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The Surface Albedo of the Greenland Ice Sheet between 1982-2015, and its Connections to Surface Mass Balance (and Ice Discharge)

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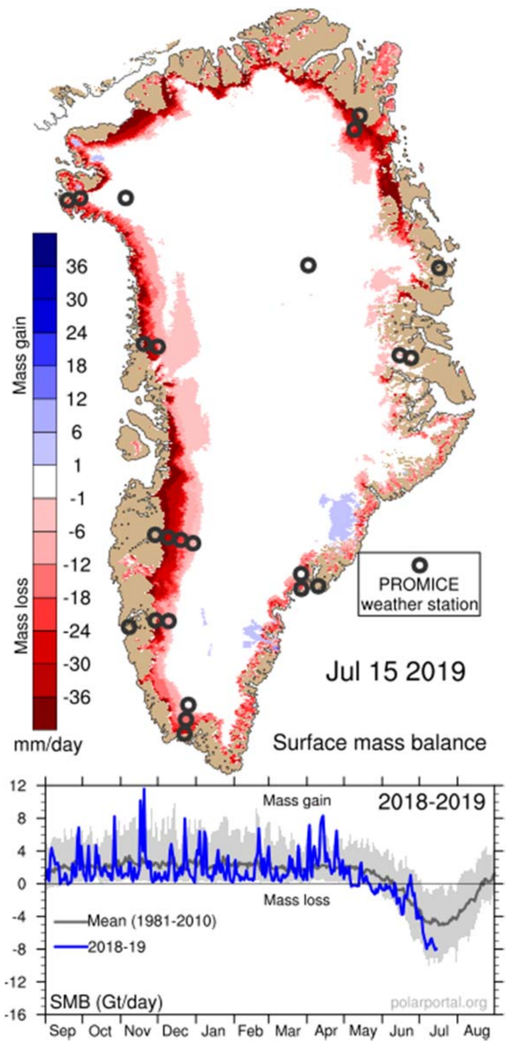
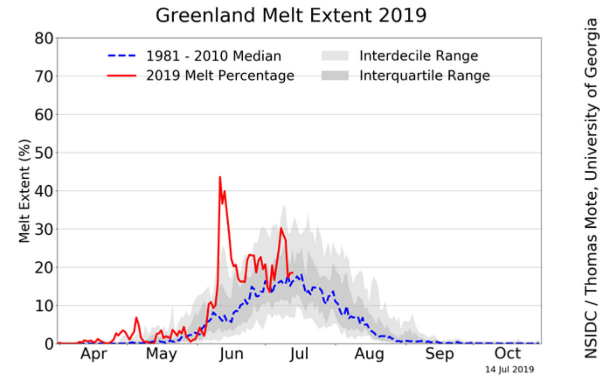
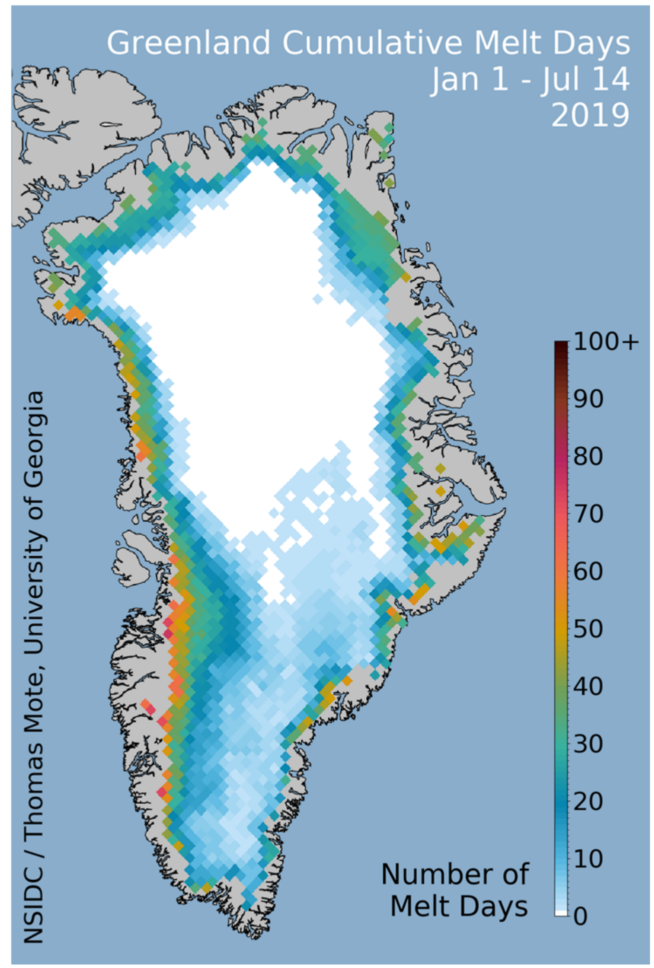
The melting ice sheet: 2019



DMI/DTU/GEUS





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The Questions

1. What are the trends in the surface albedo (black-sky) of GrIS over the past three and a half decades? What spatiotemporal variability can we see in them? What drivers can we see behind the changes?
2. Can we detect changes in the intensity of the GrIS melting seasons from albedo estimates during the 1982-2015 period?
3. Can we use the albedo estimates to empirically test if surface melt/runoff has indeed recently been the dominant driver of summer GrIS surface mass balance?

CLARA-A2 SAL

Directional-Hemispherical Reflectance (**black-sky albedo**)

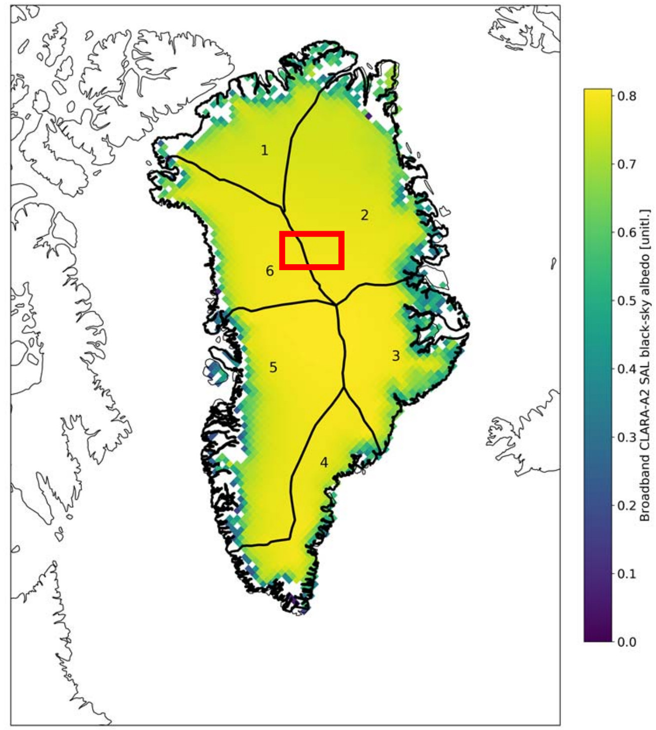
Global coverage, 1982-2015, from intercalibrated AVHRR radiances

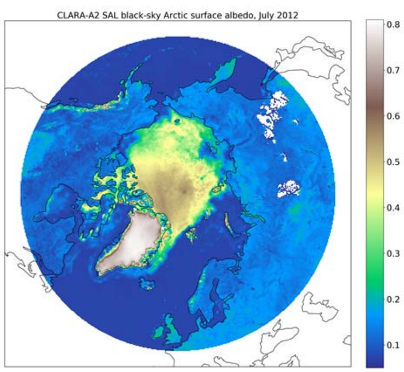
0.25 degrees / 25 km equal-area grid for polar regions

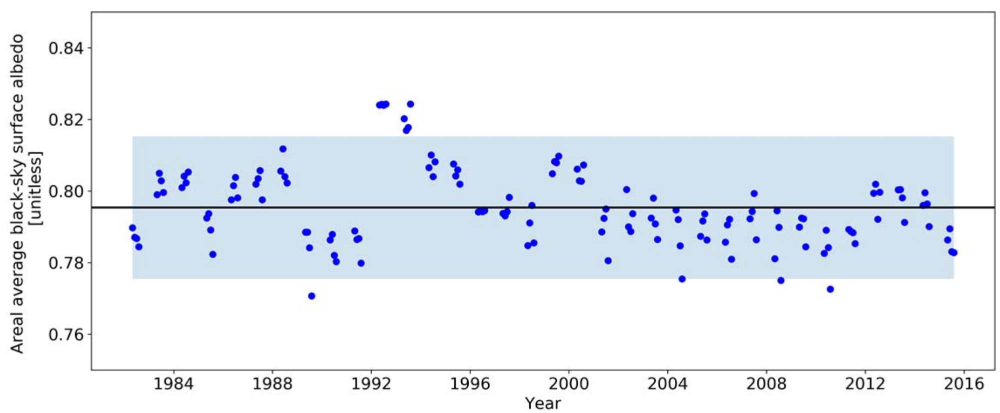
5-day and monthly mean estimates

Relies on dense angular sampling for snow/ice albedo, narrow-to-broadband conversion adapts to wet/dry snow

Produced by the CM SAF project of EUMETSAT. Free data access for anyone: wui.cmsaf.eu

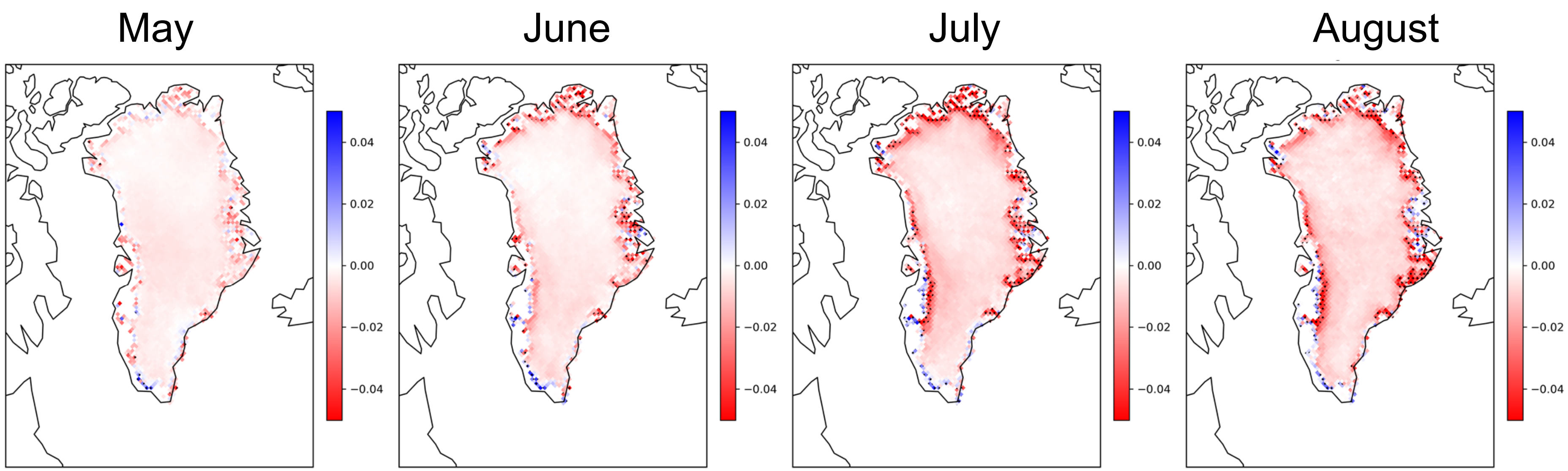






5% / 0.02 uncertainty envelope

Decadal albedo trends, 1982-2015



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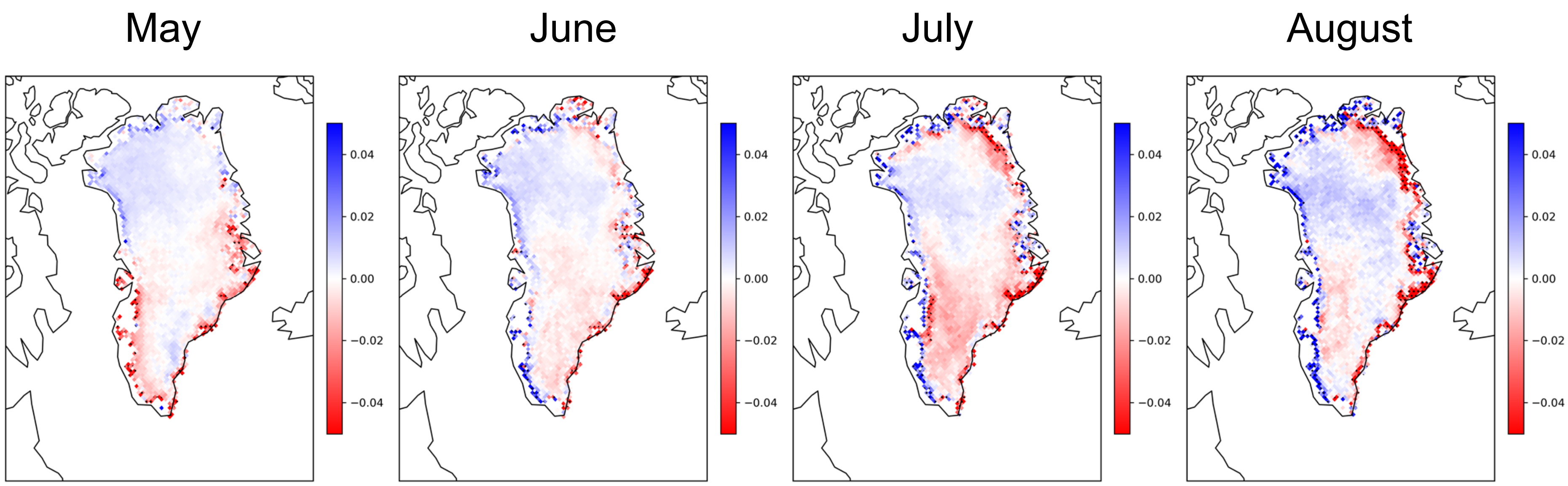
Decadal albedo trends, 1982-1999



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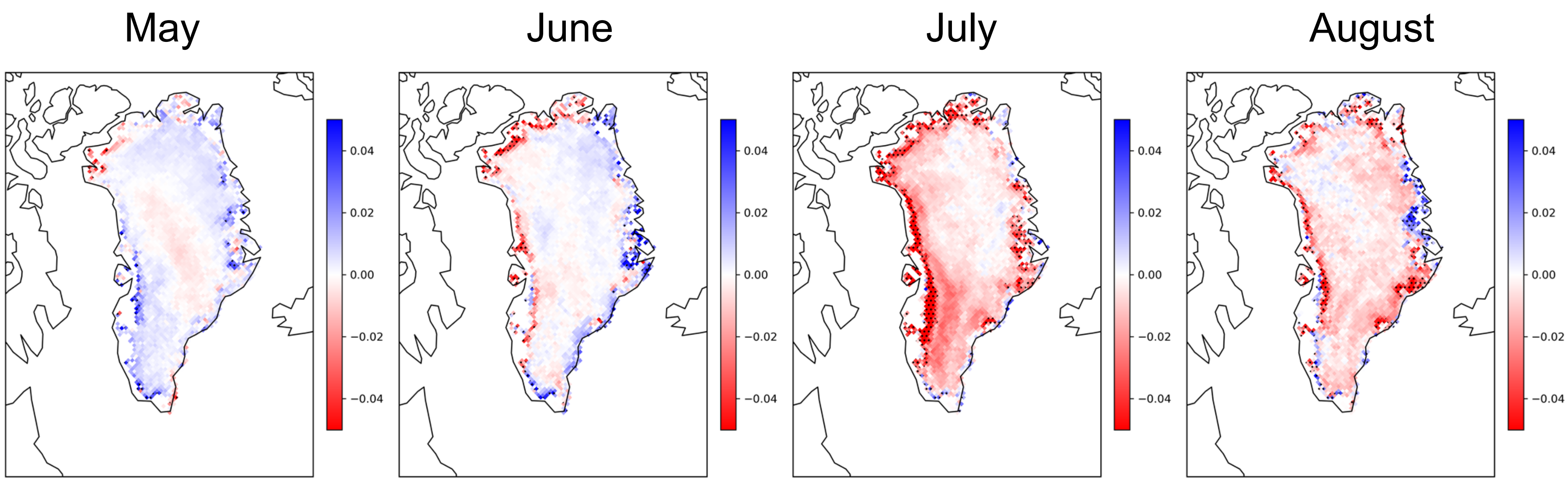
Decadal albedo trends, 2000-2015



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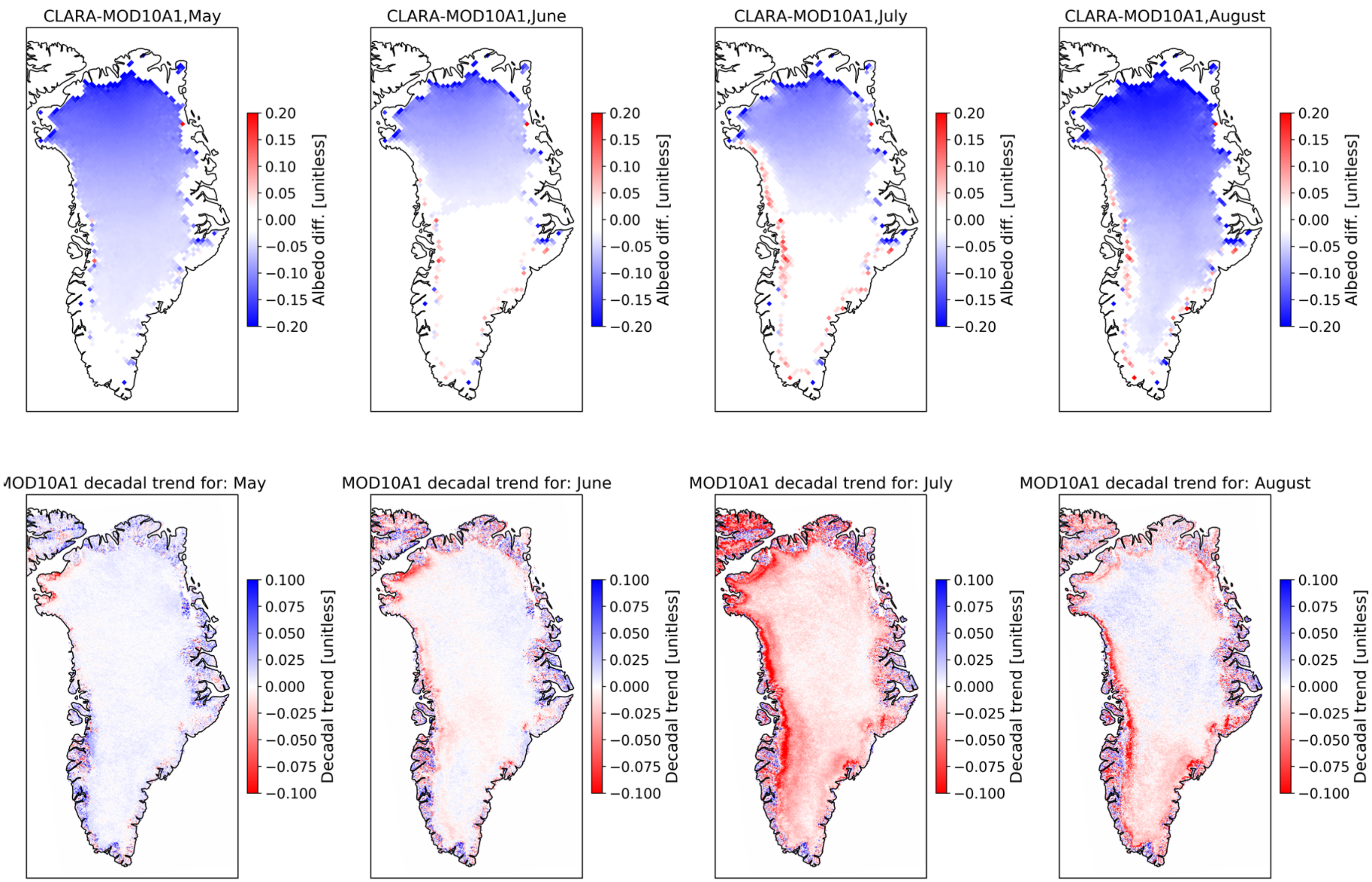
Decadal albedo trends from CLARA vs MOD10A1 (2000-2015)



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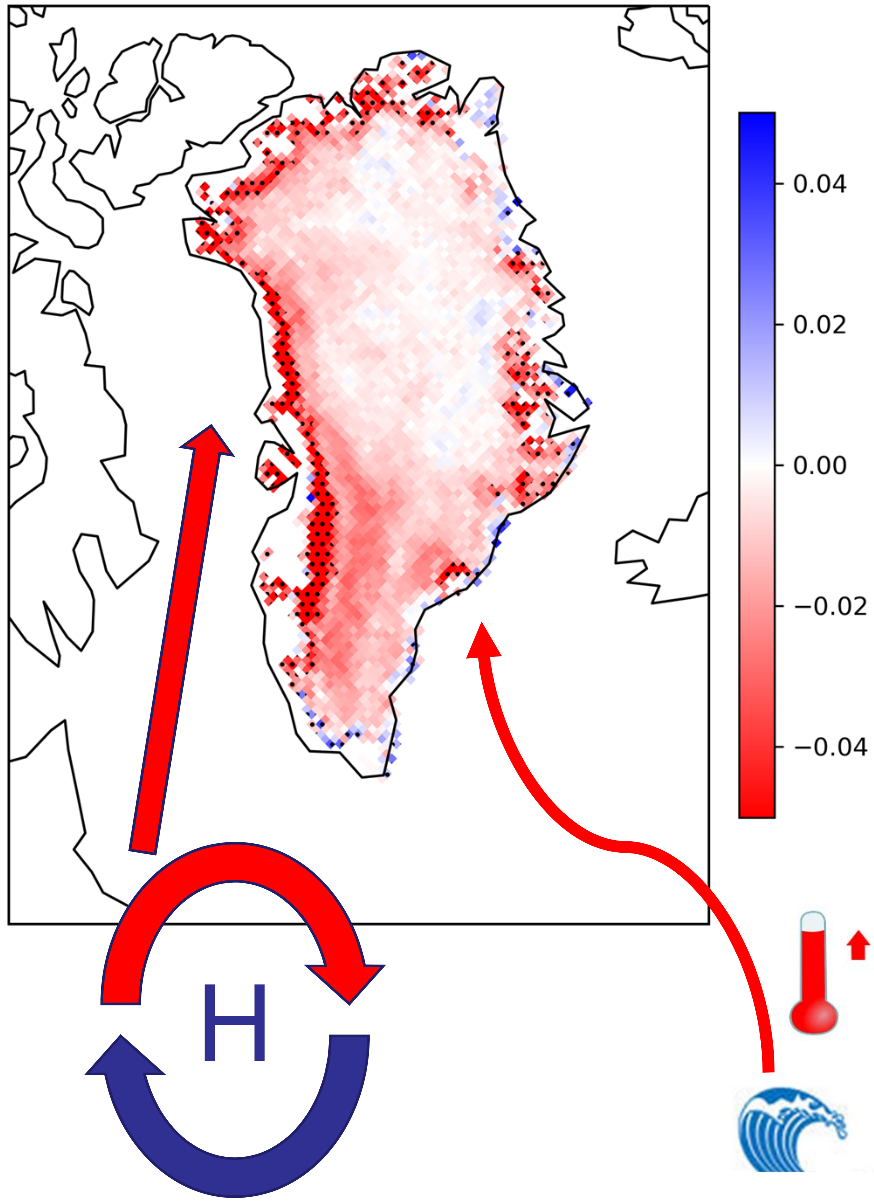
Drivers of darkening, 2000-2015

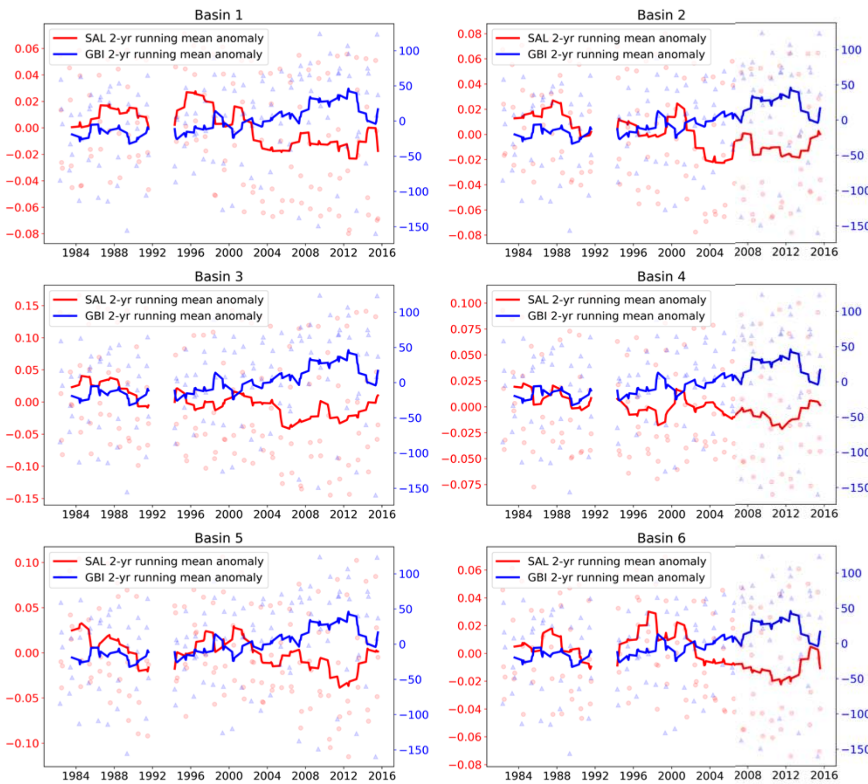
- **Increasing warm & moist air flow along the western coast**, spurred by the magnitude and longitudinal location of Atlantic anticyclonic circulation

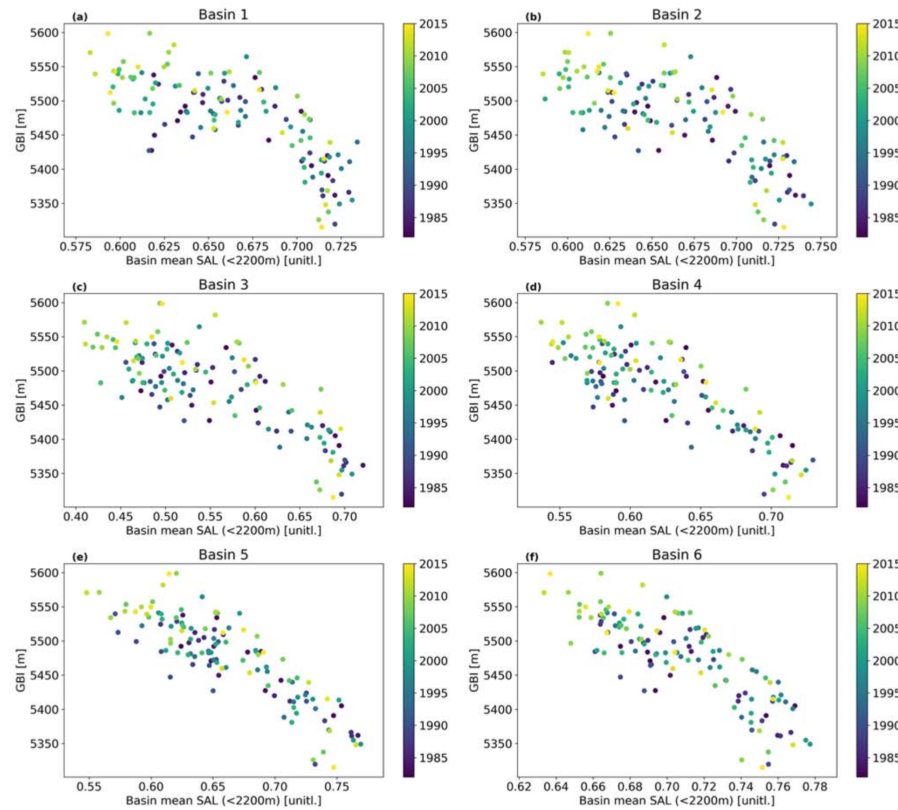
- Increasing **Greenland blocking highs** promoting cloudless conditions
- Potentially in the SE, also **the heat advected with the increasing intrusions of warm subtropical waters**

- Roles of increasing biological activity and impurity deposition/exposition?

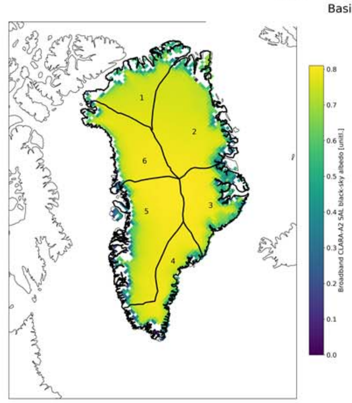


Albedo decreases and Greenland blocking highs





Greenland Blocking Index (GBI) GBI is the mean 500 hPa geopotential height for the 60-80°N, 20-80°W region.



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Changes in melt rate and probable bare ice exposure (I)

All figures show the change in anomalies between 2013-2015 and 1982-1984

Left column shows change in time needed from May 1 to reach albedo typical of bare ice / wet snow (0.58). Blue: faster, red: slower.

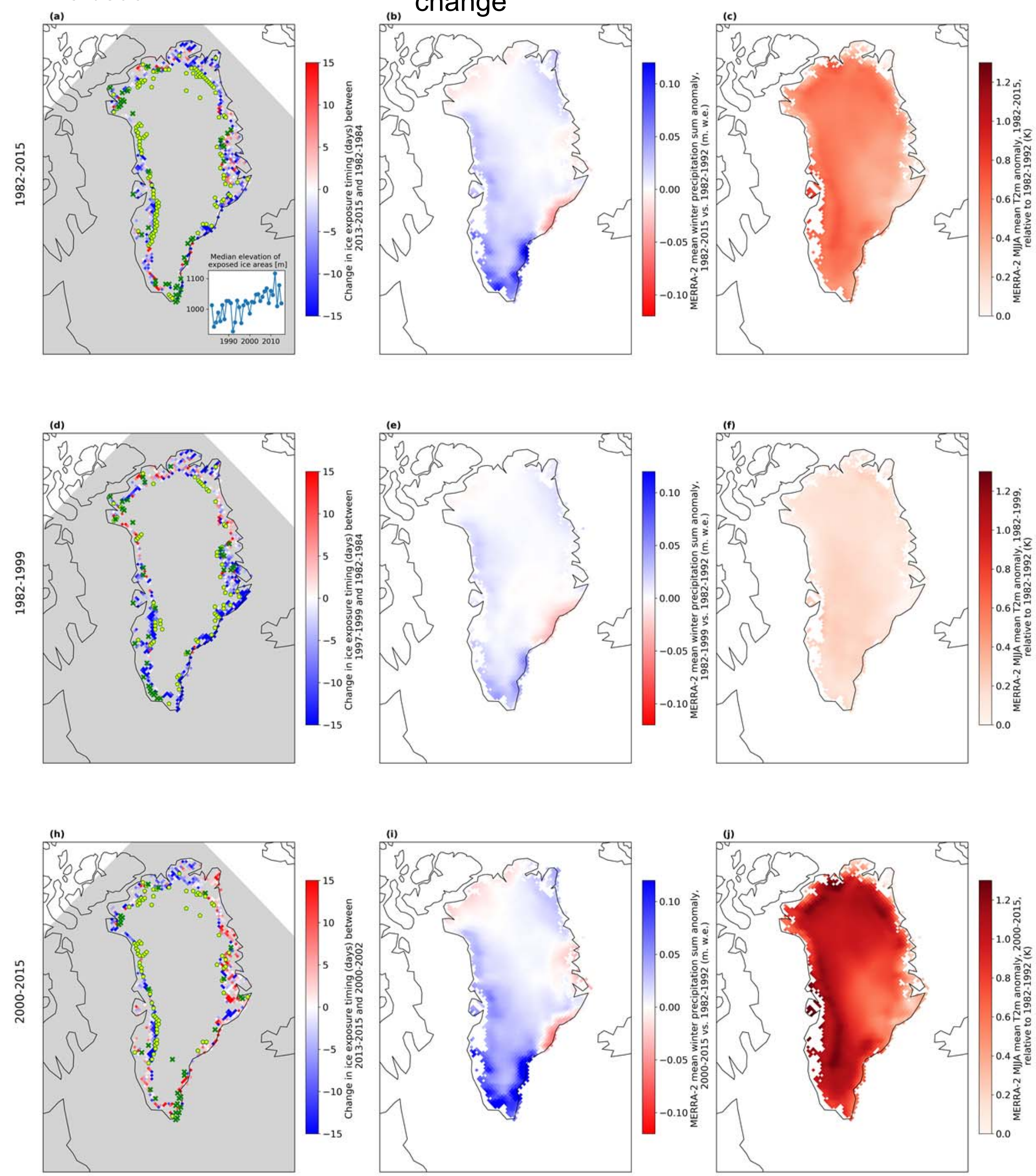
Circles indicate areas where bare ice level albedo is reached during 2013-2015, but not 1982-1984. **Crosses** show vice versa.

Middle column shows change in winter snowfall (blue: more snow, red: less snow) from MERRA-2

Change in time req'd to reach 'bare ice albedo'

MERRA-2 winter snowfall anomaly change

MERRA-2 T2m anomaly change



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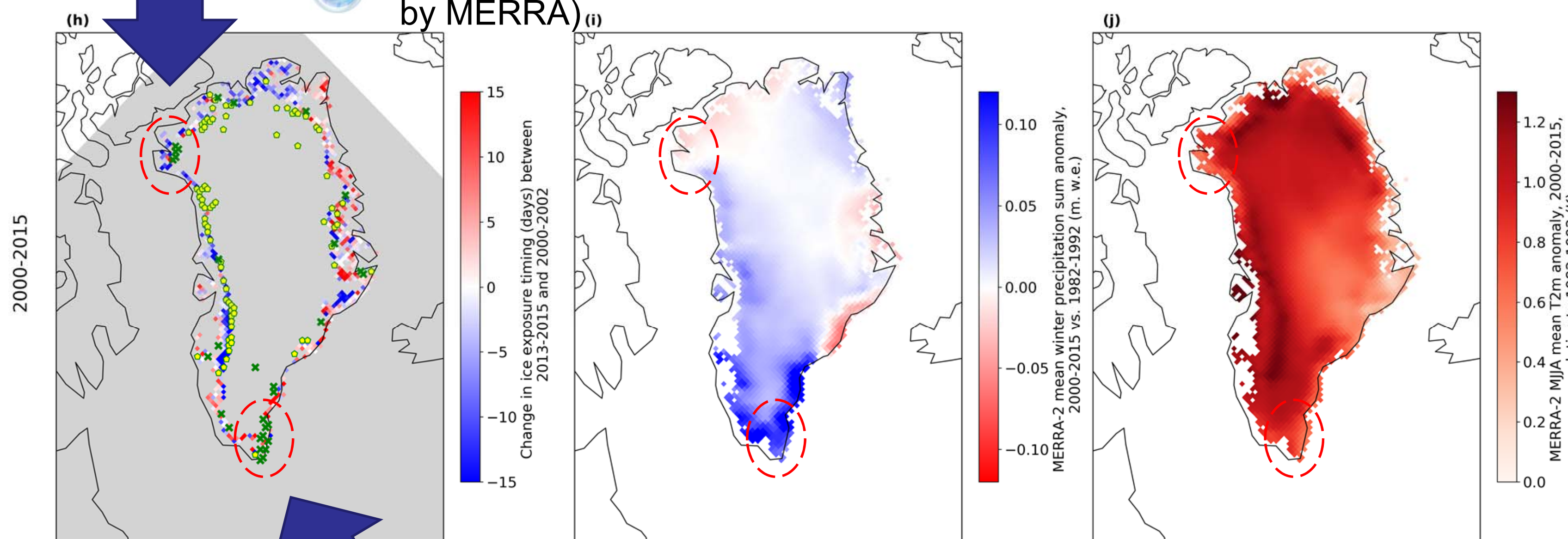
Changes in melt rate and probable bare ice exposure

Increasing cold air flows in 2013-2015 along the western coast, also increasing precip? (not seen by MERRA)



Increased winter snowfall appears to buffer the snowpack against summer melt

Left column: change in time needed to reach albedo typical of bare ice / wet snow (0.58). Blue: faster, red: slower.

Middle column shows change in winter snowfall (blue: more snow, red: less snow) from MERRA-2

Right column shows change in MERRA-2 SAT

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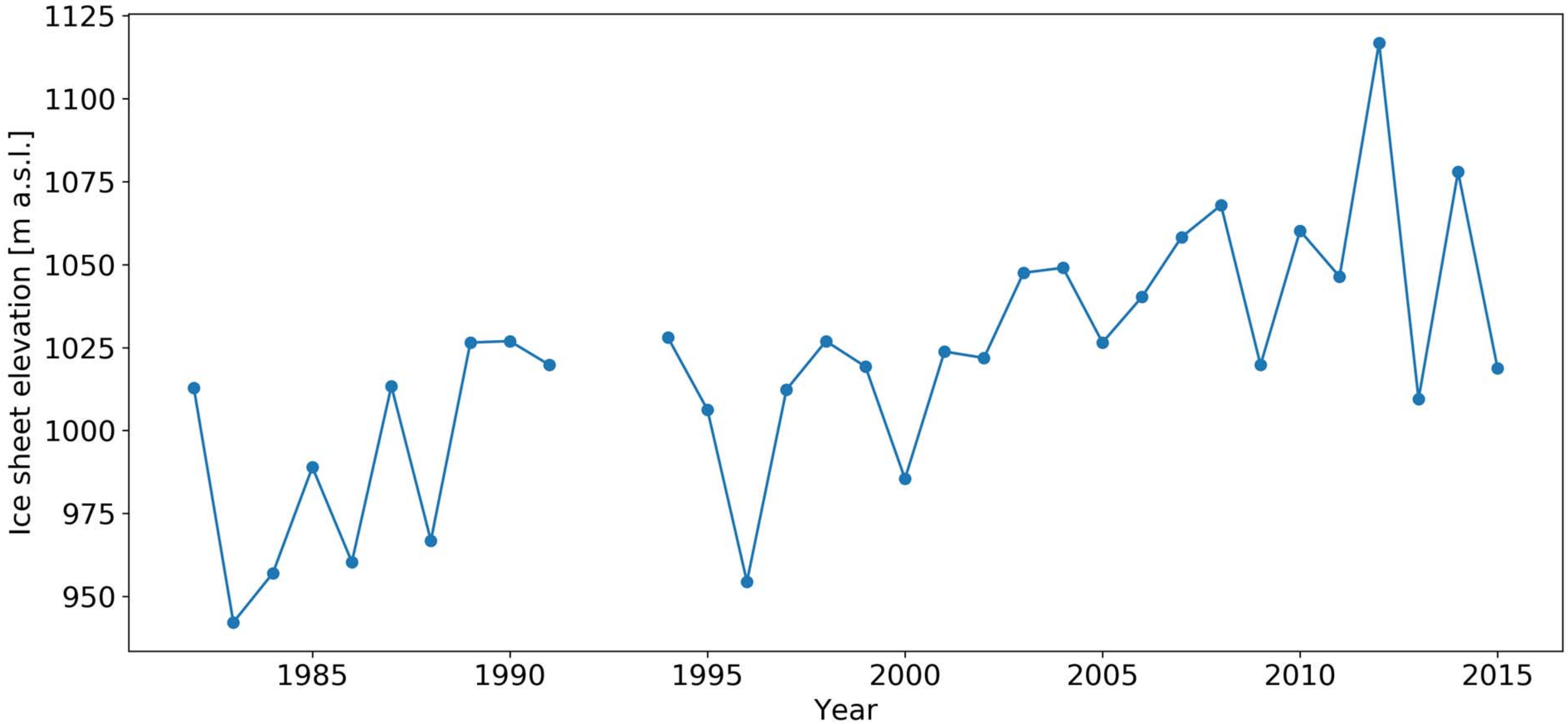
Change in annual median elevation of bare ice / very wet snow surfaces of the ice sheet



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An observational test for the dominance of surface melt in determining the summer SMB of GrIS?

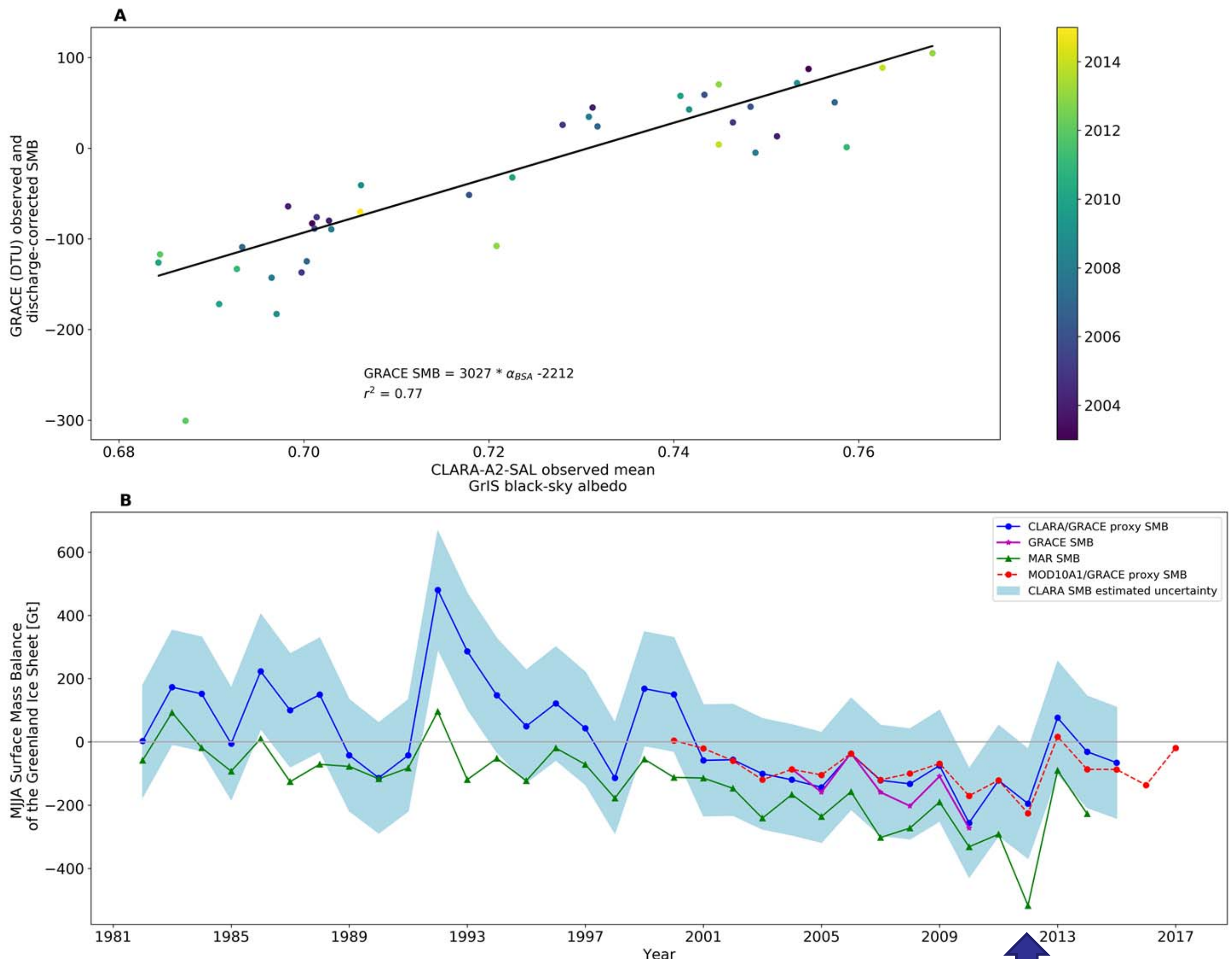
- Surface Mass Balance = Precip – Sublimation – Erosion – **Runoff**
- Assume that albedo reductions correlate with meltwater production, and that surface meltwater production dominates runoff at the whole summer scale
- Greenland CCI MB [from GRACE] + Discharge (King et al., 2018) = GRACE-derived SMB
- Calibrate CLARA albedo with GRACE-derived SMB => proxy for SMB sum over the summer
- **Test for covariability** with a state-of-the-art regional GrIS climate model (MAR v3.5.2 with ERA-Interim forcing)

Test result: confirmed

- MAR MJJA SMB is **highly covariable** with proxy SMBs derived from CLARA-GRACE and MOD10A1-GRACE calibrations.
- The increasing mass loss from mid-1990s to 2012 is largely reproduced, as is the recovery in 2013-2015.

This result is achievable only if
a) surface meltwater production dominates runoff, and
b) runoff dominates the summer-summed SMB at the scale of the whole ice sheet.

However, this method is limited; one should not expect an accurate proxy SMB for any given month, as precipitation plays a variably large role!



Also: melt-induced surface albedo reductions can only go so far, but meltwater production can go on and on, as it did in 2012

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Take-home messages

- **Late-summer albedo reductions at GrIS margins are significant almost everywhere** over the full 1982-2015 period
  - Consistent with MODIS during 2000-2015
  - Consistent with the change in atmospheric regime in mid-1990s, favoring warm and moist air mass advection from the Atlantic, particularly up along the west coast
  - Increasing algae colony impacts? Impurity deposition/exposition?

- **Albedo typical of bare ice is reached routinely at 50-100 m higher up the ice sheet** during 2013-2015 relative to 1982-1984.
  - A notable exception is found in the SE (and partly NW) margins; increasing snowfall appears to buffer the snow cover against melt enhancement
  - (Snow & ice) albedo is determined by more than temperature; **cloudiness and precipitation** play **variable but large roles**

- **An albedo/gravimetry/discharge-based proxy SMB is found highly covariable with MAR summer-aggregated SMB output**, supporting the modeling conclusion that runoff dominates the summer SMB variability.

Interested in the CM SAF CLARA dataset?

https://doi.org/10.5676/EUM_SAF_CM/CLARA_AVHRR/V002

5D / 1M temporal resolution at 25km / 0.25 degree grid cell size

Evaluated against quality-controlled in situ observations, compared against MODIS albedo (MCD43)

1982-2015 (soon 2018)

The third edition (CLARA-A3) will cover 1979-2019/2020, based on the newest AVHRR intercalibration and probabilistic cloud screening