Coupled ice-climate simulation of future Greenland ice sheet evolution: mechanisms, thresholds and feedbacks for accelerated mass loss

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Research question

- How do climate and ice sheet co-evolve under future high greenhouse gas forcing?

Method

- The newly (bi-directionally) coupled ice sheet and earth system model CISM2.1-CESM2.1
- Coupling description in Supplementary Material of https://doi.org/10.1029/2019GL086836

Geophysical Research Letters

Research Letter | Open Access

Greenland Ice Sheet Contribution to 21st Century Sea Level Rise as Simulated by the Coupled CESM2.1-CISM2.1

Laura Muntjewerf, Michele Petrini, Miren Vizcaino, Carolina Ernani da Silva, Raymond Sellevold, Meike D. W. Scherrenberg, Katherine Thayer-Calder, Sarah L. Bradley ... See all authors

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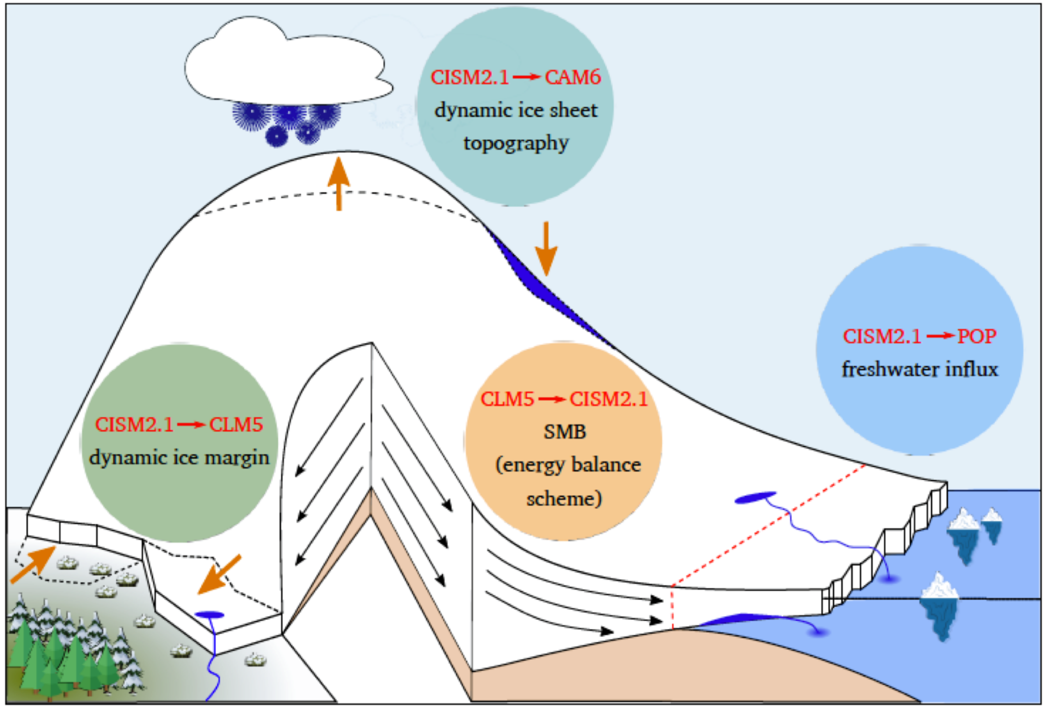

Figure by Michele Petrini

SMB calculation

- Energy Balance Scheme
- Downscaling via **elevation classes** is explained, evaluated and analyzed in https://doi.org/10.5194/tc-13-3193-2019, 2019
- Evaluation and results for present-day Greenland in https://doi.org/10.1029/2019JF005318

The Cryosphere, 13, 3193–3208, 2019
https://doi.org/10.5194/tc-13-3193-2019

TC | Volume 13, issue 12

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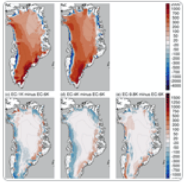
Research article

04 Dec 2019

Surface mass balance downscaling through elevation classes in an Earth system model: application to the Greenland ice sheet



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Research Article | Open Access

Present-Day Greenland Ice Sheet Climate and Surface Mass Balance in CESM2

Leonardus van Kampenhout, Jan T. M. Lenaerts, William H. Lipscomb, Stef Lhermitte, Brice Noël, Miren Vizcaíno, William J. Sacks, Michiel R. van den Broeke

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Main results

	Pre-industrial	Years 131–150	Years 331–350	
Annual mass loss	0.03 [0.23]	2.16 [0.47]	6.58 [1.04]	mm/yr sea level rise
Cumulative mass loss	11	107	1140	mm sea level rise
MB	-13 [84]	-764 [160]	-2350 [358]	
SMB	585 [85]	-367 [166]	-2259 [357]	
ID	574 [5]	378 [26]	77 [8]	Gt/yr
BMB	-24 [0]	-19 [4]	-14 [0]	
GrIS area	1.966	1.918	1.598	

- Acceleration of mass loss as critical warming is reached and ablation areas expand
- Incoming LW is the main contributor to melt before acceleration, then solar (albedo feedback) and turbulent fluxes become main contributors
- Refreezing increases at first, but does not exceed the snow accumulation rate. Then, it slightly decreases

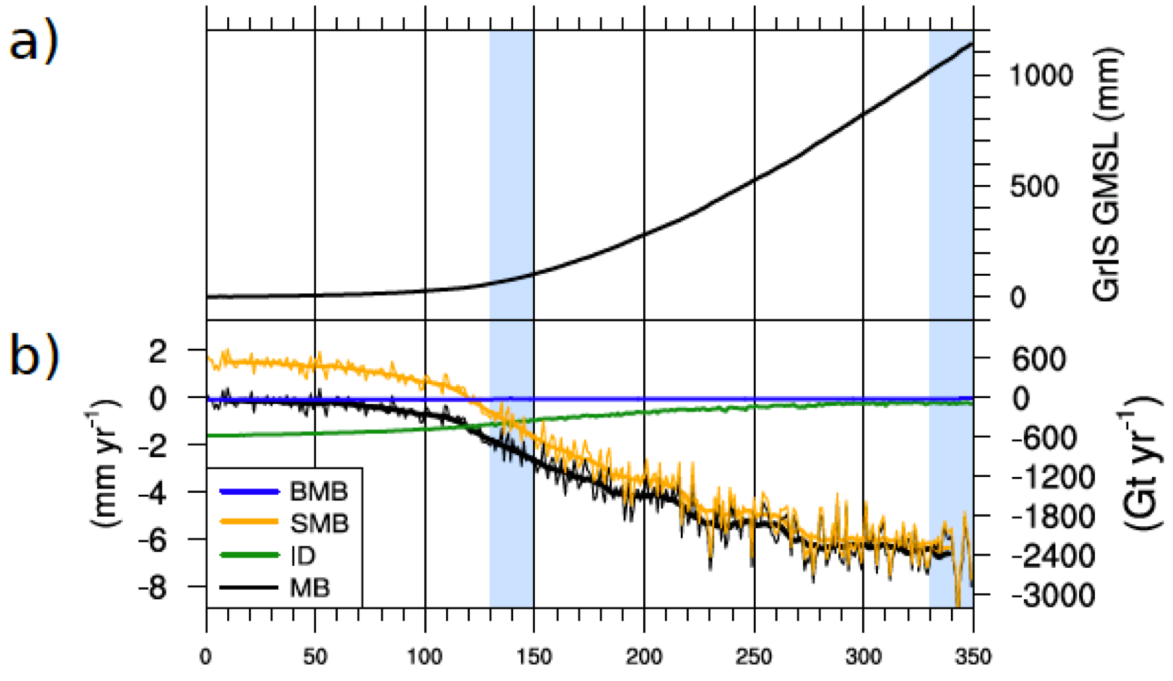
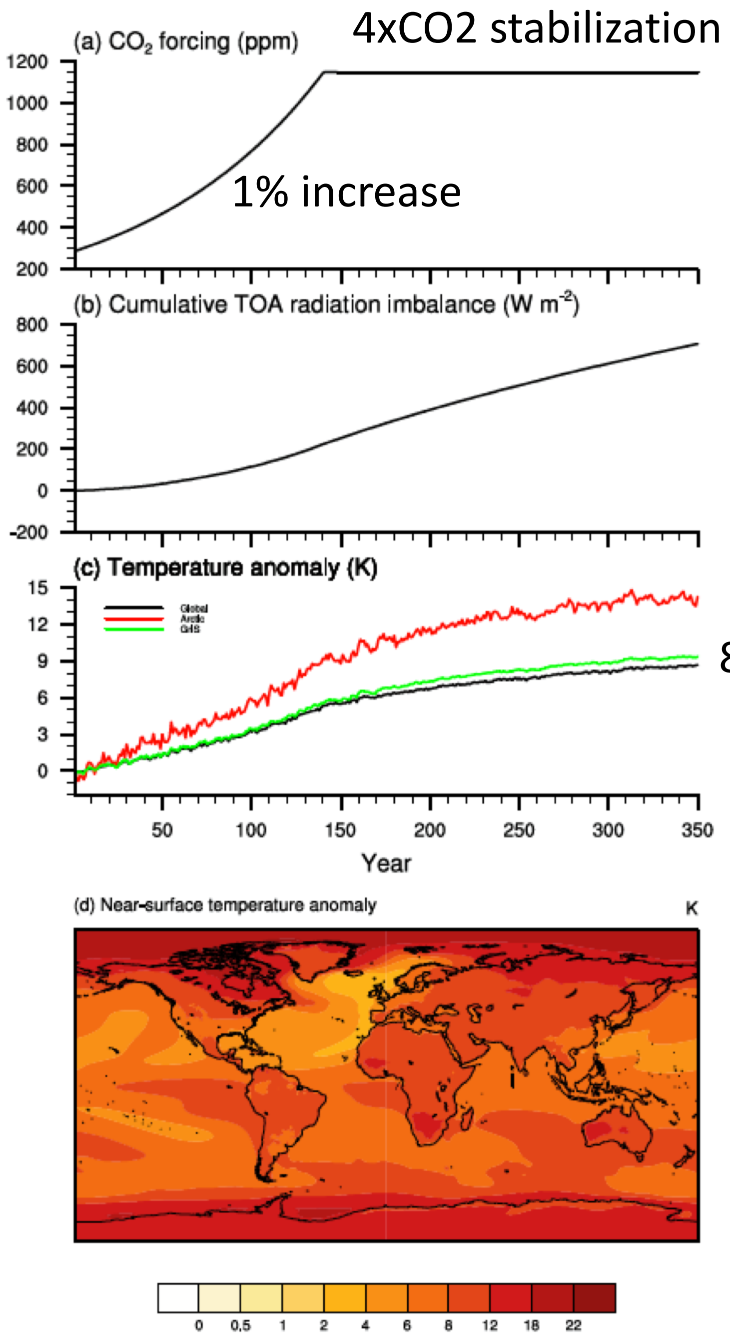


Figure 4. Cumulative (mm SLE, a) and rate (mm SLE yr^{-1} , left axis, and Gt yr^{-1}, right axis) b) GrIS contribution to global mean SLR (black, thick represents 20-year centered running mean). b) Includes the partition of mass budget in SMB (yellow), ice discharge (ID, green) and basal melt (BMB, blue) components. Note that ID and BMB are defined negative here for graphics clarity. MB = SMB + ID +BMB. Blue shade bars indicate the focused analysis periods 131–150 and 331–350.



8 K global warming

8 K global warming
(years 331-350)

Climate

Summer sub-freezing temperatures only over Greenland ice sheet interior after CO_2 stabilization

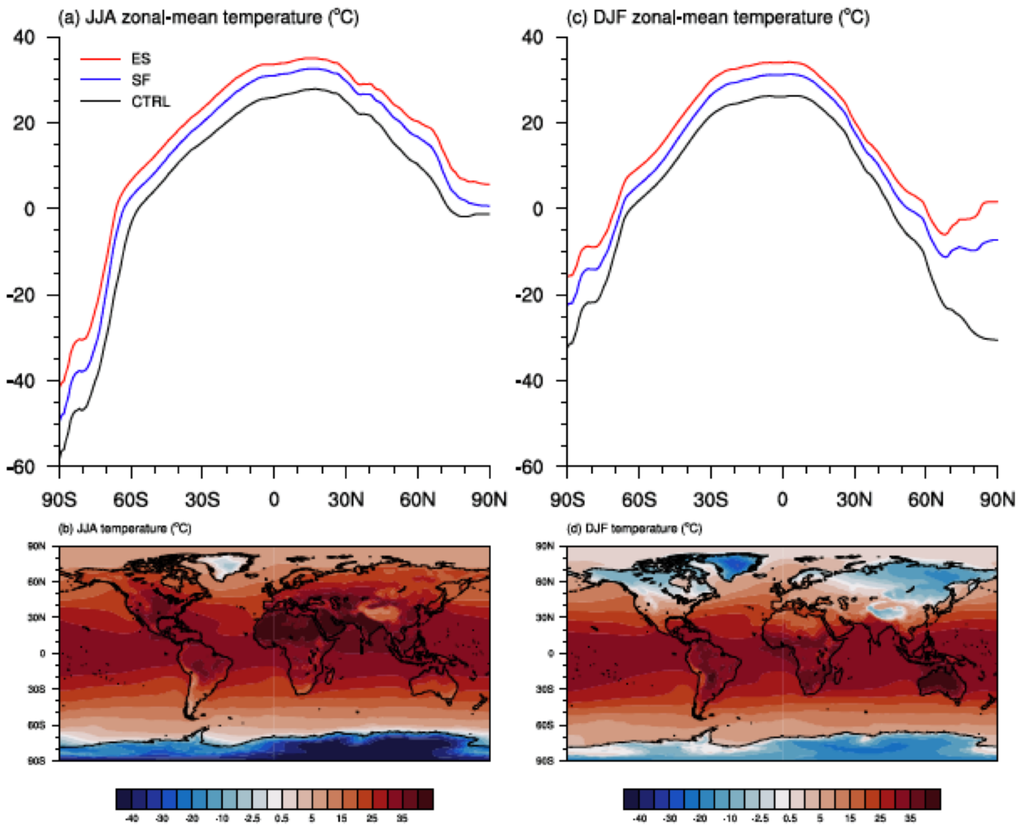


Figure 2. Zonal-mean (top) and maps (bottom) of summer (JJA; left) and winter (DJF; right) near-surface temperature (°C). The maps show the seasonal averages end-of-simulation (years 331–350).

Table 3. Annual ice sheet integrated surface mass balance and components mean [standard deviation] and anomalies of the mean with respect to pre-industrial (Gt yr^{-1}). SMB [1°] values are calculated as the sum of components as calculated in CLM. SMB [4 km] values are in CISM, after downscaling and remapping. SMB [1°] = snowfall + refreezing - melt - sublimation. Rain (%) = rain * 100 / (snowfall + rain). Refreezing (%) = refreezing * 100 / (rain + melt). All changes is the mean are significant ($p < 0.05$) except snowfall by 131–150. Differences with the downscaled SMB used by CISM2.1 (Table 1) are due to mass definition across components, for mass conservation purposes (see, e.g., Vizcaino et al., 2013).

Component	Pre-industrial	Years 131–150		Years 331–350	
		Absolute	Anomaly	Absolute	Anomaly
SMB [4 km]	585 [85]	-367 [166]	-952	-2259 [357]	-2844
SMB [1°]	544 [103]	-521 [217]	-1065	-2589 [442]	-3133
Precipitation	846 [83]	986 [97]	140	1122 [97]	276
Snowfall	780 [80]	750 [74]	-30*	683 [71]	-97
Rain	72 [12]	235 [38]	163	439 [59]	367
Refreezing	223 [54]	693 [73]	470	534 [43]	311
Melt	415 [92]	1,914 [251]	1499	3,804 [443]	3389
Sublimation	45 [4]	50 [6]	5	3 [11]	-42
Rain (%)	8 [1]	24 [3]	16	39 [4]	31
Refreezing (%)	46 [4]	32 [3]	-14	13 [1]	-33

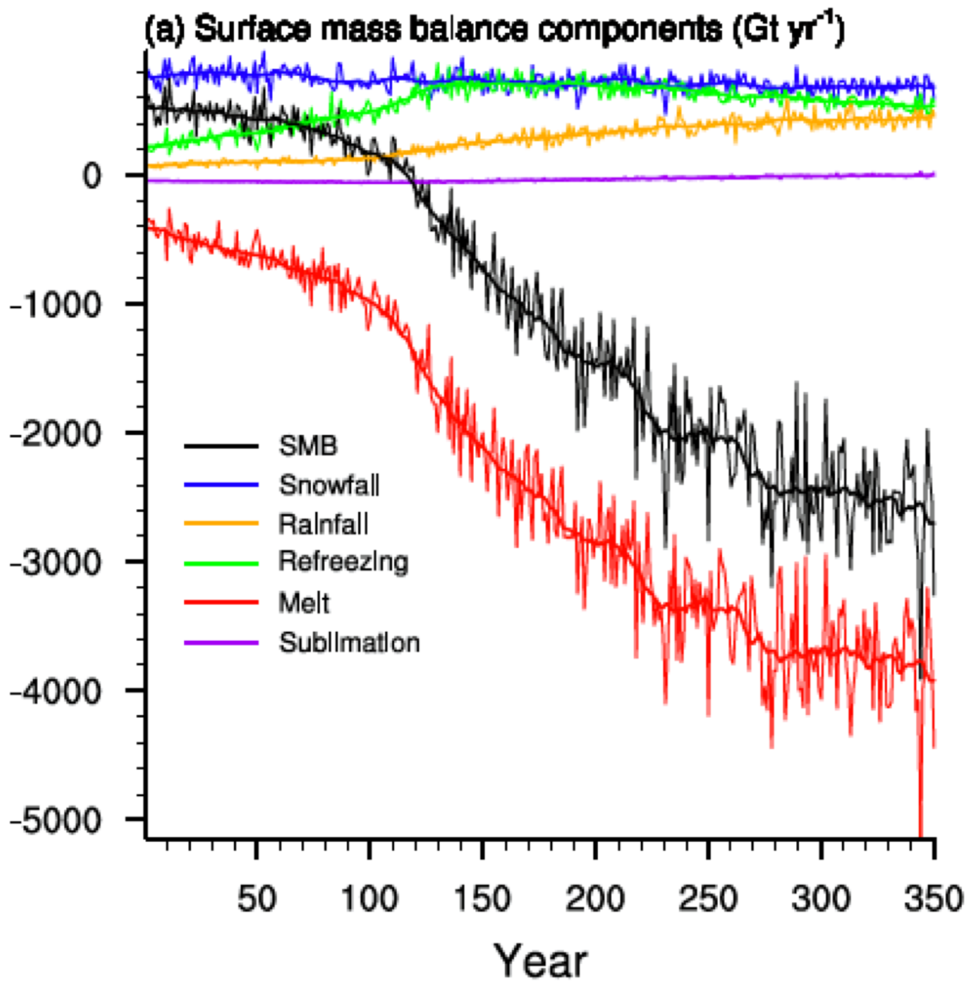
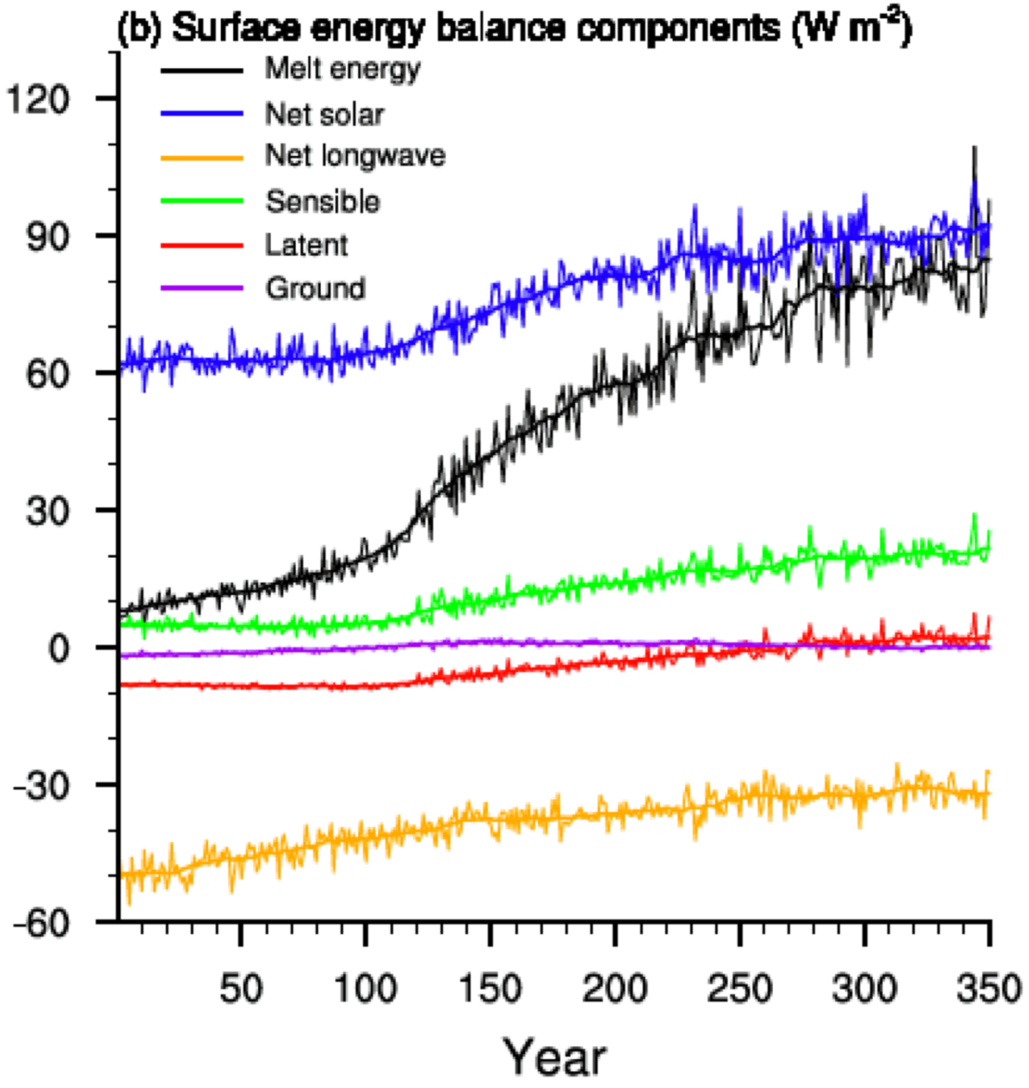


Table 2. Summer GrIS-averaged albedo (-), near-surface temperature and skin temperature (°C), incoming short-wave radiation at the surface, incoming long-wave radiation at the surface, and surface energy balance components (W m^{-2}) (mean [standard deviation]). Melt energy = net short-wave radiation SW_{net} + net long-wave radiation LW_{net} + sensible heat flux SHF + latent heat flux LHF + ground heat flux GHF. All changes in the mean are significant ($p < 0.05$)

	Pre-industrial	Years 131–150	Years 331–350
Albedo	0.78 [0.01]	0.72 [0.01]	0.62 [0.01]
T_{2m}	-7.1 [0.8]	-1.5 [0.5]	0.6 [0.3]
T_{skin}	-7.6 [0.8]	-2.3 [0.4]	-0.8 [0.2]
SW_{in}	289.6 [3.7]	264.4 [5.2]	252.6 [6.2]
LW_{in}	231.3 [3.7]	266.6 [3.5]	279.7 [3.4]
Melt energy	8.2 [2.0]	38.2 [5.0]	83.1 [9.1]
SW_{net}	62.5 [2.3]	71.3 [3.4]	91.4 [4.4]
LW_{net}	-49.8 [2.0]	-37.7 [2.7]	-31.4 [2.8]
SHF	5.0 [1.0]	9.6 [1.9]	20.8 [2.9]
LHF	-7.8 [0.4]	-6.3 [1.0]	2.1 [2.1]
GHF	-1.7 [0.3]	1.2 [0.5]	0.2 [0.4]



Outlet glaciers retreat (except in SE)

in response to SMB forcing (ocean forcing not included)