



Evolution of Access Routes to High Mountain Refuges of the Mer de Glace Basin (Mont Blanc Massif, France)

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Evolution of Access Routes to High Mountain Refuges of the Mer de Glace Basin (Mont Blanc Massif, France)

An Example of Adapting to Climate Change Effects in the Alpine High Mountains

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Introduction

- 1 The average world temperature has increased of 0.85°C between 1880 and 2012 (IPCC, 2014), and climate change is affecting most of the regions around the world. High altitude and high latitude areas in the Northern Hemisphere are warming up even faster (Beniston and Haeberli, 2001). Across the Alpine arc, the homogenised temperatures series show a 2°C warming between the end of the 19th century and the beginning of the 21st century (Auer *et al.*, 2007), which has accelerated over the past few decades. The average 0°C isotherm altitude has moved 400 m. uphill since the beginning of the 1980s (Böhm *et al.*, 2010). In the French Alps, the temperatures have risen between 1.5°C and 2.1°C since 1950 (Einhorn *et al.*, 2015) and, even above 4,000 m. a.s.l., the annual average temperature shows an increase of 1.4°C between 1900 and 2004 (Gilbert and Vincent, 2013).
- 2 In this context, the high Alpine mountains have undergone deep modifications, especially in terms of very visible glacial shrinkage and permafrost melting (the warming of permanently frozen terrains; Deline *et al.*, 2015). In the Alps, the glacier surfaces have shrunk by half between 1900 and 2012, with a strong acceleration of the

melting processes since the 1980s (Huss, 2012). During the same period, a surge in the number of rock falls (volume > 100 m³) in the rock walls has been observed (Geertsema *et al.*, 2006; Ravel and Deline, 2011; Ravel *et al.*, 2013). In the Mont Blanc massif, more than 550 rock falls occurred between 2007 and 2015 (*cf.* Ravel and Deline, 2013).

- 3 Human societies in contact with these environments are affected by the changes. The effects of global warming on human societies (IPCC, 2014, Frei *et al.*, 2007) and their adaptation strategies (Adger *et al.*, 2003; Füssel, 2007; Tabeaud, 2010) have been well studied. However, very few research works, apart from those of Behm *et al.* (2006), Ritter *et al.* (2011) and Temme (2015), among others, have been devoted to the specific question of the effects that global warming has on mountaineering, even though this practice is an iconic legacy of the high mountain regions and a significant economic activity. For example, the EU project “Eco-Innovation in Altitude” showed that 81% of the refuge keepers in the Mont Blanc area have reported a change in the security conditions of their access trail over the past 10 years and, in 96% of the cases, the trail had to be modified accordingly (Piccardi *et al.*, 2014; Vuilleumier, 2014).
- 4 Many questions still have to be addressed. How and to what extent does climate change affect high mountain routes? Which geomorphologic processes are at work? What are the effects of these changes on the practice of mountaineering? And what are the terms of the current adaptations?
- 5 The installation of a 240-metre-long Himalayan bridge, which cost 400,000 CHF, to maintain access to the Panossière refuge (Valais, Switzerland), and a 60-metre-long bridge to ensure continued access to the Conscrits refuge in the Mont Blanc massif (Piccardi *et al.*, 2014), at a cost of 130,000 EUR, are symbolic of these adaptations.
- 6 To understand how access to high mountain refuges can be affected by changes in the high mountain environment, our study retraces how access trails to five refuges in the Mer de Glace basin have changed since the beginning of the 20th century. This work is based on a geo-historical methodology, semi-structured interviews and a high-resolution LiDAR survey (Jaboyedoff *et al.*, 2010) to discuss the modalities of geomorphological terrain evolution and the concomitant adaptations of the routes. The concepts of paraglacial crisis, according to Church and Ryder (1972), and high mountain practices as a sports activity that is managed in a particular way will also be treated.

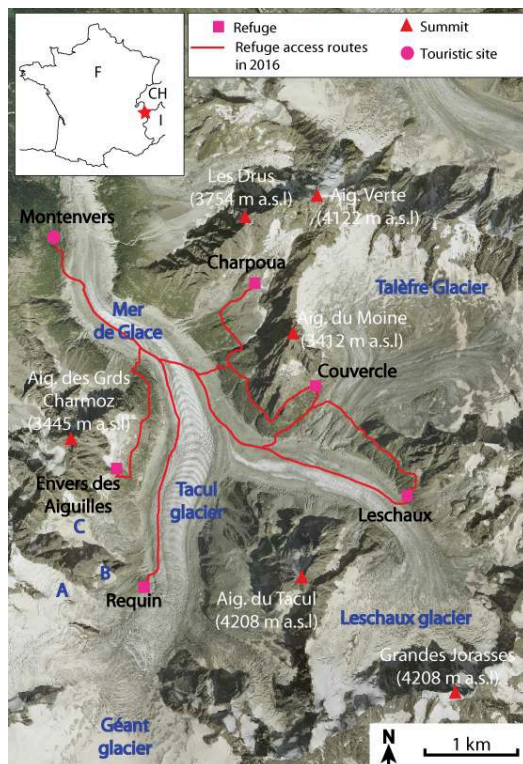
The Mer de Glace basin, a major place for mountaineering

- 7 The Mer de Glace is the largest glacier in the French Alps (length = 11.5 km, surface area = 30.4 km²) and has been the one studied the most. In the 1890s, J. Vallot was the first to take its measurements. Following the last recurrence of the Little Ice Age (1852), the glacier displayed major shrinkage. Its front end moved 2.7 km uphill. Nevertheless, this retreat is not linear and has been interrupted by three small periods of glacial advance: 1890–96, 1923–31 and 1970–95 (Reynaud and Vincent, 2000, Nussbaumer *et al.*, 2007).
- 8 Since 1995, the retreat has accelerated significantly with the ice moving uphill around 40 m. per year (Vincent, 2010). During the same time, the thickness loss has also been significant. Below the tourist site of Montanvers, between 1890 and 2013, at 1,800 m.

a.s.l., the ice thickness reduced 166 m. (GLACIOCLIM data; lgge.ujf-grenoble.fr/ServiceObs/) with an annual average loss of 4.0 ± 0.2 m. between 2000 and 2008 (Berthier and Vincent, 2012). This kind of a change usually produces dangerous geomorphological processes: The lateral moraines are no longer maintained against the slopes and are gradually eroding by rock falls, boulder falls and landslides (Deline, 2008).

- 9 The Mer de Glace basin is the birthplace and a major site for mountaineering. It has several mythical summits and walls, such as the north face of the Grandes Jorasses (4,208 m. a.s.l.), which is one of the three “great north faces of the Alps”, the Aiguille Verte (4,122 m. a.s.l.), whose ascent in 1865 by Edward Whymper and his two guides was one of the “great firsts” commemorated in 2015 on the 150-year anniversary of the Golden Age of mountaineering, and the Drus west face, a 1,000-metre-high near-vertical wall.
- 10 In the surroundings of the Mer de Glace, the increasing number of ascents during the 20th century led to the construction of five refuges between 1904 and 1957 (Fig. 1): the Charpoua (2,841 m. a.s.l., in 1904), the Couvercle (2,687 m. a.s.l., in 1904), Leschaux (2,431 m. a.s.l., in 1929), the Requin (2,523 m. a.s.l., in 1927) and the Envers des Aiguilles (2,523 m. a.s.l., in 1957).
- 11 Their accessibility is facilitated by the Montenvers railway, which climbs to 1,913 m. a.s.l. They receive a great number of visitors, with a total of more than 6,000 nights in 2015 (FFCAM/ADSM data). Between 1992 and 2003, a maintained trail connecting the five refuges was built (“The balconies of the Mer de Glace”). It has opened the area to experienced hikers who today represent a significant share of the refuge visitor numbers.
- 12 In addition, the large number of people visiting the Mer de Glace basin represents an important sports, tourist and economic attraction threatened by the effects of global warming.

Figure 1 – Location map of the five refuges of the Mer de Glace basin



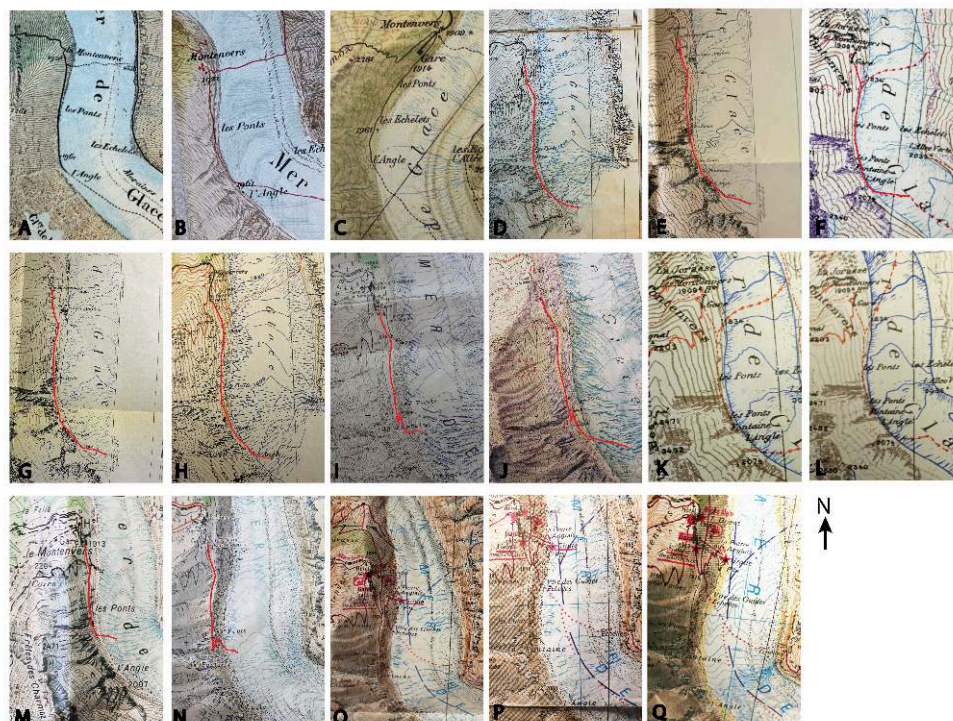
A: Envers du Plan glacier; B: Requin glacier; C: Envers de Blaitière glacier.

Photo: IGN. Realization: Mourey, 2017.

Geo-historical methodology

- 13 In order to quantify the evolution of access trails to the refuges, a three-step methodology based on multi-source documentation was used.
- 14 First, numerous documents (maps, climbing guidebooks and photographs) were collected on the 1850–2014 period. They come from the Alpine Museum of Chamonix (maps and climbing guidebooks), the National Ski and Mountaineering School (maps and climbing guidebooks) and the local archives of Chamonix (photographs).
- 15 The maps were analysed diachronically in order to date the main evolutions of the access trails (Fig. 2).

Figure 2 – Maps of the Montanvers area with the downhill route to the Mer de Glace glacier and towards the five refuges



A) MIEULET 1865, 1:40,000 ; B) VIOLET LE DUC 1876, 1:40,000 ; C) BARBEY 1906, 1:50,000 ; D) VALLOT 1907, 1:50,000 ; E) VALLOT 1931, 1:20,000 ; F) VALLOT 1943, 1:50,000 ; G) VALLOT 1945, 1:20,000 ; H) VALLOT 1946, 1:20,000 ; I) IGN 1949, 1:20,000 ; J) IGN 1950, 1:10,000 ; K) VALLOT 1956, 1:50,000 ; L) VALLOT 1960, 1:50,000 ; M) IGN 1960, 1:50,000 ; N) IGN 1975, 1:20,000 ; O) IGN 1995, 1:25,000 ; P) IGN 2001, 1:25,000 ; Q) IGN 2011, 1:25,000.

Realization: Mourey, 2017.

- 16 Then, in order to clarify the evolution of the access trails in time and space, their representations on the maps were compared with their descriptions in the climbing guidebooks "*Guide Vallot: La chaîne du Mont-Blanc*" (1925, 1947, 1949, 1951, 1966, 1975, 1977) and "*Guide de la chaîne du Mont-Blanc Kurtz*" (1892, 1935). Eventually, a corpus of 1,573 photographs led to further clarity as they cleared up some uncertainties.
- 17 Second, semi-structured interviews were conducted with 14 high mountain guides, refuge keepers, employees in charge of the management of the trails and the elected representatives of the Chamonix Mont Blanc municipality. They often brought more detailed data (dates, field information) from the 1950s. They also made it possible to develop the question of visitor numbers at the refuges and the figures' evolution in reaction to the modification of the access trails.
- 18 Finally, the sectors of transition between the glaciers' surface and the slopes were surveyed by terrestrial laser scanning in 2016. The construction of high-resolution digital terrain models (Ravel and Lambiel, 2013) made it possible to measure the equipment in place with precision.

Results: generally recent disruptions

- 19 The evolution of the refuges' access trails from the end of the 19th century to the current period can be divided into three distinct periods. To illustrate and facilitate the analysis of the results and the discussion, two examples will be developed in detail: access to the Mer de Glace from the Montenvers refuge and access to the Requin refuge.
- 20 From the end of the 19th century until the 1960s, the access trails saw a limited and very gradual evolution. Geomorphological activity was reduced and only marginally affected access. Moreover, the trails, located on the slopes and on the lateral moraines of the glacier, bypassed the glacier, which at the time was very fracture, as much as possible. The geomorphological conditions were relatively stable, which meant that security conditions were good. Several routes were used to reach the same destination, depending on the weather conditions, the season and the specific activity.
- 21 Consequently, access to the Mer de Glace from Montenvers did not evolve much between 1900 and the 1960s. The trail was located on or near the crest of the left lateral moraine of the glacier for 1.5 km, before it went down to the glacier at a point called "L'Angle" (Fig. 3A). This first trail was abandoned during the 1940s, as the path down the left lateral moraine to reach the surface of the glacier was becoming more difficult and dangerous. The passage via "les Ponts" was put in place in 1945 (Fig. 3A).
- 22 Over this first period, the Requin refuge was accessible thanks to three different routes that could be used to reach the refuge from both the north and the south. They were located on top of the right and left lateral moraines of the Tacul glacier (Fig. 3A).
- 23 The second period starts in the 1960s (Fig. 3A), when glacial retreat (Reynaud and Vincent, 2000; Gardent *et al.*, 2014) and the concomitant erosion of the lateral moraines began having a severe impact on the access routes. Steep rock slabs appeared below all the refuges, while erosion of the lateral moraines caused a high frequency of rock destabilisation. As a result, the access trails and more specifically the transitions between the glaciers and the rock slopes became more dangerous and more difficult.
- 24 In order to maintain access under acceptable conditions of technicity and security, these transitions were frequently moved to where the bedrock outcrops. Those changes avoided the dangers resulting from the erosion of the lateral moraines but required the installation of ladders to cross over the rocky slabs. Therefore, in order to avoid the glacier margins, the goal was to step on the glacier as quickly as possible, since it was becoming less fractured due to the loss of thickness and the speed of the glacier.
- 25 Over this period, access to the Mer de Glace from Montenvers required regular maintenance and development works (1960, 1971 and 1972; Fig. 3A), owing to a 32-metre loss in ice thickness between 1940 and 1980 (GLACIOCLIM data) and the erosion of the lateral moraine. In 1960 and 1971, several metres of ladders were installed, and the trail in the moraine had to be rebuilt. In 1972, some unstable blocks were mined, 39 m. of ramps and 25 pitons were put in place, steps were carved into the bedrock, and the trail in the moraine was restructured. From the 1970s, this passage via "Les Ponts" was used less often, as the passage via the "Vire des Guides", which had been used in part since the 1950s (Fig. 3A), was given priority. The passage via "Les Ponts" was definitively abandoned in 1988 after a major rockslide in the moraine in the sector of "La Fontaine".

- 26 Owing to the loss in thickness of the Tacul glacier and the erosion of its lateral moraines, the three historical access trails to the Requin refuge were abandoned in the 1970s. Because of their erosion dynamic, the lateral moraines of the Tacul glacier had to be avoided. Since then, it has been necessary to ascend the Tacul glacier through its centre before following the right flank of the Envers de Blaitière glacier and reaching the refuge from the north. This route is quite dangerous. The glacial advance between 1970 and the 1980s caused ice falls from the Envers du Plan and Requin glaciers. Moreover, the thickness loss of the Tacul glacier and the retreat of the Envers du Plan glacier over the past 30 years has caused intense erosion of the lateral moraines.
- 27 The third period starts in the mid-1990 (Fig. 3A), at a time when the acceleration in glaciers' thickness loss (Berthier and Vincent, 2012; Berthier *et al.*, 2014) produced bigger and steeper bedrock outcrops, and more hanging and unstable morainic veneers were released (Requin, Envers des Aiguilles, Montenvers; Fig. 4). At the same time, the lateral moraines became higher and steeper. Consequently, the ladder sections were regularly moved and/or extended (Fig. 3A; Tab. 1)
- 28 At the beginning of the 20th century, no ladders were necessary to reach the refuges. In 2016, the six sectors of transition between the glaciers and the slopes were equipped with ladders for a total height of 633 m, including an addition of 411 m. between 2001 and 2016 (Tab. 1). The highest section is the one leading to the Requin refuge, with a difference in level of 154 m. (Fig. 4).

Table 1 – Cumulative elevation of ladders for each refuge in 2001, 2014, 2015 and 2016, additions between each date and average additions (in metres per year) between 2001 and 2016

	2001	2014	2015	2016		2001-14	2014-15	2015-16		2001-16
Montenvers	30	74,3	81,3	94,8		+44,3	+7	+13,5		+4
Charpoua	0	19	100	100		+19	+81	+0		+6,2
Egralets	44	64,5	64,5	64,5		+20,5	+0	+0		+1,3
Leschaux	20	65	70	100		+45	+5	+30		+5
Requin	75	149,5	151,5	154,3		+74,5	+2	+2,8		+5
Envers des Aiguilles	53	113	116	119		+60	+3	+3		+4
Totals	222	485,3	583,3	632,6		+263,3	+98	+49,3		+25,7

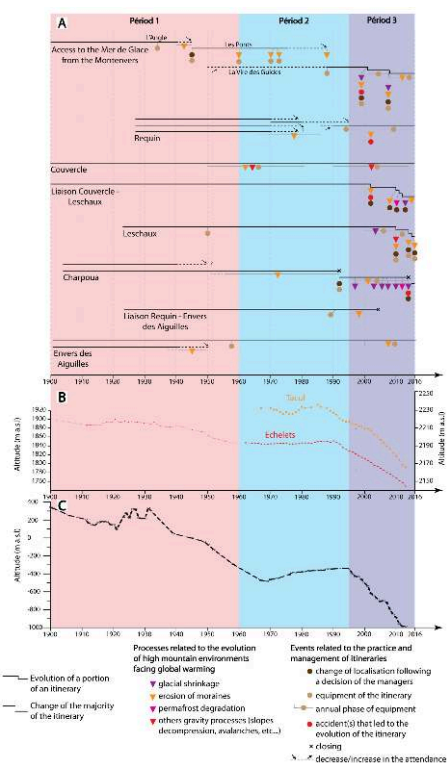
Realization: Mourey, 2017.

- 29 Over this last period, the “Vire des Guides” was still used to reach the Mer de Glace from Montenvers (Fig. 3A). However, the glacier lost 98 m. in thickness between 1988 and 2013 (GLACIOCLIM data); therefore, the access route had to be moved twice, and additional ladders were installed every year. In fact, while there had been no ladders in 1988, there were 30 m. in 2001 to provide access to the summit of a moraine that still had to be climbed down to reach the surface of the Mer de Glace.
- 30 This passage was first modified in 2001. Following a fatal accident on account of the erosion of the moraine, the track was moved a few metres towards some rock slabs to provide direct access to the glacier. Equipped with ladders, this way sidesteps the dangerous and steep moraines. Gradually, however, the glacier's loss of thickness and the associated erosion of the moraine led to the adding of 50 m. of ladders in 2008 to reach a sector with very steep bedrock. Also, the route was moved again in 2008. From the “Vire des Guides”, the route travels southward 150 m. to reach a sector where very few ladders are needed to reach the lateral moraine, which provides very easy access to

the glacier. This passage is still in use today, but the glacial retreat continues and is accelerating. This passage's 30 m. of ladders in 2008 increased to 60 m. in 2016. Moreover, the lateral moraine is getting steeper and higher and is a source of more and more gravitational processes. Several landslides have occurred directly on buried ice (in June 2016, for example), and gullies up to several metres deep were created. Mountaineers are highly exposed to those processes, which greatly increases the danger of this passage.

- 31 Concerning the Requin refuge, the northern access trail used during the 1970–80s was abandoned at the beginning of the 1990s. Ice falls from the glaciers' front and the erosion of the lateral moraines of the Tacul and Envers de Blaitière glaciers continued. Over time, the southern access trail was equipped and used again. In 1999, a 75-metre ladder section and a 40-metre-long rope to cross the lateral moraine permitted access to the glacier surface. In 2002, a big landslide on the left lateral moraine of the Tacul glacier injured several people and led to the installation of a second ladder section (Fig. 4). Since then, it has been equipped every year to compensate for the Tacul glacier's thickness loss. In 2016, this second section was 79 metres high (Fig. 4).

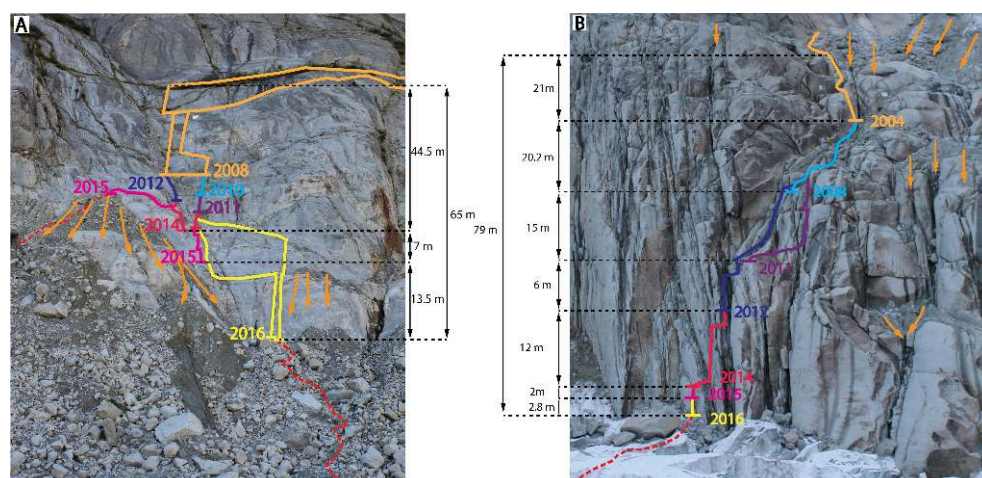
Figure 3 – Historical access routes



A: Refuge access route evolution; B: Ice thickness variations in the Echelets and Tacul profile (GLACIOCLIM data); C: Mer de Glace ice front evolution (GLACIOCLIM data).

Realization: Mourey, 2017.

Figure 4 – Successive addition of ladders on the glacier–slope transition of Montenvers and Requin



Dates: position of the lower ladders for the year in question. Arrows: main trajectories of rock falls from the moraines and the morainic veneer.

Realization: Mourey, 2017.

- 32 All eight access trails under study have been affected by the glaciers' loss of thickness and the associated erosion of the lateral moraines. However, other processes can help to explain the evolution of the access trails, like rock falls, which may be linked to permafrost melting (Magnin *et al.*, 2015), which has been the case for the link between the Couvercle and Leschaux refuges and the access trail to the Charpoua refuge (Fig. 3).
- 33 It is important to highlight that the link between the Requin and the Envers des Aiguilles refuges was closed in 2004 (Fig. 3) because of the loss of thickness of the Tacul glacier, the associated erosion of its left lateral moraine and the difficulty in finding another passage in this sector.

Adjustments brought about by glacial retreat and the associated paraglacial crisis

- 34 In the absence of stabilising permafrost at these relatively low altitudes (Magnin *et al.*, 2015), the retreat of the ice mass is the only factor that leads to the loss of support and thereby to the loss of stopping effect of the glacier on the lateral moraines (Lukas *et al.*, 2012; Raveland and Lambiel, 2013). Materials from the upper part of the moraines' inner flank are mobilised and usually redeposited at the bottom. This process forms a more or less stable moraine slope until its profile reaches an equilibrium stage (Lukas *et al.*, 2012) with a total absence of ice. Generally, erosion of the lateral moraines leads to the emergence of steep bedrock slabs, while suspended morainic veneer may persist.
- 35 Therefore, the main geomorphic processes at the root of the access trails' development are part of a double dynamic: glacial retreat and the associated paraglacial crisis (Church and Ryder, 1972; Mercier, 2011).
- 36 The concept of "paraglacial", as defined by C.K. Ballantyne (2002), designates "the non-glacial earth-surface processes (...) that are directly conditioned by glaciation and deglaciation". Also, a paraglacial sequence starts in direct response to deglaciation and

ends when all the inherited glacial sediments are out of stock or have been stabilised (Ballantyne, 2002).

- 37 Between 1900 and 1940, the glaciers melted relatively slowly, and the evolution of access trails was limited, thanks to reduced geomorphological activity (Fig. 3) and a lower traffic than today.
- 38 By contrast, between 1931 and the 1960s, the glacial retreat began to take on importance. The ice front moved more than 600 m. uphill with a thickness loss of 70 m. below Montanvers (Echelets profile; Fig. 3B, 3C). This period of intense melting processes explains the second period of evolution. Equipment and modifications are recurrent, and the danger of access increases because of the loss of glacier thickness, the associated erosion of the lateral moraines and the rock-slab outcrops.
- 39 The time offset between the melting of the glacier and its effect on the routes corresponds to a geomorphologic response period and to the time the routes managers need to take these changes into account and to modify them accordingly (see below).
- 40 The routes' modifications intensified during the third period, as the glacier's advance between 1970 and 1995 had not erased the slopes' imbalances caused by its retreat during the preceding three decades. The routes modifications were becoming more frequent and important in relation to the withdrawal dynamics that continues and accelerates (Fig. 3B, 3C) and whose effects on the glacial margins have been compounded since the 1930s. Between 1995 and 2013, the glacier front moved uphill over 700 m. for a thickness loss of 65 m. below Montanvers. This explains the importance and frequency of ladder installations in order to maintain access to the glacier.
- 41 For the highest transitions, however, the addition of ladders is less important and less commonplace. Between 2014 and 2016, 20.5 m. of ladders were added below Montanvers (1,791 m. a.s.l.), in contrast to 6 m. at Envers des Aiguilles (1,920 m. a.s.l.), 0 m. at Égralès (2,167 m a.s.l.) and 4.8 m. at Requin (2,240 m a.s.l.). The local topography and the presence/absence of lateral moraines also explain these differences.
- 42 Finally, glacial shrinkage became more intense in the 1990s (Fig. 3), and new sedimentary stocks (tills) appeared, which suggests that the "paraglacial" sequence will continue for at least several decades more. It also means that all the geomorphological processes that are currently affecting the access trails – in particular, the erosion of the lateral moraines – will continue to occur and will even intensify, especially as glacial shrinkage accelerates.
- 43 The Mer de Glace ice front is expected to retreat about 1,200 m. by 2040 (Vincent *et al.*, 2014). This would imply a thickness loss of 160 m. compared with the 2010 ice level at the Montanvers ladders. This ladder section would then be about 250 m. high, while very high and dangerous lateral moraines could continue to develop and lead to large gravitational processes that would complicate the management of the access trails even further.

Equipment management and itinerary adjustment policies

- 44 Another reason for the frequent and intense modification of the routes between the 1990s and the present (Period 3) has been the development of a specific tourist offer.
- 45 At the end of the 1980s, the municipality of Chamonix launched the “Mer de Glace balconies” project. The goal was to create a trail that would be accessible to hikers and would connect the five refuges in the Mer de Glace basin, thus boosting the number of visitors (pers. comm. *Communauté de Commune de la Vallée de Chamonix Mont Blanc CCVCMB*, March 2015).
- 46 As a result, some itineraries can be modified to make the routes easier and without there being a direct link with the geomorphological conditions. For example, the modification of the Charpoua access trail in 1992 (Fig. 3) was connected to the opening of a trail connecting the Charpoua and Couvercle refuges. At the same time, the historical Charpoua access trail was not modified, even though it had been considered dangerous since the mid-1960s. It is for the same reason of tourism that the connections between the Requin and Envers des Aiguilles refuges and the Couvercle and Leschaux refuges were built and equipped in 1990 and 2003, respectively.
- 47 Moreover, the creation of the Chamonix Department of Trail Maintenance (*Service des Pistes et Sentiers de la Ville de Chamonix*) in 2000 also explains the rapid evolution of the access. It may be held liable in case of an accident. This explains why (i) there is more regular maintenance and equipment of the access trails than in the past and (ii) only one access trail is selected and maintained for each refuge. Since the creation of this department, the CCVCMB has had the same management policy regarding the refuges’ access trails. They will be maintained and equipped to ensure acceptable security conditions for mountaineers but without using heavy equipment like Himalayan bridges (pers. comm. CCVCMB, March 2015). This decision is the result of ethical (conservation of wilderness character) and legal arguments (the Mont Blanc massif is a protected site – *site classé* – where all heavy equipment that may modify the state or aspect of the site are subject to legal authorisation; Choay and Merlin, 2005).
- 48 However, our study showed that the glacier thickness loss and the associated lateral moraines erosion make the access trails more dangerous and exposed, which always requires more maintenance and equipment.
- 49 The CCVCMB has already considered the possibility of stopping maintenance of the access trails and dismantling all the equipment if the possibility to preserve acceptable security conditions becomes too binding. This eventuality could have a severe impact on the Mer de Glace basin’s visitor numbers with respect to mountaineers and particularly hikers.
- 50 To improve the safety and attractiveness of the ladders sections, the possibility of equipping them as *via ferrata* (with safety lines) was considered, but the security requirements would be hard to meet in a high mountain context. There would also be ethical concerns and a variety of opinions, depending on the actors concerned by the high mountain environment (high mountain guides, refuge keepers, mountaineers, political decision-makers and environmental protection associations).
- 51 Those conflicts are due to different social perceptions of the mountain and of mountaineering (Piccardi *et al.*, 2014). Should the use of equipment be fostered to

maintain a strong economic activity despite the risk of spoiling the environment? Is it not one of the foundations of mountaineering to adapt to the environment? Otherwise, do these access trails not have a heritage value that could justify their maintenance?

What about the refuges' visitor numbers?

- 52 The geomorphological evolution of the Mer de Glace basin and the difficulties in adapting and managing the access trails at the glacier-slope transitions are putting into question the refuge attendance from both a quantitative and a qualitative point of view. To study this aspect, the principal data source is the number of nights sold per summer season at every refuge. Unfortunately, these data are extremely spotty, and a decline in the number of nights sold could not be directly attributed to the evolution of the access trails; many other reasons (weather conditions, sociocultural evolution etc.) might explain such a decline. Moreover, the number of nights per refuge does not provide qualitative information. Therefore, the analysis is based solely on the qualitative results of the interviews conducted with the refuge keepers from the 1990–2000 period and with the CCVCMB employees responsible for maintaining the trails.
- 53 According to the interviewed individuals, the opening of the “Mer de Glace Balconies” made the areas accessible to hikers and boosted visits to the refuges, which had been decreasing. The current refuge keepers confirm that a sizable number of hikers is visiting the site, with a peak during the 15 July–15 August period. Moreover, this use compensates for the decrease in activity when the conditions for mountaineering are not good enough – often because of hotter and hotter summers (Seneviratne *et al.*, 2014).
- 54 However, the recent evolution of the glacier-slopes transitions makes it riskier for hikers to reach the refuges, and the use of mountaineering techniques tends to become necessary. Thus, one can assume that the hikers may abandon the Mer de Glace basin as the refuges' access trails continue to evolve. In this case, the total number of visitors to this sector could decline significantly, which would have a strong economic impact on the refuge keepers, the high mountain guides and the French Alpine Club (FFCAM). According to the refuge keepers, mountaineers are less affected thanks to their ability to manage risks and assess physical risk in the case of a fall, as well as their technical abilities.

Conclusion

- 55 The evolution of the high mountain environment as a result of climate change is having an ever more drastic impact on access trails to refuges in the Mer de Glace basin. This research focused on the evolution of high mountain environments facing global warming and shows that while the evolution of the routes is directly conditioned by glacial shrinkage, it also has a historical and social dimension. From the 1960s and especially since the 1990s, the glaciers' loss of thickness and the associated erosion of their lateral moraines have required modifications and the equipment of trails more and more often. Between 2001 and 2016, 411 m. of ladders were installed, which increased the total figure to 633 m. at the end of the summer in 2016. Moreover, the glacier-slope transitions tend to become technically more difficult and more dangerous. This work also has a heritage component. A large part of the history of

mountaineering in Mont Blanc, which is the birthplace and a high place of mountaineering, has been reconstituted.

- 56 Finally, the geomorphological evolution perspectives in the study area highlight the limits of adapting access routes. This conclusion raises the question of the future management of those routes and future visits to the refuges. Up to what point is it going to be possible to equip the access trails and maintain acceptable security and technical conditions? It is then that a whole part of mountaineering and the economy linked to it in the Mer de Glace basin could be in jeopardy. Will the evolution of high mountain environments hasten the decline of mountaineering that seems to have started already (Weiss, 2011)?

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ABSTRACTS

Glacial shrinkage and the gravitational processes associated with it, which are characteristic of global warming effects in high mountain environments, are affecting mountaineering routes more and more, including access routes to high altitude refuges. These changes have almost

never been studied. Also, this research seeks to identify and explain the evolution of access trails to five refuges, located in the Mer de Glace basin (Mont Blanc massif), over more than a century. This glacier is the largest in France ($L = 11.5$ km, $SA = 30$ km²) is a major Alpine tourist attraction since 1741 and is the birthplace of mountaineering. This work is based on a three-step methodology: 1) collection and analysis of maps, climbing guidebooks and photographs, 2) semi-structured interviews and 3) analysis of high-resolution digital terrain models obtained through terrestrial laser scanning.

While there was not a significant evolution during most of the 20th century, glacier thickness loss and the associated erosion of lateral moraines have resulted in numerous modifications made to the access trails since the 1990s. Despite these adaptations, the danger they pose continues to rise, and the necessity to equip them is ever more important (633 m. of ladders at present), which raises doubts about the future accessibility of such high mountain refuges.

INDEX

Keywords: mountaineering, glacial shrinkage, paraglacial processes, high mountains, Mont Blanc massif

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