A First Look at ECOSTRESS Water Use Efficiency

ECOSTRESS Science Team Meeting, Feb. 11, 2019

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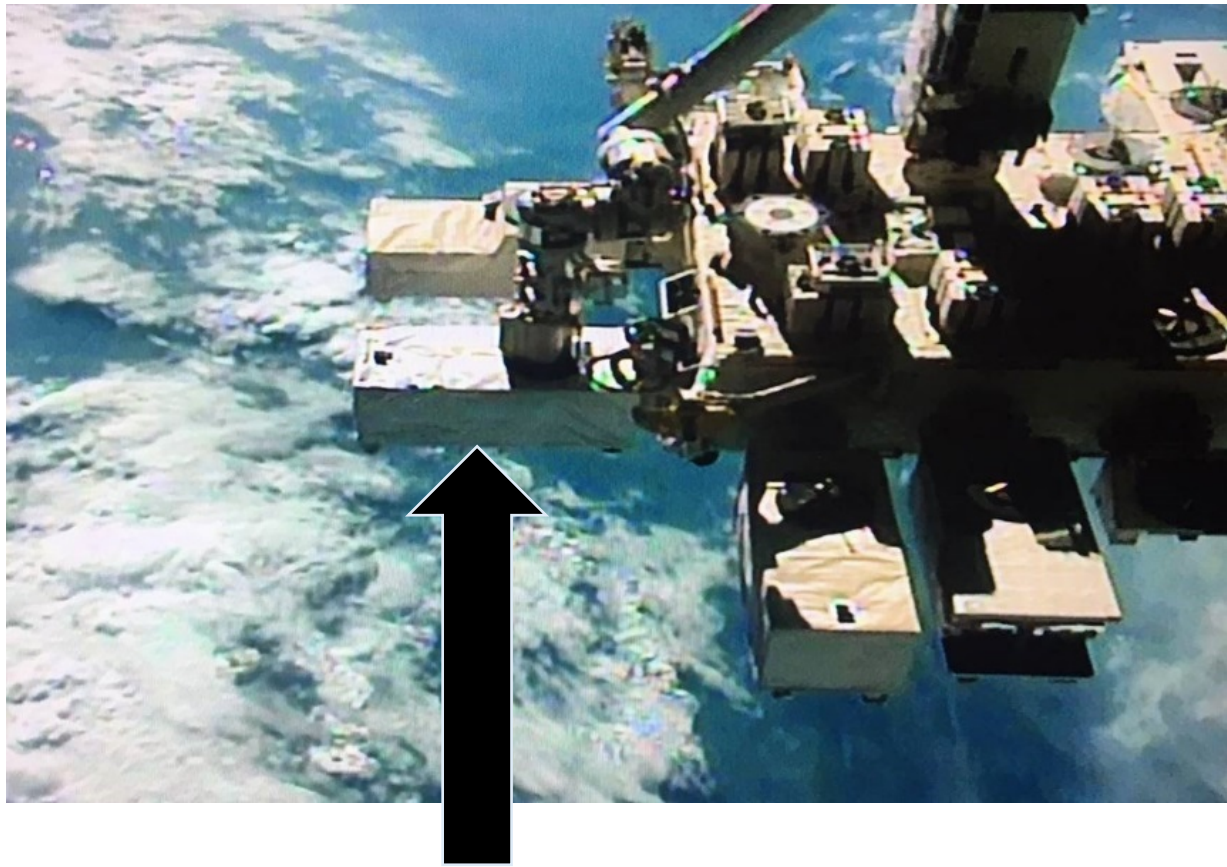
ECOSTRESS Science Questions

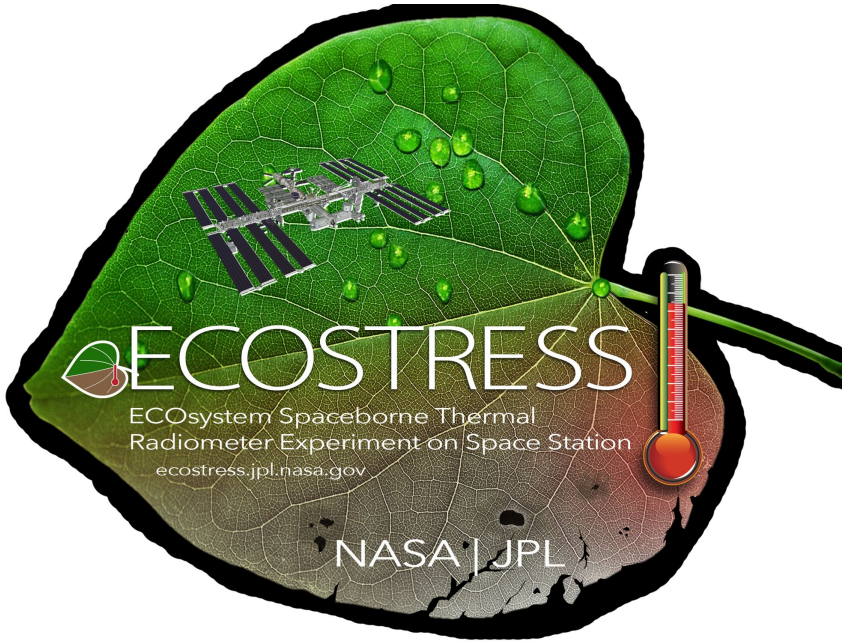
1. **How is the terrestrial biosphere responding to changes in water availability?**

2. How do changes in diurnal vegetation water stress impact the global carbon cycle?

3. Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation?

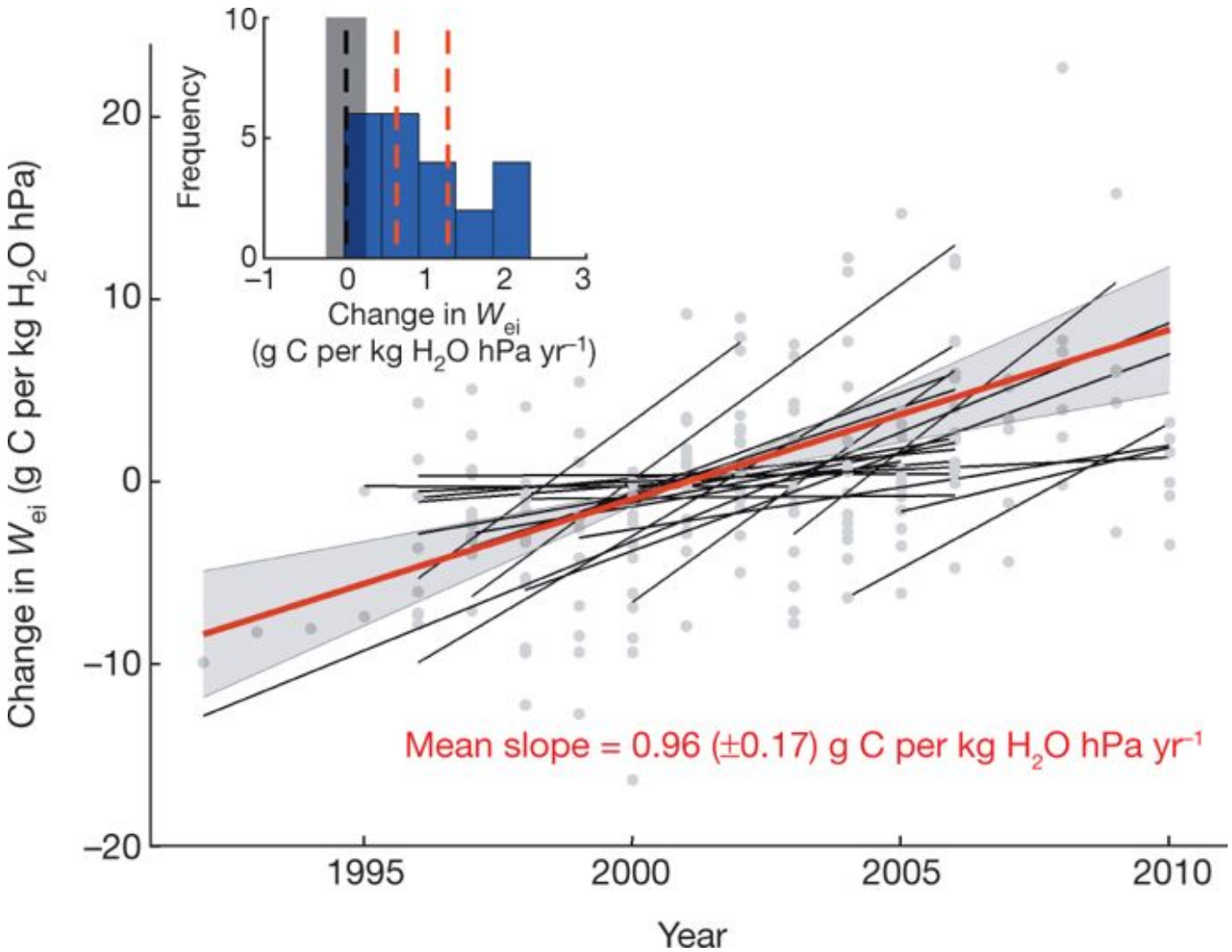


ECOSTRESS on the ISS



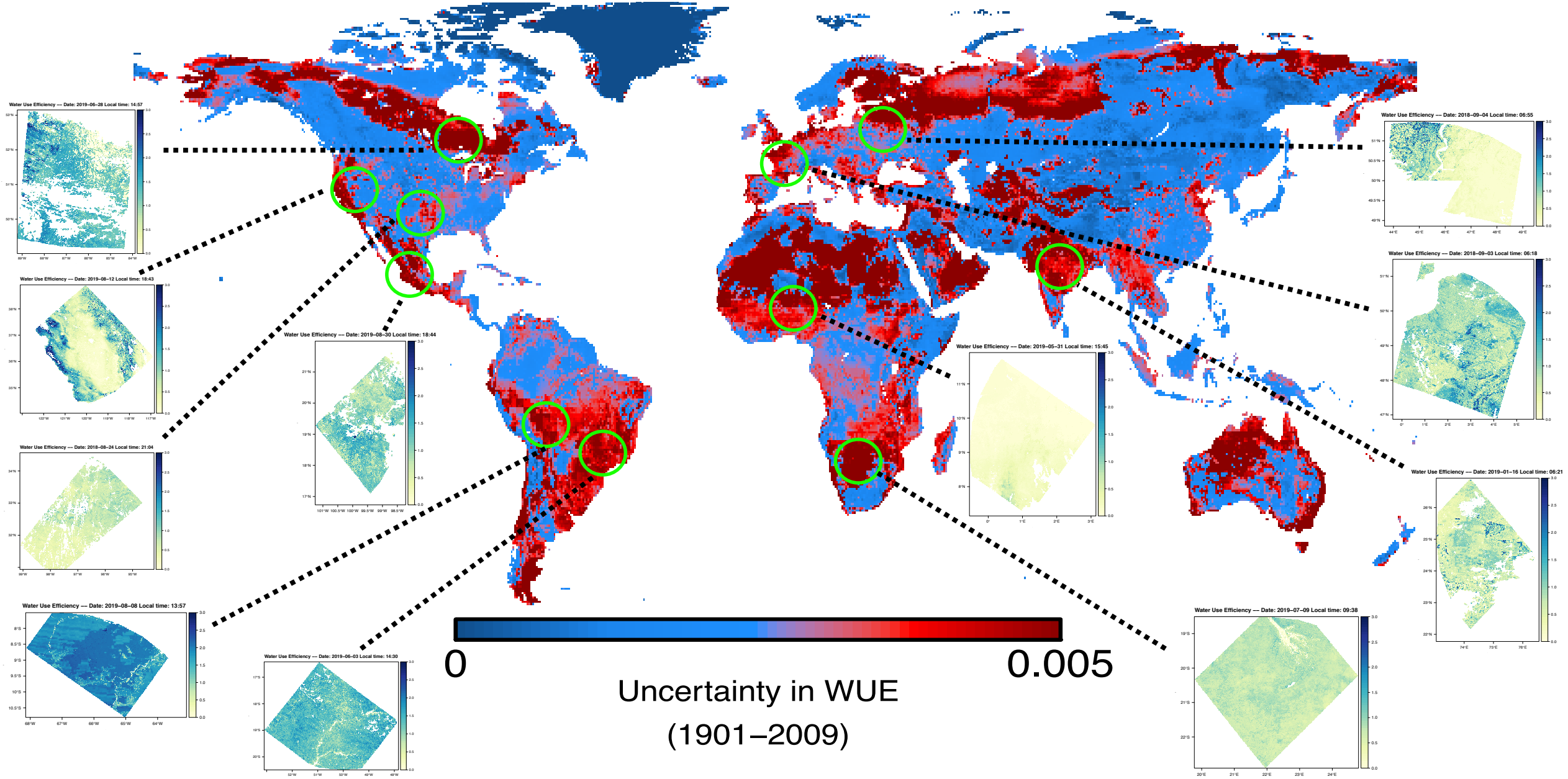
ECOSTRESS Science Data Products	
Level 2	- Surface Temperature - Surface Emissivity
Level 3	**- Evapotranspiration (ET)** (Fisher et al., 2008)
Level 4	**- Water Use Efficiency (GPP / ET)** - Evaporative Stress Index (ET/ PET)

Increasing trend in WUE



Keenan et al. (2013)

Climate Transition Hotspot Study Sites



Methods

Conduct randomization sampling over climate climate transition hotspots

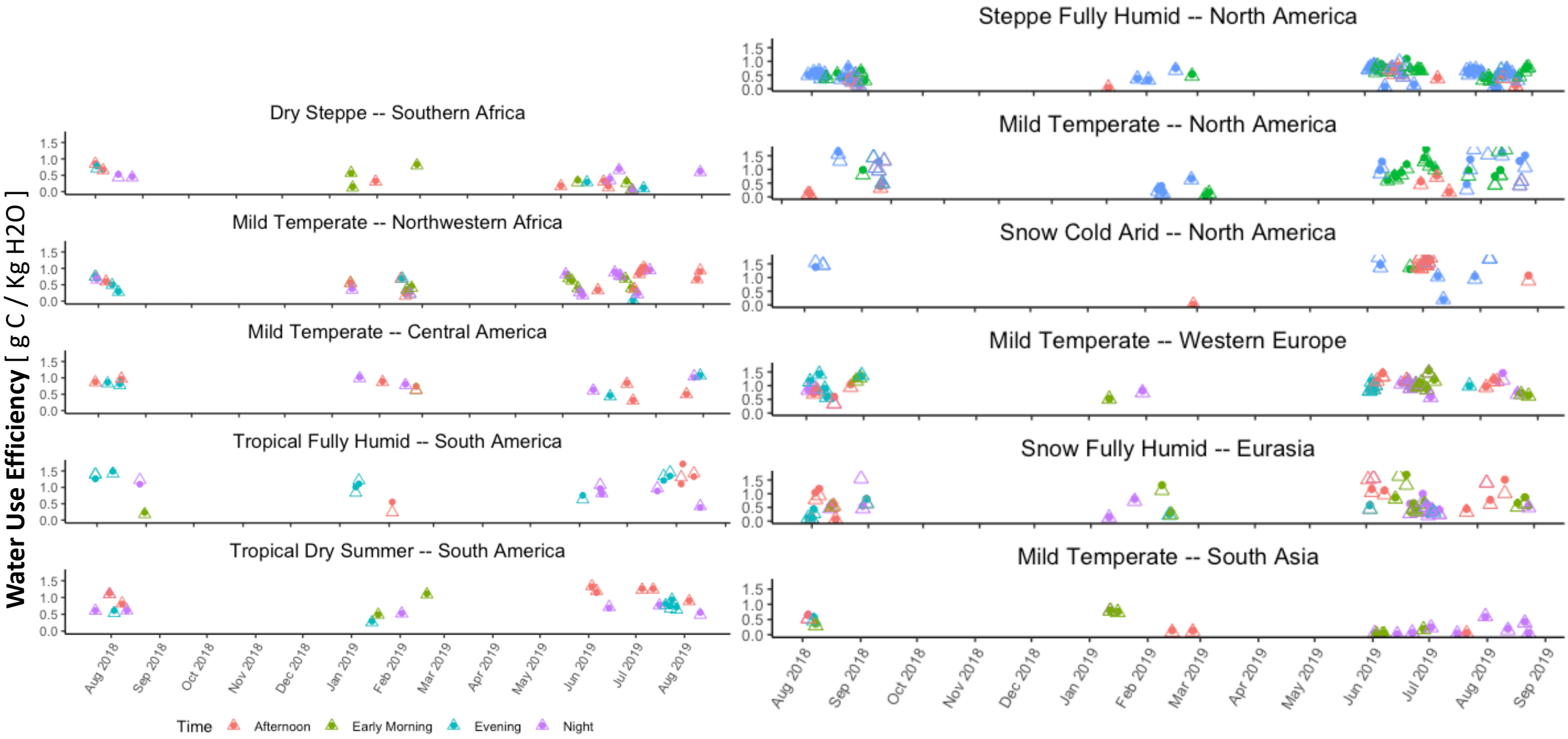
→

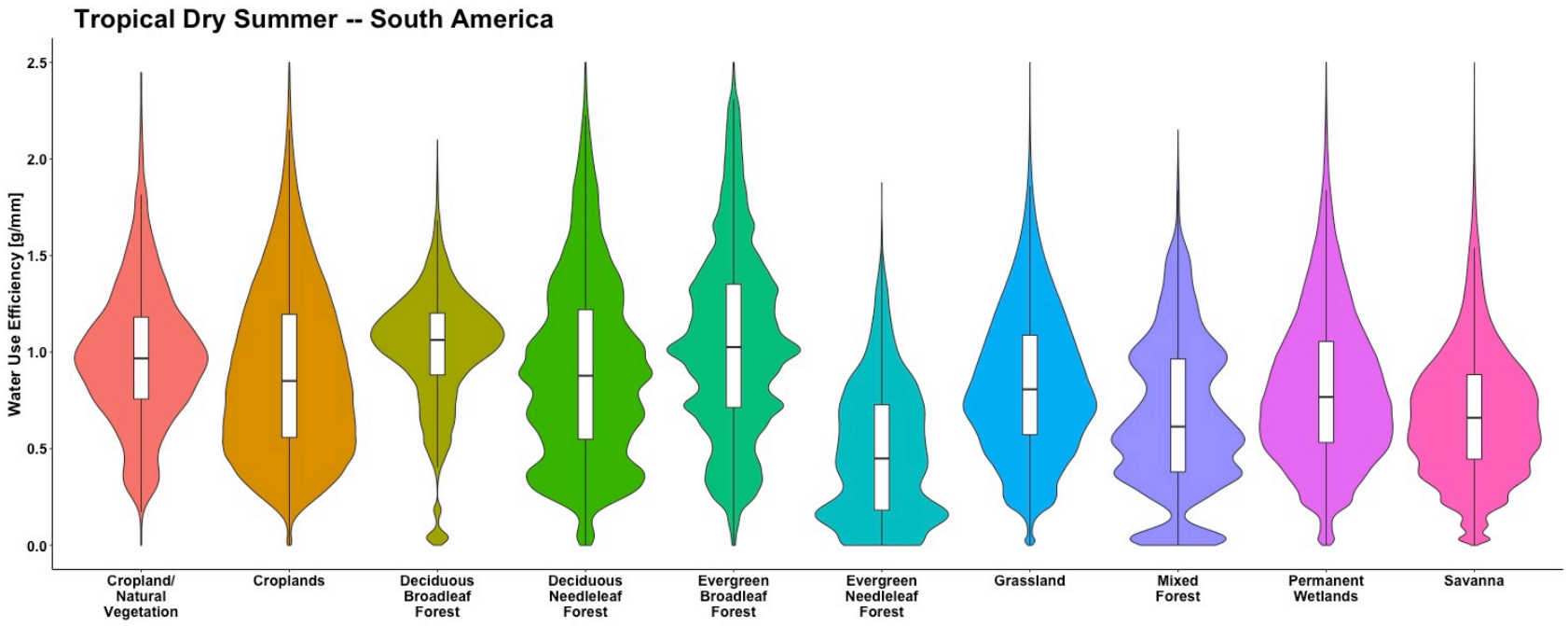
Analyze WUE across land cover

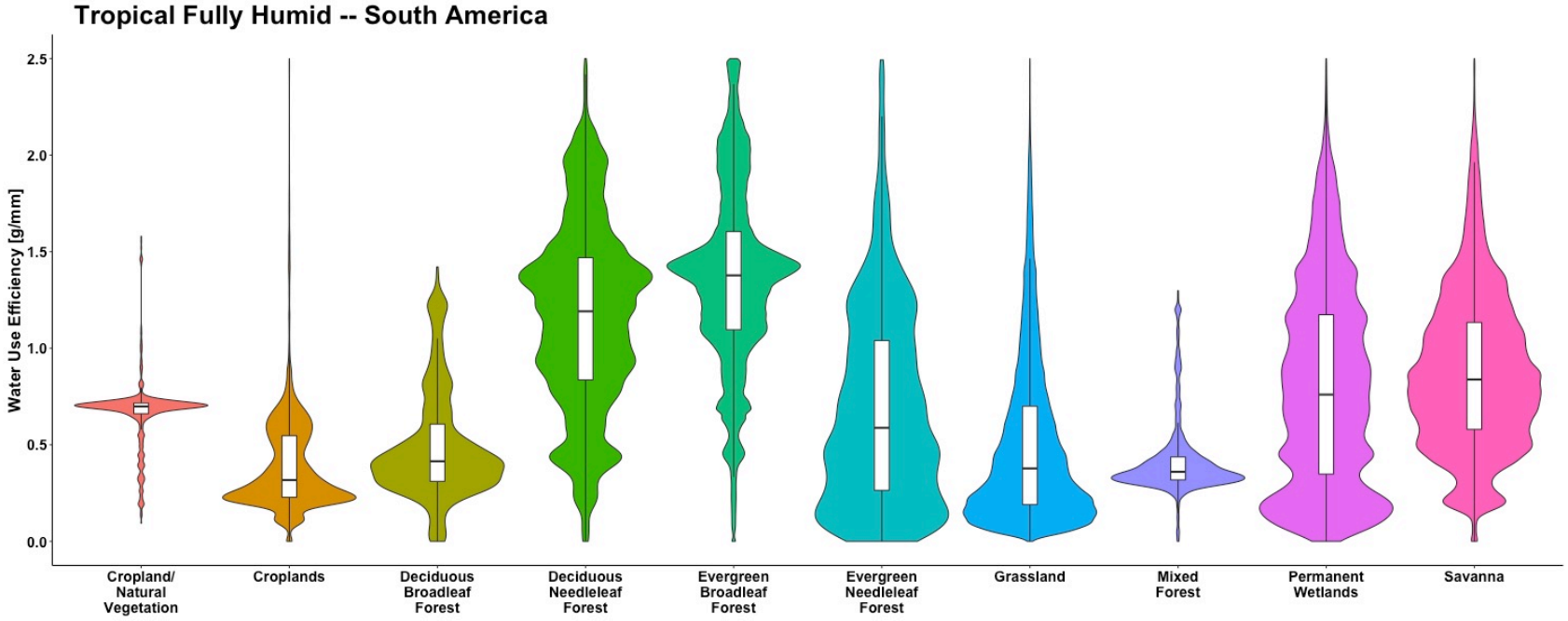
→

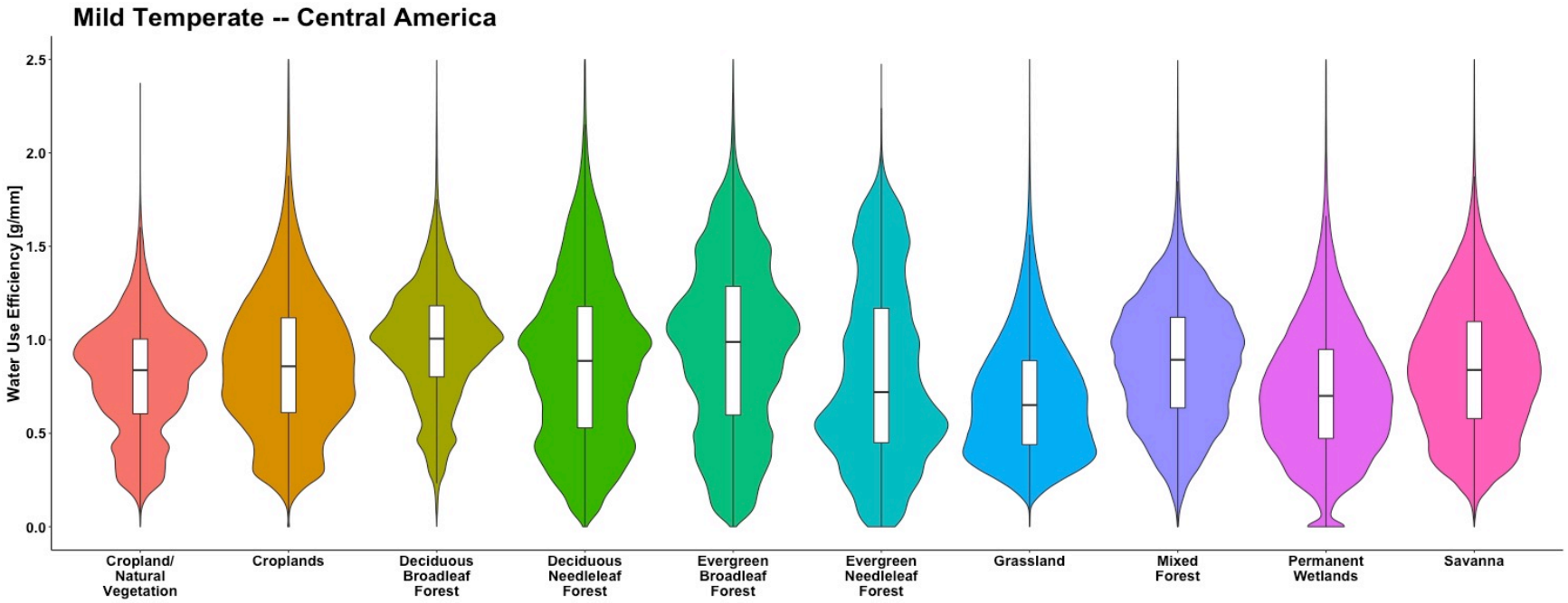
Compute WUE with and without soil evaporation

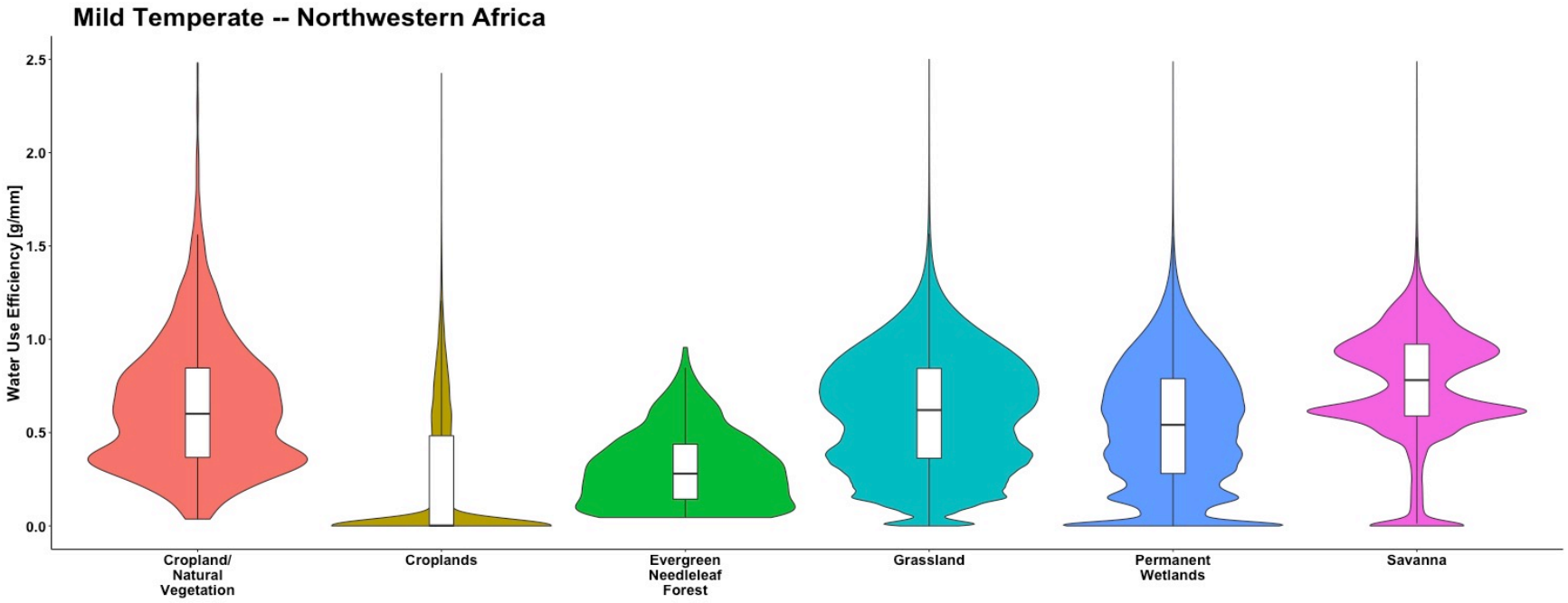
Mean WUE for each site



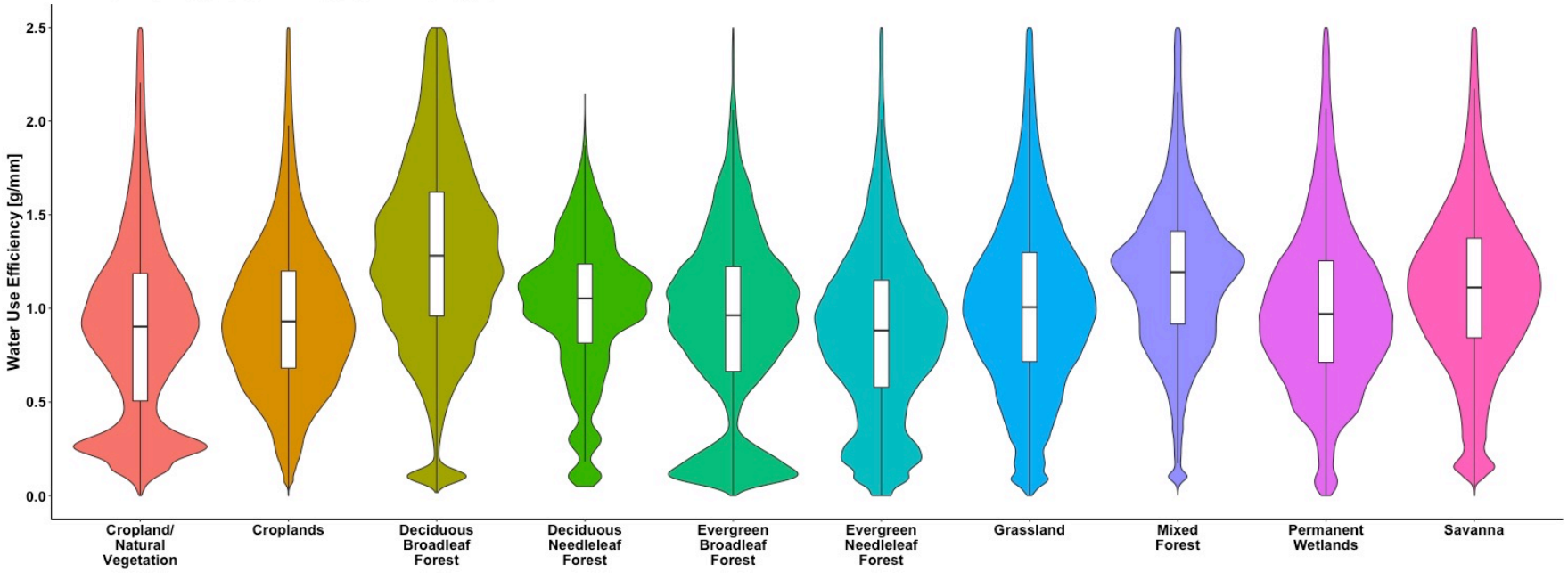

Tropical Dry Summer -- South America
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Cropland/ Natural Vegetation
Croplands
Deciduous Broadleaf Forest
Deciduous Needleleaf Forest
Evergreen Broadleaf Forest
Evergreen Needleleaf Forest
Grassland
Mixed Forest
Permanent Wetlands
Savanna


Tropical Fully Humid -- South America
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Cropland/ Natural Vegetation
Croplands
Deciduous Broadleaf Forest
Deciduous Needleleaf Forest
Evergreen Broadleaf Forest
Evergreen Needleleaf Forest
Grassland
Mixed Forest
Permanent Wetlands
Savanna

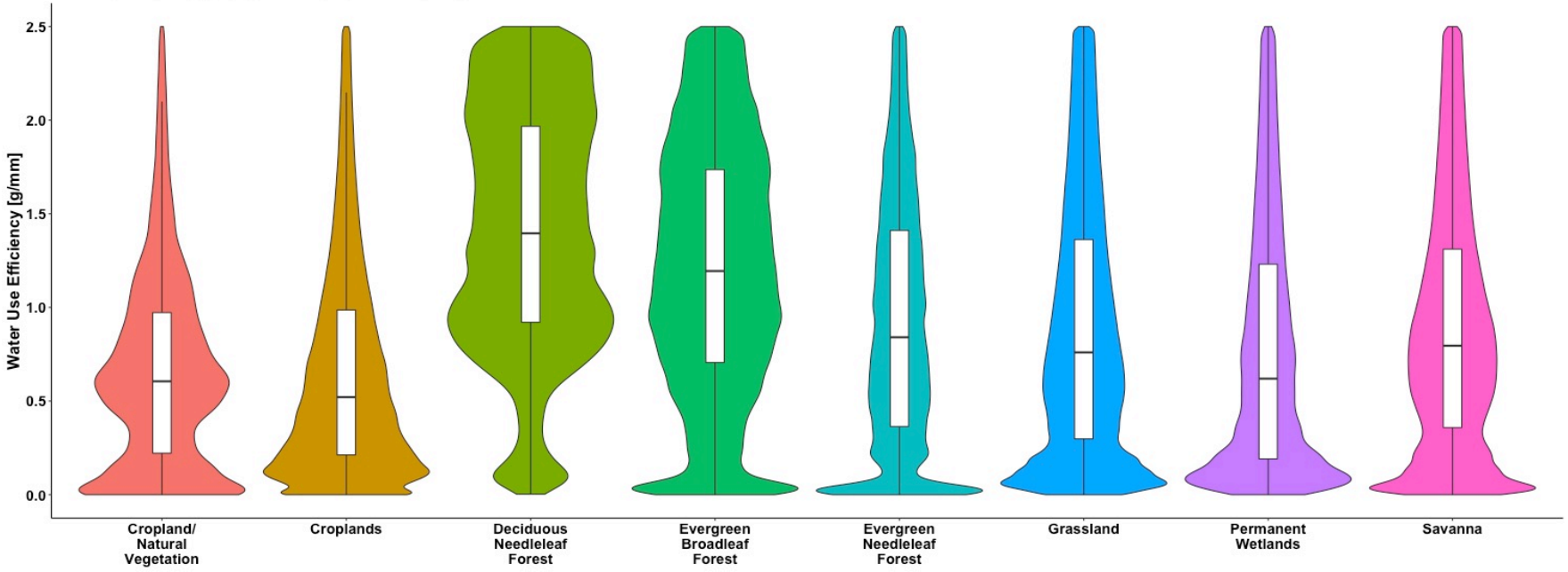

Mild Temperate -- Central America
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Cropland/ Natural Vegetation
Croplands
Deciduous Broadleaf Forest
Deciduous Needleleaf Forest
Evergreen Broadleaf Forest
Evergreen Needleleaf Forest
Grassland
Mixed Forest
Permanent Wetlands
Savanna

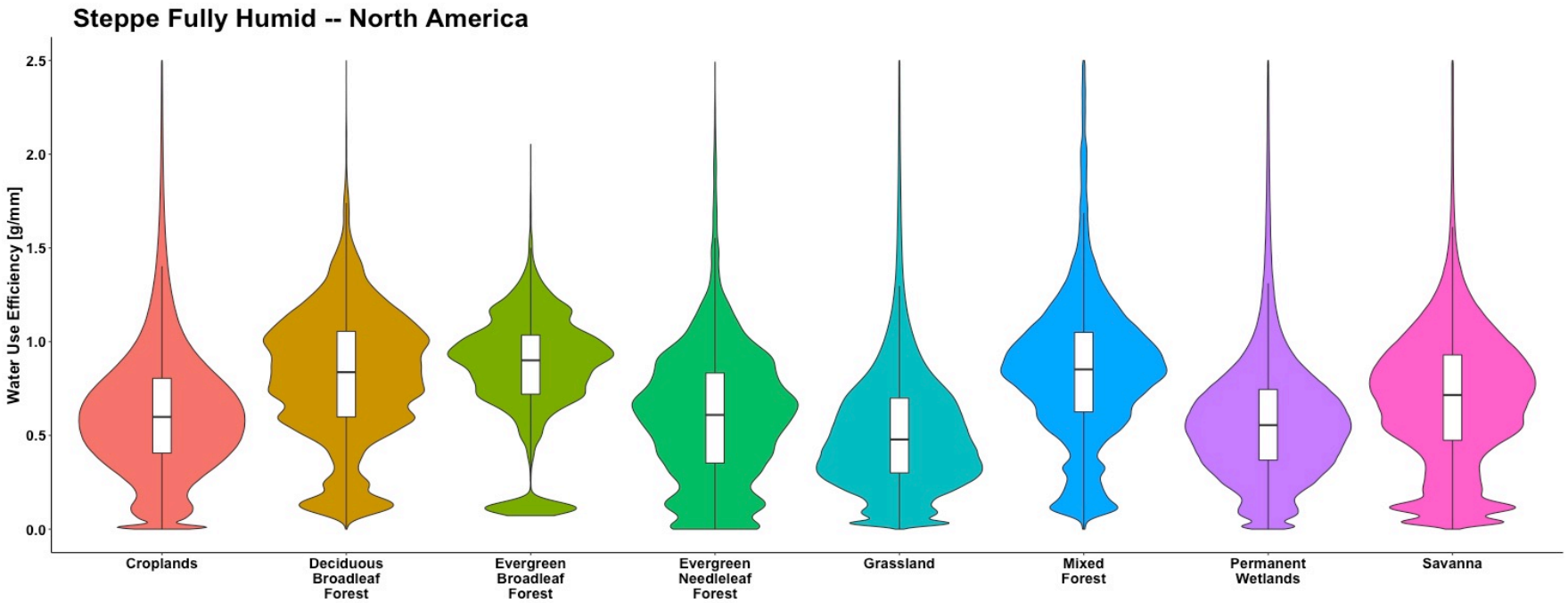

Mild Temperate -- Northwestern Africa
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Cropland/ Natural Vegetation
Croplands
Evergreen Needleleaf Forest
Grassland
Permanent Wetlands
Savanna

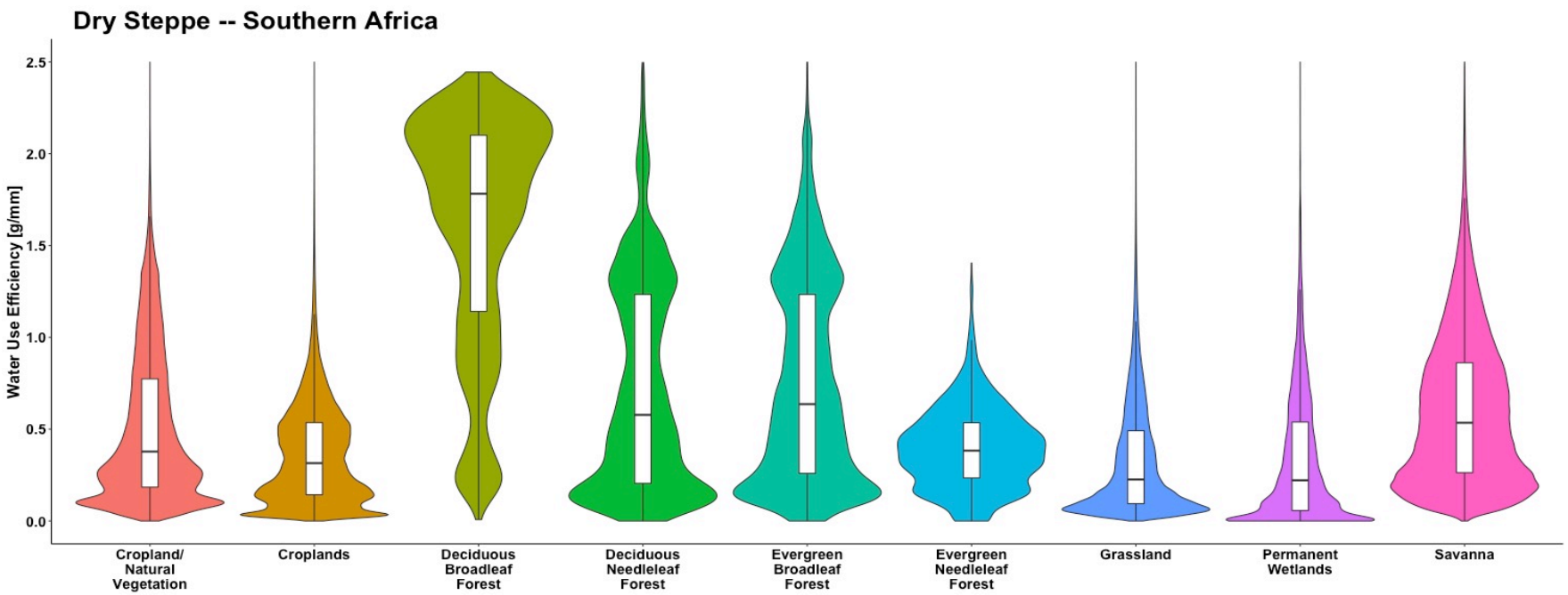
Mild Temperate -- Western Europe

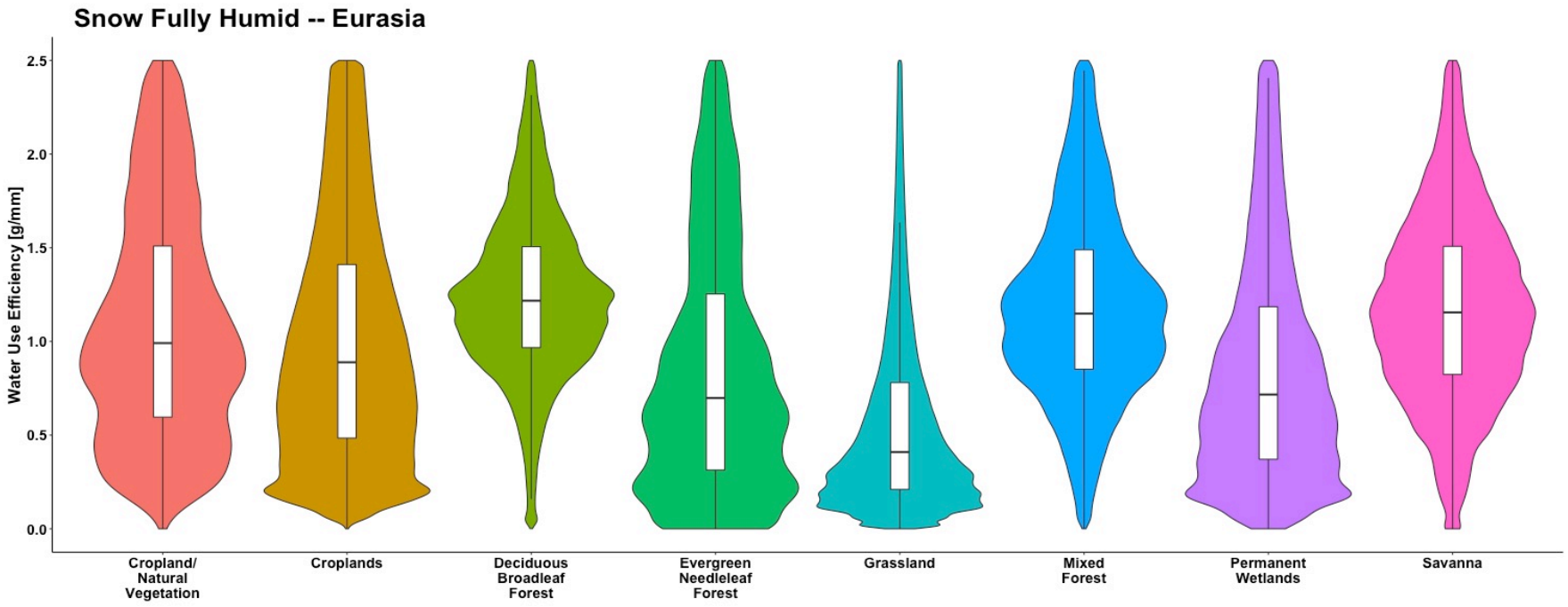


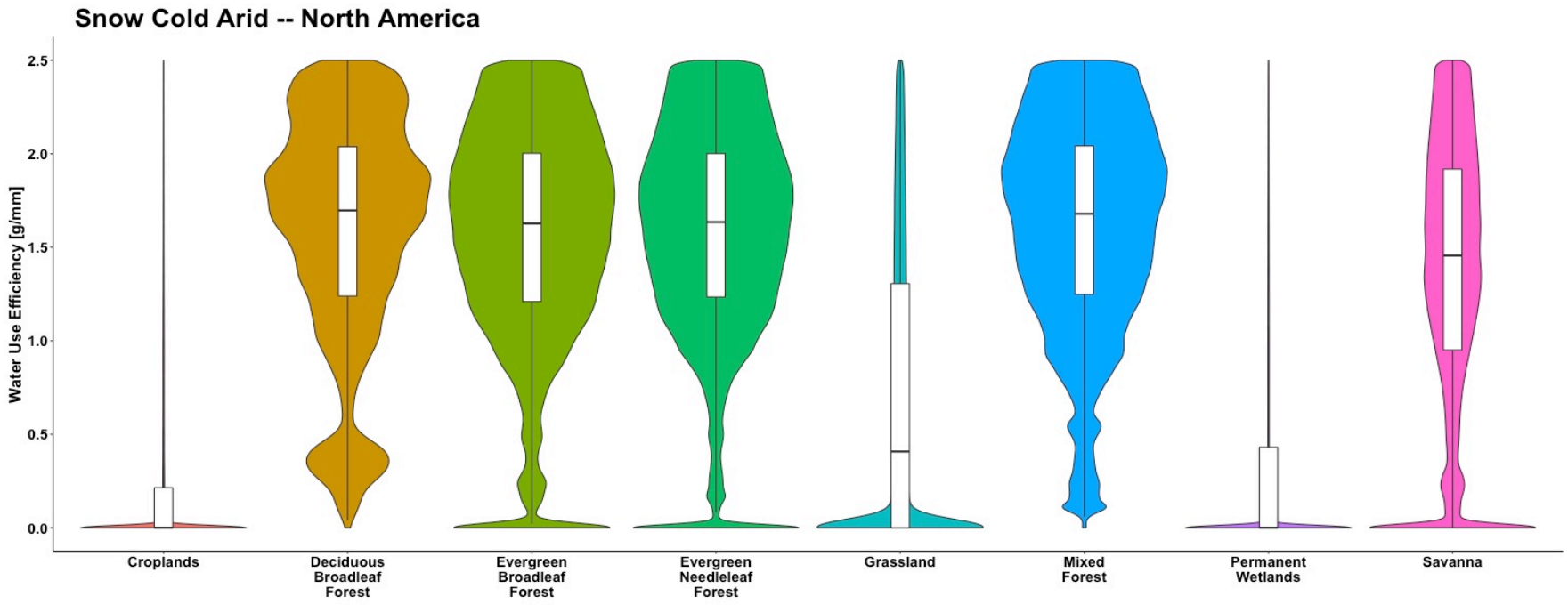
Mild Temperate -- North America



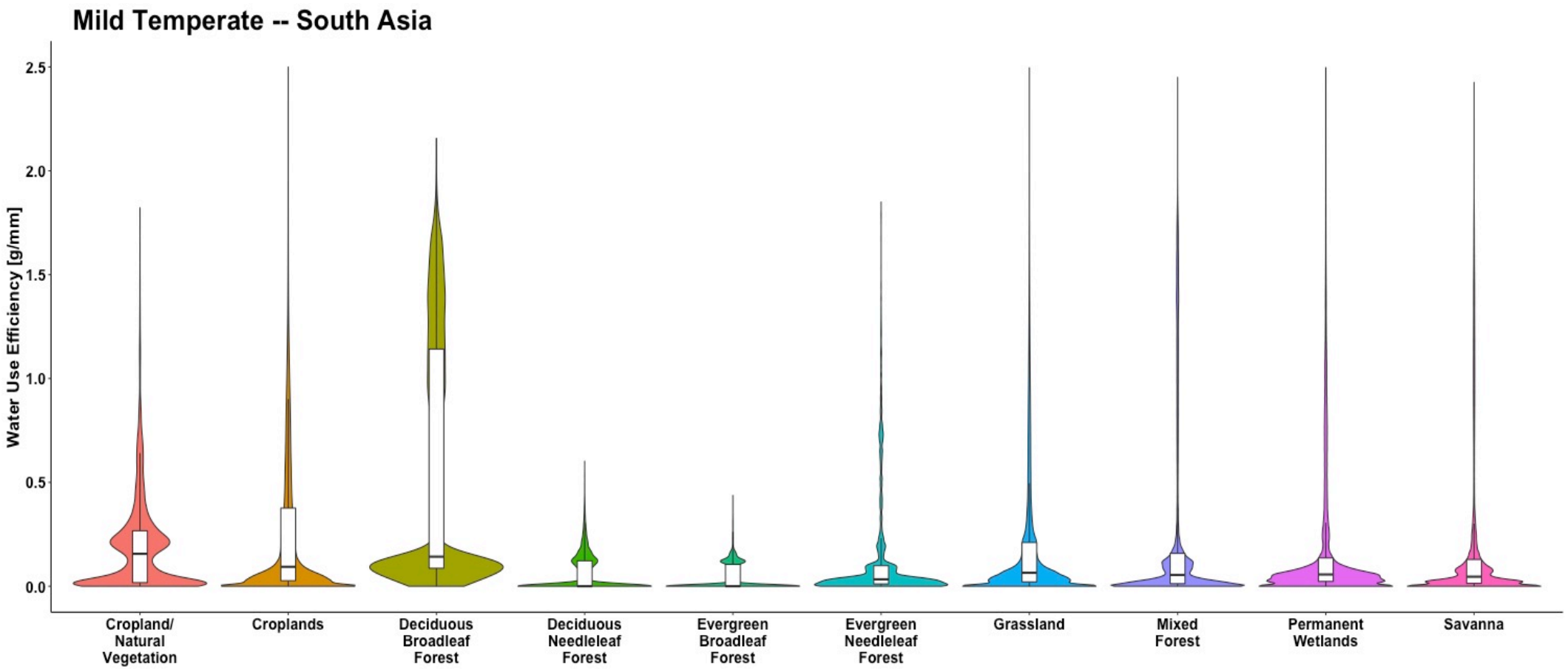

Steppe Fully Humid -- North America
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Croplands
Deciduous Broadleaf Forest
Evergreen Broadleaf Forest
Evergreen Needleleaf Forest
Grassland
Mixed Forest
Permanent Wetlands
Savanna

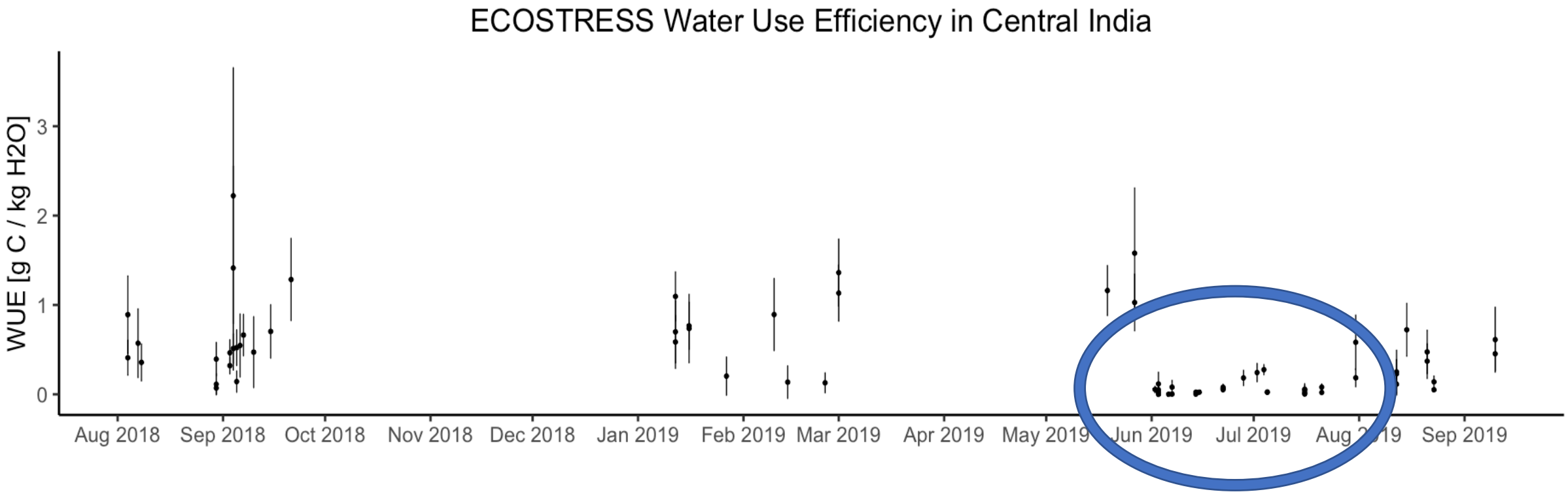

Dry Steppe -- Southern Africa
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Cropland/ Natural Vegetation
Croplands
Deciduous Broadleaf Forest
Deciduous Needleleaf Forest
Evergreen Broadleaf Forest
Evergreen Needleleaf Forest
Grassland
Permanent Wetlands
Savanna

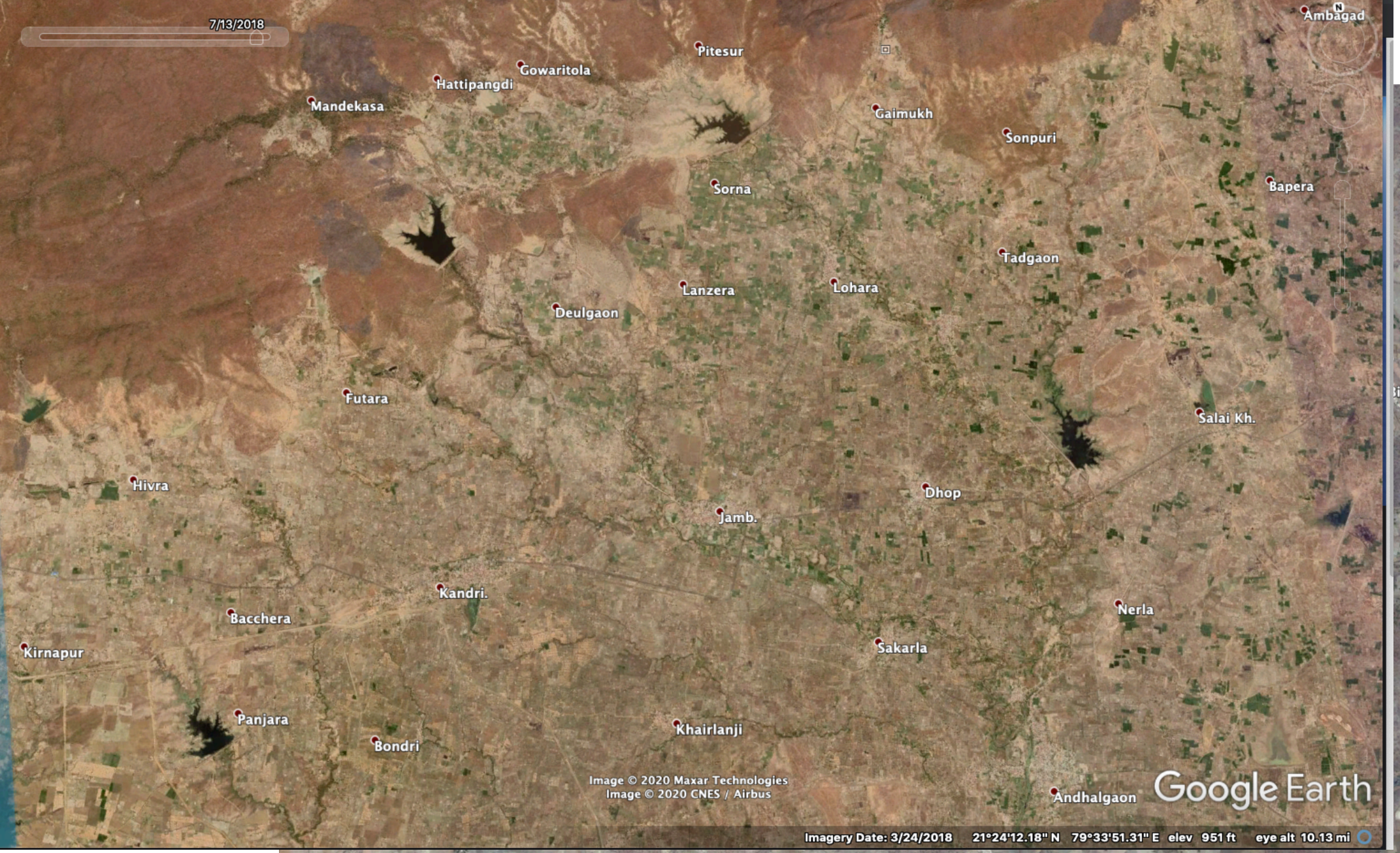

Snow Fully Humid -- Eurasia
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Cropland/ Natural Vegetation
Croplands
Deciduous Broadleaf Forest
Evergreen Needleleaf Forest
Grassland
Mixed Forest
Permanent Wetlands
Savanna


Snow Cold Arid -- North America
Water Use Efficiency [g/mm]
2.5
2.0
1.5
1.0
0.5
0.0
Croplands
Deciduous Broadleaf Forest
Evergreen Broadleaf Forest
Evergreen Needleleaf Forest
Grassland
Mixed Forest
Permanent Wetlands
Savanna

Low WUE in Central India



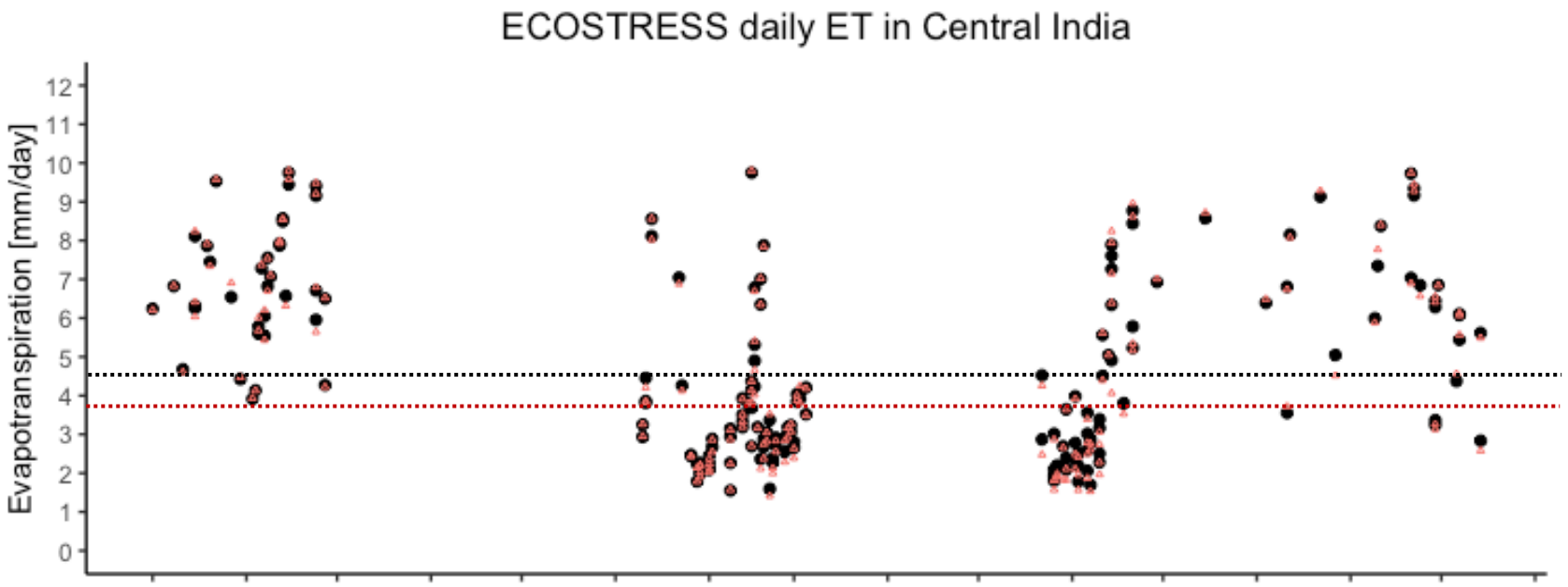

ECOSTRESS Water Use Efficiency in Central India
WUE [g C / kg H2O]
0
1
2
3
Aug 2018
Sep 2018
Oct 2018
Nov 2018
Dec 2018
Jan 2019
Feb 2019
Mar 2019
Apr 2019
May 2019
Jun 2019
Jul 2019
Aug 2019
Sep 2019


7/13/2018
Ambagad
Pitesur
Gowaritola
Hattipangdi
Mandekasa
Gaimukh
Sonpuri
Sorna
Bapera
Tadgaon
Lanzera
Lohara
Deulgaon
Futara
Salai Kh.
Hivra
Dhop
Jamb.
Kandri.
Nerla
Bacchera
Kirnapur
Sakarla
Panjara
Khairlanji
Bondri
Image © 2020 Maxar Technologies
Image © 2020 CNES / Airbus
Andhalgaon
Google Earth
Imagery Date: 3/24/2018 21°24'12.18" N 79°33'51.31" E elev 951 ft eye alt 10.13 mi


Sasna Khurd
isna Khedi

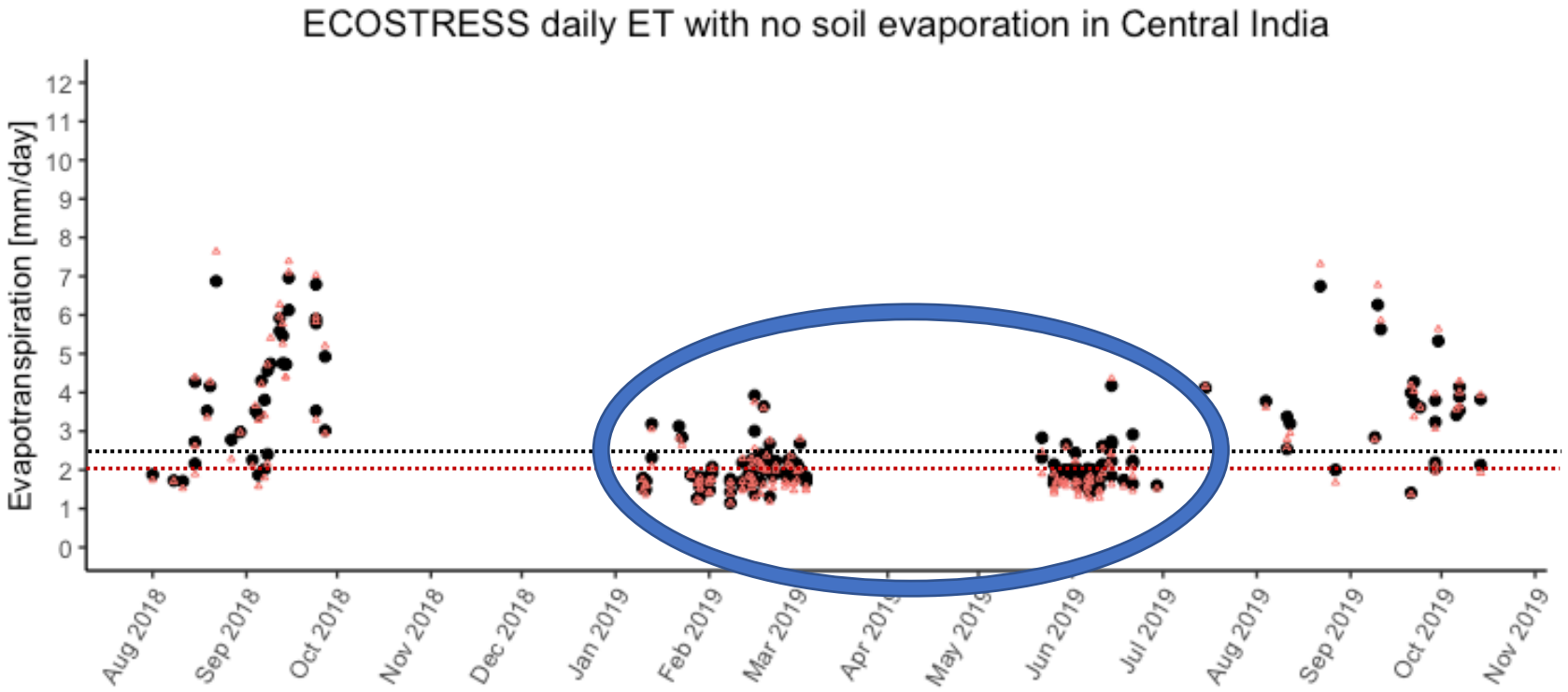

Image © 2020 Maxar Technologies
Image © 2020 Maxar Technologies
Majguwan Sarra
2003
Imagery Date: 5/18/2017 23°24'50.27" N 79°18'51.94" E elev 1211 ft eye alt 32872 ft

Google Earth
Sataperi Ryt



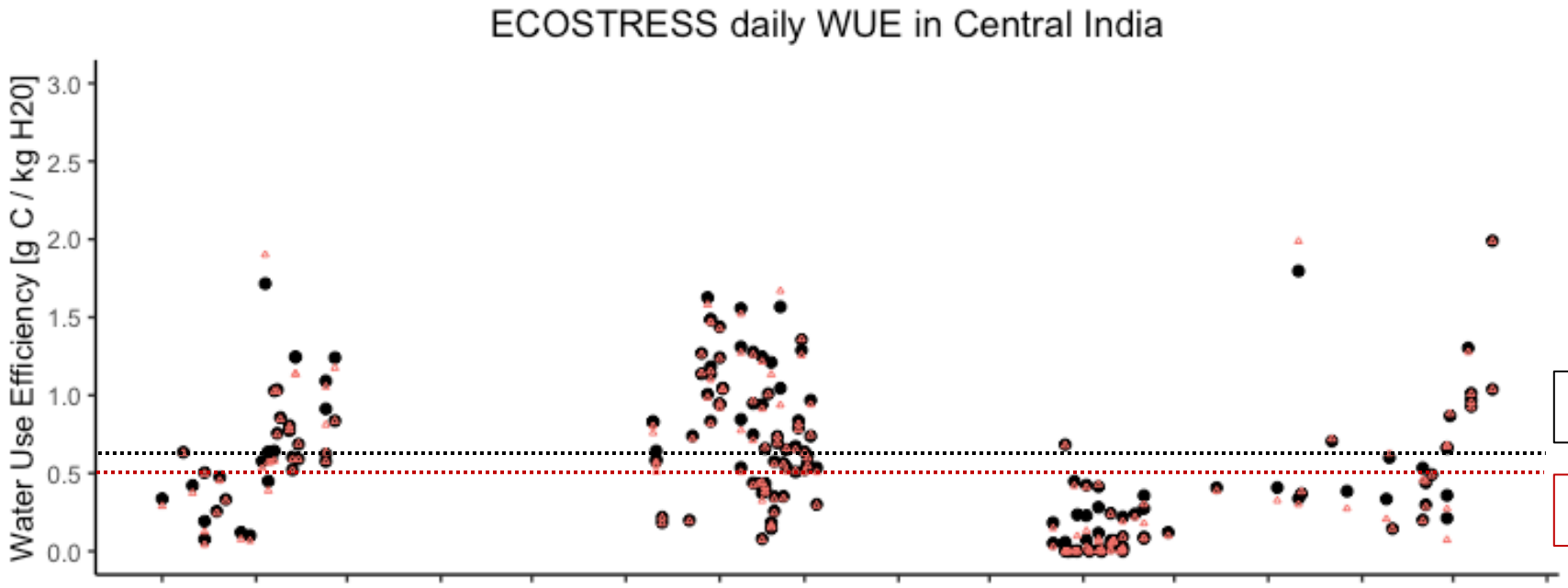
Mean = ~4.5 mm / day

Median = ~3.8 mm / day



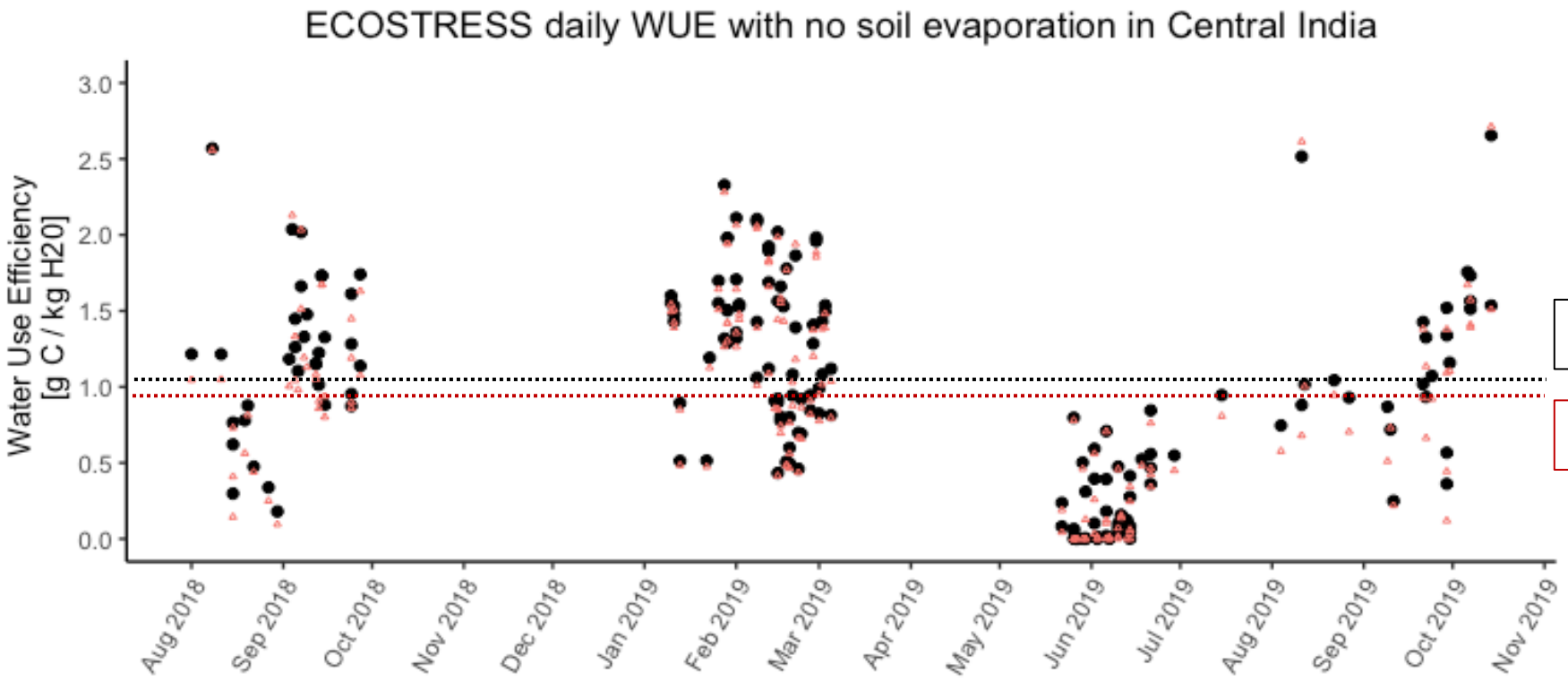
Mean = ~2.5 mm / day

Median = ~2.0 mm / day



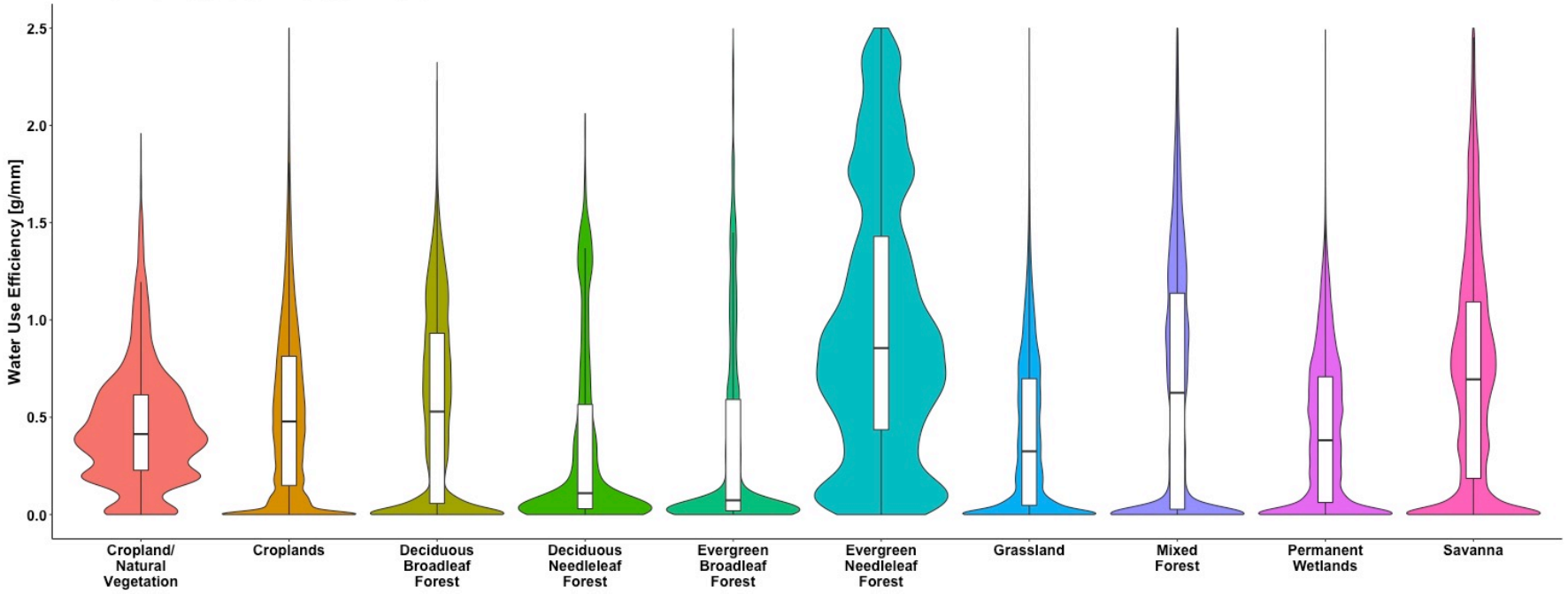
Mean = ~0.6 g C / kg H2O

Median = ~0.5 g C / kg H2O

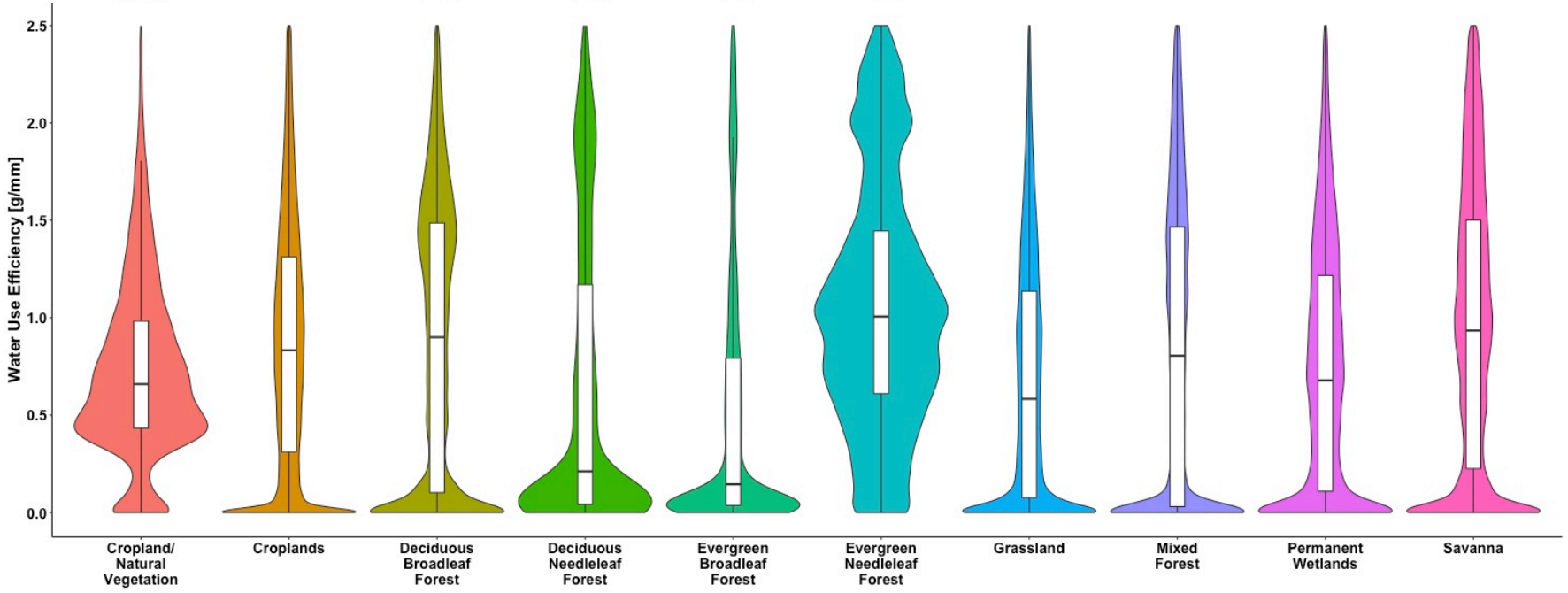


Mean = ~1.0 g C / kg H2O

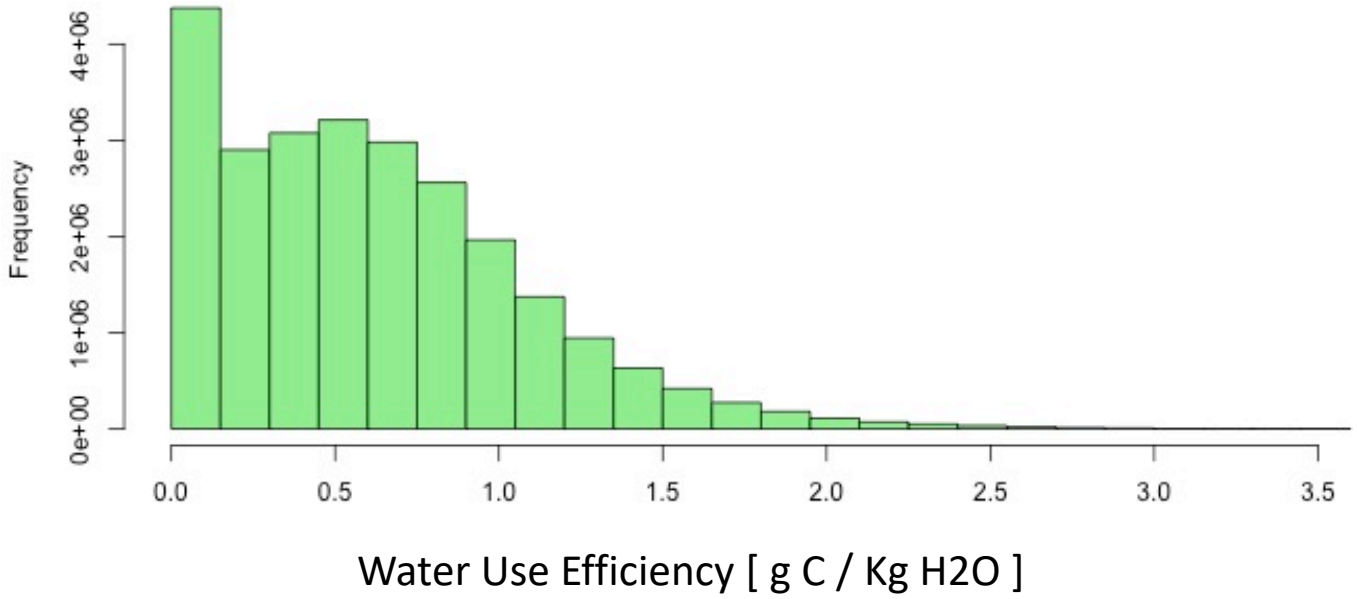
Median = ~0.9 g C / kg H2O



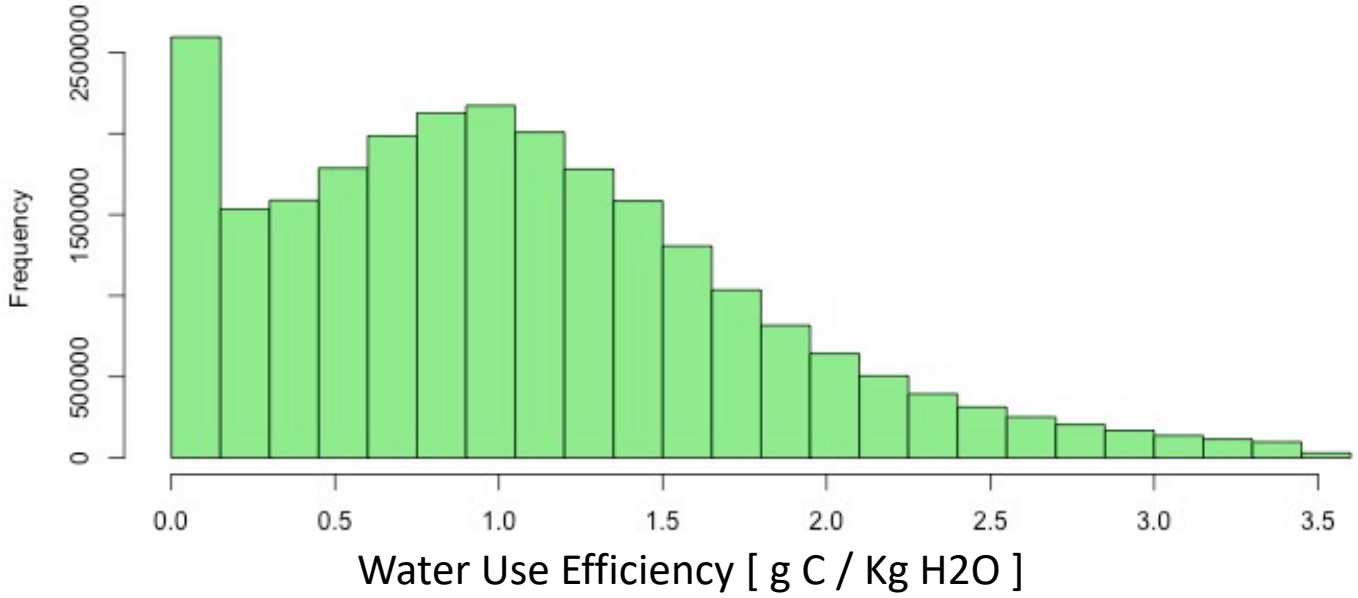
GPP/ET WUE



WUE with transpiration only



GPP/ET WUE

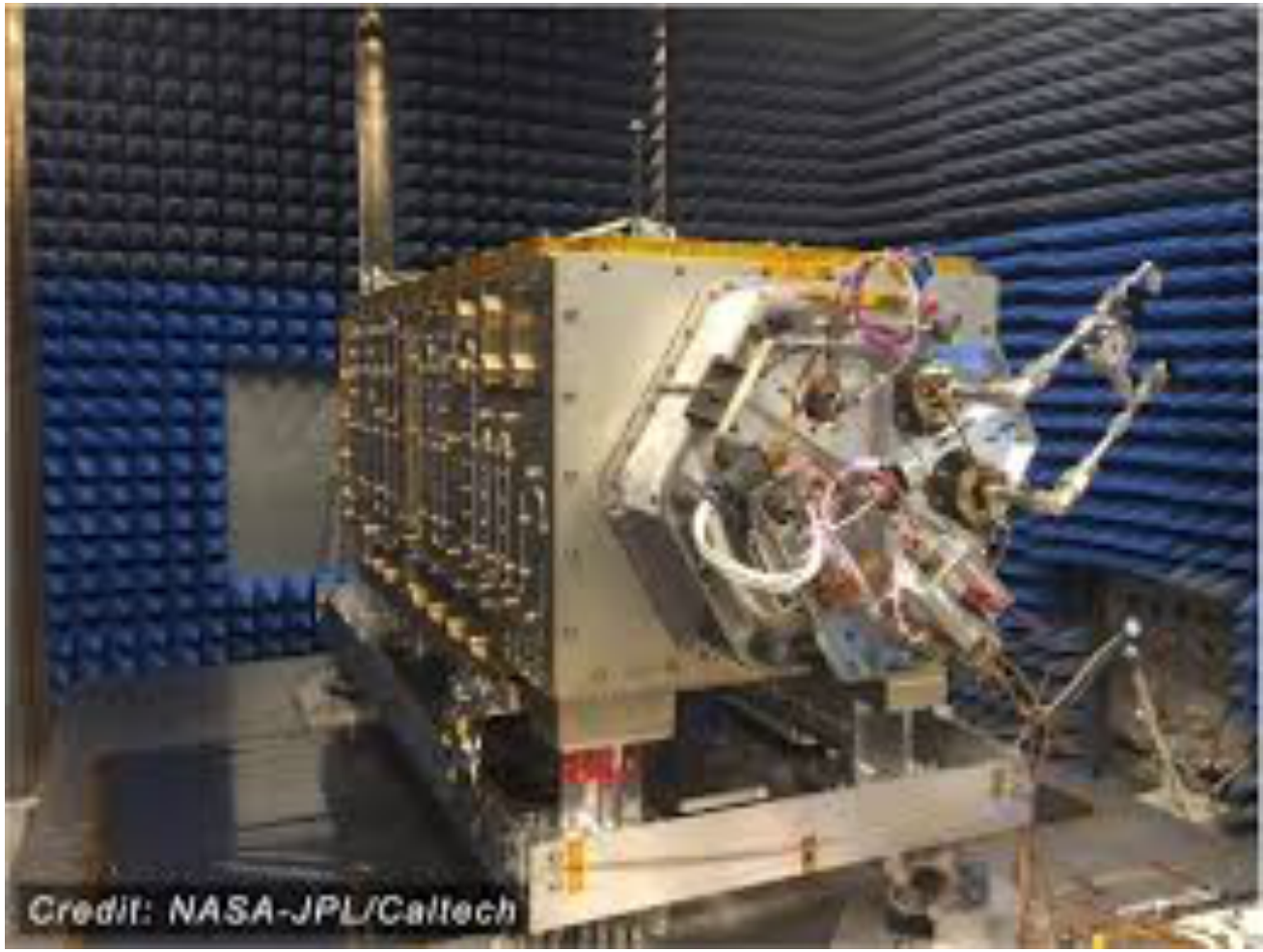


WUE with transpiration only

New Version of ECOSTRESS WUE

- ET estimate will only include transpiration component

- GPP estimate will be based on the Breathing Earth System Simulator (BESS) model (Ryu et al. 2011)



Conclusion

- Differences in the degree of WUE variability across land cover classes exist among the climate transition sites.
- Climate transition hotspots with variability in WUE arose in all major climate types and biomes: boreal (Eurasia), tropical fully humid (S. America), mild temperate (NW. Africa) and dry steppe (S. Africa).
- In these regions, forests tend to have higher WUE compared to other land cover classes, with croplands typically corresponding to lower WUE.
- This study motivates the new ECOSTRESS WUE product, which only includes transpiration.

Thank you for your attention!

ECOSTRESS Science Team Meeting, Feb. 11, 2019

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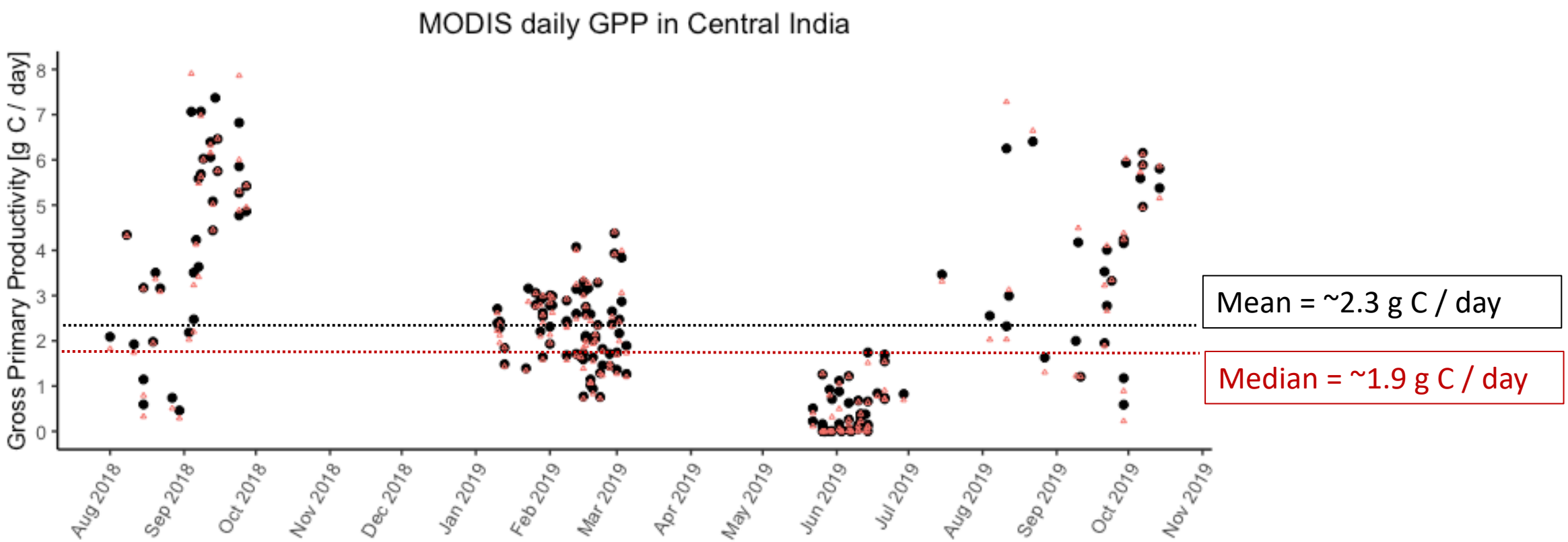
References

- Anderson, M.C., C. Hain, B. Wardlow, A. Pimstein, J.R. Mecikalski, and W.P. Kustas, 2011: Evaluation of Drought Indices Based on Thermal Remote Sensing of Evapotranspiration over the Continental United States. *J. Climate,* 24, 2025–2044.
- Fisher, J.B., Tu, K.P., Baldocchi, D.D., 2008. Global estimates of the land-atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites. *Remote Sensing of Environment* 112(3): 901-919.
- Keenan, T. F., Hollinger, D. Y., Bohrer, G., Dragoni, D., Munger, J. W., Schmid, H. P., & Richardson, A. D. (2013). Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. *Nature*, *499*(7458), 324-327.
- Lavergne, A., Graven, H., De Kauwe, M. G., Keenan, T. F., Medlyn, B. E., & Prentice, I. C. (2019). Observed and modelled historical trends in the water-use efficiency of plants and ecosystems. Global change biology.
- Ryu, Y., Baldocchi, D. D., Kobayashi, H., van Ingen, C., Li, J., Black, T. A., ... & Roupsard, O. (2011). Integration of MODIS land and atmosphere products with a coupled-process model to estimate gross primary productivity and evapotranspiration from 1 km to global scales. *Global Biogeochemical Cycles*, *25*(4).
- Swain, D. L., Langenbrunner, B., Neelin, J. D., & Hall, A. (2018). Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change*, *8*(5), 427-433.
- Yu, Z.; Wang, J.; Liu, S.; Rentch, J.S.; Sun, P.; Lu, C. Global gross primary productivity and water use efficiency changes under drought stress. Environ. Res. Lett. 2017, 12, 014016.
- Xue, B.-L.; Guo, Q.; Otto, A.; Xiao, J.; Tao, S.; Li, L. Global patterns, trends, and drivers of water use efficiency from 2000 to 2013. Ecosphere 2015, 6, art174.

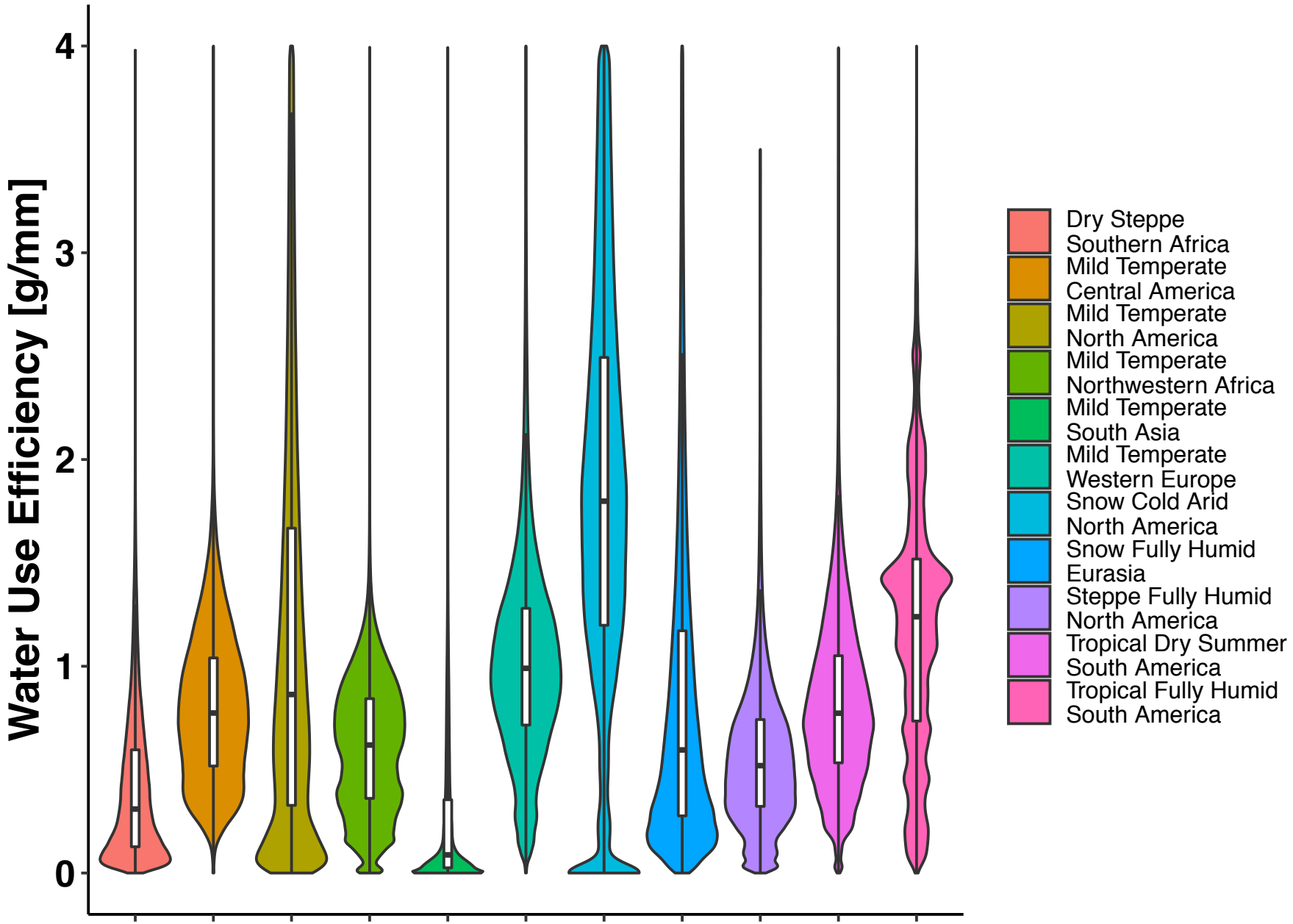

MODIS daily GPP in Central India
Gross Primary Productivity [g C / day]
0
1
2
3
4
5
6
7
8
Aug 2018
Sep 2018
Oct 2018
Nov 2018
Dec 2018
Jan 2019
Feb 2019
Mar 2019
Apr 2019
May 2019
Jun 2019
Jul 2019
Aug 2019
Sep 2019
Oct 2019
Nov 2019
Mean = ~2.3 g C / day
Median = ~1.9 g C / day

Distribution of Pixels Across Land Cover in Central India

Land Cover	Number of Pixels	% Area
Croplands	22,840,208	79.2%
Savanna	1,975,324	6.9%
Grassland	1,530,814	5.3%
Mixed Forest	1,263,127	4.4%
Deciduous Broadleaf Forest	791,590	2.7%
Permanent Wetlands	319,372	1.1%
Evergreen Broadleaf Forest	48,573	0.2%
Evergreen Needleleaf Forest	36,686	0.1%
Cropland/ Natural Vegetation	21,148	0.1%
Deciduous Needleleaf Forest	8,249	0.0%

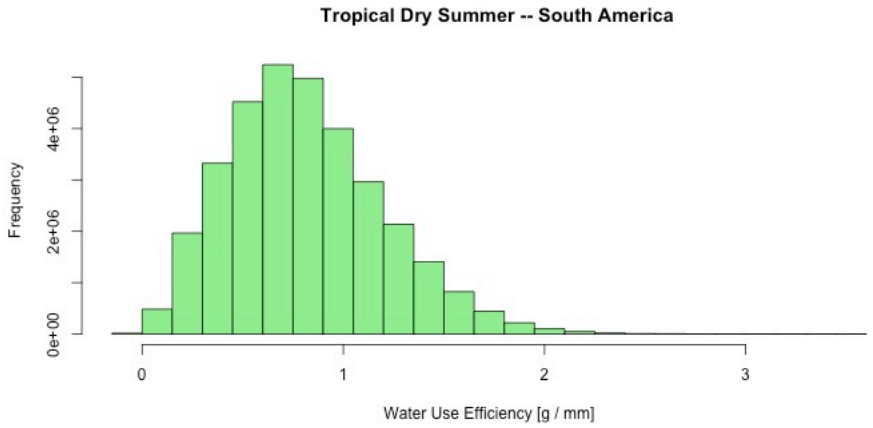
Global climate models used in WUE uncertainty estimate

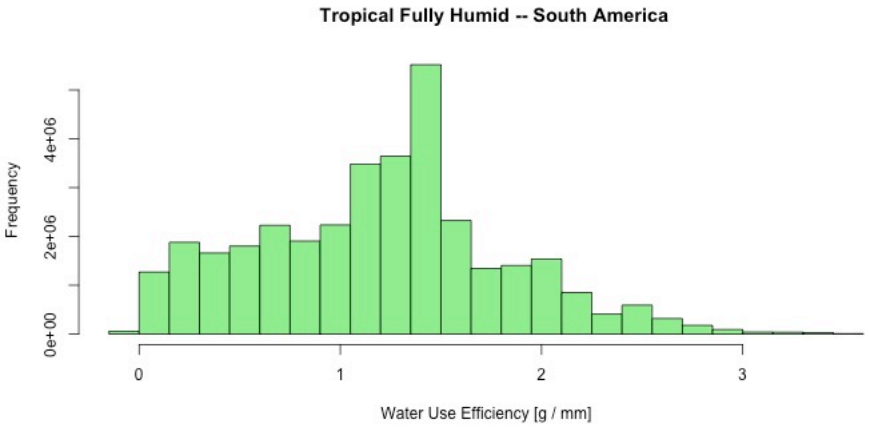
Land Surface Model	Citation
CLM4-CN	Mao, Jiafu; Shi, Xiaoying; Thornton, Peter E.; Hoffman, Forrest M.; Zhu, Zaichun; Myneni, Ranga B. 2013. "Global Latitudinal-Asymmetric Vegetation Growth Trends and Their Driving Mechanisms: 1982–2009." Remote Sens. 5, no. 3: 1484-1497.
Hyland	Levy, P. E., M. G. R. Cannell, and A. D. Friend (2004), Modelling the impact of future changes in climate, CO2 concentration and land use on natural ecosystems and the terrestrial carbon sink, Global Environmental Change, 14, 21-30.
LPJ-wsl	Sitch S, Smith B, Prentice IC, Arneth A, Bondeau A, Cramer W, Kaplan J, Levis S, Lucht, W, Sykes M, Thonicke K, Venevsky S 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ Dynamic Vegetation Model. Global Change Biology 9: 161–185.
LPJ-GUESS	Smith, B., Prentice, I.C. & Sykes, M.T. 2001. Representation of vegetation dynamics in the modelling of terrestrial ecosystems: comparing two contrasting approaches within European climate space. Global Ecology & Biogeography 10: 621-637.
OCN	Zaehle, S., Friend, A. D., Friedlingstein, P., Dentener, F., Peylin, P., and Schulz, M.: Carbon and nitrogen cycle dynamics in the O-CN land surface model, II: The role of the nitrogen cycle in the historical terrestrial C balance, Global Biogeochem. Cy., 24, 1–14, 2010.
ORCHIDEE	Krinner, G., Viovy, N., Noblet-Ducoudre, N. de, Ogee, J., Polcher, J., Friedlingstein, P., Ciais, P., Sitch, S., and Prentice, I. C (2005). A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system. Global Biogeochem. Cycles, 19, GB1015.
SDGVM	Cramer, W., Bondeau, A., Woodward, F. I., Prentice, I. C., Betts, R. A., Brovkin, V., Cox, P. M., Fisher, V., Foley, J. A., Friend, A. D., Kucharik, C., Lomas, M. R., Ramankutty, N., Sitch, S., Smith, B., White, A., and Young-Molling, C.: Global response of terrestrial ecosystem structure and function to CO2 and climate change: results from six dynamic global vegetation models, Glob. Change Biol., 7, 357–373, 2001.
TRIFFID	Clark, D. B., Mercado, L. M., Sitch, S., Jones, C. D., Gedney, N., Best, M. J., Pryor, M., Rooney, G. G., Essery, R. L. H., Blyth, E., Boucher, O., Harding, R. J., Huntingford, C., and Cox, P. M.: The Joint UK Land Environment Simulator (JULES), model description – Part 2: Carbon fluxes and vegetation dynamics, Geosci. Model Dev., 4, 701–722, doi:10.5194/gmd-4-701-2011, 2011.
VEGAS	Zeng, N., Qian, H., Roedenbeck, C., and Heimann, M.: Impact of 1998-2002 midlatitude drought and warming on terrestrial ecosystem and the global carbon cycle, Geophys. Res. Lett., 32, L22709, doi:10.1029/2005gl024607, 2005.

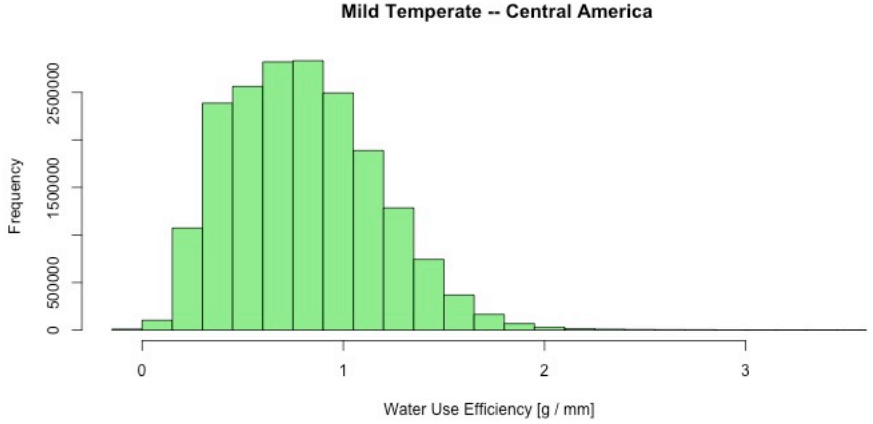

Water Use Efficiency [g/mm]
0
1
2
3
4
Dry Steppe Southern Africa
Mild Temperate Central America
Mild Temperate North America
Mild Temperate Northwestern Africa
Mild Temperate South Asia
Mild Temperate Western Europe
Snow Cold Arid North America
Snow Fully Humid Eurasia
Steppe Fully Humid North America
Tropical Dry Summer South America
Tropical Fully Humid South America

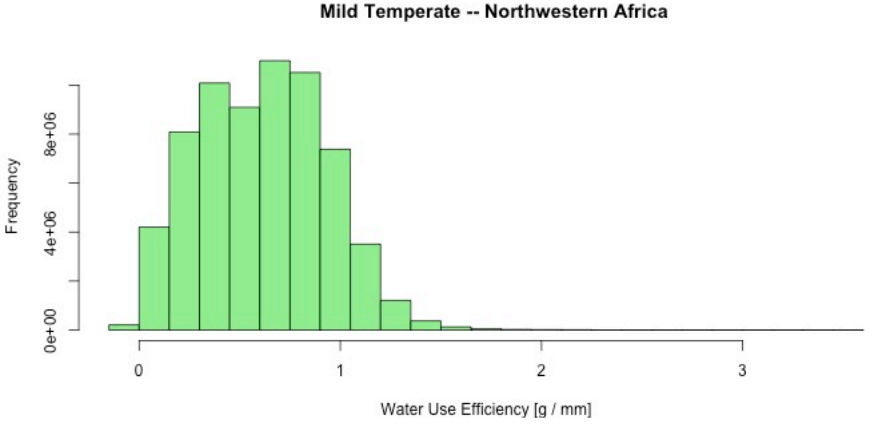
To-Do

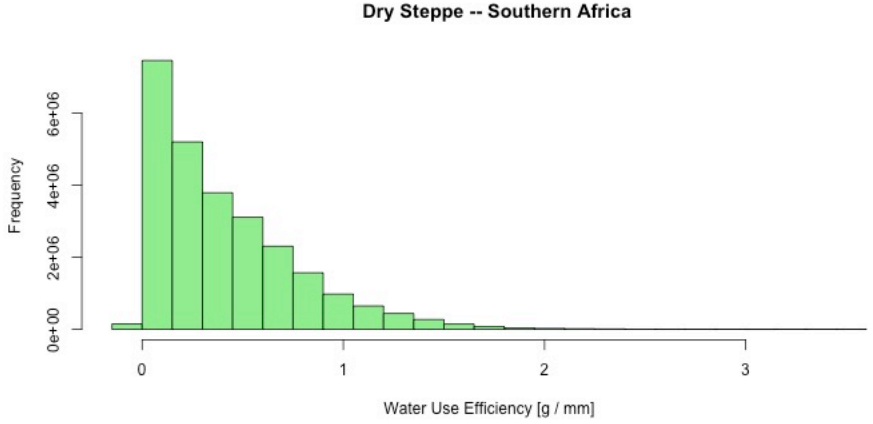
- Central India re-sampling (v2)
- Map of forest vs. non-forest WUE in Amazon to illustrate WUE violins
- Sub-section on impact of filtering in Boreal N America
-

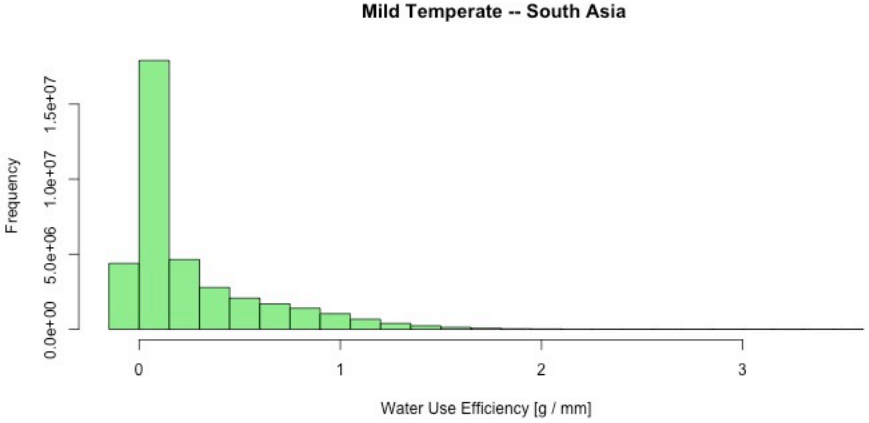

Tropical Dry Summer -- South America
Frequency
0e+00
2e+06
4e+06
0
1
2
3
Water Use Efficiency [g / mm]

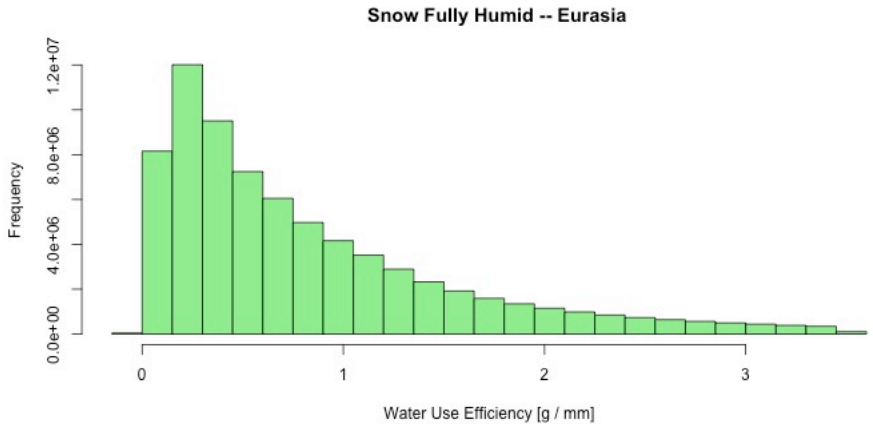

Tropical Fully Humid -- South America
Frequency
0e+00
2e+06
4e+06
0
1
2
3
Water Use Efficiency [g / mm]

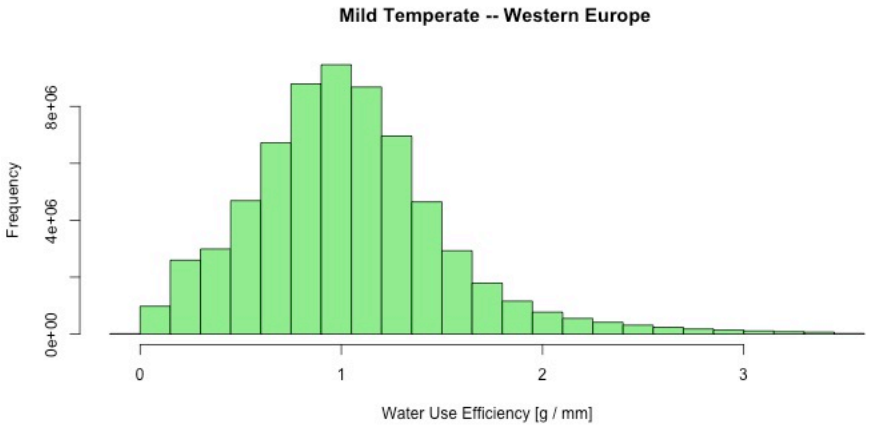

Mild Temperate -- Central America
Frequency
0
500000
1500000
2500000
0
1
2
3
Water Use Efficiency [g / mm]

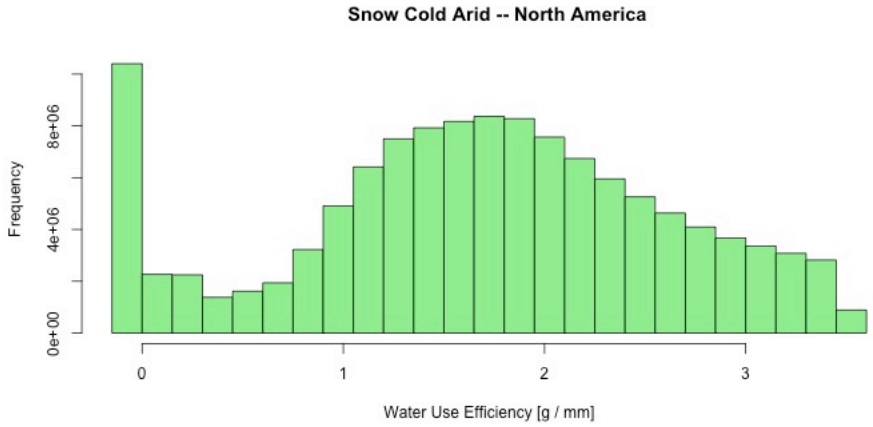

Mild Temperate -- Northwestern Africa
Frequency
0e+00
4e+06
8e+06
0
1
2
3
Water Use Efficiency [g / mm]

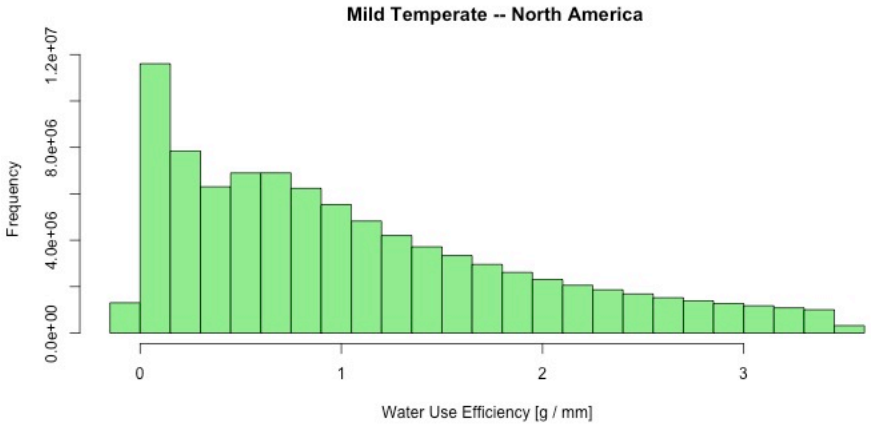

Dry Steppe -- Southern Africa
Frequency
0e+00
2e+06
4e+06
6e+06
0
1
2
3
Water Use Efficiency [g / mm]

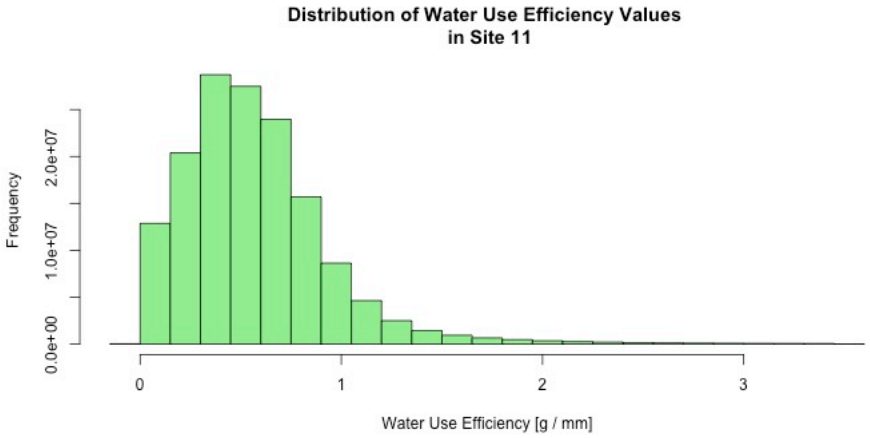

Mild Temperate -- South Asia
Frequency
0.0e+00
5.0e+06
1.0e+07
1.5e+07
0
1
2
3
Water Use Efficiency [g / mm]


Snow Fully Humid -- Eurasia
Frequency
0.0e+00
4.0e+06
8.0e+06
1.2e+07
0
1
2
3
Water Use Efficiency [g / mm]


Mild Temperate -- Western Europe
Frequency
0e+00
4e+06
8e+06
0
1
2
3
Water Use Efficiency [g / mm]


Snow Cold Arid -- North America
Frequency
0e+00
4e+06
8e+06
0
1
2
3
Water Use Efficiency [g / mm]


Mild Temperate -- North America
Frequency
0.0e+00
4.0e+06
8.0e+06
1.2e+07
0
1
2
3
Water Use Efficiency [g / mm]


Distribution of Water Use Efficiency Values
in Site 11
Frequency
0.0e+00
1.0e+07
2.0e+07
0
1
2
3
Water Use Efficiency [g / mm]