

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

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Outline

I. Introduction to Arctic sea ice and fast ice

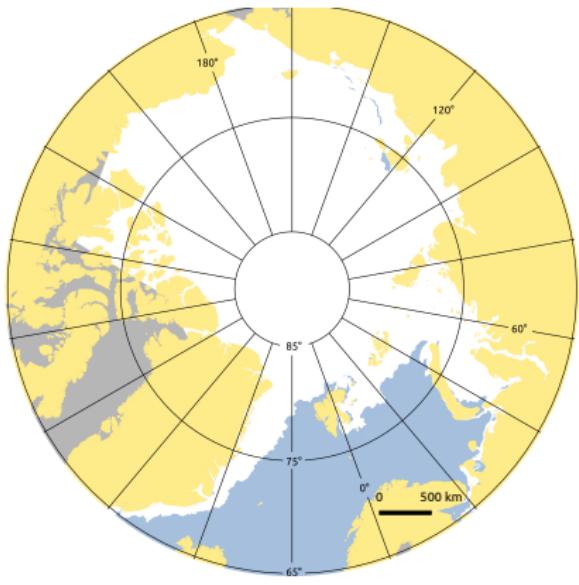
II. Variability of fast ice extent and interannual changes

III. Mechanism of fast ice development

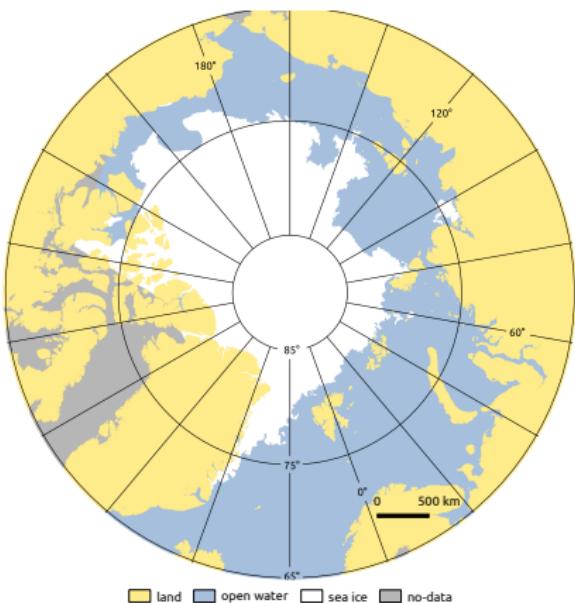
IV. Summary and outlook

I. Arctic sea ice

17 March 2015



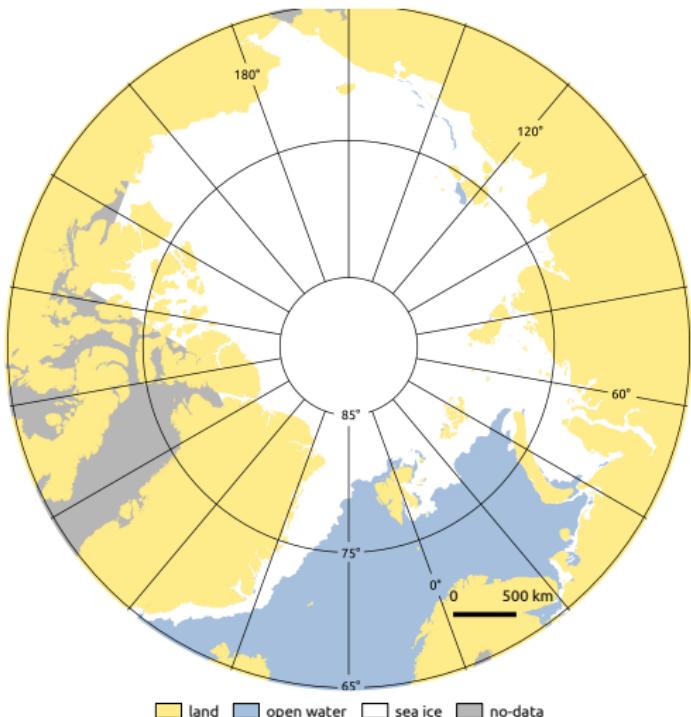
10 September 2015



Legend: land open water sea ice no-data

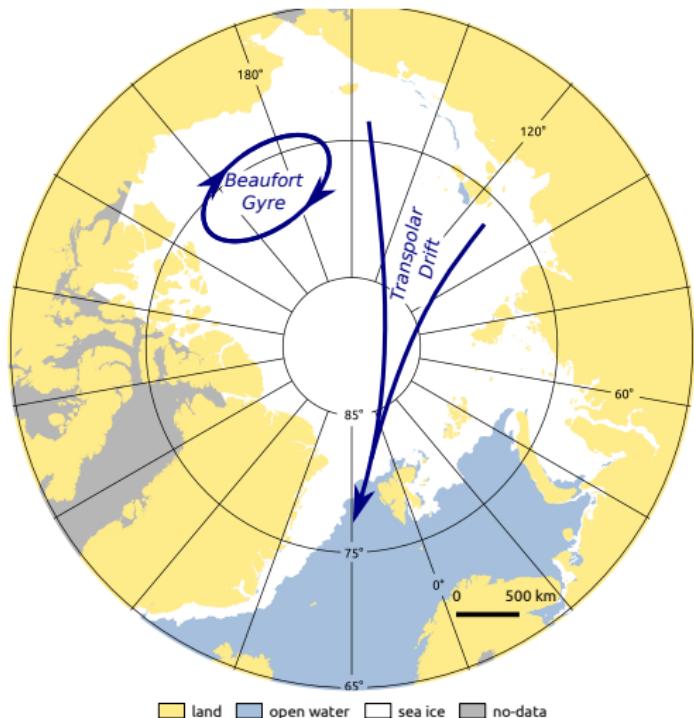
based on Operational Sea Ice Charts,
Arctic and Antarctic Research Institute, Russia (AARI Charts)

I. The importance of Arctic sea ice



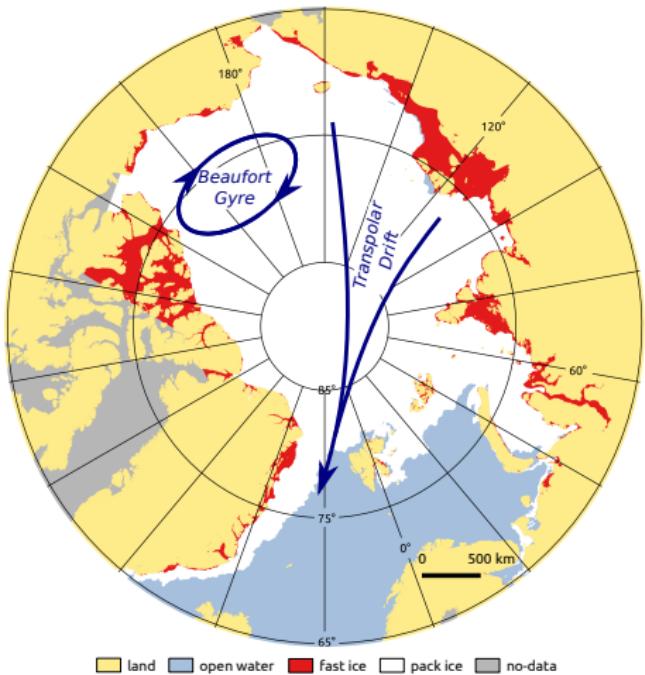
- ▶ **Climate system:**
reflects about 80% of solar radiation
- ▶ **Ecosystem:**
provides habitat and hunting platform
- ▶ **Human activity:**
navigation, exploration,
indigenous people activity

I. Arctic fast ice



17 March 2015 (AARI Charts)

I. Arctic fast ice



~ 13% of total sea ice extent

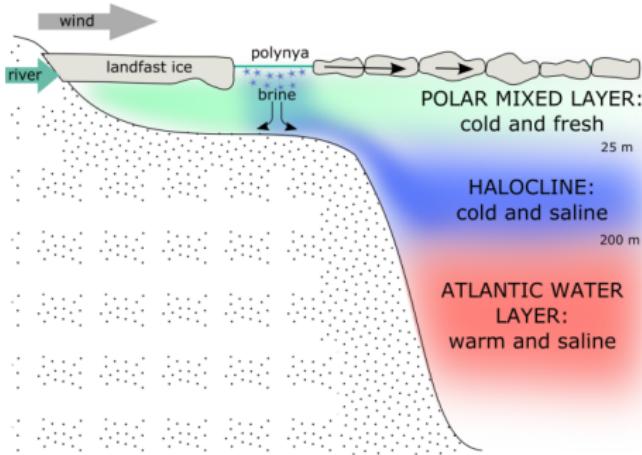
Definition

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

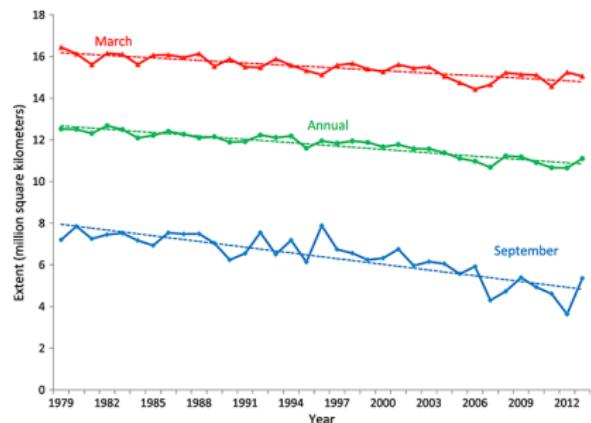


Itkin et al. 2015

- ▶ 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. Changes in Arctic sea ice and fast ice

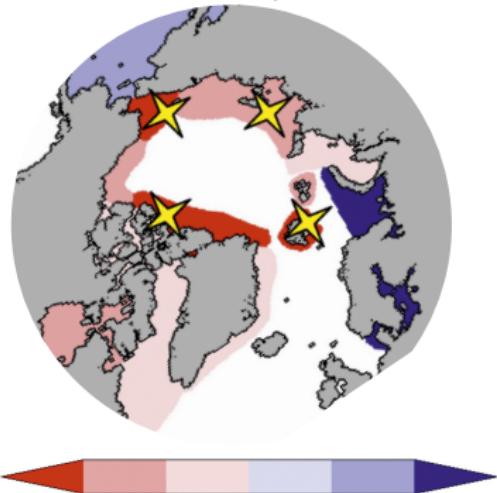
Sea ice extent, 1979-2013



(Meier et al.2014)

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

Fast ice extent, 1976-2007

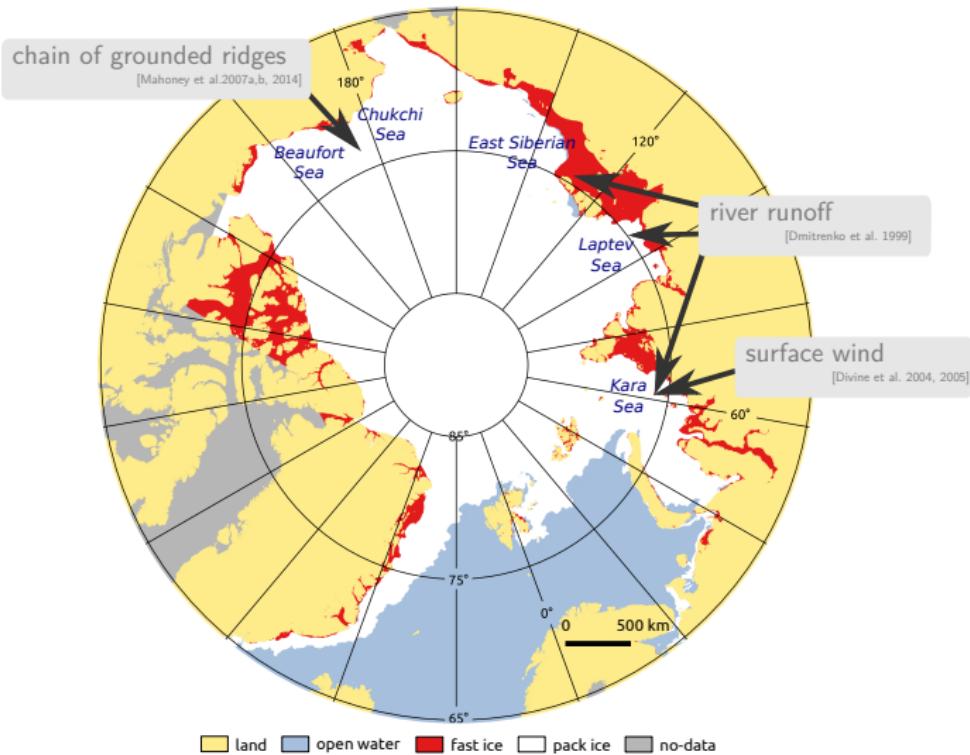


Change per Decade Relative to Mean (%)

(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

I. Factors controlling variability of fast ice winter extent



I.Objectives

Objective 1 - Annual variability

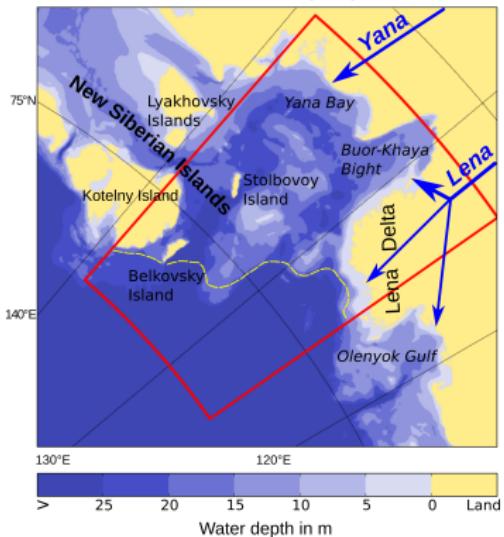
- ▶ To describe the **annual fast ice cycle** and reveal the **mechanisms driving the seasonal development** of fast ice.

Objective 2 - Interannual variability and changes

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

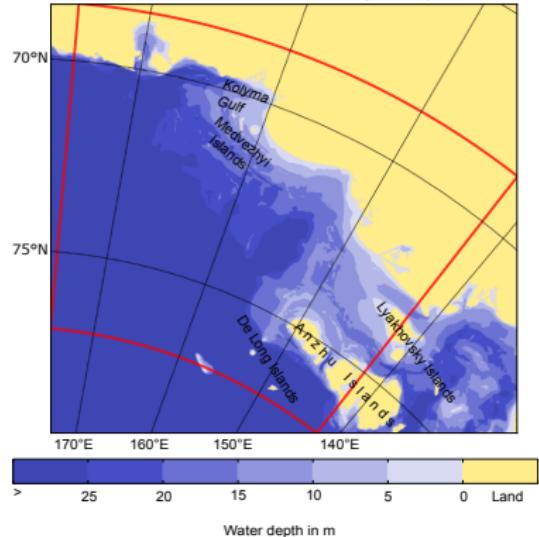
II. Regions of interest and fast ice information

Laptev Sea (LS)



AARI charts, 1999-2013, weekly

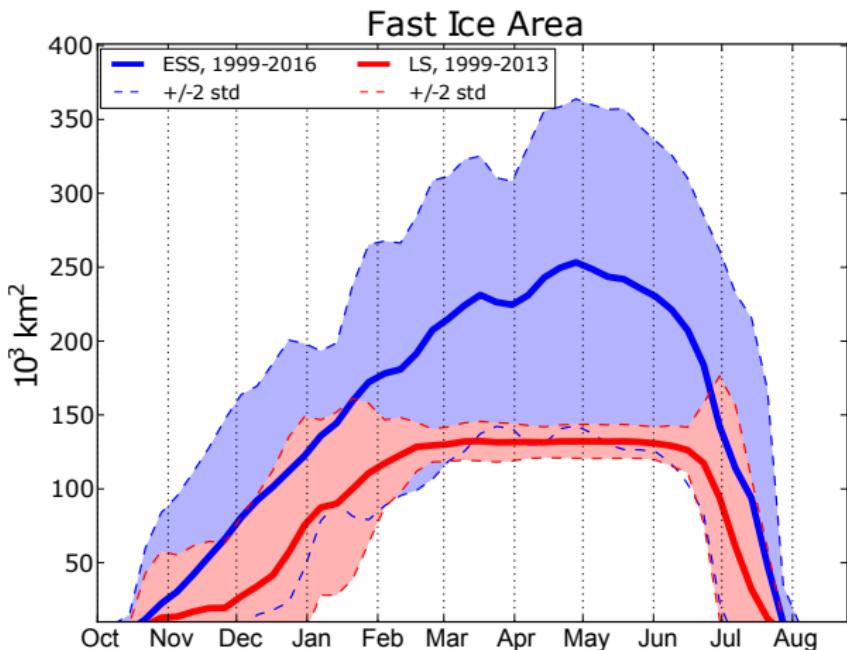
East Siberian Sea (ESS)



AARI charts, 1999-2015, weekly

II. Annual fast ice cycle, 2000-2001

II. Mean annual fast ice cycle



Interannual variability

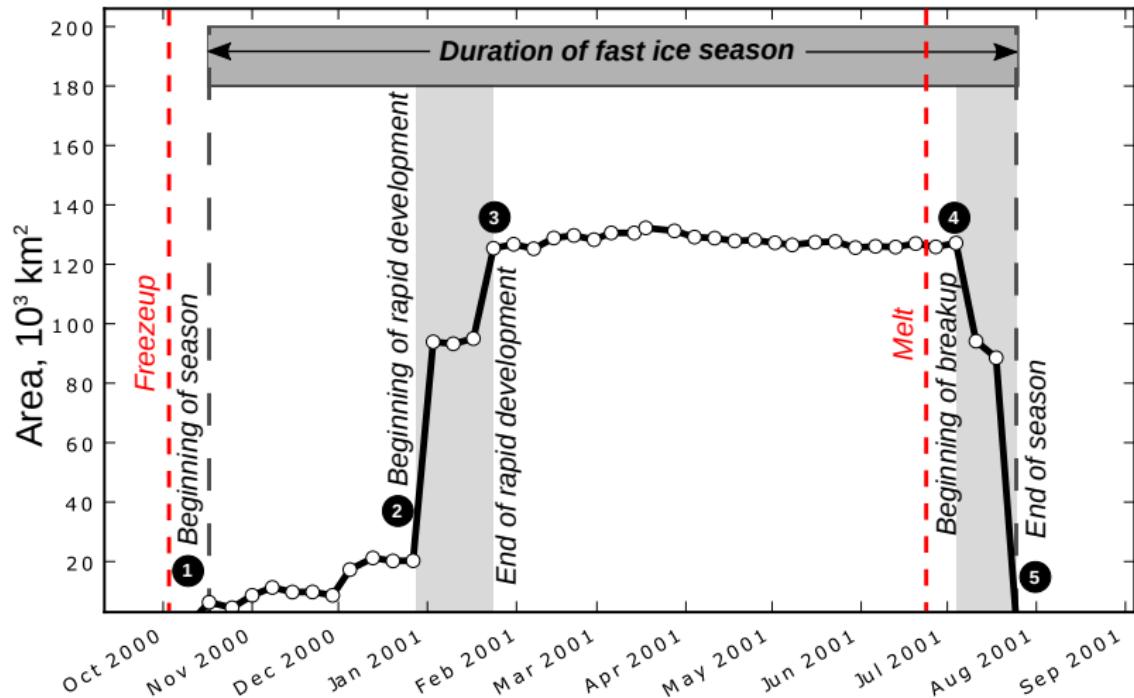
Laptev Sea:

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

East Siberian Sea:

- ▶ high in winter

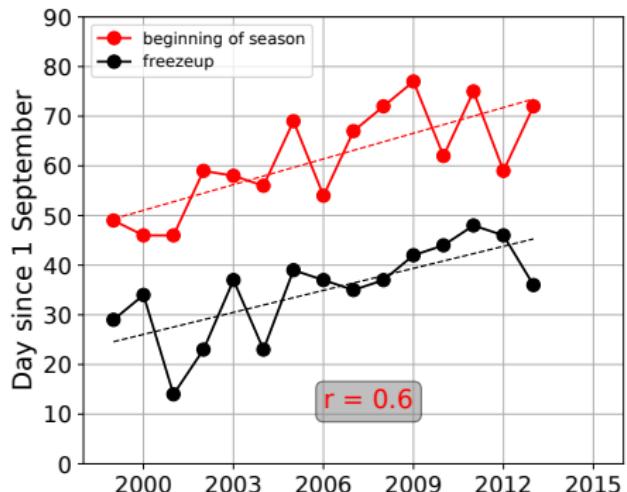
II. Key events of annual cycle



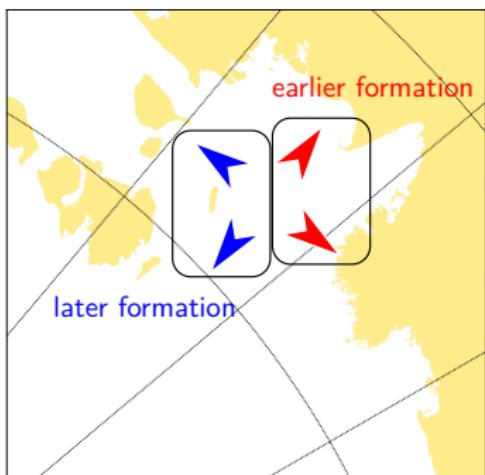
A typical annual fast ice cycle and Key events for the Laptev Sea

II. Beginning of season: LS

Beginning of season and freezeup



Wind direction

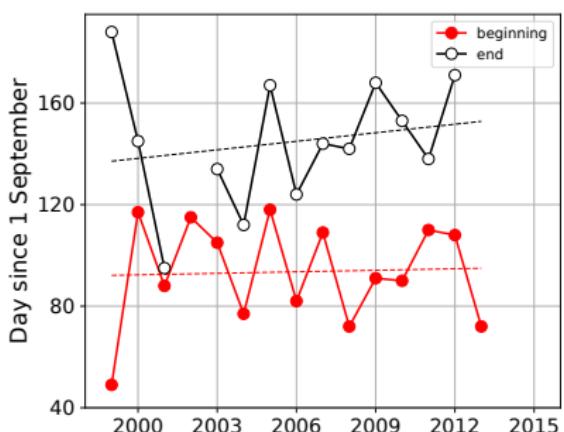


- ▶ tendency towards later formation
1.7 days/year ($p < 0.01$)
- ▶ partly explained by delay in freezeup
($r = 0.6$)

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

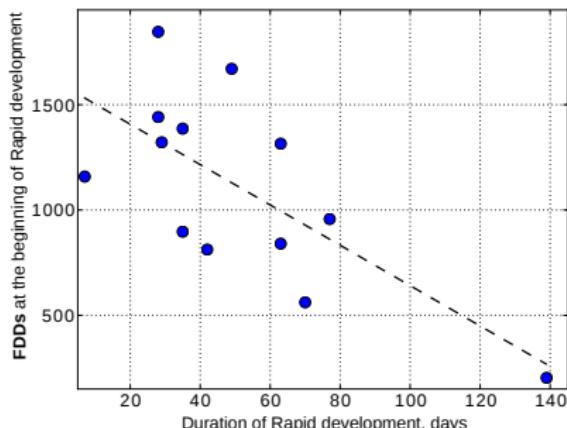
II. Rapid development: LS

Beginning and end of rapid development



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

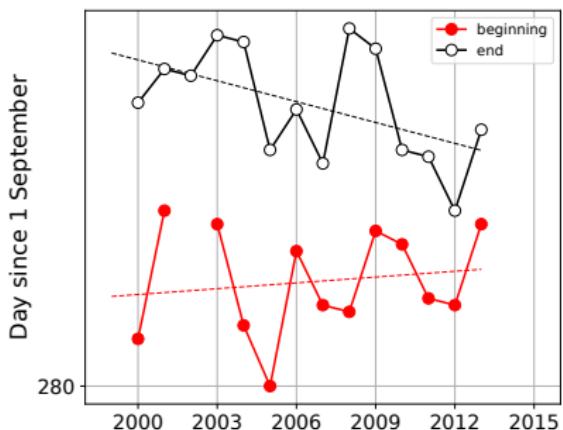
Duration of rapid development



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

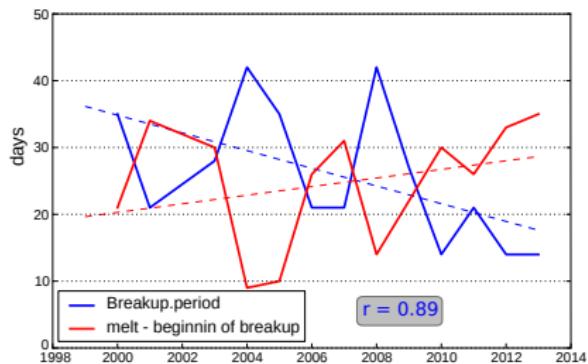
II. Breakup: LS

Beginning breakup and end season



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

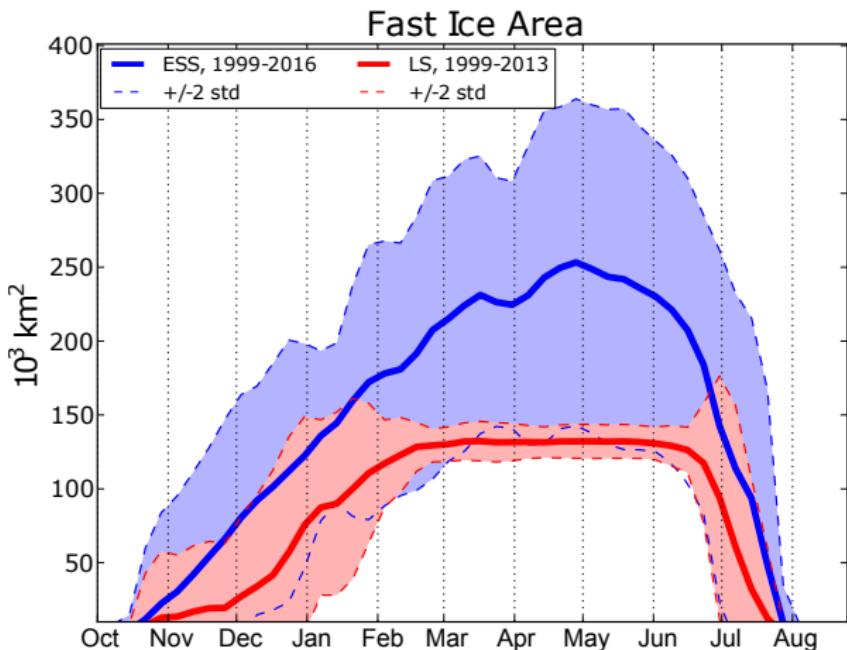
Duration of breakup



- ▶ 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

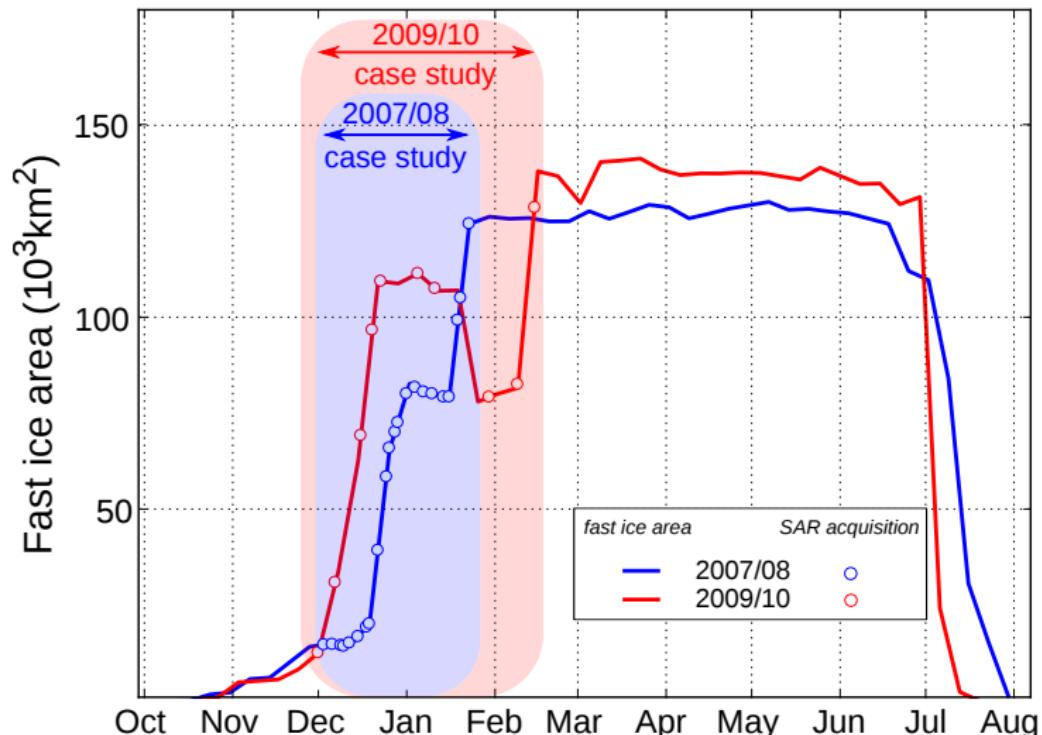
Laptev Sea:

- ▶ high in November–February
- ▶ low winter

East Siberian Sea:

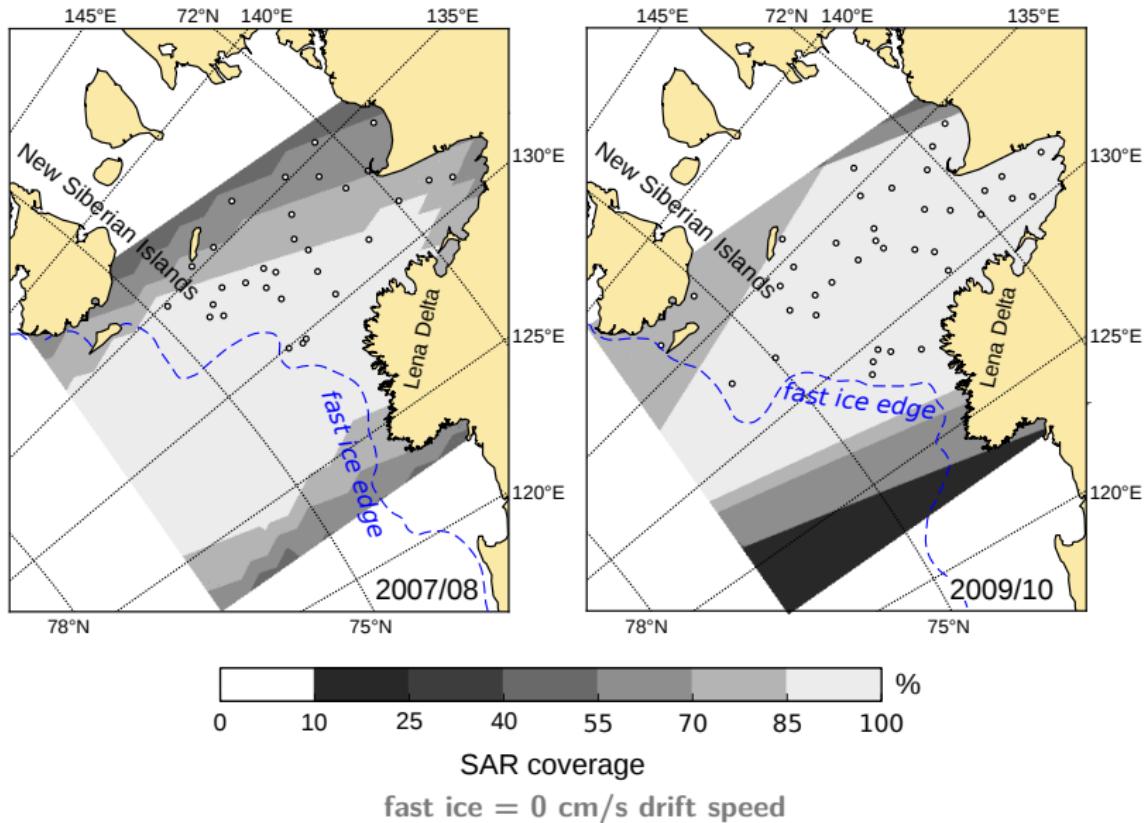
- ▶ high in winter

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

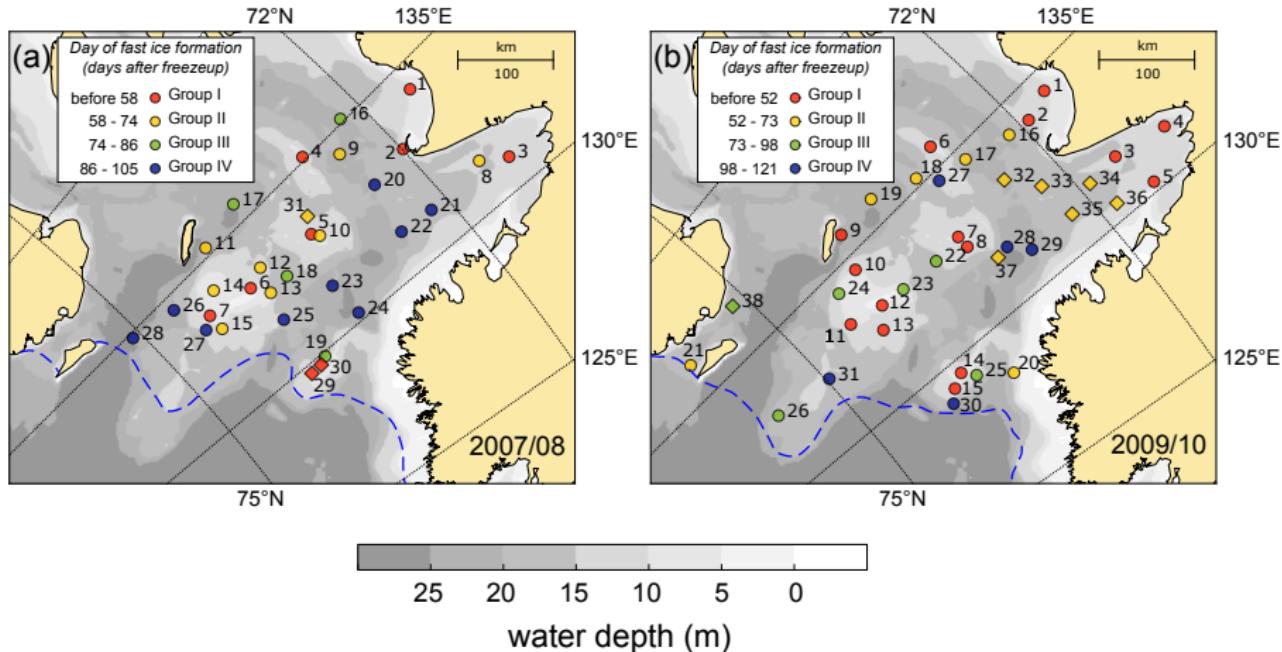


- ▶ Synthetic Aperture Radar (SAR) image every 2-14 days
- ▶ spatial resolution 150 m

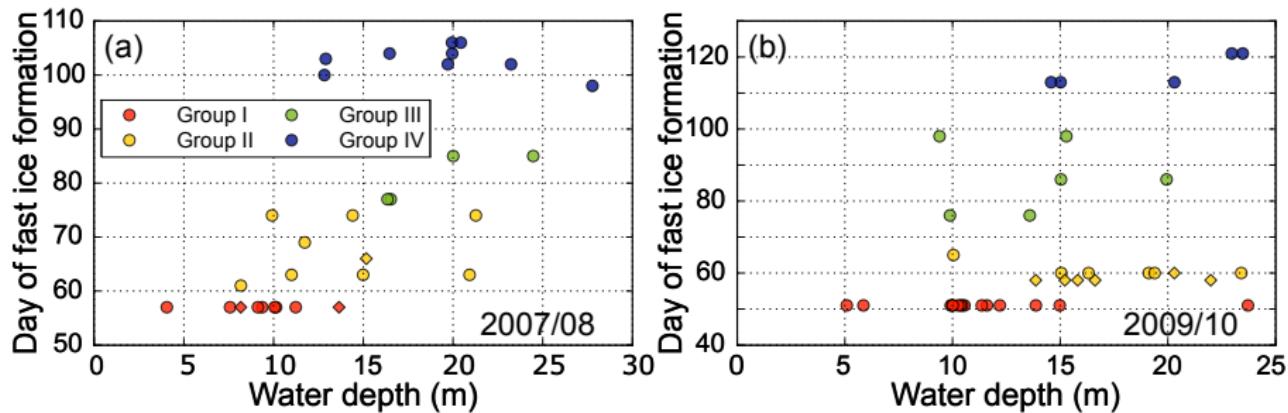
III. Tracked sea ice features



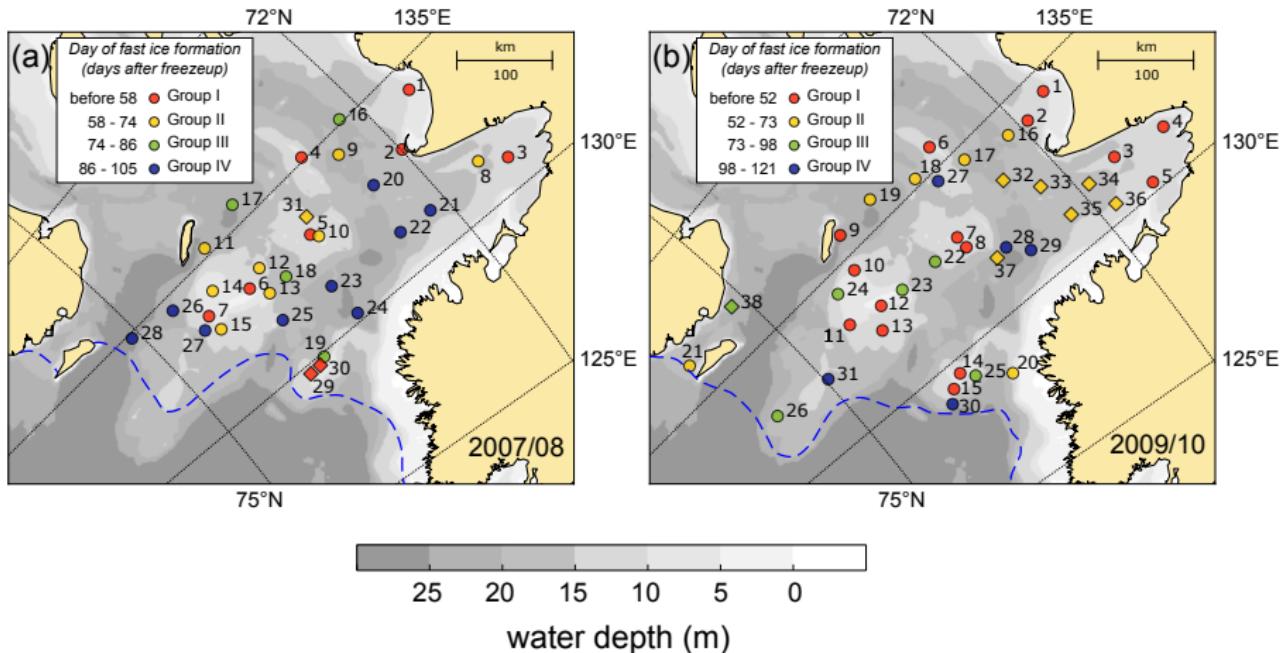
III. Final location of features



III. Water depth vs fast ice formation day



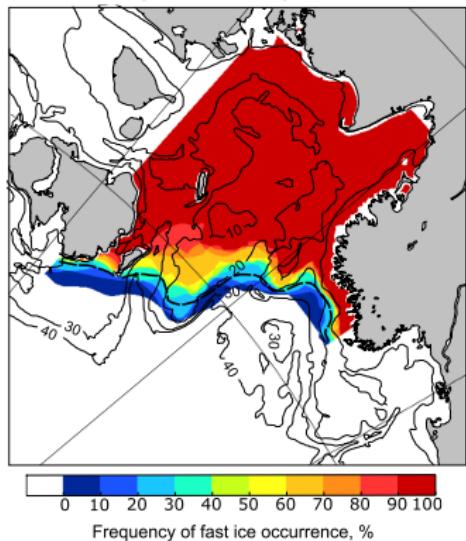
III. Final location of features



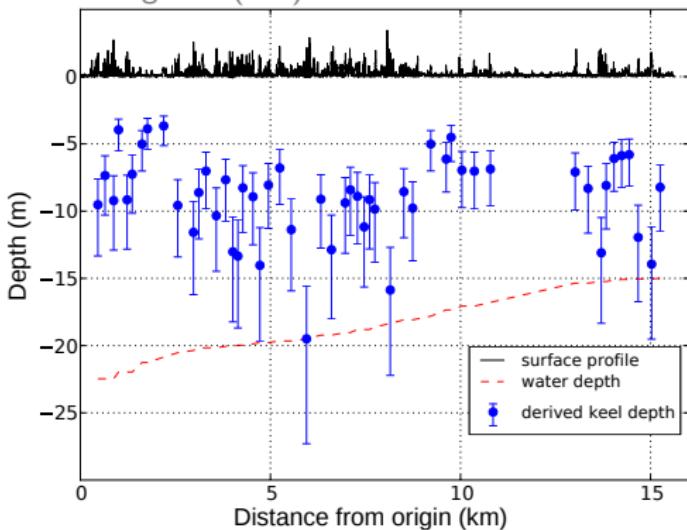
- relatively thin ice becomes grounded over the shoals
- it serves as stabilizing points for surrounding sea ice
- low variations in winter extent predefined by the bathymetry

III. Fast ice at the end of rapid development

End of Rapid Development



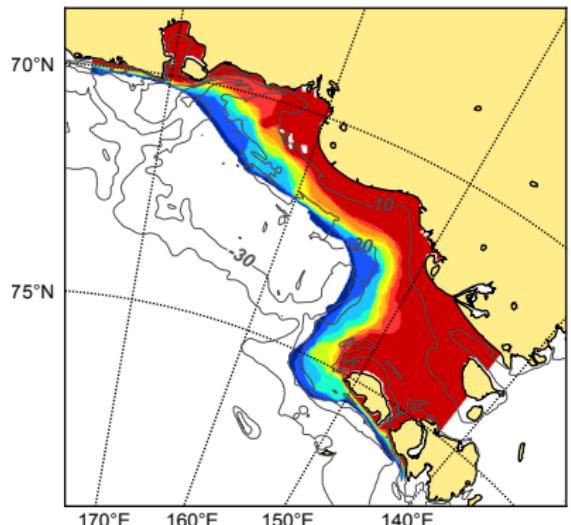
Electromagnetic (EM) ice thickness measurements



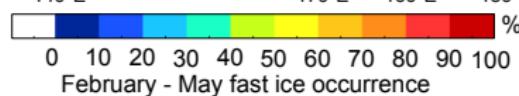
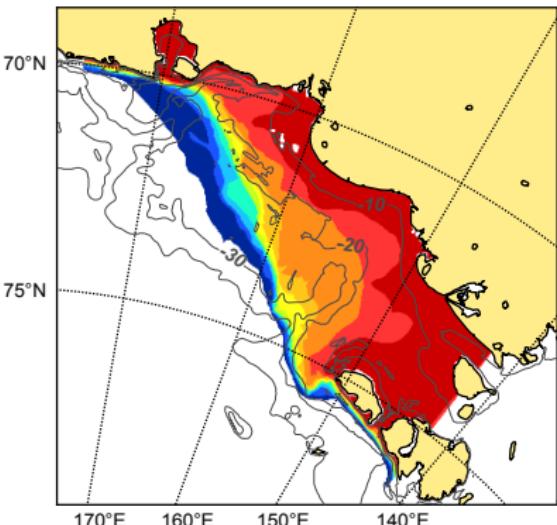
- variations in winter fast ice edge is likely controlled by grounding of deep ice ridges

III. East Siberian Sea Fast ice modes

A. Small - mode



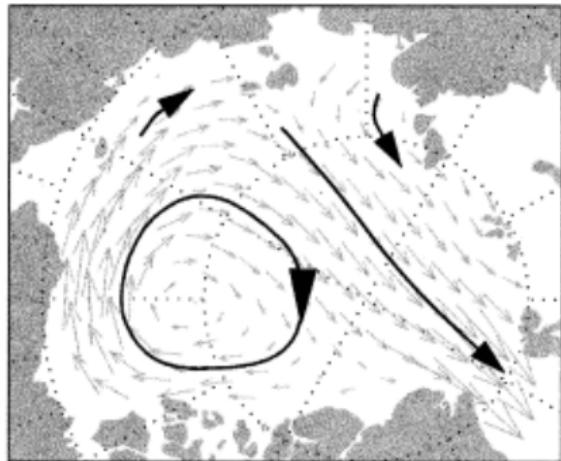
B. Large - mode



III. Arctic circulation

Negative Arctic Oscillation index (AO)

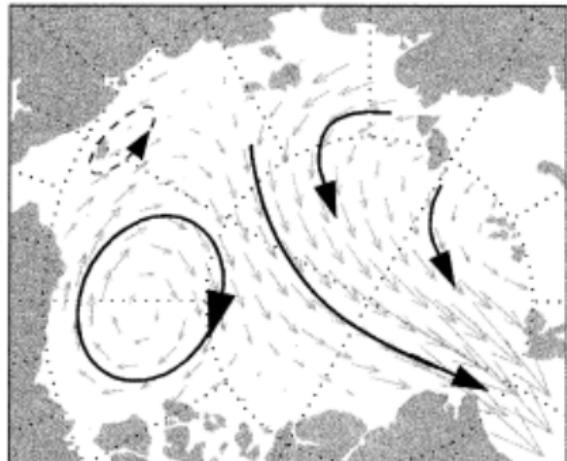
(c) Low Index



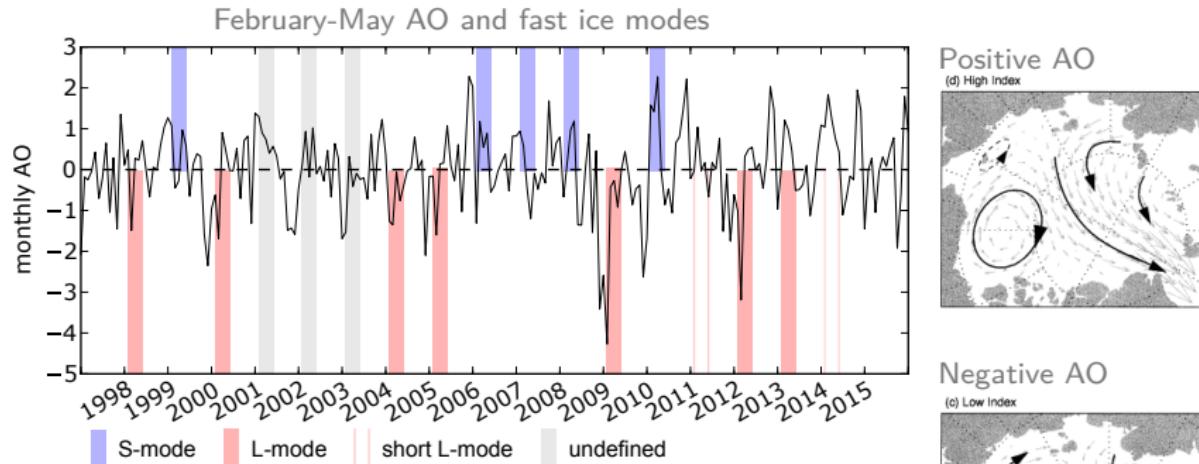
(Rigor et al. 2002)

Positive Arctic Oscillation index (AO)

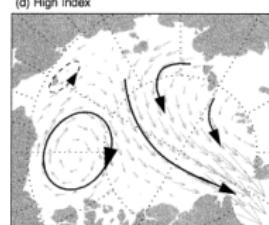
(d) High Index



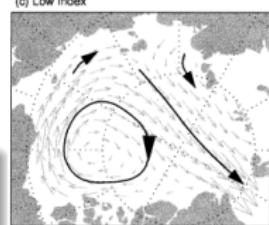
III. East Siberian Sea fast ice modes



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 $H_i > 90$ 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