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Comparing global models of terrestrial net primary productivity (NPP): introduction

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Improving the knowledge about broad-scale fluxes of carbon between the atmosphere and the biosphere is high on the scientific agenda for at least two reasons. First, productivity is fundamental to ecology. While it has been a central focus over the last three decades, beginning with the International Biological Programme (IBP) and continuing through the International Geosphere-Biosphere Programme (IGBP), there was, until recently, remarkably little progress in estimating productivity, or the carbon balance of large regions. Second, large-scale fluxes of CO_2 between the land and the atmosphere are increasingly relevant to policy, because carbon storage by land ecosystems can play an important role in limiting the rate of atmospheric increases (IGBP Terrestrial Carbon Working Group 1998).

Computer models have now gained broad acceptance for translating ecological hypotheses, derived from local observations, into estimates of regional, continental or even global outcomes of ecosystem processes. Indeed, such models are perhaps the only feasible method to make spatially detailed estimates for large regions. Such models are rather useless, however, if their behaviour cannot be evaluated. Ideally, productivity models should be evaluated based on comparions with observations. This creates a dilemma, however, for global fluxes such as net primary productivity (NPP). Direct observations of NPP are not available at the global scale, and direct validation is therefore not feasible. Model intercomparisons provide additional options for studying the behaviour of the models. Clear protocols, common data sets, and standardized output can help to ensure that results are comparable. Once a data base of model results has been created, it becomes possible to investiate specific features of the behaviour of participating models, including supporting or discarding some of the assumptions.

Under the scientific sponsorship of the IGBP, such a model intercomparison has been carried out at the Potsdam Institute for Climate Impact Research. Seventeen terrestrial biosphere models (TBMs) participated in a study with common protocols, goals, and input data summarized in the overview paper by Cramer *et al.* (pp. 1–15). The models all simulate NPP of the land biosphere for an average year, with calculations based on a broad range of structures, complexity, and driving data. One of the key differences is that some of the models use satellite data (especially AVHRR data from the NOAA weather satellites), while others use data on climte and soils alone. It was not unexpected that no two models gave identical results. Still, all models agreed on basic features of the biosphere, such as low productivity in dry and/or cold regions and high productivity in humid tropical forests. Given the sparse and incomplete database of NPP observations, no model stood out as the 'winner'. The benefits of the project, many of which are reported in the seven papers of this issue, are deeper but also richer than finding a single best model.

First, practically all modelling teams experienced 'surprises' during the intercomparison, many of which led them to reconsider specific aspects of the models. Improvements based on these reconsiderations did not emerge early enough in the comparison process for them to affect the simulations in the papers here. But opportunities for improvements were apparent to most workshop participants, and we postulate that they have indeed boosted the overall understanding of the terrestrial biosphere. Second, the analysis of Kicklighter *et al.* (pp. 16–24) identifies the geographical regions with good model agreement as opposed to those with significant differences (particularly boreal forests in summer and tropical evergreen forests in the dry season). This has direct implications for uncertainties in specific processes represented by the models. The paper by Schloss *et al.* (pp. 25–34) goes further by pointing out that NPP estimates are usually in closer agreement for regions where temperature is the main controlling variable. Water shortage over a significant part of the season introduces additional uncertainty, a phenomenon analysed more in depth by Churkina *et al.* (p. 46–55).

Both Kicklighter *et al.* and Schloss *et al.* stress that model performance is critically affected by the description of vegetation *structure* and whether that description comes from a map or is calculated by the model. The analysis by Bondeau *et al.* (p. 35–45) expands on this by comparing canopy changes through a given year against

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satellite observations. Not only the seasonal leaf development (phenology), but also the resulting productivities are different in different models. Summergreen phenologies (driven by temperature) were generally well-reproduced, while raingreen phenologies appeared uncertain in some models. The resulting annual NPP estimates seemed sometimes to be adjusted by other factors in the model, such as to produce a high difference in seasonality and less of a difference for the annual total.

Early models of land productivity did not explicitly recognize the importance of solar radiation for photosynthesis. The development of mechanistic photosynthesis formulations, such as that from the now widely used model of Farquhar *et al.* (1980) has changed this significantly. The sensitivity of NPP to absorbed photosynthetically active radiation (APAR) still differs among models, due primarily to variation in the formulation of light use efficiency; see Ruimy *et al.* (p. 56–64). Ruimy *et al.* conclude that a suitable APAR data set is sufficient to generate plausible geographical patterning of NPP, but that absolute values still require at least limited calibration against observations. Direct 'validation' of TBMs is not possible. An independent data set for constraining calculated fluxes exists through the sampling of atmospheric CO_2 concentrations at monitoring stations throughout the world. Nemry *et al.* (p. 65–76) analyse eight models that provide both NPP and heterotrophic respiration (R_H), focusing on the ability of each model to reproduce the seasonal fluxes at these stations (using estimated ocean and fossil fuel carbon fluxes, and an atmospheric transport model). Their analysis shows that uncertainty is largest in the southern hemisphere and still considerable in the tropics, probably due to limits in our ability to simulate limitations to NPP due to water balance.

Overall, the comparison documents significant progress in our understanding of productivity of the land biosphere: many basic features known from observations are accurately reproduced and, perhaps more importantly, we know where to improve the models further. The results of this comparison may not immediately and directly enhance the second goal, i.e. assisting the policy-making process related to global change. Specifically, this activity *identified*, rather than narrowed critical uncertainties. But this should not be interpreted as a failure for the scientific or the political process: only through analysis of the shortcomings in our current predictive capacities can we find better guidance for future research effors. At the heart of these are enhanced experimental and monitoring systems (flux measurements, satellite sensors, field and laboratory experiments, global data archives) which are being identified by every single paper in this collection as being important for better parameterization of terrestrial biosphere models.

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