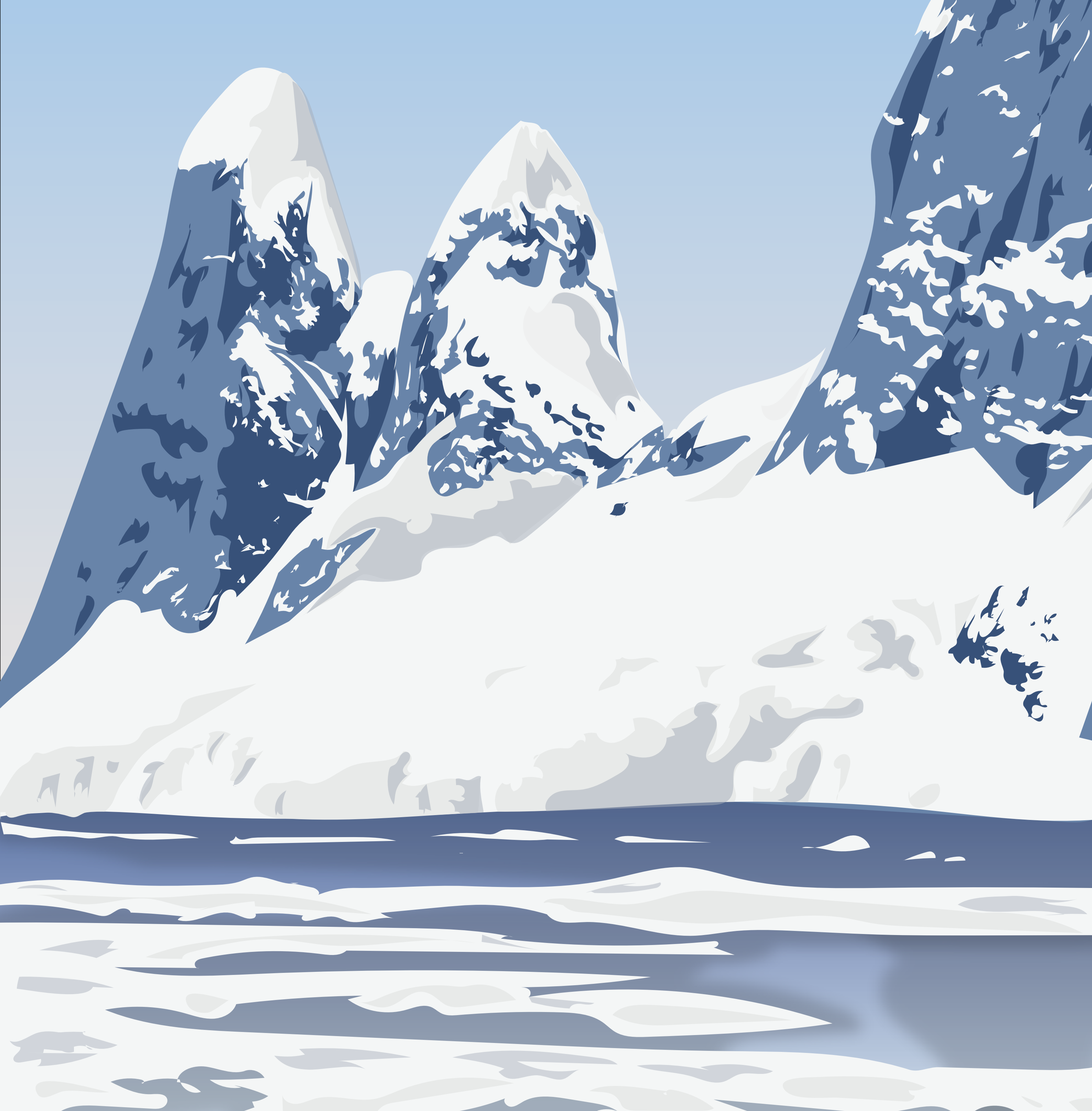
World Heritage Glaciers

Sentinels of climate change



Published in 2022 by the United Nations Educational, Scientific and Cultural Organization (UNESCO), 7, place de Fontenoy, 75352 Paris 07 SP, France and the IUCN, International Union for Conservation of Nature and Natural Resources, Rue Mauverney 28, 1196 Gland, Switzerland.

ISBN: 978-92-3-100557-2
DOI: 10.3929/ethz-b-000578916

Suggested citation: UNESCO, IUCN, 2022: World Heritage Glaciers: Sentinels of climate change, Paris, UNESCO; Gland, IUCN.

Contributors: Tales Carvalho Resende and Mikhail Stepanov (UNESCO); Jean-Baptiste Bosson and Matthew Emslie-Smith (IUCN); Daniel Farinotti, Romain Hugonnet and Matthias Huss (ETH Zurich/Swiss Federal Institute for Forest, Snow and Landscape Research) and Etienne Berthier (LEGOS/CNRS).

Proofreader: Jill Gaston

Acknowledgments: Robbert Casier, Guy Debonnet, Dorine Dubois, Lazare Eloundou Assomo, Maria Gropa, Susanna Kari, Anil Mishra, Nolwazi Mjwara, Ernesto Ottone Ramirez, Richard Veillon

Graphic design: Scienseed and Philippe Lauby

This publication is a contribution to the UNESCO "FutureKeepers" campaign (https://whc.unesco.org/en/futurekeepers) made possible by the Australian Government.

Australian Government

Short summary

Limiting global warming to 1.5°C could save glaciers in two-thirds of World Heritage sites

Glaciers are crucial sources of life on Earth as they provide vital water resources to half of humanity for domestic use, agriculture and hydropower. They are also sacred places for many local communities and attract millions of tourists globally.

Glaciers are some of the most valuable indicators for understanding climate change. Among the most dramatic evidence that Earth's climate is warming is the retreat and disappearance of glaciers around the world. Closely observing and quantifying this phenomenon is essential to develop effective adaptation responses.

Around 18,600 glaciers have been identified in 50 World Heritage sites. These glaciers span an area of about 66,000 km², representing almost 10% of the Earth's glacierized area. Research studies performed with satellite data highlight that these glaciers have been retreating at an accelerating rate since 2000. World Heritage glaciers lose on average some 58 billion tonnes of ice every year —equivalent to the total annual volume of water consumed in France and Spain together—and contribute to almost 5% of global observed sea-level rise. Projections indicate that glaciers in one-third of World Heritage glacierized sites will disappear by 2050 regardless of the applied climate scenario and glaciers in around half of all sites could almost entirely disappear by 2100 in a business-as-usual emissions scenario.

Limiting global warming to 1.5°C could save glaciers in 2/3 of World Heritage sites

The most important protective measure to counteract substantial glacier retreat worldwide is to drastically reduce greenhouse gas emissions. If emissions are drastically cut to limit global warming to 1.5°C relative to pre-industrial levels, glaciers in two-thirds of World Heritage sites could be saved. At site level, adaptative measures need to be strengthened to respond to inevitable glacier changes in the near future. These include identifying knowledge gaps and improving monitoring networks, designing and implementing early warning and disaster risk reduction measures, making glaciers a focus of targeted policy, and promoting knowledge exchange, stakeholder engagement and communication.

The successful implementation of these measures requires the mobilization of key stakeholders (e.g., governments, civil society, Indigenous Peoples, local communities and the private sector) to develop sustainable financing and investments, notably through the establishment of an international fund for glacier research and monitoring.

unesco

"Since wars begin in the minds of men and women, it is in the minds of men and women that the defences of peace must be constructed."

World Heritage Glaciers

Sentinels of climate change

Contents

Huascarán National Park (Peru) © Tainah Narducci / Shutterstock.com*

1

1. World Heritage glaciers: keystones of life

1.1 The critical importance of glaciers for sustaining life on Earth

Covering about 10% of the planet's surface, ice masses[1] are crucial for sustaining life on Earth. Glacial ecosystems provide vital resources to a significant proportion of the global population because of their high biological diversity and ecosystem services such as sediment sinks, freshwater reservoirs and habitats for biodiversity. The benefits include freshwater for domestic use, agriculture, industry and hydropower, as well as climate regulation[2,3].

About 50% of the global biodiversity hotspots on the planet are located in basins drained by glaciers[4] and contain a third of the entire terrestrial species diversity[5] . Often referred to as natural "water towers", glaciers in mountains provide lowlands with essential freshwater supply. The High Mountain ranges of Asia are covered by approximately 100,000 km^2 of glacier ice and feed the great rivers of Central Asia (Amu Darya and Syr Darya) and South Asia (Brahmaputra, Ganges and Indus), Southeast Asia (Huang He, Mekong and Yangtze).

The Antarctic and Greenland ice sheets are the largest bodies of ice in the world and play an important role in the global climate system. They serve as a global thermostat regulating ocean circulation, and their white ice cover cools the atmosphere by reflecting sunlight (albedo effect).

The benefits of glacial ecosystems are not solely physical and biological; they are also important to humans culturally. Glaciers carry huge cultural and spiritual significance for many Indigenous Peoples and local communities (Box 1)and provide economic and educational benefits through the recreation and tourism associated with them.

Box 1: Examples of the cultural importance of glaciers

According to the Māori legend, Hine Hukatere (a Māori demigod) loved to climb mountains and convinced her love Wawe to join her on one of their climbs. During this climb, Wawe was swept away by an avalanche, never to be seen again. Hine Hukatere was heartbroken, and her grief caused her to cry rivers of tears that flowed down the mountain and froze to form the glacier that stands today.

Franz Josef Glacier, or Kā Roimata ō Hine Hukatere (The Tears of Hine Hukatere) in the Te Wahipounamu – South West New Zealand (New Zealand)[7]

© Jan Mika / Shutterstock.com*

Every year, tens of thousands of pilgrims gather in the Peruvian Andes to celebrate Qoyllur Rit'i, or the Snow Star Festival. This centuries-old event is a native celebration of the stars to mark the start of the harvest season. It also honors a local glacier, which is held to be sacred. *Ukukus* (spiritual leaders) used to cut blocks of ice from the glacier to share with the other pilgrims, believing the melted water had healing powers. However, they stopped this tradition after noting a decline in the glacier's size.

The pilgrimage and associated festival were inscribed on the UNESCO Representative List of the Intangible Cultural Heritage of Humanity in 2011[6] .

Qoyllur Rit'i, or the Snow Star Festival in Peru

© National Institute of Culture (Peru), 2004*

[1]Antarctic ice sheet (8.3% of global land surface), Greenland ice sheet (1.2% of global land surface), and glaciers and ice caps (0.5% of global land surface)

[2]Biemans et al., 2019

[3]Cook et al. 2021

[4]UNEP and GRID-Arendal, 2019

[5]Körner, 2004

[6]https://ich.unesco.org/en/RL/pilgrimage-to-the-sanctuary-of-the-lord-of-qoylluriti-00567

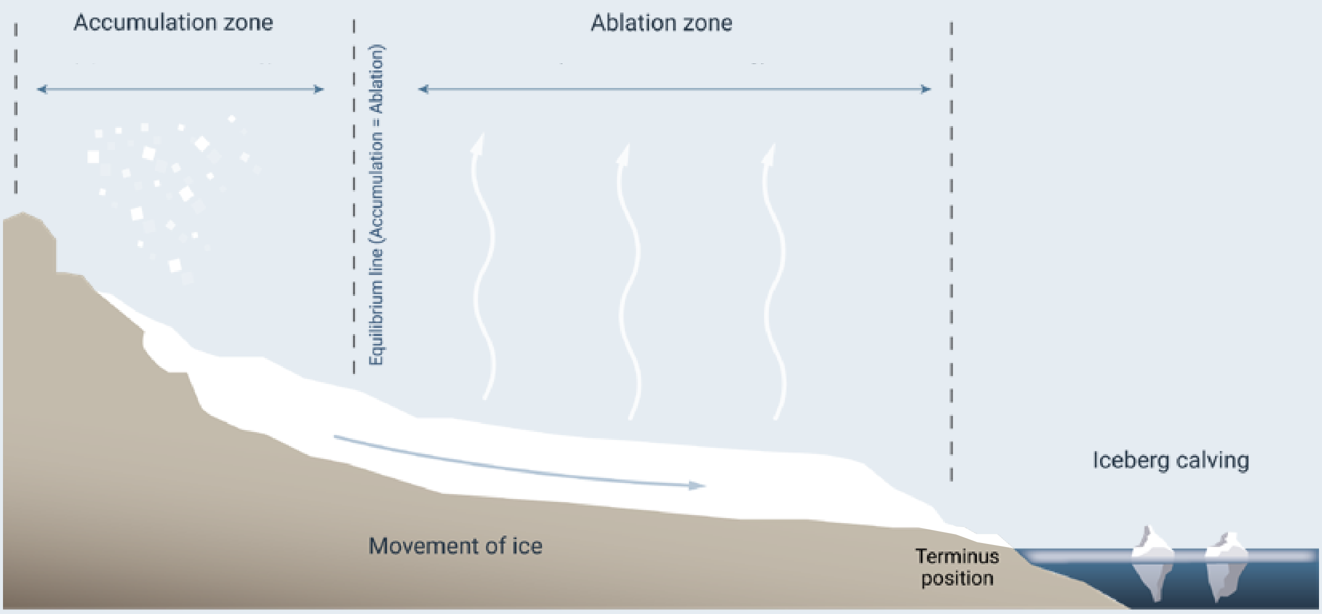
[7]https://whc.unesco.org/en/list/551/

1.2 The dynamics of glaciers

Glaciers are bodies of moving ice that develop as snow accumulated in cold places compacts and recrystallizes. The formation of a glacier takes decades to millennia, and its size varies depending on the amount of ice it retains throughout its lifespan. Each year, glaciers gain and lose mass. They gain mass from snow and precipitation in their upper portions (accumulation zone) and lose mass in their lower portions (ablation zone) by partially melting in summer. In marine-terminating glaciers, they also lose mass by calving icebergs that float away.

The balance between accumulation and ablation is the mass balance of the glacier. If accumulation is greater than ablation, then the glacier has a positive mass balance and will advance. If ablation is greater than accumulation, then the glacier has a negative mass balance and will retreat **(Figure 1)**. The glacier terminus is the end of a glacier at any given point in time. Changes in the terminus position are often used as an important indicator for monitoring the long-term dynamic behavior of glaciers. The rate of change of the glacier terminus position is determined by changes in glacier dynamics. For example, an excess accumulation will lead to increasing glacier velocity and, ultimately, an advance of its front. In marine-terminating glaciers, ocean temperature also influences the stability of the terminus (the calving front) by melting the glacier below the water line and thinning the ice that is in contact with the water.

Figure 1: Simplified diagram of glacier dynamics



Source: UNESCO

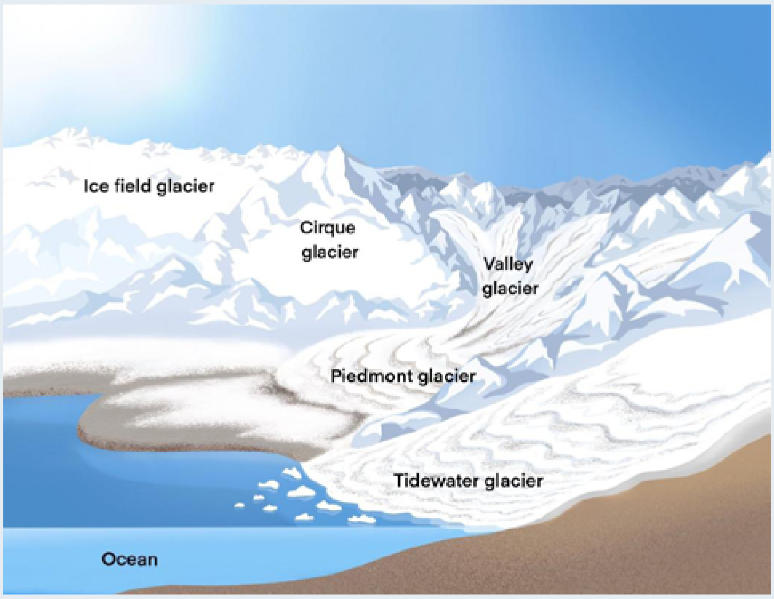
Earth's glaciers vary incredibly in their sizes and shapes, ranging from small cirque glaciers to ice masses hundreds of meters thick in mountains and ice sheets. There are two main groups of glaciers:

- **Unconstrained glaciers,** that have a morphology and flow pattern largely independent of underlying topography, e.g. polar ice caps or the Antarctic and Greenland ice sheets,

Hoffellsjökull Glacier draining the Vatnajökull National Park (Iceland)[8] ice cap

- **Constrained glaciers,** that have a morphology and flow pattern strongly dependent on underlying topography, e.g. ice field, cirque, valley, piedmont and tidewater glaciers.

Types of constrained glaciers



Source: PeakVisor

[8] https://whc.unesco.org/en/list/1604

[9] https://whc.unesco.org/en/list/1557/

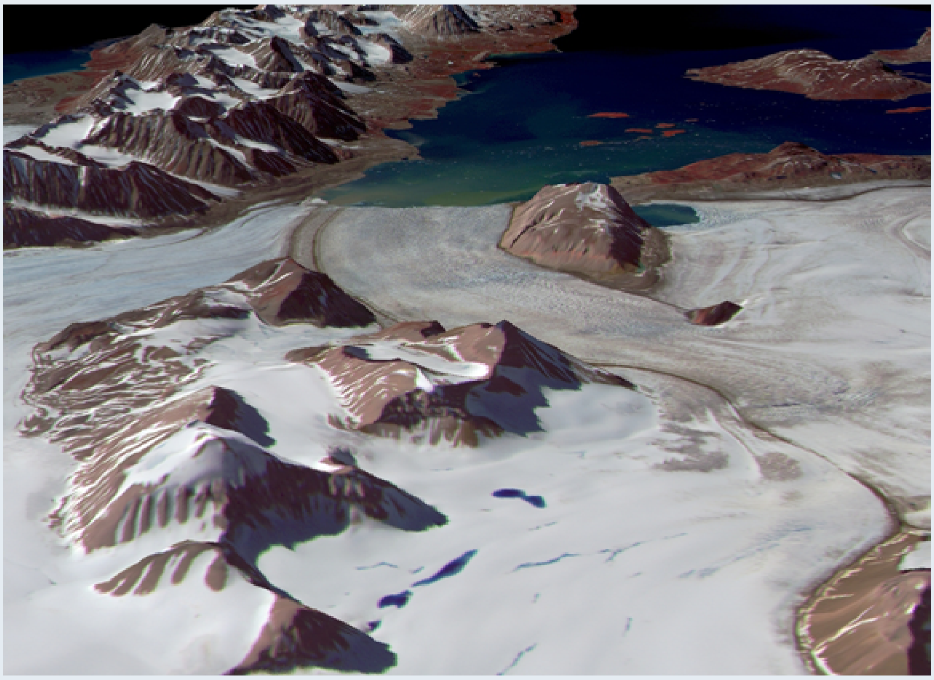
Glaciers are a sensitive indicator of climate change —and one that can be easily observed. Although there are around 200,000 glaciers on the planet, only a few hundred are currently monitored in-situ[10] because they are often difficult to access. Satellite imagery has thus become one of the most valuable methods to keep track of the world's retreating glaciers **(Box 2)**.

Box 2: Monitoring the world's glaciers using satellite imagery

The first attempts to compile a world glacier inventory were based mainly on aerial photographs and maps. Nowadays, satellite imagery is an important resource for global-scale glacier monitoring. Detailed and complete inventories of the world's glaciers[11] have been compiled with great effort over the last few decades. However, these inventories have been limited to glacier extent and surface elevation and do not provide certain key parameters such as glacier thickness.

Recent research efforts have focused on establishing a consensus to better estimate glaciers' ice thickness[12]. Knowing the thickness of glacier ice is critical for projections of future glacier changes (e.g. predicting the rate and timing of glacier retreat and disappearance), subsequent effects on local and regional hydrologic cycles and global sea level, and the associated environmental and social impacts.

Building on these efforts and using satellite-based data, researchers have created high-resolution digital elevation models of all the world's glaciers and reconstructed a time series of glacier surface elevation. This has permitted calculations of changes in the thickness and mass of the ice from 2000 to 2020[13] . For the present report, the results were extracted for glaciers located in World Heritage sites.



© CNRS / Etienne Berthier

[10]Zemp et al., 2015

[11]Gärtner-Roer et al., 2022

[12]Farinotti et al., 2019a

[13]Hugonnet et al., 2021

1.3 World Heritage sites: hosting some of the planet's most iconic glaciers

Adopted in 1972, the UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention) has, to date, been ratified by 194 States united in a shared objective to protect and cherish the world's most outstanding natural and cultural heritage **(Box 3)**. Under this unique international Convention, more than a thousand natural, cultural and mixed (both natural and cultural) sites are currently recognized for their Outstanding Universal Value – "cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity"[14] – and inscribed on the UNESCO World Heritage List[15].

Glaciers have been identified in 50 sites on the UNESCO World Heritage List. Glaciers are one of the principal reasons justifying the inscription of certain sites, including Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America)[16], Sagarmatha National Park (Nepal)[17], Los Glaciares National Park (Argentina)[18], Te Wahipounamu – South West New Zealand (New Zealand), Swiss Alps Jungfrau-Aletsch (Switzerland), Ilulissat Icefjord (Denmark)[19], West Norwegian Fjords – Geirangerfjord and Nærøyfjord (Norway)[20], Tajik National Park (Mountains of the Pamirs) (Tajikistan) [21] and Vatnajökull National Park – Dynamic Nature of Fire and Ice (Iceland)[22]. In around 30 other World Heritage sites, glaciers contribute, together with other features, to the justification for inscription on the List.

Today the UNESCO World Heritage List includes the site with the fastest glacier and largest iceberg producer in the world (Jakobshavn Isbræ Glacier in Ilulissat Icefjord in Denmark), the longest glacier outside polar ice sheets (Bering Glacier in Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek in Canada and the United States of America), the highest glacier system (next to Mount Everest in Sagarmatha National Park in Nepal), the last remaining glaciers in Africa (on Mount Kilimanjaro[23] in the United Republic of Tanzania, Mount Kenya National Park/Natural Forest[24] in Kenya, Rwenzori Mountains National Park[25] in Uganda and the Virunga National Park[26] in the Democratic Republic of the Congo) and some of the largest glaciers of Alaska, Central Asia, Central Europe, New Zealand and the Southern Andes **(Box 4)**.

[14] Paragraph 49 of the Operational Guidelines for the Implementation of the World Heritage Convention: https://whc.unesco.org/en/guidelines/

[15] 897 cultural, 218 natural and 39 mixed sites as of October 2022; list available from https://whc.unesco.org/en/list/

[16] https://whc.unesco.org/en/list/72/

[17] https://whc.unesco.org/en/list/120/

[18] https://whc.unesco.org/en/list/145/

[19] https://whc.unesco.org/en/list/1149/

[20] https://whc.unesco.org/en/list/1195

[21] https://whc.unesco.org/en/list/1252/

[22] https://whc.unesco.org/en/list/1604/

[23] https://whc.unesco.org/en/list/403

[24] https://whc.unesco.org/en/list/800/

[25] https://whc.unesco.org/en/list/684/

[26] https://whc.unesco.org/en/list/63

Box 3: World Heritage Convention: one of the most successful international instruments for nature conservation

The World Heritage Convention is considered one of the most important, efficient and representative area-based global nature conservation programmes. World Heritage sites are among the places with the highest levels of legal protection and expected to demonstrate the best management practices. More than 3.5 million km² (roughly the surface area of India) of land and sea are currently protected under the World Heritage Convention, whose implementation relies notably on the following[27] :

A thorough science-based monitoring system

The World Heritage Convention has an unparalleled system to monitor the state of conservation of sites[28] in order to identify and address emerging conservation issues that could have an impact on the Outstanding Universal Value of the sites. It draws on the expertise of a global network of heritage practitioners, like its technical Advisory Bodies on nature (IUCN) and culture (ICCROM and ICOMOS), thus ensuring scientific credibility, consistency and objectivity.

Action on the ground

The World Heritage Convention inspires communities and nations to do more to recognize and preserve natural heritage. UNESCO provides technical assistance, builds capacity and supports on-the-ground projects to address threats and promote effective management that ensure the highest level of protection for all UNESCO World Heritage sites.

Partnership for sustainable development

The World Heritage Convention recognizes heritage as a shared asset of humanity that should benefit current and future generations. Its implementation requires close alignment with the aims of sustainable development and international cooperation, led by States Parties in partnership with many stakeholders, notably the UNESCO World Heritage Centre, the Advisory Bodies to the World Heritage Committee[29], civil society, Indigenous Peoples, local communities and the private sector.

Against a backdrop of ice blocks and the Lamplugh Glacier, representatives from Glacier Bay National Park and Preserve (United States of America) and West Norwegian Fjords - Geirangerfjord and Nærøyfjord (Norway) signed a Partnership Agreement in September 2019 to share best practices between site managers, including management plans, research and monitoring protocols

[27] https://whc.unesco.org/en/guidelines/

[28] State of Conservation Information System: https://whc.unesco.org/en/soc/

[29] The World Heritage Committee is one of the governing bodies of the Convention. It consists of representatives from 21 of the States Parties. Among its mission, it decides whether a site is inscribed on the UNESCO World Heritage List, examines reports on the state of conservation of inscribed properties and asks States Parties to take action when sites are not being properly managed.

Box 4: Some outstanding World Heritage glaciers

© Ralph Rozema / Shutterstock.com*

The Jakobshavn Isbræ Glacier (also known as Sermeq Kujalleq) in Ilulissat Icefjord (Denmark) is one of the most active glaciers in the world moving several tenths of meters per day. It drains approximately 6.5% of the Greenland ice sheet and produces around 10% of all Greenland's icebergs. It is believed that the iceberg that hit the Titanic in 1912 broke off from this glacier. Studied for over 250 years, the Jakobshavn Isbræ Glacier has helped develop the modern understanding of climate change and ice sheet science.

© Michal Knitl / Shutterstock.com*

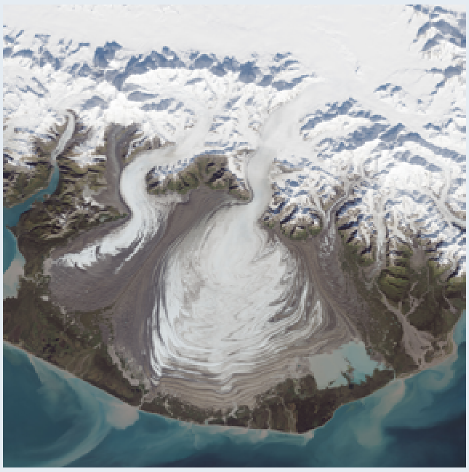
The Fedchenko Glacier in Tajik National Park (Tajikistan) is the largest valley glacier in Central Asia. It currently extends over 70 km, making it the longest glacier in the world outside of the polar ice sheets. Covering an area of over 700 km², the glacier may reach a maximum thickness of 1 km.

© Arsgera / Shutterstock.com*

With elevations up to 4,900 m at its terminus and fed by many hanging glaciers located above 8,000 m, the Khumbu Glacier, not far from the Mount Everest base camp in Sagarmatha National Park (Nepal), is part of the world's highest glacier system.

© Hyserb / Shutterstock.com*

Mount Kilimanjaro (United Republic of Tanzania), Mount Kenya National Park/National Forest (Kenya), Rwenzori Mountains National Park (Uganda) and Virunga National Park (Democratic Republic of the Congo) feature the last remaining glaciers in Africa. Although these glaciers are too small to act as significant water reservoirs, they are of eminent scientific and cultural importance and attract thousands of tourists every year.



Source: Google Earth, 24 September 2014 (NASA Earth Observatory website)

The Malaspina Glacier in southeastern Alaska in Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America) is the largest piedmont glacier in the world, a type of glacier in which the flow spills from a narrow valley onto a flat plain and spreads out like a fan. The glacier is about 65 km wide and 45 km long, with an area of some 3,900 km².

© KONDRATEV ALEXEY / Shutterstock.com*

The Great Aletsch Glacier in Swiss Alps Jungfrau-Aletsch (Switzerland), known widely by its German name Grosser Aletschgletscher, is the largest glacier in the Alps. The glacier is remarkable for creating a canyon that looks like a man-made road down the slopes to the valley. Some of the highest and most visited peaks in Europe are found in this region.

© saiko3p / Shutterstock.com*

Los Glaciares National Park (Argentina) is an area of exceptional natural beauty, with rugged, towering mountains and numerous glacial lakes, including Lake Argentino, which is 160 km long. At its farthest end, three glaciers (Upsala, Onelli and Perito Moreno) meet.

Around 18,600 glaciers have been identified in World Heritage sites and span an area of about 66,000 km², representing almost 10% of the Earth's glacierized area[30] **(Table 1)**. From very small cirque glaciers (less than 10 km²) to large ice caps (more than 1000 km²), all types of glaciers can be found in World Heritage sites. Most World Heritage glaciers are situated in mountain regions outside the polar ice sheets **(Figure 2)**[31,32]. The World Heritage site with both the largest glacierized area and number of glaciers is Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America), which accounts for approximately 60% of the total glacierized area and 30% of glaciers in World Heritage sites, respectively. The region[33] with the largest glacierized area and number of glaciers in World Heritage sites is Europe and North America (53,068 km² and 9,540 glaciers) followed by Asia and the Pacific (9,704 km² and 7,904 glaciers), Latin America and the Caribbean (3,212 km² and 1,119 glaciers) and Africa (16 km² and 37 glaciers).

Table 1: World Heritage sites ranked by glacierized area and number of glaciers

Rank	Glacierized area in 2000	Number of glaciers
All World Heritage glacierized sites (50)	66,000 km²	18,600
1	Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America) (39,074 km²)	Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America) (6,107)
2	Vatnajökull National Park – Dynamic Nature of Fire and Ice (Iceland) (8,137 km²)	Tajik National Park (Mountains of the Pamirs) (Tajikistan) (3,934)
3	Tajik National Park (Mountains of the Pamirs) (Tajikistan) (5,117 km²)	Te Wahipounamu – South West New Zealand (New Zealand) (2,278)
4	Ilulissat Icefjord (Denmark) (2,960 km²)	Canadian Rocky Mountain Parks (Canada) (878)
5	Los Glaciares National Park (Argentina) (2,612 km²)	Huascaran National Park (Peru) (563)
6	Xinjiang Tianshan (China) (1,925 km²)	Xinjiang Tianshan (China) (467)
7	Canadian Rocky Mountain Parks (Canada) (973 km²)	Golden Mountains of Altai (Russian Federation) (432)
8	Te Wahipounamu – South West New Zealand (New Zealand) (884 km²)	Waterton Glacier International Peace Park (Canada, United States of America) (407)
9	Qinghai Hoh Xil (China) (724 km²)	Qinghai Hoh Xil (China) (362)
10	Aasivissuit – Nipisat Inuit Hunting Ground between Ice and Sea (Denmark) (700 km²)	Los Glaciares National Park (Argentina) (340)

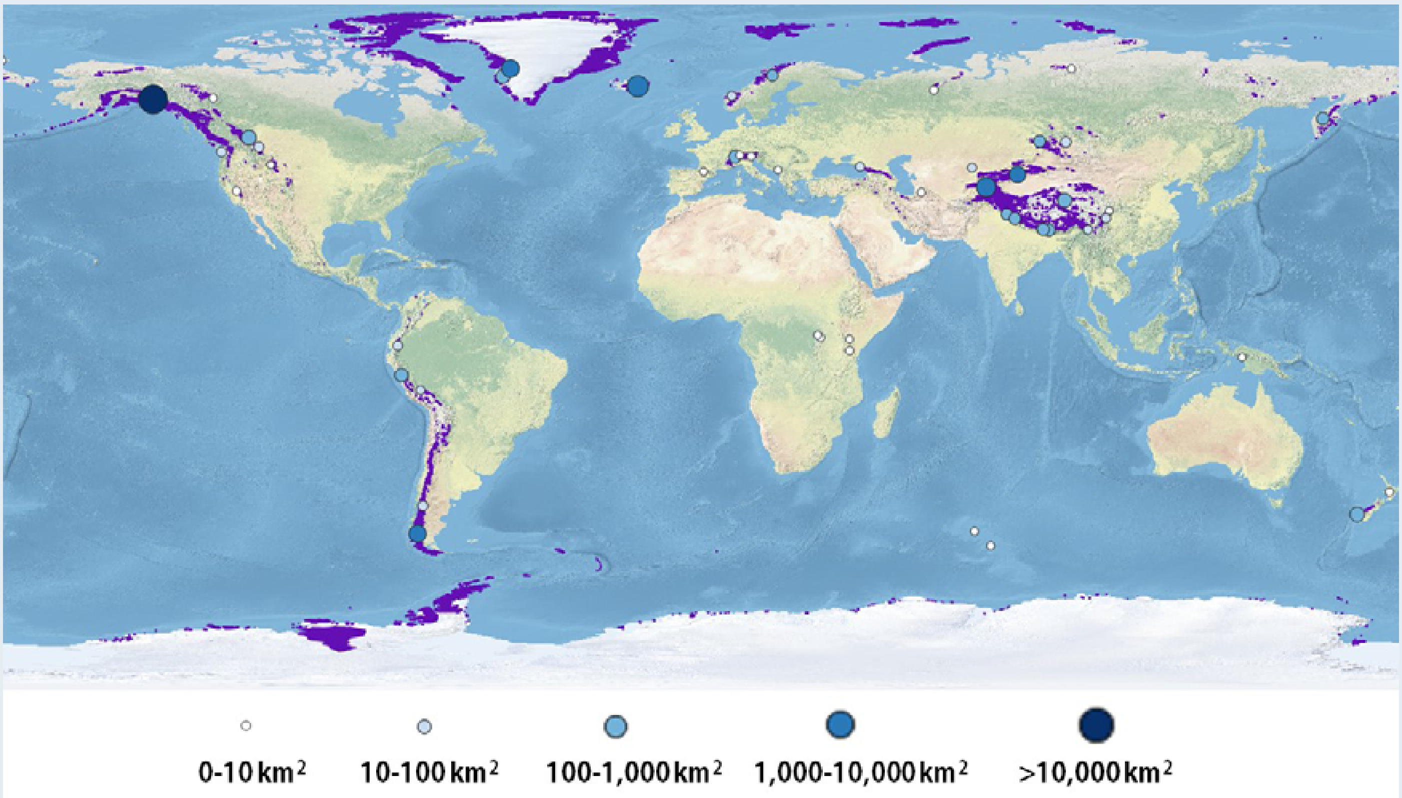
[30]Calculated based on GLIMS and NSIDC (2005, updated 2018)

[31]Only two sites are situated in Greenland, Denmark (Aasivissuit – Nipisat and Ilulissat Icefjord)

[32]No sites in Antarctica (the world's largest continental ice sheet, covering around 14 million km²) have been inscribed on the UNESCO World Heritage List; the Convention does not apply to that region because it is out of national jurisdiction. According to Article 3 of the Convention, only properties situated on the territory of a sovereign State can be inscribed.

[33]UNESCO organizes its Member States into five regional groups: Africa, Arab States, Asia and the Pacific, Europe and North America, and Latin America and the Caribbean.

Figure 2: **Map of World Heritage glacierized sites**



Note: Zones in purple correspond to glacierized areas.
Source: GLIMS and NSIDC (2005, updated 2018).

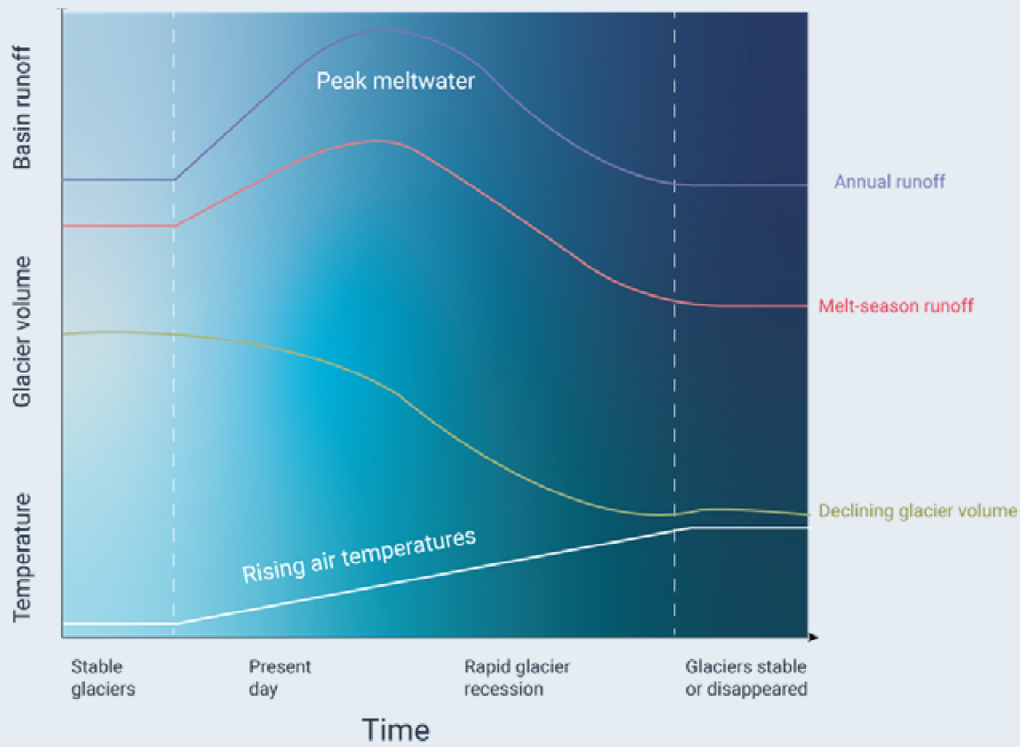
Ilulissat Icefjord (Denmark) © Michal Balada / Shutterstock.com*

World Heritage glaciers in a changing climate

2.1 Glaciers in a warming climate

Among the most dramatic evidence that Earth's climate is warming is the retreat of glaciers around the world. Glacial changes have important implications for water availability in relation to a wide array of ecosystem processes and human uses. The annual melting of glaciers provides meltwater to streams and downstream communities for their daily lives. As temperatures rise due to climate change, the amount of meltwater that glaciers produce will increase and more water from long-term glacial storage will be released. However, this increase is temporary. Once a maximum meltwater contribution (peak water) is reached, annual runoff is then reduced as the glacier shrinks beyond a size where it is no longer able to produce a large volume of meltwater (Figure 3). In a future scenario, where glaciers continue to recede, one can assume that most of the runoff will be concentrated in the wetter times of the year, while little to no base flow will be available during the dryer periods. As such, glaciers might no longer be able to provide their buffering role in years of heat waves and drought. For many small glaciers in the Andes, Central Europe and Western Canada, peak water either has passed or is expected to occur within the next decade[34]. In the Himalayas, annual glacier runoff is projected to rise until roughly 2050, followed by a steady decline thereafter[35].

Figure 3: Schematic illustration of the changes in glacier runoff and volume in response to global warming



Source: Adapted from Huss and Hock, 2018

[34]Huss and Hock, 2018

[35]Kraaijenbrink et al., 2021

The decrease in glacier runoff is likely to have negative impacts on agricultural production and food security and result in water stress that could be exacerbated by increasing demand for water due to expanding farmland to feed a growing population[36]. Changes in glacier runoff could also impact hydropower production. An estimate from one of Peru´s largest hydropower plants, Canon del Pato, suggested that there could be a reduction of 15% in the plant's energy production in the case where glaciers disappear completely[37]. Besides these impacts, glacier changes will lead to plant and animal species' shifting ranges to adapt to the changing habitat[38].

The accelerated glacier and snow melt due to climate change will increase the formation of glacial lakes[39]. These lakes are formed when meltwater fills depressions or holes created on the surface of the land by glacial erosion. Glacial lake expansion may foster positive and negative impacts. On the one hand, these lakes can provide important ecosystem services. On the other hand, they can trigger glacial hazards[40]. The banks of such lakes (moraines) may collapse when they fill up – leading to sudden and violent flooding in the downstream valleys. Floods of this sort, referred to as glacial lake outburst floods (GLOFs), can have disastrous consequences for the populations and biodiversity of the entire regions downstream of the lakes. Such collapses not only trigger floods but can also alter water quality due to high sediment loading and damage key downstream infrastructure[41].

As temperatures rise and ice melts, more water flows to the seas from glaciers and ice caps. Ocean water gets warmer and expands in volume. This combination of effects plays a major role in raising the average sea level. In marine-terminating glaciers, glacial retreat and melting can trigger landslide-induced tsunamis[42]. In addition, as more ice melts, more darker surfaces will appear, leading to more heat being absorbed, hence amplifying the cycle of warming[43].

Climate change impacts and risks are becoming increasingly complex and more difficult to manage. Multiple climate hazards can occur simultaneously, and multiple climatic and non-climatic risks can interact, resulting in compounding overall risk and in risks cascading across sectors and regions[44]. For instance, the devastating flooding in Pakistan in August 2022 that left almost one-third of the country under water is reported to have been triggered by a combination of heavier-than-usual monsoon rains. Locally, impacts of the flood may have been enhanced by glacier lake outbursts due to melting glaciers following a severe heat wave in spring.[45].

2.2 Significant ice mass loss and sea-level rise in the early 21st century

All glacierized World Heritage sites had a negative mass balance from 2000 to 2020, meaning that they lost more ice than they gained. Overall, World Heritage glaciers lost around 1,163 billion tonnes (Gt) of ice during that period[46], representing on average some 58 billion tonnes of ice per year—an amount equivalent to the total annual volume of water consumed in France and Spain together[47]. Assuming that all meltwater ultimately reached the ocean, ice loss in World Heritage sites caused around 4.5% of the observed global sea-level rise from 2000 to 2020[48] —some 3.22 millimetres.

Net ice mass loss in World Heritage sites over those two decades occurred in all regions across the world and was mainly concentrated in the Arctic region (glaciers peripherical to the Greenland ice sheet and Iceland) and North America **(Table 2)**. Around two-thirds of the World Heritage network's ice mass loss occurred in glaciers outside the polar ice sheets.

[36] Lutz et al., 2022
[37] Vergara et al., 2007
[38] Cauvy-Fraunié and Dangles, 2019
[39] Compagno et al., 2022
[40] Zheng et al., 2021
[41] Farinotti et al. 2019b
[42] Higman et al., 2018
[43] Pistone et al., 2014
[44] IPCC, 2022
[45] Pakistan Meteorological Department, 2022
[46] Estimated based on Hugonnet et al., 2021 and Mouginot et al., 2019
[47] European Environment Agency, 2022
[48] NASA Sea Level Change, https://sealevel.nasa.gov/understanding-sea-level/key-indicators/global-mean-sea-level

Table 2: Largest net ice mass losses in World Heritage sites from 2000 to 2020 and equivalent sea-level rise

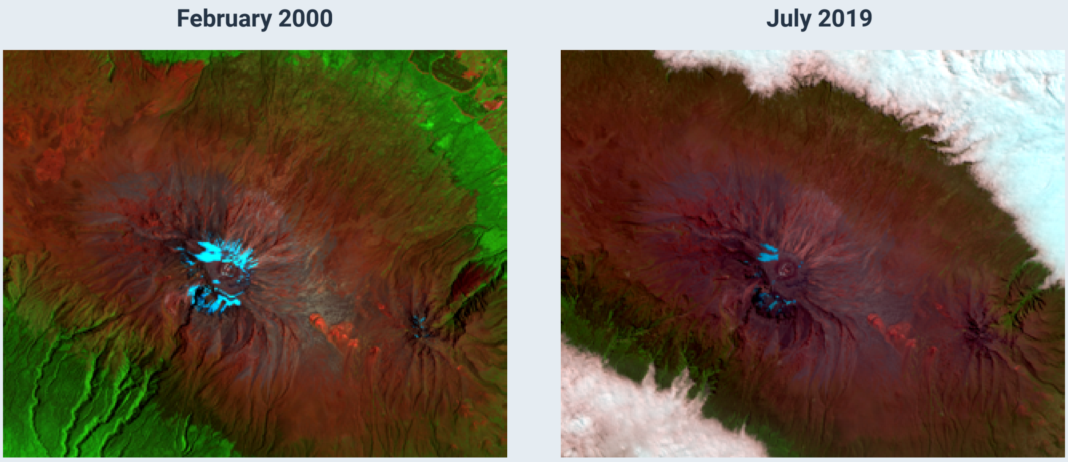
	Site	Glacier region (According to the Randolph Glacier Inventory)	Net ice mass loss from 2000 to 2020 in billion tonnes (Gt)	Equivalent sea-level rise from 2000 to 2020 (mm)
	All World Heritage glacierized sites (50)		**1,163**	**3.22**
1	Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America)	Alaska	487	1.35
2	Ilulissat Icefjord (Denmark)	Arctic (Greenland ice sheet)	350	0.97
3	Vatnajökull National Park – Dynamic Nature of Fire and Ice (Iceland)	Arctic (Iceland)	132	0.37
4	Los Glaciares National Park (Argentina)	Southern Andes	88	0.24
5	Aasivissuit – Nipisat Inuit Hunting Ground between Ice and Sea (Denmark)	Arctic (Greenland ice sheet)	39	0.11
6	Tajik National Park (Mountains of the Pamirs) (Tajikistan)	Central Asia	12	0.03
7	Te Wahipounamu – South West New Zealand (New Zealand)	New Zealand	10	0.03
8	Canadian Rocky Mountain Parks (Canada)	Western Canada and USA	9	0.02
9	Swiss Alps Jungfrau-Aletsch (Switzerland)	Central Europe	7	0.01
10	Xinjiang Tianshan (China)	Central Asia	4	0.01

Source: Analysis (Box 4) of Hugonnet et al., 2021 data in World Heritage sites outside the polar ice sheets. Results for the two sites located in Greenland were estimated using Mouginot et al., 2019. Results should be taken with caution given existing uncertainties.

The site with the largest net ice mass loss from 2000 to 2020 was Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America) (487 Gt), followed by Ilulissat Icefjord (Denmark) (350 Gt), Vatnajökull National Park – Dynamic Nature of Fire and Ice (Iceland) (132 Gt), Los Glaciares National Park (Argentina) (88 Gt) and Aasivissuit – Nipisat (Denmark) (39 Gt). These five sites together account for around 95% of the World Heritage network's total ice mass loss. Many sites that made a limited contribution to the World Heritage's overall total ice loss still lost a considerable amount of their glacier mass **(Figure 4)**. At least one-fifth of all sites lost more than 25% of their glacier mass in just 20 years **(Table 3)**.

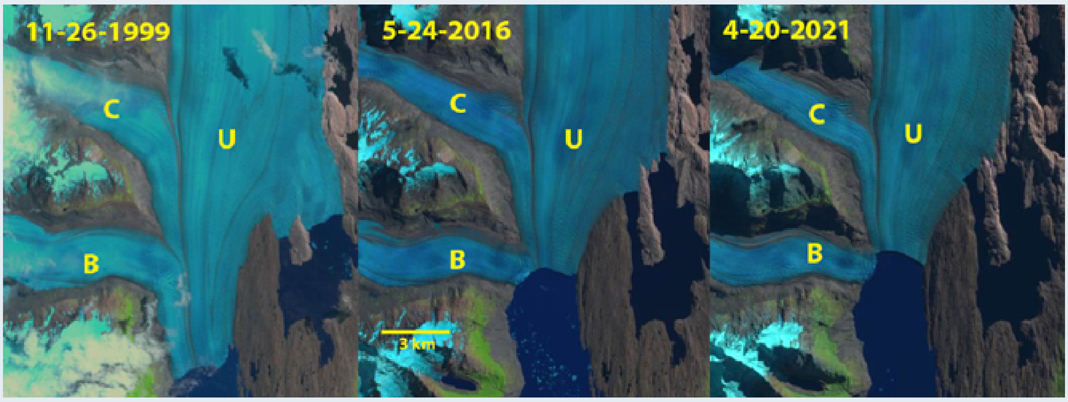
Figure 4: Glacier retreat observed by satellite imagery in selected World Heritage sites

Landsat images from 21 February 2000 (left) and 27 July 2019 (right) illustrating glacier retreat on top of Mount Kilimanjaro (United Republic of Tanzania)



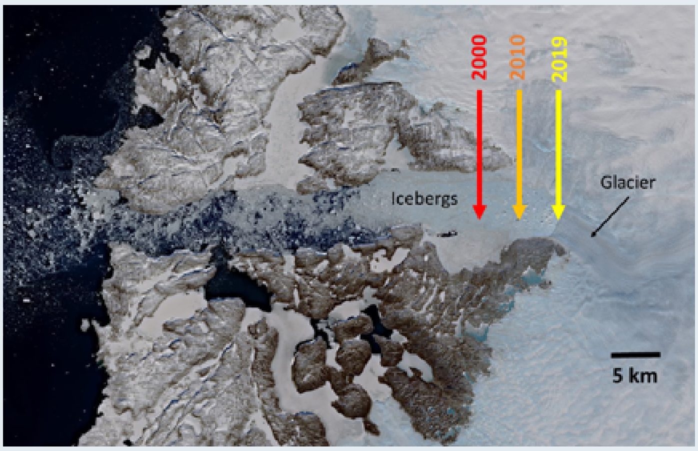
Source: U.S. Geological Survey

Landsat images from 1999, 2016 and 2021 illustrating both the retreat and the separation of the Upsala Glacier (U) from Bertacchi Glacier (B) in Los Glaciares National Park (Argentina). Cono Glacier (C) is the next tributary to the north.



Source: AGU Blogosphere

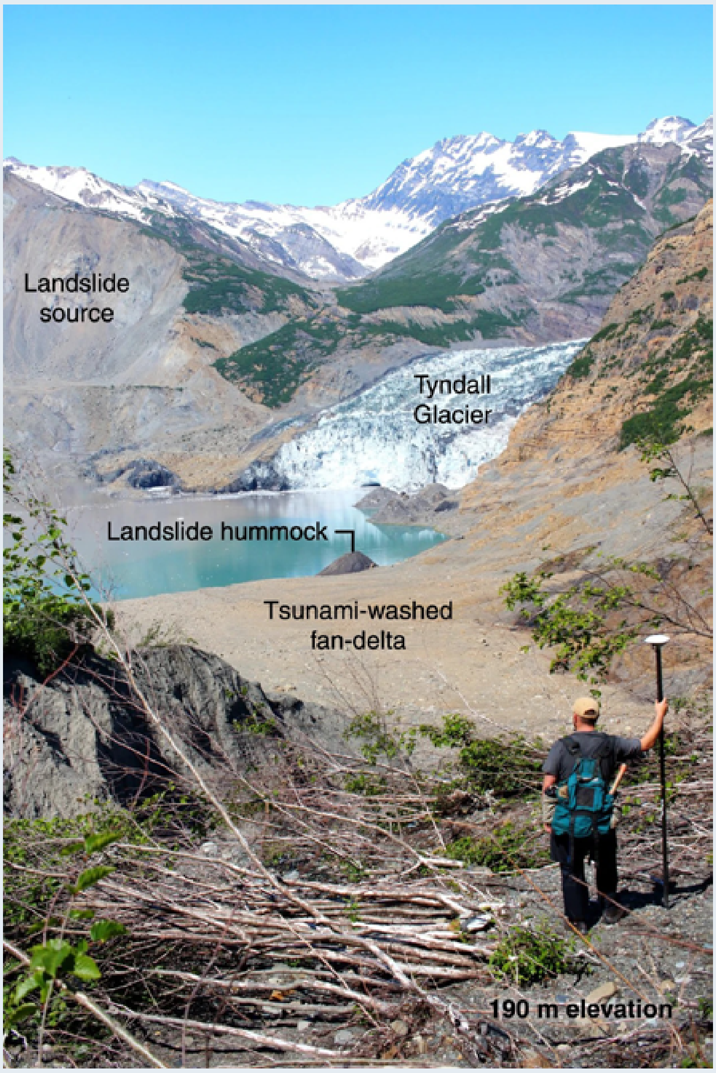
Copernicus Sentinel-2 image from 29 April 2019 of Jakobshavn Isbræ Glacier in Ilulissat Icefjord (Denmark). The red arrow shows the glacier's terminus position in 2000, the orange arrow the 2010 position and the yellow arrow the 2019 position.



Source: Adapted from ESA

Intense glacier retreat has already affected local hydrology and landscape configuration in some sites. For instance, the expansion of glacial lakes in Tajik National Park (Tajikistan)[49], and tsunamis and changes in river flow in Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America) have been associated with glacier retreat[50]. For instance, a massive landslide in Wrangell-St. Elias National Park and Preserve generated a tsunami that stripped 20km² of forest and reached elevations as high as 190 m, the fourth-highest tsunami ever recorded **(Figure 5)**. However, local impacts and direct observations of how glacier changes affect biological communities in most World Heritage sites remain poorly documented because of the remote and lightly populated character of many of these sites.

Figure 5: Impacts of the 2015 landslide and tsunami in Wrangell-St. Elias National Park and Preserve (United States of America). The person in the photo is standing just below the limit of inundation 2 km away from the Tyndall Glacier terminus at about 190 m above the fjord level.



Source: Higman et al., 2018

[49] Osipova et al., 2020

[50] Loso et al., 2021

Table 3: Glacier ice losses relative to 2000 in World Heritage sites

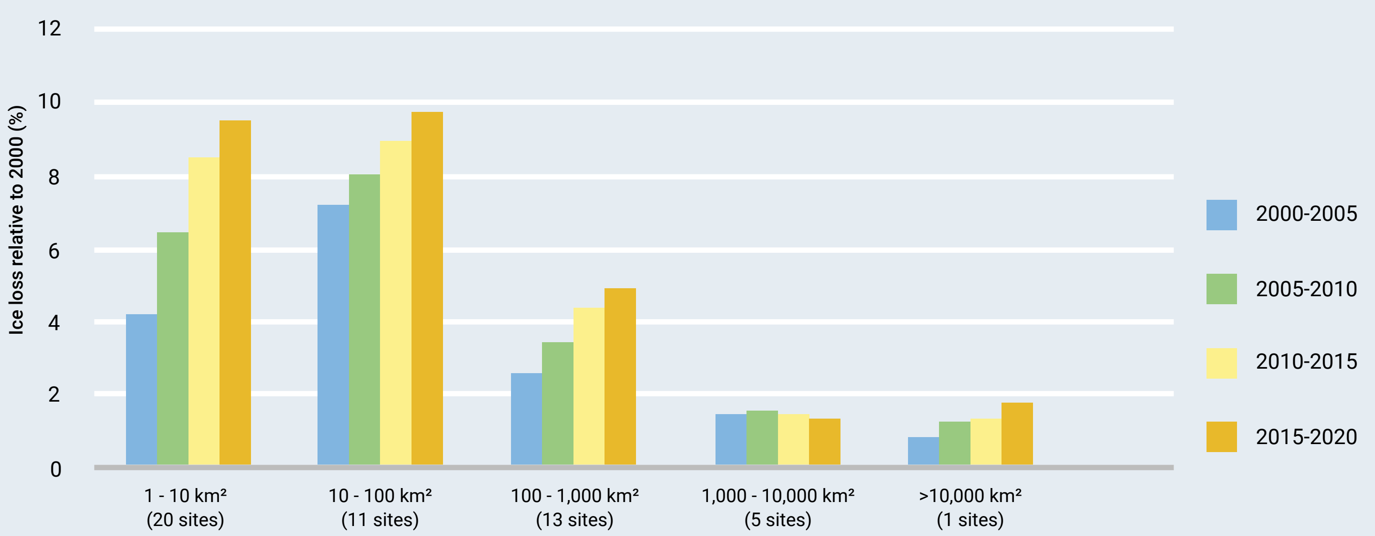
Rank	Code	Site	Glacierized area (km²)	Mass in 2000 (Gt)	Mass loss relative to 2000(%)
1	Yu	Three Parallel Rivers of Yunnan Protected Areas (China)	17	0.3	57.2
2	La	Los Alerces National Park (Argentina)	54	1.4	45.6
3	Uv	Uvs Nuur Basin (Mongolia, Russian Federation)	82	2.8	37.0
4	Si	Sichuan Giant Panda Sanctuaries – Wolong, Mt Siguniang and Jiajin Mountains (China)	28	0.7	35.9
5	Nf	West Norwegian Fjords – Geirangerfjord and Naeroyfjord (Norway)	24	0.9	33.2
6	Ts	Western Tien-Shan (Kazakhstan, Kyrgyzstan, Uzbekistan)	24	0.6	27.1
7	Ol	Olympic National Park (United States of America)	39	1.3	26.5
8	Wg	Waterton Glacier International Peace Park (Canada, United States of America)	42	0.7	26.5
9	Ja	Swiss Alps Jungfrau-Aletsch (Switzerland)	319	25.7	25.9
10	Lp	Laponian Area (Sweden)	180	9.5	25.7
11	Ma	Golden Mountains of Altai (Russian Federation)	239	10.4	19.8
12	Tw	Te Wahipounamu - South West New Zealand (New Zealand)	884	53.9	19.2
13	Ka	Volcanoes of Kamchatka (Russian Federation)	296	21.9	16.6
14	Gh	Great Himalayan National Park Conservation Area (India)	155	7.0	16.0
15	Rm	Canadian Rocky Mountain Parks (Canada)	973	59.4	15.9
16	Hu	Huascarán National Park (Peru)	493	17.9	15.2
17	Sa	Sagarmatha National Park (Nepal)	249	16.7	14.7
18	Kh	Khangchendzonga National Park (India)	284	16.2	13.0
19	Lg	Los Glaciares National Park (Argentina)	2,612	687.6	12.9
20	Nd	Nanda Devi and Valley of Flowers National Parks (India)	194	10.8	10.5
21	Mp	Historic Sanctuary of Machu Picchu (Peru)	15	0.4	8.0
22	Sg	Sangay National Park (Ecuador)	39	1.0	7.3
23	Qh	Qinghai Hoh Xil (China)	724	54.0	6.0
24	Kw	Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America)	39,074	9,295.0	5.2
25	Va	Vatnajökull National Park - Dynamic Nature of Fire and Ice (Iceland)	8,137	2,704.0	4.9
26	Xt	Xinjiang Tianshan (China)	1,925	124.0	3.3
27	Ta	Tajik National Park (Mountains of the Pamirs) (Tajikistan)	5,117	380.7	3.2

Source: Analysis (Box 4) of Hugonnet et al., 2021 data in World Heritage sites outside the polar ice sheets. Ice mass in 2000 was estimated based on Farinotti et al., 2019a. Sites with glacierized area <10 km² were not considered in the analysis as uncertainties are high for these sites.

2.3 World Heritage glaciers' accelerated melting

While glaciers have been retreating worldwide, not all of them are losing mass at the same relative rate. Similar to the global trend, glaciers in most World Heritage sites are melting at an accelerated rate due to climate change. The fastest-accelerating ice loss rates were found in sites with smaller glacierized areas, as they tend to respond more quickly to climatic changes. Ice loss rates in sites with the smallest glacierized area (less than 10 km²) more than doubled from the early 2000s to the late 2010s **(Figure 6)**.

Figure 6: Total glacier ice loss in five-year periods relative to ice volume, 2000-2020

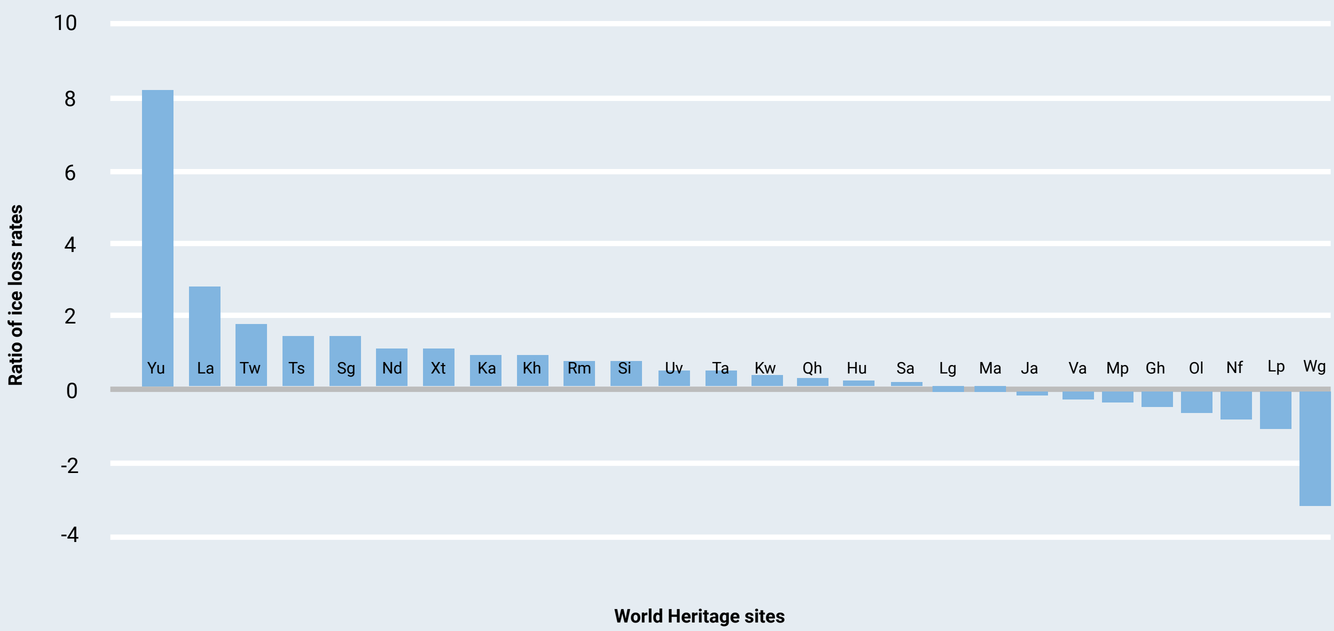


Sites with the fastest-accelerating ice loss rates are mainly located in Asian mountain ranges, while those with loss rates slowing down are mostly in Western Canada and United States of America and close to the Arctic region **(Figure 7)**. Ice loss accelerated in the sites situated in the Arctic region from the early 2000s to the mid-2010s and then declined until the end of the 2010s. This slowdown is associated with weather anomalies in the region that delivered increased snowfall and cooled ocean waters at the end of the 2010s[51]. However, recent research indicates that ice loss has accelerated again since 2020[52].

[51] Khazendar et al., 2019

[52] Sasgen et al., 2020

Figure 7: Temporal evolution of glacier ice loss rates in World Heritage sites, 2000-2020



Note: All the sites listed experienced glacier mass loss from 2000 to 2020 but at different rates. Values on the Y-axis correspond to the ratio of ice loss rates from 2000 to 2020. A site with a ratio of 2 means that ice loss rates doubled during this period. Positive values mean that glacier ice loss accelerated, and negative values show it decelerated. Codes in the X-axis represent World Heritage sites as indicated in Table 3.

2.4 Disappearing World Heritage glaciers

During the last decade, various global glacier evolution models have been used to provide estimates on the future sea-level contribution from glaciers[53]. Independent of the emission scenario applied, glaciers and ice sheets are expected to continue losing ice mass and remain important contributors to global sea-level rise in the 21st century. Glaciers and ice caps, excluding the large polar ice sheets, are projected to lose about 30% of their mass during this century for a low greenhouse gas emission scenario corresponding to a 1.5°C global warming (Representative Concentration Pathway [RCP] 2.6) and about 60% for the current business-as-usual high-emission scenario corresponding to global warming higher than 4°C (RCP8.5)[54]. The magnitude of the relative ice melt will strongly depend on the size of the glaciers. The most noticeable impact will be on small glaciers, as they rapidly respond to climatic variations, while impacts on larger glaciers will take longer.

[53] Huss and Hock, 2015

[54] IPCC, 2019

A first attempt to compute the individual responses of World Heritage glaciers was recently undertaken[55]. Projections indicate that, regardless of the applied climate scenario, glaciers in all World Heritage sites outside the polar ice sheets with glacierized areas less than 10 km^2 may almost completely disappear by 2050[56]. This represents around one-third of all World Heritage glacierized sites and includes the last remaining glaciers in Africa (on Mount Kilimanjaro, Mount Kenya and the Rwenzori-Virunga mountains) as well as other iconic sites in Europe and North America such as the Dolomites (Italy), Pyrénées – Mont Perdu (France, Spain), Yellowstone National Park and Yosemite National Park (United States of America). In a business-as-usual high-emission scenario (RCP8.5), glaciers in at least 10 other sites[57] (mainly sites with a glacierized area ranging from 10 to 100 km^2) could almost completely disappear by 2100, and ice mass loss may reach more than 8,000 Gt[58] in total (or around 20 mm sea-level rise equivalent) – an amount equal to the volume of water that could submerge the entire surface area of Brazil under one meter. However, if emissions are cut to limit global warming to 1.5°C (RCP2.6), ice mass loss could be reduced by around 30% compared to a business-as-usual scenario, and glaciers in two-thirds of World Heritage glacierized sites could be saved. These results emphasize the strong influence the reduction of emissions could have on the magnitude of ice loss and on World Heritage glaciers preservation.

[55]Bosson et al., 2019

[56]The Dolomites (Italy), Durmitor National Park (Montenegro), Huanlong Scenic and Historic Interest Area (China), Hyrcanian Forests (Iran), Kilimanjaro National Park (Tanzania), Lorentz National Park (Indonesia), Mount Kenya National Park/Natural Forest (Kenya), Nahanni National Park (Canada), Natural System of Wrangel Island Reserve (Russian Federation), Putorana Plateau (Russian Federation), Pyrénées - Mont Perdu (France, Spain), Rwenzori Mountains National Park (Uganda), Swiss Tectonic Arena Sardona (Switzerland), Virgin Komi Forests (Russian Federation), Virunga National Park (Democratic Republic of the Congo), Yellowstone National Park (United States of America) and Yosemite National Park (United States of America).

[57] Historic Sanctuary of Machu Picchu (Peru), Los Alerces National Park (Argentina), Olympic National Park (United States of America), Sangay National Park (Ecuador), Sichuan Giant Panda Sanctuary Wolong Mt Siguniang and Jiajin Mountains (China), Three Parallel Rivers of Yunnan Protected Areas (China), Waterton-Glacier International Peace Park (Canada, United States of America), West Norwegian Fjords – Geirangerfjord and Nærøyfjord (Norway), Western Caucasus (Russian Federation) and Western Tien-Shan (Kazakhstan, Kyrgyzstan, Uzbekistan).

[58]Estimates from Choi et al., 2021 were adapted for the two sites in Greenland and added to those of Bosson et al., 2019.


The Dolomites (Italy) © boerchatdanai / Shutterstock.com

Limiting global warming to 1.5°C: a critical action to protect World Heritage glaciers

The main action to counteract substantial glacier retreat worldwide due to climate change is to drastically cut greenhouse gas emissions to limit global warming to 1.5°C in line with the Paris Agreement agreed under the United Nations Framework Convention on Climate Change (UNFCCC). In its Decision 41 COM 7, the World Heritage Committee, as the Governing Body of the World Heritage Convention, reiterated to the States Parties to the Convention the importance of "*undertaking the most ambitious implementation of the Paris Agreement*" by "*holding the increase in the global average temperature to well below 2°C above pre-industrial levels and by pursuing efforts to limit the global average temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change*". The Committee further invited "*all States Parties to ratify the Paris Agreement at the earliest possible opportunity and to undertake actions to address Climate Change under the Paris Agreement consistent with their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances, that are fully consistent with their obligations within the* World Heritage Convention *to protect the [Outstanding Universal Value] of all World Heritage properties*"[59].

To protect the Outstanding Universal Value, integrity and authenticity of World Heritage sites from the adverse impacts of climate change, UNESCO and its partners have developed several institutional policies, strategies and guidelines for climate action (see list at end of report) including a dedicated policy on climate action for World Heritage, which is currently being updated. The policy document provides a framework for developing action plans at the site level. In line with this framework, the following pathways for action are proposed to foster discussion on how to reduce emissions most efficiently and to respond to inevitable changes in World Heritage glacierized sites, with the understanding that implementation must be tailored to local physical, cultural and societal contexts.

Identify knowledge gaps and improve monitoring networks

Glacier monitoring is in many ways the starting point to assess different downstream impacts and develop effective response measures. Continuous in-situ observations and monitoring of glaciers are lacking in numerous sites and many aspects of glacial changes still remain highly uncertain (e.g. glacial lakes) due to limited monitoring networks. Reasons include missing long-term financial and/or human resources, difficult access to remote regions, and a lack of infrastructure.

Monitoring strategies therefore need to be improved and different techniques such as in-situ measurements, remote sensing, satellite data and modelling must be combined to generate high-quality products. Improved data-gathering infrastructure is needed to monitor climate change at glaciers, including for example establishing a network of automated weather stations at high elevations and additional on-site monitoring. On the modelling front, more detailed climate change projections, relying on a variety of models and several different emissions scenarios are needed, particularly considering that climate change impacts are disproportionately high in mountains. Modelling should also include assessing the types of habitats that could succeed glaciers in the future.

In addition, monitoring strategies need to be more inclusive and proactively involve Indigenous Peoples and local communities. They should use co-production approaches, acknowledge the value of traditional research practices and recognize local and indigenous knowledge systems.

[59] Decision 41 COM 7 of the World Heritage Committee: https://whc.unesco.org/en/decisions/6940

Design and implement early warning and disaster risk reduction measures

Comprehensive and successful adaptation actions addressing disasters must be built on a robust foundation of the best available understanding of current and future glacier evolution. The modernization of hydrometeorological networks and disaster response capacities, as well as actions by humanitarian agencies and research organizations contribute to risk reduction. Many national governments and international partners recognize the dangers of hazards such as glacial lake outburst floods and support monitoring and response measures. However, the number of World Heritage sites with established policies, plans or processes for managing or reducing risks associated with disasters remains low[60], and disaster response mechanisms focus solely on response, rather than prevention, communication or early warning.

Local populations within and in the vicinity of many sites remain under-equipped, untrained and uninformed about nearby glacial hazards. Adaptation measures should therefore focus on implementing preventive measures, including for example creating vulnerability assessment and risk exposure maps, developing local risk plans, regulating land-use planning, and creating early warning systems to be complemented by comprehensive education and awareness programmes. For instance, in Glacier Bay National Park and Preserve, one of the components of Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (Canada, United States of America), where tsunamis resulting from increased calving rates or landslides associated with glacial retreat present a risk to local communities, tsunami hazard preparedness and community awareness programmes have been promoted, and efforts are underway to increase the number of coastal communities that are labeled as “Tsunami Ready”[61].

Make glaciers a focus of targeted adaptation policy

Despite their critical role in environmental sustainability, national adaptation policies rarely recognize the unique problems and challenges related to glaciers. Glaciers around the world are protected, either as part of their environmental protection schemes (e.g. embedded in land-use plans) or through specific legislation unto itself[62]. However, few countries possess an adequate legal and regulatory framework or public policy to protect glaciers. Laws written specifically to protect glaciers have only recently been considered within national political agendas. For instance, Argentina became the first country in the world to adopt a Glacier Protection Act in 2010. Given the importance of glaciers for water security, approaches and strategies for integrated water resources management should be developed and updated, taking into consideration new information and trends on glaciers.

On-going efforts to raise awareness of the importance of glaciers in international fora should continue and be strengthened. In 2019, the Intergovernmental Panel on Climate Change (IPCC) launched a special report on the ocean and cryosphere[63], which will provide more detailed information on glaciers to the IPCC Sixth Assessment Report (AR6) to be released in early 2023. More recently, Tajikistan called on the international community at the 77th Session of the United Nations General Assembly in 2022 to adopt a resolution declaring 2025 as an international year for glaciers' preservation and establish a specialized “International Fund for Glacier Preservation”[64] to support comprehensive

[60] https://whc.unesco.org/en/review/74

[61] TsunamiReady® Program: https://www.weather.gov/tsunamiready/

[62] Cox, 2016

[63] IPCC, 2019

[64] Statement by Mr. Sirojiddin Muhriddin, Minister of Foreign Affairs of the Republic of Tajikistan, at the General Debates of the 77th Session of the United Nations General Assembly

research and develop effective response measures. At the regional level, initiatives by the Arctic Council[65] and under the Antarctic Treaty have been coordinating international actions to address the effects of climate and environmental changes in the polar regions. In Europe, the eight states (Austria, France, Germany, Italy, Liechtenstein, Monaco, Slovenia and Switzerland) that ratified the Alpine Convention have also undertaken specific actions for glaciers preservation. However, a similar solid framework for the protection of mountain ranges in the Americas and Asia does not exist yet and should therefore be explored. World Heritage can play an important role in climate adaptation strategies. Recognising and including World Heritage in adaptation approaches and policies from site level to national and international levels can strengthen actions to adapt and build resilience to climate change.

Promote knowledge exchange, stakeholder engagement and communication

Strengthening community adaptation and resilience to climate change is reliant upon effective engagement of stakeholders and rights-holders. In particular, Indigenous Peoples and local communities are on the frontline of climate change and will be the first to experience its adverse impacts. They have been constantly adapting to the effects of environmental stresses for millennia and have thus developed sophisticated approaches towards the management of resources in their local ecosystems, many of which are embedded in culture, traditional practices and belief systems, allowing them to adapt to climate change by forecasting weather patterns, improving agricultural practices and sustainably managing natural resources. While the risks they face are manifold, Indigenous Peoples and local communities are becoming increasingly recognized as agents of change in achieving strong and meaningful climate action. Most recently, the IPCC acknowledged Indigenous Peoples and local communities as key partners to "*support the implementation of ambitious actions implied by limiting global warming to 1.5°C*"[66].

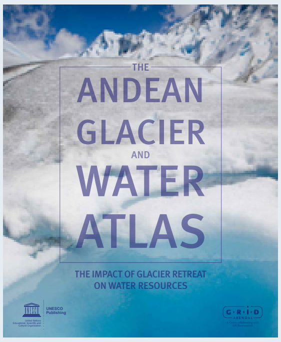
World Heritage sites offer a unique opportunity to recognize and involve Indigenous Peoples and local communities as effective stewards of glaciers through enhanced climate action governance processes and to improve diverse knowledge mobilisation, education, awareness raising, and human and institutional capacity in relation to the risks and responses arising from climate change impacts. This could include, among other actions, establishing community-based monitoring programmes and the development of processes that involve Indigenous Peoples and local communities in the collection of data and information used for adaptation planning at all levels. As such, when a wide diversity of stakeholders (including municipalities, rural communities, civil society, private sector, national governments, etc.) in a glacial ecosystem have greater awareness of its dependence on glacial meltwater, they can be prompted to adapt to the changes occurring and to prepare for some of the hazards that come with glacial decline, like short-term flooding and long-term drought. World Heritage site managers also constitute a flagship network of heritage custodians to be empowered to share experiences through site-to-site field visits, e-communication and global managers conferences.

[65] The Arctic Council is a high-level intergovernmental forum established in 1996 by eight Arctic states (Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden and the United States of America) to promote cooperation, coordination and interaction among the Arctic states, Arctic Indigenous Peoples and other Arctic inhabitants on common Arctic issues, in particular those of sustainable development and environmental protection in the Arctic.

[66] IPCC, 2018

Box 5: UNESCO's action to protect glaciers worldwide

UNESCO has been advocating for the protection of glaciers for more than 50 years. During the early 1960s, UNESCO supported the compilation and assemblage of data of the first worldwide inventory of existing ice and snow masses[67]. Since then, UNESCO has developed several initiatives on glaciers around the world, particularly in the Andean region and in Central Asia (see list at end of report). Activities focus, for example, on providing a scientific basis for national and regional strategies on climate adaptation promoting regional platforms to share knowledge and best practices, on assessing risks to local communities of hazards such as landslides and glacier lake outburst floods, and on promoting indigenous and local knowledge systems, as well as research, education and capacity development to assess the impact of climate change on glaciers.



The Andean Glacier and Water Atlas was published by UNESCO in 2018.

UNESCO has also been proactively supporting international scientific research and monitoring initiatives, such as the World Glacier Monitoring Service (WGMS), and the Ice Memory project which aims at collecting, saving and managing ice cores from glaciers in danger of degradation or disappearance[68]. In 2021, UNESCO's main governing body - the General Conference – adopted a resolution[69] calling Member States, international organizations, academic institutions, professional organizations and other relevant stakeholders to strengthen mountain glacier monitoring and research, particularly in UNESCO-designated sites (World Heritage sites, Biosphere Reserves and UNESCO Global Geoparks).

Wild red tulips blooming in the Chatkal Mountain range in Western Tian Shan (Western Tien-Shan (Kazakhstan, Kyrgyzstan, Uzbekistan)

© Uhryn Larysa / Shutterstock.com*

"Climate change impacts on mountain regions of the world", an exhibition on the changes occurring in mountainous regions, was displayed in several locations around the globe, reaching vulnerable communities.

© UNESCO / Lima

[67] UNESCO and IASH, 1970

[68] https://unesco.delegfrance.org/Inauguration-du-colloque-de-lancement-international-de-Ice-Memory-a-l-UNESCO

[69] Records of the General Conference, 41st session, Paris, 9-24 November 2021, Volume 1: Resolutions. https://unesdoc.unesco.org/ark:/48223/pf0000380399

Vatnajökull National Park - Dynamic Nature of Fire and Ice (Iceland) © Kathleen Herman / Shutterstock.com*

4

Conclusion

Climate change will inevitably cause glaciers in World Heritage sites to keep retreating, and many will even disappear. These glacial retreats will impact biodiversity and human societies and could directly affect the Outstanding Universal Value of sites that have been inscribed on the UNESCO World Heritage List for their exceptional glaciers. As stated above, glaciers in one-third of World Heritage sites will disappear by 2050 regardless of the applied climate scenario and glaciers in around half of all sites could almost entirely disappear by 2100 in a business-as-usual emissions scenario.

The most important protective measure to counteract substantial glacier retreat worldwide is to drastically reduce greenhouse gas emissions. Research efforts have demonstrated that the difference in impact between low and high greenhouse gas emission pathways on 21st-century glacier retreat and its related effects is enormous. If emissions are drastically cut to limit global warming to 1.5°C relative to pre-industrial levels, glaciers in two-thirds of World Heritage sites could be saved. At site-level, adaptative measures need to be strengthened to respond to inevitable glacier changes in the near future.

In a global context where the legal and regulatory framework on glaciers is still limited, World Heritage sites represent a unique model system for examining the effects of global warming, raising awareness on the importance of glaciers and catalyzing enhanced climate action to meet the goals of the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCC). The high profile, global reach and inspirational power of these sites underpin a strong case to mobilize key stakeholders (e.g. governments, civil society, Indigenous Peoples, local communities and the private sector) to take climate action and develop inclusive strategies that integrate different types of knowledge systems, including scientific and traditional knowledge. New inscriptions of sites could also contribute to raising awareness at both the global and local levels on the key role World Heritage glaciers can play in environmental sustainability. While the UNESCO World Heritage List already covers most of the largest and iconic glacier systems, there are still several areas across the world that could be potential future candidates (e.g. Torres del Paine and Bernardo O'Higgins National Parks in Chile, China Altay and Karakorum-Pamir in China and Central Karakorum National Park in Pakistan[70])[71].

Lack of sustainable funding is among one of the most prevalent issues hampering the effective protection and management of all World Heritage sites[72]. Hence, there is an acute need to bridge the funding gap to successfully implement actions for the effective monitoring of glaciers, notably through the establishment of an international fund for glaciers to support comprehensive research and develop effective response measures.

The impacts of climate change on glaciers in World Heritage sites show the urgent action that is required to protect the outstanding universal value of glaciers and ensure the benefits they provide to humanity. Mitigating climate change through deep reductions in greenhouse gas emissions is the most important and pressing priority for safeguarding glaciers, and must be accompanied by urgent, ambitious and coordinated action to improve knowledge and monitoring, and targeted adaptation policies and measures, through inclusive engagement and communication.

70 Jaeger, 2021

71 These sites are currently on countries' World Heritage Tentative Lists—a pre-requisite condition for inscription as a World Heritage site

72 Osipova et al., 2020


Khangchendzonga National Park © Risingmoon3377 / Shutterstock.com*

References

Biemans, H., Siderius, C., Lutz, A.F. et al. (2019). Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. Nature Sustainability, 2, pp. 594–601

https://doi.org/10.1038/s41893-019-0305-3

Bosson, J.-B., Huss, M. Osipova, E. (2019). Disappearing World Heritage Glaciers as a Keystone of Nature Conservation in a Changing Climate. Earth's Future, 7(4), pp. 469-479.

https://doi.org/10.1029/2018EF001139

Cauvy-Fraunié, S., Dangles, O. (2019). A global synthesis of biodiversity responses to glacier retreat. Nature Ecology & Evolution, 3, pp. 1675–1685.

https://doi.org/10.1038/s41559-019-1042-8

Choi, Y., Morlighem, M., Rignot, E. et al. (2021). Ice dynamics will remain a primary driver of Greenland ice sheet mass loss over the next century. Nature Communications Earth & Environment, 2(26).

https://doi.org/10.1038/s43247-021-00092-z

Compagno, L., Huss, M., Zekollari, H. et al. (2022). Future growth and decline of high mountain Asia's ice-dammed lakes and associated risk. Nature Communications Earth & Environment, 3(191).

https://doi.org/10.1038/s43247-022-00520-8

Cook, D., Malinauskaite, L., Davíðsdóttir, B., Ögmundardóttir, H. (2021). Co-production processes underpinning the ecosystem services of glaciers and adaptive management in the era of climate change. Ecosystem Services, 50, 101342.

https://doi.org/10.1016/j.ecoser.2021.101342

Cox, J. (2016). Finding a place for glaciers within environmental law: An analysis of ambiguous legislation and impractical common law. Appeal, 21, pp. 21-36.

https://ca.vlex.com/vid/finding-place-for-glaciers-862728051

European Environment Agency (2022). Water abstraction by source, 2000-2019.

https://www.eea.europa.eu/data-and-maps/daviz/water-abstraction-by-source-2000-2019

Farinotti, D., Huss, M., Fürst, J.J. et al. (2019a). A consensus estimate for the ice thickness distribution of all glaciers on Earth. Nature Geoscience, 12, pp. 168–173.

https://doi.org/10.1038/s41561-019-0300-3

Farinotti, D., Round, V., Huss, M., Compagno, L. and Zekollari, H. (2019b). Large hydropower and water storage potential in future glacier-free basins. Nature, 575, pp. 341-344.

https://doi.org/10.1038/s41586-019-1740-z

Gärtner-Roer, I., Nussbaumer, S. U., Raup, B. et al. (2022). Democratizing Glacier Data – Maturity of Worldwide Datasets and Future Ambitions. Frontiers in Climate, 4, 841103.

https://doi.org/10.3389/fclim.2022.841103

GLIMS and NSIDC (2005, updated 2018). Global Land Ice Measurements from Space glacier database. Compiled and made available by the international Global Land Ice Measurements from Space community and the National Snow and Ice Data Center, USA.

https://doi.org/10.7265/N5V98602

Higman, B., Shugar, D.H., Stark, C.P. et al. (2018). The 2015 landslide and tsunami in Taan Fiord, Alaska. Nature Scientific Reports, 8, 12993.

https://doi.org/10.1038/s41598-018-30475-w

Hugonnet, R., McNabb, R., Berthier, E. et al. (2021). Accelerated global glacier mass loss in the early twenty-first century. Nature, 592, pp 726–731.

https://doi.org/10.1038/s41586-021-03436-z

Huss, M. and Hock, R. (2015). A new model for global glacier change and sea-level rise. Frontiers in Earth Science, 3.

https://doi.org/10.3389/feart.2015.00054

Huss, M. and Hock, R. (2018). Global-scale hydrological response to future glacier mass loss. Nature Climate Change, 8, pp. 135–140.

https://doi.org/10.1038/s41558-017-0049-x

Intergovernmental Panel on Climate Change (IPCC) (2018). IPCC Special Report on the impacts of global warming of 1.5°C.

https://www.ipcc.ch/sr15/

Intergovernmental Panel on Climate Change (IPCC) (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Cambridge University Press, Cambridge, UK and New York, NY, USA.

https://doi.org/10.1017/9781009157964.

Intergovernmental Panel on Climate Change (IPCC) (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

https://www.ipcc.ch/report/ar6/wg2/

Jaeger, T. (2021). Leveraging the World Heritage Convention for conservation in the Hindu Kush Himalaya: An independent assessment of natural World Heritage potential. Gland, Switzerland: IUCN.

https://doi.org/10.2305/IUCN.CH.2021.18.en

Khazendar, A., Fenty, I.G., Carroll, D. et al. (2019). Interruption of two decades of Jakobshavn Isbrae acceleration and thinning as regional ocean cools. Nature Geoscience, 12, pp. 277–283

https://doi.org/10.1038/s41561-019-0329-3

Körner, C. (2004). Mountain Biodiversity, Its Causes and Function. Journal of the Human Environment, 33(13), pp. 11-17.

https://doi.org/10.1007/0044-7447-33.sp13.11

Kraaijenbrink, P.D.A., Stigter, E.E., Yao, T. et al. (2021). Climate change decisive for Asia's snow meltwater supply. Nature Climate Change, 11, pp. 591–597.

https://doi.org/10.1038/s41558-021-01074-x

Loso, M. G., Larsen, C.F., Tober, B.S. et al. (2021). Quo vadis, Alsek? Climate-driven glacier retreat may change the course of a major river outlet in southern Alaska. Geomorphology, 384, 107701

https://doi.org/10.1016/j.geomorph.2021.107701

Lutz, A.F., Immerzeel, W.W., Siderius, C. et al. (2022). South Asian agriculture increasingly dependent on meltwater and groundwater. Nature Climate Change, 12, pp. 566–573

https://doi.org/10.1038/s41558-022-01355-z

Mouginot, J., Rignot, E., Bjørk, A. A., et al. (2019). Forty-six years of Greenland Ice Sheet mass balance from 1972 to 2018. Proceedings of the National Academy of Sciences, USA, 116, pp. 9239–9244.

https://doi.org/10.1073/pnas.1904242116

Osipova, E., Emslie-Smith, M., Osti, M., Murai, M., Aberg, U., Shadie, P. (2020). IUCN World Heritage Outlook 3: A conservation assessment of all natural World Heritage sites. Gland, Switzerland: IUCN.

https://doi.org/10.2305/IUCN.CH.2020.16.en

Pakistan Meteorological Department (2022). Pakistan's Monthly Climate Summary August, 2022.

https://www.pmd.gov.pk/cdpc/Pakistan_Monthly_Climate_Summary_August_2022.pdf

Pistone, K., Eisenman, I. And Ramanathan, V. (2014). Observational determination of albedo decrease caused by vanishing Arctic sea ice. Proceedings of the National Academy of Sciences, USA, 111(9), pp. 3322-3326.

https://doi.org/10.1073/pnas.131820111

Radić, V. and Hock, R. (2011). Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise. Nature Geoscience, 4, pp. 91–94.

https://doi.org/10.1038/ngeo1052

Sasgen, I., Wouters, B., Gardner, A.S. et al. (2020). Return to rapid ice loss in Greenland and record loss in 2019 detected by the GRACE-FO satellites. Nature Communications Earth & Environment, 1(8).

https://doi.org/10.1038/s43247-020-0010-1

UNEP and GRID-Arendal (2019). Elevating Mountains in the post-2020 Global Biodiversity Framework.

https://www.grida.no/publications/473

UNESCO and IASH (1970). Perennial ice and snow masses: a guide for compilation and assemblage of data for a world inventory. UNESCO and International Association of Scientific Hydrology (IASH).

https://unesdoc.unesco.org/ark:/48223/pf0000192525

Vergara, W., Deeb, A., Valencia, A., et al. (2007). Economic impacts of rapid glacier retreat in the Andes. Eos Trans. AGU, 88(25), pp. 261-264.

https://doi.org/10.1029/2007EO250001

Zemp, M., Frey, H., Gärtner-Roer, I., et al. (2015). Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology, 61(228), pp. 745-762.

https://doi.org/10.3189/2015JoG15J017

Zheng, G., Allen, S.K., Bao, A., et al. (2021). Increasing risk of glacial lake outburst floods from future Third Pole deglaciation. Nature Climate Change, 11, pp. 411-417.

https://doi.org/10.1038/s41558-021-01028-3

Khangchendzonga National Park © Risingmoon3377 / Shutterstock.com*

6

Relevant UNESCO policies, strategies and guidelines on World Heritage, glaciers and climate action

Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention)

https://whc.unesco.org/en/conventiontext/

Operational Guidelines for the Implementation of the World Heritage Convention

https://whc.unesco.org/en/guidelines/

Policy Document on Climate Action for World Heritage

https://whc.unesco.org/en/climatechange/ – (currently being updated)

Climate Change and World Heritage: Report on predicting and managing the impacts of climate change on World Heritage and Strategy to implement appropriate management responses

https://whc.unesco.org/en/series/22/

State of Conservation Information System

https://whc.unesco.org/en/soc/

Climate Change Adaptation for Natural World Heritage Sites – A Practical Guide

https://whc.unesco.org/en/series/37/

Policy for the Integration of a Sustainable Development Perspective into the Processes of the World Heritage Convention

https://whc.unesco.org/en/sustainabledevelopment/

Strategy for Risk Reduction at World Heritage Properties

https://whc.unesco.org/en/disaster-risk-reduction/

Managing Disaster Risks for World Heritage

https://whc.unesco.org/en/managing-disaster-risks/

Managing Natural World Heritage

https://whc.unesco.org/en/managing-natural-world-heritage/

IHP-IX: Strategic Plan of the Intergovernmental Hydrological Programme: Science for a Water Secure World in a Changing Environment, ninth phase 2022-2029

https://unesdoc.unesco.org/ark:/48223/pf0000381318

Glossary of glacier mass balance and related terms

https://unesdoc.unesco.org/ark:/48223/pf0000192525

The Andean Glacier and Water Atlas: the impact of glacier retreat on water resources

https://unesdoc.unesco.org/ark:/48223/pf0000265810

The impact of glacier retreat in the Andes: international multidisciplinary network for adaptation strategies

https://unesdoc.unesco.org/ark:/48223/pf0000258168

Central Asian Regional Glaciological Centre

https://cargc.org/en/

Improving knowledge of Central Asian glaciers and their resilience to climate change

https://unesdoc.unesco.org/ark:/48223/pf0000382818

Reducing glacial lake hazards in Central Asia

ttps://unesdoc.unesco.org/ark:/48223/pf0000382817

A Manual for monitoring the mass balance of mountain glaciers with particular attention to low latitude characteristics

https://unesdoc.unesco.org/ark:/48223/pf0000129593

Mountains: Early warning systems for climate change

https://unesdoc.unesco.org/ark:/48223/pf0000242903

Mountain ecosystem services and climate change: a global overview of potential threats and strategies for adaptation

https://unesdoc.unesco.org/ark:/48223/pf0000248768

Climate change impacts on mountain regions of the world

https://unesdoc.unesco.org/ark:/48223/pf0000224605

Indigenous knowledge for climate change assessment and adaptation

https://unesdoc.unesco.org/ark:/48223/pf0000265504

World Heritage Glaciers
Sentinels of climate change

***World Heritage Glaciers: Sentinels of climate change* –** a report by UNESCO and the International Union for Conservation of Nature (IUCN) with contributions from ETH Zurich, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), and the Space Geophysics and Oceanography Studies Laboratory (LEGOS) of the French National Centre for Scientific Research (CNRS) – provides the first global assessment of both the current state and future scenario of glaciers in World Heritage sites.

World Heritage glaciers cover almost 10% of the Earth's glacierized area and play a crucial role in sustaining life on Earth. However, they are retreating at an accelerated rate because of climate change. By combining satellite data and projections at the site level, this study quantifies the extent of World Heritage glaciers' retreat and its impact on global sea-level rise and provides projections of glacier mass loss. It also provides key information to facilitate dialogue between policymakers and local stakeholders in the development of effective actions to counteract substantial glacier retreat and to respond to subsequent inevitable changes in glacierized sites.

unesco
World Heritage Convention
IUCN
ETH zürich
WSL
LEGOS
cnrs
9 789231 005572