Climate forcing of glacier mass balance at Vestfonna, Nordaustlandet, Svalbardbmitted to Geografiks Annaler



A paper summing up the findings from this presentation was submitted to Geografiska Annaler

Please check with the authors if you want to quote or zite anything! Thank you.

The international context: IPY & ESF Call Polarclimate



Sensitivity of Svalbard glaciers to climate change (*SvalGlac*) – 2010 -2013

Poland, Spain, Germany, Austria, Finnland, Estonia, Sweden, ….

in Germany funded at TU Berlin & RWTH Aachen by **BMBF**

Team / Co-authors

C. Schneider, Marco Möller, Oliver Käsmacher — *RWTH Aachen*

Dieter Scherer, Roman Finkelnburg, Fred Meier — *TU Berlin*

Matthias Braun — *Univ. of Fairbanks, Alaska*



Motivation – climate change projections

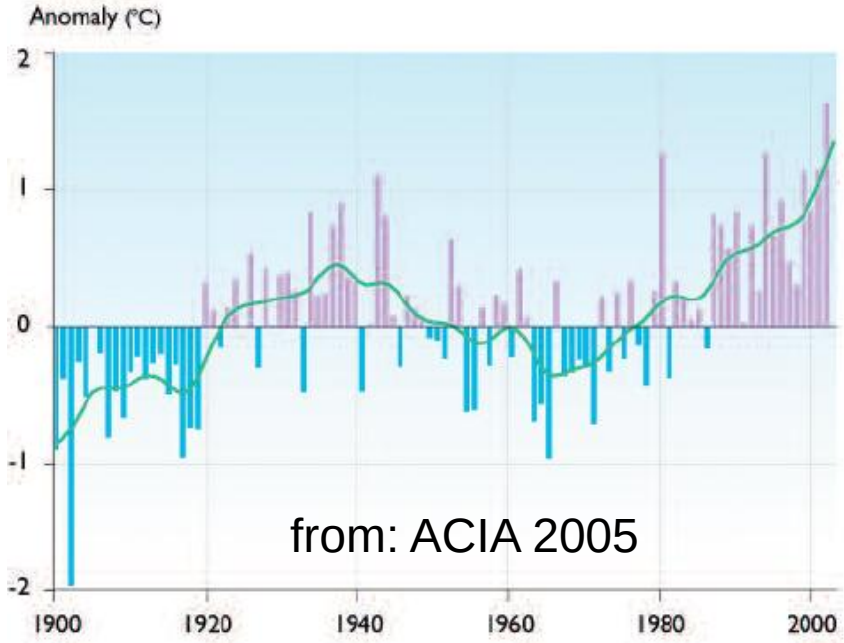
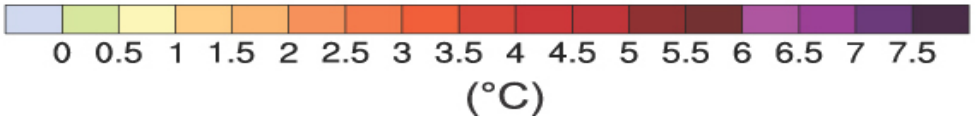


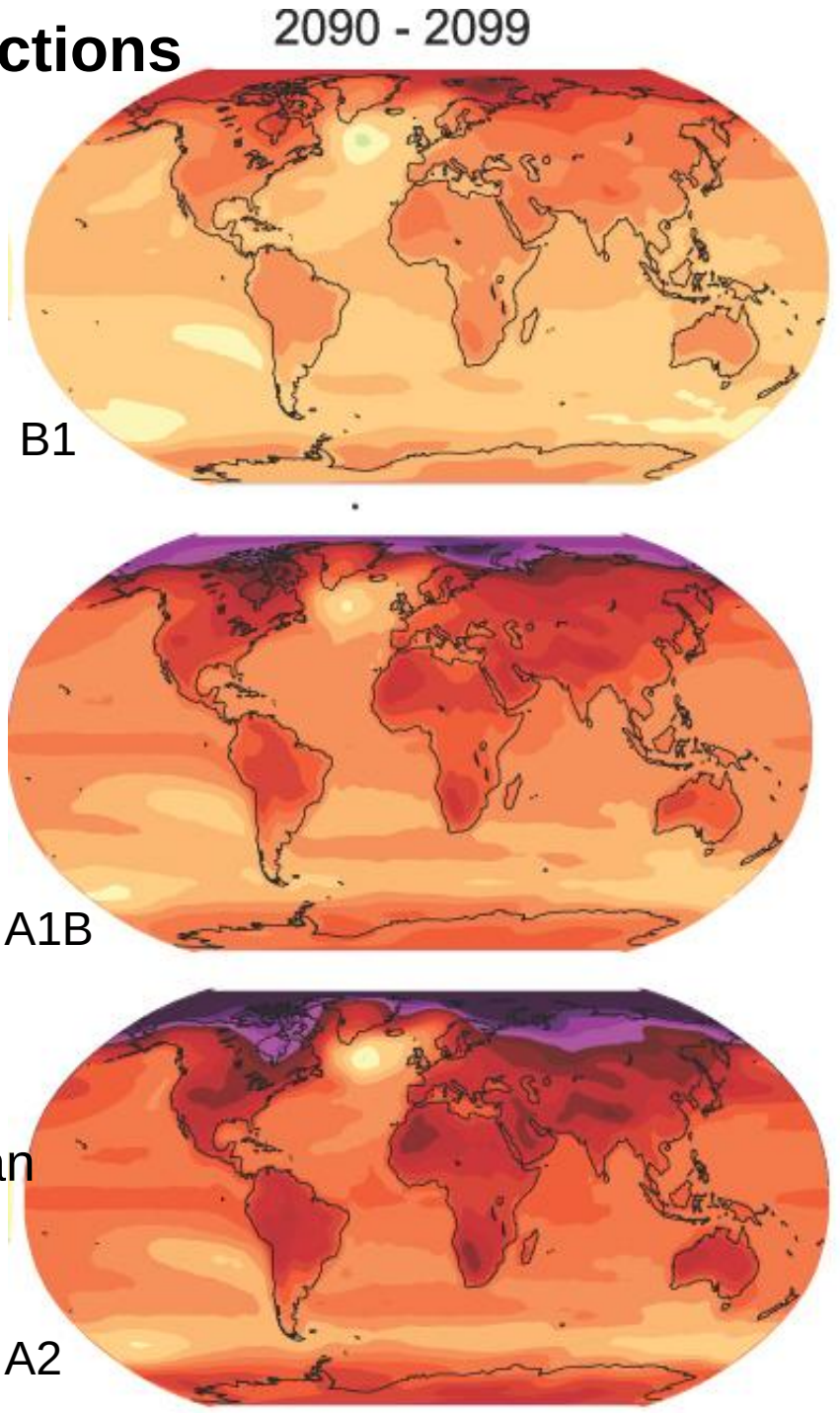
Fig. 2.6. Annual anomalies of land-surface air temperature in the Arctic (60° to 90° N) for the period 1900 to 2003 using the GHCN dataset (updated from Peterson and Vose, 1997).

- observed warming in the Arctic: double of global mean

- enhanced warming at high latitudes in the 21st century compared to global mean



warming relative to 1980-1999 (IPCC 2007)

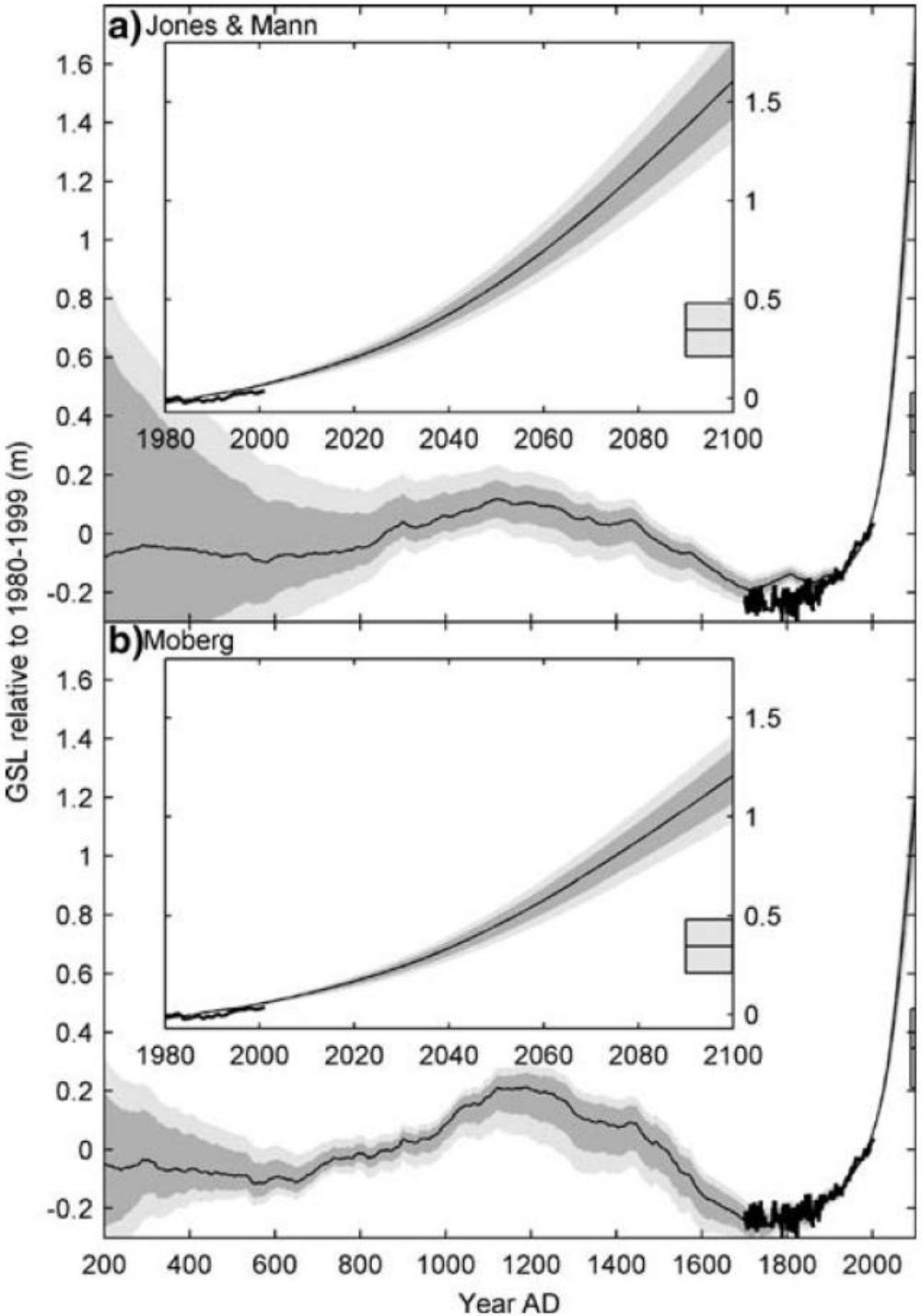


Motivation –
sea level rise likely to excee
1 m until 2100

based on statistical approaches

Projected sea level based on IPCC scenario A1B using temperature reconstructions of a) Jones and Mann (2004) and b) Moberg et al. (2005). Box shows IPCC A1B estimates 2090–2100. Insets show the projections and fits to the GSL data i greater detail.

Grinsted et al., Clim. Dyn. 2009



Motivation – sea level rise and the polar regions

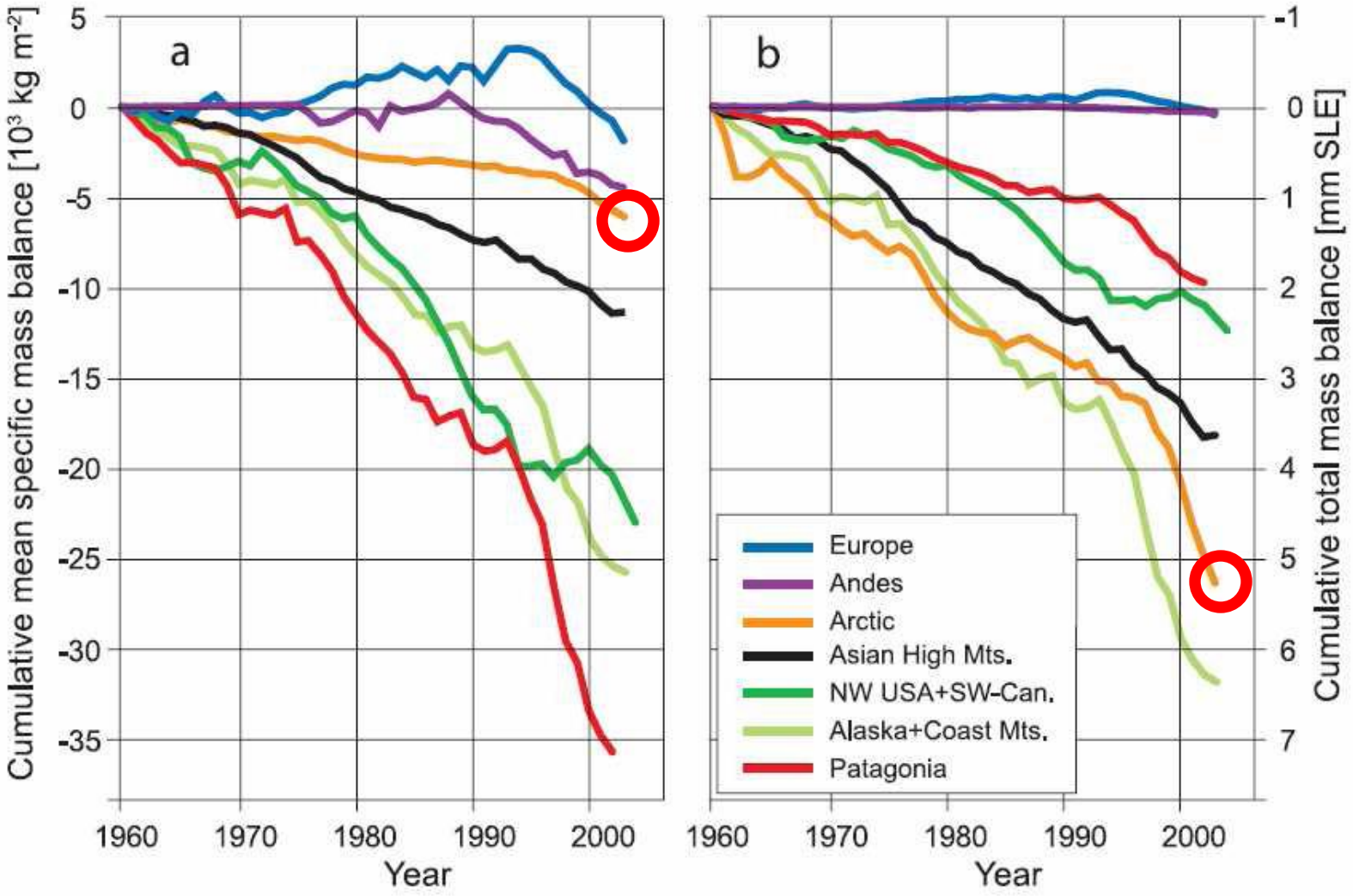
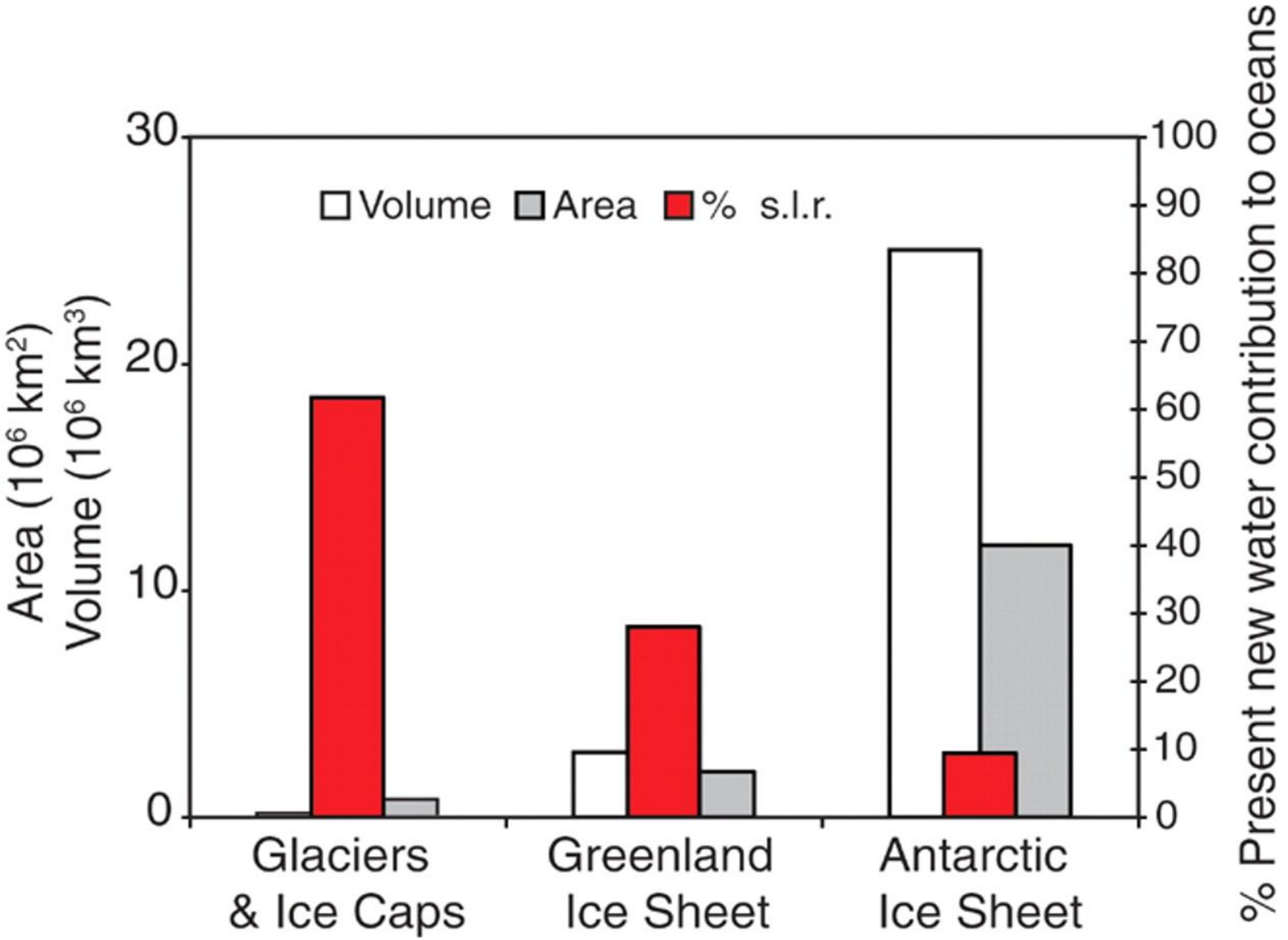


Figure 4.15. *Cumulative mean specific mass balances (a) and cumulative total mass balances (b) of glaciers and ice caps, calculated for large regions (Dyurgerov and Meier, 2005). Mean specific mass balance shows the strength of climate change in the respective region. Total mass balance is the contribution from each region to sea level rise.*

Lemke et al. (2007), IPCC AR4 WG I

Motivation – sea level rise and the polar regions



Meier and others. *Science* 2007, pp. 1064 - 1067

Outline

- team & projects

- study area

- simple approximation of recent and future surface mass balance

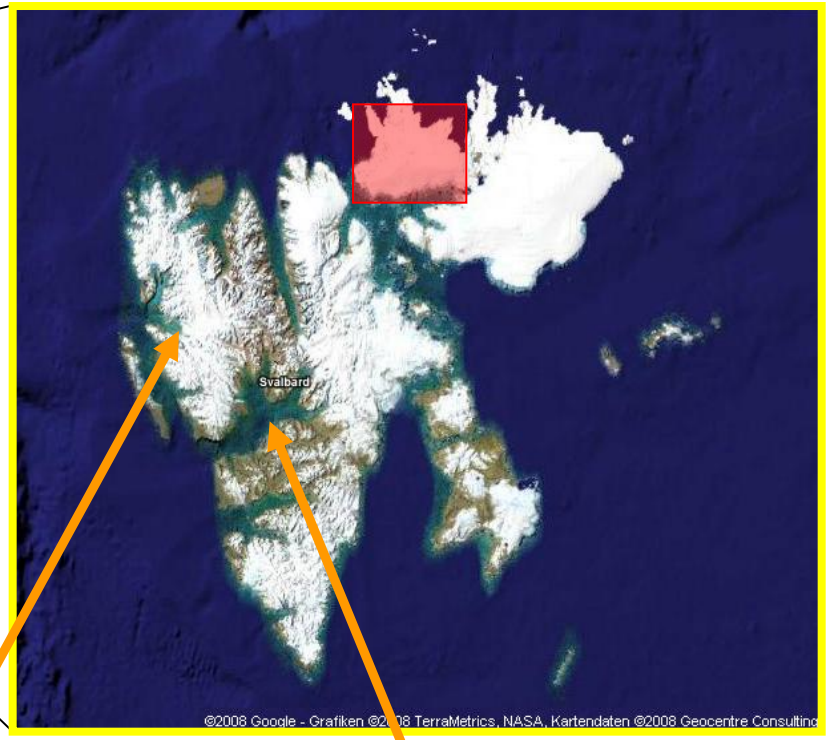
- the importance of the snow cover for glacier response

- climate variability related to atmospheric circulation



Zooming in to the European Arctic - Svalbard – Nordaustlandet - Vestfonna

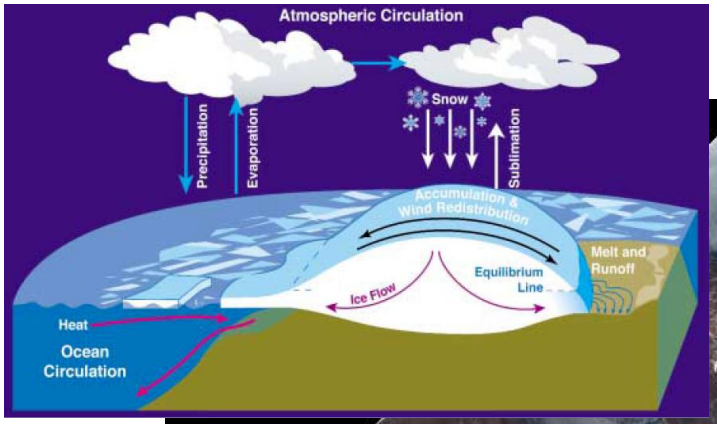




Ny-Ålesund

Longyearbyen

Vestfonna – “West Ice Cap”

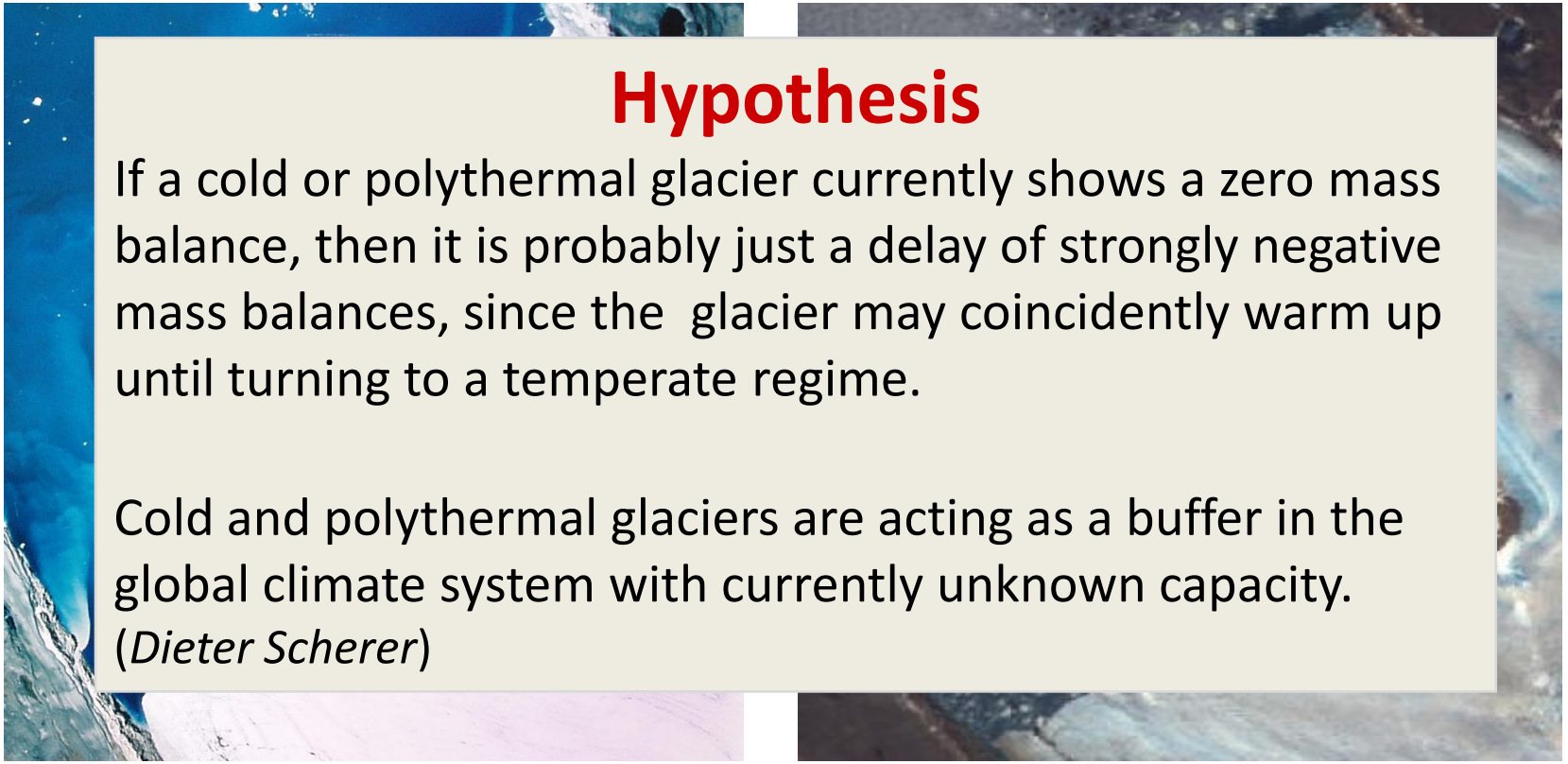


On the basis of the temperature measurements carried out in 1956–1958 Schytt (1969) postulated that the ice cap comprises two parts: 1) an inner core of ‘warm ice’, where the temperature is close to 0°C, and 2) a surrounding annulus of ‘cold ice’.

in: Erkki Palosuo (1987): A study of snow and ice temperatures on Vestfonna, Svalbard, 1956, 1957 and 1958.

Analysis of areal changes of different outlet glaciers reveals

… not much change between 1990 und 2000



Hypothesis

If a cold or polythermal glacier currently shows a zero mass balance, then it is probably just a delay of strongly negative mass balances, since the glacier may coincidently warm up until turning to a temperate regime.

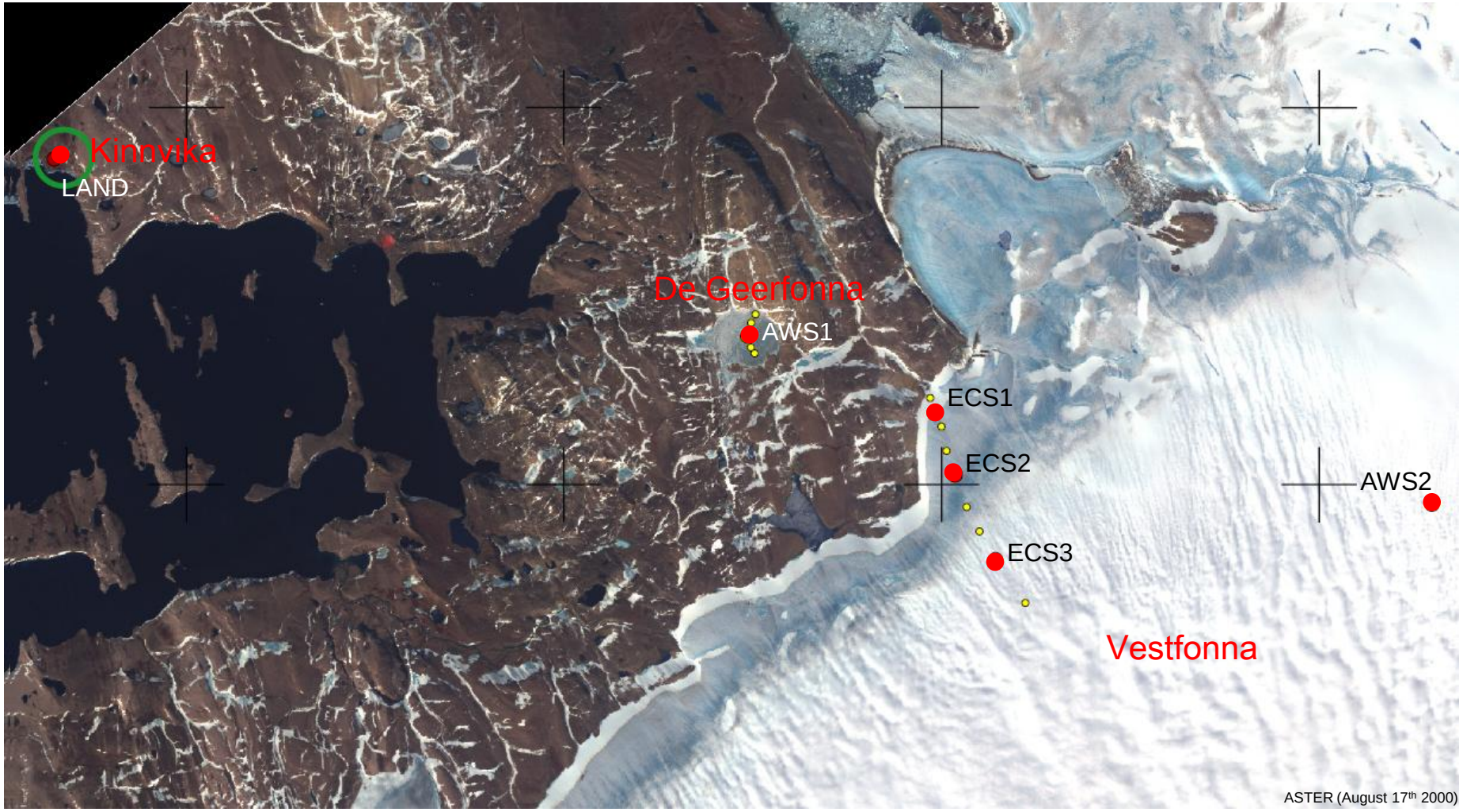
Cold and polythermal glaciers are acting as a buffer in the global climate system with currently unknown capacity. (*Dieter Scherer*)

Example: Franklinbreen

Vestfonna – “West Ice Cap”



Measurement network on Vestfonna & glaciological setup



Climate sensitivity of surface mass balance (simple DDM June 2008 to May 2009)

- Change of temperature data in steps of 1 K
- Change of precipitation data in steps of 10%

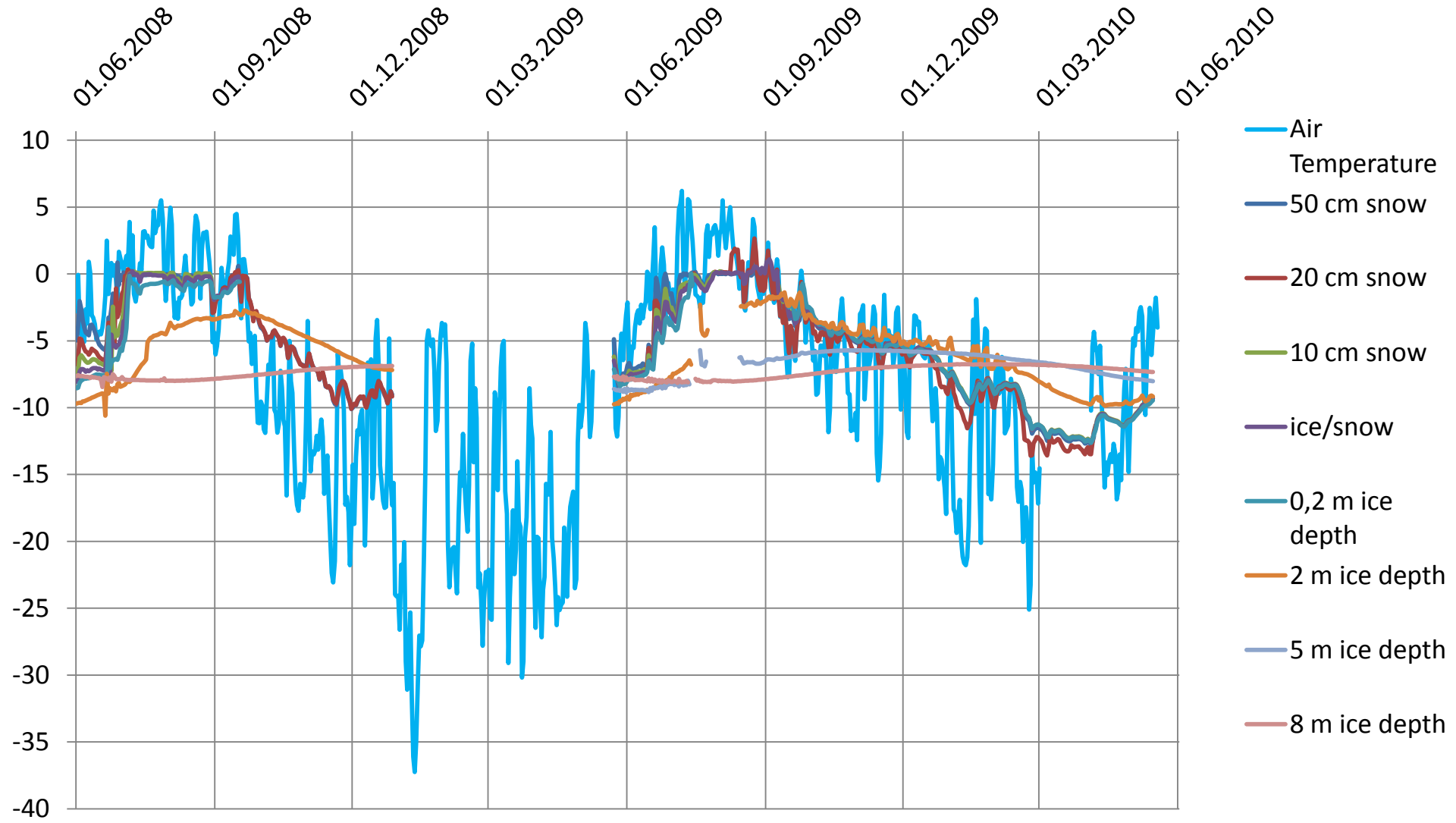
	=	+1K	+2K	+3K	+4K	+5K
+20%	+443	-255	-1249	-2514	-4048	-5738
+10%	+335	-361	-1352	-2614	-4140	-5828
=	**+227**	-468	-1456	-2714	-4232	-5916
-10%	+118	-574	-1560	-2815	-4325	-6006
-20%	+9	-680	-1664	-2915	-4420	-6097

[mm w.e.]

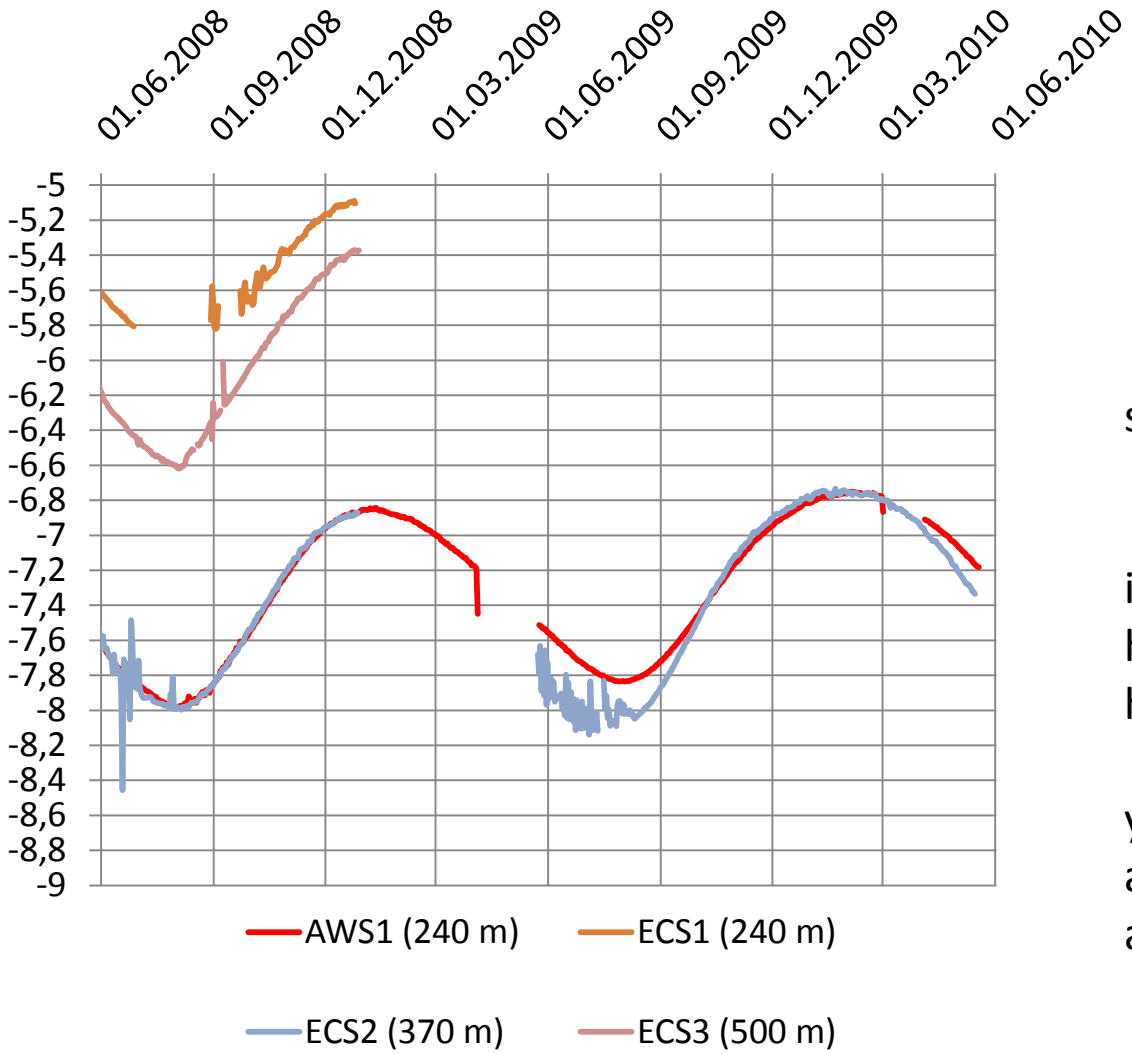
↳ Negative mass balance of few meters seems likely because of climate change in the course of the 21st century (Marco Möller, RWTH Aachen)

Air temperature and ice/snow temperatures

ECS2 at 370 m asl on Vestfonna



Ice temperatures at a depth of 8 m



solution of heat conduction equation (fourier equation) with

ice density: 900 kg/m^2
heat cap. : 2097 J kg^{-1} K^{-1}
heat cond. coeff.: 2.24 W m^{-1} K^{-1}

yields:
annual amplitude at 10 m: +/-0,5 K
annual amplitude at 8 m: +/-0,9 K

Ice temperatures at a depth of 8 m

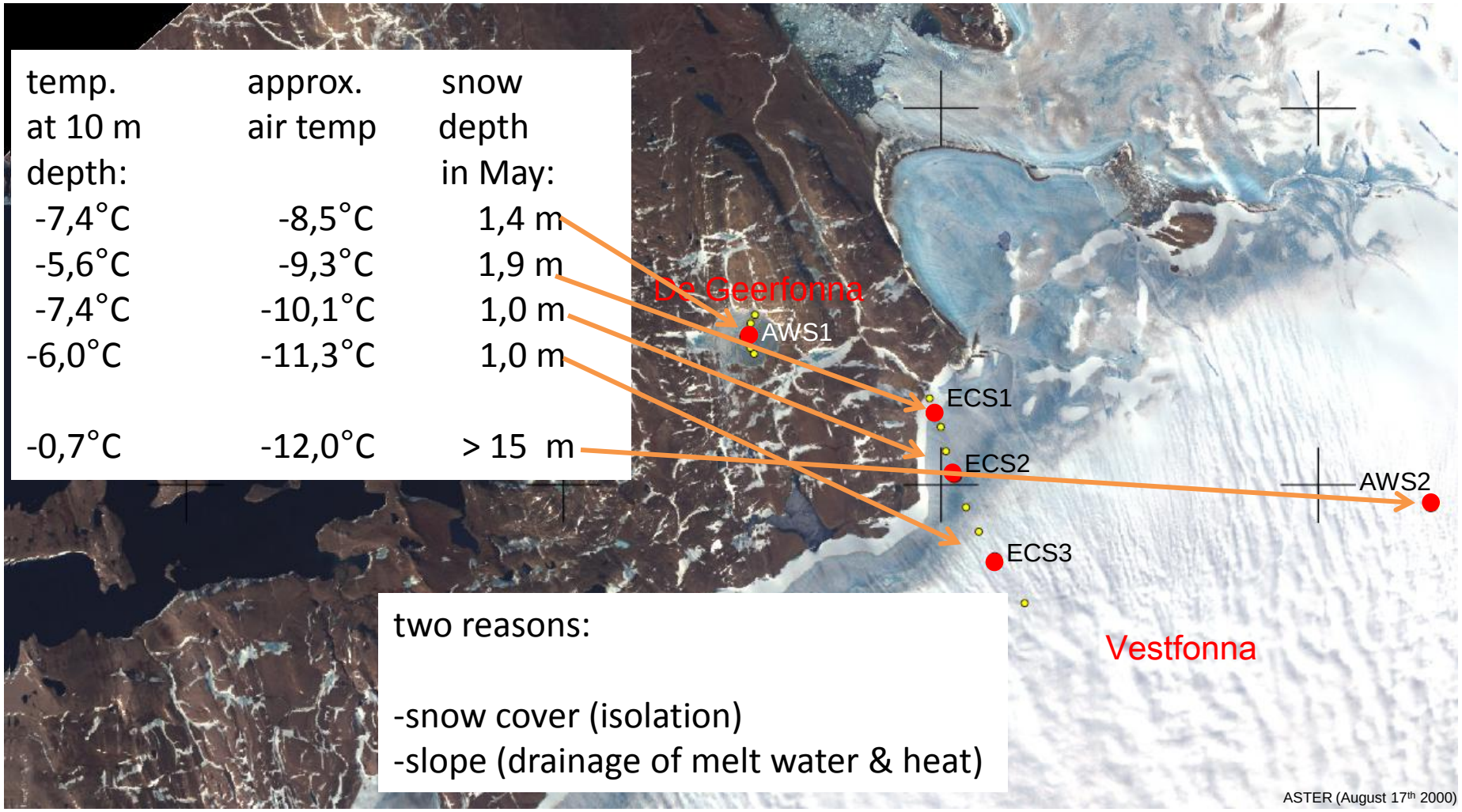
	AWS1	ECS1	ECS2	ECS3	Summit
snow cover (in May)	135	186	96	104	> 15 m
altitude asl	240	240	370	500	605
mean air temperature	-8,5	-9,3	-10,1	-11,3	-12,0
mean ice/firn temperature at 10 m below the surface	-7,4	-5,6	-7,4	-6,0	-0,7
difference air to ice/firn	1,1	3,7	2,7	5,3	11,3

solution of heat conduction equation (fourier equation) with

ice density: 900 kg/m^2
heat cap. : 2097 J kg^{-1} K^{-1}
heat cond. coeff.: 2.24 W m^{-1} K^{-1}

yields:
annual amplitude at 10 m: +/-0,5 K
annual amplitude at 8 m: +/-0,9 K

Vestfonna: warm based core, cold based fringes



So, is there any (long-term) change at all?

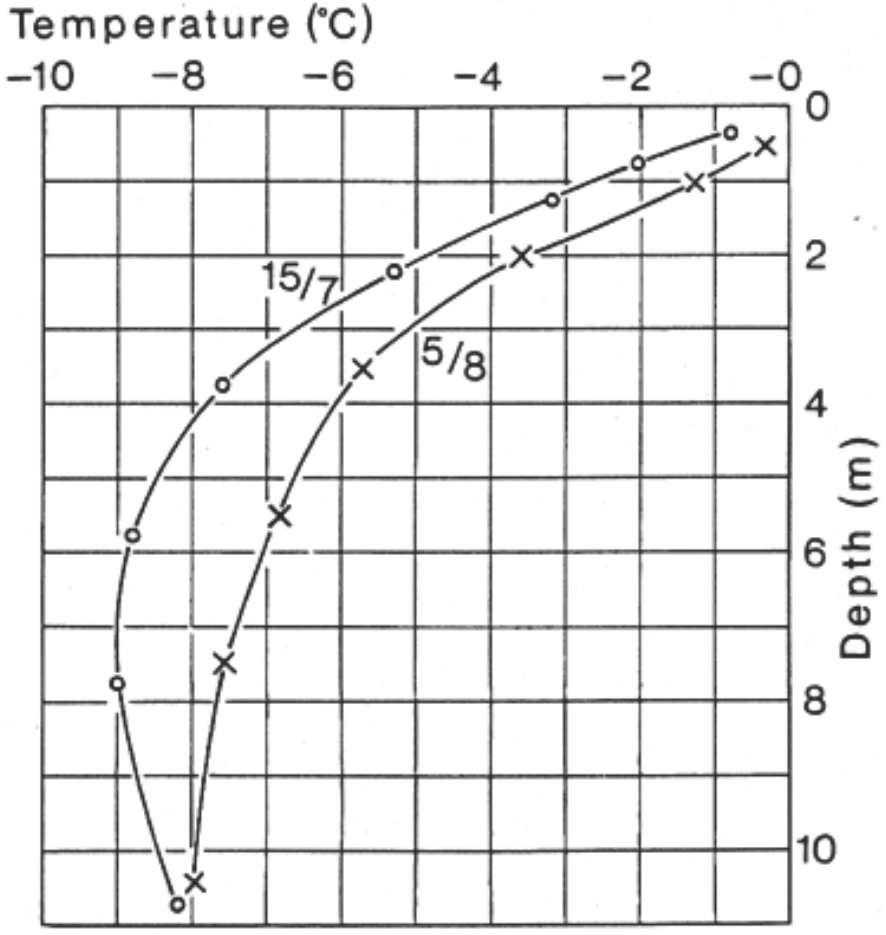


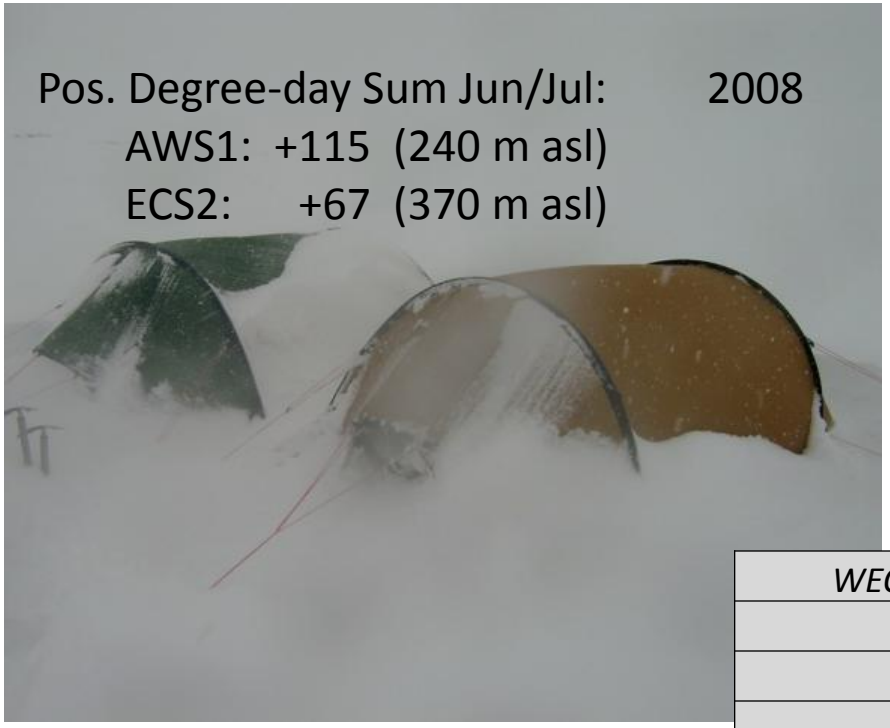
Fig. 3. Temperature conditions at Stake 0 (height 312 m, Palosuo and Schytt, 1960), in 1958. The first recording was made on July 15 and the last on 5 August.

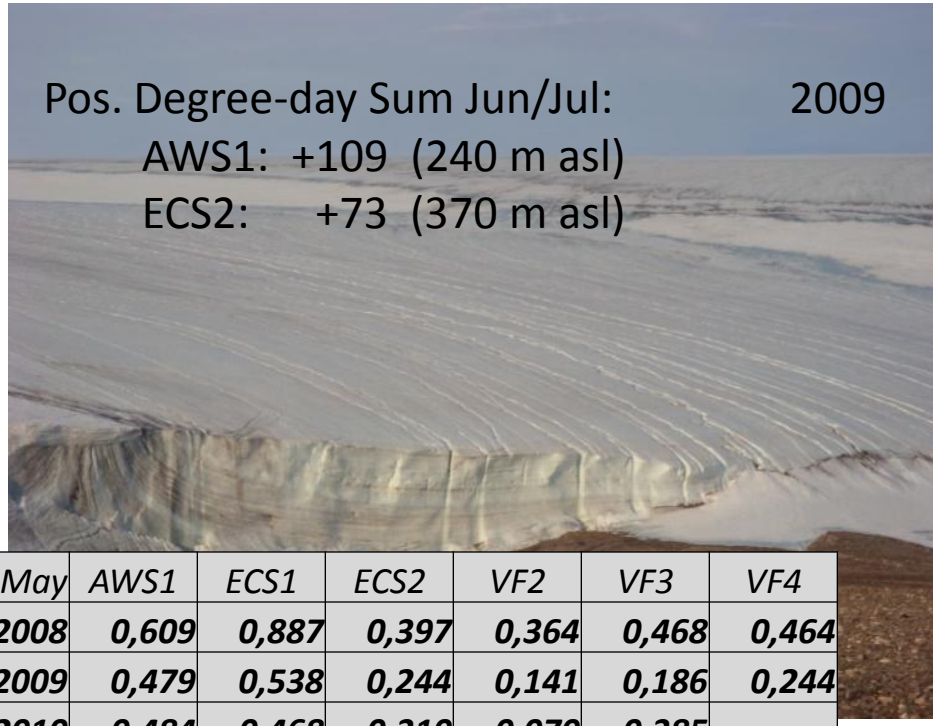
	AWS1	ECS2	Stake 0
altitude asl	240	370	312
snow cover	1,5 m	1 m	0,3 m
year	2008/09	2008/09	1957/58
ann. pos. sum of degree days	165	111	60
mean ice temp. at 10 m depth	-7,4°C	-7,4°C	-8°C

Looks like there is some change!

Erkki Palosuo (1987): A study of snow and ice temperatures on Vestfonna, Svalbard, 1956, 1957 and 1958.

Vestfonna 2008 and 2009 compared





WEQ May	*AWS1*	*ECS1*	*ECS2*	*VF2*	*VF3*	*VF4*
2008	***0,609***	***0,887***	***0,397***	***0,364***	***0,468***	***0,464***
2009	***0,479***	***0,538***	***0,244***	***0,141***	***0,186***	***0,244***
2010	***0,484***	***0,468***	***0,310***	***0,070***	***0,385***	
WEQ 09 rel. 08	*79%*	*61%*	*62%*	*39%*	*40%*	*53%*
m a.s.l.	*240*	*240*	*370*	*285*	*329*	*413*

winter accumulation?
sea ice?
albedo feedback through summer precipitation?
snow drift?
single large precipitation events?

Circulation Pattern Classification für Svalbard und Umgebung

Data:
NCEP/NCAR Reanalysis daily (2.5° x 2.5°, 1980-2009), slp, geopot500

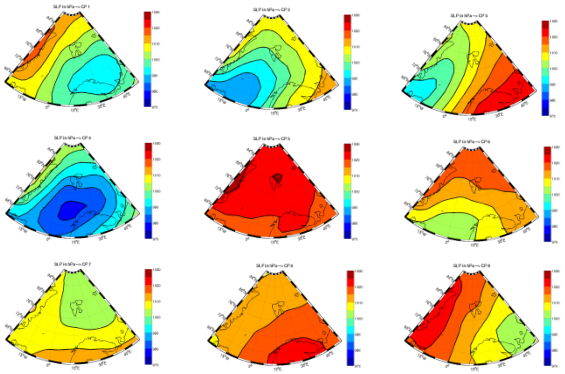
procedure:
time series centred around mean
Grid points weighted according convergence of meridians

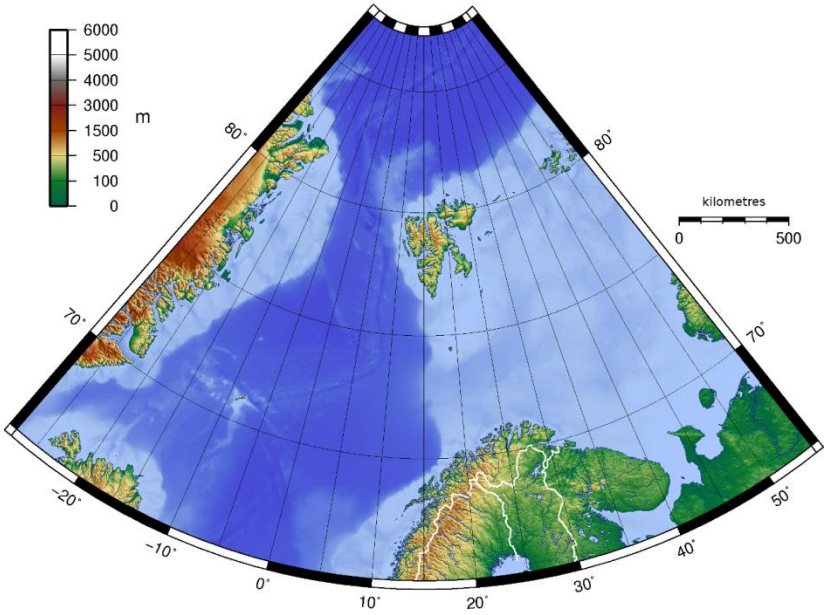
multiple clustering using Self-Organizing-Maps (SOM) algorithm

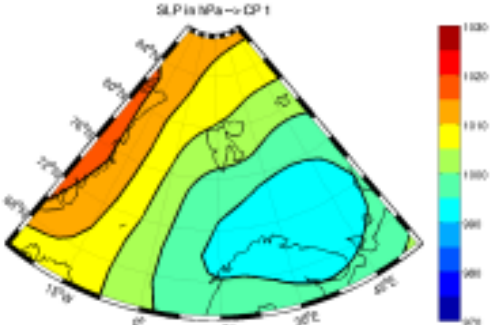
Number of cluster predetermined (subsequently from 3 to 25) and evaluated using indices (e.g. Davies-Bouldin-Index, Silhoutte-Index)

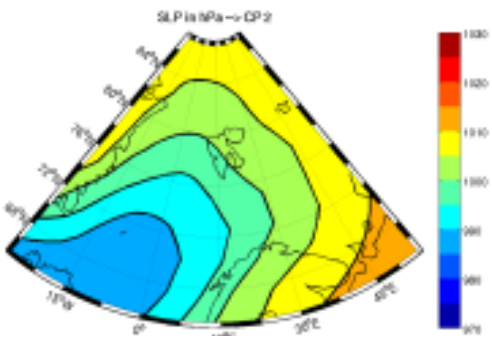
Final decision based on indices yields:

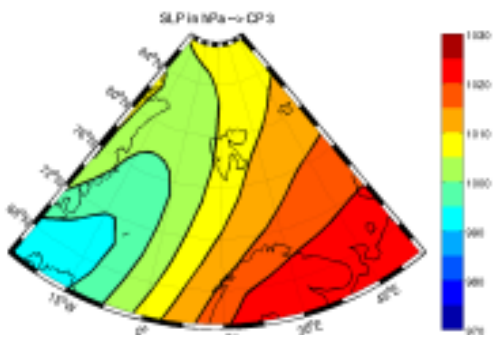
9 circulation patterns

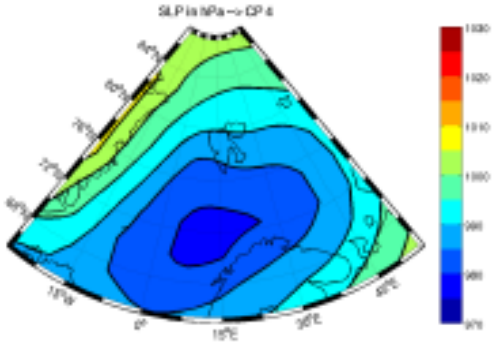


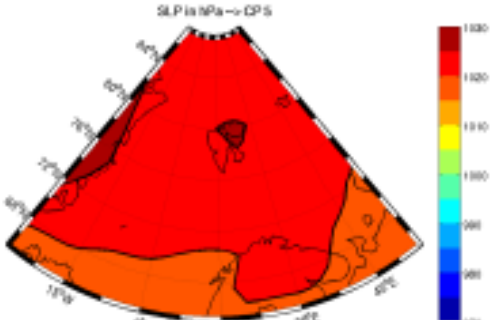


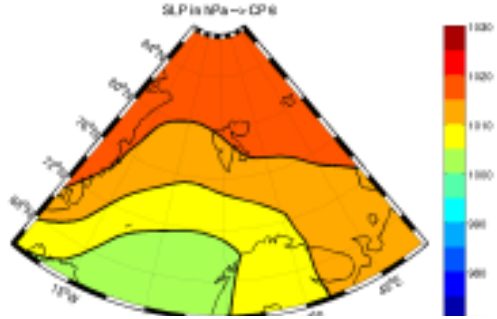

SLP in hPa --> CP 1

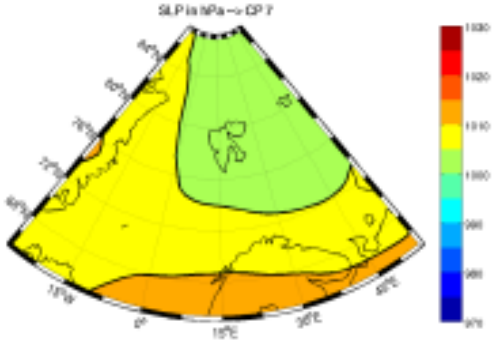

SLP in hPa --> CP 2

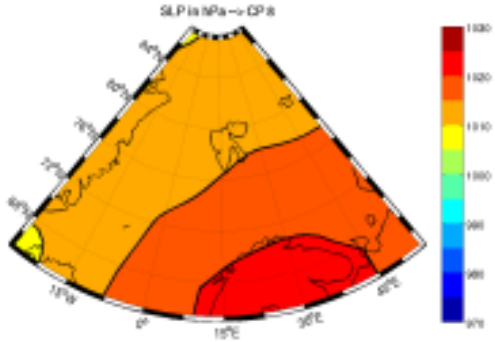

SLP in hPa --> CP 3

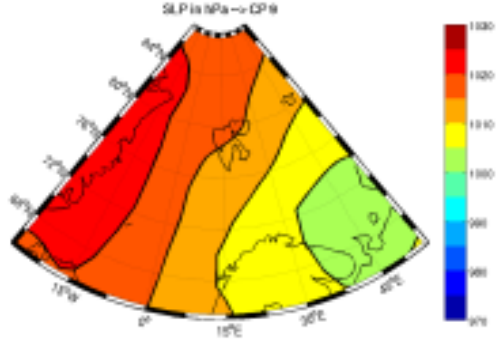

SLP in hPa --> CP 4


SLP in hPa --> CP 5


SLP in hPa --> CP 6


SLP in hPa --> CP 7


SLP in hPa --> CP 8


SLP in hPa --> CP 9

Circulation pattern & climate variables

GEOGRAPHIE RWTH AACHEN UNIVERSITY

temperature in summer

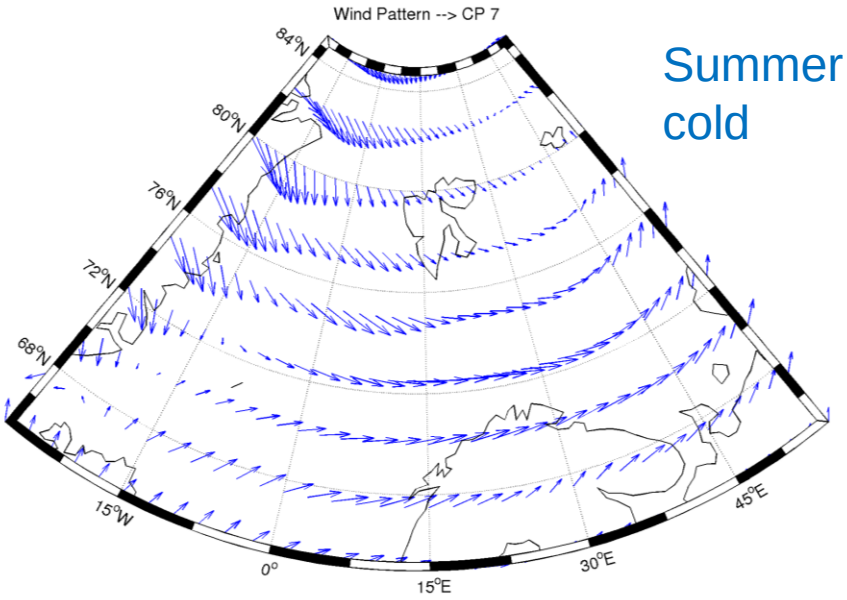
June, July, August									
Circulation Pattern No.	1	2	3	4	5	6	7	8	9
Sum of days per pattern	89	44	94	0	253	493	735	693	359
rel . Freq 1980-2009	3,2%	1,6%	3,4%	0,0%	9,2%	17,9%	26,6%	25,1%	13,0%
rel. Freq 2008 & 2009	2,7%	1,6%	2,2%	0,0%	17,4%	16,8%	15,8%	19,0%	24,5%
mean air temp. NCEP/NCAR (1980-2009) (°C)	0,3	0,9	2,0		1,1	1,7	0,7	1,4	0,7
mean temp Vestfonna 2008 und 2009 (°C)	-0,1	0,4	1,9		0,7	1,6	-0,8	0,7	-1,5
Mean PWC per pattern (kg/m²)	11,8	12,2	13,7		10,4	12,1	11,2	11,9	10,8

precipitation in winter

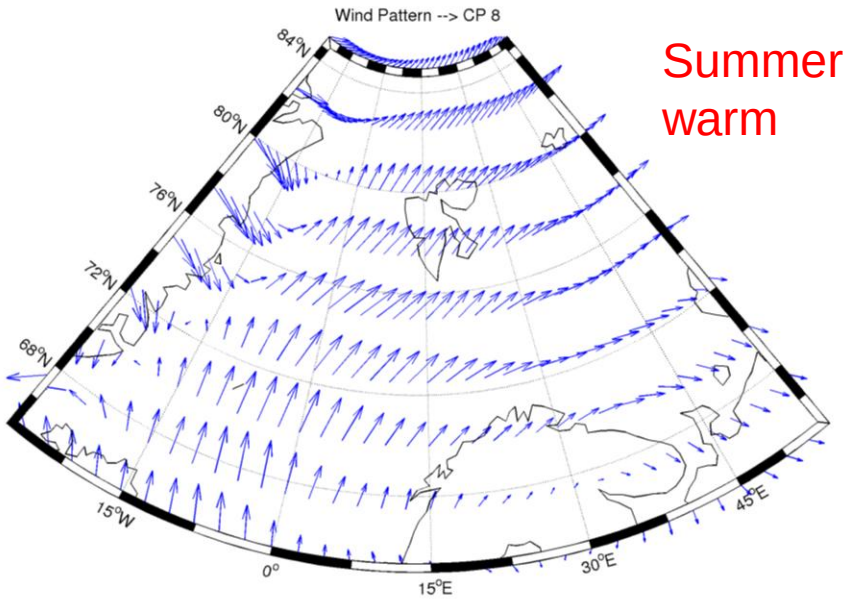
September – May									
Circulation Pattern No.	1	2	3	4	5	6	7	8	9
Sum of days per pattern	1138	887	658	536	941	1113	892	939	1094
relative frequency (1980-2009)	13,9%	10,8%	8,0%	6,5%	11,5%	13,6%	10,9%	11,5%	13,3%
difference of rel. freq. from avg. in 2007/08	2,0	1,2	0,1	1,9	3,4	-4,0	0,4	-3,3	-1,7
difference of rel. freq. from avg. in 2008/09	-1,5	0,5	2,6	-0,9	-5,8	2,3	1,8	-0,5	1,1
mean increase 2008/2009	0,32	0,21	0,44	0,13	0,22	0,55	0,66	0,17	0,18
Mean PWC per pattern (kg/m²)	3,542	4,886	6,683	3,94	4,556	4,663	4,87	6,093	3,599

-> single large precipitation events ?

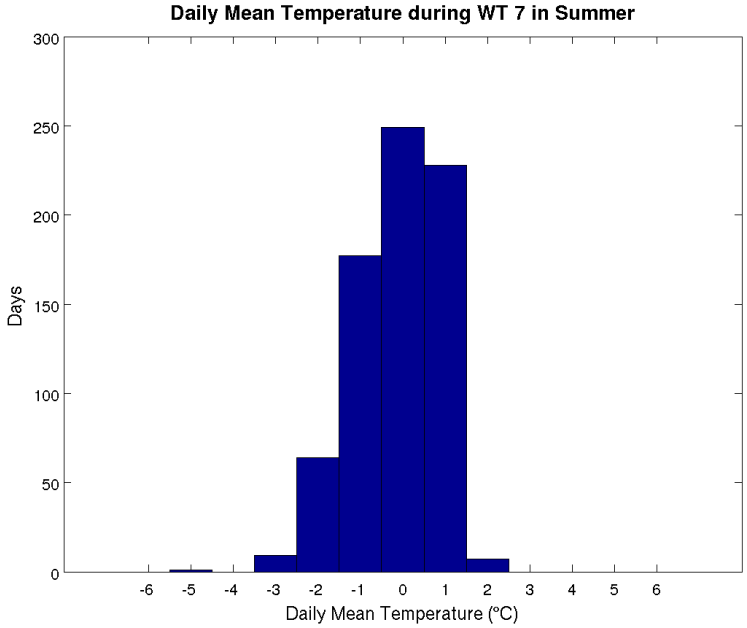
Examples: Circulation patterns dominating in summer

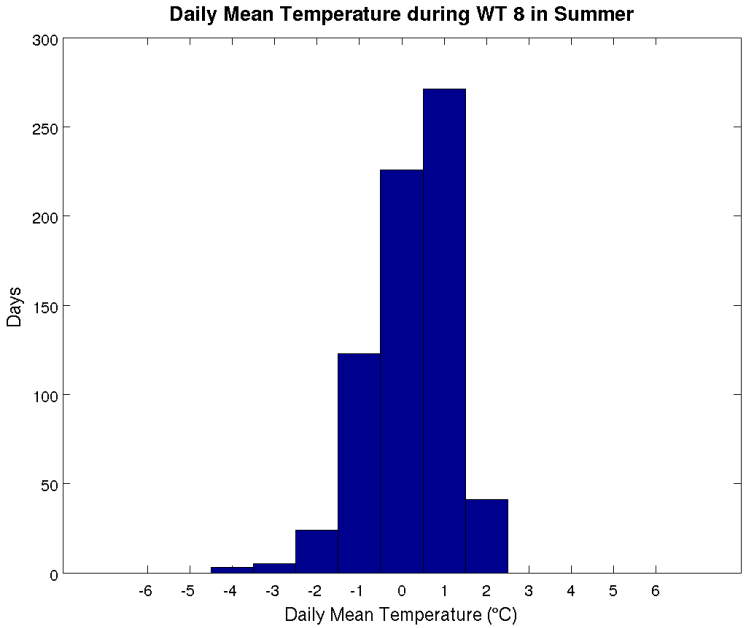


Summer; cold



Summer; warm



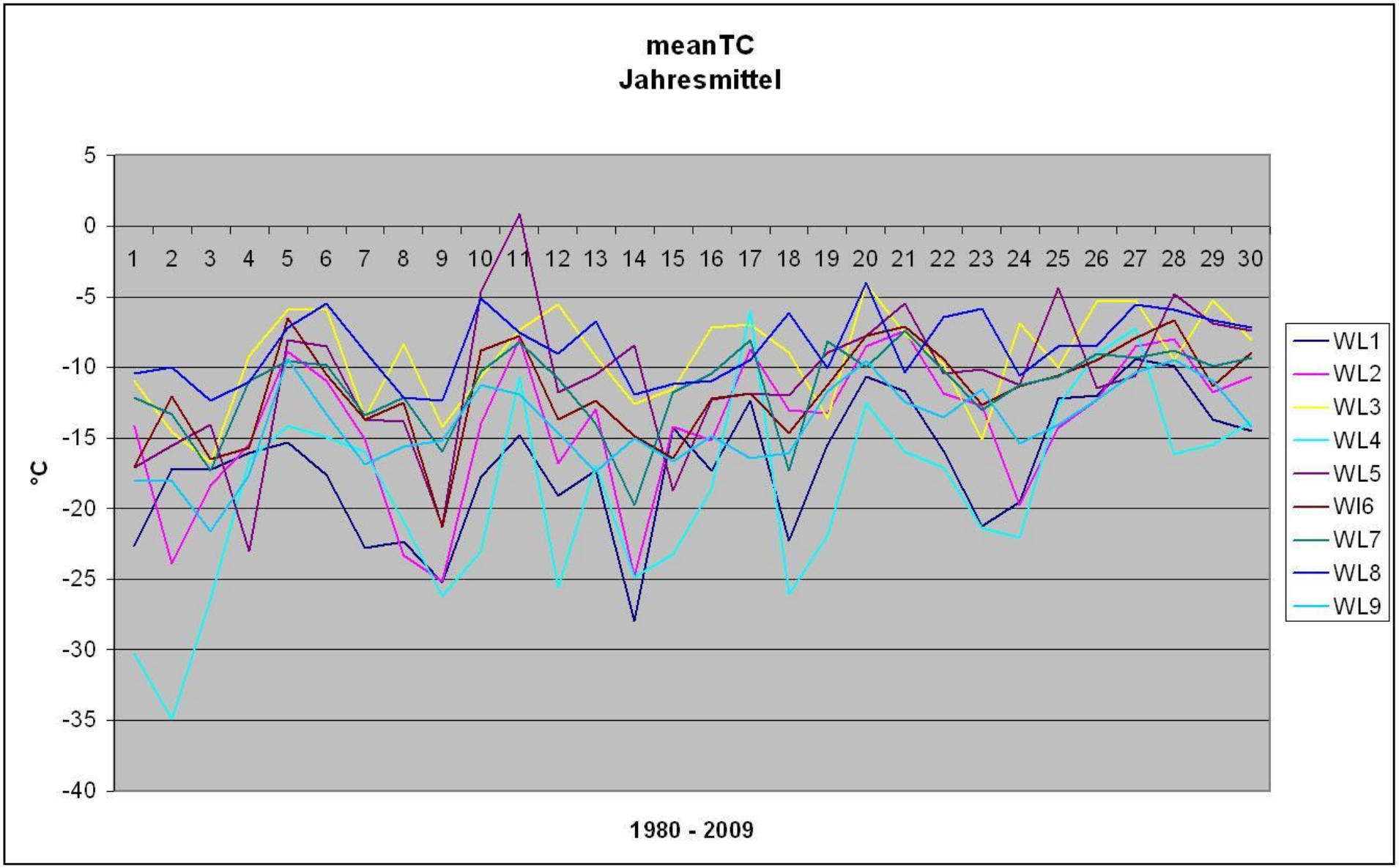


CP classification:
What can we do based on this exercise?

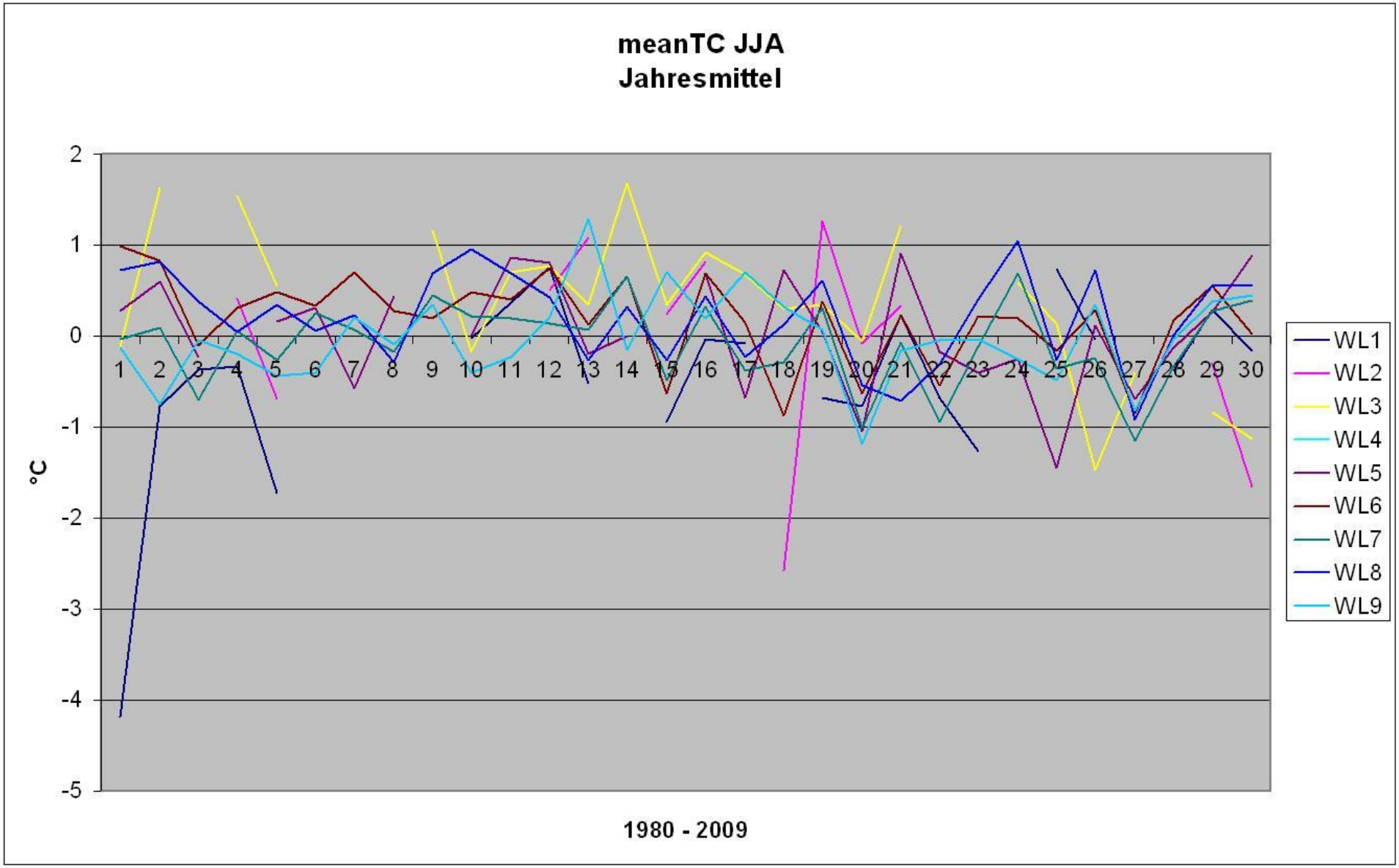
- Do CP frequency distribution vary over time? Trends?
- Are CPs internally getting warmer, wetter, windier, ….
- Does CP frequency directly relate to glacier mass balance?

Point 1: Yes, but I cannot show you due to dramtic impact on hard disk last night
Point 2: Let‘s see what indications there are
Point 3: I guess yes, but we are not there yet!

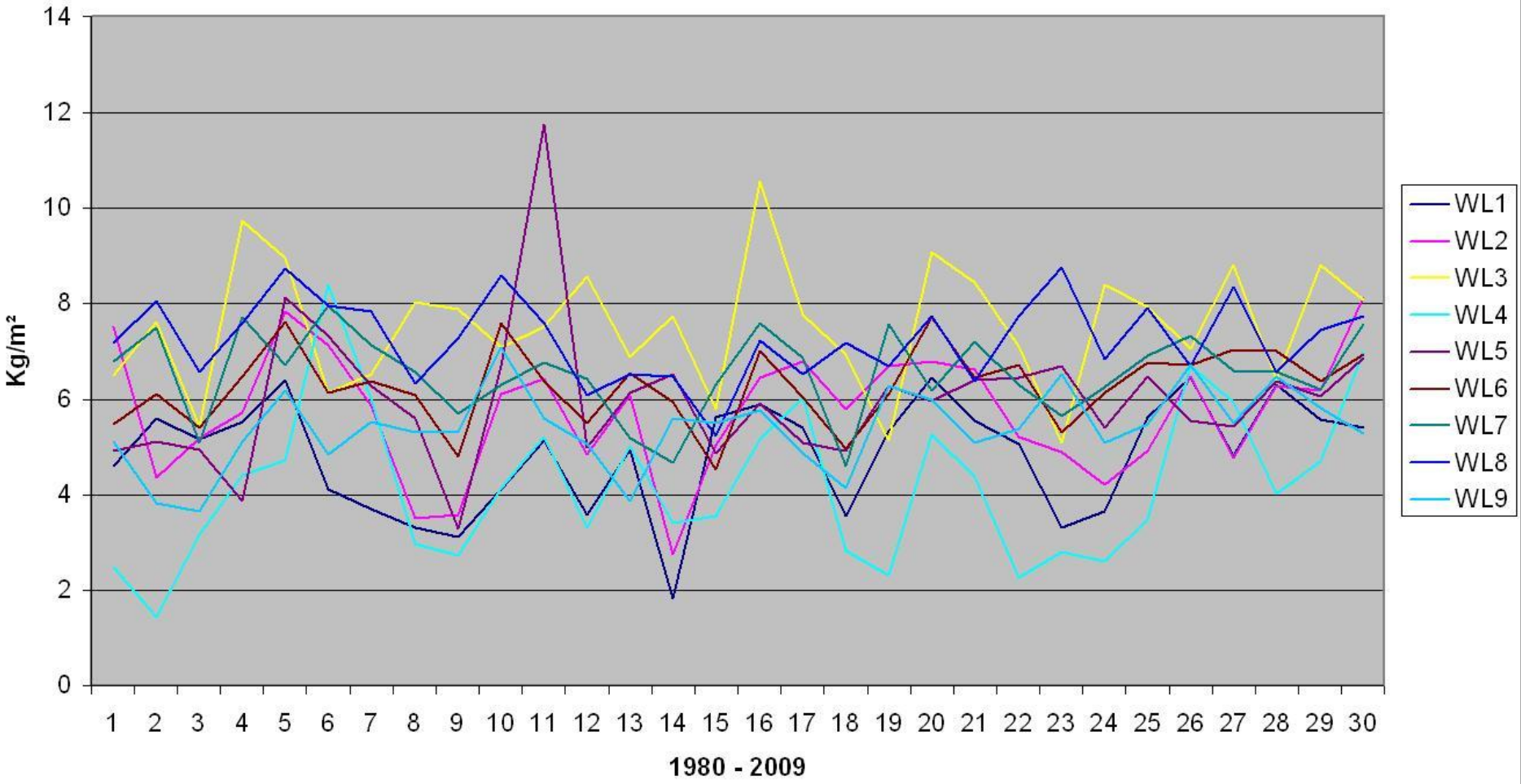
Circulation Pattern Classification for Svalbard wider area



Circulation Pattern Classification for Svalbard wider area



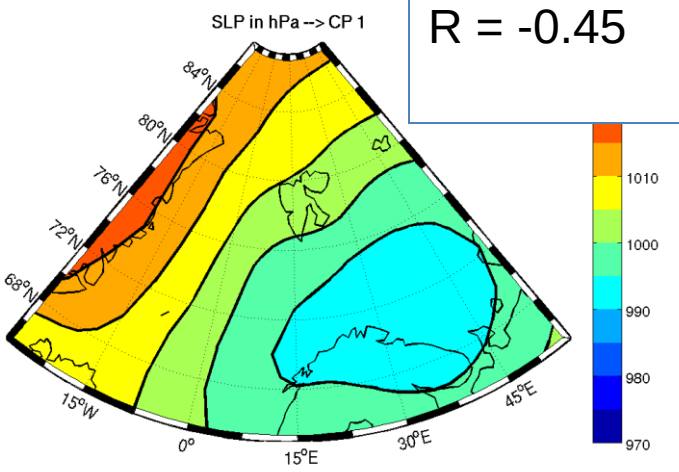
Circulation Pattern Classification for Svalbard wider area

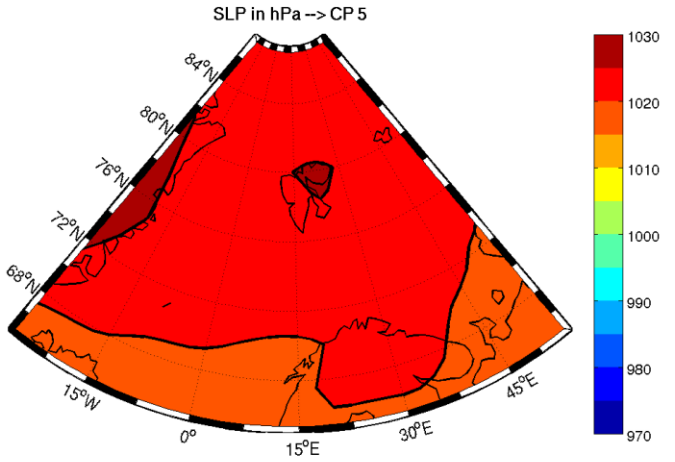


Circulation Pattern Classification for Svalbard wider area

CP with large trend

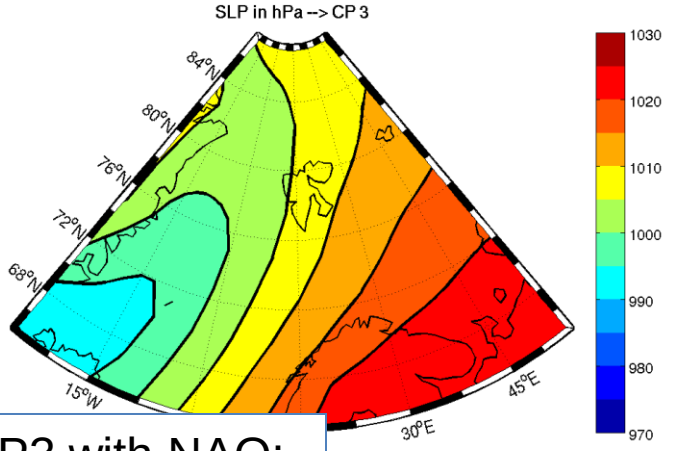
Correlation of CP1 with NAO:
R = -0.45

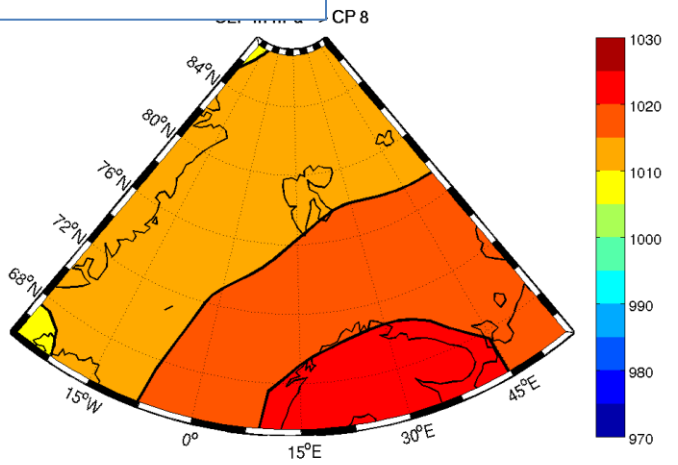




CP with little trend

Correlation of CP3 with NAO:
R= +???





Summary Vestfonna

-not much change in terms of size in recent decade at Vestfonna
- strongly negative surface mass balance likely to occur in the course of the 21st century

- heat conduction through melt water and thermal isolation effect of snow cover are important for internal cold content of the glacier & refreecing

-> possibly acting as a buffer increasing response time of glacier dynamics to climate forcing

- indication for warming of the upper ice (ca. 0.5 K)
-> increase in surface air temperature or change in snow cover

- circulation patterns reflect temperature regime in relation to large-scale circulation

-> numerical weather modelling is needed to capture individual events/processes
-> snow depth survey & spatial distribution of temperature at 10 m below the surface would be nice to have



Thank you very much for listening!







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