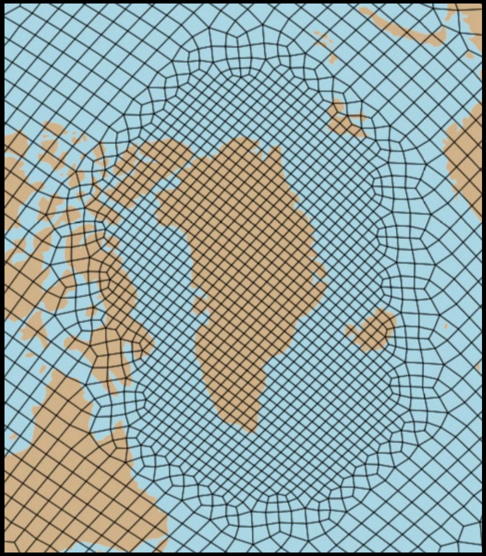
Regional grid refinement over Greenland: effects on surface mass balance



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LIWG winter meeting 2019

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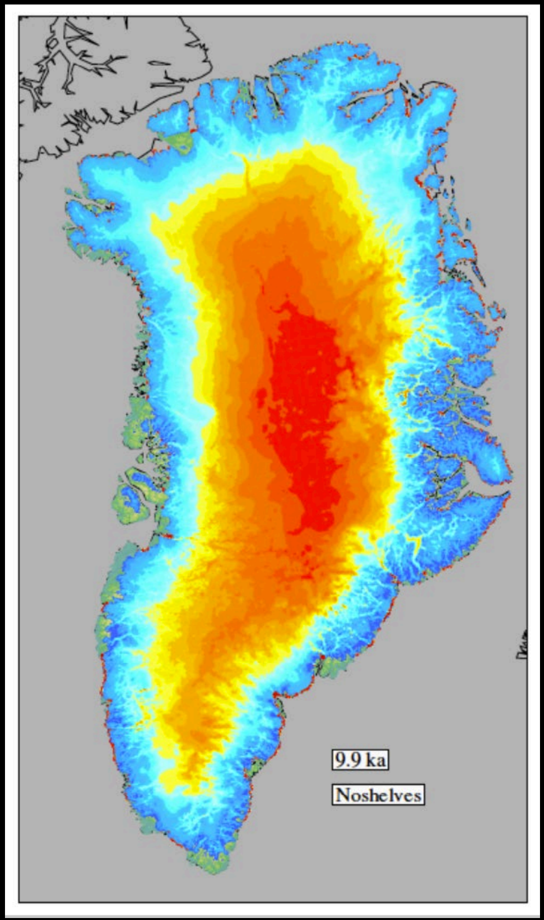
Ice sheet modelling

- for modelling ice sheets, SMB is crucial to obtain correct geometry
- biases in SMB may translate into rapid expansion of the ice sheet



...a too large Greenland ice sheet...

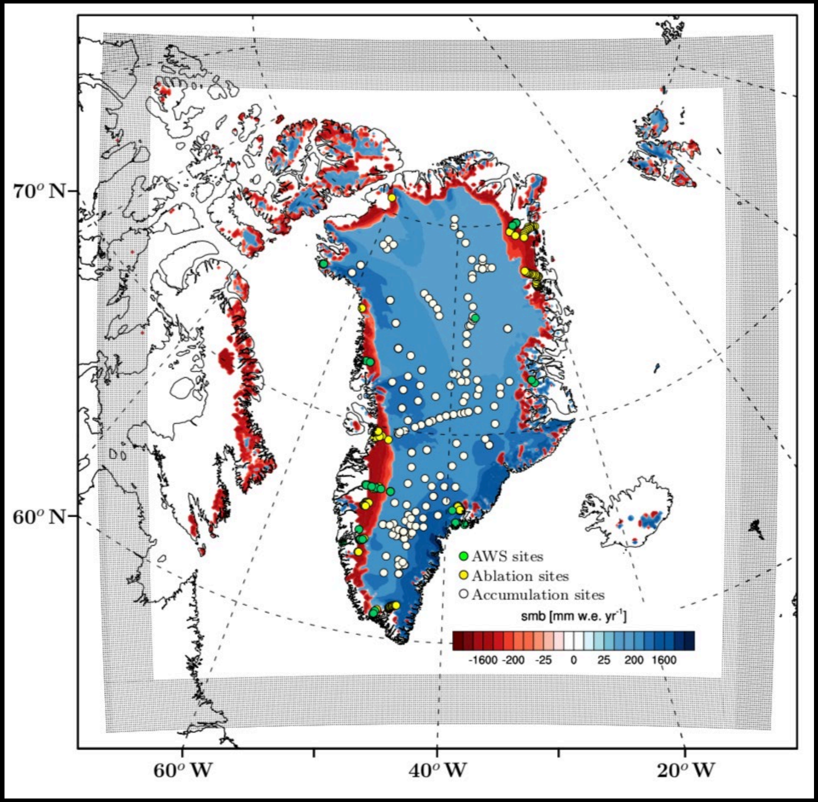
Figure courtesy of S. Bradley

SMB modelling

- best spatial SMB products are by RCMs with resolutions 5.5 – 20 km
- by contrast, CESMs grid resolution is 111 km
- too computionally expensive to run CESM at high res

SOLUTION:

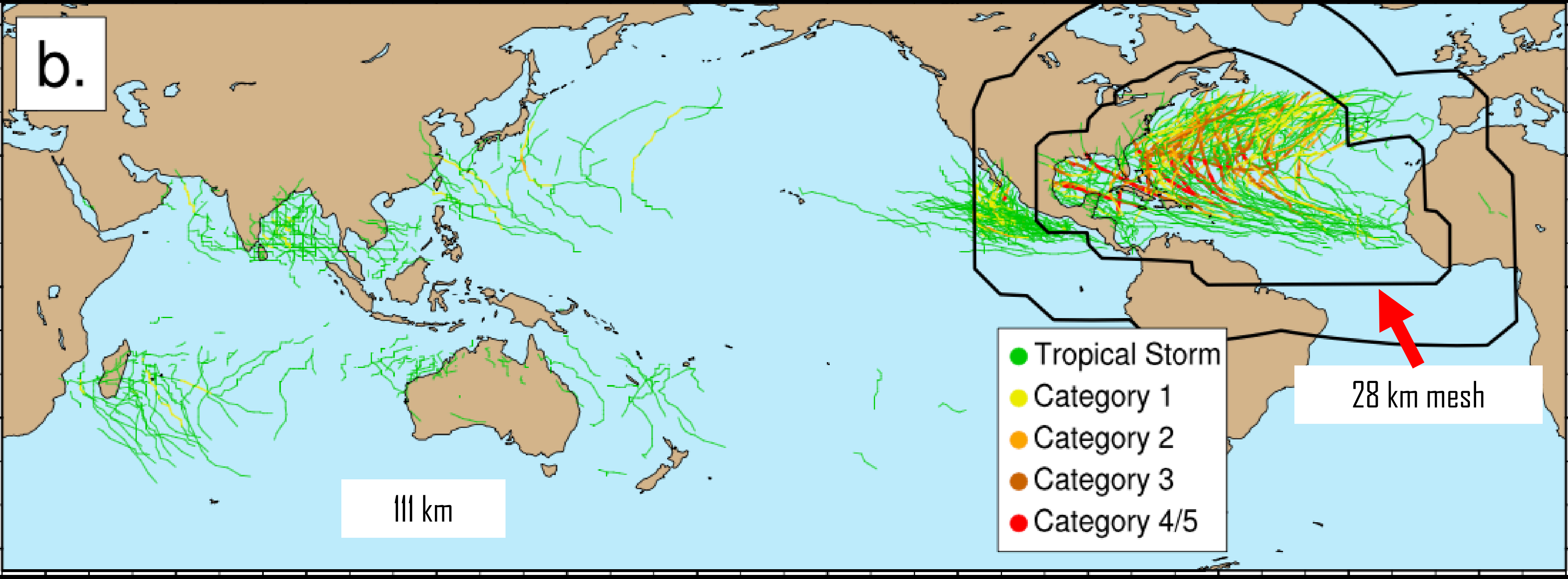
regional grid refinement



GrIS SMB at 11 km
as modelled by RACMO 2.3p2
(Noël et al. 2018)

Grid refinement

- Variable Resolution CESM (VR-CESM)
- CAM spectral element (SE) dycore
- developed to study tropical cyclones in the Atlantic (Zarzycki & Jablonowski, 2014)



Benefits w.r.t. RCM downscaling

- ✓ ease of use, single framework (CESM)
- ✓ uniform physics
- ✓ feedbacks with rest of the globe
- ✓ cheaper than global model at uniform high resolution

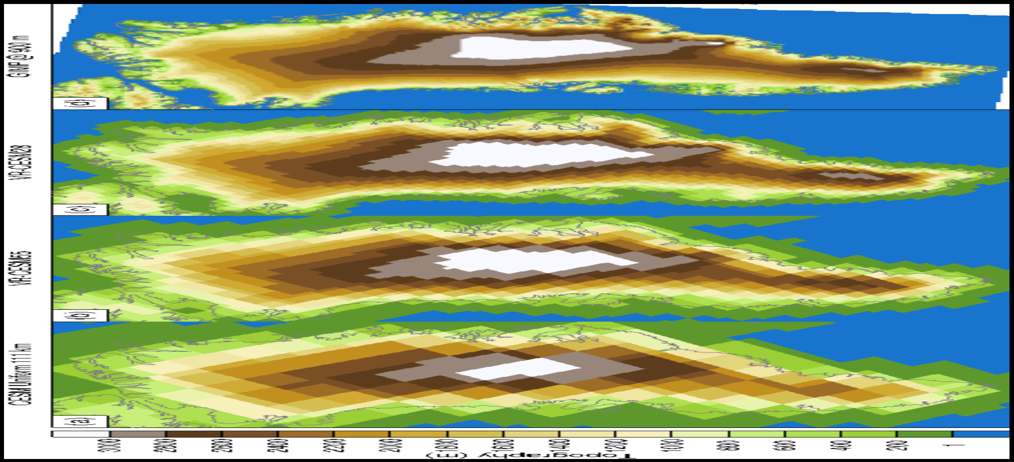
Setup

- ➢ AMIP style (F-compset)
- ➢ CAM-SE 5.4 (i.e. no CLUBB), gave best results at the time

Uniform CESM
- 111km over GrIS

VR-CESM55
- 55 km over GrIS

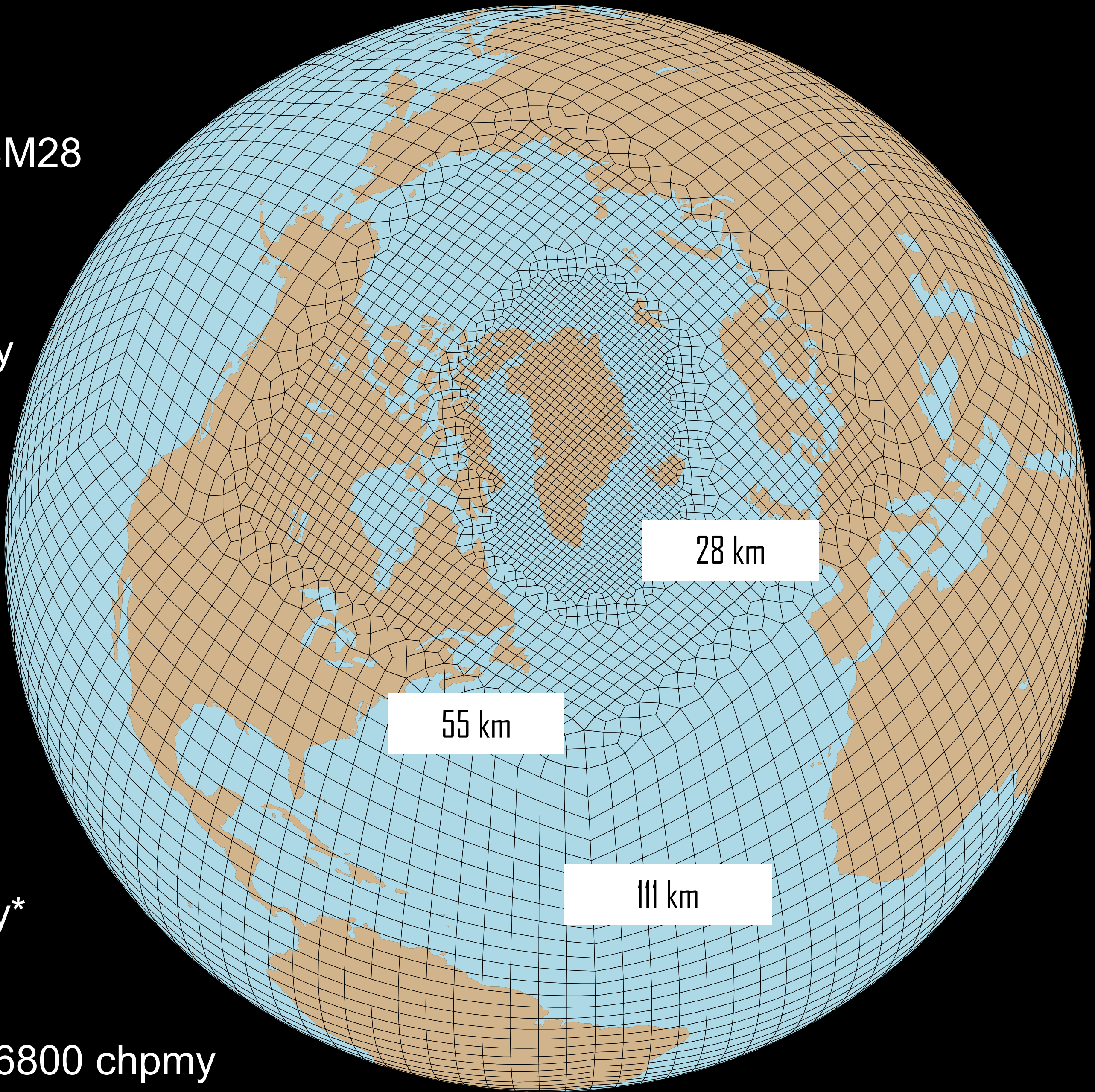
VR-CESM28
- 28 km over GrIS



- ➢ period 1980-1999
- ➢ 5 year spinup
- ➢ global snow reset at start of spinup (100 mm over land)

Setup (2)

- finest mesh VR-CESM28
- we keep at least 6 elements away from Greenland for storms to properly develop



Computational cost
- Uniform: 1070 chpmy*
- VR55 : 3250 chpmy
- VR28 : 4300 chpmy
- RACMO2 @ 11 km: 6800 chpmy

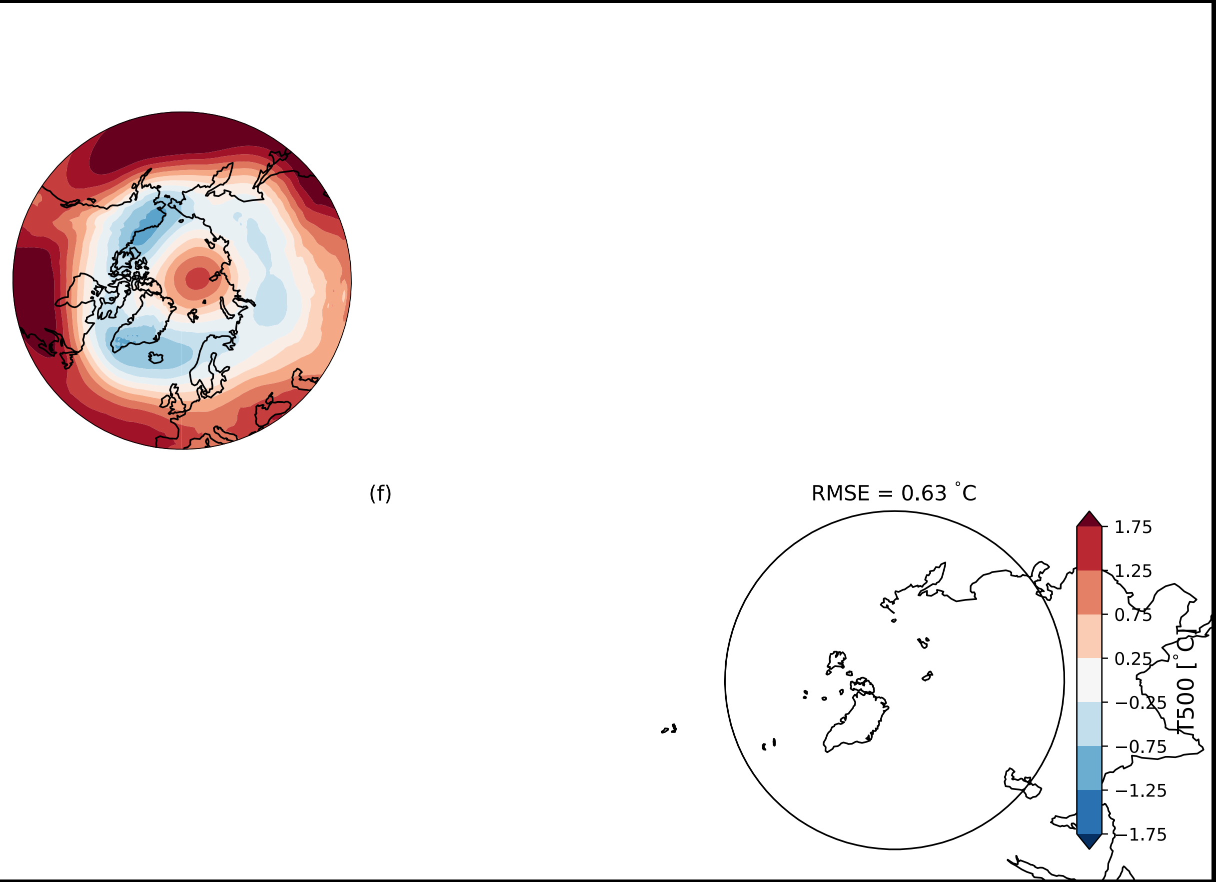
*core hours per model year

Wrap up

Results

Large scale circulation

- Circulation does not show large response, in comparison to ERA Interim
- Few areas with significant difference from Uniform CESM
- RMSE improves somewhat in JJA, but not in all seasons

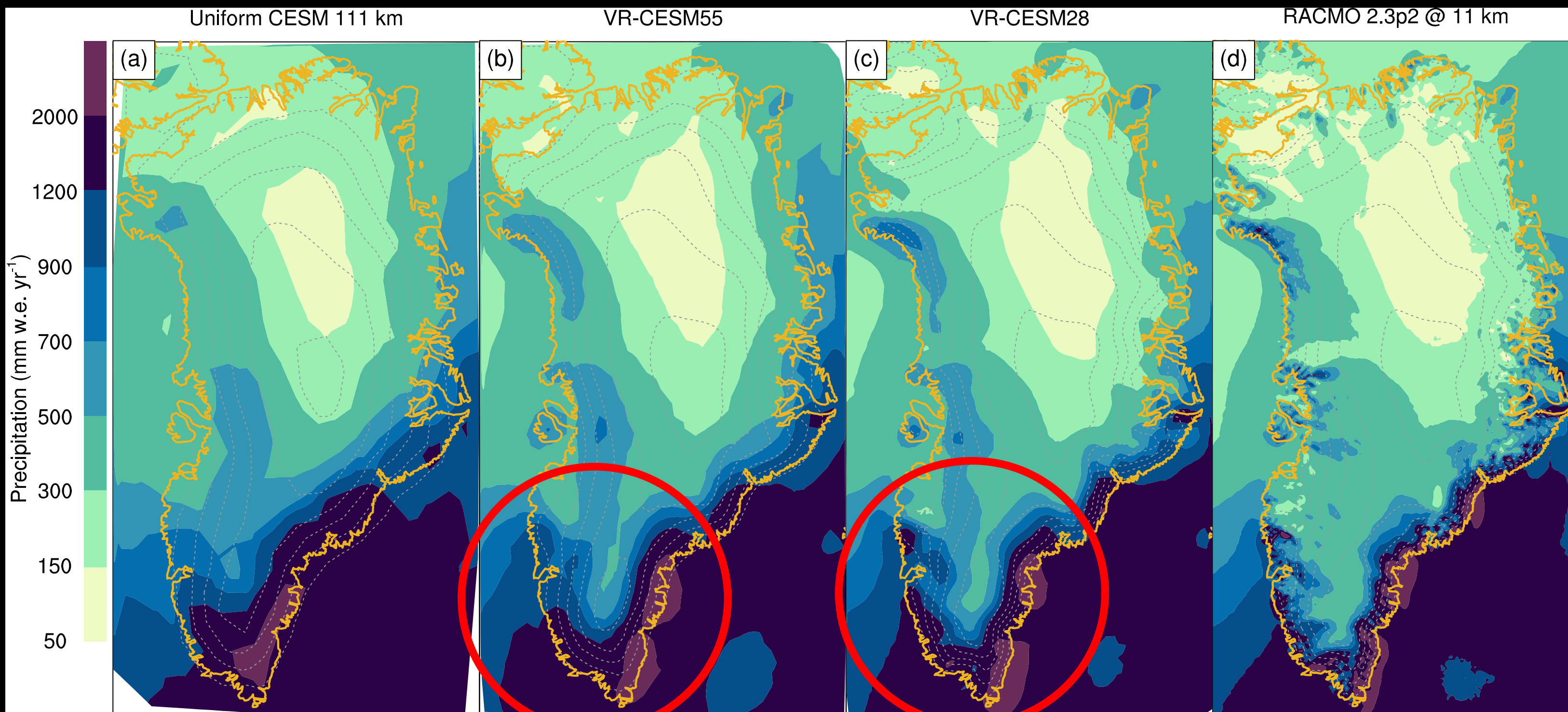


JJA geopotential height @ 500 hPa

JJA temperature @ 500 hPa

Precip

- better resolved topography forces precip changes
- drying in interior GrIS, especially south dome

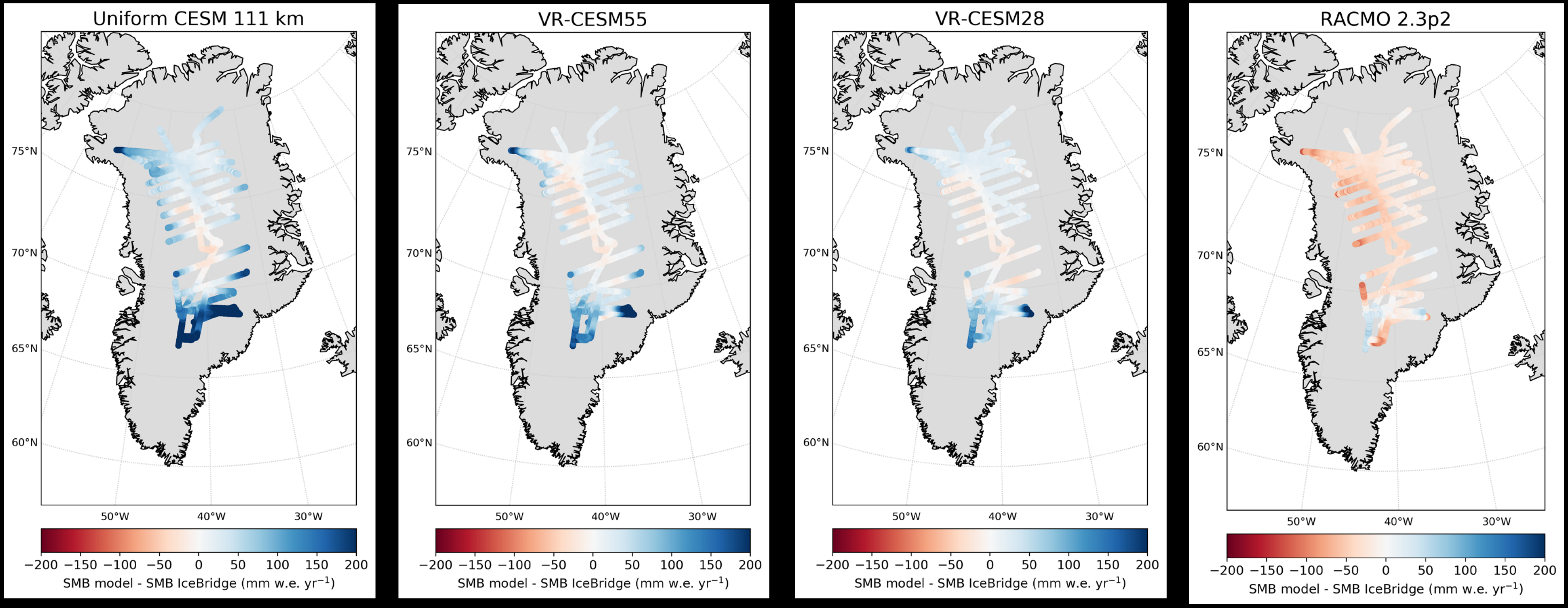


Total GrIS precip:	893 Gt +26 %	796 Gt +13 %	745 Gt +5 %	707 Gt

IceBridge

- SMB is compared to IceBridge airborne radar data

using LIVVkit



Uniform CESM 111 km	VR-CESM55	VR-CESM28	RACMO 2.3p2
bias : 81 mm	bias : 37 mm	bias : 24 mm	bias : -25 mm
r^2: 0.78	r^2: 0.88	r^2: 0.92	r^2: 0.94
RMSE: 126 mm	RMSE: 68 mm	RMSE: 46 mm	RMSE: 38 mm

In-situ observations

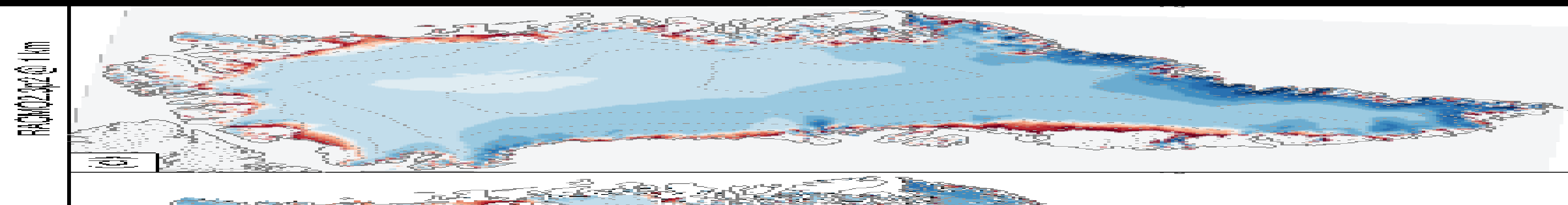
using LIVVkit

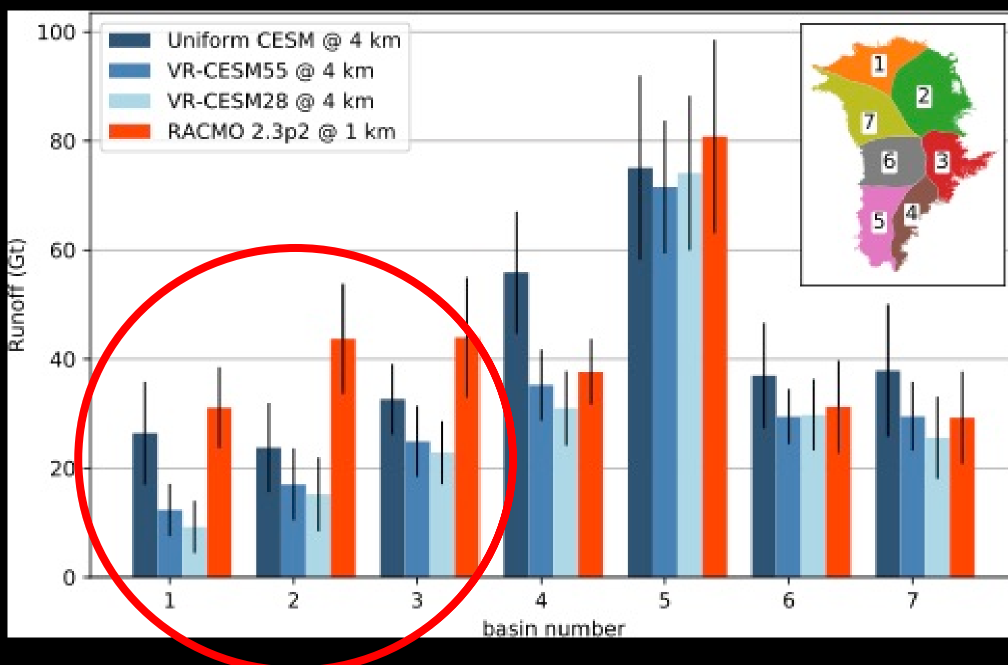
- Ablation sites comparison does not improve...

	IceBridge ($n = 18,968$)			Acc. sites ($n = 421$)			Abl. sites ($n = 163$)		
	bias (mm)	r^2	RMSE (mm)	bias (mm)	r^2	RMSE (mm)	bias (mm)	r^2	RMSE (mm)
Uniform CESM 1°	81	0.78	126	187	0.61	319	170	0.71	793
VR-CESM55	37	0.88	68	105	0.74	172	462	0.69	941
VR-CESM28	24	0.92	46	71	0.79	124	600	0.72	951
RACMO 2.3p2	-25	0.94	38	-13	0.71	91	160	0.54	922

SMB

- VR-CESM misses ablation zone in north and east

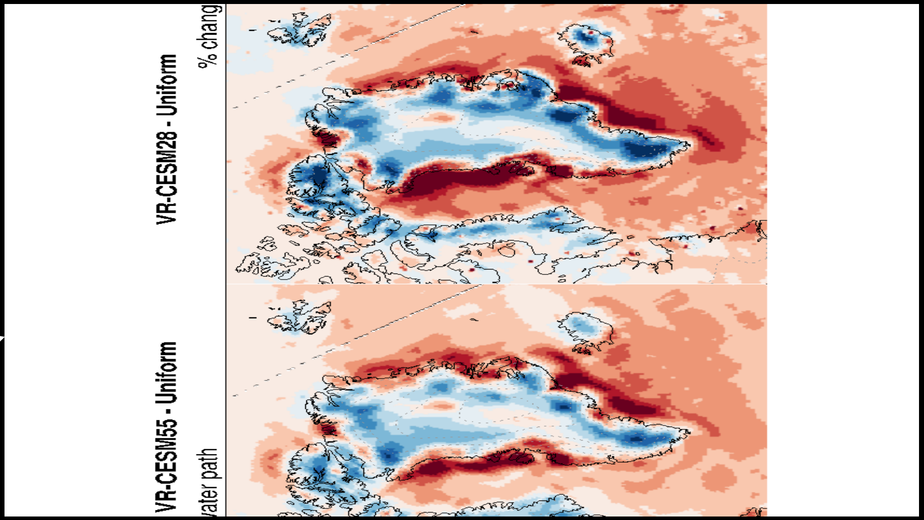




other basins OK, even improve.

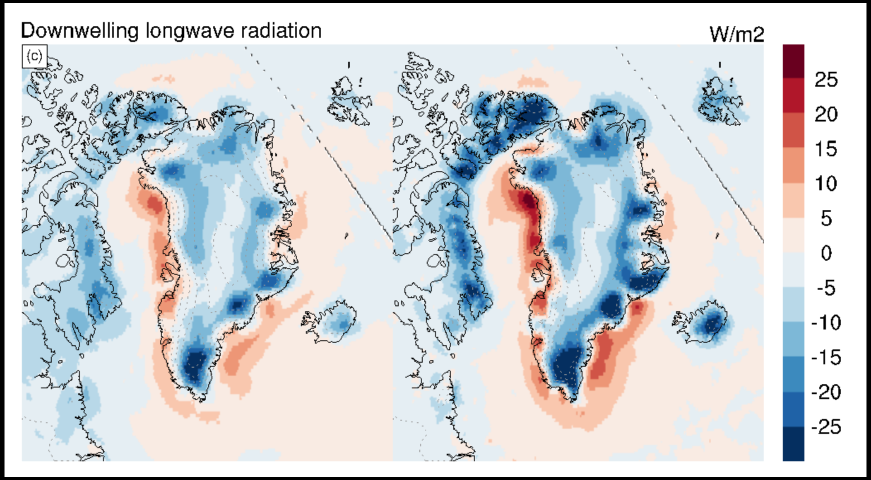
North Greenland bias

- We now believe cloud cover plays the largest role, through the longwave effect clouds have.



- Cloud cover is reduced over much of north Greenland

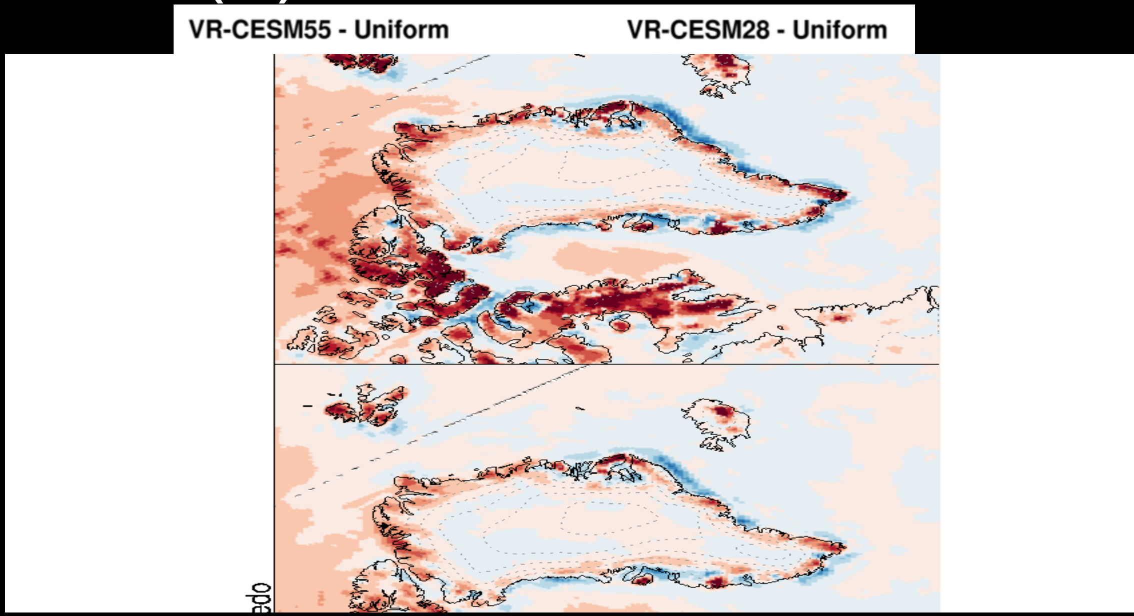
- Leads to reduction in longwave



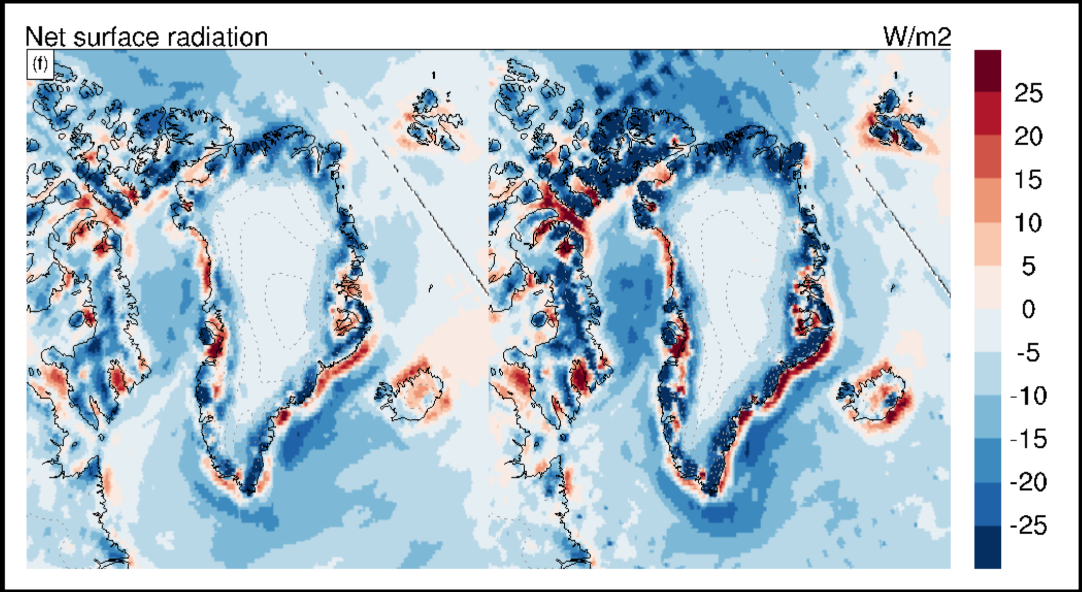
(both figures show JJA)

North Greenland bias (2)

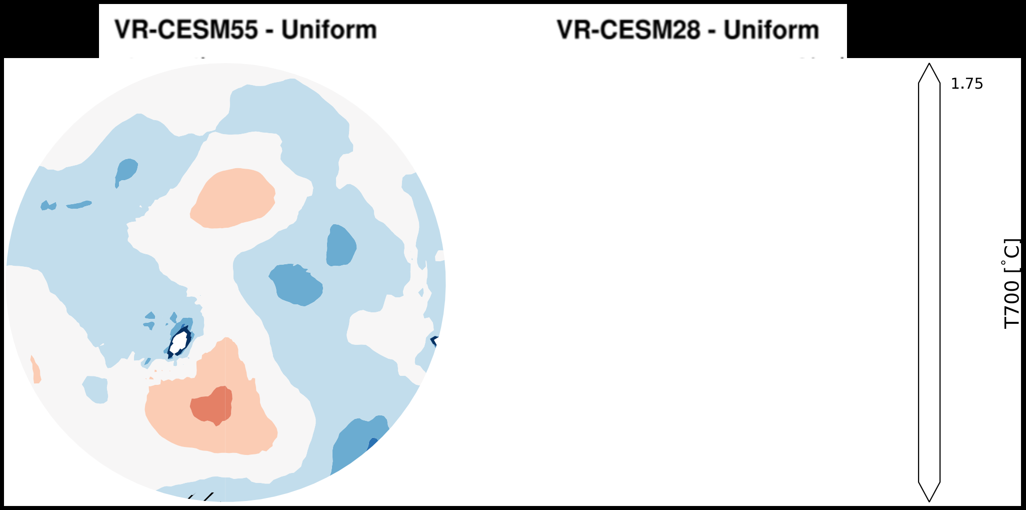
- Snow buildup in North-Greenland tundra happens in all simulations, yet albedo is increased further in VR runs.
- Note albedo increase over sea ice (SIC = identical, AMIP run)



- Reduced longwave + high albedo → major impact on net radiation



North Greenland bias (3)



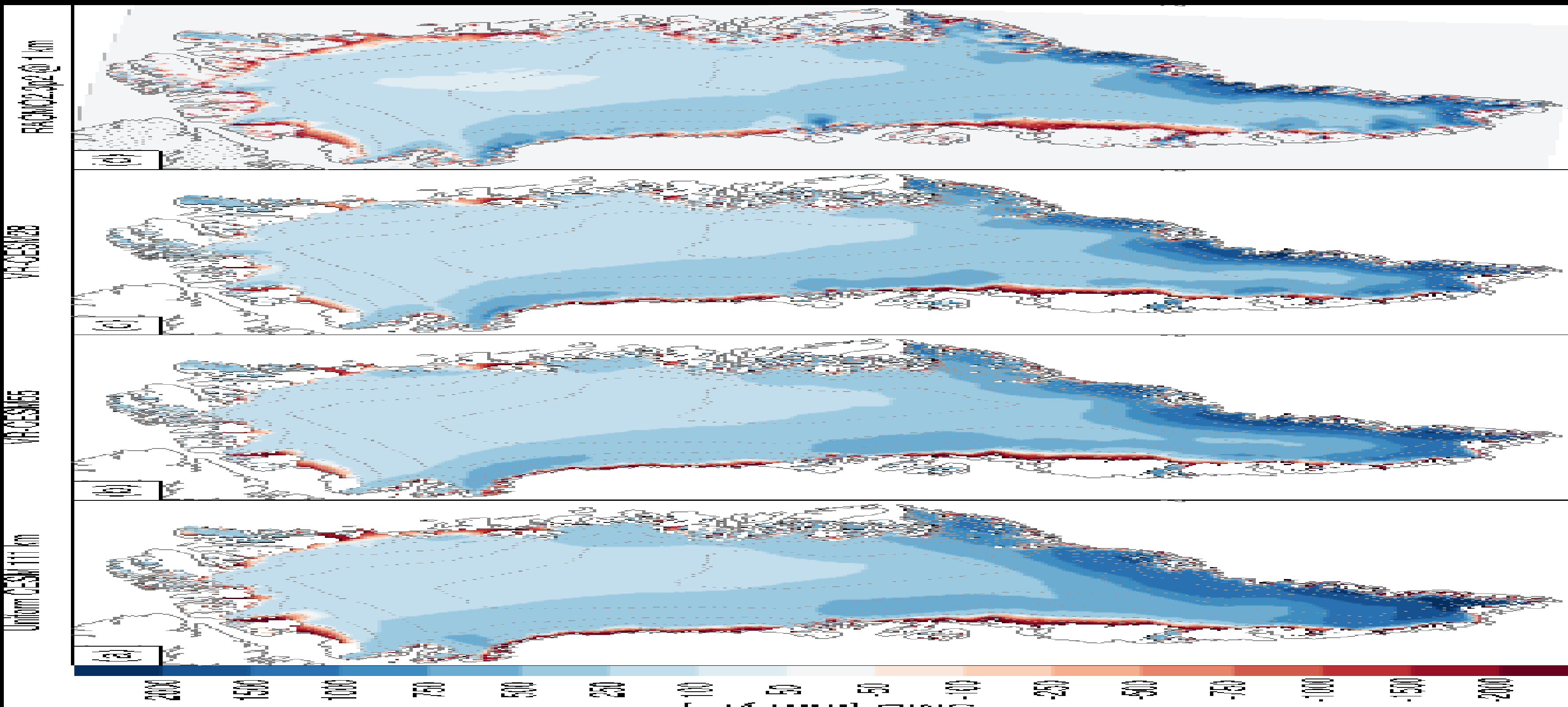
temperature
at 700 hPa

- The VR simulations are slightly cooler in the mid-troposphere, although not statistically significantly

- Bottom line: the north Greenland bias is present in all CESM simulations over the past few years, and appears to get worse with VR resolution increases.

Wrap up

SMB 1980-1999



Total GrIS SMB:	610 ± 116 Gt +62 %	557 ± 71 Gt +48 %	521 ± 77 Gt +39 %	376 ± 99 Gt

(values over common mask)

Summary

- VR-CESM has been applied over a Greenland domain at 55 and 28 km
- Precipitation is improved dramatically, on-par with regional model
- Ablation is OK in all basins except north, north-east and east (1-3)
- VR-CESM is a viable new tool in cryospheric studies, but is no silver bullet

Van Kampenhout et al, TCD
https://www.the-cryosphere-discuss.net/tc-2018-257/

Extra

- difference maps were computed after regridding CESM data to a common 0.25 degree mesh
- interpolation errors are real

Extra

Table 2. Mean GrIS mass fluxes for the period 1980-1999 in gigatonnes per year with standard deviation between brackets. The area of integration is listed in the first column and includes peripheral glaciers and ice caps (GIC). CESM data are integrated at the native resolution with elevation class weighing. The statistically downscaled 1 km RACMO2.3p2 data is averaged over the same period and described in Noël et al. (2018). RACMO2 does not differentiate between snow and ice melt in its output files so only total melt is reported.

Model name	Ice area	Precipitation	Ice melt	Total melt	Refreezing	Runoff	Sublimation	SMB
	km^2	Gt yr^{-1}	Gt yr^{-1}	Gt yr^{-1}	Gt yr^{-1}	Gt yr^{-1}	Gt yr^{-1}	Gt yr^{-1}
	native ice sheet extent, including GIC							
Uniform CESM 1°	1,812,467	946 (107)	217 (48)	468 (100)	178 (43)	349 (67)	28 (3)	567 (129)
VR-CESM55	1,812,254	870 (72)	146 (25)	387 (70)	185 (39)	260 (42)	39 (3)	571 (75)
VR-CESM28	1,812,254	821 (62)	131 (34)	377 (73)	195 (35)	239 (47)	44 (2)	538 (87)
RACMO2	1,761,475	743 (64)	-	577 (81)	309 (27)	344 (68)	33 (2)	365 (109)
	contiguous GrIS extent							
Uniform CESM 1°	1,705,508	893 (104)	157 (37)	361 (85)	150 (40)	258 (53)	26 (3)	610 (116)
VR-CESM55	1,692,629	796 (69)	115 (20)	314 (62)	159 (37)	203 (34)	36 (3)	557 (71)
VR-CESM28	1,697,054	745 (59)	105 (28)	304 (63)	165 (33)	184 (38)	40 (2)	521 (77)
RACMO2	1,700,772	707 (61)	-	509 (72)	263 (25)	298 (58)	32 (2)	376 (99)