Impact of improved bedrock geometry on Antarctic vulnerability to regional ice shelf collapse

Dan Martin

Applied Numerical Algorithms Group

Lawrence Berkeley National Laboratory

Land Ice Working Group Meeting, Feb 3, 2021

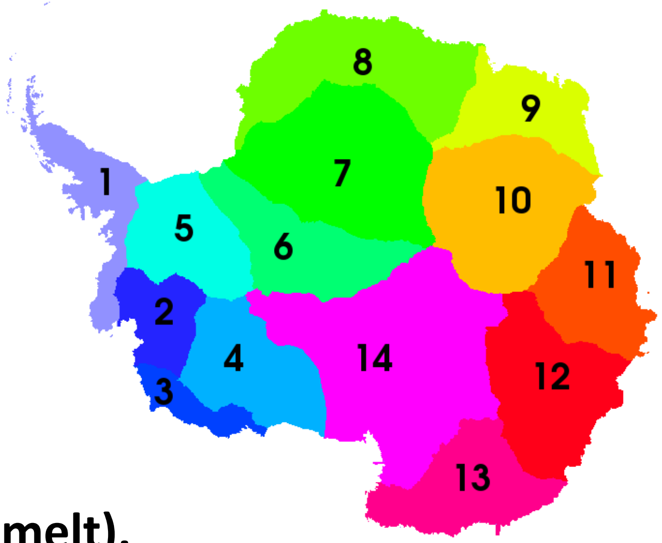
Joint work with:

- **Stephen Cornford (Swansea)**

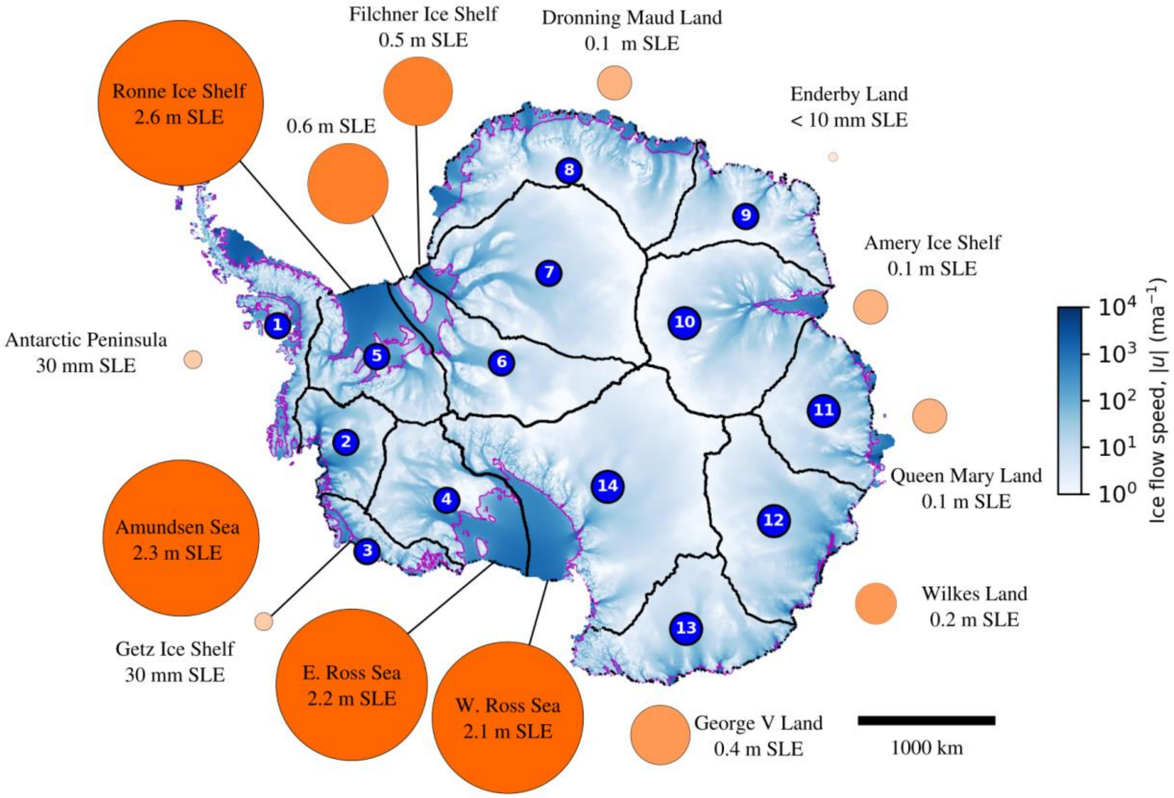
Antarctic vulnerability to warm-water forcing

- **Basic idea (Martin, Cornford, and Payne, GRL 2019) – try to understand where AIS is vulnerable to forcing from warm-water incursions**
- **Divide AIS into sectors**
- **For each sector in turn (and for some combinations), apply extreme depth-dependent melt forcing**
  - No melt for h < 100m
  - Range up to 400m/a where h > 800m.
  - **No melt applied in partially-grounded cells**
- **Run for 1000 years, compare with control (no melt).**

Antarctic sectors



Antarctic Vulnerability results:



But – that was Bedmap2 (2012)

- **Since Bedmap2,**
  - sustained campaign of observation,
  - improved interpolation ("mass-conserving" techniques)
  - Potential for greatly improve the quality of projections of Antarctic response to climate forcing
  - Bedmachine datasets (Morlighem et al)

- **To leading order, MISI is bedrock geometry dependent!**
- Waibel et al (2018) demonstrated magnitude and rate of GL retreat can be very dependent on details of bedrock topography

BERKELEY LAB

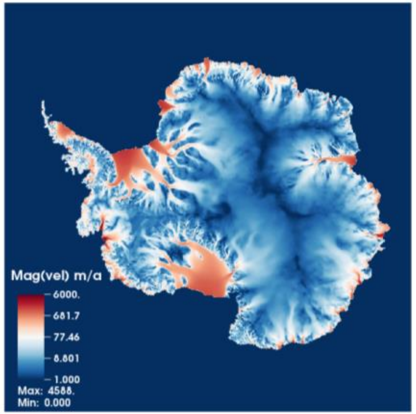
So, let's see what changed…

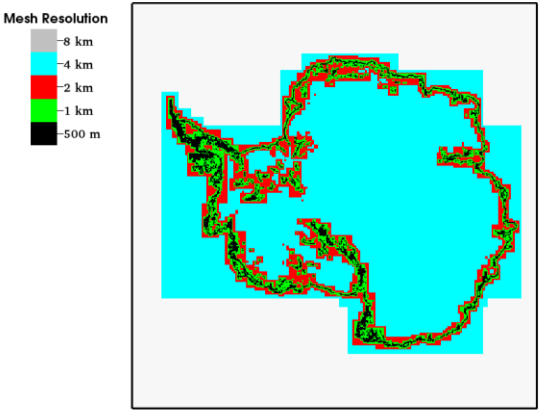
- **To try to evaluate the impact of improved datasets, we can rerun the same experiment and compare…**

Initial Condition for Antarctic Simulations

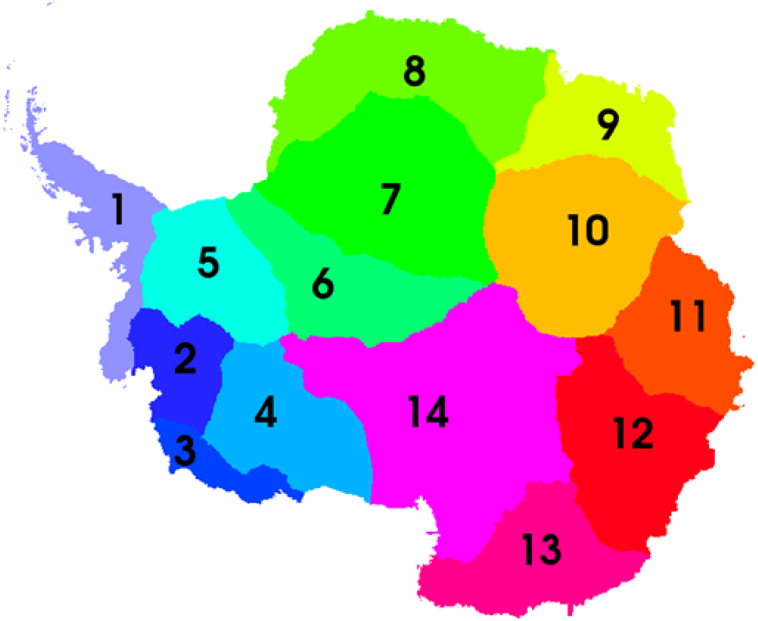
- Full-continent Bedmap2 (2013) geometry
- Full-continent Bedmachine (2019) geometry

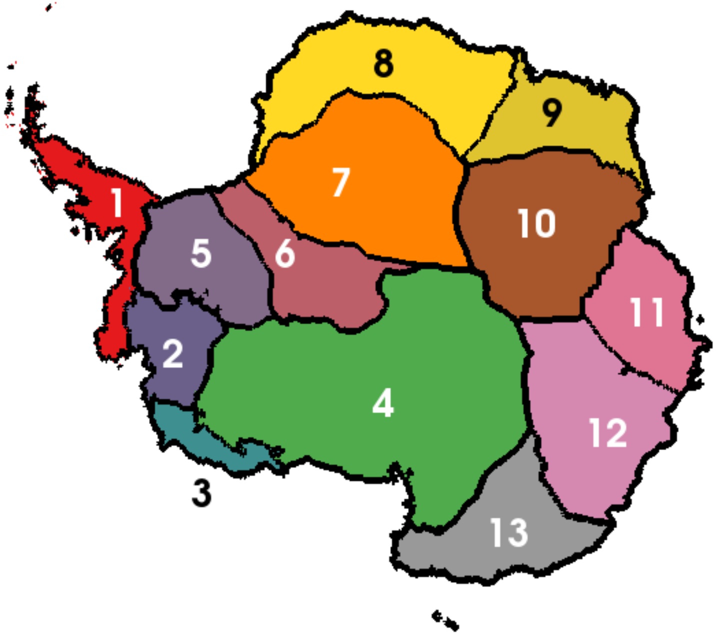
- Temperature field from Pattyn (2010)
- Temperature field from Morlighem (private communication)
- Initialize basal friction to match Rignot (2011) velocities
- Initialize basal friction to match MEaSUREs (Rignot et al, 2017)
- SMB: Arthern et al (2006)
- AMR meshes: 8 km base mesh, adaptively refine to 1km finest resolution.





Slightly modified sector map…

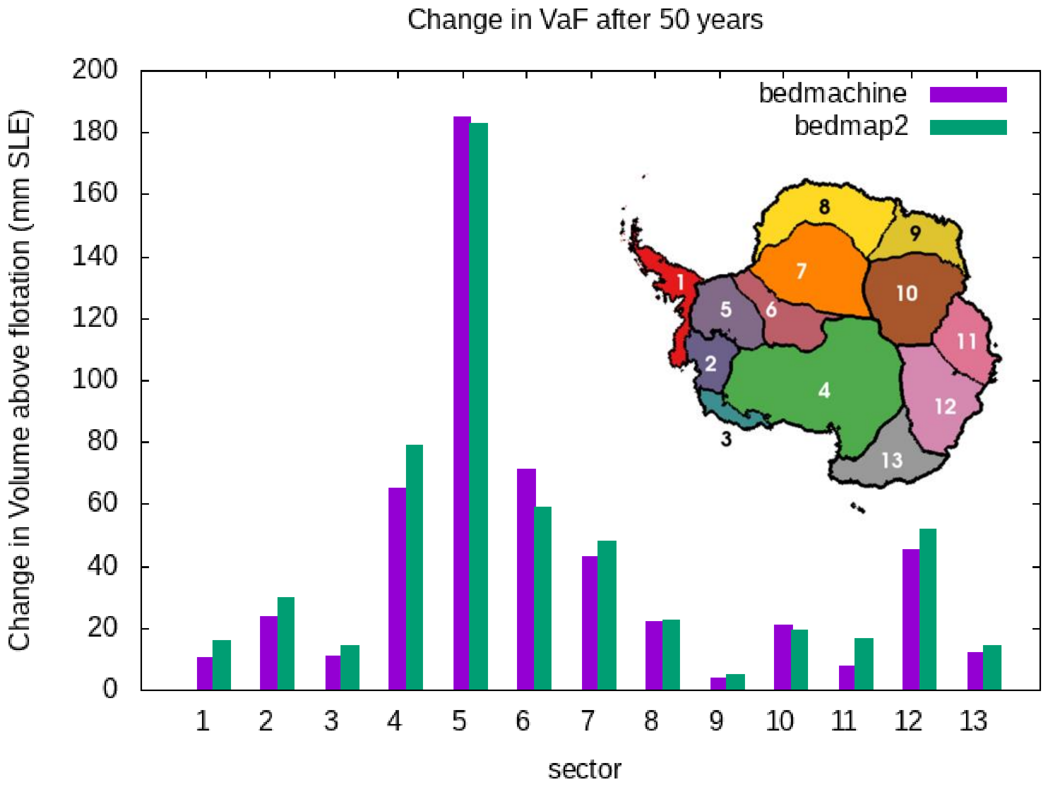




- For each sector, subject model to extreme local melting of all floating ice in the sector and evolve for 50 years
- Also ran control (no melting) and all-sector runs for comparison
- Subtract control to compute effect of regional shelf collapse

Volume over flotation

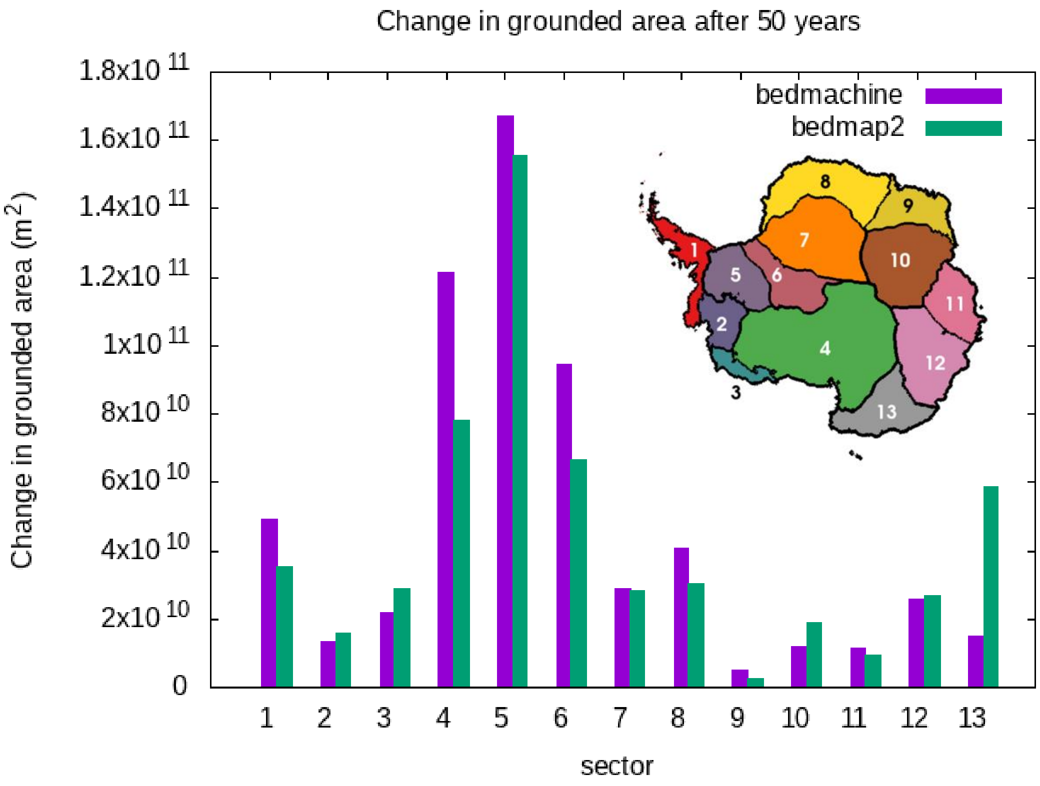
- **To leading order, broad behavior is similar (which is reassuring)**
- **All-sector forcing runs:**
  - Reduced contribution to SLR of around 5.5%
- **Some notable differences**
  - More than Bedmap2: 5,6
  - Less than Bedmap2: 2. 4, 7



Grounded Area

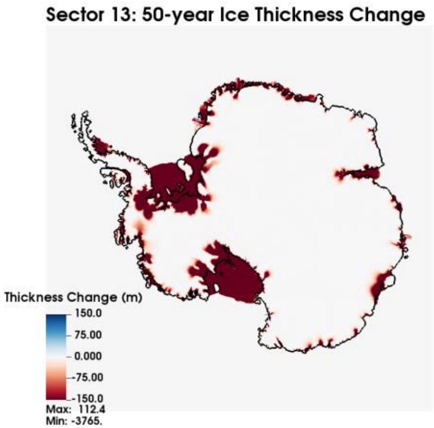
- **More differences from Bedmap2**

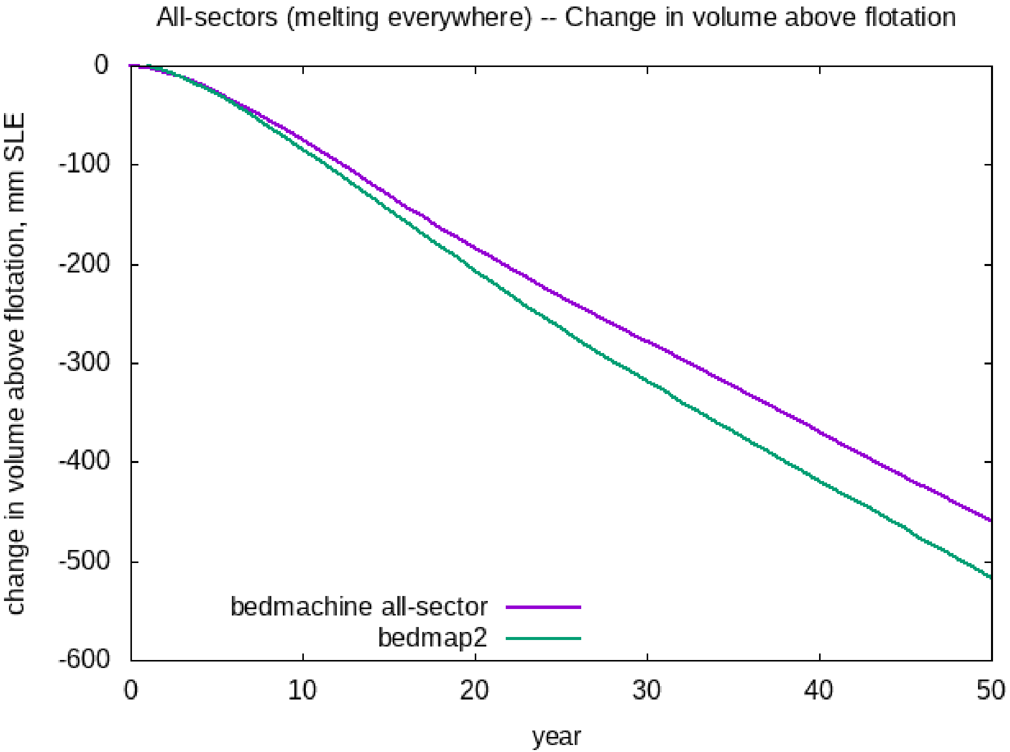
- **Some notable differences**
  - A lot more than Bedmap2: 1,4,5,6 (8)
  - More than Bedmap2: 5,6
  - Less than Bedmap2: 13



All Sectors

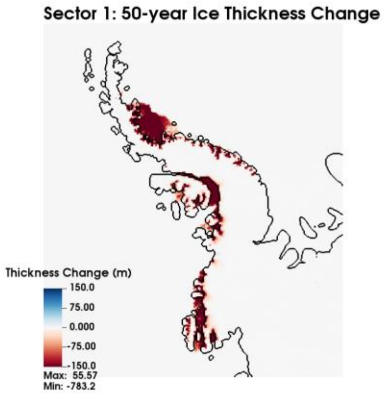
- **5.55% reduction**
  - Bedmachine: 477.9 mm SLE
  - Bedmap2: 506 mm SLE

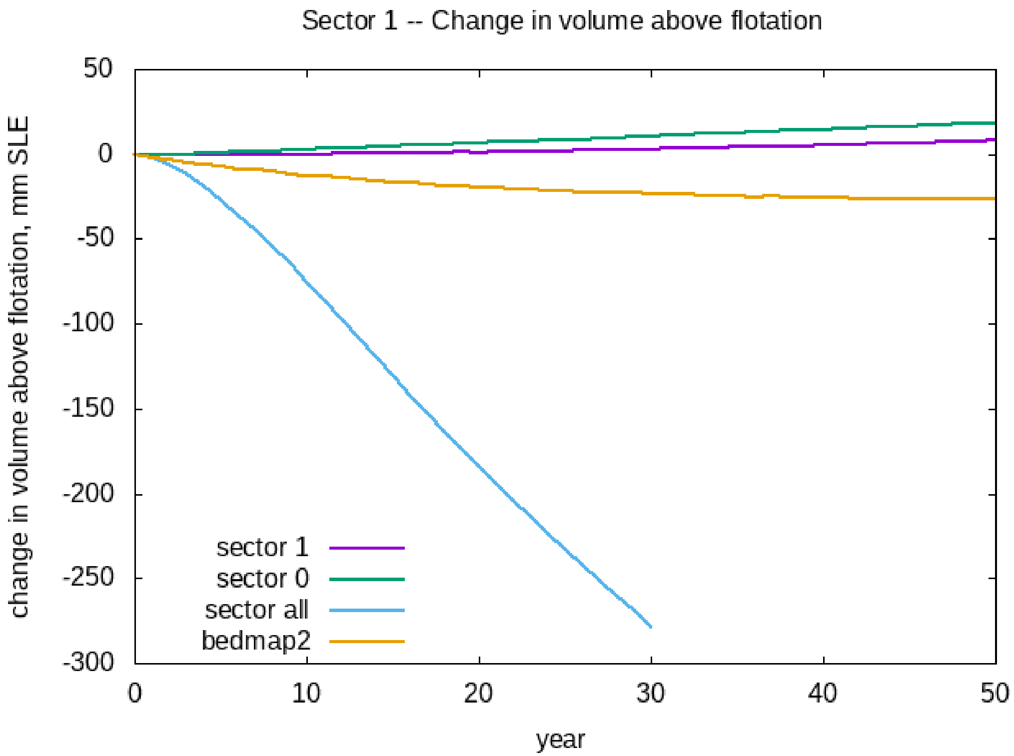




Sector 1 (Antarctic peninsula)

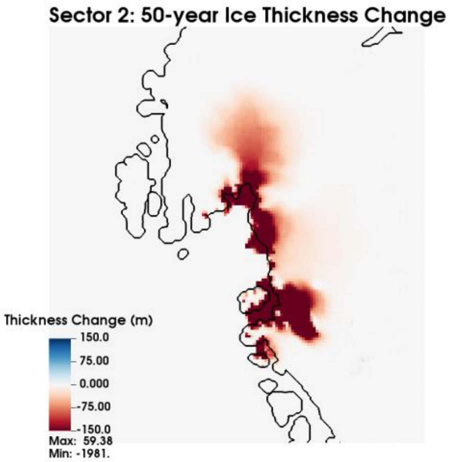
- **34% reduction**
  - Bedmachine: 10.49 mm SLE
  - Bedmap2: 16.0 mm SLE

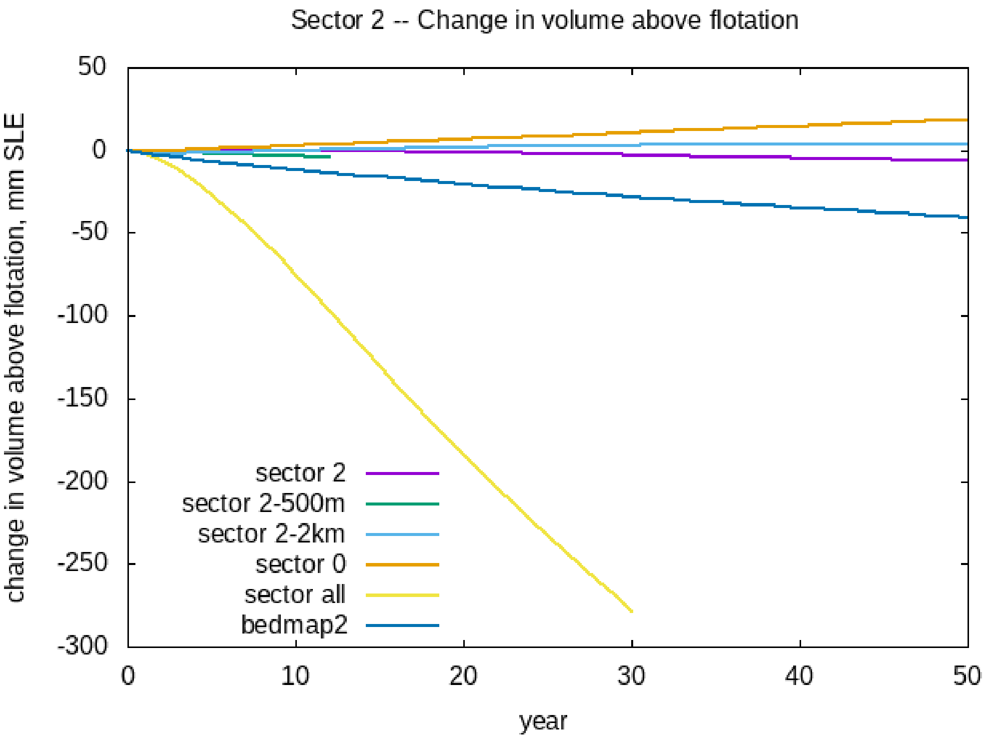




Sector 2 (Amundsen Sea Embayment)

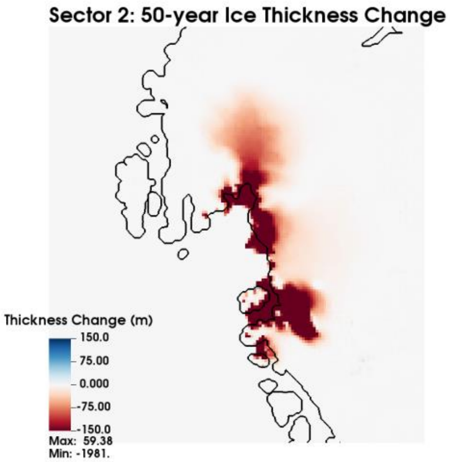
- **21% reduction**
  - Bedmachine: 23.5 mm SLE
  - Bedmap2: 29.9 mm SLE

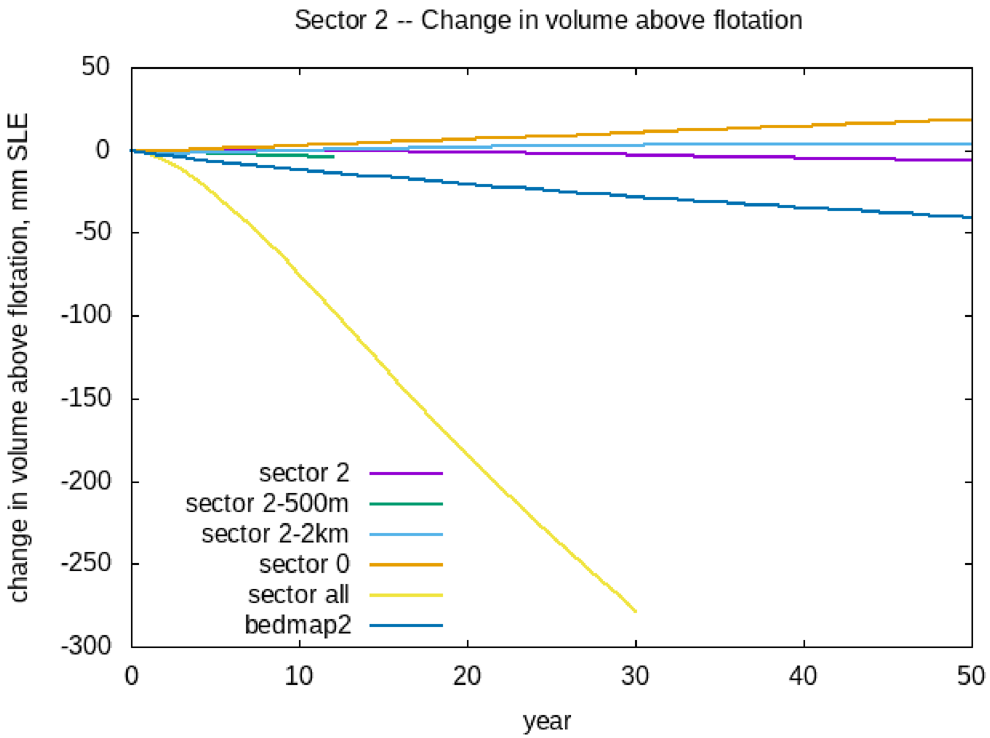




Sector 2 (Amundsen Sea Embayment)

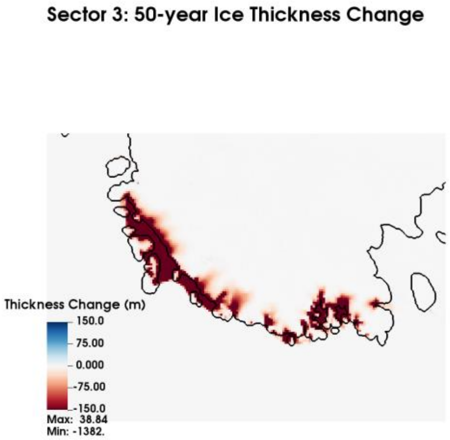
- **21% reduction**
  - Bedmachine: 23.5 mm SLE
  - Bedmap2: 29.9 mm SLE

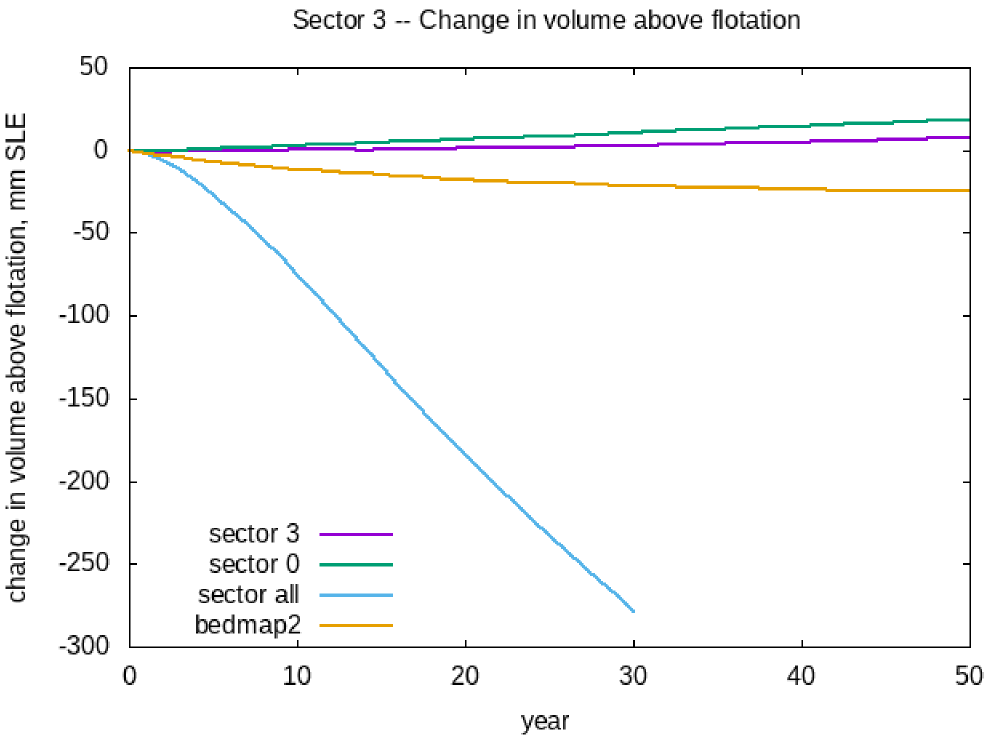




Sector 3 (Getz Ice Shelf)

- **22% reduction**
  - Bedmachine: 10.87 mm SLE
  - Bedmap2: 14.1 mm SLE



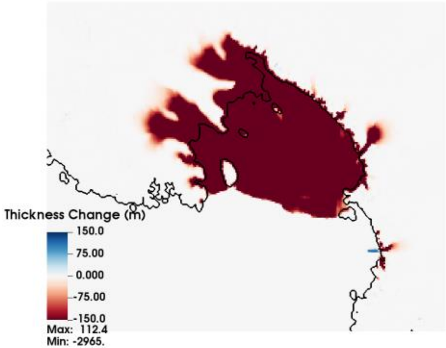


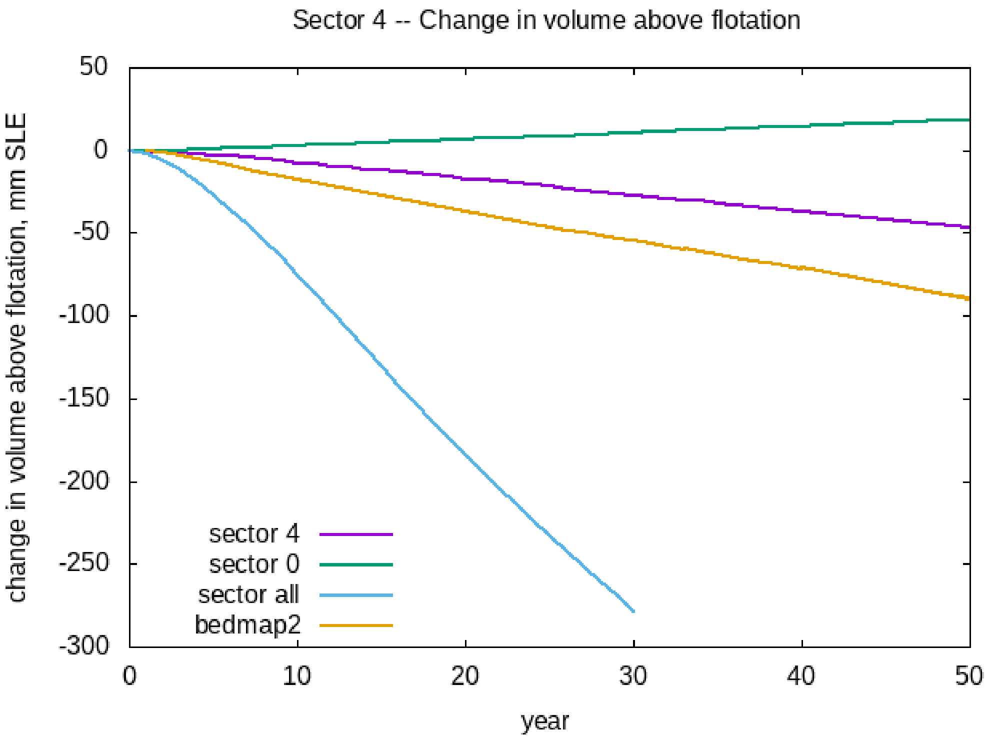
BERKELEY LAB

Sector 4 (Ross Ice Shelf)

- **17.5% reduction**
  - Bedmachine: 65.12 mm SLE
  - Bedmap2: 78.9 mm SLE

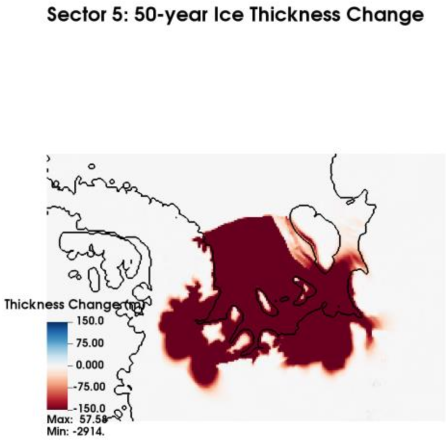
Sector 4: 50-year Ice Thickness Change

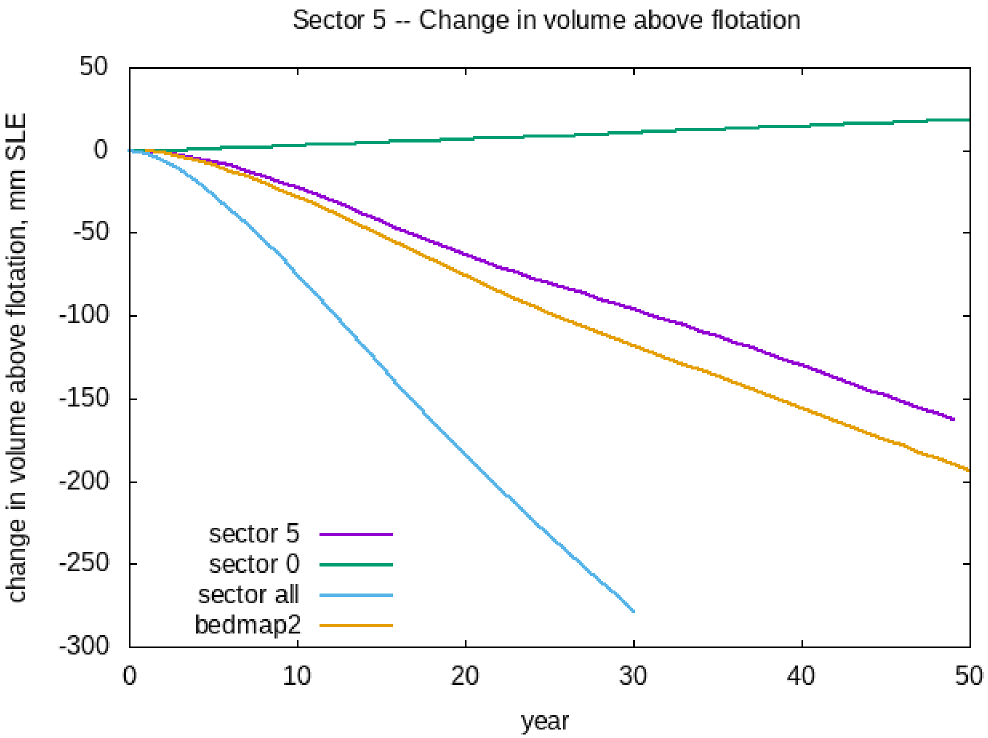




Sector 5 (Ronne Ice Shelf)

- **1.14% increase**
  - Bedmachine: 184.9 mm SLE
  - Bedmap2: 182.9 mm SLE

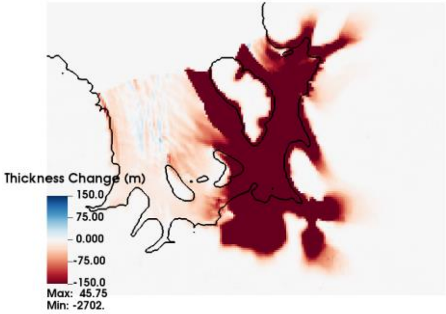


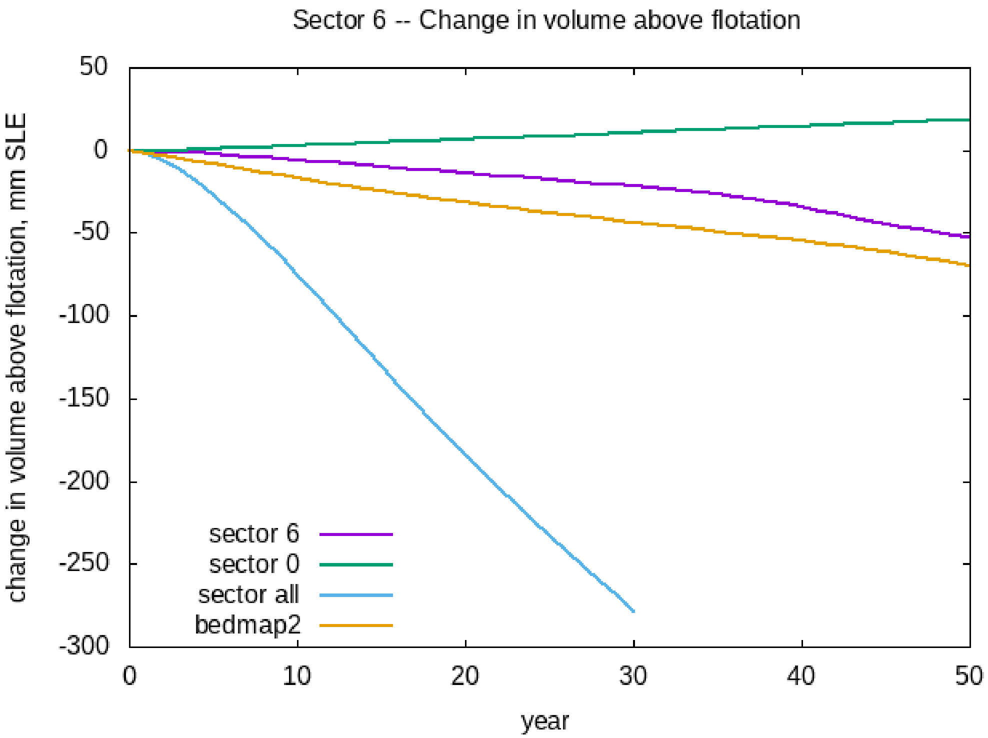


Sector 6 (Filchner Ice Shelf)

- **20.3% increase**
  - Bedmachine: 71.12 mm SLE
  - Bedmap2: 59.1 mm SLE

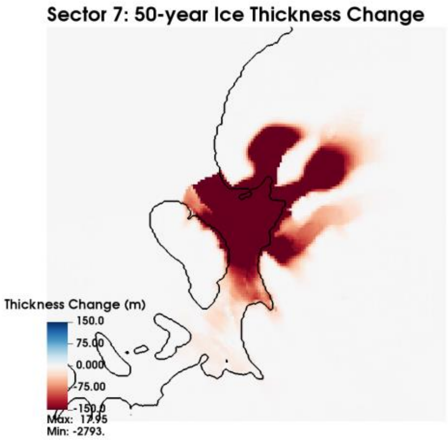
Sector 6: 50-year Ice Thickness Change

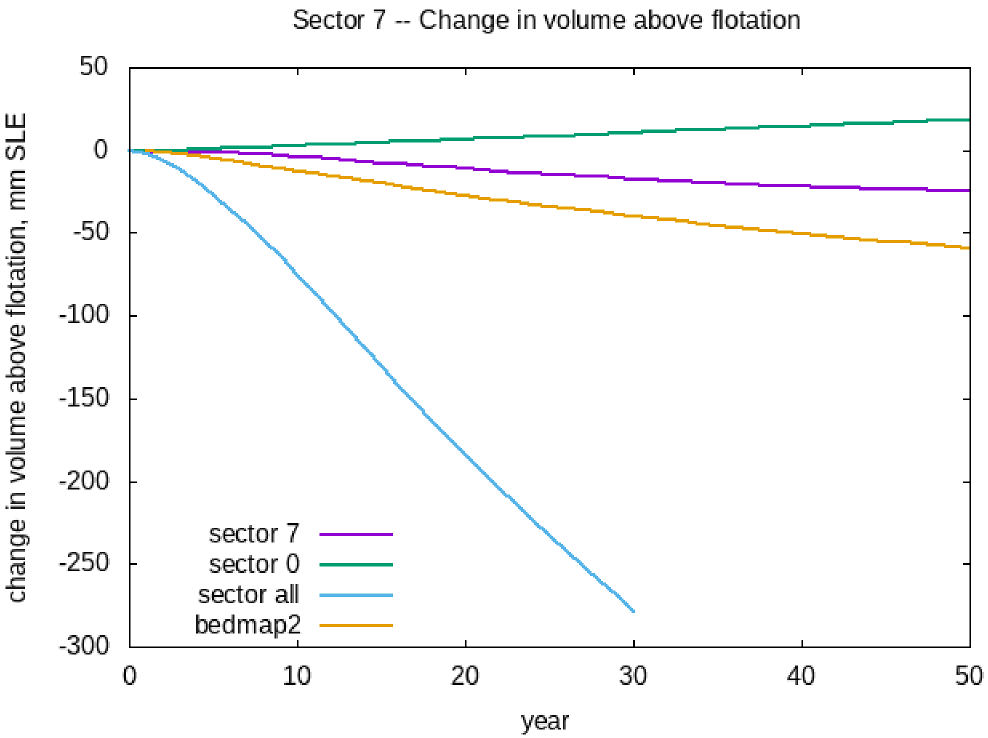




Sector 7 (Recovery)

- **10.9% increase**
  - Bedmachine: 42.96 mm SLE
  - Bedmap2: 38.2 mm SLE

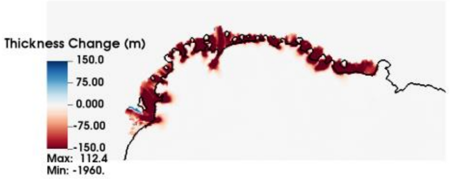


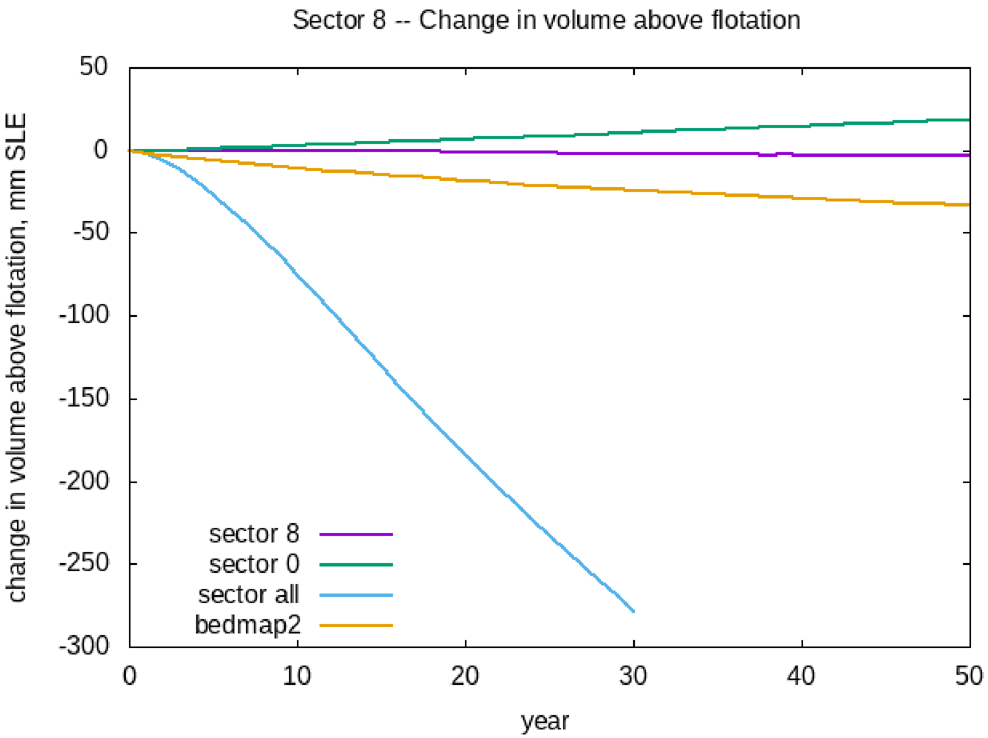


Sector 8 (Dronning Maud Land)

- **3.63% reduction**
  - Bedmachine: 21.88 mm SLE
  - Bedmap2: 22.7 mm SLE

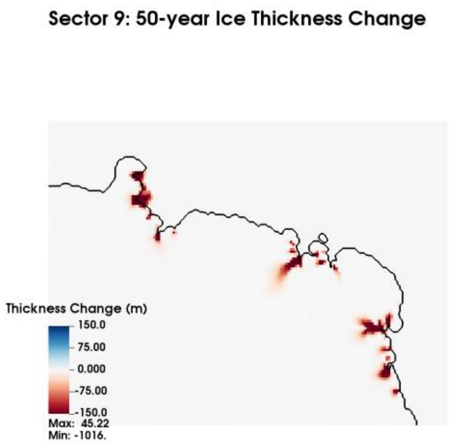
Sector 8: 50-year Ice Thickness Change

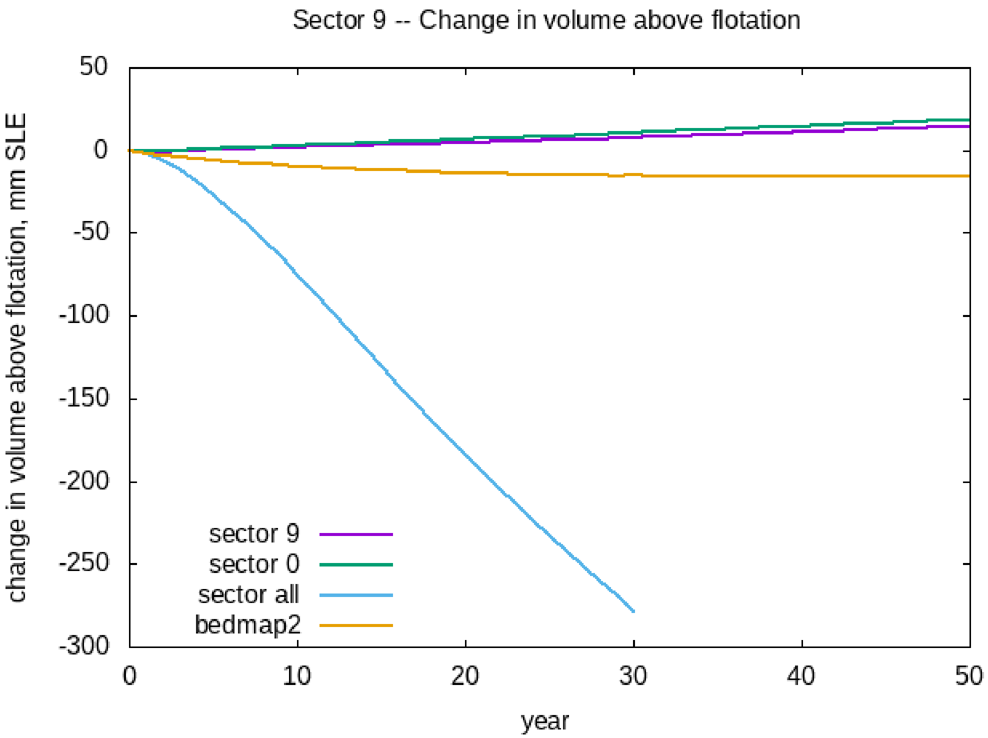




Sector 9 (Enderby Land)

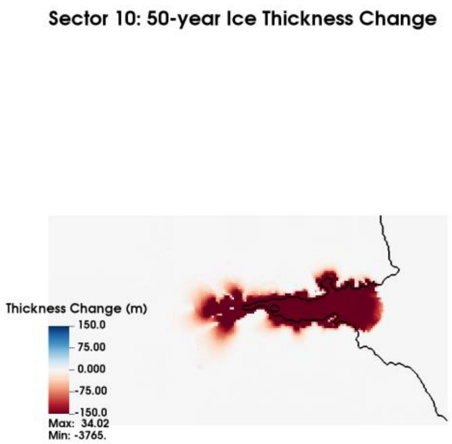
- **17.8% reduction**
  - Bedmachine: 4.03 mm SLE
  - Bedmap2: 4.9mm SLE

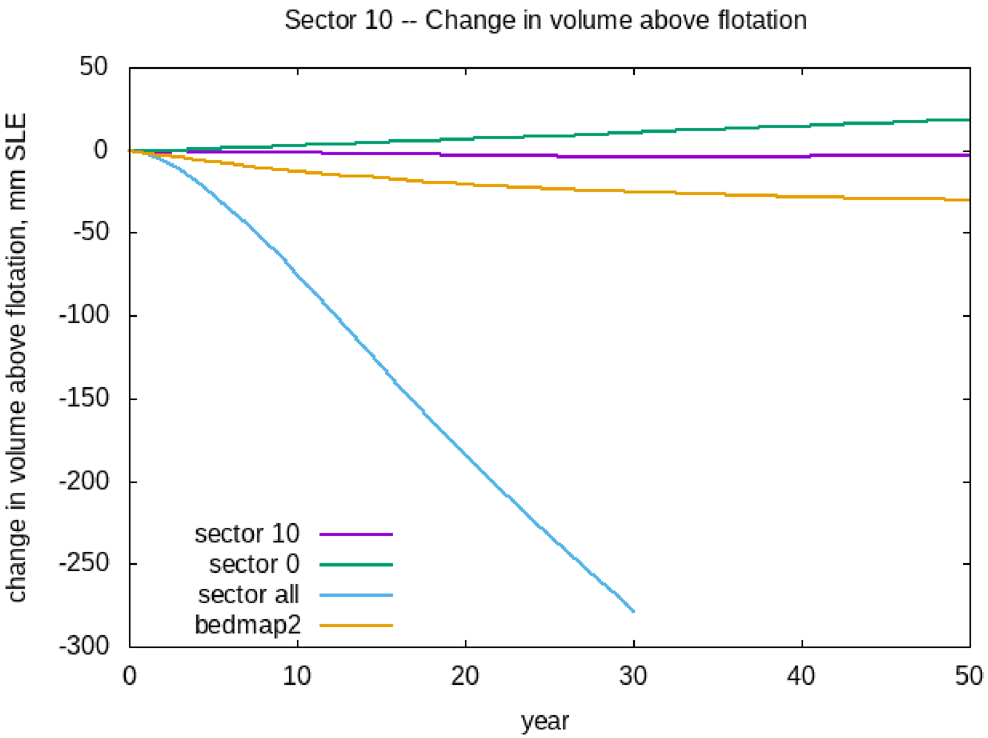




Sector 10 (Amery Ice Shelf)

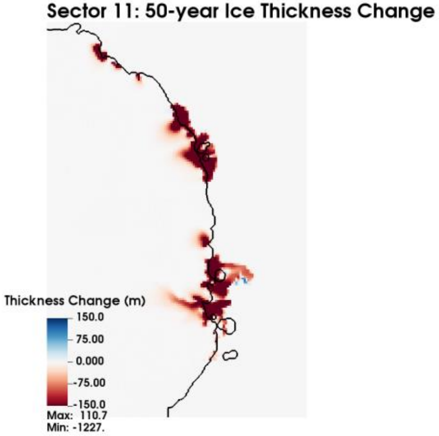
- **10.0% increase**
  - Bedmachine: 21.23 mm SLE
  - Bedmap2: 19.3 SLE

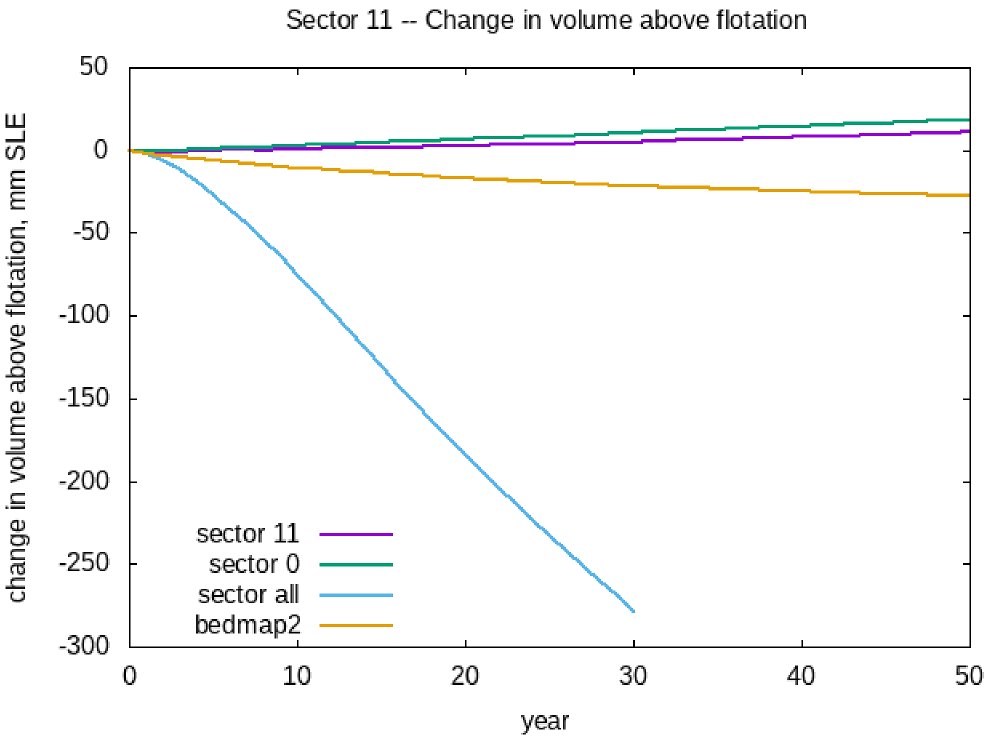




Sector 11 (Shackleton)

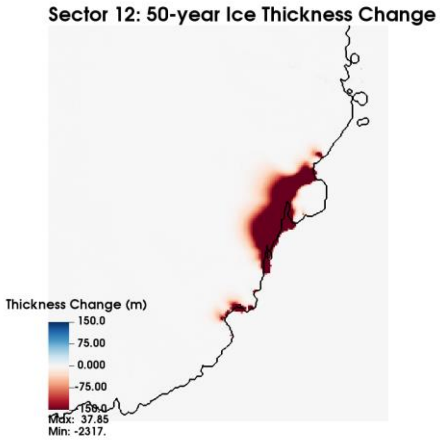
- **54.8% reduction**
  - Bedmachine: 7.51 mm SLE
  - Bedmap2: 16.6 SLE

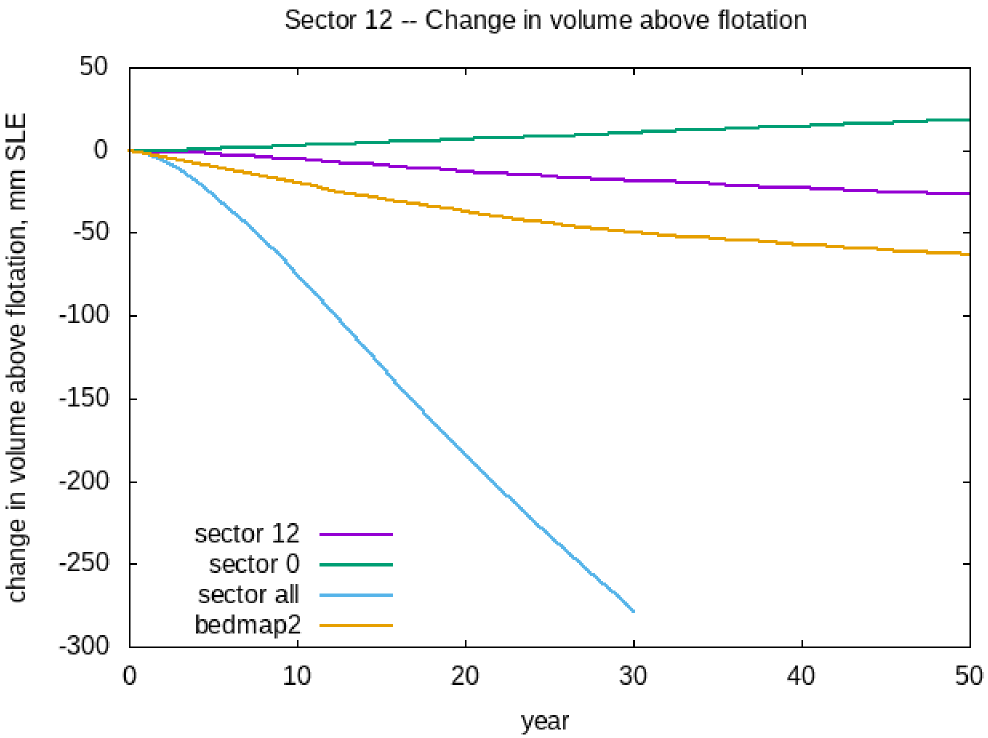




Sector 12 (Aurora Basin and Totten)

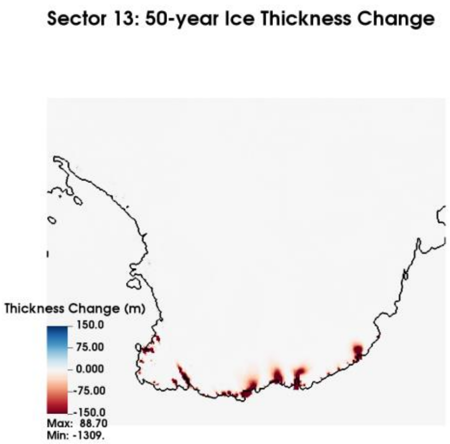
- **13.1% reduction**
  - Bedmachine: 45.26 mm SLE
  - Bedmap2: 52.1 mm SLE

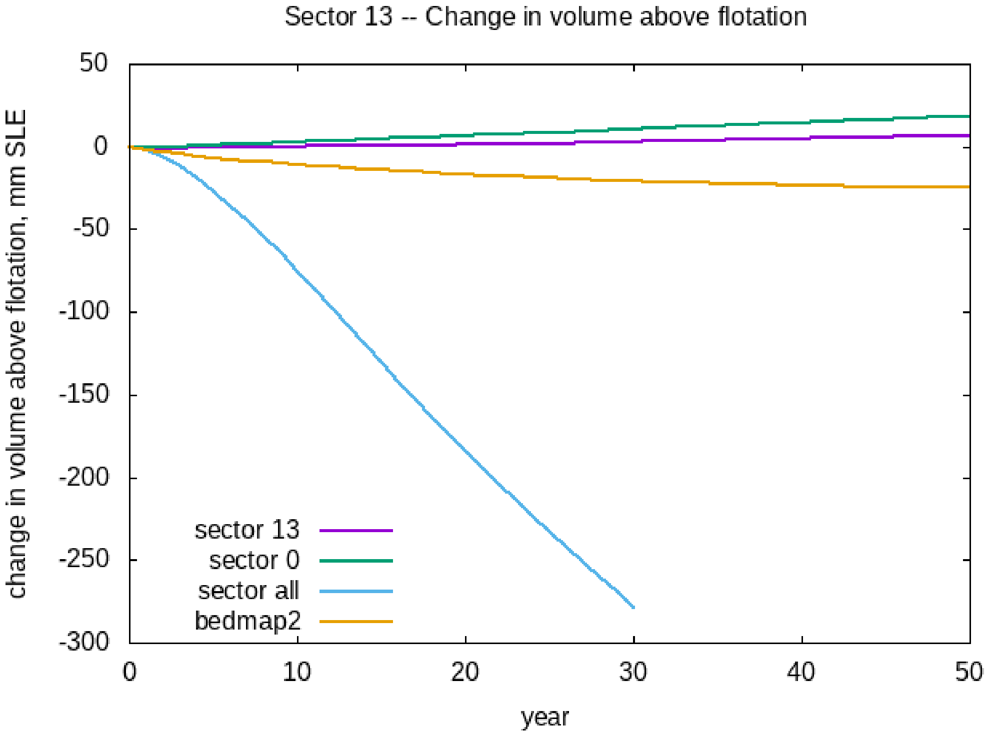




Sector 13 (Oates Land)

- **15.7% reduction**
  - Bedmachine: 11.97 mm SLE
  - Bedmap2: 14.2 mm SLE





Discussion

- **Bedmachine generally experiences slower rates of GL retreat and contribution to SLR.**
  - Suspect due to rougher bed
    - (similar to what was seen in (Waibel et al, 2018)
  - Does Bedmachine require finer resolution?
    - (exploring that now, with a 500m 1km, 2km progression)

Acknowledgements:

- US Department of Energy Office of Science (ASCR/BER) SciDAC applications program (PISCEES, ProSPecT)

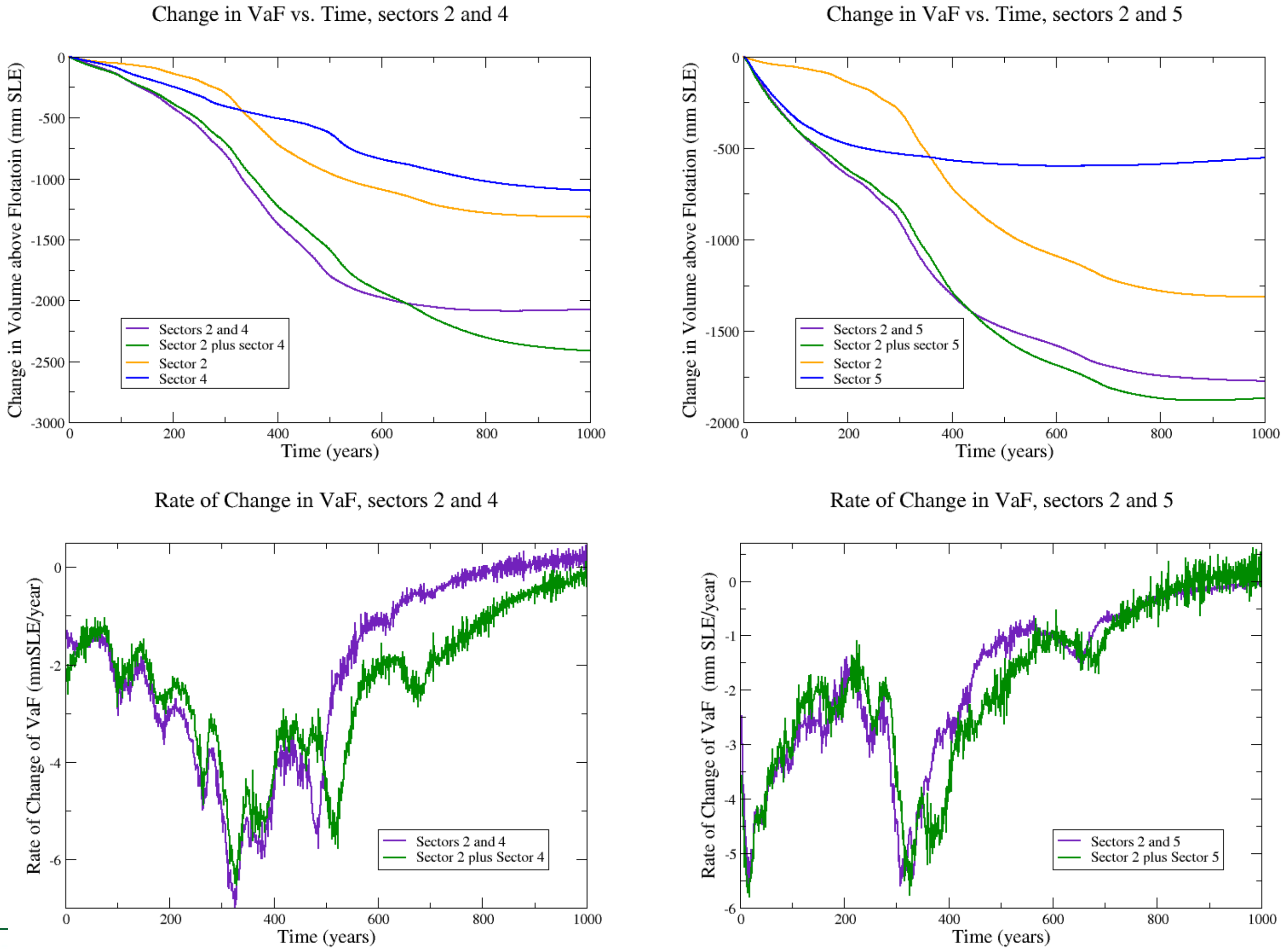
- NERSC

Thank you!

Regional Independence

- **Resource limitations often force models to look at individual sectors/drainage basins**
- **Relies on the assumption of regional independence**
- **Can look at combinations of sectors to see if they behave independently…**

- Yellow, Blue – single sectors
- Purple – combination
- Green – sum of the two single-sector runs
- For WAIS sectors, roughly independent at start, after O(200a), start to interact



U.S. DEPARTMENT OF ENERGY | Office of Science

Summary

- First fully-resolved, systematic study of millennial-scale ice sheet response to regional ice shelf collapse based on 14 drainage basins.
- Sustained ice-shelf loss in **any** of the Amundsen Sea, Ronne, or Ross sectors can lead to wholesale West Antarctic collapse.
- Even with extreme forcing, loss is relatively modest for the initial century, increasing markedly afterward in West Antarctic collapse scenarios.
- Results indicate that Antarctic drainage basins are dynamically independent for 1-2 centuries, after which dynamic interactions between basins become increasingly important (and regional modeling results will be increasingly inaccurate).
- Combination of AMR and NERSC resources made this possible – 35,000 years of fully-resolved full-continent Antarctic simulation.