EARTH AND SPACE SCIENCES **Autumn 2018**

431A *PRINCIPLES OF GLACIOLOGY* 4 Credits, SLN 14855

505A *THE CRYOSPHERE* 4 Credits, SLN 14871

M-W-F, 1:30 - 2:50 pm. ***Room:*** JHN 127
Mon.-Wed.: Lectures, Fri: Lab/Discussion

Class web page: http://courses.washington.edu/ess431/

Instructor:
Knut Christianson
218 ATG Building
knut at uw.edu

T.A.:
Brita Horlings
208B ATG Building
brita2 at uw.edu

Additional Instructors: Warren, Conway, Hallet, Light, Roe, Waddington

Office Hours: Tu, Th 10-11 am, Drop in / By Appointment (Knut)

Required Text: *The Cryosphere* by S.J. Marshall

Optional books:
Glacial Geologic Processes by D.J. Drewry
Physics of Glaciers by K. Cuffey and W.S.B. Paterson
Glaciers of North America by S. Ferguson
Avalanche Handbook by D. McClung & P. Schaerer

Knut Christianson

Ice sheet grounding zone stabilization due to till compaction

Knut Christianson,[1,2] Byron R. Parizek,[3,4] Richard B. Alley,[4] Huw J. Horgan,[5] Robert W. Jacobel,[1] Sridhar Anandakrishnan,[4] Benjamin A. Keisling,[1,6] Brian D. Craig,[1] and Atsuhiro Muto[4]

Dynamic perennial firn aquifer on an Arctic glacier

Knut Christianson[1,2], Jack Kohler[3], Richard B. Alley[4], Christopher Nuth[5], and Ward J. J. van Pelt[3]

Dilatant till facilitates ice-stream flow in northeast Greenland

Knut Christianson[a,b,*], Leo E. Peters[c], Richard B. Alley[c], Sridhar Anandakrishnan[c], Robert W. Jacobel[b], Kiya L. Riverman[c], Atsuhiro Muto[c], Benjamin A. Keisling[d,b]

Basal conditions at the grounding zone of Whillans Ice Stream, West Antarctica, from ice-penetrating radar

Knut Christianson[1], Robert W. Jacobel[2], Huw J. Horgan[3], Richard B. Alley[4], Sridhar Anandakrishnan[4], David M. Holland[5], and Kevin J. DallaSanta[5]

Sensitivity of Pine Island Glacier to observed ocean forcing

Knut Christianson[1], Mitchell Bushuk[2,3], Pierre Dutrieux[4,5], Byron R. Parizek[6,7], Ian R. Joughin[4], Richard B. Alley[7], David E. Shean[1,4], E. Povl Abrahamsen[8], Sridhar Anandakrishnan[7], Karen J. Heywood[9], Tae-Wan Kim[10], Sang Hoon Lee[10], Keith Nicholls[8], Tim Stanton[11], Martin Truffer[12], Benjamin G. M. Webber[9], Adrian Jenkins[8], Stan Jacobs[5], Robert Bindschadler[13], and David M. Holland[2]

Subglacial Lake Whillans — Ice-penetrating radar and GPS observations of a shallow active reservoir beneath a West Antarctic ice stream

Knut Christianson[a,b,*], Robert W. Jacobel[a], Huw J. Horgan[c], Sridhar Anandakrishnan[b,d], Richard B. Alley[b,d]

2016

The Nature of Kinematic Waves in Glaciers and their Application to Understanding the Nisqually Glacier, Mt. Rainier, Washington

Brita Ilyse Horlings
Portland State University

Geophysical Research Abstracts
Vol. 19, EGU2017-6094, 2017
EGU General Assembly 2017

Identifying viscosities implicit in current firn-densification models: a step toward a physical-process-based constitutive relation for firn

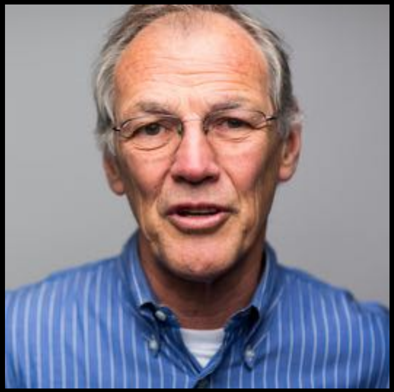
Brita I. Horlings, Edwin D. Waddington, and C. Max Stevens
Department of Earth and Space Sciences, University of Washington, Seattle, United States

Geophysical Research Abstracts
Vol. 19, EGU2017-5845-1, 2017
EGU General Assembly 2017

Evolution of air content in Greenland firn using the UW Community Firn Model

C. Max Stevens, Brita I. Horlings, Annika N. Horlings, Emma Kahle, Knut Christianson, Eric Steig, and Edwin Waddington
University of Washington, Earth and Space Sciences, Seattle, United States (edw@uw.edu)




Grade Breakdown - ESS 431:
[25%] – Problem Sets (out of class)
[30%] – Mid-term Exam
[30%] – Final Exam
[15%] – Participation (reading questions)

Grade Breakdown - ESS 505:
[25%] – Problem Sets (out of class)
[25%] – Midterm Exam
[25%] – Final Exam
[10%] – Term paper/project
[15%] – Participation (reading questions)

Late Work Policy:
Work for this class will typically be assigned with the following schedule:

1) Reading questions, due each day at the beginning of lecture
2) Lab assignments, completed in class each Friday
3) Problem sets, posted each Wednesday, due 1 week later

Reading questions can be submitted either in person or by email (in the event that you cannot be in class), but will not be accepted late. Reading assignments and labs will be graded as C/NC.

Problem sets will be graded based on the accuracy of your responses. They are due at the beginning of class, 1 week after assigned. If you feel you will not be able to complete the assignment on time, contact Knut or Brita more than 24 hours before the due date and we will accommodate you. Otherwise, late homework turned in within one week of the due date will be penalized by 10%, with additional penalties for further delay. You are encouraged to work together on solving the problems, but you are expected to write and turn in your own answers.

Missing Exam Policy:
Exams can only be made up under extraordinary circumstances, and only in the event that the instructor is notified more than 24 hours in advance of the exam.

Access and Accommodations:

Your experience in this class is important to me. If you have already established accommodations with Disability Resources for Students (DRS), please communicate your approved accommodations to me at your earliest convenience so we can discuss your needs in this course.

If you have not yet established services through DRS, but have a temporary health condition or permanent disability that requires accommodations (conditions include but not limited to; mental health, attention-related, learning, vision, hearing, physical or health impacts), you are welcome to contact DRS at:

011 Mary Gates Hall
uwdrs@uw.edu
206-543-8924 (Voice & Relay)
206-616-8379 (Fax)
disability.uw.edu.

DRS offers resources and coordinates reasonable accommodations for students with disabilities and/or temporary health conditions. Reasonable accommodations are established through an interactive process between you, your instructor(s) and DRS. It is the policy and practice of the University of Washington to create inclusive and accessible learning environments consistent with federal and state law.

Plagiarism and academic misconduct:

At the University level, passing anyone else's scholarly work (which can include written material, exam answers, graphics or other images, and even ideas) as your own, without proper attribution, is considered academic misconduct. Plagiarism, cheating, and other misconduct are serious violations of the University of Washington Student Conduct Code (WAC 478-120). We expect that you will know and follow the UW's policies on cheating and plagiarism. Any suspected cases of academic misconduct will be handled according to UW regulations. For more information, see the College of the Environment Academic Misconduct Policy and the UW Community Standards and Student Conduct website:

http://coenv.washington.edu/intranet/academics/academic-policies/academic-misconduct/.

Following a report of suspected misconduct, the instructor and/or T.A. will refer the matter to the College of the Environment's Dean's Office for review. A grade will not be assigned for the assignment or course until the investigation is concluded. If the student is found responsible for academic misconduct, a zero / no credit will be given for any assignments involving academic misconduct. All other course assignments will be evaluated and graded according to the expectations and grading method stated in the course syllabus. If the Dean's Office exonerates the student, the course instructor will reinstate the grade that the student would have received had the misconduct charge not been reported.

Course Structure:

Principles of Glaciology:

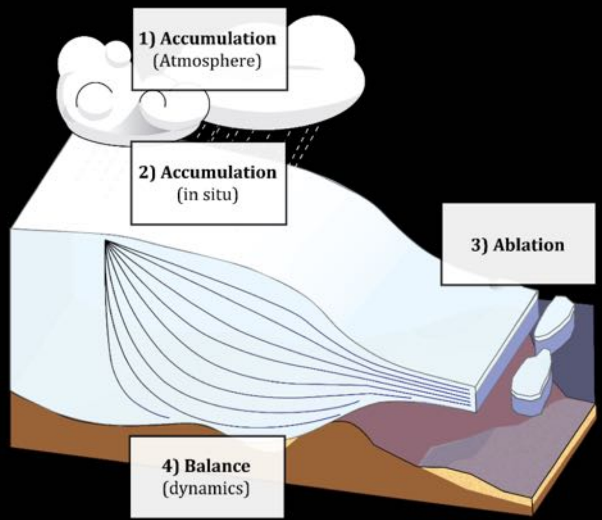
Unit 1 – Overview of the Cryosphere: what it is and how we observe it
Unit 2 – Ice formation and molecular structure/behavior
Unit 3 – Ice Dynamics
Unit 4 – Alpine and continental glacier systems

----- Midterm 1 ----- [Friday, November 9th 1:30-2:50 pm]

Special Topics in Glaciology:

Avalanches, Paleoclimate, Glacial Geology and Erosion, Sea Ice, Modern Change

----- Final Exam ----- [Monday, December 10th 2:30-4:20 pm]



https://courses.washington.edu/ess431/

Natural Occurrences of Ice: Distribution and environmental factors of seasonal snow, sea ice, glaciers and permafrost

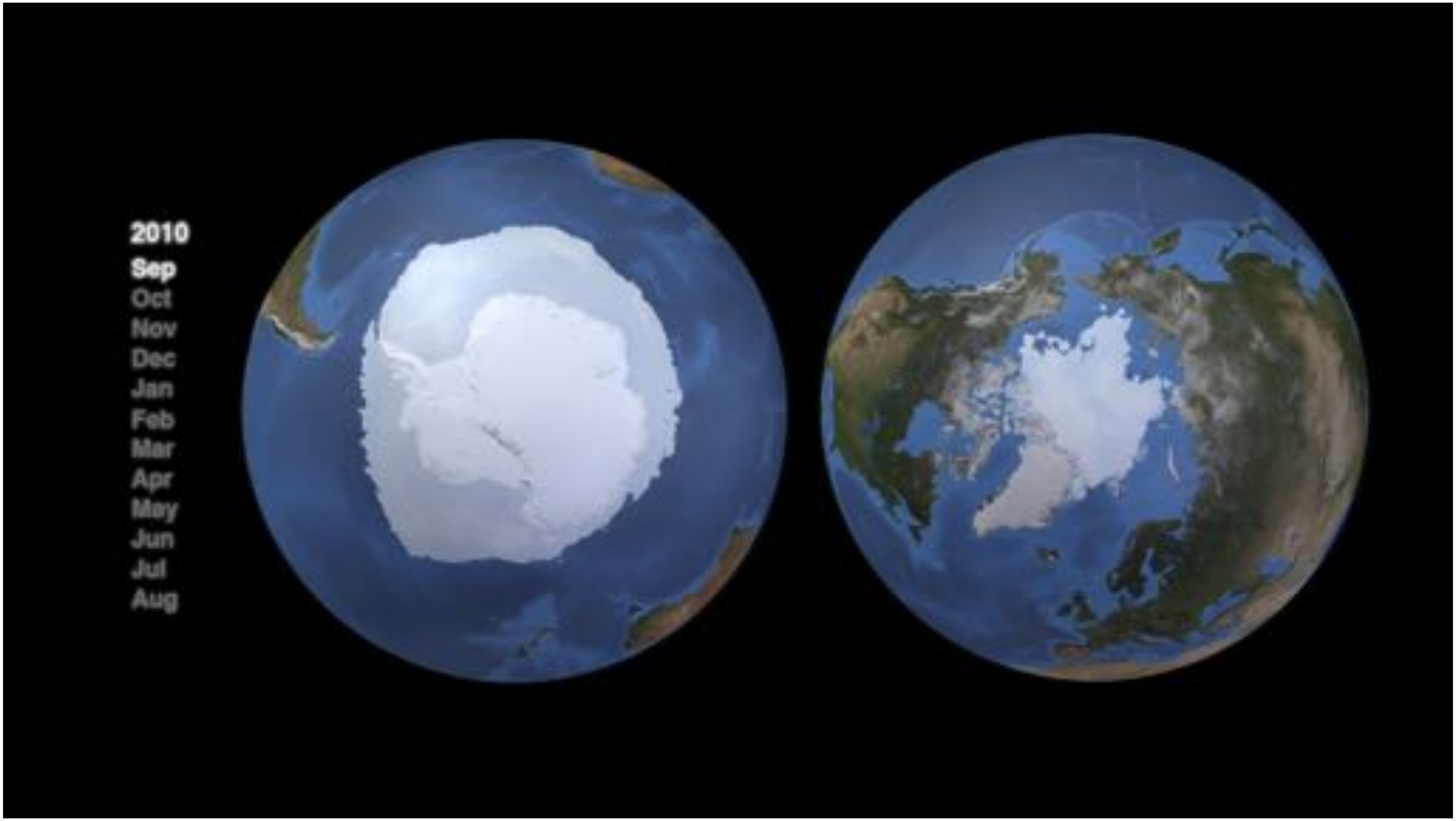
ESS431: Principles of Glaciology

ESS505: The Cryosphere

Wednesday, September 26, 2018 – Knut Christianson

Today's focus -

- What are the components of the cryosphere?
- What are their extents – in both time and space?
- How does society interact with the cryosphere?


2010
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug

The components of the cryosphere: *510 [145]*

Seasonal Snow

Mountain Glaciers

Permafrost

The Ice Sheets

Sea Ice

Areas Covered – 10^6 km^2

Earth Total: ~510 (145 is land)

The components of the cryosphere: *510 [145]*

Seasonal Snow

Mountain Glaciers

Permafrost

The Ice Sheets

Sea Ice

January – 2004

February – 2004

March – 2004

April – 2004

May – 2004

June – 2004

July – 2004

August – 2004

September – 2004

October – 2004

November – 2004

December – 2004

The components of the cryosphere: *510 [145]*

Seasonal Snow

45

Mountain Glaciers

Permafrost

The Ice Sheets

Sea Ice


Coastal Alaska


Continuous permafrost
>90% area coverage
Discontinuous/sporadic
10-90% coverage
Isolated patches

Yamal Crater, Siberia

The components of the cryosphere: *510 [145]*

Seasonal Snow

45

Permafrost

23 (0 – 1400m)

The Ice Sheets

Mountain Glaciers

Sea Ice

August – 2004

Alaskan Ice

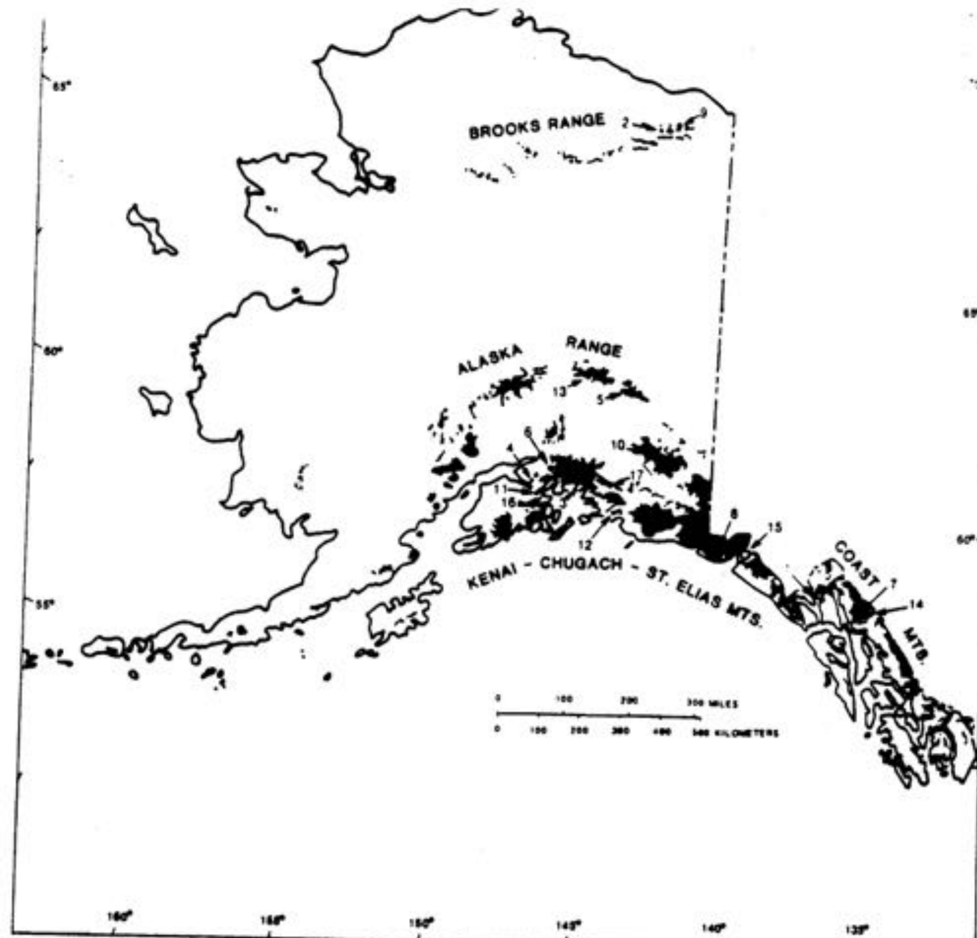
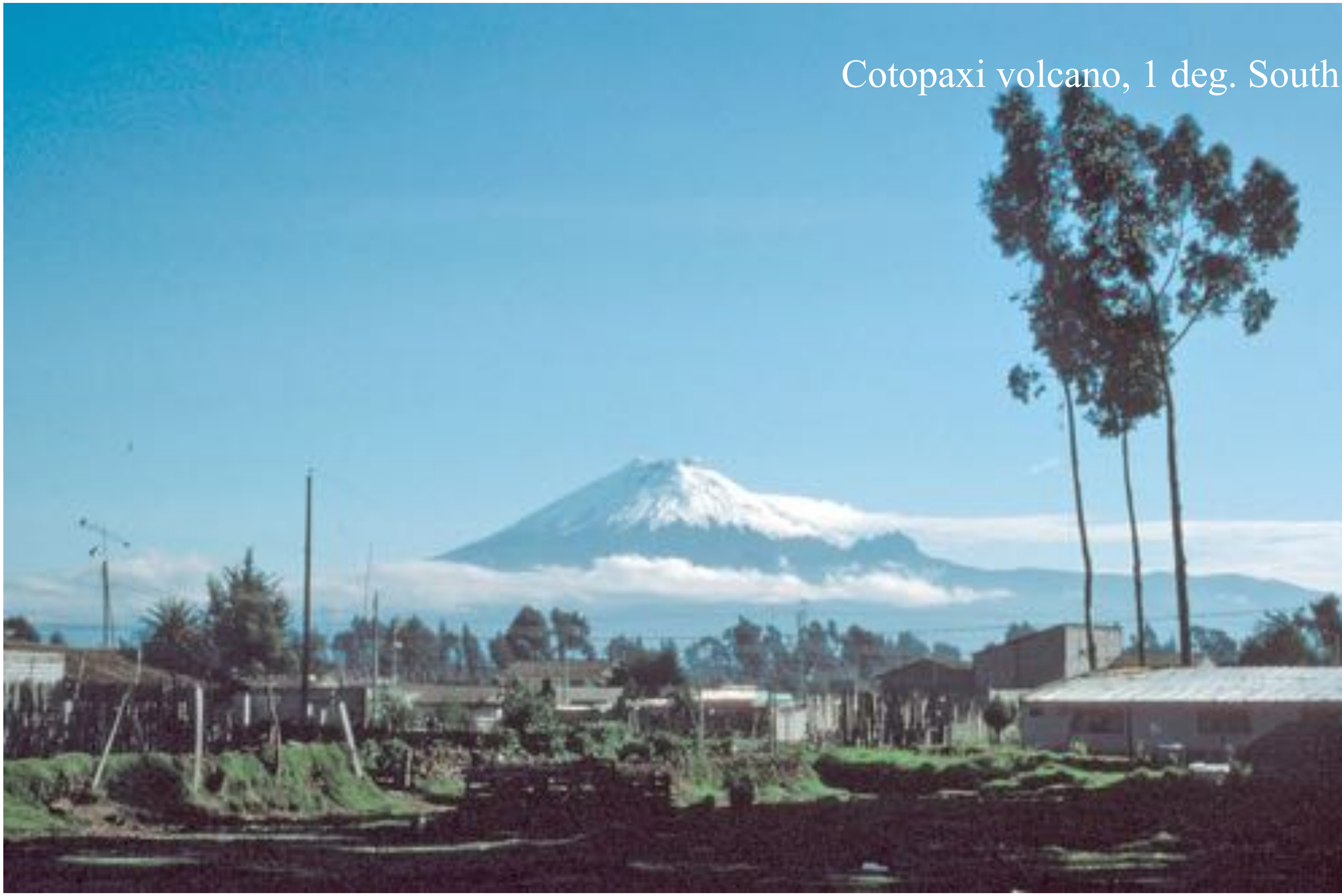


Fig. 1. Map showing locations of research glaciers in Alaska. Shaded areas are glaciers. Numbers refer to glaciers listed in Table 1.

Ice in Western USA

State	Total area of glaciers (km²)	Number of glaciers
Washington	450.5	3101
Wyoming	73.3	1477
Montana	68.6	1160
California	46.2	1788
Oregon	42.9	467
Colorado	4.8	141
Idaho	2.6	213
Nevada	0.1	1
Utah	<0.1	1*
Total	**689.1**	**8348**


Wheeler Peak, Nevada. September 2007



Cotopaxi volcano, 1 deg. South, Ecuador

Elevation 4800 m
on Cotopaxi volcano

At 2000 m on Blue Glacier, 48 N

Equatorial glaciers
of New Guinea

Hastenrath 2008

Photo 3.1.3. Irian Jaya, view to Southeast in 1936 (by J. Dozy, source Peterson Peterson, 1994).

Photo 3.1.4. Irian Jaya, view to Southeast in 1991 (source Peterson and Peterso

The components of the cryosphere: *510 [145]*

Seasonal Snow

45

Permafrost

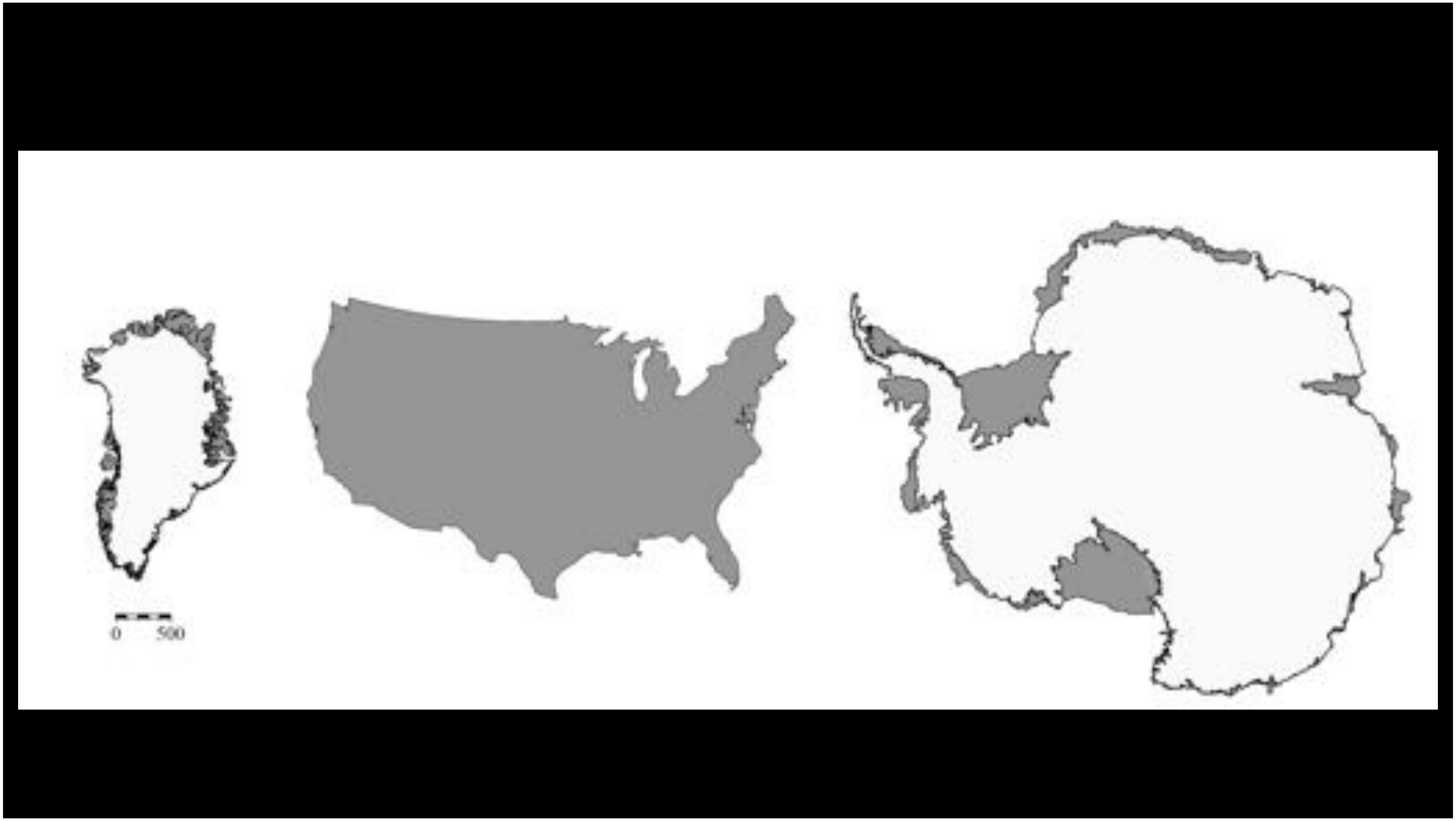
23 (0 – 1400m)

The Ice Sheets

Mountain Glaciers

1.1

Sea Ice


0
500

Depth of ice: average 1.5 km (max 3462m)

Mean annual temperature:

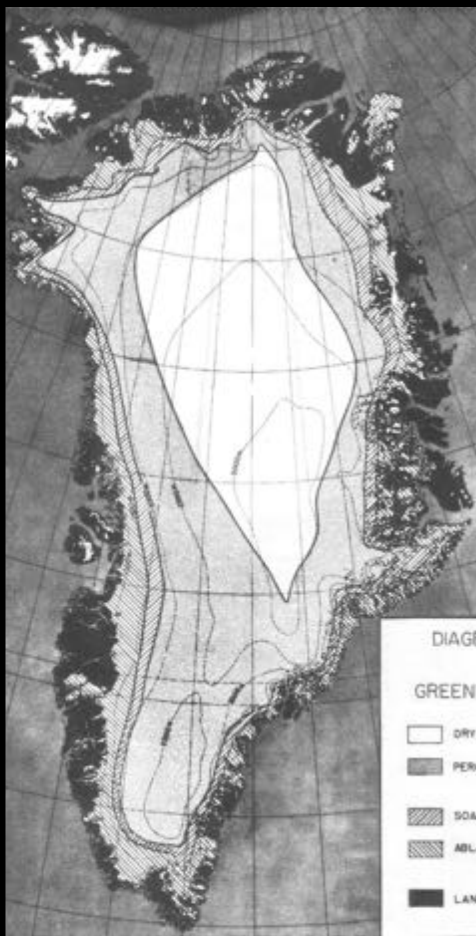
from -34°C (north-central)

to 0°C (southwest coast)

Snow accumulation

average 30 g $cm^{-2}yr^{-1}$

North-central 10 g $cm^{-2}yr^{-1}$



(Carl Benson, 1960).

As of 1960

Greenland is 18% dry land, 82% ice-covered.

Of the ice sheet area:

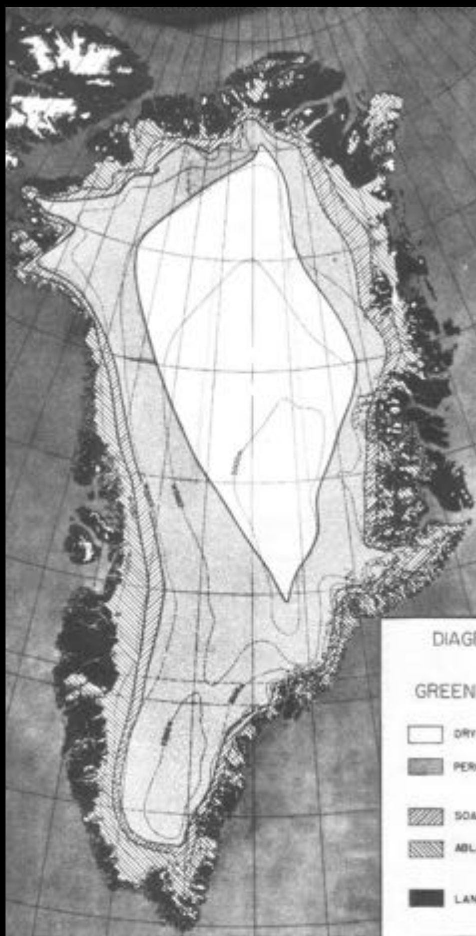
30% is *dry snow* (no melting)

55% is *wet snow* (some of the winter snow melts in summer, but not all)

- Percolation zone
- Wet-snow zone
- Slush zone

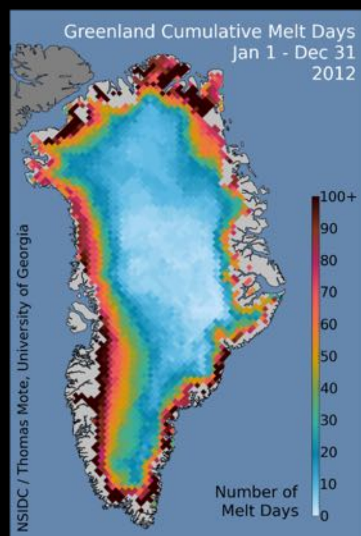
15% is the Ablation zone ("ablation" meaning "net loss": all the winter snow melts in summer, and some ice as well).

So some melting occurs on 70% of the ice sheet.



(Carl Benson, 1960).

As of 1960



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Meltwater streams on northeast Greenland in August


Ice Cliffs in Greenland: Helheim Glacier

Depth of ice: average 2.2 km, maximum 4.8 km

About 86% of the ice is in East Antarctica

Mean annual temperature

from -60°C on East Antarctic Plateau

(Vostok, Dome C, Plateau Station)

to -3°C on Antarctic Peninsula

Snow accumulation

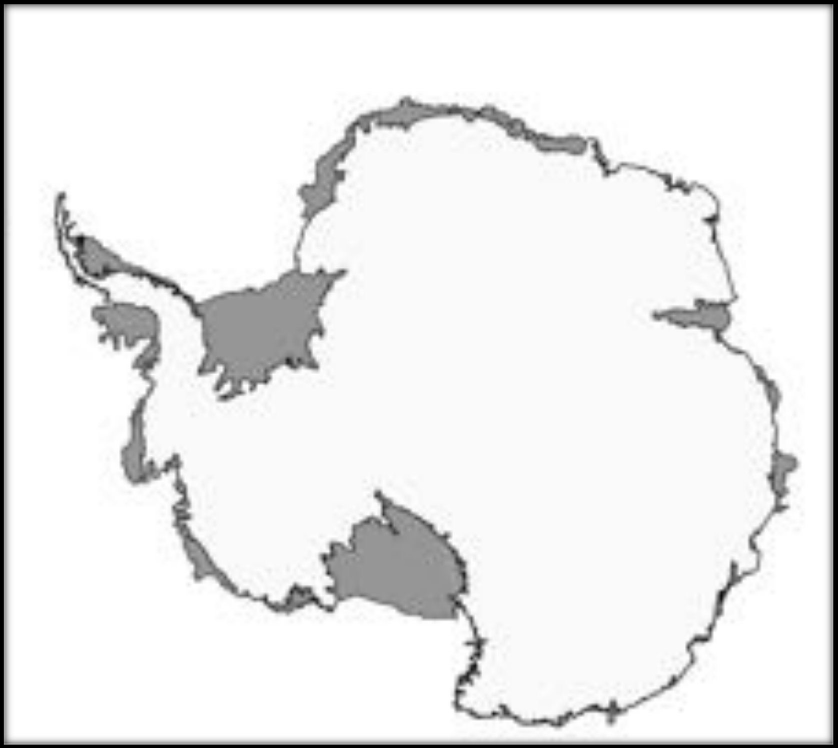
average 14-19 g cm^{-2} yr^{-1}

on Plateau 5 g cm^{-2} yr^{-1}

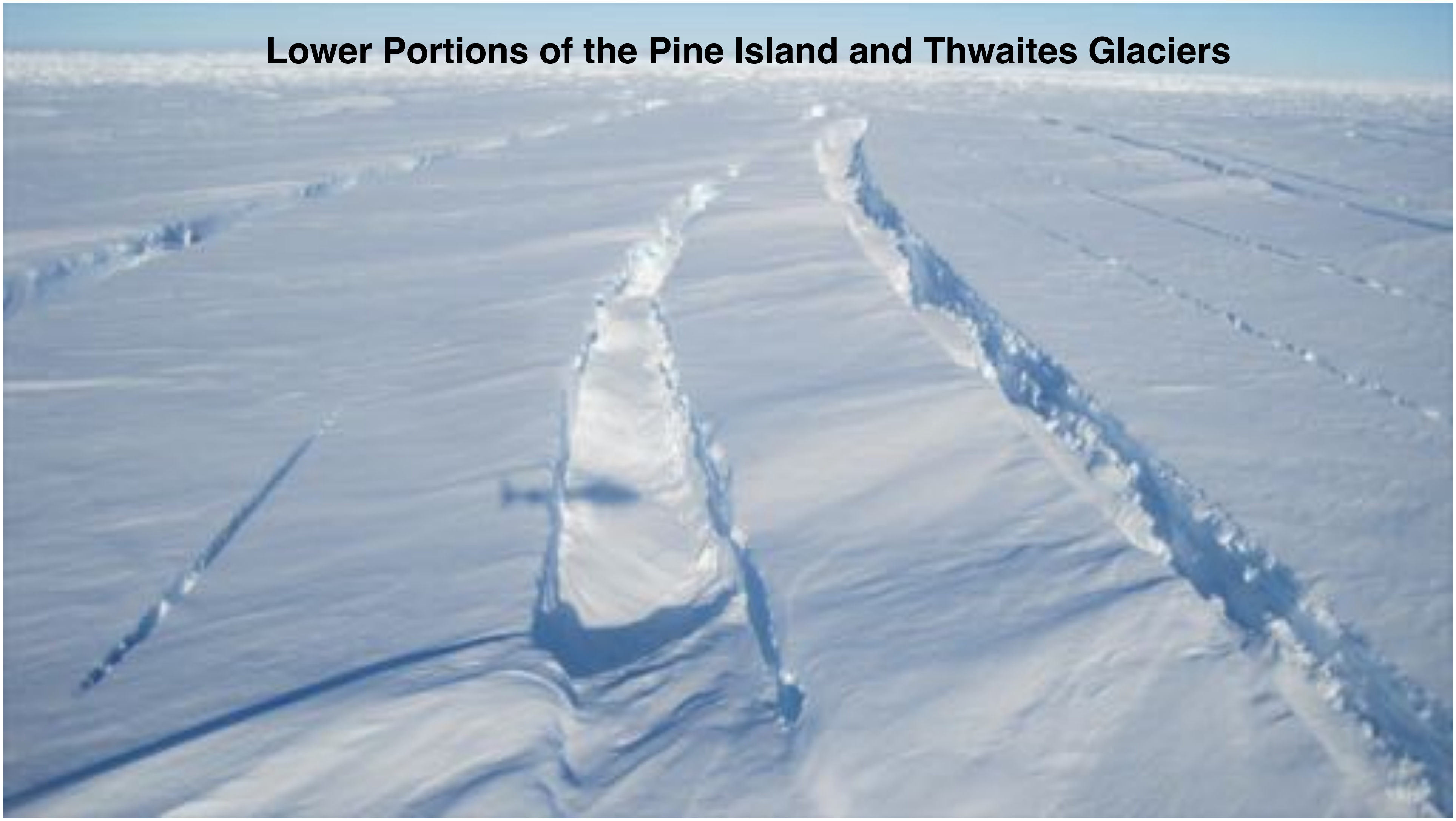
Temperature extremes at surface

World record low temperature: -89°C (at Vostok)

Record high temperature at South Pole: -14°C

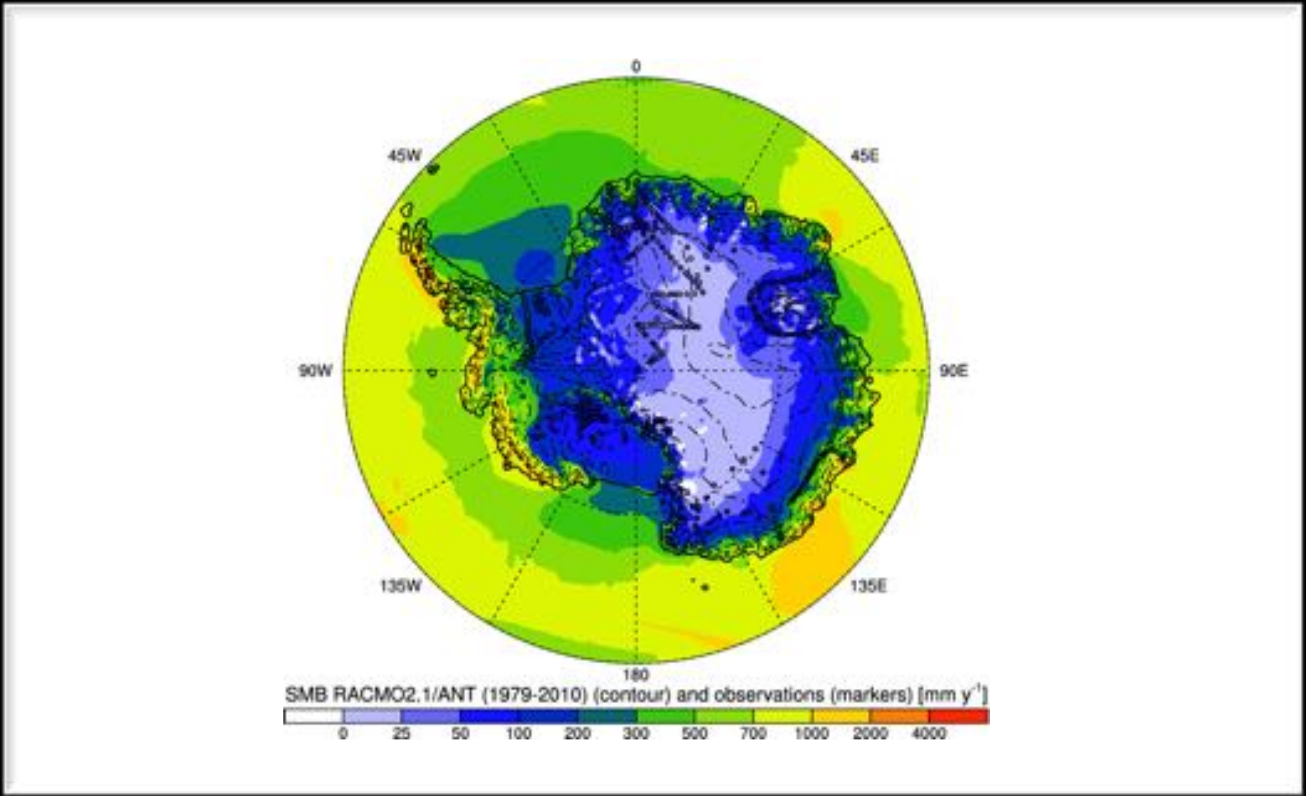


Lower Portions of the Pine Island and Thwaites Glaciers

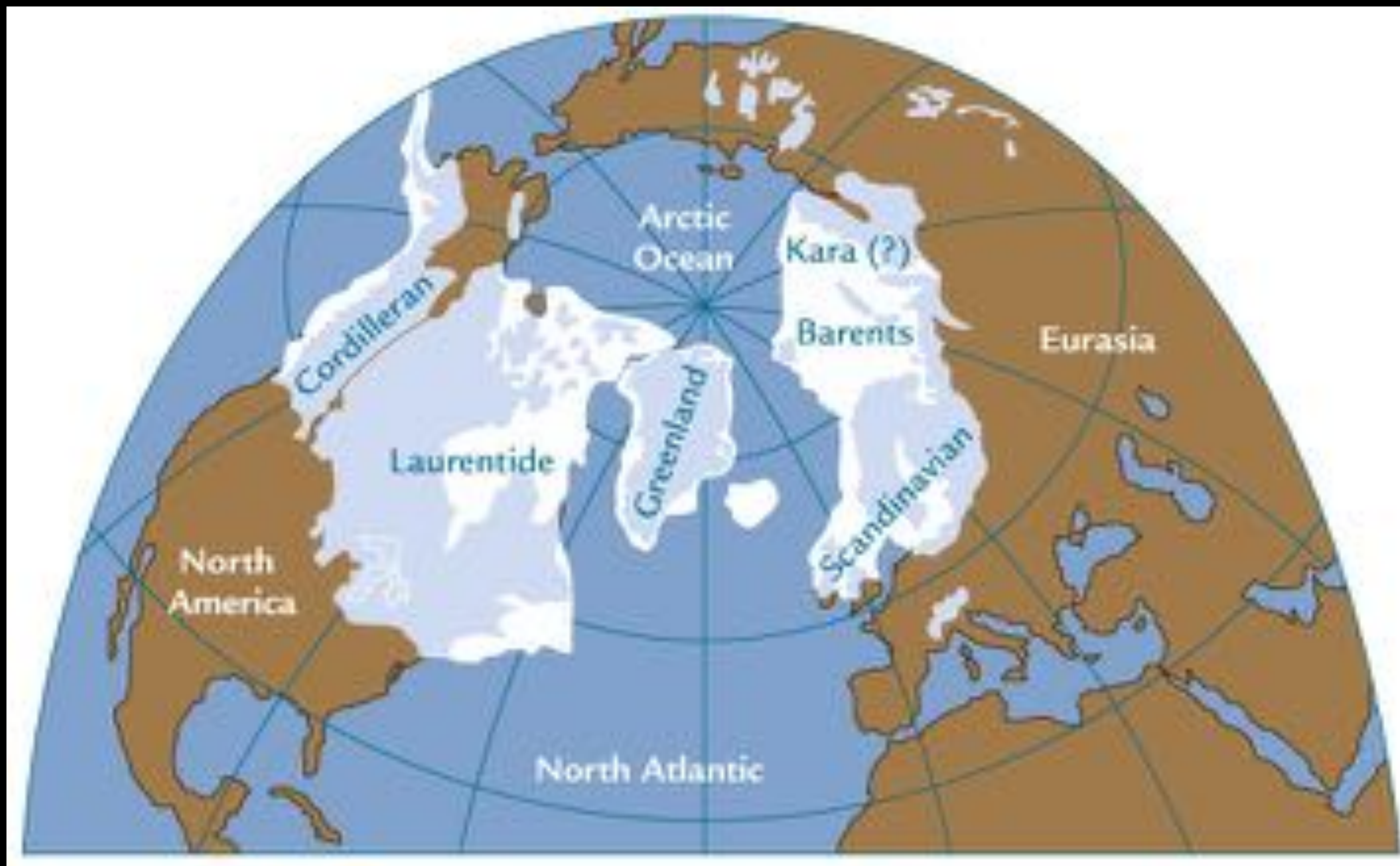



Snow surface of East Antarctic Plateau (Dome C)

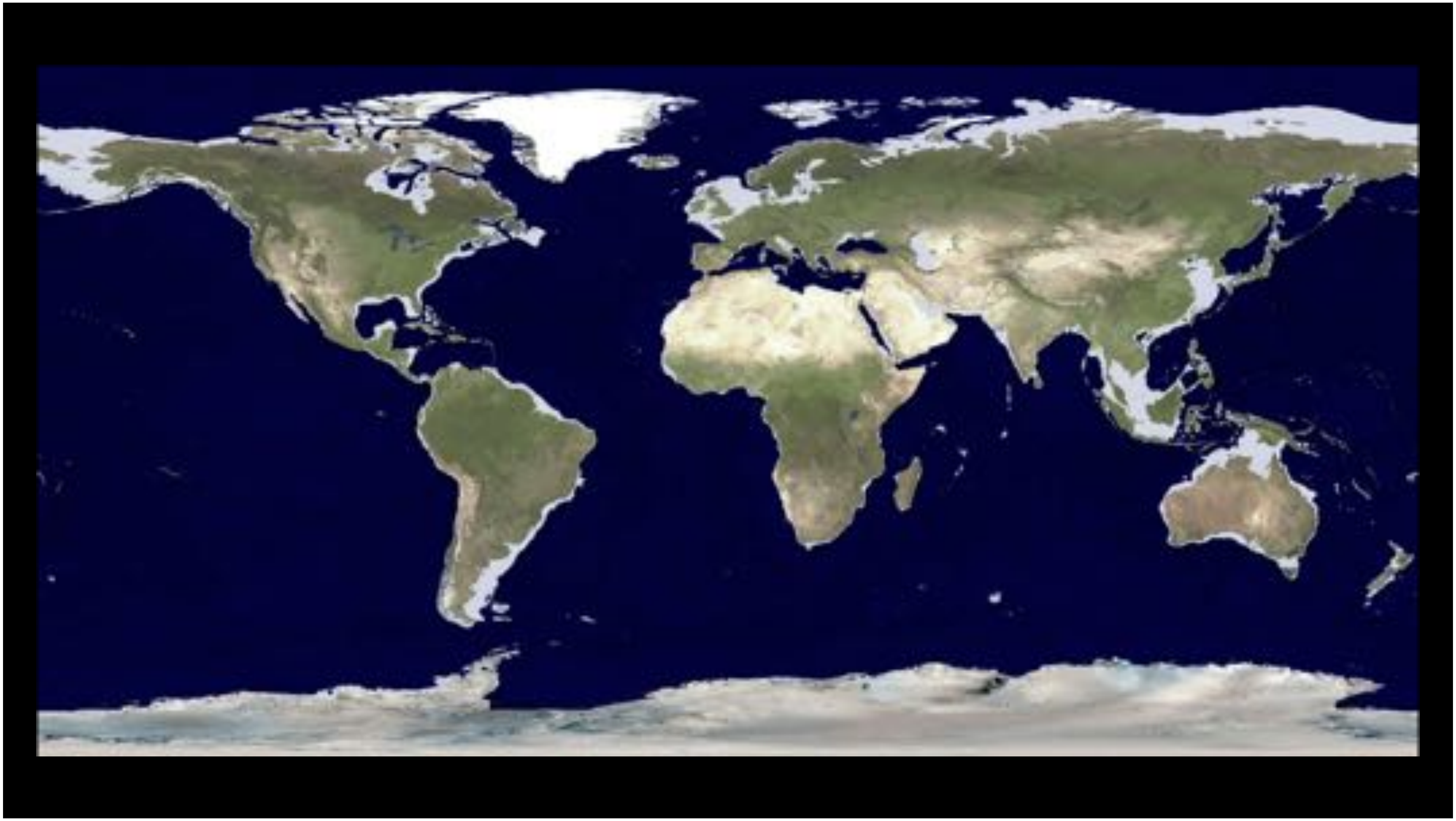
A new, high-resolution surface mass balance map of Antarctica (1979–2010) based on regional atmospheric climate modeling



Geophysical Research Letters
Volume 39, Issue 4, L04501, 21 FEB 2012 DOI: 10.1029/2011GL050713
http://onlinelibrary.wiley.com/doi/10.1029/2011GL050713/full#grl28948-fig-0001


Arctic
Ocean
Kara (?)
Cordilleran
Barents
Eurasia
Greenland
Laurentide
Scandinavian
North
America
North Atlantic


RETREAT OF WISCONSIN AND RECENT ICE
IN NORTH AMERICA
QUEBEC
ONTARIO



Glacier contrasts

Latitude vs Altitude

	Latitude of terminus	Terminus elevation	Annual precipitation
Antarctic Ice Sheet	66 S	0	17 cm
Blue Glacier WA	48 N	1300 m	500 cm
Cotopaxi	1 S	4800 m	500 cm

Glacier contrasts

Residence times of water

	Ice thickness *H*	Accumulation rate *b*	Residence time *t=H/b*
Blue Glacier WA:	100 m	5 m yr^{-1}	20 yr
Greenland summit :	3000 m	0.3 m yr^{-1}	10,000 yr

The components of the cryosphere: *510 [145]*

Seasonal Snow

45

Mountain Glaciers

1.1

Permafrost

23 (0 – 1400m)

The Ice Sheets

Antarctica – 13.3 (2160m)
Greenland – 1.7 (1500m)

Sea Ice


Nilas

[CRYOLIST] POLAR2018: Snow on sea ice Inbox x PSU Mail x PSU Mail/Cryolist x

Stefan Kern <stefan.kern@uni-hamburg.de> 8:05 AM (36 minutes ago)

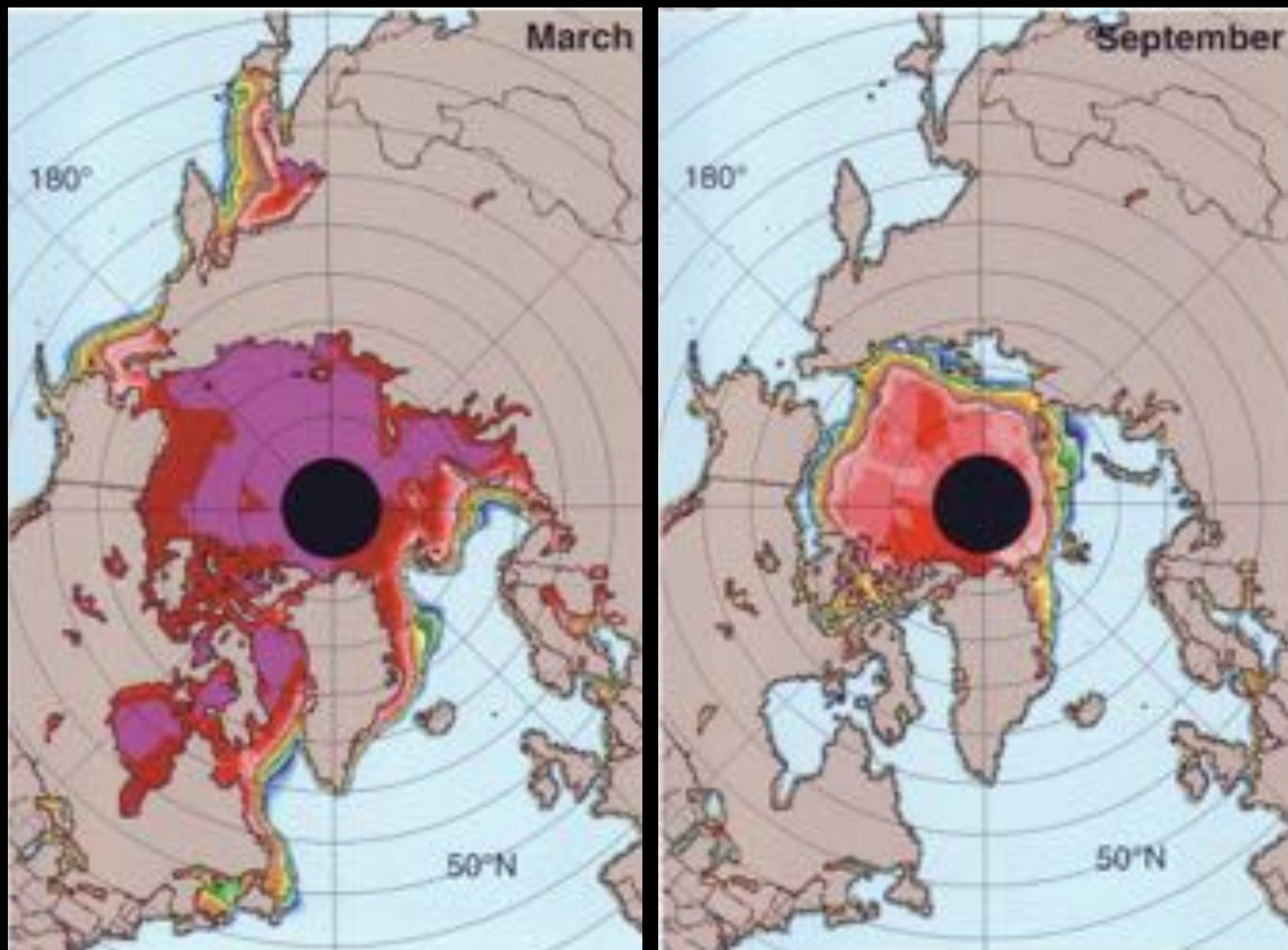
to cryolist

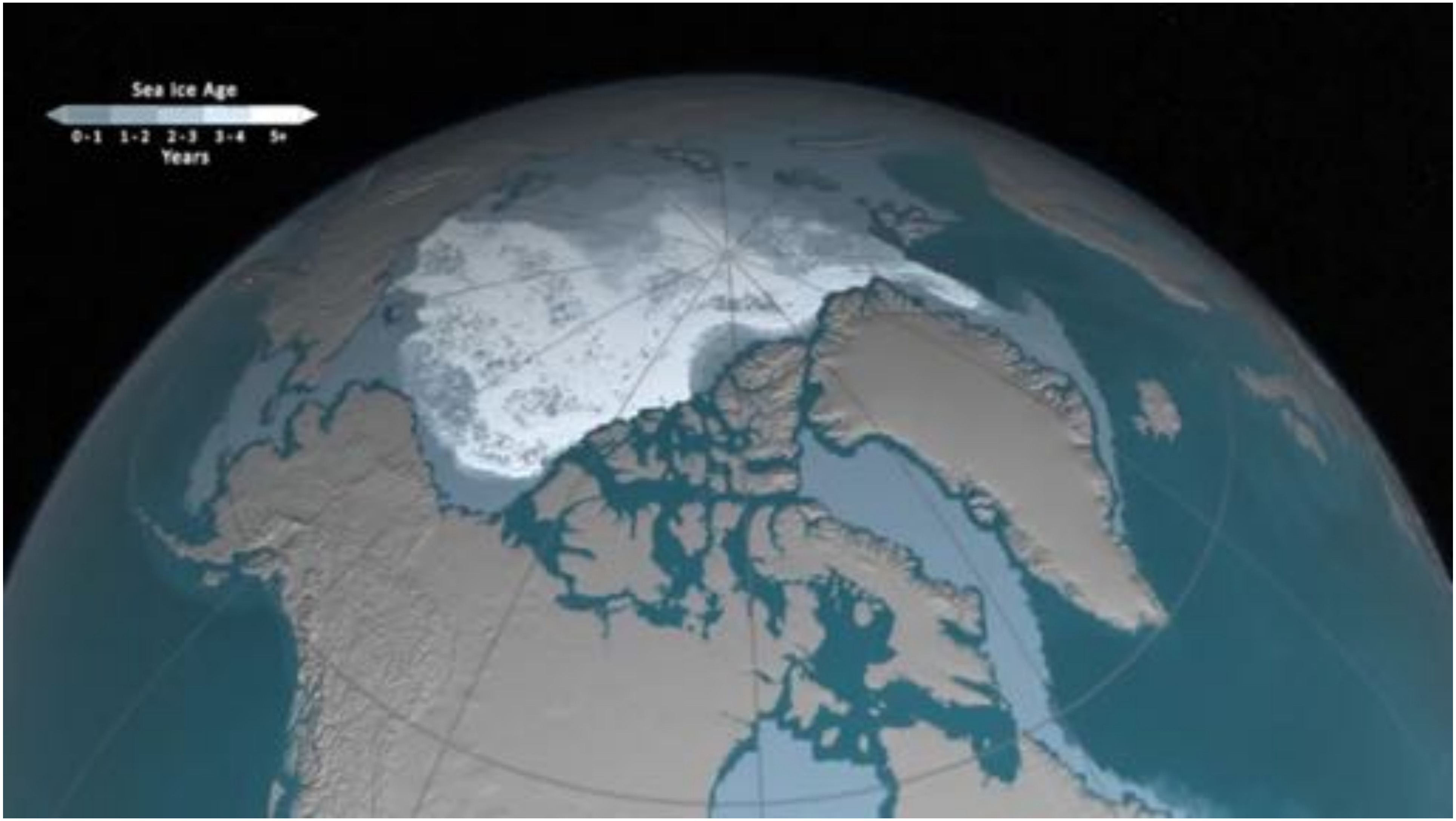
Dear colleagues,

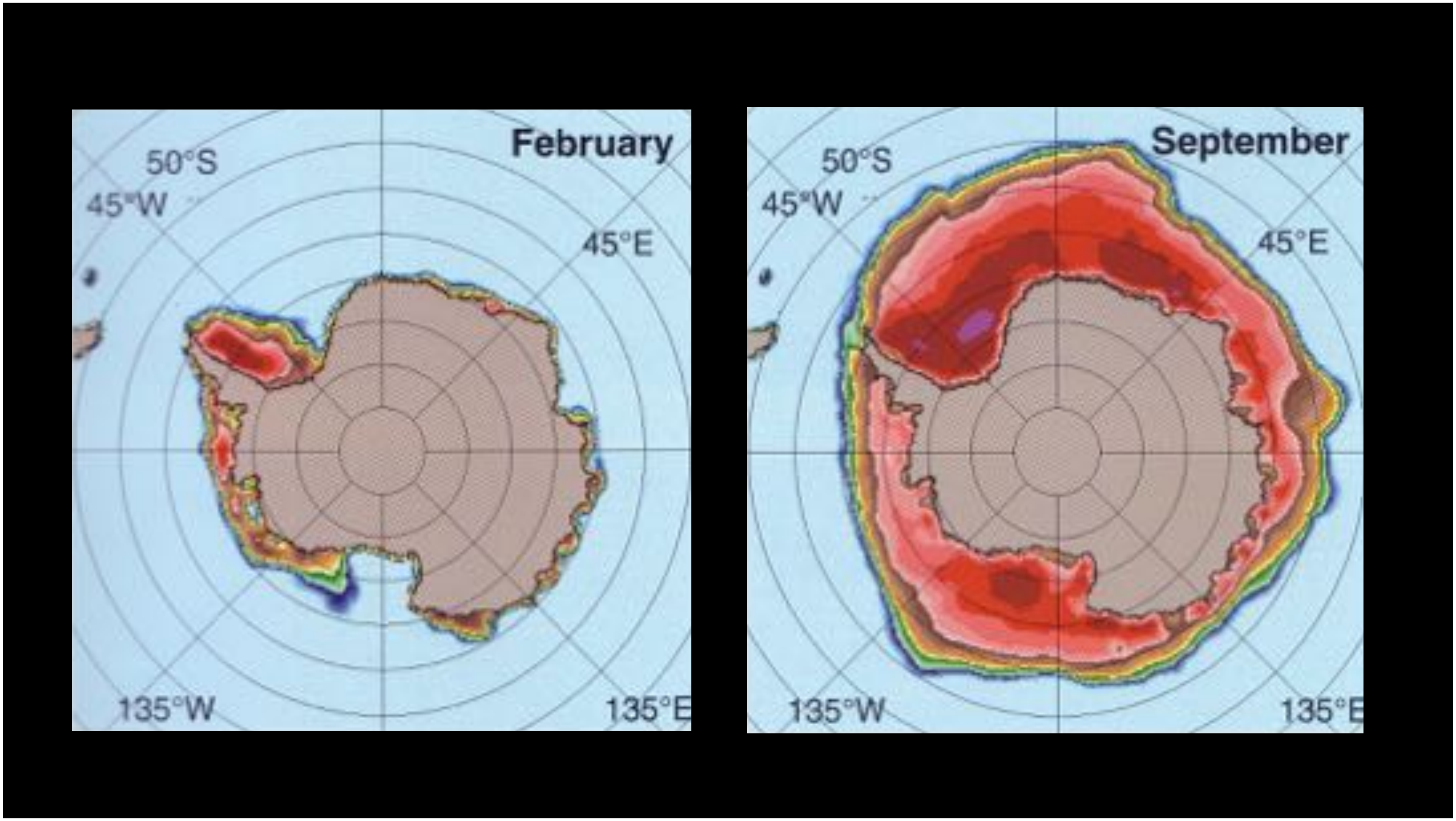
POLAR2018 is a joint event from the Scientific Committee on Antarctic Research SCAR and the International Arctic Science Committee IASC, which will take place in, Switzerland from 15 - 26 June 2018 with the open science conference from 19 - 23 June; see http://www.polar2018.org for general information.

We would like to draw your kind attention to the conference session entitled "The role of snow on sea ice for sea-ice parameter retrieval and variability". Please join us to find out answers to questions like:
"How well do we know snow on sea ice?"
"How well do we understand the role snow on sea ice has for the observed variability in sea-ice cover and thickness in both Polar Regions?"

Brown color is algae in brine-pockets


March
180°
50°N
September
180°
50°N


Sea Ice Age
0-1 1-2 2-3 3-4 5+
Years


February
50°S
45°W
45°E
135°W
135°E
September
50°S
45°W
45°E
135°W
135°E

The components of the cryosphere: *510 [145]*

Seasonal Snow

45

Permafrost

23 (0 – 1400m)

Mountain Glaciers

1.1

The Ice Sheets

Antarctica – 13.3 (2160m)
Greenland – 1.7 (1500m)

Sea Ice

Arctic – 8.4 / 15 (1-3m)
Antarctic – 3.0 / 19 (1-2m)

(in 2012, Arctic was 3.4!)

The components of the cryosphere:

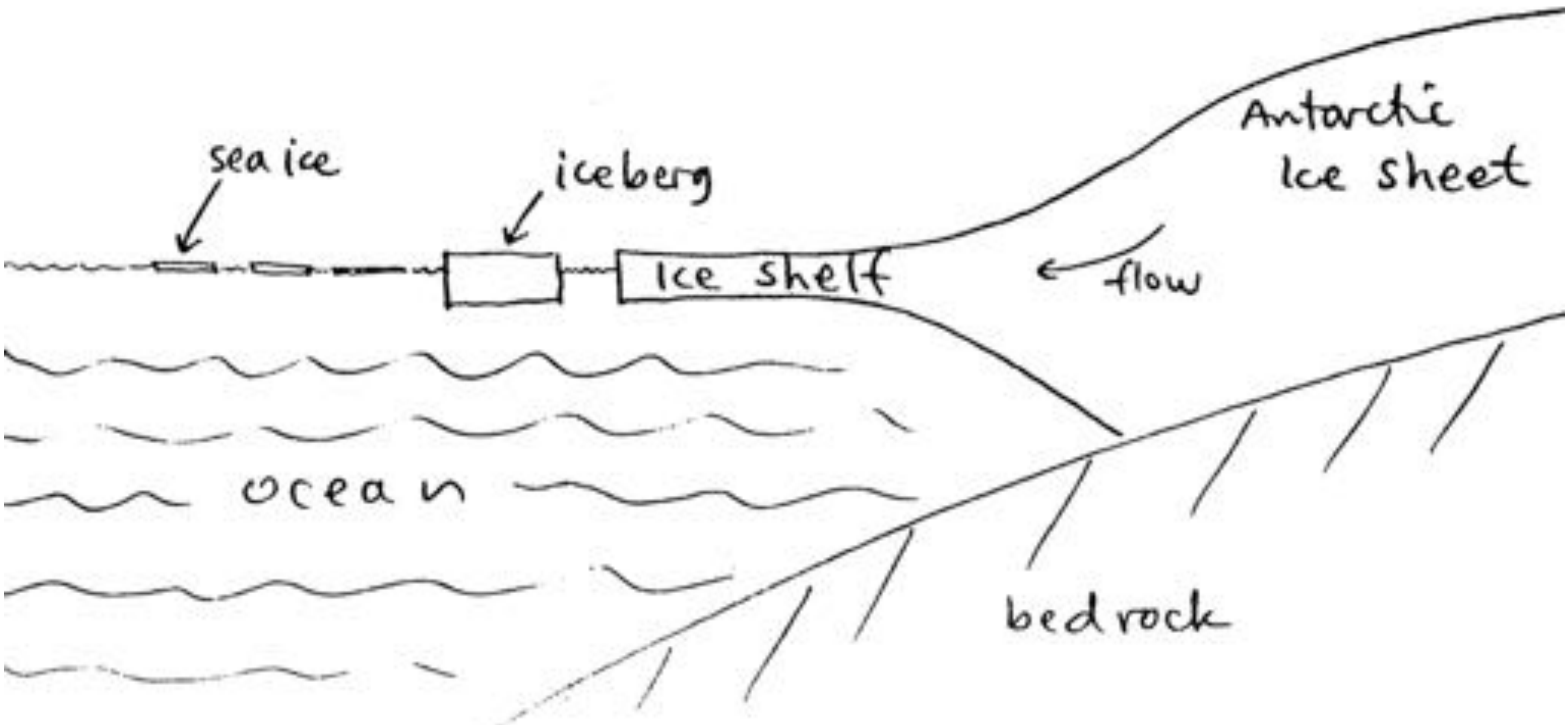
	Coverage Area	Reservoir Size (m sle)
Permafrost	23	0.1
The Ice Sheets		
Antarctica	13.3	56
Greenland	1.7	7
Mountain Glaciers	1.1	0.8
Sea Ice		
Arctic	8.4 / 15	
Antarctic	3.0 / 19	
Seasonal Snow	45	

The components of the cryosphere:

	Coverage Area	Reservoir Size (m sle)
Permafrost	23	0.1
The Ice Sheets		
Antarctica	13.3	56
Greenland	1.7	7
Mountain Glaciers	1.1	0.8
Sea Ice		
Arctic	8.4 / 15	
Antarctic	3.0 / 19	
Seasonal Snow	45	

Average Ocean Depth:
~3500m

All ice on earth ~ 2%



sea ice
iceberg
Antarctic
Ice sheet
Ice shelf
flow
ocean
bedrock

The components of the cryosphere:

Seasonal Snow

Mountain Glaciers

Permafrost

The Ice Sheets

Sea Ice

The components of the cryosphere:

Seasonal Snow

- Recreation / Hazard / Seasonal Water

Permafrost

- Engineering Challenge / Carbon Sink

The Ice Sheets

- Eustatic sea level rise
- Albedo feedback
- Orographic effects on atmosphere
- Freshwater injection into the oceans
- Relative sea level changes

Mountain Glaciers

- Short term sea-level rise
- Seasonal water storage
- Record regional climate (if you can account for internal dynamics)

Sea Ice

- Change momentum balance of the ocean / atmosphere system
- Control shipping and navigation in the Northern Hemisphere
- Ecosystem (and native) significance