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An Arctic Ocean in Transition

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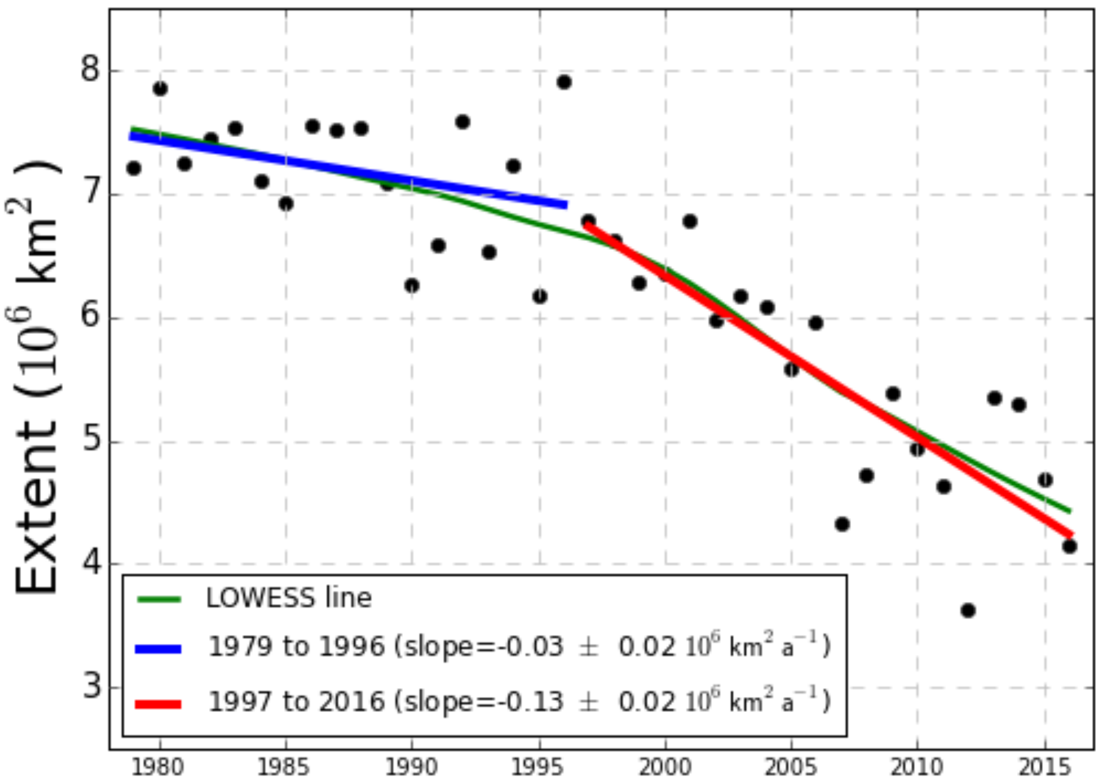
Introduction

- The last several decades have seen an accelerated rate of decline of the summer sea ice cover.



September Trends

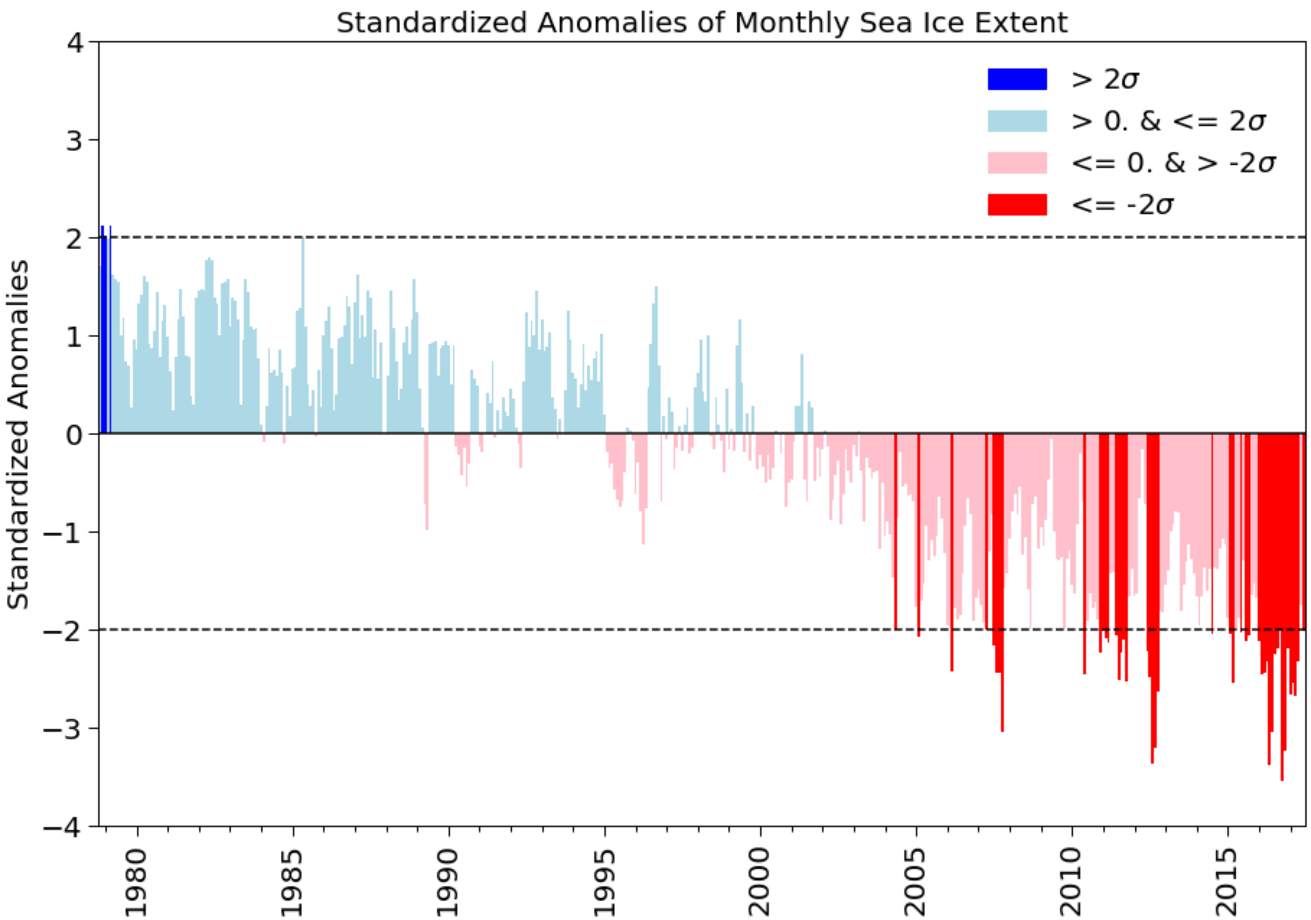
1979-2016: -87,000 km^{2}yr^{-1}

1979-1996: -30,000 km^{2}yr^{-1}

1997-2016: -130,000 km^{2}yr^{-1}

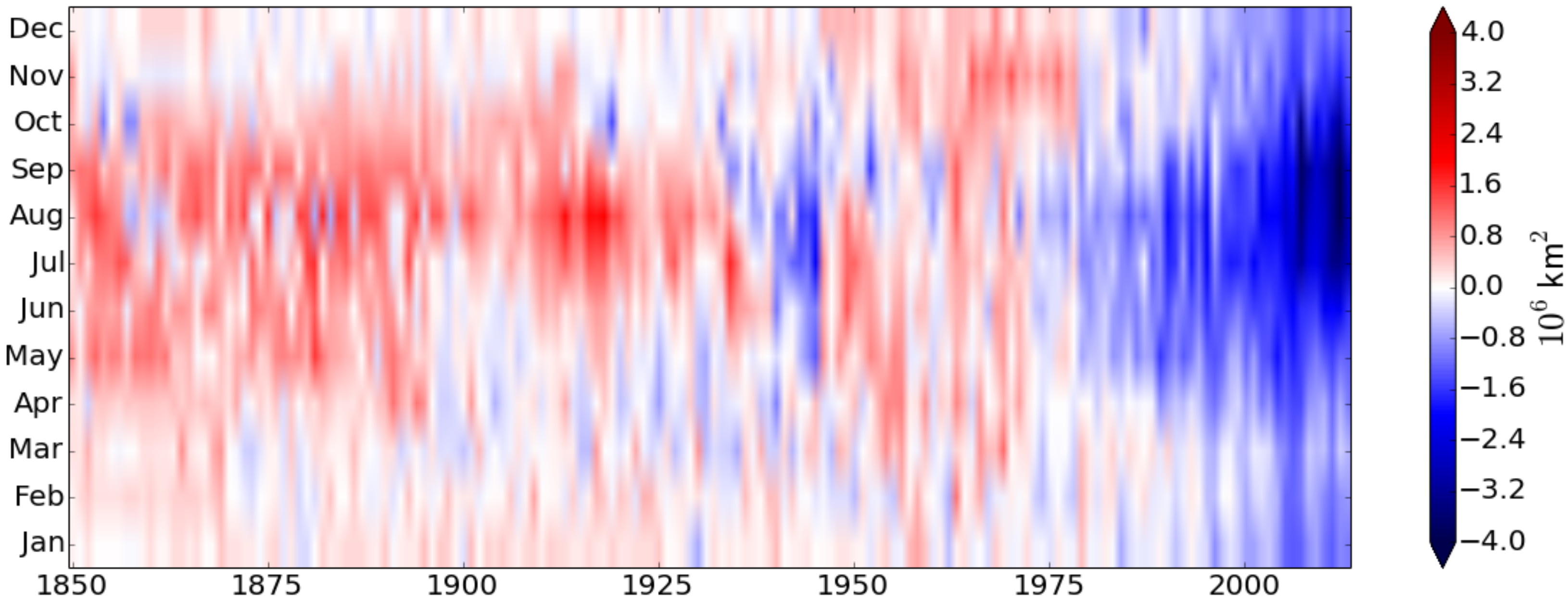
Ice loss is no longer only happening in summer

- From January 2016 through April 2017 the Arctic saw 16 consecutive months with sea ice extent more than 2σ below the 1981-2010 long-term mean.



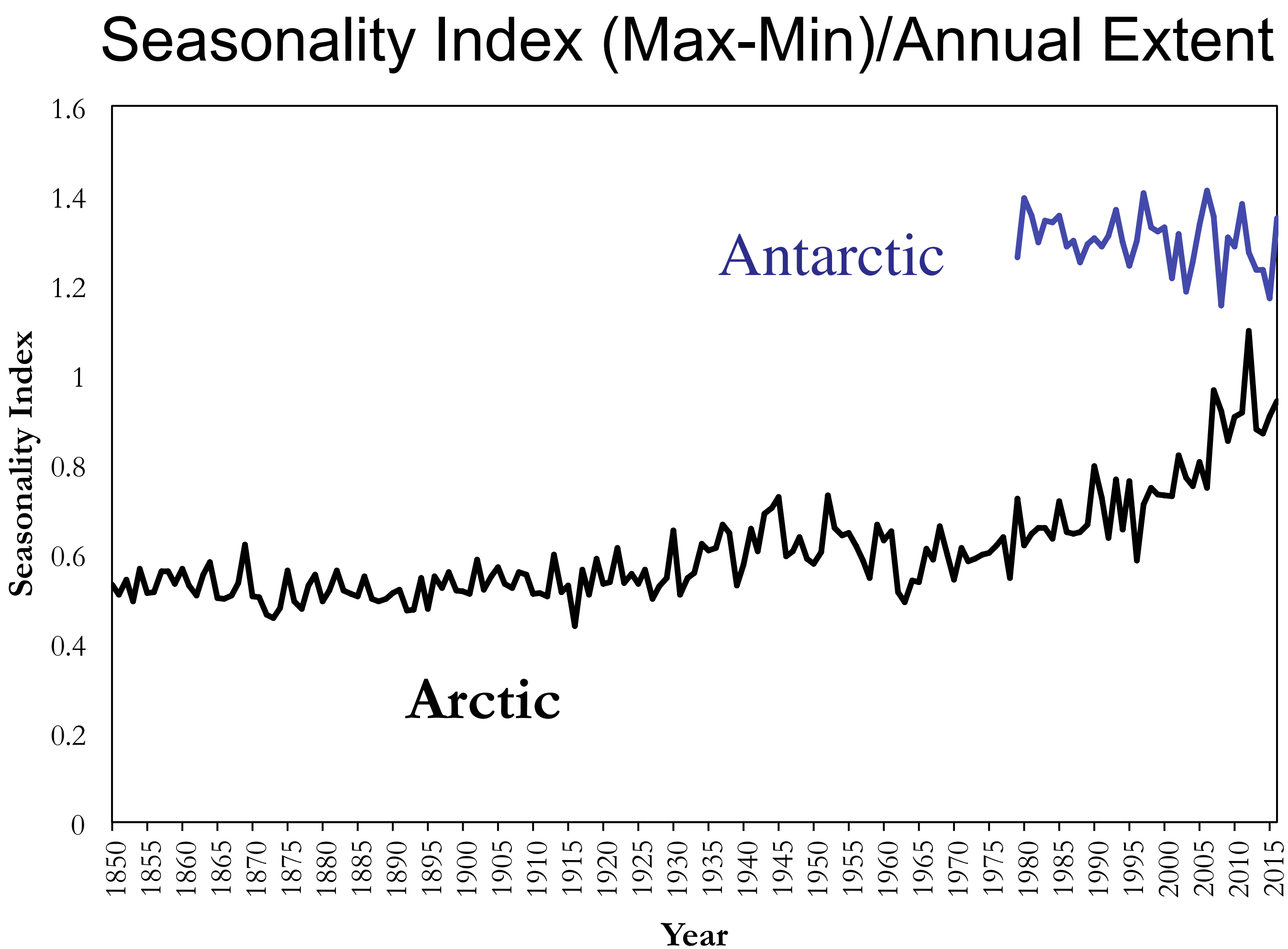
Longer-term perspective (1850-2013)

- New Walsh et al. (2014) reveals recent changes are unprecedented in the last 150 years.

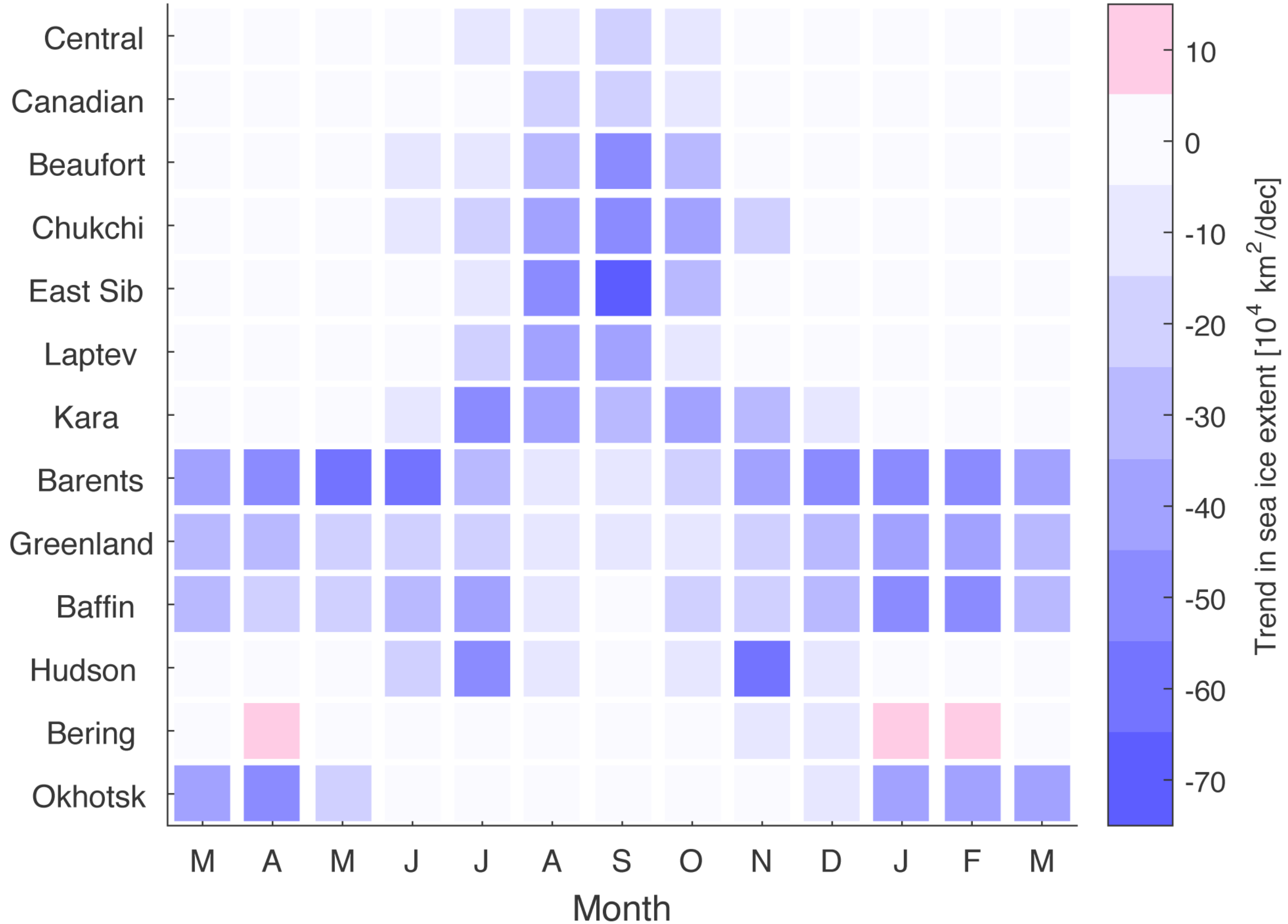


A real change in seasonality is happening

- Historical sea ice record shows a clear shift in recent years with the seasonality approaching that of the Antarctic.



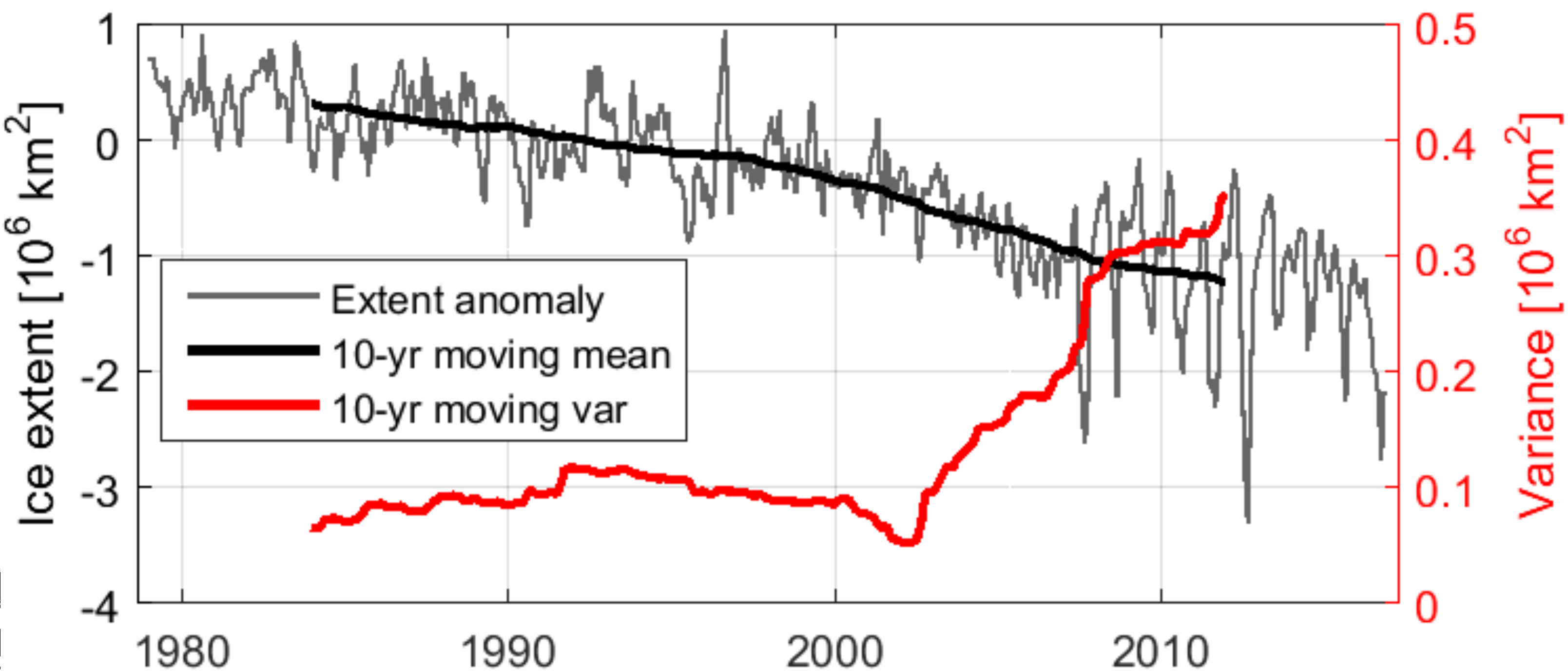
Regional monthly trends (1979-2016)



Onarheim et al., submitted

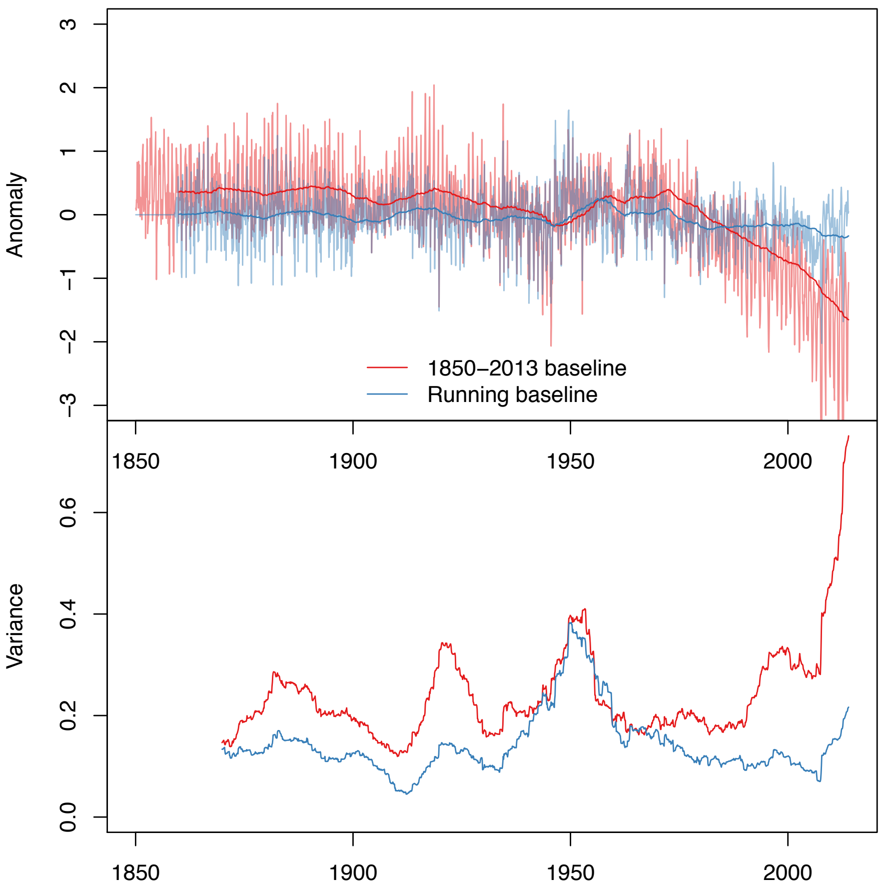
Variability appears to be increasing over time

- Looking at the observational record, we may think variability has increased dramatically since 2007.
- This makes seasonal forecasting difficult.
- Increasing variability can be an indicator towards a new climate state.



How changing seasonality impacts our interpretation

- The idea that variance is increasing is strongly dependent on the baseline chosen, if we use different baselines on the full 1850-2013 data set, interpretation changes.



- The increase in variance is not a strict increase in variance, but the result of a changing baseline, which shows both a declining trend and increase in seasonality.
- This questions the idea of increased variance as an early warming indicator for an ice-free Arctic.

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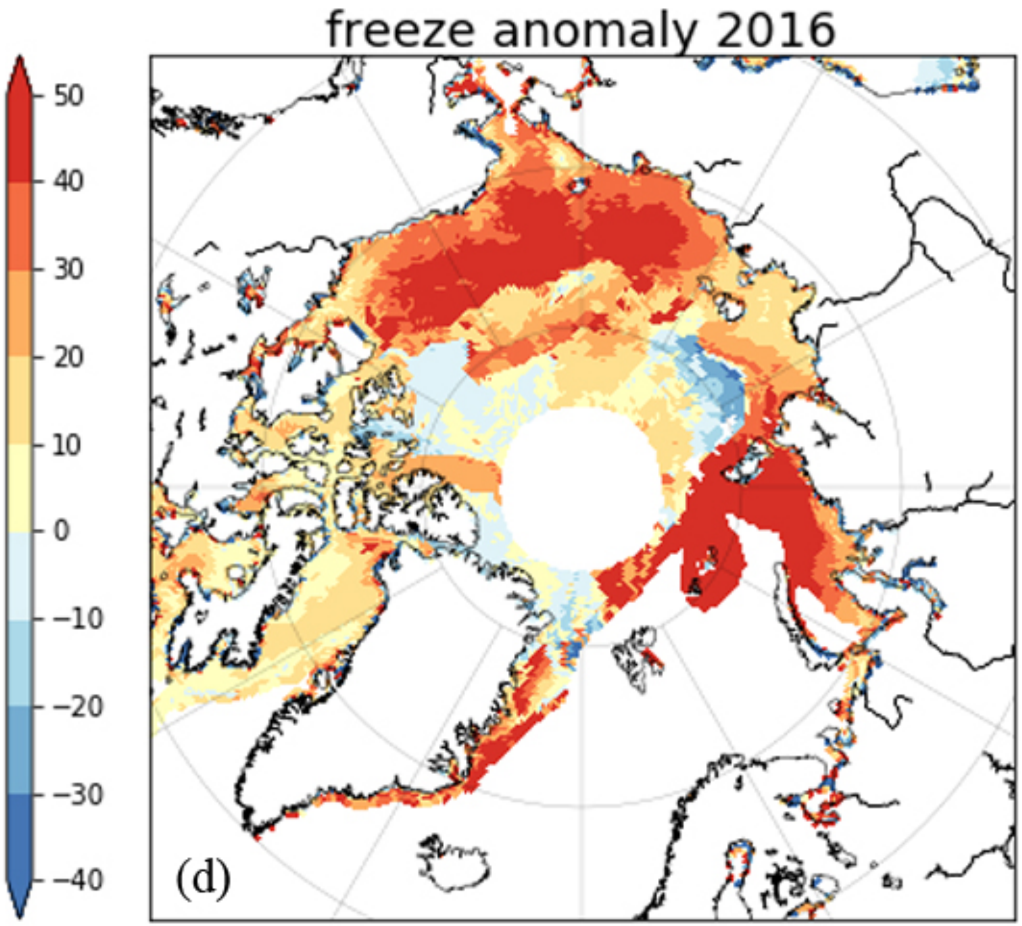
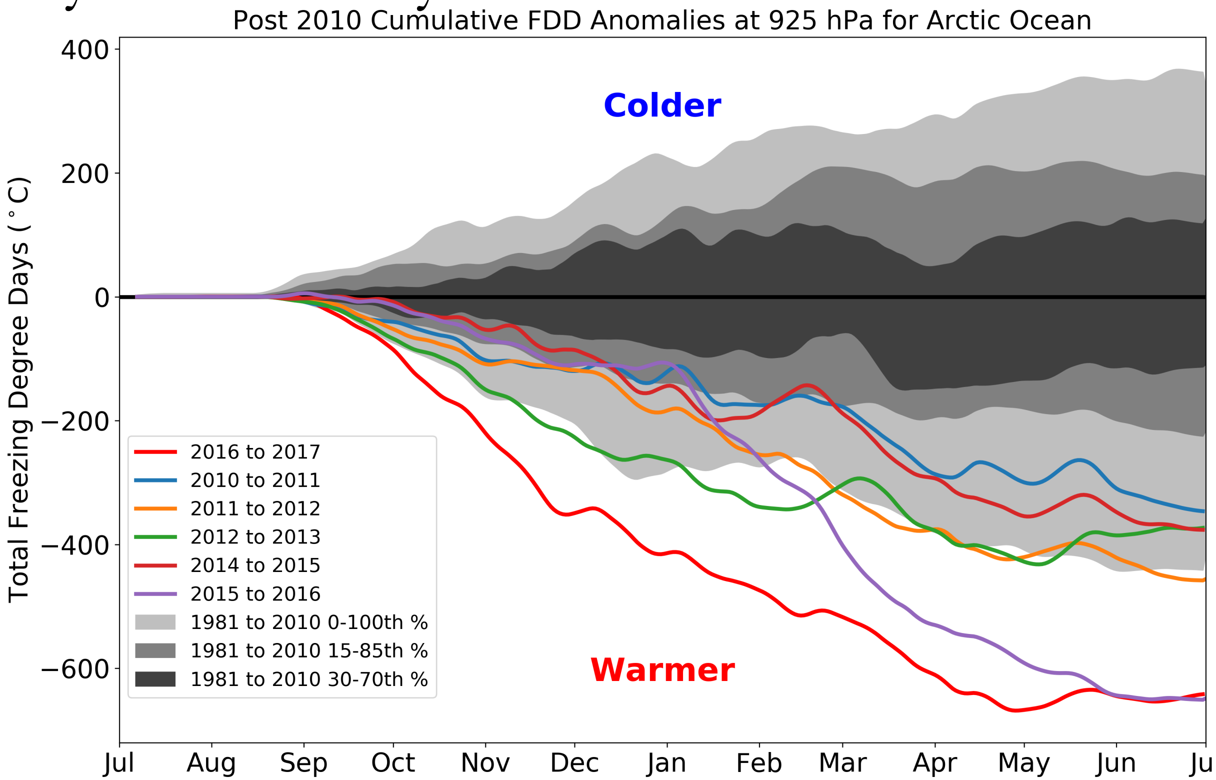
What happened after the 2016 minimum?



- Freeze-up was delayed by 20 days for the Arctic as a whole, with regions like the Bering, Beaufort Chukchi, East Siberian and Kara delayed by 3-4 weeks.
- Barents Sea saw freeze-up delayed by 60 days

The winter that followed was unusually warm

- Graham et al. 2017 suggest winters are becoming warmer and warming events are lasting longer.
- Winter 2016/2017 saw the least amount of freezing degree days recorded yet in the Arctic.



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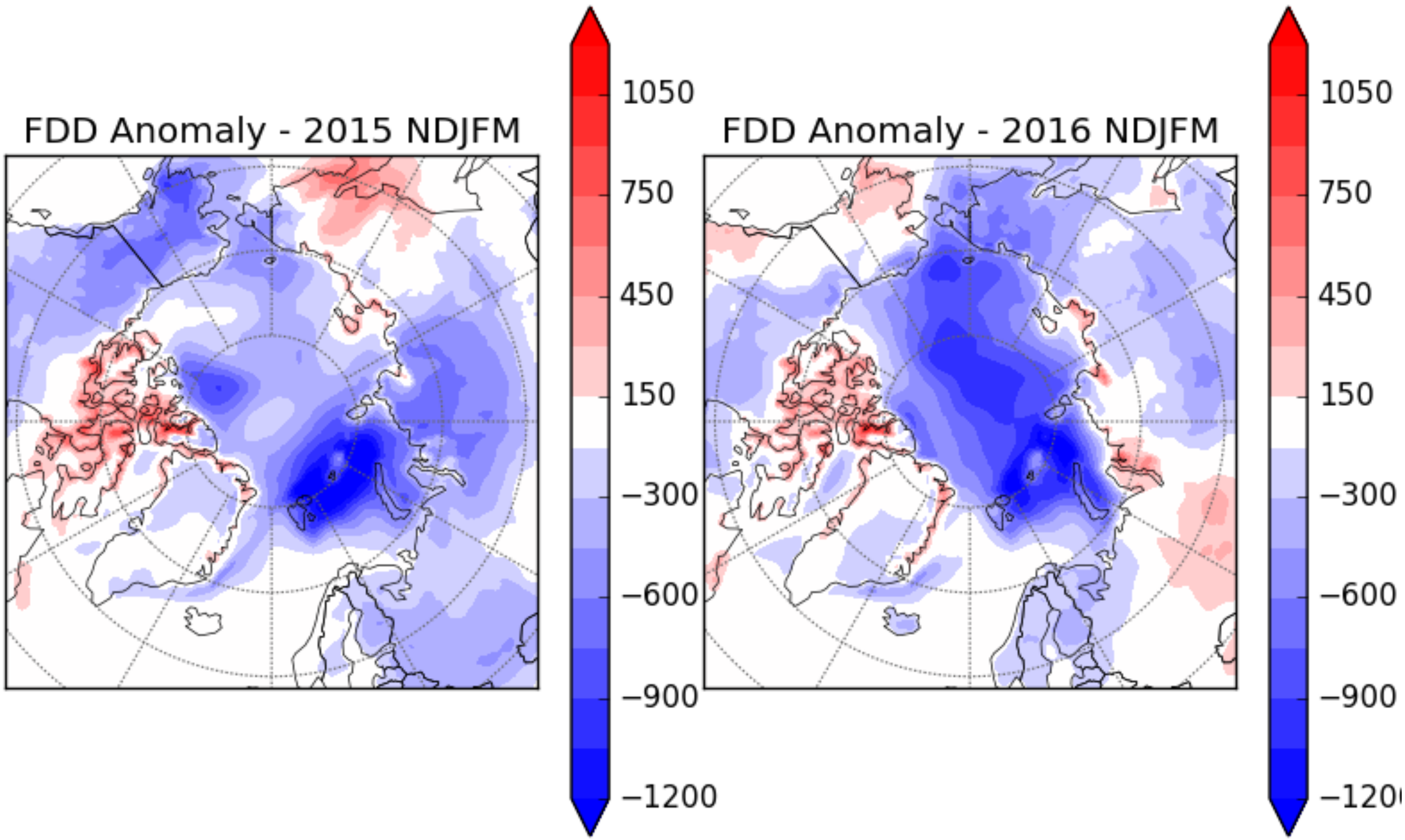
FDDs were reduced Arctic wide



What impact did this have on ice growth?

- Record lowest maximum occurred in 2017.
- Was this in part a result of the warm winter impacting ice growth or is it dynamically driven?

- Problem: current ice thickness observations are not yet suitable to address inter-annual variability.

- Solution: combine observations and model runs (CICE) to evaluate how warm winters may be impacting thermodynamic ice growth and dynamical changes.

Thickness anomaly in November

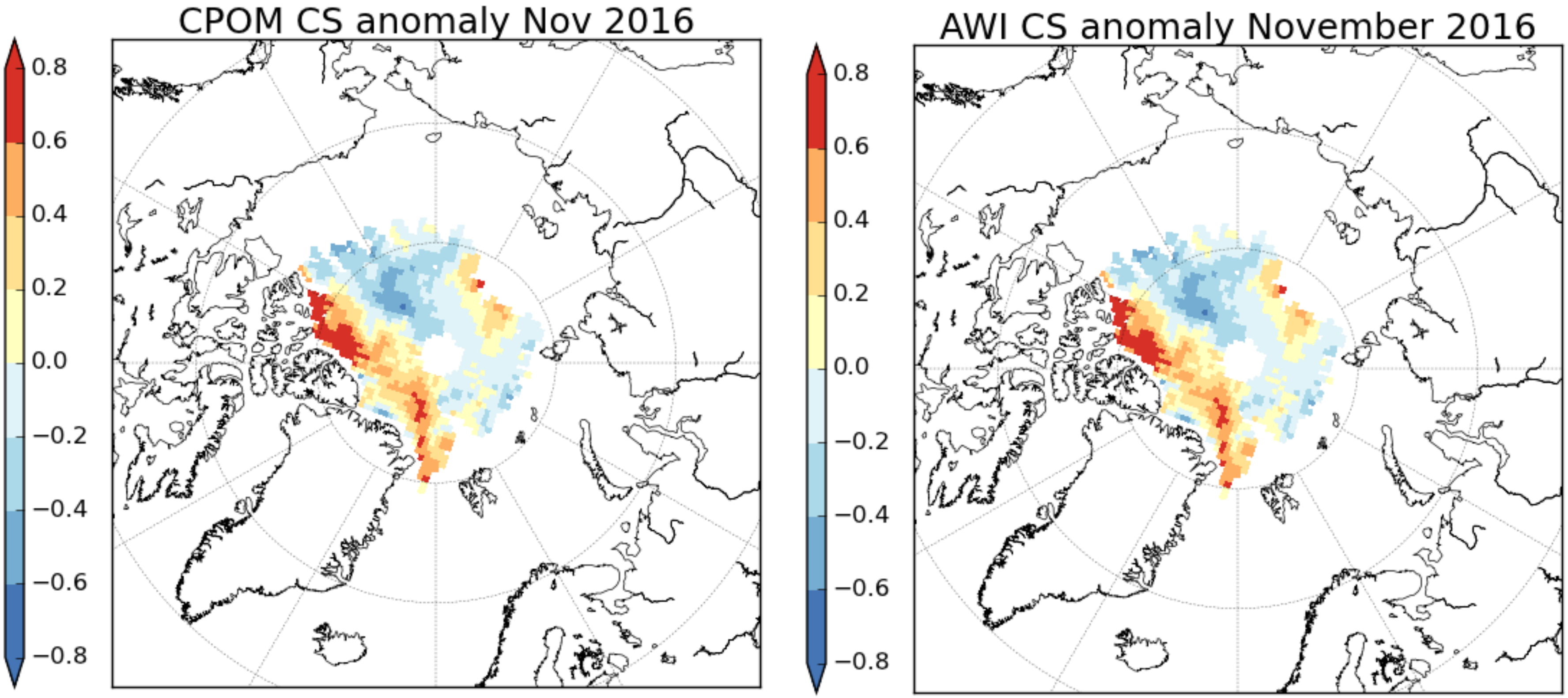
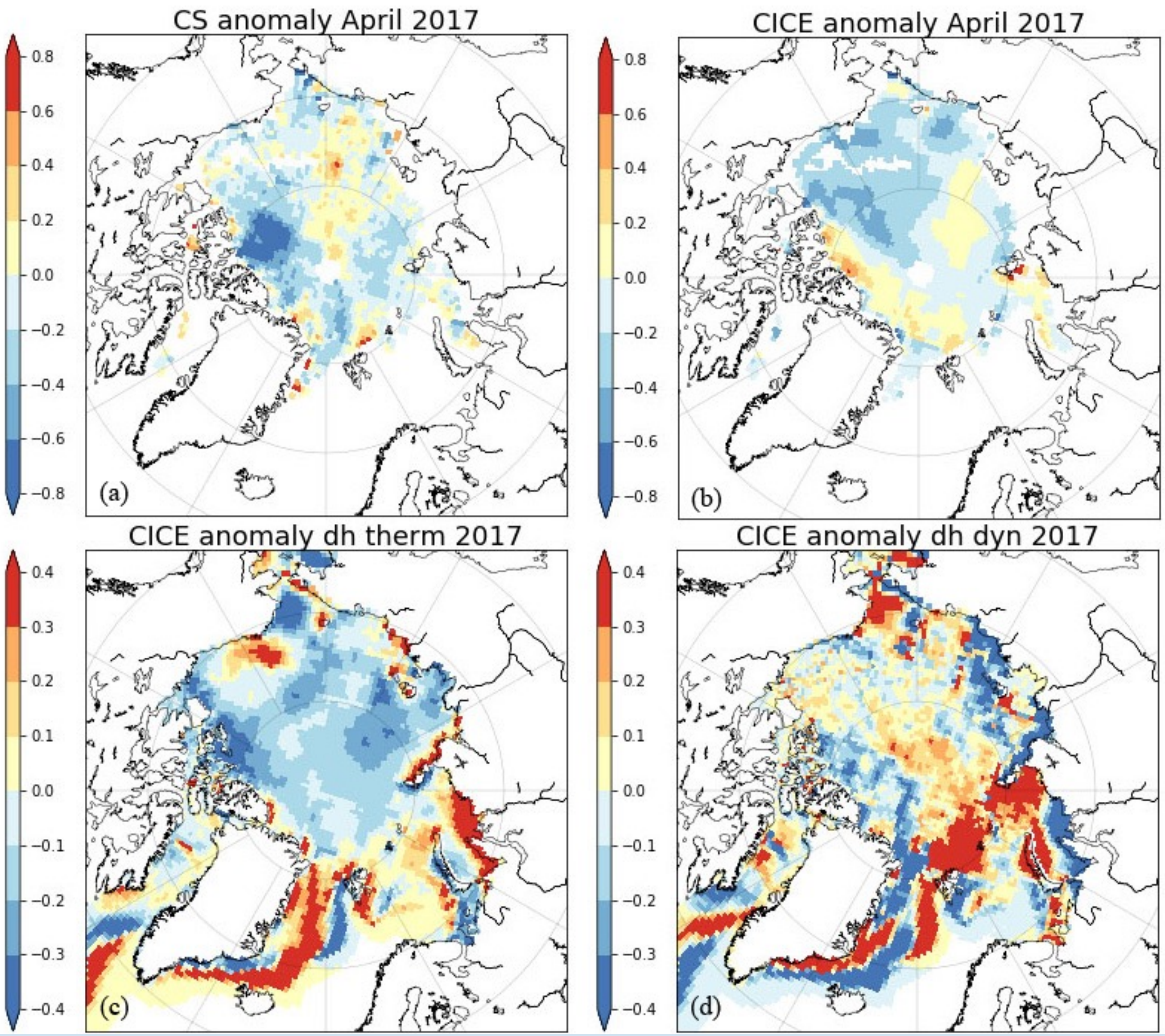


Figure from Stroeve et al., GRL, submitted

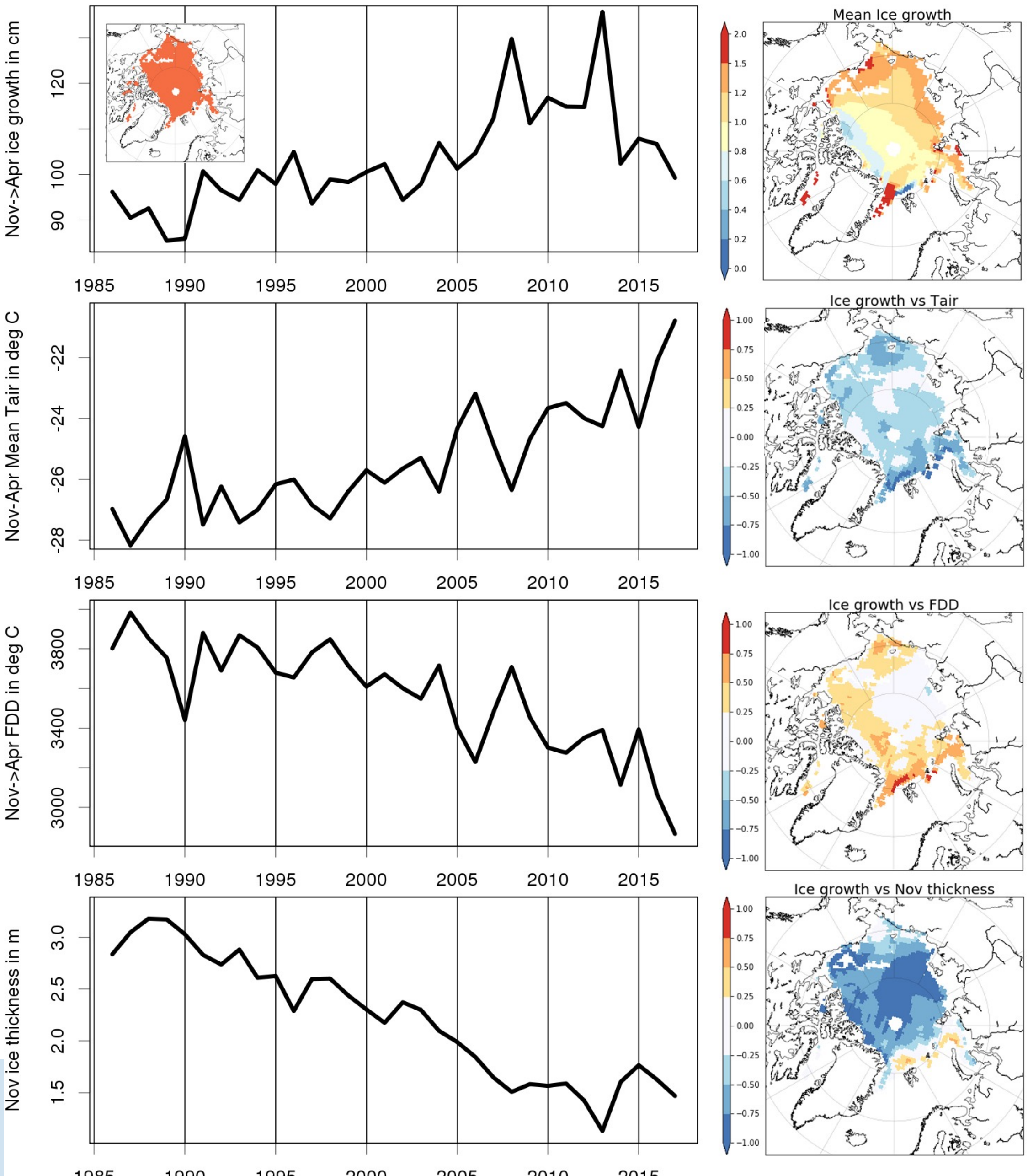
Thickness in April



- Arctic-wide ice was 13-15 cm thinner in April 2017 compared to the 2010-2017 mean.
- Thermodynamic ice growth was reduced by 11-13cm
- Dynamics led to +4cm thickening.

Figure from Stroeve et al., GRL, submitted

Negative feedbacks have dominated



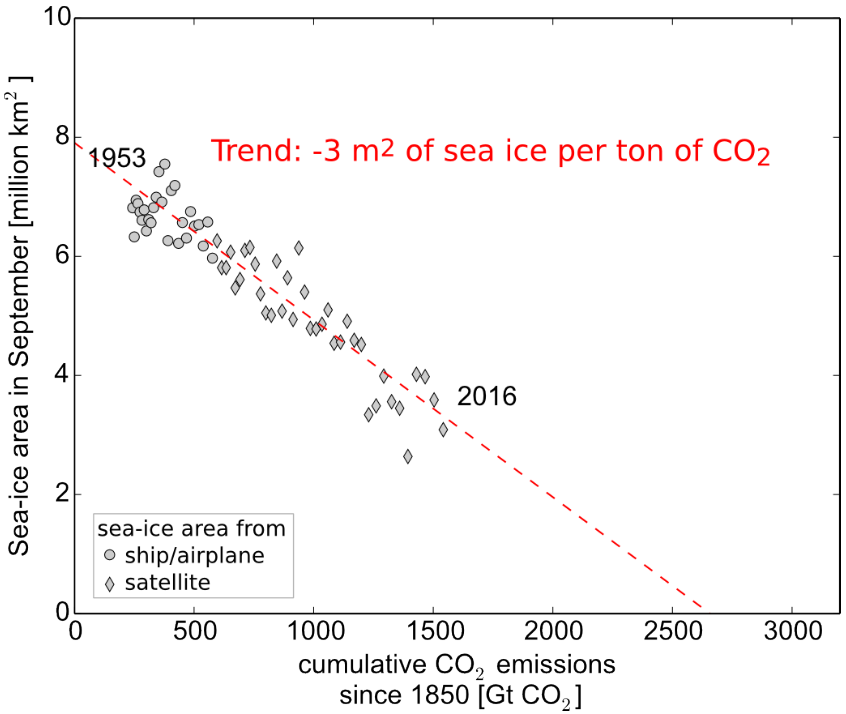
- There has been a general tendency towards increased winter ice growth over time.
- This, despite increased winter air temperatures and decreased number of FDDs.
- Ice growth is generally enhanced for thin ice.

Figure from Stroeve et al., GRL, submitted

Our current understanding driving Arctic ice loss

- Climate models are in agreement that sea ice is declining in response to warming from GHGs, though the pace of ice loss has been underestimated [*Stroeve et al.*, 2007; 2017].

- This is in part a result of smaller sensitivity of modeled ice loss to global warming [*Stroeve and Notz*, 2015] and smaller sensitivity to cumulative CO_2 [*Notz and Stroeve* 2016].



Models underestimate observed sensitivity

- Multi-model sea ice decline per ton of CO_2 is 1.75, about 42% of that observed.

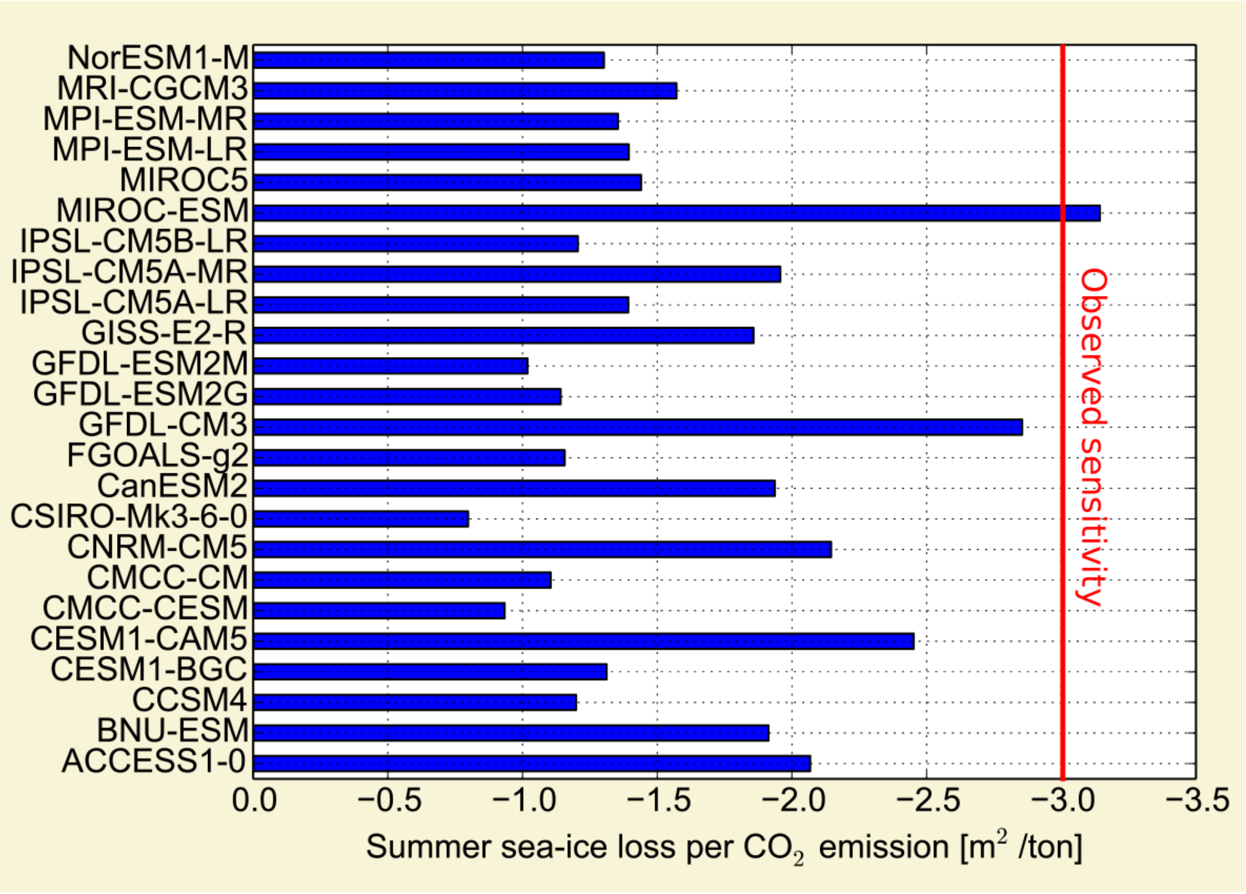
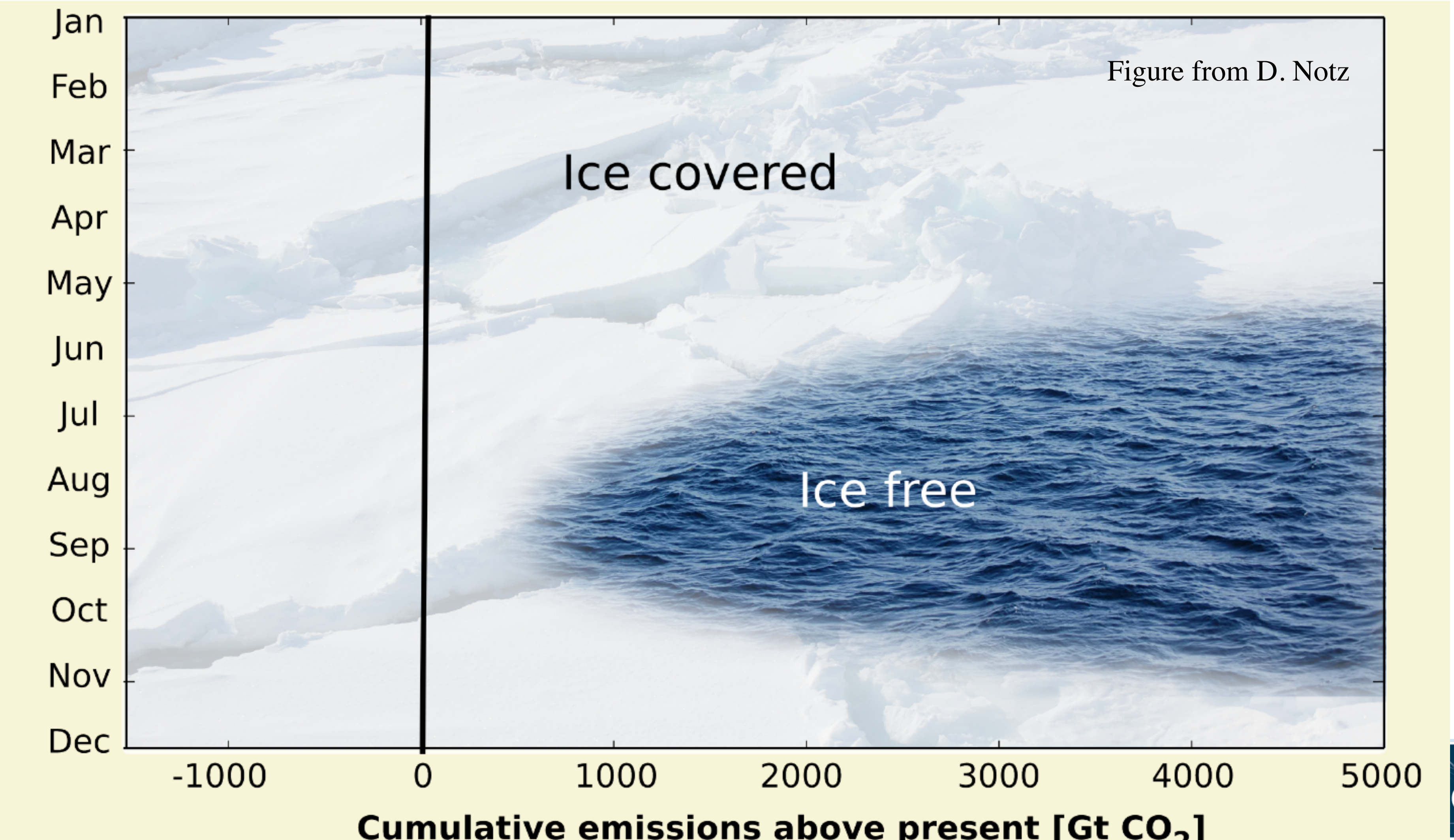


Figure from D. Notz

A sense of urgency

- There is a real possibility of a seasonally ice-free Arctic in our lifetimes.



Summary Statements

- Sea ice loss is governed by both anthropogenic greenhouse gas emissions and internal variability.
- Acceleration in time is primarily caused by the increased rate of anthropogenic greenhouse gas emissions.
- Sea ice doesn't care about time, but about greenhouse gas emissions.
- For current September sea ice area, an extra 700 Gt of CO_2 emissions will be enough for it to drop below 1 million km^2.
- At current emissions levels of 35-40 Gt per year, ice-free Septembers may be expected in the next 20 years.
- Barents Sea is already transitioning, Kara Sea is close.