Medium-range forecast of the Arctic sea-ice cover using the satellite observation data

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Recent retreat of summer Arctic sea ice increases the interest in commercial use of the Arctic sea routes due to shorter distance.
GRENE Arctic Climate Change Research Project

Fiscal years 2011-2015

Four strategic research targets:

1. Understanding the mechanism of warming amplification in the Arctic
2. Understanding the Arctic system for global climate and future change
3. Evaluation of the impacts of Arctic change on weather and climate in Japan, marine ecosystems and fisheries
4. Projection of sea ice distribution and Arctic sea routes

Sub-project 7-1: Sea ice prediction and construction of an ice navigation support system for the Arctic sea routes
There are three ranges of ice forecasts for the Arctic shipping.

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In this study,

We aim to predict the summer ice cover in spring.

We need to reveal the process controlling the summer ice cover.
Interannual change of minimum sea-ice area

Predict the summer ice area using data till the end of spring

It is useful for human activities in the Arctic

How can we predict it?
Factors controlling the interannual difference of summer ice area

Differences become obvious after May

Possible key factors:
- Weather conditions in melting season
- Cloudiness
- Temperature
- Wind

How can we predict the summer ice area in spring?

Focus on the ice thickness at the end of spring!
Observation of ice thickness

Current observations of ice thickness are insufficient in their coverage and accuracy.

from microwave sensor (by Dr. Tateyama)
from laser altimetry (ICESat) (by NASA GSFC)
Relation between spring ice thickness and summer ice cover is not strong. One of the reasons of this is large error or bias of satellite derives ice thickness.

Correlation coefficient between the ice thickness on 30 April derived from satellite microwave data and sea ice concentration of 11 September, based on 11 years data.
Key technique of our study: derivation of daily ice velocity

Data: 36GHz channel data of AMSR-E and AMSR2

Calculated by maximum cross-correlation method

Resolution: 60km x 60km

Period: 2003-2011 (AMSR-E)
       2013-2015 (AMSR2)
About 20,000 particles are arranged over the ice cover on December 1 of each year. Daily displacement of particles is calculated from the ice velocity on one-day time steps. Focus on the temporal change of the particle density! Ice convergence promotes dynamic deformation and accompanied thickening of sea ice. In the divergence area, formation of leads and polynyas promotes new ice production and results in higher fraction of thin ice. We can conjecture ice thickness distribution from the density of the particles.
2008: Large part of particles was exported from the domain → Ice area decrease rapidly

2005: Most of particles remain → Retreat of ice area is small

There is a relation between the winter ice redistribution and summer ice retreat.
Interannual change of the particle density on 30 April and ice concentration on 11 September

Clear in-phase variation of them

Winter ice redistribution

Spring ice thickness

Summer ice cover
There is a strong relationship between the winter ice redistribution (ice motion) and summer ice cover.

Correlation coefficient between the particle density on 30 April and sea ice concentration on 11 September.

Predict the summer ice area based on the particle density on April 30.
Predicted ice cover in this summer
First report of the prediction is released on 28 May
http://www.1.k.u-tokyo.ac.jp/YKWP/2015arctic_e.html
Is our forecast accurate?

You can check our forecast is right or wrong by web page everyday.
https://ads.nipr.ac.jp/vishop/ja/vishop-monitor.html
Summary

1. Sea ice forecast is essential for safe and sustainable use of the Arctic Sea Route

2. Winter ice motion and resulting redistribution of sea ice is one of the important factors to decide summer ice extent.

3. We can predict the summer ice area in spring by analyzing the satellite-derived winter ice motion.
Quality of derived ice velocity: comparison with buoy motion

Comparison between daily buoy speed and AMSR-E derived ice speed

Correlation coefficient: 0.959
RMS error: 1.21 cm/s (N=1232)

Error and bias are very small

Buoy track (yellow line) and particle track calculated from AMSR-E derived ice velocity (red line) for 2007/9/15-2008/9/14

AMSR-E-derived dataset can reproduce the ice track with high accuracy on a variety of temporal scales.
Movement of sea ice during winter

Daily displacement of particles is calculated from the ice velocity on one-day time steps. Ice convergence area promotes dynamic deformation and accompanied thickening of sea ice. We can conjecture ice thickness distribution from the density of the particles moved from 1 December.
Way of ice prediction

1. Derivation of regression line
   - Based on AMSR-E data 2003-2011
   - remove the linear trend
   - remove the 2007 data

2. Predict the ice concentration
   - Use AMSR2 data
   - Add the removed linear trend

Daily sea ice velocity

Particle distribution

Particle number on April 30

Count the particle number within 150km radius

Track the particle

Calculate the ice concentration within 150km radius
Predicted ice extent over the observed one: 2013

Retreat was not large compared with prediction
We are trying to reduce these deviation.

Deviation of ice concentration on Sep. 11 from the predicted value.

Prominent deviation is seen in 2007 and 2013.
- 2007: Lighter than prediction
- 2013: Heavier than prediction
In the Atlantic side, summer ice area is predicted well by winter ice redistribution.

In the central area and Pacific side, linear relation between the winter ice redistribution and summer ice area explains less than 10% of the total variation.

- Most part of the variation seems to be controlled by conditions in summer.

What is the controlling factor?
Case in 2007: retreat speed of ice area was faster than the prediction

Ice drifting speed: 12-15 cm/s = 320~400 km/month

Mean ice motion in August 2007

Retreat speed is nearly equal to ice drift speed

Ice drift is controlled by wind field

Wind field in summer controlled the ice retreat
Case in 2013

Ice area did not retreat as we have predicted

Air temperature in the last August is notably low

In some years, summer weather condition is the important factor controlling the summer ice area

Deviation of monthly 2m temperature in 2013 from the 2003-2013 mean
Another factor

Change in the ocean condition?

Strong decrease trend is seen in the Pacific side

The area with large error agrees well with the area with the strong reduction

Has warming trend of water temperature changed?
In the Atlantic side, a half of the variability of the summer ice area due to the winter ice redistribution.

Winter ice redistribution is strongly related to the summer ice cover.

The winter ice redistribution controls the spring ice thickness and the summer ice cover.

Arctic sea ice acts as a memory of the winter atmospheric condition until the following summer.

In the Atlantic side, a half of the variability of the summer ice area due to the winter ice redistribution.

In the central and Pacific side of the Arctic, summer area is strongly controlled by summer weather conditions.

We need to predict summer weather conditions until spring for the medium-range forecast of the ice area.

Prediction of ice area in this summer will be out by the end of May.
Deviation of ice concentration on Sep 11 from the mean value for 2003-2013

Heavy ice in the Pacific side and light ice in Atlantic side, in 2013
Standard deviation of ice concentration on September 11
mean deviation of ice concentration from the prediction: 2003-2013

Deference between two figures shows a part of interannual variation explained by the winter ice motion
Correlation coefficient between ice concentration in Sep. 11 and weather conditions: 2003-2013

Can we predict the August weather conditions by the end of April?

Correlation coefficient between summer ice concentration and each meteorological element is comparable to that with the winter ice redistribution.

There are very few studies on relation between winter and subsequent summer weather conditions.
Useful information is..

1. Distribution of multi-year ice on December 1 = yes we can!
2. Change in the ocean condition = we need to try but difficult
3. Medium-range forecast of summer weather condition = TRY!!

Prediction of ice area in this summer will be out by the end of May.

Don't miss it!
Relationship between the particle number on Apr 30 and sea ice area on Sep 11

Particle number is converted to the ice area (km²) multiplying by $37.5 \times 37.5$ under the assumption that each particle represents a $37.5 \times 37.5$ km² of area.

**Steep regression line**

**SMALL DIFFERENCE** in the winter ice redistribution results in **LARGE DIFFERENCE** in the summer ice area

- Some kind of feedback? unknown processes?
Predicted ice area on Sep 11, 2012

Predicted ice cover over the observed ice area

Record minimum in 2012 was predicted by our method
Arctic sea route is becoming a reality because of the ice decline.
The route reduces the distance between Europe and East Asia by about 40%.
In 2012, 46 voyages were conducted through the Arctic sea route.

One of the major goals of an ongoing project (GRENE-Arctic) is Sea ice prediction which leads to the assessment of the possibility of the Arctic shipping.
There is three ranges of forecasts for the Arctic shipping.

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Observation of ice thickness

from microwave sensor (by Dr. Tateyama)

from laser altimetry (ICESat) (by NASA GSFC)

This study will focus on the winter ice redistribution instead of ice thickness

2011/4/30
Sea ice redistribution during winter

Distribution of particles at the end of April moved from December 1

Sea ice cover on September 10
Relationship between the correlation coefficient and standard deviation of summer ice area

- Correlation coefficient is high in areas with large variability of summer ice area

- Summer ice area is controlled by ice thickness at spring

- Summer ice area is controlled by winter ice motion

- Summer ice area is controlled by winter wind field
Relationship between daily ice motion and wind

- Daily change in the ice motion is strongly controlled by wind field
  → Focus on the interannual change
Interannual change in wind factor

- Wind factor gradually becomes larger with shore-term change.
- Due to thinning of sea ice?

Wind factor in recent 9 years
Winter ice motion and wind field

Winter sea ice motion and sea-level pressure (left: 1988/89, right: 2003/04)

- There is a large interannual variation in the ice motion field
- It is controlled by the variation of wind field

How can we extract the information relating to ice thickness?