of hours when *WUE* is greater than its 78th percentile value.



MAH trends may amplify or dampen the corresponding *uWUE* trends. CMIP6 models do not resolve the sensitivity observed in ecosystem-scale flux measurements.



Enhanced feedbacks to solar radiation elevates ecosystem-scale *WUE*, which contributes to high correlation between *WUE* and *MAH*.

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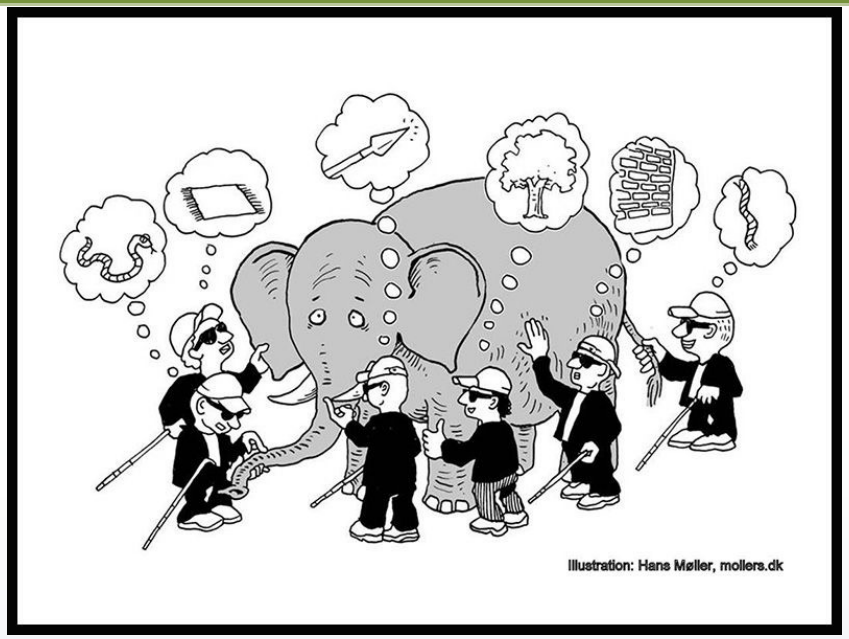
Questions?



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