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Ecosystem-to-Global Scale Modeling of Vegetation-Climate Feedbacks During the Late Paleozoic Ice Age with Fossil-Based Plant Functional Types

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The Late Paleozoic Ice Age (LPIA; ~340 to 290 Ma), Earth's penultimate icehouse, was a time of widespread coal formation, characterized by the evolution and expansion of the oldest and most extensive paleotropical forests. Increasing evidence suggests that repeated restructuring of terrestrial ecosystems during LPIA were tightly coupled with changes in atmospheric CO_2, aridity, and high-latitude ice volume, supporting the hypothesis that pre-angiosperm biomes exerted a strong influence on the climate system. Land surface models have been used to simulate the role of vegetation-climate feedbacks in past climate change, but the representation of plants in those models are typically based on modern plant functional types (PFTs) such as angiosperms and conifers, which may be poor physiological analogs for Late Paleozoic plants. Recent work has quantified key parameters of physiological functioning of extinct plants from well-preserved Pennsylvanian fossils and process-based ecosystem modeling, providing support that ancient plants were functionally distinct from their present-day relatives. Here, we incorporate six experimentally and empirically constrained paleo-floral plant functional types (paleo-PFTs) into the Community Earth System Model to simulate the response of terrestrial climate to Pennsylvanian tropical wetland and seasonally dry biomes under changing atmospheric CO_2. Our results indicate that under the same atmospheric conditions, paleo-PFTs exhibit substantially higher transpiration rates compared to modern PFTs. Tropical vegetation modulates the magnitude of drying and wetting of soil moisture by increasing and decreasing canopy transpiration rates under elevated CO_2, respectively. Modern PFTs almost uniformly suppress transpiration rates under increased CO_2 (in line with most modern vegetation), while Paleo-PFTs either suppress or enhance regional transpiration rates based on relatively low humidity (increased VPD) or high humidity (decreased VPD), respectively. These differences in water transport by plants lead to substantially drier regions of tropics with paleo-PFTs compared to modern PFTs under elevated CO_2, which better captures the regional drying inferred from paleoclimate proxy records across the Pangaean tropics. Ultimately, this work highlights the importance of accounting for paleo-plant physiology in modeling vegetation-climate feedbacks during past intervals of climate change.