Thresholds for the future of the Greenland Ice-sheet

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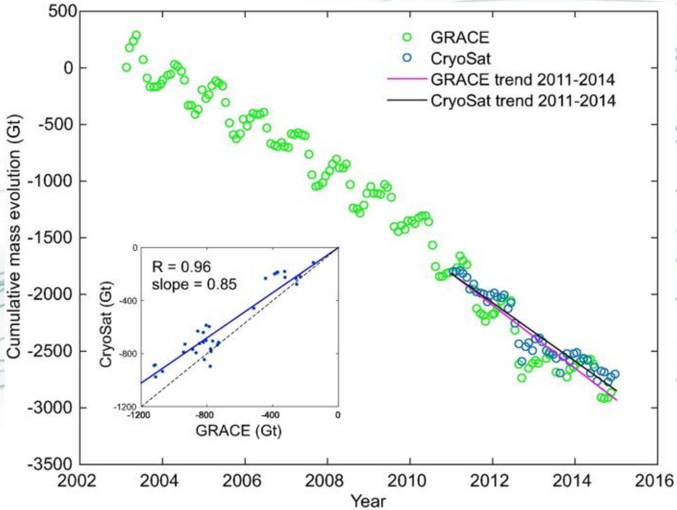
Greenland ice sheet (GrIS)

- GrIS mass is steady if surface mass balance (SMB; snowfall minus melting) equals solid-ice loss (icebergs)
- Observations show recent mass reduction; dominated by increase in surface melting, because of warming.
- GrIS has the potential of 7m global mean seal level rise (GMSLR)
- Are the present and (predicted) future changes reversible?



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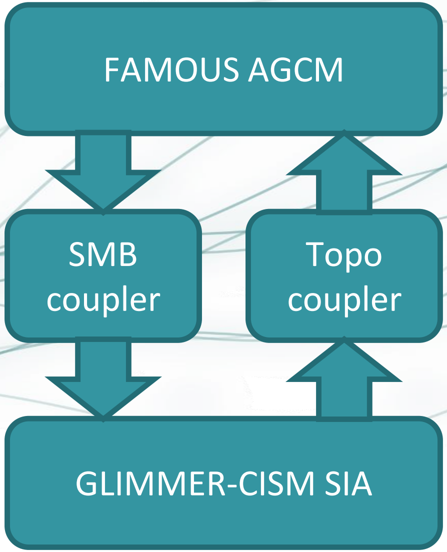
Model Setup

- Low resolution (fast) version of HadCM3 (FAMOUS) atmosphere general circulation model (AGCM), coupled to 20km resolution GLIMMER ice (x10 acceleration).
- SMB calculated in AGCM and 3D downscaled to GLIMMER ice surface.
- GLIMMER returns adjusted topography to the atmosphere.
- FAMOUS AGCM has sub-gridscale hypsometry of surface "type" on 10 elevation classes.
- Advanced (10 level) parameterisation of surface snow evolution.
- First example of a fully coupled system which can simulate ice evolution overs tens of thousands of years.



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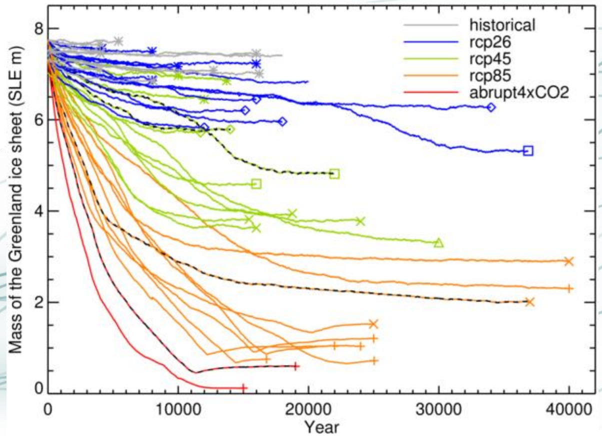
Model Simulations

- Coupled spinup with present day forcings produces GrIS topographies comparable to observed.
- Matrix of perturbed simulations; boundary conditions (SST/sea-ice) from CMIP AOGCMs for a range of RCP projections for 2081-2100.

- Snow albedo parameterisation perturbed in physically observed range. This changes radiation absorption; which also changes melt rates.
- The evolution is strongly affected by the coupling, because the ice sheet influences its own regional climate. An example is height feedback; mass loss leads to height reduction, exposing more ice to warmer (lower) temperature environments.



Perturbed climate GrIS mass loss

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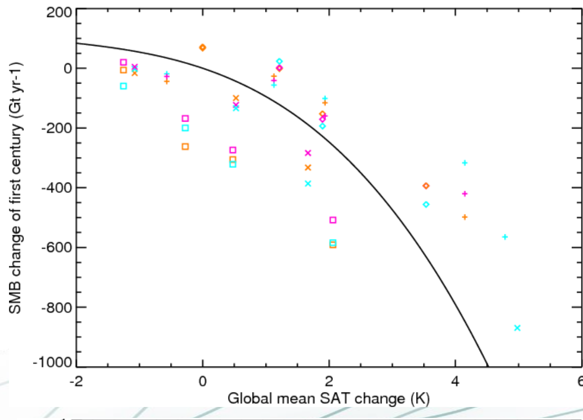
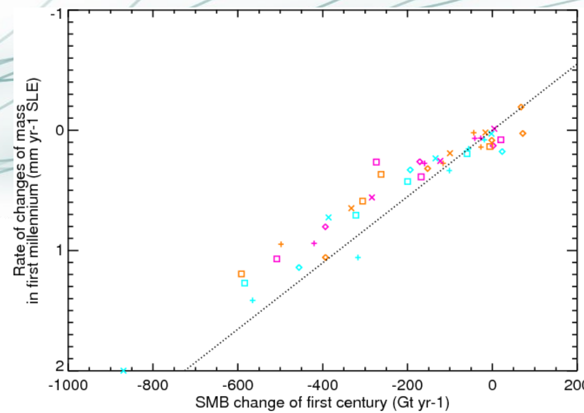
Initial Results (ice loss)

- Transient response over first millennium.
- The relationship between surface air temperature (SAT) and SMB (in the first century) roughly follows the cubic formula used in AR5 (black curve).
- The greatest warming is seen in an abrupt4xCO2 simulation, with associated SMB change of –900 Gt yr^{-1} (SLE 2.5 mm yr^{-1})
- There is a strong correlation between the initial SMB change and rate of mass loss in the subsequent millennium.





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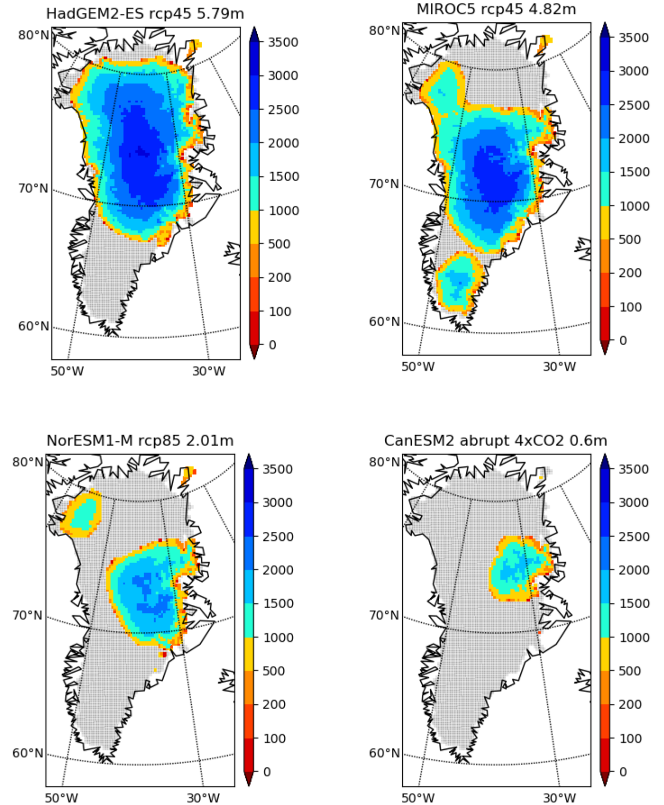
Final State (ice loss)

- Perturbed climate experiments continued until GrIS reaches new, stable configuration (up to 50 kyr).
- Final states differ in topography in distinctive ways (representative states shown; grey region coverage of original GrIS).
- The range of final steady states suggests there is no well-defined threshold SMB or global warming for the sustainability of the GrIS; contrary to assumption of previous work).
- If a warmer climate is maintained indefinitely the GrIS will contract to a steady state strongly dependent on the magnitude of the global climate change.



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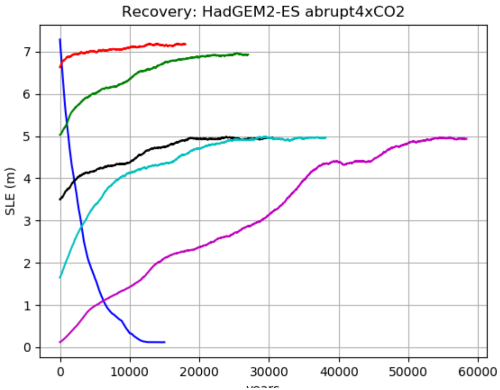
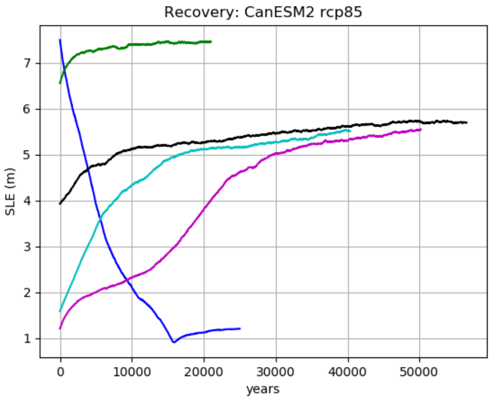
GrIS Recovery

- Recovery runs kicked off from various points along the perturbation (loss; blue lines) curve. Present day forcings applied, and model allowed to head towards equilibrium.
- Results suggest that present-day conditions will regrow a GrIS (even from a residual ice amount).

- Final size of GrIS depends on the size when recovery begins; either full recovery or partial coverage.
- Very different (diminished) starting ice conditions recover and converge on distinct ice topographies.





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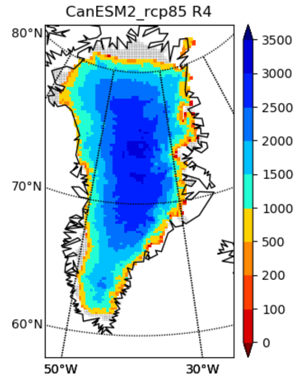
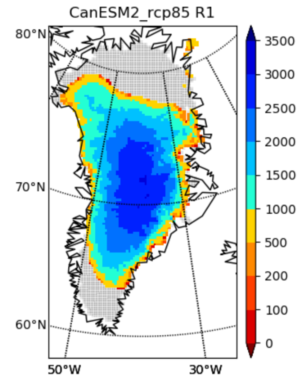
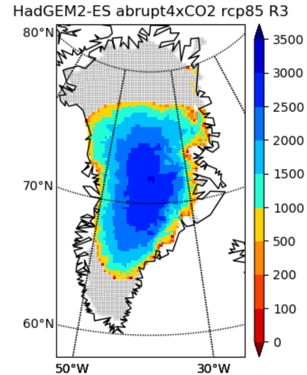
Final State (ice recovery)

- Full recovery (R4) exhibits areas of bare ice in Northern Greenland, but has a similar SLE to present (7.46m vs. 7.49m); differing ice topography.
- Southern ice-cap reformed, and the current GrIS saddle formation re-established.

- The two intermediate (stable; R1 & R3) states are similar, with the exception of a northwest node.
- We suggest that the high ridge-line to the north-east node exhibits a tendency to ice formation (and retention; see previous slide). Hence the state with this node (R1) may be the sole eventual end-state for partial recovery.







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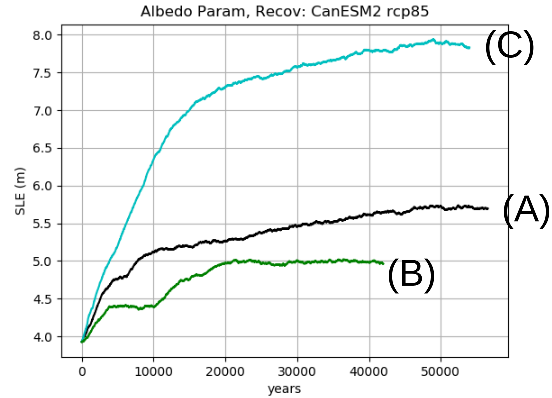
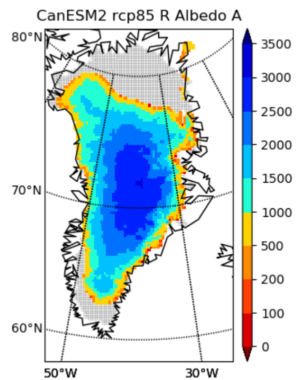
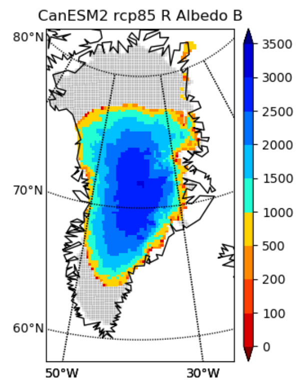
Snow Albedo

- Snow albedo is a function of snow grain size (aging). A small change in a physical albedo parameter, especially pertaining to the visible spectrum, can lead to big differences in the GrIS recovery.
- The choice of snow albedo parameterisation (A, B, C) affects the final steady state for recovery from the same initial state.
- The intermediate size final state for A and B are similar (see previous note on NW node).
- Albedo C leads to full GrIS recovery.
- System is more sensitive to albedo, than the choice of present-day, recovery boundary conditions.

- Note: Albedo uncertainty reflects scientific uncertainty about conditions in the real world.







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Conclusions

- The range of final steady states suggests there is no well-defined threshold SMB or global warming for the sustainability of the GrIS

- If a warmer climate is maintained indefinitely the GrIS will contract to a steady state strongly dependent on the magnitude of the global climate change.

- Reversal of anthropogenic forcing will lead to GrIS recovery; but final ice topography (and reduction in SLE) depends on the size of the size of the ice sheet when climate change is reversed..

- The physics of snow albedo characterisation has ongoing uncertainties.

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