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*Supplement of*

## **El Niño–Southern Oscillation (ENSO) event reduces CO<sub>2</sub> uptake of an Indonesian oil palm plantation**

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Supplement

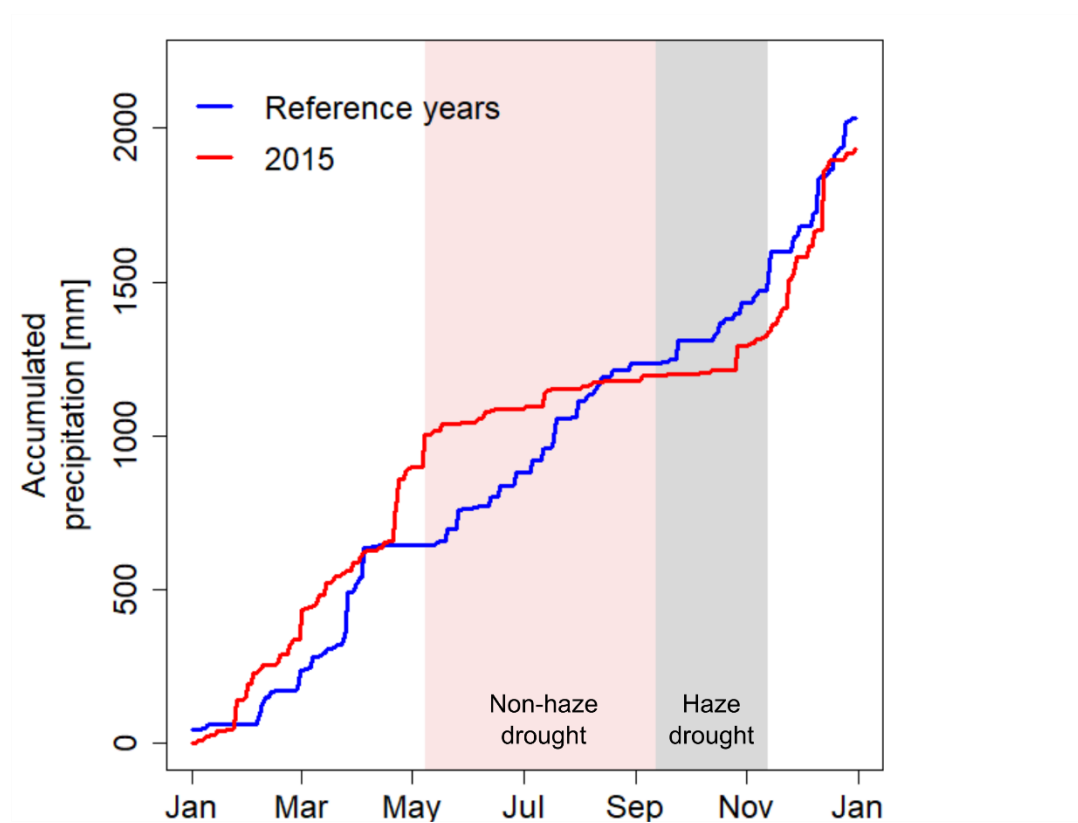
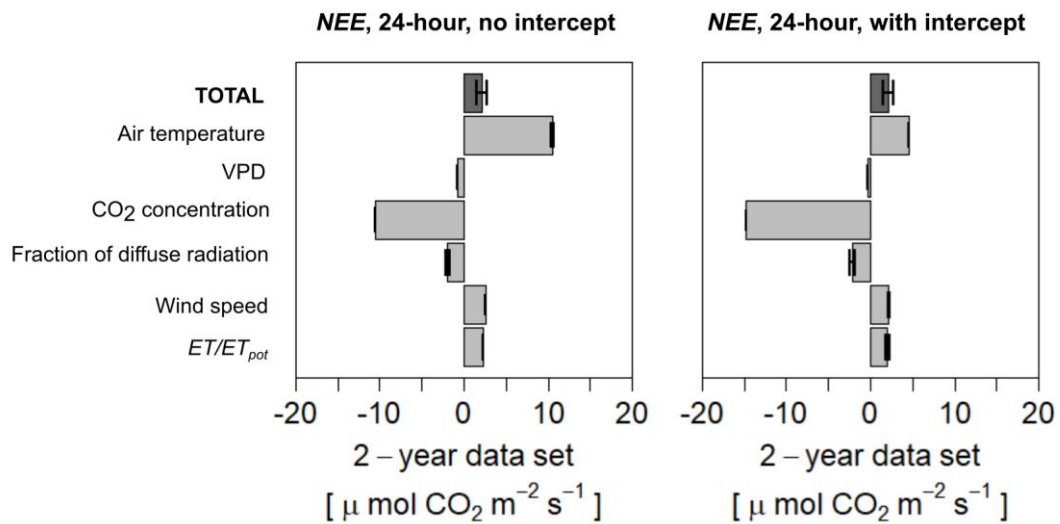


Figure S1: Accumulated precipitation in 2015 and during the reference time period. Shaded areas in red and grey mark the non-haze drought and the haze drought period in 2015, respectively.



**Figure S2: Comparison of Multiple Linear Regression Model (MLRM) results without (left) and with (right) intercept on 24-hour net ecosystem CO<sub>2</sub> exchange (NEE) during the entire study period (2014-2016). Error bars show the standard error.**

**Table S1: Contribution ( $\pm$  standard error) of meteorological parameters (predictors) on net ecosystem CO<sub>2</sub> exchange (*NEE*) derived from multiple linear regression model (*MLRM*) during different time periods (full 2-year study period, non-haze drought, haze drought, and non-haze & non-drought conditions). Negative values indicate CO<sub>2</sub> uptake for 24-hour *NEE* and midday *NEE*, and CO<sub>2</sub> release for night time *NEE*. If not otherwise stated, measurement height is 22 m above the surface.**

5

Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ], full 2-year study period									
	Air temperature	Air temperature (12 m)	Wind speed	Fraction of diffuse radiation	CO <sub>2</sub> concentration	Vapor pressure deficit	<i>ET/ET<sub>pot</sub></i>	Incoming <i>PAR</i>	Total
<b>NEE, 24-hour</b>	-10.50 ( $\pm$ 0.06)	-	-2.61 ( $\pm$ 0.12)	1.94 ( $\pm$ 0.54)	10.54 ( $\pm$ 0.01)	0.73 ( $\pm$ 0.03)	-2.23 ( $\pm$ 0.44)	-	-2.13 ( $\pm$ 1.18)
<b>NEE, midday (10-14 h)</b>	-34.48 ( $\pm$ 0.12)	-	-	6.86 ( $\pm$ 1.06)	30.30 ( $\pm$ 0.01)	6.87 ( $\pm$ 0.06)	-2.47 ( $\pm$ 1.67)	-14.68 ( $\pm$ 0.001)	-21.32 ( $\pm$ 2.93)
<b>NEE, night time (19-5:30 h)</b>	37.70 ( $\pm$ 0.29)	-28.37 ( $\pm$ 0.30)	-1.17 ( $\pm$ 0.58)	-	-	-0.98 ( $\pm$ 0.10)	0.51 ( $\pm$ 0.76)	-	7.69 ( $\pm$ 2.03)
Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ], non-haze drought									
	Air temperature	Air temperature (12 m)	Wind speed	Fraction of diffuse radiation	CO <sub>2</sub> concentration	Vapor pressure deficit	<i>ET/ET<sub>pot</sub></i>	Incoming <i>PAR</i>	Total

<b>NEE,</b>	-10.65 ( $\pm$	-	-2.96 ( $\pm$	1.82 ( $\pm$	10.39 ( $\pm$ 0.01)	0.85 ( $\pm$	-1.97 ( $\pm$	-	-2.51 ( $\pm$ 0.96)
<b>24-hour</b>	0.05)		0.11)	0.40)		0.02)	0.39)		
<b>NEE,</b>	-34.40 ( $\pm$	-	-	-5.50 ( $\pm$	29.94 ( $\pm$ 0.01)	7.00 ( $\pm$	-2.26 ( $\pm$	-15.96 ( $\pm$	-21.18 ( $\pm$ 2.26)
<b>midday</b>	0.10)			0.65)		0.04)	1.46)	0.001)	
<b>(10-14 h)</b>									
<b>NEE, night</b>	38.48 ( $\pm$	-28.69 ( $\pm$	-1.30 ( $\pm$	-	-	-1.39 ( $\pm$	0.51 ( $\pm$	-	7.61 ( $\pm$ 1.45)
<b>time (19-</b>	0.32)	0.32)	0.28)			0.06)	0.47)		
<b>5:30 h)</b>									

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**Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ], haze drought**

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	<b>Air</b>	<b>Air</b>	<b>Wind</b>	<b>Fraction of</b>	<b>CO<sub>2</sub></b>	<b>Vapor</b>	<b><i>ET/ET<sub>pot</sub></i></b>	<b>Incoming</b>	<b>Total</b>
	<b>temperature</b>	<b>temperature</b>	<b>speed</b>	<b>diffuse</b>	<b>concentration</b>	<b>pressure</b>		<b><i>PAR</i></b>	
		<b>(12 m)</b>		<b>radiation</b>		<b>deficit</b>			
<b>NEE,</b>	-10.94 ( $\pm$	-	-2.39	2.13 (0.19)	10.86 ( $\pm$	1.09 ( $\pm$	-1.96 ( $\pm$	-	-1.20 ( $\pm$ 0.35)
<b>24-hour</b>	0.01)		(0.03)		0.001)	0.004)	0.12)		
<b>NEE,</b>	-36.09 ( $\pm$	-	-	-9.39 ( $\pm$	30.95 ( $\pm$ 0.01)	9.20 ( $\pm$	-2.10 ( $\pm$	-11.49 ( $\pm$	-18.92 ( $\pm$ 2.24)
<b>midday</b>	0.10)			1.13)		0.03)	0.97)	0.0004)	
<b>(10-14 h)</b>									
<b>NEE, night</b>	39.31 ( $\pm$	-28.44 ( $\pm$	-1.07 ( $\pm$	-	-	-1.87 ( $\pm$	0.51 ( $\pm$	-	8.44 ( $\pm$ 1.11)
<b>time (19-</b>	0.23)	0.0.25)	0.35)			0.03)	0.24)		
<b>5:30 h)</b>									

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**Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ], non-drought and non-haze conditions**

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	<b>Air</b>	<b>Air</b>	<b>Wind</b>	<b>Fraction of</b>	<b>CO<sub>2</sub></b>	<b>Vapor</b>	<b>ET/ET<sub>pot</sub></b>	<b>Incoming</b>	<b>Total</b>
	<b>temperature</b>	<b>temperature</b>	<b>speed</b>	<b>diffuse</b>	<b>concentration</b>	<b>pressure</b>		<b>PAR</b>	
		<b>(12 m)</b>		<b>radiation</b>		<b>deficit</b>			
<b>NEE, 24-hour</b>	-10.38 (± 0.05)	-	-2.55 (± 0.10)	1.96 (± 0.65)	10.57 (± 0.003)	0.63 (± 0.04)	-2.42 (± 0.34)	-	-2.19 (± 1.19)
<b>NEE, midday (10-14 h)</b>	-34.26 (± 0.12)	-	-	-6.91 (± 1.33)	30.33 (± 0.01)	6.46 (± 0.08)	-2.65 (± 1.67)	-14.76 (± 0.001)	-21.78 (± 3.21)
<b>NEE, night time (19-5:30 h)</b>	37.19 (± 0.31)	-28.25 (± 0.31)	-1.14 (± 0.69)	-	-	-0.71 (± 0.20)	0.51 (± 0.86)	-	7.60 (± 2.36)

**Table S2: Case scenarios (Case 1-Case 5) of different *MLRMs* and summary of case scenarios with Akaike information criterion (*AIC*) score and model goodness of fit.**

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**Case 1:**  $lm(\text{formula} = \text{scale}(\text{NEE}) \sim \text{scale}(\text{VPD}) + \text{scale}(\text{CO2}) + \text{scale}(\text{fdifRad}) + \text{scale}(\text{wind}) + \text{scale}(\text{Tair}))$

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<b>Coefficients:</b>	<b>Estimate</b>	<b>Std. Error</b>	<b>t-value</b>	<b>Pr (&gt; t )</b>
(Intercept)	-0.112342	0.05100	-2.203	0.028650 *
scale(VPD)	0.020793	0.086572	0.240	0.810408
scale(CO2)	0.177867	0.052516	3.387	0.000837 ***
scale(fdifRad)	0.121650	0.052972	2.296	0.022589 *
scale (wind)	-0.177130	0.053028	-3.340	0.000983 ***
scale(Tair)	0.009968	0.088540	0.113	0.910466

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**Case 2:**  $lm(\text{formula} = \text{scale}(\text{NEE}) \sim \text{scale}(\text{CO2}) + \text{scale}(\text{fdifRad}) + \text{scale}(\text{wind}))$

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<b>Coefficients:</b>	<b>Estimate</b>	<b>Std. Error</b>	<b>t-value</b>	<b>Pr (&gt; t )</b>
(Intercept)	-0.10971	0.04848	-2.263	0.024591 *
scale(CO2)	0.17776	0.05231	3.399	0.000803 ***
scale(fdifRad)	0.11620	0.04873	2.385	0.017930 *
scale (wind)	-0.17344	0.04763	-3.641	0.000338 ***

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**Case 3:**  $lm(\text{formula} = \text{NEE} \sim \text{VPD} + \text{CO2} + \text{fdifRad} + \text{wind} + \text{Tair} - 1)$

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<b>Coefficients:</b>	<b>Estimate</b>	<b>Std. Error</b>	<b>t-value</b>	<b>Pr (&gt; t )</b>
VPD	0.126540	0.057204	2.212	0.02798 *
CO2	0.014808	1.753	1.753	0.08095
fdifRad	2.144689	1.297013	1.654	0.09964
wind	-1.635912	0.288365	-5.673	4.37e-08 ***
Tair	-0.313711	0.114494	-2.740	0.00665 **



Case 4:  $lm(formula = NEE \sim VPD + CO2 + fdifRad + wind + Tair)$

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Coefficients:	Estimate	Std. Error	t-value	Pr (> t )
(Intercept)	-19.78924	6.57646	-3.009	0.002926 **
VPD	0.01612	0.06711	0.240	0.810408 10
CO2	0.03960	0.01169	3.387	0.000837 ***
fdifRad	2.99722	1.30513	2.296	0.022589 * 15
wind	-1.11112	0.33264	-3.340	0.000983 ***
Tair	0.01772	0.15742	0.113	0.910466 20

Case 5:  $lm(formula = NEE \sim CO2 + fdifRad + wind)$

25

Coefficients:	Estimate	Std. Error	t-value	Pr (> t )
(Intercept)	-19.11845	4.67333	-4.091	6.01e-05 ***
CO2	0.03958	0.01165	3.399	0.000803 *** <sup>30</sup>
fdifRad	2.86305	1.20054	2.385	0.017930 *
wind	-1.08794	0.29880	-3.641	0.000338 *** <sup>35</sup>

Case number	Goodness of fit	Insignificant p-values	AIC score
1	0.20	Temperature, VPD [0.8 to 0.9]	494
2	0.21	none	490
3	0.74	none	808
4	0.20	Temperature, VPD [0.8 to 0.9]	801
5	0.21	none	798

55

AIC scores differed substantially between models that used original and scaled data, where the model that used the scaled data had low values of *AIC* score. The model (case 3) that used the original data but excluded the intercept had a relatively high value of goodness of fit when compared with all other cases. Because the *AIC* score didn't change much between cases 3 and 4 and that case 3 had a relatively high goodness of fit value, we chose to use the model in case 3 for this study.

5



**Table S3: Multiple Linear Regression Model (MLRM): Statistics of midday (10-14 h local time), night time (19-5:30 h) and 24-hour averaged environmental parameters. If not otherwise stated, measurement height is 22 meter above the surface.**

<b>Parameter (midday)</b>	<b>Estimate</b>	<b>SE</b>	<b>t-value</b>	<b>P-value</b>
Incoming PAR	-0.01	0.00	-12.44	<0.001
Air temperature	-1.15	0.14	-8.50	<0.001
Vapor pressure deficit	0.56	0.07	7.98	<0.001
CO <sub>2</sub> concentration	0.08	0.01	9.09	<0.001
Fraction of diffuse radiation	-9.98	1.20	-8.29	<0.001
<i>ET/ET<sub>pot</sub></i>	-5.58	1.90	-2.94	<0.001
<b>Parameter (night time)</b>	<b>Estimate</b>	<b>SE</b>	<b>t-value</b>	<b>P-value</b>
Air temperature	1.50	0.17	8.68	<0.001
Vapor pressure deficit	-0.35	0.06	-6.07	<0.001
<i>ET/ET<sub>pot</sub></i>	1.65	0.45	3.67	<0.001
Air temperature (12 m)	-1.14	0.17	-6.52	<0.001
Wind speed	-0.88	0.34	-2.59	<0.01
<b>Parameter (24-hour)</b>	<b>Estimate</b>	<b>SE</b>	<b>t-value</b>	<b>P-value</b>
Vapor pressure deficit	0.12	0.06	2.11	0.04
CO <sub>2</sub> concentration	0.03	0.01	2.80	0.01
Fraction of diffuse radiation	2.18	1.22	1.79	0.08
Wind speed	-1.70	0.27	-6.31	<0.001
Air temperature	-0.39	0.12	-3.15	<0.001
<i>ET/ET<sub>pot</sub></i>	-4.33	0.99	-4.39	<0.001

**Table S4: Multiple Linear Regression Model (MLRM): Correlations of midday (10-14 h local time), night time (19-5:30 h) and 24-hour averaged environmental parameters. If not otherwise stated, measurement height is 22 meter above the surface.**

<b>Midday</b>	Incoming PAR	Air temperature	Vapor pressure deficit	CO <sub>2</sub> concentration	Fraction of diffuse radiation	<i>ET/ET<sub>pot</sub></i>
Incoming PAR	1.00	0.55	0.56	-0.42	-0.82	-0.28
Air temperature	0.55	1.00	0.89	-0.22	-0.33	-0.52
Vapor pressure deficit	0.56	0.89	1.00	-0.18	-0.30	-0.53
CO <sub>2</sub> concentration	-0.42	-0.22	-0.18	1.00	0.33	0.14
Fraction of diffuse radiation	-0.82	-0.33	-0.30	0.33	1.00	0.16
<i>ET/ET<sub>pot</sub></i>	-0.28	-0.52	-0.53	0.14	0.16	1.00
<b>Night time</b>	Air temperature	Vapor pressure deficit	Air temperature (12 m)	Wind speed	<i>ET/ET<sub>pot</sub></i>	
Air temperature	1.00	0.71	0.76	0	-0.01	
Vapor pressure deficit	0.71	1.00	0.44	0.24	-0.02	
Air temperature (12 m)	0.76	0.44	1.00	0.04	-0.03	
Wind speed	0	0.24	0.04	1.00	-0.06	
<i>ET/ET<sub>pot</sub></i>	-0.01	-0.02	-0.03	-0.06	1.00	

<b>24-hour</b>	Vapor pressure deficit	CO <sub>2</sub> concentration	Fraction of diffuse radiation	Wind speed	Air temperature	<i>ET/ET<sub>pot</sub></i>
Vapor pressure deficit	1.00	0.05	-0.14	0.25	0.76	-0.62
CO <sub>2</sub> concentration	0.05	1.00	0.29	-0.30	0.09	0.13
Fraction of diffuse radiation	-0.14	0.29	1.00	-0.22	-0.19	0.25
Wind speed	0.25	-0.30	-0.22	1.00	-0.09	-0.14
Air temperature	0.76	0.09	-0.19	-0.09	1.00	-0.69
<i>ET/ET<sub>pot</sub></i>	-0.62	0.13	0.25	-0.14	-0.69	1.00

**Table S5: Effect of meteorological parameters (predictors,  $\pm$  standard error) on net ecosystem CO<sub>2</sub> exchange (*NEE*) during non-haze drought conditions derived from multiple linear regression model (*MLRM*). Negative values indicate decrease in CO<sub>2</sub> uptake for 24-hour *NEE* and midday *NEE*, and increase in CO<sub>2</sub> release for nighttime *NEE*. If not otherwise stated, measurement height is 22 m above the surface.**

	Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ]								
	Air	Air	Wind	Fraction of	CO <sub>2</sub>	Vapor	<i>ET/ET<sub>pot</sub></i>	Incoming	Total
	temperature	temperature	speed	diffuse	concentration	pressure		<i>PAR</i>	
		(12 m)		radiation		deficit			
<b>NEE, 24-hour</b>	0.26 ( $\pm$ 0.01)	-	0.41 ( $\pm$ 0.01)	0.14 ( $\pm$ 0.25)	0.18 ( $\pm$ 0.0002)	-0.22 ( $\pm$ 0.02)	-0.45 ( $\pm$ 0.04)	-	0.32 ( $\pm$ 0.23)
<b>NEE, midday</b>	0.14 ( $\pm$ 0.02)	-	-	-1.40 ( $\pm$ 0.68)	0.39 ( $\pm$ 0.001)	-0.54 ( $\pm$ 0.0003)	-0.39 ( $\pm$ 0.21)	1.20 ( $\pm$ 0.0003)	-0.60 ( $\pm$ 0.95)
<b>NEE, nighttime (19-5:30 h)</b>	-1.29 ( $\pm$ 0.02)	0.44 ( $\pm$ 0.01)	0.1 ( $\pm$ 0.41)	-	-	0.68 ( $\pm$ 0.14)	0 ( $\pm$ 0.39)	-	-0.02 ( $\pm$ 0.91)

**Table S6: Effect of meteorological parameters (predictors,  $\pm$  standard error) on net ecosystem CO<sub>2</sub> exchange (*NEE*) during haze drought conditions derived from multiple linear regression model (*MLRM*). Negative values indicate decrease in CO<sub>2</sub> uptake for 24-hour *NEE* and midday *NEE*, and increase in CO<sub>2</sub> release for nighttime *NEE*. If not otherwise stated, measurement height is 22 m above the surface.**

	Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ]								
	Air temperature	Air temperature (12 m)	Wind speed	Fraction of diffuse radiation	CO <sub>2</sub> concentration	Vapor pressure deficit	<i>ET/ET<sub>pot</sub></i>	Incoming <i>PAR</i>	Total
<b>NEE, 24-hour</b>	0.55 ( $\pm$ 0.05)	-	-0.16 ( $\pm$ 0.07)	-0.17 ( $\pm$ 0.46)	-0.29 ( $\pm$ 0.003)	-0.46 ( $\pm$ 0.04)	-0.46 ( $\pm$ 0.22)	-	-0.99 ( $\pm$ 0.84)
<b>NEE, midday</b>	1.83 ( $\pm$ 0.02)	-	-	2.48 ( $\pm$ 0.20)	-0.62 ( $\pm$ 0.001)	-2.74 ( $\pm$ 0.05)	-0.55 ( $\pm$ 0.70)	-3.27 ( $\pm$ 0.001)	-2.86 ( $\pm$ 0.97)
<b>NEE, nighttime (19-5:30 h)</b>	-2.12 ( $\pm$ 0.08)	0.19 ( $\pm$ 0.06)	-0.07 ( $\pm$ 0.33)	-	-	1.16 ( $\pm$ 0.17)	0	-	-0.84 ( $\pm$ 1.25)



**Table S7: Effect of meteorological parameters (predictors,  $\pm$  standard error) on net ecosystem CO<sub>2</sub> exchange (NEE) during increased non-haze drought (NHD+) scenario derived from multiple linear regression model (MLRM). Negative values indicate decrease in CO<sub>2</sub> uptake for 24-hour NEE and midday NEE, and increase in CO<sub>2</sub> release for nighttime NEE. If not otherwise stated, measurement height is 22 m above the surface.**

	Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ]								
	Air	Air	Wind	Fraction of	CO <sub>2</sub>	Vapor	$ET/ET_{pot}$	Incoming	Total
	temperature	temperature	speed	diffuse	concentration	pressure		PAR	
		(12 m)		radiation		deficit			
<b>NEE, 24-hour</b>	2.39 ( $\pm$ 0.02)	-	0.41 ( $\pm$ 0.003)	0.50 ( $\pm$ 0.13)	0.18 ( $\pm$ 0.00003)	-0.39 ( $\pm$ 0.01)	-0.84 ( $\pm$ 0.04)	-	2.25 ( $\pm$ 0.17)
<b>NEE, midday</b>	7.02 ( $\pm$ 0.16)	-	-	-2.50 (1.71)	0.39 ( $\pm$ 0.001)	-1.94 ( $\pm$ 0.08)	-0.84 ( $\pm$ 0.17)	4.40 ( $\pm$ 0.001)	6.52 ( $\pm$ 1.80)
<b>NEE, nighttime (19-5:30 h)</b>	-8.99 ( $\pm$ 0.13)	6.18 ( $\pm$ 0.08)	0.15 ( $\pm$ 0.06)	-	-	0.96 ( $\pm$ 0.13)	0.10 ( $\pm$ 0.04)	-	-1.59 ( $\pm$ 0.29)

**Table S8: Effect of meteorological parameters (predictors,  $\pm$  standard error) on net ecosystem CO<sub>2</sub> exchange (NEE) during increased haze drought (HD+) scenario derived from multiple linear regression model (MLRM). Negative values indicate decrease in CO<sub>2</sub> uptake for 24-hour NEE and midday NEE, and increase in CO<sub>2</sub> release for nighttime NEE. If not otherwise stated, measurement height is 22 m above the surface.**

	Predictor [ $\mu\text{mol m}^{-2} \text{s}^{-1}$ ]								
	Air	Air	Wind	Fraction of	CO <sub>2</sub>	Vapor	<i>ET/ET<sub>pot</sub></i>	Incoming	Total
	temperature	temperature	speed	diffuse	concentration	pressure		<i>PAR</i>	
		(12 m)		radiation		deficit			
<b>NEE, 24-hour</b>	2.74 ( $\pm$ 0.13)	-	-0.16 ( $\pm$ 0.01)	-0.60 ( $\pm$ 0.28)	-2.46 ( $\pm$ 0.01)	-0.68 ( $\pm$ 0.03)	-0.85 ( $\pm$ 0.19)	-	-2.01 ( $\pm$ 0.38)
<b>NEE, midday</b>	9.05 ( $\pm$ 0.21)	-	-	4.36 ( $\pm$ 0.87)	-6.80 ( $\pm$ 0.01)	-4.58 ( $\pm$ 0.23)	-0.97 ( $\pm$ 0.68)	-5.57 ( $\pm$ 0.003)	-4.51 ( $\pm$ 0.16)
<b>NEE, nighttime (19-5:30 h)</b>	-9.98 ( $\pm$ 0.76)	5.88 ( $\pm$ 0.36)	-0.07 ( $\pm$ 0.02)	-	-	1.54 ( $\pm$ 0.26)	0.10 ( $\pm$ 0.06)	-	-2.53 ( $\pm$ 0.10)