PISM
PARALLEL ICE SHEET MODEL

Ice sheet modeling with PISM

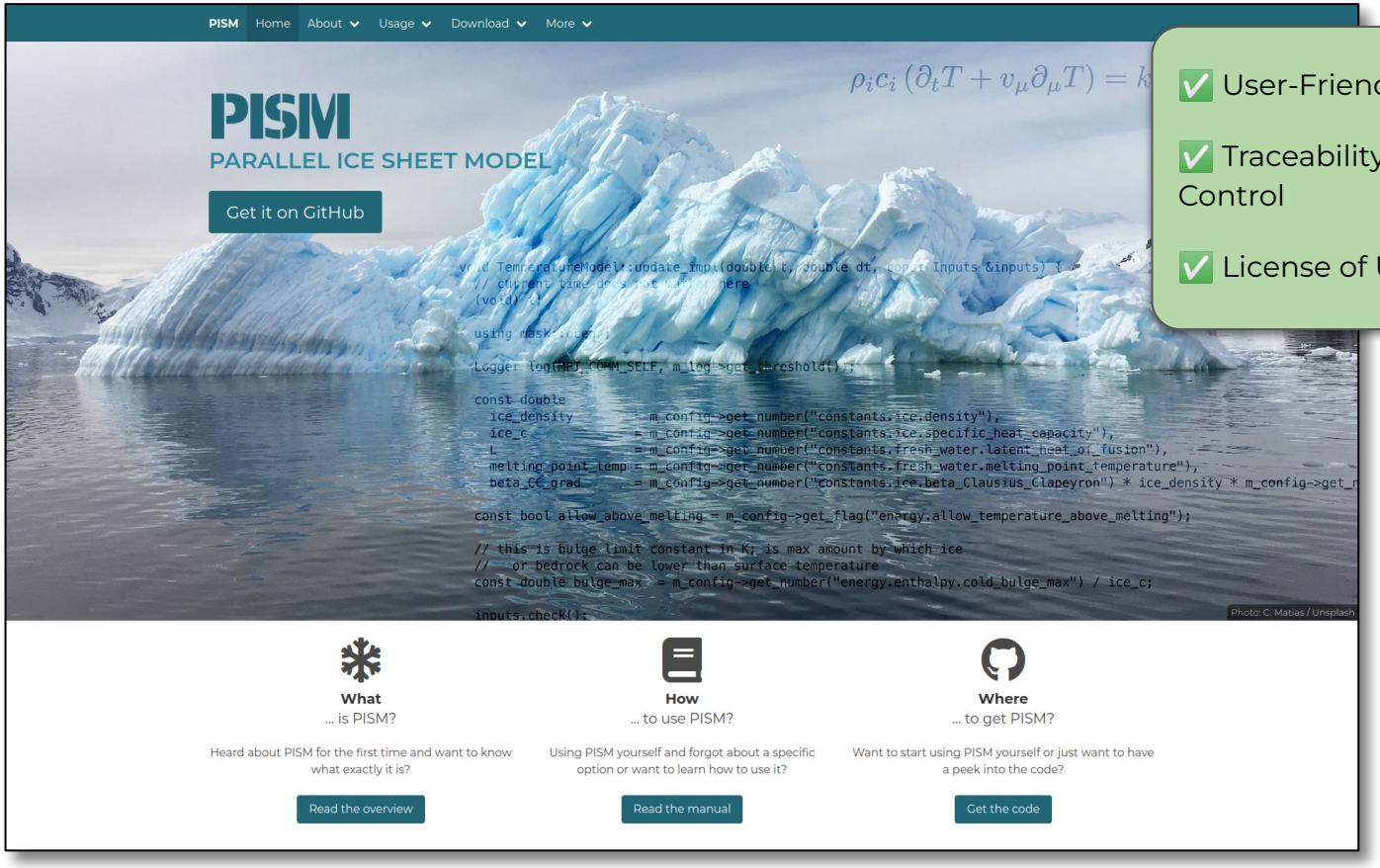
From paleo applications to sea-level projections and tipping dynamics

Background: Matias / Unsplash

natESM KickOff Ice Sheet Component
Torsten Albrecht, Ricarda Winkelmann
October 25, 2023

PIK

natESM



✅ User-Friendly and Well Documented

✅ Traceability, Reproducibility, and Version Control

✅ License of Useful Open-Source Type

Website
pism.io

Open-source
github.com/pism

Documentation
pism.io/docs

PISM – an open source project

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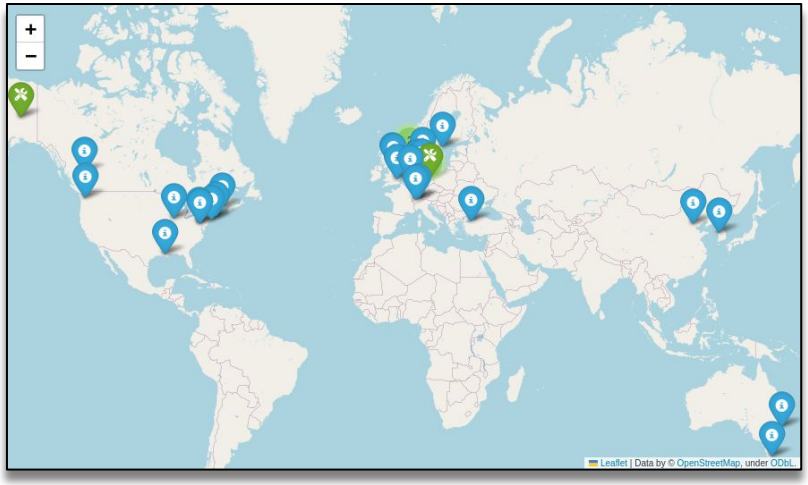
- **Co-development** at **PIK** since 2008 (Winkelmann et al., 2011) and at **UAF, Alaska** (Bueler & Brown, 2009) [1,2]
- Many users and contributions worldwide (see map [3]) with ~200 peer-reviewed publications [4]
- PISM user meetings in Hamburg, Potsdam and Copenhagen
- Community support on Github and Slack



UAF UNIVERSITY OF ALASKA FAIRBANKS

PIK

[1] https://www.pism.io/history
[2] https://www.pism.io/team
[3] https://www.pism.io/usersmap
[4] https://www.pism.io/publications

The Parallel Ice Sheet Model

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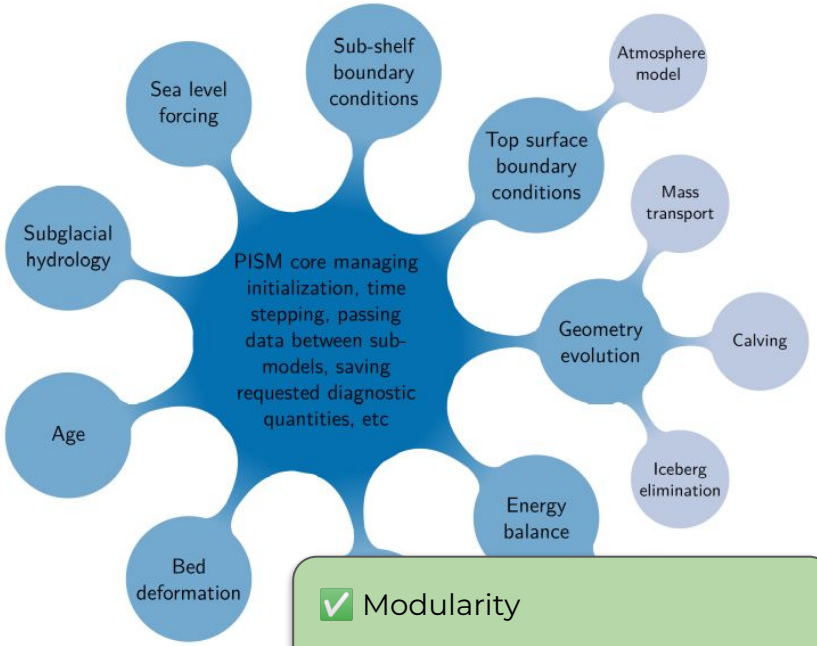
Technical details

- C++ code, MPI **parallelization** using PETSc toolkit
- GPL-3.0 “copyleft” **license**
- Well modularized (testing)
- **Easy coupling** to ocean, atmosphere and Earth components
- Finite difference/volume (finite-element for SSA optional)
- **Hybrid shallow** stress balance (SSA+SIA), to resolve ice stream and ice shelf flow with a **computationally low cost**
- **Higher-order** stress balance (Blatter-Pattyn) optional
- Various **calving** and **basal drag** schemes available
- **Subglacial hydrology** routing scheme optional
- Latest implementations (v2.1 soon to be released):
  - **3-D age** module for isochrone layer tracing
  - **Proglacial-lake** module



Graphic: Khrulev, UAF

https://github.com/pism/pism

Standalone applications (I): Paleo

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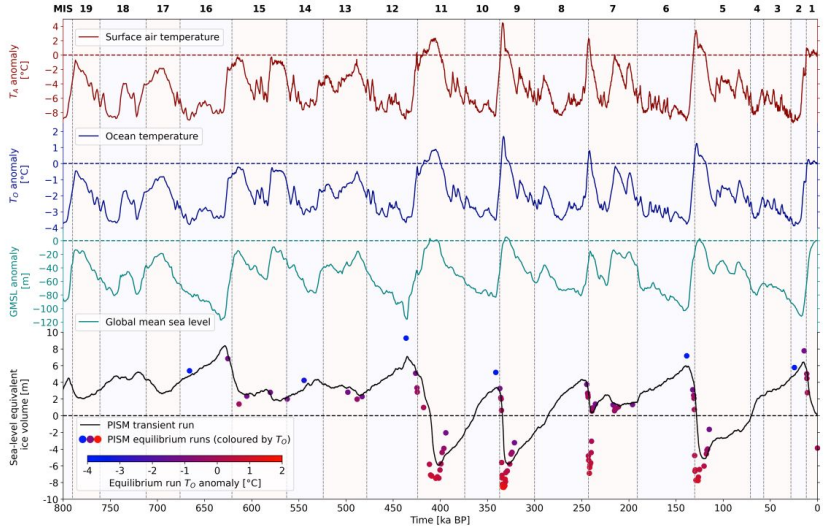
Glacial cycle simulations for Antarctica

Video: https://youtu.be/98-Xf_RvFmI



Albrecht, Kingslake, Scherer et al. (Nature, 2018)
Albrecht et al. (TC, 2020a,b)

Sutter et al. (Geo Res Let, 2020)
Chandler et al. (Nat Geo, in review)

Standalone applications (II): Projections

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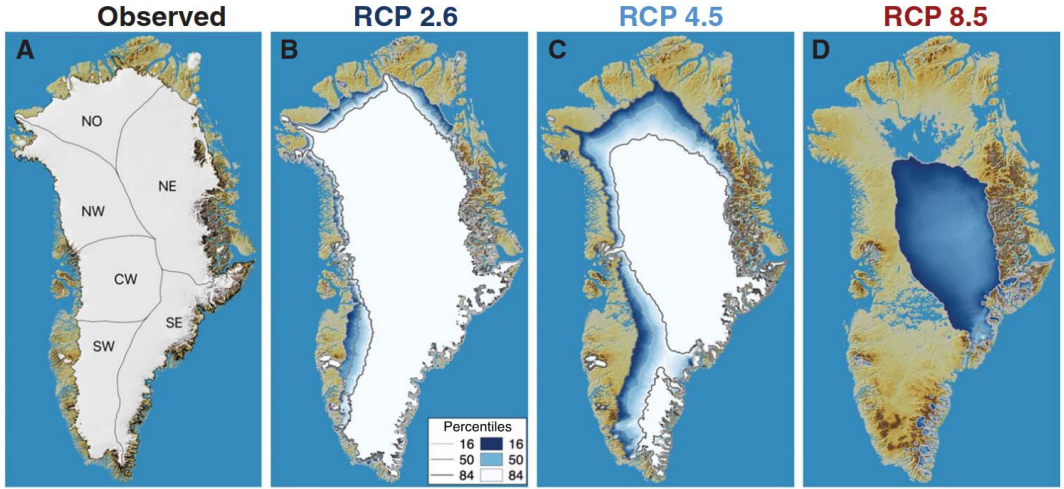
High-resolution (up to 450m) Greenland Ice Sheet projections until the year 3000

ISMIP6 **sea-level projections** (Greenland & Antarctica)

✅ Exascale-Ready



Video: https://youtu.be/p1DkXp_vpbM

"Greenland will very likely become ice free within a millennium without substantial reductions in greenhouse gas emissions."

Aschwanden et al. (Nat Comm, 2016)
Aschwanden et al. (Sci Adv, 2019)

Golledge et al. (Nature, 2019)
Seroussi et al. (TC, 2020) / Goelzer et al. (TC, 2020)

Edwards et al. (Nature, 2021)
Sutter et al. (Nat Clim Ch, 2023)

Standalone applications (III): Tipping points

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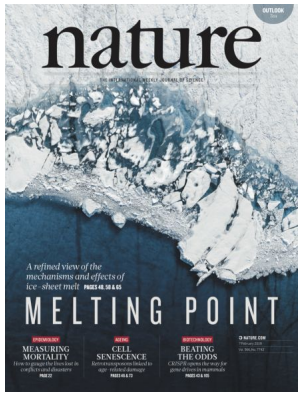
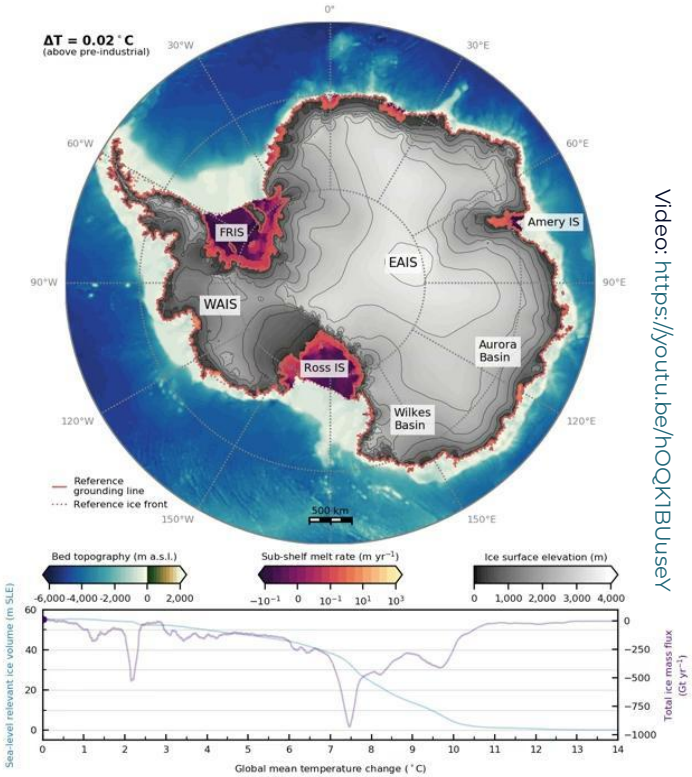
Long-term stability and tipping points of the Antarctic Ice Sheet

- **First tipping point at around 2 °C warming**
  … caused by ice-ocean interaction and marine ice sheet instability
- **Second tipping point between 6 °C and 8 °C warming**
  … surface processes become dominant

Garbe et al. (Nature, 2020)



Golledge et al. (Nature, 2019)



Video: https://youtu.be/hOQKIBUuseY

Mengel & Levermann (Nat Clim Ch, 2014)
Winkelmann et al. (Sci Adv, 2015)

Feldmann & Levermann (PNAS, 2015)
Golledge et al. (Nature, 2015)

Clark et al. (Nat Clim Ch, 2016)
Garbe et al. (Nature, 2020)

Coupling interfaces

✅ Well-defined Interfaces between Earth System Components

✅ Allows Simulations from Global to Local

✅ Portability

ATMOSPHERE
(surface mass balance)

- dEBM-simple
- PDD
- MAR
- ECHAM (MPI-ESM, AWI-ESM)
- IFS (EC-Earth)
- (ModelE)

PISM
(ice sheet model)

~200 PISM-related peer-reviewed papers

OCEAN
(global ocean circulation)

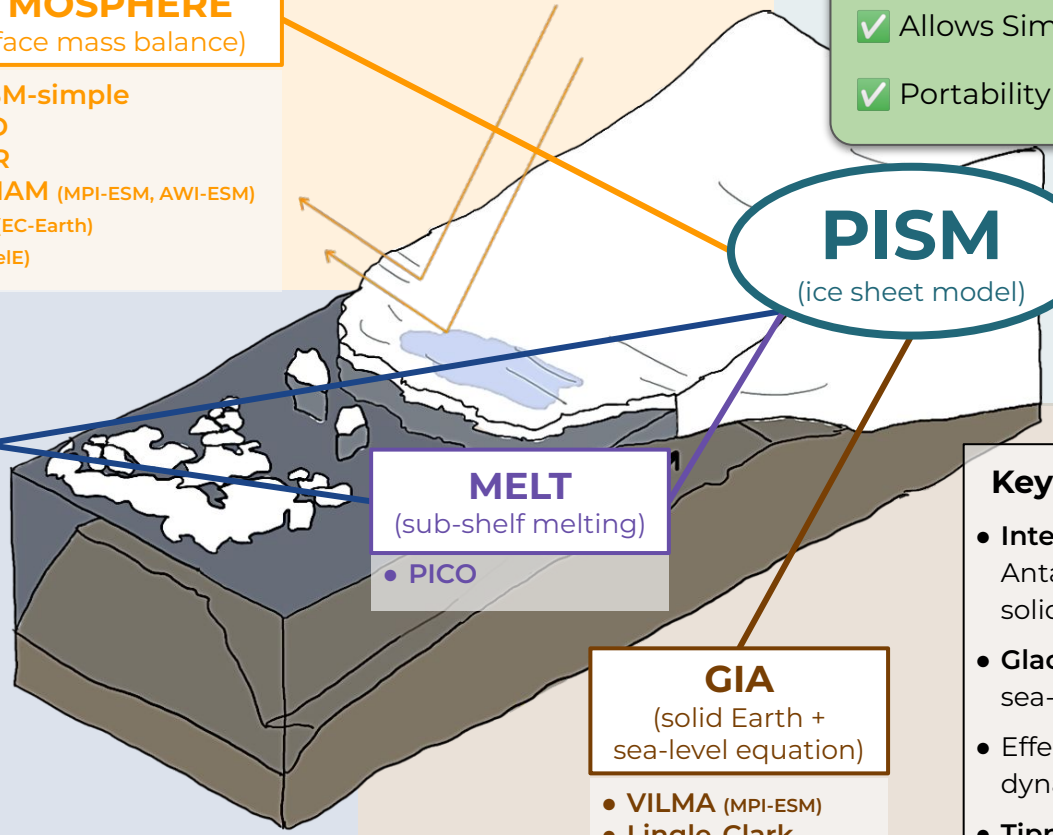
- MOM5/6 (POEM)
- FESOM (AWI-ESM)
- MPIOM (MPI-ESM)
- NEMO (EC-Earth)
- (ModelE)

MELT
(sub-shelf melting)

- PICO

GIA
(solid Earth + sea-level equation)

- VILMA (MPI-ESM)
- Lingle-Clark



Graphic: Nicola, PIK

Key research topics

- **Interaction** between Greenland and Antarctica via ocean, atmosphere, and solid Earth
- **Glacial cycle** simulations and future sea-level **projections**
- Effect of **extreme events** on ice dynamics
- **Tipping points** and risk of tipping **cascades**

Project collaborations & couplings

✅ Scalable Workflows

✅ Standardization

- **PISM coupled in Earth System Models and General Circulation Models**
  - MPI-ESM (Hamburg, DE)
  - AWI-ESM (Bremerhaven, DE)
  - EC-Earth (Copenhagen, DK)
  - NASA/GISS ModelE (Fairbanks, USA)
  - PIK POEM (Potsdam, DE)
  - MAR (Liège, BE)
- **Project collaborations**
  - **DFG:** SPP 1158 Antarktisforschung
  - **BMBF:** PalMod (PISM in MPI-ESM & AWI-ESM, PISM-MOM-VILMA)
  - **EU:** PROTECT, OCEAN:ICE, TiPACCs, OptimESM, ClimTip, RESCUE …
- **International MIPs:** TIPMIP, ISMIP, LARMIP, MISMIP, ABUMIP, …

ANTARKTIS FORSCHUNG
mit vergleichenden Untersuchungen in arktischen Eisgebieten

PAL MOD

Protect
CRYOSPHERE & SEA LEVEL

TiPACCs
Tipping Points in Antarctic Climate Components

OCEAN:ICE

ISMIP6
Ice Sheet Model Intercomparison Project for CMIP6

TIPMIP

https://www.pism.io/collaborations

Technical criteria for natESM

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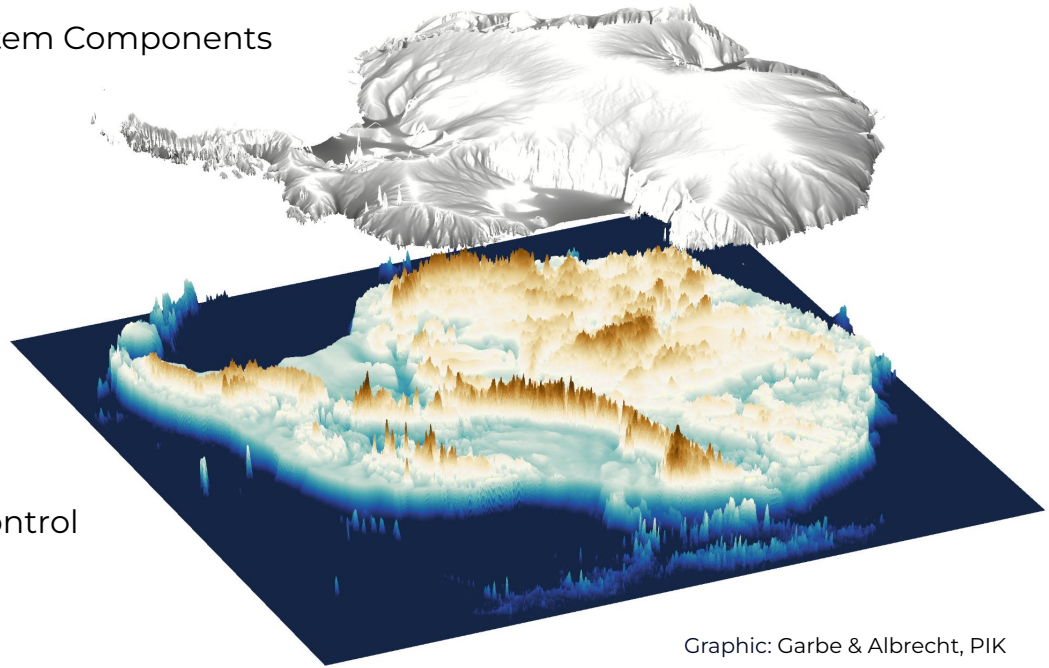
Technical criteria for becoming part of the natESM system

1. ✅ Well-defined Interfaces between Earth System Components
2. ✅ Allows Simulations from Global to Local
3. ✅ Exascale-Ready
4. ✅ Scalable Workflows
5. ✅ Portability
6. ✅ Modularity
7. ✅ Data Assimilation Capacity
8. ✅ Diagnostic Capacity
9. ✅ User-Friendly and Well-Documented
10. ✅ Traceability, Reproducibility, and Version Control
11. ✅ Standardization
12. ✅ License of Useful Open-Source Type



Graphic: Garbe & Albrecht, PIK