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Environmental Controls of Carbon Dioxide (CO_2) Fluxes in Freshwater Wetlands Across the Globe

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Background

- Wetlands are crucial in global carbon dynamics due to
  - substantial soil carbon reservoirs,
  - high methane emissions, and
  - ability to sequester carbon through peat formation, sediment deposition, and plant biomass accumulation (Turunen et al., 2002 and Mitra et al., 2005).

- Freshwater wetlands are important components in the global carbon budget by contributing to
  - the net source or sink of major greenhouse gas (GHG) fluxes, such as carbon dioxide (FCO_2) and methane (FCH_4) (Nahlik and Fennessy, 2016).

Study sites

- 38 Fluxnet Freshwater wetland sites.

- 5 major Koppen climate regions
  - Tropical or megathermal (A)
  - Dry or arid (B)
  - Temperate or mesothermal (C)
  - Continental or microthermal (D)
  - Polar or alpine climates (E)

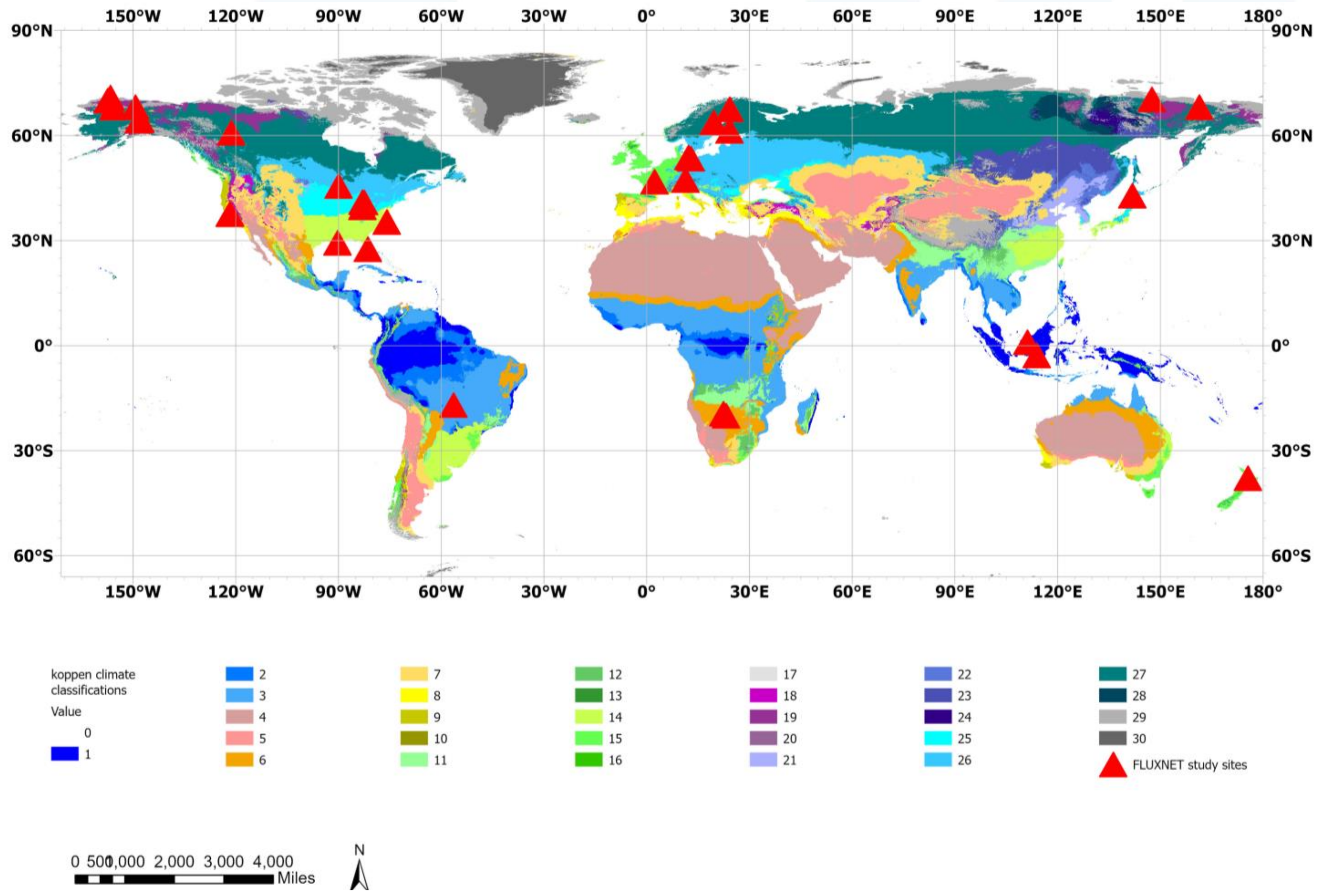
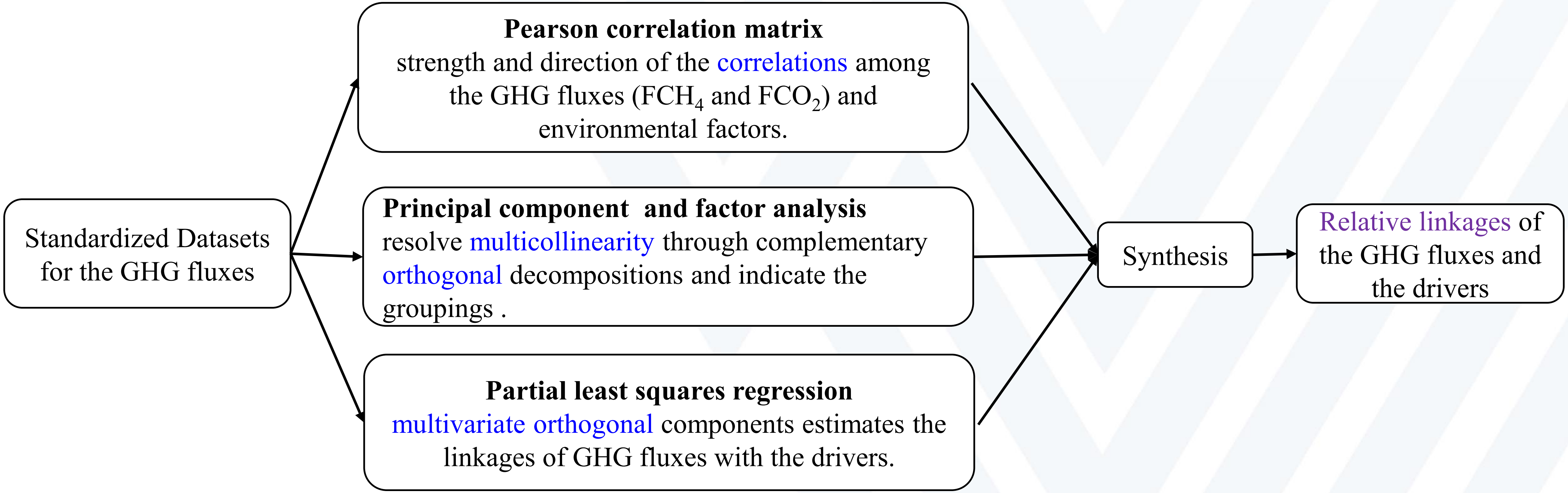


Fig. 1: Geographical locations of 38 freshwater wetland sites across the globe.

Data analytics



Correlation coefficients

Table 1 Pearson Correlation Matrix for the Net uptake Fluxes of FCO_2

Climatic Zones	PAR	LE	H	WS	USTAR	TS	VPD	WL
Tropical Climate (A)	**0.47**	**0.43**	0.06	**-0.62**	0.04	**0.77**	**0.38**	0.27
Dry Climates (B)	0.44	0.21	0.07	-0.16	-0.16	-0.02	-0.23	
Temperate Climate(C)	**0.50**	**0.60**	-0.05	0.02	**0.30**	**0.61**	**0.44**	**-0.22**
Continental Climates (D)	**0.57**	**0.59**	**0.39**	**-0.34**	**0.44**	**0.50**	**0.50**	**-0.35**
Polar Climates (E)	**0.27**	**0.54**	**0.64**	0.02	**0.32**	**0.38**	**0.40**	

Biplots for FCO_2 from principal component analysis

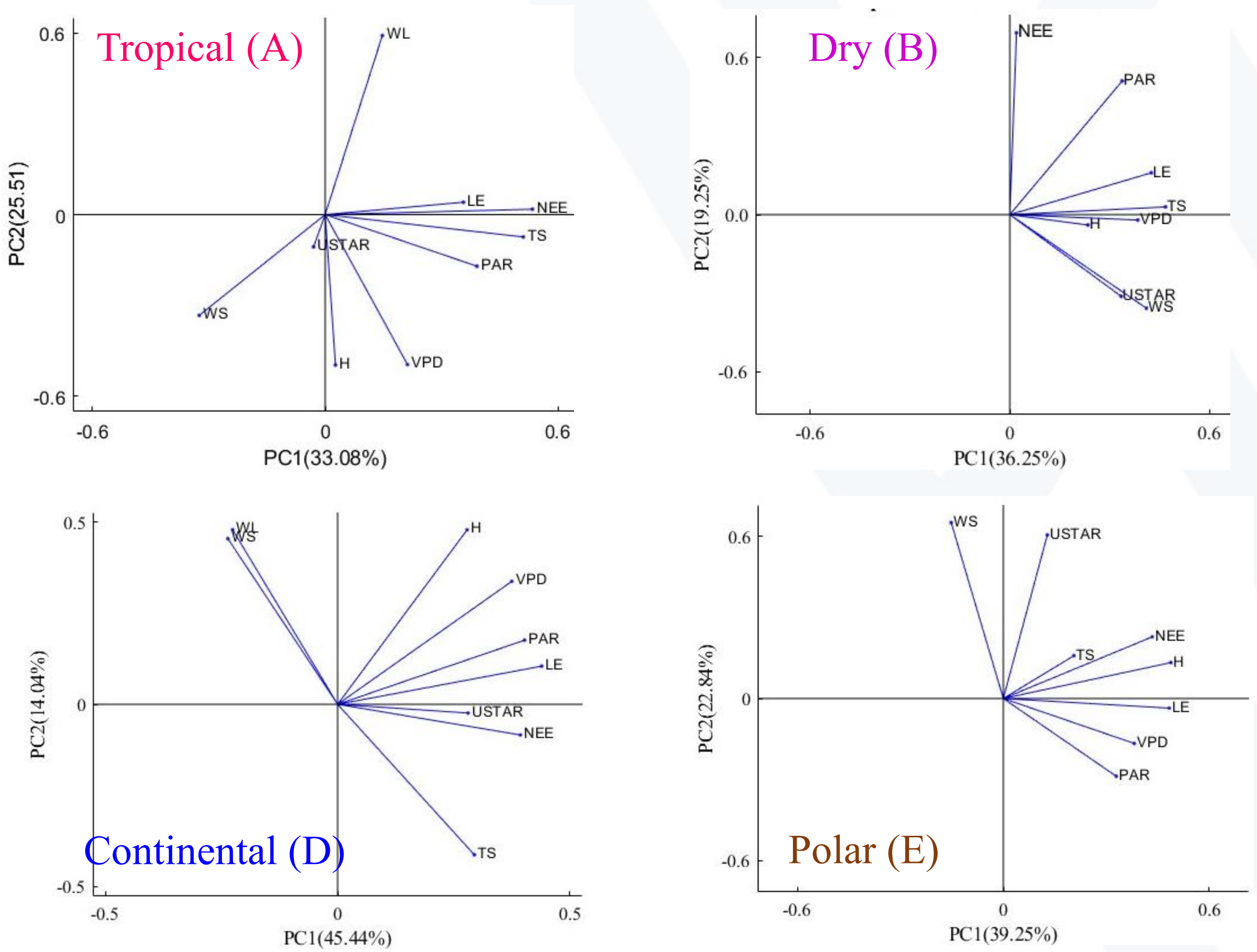


Fig. 2 Biplots obtained from principal component analysis showing the interrelationship of the climatic and ecohydrological drivers for (a) tropical climate (b)dry climate(c)temperate climate (d)continental climate and (e) polar climate.

Factor loadings

Table 2: Dominant Factors and Optimized Loadings of the Methane Fluxes (FCO_2) and the Environmental Variables.

Climatic Zones	Factors	PAR	LE	H	WS	USTAR	TS	VPD	WL	FCO_2
Tropical Climate (A)	Fac 1	**0.71**	**0.66**	-0.02	-0.11	0.14	**0.83**	0.33	0.07	**0.74**
	Fac 2	0.09	-0.14	**0.73**	0.12	-0.04	0.08	**0.74**	**-0.78**	0.12
	Fac 3	-0.07	-0.08	0.01	-0.96	-0.14	0.27	0.04	0.54	**0.58**
Dry Climates (B)	Fac 1	**0.57**	**0.63**	0.03	0.20	0.19	**0.58**	**0.83**		0.02
	Fac 2	0.07	0.15	0.46	**0.97**	**0.52**	0.40	0.09		-0.07
	Fac 3	0.43	0.20	0.11	-0.10	-0.12	-0.01	-0.24		**0.99**
Temperate Climate(C)	Fac 1	**0.71**	**0.80**	-0.09	0.01	0.37	**0.81**	**0.70**	-0.22	**0.74**
	Fac 2	0.28	-0.06	0.01	**0.96**	**0.72**	0.27	0.00	0.37	0.01
	Fac 3	0.10	0.39	-0.21	0.00	0.18	-0.10	0.18	**0.55**	-0.05
Continental Climates (D)	Fac 1	**0.75**	**0.72**	0.51	-0.20	0.20	0.15	**0.90**	-0.08	**0.47**
	Fac 2	0.33	0.46	-0.01	-0.32	0.14	**0.99**	0.14	-0.34	0.46
	Fac 3	0.06	0.32	0.28	-0.21	**0.97**	-0.06	0.05	-0.26	0.29
Polar Climates (E)	Fac 1	**0.59**	**0.74**	0.88	-0.35	0.26	0.14	**0.61**		**0.63**
	Fac 2	-0.29	-0.07	0.24	**0.71**	**0.95**	0.01	-0.11		0.21
	Fac 3	0.04	0.32	0.06	0.24	-0.15	**0.96**	-0.11		0.30
		Radiation energy component(β_{RE})			**Aerodynamic component(β_{AD})**		**Hydro-climatic component(β_{HC})**			

PLSR coefficients

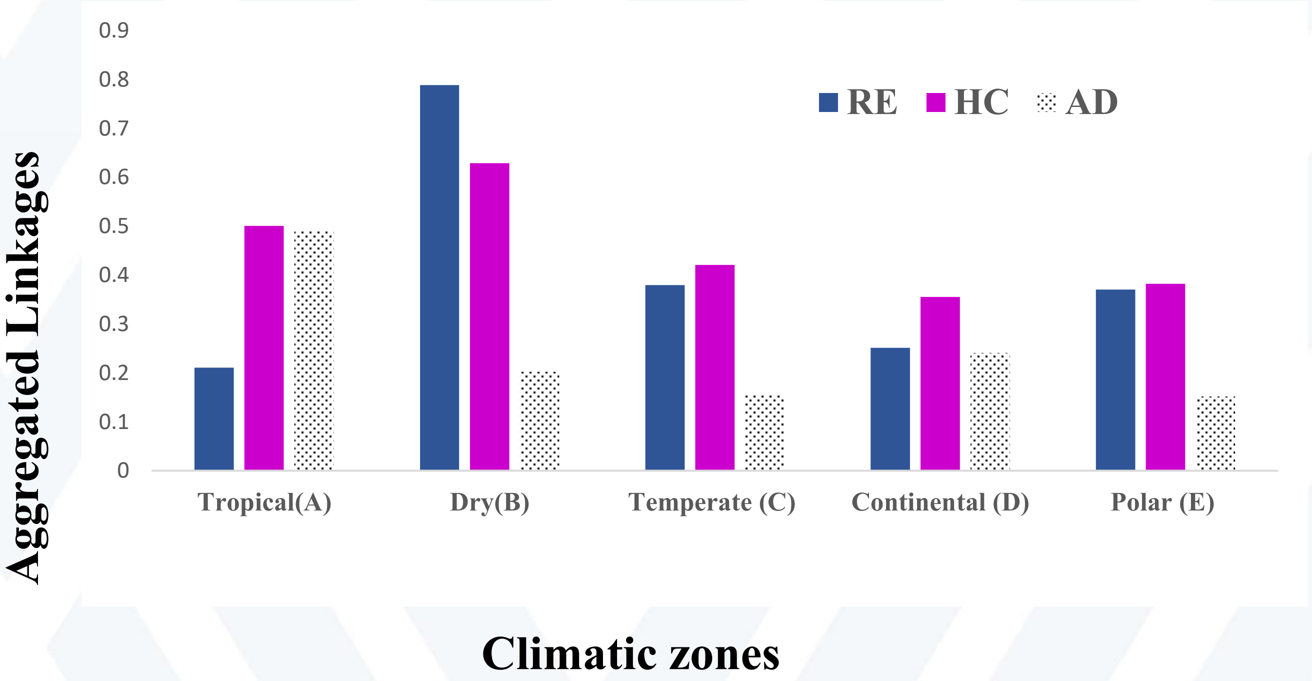
Table 3: Coefficients (β) of the log10-transformed, standardized (Z-score) PLSR models for methane emission fluxes(FCO_2) for five different climatic zones.

Variables	Tropical climates (A)	Dry climates (B)	Temperate climates (C)	Continental climates (D)	Polar climates (E)
PAR	0.06	**0.63**	0.09	**0.19**	-0.01
LE	0.20	**0.47**	**0.37**	-0.01	0.07
H	-0.03	0.06	0.03	0.16	**0.36**
WS	**-0.46**	-0.04	-0.06	-0.03	0.00
USTAR	0.16	-0.20	0.14	**0.24**	0.15
TS	**0.36**	-0.17	**0.32**	**0.33**	**0.34**
VPD	**0.34**	**-0.61**	-0.10	0.11	**0.17**
WL	0.05		**-0.25**	-0.06	
NSE	0.84	0.61	0.52	0.54	0.62
RSR	0.40	0.61	0.69	0.68	0.59

Relative linkages

$$\beta_{RE} = \sqrt{\beta_{PAR}^2 + \beta_{LE}^2 + \beta_H^2}$$
$$\beta_{HC} = \sqrt{\beta_{TS}^2 + \beta_{VPD}^2 + \beta_{WL}^2}$$
$$\beta_{AD} = \sqrt{\beta_{WS}^2 + \beta_{USTAR}^2}$$

- HC: strongest linkages in tropical(A), temperate(C),continental(D) and polar(E) region.
- RE: strongest linkages in dry(B), region.



Model performance

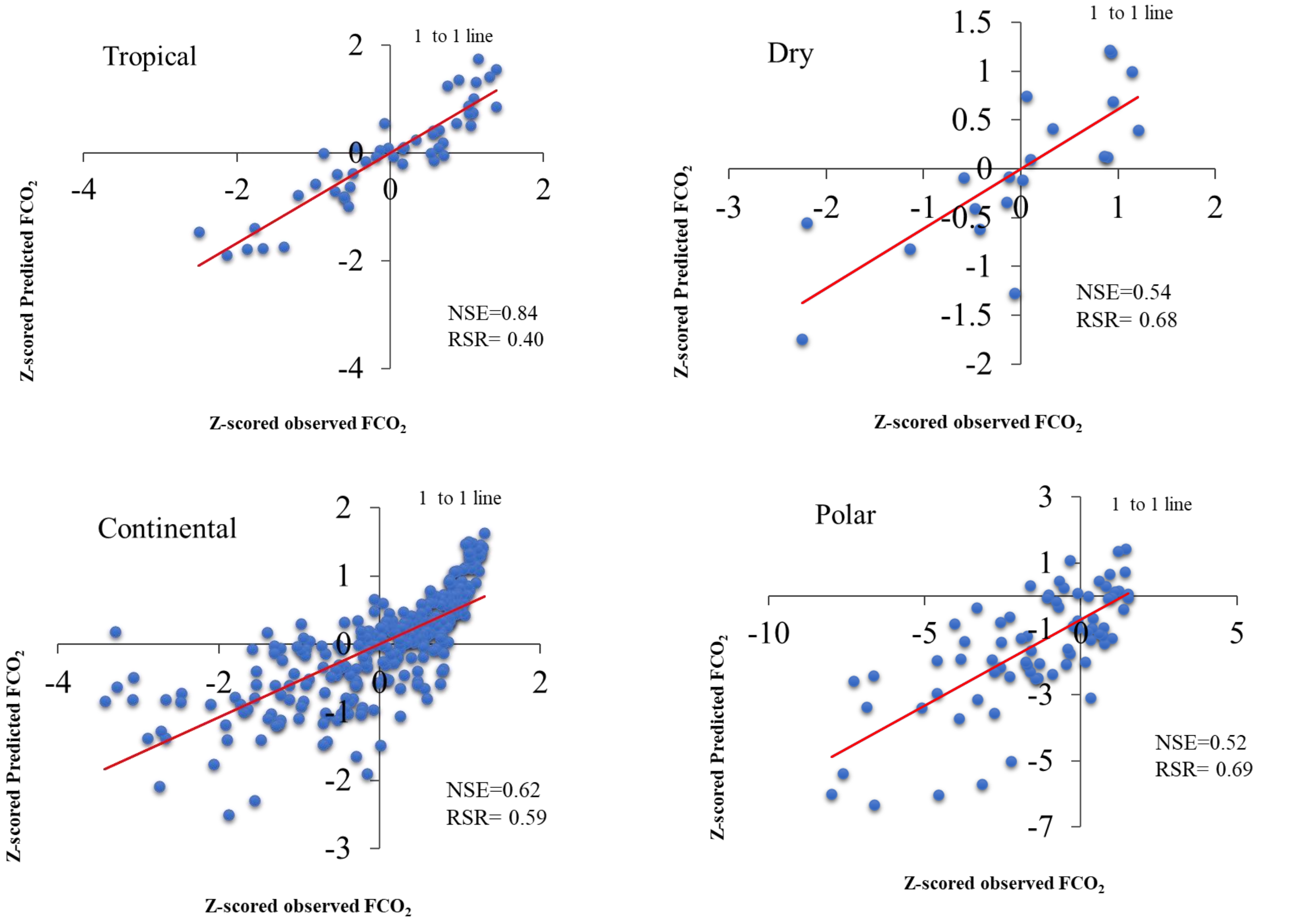


Fig 3: Observed vs predicted fluxes of FCO_2 in five climatic zones .
NSE=Nash-Sutcliffe efficiency
RSR=ratio of root-mean-square error to the standard deviations of the observations

Conclusion

- In tropical regions , FCO_2 fluxes are mainly controlled by PAR, TS, WS, and VPD.
- In dry regions, LE ,VPD, PAR, TS, and USTAR, dominate FCO_2 fluxes.
- WL, TS, and LE are primary controlling factors in temperate regions.
- In continental wetlands, PAR, LE, TS, VPD, and USTAR are dominant controlling factors.
- In wetlands of the polar region, H has a strong linkage with FCO_2 fluxes, along with PAR, TS, VPD, WS, and USTAR.

Conclusions

- "Hydro climatic" component (TS, VPD, WL) has a stronger influence on FCO_2 uptake compared to "radiation energy" component (PAR, LE, and H) and "aerodynamic" exchange component (WS and USTAR), with approximately two to three times stronger controls on FCO_2 uptake than the other two components.
- In dry regions, the radiation energy component (PAR, LE, H) is the dominant control, with approximately 1.5 times stronger controls than the hydro climatic component and 4 times stronger controls than the aerodynamic component.

Discussion and recommendation

- The research findings and global knowledge on the major controls of GHG fluxes(such as Carbon Dioxide) would help develop effective strategies for mitigating global warming such as through
  - Wetland restoration and maintenance, minimizing anthropogenic disturbances, and/or
  - Promoting appropriate (e.g., native) plant species that enhances the atmospheric carbon uptake, while reducing the net emissions of GHG (such as Carbon Dioxide) fluxes to the atmosphere.
- The differential environmental controls on the GHG fluxes (such as Carbon Dioxide) among the different climatic zones suggest that a uniform set of wetland management strategies would not effective everywhere.
- We, therefore, recommend climatic zone-specific interventional measures to maximize the contributions of global freshwater wetlands as an ecological (i.e., green) technology to the mitigation of global warming and climatic changes.

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