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Exploring the Potential of Satellite Solar-Induced Fluorescence to Constrain Global Transpiration Estimates

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Introduction

The following figures and tables are an overview of the data used and various validations. A series of quality checks are applied to eliminate towers in which net radiation (Rn) at the tower footprint could be unrepresentative of the pixel-scale true value. A minimum of 175 observations (days) is required for each tower to be included in the final validation set. Similarly, average daily net radiation is compared between towers and Clouds and Earth's Radiant Energy System (CERES) data. Towers with Pearson's correlation coefficient (R) < 0.25 or unbiased root mean square error (RMSE) > 250 W/m2 are also omitted. Finally, towers within 0.5° pixels where fraction of water exceeds 10% are masked to minimize open water influence on evaporation for models. The choice of these thresholds is admittedly subjective, and remains a trade-off between data quality and data quantity, yet it does not affect the relative findings of the analysis.

Table S1. List of adjusted α values implemented per biome type, as calculated by Maes et al. [1] using a subset of unstressed days.

Biome Type	α[-]
CRO	0.86
GRA	0.74
DBF	0.80
EBF	0.74
ENF	0.62
MF	0.64
CSH	0.64
WSA	0.70
SAV	0.68
OSH	0.58
WET	0.75

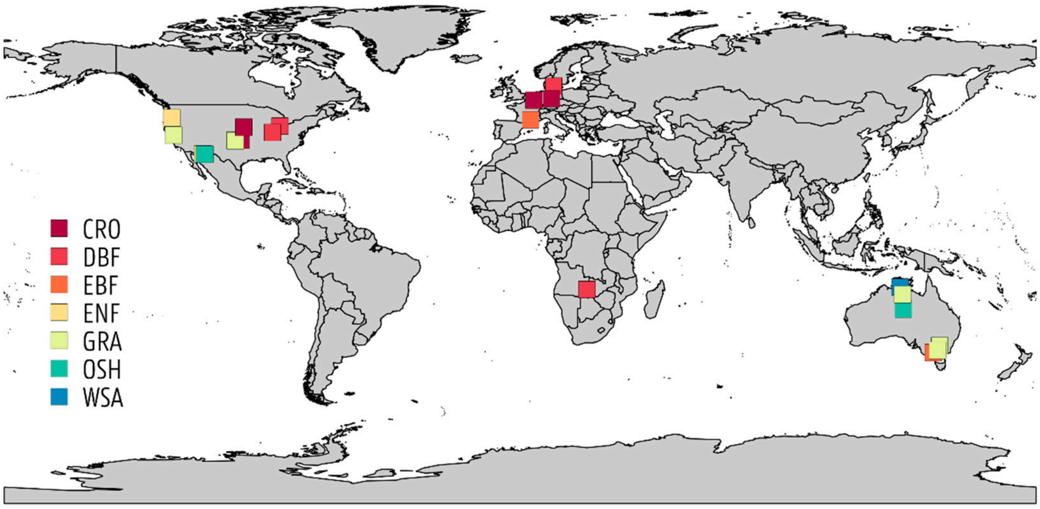

Figure S1. FLUXNET towers used for comparisons. Varying colors indicate the International Geosphere-Biosphere Programme (IGBP) biome type.

Table S2. List of FLUXNET sites used for this analysis.

FLUXNET-ID	Years Used	Land Class	Reference/PI
AU-RDF	2011 – 2013	WSA	[2]
AU-Rig	2011 – 2014	GRA	[3]
AU-Stp	2008 – 2014	GRA	[4]
AU-TTE	2012 – 2014	OSH	[5]
AU-Wom	2010 – 2014	EBF	[6]
AU-Ync	2012 – 2014	GRA	[7]
BE-Lon	2007 – 2014	CRO	[8]
DE-Geb	2007 – 2014	CRO	[9]
DK-Sor	2007 – 2014	DBF	[10]
FR-Pue	2007 – 2014	EBF	[11]
US-AR1	2009 – 2012	GRA	[12]
US-AR2	2009 – 2012	GRA	[12]
US-ARM	2007 – 2012	CRO	[13]
US-MMS	2007 – 2014	DBF	[14]
US-Me2	2007 – 2014	ENF	[15]
US-Ne1	2007 – 2013	CRO	[16]
US-Ne2	2007 – 2013	CRO	[16]
US-Ne3	2007 – 2013	CRO	[16]
US-Oho	2007 – 2013	DBF	[17]
US-SRC	2008 – 2014	OSH	Shirley Kurc
US-SRG	2008 – 2014	GRA	[18]
US-Var	2007 – 2014	GRA	[19]
US-Whs	2007 – 2014	OSH	[20]
US-Wkg	2007 – 2014	GRA	[21]
ZM-Mon	2007 – 2009	DBF	[22]

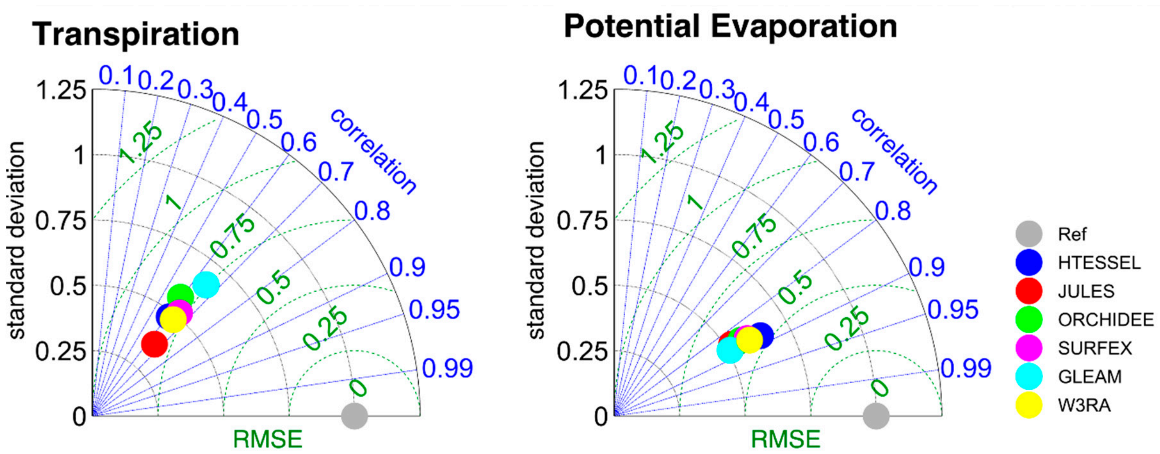

Figure S2. Taylor diagrams depicting the average normalized standard deviation, normalized centered RMSE, and correlation across the 25 flux towers in Figure S1. Results are for biweekly average transpiration (**left**) and potential evaporation (**right**).

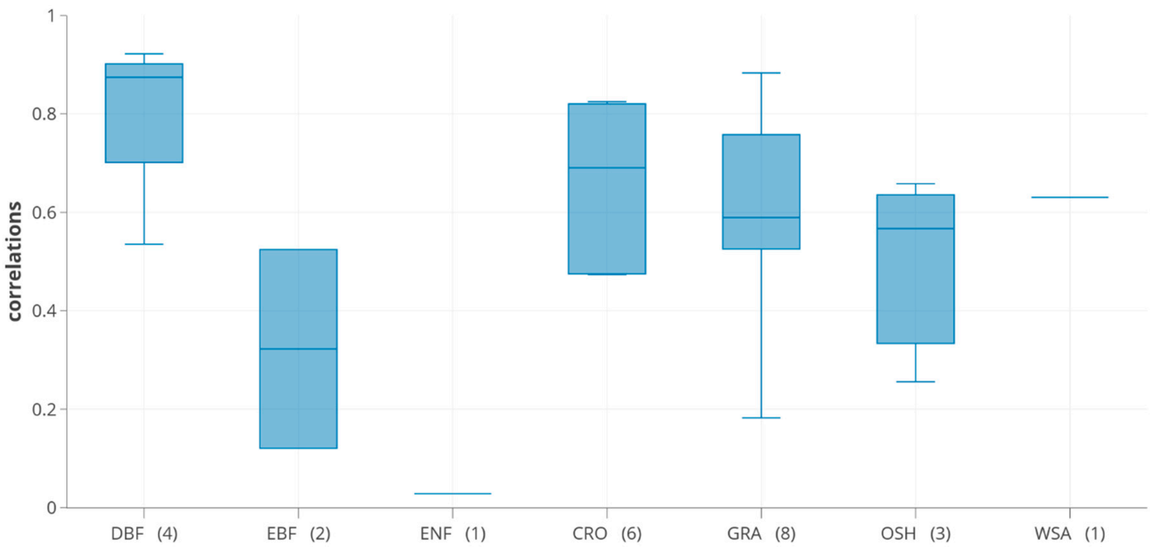

Figure S3. SIF/PAR correlations against tower τ grouped by International Geosphere-Biosphere Programme (IGBP) classifications for the 25 towers from Figure S1. Numbers in parentheses indicate the number of sites within each classification.

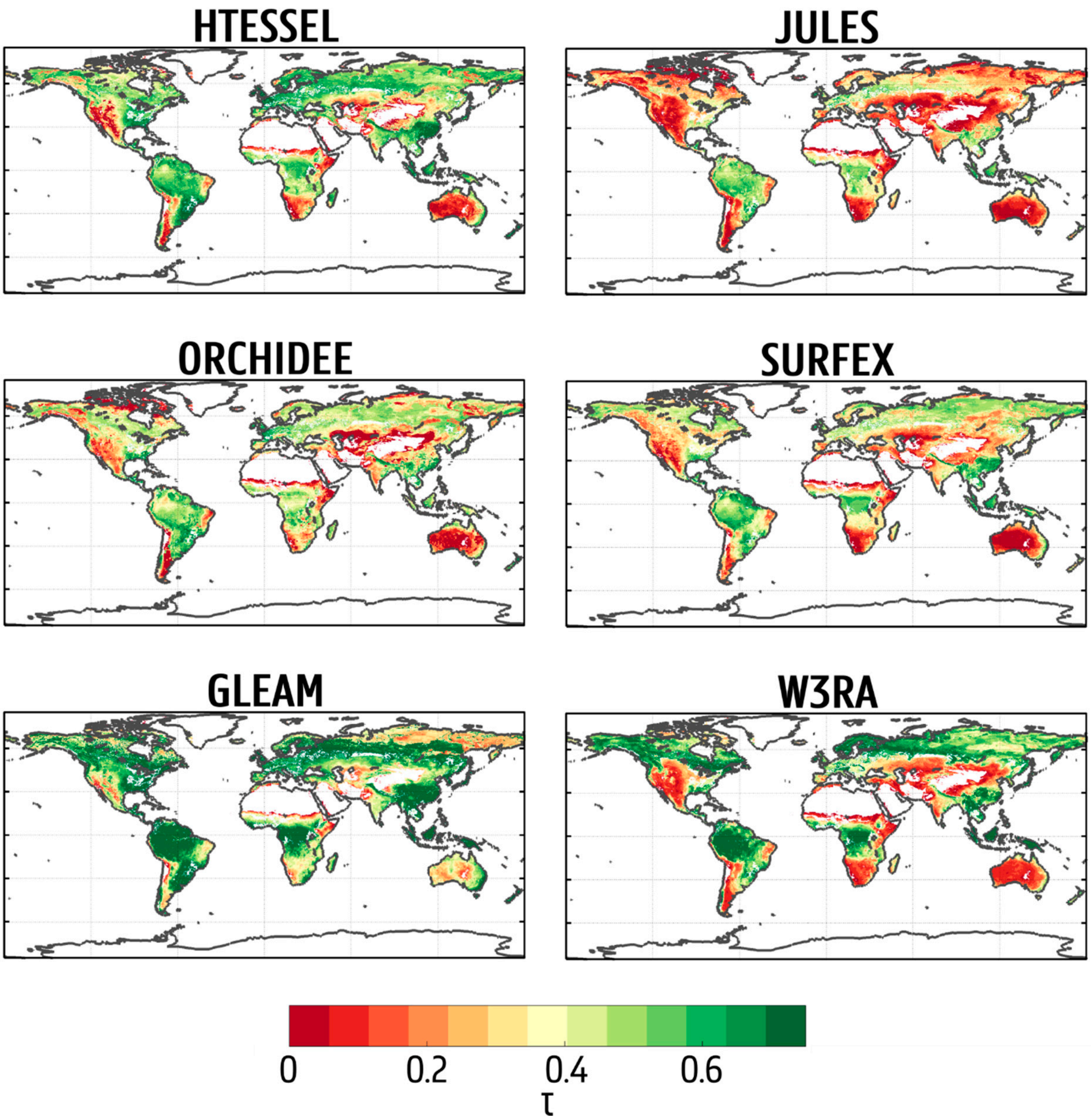

Figure S4. Average values for τ from each eartH2Observe model globally. The time period considered is 2007–2014. Pixels designated as barren or snow and ice from IGBP classifications are masked out.

References

1. Maes, W.H.H.; Gentine, P.; Verhoest, N.E.C.E.C.; Miralles, D.G.G. Potential evaporation at eddy-covariance sites across the globe. *Hydrol. Earth Syst. Sci. Discuss.* **2019**, 1–33, doi:10.5194/hess-2017-682.
2. Beringer, J. Red Dirt Melon Farm OzFlux tower site OzFlux: Australian and New Zealand Flux Research and Monitoring. Available online: http://hdl.handle.net/102.100.100/14245 (accessed on 1 October 2017).
3. Beringer, J. Riggs Creek OzFlux tower site. OzFlux: Australian and New Zealand Flux Research and Monitoring. Available online: http://hdl.handle.net/102.100.100/14246 (accessed on 1 October 2017).
4. Beringer, J. Sturt Plains OzFlux tower site OzFlux: Australian and New Zealand Flux Research and Monitoring. Available online: http://hdl.handle.net/102.100.100/14230 (accessed on 1 October 2017).
5. Cleverly, J. Ti Tree East OzFlux Site OzFlux: Australian and New Zealand Flux Research and Monitoring. Available online: http://hdl.handle.net/102.100.100/14225 (accessed on 1 October 2017).
6. Arndt, S. Wombat State Forest OzFlux-tower site OzFlux: Australian and New Zealand Flux Research and Monitoring. Available online: http://hdl.handle.net/102.100.100/14237 (accessed on 1 October 2017).
7. Beringer, J. Yanco JAXA OzFlux tower site OzFlux: Australian and New Zealand Flux Research and

Monitoring. Available online: http://hdl.handle.net/102.100.100/14235 (accessed on 1 October 2017).
8. Moureaux, C.; Debacq, A.; Bodson, B.; Heinesch, B.; Aubinet, M. Annual net ecosystem carbon exchange by a sugar beet crop. *Agric. For. Meteorol.* **2006**, *139*, 25–39.
9. Bonan, G.B.; Lawrence, P.J.; Oleson, K.W.; Levis, S.; Jung, M.; Reichstein, M.; Lawrence, D.M.; Swenson, S.C. Improving canopy processes in the Community Land Model version 4 (CLM4) using global flux fields empirically inferred from FLUXNET data. *J. Geophys. Res.* **2011**, *116*, 1–22.
10. Pilegaard, K.; Mikkelsen, T.N.; Beier, C.; Jensen, N.O.; Ambus, P.; Ro-Poulsen, H. Field measurements of atmosphere – biosphere interactions in a Danish beech forest. *Boreal Environ. Res.* **2003**, *8*, 315–333.
11. Rambal, S.; Joffre, R.; Ourcival, J.M.; Cavender-Bares, J.; Rocheteau, A. The growth respiration component in eddy CO2 flux from a Quercus ilex mediterranean forest. *Glob. Chang. Biol.* **2004**, *10*, 1460–1469.
12. Gilmanov, T.G.; Aires, L.; Barcza, Z.; Baron, V.S.; Belelli, L.; Beringer, J.; Billesbach, D.; Bonal, D.; Bradford, J.; Ceschia, E.; et al. Productivity, respiration, and light-response parameters of world grassland and agroecosystems derived from flux-tower measurements. *Rangel. Ecol. Manag.* **2010**, *63*, 16–39.
13. Fischer, M.L.; Billesbach, D.P.; Berry, J.A.; Riley, W.J.; Torn, M.S.; Fischer, M.L.; Billesbach, D.P.; Berry, J.A.; Riley, W.J.; Torn, M.S. Spatiotemporal Variations in Growing Season Exchanges of CO_2, H_2O, and Sensible Heat in Agricultural Fields of the Southern Great Plains. *Earth Interact.* **2007**, *11*, 1–21.
14. Schmid, H.P.; Grimmond, C.S.B.; Cropley, F.; Offerle, B.; Su, H.B. Measurements of CO2 and energy fluxes over a mixed hardwood forest in the mid-western United States. *Agric. For. Meteorol.* **2000**, *103*, 357–374.
15. Vickers, D.; Thomas, C.K.; Pettijohn, C.; Martin, J.G.; Law, B.E. Five years of carbon fluxes and inherent water-use efficiency at two semi-arid pine forests with different disturbance histories. *Tellus, Ser. B Chem. Phys. Meteorol.* **2012**, *64*, 1–14.
16. Simbahan, G.C.; Dobermann, A.; Goovaerts, P.; Ping, J.; Haddix, M.L. Fine-resolution mapping of soil organic carbon based on multivariate secondary data. *Geoderma* **2006**, *132*, 471–489.
17. Noormets, A.; McNulty, S.G.; DeForest, J.L.; Sun, G.; Li, Q.; Chen, J. Drought during canopy development has lasting effect on annual carbon balance in a deciduous temperate forest. *New Phytol.* **2008**, *179*, 818–828.
18. Scott, R.L.; Biederman, J.A.; Hamerlynck, E.P.; Barron-Gafford, G.A. The carbon balance pivot point of southwestern U.S. semiarid ecosystems: Insights from the 21st century drought. *J. Geophys. Res. Biogeosciences* **2015**, *120*, 2612–2624.
19. Ma, S.; Baldocchi, D.D.; Xu, L.; Hehn, T. Inter-annual variability in carbon dioxide exchange of an oak/grass savanna and open grassland in California. *Agric. For. Meteorol.* **2007**, *147*, 157–171.
20. Scott, R.L. Using watershed water balance to evaluate the accuracy of eddy covariance evaporation measurements for three semiarid ecosystems. *Agric. For. Meteorol.* **2010**, *150*, 219–225.
21. Scott, R.L.; Hamerlynck, E.P.; Jenerette, G.D.; Moran, M.S.; Barron-Gafford, G.A. Carbon dioxide exchange in a semidesert grassland through drought-induced vegetation change. *J. Geophys. Res. Biogeosciences* **2010**, *115*, 1–12.
22. Ciais, P.; Bombelli, A.; Williams, M.; Piao, S.L.; Chave, J.; Ryan, C.M.; Henry, M.; Brender, P.; Valentini, R. The carbon balance of Africa: Synthesis of recent research studies. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2011**, *369*, 2038–2057.