# Coupled ice sheet-ocean modelling using FISOC

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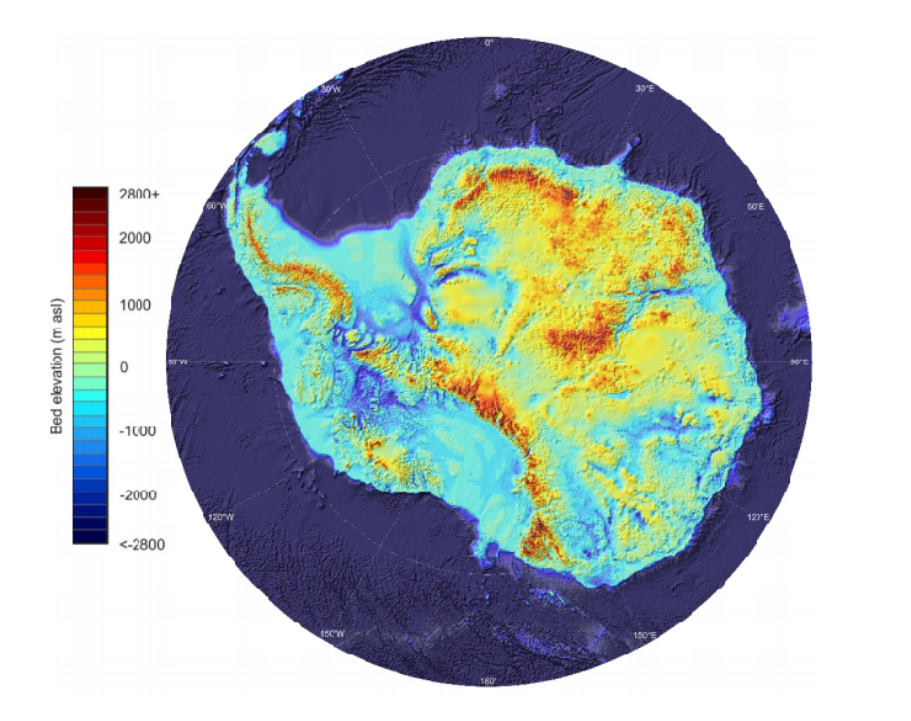
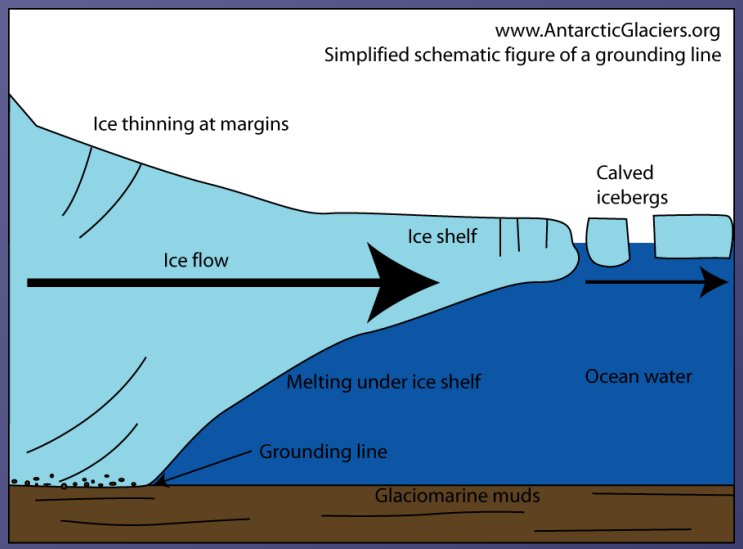
# Ice sheet-Ocean interactions




Bed Elevation (Bedmap2)

Marine ice sheets susceptible to instability and rapid retreat.

Ice shelves provide buttressing: thinning and collapse of floating ice shelves leads to glacier acceleration, thinning and grounding line retreat.



# Why couple to an ocean model?

How to deal with melt rates below newly ungrounded ice?

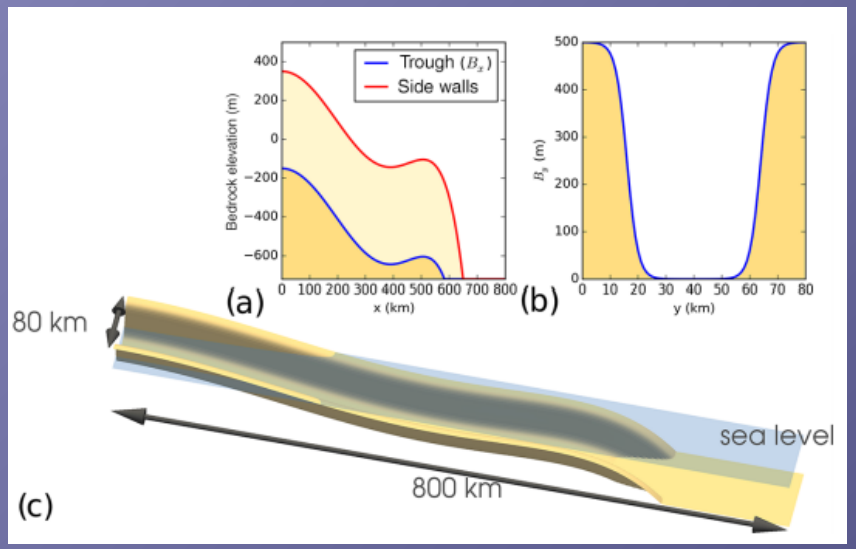
- Use a parameterisation:
  - Mostly linear with depth (piecewise)

- Use values from observations:
  - Ok for short runs
  - No longer valid when cavity evolves

# Planned applications: MISOMIP1

**Experimental design for three interrelated marine ice sheet and ocean model intercomparison projects: MISMIP v. 3 (MISMIP+), ISOMIP v. 2 (ISOMIP+) and MISOMIP v. 1 (MISOMIP1)**

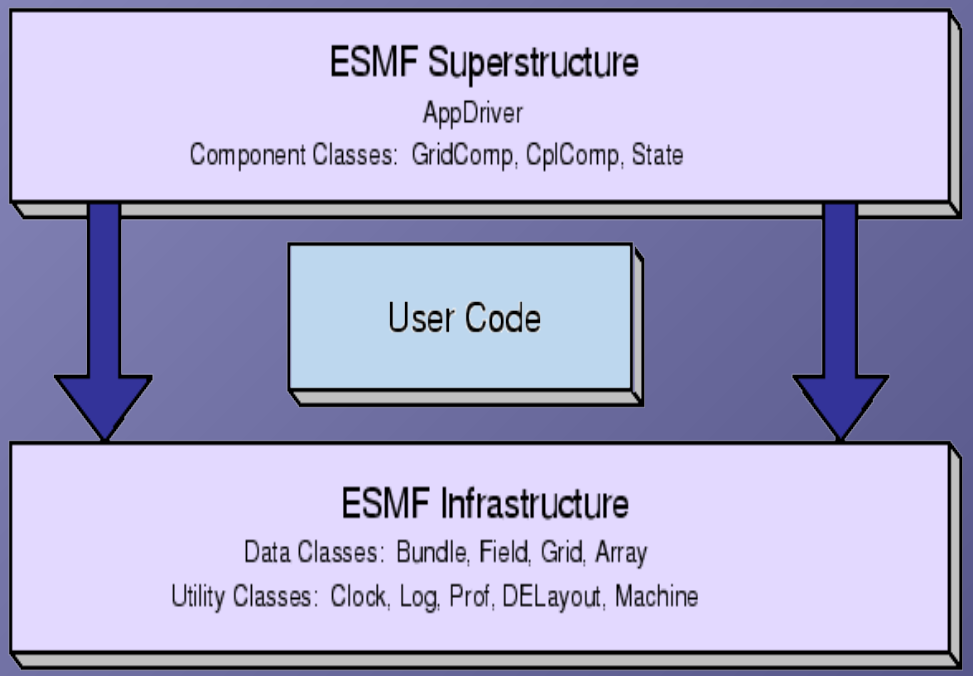
**Xylar S. Asay-Davis[1], Stephen L. Cornford[2], Gaël Durand[3,4], Benjamin K. Galton-Fenzi[5,6], Rupert M. Gladstone[6,7], G. Hilmar Gudmundsson[8], Tore Hattermann[9,10], David M. Holland[11], Denise Holland[12], Paul R. Holland[8], Daniel F. Martin[13], Pierre Mathiot[8,14], Frank Pattyn[15], and Hélène Seroussi[16]**




Ocean model provides melt rates to ice sheet model.
Ice sheet model provides a changed geometry to the ocean model.
We are contributing to MISOMIP1 with ROMS and Elmer/Ice

Geosci. Model Dev., 0 247-2497, 2016

# What is the Earth System Modelling Framework (ESMF)?

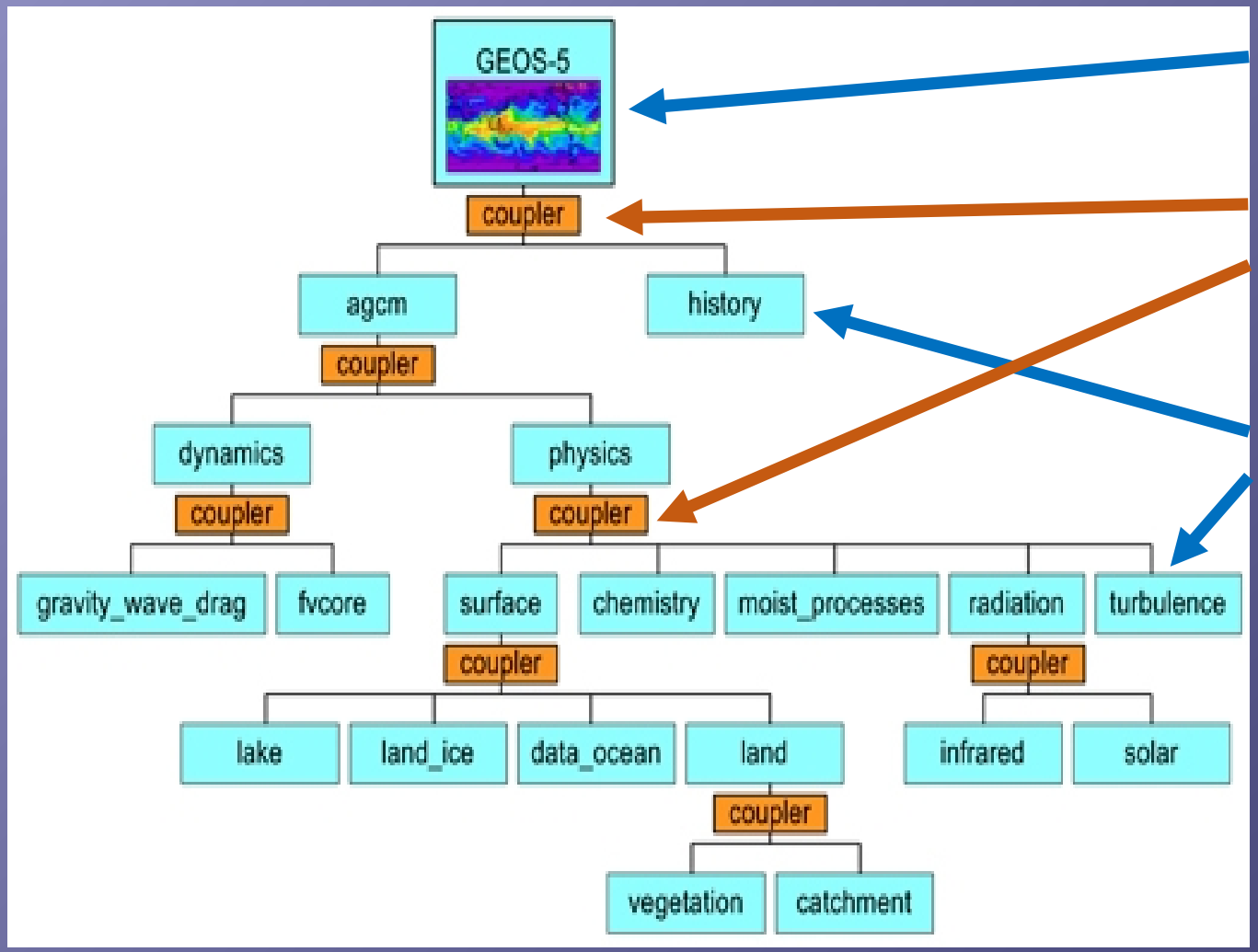



"The *Earth System Modeling Framework* (*ESMF*) is high-performance, flexible software infrastructure for building and coupling weather, climate, and related Earth science applications."

Component based architecture, where a "component" is either a (sub) model or a coupler.

Provides superstructure (e.g. drivers, wrappers) and infrastructure (e.g. fields, grids, clock utilities)

# Example ESMF component hierarchy



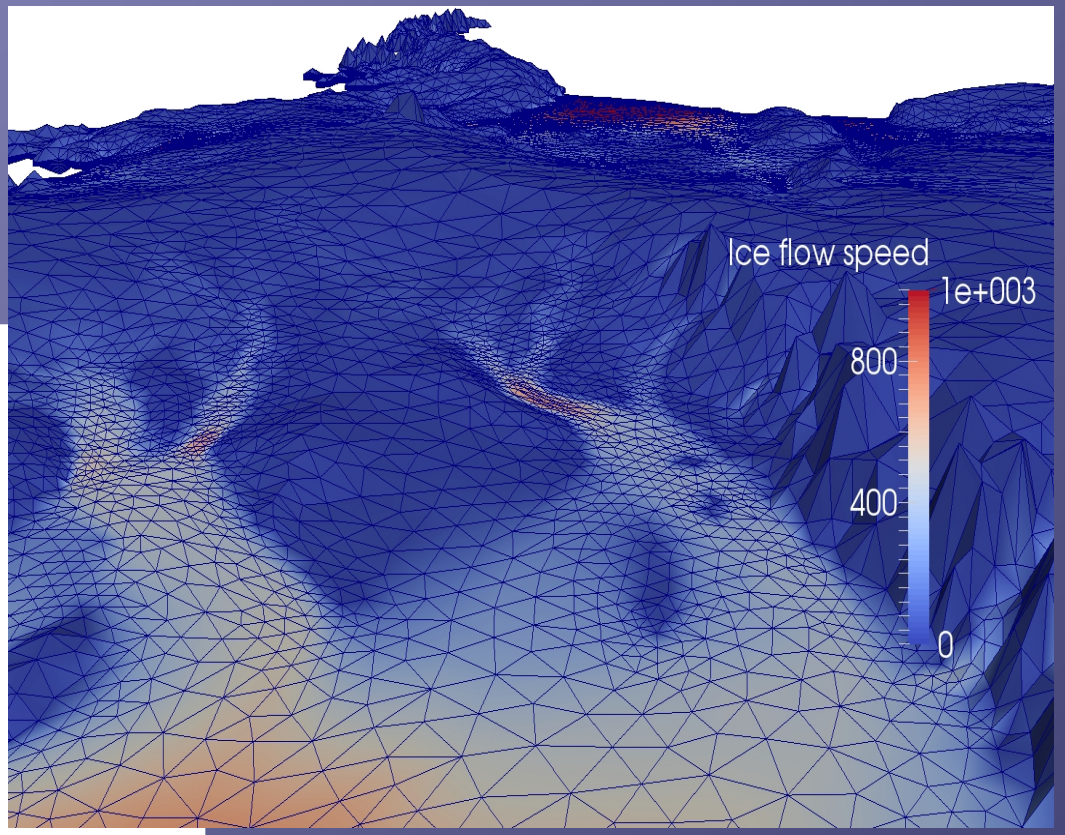

Top level driver

Coupler components exchange data and call regridding routines

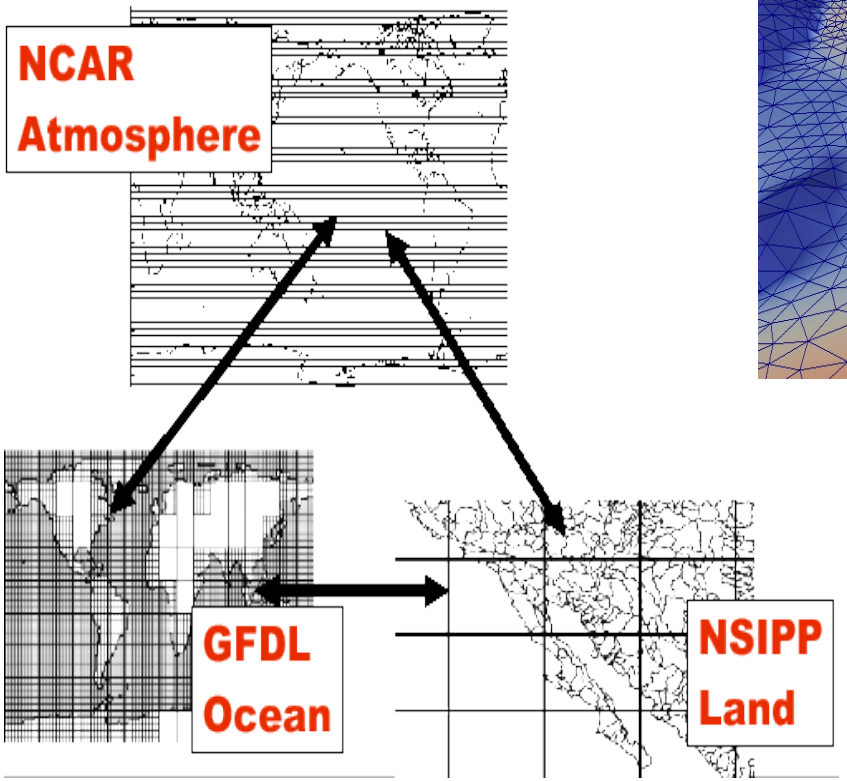
Gridded components wrap individual models or sub/models.

Plots/quote from ESMF web site https://www.earthsystemcog.org/projects/esmf/

# ESMF regridding options include unstructured meshes



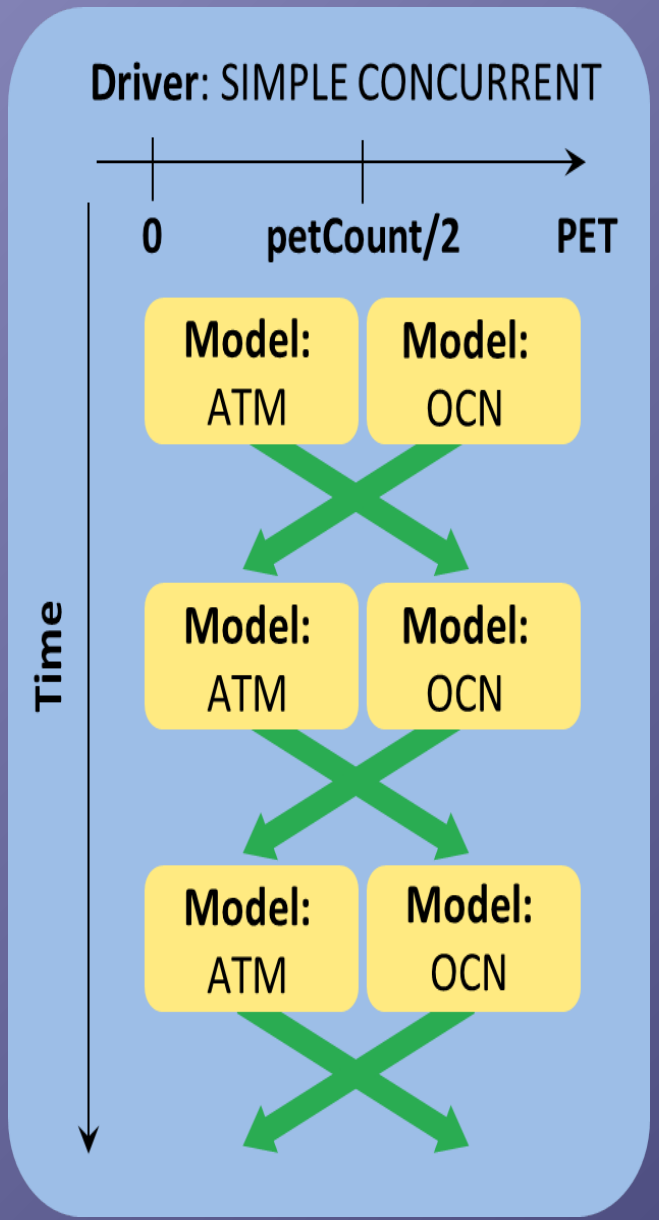

Elmer/Ice example mesh

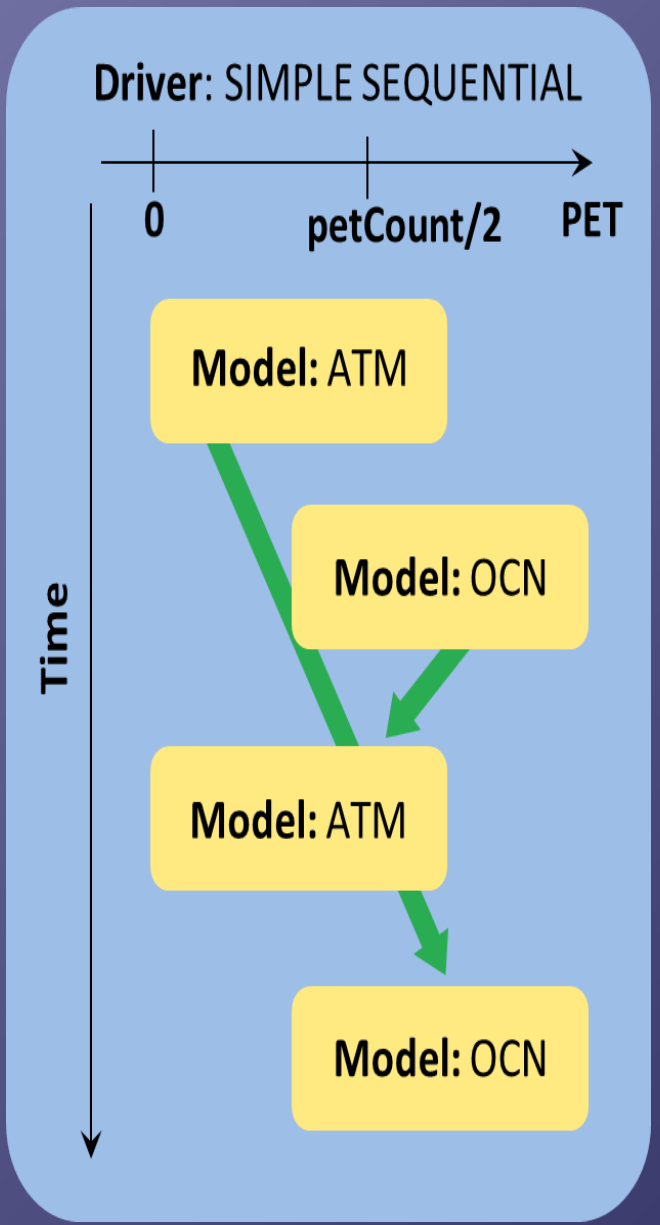



ESMF example grids

ESMF parallelism options: concurrent vs sequential (combinations and more complex models are possible)

ESMF terminology: Persistent Execution Thread (PET) is an abstraction of the concept of a process



# FISOC Concept

Concept: flexible coupling framework to allow Ice Sheet Models (ISMs) and Ocean Models (OMs) to interact at run time

Key features:

- Regridding capabilities between different types of grids/meshes
- Flexibility: relatively easy to couple in new ISMs or OMs
- Asynchronous coupling options due to differing ice and ocean timescales
- Based on the Earth System Modelling Framework (ESMF)

Participating models:

- Regional Ocean Modelling System (ROMS)
- Elmer/Ice (Stokes and more)
- FISh (Frank‘s Ice Shelf model – toy model for testing)

# Elmer/Ice

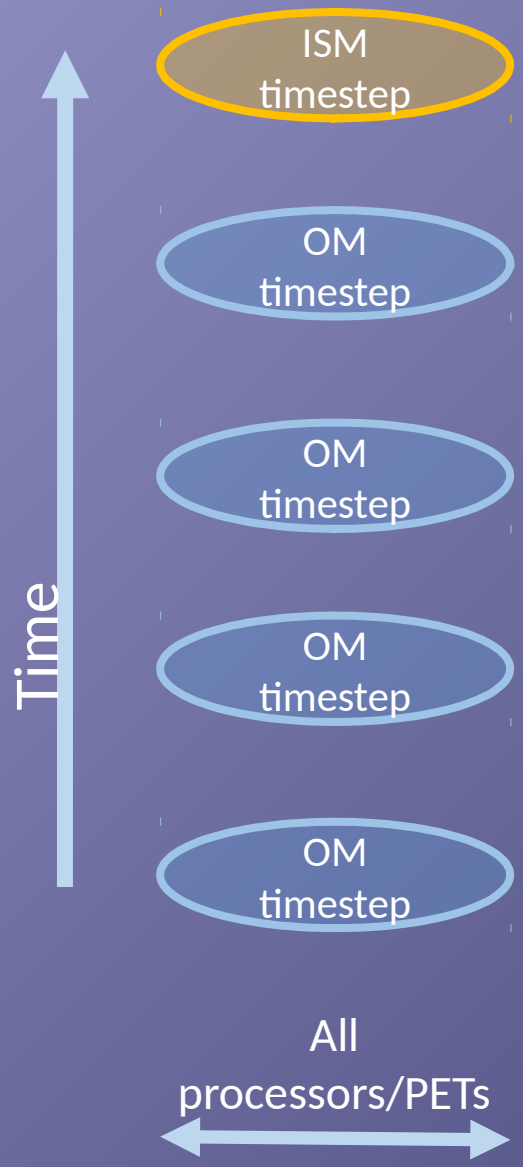

Elmer is an open-source, parallel, 3D, finite element code.

Elmer/Ice is based on Elmer and includes developments related to glaciological problems.

Solves full Stokes equations, also includes common approximations Shallow Ice Approximation (SIA) and Shallow Shelf Approximation (SSA).

Includes different friction laws and ice rheologies, grounding line dynamics, solvers for stress and strain rates ….

# Asynchronous coupling in FISOC




Ocean Model (OM) requires finer temporal resolution

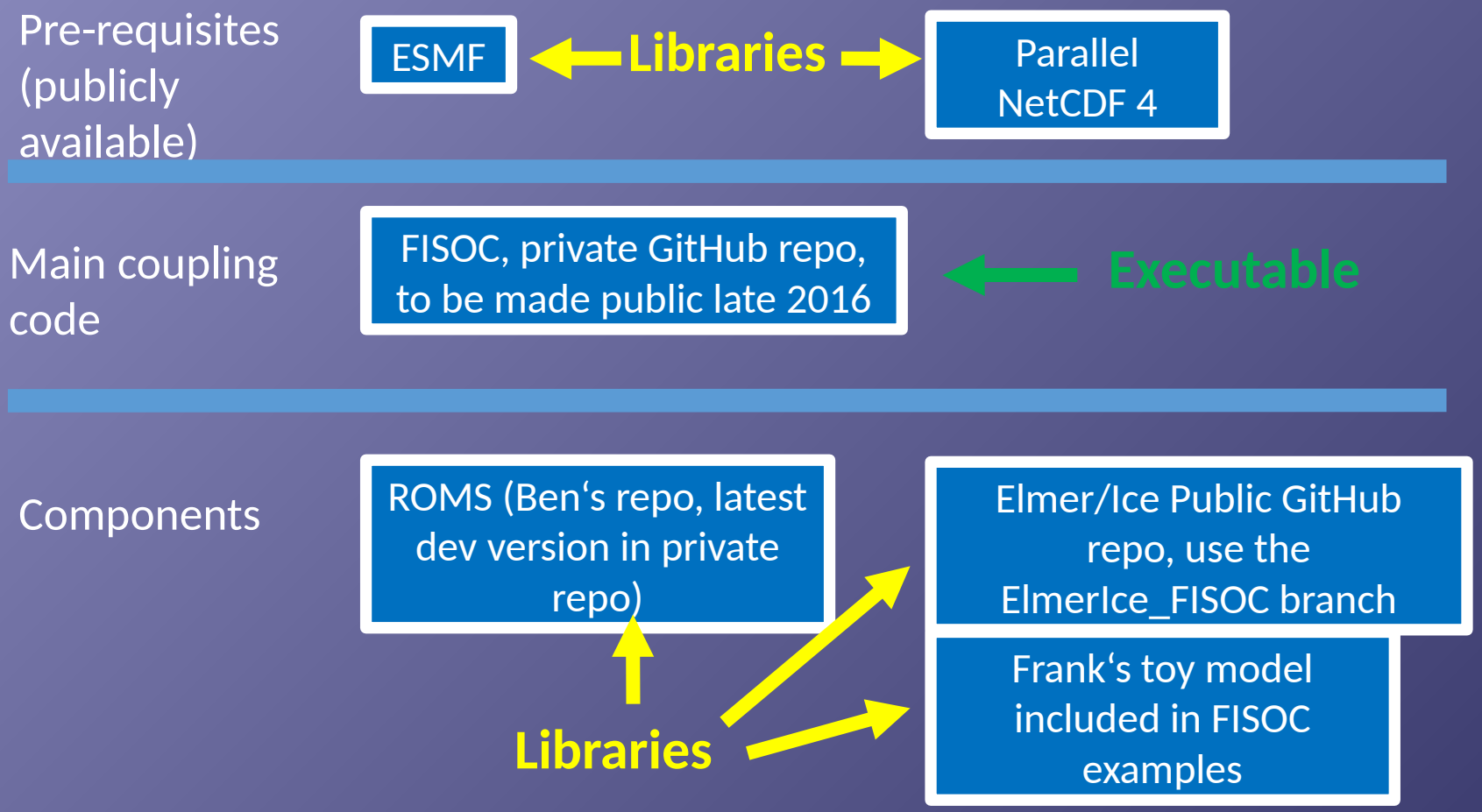
FISOC assumes the Ice Sheet Model (ISM) timestep is an exact multiple of the OM timestep.

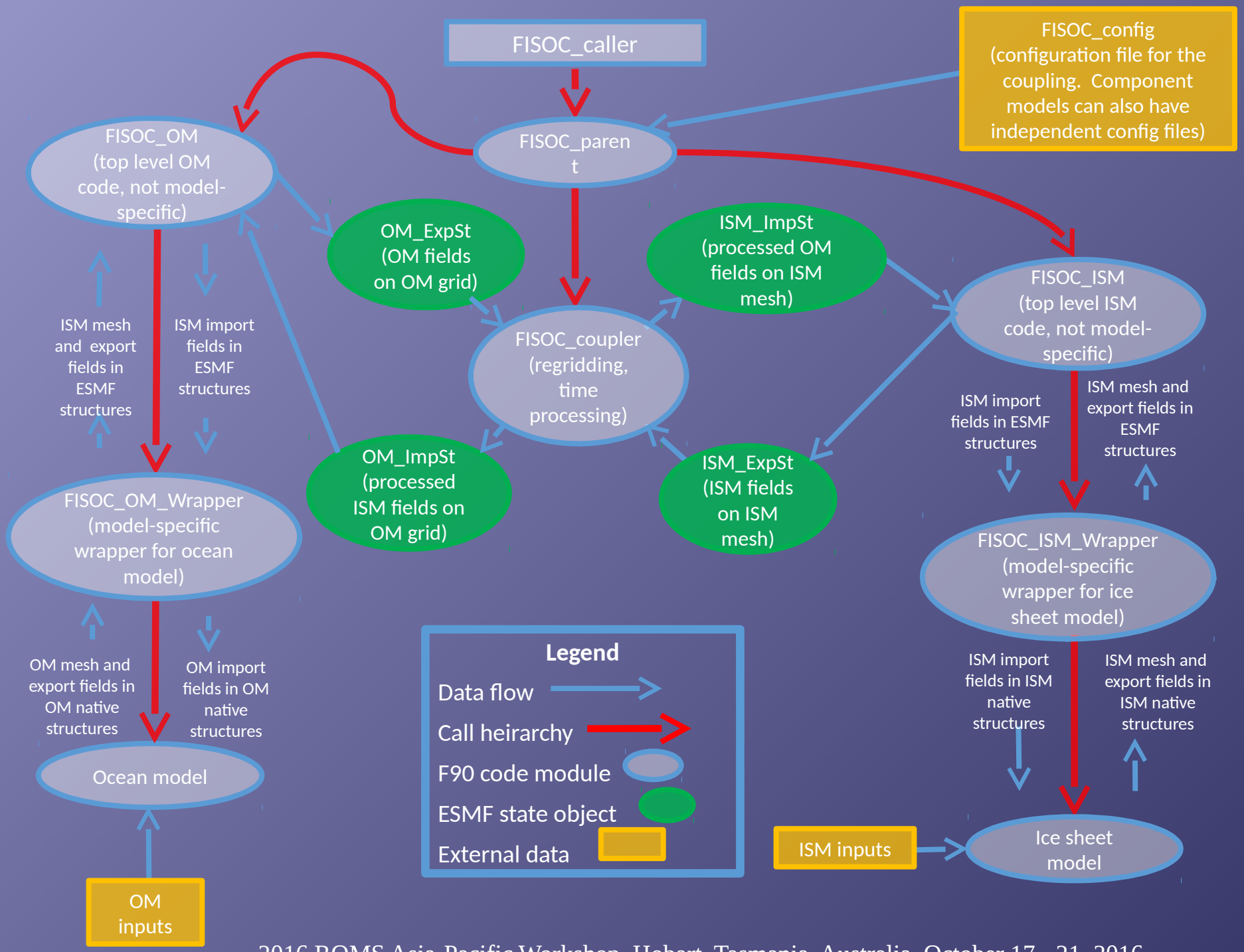
Sequential coupling (both components run alternately on all processors).

ISM can pass geometry rate instead of geometry snapshot to reduce shock to the OM (multiple options being implemented in FISOC).

Irregular steady state asynchronous coupling may be implemented for very long timescale simulations.

# FISOC Code organisation




FISOC_caller
FISOC_config (configuration file for the coupling. Component models can also have independent config files)
FISOC_OM (top level OM code, not model-specific)
FISOC_parent
OM_ExpSt (OM fields on OM grid)
ISM_ImpSt (processed OM fields on ISM mesh)
FISOC_ISM (top level ISM code, not model-specific)
ISM mesh and export fields in ESMF structures
ISM import fields in ESMF structures
FISOC_coupler (regridding, time processing)
ISM import fields in ESMF structures
ISM mesh and export fields in ESMF structures
OM_ImpSt (processed ISM fields on OM grid)
ISM_ExpSt (ISM fields on ISM mesh)
FISOC_OM_Wrapper (model-specific wrapper for ocean model)
FISOC_ISM_Wrapper (model-specific wrapper for ice sheet model)
Legend
Data flow
Call heirarchy
F90 code module
ESMF state object
External data
OM mesh and export fields in OM native structures
OM import fields in OM native structures
ISM import fields in ISM native structures
ISM mesh and export fields in ISM native structures
Ocean model
ISM inputs
Ice sheet model
OM inputs

# To run you model through FISOC

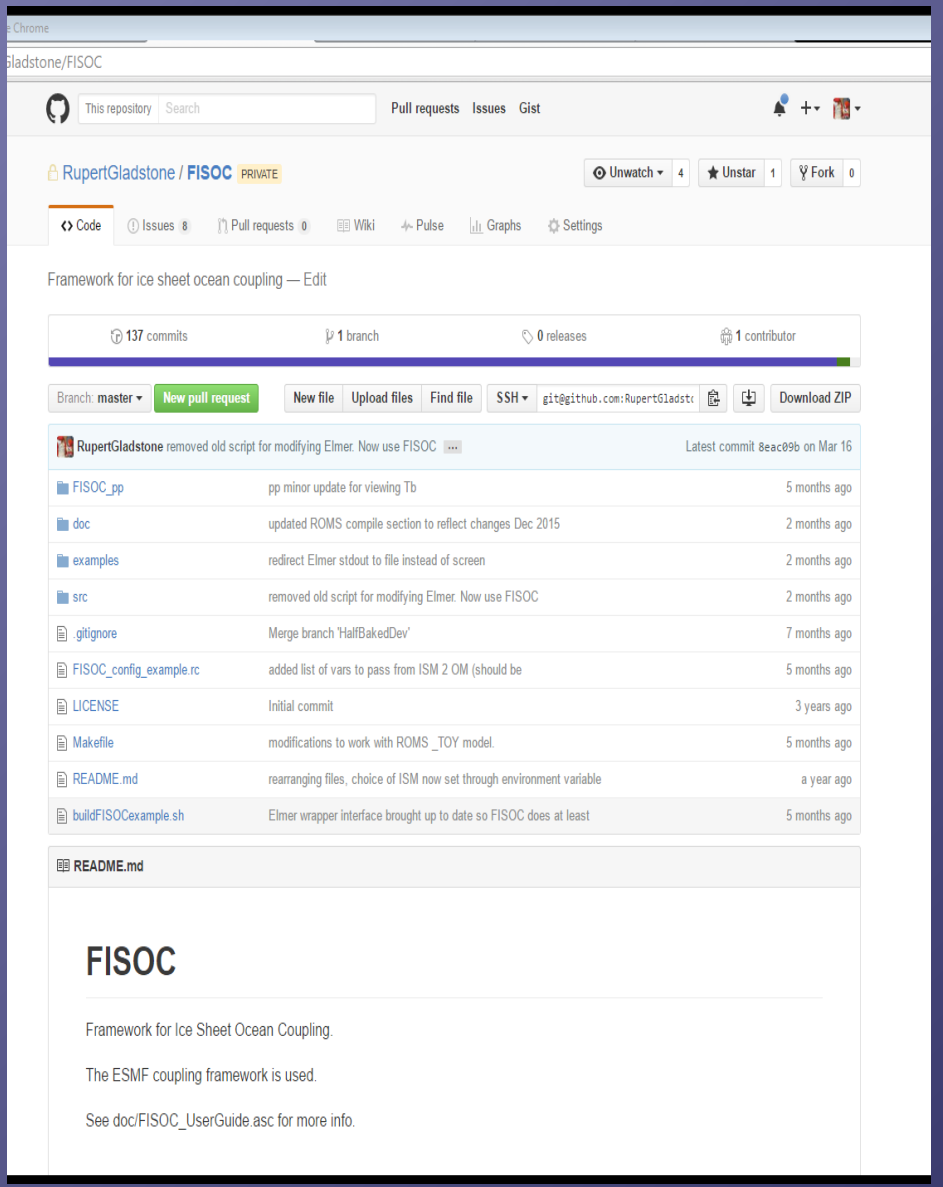
- ESMF compliance: structured to have initialise, run and finalise routines.
- Understand ESMF mesh/grid and field structures sufficiently to write code to put your model‘s variables into an ESMF field object.
- Write a model-specific wrapper to stick in the FISOC framework (you can start with copy and paste from existing wrapper).

# Github Repository

We‘ve got a github repository….

Currently private, should go public late 2016, but let us know if you want access before then.

We‘re using GitHub for raising issues, and will start using the wiki there soon.



# Manual under development

Framework for Ice Sheet - Ocean Coupled modelling (FISOC) Manual

Rupert Gladstone (RupertGladstone1972@gmail.com)
Lenneke Jong Ben Galton-Fenzi

Version 0.2, April 2016

Contents

# Development time scales

Development was mostly carried out in 2015.

Now: FISOC is currently under development. It is functional but undergoing change. Ask for access to private repository if you want to be involved at this stage.

Late 2016/early 2017: we anticipate contributing results to MISOMIP1 with ROMS and Elmer/Ice.

Also late 2016/early 2017: we'll tag a beta release. At this point we'll make the repository public. Until then expect frequent change and pull from the repository often if you want to use FISOC. Maybe GMD paper.

# Sample FISOC output

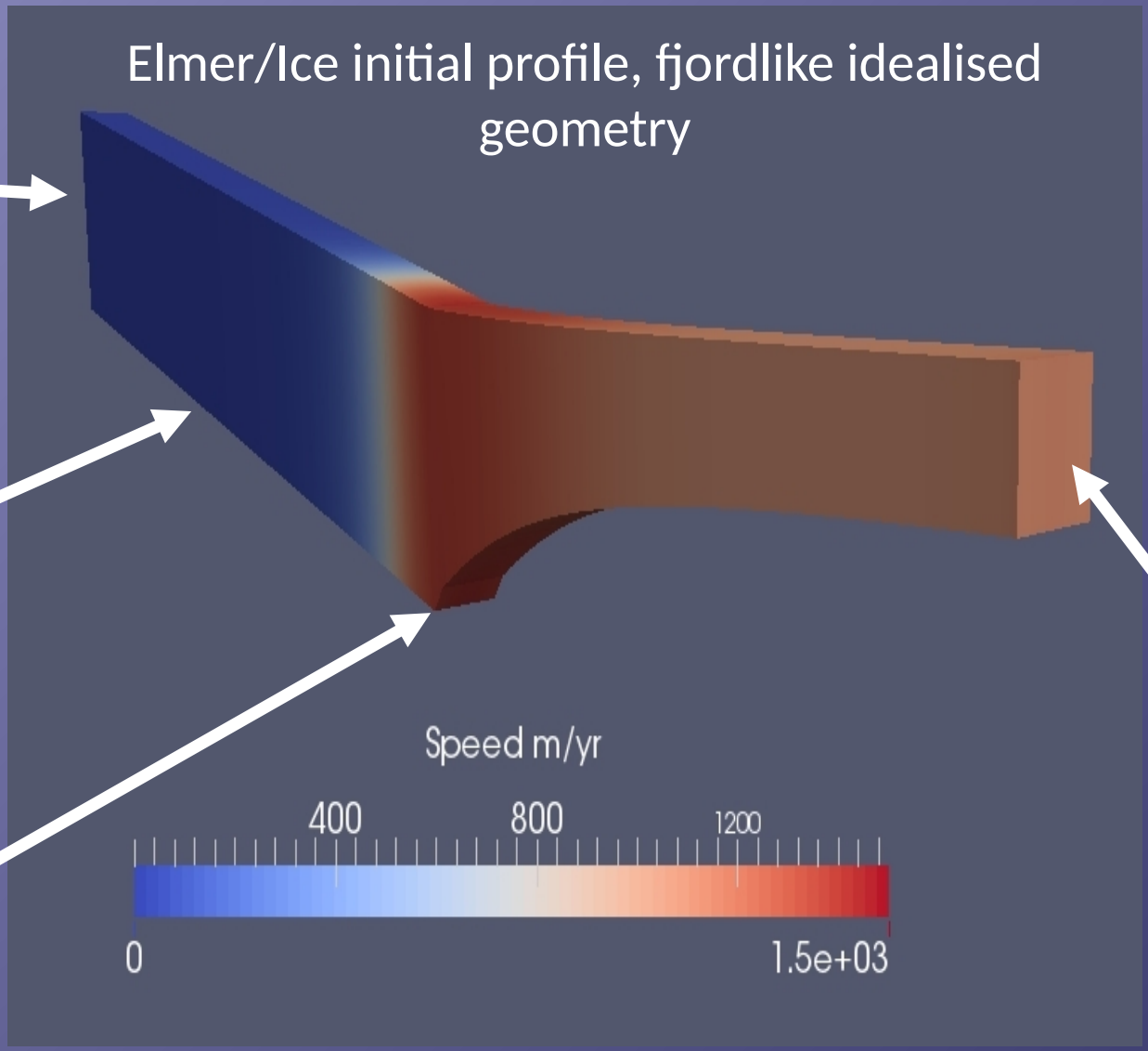
Inland boundary (Dirichlet zero velocity)

Linear downsloping bed (pressure dependent coulomb cavity sliding law)

Grounding line (contact condition)

Side walls: zero normal velocity, lateral drag with Weertman like sliding law)

ocean boundary (water pressure condition)

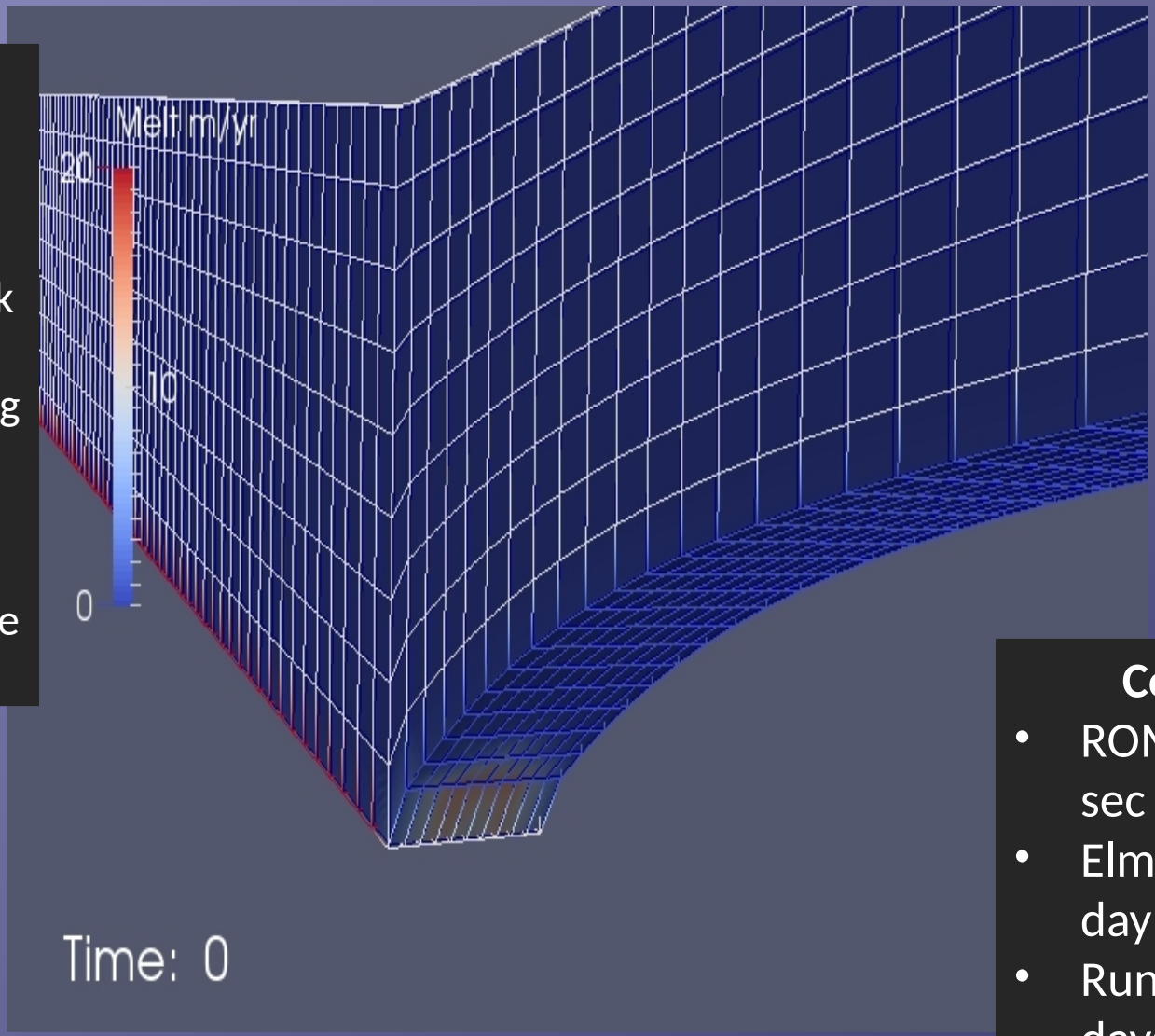


# Grounding and Melting

**Key**

Wireframe: Elmer/Ice grounded mask (grounded in red and floating in blue).

Solid colour: ROMS melt rate (red = 20 m/yr




**Coupling**

- ROMS dt = 300 sec
- Elmer/Ice dt = 1 day
- Run length = 18 days

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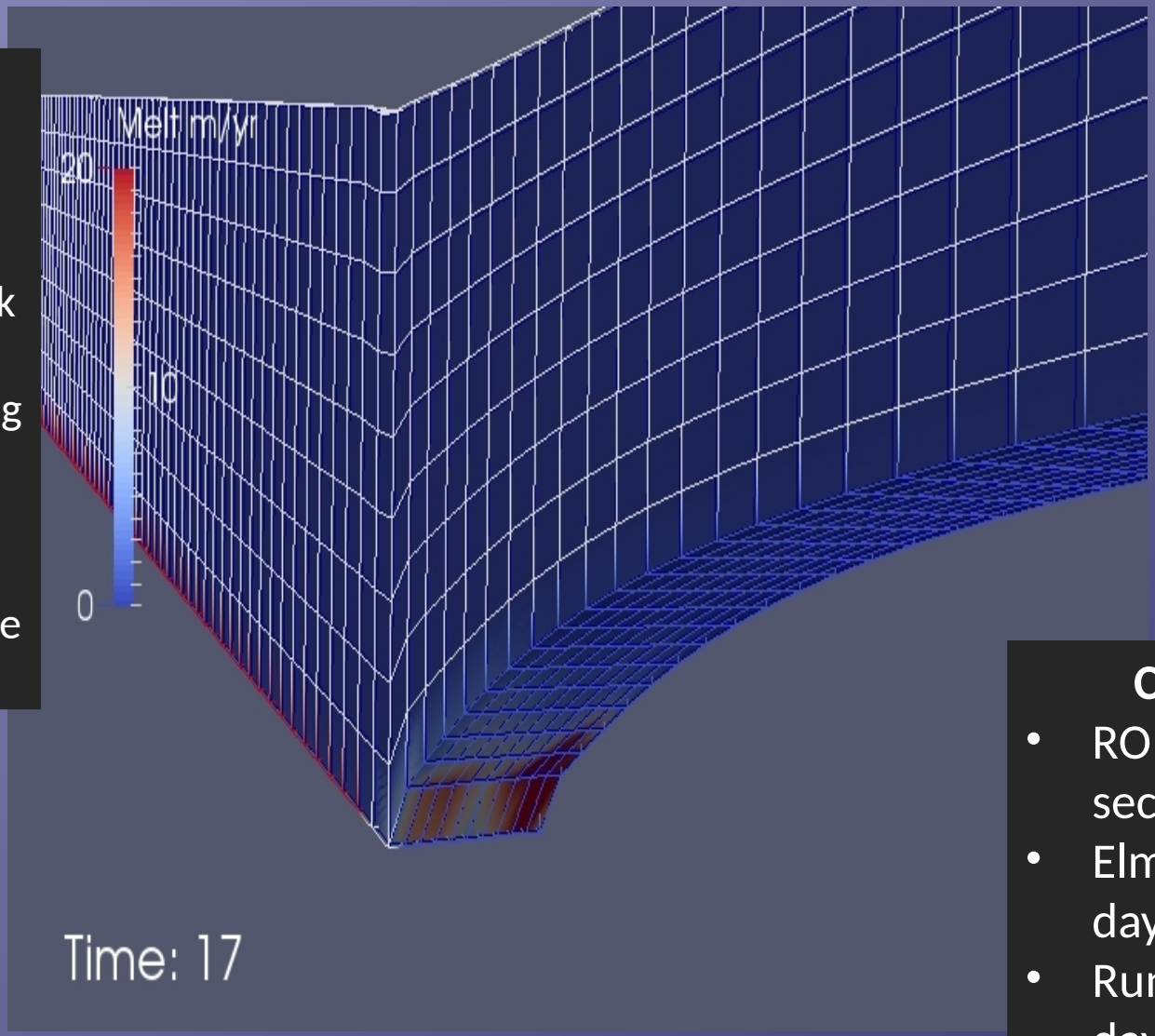


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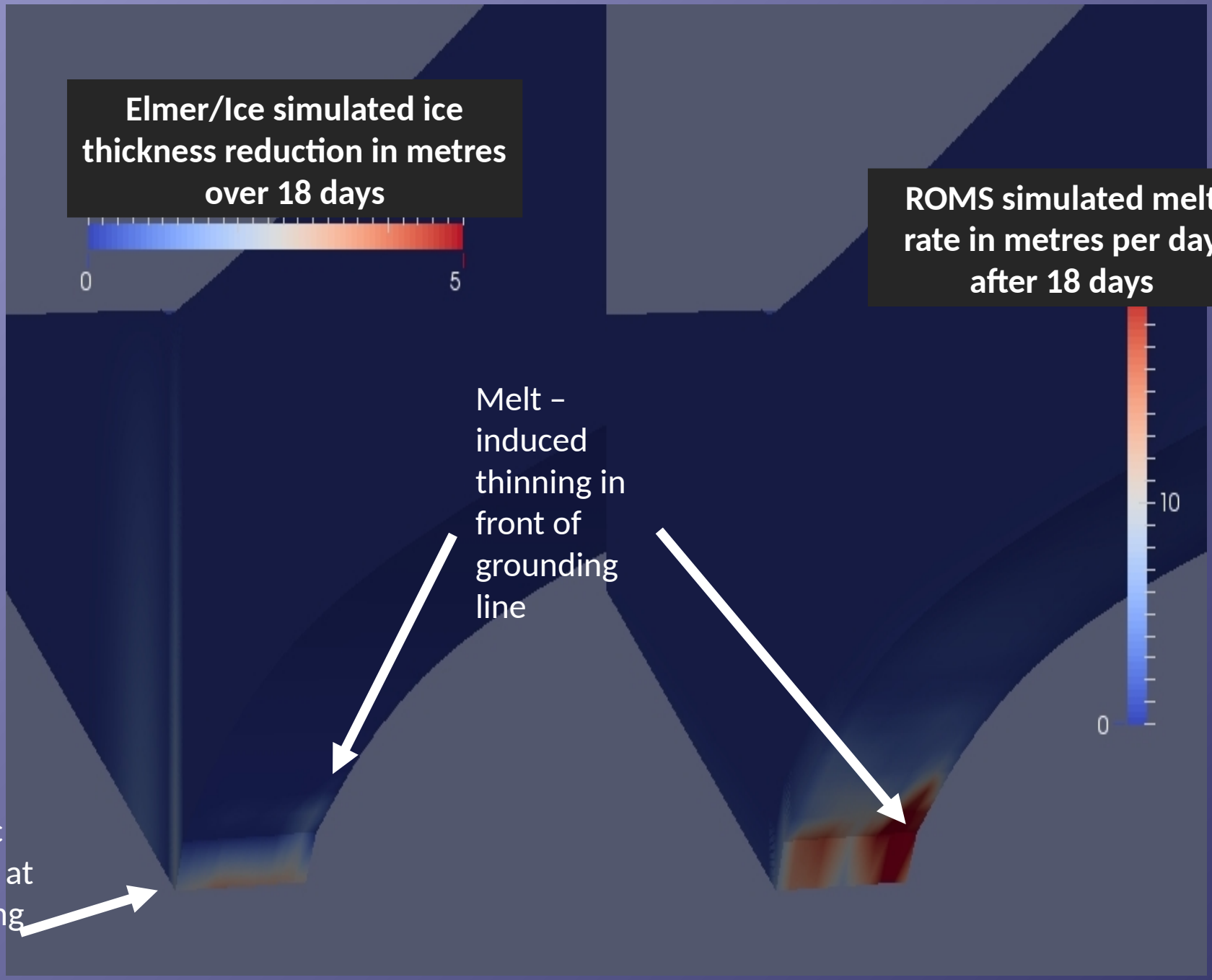
Elmer/Ice simulated ice thickness reduction in metres over 18 days
0
5
ROMS simulated melt rate in metres per day after 18 days
10
0
Melt – induced thinning in front of grounding line
Dynamic thinning at grounding line

# Final thoughts

- FISOC works… and will work better by the end of the year.
- We have various Antarctic and idealised applications in mind for FISOC.
- If you want to use FISOC with ROMS and Elmer/Ice let us know.
- Next developments: triangular meshes, MISOMIP1 experiments with SSA