# 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

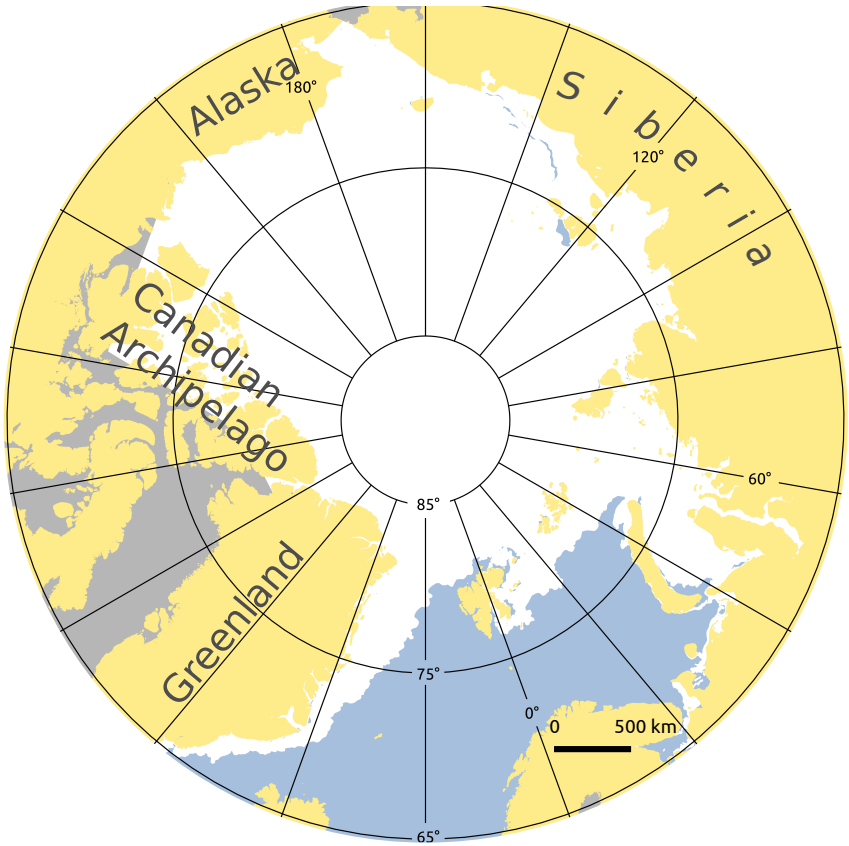
**III. Mechanism of fast ice development**

- case study, sea ice grounding

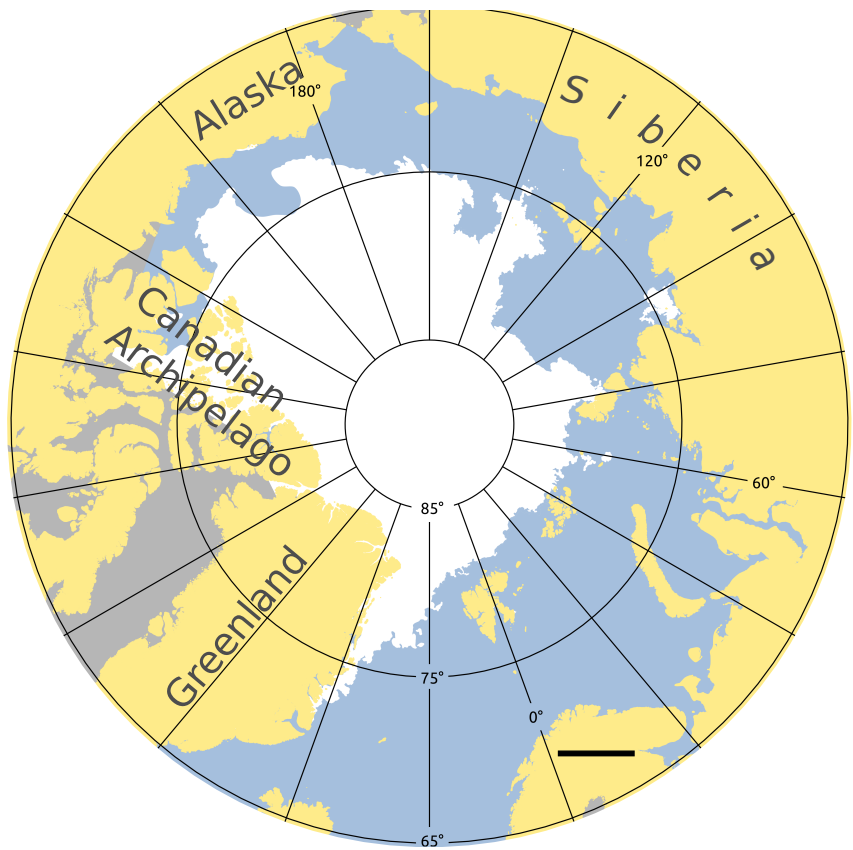
**IV. Summary and outlook**

# I. Arctic sea ice

## 17 March 2015



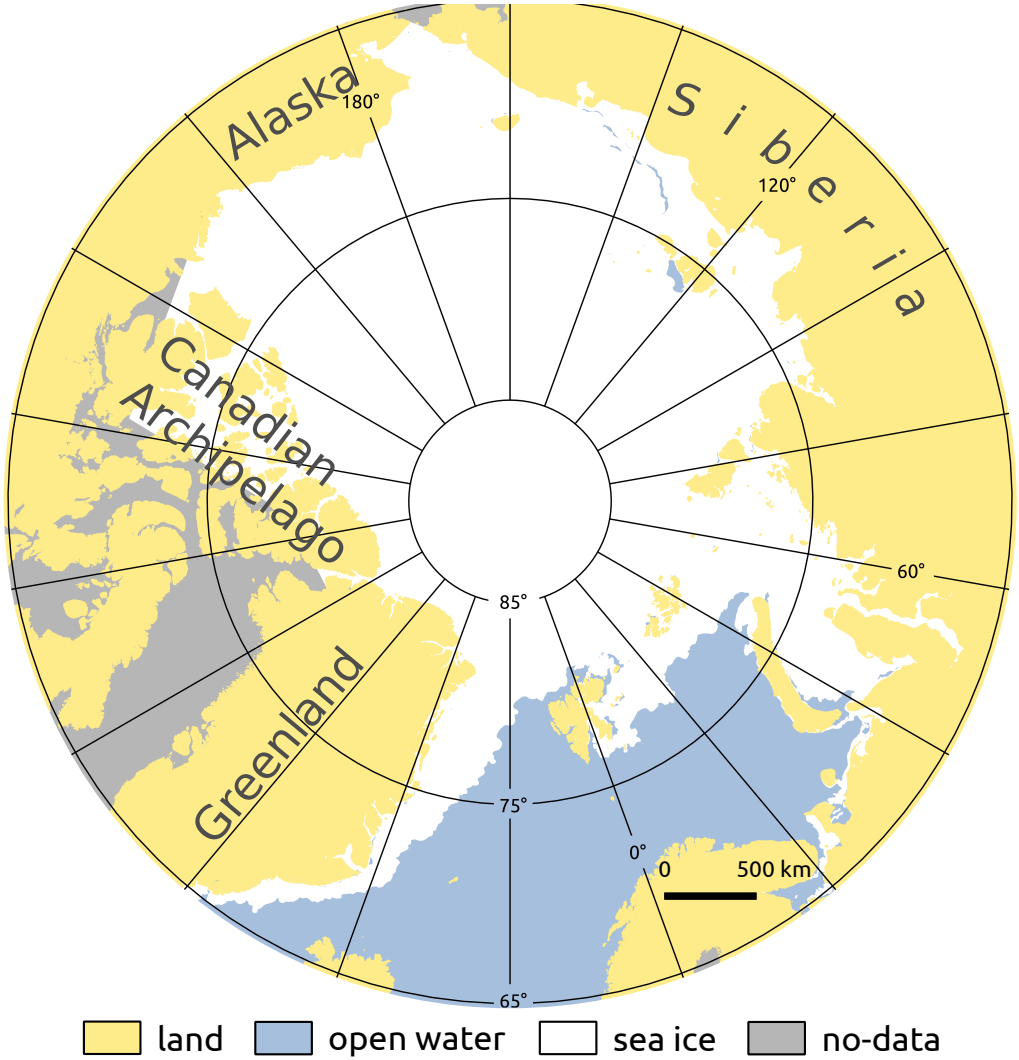

## 10 September 2015




land | open water | sea ice | no-data

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

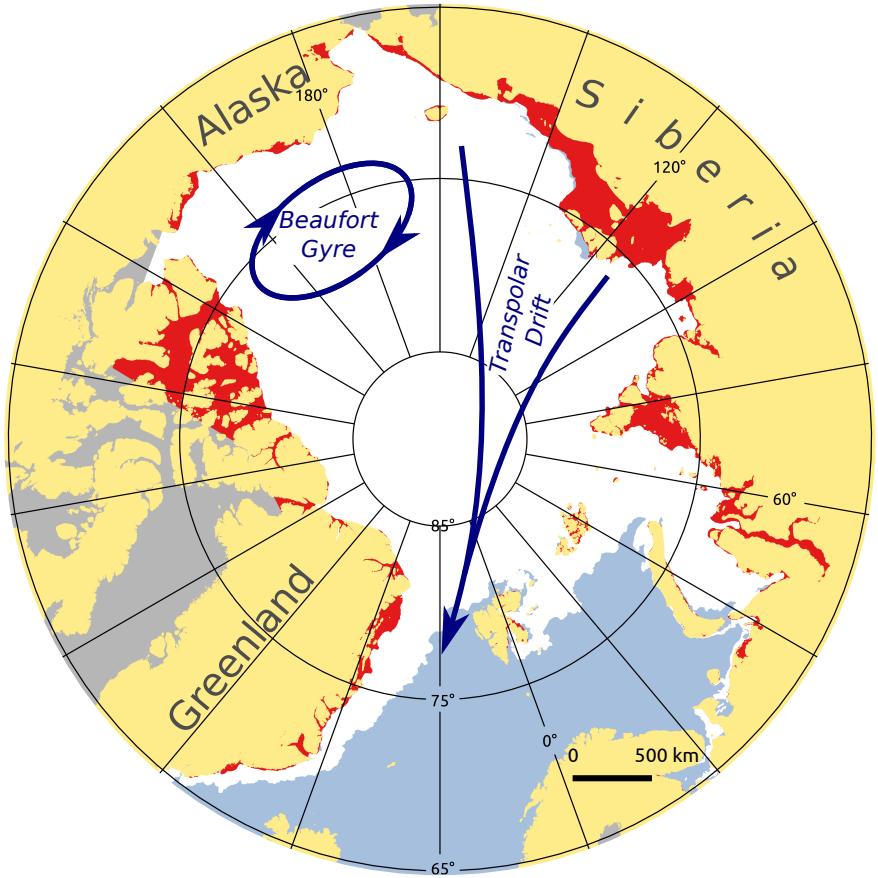
# I. The importance of Arctic sea ice




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)

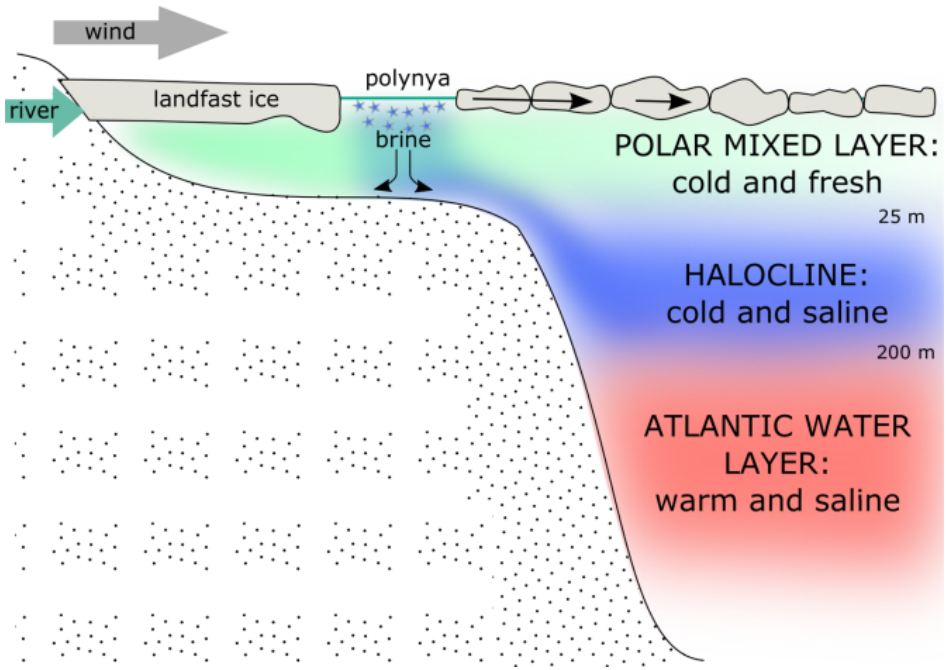
**$\sim$ 13% of total sea ice extent**

**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

- 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

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

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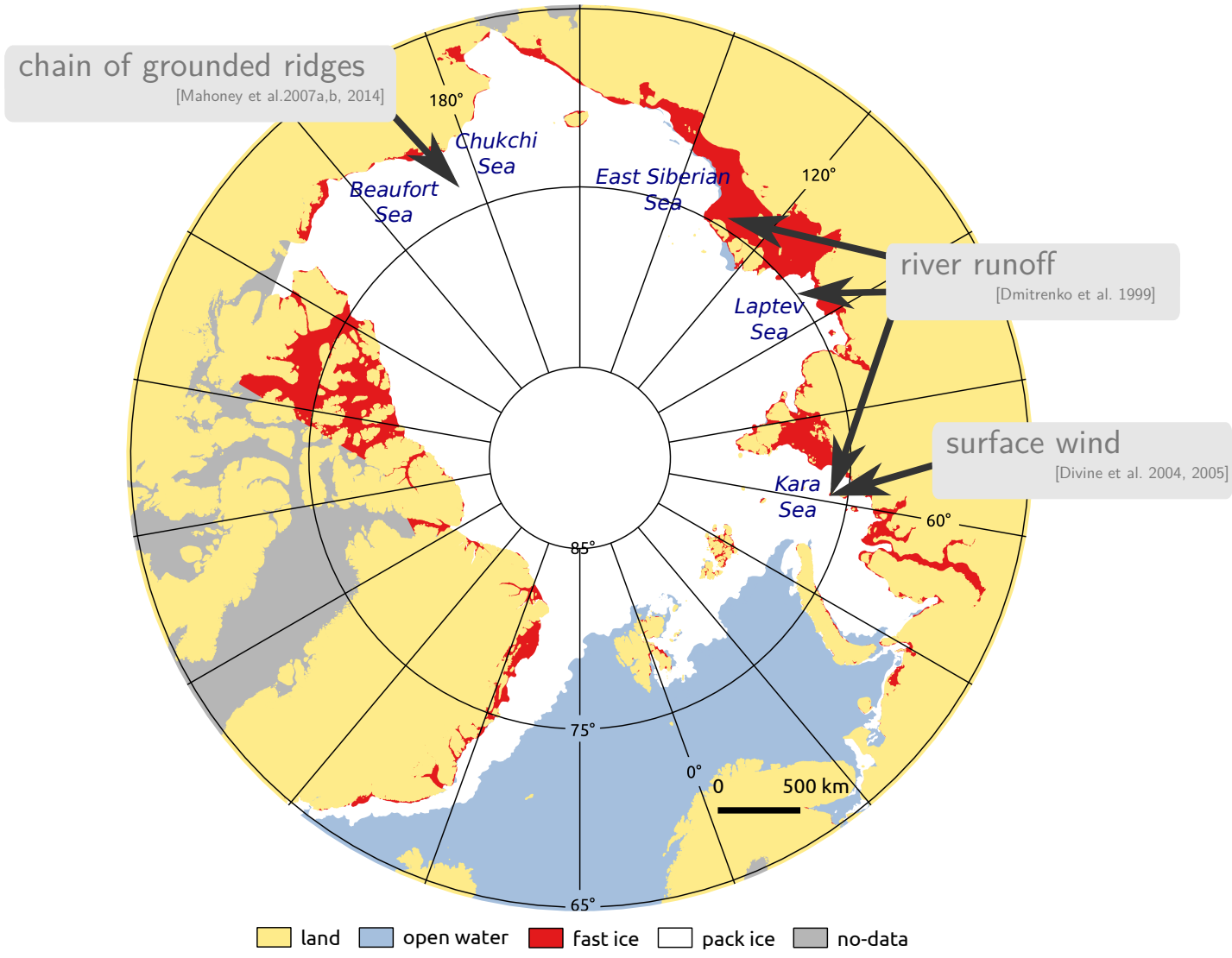
  (Maqueda et al. 2004, Itkin et al. 2015)
- protects coasts from erosion
  (Rachold et al. 2000, Eicken et al. 2005)
- helps to maintain submarine permafrost
  (Rachold et al. 2000)
- **affects human activity**
  (Johannessen et al. 2005, Hughes et al. 2011, Weintrit 2013)

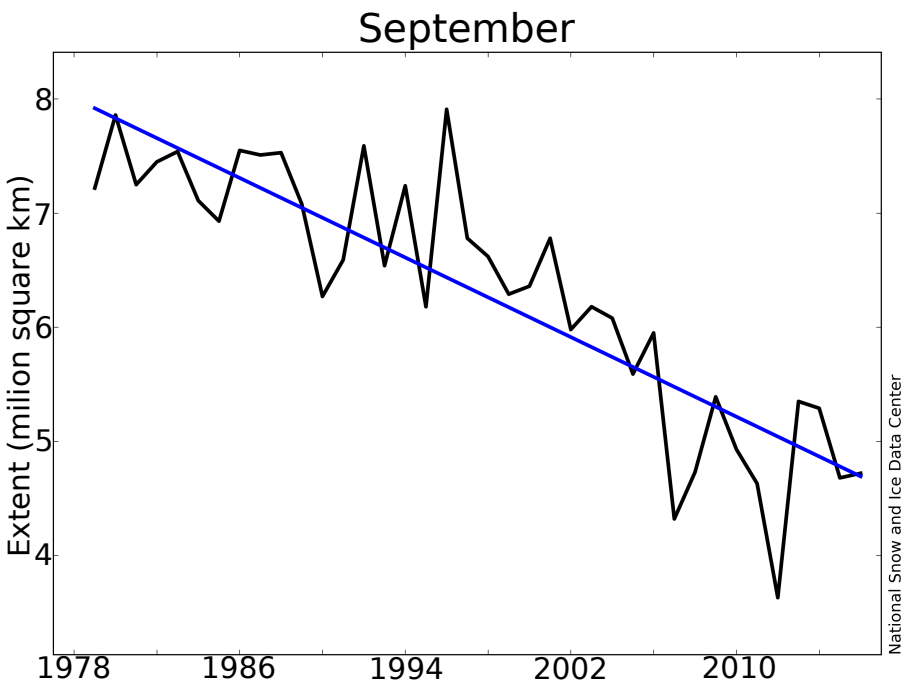
# I. Factors controlling variability of fast ice winter extent




17 March 2015 (AARI Charts)

# I. Changes in Arctic sea ice and fast ice

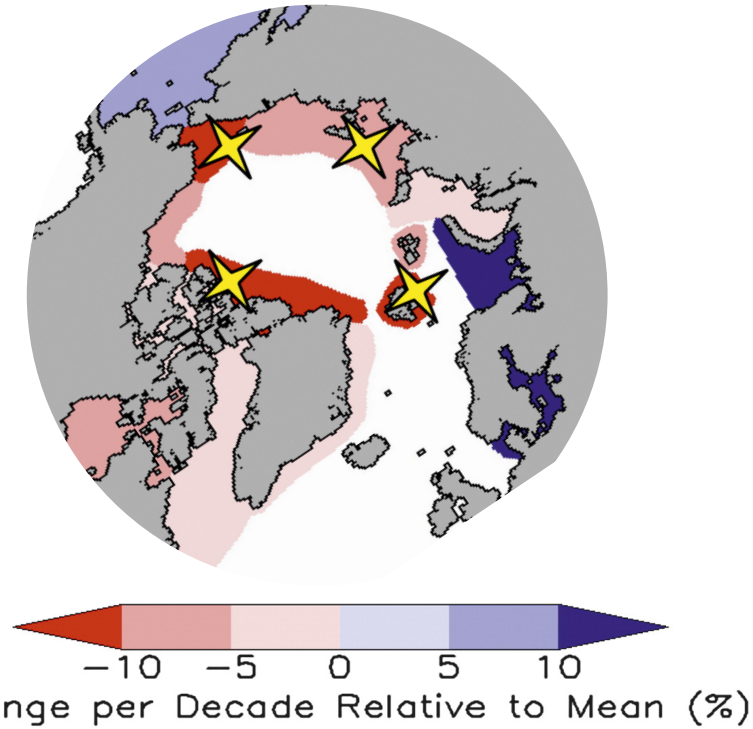
## Sea ice extent, 1979-2016




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

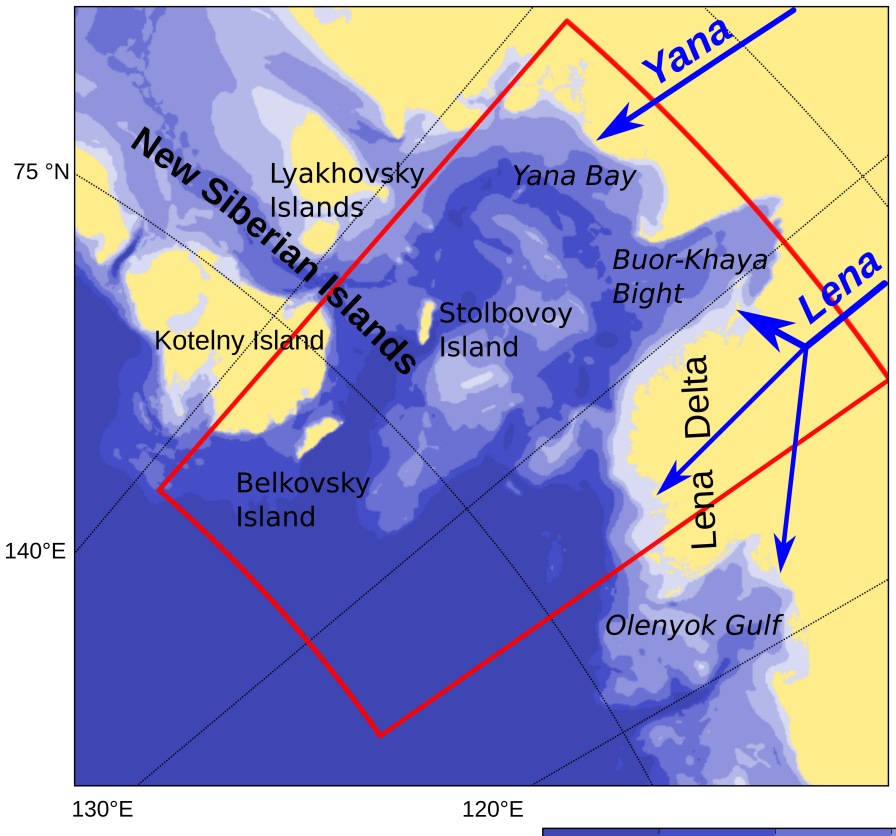
- To describe the **annual fast ice cycle** and reveal the **mechanisms driving the seasonal development** of fast ice.

Objective 2 - Interannual variability and changes

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

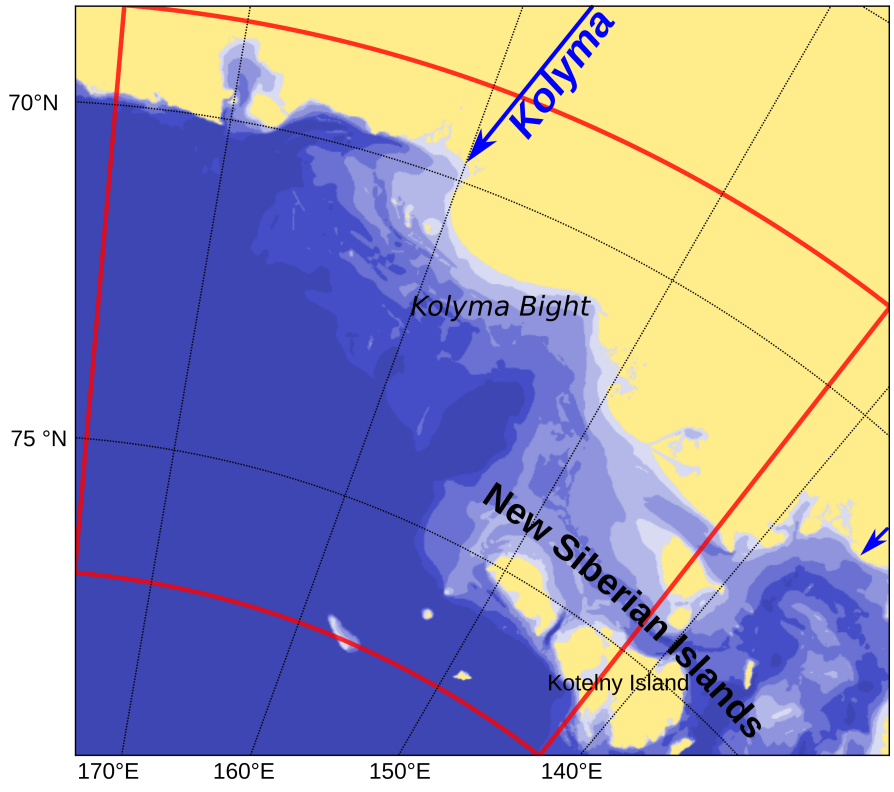
# II. Regions of interest and fast ice information

## Laptev Sea (LS)

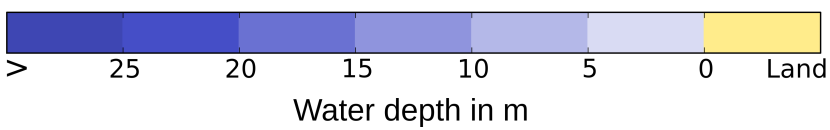



AARI charts, 1999-2013, weekly

## East Siberian Sea (ESS)

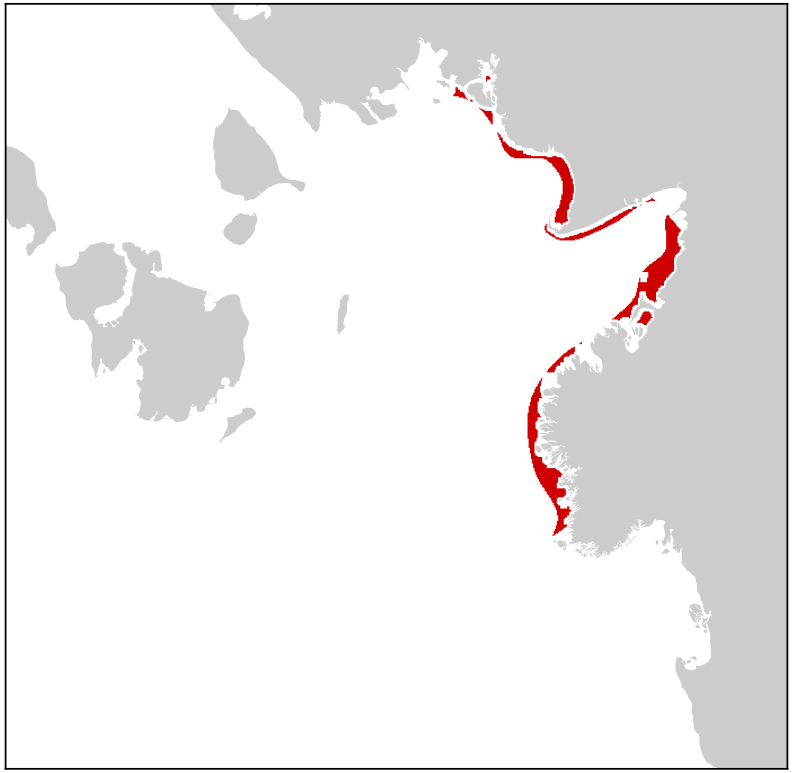



AARI charts, 1999-2015, weekly



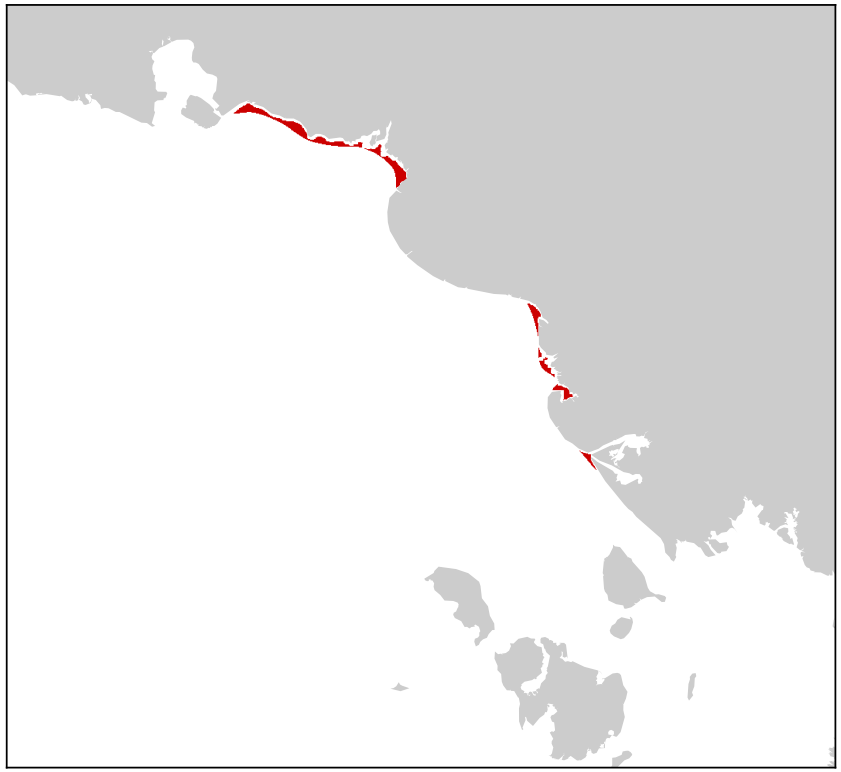
# II. Weekly AARI charts, 2000-2001

2000.10.17



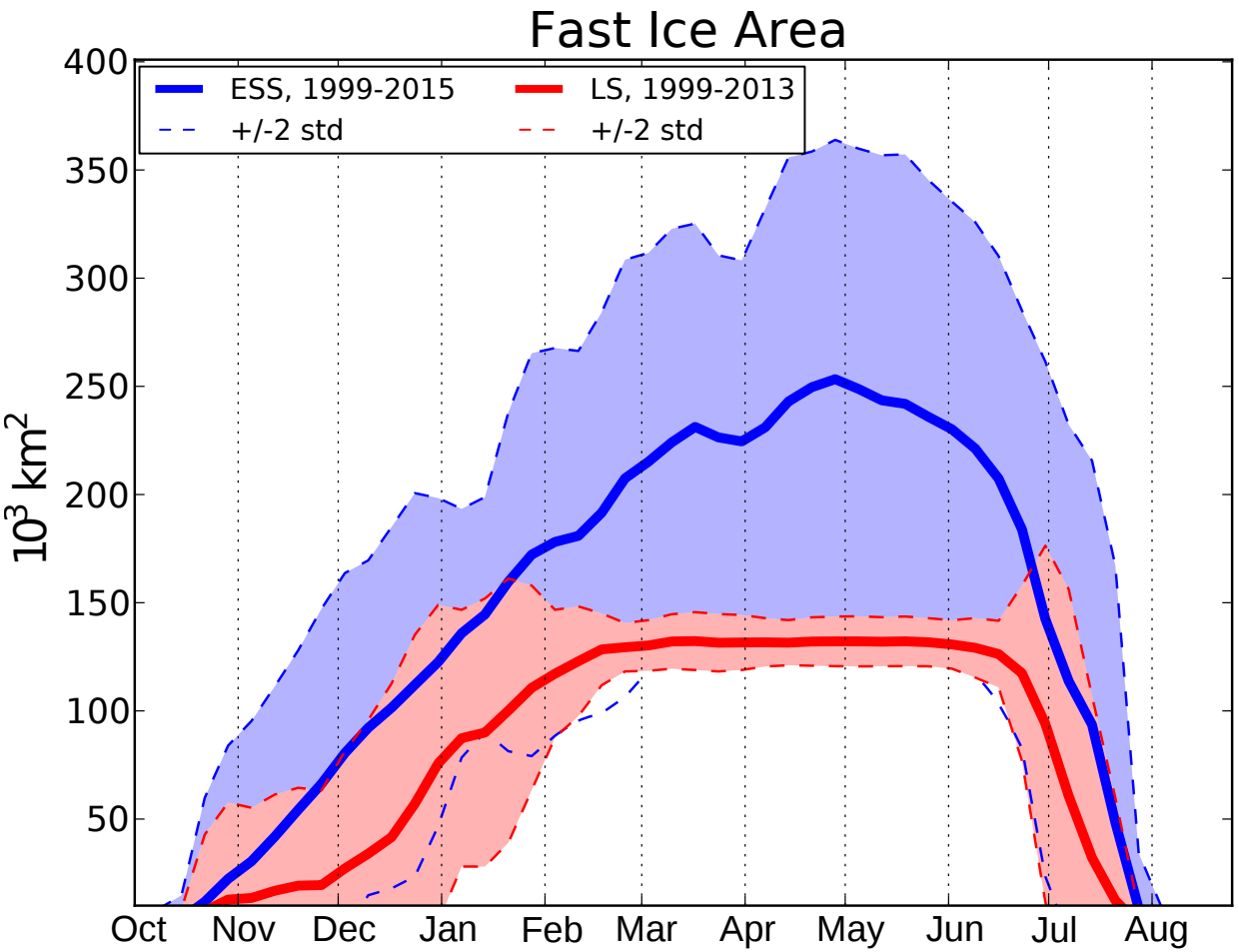
Laptev Sea

2000.10.17



East Siberian Sea

# II. Mean annual fast ice cycle




**Interannual variability**

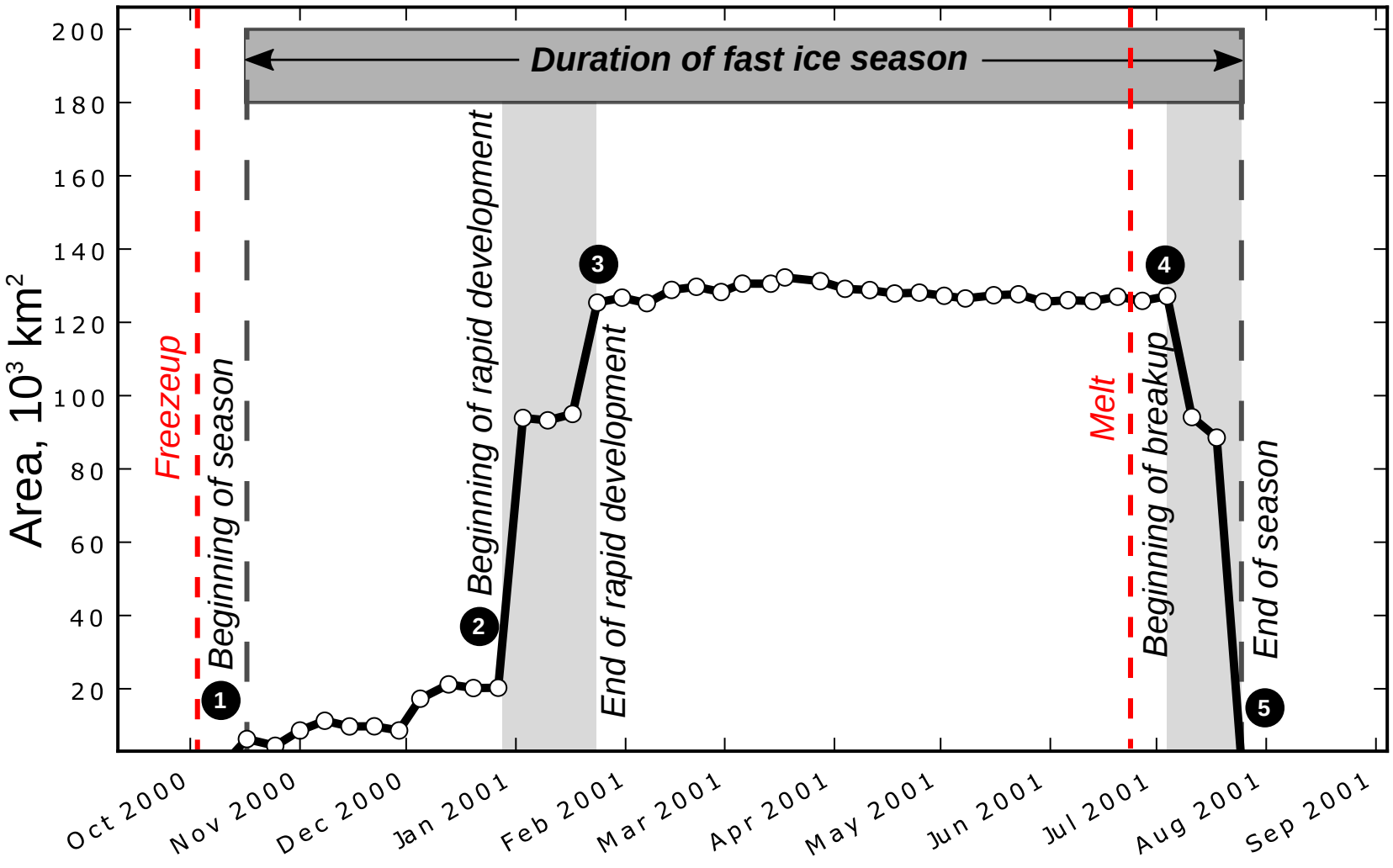
**Laptev Sea:**

- high in November-February
- low in winter

**East Siberian Sea:**

- high in winter

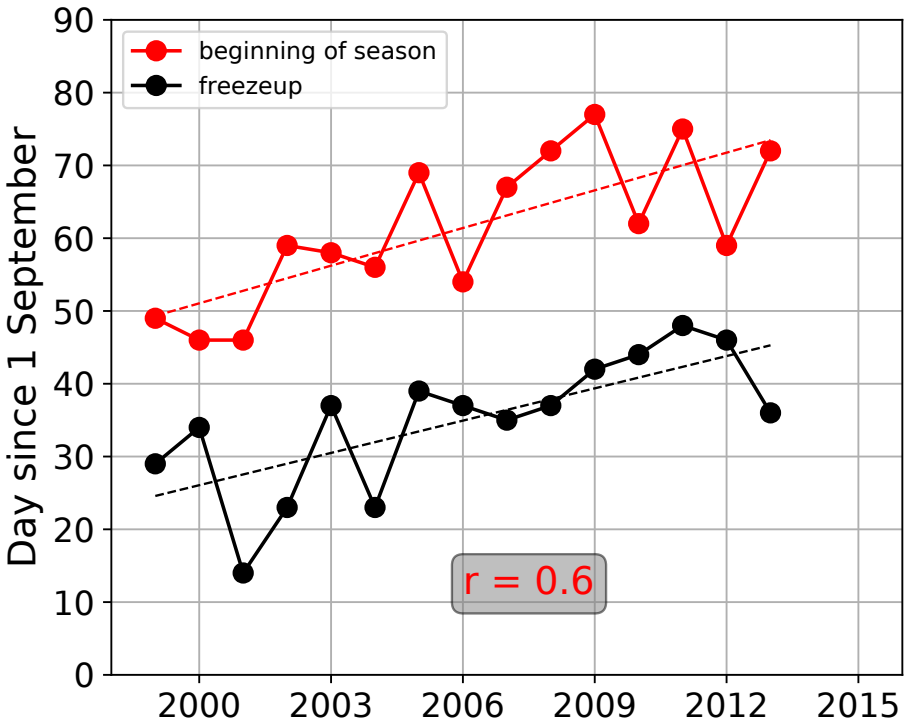
# II. Key events of annual cycle




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

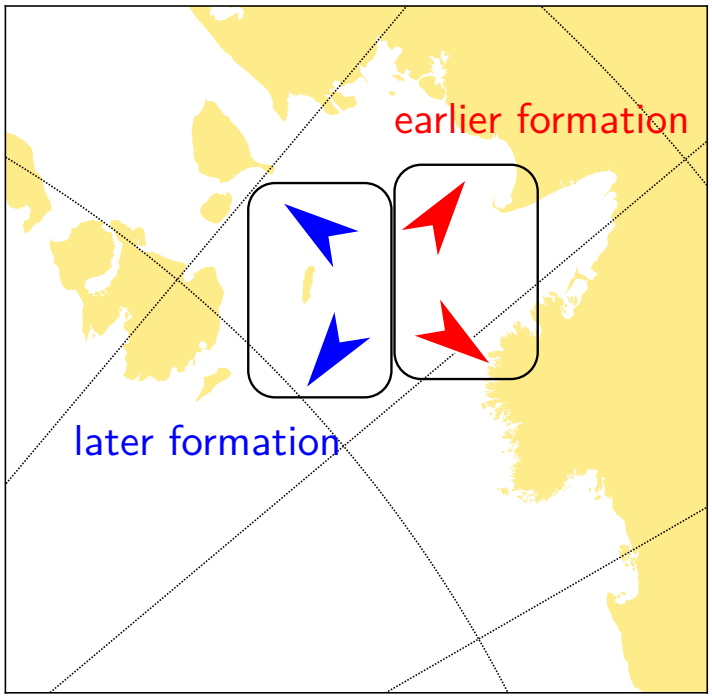
# II. Beginning of season: LS

## Beginning of season and freezeup




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

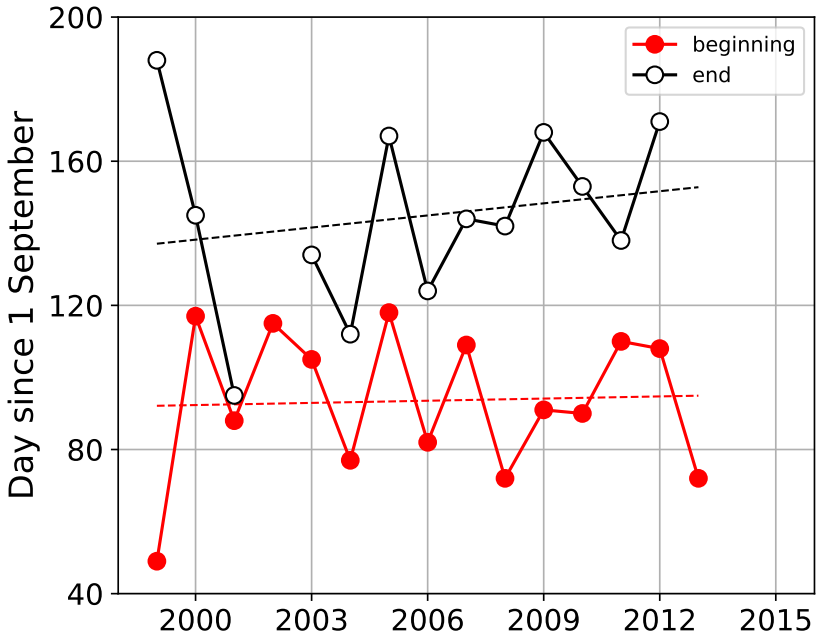
## Wind direction




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

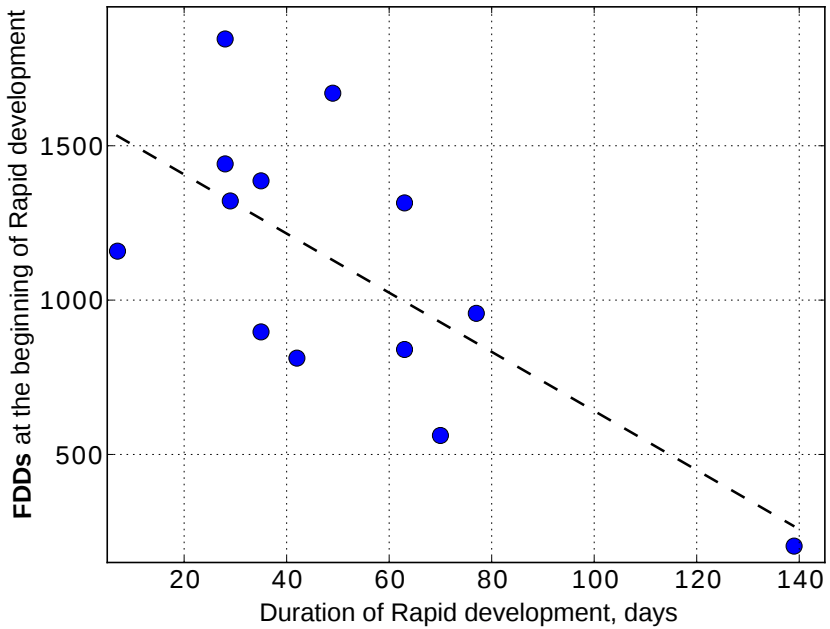
# II. Rapid development: LS

## Beginning and end of rapid development




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

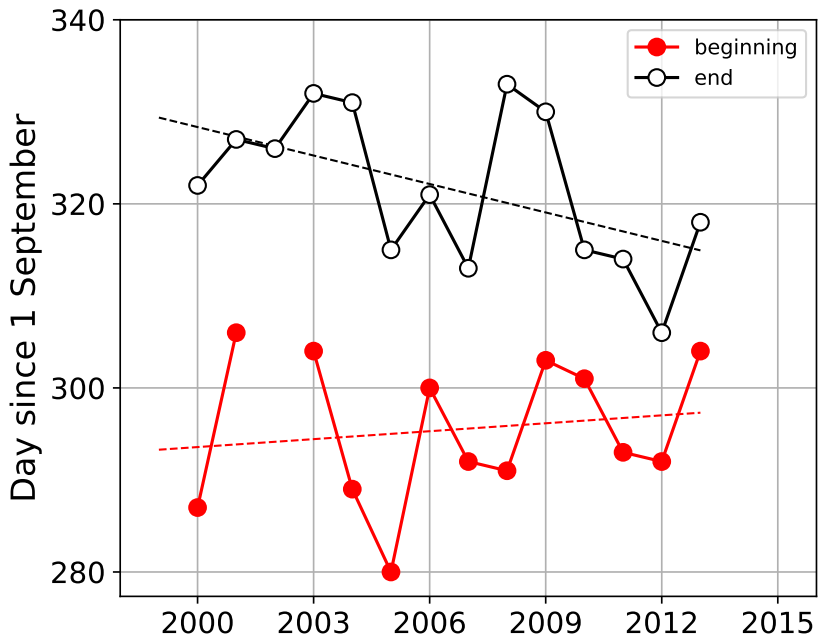
## Duration of rapid development




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

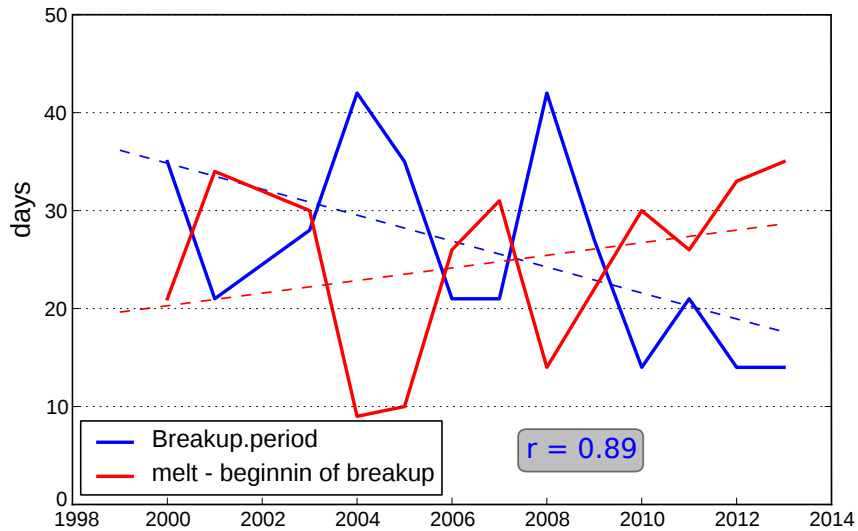
# II. Breakup: LS

## Beginning breakup and end season



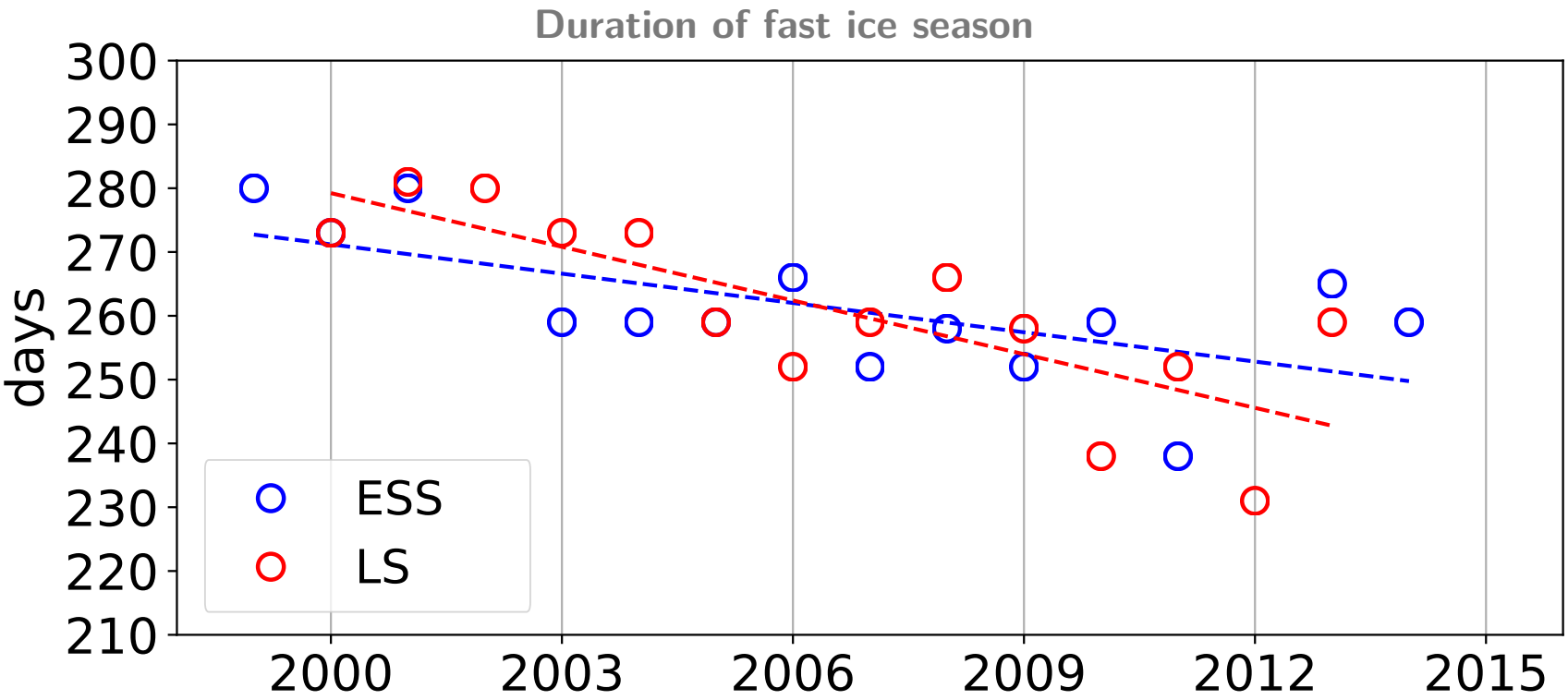

- no changes in beginning
  0.3 days/year (p=0.63)
- tendency towards earlier end
  -1.0 days/year (p=0.06)

## Duration of breakup



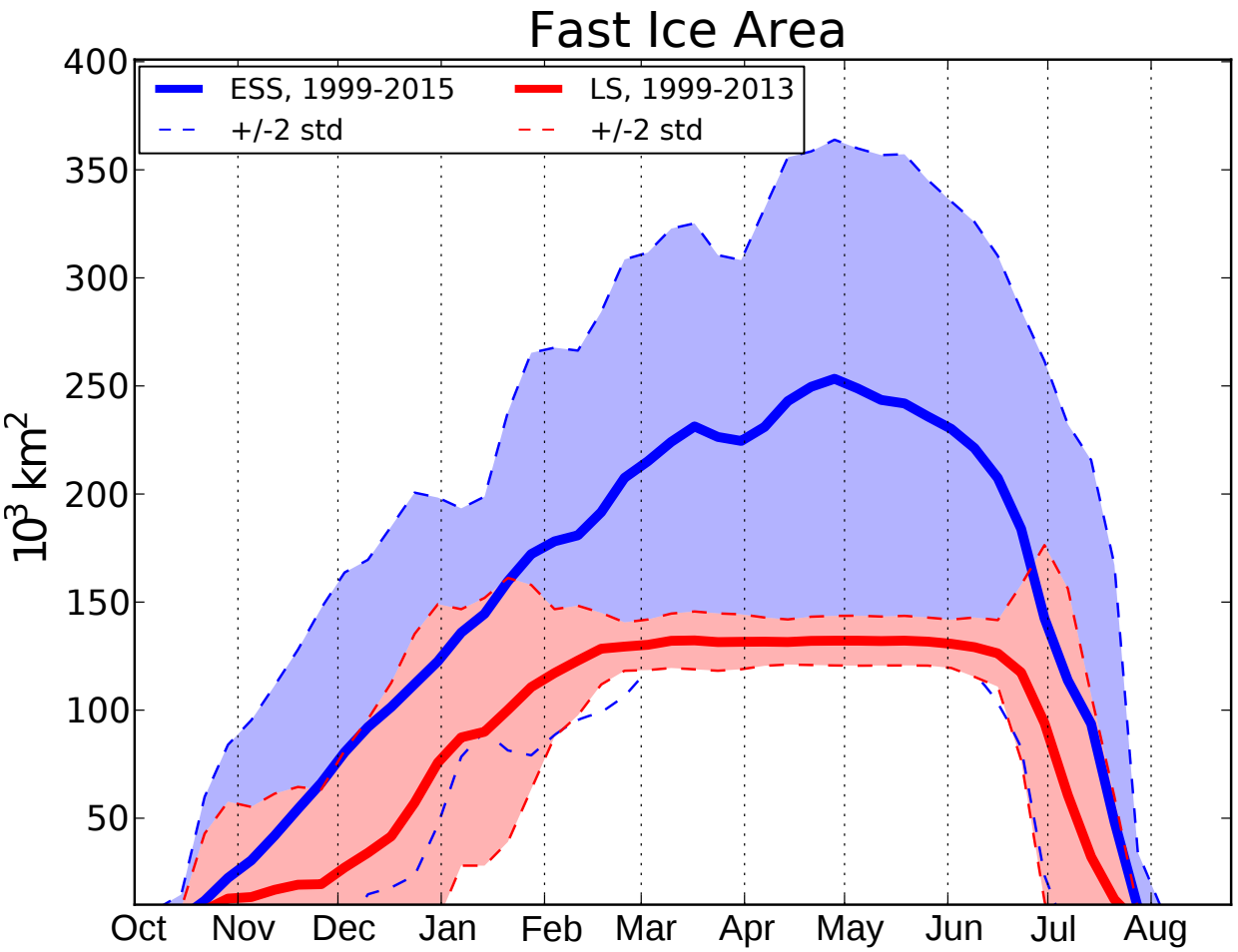

- fast ice needs less time to breakup
- duration of breakup depend on TDD acquired prior beginning of breakup

# 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**

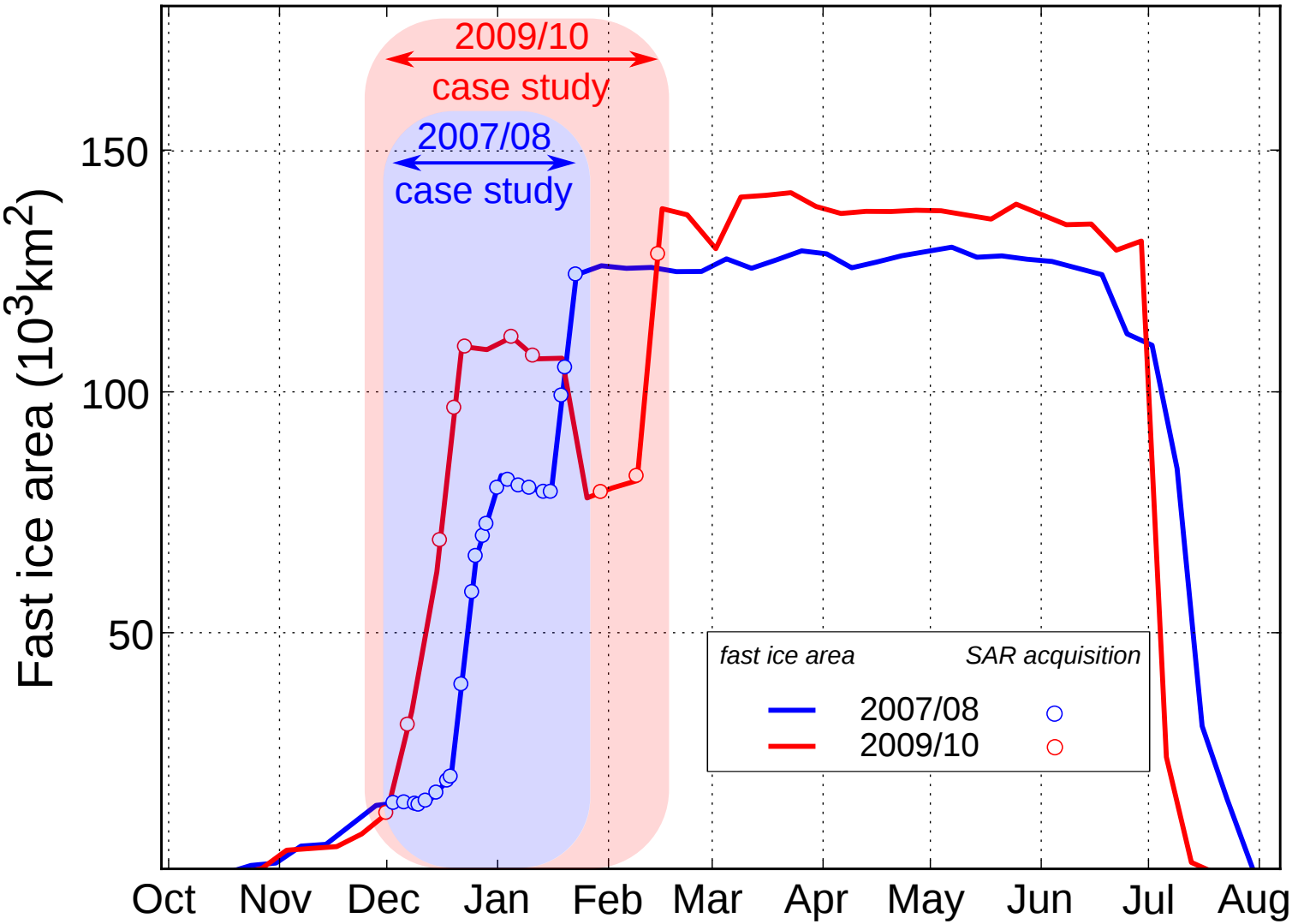
**Laptev Sea:**

- high in November-February
- low winter

**East Siberian Sea:**

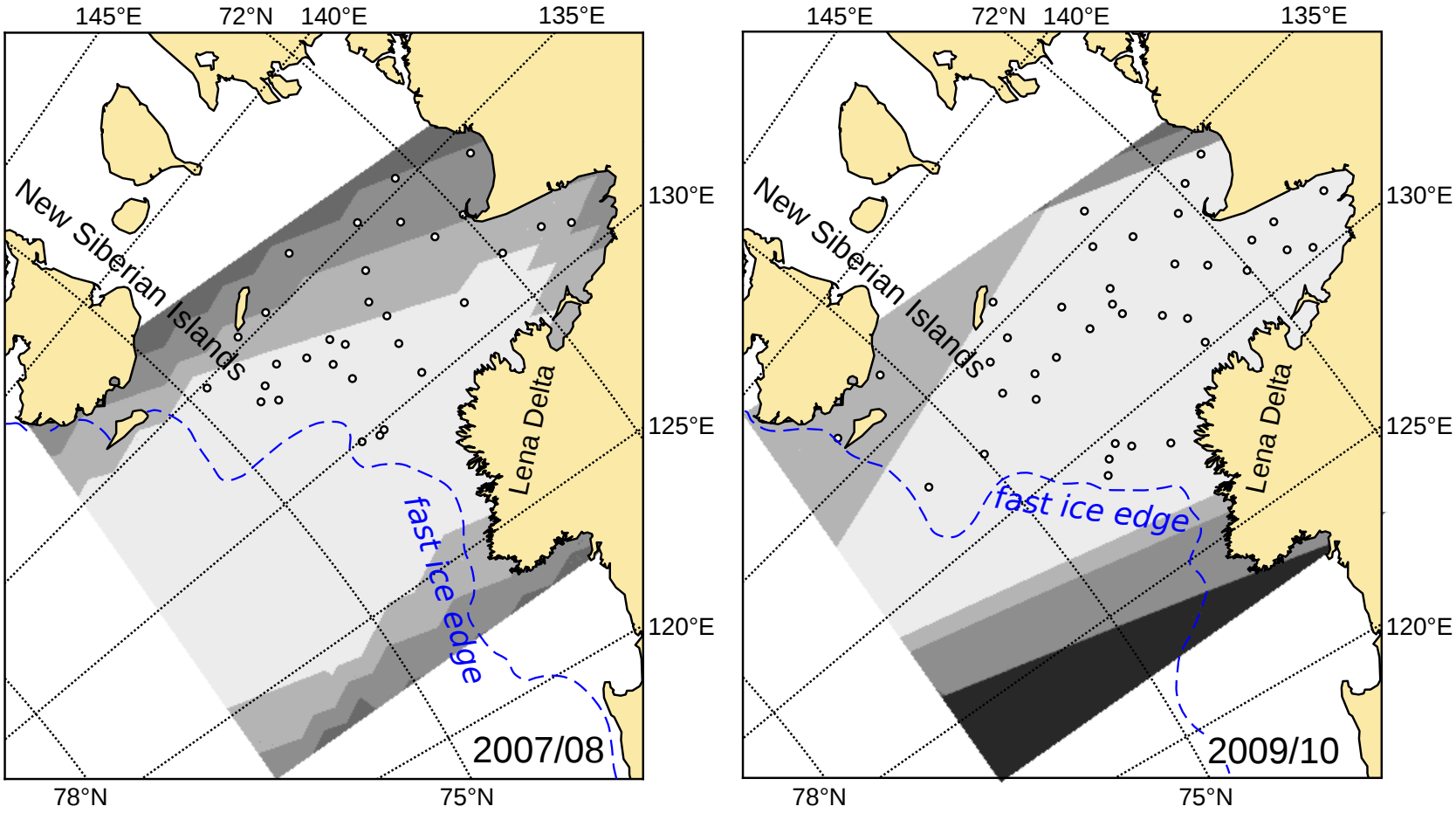
- high in winter

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



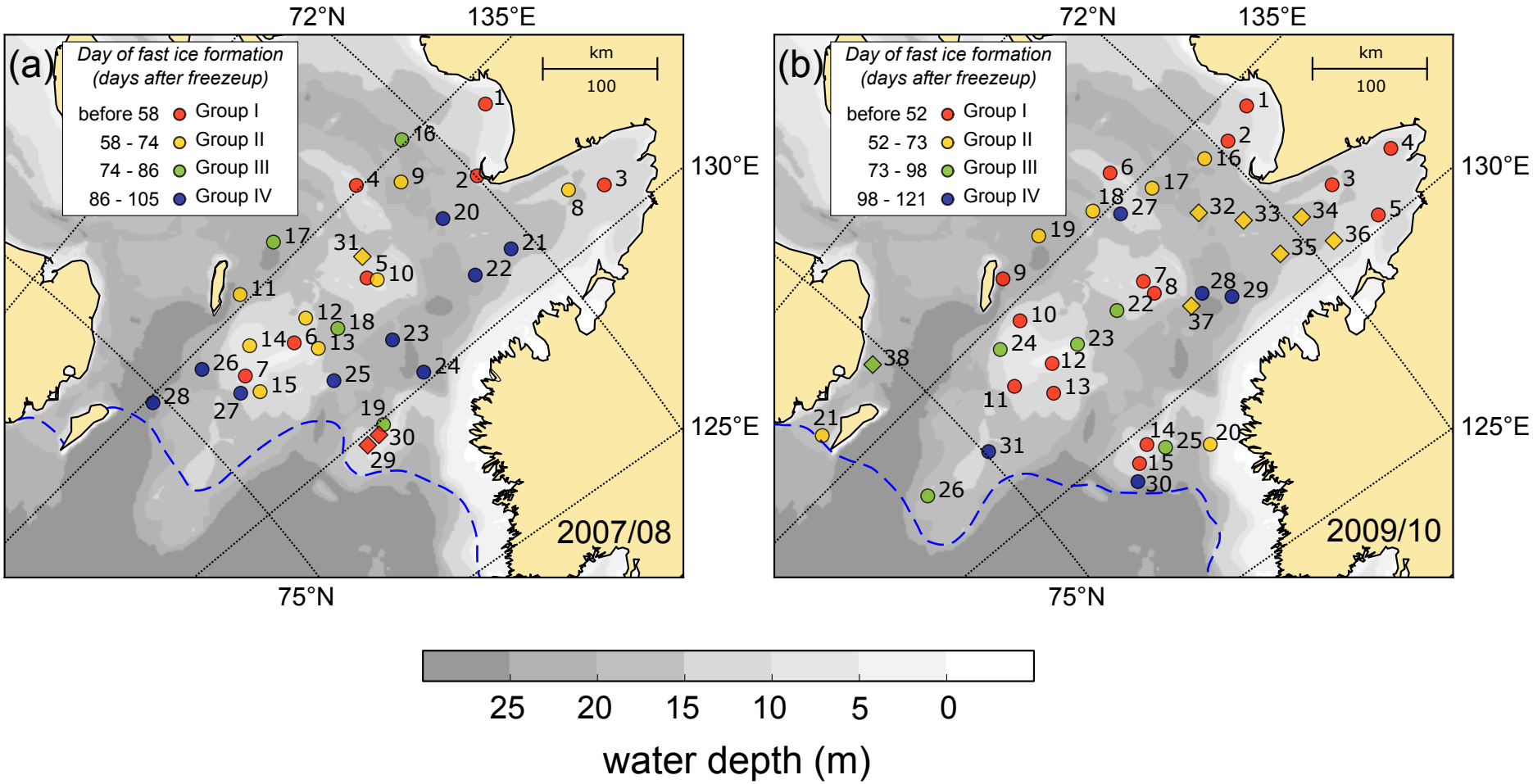

- Synthetic Aperture Radar (SAR) image every 2-14 days
- spatial resolution 150 m

# III. Tracked sea ice features

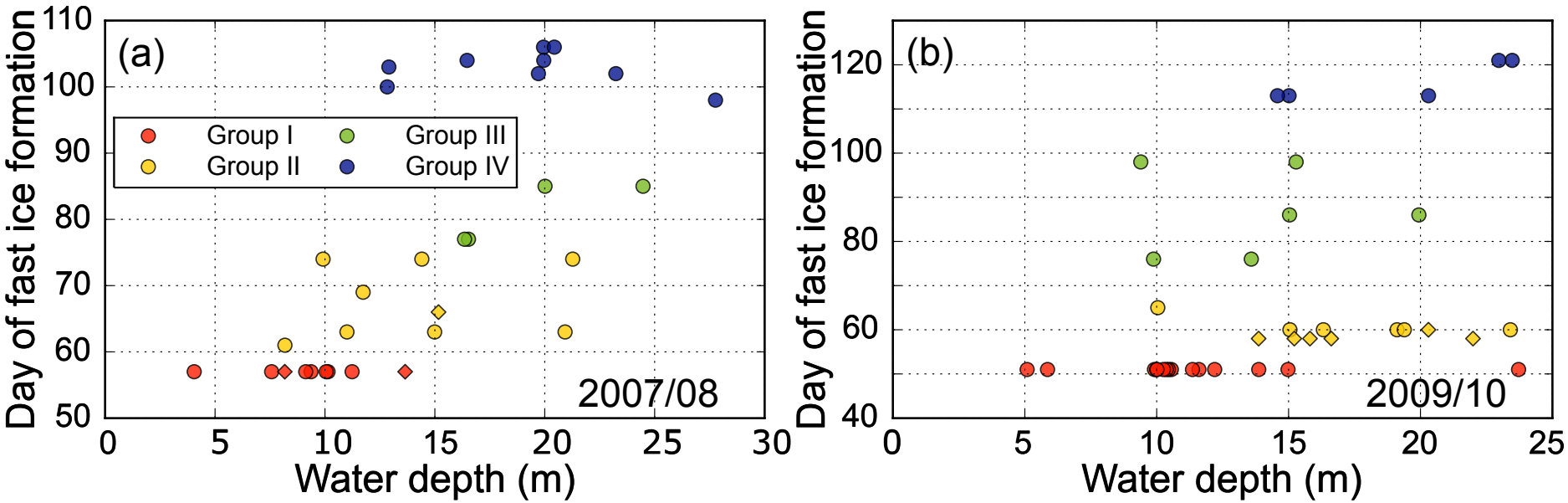



**fast ice = 0 cm/s drift speed**

# III. Final location of features



# III. Water depth vs fast ice formation day



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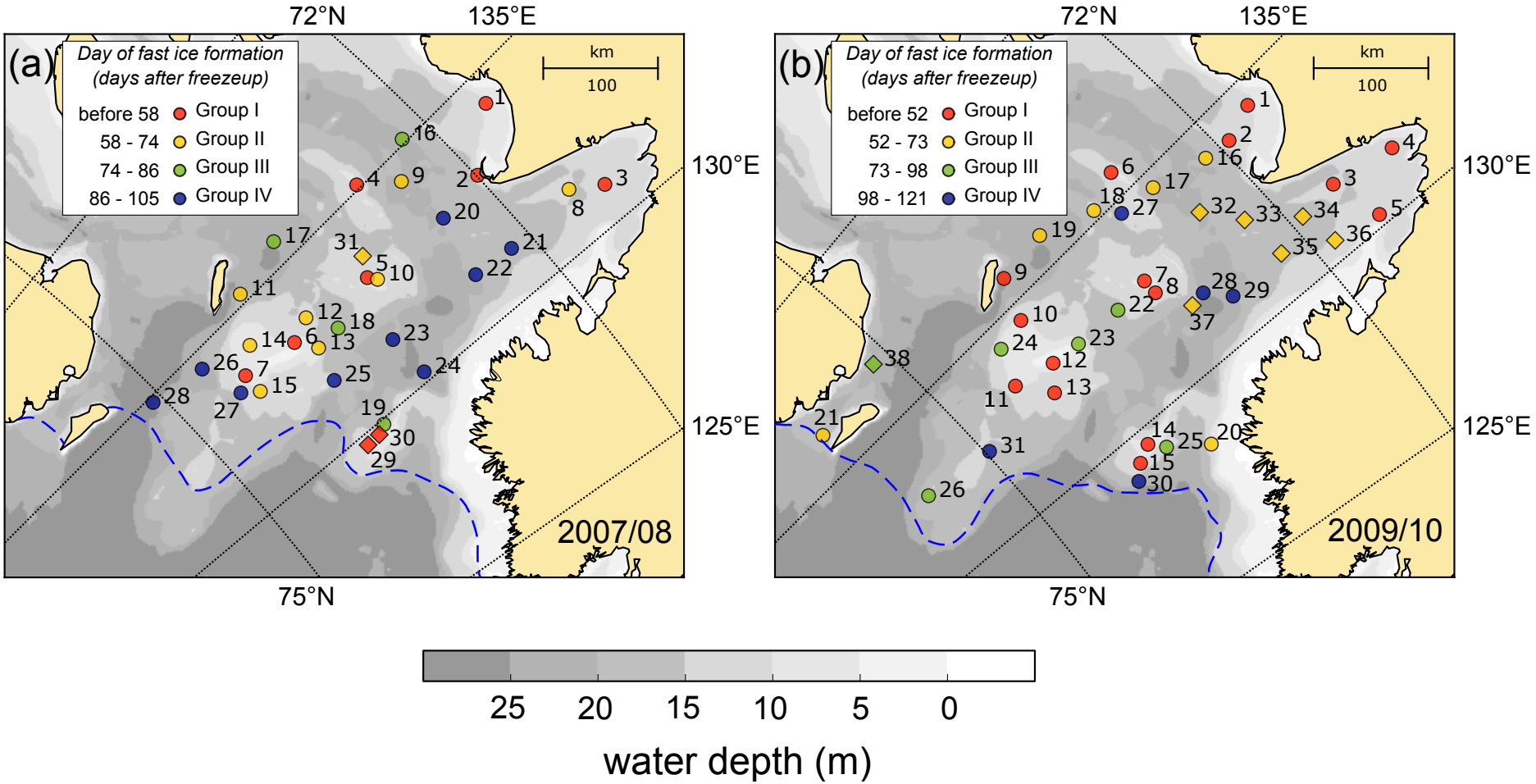
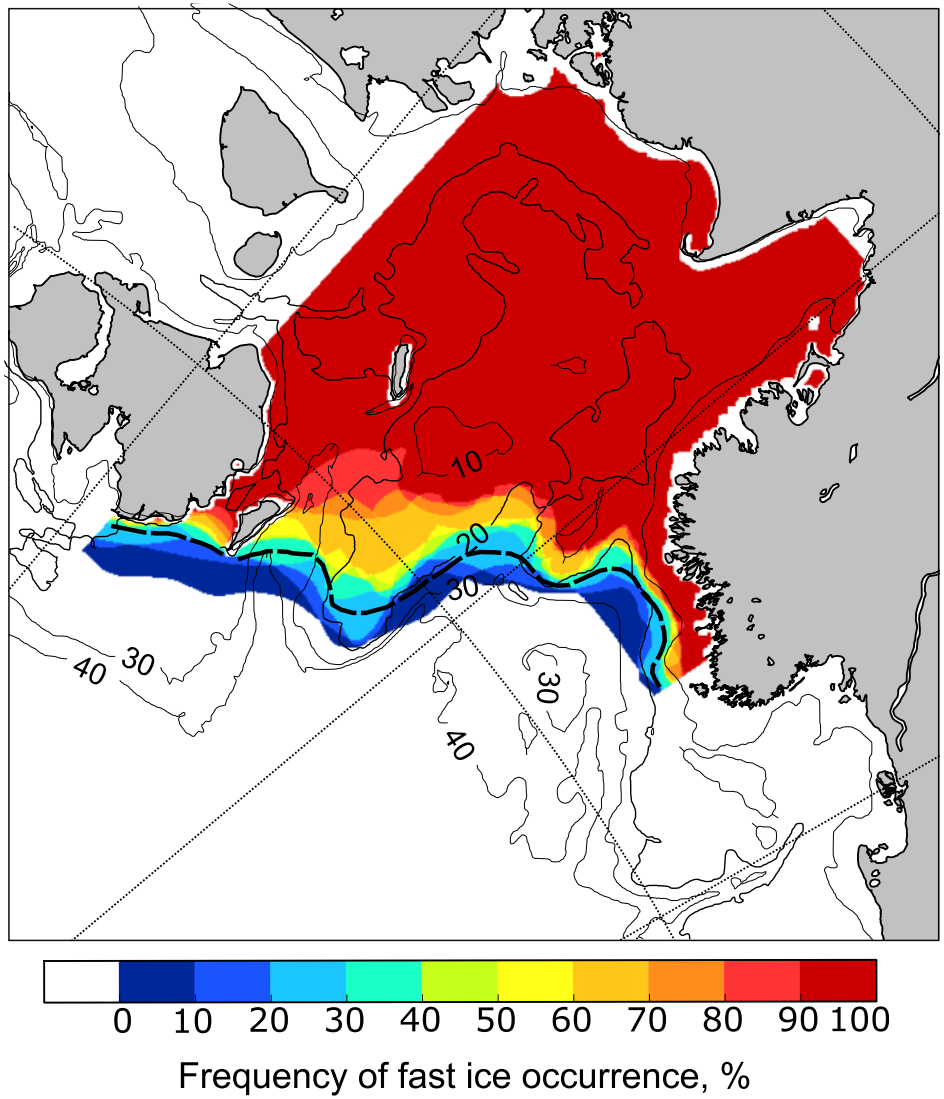



- relatively thin ice becomes grounded over the shoals
- it serves as stabilizing points for surrounding sea ice
- low variations in winter extent predefined by the bathymetry

# III. Fast ice at the end of rapid development

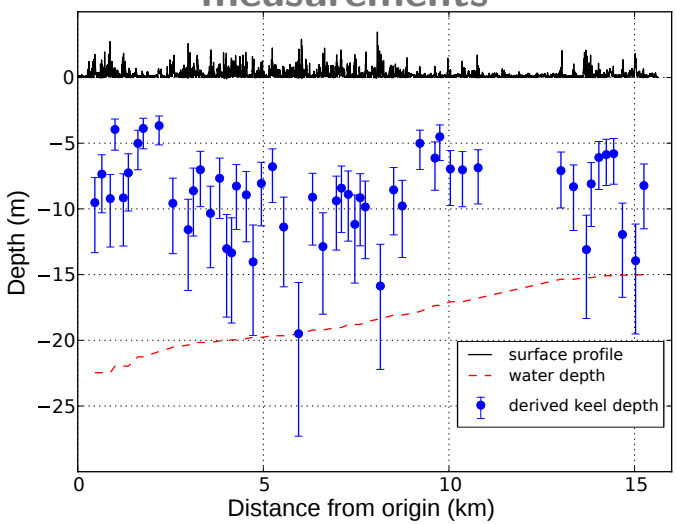
1999-2013



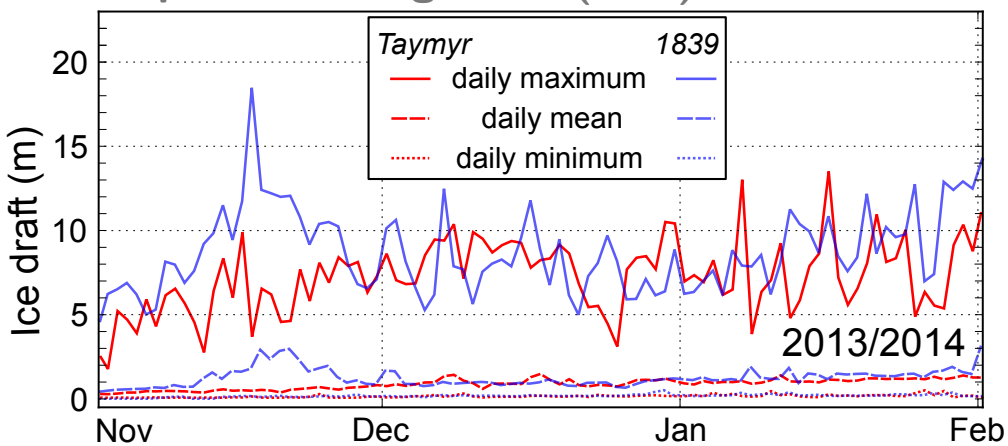

- location of grounded features pre-define winter extent

# III. Deep sea ice ridges

## Electromagnetic (EM) ice thickness measurements

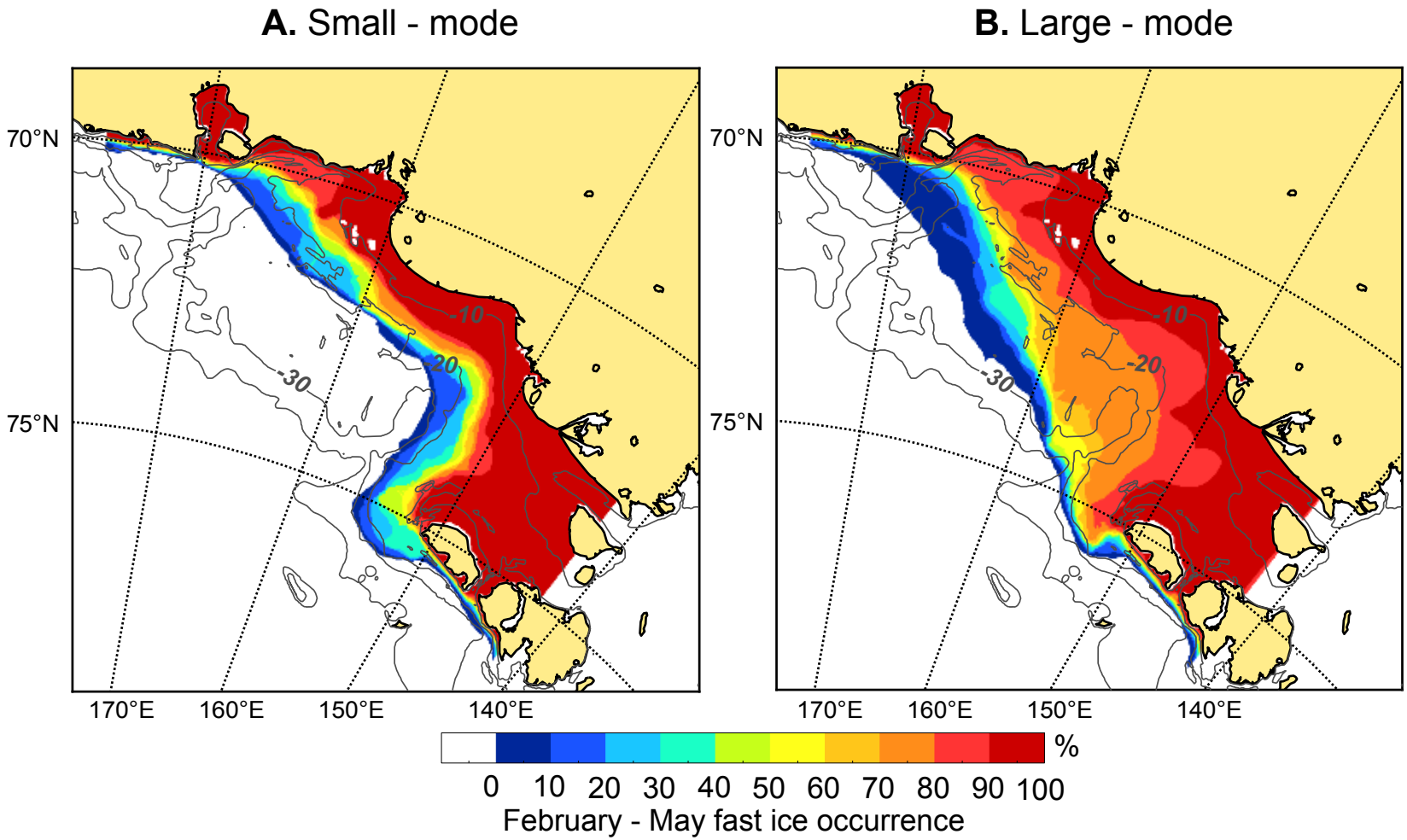



## Upward looking sonar (ULS) ice draft



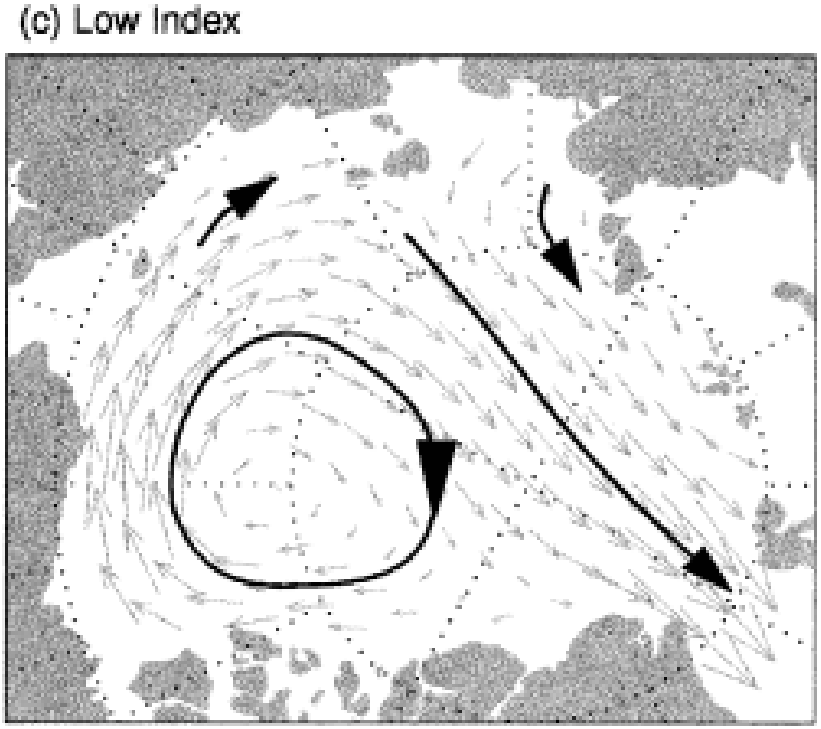

- formation of deep ice ridges in the region confirmed by measurements

# III. East Siberian Sea Fast ice modes

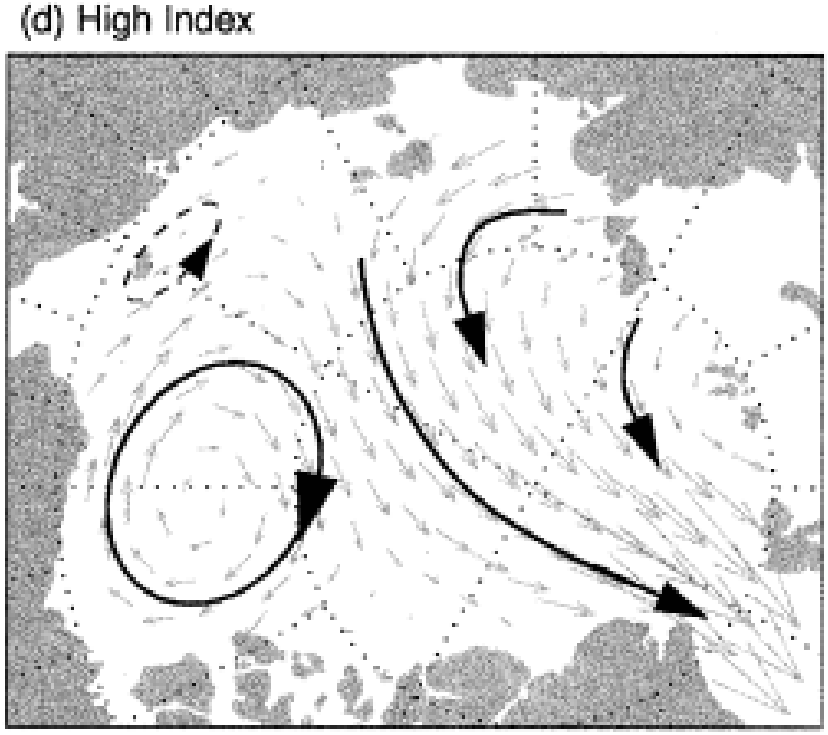


# III. Arctic circulation

Negative Arctic Oscillation index (AO)

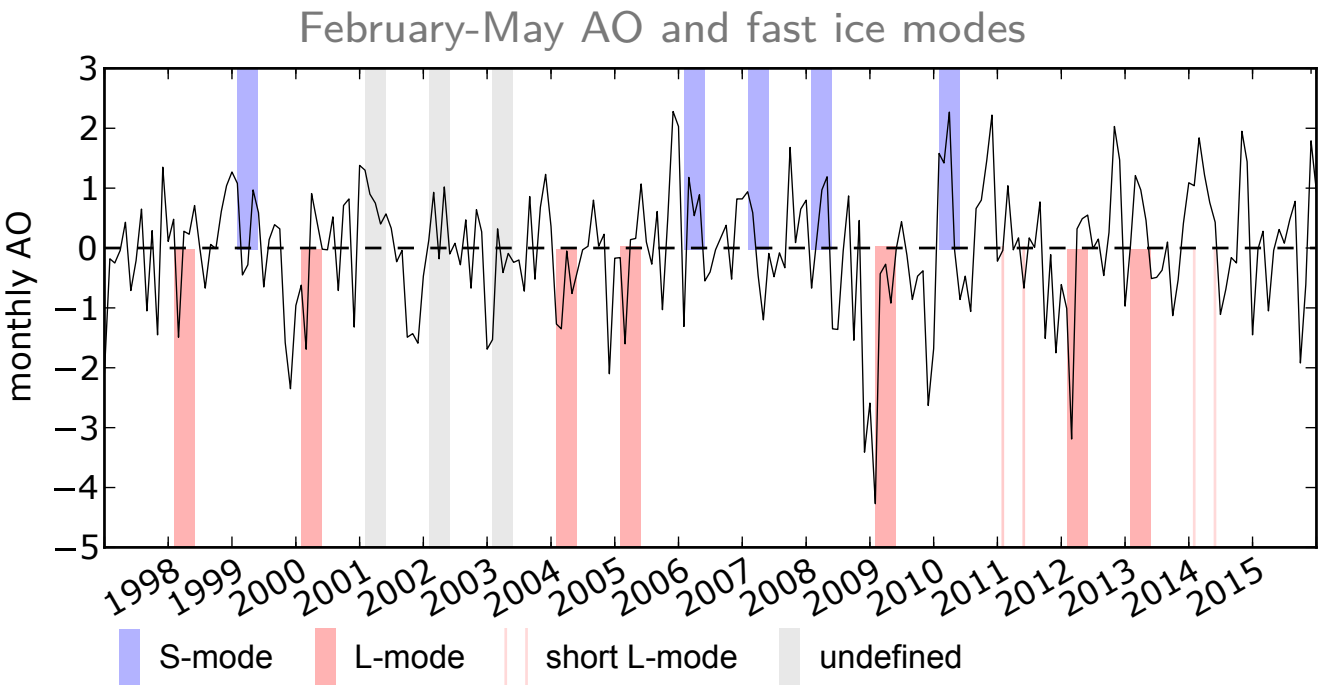



Positive Arctic Oscillation index (AO)

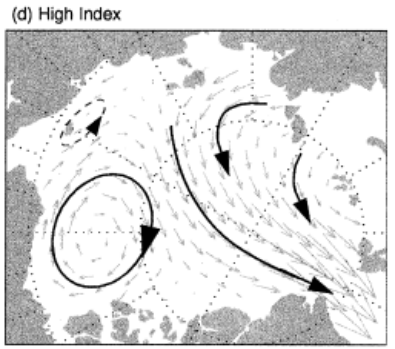



(Rigor et al. 2002)

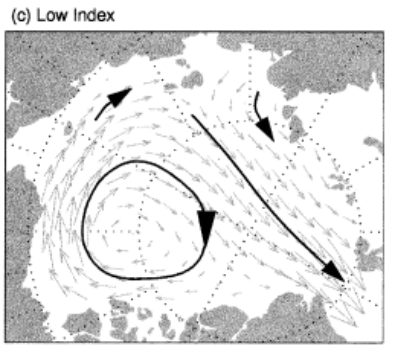
# III. East Siberian Sea fast ice modes




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

**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