Surface hydrology in Antarctica

Why should we care?
What do we currently know about its future?
Where do the uncertainties come from?

Crédit : R. Fletcher

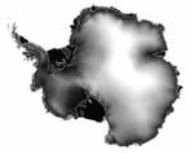
Charles AMORY and many others

Snow workshop – 9 June 2022, Grenoble

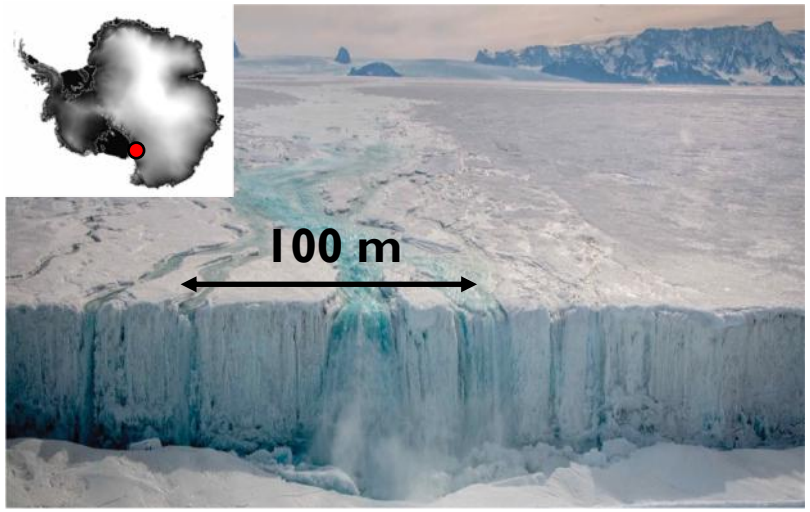
Ice sheet mass balance is the main uncertainty in sea level projections

Surface mass balance

Mass Balance = Precipitation – Sublimation – Erosion – Runoff – Ice discharge → sea level rise (since ~1980)

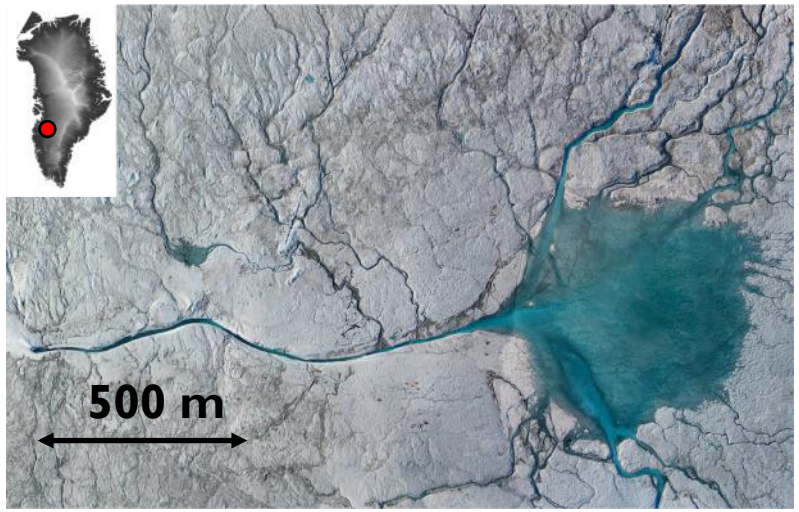
	100%	3%	4%	**45%**	48%	+13 mm
	100%	1%	>5%	**1%**	>90%	+14 mm

Nansen ice shelf - Antarctica



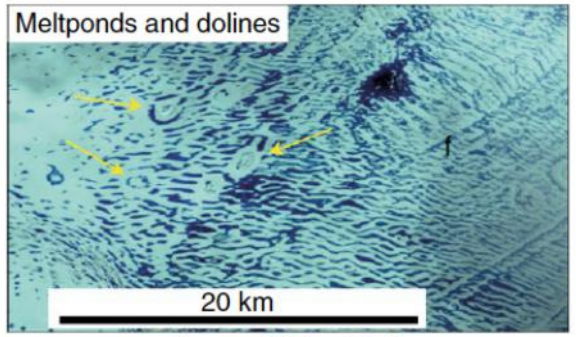
Credit : R. Fletcher

Russell Glacier – Greenland



Credit : L. C. Smith

Melting is pervasive along the ice surrounding Antarctica

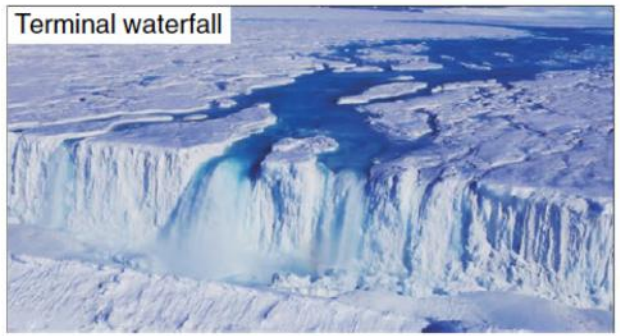


a

George VI Ice Shelf
10 January 2003

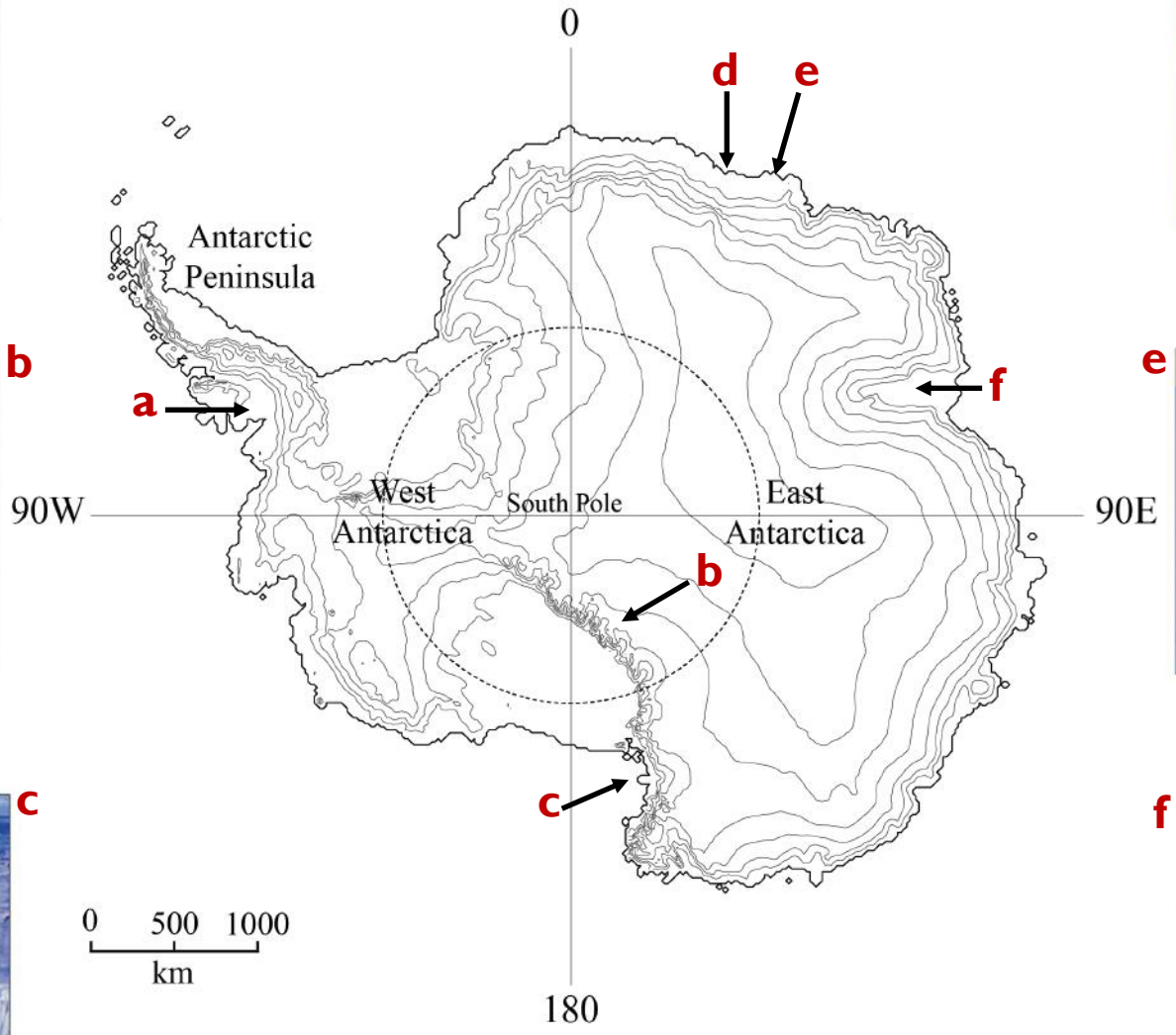
b

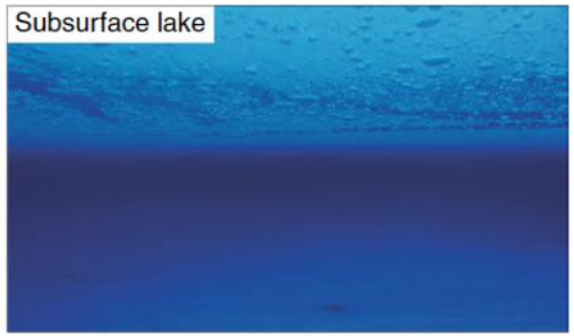
Law Glacier (~1,830 m a.s.l.)
14 January 2017



c

Nansen Ice Shelf
12 January 2014



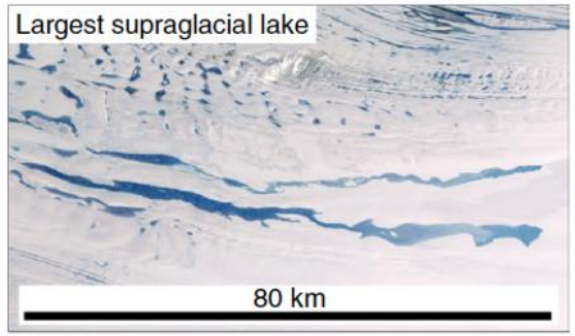


d

Western Roi Baudouin Ice Shelf
January/February 2016

e

Eastern Roi Baudouin Ice Shelf
January/February 2016



f

Amery Ice Shelf
21 February 1988

Examples of major components of surface hydrological systems in Antarctica (adapted from Bell et al. 2018).

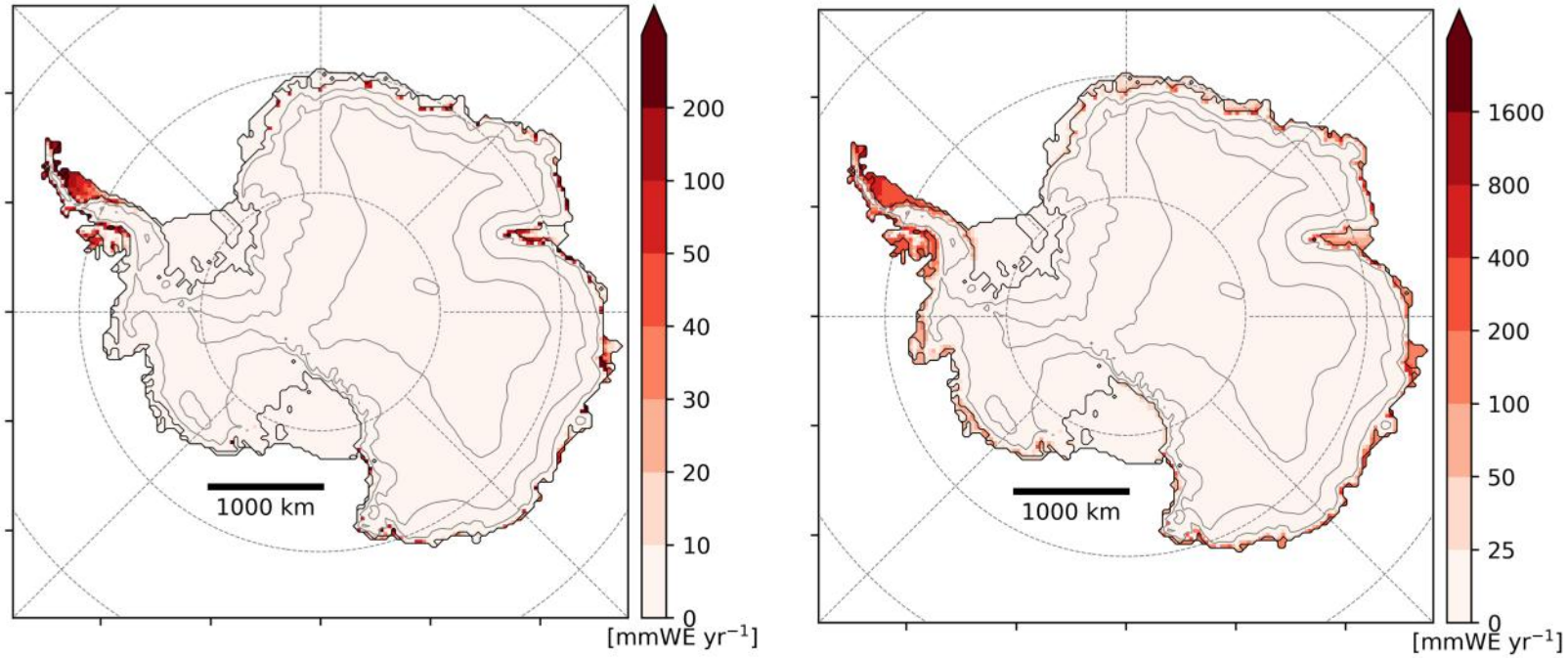
Estimates of melt and runoff rates rely entirely on models

Runoff

54 ± 14 Gt y^{-1}

Melt

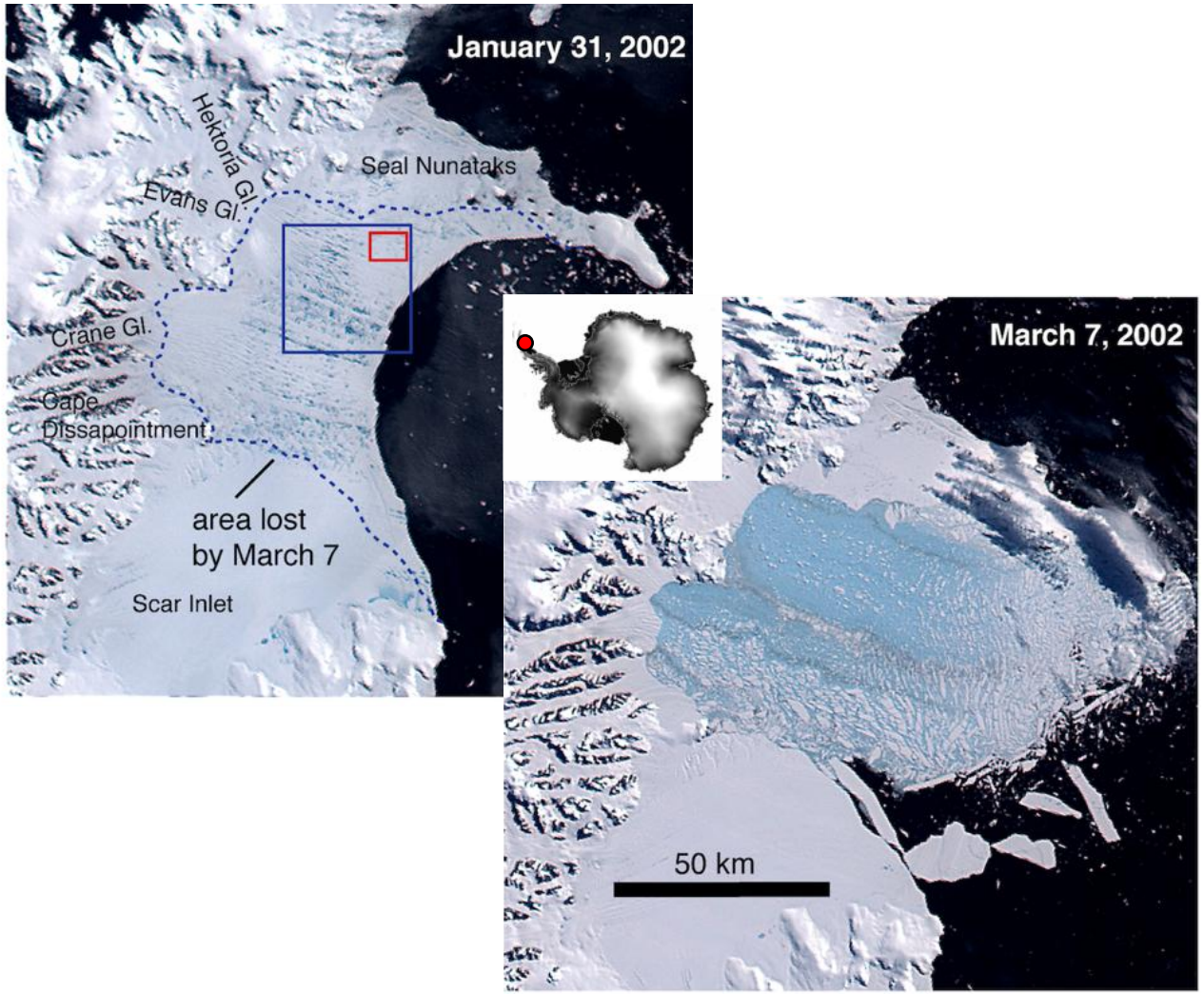
174 ± 38 Gt y^{-1}



MAR(ERA5) 1979-2021

- No current trend
- Occurs mostly over peripheral ice shelves (~~GRACE~~)
- Runoff into ocean?
- Meltwater mostly refreezes
- Depends on models, resolution, rocks….

Surface hydrology can enhance dynamical mass loss



Desintegration of Larsen B in 2002 (Scambos et al. 2003)

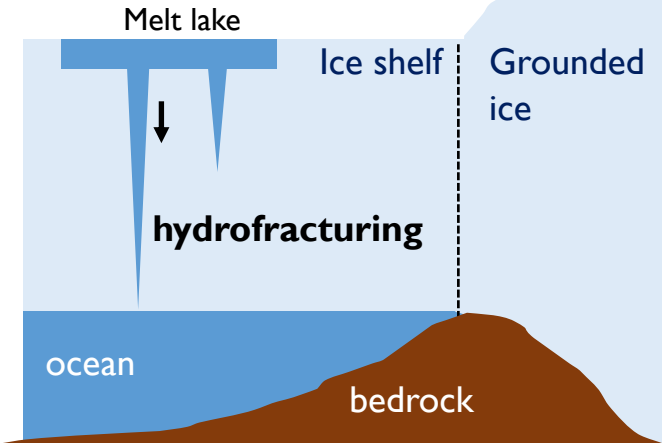
Surface hydrology influences :

- Ice-sheet surface mass balance
  (runoff, melt-albedo feedback)

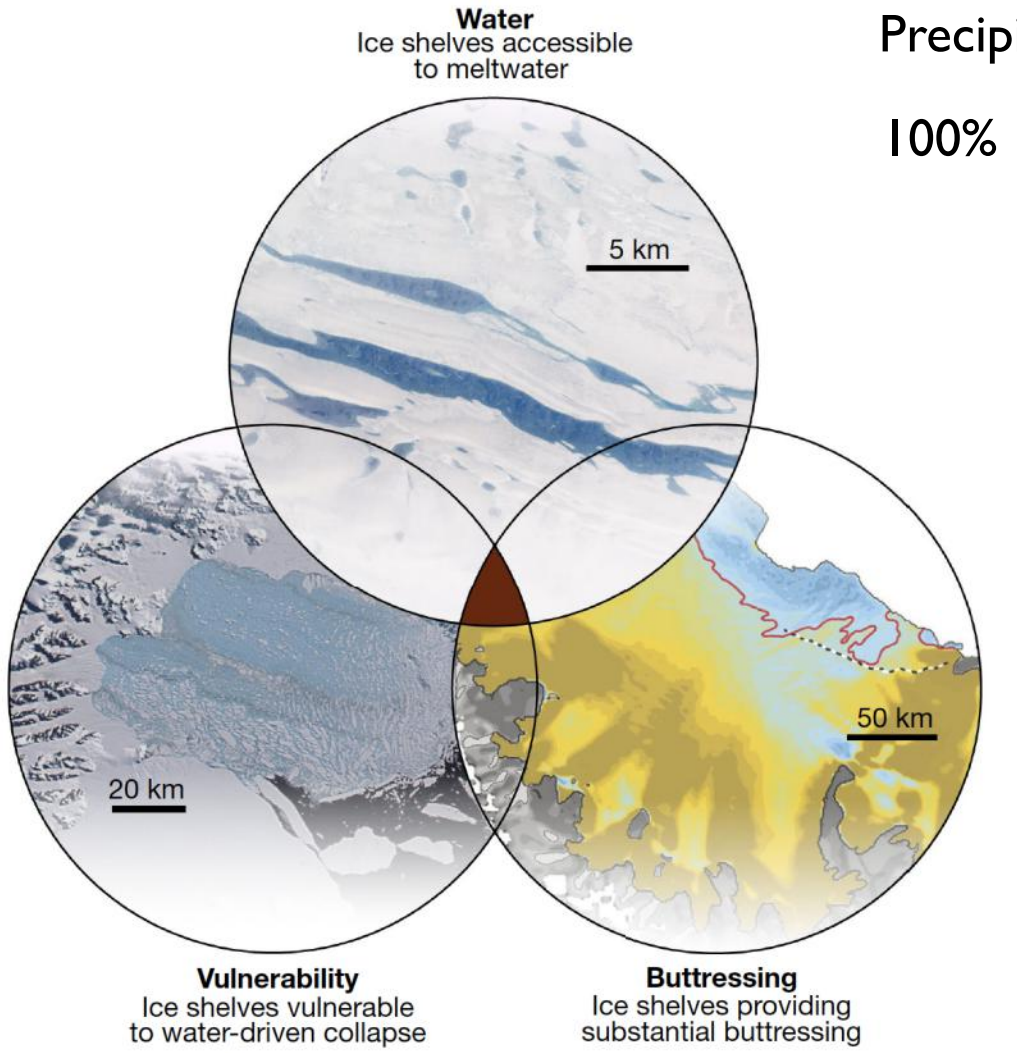
- Ice-sheet dynamics
  (lubrification, basal melting, hydrofracturing)

⬇

Extreme projected mass losses



Future surface hydrology increases risk of ice shelf disintegration

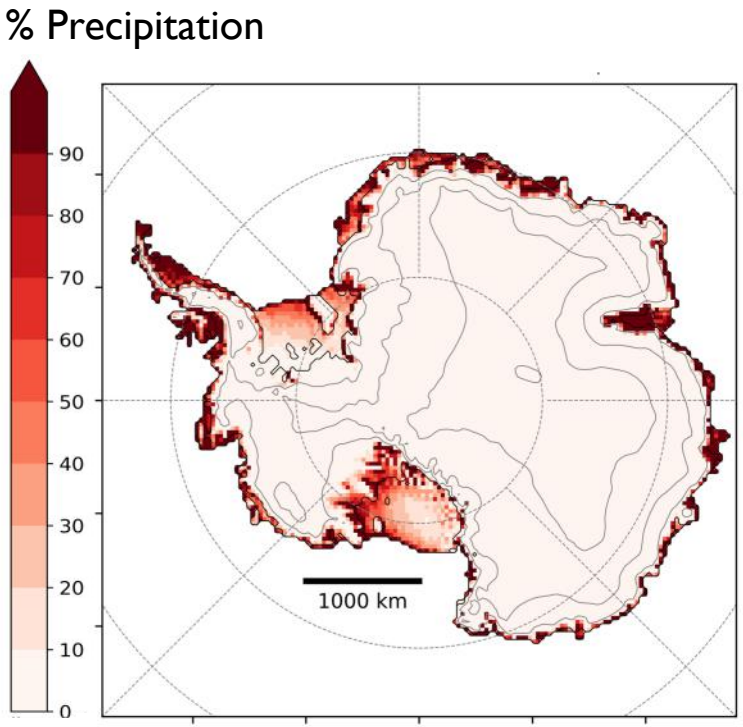


Conceptualizing the regions of Antarctic ice shelves that will control the ice sheet's response to atmospheric warming (Lai et al. 2020).

Precipitation – Sublimation – Erosion – Runoff – Ice discharge

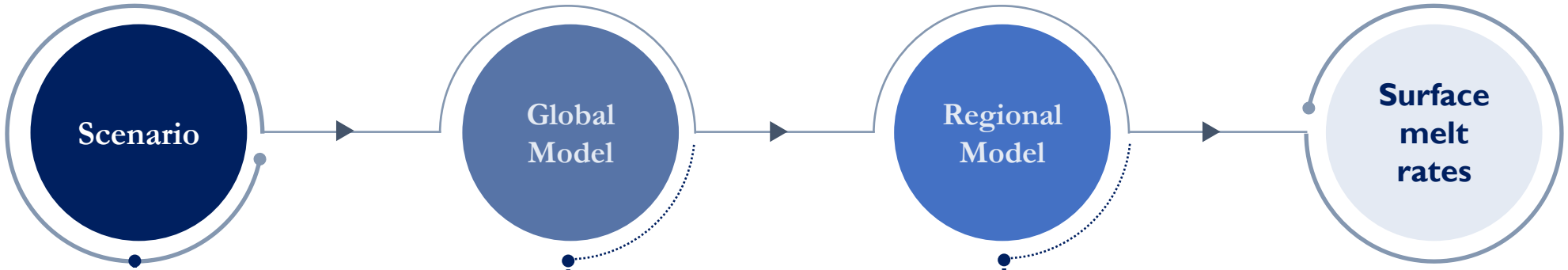
100% 1% >5% 1% (22% ?) >90%

Present day (end of century)



Runoff *at the surface of Antarctica in 2100 as simulated by MAR driven by CNRM-CM6-1 under ssp5-8.5 (Kittel et al. 2021a).*

Producing melt estimates involves a long calculation chain



- Emission trajectories
  - ssp119
  - ssp126
  - ssp245
  - ssp370
  - ssp585
- Large-scale circulation
- Surface oceanic conditions
- Climate sensitivity
  - CMIP5
  - CMIP6
- High resolution
- Polar atmosphere physics
- Snowpack processes

Driving global models need to be carefully selected

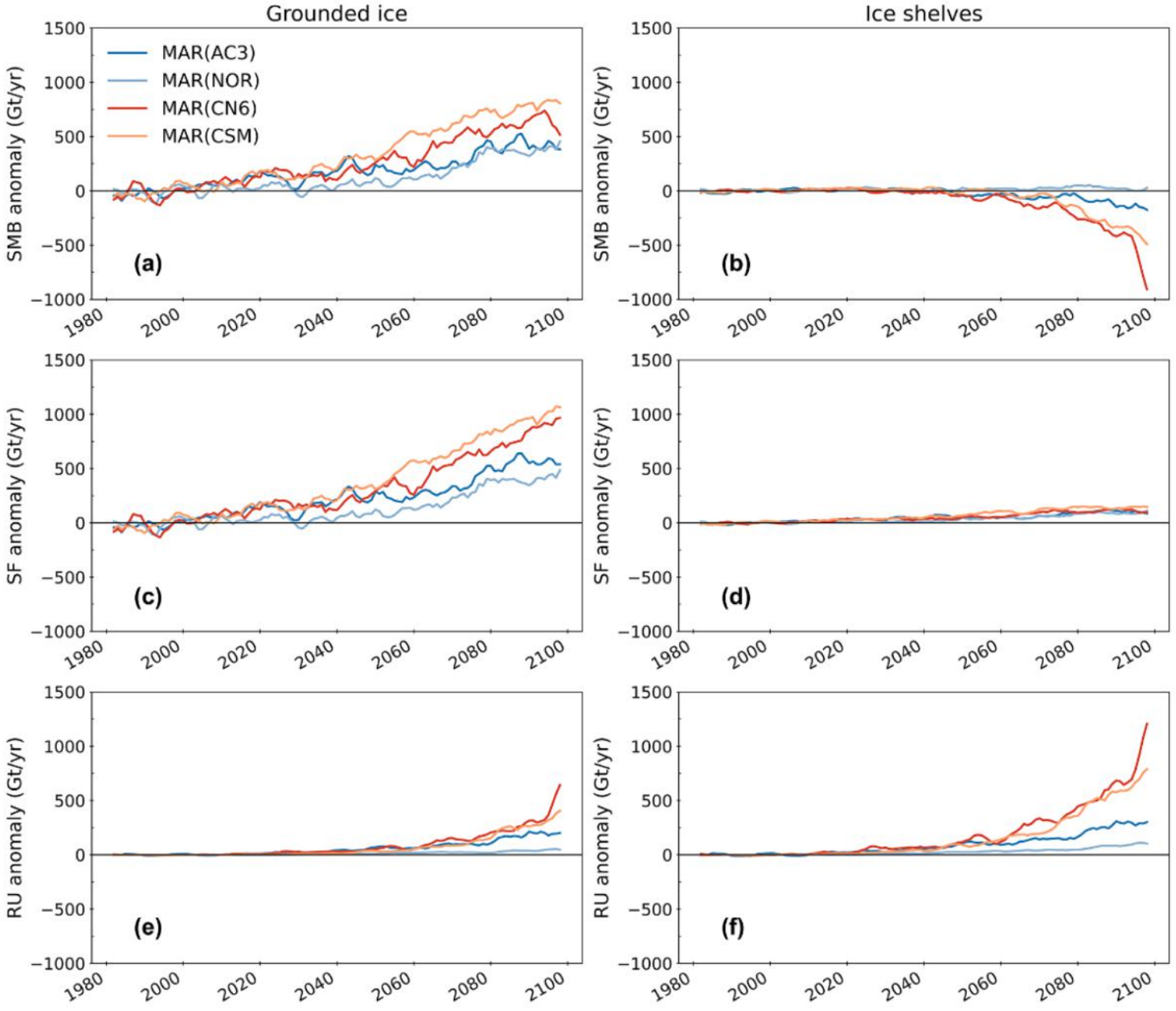
CMIP5 model number	Model	ECS
1	ACCESS1-0	3.8
2	ACCESS1-3	3.5
3	BNU-ESM	3.9
4	CCSM4	2.9
5	CNRM-CM5	3.3
6	CNRM-CM5-2	
7	CSIRO-Mk3-6-0	4.1
8	CanESM2	3.7
9	FGOALS-g2	3.4
10	FGOALS-s2	4.2
11	GFDL-CM3	4.0
12	GFDL-ESM2G	2.4
13	GFDL-ESM2M	2.4
14	GISS-E2-H	2.3
15	GISS-E2-R	2.1
16	HadGEM2-ES	4.6
17	IPSL-CM5A-LR	4.1
18	IPSL-CM5A-MR	
19	IPSL-CM5B-LR	2.6
20	MIROC-ESM	4.7
21	MIROC5	2.7
22	MPI-ESM-LR	3.6
23	MPI-ESM-MR	3.5
24	MPI-ESM-P	3.5
25	MRI-CGCM3	2.6
26	NorESM1-M	2.8
27	bcc-csm1-1	2.8
28	bcc-csm1-1-m	2.9
29	inmcm4	2.1

CMIP6 model number	Model	ECS
30	ACCESS-CM2	4.7
31	ACCESS-ESM1-5	3.9
32	AWI-CM-1-1-MR	3.2
33	BCC-CSM2-MR	3.0
34	BCC-ESM1	3.3
35	CAMS-CSM1-0	2.3
36	CESM2	5.2
37	CESM2-WACCM	4.8
38	CNRM-CM6-1	4.8
39	CNRM-CM6-1-HR	4.3
40	CNRM-ESM2-1	4.8
41	CanESM5	5.6
42	E3SM-1-0	5.3
43	EC-Earth3	4.3
44	EC-Earth3-Veg	4.3
45	FGOALS-f3-L	3.0
46	GFDL-CM4	3.9
47	GFDL-ESM4	2.6
48	GISS-E2-1-G	2.7
49	GISS-E2-1-H	3.1
50	GISS-E2-2-G	2.4
51	HadGEM3-GC31-LL	5.6
52	HadGEM3-GC31-MM	5.4
53	IITM-ESM	
54	INM-CM4-8	1.8
55	INM-CM5-0	1.9
56	IPSL-CM6A-LR	4.6
57	KACE-1-0-G	4.5
58	MCM-UA-1-0	3.7
59	MIROC-ES2L	2.7
60	MIROC6	2.6
61	MPI-ESM1-2-HR	3.0
62	MPI-ESM1-2-LR	3.0
63	MRI-ESM2-0	3.2
64	NESM3	4.7
65	NorCPM1	
66	NorESM2-LM	2.5
67	SAM0-UNICON	3.7
68	UKESM1-0-LL	5.3

Models were chosen :

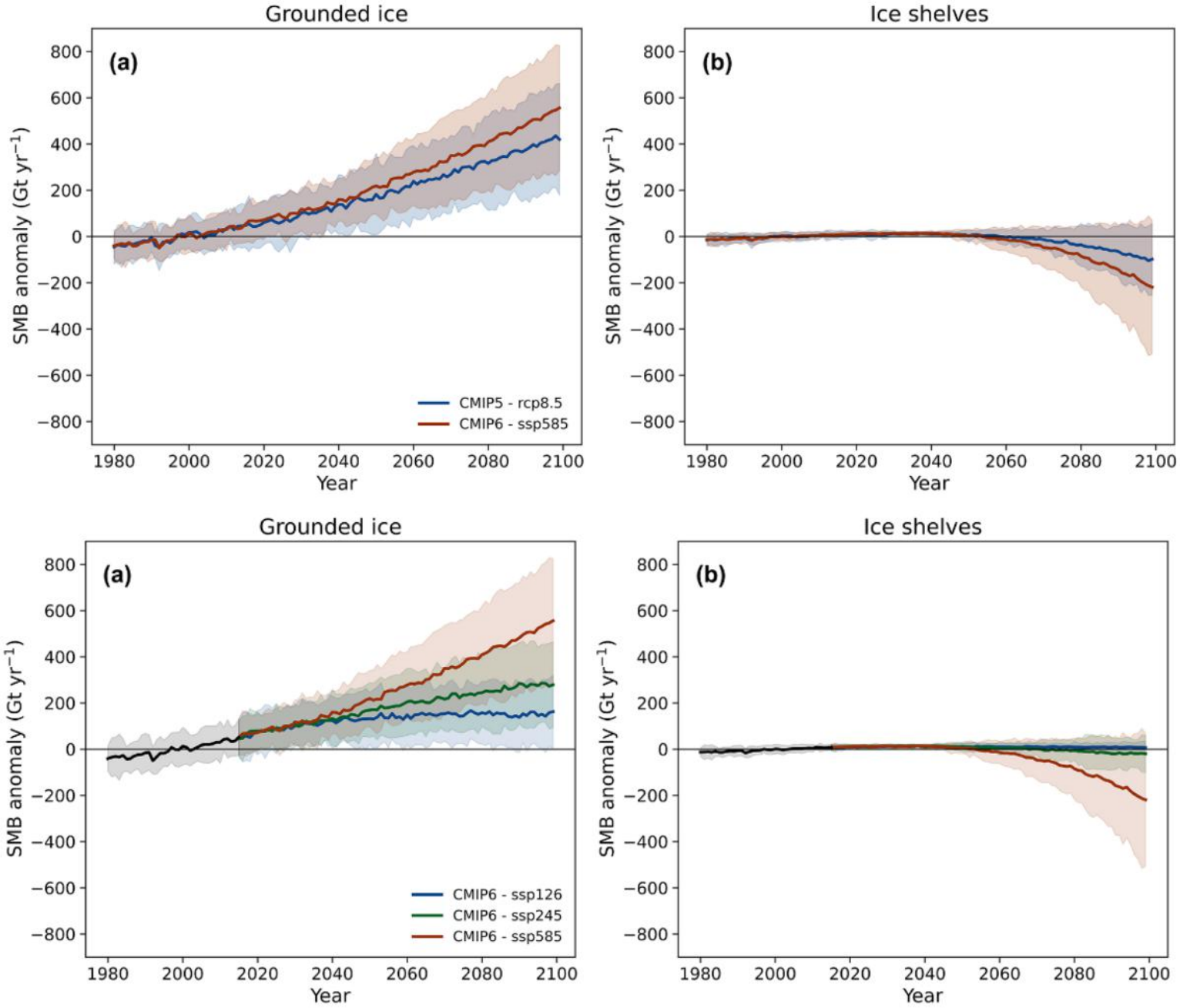
- according to their ability to represent the current Antarctic climate
- to account for the large diversity in projected climate changes

Surface hydrology causes futur SMB to decrease over ice shelves



Kittel et al. (2021a)

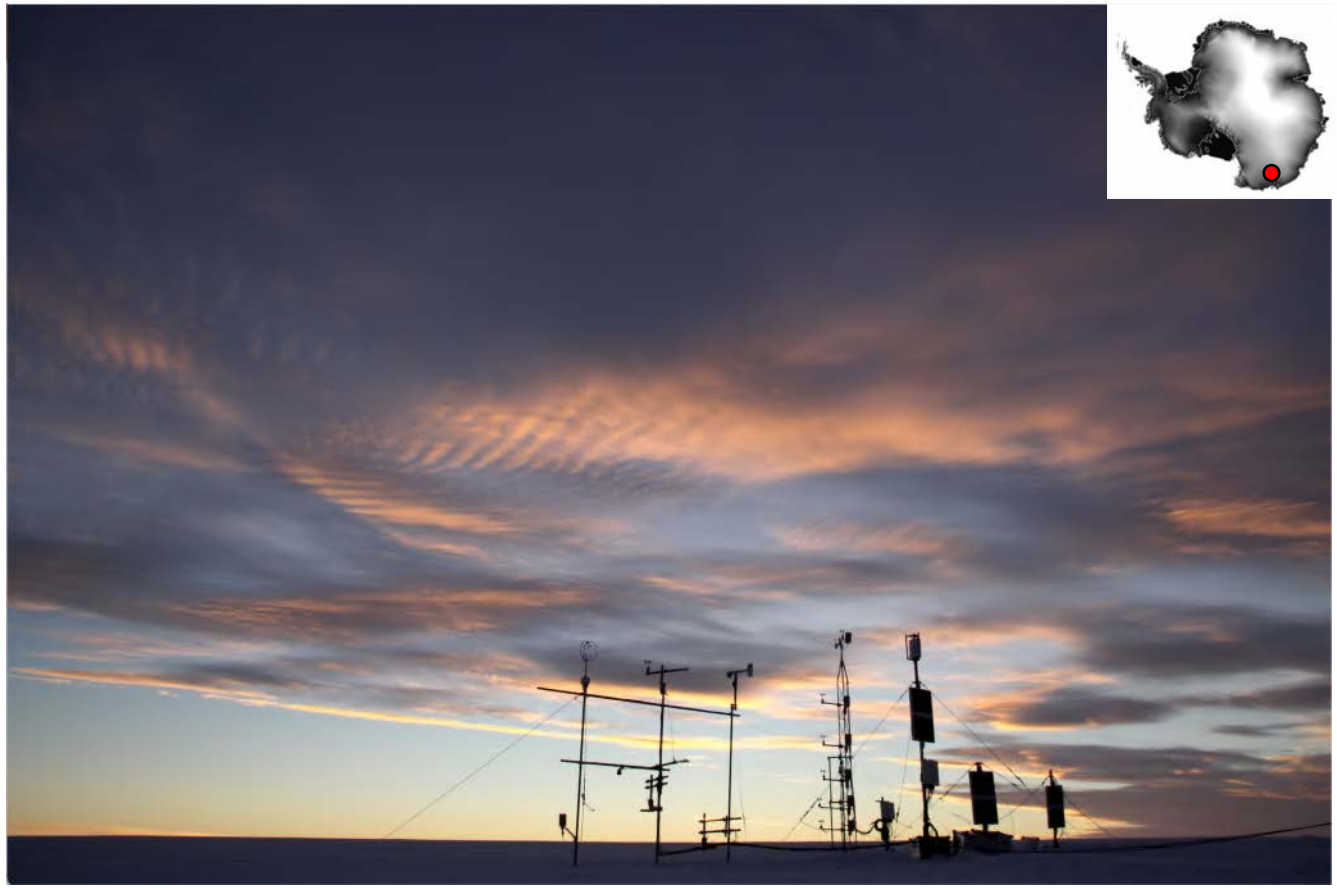
Extrapolating end-of-century SMB

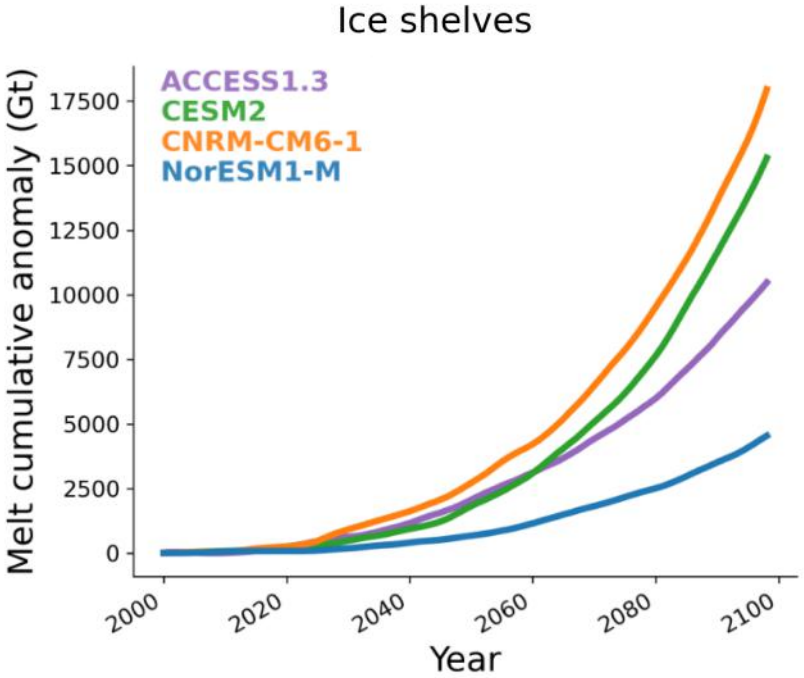


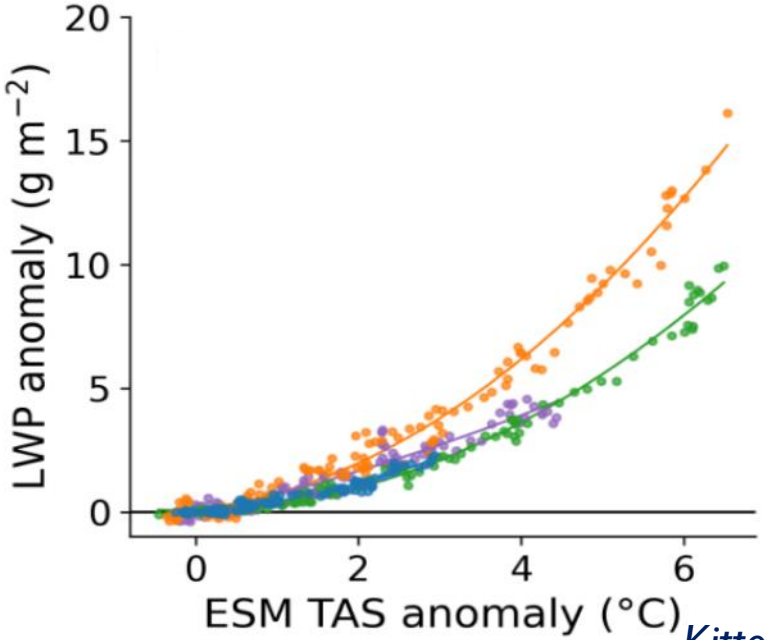
Kittel et al. (2021a)

Clouds drive differences in surface melt projections

Twilight clouds in Adelie Land



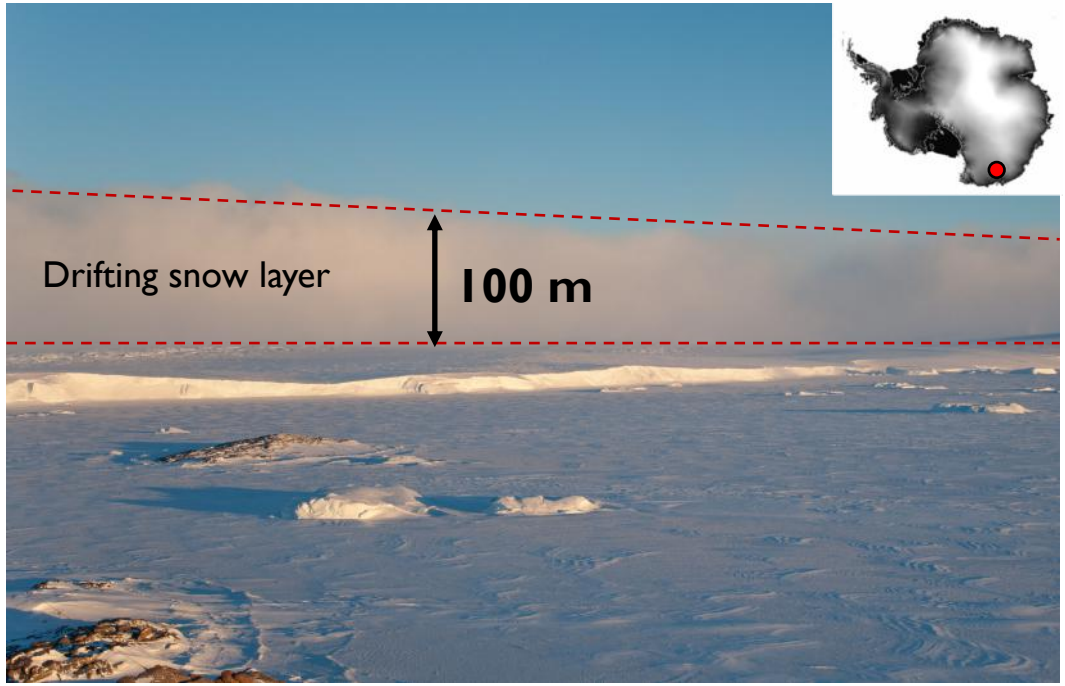




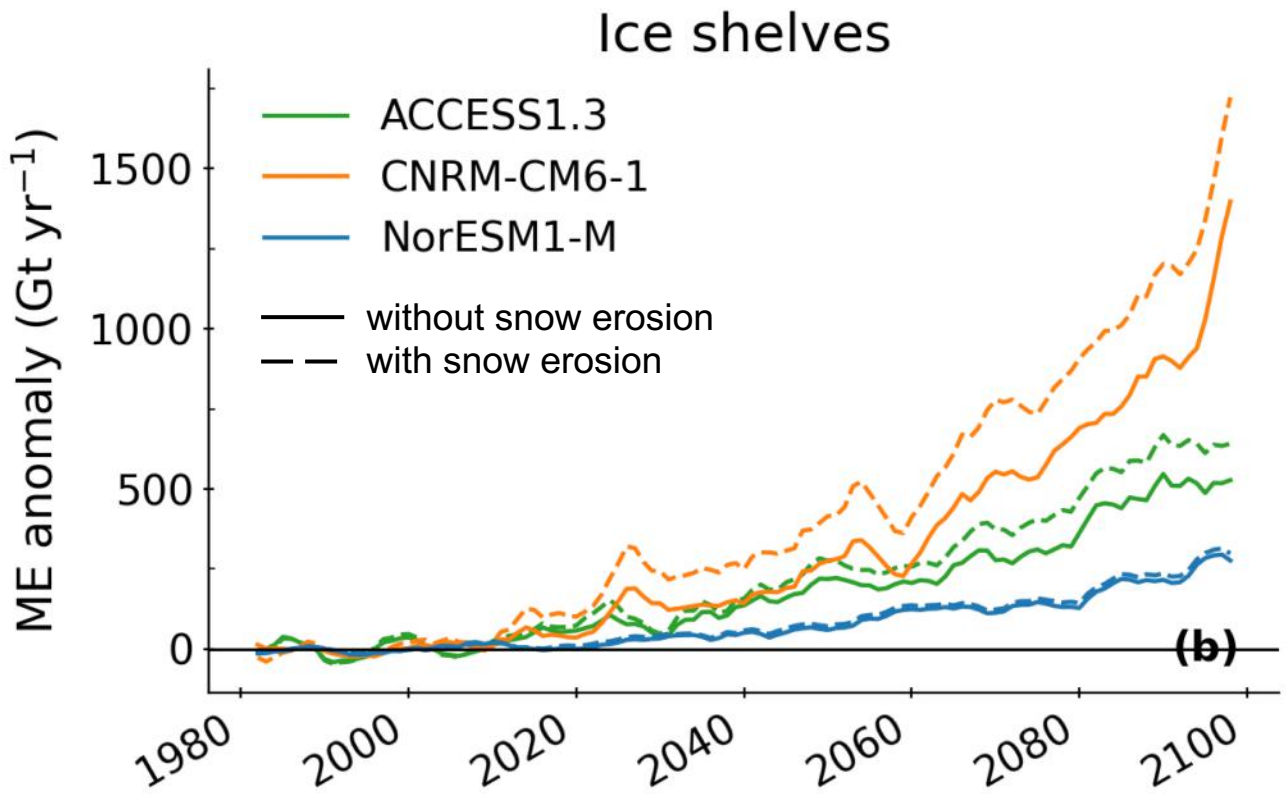
Kittel et al. (2021b)

Erosion enhances future surface melt

Snow transport in Adelie Land

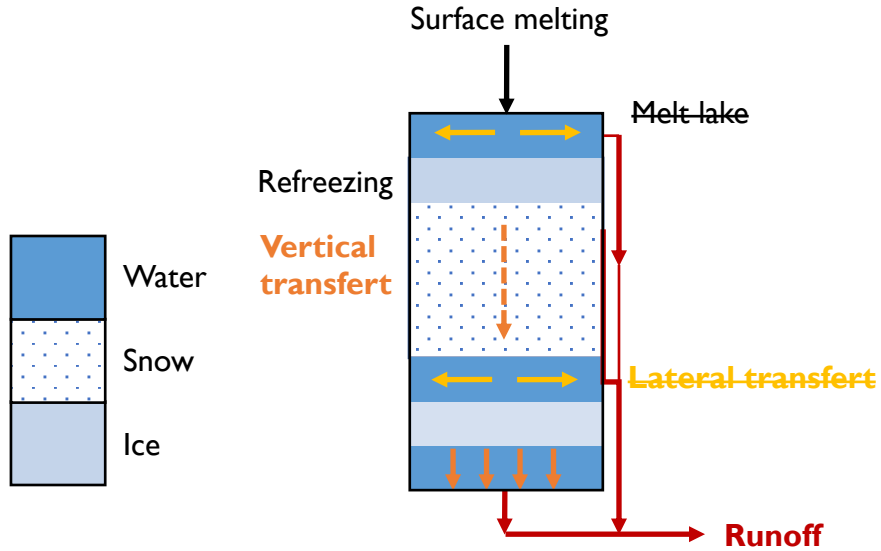


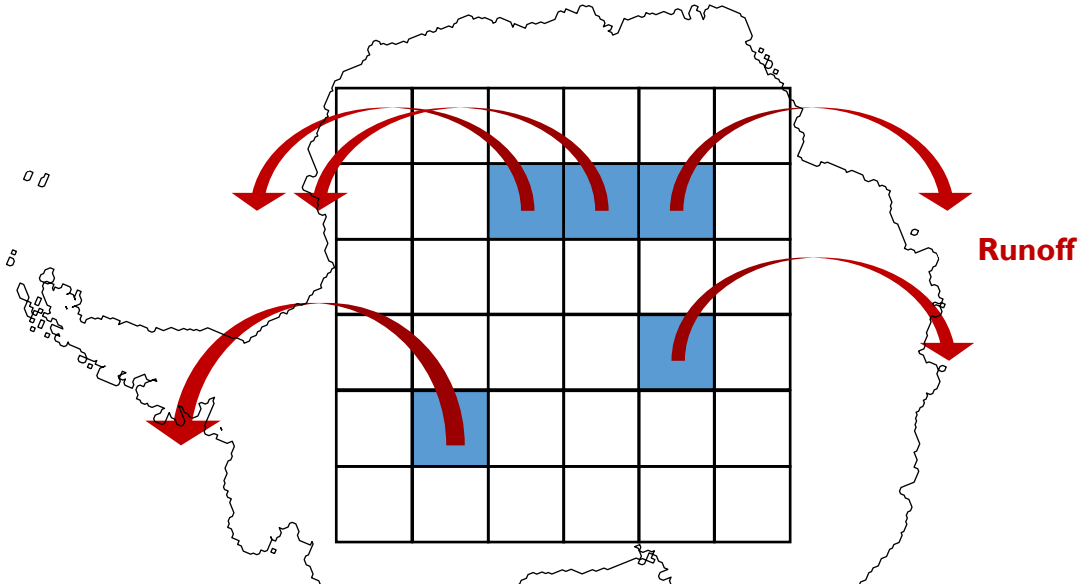
Crédit : J. Guilhermet



No lateral transfert of water in current parameterizations

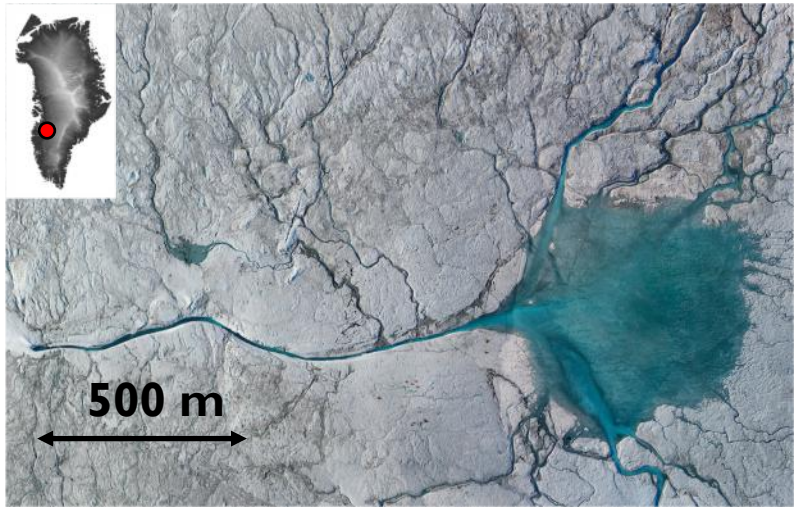
1-D approach





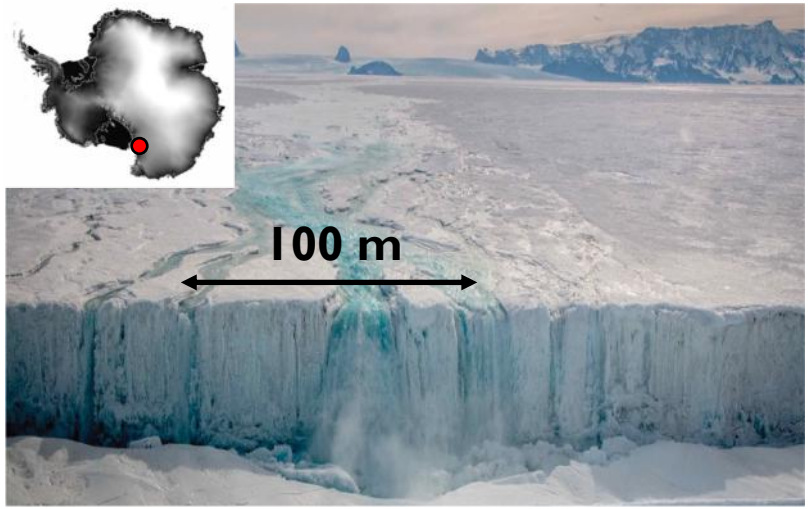
3-D process

Russell Glacier - Greenland



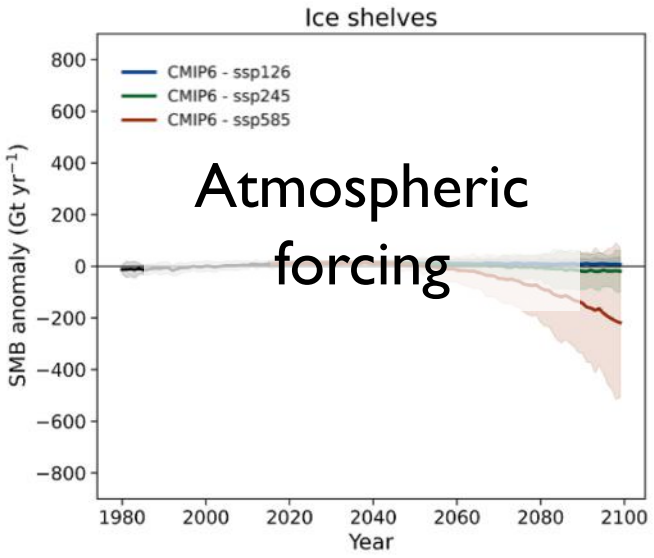
Crédit : L. C. Smith

Nansen ice shelf - Antarctica

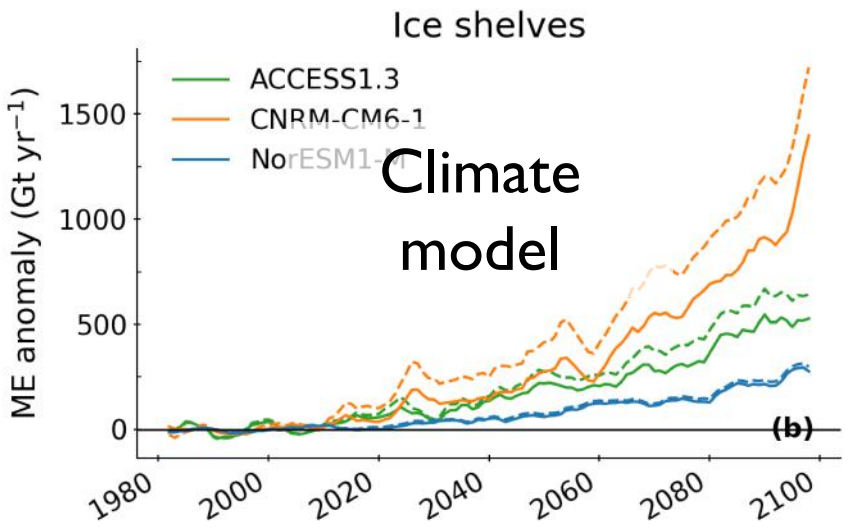


Crédit : R. Fletcher

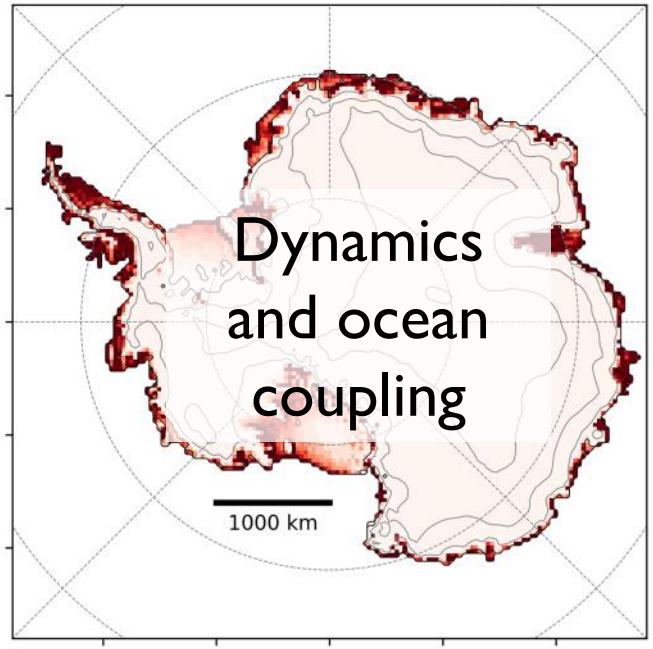
Sources of simulation uncertainty



- Scenario
- Large-scale forcing



- Physics package
- Spin-up time, initialization
- Snowpack depth
- 1-D surface hydrology



- Ice sheet topography
- Ice sheet geometry
- Oceanic interactions