Stability of the Greenland Ice Sheet

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Motivation

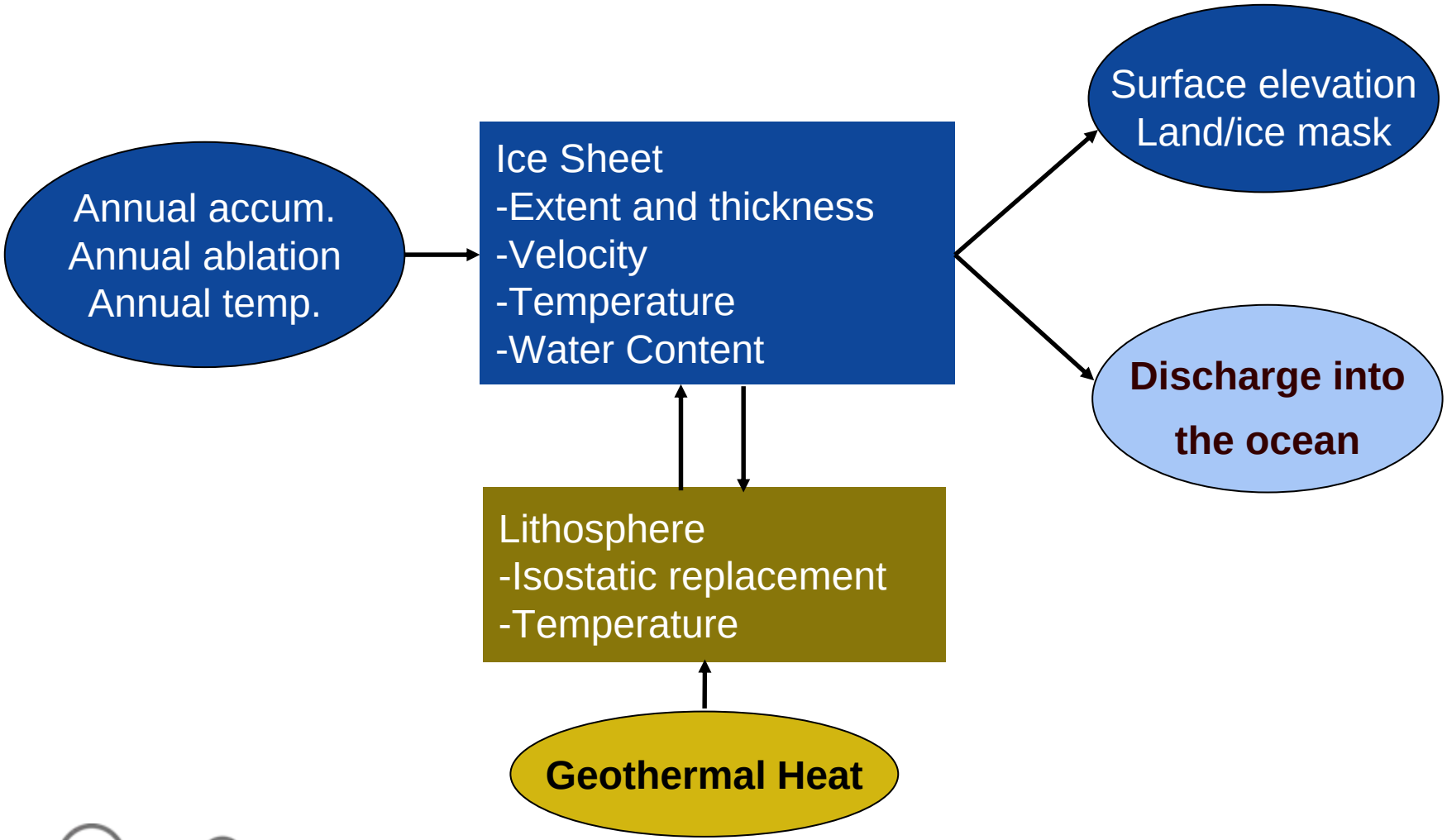
- Greenland ice sheet (GIS) is an important tipping element.
- GIS corresponds to 7 m sea level rise.
- Up to 0.1 Sv additional fresh water flux (if a decay in 1000 years is assumend).
- There is interaction with ocean.
- This talk is on stability of GIS, thresholds.

Modells

• Polythermal ice sheet model SICOPOLIS (Ralf Greve, ILTS).

• Regional Energy-Moisture Balance MOdel REMBO (Alex Robinson, Andrey Ganopolski).

Polythermal ice sheet model SICOPOLIS



REMBO

Temperatur

$$c_p \rho_a H_a \frac{\partial T_{\mathrm{SL}}}{\partial t} = D_T \nabla^2 T_{\mathrm{SL}} + (1-\alpha_p) S - [A + BT] + L_w P_w + L_s P_s - L_s M_{s,\mathrm{net}} + R(CO_2)$$

$$T = T_{\mathrm{SL}} - \gamma_a z_s$$

Moisture

$$\rho_a H_e \frac{\partial Q}{\partial t} = D_Q \nabla^2 Q - P$$

Slope effect

$$P = (1 + k|\nabla z_s|)\left(\frac{Q}{\tau}\right)$$

Temperature and humidity at the boundary from ERA-40 reanalysis data.

REMBO include snow pack model.

Melt Models

Positive degree-day (PDD)

- Melt rate determined by temperature and degree-day factors

$$PDD = \frac{1}{\sigma\sqrt{2\pi}} \int_{year} \int_{0}^{\infty} T \exp\left(\frac{-(T - T_m)^2}{2\sigma^2} \right) dT dt$$

$$M = \alpha \cdot PDD, \quad \alpha = \begin{cases} 0.003, & snow \\ 0.008, & ice \end{cases}$$

- Implicitly accounts for albedo difference through higher melt factor for ice
- Based on present-day empirical observations

Insolation-Temperature Melt (ITM)

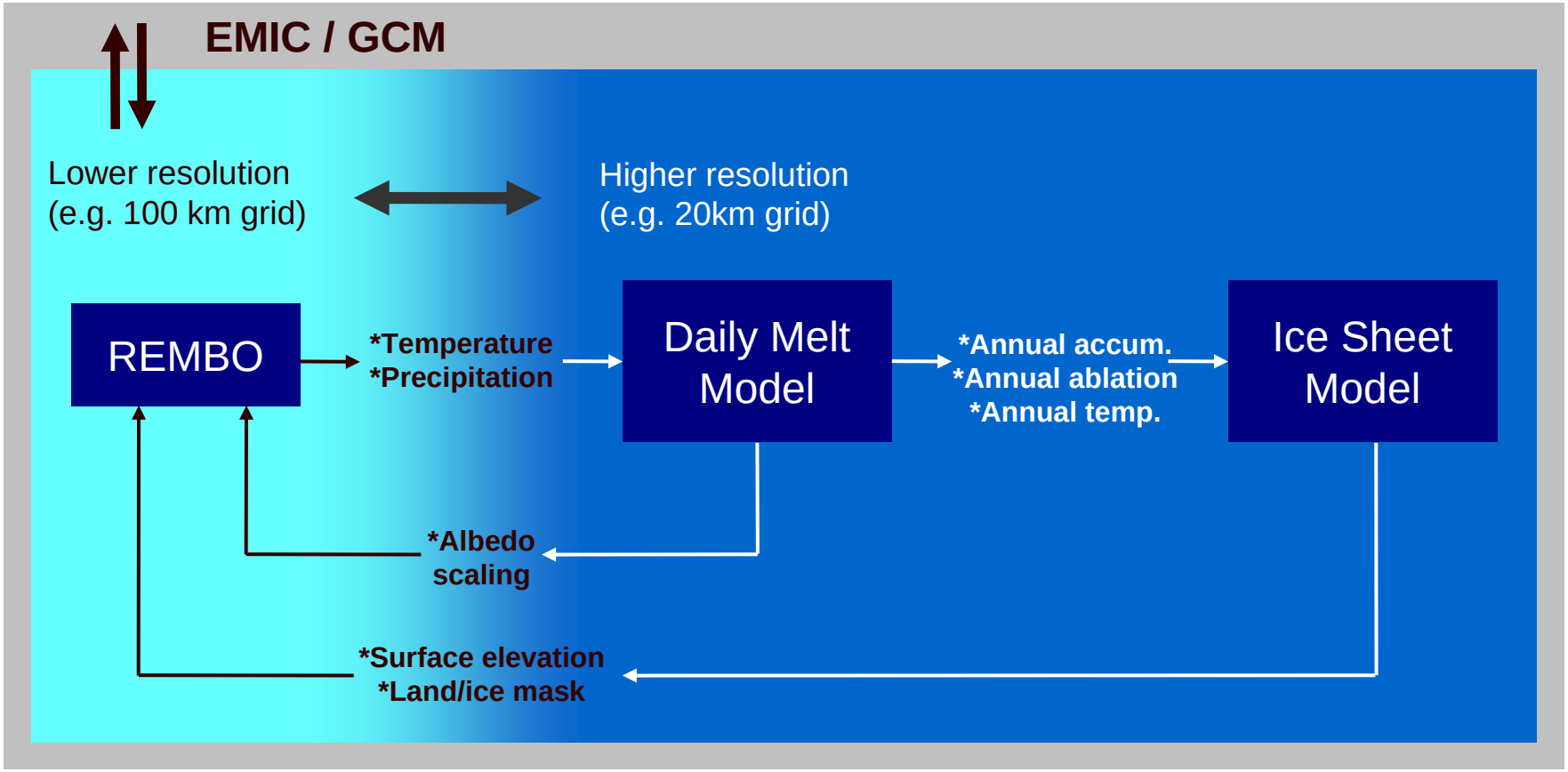
- Melt rate determined by physical contributions

$$M = \frac{1}{\rho_w L_m} \left[\tau (1 - a_s) S + c + \lambda T \right]$$

Adapted from van den Berg and Oerlemans, 2008

- Melt explicitly depends on albedo changes
- Potentially useful for paleo studies and in situations with large topographical changes

Coupling


EMIC / GCM
Lower resolution
(e.g. 100 km grid)
Higher resolution
(e.g. 20km grid)
REMBO
*Temperature
*Precipitation
Daily Melt Model
*Annual accum.
*Annual ablation
*Annual temp.
Ice Sheet Model
*Albedo scaling
*Surface elevation
*Land/ice mask

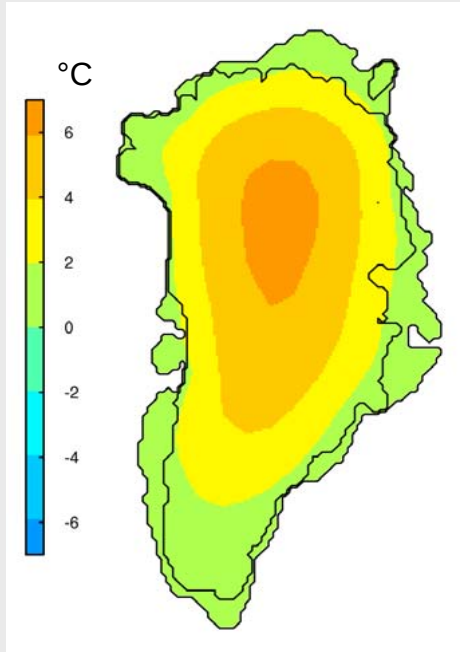
Results REMBO

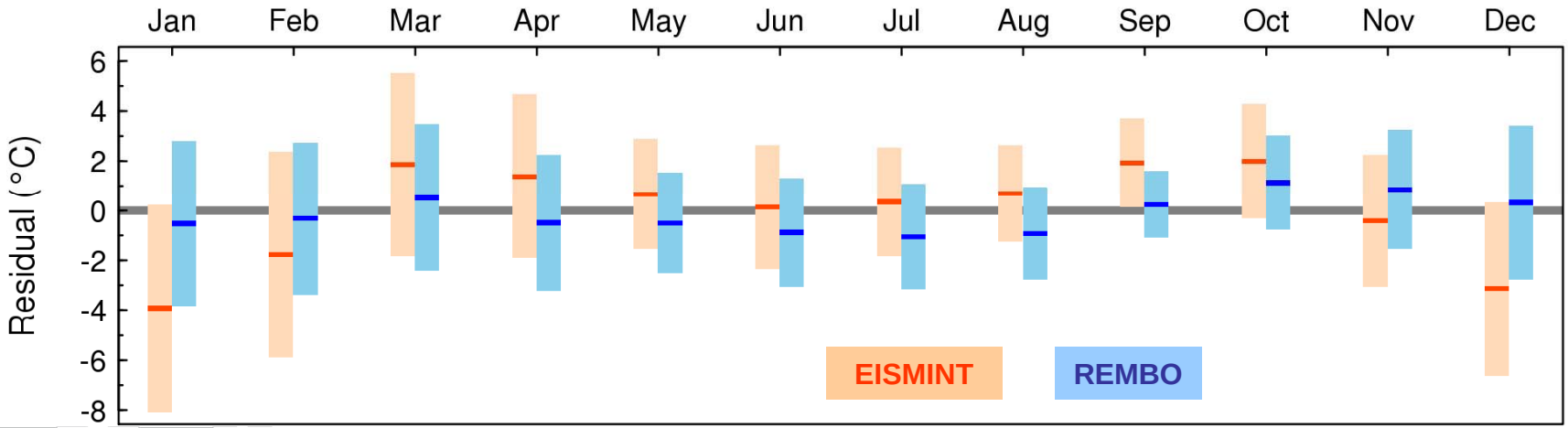
Present-day Temperature

- Simulated monthly temperatures compared with observations at 53 locations both on and around the ice sheet
- REMBO monthly averages are within ~1°C of observations

Seasonality – ice-free

- REMBO exhibits increased seasonality for ice-free conditions
- Compares well to GCM results from Toniazzo et al. (2004)



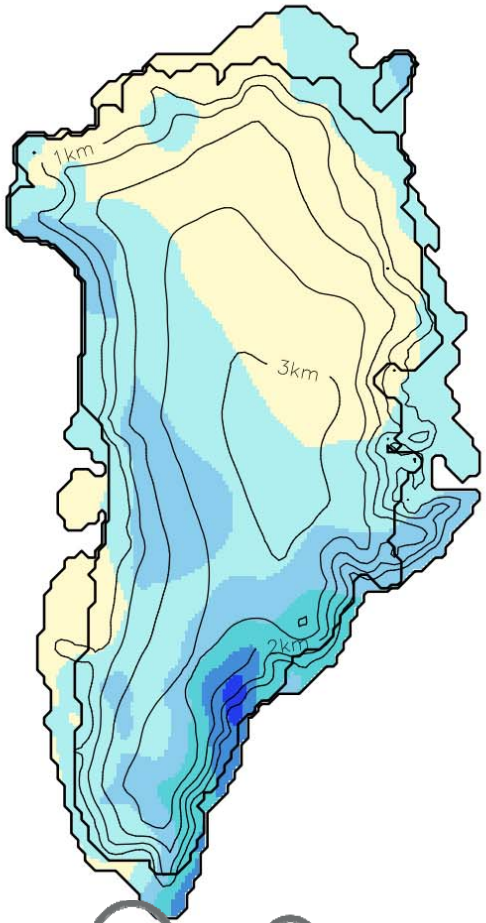


Observations obtained from the Danish Meteorological Institute (DMI) and the Greenland Climate Network (GC-NET)

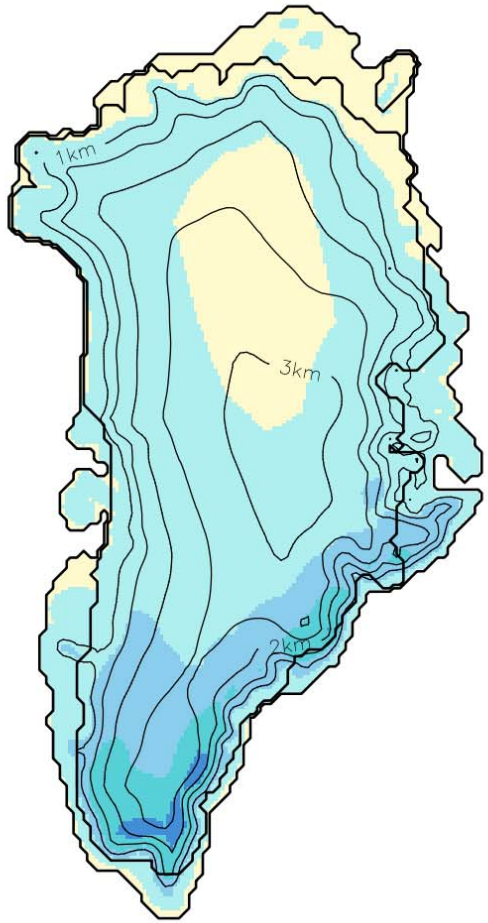
PIK

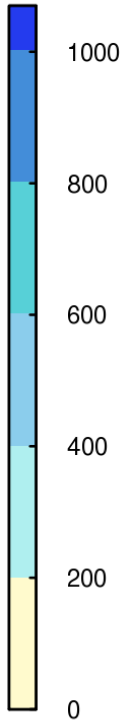
Results REMBO

Data
Bales et al. (2009)
Present day



REMBO
Present day

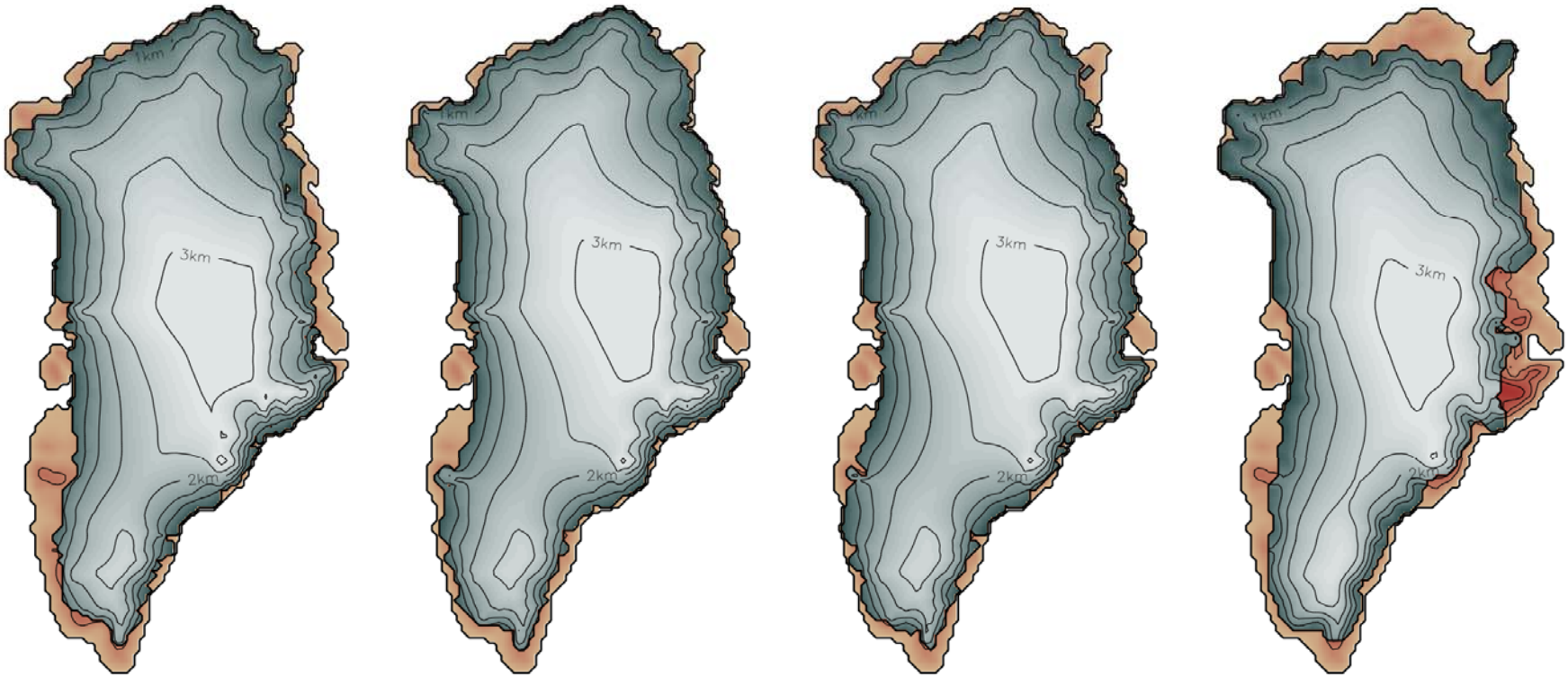




Annual Accumulation mm/yr

Present-day GIS with Rembo-SICOPOLIS

EISMINT Annual PDD	REMBO Daily PDD	REMBO Daily ITM	Data Bamber et al. (2001)



PIK

Parameter Constraints through Paleo Simulation

Constraints

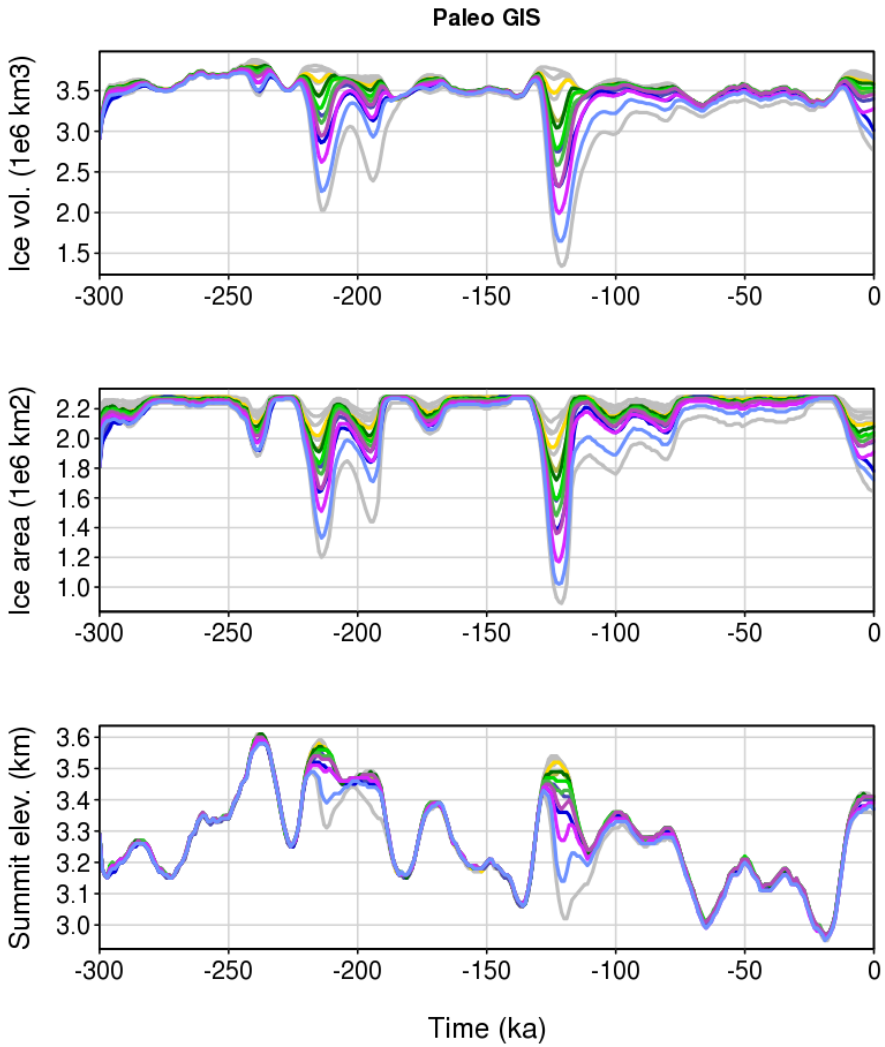
1. Present-day volume +/- 20%
2. Present-day area +/- 20%
3. Summit > 3 km
4. Eemian minimum volume/area less than present-day volume/area

PDD scaling

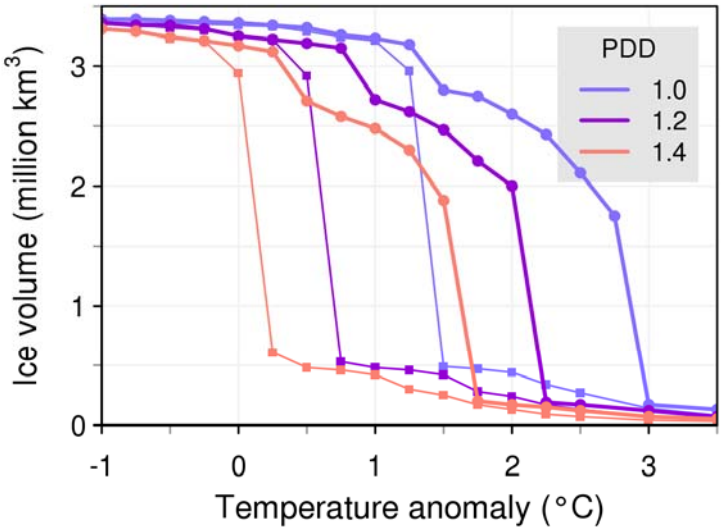
0.6, 0.8 **1.0, 1.2, 1.4,** 1.6

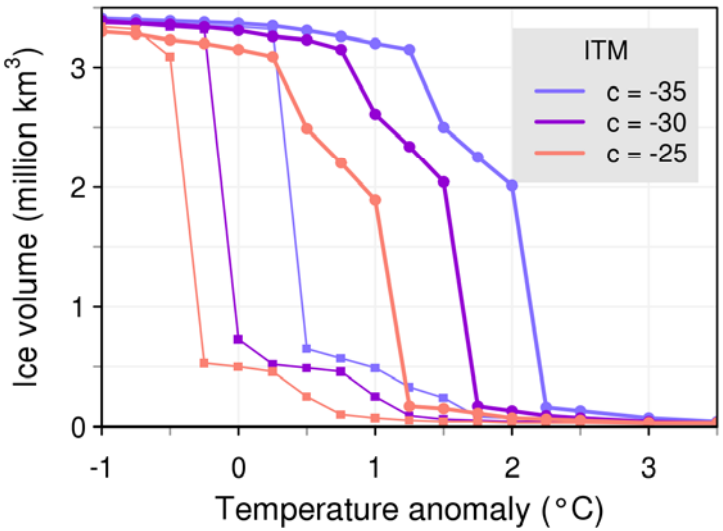
ITM parameter *c*

-20, **-22, -25, -28, -30, -32, -35,** -40, -50



Stability Diagram

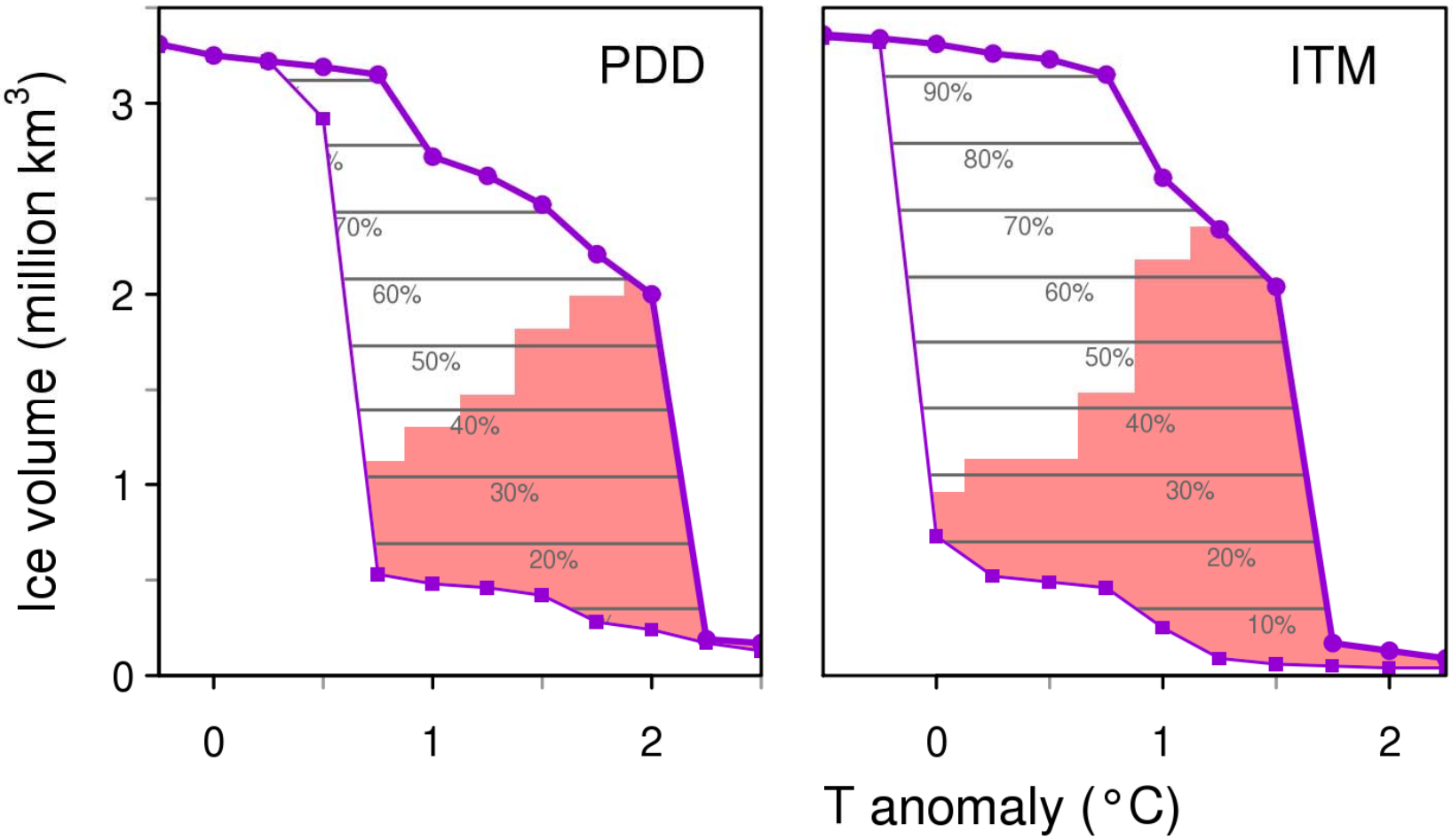




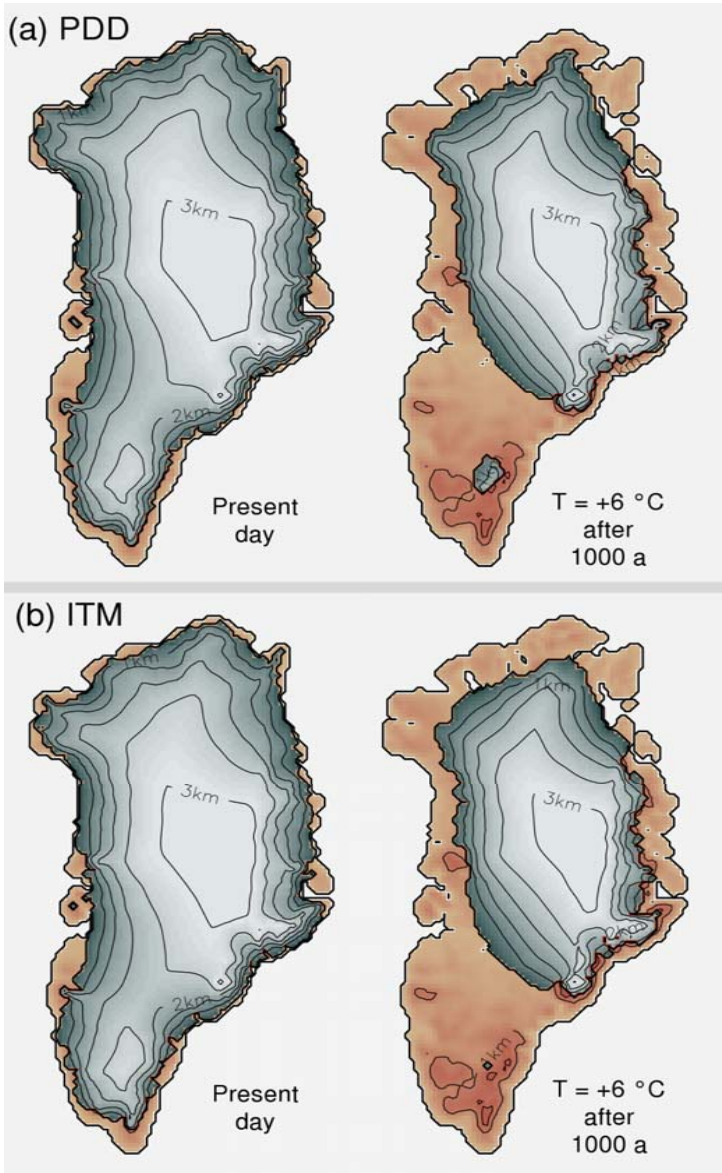
- Similar behavior of PDD and ITM hysteresis, bistability, ice-free and ice covered stable branches

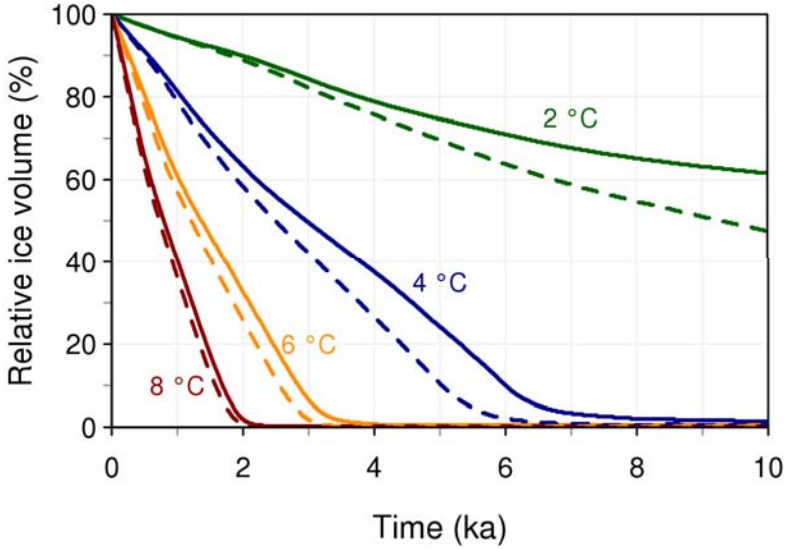
- Thresholds for total meltback: 1-3 °C

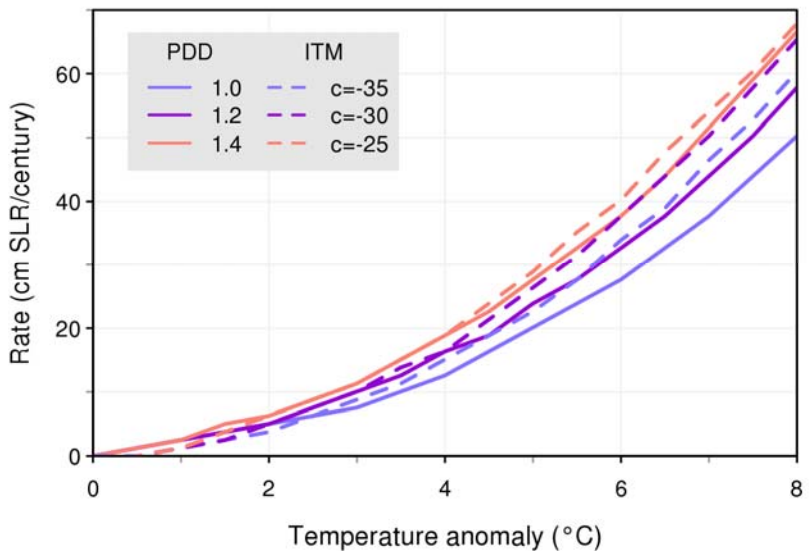
Basins of Attraction



GIS under global warming







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Conclusions

- Developed Regional Energy-Moisture Balance Model.
- GIS shows hysteresis and bistability.
- Thresholds for melt down 1-3°C in our model.
- Time of full GIS meltback is measured in some thousands years/several hundreds of years.

Outlook

- Fast processes GIS – sliding/ice streams.
- Further, constraints of parameters by paleo simulations.
- Long-term (1000 years) and short-term (100 years) future of GIS.
- Providing spatial dependent fresh water scenarios for ocean modelling.
- SICOPOLIS 3.0 (coming soon) will include shelf ice.
- Considering ice streams, work is in process.

Thank you for your attention!