

High Sensitivity of Amazon Net Ecosystem Exchange Projections to Photosynthetic Optimal Temperature

Angel Liduvino Vara-Vela^{1,*}, Luiz A. T. Machado^{1,8}, Luciana V. Rizzo¹, Noelia Rojas Benavente¹, Paulo Artaxo¹, Hella van Asperen², Mario Cárdenas-Vélez³, Alessandro Carioca de Araújo⁴, Micael A. Cecchini⁵, Ivan Mauricio Cely-Toro⁶, Cléo Q. Dias-Júnior⁷, Michał Gałkowski^{3,11}, David Ho³, Ulrich Pöschl⁸, Julia Shimbo⁹, Xiyan Xu¹⁰, and Santiago Botía³

¹Institute of Physics, University of São Paulo, São Paulo, Brazil

²Department of Biogeochemical Processes, Max Planck Institute for Biogeochemistry, Jena, Germany

³Department of Biogeochemical Signals, Max Planck Institute for Biogeochemistry, Jena, Germany

⁴Brazilian Agricultural Research Corporation (EMBRAPA), Embrapa Amazônia Oriental, Belém, Brazil

⁵Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo, São Paulo, Brazil

⁶Atmospheric Turbulence and Diffusion Division, Air Resources Laboratory, NOAA, Oak Ridge, United States

⁷National Institute for Amazonian Research, Manaus, Brazil

⁸Multiphase Chemistry Department, Max Planck Institute for Chemistry, Mainz, Germany.

⁹Amazon Environmental Research Institute (IPAM), Asa Norte CLN 211, Brasília, 70863-520, DF, Brazil

¹⁰Key Laboratory of Regional Climate-Environment for Temperate East Asia, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

¹¹Faculty of Physics and Applied Computer Science, AGH University of Kraków, Kraków, Poland

Correspondence: Angel Liduvino Vara-Vela (angel@if.usp.br)

1 Supplementary Figures and Tables

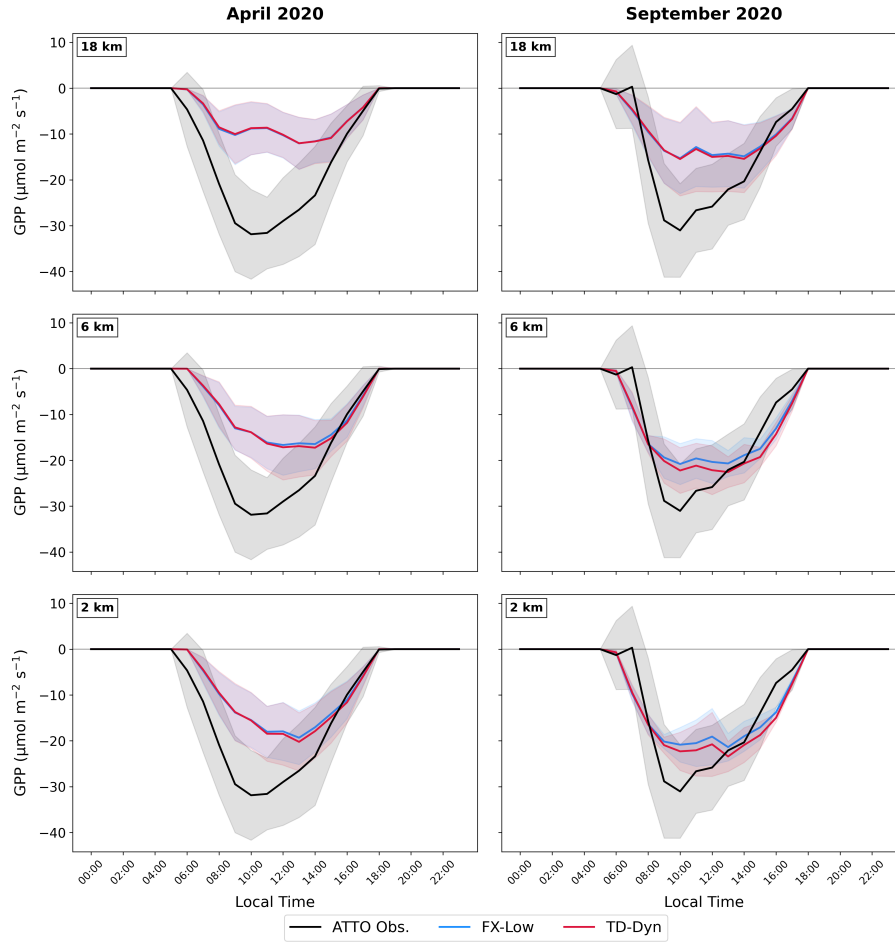


Figure S1. Evaluation of simulated and observed GPP diurnal cycles at the Amazon Tall Tower Observatory (ATTO) site for April and September 2020. The black solid lines represent eddy covariance observations, with the shaded light gray envelope indicating ± 1 standard deviation of the daily variability. Colored lines represent VPRM simulations from the 18 km (top panels), 6 km (middle panels) and 2 km (bottom panels) modeling domains for two T_{opt} parameterization scenarios: FX-Low (blue) and TD-Dyn (red). For 2020, the FX-High and TD-Dyn scenarios are identical (see Table 3). Colored shaded envelopes represent the corresponding ± 1 standard deviation for each model scenario. All fluxes are expressed in $\mu\text{mol m}^{-2} \text{s}^{-1}$ and are plotted in local time (UTC-4).

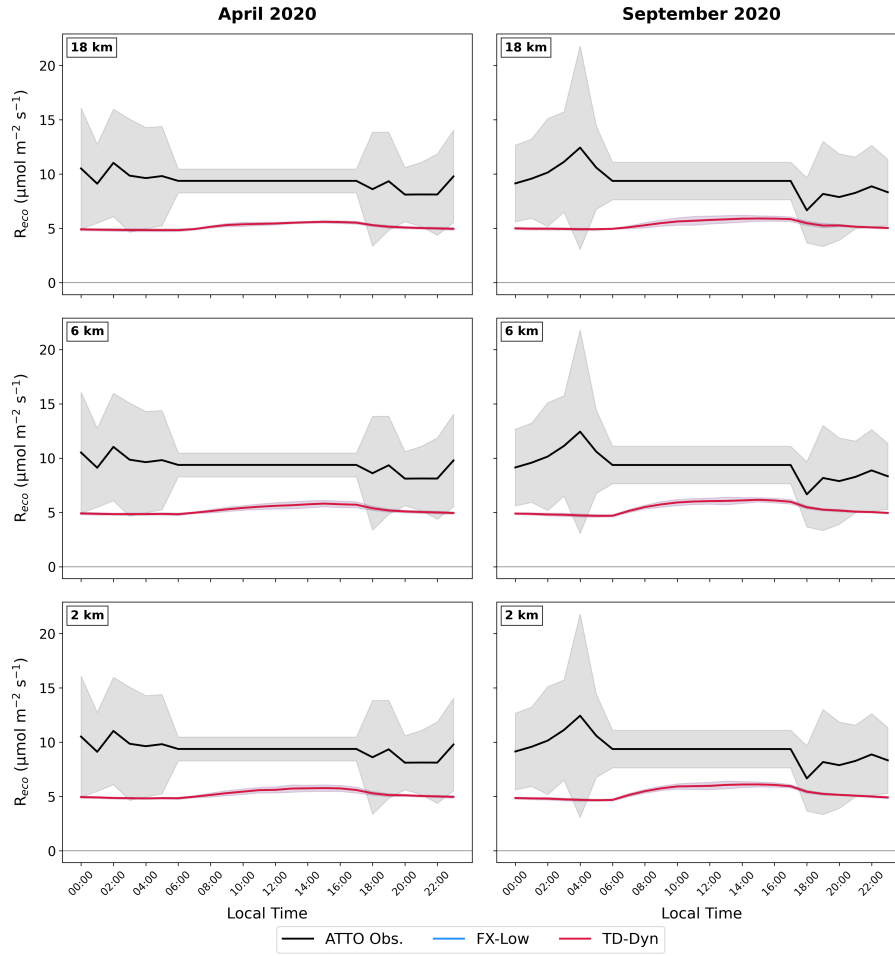


Figure S2. Evaluation of simulated and observed R_{eco} diurnal cycles at the Amazon Tall Tower Observatory (ATTO) site for April and September 2020. The black solid lines represent eddy covariance observations, with the shaded light gray envelope indicating ± 1 standard deviation of the daily variability. Colored lines represent VPRM simulations from the 18 km (top panels), 6 km (middle panels) and 2 km (bottom panels) modeling domains for two T_{opt} parameterization scenarios: FX-Low (blue) and TD-Dyn (red). For 2020, the FX-High and TD-Dyn scenarios are identical (see Table 3). Colored shaded envelopes represent the corresponding ± 1 standard deviation for each model scenario. All fluxes are expressed in $\mu\text{mol m}^{-2} \text{s}^{-1}$ and are plotted in local time (UTC-4).

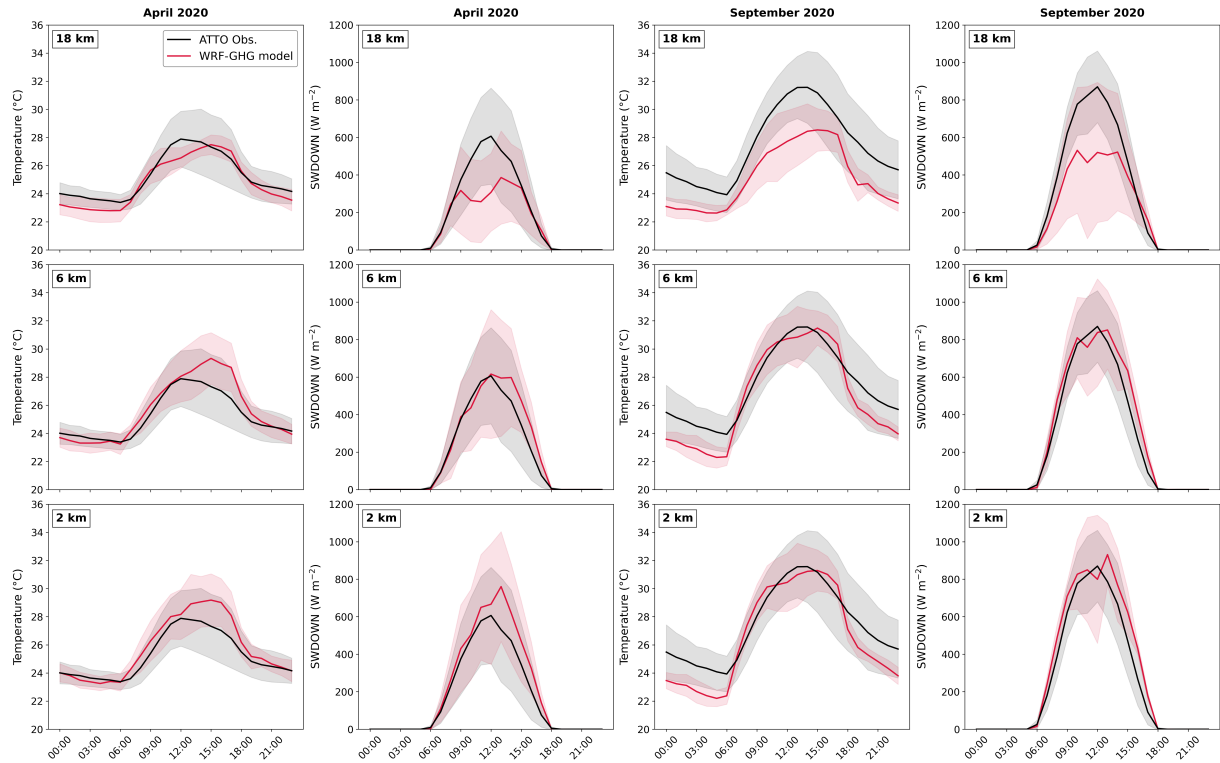


Figure S3. Monthly average diurnal cycles of T_{2m} and SWDOWN, simulated by WRF-GHG (crimson curves) and derived from ATTO observations (black curves). Panels are organized by spatial resolution along the rows (18 km, 6 km, and 2 km) and by month (April and September 2020) along the columns. Solid lines represent the monthly mean for each local hour, while shaded envelopes denote ± 1 standard deviation ($\pm 1\sigma$) representing day-to-day variability. All time axes are given in local time (UTC−4).

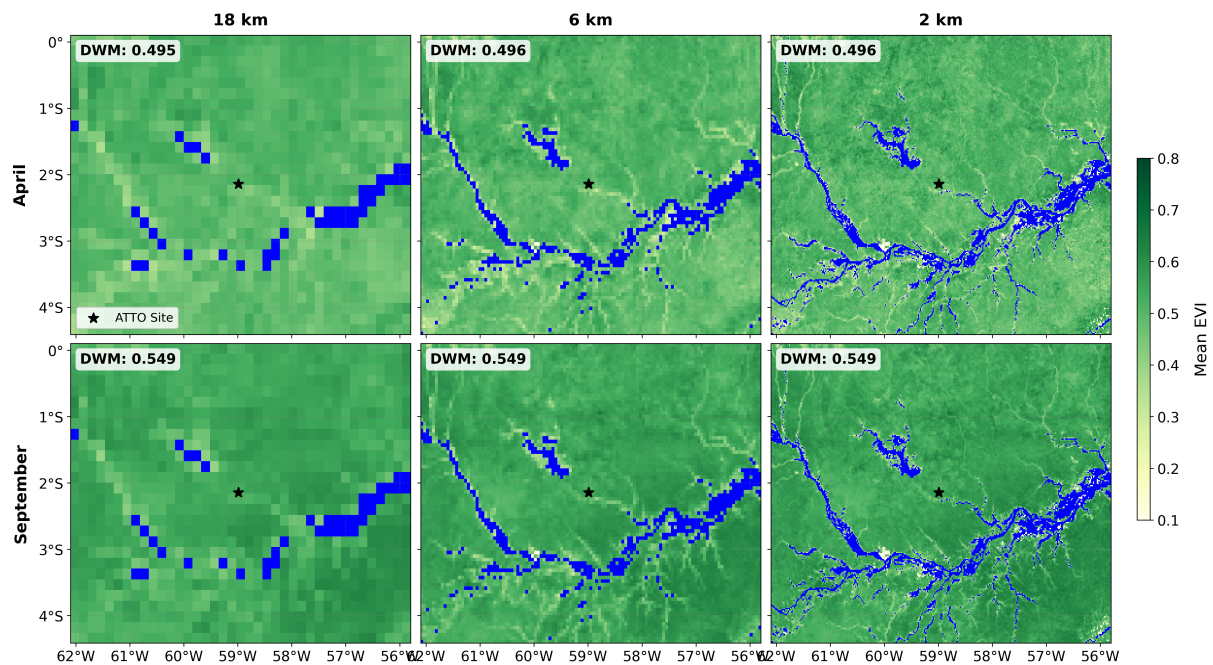


Figure S4. Spatial distribution of monthly mean EVI for the Forest land-use category over the innermost model domain for April and September 2020 under the TD-Dyn scenario. Panels compare the spatial patterns at the 18 km, 6 km, and 2 km model resolutions. The 18 km and 6 km domains were clipped to the spatial extent of the 2 km domain to facilitate direct comparison. DWM denotes the domain-wide mean, calculated over the resulting common spatial footprint. Grid cells classified as water bodies are masked and shown in solid blue.

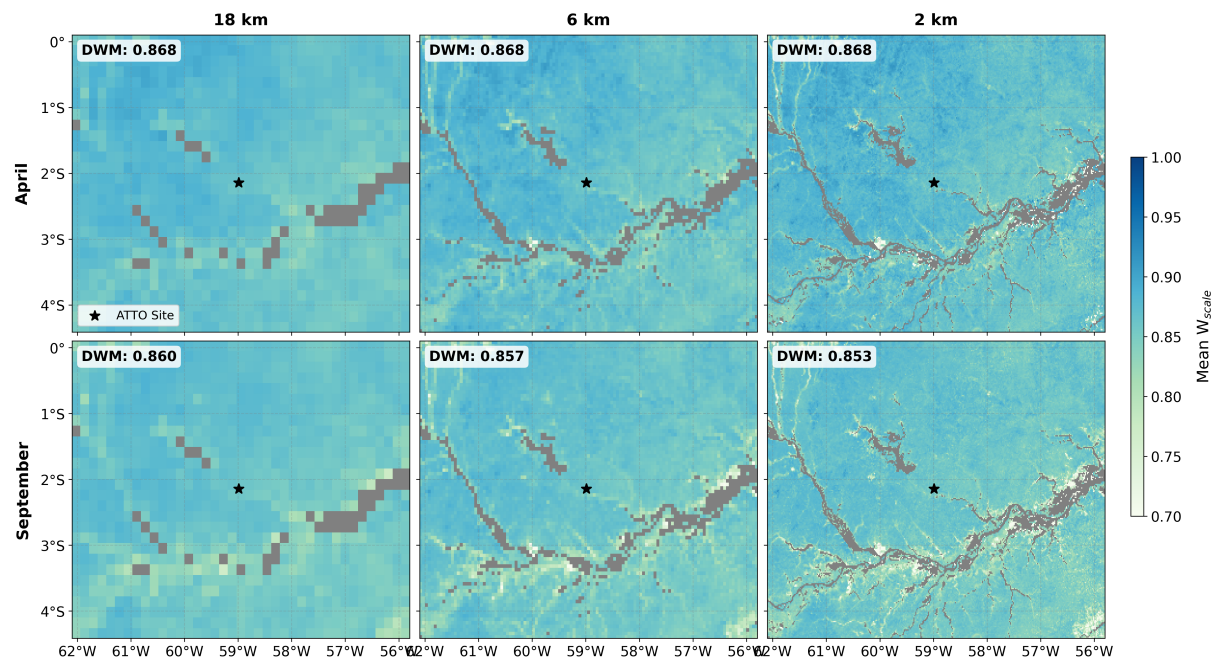


Figure S5. Spatial distribution of monthly mean W_{scale} for the Forest land-use category over the innermost model domain for April and September 2020 under the TD-Dyn scenario. Panels compare the spatial patterns at the 18 km, 6 km, and 2 km model resolutions. The 18 km and 6 km domains were clipped to the spatial extent of the 2 km domain to facilitate direct comparison. DWM denotes the domain-wide mean, calculated over the resulting common spatial footprint. Grid cells classified as water bodies are masked and shown in solid gray.

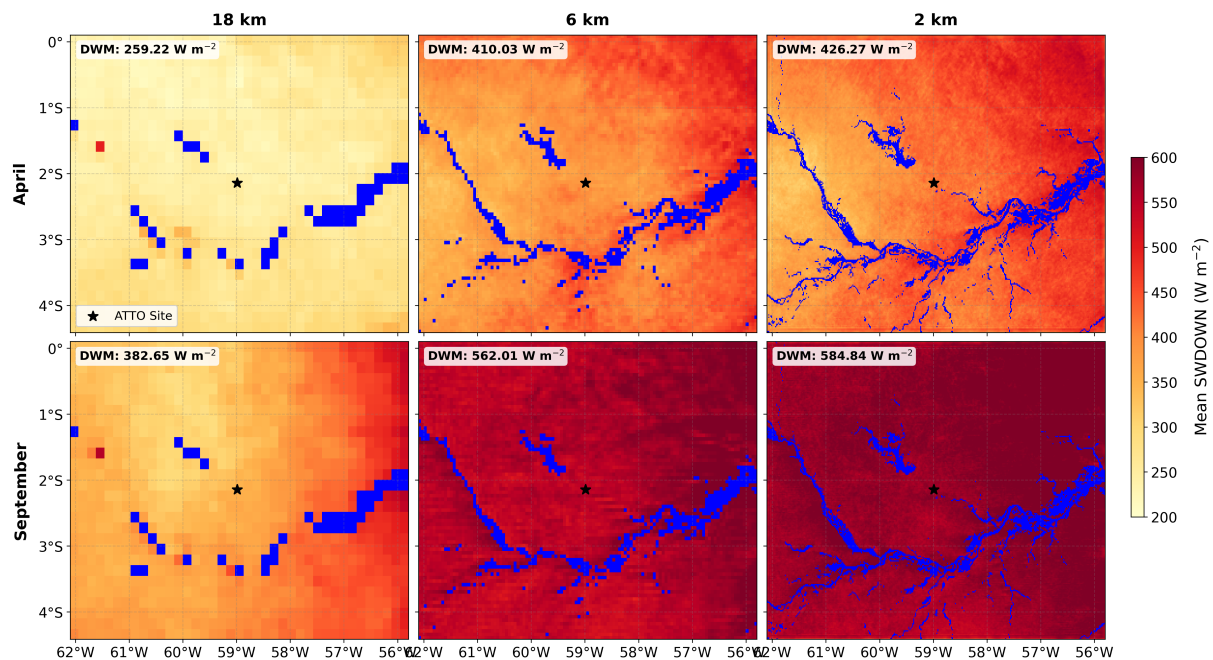


Figure S6. Spatial distribution of monthly mean SWDOWN over the innermost model domain for April and September 2020 under the TD-Dyn scenario. Panels compare the spatial patterns at the 18 km, 6 km, and 2 km model resolutions. The 18 km and 6 km domains were clipped to the spatial extent of the 2 km domain to facilitate direct comparison. DWM denotes the domain-wide mean, calculated over the resulting common spatial footprint. Grid cells classified as water bodies are masked and shown in solid blue.

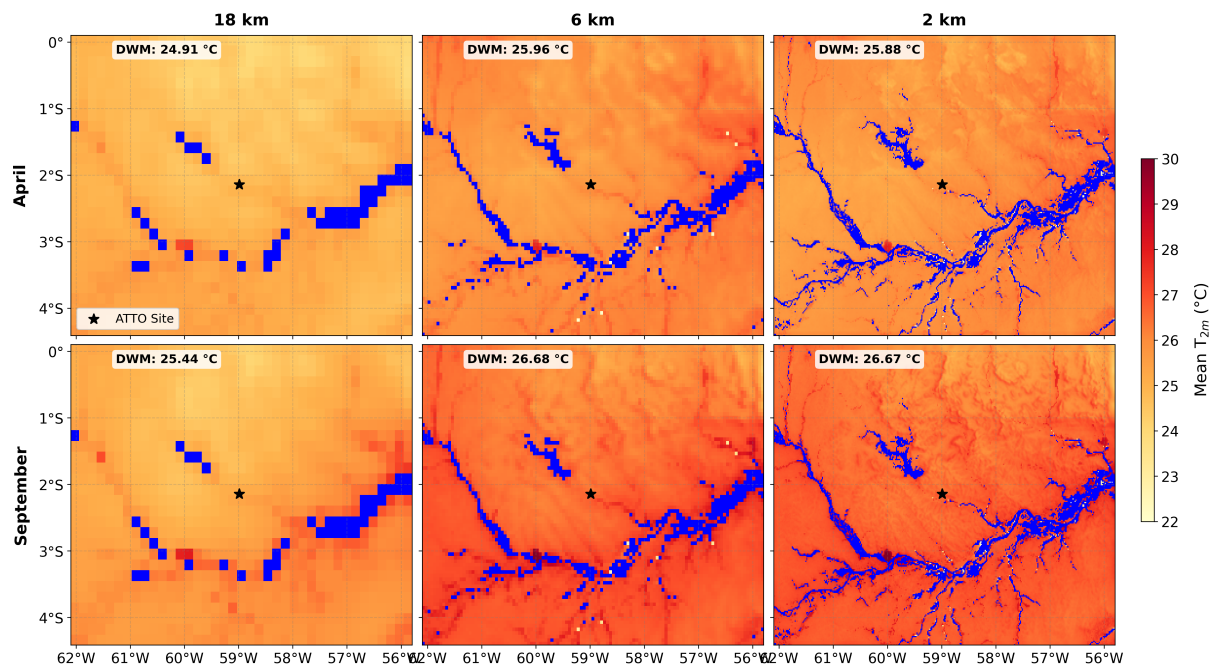


Figure S7. Spatial distribution of monthly mean T_{2m} over the innermost model domain for April and September 2020 under the TD-Dyn scenario. Panels compare the spatial patterns at the 18 km, 6 km, and 2 km model resolutions. The 18 km and 6 km domains were clipped to the spatial extent of the 2 km domain to facilitate direct comparison. DWM denotes the domain-wide mean, calculated over the resulting common spatial footprint. Grid cells classified as water bodies are masked and shown in solid blue.

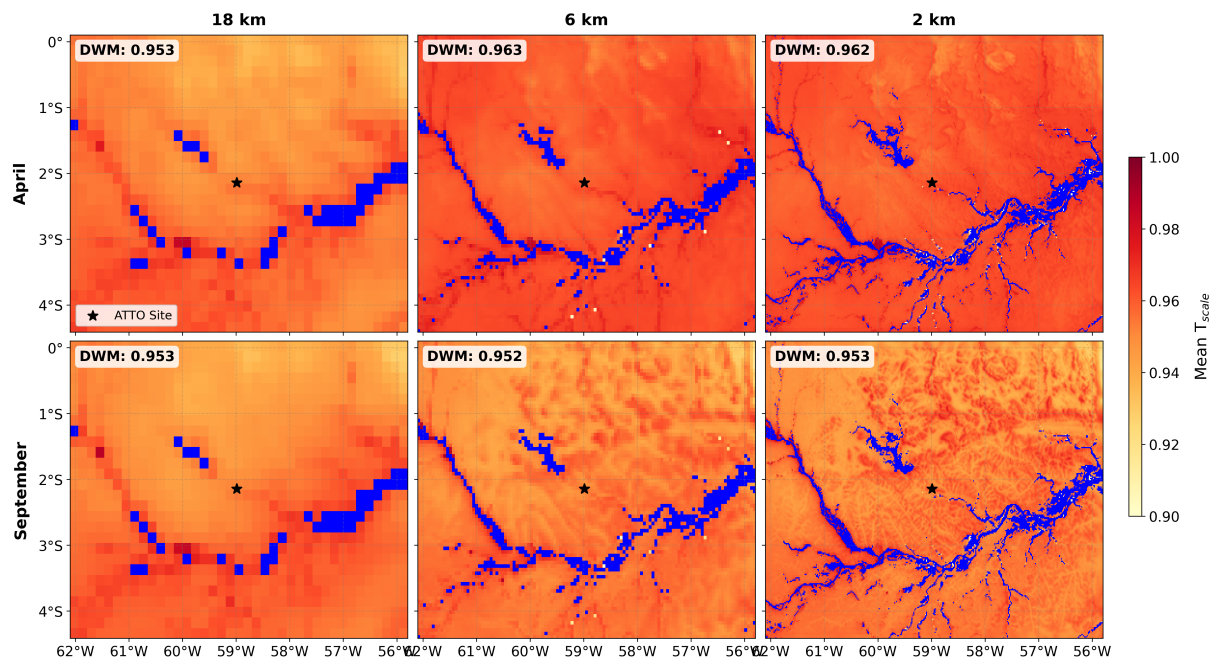


Figure S8. Spatial distribution of monthly mean T_{scale} for the Forest land-use category over the innermost model domain for April and September 2020 under the TD-Dyn scenario. Panels compare the spatial patterns at the 18 km, 6 km, and 2 km model resolutions. The 18 km and 6 km domains were clipped to the spatial extent of the 2 km domain to facilitate direct comparison. DWM denotes the domain-wide mean, calculated over the resulting common spatial footprint. Grid cells classified as water bodies are masked and shown in solid blue.

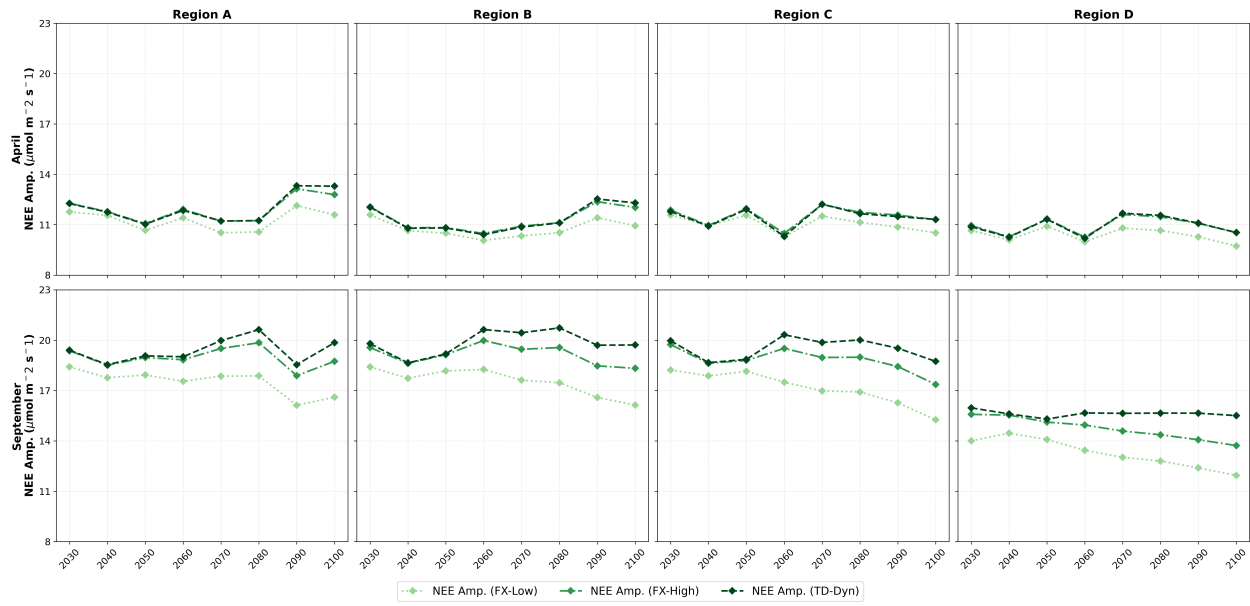


Figure S9. Decadal evolution (2030–2100) of diurnal net ecosystem exchange amplitude ($\mu\text{mol m}^{-2} \text{s}^{-1}$; $\Delta\text{NEE} = \text{NEE}_{\text{Max}} - \text{NEE}_{\text{Min}}$) for the Forest land-use category across Regions A–D during April (top row) and September (bottom row). The NEE amplitude is shown for three T_{opt} scenarios: FX-Low (light green, dotted), FX-High (medium green, dash-dotted), and TD-Dyn (dark green, dashed).

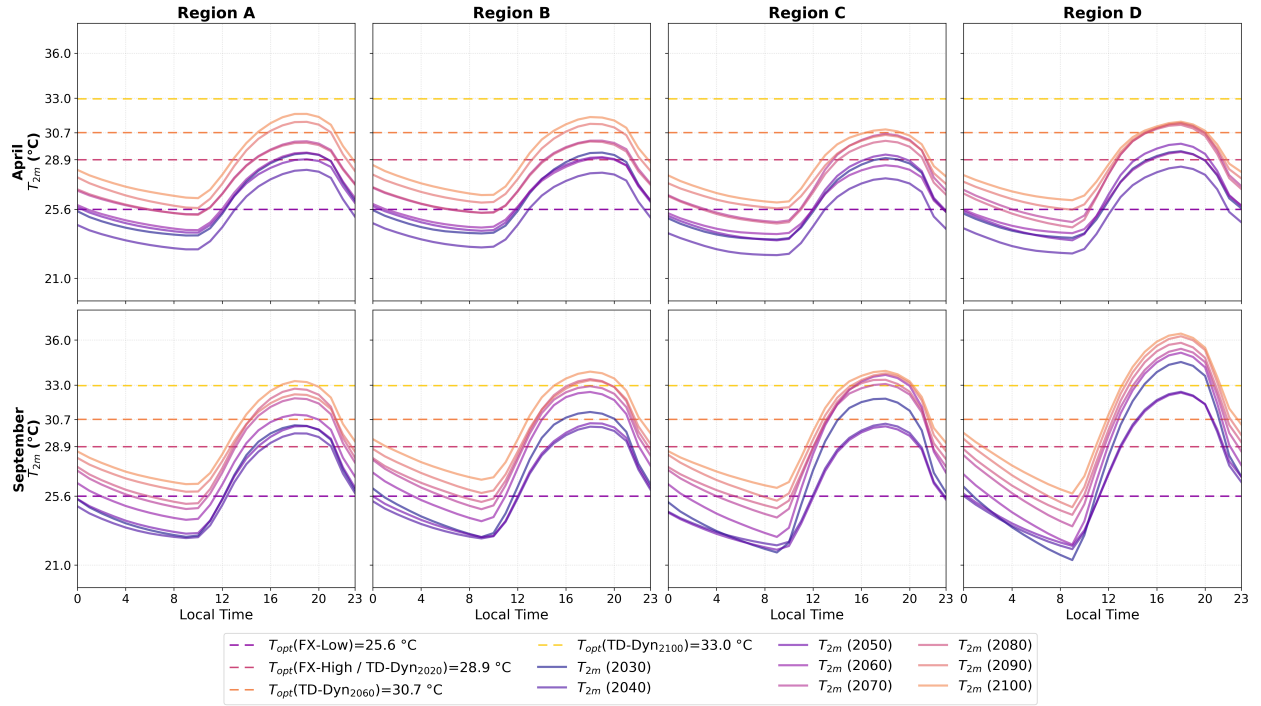


Figure S10. Decadal evolution (2030–2100) of diurnal 2 m air temperature (T_{2m}) hourly profiles across regions A–D during April (top row) and September (bottom row). The horizontal dashed lines indicate the temperatures for different T_{opt} scenarios: FX-Low at 25.6 °C, FX-High and TD-Dyn for 2020, both at 28.9 °C, TD-Dyn for 2060 at 30.7 °C, and TD-Dyn for 2100 at 33.0 °C.

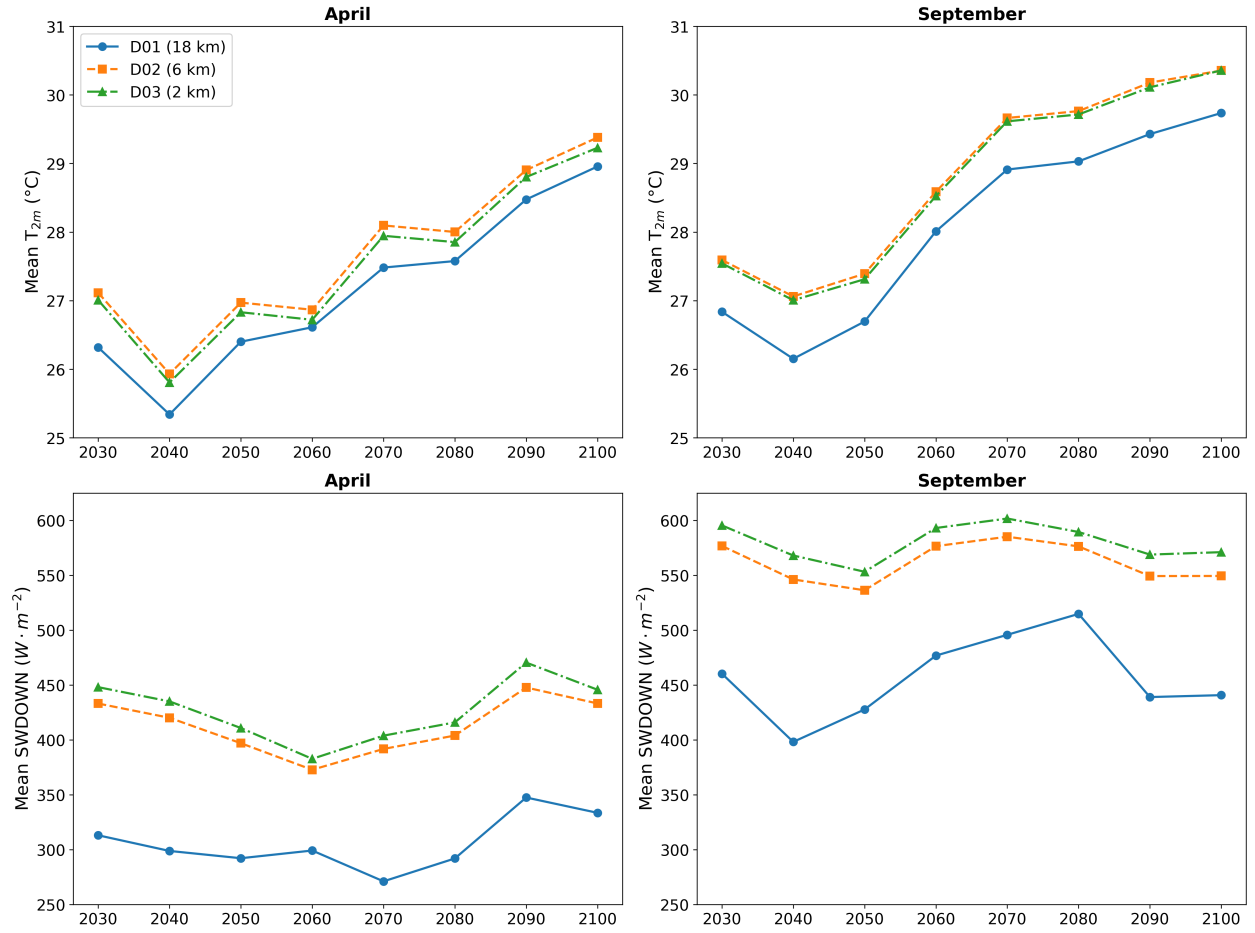


Figure S11. Decadal evolution (2030–2100) of the domain-averaged T_{2m} (top) and daytime-only SWDOWN (bottom) over the innermost model domain. Panels compare monthly mean trends for April (left) and September (right) across the 18 km (blue), 6 km (orange), and 2 km (green) modeling domains. Before computing the averages, the 18 km and 6 km domains were clipped to the exact boundary extent of the 2 km modeling domain to facilitate direct comparison. Averages are aggregated over terrestrial grid cells, omitting water surfaces to isolate land-atmosphere feedback dynamics.

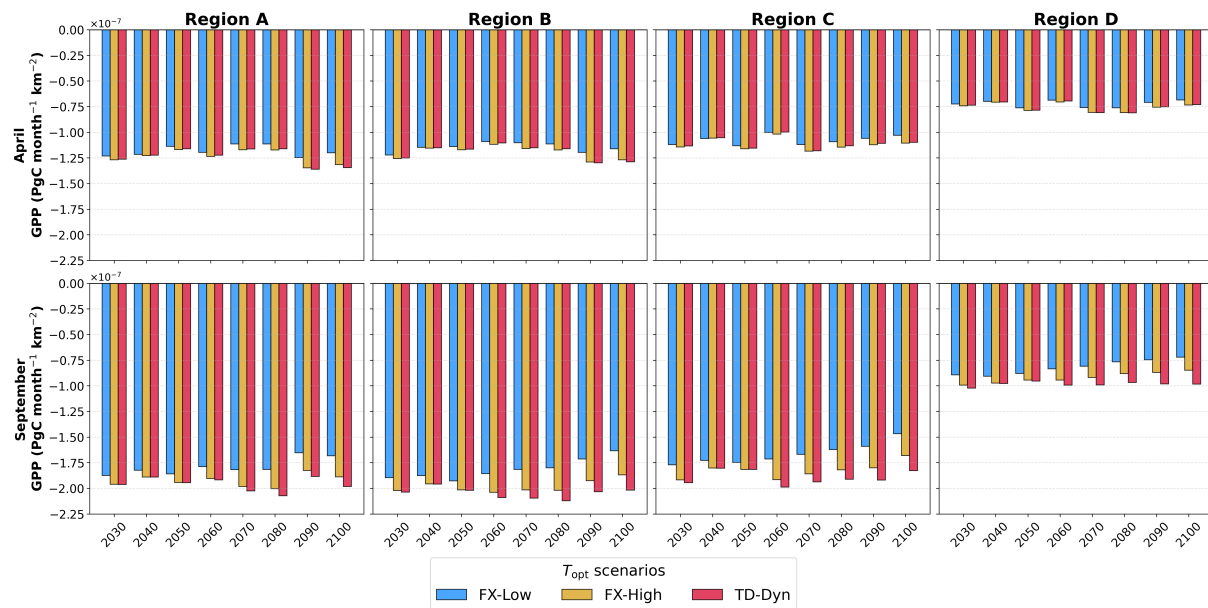


Figure S12. Decadal evolution (2030–2100) of area-normalized monthly gross primary productivity ($\text{PgC month}^{-1} \text{ km}^{-2}$) during April (top) and September (bottom) across Regions A–D, derived from the 18 km model simulations using the adjusted VPRM parameter set. Bar colors denote the three T_{opt} scenarios: FX-Low (blue), FX-High (gold), and TD-Dyn (red). Note that a uniform y-axis range is applied across all panels to facilitate direct regional comparisons.

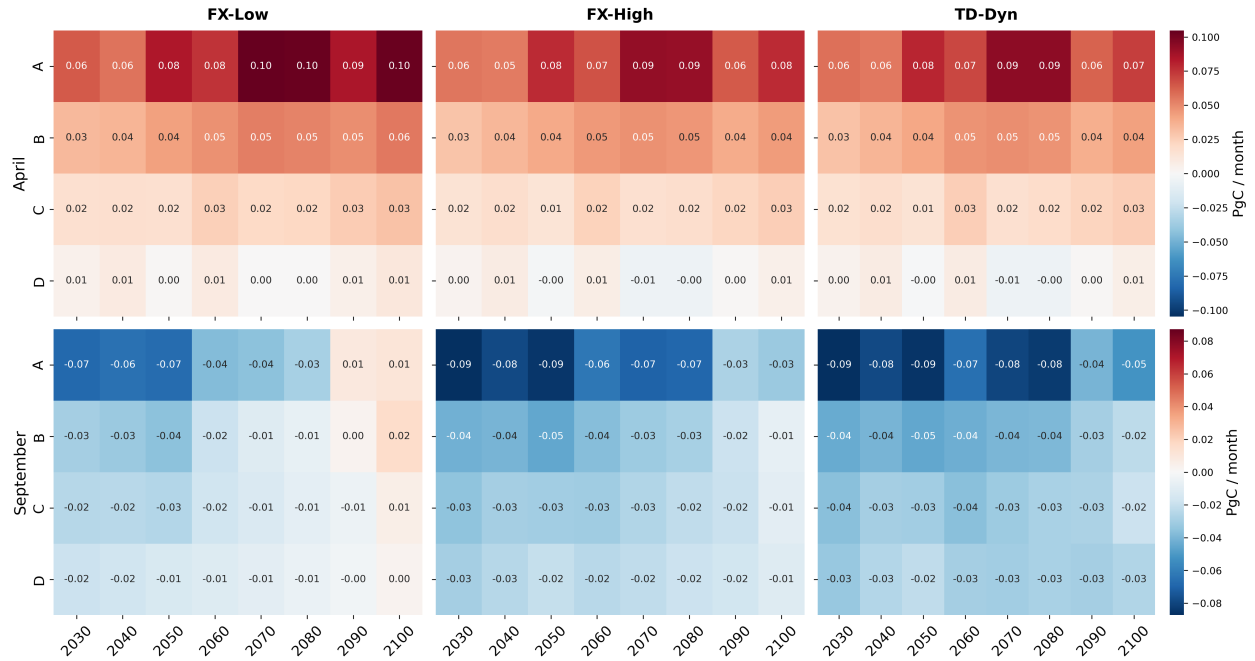


Figure S13. Spatiotemporal heatmap of monthly-integrated net ecosystem exchange (PgC month^{-1}) across decades (2030–2100) for Regions A–D using the Adjusted parameter set. Panels display wet-to-dry transition (April, top) and late dry season (September, bottom) dynamics, subdivided by thermal threshold formulations: FX-Low (left), FX-High (center), and TD-Dyn (right). The color scale ranges from net sink (blue) to net source (red), with numerical cell labels indicating absolute regional monthly integrated fluxes.

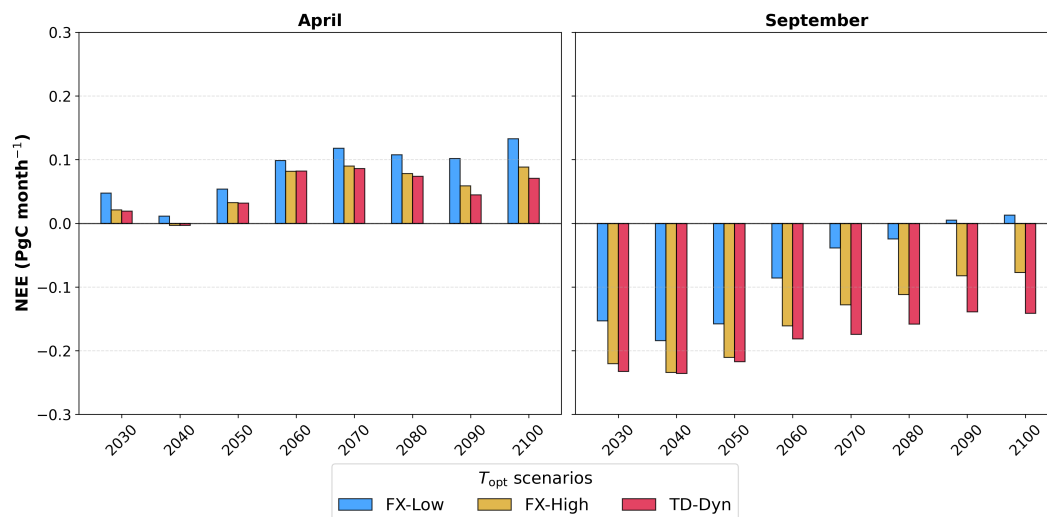


Figure S14. Decadal evolution (2030–2100) of domain-integrated net ecosystem exchange (PgC month^{-1}) for April (left) and September (right) from the 2 km model simulations using the Adjusted parameter set. Bar colors indicate the three T_{opt} formulations: FX-Low (blue), FX-High (orange), and TD-Dyn (red).