

Abstract

The first part of this thesis describes the further development of a dynamic global vegetation model, LPJ, and its application to selected scientific questions. LPJ has been extended to include isotopic fractionation of ^{13}C at the leaf level during assimilation and includes a full isotopic terrestrial carbon cycle. Hence, it simulates the isotopic signature of the heterotrophic respiration fluxes. The model thus allows a quantitative analysis of the net biosphere exchange of CO_2 and $^{13}\text{CO}_2$ with the atmosphere as a function of changes in climate, land cover, atmospheric CO_2 , and the isotope ratio of CO_2 .

The extended version of LPJ has been used to study the response of the global vegetation distribution to an abrupt climate change event (Younger Dryas) and the thereby incurred changes in the terrestrial carbon pools and fluxes and their isotopic $^{13}\text{C}/^{12}\text{C}$ ratio. Climate data from a 850-year-long coupled ocean-atmosphere general circulation model (ECHAM3/LSG) is used for these simulations. The comparison of the modelled vegetation distribution and shifts during this idealized Younger Dryas event with reconstructed vegetation maps for North America and Europe based on pollen records shows a reasonable agreement. The impact of the terrestrial carbon release during the Younger Dryas on the atmospheric CO_2 and $\delta^{13}\text{C}$ is analyzed using a simplified ocean model and compared to ice core measurements. In the standard case the simulation exhibits a significant change in global total terrestrial carbon stocks of about 180 Pg C leading to an atmospheric CO_2 increase of ≈ 28 ppmv as a consequence of the climate change event. The robustness of the terrestrial signal during the Younger Dryas is studied by several sensitivity experiments concerning the initial values of the carbon pool sizes as well as the CO_2 fertilization effect and the temperature dependency of the carbon decomposition rates. The resulting increase of atmospheric CO_2 concentrations for the cold event varies between 16 to 33 ppmv among the different experiments. The simulated atmospheric $\delta^{13}\text{C}$ values which are about 0.4‰ lower during the cold phase reflect major findings from ice core measurements and are fairly robust against the sensitivity experiments.

The isotope version of LPJ has also been used to study the effects of climate variability, fire, and changes in land use on the exchange fluxes of CO_2 and $^{13}\text{CO}_2$ between the terrestrial biosphere and atmosphere for the last 100 years in greater detail. A transient, spatially explicit dataset of C_4 crops and tropical C_4 pastures has been compiled which, in combination with a land use scheme, allows the analysis of the impact of land use and C_4 cultivation on the terrestrial stable isotope composition. LPJ simulates a global mean isotopic fractionation of 17.7‰ at the leaf level with interannual variations of ca. 0.3‰ in the case without land use for the years 1950 to 1998. In this case, interannual variability in the net $^{13}\text{CO}_2$ flux between atmosphere and terrestrial biosphere is of the order of 15 Pg C ‰ yr $^{-1}$. It is reduced to 4 Pg C ‰ yr $^{-1}$ if the leaf-level fractionation factor is held constant at the long term mean. Depending on the chosen

land use scheme modelled values of leaf discrimination vary between 17.9‰ and 17.0‰ with results from the experiment specifying C₄ crops and C₄ pastures being the lowest. Modelled values of isotopic disequilibrium similarly depend on the amount of prescribed C₄ vegetation (crops and pastures) and vary between 37.9 Pg C ‰ yr⁻¹ and 23.9 Pg C ‰ yr⁻¹ averaged over the years 1985 to 1995. In addition, the effect of fire on the isotopic disequilibrium has been estimated to lead to a reduction of ≈10 Pg C ‰ yr⁻¹.

The second part of the thesis describes the construction and application of a terrestrial Carbon Cycle Data Assimilation System (CCDAS). In the assimilation step parameters of a terrestrial biosphere model, BETHY, are constrained subject to observations. The technique is demonstrated by using atmospheric CO₂ concentration observations from 1979 to 1999 and satellite remote sensing data (identifying vegetation activity) for the years 1989 and 1990 to optimize the tunable parameters in the model (some spatially explicit, some global) and also give an estimate of their uncertainties. Quantities (global and spatially explicit carbon fluxes) derived from the prognostic step of CCDAS are then analyzed with respect to climate anomalies. Processes responsible for the mean terrestrial fluxes and their variability are identified. A highly significant correlation between El Nino/Southern Oscillation and terrestrial CO₂ fluxes, with CO₂ lagging by a few months was found. Net CO₂ outgassing during El Nino events is caused mainly by reduction of photosynthesis in large parts of the tropics, notably the Amazon basin and Central Africa. The most important deviation of this pattern is found after the eruption of Mount Pinatubo in 1991.