Geomorphology 228 (2015) 116–123

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Dendrogeomorphic reconstruction of flash floods in the Patagonian Andes

Alejandro Casteller [a,b,*], Markus Stoffel [c,d], Sebastián Crespo [a], Ricardo Villalba [a], Christophe Corona [c], Emilio Bianchi [e]

[a] Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), CCT-CONICET-Mendoza, Avenida Ruiz Leal s/n, 5500 Mendoza, Argentina
[b] WSL Institute for Snow and Avalanche Research, SLF, Flüelastrasse 11, 7260 Davos Dorf, Switzerland
[c] Dendrolab.ch, Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3, CH-3012 Bern, Switzerland
[d] Climatic Change and Climate Impacts, Institute for Environmental Sciences, University of Geneva, Chemin de Drize 7, CH-1227 Carouge-Geneva, Switzerland
[e] Instituto Nacional de Tecnología Agropecuaria (INTA), Estación Experimental Agropecuaria Bariloche, Área de Recursos Naturales, Modesta Victoria 4450, 8400 Bariloche, Río Negro, Argentina

ARTICLE INFO

Article history:
Received 17 February 2014
Received in revised form 31 July 2014
Accepted 3 August 2014
Available online 16 September 2014

Keywords:
Flash floods
Dendrogeomorphology
Austrocedrus chilensis
Pseudotsuga menziesii
Nothofagus dombeyi
Patagonian Andes

ABSTRACT

Flash floods represent a significant natural hazard in small mountainous catchments of the Patagonian Andes and have repeatedly caused loss to life and infrastructure. At the same time, however, documentary records of past events remain fairly scarce and highly fragmentary in most cases. In this study, we therefore reconstruct the spatiotemporal patterns of past flash flood activity along the Los Cipreses torrent (Neuquén, Argentina) using dendrogeomorphic methods. Based on samples from *Austrocedrus chilensis*, *Pseudotsuga menziesii*, and *Nothofagus dombeyi*, we document 21 flash flood events covering the period A.D. 1890–2009 and reconstruct mean recurrence intervals of events at the level of individual trees being impacted, which varies from 4 to 93 years. Results show that trees tend to be older (younger) in sectors of the torrent with gentler (steeper) slope gradients. Potential triggers of flash floods were analyzed using daily temperature and precipitation data from a nearby weather station. Weather conditions leading to flash floods are abundant precipitations during one to three consecutive days, combined with temperatures above the rain/snow threshold (2 °C) in the whole watershed.

1. Introduction

Flash floods periodically cause serious risk to life and destruction of buildings and infrastructure (Gaume et al., 2009). These natural hazards typically occur in ungauged watersheds not larger than a few hundred square kilometers (Ruiz-Villanueva et al., 2010) where heavy precipitation events may lead to a sudden and often massive increase in (peak) discharge (Borga et al., 2007). In mountainous areas, abundant rainfall (often in combination with rapid snowmelt) has been described as the main trigger of flash floods. These may then travel downvalley to reach populated areas with no or only limited time for warning. In such areas, the documentation of past as well as the characterization of potential future events, also including those with low probability of occurrence but associated high damage potential, is important, also in view of the mitigation of related risks using specific land planning tools (Merz et al., 2009; Canelli et al., 2012).

Historical records of past flash floods are in general short, scarce, and fragmentary (Cook, 1987). In some cases, records cover several centuries, although information on peak discharge and affected areas often tends to remain uncertain for the oldest records (Payrastre et al., 2005). Mountainous regions with expanding infrastructure, as is the case in the Patagonian Andes of South America, are particularly exposed to flash floods as a result of the meteorological and orographic characteristics of the Andes. Moreover, largely lacking records or systematic data on previous events hinders the application of effective mitigation measures. As a consequence, and in view of increasing land needs for construction, additional sources are needed to supplement the limited available records.

Dendrogeomorphology is an accurate method to reconstruct spatial and temporal patterns of past torrential processes (Alestalo, 1971; Shroder, 1978; Stoffel and Bollschweiler, 2008). The analysis of growth rings of trees affected by flash floods can provide valuable information on past events (Yanosky and Jarrett, 2002; Zielonka et al., 2008), mostly with yearly, but sometimes even with seasonal precision (Stoffel, 2008). Classical (flash) flood reconstructions included (i) the dating of scars in the trees (McCord, 1996), (ii) determination of the age of sprouts resulting from trunk tilting or crown damage (Sigafoos, 1964), and (iii) the inference of event dates based on ages of trees colonizing the

* Corresponding author at: Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), CCT-CONICET-Mendoza, Avenida Ruiz Leal s/n, 5500 Mendoza, Argentina. Tel.: +54 261 5244273; fax: +54 261 5244200.
E-mail address: casteller@mendoza-conicet.gob.ar (A. Casteller).

http://dx.doi.org/10.1016/j.geomorph.2014.08.022
0169-555X/

new surfaces after catastrophic flooding (Costa, 1978). More recent studies focused on anatomical responses of trees to flash floods, including conifers (Mayer et al., 2010; Ruiz-Villanueva et al., 2010; Procter et al., 2012) and broad-leaved trees (Arbellay et al., 2010; Ballesteros et al., 2010). Dendrogeomorphic indicators in combination with one-dimensional (Corriell, 2002) and two-dimensional (Ballesteros Cánovas et al., 2011) hydraulic models have also been implemented to estimate flash flood discharge.

In this study, we reconstructed the spatiotemporal patterns of flash floods in a torrent located in the Patagonian Andes using 58 samples from *Austrocedrus chilensis*, *Nothofagus dombeyi*, and *Pseudotsuga menziesii* trees covering the period A.D. 1795–2008. The tree-ring based chronology of events was used to determine potential triggers of flash floods in the torrent through the analysis of regional climatic data.

2. Study area

The sampling was conducted at Los Cipreses torrent in the Neuquén Province, Patagonian Andes, Argentina (40°56′00″ S., 71°24′45″ W.; Fig. 1). The catchment area and the torrent length are ~7.5 km^2 and 4.9 km, respectively. The elevational range between the highest summit (Cerro Alto Bonito; 1963 m asl) and Lago Nahuel Huapi (768 m asl) is close to 1200 m. The torrent crosses National Road 231, an important international connection between San Carlos de Bariloche (Argentina) and Osorno (Chile) at an elevation of 792 m asl. Stream gauge stations do not exist in this or its neighboring torrents.

The torrent flows through Los Machis outcrops primarily composed of granodioritic rocks, together with tonalites and quartz monzonites (Servicio Geológico Minero Argentino, 1995). Total annual precipitation and mean annual temperature (1914–2011) recorded at San Carlos de Bariloche airport, located 33 km to the SE (41°09′02″ S., 71°09′24″ W.; 840 m) of Los Cipreses torrent, are 955 mm and 8 °C, respectively (Fig. 2). A large proportion (60%) of the precipitation occurs in late fall and winter (May, June, July, and August); at elevations above 1000–1100 m asl, precipitation occurs commonly as snow.

The study reach, with a length of 560 m and an area of ~7000 m^2, is located on the alluvial fan of Los Cipreses torrent. Abundant evidence of flash flood activity in the torrent is provided by depositional forms of past flash floods in the form of lobate deposits and abandoned channels, as well as through broken, bent, and uprooted trees growing on the fan (Fig. 3). In many cases, channel wall erosion has partially exposed root systems (Stoffel et al., 2012). Historical records of past flash floods do not exist for the torrent, but newspaper articles (Lanación.com, 2004) and eyewitness reports (Gustavo Villarosa, *verbatim*) allude to a heavy precipitation event in winter 2004 and related flash flood occurrences causing casualties and damage to infrastructure in the area. The study area is only affected by flash floods; signs of other geomorphic processes, such as snow avalanches or rockfalls, are clearly missing at the study site.

3. Material and methods

3.1. Sampling procedure

The main tree species growing in Los Cipreses torrent are Chilean cedar (*A. chilensis* (D. Don) Florin et Boutelje), Southern coihue beech (*N. dombeyi* (Mirb.) Oerst.), and Douglas-fir (*P. menziesii* (Mirb.)

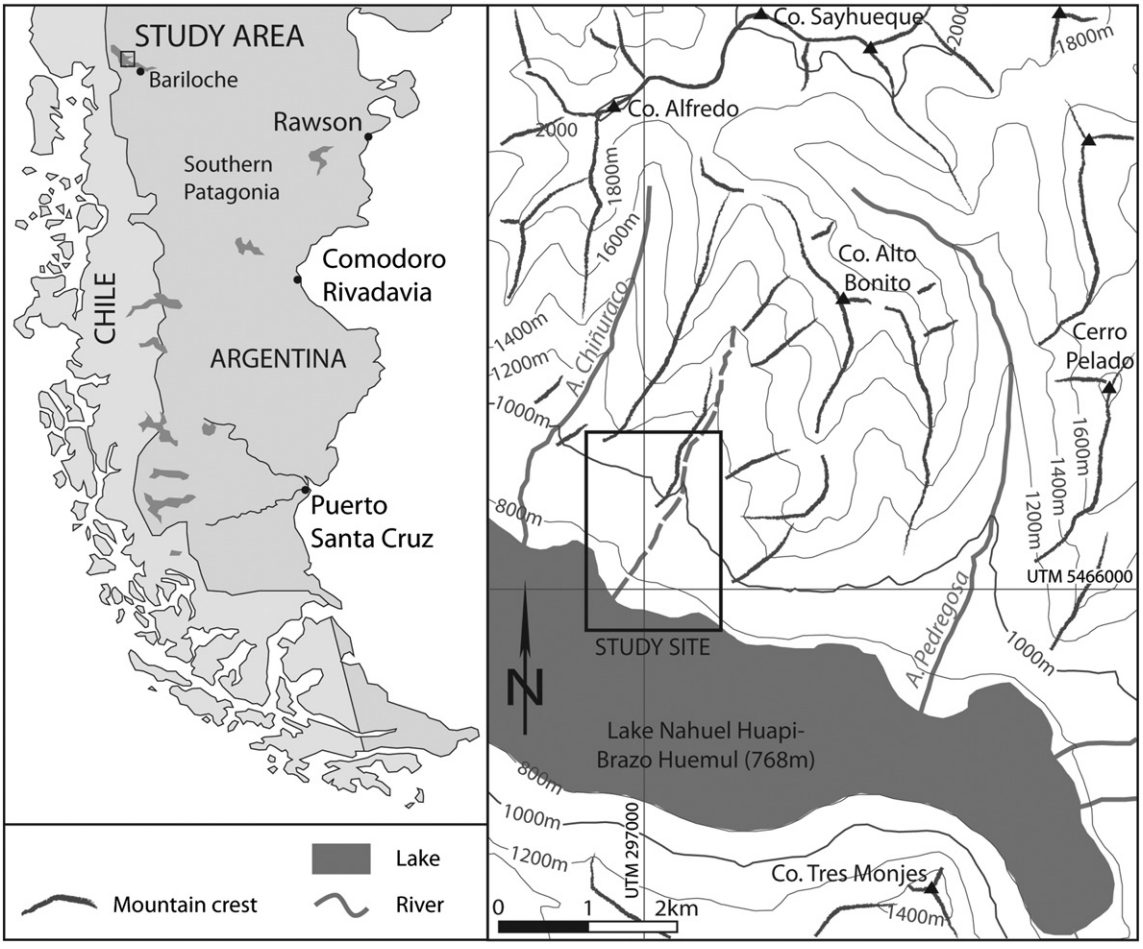

Fig. 1. Study area (rectangle) located in the province of Neuquén, Argentina. The Los Cipreses torrent has a catchment area of 7.5 km^2 and a channel length of 4.9 km. The torrent enters Nahuel Huapi Lake at 768 m asl. The elevational range spans ~1.2 km.