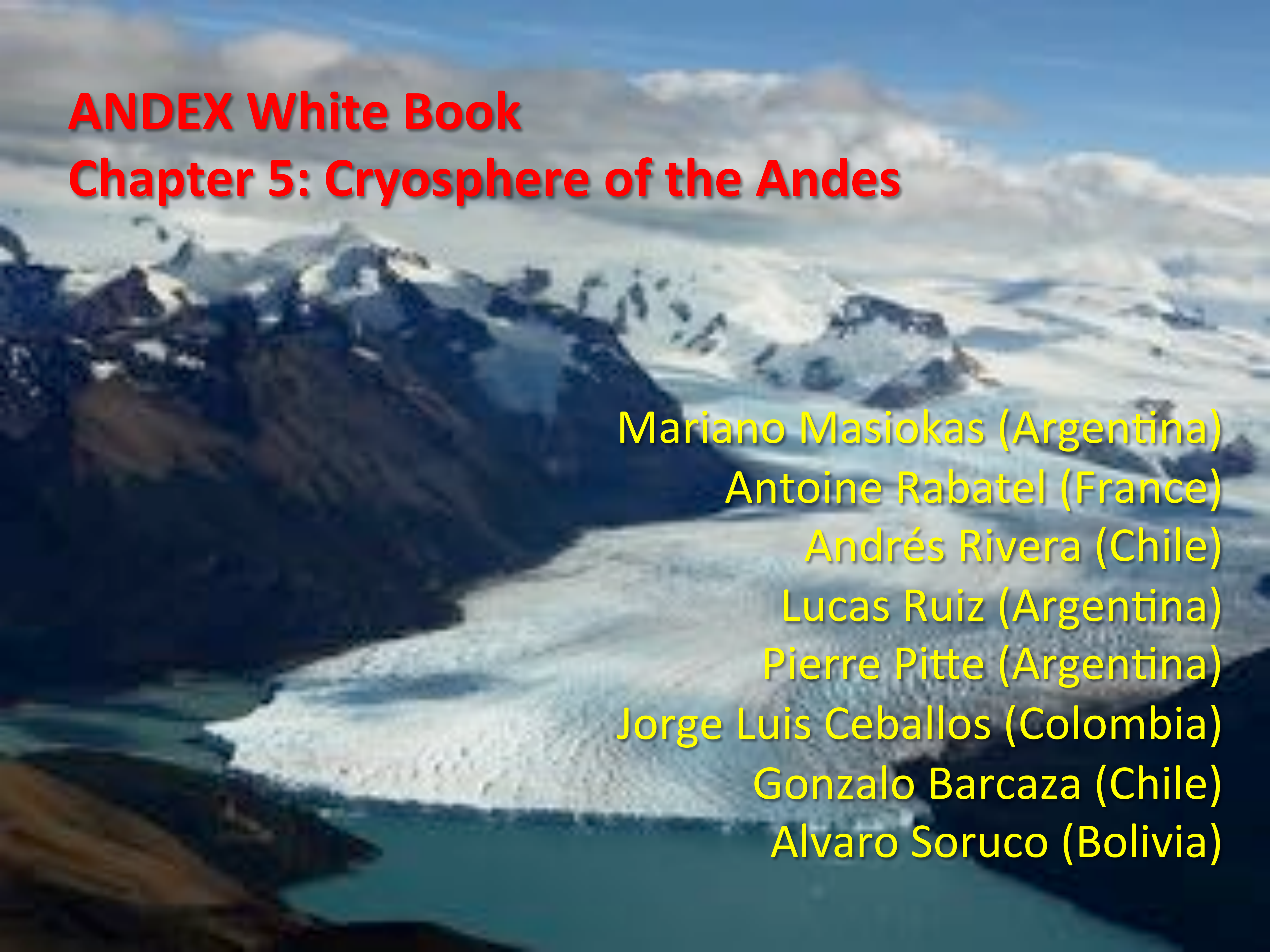


ANDEX White Book
Chapter 5: Cryosphere of the Andes

Mariano Masiokas (Argentina)
Antoine Rabatel (France)
Andrés Rivera (Chile)
Lucas Ruiz (Argentina)
Pierre Pitte (Argentina)
Jorge Luis Ceballos (Colombia)
Gonzalo Barcaza (Chile)
Alvaro Soruco (Bolivia)

Introduction

The Andes portray an impressive variety of topographic and climatic conditions that result in a vast and diverse cryosphere

Probably no other mountainous region on Earth contains such a diversity of cryospheric features and ice masses

- ✓small tropical glaciers above 5000 m (in the tropical Andes from Colombia to Bolivia)
- ✓ large continuous areas integrating clean ice and rock glaciers (semi-arid Andes of Chile and Argentina)
- ✓extensive temperate glaciers and icefields calving into the sea (southwestern Patagonia and Tierra del Fuego)

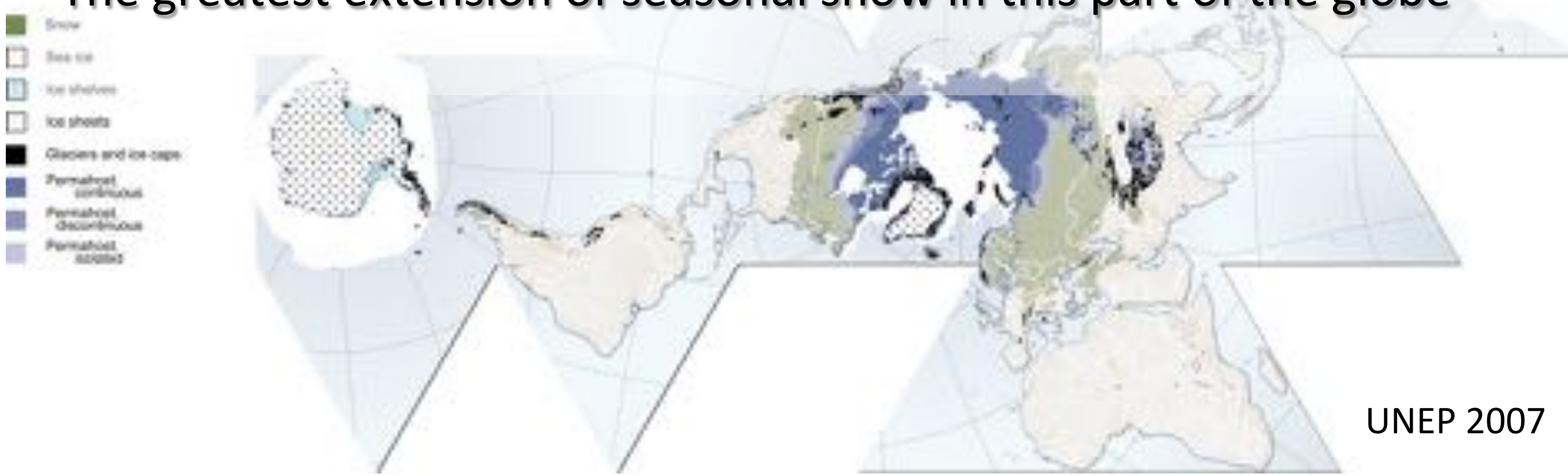
Introduction II

Outside Antarctica, the Andes include the largest glacierized area in the Southern Hemisphere

The largest extension of tropical glaciers on Earth

One of the greatest concentrations of mountain permafrost and rock glaciers outside the Himalayas

The greatest extension of seasonal snow in this part of the globe



UNEP 2007

Organization of the chapter

1. Introduction
2. Seasonal snow
    1. General description
    2. ENSO and seasonal snow
    3. West-East gradients
    4. Recent trends
3. Glaciers
    1. Tropical / Southern Andes
        1. Current state
        2. Recent changes
4. Mountain permafrost
5. Knowledge gaps and future challenges

2. Seasonal snow

Compared to some years ago, currently we have a much larger array of tools to study seasonal snow in the Andes

- ✓ increased variety and temporal/spatial resolution of remote sensing data
- ✓ better modeling capabilities
- ✓ better access to instrumental datasets

Snow cover from MODIS, February 2018

2. Seasonal snow

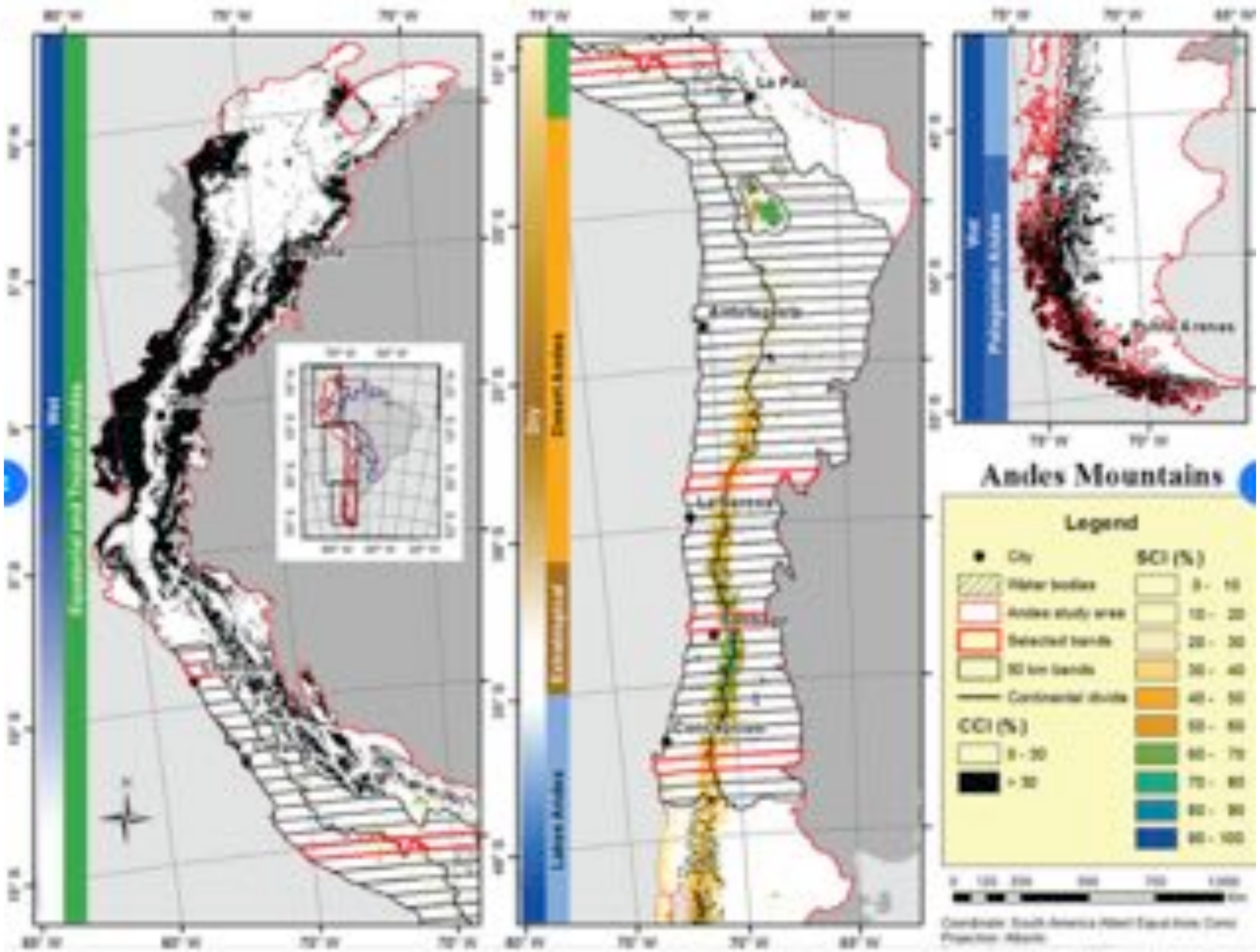
Snow cover from MODIS, September 2018

2. Seasonal snow

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. (2016)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.4795

A snow climatology of the Andes Mountains from MODIS snow cover data

Freddy A. Saavedra,[a*] Stephanie K. Kampf,[b] Steven R. Fassnacht[b,d,e] and Jason S. Sibold[c]



The Cryosphere, 12, 1027–1046, 2018
https://doi.org/10.5194/tc-12-1027-2018

The Cryosphere

Changes in Andes snow cover from MODIS data, 2000–2016

Freddy A. Saavedra[1,2], Stephanie K. Kampf[3], Steven R. Fassnacht[3,4,5,6], and Jason S. Sibold[7]

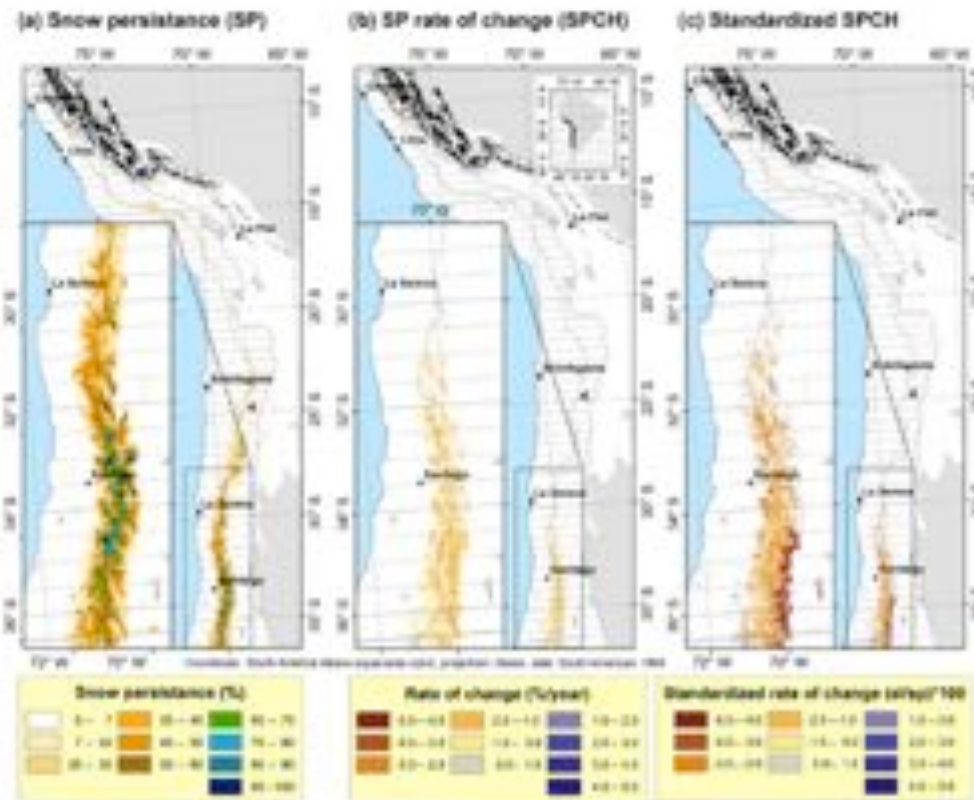


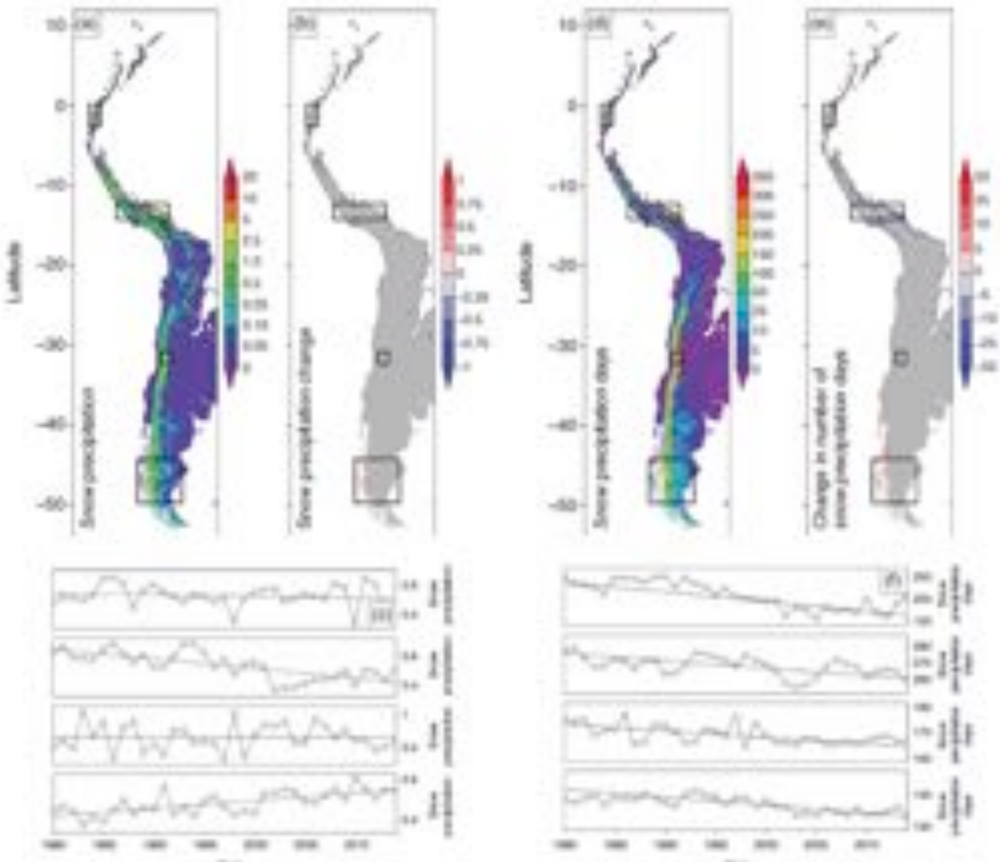
Figure 3. Spatial patterns of (a) snow persistence (SP) 2000–2016, (b) rate of change (Theil–Sen slope) in annual SP 2000–2016, and (c) standardized rate of change (Theil–Sen slope / SP); pixels are only colored in panels (b) and (c), where the trend is significant at $p \leq 0.05$. All images exclude areas with little to no snow (mean annual SP ≤ 7 %). Areas with frequency of cloud greater that 30 % are marked in black.

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **37**: 1680–1698 (2017)
Published online 28 June 2016 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.4804

RMetS
Royal Meteorological Society

The Andes Cordillera. Part I: snow distribution, properties, and trends (1979–2014)

Sebastian H. Mernild,[a,b,f,*] Glen E. Liston,[c] Christopher A. Hiemstra,[d] Jeppe K. Malmros,[e] Jacob C. Yde[f] and James McPhee[g]



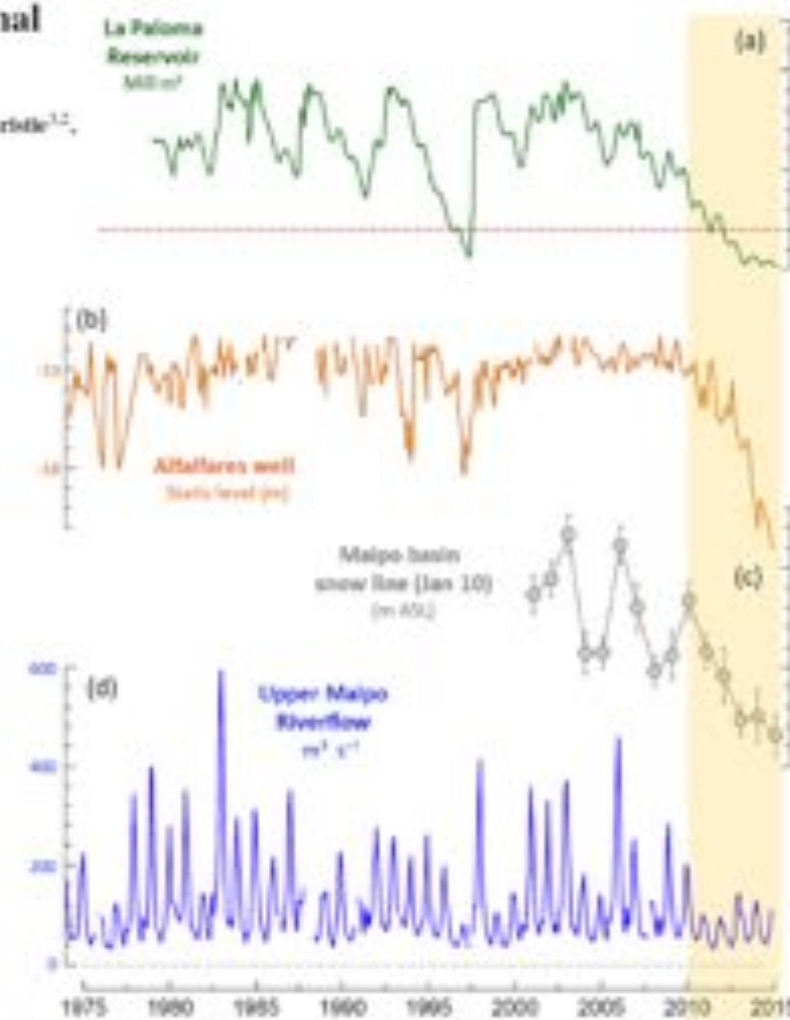
The seasonal snow that accumulates each winter in the central Andes of Chile and Argentina represents a crucial water resource for human activities in the region

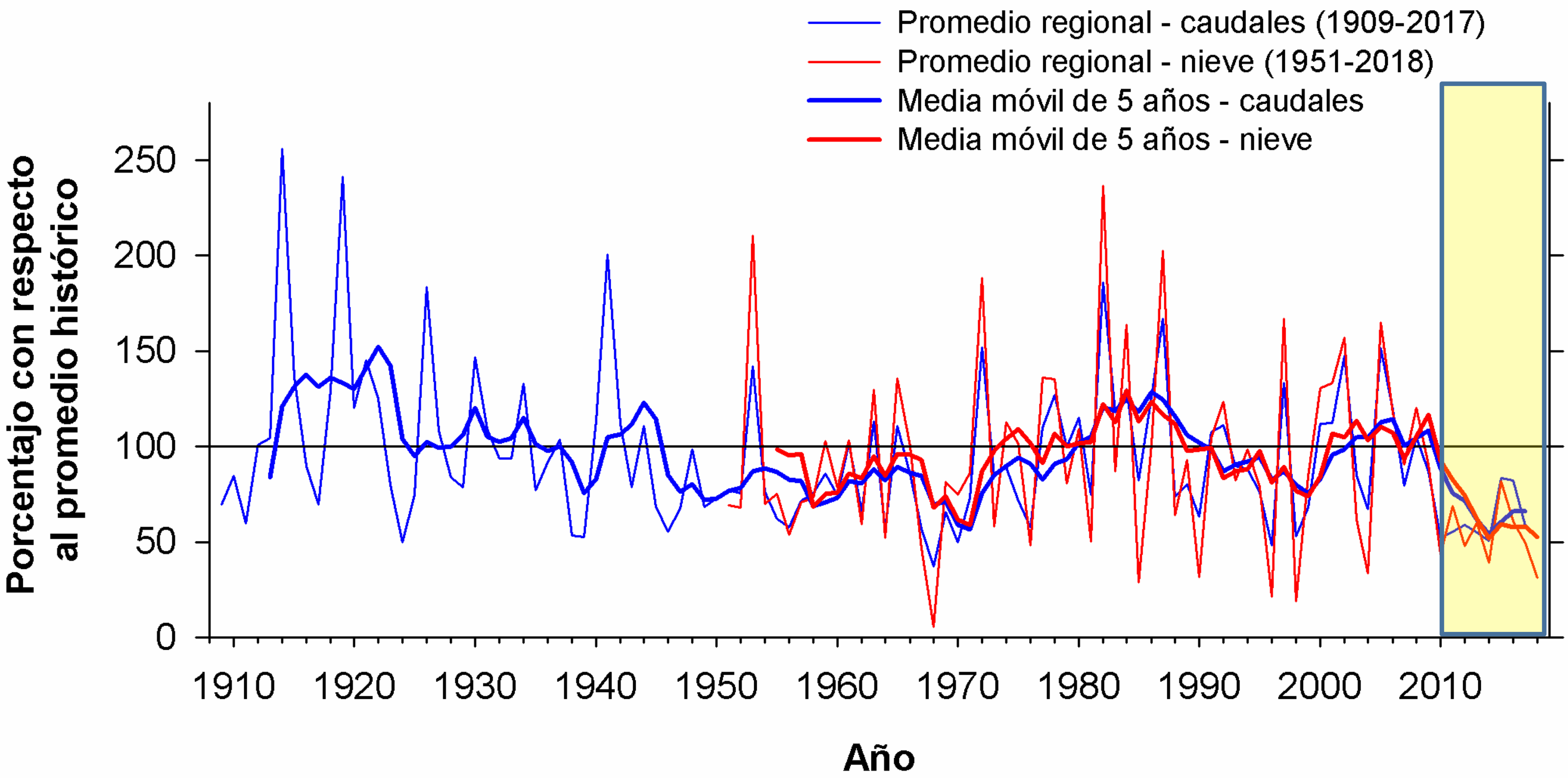
Hydrol. Earth Syst. Sci., 21, 6307–6327, 2017
https://doi.org/10.5194/hess-21-6307-2017

Hydrology and Earth System Sciences
EGU

The 2010–2015 megadrought in central Chile: impacts on regional hydroclimate and vegetation

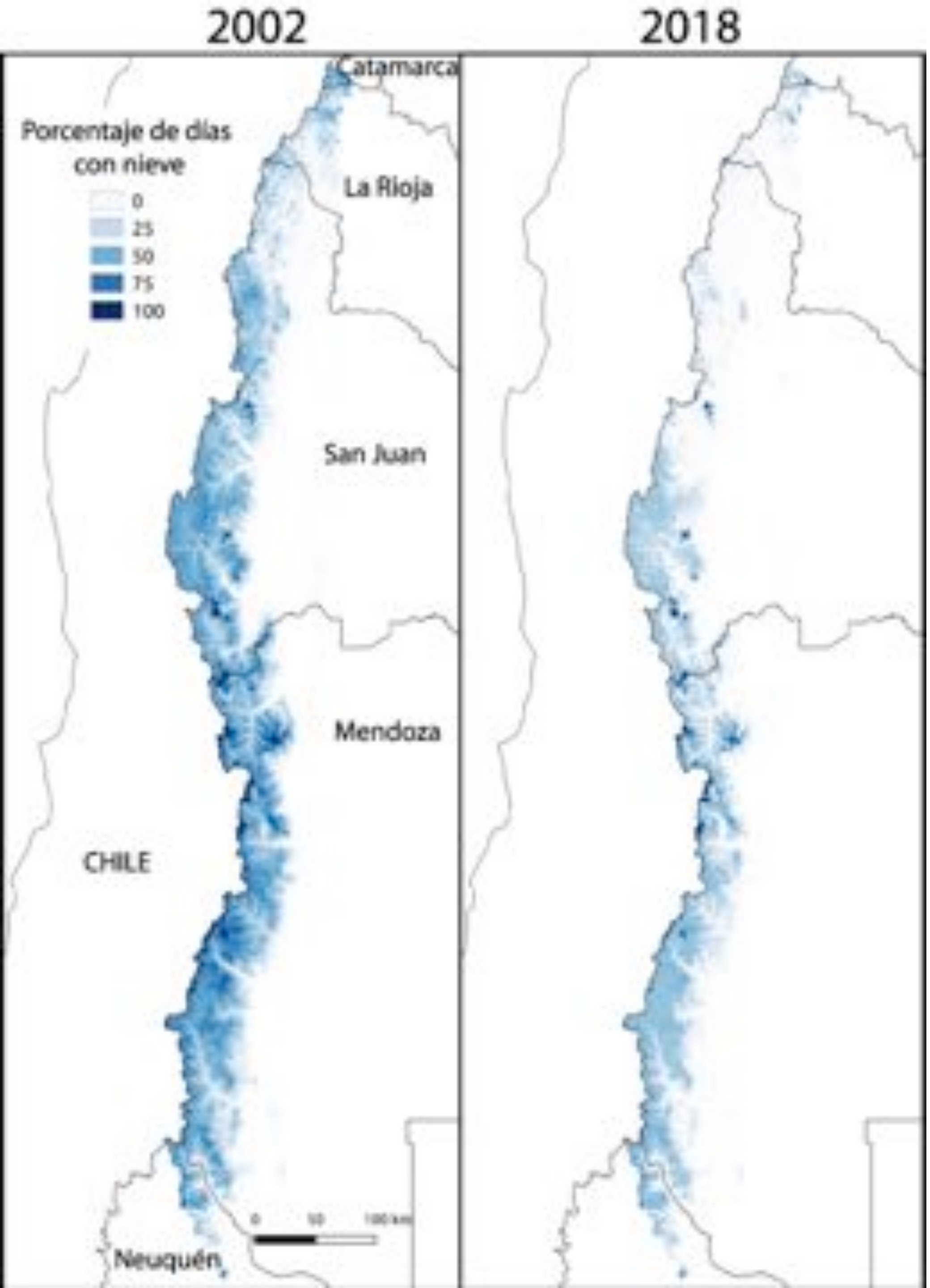
René D. Garreaud[1,2], Camila Alvarez-Garreton[3,2], Jonathan Barichivich[3,2], Juan Pablo Boisier[1,2], Duncan Christie[3,2], Mauricio Galleguillos[4,2], Carlos LeQuesne[3], James McPhee[5,6], and Mauricio Zambrano-Bigiarini[7,2]



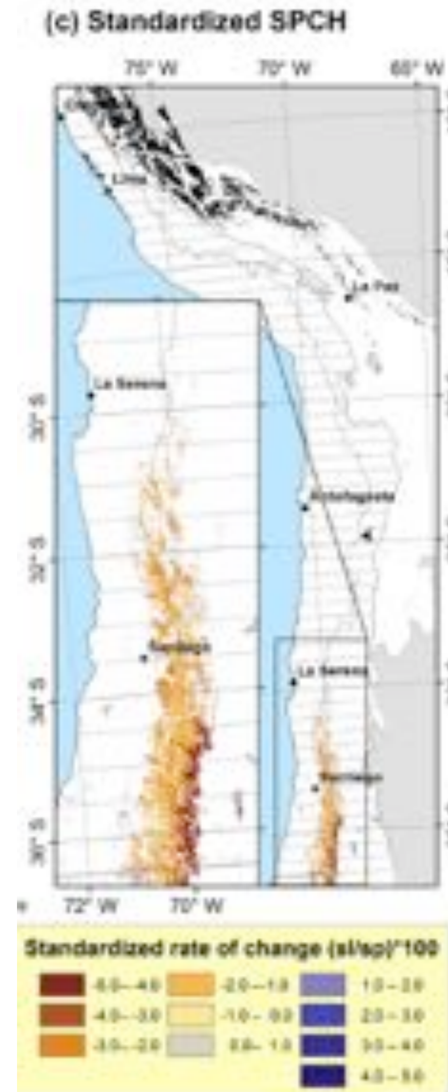


Adding data for the last few years shows that the "Megadrought" is still alive

Updated from Masiokas et al. 2013



In the Argentinean (drier) side of the Andes, the recent lack of snow is particularly worrysome



3. Glaciers

A growing number of studies are available to describe the current state and/or the recent changes of glaciers in the Andes

Randolph Glacier Inventory, GLIMS

The better availability of remote sensing data has been crucial for large-scale assessments

Annals of Glaciology (2017), Page 1 of 15 doi: 10.1017/aog.2017.28

Glacier inventory and recent glacier variations in the Andes of Chile, South America

Gonzalo BARCAZA,[1] Samuel U. NUSSBAUMER,[2,3] Guillermo TAPIA,[1] Javier VALDÉS,[1] Juan-Luis GARCÍA,[4] Yohan VIDELA,[5] Amapola ALBORNOZ,[6] Víctor ARIAS[7]

Barcaza et al. 2017

In May 2018 the first national glacier inventory was also published in Argentina

www.glaciaresargentinos.gob.ar

- Clean ice and debris-covered glaciers
- Permanent snow patches
- Rock glaciers

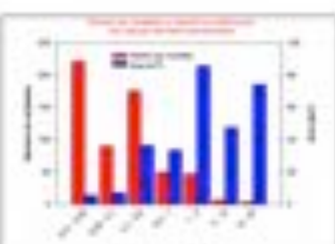
Larger than 0,01 km^2

Maps

INVENTARIO NACIONAL DE GLACIARES

Cuenca del río Mendoza

Subcuenca del río Tupungato
Provincia de Mendoza



INVENTARIO NACIONAL DE GLACIARES

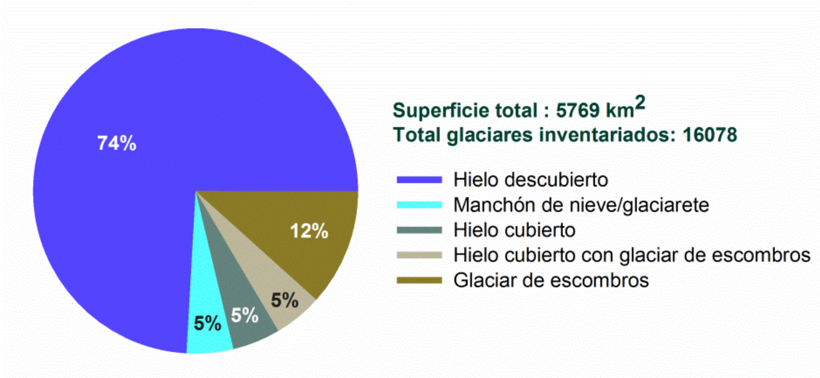
Secretaría de Ambiente y Desarrollo Sustentable de la Nación

Totals

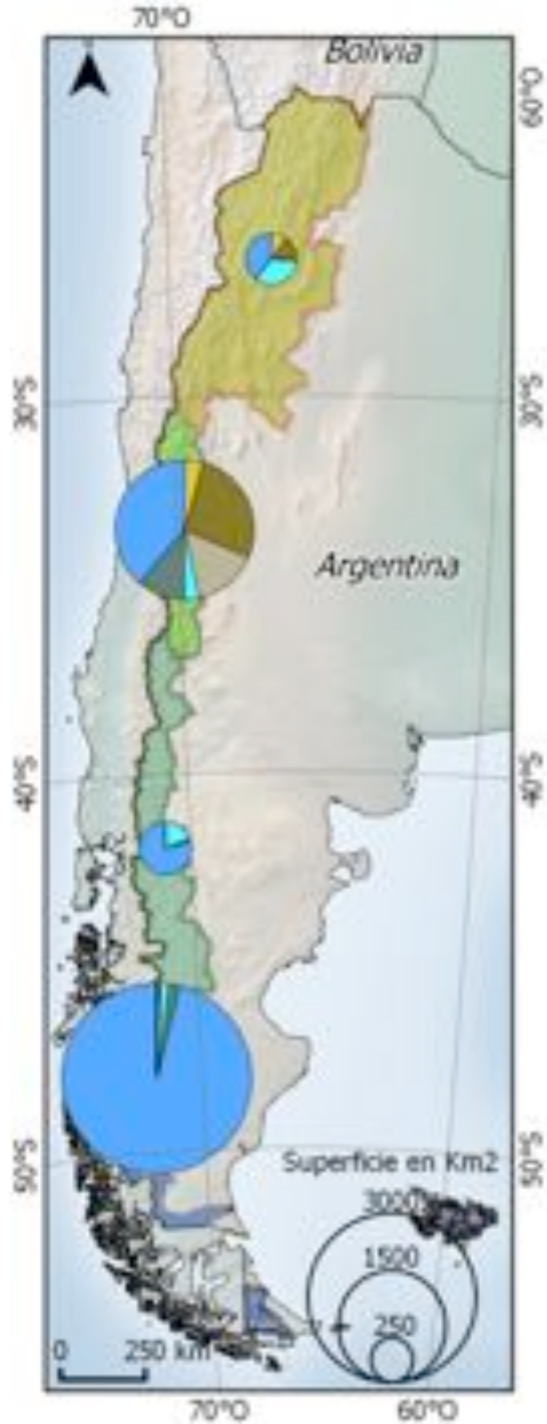
5768 km^2

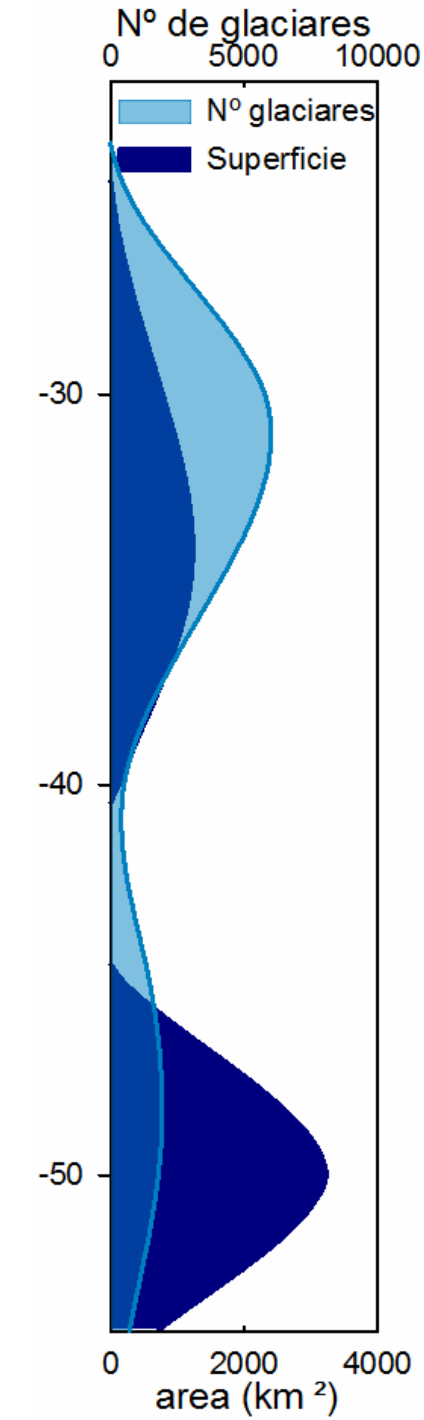
16078 ice bodies

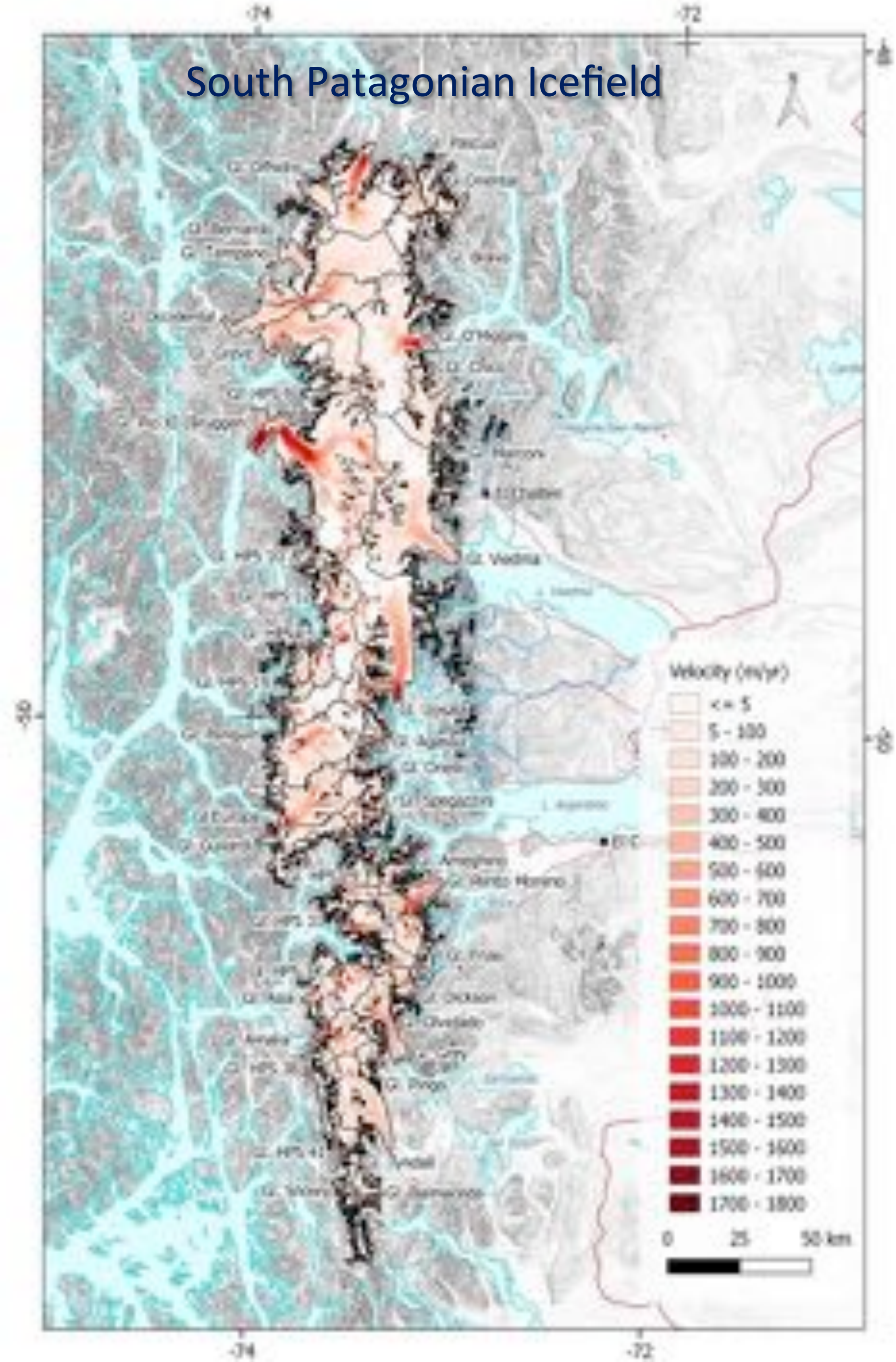
Global values



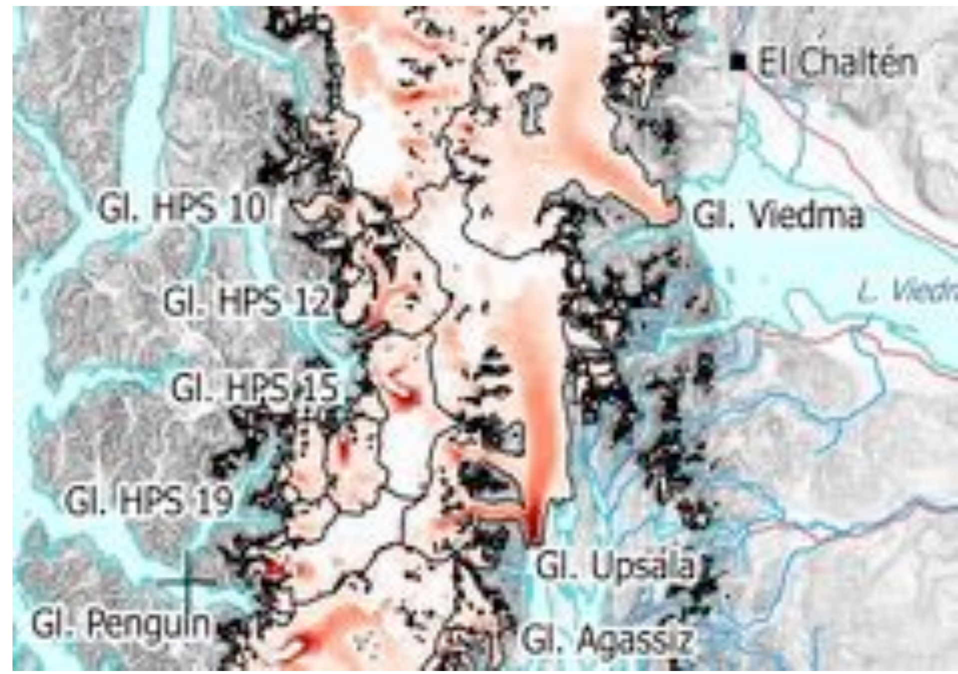
- Glaciar descubierto
- Glaciar cubierto
- Manchón de nieve
- Glaciar cubierto con GE
- Glaciar de escombros activo
- Glaciar de escombros inactivo







Valuable information on glacier dynamics are also now freely available



Velocity fields

Mouginot and Rignot 2015

Recent glacier changes

Earth-Science Reviews 176 (2018) 195–213

Contents lists available at ScienceDirect

Earth-Science Reviews

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

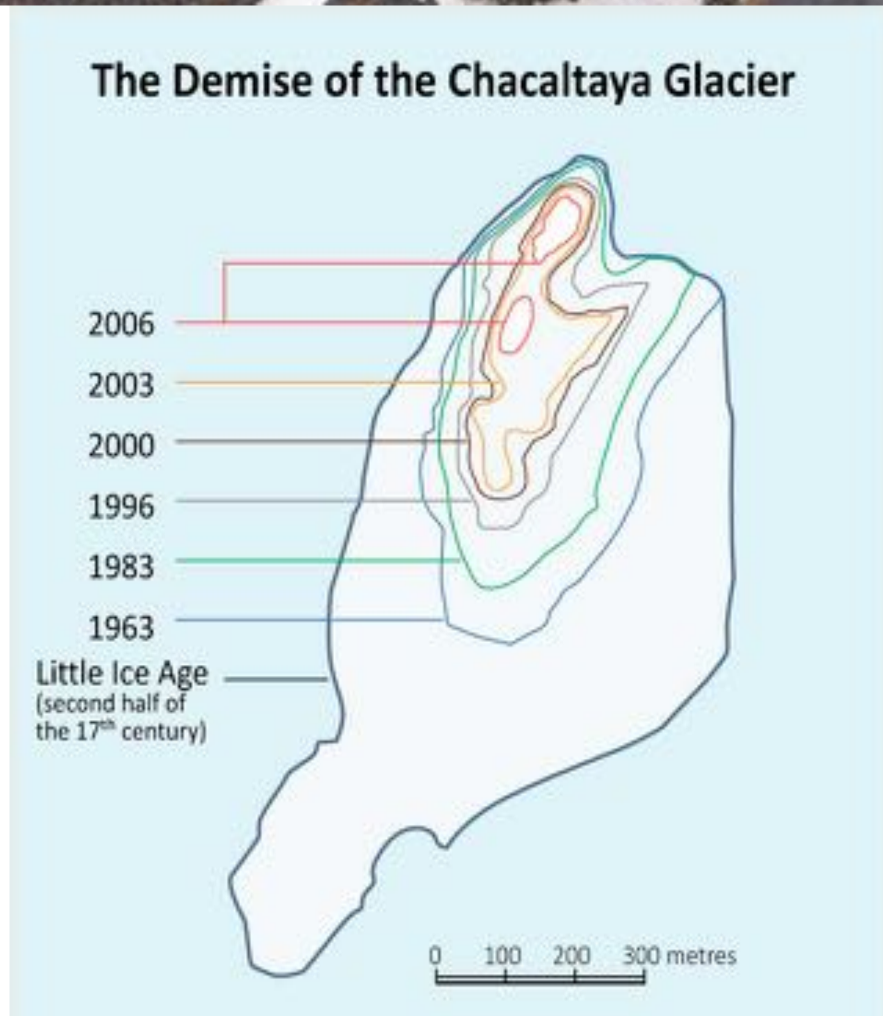
Invited review

Rapid decline of snow and ice in the tropical Andes – Impacts, uncertainties and challenges ahead

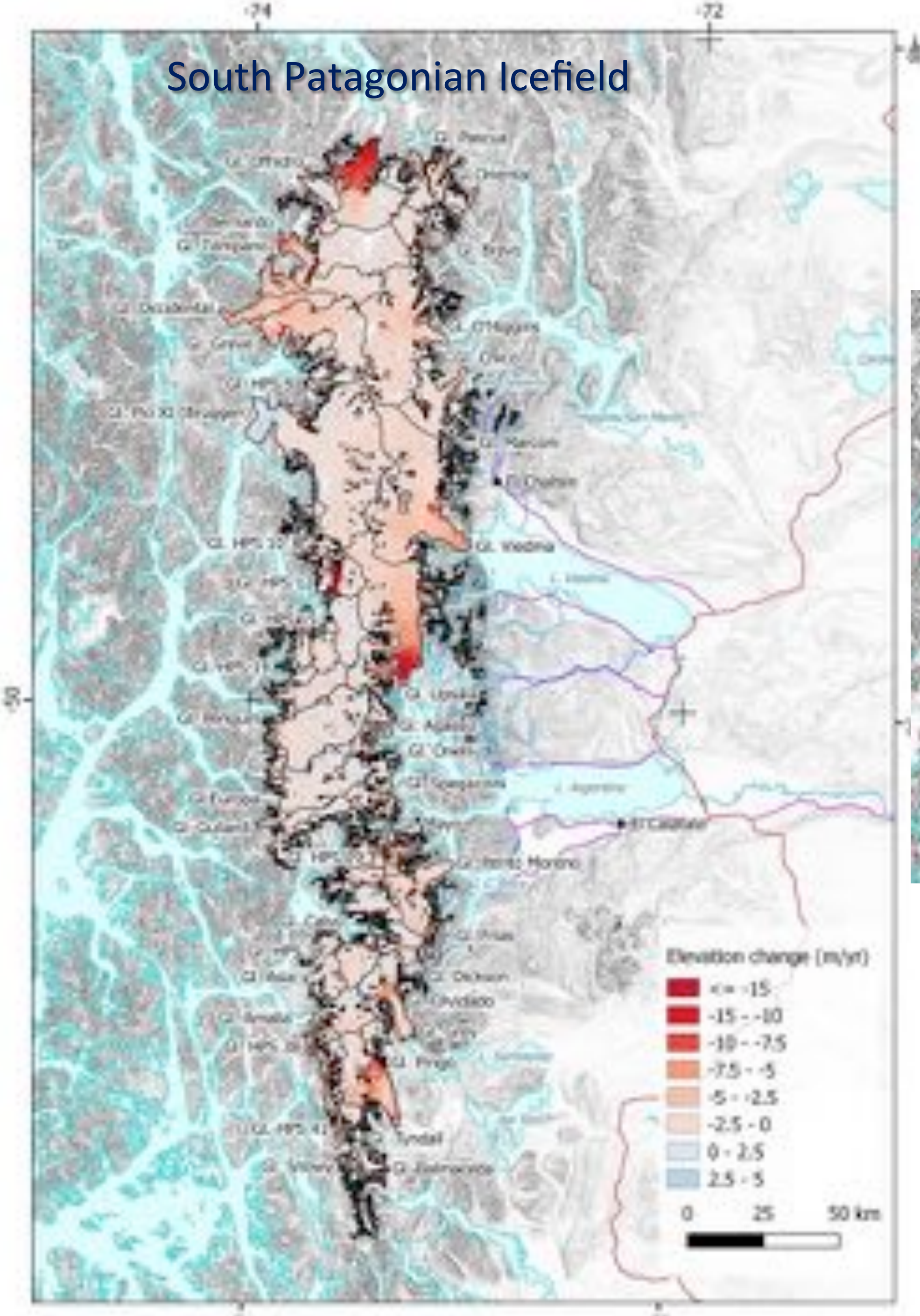
Mathias Vuille[a,*], Mark Carey[b], Christian Huggel[c], Wouter Buytaert[d], Antoine Rabatel[e], Dean Jacobsen[f], Alvaro Soruco[g], Marcos Villacis[h], Christian Yarleque[e], Oliver Elison Timm[a], Thomas Condom[e], Nadine Salzmann[c,i], Jean-Emmanuel Sicart[e]

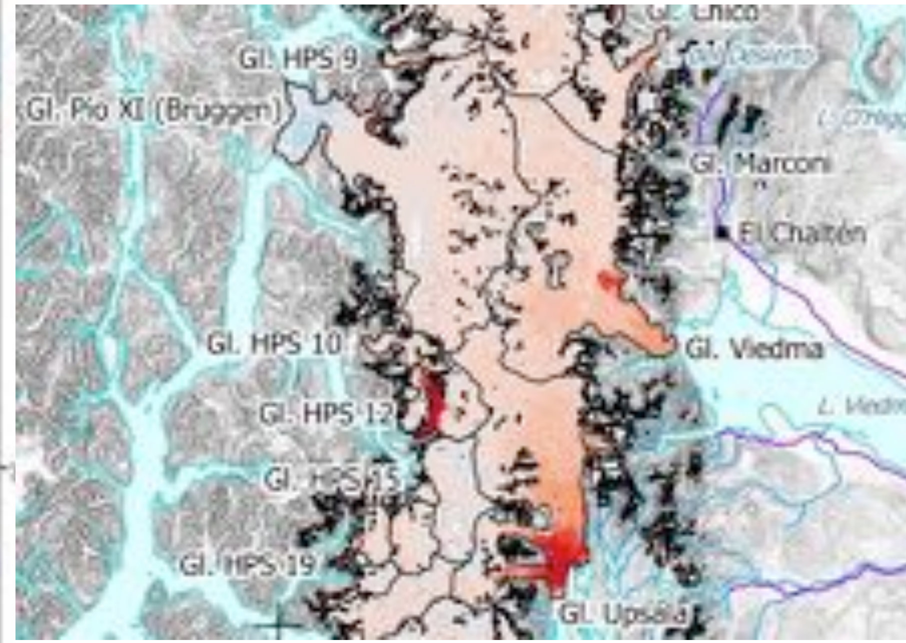
The glacier mass loss in recent decades is widespread throughout the Andes


Chacaltaya
Christian Mehlführer/
Wikicommons/CC-BY-3.0


The Demise of the Chacaltaya Glacier
2006
2003
2000
1996
1983
1963
Little Ice Age
(second half of
the 17th century)
0
100
200
300 metres

UNEP

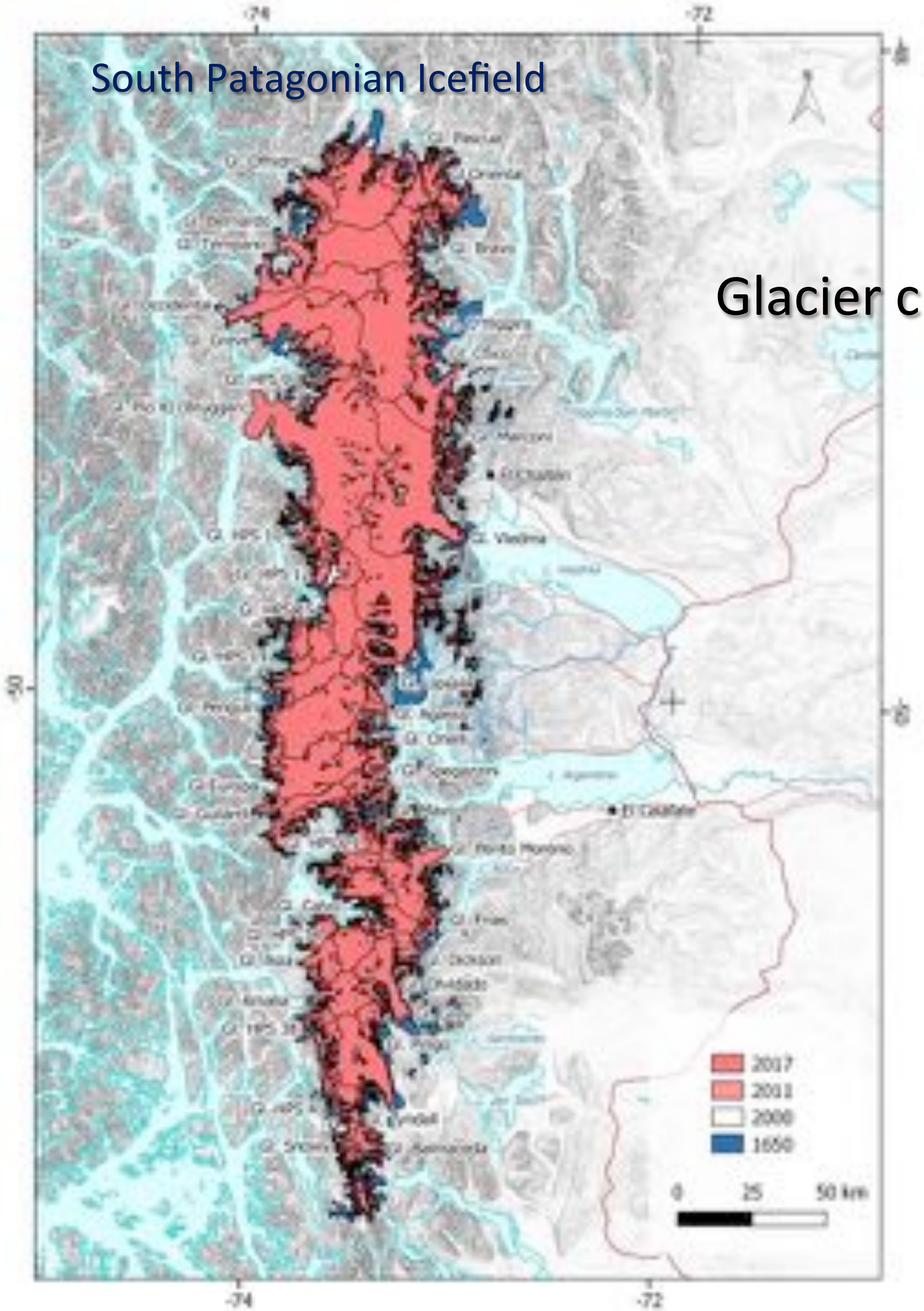




Elevation changes

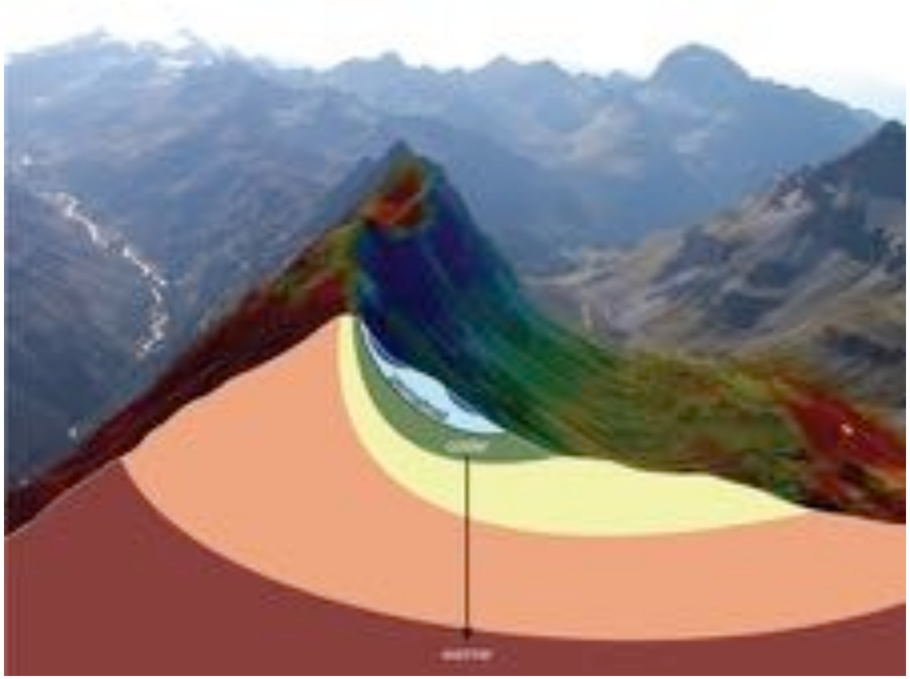
Willis et al. 2012

Glacier changes since the Little Ice Age



Glasser et al. 2011

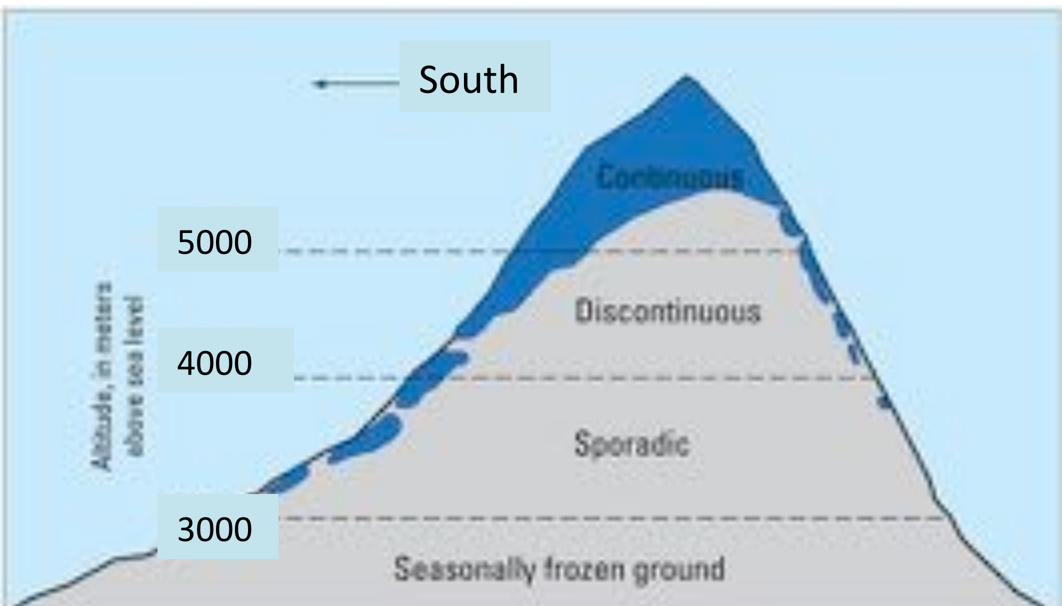
4. Mountain permafrost



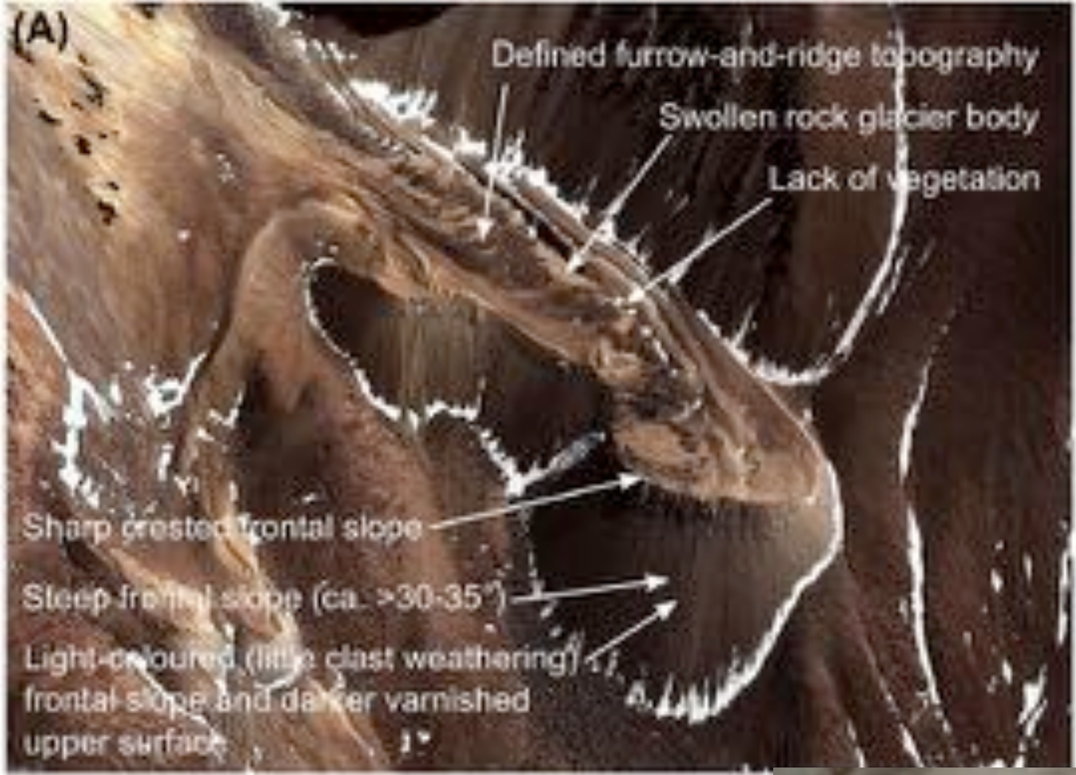
Permafrost distribution is complex in the Andes

Depends on several factors

- -Elevation
- -Orientation
- -Precipitation



Idealized distribution of mountain permafrost



Rock glaciers are indicators of permafrost conditions

Argentina (ING)

Bolivia (Jones et al. 2018)

www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Mountain rock glaciers contain globally significant water stores

D. B. Jones[1], S. Harrison[1], K. Anderson[2] & R. A. Betts[3,4]

Received: 23 May 2017
Accepted: 1 February 2018
Published online: 12 February 2018

Glacier- and snowpack-derived meltwaters are threatened by climate change. Features such as rock glaciers (RGs) are climatically more resilient than glaciers and potentially contain hydrologically valuable ice volumes. However, while the distribution and hydrological significance of glaciers is well studied, RGs have received comparatively little attention. Here, we present the first near-global RG database (RGDB) through an analysis of current inventories and this contains >73,000 RGs. Using the RGDB, we identify key data-deficient regions as research priorities (e.g., Central Asia). We provide the first approximation of near-global RG water volume equivalent and this is 83.72 ± 16.74 Gt. Excluding the Antarctic and Subantarctic, Greenland Periphery, and regions lacking data, we estimate a near-global RG to glacier water volume equivalent ratio of 1:456. Significant RG water stores occur in arid and semi-arid regions (e.g., South Asia East, 1:57). These results represent a first-order approximation. Uncertainty in the water storage estimates includes errors within the RGDB, inherent flaws in the meta-analysis methodology, and RG thickness estimation. Here, only errors associated with the assumption of RG ice content are quantified and overall uncertainty is likely larger than that quantified. We suggest that RG water stores will become increasingly important under future climate warming.

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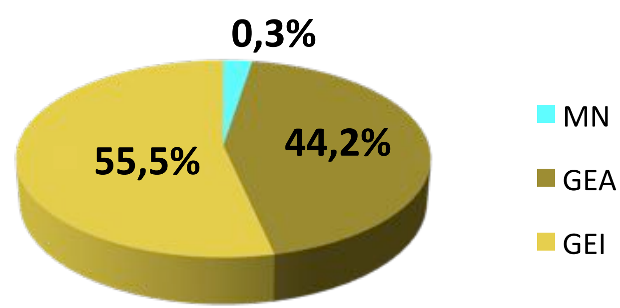
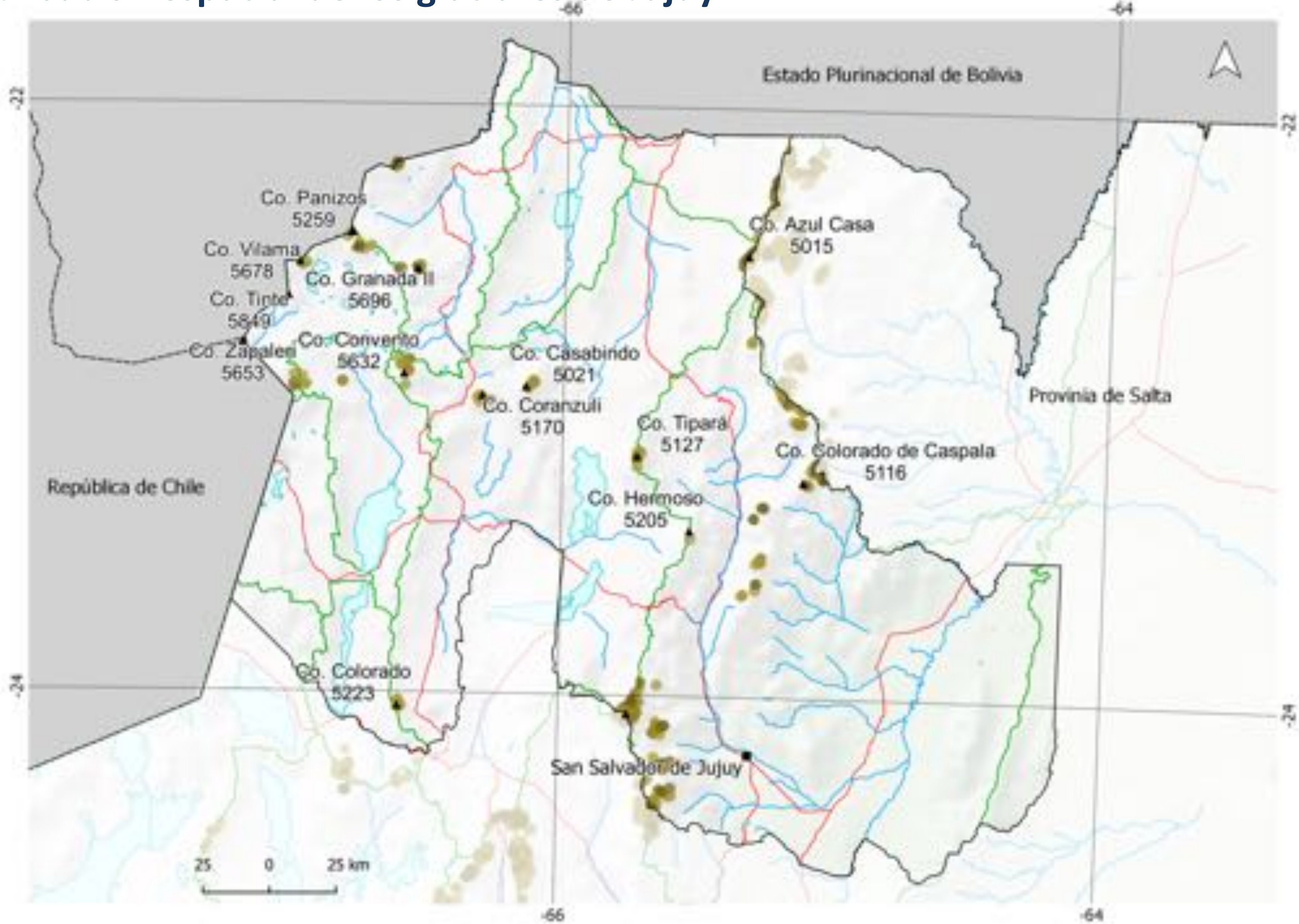
drwilliambowen@hotmail.com


REPÚBLICA PLURINACIONAL DE BOLIVIA
REPÚBLICA DE CHILE
San Salvador de Jujuy
Salta
San Miguel de Tucumán
Santiago del Estero
La Rioja
Cerro
Localidad
Límite internacional o provincial
Curso de agua
Ruta nacional
Cuerpo de agua
Límite de la región
Geoformas glaciares y periglaciales
Glaciar descubierto
Manchón de nieve
Glaciar cubierto
Glaciar cubierto con glaciar de escombros
Glaciar de escombros activo
Glaciar de escombros inactivo


0,3%
44,2%
55,5%
MN
GEA
GEI

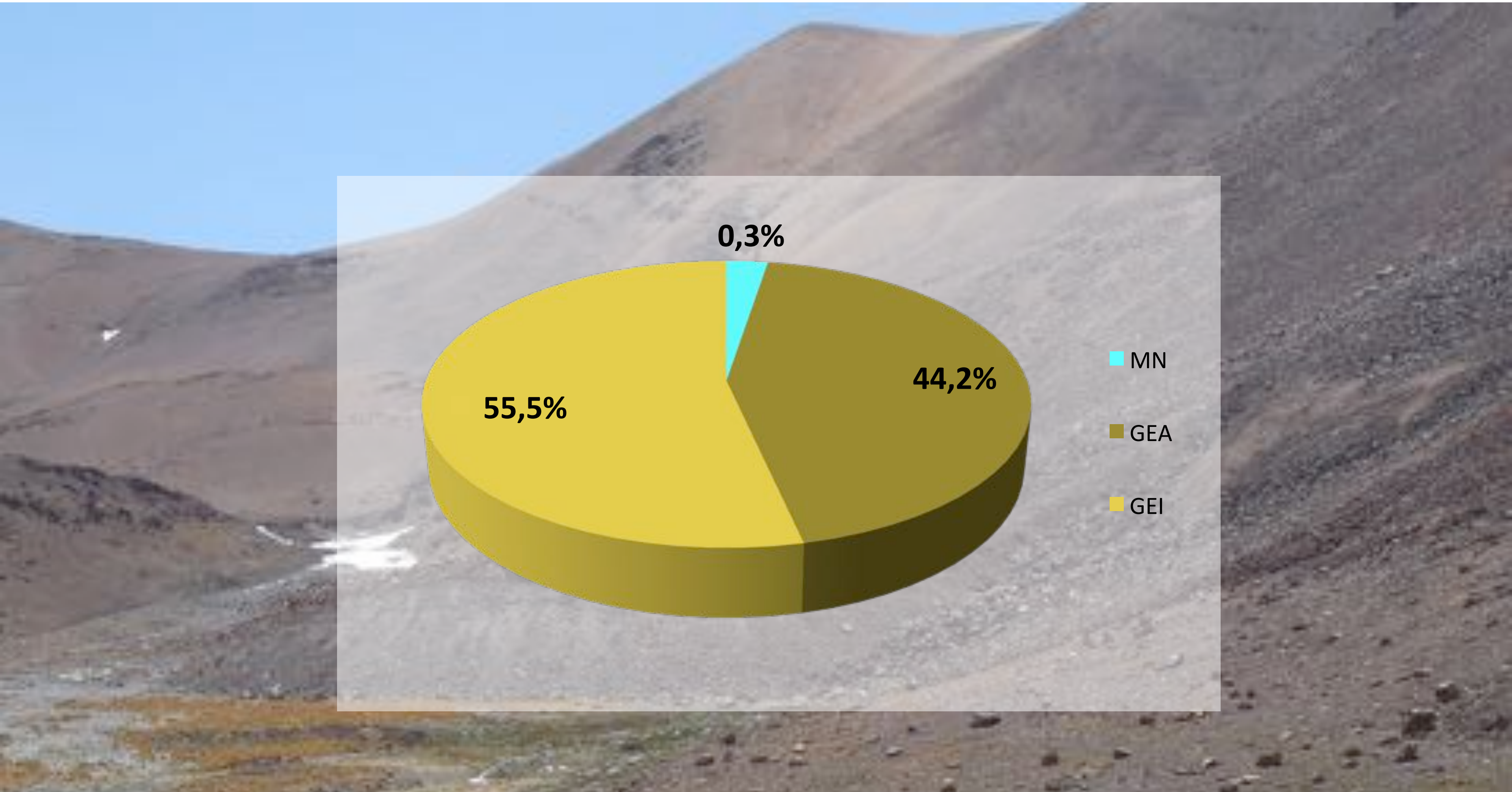
Distribución espacial de los glaciares de Jujuy



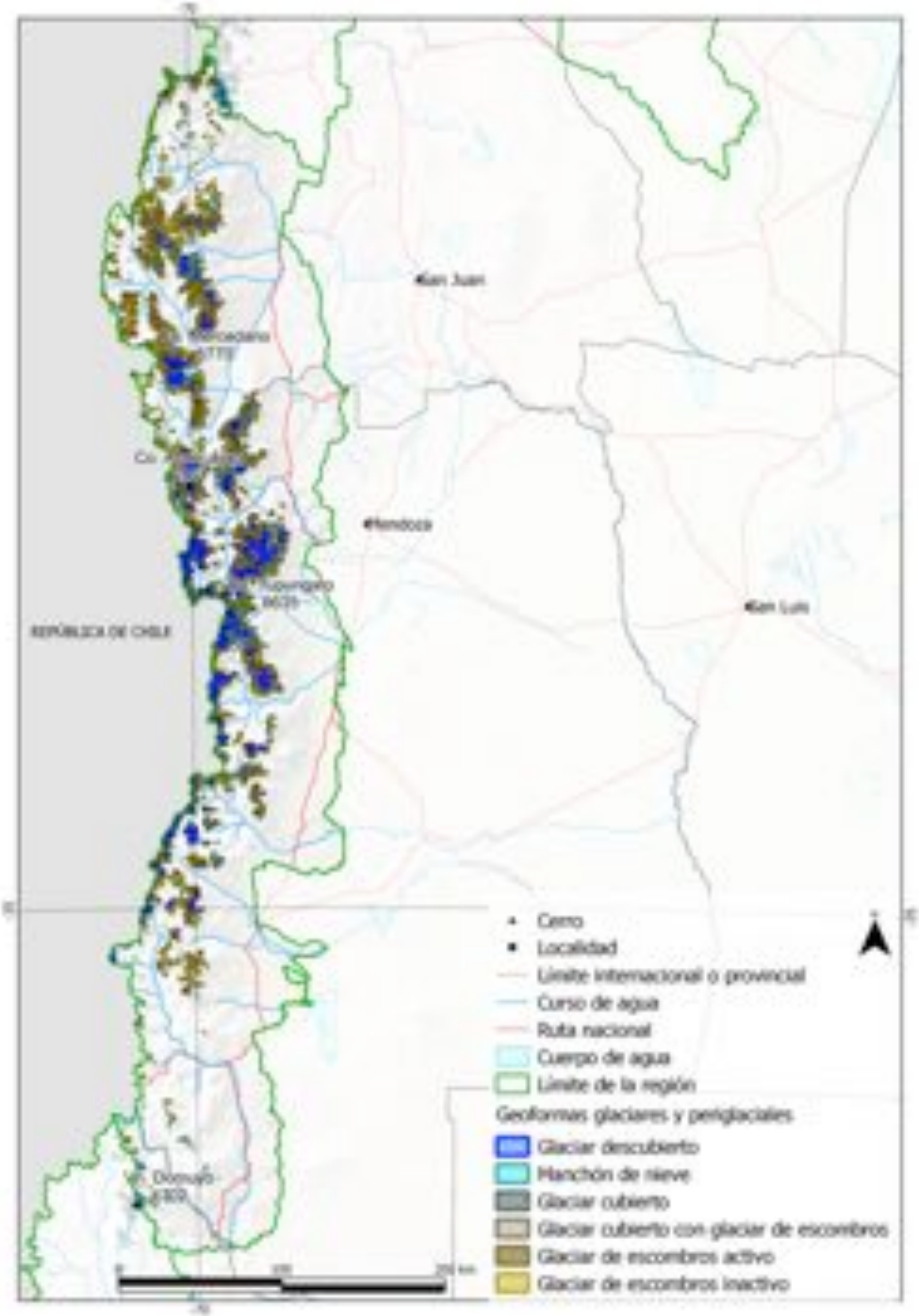
Los glaciares se distribuyen de una manera dispersa en la ladera de los cerros de mayor altura
Alcanzan una mayor densidad en el sector sur sobre la cordillera Oriental (Nevado de Chañi y Nevado General Güemes)

Resultados

Porcentaje de la superficie cubierta por tipo de glaciar a nivel provincial



Glaciar de escombros en la cuenca del río Pilcomayo


San Juan
Mendoza
San Luis
REPÚBLICA DE CHILE
Cerro
Localidad
Límite internacional o provincial
Curso de agua
Ruta nacional
Cuerpo de agua
Límite de la región
Geoformas glaciares y periglaciales
Glaciar descubierto
Manchón de nieve
Glaciar cubierto
Glaciar cubierto con glaciar de escombros
Glaciar de escombros activo
Glaciar de escombros inactivo




Glaciar de escombros Morenas Coloradas

D. Trombotto IANIGLA

The Cryosphere, 11, 877–890, 2017
www.the-cryosphere.net/11/877/2017/
doi:10.5194/tc-11-877-2017

The Cryosphere | EGU

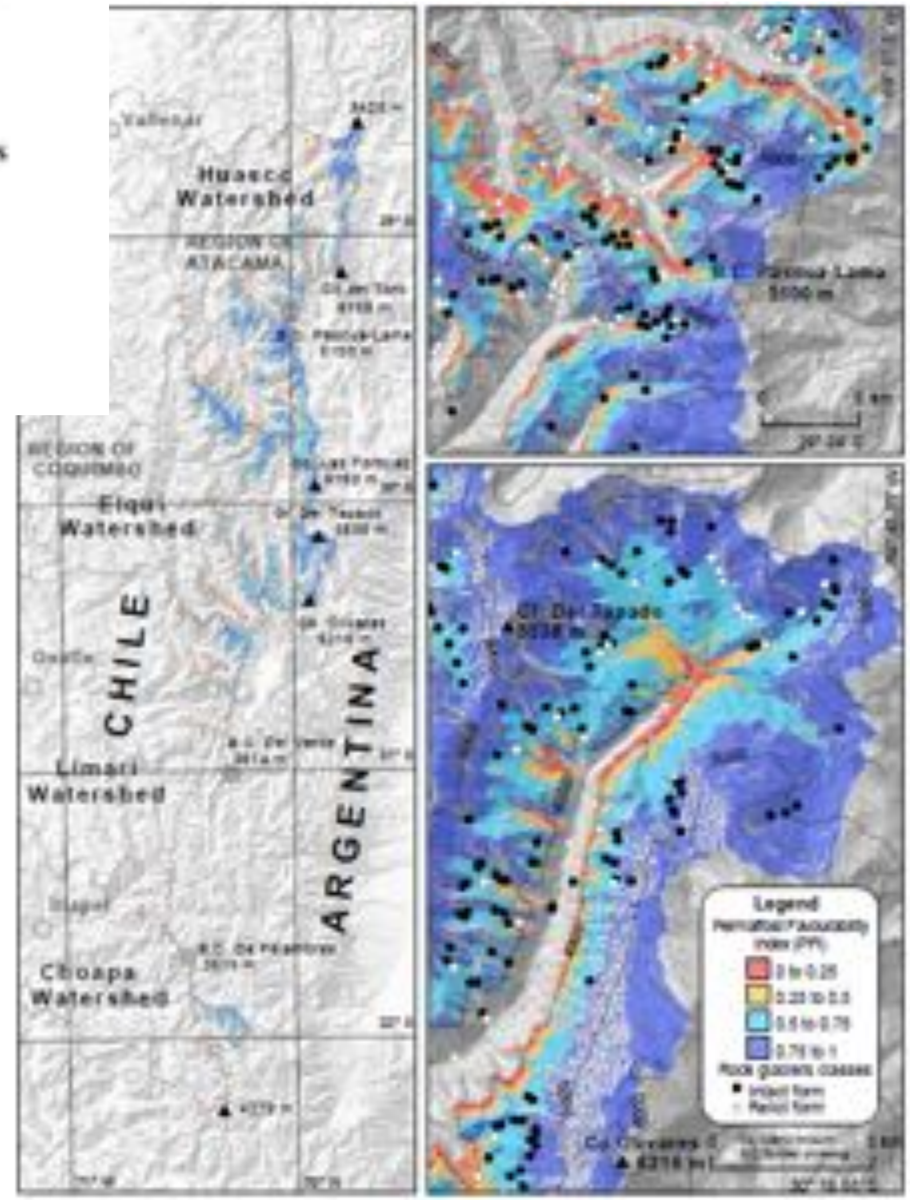
Permafrost distribution modelling in the semi-arid Chilean Andes

Guillermo F. Azócar[1], Alexander Brenning[1,2], and Xavier Bodin[3]

[1]Department of Geography and Environmental Management, University of Waterloo, Ontario, Canada
[2]Department of Geography, Friedrich Schiller University, Jena, Germany
[3]Laboratoire EDYTEM, Université de Savoie Mont Blanc, CNRS, Le Bourget-du-Lac, France

Correspondence to: Alexander Brenning (alexander.brenning@uni-jena.de)

Received: 25 April 2016 – Discussion started: 16 June 2016
Revised: 27 January 2017 – Accepted: 30 January 2017 – Published: 6 April 2017



High resolution remote sensing data + modeling now allows the detailed mapping of potential permafrost distribution

5. Knowledge gaps and future challenges

- Estimations of current glacier volumes
- Projections of future glacier changes
- Hydrological contribution of ice masses
- Highlight the urgent need for more in situ cryospheric measurements…
- …
- …

Is it OK to use boxes in the chapter?

¡Muchas gracias!