AsiaFlux

The spatial variability of water use efficiency and its underlying mechanisms in terrestrial ecosystems of China

Xian-Jin Zhu, Gui-Rui Yu, Zhong-Min Hu, Qiu-Feng Wang, Hong-Lin He, Sheng-Gong Li, Ying-Nian Li, Pei-Li Shi, Xiao-Min Sun, Hui-Min Wang, Yan-Fen Wang, Jun-Hua Yan, Jun-Hui Zhang, Lei-Ming Zhang, Yi-Ping Zhang, Feng-Hua Zhao, Liang Zhao, Han Zheng

Correspondence to: Gui-Rui Yu (yugr@igsnrr.ac.cn)

Outlines

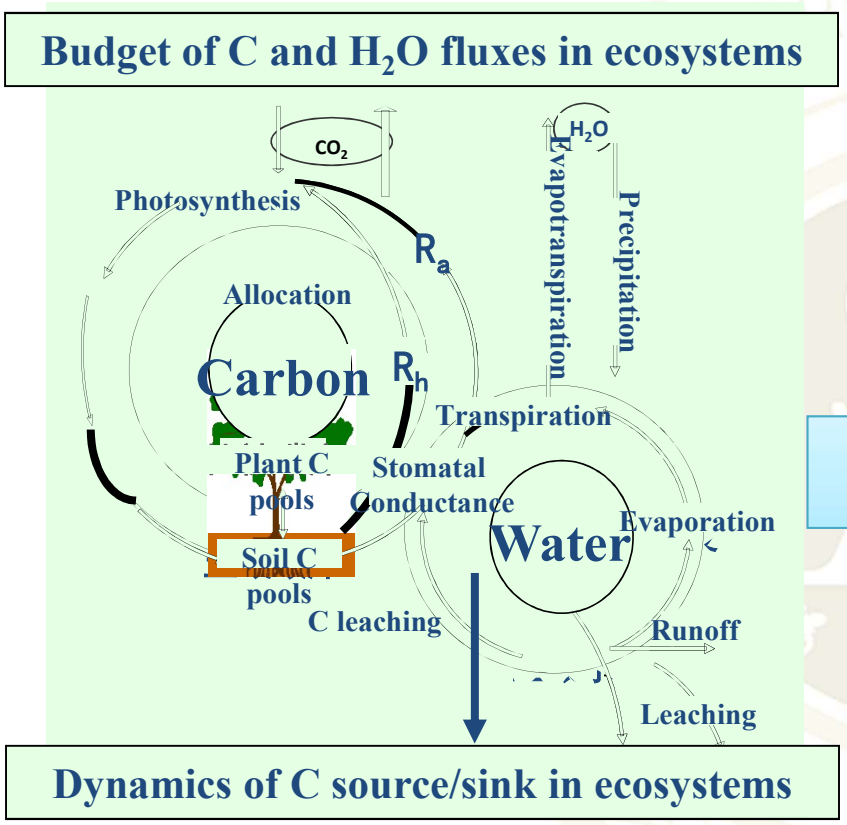
1 Introduction

2 How WUE spatially varied?

3 Why WUE spatially varied?

4 Summary

Introduction



Coupling relation between C and H_2O cycles

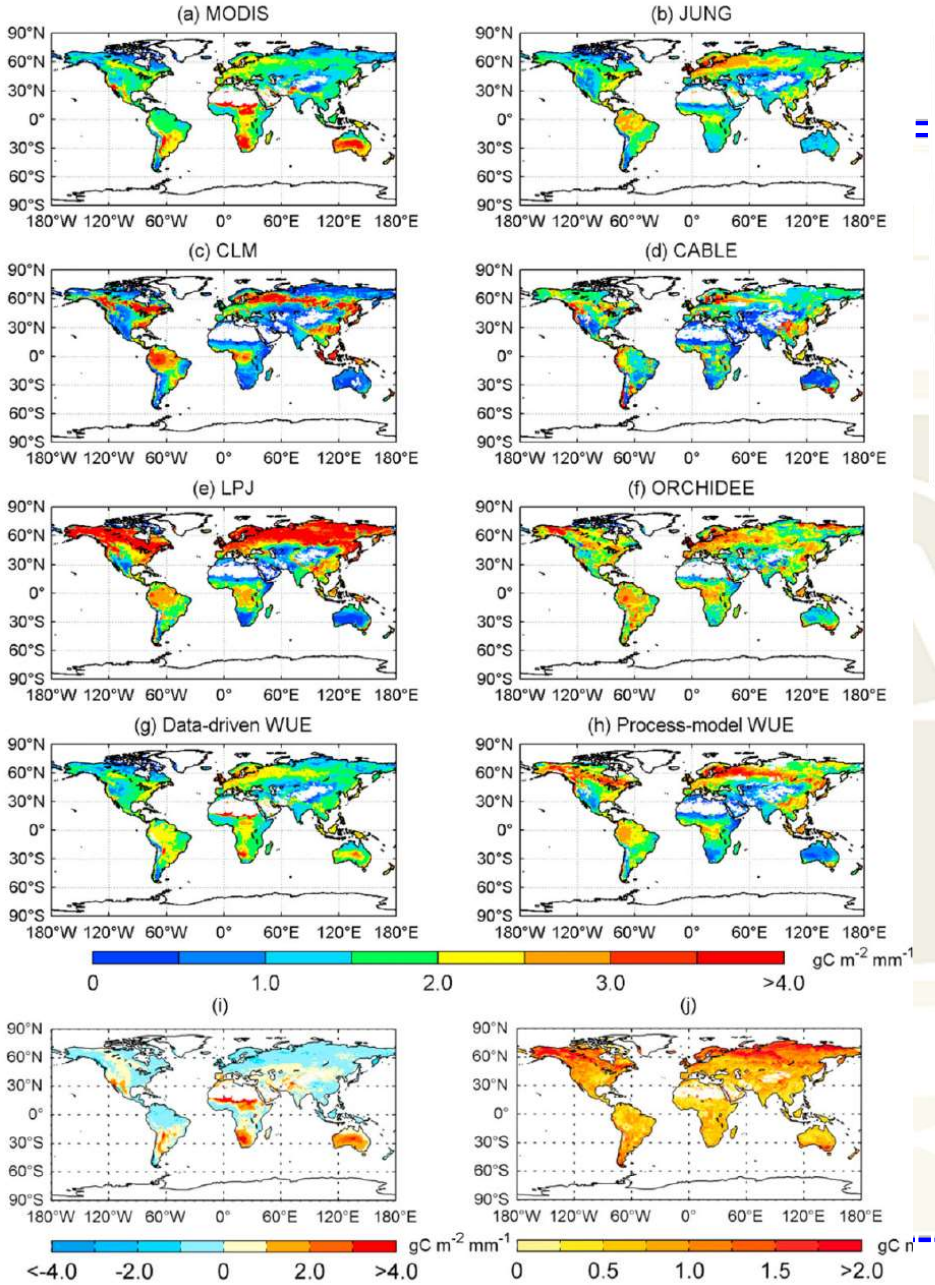
spatial pattern of climate

water cost of carbon uptake

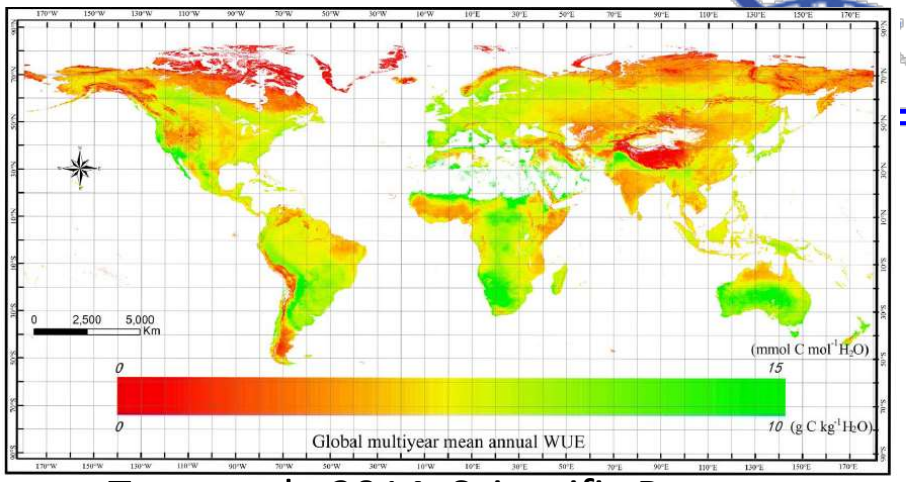
WUE spatial variability

Understanding on carbon cycle process at a large scale

Spatial variation of WUE



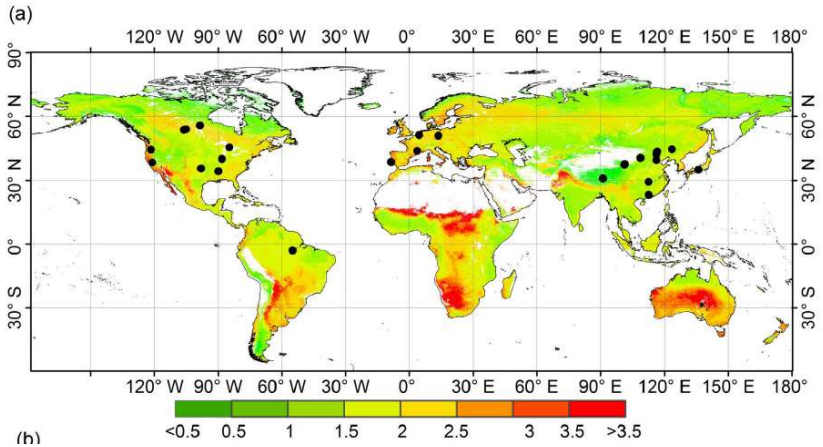
Sun et al., 2016, GEB



Tang et al., 2014, Scientific Reports

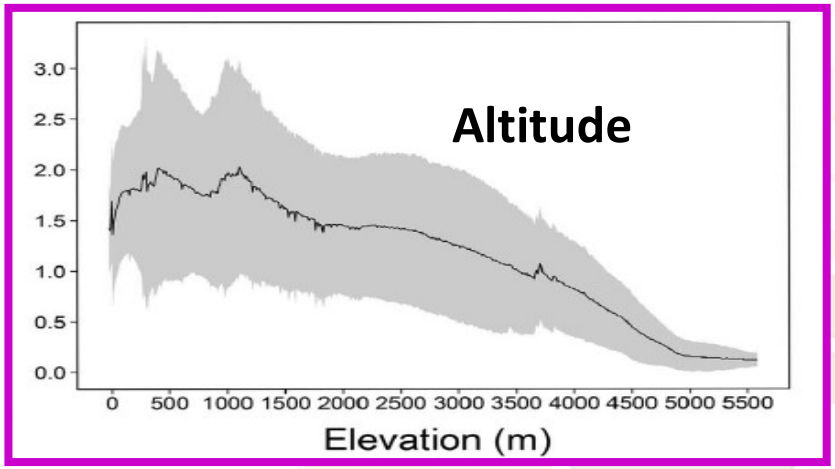
Data-driven or modeled GPP and ET

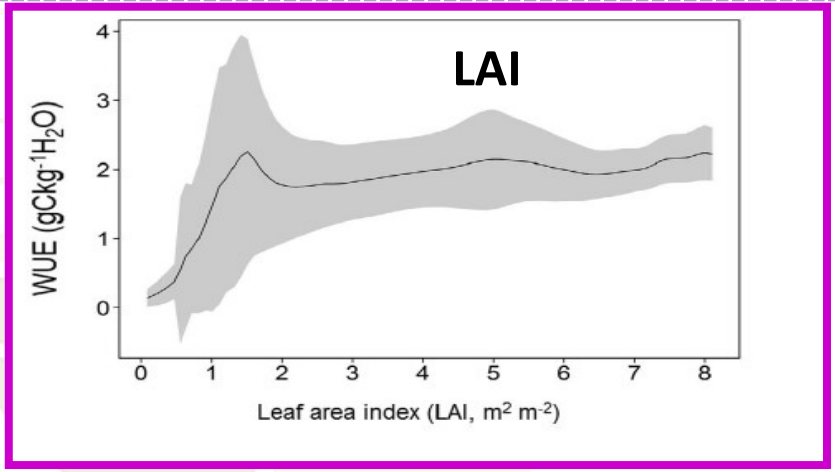
MODIS, JUNG's Data, process models

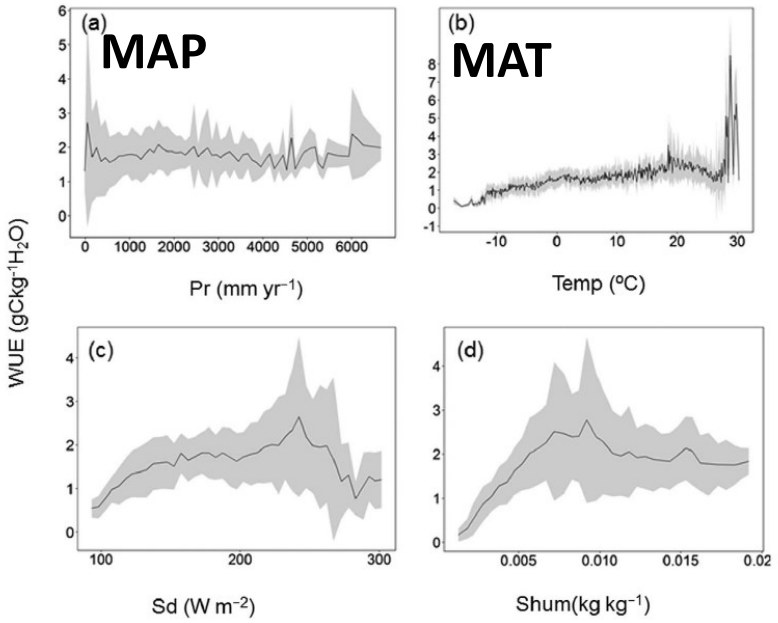


Xue et al., 2015, Ecoshpere

Affecting factors

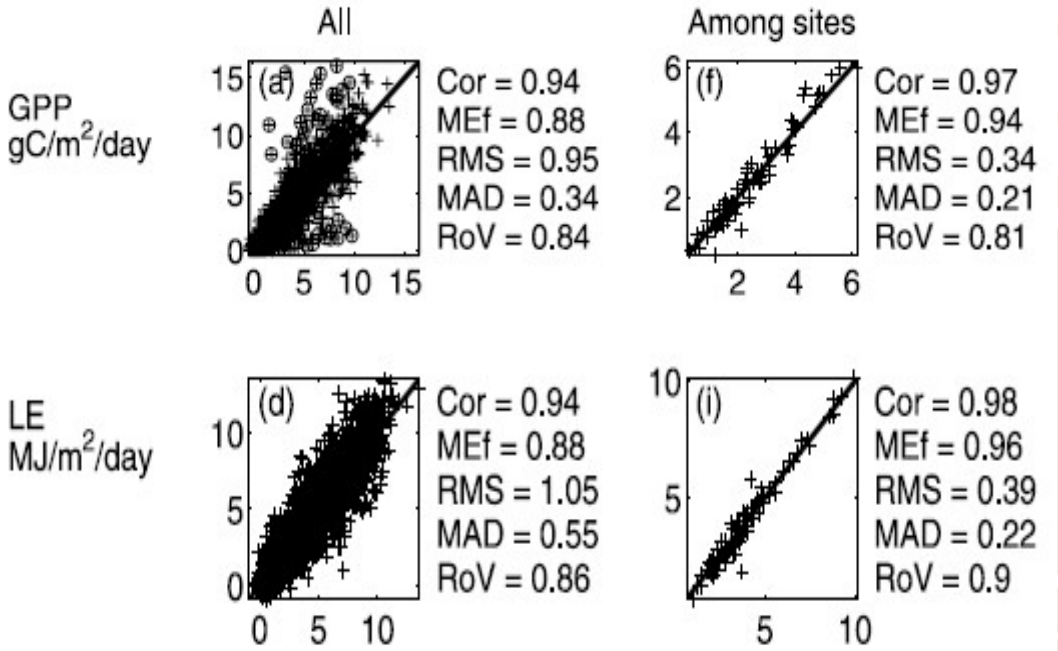






Many factors were found to affect the spatial variation of WUE

Xue et al., 2015, Ecosphere



Jung et al., 2011, JGR

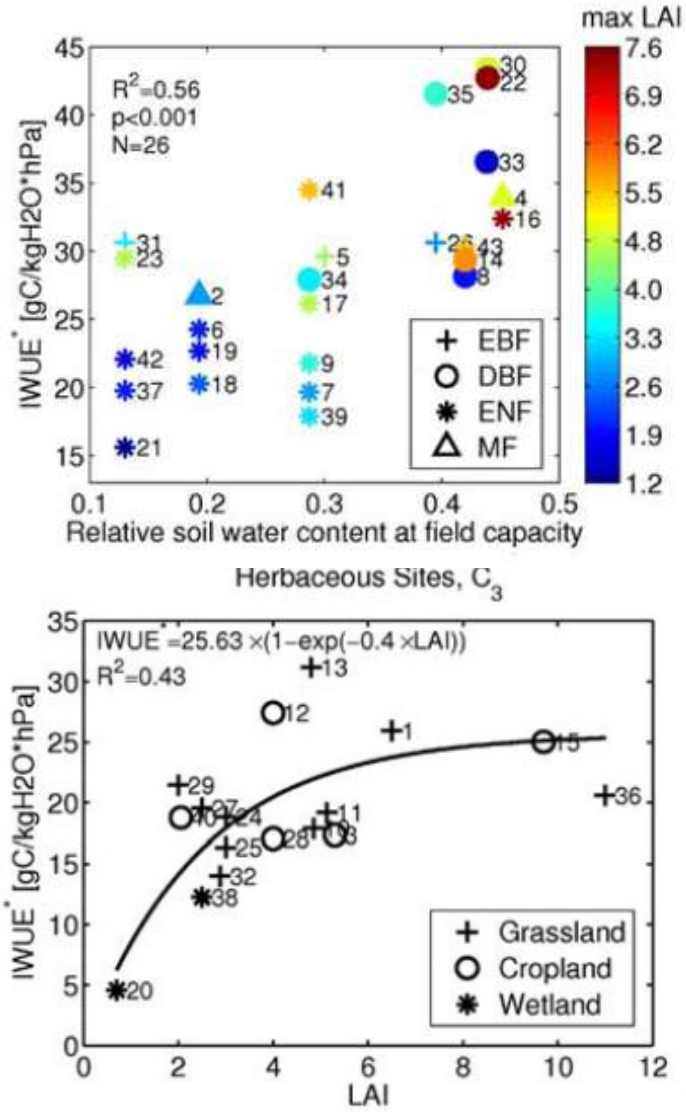
Uncertainties in data-driven or process-modelled GPP and ET

Uncertainties in WUE

Measuring GPP and ET

An alternative approach to unravel the spatial variation of WUE

FLUXNET



Beer et al., 2009, GBC

Table 2. Characteristics of Flux Tower Sites Used in This Study[a]

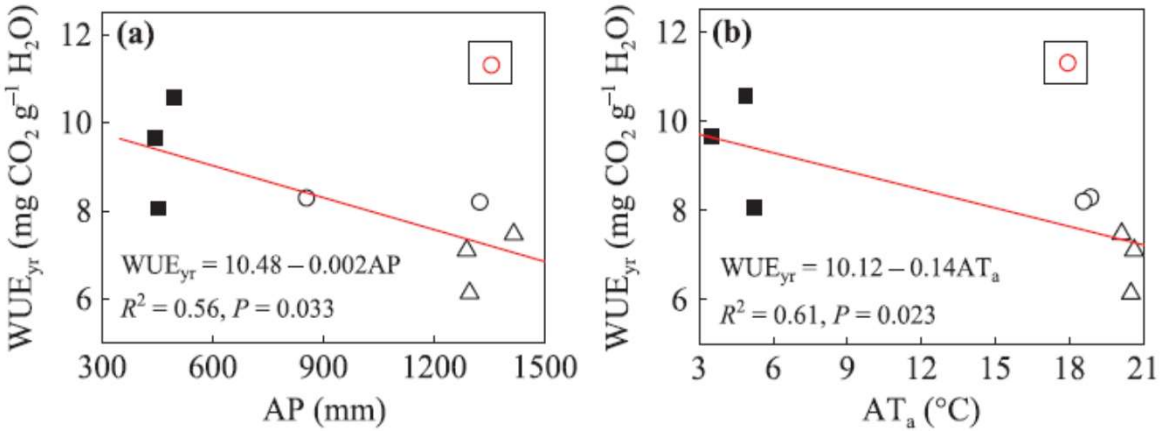
	Lat	Long	ID	Veg	LAI	Soil	WUE*	IWUE*	Reference
1	47.12	11.32	AT-Neu	GRA	6.5	0	3.79	25.94	*Wohlfahrt et al.* [2008a]
2	51.31	4.52	BE-Bra	MF	3	3	3.99	26.71	*Carrara et al.* [2004]
3	50.55	4.74	BE-Lon	CRO	5.3	0	2.83	17.35	*Moureaux et al.* [2006]
4	50.31	6	BE-Vie	MF	5.1	5	5.08	33.91	*Aubinet et al.* [2002]
5	−2.61	−60.21	BR-Ma2	EBF	4.7	6	2.82	29.6	n.a.
6	49.87	−125.29	CA-Ca2	ENF	2.2	3	3.06	24.26	*Humphreys et al.* [2005]
7	49.53	−124.90	CA-Ca3	ENF	3	1	3.53	19.65	*Jassal et al.* [2008]
8	53.63	−106.2	CA-Oas	DBF	2.1	10	3.41	28.18	*Krishnan et al.* [2006]
9	54	−105.12	CA-Obs	ENF	3.8	1	3.05	21.77	*Krishnan et al.* [2008]
10	47.29	7.7	CH-Oe1	GRA	4.85	0	2.86	17.88	*Ammann et al.* [2007]
11	31.52	122	CN-Do1	GRA	5.13	0	2.62	19.15	*Wu et al.* [2005]
12	51.10	10.91	DE-Geb	CRO	4	0	4.02	27.39	*Anthoni et al.* [2004b]
13	50.95	13.51	DE-Gri	GRA	4.8	0	4.35	31.17	*Gilmanov et al.* [2007]
14	51.08	10.45	DE-Hai	DBF	6	10	5.31	29.37	*Knohl et al.* [2003; *Kutsch et al.*, 2008]
15	50.89	13.52	DE-Kli	CRO	9.7	0	3.58	25.01	n.a.
16	50.96	13.57	DE-Tha	ENF	7.6	5	4.55	32.4	*Grünwald and Bernhofer* [2007]
17	50.45	11.46	DE-Wet	ENF	4.75	1	5.42	26.17	*Anthoni et al.* [2004a]
18	39.35	−0.32	ES-ES1	ENF	2.63	3	2.77	20.27	*Sanz et al.* [2004]
19	61.85	24.3	FI-Hyy	ENF	2.1	3	3.61	22.68	*Suni et al.* [2003]
20	69.14	27.3	FI-Kaa	WET	0.7	0	1.23	4.58	*Aurela et al.* [2004]
21	67.36	26.64	FI-Sod	ENF	1.2	2	2.82	15.6	*Thum et al.* [2007]
22	48.67	7.07	FR-Hes	DBF	7.6	8	4.51	42.71	*Granier et al.* [2000]
23	44.71	−0.77	FR-LBr	ENF	4.8	2	2.63	29.47	*Berbigier et al.* [2001]
24	45.64	2.74	FR-Lq1	GRA	3	0	2.75	18.79	*Allard et al.* [2007]
25	45.64	2.74	FR-Lq2	GRA	3	0	2.42	16.36	*Allard et al.* [2007]
26	43.74	3.63	FR-Pue	EBF	2.9	7	3.14	30.61	*Rambal et al.* [2003]
27	46.69	19.60	HU-Bug	GRA	2.5	0	2.1	19.53	*Nagy et al.* [2007]
28	47.84	19.73	HU-Mat	CRO	4	0	2.32	17.05	*Nagy et al.* [2007]
29	41.90	13.61	IT-Amp	GRA	2	0	3.16	21.45	*Wohlfahrt et al.* [2008b]
30	41.85	13.59	IT-Col	DBF	5	8	6.07	43.39	*Valentini et al.* [1996]
31	41.70	12.38	IT-Cpz	EBF	3.5	2	3.51	30.61	*Tirone et al.* [2003]
32	46.01	11.05	IT-MBo	GRA	2.88	0	3	13.99	n.a.
33	44.69	11.09	IT-Non	DBF	1.7	11	3.15	36.56	n.a.
34	45.20	9.06	IT-PT1	DBF	3.5	1	2.98	27.91	n.a.
35	42.39	11.92	IT-Ro2	DBF	3.9	7	3.54	41.54	*Tedeschi et al.* [2006]
36	51.97	4.93	NL-Ca1	GRA	11	0	2.29	20.58	*Jacobs et al.* [2007]
37	52.17	5.74	NL-Loo	ENF	2.2	2	3.77	19.77	*Dolman et al.* [2002]
38	52.76	16.31	PL-Wet	WET	2.5	0	1.73	12.24	n.a.
39	64.11	19.46	SE-Fla	ENF	3.4	1	2.66	17.88	*Lindroth et al.* [2007]
40	36.61	−97.49	US-ARM	CRO	2.05	0	1.57	18.76	*Fischer et al.* [2007]
41	45.20	−68.74	US-Ho1	ENF	5.7	1	3.98	34.5	*Hollinger et al.* [2004]
42	29.75	−82.16	US-SP3	ENF	1.94	2	2.35	22.08	*Clark et al.* [2004]
43	−15.44	167.19	VU-Coc	EBF	5.65	10	3.17	30.33	*Roupsard et al.* [2006]

[a]The number in the first column is used in Figures 7 and 8 to indicate the sites. The station ID consists of two characters describing the country and 3 characters as abbreviation for the site name (cf. http://www.fluxnet.ornl.gov/fluxnet/index.cfm). Also shown are coordinates, vegetation class (EBF = evergreen broad-leaved forest, DBF = deciduous broad-leaved forest, ENF = evergreen needle-leaved forest, MF = mixed forest, GRA = grassland, CRO = cropland, WET = wetland), maximum leaf area index, soil texture type for forests according to [*Cosby et al.*, 1984] (otherwise 0), mean WUE* [g C/kg H_2O], mean IWUE* [g C · hPa/kg H_2O], and a reference to site characteristics.

Covering few Chinese sites

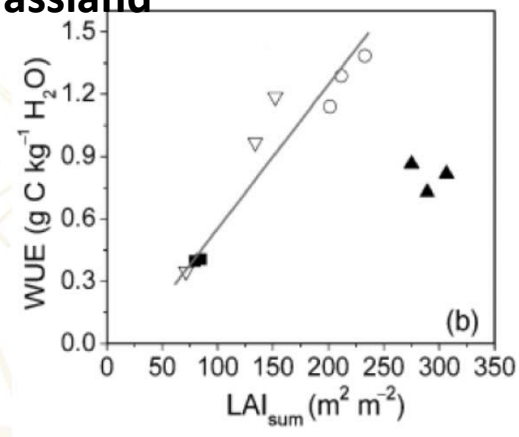
China

Forest



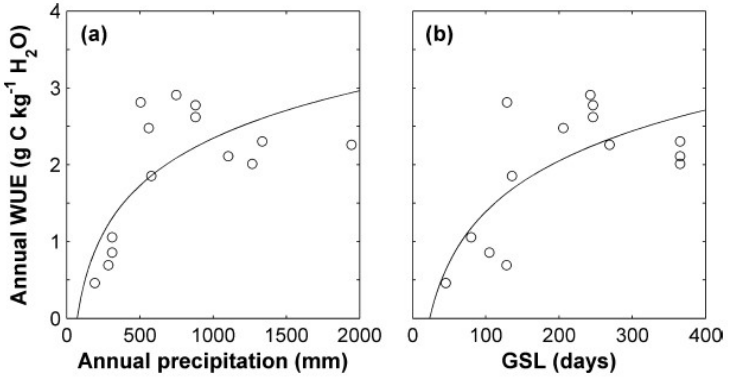
(Yu et al. 2008,New Phytologist)

Grassland



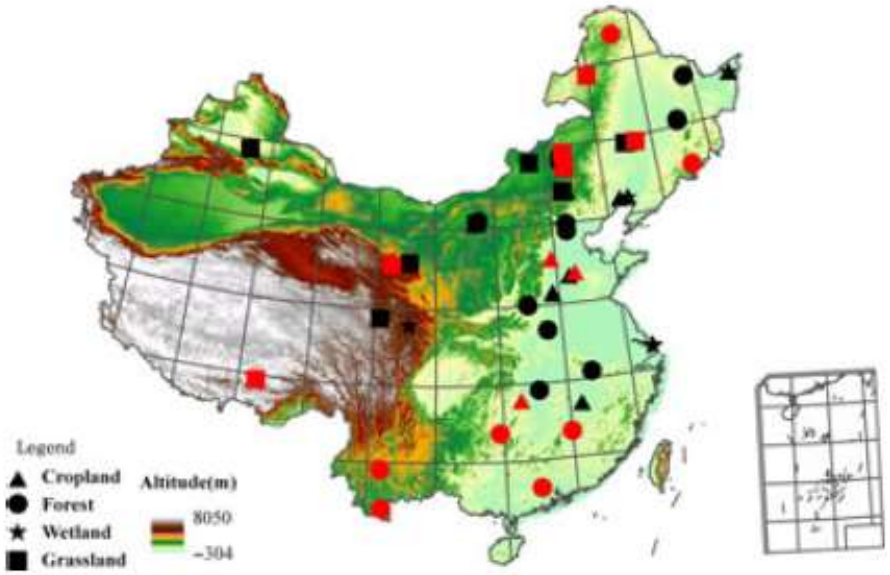
(Hu et al. 2008,GCB)

14 sites



(Xiao et al. 2013,AFM)

Inhibiting full understanding on the spatial variability of WUE in China based on measurements



(Yu et al. 2013, GCB)

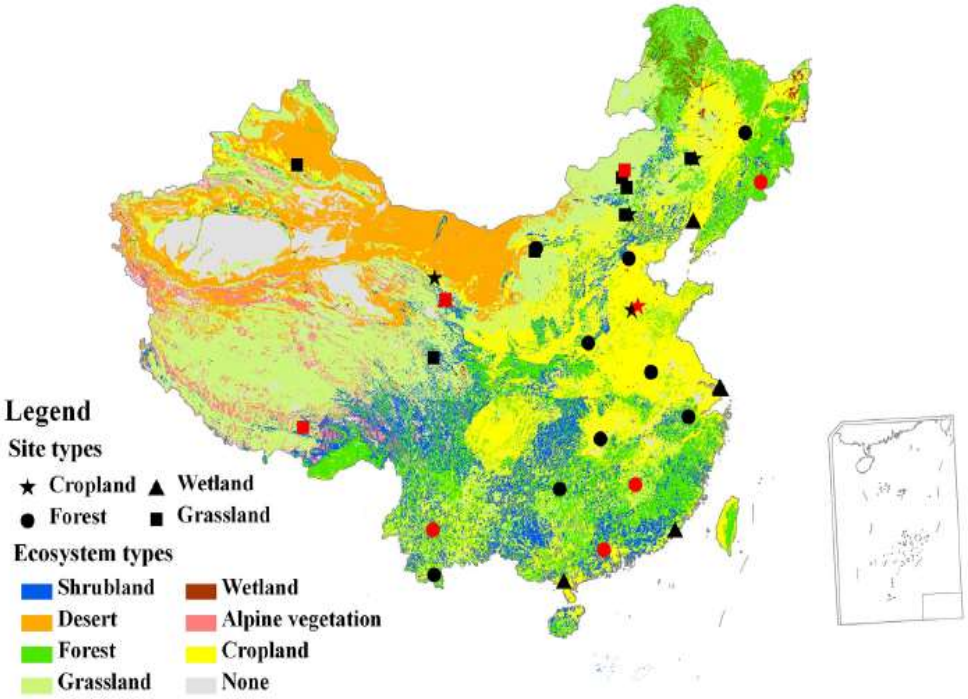
Conducting eddy covariance measurements since 2002

Accumulating a great deal of CO_2 and H_2O flux data

Objectives:

- **How WUE spatially varied?**
- **Why WUE spatially varied?**

How WUE spatially varied?



Sites used in this study

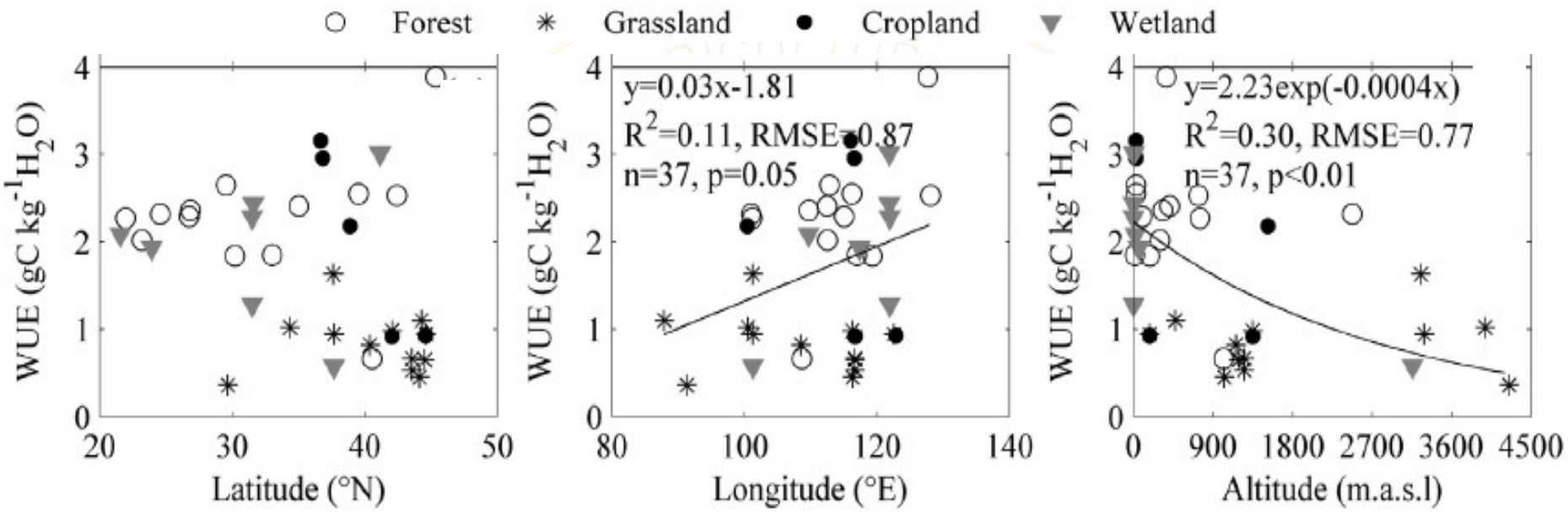
Selecting criteria

- Eddy covariance measurements
- Conducted for at least 1 year
- annual total GPP and ET were available
- GPP and ET were observed in the same year

Forests: 9; Grasslands: 9; Croplands:9; Wetlands: 6

(Zhu et al. 2015, GPC)

Geographical pattern

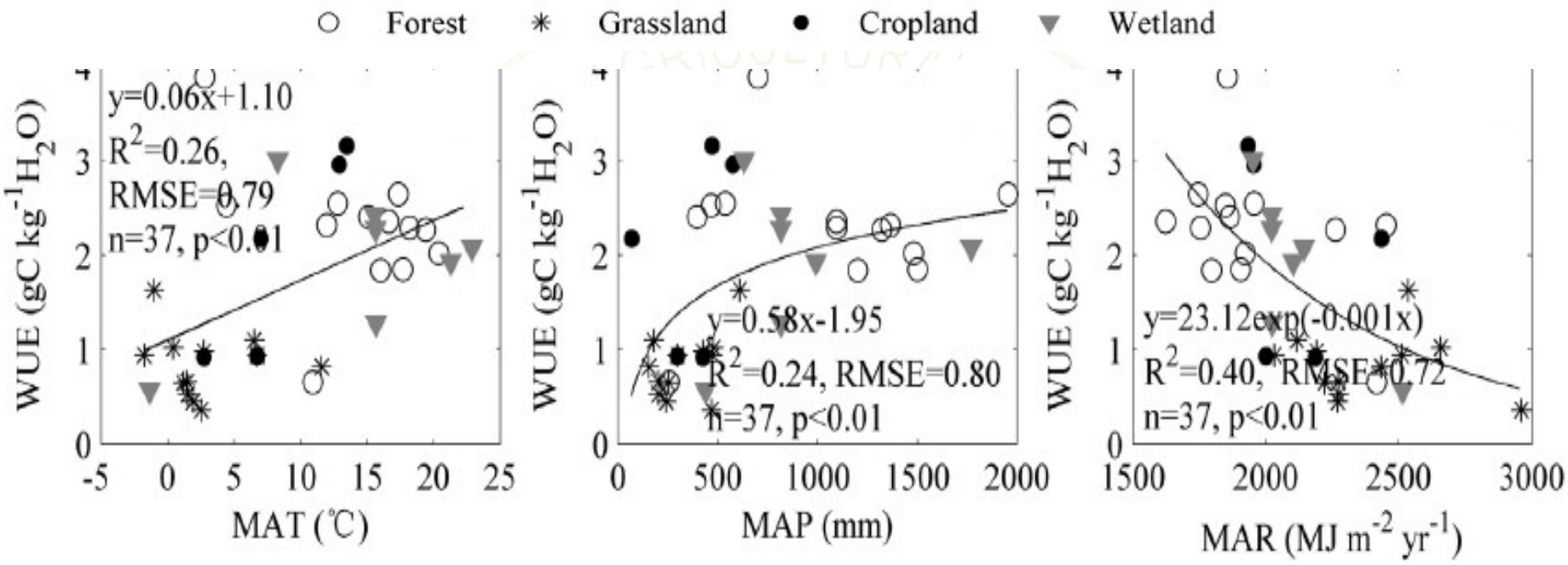


Geographical pattern of WUE in terrestrial ecosystems

- **Latitude: No significant**
- **Longitude: Slight increasing**
- **Altitude: Obvious decreasing**

(Zhu et al. 2015, GPC)

Climatic effects

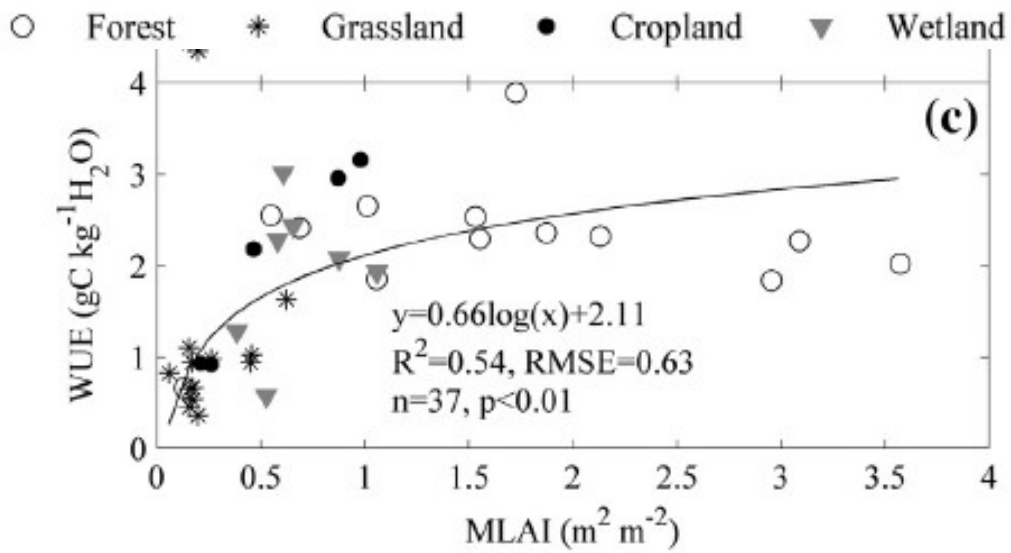


Climatic effects on the spatial variation of WUE

- **MAT: Linearly increasing**
- **MAP: Logarithmically increasing**
- **PAR: Exponentially decreasing**

(Zhu et al. 2015, GPC)

Biotic effect



Biotic effect on the spatial variation of WUE

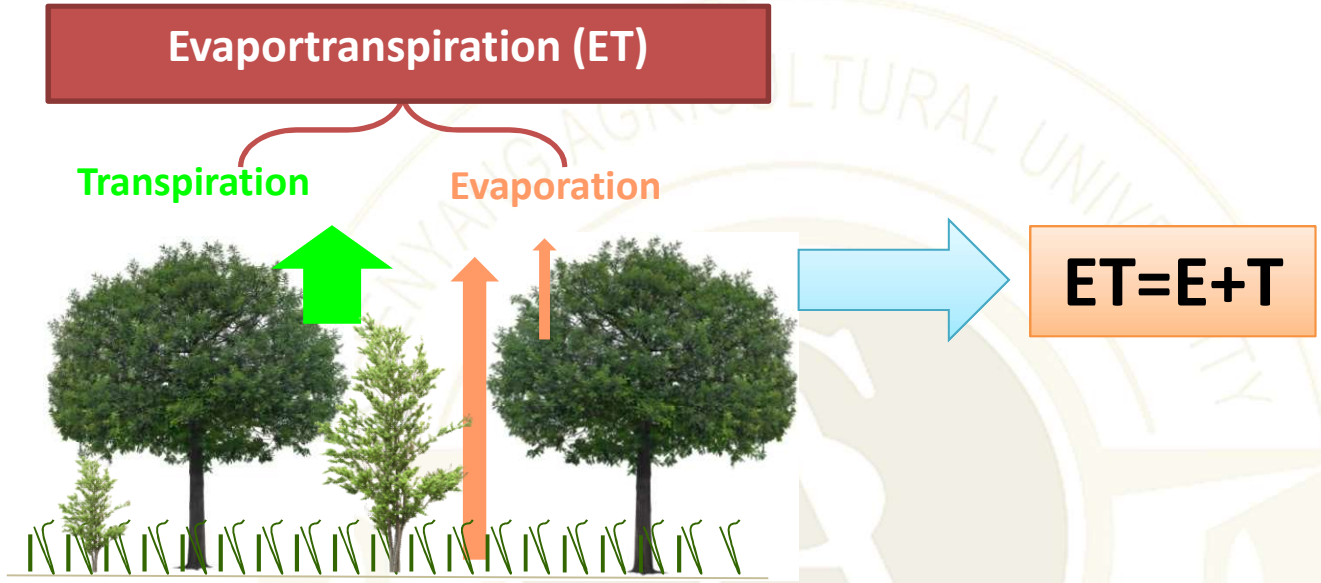
- **LAI: Logarithmically increasing**

- **Altitude and LAI explained most spatial variation of WUE**

$$\mathrm{WUE} = 0.58\log(\mathrm{MLAI}) - 0.0003\mathrm{Altitude} + 2.32,$$
$$R^2 = 0.65,\ \mathrm{RMSE} = 0.55$$

(Zhu et al. 2015, GPC)

Why WUE spatially varied?



$$WUE = \frac{GPP}{ET} = \frac{GPP}{T} \times \frac{T}{ET}$$

The relationships between GPP/T and factors would be confounded by the effect of VPD on T [*Baldocchi et al.*, 1985; *Beer et al.*, 2010]

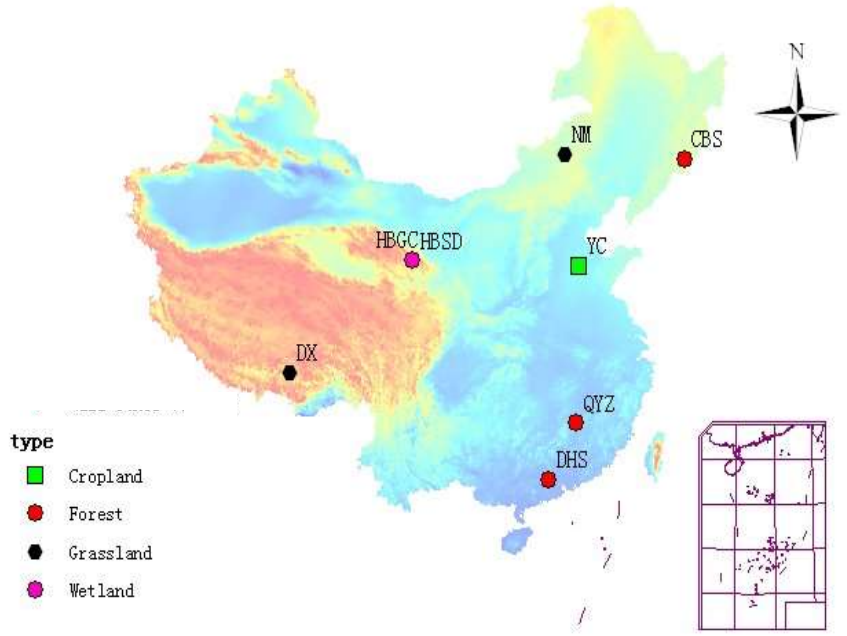
The effect of VPD on T would only also occur in the **growing-season**

$$IWUE=GPP\times VPD_{gs}/T$$

$$WUE=IWUE\times 1/VPD_{gs}\times T/ET$$

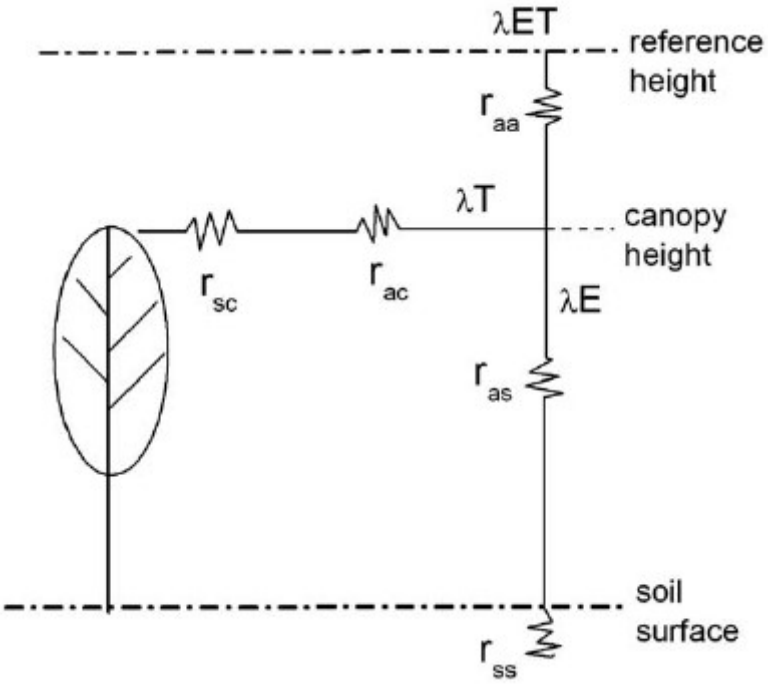
Analysing factors affecting the spatial variations of WUE components would reveal why various factors affected the spatial variation of WUE

Materials



ChinaFLUX observation sites

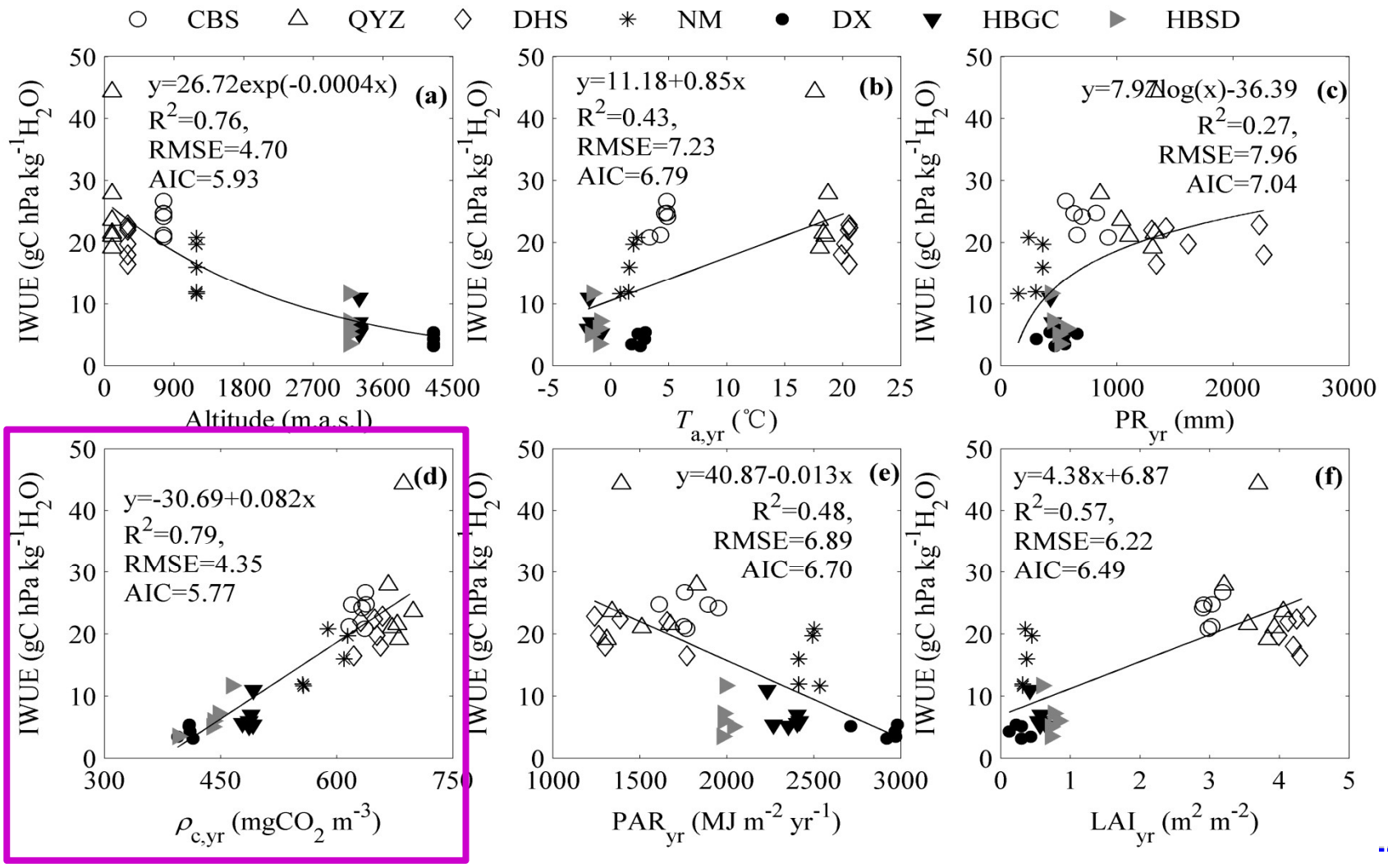
Eddy covariance measured GPP and ET



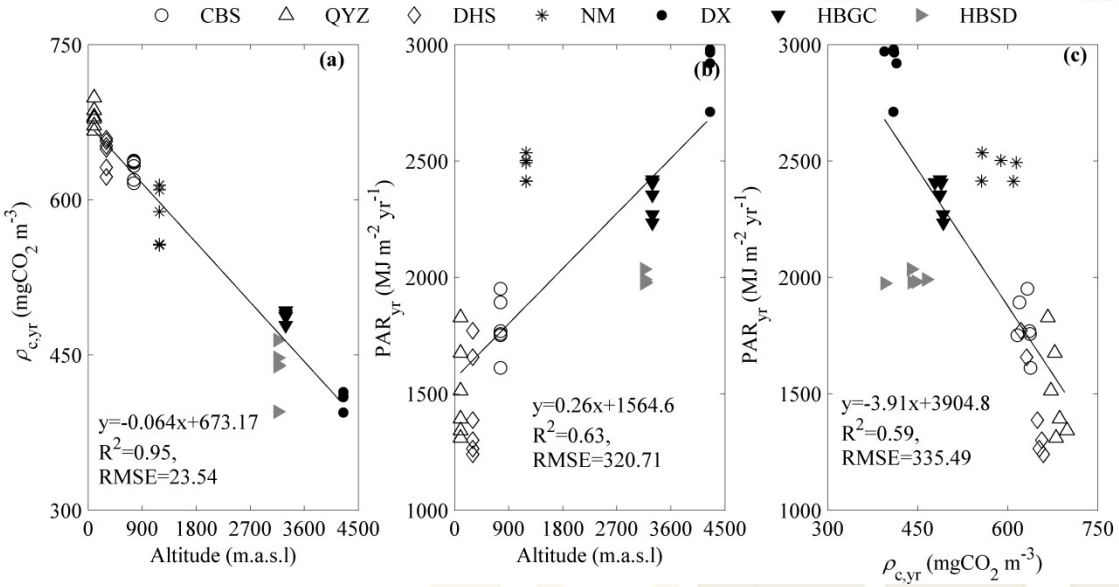
Scheme of Shuttleworth-Wallace model

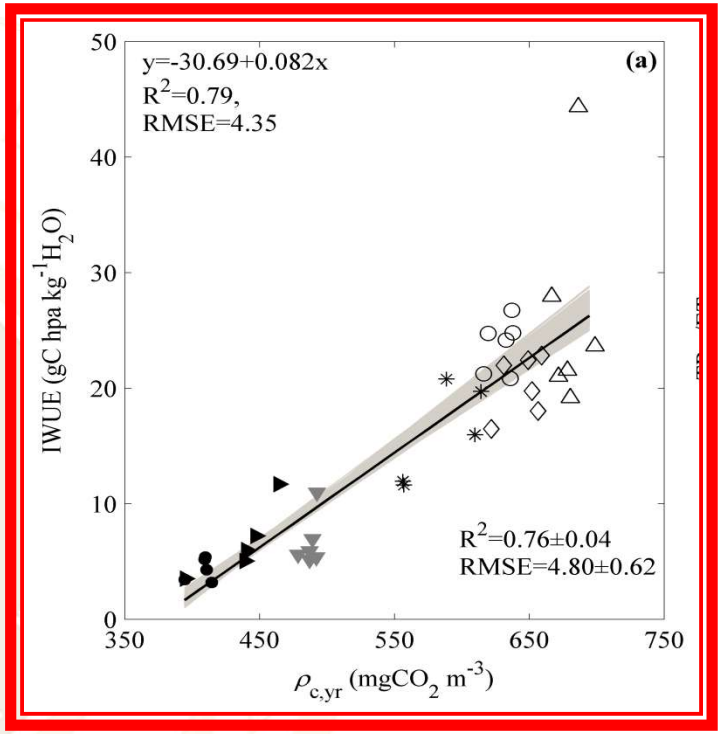
Using S-W model separating ET into E and T

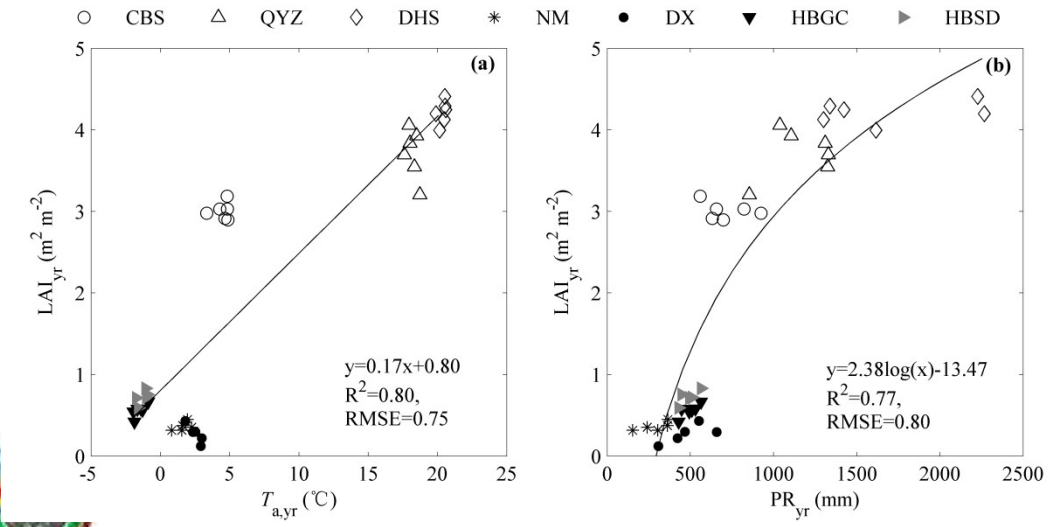
IWUE



Factors affecting the spatial variability of IWUE

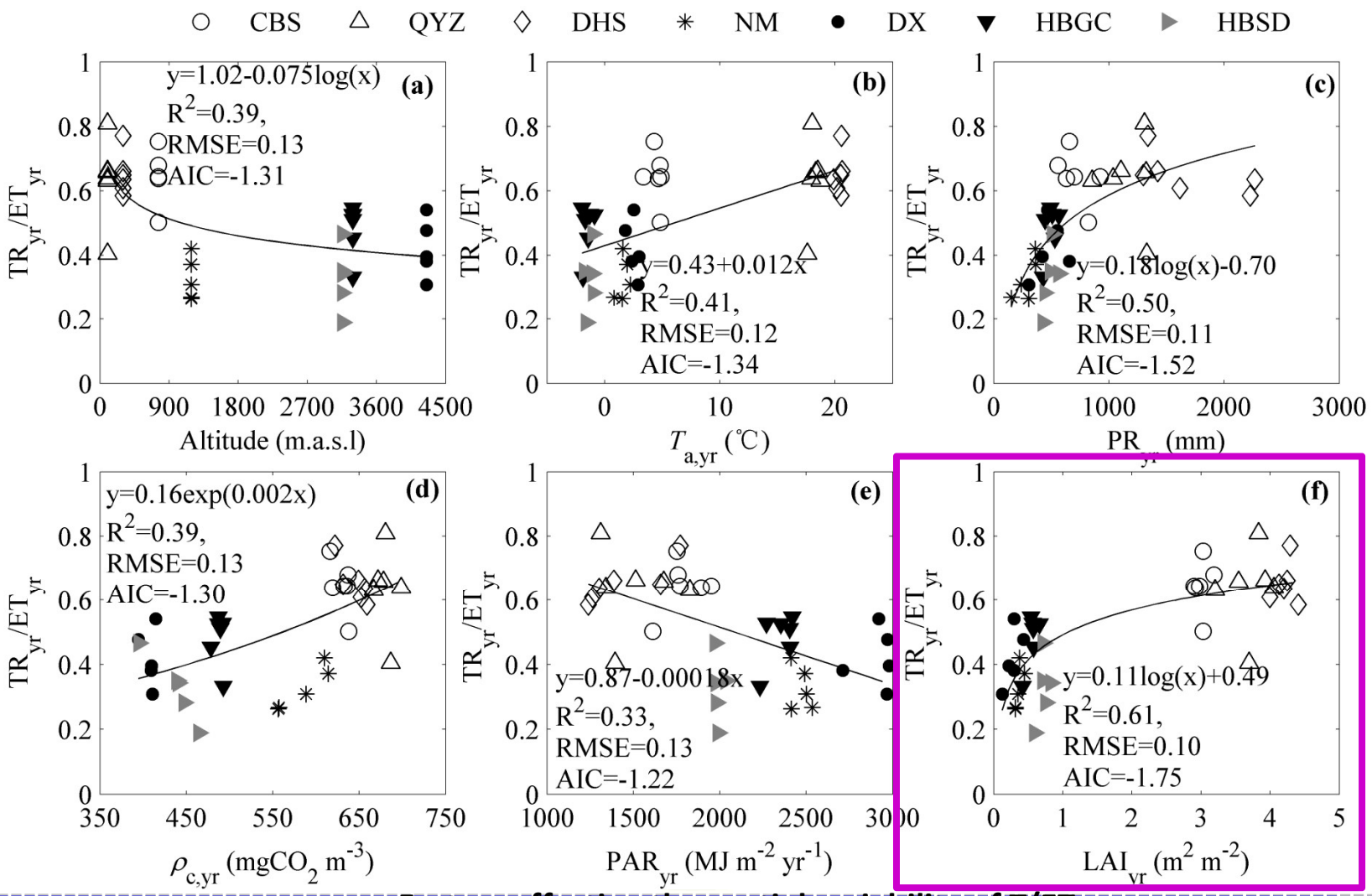






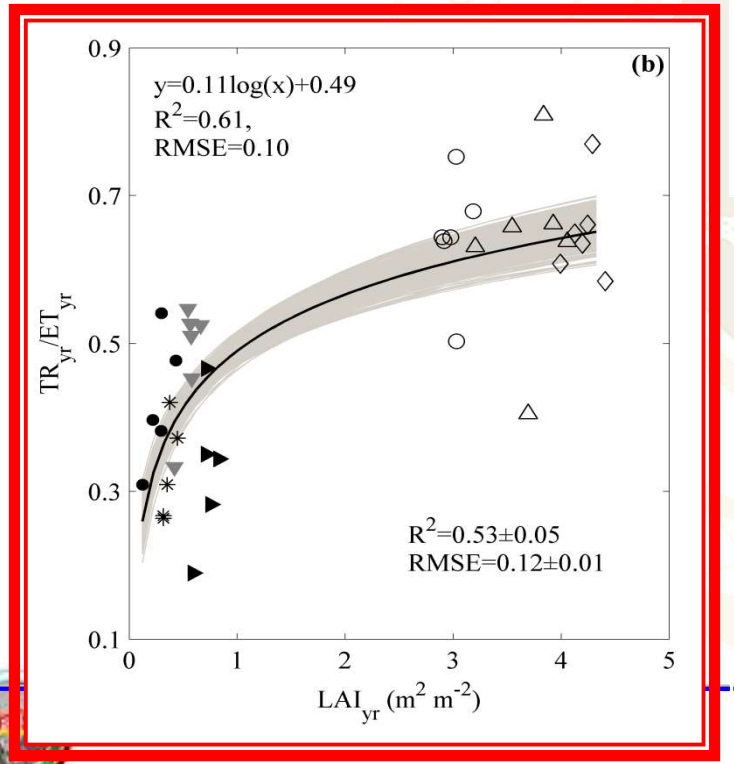
$\rho_{c,yr}$ dominated the spatial variation of IWUE

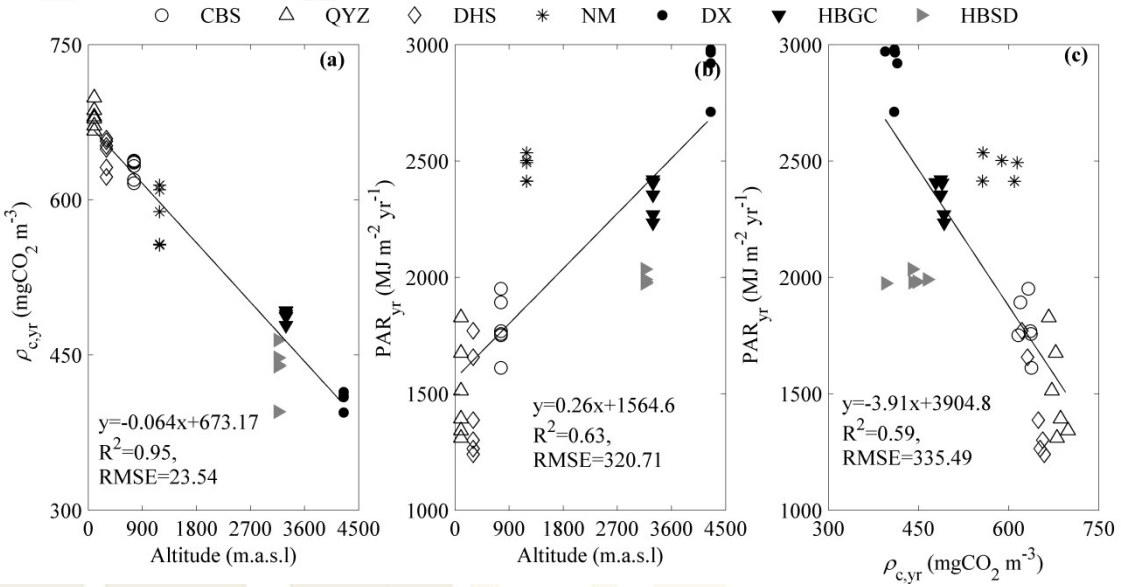
T/ET

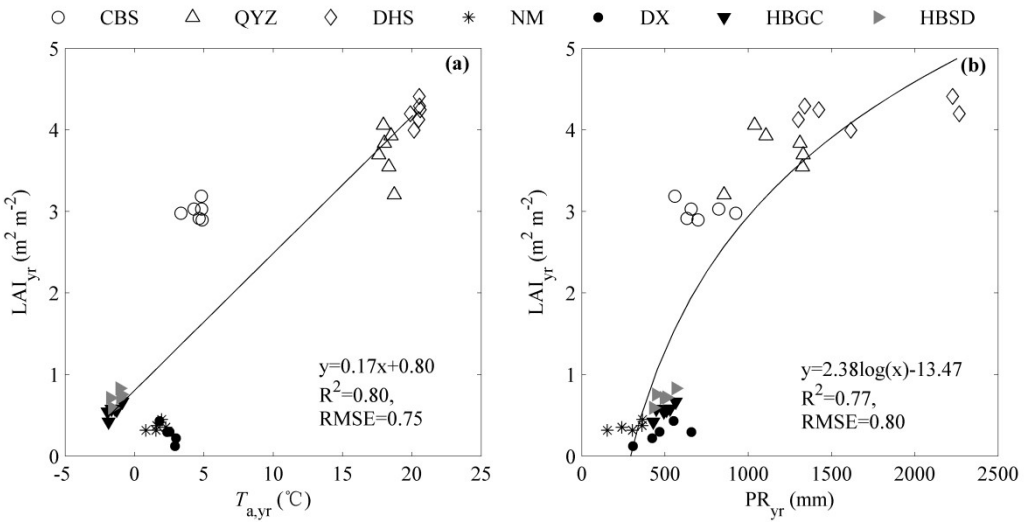


Factors affecting the spatial variability of T/ET

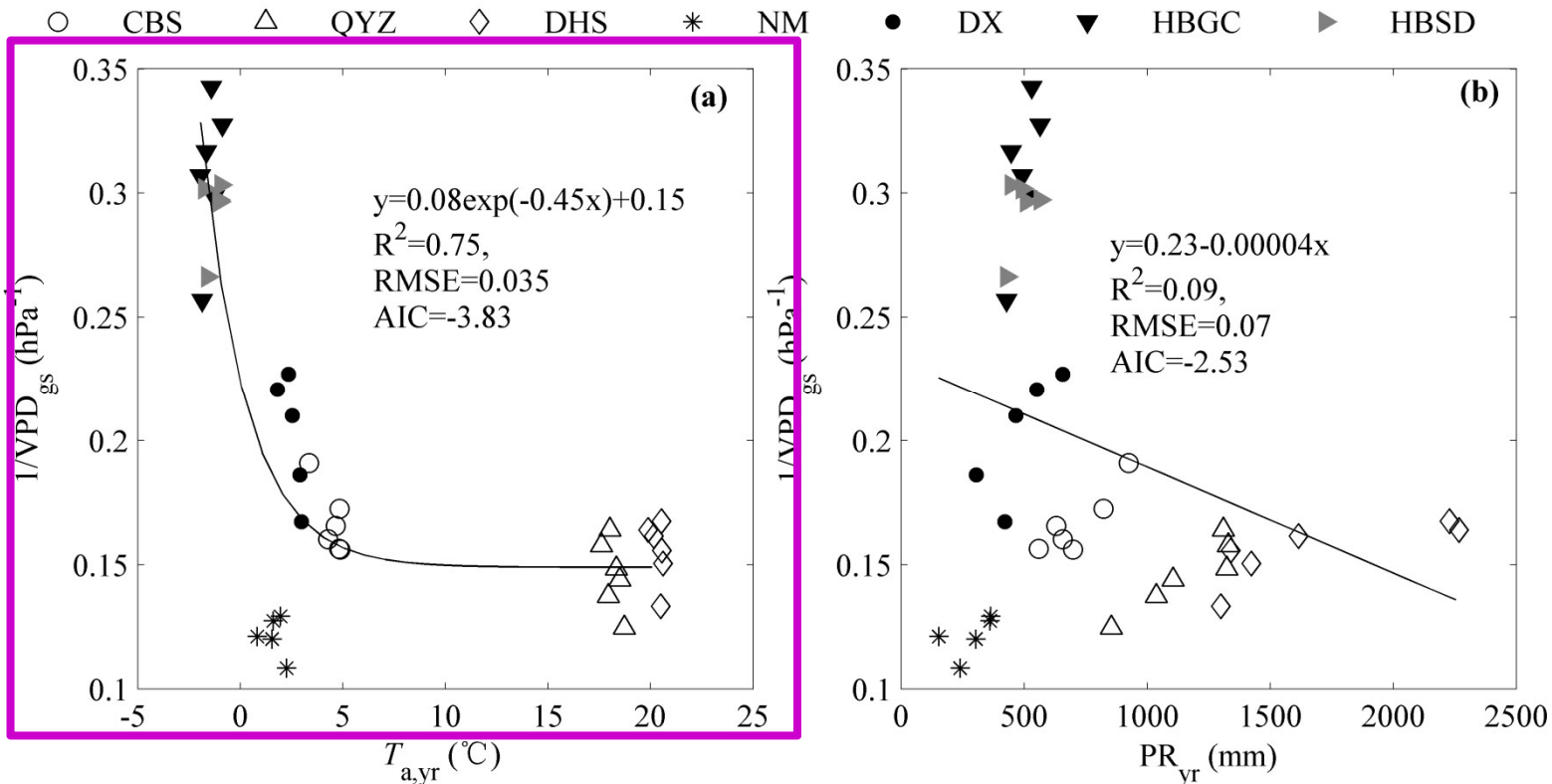
LAI closely related to the spatial variation of T/ET







$1/VPD_{gs}$



Factors affecting the spatial variability of $1/VPD_{gs}$

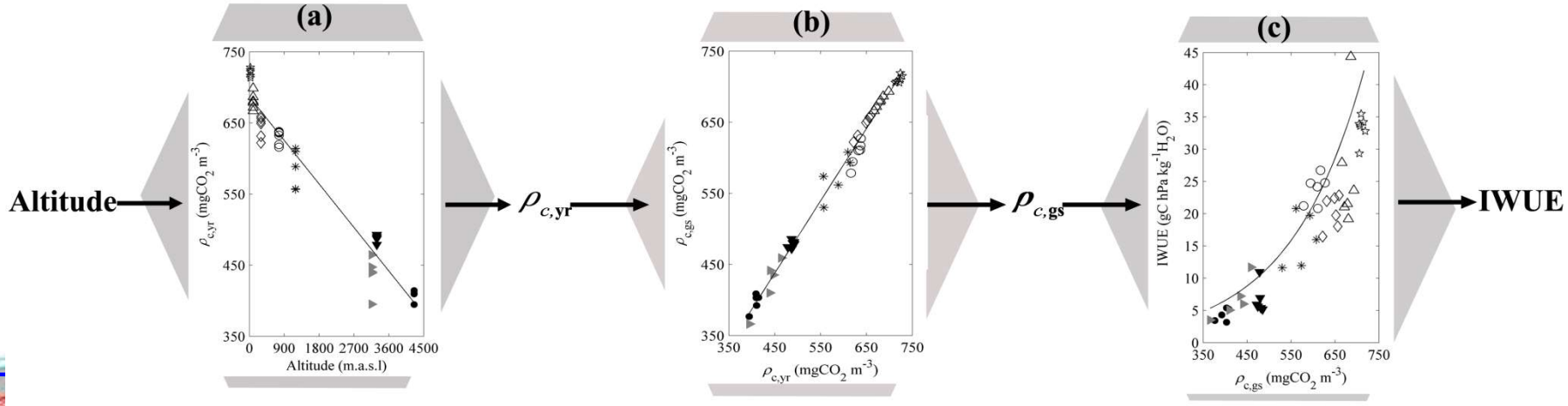
MAT dominated the spatial variation of $1/VPD_{gs}$

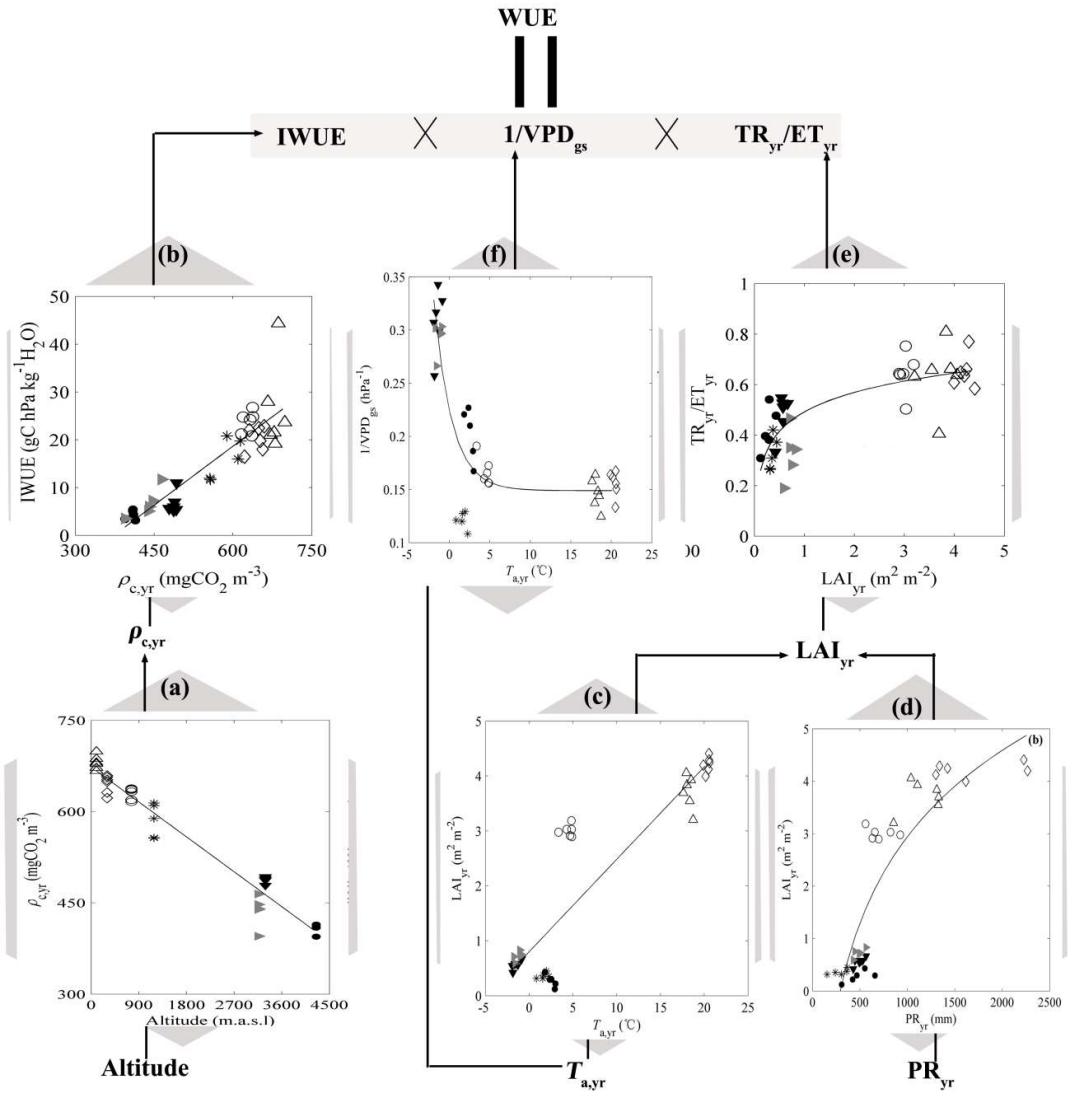
Mechanisms

$$GPP = G_c \times D\rho_c = G_c \times (\rho_c - \rho_{ci})$$

$$Tr = G_w \times D\rho_c = G_w \times (\rho_{wi} - \rho_{wa})$$

$$IWUE \propto \frac{\rho_{c,gs}(1-\rho_{ci}/\rho_c)_{gs}}{R}$$





- **Altitude** affected the spatial variation of WUE through the effect of $\rho_{c,yr}$ on **IWUE;**
- **MAP** influenced the spatial variation of WUE through the effect of **LAI** on **T/ET**
- **MAT** affected the spatial variation of WUE through its effect on **T/ET** and **1/VPD$_{gs}$.**
- **WUE was the product of IWUE, T/ET, and 1/VPD$_{gs}$.**

Summary

- WUE exhibited a decreasing trend with the increasing altitude, but increased with MAT, MAP, and LAI.
- The spatial variation of WUE could be depicted by the equation of altitude and mean annual leaf area index.
- $\rho_{c,yr}$ dominated the spatial variation of IWUE through the altering altitude while LAI affected the spatial variation of T/ET, but MAT determined the spatial variation of $1/VPD_{gs}$
- WUE was the product of IWUE, T/ET, and $1/VPD_{gs}$.

Acknowledgements

- I am very grateful for data provider in ChinaFLUX providing eddy covariance observation data, including sites as CBS, QYZ, DHS, NM, DX, HBGC, HBSD, YC.
- Many thanks to the finance support by the National Key Research and Development Program and National Natural Science Foundation of China

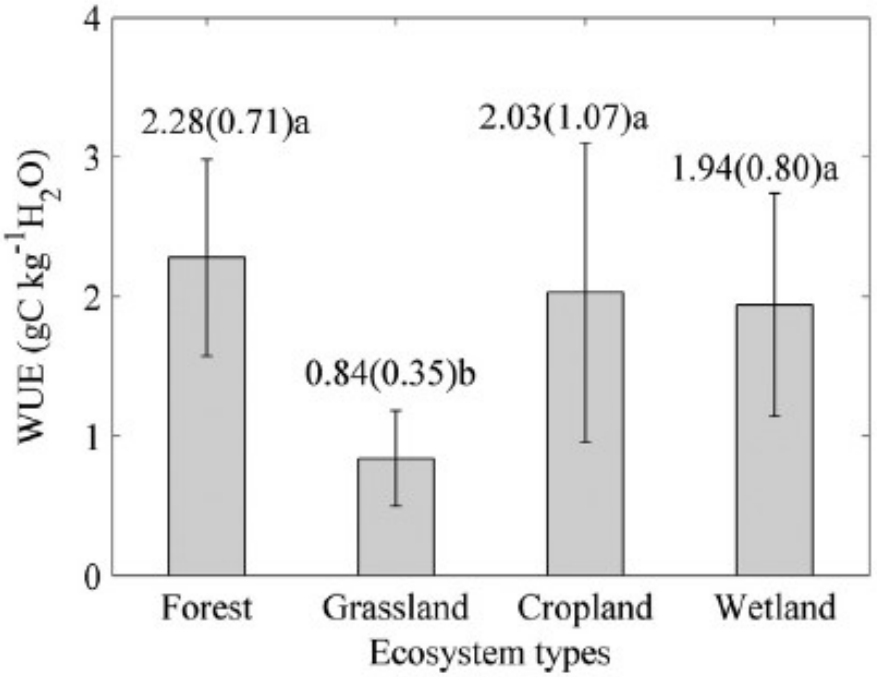
Thank you for your attention!

Further implications

- CO_2 not only affects the temporal variation of WUE, but also affects its spatial variation.

- $\rho_{c,yr}$ may be a potential climatic factor affecting the spatial variation of carbon fluxes

Statistical values



Statistical values of WUE among ecosystem types

- **Forest, Cropland, Wetland were comparable**
- **Grassland was significantly lower than other ecosystems**

(Zhu et al. 2015, GPC)