Large-scale simulation of the Antarctic ice sheet over climate cycles

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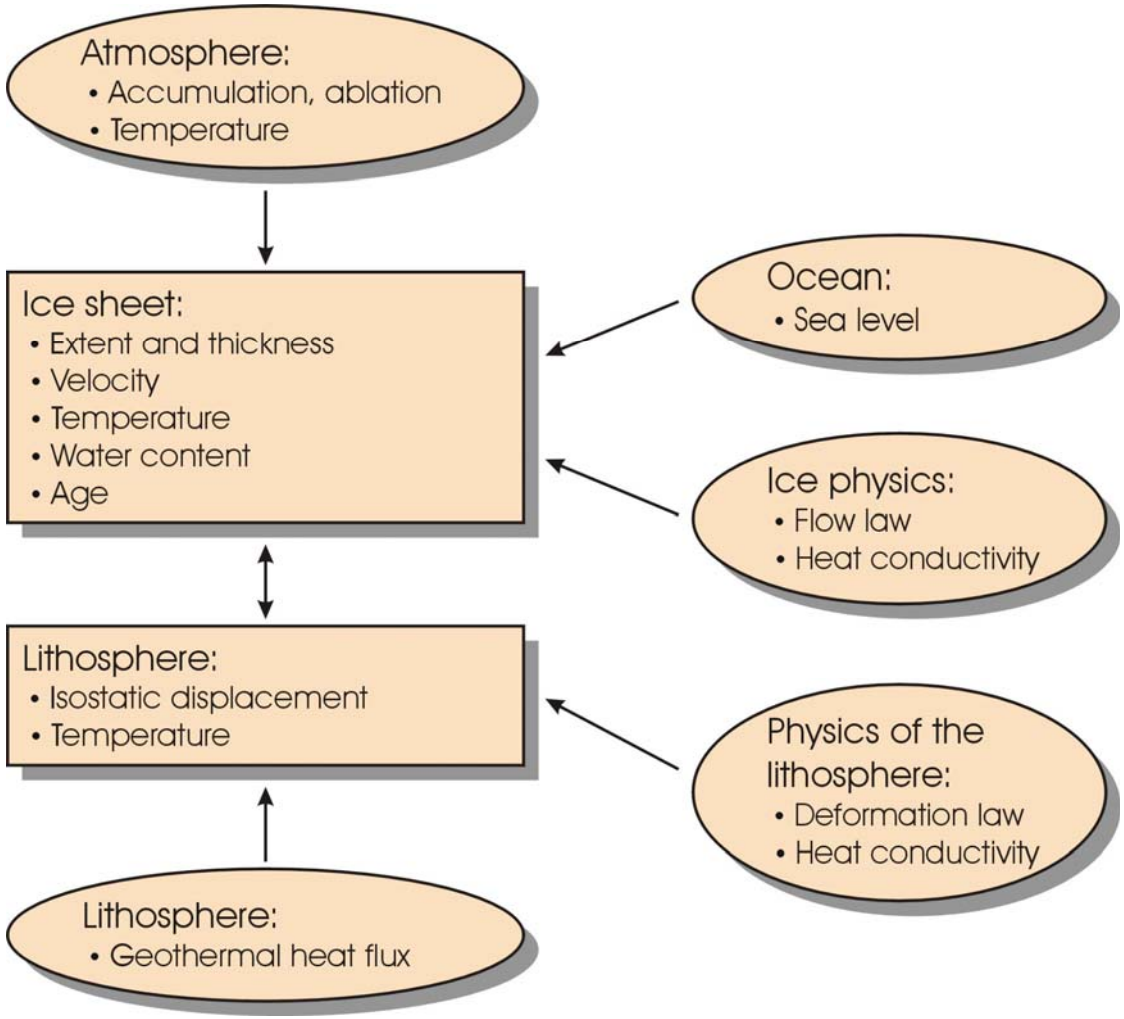
Ice-sheet model SICOPOLIS

Ice-sheet model SICOPOLIS (SImulation COde for POLythermal Ice Sheets):

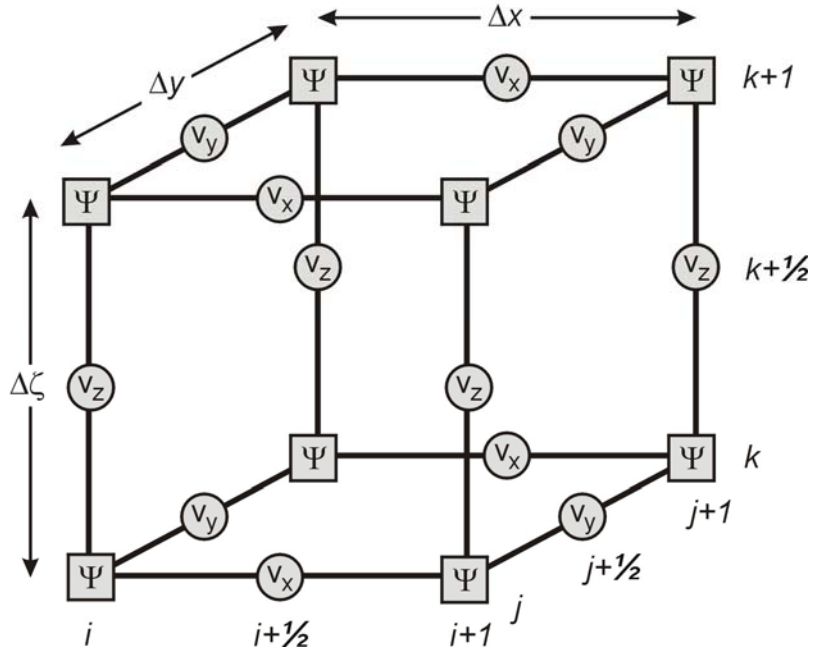
3-d dynamic and thermodynamic ice-sheet model.



Ice-sheet model SICOPOLIS

Numerics

- FD scheme on staggered Arakawa-C grid.
- Sigma coordinates: Vertical ice columns mapped to [0,1] intervals.
- Upstream differences for advection terms, otherwise central differences.
- Mixed explicit/implicit time-stepping.



Paleoclimatic simulation

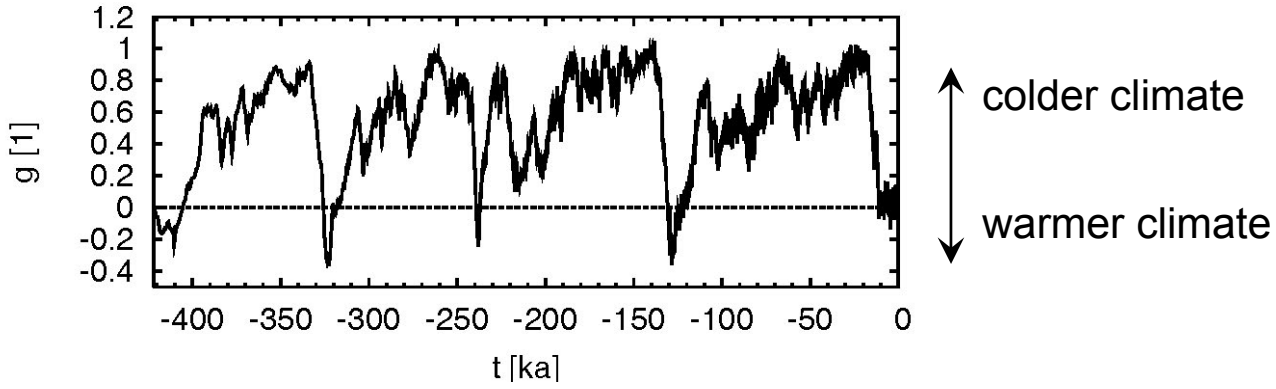
Set-up

- Model time: t = 422 ka BP ... 0 (present).
- Grid spacing: Δx = 40 km.
- Vertical resolution:
  Cold-ice layer: 81 grid points.
  Temperate-ice layer (if existing): 11 grid points.
  Lithosphere: 11 grid points.
- Time-step: Δt = 10 a.
- Glen's flow law with n = 3,
  Weertman-type basal sliding $v_b \sim \tau_b^3 / P_b^2$ with sub-melt sliding.
- Flow enhancement factor:
  E = 1 for Holocene and Eemian ice, otherwise E = 3.

Paleoclimatic simulation

Atmospheric forcing

- Glacial index $g(t)$ from Vostok δD record.

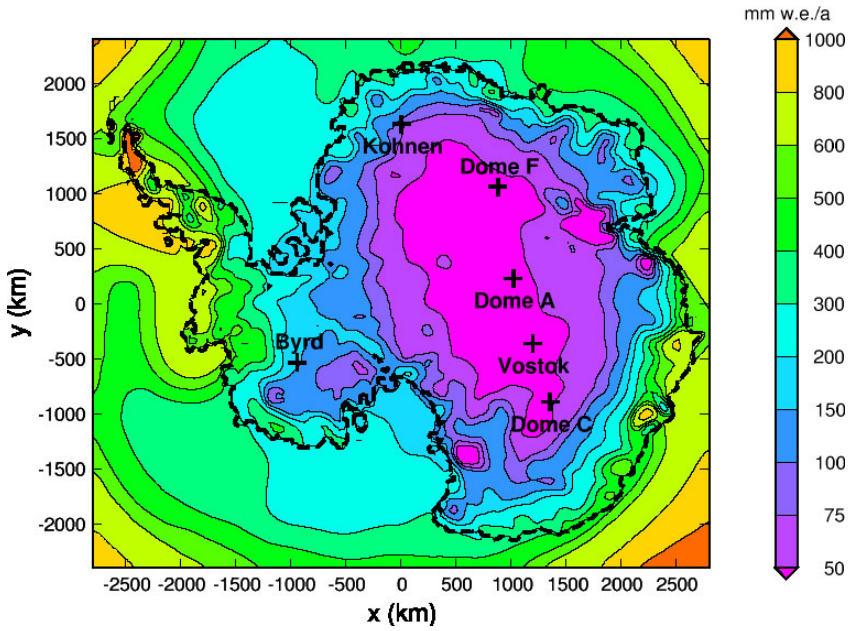


- Surface temperature, precipitation: Interpolation between present and LGM conditions, weighed by $g(t)$.
- Surface melting: Positive-degree-day (PDD) method
  → melt rate ~ surface temperature excess above 0°C.

Paleoclimatic simulation

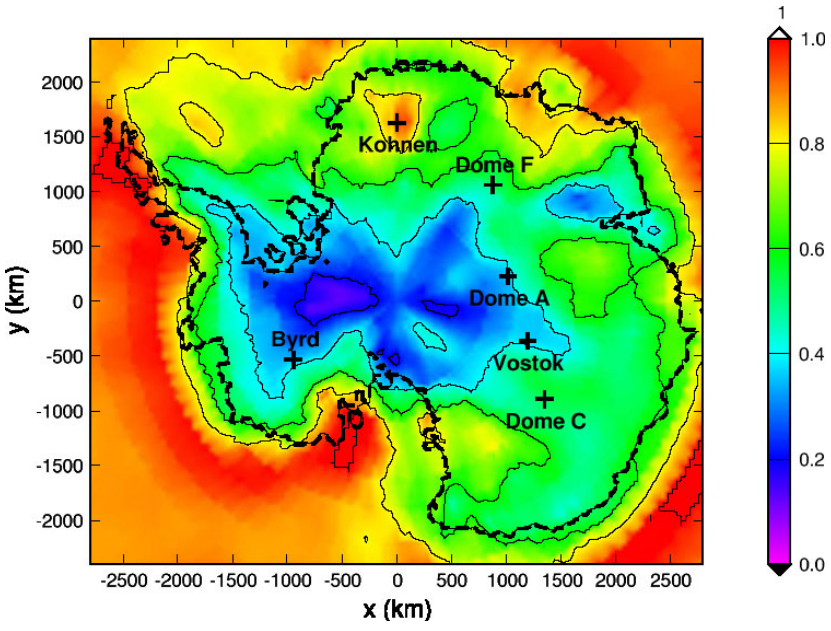
Climatic forcing fields

Present precipitation:



Vaughan et al. (1999), Jaeger (1976)

LGM precipitation anomaly (ratio):



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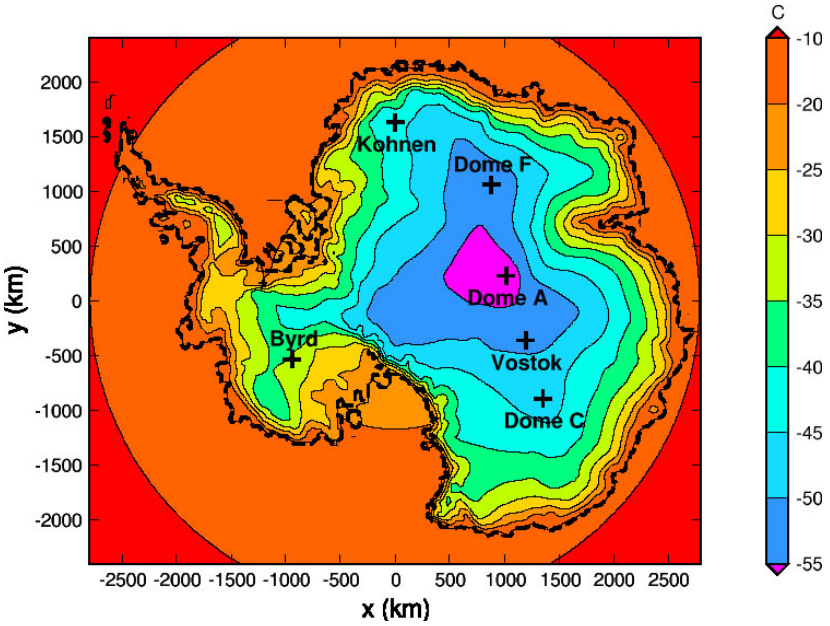
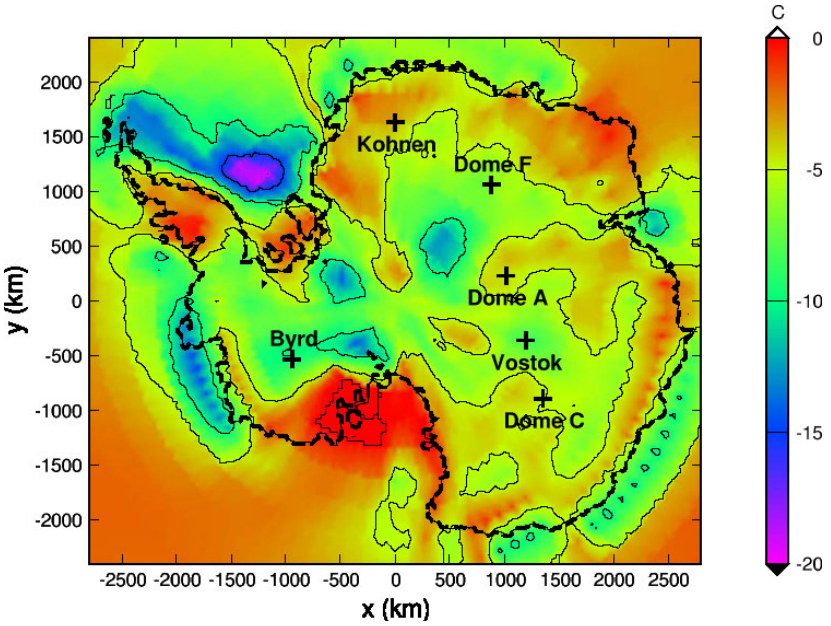
Paleoclimatic simulation

Present mean annual T_s:



Huybrechts (1992)

LGM anomaly (difference) of mean annual T_s:



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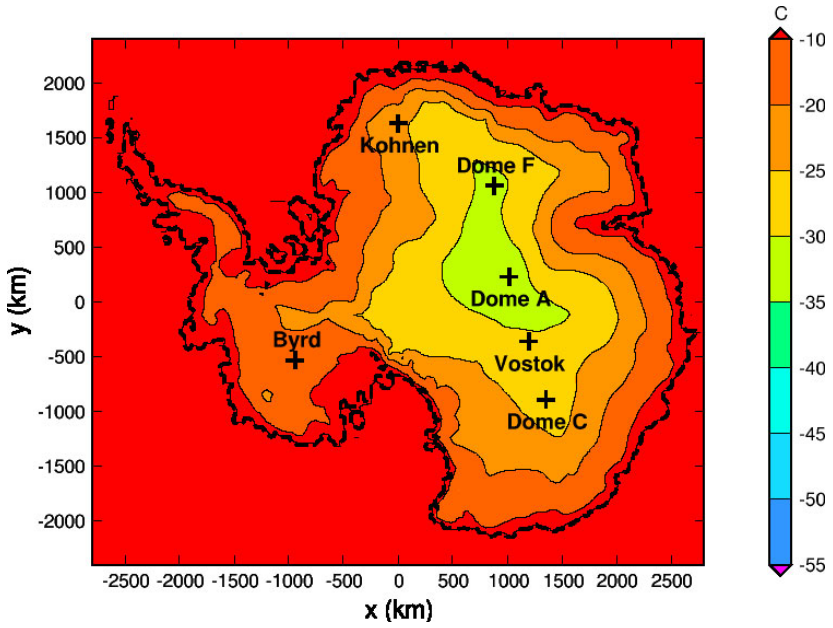
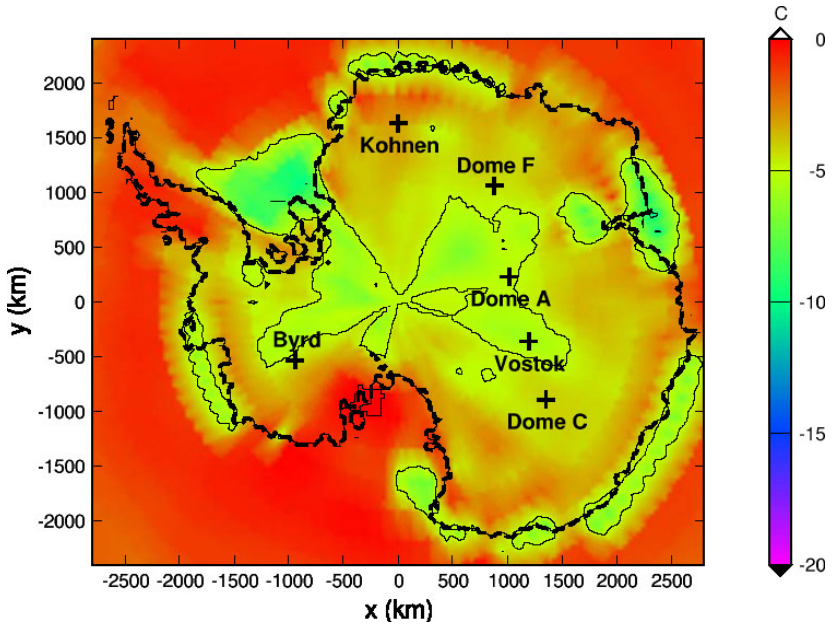
Paleoclimatic simulation

Present mean January T_s:



Huybrechts (1992)

LGM anomaly (difference) of mean January T_s:



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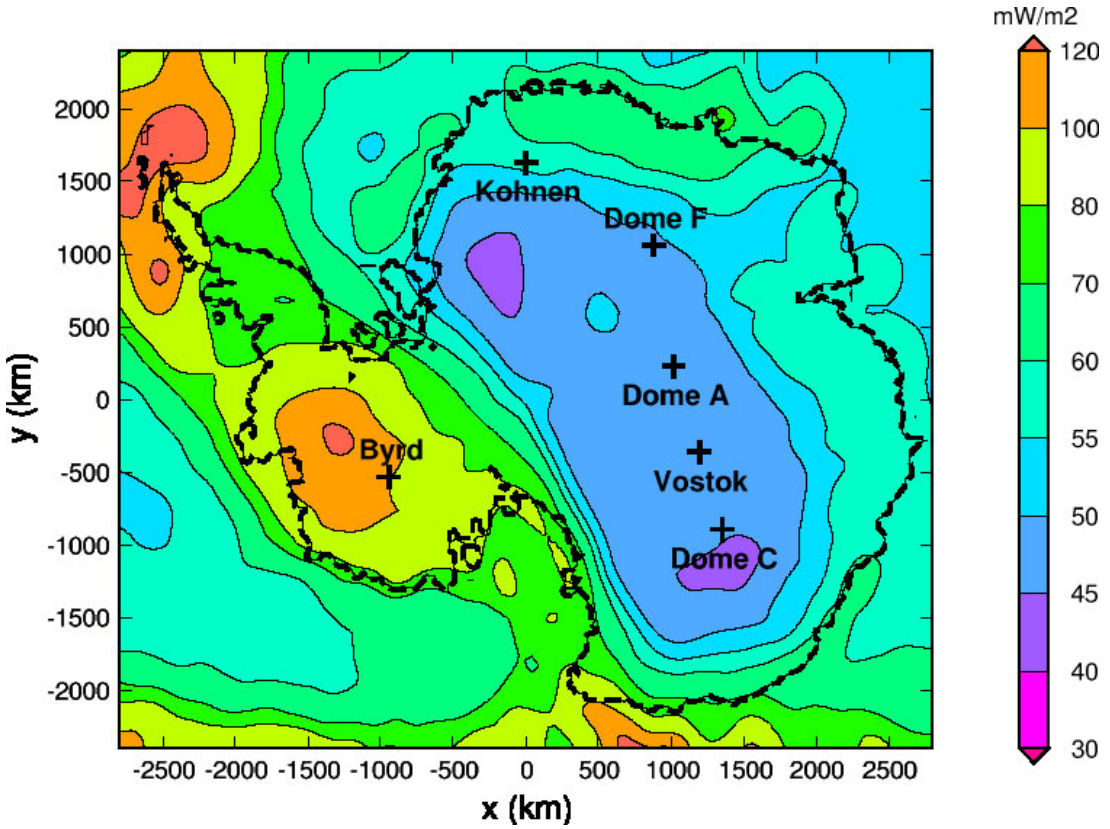
Paleoclimatic simulation

Geothermal heat flux

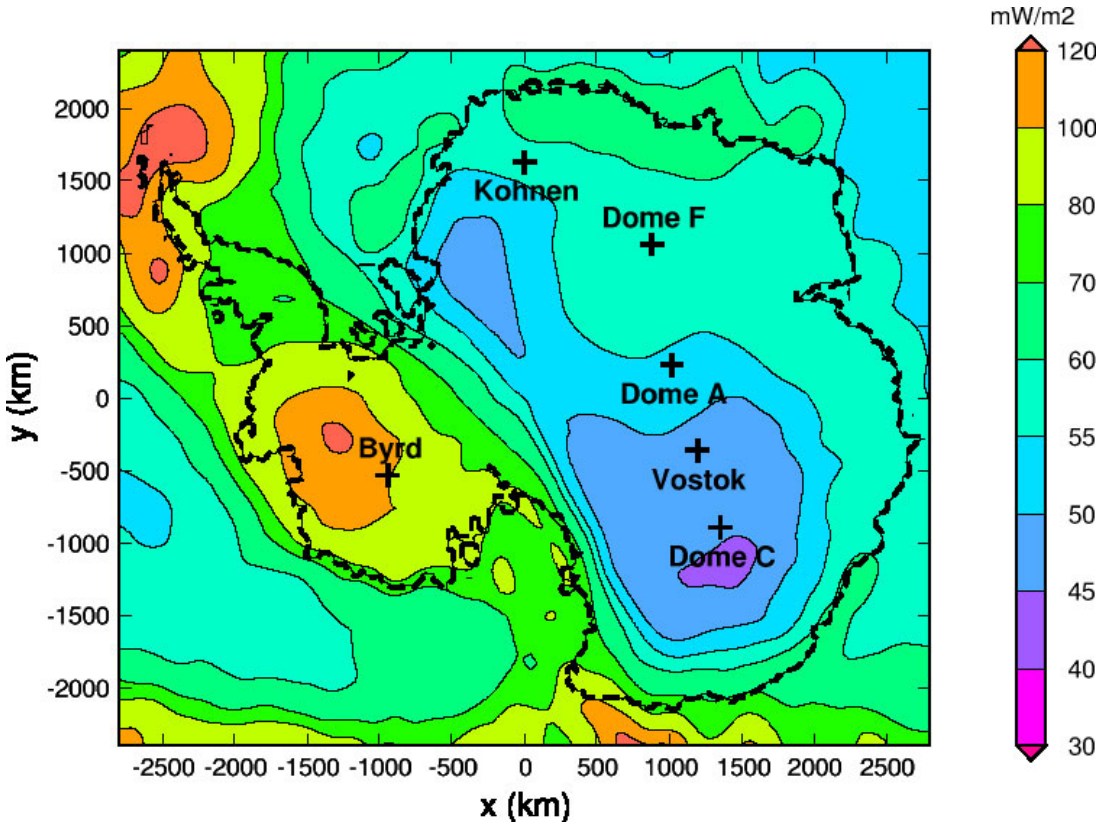
- Background distribution by Shapiro and Ritzwoller (2004) [extrapolation of measurements with a global seismic model].



Paleoclimatic simulation

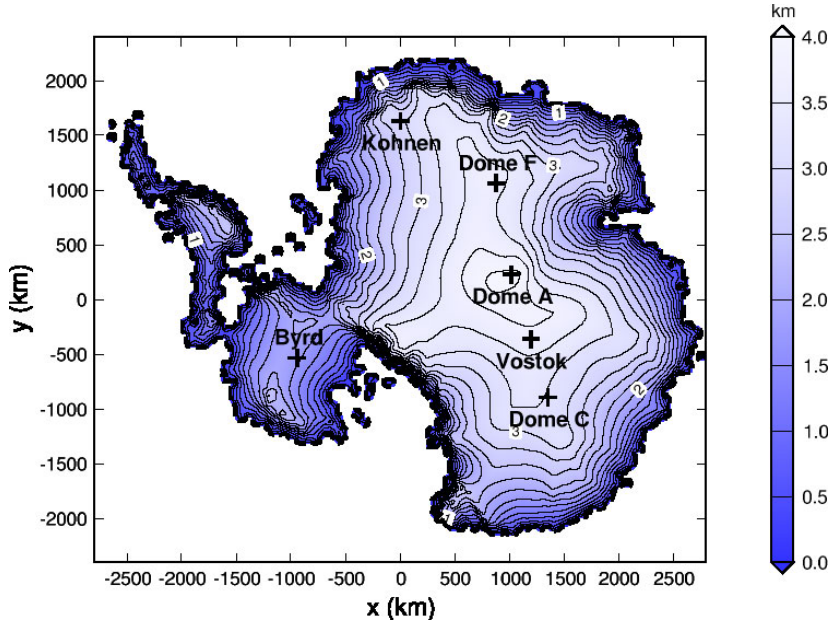
Geothermal heat flux

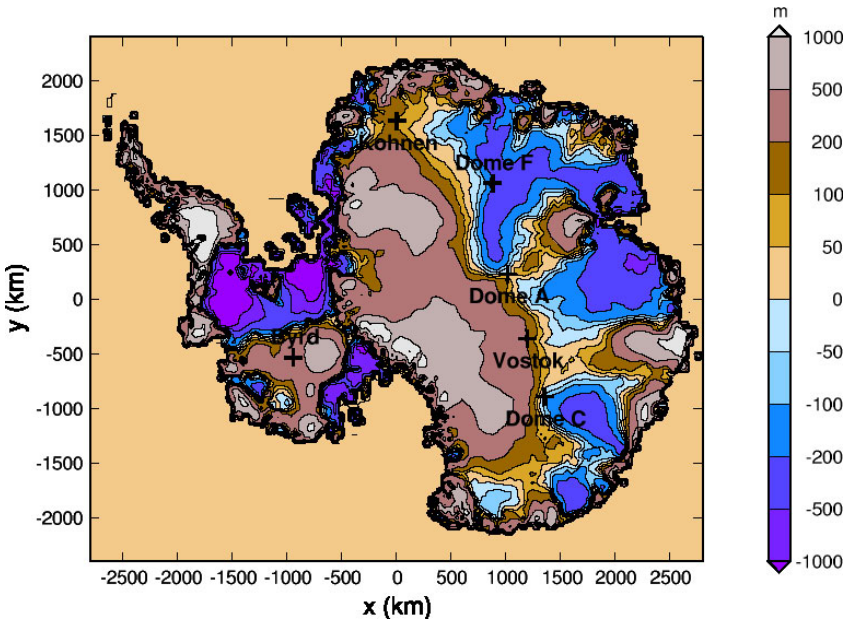
- Background distribution by Shapiro and Ritzwoller (2004) [extrapolation of measurements with a global seismic model].
- Dome F: q_{geo} = 60 mW/m^2.
- Information from further ice cores will be assimilated later.



Paleoclimatic simulation

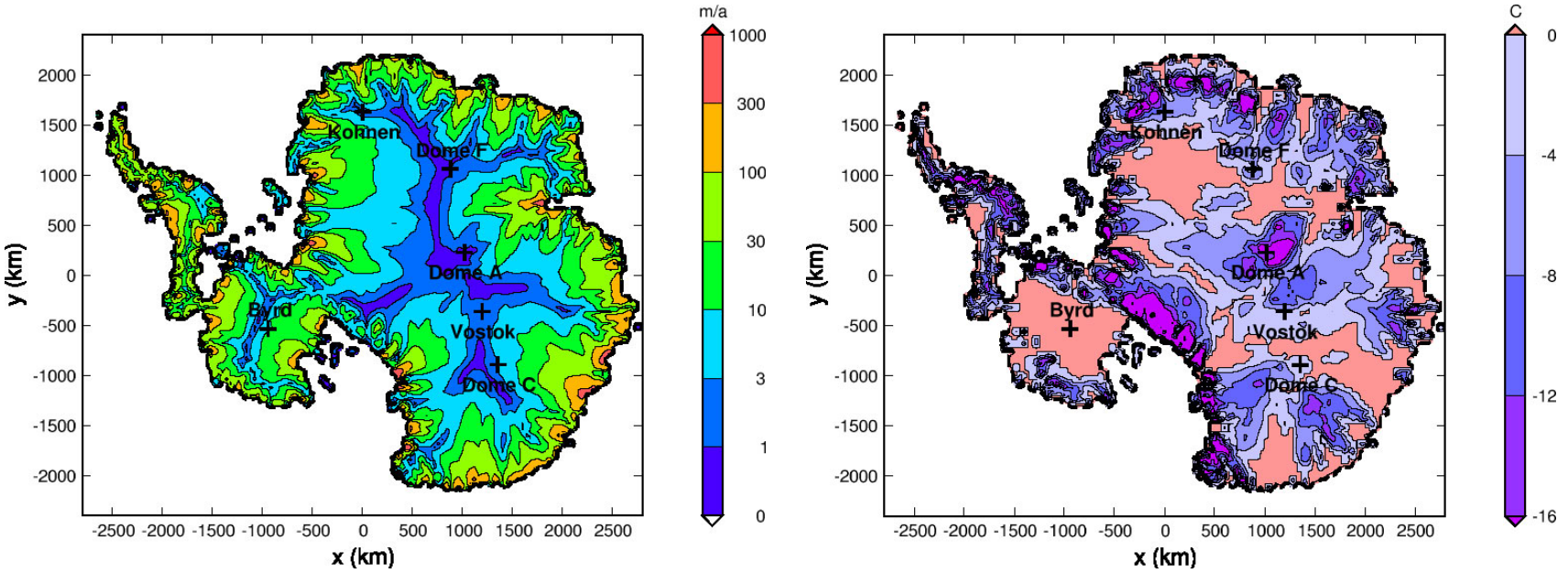
Results: Topography, ice-thickness misfit (sim – obs)





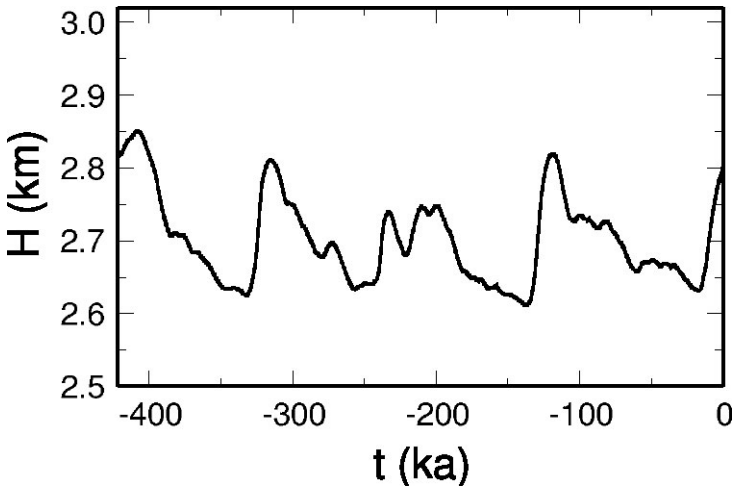
Paleoclimatic simulation

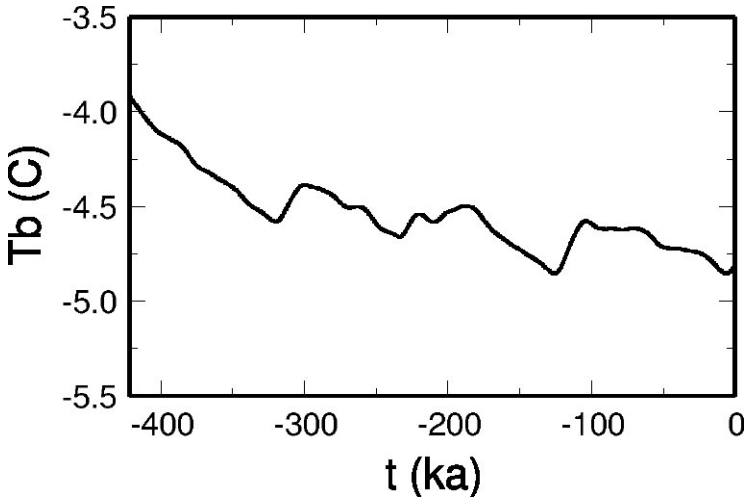
Results: Surface velocity, basal temperature (rel. to pmp)



Paleoclimatic simulation

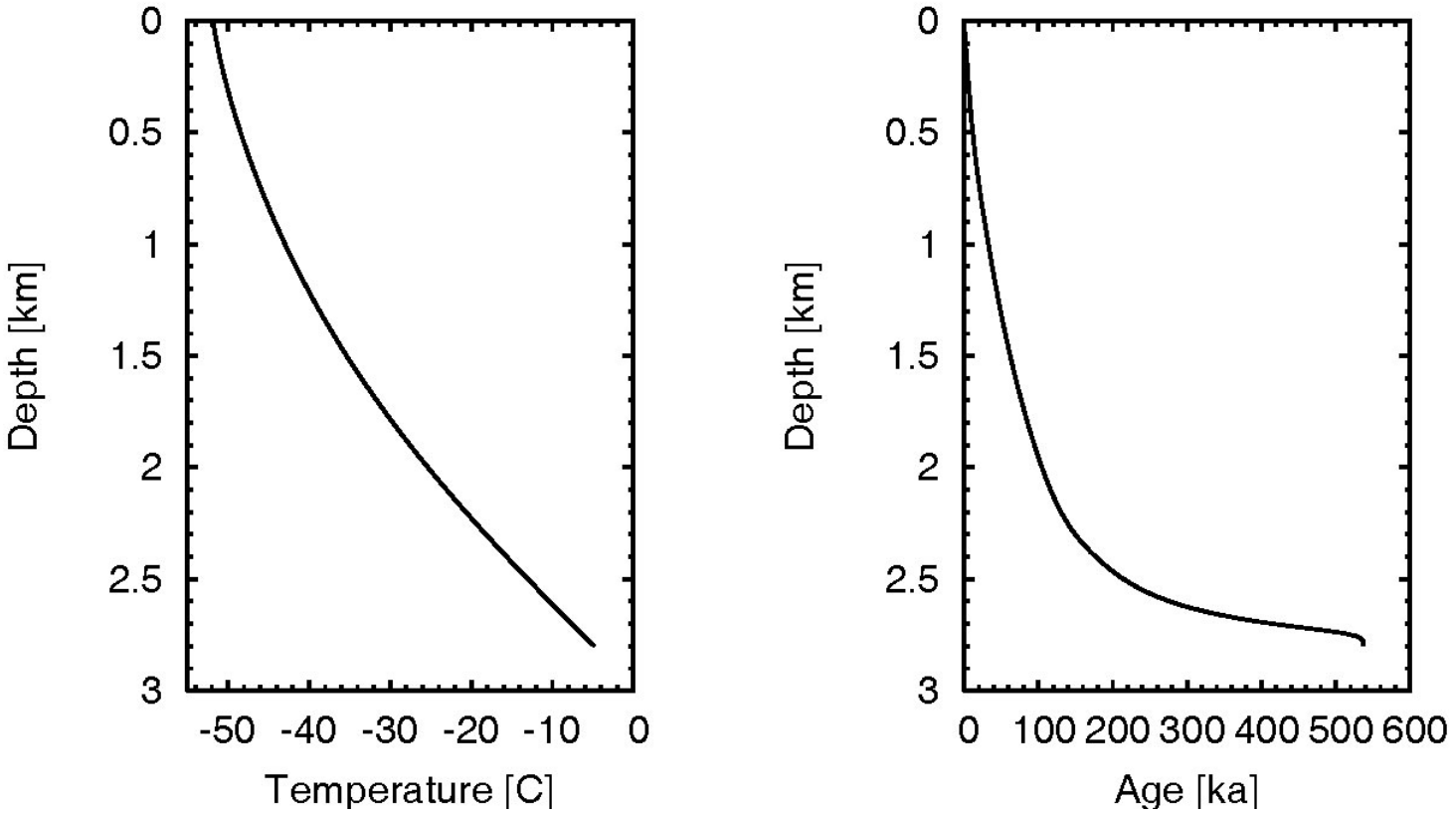
Results:
Evolution of ice thickness and basal temperature at Dome F





Paleoclimatic simulation

Results: Temperature and age profiles at Dome F

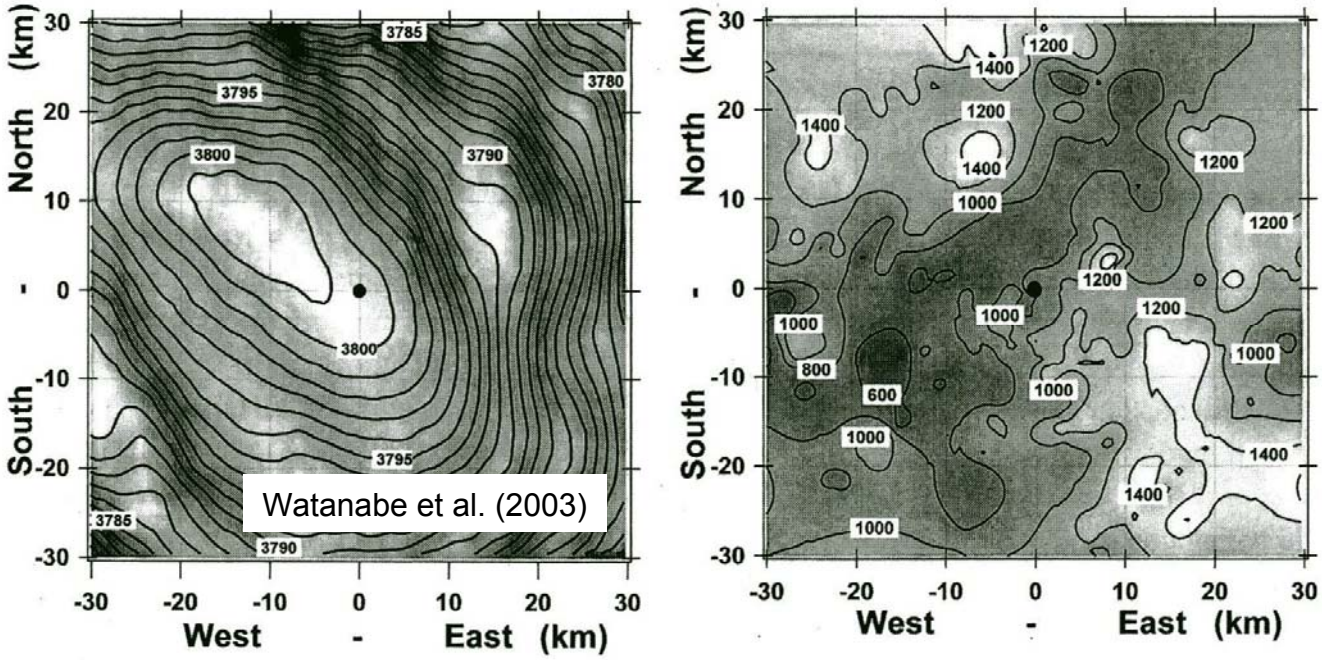


Outlook: Nesting with regional model

Elmer/Ice

(Hakime SEDDIK's PhD thesis)

- Full-Stokes solver for ice-flow problems based on the open-source FE tool Elmer (CSC, Espoo, Finland).
- 60 x 60 km domain for the vicinity of Dome F:



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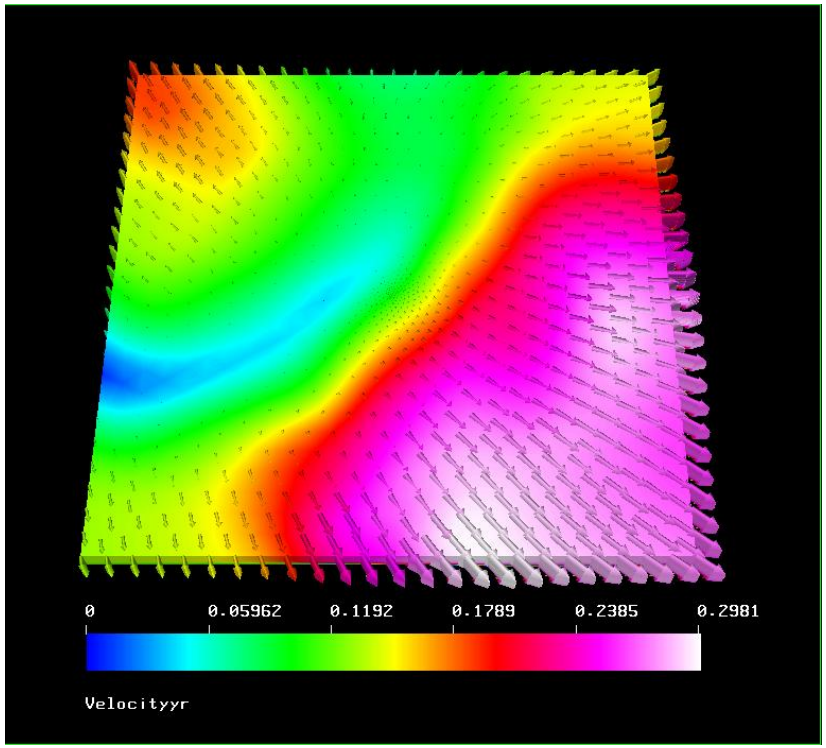
Outlook: Nesting with regional model

- High-resolution triangulation in this domain.
- Boundary conditions to be provided by SICOPOLIS (→ suitable downscaling?).
- Detailed computation of flow field, englacial temperature and age profile.

Outlook: Nesting with regional model

Surface velocity, computed for steady-state conditions and shallow-ice stresses as boundary conditions



To-Do List

- Higher resolution (20 km).
- Longer simulation time (> 1 Ma).
- Assimilation of further ice-core data for map of q_{geo}.
- Nesting of regional Elmer/Ice model.

Thanks for your interest!

Ralf Greve