September 2010 Regional Sea Ice Outlooks: June Report

Community Contributions
Table of Contents

Gerland, et al ................................................................. 3-6
Gudmansen ................................................................. 7-9
Howell, Agnew ......................................................... 10-12
Lindsay, Zhang ......................................................... 13-22
Maslanik ................................................................. 23-25
Petrich, et al ............................................................. 26-29
Pokrovsky ................................................................. 30-36
Tivy ................................................................. 37-42
Zhang ................................................................. 43-44
Regional sea ice outlook for Greenland Sea and Barents Sea
- based on data until the end of May 2010

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The monthly mean sea ice extent for May 2010 based on Norwegian ice charts produced primarily from passive microwave satellite data, supplemented with high resolution SAR imagery from 2007, is compared with the corresponding monthly mean for May for the previous years 2007-09 (Fig. 1), and with 30, 20, and 10 year averages for monthly means for the periods 79-08, 80-99 and 99-08 (Fig. 2).

The sea ice systems in the Greenland Sea and Barents Sea are substantially different. Sea ice in the Greenland Sea is (see e.g. Vinje et al. 1998) dominated by ice drifting with the transpolar drift and the East Greenland current out of the Arctic Basin southwards, whereas sea ice in the Barents Sea (see e.g. Vinje and Kvambeck 1991) consists to a high degree of seasonal ice formed in the same area during the past winter.

In the Greenland Sea ice extent in May for 2010 was slightly larger in the southwest and smaller in the northeast, compared with previous years 2007-2009 (Fig. 1). In the southwest, the extent appears roughly similar for May 2010 compared with all May means calculated for 10-30 year periods (Fig. 2). However, in the northeast (northwest of Spitsbergen), the ice edge for May 2010 is located further north than ice extent for the previous three years and for all monthly averages (10 to 30 year means). The 2010 ice edge suggests already open water towards the Hinlopen Strait (between Spitsbergen and Nordaustlandet); however, the resolution of passive microwave satellite data is not sufficient and the near coast reduces data quality, meaning the local ice situation there cannot be assessed in detail. One can speculate that the influence of Atlantic water could be the reason for change in the ice edge position. To discuss this more one would need to look into more individual monthly mean data for that region, in addition to in situ oceanographic and atmospheric data. It should also be noted that in May 2010 there was ice seen in passive microwave data off southwest Spitsbergen, where in 10-30 year May means and Mays in the previous three years no significant amounts of ice were seen. Ice in this region usually is advected from the Barents Sea.

Compared with the Greenland Sea, the sea ice extent in the Barents Sea shows more variability between individual years and also between the 10, 20 and 30 year averages for June, especially for the eastern part (Fig. 1 and 2). As known from Barents Sea monitoring studies (Gerland et al. 2010a, b), the inter-annual variability of the position of the ice edge in spring and autumn is high, but shows a clear negative trend since 1979. In
May 2010, ice extent was substantially less than the May 2009 extent and the 10, 20 and 30 year averages in the north eastern Barents Sea (area between Franz Josef Land and Novaya Zemlya). The ice edge in May in the eastern Barents Sea was further south in 2007 and 2008, but the Arctic minimum extent record year 2007 come close to the 2010 May extent in this area (blue and red lines in Fig. 2). Towards Svalbard, the differences between different years/means become less. It is remarkable that in the May mean for 2010, the entire west coast of Novaya Semlja appears ice free, as was also the case in 2007. In May 2010, more ice is visible in the south-eastern Barents Sea as in the same month in the years 2007-2009 and as in the 10-30 year May means.

The Norwegian ice chart data provides a record extending back to 1967 (44 years), for the area around Svalbard (box extending from 72 to 85°N and 0 to 40°E). The ice charts use 6 categories for ice concentration: open water (0-10%), very open drift ice (10-40%), open drift ice (40-70%), close drift ice (70-90%), very close drift ice (90-100%), and fast ice (100%). The sum of these values was taken to be the overall mean ice extent. May 2010 was the third lowest mean extent on record at 476,038 km². The record low for this area was 379,835 km² in 2006, followed by 469,682 km² in 2004. 2007, 2008, 2009 were 7th, 15th, and 13th lowest respectively, and is 175,663 km² lower than last year (2009, 555,497 km²). A reason for the low extent in 2010 could be a higher sea surface temperature (SST) in the West Spitsbergen Current. SST data from the NOAA Extended Reconstructed Sea Surface Temperature (SST) V3b (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html) reports the May 2010 average of this to be 2.74 °C, the second highest in that record and only exceeded by 2.84 °C in 1984.

Using the monthly ice chart data, SST and Arctic Oscillation (AO) values from NOAA (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html) it is possible to attempt a simple forecast for the Svalbard area, based on statistical regression. From the data for 1967 to 2009, we find a relationship for the September ice extent:

\[
Ice_{September} = 443665 + (13893.36 \times AO_{March}) \\
+ (0.22654 \times Ice_{April}) \\
+ (-112854 \times SST_{May})
\]

This gives an initial predicted ice chart mean ice extent in September 2010 of 255,788 km² (with an error of ±50,000 km²), at 9th in the record of September ice extents. We will attempt to refine this further over the next few months. It should be noted that we do not say this is a minimum ice extent for the Svalbard area, simply because the regional ice extent minimum is highly variable and can occur any time between July and November.

References


Fig. 1: Ice extent (monthly means, May) southern border of 30% ice concentration, in the Greenland Sea / Fram Strait and Barents Sea, based on passive microwave satellite data (red = May 2010, orange = May 2009, green = May 2008, blue = May 2007).

Fig. 2: Ice extent (monthly means, May) southern border of 30% ice concentration, in the Greenland Sea / Fram Strait and Barents Sea, based on passive microwave satellite data (red = May 2010, orange = mean May 1999-2008, green = mean May 1979-2008, purple = mean May 1980-1999).
Lincoln Sea and Nares Strait

Preben Gudmandsen, Technical University of Denmark

The Lincoln Sea acts as a buffer between the Arctic Ocean and the Nares Strait with floes entering over the continental slope delimiting the Sea towards north. An impression of this in-flow of multiyear ice may be obtained from Figure 1 that shows the tracks of three floes that happened to be observed already on 27 August 2009 – the northern floes – and on 31 August 2009 – the western floe. The floes could be tracked until 13 June when their characteristics vanished due to summer melt that actually began in the Lincoln Sea on that day. Observations were made at irregular intervals partly determined by the acquisition of the Advanced Synthetic Aperture Radar (ASAR) on Envisat operated in its wide swath mode (AWS). Although widely separated it is noted that the overall movements of the floes are very similar, an observation that was also made in previous experiments with deployment of drifting buoys in the region.

In the period floes advected into the Nares Strait interrupted by ice barriers that formed just north of the entrance to the Strait. The first one formed in the period 11-13 January and lasted until 18 January 2010. A second one became solid by 5-7 March to break down slowly in the period 26 April to 2 May 2010. The presence of these barriers is reflected in the drift patterns of the three floes.

An additional impression of the overall situation in the Lincoln Sea may be obtained from Figure 2 that is an ASAR scene acquired on 4 April 2010 overlaid with two drift patterns showing vectors of floe movements. One pattern represents the 27-day period 4 to 31 January 2010 with in-flow from northwest and the other the 45-day period between 18 February and 4 April 2010. It is noted that the 100-km vectors passing the 65ºW meridian in the first period essentially are the sums of two shorter periods of four and one day only constituting the only major in-flow from northwest this past winter. The other vector pattern shows east-to-west (also) 100-km movements along the 85º and 86ºN latitude that is part of the prevailing large-scale clockwise circulation in the Arctic Ocean present this late winter. It is noted that the in-flow to the Lincoln Sea is only a fraction of the overall transport.

Figure 2 also shows the ice barrier referred to above. The composition of the barrier is different from many earlier barriers in that it includes a relatively large fraction of new ice between – and behind - multiyear ice floes. The mechanism of ice barriers is so far unknown but we would expect that a barrier with these characteristics would not last for so long a period (55 days). This may indicate that it has not been subject to strong northern winds.

With a great part of the Lincoln Sea covered by multiyear ice from the previous winter and additional ice advected into the Sea that has stayed for two months and more under the prevailing low-temperature regime we expect that floes have increased in thickness compensating for the melt processes the preceding summer – modified by the coming new melt season.
Figure 1.
Tracks of three floes in the period end August 2009 to 13 June 2010 plotted on an ASAR scene acquired by Envisat on the latter date. The dark surfaces indicate the beginning of the melt season.
Figure 2.
Patterns of drift vectors obtained in two periods: 4 – 31 January (white) and 18 February to 4 April 2010 (cyan), plotted on an ASAR acquisition of 4 April 2010. The vectors are derived by way of an interactive program with observations of characteristic features in two consecutive radar scenes.
Clearing of the Northwest Passage:
As the melt season begins in the Western Parry Channel region of the Northwest Passage, multi-year ice (MYI) conditions are well below the historical 1968-2000 average (Figure 1; Figure 2). What’s more is that they are only slightly above the record low conditions of 1999 and less than 2007 when the region cleared for the first time during the satellite era (Figure 2). However, light ice conditions at the start of the melt season within the Western Parry Channel are not a precursor to complete clearing – 1999, 2008 and 2009 are evidence of this. The spatial distribution of MYI in the surrounding regions and the flux of MYI from Queen Elizabeth Islands into the region are both vital to its clearing. Given these factors and particularly the spatial distribution of MYI in the M’Clintock Channel (Figure 1) it seems the region will not clear during 2010.

Method:
The method is based on the distribution of MYI at the start of the melt season. Since MYI is harder to melt than first year ice, much of MYI will likely survive the melt season and cause difficulties for marine transportation. This of course will also depend on the severity of the summer melt so the forecast is updated each month based on the previous month’s distribution of MYI. There are key locations in the Canadian Arctic Archipelago where the presence of MYI will make it more likely that Northwest Passage routes will be blocked with ice.

Rationale:
If MYI concentrations are high in the M’Clintock Channel this limits the flux of MYI from the Queen Elizabeth Islands but it also means less sea ice will be transported southward hence, concentrations remains high in the central Western Parry Channel during the melt season – this was the case in 2009. Conversely, if the M’Clintock Channel contains little MYI then sea ice can be transported southward but the flux of MYI from the Queen Elizabeth Islands directly across the Western Parry Channel increases – this was the case in 2008. Indeed, there is very little MYI present in the Western Parry Channel but within the M’Clintock Channel, MYI conditions mirror the 1968-2000 historical average (Figure 3). The latter will likely delay breakup in the central region of the Western Parry Channel in a similar process to 2009.
Figure 1. Spatial distribution of multi-year ice (in tenths) within the Western Parry Channel region of the Northwest Passage on May 1st for a heavy ice year (2004), a light year ice (1999), clearing year (2007), last year (2009), and 2010. Data is from the Canadian Ice Service.

Figure 2. Time series of the evolution of multi-year ice (MYI) for selected years within the Western Parry Channel. Data is from the Canadian Ice Service.
Figure 3. Time series of the evolution of multi-year ice (MYI) for selected years within the M’Clintock Channel. Data is from the Canadian Ice Service.
Predictions of Alaskan Summer Ice Conditions from May 2010

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Here we attempt to predict the ice conditions near Barrow Alaska as listed in Table 4 of the Seasonal Outlook For North American Arctic Waters Summer 2010 prepared by the North American Ice Service in a collaboration with the Canadian Ice Service, 02 June 2010. These are various measures of the amount or duration of open water near Barrow.

The predictions are based on the output of a coupled ice-ocean model which provides us with retrospective estimates of the current ice and ocean conditions. The model is the PIOMAS model developed and operated by Dr. Jinlun Zhang (http://psc.apl.washington.edu/zhang/IDAO/seasonal_outlook.html). The model uses the observed air temperature, wind, clouds, and precipitation to estimate maps of the ice motion, ice thickness distribution, and ocean temperatures and currents for past years, up to and including the most recent month. The observed ice concentration is assimilated so that the model ice extent is close to the observed ice extent. Statistical relationships between the model parameters in May (or any other month) and the various measures of the ice conditions are found from past years using a method developed by Dr. Sheldon Drobot (Drobot et al, 2006). This relationship is then used with the current month model output to predict the ice parameters listed below. The method may be used to predict either the pan-Arctic ice extent or any other scalar quantity such as those listed in the Ice Service outlook. Updates are posted at http://psc.apl.washington.edu/lindsay/prediction.html

The Alaskan ice parameters predicted here are

1. Distance from Point Barrow northward to ice edge on 10 Aug (nautical miles).
2. Distance from Point Barrow northward to ice edge 15 Sept (nautical miles).
3. Distance from Point Barrow northward to boundary of five-tenths ice concentration on 10 Aug (nautical miles).
4. Distance from Point Barrow northward to boundary of five-tenths ice concentration on 15 Sept (nautical miles).
5. Initial date entire sea route to Prudhoe Bay less than/equal to five tenths ice concentration (year day).
6. Date that combined ice concentration and thickness dictate end of prudent navigation (year day).
7. Number of days entire sea route to Prudhoe Bay ice free.
8. Number of days entire sea route to Prudhoe Bay less than/equal to five-tenths ice concentration.
9. Number of days between initial opening date and 1 Oct
10. Barnett Ice Severity Index, high numbers indicate large expanses of open water.
11. Rank of the BIS index
We have determined the single most effective predictor for each of these variables for each predictor month and the amount of the variance explained by the predictor. The candidate predictors include fields of the ice thickness (H), the ice concentration (IC), the ice extent (IX, 0 or 1 for each grid cell), the fraction of the area with open water or ice less than 0.4m (G0.4m), less than 1.0 m (G1.0m), or less than 1.9 m (G1.9m). Table 1 lists each of the Alaskan ice parameters, the percent of the variance explained and the most effective predictor variable using model output through the end of each month, May to August. The method uses monthly averaged model output, so for predictions using the month of May, the model is run through the end of May and the fields of the average values for each predictor variable are used to make the prediction.

Table 2 gives the prediction for each Alaskan ice parameter using May data. Parameters for which the method predicts a 50% or greater chance of a new record value are printed in bold and the standard deviation of the regression error gives an indication of the uncertainty of the prediction. The prediction for the amount of open water as seen in the BIS index is 1145, very close to the previous maximum of 1136 seen in 2007 or the 1103 seen last year.

A set of four panels is shown for each Alaskan ice parameter. The first is shows the observed value for the last 22 years, 1988–2009, the values of the regression fit (blue) and the predicted value for 2010 (orange) with the one-standard-deviation error bar. The trend line and the trend prediction is also shown (black). The three maps show the correlation between the ice parameter and the best predictor (right), the anomaly of the best predictor for May 2010 (center), and the product of the correlation and the anomaly (left). It is the integral of the last map that makes the single predictor variable used in the regression equation.
Table 1. Percent variance explained and best predictor for each parameter using model data from the end of each month, May to August.

<table>
<thead>
<tr>
<th>Ice Parameter</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>R²</th>
<th>Predictor</th>
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<td>ice_dist_10Aug</td>
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<td>0.72</td>
<td>0.77</td>
<td>0.77</td>
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<td>IC IC IC</td>
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<tr>
<td></td>
<td>G1.0m</td>
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<td>IC</td>
<td>IC</td>
<td>IC</td>
<td></td>
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<td></td>
<td>G1.0m</td>
<td>G1.0m</td>
<td>IC</td>
<td>IC</td>
<td>IC</td>
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<td>0.79</td>
<td>0.75</td>
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<td>0.40</td>
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<tr>
<td>BSI_Index</td>
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<td>0.78</td>
<td>0.84</td>
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<td>0.69</td>
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<td>G1.9m G1.9m G1.9m G1.9m G1.0m</td>
</tr>
</tbody>
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Table 2. Predictions using data from the end of May

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<th>Ice Parameter</th>
<th>Prediction Error</th>
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<td>ice_dist_15Sep</td>
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<td>ice_05_10Aug</td>
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<td>date_start</td>
<td>184.0 (3 July)</td>
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<td>date_end</td>
<td>307.8 (4 November)</td>
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<tr>
<td>Ndays_ice_free</td>
<td>93.6</td>
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<tr>
<td>Ndays_ice_05</td>
<td>114.1</td>
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<td>Ndays_start_1oct</td>
<td>89.8 (3 July)</td>
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<td>BSI_Index</td>
<td>1145.0</td>
</tr>
<tr>
<td>Rank</td>
<td>-1.0</td>
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</tbody>
</table>
References
Figures
The graphs show the correlation and anomaly patterns of two datasets:

**Ndays_start_toct**
- **Predictor:** IC
- **Predictions:** 90. +/- 12.
- **R^2 of Fit:** 0.63

**Obs_Index**
- **Predictor:** 01.0m
- **Prediction:** 1145. +/- 215.
- **R^2 of Fit:** 0.78

Both graphs include maps showing the spatial distribution of anomalies and weighted anomalies.
The following is based on consideration of the U. of Colorado satellite-derived (Lagrangian drift) sea ice age in the context of conditions in previous years (see attached figure) along with review of atmospheric fields and a variety of other data sets.

A. Regional outlook for Beaufort and Chukchi seas

(1) A prominent feature is the lobe of old ice extending through the Beaufort Sea and into the Chukchi Sea at the end of April (top-left panel in Figure 1). Based on our age data, the strip of ice on the southern edge of this area is 5+ year-old ice (red), which is likely to be particularly thick and strong. One might expect it and the 3+ year-old ice to survive well into the melt period, at fairly high ice concentrations. Our data and other data we have examined suggest that the floes are large but with some separation by first-year ice. Given the likelihood of 3+ year-old ice being present, then some residual and perhaps quite small multiyear ice floes may well survive into autumn, with the associated potential hazards they pose for shipping, etc. These surviving floes may end up relatively close to the coast and therefore might be entrained into new land-fast ice, thus helping stabilize the fast ice. Note that our ice age product uses a 40% ice concentration cut-off, so it is possible and even likely that some old ice extends beyond the bounds we show, and particularly so at the westernmost tip of the old ice lobe.

(2) Wind patterns during most of May have continued to push this ice to the west, placing more ice into the Chukchi Sea and keeping the ice further south than in recent years. Given the extent of melt over the past several years and the southern location of this old ice, we expect that it will completely melt out (excluding some residual floes) from the central Beaufort and Chukchi seas. Some of the oldest ice may survive melt in the Banks Island area, but unlike most other years, the multiyear ice is shifted toward the west, leaving a fairly large area of first-year ice between it and the eastern Beaufort Sea area to the south.

(3) There is little reason to expect that first-year ice in these areas will survive melt. While the lobe of multiyear ice will persist later into the melt season, the first-year ice to the north will melt out earlier, yielding a “semi polynya” of open water/low concentration ice partially surrounded by multiyear ice into late summer.

B. Overall outlook for minimum sea ice extent
Our best guess at this point for end-of-summer ice extent ranges from $4.5 \times 10^6$ km$^2$ at the high end to $3.8 \times 10^6$ km$^2$ at the low end.
Figure 1. Estimated ice age at the end of April (left-hand panels) for 2010 (top), 2005 (center) and 2004 (bottom). Panels on the right are age coverages for mid-August 2005 and 2004. Warmer colors indicate older ice.


Region: Chukchi Sea / Beaufort Sea

Local outlook for break-up of landfast ice at the Chukchi Sea coast at Barrow, Alaska (Chris Petrich, Matthew Druckenmiller, Hajo Eicken, Geophysical Institute, University of Alaska Fairbanks, Fairbanks, USA)

We operate a break-up forecast model for landfast ice at the Chukchi Sea coast at Barrow, Alaska. Up-to-date predictions are available on http://seaice.alaska.edu/gi/observatories/barrow_breakup

In typical years, the timing of break-up appears to be associated with the amount of incoming solar radiation. We use a combination of data from the Department of Energy Atmospheric Radiation Measurement program, NOAA weather observations, and a 16-day GFS-based WRF weather forecast (Zhang and Krieger).

The current 16-day weather forecast does not reach far enough into the future to allow us to project a specific break-up date. In the plot above, the trajectories of incident cumulative solar energy are plotted until break-up for previous years. 2002, 2003, 2004, and 2007 were marked by an absence of grounded, stabilizing pressure ridges. The line marked “2010???” is entirely based on weather prediction at the time of writing. We expect specific break-up forecasts for the second half of June.
Breakup

We define breakup as the first detectable movement of landfast ice shoreward of grounded ridges within the 20 m-isobath off NARL, approximately 5 miles north of Barrow. Typically, ice movement is parallel to the coast, confined by grounded pressure ridges at the 20 m-isobath. However, we exclude ice affected by dust from town and a coastal road, i.e., ice within approx. 100 m offshore. We detect movement from coastal RADAR and from satellite imagery. In previous years, webcam images near NARL were available.

Breakup process

Breakup proceeds in two stages: Initially ice shoreward of grounded pressure ridges begins to move collectively, followed by a period of sporadic break-out events of individual grounded ridges. After the disappearance of the snow cover in the first half of June, landfast ice closest to the shore weakens structurally due to solar heating of dirty ice and ice under meltponds. Eventually, winds of usual speed are able to push the ice along shore. With reduced snow cover, more solar energy is absorbed and the oceanic heat flux to the ice increases, eroding grounded pressure ridges from below. Some years in the past have seen insufficient stabilization by grounded pressure ridges, leading to the sudden disappearance of the entire coastal ice within 24 hours during the second half of June. These cases cannot be predicted with the approach presented here. However, if significant grounded ridges are present, break-up should take place in the first half of July, with some grounded ridges possibly persisting into early August.

Current ice situation

As usual, landfast ice off Barrow comprises of patches of deformed ice (rubble) and ice grown in place close to shore, sheltered by pressure ridges at the 20 m-isobath (approx. 0.5 to 5 km off shore), and attached ice further toward the coastal polynia.

In mid May, smooth landfast ice had a deeper snow cover than last year (30 cm in 2010 vs. 20 cm in 2009). There was evidence of desalination in the upper 15 cm as early as mid May (approx. 1 to 2 weeks earlier than expected), possibly the result of warm ice due to deep snow and above-average temperature in April. However, the ice reached its usual thickness of 1.3 to 1.6 m, presumably because freeze up happened a few weeks earlier than in previous years. Grounded pressure ridges seem to be in place between Barrow and Point Barrow. However, South of Barrow, landfast ice is essentially smooth and only few if any grounded ridges are present. [See section below on winter-spring landfast ice development] (Update after initial deadline for the submission of this outlook: Both the reduction of surface albedo on the tundra and meltpond formation South of Point Barrow began around 10 June, which is almost one week later than in the previous three years but similar to 2000 and 2001.)

Uncertainties
The break-up forecast applies to snow-covered landfast ice with a relatively clean snow surface. For this year, we expect near-shore landfast ice to be held in place by grounded pressure ridges, allowing it to weaken in place starting with the appearance of meltponds, before drifting out past grounded pressure ridges either to the North or to the South. However, the coastal road became snow-free already in mid May, resulting in dust deposited on the snow on sea ice clearly visible on the 100 to 200 m closest to the shore. Hence, we expect the ice adjacent to coastal infrastructure to develop meltponds and subsequently disintegrate earlier than the ice this forecast applies to. In particular, large portions of ice overlooked by the Barrow SIZONet webcam are affected by dust.

The start date of integration is the assumed beginning of meltpond formation. As last year, we use June 5 as start date for heat flux integration. The break-up forecast relies on a weather forecast that needs to produce accurate solar energy averaged over one to two weeks. Based on GFS ensemble runs, the uncertainty of cumulative solar shortwave radiation is equivalent to approx. +2 days in break-up prediction, based on a 16-day forecast.

This forecast is sponsored by the NOAA Alaska Center for Climate Assessment and Policy (ACCAP) at the University of Alaska Fairbanks (UAF). Data are acquired through grants from NSF (SIZONet) and DHS, and courtesy NOAA and NASA. Data of a 16-day weather forecast are courtesy Jing Zhang and Jeremy Krieger at the Arctic Regions Supercomputing Center (ARSC) and UAF. Break-up information is available on [http://seaice.alaska.edu/gi/observatories/barrow_breakup](http://seaice.alaska.edu/gi/observatories/barrow_breakup)

**Winter-Spring Landfast Ice Development**

The landfast sea ice off Barrow, Alaska was of narrow and variable extent through much of the winter and early spring. While small concentrations of multi-year (MY) floes were likely present in the landfast ice earlier in the year northwest of Point Barrow, it wasn’t until March 26 that MY ice became incorporated in the landfast ice off Barrow. These floes ranged from 10 to 400 m in diameter and with an average thickness of 2.4 m (derived from ground-based EM measurements). Given the general regional drift pattern of MY ice as revealed by Envisat satellite imagery, this ice most likely arrived from the northeastern Beaufort Sea. While these “low profile” floes did not directly contribute significantly to the anchoring strength of the landfast ice, their dynamic entrainment likely led to ice convergence at grounded first year (FY) ridges within the 20m isobath in some areas along the coast.

In mid-April, landfast ice extent off Barrow increased to what has been more typical in recent years (approx. 6 to 8 km). The ice that was added was largely FY ice of average level undeformed thicknesses only slightly below the thickness measured at our mass balance site, which is in level FY ice that has frozen in place since mid November. This ice was weakly anchored yet stayed attached throughout May (to the advantage of the local native whaling community, which harvest 14 bowheads from this newly added ice) due largely to steady East winds that kept the pack ice well offshore. Also, heavy shear ridges NW of Point Barrow likely provided protection by deflecting pack ice moving SW from the Beaufort Sea away from the landfast ice off Barrow.
For the previously discussed break-up forecast these observations are relevant in the sense that the seasonal persistence of grounded ridges provides confinement for the shoreward level ice for which the model's forcings are applied.
2010 Sea Ice Outlook
June Report based on May Data

Oleg Pokrovsky
Main Geophysical Observatory (RosHydroMet)

1. Extent Projection
Sea ice projection for the September monthly mean arctic sea ice extent – 5.5-5.6 (in million square kilometers)

2. Methods / Techniques
Statistical analysis of the AMO, PDO and AO time series based on specific regression model

3. Rationale
There are three major climate factors impacted on the Arctic sea ice extent (SIE): AMO, PDO and AO.
PDO (fig.1) as an oscillation between positive and negative values shows no long-term trend, while temperature shows a long term warming trend. When the PDO last switched to a cool phase, global temperatures were about 0.4C cooler than currently. E.g., in 1905, PDO switched to a warm phase as global warming began. In 1946, PDO switched to a cool phase as temperatures cool mid-century. In 1977, PDO switched to a warm phase around the same time as the modern global warming period. First of all, PDO impacts on the regime of atmospheric circulation in North Pacific and in Pacific sector of Arctic, secondary- on the SST anomaly in Bering and Chukcha Seas. This year is a cold one in this region due to the north wind domination (fig.2). That explains that the SIE in Pacific sector of Arctic exceeds climate (20-th century) magnitudes (fig.3).
The AMO (fig.4) determines the temperatures of inflow waters in Arctic Ocean and thus it impacts on the SIE values in Atlantic sector of Arctic. Primarily, I mean Russian margin seas (Barents, Kara Seas and others). AMO entered into negative phase since 2003. But this spring SST attained small positive values in North-East Atlantic (fig.5). That explains that now in the eastern part of Barents Sea there is a significant area of the sea surface free of ice (fig.3).
The "high index" of the Arctic Oscillation (AO) is defined as periods of below normal Arctic SLP, enhanced surface westerlies in the north Atlantic, and warmer and wetter than normal conditions in northern Europe. This is depicted as the "warm phase" in the following figure. "Low index" AO conditions are described in the "cool phase" panel. The outflow of broken ice masses from these seas to North Atlantic are regulated by Arctic Oscillation (pattern of atmospheric circulation in Artic). This spring AO values (after negative phase in past year (fig.6)) are close to zero and so there is probability that outflow mechanism will be weak. Above let us to say that September SIE anomaly should demonstrate tendencies in more ice in Pacific and lesser ice in Atlantic sectors. But, in general SIE should attain higher value than in past year.

4. Executive Summary
Future SIE estimates in Arctic might be obtained by joint analysis of time series of three climate indicators: AMO, PDO, AO for last thirty years. I used a modified regression analysis approach.
Pacific Decadal Oscillation (PDO)
Univ of Washington, JISAO: Jan., 1990 to Mar, 2010

Data Source: http://jisao.washington.edu/pdo/PDO.latest
D Kelly O'Day - http://chartgraphs.wordpress.com

Figure 1.
Figure 2.
Figure 3.
Figure 4.
Figure 5.

NOAA OI SST
Surface SST (°C) Composite Anomaly 1971–2000 climate

Jan to Apr: 2010

NOAA/ESRL Physical Sciences Division

-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
Figure 6.
Pre-Season Forecast: Pan-Arctic and Regional September 2010 Sea Ice Area

Overview

May 2010

Below is a “pre-season” forecast for pan-arctic and regional September sea ice area, provided by Adrienne Tivy (mailto:ativy@iarc.uaf.edu), a post-doctoral fellow at the International Arctic Research Center (IARC).

This outlook is a statistical forecast, which relies on empirical relationships between pre-season climate variables and the variable being predicted—in this case, September sea ice area. The 2010 forecast results are summarized in Table 1.

Pan-arctic ice area is expected to be greater than in 2009 but still remain below normal. Regionally, increases in ice area compared to 2009 are expected in the Beaufort/Chukchi Seas, the East Siberian/Laptev Seas, the Barents/Kara Seas, and the Central Arctic Ocean. Decreases in ice area compared to 2009 are expected in the Greenland Sea and the Canadian Arctic Archipelago.

<table>
<thead>
<tr>
<th>Location/Region</th>
<th>September Ice Area (million square kilometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2009 actual</td>
</tr>
<tr>
<td><strong>Pan-Arctic</strong></td>
<td>3.730</td>
</tr>
<tr>
<td></td>
<td>Below Normal</td>
</tr>
<tr>
<td><strong>Beaufort/Chukchi Seas</strong></td>
<td>0.530</td>
</tr>
<tr>
<td></td>
<td>Below Normal</td>
</tr>
<tr>
<td><strong>East Siberian/Laptev Seas</strong></td>
<td>0.226</td>
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<tr>
<td></td>
<td>Below Normal</td>
</tr>
<tr>
<td><strong>Barents/Kara Seas</strong></td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>Below Normal</td>
</tr>
<tr>
<td><strong>Greenland Sea</strong></td>
<td>0.185</td>
</tr>
<tr>
<td></td>
<td>Near Normal</td>
</tr>
<tr>
<td><strong>Canadian Arctic Archipelago</strong></td>
<td>0.220</td>
</tr>
<tr>
<td></td>
<td>Below Normal</td>
</tr>
<tr>
<td><strong>Central Arctic Ocean (&gt;85N)</strong></td>
<td>2.504</td>
</tr>
<tr>
<td></td>
<td>Near Normal</td>
</tr>
</tbody>
</table>

Table 1. Categorical and deterministic forecasts of September ice area for 2010; the actual ice area for 2009 is shown for comparison.

Model Details

The pan-arctic (Figure 1, below) and regional forecasts (Figures 3 to 8, below) for September ice area were generated from simple linear regression models. This statistical approach follows work done by Drobot et al. (2006, 2003) for forecasting the Beaufort Severity Index and the September minimum ice extent.

The predictors were chosen using an automated selected scheme (Tivy et al., 2007) based in part on step-wise regression and where the maximum number of predictors is restricted to two. Predictors included in the original predictor pool are: Sea Ice (Northern Hemisphere ice concentration, Northern Hemisphere multi-year ice concentration); Ocean (Near-global sea surface temperature, ENSO, PDO); and Atmosphere (Northern Hemisphere z500, Pan-Arctic [north of 60N] SAT and SLP, teleconnection indices). Each predictor was tested at lags ranging from 5 to 18 months. The models are trained on the 27-year period from 1981–2006. Independent forecasts were generated for 2007–2010. The 2010 forecast is expressed both categorically and deterministically (Table 1).
Pan-Arctic Forecast

The predictor for pan-arctic (northern hemisphere) September ice area is the preceding summer (May-June-July) sea surface temperature in the North Atlantic and North Pacific close to the marginal ice zone (14-month lag), where warm sea surface temperature (SST) anomalies are associated with reduced ice area. The regression $r^2$ and cross-validated $r^2$ are 0.83 and 0.78 respectively; the categorical forecast skill over the training period is 81%. While the model over-estimated ice area for the three independent forecast years (2007–2009), the categorical forecasts of below normal ice area were correct for each year.

![Figure 1](http://www.arcus.org/files/page/images/639_figure1.png)

*Figure 1. Regression-based forecast for the 2010 pan-arctic September ice area. The model is trained on the 27-year period from 1981–2006 (dark red) and independent forecasts were generated for 2007–2010 (red); actual values are shown in black. The 2010 forecast is expressed both categorically, Below Normal, and deterministically, 4.539 million square kilometers.*

Regional Forecasts

Six regional forecasts were completed for the following regions: Beaufort/Chukchi Seas, East Siberian/Laptev Seas, Barents/Kara Seas, Greenland Sea, Canadian Arctic Archipelago, and Central Arctic Ocean (> 85N).

![Regional Forecasts](http://www.arcus.org/files/page/images/639figure2.png)
Beaufort/Chukchi Sea

The main predictor is winter (Dec-Jan-Feb) air temperature over the Beaufort Sea, Alaska and the Canadian High Arctic (7-month lag), where warm surface air temperature (SAT) anomalies are associated with reduced ice area. The regression $r^2$ and cross-validated $r^2$ are 0.79 and 0.69 respectively; the categorical forecast skill over the training period is 77%. The model over-estimated ice area for the three independent forecast years (2007–2009), the model incorrectly predicted near normal years for 2007 and 2008 but correctly predicted 2009 as below normal.

![Beaufort/Chukchi Sea](http://www.arcus.org/files/page/images/639/figure3.png)

Figure 3. Regression-based forecast for the 2010 Beaufort/Chukchi Seas September ice area. The model is trained on the 27-year period from 1981–2006 (dark red) and independent forecasts were generated for 2007–2010 (red); actual values are shown in black. The 2010 forecast is expressed both categorically, Below Normal, and deterministically, 0.803 million square kilometers.

East Siberian/Laptev Seas

The main predictor is summer (Aug-Sept-Oct) sea surface temperature in the North Atlantic (10-month lag), where warm SST anomalies are associated with reduced ice area. The regression $r^2$ and cross-validated $r^2$ are 0.62 and 0.56 respectively; the categorical forecast skill over the training period is 69%. While the model over-estimated ice area for the three independent forecast years (2007–2009), the categorical forecasts of below normal ice area were correct for two of the three years.

![East Siberian/Laptev Seas](http://www.arcus.org/files/page/images/639/figure4.png)
Barents/Kara Seas

The main predictor is winter (Jan-Feb-Mar) sea level pressure over the Kara and Laptev Seas (6-month lag), where high sea level pressure (SLP) anomalies are associated with increased ice area. The regression $r^2$ and cross-validated $r^2$ are 0.72 and 0.65 respectively; the categorical forecast skill over the training period is 69%. The model over-estimated ice area for the three independent forecast years (2007-2009), the model incorrectly predicted near normal ice area for 2007 and 2009 but correctly predicted 2008 as below normal.

![Barents/Kara Seas: Sept. Ice Area](http://www.arcus.org/files/page/images/639/figure5.png)

Greenland Sea

The main predictor is fall (Sept-Oct-Nov) sea surface temperature in the North Atlantic (9-month lag), where warm SST anomalies are associated with reduced ice area. The regression $r^2$ and cross-validated $r^2$ are 0.62 and 0.44 respectively; the categorical forecast skill over the training period is 58%. The model under-estimated ice area for the three independent forecast years (2007-2009), the model incorrectly predicted below normal ice area for 2007 and 2009 but correctly predicted 2008 as below normal.

![Greenland Sea: Sept. Ice Area](http://www.arcus.org/files/page/images/639/figure5.png)
Figure 6. Regression-based forecast for the 2010 Greenland Sea September ice area. The model is trained on the 27-year period from 1981–2006 (dark red) and independent forecasts were generated for 2007–2010 (red); actual values are shown in black. The 2010 forecast is expressed both categorically, Below Normal, and deterministically, 0.095 million square kilometers.

Canadian Arctic Archipelago
The main predictor is summer (May–June–July) multi-year ice (MYI) concentration in the Beaufort Sea (14-month lag), where increased MYI concentrations are associated with increased ice area. The regression $r^2$ and cross-validated $r^2$ are 0.6 and 0.56 respectively; the categorical forecast skill over the training period is 58%. The model incorrectly predicted near normal ice area for 2007 and below normal ice area for 2009 but correctly predicted 2008 as below normal.

Central Arctic Ocean
The main predictor is preceding spring (March–April–May) multi-year ice (MYI) concentration in the Greenland Sea (17-month lag), where increased MYI concentrations are associated with increased ice area. The regression $r^2$ and cross-validated $r^2$ are 0.79 and 0.73 respectively; the categorical forecast skill over the training period is 65%. While the model over-estimated ice area for the 3 independent forecast years (2007–2009), the categorical forecasts of below normal ice area were correct for each year.
Figure 8. Regression-based forecast for the 2010 Central Arctic Ocean September ice area. The model is trained on the 27-year period from 1981–2006 (dark red) and independent forecasts were generated for 2007–2010 (red); actual values are shown in black. The 2010 forecast is expressed both categorically, Below Normal, and deterministically, 2.59 million square kilometers.

References and Acknowledgements


The code for the automated regression program was developed at the Canadian Ice Service with funding from the Canadian Long-Range Ice Forecasting (CLIF) project. Thank you to Kenneth Ho and Bev Alt for helping with the model runs. Thanks also to Jim Maslanik and Chuck Fowler at the University of Colorado for providing the multi-year ice concentration dataset.
Outlook of 9/2010 Arctic sea ice from 6/1/2010

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The predicted September 2010 ice extent is 4.7 million square kilometers. This is based on ensemble predictions starting on 6/1/2010. The ensemble predictions are based on a synthesis of a model, NCEP/NCAR reanalysis data, and satellite ice concentration data. The model is the Pan-arctic Ice-Ocean Modeling and Assimilation System (PIOMAS), which is forced by NCEP/NCAR reanalysis data. It is able to assimilate satellite ice concentration data. The ensemble consists of seven members each of which uses a unique set of NCEP/NCAR atmospheric forcing fields from recent years, representing recent climate, such that ensemble member 1 uses 2003 NCEP/NCAR forcing, member 2 uses 2004 forcing, …, and member 7 uses 2009 forcing. Each ensemble prediction starts with the same initial ice–ocean conditions on 6/1/2010. The initial ice-ocean conditions are obtained by a retrospective simulation that assimilates satellite ice concentration data. No data assimilation is performed during the predictions. More details about the prediction procedure can be found in Zhang et al. (2008) http://psc.apl.washington.edu/zhang/Pubs/Zhang_etal2008GL033244.pdf. Additional information can be found in http://psc.apl.washington.edu/zhang/IDAO/seasonal_outlook.html.

Figure 1. (a) Ensemble prediction of September 2010 sea ice thickness and (b) ensemble standard deviation (SD) of ice thickness which shows the uncertainty of the prediction. The white line represents satellite observed September 2009 ice edge defined as of 0.15 ice concentration, while the black line model predicted September 2010 ice edge.
Figure 2. Ensemble prediction of September 2010 sea ice thickness in the Northwest Passage (NWP) region.