Potential Tipping Points of Antarctic Ice Sheet Basins

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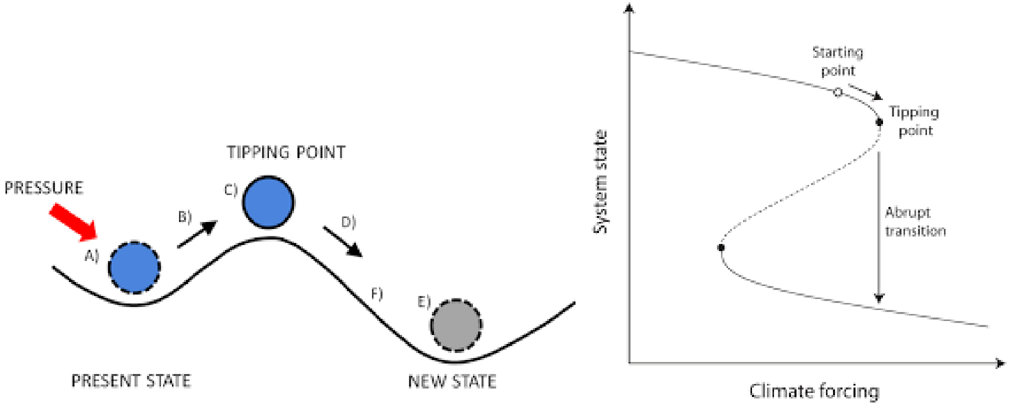
Motivation

Antarctica is losing mass in an accelerating way and these losses are considered as the major source of sea-level rise in the coming centuries. Ice-sheet mass loss is mainly triggered by the decreased buttressing from ice shelves mainly due to ice-ocean interaction. This loss could be self-sustained in potentially unstable regions where the grounded ice lies on a bedrock below sea level sloping down towards the interior of the ice sheet, leading to the so-called marine ice sheet instability (MISI).

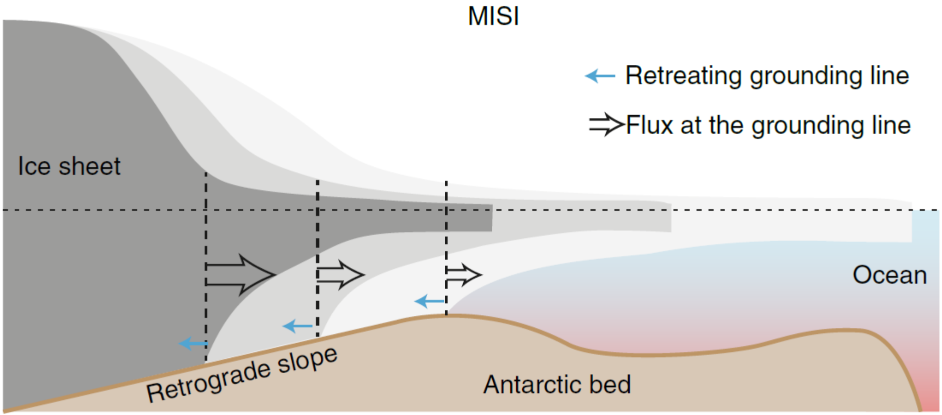
Summary

In this study, we present an ensemble of simulations of the Antarctic ice sheet using the f.ETISh ice-sheet model to evaluate tipping points that trigger MISI by forcing the model with sub-shelf melt pulses of varying amplitude and duration.

Tipping Point-A threshold



Marine Ice Sheet Instability–a tipping point phenomenon



MISI : For a bed sloping down towards the interior, weakening of ice shelf triggered by ocean warming could lead to a irreversible retreat (grounding line retreat->higher ice discharge->further retreat of grounding line).

f.ETISh (Pattyn 2017, The Cryosphere)

Stress balance

- Hybrid SIA-SSA

Essential Processes

- Thermomechanical coupled
- Grounding-line flux : Boundary layer theory (Schoof, 2007)
- Power-law basal sliding (Weertman)

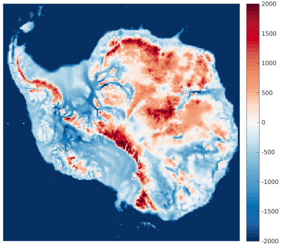
Initialization

- Optimize basal sliding coefficients : Inverse method (Pollard and DeConto, 2012)

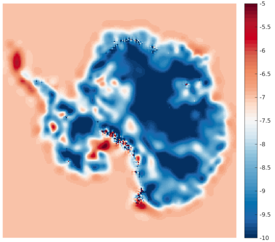
Climate Forcing

- SMB : RACMO2.3
- Sub-shelf melting : ISMIP6 non-local

Bed (Bedmachine)



Sliding Coefficient



Experiments set up

Sub-shelf Melting

$$m=\gamma_0 \times \left(\frac{\rho_{sw} C_{pw}}{\rho_i L_f}\right)^2 \times (TF + \delta T_{basin}) \times |TF_{basin} + \delta T_{basin}|$$

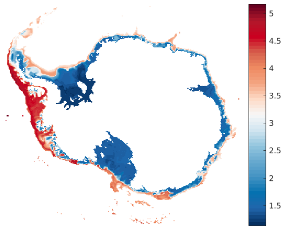
Forcing Parameters

- γ_0 : $1.45 \times 10^4 \times [0\ 1.5]$ m/yr
- ΔTF : [0 3] ^oC
- Perturbation duration : [0 500] years

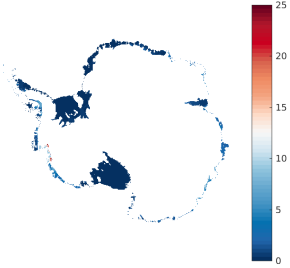
Ensembles

- Sampling Method : Latin Hypercube
- 100 simulations
- 5000 years

Thermal Forcing (TF)



Present Day Melt



Results

Overview

- Present day forcing : Collapse of Amundsen Embayment in ∼1000 years
- Maximum contribution : ∼9 m SLC
  - WAIS : ∼3 m (high probability)
    - Amundsen : ∼1.7 m
    - Siple Coast : ∼1.3 m
  - EAIS : ∼6 m (low probability)
    - Wilkes basin : ∼2.8 m
    - Weddell Sea basin : ∼1.5 m
    - Aurora : ∼0.7 m

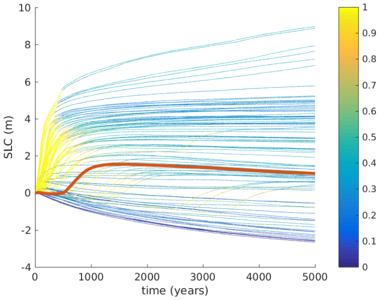


FIGURE – Sea level contribution of Antarctic ice sheet for the ensemble simulations. The color of the line shows the mean sub-shelf melt rates for all ice shelves in Antarctica. The red curve is the result under present-day ocean forcing.

Amundsen Embayment : MISI

Grounded Probability

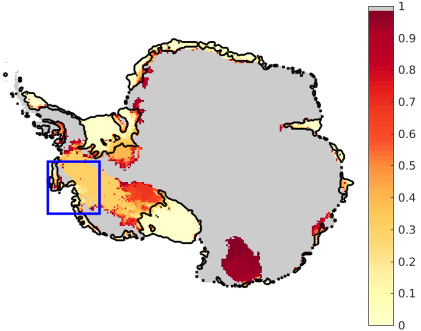


FIGURE – The probability of ice being grounded at the end of simulations. Vast region of Amundsen sea embayment has the same value of $\sim$40%. Similar behavior is shown in Rutford ice stream and the Siple coast.

Grounded Area

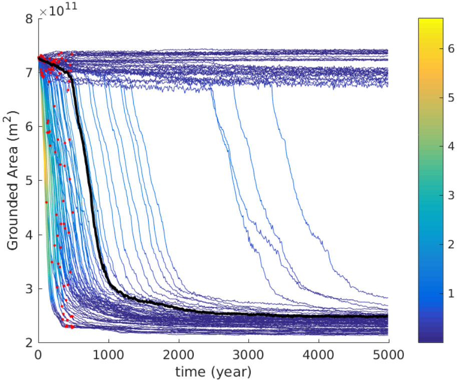
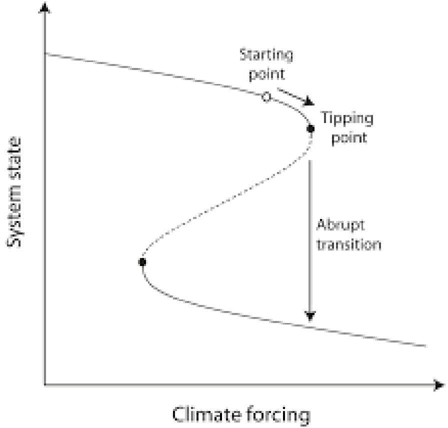
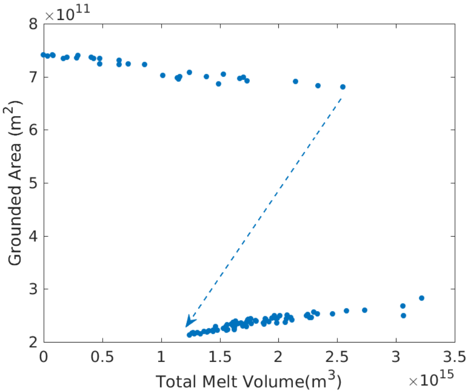


FIGURE – Grounded area of all simulations. Red dots mark the end of purturbation. Color of each curve stand for the mean melt rate of ice shelves in Amundsen sea embayment. The black curve is the result under present day forcing.

Amundsen Sea : Tipping Point ?





To push through tipping point : Ice volume removal due to sub-shelf melting : [1.2-2.5]$\times 10^{15} m^3$

Amundsen Sea : Tipping Point

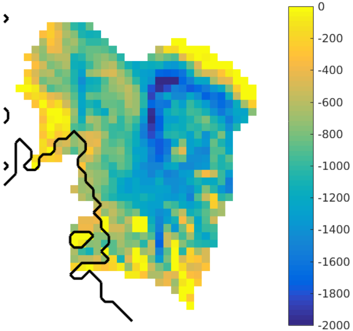


FIGURE – Bedrock elevation

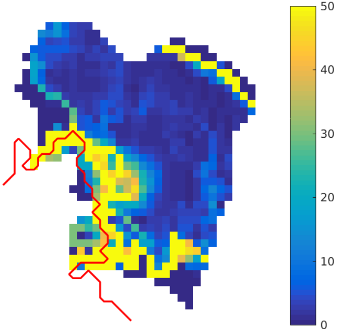


FIGURE – Mean duration of grounding line stay.

Once the grounding line retreat to a steeper reverse slope in Thwaites glacier, it will retreat fast and irreversable. Topography features such as ice rises, pining points have a stablizing effect.

Conclusion

- Amundsen Embayment is in unstable state : present day ocean forcing might be able to trigger MISI
- Ice streams in Amundsen Embayment are sensitive to buttressing from ice shelves
- Bedrock topography determines if the tipping point to ocean forcing exist
- Ice shelf-ocean interaction scheme is essential to predict the ice sheet evolution
- Higher resolution simulation and/or data could change the timing and energy needed to arrive tipping point

Thanks !

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