Inauguration of Glaciology Center and Conference on Glaciers and Mountain Ecology Karakoram International University Gilgit, Pakistan December 27, 2021

Guglielmina A. Diolaiuti and Roberto Ambrosini,

Environmental Science and Policy Department (ESP)

University of Mila, Italy

guglielmina.diolaiuti@unimi.it

roberto.ambrosini@unimi.it

EvK2CNR PAKISTAN

Karakoram International University

ITALIAN AGENCY FOR DEVELOPMENT COOPERATION

UNDP

UNIVERSITÀ DEGLI STUDI DI MILANO

Currently, most people in the world know that the Karakoram is the most important part of the third Pole and that surveying and studying glaciers here is of crucial importance to develop an actual and reliable picture of glacier extent on the Planet.

Climate Change and Mountain Topographic Evolution in the Central Karakoram, Pakistan

Michael P. Bishop,* Andrew B. G. Bush,† Luke Copland,‡ Ulrich Kamp,§ Lewis A. Owen,# Yeong B. Seong,¶ and John F. Shroder, Jr.*

*Department of Geography and Geology, University of Nebraska–Omaha
†Department of Earth and Atmospheric Sciences, University of Alberta
‡Department of Geography, University of Ottawa
§Department of Geography, The University of Montana
#Department of Geology, University of Cincinnati
¶Department of Geography Education, Korea University

Mountain geodynamics represent highly scale-dependent interactions involving climate, tectonic, and surface processes. The central Karakoram in Pakistan exhibit strong climate–tectonic feedbacks, although the detailed tectonic and topographic responses to climate perturbations need to be systematically explored. This study focuses on understanding climate variations in relation to glacier erosion and relief production. Field data, climate modeling, remote sensing, geomorphometry, geochronology, glaciology, and geomorphological assessment are utilized to characterize climate change and geomorphic response. Climate simulations suggest that the region has experienced significant climate change due to radiative forcing over at least the past million years due to changes in Earth's orbital configuration, as well as more temporally rapid climate dynamics related to the El Niño Southern Oscillation. Paleoclimate simulations support geomorphological evidence of multiple glaciations and long-term glacier retreat. Mesoscale relief patterns clearly depict erosion zones that are spatially coincident with high peaks and rapid exhumation. These patterns depict extreme spatial and temporal variability of the influence of glacier erosion in the topographic evolution of the region. Results support the interpretation of high-magnitude glacial erosion as a significant denudational agent in the exhumation of the central Karakoram. Consequently, a strong linkage is seen to occur between global, or at least hemispheric, climate change and the topographic evolution of the Karakoram and the western Himalaya. Key Words: central Karakoram, climate forcing, erosion, glaciation, landscape evolution.

Annals of Glaciology 57(71) 2016 doi: 10.3189/2016AoG71A627 119

© The Author(s) 2016. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution, and reproduction in any medium, provided the original work is properly cited.

Modelling glacier-bed overdeepenings and possible future lakes for the glaciers in the Himalaya–Karakoram region

A. LINSBAUER,[1,2] H. FREY,[1] W. HAEBERLI,[1] H. MACHGUTH,[3] M.F. AZAM,[4,5] S. ALLEN[1,6]

[1]Department of Geography, University of Zurich, Zurich, Switzerland
[2]Department of Geosciences, University of Fribourg, Fribourg, Switzerland
[3]Centre for Arctic Technology, Danish Technical University, Lyngby, Denmark
[4]School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India
[5]IRSTEA/UR – Geneticle HGAR/SG-INP, LGGE UMR 5183, LTHE UMR 5564, Grenoble, France
[6]Institute of Environmental Sciences, University of Geneva, Switzerland
Correspondence: Andreas Linsbauer <andreas.linsbauer@geo.uzh.ch>

ABSTRACT. Surface digital elevation models (DEMs) and slope-related estimates of glacier thickness enable modelling of glacier-bed topographies over large ice-covered areas. Due to the erosive power of glaciers, such bed topographies can contain numerous overdeepenings, which when exposed following glacier retreat may fill with water and form new lakes. In this study, the bed overdeepenings for ~28 000 glaciers (40 775 km²) of the Himalaya–Karakoram region are modelled using GlabTop2 (Glacier Bed Topography model version 2), in which ice thickness is inferred from surface slope by parameterizing basal shear stress as a function of elevation range for each glacier. The modelled ice thicknesses are uncertain (±10%), but spatial patterns of ice thickness and bed elevation primarily depend on surface slopes as derived from the DEM and, hence, are more robust. About 16 000 overdeepenings larger than 10⁴ m² were detected in the modelled glacier beds, covering an area of ~2200 km² and having a volume of ~120 km³ (3–4% of present-day glacier volume). About 5000 of those overdeepenings (3000 km²) have a volume larger than 10⁶ m³. The results presented here are useful for anticipating landscape evolution and potential future lake formation with associated opportunities (tourism, hydropower) and risks (lake outbursts).

KEYWORDS: glacier geomorphology, glaciological model experiments, processes and landforms of glacial erosion

Mountain Research and Development Vol 25 No 4 Nov 2005: 332–340

Kenneth Hewitt

The Karakoram Anomaly? Glacier Expansion and the 'Elevation Effect,' Karakoram Himalaya

In the late 1990s widespread evidence of glacier expansion was found in the central Karakoram, in contrast to a worldwide decline of mountain glaciers. The expansions were almost exclusively in glacier basins from the high east parts of the range and developed quickly after decades of decline. Exceptional numbers of glacier surges were also reported. Unfortunately there has been no ongoing measurement of climatic or glaciological variables at these elevations. The present article examines possible explanations for this seemingly anomalous behavior using evidence from short-term monitoring programs, low-altitude weather stations, and the distinctive environmental characteristics of the region. The latter involve interactions between regional air mass circulation, its seasonality, topoclimatic or vertically offsets on glaciers with extreme altitudinal range, climatic sensitivities of heavy debris that supraglacial debris, and complex temperature distributions in ice masses with ice falls throughout critical elevations. Valley climate stations indicate increases in precipitation over the past 50 years and small declines in summer temperatures, which may indicate positive trends in glacier mass balance. However, the subtleties of the interactions of moisture, ice, and debris in their confinement to glaciers from the highest watersheds while others continue to retreat. Thermal shifts in ice masses with extreme altitude ranges may be even more critical, leading to an accelerated restriction of ice mass by elevation.

Keywords: High relief glaciers; climate change; Asia (arctic nonalpine); supraglacial debris; ice thermal regimes; Karakoram; Inner Asia.

Peer reviewed: June 2005 Accepted: September 2005

Introduction

In recent decades most of the world's mountain glaciers have undergone negative mass balance and terminal recessions (Haeberli et al 1989; Oerlemans 2005). Rapid declines are reported throughout the Greater Himalaya and most of mainland Asia (Ageta 2000). These trends have been attributed to global atmospheric warming. From the 1950s to the early 1990s most glaciers of the Karakoram Himalaya were also observed to diminish, except for some short-term advances in the 1970s and surges. However, in the late 1990s, many central Karakoram glaciers began expanding (Figure 1).

Perennial snow and ice covers about 18,500 km² of the Greater Karakoram (Hewitt 2005; Raj Ranges and is dominated by large glaciers (von Wissmann 1959). The expansions apply only to the highest watersheds of the central Karakoram. Most glaciers of lowest neighbors above 7000 m and have elevation ranges of over 4500 m. Some descend as low as 2500 m, much lower than in the Greater Himalaya of India and Nepal. Generally, the glaciers differ in size, elevation, and latitude from most glaciers used to track contemporary global changes (Oerlemans 2005; Haeberli 2004; WGMS 2001). Other distinctive features include the regional climate, glacier nourishment, and extreme vertical gradients. Hence debris covers, steepness, and thermal characteristics distinguish the ice masses themselves. However, there is another unfortunate 'anomaly' for understanding these glaciers and their changes: the absence of on-going measurement programs for climatic and glaciological variables, necessary to identify changes in mass balance and other properties influencing ice behavior. In part this reflects the high costs and difficulties of working in the region, in part the need to develop alternative methods from those most widely deployed elsewhere (Young and Hewitt 1983). All of this contributes to the comparative neglect of Karakoram glaciers in the recent literature. The present article first describes the observed changes, and then provides an overview of what is known of conditions in the Karakoram that may help to explain the apparent anomaly and to identify future monitoring needs.

Recent glacier changes

In surveys between 1997 and 2002, 15 glaciers of intermediate size—10 to 20 km in length—were found to be advancing, as were 16 disconnected tributaries of large glaciers (Table 1). Some of the larger glaciers—40 to 70 km in length—exhibited 5 to 15 m of thickening over substantial ablation zone areas, locally more than 20 m (Figure 2). Along 8 glaciers, renewed lateral moraine building involved thicker, more active ice overriding moraines that were ice-free for 50 years or more (Figure 3). Exceptional numbers of glacier surges were reported, 6 of a possible 9 confirmed between 1986 and 1996—the most in any decade since the 1830s (Hewitt 1969b). Thickening appears irregular in amount and incidence, with zone-like zones of higher ice moving down the glacier. The expansion developed quickly where thinning and recession had been observed between 1980 and 1990 (Hewitt 1998a).

The changes detailed in Figure 2 and Table 1 are based on ground observations between 1988 and 2001. They were first identified at Snaltar, Barpu, Hispar, and

Zeitschrift für Geomorphologie Vol. 55, Suppl. 3, 205–231 Article
Stuttgart, April 2011

Trends in 20th century and recent glacier fluctuations in the Karakoram Mountains

L. Iturrizaga

with 18 figures

Summary. The article provides an overview on the trends of 20th century and recent glacier fluctuations since the end of the 19th century in the Karakoram Mountains. Recent glacier variations in the subtropical mountain range of the Karakoram Mountains were surveyed on the base of field observations carried out in the period of 1992–2006 on 57 glaciers. Historical documents, such as photographs and travel reports, as well as air and satellite images have been included in the compilation. The occurrence of ice-dammed lakes, which have mainly been formed by advances of tributary glaciers into the trunk valleys, has been used as further indicators for glacier fluctuations. Even though a considerable part of the Karakoram glaciers have shown signs of glacier retreat, most of the longer glaciers (> 45 km), such as the Baltoro and Batura glaciers, have been rather stationary in the last century. Even some of the clean glaciers, such as the Yazghil and Barpu glaciers, did not retreat significantly. Singular glacier advances and surges occurred over the entire study period, whereas the average distance of the surges has apparently become smaller over time. The glacier behaviour of the avalanche fed glacier is highly dynamic. Geomorphological indicators, as localised glacier thickening resulting in overtopping and breakthroughs of lateral moraines, the new moraine formation and the shape of the glacier tongue has to be handled carefully for drawing conclusions on the entire mass balance of a glacier.

In the whole, the dynamics of the Karakoram glaciers proves to be different from the neighbouring mountain ranges, such as the Himalayas and Tienshan, which are characterized by a dominant glacier retreat. The reasons lie in the different topographical and climatic settings. Topography is apart from the complex climatic situation one of the major controlling factors governing the individual glacier fluctuations in the Karakoram Mountains.

Keywords: Karakoram, glacier fluctuations, glacier surges, glacial lake outbursts

Glacier surges in the Karakoram Himalaya (Central Asia)[1]

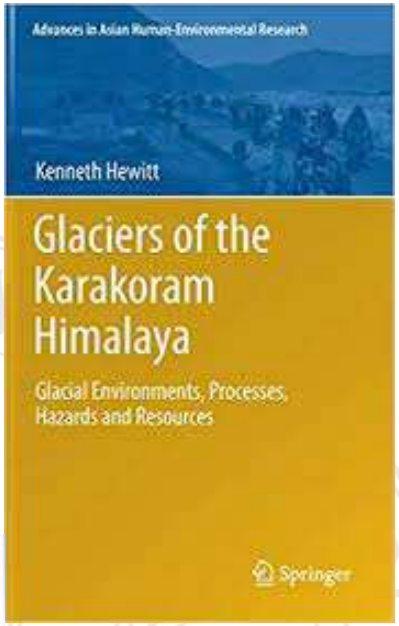
KENNETH HEWITT
Department of Geography, University of Toronto, Toronto 5, Ontario

Received January 14, 1969
Accepted for publication April 3, 1969

The Karakoram and Alaska–Yukon region between them account for perhaps 90% of the known surging glacier events. While modern research and information is available for the latter region, the Karakoram, though often referred to, remains virtually unknown except in a very general sense. The prime aim of this paper is to collate all the information that is available for the Karakoram from the usually old and inaccessible documents where it is found. It establishes eleven instances of surges with reasonable certainty and the probability of many more. The (rare) instances of detailed descriptions of the phenomena are quoted. A short discussion is given of the degree to which the information, and knowledge of the Karakoram environment, equate with various mechanisms put forward to explain surging glacier events.

Introduction

This paper describes what is known of surging glaciers in the Karakoram Range (Fig. 1) and attempts to pin-point information which seems relevant to the interpretation of the phenomenon of surges. An examination of the modern literature on the subject indicates that perhaps 90% of the known surging glaciers lie in the Alaska–Yukon and Karakoram regions. Surges have also occurred in the Southern Andes and the Pamirs and there is a possibility of others in the northwestern part of the Greater Himalaya. However, it is unlikely that any other areas match the numbers and frequency of one of great local relief associated with recent dissection. The resulting orographic effect produces large climatic differences between the widely ramifying fluvial valleys and immediately adjacent upper slopes and crest-lines. Heavy snowfall is concentrated at high altitude, and many medium and large valley glaciers commence in areas where precipitation may exceed 140 cm but have their lower ablation zones in semi-arid areas (Hewitt 1968). Some similarity can be seen between these gross environmental characteristics for the Karakoram and the surging glacier areas of the Alaska–Yukon region.



Advances in Asian Human-Environmental Research

Kenneth Hewitt

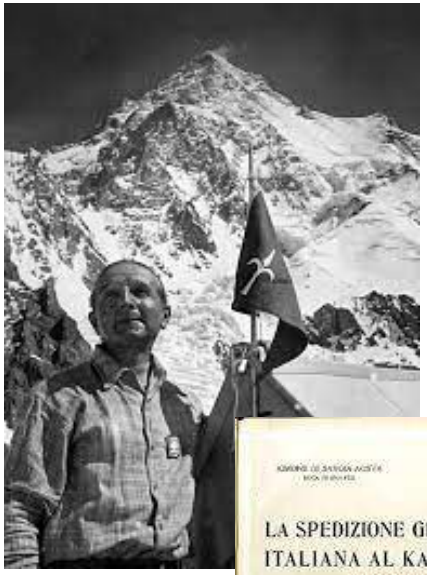
Glaciers of the Karakoram Himalaya

Glacial Environments, Processes, Hazards and Resources

Springer

UNIVERSITÀ DEGLI STUDI DI MILANO

We like to underline that our interest and attention on your glaciers started more than 70 years ago!



In more recent times Claudio Smiraglia organized and led - under the umbrella of the EvK2 association - scientific investigations in the Karakoram.....

Liligo Glacier, Karakoram, Pakistan: a reconstruction of the recent history of a surge-type glacier

In the last years, I have organized some scientific field works in the Karakoram (in 2008, 2011, 2013, 2015, 2016) always in cooperation and with the support of the EvK2 Association, devoted to study Pakistan glaciers and their ecological features. Prof Roberto Ambrosini was part of the scientific team of one these expeditions and now we work together at the Department of Environmental Science and Policy of the University of Milan.

Mountain Research and Development (MRD)
An International, peer-reviewed open access journal published by the International Mountain Society (IMS)
www.mrd-journal.org

MountainResearch
Systems knowledge

Analysis of Glacial Meltwater in Bagrot Valley, Karakoram

Based on Short-term Ablation and Debris Cover Observations on Hinarche Glacier

Christoph Mayer[1], Astrid Lambrecht[2], Claudia Mihalcea[3,4], Marco Baio[3,4], Guglielmina Diolaiuti[3,4], Claudio Smiraglia[3,4], and Furrukh Bashir[5]*

[1] Bavarian Academy of Sciences and Humanities, Commission for Glaciology, Alfons-Goppel Strasse 11, D-80539 Munich, Germany
[2] Institute of Meteorology and Geophysics, University of Innsbruck, Innrain 52, A-6020 Innsbruck, Austria
[3] Dipartimento di Scienze della Terra 'A. Desio', Università degli Studi di Milano, via Mangiagalli 34, Milan, Italy
[4] EvK2-CNR Committee, Via San Bernardino 145, 24126 Bergamo, Italy
[5] Hindu Kush-Karakoram-Himalaya Research and Development Division, Headquarters Office Sector H-8/2, Islamabad, Pakistan

* Corresponding author: Christoph.Mayer@lrz.badw-muenchen.de

Open access article: please credit the authors and the full source.

People in the Karakoram use discharge from glaciers during summer for irrigation and other purposes. While the glacial meltwater supply during hot and dry periods will vary as a result of climate change, Karakoram glaciers so far have not shown a consistent reaction to climatic change, although climate scenarios indicate severe future impacts in the high-elevation regions of the Himalaya and Karakoram. Field measurements on Hinarche Glacier in Bagrot Valley are combined with remote sensing information and climate observations to investigate the meltwater production of the glacier and estimate the meltwater discharge in the valley. Special emphasis was placed on ice melt beneath supraglacial debris, which is the common process on the glacier tongues in the region. The calculated annual meltwater production of about 130 million m^3 for Hinarche Glacier shows the order of magnitude for glacier runoff in such environments. Glacial meltwater production is about 300 million m^3 per year for the entire valley under balanced conditions. This analysis serves as a basis for further investigations concerning temporal meltwater variability and potential water usage by the local population.

Keywords: Climate change; debris-covered glacier; glacierized mountain areas; water resources; Karakoram; monitoring strategies; ice and snow melt; Pakistan.

Peer-reviewed: January 2010 **Accepted:** February 2010

Hindawi Publishing Corporation
Advances in Meteorology
Volume 2014, Article ID 215182, 12 pages
http://dx.doi.org/10.1155/2014/215182

Hindawi

Research Article

Accumulation Studies at a High Elevation Glacier Site in Central Karakoram

Christoph Mayer,[1] Astrid Lambrecht,[1] Hans Oerter,[2] Margit Schwikowski,[3] Elisa Vuillermoz,[4] Nicola Frank,[5,6] and Guglielmina Diolaiuti[7]

[1] Commission for Geodesy and Glaciology, Bavarian Academy of Sciences and Humanities, Alfons-Goppel Straße 11, 80539 München, Germany
[2] Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Am Handelshafen 12, 27570 Bremerhaven, Germany
[3] Paul Scherrer Institute, Labor für Radio- und Umweltchemie, 5232 Villigen, Switzerland
[4] Associazione EvK2CNR, Via San Bernardino 145, 24126 Bergamo, Italy
[5] Institut für Umweltsozialwissenschaften und Geographie, Albert-Ludwigs-Universität Freiburg, Werthmannstraße 4, 79098 Freiburg, Germany
[6] OEKOS GmbH, Hamburg, Germany
[7] Ardito Desio Earth Sciences Department, Università degli Studi di Milano, Via Mangiagalli 34, 20133 Milan, Italy

Correspondence should be addressed to Christoph Mayer; christoph.mayer@lrz.badw-muenchen.de

Received 4 July 2014; Accepted 26 August 2014; Published 17 September 2014

Academic Editor: Eduardo Garcia-Ortega

Theor Appl Climatol (2013) 113:611–641
DOI 10.1007/s00704-012-0803-y

ORIGINAL PAPER

Recent (1980–2009) evidence of climate change in the upper Karakoram, Pakistan

Daniele Bocchiola · Guglielmina Diolaiuti

Received: 13 February 2012 / Accepted: 16 November 2012 / Published online: 7 December 2012

Abstract We investigate here recent (1980–2009) climate variability in the upper Karakoram, Northern Pakistan, of particular interest given the peculiar glacier behavior during the last two decades. Differently from other glacierized regions in the Hindu Kush–Karakoram–Himalaya region, glaciers in the Karakoram display limited ice thinning, and in some cases advancing has been detected. Climate analysis is required to describe recent (i.e., last three decades) variability, to aid highlighting of the factors driving glacier evolution. Starting from monthly data, we analyze seasonal values of total precipitation, number of wet days, maximum (max) and minimum (min) air temperature, max precipitation in 24 h, and cloud cover for 17 weather stations in the upper Karakoram, clustered within three climatic regions as per use of principal components analysis. We detect possible nonstationarity in each of these regions by way of (1) linear regression, (2) moving window average, and (3) Mann–Kendall test, also in progressive form, to detect the onset date of possible trends. We then evaluate linear correlation coefficients between Northern Atlantic Oscillation (NAO) index and climate variables to assess effectiveness of teleconnections, claimed recently to affect climate in this area. Also, we compare temperature within the investigated zone against global temperature anomalies, to evidence enhanced warming within this area. We found mostly nonsignificant changes of total precipitation, unless for few stations displaying increase in Chitral-Hindu Kush region and Northwest Karakoram, or Gilgit area, and decrease in Western Himalaya, Kotli region. Max precipitation is mostly unchanged, unless for slight increase in Chitral and Gilgit areas, and slight decrease in Kotli region. Number of wet days is mostly increasing in Gilgit area, and decreasing in Chitral area, with no clear signal in Kotli region. Min temperatures increase always but during Summer, when decreasing values are detected, especially for Gilgit and Chitral regions. Max temperatures are found to increase everywhere. Cloud cover is significantly increasing in Gilgit area, but decreasing otherwise, especially in Kotli region. Max temperature regime is significantly positively correlated against global thermal anomaly, while min temperature regime is nonsignificantly negatively correlated. Max and min temperatures seem mostly negatively correlated to NAO. Some dependence of trend intensity for the considered variables against altitude is found, different for each region, suggesting that investigation of weather variables at the highest altitudes is warranted to discriminate further climate variability in the area.

D. Bocchiola (✉)
Department of Hydrologic, Environmental, Roads and Surveying Engineering, Politecnico di Milano, L. Da Vinci, 32, 20133 Milan, Italy
e-mail: daniele.bocchiola@polimi.it

G. Diolaiuti
Earth Science Department, Università degli Studi di Milano, Mangiagalli, 34, Milan, Italy

G. Diolaiuti
e-mail: guglielmina.diolaiuti@unimi.it

1 Introduction

The Hindu Kush–Karakoram–Himalaya (HKKH) stretches for more than 2,000 km in length from North to South. These areas differ in climate, in source and type of precipitation (P_{tot}), and consequently in the behavior and evolution of the cryosphere therein. The HKKH nests ca. 60,000 km^2 of ice bodies, glaciers, glacierets, and perennial surface ice

Future Hydrological Regimes in the Upper Indus Basin: A Case Study from a High-Altitude Glacierized Catchment

ANDREA SONCINI,* DANIELE BOCCHIOLA,+ GABRIELE CONFORTOLA,* ALBERTO BIANCHI,* RENZO ROSSO,* CHRISTOPH MAYER,# ASTRID LAMBRECHT,@ ELISA PALAZZI,& CLAUDIO SMIRAGLIA,** AND GUGLIELMINA DIOLAIUTI**

* Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
+ Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, and Ev-K2-CNR Association, Bergamo, Italy
# Bavarian Academy of Sciences, Munich, Germany
@ Institute of Atmospheric Sciences and Climate, National Research Council, Turin, Italy
** Department of Earth and Environmental Sciences, University of Milan, Milan, Italy

(Manuscript received 28 February 2014, in final form 15 October 2014)

ABSTRACT

The mountain regions of the Hindu Kush, Karakoram, and Himalayas (HKH) are considered Earth's "third pole," and water from there plays an essential role for downstream populations. The dynamics of glaciers in Karakoram are complex, and in recent decades the area has experienced unchanged ice cover, despite rapid decline elsewhere in the world (the Karakoram anomaly). Assessment of future water resources and hydrological variability under climate change in this area is greatly needed, but the hydrology of these high-altitude catchments is still poorly studied and little understood. This study focuses on a particular watershed, the Shigar River with the control section at Shigar (about 7000 km^2), nested within the upper Indus basin and fed by seasonal melt from two major glaciers (Baltoro and Biafo). Hydrological, meteorological, and glaciological data gathered during 3 years of field campaigns (2011–13) are used to set up a hydrological model, providing a depiction of instream flows, snowmelt, and ice cover thickness. The model is used to assess changes of the hydrological cycle until 2200, via climate projections provided by three state-of-the-art global climate models used in the recent IPCC Fifth Assessment Report under the representative concentration pathway (RCP) emission scenarios RCP2.6, RCP4.5, and RCP8.5. Under all RCPs, future flows are predicted to increase until midcentury and then to decrease, but remaining mostly higher than control run values. Snowmelt is projected to occur earlier, while the ice melt component is expected to increase, with ice thinning considerably and even disappearing below 4000 m MSL until 2100.

1. Introduction

The mountain range of the Hindu Kush, Karakoram, and Himalayas (HKH), known as the "third pole" of our planet (e.g., Smiraglia et al. 2007; Kehrwald et al. 2008; Minora et al. 2013), contains a large amount of glacier ice, delivering water for agriculture, drinking, and power production. According to recent estimates, more than 50% of the water flowing in the upper Indus basin, in northern Pakistan, is due to snow and ice melt (Immerzeel et al. 2010). Relying on agriculture, the economy of the Himalayan regions is highly dependent on water availability and irrigation systems (e.g., Akhtar et al. 2008). The Indo-Gangetic Plain (IGP; including regions of Pakistan, India, Nepal, and Bangladesh) is challenged by increasing food production. Any perturbation in agriculture will considerably affect the food systems of the region and increase the vulnerability of the resource-poor population (e.g., Aggarwal et al. 2004; Kahlown et al. 2007). The HKH stores a considerable amount of water within its extensive glacier cover (about 16 300 km^2), while lower-altitude areas are very dry. Along the HKH range, there is considerable variability in climate conditions, including varying precipitation sources and types (e.g., Bocchiola and Diolaiuti 2013), influencing the behavior and evolution of the cryosphere. Eastern and central HKH glaciers are subject to general retreat and have lost a significant amount of mass and area in the last few decades (Bolch et al. 2011).

*Corresponding author address: Daniele Bocchiola, Department of Civil and Environmental Engineering, Politecnico di Milano, L. da Vinci 32, 20133 Milan, Italy.
E-mail: daniele.bocchiola@polimi.it

DOI: 10.1175/JHM-D-14-0043.1

Geogr. Fis. Dinam. Quat.
40 (2017): 137-159

DOI 10.4461/GFDQ.2017.40.10

ALEXANDER R. GROOS [1*], CHRISTOPH MAYER [2], CLAUDIO SMIRAGLIA [3], GUGLIELMINA DIOLAIUTI [3], ASTRID LAMBRECHT [2]

A FIRST ATTEMPT TO MODEL REGION-WIDE GLACIER SURFACE MASS BALANCES IN THE KARAKORAM: FINDINGS AND FUTURE CHALLENGES

ABSTRACT: GROOS A.R., MAYER C., SMIRAGLIA C., DIOLAIUTI G., LAMBRECHT A., *A first attempt to model region-wide glacier surface mass balances in the Karakoram: findings and future challenges*. (IT ISSN 0391-9838, 2017).

In contrast to the central and eastern part of High Mountain Asia (HMA), no extensive glacier mass loss has been observed in the Karakoram during previous decades. However, the potential meteorological and glaciological causes of the so-called Karakoram Anomaly are diverse and still under debate. This paper introduces and presents a novel glacier Surface Mass Balance Model (glacierSMBM) to test whether the characteristic regional mass balance pattern can be reproduced using recent field, remote-sensing and reanalysis data as input. A major advantage of the model setup is the implementation of the non-linear effect of supra-glacial debris on the sub-surface ice melt. In addition to a first assessment of the annual surface mass balance from 1st August 2010 until 31st July 2011, a sensitivity analysis was performed to investigate the response of Karakoram glaciers to recent climate change. The mean modelled glacier mass balance for the Karakoram during the observation period is -0.92 m water equivalent (m.w.e.) a^{-1} and corresponds to an annual melt water contribution of -12.66 km^3. Data inaccuracies and the neglected process of snow redistribution from adjacent slopes are probably responsible for the bias in the model output. Despite the general offset between mass gain and mass loss, the model captures the characteristic features of the anomaly and indicates that positive glacier mass balances are mainly restricted to the central and northeastern part of the mountain range. From the evaluation of the sensitivity analysis, it can be concluded that the complex glacier response in the Karakoram is not the result of a single driver, but related to a variety of regional peculiarities such as the favourable meteorological conditions, the extensive supra-glacial debris and the timing of the main precipitation season.

KEY WORDS: Glacier surface mass balance modelling, Debris-covered glaciers, Ice and snow ablation, Karakoram Anomaly.

INTRODUCTION

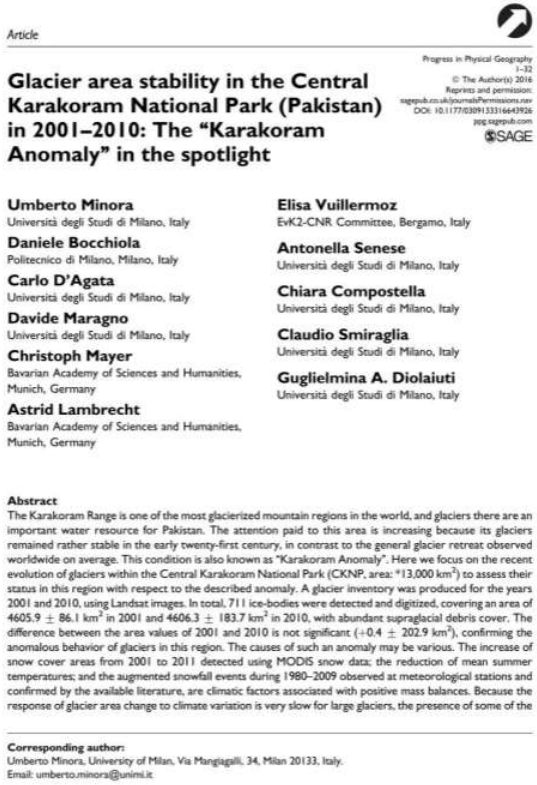
The Karakoram in the northwestern part of High Mountain Asia (HMA) is one of the most extensively glacierised areas outside the polar regions (Dyurgerov & Meier, 2005) and has increasingly attracted attention in recent years due to its glaciological and climatological peculiarities. In contrast to the central and eastern Himalaya, where many glaciers have responded to global climate change in the form of ice mass loss and negative length or area changes (e.g. Bolch & *alii*, 2011; Cogley, 2011; Bolch & *alii*, 2012; Kääb & *alii*, 2012; Cogley, 2016), expansion of individual glaciers has repeatedly been reported from the Karakoram based on in-situ and remote sensing observations (Hewitt, 2005; Hewitt, 2011; Rankl & *alii*, 2014). Several satellite-based geodetic measurements provide evidence that the glacial stability, known as Karakoram Anomaly (Hewitt, 2005), is indeed a regional phenomenon dating back to the 1970s (e.g. Gardelle & *alii*, 2012, 2013; Kääb & *alii*, 2015; Rankl & Braun, 2016; Agarwal & *alii*, 2017; Bolch & *alii*, 2017; Zhou & *alii*, 2017). Investigations

[1] Institute of Geography, University of Bern, Hallerstrasse 12, CH-3012, Bern, Switzerland
[2] Commission for Geodesy and Glaciology, Bavarian Academy of Sciences and Humanities, Alfons-Goppel Straße 11, D-80539 München, Germany
[3] Dipartimento di Scienze della Terra, Università degli Studi di Milano, Via Mangiagalli 34, I-20133, Milano, Italy
* Corresponding author: A.R. Groos, alexander.groos@giub.unibe.ch

The field work during summer 2011 and 2013 was organised and funded by the Ev-K2-CNR Association in the framework of the Pasvika and SEED projects. We thank the Pakistan Meteorological Department (PMD) for providing meteorological data and the TU Berlin (Department of Ecology, Chair of Climatology) for making the comprehensive High Asia Refined Analysis dataset (HAR) available. SRTM and Landsat data were downloaded from USGS' EarthExplorer and MODIS Snow Cover data from NASA's National Snow and Ice Data Center (NSIDC). The Leibniz Supercomputing Centre in Munich is appreciated for giving access to its Linux-Cluster where the model runs were performed.

Supplementary material as well as all figures and tables presented in this article are stored in the open access library PANGAEA (Groos & alii, 2017). The input raster data as well as the model results are available upon request by email to the first author (alexander.groos@giub.unibe.ch). For the download of the model, please access CRAN - the Comprehensive R Archive Network: https://CRAN.R-project.org/package=glacierSMBM.

We analysed snow accumulation, glacier micro-meteorology, surge phenomena, area changes, gurface conditions and changes, and we modelled ice- and snowmelt and glacier-derived meltwater runoff, …….



Article

Progress in Physical Geography
1–32
© The Author(s) 2016
Reprints and permission:
sagepub.co.uk/journalsPermissions.nav
DOI: 10.1177/0309133316643926
ppg.sagepub.com
SAGE

Glacier area stability in the Central Karakoram National Park (Pakistan) in 2001–2010: The "Karakoram Anomaly" in the spotlight

Umberto Minora
Università degli Studi di Milano, Italy

Daniele Bocchiola
Politecnico di Milano, Milano, Italy

Carlo D'Agata
Università degli Studi di Milano, Italy

Davide Maragno
Università degli Studi di Milano, Italy

Christoph Mayer
Bavarian Academy of Sciences and Humanities, Munich, Germany

Astrid Lambrecht
Bavarian Academy of Sciences and Humanities, Munich, Germany

Elisa Vuillermoz
EvK2-CNR Committee, Bergamo, Italy

Antonella Senese
Università degli Studi di Milano, Italy

Chiara Compostella
Università degli Studi di Milano, Italy

Claudio Smiraglia
Università degli Studi di Milano, Italy

Guglielmina A. Diolaiuti
Università degli Studi di Milano, Italy

Abstract

The Karakoram Range is one of the most glacierized mountain regions in the world, and glaciers there are an important water resource for Pakistan. The attention paid to this area is increasing because its glaciers remained rather stable in the early twenty-first century, in contrast to the general glacier retreat observed worldwide on average. This condition is also known as "Karakoram Anomaly". Here we focus on the recent evolution of glaciers within the Central Karakoram National Park (CKNP, area: ~13,000 km^2) to assess their status in this region with respect to the described anomaly. A glacier inventory was produced for the years 2001 and 2010, using Landsat images. In total, 711 ice-bodies were detected and digitized, covering an area of 4605.9 ± 86.1 km^2 in 2001 and 4606.3 ± 183.7 km^2 in 2010, with abundant supraglacial debris cover. The difference between the area values of 2001 and 2010 is not significant (+0.4 ± 202.9 km^2), confirming the anomalous behavior of glaciers in this region. The causes of such an anomaly may be various. The increase of snow cover areas from 2001 to 2011 detected using MODIS snow data; the reduction of mean summer temperatures; and the augmented snowfall events during 1980–2009 observed at meteorological stations and confirmed by the available literature, are climatic factors associated with positive mass balances. Because the response of glacier area change to climate variation is very slow for large glaciers, the presence of some of the

Corresponding author:
Umberto Minora, University of Milan, Via Mangiagalli, 34, Milan 20133, Italy.
Email: umberto.minora@unimi.it

202 Annals of Glaciology 56(70) 2015 doi: 10.3189/2015AoG70A206

A simple model to evaluate ice melt over the ablation area of glaciers in the Central Karakoram National Park, Pakistan

U. MINORA,[1,2] A. SENESE,[1] D. BOCCHIOLA,[2,3] A. SONCINI,[2] C. D'AGATA,[1,3] R. AMBROSINI,[4] C. MAYER,[3,5] A. LAMBRECHT,[5] E. VUILLERMOZ,[3] C. SMIRAGLIA,[1,3] G. DIOLAIUTI[1,3]

[1]'A. Desio' Department of Earth Sciences, Università degli Studi di Milano, Milan, Italy
[2]Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
[3]Ev-K2-CNR, Bergamo, Italy
[4]Department of Biotechnology and Biosciences, Università degli Studi di Milano Bicocca, Milan, Italy
[5]Bavarian Academy of Sciences and Humanities, Munich, Germany
Correspondence: A. Senese <antonella.senese@unimi.it>

ABSTRACT. This study provides an estimate of fresh water derived from ice melt for the ablation areas of glaciers in the Central Karakoram National Park (CKNP), Pakistan. In the CKNP there are ~700 glaciers, covering ~4600 km^2, with widespread debris cover (518 km^2). To assess meltwater volume we applied a distributed model able to describe both debris-covered and debris-free ice ablation. The model was calibrated using data collected in the field in the CKNP area and validated by comparison with ablation data collected in the field, independent of the data used in building the model. During 23 July–9 August 2011, the mean model-estimated ablation in the CKNP was 0.024 m w.e. d^{-1} in debris-covered areas and 0.037 m w.e. d^{-1} in debris-free areas. We found a mean error of +0.01 m w.e. (corresponding to 2%) and a root-mean-square error equal to 0.09 m w.e. (17%). According to our model, the ablation areas of all the glaciers in the CKNP produced a water volume of 1.963 km^3 during the study period. Finally, we performed several sensitivity tests for assessing the impact of the input data variations.

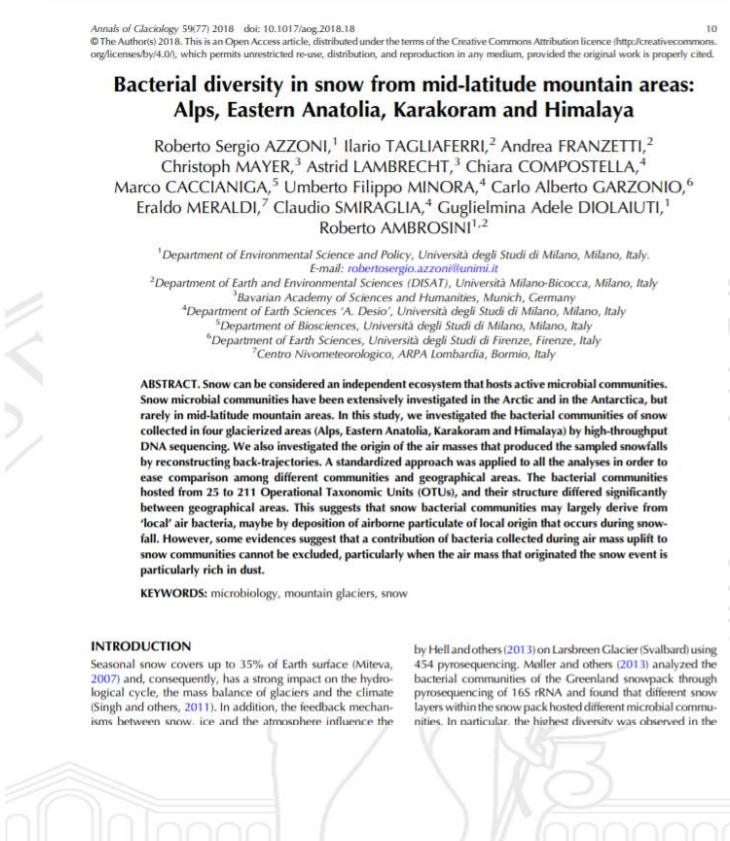
KEYWORDS: debris-covered glaciers, glacier ablation phenomena, glacier modelling, remote sensing, surface melt

1. INTRODUCTION

The largest glacierized region outside the Arctic and the Antarctic is High Mountain Asia (HMA), which covers an area of 118 200 km^2 (Gardner and others, 2013). Changes in glacier extent and volume in this region are spatially heterogeneous and poorly known (Bolch and others, 2012). Indeed, recent studies revealed that most of the northwestern Himalaya have experienced less glacier shrinkage than the eastern parts of the same mountain range (Bhambri and Bolch, 2009; Bolch and others, 2012; Kääb and others, 2012). In the western and central Karakoram region, glaciers showed long-term irregular behavior with frequent advances, and possible slight mass gain in the last decade (Copland and others, 2011; Hewitt, 2011; Bolch and others, 2012; Gardelle and others, 2012, 2013; Kääb and others, 2012; Minora and others, 2013; Soncini and others, 2015). Gardelle and others' (2012, 2013) recent studies demonstrate how, in contrast to widespread global glacier retreat, glaciers in the Karakoram region as a whole have exhibited a general mass-balance stability (the so called 'Karakoram anomaly'; Hewitt, 2005, 2011). Advances of individual glaciers have also been reported in the Shyok valley (eastern Karakoram) during the last decade (Raina and Srivastva, 2008). These individual advances and mass gain episodes could be attributed to surging (Barrand and Murray, 2006; Hewitt, 2007; Copland and others, 2011; Quincey and others, 2011), temperature drops (Shekhar and others, 2010) and increased solid precipitation in the accumulation areas (Fowler and Archer, 2006; Bocchiola and Diolaiuti, 2013). The Karakoram glaciers are a strategic resource for Pakistan, because they provide fresh water for civil use, hydropower production and farming. The glacierized Karakoram is therefore a key area for studying the effects of ongoing climate change on present and future meltwater discharge.

This study focuses on the glacier ablation areas within the Central Karakoram National Park (CKNP), with the aim of assessing the magnitude and rate of ice ablation and evaluating the derived meltwater amount. For this purpose, we applied a distributed model able to describe ablation in debris-covered and debris-free conditions (Pellicciotti and others, 2005; Mihalcea and others, 2008a). Indeed, a significant portion of the glaciers in the CKNP is covered by a supraglacial debris layer, modulating the magnitude and rate of ice ablation (Nakawo and Young, 1981; Nakawo and Takahashi, 1982; Nicholson and Benn, 2006; Mihalcea and others, 2008a,b; Reid and Brock, 2010). This debris layer must therefore be accurately considered in distributed modeling of ice melt.

While quite a few energy- and mass-balance studies have been performed on debris-free glaciers, studies including debris-covered ice are not numerous. In the recent past, some authors have focused their attention on debris-covered ice only, and at single-point sites. For example, Nicholson and Benn (2006) presented a modified surface energy-balance model to calculate melt beneath a debris layer from daily mean meteorological data on two European debris-covered glaciers (Ghiacciaio del Belvedere, Italy, and



Annals of Glaciology 59(77) 2018 doi: 10.1017/aog.2018.18 10

Bacterial diversity in snow from mid-latitude mountain areas: Alps, Eastern Anatolia, Karakoram and Himalaya

Roberto Sergio AZZONI,[1] Ilario TAGLIAFERRI,[2] Andrea FRANZETTI,[2] Christoph MAYER,[3] Astrid LAMBRECHT,[3] Chiara COMPOSTELLA,[4] Marco CACCIANIGA,[5] Umberto Filippo MINORA,[4] Carlo Alberto GARZONIO,[6] Eraldo MERALDI,[7] Claudio SMIRAGLIA,[4] Guglielmina Adele DIOLAIUTI,[1] Roberto AMBROSINI[1,2]

[1]Department of Environmental Science and Policy, Università degli Studi di Milano, Milano, Italy. E-mail: robertosergio.azzoni@unimi.it
[2]Department of Earth and Environmental Sciences (DISAT), Università Milano-Bicocca, Milano, Italy
[3]Bavarian Academy of Sciences and Humanities, Munich, Germany
[4]Department of Earth Sciences 'A. Desio', Università degli Studi di Milano, Milano, Italy
[5]Department of Biosciences, Università degli Studi di Milano, Milano, Italy
[6]Department of Earth Sciences, Università degli Studi di Firenze, Firenze, Italy
[7]Centro Nivometeorologico, ARPA Lombardia, Bormio, Italy

ABSTRACT. Snow can be considered an independent ecosystem that hosts active microbial communities. Snow microbial communities have been extensively investigated in the Arctic and in the Antarctica, but rarely in mid-latitude mountain areas. In this study, we investigated the bacterial communities of snow collected in four glacierized areas (Alps, Eastern Anatolia, Karakoram and Himalaya) by high-throughput DNA sequencing. We also investigated the origin of the air masses that produced the sampled snowfalls by reconstructing back-trajectories. A standardized approach was applied to all the analyses in order to ease comparison among different communities and geographical areas. The bacterial communities hosted from 25 to 211 Operational Taxonomic Units (OTUs), and their structure differed significantly between geographical areas. This suggests that snow bacterial communities may largely derive from 'local' air bacteria, maybe by deposition of airborne particulate of local origin that occurs during snowfall. However, some evidences suggest that a contribution of bacteria collected during air mass uplift to snow communities cannot be excluded, particularly when the air mass that originated the snow event is particularly rich in dust.

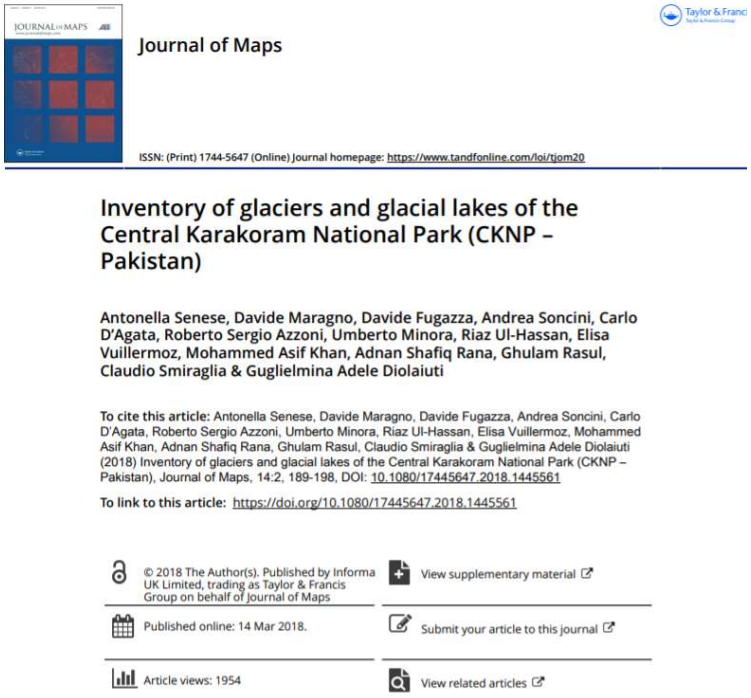
KEYWORDS: microbiology, mountain glaciers, snow

INTRODUCTION

Seasonal snow covers up to 35% of Earth surface (Miteva, 2007) and, consequently, has a strong impact on the hydrological cycle, the mass balance of glaciers and the climate (Singh and others, 2011). In addition, the feedback mechanisms between snow, ice and the atmosphere influence the

by Hell and others (2013) on Larsbreen Glacier (Svalbard) using 454 pyrosequencing. Møller and others (2013) analyzed the bacterial communities of the Greenland snowpack through pyrosequencing of 16S rRNA and found that different snow layers within the snow pack hosted different microbial communities. In particular, the highest diversity was observed in the

One the most important results we obtained is the CKNP Glacier Inventory



Journal of Maps

ISSN: (Print) 1744-5647 (Online) Journal homepage: https://www.tandfonline.com/loi/tjom20

Inventory of glaciers and glacial lakes of the Central Karakoram National Park (CKNP – Pakistan)

Antonella Senese, Davide Maragno, Davide Fugazza, Andrea Soncini, Carlo D'Agata, Roberto Sergio Azzoni, Umberto Minora, Riaz Ul-Hassan, Elisa Vuillermoz, Mohammed Asif Khan, Adnan Shafiq Rana, Ghulam Rasul, Claudio Smiraglia & Guglielmina Adele Diolaiuti

To cite this article: Antonella Senese, Davide Maragno, Davide Fugazza, Andrea Soncini, Carlo D'Agata, Roberto Sergio Azzoni, Umberto Minora, Riaz Ul-Hassan, Elisa Vuillermoz, Mohammed Asif Khan, Adnan Shafiq Rana, Ghulam Rasul, Claudio Smiraglia & Guglielmina Adele Diolaiuti (2018) Inventory of glaciers and glacial lakes of the Central Karakoram National Park (CKNP – Pakistan), Journal of Maps, 14:2, 189-198, DOI: 10.1080/17445647.2018.1445561

To link to this article: https://doi.org/10.1080/17445647.2018.1445561

View supplementary material

Published online: 14 Mar 2018.

Submit your article to this journal

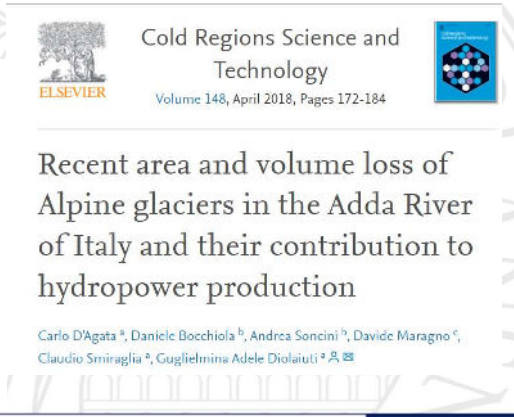
Article views: 1954

View related articles

https://sites.unimi.it/glaciol/wp-content/uploads/2019/02/CKNP-Glacier-inventory_2dic16.pdf

The next steps….

1. *An inventory of all the Pakistan glaciers (>5000) based on the most recent methods of remote sensing (with field validation of the data)*
2. *The evaluation of the current and expected impacts of climate change on Pakistan glaciers and the derived meltwater discharge, including the economic ones on hydropower production based on our pilot studies in Italy*
3. *The description other ecological features of glacier (microplastics?)*
4. *Last but not least, a contribution to the training of young Italian and Pakistani researchers who will become experts in the field of glaciology and glacier ecology and able to face the scientific challenges of this century*



Glaciers are ecosystems and host life forms and active ecological processes

Opinion

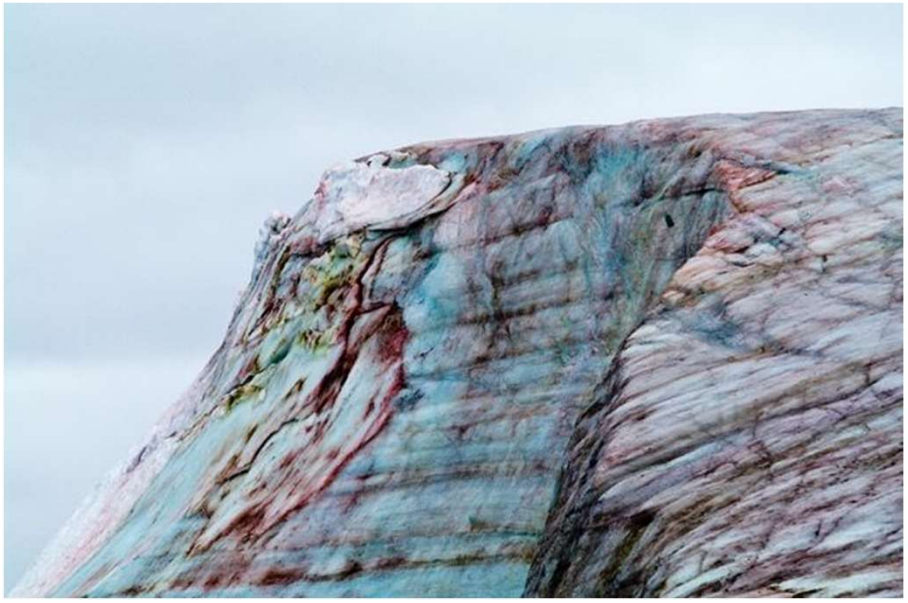
Trends in Ecology and Evolution, April 2012

Cell PRESS

Glaciers and ice sheets as a biome

Alexandre M. Anesio and Johanna Laybourn-Parry

Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol, UK, BS8 1SS



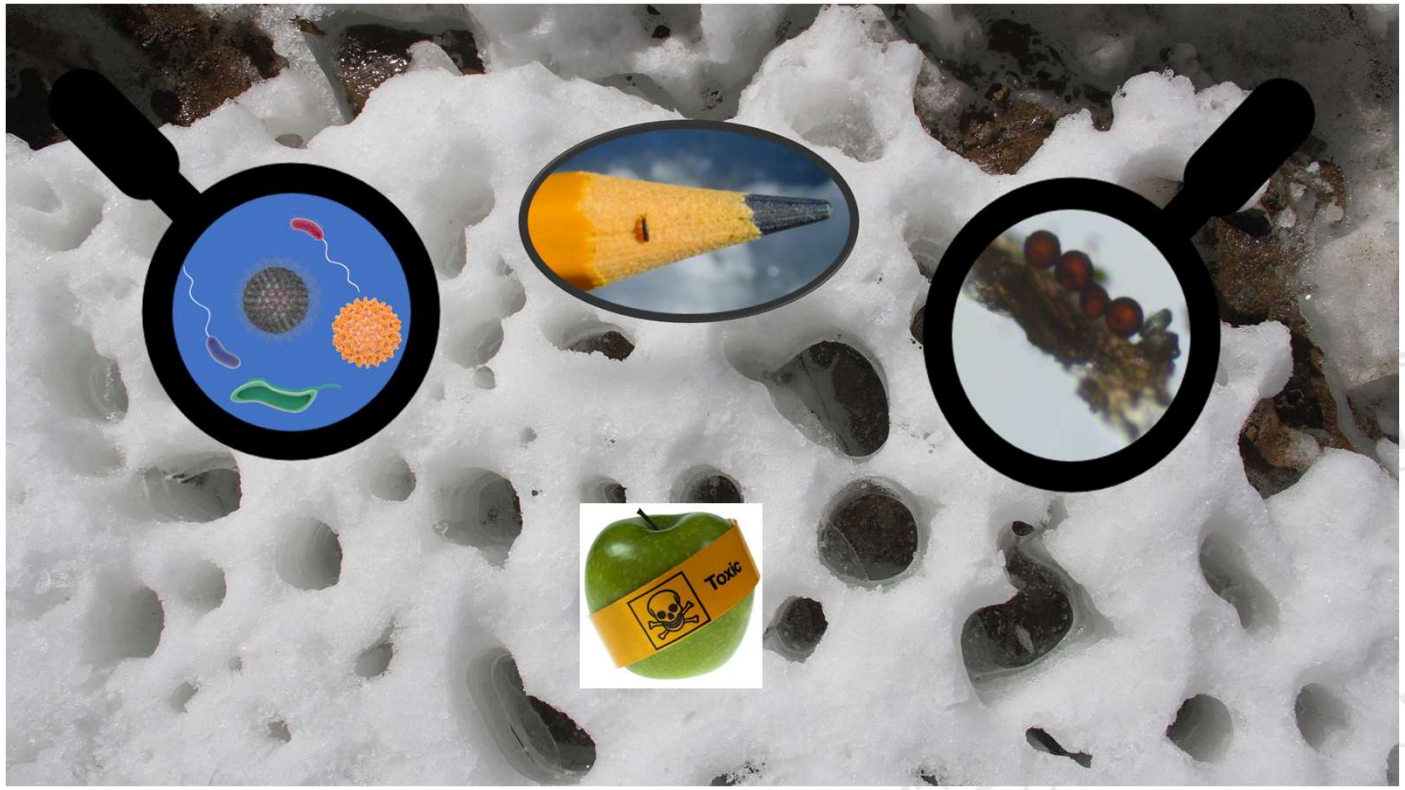
Ecological Monographs, 78(1), 2008, pp. 41–67

GLACIAL ECOSYSTEMS

ANDY HODSON,[1,9] ALEXANDRE M. ANESIO,[2] MARTYN TRANTER,[3] ANDREW FOUNTAIN,[4] MARK OSBORN,[5] JOHN PRISCU,[6] JOHANNA LAYBOURN-PARRY,[7] AND BIRGIT SATTLER[8]

… that, in turn, can affect glacier dynamic

Cryoconite holes are hot-spots of biodiversity on glaciers ...



… and bio-geo-reactors where most ecological processess occur, including pollutant degradation

Our 2013 studies on Baltoro glacier led us proposing a new carbon interactome among cryoconite bacteria

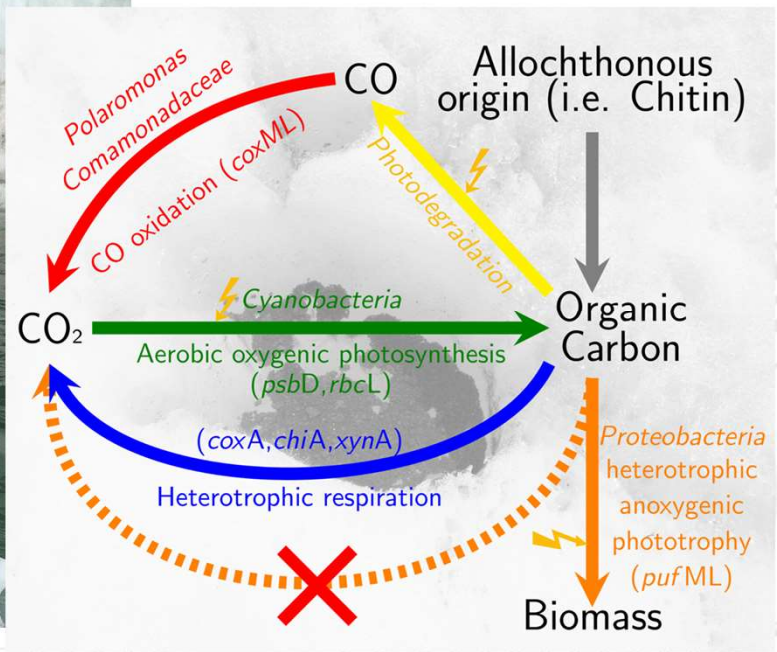
The ISME Journal (2016) 10, 2984–2988

www.nature.com/ismej

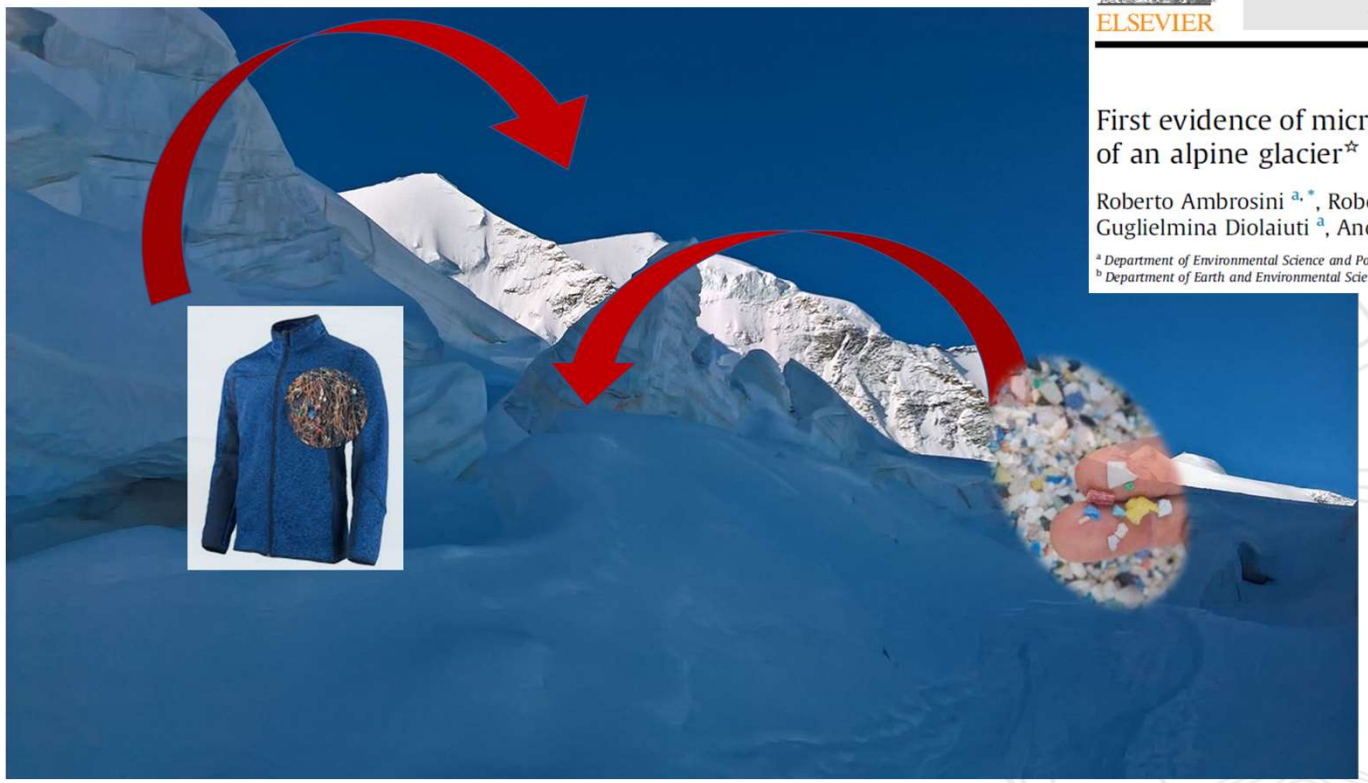
SHORT COMMUNICATION

Light-dependent microbial metabolisms drive carbon fluxes on glacier surfaces

Andrea Franzetti[1], Ilario Tagliaferri[1], Isabella Gandolfi[1], Giuseppina Bestetti[1], Umberto Minora[2,4], Christoph Mayer[3], Roberto S Azzoni[2], Guglielmina Diolaiuti[2], Claudio Smiraglia[2] and Roberto Ambrosini[1]



In 2019 we were the first to demonstrate that microplastics are present on glaciers



Environmental Pollution 253 (2019) 297–301

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

First evidence of microplastic contamination in the supraglacial debris of an alpine glacier☆

Roberto Ambrosini [a, *], Roberto Sergio Azzoni [a], Francesca Pittino [b], Guglielmina Diolaiuti [a], Andrea Franzetti [b], Marco Parolini [a]

[a] Department of Environmental Science and Policy, University of Milan, Via Celoria 26, I-20131, Milano, Italy
[b] Department of Earth and Environmental Science, University of Milano-Bicocca, Piazza della Scienza 1, I-20126, Milano, Italy

Since then, we have found microplastics on all the glaciers we have sampled (> 10 from Arctic to Patagonia – the results are still unpublished)

The next steps….

1. *To investigate the ecology of Pakistan glacier in particular:*
    1. *Biodiversity*
    2. *Anthropic impacts*
2. *To assess the contribution of ecological processes on glacier ice mass balance*
3. *The description of other ecological features of glacier (microplastics?)*
4. *To contribute to the training of young Italian and Pakistani researchers*

DNA

HiSeq 2000™

Eos Science News by AGU

SIGN UP FOR NEWSLETTER

ABOUT SPECIAL REPORTS TOPICS PROJECTS NEWSLETTER SUBMIT TO *EOS*

Microplastics' Hidden Contribution to Snow Melting

Microplastic particles, present everywhere on the planet, may complicate assessments of black carbon's role in the melting of snow and of its contributions to Earth's radiative balance.

By J. Ming and F. Wang 8 March 2021

UNIVERSITÀ DEGLI STUDI DI MILANO

Thank you for your kind attention