

# Physics & Hydrology of Snow



**Welcome !**

**EPFL**

**Fall Semester 2025**

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## Teachers Team:



Hendrik  
Huwald –  
Lecturer



Michael  
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- THUs, 14:15 – 18:00, room: GR-B3-30
- Lectures: 14:15 – 16:00 (including a break)
- Exercises: 16:15 – 18:00 (GR-B3-30 or GR-C0-02)
- Course value: 4 ECTS credits, optional course; course language: English
  
- Requirements for successful completion:
  - Regular and active participation
  - Exercises / mini projects (counts 50% of final grade)
  - Written exam during exam session (counts 50% of final grade)
  
- Course repository and information/communication tool: **Moodle**  
<http://moodle.epfl.ch/course/view.php?id=9791>

**Slides** (normally) available on Moodle during the morning of the course day at the latest

- Official course description: see EPFL course book ([is-academia.epfl.ch](http://is-academia.epfl.ch))
  
- Participants from **other Sections** please make sure that course credits are accepted



## Textbooks and Reading:

### Textbooks:

- Armstrong, R.L. and E. Brun, (Eds.), 2008. Snow and climate, Cambridge University Press, 222 pp.
- Barry, R.G. and T.Y. Gan, 2022. The global cryosphere, Cambridge University Press, 573 pp.
- DeWalle, D.R. and A. Rango, 2008. Principles of snow hydrology, Cambridge University Press, 410 pp.
- McClung, D., and P.A. Schaerer. The avalanche handbook. The Mountaineers Books, 2006.

The course slides do not replace/exclude complementary literature and are not a full-scale textbook !

Some additional texts and articles will be available on Moodle; reading is strongly recommended.

### Journal articles:

In case of particular interest, teachers will provide references for topical reading or research papers.



## Exercises and Homework:

- current plan: 6 exercise series will be assigned
- to be addressed during the exercise hour (TA's present/available), and after course hours (no TA's, but "office hours" and course forum)
- due 2 weeks later at the beginning of class (if not specified otherwise) see assignments on Moodle (normally online submission, pdf)
- homework/exercises are **individual** (if not specified otherwise)  
mini projects: **snow model exercises** are completed in **teams of two**, if possible, keep teams during the semester
- missing (or unexcused late) submission results in a **grade 1** for the respective assignment



## Teaching methods:



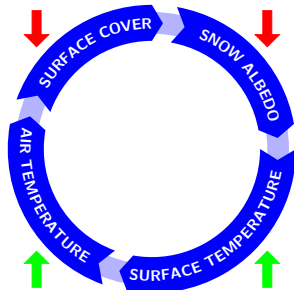
- Interactive lectures, however, ...
- Independent studying is expected at MSc level !  
Application of established **self-learning** techniques and practices is encouraged.
- Take notes !!! Go **beyond** the course slides !
- We want **you** to **participate**. Feel free to ask questions or request additional explanation / clarification when needed. There are no "stupid" questions, so don't be shy.
- We are happy to **help!** Please ask if something remains unclear.  
(Also related to language comprehension, e.g. technical terms etc.).



Date	#	Topic / Subject (tentative schedule)	Exercise
11.09.	01	Introduction & Overview / Snow properties: physical, thermal, optical, (mechanical)	---
18.09.	02	Snow energy balance, atmospheric boundary layer	<b>EX1</b>
25.09.	03	Introduction to the SNOWPACK model – heat and mass transfer in snow	---
02.10.	04	Introduction to the SNOWPACK model – practical introduction as lab session	<b>EX2</b>
09.10.	05	Snow formation in the atmosphere, Snow micro-structure and metamorphism	---
16.10.	06	Snow melt and runoff processes (thermo-/dynamics and modeling)	<b>EX3</b>
30.10.	07	Snow mass balance, transport, snow drift, snow redistribution	---
06.11.	08	Spatio-temporal variability of the snow cover	<b>EX4</b>
13.11.	09	Snow interception, canopies, vegetation / Permafrost	---
20.11.	10	Stable water isotopes in snow	<b>EX5</b>
27.11.	11	Snow (-related) measurement techniques, and field methods	---
04.12.	12	Snow & avalanche mechanics #1	<b>EX6</b>
11.12.	13	Snow & avalanche mechanics #2	---
18.12.	14	Snow cover & climate (change), climatology, feedback mechanisms	---

- This course provides a **comprehensive introduction** to the principles of snow **physics**, snow **hydrology**, snow-atmosphere interaction, and snow **modeling**.
- Dynamics and thermodynamics of snow will be discussed to develop a **theoretical** and **practical** understanding of **physical processes** within the snow and at its interfaces with the atmosphere and the ground.

(a) qualitatively / schematically



Example

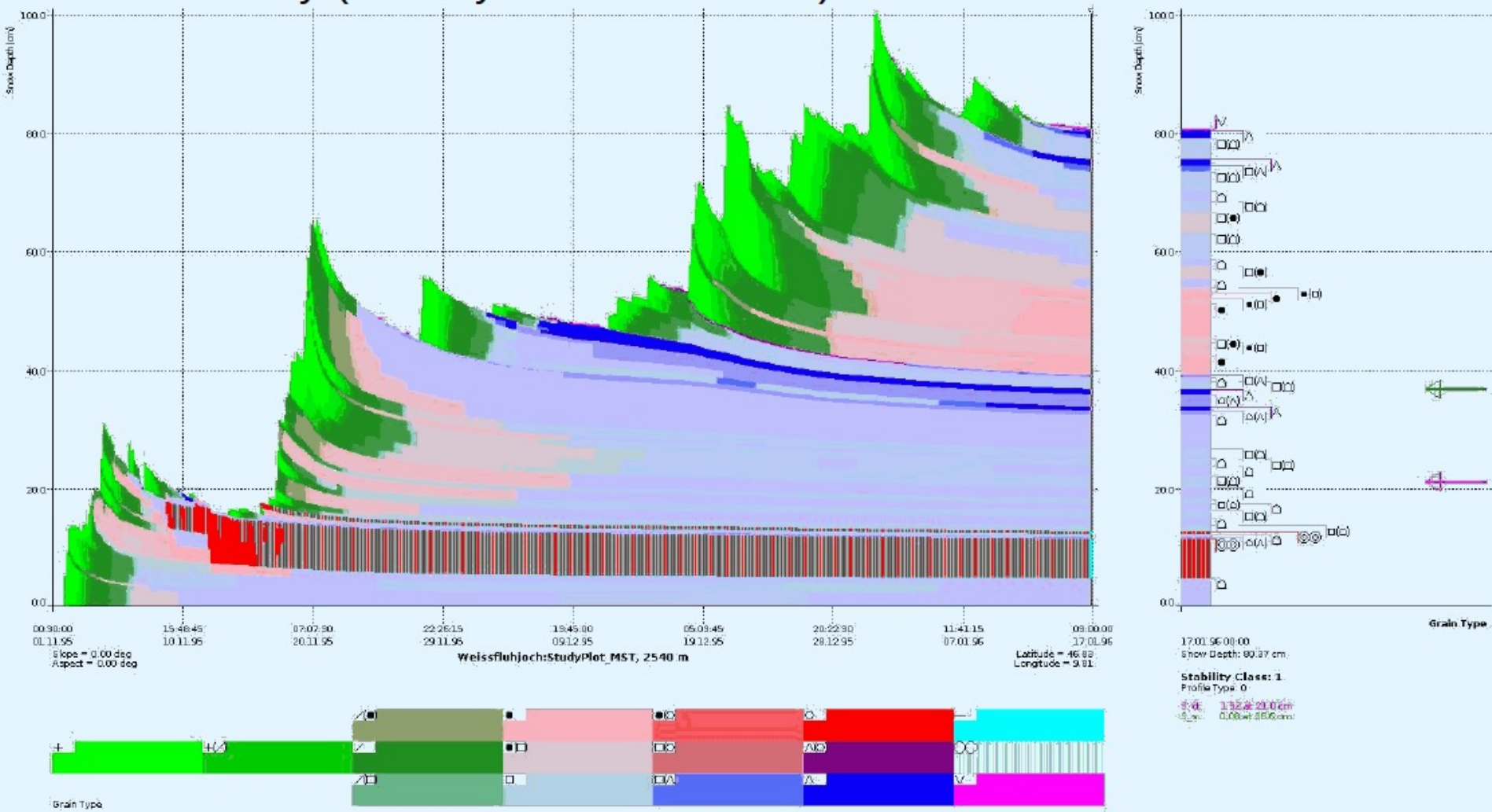
(b) quantitatively / mathematically

$$Q_{net} = (1 - \alpha)(SW_{dir} + SW_{dif}) + LW_{inc} - \varepsilon\sigma T_s^4 + \left(-k_s \frac{dT}{dz}\right) + \rho_a c_{pa} \left(\frac{k}{\ln(z/z_0)}\right)^2 \bar{u}(T_a - T_s) + \rho_a L_s \left(\frac{k}{\ln(z/z_0)}\right)^2 \bar{u}(q_a - q_s)$$

Example

- The course covers the broad field of snow science including field, laboratory, and modeling techniques. **Practical work** will include modeling problems with the snow model “SNOWPACK” and MAYBE an **excursion**, depending on weather and suitable date.

Learning and using SNOWPACK for simulations, validations, scenario calculations







**Questions?  
Comments?**

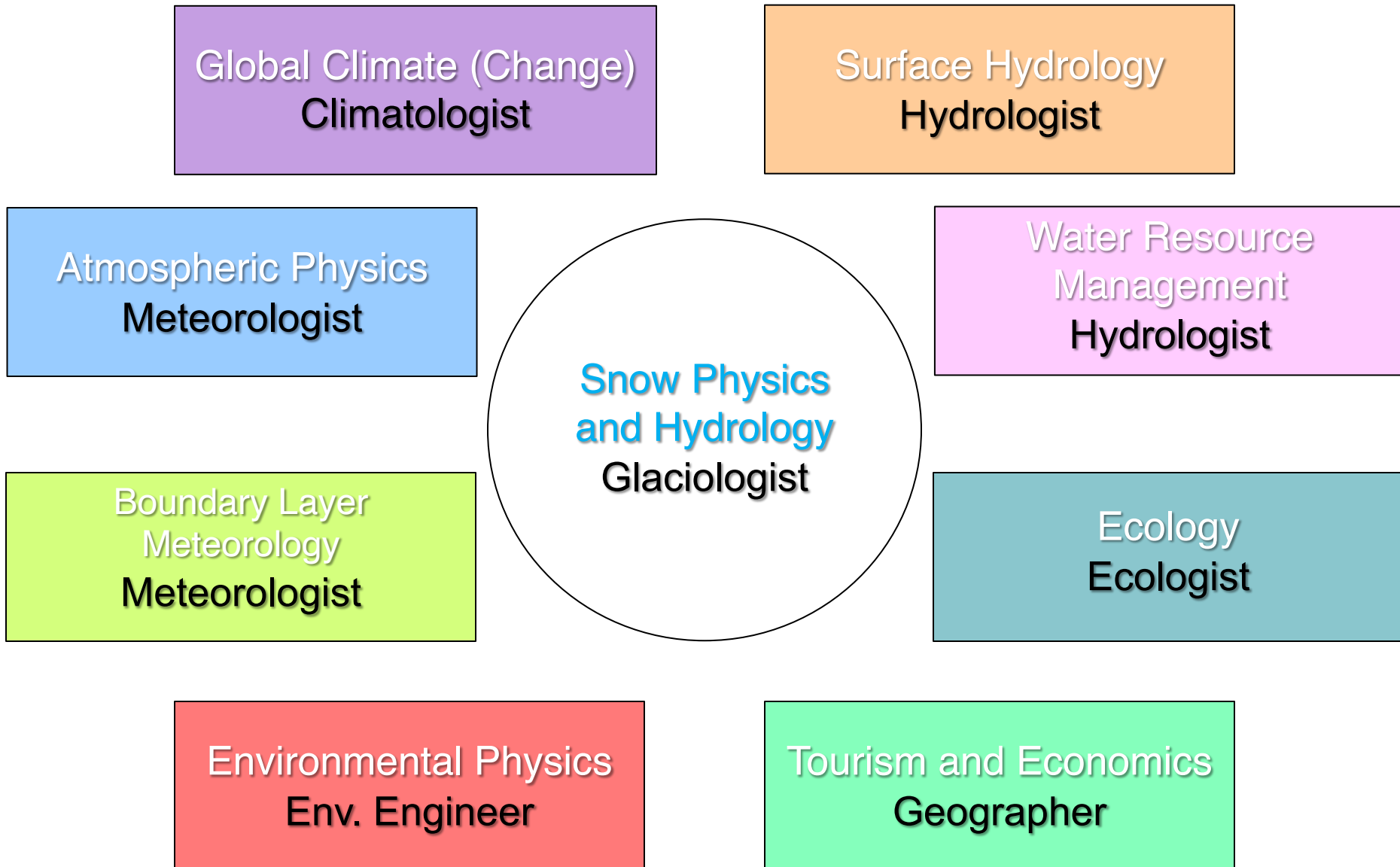
**Feel free to ask anytime,  
→ interactive discussion**



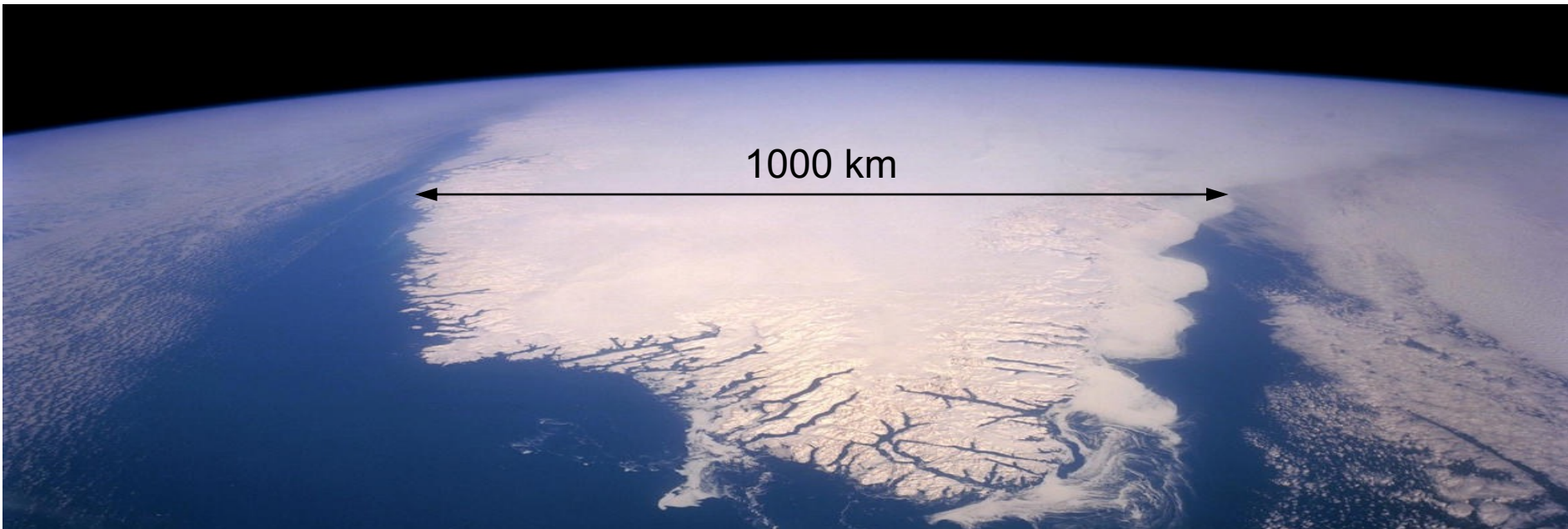
The larger context / framework:

- Snow (seasonal and perennial)
- Glaciers (alpine and polar), incl. ice caps
- Ice sheets (Greenland, Antarctica)
- Sea ice (Arctic and Circum-Antarctic = Southern Ocean)
- Ice shelves and icebergs
- Permafrost (frozen ground)
- Lake and river ice





# Snow across scales ...



- porous...
- granular...
- multi-grain...
- multi-phase...
- transformative...
- stratified/layered...
- visco-elastic...

material. →

Water in 3 phases

- + Air and trace gases
- + pollutants, algae, bacteria, etc.)





## 1. Natural snow:

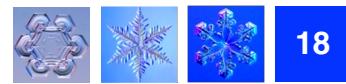
naturally deposited with characteristic internal structure

## 2. Disturbed snow:

loss of original structure due to avalanches, management (street and slope grooming, snowplow, snow cat), anthropogenic influence and redistribution or compaction (e.g., skiing)

## 3. Artificial snow:

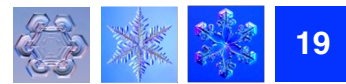
snow guns / cannons, snow production for winter sports



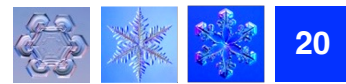
- **Reflects** large fraction of incoming solar radiation (VIS)
- High **emissivity** for infrared radiation (NIR / TIR)  
(increases radiative losses from the snow surface)
- Acts as an efficient thermal **insulator**

## Consequences:

- Due to transmission and absorption, snow is still a radiative sink for VIS
- Radiative losses (NIR, TIR) at the surface are not replaced quickly by vertical (conductive) heat fluxes from below  
(→ nighttime cooling very efficient)
- Large vertical temperature gradients ( $\gg 10\text{K/m}$ ) may exist



- Energy buffer controlling ambient thermal conditions
  - this is especially the case when melt occurs (→ latent heat)
  - large amount of energy is required to change to liquid phase
  - melt water is typically lost (drains to the snowpack base)
  - ( (melt-) water may be a source of latent heat; refreezing)
- Snow cover reduces aerodynamic roughness of the landscape
  - reduces turbulence and mixing and therefore
  - reduces latent and sensible heat transfer over the landscape  
(when compared with non-snow-covered surfaces)



Local boundary layer effects:

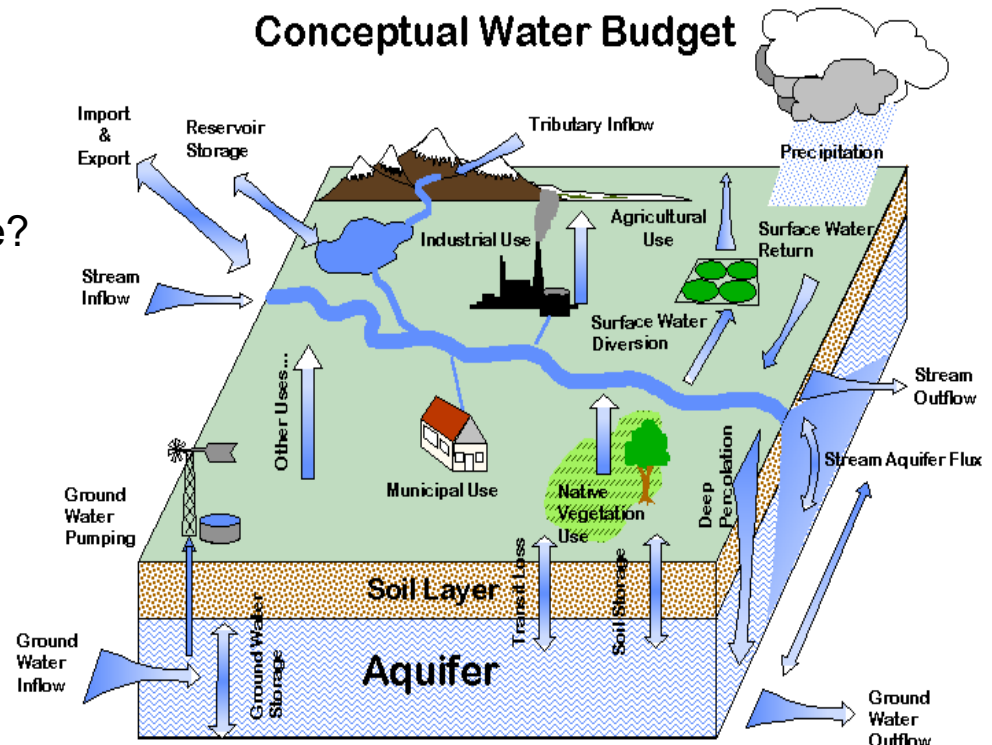
- Boundary layer **air temperatures** are decreased over snow
- Atmospheric **stability** is increased
- Temperature **inversions** are common →
- Cold air drainage from upland to lowland areas (katabatic flow)
- Increased pollution in cities and basins adjacent to mountains

**IN SUMMARY:** snow significantly changes the surface energy budget from local to global scale and consequently the surface hydrology

- Longer residence time of snow cover means higher reliability of water resources.
- Many water resource management issues and benefits are linked to snowmelt runoff (e.g. timing & intensity).
- Climate change impacts on water resources are critical:  
(earlier melt, less snow, higher evaporation, longer dry season).

Figure – essential points:

- a) where does most of the runoff originate?
  - b) where is a large fraction of the water temporarily stored ?
- a. Mountains and high altitude
  - b. Seasonal snow cover
  - c. Aquifer (ground water)
  - d. Lakes and reservoirs

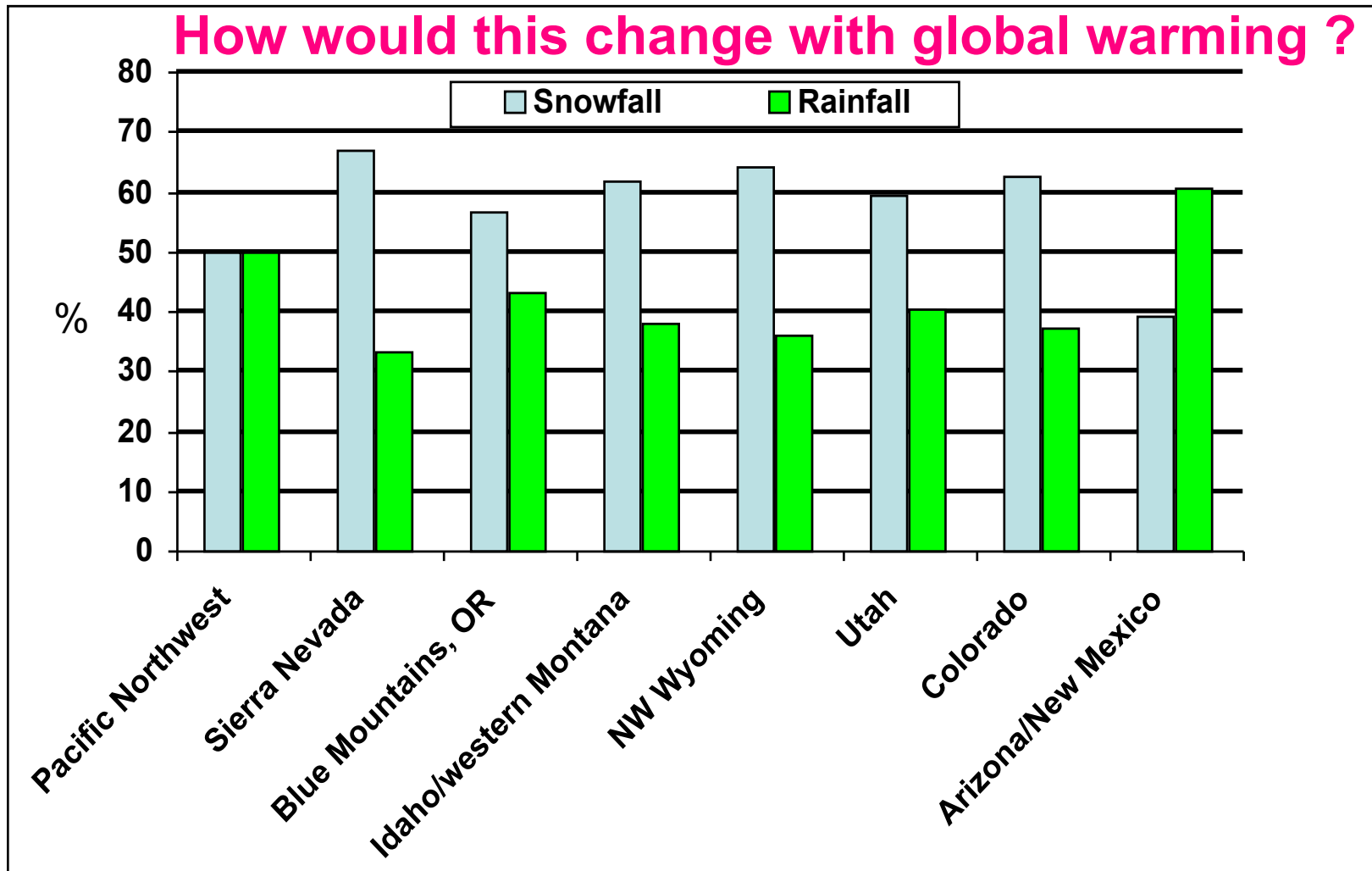




- Snow drastically modifies (dominates) the energy and water fluxes at or near the land surface – even at long distance from the snow cover
- Creates very important feedback on climate
- Acts as temporary water storage
- Controls ground water recharge
- Constitutes water supply for agriculture and irrigation
- Moderates demand-supply problems in water-scarce regions



Relative amounts of snow and rain in the Western US (large dry areas)



# Global snow cover: Northern Hemisphere



**Seasonal snow vs. Permanent (perennial) snow**

# Global snow cover: Europe & Asia



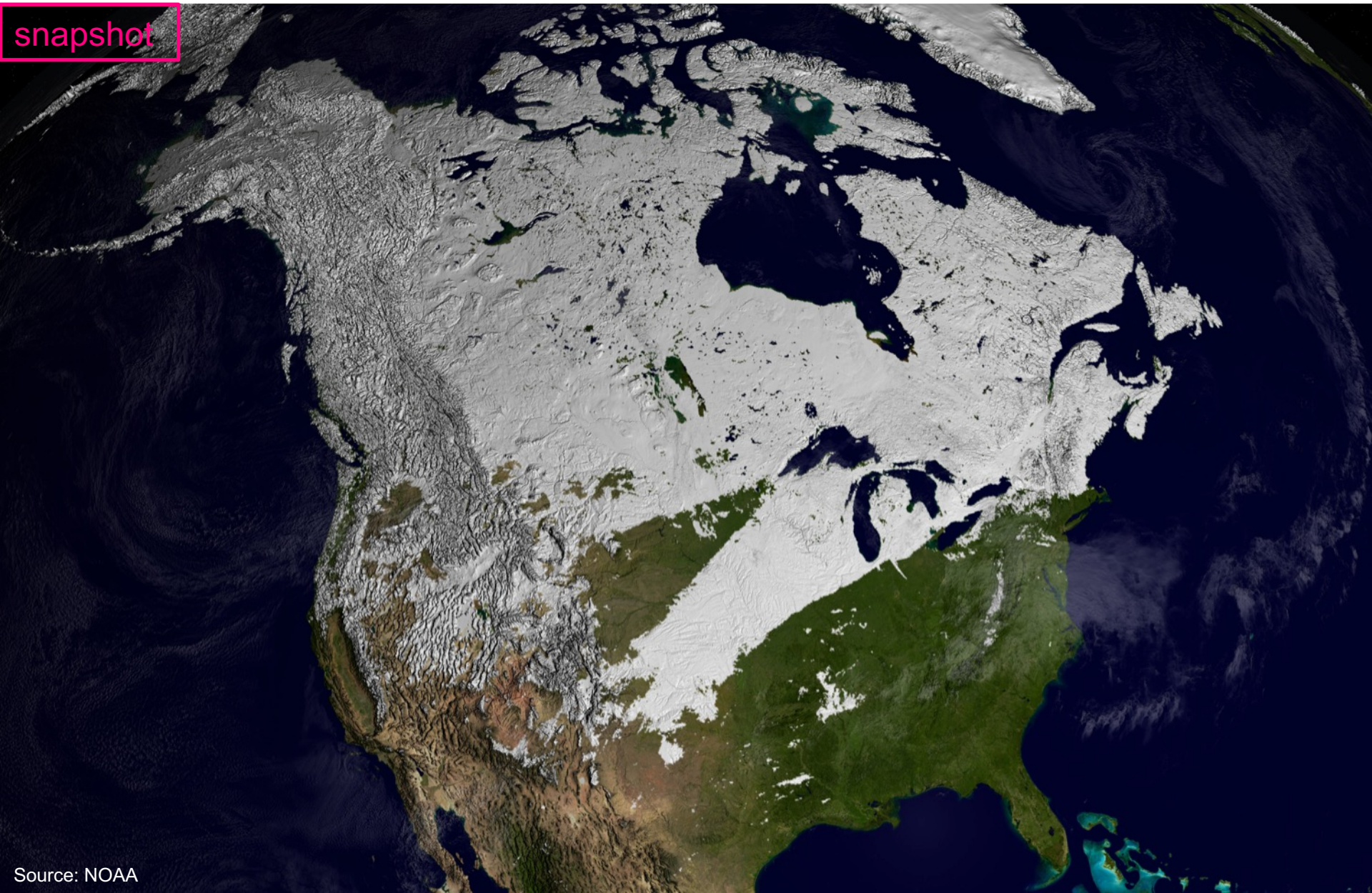
snapshot



# Global snow cover: North America



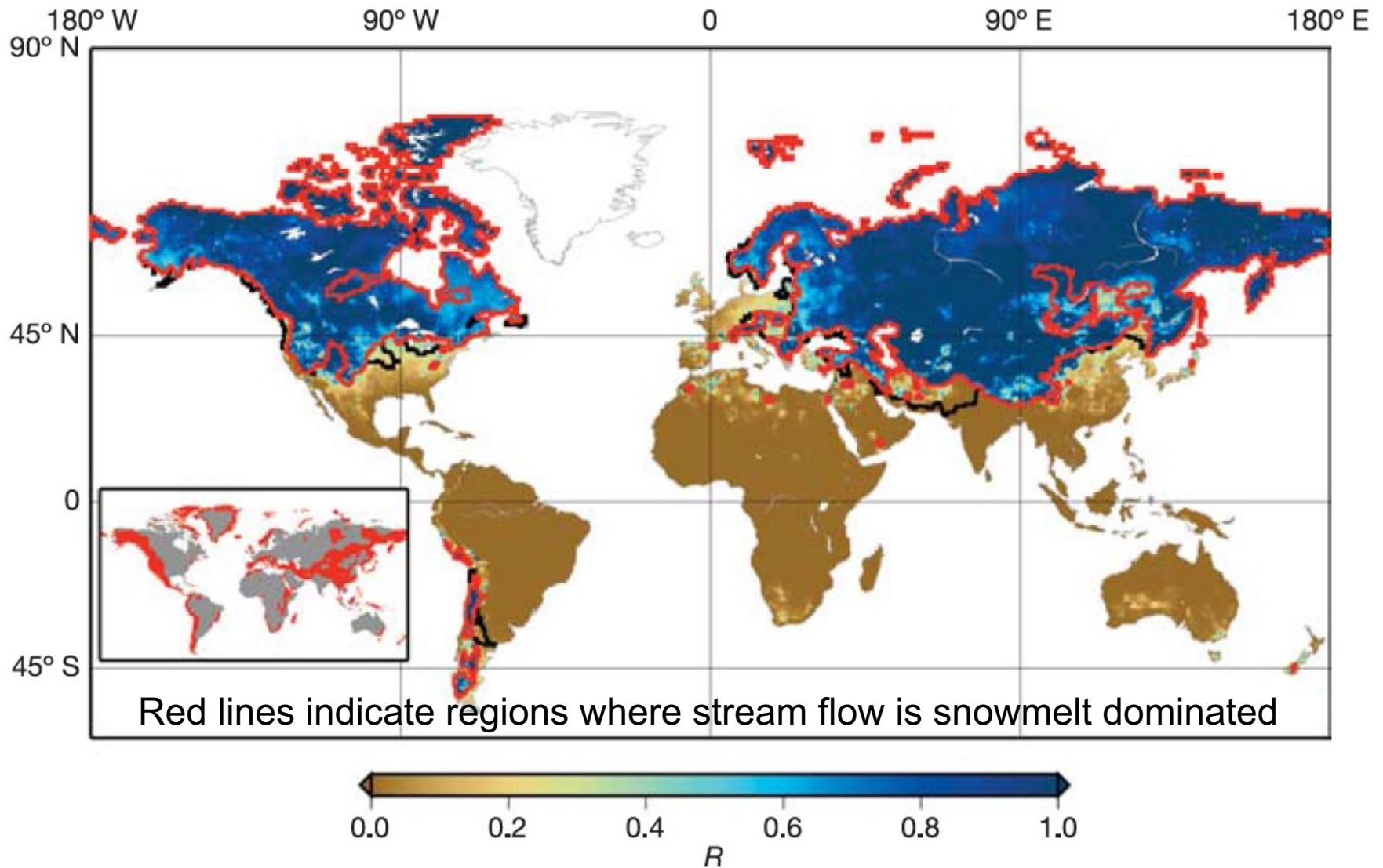
snapshot



# Composite hemispheric snow cover



Source: NOAA



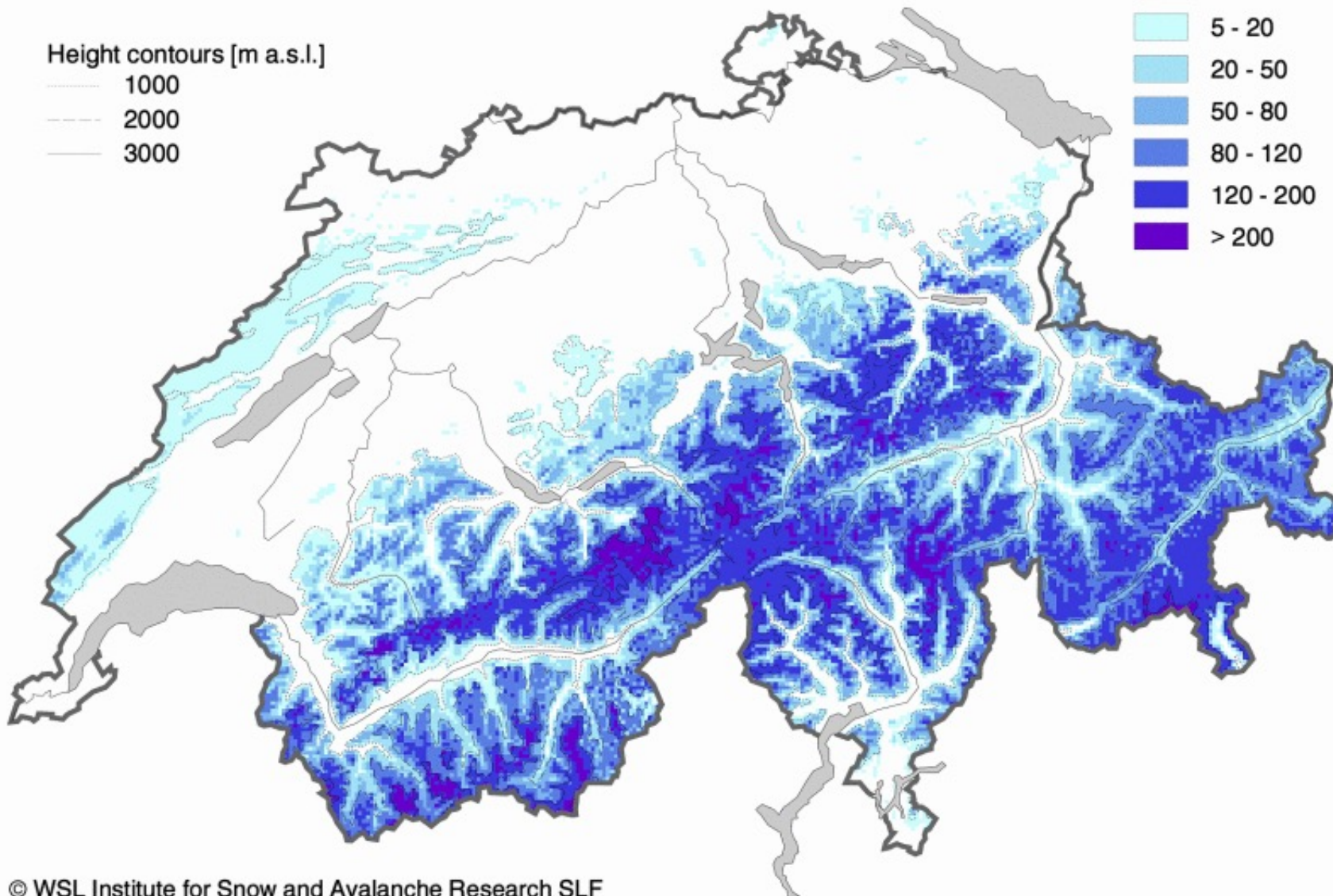
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Height contours [m a.s.l.]

----- 1000  
----- 2000  
----- 3000

Snow depth [cm]

0 - 5  
5 - 20  
20 - 50  
50 - 80  
80 - 120  
120 - 200  
> 200





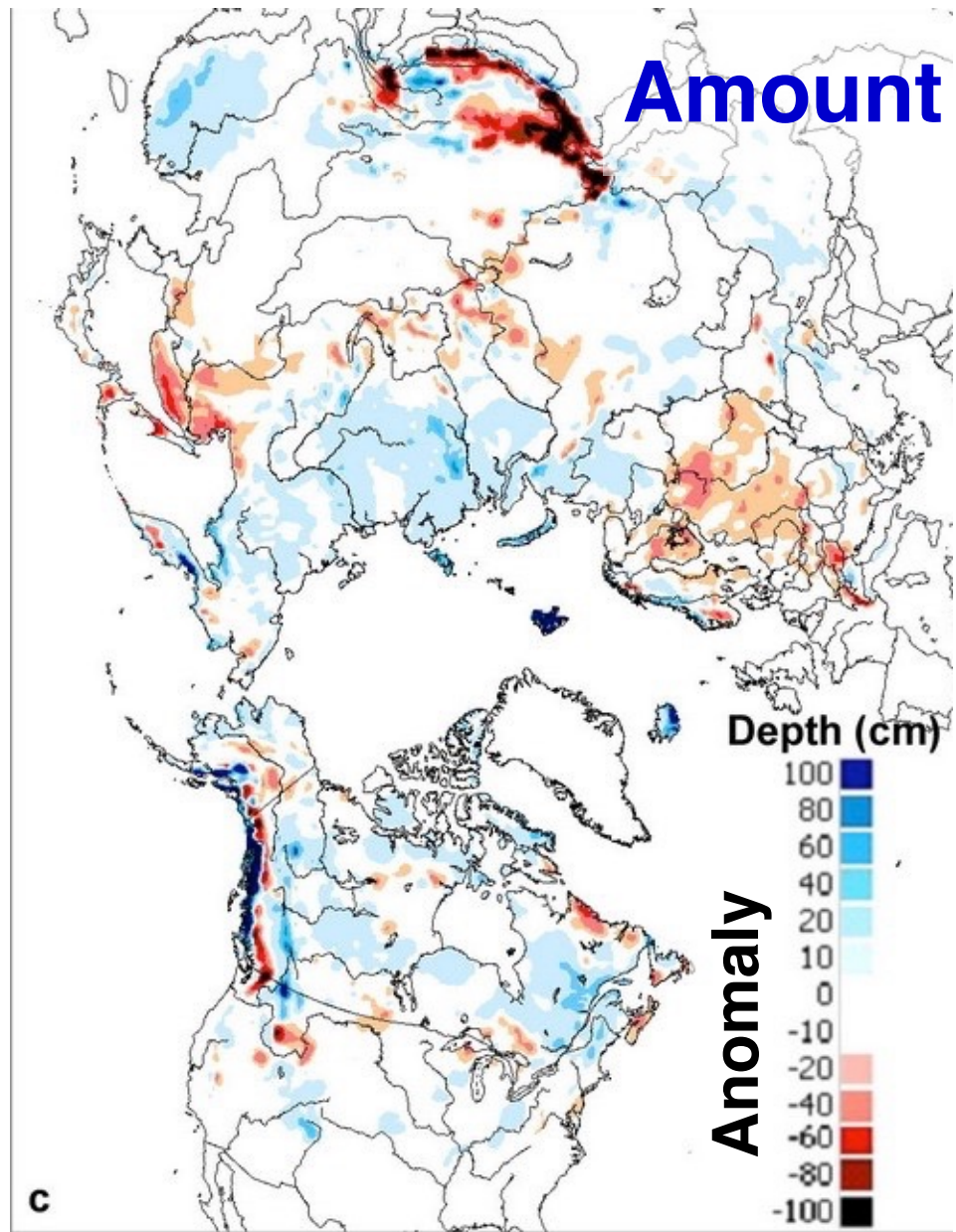
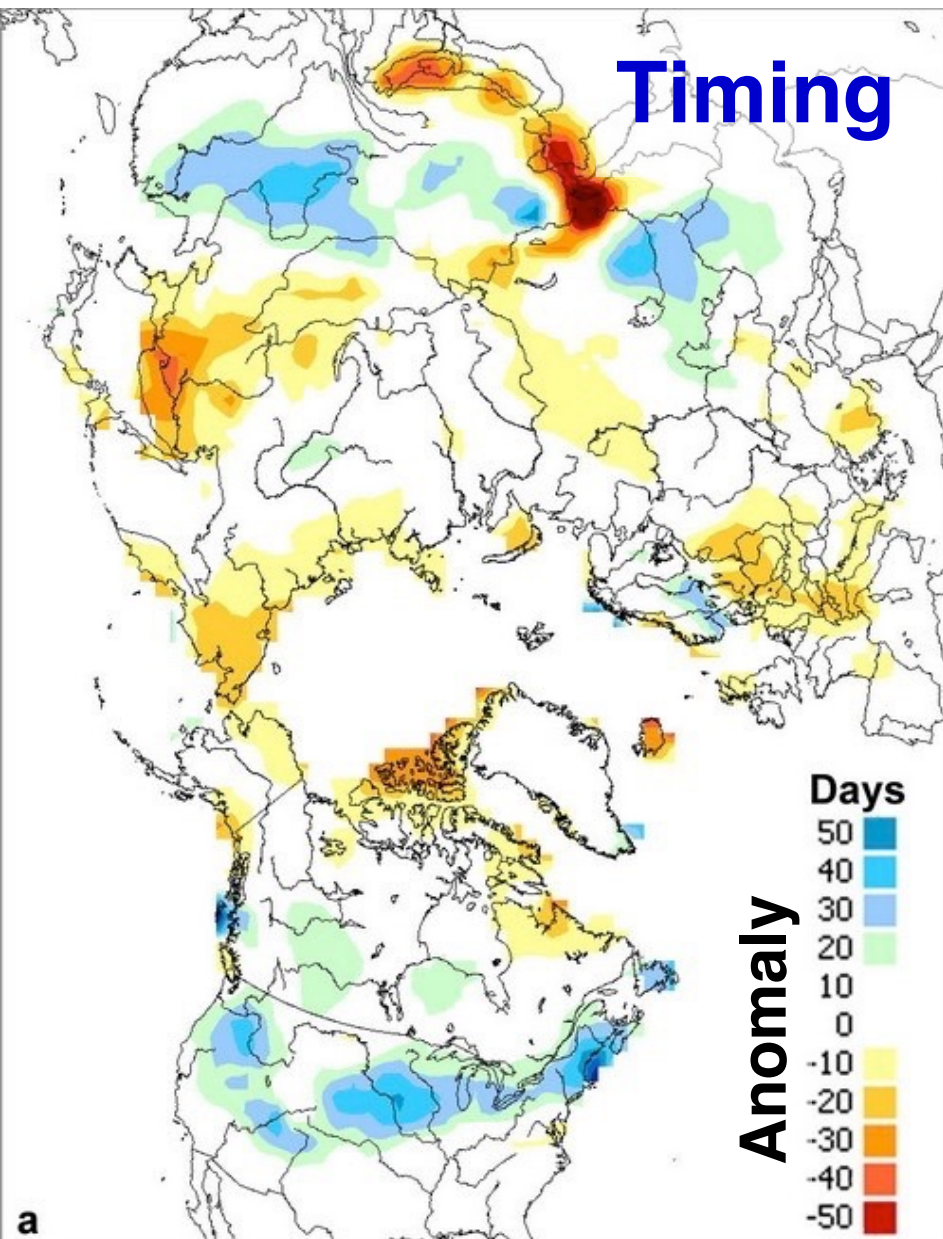
Depends on:

- Latitude (climate)
- Elevation
  - decrease of air temperature with altitude
  - increase of precipitation with altitude
  - snow fraction of precipitation increases
- Continentality (distance to ocean)

Land above 40°N latitude typically has seasonal snow cover

Large seasonal variability in space and time (see following slides)

Large inter-annual variability in space and time (see following slides)





Variability of snow accumulation and persistence occurs at three scales:

- **Macro-scale** (continent), [Time scale: multi-year]
  - linear distances of 100 - 1000 km
  - depends on latitude, altitude, large-scale meteorology, proximity to large water bodies
- **Meso-scale** (region), [Time scale: season]
  - linear distances of 1 - 100 km
  - depends on orographic cooling/warming, slope/aspect, avalanches, wind redistribution
- **Micro-scale** (local), [Time scale: days]
  - linear distances of 10 m - 1 km
  - depends on surface roughness, vegetation, wind, snow surface characteristics

Dynamic meteorological effects dominate:

- Standing waves in the atmosphere (Rossby waves; e.g. jet stream position)
- Air flow around large mountain ranges
- Latitudinal temperature gradients and their changes
- Continentality (climate, synoptic scale weather patterns)



Driven by:

- Finer scale wind flow modifications as a result of distinct topographic changes, e.g., valleys, mountain ridge
- Orographic lifting and changes in adiabatic cooling → lapse rates: 1K/100m for dry air, 0.6K/100m for moist air)
- Convective precipitation (in response to addition of heat and moisture from large water reservoirs)

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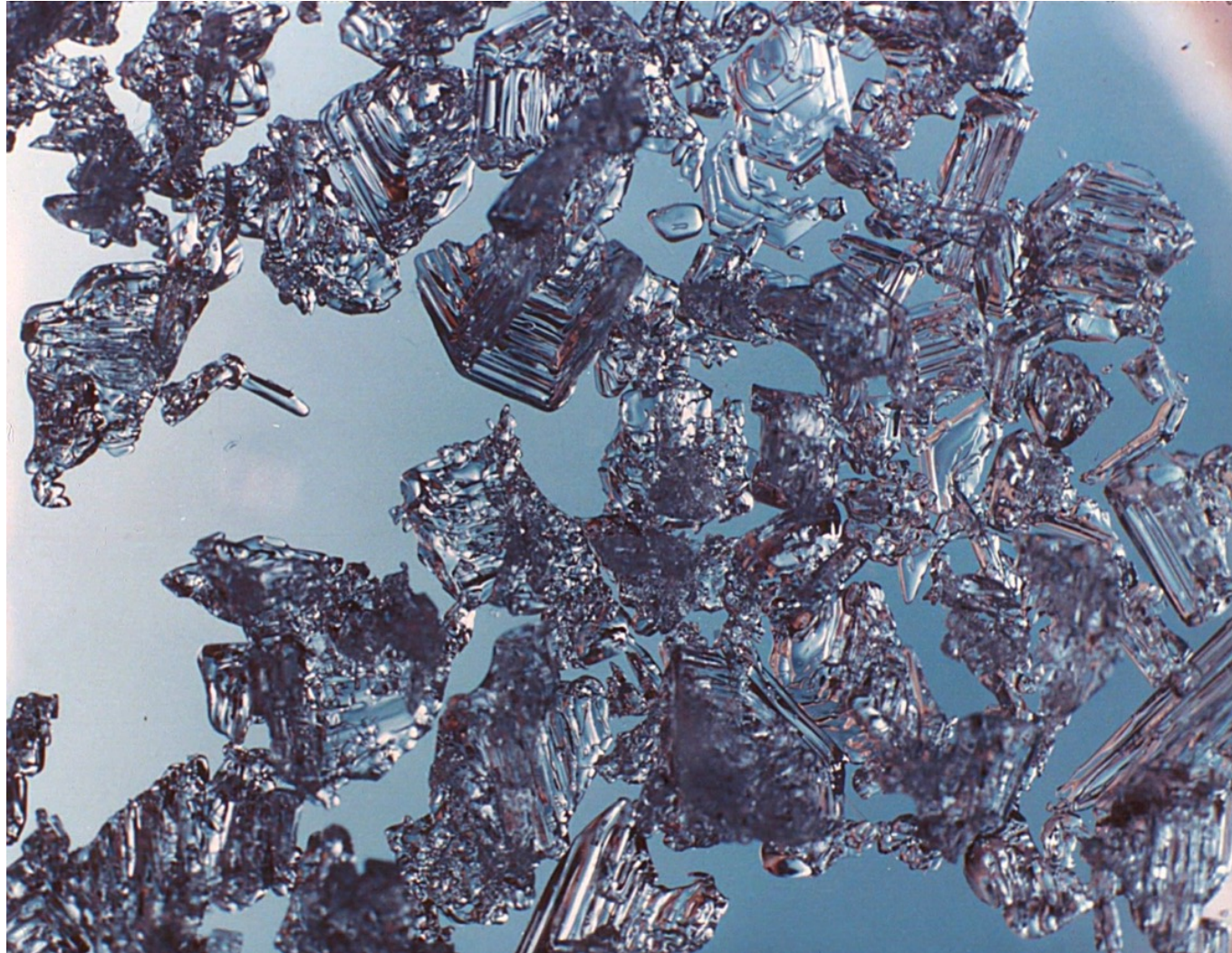


Snow accumulation depends on:

- Vegetation cover (canopy density, canopy structure and gap fraction)
- Fine-scale topography and corresponding surface energy balance



Snow pack stratigraphy and micro-structure, individual grains and matrix





## Journal name (Publisher)

- Journal of Glaciology (IGS)
- Annals of Glaciology (IGS)
- Journal of Geophysical Research (AGU)
- Geophysical Research Letters (AGU)
- Water Resources Research (AGU)
- The Cryosphere (EGU)
- Cold Regions Science and Technology (Elsevier)
- Journal of Atmospheric and Oceanic Technology (AMS)
- Journal of Applied Meteorology and Climatology (AMS)
- Journal of the Atmospheric Sciences (AMS)
- Journal of Hydrometeorology (AMS)
- Journal of Climate (AMS)
- Journal of Hydrology (Elsevier)
- Hydrological Processes (Wiley)
- Advances in Water Resources (Elsevier)
- Environmental Science and Technology (ACS)
- Frontiers in Earth Science: Cryosphere (Frontiers Media SA)
- etc.



# **Snow physical properties**

