Update on Development and Applications of the Community Ice Sheet Model

Stephen Price and William Lipscomb

Climate Ocean and Sea Ice Modeling Project
Fluid Dynamics and Solid Mechanics Group
Los Alamos National Laboratory

Support courtesy of DOE Office of Science ASCR, BER, and SciDAC programs

Calving front of Jakobshavn Isbrae, Greenland

(1) CISM / CISM 2.0 update

(2) PISCEES summary

(3) LIWG computing resources

(4) CISM results for SeaRISE and Ice2Sea

Jakobshavn Isbrae, Greenland

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Jakobshavn Isbrae, Greenland

CISM / CISM 2.0 update

Full parallelism of SEACISM dycore complete; release in fall as CISM 2.0

Coupling to BISICLES / Chombo ongoing; release with CISM ≥ 2.0

For realistic, 2-5 km resolution Greenland problems, SEACISM scaling to ~10^3 cpus (running on ~10^4 cpus)

CISM 2.0 currently undergoing testing, “robustification”, and general code clean-up (e.g., splitting of SIA and HO code; test cases; documentation; improving build system)

Work on implementation of CISM 2.0 in CESM 1.1 ongoing

Work on ocean model coupling ongoing

Work on coupling to other dycores (e.g., ISSM, PISM) and coupling to other climate models (e.g., NASA GISS, NASA Goddard)

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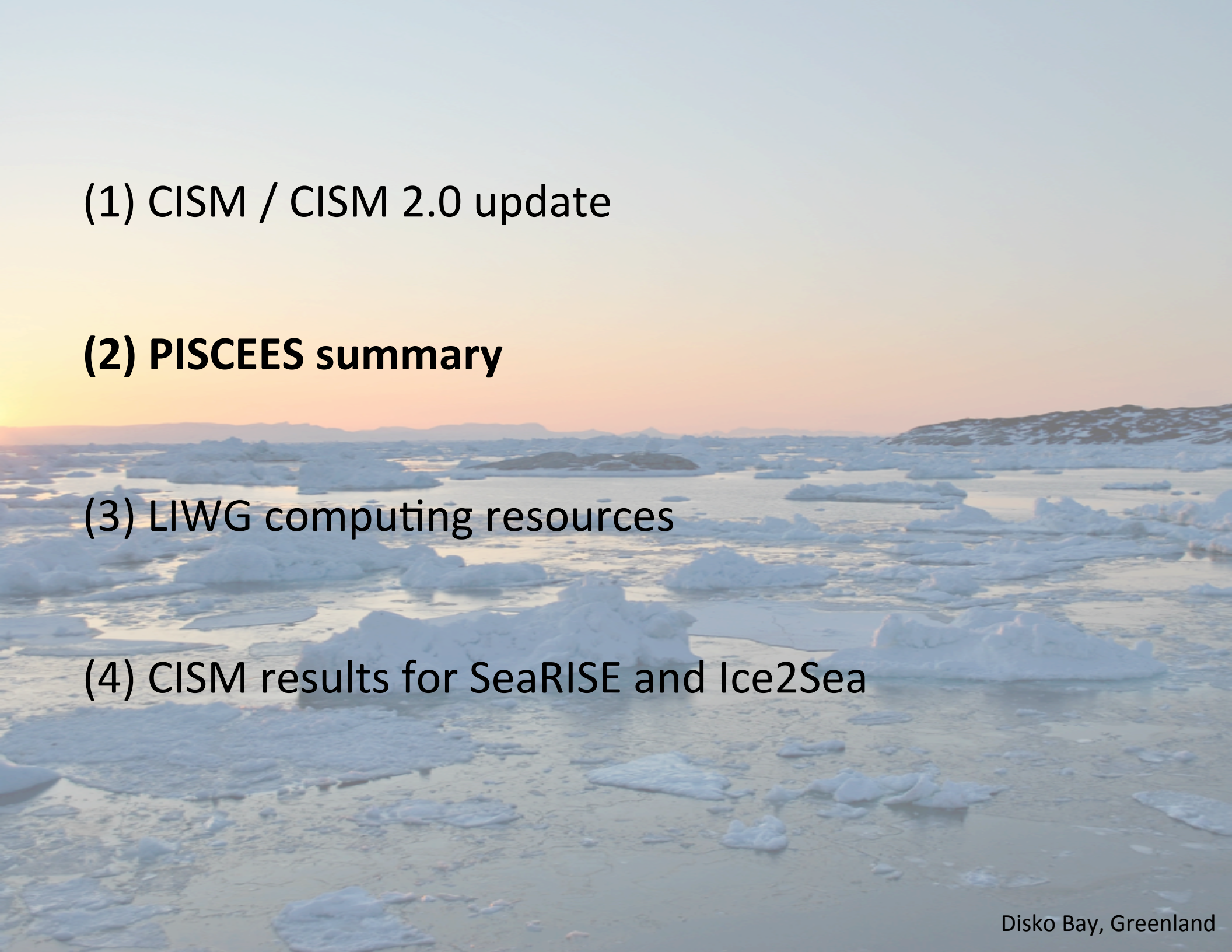


Disko Bay, Greenland

Predicting **I**ce **S**heet and **C**limate **E**volution at **E**xtreme **S**cales (PISCEES)

5 yr SciDAC[1] Earth System Modeling project with goals to:

- develop and apply robust, accurate, and scalable dynamical cores ("dycores") for ice sheet modeling on structured and unstructured meshes with adaptive refinement
- evaluate ice sheet models using new tools and data sets for verification and validation (V&V) and uncertainty quantification (UQ)
- integrate these models and tools in the Community Ice Sheet Model (CISM) and Community Earth System Model (CESM)
- Links to DOE SciDAC Institutes (FASTMath, SUPER, QUEST)

[1]Jointly funded by the DOE Office of Science offices of Biological and Environmental Research (BER) and Office of Advanced Scientific Computing Research (ASCR)

PISCEES participants

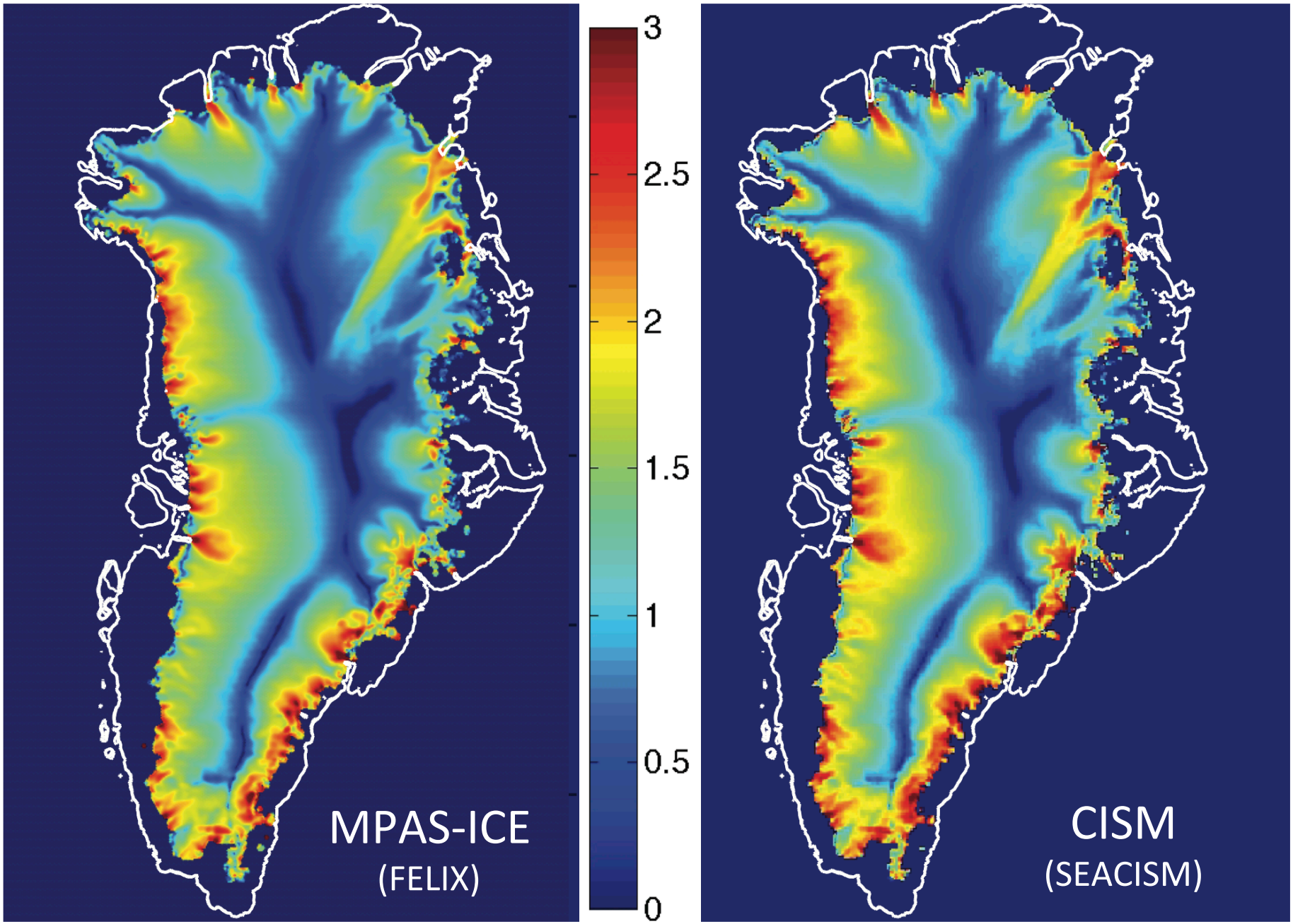
- **LANL** (W. Lipscomb (PI), S. Price)
- **LBNL** (E. Ng, D. Martin, S. Williams)
- **ORNL** (K. Evans, P. Worley, M. Normal)
- **SNL** (A. Salinger, M. Eldred, R. Tuminaro)
- **Florida State Univ.** (M. Gunzburger)
- **MIT** (P. Heimbach)
- **Univ. South Carolina** (L. Ju)
- **Univ. Texas at Austin** (C. Jackson, G. Stadler, O. Ghattas)
- **NCAR** (M. Vertenstein, W. Sacks)

PISCEES dynamical cores

Building on **ISICLES** dycores, we will develop two scalable, hierarchical (e.g., Stokes/1st-order/shallow-shelf/shallow-ice) dycores for CISM:

- **FELIX** (**F**inite **E**lements for **L**and **I**ce e**X**periments)
  - Finite element methods on unstructured, variable-resolution grids
  - will use SEACISM's JFNK/Trilinos framework
  - will use Model for Prediction Across Scales (MPAS) framework

- **BISICLES** (**B**erkeley **ISICLES**)
  - Extend current model to solve different equations (e.g., Stokes and 3D higher-order) in different regions
  - Use embedded boundaries to improve grounding-line treatment
  - will continue to use Chombo's block-structured adaptive mesh refinement


MPAS-ICE
(FELIX)
3
2.5
2
1.5
1
0.5
0
CISM
(SEACISM)

PISCEES project website: **www.scidac.gov/PISCEES**

- add publications, presentations, highlights, and links to personal web pages
- thanks to Daniel Pack, ORNL

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(4) CISM results for SeaRISE and Ice2Sea

Sastrugi, Jakobshavn Isbrae catchment, Greenland

LIWG Computing Resources

The CESM Land Ice Working Group will receive ~4 million cpu-hrs for CISM development on Yellowstone, from fall 2012 to early 2014.

- Most of this time has been set aside for PISCEES; should be enough for development
- Also have ALCC and LANL institutional resources in 2012-13 for POP/CISM runs
- May need additional resources (ALCC, INCITE) for production runs down the road

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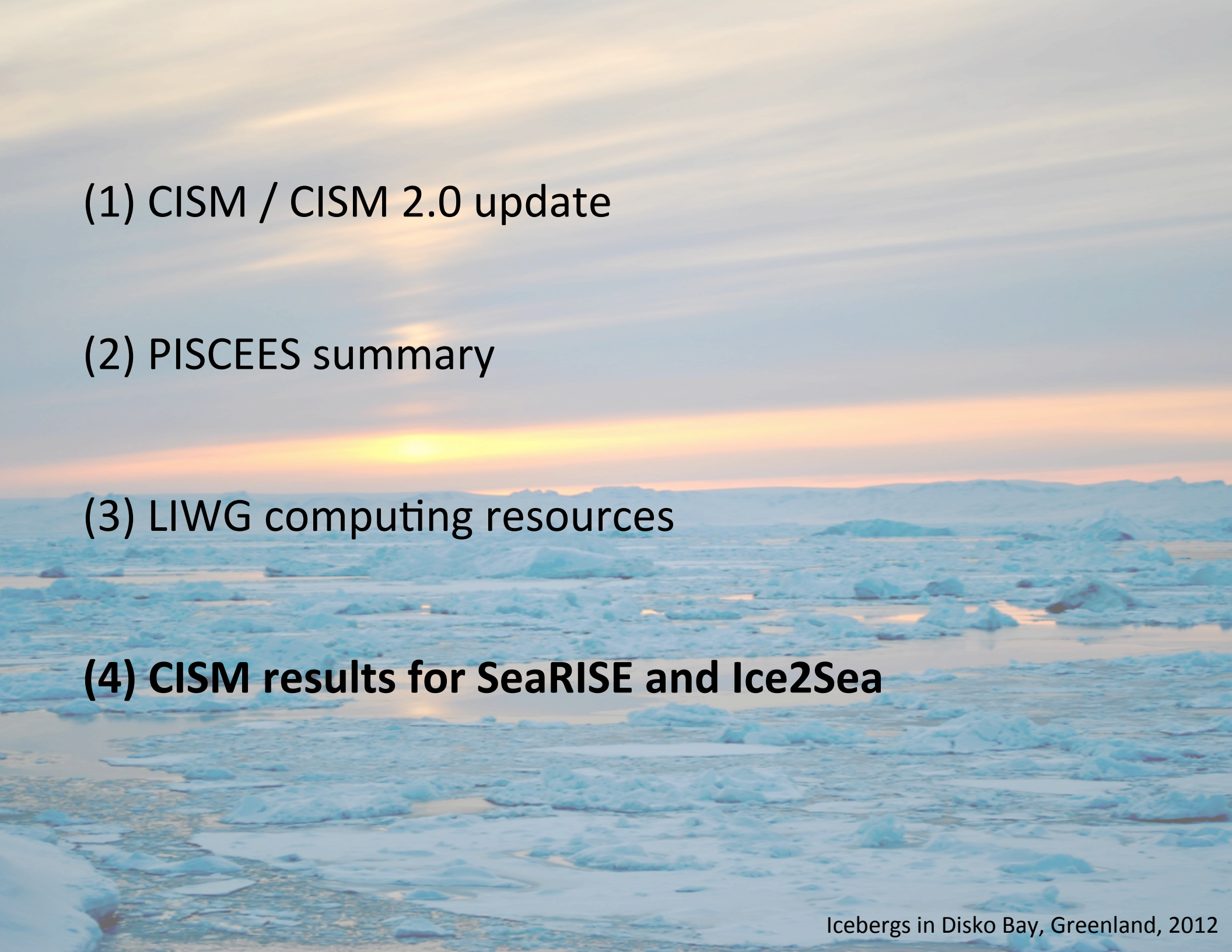


Icebergs in Disko Bay, Greenland, 2012

SeaRISE and Ice2Sea Greenland simulations

SeaRISE

8 simulations; control, 3 climate forcing only (1-3x A1B SMB, Ts anomalies), 3 sliding forcing only (2-3x sliding), 1 combo (1x A1B SMB + 2x sliding)

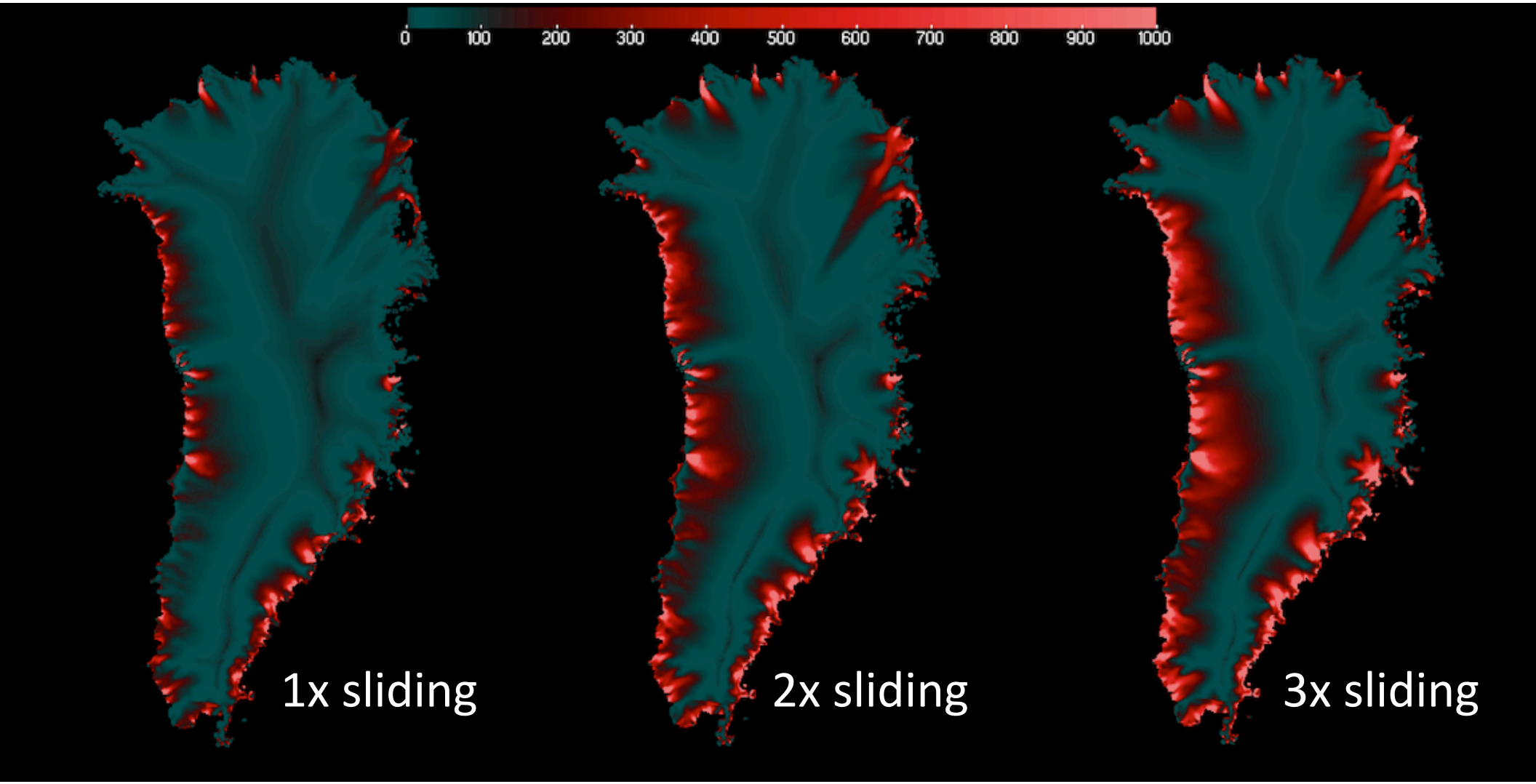
Ice2sea

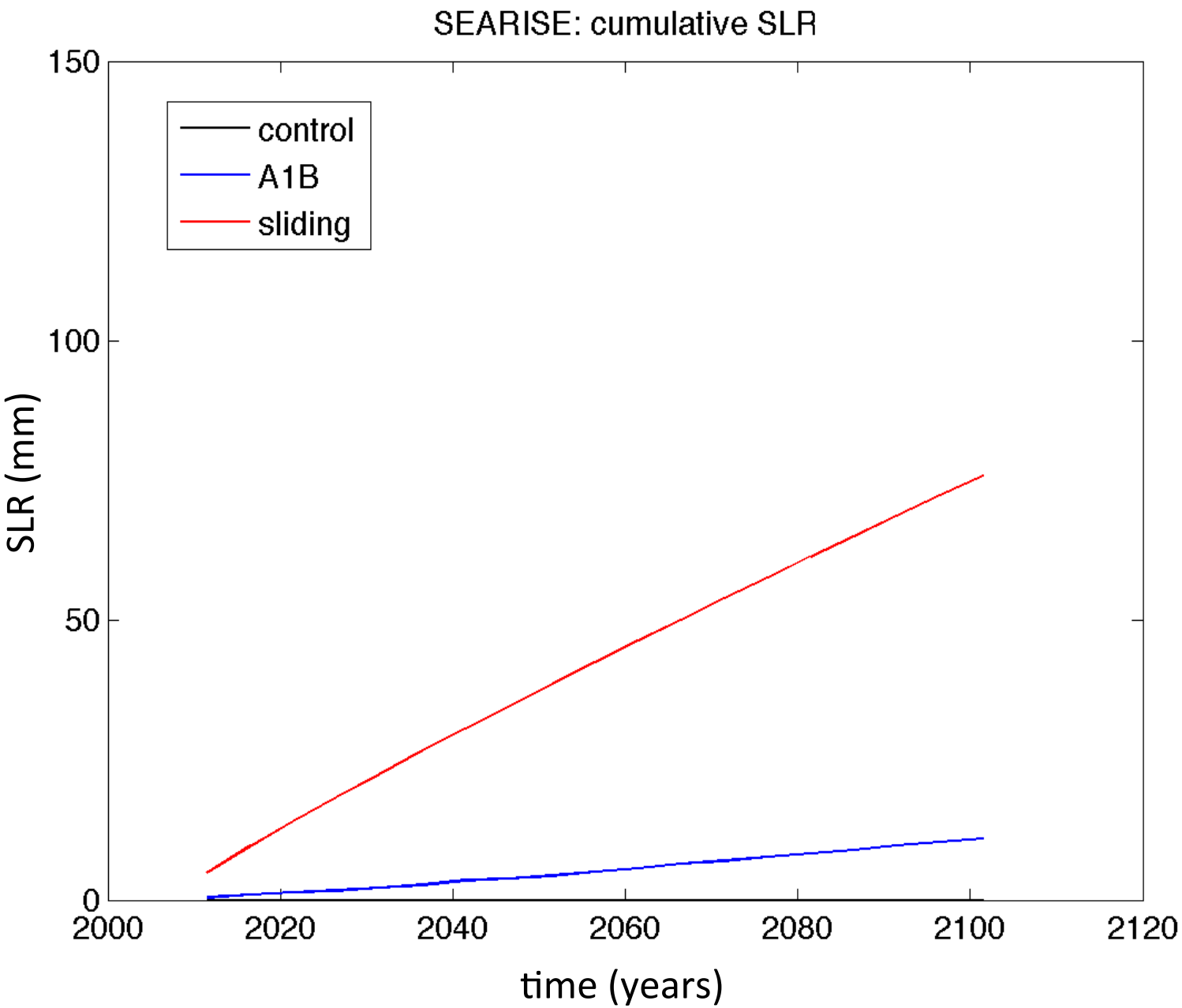
4 simulations; control, 1 climate forcing only (A1B SMB anomalies), 2 combo (A1B SMB + high/low sliding forcing)

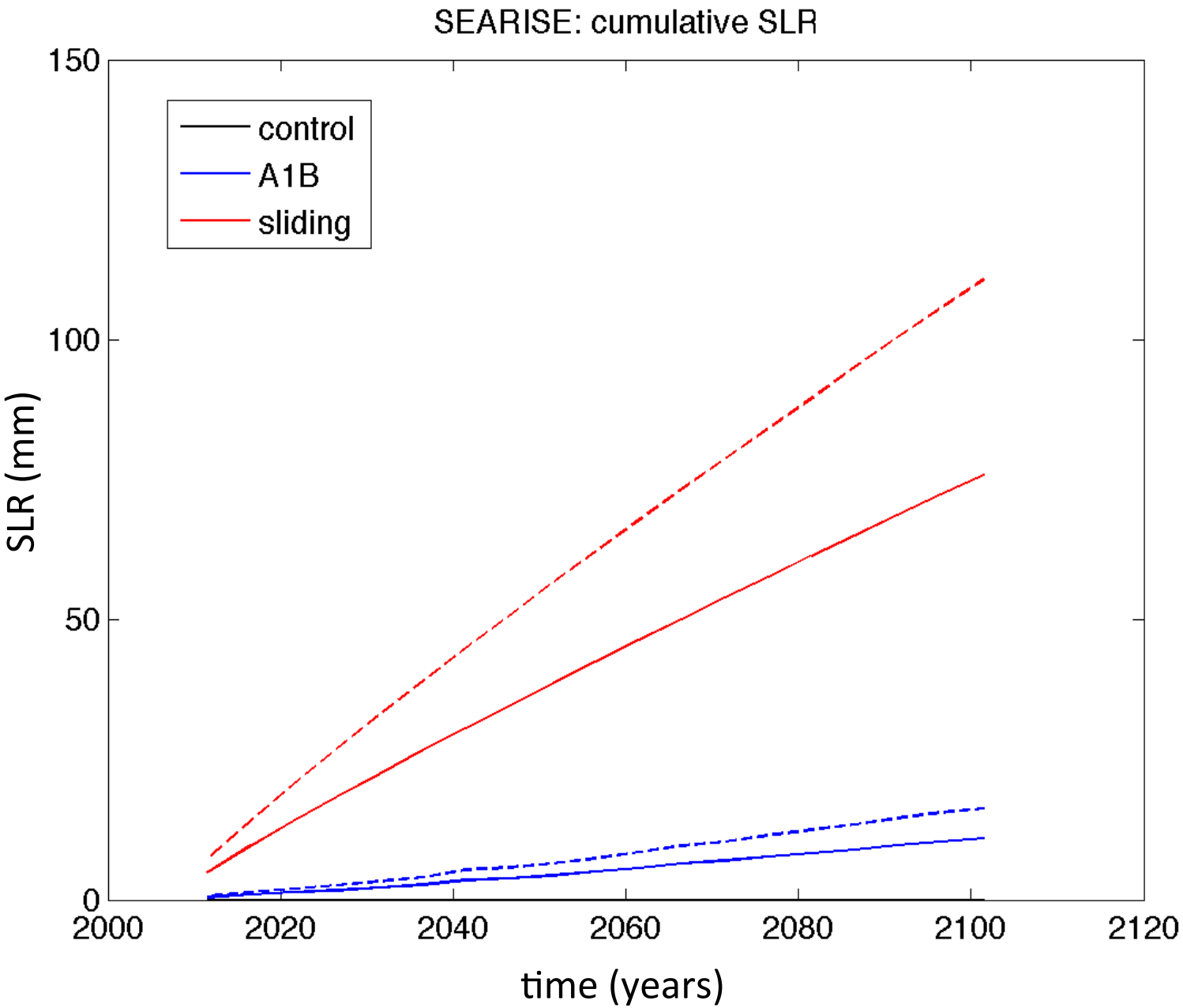
Notes

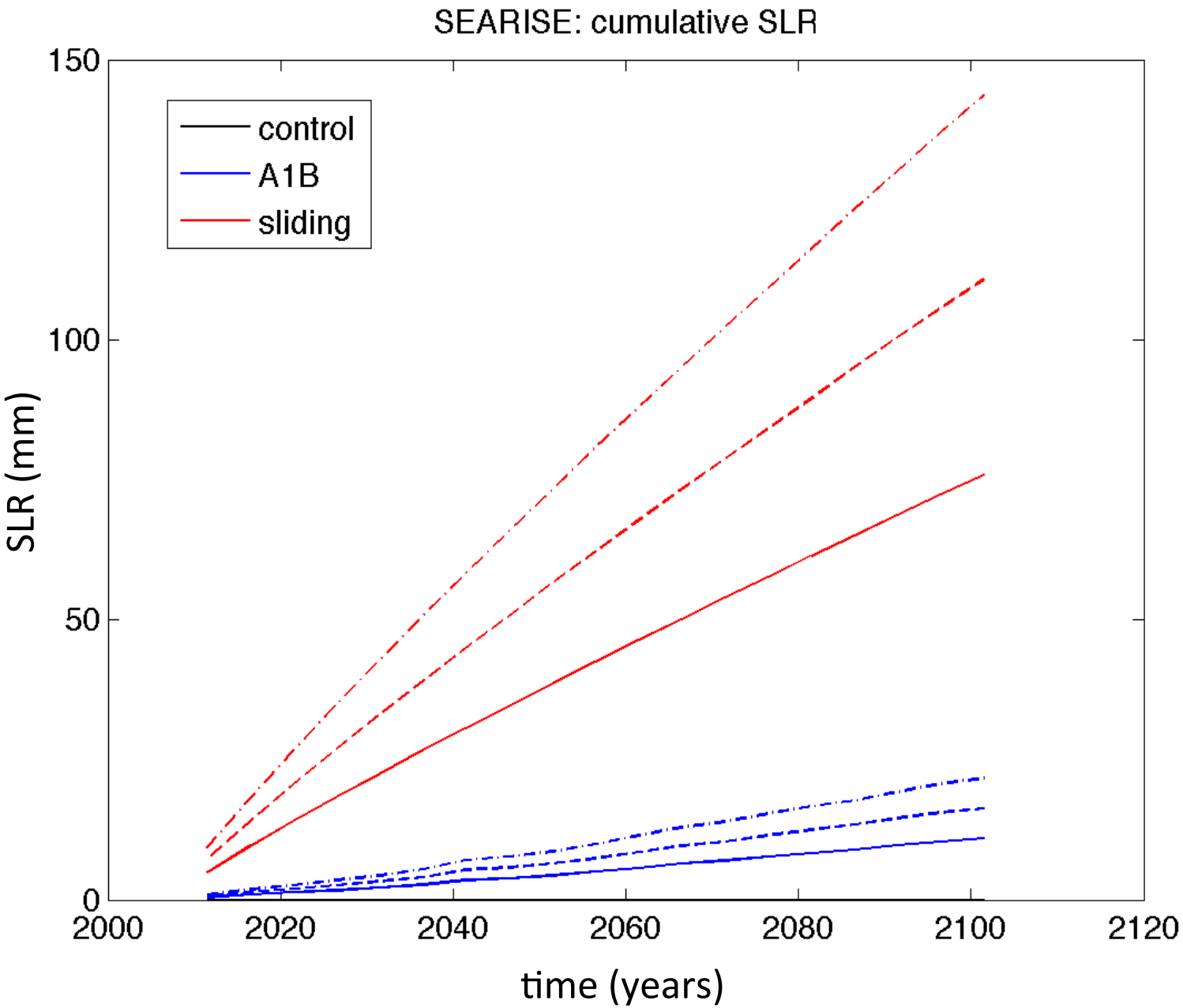
SMB forcing for SeaRISE is probably biased LOW w.r.t. SLR (our problem)
Sliding forcing for SeaRISE is probably biased HIGH w.r.t. SLR
Sliding forcing for Ice2Sea based on observations of speedup vs. runoff

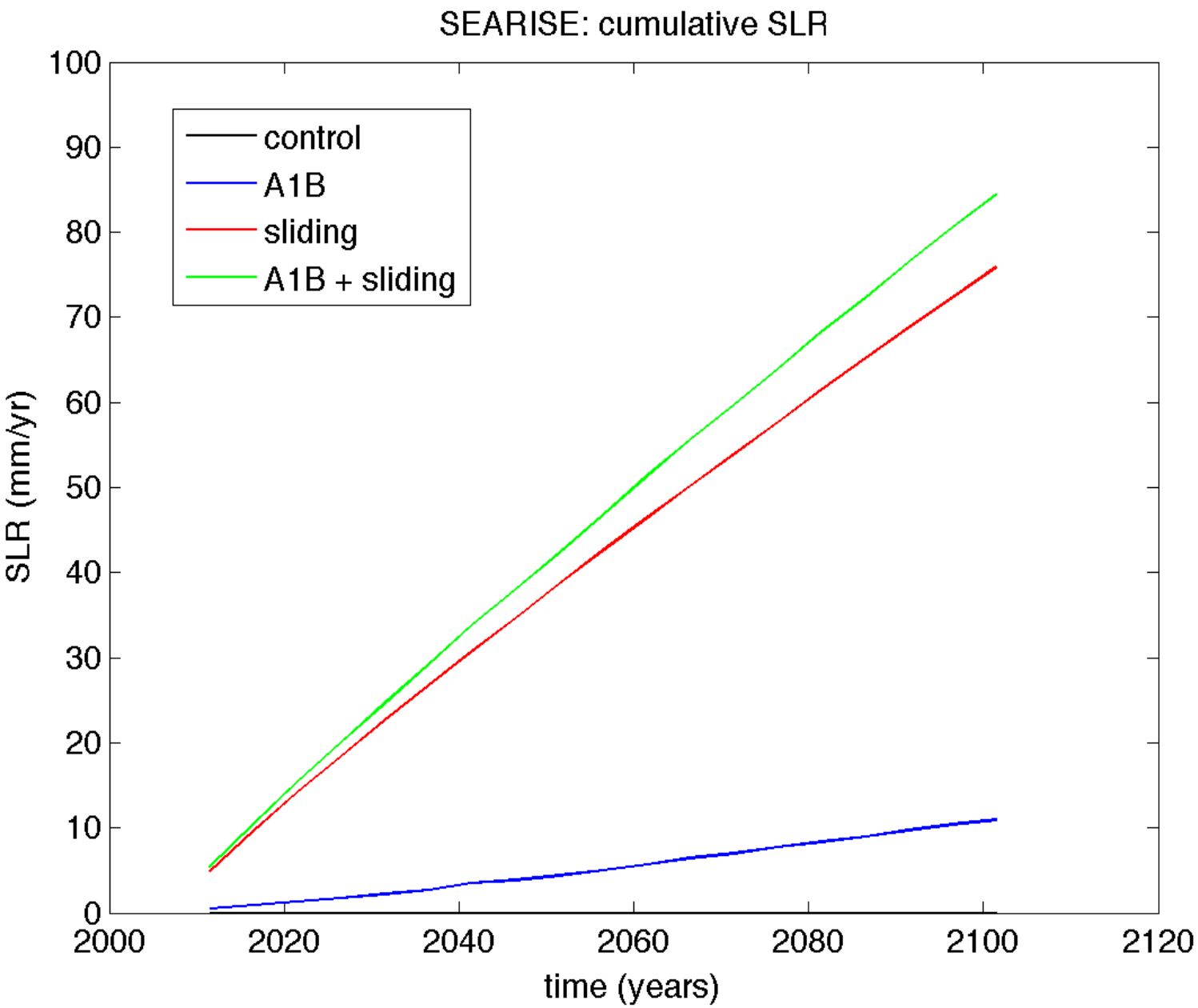
GIS diagnostic ice speed for SeaRISE sliding experiments

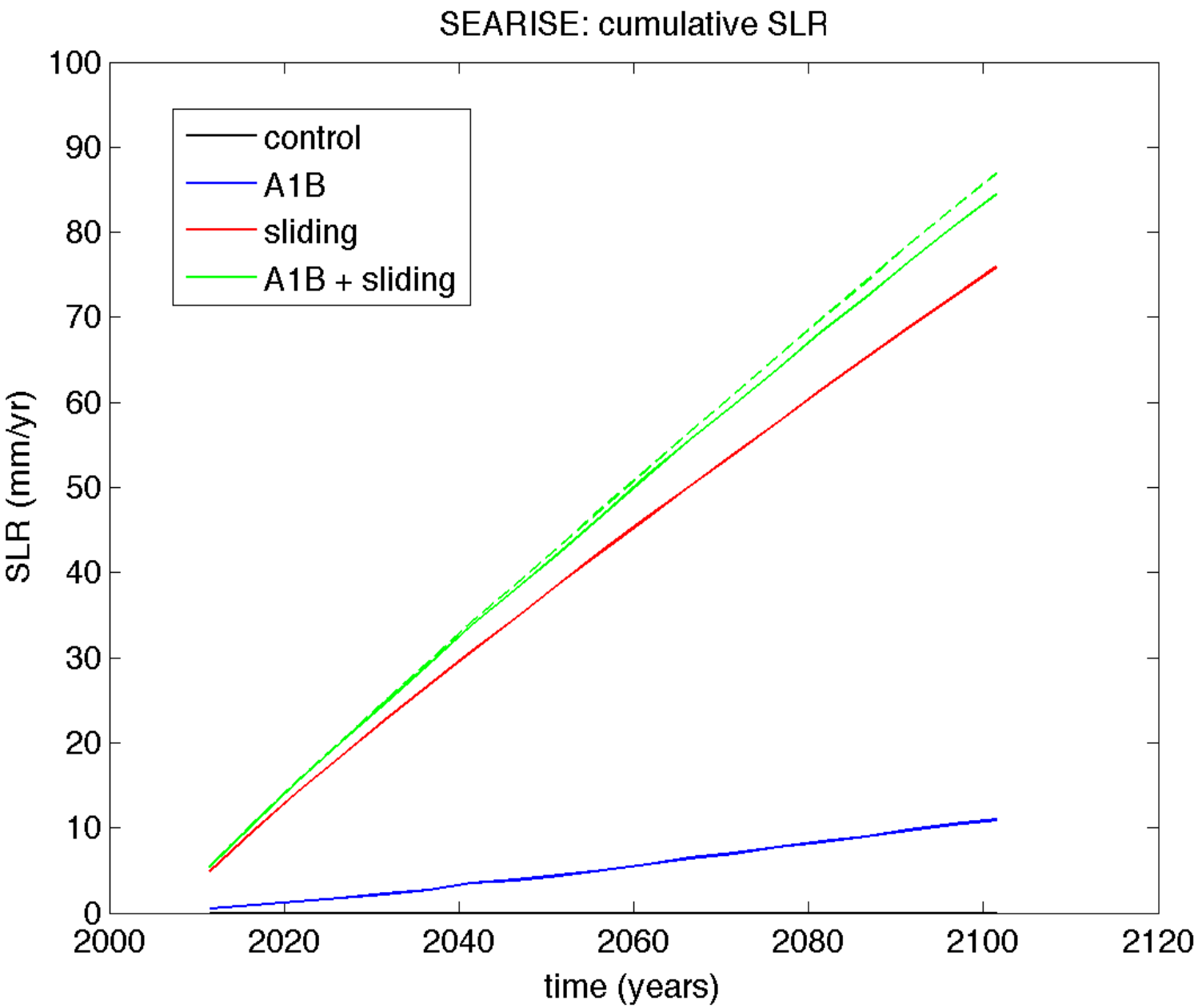


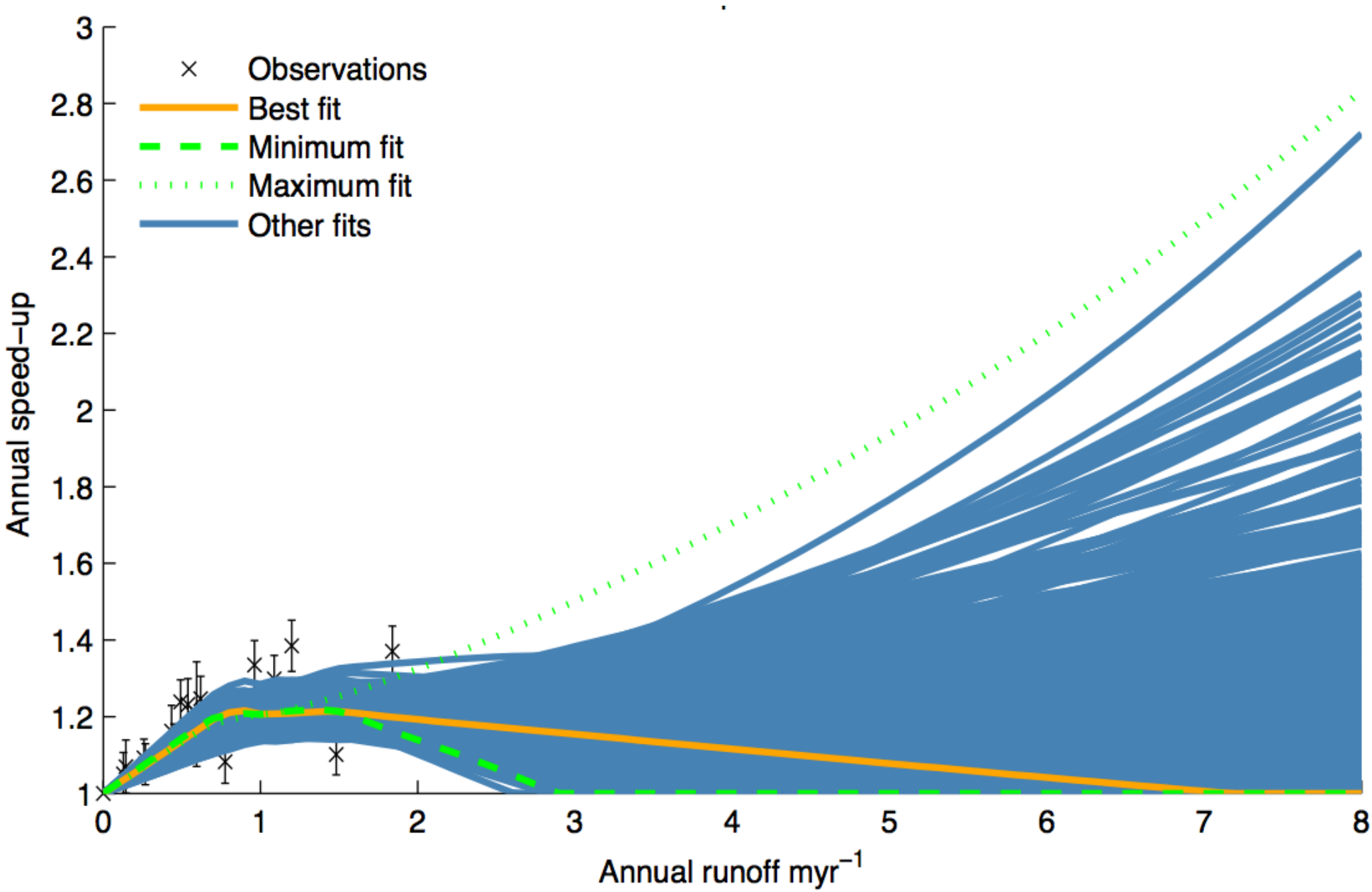

SEARISE: cumulative SLR
150
100
50
0
SLR (mm)
control
A1B
sliding
2000
2020
2040
2060
2080
2100
2120
time (years)

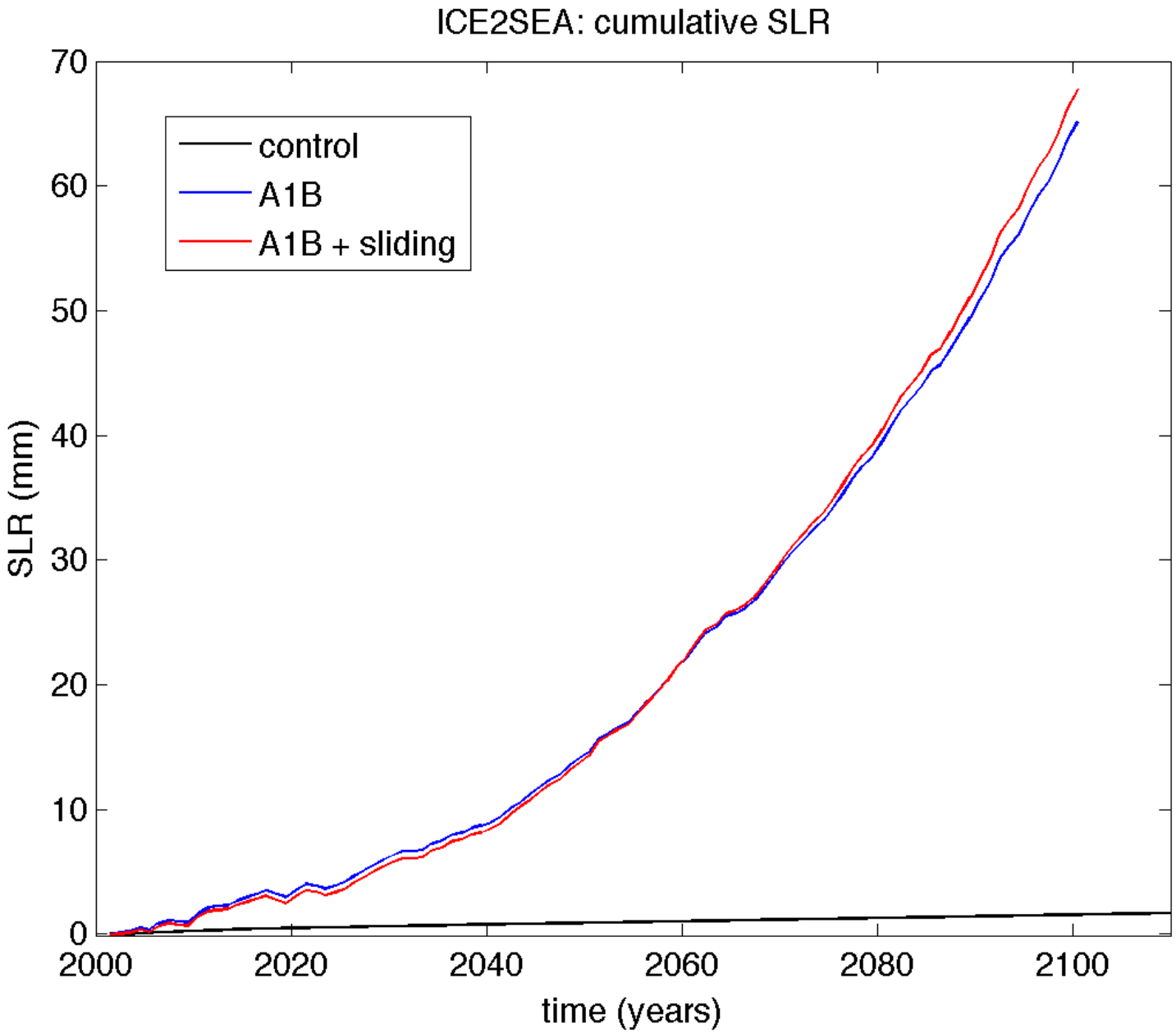

SEARISE: cumulative SLR
150
100
50
0
SLR (mm)
control
A1B
sliding
2000
2020
2040
2060
2080
2100
2120
time (years)

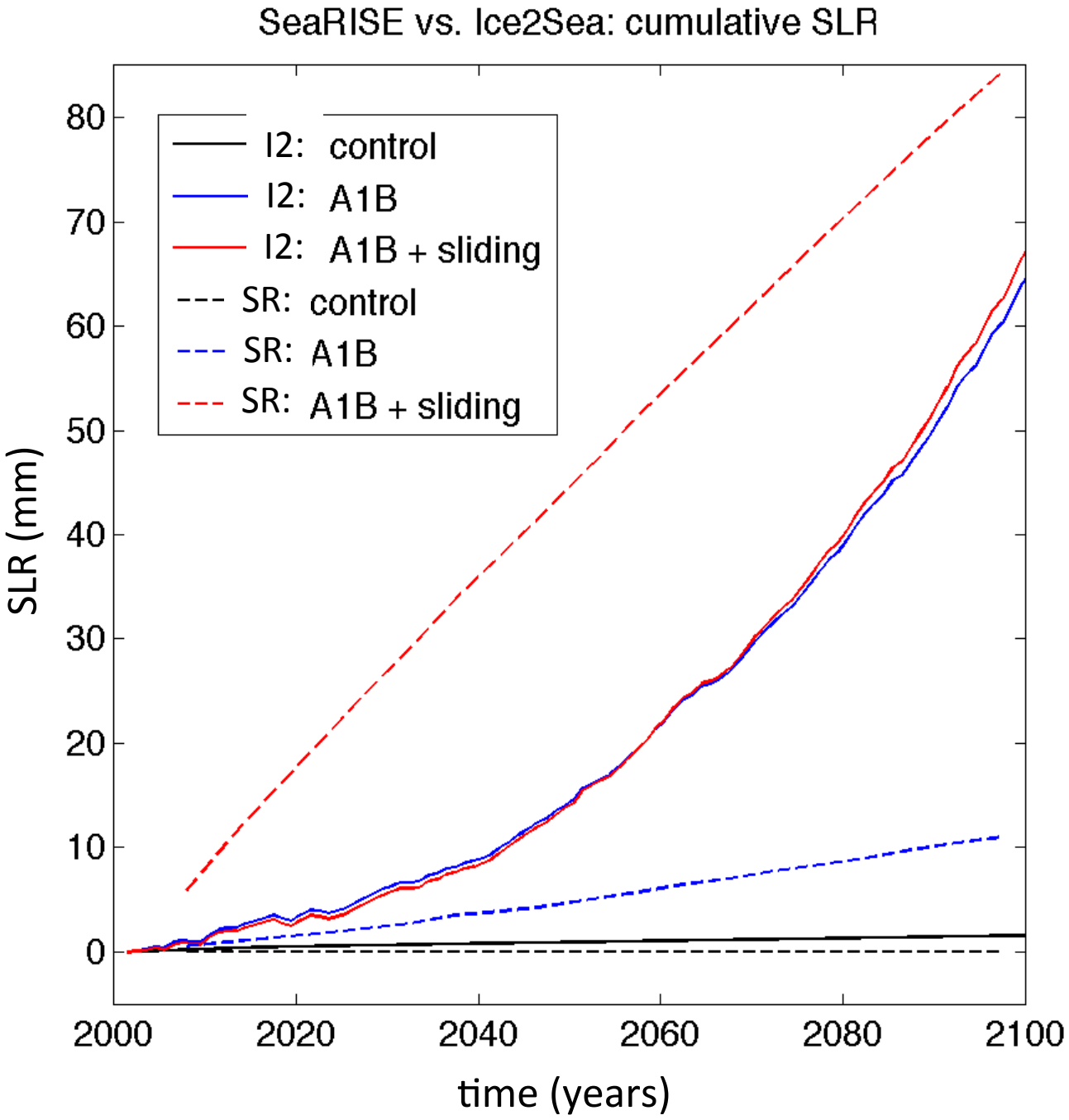

SEARISE: cumulative SLR
control
A1B
sliding
150
100
50
0
SLR (mm)
2000
2020
2040
2060
2080
2100
2120
time (years)

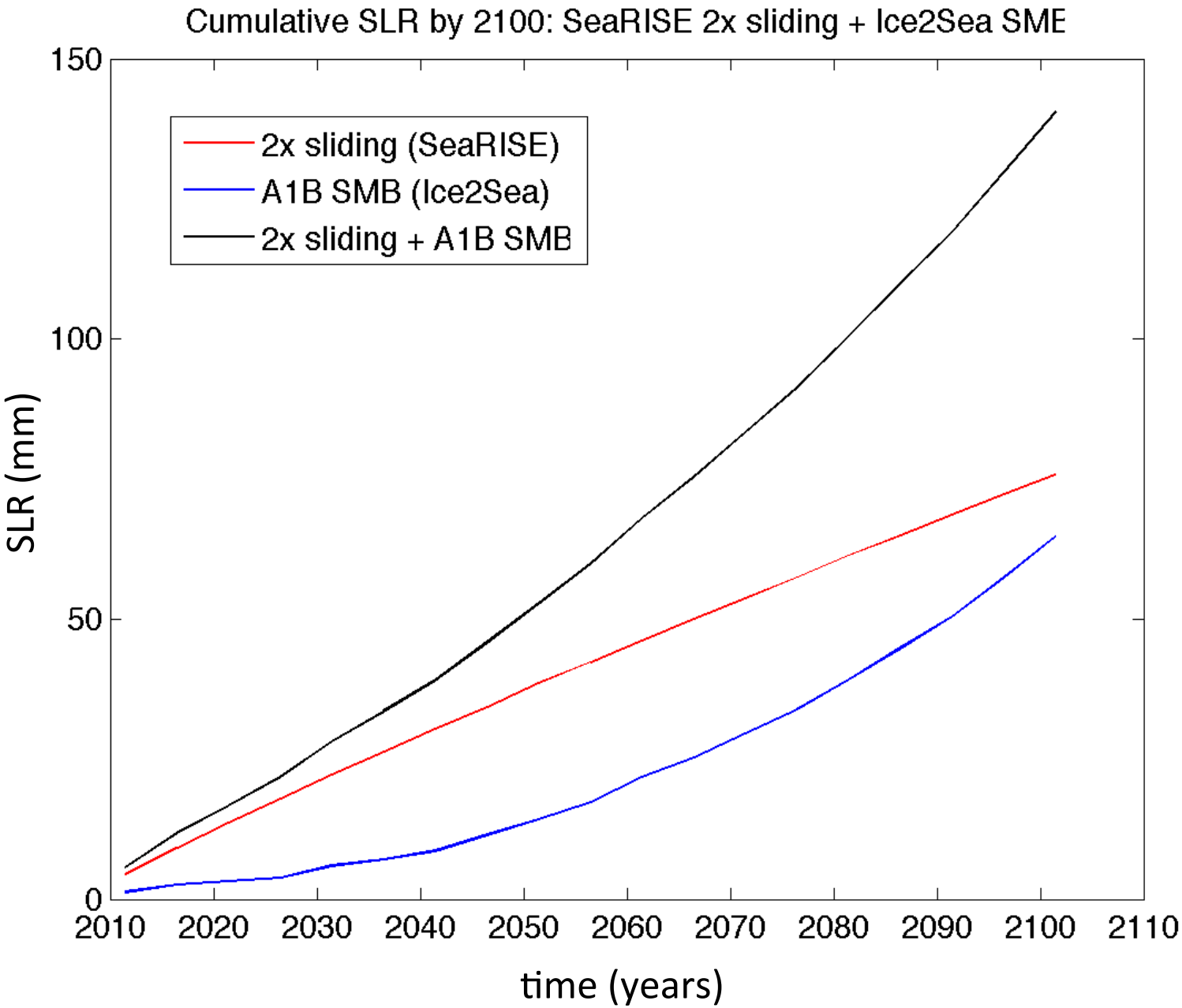

SEARISE: cumulative SLR
control
A1B
sliding
A1B + sliding
SLR (mm/yr)
time (years)
0
10
20
30
40
50
60
70
80
90
100
2000
2020
2040
2060
2080
2100
2120

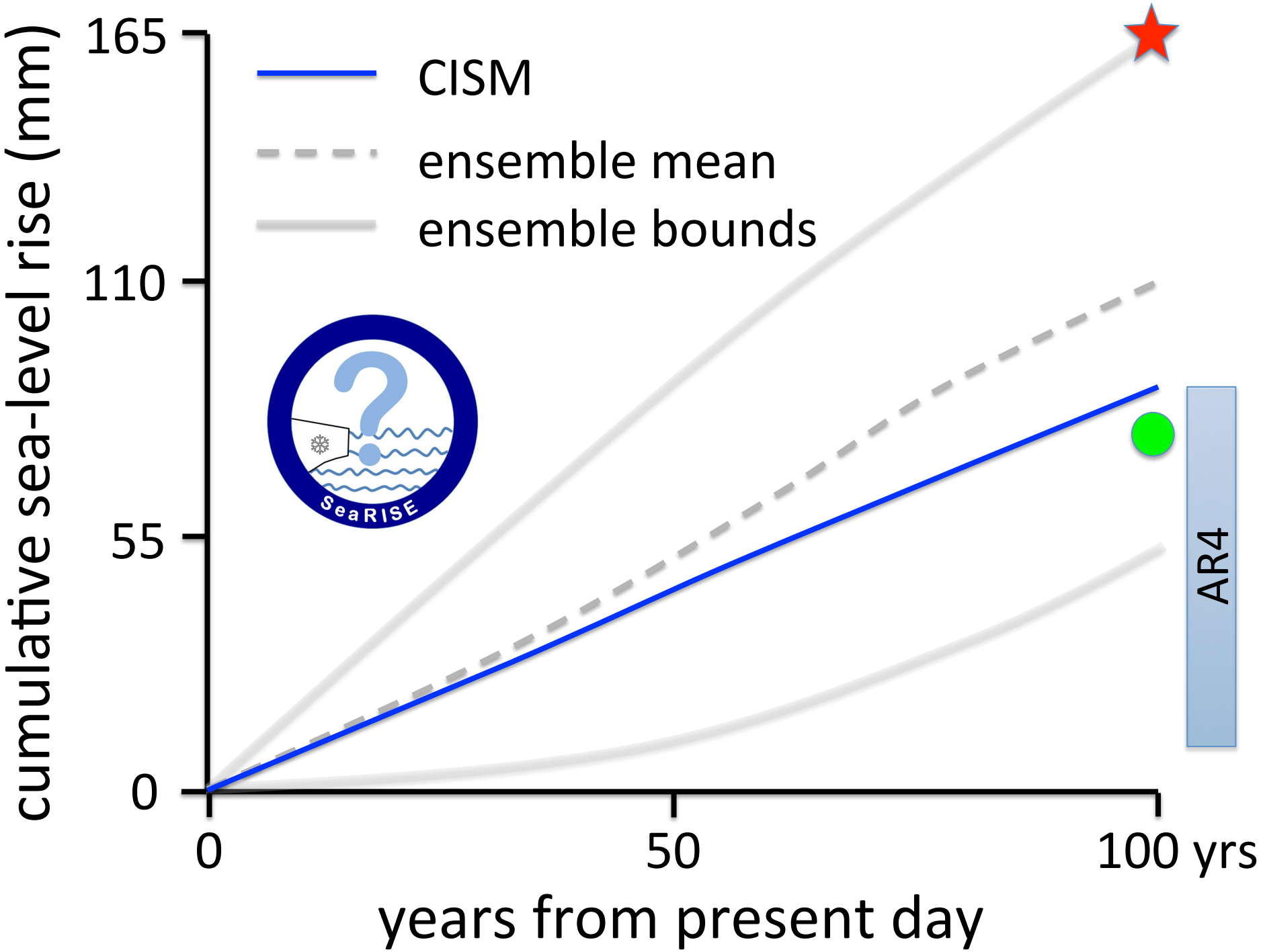

SEARISE: cumulative SLR
control
A1B
sliding
A1B + sliding
SLR (mm/yr)
time (years)
0
10
20
30
40
50
60
70
80
90
100
2000
2020
2040
2060
2080
2100
2120

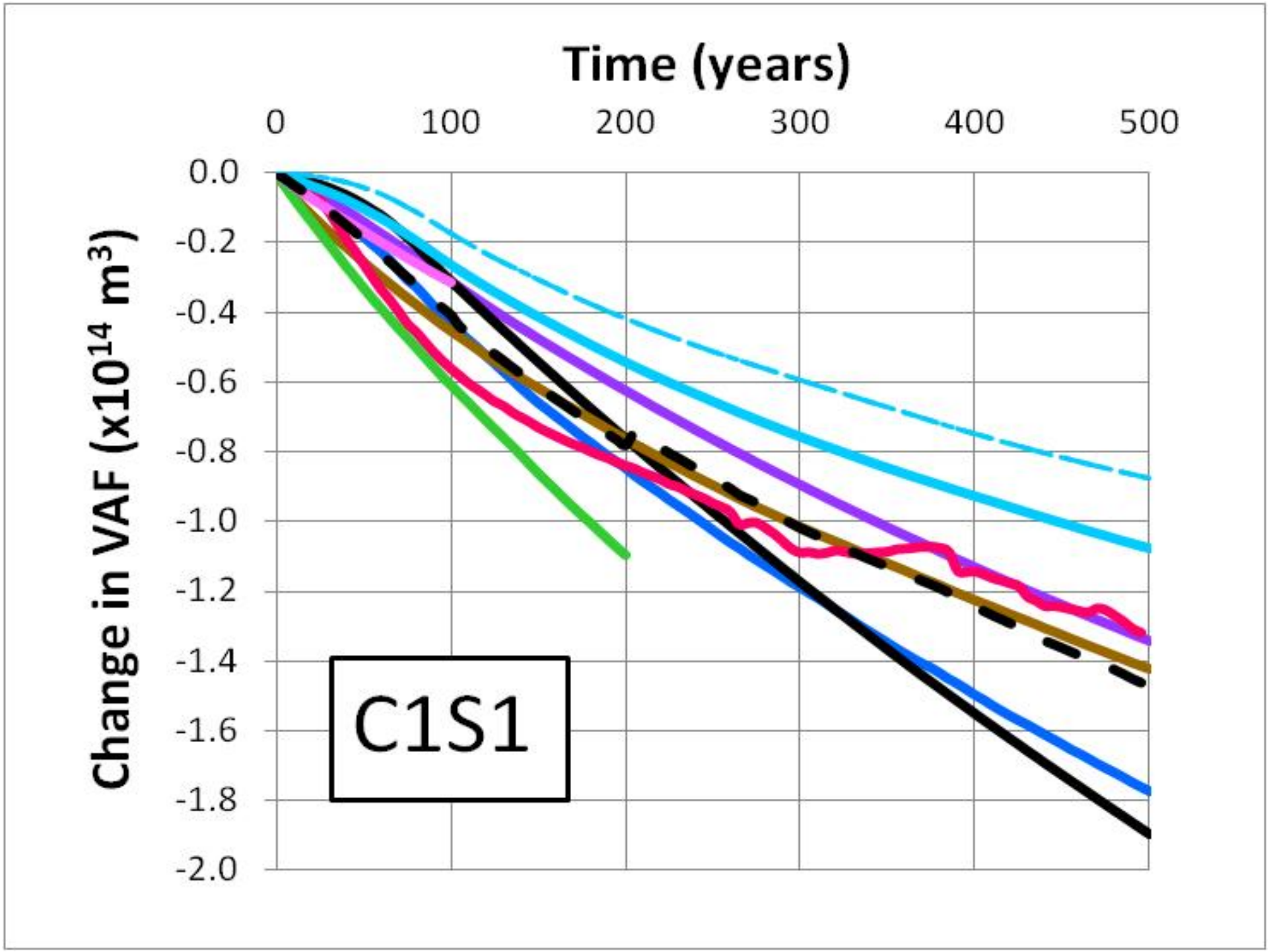

Observations
Best fit
Minimum fit
Maximum fit
Other fits
Annual speed–up
Annual runoff myr^{-1}
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
1
2
3
4
5
6
7
8


ICE2SEA: cumulative SLR
control
A1B
A1B + sliding
SLR (mm)
time (years)
0
10
20
30
40
50
60
70
2000
2020
2040
2060
2080
2100


SeaRISE vs. Ice2Sea: cumulative SLR
I2: control
I2: A1B
I2: A1B + sliding
SR: control
SR: A1B
SR: A1B + sliding
SLR (mm)
0
10
20
30
40
50
60
70
80
2000
2020
2040
2060
2080
2100
time (years)


Cumulative SLR by 2100: SeaRISE 2x sliding + Ice2Sea SME
2x sliding (SeaRISE)
A1B SMB (Ice2Sea)
2x sliding + A1B SMB
SLR (mm)
time (years)
0
50
100
150
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110


cumulative sea-level rise (mm)
165
110
55
0
CISM
ensemble mean
ensemble bounds
SeaRISE
AR4
0
50
100 yrs
years from present day


Time (years)
0
100
200
300
400
500
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
Change in VAF (x10^14 m^3)
C1S1

Starting point: ISICLES

Two parallel, higher-order dynamical cores developed for the ASCR ISICLES project are being integrated in CISM and CESM:

- SEACISM (ORNL/SNL/LANL)
  - Payne-Price velocity solver (3D higher-order equations)
  - Trilinos linear and nonlinear solvers
  - Structured grid, finite difference
  - To be released in CISM 2.0, CESM 1.1 (fall 2012)
- BISICLES (LBNL/LANL/U. Bristol)
  - Chombo adaptive mesh refinement framework
  - Vertically integrated higher-order equations
  - Nested block structure (fine mesh < 1 km), finite volume
  - Has been linked to CISM

  - higher-order dycore
  - FastMATH (scalable algorithms and software tools)
  - SUPER (computer performance science/engineering)
  - QUEST (uncertainty quantification)
- IMPACTS (abrupt climate change)
  - LANL project on ice-sheet/ocean coupling and marine ice sheet instability
- CESM

Status of MPAS land ice / FELIX dycore

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 (FELIX: Stokes, 1st-order, LIL2, etc.) based on MPAS SCVT mesh generation and modeling framework

- Stokes, 1st-order, LIL2, SSA, and SIA solvers and tested[1,2] (outside of MPAS)
- coupling between 1st-order solver and MPAS complete / tested (LIL2, SSA, SIA partially complete / tested)
- coupling between Stokes solver partially working / partially tested
- mass transport / evolution working in MPAS (simple 1st-order upwinding for now; FCT later?)
- temperature evolution schemes partially done (straightforward)

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

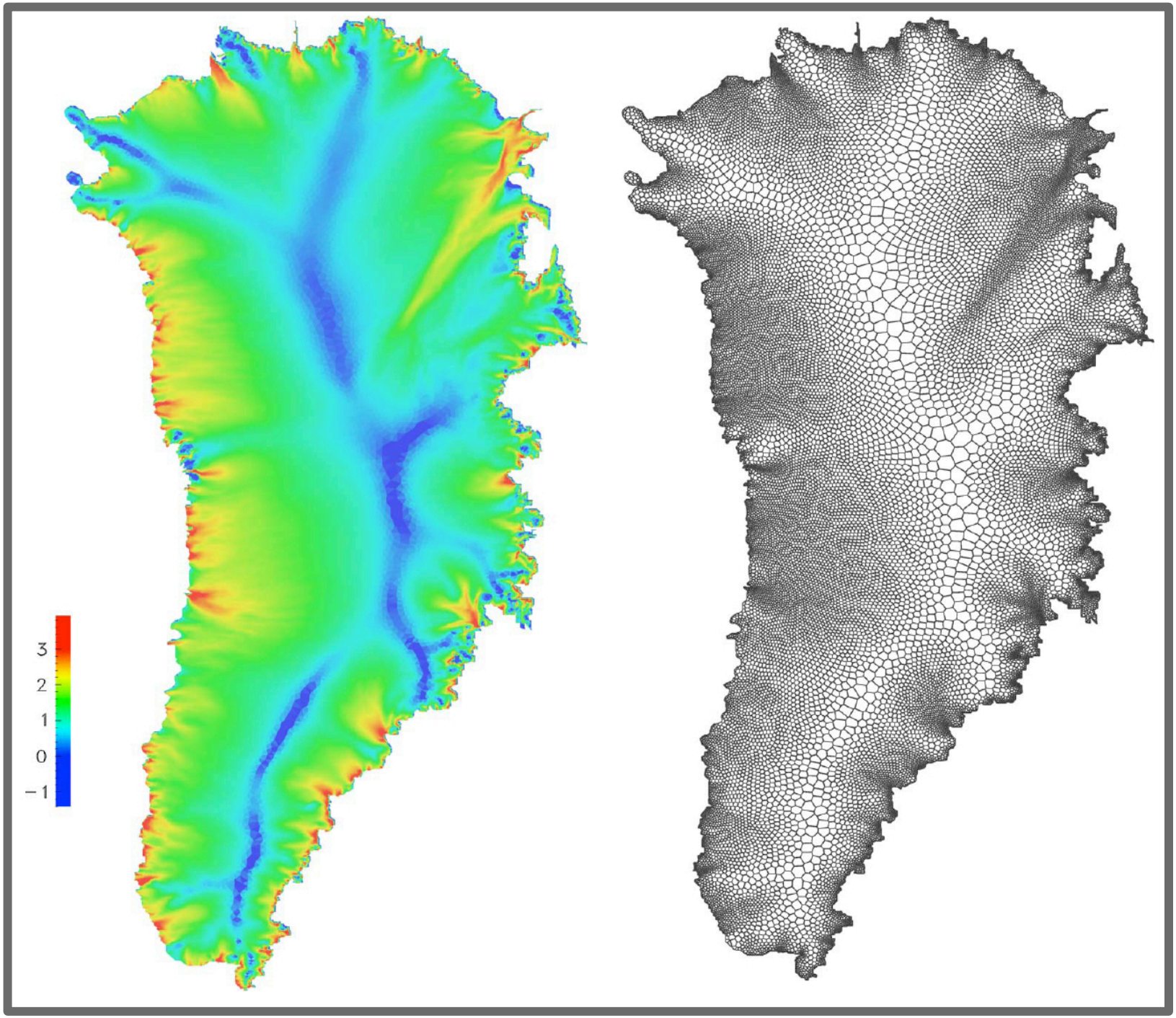
Status of MPAS land ice / FELIX dycore (cont.)

- Native MPAS SIA solver (not using LifeV)
- handles floating vs. grounded ice
- handles margin advance / retreat naturally
- linear friction basal boundary condition ("betasquared")
- allows for non-zero, time evolving SMB field
- tools external to MPAS for:
    - setting up ice sheet grids (e.g., data copies from CISM to MPAS)
    - diagnostic tools (e.g., visualizing output)

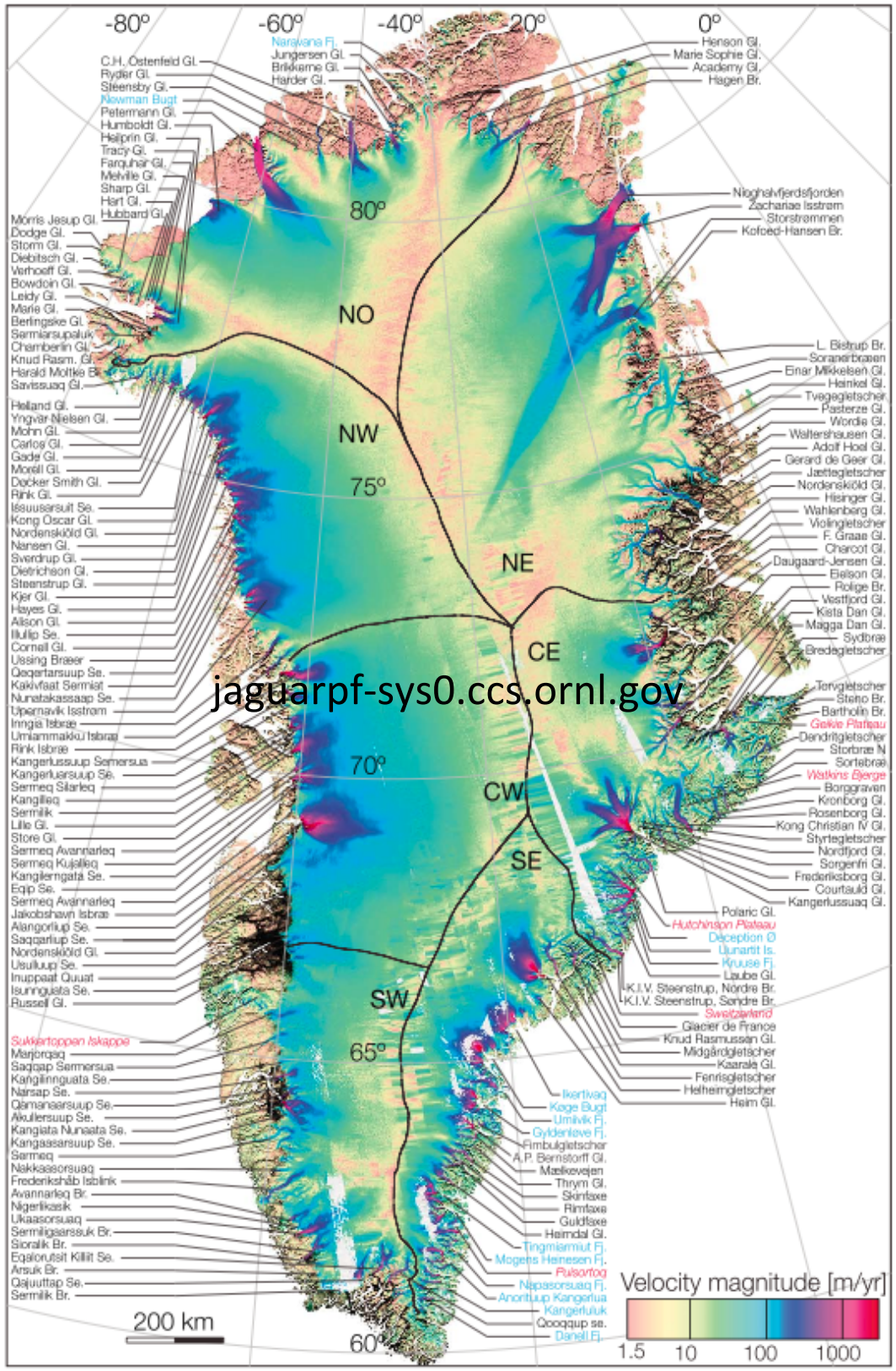
Next Steps:

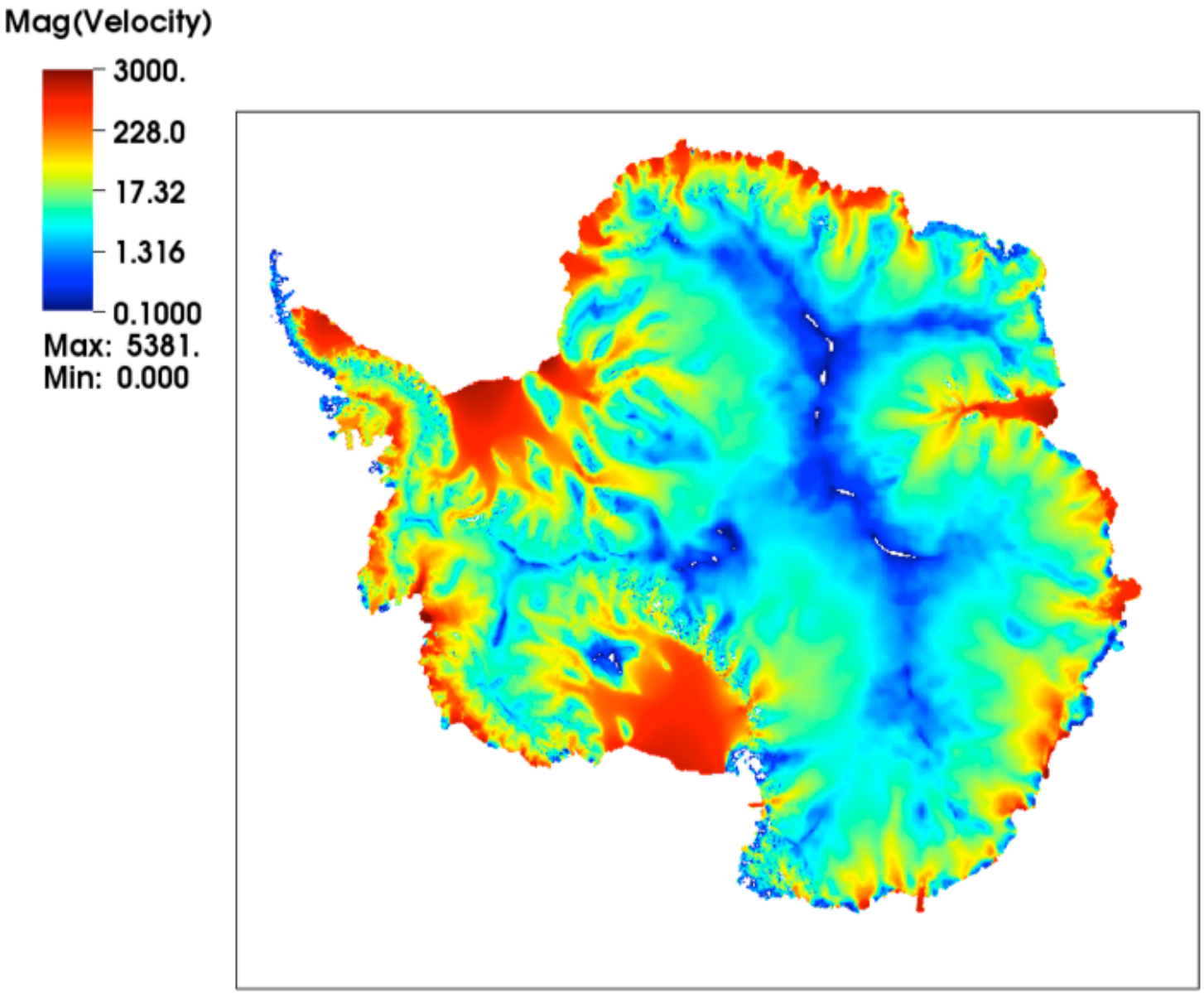
- allow for variable resolution meshes
- tracer advection using MPAS routines (e.g., heat advection)
- HO thickness advection using MPAS routines
- Merge current MPAS ice with trunk for updates (e.g., PIO)
- (long term) move from LifeV to Trilinos

Variable-resolution grids (MPAS)



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


-80°
-60°
-40°
-20°
0°
80°
75°
70°
65°
60°
NO
NW
NE
CE
CW
SE
SW
jaguarpf-sys0.ccs.ornl.gov
Narajvana Fj.
Jungersen Gl.
Brikkerne Gl.
Harder Gl.
Henson Gl.
Marie Sophie Gl.
Academy Gl.
Hagen Br.
C.H. Ostenfeld Gl.
Rydet Gl.
Steensby Gl.
Newman Bugt
Petermann Gl.
Humboldt Gl.
Heilprin Gl.
Tracy Gl.
Farquhar Gl.
Melville Gl.
Sharp Gl.
Hart Gl.
Hubbard Gl.
Nioghalvfjerdsfjorden
Zachariae Isstrøm
Storstrømmen
Kofoed-Hansen Br.
Morris Jesup Gl.
Dodge Gl.
Storm Gl.
Diebitsch Gl.
Verhoeff Gl.
Bowdoin Gl.
Leidy Gl.
Marie Gl.
Berlingske Gl.
Sermiarsupaluk
Chamberlin Gl.
Knud Rasm. Gl.
Harald Moltke Br.
Savissuaq Gl.
L. Bistrup Br.
Sorgenfribræen
Einar Mikkelsen Gl.
Heimkel Gl.
Tvegegletscher
Pasterze Gl.
Wordie Gl.
Waltershausen Gl.
Adolf Hoel Gl.
Gerard de Geer Gl.
Jættegletscher
Nordenskiöld Gl.
Hisinger Gl.
Wahlenberg Gl.
Violingletscher
F. Graae Gl.
Charcot Gl.
Daugaard-Jensen Gl.
Eielson Gl.
Rolige Br.
Vestfjord Gl.
Kista Dan Gl.
Magga Dan Gl.
Sydbræ
Bredegletscher
Helland Gl.
Yngvar Nielsen Gl.
Mohn Gl.
Carlos Gl.
Gade Gl.
Morell Gl.
Dæcker Smith Gl.
Rink Gl.
Issuusarsuit Se.
Kong Oscar Gl.
Nordenskiöld Gl.
Nansen Gl.
Sverdrup Gl.
Dietrichson Gl.
Steenstrup Gl.
Kjer Gl.
Hayes Gl.
Alison Gl.
Illullip Se.
Cornell Gl.
Ussing Bræer
Qeqertarsuup Se.
Kakivfaat Sermiat
Nunatakassaap Se.
Upernavik Isstrøm
Inngia Isbræ
Umiammakku Isbræ
Rink Isbræ
Kangerlussuup Sermersua
Kangerluarsuup Sø.
Sermeq Silarleq
Kangilleq
Sermilik
Lille Gl.
Store Gl.
Sermeq Avannarleq
Sermeq Kujalleq
Kangilerngata Se.
Eqip Se.
Sermeq Avannarleq
Jakobshavn Isbræ
Alangorliup Se.
Saqqarliup Se.
Nordenskiöld Gl.
Usulluup Se.
Inuppaat Quuat
Isunngiata Se.
Russell Gl.
Tervgletscher
Steno Br.
Bartholin Br.
Gekie Plateau
Dendritgletscher
Storbræ N
Sortebræ
Watkins Bjerge
Borggraven
Kronborg Gl.
Rosenborg Gl.
Kong Christian IV Gl.
Styrtegletscher
Nordfjord Gl.
Sorgenfri Gl.
Frederiksborg Gl.
Courtauld Gl.
Kangerlussuaq Gl.
Polaric Gl.
Hutchinson Plateau
Déception Ø
Ujunartit Is.
Kruuse Fj.
Ljubbe Gl.
K.I.V. Steenstrup, Nordre Br.
K.I.V. Steenstrup, Søndre Br.
Sweetzerland
Glacier de France
Knud Rasmussen Gl.
Midgårdgletscher
Kaarale Gl.
Fenrisgletscher
Helheimgletscher
Heim Gl.
Sukkertoppen Iskappe
Manjorqaq
Saqqap Sermersua
Kangilinnguata Se.
Narsap Se.
Qamanaarsuup Se.
Akullersuup Se.
Kangiata Nunaata Se.
Kangaasarsuup Se.
Sermeq
Nakkaasorsuaq
Frederikshåb Isblink
Avannarleq Br.
Nigerlikasik
Ukaasorsuaq
Sermiligaarssuk Br.
Sioralik Br.
Eqalorutsit Killiit Se.
Ansuk Br.
Qajuuttap Se.
Sermilik Br.
Ikertivaq
Køge Bugt
Umiivik Fj.
Gyldenløve Fj.
Fimbulgletscher
A.P. Bernstorff Gl.
Mælkevejen
Thrym Gl.
Skinfaxe
Rimfaxe
Guldfaxe
Heimdal Gl.
Tingmiarmiut Fj.
Mogens Heinesen Fj.
Pulsartog
Napasorsuaq Fj.
Anoritup Kangerlua
Kangerluluk
Qooqqup se.
Daniell Fj.
200 km
Velocity magnitude [m/yr]
1.5
10
100
1000


Mag(Velocity)
3000.
228.0
17.32
1.316
0.1000
Max: 5381.
Min: 0.000

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Stephen Price[1]

and

The Community Earth System Model (CESM)
Land Ice Working Group (LIWG)

[1]Climate Ocean and Sea Ice Modeling Project
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Support courtesy of DOE Office of Science ASCR, BER, and SciDAC programs

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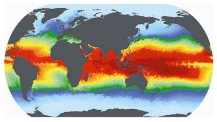
Los Alamos NATIONAL LABORATORY EST.1943



Climate, Ocean, and Sea Ice Modeling Project

CESM 2012

Land Ice Working Group Summary

Stephen Price, William Lipscomb (COSIM / LANL)

and

The Land Ice Working Group

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Office of Science U.S. DEPARTMENT OF ENERGY

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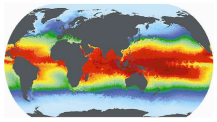

Climate, Ocean, and Sea Ice Modeling Project