

# Laptev Sea and East Siberian Sea landfast ice: Mechanism of formation and variability of extent

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October 9, 2017

# Outline

I. Introduction to Arctic sea ice and fast ice

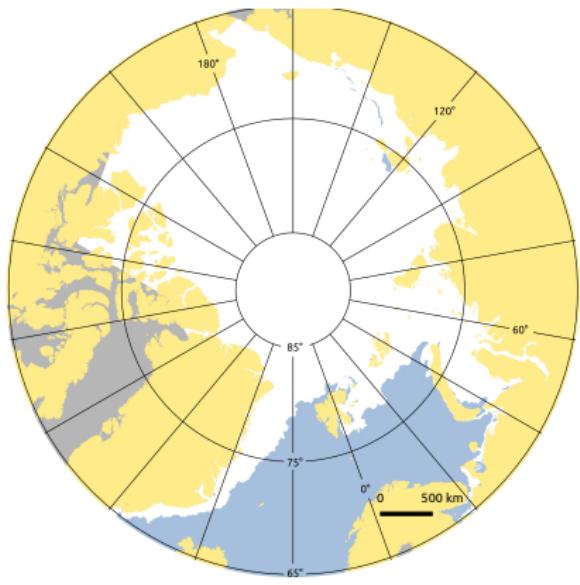
II. Variability of fast ice extent and interannual changes

III. Mechanism of fast ice development

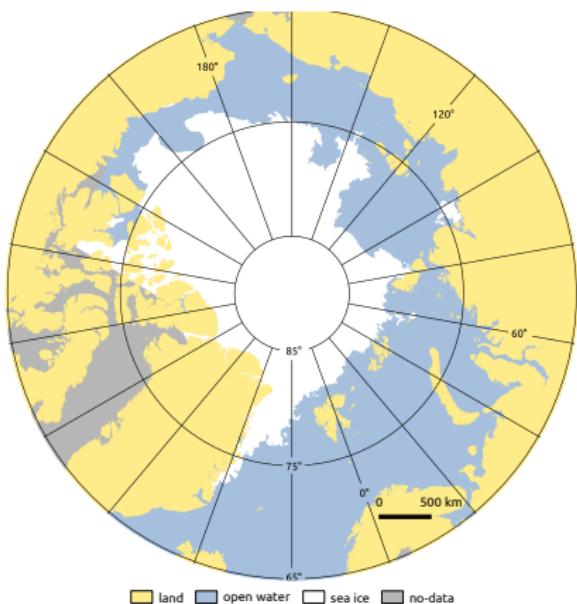
IV. Summary and outlook

# I. Arctic sea ice

17 March 2015

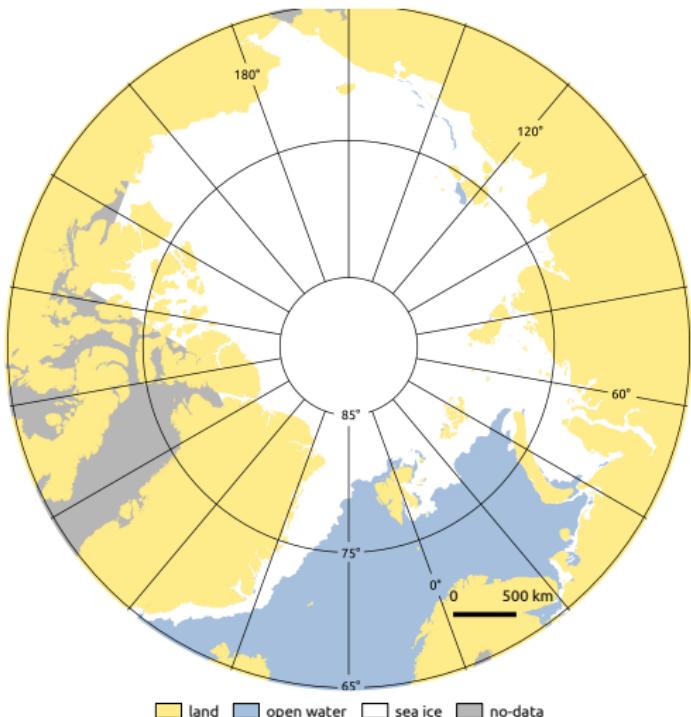


10 September 2015



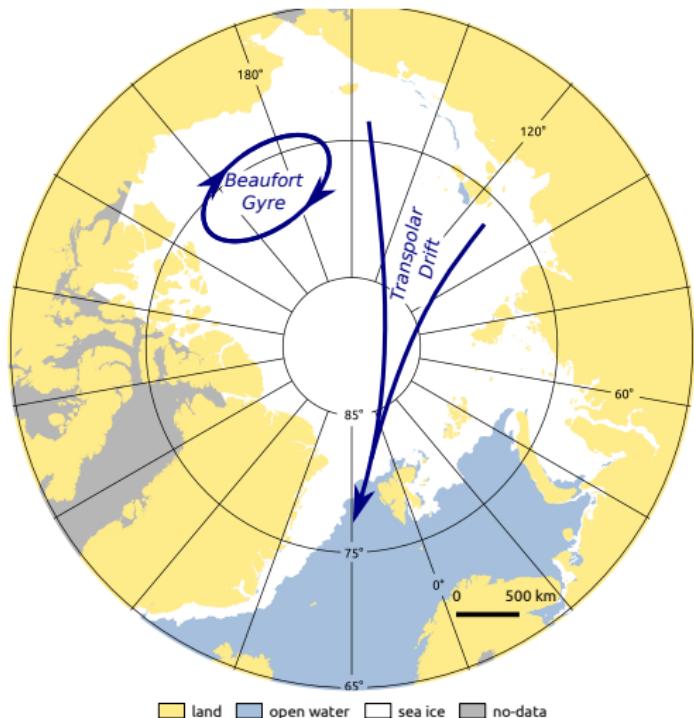
based on Operational Sea Ice Charts,  
Arctic and Antarctic Research Institute, Russia (AARI Charts)

# I. The importance of Arctic sea ice



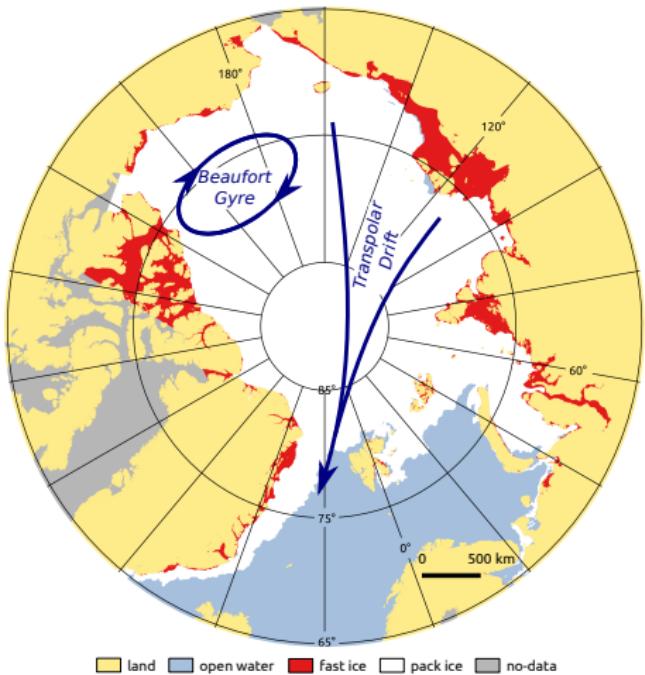
- ▶ **Climate system:**  
reflects about 80% of solar radiation
- ▶ **Ecosystem:**  
provides habitat and hunting platform
- ▶ **Human activity:**  
navigation, exploration,  
indigenous people activity

# I. Arctic fast ice



17 March 2015 (AARI Charts)

# I. Arctic fast ice



~ 13% of total sea ice extent

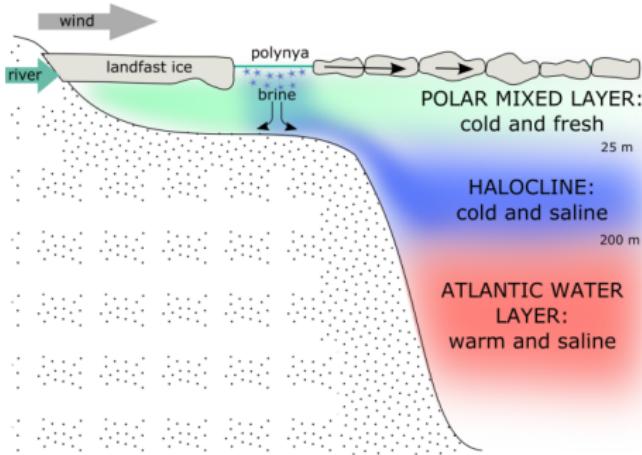
## Definition

Motionless and adjacent to the shore

- ▶ Operational charts - experts opinion  
(2-7 days, e.g. AARI charts)
- ▶ Remote sensing techniques
  - time interval between images  
(e.g. 25 days - Mahoney et al. 2005)

17 March 2015 (AARI Charts)

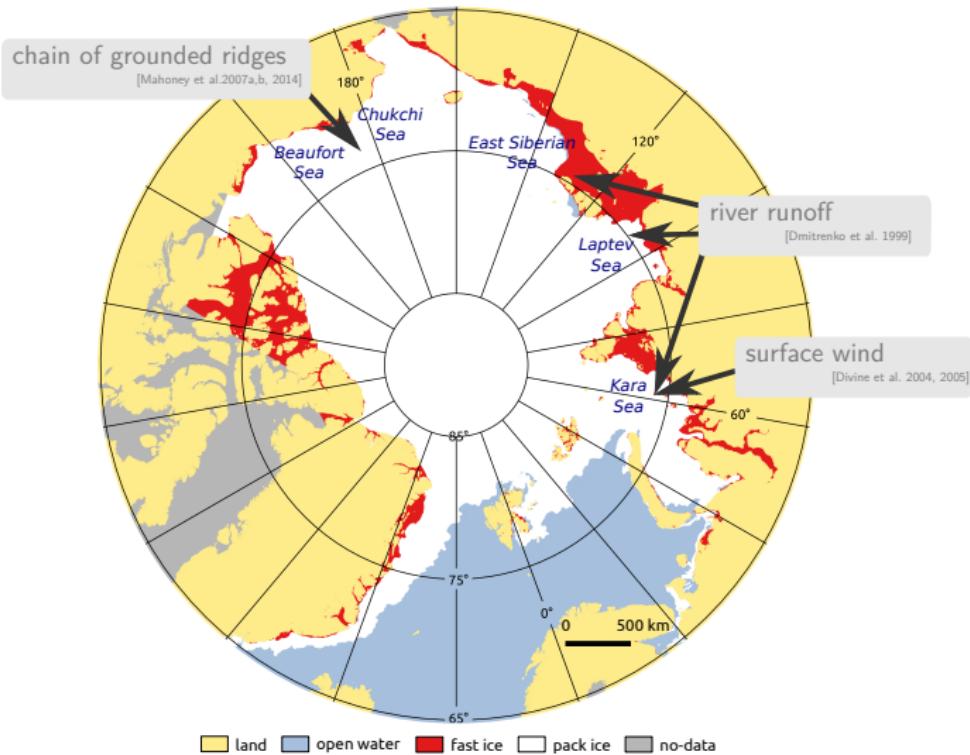
## I.Importance of Arctic fast ice



Itkin et al. 2015

- ▶ affects state of the Arctic Ocean and atmosphere  
(Maqueda et al. 2004, Itkin et al. 2015)
- ▶ protects coasts from erosion  
(Rachold et al. 2000, Eicken et al. 2005)
- ▶ helps to maintain submarine permafrost  
(Rachold et al. 2000)
- ▶ affects human activity  
(Johannessen et al. 2005, Hughes et al. 2011, Weintrit 2013)

# I. Factors controlling variability of fast ice winter extent



# I.Objectives

## Objective 1 - Annual variability

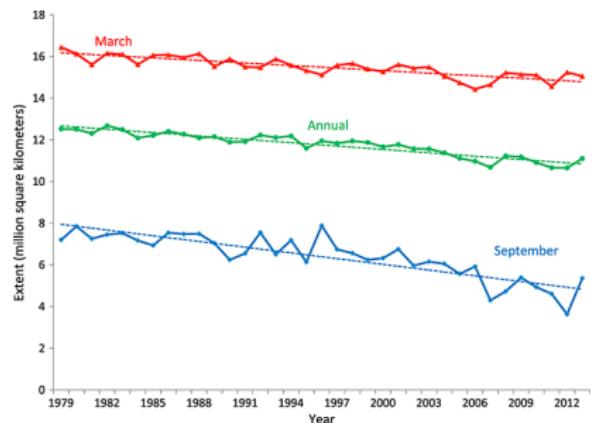
- ▶ To describe the **annual fast ice cycle** and reveal the **mechanisms driving the seasonal development** of fast ice.

## Objective 2 - Interannual variability and changes

- ▶ To evaluate **changes** in fast ice cover **on interannual scales** and link them to climate processes.

# I. Changes in Arctic sea ice and fast ice

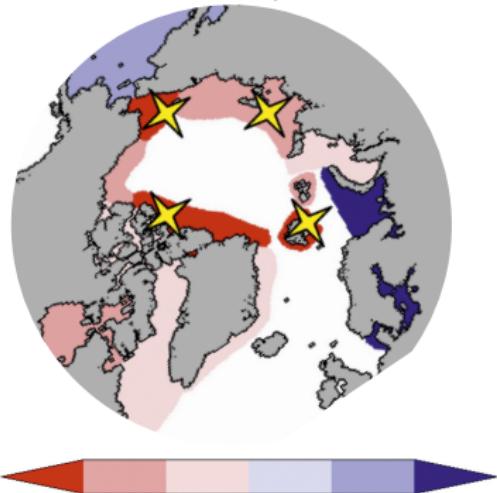
Sea ice extent, 1979-2013



(Meier et al.2014)

- ▶ declining trend thought all month
- ▶ acceleration over the past decade

Fast ice extent, 1976-2007



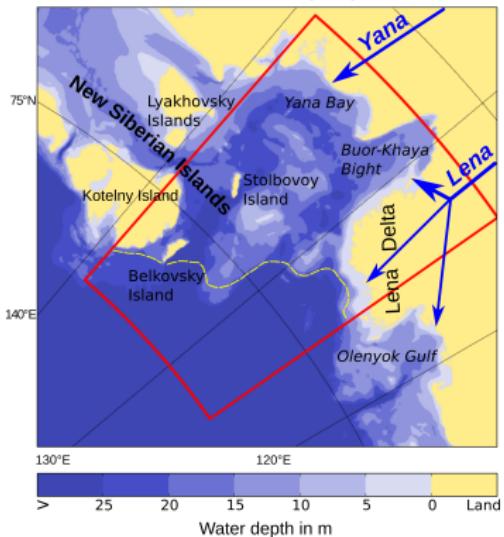
Change per Decade Relative to Mean (%)

(Yu et al.2014)

- ▶ overall decrease in extent - 7 % per decade  
Laptev Sea - 8.4% per decade
- ▶ shorter landfast ice season  
Laptev and East Siberian Seas - 2.5 weeks per decade

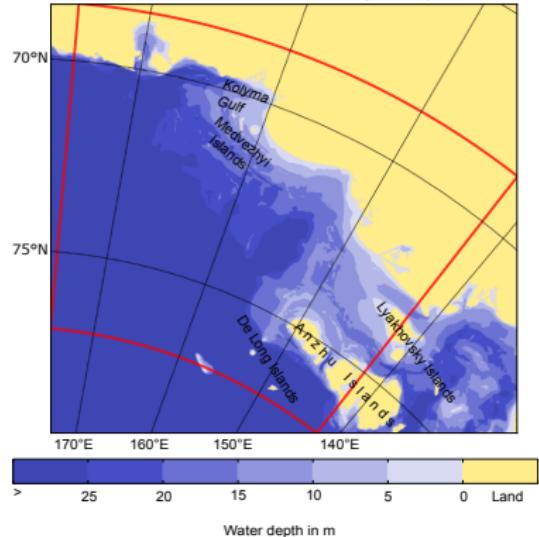
## II. Regions of interest and fast ice information

Laptev Sea (LS)



AARI charts, 1999-2013, weekly

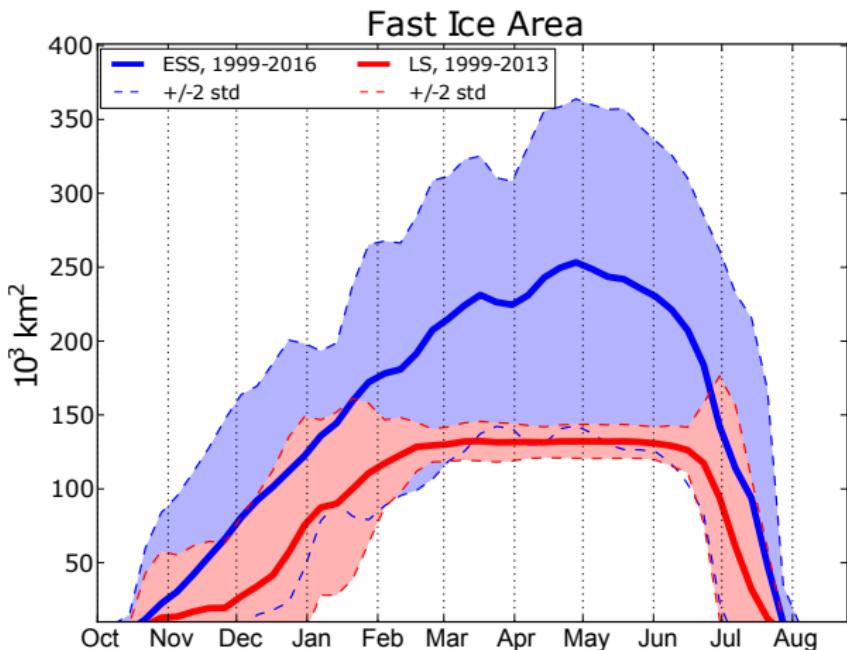
East Siberian Sea (ESS)



AARI charts, 1999-2015, weekly

## II. Annual fast ice cycle, 2000-2001

## II. Mean annual fast ice cycle



Interannual variability

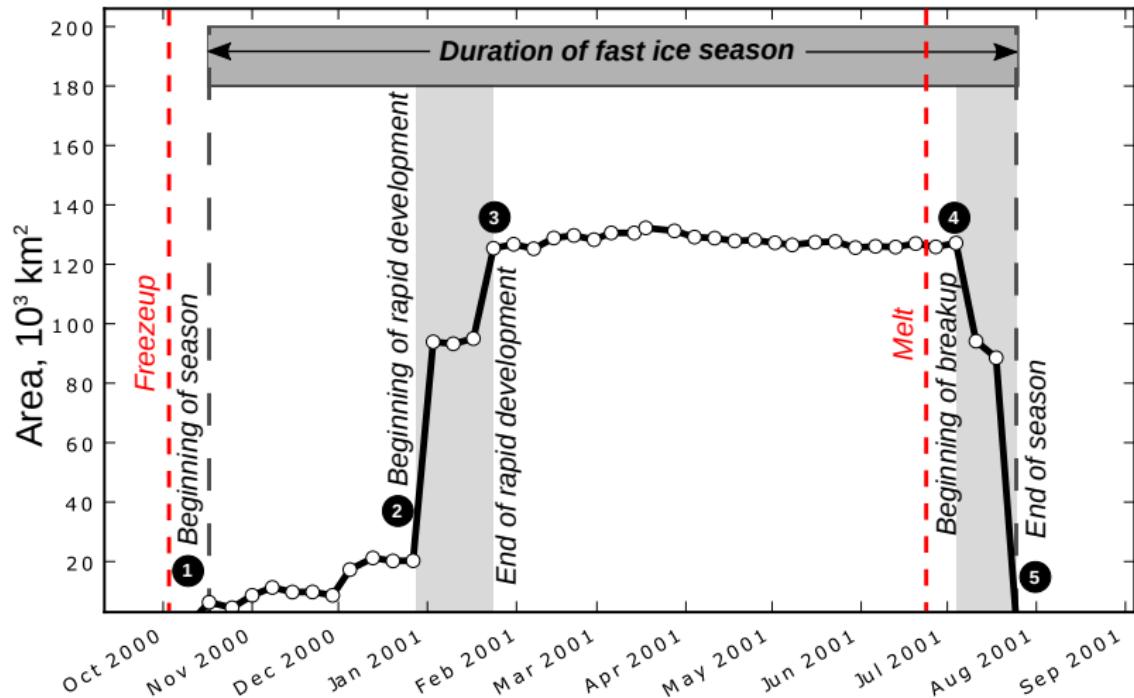
**Laptev Sea:**

- ▶ high in November–February
- ▶ low in winter

**East Siberian Sea:**

- ▶ high in winter

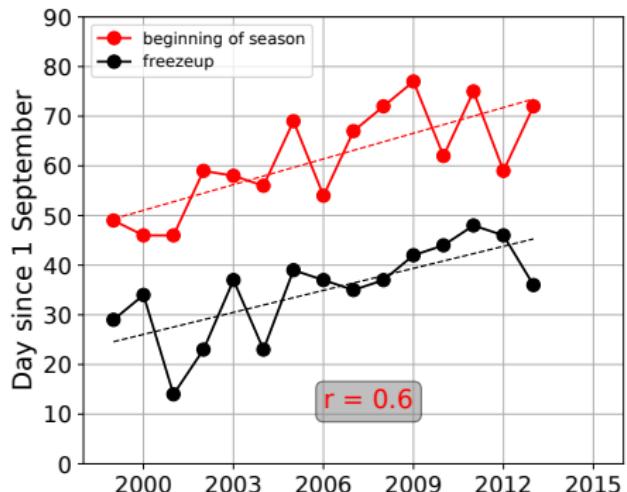
## II. Key events of annual cycle



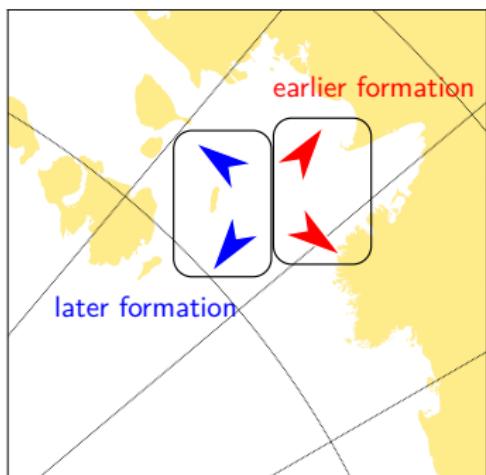
A typical annual fast ice cycle and Key events for the Laptev Sea

## II. Beginning of season: LS

Beginning of season and freezeup



Wind direction

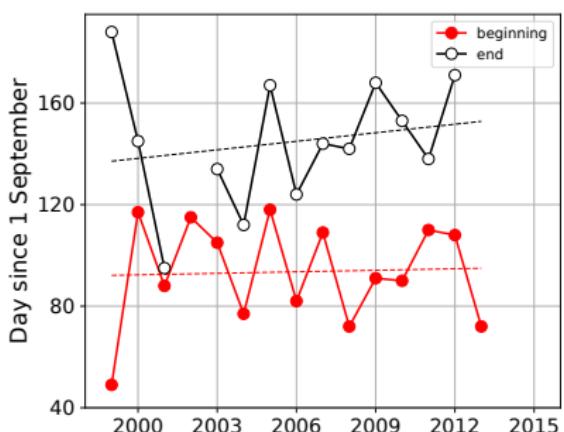


- ▶ tendency towards later formation  
1.7 days/year ( $p < 0.01$ )
- ▶ partly explained by delay in freezeup  
( $r = 0.6$ )

- ▶ onshore wind - earlier fast ice formation
- ▶ offshore wind - later fast ice formation

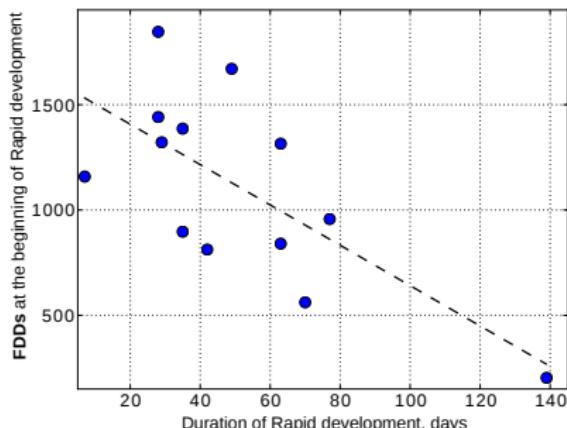
## II. Rapid development: LS

Beginning and end of rapid development



- ▶ high variability of dates
- ▶ tendency towards later end  
0.4 days/year ( $p=0.07$ )

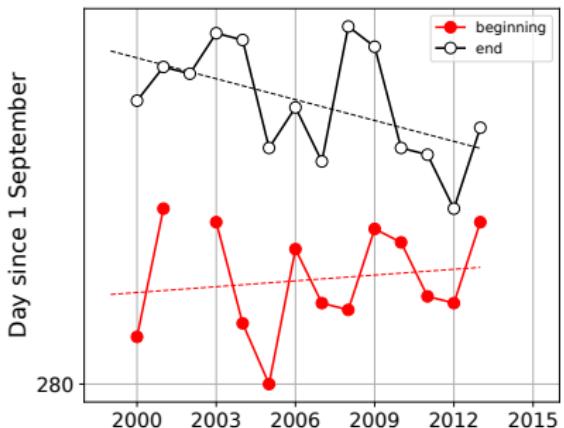
Duration of rapid development



- ▶ duration of period depends on accumulated FDD
- ▶ Modal ice thickness  $Hi(FDD) = 70-80$  cm

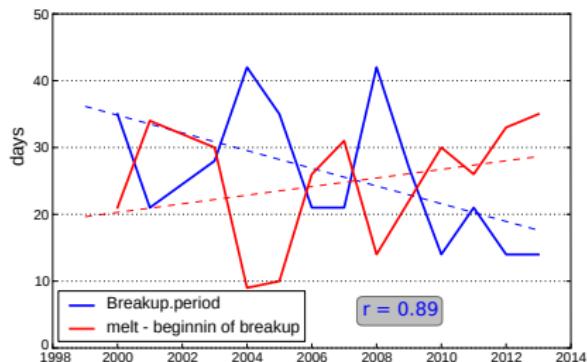
## II. Breakup: LS

Beginning breakup and end season



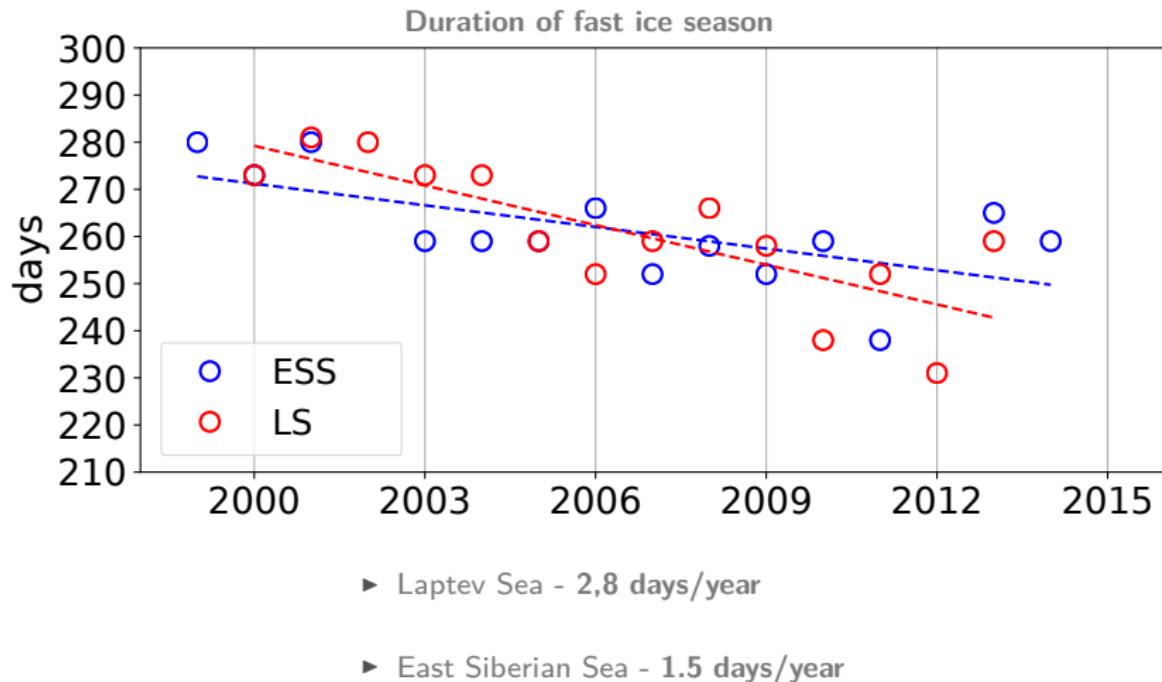
- ▶ no changes in beginning  
0.3 days/year ( $p=0.63$ )
- ▶ tendency towards earlier end  
-1.0 days/year ( $p=0.06$ )

Duration of breakup

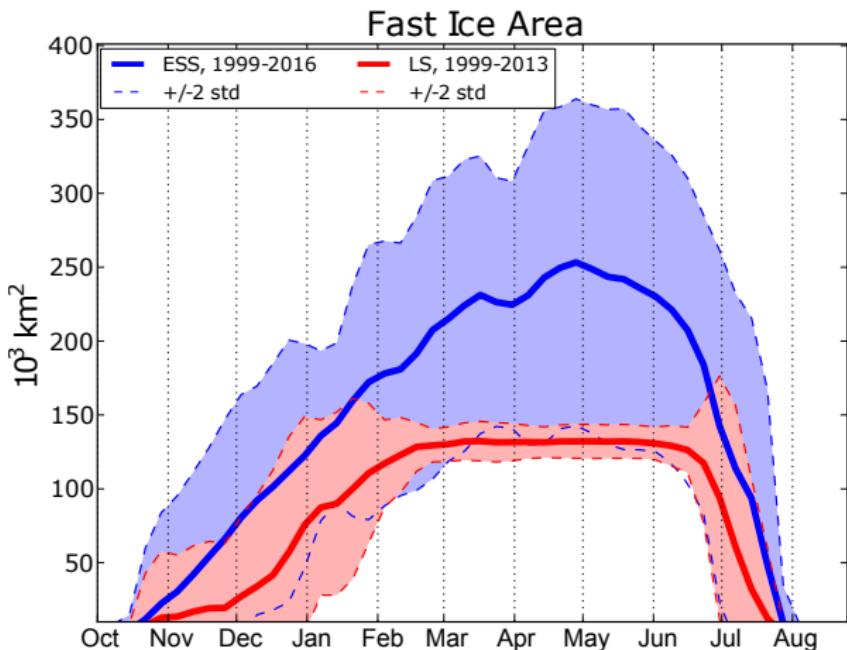


- ▶ fast ice needs less time to breakup
- ▶ duration of breakup depend on TDD acquired prior beginning of breakup

## II. Duration of fast ice season



## II. Mean annual fast ice cycle



Interannual variability

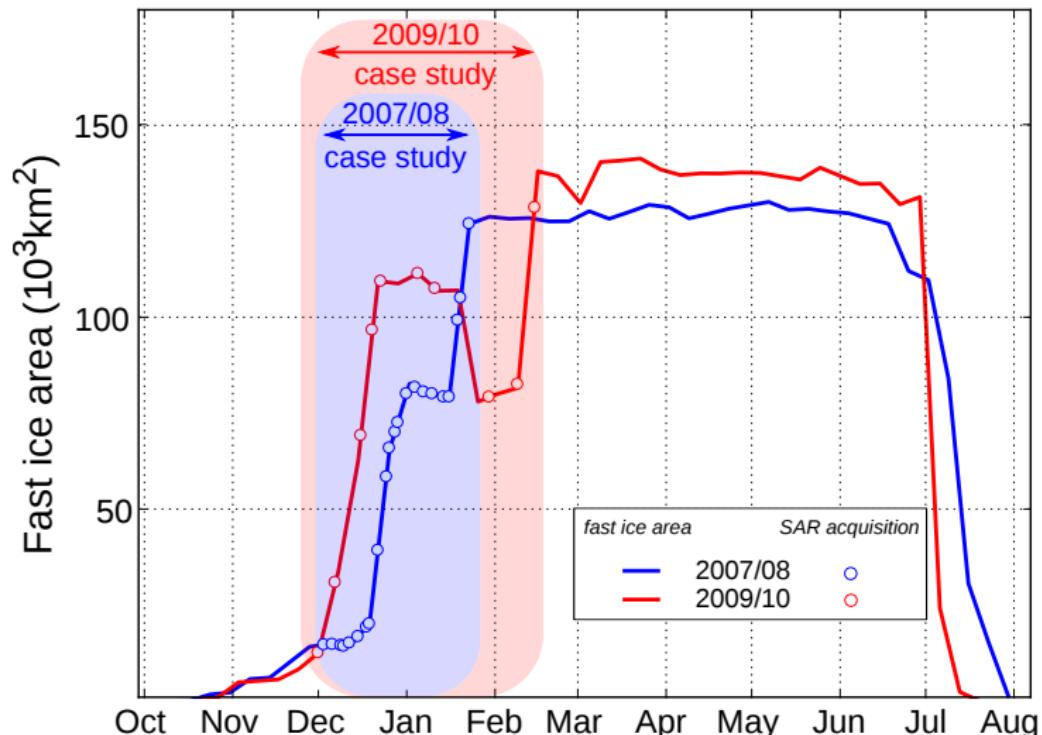
**Laptev Sea:**

- ▶ high in November-February
- ▶ low winter

**East Siberian Sea:**

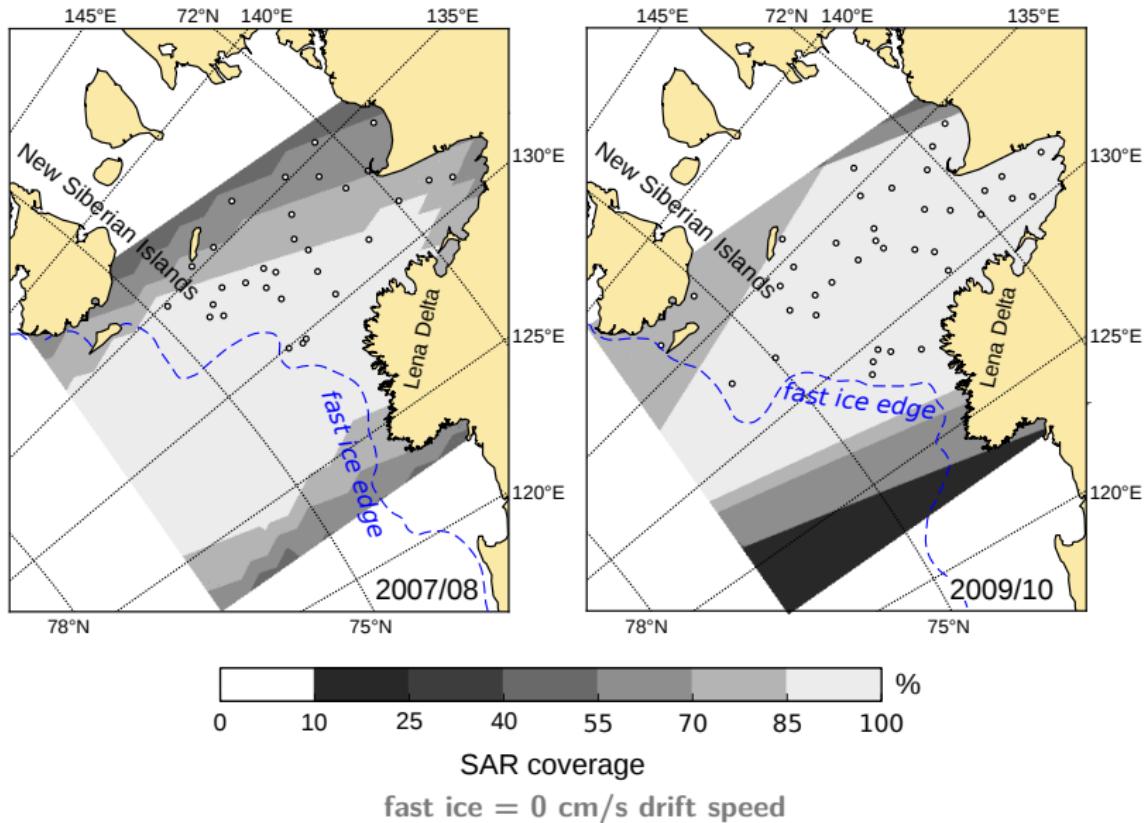
- ▶ high in winter

### III. Laptev Sea : Case study 2008/09 and 2009/10

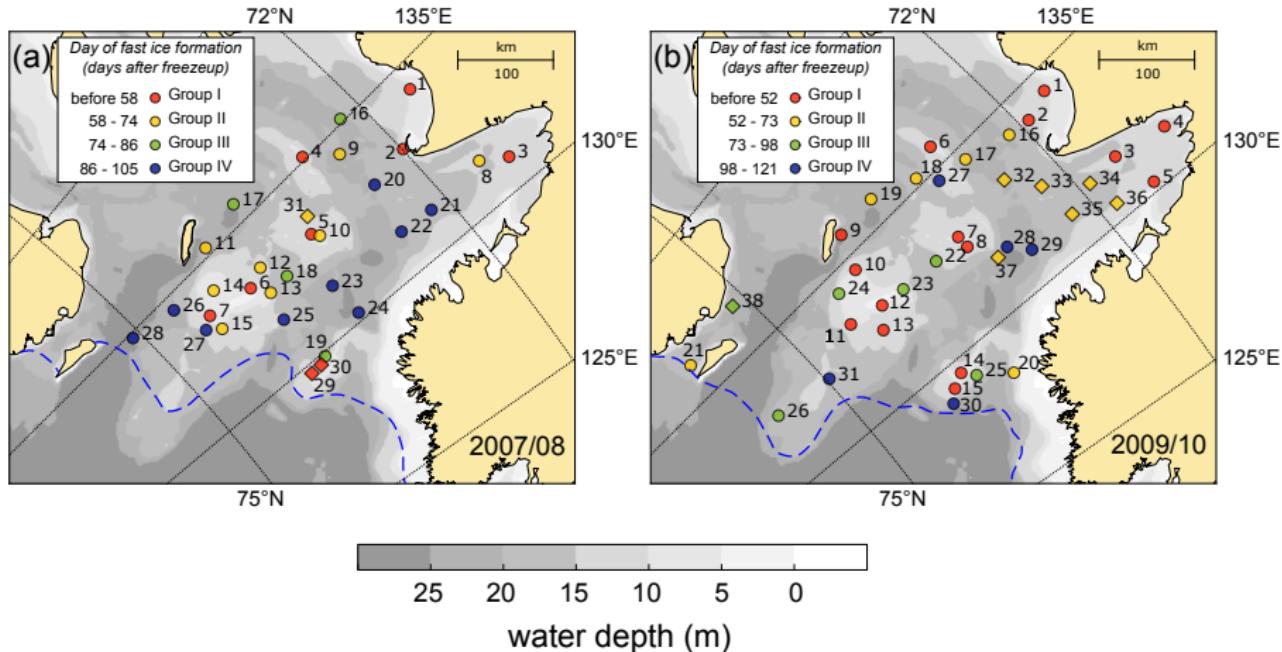


- ▶ Synthetic Aperture Radar (SAR) image every 2-14 days
- ▶ spatial resolution 150 m

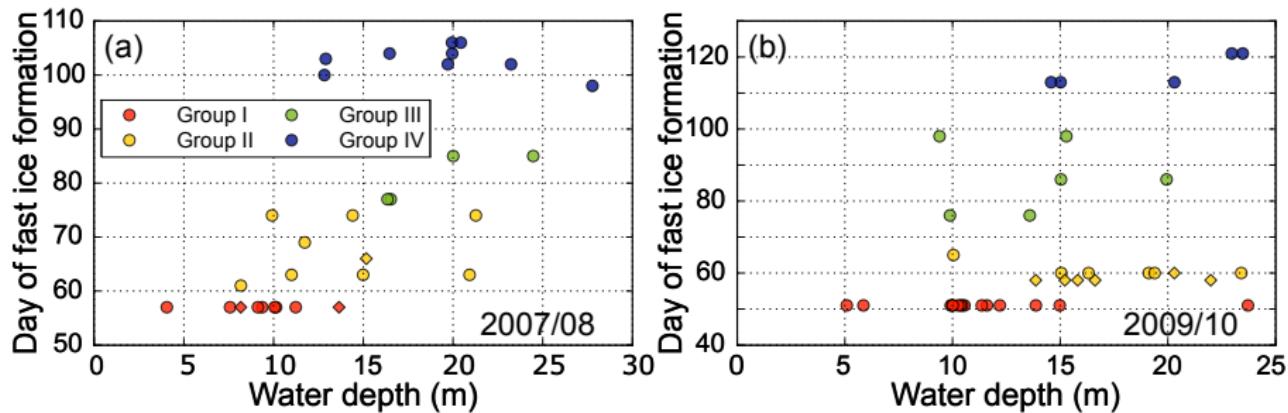
### III. Tracked sea ice features



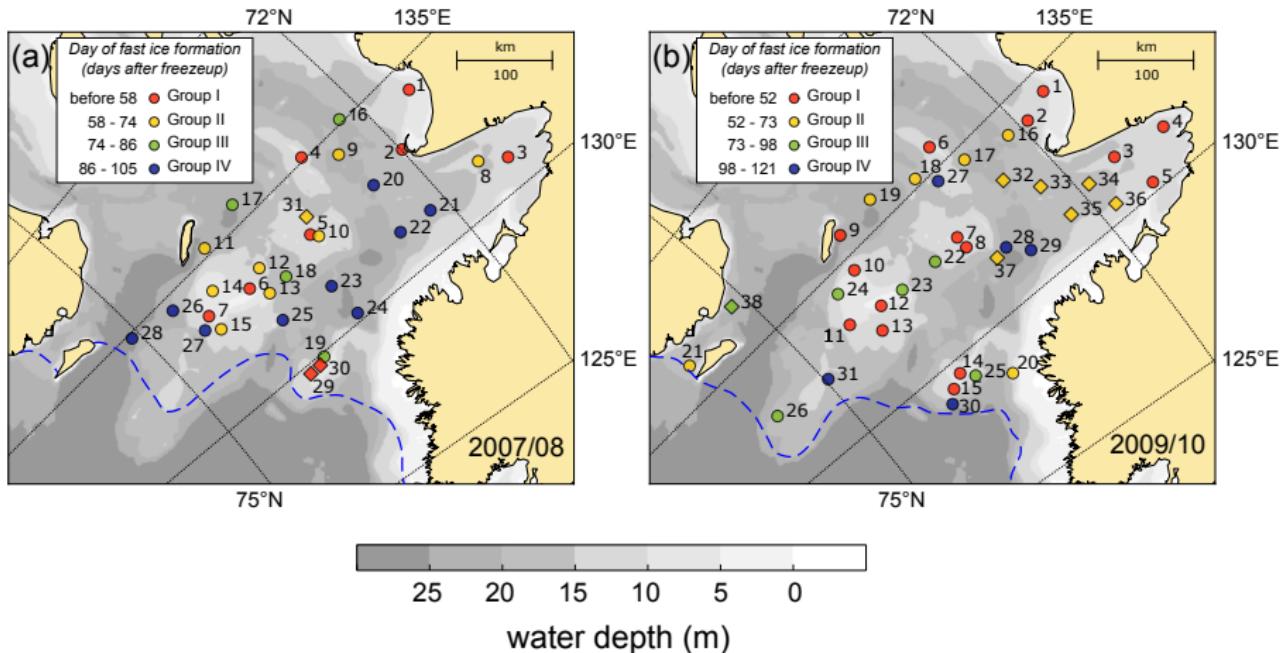
### III. Final location of features



### III. Water depth vs fast ice formation day



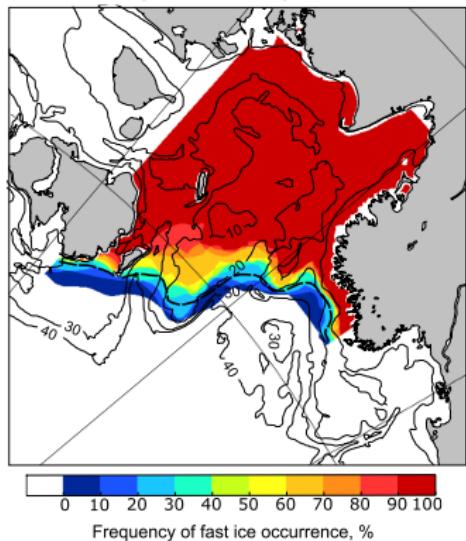
### III. Final location of features



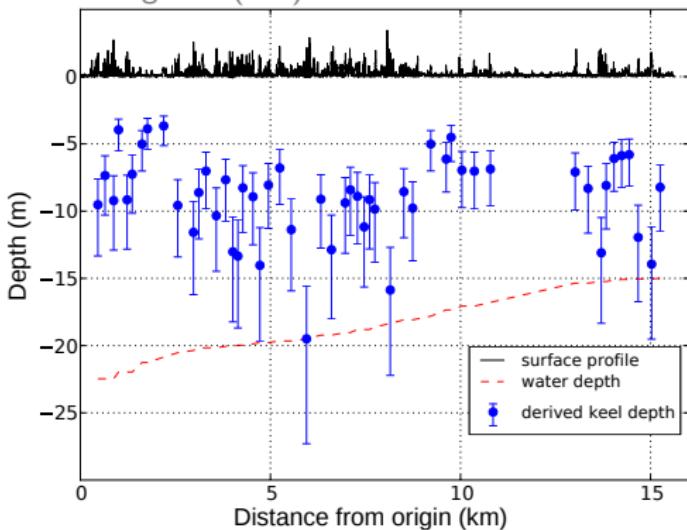
- relatively thin ice becomes grounded over the shoals
- it serves as stabilizing points for surrounding sea ice
- low variations in winter extent predefined by the bathymetry

### III. Fast ice at the end of rapid development

End of Rapid Development



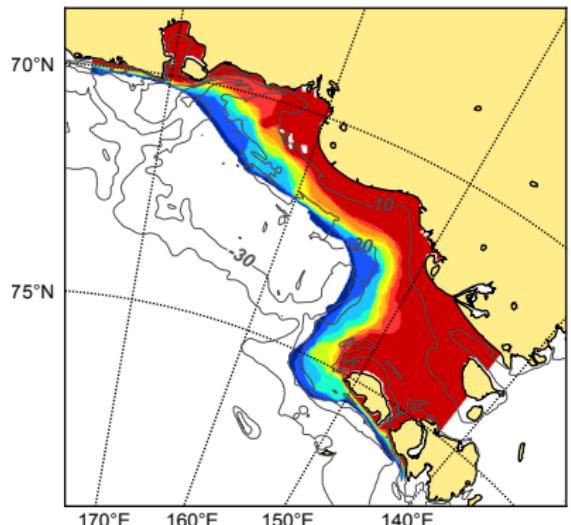
Electromagnetic (EM) ice thickness measurements



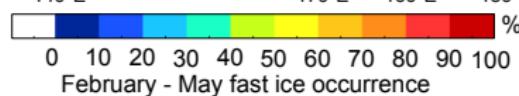
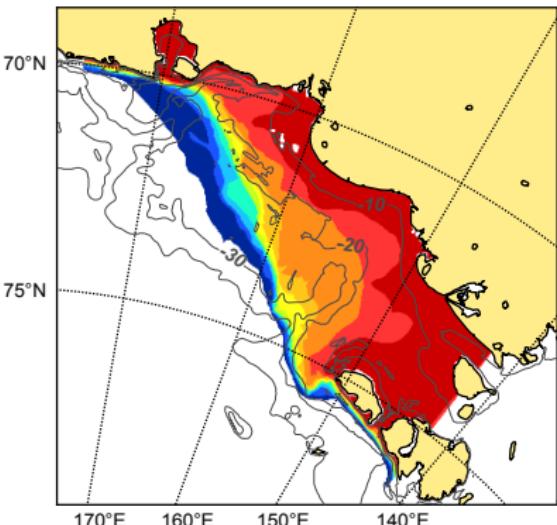
- variations in winter fast ice edge is likely controlled by grounding of deep ice ridges

### III. East Siberian Sea Fast ice modes

A. Small - mode



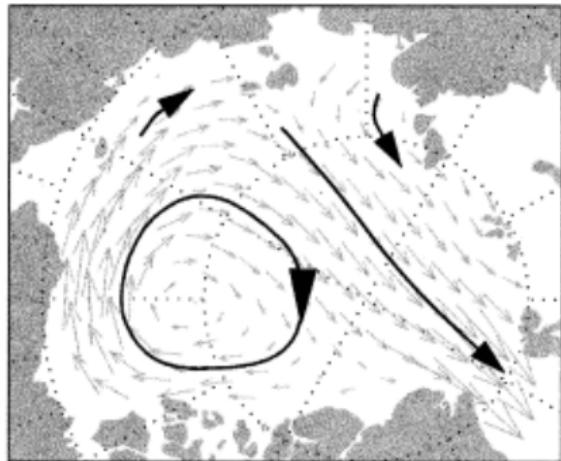
B. Large - mode



### III. Arctic circulation

Negative Arctic Oscillation index (AO)

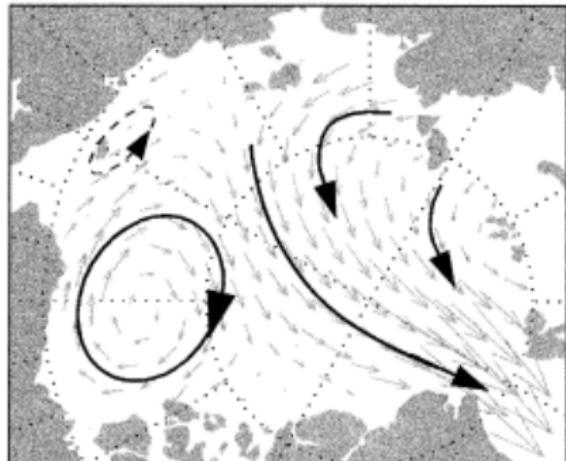
(c) Low Index



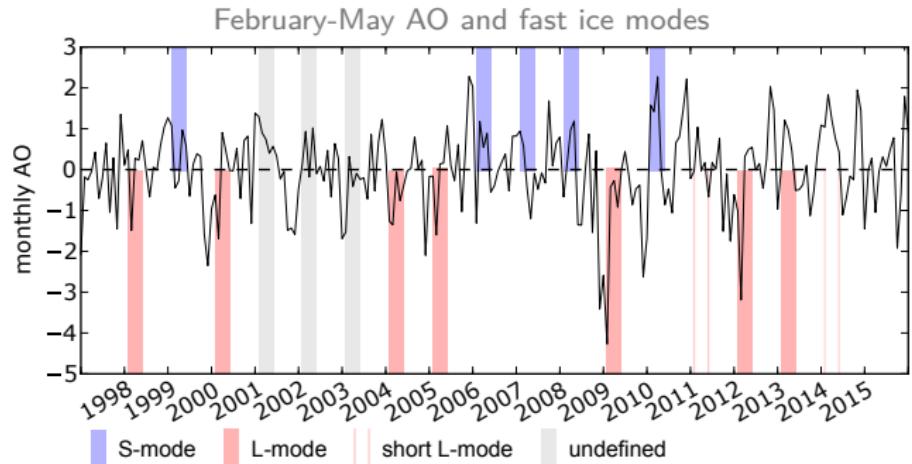
(Rigor et al. 2002)

Positive Arctic Oscillation index (AO)

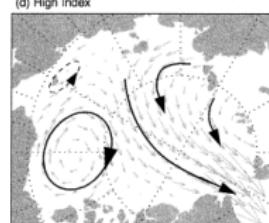
(d) High Index



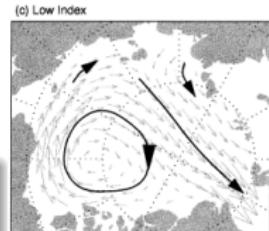
### III. East Siberian Sea fast ice modes



Positive AO



Negative AO



#### Hypothesis

Sea ice import during AO - leads to formation thick ice ridges, which become grounded and stabilize fast ice in L-mode.

## IV. Summary and outlook

### Objective 1 - Annual variability

- ▶ Annual fast ice cycle described with Key events
- ▶ Sea ice grounding is a key process in annual fast ice development

#### Laptev Sea

- ▶ re-occurring grounded features define **stable configuration**
- ▶ **stable configuration** reached when  $Hi > 90$  cm

### Open questions

- ▶ role of grounding in the East Siberian Sea requires verification
- ▶ mechanisms of breakup are not well-understood

## IV. Summary and outlook

### Objective 2 - Interannual variability and changes

- ▶ Tendency towards shorter fast ice season (LS - 2,8 days/year, ESS - 1.5 days/year)
  - ▶ later fast ice formation increase probability of coastal polynya events
  - ▶ higher rates of coastal erosion
  - ▶ sediment entrainment
  - ▶ methane release
- ▶ No changes in winter fast ice extent
- ▶ Shorter time required for the Laptev Sea fast ice to breakup in summer