Andrew Ireson andrew.ireson@usask.ca
School for Environment and Sustainability/Global Institute for Water Security

1. Challenges of cold regions hydrology

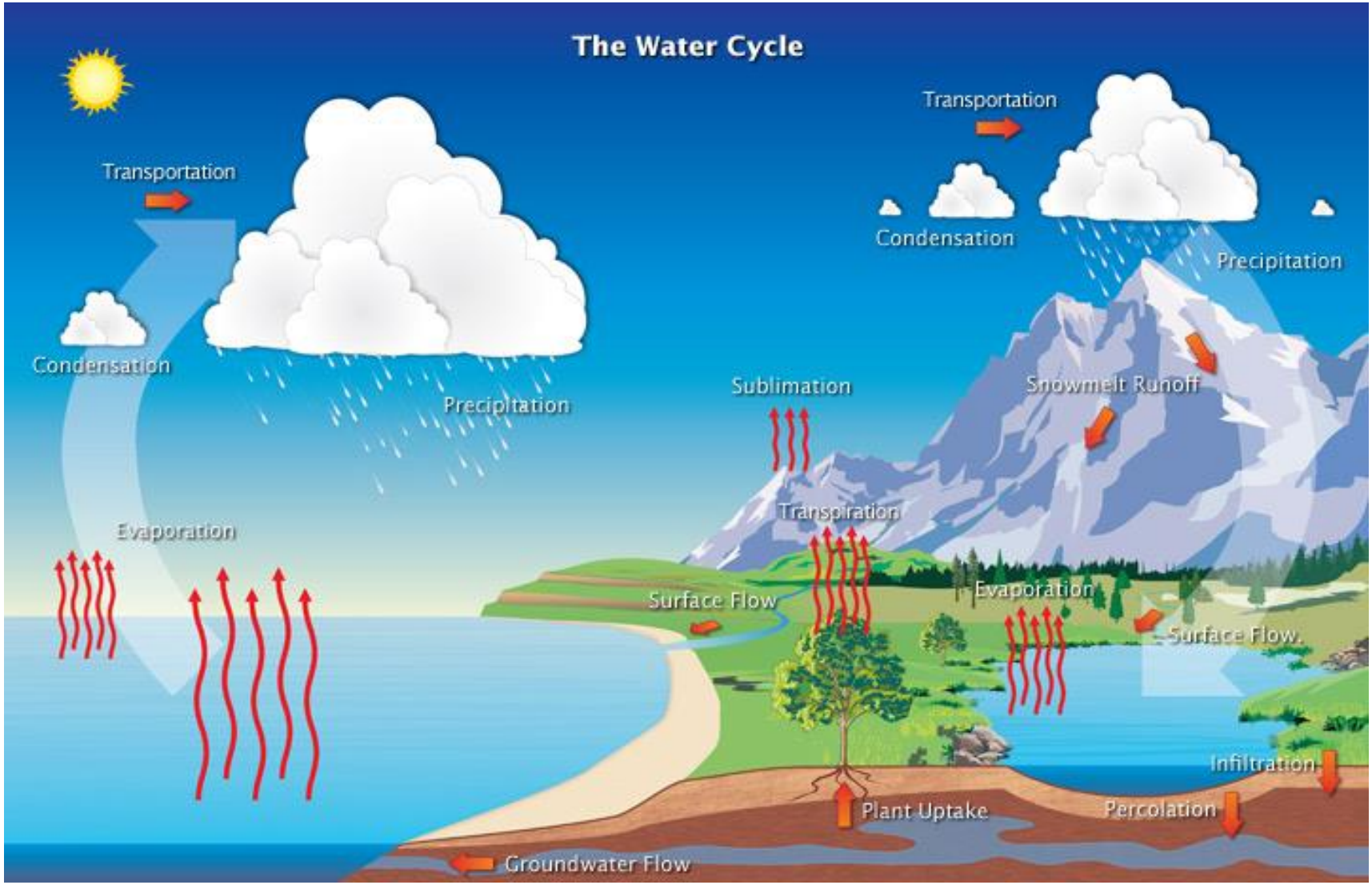
Baker Creek, Northwest Territories
Photo: Alana Muenchrath

Learning Objectives

After this lecture you should be able to:

- Contrast hydrological processes in temperate vs cold regions
- Describe the cryosphere – where it is found and what components it comprises
- Understand what each of these is and what is their role in the hydrological cycle:
    - Snow
    - Frozen soil
    - River and lake ice
    - Glaciers
    - Ice sheets and sea ice

The natural hydrological cycle



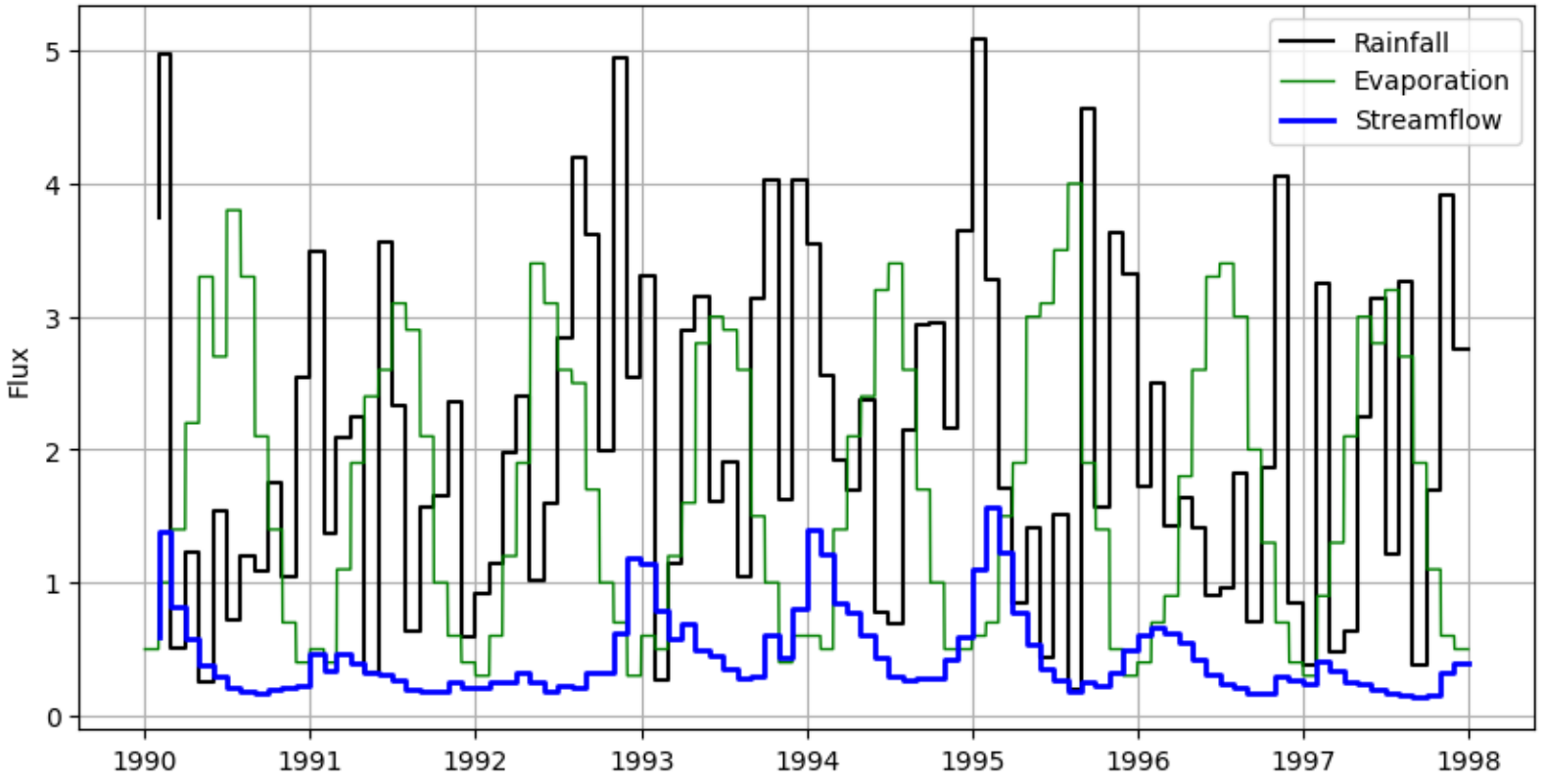
https://pmm.nasa.gov/education/water-cycle/hydrologic-cycle

Human impacts on the hydrological cycle

- Dams and reservoirs
- Hydropower
- Irrigation
- Abstraction (rivers, reservoirs, groundwater)
- Transmission (pipes, canals)
- Domestic water usage
- Industrial water usage
- Water treatment
- Waste water treatment
- Waste effluent
- Storm drains

http://www.pacificwater.org/pages.cfm/water-services/water-demand-management/water-distribution/the-water-cycle.html

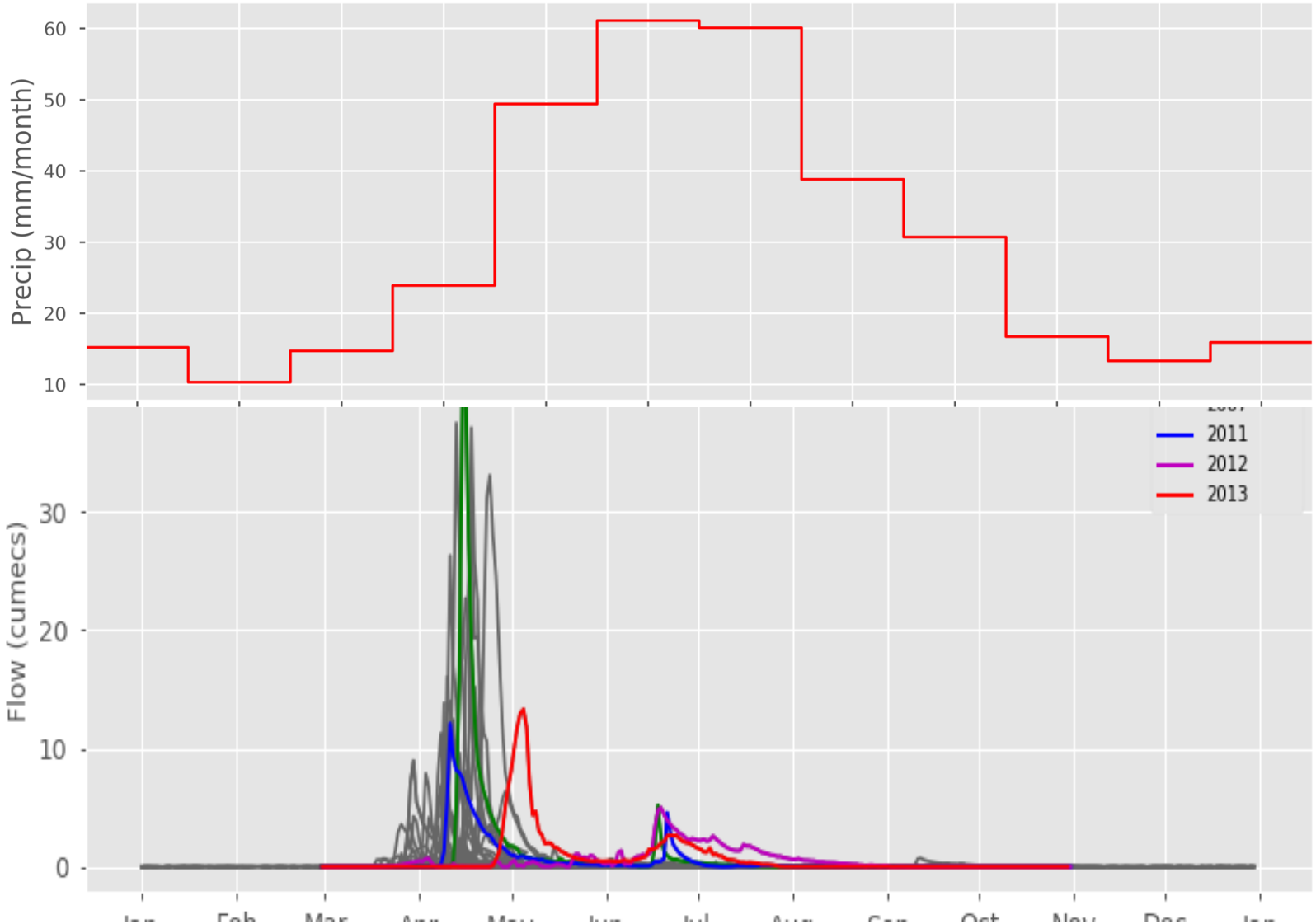
Streamflow in temperate watersheds



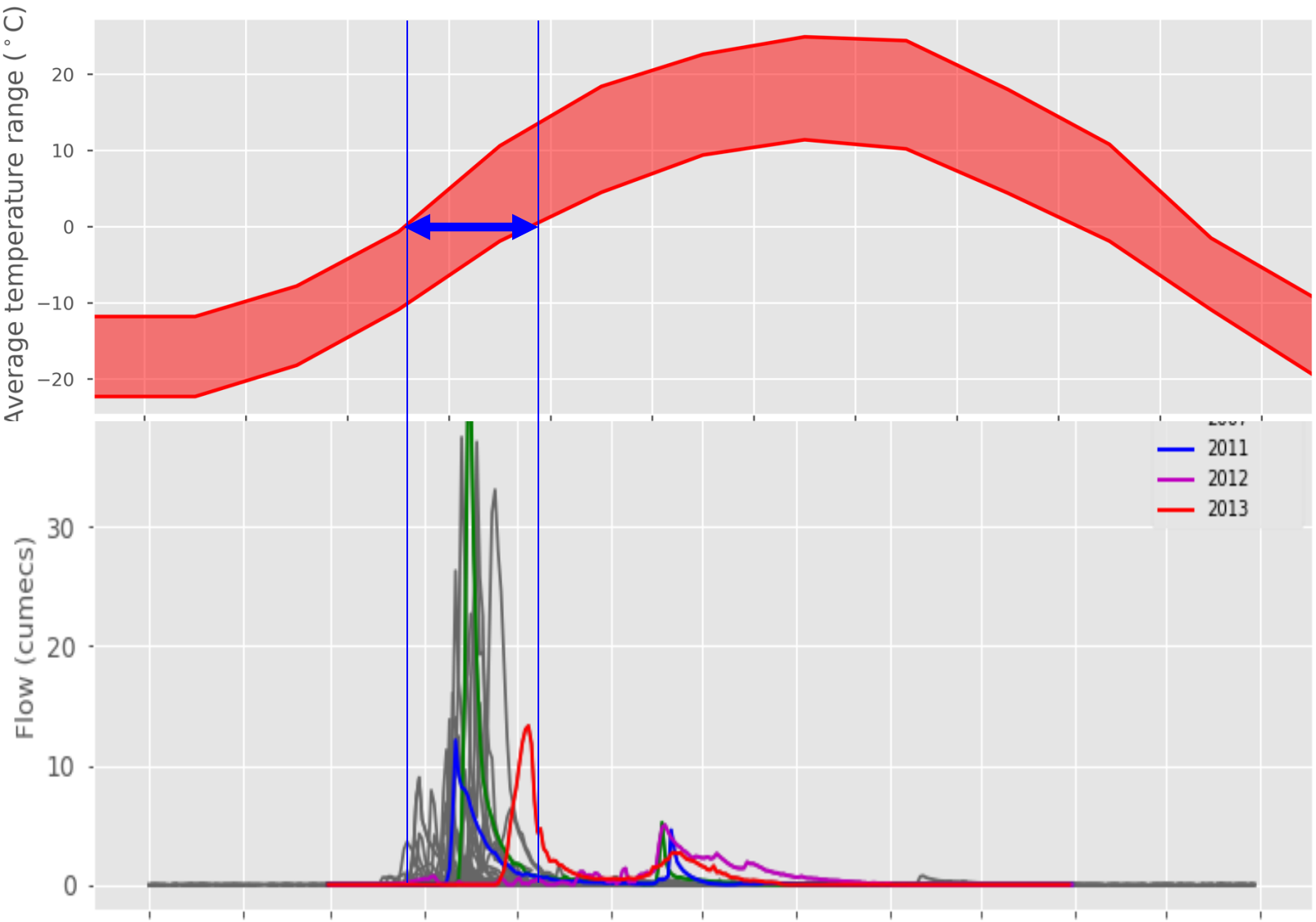
In a temperature watershed we see:

- Runoff (streamflow) responds directly to rainfall: rainfall-runoff
- Runoff is lowered when evaporation is higher

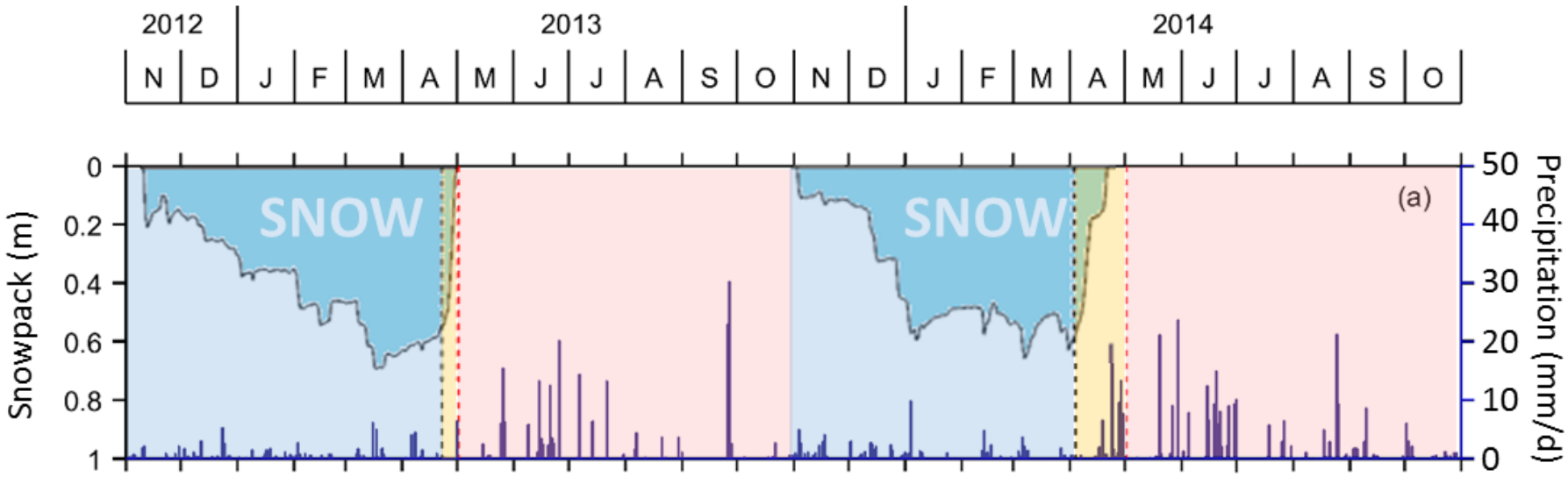
Streamflow in cold-regions watersheds



Temperature-runoff



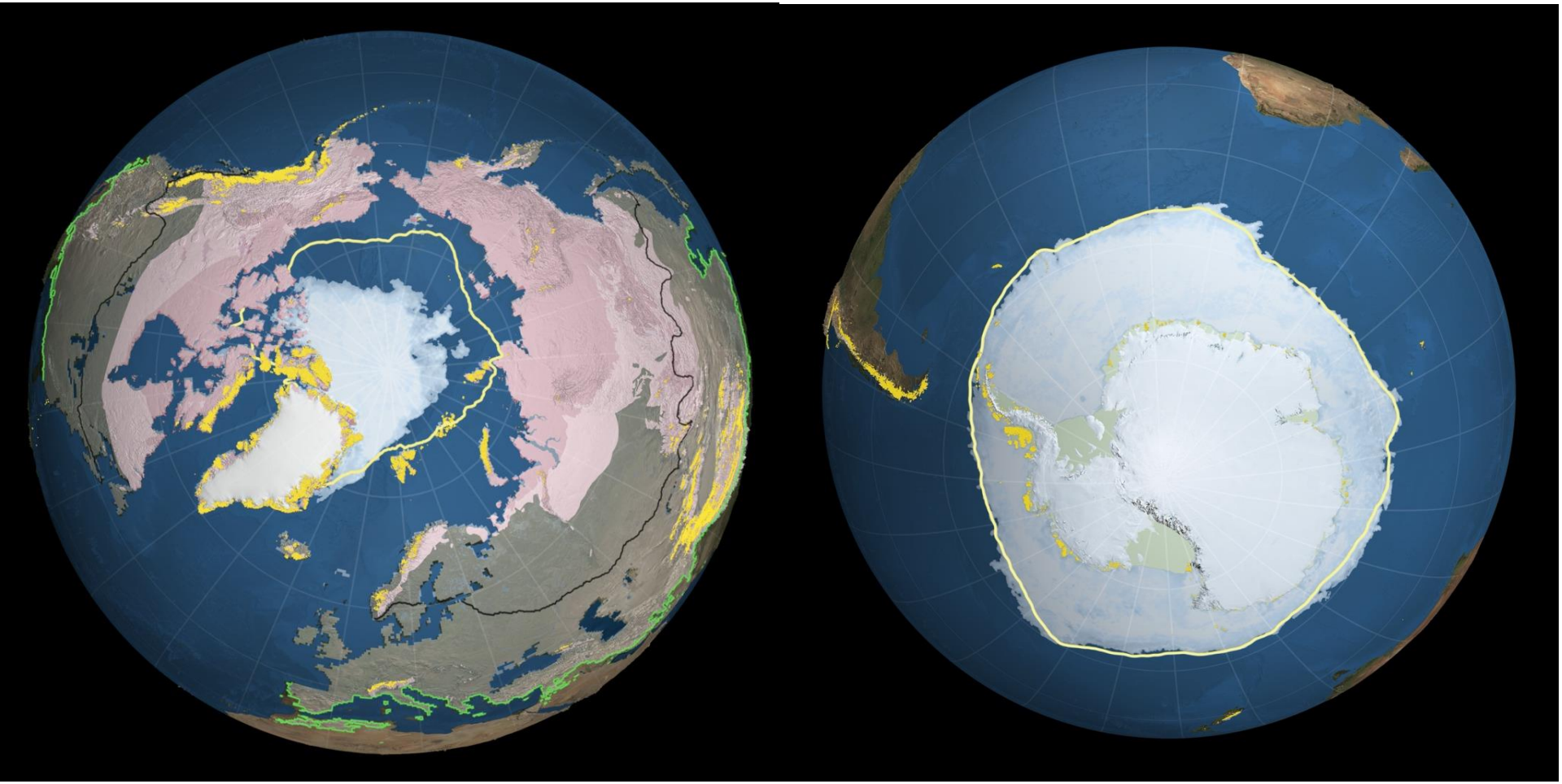
Cold regions seasonality



- Season 1: Snow accumulation (long and cold, slow hydrology)
- Season 2: Snowmelt (short and wet, dynamic hydrology)
- Season 3: Summer/growing season (variable)
- Northern-hemisphere “water year” typically Oct-Sept.

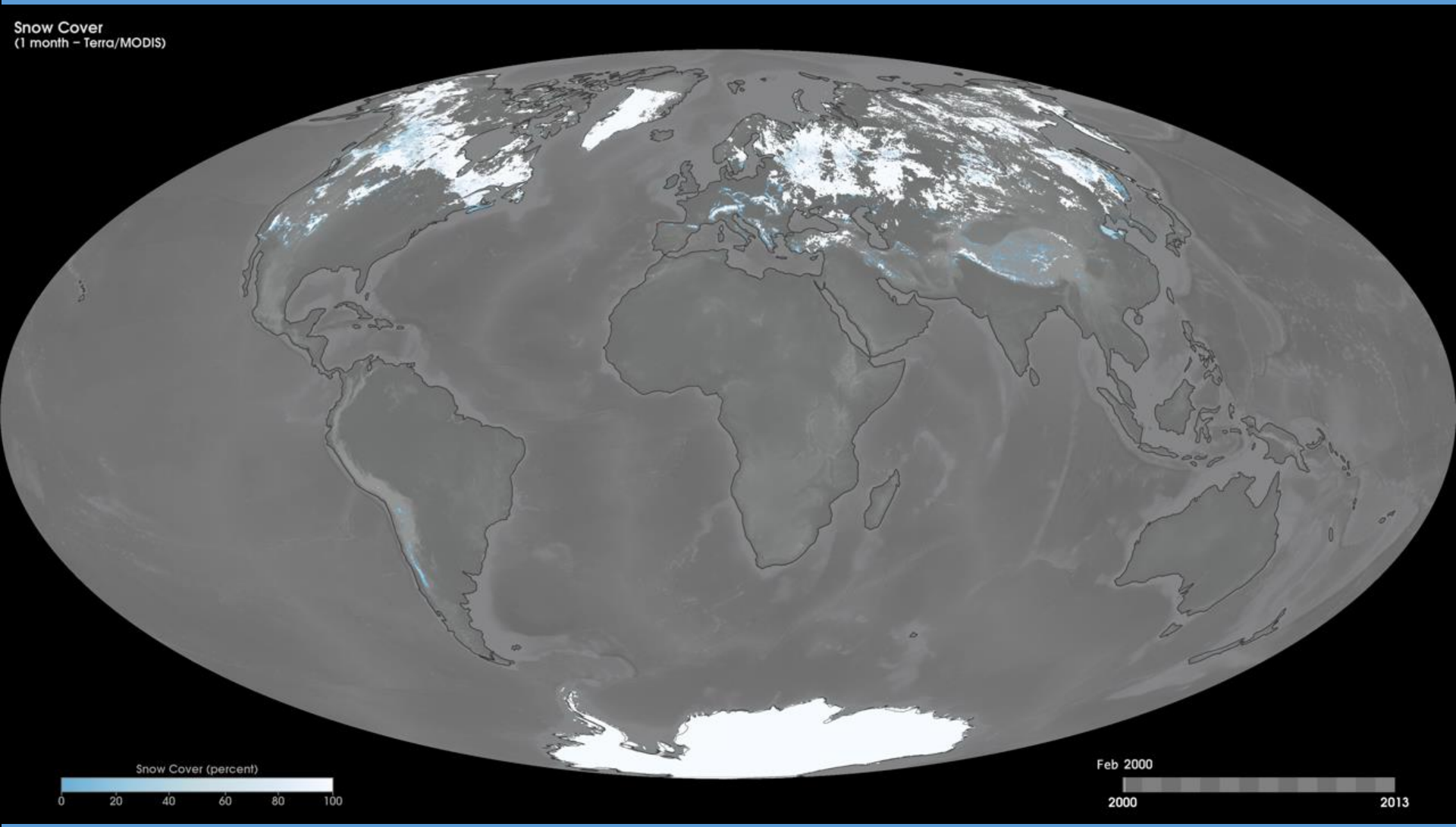
https://doi.org/10.5194/hess-21-5401-2017

The Cryosphere



Snow dominates at high latitudes and high altitudes

NASA/Goddard Space Flight Center Scientific Visualization Studio



NASA SVS: https://svs.gsfc.nasa.gov/30372

Estimated global water resources

Global distribution of water in quantities of km^3

Water source	Total	% total water	% freshwater	Available to biosphere	
Oceans, seas and bays	1,338,000,000	96.5 %	-	-	-
Permanent snow & ice	24,064,000	1.7 %	68.7 %	-	-
Groundwater			-	-	-
Fresh	*10,530,000	0.76 %	30.1 %	5,265,000	97.5%
Saline	12,870,000	0.93 %	-	-	-
Permafrost	300,000	0.022%	0.86 %	-	-
Lakes			-	-	-
Fresh	91,000	0.007 %	0.26 %	91,000	1.69%
Saline	85,400	0.006 %	-	-	-
Soil moisture	16,500	0.0012 %	0.05 %	16,500	0.31%
Atmosphere	12,900	0.0009 %	0.04 %	12,900	0.24%
Swamp water	11,470	0.0008 %	0.03 %	11,470	0.21%
Rivers	2,120	0.0002 %	0.006 %	2,120	0.04%
Biological water	1,120	0.0001 %	0.003 %	1,120	0.02%
Total	1,385,984,510			5,400,110	

After Gleick, P. H. (1996) Water resources. In *Encyclopaedia of Climate and Weather*, Ed. S. H. Schneider, Oxford University Press, New York, Vol. 2, 817-823.

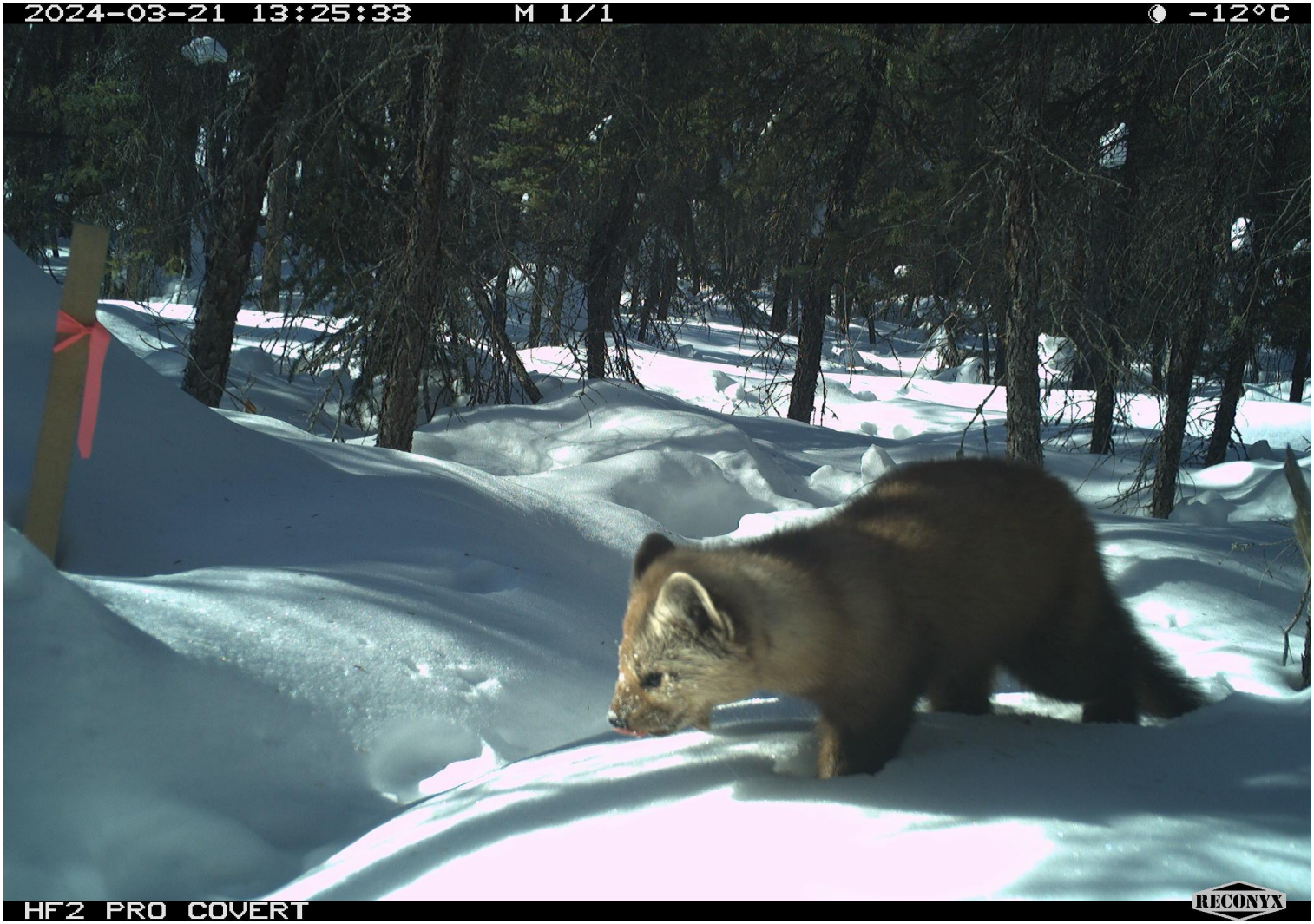
*only 50% of which is < 800 m depth

Components of the cryosphere

The cryosphere is all parts of the planet where water is present in the **solid phase**. Components are:

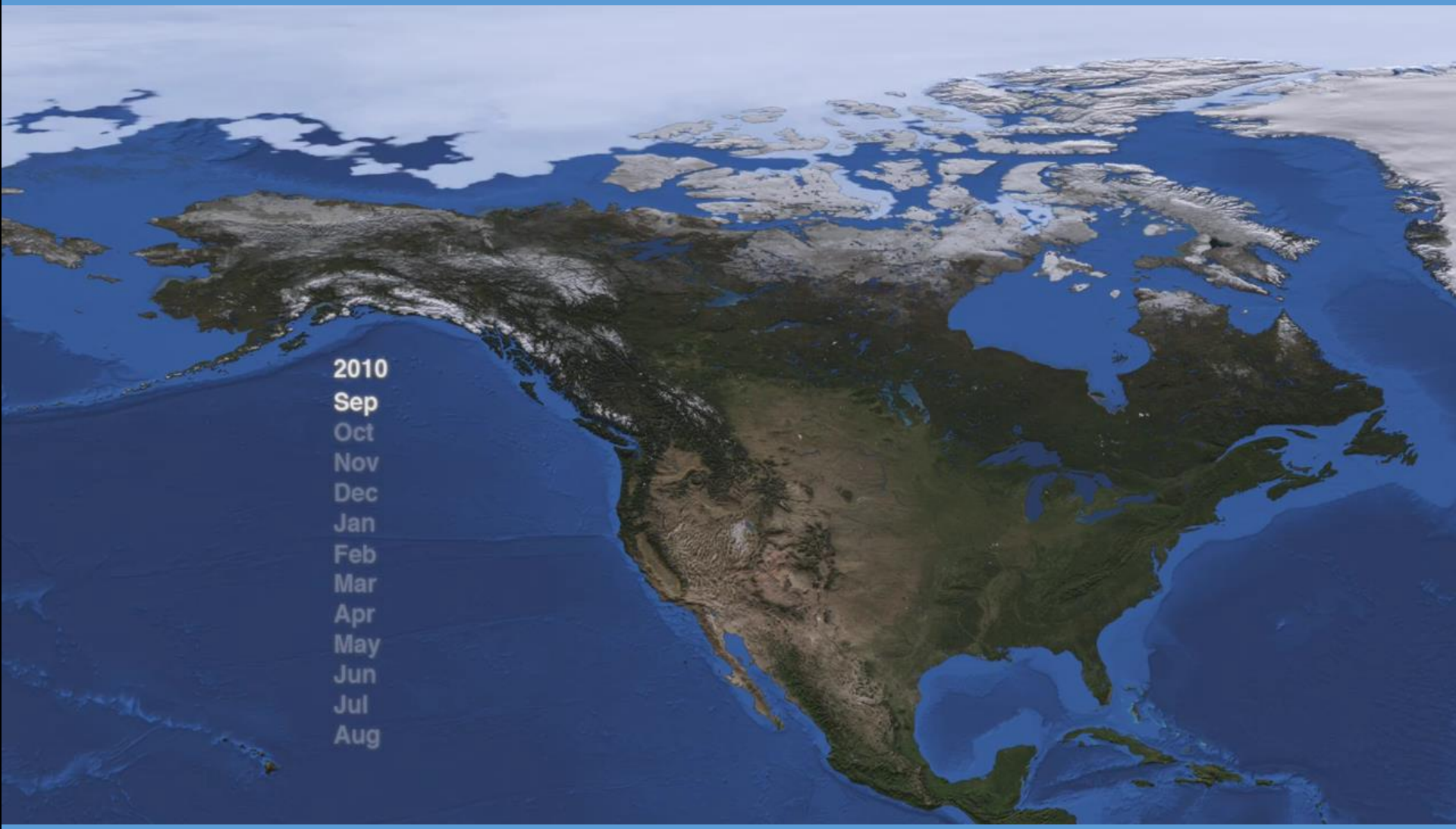
1. Snow
2. Frozen ground
    - Permafrost
    - Seasonally frozen ground
3. Lake ice
4. River ice
5. Glaciers
6. Ice sheets and sea ice

1. Snow



Baker Creek watershed in Northwest Territories
Photo: Alana Muenchrath

NASA/Goddard Space Flight Center Scientific Visualization Studio

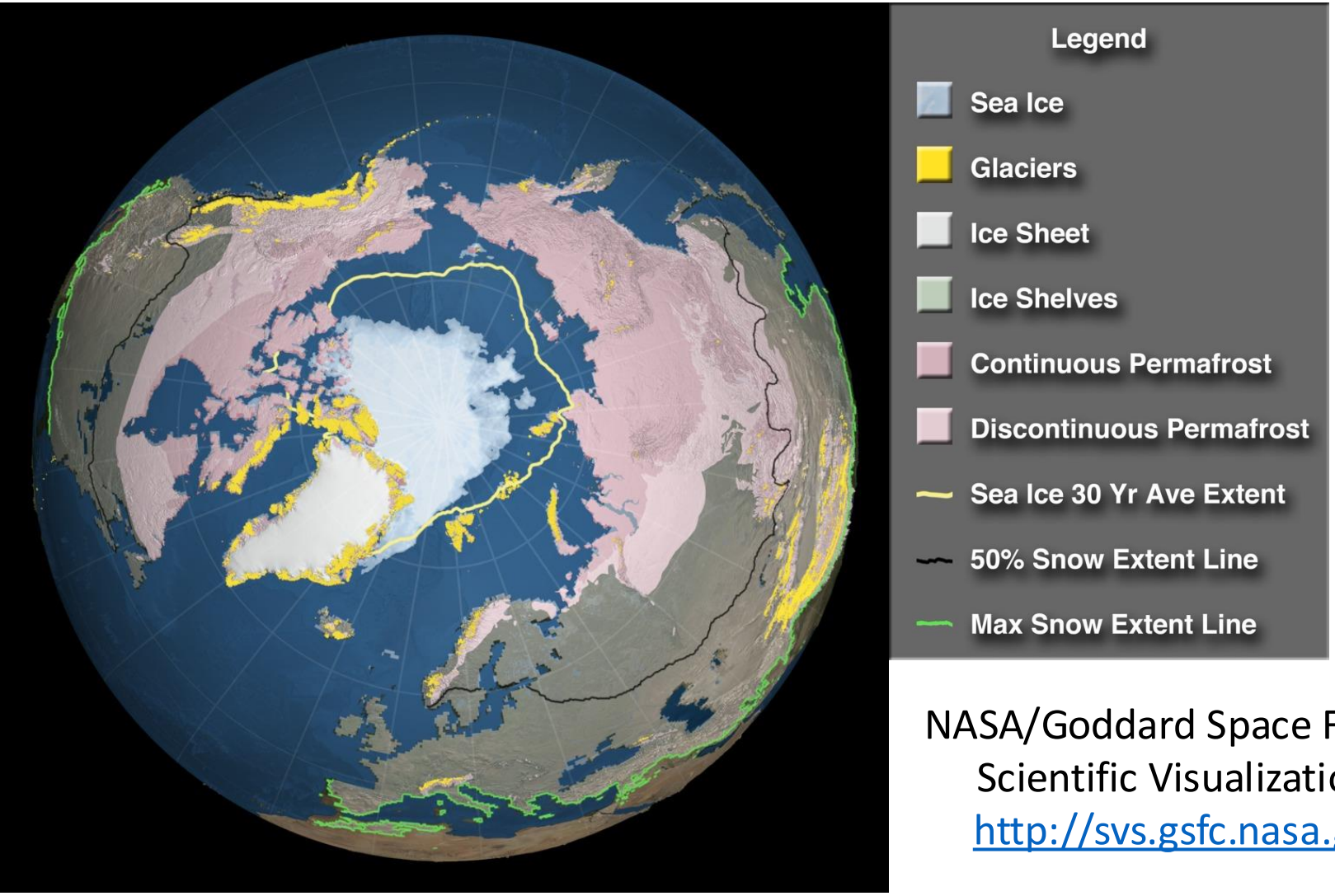


NASA SVS: https://svs.gsfc.nasa.gov/3899

Basic snow processes

- **Snowfall:** In cold regions (high latitude/high altitude) precipitation in the winter falls as snow
- **Snow accumulation**: Over the winter months snow accumulates on the ground and on plants. Due to redistribution by wind, snow accumulates preferentially in depressions and against vegetation and fences
- **Snow ablation**: refers to all the processes that deplete the snowpack, which include:
    - **Snowmelt**: ice in the snow turns to liquid water, which may drain from the snow and form runoff or infiltration
    - **Sublimation**: evaporation of the snowpack – directly from solid phase to vapour phase
    - **Blowing snow**: wind redistribution
- **In spring** snowmelt occurs over a short period of time, injecting a large volume of water into streams, soils and groundwater systems
- We will talk more about this in Lecture 3.

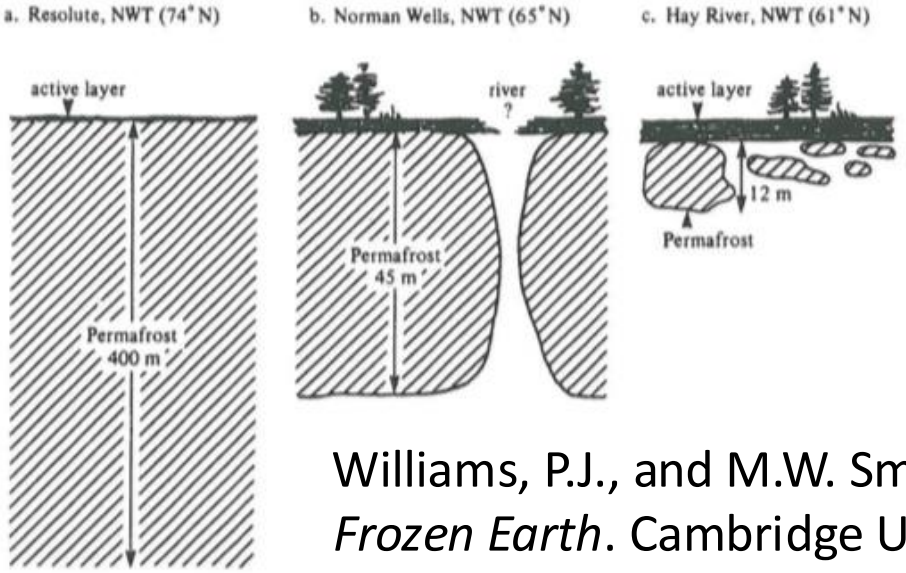
2. Frozen ground



NASA/Goddard Space Flight Center
Scientific Visualization Studio
http://svs.gsfc.nasa.gov/3885

Permafrost

- Generally found in areas where the mean annual temperature is below -1°C.
- "Continuous" vs "Discontinuous" is a spatial distinction:

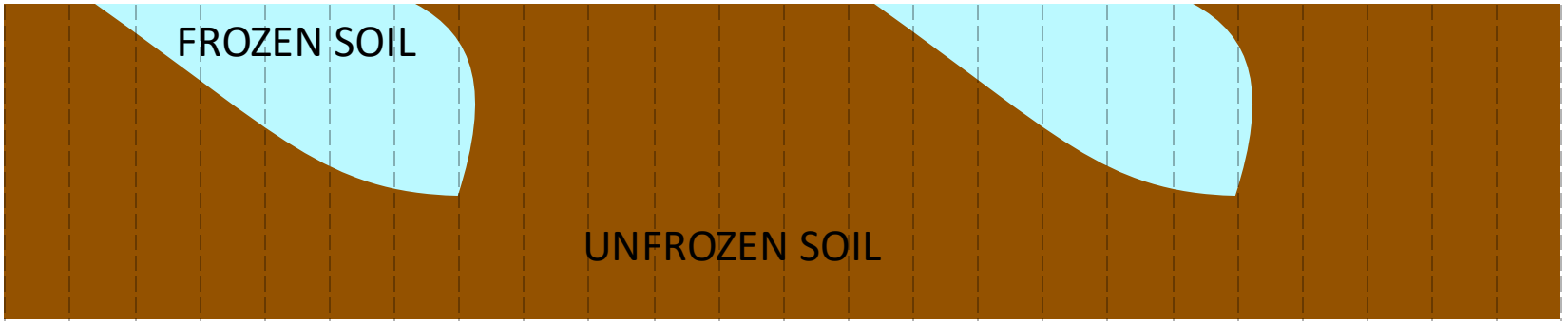


Williams, P.J., and M.W. Smith. 1989. *The Frozen Earth*. Cambridge University Press.

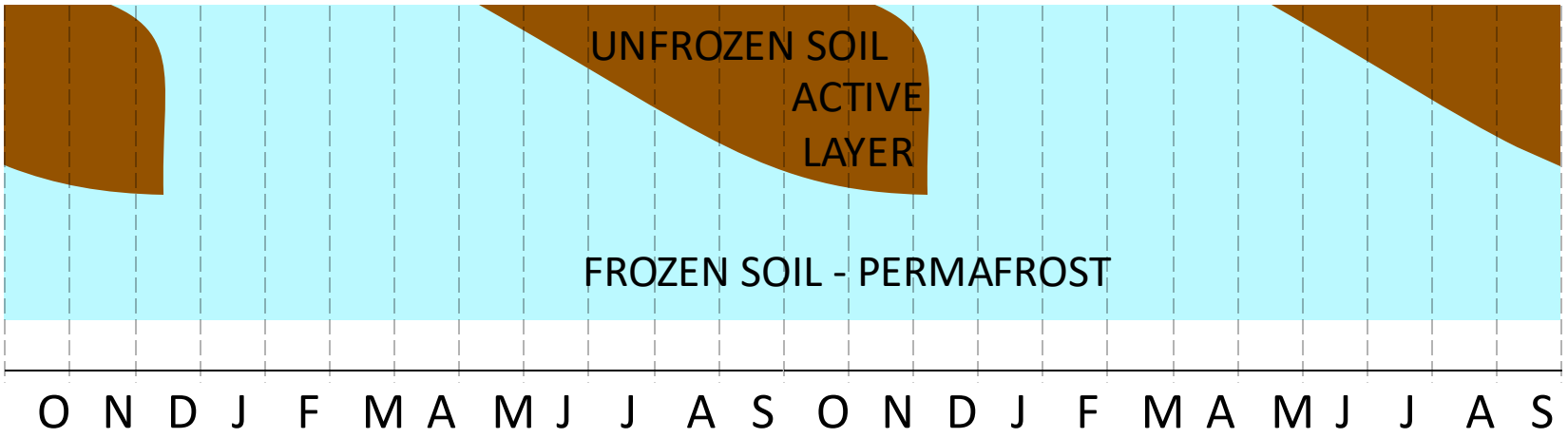
- Permafrost thaw is associated with the release of CH_4 (major GHG)
- Permafrost thaw causes subsidence which can affect trees, roads, pipelines, etc.

Frozen soil – temporal patterns

Seasonally Frozen Soil (Definition: frozen soil that is not permafrost)



Permafrost (Definition: complete thaw frequency < 1 per 2yrs, on average)



Snowmelt runoff vs infiltration

Much of the flooding that happens in the Canadian prairies is caused by snowmelt

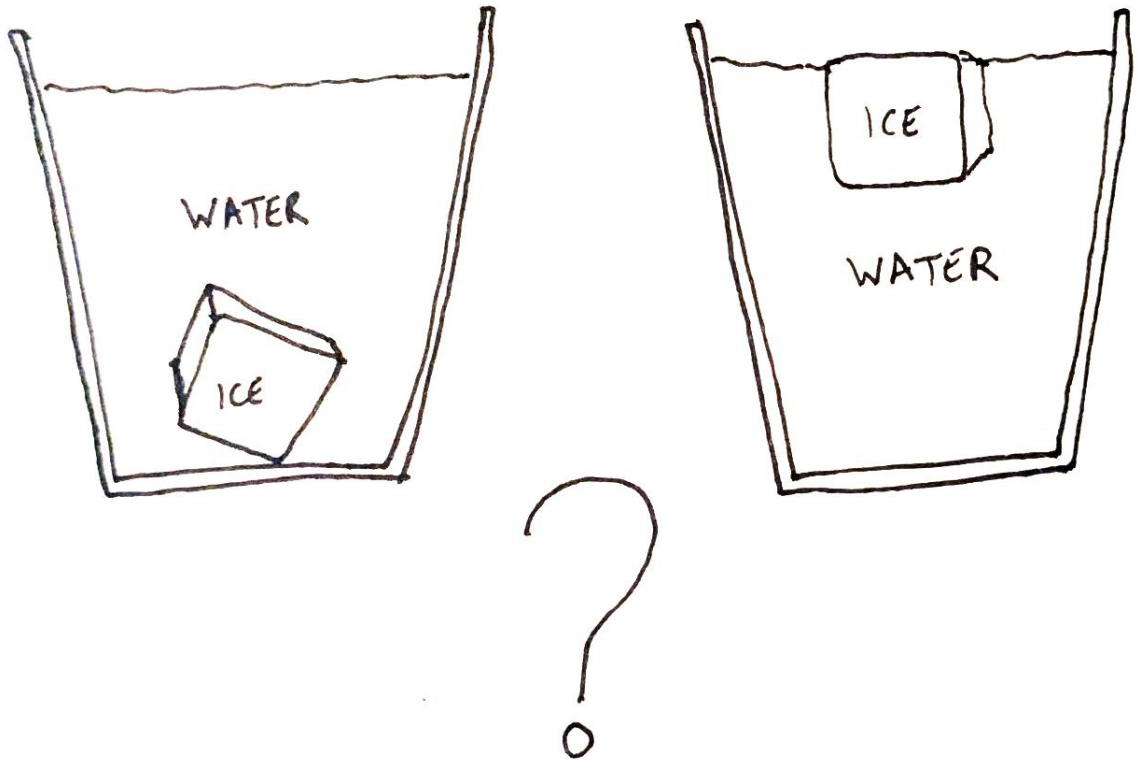
The same snowpack in different years can cause a completely different response?

Why? We shall see in lecture 4.

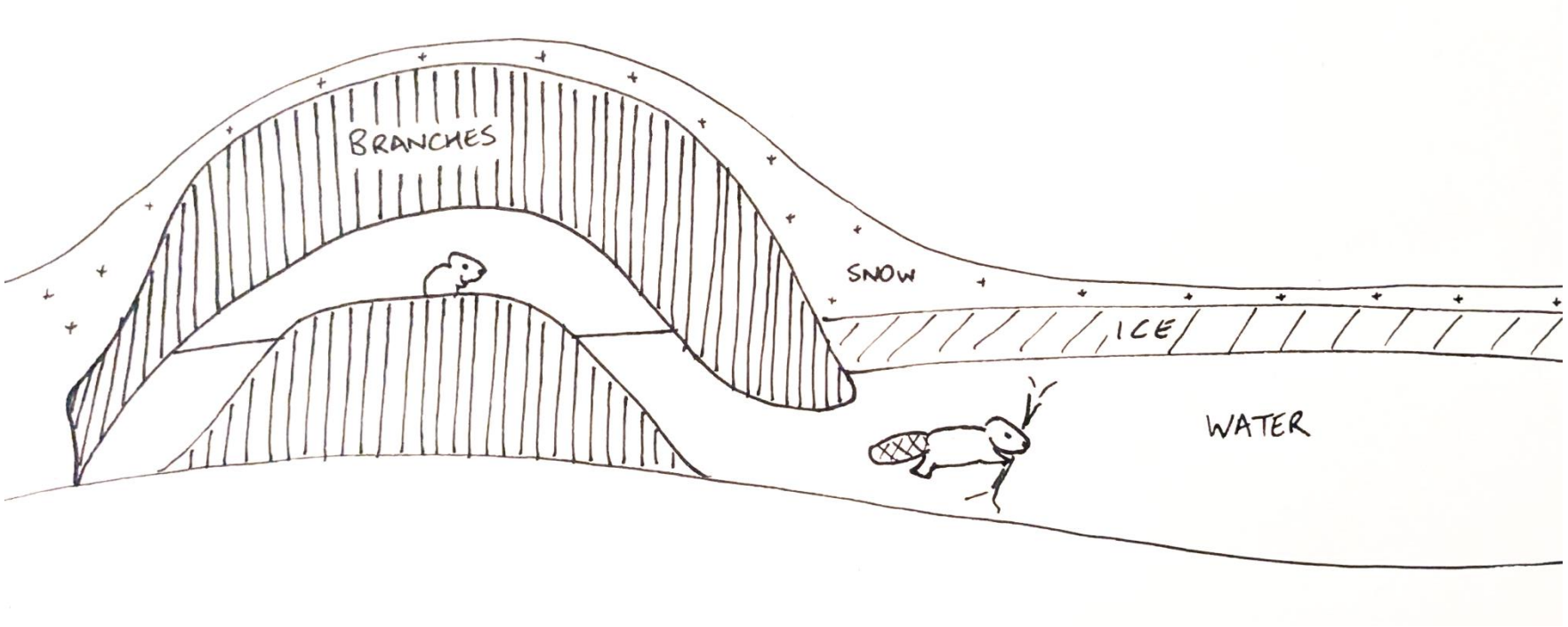
3. Lake ice

Baker Creek watershed in Northwest Territories
Photo: Alana Muenchrath

Which of these is correct?



Beaver habitat under the ice

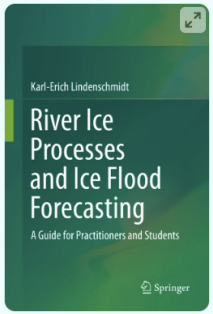


3. Lake ice

https://rescue.borealriver.com/blogs/ice-safety-and-rescue/6-fundamentals-of-ice-assessment

River ice

Ice jams



River Ice Processes and Ice Flood Forecasting

A Guide for Practitioners and Students

Textbook | © 2020

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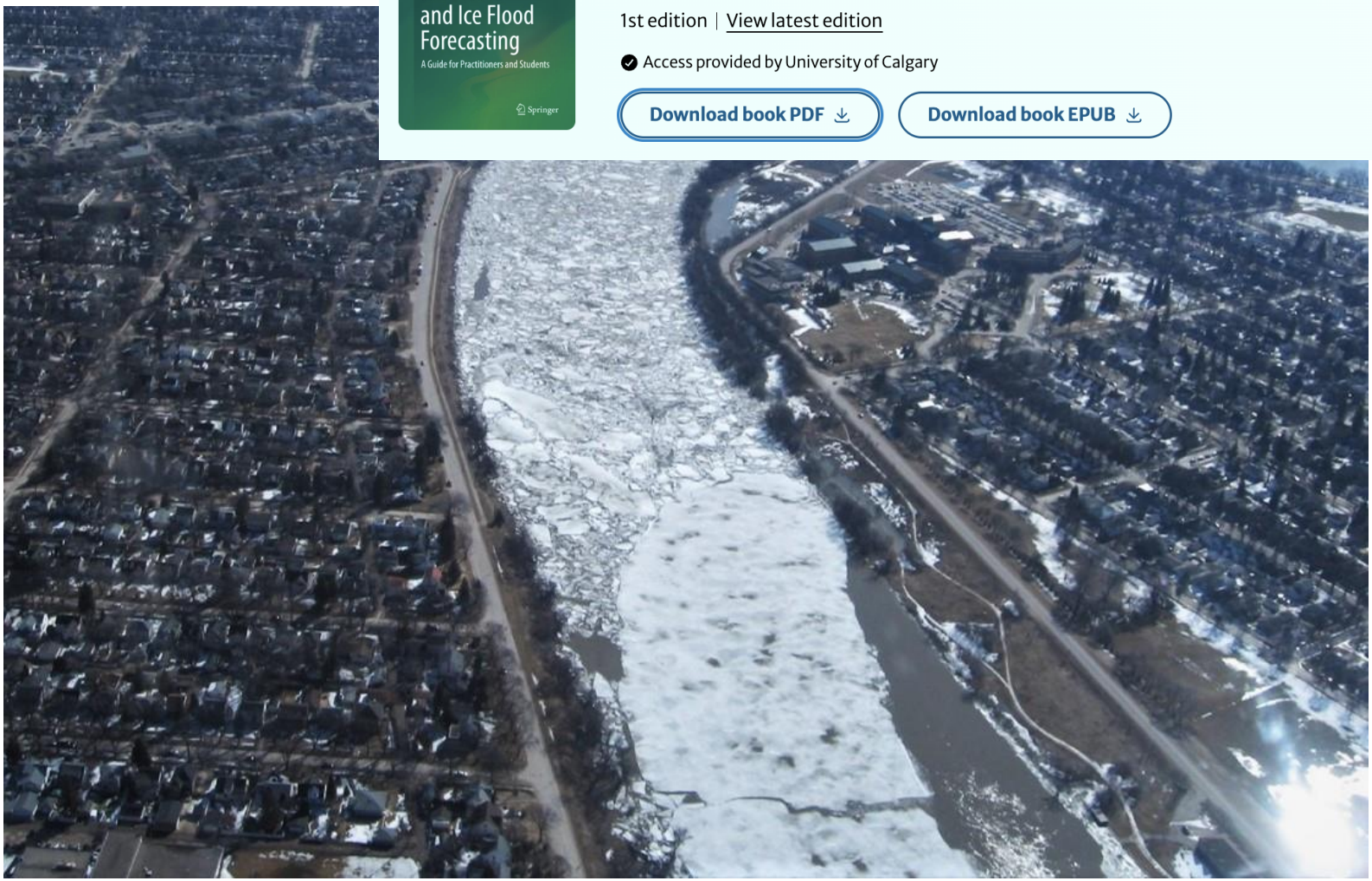
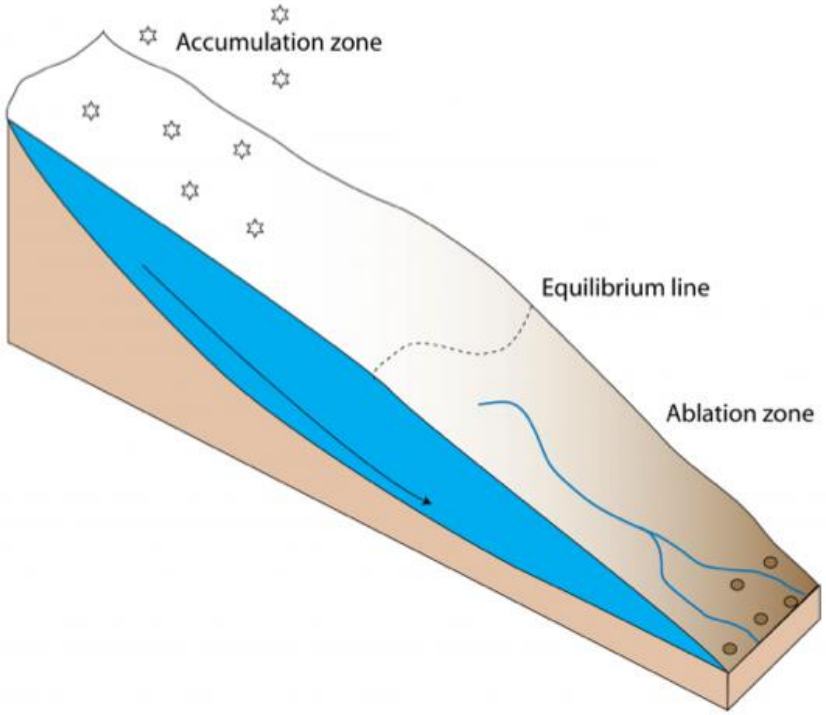


Photo: Ice accumulation and jamming in Winnipeg, Manitoba [by Dr. Karl-Erich Lindenschmidt]

Glaciers

- Formed when Snow accumulation > Snow ablation for many years
- Pressure fuses snow into dense glacial ice
- Ice deforms and flows due to stress of own weight
- Defined as an ice body with area > 0.1 km^2 and thickness > 50 m

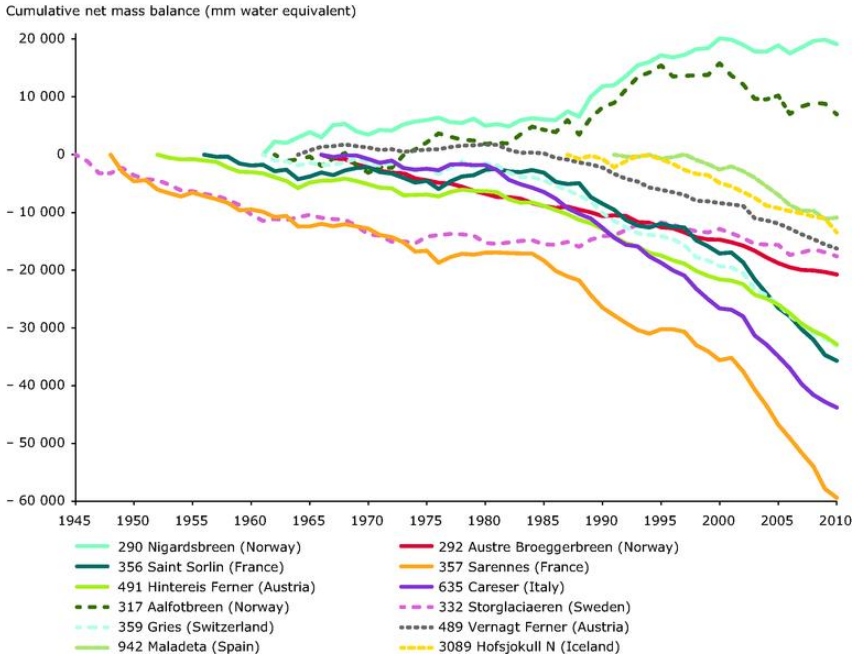



The Athabasca Glacier near Banff, Alberta

http://www.antarcticglaciers.org/

Glacier retreat

- When snow ablation > snow accumulation glaciers retreat
- This does not mean the end of water resources in the downstream community
- It does mean removal of the glaciers buffering capacity for wet/dry years

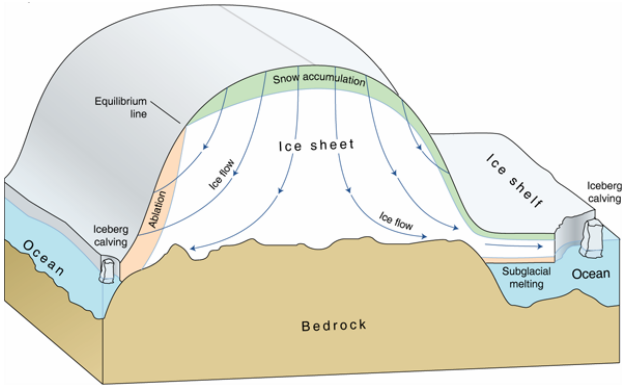


From Glaciers (CLIM 007) assessment, taken from http://www.antarcticglaciers.org/

NASA/Goddard Space Flight Center Scientific Visualization Studio
https://svs.gsfc.nasa.gov/30788

Ice sheets and sea ice

- An ice sheet is basically a glacier that is > 50,000 km^2
- Ice sheets are on land – think Greenland



http://nsidc.org/cryosphere/sotc/ice_sheets.html

- Sea ice expands and contracts seasonally:

	Northern hemisphere	**Southern hemisphere**
Sea ice: DJF	14-16m km^2	3-4m km^2
Sea ice: JJA	4-6m km^2	12-20m km^2

- These are both hugely important to the climate system and to the oceans…
- … but they are not important to hydrology (i.e. the terrestrial water cycle), so I will say no more about them!

Summary of challenges

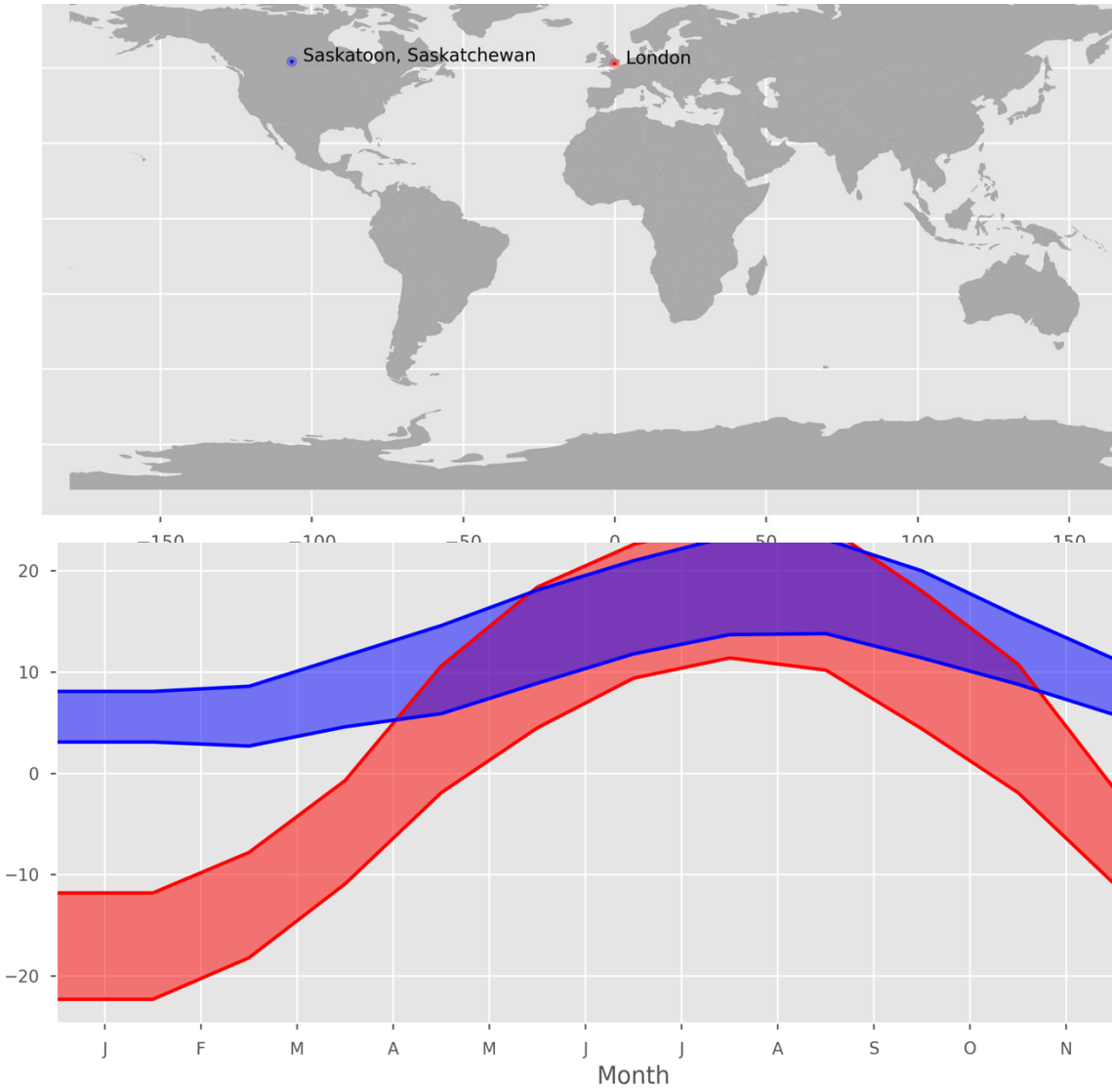
- Managing and predicting water resources and floods is more challenging in cold regions
- The physical processes are more complicated because water exists in the solid phase as well as liquid and gas
- The processes of freezing/thaw are strongly dependent on the energy balance of the Earth's surface. In the next lecture we will talk about energy – or thermodynamic – processes
- Snow accumulates over winter, is redistributed by wind and then melts rapidly in spring – dominating the hydrological cycle
- Ice is less dense than liquid water, so it floats – this is critical for many aquatic life forms

Exercise 1 – discussion of climate

In a group, discuss the following:

1) **Observe** – what are the differences in temperature between Saskatoon and London, UK?

2) **Explain** – why are the temperatures so different? What factors are the same and what factors are different? Think about the sun!

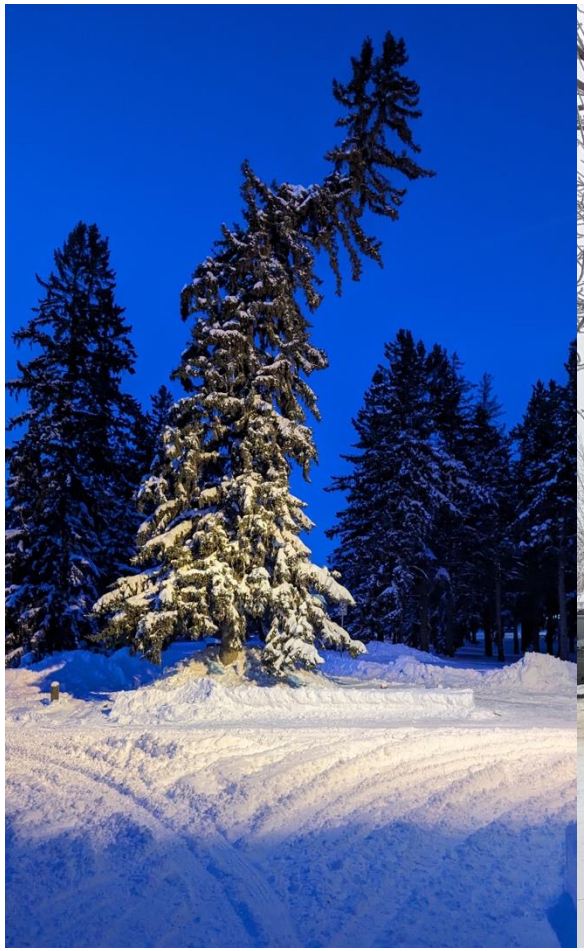


Exercise 2 – trees and snow

In a group, discuss the following:

1) **Observe** – look at these two trees. They are different types of tree. What differences do you see? Do you know what we call each type?

2) **Interpret** – what do you think the role of trees is when it comes to snow processes? What difference do trees make to a watershed?



Exercise 3 – floating ice calculation

Density of liquid water, $\rho_L = 1000$ kg/m^3

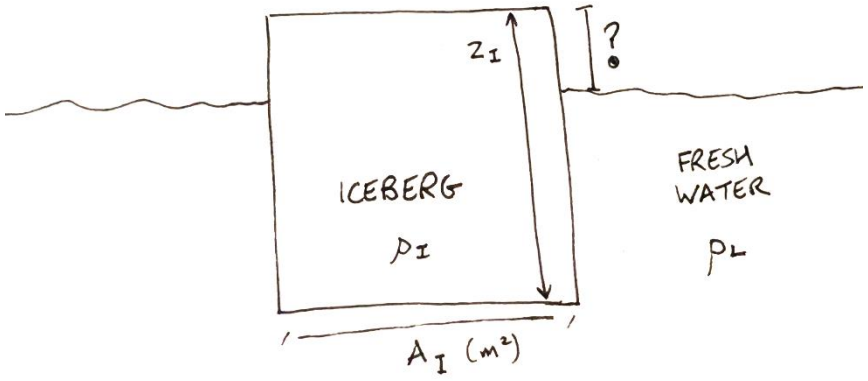
Density of ice, $\rho_I = 918$ kg/m^3

Hydrostatic water pressure $P = \rho_L g z$

Where z is depth below the water surface

Mass of water/ice $m = \rho V$

Use the above to calculate how high an iceberg sticks up above the water surface. To make this simpler consider a square iceberg, as shown:



Exercise 4 – mass, density, volume

Note that $m = \rho V$

Consider that you have 1 liter of water at 0 ^{o}C.

You place a 120 gram ice cube in the water, the ice cube is also at 0 ^{o}C.

Assuming no heat exchange with the surroundings, what happens to the water and cube and why?

What is the volume of the ice cube?

What is the mass of this mixture?