Characterizing Arctic Sea Ice Variability and Extreme Events in CESM-LE

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CESM Polar Climate Working Group
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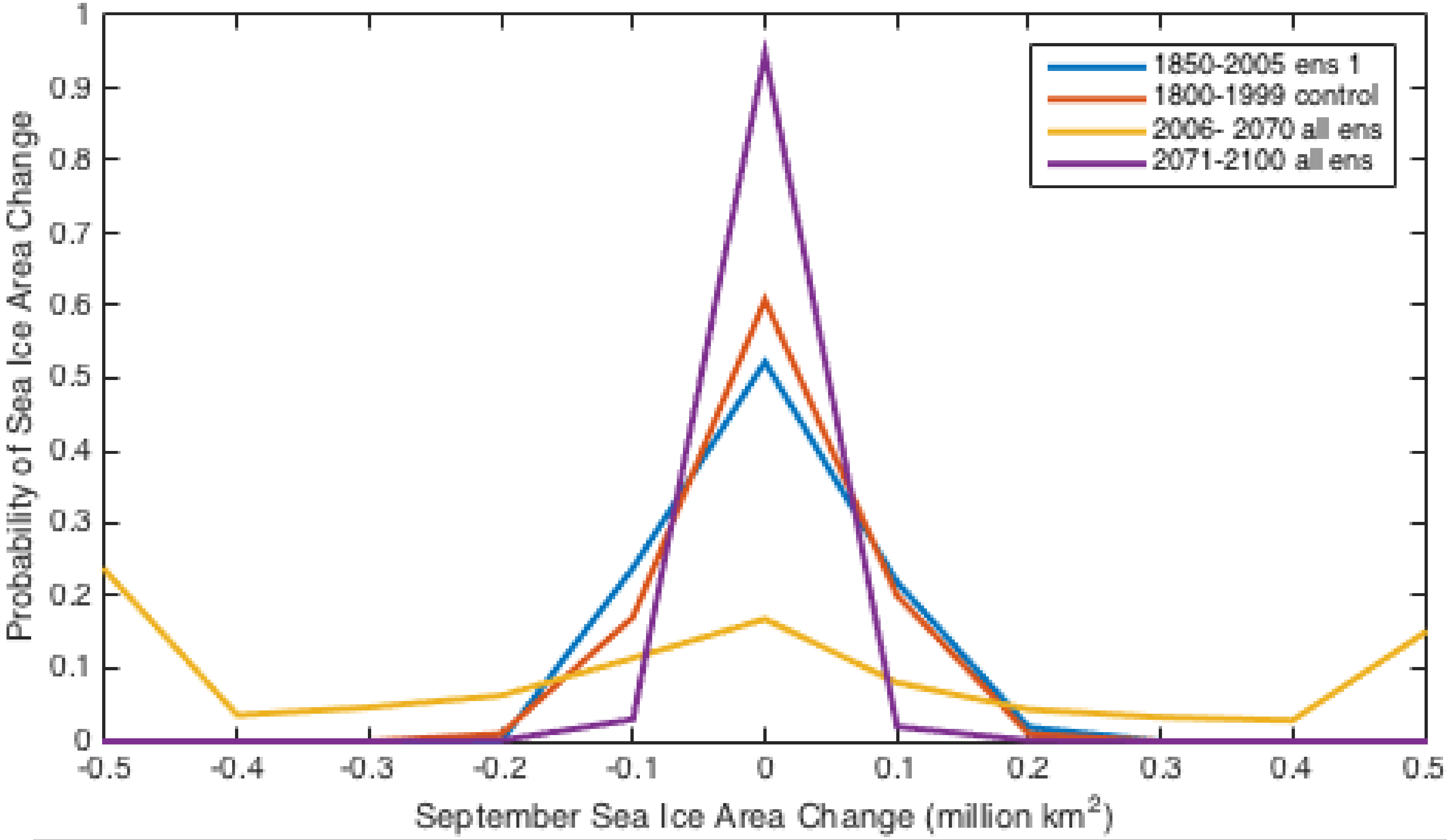
Project Background

- NOAA CVP: Understanding Arctic Sea Ice Mechanisms and Predictability
- Sea ice area: trends and variability
- Practical applications: Shipping interests and Ice Numeral
- Rapid ice loss and ice gain events
- Relationship with atmospheric circulation, and beyond…

Changing September Sea Ice Variability

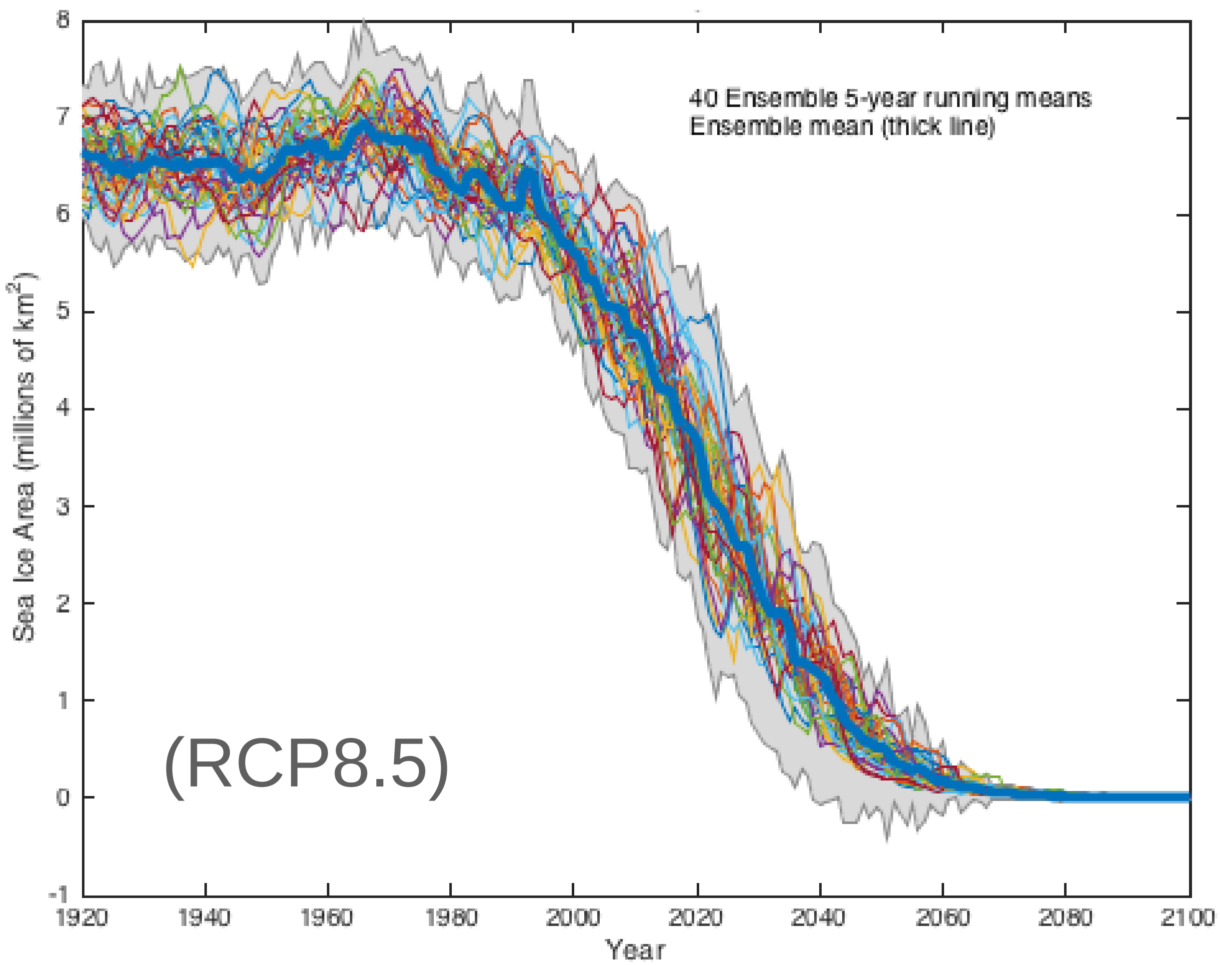
PDF of Inter-annual Change in September Ice Area



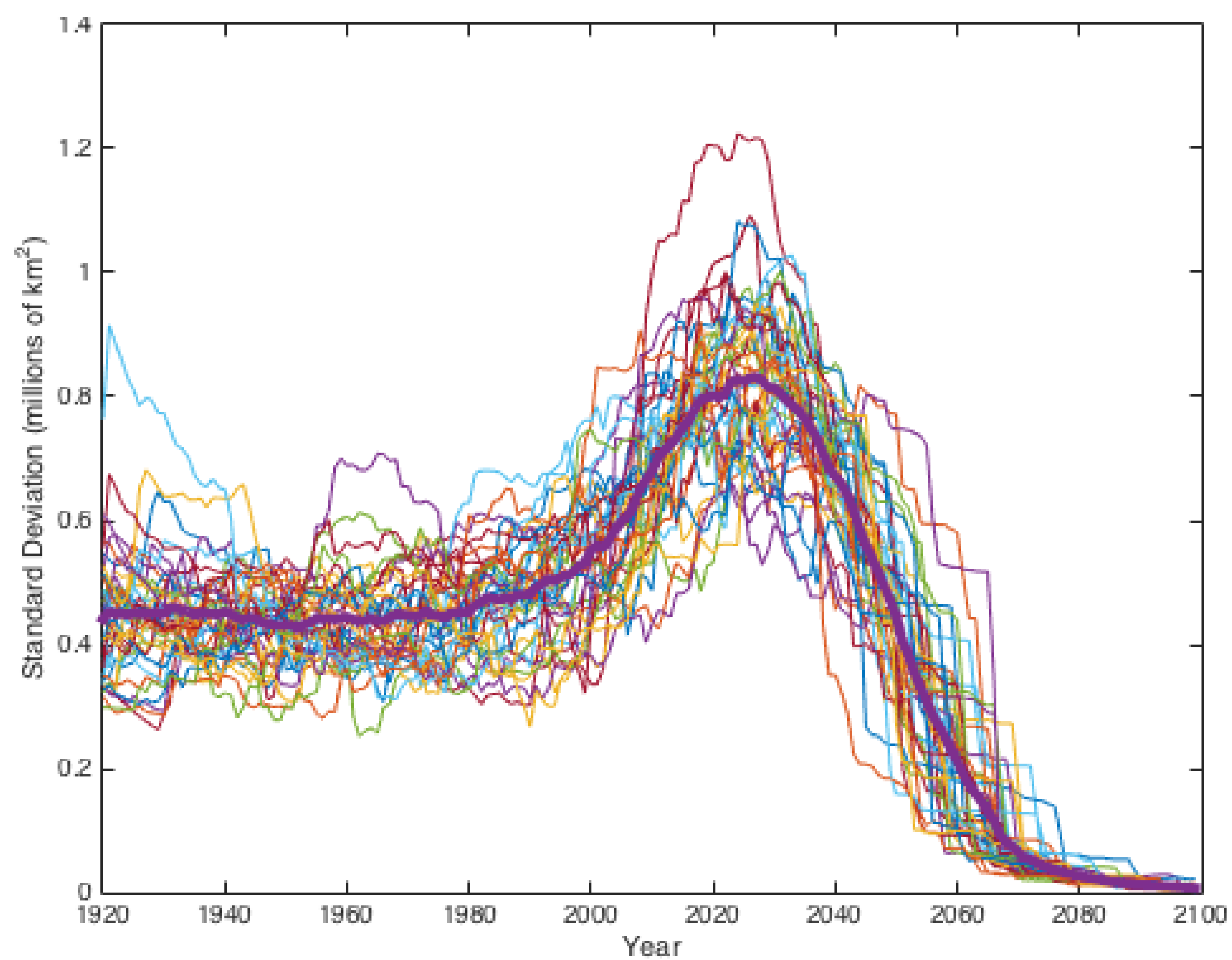
- Much higher variability 2006-2070

September Sea ice in CESM-LE

95% Confidence Interval of September Sea Ice Area



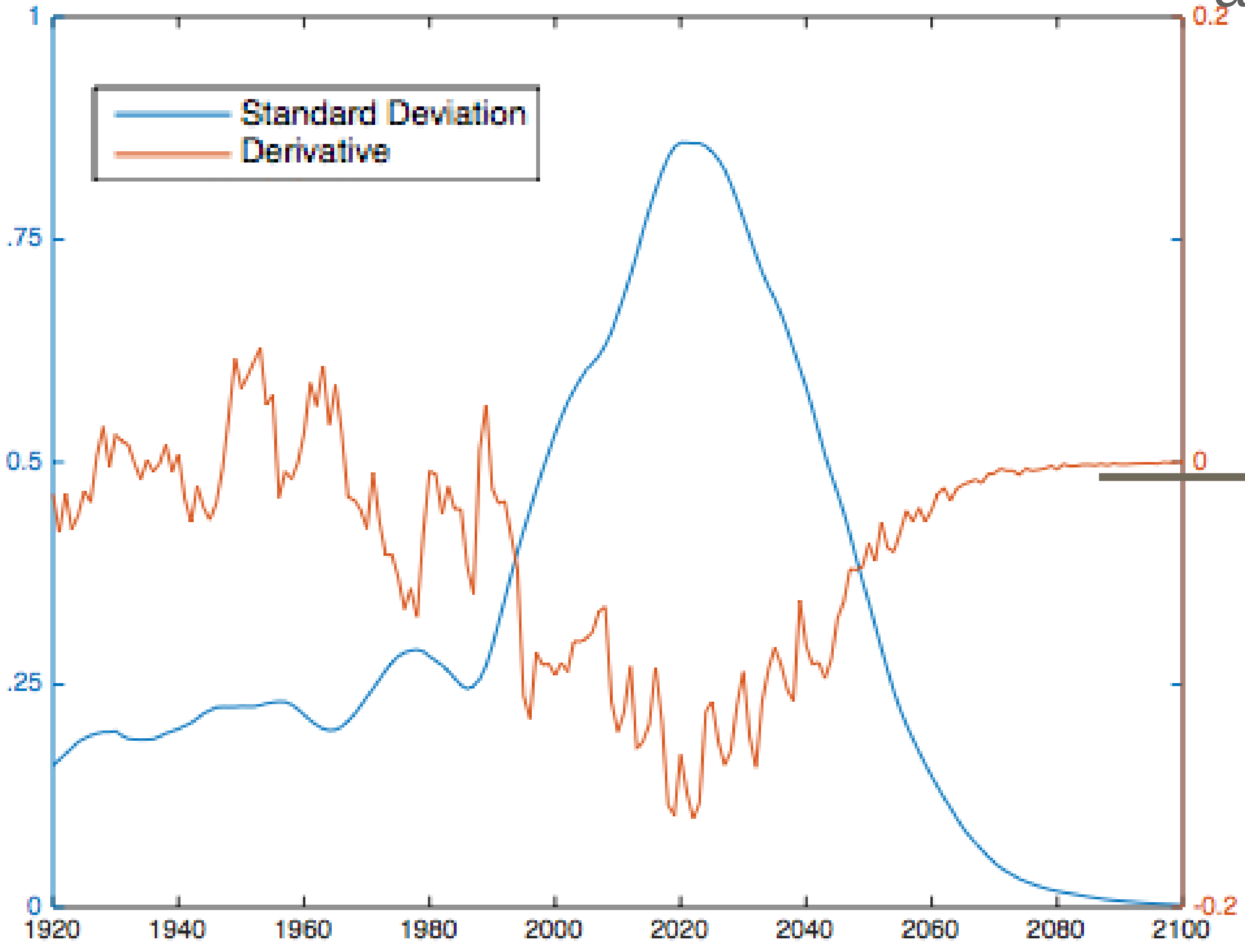
10-Year Running Standard Deviation

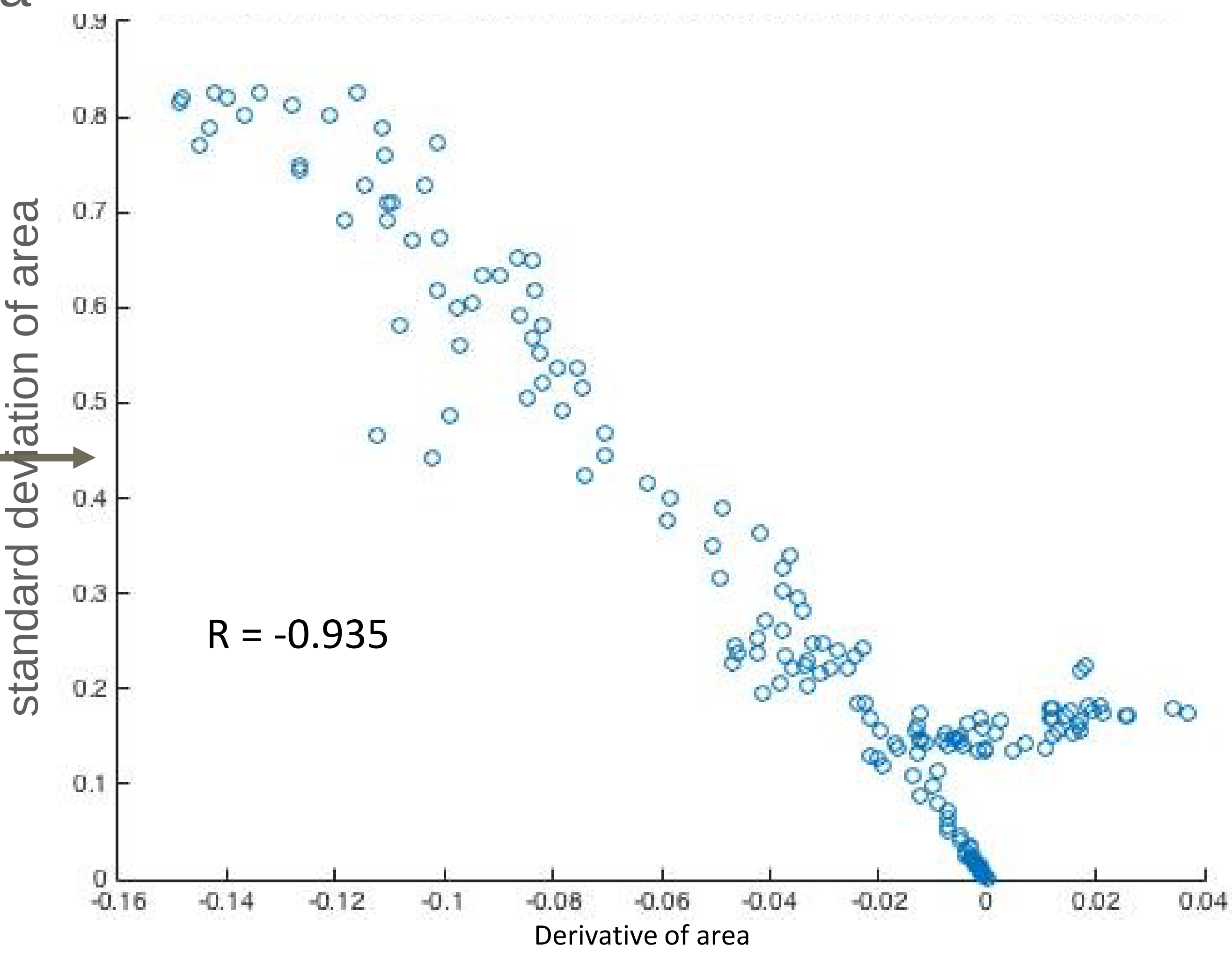


- Increase in variability coincides with the period of ice loss

Increased Variability with the Downward Trend

Relationship between standard deviation and derivative of mean sea ice area





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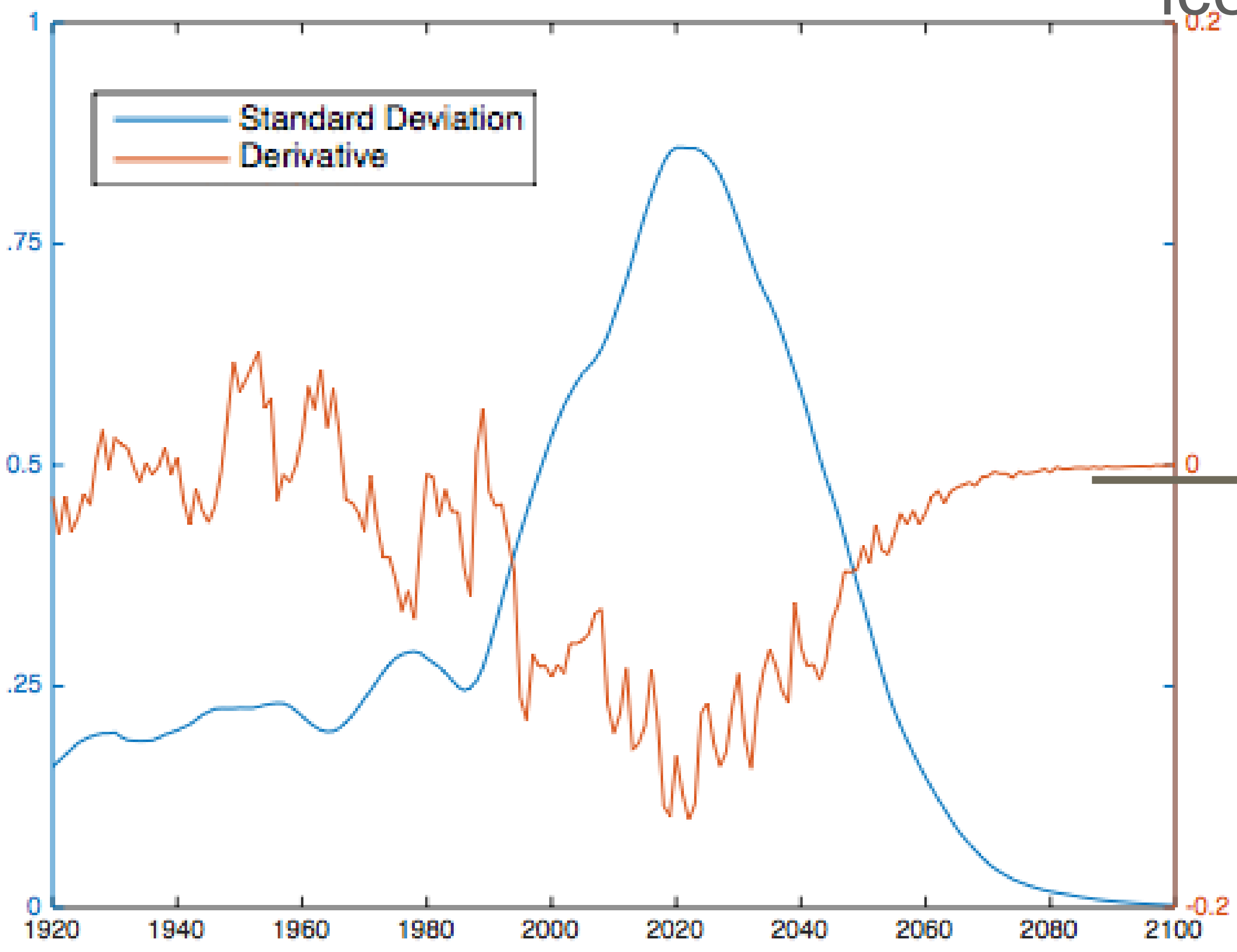
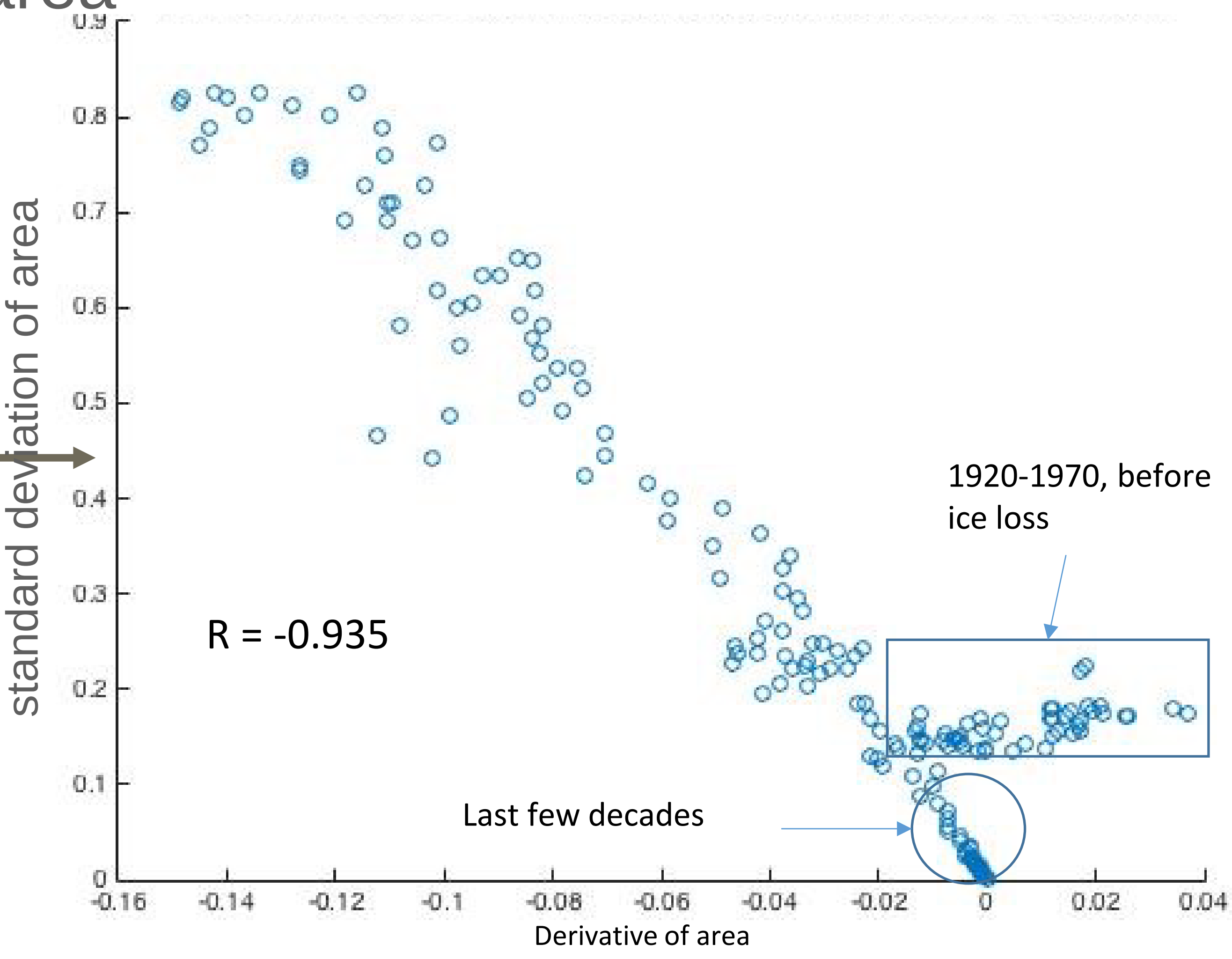
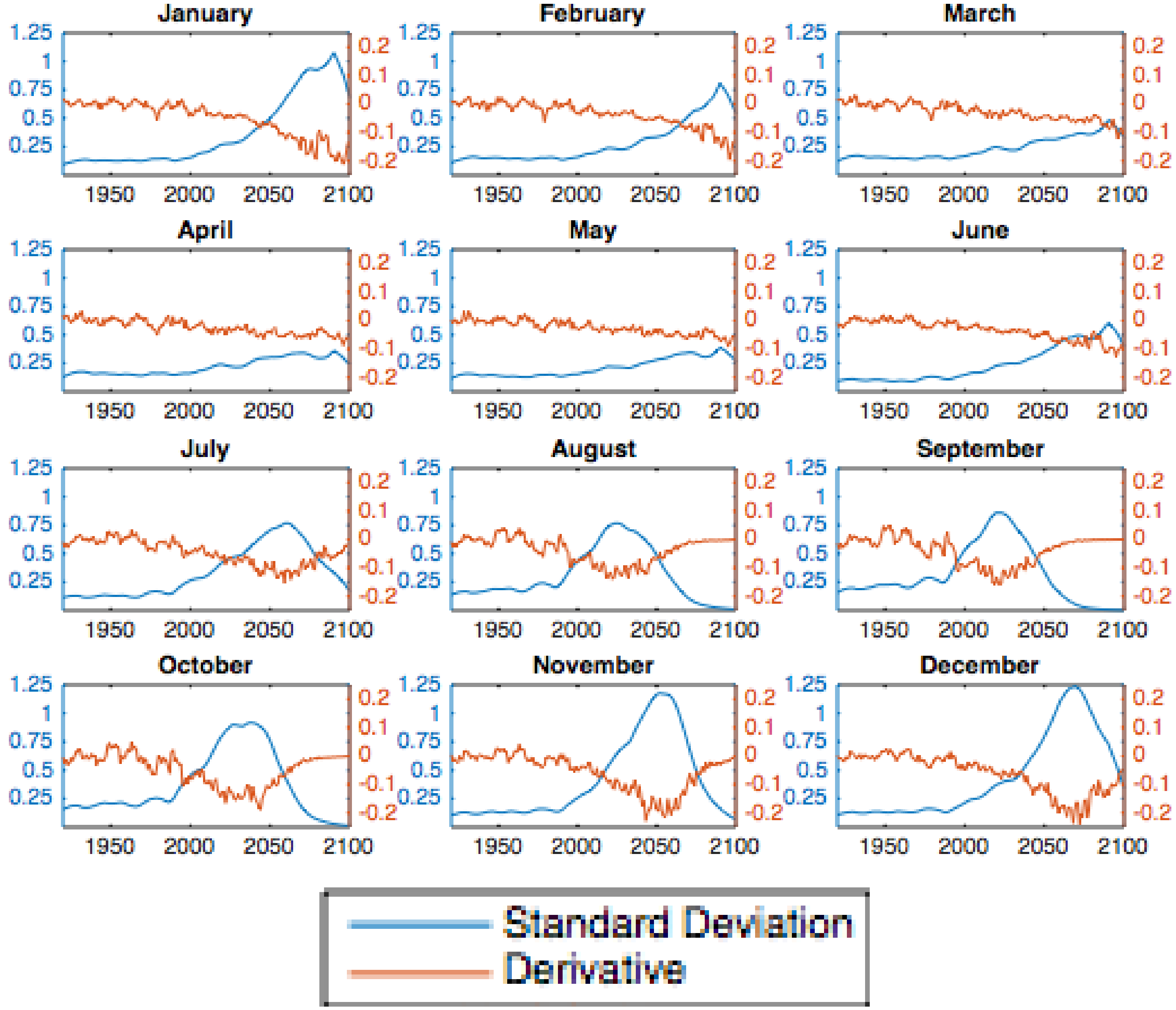


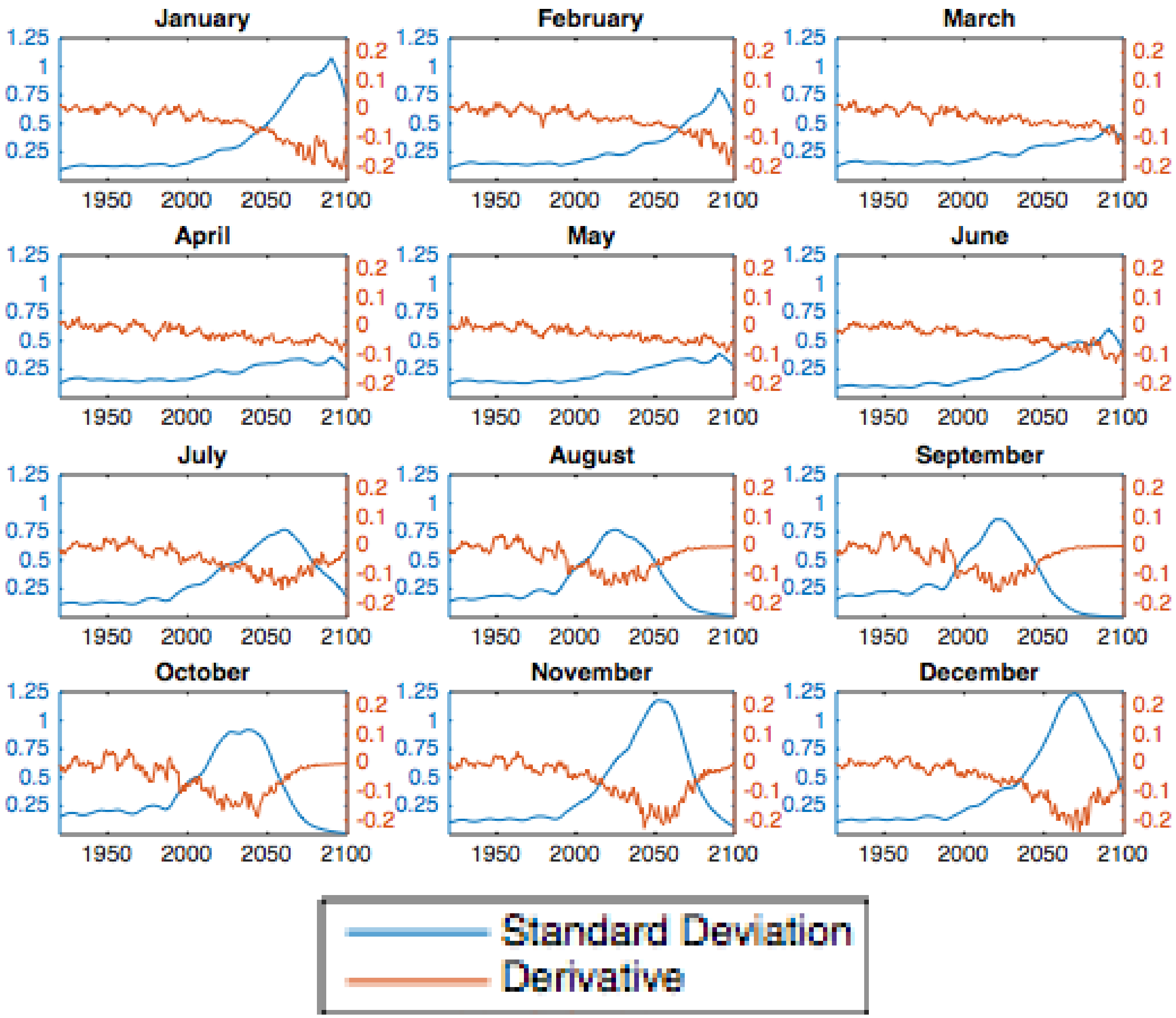


Variability Peak Coincides with Downward Trend



- Relationship holds up in all months; standard deviation is much higher in autumn/winter than spring

Variability Peak Coincides with Downward Trend



In which decade does each month reach maximum variability?

Month	Decade	Standard Deviation
January	2080-2089	0.953
February	2080-2089	0.664
March	2080-2089	0.395
April	2060-2069	0.323
May	2080-2089	0.322
June	2080-2089	0.501
July	2050-2059	0.715
August	2020-2029	0.726
September	2020-2029	0.805
October	2030-2039	0.875
November	2050-2059	1.136
December	2060-2069	1.157

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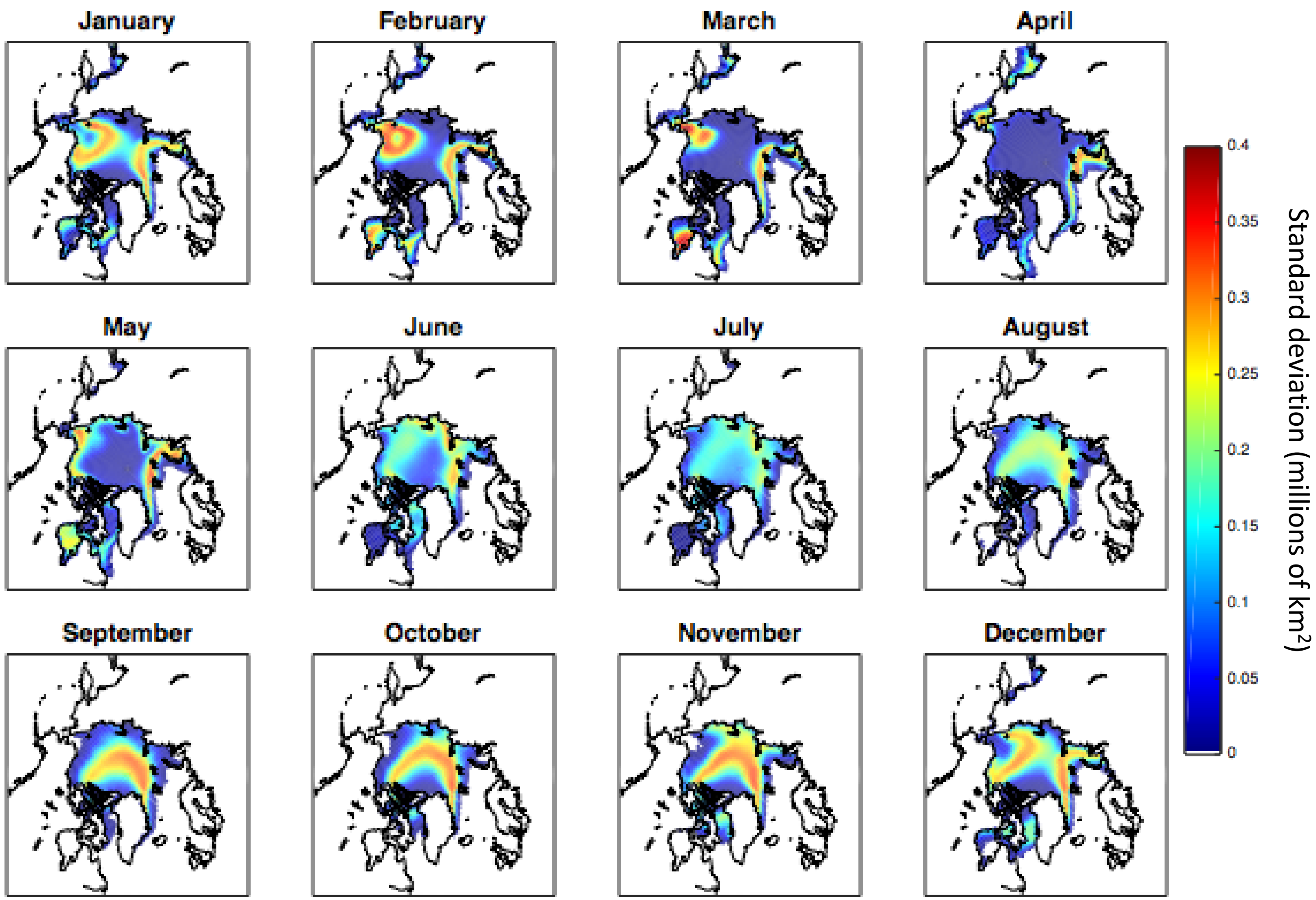
Sea Ice Standard Deviation Varies Seasonally

Standard Deviation in Decade When it Reaches its Maximum



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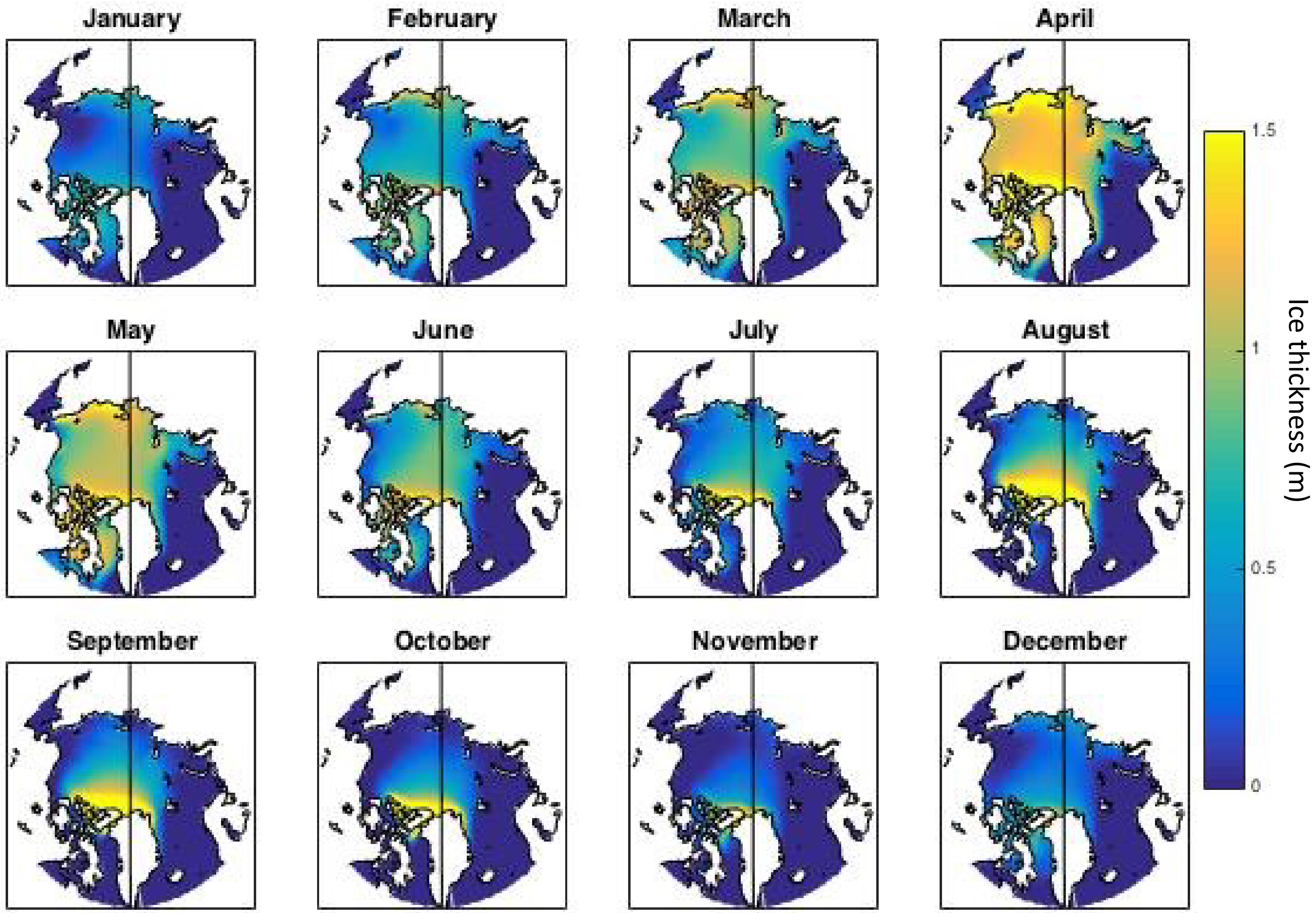
- possible explanations include: continental configuration (Eisenman 2010); area of thin ice

Sea Ice Standard Deviation Varies Seasonally

Mean Ice Thickness in Decade When it Reaches its Maximum

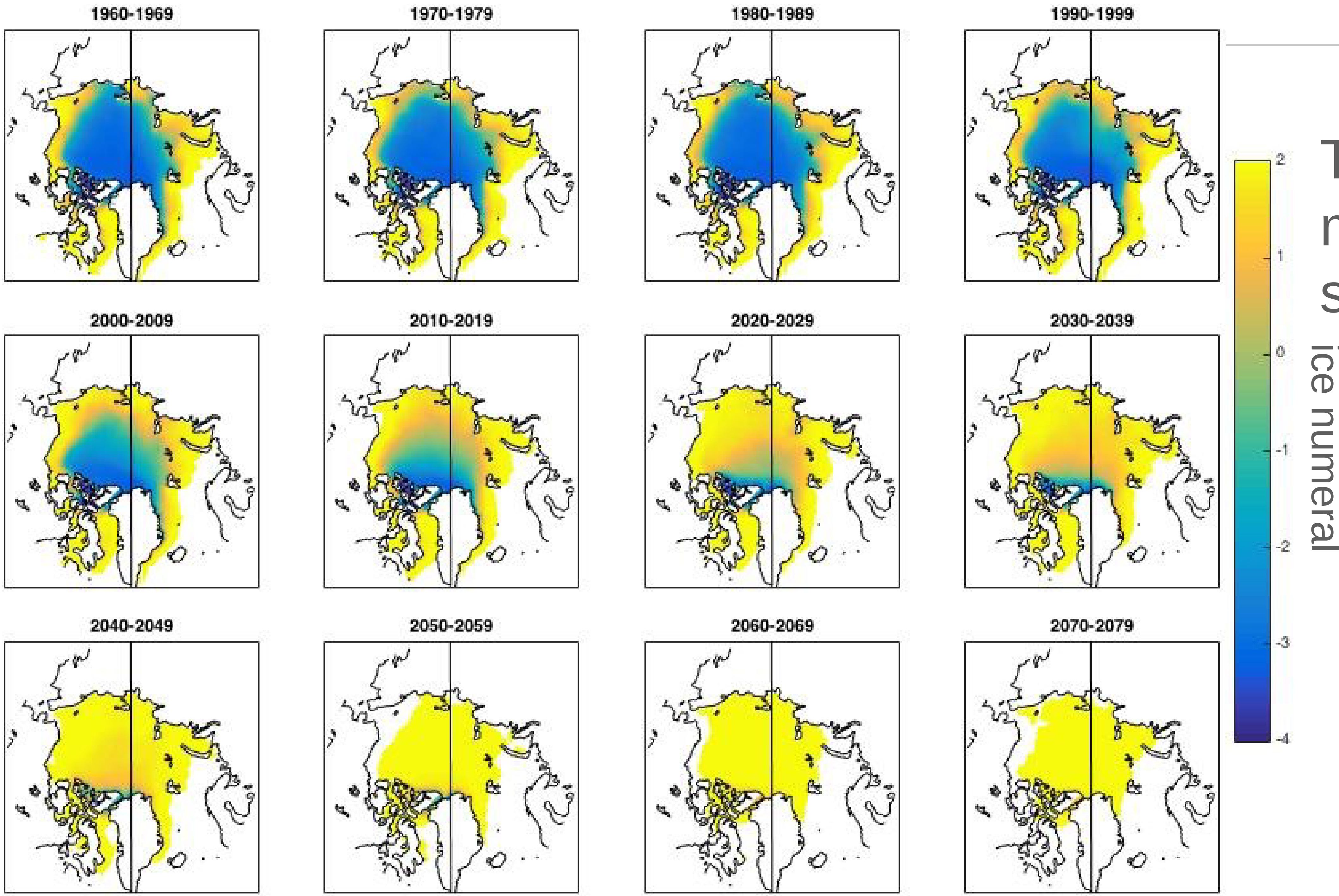


Area of ice under 1 meter is best predictor for high decadal variability

Ice Numeral Analysis

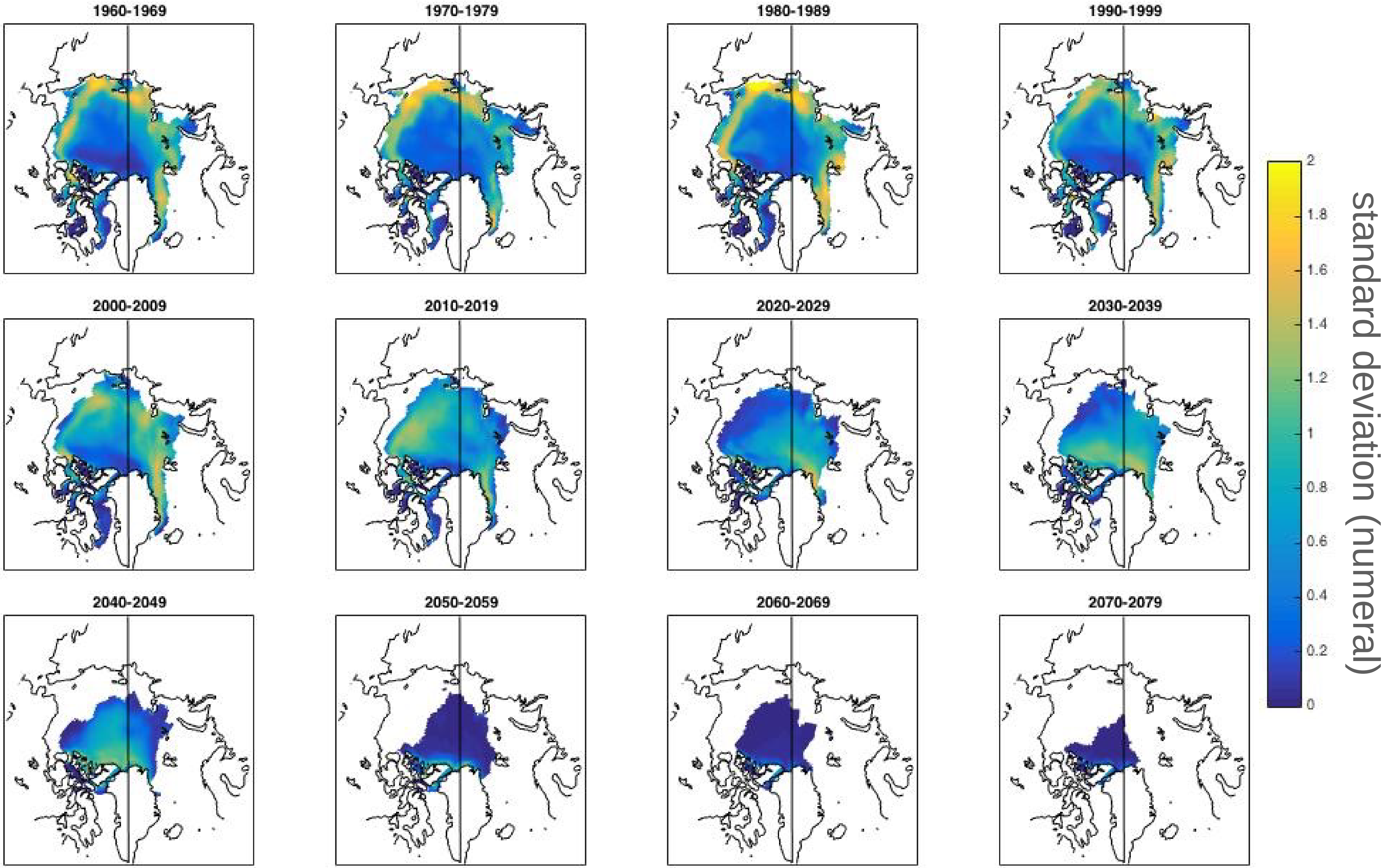
- Ice Numeral = $C_1 * IM_1 + C_2 * IM_{2+} \ldots (C_N * IM_N)$
  - IM is the ice multiplier, a function of ice thickness for a given vessel type
  - C is grid cell ice concentration
  - N = # of ice categories = 5
- ranges from -4 to 2, negative numbers being the major navigational hazards (Smith and Stephenson 2013)

Changing September Ice Numeral



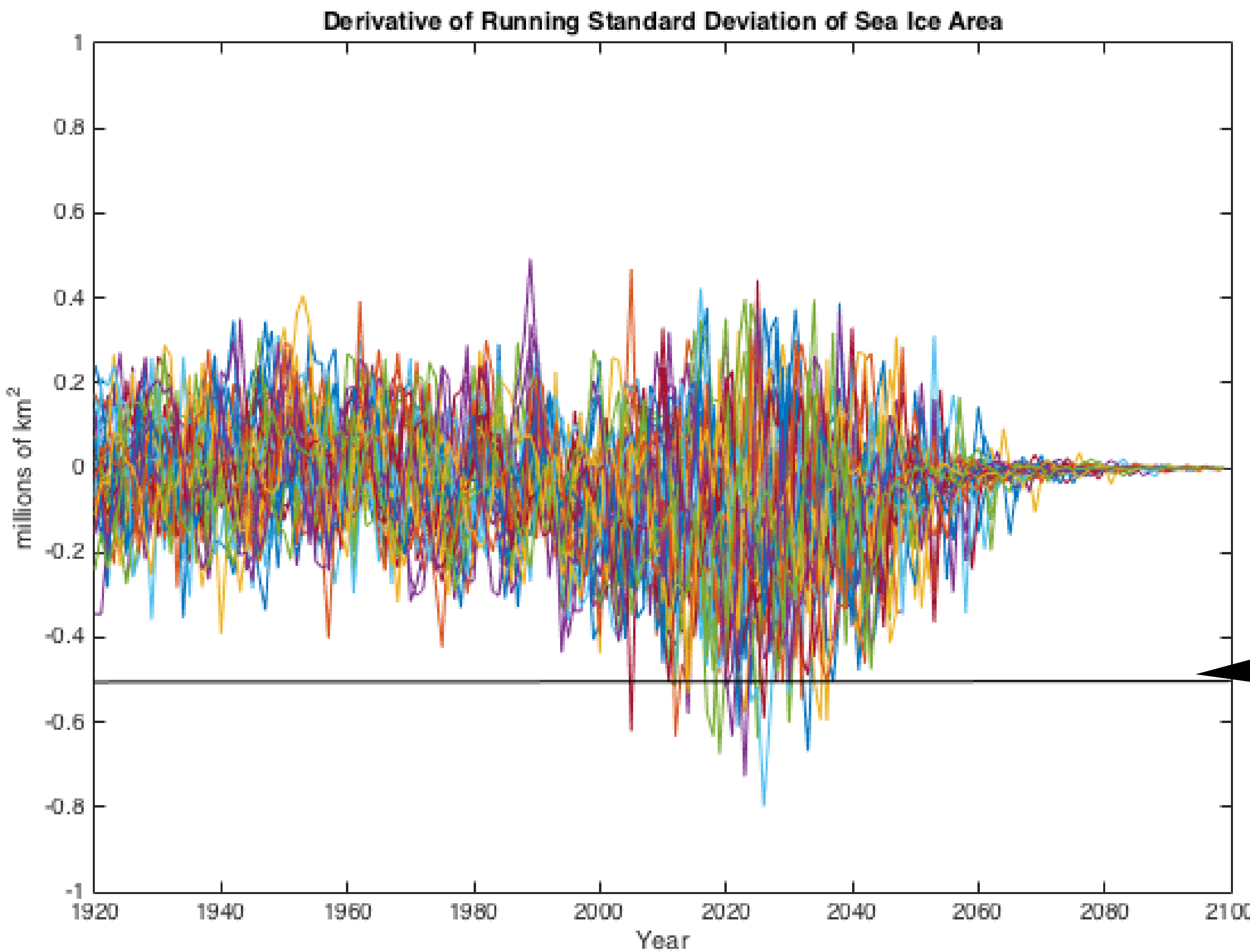
Type C vessels moderately ice-strengthened

Variability in September Ice Numeral



Rapid ice loss (and gain) events

- traditionally RILES (Holland et al 2006)



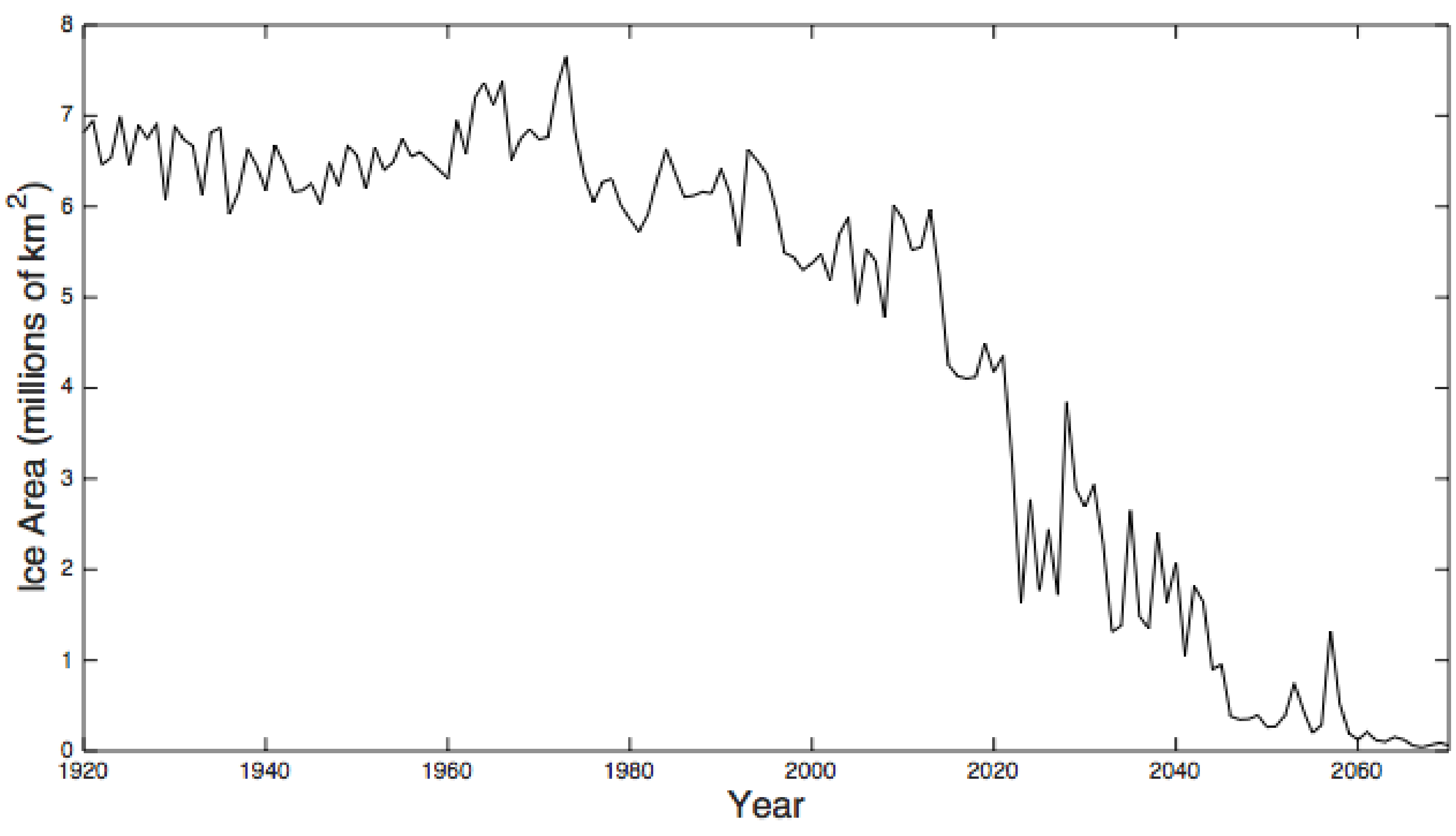
Below 0.5 million km^2 is starting point of a RILE

Rapid ice loss (and gain) events

- Many criteria in mind when trying to define them:
  - equal number of positive and negative events, 20 of each (avg. of 1 per ensemble member)
  - occur largely in the 21st century
  - event length of 4-11 years, ~ evenly distributed
  - can be applied across seasons
  - intuitive; not complex

Defining Events in CESM-LE

Ensemble 28



Formula:

△Ice Area + (△Ice Area/time)

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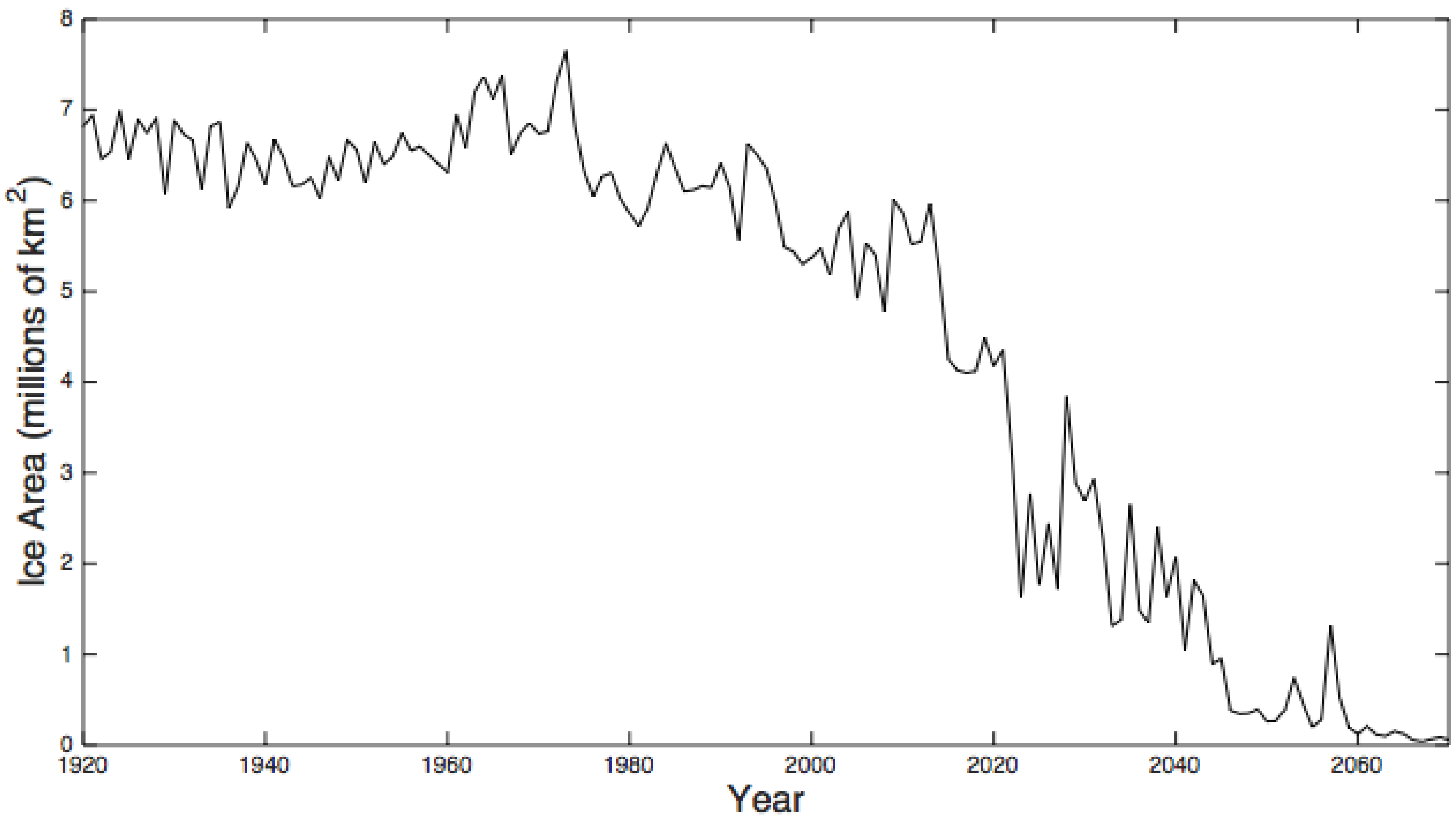


Formula:

△Ice Area + (△Ice Area/time)

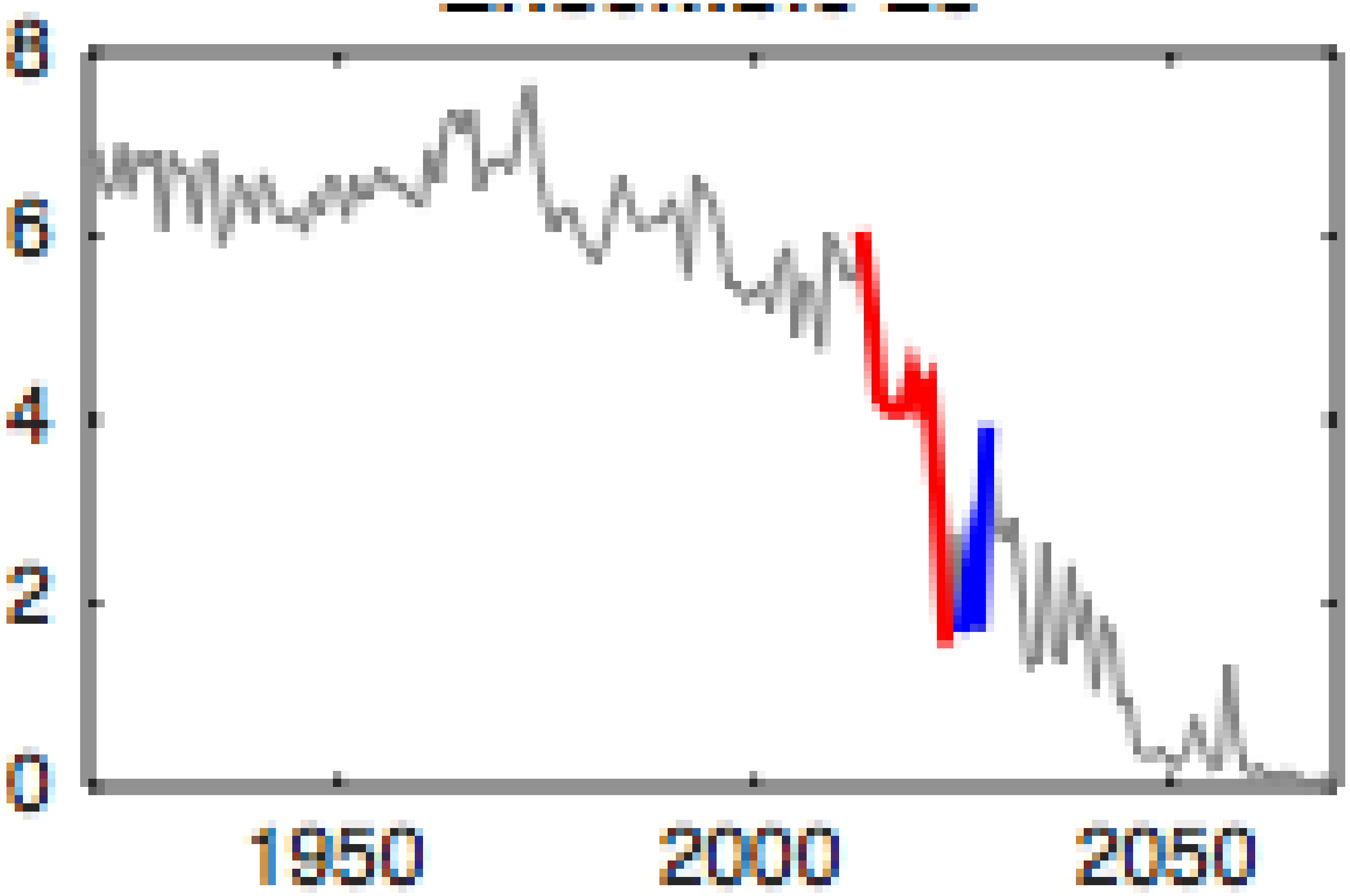
Thresholds:

Positive: > 2.543

Negative: < -3.855

Defining events: Example

Ensemble 28



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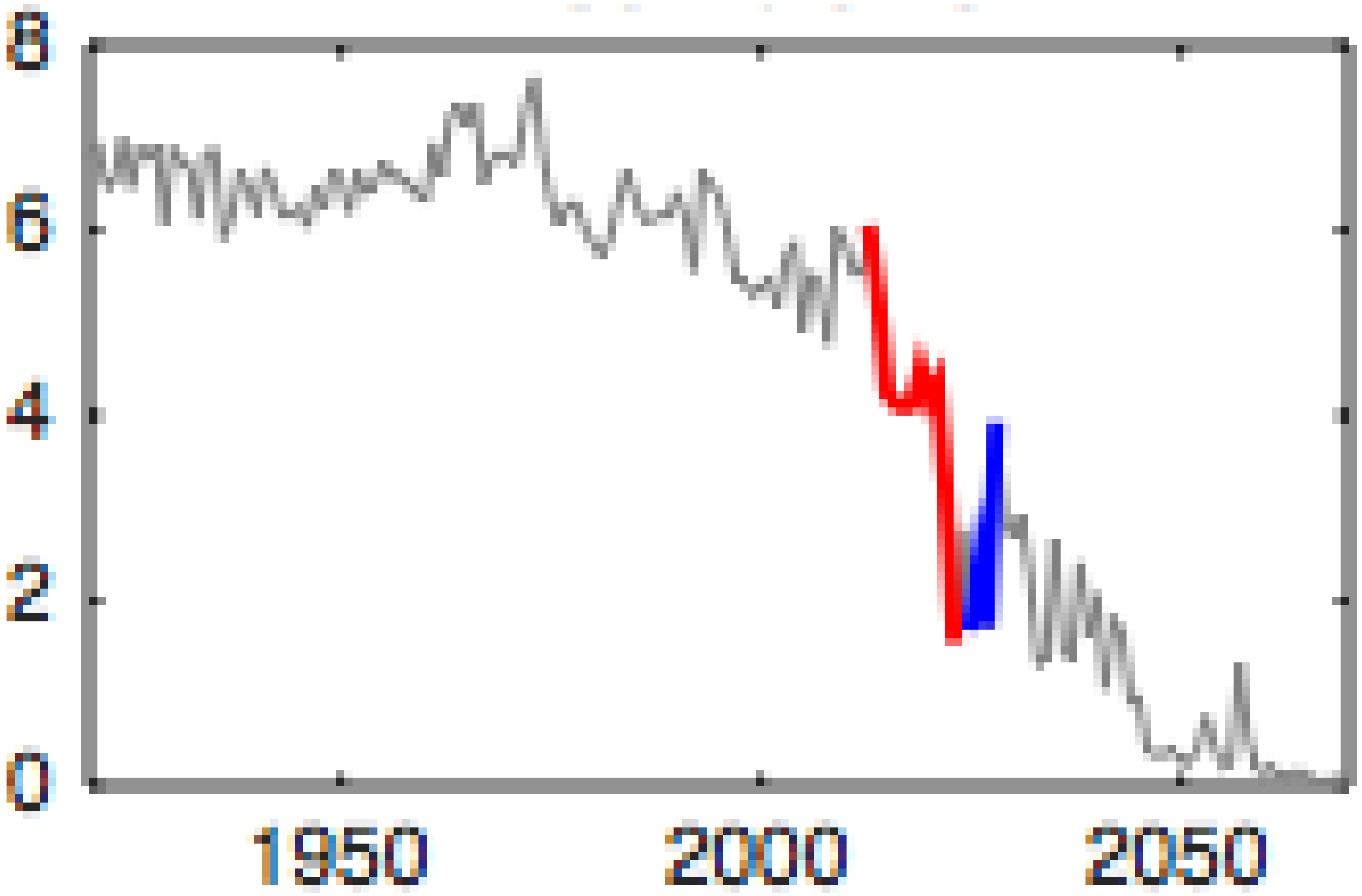
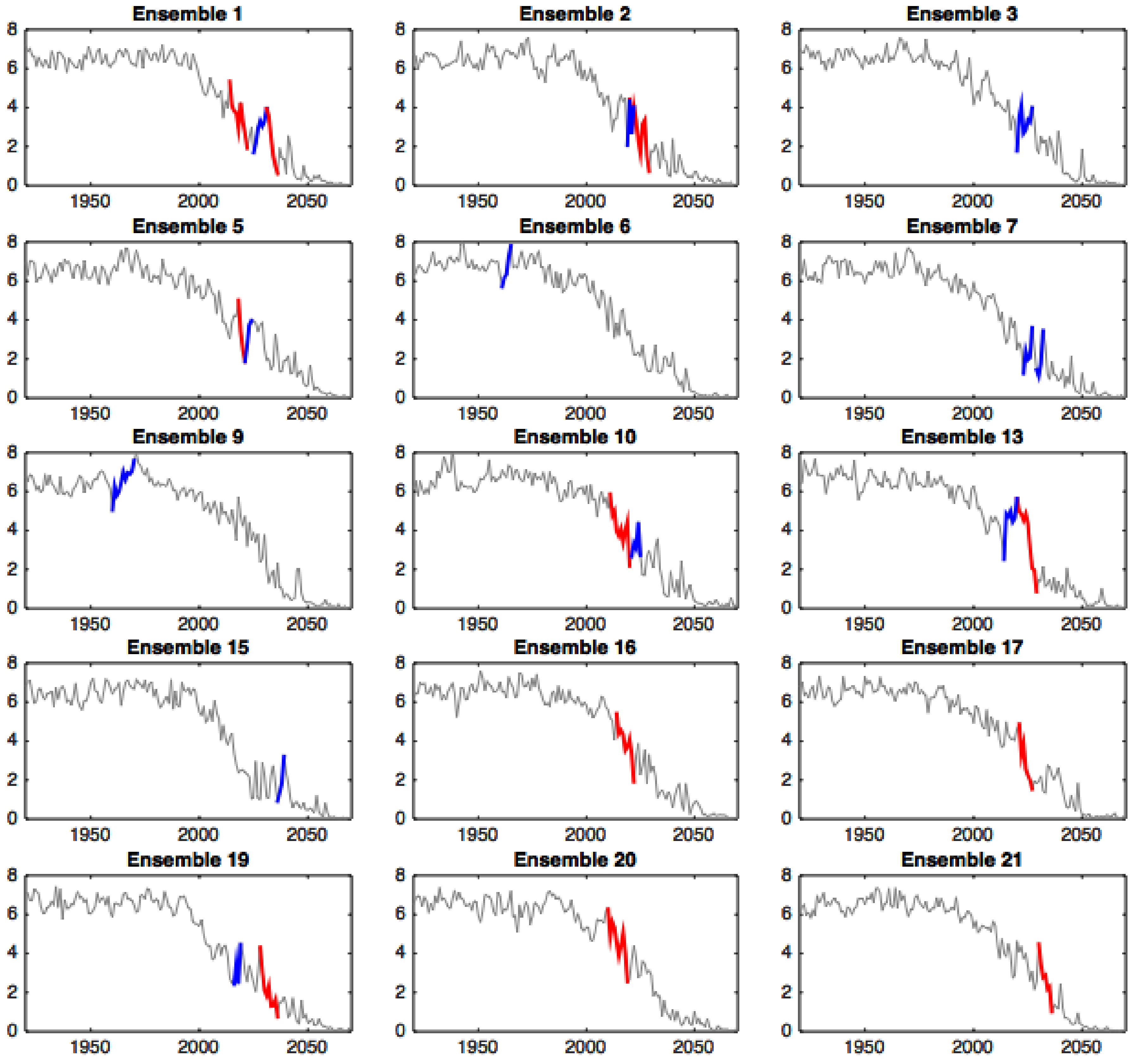


Candidates for ice loss event:

Start	Length	Value
2014	11 yr	-4.765
2015	10 yr	-4.001

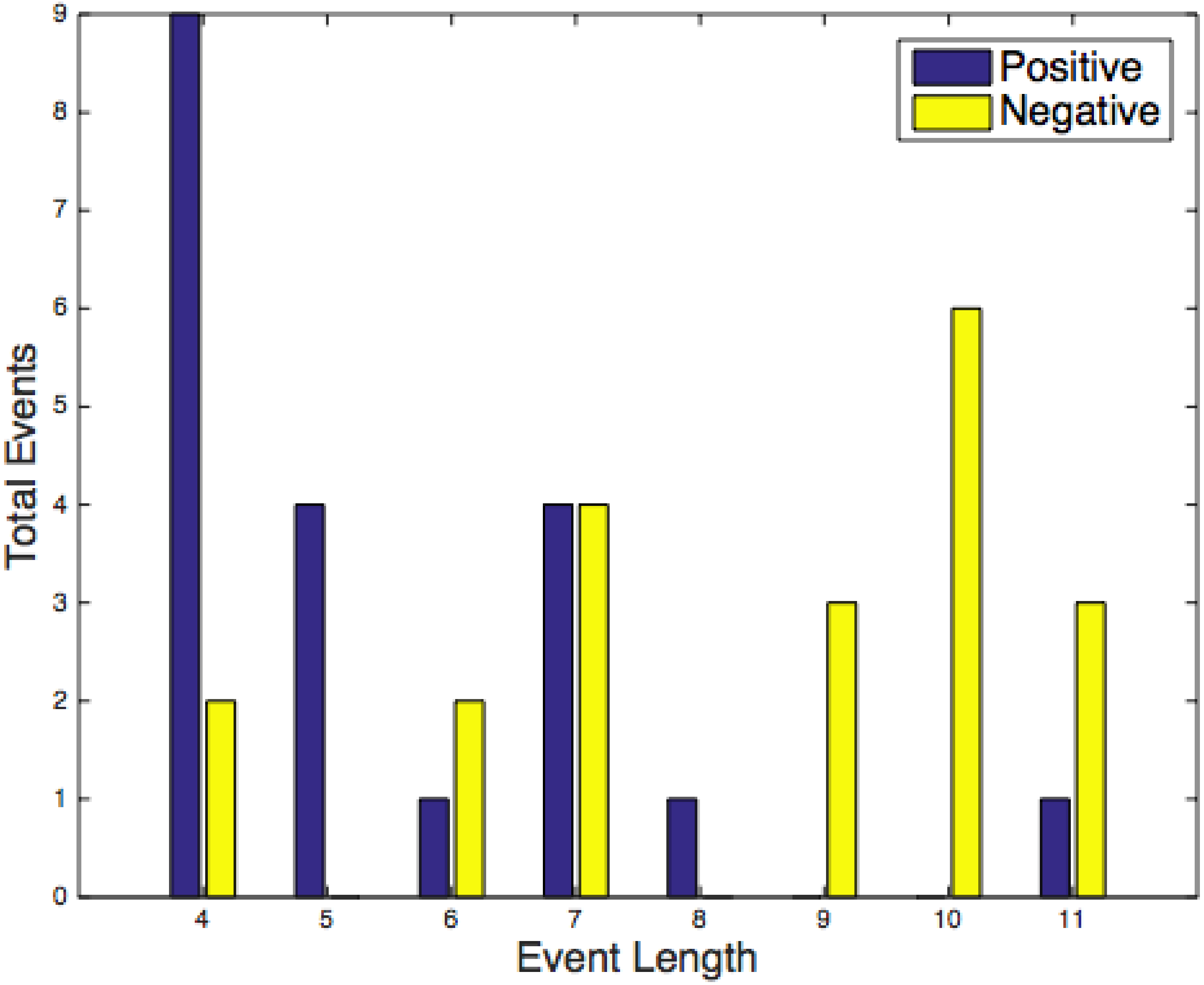
Change = -4.335 million km
Rate = -0.4331 million km/yr
Change + Rate = -4.765



First 20 rapid change events

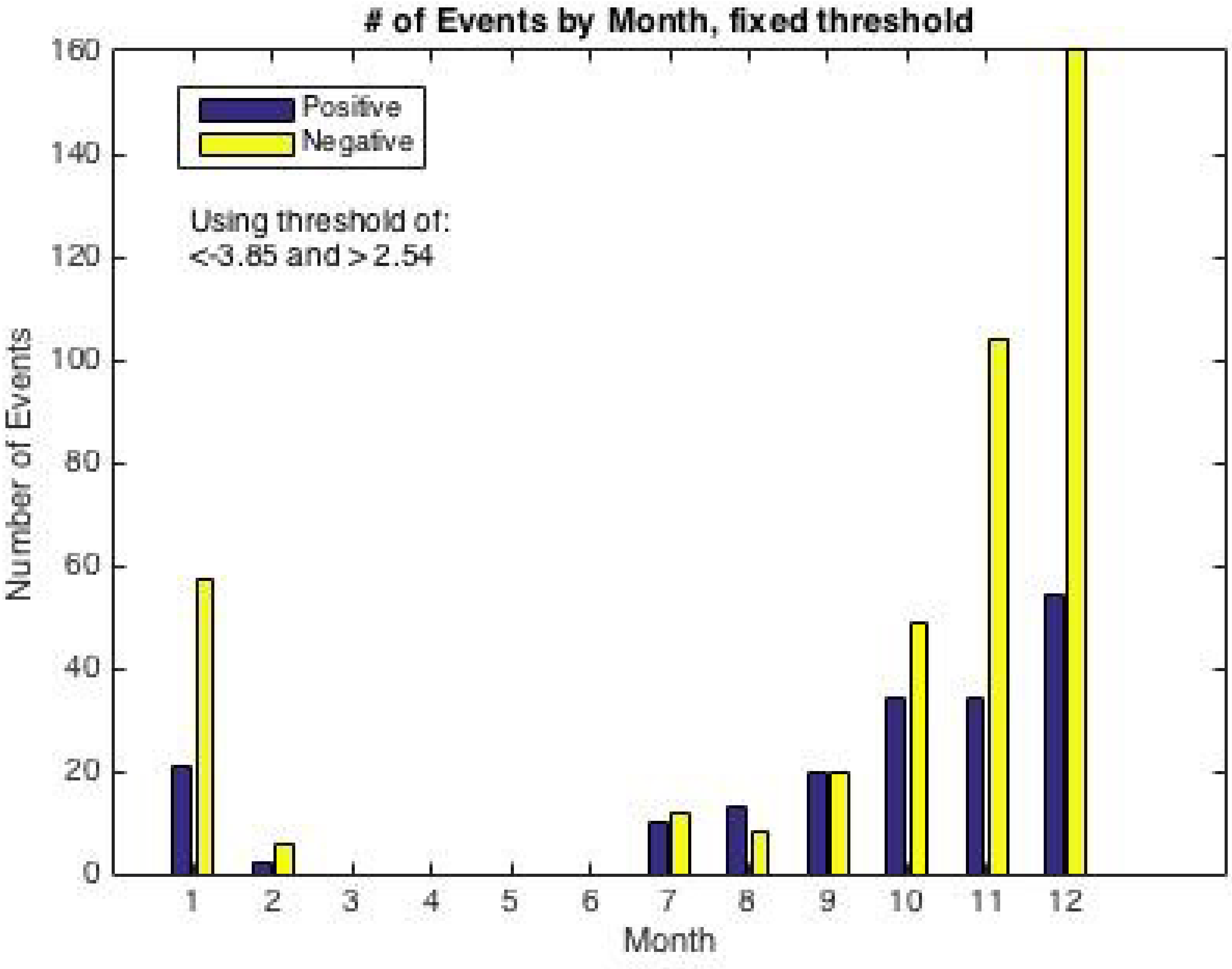
Positive events occur almost anywhere; negative are confined to the downward trend

Events by Window Length



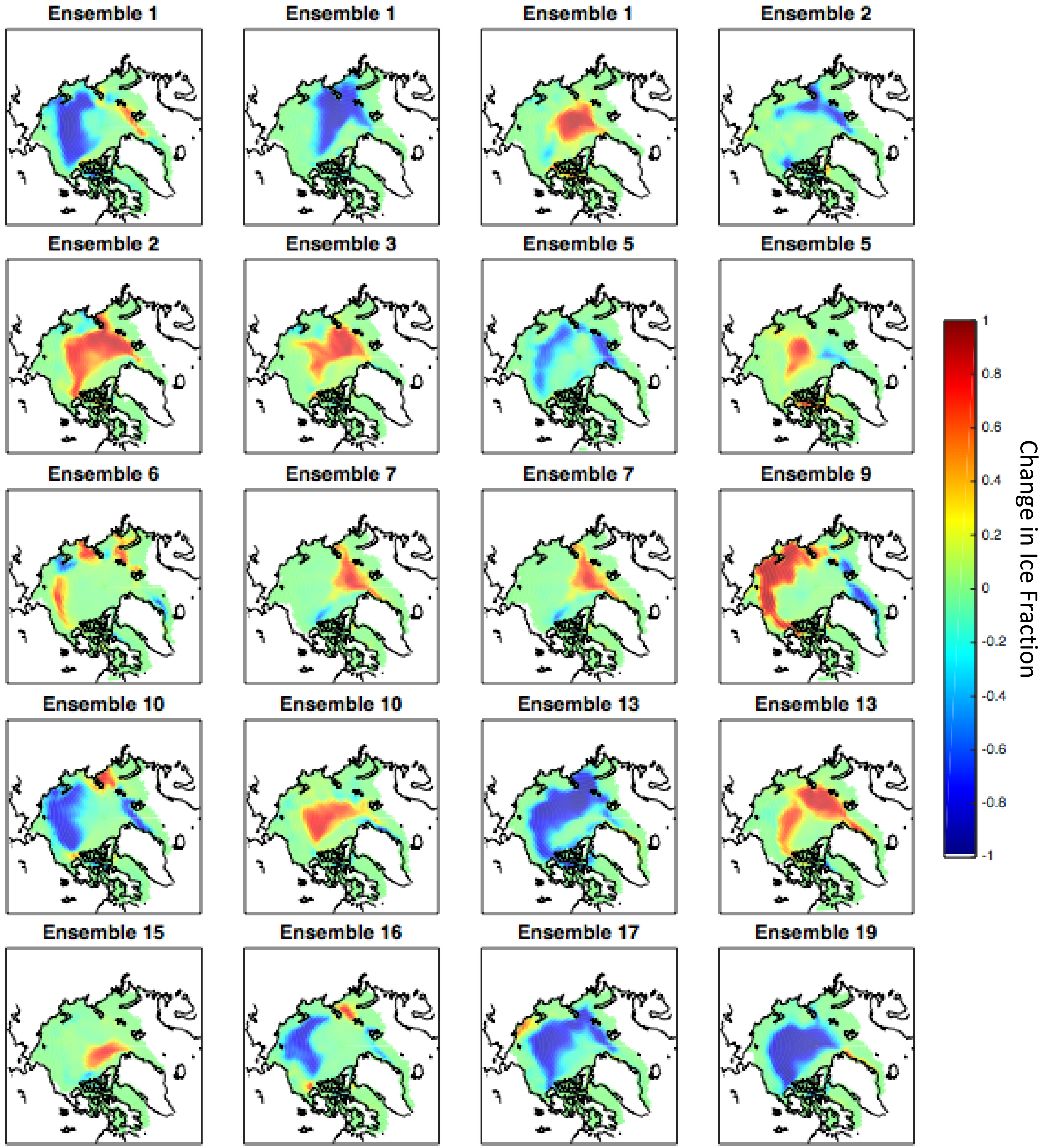
- Ice loss events tend to be longer, gains tend to be shorter

Events by month



- using the same threshold there are no events in spring and many more in late fall and early winter
- the latter is likely due to having more ice to lose at these times, and higher standard deviation in these months

First 20 rapid change events - ice fraction in last year minus first year



Summary and Next Steps

- All ensembles predict increased variability in ice area in all months coinciding with ice loss
- Ice numeral shows promising practical applications
- Rapid ice loss/gain events redefined; more detailed analysis is ongoing
- Next phase incorporates atmospheric and oceanic variables; extreme cyclone frequency; regional drivers and responses