Amplified climate change and ecological sensitivity of polar and cold climate environments are key global environment issues. Understanding how projected climate change will alter surface environments in these regions is only possible when present-day source-to-sink fluxes can be quantified.

The book provides the first global synthesis and integrated analysis of environmental drivers and quantitative rates of solute and sedimentary fluxes in cold environments, and the likely impact of projected climate change. The focus on largely undisturbed cold environments allows ongoing climate change effects to be detected and, moreover, distinguished from anthropogenic impacts. A novel approach for coordinated and integrative process geomorphic research is introduced to enable better comparison between studies.

This highly topical and multidisciplinary book, which includes case studies covering Arctic, Antarctic, and alpine environments, will be of interest to graduate students and researchers in the fields of geomorphology, sedimentology, and global environmental change.

ACHIM A. BEYLICH is a senior research scientist at the Geological Survey of Norway, Trondheim. He has also held an Associate Professor position at the Norwegian University of Science and Technology (NTNU) in Trondheim. Dr. Beylich has more than 20 years of experience in field- and laboratory-based quantitative process geomorphic research in cold climate environments in Iceland, Sweden, Finland, Norway, Canada, Russia, and the German Alps. He initiated the SEDIBUD (Sediment Budgets in Cold Environments) working group of the International Association of Geomorphologists (IAG), which he has chaired and led since 2005.

JOHN C. DIXON is professor of Geosciences at the University of Arkansas, USA. His principal research interests lie in the area of landscape evolution in cold and warm dry climates and, in particular, the role of chemical processes in soil and regolith formation. Professor Dixon has worked in Swedish Lapland, Alaska, the Rocky Mountains, southern Australia, and southern Norway and has published over 100 refereed journal articles and book chapters.

ZBIGNIEW ZWOLIŃSKI is a professor at the Institute of Geoecology and Geoinformation at Adam Mickiewicz University in Poznań, Poland. His main research interests include fluvial geomorphology and sedimentology, GIScience, geodiversity, and global changes. He conducts research on desert landforms as well as landforms in tropical and Polar Regions and has participated in many summer expeditions to the High Arctic (Spitsbergen, Iceland) and Antarctica (King George Island).
Source-to-Sink Fluxes in Undisturbed Cold Environments

Edited by

ACHIM A. BEYLICH
Trondheim, Norway

JOHN C. DIXON
Fayetteville, Arkansas, USA

ZBIGNIEW ZWOLIŃSKI
Poznań, Poland
## Contents

**List of contributors**  
page vii

**Preface**  
xi

**Part I: Solute and sedimentary fluxes and budgets in changing cold climate environments**  
1

1 Introduction to the theme  
ACHIM A. BEYLICH  
3

2 The I.A.G./A.I.G. SEDIBUD (Sediment Budgets in Cold Environments) program  
ACHIM A. BEYLICH  
5

**Part II: Climate change in cold environments and general implications for contemporary solute and sedimentary fluxes**  
11

3 The changing cryosphere – implications for solute and sedimentary fluxes in cold climate environments  
IVAR BERTHLING AND BERND ETZELMÜLLER  
13

4 Changes in vegetation cover and implications for solute and sedimentary fluxes in cold climate environments  
ULF MOLAU  
30

**Part III: Solute and sedimentary fluxes in subarctic and Arctic environments**  
37

5 Contemporary solute and sedimentary fluxes in Arctic and subarctic environments: current knowledge  
JOHN C. DIXON  
39

6 The use of dendrogeomorphology to recognize the spatiotemporal distribution of snow avalanches in Northern Iceland – case studies from Dalsmynn, Ljósavatnsskarð, and Fnjóskadalur  
ARMELLE DECAULNE, ÓLAFUR EGGERTSSON, AND THORSTEINN SÆMUNDSSON  
52

7 A contemporary assessment of sediment and solute transfers in Kärkevagge, Swedish Lapland  
JOHN C. DIXON  
67

8 Hillslope processes and related sediment fluxes on a fine-grained scree slope of Eastern Canada  
DANIEL GERMAIN AND BERNARD HÉTU  
79

9 Sediment and solute transport from Greenland  
BENT HASHOLT  
96

10 Measurements of bedload flux in a high Arctic environment  
WALDEMAR KOČIUBA  
116

11 Solute and particulate fluxes in catchments in Spitsbergen  
GRZEGORZ RACHLEWICZ, GRAŻYA SZPIKOWSKA, JÓZEF SZPIKOWSKI, AND ZBIGNIEW ZWOLIŃSKI  
133

12 Sediment and solute fluxes at the Igarka field site, Russian subarctic  
NIKITA I. TANANAEV  
144

13 Variability and controls of solute and sedimentary fluxes in subarctic and Arctic environments  
JOHN C. DIXON  
154
Part IV: Solute and sedimentary fluxes in sub-Antarctic and Antarctic environments

16 Environmental impact on contemporary solute and sedimentary fluxes in Antarctica: current knowledge
ZBIGNIEW ZWOLIŃSKI, SERGEY BOLTRAMOVICH, MAREK KEJNA, ALEXANDER LASTOCHKIN, AND ANDREY ZHIROV

18 Solute and solid cascade system in the Antarctic oases
ZBIGNIEW ZWOLIŃSKI

19 Environmental controls on sediment composition and particle fluxes over the Antarctic continental shelf
ENRIQUE ISLA

20 Solute and sedimentary fluxes on King George Island
ZBIGNIEW ZWOLIŃSKI, MAREK KEJNA, GRZEGORZ RACHLEWICZ, IRENEUSZ SOBOTA, AND JÓZEF SZPIKOWSKI

22 Dynamics of the Antarctica ice cap
ALEXANDER N. LASTOCHKIN

24 Rates of slope and channel processes in the Reintal valley, Bavarian Alps
DAVID MORCHE, MICHAEL KRAUTBLATTER, TOBIAS HECKMANN, FLORIAN HAAS, AND JOACHIM GÖTZ

25 Comparative analysis of sediment routing in two different alpine catchments
JOHANNES STANGL, ERIC RASCHER, AND OLIVER SASS

Part V: Solute and sedimentary fluxes in alpine/mountain environments

26 Controls and variability of solute and sedimentary fluxes in alpine/mountain environments
ACHIM A. BEYLICH

Part VI: Quantitative analysis of solute and sedimentary fluxes in cold climate environments

27 Environmental drivers, spatial variability, and rates of chemical and mechanical fluvial denudation in selected glacierized and nonglacierized cold climate catchment geosystems: from coordinated field data generation to integration and modeling
ACHIM A. BEYLICH

28 Summary of key findings from Arctic, Antarctic, and mountain environments
ACHIM A. BEYLICH, JOHN C. DIXON, AND ZBIGNIEW ZWOLIŃSKI

Index
Contributors

IVAR BERTHLING
Department of Geography, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

ACHIM A. BEYLICH
Geo-Environment Division, Geological Survey of Norway (NGU), Trondheim, Norway

SERGEY BOLTRAMOVICH
Institute of Earth Sciences, St. Petersburg State University, St. Petersburg, Russia

ARMELLE DECAULNE
Le Centre national de la recherche scientifique (CNRS), University of Nantes, Nantes, France

STEPHEN J. DÉRY
Environmental Science and Environmental Engineering Program, University of Northern British Columbia, Prince George, British Columbia, Canada

JOHN C. DIXON
Department of Geosciences, University of Arkansas, Fayetteville, Arkansas, U.S.A.

ÓLAFUR EGGERTSSON
Research Branch, Icelandic Forest Service, Reykjavik, Iceland

BERND ETZELMÜLLER
Department of Geosciences, University of Oslo, Oslo, Norway

BARRY J. FORRESTER
Faculty of Education, Health & Community, Liverpool John Moores University, Liverpool, United Kingdom

MONIQUE FORT
Laboratoire de géographie PRODIG, Paris Diderot University, Paris 7, Paris, France

ANDREW G. FOUNTAIN
Department of Geology, Portland State University, Portland, Oregon, U.S.A.

DANIEL GERMAIN
Département de géographie, University of Quebec at Montréal, Montréal, Quebec, Canada

JOACHIM GÖTZ
Department of Geography and Geology, University of Salzburg, Salzburg, Austria

FLORIAN HAAAS
Physical Geography, Catholic University of Eichstätt-Ingolstadt, Eichstätt, Germany

BENT HASHOLT
Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark

TODIAN HECKMANN
Physical Geography, Catholic University of Eichstätt-Ingolstadt, Eichstätt, Germany
List of contributors

BERNARD HÉTU
Département de biologie, chimie et géographie,
University of Quebec at Rimouski, Rimouski,
Quebec, Canada

ENRIQUE ISLA
Institut de Ciencies del Mar-CSIC, Barcelona,
Spain

MAREK KEJNA
Faculty of Earth Sciences, Nicolaus Copernicus
University, Toruń, Poland

WALDEMAR KOCIUBA
Institute of Earth Sciences, Maria Curie-Skłodowska
University, Lublin, Poland

MAREK KEJNA
Faculty of Earth Sciences, Nicolaus Copernicus
University, Toruń, Poland

MAREK KEJNA
Faculty of Earth Sciences, Nicolaus Copernicus
University, Toruń, Poland

ALEXANDER N. LASTOCHKIN
Institute of Earth Sciences, St. Petersburg
State University, St. Petersburg, Russia

KATJA LAUTE
Geo-Environment Division, Geological
Survey of Norway (NGU), Trondheim, Norway

MIKE S. LEGGAT
Environmental Science and Environmental
Engineering Program, University of Northern
British Columbia, Prince George, British
Columbia, Canada

JOSEPH S. LEVY
Department of Geological Sciences, University
of Texas at Austin, Austin, Texas, U.S.A.

WILLIAM BERRY LYONS
School of Earth Sciences, Ohio State University,
Columbus, Ohio, U.S.A.

DIANE M. MCKNIGHT
Institute of Arctic and Alpine Research,
University of Colorado, Boulder,
Colorado, U.S.A.

BRIAN MENOUNOS
Geography Program and Natural Resources
and Environmental Studies Institute, University of
Northern British Columbia, Prince George, British
Columbia, Canada

ULF MOLAU
Department of Biological & Environmental Sciences,
University of Gothenburg, Göteborg, Sweden

DAVID MORCHE
Institute for Geosciences and Geography, Martin
Luther University Halle-Wittenberg, Halle (Saale),
Germany

PHILIP N. OWENS
Environmental Science and Environmental Engineer-
ing Program, University of Northern British Columbia,
Prince George, British Columbia, Canada

GRZEGORZ RACHLEWICZ
Institute of Geocology and Geoinformation, Adam
Mickiewicz University, Poznań, Poland

ERIC RASCHER
Department of Geography and Regional Science,
University of Graz, Graz, Austria

THORSTEINN S. EMUNDSSON
Institute of Earth Sciences, University of Iceland,
Reykjavik, Iceland

OLIVER SASS
Department of Geography and Regional Science,
University of Graz, Graz, Austria

IRENEUSZ SOBOTA
Faculty of Earth Sciences, Nicolaus Copernicus
University, Toruń, Poland

JOHANNES STANGL
Department of Geography and Regional Science,
University of Graz, Graz, Austria

TIM A. STOTT
Faculty of Education, Health & Community, Liverpool
John Moores University, Liverpool, United Kingdom
<table>
<thead>
<tr>
<th>List of contributors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Grażyna Szpikowska</td>
<td>Kathleen A. Welch</td>
</tr>
</tbody>
</table>
Geoeccological Station, Adam Mickiewicz University, Grzmiąca, Poland | Byrd Polar Research Center, Ohio State University, Columbus, Ohio, U.S.A. |
| Józef Szpikowski | Andrei Zhirov |
Institute of Geoecology and Geoinformation, Adam Mickiewicz University, Poznań, Poland | Institute of Earth Sciences, St. Petersburg State University, St. Petersburg, Russia |
| Nikita I. Tananaev | Zbigniew Zwoliński |
Igarka Geocryology Laboratory, Siberian Branch, Russian Academy of Sciences, Igarka, Krasnoyarsk Krai, Russia | Institute of Geoecology and Geoinformation, Adam Mickiewicz University, Poznań, Poland |
Preface

Amplified climate change and ecological sensitivity of largely undisturbed polar and high-altitude cold climate environments have been highlighted as key global environmental issues. The effects of projected climate change will change surface environments in cold regions and alter the fluxes of sediments, nutrients, and solutes, but the absence of quantitative data and coordinated geomorphic process monitoring, analysis, and modeling to understand the sensitivity of the Earth surface environment in these largely undisturbed environments is acute.

This book, *Source-to-Sink Fluxes in Undisturbed Cold Environments*, addresses this key knowledge gap and aims at an integrated analysis of environmental drivers and rates of contemporary solute and sedimentary fluxes in cold climate catchment geosystems. It summarizes and synthesizes achievements of the International Association of Geomorphologists’ (I.A.G./A.I.G.) SEDIBUD (Sediment Budgets in Cold Environments) program which has been active over the last eleven years, since 2005. In the focus of the book are selected examples of natural and largely undisturbed catchment geosystems (SEDIBUD key test sites) from different characteristic cold climate environments worldwide. The book is not aiming at a geographical survey or inventory of these environments. The key focus is on the quantitative analysis and understanding of environmental controls and rates of contemporary solute and sedimentary fluxes in defined cold climate catchment geosystems. Referring to the issue of glacial environments versus cold environments both glacierized and nonglacierized catchment geosystems are investigated.

For reaching a global cover of different cold climate environments the book is, after providing an introductory part, “Solute and sedimentary fluxes and budgets in changing cold climate environments” (Part I) and a general part, “Climate change in cold environments and general implications for contemporary solute and sedimentary fluxes” (Part II), dealing in different defined book parts with “Solute and sedimentary fluxes in sub-Arctic and Arctic environments” (Part III), “Solute and sedimentary fluxes in sub-Antarctic and Antarctic environments” (Part IV), and “Solute and sedimentary fluxes in alpine/mountain environments” (Part V). In Part VI, “Quantitative analysis of solute and sedimentary fluxes in cold climate environments,” the key findings from the previous book parts are summarized and main conclusions are drawn. In addition, comparable datasets on contemporary solute and sedimentary fluxes and yields generated during coordinated research efforts in different selected cold climate catchment geosystems are integrated with the key goals to (1) identify the main environmental drivers and rates of contemporary solute and sedimentary fluxes, (2) explain the spatial variability of contemporary solute and sedimentary fluxes and yields found across different cold climate environments, and (3) assess possible effects of projected climate change on solute and sedimentary fluxes in these cold climate environments.

All chapters of this SEDIBUD synthesis book went through a peer-review process, and the completion of this book would not have been possible without the valuable help of numerous peer reviewers. We would like to thank all these anonymous reviewers for their important work and contributions. In addition, we would like to express our special thanks to Professor Dr. Olav Slaymaker (Vancouver, Canada), who provided essential scientific advice throughout the duration of the SEDIFLUX and SEDIBUD programs and during the process of preparing this book.

Achim A. Beylich, John C. Dixon, and Zbigniew Zwoliński