Morphodynamics of the Mont Blanc glaciers and their recent evolution

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1 Supplementary material

10 ### 1.1 Single glaciers description

In this supplementary section we give a brief geographical and geomorphological description for every glacier on which the velocity time series analysis of our study was performed. The 30 glaciers are described in order of their ID number of the study that follows increasing Randolph Glacier Inventory numbering.

15 ID:1 A Neuve N Glacier: this (RGI60-11.02859) is a small (Area= 0.269km2) glacier located in the Swiss part of the Mont Blanc massif. It is the northernmost of different small glaciers formed by the retreat and fragmentation of the once unique A Neuve Glacier. Its aspect is mostly south-east and its accumulation area is overlooked by Grand-Luy Peak (3508m) by less than 100 vertical meters of cliffs. It drains in the Swiss Val Ferret in the Canton of Wallis.

ID:2 A Neuve Central Glacier: this (RGI60-11.02864) is a medium-sized (Area: 0.889km2) glacier located in the Swiss part 20 of the Mont Blanc massif. The analysed part of the A Neuve Glacier is the central section, one which is nowadays distinct from the northern (RGI60-11.02859) and southern parts (RGI60-11.02884); its aspect is mostly east and its accumulation area is overlooked by Tour Noir (3836m) from which the glacier originates with rock walls as high as 800m. It drains in the Swiss Val Ferret in the Canton of Wallis.

ID:3 Pré de Bard Glacier: this (RGI60-11.02916) is a medium-sized (Area: 3.011km2) glacier located in the Italian part of the 25 Mont Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by rock faces from Mont Dolent (3823m), reaching a vertical drop as high as 600m. It drains in Val Ferret, in the Aosta valley region.

ID:4 Greuvettaz E Glacier: this (RGI60-11.02978) is a small (Area: 0.196km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by rock faces from Mont Greuvettaz (3684m), reaching a vertical drop as high as 400m. It drains in the Val Ferret, in the Aosta valley region.

30 ID:5 Greuvettaz W Glacier: this (RGI60-11.02981) is a small (Area: 0.169km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by rock faces from Mont Greuvettaz (3684m), reaching a vertical drop as high as 400m. It drains in the Val Ferret, in the Aosta valley region.

ID:6 Planpincieux Glacier: this (RGI60-11.02991) is a medium-sized (Area: 1.013km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south and its accumulation area is overlooked by rock faces from Grandes 35 Jorasses (4208m), reaching a vertical drop as high as 700m. It drains in Val Ferret, in the Aosta valley region.

ID:7 Grandes Jorasses Glacier: this (part of RGI60-11.02991) is a small (Area: 0.482km2) glacier located in the Italian part of the Mont Blanc massif. It is mapped as a single glacier together with Planpincieux glacier in the Randolph Glacier inventory but it is classified as a single glacial complex in the Italian glacier inventory (Smiraglia, 2015). Its aspect is mostly south-east and its accumulation area is overlooked by Grandes Jorasses (4208m) from which the glacier originates with almost no cirque. It drains in Val Ferret, in the Aosta valley region.

ID:8 Pra-Sec Glacier: this (RGI60-11.02996) is a small (Area: 0.119km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by rock faces from Grandes Jorasses (4208m), reaching a vertical drop as high as 1000m. It drains in Val Ferret, in the Aosta valley region.

ID:9 Rochefort Glacier: this (RGI60-11.03000) is a small (Area: 0.558km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south and its accumulation area is overlooked by rock faces from Dent du Géant (4014m), reaching a vertical drop as high as 900m. It drains in Val Ferret, in the Aosta valley region.

ID:10 Brenva Glacier: this (RGI60-11.03001) is a large (Area: 6.579km2) glacier located in the Italian part of the Mont Blanc massif. Despite a unique glacial complex reaching as low as 1400m, as mapped in the Randolph glacier inventory, since 2005 it has separated into a lower stagnant tongue and a higher part. Its aspect is mostly south-east and its accumulation area is overlooked by the Mont Blanc summit (4809m). Huge cirque head rockwalls dominate the accumulation areas towards Mont Maudit (4465m) on the eastern part and towards Aiguille Blanche de Peuterey (4112m) on the western side. It drains in Val Veny, in the Aosta valley region.

ID:11 Thoula Glacier: this (RGI60-11.03002) is a small (Area: 0.580km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by rock faces from Aiguille d'Entrèves (3596m), reaching a vertical drop as high as 400m. It drains in Val Ferret, in the Aosta valley region.

ID:12 Mont Blanc Glacier: this (part of RGI60-11.03005 - Miage Glacier complex) is a medium-sized (Area: 0.764km2) glacier located in the Italian part of the Mont Blanc massif. As mapped in the Randolph glacier inventory and other glacier inventories, it is a tributary of the large Miage Glacier complex. Even though it is part of the same glacier for inventory purposes, it has both a particular distinct behaviour in terms of cinematics and it has its own topographical designation in cartographies from all of the three bordering nations. Therefore, manual digitalisation of the glacier area was carried out based on Sentinel-2 Satellite Imagery. Its aspect is mostly south-east and its accumulation area is overlooked by the Mont Blanc summit (4809m). Huge cirque head rock walls dominate the accumulation areas towards Mont Maudit (4465m) on the eastern part and towards Aiguille Blanche de Peuterey (4112m) on the western side. It drains in Val Veny, in the Aosta valley region.

ID:13 Dome Glacier: this (part of RGI60-11.03005 - Miage Glacier complex) is a medium-sized (Area: 1.973km2) glacier located in the Italian part of the Mont Blanc massif. As for the Mont Blanc Glacier, as a tributary of the large Miage Glacier complex, it has been remapped in order to obtain morphometrical information of the single glacial body. Its aspect is mostly south-west and its accumulation area is overlooked by the Dome du Gouter summit (4304m) in the western part and by the Mont Blanc summit (4809m) in the eastern part. It drains in Val Veny, in the Aosta valley region.

ID:14 Bionassay Glacier (Italian – it has an homonymous in France): this (part of RGI60-11.03005 - Miage Glacier complex) is a medium-sized (Area: 1.354km2) glacier located in the Italian part of the Mont Blanc massif. The Mont Blanc and Dome Glaciers, as a tributary of the large Miage Glacier complex, was remapped in order to obtain morphometrical information of the single glacial body. Its aspect is mostly south-west and its accumulation area is overlooked by Dome du Gouter summit (4304m). It drains in Val Veny, in the Aosta valley region.

ID:15 Tré-la-Tête N Glacier (Italian – it has a homonymous in France): this (part of RGI60-11.03005 - Miage Glacier complex) is a medium-sized (Area: 0.312km2) glacier is located in the Italian part of the Mont Blanc massif. The Mont Blanc, Bionassay and Dome Glaciers, as a tributary of the large Miage Glacier complex, was remapped in order to obtain

morphometrical information of the single glacial body. Its aspect is mostly north-east and its accumulation area is overlooked by Aiguille de Tré-la-Tête (3920m). It drains in Val Veny, in the Aosta Valley region.

80 ID:16 Freney Glacier: this (RGI60-11.03013) is a medium-sized (Area: 1,017km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by the Mont Blanc summit (4809m). Huge cirque head rockwalls dominate the accumulation areas. It drains in Val Veny, in the Aosta valley region.

ID:17 Brouillard Glacier: this (RGI60-11.03014) is a medium-sized (Area: 1.166km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south and its accumulation area is overlooked by the Mont Blanc summit (4809m).

85 Huge cirque head rockwalls dominate the accumulation areas. It drains in Val Veny, in the Aosta valley region.

ID:18 Lex Blanche Glacier: this (RGI60-11.03020) is a medium-sized (Area: 2.640km2) glacier located in the Italian part of the Mont Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by Aiguilles de Tré-la-Tète (3923m). Cirque head rockwalls dominate the accumulation areas by as much as 600-700m. It drains in Val Veny, in the Aosta valley region.

90 ID:19 Petit Mont Blanc Glacier: this (Part of RGI60-11.03020 – Lex Blanche Glacier) is a small (Area: 0.556km2) glacier located in the Italian part of the Mont Blanc massif. It is mapped in the RGI as a unique glacier complex together with the Lex Blanche Glacier (RGI60-11.03020). Its aspect is mostly south and its accumulation area originates at Aiguille de Tré-la-Tète (3920m). It drains in Val Veny, in the Aosta valley region.

ID:20 Estelette Glacier: this (RGI60-11.03022) is a small (Area: 0.291km2) glacier located in the Italian part of the Mont
95 Blanc massif. Its aspect is mostly south-east and its accumulation area is overlooked by Aiguille des Glaciers (3815m). Cirque head rockwalls dominate the accumulation areas by as much as 600m. It drains in Val Veny, in the Aosta valley region.

ID:21 Pierre Joseph Glacier: this (RGI60-11.03258) is a small (Area: 0.275km2) glacier located in the French part of the Mont Blanc massif. Its aspect is mostly south-west and it originates from Aiguille de Talèfre (3730m) with rockwalls as high as
100 400m. It drains in the Isère valley, in the Haute Savoie Département.

ID:22 Nant Blanc Glacier: this (RGI60-11.03263) is a small (Area: 0.363km2) glacier located in the French part of the Mont Blanc massif. Its aspect is mostly west and it is overlooked by Aiguille Verte (4122m) with up to 800m of cirque headwalls. It drains in the Isère valley, in the Haute Savoie Département.

ID:23 Charpoua Glacier: this (RGI60-11.03284) is a small (Area: 0.405km2) glacier located in the French part of the Mont
105 Blanc massif. Its aspect is mostly south-west and its accumulation area is overlooked by high rock faces from Aiguille Verte (4122m), reaching a vertical drop as high as 700m. It drains in the Vallée de l'Arve, in the Haute Savoie Département.

ID:24 Aiguille des Glaciers Glacier: this (RGI60-11.03339) is a small (Area: 1.091km2) glacier located in the French part of the Mont Blanc massif. Its aspect is mostly south and it originates straight from the very top of Aiguille des Glaciers (3815m). It drains in the Isère valley, in the Haute Savoie Département.

110 ID:25 Talèfre Glacier N: this (RGI60-11.03466) is a medium-sized (Area: 2.037km2) glacier located in the French part of the Mont Blanc massif. We concentrated the study on the westernmost part of the glacier that we mapped accordingly, as it is now almost totally disconnected from the rest of the Talèfre Glacier. It originates from the foot of Aiguille Verte (4122m) with up to 600m of cirque headwalls. It drains in the Vallée de l'Arve, in the Haute Savoie Département.

ID:26 Argentière Glacier: this (RGI60-11.03638) is a large (Area: 13.109km2) glacier located in the French part of the Mont
115 Blanc massif. It originates from the ridges in between Aiguille de Triolet (3870m) and Mont Dolent (3823m). It drains in the Vallée de l'Arve, in the Haute Savoie Département.

ID:27 Mer de Glace Glacier: this (RGI60-11.03646) is a large (Area: 23.556km2) glacier located in the French part of the Mont Blanc massif. It originates from a large accumulation area comprised in between Col du Midi (3522m), Mont Blanc du Tacul (4248m) and Dent du Géant (4014m). It drains in the Vallée de l'Arve, in the Haute Savoie Département.

120 ID:28 Bossons Glacier: this (RGI60-11.03646) is a large (Area: 11.319km2) glacier located in the French part of the Mont Blanc massif. It originates straight from the very top of the Mont Blanc summit (4809m). It drains in the Vallée de l'Arve, in the Haute Savoie Département.

ID:29 Taconnaz Glacier: this (RGI60-11.03647) is a medium-sized (Area: 4,898km2) glacier located in the French part of the Mont Blanc massif. Its aspect is mostly north and it originates straight from the very top of Dome du Gouter (4304m). It
125 drains in the Vallée de l'Arve, in the Haute Savoie Département.

ID: 30 Bionassay Glacier (FR): this (RGI60-11.03648) is a small (Area: 4.774km2) glacier located in the French part of the Mont Blanc massif. Its aspect is mostly north-east and, like the Taconnaz Glacier, it originates straight from the very top of Dome du Gouter (4304m). It drains in the Vallée de l'Arve, in the Haute Savoie Département.

1.2 Mean average velocity map of Mont Blanc 2016-2022 with velocity mapping of ice-free terrain.

130 In order to give a representation for the reader about data quality outside glaciated terrain, we hereby show in Figure S1 a map with Mean average velocity map of Mont Blanc 2016-2022 with velocity mapping of ice-free terrain.
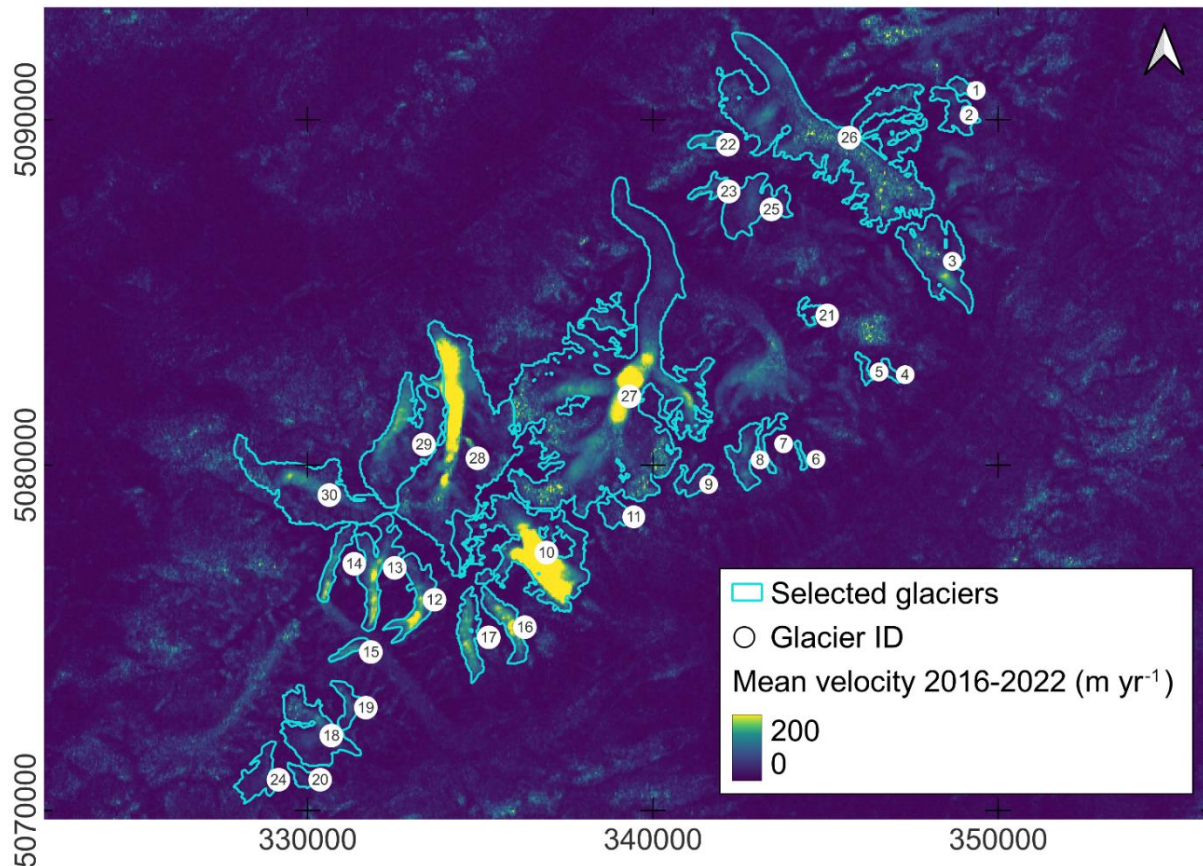
Figure S1. Surface glacier velocity map averaged in the 2016-2022 period. Selected glaciers for specific analyses are outlined in cyan.

1.3 Glacier normalised features

In Figure S2, the normalised features of the 30 selected glaciers of the study considered in the PCA analysis are represented.
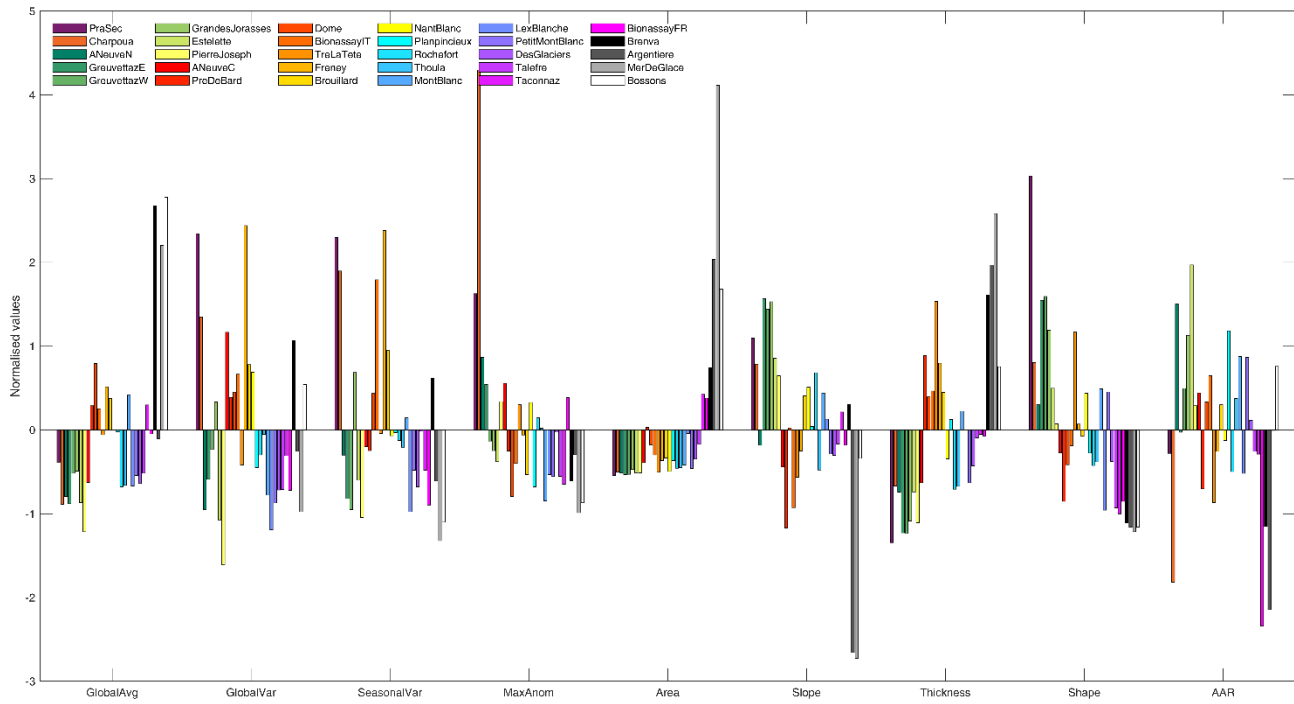
Figure S2. Glacier normalised features considered in the PCA.

1.4 Meteorological conditions

To estimate the meteorological conditions during the period of study, we analysed the data of ERA5-Land monthly averaged data of temperature and precipitation. We calculated the mean temperature and precipitation and the robust linear trends over the periods 2016-2019 and 2020-2022, considering the annual data (i.e., using all the months), the winter data (i.e., months from November to April) and summer months (i.e., from June to September). We averaged the data over the area 45.71°N–46.01°N and 6.60°E–7.10°E. We observed that, on an annual base, the temperature was +0.4°C higher in the second period, when the difference was more marked during winter (+0.6°C), but show a decrease in summer (–0.2°C). Concerning the precipitation, in the second period there was a decrease of 10% (-0.4 mm day^{-1}) on an annual base, which was mostly due by the winters 2018 and 2022, when the precipitation was respectively much higher and lower that the average, while the summer precipitation in 2020–2022 was +5% compared to 2016–2019 (Table S1). Considering the trends, in the first period both temperature and precipitation did not show much variation. In the second period, winter precipitation and temperature remained constant, while we observed similar temperature increase and precipitation decrease on an annual and summer basis (Figure S3).

TableS1. Mean values of monthly temperature (T) and daily precipitation (P) calculated over the periods between 2016–2019 and 2020–2022 considering the whole year, winter (from November to April) and summer (from June to July) months.

Period	Annual mean T [°C]	Winter mean T [°C]	Summer mean T [°C]	Annual mean P [mm/day]	Winter mean P [mm/day]	Summer mean P [mm/day]
2016-2019	2.2	-4.4	11.1	4.4	5.0	3.6
2020-2022	2.6	-3.8	10.9	4.0	4.0	3.8
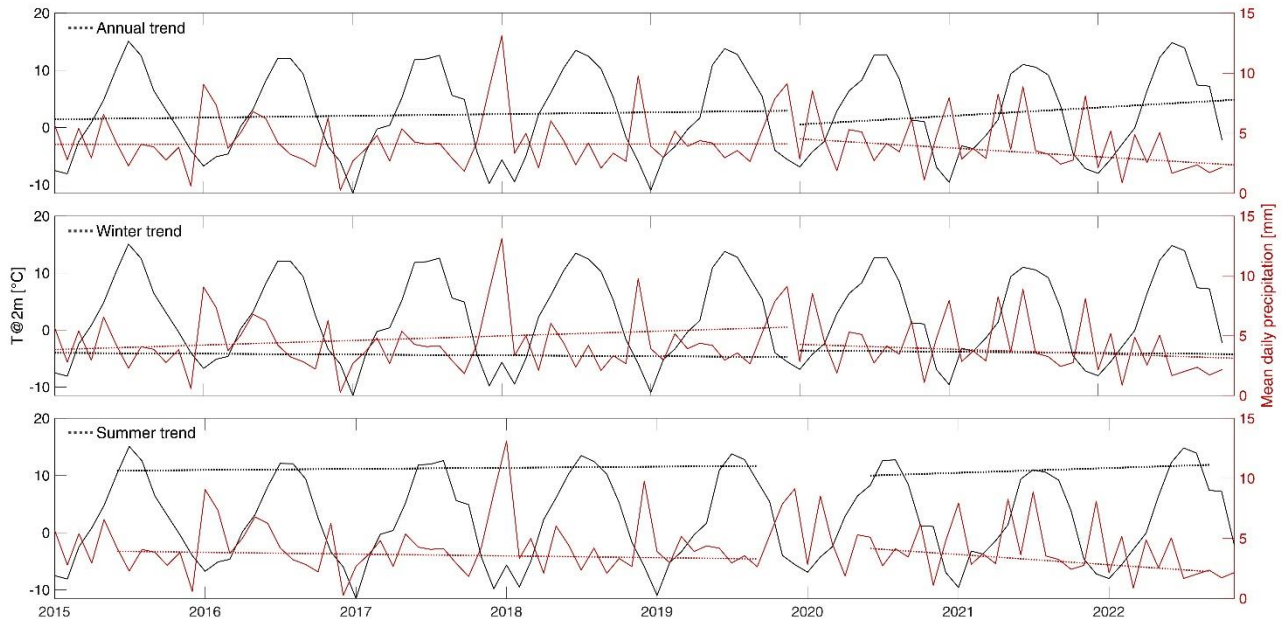
Figure S3. Mean monthly temperature (solid black line) and daily precipitation (solid red line). From the top to the bottom, the dashed lines represent the robust linear trends calculated over the periods 2016-2019 and 2020-2022 using the whole year, winter and summer months.