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

- definition, importance, state-of-the-arts, objectives

II. Variability of fast ice extent and interannual changes

- annual cycle, key events, tendencies

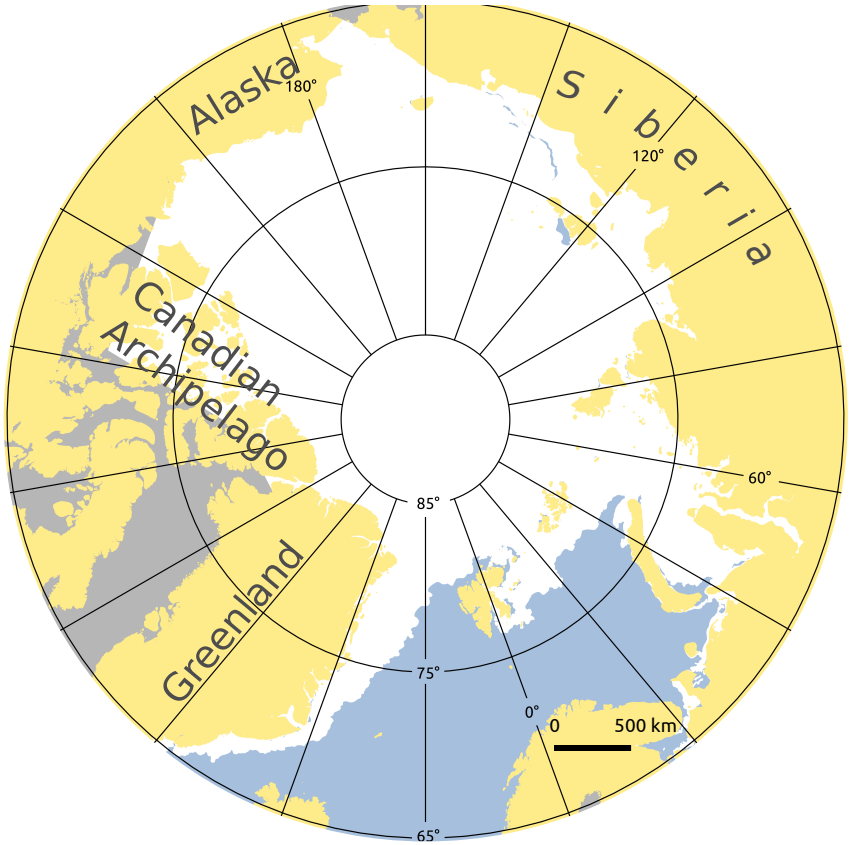
III. Mechanism of fast ice development

- case study, sea ice grounding

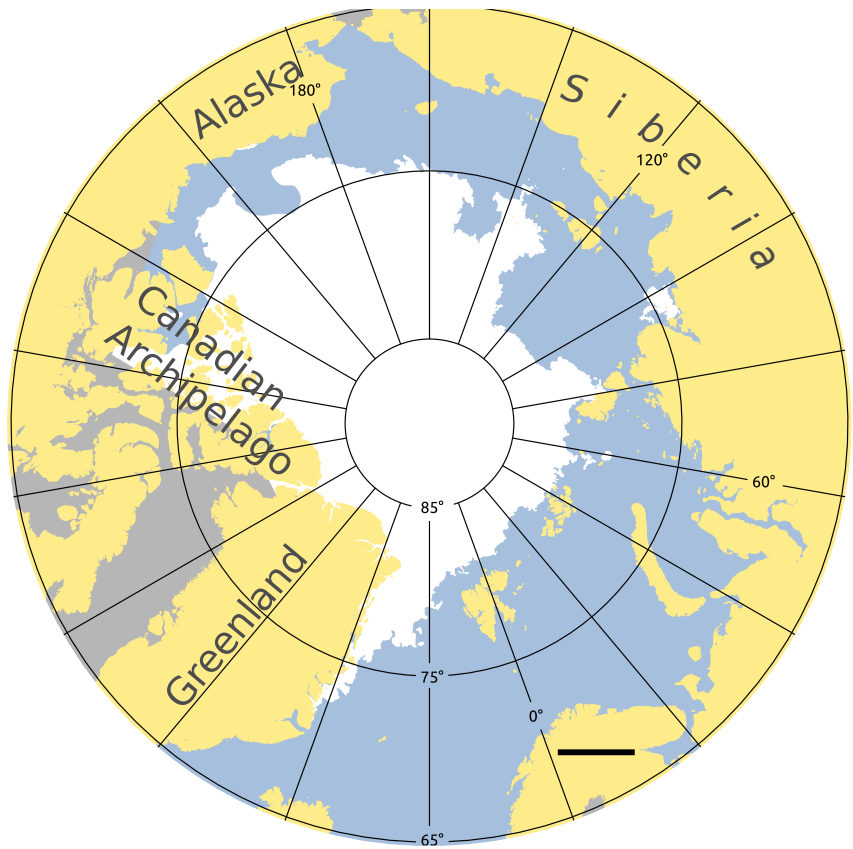
IV. Summary and outlook

I. Arctic sea ice

17 March 2015



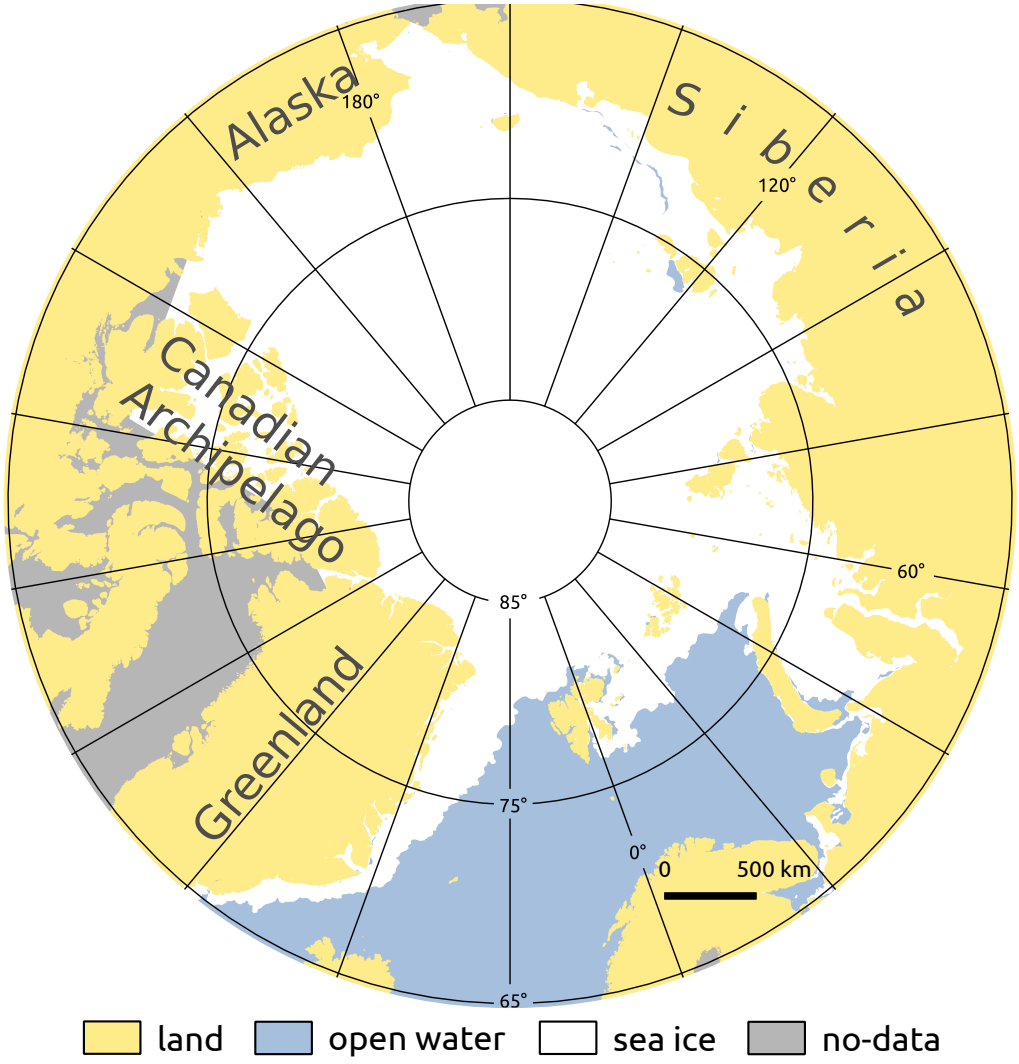
10 September 2015



land | open water | sea ice | no-data

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

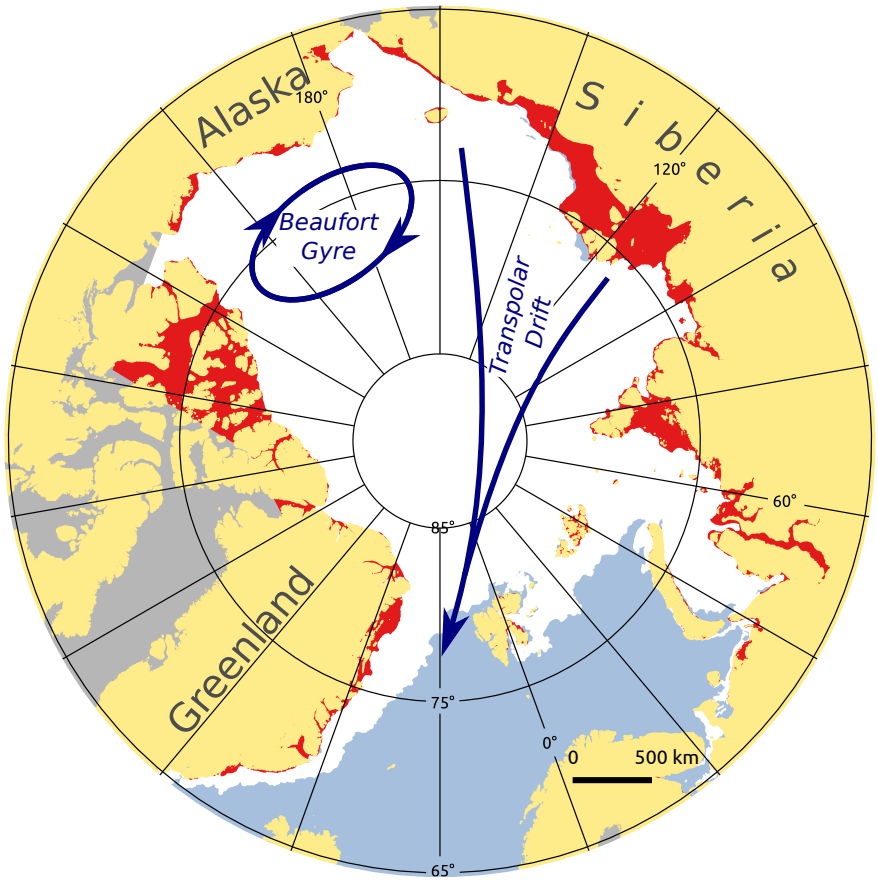
I. The importance of Arctic sea ice



17 March 2015 (AARI Charts)

- **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



land | open water | fast ice | pack ice | no-data

17 March 2015 (AARI Charts)

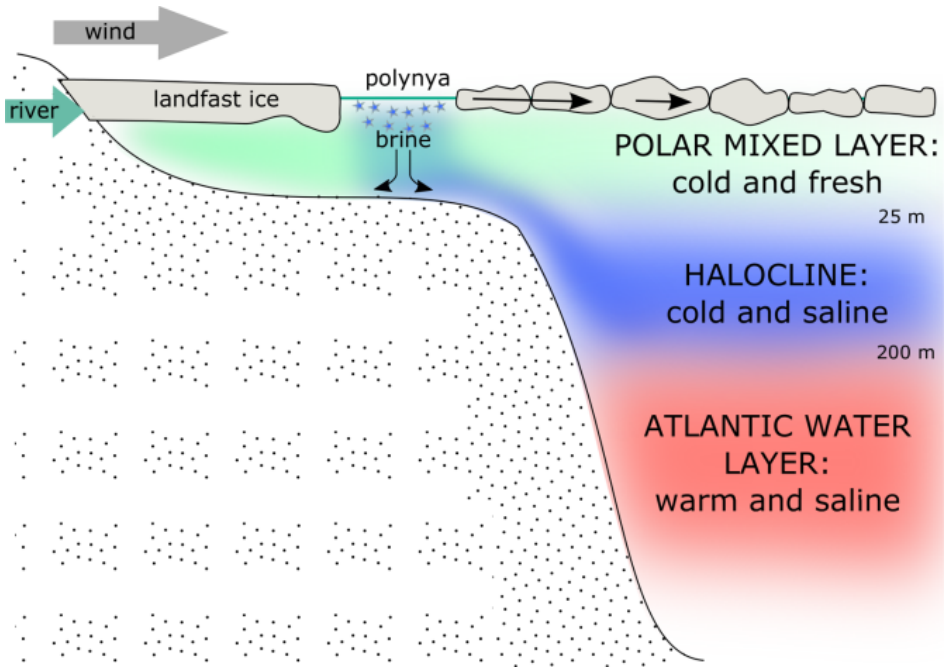
$\sim$ 13% of total sea ice extent

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)

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. Importance of Arctic fast ice

Crumbling blocks of permafrost along the Beaufort Coast
USGS

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  (Maqueda et al. 2004, Itkin et al. 2015)
- **protects coasts from erosion**
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I. Importance of Arctic fast ice

Whaling boat and whaler, Barrow, Alaska
Photo by Billy Adams

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- protects coasts from erosion
  (Rachold et al. 2000, Eicken et al. 2005)
- helps to maintain submarine permafrost
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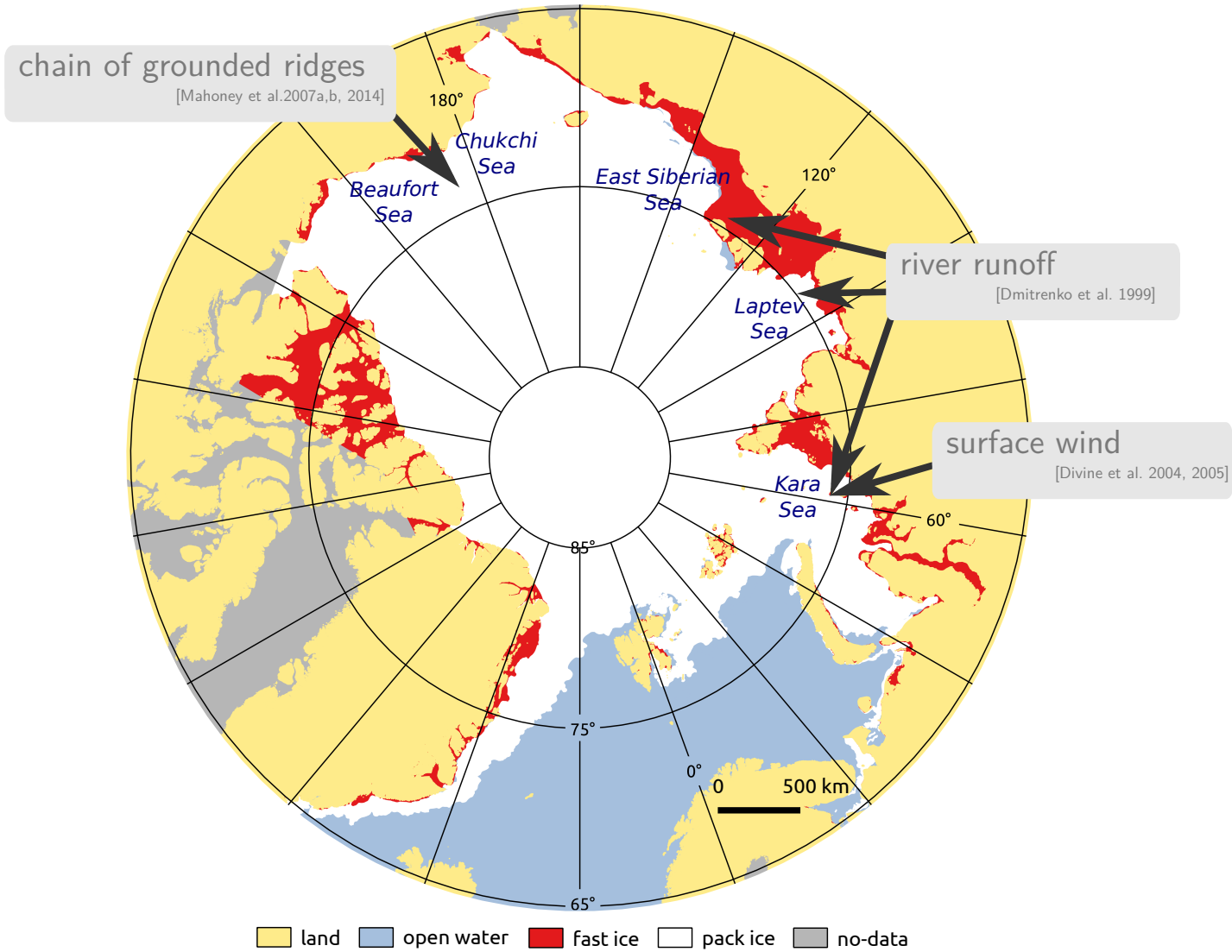
- **affects human activity**
  (Johannessen et al. 2005, Hughes et al. 2011, Weintrit 2013)

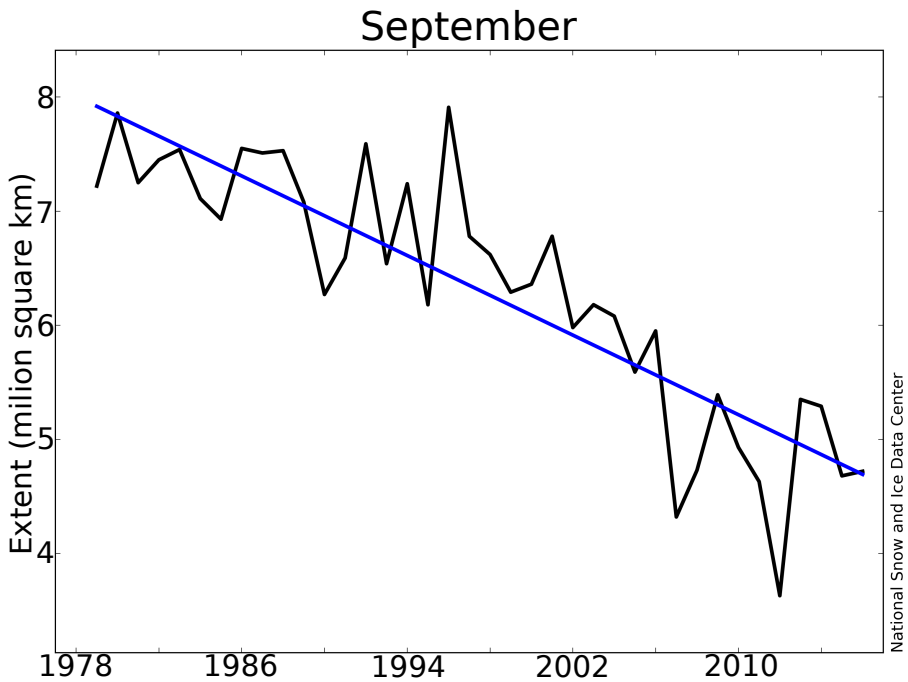
I. Factors controlling variability of fast ice winter extent



17 March 2015 (AARI Charts)

I. Changes in Arctic sea ice and fast ice

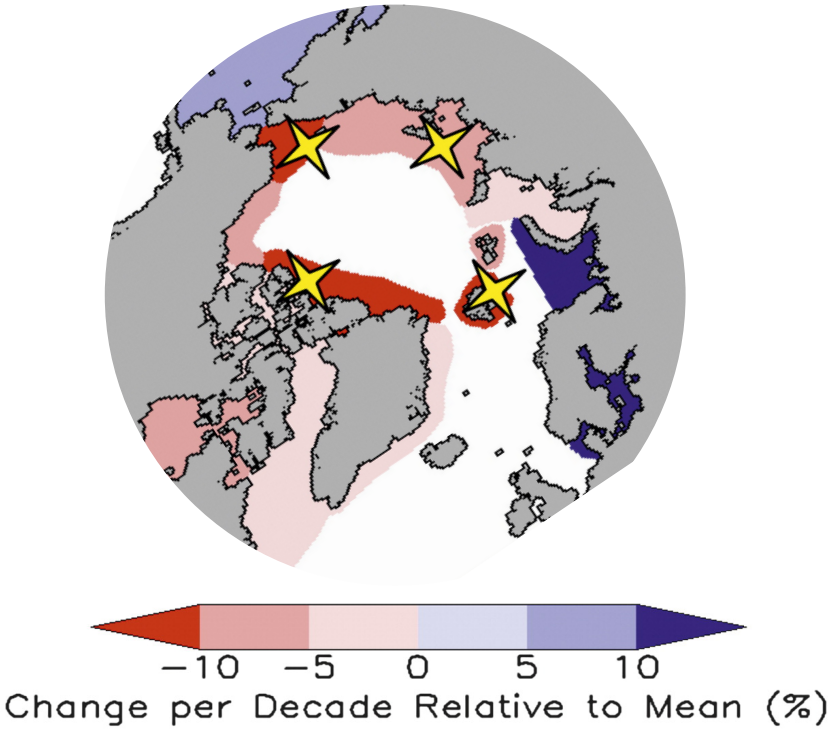
Sea ice extent, 1979-2016



NSIDC

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

Fast ice extent, 1976-2007



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.Objectives

Objective 1 - Annual variability

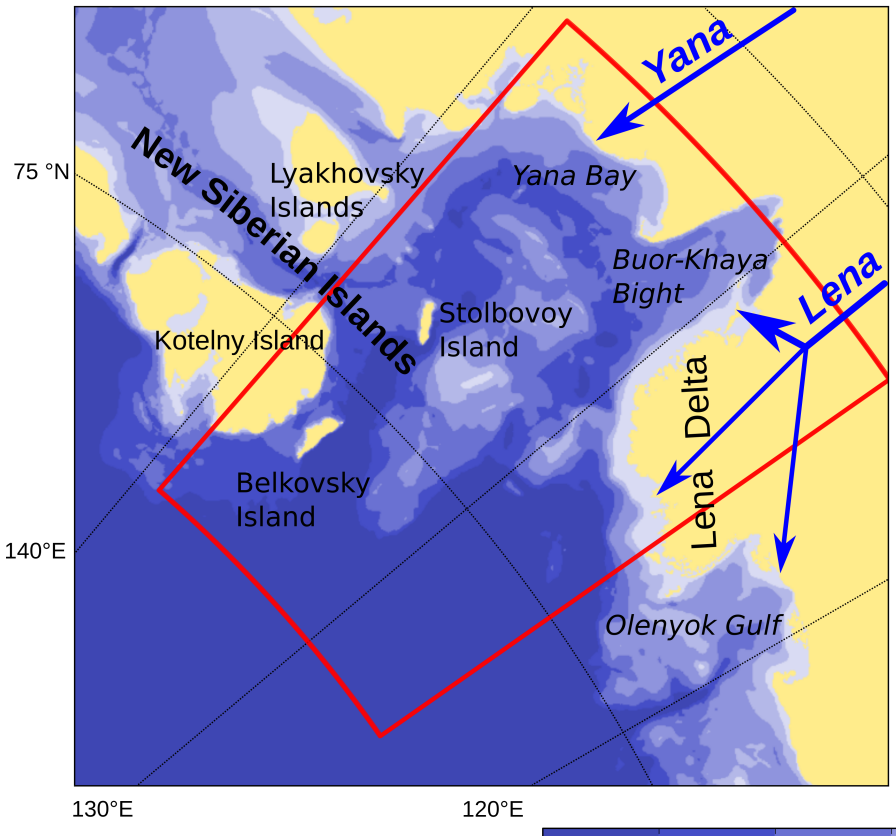
- To describe the **annual fast ice cycle** and reveal the **mechanisms driving the seasonal development** of fast ice.

Objective 2 - Interannual variability and changes

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

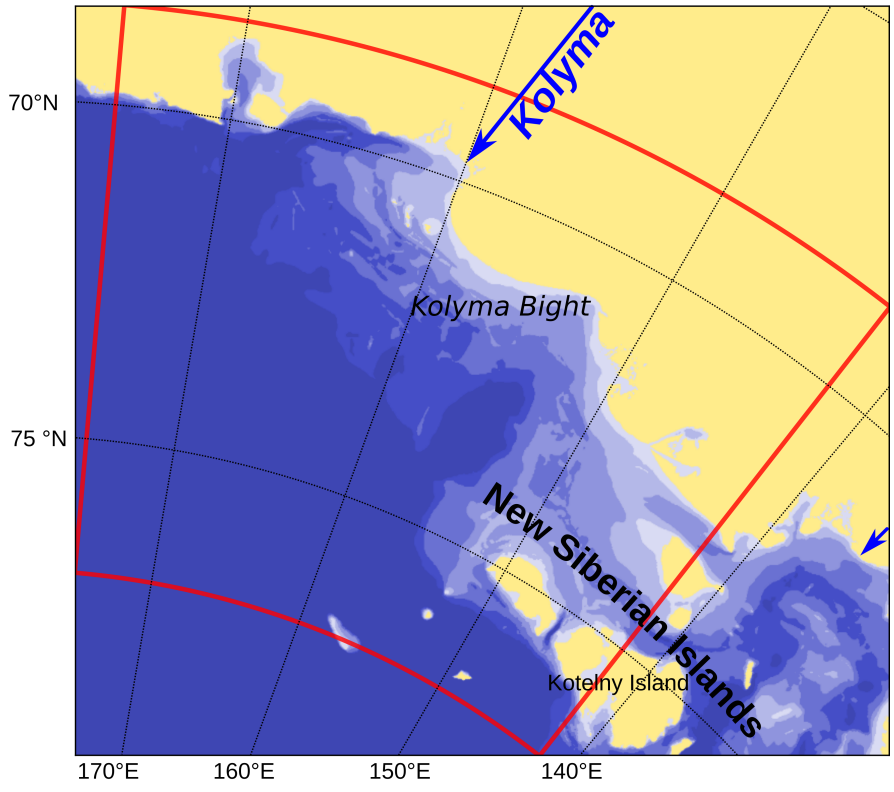
II. Regions of interest and fast ice information

Laptev Sea (LS)

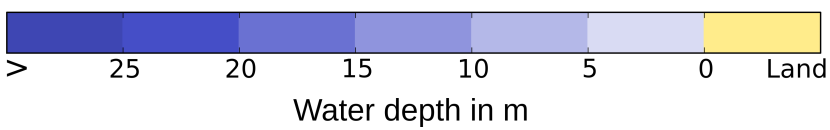


AARI charts, 1999-2013, weekly

East Siberian Sea (ESS)

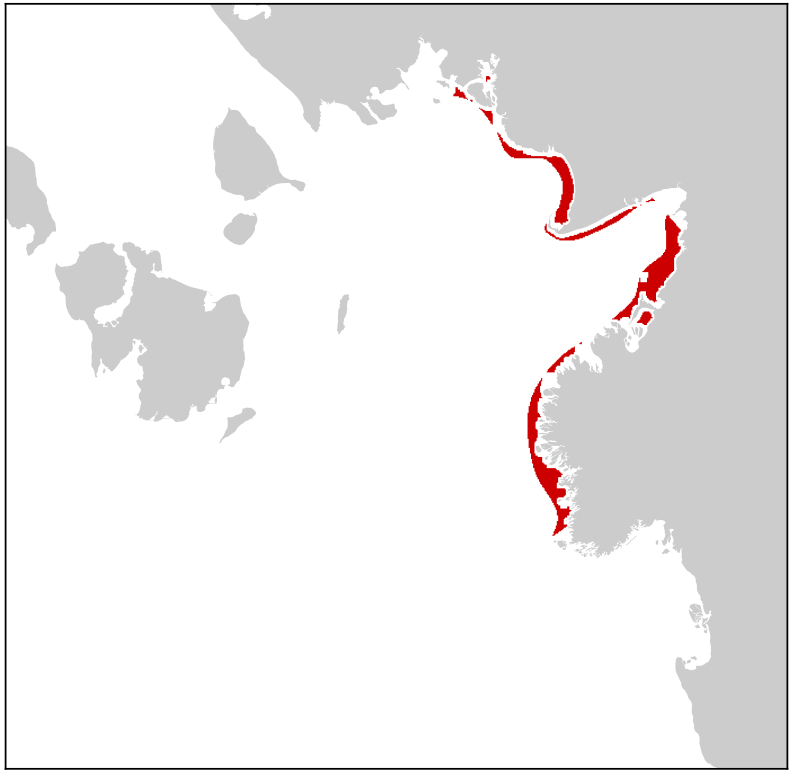


AARI charts, 1999-2015, weekly



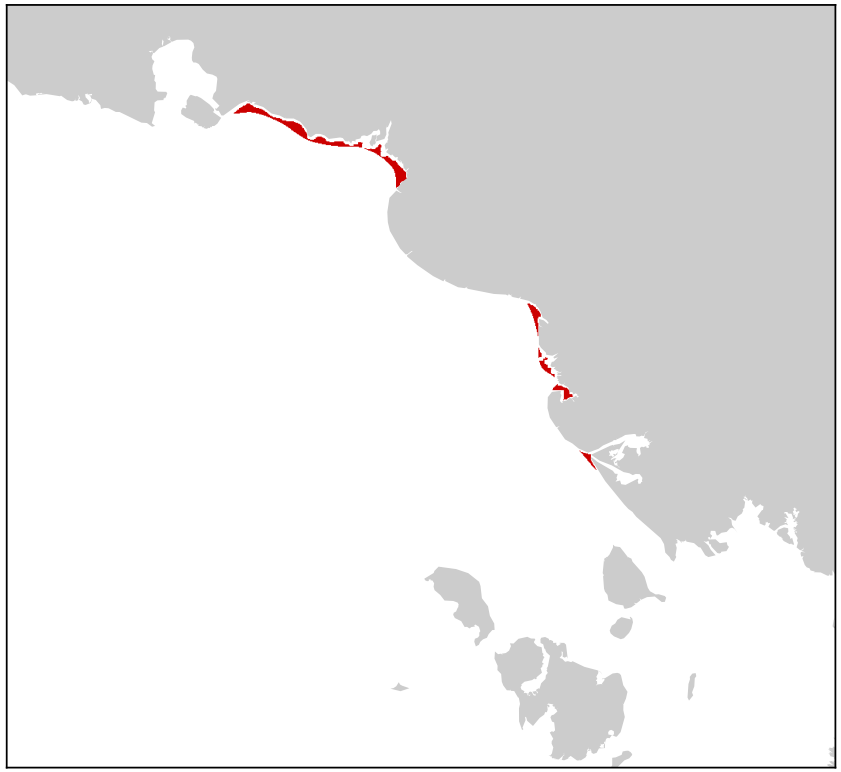
II. Weekly AARI charts, 2000-2001

2000.10.17



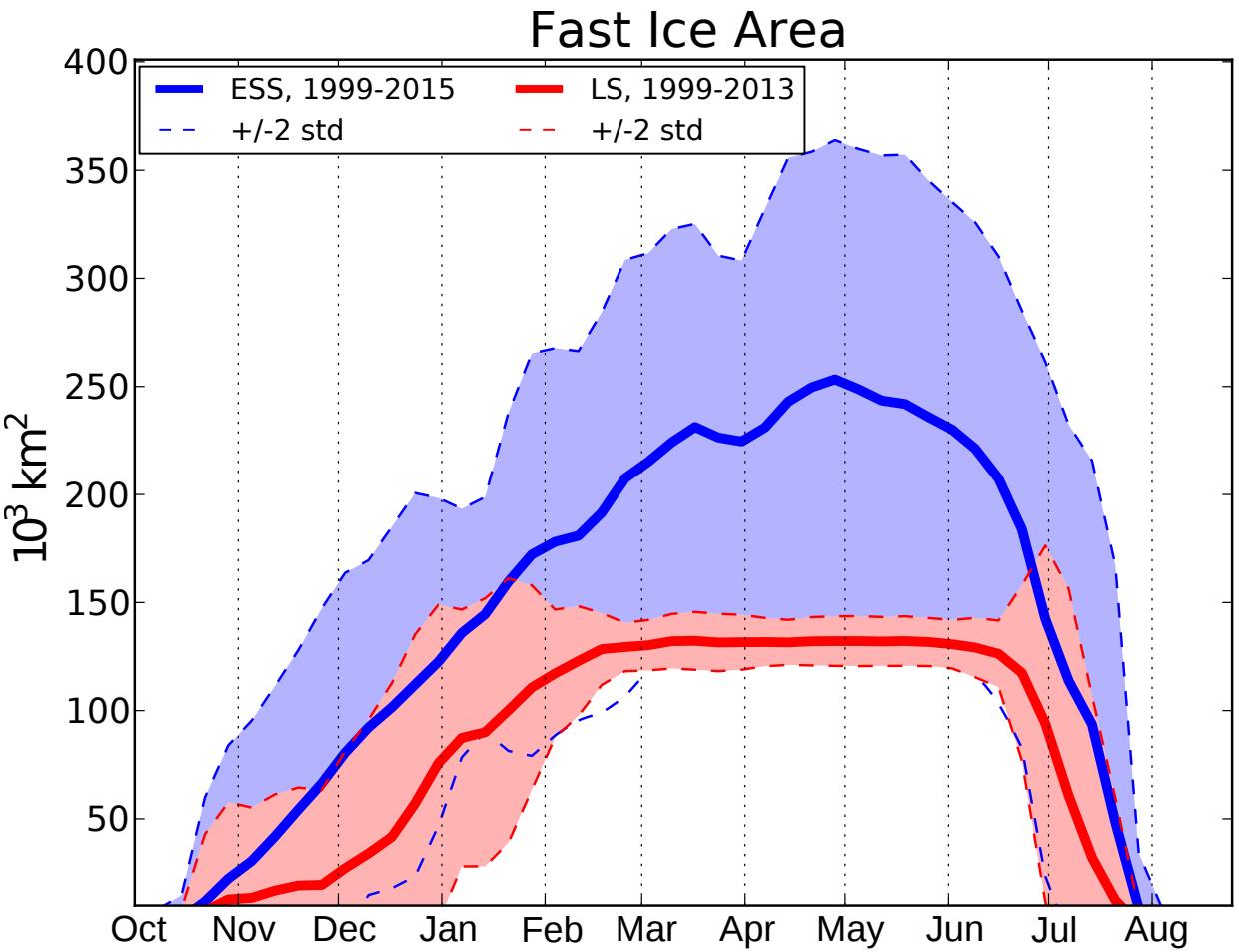
Laptev Sea

2000.10.17



East Siberian Sea

II. Mean annual fast ice cycle



Interannual variability

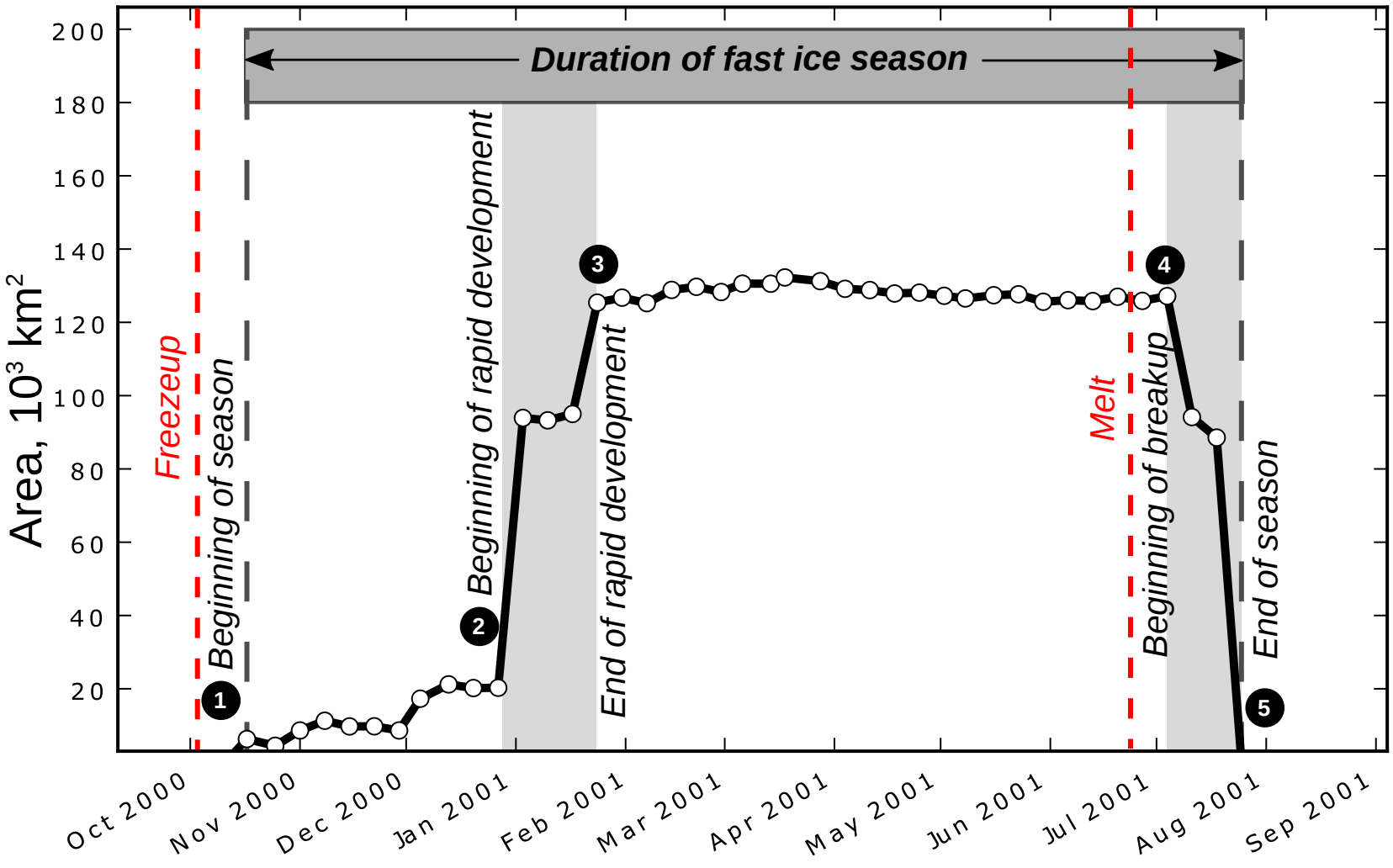
Laptev Sea:

- high in November-February
- low in winter

East Siberian Sea:

- high in winter

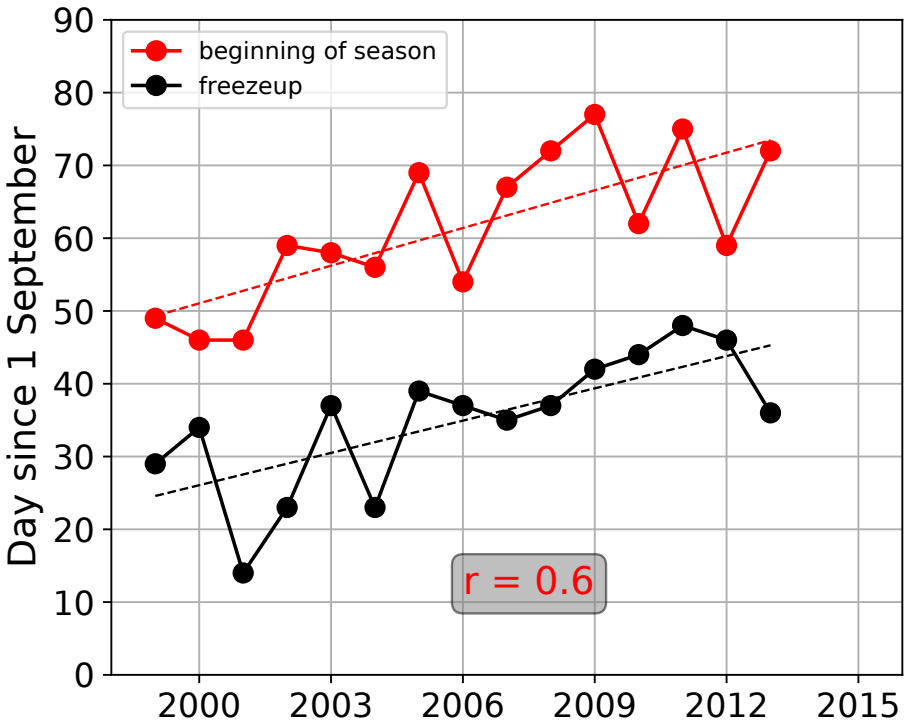
II. Key events of annual cycle



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

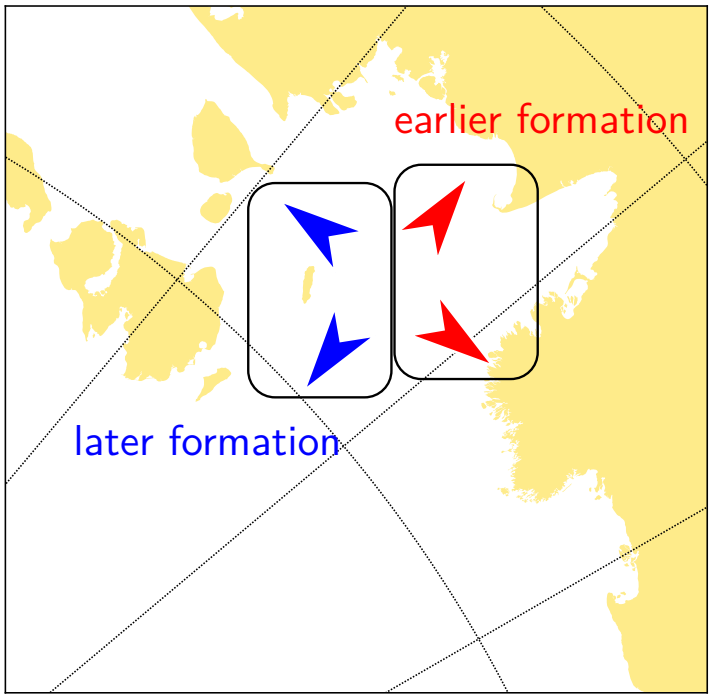
II. Beginning of season: LS

Beginning of season and freezeup



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

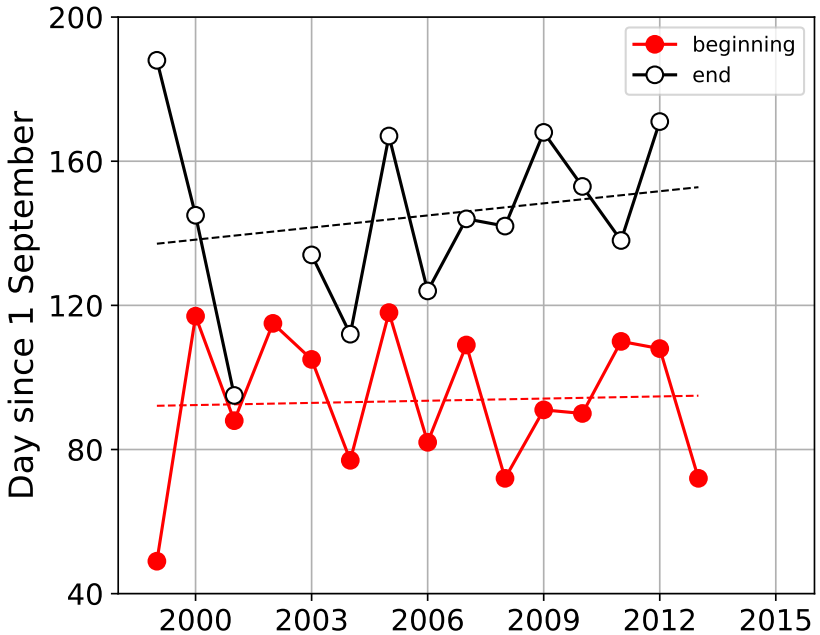
Wind direction



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

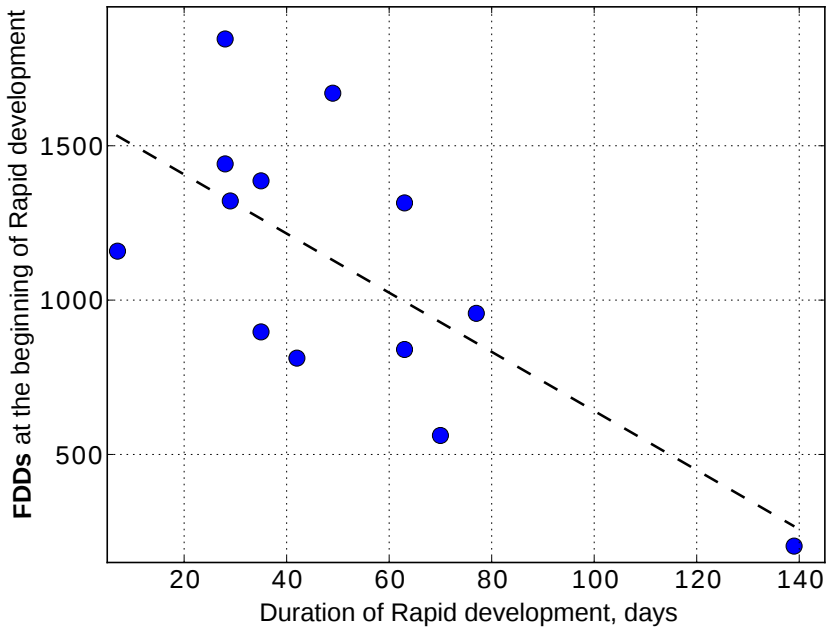
II. Rapid development: LS

Beginning and end of rapid development



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

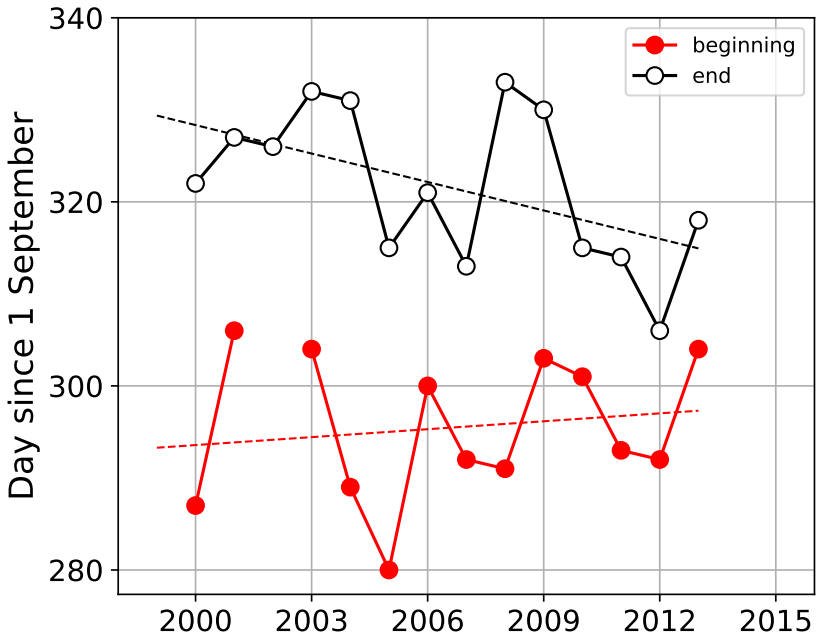
Duration of rapid development



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

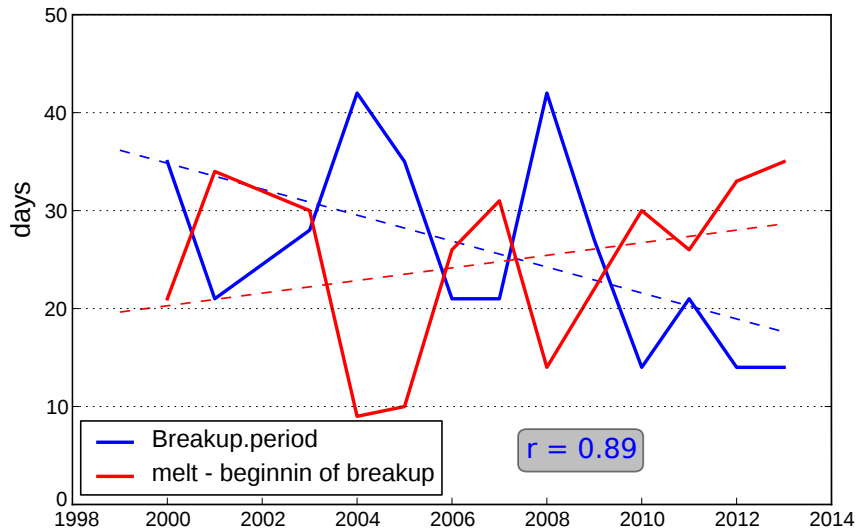
II. Breakup: LS

Beginning breakup and end season



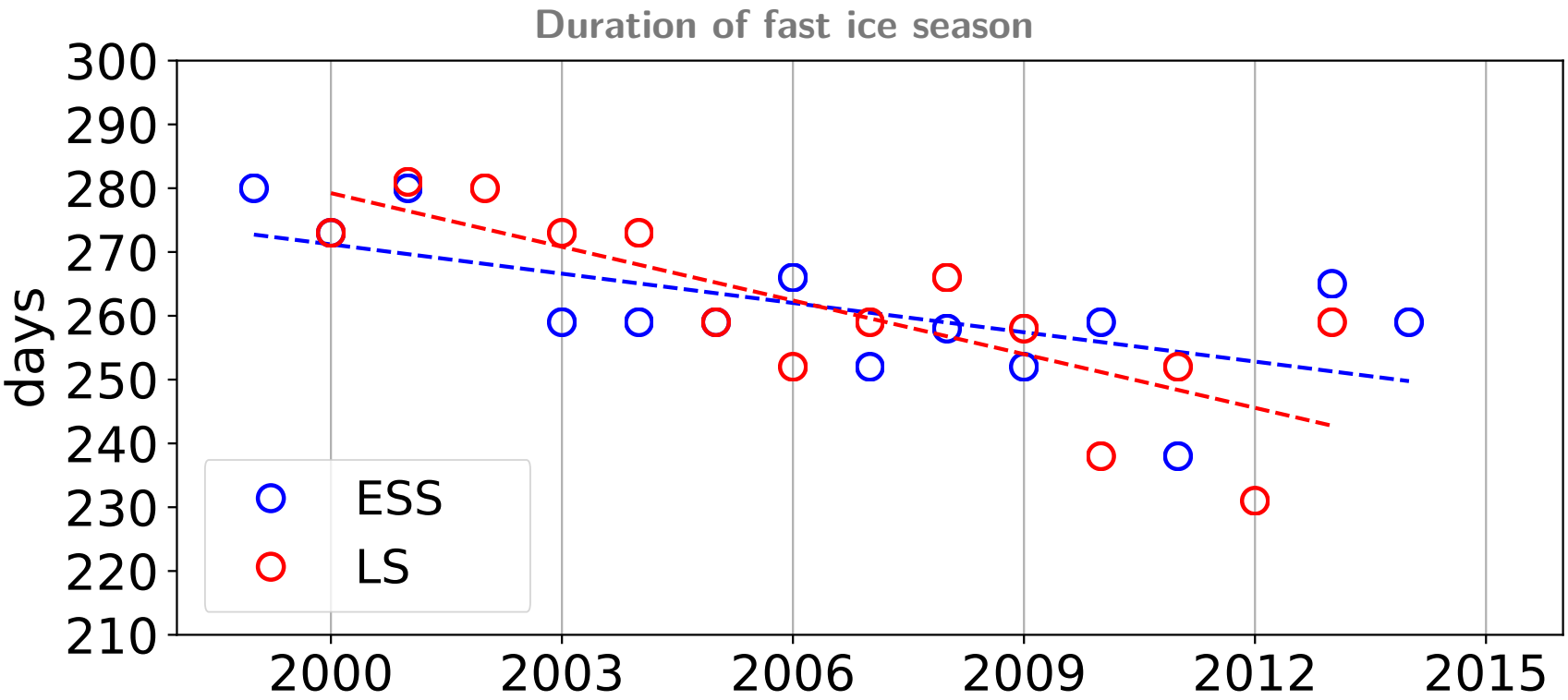
- no changes in beginning
  0.3 days/year (p=0.63)
- tendency towards earlier end
  -1.0 days/year (p=0.06)

Duration of breakup



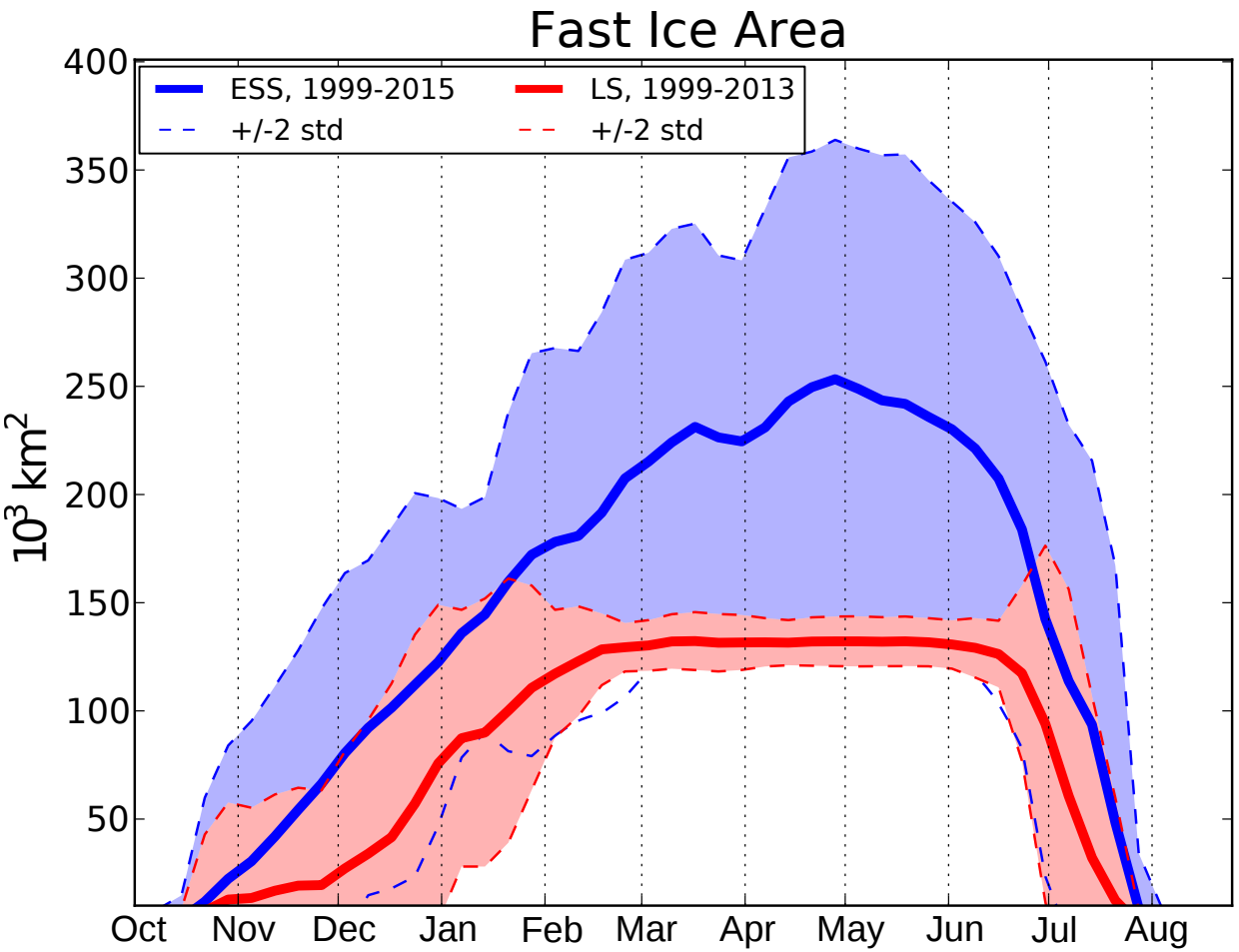
- fast ice needs less time to breakup
- duration of breakup depend on TDD acquired prior beginning of breakup

II. Duration of fast ice season



- Laptev Sea - **2.8 days/year**
- East Siberian Sea - **1.5 days/year**

II. Mean annual fast ice cycle



Interannual variability

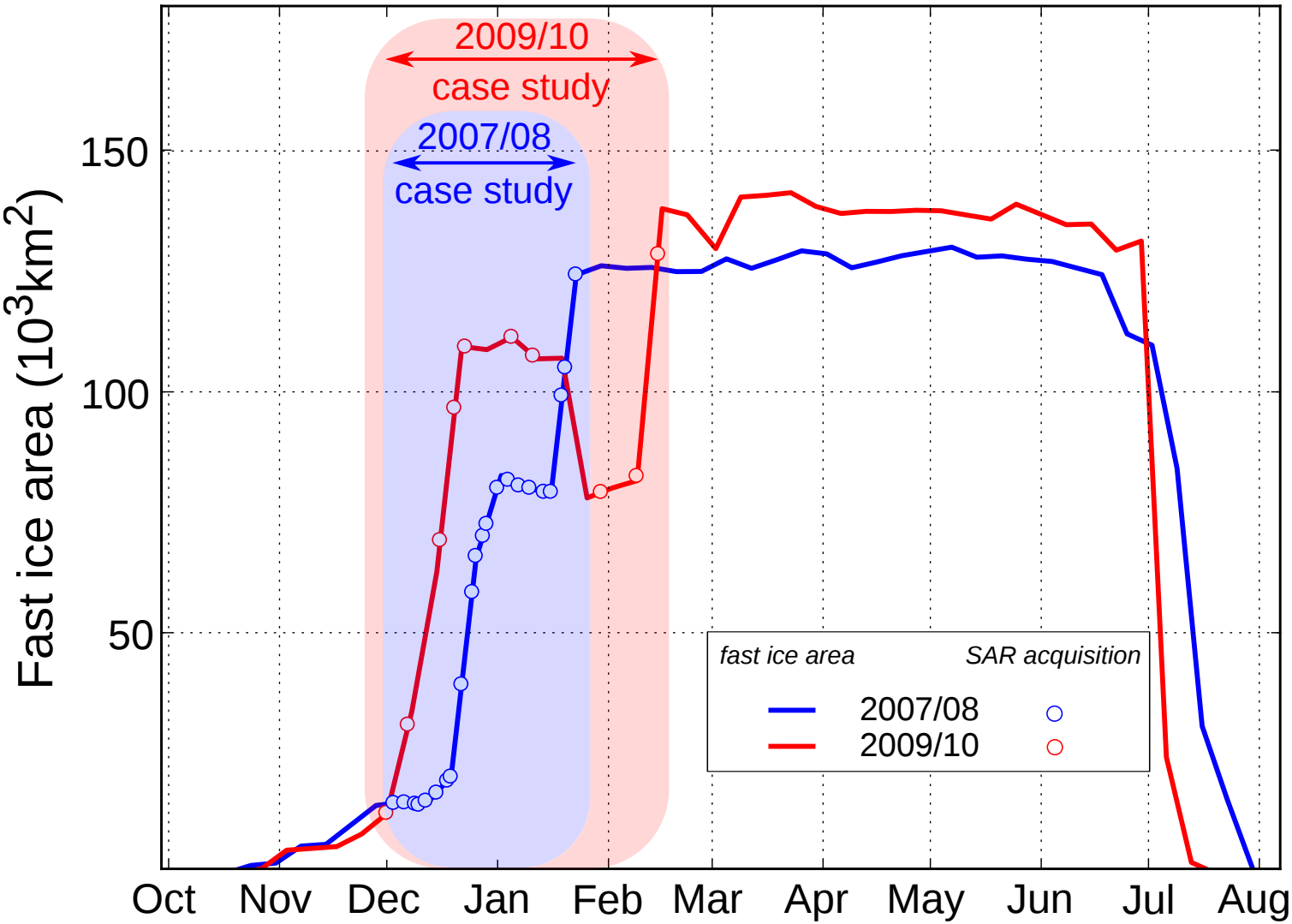
Laptev Sea:

- high in November-February
- low winter

East Siberian Sea:

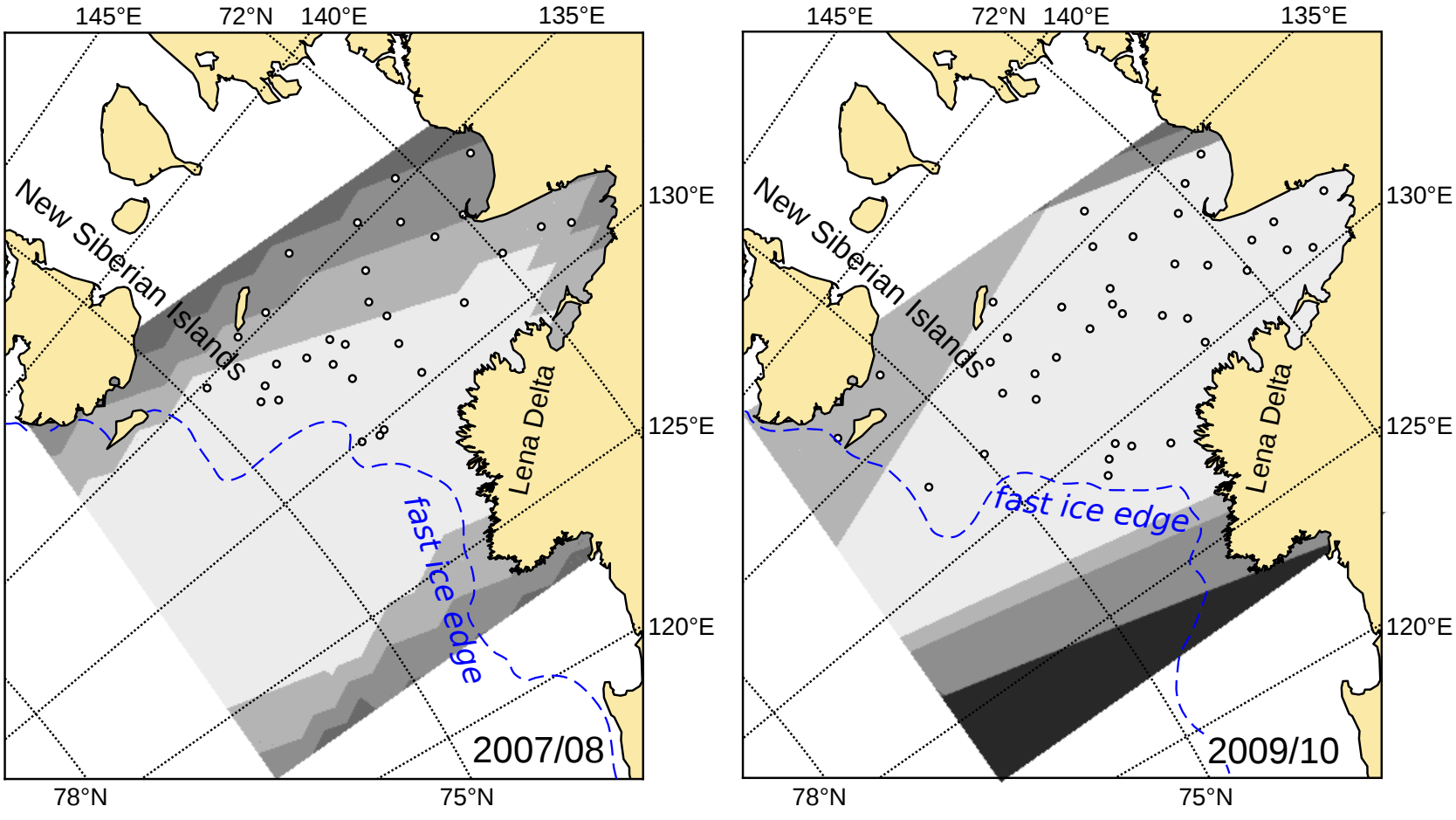
- high in winter

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



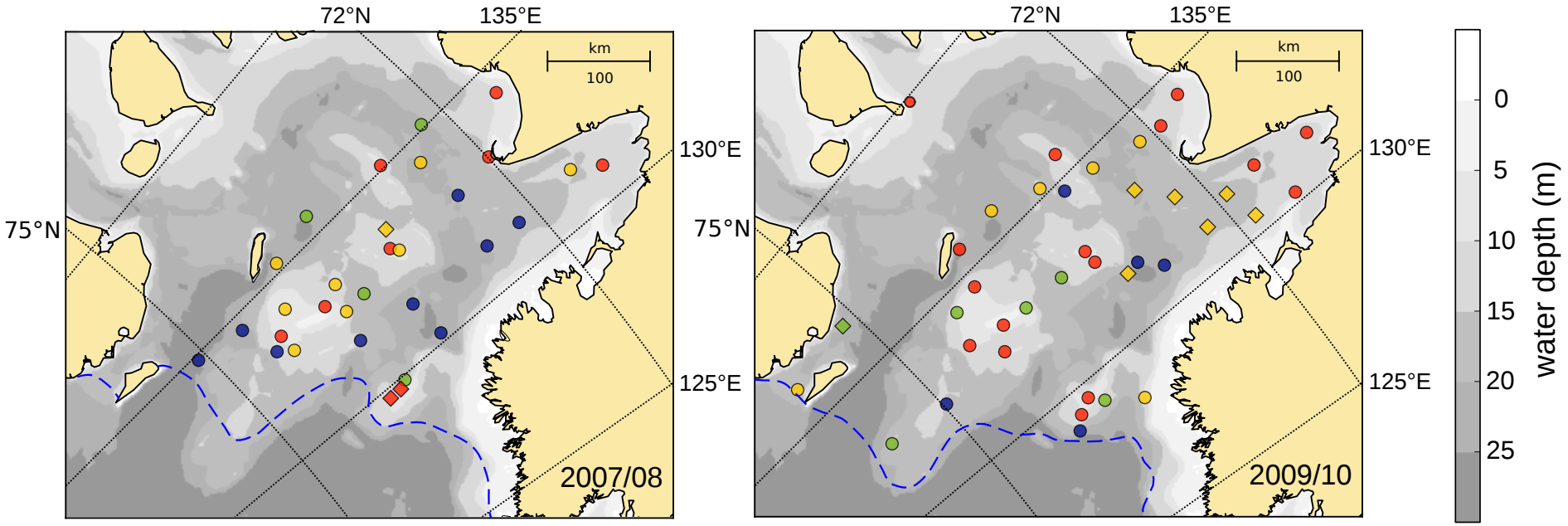
- Synthetic Aperture Radar (SAR) image every 2-14 days
- spatial resolution 150 m

III. Tracked sea ice features



fast ice = 0 cm/s drift speed

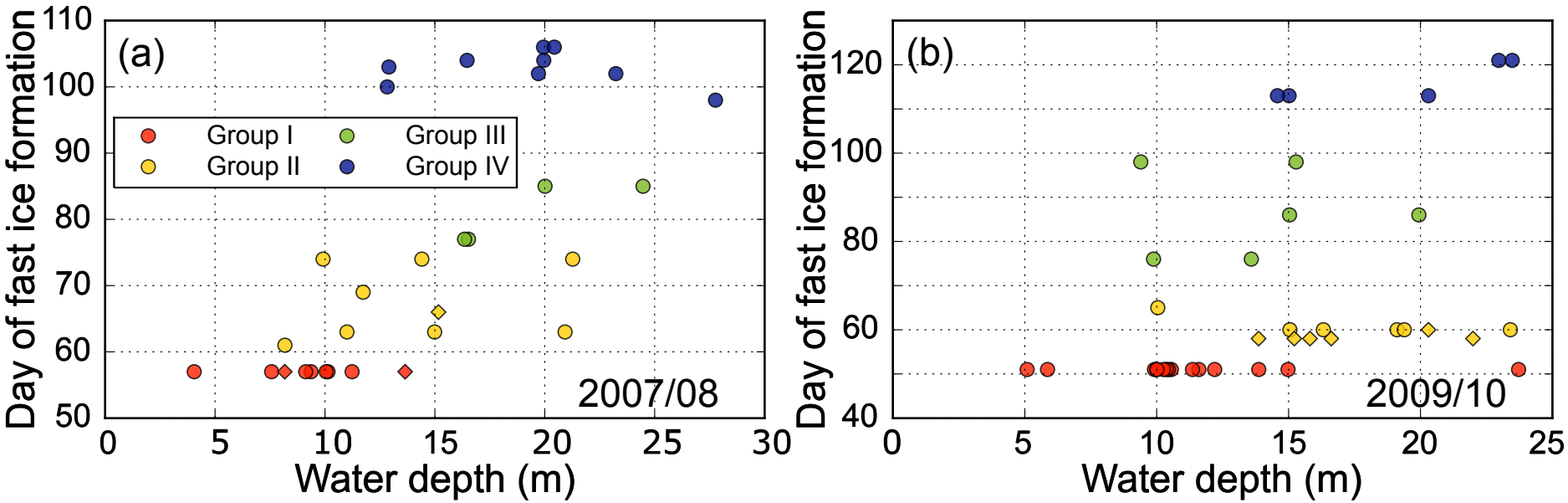
III. Final location of features



Day of fast ice formation (days after freezeup)

- Group I - 58 days
- Group II - 74 days
- Group III - 98 days
- Group IV - 121 days

III. Water depth vs fast ice formation day



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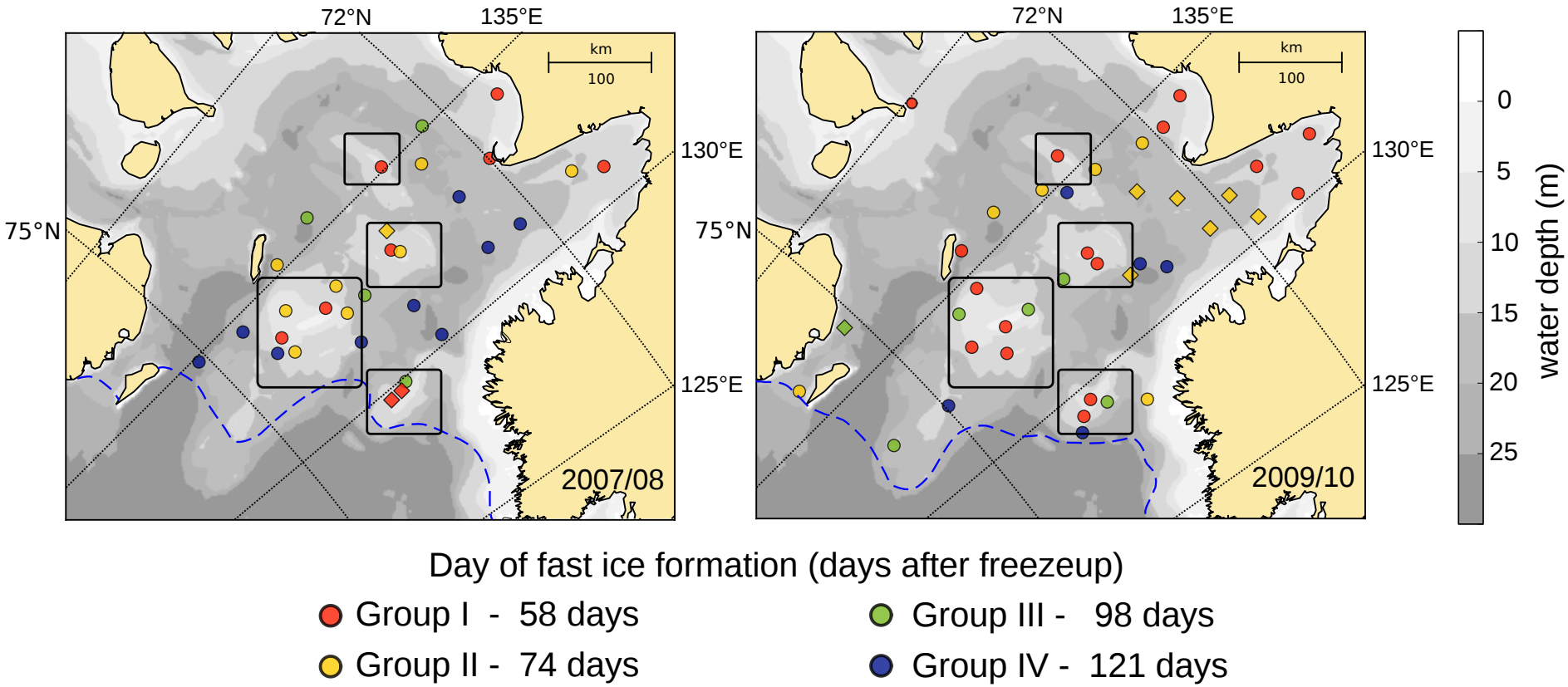
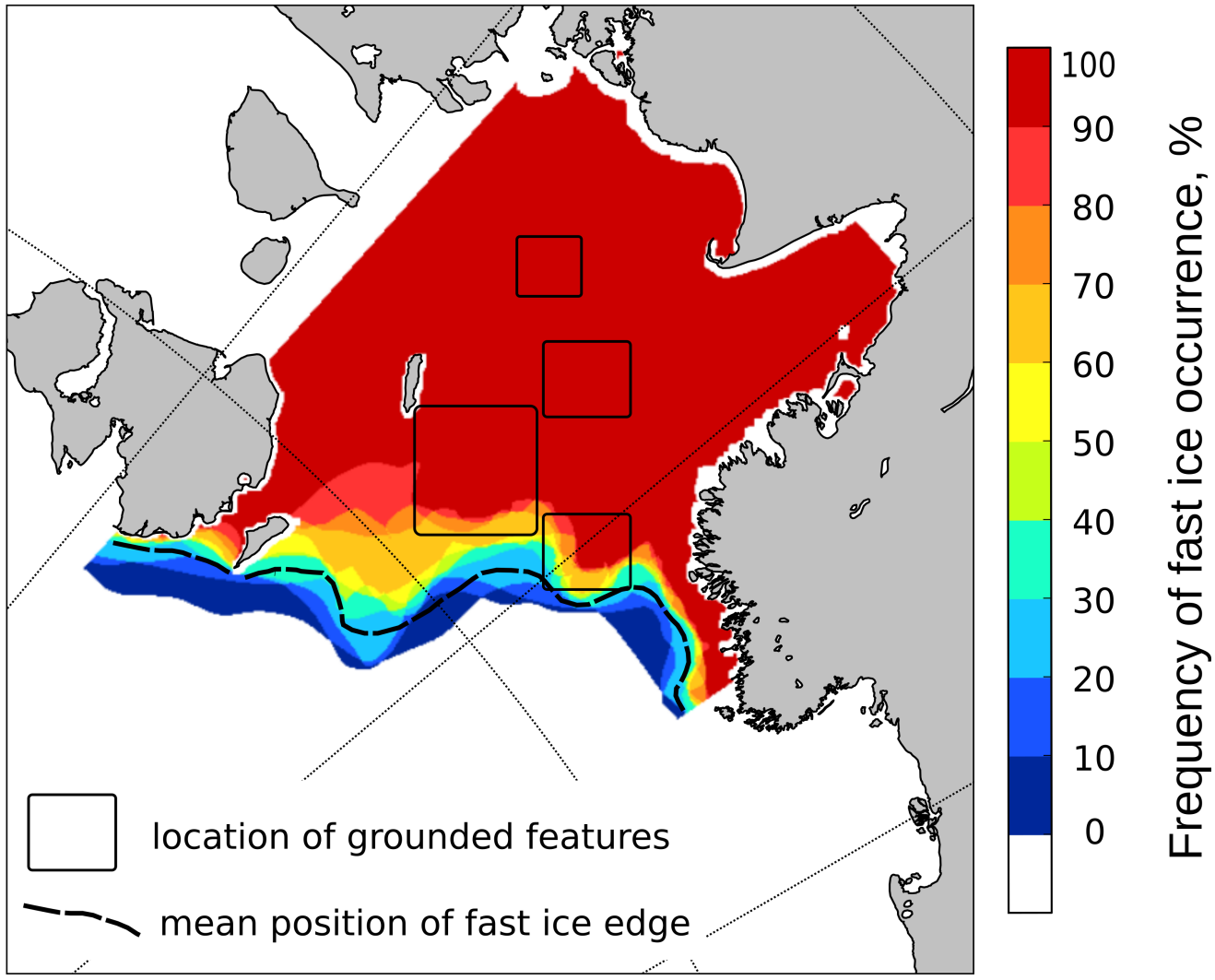


- relatively thin ice becomes grounded over the shoals
- it serves as stabilizing points for surrounding sea ice

III. Fast ice at the end of rapid development

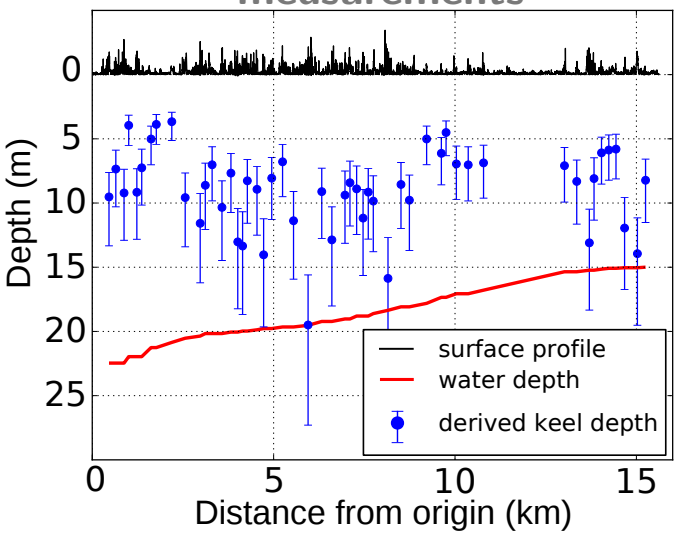
1999 - 2013



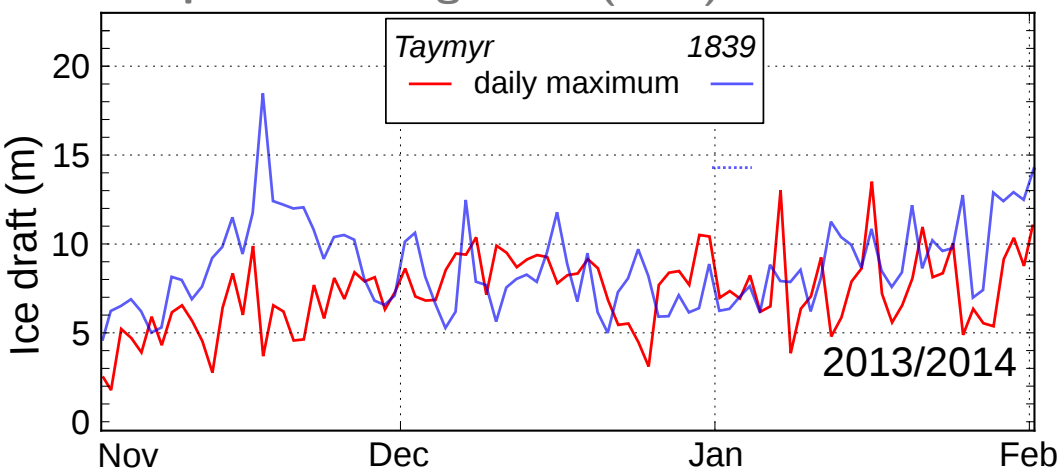
- re-occurring grounded features result in low variation in winter extent

III. Deep sea ice ridges

Electromagnetic (EM) ice thickness measurements

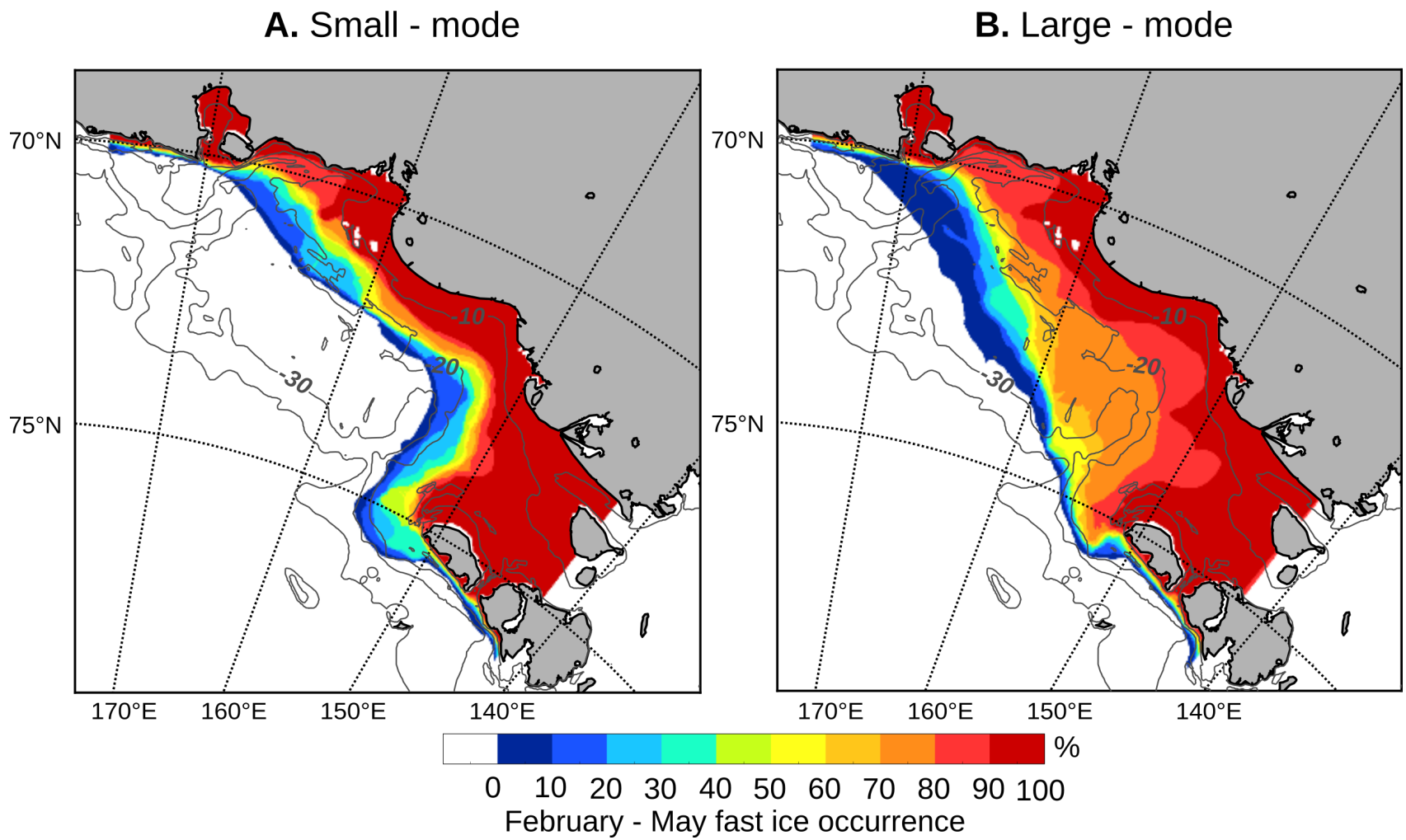


Upward looking sonar (ULS) ice draft

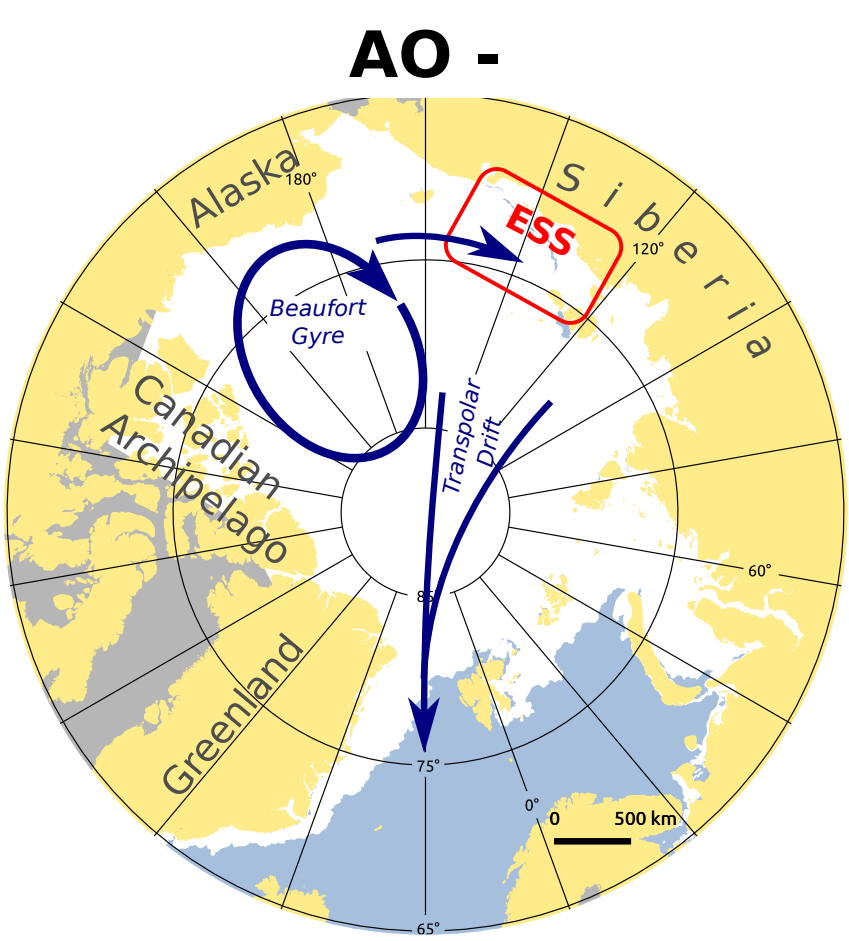


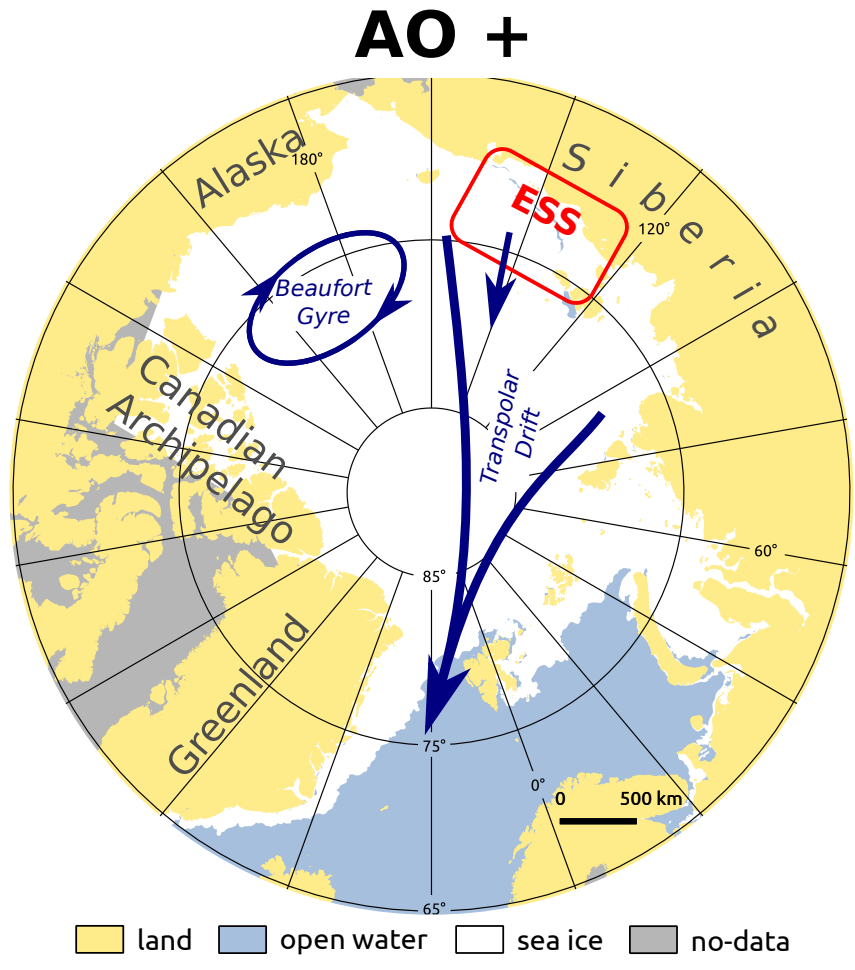
- formation of deep ice ridges in the region confirmed by measurements

III. East Siberian Sea Fast ice modes



III. Arctic Oscillation Index (AO)

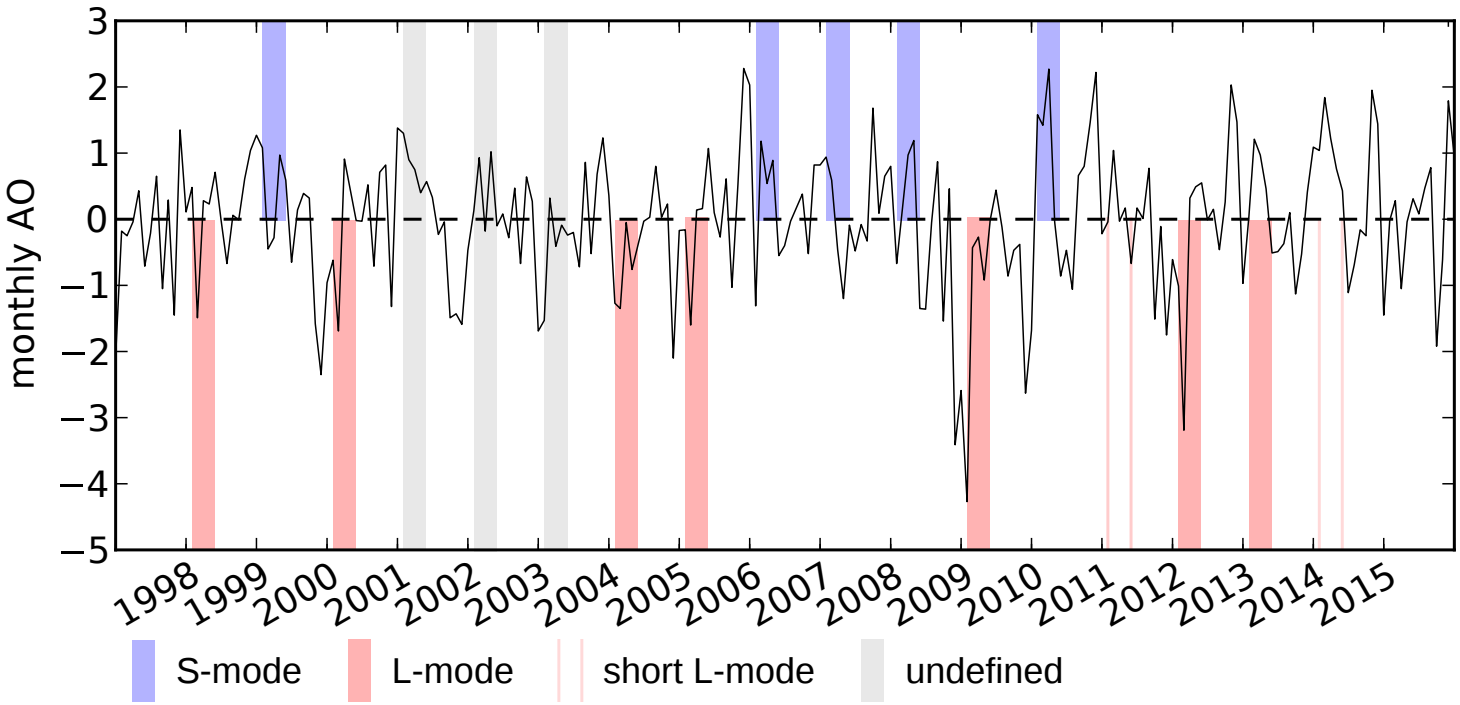


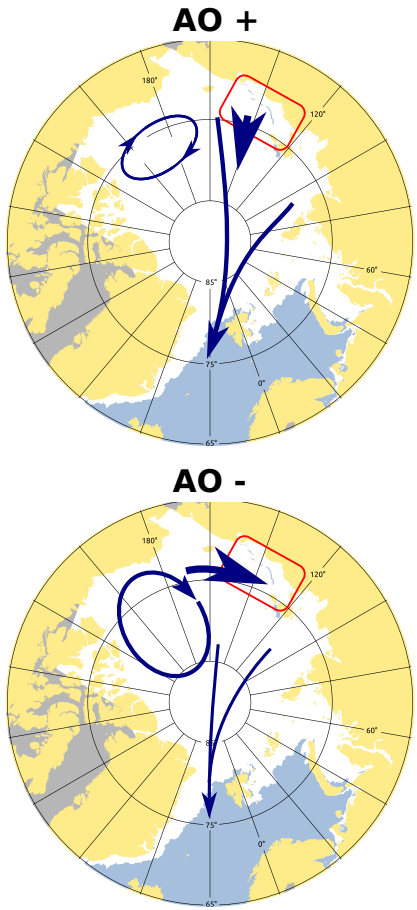


Rigor et al. 2002

III. East Siberian Sea fast ice modes

February-May AO and fast ice modes





Hypothesis

Sea ice import during AO - leads to formation of sea 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

East Siberian Sea

- bimodal fast ice extent

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
  - sediment entrainment
  - higher rates of coastal erosion

- No changes in winter fast ice extent
- Shorter time required for the Laptev Sea fast ice to breakup in summer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