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Encyclopedia of Snow, Ice and Glaciers

Vijay P. Singh
Texas A & M University - College Station

Pratap Singh

Umesh K. Haritashya
University of Dayton, uharitashya1@udayton.edu

ENCYCLOPEDIA OF EARTH SCIENCES SERIES

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edited by

VIJAY P. SINGH
Texas A&M University
College Station, Texas
USA

PRATAP SINGH
New Delhi
India

UMESH K. HARITASHYA
University of Dayton
Dayton, Ohio
USA

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Contents

Contributors

James S. Aber
Emporia State University
Emporia, KS 66801-5087
USA
jaber@emporia.edu

Vladimir Aizen
College of Science, Mines Building
University of Idaho
Moscow, ID 83844-3025
USA
aizen@uidaho.edu

Ian Allison
Australian Antarctic Division and Antarctic Climate and Ecosystems CRC
Private Bag 80
Hobart, Tasmania 7001
Australia
ian.allison@utas.edu.au

John T. Andrews
Institute of Arctic and Alpine Research
and Department of Geological Sciences
University of Colorado
Boulder, CO 80309
USA
andrewsj@colorado.edu

Manoj K. Arora
Department of Civil Engineering
Indian Institute of Technology Roorkee
Roorkee 247667
India
manojfce@iitr.ernet.in

Monohar Arora
National Institute of Hydrology (NIH)
Roorkee 247667, UA
India
arora@nih.ernet.in

Cliff Atkins
School of Geography, Environment and Earth Sciences
Victoria University of Wellington
P.O. Box 600
Wellington 6140
New Zealand
Cliff.Atkins@vuw.ac.nz

David B. Bahr
Department of Physics and Computational Science
Regis University
3333 Regis Blvd
Denver, CO 80221-1099
USA
dbahr@regis.edu

Ian Baker
Thayer School of Engineering
Dartmouth College
Hanover, NH 03755
USA
Ian.Baker@Dartmouth.edu

Jostein Bakke
Department of Geography/Bjerknes Centre for Climate Research
University of Bergen
Fosswinckelsgate 6
5020 Bergen
Norway
Jostein.Bakke@geog.uib.no

Lars Bengtsson
Department of Water Resources Engineering
Lund University
P.O. Box 118
22100 Lund
Sweden
Lars.Bengtsson@tvrl.lth.se

Martin Beniston
Interdisciplinary Institute for Environmental Dynamics
University of Geneva
7 route de Drize
1227 Carouge, Geneva
Switzerland
martin.beniston@unige.ch

Matthew R. Bennett
The School of Applied Sciences
Bournemouth University Talbot Campos
Fern Barrow
Dorset BH12 5BB
UK
MBennett@bournemouth.ac.uk

Andrzej Ber
Polish Geological Institute – Polish Research Institute
Warszawa
Poland
andrzej.ber@pgi.gov.pl

Etienne Berthier
LEGOS/CNRS/UPS
14 av. Ed. Belin
31400 Toulouse
France
etienne.berthier@legos.obs-mip.fr

Nancy A. N. Bertler
Joint Antarctic Research Institute
Victoria University of Wellington and GNS Science
P.O. Box 600
Wellington 6140
New Zealand
Nancy.Bertler@vuw.ac.nz

Achim A. Beylich
Quaternary Geology and Climate Group
Geological Survey of Norway (NGU)
Leiv Eirikssons vei 39
7491 Trondheim
Norway
and
Department of Geography
Norwegian University of Science and Technology
(NTNU)
Dragvoll
7491 Trondheim
Norway
achim.beylich@NGU.NO

Mahendra R. Bhutiyani
Hazard Assessment and Forecasting Division
Snow and Avalanche Study Establishment
Plot No. 1, Sector 37 A, Him Parisar
Chandigarh 160036
India
mahendra_bhutiyani@yahoo.co.in

Richard Bintanja
Royal Netherlands Meteorological Institute (KNMI)
Wilhelminalaan 10
3732 De Bilt
The Netherlands
R.Bintanja@knmi.nl

Farjana S. Birajdar
Centre of Studies in Resources Engineering
Indian Institute of Technology Bombay
Powai, Mumbai 400076, Maharashtra
India

Michael P. Bishop
Department of Geography and Geology
University of Nebraska-Omaha
6001 Dodge Street
Omaha, NE 68182
USA
mpbishop@mail.unomaha.edu

Tobias Bolch
Department of Geography
University of Zürich-Irchel
Winterthurerstr. 190
8057 Zürich
Switzerland
tobias.bolch@geo.uzh.ch

Sarah Boon
Department of Geography
University of Lethbridge
4401 University Dr
Lethbridge, AB T1K 3M4
Canada
sarah.boon@uleth.ca

David A. Braaten
Center for Remote Sensing of Ice Sheets
Department of Geography
University of Kansas
Lawrence, KS 66045
USA
braaten@ku.edu

Roger J. Braithwaite
Geography Programme, School of Environment and Development
University of Manchester
Oxford Road
Manchester M13 9PL
UK
r.braithwaite@manchester.ac.uk

Claudio Bravo
Centro de Estudios Científicos, CECS
Arturo Prat 514
Valdivia
Chile
cbravo@cecs.cl

Gary J. Brierley
School of Environment
The University of Auckland
10 Symonds Street
Private Bag 92019, Auckland 1142
New Zealand
g.brierley@auckland.ac.nz

Jason P. Briner
Department of Geological Sciences
University at Buffalo
Buffalo, NY 14260
USA
jbriner@buffalo.edu

Margo M. Burgess
Geological Survey of Canada
Natural Resources Canada
601 Booth Street
Ottawa, ON K1A 0E8
Canada
Margo.Burgess@nrcan-rncan.gc.ca

Paolo Burlando
Institute of Environmental Engineering
ETH Zurich
8093 Zurich
Switzerland
paolo.burlando@ifu.baug.ethz.ch

Katie Burles
Department of Geography
University of Lethbridge
4401 University Dr
Lethbridge, AB T1K 3M4
Canada

Andrew B. G. Bush
Department of Earth and Atmospheric Science
University of Alberta
1-26 Earth Sciences Building
Edmonton, AB T6G 2E3
Canada
andrew.bush@ualberta.ca

David R. Butler
Mountain GeoDynamics Research Group
Department of Geography
Texas State University-San Marcos
San Marcos, TX 78666-4616
USA
db25@txstate.edu

Fay Campbell
Department of Geographical and Earth Sciences
University of Glasgow
Glasgow G12 8QQ
UK

Norm R. Catto
Department of Geography
Memorial University of Newfoundland
St. John’s, NL A1B 3X9
Canada
ncatto@mun.ca

Fiona Cawkwell
Department of Geography
University College Cork
Cork
Ireland
f.cawkwell@ucc.ie

Anny Cazenave
Laboratoire d’Etudes en Géophysique et Océanographie Spatiales (LEGOS)
LEGOS-CNES, Observatoire Midi-Pyrénées
18 Av. E. Belin
31400 Toulouse
France
Anny.Cazenave@legos.obs-mip.fr
anny.cazenave@gmail.com

Stanley A. Changnon
University of Illinois
Urbana, IL 61853
USA
schangno@illinois.edu

Arun Chaturvedi
Antartic Division
Geological Survey of India
NH 5P
Faridabad 121001
India
arun.daak@gmail.com

Anju Chaudhary
Water Resources System Division
National Institute of Hydrology
Roorkee 247667
India
anju@nih.ernet.in

Jie Cheng
College of Global Change and Earth System Science
Beijing Normal University
19 Xinjiekouwai Street
Beijing 100875
China
brucechan2003@126.com

Jessica Ellen Cherry
International Arctic Research Center and Institute of Northern Engineering
University of Alaska Fairbanks
930 Koyukuk Dr.
Fairbanks, AK 99775-7335
USA
jcherry@iarc.uaf.edu

Poul Christoffersen
Scott Polar Research Institute
University of Cambridge
Lensfield Road
Cambridge CB2 1ER
UK
pc350@cam.ac.uk

John J. Clague
Department of Earth Sciences
Centre for Natural Hazard Research
Simon Fraser University
8888 University Drive
Burnaby, BC V5A 1S6
Canada
jclague@sfu.ca

J. Graham Cogley
Department of Geography
Trent University
Peterborough ON, K9J 7B8
Canada
gcogley@trentu.ca

Jeffrey D. Colby
Department of Geography and Planning
Appalachian State University
Boone, NC 28608
USA
colbyj@appstate.edu

Simon J. Cook
Centre for Glaciology
Institute of Geography and Earth Sciences
Aberystwyth University
H5, Llandinam
Ceredigion, Wales SY23 3DB
UK
smc@aber.ac.uk
basalice@gmail.com

Luke Copland
Department of Geography
University of Ottawa
Ottawa, ON K1N 6N5
Canada
luke.copland@uottawa.ca

Michel Crucifix
Georges Lemaitre Centre for Earth and Climate Research
Université catholique de Louvain
2 chemin du Cyclotron
1348 Louvain-la-Neuve
Belgium
michel.crucifix@uclouvain.be

Ronald P. Daanen
Geophysical Institute
University of Alaska Fairbanks
903 Koyukuk Dr.
Fairbanks, AK 99775-7320
USA
rdaanen@alaska.edu

Prem Datt
Research and Design Center (RDC)
Snow and Avalanche Study Establishment
Plot No-1, Sector 37-A
Himparishar 160036, Chandigarh
India
datt_prem@rediffmail.com

Carmen de Jong
The Mountain Institute
University of Savoy
73376 Pôle Montagne, Le Bourget du Lac
France
carmen.dejong@institut-montagne.org

Reynald Delaloye
Department of Geosciences
Geography University of Fribourg
Ch. du Musee 4
1700 Fribourg
Switzerland
reynald.delaloye@unifr.ch

Philip Deline
EDYTEM Lab
Université de Savoie, CNRS
73376 Le Bourget du Lac
France
pdeli@univ-savoie.fr

Michael N. Demuth
Glaciology Section, Geological Survey of Canada
Earth Sciences Sector Program on Climate Change
Geoscience
Natural Resources Canada
601 Booth Street
Ottawa, ON K1A 0E8
Canada
Mike.Demuth@NRCan-RNCan.GC.CA

Stephen J. Déry
Environmental Science and Engineering Program
University of Northern British Columbia
3333 University Way
Prince George, BC V2N 4Z9
Canada
sdery@unbc.ca

Guglielmina Diolaiuti
Department of Earth Sciences "A. Desio"
University of Milano
Via Mangiagalli 34
20133 Milano
Italy
guglielmina.diolaiuti@unimi.it

D. P. Dobhal
Wadia Institute of Himalayan Geology
33, General Mahadev Singh Road
Dehradun 248001, Uttarakhand
India
dpdobhal@rediffmail.com

Florent Domine
Laboratoire de Glaciologie et Géophysique de l'Environnement
CNRS
BP 96, 54 rue Molière
38402 Saint Martin d'Hères
France
florent@lgge.obs.ujf-grenoble.fr

Divya Dudeja
Department of Geology
DBS (P.G.) College
Dehradun 248001, Uttarakhand
India
divyadudeja@yahoo.co.in

Michael Durand
Byrd Polar Research Center
Ohio State University
108 Scott Hall, 1090 Carmack Road
Columbus, OH 43210
USA
durand.8@osu.edu

Jürgen Ehlers
Geologisches Landesamt
Billstrasse 84
20539 Hamburg
Germany
juergen.ehlers@bsu.hamburg.de

Heidi Escher-Vetter
Commission for Glaciology
Bavarian Academy of Sciences and Humanities
Alfons-Goppel-Strasse 11
80539 Munich
Germany
Heidi.Escher@kfg.badw.de

Richard Essery
School of GeoSciences
University of Edinburgh
Edinburgh EH9 3JW
UK
richard.essery@ed.ac.uk

Steven Fassnacht
Snow Hydrology, Watershed Science Program
Colorado State University
Natural Resources Building Room 335
Fort Collins, CO 80523
USA
srf@warnercnr.colostate.edu

Jiang Fengqing
Xinjiang Institute of Ecology and Geography, CAS
Chinese Academy of Sciences
40-3 South Beijing Road
Urumqi, Xinjiang 830011
China
jiangfengqing@gmail.com
jiangfq@ms.xjb.ac.cn

Xavier Fettweis
Institute for Marine and Atmospheric Research
Utrecht University
Princetonplein 5
3584 CC Utrecht
Netherlands
and
Department of Geography
University of Liège
Allée du 6 Août, 2
4000 Liège
Belgium
xavier.fettweis@ulg.ac.be

Charles Fierz
WSL Institute for Snow and Avalanche Research SLF
7260 Davos Dorf
Switzerland
fierz@slf.ch

Sean J. Fitzsimons
Department of Geography
University of Otago
P.O. Box 56
Dunedin 9054
New Zealand
sjf@geography.otago.ac.nz

Andrew G. Fountain
Department of Geology
Portland State University
P.O. Box 751
Portland, OR 97207-0751
USA
andrew@pdx.edu

Hugh M. French
University of Ottawa (retired)
10945 Marti Lane
North Saanich, British Columbia V8L 5S5
Canada
hmfrench@shaw.ca

Ping Fu
Department of Earth and Atmospheric Sciences
Purdue University
550 Stadium Mall Dr
West Lafayette, IN 47907
USA
pfu@purdue.edu

Yoshinori Furukawa
Research Group for Phase Transition Dynamics of Ice
Institute of Low Temperature Science
Hokkaido University
N19 W8
Sapporo 060-0819
Japan
frkw@lowtem.hokudai.ac.jp

Olivier Gagliardini
Laboratoire de Glaciologie et Géophysique de
l'Environnement du CNRS/UJF
54, rue Molière BP 96
38402 Grenoble
France
gagliardini@lgge.obs.ujf-grenoble.fr

Isabelle Gärtner-Roer
Glaciology, Geomorphodynamics and Geochronology
Department of Geography
University of Zürich
Winterthurerstrasse 190
8057 Zürich
Switzerland
isabelle.roer@geo.uzh.ch

John R. Giardino
Department of Geology and Geophysics
Texas A&M University
College Station, TX 77843-3115
USA
rickg@tamu.edu

Philip Gibbard
Quaternary Palaeoenvironments Group, Cambridge
Quaternary
Department of Geography
University of Cambridge
Downing Street
Cambridge CB2 3EN
UK
plg1@cam.ac.uk

Alan R. Gillespie
Department of Earth and Space Sciences
Quaternary Research Center
University of Washington
Seattle, WA 98195-1310
USA
arg3@u.washington.edu

Neil F. Glasser
Centre for Glaciology, Institute of Geography & Earth
Sciences
Aberystwyth University
Aberystwyth, Ceredigion, Wales SY23 3DB
UK
nfg@aber.ac.uk

Manmohan Kumar Goel
Water Resources System
National Institute of Hydrology
Roorkee 247667, Uttarakhand
India
goel_m_k@yahoo.com
mkg@nih.ernet.in

Gavin Gong
Department of Earth and Environmental Engineering
Henry Krumb School of Mines
Columbia University
500 West. 120th Street, MC4711
New York, NY 10027
USA
gg2138@columbia.edu

Alastair G. C. Graham
Ice Sheets Programme, British Antarctic Survey
High Cross, Madingley Road
Cambridge CB3 0ET
UK
alah@bas.ac.uk

Amanda M. Grannas
Department of Chemistry
Villanova University
800 Lancaster Ave
Villanova, PA 19085
USA
amanda.grannas@villanova.edu

Thomas C. Grenfell
Department of Atmospheric Sciences
University of Washington
Seattle, WA 98195-1640
USA
tcg@atmos.washington.edu

G. Hilmar Gudmundsson
British Antarctic Survey
High Cross Madingley Road
Cambridge CB3 0ET
UK
ghg@bas.ac.uk

Ravi P. Gupta
Department of Earth Sciences
Indian Institute of Technology Roorkee
Roorkee 247667, UA
India
rpgupta.iitr@gmail.com
rpgesfes@iitr.ernet.in

Wilfried Haeberli
Glaciology, Geomorphodynamics & Geochronology
Geography Department
University of Zurich
Winterthurerstrasse 190
8057 Zurich
Switzerland
wilfried.haeberli@geo.uzh.ch

Brenda L. Hall
Department of Earth Sciences and
Climate Change Institute
Bryand Global Sciences Center
University of Maine
Orono, ME 04469
USA
BrendaH@maine.edu

Dorothy K. Hall
Crysopheric Sciences Branch
Code 614.1, NASA/Goddard Space Flight Center
Greenbelt, MD 20771
USA
dorothy.k.hall@nasa.gov

Michael J. Hambrey
Centre for Glaciology
Institute of Geography & Earth Sciences
Aberystwyth University
Aberystwyth, Ceredigion, Wales SY23 3DB
UK
mjh@aber.ac.uk

Jonathan Harbor
Department of Earth and Atmospheric Sciences
Purdue University
550 Stadium Mall Dr
West Lafayette, IN 47907
USA
jharbor@purdue.edu

Douglas R. Hardy
Climate System Research Center and
Department of Geosciences
University of Massachusetts
Morrill Science Center
611 North Pleasant Street
Amherst, MA 01003-9297
USA
dhardy@geo.umass.edu
doug.hardy@valley.net

Spencer P. Hardy
Hanover High School
41 Lebanon St
Hanover, NH 03755
USA

Chelamallu Hariprasad
Centre for Studies in Resource Engineering
Indian Institute of Technology, Bombay
Powai, Mumbai 400076, Maharashtra
India
chariprasad@iitb.ac.in

Umesh K. Haritashya
Department of Geology
University of Dayton
300 College Park
Dayton, OH 45469-2364
USA
ukharit@yahoo.com
Umesh.Haritashya@notes.udayton.edu

Stephan Harrison
School of Geography, Archaeology and Earth Resources
University of Exeter
Cornwall Campus
Penryn, Cornwall TR10 9EZ
UK
stephan.harrison@exeter.ac.uk

Kenneth Hewitt
Cold Regions Research Centre
Wilfrid Laurier University
75 University Avenue West
Waterloo, ON N2L 3C5
Canada
khewitt@wlu.ca

Christopher A. Hiemstra
Cold Regions Research and Engineering Laboratory
(CRREL)
U.S. Army Corps of Engineers, ERDC
P.O. Box 35170
Fort Wainwright, AK 99703-0170
USA
Christopher.A.Hiemstra@usace.army.mil

Richard Hodgkins
Department of Geography
Loughborough University
Leicestershire LE11 3TU
UK
r.hodgkins@lboro.ac.uk

Bryn Hubbard
Centre for Glaciology
Institute of Geography and Earth Sciences
Aberystwyth University
Llandinam Building
Aberystwyth, Ceredigion, Wales SY23 3DB
UK
byh@aber.ac.uk

Philip D. Hughes
Geography, School of Environment and Development
The University of Manchester
Arthur Lewis Building
Manchester M13 9PL
UK
philip.hughes@manchester.ac.uk

Terry Hughes
Department of Earth Science
University of Maine
Orono, ME 04469-5790
USA
and
Climate Change Institute
University of Maine
Orono, ME 04469-5790
USA
terry.hughes@maine.edu

Lasafam Iturrizaga
Department of Geography/High Mountain
Geomorphology
Institute of Geography
University of Göttingen
Goldschmidtstr. 5
37077 Göttingen
Germany
liturri@gwdg.de

C. K. Jain
National Institute of Hydrology
Centre for Flood Management Studies
G. S. Road, Sapta Sahid Path, Mathura Nagar
Dispur, Guwahati 781006, Assam
India
ckj_1959@yahoo.co.in

Manoj K. Jain
Department of Hydrology
Indian Institute of Technology
Roorkee 247667, Uttarakhand
India
jain.mkj@gmail.com

Sanjay K. Jain
National Institute of Hydrology
Roorkee, 247667 Uttarakhand
India
Sjain@nih.ernet.in

Adrian Jenkins
British Antarctic Survey
Natural Environment Research Council
High Cross, Madingley Road
Cambridge CB3 0ET
UK
ajen@bas.ac.uk
a.jenkins@bas.ac.uk

Hester Jiskoot
Department of Geography
University of Lethbridge
4401 University Drive W
Lethbridge, AB T1K 3M4
Canada
hester.jiskoot@uleth.ca

Jerome B. Johnson
Institute of Northern Engineering
University of Alaska Fairbanks
P.O. Box 755910
Fairbanks, AK 99775-5910
USA
jerome.b.johnson@alaska.edu

Tobias Jonas
Snow Hydrology Research Group
WSL Institute for Snow and Avalanche Research SLF
7260 Davos
Switzerland
jonas@slf.ch

M. Torre Jorgenson
Alaska Ecoscience
Fairbanks, AK 99709
USA
tjorgenson@abrinc.com

Andreas Kääb
Department of Geosciences
University of Oslo
Sem Sælands vei 1, 1047
Blindern, 0316 Oslo
Norway
kaeaeb@geo.uio.no

M. Z. Kanevskiy
Department of Civil and Environmental Engineering
University of Alaska Fairbanks
245 Duckering Building, P.O. Box 755900
Fairbanks, AK 99775-59000
USA
mkanevskiy@alaska.edu

Shichang Kang
Key Laboratory of Tibetan Environmental Changes and Land Surface Processes
Institute of Tibetan Plateau Research
Chinese Academy of Sciences
No.18, Shuangqing Rd., P.O. Box 2871
Haidian District, Beijing 100085
China
and
State Key Laboratory of Cryospheric Sciences
Chinese Academy of Sciences
Lanzhou 730000
China
Shichang.Kang@itpcas.ac.cn

Martin Kappas
Cartography, GIS and Remote Sensing Section
Institute of Geography
Georg-August University Göttingen
Goldschmidtstr. 5
37077 Göttingen
Germany
mkappas@gwdg.de

Rijan B. Kayastha
Himalayan Cryosphere, Climate and Disaster Research Center (HiCCDRC)
Kathmandu University
Dhulikhel, Kavre
P.O. Box 6250, Kathmandu
Nepal
rijan@ku.edu.np

Matt A. King
School of Civil Engineering and Geosciences
Newcastle University
Cassie Building
Newcastle upon Tyne NE1 7RU
UK
m.a.king@ncl.ac.uk

Martin P. Kirkbride
Geography, School of the Environment
University of Dundee
Perth Road
Dundee DD1 4HN, Scotland
UK
m.p.kirkbride@dundee.ac.uk

Peter G. Knight
School of Physical and Geographical Sciences
Keele University
William Smith Building
Staffordshire ST5 5BG
UK
p.g.knight@esci.keele.ac.uk

Johannes Koch
Department of Earth Sciences
Simon Fraser University
Burnaby, BC V5A 1S6
Canada
jkoch@sfu.ca

Lynn Koehler
University of Victoria Tree-Ring Laboratory
Department of Geography
University of Victoria
Victoria, British Columbia V8W 3R4
Canada
lynn.koehler@gmail.com

Markus Konz
Institute of Environmental Engineering
Hydrology and Water Resources Management
ETH Zürich
Wolfgang-Pauli-Str. 15
8093 Zurich
Switzerland
markus.konz@ifu.baug.ethz.ch

Nadine Konz
Institute of Environmental Geosciences
University of Basel
4003 Basel
Switzerland
nadine.konz@unibas.ch

Akhouri Pramod Krishna
Department of Remote Sensing
Birla Institute of Technology (BIT)
Deemed University
P.O. Mesra
Ranchi 835215, Jharkhand
India
apkrishna@ewca.eastwestcenter.org
apkrishna@bitmesra.ac.in

Matthias Kuhle
Department of Geography and High Mountain Geomorphology
Geographical Institute
University of Göttingen
Goldschmidtstr. 5
37077 Göttingen
Germany
mkuhle@gwdg.de

Amit Kumar
Department of Geology
Centre of Advanced Study in Geology
Punjab University
Sector-14
Chandigarh 160014, Punjab
India
amithydrocoin@gmail.com
amitwalia@wihg.res.in

Bhishm Kumar
Hydrological Investigations Division
National Institute of Hydrology
Roorkee 247667, Uttarakhand
India
bk@nih.ernet.in
bhishm_nih@yahoo.co.in

Rajesh Kumar
School of Engineering and Technology
Sharda University
32–34, Knowledge Park-III
Greater Noida 201306, NCR
India
and
Remote Sensing Division
Birla Institute of Technology, Extension Centre Jaipur
27, Malviya Industrial Area
Jaipur 302017, Rajasthan
India
rajeshbhu@yahoo.com

Vijay Kumar
National Institute of Hydrology
Roorkee 247667, Uttarakhand
India
vijay@nih.ernet.in
vk_nih@yahoo.com

Christophe Lambiel
Institute of Geography
University of Lausanne
Bâtiment Anthropole
1015 Lausanne
Switzerland
christophe.lambiel@unil.ch

Wendy Lawson
Department of Geography
University of Canterbury
Private Bag 4800
Christchurch 8140
New Zealand
wendy.lawson@canterbury.ac.nz

Daniel J. Leathers
Department of Geography
University of Delaware
Newark, DE 19716-2541
USA
leathers@udel.edu

Jean-Michel Lemieux
Département de géologie et de génie géologique
Université Laval
1065 avenue de la Médecine
Québec, QC G1V 0A6
Canada
jmlemieux@ggl.ulaval.ca

Eric M. Leonard
Department of Geology
Colorado College
14E Cache la Poudre
Colorado Springs, CO 80903
USA
eleonard@coloradocollege.edu

Matti Leppäranta
Department of Physics
University of Helsinki
P.O. Box 64, (Gustaf Hällströmin katu 2a)
00014 Helsinki
Finland
matti.lepparanta@helsinki.fi

Delphis F. Levia
Department of Geography
University of Delaware
Newark, DE 19716-2541
USA
dlevia@udel.edu

Shunlin Liang
Department of Geography
University of Maryland
2181 LeFrak Hall
College Park, MD 20742
USA
sliang@umd.edu

Kenneth G. Libbrecht
Department of Physics
Caltech
264-33 Caltech
Pasadena, CA 91125
USA
kgl@caltech.edu

Ron Lindsay
Polar Science Center
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, WA 98105-6698
USA
lindsay@apl.washington.edu

Glen E. Liston
Cooperative Institute for Research in the Atmosphere
Colorado State University
1375 Campus Delivery
Fort Collins, CO 80523-1375
USA
liston@cira.colostate.edu

Jingshi Liu
Institute of Tibetan Plateau Research
Chinese Academy of Sciences
18 Shuangqing Rd.
Haidian District, Beijing 100085
China
jsliu@itpcas.ac.cn

Yongqin Liu
Laboratory of Tibetan Environment Changes and Land Surface Processes (TEL)
Institute of Tibetan Plateau Research
Chinese Academy of Sciences
No. 18 Shuangqing Rd, P.O. Box 2871
Haidian District, Beijing 100085
China
yqliu@itpcas.ac.cn

Christopher Lloyd
Department of Geography
University of Sheffield
Sheffield S10 2TN
UK
ggp08ctl@sheffield.ac.uk

Rachel W. Lomonaco
Thayer School of Engineering
Dartmouth College
Hanover, NH 03755
USA

Reginald D. Lorrain
Département des Sciences de la Terre et de l’Environnement
Université Libre de Bruxelles
Bruxelles
Belgium
rlorrain@ulb.ac.be

Mira Losic
Department of Geography
University of Calgary
Earth Sciences 356, 2500 University Dr NW
Calgary, AB T2N 1N4
Canada
mlosic@ucalgary.ca

Sven Lukas
Department of Geography
Queen Mary University of London
Mile End Road
London E1 4NS
UK
S.Lukas@qmul.ac.uk

Juha P. Lunkka
Institute of Geosciences
University of Oulu
P.O. Box 3000
90014 Oulu
Finland
juha.pekka.lunkka@oulu.fi

Kelly MacGregor
Geology Department
Macalester College
1600 Grand Avenue
Saint Paul, MN 55105
USA
macgregor@macalester.edu

William C. Mahaney
Quaternary Surveys
26 Thornhill Ave
Thornhill, ON L4J 1J4
Canada
arkose@rogers.com
bmahaney@yorku.ca

Shawn J. Marshall
Department of Geography
University of Calgary
Earth Sciences 356, 2500 University Dr NW
Calgary, AB T2N 1N4
Canada
shawn.marshall@ucalgary.ca

Richard A. Marston
Department of Geography
Kansas State University
118 Seaton Hall
Manhattan, KS 66506-2904
USA
Rmarston@ksu.edu
Rmarston@k-state.edu

Christoph Marty
WSL Institute for Snow and Avalanche Research SLF
Flüelastr. 11
7260 Davos
Switzerland
marty@slf.ch

Robert D. McCulloch
School of Biological and Environmental Science
University of Stirling
Stirling FK9 4LA, Scotland
UK
robert.mcculloch@stir.ac.uk

Brian Menounos
Geography Program and Natural Resources and Environmental Studies Institute
University of Northern British Columbia
3333 University Way
Prince George, BC V2N 4Z9
Canada

Justin R. Minder
Department of Atmospheric Science
University of Washington
Box 351640
Seattle, WA 98195-1640
USA
juminder@atmos.washington.edu

Debasmita Misra
Department of Mining and Geological Engineering
College of Engineering and Mines
University of Alaska Fairbanks
P.O. Box 755800
Fairbanks, AK 99775-5800
USA
debu.misra@alaska.edu

Vanya I. Miteva
Department of Biochemistry and Molecular Biology
The Pennsylvania State University
211 South Frear
University Park, PA 16802
USA
vim1@psu.edu

Thomas Mölg
Center for Climate & Cryosphere
University of Innsbruck
6020 Innsbruck
Austria

Peter Molnar
Institute of Environmental Engineering
ETH Zurich
8093 Zurich
Switzerland
molnar@ifu.baug.ethz.ch

Bruce F. Molnia
U.S. Geological Survey
562 National Center, 12201 Sunrise Valley Drive, 12201
Reston, VA 20192
USA
bmolnia@usgs.gov

Brian Morse
Department of Civil and Water Engineering
Laval University
1065, ave de la Médecine
Quebec, QC G1V 0A6
Canada

Nozomu Naito
Department of Global Environment Studies
Hiroshima Institute of Technology
Miyake 2-1-1, Saeki-ku
Hiroshima 731-5193
Japan
naito@cc.it-hiroshima.ac.jp

Jacob Napieralski
Department of Natural Sciences
University of Michigan-Dearborn
Dearborn, MI 48128
USA
jnapiera@umd.umich.edu

Atle Nesje
Department of Earth Science\Bjerknes Centre for Climate Research
University of Bergen
Allégaten 41
5007 Bergen
Norway
atle.nesje@geo.uib.no

Thomas A. Neumann
NASA Goddard Space Flight Center
Greenbelt, MD 20771
USA
thomas.neumann@nasa.gov

Peter W. Nienow
School of Geosciences
University of Edinburgh
Drummond Street
Edinburgh EH8 9XP
UK
pnienow@geo.ed.ac.uk

David C. Nobes
Department of Geological Sciences
University of Canterbury
Private Bag 4800
Christchurch 8140
New Zealand
david.nobes@canterbury.ac.nz

Rachel W. Obbard
Thayer School of Engineering
Dartmouth College
Hanover, NH 03755
USA
Rachel.w.obbard@dartmouth.edu

Øyvind Paasche
Bjerknes Centre for Climate Research
University of Bergen
Allégaten 55
5007 Bergen
Norway
and
Department of Research Management
University of Bergen
Professor Keysers gt. 8
5020 Bergen
Norway
oyvind.paasche@uni.no

Thomas H. Painter
Jet Propulsion Laboratory/Caltech
4800 Oak Grove Drive
Pasadena, CA 91109
USA
Thomas.Painter@jpl.nasa.gov

Pratima Pandey
Centre of Studies in Resources Engineering
Indian Institute of Technology Bombay
Powai, Mumbai 400076, Maharashtra
India
pratimapandey@iitb.ac.in

Himali Panthri
Department of Geology
D.B.S (P.G) College
Dehradun 248001, Uttarakhand
India
himali.geo@gmail.co

Frank Paul
Department of Geography
University of Zurich
Winterthurerstrasse 190
8057 Zurich
Switzerland
frank.paul@geo.uzh.ch

Francesca Pellicciotti
Institute of Environmental Engineering
ETH Zurich
8093 Zurich
Switzerland
francesca.pellicciotti@ifu.baug.ethz.ch

Mauri S. Pelto
Department of Environmental Science
Nichols College
Dudley, MA 01571
USA
mauri.pelto@nichols.edu

Christine Pielmeier
WSL Institute for Snow and Avalanche Research SLF
Warning and Prevention
Flüelastrasse 11
7260 Davos Dorf
Switzerland
pielmeier@slf.ch

Jan A. Piotrowski
Department of Earth Sciences
University of Aarhus
Høegh-Guldbergs Gade 2
8000 Aarhus C
Denmark
and
Department of Geography
University of Sheffield
Sheffield S10 2TN
UK
jan.piotrowski@geo.au.dk

Philip R. Porter
Division of Geography and Environmental Sciences
School of Life Sciences
University of Hertfordshire
Hatfield, Hertfordshire AL10 9AB
UK
p.r.porter@herts.ac.uk

George Postma
Faculty of Geosciences
EUROTANK Laboratories
P.O. Box 80.021
3508 TA Utrecht
The Netherlands
gpostma@geo.uu.nl

P. Pradeep Kumar
Department of Atmospheric and Space Sciences
Pune University
Pune 411007, Maharashtra
India
ppk@physics.unipune.ac.in

Daniel J. Pringle
Arctic Region Supercomputing Center and Geophysical Institute
University of Alaska
Fairbanks, AK 99775
USA
danielpringle75@gmail.com

John C. Priscu
Department of Land Resources and Environmental Sciences
Montana State University
Bozeman, MT 59717
USA
jpriscu@montana.edu

Duncan J. Quincey
Institute of Geography and Earth Sciences
Penglais Campus
Aberystwyth University
Aberystwyth, Wales SY23 3DB
UK

Camilo Rada
Centro de Estudios Científicos, CECS
Arturo Prat 514
Valdivia
Chile

Y. S. Rao
Centre of Studies in Resources Engineering
Indian Institute of Technology
Powai, Mumbai 400076
India
ysrao@iitb.ac.in

Donald Rapp
Independent Contractor
1445 Indiana Avenue
South Pasadena, CA 91030
USA
drdrapp@earthlink.net

Rasik Ravindra
National Centre for Antarctic and Ocean Research
Headland Sada, Vasco-Da-Gama
Goa 403804
India
rasik@ncaor.org

Netra R. Regmi
Department of Geology and Geophysics
Texas A&M University
College Station, TX 77843-3115
USA
netraregmi@neo.tamu.edu

Helen E. Reid
School of Environment
The University of Auckland
10 Symonds Street
Private Bag 92019, Auckland 1142
New Zealand
h.reid@auckland.ac.nz

Alan W. Rempel
Department of Geological Sciences
University of Oregon
Eugene, OR 97403-1272
USA
rempel@uoregon.edu

Jeffrey Ridley
Met Office, Hadley Centre
FitzRoy Road
Exeter EX1 3PB
UK

George A. Riggs
SSAI
10210 Greenbelt Road, Suite 600
Lanham, MD 20706
USA
george.a.riggs@nasa.gov

Eric Rignot
Department of Earth System Science
University of California Irvine
Irvine, CA 92697
USA
and
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91214
USA
erignot@uci.edu

Vinvent Rinterknecht
School of Geography and Geosciences
University of St Andrews
North Street
St Andrews KY16 9AL, Scotland
UK
vr10@st-andrews.ac.uk

Daniel Riseborough
Geological Survey of Canada
601 Booth Street
Ottawa, ON K1A 0E4
Canada
drisebor@nrcan.gc.ca

Andrés Rivera
Centro de Estudios Científicos, CECS
Arturo Prat 514
Valdivia
Chile
and
Universidad de Chile
Marcoleta 250
Santiago
Chile
and
Centro de Ingeniería de la Innovación, CIN
Arturo Prat 514
Valdivia
Chile
arivera@cecs.cl

Gerard H. Roe
Department of Atmospheric Science
University of Washington
Box 351640
Seattle, WA 98195-1640
USA
and
Department of Earth and Space Sciences
University of Washington
2206 N41 St
Seattle, WA 98103
USA
gerard@ess.washington.edu

Neil Ross
School of Geosciences
University of Edinburgh
Geography Building
Drummond Street
Edinburgh EH8 9XP
UK
neil.ross@ed.ac.uk

Anders Schomacker
Institute of Earth Sciences
University of Iceland
Askja, Sturlugata 7
101 Reykjavík
Iceland
and
Department of Geology
Norwegian University of Science and Technology
7491 Trondheim
Norway
anders@hi.is

Bob E. Schutz
Center for Space Research
University of Texas at Austin
Austin, TX 78759
USA
schutz@csr.utexas.edu

Annette Semádeni-Davies
Department of Water Resources Engineering
Lund University
22100 Lund
Sweden
annette.davies@tvrl.lth.se

Hung Tao Shen
Department of Civil and Environmental Engineering
Clarkson University
P.O. Box 5710
Potsdam, NY 13699-5710
USA
htshen@clarkson.edu

Arun B. Shrestha
International Centre for Integrated Mountain Development (ICIMOD)
Khumaltar, Lalitpur, GP.O. Box 3226
Kathmandu
Nepal
abshrestha@icimod.org

John F. Shroder
Department of Geography and Geology
University of Nebraska at Omaha
6001 Dodge Street
Omaha, NE 68182
USA
jshroder@mail.unomaha.edu

Aparna Shukla
Uttarakhand Space Application Centre
Dehradun
India
aparna.shukla22@gmail.com

Yuri Shur
Department of Civil and Environmental Engineering
University of Alaska Fairbanks
245 Duckering Building, P.O. Box 755900
Fairbanks, AK 99775-59000
USA
yshur@alaska.edu

Martin J. Siegert
School of GeoSciences
University of Edinburgh
Grant Institute
West Mains Road
Edinburgh EH9 3JW
UK
m.j.siegert@ed.ac.uk

Oddur Sigurðsson
Veðurstofu Íslands
Icelandic Meteorological Office
Bústaðavegi 9
150 Reykjavík
Iceland
oddur@vedur.is

A. K. Singh
DIAT (Deemed University)
Girinagar
Pune 411025, Maharashtra
India
draksingh@hotmail.com
aksingh@diat.ac.in

Gulab Singh
Centre of Studies in Resources Engineering
Indian Institute of Technology Bombay
Powai
Mumbai 400076, Maharashtra
India
gskaliar@iitb.ac.in

Pratap Singh
Integrated Natural Resources Management (INRM) Consultants Pvt. Ltd
An Incubatee Company of IIT Delhi
New Delhi
India
and
Hydro Tasmanier Consulting
Nehru Place
New Delhi 110019
India
pratap_singh_1@yahoo.com
pratapsingh.iitd@gmail.com

Vijay P. Singh
Department of Biological and Agricultural Engineering
Texas A&M University
Scoates Hall
2117 TAMU
College Station, TX 77843-2117
USA
vsingh@tamu.edu

Subhajit Sinha
DBS College
Dehradun, Uttarakhand
India
sinha_subho@rediffmail.com

Claudio Smiraglia
Department of Earth Sciences "A. Desio"
University of Milano
Via Mangiagalli 34
20133 Milano
Italy
claudio.smiraglia@unimi.it

Andy M. Smith
British Antarctic Survey, High Cross
Madingley Road
Cambridge CB3 0ET
UK
amsm@bas.ac.uk

Dan J. Smith
University of Victoria Tree-Ring Laboratory
Department of Geography
University of Victoria
Victoria, British Columbia V8W 3R4
Canada

Sharon L. Smith
Geological Survey of Canada
Natural Resources Canada
601 Booth Street
Ottawa, ON K1A 0E8
Canada
Sharon.Smith@nrcan-rncan.gc.ca

Rudolph R. Stea
Stea Surficial Geology Services
851 Herring Cove Road
Halifax, Nova Scotia B3R 1Z1
Canada
ralphstea@eastlink.ca

Chris R. Stokes
Department of Geography
Durham University
Science Site, South Road
Durham DH1 3LE
UK
c.r.stokes@durham.ac.uk

Tim Stott
Physical Geography and Outdoor Education
Liverpool John Moores University
I. M. Marsh Campus, Barkhill Road
Liverpool L17 6BD
UK
t.a.stott@ljmu.ac.uk

Edward A. Sudicky
Department of Earth and Environmental Sciences
University of Waterloo
Waterloo, ON N2L 3G1
Canada
sudicky@sciborg.uwaterloo.ca

Kazuyoshi Suzuki
Research Institute for Global Change
Japan Agency for Marine-Earth Science and Technology
3173-25 Showa-machi
Yokohama 236-0001
Japan
skazu@jamstec.go.jp

Ryohei Suzuki
Graduate School of Environmental Studies
Nagoya University
c/o Hydrospheric Atmospheric Research Center
Furo-cho Chikusa-ku
Nagoya 464-8601
Japan
cryosuzuki@nagoya-u.jp

Darrel A. Swift
Department of Geography
University of Sheffield
Sheffield S10 2TN
UK
D.A.Swift@sheffield.ac.uk

Nozomu Takeuchi
Department of Earth Sciences
Graduate School of Science
Chiba University
1-33 Yayoicho, Inage-ku, Chiba-city
Chiba 263-8522
Japan
ntakeuch@faculty.chiba-u.jp

Renoj J. Thayyen
Western Himalayan Regional Centre
National Institute of Hydrology
Jammu (J&K) 180003
India
renojthayyen@gmail.com

Malte Thoma
Bavarian Academy and Sciences, Commission for Glaciology
Alfons-Goppel-Str. 11
80539 Munich
Germany
and

Alfred Wegener Institute for Polar and Marine Research
Bussestrasse 24
27570 Bremerhaven
Germany
Malte.Thoma@awi.de

David N. Thomas
School of Ocean Sciences, College of Natural Sciences
Bangor University
Menai Bridge, Anglesey LL59 5AB
UK
d.thomas@bangor.ac.uk

Anita M. Thompson
Department of Biological Systems Engineering
University of Wisconsin-Madison
230 Ag. Eng. Building, 460 Henry Mall
Madison, WI 53706
USA
amthompson2@wisc.edu

Thierry Toutin
Canada Centre for Remote Sensing
Natural Resources Canada
Ottawa, ON K1A 0Y7
Canada
thierry.toutin@ccrs.nrcan.gc.ca

Martyn Tranter
Bristol Glaciology Centre
School of Geographical Sciences
University of Bristol
University Road
Bristol BS8 1SS
UK
m.tranter@bristol.ac.uk

Donna F. Tucker
Department of Geography
University of Kansas
1475 Jayhawk Blvd., Room 213
Lawrence, KS 66045-7613
USA
dtucker@ku.edu

Hugh Tuffen
Lancaster Environment Centre
Lancaster University
Lancaster LA1 4YQ
UK
h.tuffen@lancaster.ac.uk

Fiona Tweed
Department of Geography
Staffordshire University
College Road
Stoke-on-Trent, Staffordshire ST4 2DE
UK
f.s.tweed@staffs.ac.uk

Michiel Van den Broeke
Institute for Marine and Atmospheric Research
Utrecht University
Princetonplein 5
3584 CC Utrecht
Netherlands
m.r.vandenbroeke@uu.nl

C. J. van der Veen
Department of Geography and
Center for Remote Sensing of Ice Sheets
University of Kansas
203 Lindley Hall
1475 Jayhawk Blvd
Lawrence, KS 66045-7613
USA
cjvdv@ku.edu

Veerle Vanacker
TECLIM, Earth and Life Institute
University of Louvain
Place L. Pasteur, 3
1348 Louvain-la-Neuve, BW
Belgium
veerle.vanacker@uclouvain.be

Dominic Vella
Department of Applied Mathematics and Theoretical Physics
Institute of Theoretical Geophysics
University of Cambridge
Wilberforce Road
Cambridge CB3 0WA
UK
d.vella@damtp.cam.ac.uk

G. Venkataraman
Centre of Studies of Resources Engineering
Indian Institute of Technology Bombay
Mumbai 400076
India
gv@iitb.ac.in

Ashok Kumar Verma
Department of Geography and Environmental Studies
Cold Regions Research Center
Wilfrid Laurier University
75 University Ave. West
Waterloo, ON N2L 3C5
Canada
ashokpph@gmail.com
verm3620@wlu.ca

Andreas Vieli
Department of Geography
Durham University
Durham DH1 3LE
UK
Andreas.Vieli@durham.ac.uk

Timo Vihma
Finnish Meteorological Institute
Erik Palménin aukio 1, P.O. Box 503
00101 Helsinki
Finland
timo.vihma@fmi.fi

John D. Vitek
Department of Geology and Geophysics
Texas A&M University
College Station, TX 77843-3115
USA
jvitek@neo.tamu.edu

Mathias Vuille
Department of Atmospheric and Environmental Sciences
University at Albany
State University of New York
1400 Washington Avenue
Albany, NY 12222
USA
mathias@atmos.albany.edu

John Wahr
Department of Physics and CIRES
University of Colorado
Boulder, CO 80309-0390
USA
wahr@lemond.colorado.edu

Stephen J. Walsh
Department of Geography
University of North Carolina
Chapel Hill, NC 27599-3220
USA
swalsh@email.unc.edu

Charles R. Warren
School of Geography and Geosciences
University of St. Andrews
Irvine Building
St. Andrews, Fife KY16 9AL, Scotland
UK
charles.warren@st-andrews.ac.uk

Daniel J. Weiss
Department of Geography
University of North Carolina
Chapel Hill, NC 27599-3220
USA

John Wettlaufer
Yale University
New Haven, CT 06520-8109
USA
john.wettlaufer@yale.edu

Roger Wheate
Geography Program and Natural Resources and
Environmental Studies Institute
University of Northern British Columbia
3333 University Way
Prince George, BC V2N 4Z9
Canada
wheate@unbc.ca

Ian C. Willis
Department of Geography
Scott Polar Research Institute
University of Cambridge
Lensfield Road
Cambridge CB2 1ER
UK
iw102@cam.ac.uk

John Woodward
Division of Geography
School of Applied Sciences
Northumbria University
Ellison Place
Newcastle upon Tyne NE1 8ST
UK
john.woodward@unn.ac.uk

Cunde Xiao
State Key Laboratory of Cryospheric Sciences
Cold and Arid Regions Environmental and Engineering
Research Institute, Chinese Academy of Sciences
Lanzhou, Gansu 730000
China
cdxiao@ns.lzb.ac.cn
cdxiao@cams.cma.gov.cn

Zhang Yanwei
Xinjiang Institute of Ecology and Geography
Chinese Academy of Sciences
40-3 South Beijing Road
Urumqi, Xinjiang 830011
China

Tandong Yao
Laboratory of Tibetan Environment Changes and Land Surface Processes (TEL)
Institute of Tibetan Plateau Research
Chinese Academy of Sciences
No. 18 Shuangqing Rd, P.O. Box 2871
Haidian District, Beijing 100085
China
tdyao@itpcas.ac.cn

Jacob C. Yde
Center for Geomicrobiology
University of Aarhus
Ny Munkegade building 1540
8000 Århus C
Denmark
and
Bjerknes Centre for Climate Research
University of Bergen
Allégaten 55
5007 Bergen
Norway
yde@phys.au.dk

Wusheng Yu
Laboratory of Tibetan Environment Changes and Land Surface Processes (TEL)
Institute of Tibetan Plateau Research
Chinese Academy of Sciences
No. 18 Shuangqing Rd, P.O. Box 2871
Haidian District, Beijing 100085
China

Tingjun Zhang
National Snow and Ice Data Center
Cooperative Institute for Research in Environmental Sciences
University of Colorado at Boulder
Boulder, CO 80309-0449
USA
tzhang@nsidc.org

Huabiao Zhao
Laboratory of Tibetan Environment Changes and Land Surface Processes (TEL)
Institute of Tibetan Plateau Research
Chinese Academy of Sciences
No. 18 Shuangqing Rd, P.O. Box 2871
Haidian District, Beijing 100085
China

H. J. Zwally
NASA Goddard Space Flight Center
Greenbelt, MD 20771
USA
zwally@icesat2.gsfc.nasa.gov

Preface

Snow, ice and glaciers (SIG) are the components constituting what is called cryosphere. They exist at all latitudes and contain the majority of the earth's fresh water. Due to their dominant prevalence, they influence weather, climate, ecosystems, vegetation, and life and human activities in a variety of ways. Indeed they shape human civilization. Owing to looming climate change and global warming, temperature changes now seem inevitable and are changing the landscape of snow, ice and glaciers, or even the existence thereof. In fact, the changes occurring in SIG can be construed as major indicators of climate change. The nature of cryosphere is highly interdisciplinary and calls for an updated interdisciplinary account of its dynamics. Recent decades have witnessed increasing attention to SIG and scientific communities have started working collectively to develop the basic foundation upon which the broad understanding of cryosphere rests. However, there is still a long way to go.

Discussions on climate change and global warming now seem to be occupying the center stage in public debates, professional forums, news media, and political dialog. As a result, the general public has become much more aware of what is happening to our climate. Since both climate change and climate variability have been found to be closely linked with the cryosphere, it is important for scientists and professionals in the field of earth, environmental, oceanic and atmospheric sciences to develop a better understanding of this sphere from conceptual, theoretical, technical and applied viewpoints. This is especially important for snow, ice and glacier covered areas, since they are rarely stable and are continuously changing in their thickness, areal extent, and flow speeds. Recent advances in field-based studies and quantitative and numerical modeling have provided answers to several key questions but have also highlighted the urgent need for cryospheric studies in many areas, for example, contribution of snow, ice and glacier melt to the sea level rise; importance of snow and glacier to water resources; and so on.

The objective of this Encyclopedia is to present the current state of scientific understanding of various aspects of earth's cryosphere – snow, glaciers, ice caps, ice sheets, ice shelves, sea ice, river and lake ice, and permafrost – and their related interdisciplinary connections under one umbrella. Therefore, every effort has been made to provide a comprehensive coverage of cryosphere by including a broad array of topics, such as the atmospheric processes responsible for snow formation; snowfall observations; snow cover and snow surveys; transformation of snow to ice and changes in their properties; classification of ice and glaciers and their worldwide distribution; glaciation and ice ages; glacier dynamics; glacier surface and subsurface characteristics; geomorphic processes and landscape formation; hydrology and sedimentary systems; hydrochemical and isotopic properties; permafrost modeling; hazards caused by cryospheric changes; trends of glacier retreat on a global scale along with the impact of climate change; and many more quantitative estimates of various glacier parameters, such as degree-day, mass balance, extent and volume, and downwasting. Also included are articles on GPS application, and satellite image application in glaciology; GPR analysis; and sea level rise.

For purposes of the Encyclopedia 463 articles were selected. Literature on snow, ice and glaciers has grown too large to be fully treated in a single volume; therefore, the selection of articles included some subjectivity but was reviewed by many experts who have long been at the forefront of research in the field of cryosphere. We truly understand that given the scope of this subject it is almost impossible to include each and every topic in this type of reference book, but we have tried our best to avoid any glaring omissions or miss something which could significantly hamper the quality of the Encyclopedia. Therefore, we have made the contents of the Encyclopedia exhaustive, but we understand that we might have missed certain topics. We are also aware of some partial omissions. As it frequently happens, willing contributors cannot unfortunately be always found for all the suggested topics. It may be noted that if the reader does not see an entry for the particular topic that interests him or her, then he or she should look in the index because that topic may have been covered under a different heading and perhaps in more than one article. In making the list exhaustive, it is possible that there might be a little bit of repetition here and there, but we do not want readers to read two articles to understand one.

The material presented in the articles consists of established information on a particular topic and represents easily accessible digested knowledge. The level of material is such that a graduate student can benefit from the presentation which is not necessarily from his or her area of expertise. An effort has been made such that each article stands on its own, without an assumption that a reader will be seeing any other portion of the Encyclopedia. Although entries are presented in alphabetical order, they have been organized under major compilation headings which should become particularly obvious when the reader uses the cross-references with each entry. This is not an exhaustive list but hopefully it gives a structure to the Encyclopedia's contents. Of equal value are the many references given with the entries.

This *Encyclopedia of Snow, Ice and Glaciers* is supposed to provide clear explanations of current topics, and is not structured as a student textbook, but it is rather for quick access to particular terms and concepts in self-contained entries. We hope that this volume will also tempt the casual reader to browse through and become curious about the different facets and foci of cryosphere.

The contributors represent varying backgrounds and many of them represent WHO'S WHO in the cryosphere. It is hoped that the Encyclopedia will serve as a reference to scholars and students. The Encyclopedia will also be a valuable resource for geologists, geographers, climatologists, hydrologists, and water resources engineers; as well as to those who are engaged in the practice of agricultural and civil engineering, earth sciences, environmental sciences and engineering, ecosystems management, and other relevant fields.

The encyclopedia is comprised of articles under three categories: A, B, and C. Tables 1, 2 and 3 provide a list of major headings of articles included in the encyclopedia for a quick reference (see List of Articles, pages 1233–1237). 64 articles in category A represent major divisions and review topics. These also serve to coordinate the widely scattered entries of categories B and C. 182 Category B articles constitute building block items, inspired by textbook subheads, but also the cookbook items. 217 articles in category C are mini-entries dealing with materials, fancy terms, or outdated concepts. All these categorical entries on different topics are compiled in an alphabetical order, with their length being related to their relative importance.

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Vijay P. Singh
Pratap Singh
Umesh K. Haritashya
(Editors-in-Chief)

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Guide to the Reader

For the beginners, it is good to start with a general article, then track the list of cross-references provided at the end of the article to locate similar or relevant articles. For example, if one wants to learn about hydrological aspects of snow and glaciers, then one should go to Glacier Hydrology and Snow Hydrology, then Melt Runoff Modeling, then Impacts of Snow and Glaciers on Runoff, then Hydrochemical Characteristics of Snow, Ice and Glaciers, then Hydropower: Hydroelectric Power Generation from Alpine Glacier Melt, or several other specific Snow or Glacier Hydrology related articles. The list of cross-references provided at the end of the article is not exhaustive, otherwise it would lead to a long listing, rather it is a guide for the reader to find other relevant articles, which are further cross-referenced.

Experts or other readers with background in cryosphere may directly search for specific topics. For example, Ice Age Cycles: Data, Models, and Uncertainties, or Basal Sediment Evacuation by Subglacial Drainage Systems. If one does not find the topic one is looking for, it is possible that it may have been covered under a different heading. Therefore, one should go to the index that would lead to the articles that may cover the topic of interest. If a reader is looking for more explanation than what is already described under any particular topic, then most articles provide important and landmark bibliographic references that relate to both general and research articles. Some articles provide older references which allow readers to find the historical aspect of the topic.

As depth increases, firn porosity decreases and air mixing becomes more restricted (Schwander et al., 1997; Bender et al., 1997). Seasonal layering can also affect the rate of air movement through firn (Albert, 1996) and may produce impermeable layers in the non-diffusive zone. These prevent air from equilibrating with that in the diffusive zone (Sowers et al., 1992; Schwander et al., 1997). While air may mix locally, within the summer layer for example, impermeable winter layers impede its vertical diffusion (Fain et al., 2008).

Firn measurements

Borehole logging is used to measure firn properties in situ. These include temperature, density, and vertical strain. Unlike snow, which must be sampled at depth by digging a large snow pit and sampling from the sides, firn has enough cohesion (Cohesion) to permit the extraction of intact cores that are used to measure density, porosity and permeability, grain size, and anisotropy.

Because firn is compressible, seasonal layers thin with depth. It is also porous and subject to the migration of chemical species deposited with the snow (Chemical Composition of Snow, Ice, and Glaciers). Both of these aspects can complicate age-depth calculations. Where annual layers cannot be distinguished optically or from the geochemical record, a density profile produced from a borehole log of vertical strain or measurements of mass, length, and diameter of core sections can reveal seasonal layering.

Summary

A transitional state between fallen snow and meteoric ice, firn is a complex material where vast morphological and chemical changes are taking place.

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Cross-references

Antarctica
Chemical and Microbe Records in Snow and Ice
Chemical Composition of Snow, Ice, and Glaciers
Cohesion
Geochemistry of Snow and Ice
Glacier
Ice
Isotopic Characteristics of Ice, Snow, and Glaciers
Layering of Snow
Overburden Pressure
Snow Grains
Stratigraphy of Snowpacks
Temperate Glaciers

FJORDS

Umesh K. Haritashya[1], Vijay P. Singh[2], Pratap Singh[3]
[1]Department of Geology, University of Dayton, Dayton, OH, USA
[2]Department of Biological and Agricultural Engineering, Texas A&M University, College Station, TX, USA
[3]Tahal Consulting Engineers Ltd, New Delhi, India

Synonyms

Fiord

Definition

Fjords are long, narrow, and over-deepened features with steep sides and are carved into bedrock by the glacial activity and flooded by melting water (Figure 1).

Fjords, Figure 1 Fjord as seen in Milford Sound, New Zealand. Photo courtesy Dr. Luke Copland.

Fjords are erosional landforms that represent the movement of a glacier within a confined channel along the valley bottom. The movement of a glacier and formation of fjords is entirely controlled by topography. They are common in the polar regions, but can also be found in subpolar and temperate regions (Table 1). Fjords have existed for millions of years and they range from a few kilometers to several tens of kilometers wide and several kilometers long. Because of their location and relationship with the sea level on one side and tectonically active high mountains on the other side, they are an important feature. They also possess unique characteristics of oceanic processes and ice-ocean interface (Straneo et al., 2010), and therefore, they are appropriately termed as one of the complex and dynamic landsystems that provide information about glacial, fluvial, and oceanographic features.

Most fjords are a Palimpsest feature which makes them an extremely important feature, because they can provide information about the successive glaciations through floor sediments. However, these sediments need to be carefully analyzed, since they may have been buried by younger glacimarine sediments. Fjords act as natural sediment traps and typically have high sediment accumulation rates, providing the potential for high-resolution palaeoclimatic and palaeoenvironmental studies on decadal to centennial timescales and presenting a unique opportunity to study land–ocean interactions. Cowan et al. (2010) used the fjord sediment to identify two prominent glacial erosion surfaces associated with Last Glacial Maximum advance and Little Ice Age advance. Fjords comprise several rock basins, but many of them are deepest at the beginning and become gradually shallower toward the sea. This could be related to the erosive power of glaciers, which becomes lesser and lesser toward the end of the feature.

Sediment deposition in fjords can be related to retreating glaciers by depositional zones moving in the upward direction and hiatuses in retreat by push moraines or morainal banks. Powell and Molnia (1989) has shown various depositional system models associated with retreating glaciers, and he (Powell, 2003) has discussed such models in various types of environment from polar to temperate. Sediment deposition can also be related to advancing glaciers in the form of increasing till thickness from head of a fjord toward the sea limit.

Fjords also provide critical information about marine limits and relate to with the isostaic uplift of deglaciated outer coasts.

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Cross-references

Sediment Core and Glacial Environment Reconstruction

Fjords, Table 1 Some of the major local controls on modern fjord landsystems (Adopted from Powell, 2003)

Climatic zone	Glacial flow velocity	Internal ice condition	Bed condition	Subglacial water free	Glacier terminus	Sediment contribution										Modern examples
						Glacial		Glacifluvial		Marine			Terrestrial			
						Sub-	En-/ supra	Sub-	En-/ supra	icebergs	Sea ice	biogenic	Fluvial	Mass flow	Wind	
Temperate	Fast	Temperate	Deforming till, local	Conduit flow	Tidewater cliff	2	2	5	1	2		1	3	3	1	Alaska, British Columbia, Chile
Subpolar	Fast	Slightly cold	Deforming till	Conduit flow	Tidewater cliff	3	1	3	1	1	2	1	3	1	1	Svalbard, Canadian and Russian Arctic
	Moderate	Cold	Mostly frozen, local till	None to minor conduit flow	Short floating tongue or tidewater cliff	2		2		1		2	1		1	Antarctic Peninsula
Polar	Fast	Cold	Deforming till	Local conduit thin film	Floating tongue	3	1	3		3	1	1	2	1	1	Greenland, Ellesmere Island, Baffin Island
	Moderate	Very cold	Deforming till	None	Floating tongue	3	1			1	1	1	1	1	3	Antarctica (Mackay)
	Slow	Very cold	Mostly frozen, some till	None	Floating tongue or tidewater cliff	1	1			1	1	1		1	3	Antarctica (Ferrar and Blue)