Supplementary Material

Emergent constraints on climate—carbon cycle feedbacks from tropical atmospheric aridity

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- Figure 1: Yearly Global CO_2 growth rate anomalies versus tropical NBE anomalies.
- Figure 2: Causality analysis (CCM) using observed record of CGR and VPD
- Figure 3: Causality analysis (CCM) based on earth system models (ESMs)
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- Table 2: Short-term sensitivity of NBE versus VPD and long-term response of land carbon uptake to atmospheric aridity in 12 ESMs.

1 Calculating VPD

To calculate VPD we use the following equation (Eq.1) based on annual near surface air temperature (T) and dew point (T_d) (Seager et al., 2015)

$$VPD = c_1 \times exp(\frac{c_2 * T}{c_3 + T}) - c_1 \times exp(\frac{c_2 * T_d}{c_3 + T_d}) \tag{1}$$

Where, c_1 = 0.611 KPa, c_2 = 17.5, c_3 = 240.978 °C. T and T_d are in °C and VPD is in KPa. The first and the second term in Eq. 1 are the saturation vapor content of air T (SVP) and the actual vapor pressure (AVP), respectively. Temperature (T) and relative humidity (RH) are used to calculate dew point (T_d) in climate models based on the following equation (Eq. 2):

$$T_d = \frac{a_1 * \{ln(\frac{RH}{100}) + \frac{a_2 * T}{a_1 + T}}{a_2 - \{ln(\frac{RH}{100}) + \frac{a_2 * T}{a_1 + T}\}} \tag{2}$$

Where, a_1 = 243.04, a_2 = 17.625.

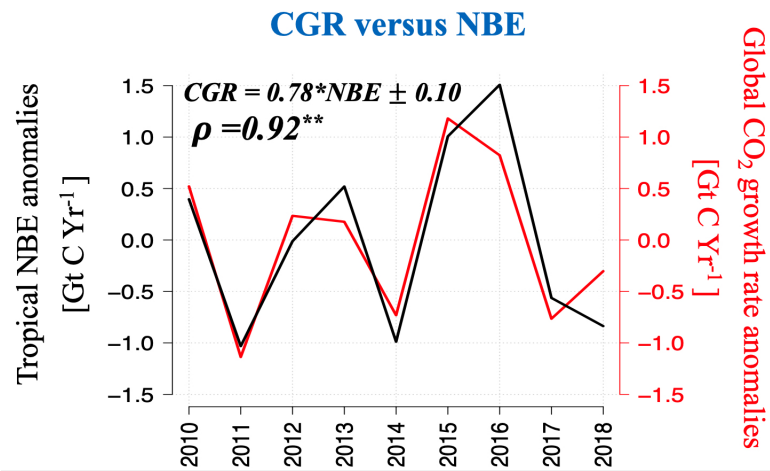


Figure 1: Yearly Global CO_2 growth rate (CGR) versus Tropical CMS-Flux NBE anomalies. **Note**:The vertical axes is inverted for NBE.

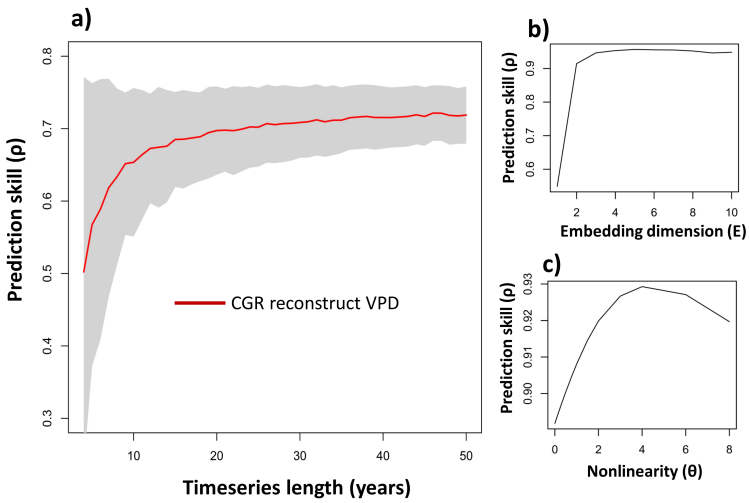


Figure 2: **a**) Convergent cross-mapping for reconstruction of variations in VPD from variations in CGR. **b**) Identifying the optimal embedding dimension (E) which describes the size of the time windows used for prediction. **c**) Testing the "predictability" of VPD time series

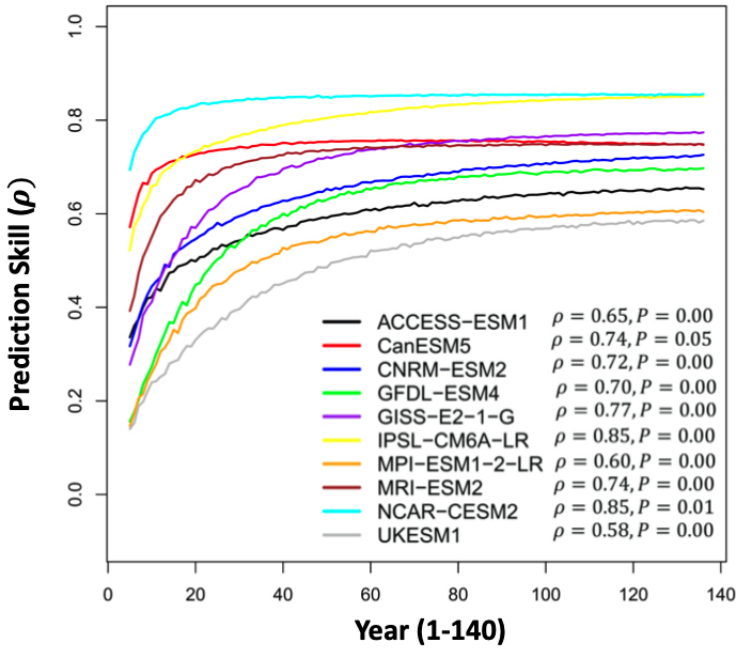
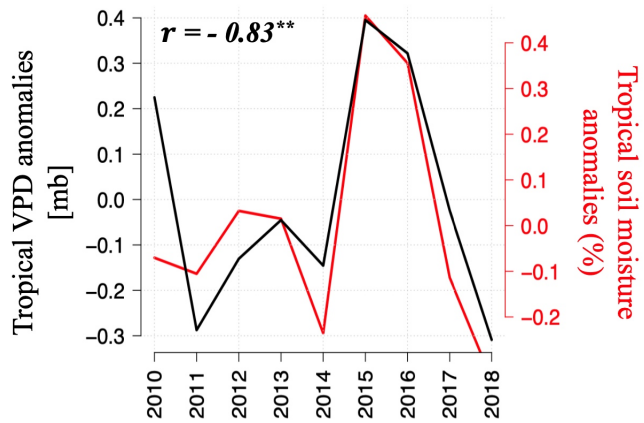


Figure 3: Convergent cross-mapping for reconstruction of variations in tropical VPD from variations in NBP (net biome productivity). Climate models show that the NBP-reconstructed VPD curve (the prediction skill, ρ) gradually converges to a statistically signicant values as time-series length increases.



[**Note:** The vertical axes is inverted for soil moisture]

Figure 4: Tropical vapor pressure deficit (VPD) detrended anomalies versus Tropical soil moisture anomalies. **Note**:The vertical axes is inverted for soil moisture.

Table 1: Confounding effects of VPD and Temperature on correlations with NBE in 12 Earth System models. All correlations coefficients are significant at $P = 0.00$ level, except two cases that are shown by italic fonts.

	Model	$r(NBE, VPD)$	$r(NBE, VPD\|Temp)$
1	ACCESS-ESM1.5	-0.92	-0.62
2	CanESM5	-0.87	-0.27
3	CNRM-ESM2-1	-0.80	-0.32
4	GFDL-ESM4	-0.85	-0.57
5	GISS-E2-1-G	-0.78	-0.26
6	IPSL-CM6A-LR	-0.83	-0.39
7	MPI-ESM1.2-LR	-0.80	*0.21*
8	MRI-ESM2	-0.81	*0.13*
9	NCAR-CESM2	-0.70	-0.44
10	UKESM1	-0.92	-0.30
11	NorESM2-LM	-0.75	-0.25
12	MIROC-ES2L	-0.80	-0.30

Table 2: Short-term sensitivity of NBE versus VPD (γ_{VPD}^{NBE}) and long-term response of land carbon uptake to atmospheric aridity (γ_{TL}) in 12 Earth System Models used in this study.

	Model	γ_{VPD}^{NBE} (GtC/yr/mb)	γ_{LT} (GtC/mb)
1	ACCESS-ESM1.5	-3.4 ± 0.17	-10.9
2	CanESM5	-3.8 ± 0.50	-37.5
3	CNRM-ESM2-1	-2.3 ± 0.38	-35.4
4	GFDL-ESM4	-11.4 ± 1.3	-68.5
5	GISS-E2-1-G	-1.9 ± 0.31	-20.8
6	IPSL-CM6A-LR	-3.1 ± 0.48	-15.9
7	MPI-ESM1.2-LR	-1.7 ± 0.23	-1.6
8	MRI-ESM2	-11.6 ± 0.8	-65.5
9	NCAR-CESM2	-1.1 ± 0.24	-13.2
10	UKESM1	-3.8 ± 0.32	-25.5
11	NorESM2-LM	-1.9 ± 0.15	-15.2
12	MIROC-ES2L	-6.5 ± 0.30	-35.2

References

Seager, R., Hooks, A., Williams, A. P., Cook, B., Nakamura, J., and Henderson, N. (2015). Climatology, variability, and trends in the us vapor pressure deficit, an important fire-related meteorological quantity. *Journal of Applied Meteorology and Climatology*, 54(6):1121–1141.