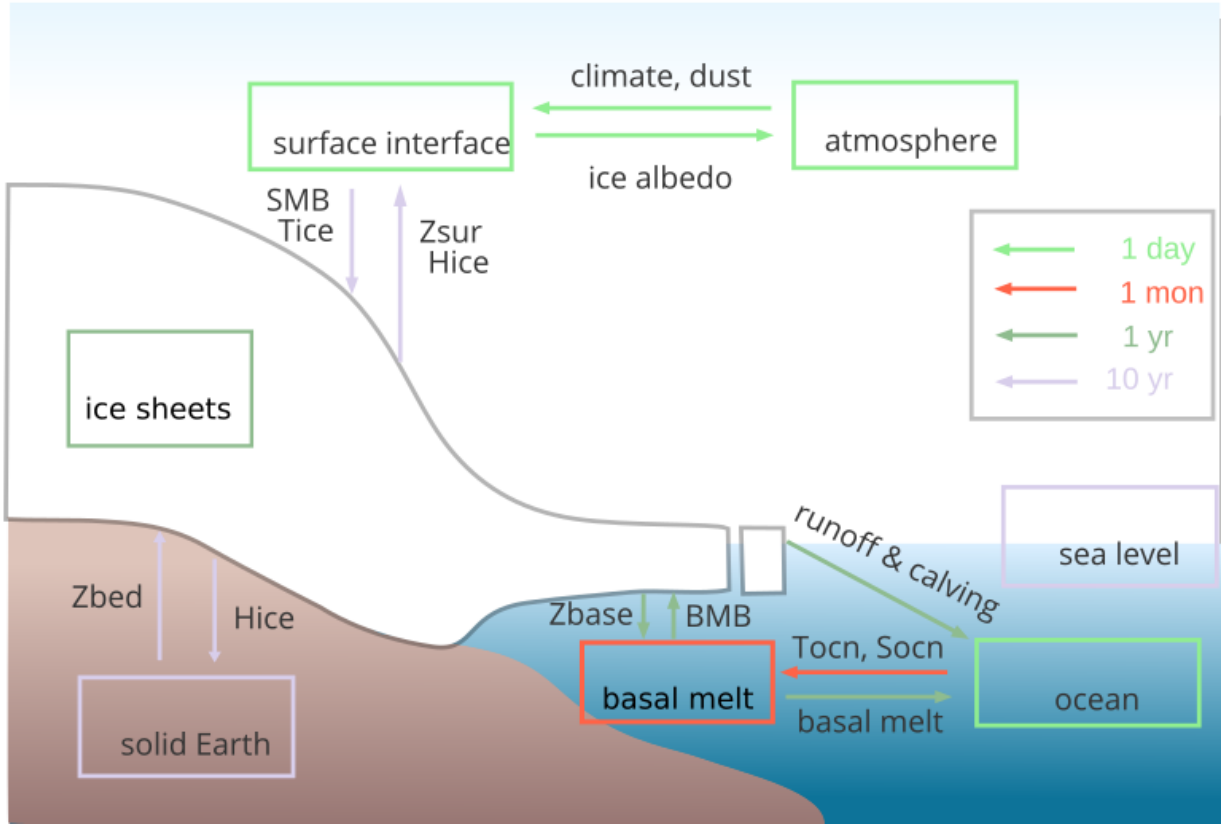
natESM community workshop – land ice component



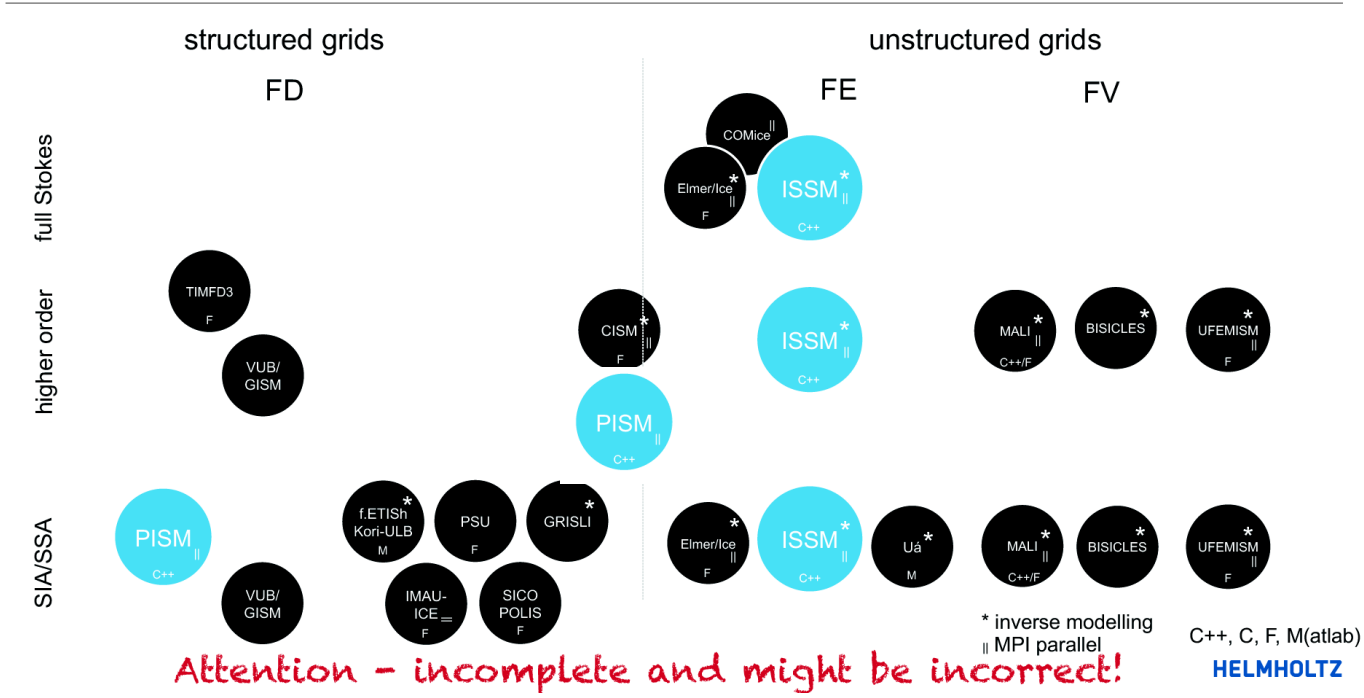
Example of interaction of ice sheet component with other ESM components, courtesy Matteo Willeit (PIK)

Why do we care about ice sheets, ice caps and glaciers?

- glacial cycles
- abrupt changes
- sea level change (projections, commitment)
- fresh water fluxes (calving, melt, runoff)
- feedbacks (ice-ocean, ice-atmosphere)
- teleconnections across hemispheres
- process understanding:
  - subglacial hydrology
  - firn compaction
  - fracture mechanics, calving

  → structural uncertainties

The model zoo



Ice sheet model landscape, modified after Angelika Humbert (AWI)

Ice sheet models have:

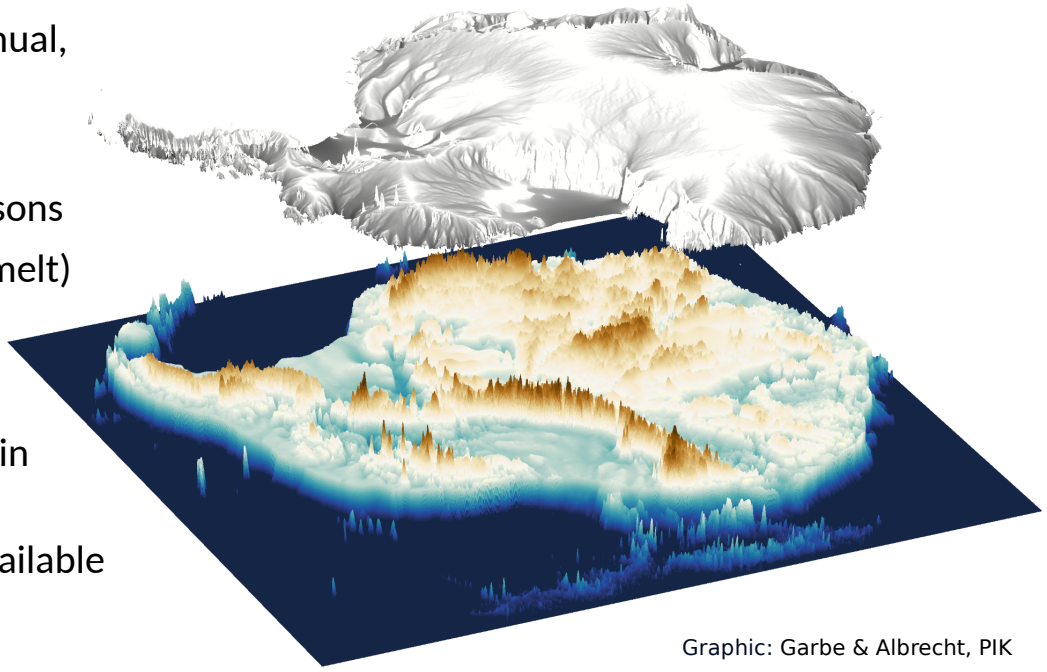
- different grid structures
- stress balance approximations
- initialization procedures
  - equilibrium or paleo spin-up
  - inversion (data assimilation)

→ Choice of model very much depends on scientific questions, and involved spatial and temporal scales (alpine glaciers?)

PISM and ISSM

Both land ice models:

- are co-developed in USA and Germany, and user base within Germany
- use version control, have an open source license, user manual, documentation, C++
- use thermo-coupling (enthalpy)
- model ice front migration (calving) → model intercomparisons
- use sub-grid grounding line interpolation (friction and/or melt)
- use PETSc for expensive mathematical operations
- performance studies exist and sprint check completed
- horizontal resolution up to 450m (PISM) and 250m (ISSM) in Greenland application
- surface mass balance modules of different complexities available
- sea-level fingerprinting



Graphic: Garbe & Albrecht, PIK

Coupling interfaces – ESM experience with PISM

PARALLEL ICE SHEET MODEL

ATMOSPHERE
(surface mass balance)

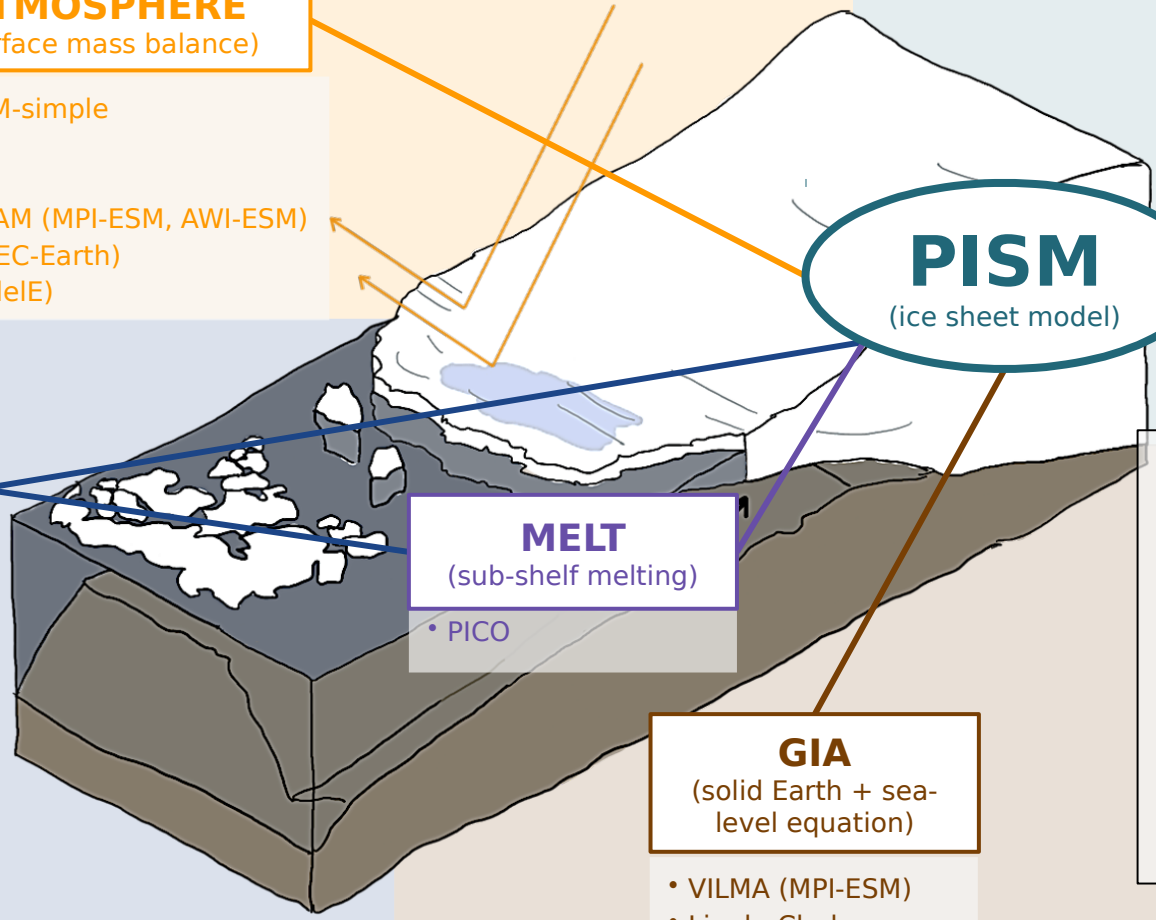
- dEBM-simple
- PDD
- MAR
- ECHAM (MPI-ESM, AWI-ESM)
- IFS (EC-Earth)
- (ModelE)

~200 PISM-related peer-reviewed papers

PISM
(ice sheet model)

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)

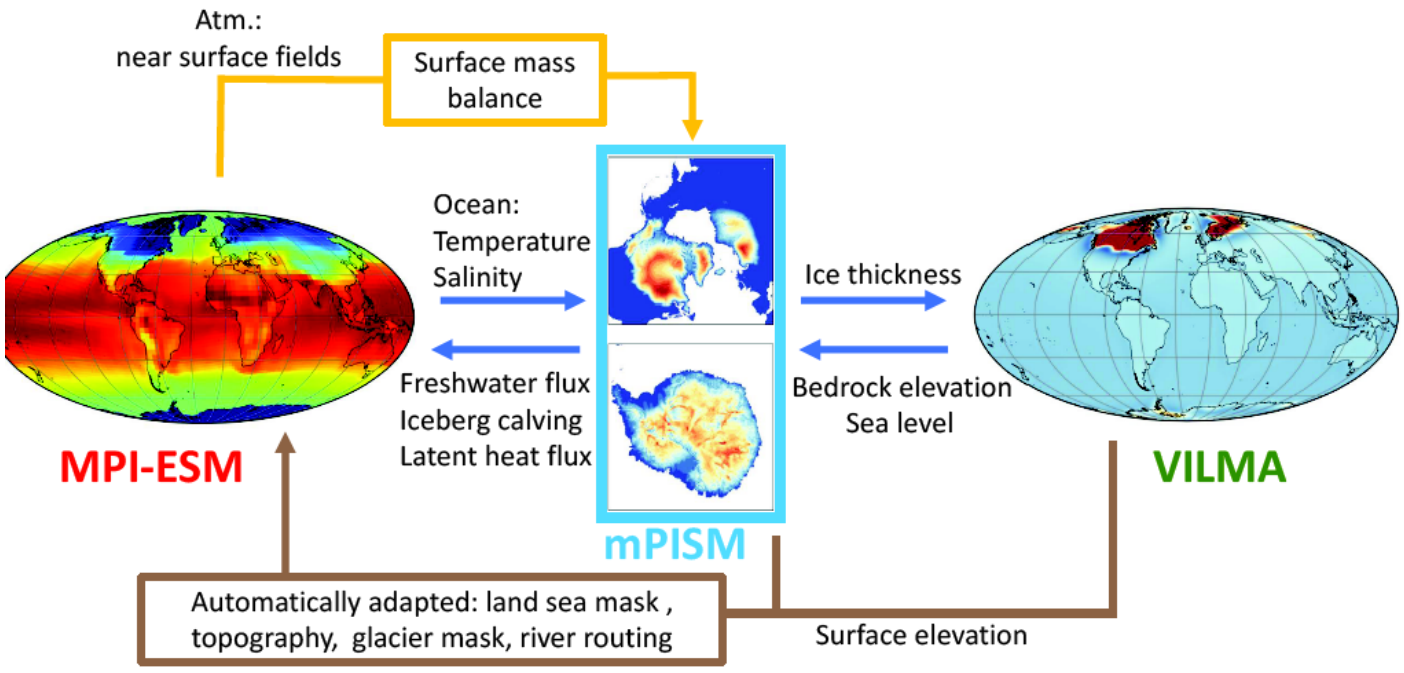
- VILMA (MPI-ESM)
- Lingle-Clark

More features in PISM

- Subglacial hydrology scheme
- Continuous damage mechanics module
- Various calving and basal drag schemes
- 3-D age module for isochrone layer tracing
- Proglacial-lake module

Graphic: Nicola, PIK

Glacial cycle simulations with PISM in MPI-ESM



Credit: K. Six

in coarse-resolution mode
(ECHAM6-T31L31, MPIOM GR30L40, JSBACH, PISM 10/15km resolution)

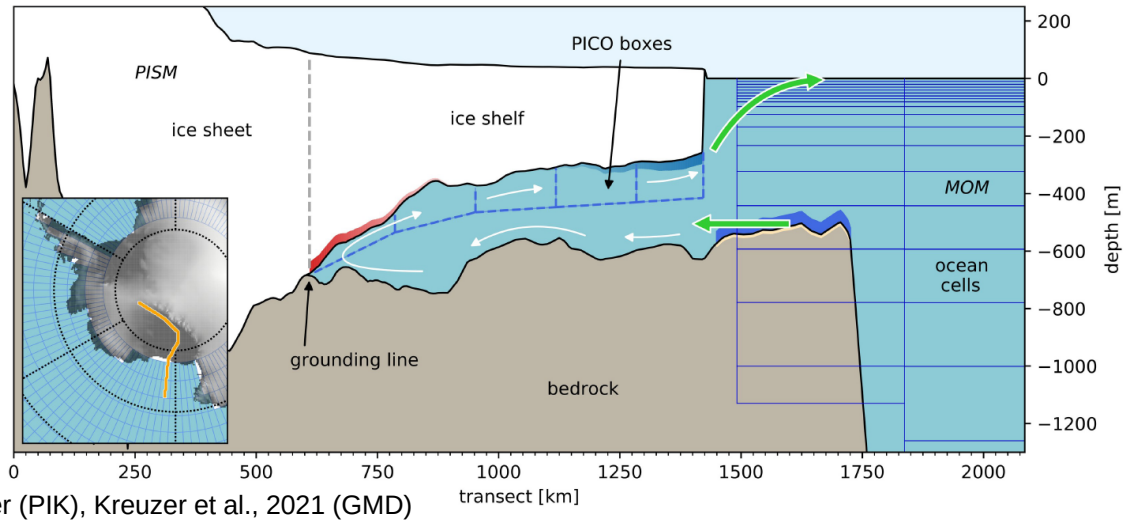
PISM requires only about 6% of total computational cost
(860 CPU core hours per 10 mod. Years)

Where are the bottlenecks?

→ many processes not considered
(subglacial hydrology, fracture mechanics)

Challenges / Model choices

- Spin-up of the model system (spin-up vs. data assimilation)
- Type of coupling (“offline” coupling via restart files vs. online coupling via coupler e.g. YAC etc.)
- Ocean cavities (parameterisation via PICO etc. or fully dynamic cavities)
- Liquid and solid discharge fluxes from ice sheet to ocean



List by Clemens Schannwell (MPI-M), graphic courtesy Moritz Kreuzer (PIK), Kreuzer et al., 2021 (GMD)

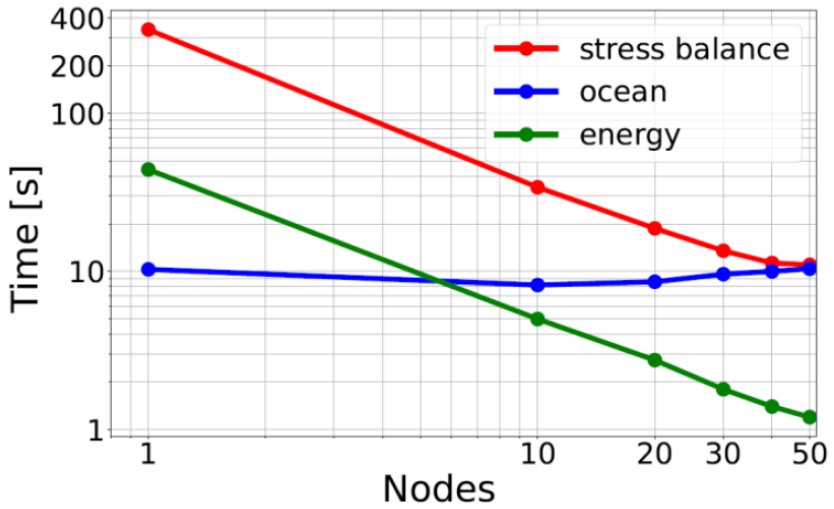
Discussion of sprint check

Options for sprint application:

- 6 months sprint application to improve **CPU** strong scaling:
  - ocean component numerical algorithm or
  - PIO issue 1768 fix with involvement of PIO library developers from NCAR

- 3/4 months sprint application about investigating PETSc performance on **GPU** for PISM with a main focus on stress balance component because it is the most computationally expensive and the one which scales better

→ We agreed that there is still lots of scope to optimize for CPU performance, as requirement for GPU optimization



Scaling Analysis by Enrico DeGregorie and Wilton Loch (DKRZ)

Further conclusions from discussions

→ interactive ice sheets in ESM and climate models: relevant and plenty of opportunities
- role of fast ML-based emulators?

→ scientific applications from deep paleo to km-scale process understanding
- scientific questions may widen with more computational capabilities, Germany as frontier?
- role of glaciers?

→ ownership / community engagement from modelers
- PISM is ready, ISSM still unclear

Background: Matias / Unsplash