Summary of CISM dynamical core and physics development efforts

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U.S. DEPARTMENT OF ENERGY
Office of Science

Los Alamos NATIONAL LABORATORY EST. 1943

Climate, Ocean, and Sea Ice Modeling Project

Summary of CISM dynamical core development efforts**

- SEACISM
- BISICLES
- MPAS-land-ice

Summary of CISM physics development efforts

- basal sliding
- glacier and ice sheet hydrology
- iceberg calving

** All funded largely through the DOE ASCR ISICLES project

SEACISM

Scalable **E**fficient and **AC**curate **CISM**

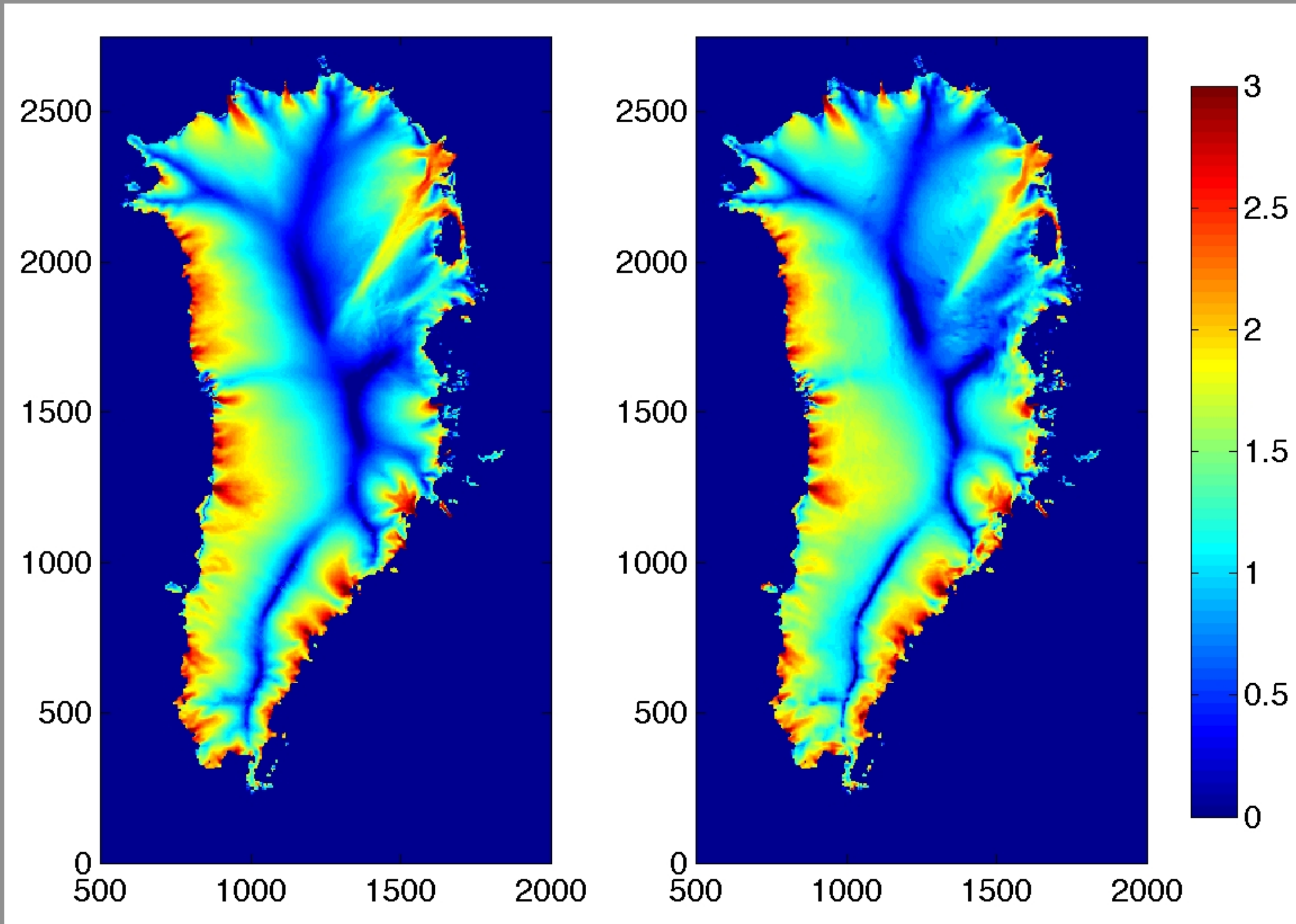
ORNL, SNL, LANL, FSU, NYU

Goal: Parallelize and improve on existing 3d mass, energy, and conservation / evolution schemes in CISM

- links to Trilinos library (better linear solvers, precond., etc.)
- Jacobian Free Newton Krylov nonlinear solver added[1]
- highly scalable parallelization of 3d, 1st-order momentum balance complete[2]
- parallelization and improvement of temperature and mass evolution schemes ongoing
- being used for SeaRISE and Ice2Sea experiments

[1]Lemieux et al., *JCP*, **230** (2011)   [2]Evans et al., *IJHPCA* (2012)

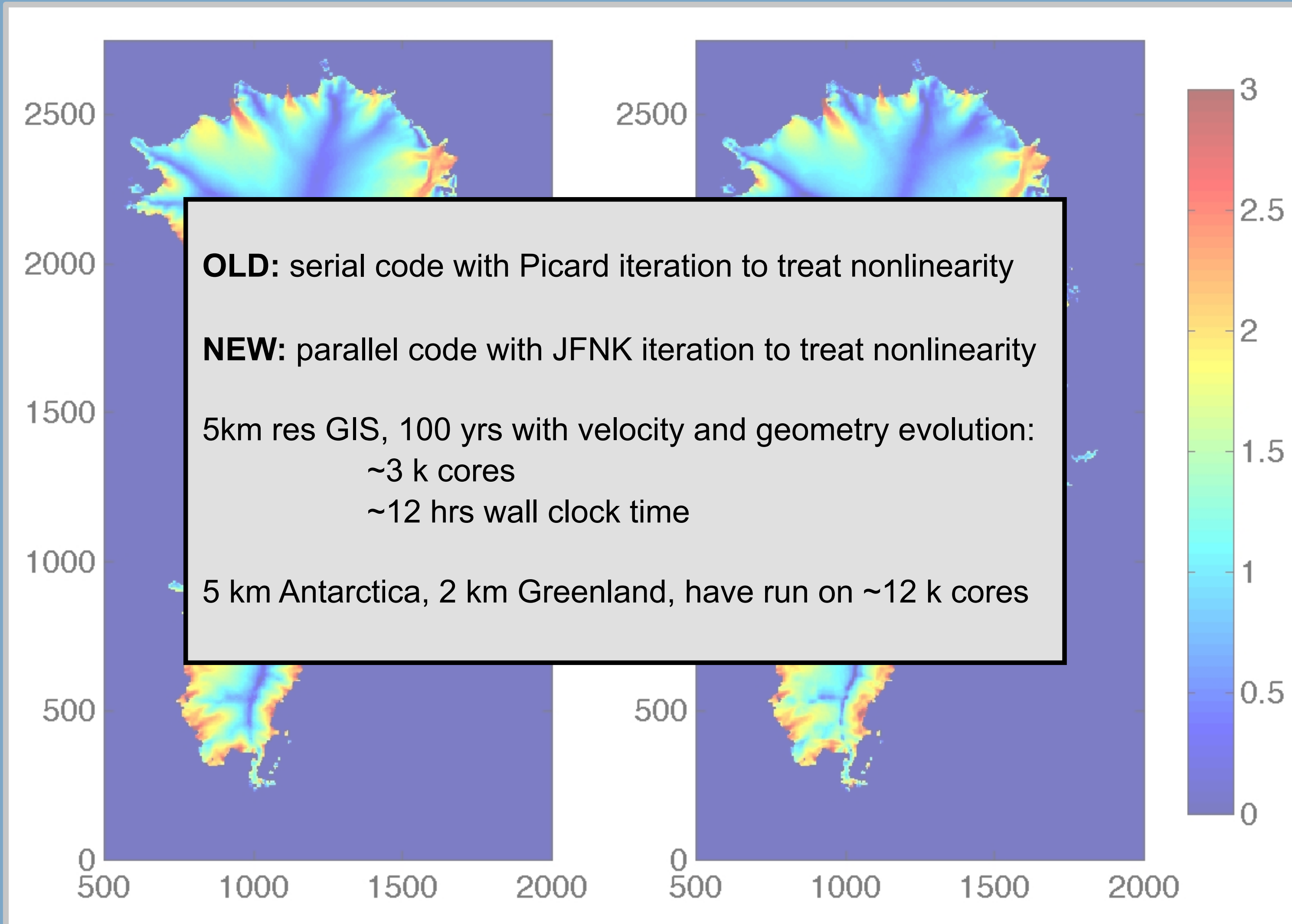
SEACISM



Left panel: balance velocities (log10 of m/yr) based on modern-day observations (Ice2Sea GIS geometry (Bamber, Griggs); SMB from Ettema et al., *GRL*, **36**, 2009)

Right panel: depth-ave. velocity from 1st-order CISM with tuned basal parameters.

SEACISM



OLD: serial code with Picard iteration to treat nonlinearity

NEW: parallel code with JFNK iteration to treat nonlinearity

5km res GIS, 100 yrs with velocity and geometry evolution:
~3 k cores
~12 hrs wall clock time

5 km Antarctica, 2 km Greenland, have run on ~12 k cores

Left panel: balance velocities (log10 of m/yr) based on modern-day observations (Ice2Sea GIS geometry (Bamber, Griggs); SMB from Ettema et al., *GRL*, **36**, 2009)

Right panel: depth-ave. velocity from 1st-order CISM with tuned basal parameters.

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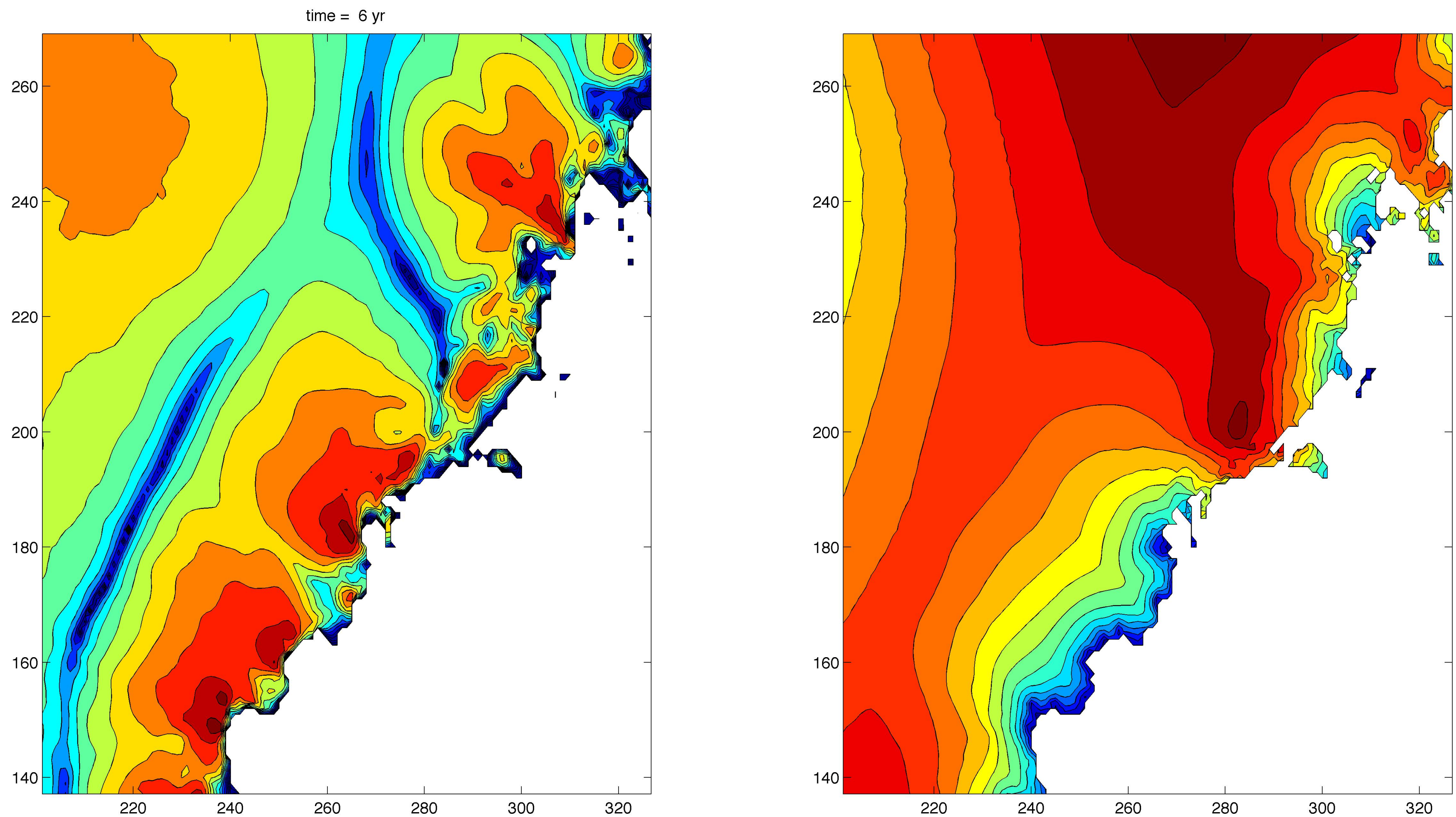

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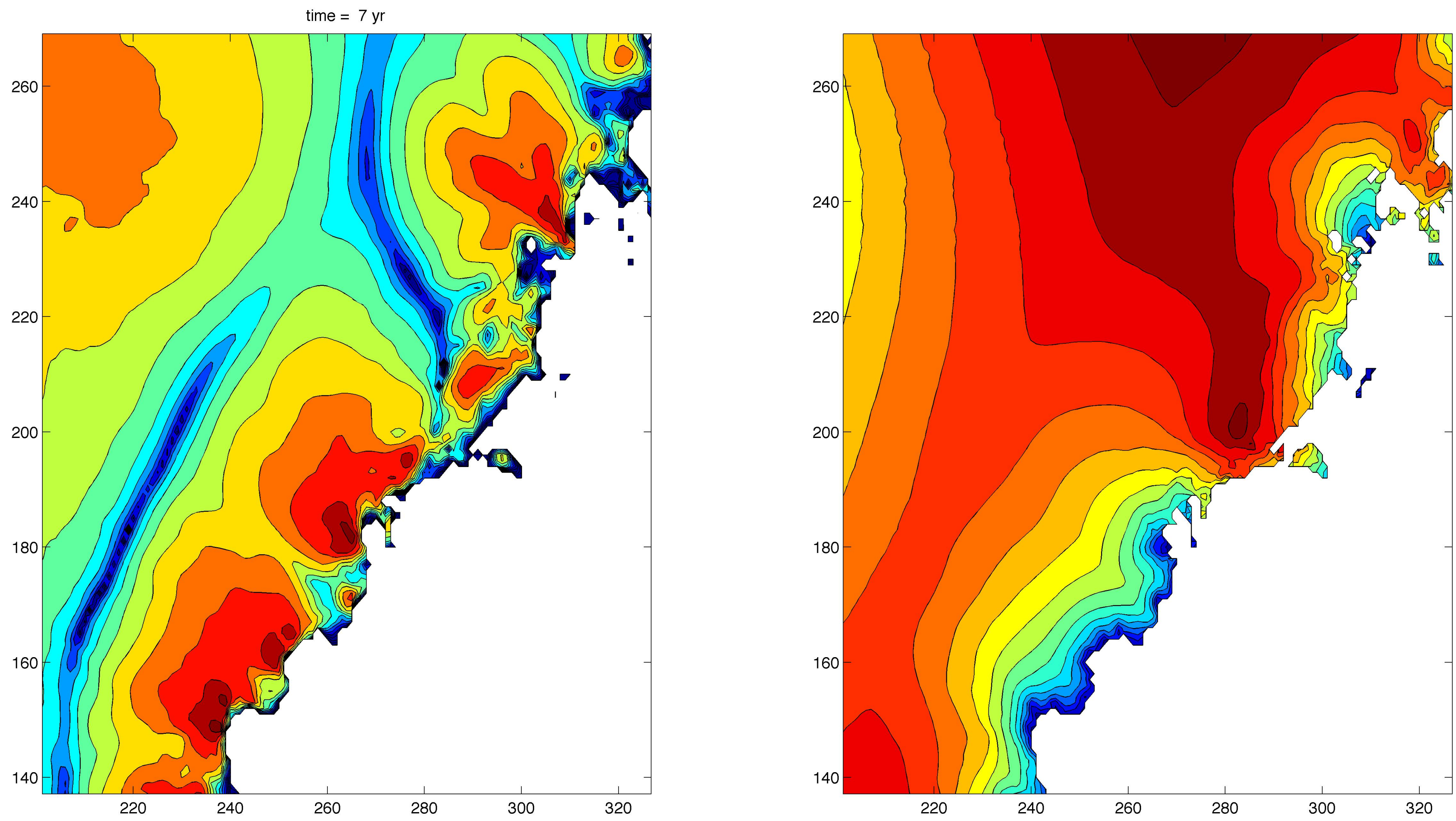
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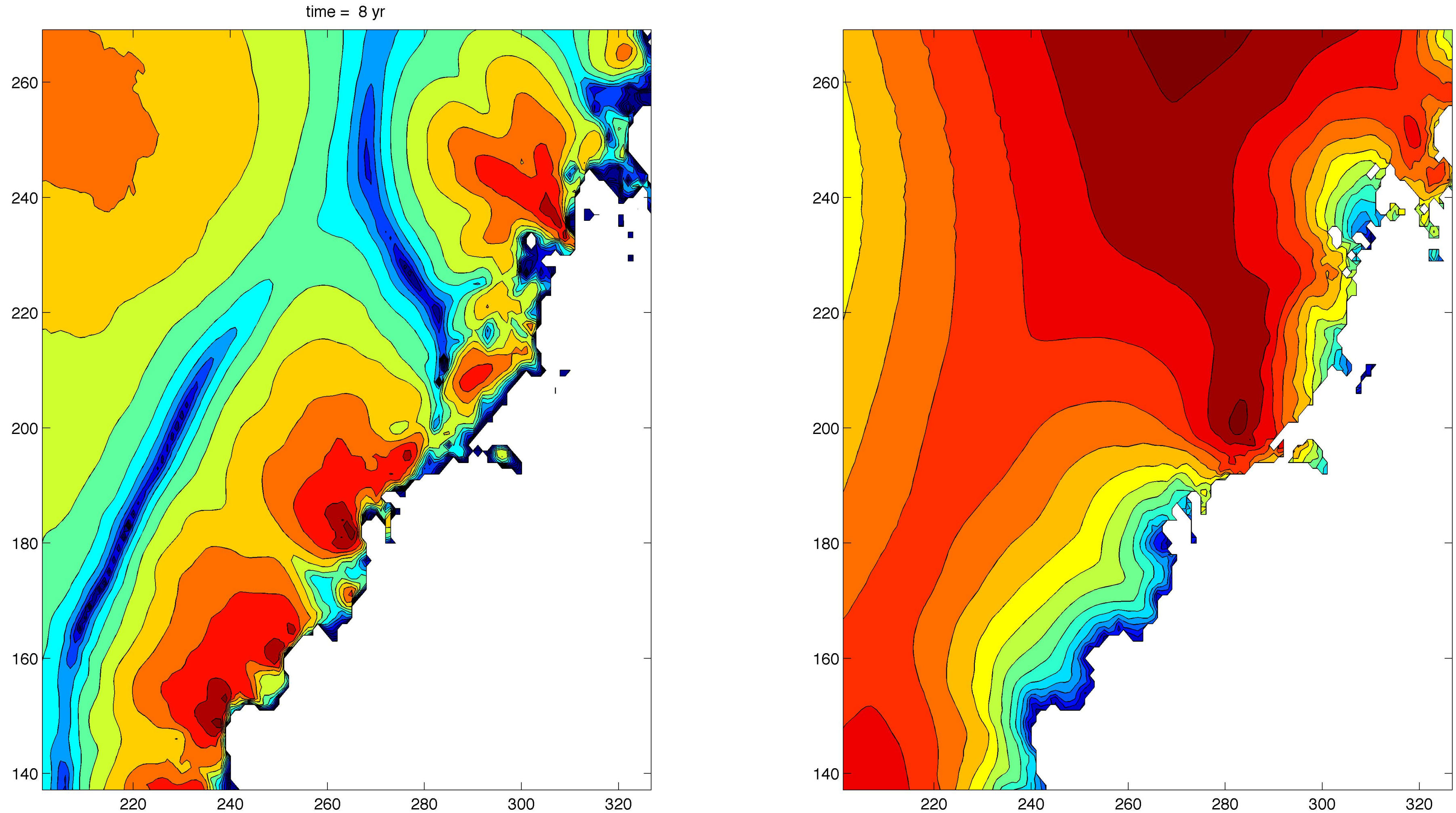
320

SEACISM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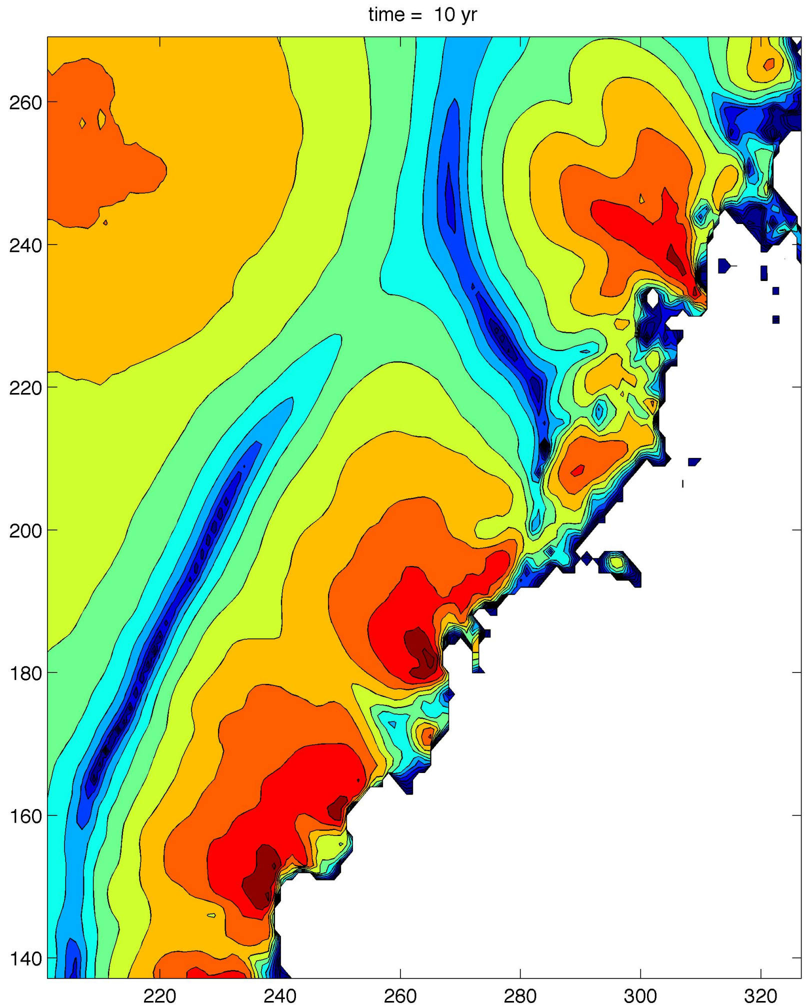
SEACISM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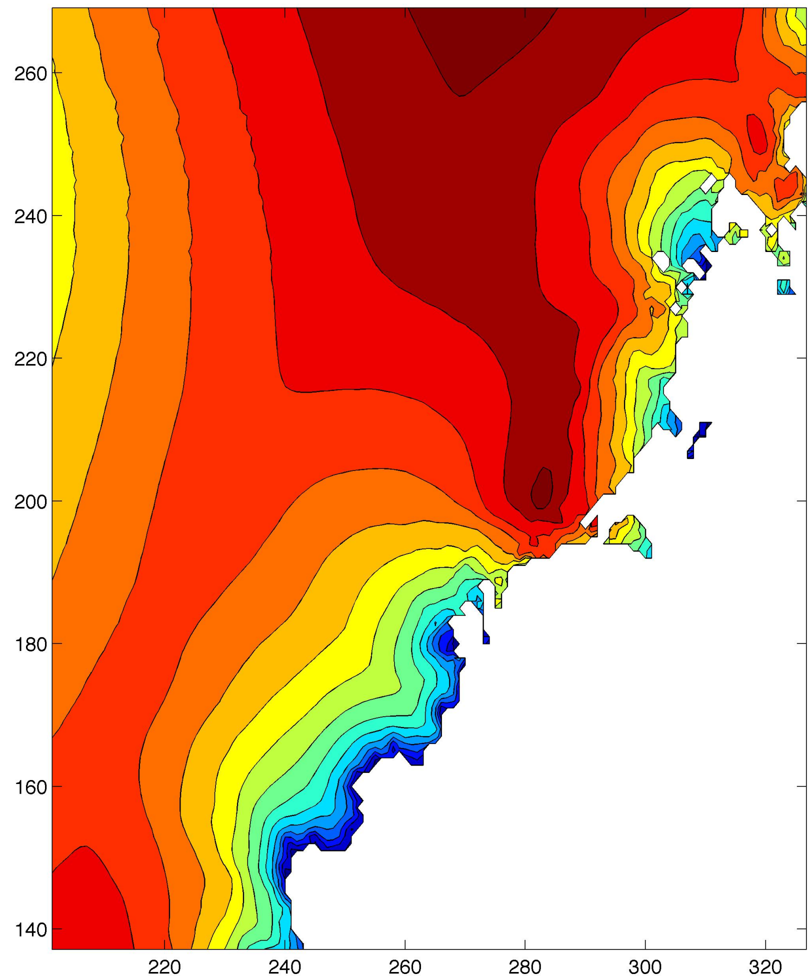
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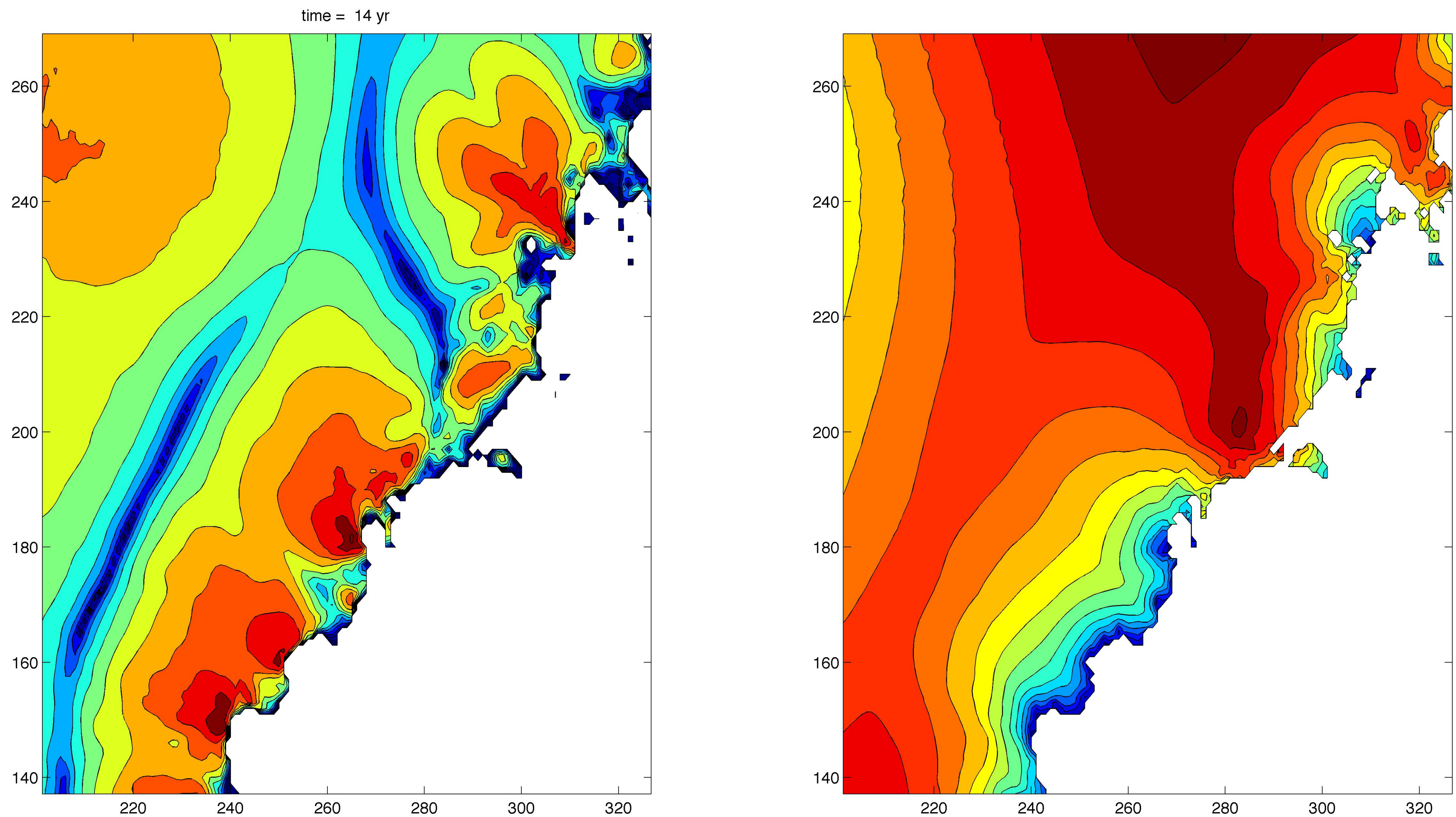
SEACISM



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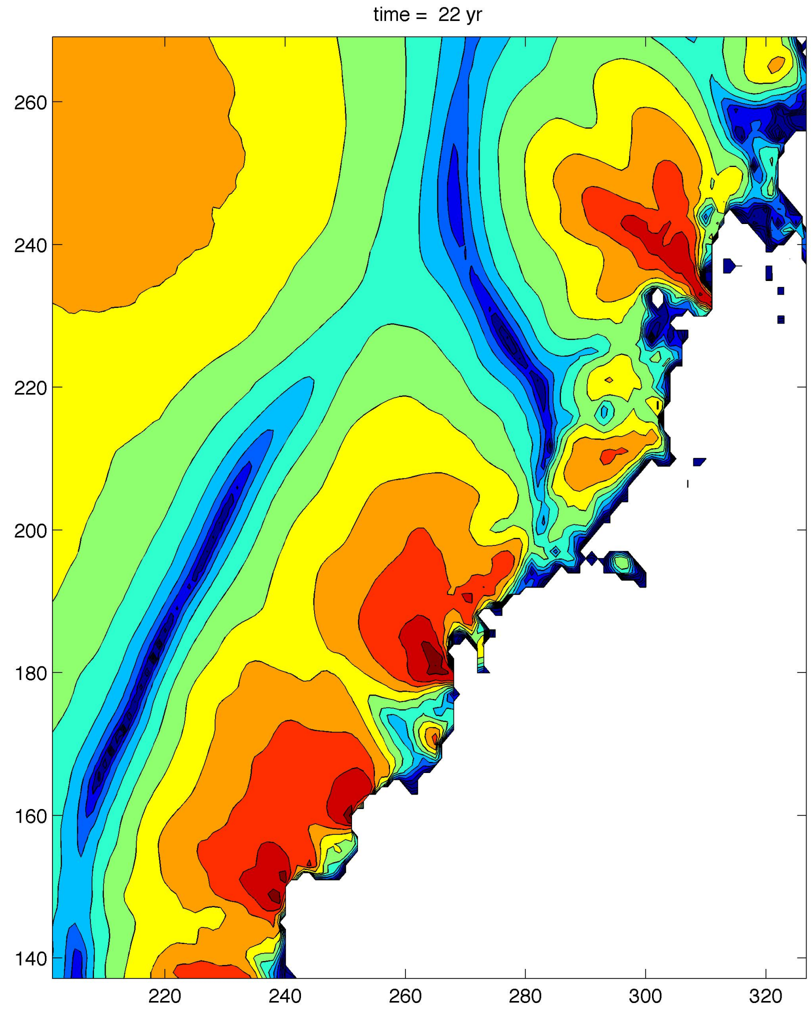
SEACISM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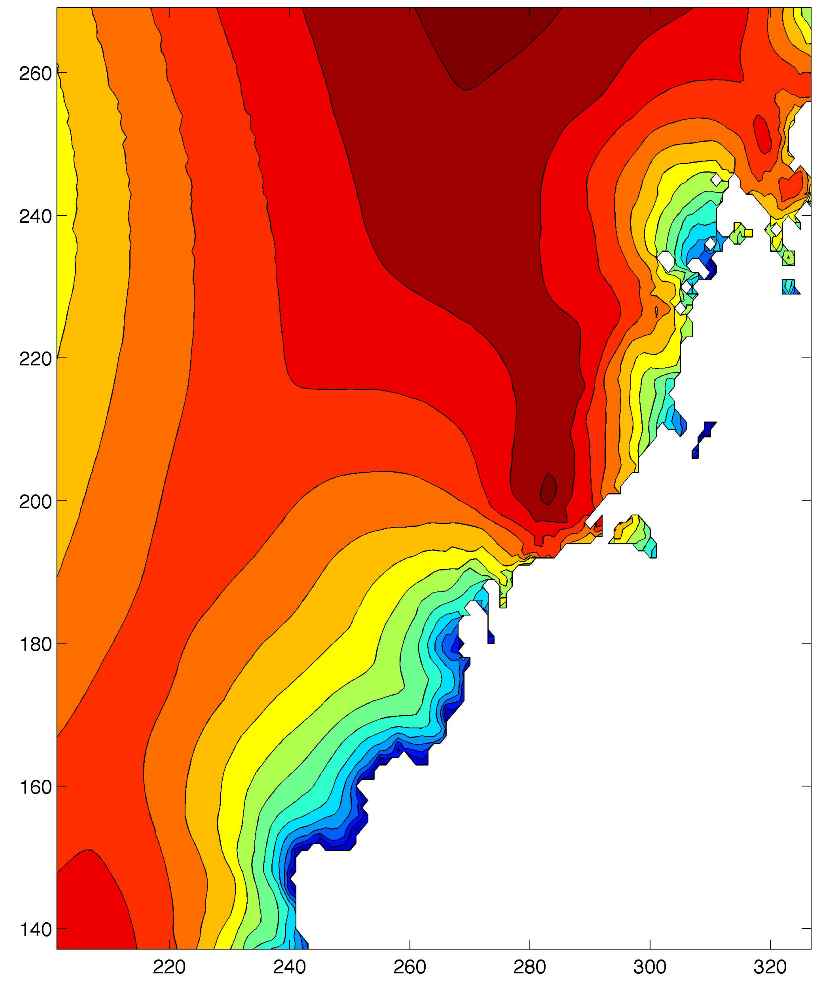
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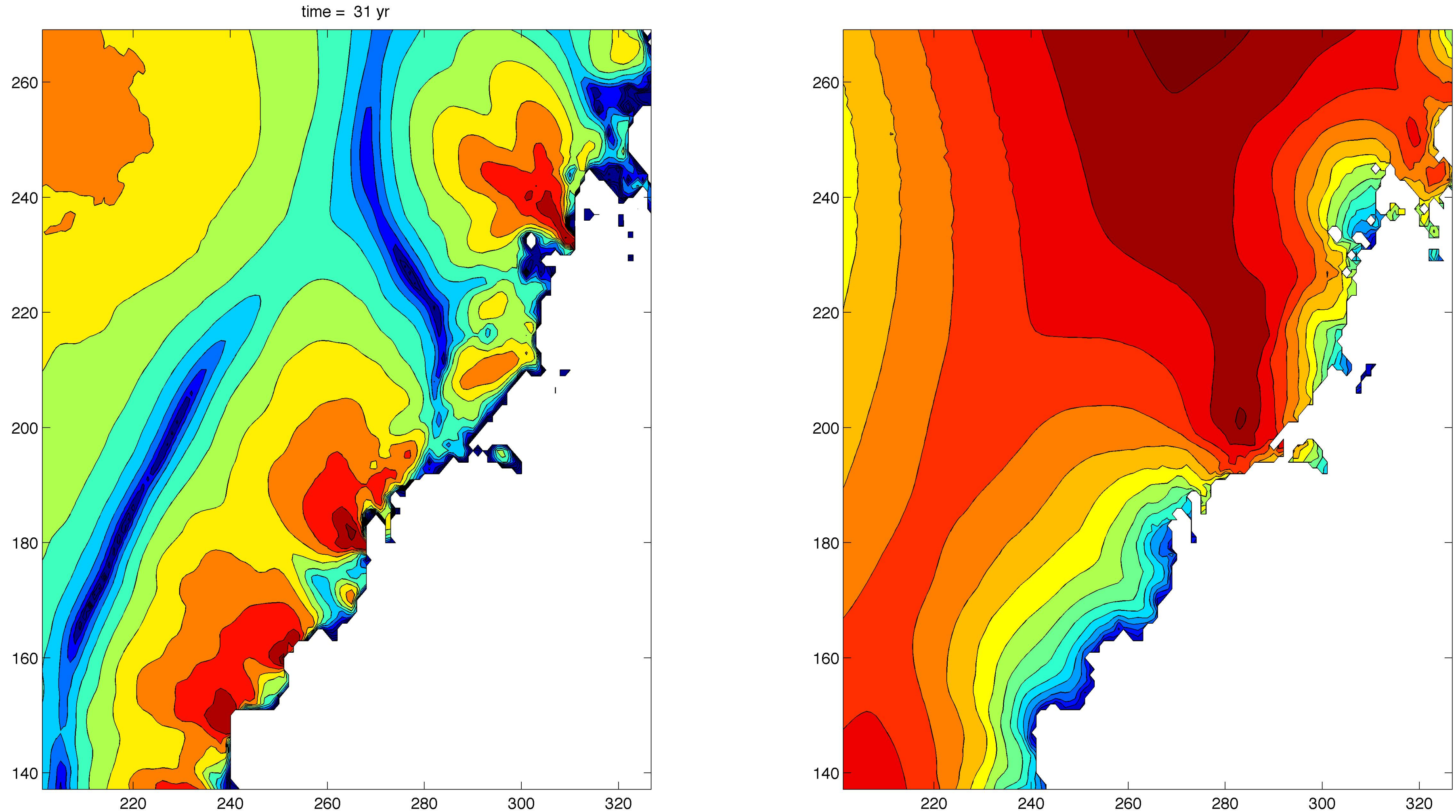
SEACISM



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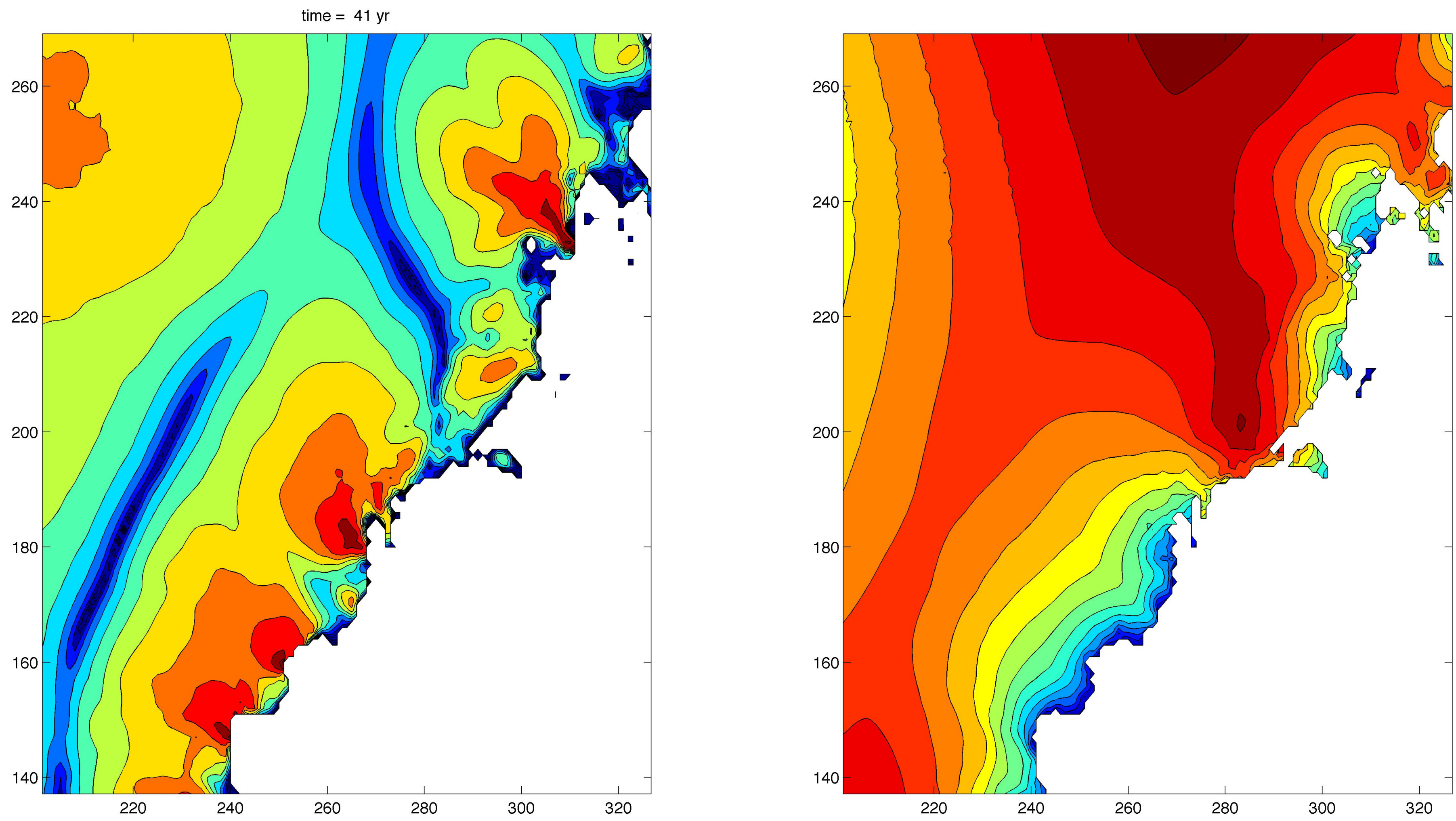

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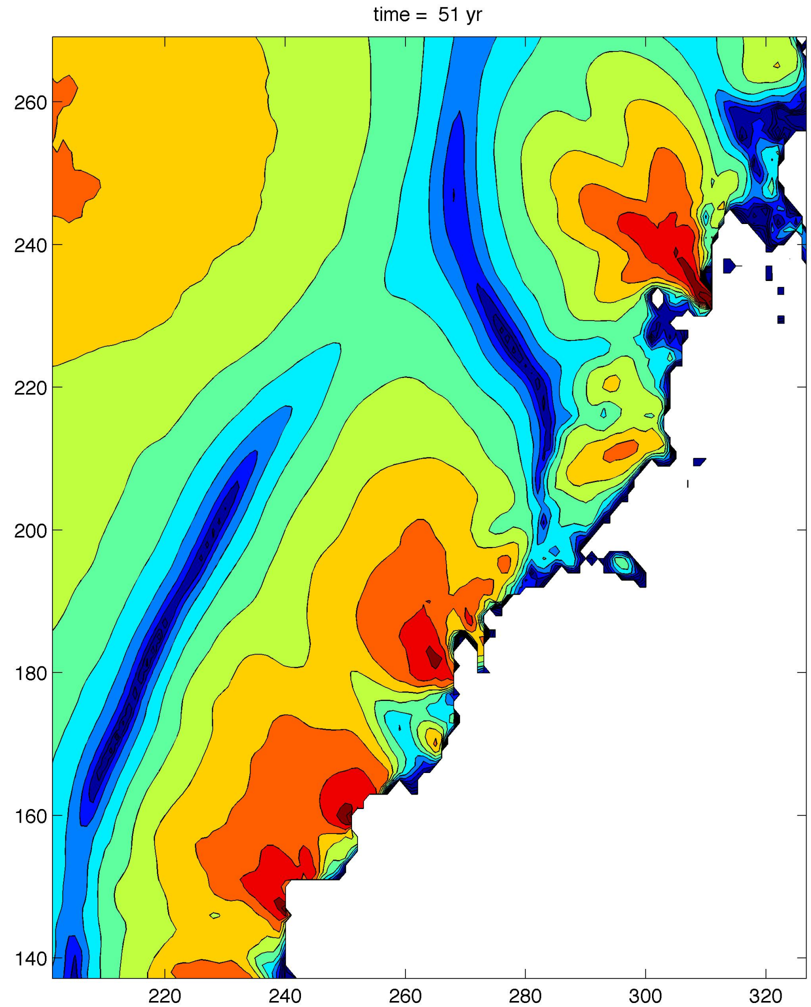
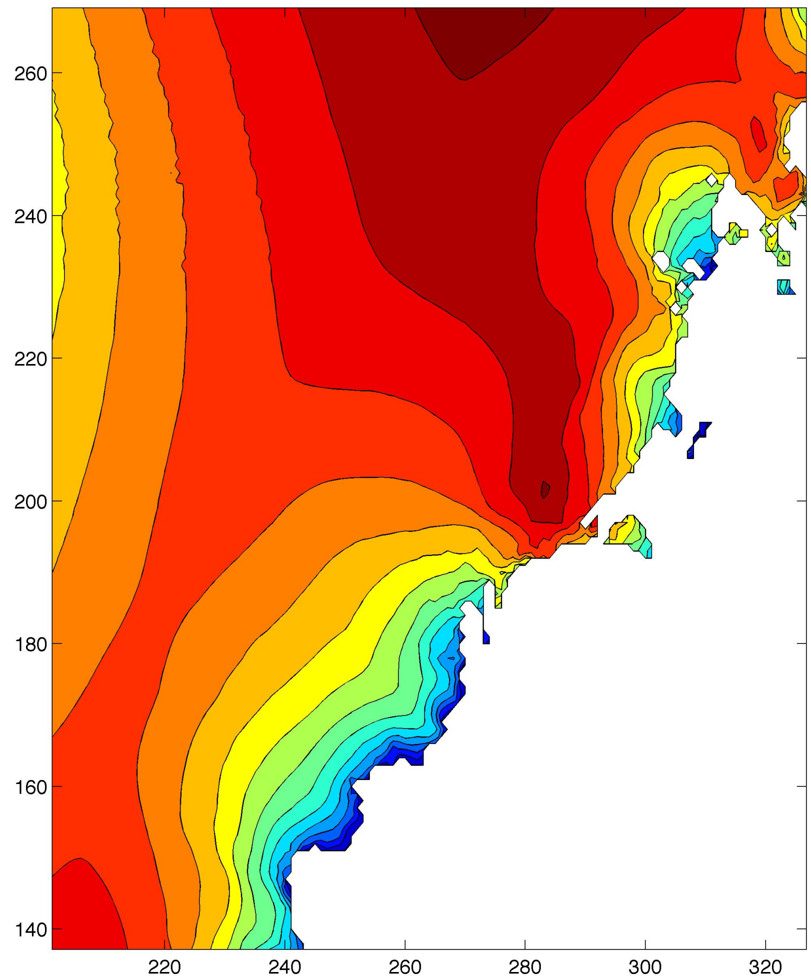




See related talk by Kate Evans at 3:45 pm Thurs.

BISICLES

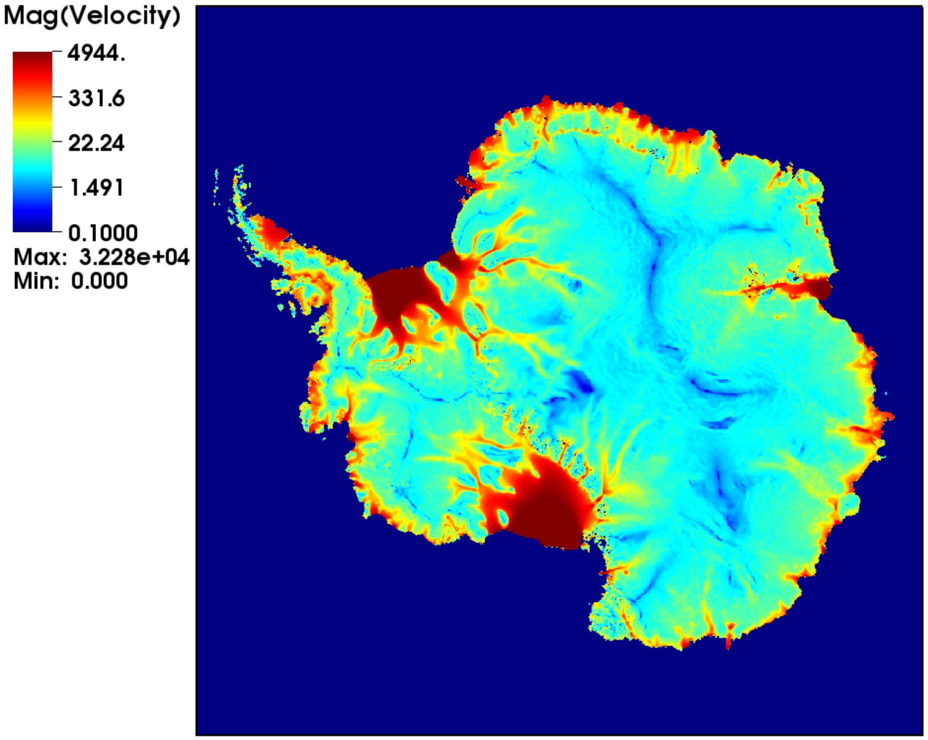
Berkeley **ISICLES:** LBNL, LANL, UOB

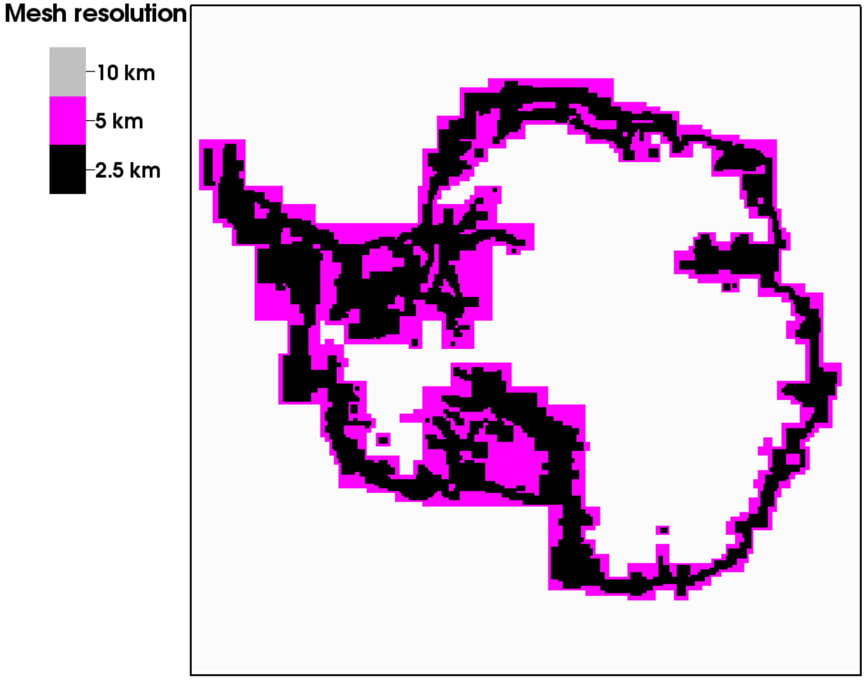
Goal: Parallel, 1st-order accurate dynamical core with block-structured, adaptive mesh refinement capabilities

- uses LBNL Chombo package
- Picard and Newton based treatments of ice flow nonlinearity
- highly scalable, parallel solution of depth-integrated,1st-order accurate "LIL2" momentum balance[1]
- temperature and mass evolution work ongoing
- being used for SeaRISE and Ice2Sea experiments
- ideal model for use in simulations with marine based ice and grounding line advance and retreat[1]

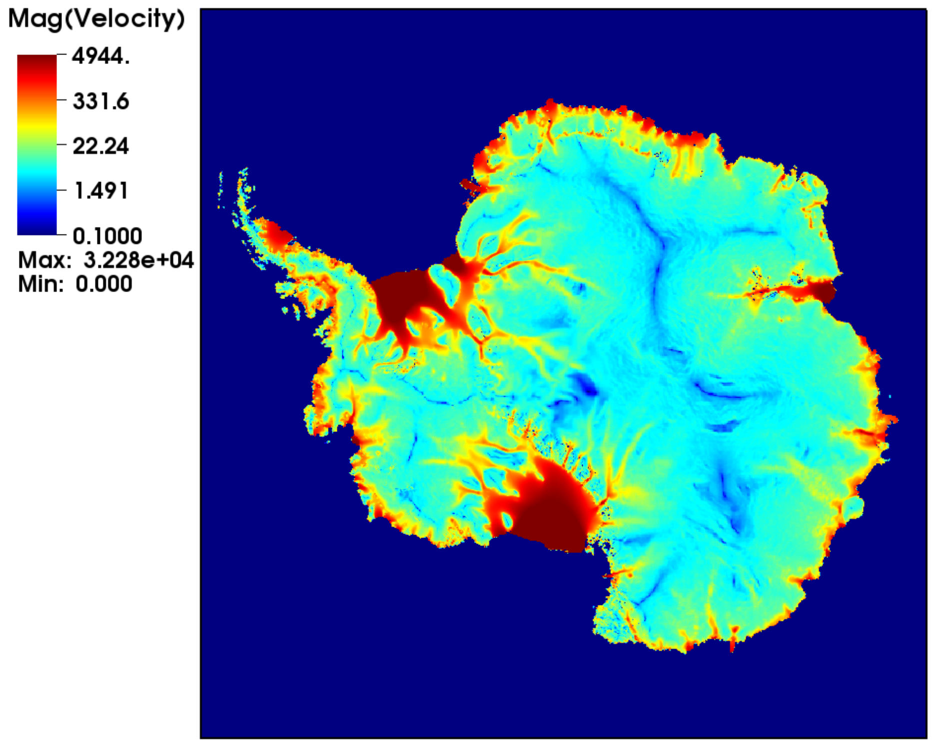
[1]Cornford et al., *JCP* (submitted)

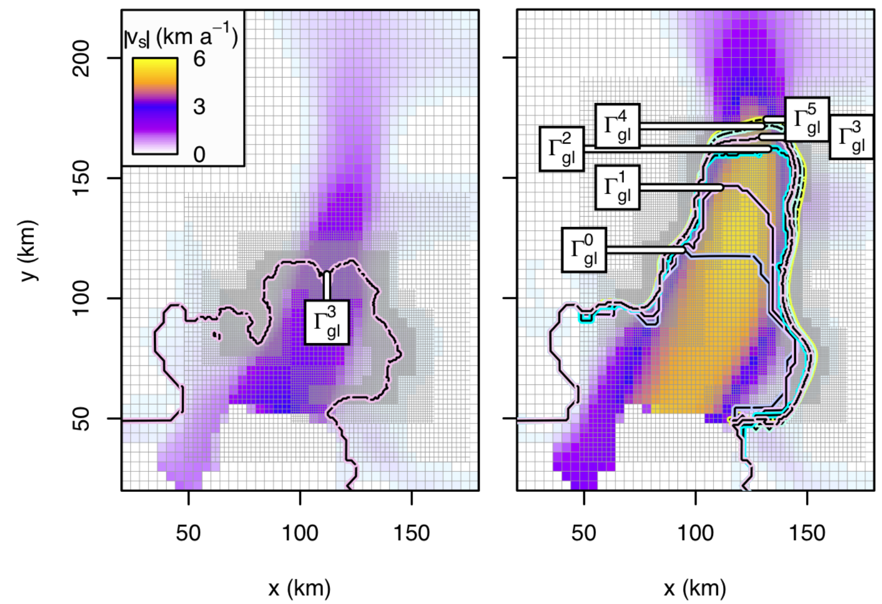
BISICLES


Mag(Velocity)
4944.
331.6
22.24
1.491
0.1000
Max: 3.228e+04
Min: 0.000


Mesh resolution
10 km
5 km
2.5 km

BISICLES





See related talk by Dan Martin at 3:30 pm Thurs.

MPAS land ice

Modeling for **P**rediction **A**cross **S**cales land ice component

LANL, NCAR, FSU, USC, ORNL, SNL

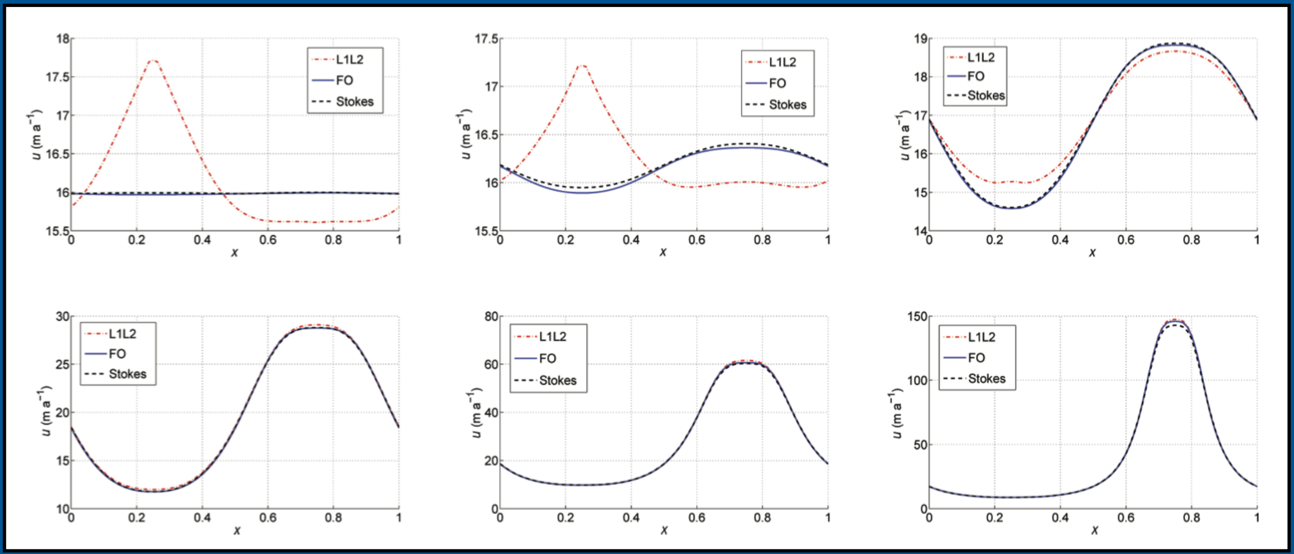
Goal: Hierarchical suite of FEM-based ice sheet dynamical cores (Stokes, 1st-order, LIL2, etc.) based on MPAS SCVT mesh generation and modeling framework

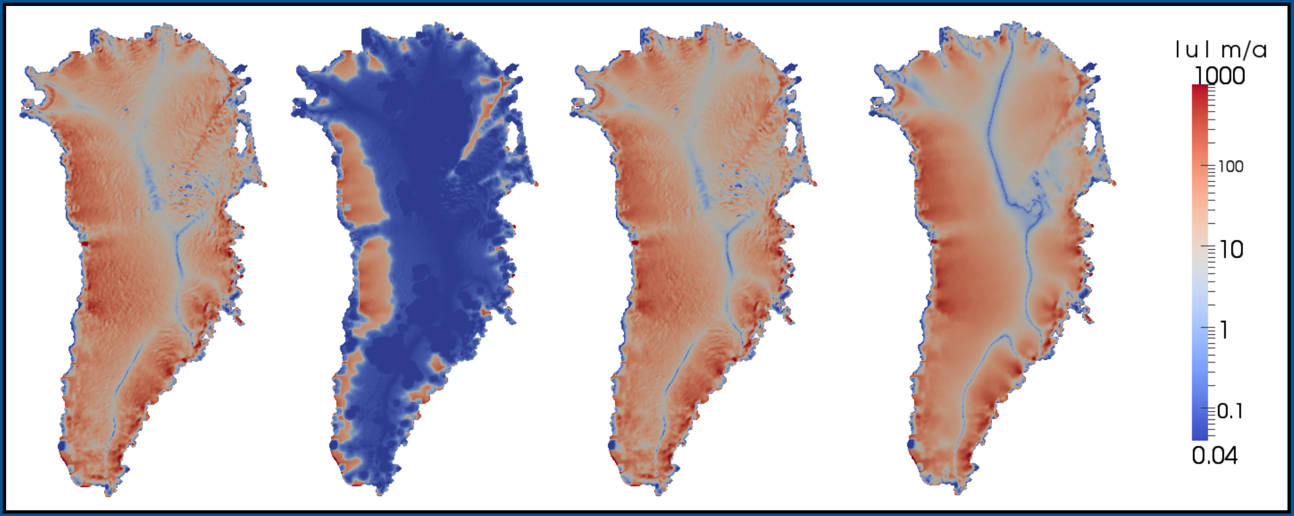
- Stokes, 1st-order, LIL2, SSA, and SIA solvers implemented and tested[1,2]
- Initial coupling between FSU solver, Trilinos, and MPAS ongoing
- plans for coupling between USC (Stokes) solver and MPAS
- initial mass and temperature evolution schemes will be largely based on available capabilities in MPAS-atmos and MPAS-ocean (e.g. advection schemes, time stepping)

[1]Leng et al., *JGR,* **117** (2012) [2]Perego et al., *J. Glac.* **58** (2012)

MPAS land ice

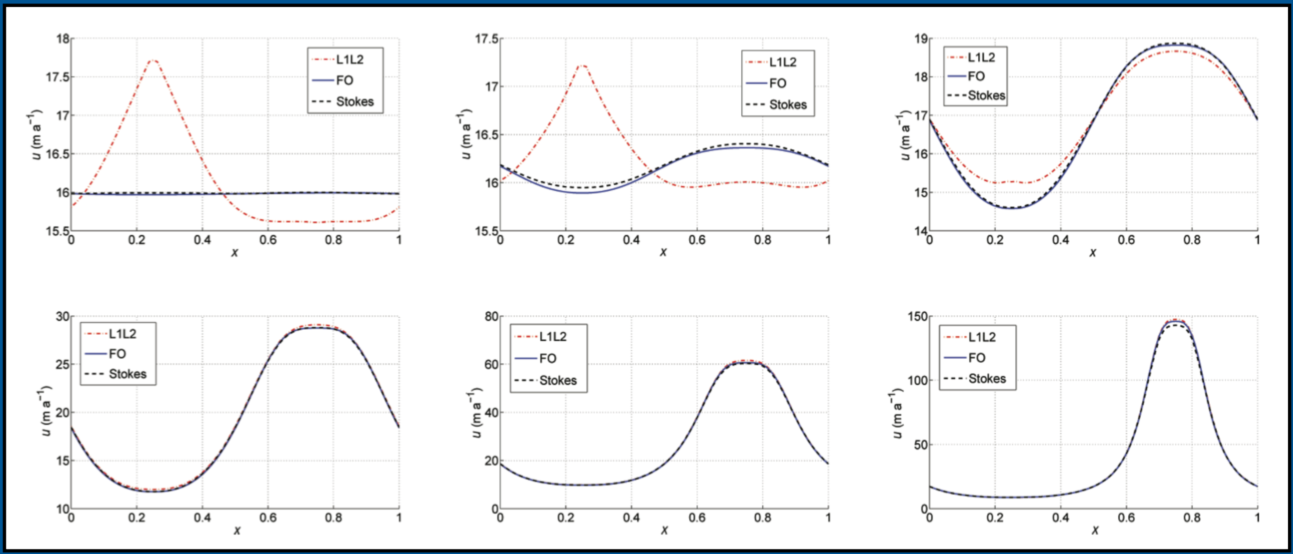
Perego et al., *J. Glac.*, **58** (2012)

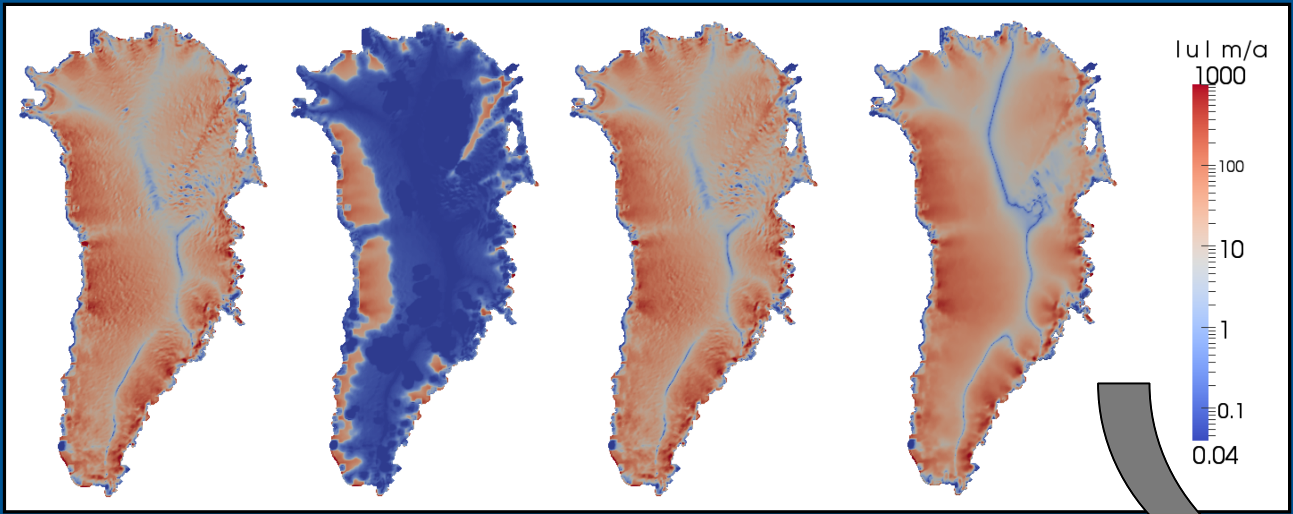


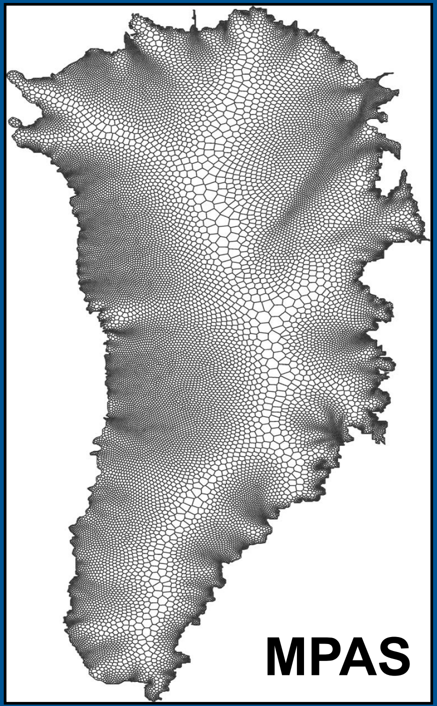


MPAS land ice

Perego et al., *J. Glac.*, **58** (2012)





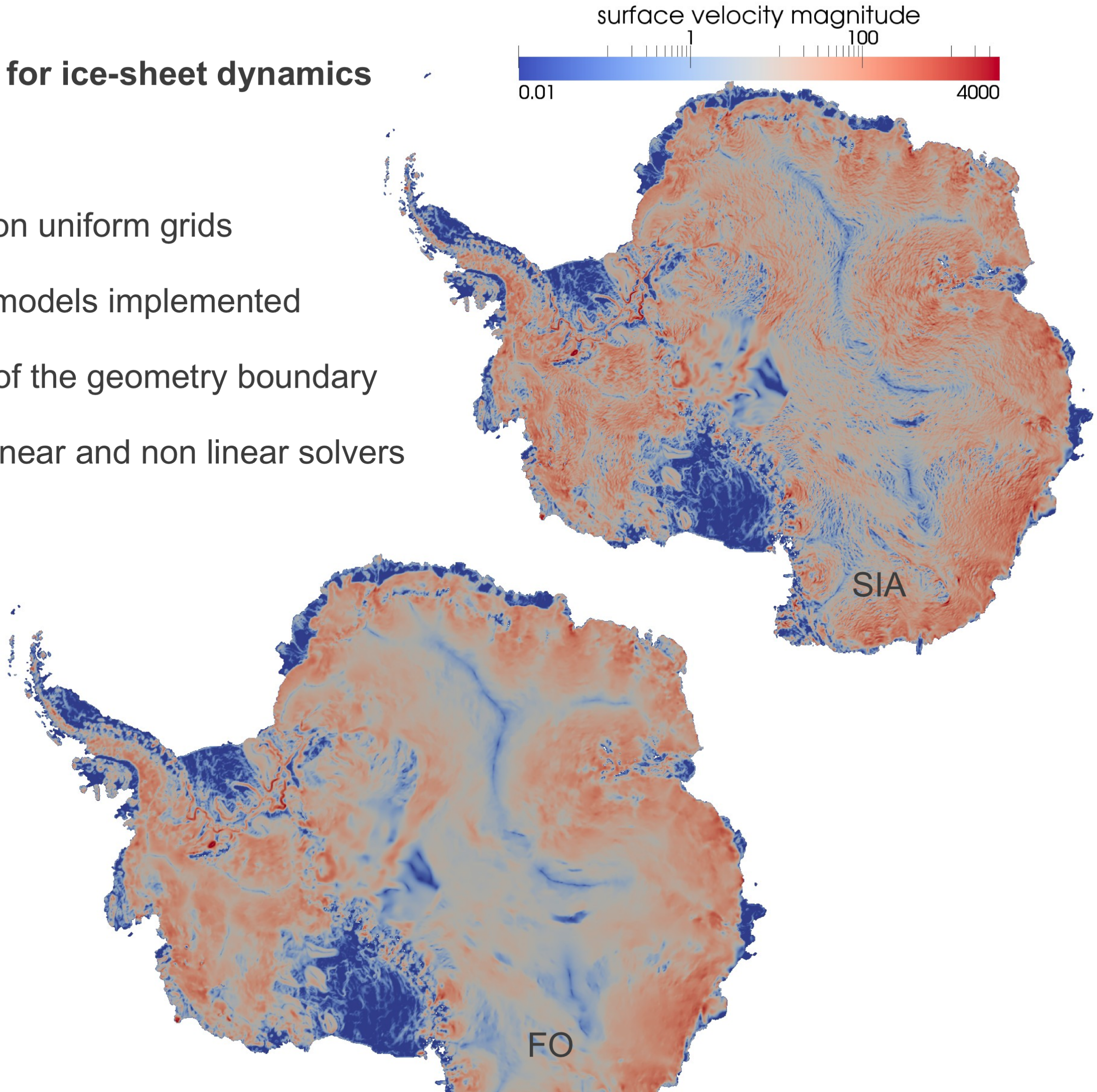


Ringler et al., *Ocean Dyn.* (2008)

MPAS land ice

Finite element solver for ice-sheet dynamics

- non structured and non uniform grids
- FO, L1L2, SSA, SIA models implemented
- accurate description of the geometry boundary
- relies on Trilinos for linear and non linear solvers
- interfaces with MPAS



See related talk by Mauro Perego at 4:00 pm Thurs.

Basal Sliding

Improved solution of nonlinearities associated with basal sliding over plastic subglacial till[1]

Addition of basal processes submodel for simulating interaction of subglacial hydrology and subglacial till[2]

Addition of new theoretically-based[3] and observationally supported[4] Coulomb-friction sliding law with dependence on subglacial water pressure

[1]Price and Stadler (in prep.) [2]Bougamont et al., *JGR*, **116** (2011) [3]Schoof, *Proc. R. Soc. A* (2005)
[4]Iverson et al., J. Glac., **206** (2011)

Basal Sliding

$$\tau_b = C\left(\frac{u_b}{u_b + N^n \Lambda}\right)^{1/n} N, \qquad \Lambda = \frac{\lambda_{max} A}{m_{max}},$$

basal traction

sliding speed

bedrock roughness term

max bedrock bump wavelength

dimensionless constant

effective pressure (ice overburden – water pressure)

max bedrock bump slope

Sliding law after Schoof, *Proc. R. Soc. A* (2005)

Basal Sliding

sliding speed

basal traction

bedrock roughness term

max bedrock bump wavelength

$$\tau_b = C\left(\frac{u_b}{u_b + N^n \Lambda}\right)^{1/n} N, \qquad \Lambda = \frac{\lambda_{max} A}{m_{max}},$$

dimensionless constant

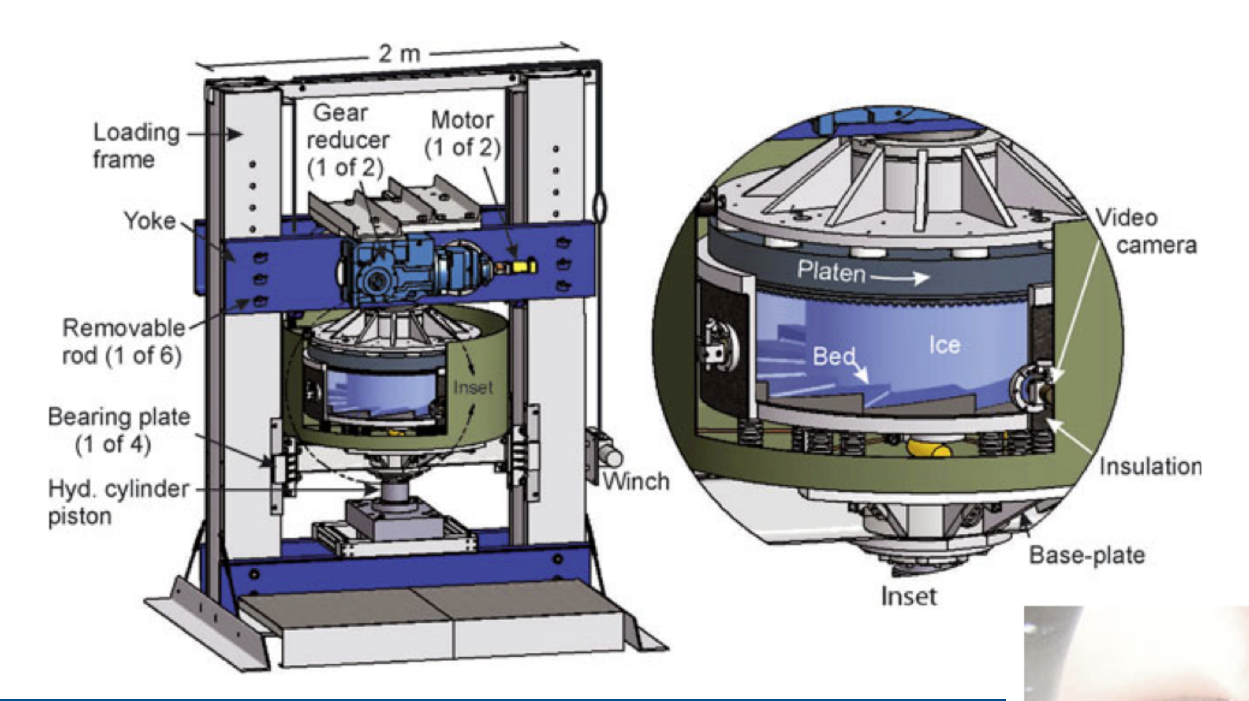
effective pressure (ice overburden – water pressure)

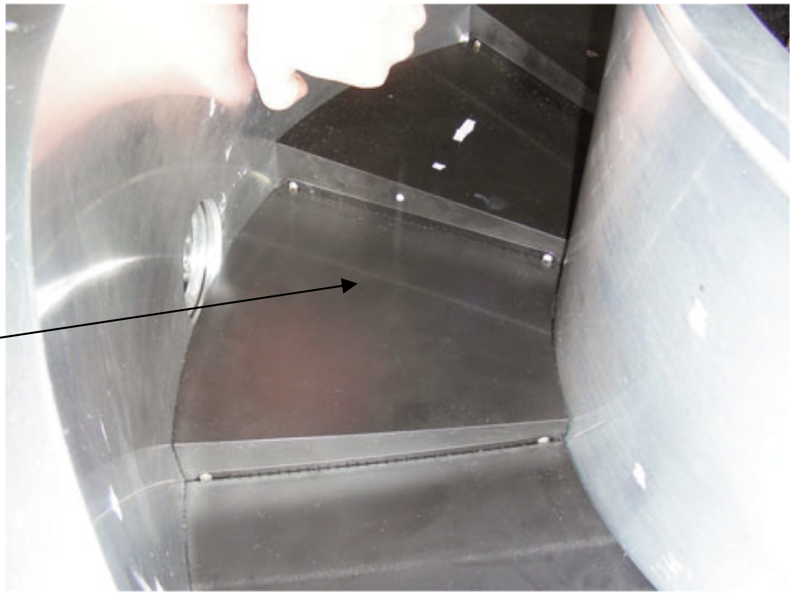
max bedrock bump slope

Note that for *N*=*n*=1, *Λ*=0, and *C*=yield strength, this becomes the standard sliding law and implementation for water saturated subglacial till.

Sliding law after Schoof, *Proc. R. Soc. A* (2005)

Basal Sliding





Laboratory controlled "bedrock" bump slope and wavelength & basal water pressure

Figures after Iverson et al., J. Glac., **206** (2011)

Glacier and Ice Sheet Hydrology

Eos, Vol. 92, No. 19, 10 May 2011

MEETINGS

Improving Hydrology in Land Ice Models

Community Earth System Model Land Ice Working Group Meeting; Boulder, Colorado, 13 January 2011

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CISM developers have an ongoing collaboration with researchers** at UBC, SFU, and LDEO

A second informal meeting took place in the fall of 2011 at the NWG meeting (Portland State Univ.)

New LANL postdoc (Matt Hoffman) has been working on adding improved subglacial hydro models to CISM

** T. Creyts, G. Flowers, I. Hewitt, C. Schoof, M. Werder

Glacier and Ice Sheet Hydrology

Goals:

Mass conserving model of subglacial water flow, which calculates subglacial water pressure

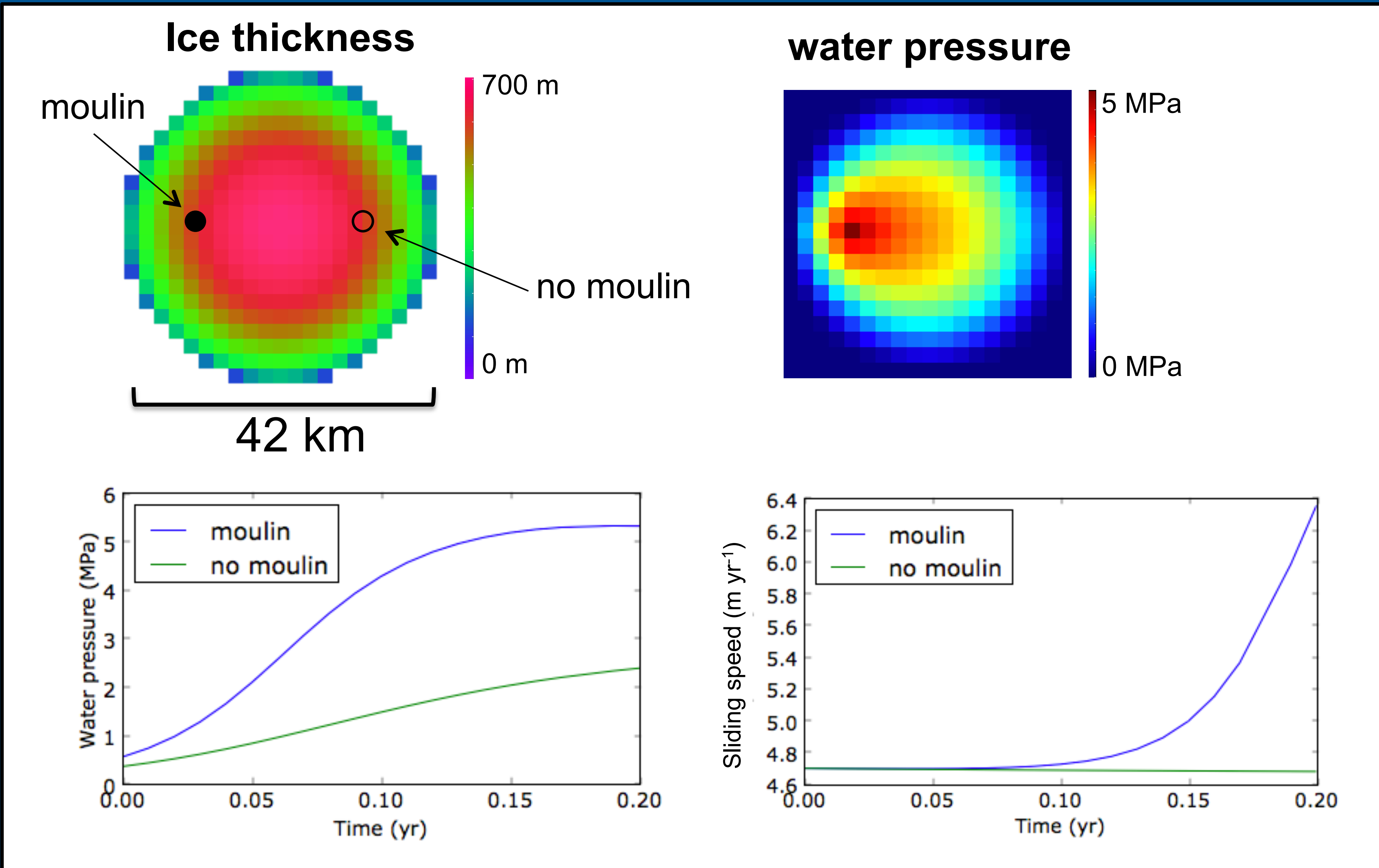
Coupling to sliding law consistent with theory and observations and with dependence on subglacial water pressure

Allowance for supra- and en-glacial water sources

Common development platform (e.g. CISM)

Standardized test cases

Dome test case with coupled sliding, subglacial hydrology, and "moulin" water source



See related talks by M. Werder, T. Creyts, and M. Hoffman 10:10-10:45 am Fri.

Iceberg Calving

Greenland: ~50% of mass loss to oceans by calving

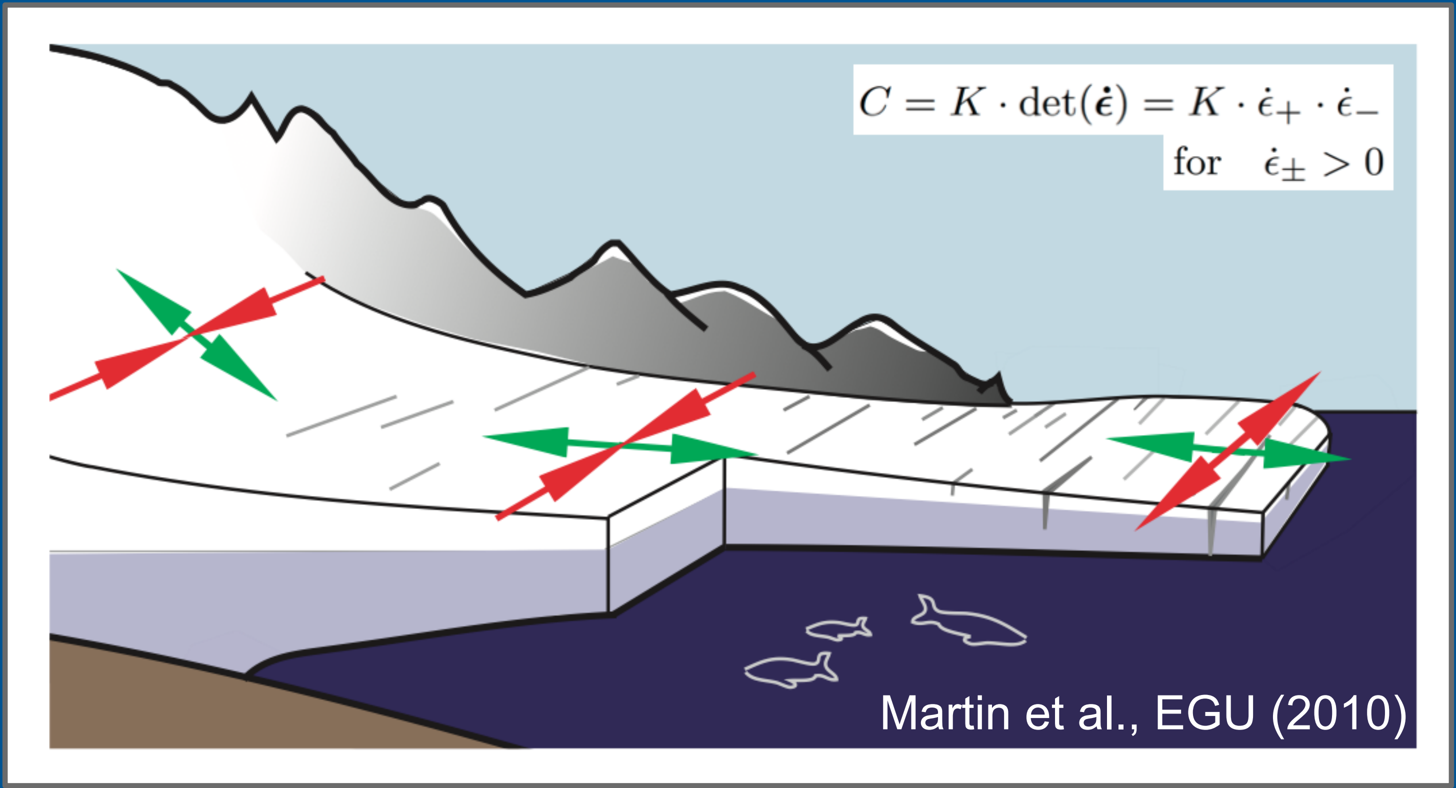
Antarctica: ~100% of mass loss to oceans by calving

In most ice sheet models, calving is either ignored (calving front is assumed fixed) or greatly simplified (calving occurs when floating ice reaches a minimum thickness)

Realistic evolution of ice shelves and tongues and accounting for their impact on grounded ice flow requires improved representations of iceberg calving

Iceberg Calving

One relatively simple improvement is the "eigencalving" law in the PISM-PIK model; calving is proportional to product of principal strain rates IF that product is positive:



PISM-PIK also employs a parameterization allowing for sub-grid scale advance and retreat of the calving front

Iceberg Calving

Longer-term plan is to leverage collaborations with externally funded university partners:

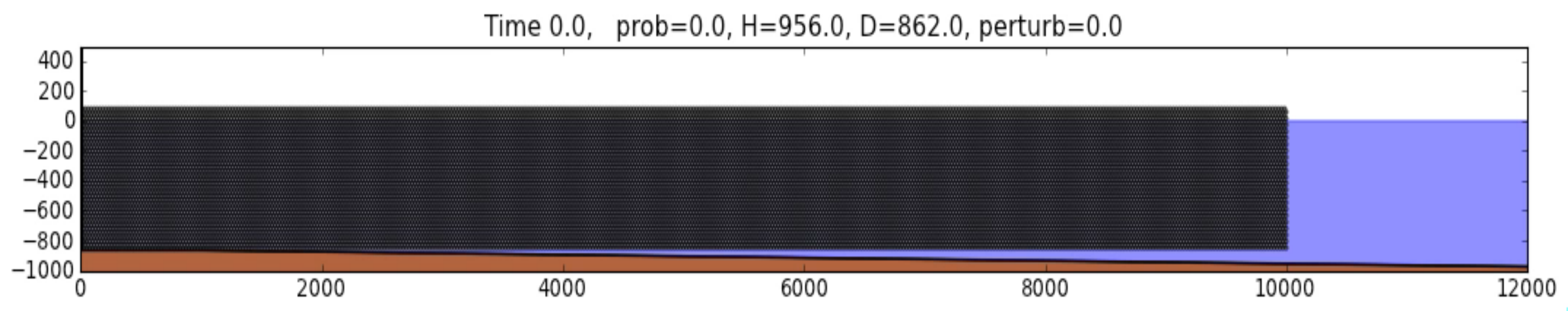
NSF funded project with J. Bassis (Univ. of Michigan)

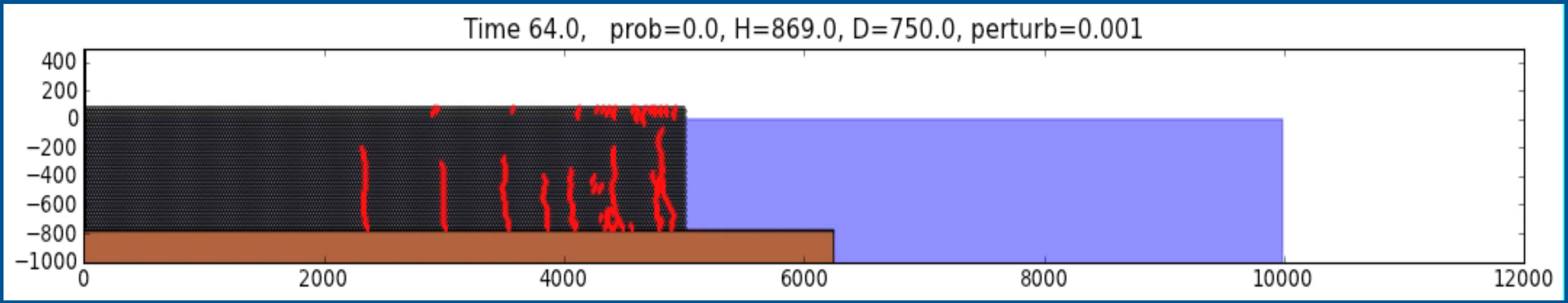
NASA project (pending) with J. Bassis, I. Howat, L. Padman

Challenges:

- Wide range of calving styles in different environments
- disparity of scales (fracture mechanics scale vs. cont. scale models of ice dynamics)
- probabilistic nature of calving events

Iceberg Calving





Movies courtesy of Jeremy Basis (Univ. of Michigan)

Summary

Eos, Vol. 90, No. 3, 20 January 2009

MEETING

A Community Ice Sheet Model for Sea Level Prediction

Building a Next-Generation Community Ice Sheet Model; Los Alamos, New Mexico, 18–20 August 2008

Summary

The workshop was attended by 35 scientists from U.S., U.K., and Canadian institutions. The discussion was organized around four focus areas: (1) ice sheet dynamics and physics, (2) ice shelf/ocean interactions, (3) software design and coupling, and (4) initialization, verification, and validation. Because of the short timescale for including ice sheet forecasts in the next IPCC assessment, participants prioritized model improvements according to their importance for sea level prediction. The following improvements were deemed critical:

- a higher-order flow model with a unified treatment of vertical shear stresses and horizontal-plane stresses;
- improved models of basal sliding over hard and soft beds, with explicit ice sheet hydrology;
- a well-validated parameterization of melting and refreezing beneath ice shelves;
- an accurate, semiempirical law for iceberg calving; and
- an accurate, numerically robust treatment of grounding-line migration.

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