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Variation of the isotopic composition of dissolved organic carbon during the runoff cycle in the Amazon River and the floodplains

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ABSTRACT

Given the relative scarcity of stable isotope data on dissolved organic carbon (DOC) in the Amazon Basin, we hypothesized that the variability in DOC sources may be underestimated in such major river basins. To explore the links between the mainstem and tributaries and the floodplain, particular efforts were made during five distinct cruises at different stages of the hydrograph between October 2008 and January 2011, to document the spatial and temporal variation of DOC concentrations and δ^{13}C-DOC in the central Amazon River system (Brazil). Based on more than 200 data, the spatial and temporal variability of δ^{13}C-DOC values was found to be larger than previously reported in the same area. Although a small range of variation was observed throughout the hydrological cycle in the upper reach of the studied section (−29.2 to −29.5‰ in the Rio Negro and −28.7 to −29.0‰ in the Rio Solimões), a much larger one (−28.0 to −34.6‰) was found in the lower reach of the river, as the proportion of open lakes increased downstream in the floodplains. The low variability in the upper reaches suggests constant and homogeneous DOC sources from upland soils and flooded forest, while lower δ^{13}C-DOC values recorded in the lower reach mainstem at high and falling waters can be attributed to a greater export of plankton-derived ^{13}C-depleted DOC from flooded lakes. Noteworthy are the higher δ^{13}C-DOC values measured in the Rio Madeira and the associated flooded lakes (−26.5 to −28.8‰), which may reflect the imprint from upland headwaters and a weaker density of flooded forest in the watershed. The higher δ^{13}C-DOC values observed in the lower reach during low waters are still not fully understood.

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Floating meadows principally consisting of C_4 macrophytes were found to increase δ^{13}C-DOC values by ~1.5‰ in their vicinity, but this impact was no longer noticeable at distances of ~10 m from the plant rafts. This rather modest ^{13}C-enrichment suggests rapid decomposition and/or dilution of this wetland-derived DOC.

1. Introduction

Our understanding of the driving forces of carbon fluxes in the Amazon River needs to be improved to better explain CO_2 outgassing pathways (Abril et al., 2014; Richey et al., 2002). Stable isotope data are powerful tools to constrain the sources of respired carbon from upland soils, flooded forest C_3 plants, macrophyte C_4 plants, and phytoplankton, but the majority of δ^{13}C data were measured on either dissolved inorganic carbon (DIC) or particulate organic carbon (POC) (Ellis et al., 2012; Mayorga et al., 2005; Moreira-Turcq et al., 2013; Mortillaro et al., 2011; Quay et al., 1992). In existing data, δ^{13}C-DOC values are generally slightly lower than δ^{13}C-POC values, and natural variation seemed limited (Aufdenkampe et al., 2007; Ellis et al., 2012; Hedges et al., 1994; Mayorga et al., 2005). Limited natural variations in δ^{13}C-DOC compared to δ^{13}C-POC may be consistent with a limited contribution of in situ aquatic primary production and the advanced degradation status of the river-transported dissolved organic matter pool (Hedges et al., 1994; Quay et al., 1992), which is also generally more recent in origin (Marwick et al., 2015; Mayorga et al., 2005). The aim of this study was to test if the variability in natural DOC sources is not underestimated due to the relative scarcity of DOC stable isotope data for the middle Amazon Basin reach, with the risk to incorrectly identify the carbon flux sources at the level of water–mass exchanges in the floodplain or to underestimate specific (production/transformation) mechanisms. Thus, particular efforts were made to document the spatial and temporal variation of DOC concentrations and δ^{13}C-DOC in the central Amazon River, to explore the links between the mainstem, tributaries, and the floodplain. We used a detailed spatial and temporal sampling strategy to describe how DOC from various potential sources might be transported in the river in relation with the flood pulse. We also take advantage of a river section located along a floodplain gradient to document potential contrasts between upland soils, C_3 and C_4 wetland sources, and phytoplankton.

2. Material and methods

2.1. Field campaign and sampling

Water samples were collected on a ~800-km transect along the lower Amazon River basin from Manacapuru on the Solimões River, to Santarem at the mouth of the Tapajós River, located in a gradient of decreasing flooded forest area and increasing open lake area (Fig. 1). The three characteristic types of water found in the Amazon (Sioli, 1984) were sampled in the mainstem and tributaries: the "white waters" characterized by high levels of suspended sediments, high nutrient concentrations, and high conductivity in the Solimões and Madeira rivers, the two main tributaries of the Amazon River flowing from the Andes; the "black waters" with low conductivities in the Manacapuru and Negro rivers draining the lowest Amazonian forest dominated by podzol soils and intensely colored by humic organic matter; the organic poor "clear waters" with low suspended sediment concentrations, and low conductivity and nutrient concentrations in the Tapajós, Urubu, and Trombetas. We also sampled five floodplains along the gradient from flooded forest to open lakes. Upstream, the Várzea of Cabaliana and Janauacá receive large inputs of white waters from the Solimões River and are surrounded by large areas of flooded forest (Fig. 1). In the middle region of the Amazon River, we sampled two floodplain lakes just downstream of the Amazon–Madeira confluence (Fig. 1), Lakes Canaçari and Miratuba, mainly receiving white water from the flooding of the Amazon and Madeira Rivers. Lake Miratuba, receiving Madeira's waters from the south through a network of small channels, is surrounded by large flooded forests and dries up substantially (a 70% decrease in surface area) during the low waters. This is not the case in Lake Canaçari, which is a very homogeneous lake, connected to small flooded forests and which does not dry up by more than 20% at low water (Fig. 1). Canaçari mainly receives white waters from the Amazon, as the clear waters from the Urubu River that drains the northern local basin are by-passed to the north and rarely enter the lake. Finally, in the most downstream part of the studied area (Fig. 1), the Várzea of Curuaí is composed of more than 30 interconnected lakes of mostly white water temporally or permanently connected to the Amazon mainstem by small channels (Bonnet et al., 2008; Hess et al., 2003). Moreover, the Várzea of Curuaí is not strongly connected to flooded forests, most of the floodplain consisting of open lakes (Fig. 1).

Sampling for DOC and δ^{13}C-DOC was performed during five cruises at different stages of the hydrograph (Fig. 2). The low-water (LW) season was sampled in October 2008 and October 2009, the rising water (RW) season was sampled in January–February 2011, the high-water (HW) season in June–July 2009, and the falling water (FW) season in August–September 2010. During 2009, the lowest water stage was delayed, thus the October cruise sampled the second part of the falling period. For the more downstream stations, the end of this period shows water