International Summer School in Glaciology

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GEOGRAPHY OF GLACIERS 1

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OUTLINE

- Why do we need a geography of glaciers?
- Where are the glaciers?
- What are the glaciers doing?
- What does a geography of glaciers look like?

2. Glacier mass balance and global sea level

The relationship between glaciers, climate and sea level can be illustrated by the general equation:

$$\mathrm{SLR} = -(1/A_0)\sum_{r=1}^{r=R} S_r \underline{b}_r \qquad (1)$$

where SLR is the global average sea level rise ($\mathrm{m\,a^{-1}}$) due to melting of glaciers and ice caps and $\underline{b}_r$ is the glacier mass balance ($\mathrm{m\,a^{-1}}$) in the rth region with a glacier area of S_r ($\mathrm{km^2}$). R is the total number of glacierized regions in the world and A_0 is the total area of the oceans ($\mathrm{km^2}$). The minus sign in (1) is necessary because a decrease in mass balance corresponds to an increase in sealevel rise. The sensitivity of SLR to temperature change is given by

$$\Delta\mathrm{SLR}/\Delta T_\mathrm{G} = -(1/A_0)\sum_{r=1}^{r=R} S_r(\Delta\underline{b}_r/\Delta T_r)(\Delta T_r/\Delta T_\mathrm{G}) \qquad (2)$$

where $\Delta\mathrm{SLR}/\Delta T_\mathrm{G}$ is the sensitivity of SLR ($\mathrm{m\,a^{-1}\,K^{-1}}$) to change in global temperature T_G. $\Delta\underline{b}_r/\Delta T_r$ is the sensitivity of glacier mass balance ($\mathrm{m\,a^{-1}\,K^{-1}}$) in the rth region to temperature changes ΔT_r in the region. $\Delta T_r/\Delta T_\mathrm{G}$ is the sensitivity of regional temperature to changes in global temperature ΔT_G. The regional tem-

CONSIDER GLACIER EFFECT ON GLOBAL SLR

- Global SLR is sum of contributions from different regions
- Need to define regions and assess $S_r\underline{b}_r$ and $\Delta\underline{b}_r/\Delta T_r$ in each region

SENSITIVITY STUDY

Braithwaite and Raper (2002)

Table 1
Global sea level sensitivity for five different scenarios of mass balance sensitivity applied to all mountain glaciers and ice caps, excluding Greenland and Antarctic

MB Sensitivity ($m\,a^{-1}\,deg^{-1}$)		Global glacier area, Sea level sensitivity ($mm\,a^{-1}\,deg^{-1}$)	
		0.52×10^6 km^2	0.68×10^6 km^2
Very low	−0.2	0.3	0.4
Low	−0.4	0.6	0.8
Medium	−0.6	0.9	1.1
High	−0.8	1.2	1.5
Very high	−1.0	1.5	1.9

Calculations made for two different estimates of global glacier area. The higher value (0.68×10^6 km^2) from Dyurgerov and Meier (1997) may be more correct but only about 0.52×10^6 km^2 are presently localised within 1° of latitude and longitude.

•Realistic global figure?

•Could be even higher in regions like New Zealand!

GEOGRAPHY OF GLACIERS

- Mass balance sensitivity is not constant!
- A "geography of glaciers" would show the variations in $S_r \underline{b}_r$ and $\Delta \underline{b}_r / \Delta T_r$ across the world
- Start by explaining time and space variations in glacier areas S_r, mass balance $\underline{b}_r$ and mass balance sensitivity $\Delta \underline{b}_r / \Delta T_r$

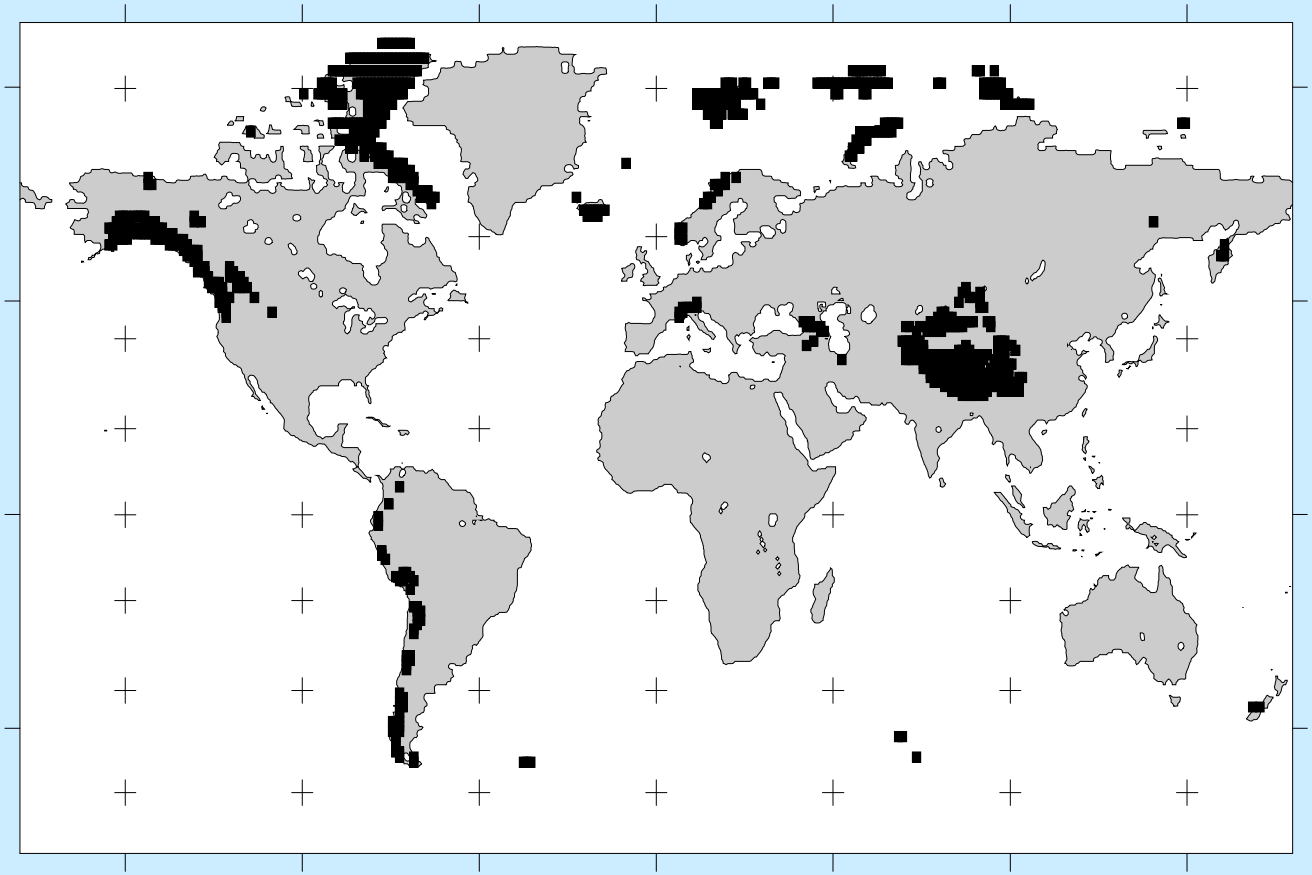
CONDITIONS FOR FORMING GLACIERS

- Need topography on which the glacier can lie
- Need high topography and low temperature to form an accumulation area at high altitude
- Need a path down which the glacier can flow to lower altitude
- Need high temperature at low elevation to melt all the ice flow from higher elevations

Note that “high” and “low” are relative. Note we are only talking about glaciers with melt

GLOBAL DISTRIBUTION OF GLACIERS

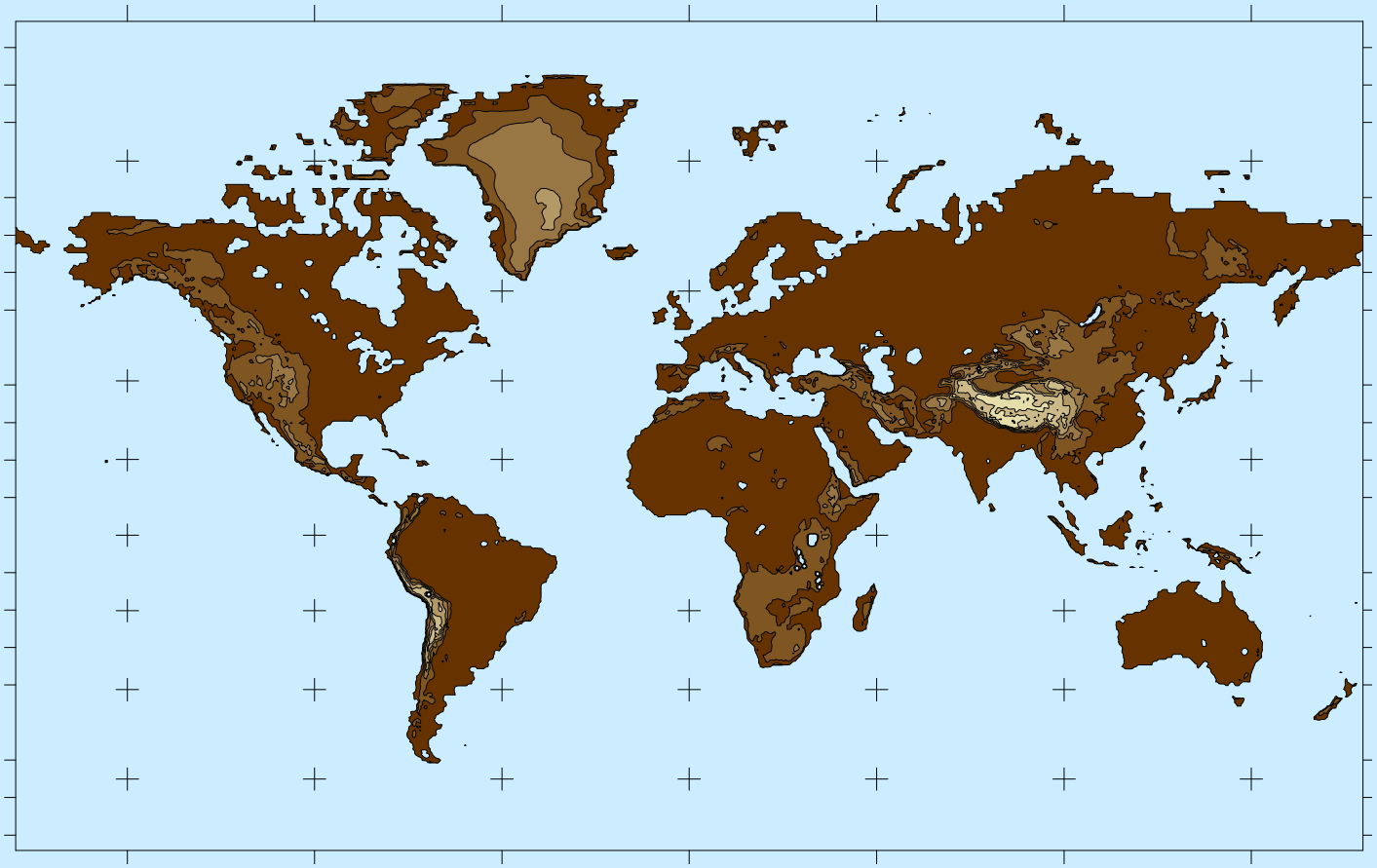
(20 km^2 per 1 degree latitude/longitude)



- Where are they?
- Why are they there?
- Why are they not in other places

GLOBAL TOPOGRAPHY

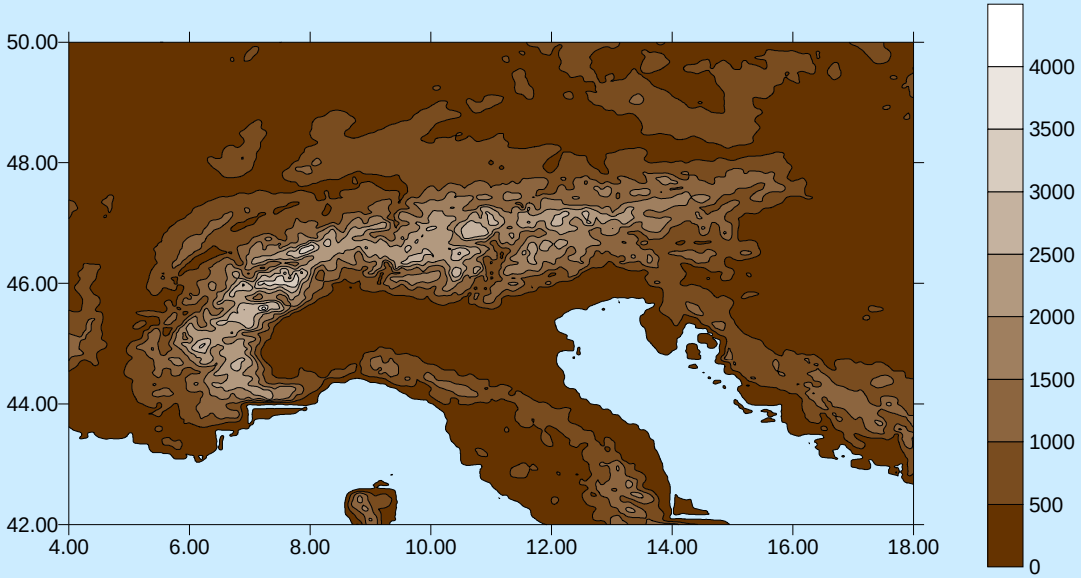
(5 min topography)

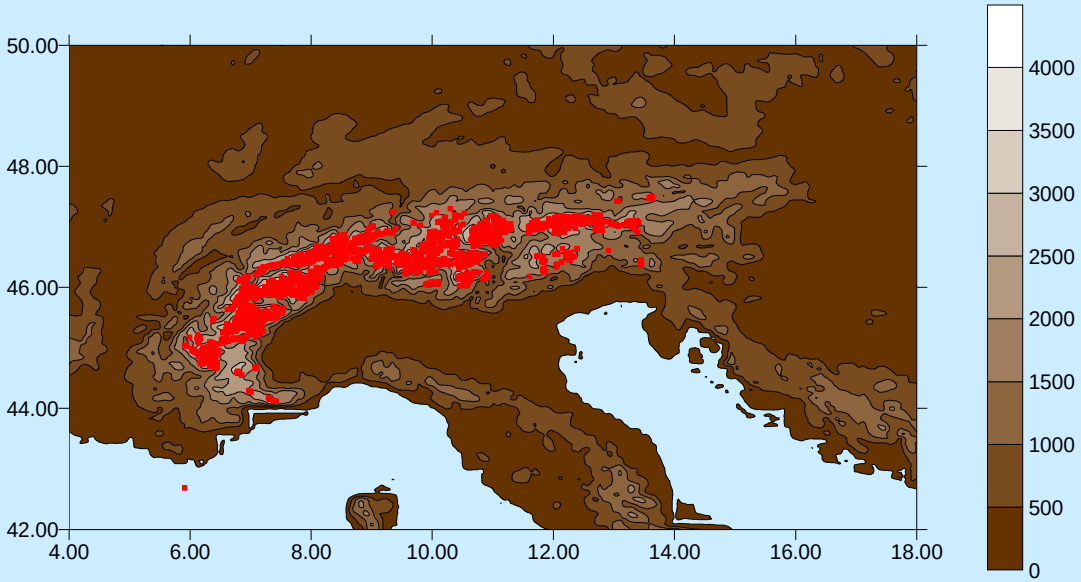


- Generally found in high mountains
- “High” is relative
- Glaciers are lower in Arctic and higher in temperate and tropical areas

GLACIERS AND TOPOGRAPHY IN THE ALPS

- Topography from 5 min global topography
- 5,000 glaciers from World Glacier Inventory

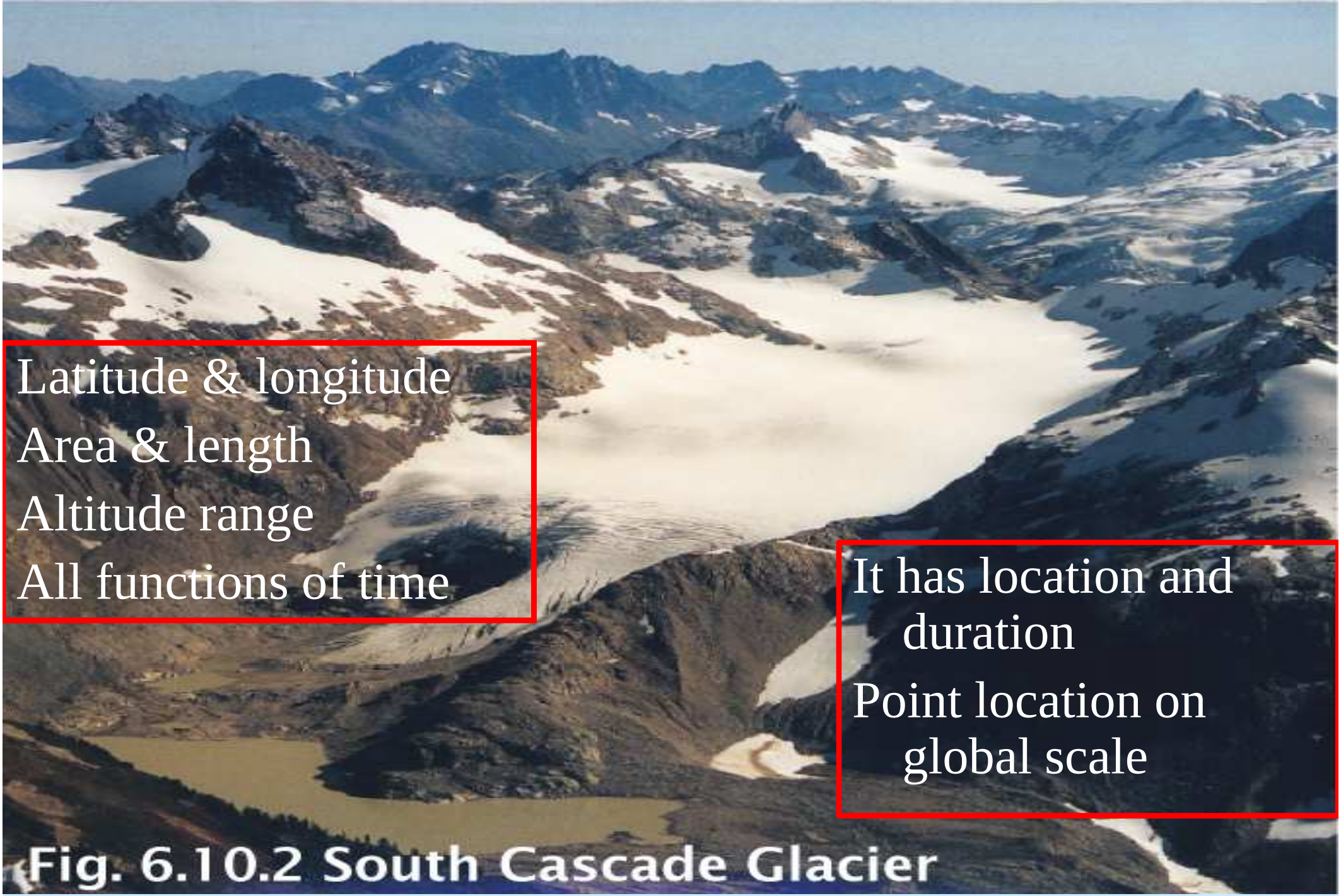




IMPORTANCE OF TOPOGRAPHY

- Geography of glaciers must explain how some glaciers can exist at hundreds of metres above sea level while other glaciers can only exist at thousands of metres above sea level
- If your topography is not high enough, you can't have a glacier!

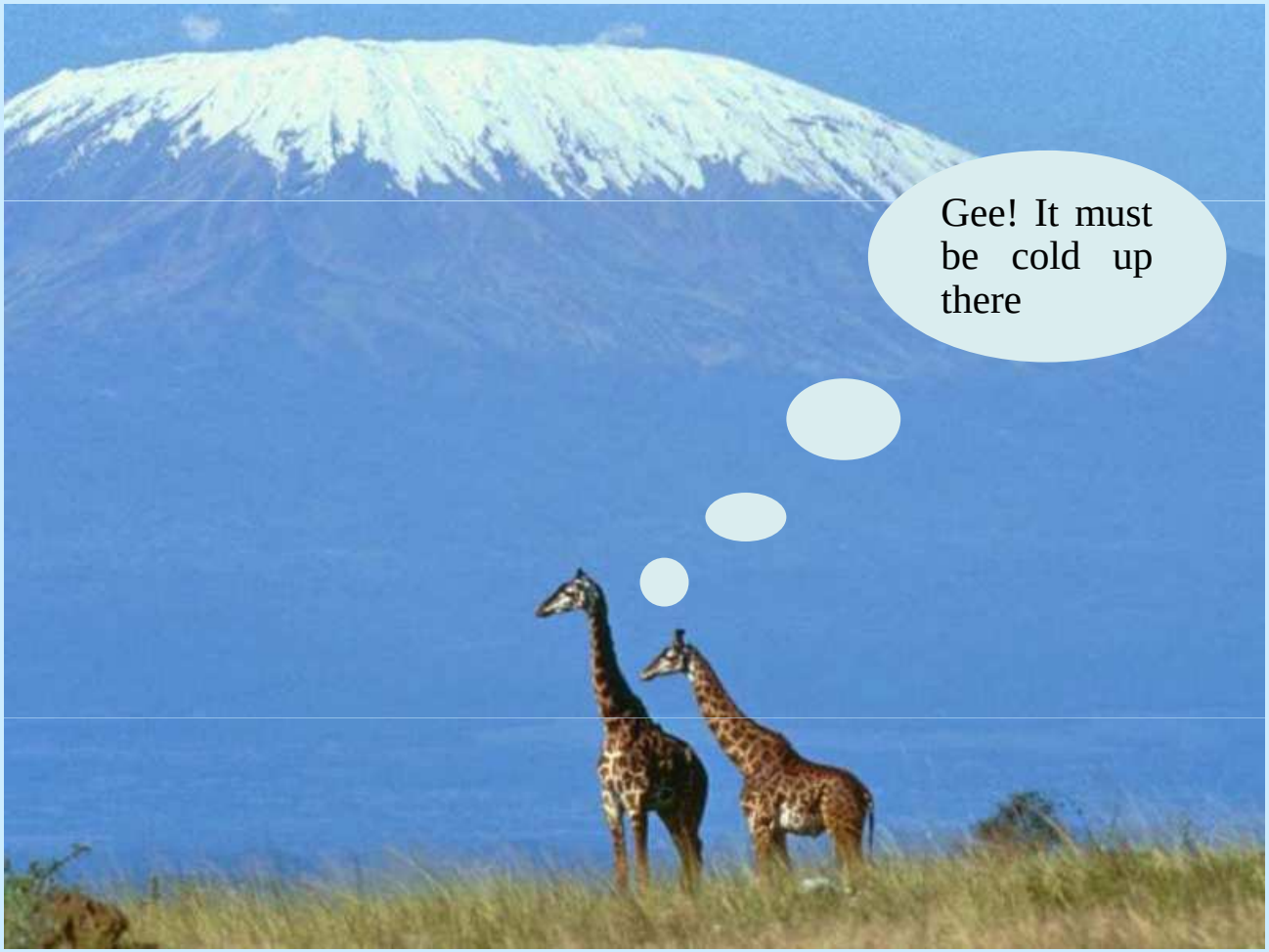
We had glaciers at low altitude in the UK in the Younger Dryas but our mountains are not high enough to maintain an ELA under present climate


Latitude & longitude
Area & length
Altitude range
All functions of time
It has location and duration
Point location on global scale
Fig. 6.10.2 South Cascade Glacier

IMPORTANCE OF ELA - 1

- ELA is equilibrium line altitude
- Mass balance = zero at ELA, i.e. ablation = accumulation
- Ablation < accumulation above ELA
- Ablation > accumulation below ELA
- ELA is somehow at the “middle of the glacier”
- ELA is key to glacier geography
- Related concepts are snow line and glaciation level/limit

DISCOVERY OF SNOW LINE



Note: we are not suggesting that giraffes live in South America

- P. Bourguer (1698-1758) "discovered" snow line in tropical South America
- Ability to see snow above you while you are in high temperature leads to concept of "temperature lapse" rate

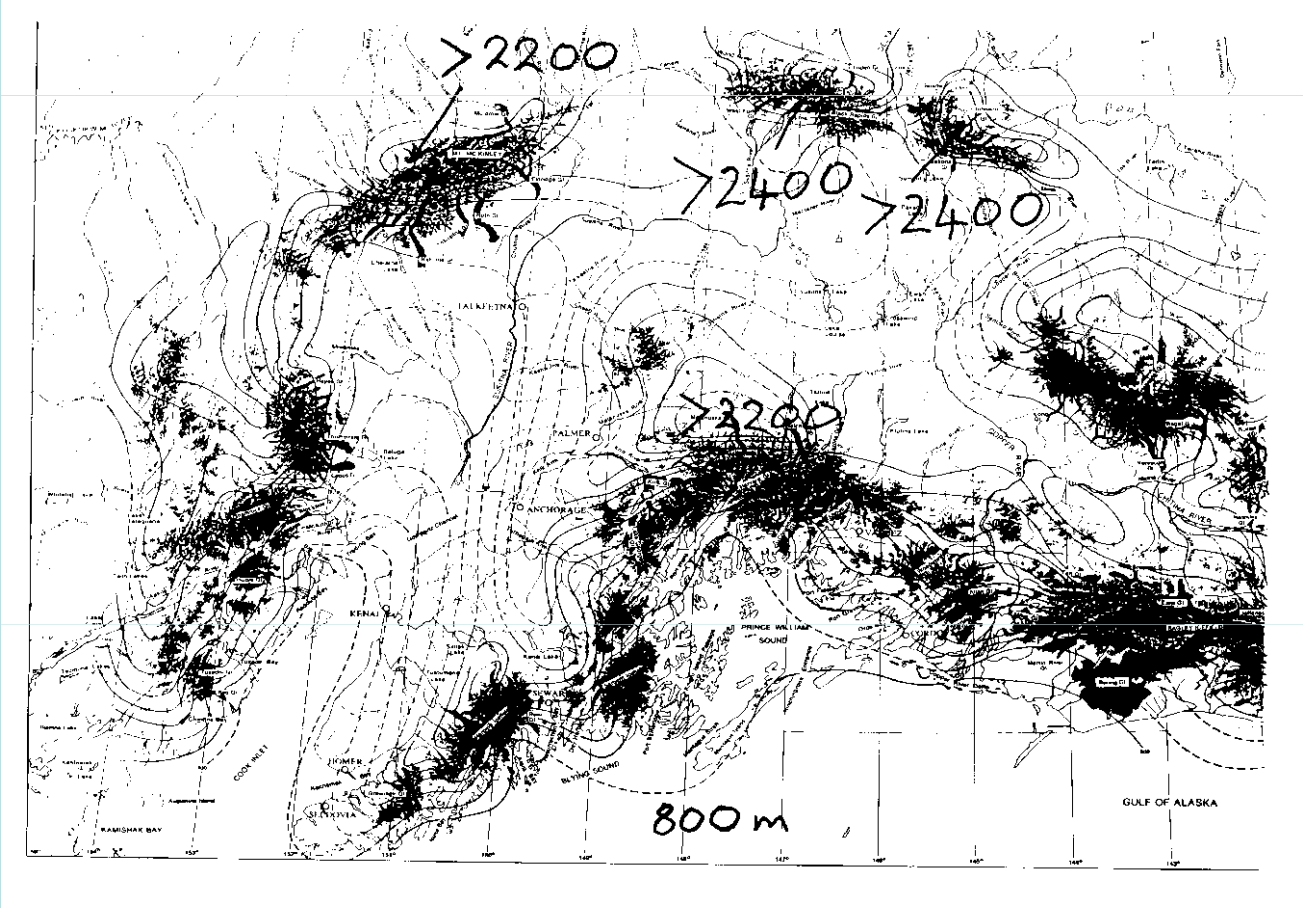
GLACIATION LEVEL IN SOUTHERN ALASKA

(Østrem et al. 1981)

The glaciation level in southern Alaska. *Geografiska Annaler* 63A, 3-4, 251-260)

Glaciation level is rough proxy for ELA

Glaciation level rises from coast to the interior



PRECIPITATION AT GLACIATION LEVEL

(Østrem et al. 1981

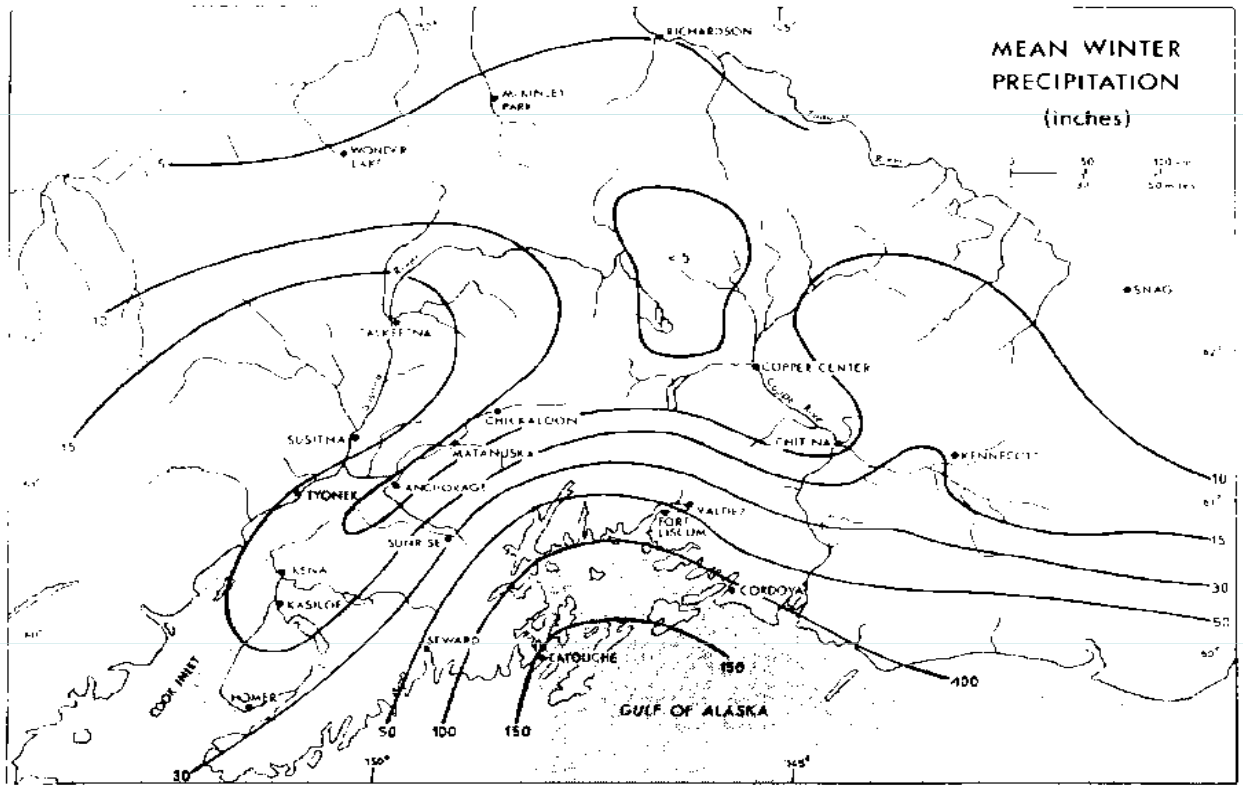


Fig. 4. Distribution of winter precipitation (September through April) in parts of Alaska and Yukon, based upon average monthly totals for selected stations (cf. Table 1) and precipitation maps given in "Climatic Atlas for Alaska" (Weather Information Branch, 1943). Some data were taken from "Climatic summaries for selected meteorologic stations in Canada" (Department of Transport, 1954). The isohyets, drawn for selected values of winter precipitation in inches (5, 10, 15, 30 etc.), demonstrate a pattern which coincides fairly well with the pattern of isolines for the height of the glaciation level, compare the enclosed map.

The glaciation level in southern Alaska. *Geografiska Annaler* 63A, 3-4, 251-260)

Winter precipitation falls from coast to the interior

Sorry about the units!

TEMPERATURE AT GLACIATION LEVEL

(Østrem et al. 1981)

The glaciation level in southern Alaska. *Geografiska Annaler* 63A, 3-4, 251-260)

- Summer temperature at the glaciation level <u>falls</u> from coast to interior
- Sounds counter-intuitive as temperature <u>rises</u> when we go inland. <u>But glaciation level rises</u>

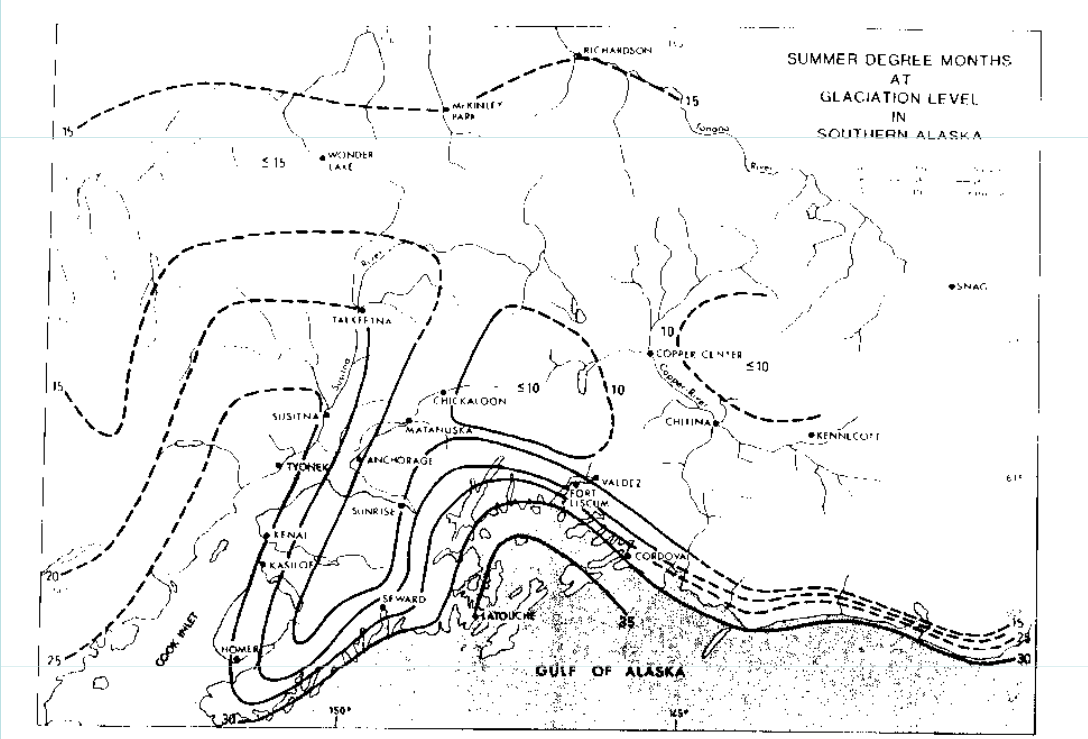


Fig. 6. The construction of this map was based upon data shown in Table 2. The monthly mean temperatures at each station were reduced to the height of the glaciation level in each case. Months with a positive mean temperature (after reduction) were termed summer months. The number of positive degree-months was calculated for each station and iso-lines were drawn for 10, 15, 20 etc. units. A higher number is an indication of a larger amount of energy delivered at the glaciation level.

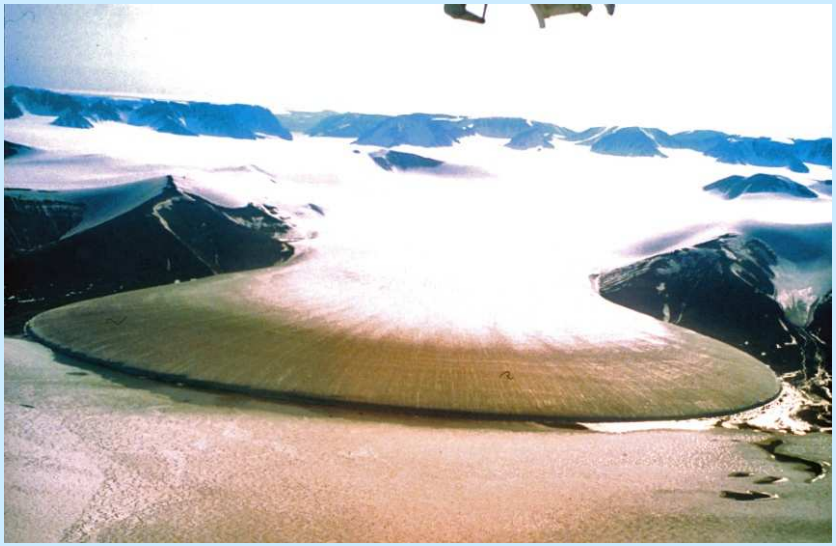
MARITIME/CONTINENTAL EFFECTS

- The air in the interior of a continent is generally warmer and drier in summer than air over the ocean at the <u>same latitude and altitude</u>
- Precipitation is generally higher over oceans than over continents at the <u>same latitude and altitude</u>
- Relative dryness of continental; climate means that glaciers have to be <u>higher</u> to exist in colder temperatures with lower precipitation

DUAL NATURE OF ELA

As a variable (annual ELA) from year to year

Measure as part of an mass balance programme



As a parameter

n. (*math.*). Quantity constant in case considered, but varying in different cases (OED)

IT HAS ALL BEEN DONE BEFORE

HEIGHT OF THE LIMIT OF PERPETUAL SNOWS IN THE TWO HEMISPHERES, DETERMINED BY DIRECT MEASUREMENTS.

CHAINS OF MOUNTAINS.	LATITUDES.	Lower Limit of Perpetual Snows.	Mean Temperatures of the Plains in the same Latitudes.	
			Entire Year.	Summer.
I. *Northern Hemisphere.*				
Coast of Norway, Isle Magerœ .	71° 15′ N.	720m	0°,2	6°,4
Inner Norway .	70°–70 15	1072	3 ,0	11 ,2
Inner Norway .	66 –67 30	1266	"	
Iceland, Oosterjoekull . . .	65	936	4	
Inner Norway .	60 62	1560	4	
Siberia, Chain of Aldan . . .	60 55	1364	"	
North Ourals .	59 40	1460	1	
Kamtschatka, Volcano of Chevelutch . . .	56 40	1600	2	
Ounalaschka .	53 44	1070	4	
Altaï	49° 15′–51°	2144	2 ,8	17 ,8
Alps	45 45 –46	2708	11 ,2	18 ,4

The height of the snow-line being a function of the quantity that falls in winter and of the heat of the summers, it is clear that, in equal latitudes, it must be higher in the interior of continents, where less snow falls, and where the summers are warmer, than on the coasts. Thus it is 650

LIMIT OF ETERNAL SNOWS. 229

CHAINS OF MOUNTAINS.	LATITUDES.	Lower Limit of Perpetual Snows.	Mean Temperatures of the Plains in the same Latitudes.	
			Entire Year.	Summer.
Caucasus, Elbrouz	43° 21′ N.	3372m	13 ,8	21 ,6
Caucasus, Kasbek	"	3235	"	"
Pyrenees . . .	42° 30′–43°	2728	15°,7	24°,0
Ararat	39° 42′	4318?	17 ,4	25 ,6
Asia Minor, Mont Argæus . .	38 33	3262	"	"
Bolor	37 30	5185	"	"
Sicily, Ætna . .	37 30	2905	18 ,8	25 ,1
Spain, Sierra-Nevada of Grenada	37 10	3410?	"	"
Hindou-Kho .	34 30	3956	"	"
Himalaya, N. side	30° 15′–31°	5067	"	"
" S. side	"	3956	20 ,2	25 ,7
Mexico . . .	19°–19° 15′	4500	25 ,0	27 ,8
Abyssinia . . .	13 10	4287	"	"
S. America, Sierra Nevada de Me				
Chili	14° 30′–18°	"	"	"
E. Cordilleras .	"	4853	"	"
W. Cordilleras .	"	5646	"	"
Chili, Portillo and Volcano of Peuquenes . . .	33	4483	"	"
Chili, Andes along the Coast . .	41°–44°	1832	"	"
Straits of Magellan	53°–54°	1130	"	"

This is from L. F. Kaemtz (1801-1867) who is quoting Alexander Von Humboldt

IT HAS ALL BEEN DONE BEFORE

Uebersicht der Verbreitung und

Bezeichnung der Alpentheile und der einzelnen Gebirgsgruppen.	Zahl der Gletscher.			Höhenverhältnisse der Schnee-			
	Summe.	prim.	secund.	Schneegrenze.		Mittl. Höhe der Gl.	
Cottische Alpen.							
Massiv des Mont Pelvoux	50	4	46	8700′	2760 M.	6740′	2190 M.
Graiische Alpen.							
Umgebungen des Mont Iséran und des Pic de Cogne	30	1	29	8800	2790	6900	2240
Penninisch							
A. Mont-Blanc Bonhomme und							
B. Monte Rosa hard und Simp							
Schweizer Alpen.							
Das ganze Alpengebiet zwischen den penn. und rhät. Alpen umfassend	120	13	107	8300	2695	6570	2130
Rhätische Alpen.							
A. Graubündtner Alpen.	70	4	67	8700	2825	6960	2260
B. Umgebungen des Ortles	80	2	78	8400	2730	6800	2210
C. Oetzthaler Gruppe.	180	8	172	8300	2695	6980	2265
D. Vereinzelte secund. Gletscher in den rhät. u. karnischen Alpen.	40	—	40				
Norische Alpen.							
A. Tauern	240	5	235	8300	2695	7300	2370
B. Salzkammergut	10	—	10	8100	2630	7300	2370

This was published in 1854 by A. Schlaginweit (1829-1857) and H. Schlaginweit (1826-1882)

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wgms
national correspondents
guest scientists and trainees

wgms

welcome to the

world glacier monitoring service

under the auspices of: ICSU (WDS), IUGG (IACS), UNEP, UNESCO, WMO

For more than a century, the World Glacier Monitoring Service (WGMS) and its predecessor organizations have been compiling and disseminating standardized data on glacier fluctuations. Thereto, the WGMS annually collects glacier data through its scientific collaboration network that is active in more than 30 countries. More...

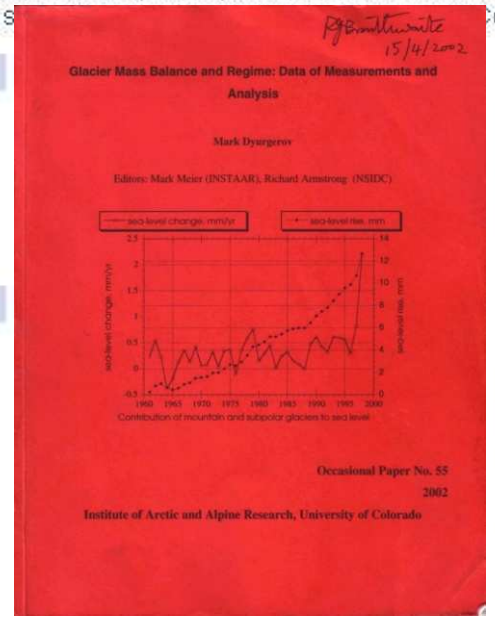
In close collaboration with the U.S. National Snow and Ice Data Center (NSIDC) and the Global Land Ice Measurements from Space (GLIMS) initiative, the WGMS runs the Global Terrestrial Network for Glaciers (GTN-G) in s convention on Climate Change (UNFCC). More...

QUICK LINKS

GMBB No. 11 (2008-2009)
FoG Vol. IX (2000-2005)
Global Glacier Changes: facts and figures
AGU session 2011

ANNOUNCEMENTS

Preliminary mass balance data 2009/10 now available!
GMBB No. 11 now published!
Call-for-data 2009/10 now open!
EGU session 2012
Mass-balance monitoring in Kyrgyzstan resumed
Extending glacier monitoring into the LIA
General Assembly NCs Zermatt 2010



Dyurgerov and Meier (2005) is also valuable source of unpublished data from earlier years

phot

last

If you measure glacier mass balance send it to WGMS

If you need data, can get it from WGMS

National Snow & Ice Data Center

HOME DATA

World Glacier Inventory

Home | Documentation | Search Tips | Search Entire Inventory | Extract

Extract Data for Select Regions

Select an entire region (e.g., Europe) or subregion (e.g., Alps Mountains) to extract data for

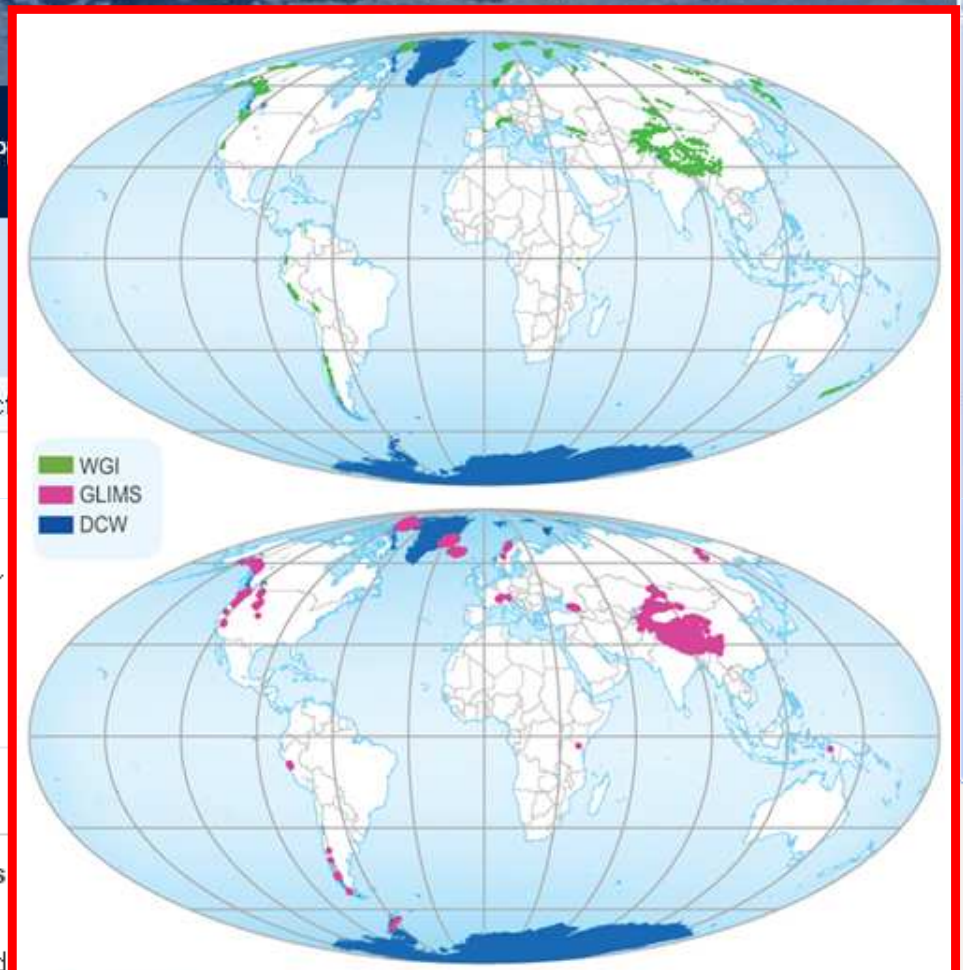


Fig. 3.6 Global glacier inventories

- WGI includes mid- to late-20th Century glacier states but is incomplete
- GLIMS will cover whole globe in its early 21st Century state

Europe (map)

Arctic Archipelagoes

Novaya Zemlya

Franz Joseph Land

Svalbard

Jan Mayen

Scandinavia (map)

Northern Urals

Severnaya Zemlya and Putorana

Rich countries (China and Russia) have completed their parts of WGI

Poor countries (Canada and USA) have not

Labrador (map)

Southwestern Greenland (map)

Danube River Drainages

Altai

Eastern Sayan

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