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## RESEARCH LETTER

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## Climate Change Will Increase Biomass Proportion of Global Forest Carbon Stocks Under an SSP5–8.5 Climate Trajectory

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### Key Points:

- Global forest carbon pools exhibit spatial heterogeneity driven by local differences in climatic and environmental factors
- Annual precipitation, elevation, soil, and wildfire were the primary controls of these differences in forest carbon pool fractions
- The ratio of biomass to ecosystem carbon in global forests will increase across the 21st century

### Supporting Information:

Supporting Information may be found in the online version of this article.

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**Abstract** A large amount of carbon is stored in global forests. However, the fraction of carbon stored as plant biomass versus soil organic carbon (SOC) varies among forest types, and potential changes over the 21st century are uncertain. Here, we used extensive data derived from inventories and remote sensing and Coupled Model Intercomparison Project Phase 6 (CMIP6) models to examine the current and 21st century dynamics in the proportion of biomass and SOC across global forests. We found that precipitation, elevation, soil, and wildfire were the primary controls of these differences in carbon pools. Under the SSP5–8.5 climate scenario, CMIP6 models project that the ratio of biomass to ecosystem carbon in global forests will increase across the 21st century, with the largest increases in boreal forests ( $95 \pm 37\%$ ) compared to moist tropical forests ( $16 \pm 15\%$ ). Changes in forest carbon pools resulting in greater biomass fraction will affect disturbance, and ecosystem carbon and energy balances, all of which interact with the climate system.

**Plain Language Summary** The fraction of carbon stored as plant biomass versus soil organic carbon varies among forest types. The extent to which biomass and soil carbon pools may change over the 21st century is uncertain. In this study, we examined current and 21st century dynamics in the proportion of biomass and soil carbon across global forests. Our results show that global forest carbon pools exhibit spatial heterogeneity driven by local differences in climatic and environmental factors. Over the 21st century, we showed that the ratio of biomass to ecosystem carbon in global forests will increase, with the largest increases in boreal forests and lowest increases in moist tropical forests. These changes in forest ecosystem carbon pools have important implications for global ecosystem carbon balances and the climate system.

## 1. Introduction

Forests play an important role in the global carbon cycle by absorbing and storing a large amount of atmospheric CO<sub>2</sub> (Pan et al., 2011; Sedjo, 1993). Global forests contain more carbon in their biomass and soil than the total amount of carbon in the atmosphere (Pan et al., 2011). Over the past decades, global forests have been a strong carbon sink (Pan et al., 2011) with net ecosystem carbon uptake of  $1.1 \pm 0.8$  Pg C yr<sup>-1</sup>. Recent observations show that the contribution of forests in colder (e.g., boreal forest) versus warmer (e.g., tropical forest) climates differ in their contributions to the terrestrial carbon sink (Tagesson et al., 2020). Although tropical and boreal forest ecosystems store large amounts of total carbon, they have significant differences in their ecosystem structure and ability to store carbon in vegetation versus soil (Pan et al., 2011). With projected climate change, the extent to which global forest plant biomass and soil organic carbon (SOC) pools will change is uncertain (Ito et al., 2020; Koch et al., 2021). Climate change may affect these carbon pools through effects on plant carbon uptake and thus biomass accumulation, litter inputs to the soil, and SOC decomposition rates (Nottingham et al., 2015, 2020; L. Xu et al., 2021).

The boreal forest in the northern hemisphere high-latitude region contains large amounts of SOC that has accumulated over thousands of years (Hobbie et al., 2000; Oechel et al., 1992). Much of this SOC is trapped in permafrost (Natali et al., 2019; Schuur et al., 2015) as a result of colder climate and thus slower SOC decomposition (Gorham, 1991; Oechel et al., 1992). Boreal forest ecosystem carbon fixation rates are also slow from colder climate, nutrient limitations (Strömgren & Linder, 2002; Turkington et al., 1998), and a shorter growing season (Shirley et al., 2022; Suni et al., 2003), resulting in low plant productivity and thus biomass accumulation (Fernández-Martínez et al., 2014; Santoro et al., 2021). On the other hand, tropical forests in moist warmer climates have higher biomass driven by greater carbon fixation rates, and rapid SOC decomposition that enhances nutrient availability (Leff et al., 2012; Lewis et al., 2009; Vitousek & Sanford, 1986). Although litter inputs to the soil are high in moist tropical forests, rapid decomposition results in relatively high SOC turnover rates (Sayer

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et al., 2011; Stephenson & Mantgem, 2005). In temperate forests, soil parent material and litter quality have been shown to control forest soil carbon dynamics (Rasmussen et al., 2008). As a result of these variations in climatic and environmental drivers, global forests vary in ecosystem structure, spatial distribution, and relative amounts of accumulated carbon in plants and soil (Pan et al., 2011).

Anthropogenic climate warming and elevated atmospheric CO<sub>2</sub> concentrations are changing the carbon pools of global forest ecosystems (Lewis et al., 2009; Pan et al., 2011). Recent studies using measurements from ground, air, and space have shown increases in biomass across much of the global forests (Köhl et al., 2015; L. Xu et al., 2021). Changes in vegetation productivity inferred from Normalized Difference Vegetation Index trends, forest inventories, and tree-ring data across boreal forests show contrasting responses of greening, browning, and changes of biomass (Berner & Goetz, 2022; M. P. Girardin et al., 2016; Kauppi et al., 2010; Lloyd et al., 2011; Sulla-Menashe et al., 2018). Observed biomass increases in tropical forests have likely been in response to increasing atmospheric CO<sub>2</sub> concentrations (Lewis et al., 2009). Under a warmer climate, higher biomass of global forests (Köhl et al., 2015; L. Xu et al., 2021) may result in greater litter inputs to soil, which can increase SOC but also accelerate soil carbon release by stimulating existing carbon decomposition through priming (Sayer et al., 2011). In boreal regions, warming has threatened historical trends of SOC accumulation by driving rapid SOC decomposition from warmer soils and deepening of the active layer (Natali et al., 2019; Schuur et al., 2015). Effects of warming on SOC decomposition in tropical forests may vary depending on temperature sensitivity to decomposition and vegetation composition that controls litter quality (Nottingham et al., 2015; Yang & Chen, 2009).

In this study, we disentangled the current dominant climatic and environmental controls on the spatial distribution and relative proportion of biomass and SOC across global forests. We also examined changes to this proportion over the 21st century under climate change. We hypothesize that climate warming and increases in atmospheric CO<sub>2</sub> concentrations will increase the proportion of carbon stored as biomass, particularly in colder regions of the boreal and temperate versus tropical and subtropical forests.

## 2. Data and Methods

### 2.1. Study Area

Global forests cover  $4.1 \times 10^9$  ha of land area (Dixon et al., 1994). In this study, we define the boundaries of global forest biomes based on the L. Xu et al. (2021) land cover map, which is derived from the MODIS International Geosphere-Biosphere Program land cover product. We used this vegetation classification to mask four major global forest biomes: moist tropical forests, tropical and subtropical dry forests, temperate forests, and boreal forests (Figure S1 in Supporting Information S1).

### 2.2. Biomass and SOC Stocks, Climatic, and Environmental Controls

Biomass data were obtained from a global above- and belowground live biomass carbon product (Saatchi et al., 2011), which was derived from in situ inventory plots, satellite light detection and ranging (Lidar) samples, and optical and microwave imagery (Table S1 in Supporting Information S1). Data for the total SOC stocks for global forests were taken from the Harmonized World Soil Database v1.2 data set (Wieder et al., 2014), which combined soil information from existing regional and national soil databases.

Many interacting factors affect biomass and SOC decomposition and accumulation in global forests. We identified eight major climatic and environmental controls (mean annual surface air temperature, annual precipitation, annual incoming shortwave radiation, elevation, parent material, wildfire, land cover change from forest harvest, and permafrost) that affect global forest productivity and thus biomass, soil development, and SOC accumulation (Table S1, Figure S2 in Supporting Information S1). As described below, we obtained these variables from global gridded data sets, which are derived from observations, inventories, and remote sensing products and models.

The surface air temperature data was taken from monthly CRU TS3.21 mean temperature observations (Jones & Harris, 2013). Precipitation data was generated from monthly CPC Merged Analysis of Precipitation global gridded precipitation product (Xie et al., 2007). The precipitation data was interpolated from the original resolution of  $2.5^\circ \times 2.5^\circ$  to  $0.5^\circ \times 0.5^\circ$ . Surface incoming shortwave radiation was taken from Clouds and the Earth's Radiant Energy System Energy Balanced and Filled Top-of-Atmosphere (TOA) product (Loeb et al., 2018). The

original spatial resolution of  $1^\circ \times 1^\circ$  was regridded to  $0.5^\circ \times 0.5^\circ$ . The elevation data were taken from the Global Multi-resolution Terrain Elevation Data 2010 (Danielson & Gesch, 2011). The soil parent material data were taken from Global Unconsolidated Sediments Map database (Börker et al., 2018). Total wildfire burned area fractions during fire events from 1997 to 2016 were derived from the Global Fire Emissions Database version 4.1 burned area fraction, which includes small fires (GFED4.1s) (Randerson et al., 2018). The total area of land cover change from forest harvest was derived from the Land-Use Harmonization 2 data set by merging total land cover change transitions among land-use states driven by wood harvest areas from primary, secondary mature, and secondary young forests (Hurt et al., 2020). The permafrost (permanently frozen ground) spatial domain, which includes discontinuous, sporadic, and isolated permafrost boundaries, was taken from the Circum-Arctic Map of Permafrost and Ground-Ice Conditions, Version 2, published by National Snow and Ice Data Center (Brown et al., 2002). Based on this permafrost data, we re-grouped the data set and reclassified the global forest land grid cells into areas with versus without permafrost.

### 2.3. CMIP6 Models

Biomass and SOC stocks and thus their relative proportion across global forests may be altered under future climate. To examine the effects of projected climate warming and increased atmospheric  $\text{CO}_2$  on global forest biomass and SOC stocks over the 21st century, we used modeled outputs of global forest biomass and SOC and calculated the ratio of biomass to ecosystem carbon ( $R_B$ ) from 11 Coupled Model Intercomparison Project Phase 6 (CMIP6) models (ACCESS-ESM1-5, BCC-CSM2-MR, CESM2, CMCC-CM2-SR5, CNRM-ESM2-1, CanESM5, EC-Earth3, IPSL-CM6A-LR, NorESM2-LM, TaiESM1, UKESM1-0-LL) under the Shared Socio-economic Pathway (SSP5–8.5) climate scenario (Eyring et al., 2016). The SSP5–8.5 climate scenario was chosen since the trend of global carbon emissions is broadly consistent with this high emissions scenario. We also tested the performance of these CMIP6 models in simulating  $R_B$  against the data-derived values described above.

### 2.4. Data Analysis

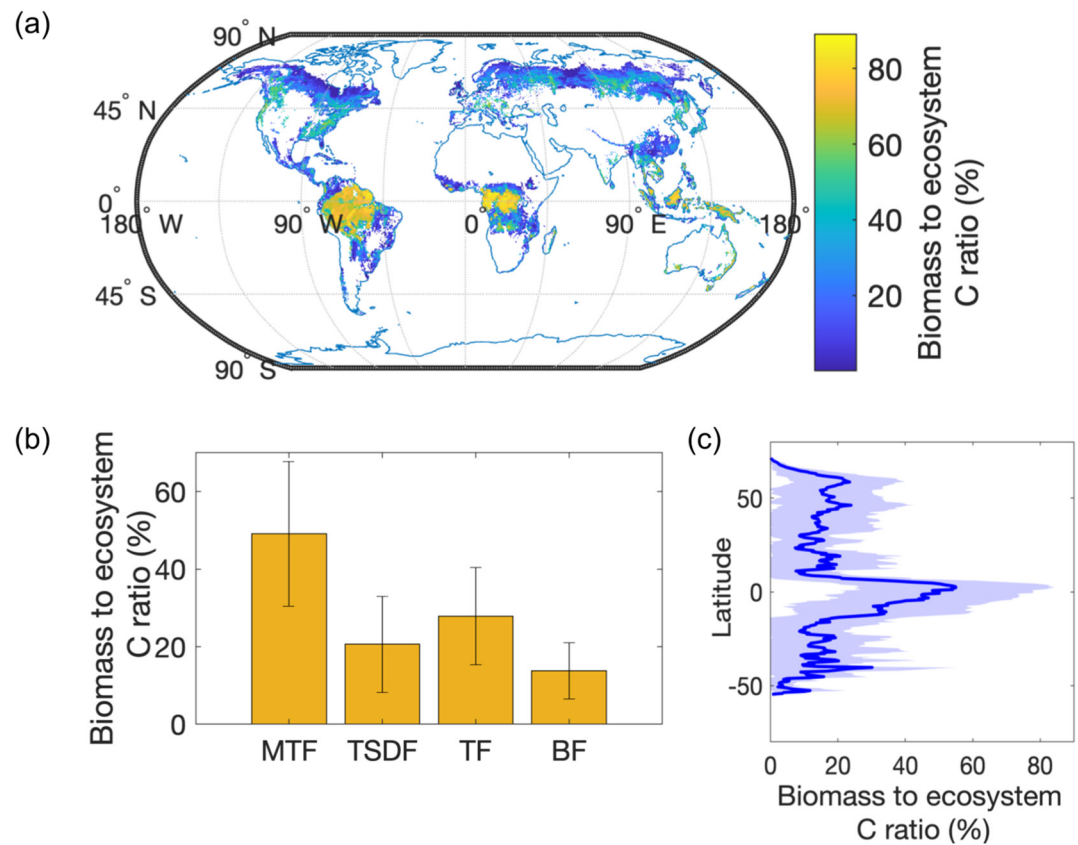
To ensure consistent spatial resolution, all spatial data sets including biomass, SOC, climate and environmental drivers, and CMIP6 models were regridded to  $0.5^\circ \times 0.5^\circ$  spatial resolution, across four major global forest biomes (moist tropical, tropical and subtropical dry, temperate, and boreal forests; Figure S1 in Supporting Information S1). We examined the relationship between climatic and environmental factors with global forest biomass, SOC, and  $R_B$ . The non-linear relationships and relative importance of the eight climatic and environmental factors that directly or indirectly affect plant biomass and SOC accumulation and thus control the spatial distribution of  $R_B$  across global forests were estimated using the random forest method (Breiman, 2001). We also examined ecosystem carbon turnover rates of global forests (Carvalho et al., 2014) and the relative importance of soil properties (bulk density, field capacity, wilting point, thermal capacity, and total nitrogen density) to  $R_B$  using data (Figure S3 in Supporting Information S1) obtained from the Global Gridded Surfaces of Selected Soil Characteristics (Global, 2000).

The performance of CMIP6 models in simulating  $R_B$  under current climate was tested against data-derived values. These evaluations were conducted using a Taylor diagram (Taylor, 2001) that graphically illustrate the closeness of interannual and spatial patterns of the different sets of simulated biomass to ecosystem carbon ratios to the data-derived benchmark values. The Taylor diagram considered closeness of CMIP6 modeled versus data-derived values based on correlation, central root mean square difference (RMSD), and standard deviation (SD) between modeled and data-derived values. Simulated values nearest to the data-derived values were considered to be the closest to observations, as determined by highest correlation, lowest RMSD, and closest SD.

## 3. Results and Discussion

### 3.1. Spatial Distribution of Biomass and SOC Carbon Pools

Different global forest biomes exhibit unique patterns in the distribution of ecosystem carbon pools (Figure 1). Our results show contrasting biomass and SOC carbon pools across forests in colder versus moist warmer climates (Figure S4 in Supporting Information S1). Tropical forests have the largest spatial average biomass ( $15 \pm 9 \text{ kgC m}^{-2}$ ) while the boreal forests have the smallest biomass ( $2.6 \pm 2 \text{ kgC m}^{-2}$ ). In contrast, boreal

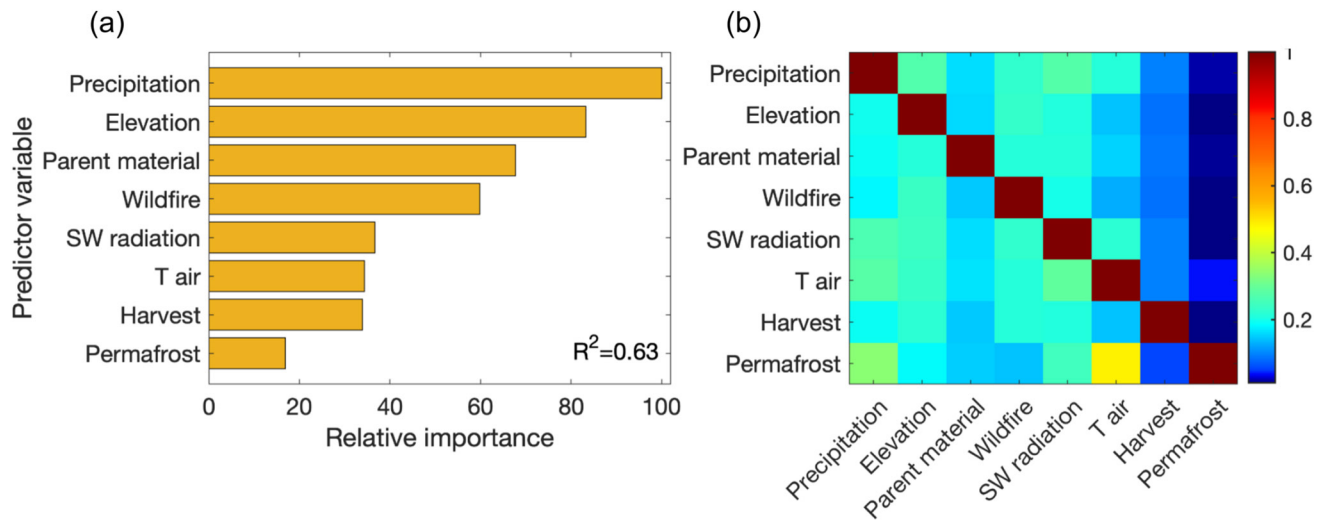


**Figure 1.** Observationally-inferred biomass to ecosystem carbon ratio varies across global forest biomes. Under current climate, data-derived plant biomass to ecosystem carbon ratios (plant biomass/ecosystem carbon)  $\times 100$ ; ecosystem carbon = plant biomass + soil organic carbon) across (a) global land areas covered by forests, (b) global forest biomes (moist tropical forests (MTF), tropical and subtropical dry forests (TSDF), temperate forests (TF), and boreal forests (BF); Figure S1 in Supporting Information S1), and (c) across latitudes. The error bars in panel (b) and the shaded area in panel (c) represent one standard deviation.

forests store the largest amount of SOC ( $19 \pm 8 \text{ kgC m}^{-2}$ ) followed by temperate forests ( $13.6 \pm 5 \text{ kgC m}^{-2}$ ). The temperate and tropical and subtropical dry forests have  $11.6 \pm 4$  and  $9.5 \pm 4 \text{ kgC m}^{-2}$ , respectively. We found that the distribution in the  $R_B$  of global forests has distinct latitudinal gradients (Figure 1).  $R_B$  is highest in tropical moist climates and decreases northward and southward from the tropics (Figure S4 in Supporting Information S1). Most boreal forest ecosystem carbon is stored as SOC with only  $14 \pm 7\%$  in plant biomass (Figure 1b). In contrast, moist tropical forests store  $50 \pm 18\%$  of their carbon as biomass. The temperate and tropical and subtropical dry forests have intermediate values of biomass carbon ratios ( $28 \pm 13\%$  and  $21 \pm 12\%$ , respectively). These results are consistent with other studies that demonstrate variations in plant and soil carbon pools among different forests (Eswaran et al., 1993; Post et al., 1982). While colder regions exhibit lower biomass carbon ratios compared to the warmer moist tropics, our results show substantial spatial heterogeneity within each forest biome; for example, the high ratios in parts of the Eurasian boreal forests and the Amazon and Congo Basin moist tropical forests.

### 3.2. Climatic and Environmental Controls of Forest Carbon

Forest biomass and SOC pools are controlled by several climatic and environmental factors. Our results from the random forest model using data derived from inventories and remote sensing ( $R^2 = 0.63$ ) show that annual precipitation, elevation, soil, and wildfire are the most important environmental and climatic controls on  $R_B$  (Figure 2). These controls differ in their relative effects on  $R_B$ , biomass, and SOC pools of global forests (Figure 2; Figure S3 in Supporting Information S1). For example, annual precipitation is the most important controller for  $R_B$  (Figure 2) through effects on both biomass and SOC stocks (Figure S5 in Supporting Information S1). The

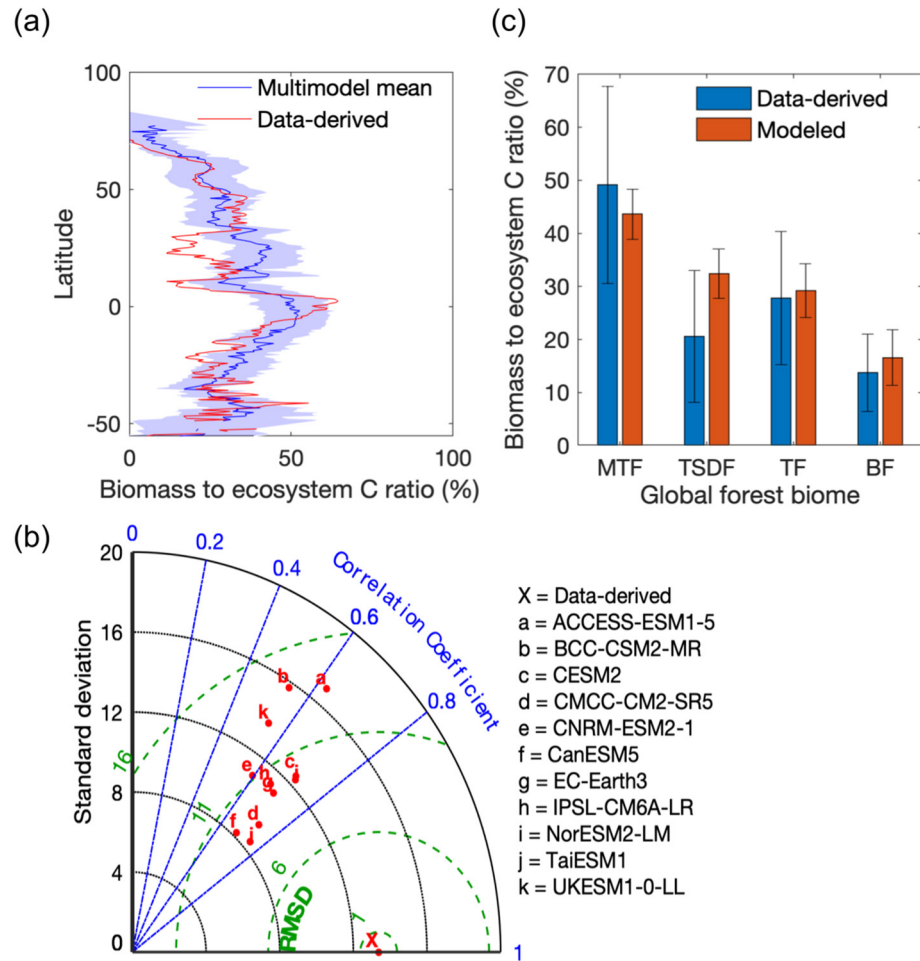


**Figure 2.** Annual precipitation is the most important climatic control on observed biomass to ecosystem carbon ratio. The relative importance of the eight climatic and environmental factors that affect observed biomass to ecosystem carbon ratio estimated using a random forest method (Breiman, 2001): (a) unbiased predictor importance estimates and (b) predictor association estimates. T air denotes surface air temperature, and SW denotes incoming shortwave radiation.

importance of precipitation in controlling forest carbon pools is consistent with a study that shows soil and biomass carbon pools across precipitation gradients (Meier & Leuschner, 2010). Elevation, primarily through its effects on SOC, is the second most important factor that affects  $R_B$  (Figure 2; Figure S3 in Supporting Information S1). Elevation indirectly affects several more direct controllers on  $R_B$ , including air temperature, precipitation, and soil development (Moser et al., 2011). Variations in landscape elevation can indirectly influence plant growth and the subsequent accumulation of soil carbon through its effect on hydrology. Soil parent material affects soil formation and subsequent soil physical and chemical properties (Wilson, 2019), consistent with its large inferred control on SOC stocks (Figure S5 in Supporting Information S1). Wildfires also affect forest biomass and SOC (Curtis et al., 2018; Turetsky et al., 2010; Van Der Werf et al., 2003), and recent estimates from satellite-derived data show that  $38 \pm 9\%$  of global forest loss was associated with fire (van Wees et al., 2021). Consistent with that study, our results show that wildfire is one of the dominant controllers of global forest biomass and SOC (Figure S5 in Supporting Information S1). We also conducted further analysis to examine the effects of soil physical, hydrological, and thermal properties and identified soil nitrogen content, field capacity, and wilting point as important soil variables that control  $R_B$  (Figure S6 in Supporting Information S1). These soil properties affect soil moisture and nutrients availability and thus forest growth and biomass accumulation (Kimmins et al., 1990; Pastor & Post, 1986).

### 3.3. Forest Carbon Predictions of CMIP6 Models

Our analysis using 11 CMIP6 models shows that prediction of current global forest carbon pools vary widely among the models (Figure 3; Figure S7 in Supporting Information S1). Spatially averaged across latitudes, most of the models did not accurately capture the data-derived  $R_B$  patterns (Figure 3a; Figure S8 in Supporting Information S1). Large differences also existed in correlations, RMSDs, and SD between modeled and data-derived values (Figure 3b). However, consistent with data-derived values, the multimodel ensemble spatial average  $R_B$  were lower in boreal and temperate versus in moist tropical forests.  $R_B$  values were overestimated in tropical and subtropical dry forests (Figure 3c). In contrast to the observations, the models exhibit greater latitudinal variability in the northern hemisphere compared to the southern hemisphere. While multimodel mean  $R_B$  values are generally consistent with data-derived values, in some regions, particularly within  $20^\circ\text{N}$ – $30^\circ\text{N}$ , the multimodel mean substantially overestimated  $R_B$  (Figure 3a). This bias was partly attributed to overestimation of modeled biomass in the tropical and subtropical dry forests and underestimation of biomass in parts of the moist tropical forests (Figure S7 in Supporting Information S1). Greater differences in CMIP6 modeled SOC were found more in the boreal than tropical forests (Figure S7 in Supporting Information S1). While the spatially averaged SOC values were reasonably captured by the multimodel mean across three of the four global forest biomes, most



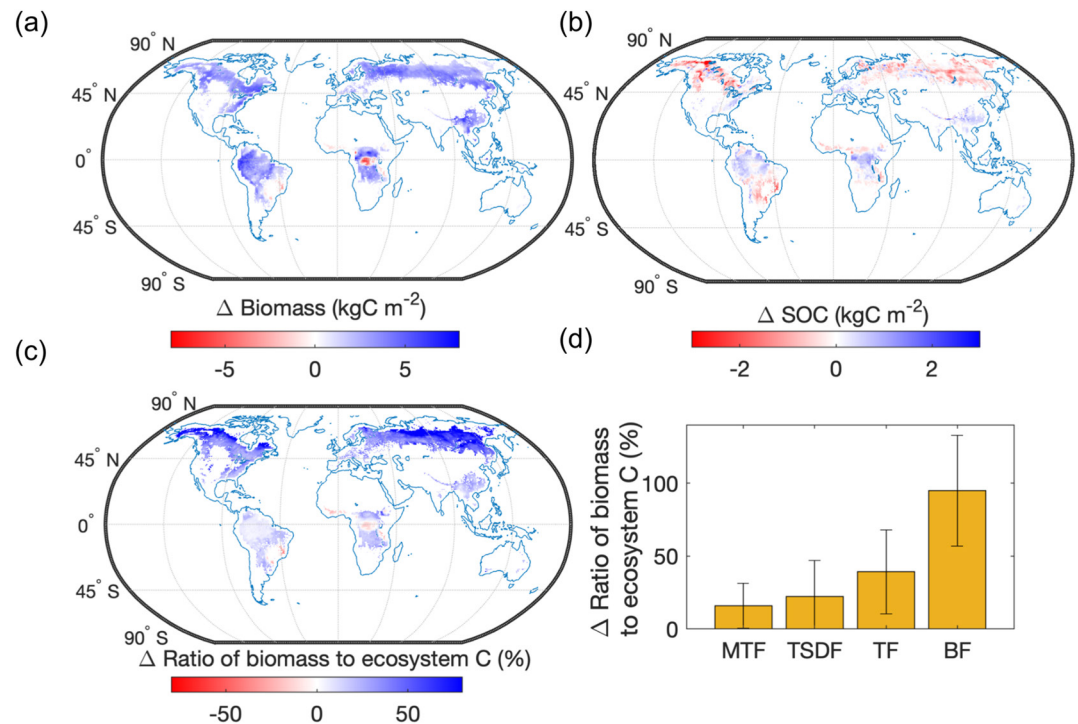
**Figure 3.** Coupled Model Intercomparison Project Phase 6 (CMIP6) models predict very different biomass to ecosystem carbon ratios. Eleven CMIP6 models predicted ratios of biomass to ecosystem carbon (a) zonally compared with data-derived values; (b) differences in correlations, root-mean square differences, and standard deviations between modeled and data-derived values; and (c) multimodel mean spatially averages across global forest biomes. The shaded region in panel (a) represents one standard deviation computed from 11 CMIP6 models, and the error bars in panel (b) represent one standard deviation computed from spatial variability.

models and the multimodel mean overestimated SOC in the boreal forest regions of the northern hemisphere (Figure S7 in Supporting Information S1).

### 3.4. 21st Century Changes in Fraction of Forest Biomass Carbon

Our analysis of CMIP6 models under the SSP5–8.5 climate scenario shows that biomass will increase across much of the global forests in the 21st century (Figure 4a). However, localized declines in biomass were modeled in parts of the Amazon and the Congo basin. Changes in SOC exhibit spatial heterogeneity with overall declines in the boreal forests and both increases and decreases in parts of the tropical forests (Figure 4b). Observational studies have indicated that increases in biomass likely results in increased litter inputs to the soil, thereby accelerating SOC decomposition in high-latitude regions under warming (Bronson et al., 2008; Lawrence & Slater, 2005; S. Xu et al., 2013), and accelerating decomposition in the tropics stimulated by fresh litter inputs (Sayer et al., 2011, 2019). Although these mechanisms are represented differently (or not at all) in the CMIP6 models, the models project SOC declines or slight increases across much of the global forests (Figures 4a and 4b).

Projected changes in multimodal mean  $R_B$  values of the 11 CMIP6 models had distinct patterns across the global forests (Figure 4c). These results show that global forests will gain biomass carbon and lose SOC in much of the forest regions by the year 2100. Projected 21st century changes from these CMIP6 models show that  $R_B$  will



**Figure 4.** Projected changes in biomass, soil organic carbon (SOC), and ratio of biomass to ecosystem carbon vary across forests in the 21st century. The Coupled Model Intercomparison Project Phase 6 multimodel mean changes (2100–2015) in (a) biomass carbon, (b) SOC, (c) % change in  $R_B$  values, and (d) spatial average % change in  $R_B$  values across the four major global forest biomes. The error bars in panel (d) represent one standard deviation.

increase across much of the global forests (Figure 4). These increases are more pronounced in the boreal and temperate forests versus a slight increase or localized declines in tropical forests (particularly parts of the Amazon and Congo basin) (Figure 4a). The multimodel spatial average  $R_B$  for the boreal forests will increase by  $95 \pm 37\%$  compared to only a  $16 \pm 15\%$  increase for moist tropical forests by the year 2100 (Figure 4b). Intermediate increases in spatial average  $R_B$  values were found for temperate forests (22%) and tropical and subtropical dry forests (39%). These differences in  $R_B$  changes are partly attributed to the higher positive temperature sensitivity of carbon fixation to climate warming that enhances productivity (Kauppi et al., 2014) and drives higher forest biomass (Kauppi et al., 2010; Stinziano & Way, 2014) in the colder boreal and temperate climates (Figure 4), as opposed to adverse effects of warming in tropical climates (Doughty & Goulden, 2008). In the tropical climate, the adverse effect of warming is partly offset by increased atmospheric  $\text{CO}_2$  concentrations that benefit forest growth through enhancing carbon fixation (Fernández-Martínez et al., 2018) and increasing water use efficiency (Keenan et al., 2013). Similarly, warming may affect modeled SOC dynamics through its effect on decomposition rates and indirectly through alterations in plant functional types and biomass, which, in turn, modify litter quantity and quality (Conant et al., 2008; Hopkins et al., 2012; Wang et al., 2016).

Our results highlight that global forests have very different relative proportions of plant biomass and SOC pools. While spatial heterogeneity in carbon pools is driven by local variations in climatic and environmental factors, the proportion of forest ecosystem carbon in plants versus soil follows distinct latitudinal gradients and varies among different forests (Figure 1). The  $R_B$  derived from data and CMIP6 models are also related to forest productivity and carbon turnover rates. We found from data-derived products that under current conditions, ecosystem carbon turnover rates vary with forest biomes (Figure S9 in Supporting Information S1). This variation in turnover time spatial pattern is inversely related to variation in biomass and  $R_B$  (Figure 1 vs. Figure S9 in Supporting Information S1) and is consistent with studies that concluded that global forest turnover rates are linked with forest net primary productivity, and thus biomass (C. A. J. Girardin et al., 2010; Keeling & Phillips, 2007; Stephenson & Mantgem, 2005).

We note that our estimates of the relative magnitude of biomass and SOC pools under current and 21st century conditions may be subject to a number of uncertainties. For instance, the spatial resolution of the original data



sets we used were different and sub-gridcell heterogeneity below our  $0.5^\circ \times 0.5^\circ$  spatial resolution is not captured in our analysis and should be addressed in future study. Uncertainties in modeled soil carbon stocks attributed to differences in belowground process representations were also shown in CMIP6 models (Varney et al., 2022). Fan et al. (2020) also reported that uncertainties in ecosystem carbon turnover rates are mostly attributed to global soil carbon estimates. Our results are also subject to uncertainties from CMIP6 models driven by differences in model structure and parameterization, vegetation types, and climate (Eyring et al., 2016). In this regard, recent work has argued that model selection for ensemble calculations should account for model accuracy under current conditions, rather than assuming a “model democracy” (Hausfather et al., 2022). We therefore re-evaluated our conclusions using a “model meritocracy,” that is, the 4 best CMIP6 models compared to current observations (Figure S10 in Supporting Information S1). We found no substantial differences in changes in spatial pattern and relative proportions of plant biomass to ecosystem carbon ratio of the global forests compared to results from the overall ensemble, lending additional confidence to our results.

#### 4. Conclusions

We found from data-derived products and CMIP6 models that global forests have very different structure and ability to store carbon in vegetation versus soil. Under current conditions, these differences in ecosystem carbon pools are mainly controlled by annual precipitation, elevation, soil parent material, and wildfire (Figure 2). Warmer 21st century climate and wildfire will likely increase the relative proportion of plant biomass carbon in ecosystems (Figure 4). Our result of projected increases in biomass versus SOC under 21st century climate may result in several ecological and climatic feedbacks. Forest ecosystems with greater biomass typically have higher fuel loads that can exacerbate wildfire through interaction with warmer climates (Pausas & Keeley, 2021). Biomass is more vulnerable than SOC to natural disturbances, such as fungal and insect attacks, drought, and forest dieback that reduce ecosystem carbon uptake (Allen et al., 2010; Doughty et al., 2015; Huang & Anderegg, 2012), and these disturbances are not well-represented in CMIP6 models. Biomass is also vulnerable to anthropogenic disturbances such as deforestation. Overall, alterations in the structure of global forests and the distribution of carbon within ecosystems, leading to a higher proportion of carbon stored in plant biomass, will have implications for surface energy balances, disturbance regimes, ecosystem carbon balance, and thus feedbacks with the climate system.

#### Data Availability Statement

Data products that are used and support the findings of this study are publicly available at <https://www.ilamb.org/datasets.html> and <https://esgf-node.llnl.gov/projects/cmip6/>.

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