Cryosphere degradation in a changing climate

José M. Fernández-Fernández[1*], Marc Oliva[2], Adriano Ribolini[3], Þorsteinn Sæmundsson[4]

[1] Department of Geography, Universidad Complutense de Madrid, Madrid, Spain. *josemariafernandez@ucm.es

[2] Department of Geography, Universitat de Barcelona, Barcelona, Spain

[3] Department of Earth Sciences, Universitá di Pisa, Pisa, Italy

[4] Department of Geography and Tourism, University of Iceland, Reykjavík, Iceland

Abstract

Over the last few decades, the instrumental climate record shows a progressive global warming. As one of the most sensitive elements of the Earth's climate system, the cryosphere is significantly affected by this trend. As a result, its various components are readjusting in a situation of disequilibrium with the climate through a series of dynamics. These include the thinning and retreat of glaciers that may lead to the formation of new lakes; the thawing of ground ice, leading to the deformation of terrain; the reduction of snow cover; and the occurrence of mass movements that threaten populations and infrastructures. This Special Issue contains 23 scientific papers with case studies that explore the above issues in the Arctic, Antarctic and high mountain regions.

Key words: Cryosphere, climate variability, glaciers, permafrost, snow

Corresponding author: José M. Fernández-Fernández, Department of Geography, Faculty of Geography and History, Universidad Complutense de Madrid, Profesor Aranguren Street, 28040 Madrid, Spain. E-mail address: josemariafernandez@ucm.es

Preface

Since the end of the 19th century, the Earth's climate has been undergoing a long-term warming trend, which has particularly intensified in recent decades (**PAGES 2k Consortium, 2013; Hegerl et al., 2018**). It affects the cryosphere as one of the most climatically sensitive components of the Earth's climate system, and its adjustment towards a new equilibrium with the climate triggers abrupt changes in the various pieces of the complex puzzle it forms (**Ding et al., 2021**). This is particularly evident in the high latitudes, where the climate has warmed significantly compared to the global average due to the so-called 'polar amplification' (**Taylor et al., 2013**).

One of the most dramatic dynamics is glacier shrinkage and associated retreat, which is occurring in both high-latitude and mountainous areas (see e.g. **Dussaillant et al., 2019**; **Sommer et al., 2020**). Ice loss dynamics has been observed on different timescales and can in some cases induce the degradation of glaciers and the appearance of a series of transitional landforms (e.g. debris-covered glaciers, ice-cored moraines, etc.; see **Palacios et al., 2021**). On the other hand, this glacial trend also triggers glacial thinning and the activation of paraglacial processes (e.g. deep-seated rock slope deformation, rockslides, rock avalanches, etc.; **Ballantyne, 2002**) and the increase in the number and size of glacial lakes (**Shugar et al., 2020**), the consequences of which can be catastrophic (e.g. glacial lake outburst floods; **Zheng et al., 2021**; **Taylor et al., 2023**). However, this degradation also contributes to the creation of new surfaces exposed to erosion and new terrestrial ecosystems (**Bosson et al., 2023**).

Global warming also affects the thermal state of permafrost (**Smith et al., 2022**), including changes in the active layer and thawing of the ground ice, amongst others. Permafrost degradation has a wide range of climate-related impacts (e.g. release of greenhouse gases; **Natali et al., 2021**), geomorphological processes (e.g. thermokarst, rock glacier collapse, increase in erosion) and natural hazards (e.g. catastrophic mass movements triggered by ground ice thaw, which pose a great threaten to human settlements and infrastructure in high latitudes and mountain areas (.e.g. **Sæmundsson et al., 2018**; **Hjort et al., 2022**).

In addition, climate variability has a profound impact on snow by reducing water availability, increasing surface runoff and associated slope mass movements, altering radiative balance of the Earth's surface (i.e. albedo), and changing the frequency and nature of avalanche events. Climate models predict a decrease in the duration (**Notarnicola, 2022**) and thickness of the snow cover, which also implies a reduction in its insulating effect, with direct consequences for vegetation and wildlife.

This special issue explores these dynamics in more detail and presents 23 research papers on the state of different components of the cryosphere in different regions. The papers show how the rapid and intense Holocene climate changes, especially in the last decades, have led to profound changes in the landscape of cold regions. Mountain ranges, proglacial and coastal areas at different latitudes - from the Arctic and sub-Arctic to the European mountain ranges - have undergone geomorphological changes consisting of glacier retreat and imminent disappearance, the creation of vast areas dominated by buried dead ice transformation, the increase of glacial-fed lakes, and pronounced marine erosion in permafrost or recently deglaciated coastal areas.

The global climate warming trend that has characterised the recent decades has had a major impact on the cryosphere, probably the most sensitive component of the Earth system, consisting of snow, glacial ice, and permafrost. In this Special Issue, **Knight & Harrison (2023)** presented a thorough review of the sensitivity of each of these components and the implications for the spatio-temporal patterns of glacial retreat, geomorphic change, surface instability and natural hazards. From various study cases, the authors inferred directions of geomorphic change for different mountains and proposed an integrated evolutionary model for mountain system evolution under the current climate change.

As a result of this trend, snowfall and snowpack characteristics are undergoing important changes (Bonsoms et al., 2024), with a direct impact on avalanche activity. This geohazard represents a major threat to mountain populations and their infrastructure, especially road networks. This issue is examined by **Kern et al. (2023)**, who studied the spatial and temporal correlations between meteorological snowpack conditions, snow avalanche deposits, and road network vulnerability in two valleys of the French Alps.

Current climate warming is particularly affecting glaciers worldwide, causing melting, thinning and retreat at different timescales. The low-latitude glaciers of the Cocuy-Güican Mountains (Colombian Andes) are a good example; in this area, **López-Moreno et al. (2022)** reconstructed the evolution of the glacier cover since the Little Ice Age (LIA), measured ice surface and volume loss, and analysed the topographic and climatic factors that may have contributed to a recent slowdown of glacier retreat and to near-equilibrium conditions. On the other hand, **Martínez-Fernández et al. (2023)** focused on the evolution of a mid-latitude glacier in the Spanish Pyrenees to demonstrate how small glaciers are one of the best indicators of climatic variability. The authors covered the decade 2010-2020 using several geomatic techniques (GPS survey, terrestrial laser scanner, UAV photogrammetry) and reported the dramatic surface, thickness, and volume loss of this glacier (0.2 ha yr^{-1}, 1.7 m yr^{-1}, 21 x 10^3 m^3 yr^{-1}). The data show that the glacier has evolved from a tongue-glacier climatically sensitive to a cirque glacier whose behaviour is strongly influenced by the local topography. According to the measured trend, it could disappear by the end of the 2030s.

Over the last century, several retreating marine glaciers have become land-based glaciers, with important implications for the ecosystem dynamics of the surrounding fjords. In many cases, this has resulted in the creation of new islands due to the retreat of tidewater glaciers, which is one of the less understood and studied consequences of cryospheric degradation in marine areas. **Ziaja &Haska (2022)** explored this phenomenon using available maps and satellite imagery, which allowed them to detect, describe and monitor the size of new islands in Greenland and the European and Asian Arctic. In inland areas, glacier shrinkage is also of great importance because of its geoecological implications. This topic has been studied extensively in the high latitudes of both hemispheres. In the northern hemisphere, **García-Oteyza Ciria et al. (2023)** reconstructed the glacial response of the Greenland Ice Sheet (GrIS) to the climate variability over the last millennia and the subsequent deglaciation through the application of cosmic-ray exposure (CRE) and optically stimulated luminescence (OSL) dating. Focusing on the Tyroler Valley (NE Greenland) the authors found that the deglaciation began in the Early Holocene (at ca. 10–8.5 ka, CRE age) and experienced a non-linear trend, interrupted by three phases of glacial advance during the Neoglacial (before ca. 5.9 ka, CRE age) and the LIA (0.6 ka and 0.3 ka, CRE age) cooling periods. The authors also highlighted a different geomorphological configuration during the LIA, which favoured the formation of an ice-dammed lake (0.53 ± 0.06 ka, OSL age). On the other hand, in the Southern Hemisphere, less of the 0.4% of Antarctica, corresponds to new ice-free areas resulting from the Holocene deglaciation. This is the case of the northern Fildes Peninsula, on King George Island, where **Oliva et al. (2023)** used ^{36}Cl cosmic-ray exposure dating on glacially polished rock outcrops, aiming to reconstruct the spatio-temporal patterns of the deglaciation. The authors pointed that the deglaciation process was not continuous as suggested by some cirque moraines in the valley with mid-Holocene glacial deposits, although no evidence of a LIA glacial advance was found.

However, surface changes do not only affect to the ice itself but some of the most dynamic areas are the proglacial regions where a common phenomenon is the formation of glacial lakes, in the vicinity of the melting terminus. In the High Arctic, where temperatures have risen almost four times faster than the global average over the past four decades (Rantanen et al., 2022), polar amplification (Dai et al., 2019) is rapidly reshaping the environmental dynamics of the region, with widespread glacier retreat. This has been observed, for example, in the Austerdalsbreen glacier, one of the outlets of the Jostedalsbreen ice cap (W Norway). Here, **Seier et al. (2023)** analysed the evolution of the glacial and proglacial area using a variety of remote sensing data to quantify glacier surface lowering and the interactions between the lake and terminus. On the SE Tibetan Plateau (SETP), the analysis of glaciers and glacial lakes in the time interval 1990 to 2021 revealed a glacier area reduction of ~25.3%, and an increase in the glacial lake area and number of ~21.5% and ~27.3%, respectively, as reported by **Dou et al. (2023)** in their study. Comparison of these results with meteorological data revealed an inverse correlation between the glacier area and air temperature, and an inverse correlation between cumulative precipitation (decreasing) and glacial lake level (increasing) and area (increasing). **Śledź et al. (2023)** also focused on proglacial areas; in this case, in the Kviárjökull glacier (SE Iceland). The authors used UAV imagery to track the recent geomorphic evolution of several landforms in the foreland and to measure elevation and volumetric changes. A similar methodology was also used by **Błaszkiewicz et al. (2023)**, who analysed how the temporally differentiated melting of glacier tongues and patches of dead ice were profoundly altering the landscape of glacial margins. The authors found that the result was the generation of a new landscape dominated by dead-ice landforms, attributed to thermokarst processes and the occurrence and development of permafrost. Nevertheless, accelerated glacier shrinkage has important geo-ecological implications in terms of the emergence of new coastal areas and the triggering of paraglacial processes, as demonstrated by **Kavan & Strzelecki (2023)** in their study. In the same line, **Dudek et al. (2023)** provided insights into the rate of post- LIA deglaciation and associated paraglacial transformations in the Gåsbreen (Svalbard), by using archival and imagery data, maps, digital elevation models and geomorphological mapping.

These previous studies highlight the main consequences of permafrost thawing in today's warming climate. One of the most obvious is the accelerated development of thermokarst terrain, particularly through retrogressive thawing slumps. This process was studied by **Jiao et al. (2023)** on the Qinghai-Tibet Plateau, in the Himalayas, where a coupled heat-water-mass transport model was used to quantify the effects of erosion processes associated with freeze-thaw cycles and to better assess their geo-ecological implications. The detection and quantification of terrain deformation over large areas is greatly aided by remote sensing techniques such as InSAR, as shown by **Ishikawa et al. (2023)**. The authors measured terrain deformation in Mongolia from 2007 to 2017 and explained the main climatic and hydrological factors that control surface subsidence and uplift associated with ground ice. At high latitudes, permafrost degradation is leading to profound landscape changes, such as in the coastal areas of Svalbard. In Sørkappland, **Ziaja et al. (2023)** used old maps, archival documents, remote sensing data (interval 1990-2021) and fieldwork to track the progressive degradation of the coastal cryosphere. As a result, the authors found that glacial retreat during the 20th and 21st centuries, together with the shortening of the sea-ice season, caused the transformation of a bay with beaches into a coastal plain characterised by a lake. They also reported the progressive reduction of the lake in recent decades until its disappearance and reoccupation by the sea, as well as the ongoing erosion on cliffs, beaches, and ice-cored moraines by the sea, demonstrating how the degradation of the cryosphere can lead to pronounced coastal instability.

However, an accurate assessment of cryospheric sensitivity and its associated geomorphological processes under the current climate warming also requires a detailed knowledge of the spatial and temporal patterns of ground surface temperature. To this end, **Kasprzak & Szymanoswki (2023)** combined direct thermistor measurements, satellite-derived land surface temperatures (LST) and electrical resistivity tomography in a small catchment in SW Spitsbergen (Svalbard). Using this methodology, the authors presented key data such as near-surface temperature, active layer thickness, depth of ground thaw and the environmental variables that determined the spatial distribution of ground temperature. In this area, the distribution of mountain permafrost is still under debate. To shed some light on this issue, **Pradhan & Shukla (2023)** presented new maps of probable permafrost distribution based on Landsat 8 LST, which is key to studying environmental processes in ice-free areas in high mountain regions, as well as natural hazards affecting local communities. However, the study and characterisation of periglacial dynamics is not limited to high mountain areas. In the Spanish Central System, a temperate mid-latitude mountain range, a top-to-bottom multidisciplinary approach was used for the characterisation of the Calderuelas hydrolaccolith by **Fernández-Lozano et al. (2024)**; in this study, the authors used both high-resolution UAV mapping, surface temperature measurements, geoelectric surveying, core sampling and magnetic susceptibility profiling, and ^{14}C-AMS dating. Nevertheless, there is room for technological innovation in periglacial research. Indeed, **Zagórski et al. (2023)** proposed a new measurement system based on the photonic sensor technology to provide higher spatial resolution in the vertical profiles and more detailed information on the evolution of the active layer thickness and the thermal state of the permafrost.

The effects of a changing climate on permafrost are not only limited to geomorphological changes, but also affect the hydrochemical properties of surface and subsurface water. **Lehmann-Konera et al. (2023)** studied the effects of temperature and precipitation on the discharge and lowering of the groundwater table, and on its chemical properties in a small permafrost catchment also in SW Spitsbergen, with interesting results on the physical and chemical processes operating in the area. **Szumińska et al. (2023)** also investigated the freshwater chemistry of a continuous permafrost zone in NE Siberia, in particular the mobility of metals, metalloids and non-metals released by permafrost thaw.

Acknowledgements

This Special Issue is linked to the research themes of the NEOICE (PID2020-113798GB-C32) and NEOGREEN (PID2020-113798GB-C31) projects, both funded by the Spanish Ministry of Economy and Competitiveness. We are also grateful to the GFAM (High Mountain and Polar Regions Physical Geography; UCM-GR17-931562) and ANTALP (Antarctic, Arctic, Alpine Environments; 2021-SGR-00269) research groups.

References

General introduction

Ballantyne, C.K. (2002). Paraglacial geomorphology. Quaternary Science Reviews, 21 (18-19), 1935-2017. https://doi.org/10.1016/S0277-3791(02)00005-7

Bonsoms, J.; López-Moreno, J.I.; Alonso-González, E.; Deschamps-Berger, C. & Oliva, M. (2024). Rain-on-snow responses to warmer Pyrenees: a sensitivity analysis using a physically based snow hydrological model. Natural Hazards and Earth System Sciences, 24: 245–264.

Bosson, J.B., Huss, M., Cauvy-Fraunié, S., Clément, J.C., Costes, G., Fischer, M., Poulenard, J., Arthaud, F. (2023). Future emergence of new ecosystems caused by glacial retreat. Nature, 620, 562-569. https://doi.org/10.1038/s41586-023-06302-2

Dai, A., Luo, D., Song, M., Liu, J. (2019). Arctic amplification is caused by sea-ice loss under increasing CO_2. Nature Communications, 10, 121. https://doi.org/10.1038/s41467-018-07954-9

Ding, Y., Mu, C., We, T., Hu, G., Zou, D., Wang, D., Li, W., Wu, X. (2021). Increasing cryospheric hazards in a warming climate. Earth-Science Reviews, 2021, 103500. https://doi.org/10.1016/j.earscirev.2020.103500

Dussaillant, I., Berthier, E., Brun, F., Masiokas, M., Hugonnet, R., Favier, V., Rabatel, A., Pitte, P., Ruiz, L. (2019). Two decades of glacier mass loss along the Andes. Nature Geoscience, 12, 802-808. https://doi.org/10.1038/s41561-019-0432-5

Hegerl, G.C., Brönnimann, S., Schurer, A., Cowan, T. (2018). The early 20th century warming: Anomalies, causes, and consequences. WIREs Climate Change, 9 (4), e522. https://doi.org/10.1002/wcc.522

Hjort, J., Streletskiy, D., Doré, G., Wu, Q., Bjella, K., Luoto, M. (2022). Impacts of permafrost degradation on infrastructure. Nature Reviews Earth & Environment, 3, 24-38. https://doi.org/10.1038/s43017-021-00247-8

Natali, S.M., Holdren, J.P., Rogers, B.M., Treharne, R., Duffy, P.B., Pomerance, R., MacDonald, E. (2021). Permafrost carbon feedbacks threaten global climate goals. Proceedings of the National Academy of Sciences of the United States of America, 118 (21), e2100163118. https://doi.org/10.1073/pnas.2100163118

Notarnicola, C. (2022). Overall negative trends for snow cover extent and duration in global mountain regions over 1982–2020. Scientific Reports, 12, 13731. https://doi.org/10.1038/s41598-022-16743-w

PAGES 2k Consortium (2013). Continental-scale temperature variability during the past two millennia. Nature Geoscience, 6, 339-346. https://doi.org/10.1038/ngeo1797

Palacios, D., Rodríguez-Mena, M., Fernández-Fernández, J.M., Schimmelpfennig, I., Tanarro, L.M., Zamorano, J.J., Andrés, N., Úbeda, J., Sæmundsson, Þ., Brynjólfsson, S., Oliva, M., A.S.T.E.R. Team. (2021) Reversible glacial-periglacial transition in response to climate changes and paraglacial dynamics: A case study from Héðinsdalsjökull (northern Iceland). Geomorphology, 388, 107787. https://doi.org/10.1016/j.geomorph.2021.107787

Rantanen, M., Karpechko, A. Yu., Lipponen, A., Nordling, K., Hyvärinen, O., Ruosteenoja, K., Vihma, T., & Laaksonen, A. (2022). The Arctic has warmed nearly four times faster than the globe since 1979. Communications Earth & Environment, 3(1), 168. https://doi.org/10.1038/s43247-022-00498-3

Sæmundsson, Þ., Morino, C., Helgason, J.K., Conway, S., Pétursson, H.G. (2018). The triggering factors of the Móafellshyrna debris slide in northern Iceland: Intense precipitation, earthquake activity and thawing of mountain permafrost. Science of the Total Environment, 621, 1163-1175. https://doi.org/10.1016/j.scitotenv.2017.10.111

Shugar, D.H., Burr, A., Haritashya, U.K., Kargel, J.S., Watson, C.S., Kennedy, M.C., Bevington, A.R., Betts, R.A., Harrison, S., Strattmanm, K. (2020). Rapid worldwide growth of glacial lakes since 1990. Nature Climate Change, 10, 939-945. https://doi.org/10.1038/s41558-020-0855-4

Smith, S.L., O'Neil, H.B., Isaksen, K., Noetzli, J., Romanovsky, V.E. (2022). The changing thermal state of permafrost. Nature Reviews Earth & Environment, 3, 10-23. https://doi.org/10.1038/s43017-021-00240-1

Sommer, C., Malz, P., Seehaus, T.C., Lippl, S., Zemp, M., Braun, M.H. (2020). Rapid glacier retreat and downwasting throughout the European Alps in the early 21st century. Nature Communications, 11, 3209. https://doi.org/10.1038/s41467-020-16818-0

Taylor, C., Robinson, T.R., Dunning, S., Carr, J.R., Westboy, M. (2023). Glacial lake outburst floods threaten millions globally. Nature Communications, 14, 487. https://doi.org/10.1038/s41467-023-36033-x

Taylor, P.C., Cai, M., Hu, A., Meehl, J., Washington, W., Zhang, G.J. (2013). A Decomposition of Feedback Contributions to Polar Warming Amplification. Journal of Climate, 26, 7023-7043. https://doi.org/10.1175/JCLI-D-12-00696.1

Zheng, G., Allen, S.K., Bao, A., Ballesteros-Cánovas, J.A., Huss, M., Zhang, G., Li, J., Yuan, Y., Jiang, L., Yu, T., Chen, W., Stoffel, M. (2021). Increasing risk of glacial lake outburst floods from future Third Pole deglaciation. Nature Climate Change, 11, 411-417. https://doi.org/10.1038/s41558-021-01028-3

Special issue contributions

Błaszkiewicz, M., Andrzejewski, L., Dudek, J., Sobota, I., & Czarnecki, K. (2023). The role of dead ice in transforming glacier forelands under the rapid climate warming of recent decades, Oscar II Land, Svalbard. Land Degradation & Development, 34(14), 4328–4345. https://doi.org/10.1002/ldr.4780

Dou, X., Fan, X., Wang, X., Fang, C., Lovati, M., Zou, C. (2023). The response of glaciers and glacial lakes to climate change in the Southeastern Tibetan Plateau over the past three decades. Land Degradation & Development, 34(18), 5675–5696. https://doi.org/10.1002/ldr.4870

Dudek, J., Wieczorek, I., Suwiński, M.K. & Strzelecki, M.C. (2023). Paraglacial transformation and ice-dammed lake dynamics in a high Arctic glacier foreland, Gåsbreen, Svalbard. Land Degradation & Development, 34(14), 4252–4271. https://doi.org/10.1002/ldr.4773

Fernández-Lozano, J., Turu, V., Carrasco, R.M., Soteres, R.L., Sánchez-Vizcaino, J., Karampaglidis, T., Ros, X., Merlo, O. and Pedraza, J. (2024). The mid-latitude hydrolaccolith of the Spanish Central System (Southern Europe): A top-to-bottom integration of geomatic, geophysical and sedimentary datasets for characterising a singular periglacial landform. Land Degradation & Development, 35:1029–1049. https://doi.org/10.1002/ldr.4968

Garcia-Oteyza Ciria, J., Oliva, M., Palacios, D., M. Fernández-Fernández, J., Schimmelpfennig, I., Medialdea, A., Fernandes, M., Giralt, S., Jomelli, V., Antoniades, D., & ASTER TEAM (2023). Holocene glacial oscillations in the Tyroler Valley (NE Greenland). Land Degradation & Development, 34(9), 2589–2606. https://doi.org/10.1002/ldr.4633

Ishikawa, M., Avtar, R., & Mo, S. (2023). Using interferometric synthetic aperture rader (InSAR) analysis to detect ground deformation related to irreversibly changing ground ice, Mongolia. Land Degradation & Development, 34(9), 2707–2719. https://doi.org/10.1002/ldr.4644

Jiao, C., Wang, Y., Shan, Y., He, P., & He, J. (2023). Quantifying the effect of a retrogressive thaw slump on soil freeze–thaw erosion in permafrost regions on the Qinghai–Tibet Plateau, China. Land Degradation & Development, 34(9), 2573–2588. https://doi.org/10.1002/ldr.4631

Kasprzak, M., & Szymanowski, M. (2023). Spatial and temporal patterns of near-surface ground temperature in the Arctic mountain catchment. Land Degradation & Development, 34(17), 238–5258. https://doi.org/10.1002/ldr.4841

Kavan, J., & Strzelecki, M. C. (2023). Glacier decay boosts the formation of new Arctic coastal environments—Perspectives from Svalbard. Land Degradation & Development, 34(12), 3467–3474. https://doi.org/10.1002/ldr.4695

Kern, H., Jomelli, V., Eckert, N., Grancher, D., Deschatres, M., & Arnaud-Fassetta, G. (2023). Influence of snow and meteorological conditions on snow-avalanche deposit volumes and consequences for road-network vulnerability. Land Degradation & Development, 34(12), 3487–3499. https://doi.org/10.1002/ldr.4697

Knight, J., & Harrison, S. (2023). The sensitivity and evolutionary trajectory of the mountain cryosphere: Implications for mountain geomorphic systems and hazards. Land Degradation & Development, 34(9), 2464–2482. https://doi.org/10.1002/ldr.4630

Lehmann-Konera, S., Zagórski, P., Nowiński, K., Raczyński, K., Frankowski, M., Franczak, Ł., Dobek, M., Szumińska, D., Ruman, M., Al Bakain, R., & Polkowska, Z. (2024). Spatial variability of the hydrochemistry of shallow groundwaters and surface waters of the Rensdyrbekken: A case study of a permafrost catchment in Bellsund (SW Spitsbergen, Svalbard). Land Degradation & Development, 35(5), 1874–1887. https://doi.org/10.1002/ldr.5028

López-Moreno, J. I., Rojas-Heredia, F., Ceballos, J. L., Morán-Tejeda, E., Alonso-Gonzalez, E., Vidaller, I., Deschamps-Berger, C., & Revuelto, J. (2022). Recent evolution of glaciers in the Cocuy-Güican Mountains (Colombian Andes) and the hydrological implications. Land Degradation & Development, 33(14), 2606–2618. https://doi.org/10.1002/ldr.4336

Martínez-Fernández, A., Serrano, E., de Sanjosé, J. J., Gómez-Lende, M., Sánchez-Fernández, M., López-Moreno, J.I., Rico, I., & Pisabarro, A. (2023). The final countdown? Monitoring the rapid shrinkage of the Maladeta glacier (2010–2020), Southern Pyrenees. Land Degradation & Development, 34(18), 5905–5922. https://doi.org/10.1002/ldr.4886

Oliva M., Palacios D., Fernández-Fernández J. M., Fernandes M., Schimmelpfennig I., Vieira G., Antoniades D., Pérez-Alberti A., García-Oteyza J. & ASTER TEAM (2023). Holocene deglaciation of the northern Fildes Peninsula, King George Island, Antarctica. Land Degradation & Development, 34, 3972-3990. https://doi.org/10.1002/ldr.4730

Oliva, M., Palacios, D., Fernández-Fernández, J. M., Fernandes, M., Schimmelpfennig, I., Vieira, G., Antoniades, D., Pérez-Alberti, A., García-Oteyza, J., & ASTER TEAM (2023). Holocene deglaciation of the northern Fildes Peninsula, King George Island, Antarctica. Land Degradation & Development, 34(13), 3973–3990. https://doi.org/10.1002/ldr.4730

Pradhan, I. P., & Shukla, D. P. (2024). Biennial analysis of probable permafrost distribution for Kullu district, North-west Himalaya using Landsat 8 satellite data. Land Degradation & Development, 35(1), 360–377. https://doi.org/10.1002/ldr.4921

Seier, G., Abermann, J., Andreassen, L. M., Carrivick, J. L., Kielland, P. H., Löffler, K., Nesje, A., Robson, B. A., Røthe, T. O., Scheiber, T., Winkler, S., & Yde, J. C. (2024). Glacier thinning, recession and advance, and the associated evolution of a glacial lake between 1966 and 2021 at Austerdalsbreen, western Norway. Land Degradation & Development, 35(1), 394–414. https://doi.org/10.1002/ldr.4923

Śledź, S., Ewertowski, M. W., & Evans, D. J. A. (2023). Quantification of short-term transformations of proglacial landforms in a temperate, debris-charged glacial landsystem, Kvíárjökull, Iceland. Land Degradation & Development, 34(17), 5566–5590. https://doi.org/10.1002/ldr.4865

Szumińska, D., Kozioł, K., Chalov, S. R., Efimov, V. A., Frankowski, M., Lehmann-Konera, S., & Polkowska, Z. (2023). Reemission of inorganic pollution from permafrost? A freshwater hydrochemistry study in the lower Kolyma basin (North-East Siberia). Land Degradation & Development, 34(17), 5591–5605. https://doi.org/10.1002/ldr.4866

Zagórski, P., Dobrowolski, R., Pa´zdzior, A., Nasiłowski, T., Kultys, K., Misztal, K., Piątek, P., Lis, D., Polakowski, C., Łukowski, M., Berus, W., Mergo, P., & Bieganowski, A. (2023). New concept of permafrost degradation monitoring based on photonics technologies: Case study from Calypsostranda (Bellsund, Svalbard). Land Degradation & Development, 34(18), 5744–5755. https://doi.org/10.1002/ldr.4874

Ziaja, W., & Haska, W. (2023). The newest Arctic islands and straits: Origin and distribution, 1997–2021. Land Degradation & Development, 34(7), 1984–1990. https://doi.org/10.1002/ldr.4583

Ziaja, W., Ostafin, K., Maciejowski, W., & Kruse, F. (2023). Coastal landscape degradation and disappearance of Davislaguna Lake, Sørkappland, Svalbard, 1900–2021. Land Degradation & Development, 34(16), 4823–4832. https://doi.org/10.1002/ldr.4765