Greenland surface ablation areas in CESM

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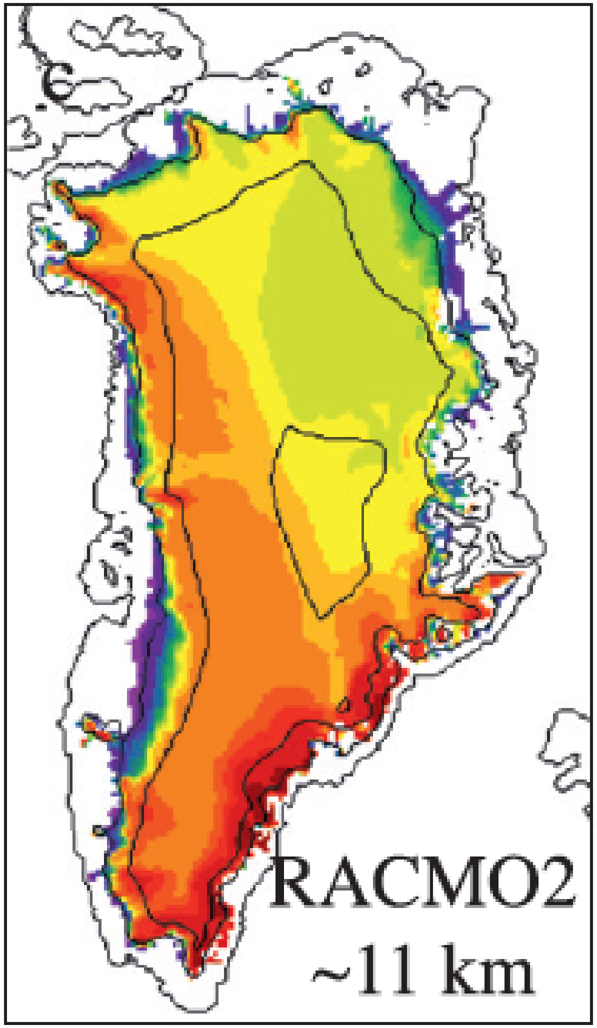
Ablation areas: SMB <0



SMB = accumulation – ablation = precipitation – runoff - su

SMB= snowfall – melt + refreezing - su

SMB = snowfall – snow melt – "firn/ice melt" + refreezing - su

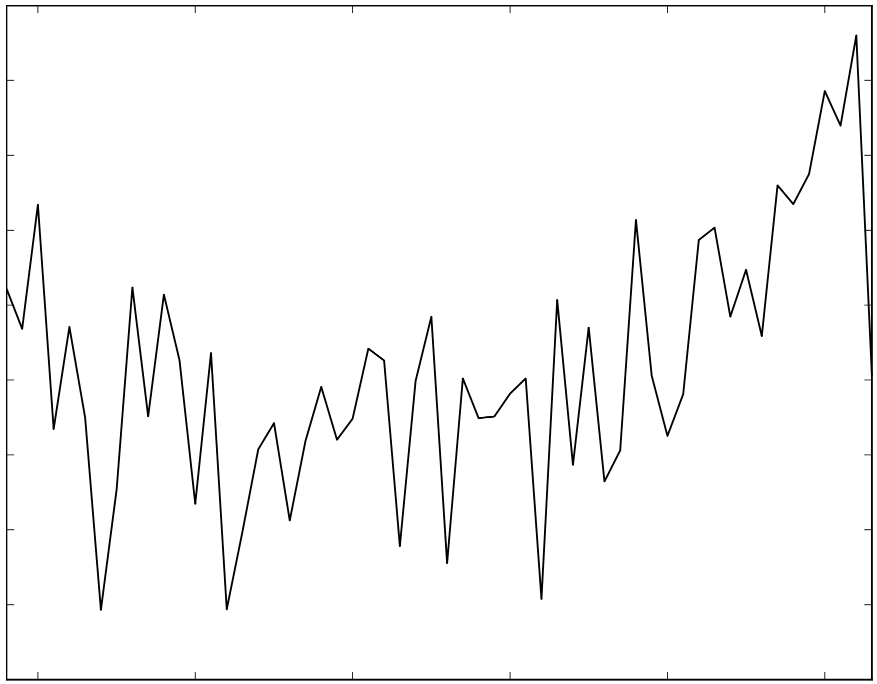
Over the ablation area:

- **annual snowfall accumulation is melted away**

and

- **firn/ice is exposed by the end of melt season.**

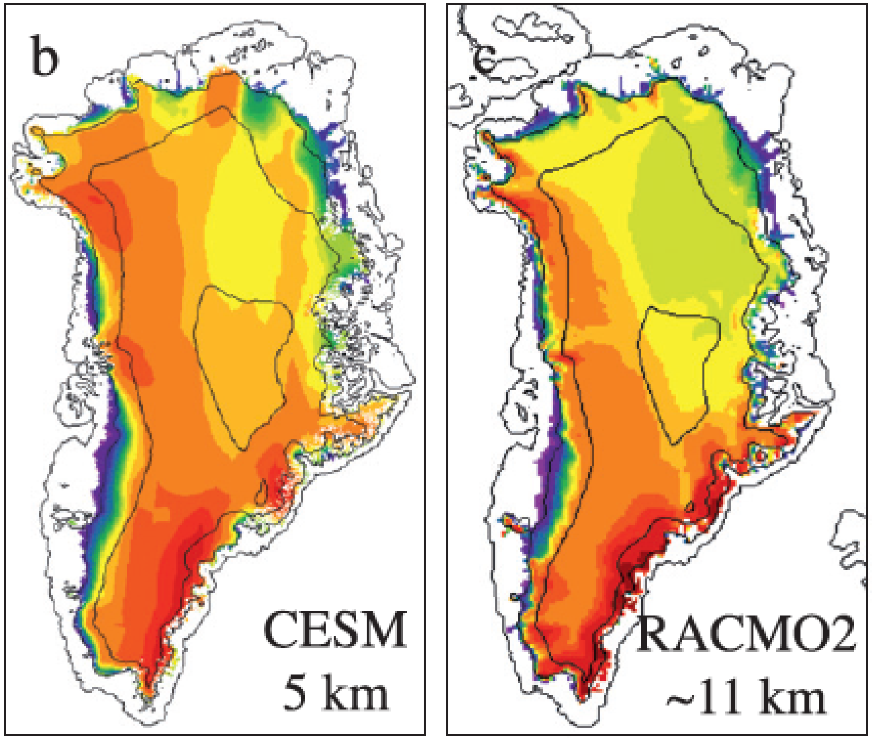
Ablation area variations



- RACMO2.3 shows some inter-annual variations and a trend after 1990:
  - Range: 6-21%
  - Peak in 2012

Ablation definition in CISM

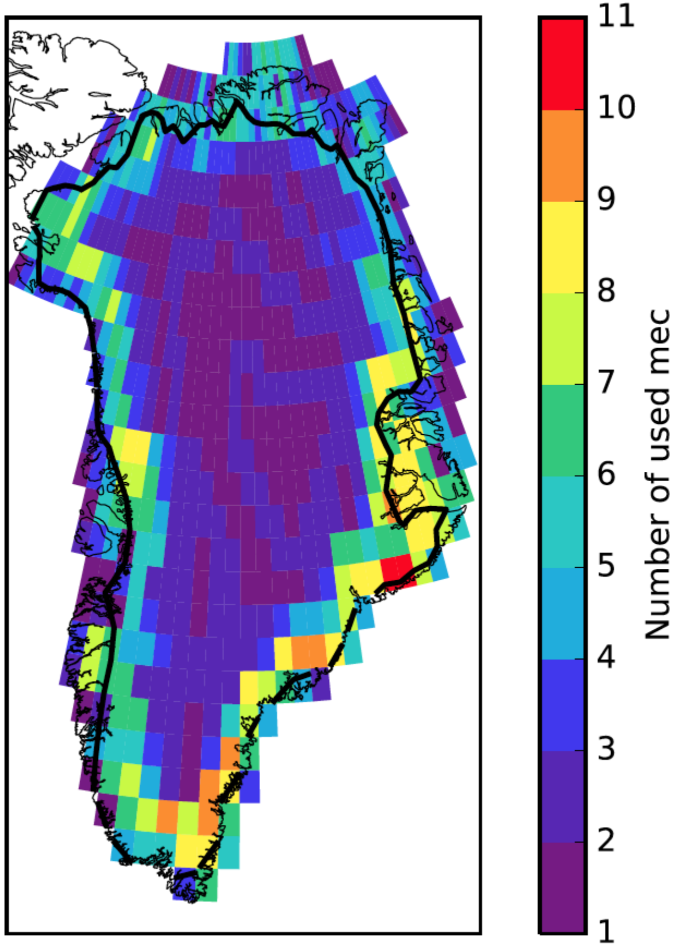
SMB = snowfall – snow melt – “firn/ice melt” + snow ref - su



CESM1.0

- takes into account only “ice melt”: **bare ice exposure** is a must

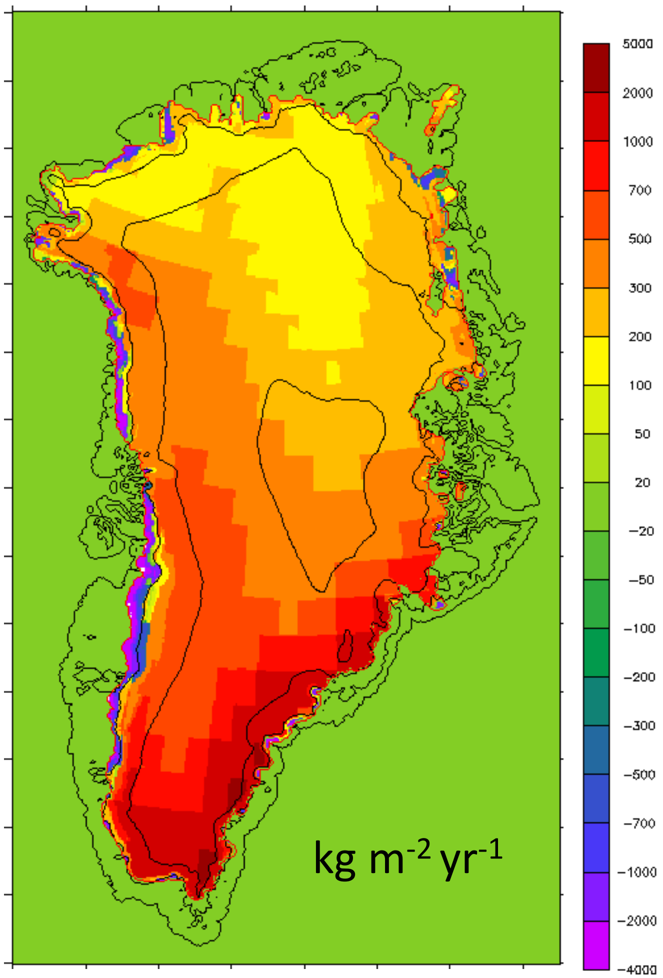
GrIS SMB is calculated at several elevation classes (EC) per CLM grid cell

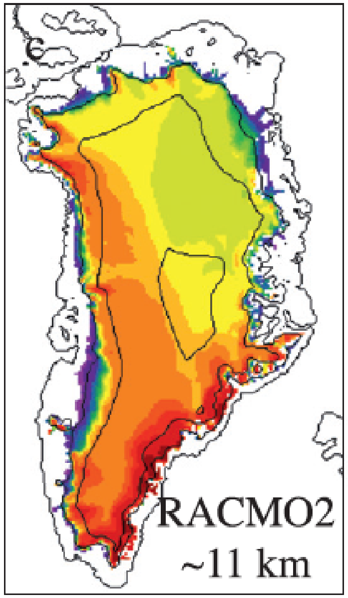


- **In coupling to CAM**, CLM sends **averaged flux** over these elevation classes (and other land units if existing)
- For SMB **downscaling** to CISM (~4 km), horizontal bilinear and vertical **linear interpolation** between EC's is applied

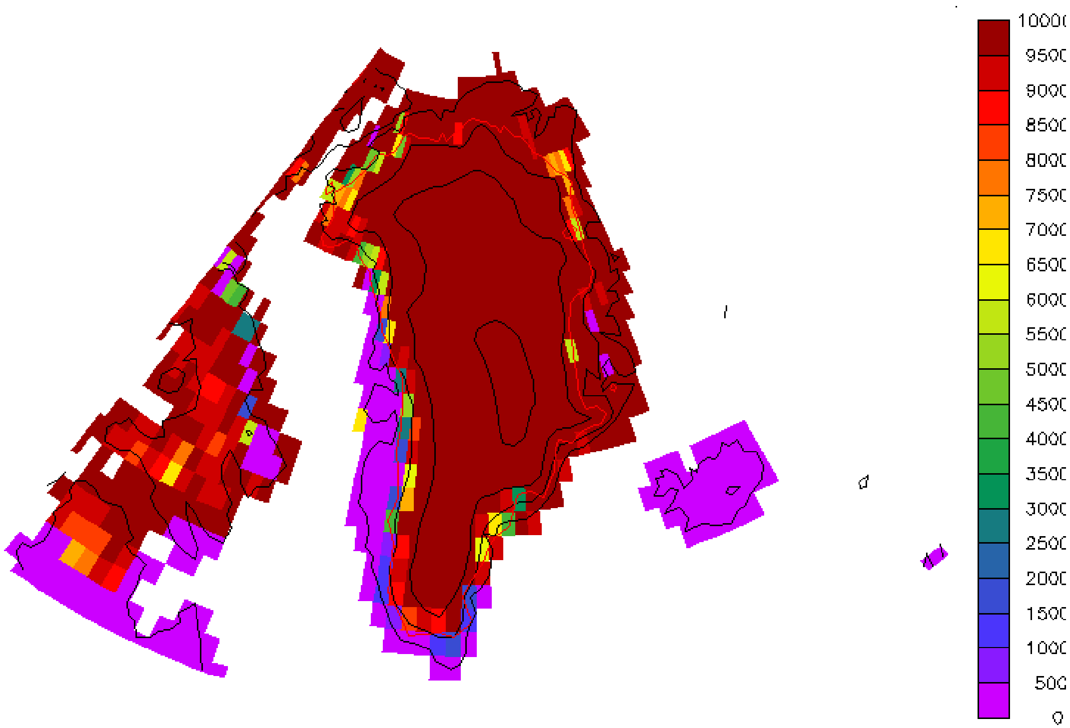
	CLM4 (CESM1.0)	CLM5	RCMs (RACMO)	Observations
Components	Snow	**Snow/firn**	Snow/firn/ice	Snow/firn/ice
Ice transition	Ice is “soil”	**Ice is “soil”**	density	density
Cap (m w.e.)	1	**10**	N/A	N/A
Ablation	Realistic ~12%	**?**	Realistic ~12%	~12%
Ablation by 2100	30% GrIS	**?**	Similar to CLM4	N/A
Refreezing	~40%	**?**	~40%	?
Refreezing by 2100	Unrealistically quick saturation	**?**	Physics-based decrease	
N Greenland tundra	Permanent snow cover	**?**	Seasonal snow cover	Seasonal snow cover
N Greenland tundra 2100	Seasonal snow cover	**?**		N/A

Ablation in PI control BG #119





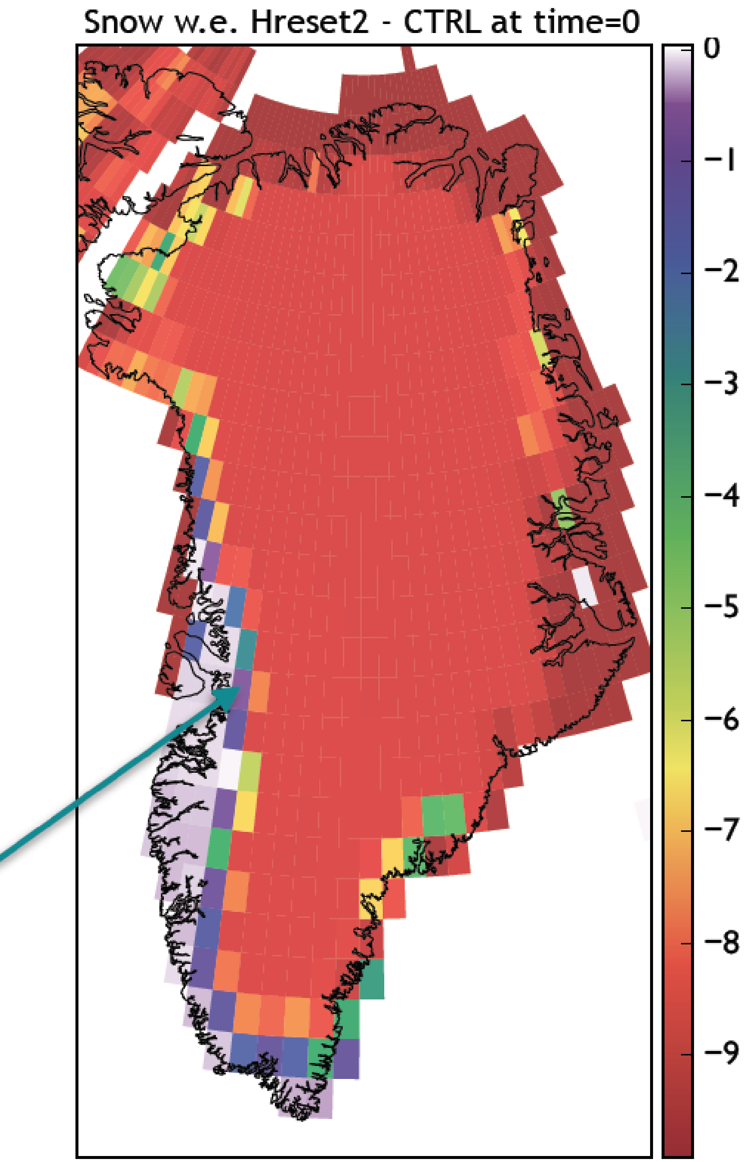
- Ablation areas underestimated (only 3.5% of total GrIS area)
- Despite ok summer surface energy fluxes

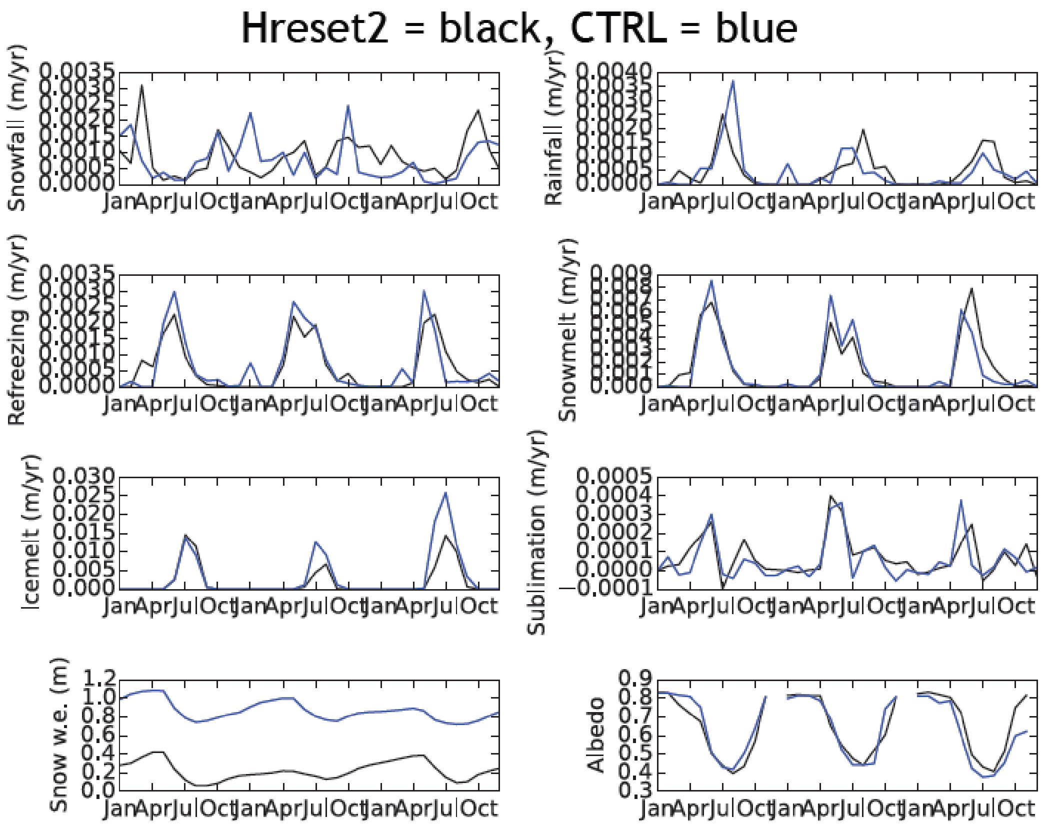


Cell-averaged snow thickness #119 (m w.e.)

- **High snow thickness** along observed ablation areas (**low/no bare ice exposure**) and tundra (permanent snow cover)
- Problem statement: these high thickness columns need to get to ice/soil transition: **How?**

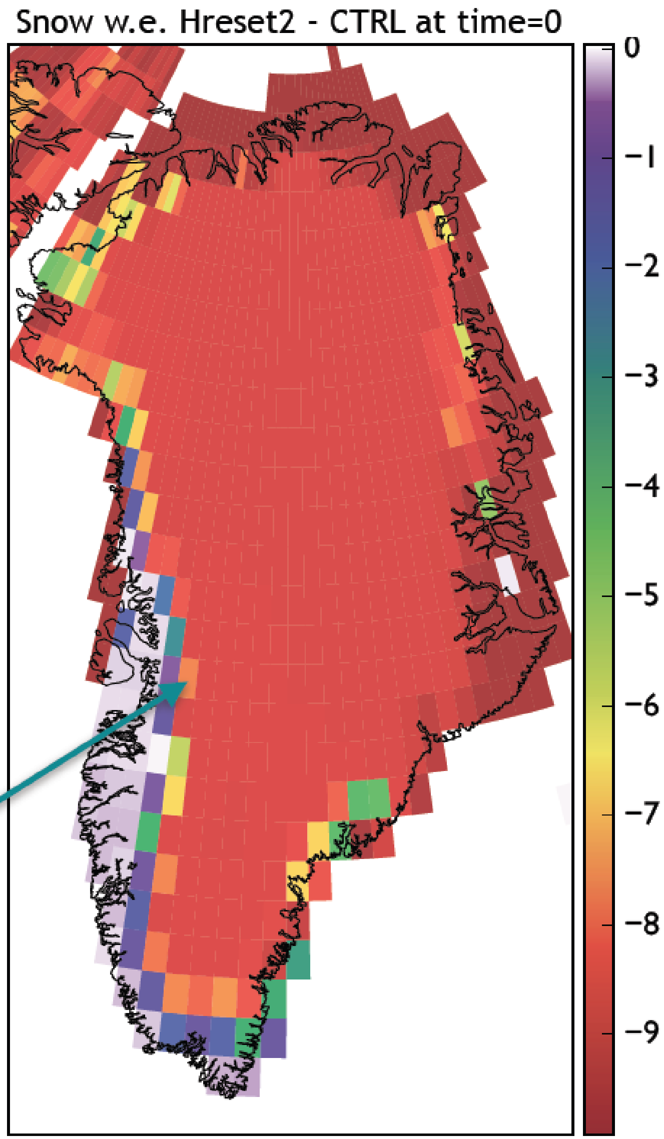
RESETTING SNOW THICKNESS (CONTROL RUN #126)

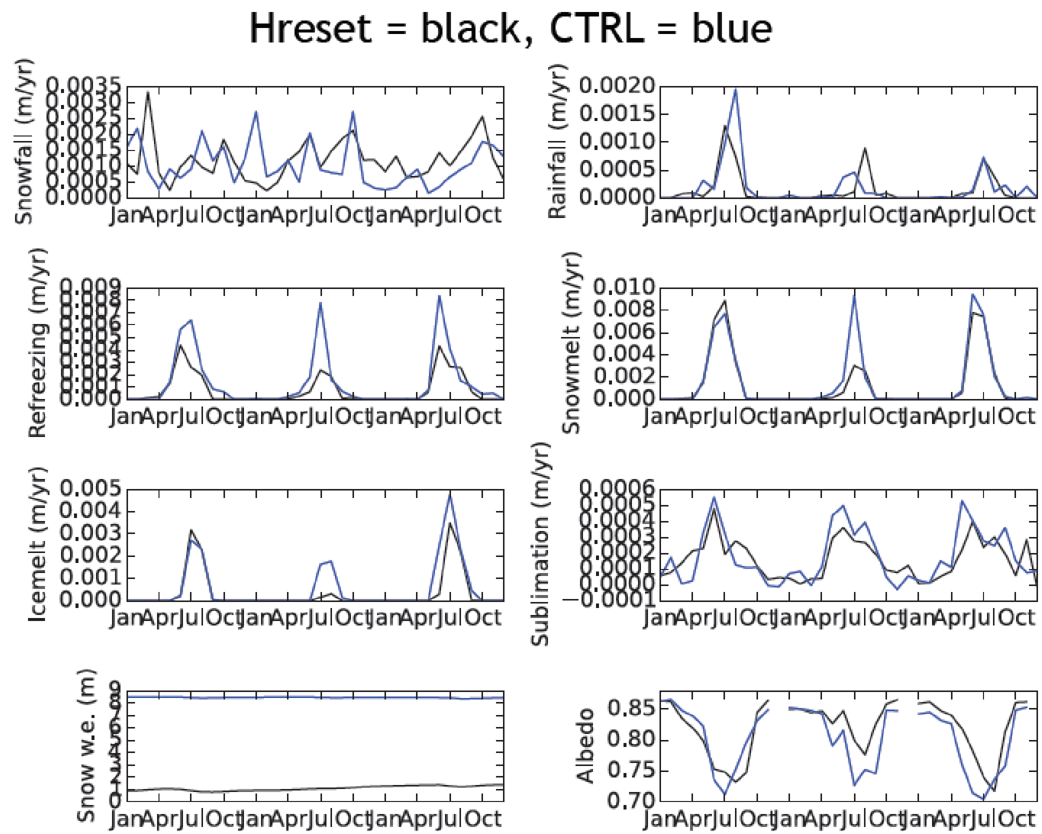




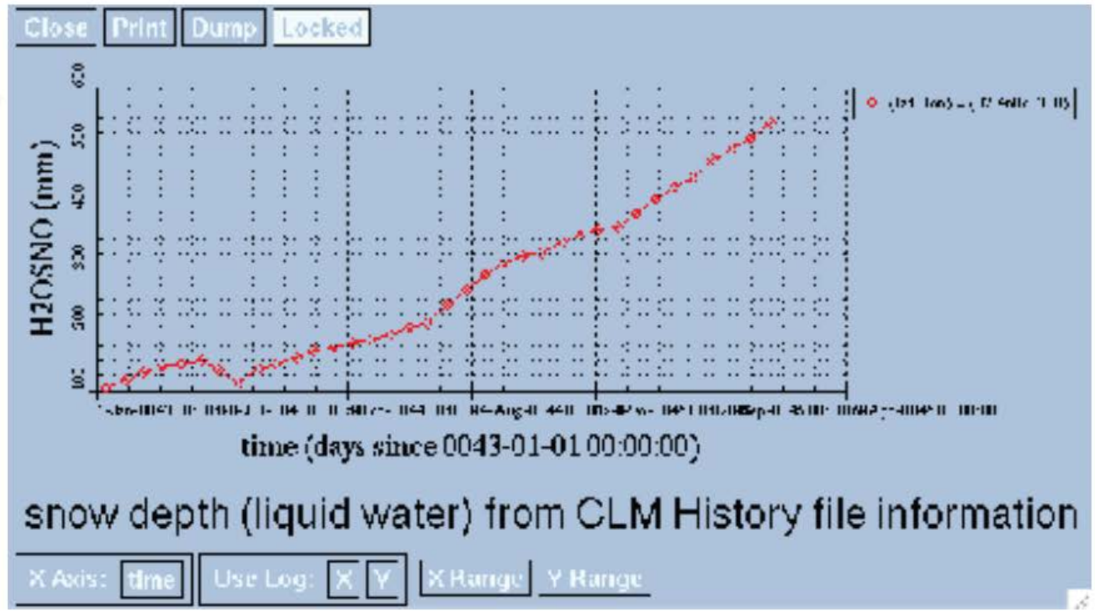
* More snowfall during first and last winter
* Refreezing rates lower, but extended (lower capacity + less rain)
* Snowmelt lower in two first years
* Less ice melt in last year (though there is less snow…)
* Albedo slightly reduced first year and heightened last year

Run #126 CTRL-Hreset2





Run #126 Hreset2



- Over N tundra, snow depth regrows:
  - Is it CAM/POP/CICE? (cold bias)
  - Is it CLM?

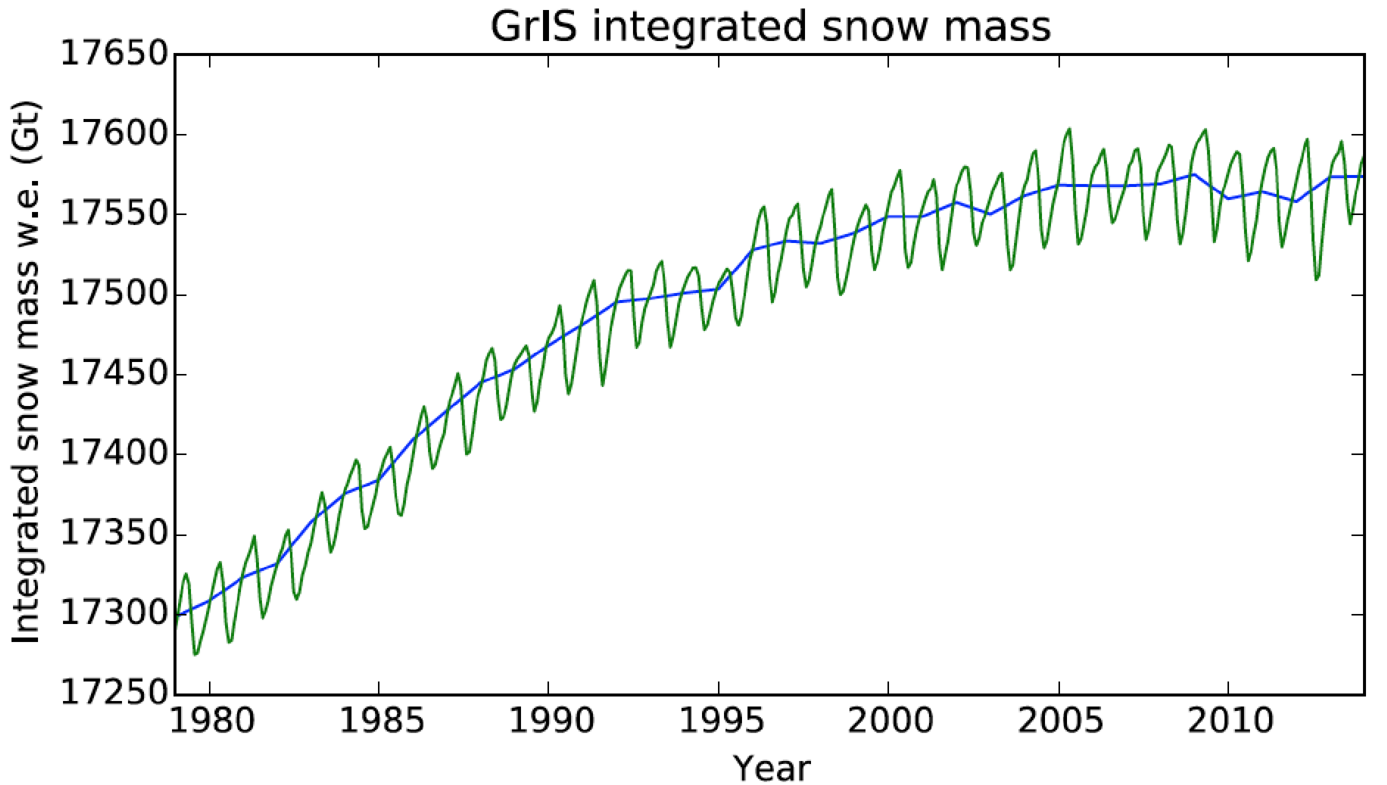
ERA-INTERIM SIMULATIONS WITH FIRN ON/OFF

Two simulations

	NO FIRN (CLM5 with modified capping)	SNOW/FIRN (default CLM5)
Forcing	ERA-Interim 1979-2014	
Capping	1 m w.e.	10 m w.e. (default)
Initialization	0.1 m w.e. tundra 0.5 m w.e. ice sheet	From PI control BG #119

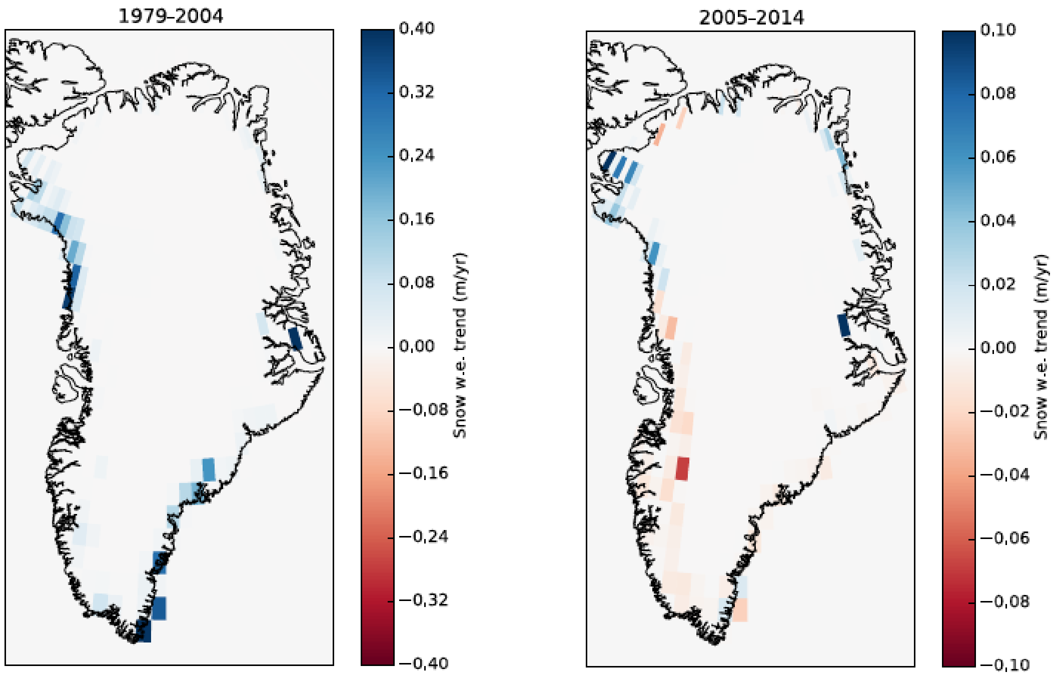
Target: to evaluate the impact of development of thick snow/firn columns along ice sheet margins

Equilibrating snow mass



- When switching to ERA-I, snow mass is not in equilibrium until around 2005
- Only years 2005-2014 can be used for evaluation

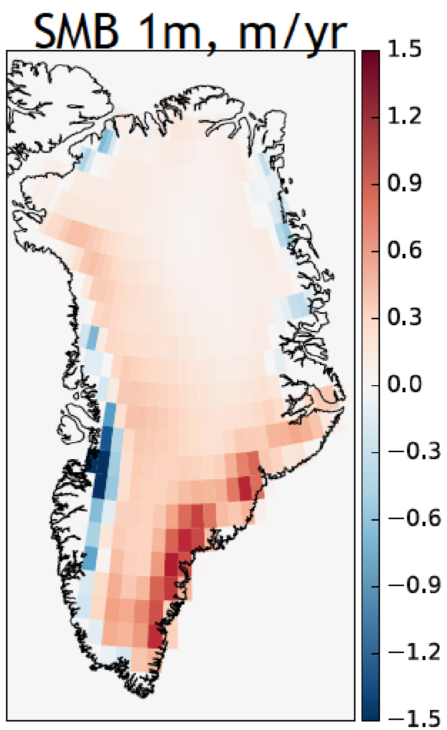
Equilibrating snow mass



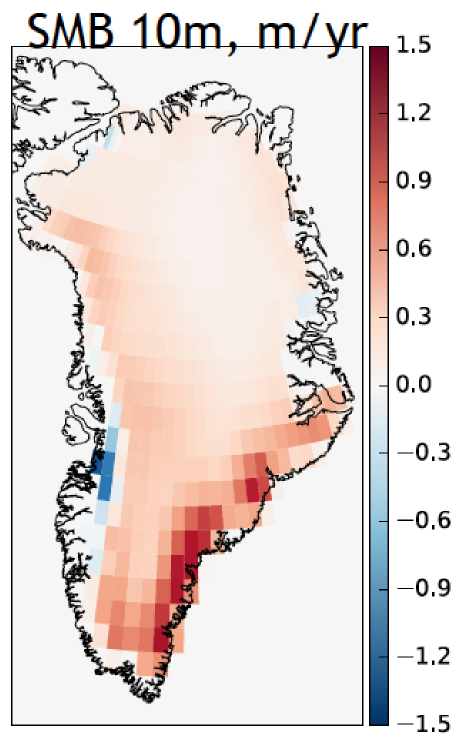
- 1979-2004: Fastest gain of snow in high precip areas in South-East and North-West
- 2005-2014: Fastest loss of snow in West, South-West and South-East

Greenland at 100km, 2005-2014

	Snow	Rain	Refreezing	Snow melt	Ice melt	Sublimation	SMB
IG erai/clm5 10m	643 (65)	45 (12)	243 (42)	275 (48)	50 (13)	42 (4)	519 (67)
IG erai/clm5 1m	645 (65)	43 (11)	204 (35)	310 (56)	123 (39)	57 (4)	358 (84)



no firn



firn

- Refreezing capacity is higher for firn (70% vs 50% for no-firn)
- Ice melt is reduced with introduction of firn
- Snow melt is also reduced
- Firn reduces total ablation area

TUNDRA

Motivation

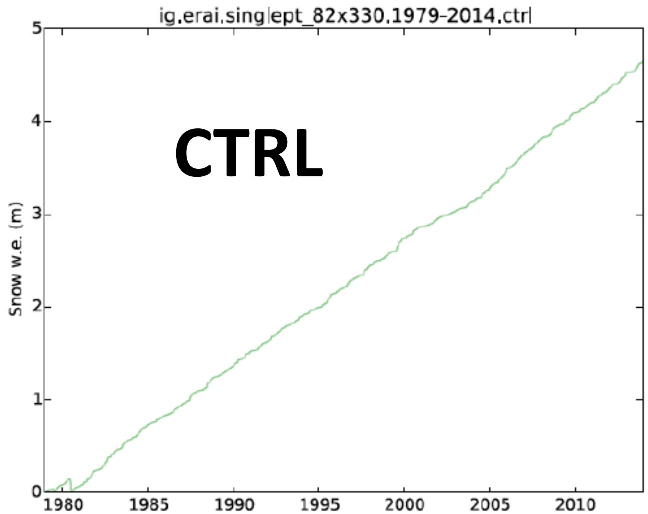
- CLM simulates a permanent snow cover over N Greenland tundra:
  - Pre-industrial controls: since at least #119 (not exclusively tied to post-#125 cold bias)

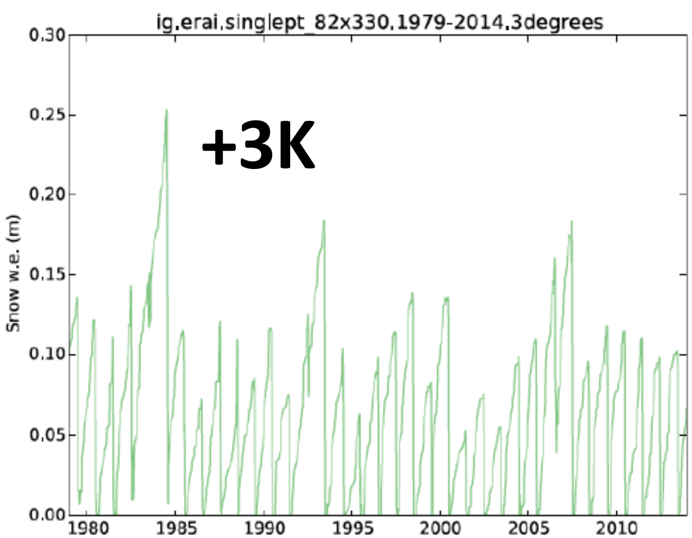
Method

- Single column model, IG run
- Location: 82 N, 330 W
- 1979-2014 ERA-Interim forcing
- Simulations start in January

Name	Description	Initial condition
CTRL		"out-of-the-box": 0.1 mm w.e.
+3K	+3K added to temperature forcing every 6 hours	"out-of-the-box":0.1 mm w.e.
+3K_ctrl	"	From year 2014 of CTRL

Snow thickness (m w.e.)

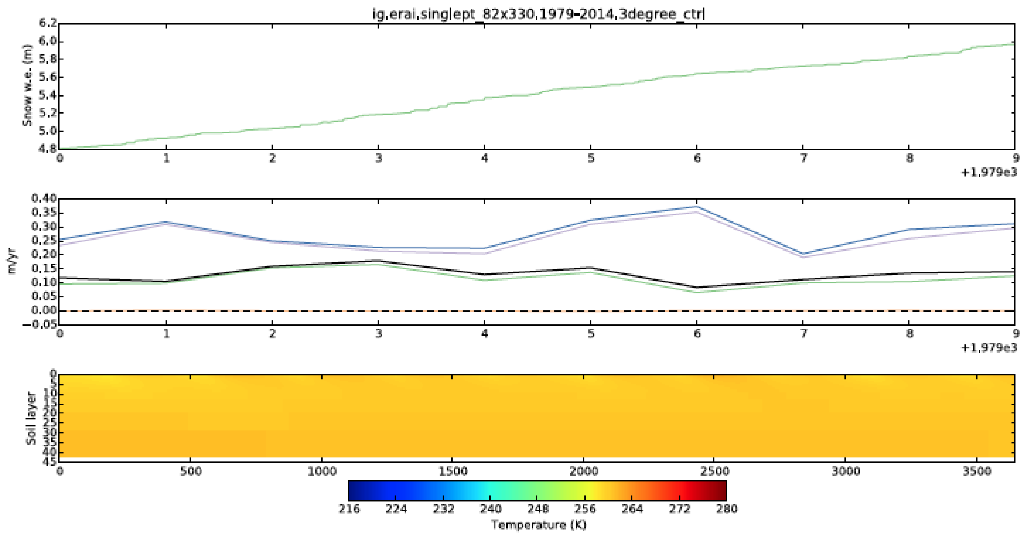




simulation	Snow	Refreez	Melt	Sub/Evap or Depos/Cond	Net
CTRL	12.4 (2.7)	15.1 (8.9)	15.2 (8.6)	1.2 (0.4)	13.5 (3.8)
+3K	11.1 (2.6)	6.7 (2.5)	18.4 (5.8)	-4.7 (1.6)	-5.5 (4.4)

- Permanent snow thickness since refreezing = melt
- With added warming, snow cover is seasonal

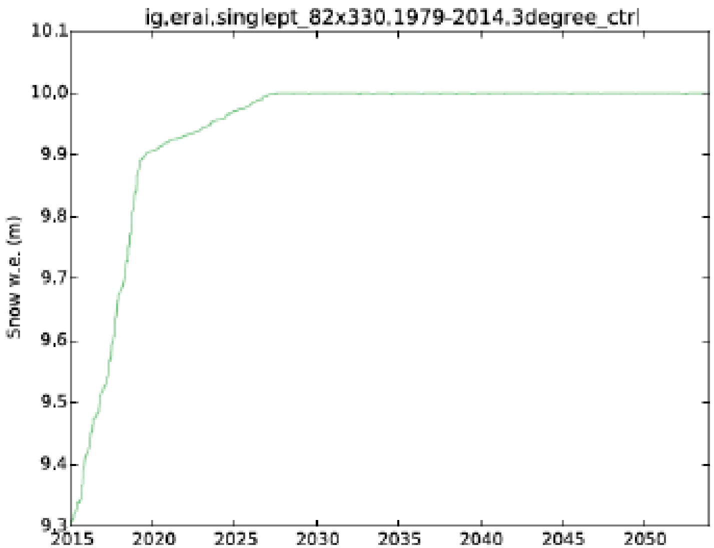
+3K_CTRL
(initial thickness: 4.6 m w.e.)



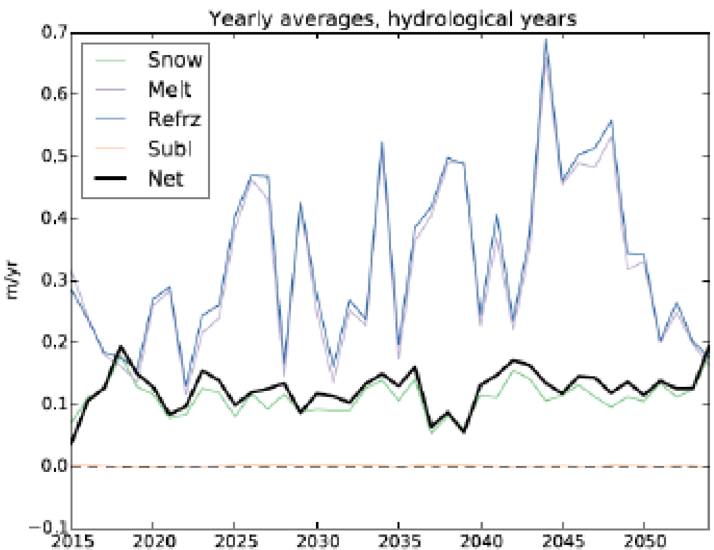
simulation	Snow	Refreez	Melt	Sub/Evap or Depos/Cond	Net
CTRL	12.4 (2.7)	**15.1** (8.9)	**15.2** (8.6)	1.2 (0.4)	13.5 (3.8)
+3K	11.1 (2.6)	**6.7** (2.5)	**18.4** (5.8)	-4.7 (1.6)	-5.5 (4.4)
+3K_ctrl	11.1 (2.6)	**36.8** (12.7)	**35.1** (12.8)	-0.2 (0.1)	12.5 (2.8)

- Warming **doubles melt** (**>in +3K** due to greater mass), but **refreezing catches up**
- **Growth rates almost as in CTRL** regardless of artificial warming!!
- By 2014, thickness is 9.3 m w.e. (not shown)

3K_CTRL_cont

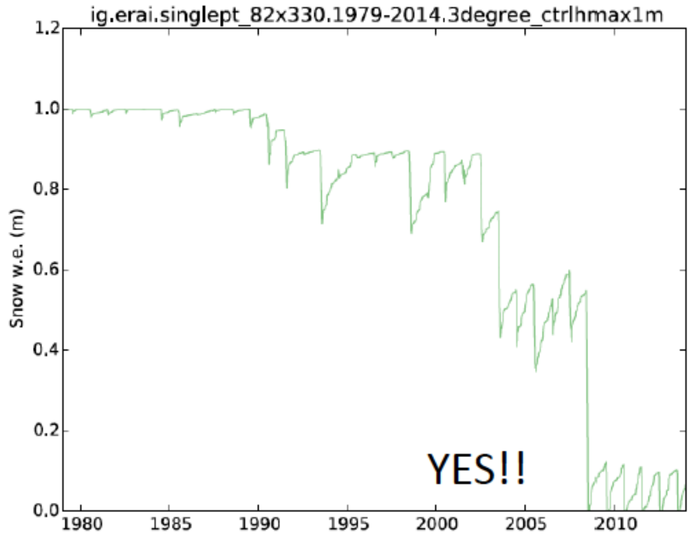


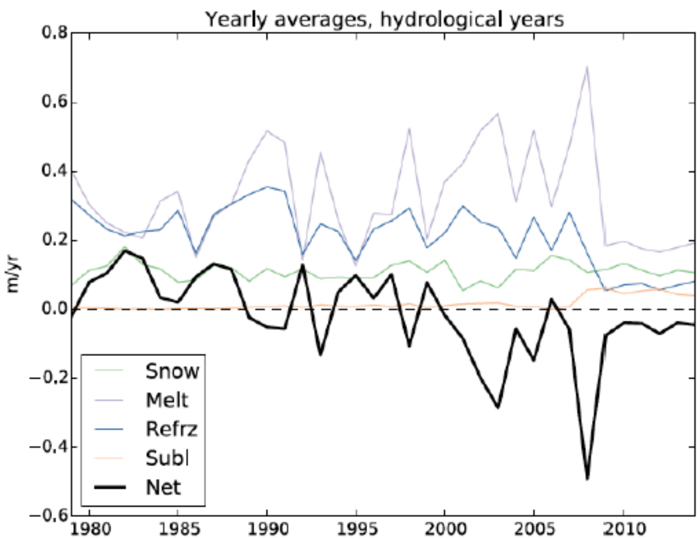
simulation	Snow	Refreez	Melt	Sub/Evap or Depos/Cond	Net
CTRL	12.4 (2.7)	**15.1** (8.9)	**15.2** (8.6)	1.2 (0.4)	13.5 (3.8)
+3K	11.1 (2.6)	**6.7** (2.5)	**18.4** (5.8)	-4.7 (1.6)	-5.5 (4.4)
+3K_ctrl	"	**36.8** (12.7)	**35.1** (12.8)	-0.2 (0.1)	12.5 (2.8)
+3K_ctrl _cont	"	**34.3**	**32.6**	-0.2	12.7



- After cycling 2x 1979-2014 ERA-Interim, model reaches 9.3 m w.e.
- Capping slightly **reduces melt and refreezing**
- Net is slightly higher after capping
- **Permanent snow cover without signs of decay after 72 years** of corrected (+3K) forcing

3K_CTRL_Hmax1m





simulation	Snow	Refreez	Melt	Sub/Evap or Depos/Cond	Net
CTRL	12.4 (2.7)	**15.1** (8.9)	**15.2** (8.6)	1.2 (0.4)	13.5 (3.8)
CTRL_Hmax1m	"	14.9	15.8	1.0	12.6
3K_CTRL_Hmax1m	**11.1**	**21.5**	**32.7**	**-1.5**	**2.0**
+3K_CTRL_cont	"	34.3	32.6	-0.2	12.7

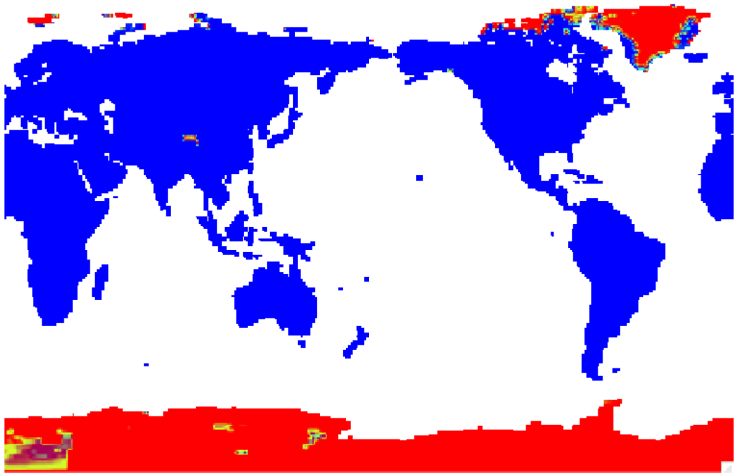
- **Increased melt from post-1990 Greenland warming reduces snow thickness**
- From 2008 (extreme melt), **snow cover becomes seasonal !!!**
- Melt rates are lower after this transition (less total mass)
- Compared with capping at 10 m w.e., *melt rates are lower*, but also % refreezing

Conclusions

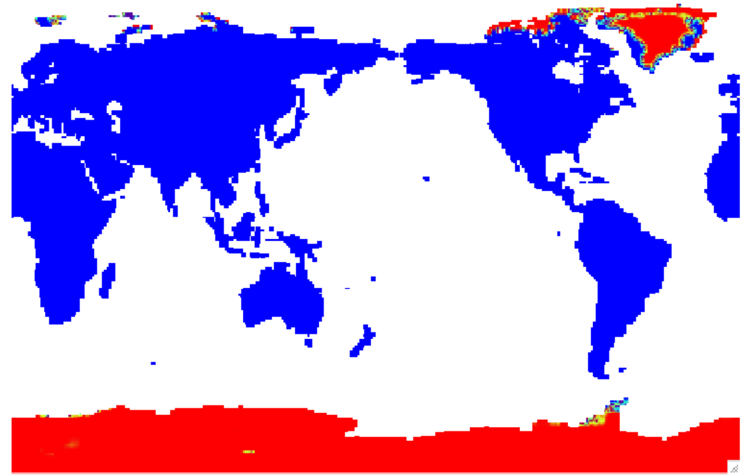
- **Sensitivity to warming strongly dependent on snow thickness** via refreezing and snow/soil albedo transition
- **For 1 m w.e. capping, permanent snow cover is removed** under warming; **for 10 m w.e. capping it is not**

4XCO2 (#125) RUN

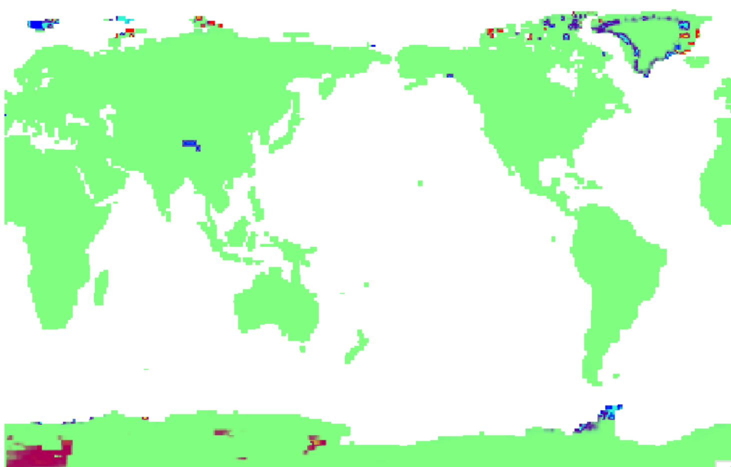
July, 1st year



July, 69th year

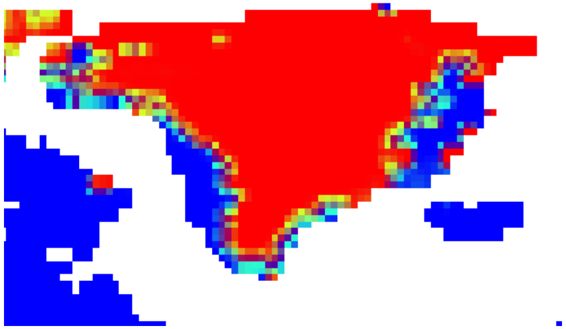


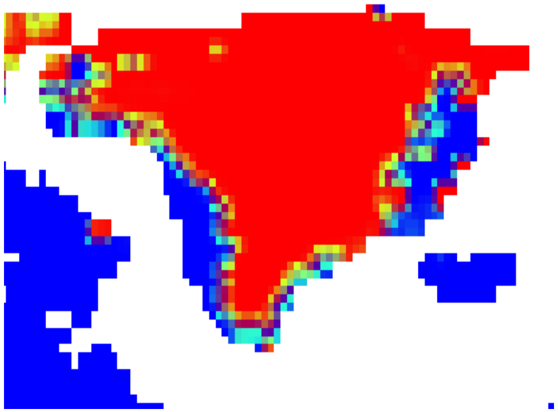
69th - 1st



Sensitivity of snow/firn thickness to 4xCO2 warming by year 69 [mm w.e.]

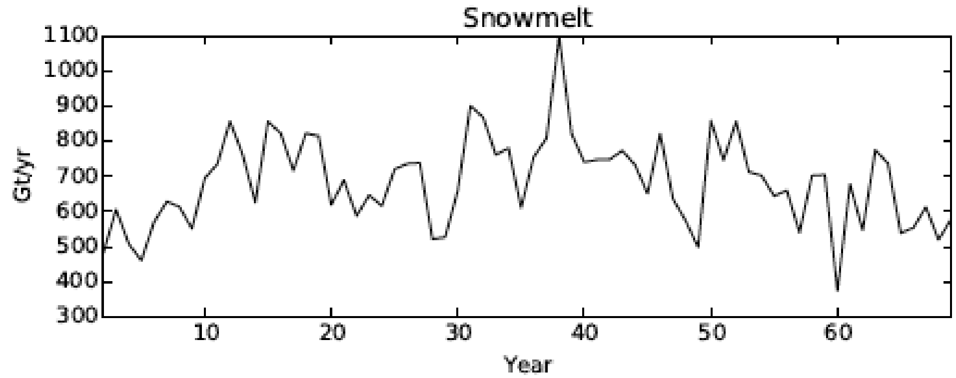
Thickness at year 1



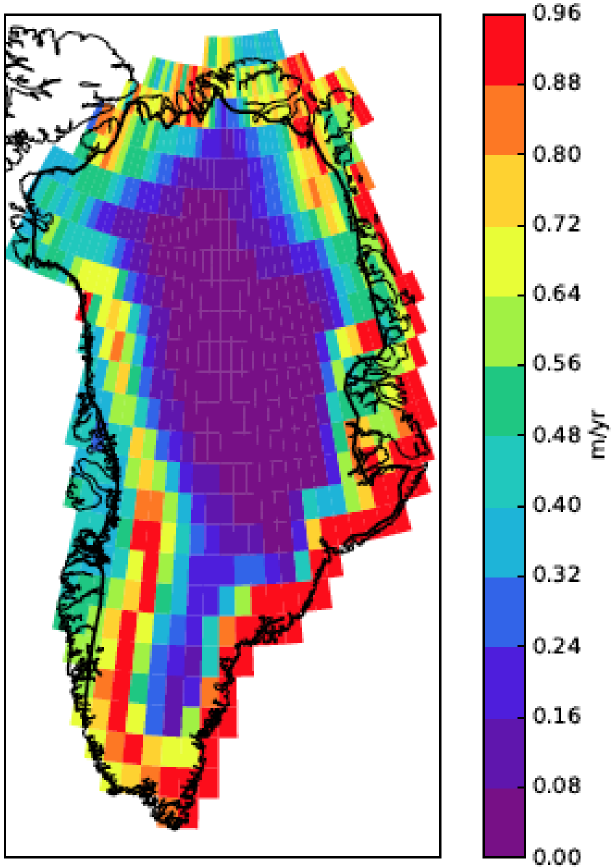


Change by year 69

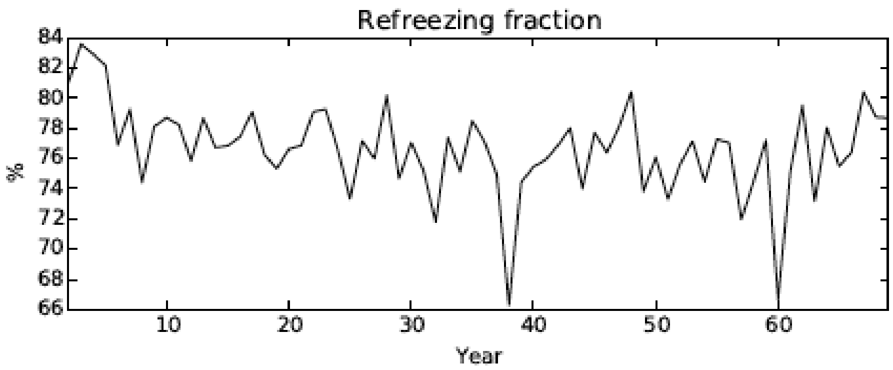
- N Greenland and N Canada tundra remains in place
- Snow/firn decreases along Greenland margins (by ~8 m w.e.)



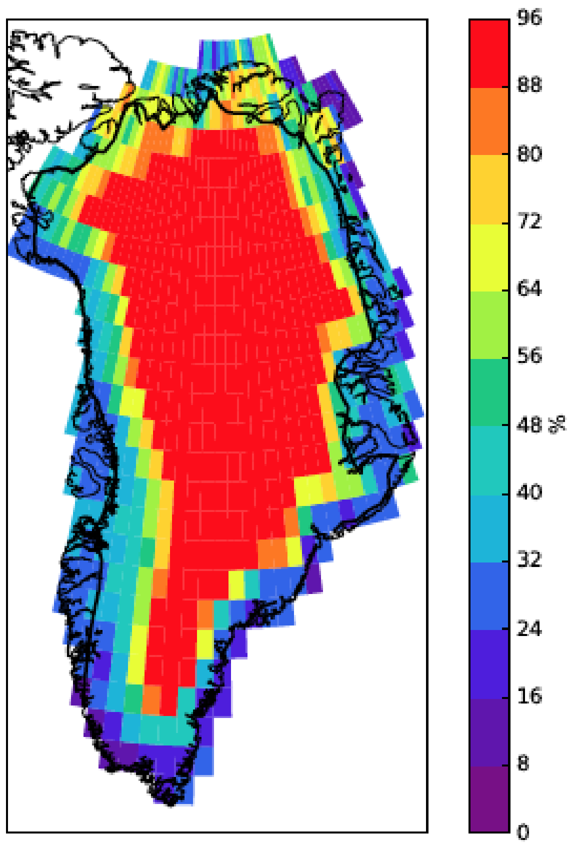
Mean
years 1-69



- Snowmelt declines after peak in year 38 (?)
- SW melt is not highest at lowest elevation in SW



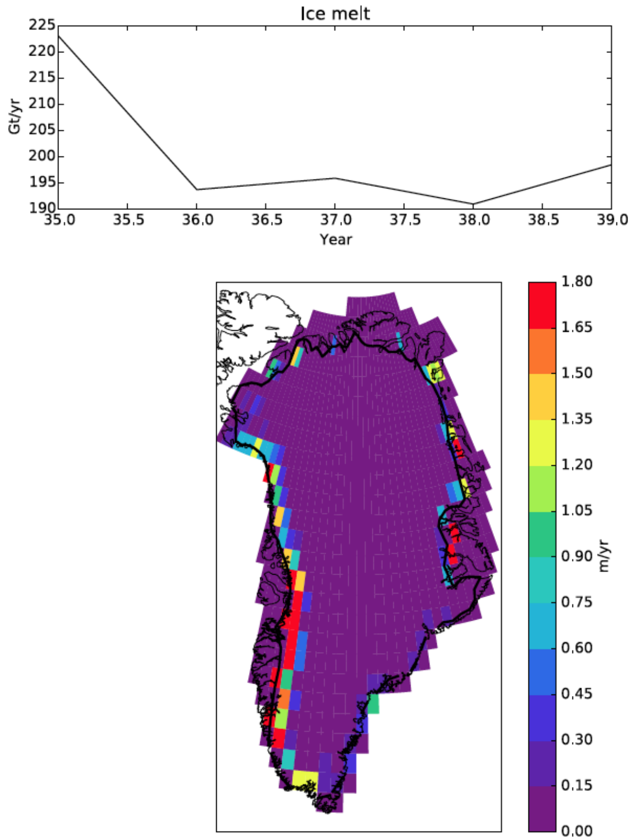
Mean
years 1-69



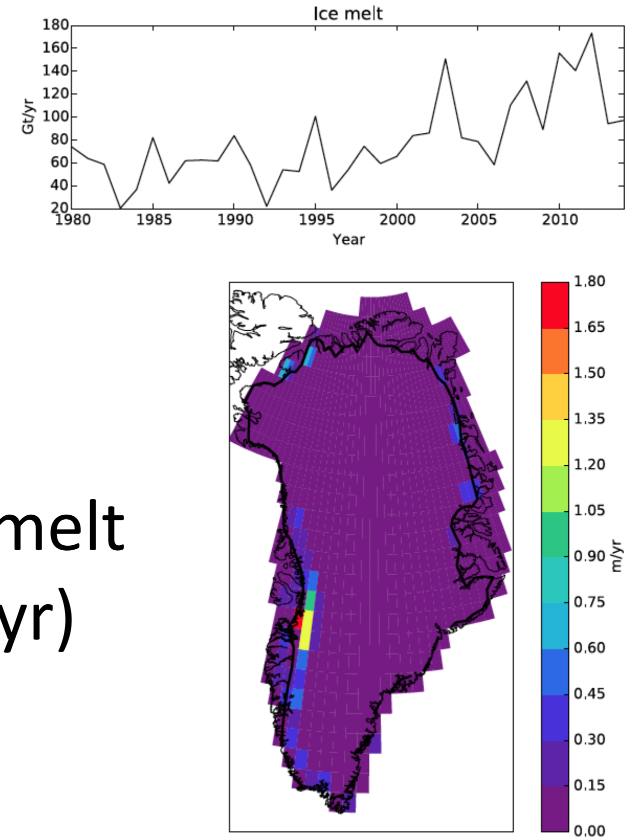
- Refreezing capacity is high and does not decline with warming

EFFECT OF MODIFIED SNOW COVER FRACTION (SCF) PARAMETERIZATION

BG-newSCF



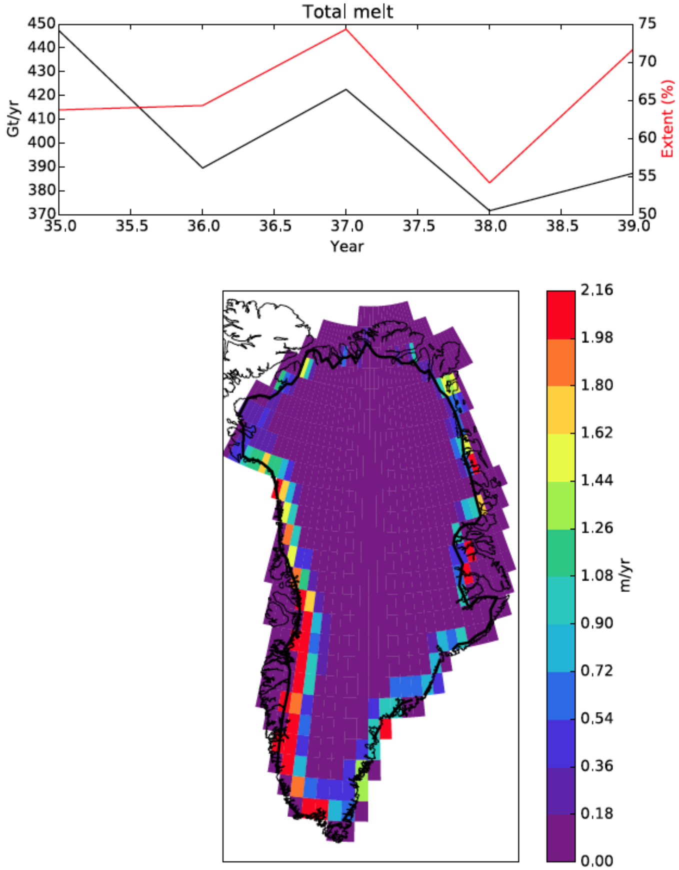
ERAI-nofirn



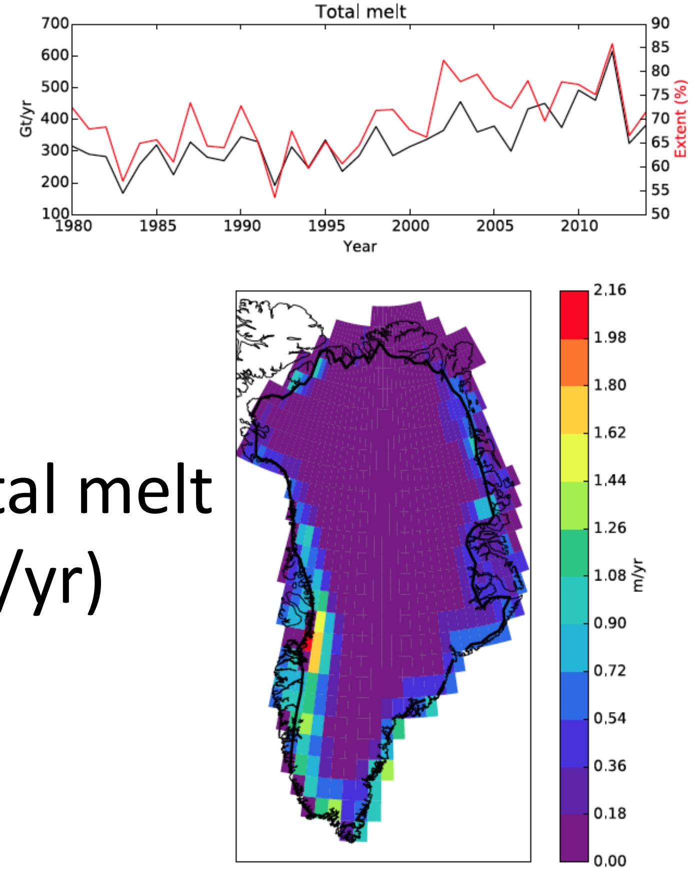
Ice melt (m/yr)

- New SCF **increases gives higher bare ice exposure than previous BG's**
- But not in all areas: high snow thickness not affected by SCF parameterization
- High values per location likely related to lower ice albedo parameter

BG-newSCF



ERAI-nofirn



Total melt (m/yr)

- High melt rates along W margin
- Low melt in N and NE

	Snow	Rain	Rainfrac	Qsnofrz	Qsnofrz frac	Qsnomelt	Qice_melt	Qsoil	SMB
ig.erai. 1979-2014 .h1m	650 (63)	40 (8)	2.8 (0.5)	176 (31)	59 (6)	256 (55)	79 (36)	79 (4)	435 (93)
leo_B9	677 (47)	56 (11)	3.5 (0.3)	147 (11)	63 (7)	203 (19)	200 (12)	22 (1)	399 (61)

- High ice melt (Mean RACMO2.1 1960-2005: 82 Gt)
  - due to longer/more extended bare ice exposure and lower albedo
- Relatively high refreezing (63%): how much happening in high thickness columns that should have net ablation?

	CLM4 (CESM1.0)	CLM5	RCMs (RACMO)	Observations
Components	Snow	Snow/firn	Snow/firn/ice	Snow/firn/ice
Ice transition	Ice is “soil”	Ice is “soil”	density	density
Cap (m w.e.)	1	10	N/A	N/A
Ablation PD	Realistic ~12%	**Improving**	Realistic ~12%	~12%
Ablation by 2100	30% GrIS	**Expansion**	Similar to CLM4	N/A
Refreezing PD	~40%	**~60% in PI with new SCF**	~40%	?
Refreezing by 2100	Unrealistically quick saturation	**Does not decline**	Physics-based decrease	
N Greenland tundra	Permanent snow cover	**Permanent, 10 m w.e.**	Seasonal snow cover	Seasonal snow cover
N Greenland tundra 2100	Seasonal snow cover	**Permanent, 10 m w.e.**		N/A

Conclusions

- Problem of low ablation has links to thick snow/firn and high refreezing
- Bare ice exposure increases with new SCF, but some areas remain insensitive (under PI):
  - Possible fix for H_{snow} > 2 m w.e.: re-initialization?
- Insensitivity of permanent snow cover over tundra to 4xCO2 warming
- GrIS margins sensitive to 4xCO2 warming