



# Multitemporal glacier inventory of the French Alps from the late 1960s to the late 2000s



Marie Gardent<sup>a,\*</sup>, Antoine Rabatel<sup>b,c</sup>, Jean-Pierre Dedieu<sup>d,e,f</sup>, Philip Deline<sup>a</sup>

<sup>a</sup> EDYTEM Lab., Univ. Savoie, CNRS, F-73376 Le Bourget-du-Lac, France

<sup>b</sup> Univ. Grenoble Alpes, LGGE, F-38000 Grenoble, France

<sup>c</sup> CNRS, LGGE, F-38000 Grenoble, France

<sup>d</sup> Univ. Grenoble Alpes, LTHE, F-38000 Grenoble, France

<sup>e</sup> CNRS, LTHE, F-38000 Grenoble, France

<sup>f</sup> IRD, LTHE, F-38000 Grenoble, France

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## ABSTRACT

The most recent and complete French glacier inventory was previously the Vivian database, dating from the end of the 1960s but incorporated in the World Glacier Inventory database at the end of the 1990s. Because of the important changes in glacier extent over recent decades an update of the inventory of glaciers of the French Alps was made in a digital vector format (with the associated database) for several dates covering the last 40 years. Such a multitemporal glacier inventory matches a key demand of the Global Terrestrial Network for Glaciers and the Global Land Ice Measurements from Space initiative (GLIMS). Topographical maps, aerial photographs and satellite images were used to map the extent of glaciers using both manual and automatic methods; and the database was generated considering the design of the GLIMS database. Glaciers in the French Alps covered 369 km<sup>2</sup> in 1967/71, 340 km<sup>2</sup> in 1985/86, 300 km<sup>2</sup> in 2003, and 275 km<sup>2</sup> in 2006/09. This represents a decrease in surface area of about 25% over the entire study period. Acceleration in glacier shrinkage during the study period was revealed, probably linked to the increase in average air temperature in the 20th century, which has been particularly pronounced since the 1970s. The behaviour of glaciers of the French Alps is in agreement with that of glaciers observed by other studies across the European Alps. We also report the distribution of the morpho-topographic variables (aspect, elevation, etc.) of glaciers of the French Alps for the period 2006/09, and analyse changes of these variables in the last four decades.

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## 1. Introduction

As in most mountain ranges worldwide (e.g. Berthier et al., 2010; Rabatel et al., 2013a; Vincent et al., 2013), the Alps have seen general glacier shrinkage over the last decades (Abermann et al., 2009; Paul et al., 2011; Thibert et al., 2013). In this context, the accurate quantification of glacier changes is needed to better understand relationships with climate changes; and the glacier area survey is necessary to estimate at regional/global scales the ice volume, through area/volume relationships, and therefore the impacts of glacier changes on water resources or on sea level (Huss et al., 2010; Kaser et al., 2010; Bahr and Radić, 2012). Since the mid-1970s, international inventories like the World Glacier Inventory (WGI), services like the World Glacier Monitoring Service (WGMS), initiatives like GLIMS (Global Land Ice Measurements from Space), and projects like GlobGlacier have been established to

address the question of glacier changes in mountainous areas by gathering measured data worldwide.

An inventory of the glacierized areas of the Alps was made by Paul et al. (2011) in the framework of GlobGlacier; it used automated techniques to identify glacier outlines on Landsat TM images acquired in 2003, with manual corrections. Previously, glacier inventories in the Alps had only been conducted at country or regional scales (Table 1). For the French Alps, two inventories were made by Mougin (1925) using topographical maps dating from the mid-19th century, and Vivian (1975) at the end of the 1960s based on topographical maps and aerial photographs; few subsequent updates were conducted at local scale for different dates (Table 1). The Vivian database was not originally in digital vector format; it was incorporated in the WGI database at the end of the 1990s as a table, and is available in digital format where each glacier or group of glacierets is represented as a single point. The lack of cartographic representation of the outlines of the glaciers and the fragmentation of glaciers since the 1970s make it difficult to compare the WGI database with the other local datasets. In addition, the exact date when the data for each glacier were collected is missing.

\* Corresponding author at: Université de Savoie, Laboratoire EDYTEM, F-73376 Le Bourget du Lac cedex.

E-mail address: [marie.gardent@univ-savoie.fr](mailto:marie.gardent@univ-savoie.fr) (M. Gardent).