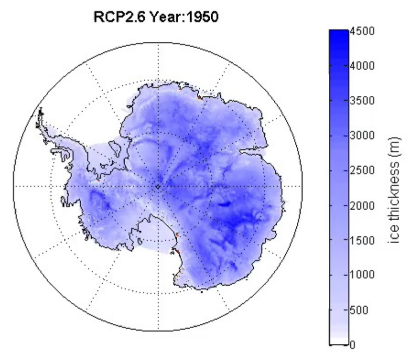
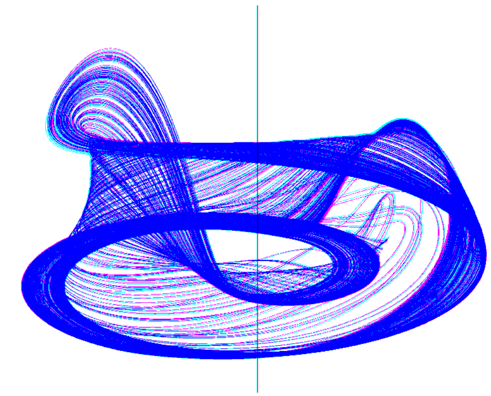
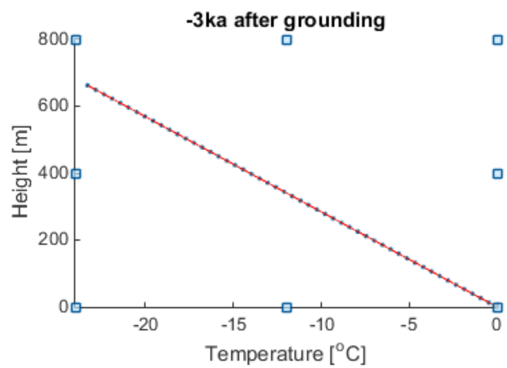
Glaciology
EESCGU4220

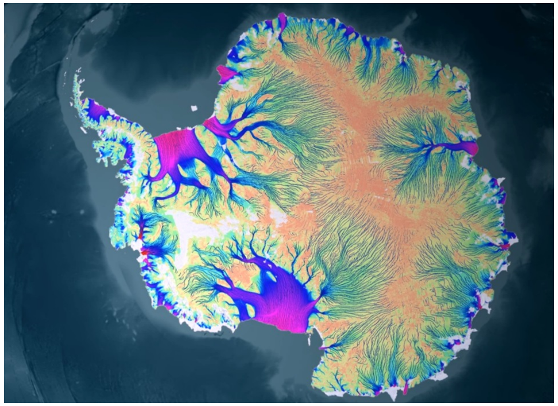
3 credits
Spring 2023

Instructor:
Jonny Kingslake









Glaciology
EESCGU4220

3 credits
Spring 2023

Class sessions
Tuesdays: 1:10 pm ET
Thursdays: 1:10 pm ET

Instructor:

Jonny Kingslake

Office hours
When works best for you?

Lecture 1: Introduction to Glaciers and Ice Sheets

- Introductions
- The course
  - Grading
  - Assignments
  - Expectations
  - Textbooks
- Glaciers and ice sheets
- Overview of course topics

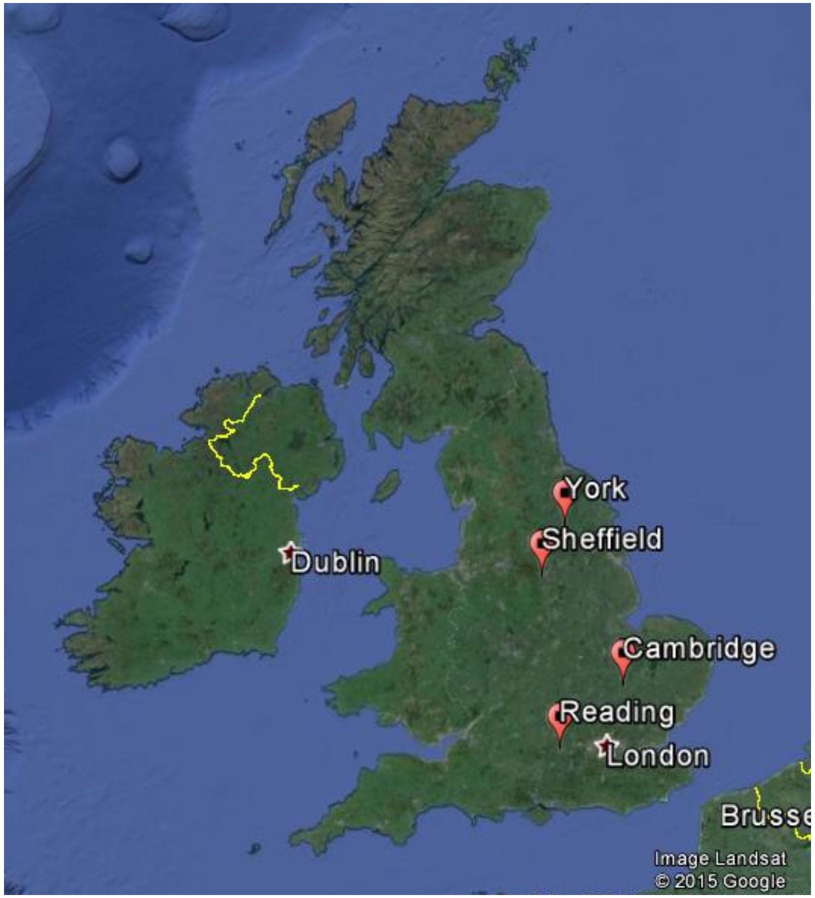
Bio

Undergraduate degree in **physics**,
The University of York.

PhD in **mathematical glaciology,**
The University of Sheffield:
'Modelling ice-dammed lake drainage'.

Glacier geophysicist
British Antarctic Survey, Cambridge.

Assistant/Associate Professor
Lamont-Doherty Earth Observatory,
Columbia University



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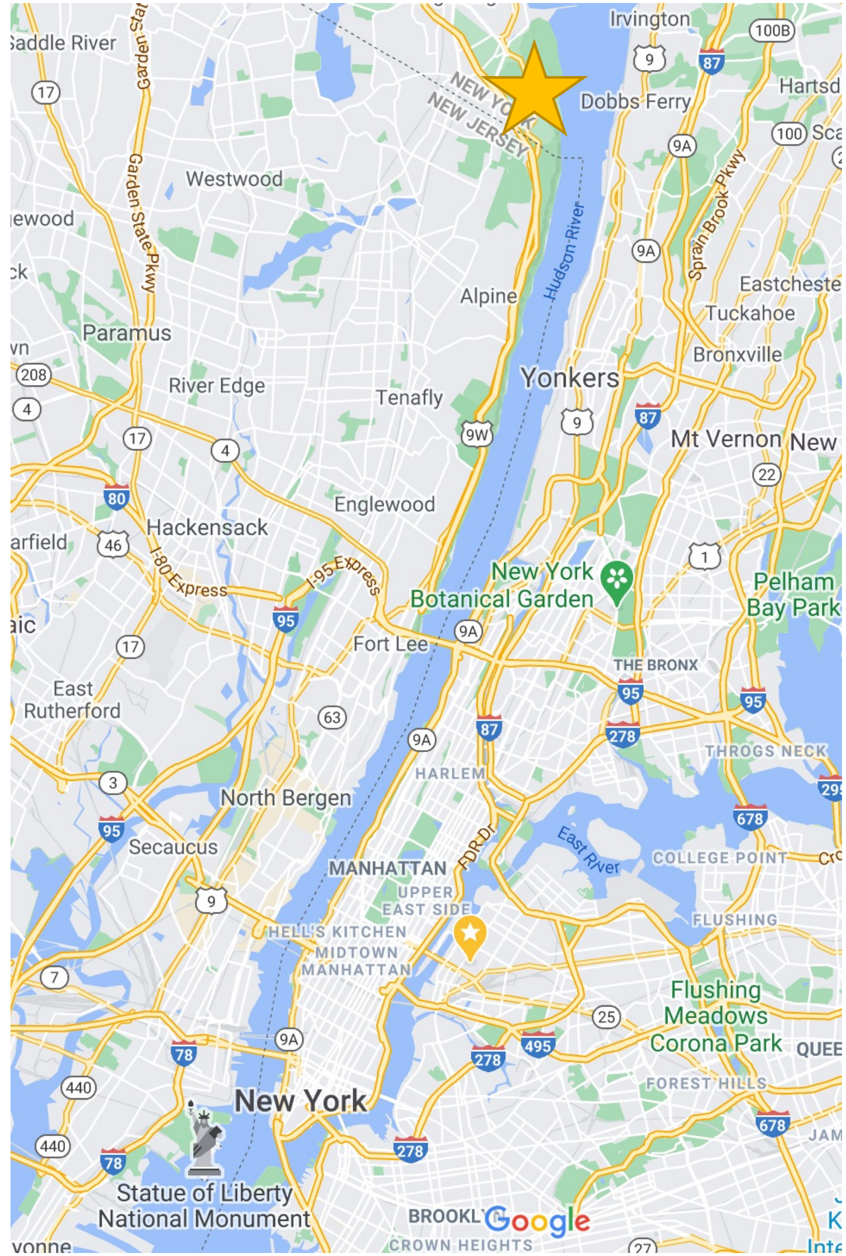


Introductions

- Name

Jonny (he/him)

- Current main scientific interest

Flow of water and ice in glaciers and ice sheets
(mostly Antarctica).

- Reasons for being here

Because I enjoy talking about glaciology
(also its my job).

- One thing that you want to better understand this semester (with a figure if you like).

PyTorch ICE PACK

Lauren Lewright

- I am interested in solid earth deformation and sea level change caused by past and current changes in ice mass
- My research has a lot to do with the effects of melting/growing an ice sheet, but I don't really know much about the physical processes that control that. I'd like to learn more to put some contextual understanding to my research.
- Id like to understand better the feedbacks associated with melting ice sheets

Emily Glazer (she/her)
2nd year PhD student
Polar Geophysics Group
Interests: climatic and structurally-controlled melt, ice shelf basal processes, Antarctic mass balance

- **Current main scientific interest:** surface hydrology on Antarctic Peninsula ice shelves (focus on George VI Ice Shelf)
  - Where is meltwater produced?
  - Will the extent of meltwater increase as the climate warms?
  - What will this do to ice shelf stability?
- **Reasons for being here:**
  - Excited about getting more formal/broader instruction in glaciology
  - Quals prep??
- **One thing I'd like to better understand this semester:** Numerical modelling skills in glaciology, how to incorporate data/observations into models

Introductions

- **Name:** Chiemi Tagami

- **Current main scientific interest:** Ice behavior in the Antarctic Ice Sheet

- **Reasons for being here:**

To deepen my understanding of the physical processes that influence the response of ice sheets to climate

- **One thing that you want to better understand this semester (with a figure if you like).**

I am excited to acquire the numerical modeling and data analysis skills for glaciology!

Korie DeBellis

(she/her)

Current scientific interest: North Atlantic Heinrich events and their relation to ocean circulation patterns

Reasons for being here: I think this course complements my research interests and will help me have a better understanding of my current research

This semester, I hope to have a clearer understanding of: the impact of glacial events on ocean systems and climate feedback loops.

Eojin Lee
she/her

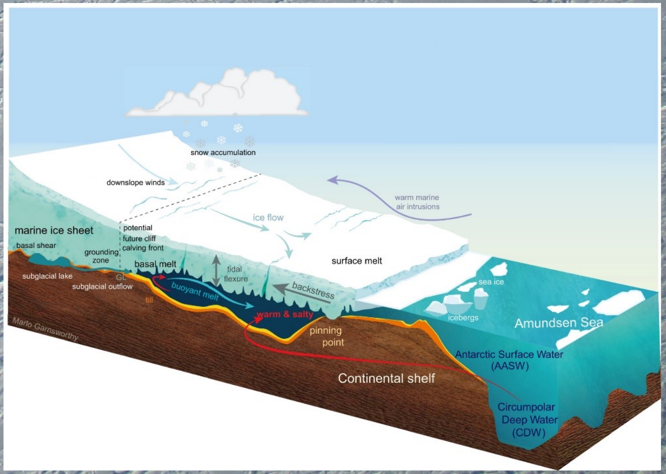
- Currently working on an ice sheet feature detection algorithm, but I'm also super interested in glacial hydrology
- Reasons for being here:
  - I'm a huge fan of ice and water
  - I would like to develop a more physically-grounded understanding of glacial processes
  - Learn more about the current state of the field
- I would love to better understand numerical modelling of ice sheets!

Caitlin Locke (she/her)

- Current main scientific interests:
  - Determining how rocks/bed topography influence ice flow
  - Modeling bathymetry beneath ice shelves

- Reasons for being here:
  - I'm a 2nd year graduate student in DEES studying how the rocks and bed topography beneath ice sheets and ice shelves influence ice flow in Antarctica. I want to take this course to expand my knowledge of glaciology and the cryosphere.

- One thing that you want to better understand this semester:
  - I want to better understand ice shelf formation, ice shelf collapse, and how ice shelves stabilize ice sheets this semester.



From Larter, R. D. (2022). A schematic of Thwaites Glacier Eastern Ice Shelf illustrating various processes and a pinning point.

Introductions

- Dean Wilson Gelling

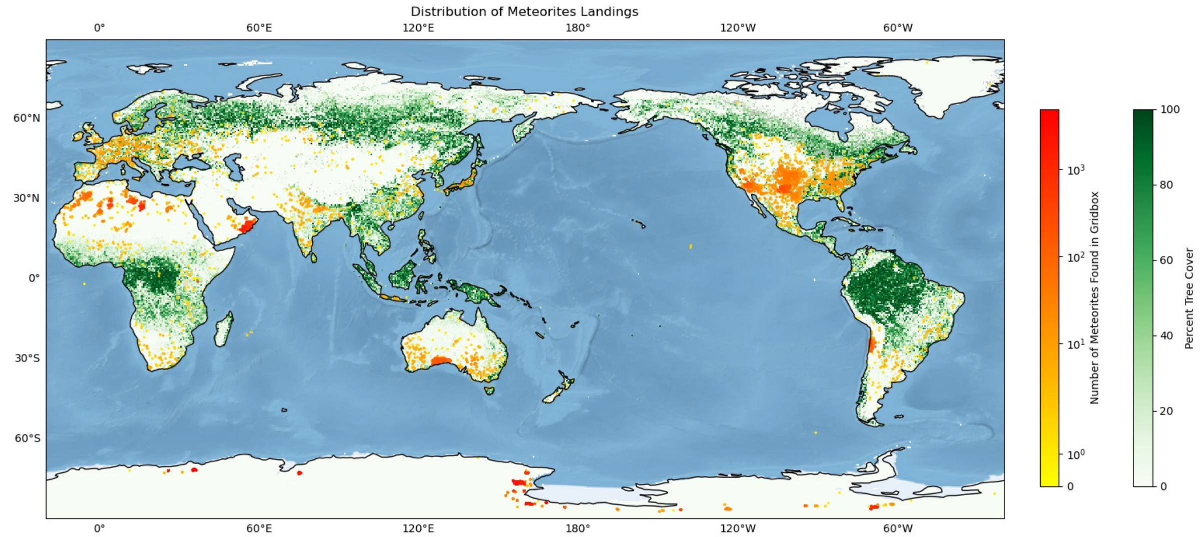
- Current main scientific interest
  - Marine Biochemistry, Land-Sea-Ice interactions
- Reasons for being here
  - Loved the glaciology section of Solid Earth Systems, wanted to learn more about ice and the cryosphere
- One thing that you want to better understand this semester (with a figure if you like).
  - I want to learn more about the methods and trends of current glaciological research, and try to identify a thesis topic

Introductions

- Name: George Lu
- Current main scientific interest: ice sheet/subglacial hydrology modelling, applications of climate data, ice penetrating radar
- Reasons for being here: want to formally improve glaciology fundamentals
- One thing that you want to better understand this semester (with a figure if you like): techniques/standards for working with large ice data sets (satellite/remotely sensed data)

Introductions

- My name is Julia Gonzales☺
- I study meteorites to understand the beginnings of planet formation in our solar system.



- Typically, most of the classes offered do not directly relate to my research, so I tend to choose classes I find most interesting!
- It would be cool to understand some of the processes that lead to the accumulation of meteorites in specific regions of Antarctica.

Katherine (Katie) Parker

Graduate student in Climate School: Climate + Society

- Current main scientific interest:
  - Reproduction of climate-resistant corals/Climate Educatio Coastal Communities

- Reasons for being here:
  - Understand climate processes of involved in the study of ice and how it will affect other natural processes

- One thing that you want to better understand this semester:
  - Flows of Ice Masses - ice flow in Antarctica

The course

Tuesdays: 1:10 pm
558 Schermerhorn
Extension

Tuesdays: lectures (and discussion).

- 1hr 15 mins
- Introduce and discuss the most important processes
- Observations
  - Satellite
  - Geophysics
  - Lab experiments
- Mathematical models
  - Fundamental physics (balance of energy, mass and stress).
  - Partial differential equations
  - These will be very simplified
- Examine models analytically.

Emphasis on discussion and understanding processes!

Format:

Thursdays: practical sessions.

Thursdays: 1:10pm 558 Schermerhorn Extension

Practicals:

- 1hr 15 mins

Format:

Thursdays: practical sessions.

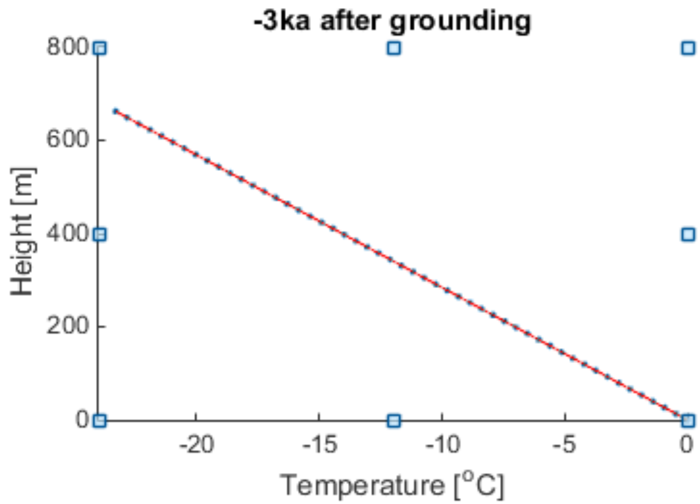
Thursdays: 1:10pm 558
Schermerhorn Extension

Practicals:

$$q = u_b \mathrm{H} + \frac{2A}{n+2}\rho g H^{n+2}$$

- 1hr 15 mins

- Analyzing mathematical models numerically
    - a simple sets of equations for ice flow
    - heat flow through ice sheets



Format:

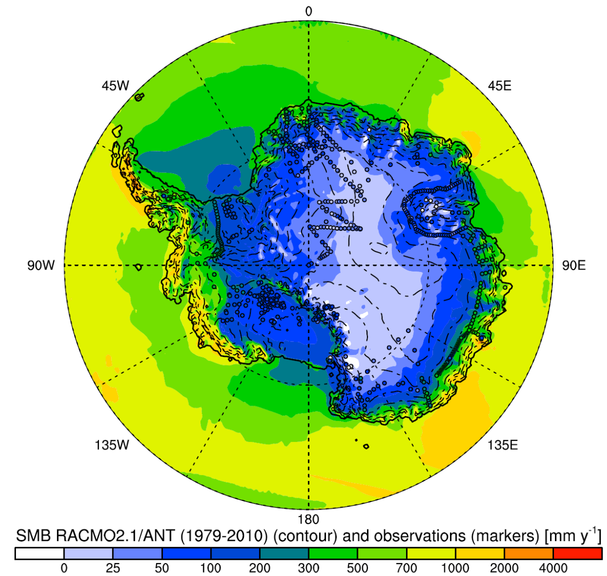
Thursdays: practical sessions.

Practicals:

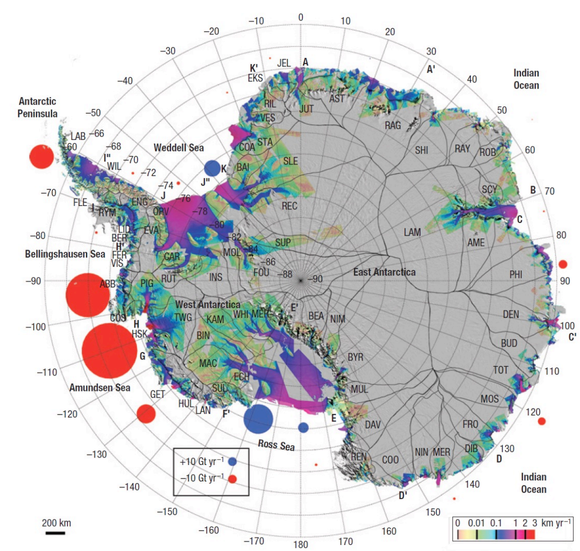
- 1hr 15 mins

- Analyzing mathematical models numerically
    - a simple sets of equations for ice flow
    - heat flow through ice sheets

- Data analysis
    - analyzing Antarctic climate
    - flow velocities of Antarctic glaciers



Lenaerts et al. (2012)



Rignot (2008)

Grading

Assignments (3): 40%

Final paper/project: 40%

A written paper on a glaciological topic, going beyond what we discuss in class, or

A report on a computer-based project
(could extend a model or data analysis exercise from class).

(0.5-page plan by April 7^{th} and submit by May 5^{th})

Class participation: 20%

Discussion/contribution in lectures and practicals

Grade	lower bound
A+	97.0
A	93.0
A-	90.0
B+	87.0
B	83.0
B-	80.0
C+	77.0
C	73.0
C-	70.0
D+	67.0
D	63.0
D-	60.0

Schedule

Week	Date	Day	Description
1	**17-Jan**	Tuesday	
	19-Jan	Thursday	L1: Introduction to glaciers
2	**24-Jan**	Tuesday	L2: Introduction to glaciology
	26-Jan	Thursday	L3: Surface mass balance I: accumulations zones
3	**31-Jan**	Tuesday	P1: Intro to data analysis in Matlab
	2-Feb	Thursday	L4: Mass balance II: ablation
4	**7-Feb**	Tuesday	P2: Antarctic climate data
	9-Feb	Thursday	L5: Ice as a nonlinear fluid
5	**14-Feb**	Tuesday	P3: Intro to solving equations numerically
	16-Feb	Thursday	L6: Slow ice flow
6	**21-Feb**	Tuesday	P4: Ice sheet modelling I
	23-Feb	Thursday	L7: Basal motion.
7	**28-Feb**	Tuesday	P5a: Ice sheet modelling II: extending the model
	2-Mar	Thursday	L8: Ice flow extremes: ice divides and grounding lines
8	**7-Mar**	Tuesday	P5b: Ice sheet modelling II: extending the model
	9-Mar	Thursday	L9: Ice shelves
9	**14-Mar**	Tuesday	Spring break
	16-Mar	Thursday	Spring break
10	**21-Mar**	Tuesday	P6: Computing ice thickness and speed
	23-Mar	Thursday	L10: Heat flow in ice sheets
11	**28-Mar**	Tuesday	P7a: the advection-diffusion equation in ice sheets I
	30-Mar	Thursday	L11: Glacial hydrology I
12	**4-Apr**	Tuesday	P7b: the advection-diffusion equation in ice sheets II
	6-Apr	Thursday	L12: Glacial hydrology II
13	**11-Apr**	Tuesday	P7c: the advection-diffusion equation in ice sheets III
	13-Apr	Thursday	L13 Ice sheet isochrones and age structure
14	**18-Apr**	Tuesday	P8: Age equation practical
	20-Apr	Thursday	Review and chance to discuss student papers
15	**25-Apr**	Tuesday	class presentations 1
	27-Apr	Thursday	class presentations 2
	5/5/23	Friday	Deadline for final projects

Assignments

Started in practical sessions.

Completed in your own time.

Will require a short write-up, ~1 page, with figures.

Three, spread through the semester.

Antarctic climate “data” (Feb 21st)

Ice sheet model (Mar 21st)

Heat flow modelling (Apr 18th)

Grade	lower bound
A+	97.0
A	93.0
A-	90.0
B+	87.0
B	83.0
B-	80.0
C+	77.0
C	73.0
C-	70.0
D+	67.0
D	63.0
D-	60.0

Expectations

Expectations of me:

- Explain everything clearly enough for everyone to understand in class or in office hours.
- Care about everyone getting the most out of the course.
- Respond to things in a timely way.

Expectations

Expectations of me:

- Explain everything clearly enough for everyone to understand in class or in office hours.
- Care about everyone getting the most out of the course.
- Respond to things in a timely way.

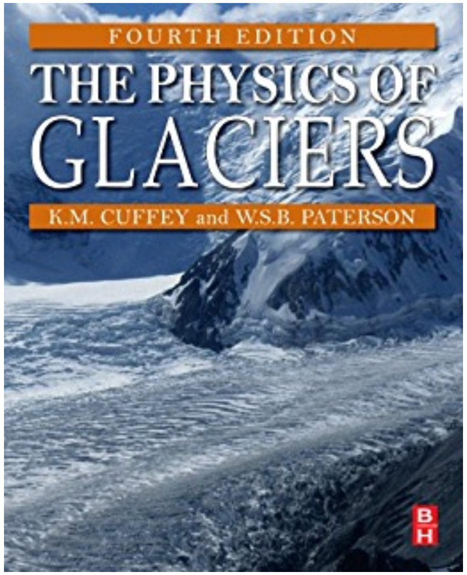
Expectations of you:

- Be interested.
- Turn in practical work in plenty of time.
- Let me know if you don't understand something.
- Contribute to discussions.

Textbooks

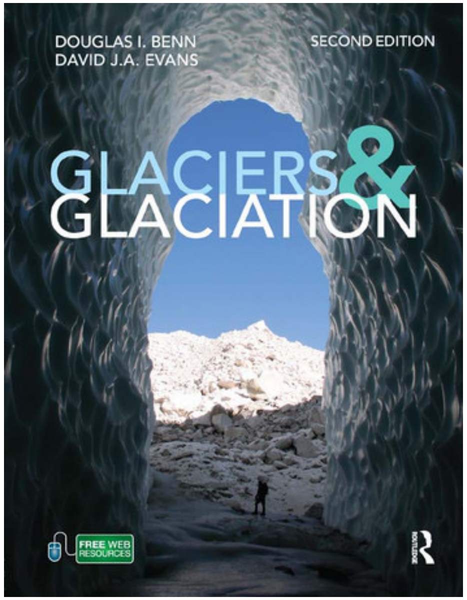
Cuffey, K.M. & W.S.B. Paterson (2010).
The physics of glaciers
Academic Press, 4th Edition.

More mathematical
More references



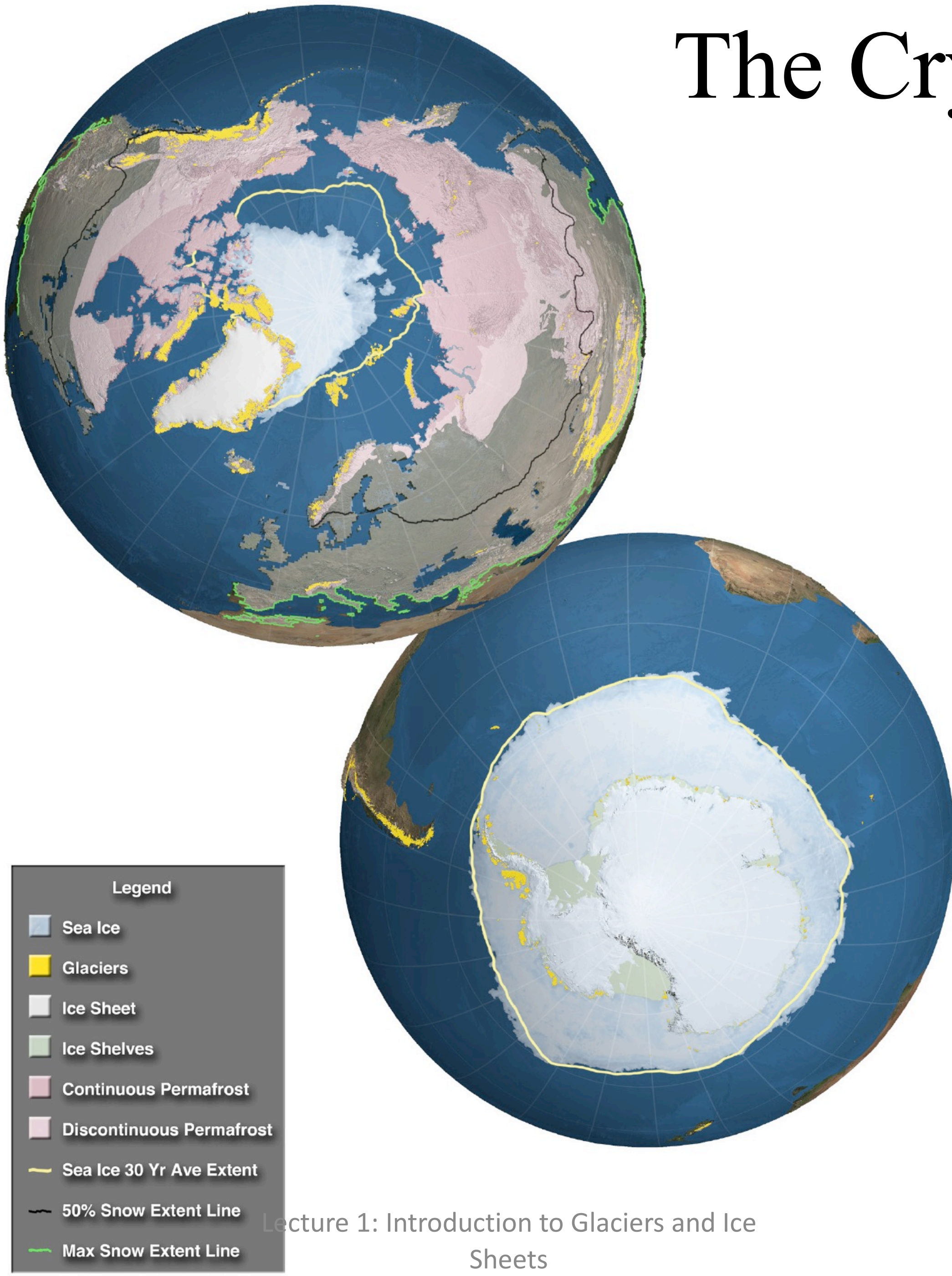
Benn, D. & D. Evans (2010)
Glaciers and Glaciation
Routledge, 2nd Edition.

More descriptive
Fewer references



Both out-of-date.

The Cryosphere



What are glaciers and ice sheets?

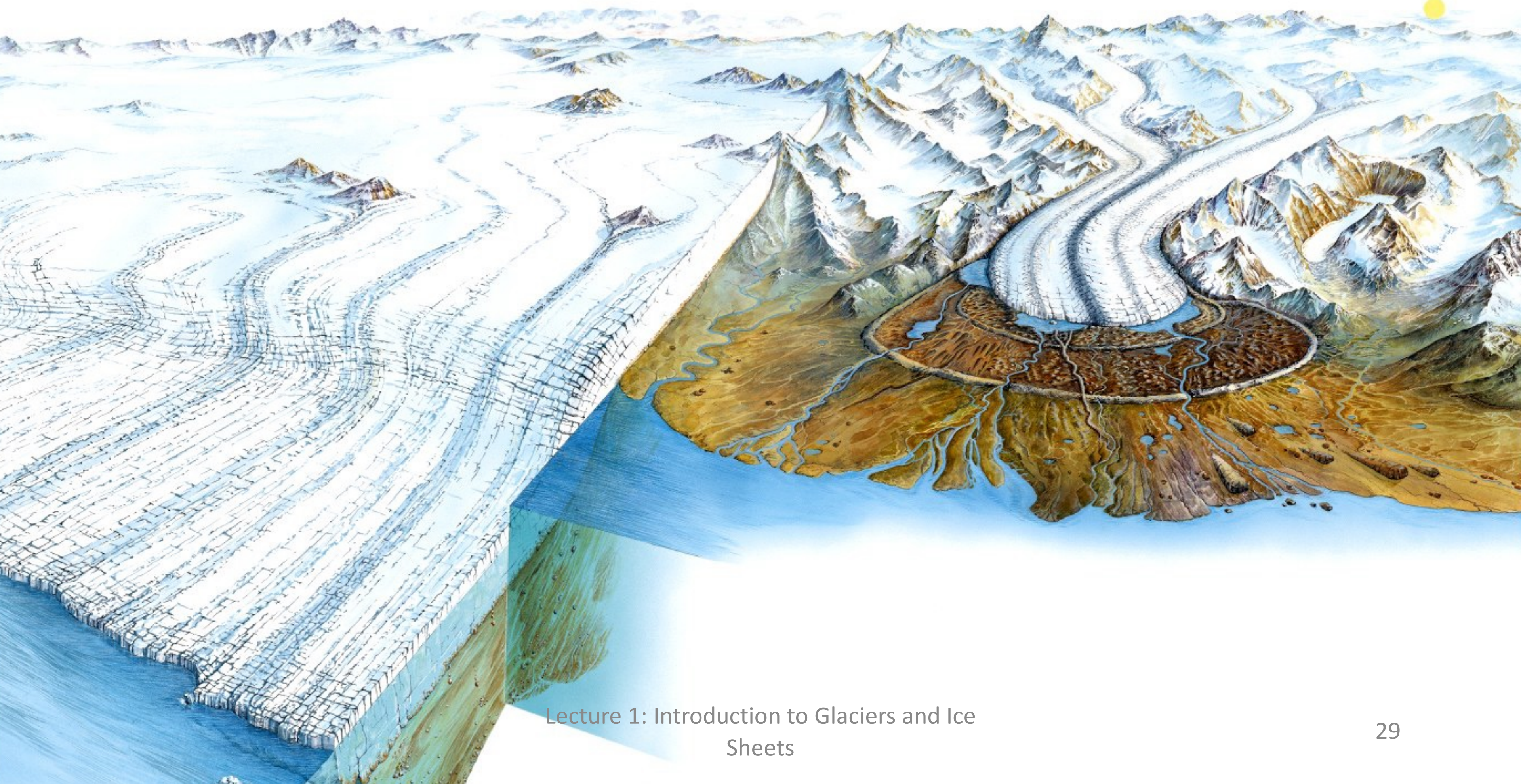
Glaciers and ice sheets

Ice masses that are thick enough to flow under their own weight

10's to 1000's of m thick

Ice sheets

Glaciers

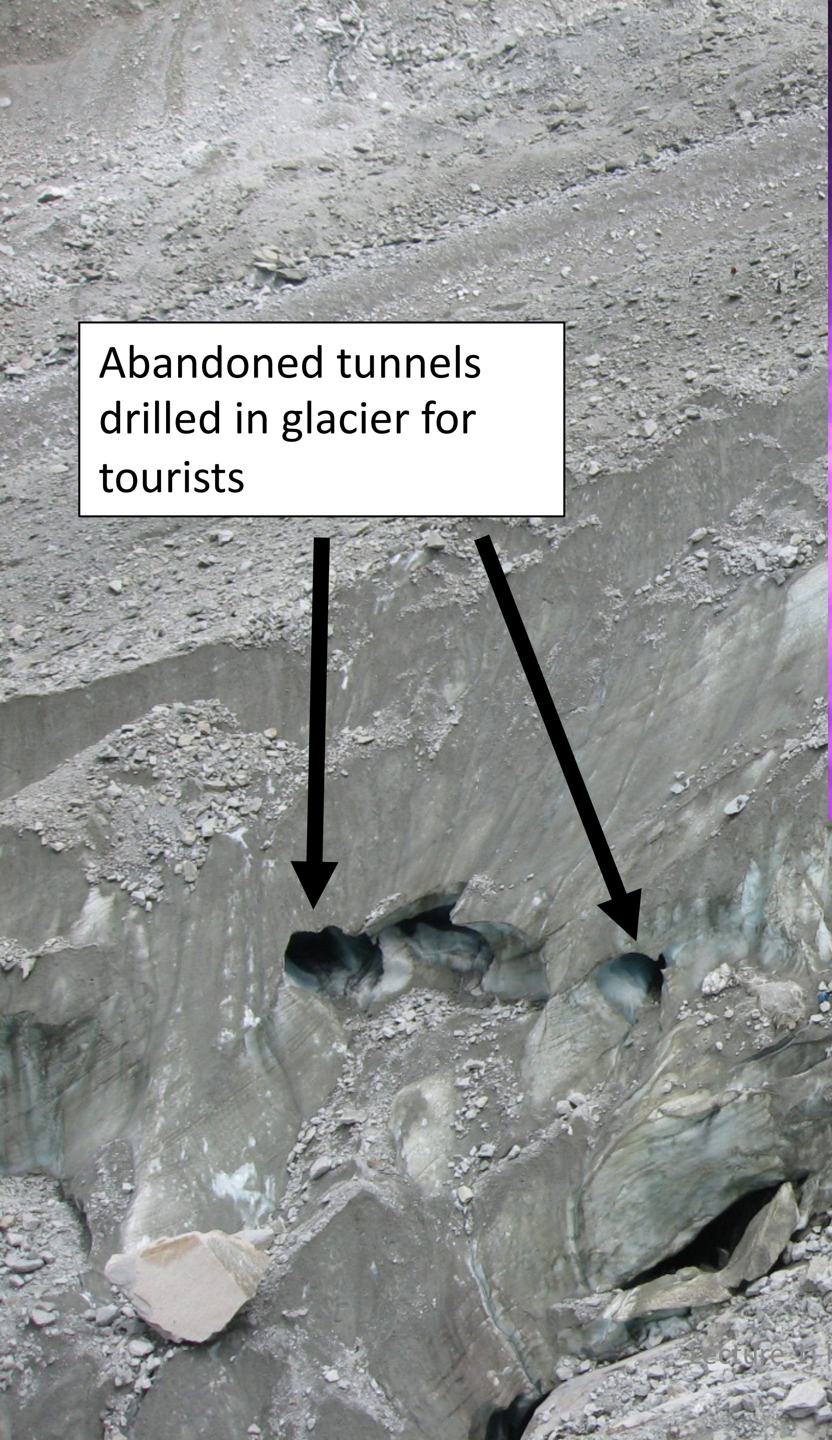


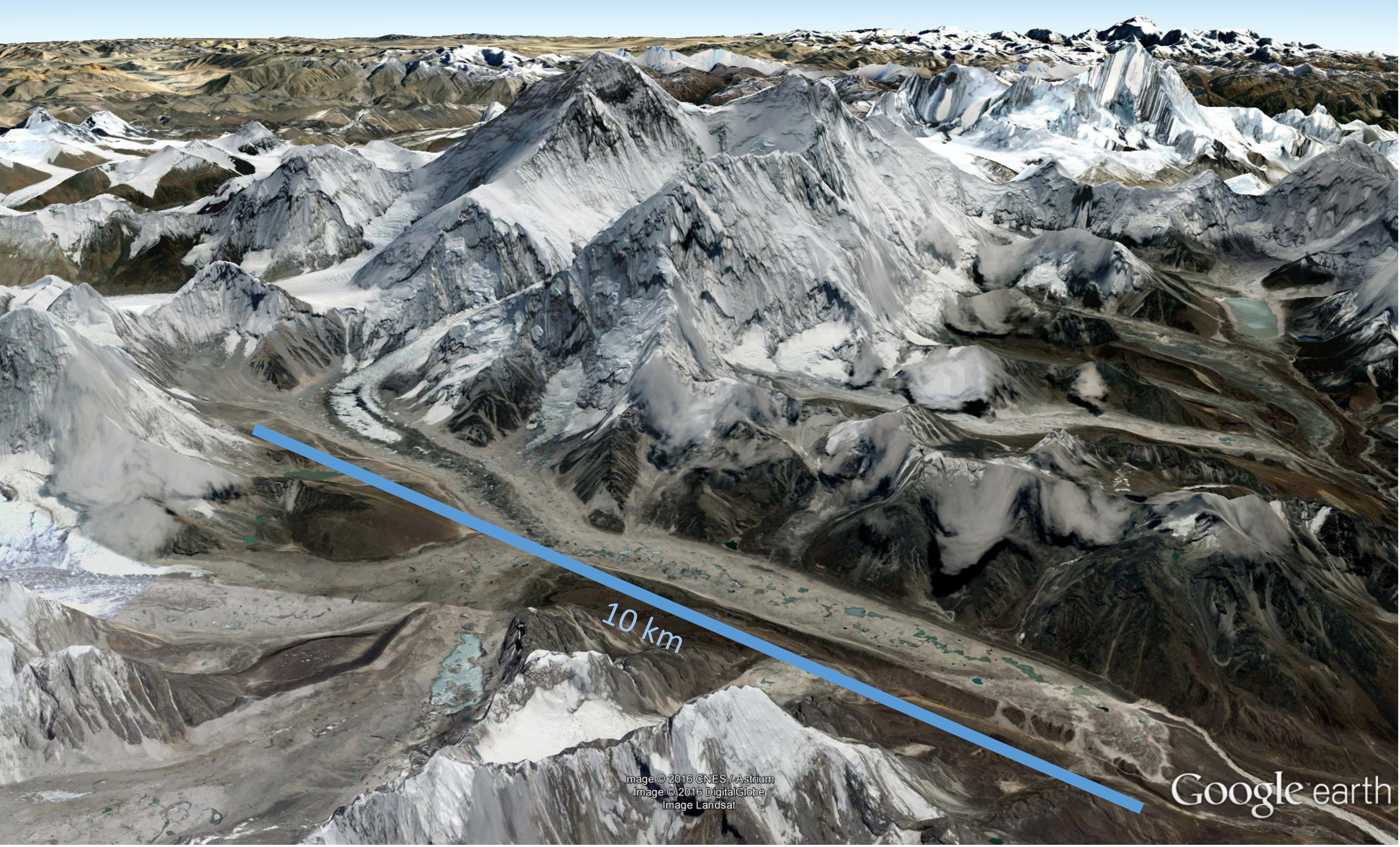
Mer de Glace, France

N45.913445° W006.926815° (looking south)

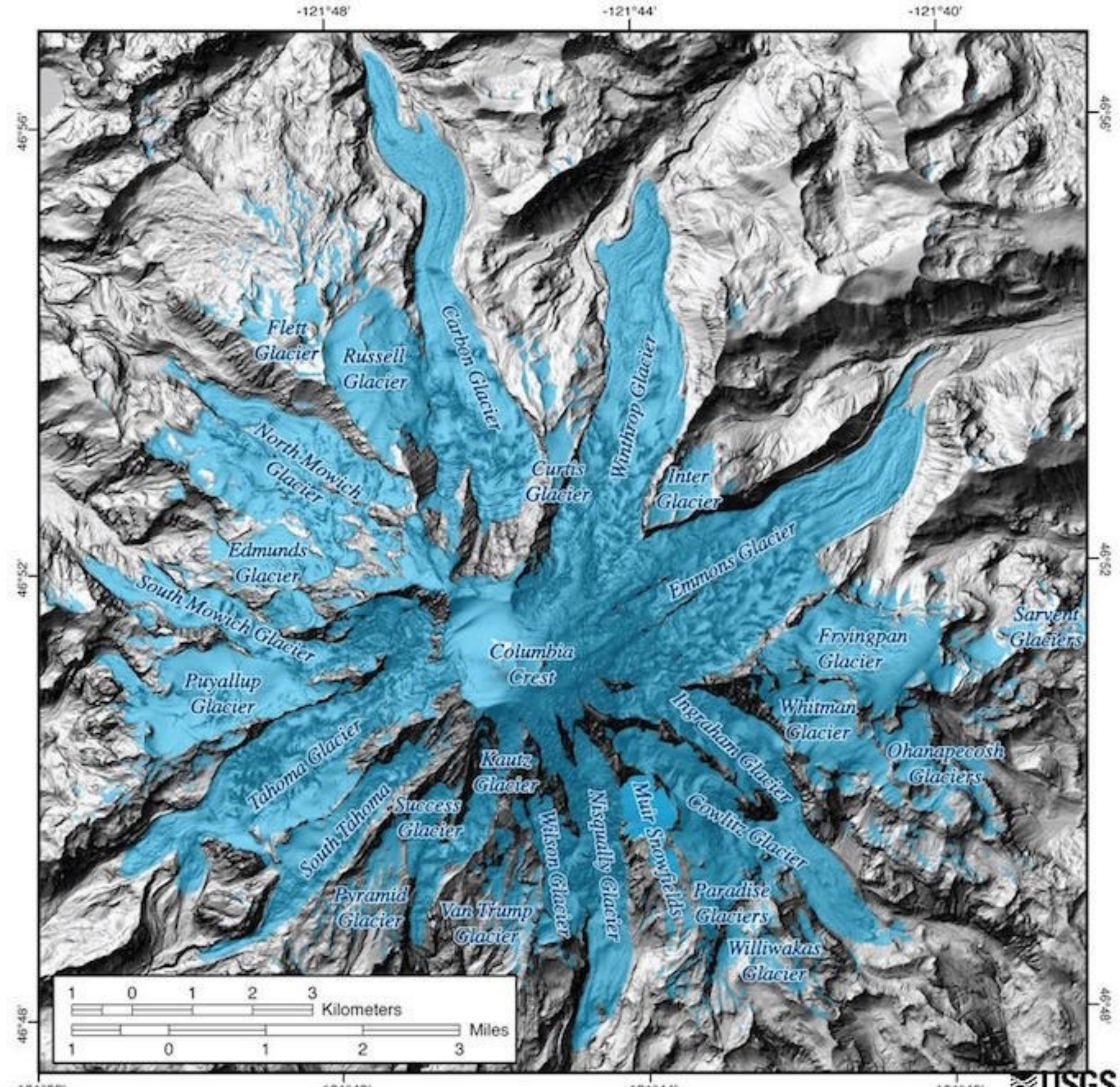
Figure 4**: The Mer de Glace Glacier and Mont-Blanc seen from the Le Moine summit (looking towards the West); ice limits during the last ice age (Würm), and maximum ice extension during the Little Ice Age are indicated by glacial abrasion of the bedrock. Foto: Jean-François Hagenmuller , interpretation: Luc Moreau

Wildi (2014)


Abandoned tunnels drilled in glacier for tourists



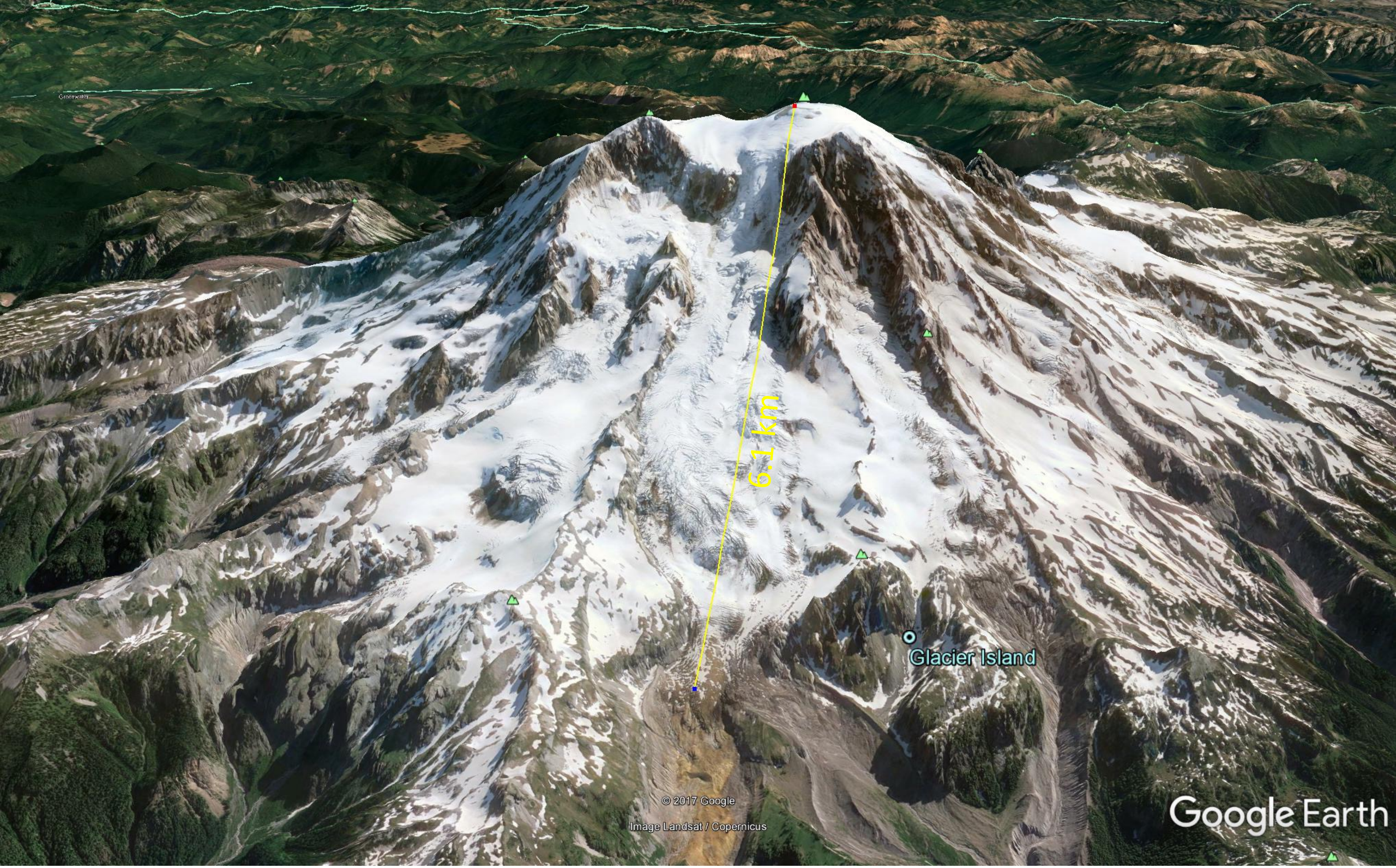
Khumbu Glacier, Nepal
Partly debris-covered mountain glacier.
N27.961978°   E086.837274° (looking north)



LIDAR DEM image from USGS

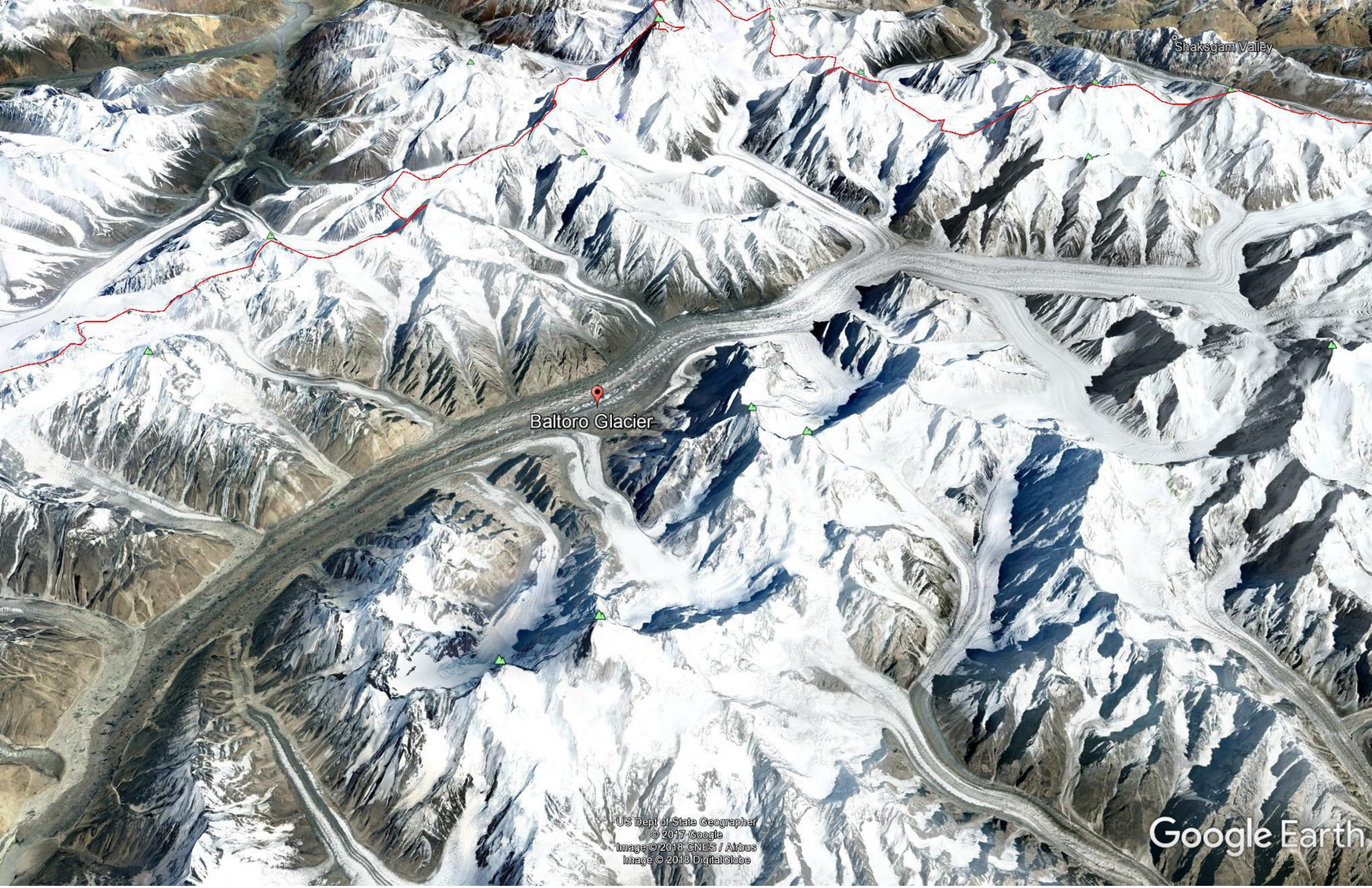
Mt. Rainer, Washington State

N46.854203° W121.746943°

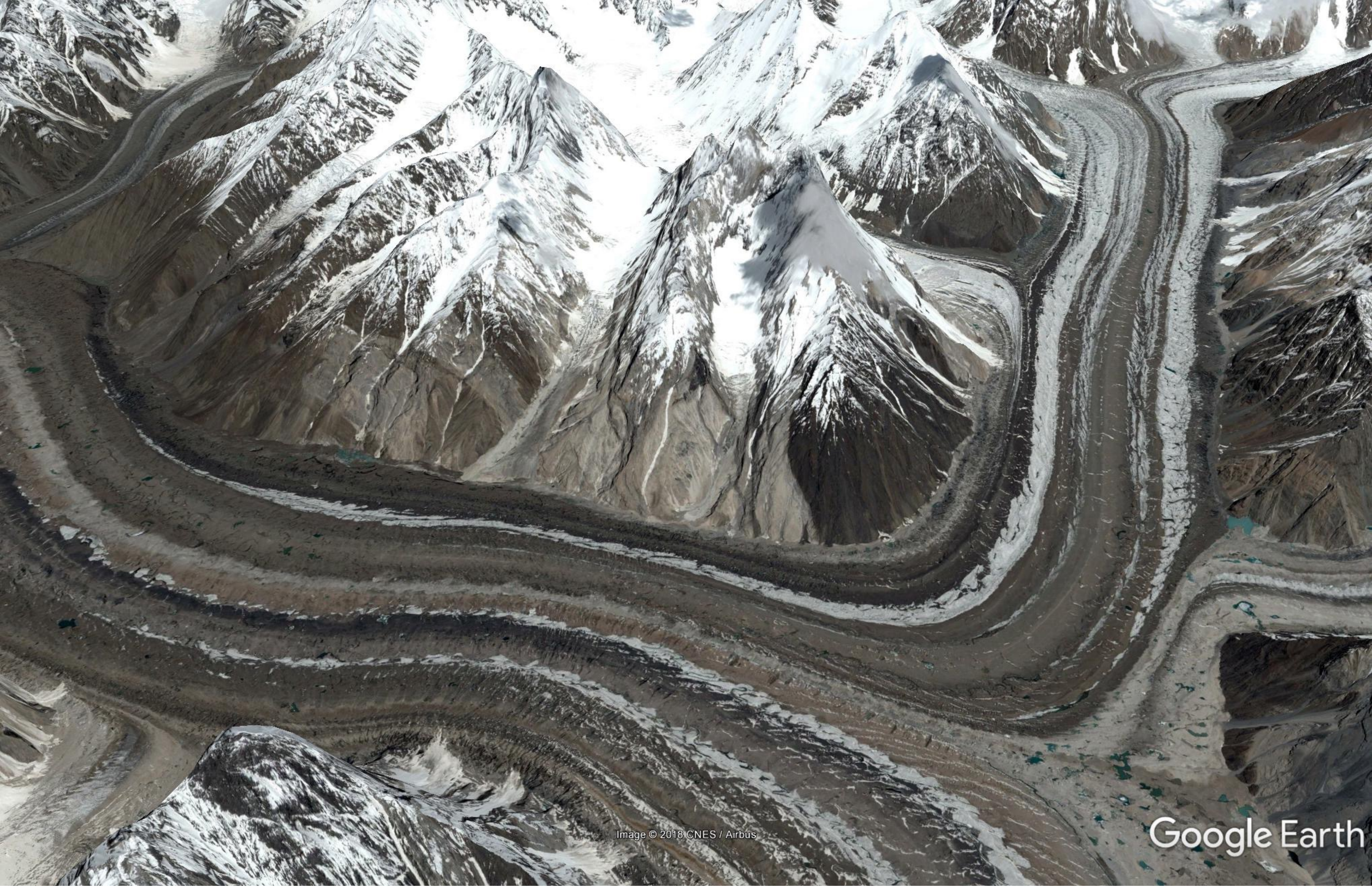


Tacoma Glacier, Washington State

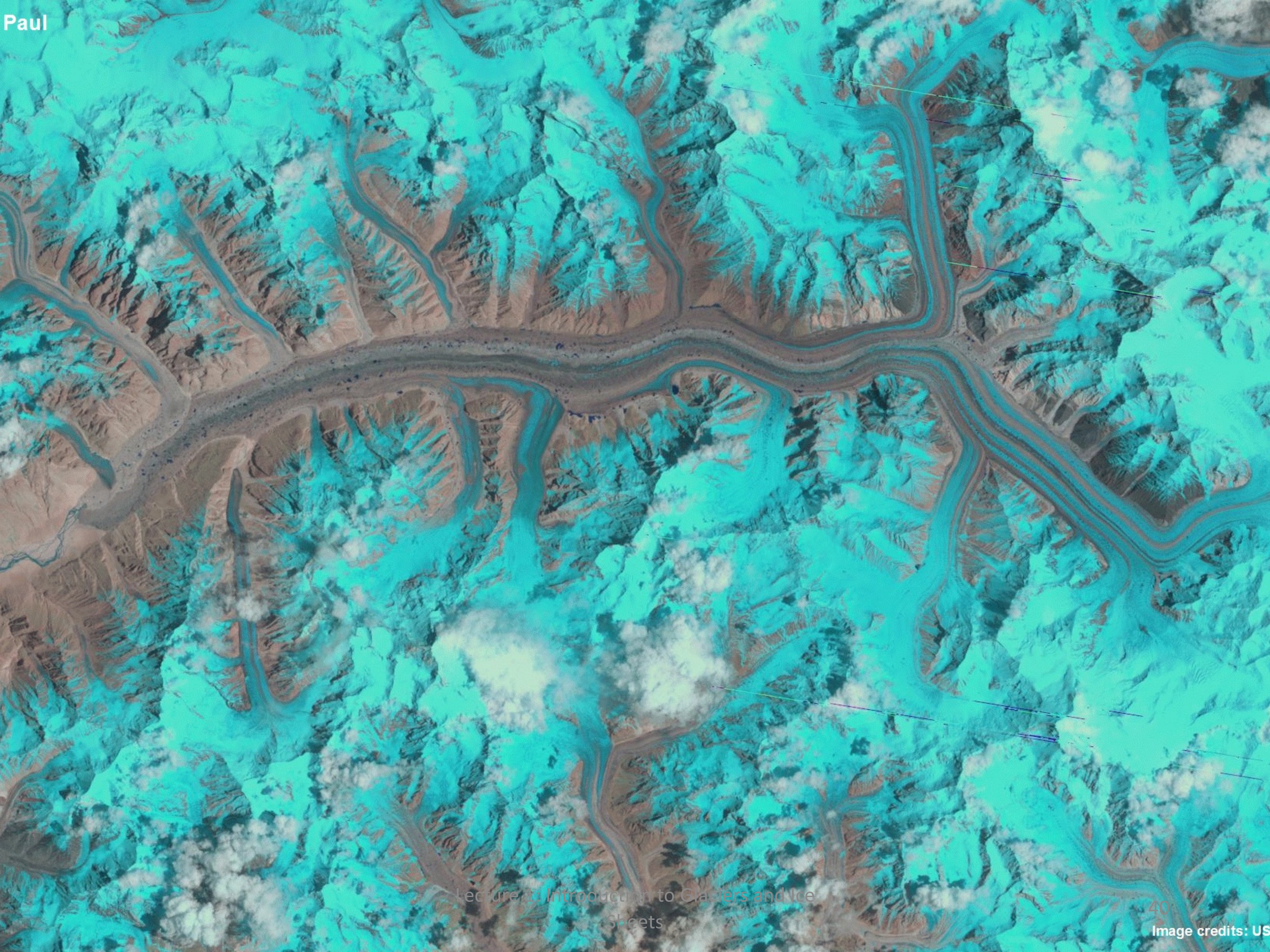
N46.854203° W121.746943° (looking north east)



Baltoro Glacier, Pakistan >60km long N35.694420° E076.376977°



Baltoro Glacier, Pakistan >60km long N35.694420° E076.376977°


Paul
Image credits: US

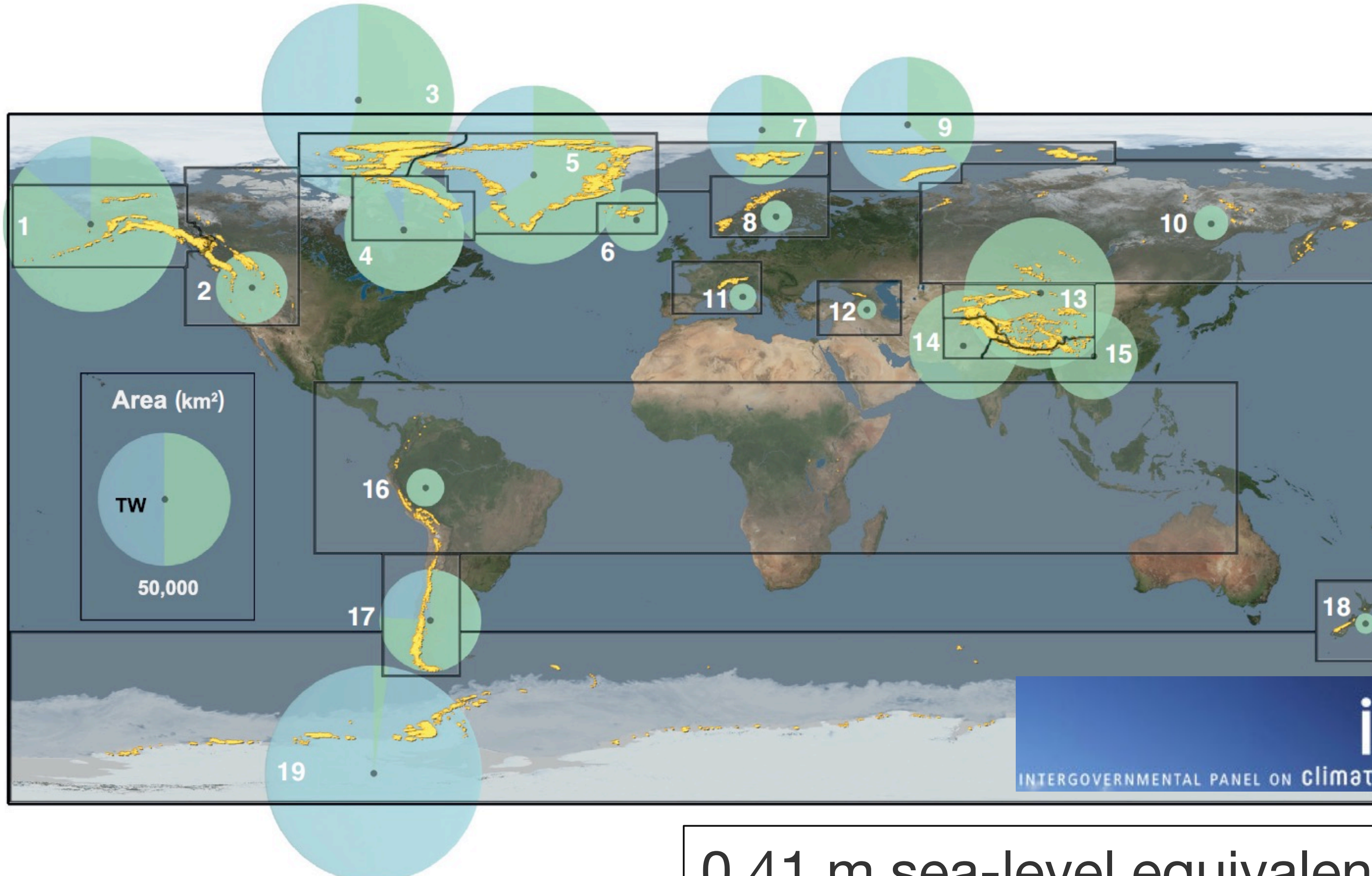
Global distribution of glaciers

Randolph Glacier Inventory 6.0

Region number	Region name	Glacier count	Glacierized area (km^2)
00	World	215547	705738.793
01	Alaska	27108	86725.053
02	Western Canada and US	18855	14524.224
03	Arctic Canada North	4556	105110.642
04	Arctic Canada South	7415	40888.228
05	Greenland Periphery	19306	89717.066
06	Iceland	568	11059.700
07	Svalbard	1615	33958.934
08	Scandinavia	3417	2949.103
09	Russian Arctic	1069	51591.600
10	North Asia	5151	2410.051
11	Central Europe	3927	2092.146
12	Caucasus and Middle East	1888	1306.992
13	Central Asia	54429	49303.415
14	South Asia West	27988	33568.298
15	South Asia East	13119	14734.204
16	Low Latitudes	2939	2341.036
17	Southern Andes	15908	29429.080
18	New Zealand	3537	1161.801
19	Antarctic and Subantarctic	2752	132867.220

RGI Consortium (2017)

Global distribution of glaciers



ipcc
INTERGOVERNMENTAL PANEL ON climate change

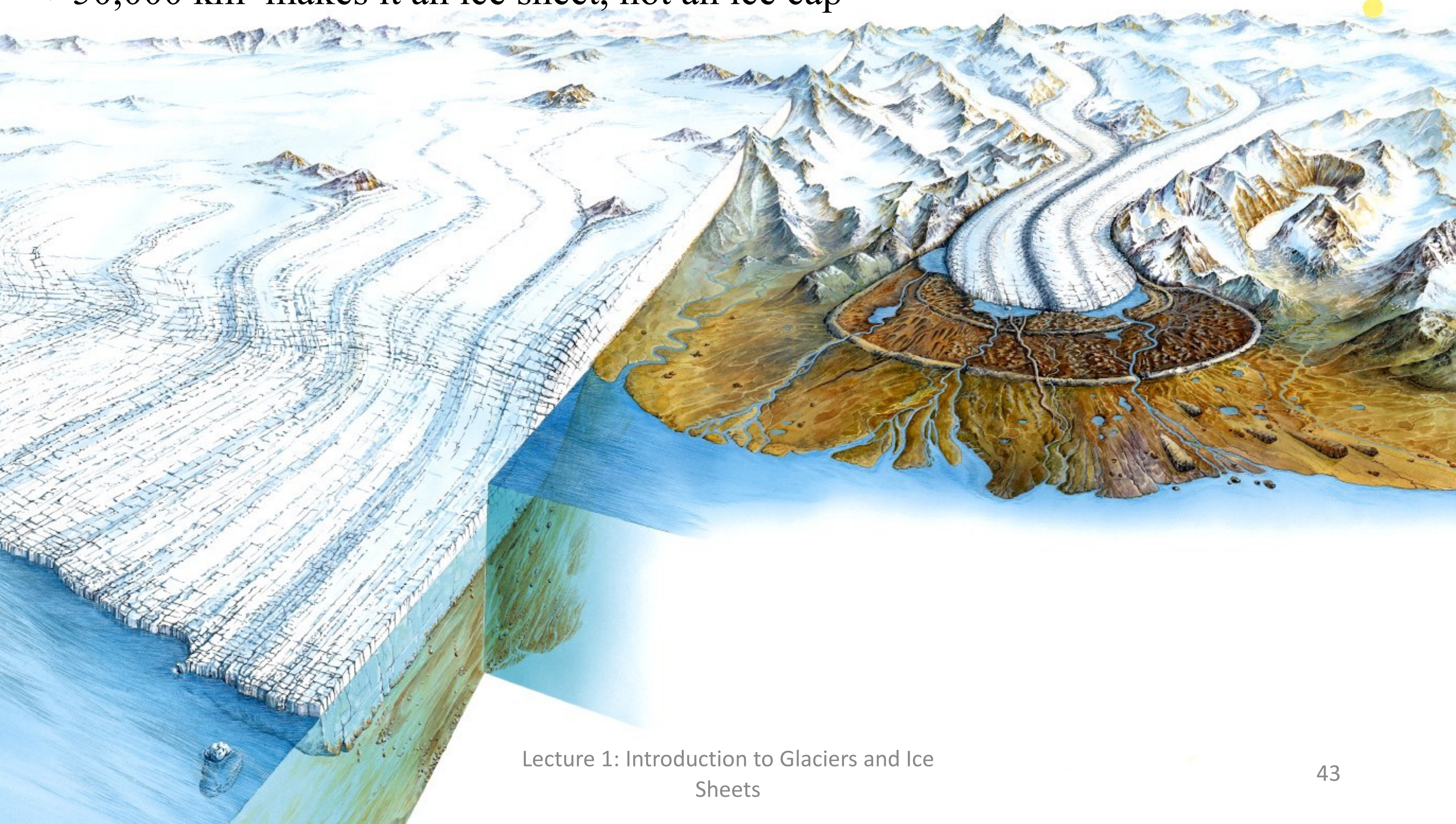
0.41 m sea-level equivalent
IPCC AR5 (Vaughan et al, 2013)

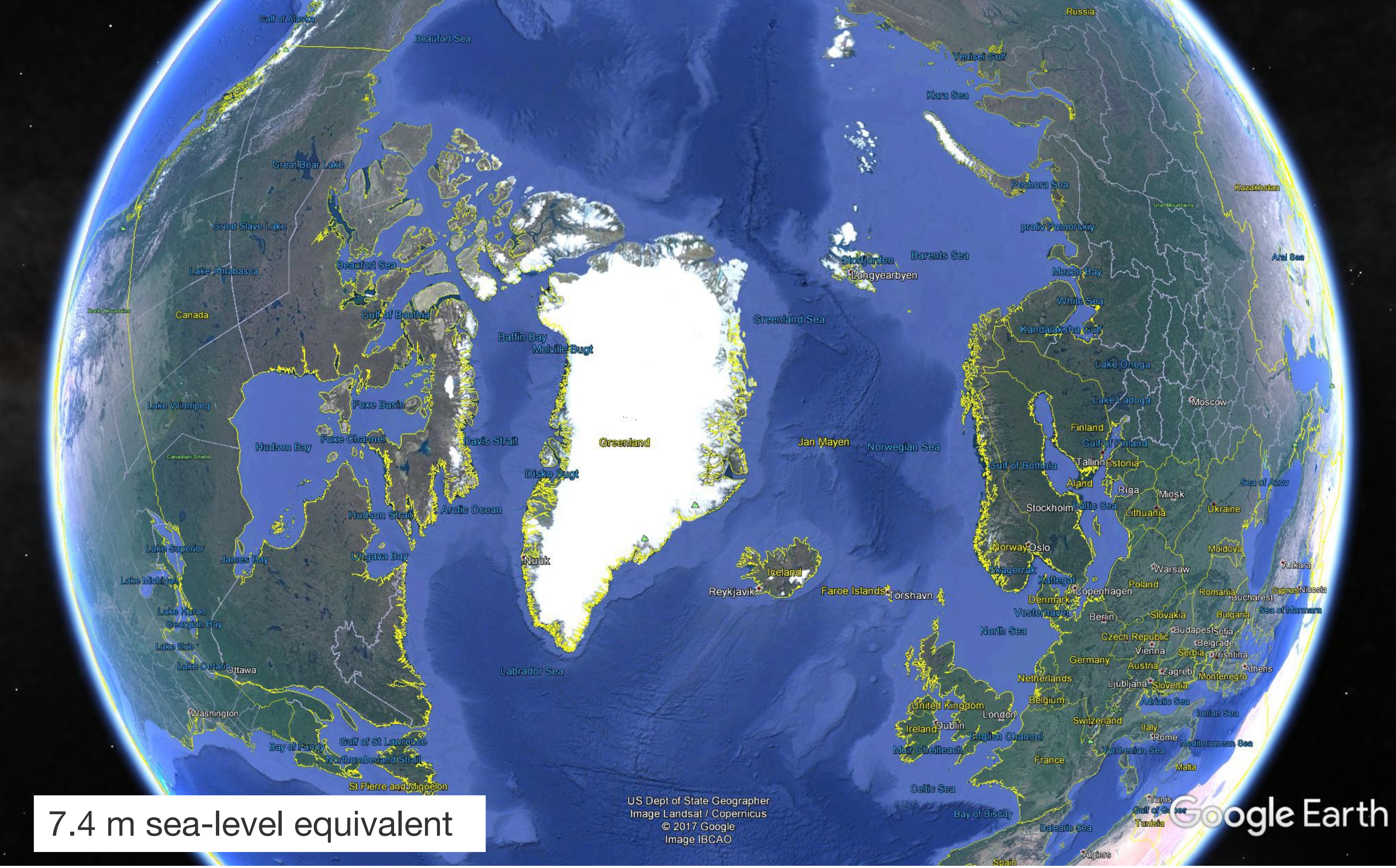
Ice sheets: 100's to 1000's of m thick.

Inundate terrain

Flow outwards from a 'flow center' towards the 'margin' (ocean or terrestrial).

>50,000 km^2 makes it an ice sheet, not an ice cap





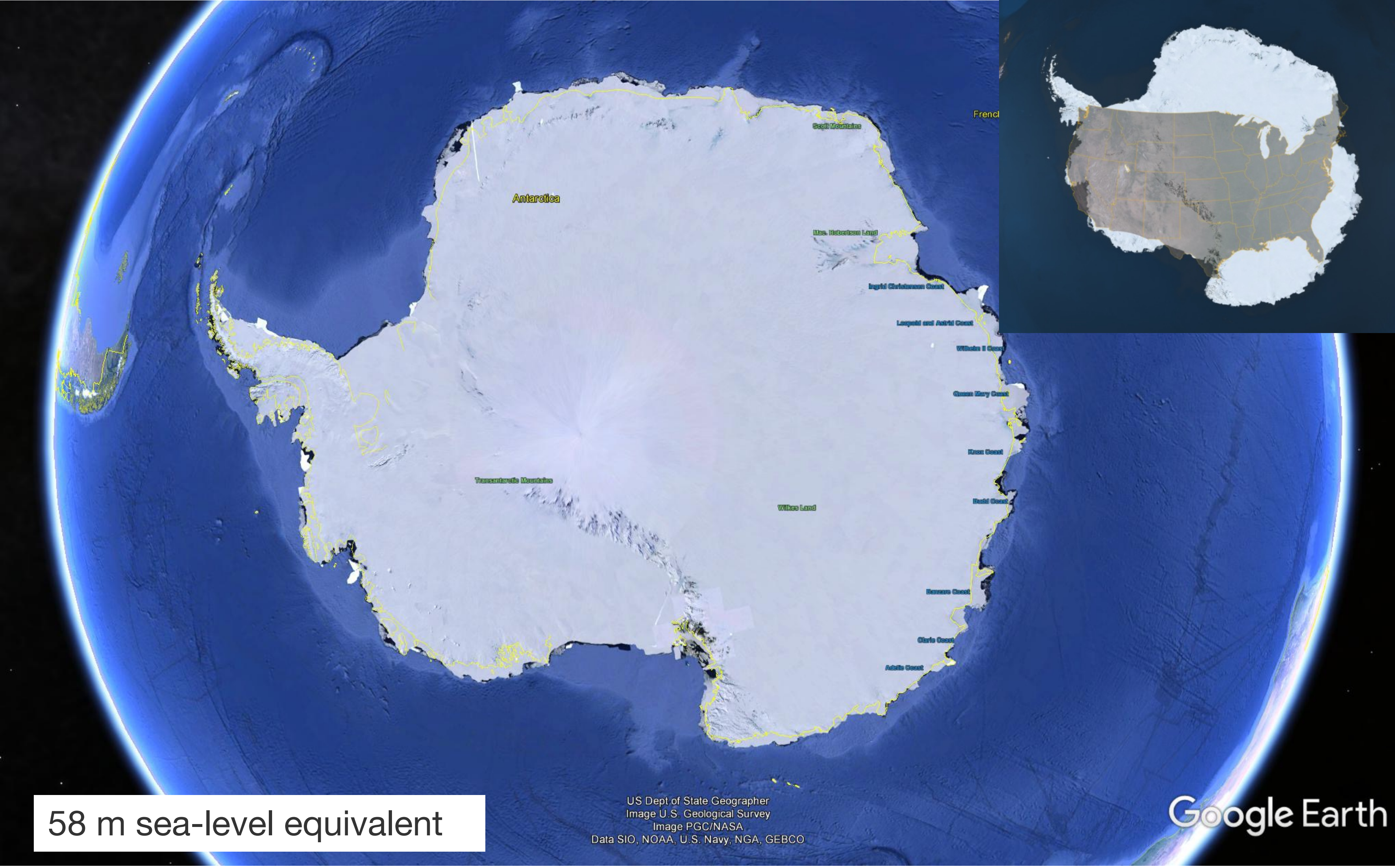
7.4 m sea-level equivalent

1.7 million km^2

2400 x 1000 km

~ 3000 m thick

Morlighem et al. (2017)



58 m sea-level equivalent

4 million km^2

4000-5000 km across

~4800 m thick

Fretwell and Pritchard et al. (2013)

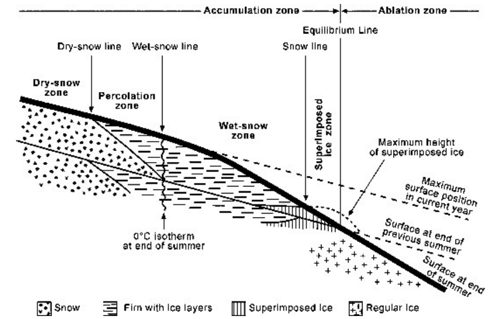
Topics we will cover

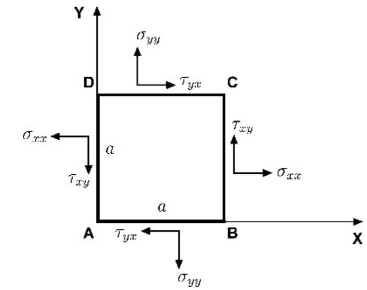
- Accumulation zone processes
- Surface energy balance
- Ablation
- Ice deformation
  - -- Grain-scale deformation process
  - -- Large-scale deformation
- Ice-sheet dynamics
  - -- Slow flowing areas
  - -- Ice streams
  - -- Ice shelves
  - -- Basal motion

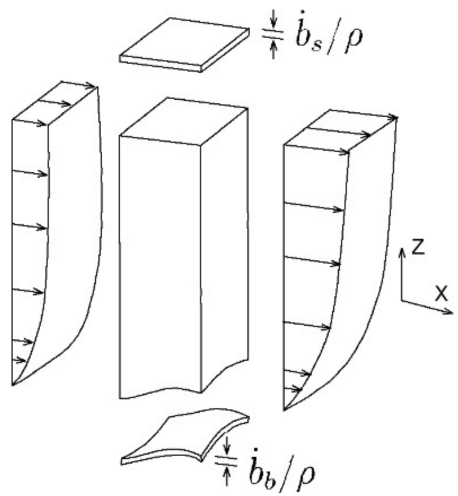
Reading week

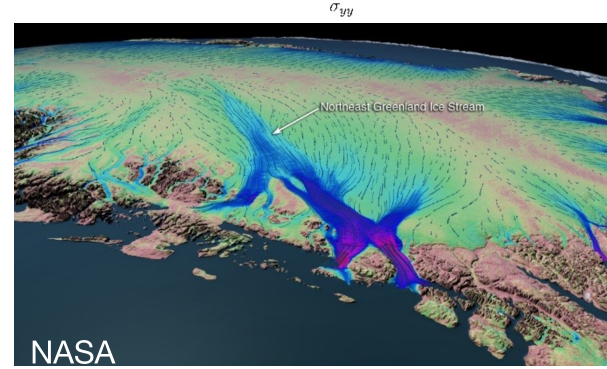
- Heat flow
- Glacier hydrology
- (Ice sheets, GIA and sea level
- Ice-ocean interactions
- The age of ice)


Gavin McNamara.









NASA


Cuffey and Paterson (2010)

Short reading for Thursday

Cuffey and Paterson

Chapter 1: Introduction (pages 1 – 6)

(scan on Canvas)

Tuesday’s lecture is at the same time (1:10 pm)

References

Benn, D. and Evans, D.J., 2010. *Glaciers and glaciation*. Routledge.

Cuffey, K.M. and Paterson, W.S.B., 2010. *The physics of glaciers*. Academic Press.

Fretwell, P., Hamish D. Pritchard, David G. Vaughan, J. L. Bamber, N. E. Barrand, R. Bell, C. Bianchi et al. "Bedmap2: improved ice bed, surface and thickness datasets for Antarctica." The Cryosphere 7, no. 1 (Feb., 2013)

Fowler, A.C., 1999. Breaking the seal at Grímsvötn, Iceland. *Journal of Glaciology*, *45*(151), pp.506-516.

Kieffer, H.H., Chase, S.C., Martin, T.Z., Miner, E.D. and Palluconi, F.D., 1976. Martian north pole summer temperatures: Dirty water ice. *Science*, *194*(4271), pp.1341-1344.

Kingslake, J., 2015. Chaotic dynamics of a glaciohydraulic model. *Journal of Glaciology*, *61*(227), pp.493-502.

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