Global Climate Change and the Equilibrium Responses of Carbon Storage in Arctic and Subarctic Regions

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The Terrestrial Ecosystem Model (TEM; Raich et al., 1991; McGuire et al., 1992; Melillo et al., 1993) is a process-based ecosystem simulation model that uses spatially referenced information on climate, elevation, soils, vegetation, and water availability to make monthly estimates of important carbon and nitrogen fluxes and pool sizes. Carbon enters the vegetation pool as gross primary productivity (GPP) and transfers to the soil pool as litter; it leaves the soil in the decomposition process of heterotrophic respiration. Nitrogen inputs from outside the ecosystem enter the inorganic N pool; losses leave this pool. Nitrogen in the vegetation occurs either in the structural pool or the labile pool. Structural N in vegetation is constructed from N that is derived from either the labile pool (exchange) or from soil inorganic N pool (uptake). The labile pool is replenished from N that is resorbed from senescing tissue (decay), N that is allocated for storage (exchange), or N in uptake that does not enter directly into tissue construction (uptake). Nitrogen is transferred from vegetation to the soil organic pool in litterfall. Net N mineralization accounts for N exchanged between the organic and inorganic N pools of the soil.

There are 12 input variables needed to drive TEM: PAR (photosynthetically active radiation), PET (potential evapotranspiration), rainfall, snow recharge, soil moisture, actual evapotranspiration, leaf-display duration, atmospheric CO_2 concentration, nitrogen inputs, vegetation type (18 total classes), air temperature and soil texture. The data sets are gridded at a resolution of 0.5° latitude by 0.5° longitude. The application of TEM to a grid cell requires the use of monthly data on climate, hydrology, and leaf-display duration.

We extrapolated version 4.0 of the TEM (McGuire et al., 1995) and the Marine Biological Laboratory implementation of the BIOME biogeography model (MBL-BIOME) across the globe at 0.5° resolution to estimate the equilibrium responses of carbon storage to the doubled CO_2 climates of three general circulation models (GCMs). For contemporary climate and an atmospheric CO_2 concentration of 312.5 ppmv, TEM estimates global carbon storage of 1781.4 x 10^{15} g C (Pg C). This estimate does not include the carbon content of inert soil organic matter. Arctic and Subarctic ecosystems account for 17.3% of global vegetation carbon storage and 39.8% of global soil carbon storage. The land area north of 60° N accounts for 240.1 Pg C (13.5%) of global carbon storage, with 70.3 Pg C in vegetation and 169.8 Pg C in soils. For an atmospheric concentration of 625.0 ppmv and climate changes estimated by GCMs of Oregon State University (OSU), Geophysical Fluid Dynamics Laboratory (GFDL), and the Goddard Institute for Space Studies (GISS), we ran TEM to equilibrium for vegetation distributions estimated by MBL-BIOME. Among the climate scenarios, MBL-BIOME estimates that north of 60° N the area of polar desert is reduced by between 80% and 85% by the migration of tundra northward. Similarly, the area of tundra is reduced by between 45% and 55% by the migration of boreal forest northward; forested area increases between 35% and 40% north of 60° N. For 625.0 ppmv CO_2 and associated changes in climate and vegetation, the equilibrium total carbon storage of the land area north of 60° N increases between 42.1 Pg C and 48.4 Pg C. The increase in total carbon storage is primarily attributable to change in vegetation carbon storage, which increases between 39.2 Pg C and 49.2 Pg among the climate scenarios. The migration of boreal forest northward is responsible for the increases in vegetation carbon storage. Changes in soil carbon storage range between a decrease of 2.8 Pg C and an increase of 9.3 Pg C. Soil carbon storage does not substantially decrease because increases in net primary production (NPP), which cause inputs of carbon into the soil to increase, offset soil carbon losses that are caused by higher soil temperature. Increases in NPP are primarily driven by the effect of elevated temperature in enhancing the mineralization of nitrogen in northern soils, which allows plants to incorporate elevated CO_2 into production. The equilibrium responses of carbon storage to climate change in these simulations suggest that high latitudes have the potential to act as a carbon sink if the atmospheric concentration of CO_2 is stabilized. The responses also indicate that both ecosystem structure and function are important in the long-term potential for high latitudes to stabilize the atmospheric concentration of CO_2. Further progress in modeling the role of high latitudes in stabilizing/destabilizing the atmospheric concentration of CO_2 requires considering at large spatial scales the transient dynamics of functional (i.e., soil) and structural (i.e., vegetation) responses of carbon storage.

References

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