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Decadal changes in Arctic snow and ice cover properties from satellite observations

Kerttu Kouki

9.2.2023 EUMeTrain High Latitudes Event Week

Outline

1 **Introduction**
Why studying snow cover is important?
Basics of microwave and optical satellite methods

2 **Changes in snow and ice cover**
Snow cover extent (SCE)
Albedo
Snow water equivalent (SWE)
Melt season

3 **Future changes in snow and ice cover**

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Future changes in snow and ice cover

Seasonal snow and ice cover is an important part of the global climate system

- Snow and ice have high albedo (reflectivity)
  - Darker snow-free and ice-free surface absorbs more solar radiation
- Snow and ice cover influences Earth´s energy budget

March 15, 2002

Image courtesy Jacques Descloitres, MODIS Land Rapid Response Team at NASA GSFC

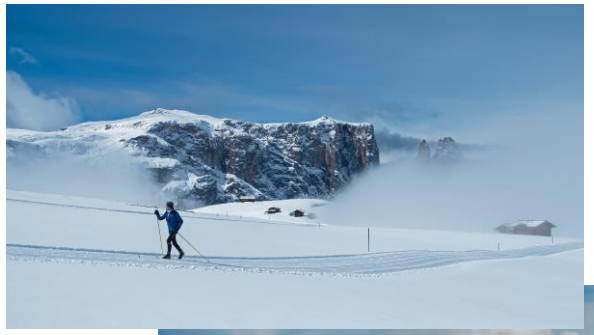
Changing snow cover affects our everyday lives

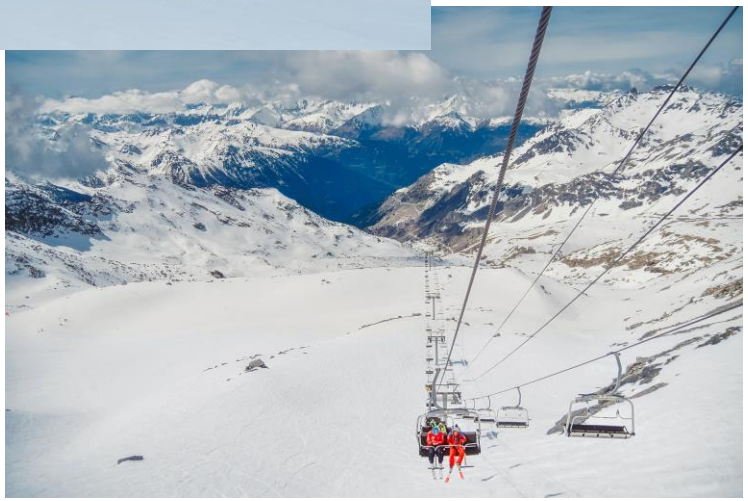
Road maintenance

Flooding

Water shortages

Tourism





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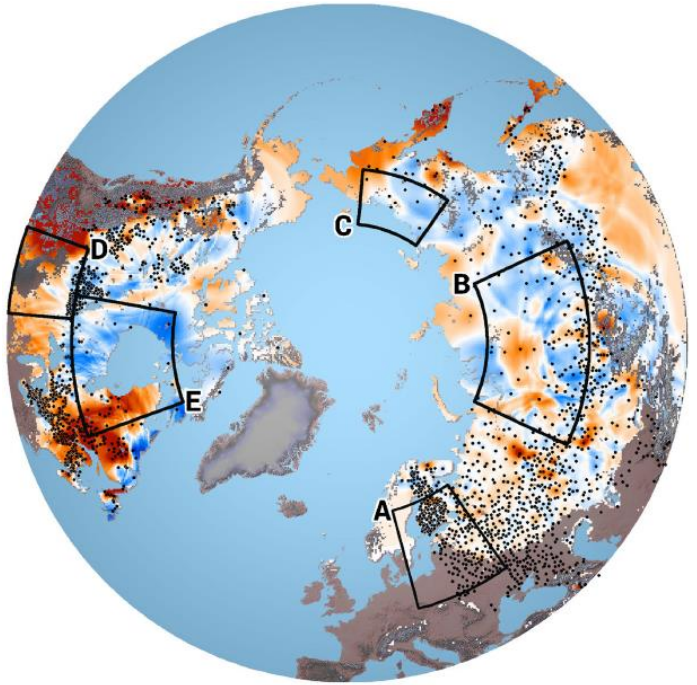
Using satellite data for snow and ice cover monitoring

- Sparse in situ measurements in the Arctic

→ Snow cover monitoring at the continental scale is only possible from satellites

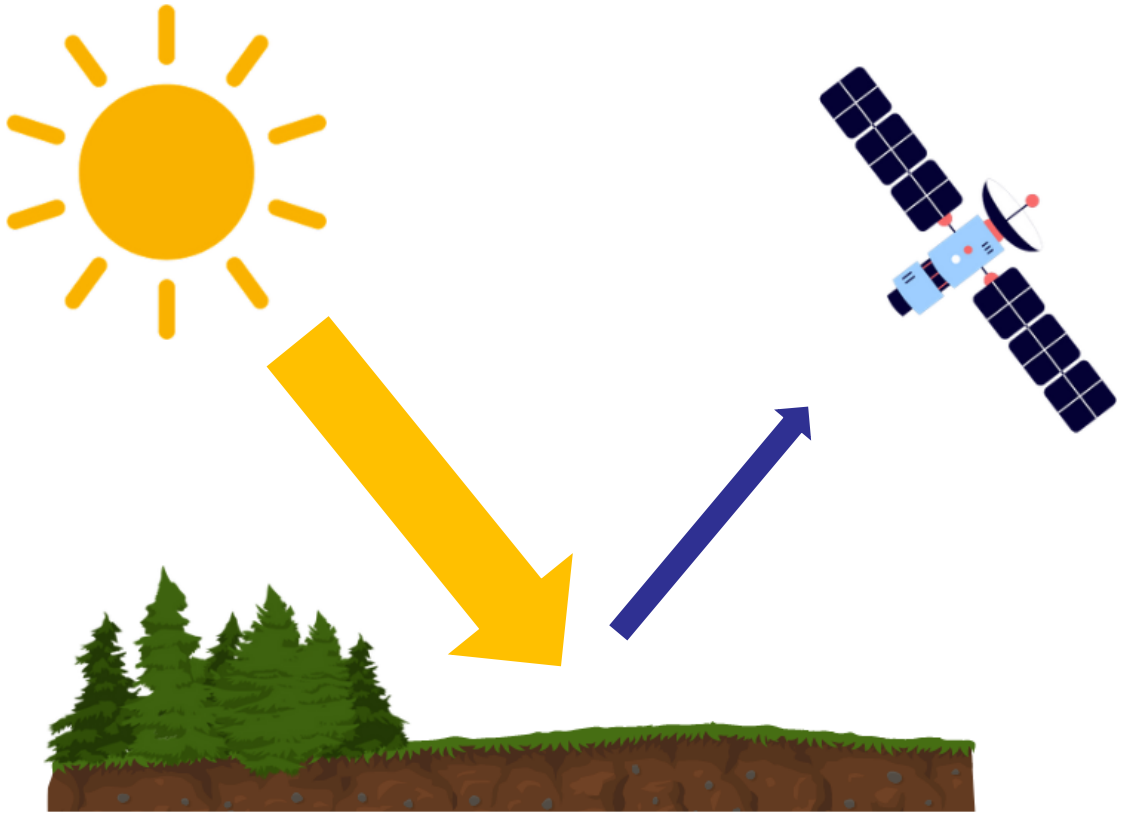
- Satellite-based estimates are constantly improving
- Both optical and microwave satellite methods can be used to monitor snow and ice cover



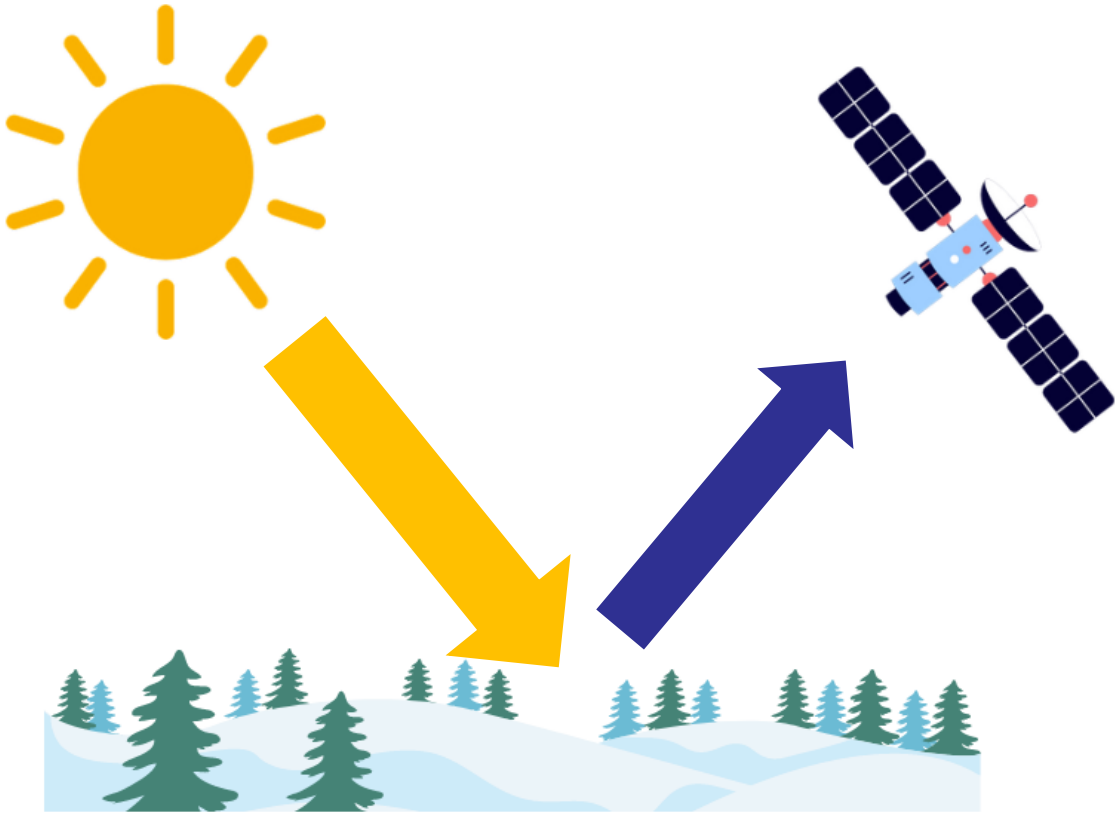
Pulliainen et al. (2020)

Optical satellite method

No snow on the ground

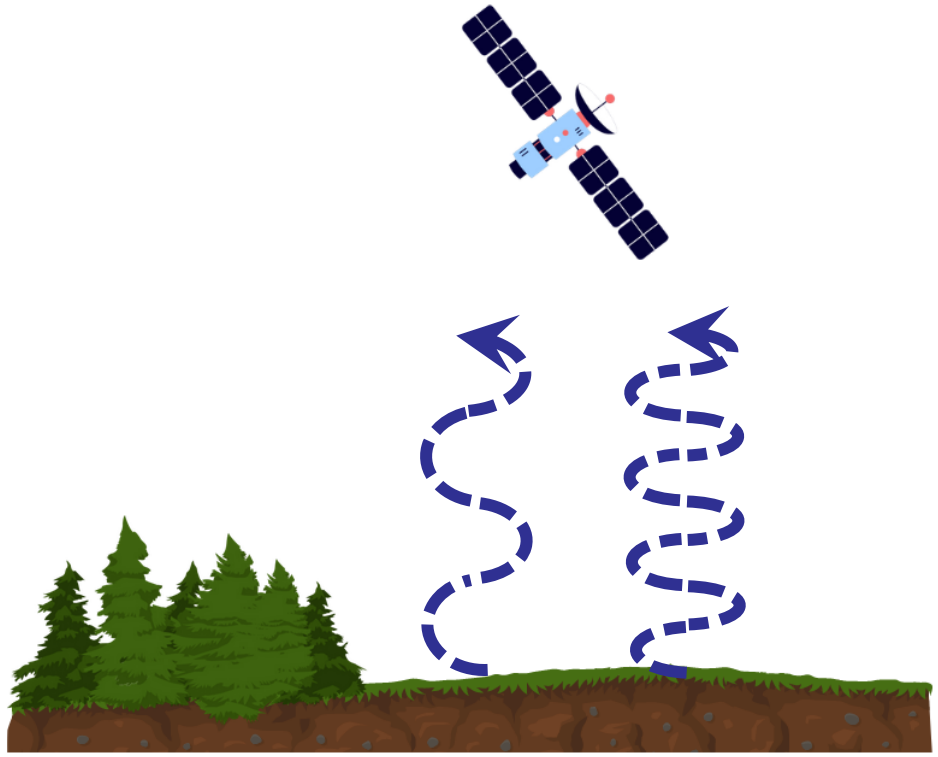


Snow on the ground

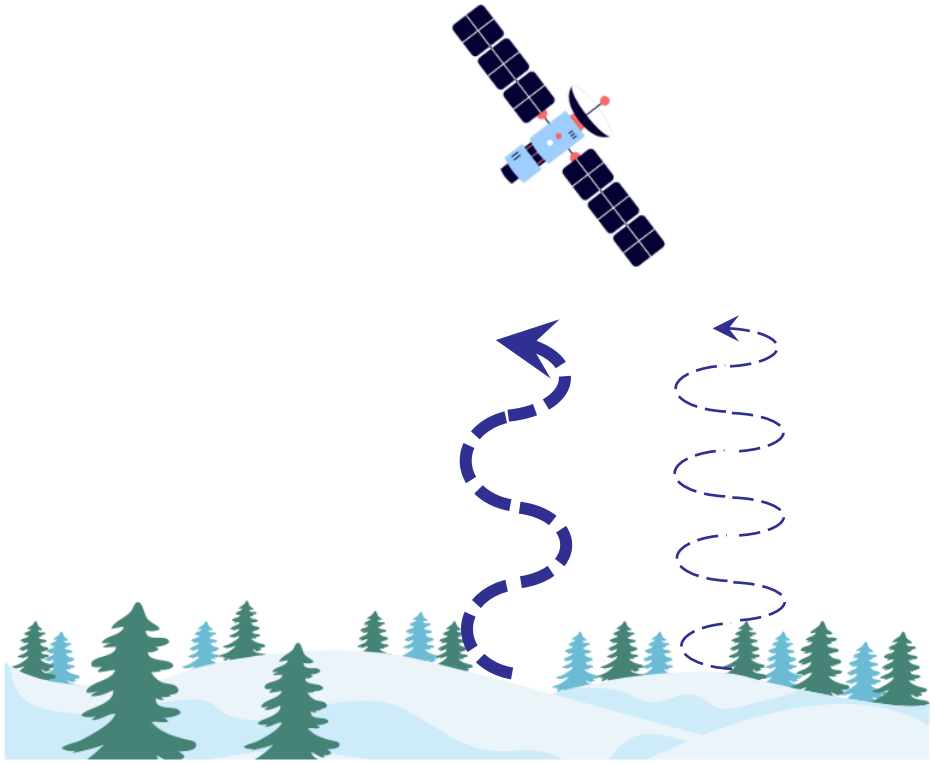


Passive microwave satellite method

No snow on the ground



Snow on the ground



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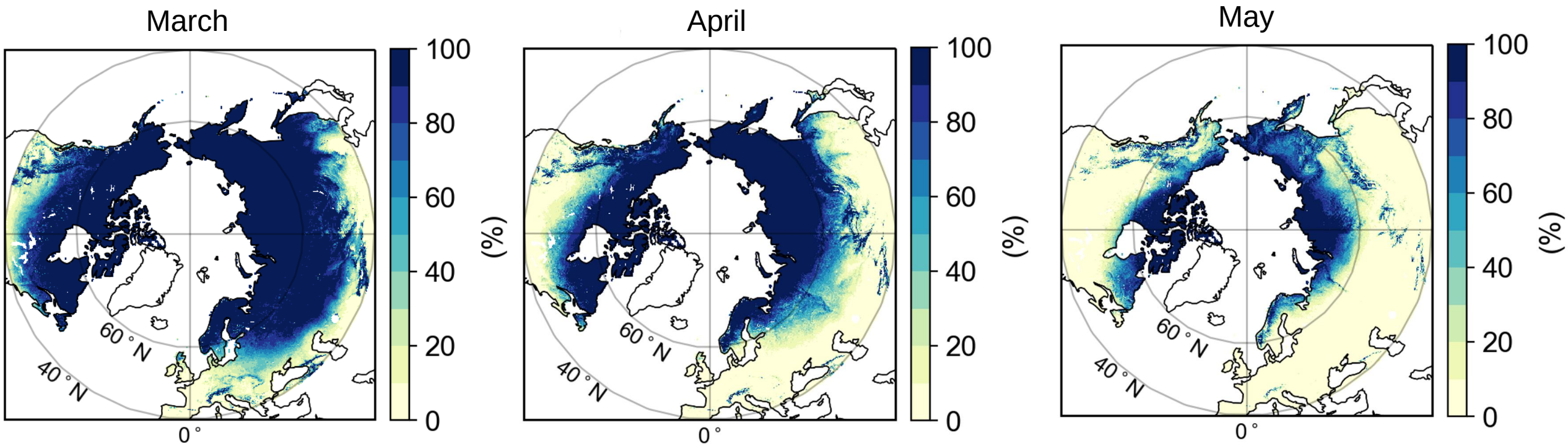
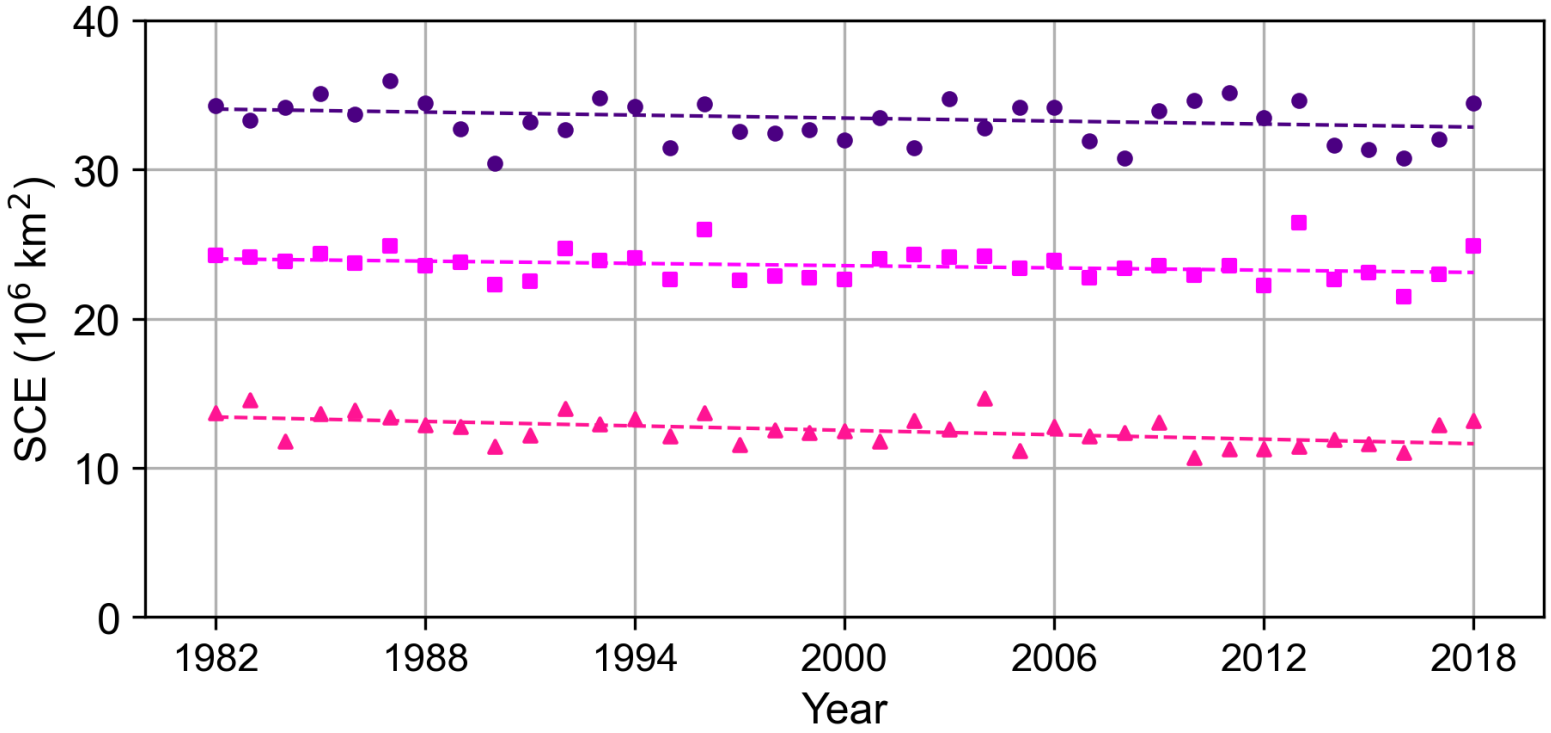
Snow cover extent

Mean snow cover extent in spring 1982-2018



Statistically significant negative trend exists in May

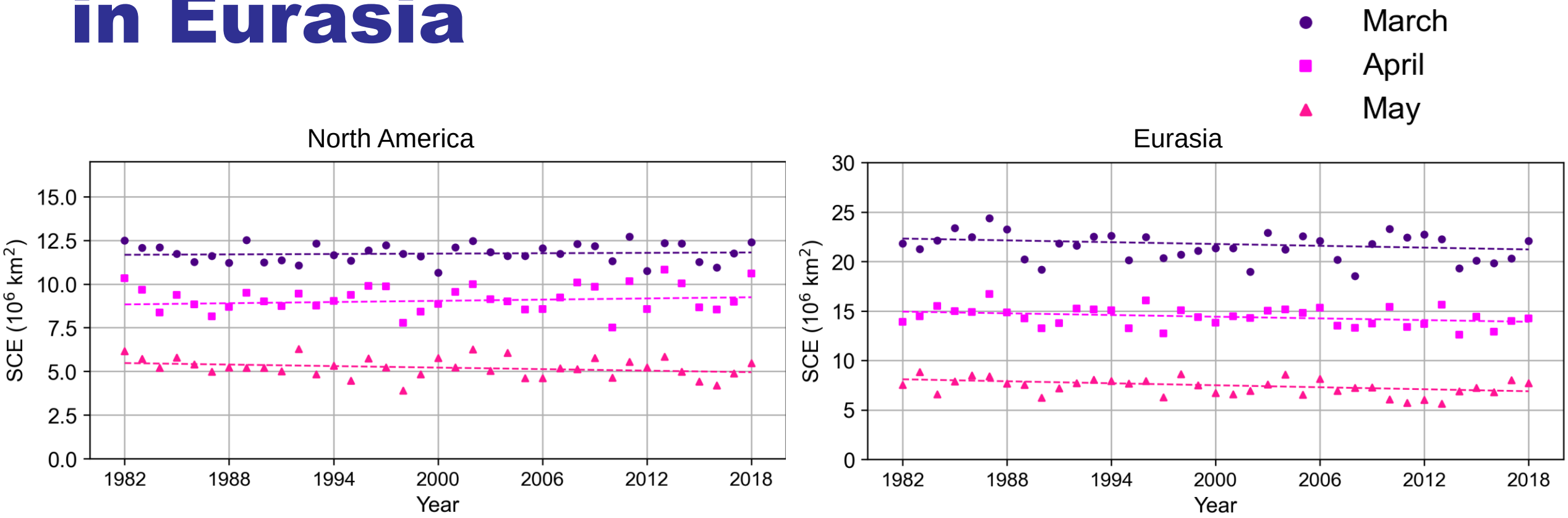


Land areas north of 40 °N
(glaciers excluded)

Data: JAXA JASMES

March -0.34 million km^2/decade
April -0.25 million km^2/decade
May -0.50 million km^2/decade*

Negative trend is more prominent in Eurasia



March +0.04 million km^2/decade
April +0.11 million km^2/decade
May -0.15 million km^2/decade

March -0.31 million km^2/decade
April -0.29 million km^2/decade
May -0.34 million km^2/decade*

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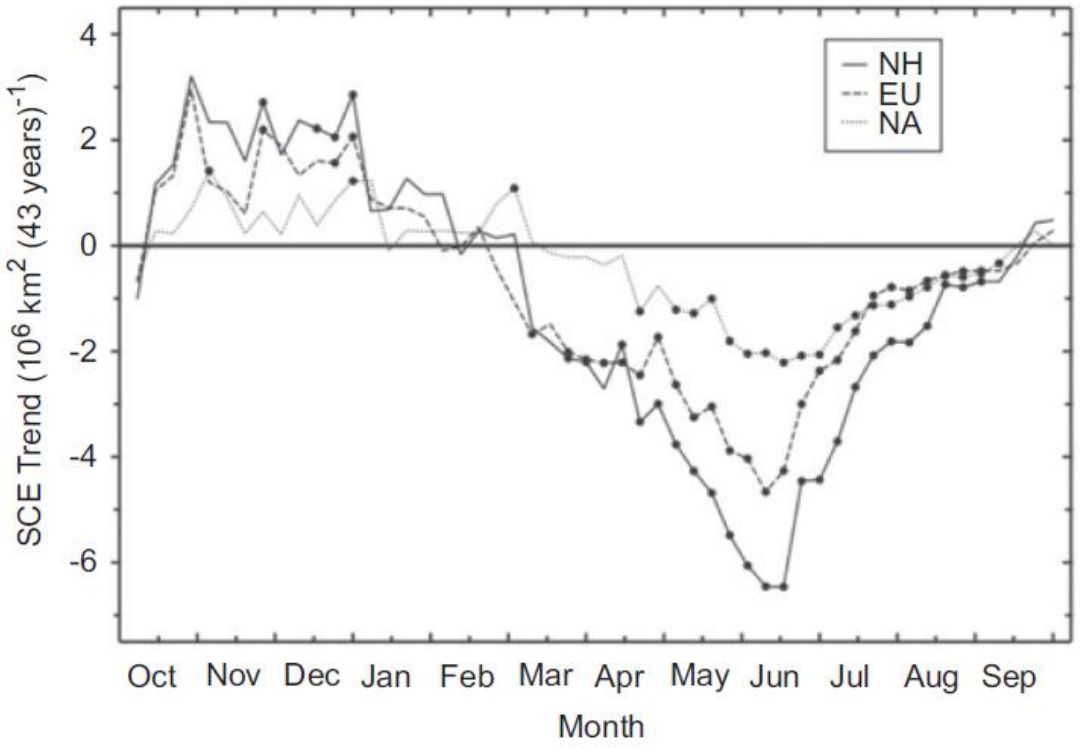
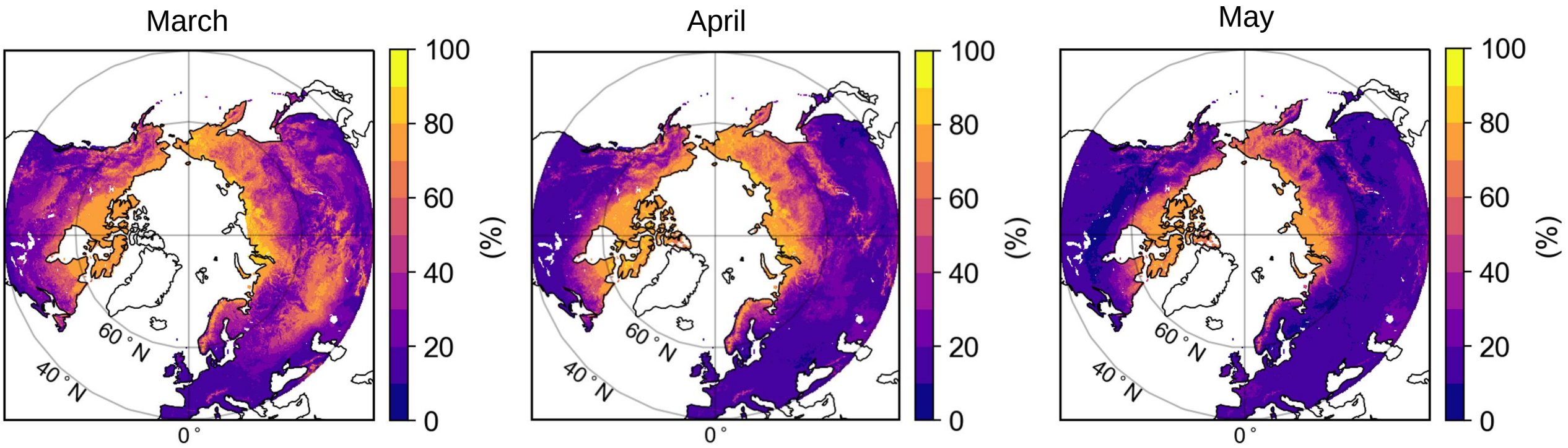
Trend in SCE varies seasonally



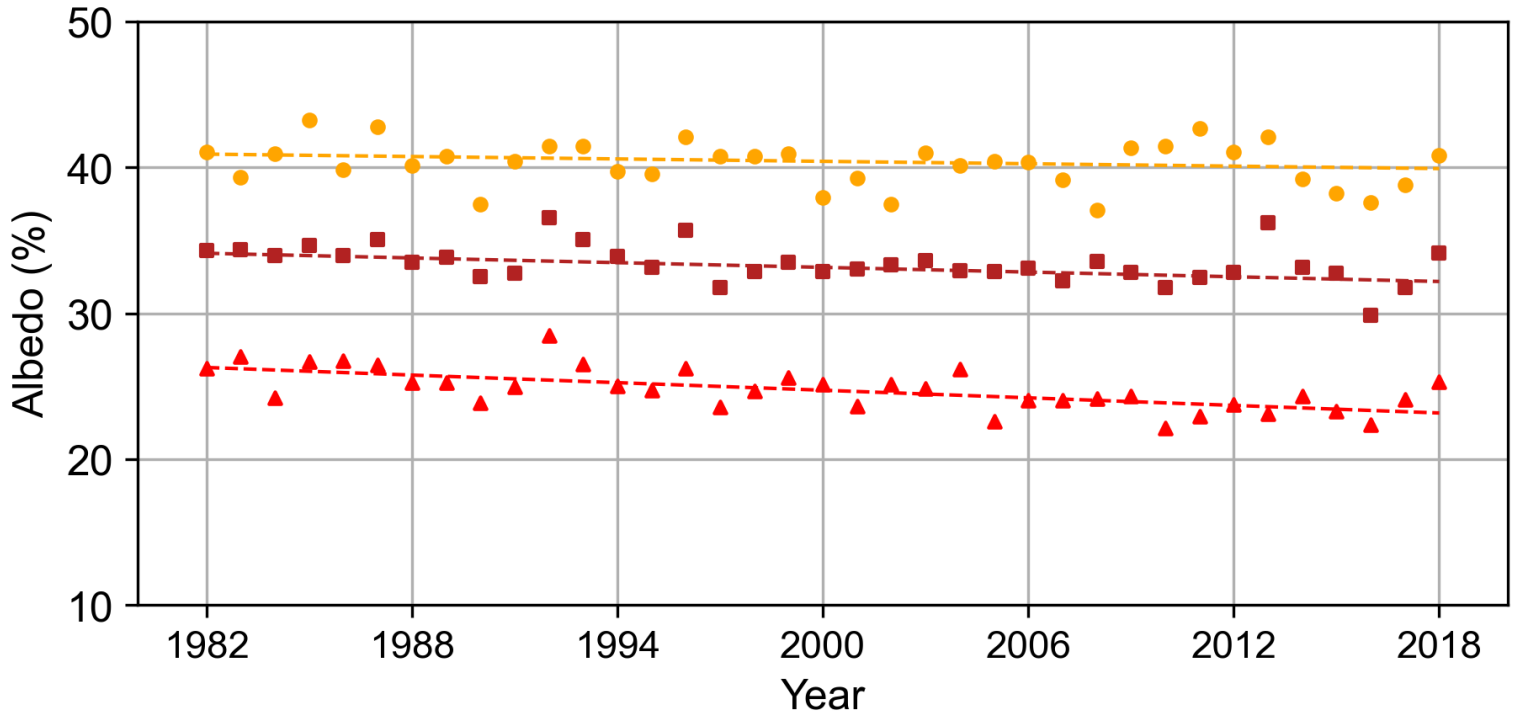
Hernández-Henríquez et al. (2015)

Albedo

Mean surface albedo in spring 1982-2018



Statistically significant negative trend exists in April and May

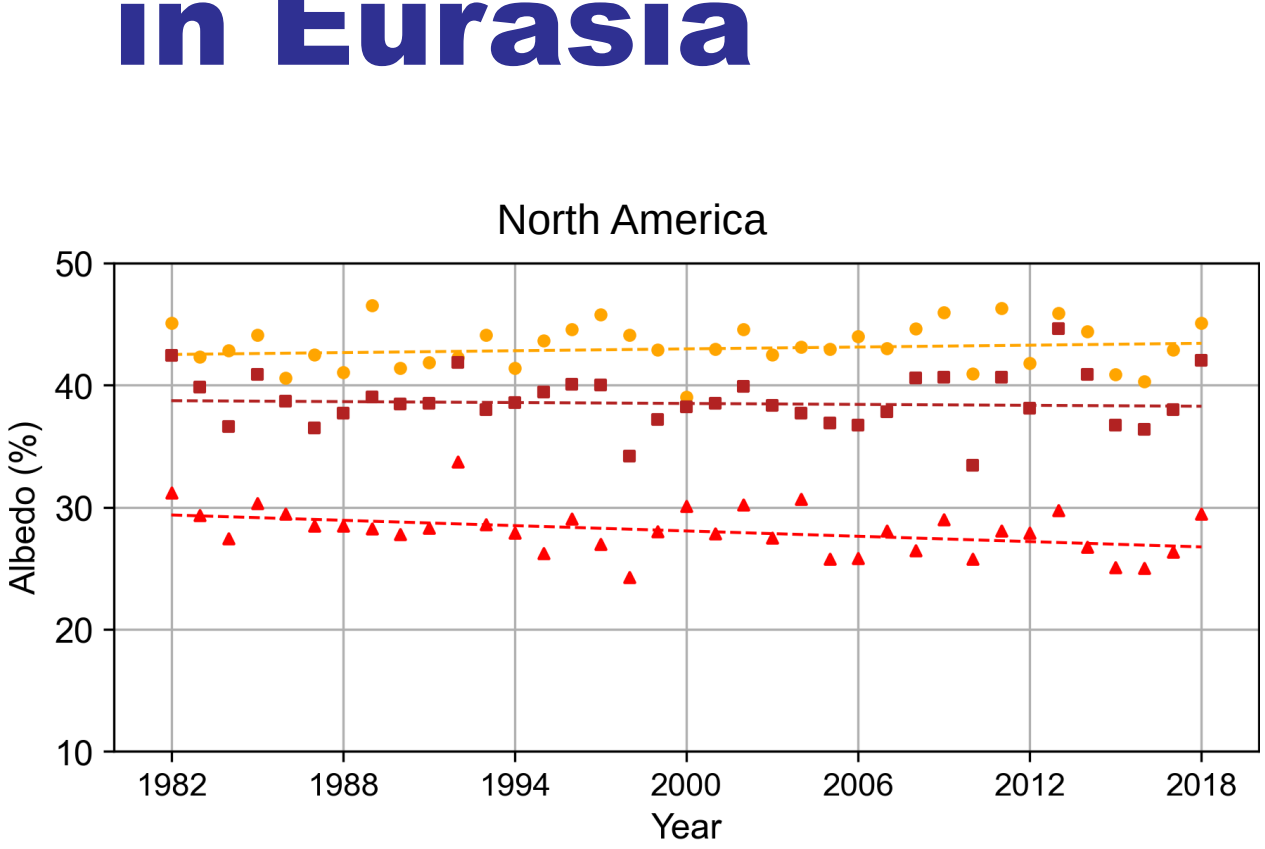


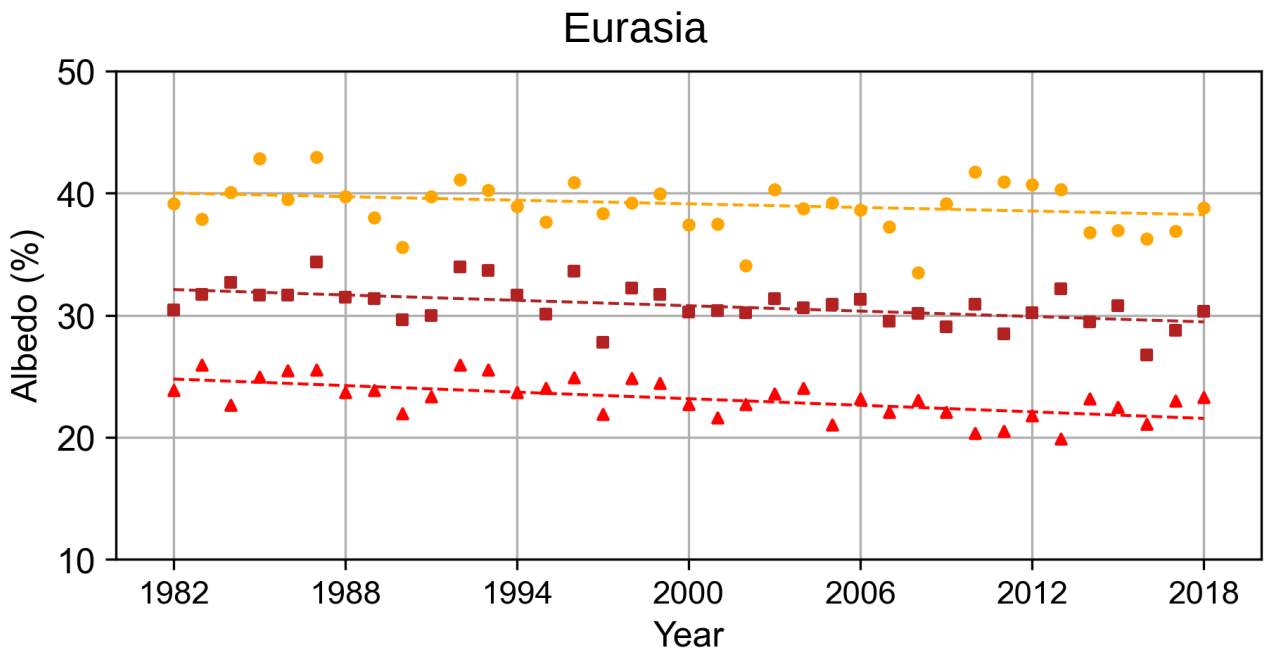
Land areas north of 40 °N (glaciers excluded)

Data: CLARA-A2 SAL

March -0.28 percentage units per decade
April -0.54 percentage units per decade*
May -0.87 percentage units per decade*

Negative trend is more prominent in Eurasia

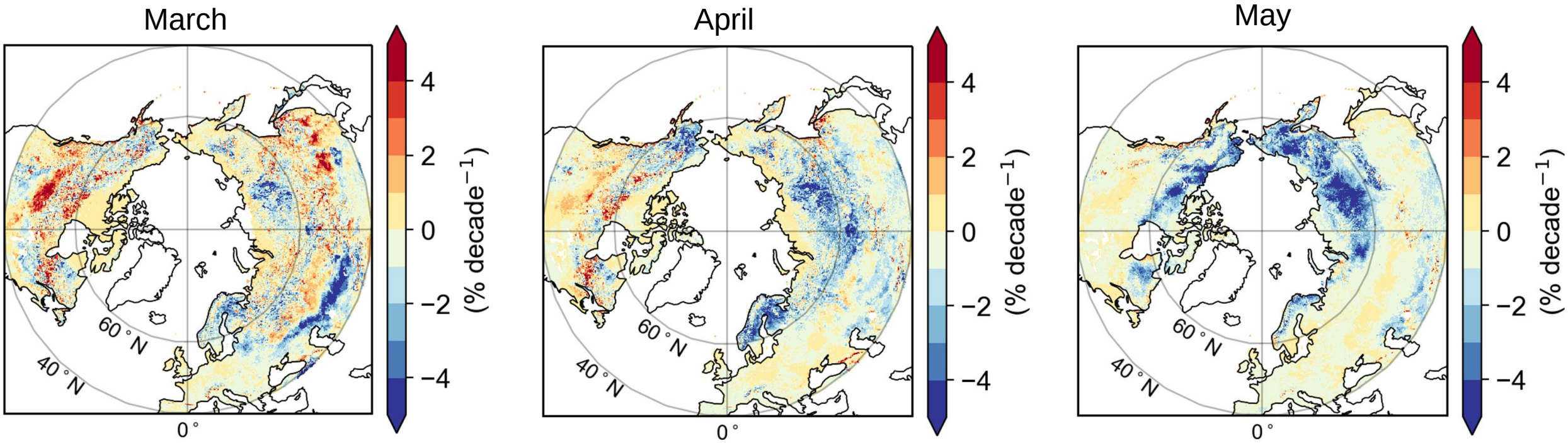




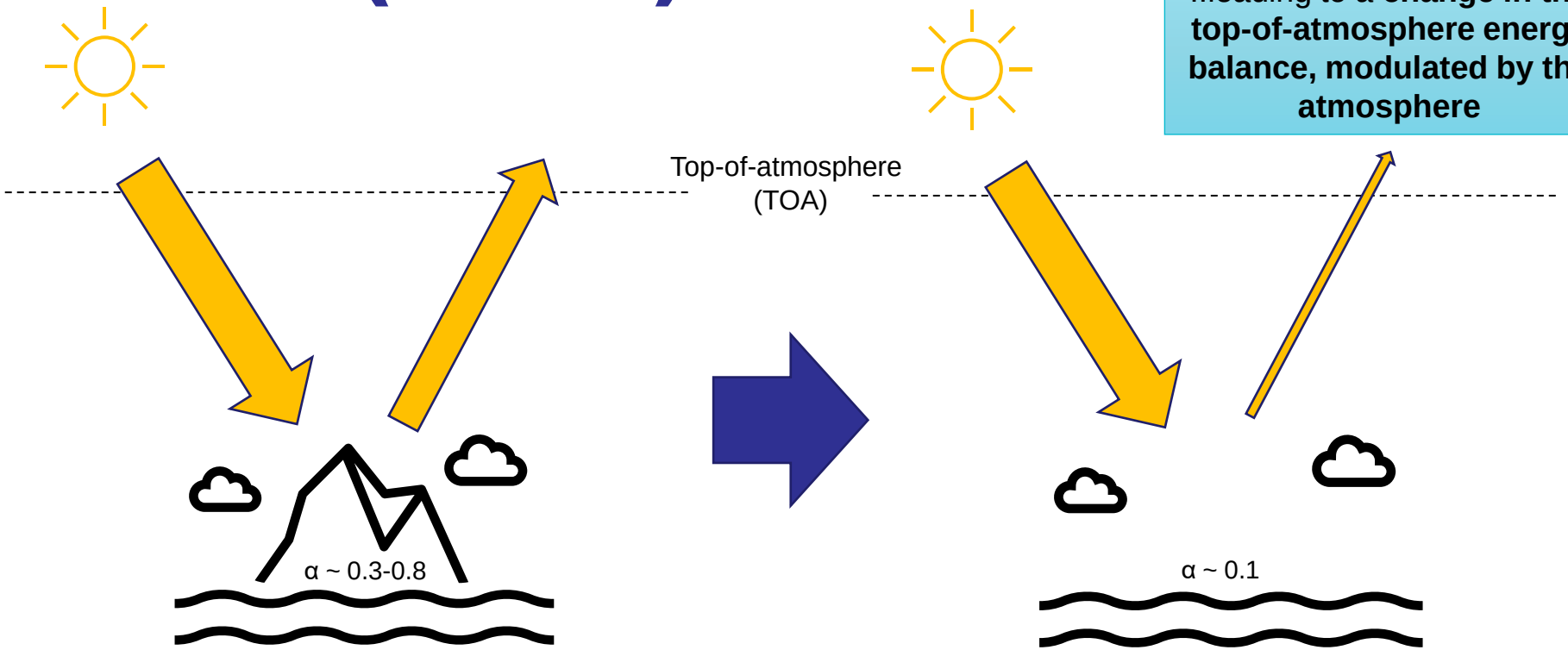
March +0.25 percentage units per decade
April -0.13 percentage units per decade
May -0.73 percentage units per decade*

March -0.50 percentage units per decade
April -0.74 percentage units per decade*
May -0.90 percentage units per decade*

Area with negative trend moves northward in spring



What is the snow and ice albedo feedback (SIAF)?



..leading to a **change in the top-of-atmosphere energy balance, modulated by the atmosphere**

A change in snow and ice cover alters the surface radiative energy balance…

So we need to quantify surface albedo changes and the modulating effect of the atmosphere…

- Enter the radiative kernel technique:

$$SIAF = \sum k * \Delta\alpha \qquad [\text{W m}^{-2}]$$

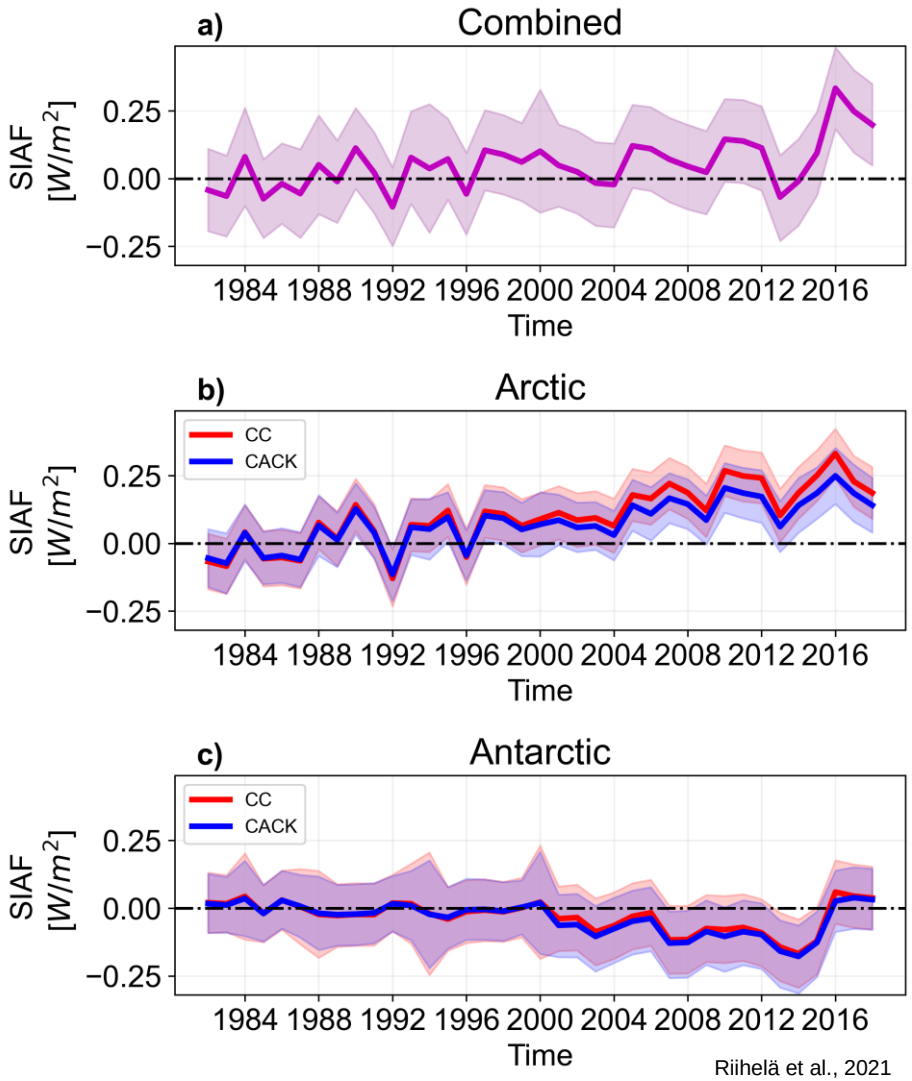
Summed over all grid cells in the study area (over the year), and usually projected against the full surface area of the Earth

Disturbance in TOA SW radiative energy balance per unit change (0.01) in surface albedo

✖

Change in surface albedo (relative to some reference/baseline condition)

Annual global mean SIAF vs. 1982-91 baseline

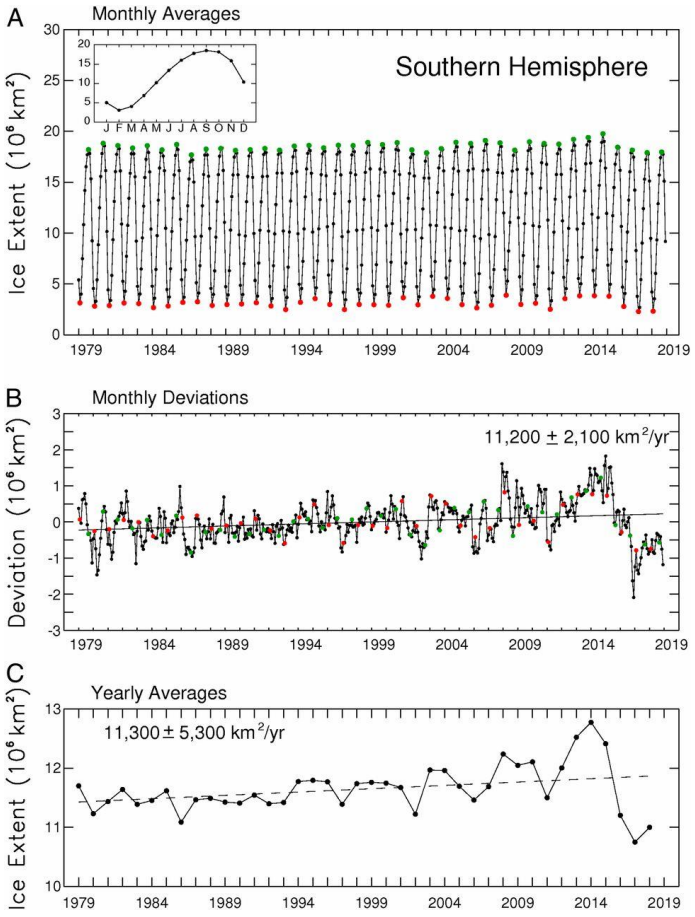


Riihelä et al., 2021

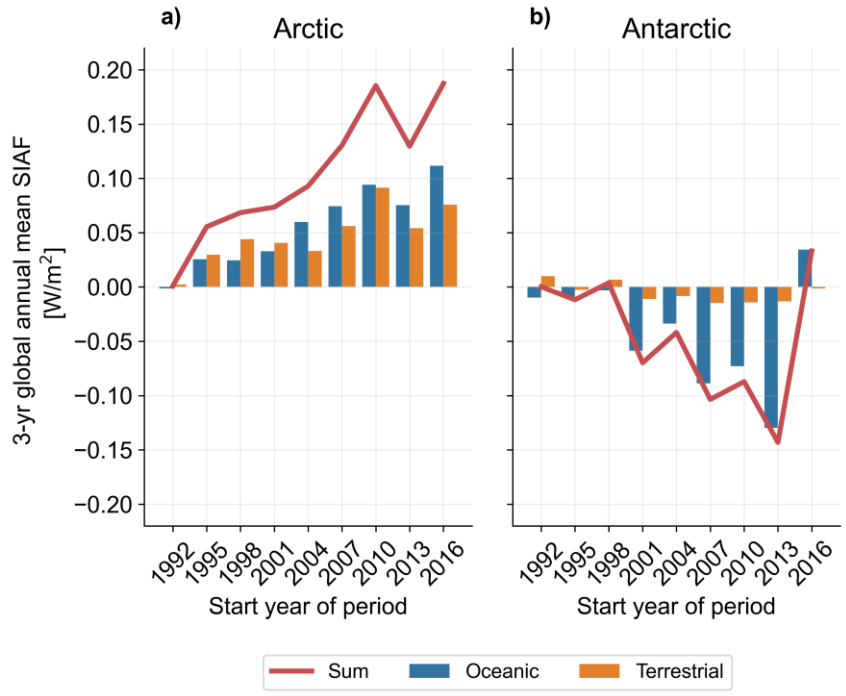
>50 °N

<-50 °N

Antarctic reversal in 2016-2018 – Arctic snow/ice losses continue



Parkinson (2019): **A 40-y record reveals gradual Antarctic sea ice increases followed by decreases at rates far exceeding the rates seen in the Arctic. Proceedings of the National Academy of Sciences.**



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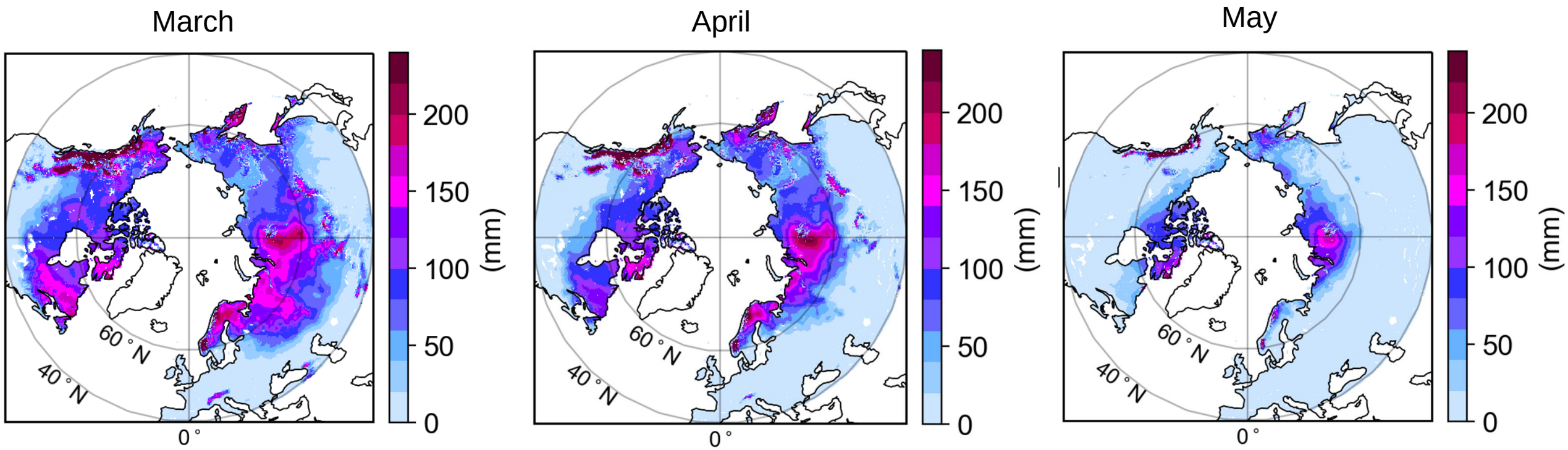
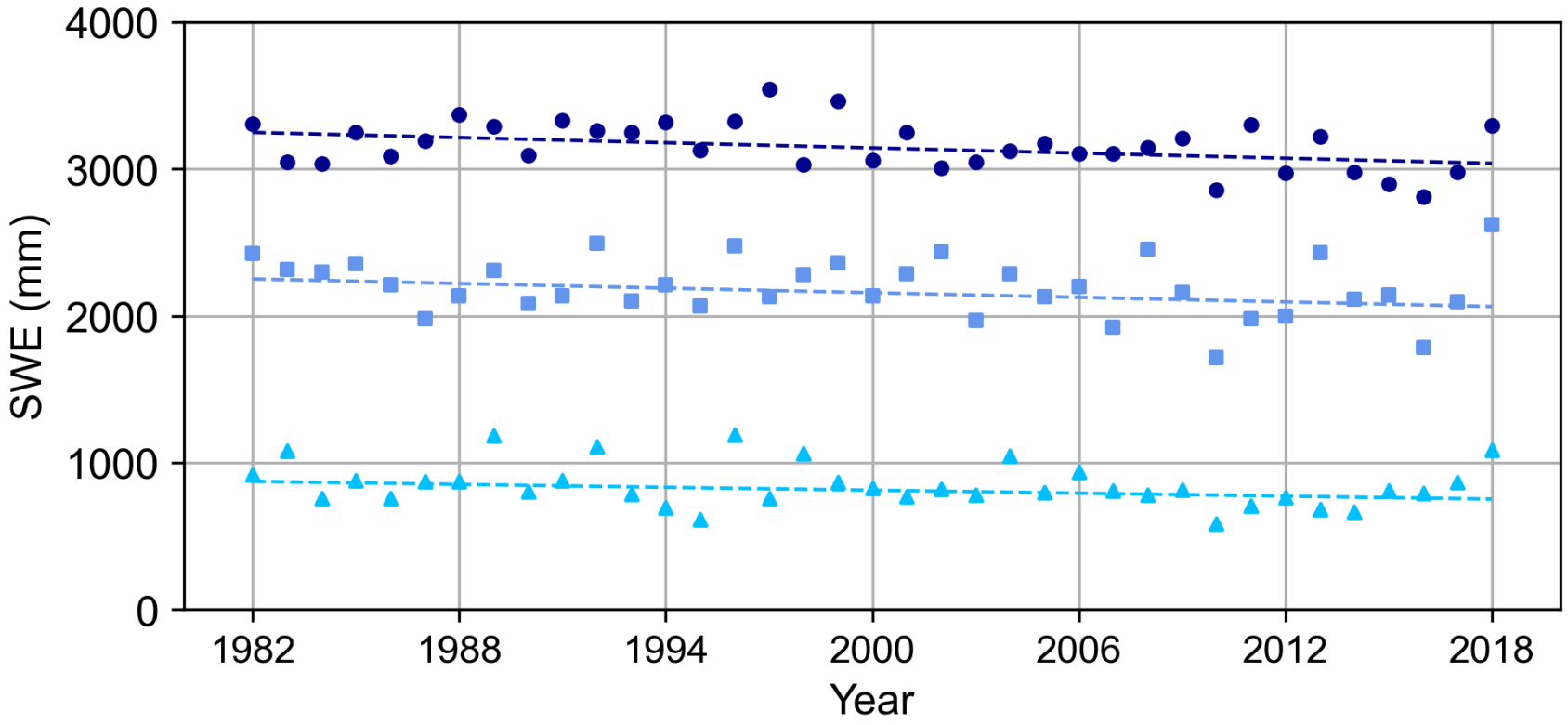
SWE

SWE is the height of the water layer (in units of mm) that would result from melting the whole snowpack instantaneously.

Mean SWE in spring 1982-2018



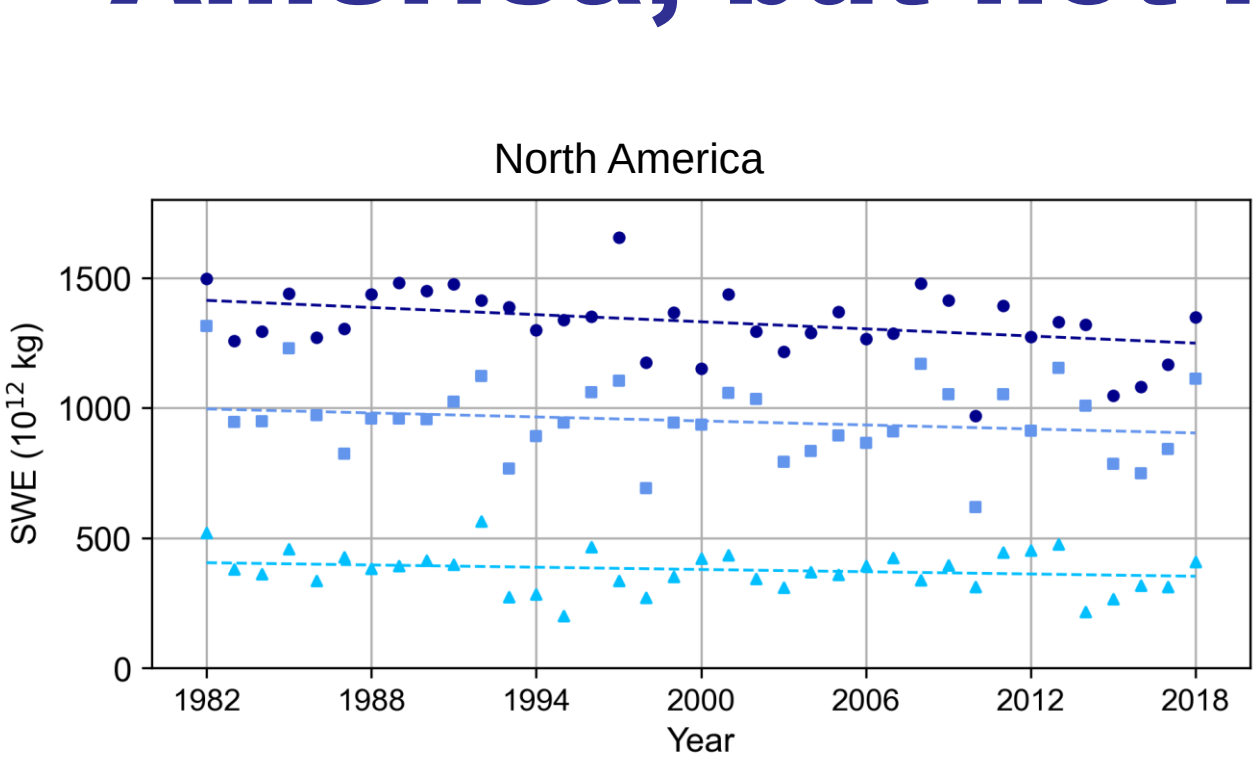
Global SWE has been decreasing

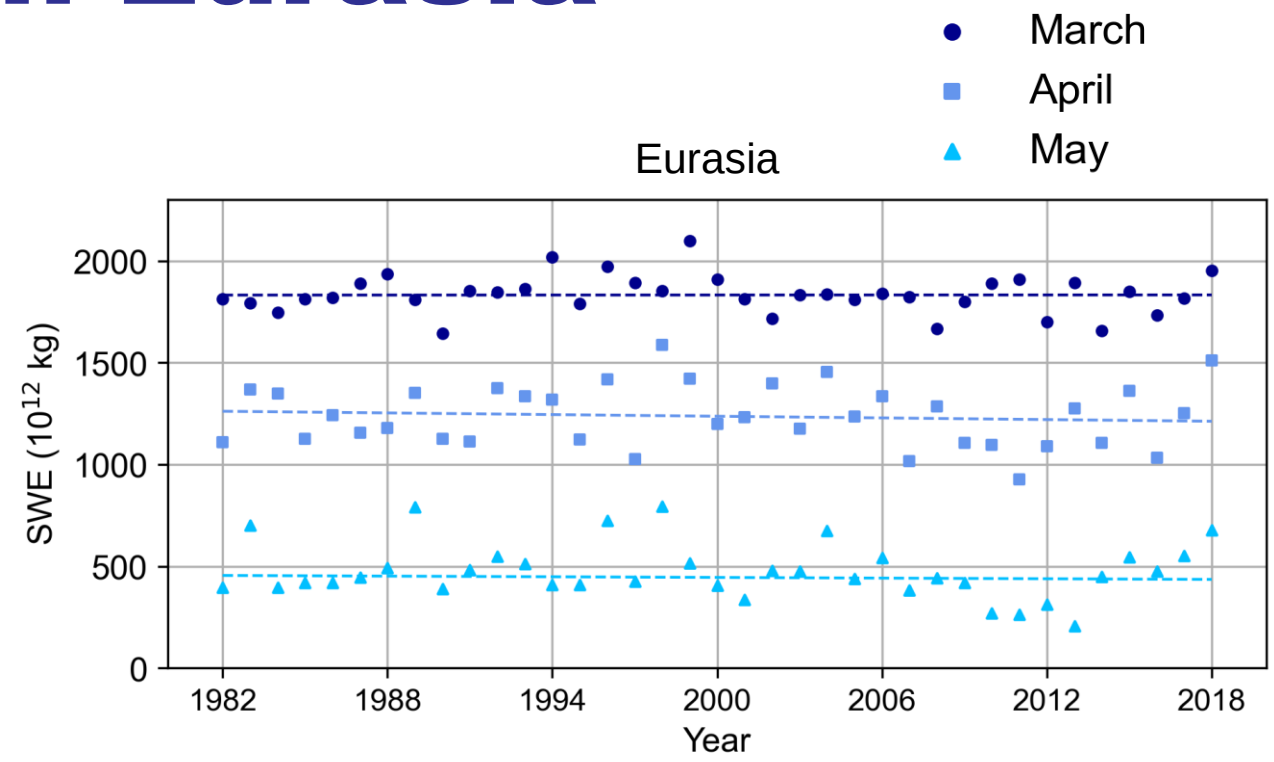


Land areas north of 40 °N
(glaciers excluded)

March -58 mm/decade*
April -52 mm/decade
May -33 mm/deacde

SWE has decreased in North America, but not in Eurasia



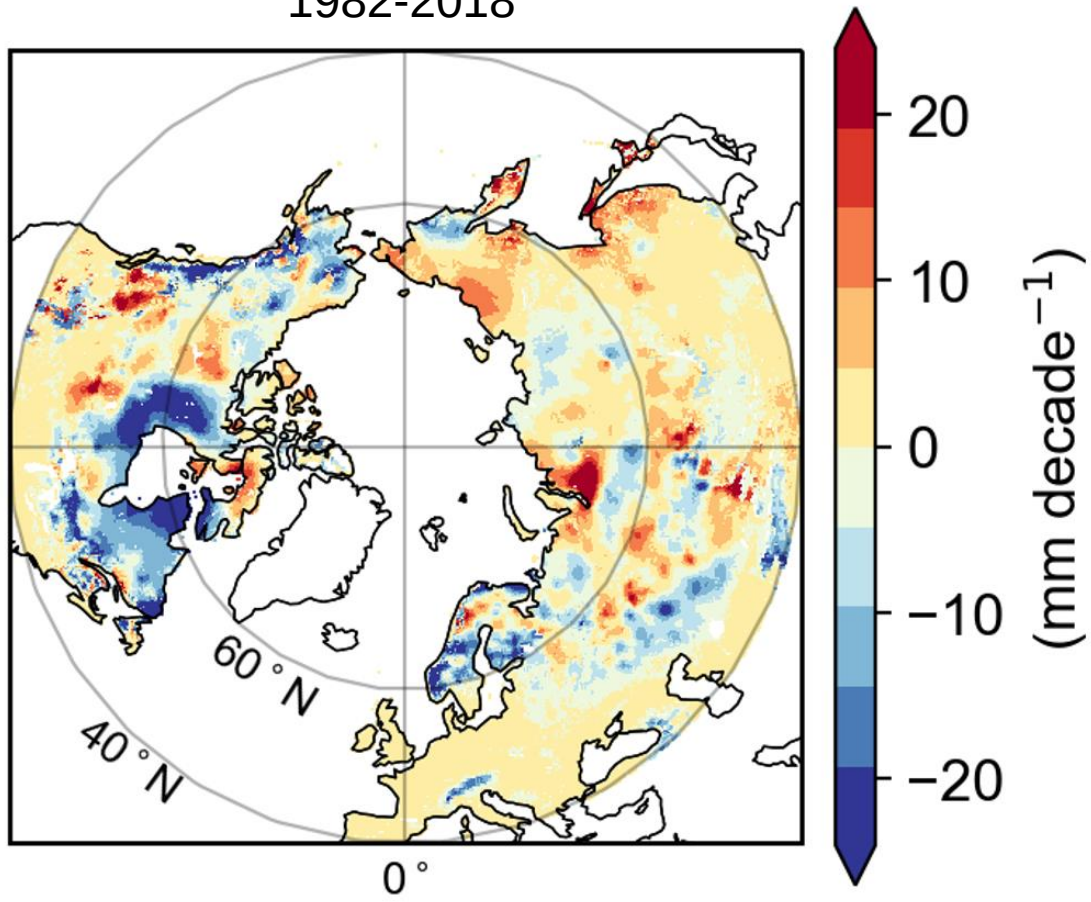


March -46 mm/decade*
April -26 mm/decade
May -14 mm/deacde

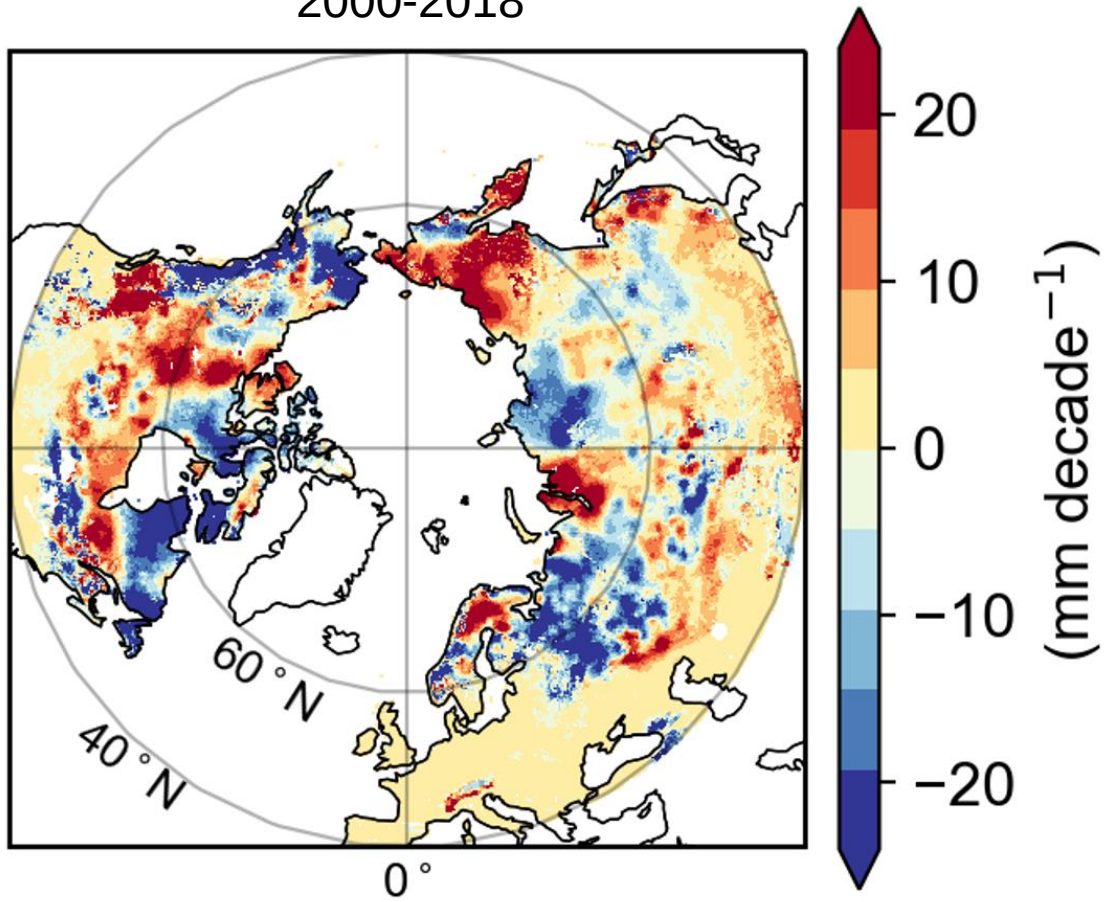
March +0.21 mm/decade
April -14 mm/decade
May -5.4 mm/deacde

Spatial SWE trends in March

1982-2018

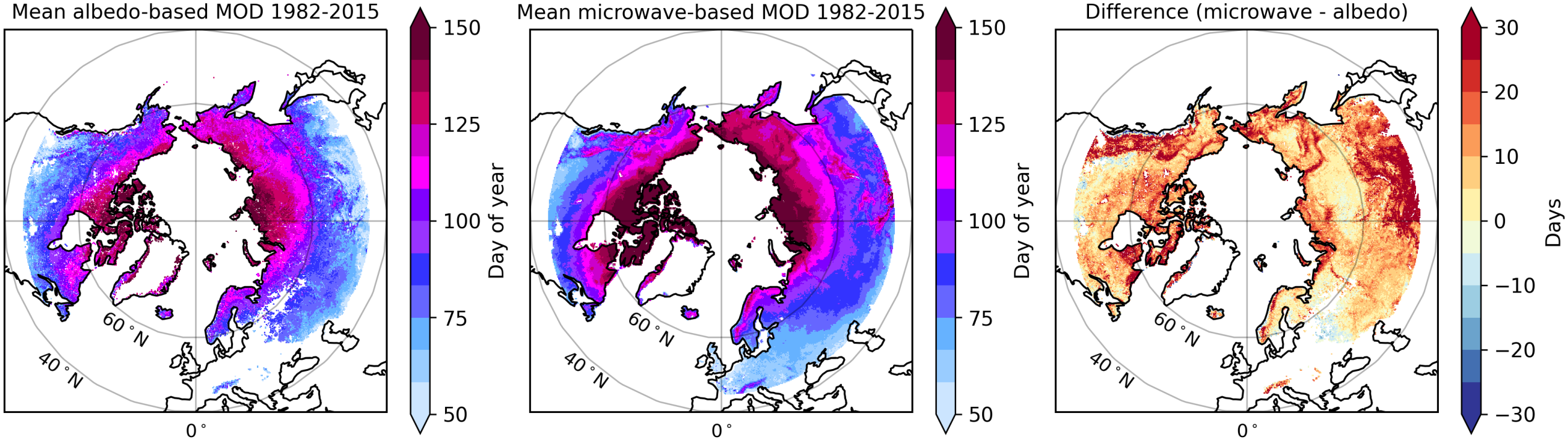


2000-2018



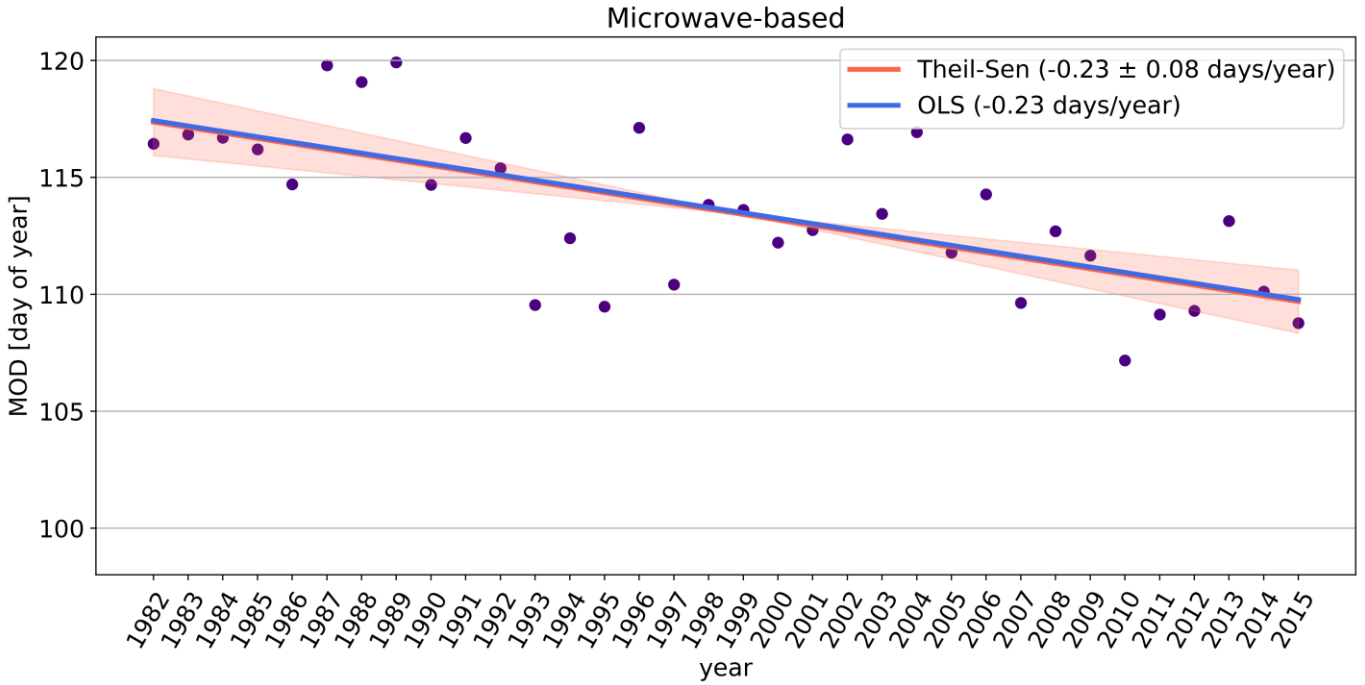
Melt season

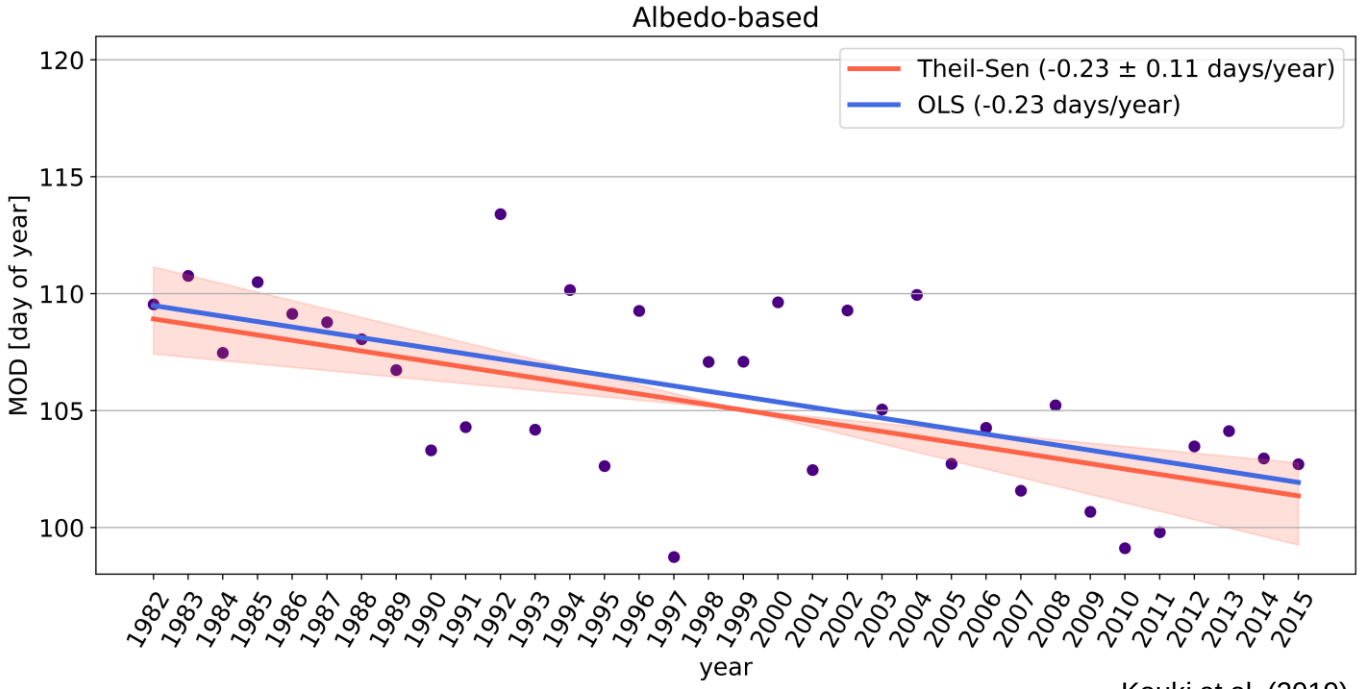
Melt onset in Northern Hemisphere



MOD = melt onset date

Statistically significant trend exists towards earlier melt onset

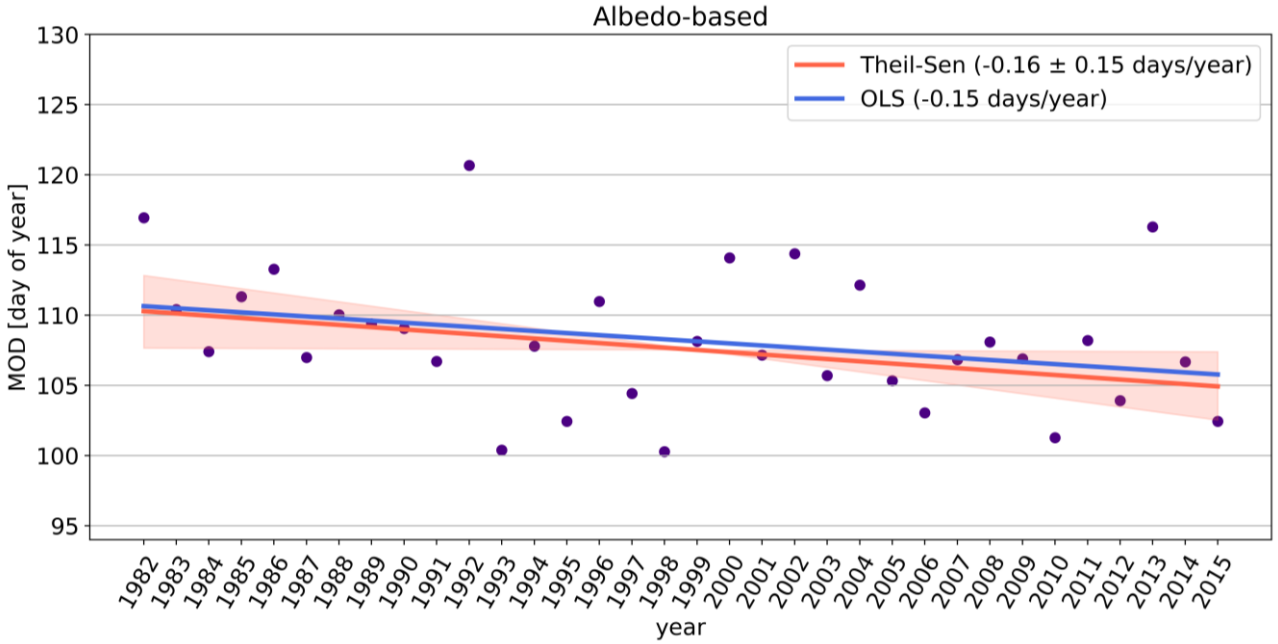




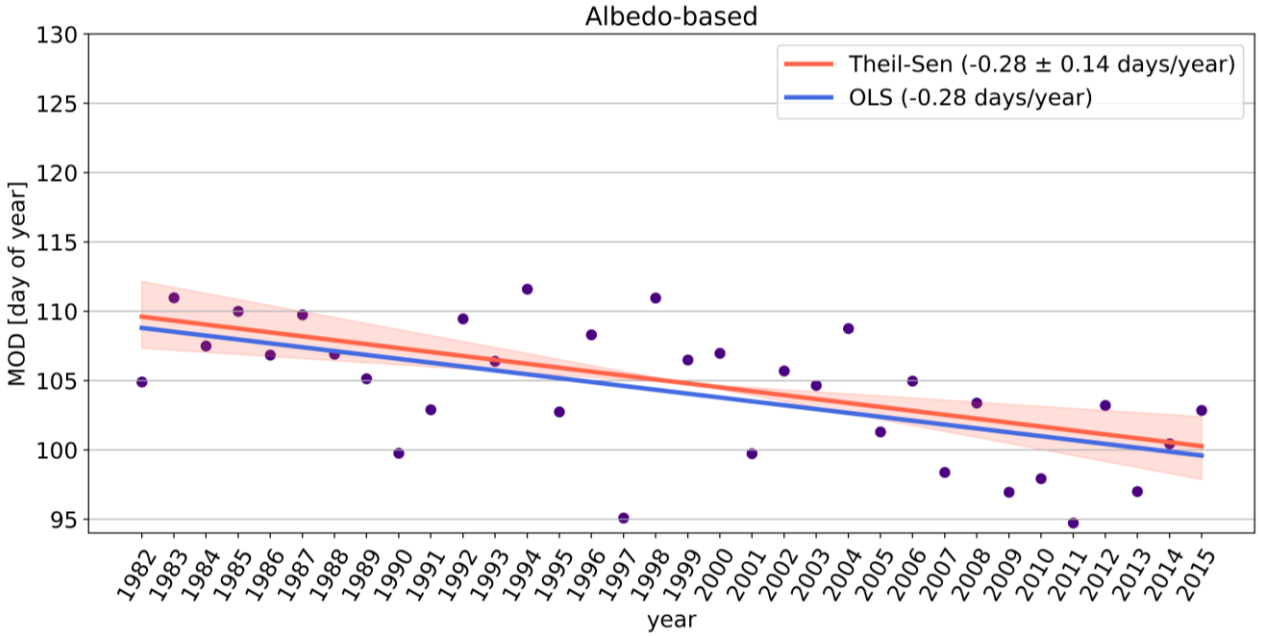
Kouki et al. (2019)

The trend towards earlier melt onset is larger in Eurasia than in North America

North America



Eurasia



Kouki et al. (2019)

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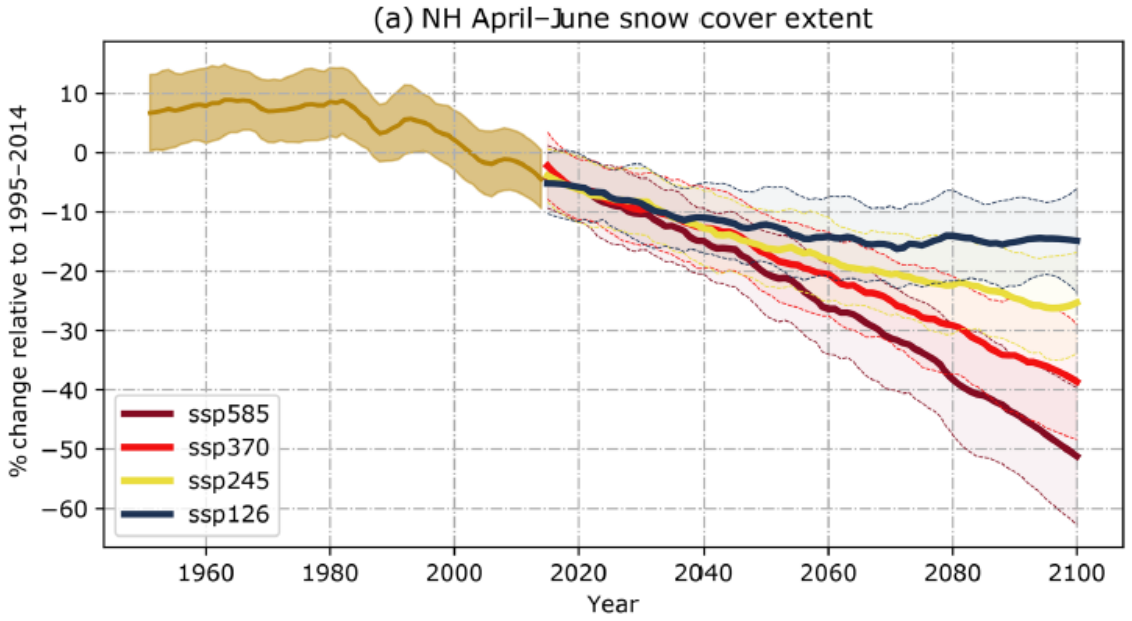
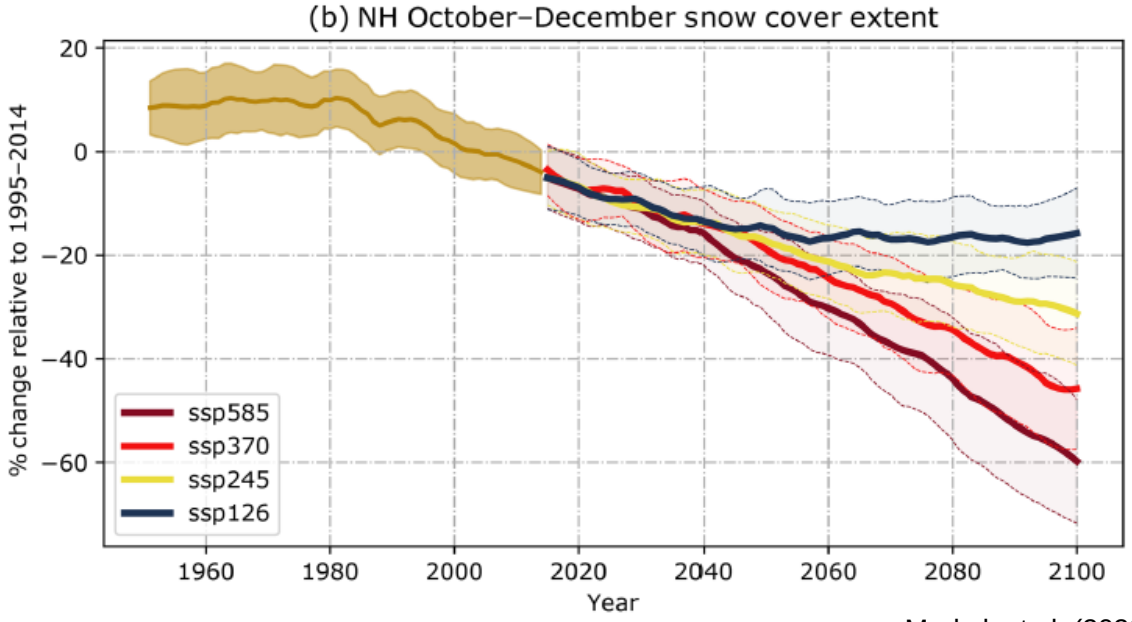
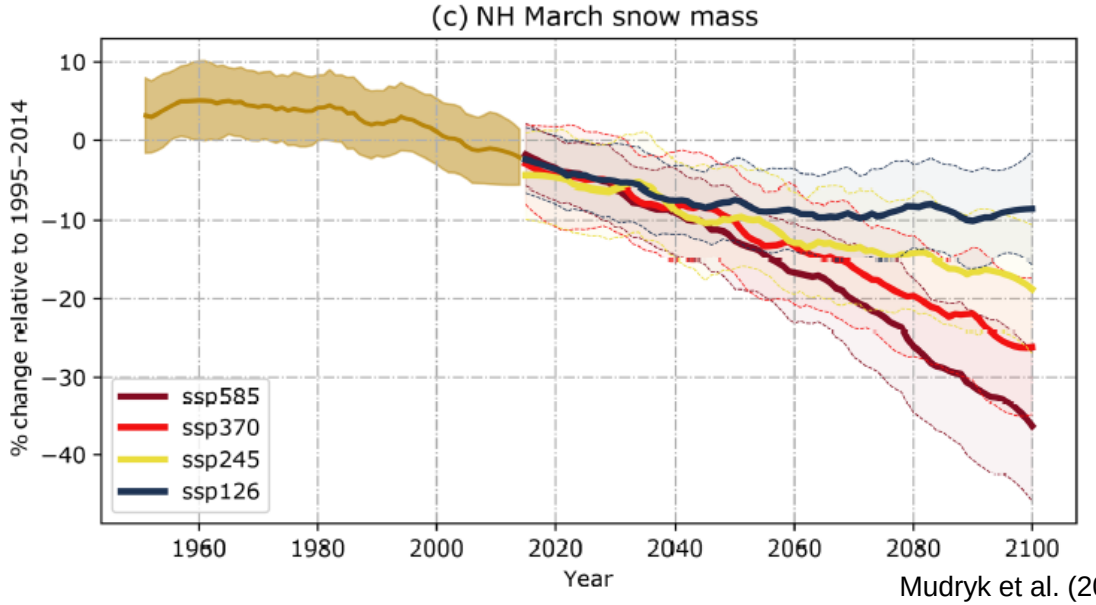
Snow cover extent will decrease in the future





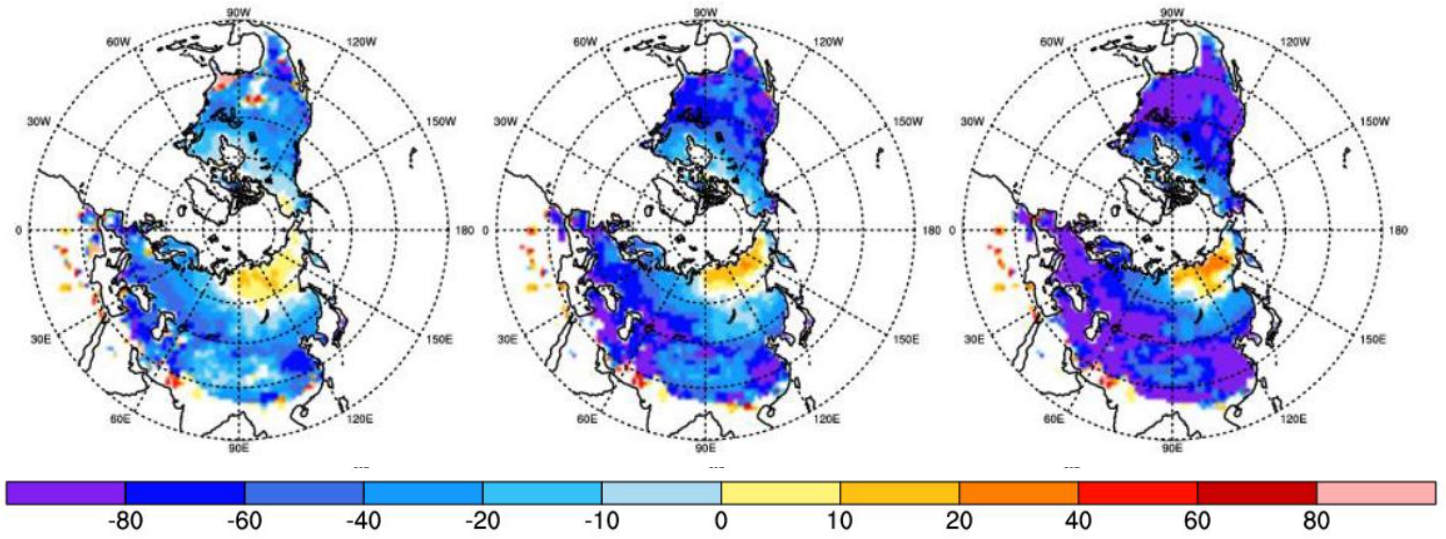
Mudryk et al. (2020)

SWE will decrease but spatial variability exists



Mudryk et al. (2020)

Projected relative change in mean SWE in spring (% relative to 1986–2005 reference period) by the CMIP5 ensemble for RCP8.5



Shi and Wang (2015)

Summary

Snow and ice cover show mostly negative trends, but seasonal and spatial variability exists

Snow cover extent is decreasing in late spring and summer

- The negative trend is more prominent in Eurasia than in North America

Snow water equivalent is decreasing especially in North America in March

- Large spatial variability exists in SWE trends

Statistically significant trend exists towards earlier **melt onset**

SWE and SCE will decrease **in the future**, but spatial variability exists

References:

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Riihelä, A., Bright, R. M., & Anttila, K. (2021). Recent strengthening of snow and ice albedo feedback driven by Antarctic sea-ice loss. *Nature Geoscience*, *14*(11), 832-836.

Shi, H. X., & Wang, C. H. (2015). Projected 21st century changes in snow water equivalent over Northern Hemisphere landmasses from the CMIP5 model ensemble. *The Cryosphere*, *9*(5), 1943-1953.

Thank you!

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