Moving the boundaries: coupling interactive ice sheets in UKESM1

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theory: the usual problems

:(Climate modellers: “ice sheets change shape so slowly, why bother?”
:(Ice modellers: “climate models are so low resolution and biassed - if we use them the ice state will be hopelessly wrong”

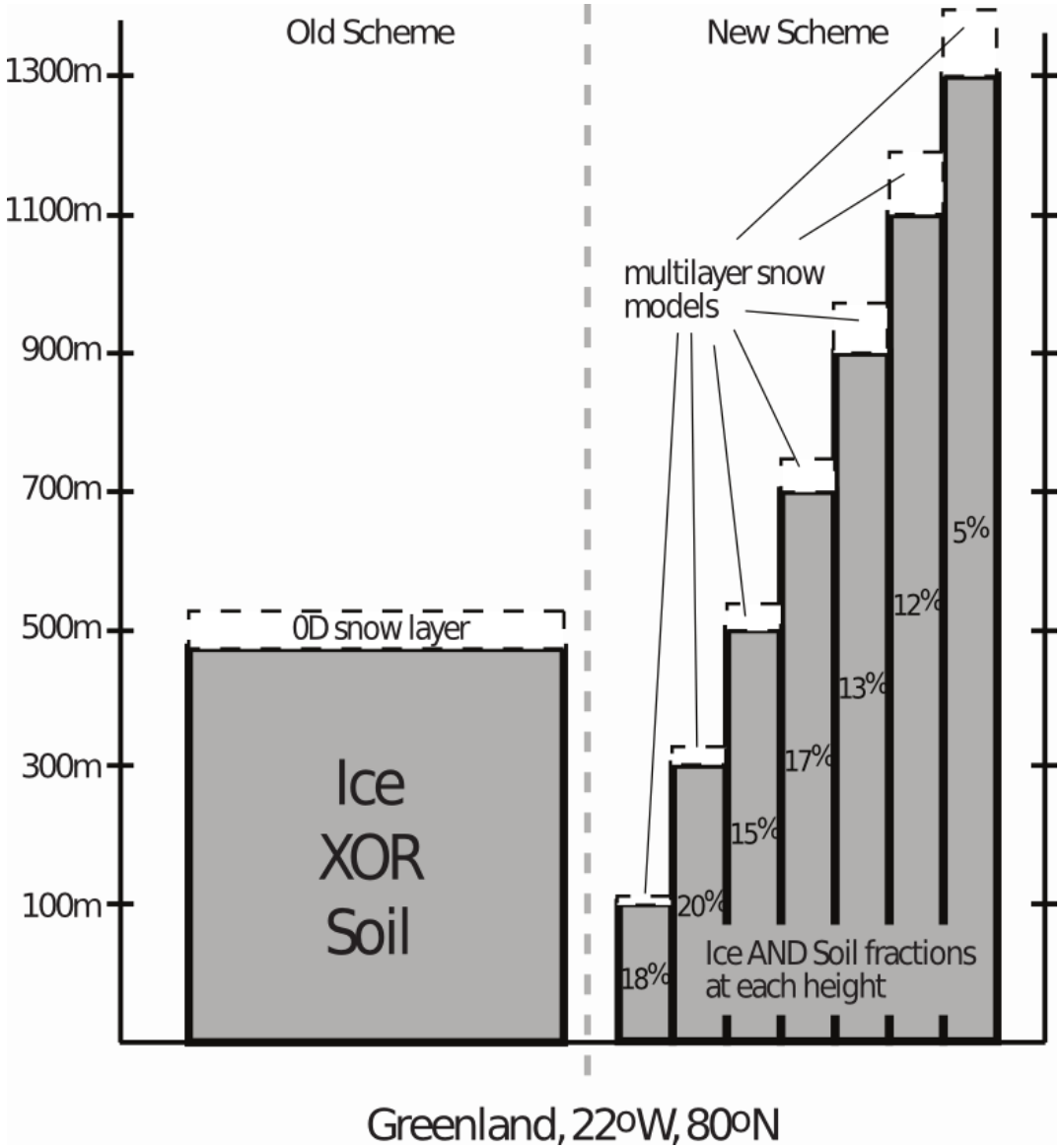
- Ice flow physics cares about patchily distributed, O(10m->1km) features on O(100yr+) timescales
- Surface snow/basal melt processes interact with the atmosphere/ocean on daily timescales
- Sea level rise changes the coastline, moves areas between land and ocean domains
- Climate models physics often doesn’t perform well for ice sheet conditions
- Climate and Ice flow modellers aren’t used to thinking of the other boundary condition as interactive

We all want to get consistent sea-level rise projections. That means the ice *has* to change, and there are a range of important atmosphere and ocean feedbacks

- Different groups are trying different approaches
- Greenland can largely be done with only land surface coupling
- Antarctica requires both land and ocean coupling
- UKESM1-ice does both ice sheets

theory: coupling => downscaling, not just regridding

- We can get round climate / ice flow timescale issues – often by brute force
- Spatial scale issues are harder – essential features of the ice are simply not present in the climate
- This brings science decisions / parameterisations into the coupling - can be model dependent
- Previous generations used *very* simplified coupling parameterisations, easily downscaled and empirically tuned – but often not appropriate?
- Where should different bits of physics sit? Affects what, how and when fields are passed
- Automating moving the ice, land and sea domains in most coupled systems built on standalone GCM components is non-trivial and model dependent!



practice: what we actually do, climate → ice

UKESM ice coupling works with file system coupling
UKESM ice coupling relies on the AOGCM components being submitted to HPC in sub-annual, restarted chunks, coordinated by cylc task scheduler (cylc.github.io)

Atmosphere
- surface exchange, snow pack physics calculated on sub-grid tiles inside land surface model
- annually averaged SMB and under-snowpack heat flux is diagnosed and accumulated

Ocean
- melt and heat fluxes along the underside of the ice shelf calculated inside ocean model

once a year AOGCM submission is paused to run the coupling scripts and ice

Coupler
- 2D interpolation of fields along the ice shelf basal surface
- Cutting global fields to match individual regional ice sheet domains

Ice initialisation
- 3D interpolation of the tiled land surface fields

practice: what we actually do, ice → climate

So far, no problem. Ice models are formulated to move the ice, and expect the boundary conditions supplied to just follow

Ice

- remasks (sometimes adjusts) climate boundary conditions as ice domain moves
- diagnoses total mass and location of icebergs calved

Coupler

- prepares statistics of small-scale surface topography for atmospheric drag etc schemes
- remakes average ice sheet height on atmosphere grid
- recalculates tile area fractions to reflect new height and extent of ice surface
- adjusts land surface snow packs for conservation on new extent
- moves icebergs to nearest wet ocean grid cell
- maps ice shelf shape onto ocean grid
- stitches regional ice output to global fields

Ocean initialisation

- discretises 2D ice shelf topography onto C grids, partial vertical cells
- adjusts discretisation for flow stability criteria
- smooths initial flow divergence field

practice: what we actually do, problems

- Land-sea mask cannot move
  - No ice shelf collapse
  - No actual sea-level rise!

- If you do create/destroy land, what about soil carbon/water conservation?

- Separating the snowy surface from underlying horizontal ice flow in different models makes real, local conservation of that snow *hard*

- Greenland marine-terminating glaciers and fjords too small to be represented on OGCM grid

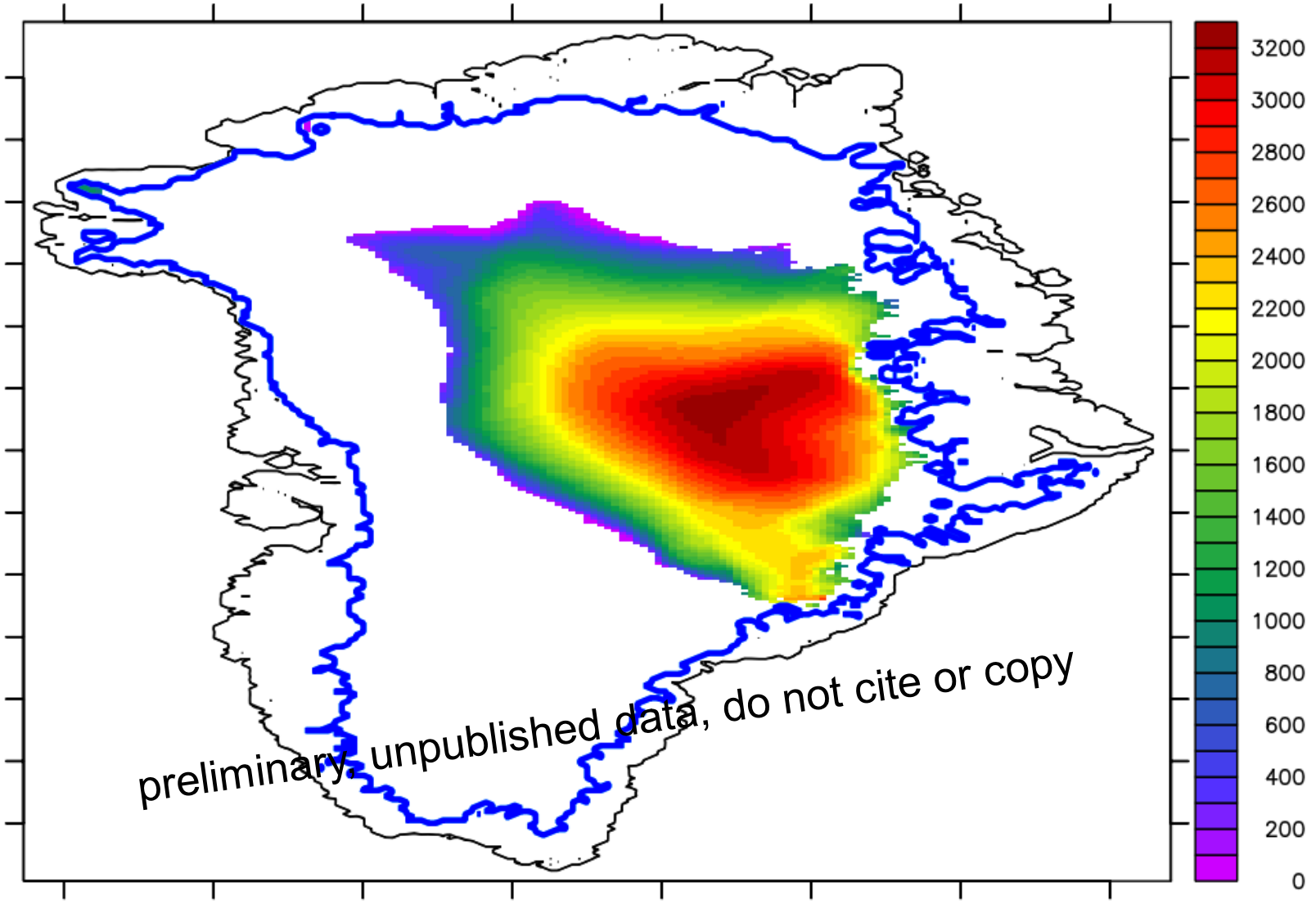
- We prioritise ocean stability. Stability is still not guaranteed, and: we break conservation; sometimes don't honour features of the shelf BISICLES has in fitting it on NEMO grid

- It's a collection of ad-hoc workarounds to force changes in aspects of the climate models that were always assumed to stay fixed – sometimes in non-obvious ways

practice: does it work?

Yes! Within the technical design limits…

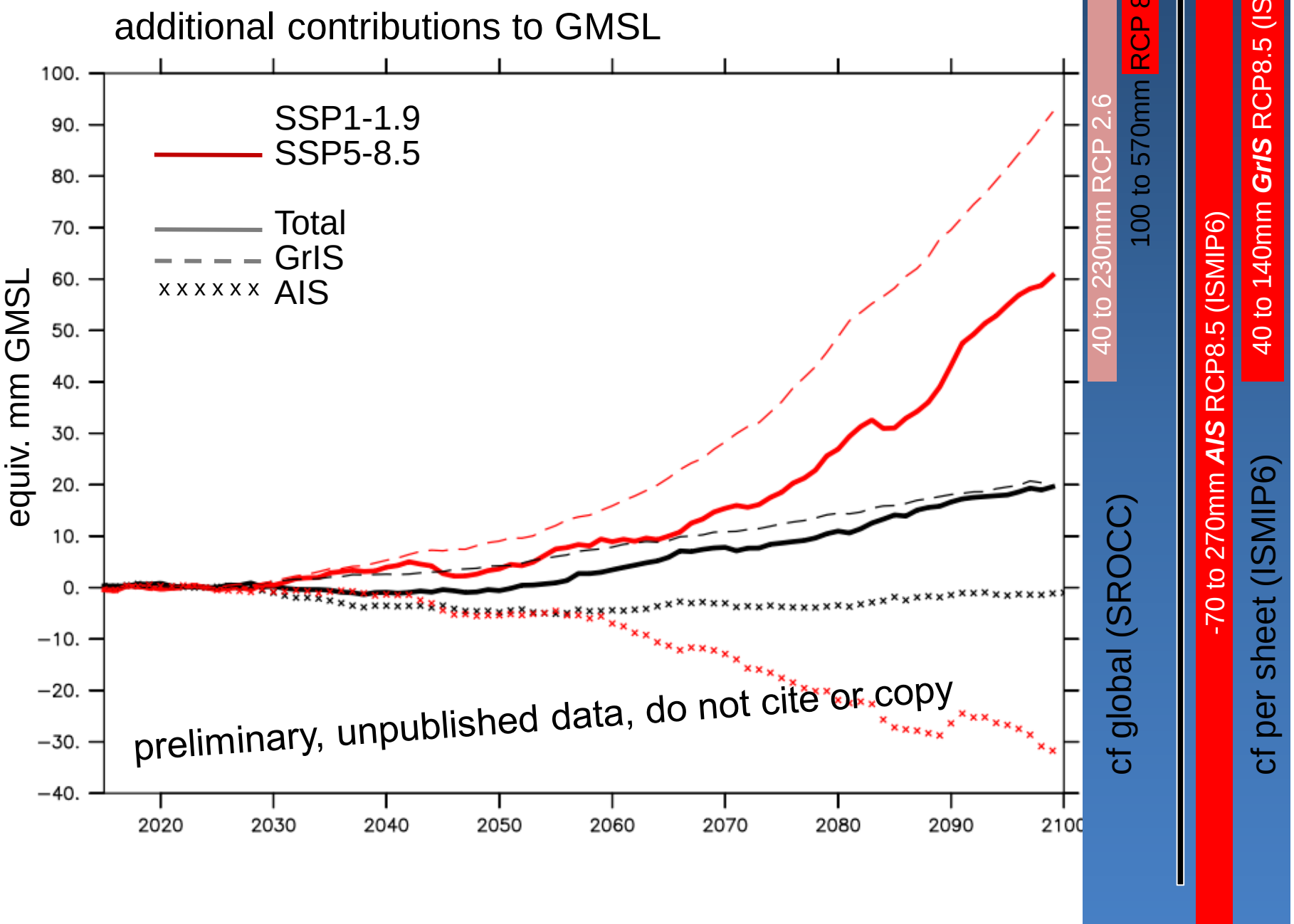
Greenland Ice sheet surface height ~ 3600CE



1600 years of ice evolution in a 4xCO2 climate.

black contour: modern coast
blue contour: original ice extent

Global Mean Sea Level Rise



UKESM

Met Office

Natural Environment Research Council

Loss of ice volume above flotation is crude estimate here

practice: does it work?

Yes! Within the technical design limits…

- Scientifically, the limiting factor is the climate model
  - Some of that is in the ability to provide the detail the ice now needs
  - Mostly, common biases in GCM climate. Some simply ignored previously because they are in “less important” regions!

- Coupled climate-ice initialisation / spin up is a major issue
  - Long coupled spin up – but where is the equilibrium?
  - Flux adjustments?
  - How much drift can one live with?

- Even given our limitations there’s a lot of useful science we can do.
  - Future Greenland ice retreats from the coasts – lack of marine coupling reduces in importance
  - Antarctic shelf collapse influence on the dynamics of grounded ice upstream will still occur with very thin shelf ice present

future coupling work

- Doing science with what we have!
- Moving the land-sea mask – however crudely
- More sophisticated, unified regridding framework
- Simply keeping up with underlying HPC, AOGCM baseline
- working with other groups evaluating their approaches

Model intercomparison efforts that include coupled climate-ice model protocols

ISMIP6

MISOMIP2