Abstract. Carbon storage and flow through forest ecosystems are major components of the global carbon cycle. The cycle of carbon is intimately coupled with the cycle of nitrogen and the flow of water through forests. The supply of water for tree growth is determined by climate and soil physical properties. The rate at which nitrogen mineralization occurs depends on climate and the type of carbon compounds with which the nitrogen is associated. Species composition, which is also affected by climate, can greatly influence the composition of carbon compounds and subsequently nitrogen availability. Climate change can therefore have a direct effect on forest ecosystem production and carbon storage through temperature and water limitations, and an indirect effect through the nitrogen cycle by affecting species composition. Model simulations of these interactions show that climate change initiates a complex set of direct and indirect responses that are sensitive to the exact nature of the project climate changes. We show results using four different climate-change projections for a location in northeastern Minnesota. Modeled forest responses to each of these climate projections is different indicating that uncertainties in the climate projections may be amplified further as a result of shifts in balance between positive and negative ecosystem feedbacks.

The LINKAGES model simulates ecosystem carbon and nitrogen storage and cycling by considering the interactions between physiological processes determining individual tree growth, demographic processes determining tree-population dynamics, microbial processes determining nitrogen availability, and environmental processes determining water availability. Figure 1 is a diagram of these hypothesized relationships. LINKAGES is based on the individual tree model FORET (Shugart and West, 1977) but incorporates additional ecosystem functions of soil–water balance, litter return and decomposition along with associated nitrogen dynamics, and the effect of these on tree establishment and growth. The soil–water balance is computed using the procedures of Thornthwaite and Mather (1957). The decomposition and nitrogen dynamics is based on the theory developed by Aber and Melillo (1980, 1982a). Some aspects of the nitrogen dynamics is similar to those included in the FORTNITE model (Aber and Melillo, 1982b). A complete description of LINKAGES is given in Pastor and Post (1986). Model documentation including FORTRAN source code is available from the authors (Pastor and Post, 1985).

In the depiction of ecosystem function shown in Figure 1, soil and climate are constraints within which feedback relationships between vegetation and light availability and between vegetation and nitrogen availability operate. The feedback loop involving light availability is a negative feedback. A feedback is called negative
when it involves processes that tend to restore steady-state conditions when perturbed. For example, a perturbation that reduces net primary production (NPP) will result in a smaller canopy mass, increasing canopy light penetration, enabling the establishment of new individual trees which, in turn, increase NPP. The feedback loop in Figure 1 involving decomposition and resultant nitrogen availability introduces a positive feedback into the model of a forest ecosystem. Initial deviations, in NPP for example, are amplified by this feedback loop. Increases in NPP result in more litter production, decomposition, and available nitrogen, eventually resulting in further increases in NPP. Similarly, declines in NPP will set into play processes that result in reduced nitrogen availability and further declines in NPP.

LINKAGES assembles a forest ecosystem according to the configuration in Figure 1 by modeling the establishment, growth, and death of organisms that represent individuals from any of 72 eastern North-America species. Correlation between species properties, particularly shade tolerance, litter quality (lignin:N ratio), and drought tolerance, and the effect of these individual’s properties on population and ecosystem processes result in a complex ecosystem response to climate change at the boreal/northern-hardwood border (Post and Pastor, 1990).