Cryosphere Campaign Update

June 2021

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E3SM Energy Exascale Earth System Model
U.S. DEPARTMENT OF ENERGY

Background / Motivation

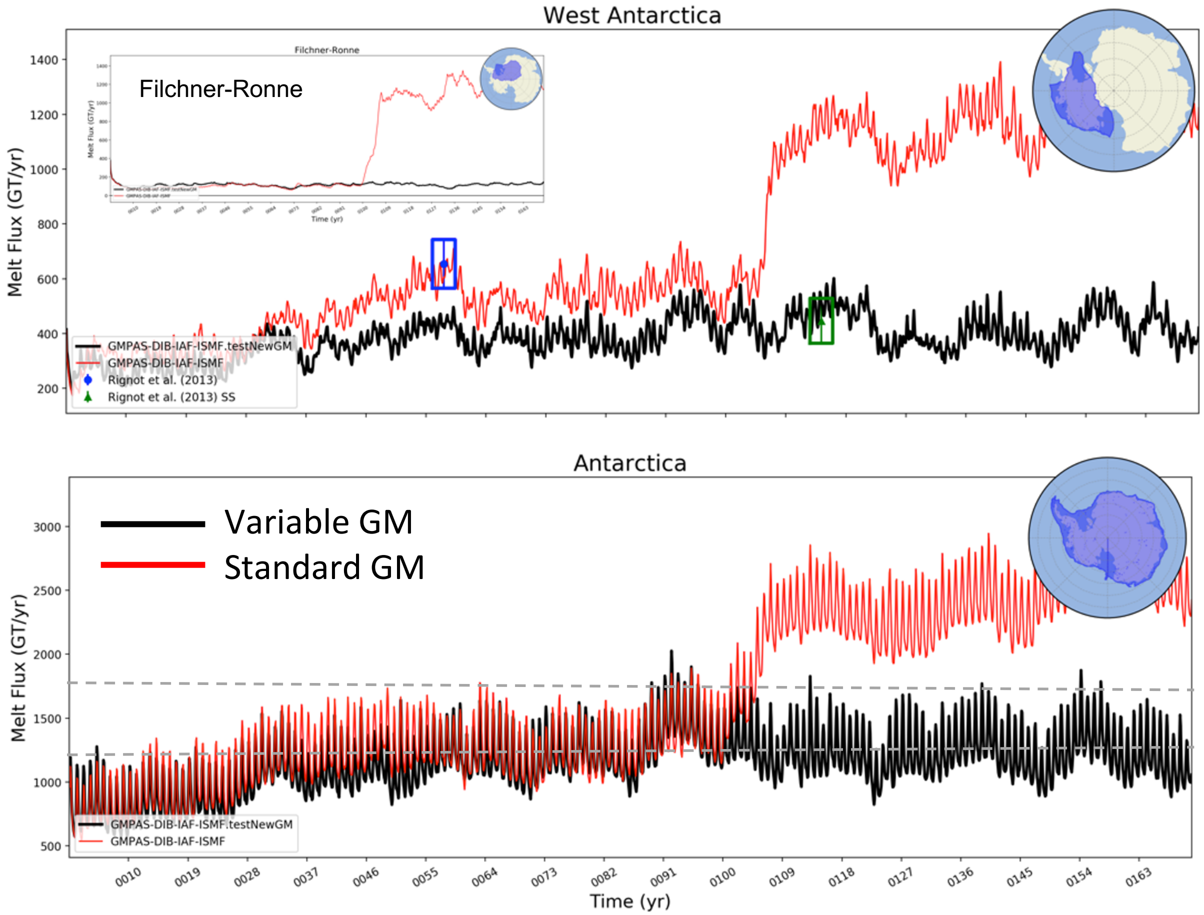
- What are the impacts of ocean-ice shelf interactions on melting of the Antarctic Ice Sheet, the global climate, and sea level rise?
- How will the atmosphere, ocean and sea-ice systems mediate sources of sea-level rise from the Antarctic ice sheet over the next 30 years?

Summary of past year's efforts

- New Cryosphere campaign compsets and configurations:
  - CRYO1850 (~WCYCL1850 but with ice shelf melt fluxes, icebergs)
  - Southern Ocean Regionally Refined Mesh (SORRM) + low-res. atmos / land
- Simulations:
  - ~150 years of SORRMr0 in v2 "alpha" configuration
  - >150 years of SORRMr4 (beta1, beta4, rc1a, rc1c, rc3e …)
- Polar analysis on most "rc" WC tuning runs
- Improvements to sea ice coupling and heat / mass conservation
- New polar atmospheric analysis capabilities
- Dynamic Greenland ice sheet:
  - high res. initial conds., calving physics, new snowpack model
  - new E3SM compsets, configurations, and analysis capabilities

V1: Low Res. Configuration

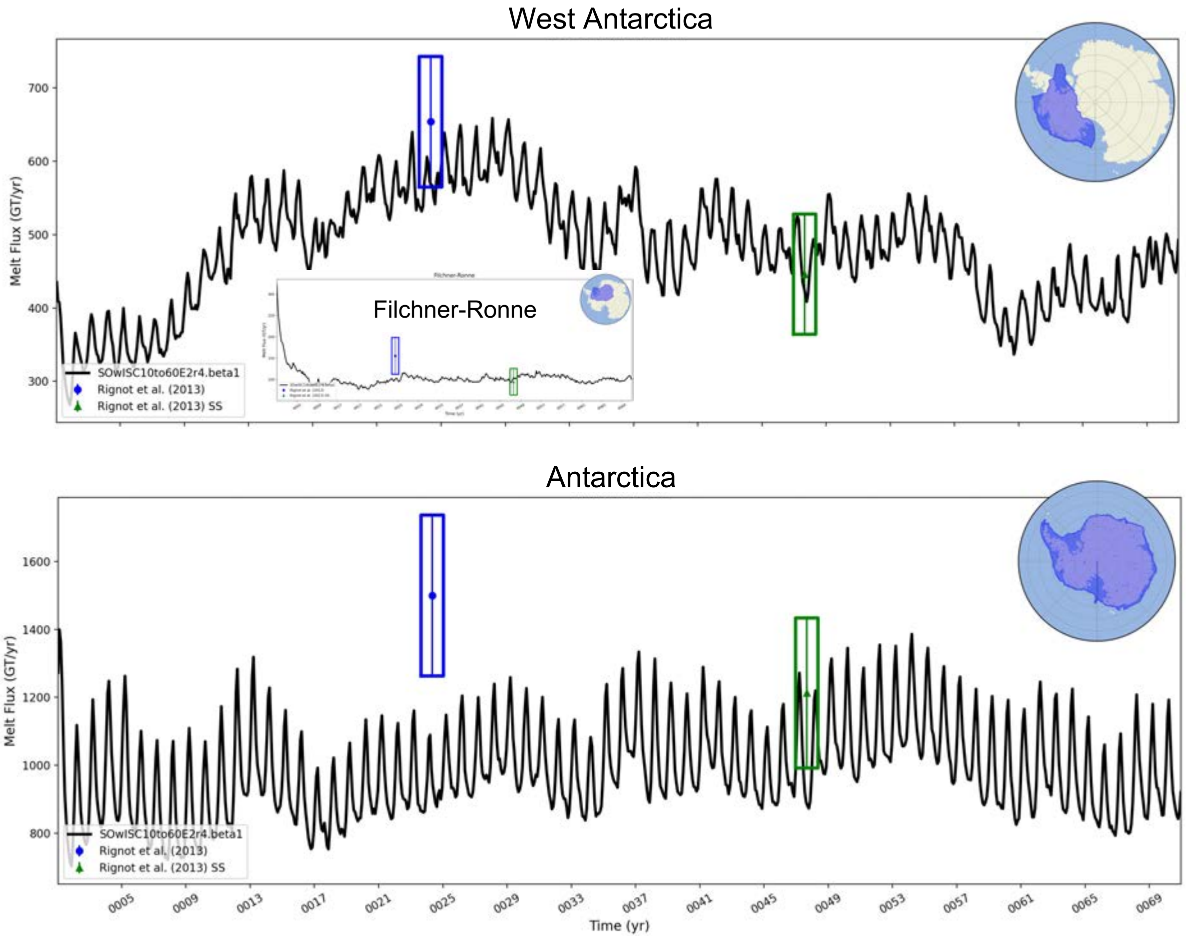
- rapid switch in sub- shelf melting under one large ice shelf
- increased melting triggers runaway melt feedback
- approx. doubling of total Antarctic melt flux (from realistic to non- realistic)
- vastly improved by tuning of ocean eddy parameterization



Comeau et al. (in re-review), Hoffman et al. (in prep.)

V2: SORRM Configuration

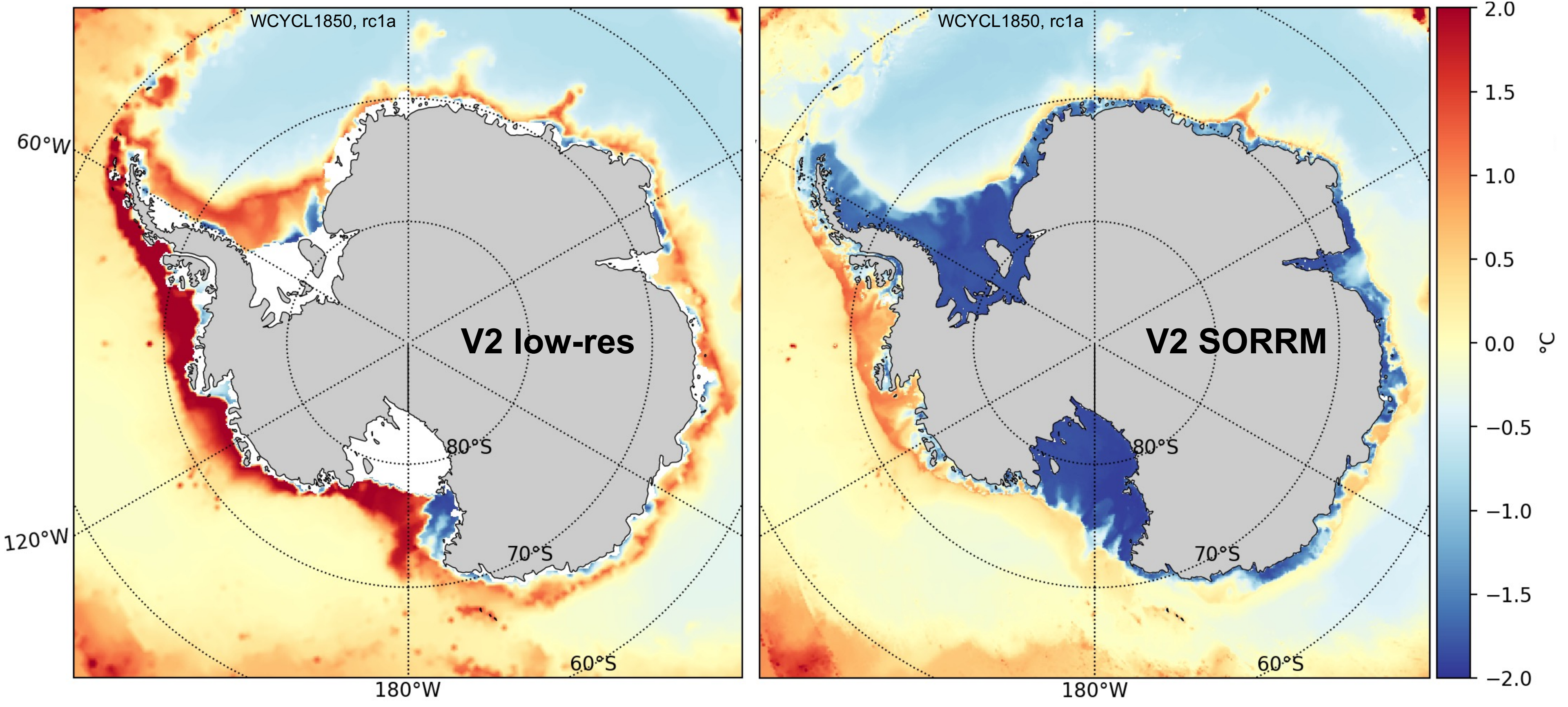
- realistic sub-ice shelf melt rates (70 years**)
- no indication of the instability seen for v1 low-res. configurations
- no additional tuning
- similar for all configs. run recently (e.g., ~150 years of SORRMr0)



** SORRM B-case using beta1 tunings

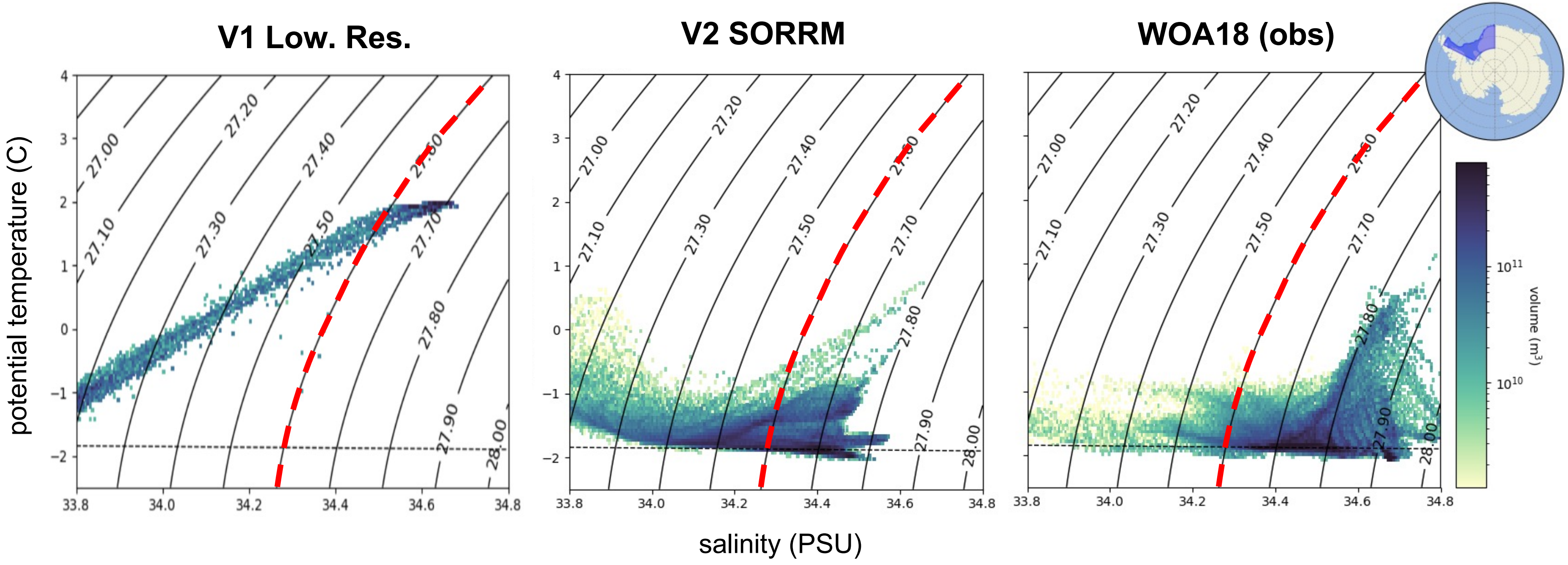
Low-Res. vs. SORRM Configuration

Ocean Bottom Temperature (°C)



S. Ocean Water Mass Properties (V1 vs. V2)

Weddell Sea Shelf: temperature, salinity, and density



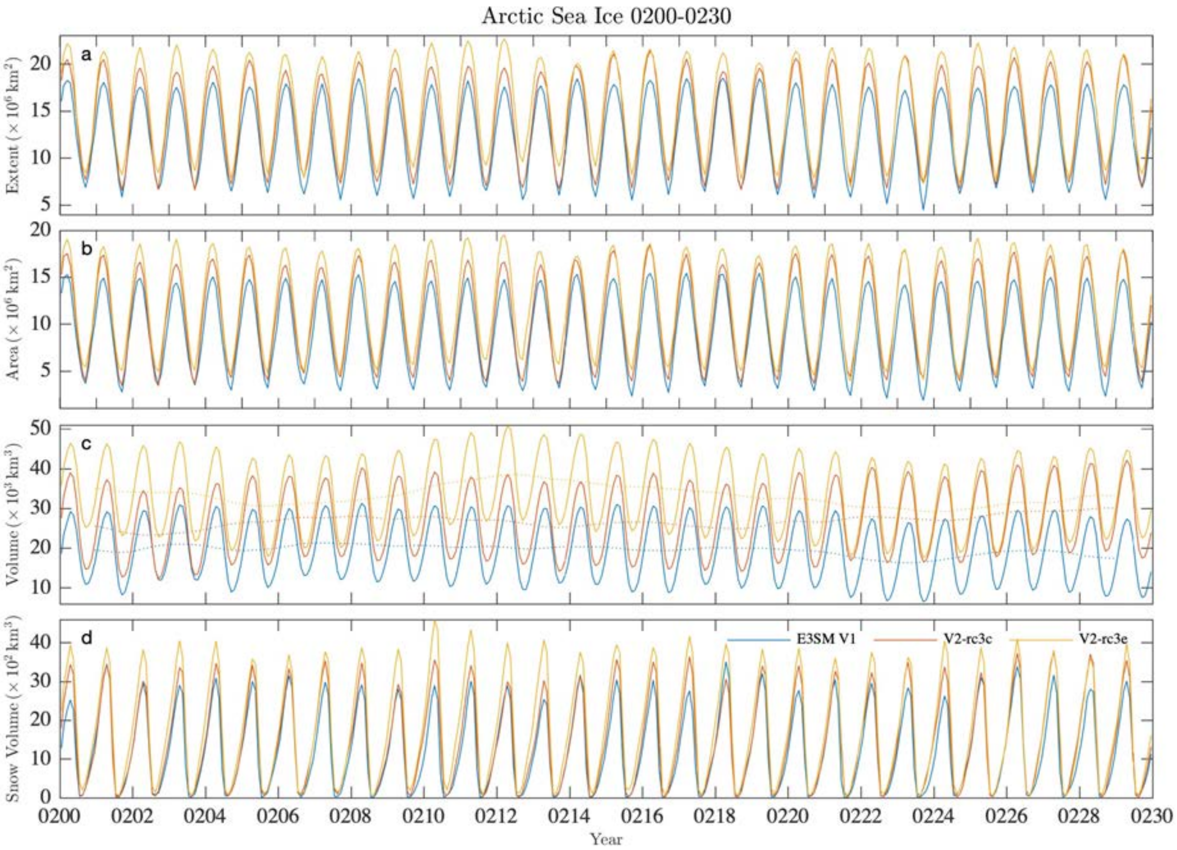
V2 Sea Ice & Ocean-Ice Coupling Improvements

1. fixed frazil bug accounting for ~0.1W m^{-2} global heat leak (**thicker V2 sea ice**)

2. homogenization of snow radiative transfer over land and sea ice (SNICAR_AD)

3. sophisticated snow morphology over sea ice (including 5 snow layers)

4. harmonization of sea ice basal temperature with the ocean equation of state



Dashed lines are 12-month filtered sea ice volume

V2 Sea Ice & Ocean-Ice Coupling Improvements

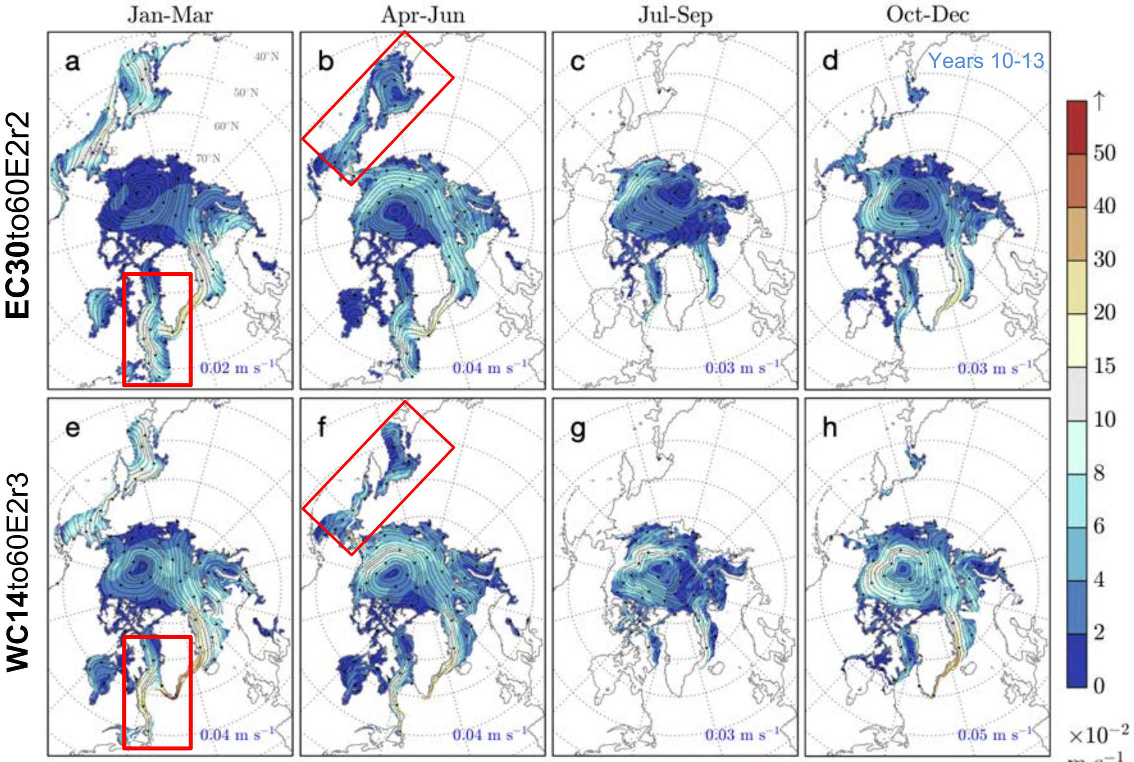
5. removed sea surface height filtering previously needed to damp high-frequency coupling

6. removed checker-boarding in sea ice ocean melt (associated with ocean advection bug)

7. identified ocean eddies / eddy parameterization as a primary driver of accurate sea ice edge and ice drift speed.

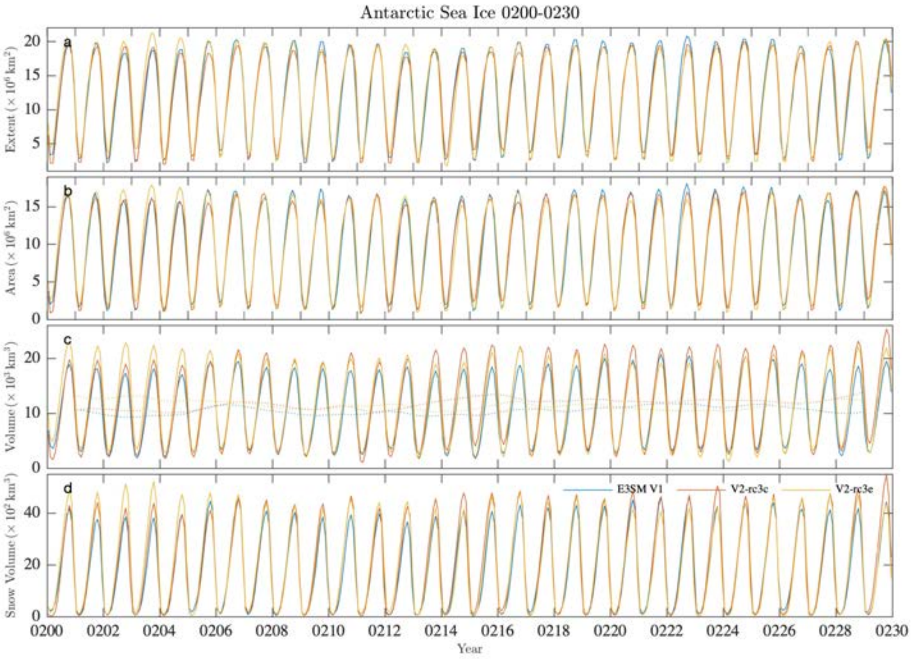
8. improved analysis tools for diagnosis of coupling inconsistencies between model components

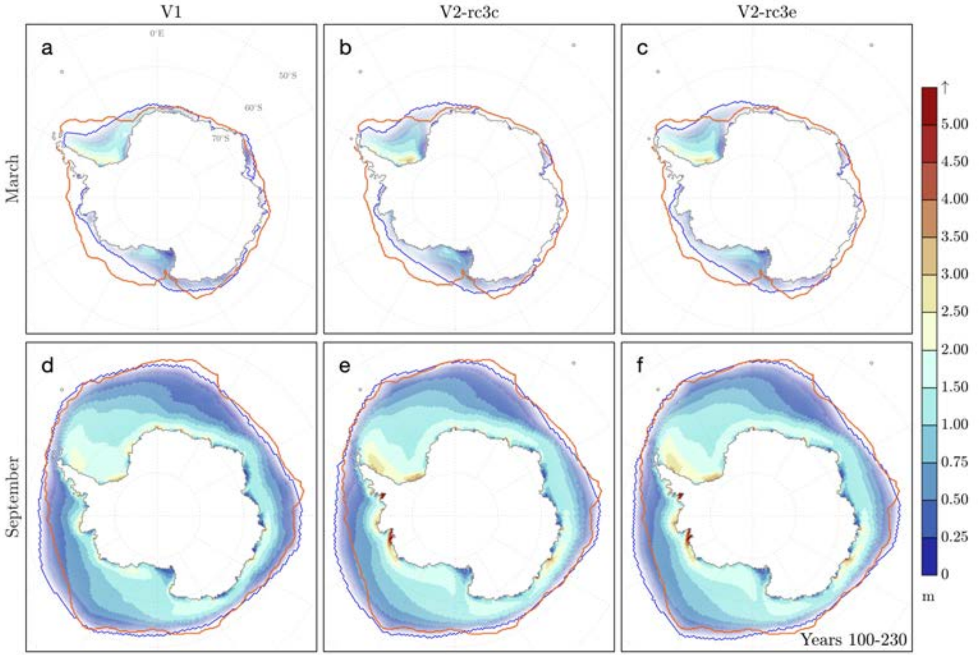
Sea Ice Drift at Standard Atmospheric Resolution (V2rc3c)



Fully-coupled Arctic ice-edge bias still exists in V2 at standard resolution, but is rectified on the WC14 ice-ocean mesh

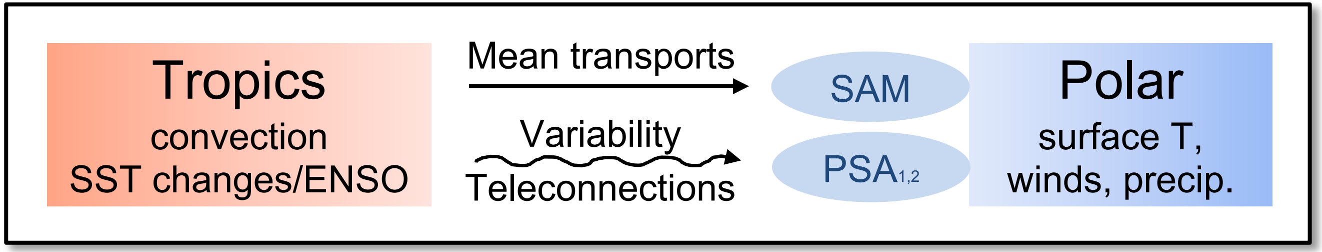
Antarctic Sea Ice in Version 2





- Main sea ice changes and thickness improvements are in the Arctic.
- Total Southern Ocean sea ice volume at low resolution is similar to V1 …
- … but ice is thicker in important coastal areas (Weddell, Amundsen, Bellingshausen Seas, EAIS)

S. Hemis. Atmos. Diagnostic Package: Motivation



- ❑ Diagnose surface mass and energy balances and contributing factors
  - Complement e3sm_diags with focus on SH polar region
  - Make part of e3sm_diags when finalized
- ❑ Facilitate research of tropical-polar teleconnections
  - Atmospheric meridional circulation (Hadley Cell): extent and strength
  - Large-scale modes of variability:
    - Southern Annular Mode (SAM), Pacific Southern-America (PSA) pattern
    - Lead to storm tracks variations, westerly jets, extratropical wave trains
    - Known impacts on Antarctica surface climate (seasonal with regional diffs.)
- ❑ Assess model’s ability to simulate means, modes and connections
- ❑ Understand Antarctic climate response (changes and trends) to:
  - tropical sst changes, ozone recovery, greenhouse warming

(work by S. Zhang and W. Lin)

S. Hemis. Atmos. Diagnostic Package: Status

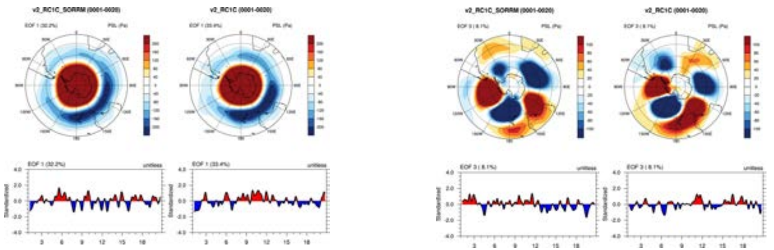
1. Fast track Shell-NCL-based automatic workflow for diagnosis & viz :
   - Github: https://github.com/zhangshixuan1987/polar_diag

2. Model-to-Model and Model-to-Observation comparisons :
   - Multiple reanalysis: ERA5, ERA20C and NOAA20C

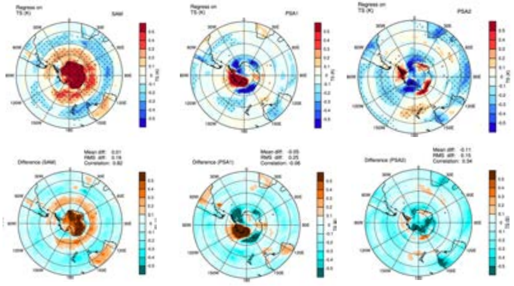
Plot set or Feature	Implemented
SH large-scale modes	✓
Polar jet stream	✓
Hadley circulation	✓
ENSO teleconnections	✓
Polar vortex	✓
Regression analysis	✓
Composite by polarity	TBD
Weather regime analysis	TBD
Jet-Cloud Radiative Effect	TBD

(work by S. Zhang and W. Lin)

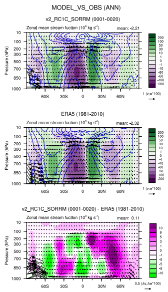
Large-scale mode analysis



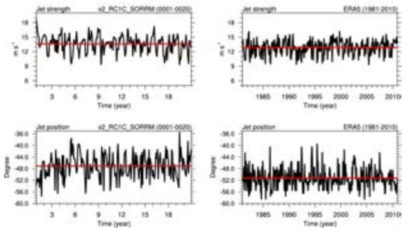
Regression analysis



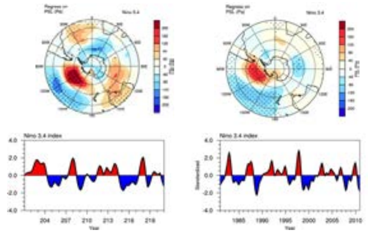
Hadley circulation



Polar jet stream analysis



ENSO analysis



Greenland Ice Sheet in E3SM

- dynamic Greenland ice sheet model
  - high-resolution (~2km), optimized to obs., targeting quasi-equilib. with E3SM climate forcing
  - new calving physics appropriate for marine terminating outlet glaciers[1]
  - also exploring parameterizations for coupling calving to ocean conditions[1]
- new ELM snowpack model appropriate for ice sheet surface mass balance[2]
- new E3SM compsets / configurations:
  - data atmospheric forcing (IG) and fully coupled (BG) PI 1850
  - low-res. atm / lnd bi- and tri-grid (r05); high-res. atm / lnd tri-grid (r0125)
- detailed analysis of surface energy and mass balance components (LIVVkit)

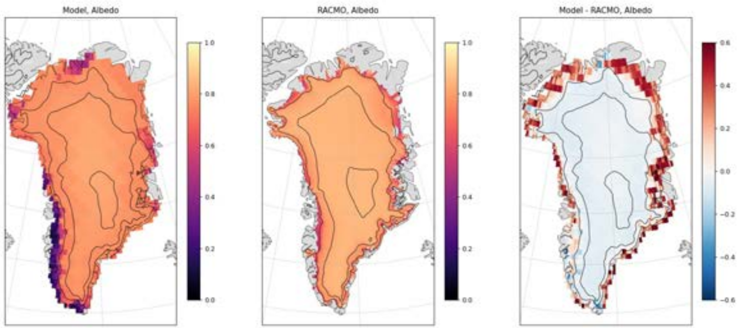
[1]Hillebrand et al. (in prep.)   [2]Schneider et al. (in review)

Greenland Ice Sheet: surface climate validation

Surface energy validation (LIVVkit):

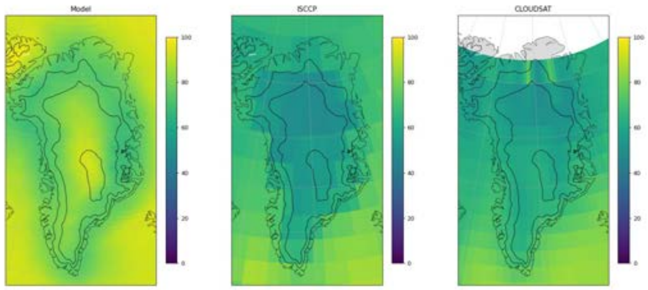
- low, high, total cloud cover
- summertime albedo, latent heat flux, downward & net longwave
- 2-m air temperature (winter, summer, annual)

M. Kelleher, A. Schneider, C. Zender, K. Evans, J. Kennedy

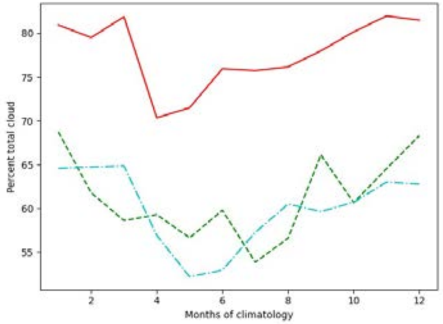


Above: Maps of summer albedo from E3SM (left), RACMO (middle), and difference (right).

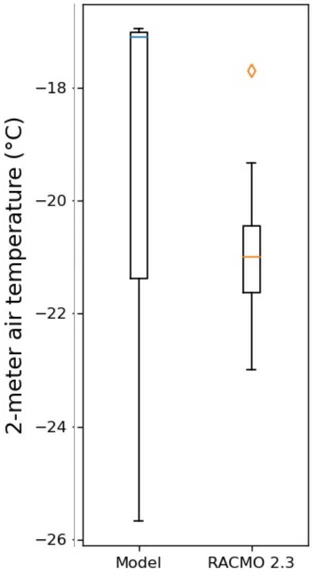
Left: 2-m air temperature statistics for E3SM vs. RACMO.

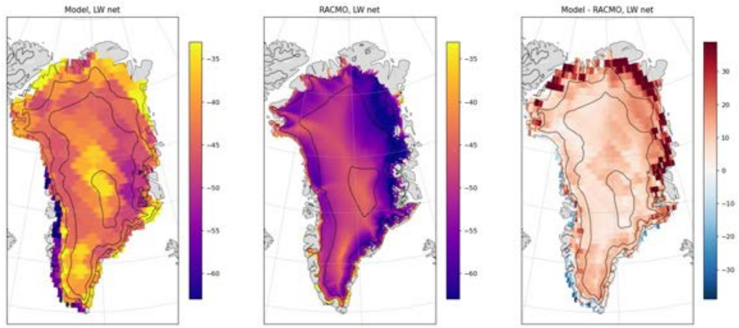


Above: Maps of total cloud cover from E3SM (left), ISCCP (middle), and CLOUDSAT (right).



Left: Total cloud cover (climatology) from E3SM (red), ISCCP (green), and CLOUDSAT (cyan).





Above: Maps of summer longwave net from E3SM (left), RACMO (middle), and difference (right).

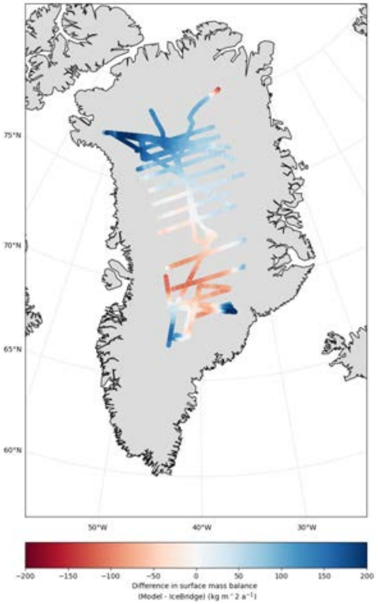
Greenland Ice Sheet: surface climate validation

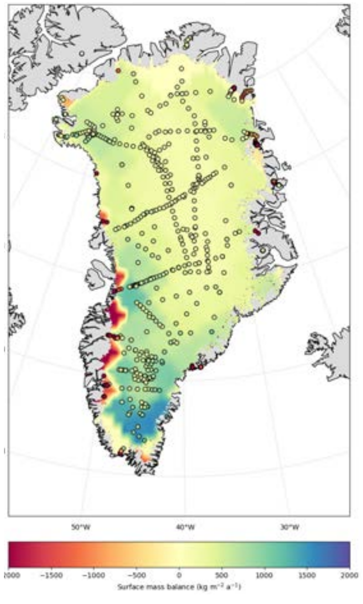
Surface mass balance validation (LIVVkit):

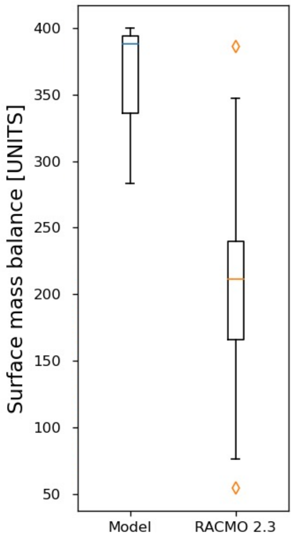
- surf. mass balance (SMB) compared to ice cores & altimetry

M. Kelleher, A. Schneider, C. Zender, K. Evans, J. Kennedy

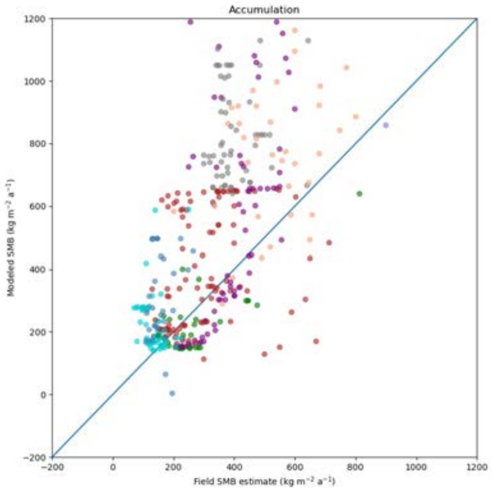
Below: SMB relative to observations. (left) E3SM minus altimetry observations. (right) Map of SMB from E3SM vs. that determined from ice cores (circles).





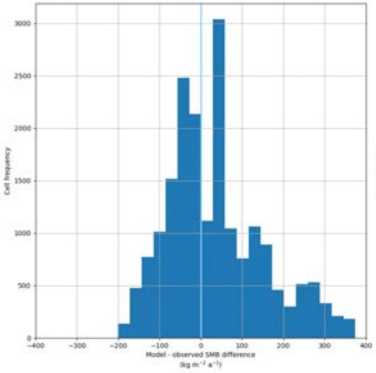


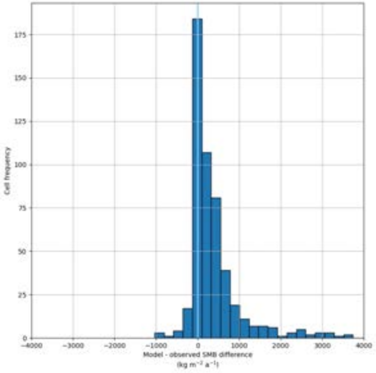
Left: SMB statistics for E3SM vs. RACMO



Above: Modeled vs. observed SMB

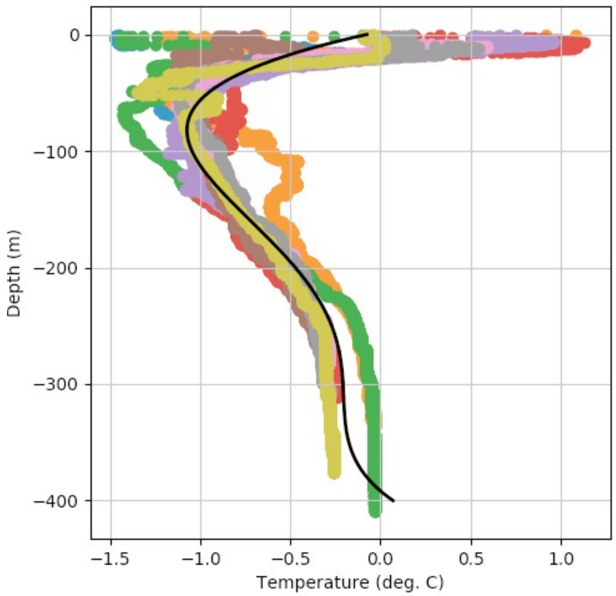
Right: Histograms of SMB differences from altimetry (left) & ice cores (right).





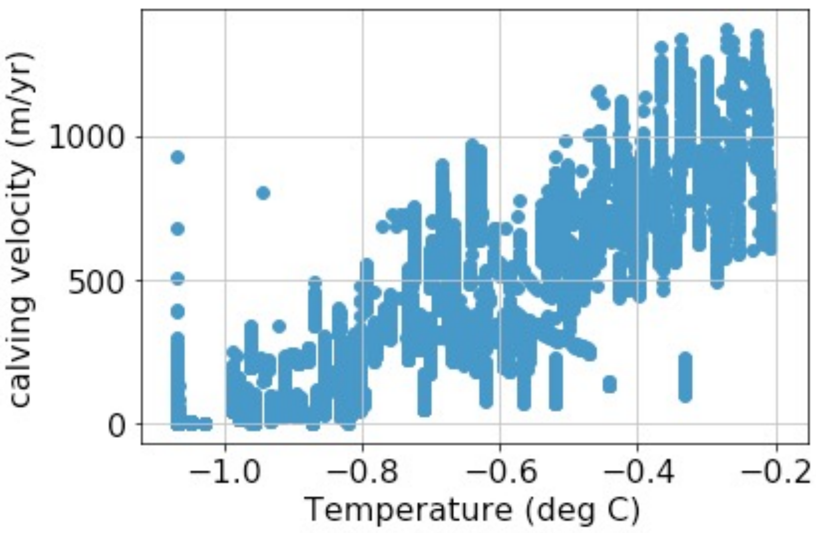
Greenland Ice Sheet in E3SM: Ocean Coupling

- ~1/2 of current Greenland mass loss is due to iceberg calving from marine outlet glaciers
- calving and marine outlet glacier retreat are (in part) a function of ocean forcing …
- … but narrow (kms) fjords will remain unresolved by ocean model for foreseeable future
- work on Humboldt Glacier[1] (N. Greenland) suggests a possible parameterization



Right: Calving rate needed to match observed Humboldt Glacier retreat from 2007-2017 compared with ocean temperature at grounding line.

Left: CTD-based ocean temperature vs. depth observations from near the front of Humboldt Glacier, Greenland.



[1]Hillebrand et al. (in prep.)

Looking Forward

Timeline for coupled, dynamic ice sheets in E3SM:

- end phase 2 : operational GIS
- end phase 3 : validated GIS; operational AIS
- phase 4 : validated AIS

Looking Forward

Possible areas for closer *Water Cycle* and *Cryosphere* collaboration in phase 3:

- *tropical polar teleconnections:* leading cause of variability and trends in climate forcing impacting Antarctic ice sheet[1] (also important feedbacks *back to* tropical climate[2,3])

- *alpine water resources:* leverage variable res. atmos. / land and SMB / glacier expertise for improved modeling of mountain glacier / snowpack evolution

[1]Li et al., *Nature Revs. Earth Env.* (in press) [2]Hwang et al., *PNAS* (2013) [3]Kay et al., *J. Climate* (2016)