Inundation and sediment dispersion on a natural floodplain along the Rio Beni, Bolivian Amazon

Inondation et dispersion des sédiments dans une plaine inondable naturelle le long du Rio Beni, en Amazonie Bolivienne

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RÉSUMÉ

La stratigraphie et le fonctionnement hydro-écologique des plaines inondables naturelles sont conditionnés par des processus érosifs et sédimentaires, prenant en compte l'érosion des berges, la sédimentation sur les berges lors des crues et le comblement des méandres abandonnés. La forte hétérogénéité spatiale des dépôts en termes de taille et d'âge des grains, et les schémas de végétation et de topographie, cette dernière souvent masquée par de vastes forêts, constituent un contexte difficile pour la modélisation de l'inondation et du dépôt des sédiments en suspension. Cependant, la pression croissante exercée sur ces plaines inondables par l'agriculture et les installations humaines exige des informations détaillées afin de guider ces développements. Cette étude présente un modèle hydraulique qui permet de simuler l'étendue et la profondeur de l'inondation ainsi que la concentration de sédiments en suspension dans le bassin versant du très dynamique Rio Beni en Amazonie Bolivienne pendant une saison des inondations. Les résultats du modèle s'ajustent bien avec l'étendue de l'inondation dérivée de l'imagerie satellitaire durant la saison des crues de 2011, et pourrait être utilisé dans des études à long terme sur l'évolution des plaines inondables lorsque la migration des méandres est prise en compte.

ABSTRACT

Stratigraphy and hydro-ecological functioning of natural floodplains are conditioned by erosional and sedimentary processes, including bank erosion, overbank sedimentation during floods and the fill of abandoned meanders. The high spatial heterogeneity of deposits in terms of grain size and age, and the resulting vegetation patterns and topography, the latter often masked by extensive forests, are a challenging environment for the modelling of inundation and dispersion of suspended sediment. However, the increasing pressure on these floodplains from agriculture and settlement require detailed information in order to guide these developments. This study presents an hydraulic model that allows the simulation of the extent and depth of inundation as well as the suspendend sediment concentration in the foreland basin of the highly dynamic Rio Beni in the Bolivian Amazon during a flood season. The model compares well with the extent of inundation derived from satellite imagery during the 2011 flood season and has potential to be used in long-term studies of floodplain evolution when meander migration is taken into account.

KEYWORDS

floodplain sedimentation, hydraulic model, inundation model, overbank flow, sediment dispersion

1 EXTENDED ABSTRACT

The evolution of natural floodplains is a function of sedimentary processes such as the infill of abandoned channels, formation of splays and overbank sedimentation, and erosional processes. The latter include erosion on the floodplain by overland flows and bank erosion driven by meander bend migration. However, these types of processes are not decoupled from each other and cannot be considered in isolation. Infill of abandoned channels and overbank sedimentation create a complex floodplain stratigraphy with spatial variation in deposit age, grain size and organic carbon content. This heterogeneity in deposit characteristics leads to spatial variability in resistance to bank erosion and hydraulic connectivity between channel and floodplain which influences channel migration and thus planform development (Schwendel et al., 2015; Lewin et al., 2017)). The interaction between erosion and deposition is also a key control on channel capacity, flood conveyance and avulsion.

Understanding the spatial distribution of these deposit properties and the feedback on channel migration is a key to understanding floodplain evolution which, in the long-term has implications for the development of hydrocarbon reservoirs and channel belt avulsion. In the shorter term it provides insights into channel planform development, channel avulsion and ecological functioning of the river-floodplain complex. An improved understanding of floodplain evolution also facilitates prediction of flood frequency, extent of floodplain inundation and distribution of sediment and associated carbon, nutrients and pollutants on the floodplain.

Floodplains are a preferential setting for human settlements for various reasons, including suitable topography, nutrient-rich soils, supply of water and food, and river navigation. As such even the remotest floodplains have been settled by humans for millennia. However, with increasing population figures and technological advances the population pressure on quasi-unmodified floodplains has increased dramatically in recent decades. This study draws on the example of the Rio Beni in the Bolivian Amazon (Fig. 1a) where numerous villages have been set up along the river in the last 30 years and increasing area of floodplain is converted from forest to farmland. The success of these ventures is affected by flooding and channel migration which has forced sudden relocation of settlements and abandonment of previously cleared farmland. Understanding the interplay between floodplain sedimentation and channel migration may allow avoidance of inconvenience to humans and the preservation of some of the ecological functioning of the river-floodplain complex by guiding future development.

This study investigates channel migration patterns of the meandering, sand-bed Rio Beni (Fig. 1a) and relates them to floodplain sedimentation, in particular the deposition of suspended sediment during floods and the infill of abandoned channels. Overbank deposition, and channel migration are assessed at a meander bend scale and inundation and sediments dispersal are modelled for the entire foreland basin. Planform geometry is analysed over a 55 year period based on GIS analysis of aerial and satellite imagery (Schwendel et al., 2015). The spatial distribution, extent and age of overbank sediments were assessed at 18 meander bends and throughout the foreland basin from soil cores which underwent ^{210}Pb chronology. This allowed the calculation of sedimentation rates and the detection of episodical or continuous deposition. These shallow depth cores were complemented at one bend by three electrical resistivity transects that allowed characterisation of stratigraphy and grain size across a point bar and an abandoned channel. This information was fed into a combined 1D and 2D hydraulic model which uses a finite volume approach to solve the shallow water equations in order to simulate floodplain inundation (Fig. 1b). It includes the effect of local precipitation as this is an important influence on floodplain hydraulics at the Rio Beni (Aalto et al., 2003). This model was coupled with an advection diffusion model to predict dispersal of sand, silt and clay fractions across the floodplain (Fig. 1c). The inundation model exhibited a high level of maximal fit compared to inundation extent derived from satellite imagery.

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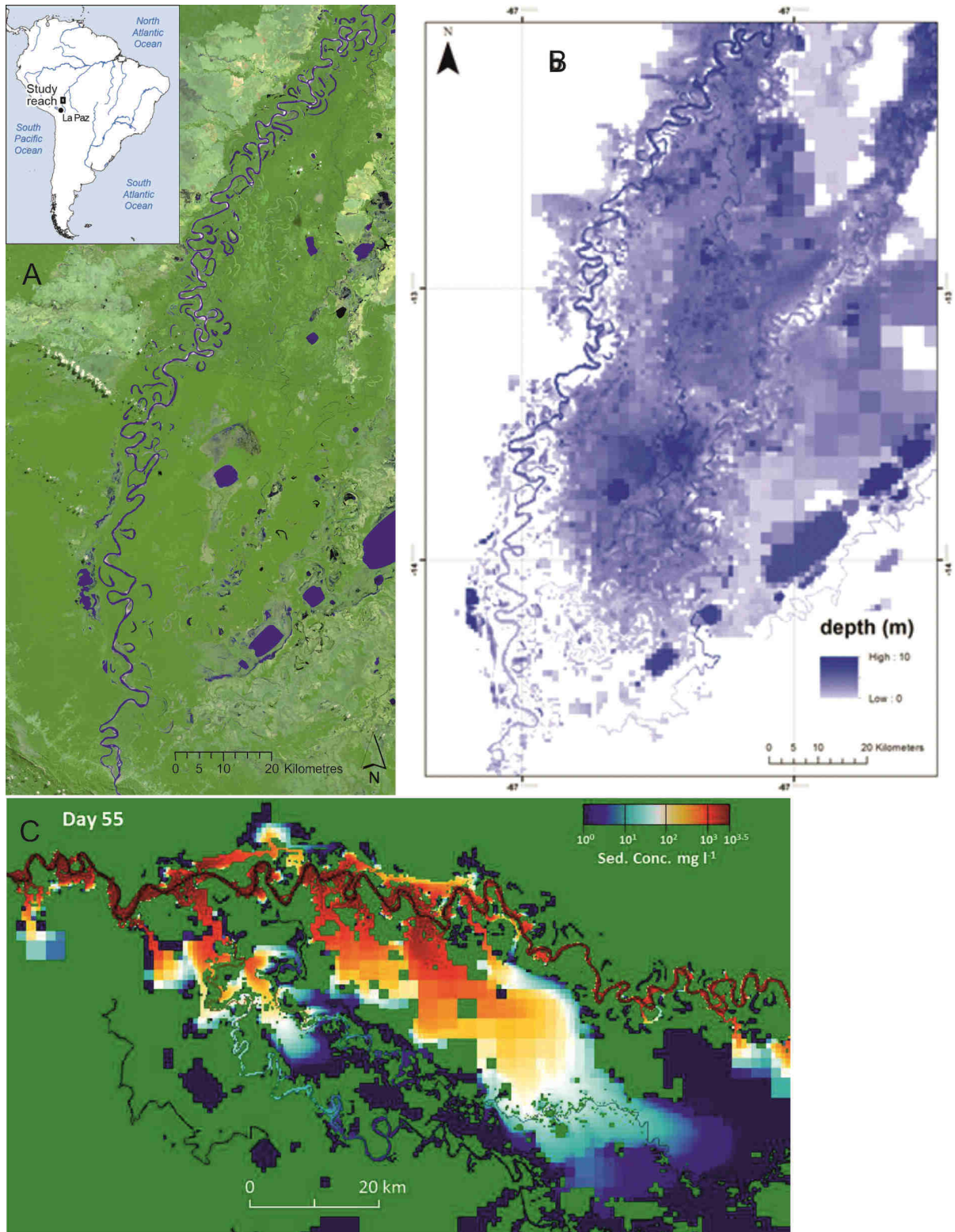
Figure 1. Study reach of the Rio Beni (A), simulation of inundation extent and depth on the receding limb of a flood (B) and modelled sediment dispersion on day 55 of a 6 month wet season hydrograph (C).