Mango-GPP: A Process-Based Model for Simulating Gross Primary Productivity of Mangrove Ecosystems

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1. Introduction

Mangrove ecosystems are becoming increasingly important in global climate mitigation, but are greatly under-represented in current ecosystem models. Large gaps still exist in evaluating mangroves' gross primary productivity (GPP). This study developed a process-based biogeochemical model (Mango-GPP),which is assumed to run at ecosystem scale on daily step, to improve the GPP simulation and prediction for both natural and restored mangrove ecosystems.

2. Model Description

Mango-GPP describes the detailed behavior of the soil-plant-atmosphere photosynthesis routines under biological, climatic, and edaphic controls. Moreover, it pays more attention to the mangrove-specific physiological processes, such as temperature and salt stresses as well as light absorption and use efficiency. This model assumes that GPP is determined by the CO2-limited photosynthetic rate (P_C) and light-limited photosynthetic rate (P_I). The submodule for calculating P_C describes the processes of atmospheric CO_2 entering the chloroplast through the stomata and being converted to organic C. The submodule for simulating P_I emulates the physiological processes of light energy absorption and use by canopy leaves.

$$GPP = \frac{P_C \times P_I}{P_C + P_I} \times (s_1 \times hr + s_2)$$

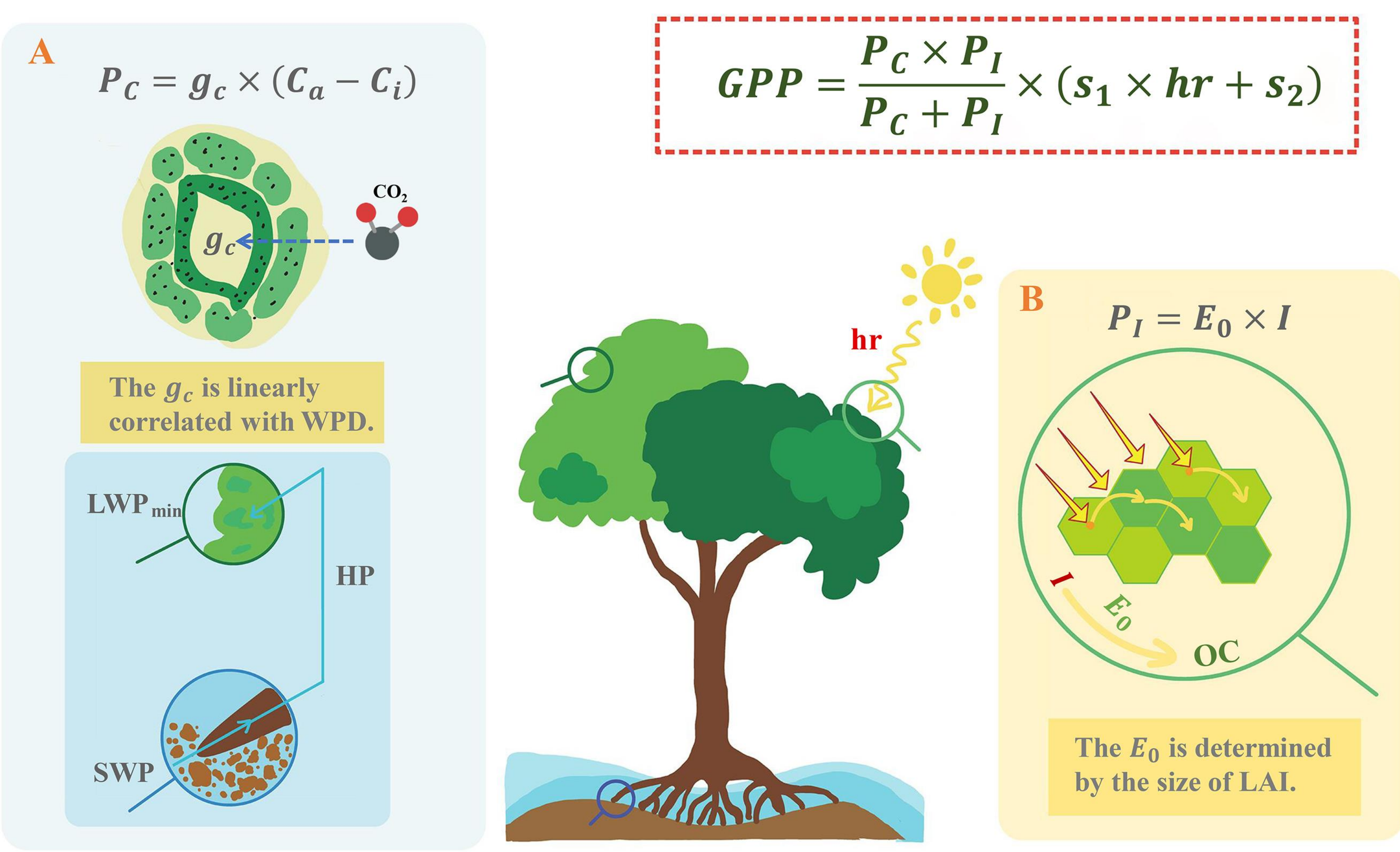

Figure 1. Conceptual explanation of Mango-GPP. P_C: CO2-limited photosynthetic rate, P_I: light-limited photosynthetic rate, s1 and s2: daylength coefficients, hr: sunshine hours; In Section A, g_c: canopy stomatal conductance, C_a: atmospheric CO_2 concentration, C_i: intercellular CO2 concentration, WPD: water potential difference, LWP: leaf water potential, HP: height potential, SWP: soil water potential; In Section B, E_0: canopy quantum yield, I: incident shortwave radiation flux, LAI: leaf area index, and OC: organic carbon.

3. Model Validation

Model environmental drivers, include minimum, maximum, and average air temperature, shortwave radiation flux, leaf area index, and soil salinity on a daily step, as well as six constant drivers of atmospheric CO_2 concentration, latitude, proportion of major species, canopy height, canopy minimum leaf water potential, and foliar nitrogen concentration. The study sites include two natural mangrove sites (MP and ZJ) and one restored mangrove site (NS).

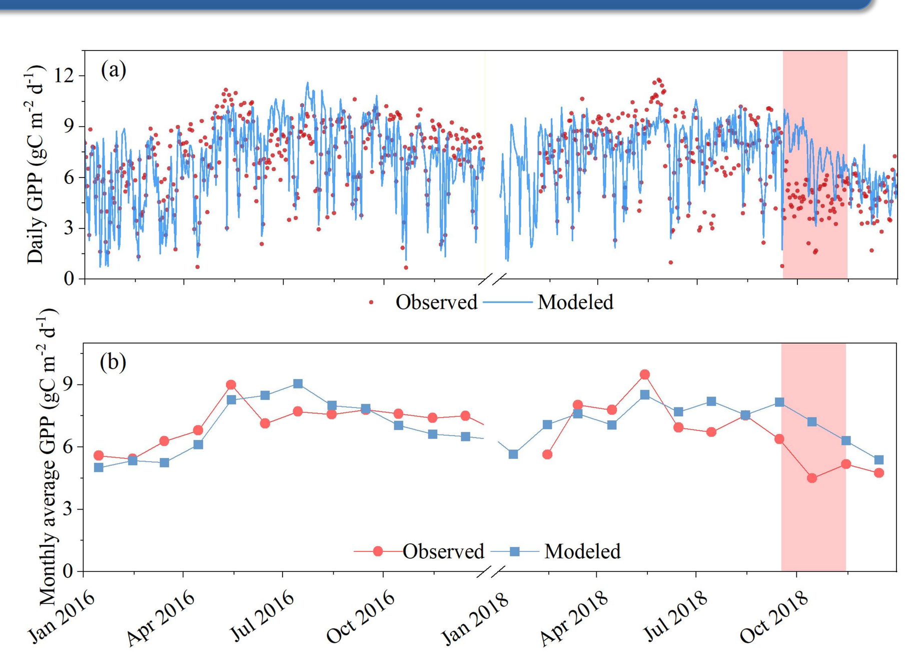

Figure 2. Modeled and observed seasonal patterns of (a) daily GPP (gC m^{-2} d^{-1}) and (b) monthly average GPP (gC m^{-2} d^{-1}) at the MP site. The red-shaded area indicates the period affected by the Super Typhoon Mangkhut.

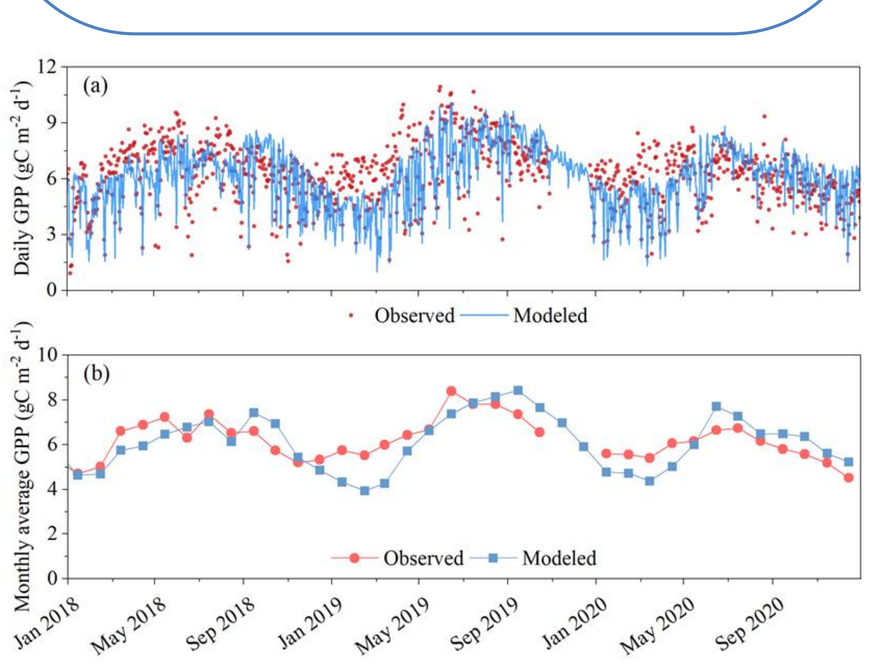

Figure 3. Modeled and observed seasonal patterns of (a) daily GPP (gC m-2 d-1) and (b) monthly average GPP (gC m-2 d-1) at the ZJ site.

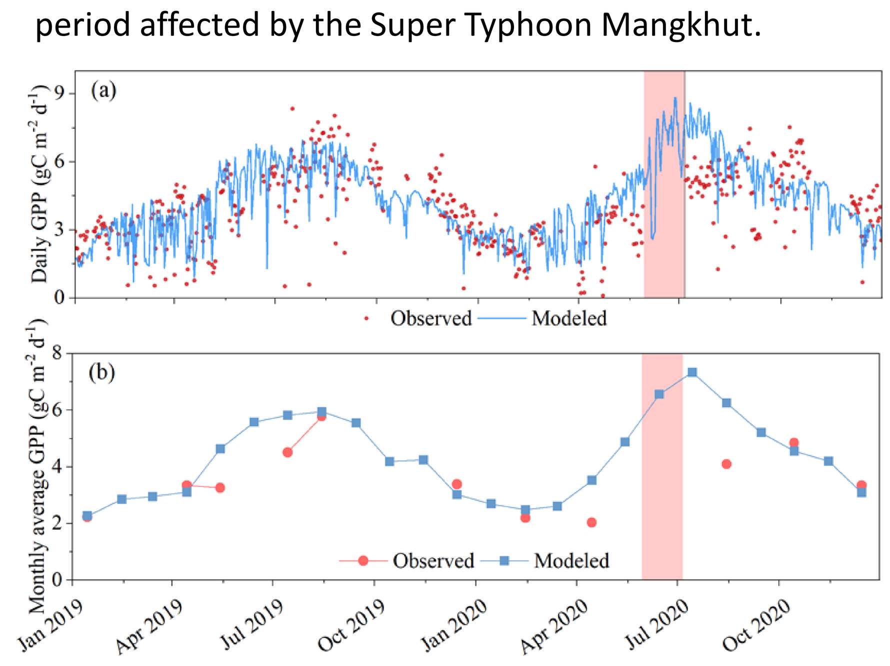

Figure 4. Modeled and observed seasonal patterns of (a) daily GPP (gC m^{-2} d^{-1}) and (b) monthly average GPP (gC m^{-2} d^{-1}) at the NS site. The red-shaded area shows the tower change period (30 May to 6 July 2020).

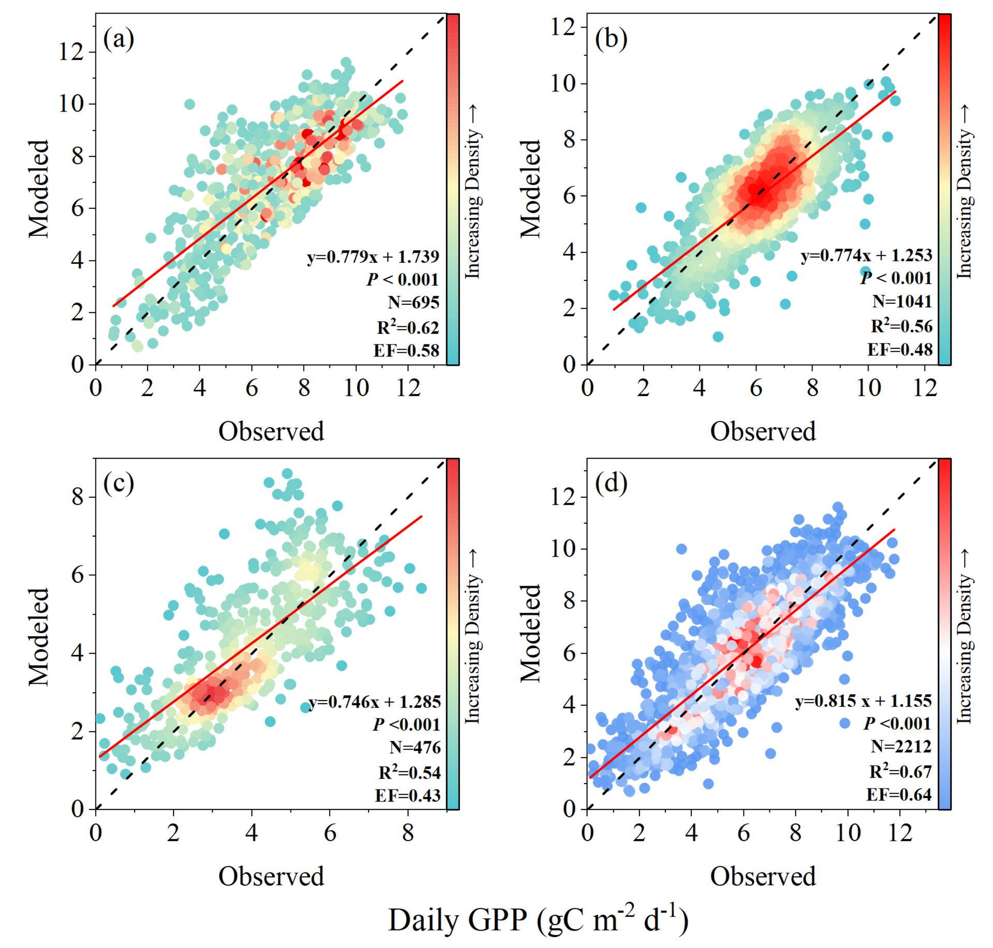

Figure 5. Regression of modeled against observed daily GPPs (gC m^{-2} d^{-1}) at (a) the MP site, (b) the ZJ site, (c) the NS site, and (d) all three sites. The black dash lines are 1:1 lines for reference. The solid red lines denote the regression lines.

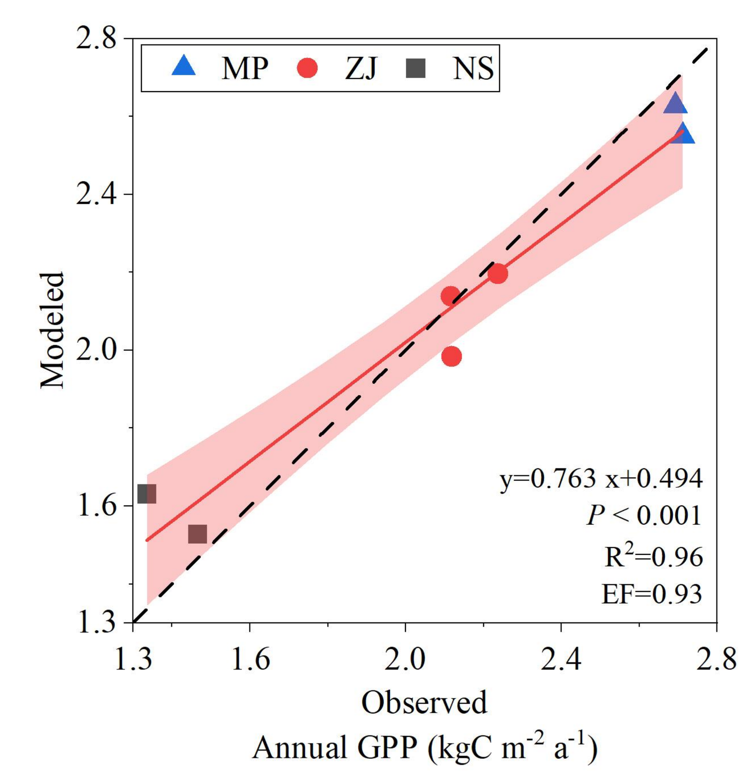

Figure 6. Regression of simulated against observed annual GPPs (kgC m-2 a-1) from the MP, ZJ, and NS sites. The black dash line is a 1:1 line for reference. The solid red lines denote the regression lines. The red area is the 95% confidence interval of simulated annual GPPs.

The simulated daily GPP agreed well with the observations and yielded an R^2 of 0.67, an RMSE of 21.4%, and an EF of 0.64. The simulated annual GPP (2093.6 ± 991.9 gC m^{-2} a^{-1}) was also consistent with the observations (2096.9 ± 537.2 gC m^{-2} a^{-1}). The RMSE, R^2, and EF values between the modeled and observed annual GPPs are 6.8%, 0.96, and 0.93, respectively.

4. Performance Comparison

Table 1

Validation results of Mango-GPP, GLASS, and MODIS 8-day mean GPP against in situ measurements

	MP			ZJ			NS			Three sites		
	R^2	RMSE	MAE	R^2	RMSE	MAE	R^2	RMSE	MAE	R^2	RMSE	MAE
Mango-GPP	0.47	15.8%	12.7%	0.57	14.2%	11.9%	0.65	24.7%	18.0%	0.68	16.0%	12.8%
GLASS	0.14	23.2%	16.6%	0.38	46.4%	44.1%	0.38	56.1%	50.3%	0.37	39.2%	33.6%
MODIS	-	-	-	0.33	51.1%	48.7%	-	-	-	-	-	-
EC-LUE	-	-	-	-	-	-	-	-	-	-	-	-

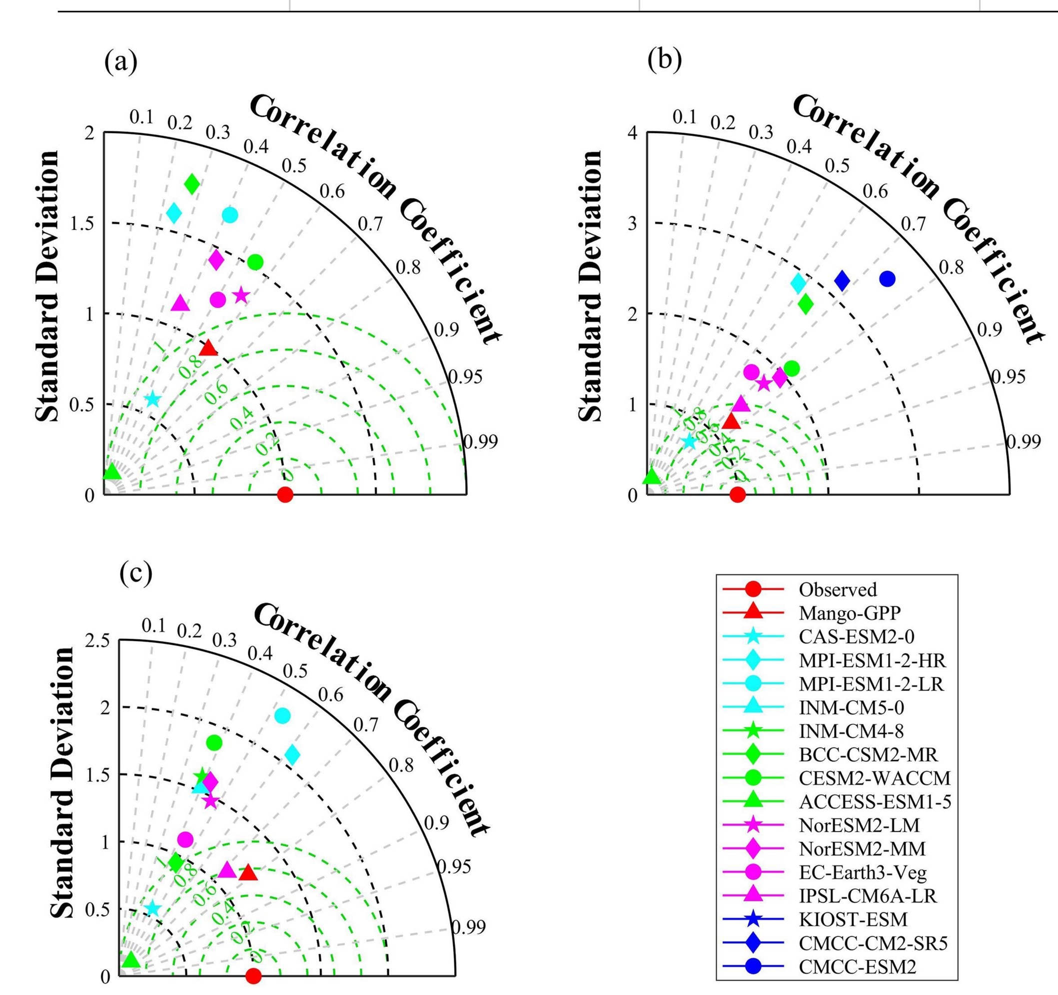

Figure 7. Taylor diagrams of Mango-GPP and 15 Earth System Models for monthly mean distribution of GPP with respect to the corresponding observations at the (a)MP, (b)ZJ, and (c)NS sites. The radius from the model point to the observation point represents the centered root mean square error of the simulations and observations. The distance from the model point to the origin represents the ratio of the standard deviation of the modeled and the observed. The closer to 1, the more consistent the amplitude of the model is with observation. The radial axis from the origin through the model point to the circumference identifies the correlation coefficient between the modeled and the observed.

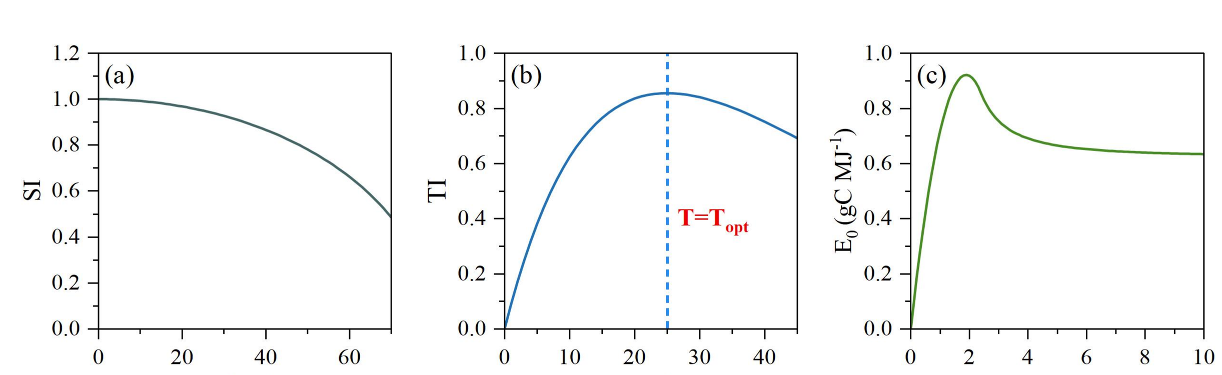

Figure 8. Unique impact functions in Mango-GPP (a) Variation of salinity influence index (SI) with soil salinity (s), (b) variation of temperature influence index (TI) with daily average temperature (T) (blue dash line indicates optimum temperature Topt), (c) variation of canopy quantum yield (E0) with leaf area index (LAI).

5. Conclusion

1. **The model incorporates the effects of salinity and temperature, as well as light absorption and use efficiency on mangroves' GPP and requires only 12 easily accessible inputs.**
2. **The model can reasonably describe the observed daily, seasonal and interannual GPP variations of natural mangroves in Mai Po Nature Reserve and Zhangjiang Estuary Mangrove National Nature Reserve, as well as the artificially restored mangrove in Nansha coastal wetland park.**
3. **The model performs better than satellite-based GPP products and the Earth System Models generally designed for all ecosystems.**