21st-Century Contribution of Greenland to Global Mean Sea-Level Rise

Steve George | **Robin Smith** | Jonathan Gregory

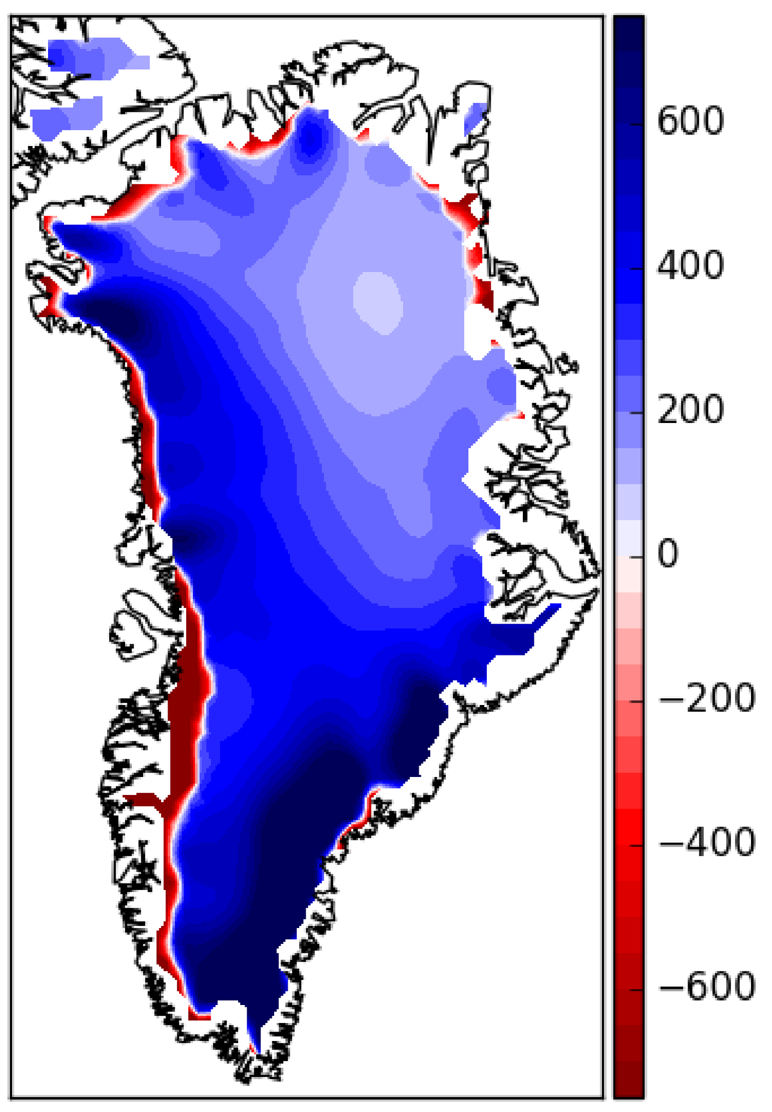
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL
University of Reading

1. Introduction

At the 21st Conference of the Parties in December 2015 (COP21), 195 countries agreed to hold the increase in global average temperature to below 2.0C above pre-industrial levels, and pursue efforts to limit the temperature increase to 1.5C. Understanding the global physical response to such temperature changes, especially in the context of possible "tipping points", is vital for planning the response to future impact scenarios.

One predicted impact of global temperature increase is a rise in global mean sea-level (GMSLR). The present-day rate of GMSLR is equivalent to about 0.3m per century, with the increase predominantly due to a combination of ocean thermal expansion and enhanced melting of mountain glaciers. In contrast, a complete loss of the Greenland ice-sheet would lead to a GMSLR of around 7m. The present study assesses the sensitivity of the Greenland ice-sheet (GrIS) to proposed limits on global temperature increase.

GrIS Surface Mass Balance (SMB)



Current Conditions

- Snowfall; **637± 55 Gt yr^{-1}**
- Run-off; **266 ± 66 Gt yr^{-1}**
- SMB = Snowfall – Run-off
- Thus, accumulation exceeds melt (blue vs. red in Figure 1).
- In a steady state, iceberg discharge at the ocean margins balances the net SMB gain.

Figure 1: *Mean SMB (kg m^{-2}yr^{-1}) simulated for 1980-199 by Modèle Atmosphérique Régional (MAR).*

Future Condition

An increase in atmosphere temperature will lead to increased ice ablation (melt), potentially exceeding any increase in snowfall.

A simple formula has been developed (see Fettweis[2013]*), relating future changes in SMB (***ΔS***) to anomalies in global surface temperature (***ΔT_G***; with respect to 1980-1999):

$$\Delta S \cong -71.5 \cdot \Delta T_G - 20.4 \cdot (\Delta T_G)^2 - 2.8 \cdot (\Delta T_G)^3 \quad [1]$$

Equation [1] is subsequently adjusted (as per IPCC AR5) to account for methodological uncertainties (***F***), and surface topographic feedback (***E***), such that: $\Delta S_F = \Delta S \cdot F \cdot E$

- $F = e^N$, where ***N*** is a normal distribution of mean 0, and standard deviation 0.4 (representing a range of SMB models).
- ***E*** is a uniform distribution with range 1.00 to 1.15 (representing estimates of the increasing ablation as the surface altitude falls).
- A Monte Carlo methodology is employed to convolve the time-dependent uncertainties.

*Fettweis, X. *et al*., 2013, The Cryosphere, doi:10.5194/tc-7-469-2013

3. Results

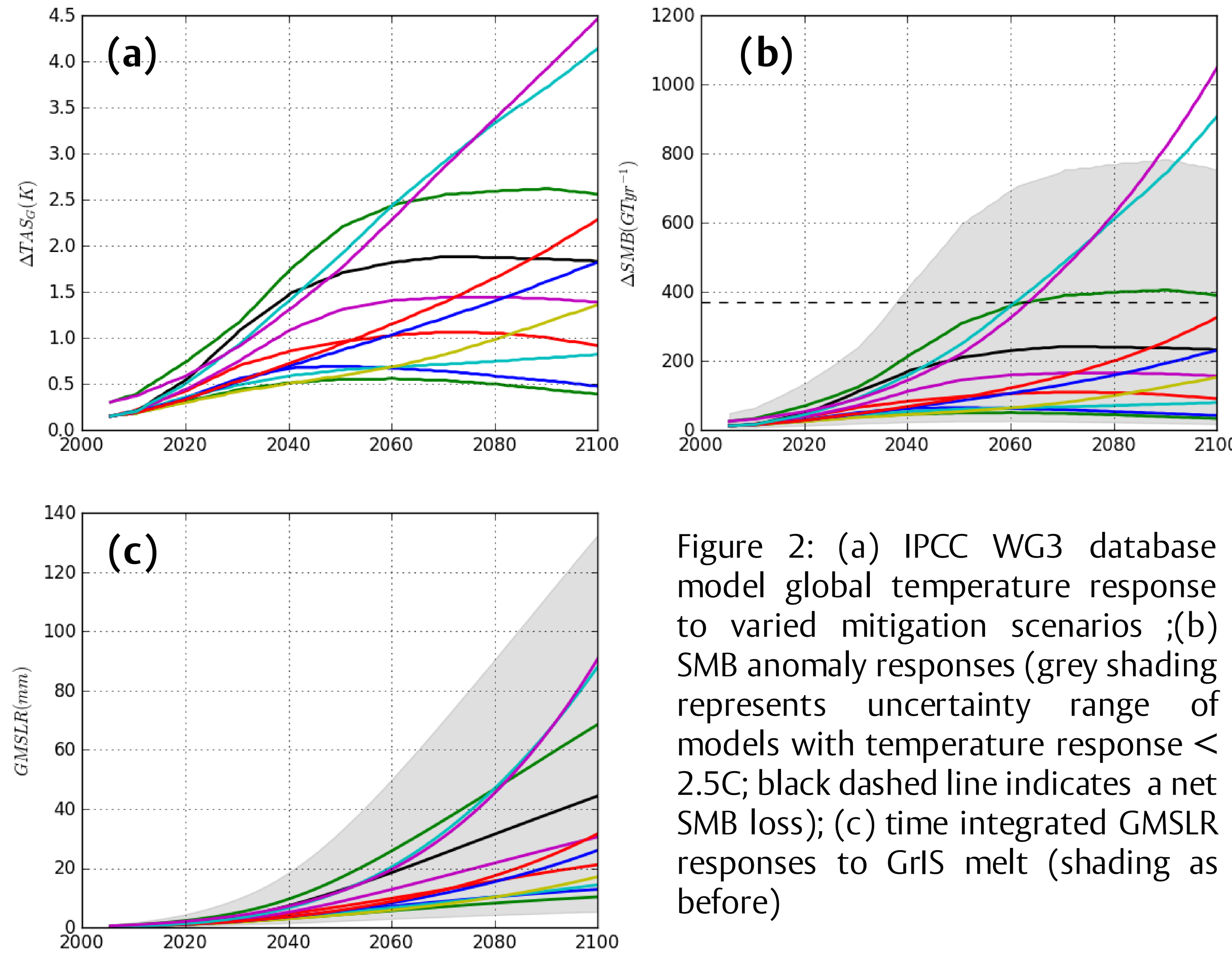


Figure 2: (a) IPCC WG3 database model global temperature response to varied mitigation scenarios ;(b) SMB anomaly responses (grey shading represents uncertainty range of models with temperature response < 2.5C; black dashed line indicates a net SMB loss); (c) time integrated GMSLR responses to GrIS melt (shading as before)

Figure 2(a) shows IPCC WG3 database model responses to 10 emission scenarios which lead to a 2100 temperature increase of less than 2.5C, plus two scenarios with a response similar to RCP85 (these are the two with the largest *ΔT*). A subset of models are selected in pairs, such that comparable end temperatures are achieved via differing mitigation pathways.

The majority of the SMB anomaly distributions (fig. 2|(b)) have a median value that retains a net positive SMB (integrated over GrIS). This is tempered by large uncertainty suggestive of the potential for a large negative SMB.

The GMSLR response reveals the choice of mitigation pathway to be as important as a target temperature (see table to right). A late mitigation path (L) with the same *ΔT* as of that with an early response (E) has median response of 69mm in GMSLR compared to 32 mm. This is because the amount of mass loss depends on the duration of the temperature anomaly, as well as its magnitude

MP@2100 (ΔT (C))	GMSLR med/p95 (mm)
L(2.56)	69/134
E(2.3)	32/62
L(1.83)	45/87
E(1.83)	26/51
L(1.38)	31/60
E(1.37)	17/33
L(0.91)	21/41
E(0.82)	14/28

4. Conclusions and Future Work

The time integrated nature of GMSLR indicates that the choice of mitigation pathway is as important as a long term goal of aiming to stay below a specific global average temperature.

There are large uncertainties in the SMB response of the GrIS to changes in global atmospheric temperature (and associated uncertainties in GMSLR).

To reduce some of these uncertainties a more physical representation of the ice-sheet surface topographic feedback is required. Specifically, the atmospheric component of the FAMOUS AOGCM is being coupled to a 3D dynamic Greenland ice-sheet model (the former employing an advanced SMB scheme, employing sub-gridscale elevation tiling, and a multi-level snow model). Results coming soon. These developments will also allow investigations into the GrIS steady-state and thresholds for loss irreversibility.

Contact information

- NCAS-Climate, Department of Meteorology, University of Reading, Whiteknights, RG6 6BB
- Email: s.e.george@reading.ac.uk | www.met.rdg.ac.uk/~seg/