Progress towards coupling ice sheet and ocean models

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FISOC overview

FISOC: A Framework for Ice Sheet - Ocean Coupling

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Type	Name	Notes
OM	ROMS	3D, gridded, sigma coord
OM	FVCOM	3D, unstructured mesh, sigma coord
ISM	Elmer/Ice	3D, full Stokes and shallow models
ISM	Icepack	2D, higher order and shallow models

- **Framework for Ice Sheet - Ocean Coupling (FISOC)**
- **Key features:**
  - **Provide flexible swapping between different ice sheet models or between different ocean models**
  - **Provide options for handling differing ice and ocean time scales (fully synchronous /semi-synchronous).**
  - **Provide access to ESMF tools, including multiple regridding and interpolation options between regular grids and unstructured meshes.**
  - **Grounding line movement is implemented using geometry change rates and a modified wet/dry scheme in the ocean component, with multiple options for updating cavity geometry.**
  - **Provide flexible parallelisation options. Currently sequential coupling is implemented but any combination of sequential and concurrent parallelisation is possible with minimal coding effort.**
  - **FISOC can be embedded within any ESMF-based modelling system**
  - **Currently couples ROMS, FVCOM to Elmer/Ice, ICEPACK**
- **Future developments could include:**
  - **Additional components (e.g. atmosphere, subglacial hydrology, sea ice).**
  - **Thermodynamic coupling**
  - **Concurrent parallel coupling, or a mix of sequential/ concurrent parallel coupling.**

COLD + BNU group

Strength and shortcoming of FISOC

Strength

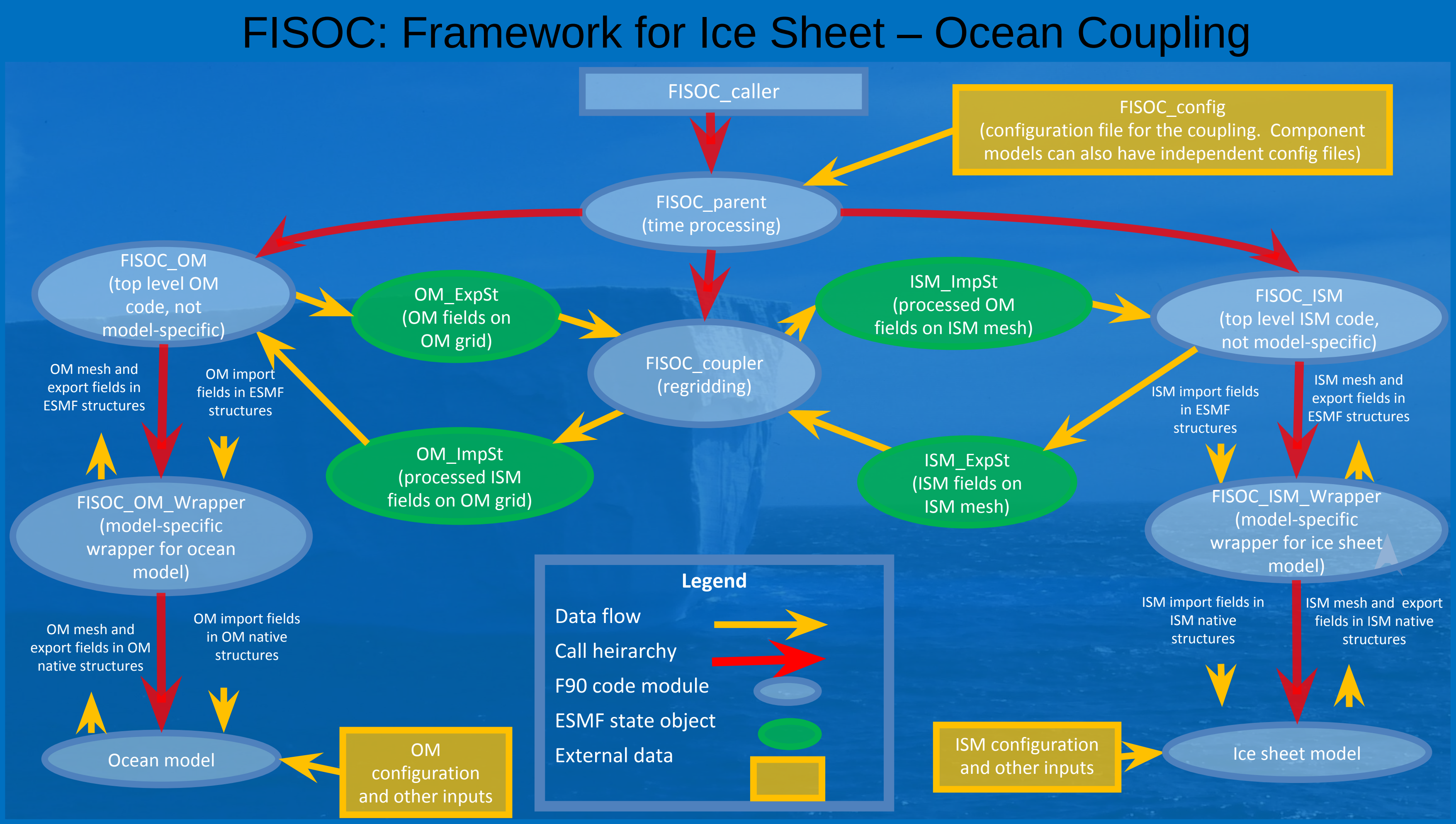
Flexible

- It uses ESMF and can access any ESMF regridding methods.
- Modular structure makes it fairly easy to couple new models into FISOC.
- Most decisions about regridding methods, time stepping, which variables to exchange, can be made through a run-time configuration file.
- Different timescale options: fully synchronous, semi-synchronous and asynchronous
- While parallel coupling is currently sequential, it would require only modest effort to make it possible to use any combination of sequential/concurrent coupling.

Efficient: ESMF regridding methods are fully parallelised.

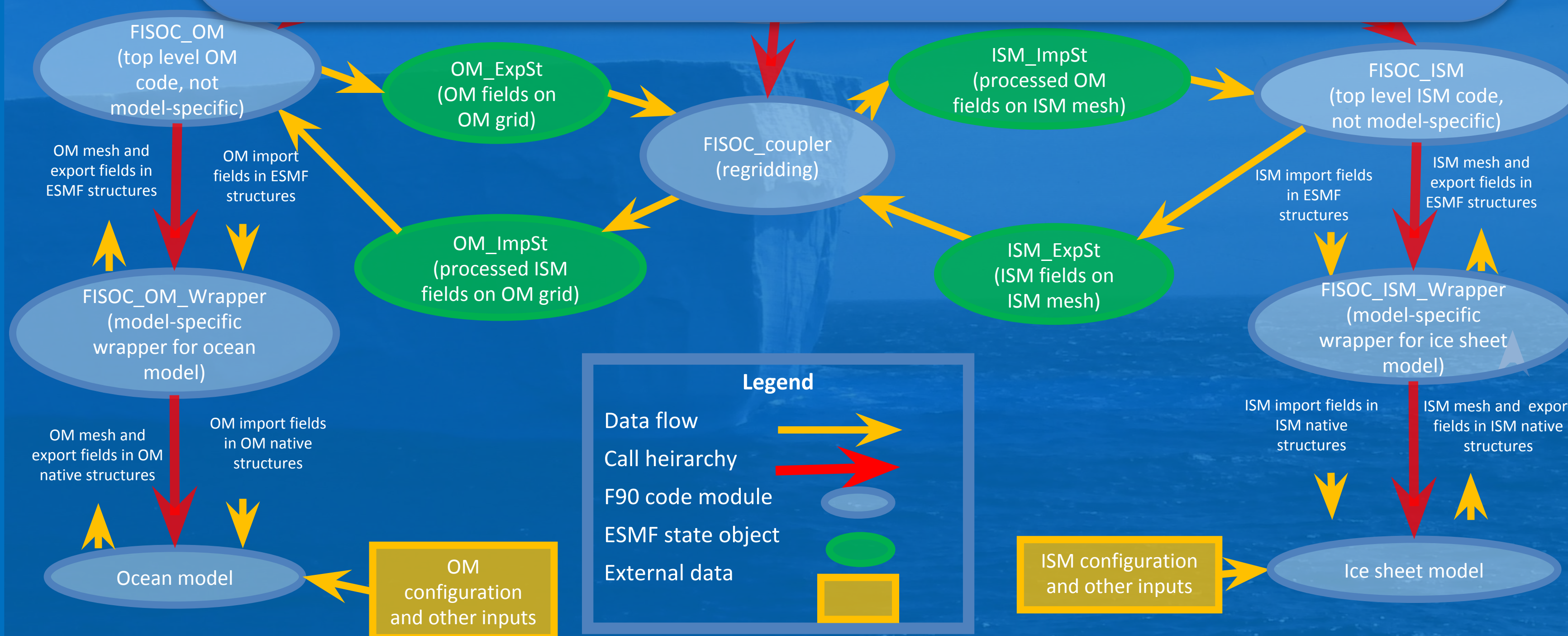
The ocean models (ROMS, FVCOM) use sigma coordinate system resolve the ocean circulation (e.g. buoyant plumes) well near the ice-ocean interface.

FISOC structure



Ice sheet and Ocean Wrappers

- Used to call model's initialize, run, and finalize routines as required.
- Used to convert the model grid or mesh to ESMF format.
- Is the communicator, responsible for reading from or writing to the required variables between models, converting between the model native data structures and ESMF data structures.
- Further processing of variables, like calculating the cavity change rate or basal melting rate, are implemented by the original ice sheet and ocean model.



Strength and shortcoming of FISOC

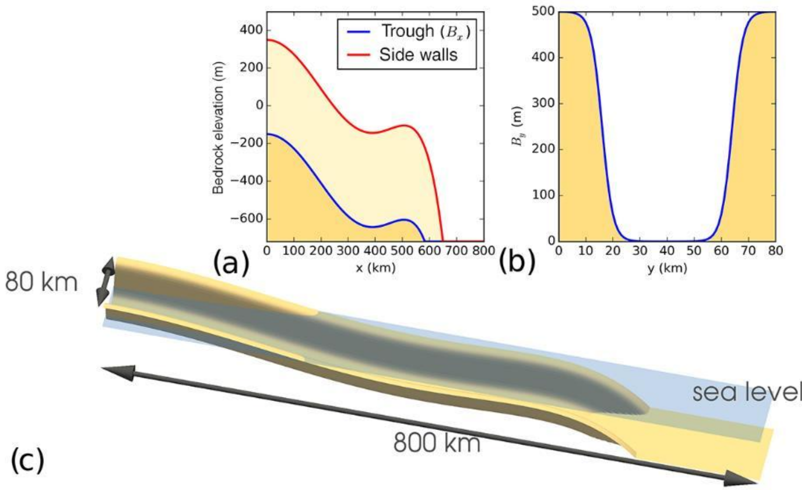
Shortcoming

- Ocean models (ROMS, FVCOM) are sigma coord models vulnerable to pressure gradient errors in the presence of steep gradients in the geometry.
- Not intended to be used for glaciers with calving fronts (e.g. Greenland) some modifications and testing to allow coupling through a vertical ice cliff, but achievable with modest effort. Full 3D coupling to a complex 3D front geometry would be very challenging.
- Coupling in a new model requires ESMF compatibility more code intervention in the new model is needed

FISOC applications: MISOMIP1

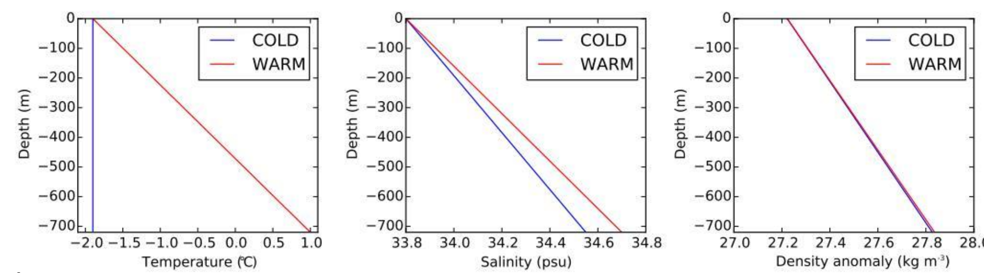
Experimental design for three interrelated marine ice sheet and ocean model intercomparison projects: MISMIP v. 3 (MISMIP+), ISOMIP v. 2 (ISOMIP+) and MISOMIP v. 1 (MISOMIP1)

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]



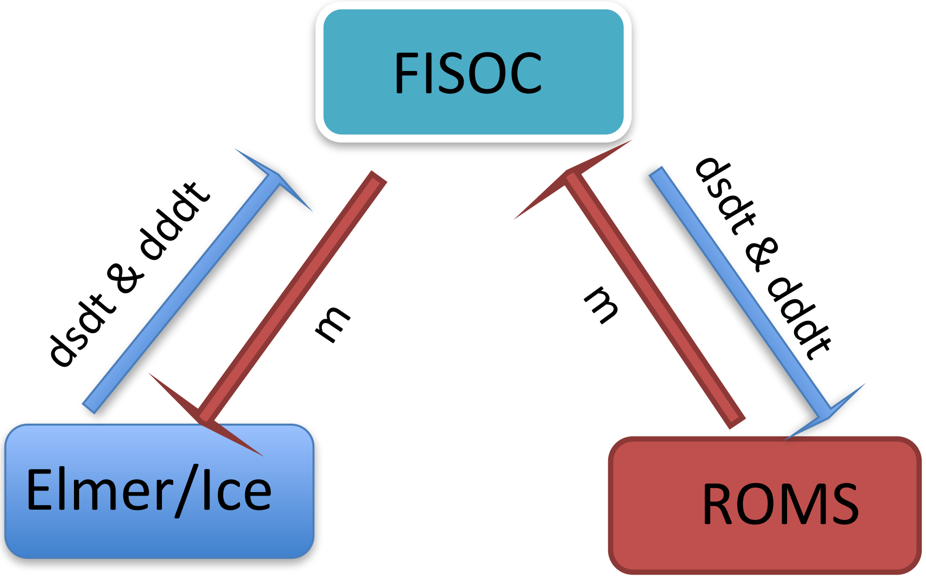
Qualitative similarity to the Pine Island Glacier Ice Shelf and the adjacent Amundsen Sea region □ explore the effects of changes in ocean conditions on ice dynamics and basal melting

MISOMIP1	IceOcean1r	100-year coupled run with no dynamic calving, COLD initial conditions and WARM forcing
MISOMIP1	IceOcean1ra	100-year coupled run from end of IceOcean1r with no dynamic calving and COLD forcing

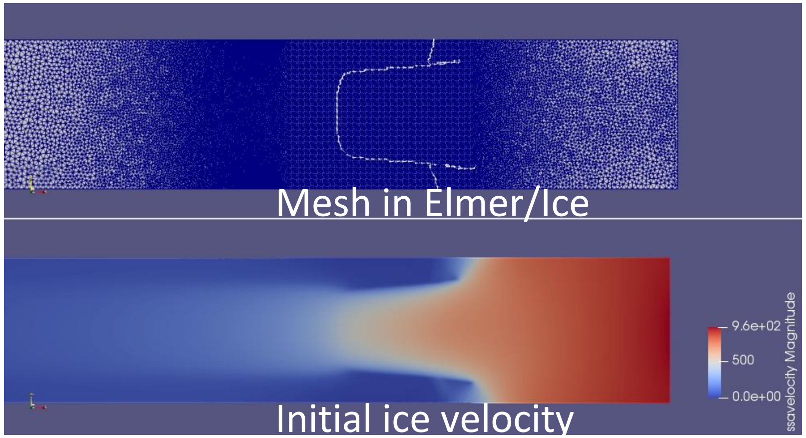


WARM and COLD temperature, salinity, and density profiles used in MISOMIP1 (Asay-Davis et al., 2016)

FISOC applications: MISOMIP1



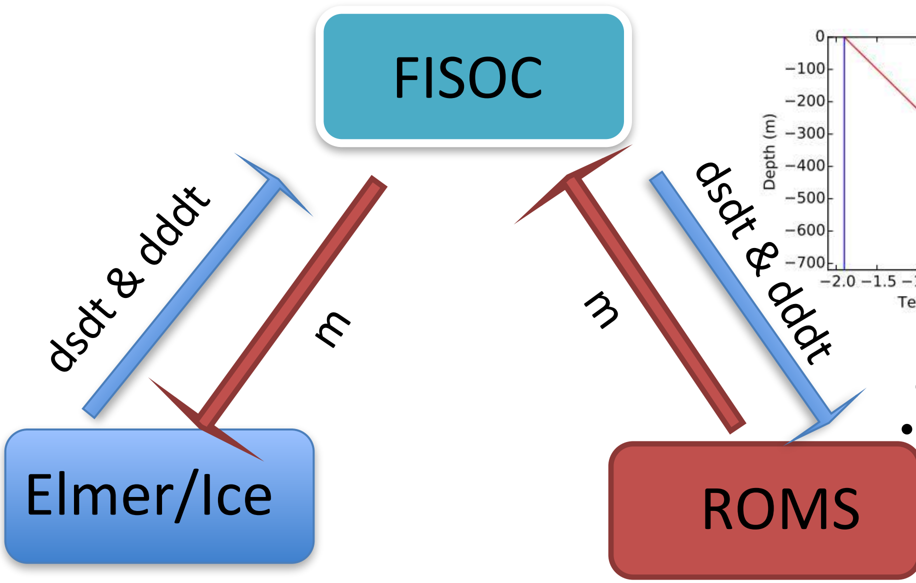
dddt: ice draft change rate
dsdt: ice surface elevation change rate
m: basal melt rate

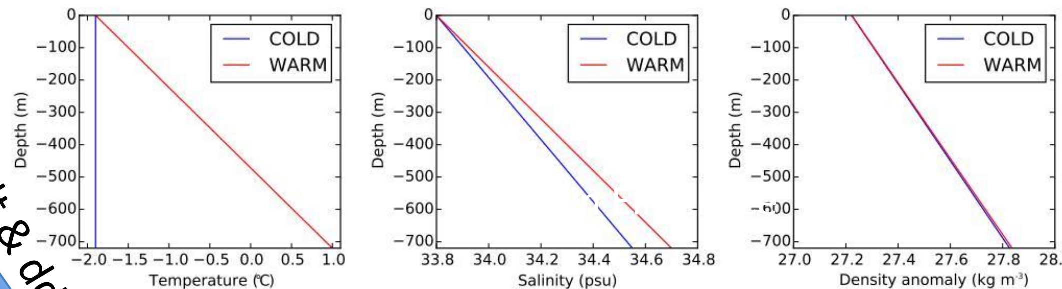


Setup of Elmer/Ice

- Shallow Shelf Approximation (SSA) model
- Initial condition steady state ice sheet
- Constant ice temperature
- Thermal conductivity of ice = 0 No heat flux into ice at the ice-ocean interface only flux across the ice ocean interface is of meltwater

FISOC applications: MISOMIP1





dddt: ice draft change rate
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Setup of ROMS

- Initial state
  - steady state ice topography from ice sheet model
  - COLD salinity and temperature profiles
  - cold enough to produce low melt rates (~ 0.2 m/yr) that are approximately consistent with the ice sheet's initial state
- Only freshwater fluxes melting water
- WARM forcing strong melting and rapid grounding line retreat

FISOC applications: MISOMIP1

Setup of FISOC□ FISOC_config.rc

- Configuration files for both ice and ocean components
- Grid types and regridding method
- Cavity update option
- Variables used for communication
- Output files
- Timestepping □ Semi-synchronous

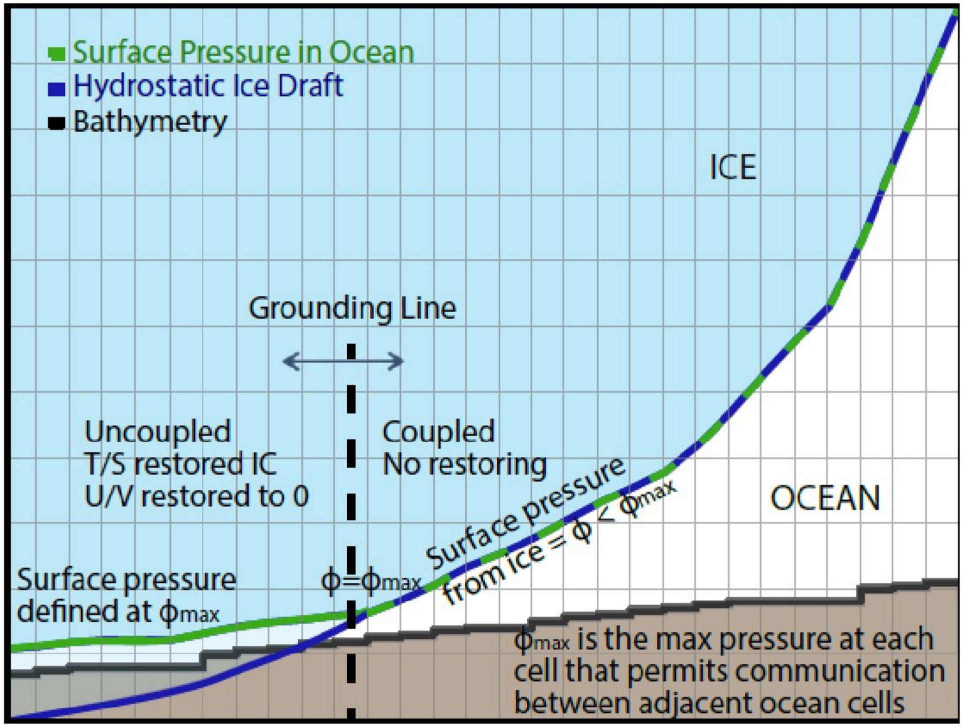
  dt_ice = 1 month, dt_ocean = 100 s

FISOC_config.rc

```
ISM_configFile:      Ice1r.sif
FISOC_ISM_ReqVars:   ISM_z_l0 ISM_thick ISM_gmask
ISM_varNames:        Zb H GroundedMask
FISOC_ISM_DerVars:   ISM_z_lts ISM_z_l0_previous ISM_z_lts_previous ISM_dddt ISM_dsdt


ISM2OM_vars:         #ISM_dddt #ISM_dsdt  # ISM_dTdz_l0 # ISM_z_l0_linterp #
ISM_maskOMvars:      .TRUE. # set the basal melting mask for the ice part
ISM2OM_init_vars:    .FALSE.
ISM_stdoutFile:      ./EI_out.asc
ISM_gridType:        ESMF_mesh
ISM2OM_regrid:       ESMF_REGRIDMETHOD_BILINEAR
ISM_BodyID:          1

OM_configFile:      ocean_isomip_plus_ocn3.in
OM_stdoutFile:      ./ROMS_output/ROMS_stdout.asc
OM_writeNetcdf:      .TRUE.
OM_NCfreq:           all
output_dir:          ./FISOC_output

OM_cavityUpdate:     CorrectedRate # Linterp
FISOC_OM_ReqVars:    OM_dBdt_l0 OM_z_l0 OM_bed OM_z_lts #OM_temperature_l0
OM_ReqVars_stagger:  CENTER CENTER CENTER CENTER #CENTER
OM2ISM_vars:         #OM_dBdt_l0
OM_initCavityFromISM: .TRUE.
OM_gridType:         ESMF_grid
OM_WCmin:            20.0
OM2ISM_regrid:       ESMF_REGRIDMETHOD_BILINEAR

OM_outputInterval:   1
OM_dt_sec:           1296000 #2592000 # one month oneyear=360*24*60*60
dt_ratio:            1 # 720   # 86400 secperday / 1200 sec = 72
start_year:          1
start_month:         1
end_year:            51
end_month:           1

verbose_coupling:    .TRUE.
Profiling:           .TRUE.
```

Grounding line movement

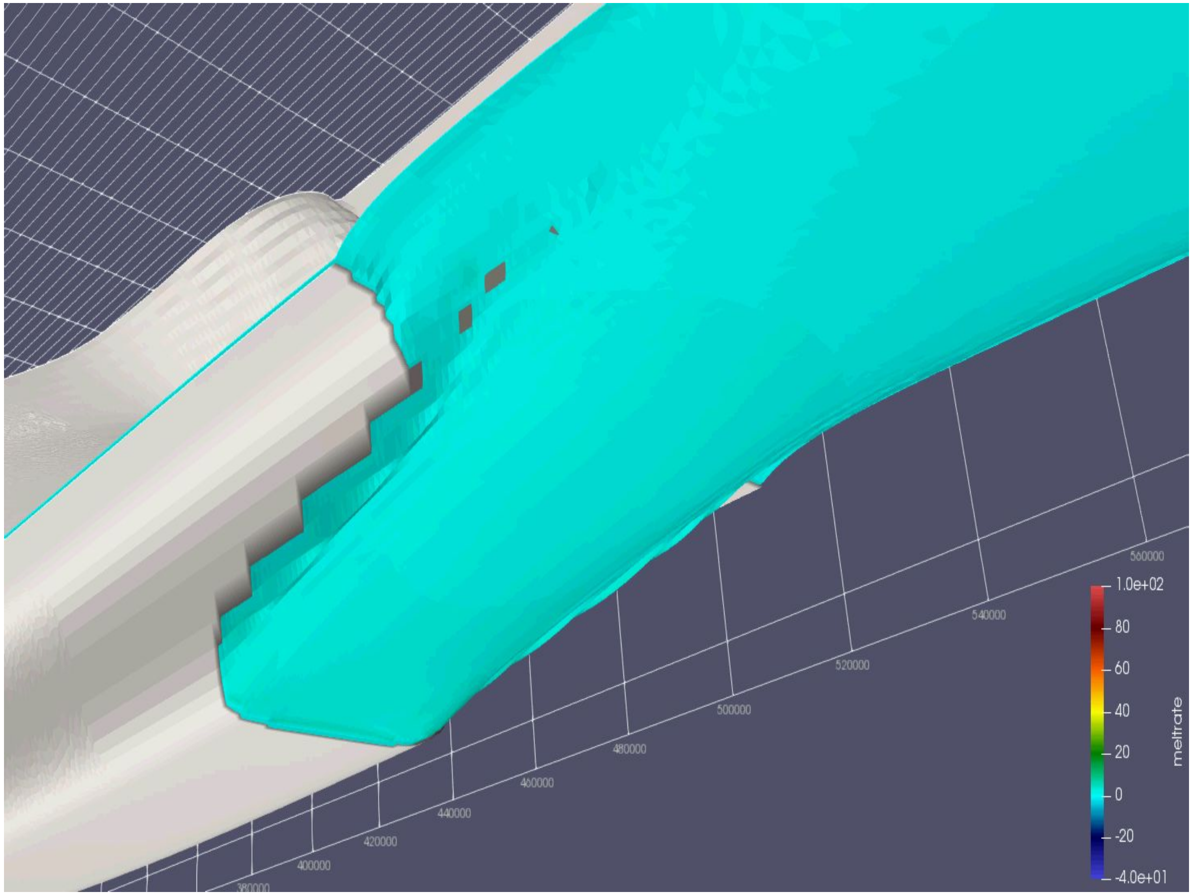
The ”thin film” approach to wetting and drying



(Snow et al. (2017), GRL)

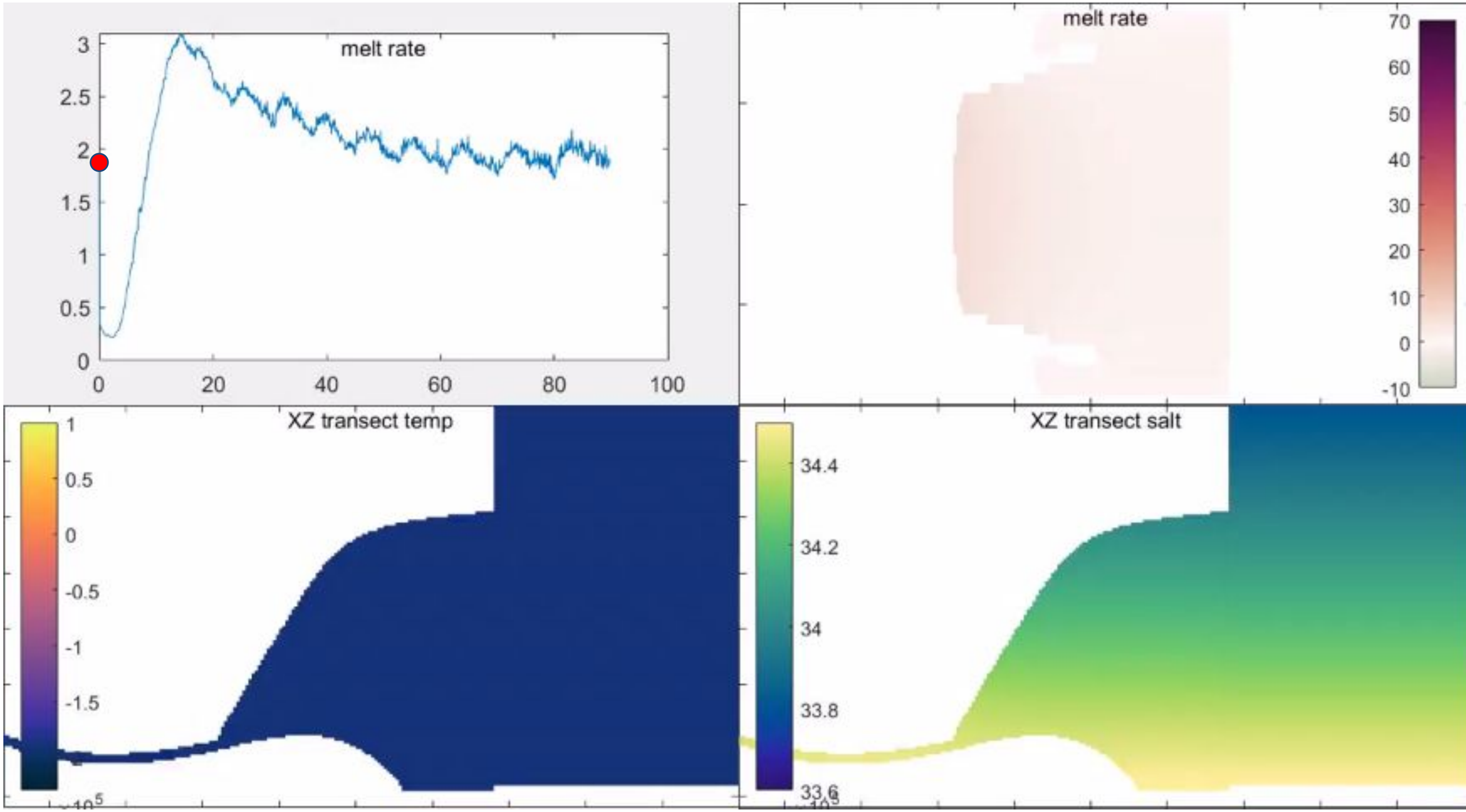
- **“thin-film” approach (Medeiros and Hagen, 2013)**: enforce a thin ocean layer everywhere beneath grounded ice, which could potentially unground.
- The layer is defined by a max surface pressure field and restored to initial tracer conditions with zero velocities and zero heat flux into the ice.

Idealised MISOMIP1 simulation (IceOcean1)

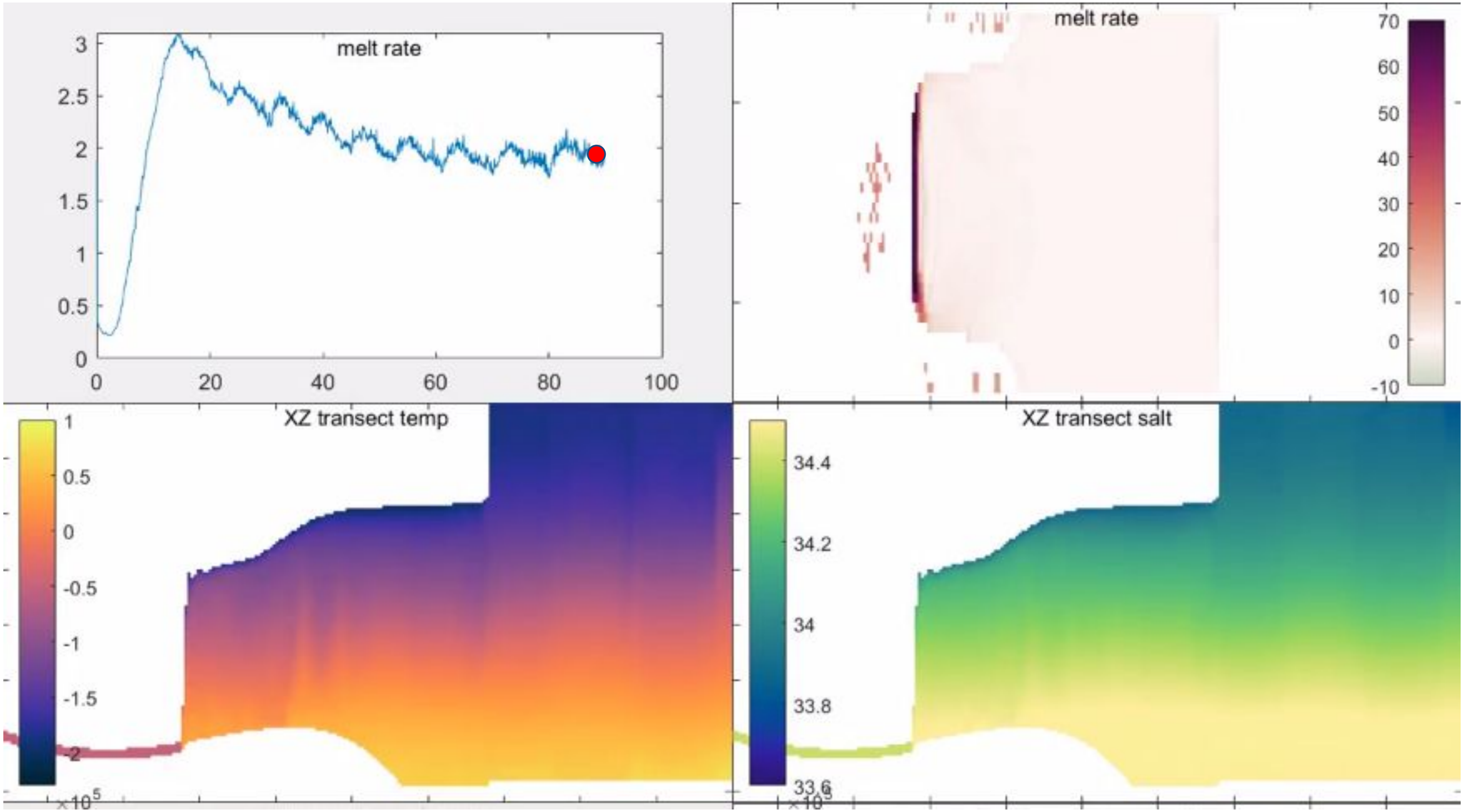


IceOcean1r:
100 year coupled run with COLD initial condition and WARM forcing

Initial time

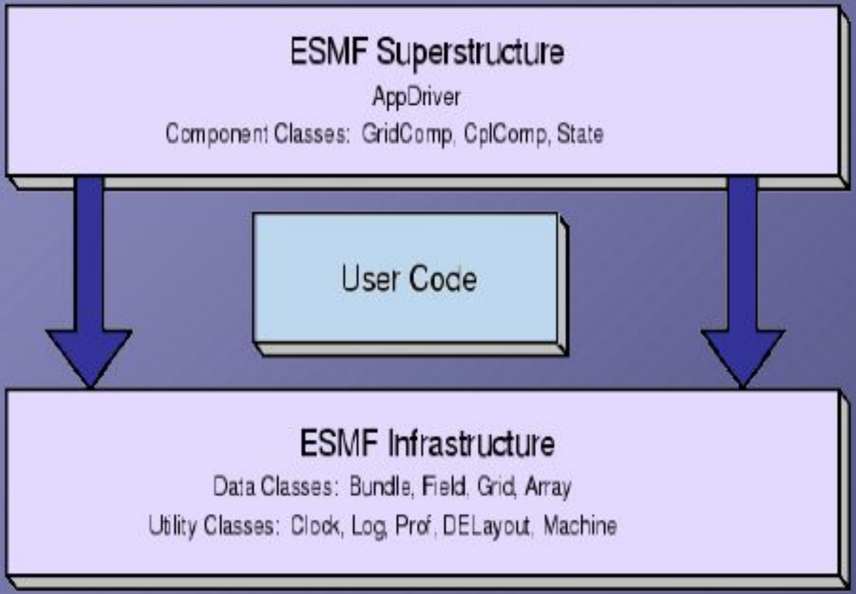


Final time



Solution appears sensitive to the choice of values in the “dry” cells (not shown).

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)