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Assessing carbon dynamics in Amazonia with the Dynamic Global Vegetation Model LPJmL – discharge evaluation

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Introduction

The Amazon Basin covers an area of approximately 6 million km^2 and plays a vital role in global water and carbon cycles (Schlesinger & Melack 1981, Brown et al. 1993, Meybeck 1993, Andreae et al. 2002). The Amazon River discharges nearly 15% of the earth´s fresh water (Gaillardet et al. 1997).

In this huge system the transport and the retention of dissolved and particulate carbon are influenced by climatic variations (e.g. El Niño) and climate change (Aalto et al. 2003, Lewis et al. 2004, Schoengart et al. 2004) as well as local and regional land use management (Fearnside & Barbosa 1998, Bernardes et al. 2004, Thomas et al. 2004). The main components of the carbon flow through Amazonia are net ecosystem productivity in terrestrial ecosystems (affected by climate, CO_2, and land use), transformation of organic matter in the terrestrial and the aquatic ecosystem, and net export of carbon from land to river water body (affected by litter production, erosion, and flooding regime) (Fearnside 1997, Hedges et al. 2000, Waterloo et al. 2006).

A substantial, globally significant carbon flow exists between the atmosphere, land ecosystems, and aquatic ecosystems in the Amazon basin, probably leading to a major, yet poorly constrained carbon export to the Tropical Atlantic. One estimate of the annual export of carbon to the ocean is 40 Tg C/yr (Moreira-Turcq et al. 2003). The total basin evasion has been estimated to be as much as 470 Tg C/yr (Richey et al. 2002).

To understand the complex interactions between land, river, climate change, and land use change, we use the dynamic global vegetation model LPJmL, a terrestrial biosphere model (Sitch et al. 2003, Bondeau et al. 2007). For our purpose, we modify the model and link the terrestrial processes with a hydrological runoff model to include the riverine fluxes. This enables us to assess the influence of changes in land use and climate on regional and global carbon fluxes.

Key words: Amazon, dynamic global vegetation model, riverine carbon fluxes~~,~~

Study site

The simulated Amazon basin is enclosed by coordinates 4.75°N to 20.25°S and 50.25°W to 79.25°W. This geographical dimension is defined by a hydrological runoff model (Jachner et al. in press) and corresponds with published data (Birkett et al. 2002, Coe et al. 2002). Amazonia is characterized by annual flooding, mainly driven by precipitation (Schoengart et al. 2004). During the high-water stage from March to June, the river rises up to 15 m (Junk & Weber 1996), connecting the riverine and terrestrial system.

Methods

We use LPJmL, a process-based dynamic global vegetation and hydrology model. It simulates growth, abundance, and population dynamics of natural vegetation and agricultural crops at a resolution of 0.5° (latitude/longitude).

The simulations were driven by monthly climate data (mean temperature, precipitation, number of wet days, sunshine hours) based on CRU05 (New et al. 2000, Österle et al. 2003). Soil texture data as well as atmospheric CO_2 concentration were used, as in Sitch et al. (2003).

The model was brought into equilibrium by running 1000 years of spin-up, followed by the transient simulation from 1901 to 2003. The hydrology model was adjusted for the Amazon with a velocity of 0.25 m/s, a value in the dimension of published data (Birkett et al. 2002, Hu et al. 2004). We compared the simulated and the observed discharge at 3 gauging stations in the Amazon basin using data from the 'River Discharge Database' (SAGE). The only stations in the Amazon Basin are Alta Mira at the Rio Xingu (3.25°S; 52.25°W; years 1976–1979), Porto Velho at the Rio Madeira (8.75°S; 63.75°W; years 1969–1979), and Obidos at the mainstem of the Rio Amazon (1.75°S; 1.75°W; years 1971–1983). Our comparison used the simulated data from years for which we had observed data for each site.

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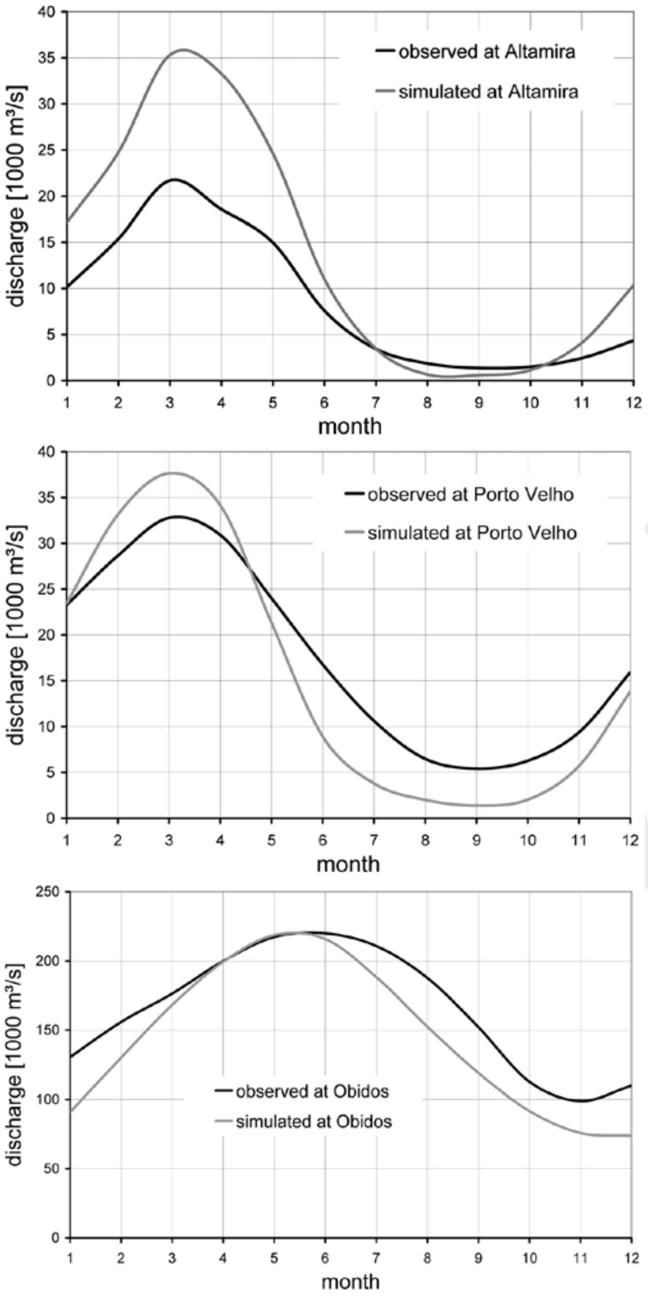

Fig. 1. Comparison of observed and simulated monthly discharge at Altamira (a), Porto Velho (b), and Obidos (c).

Results

We compared the annual and monthly discharge at the 3 stations (Fig. 1).

Alta Mira: The annual total simulated discharge is 1.63 ± 0.11 times the observed discharge. Both simulated and observed high water peaks are in March. The simulated high water discharge is 1.63 times the observed discharge.

Porto Velho: The annual total simulated discharge is 0.90 ± 0.12 times the observed discharge. Both high water peaks are in March and the simulated discharge in March is 1.15 times the observed discharge.

Obidos: The annual total simulated discharge is 0.88 ± 0.06 times the observed. The observed high water peak is in June, but the simulated peak is in May. The simulated discharge at the high water peak is 0.99 times the observed discharge.

For all stations the annual total simulated discharge is 1.00 ± 0.28 times the observed, and the simulated high water discharge is 1.26 ± 0.33 times the observed.

Discussion

Our purpose is to understand the carbon fluxes in the Amazon basin, including fluxes between the terrestrial and the riverine part. Therefore, it is of special importance to reproduce the seasonal dynamics and the height of flooding.

The differences between the annual discharge for all station is very low. Our intention was to optimize the annual discharge, and therefore we had to accept the differences in discharge during the high water peak (factor ranging from 0.99 to 1.63). The differences in the time of high water peak for Obidos between the simulated (May) and the observed (June) data can be explained be the nature of the data. Both datasets are monthly data. A weekly resolution (for which no data are available) could indicate a peak between May and June and would thereby support our findings.

The high water peak in Altamira and Porto Velho is simulated earlier than the peak in Obidos. This matches the observed pattern where the tributary discharge is out of phase with the mainstem (Richey et al. 1986).

Our results support that LPJmL can reproduce the pattern and can therefore be applied to riverine carbon flux modelling. Prospective results of LPJmL can include prognosis of the "tipping point" in Amazonia (Schellnhuber et al. 2005).

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References

Aalto, R., L. Maurice-Bourgoin, T. Dunne, D.R. Montgomery, C.A. Nittrouer & J.L. Guyot. 2003. Episodic sediment accumulation on Amazonian flood plains influenced by El Niño/Southern Oscillation. Nature **425**: 493–497.

Andreae, M.O., P. Artaxo, C. Brandao, F.E. Carswell, P. Ciccioli, A.L. da Costa, A.D. Culf, J.L. Esteves, J.H.C. Gash, J. Grace, P. Kabat, J. Lelieveld, Y. Malhi, A.O. Manzi, F. X. Meixner, A.D. Nobre, C. Nobre, M. Ruivo, M.A. Silva-Dias, P. Stefani, R. Valentini, J. von Jouanne & M.J. Waterloo. 2002. Biogeochemical cycling of carbon, water, energy, trace gases, and aerosols in Amazonia: The LBA-EUSTACH experiments. J. Geophys. Res. (Atmospheres) **107**(D20).

Bernardes, M.C., L.A. Martinelli, A.V. Krusche, J. Gudeman, M. Moreira, R.L. Victoria, J.P.H.B. Ometto, M.V.R. Ballester, A.K. Aufdenkampe, J.E. Richey & J.I. Hedges. 2004. Riverine organic matter composition as a function of land use changes, Southwest Amazon. Ecol. Appl. **14**: S263–S279.

Birkett, C.M., L.A.K. Mertes, T. Dunne, M.H. Costa & M.J. Jasinski. 2002. Surface water dynamics in the Amazon Basin: Application of satellite radar altimetry. J. Geophys. Res. (Atmospheres) **107**(D20).

Bondeau, A., P.C. Smith, S. Zaehle, S. Schaphoff, W. Lucht, W. Cramer & D. Gerten. 2007. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. Global Change Biol. **13**: 679–706.

Brown, S., C.A.S. Hall, W. Knabe, J. Raich, M.C. Trexler & P. Woomer. 1993. Tropical Forests - Their Past, Present, and Potential Future-Role in the Terrestrial Carbon Budget. Water Air Soil Pollut. **70**: 71–94.

Coe, M.T., M.H. Costa, A. Botta & C. Birkett. 2002. Long-term simulations of discharge and floods in the Amazon Basin. J. Geophys. Res. (Atmospheres) **107**(D20).

Fearnside, P.M. 1997. Greenhouse gases from deforestation in Brazilian Amazonia: Net committed emissions. Climatic Change **35**: 321–360.

Fearnside, P.M. & R.I. Barbosa. 1998. Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. For. Ecol. Manag. **108**: 147–166.

Gaillardet, J., B. Dupre, C.J. Allegre & P. Negrel. 1997. Chemical and physical denudation in the Amazon River basin. Chem. Geol. **142**: 141–173.

Hedges, J.I., E. Mayorga, E. Tsamakis, M.E. McClain, A. Aufdenkampe, P. Quay, J.E. Richey, R. Benner, S. Opsahl, B. Black, T. Pimentel, J. Quintanilla & L. Maurice. 2000. Organic matter in Bolivian tributaries of the Amazon River: A comparison to the lower mainstream. Limnol. Oceanogr. **45**: 1449–1466.

Hu, C.M., E.T. Montgomery, R.W. Schmitt & F.E. Muller-Karger. 2004. The dispersal of the Amazon and Orinoco River water in the tropical Atlantic and Caribbean Sea: Observation from space and S-PALACE floats. Deep-Sea Res. (II Top. Stud. Oceanogr.) **51**: 1151–1171.

Jachner, S., D. Gerten, A. Bondeau, W. Lucht, J. Rohwer & S. Schaphoff. In press. Agricultural green and blue water consumption and its influence on the global water system. Water Resour. Res.

Junk, W.J. & G.E. Weber. 1996. Amazonian floodplains: A limnological perspective. Verh. Internat. Verein. Limnol. **26**: 149–157.

Lewis, S.L., Y. Malhi & O.L. Phillips. 2004. Fingerprinting the impacts of global change on tropical forests. Philos. Trans. R. Soc. Lond. (B Biol. Sci.) **359**: 437–462.

Meybeck, M. 1993. Riverine transport of atmospheric carbon-sources, global typology and budget. Water Air Soil Pollut. **70**: 443–463.

Moreira-Turcq, P., P. Seyler, J.L. Guyot & H. Etcheber. 2003. Exportation of organic carbon from the Amazon River and its main tributaries. Hydrol. Process. **17**: 1329–1344.

New, M., M. Hulme & P. Jones. 2000. Representing 20th century space-time climate variability. Part II: Development of 1901–96 monthly grids of terrestrial surface climate. J. Clim. **13**: 2217–2238.

Österle, H., F.W. Gerstengarbe & P.C. Werner. 2003. Homogenisierung und Aktualisierung des Klimadatensatzes des Climate Research Unit der Universitaet of East Anglia, Norwich. 6. Deutsche Klimatagung 2003 Potsdam, Germany. Terra Nostra 2003/**6**: 326–329 (in German).

Richey, J.E., R.H. Meade, E. Salati, A.H. Devol, C.F. Nordin & U. Dossantos. 1986. Water discharge and suspended sediment concentrations in the Amazon River 1982–1984. Water Resour. Res. **22**: 756–764.

Richey, J.E., J.M. Melack, A.K. Aufdenkampe, V.M. Ballester & L.L. Hess. 2002. Outgassing from Amazonian rivers and wetlands as a large tropical source of atmospheric CO_2. Nature **416**: 617–620.

[SAGE] Center for Sustainability and the Global Environment. 2007. http://www.sage.wisc.edu/riverdata. Accessed 31 July 2007.

Schellnhuber, H.J., P.J. Crutzen, W.C. Clark & J. Hunt. 2005. Earth system analysis for sustainability. Environment **47**: 10–25.

Schlesinger, W.H. & J.M. Melack. 1981. Transport of organic-carbon in the worlds rivers. Tellus **33**: 172–187.

Schoengart, J., W.J. Junk, M.T.F. Piedade, J.M. Ayres, A. Huttermann & M. Worbes. 2004. Teleconnection between tree growth in the Amazonian floodplains and the El Niño-Southern Oscillation effect. Glob. Change Biol. **10**: 683–692.

Sitch, S., B. Smith, I.C. Prentice, A. Arneth, A. Bondeau, W. Cramer, J.O. Kaplan, S. Levis, W. Lucht, M.T. Sykes, K. Thonicke & S. Venevsky. 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Glob. Change Biol. **9**: 161–185.

Thomas, S., C. Neill, L.A. Deegan, A. Krusche, V. Ballester & R. Victoria. 2004. Influences of land use and stream size on particulate and dissolved materials in a small Amazonian stream network. Biogeochemistry **68**: 135–151.

Waterloo, M.J., S.M. Oliveira, D.P. Drucker, A.D. Nobre, L.A. Cuartas, M.G. Hodnett, I. Langedijk, W.W.P. Jans, J. Tomasella, A.C. de Araujo, T.P. Pimentel & J.C.M. Estrada. 2006. Export of organic carbon in run-off from an Amazonian rainforest blackwater catchment. Hydrol. Process. **20**: 2581–2597.

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