

What are the most important factors for climate—carbon cycle coupling?

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Abstract: The mechanisms that drive changes in ecosystem carbon balance in response to climate change are evaluated using data from long-term measurements of CO₂ fluxes, environmental parameters, and ecological factors in boreal, mid-latitude and tropical ecosystems. We find that most model parameterizations overestimate the temperature sensitivity of ecosystem respiration and underestimate the role of soil water balance in controlling respiration and flammability. We conclude that models of climate—carbon feedbacks must carefully simulate regional precipitation, evaporation, evapotranspiration, and water balance, including factors leading to fires (e.g. sources of ignition), in addition to assessing changes in temperature. Covariances among these drivers of ecosystem change, along with the severity and frequency of extreme events, may also be critically important for understanding coupling between ecosystems and climate.

Extended Abstract:

Introduction

Climate change could be accelerated by positive feedback between climate warming and release of CO₂ from major ecosystems, but model simulations predict a very wide range of sensitivities to rising temperature [Cox *et al.*, 2003]. Here we use data from long-term eddy flux measurements in boreal Canada, New England, and Amazônia, to assess the responses of ecosystem carbon balance and vegetation structure to changes in temperature and precipitation.

Figure 1 shows the simulation of monthly respiration (R) by a leading ecosystem model [IBIS, Kucharik *et al.*, 2000] driven by meteorological data from Harvard Forest (Massachusetts). IBIS treats carbon allocation by plants and heterotrophic respiration using parameterizations derived from ecosystem observations, and annual mean respiration is accurately computed. But model R is significantly too low in cold seasons and too high in warm seasons, and the temperature sensitivity on annual time scales is markedly overestimated. It appears that this error may arise from conflating seasonal changes in ecosystem component activities with the temperature dependence of basic metabolic processes, and with overly simple treatments of soil energy budgets and snow cover.

Figure 2 illustrates the important role of water table variations in the carbon budget of boreal peatlands in Manitoba [Dunn *et al.*, 2005]. The observed respiration of the forest-bog-fen mosaic (45%, 45%, 10%, of land cover, respectively) depends sensitively on both water table depth and on temperature of the thawed, unsaturated zone; a simple model of ecosystem R using these factors accounted for ~82% of the daily variance, more than half due to water table fluctuations. These results help explain why this system switched from a source to a sink for carbon between 1994 and 2004: the effect of rising temperatures was offset by increased rainfall and higher water tables in recent years. Ecosystem water balance is also critical in determining long-term carbon budgets, as water tables control the depth of peat burned in boreal fires.

Finally we consider the factors that appear to regulate the transition between equatorial evergreen forest and cerrado in Amazônia. Using tower flux data [Saleska *et al.*, 2003] for evapotranspiration, we developed an empirical model of soil water balance and combined it with the CRU climate reconstruction [Mitchell *et al.*, 2003]. The results indicate that the current distribution of forest is bounded by a climatic conditions, with forest unlikely to persist were there are several severe droughts occur per decade (Fig. 3). It appears that high-order statistical properties of the precipitation, and covariance between precipitation and temperature, (e.g. occurrence of sequential drying events) are important parameters for the vegetation transition and for regeneration after stand clearing for agriculture or logging.

References

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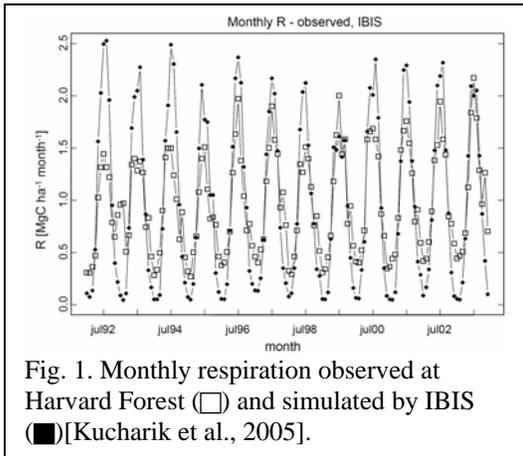


Fig. 1. Monthly respiration observed at Harvard Forest (\square) and simulated by IBIS (\blacksquare) [Kucharik *et al.*, 2005].

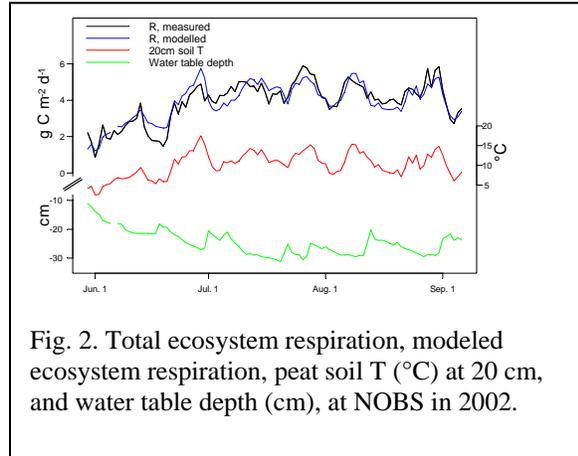


Fig. 2. Total ecosystem respiration, modeled ecosystem respiration, peat soil T ($^{\circ}$ C) at 20 cm, and water table depth (cm), at NOBS in 2002.

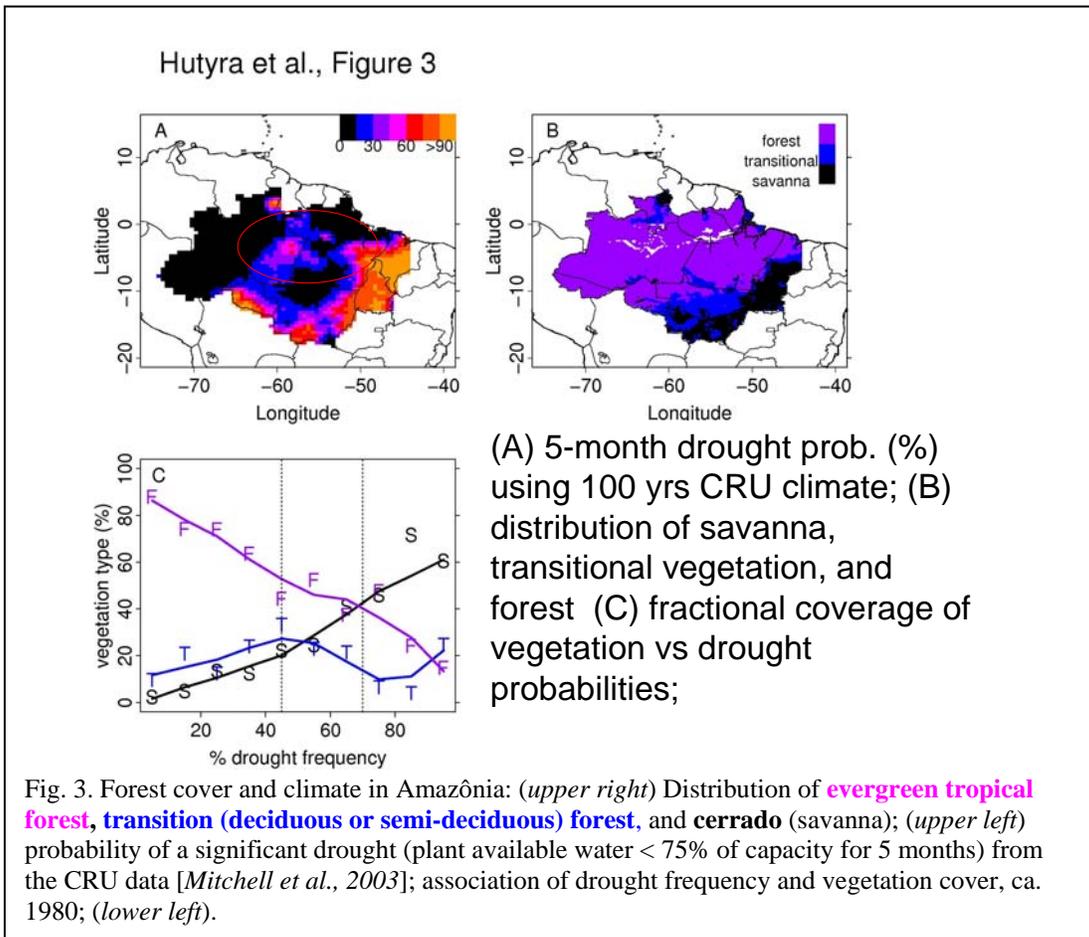


Fig. 3. Forest cover and climate in Amazônia: (*upper right*) Distribution of **evergreen tropical forest**, **transition (deciduous or semi-deciduous) forest**, and **cerrado** (savanna); (*upper left*) probability of a significant drought (plant available water < 75% of capacity for 5 months) from the CRU data [Mitchell *et al.*, 2003]; association of drought frequency and vegetation cover, ca. 1980; (*lower left*).