# Surface Mass Balance and Melt Over the Greenland Ice Sheet in NASA GMAO Analysis Systems

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Global Modeling & Assimilation Office, NASA Goddard Space Flight Center

- The Global Modeling and Assimilation Office (GMAO) uses computer models and data assimilation techniques to enhance NASA's program of Earth Observations.

- The GMAO utilizes the Goddard Earth Observing System (GEOS), an adaptable framework for modeling and data assimilation.

- Research activies have five major themes,
  - Weather Analysis and Prediction
  - Seasonal-Decadal Analysis and Prediction
  - Reanalysis
  - Global Mesoscale Modeling
  - Observing System Science
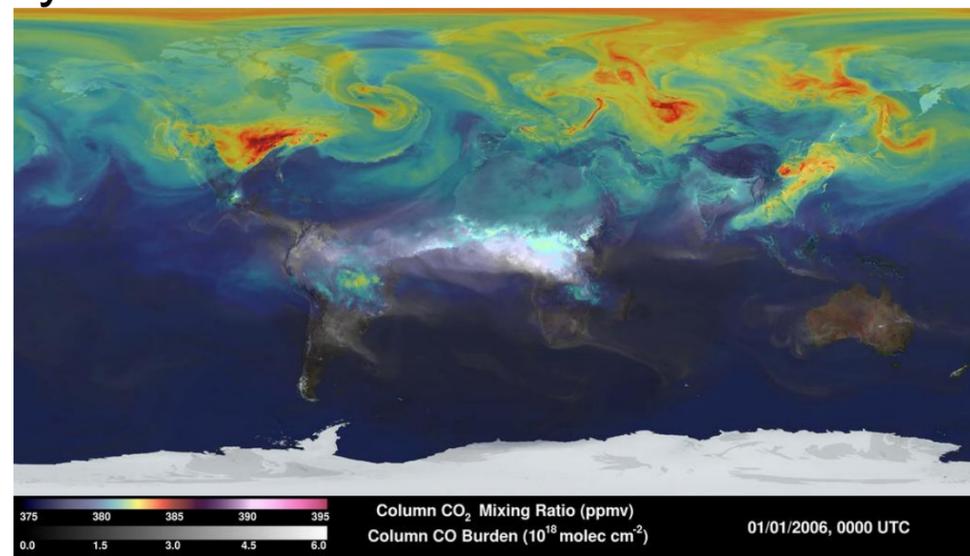
GEOS Configurations

- Convection-Permitting Modeling (GEOS-CAM).

- Observing System Simulation Experiments (OSSEs).

- Chemistry Climate Modeling (GEOS-CCM).

- Chemistry Transport Modeling (GEOS-CTM).

- Offline land/land-ice model & data assimilation platform (**GEOSldas**).

GMAO Products

- Routine NWP Forecasting: GEOS-FP

- Misson Support: GEOS-IT

- Atmospheric Composition: GEOS-CF v.2

- Seasonal Prediction: **GEOS_S2S_3**

- Reanalysis.

Column CO_2 Mixing Ratio (ppmv)
Column CO Burden (10^{18} molec cm^{-2})
01/01/2006, 0000 UTC

Arctic & Antarctic are a particular focus --

• Significant role of polar regions in global energy and water budgets.

• Recent enhanced warming in the Arctic.

• Areas for improvement in reanalyses. Reanalyses are known to have particular difficulty in high latitudes:

  • Scarcity or episodic in situ observational data,
  • Difficulties in remote sensing over ice and snow surfaces,
  • Complex physical processes.

• Reduced numerical weather prediction skill relative to other locations.

Dynamical Ice Sheet Model Coupling
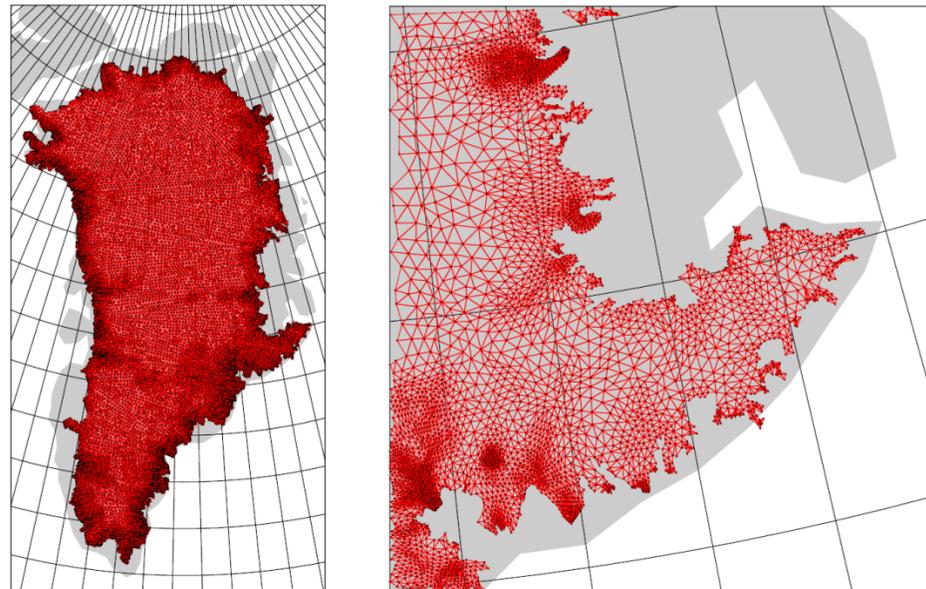
ISSM mesh, and GEOS AGCM grid.
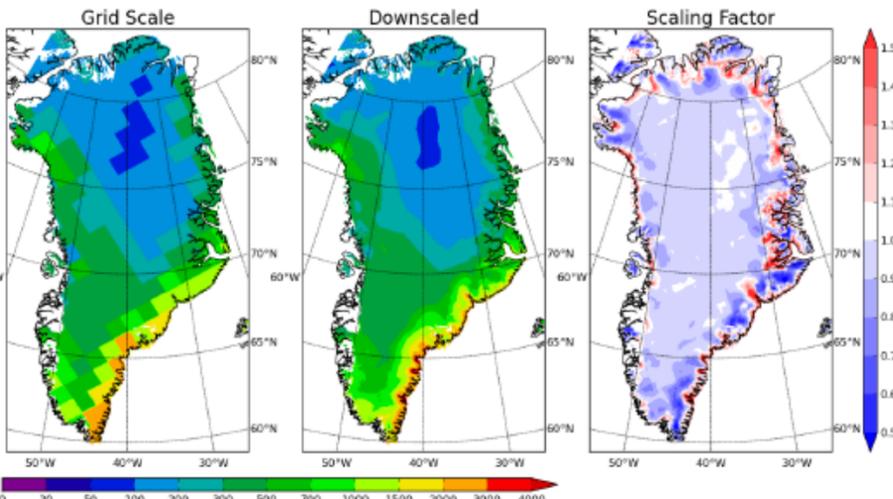
GEOS precipitation downscaling scheme.

- The GEOS surface exchange grid allows the surface column model to run independently over tile areas that are smaller than the GCM grid box. Fluxes are then aggregated to communicate with the atmosphere.

- A surface tile was assigned to each ISSM element. The atmospheric forcing for the tile was horizontally interpolated and then vertically downscaled to the element.

- This works for a reasonable number of ISSM elements: e.g., order of 10^5.
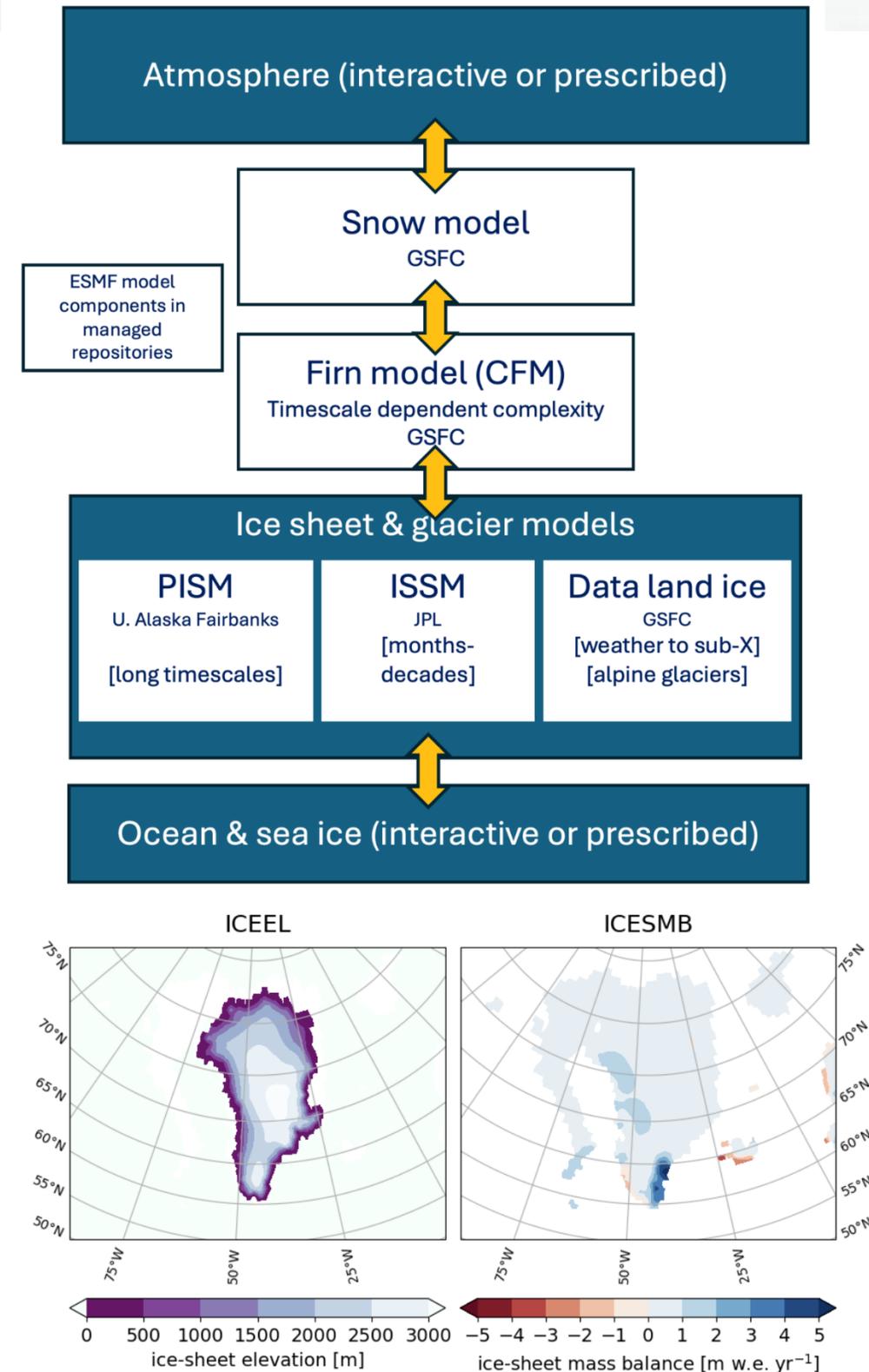

(Stubblefield & Andrews, in progress)

# GMAO reanalysis products
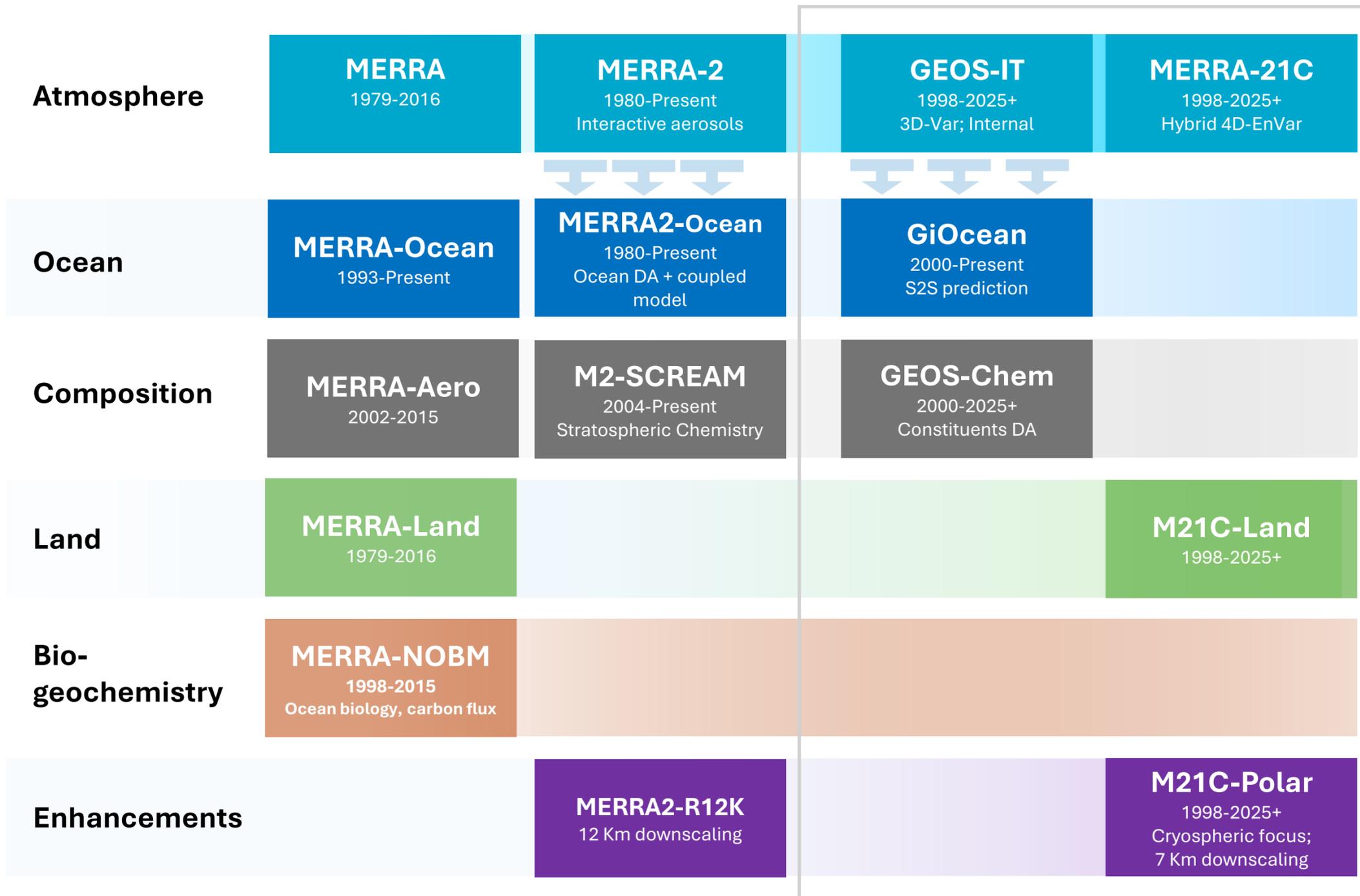
MERRA-21C

An enhanced Atmospheric Reanalysis for the early 21st century

MERRA-21C is the first application of GMAO's hybrid 4D-EnVar system for reanalysis.

- Use of the hybrid 4DEnVar assimilation technique in an advanced GEOS model;
- Integration of all-sky microwave radiances from TRMM/TMI and GPM/GMI, as well as from operational sensors;
- Use of microwave and infrared radiances to constrain the SST and lowermost atmosphere;
- Extended use of hyperspectral infrared radiances, using advanced channel correlation selection and other thinning techniques;
- Integration of post-EOS-era observations, such as SNPP and JPSS-era instrumentation;
- Enhanced spatial resolution, using a model configuration of 25km with 72 layers.

Surface Mass Balance, Available Years 1998-2022* [mm yr^{-1} w.e.]

MERRA-2
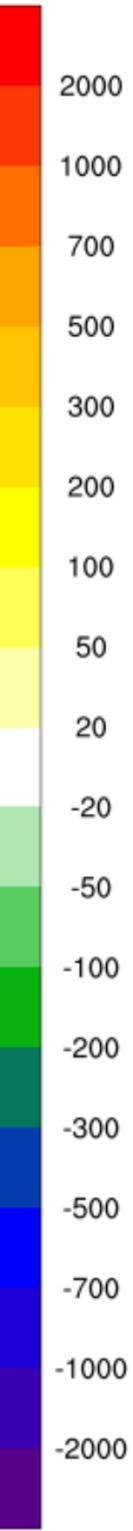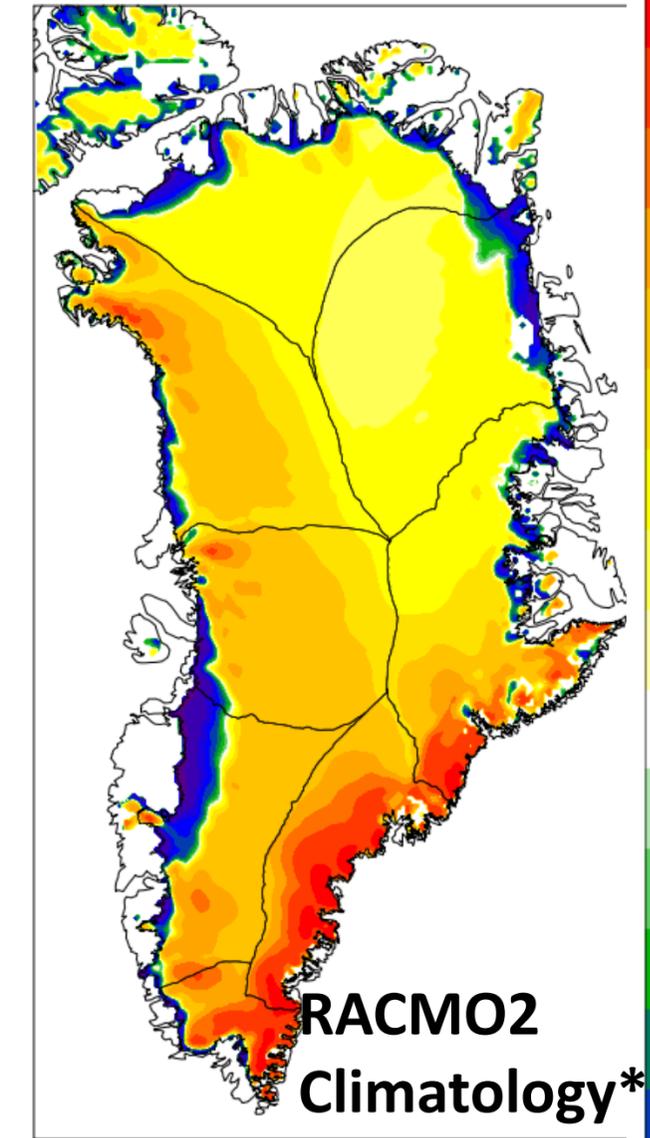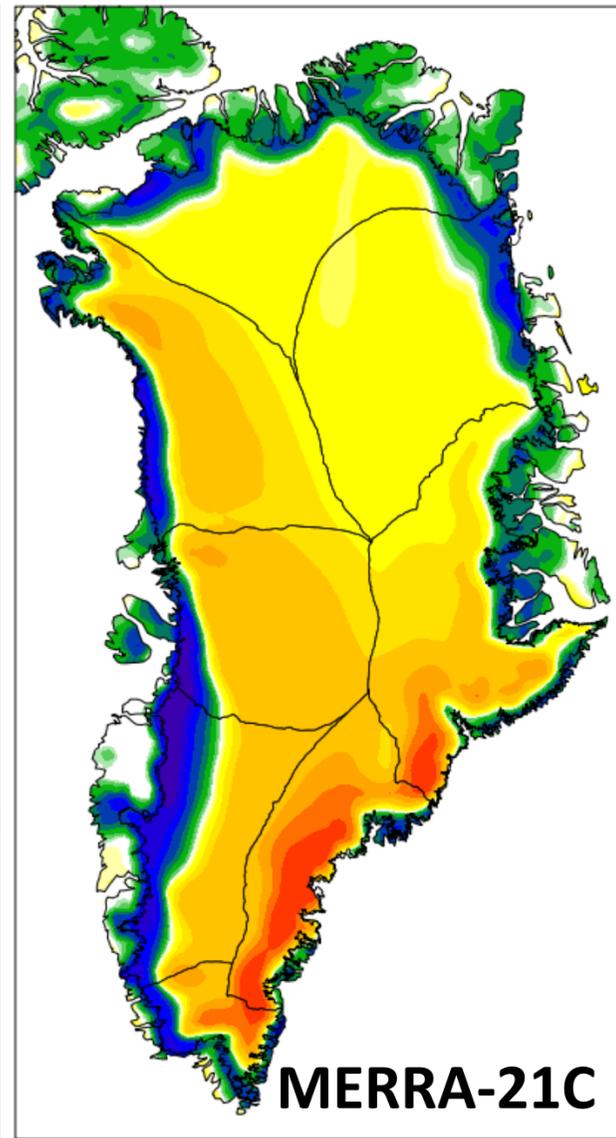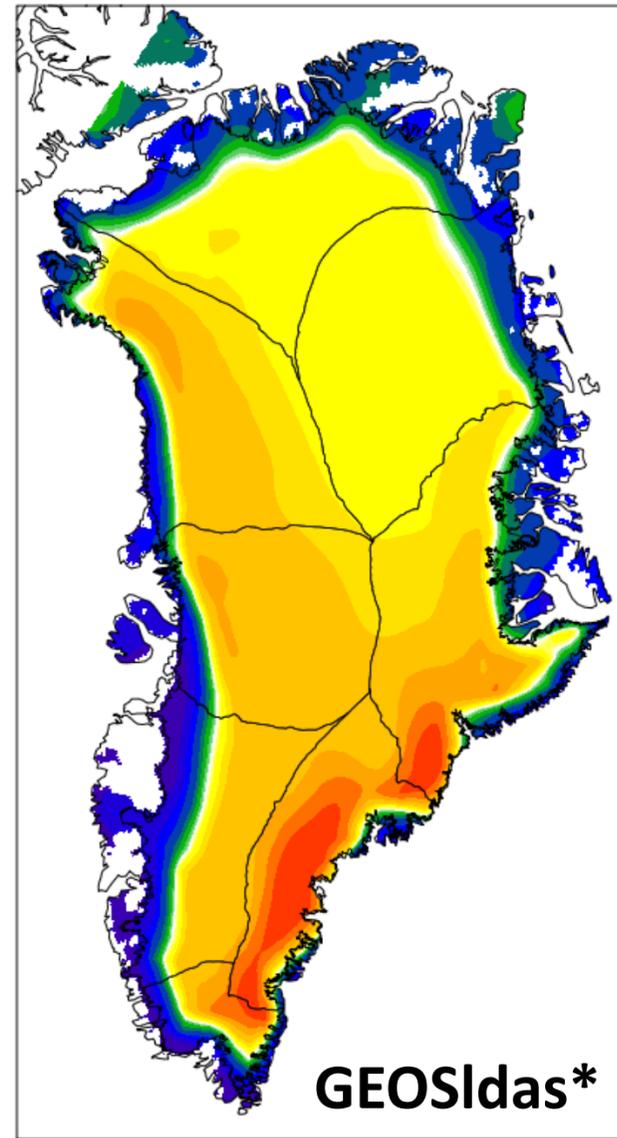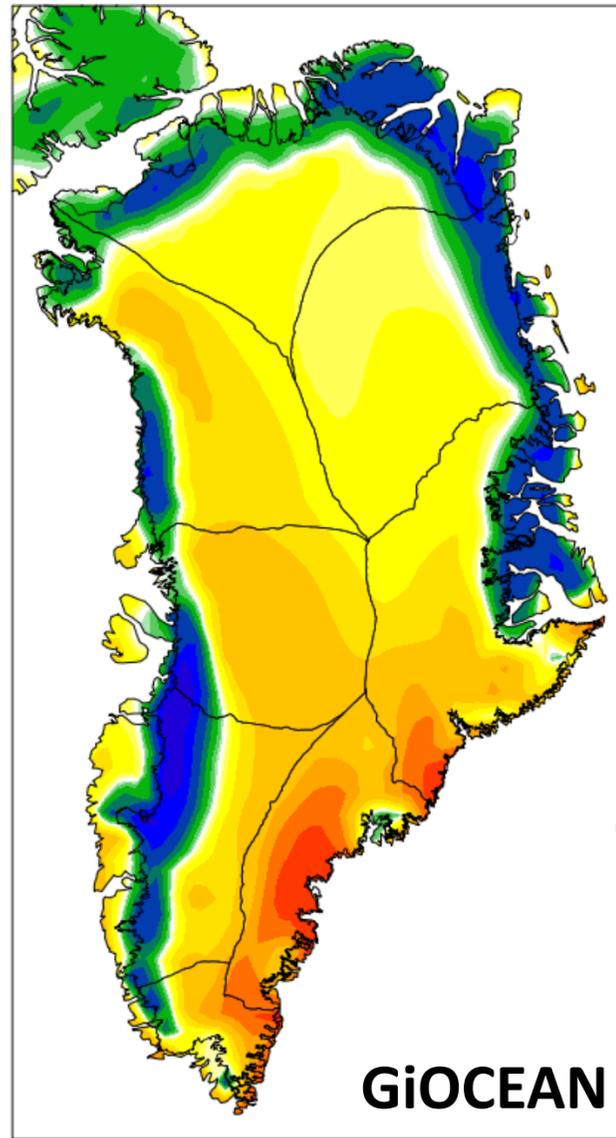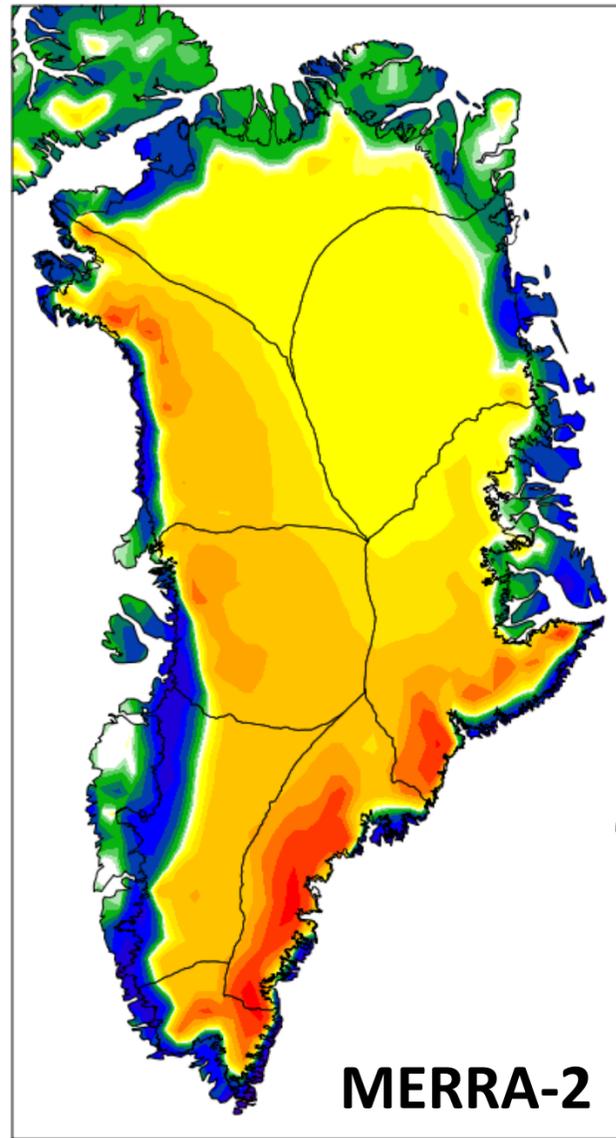
GiOCEAN

Weakly Coupled
Atmosphere/Ocean
Assimilation Replaying to
GEOS-IT ; Two-Moment Cloud
Microphysics

GEOSldas*

*2016-2024

Land Surface Forced
With GEOS-IT

MERRA-21C

**RACMO2
Climatology***

*1958-2007

RCM Forced
With ECMWF

SMB for GiOCEAN, M21C

Annual Surface Mass Balance [Gt]
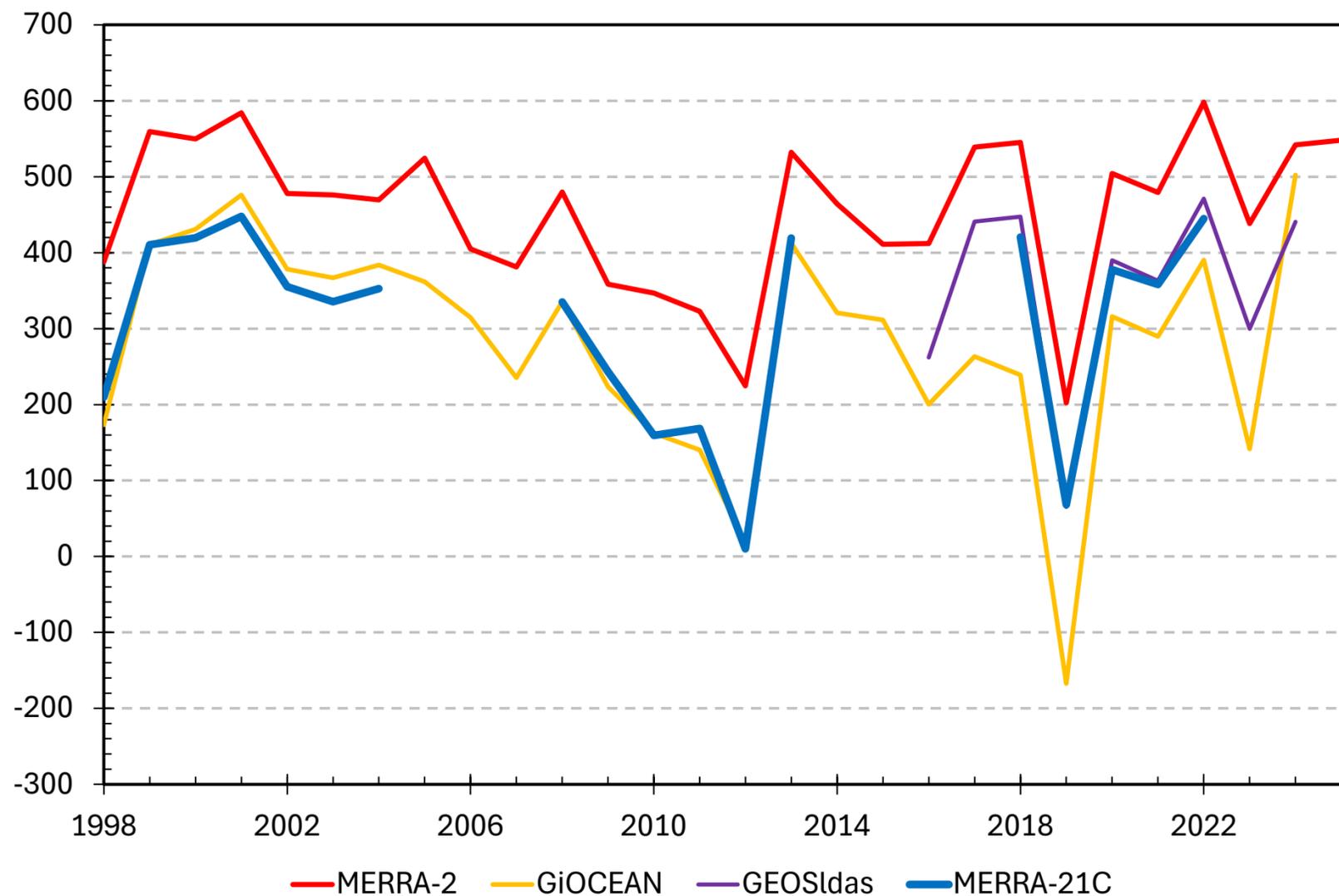
Annual Precipitation [Gt]

Annual Runoff [Gt]

MERRA-2   GiOCEAN   GEOSldas   MERRA-21C
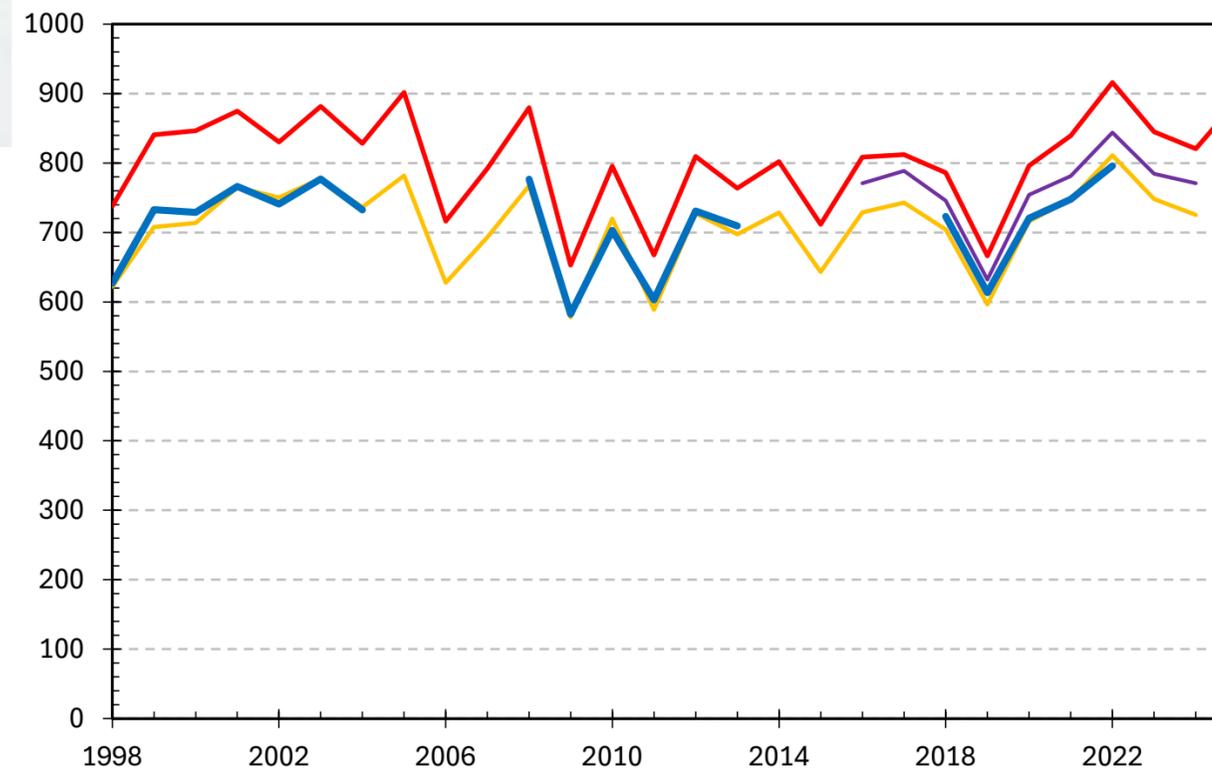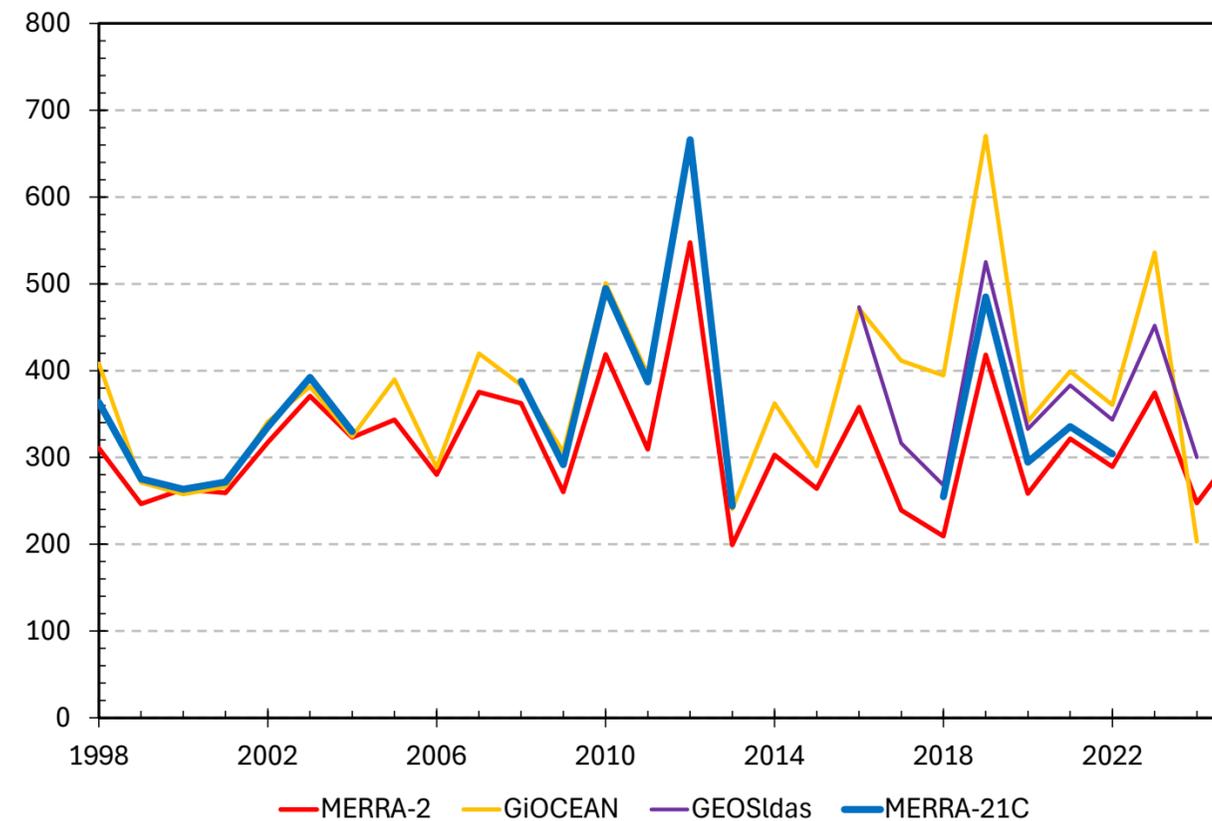
Model Ice Sheet Surface Hydrology
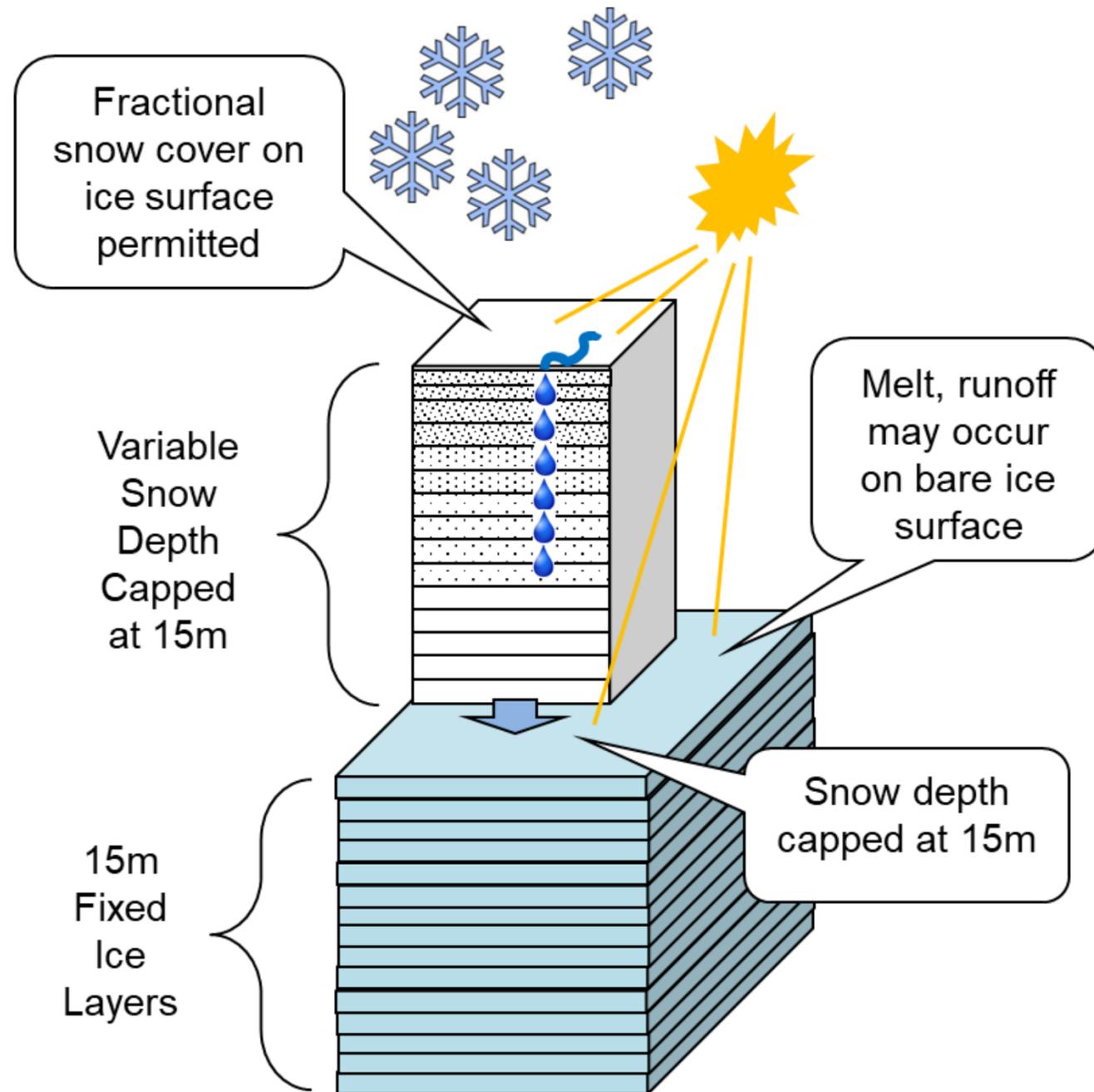
- GEOS ice sheet surface hydrology is based on the Stieglitz (1994) snow model.
- Model of intermediate complexity. Prognostic variables layer thickness, water equivalent, and heat content.
- Capped layer snow density (500 kg m^{-3}).
- Adapted for land-ice. 15 snow layers and 15 fixed ice layers to resolve heat conductivity.
- No explicit representation of firn.

Microwave Estimation of Meltwater

- Passive microwave have been used as an effective tool for estimating melt area due to the step-change in emissivity as liquid water forms in dry snow. These methods rely on high frequency channels for radiation from near surface snow.
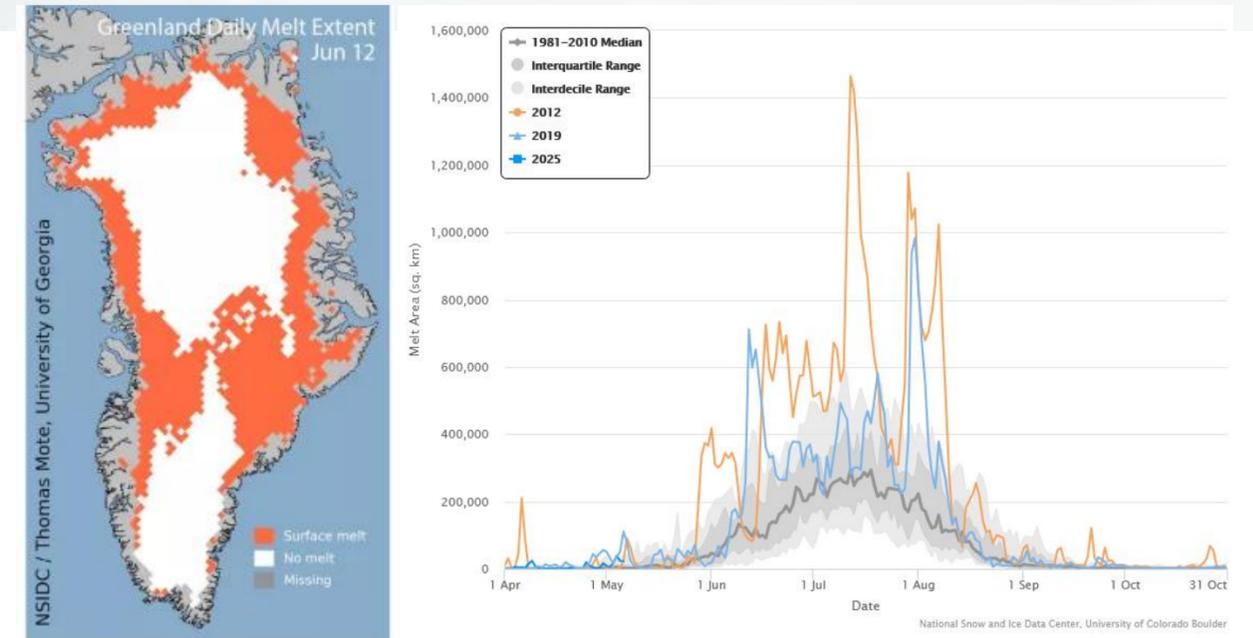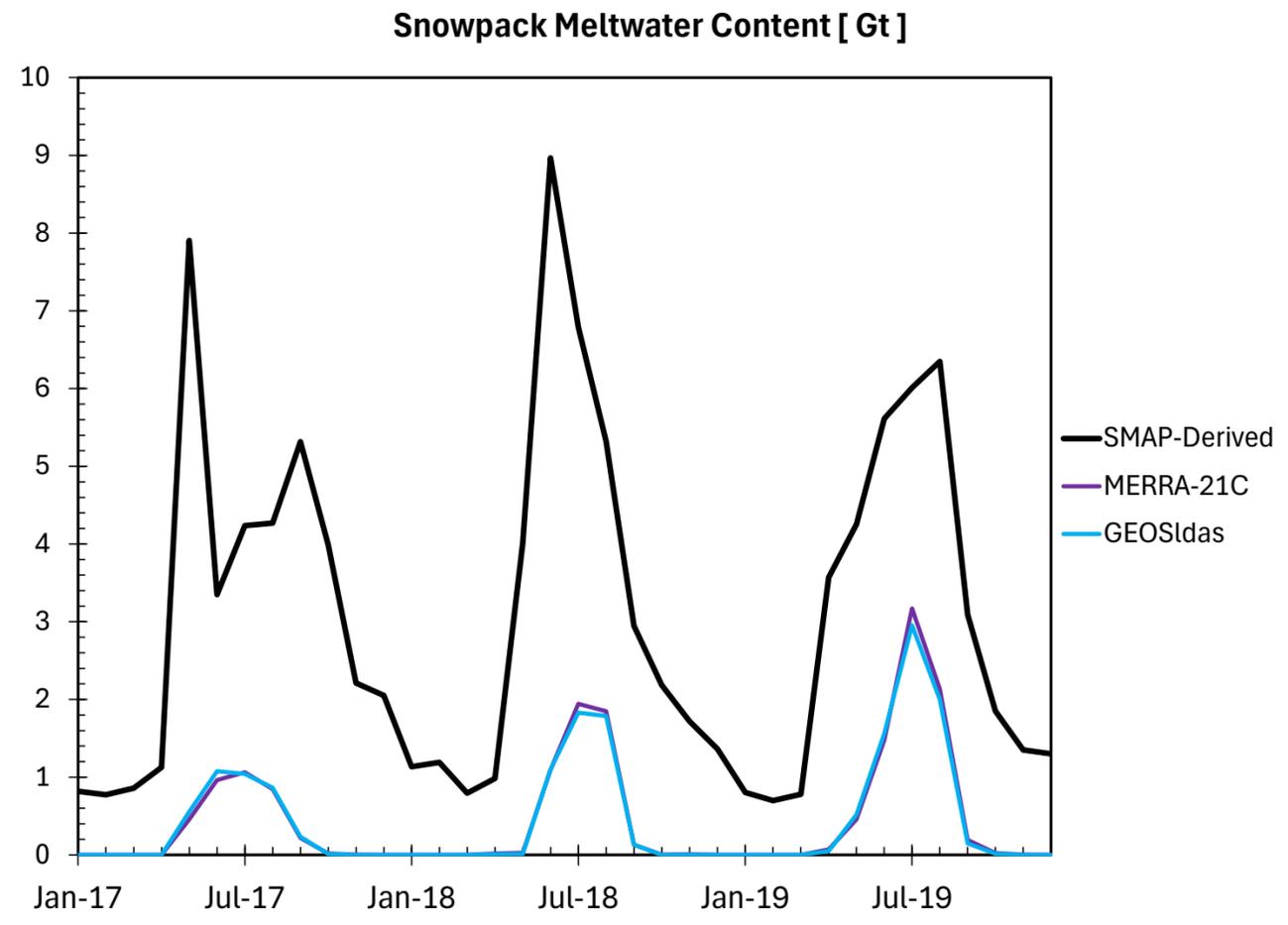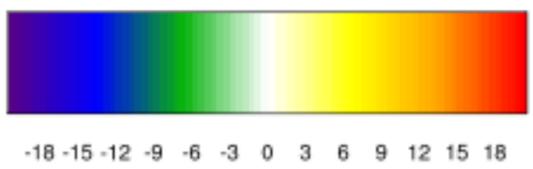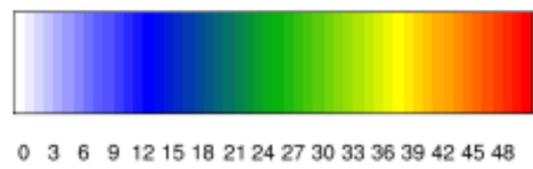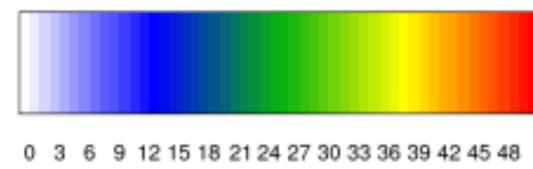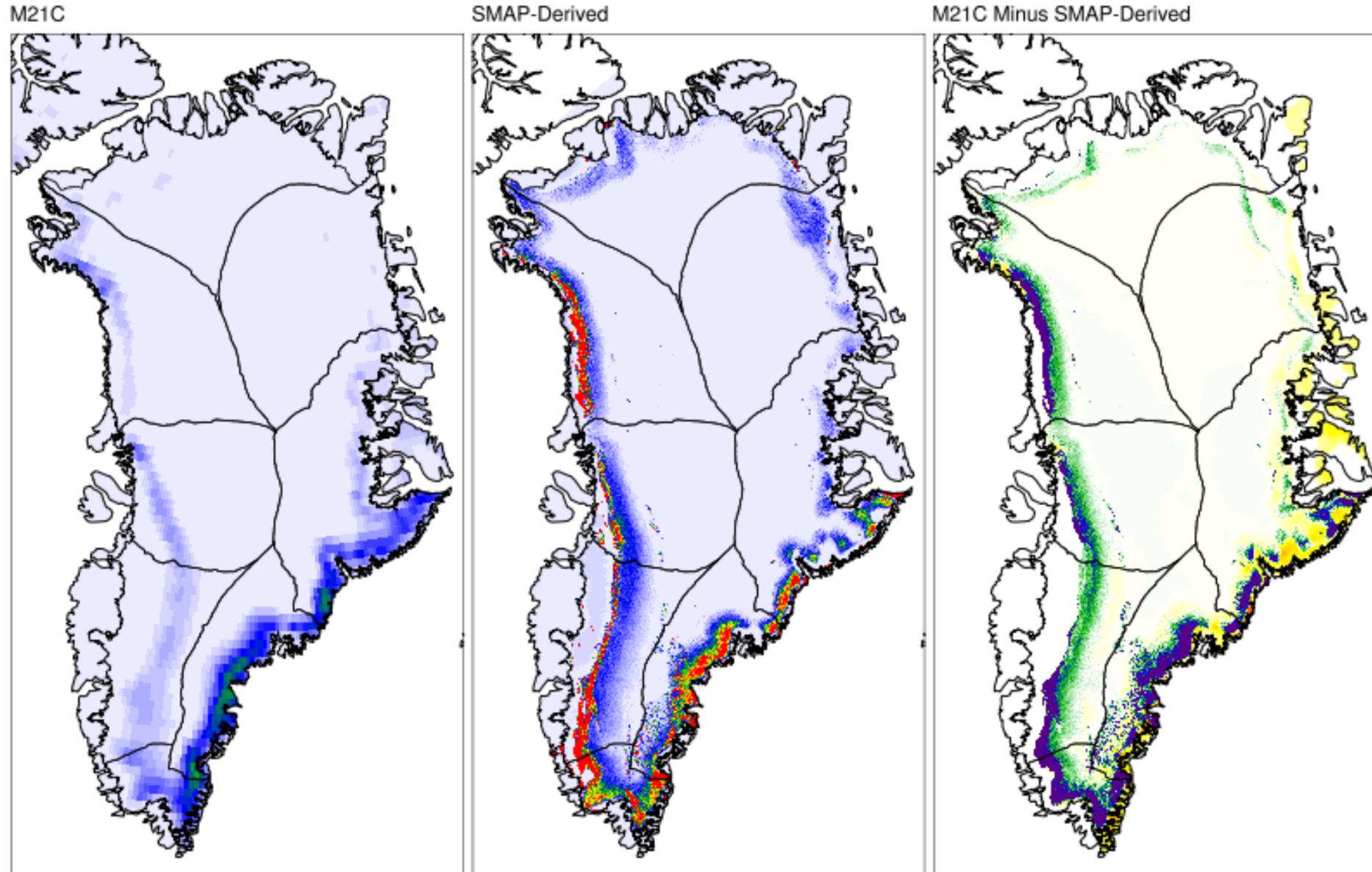
- A volumetric retrieval uses lower frequency radiance channels from the Soil Moisture Active Passive satellite (SMAP) and the Advanced Microwave Scanning Radiometer 2 (AMSR2). These bands are sensitive to liquid water content in snow/firn layers. The approach has been calibrated with in situ observations.
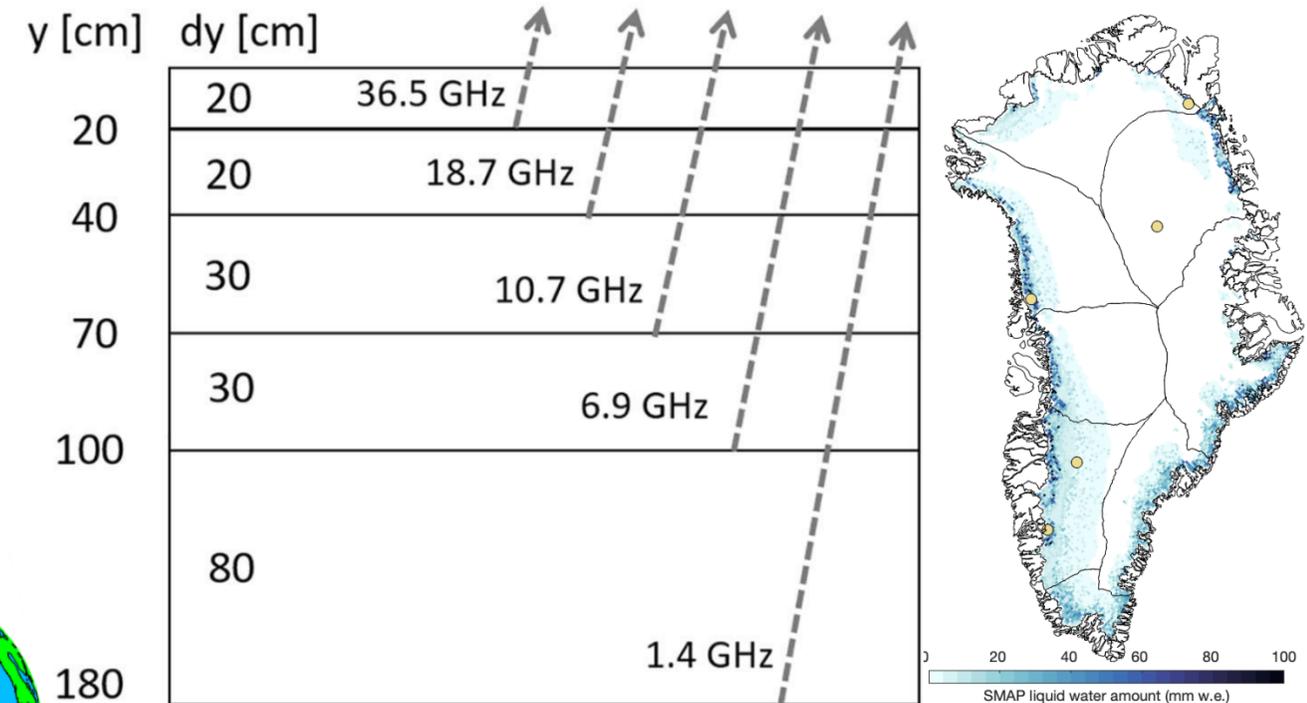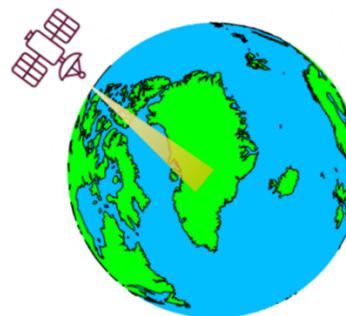
MERRA-21C
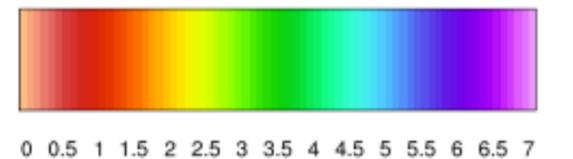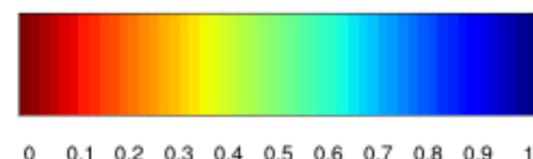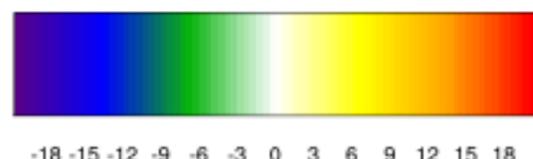

Meltwater Content, July 2017-19 [mm w.e.]

M21C

SMAP-Derived

M21C Minus SMAP-Derived

0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48

0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48

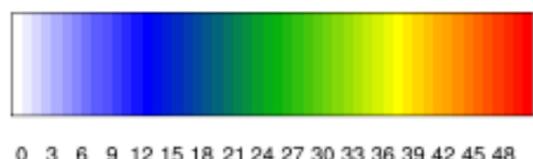-18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18

Snowpack Meltwater Content [Gt]
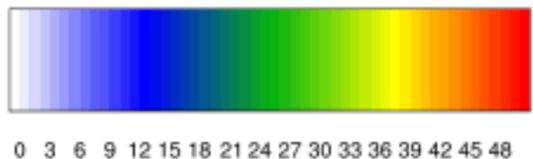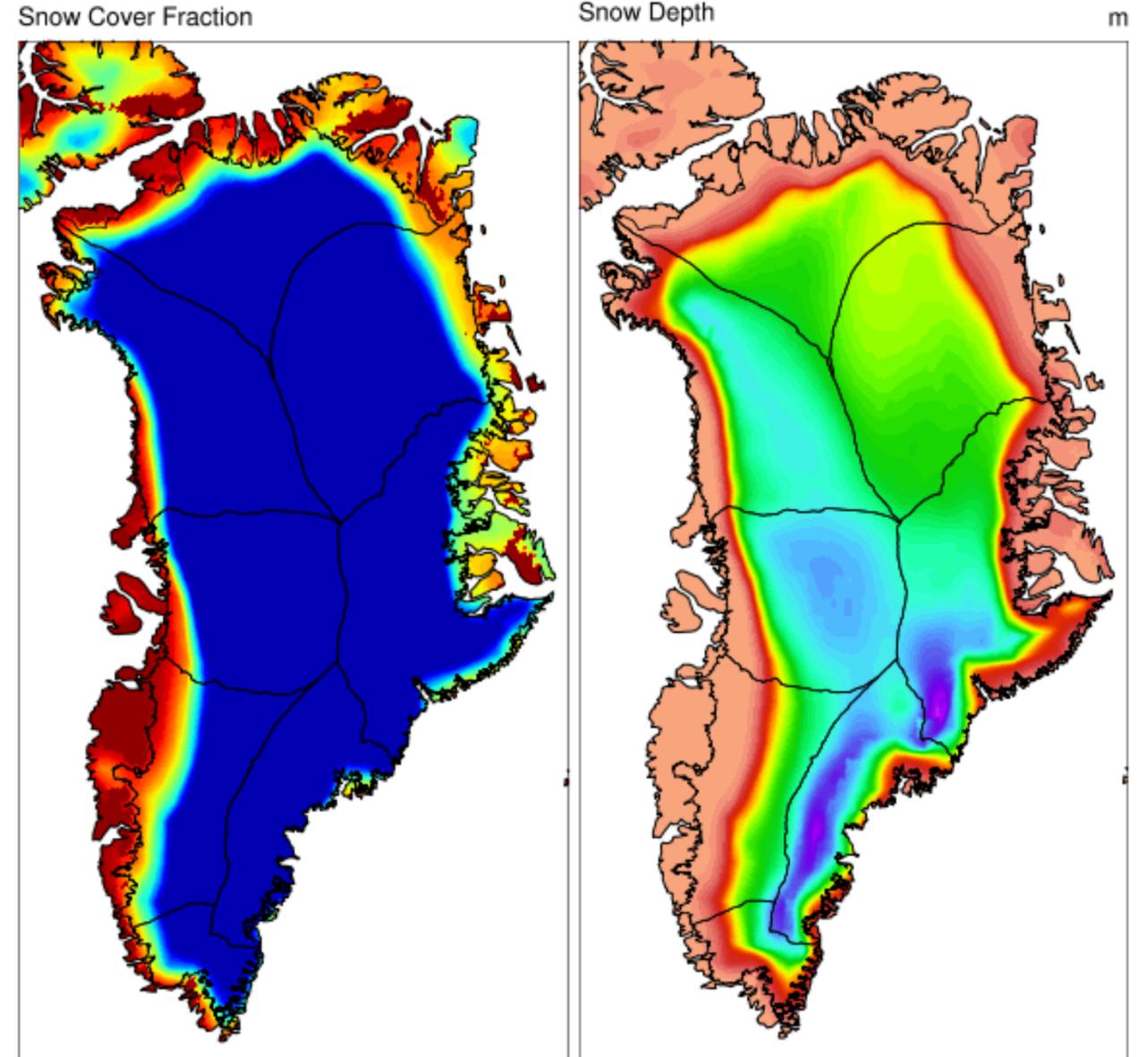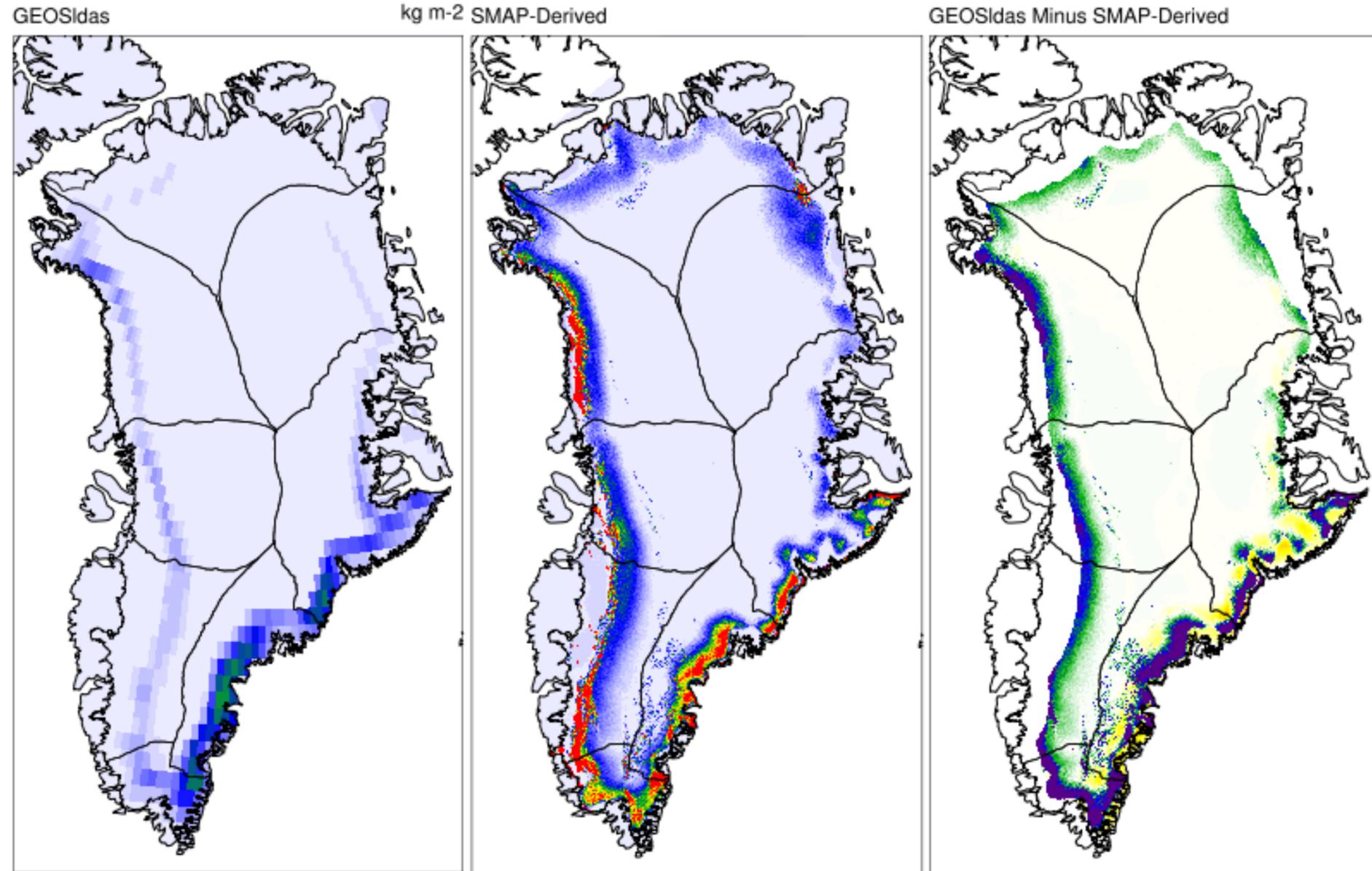
SMAP-Derived
MERRA-21C
GEOSldas

GEOS-LDAS, 2015-2020
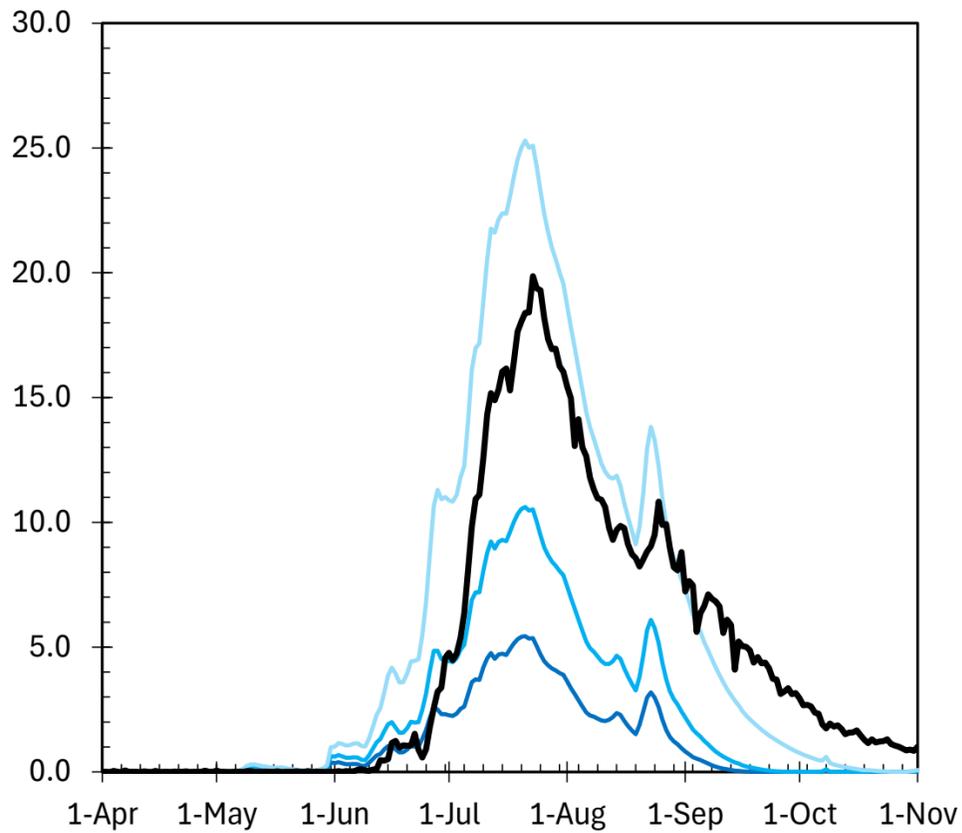

Meltwater Content, July 2015-2020 [mm w.e.]
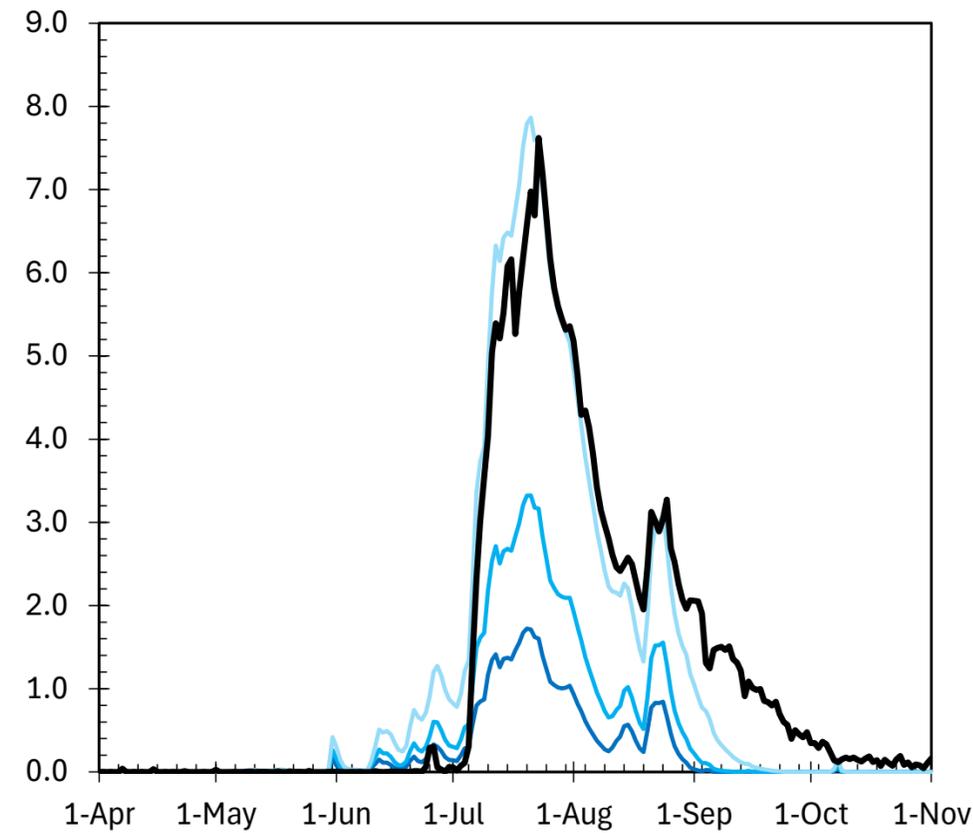
GEOS-LDAS Snowpack, July 2015-2020

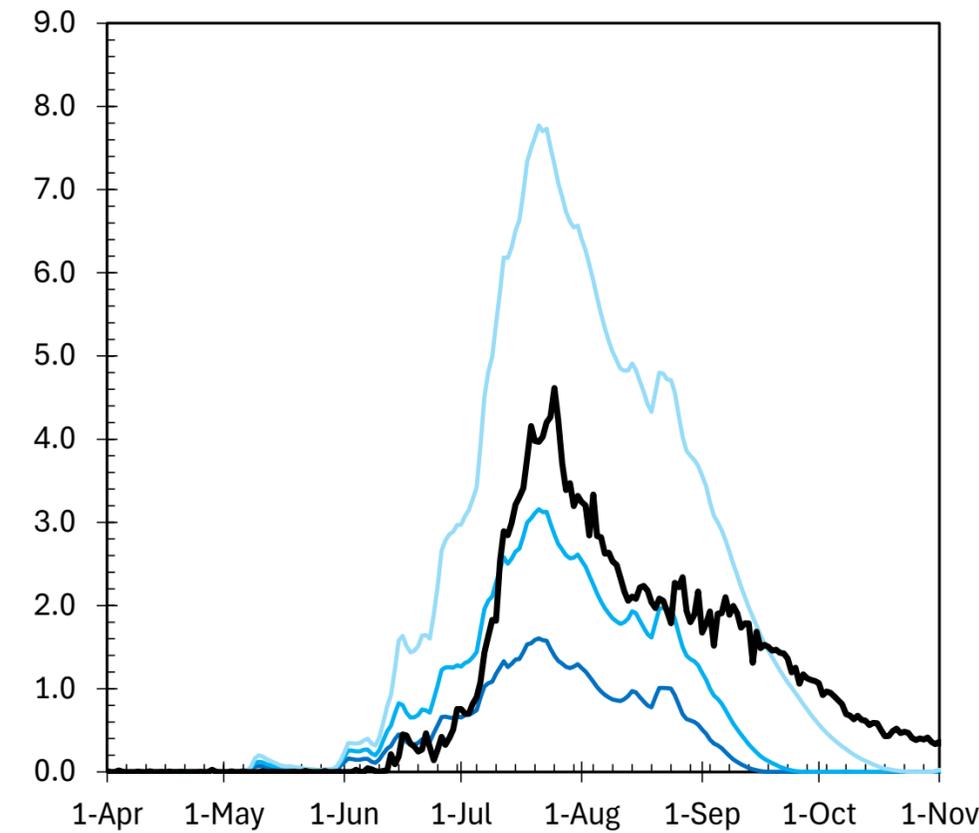# Daily Meltwater Percolation Holding Capacity Experiments

Meltwater Content, Pan-GrIS, 2023 [Gt]

Meltwater Content, Southwest GrIS, 2023 [Gt]
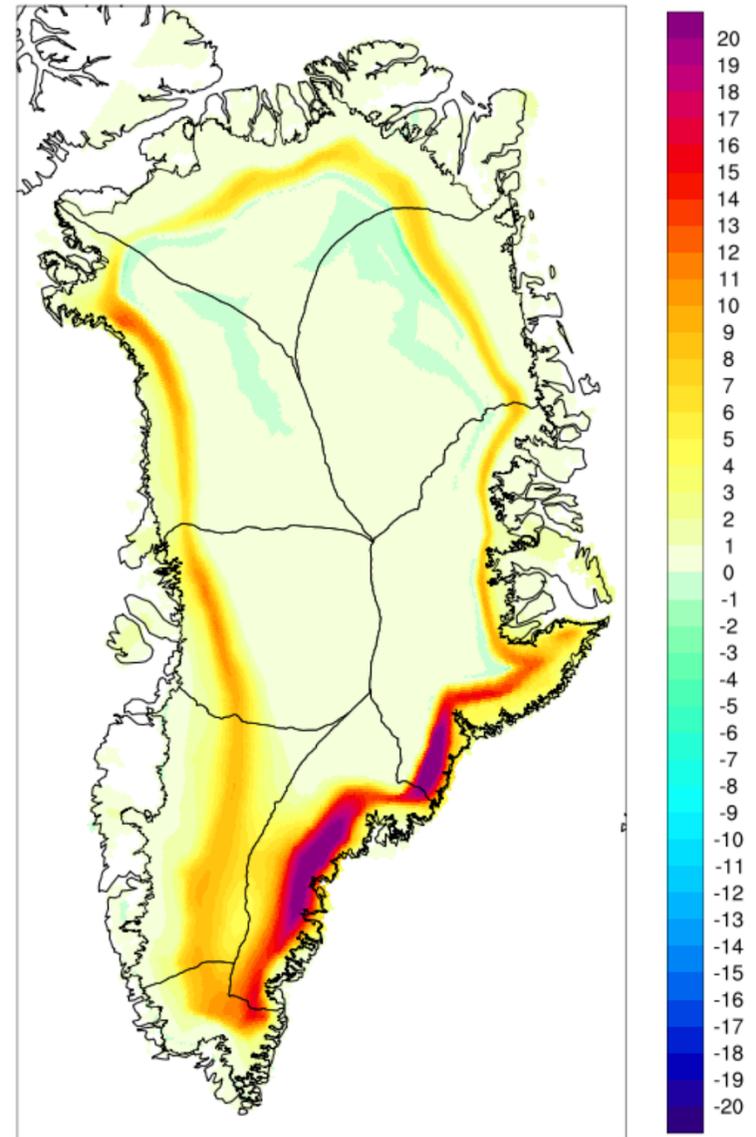
Meltwater Content, Southeast GrIS, 2023 [Gt]

GEOSldas, 1%
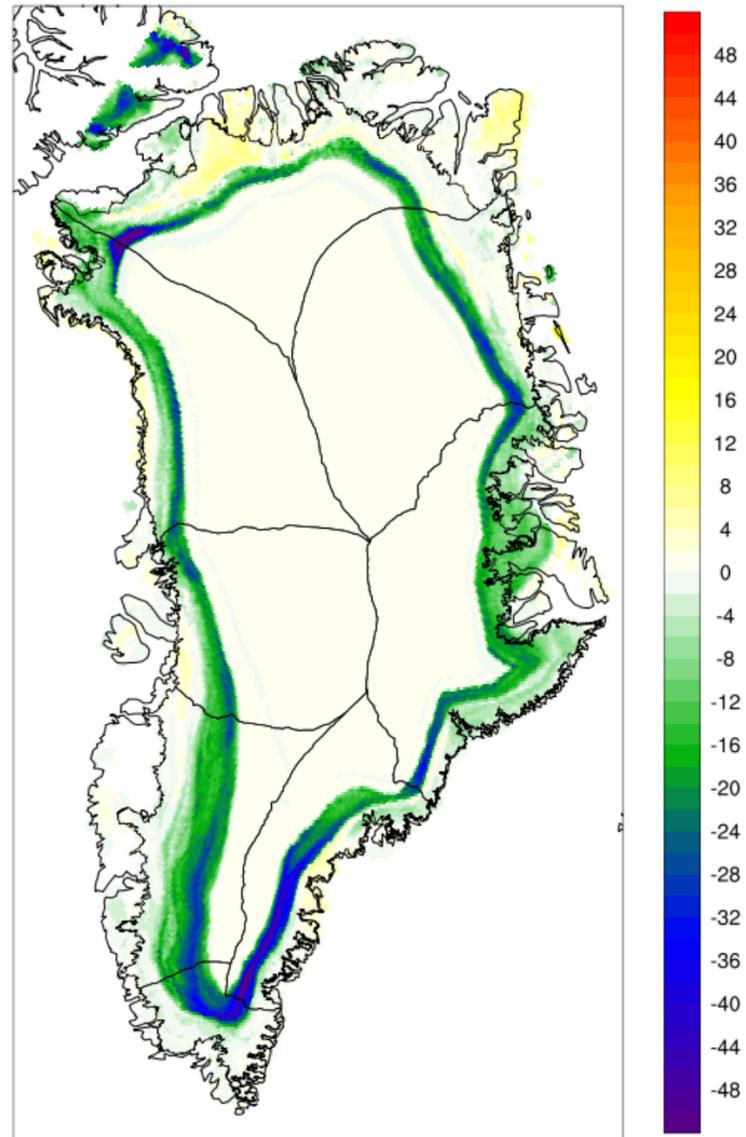GEOSldas, 2%
GEOSldas, 5.5%
SMAP

Holding Capacity Experiments

2%HC Minus 1%HC, July 2023

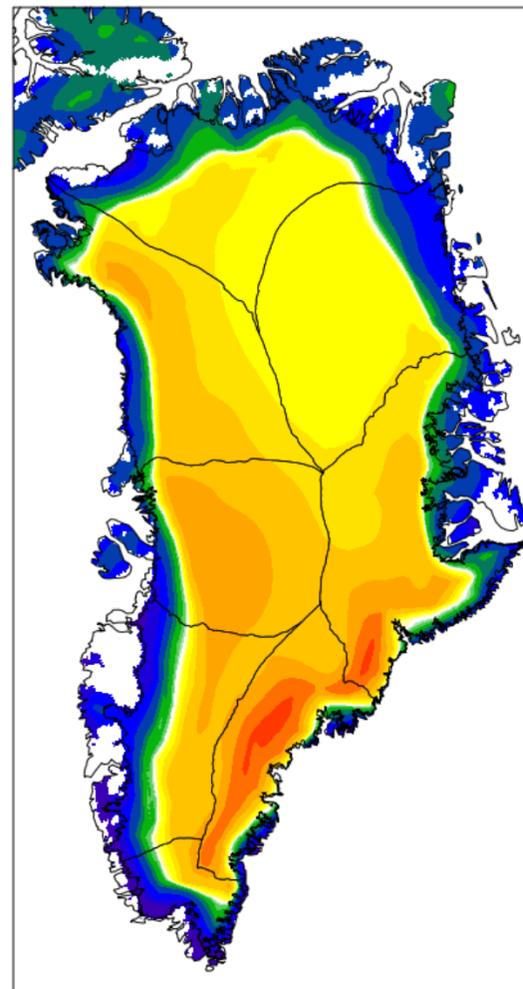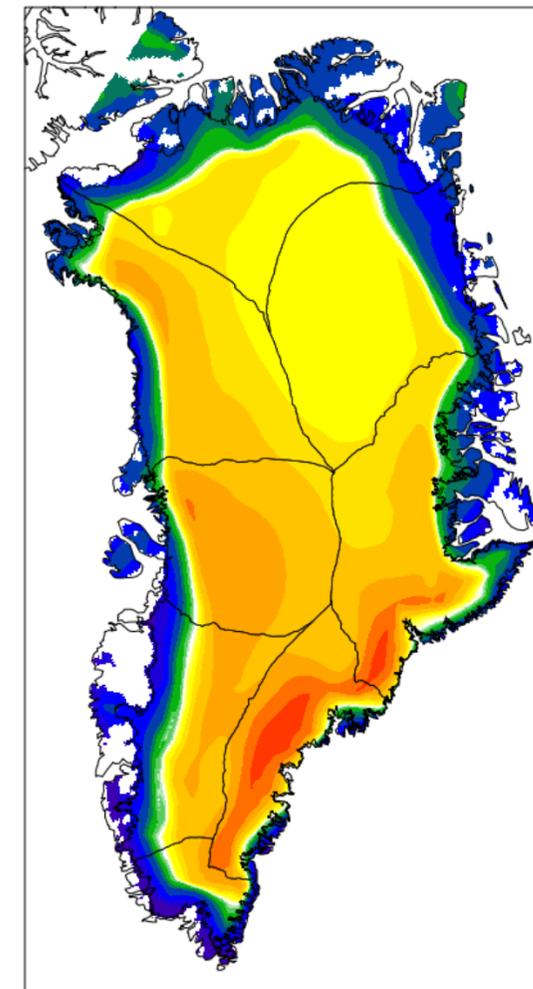Meltwater Content [kg m^{-2}] Runoff [kg m^{-2}]

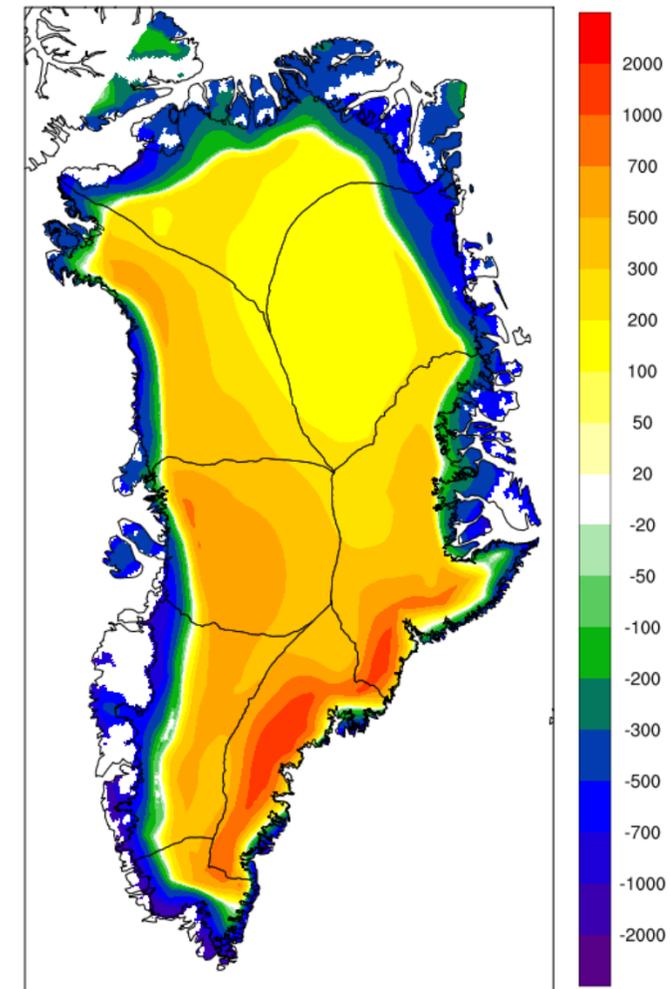## 2023 Surface Mass Balance [mm yr^{-1} w.e.]

1% H.C.   2% H.C.   5.5% H.C.

Summary

- GMAO is soon releasing new products relevant to polar regions including GEOS-S2S_3 & its weakly coupling initialization analysis, GiOCEAN, & MERRA-21C reanalysis.

- GEOSldas has been developed for land-ice as an offline evaluation tool for advances to the surface representation. GEOSldas will serve as a platform for land-ice data assimilation.

- Efforts are being made to update ice sheet surface representation in response new atmospheric model forcing & new observations.

- Novel quantitative meltwater estimates show large differences with GEOS model values. This can be resolved with adjustments to model layer holding capacity, but it produces significant changes to surface mass balance.

- Southeastern Greenland SMB is particularly sensitive to snowpack meltwater holding capacity.