September 2009 Sea Ice Outlook:
June Report

Community Contributions

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September 2009 Sea Ice Outlook: June Report
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NIC Provisional Outlook for September Minimum

Issued June 5, 2009

National/Naval Ice Center, Suitland, MD

Best Guess: 4.736 million km^2
Method: Statistical/Heuristic

Overview:

For this outlook we use a heuristic approach based on the National Ice Center (NIC) ice charts and statistics spanning 1972-2008. This outlook was prepared by considering a NIC chart of Ice Conditions for May 25, 2008, the most recent NIC hemispheric chart. Any ice containing multiyear ice (MYI) was identified and classified by the partial amount (1/10, 2/10, etc.). All other ice was considered first year ice (FYI). In 2008, much of the central Arctic was devoid of MYI, a situation not observed prior in the satellite era. Because NIC and CIS make no distinction between second year ice and MYI, the ice in the central basin is once again MYI. However, we note that it is likely to be thinner and weaker than "traditional" MYI.

Analysis of previous summers indicates that much of the FYI will melt. Even with the central pack, only 13% of FYI remained from its March maximum. For this summer, we remove any parcel containing only FYI will melt out regardless of location. Once again, we present 4 outlook levels of severity: Conservative, Moderate, Aggressive, and Extreme. Conservative represent the cautious end of the spectrum, while Extreme would be the case of a warm Arctic summer combined with the "Transpolar Express" of 2007.

The summer minimum will depend on how much ice is lost during the melt season (July-September). It should be noted that the primary ice type represents the final stage of development of the ice (based on a theoretical ice thickness model using cumulative freezing-degree days). For example, ice classified as thick FYI may not necessarily be thicker than 120 cm at present. Thus, the actual ice thickness may be much thinner than the primary ice type would indicate. This is especially true of the second-year MYI.

The primary question about summer 2009 continues to be the fate of the FYI in the central Arctic, but for this outlook we have tied it to the presence of MYI.

The current conditions (figure 1):

Ice extent 11.842 million km^2
Ice Area 10.527 million km^2,
Avg concentration 88.9%

Multiyear ice extent 5.224 million km^2
Multiyear ice area 2.600 million km^2
Avg concentration: 49.8%

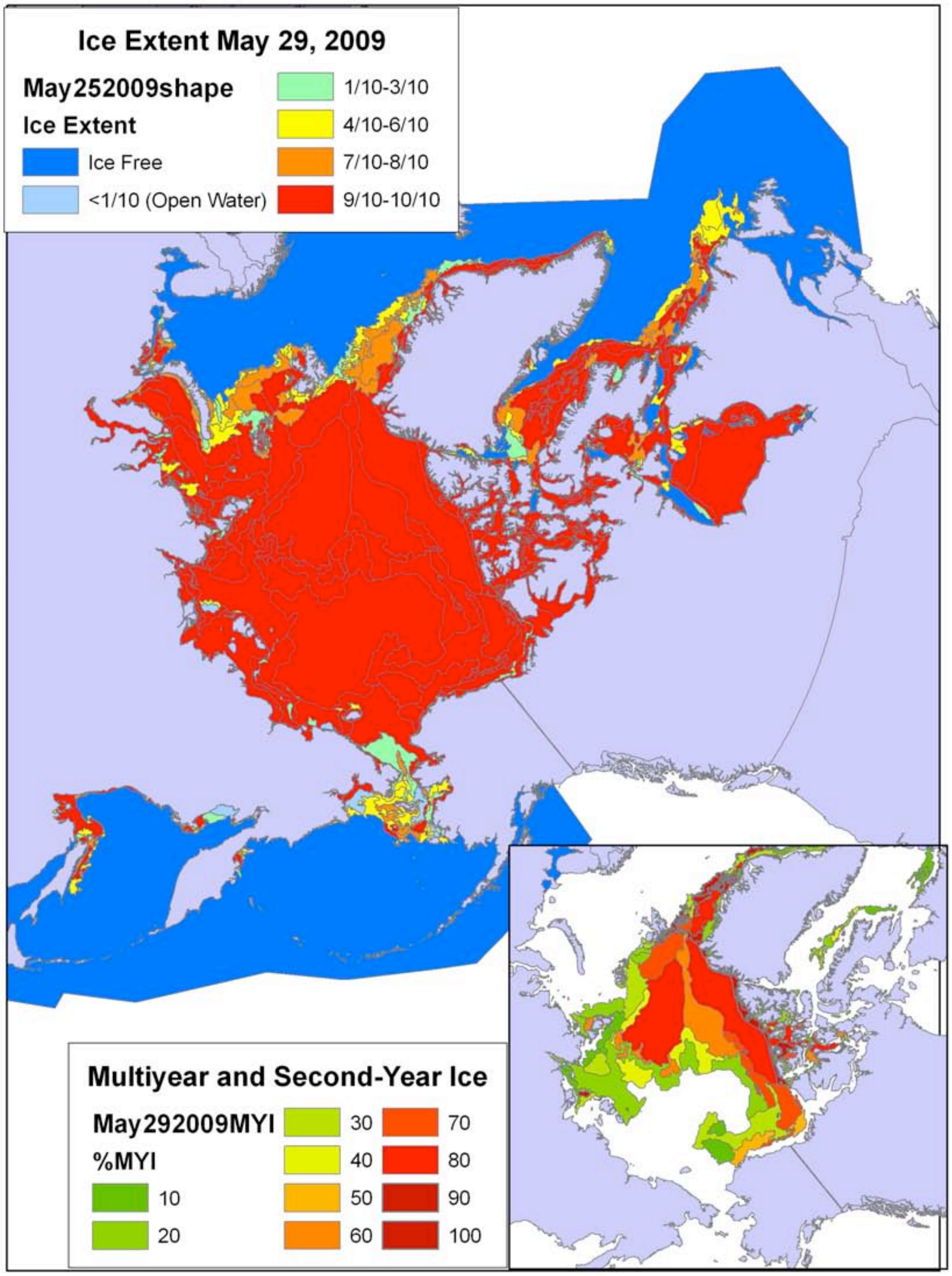

Figure 1: Sea ice conditions for May 29, 2009, and multiyear ice by percentage (inset).

Methodology:

Using the most current hemispheric ice chart and ArcGIS, the map is edited to select all parcels with MYI as the primary ice type. All other parcels are discarded. The remaining ice is edited following the assumptions below. A senior ice analyst (Mr. Szorc) examines and approves the outlooks.

The Seasonal Outlooks:

Conservative: Any area with MYI survives
Ice extent: 5.224 million km^2
Ice area: 4.832 million km^2
Avg concentration: 92.5%
MYI extent: 5.224 million km^2 (includes all parcels containing MYI)
MYI area: 2.600 million km^2
Avg concentration: 49.8%

Moderate: Any area with 20% or more MYI survives
Ice extent: 4.763 million km^2
Ice area: 4.400 million km^2
Avg concentration: 92.4%
MYI extent: 4.763 million km^2
MYI area: 2.553 million km^2
Avg concentration: 53.6%

Aggressive: Any area with 40% or more MYI survives
Ice extent: 3.440 million km^2
Ice area: 3.253 million km^2
Avg concentration: 94.6%
MYI extent: 3.440 million km^2
MYI area: 2.150 million km^2
Avg concentration: 62.5%

Extreme: Any area with 70% or more MYI survives
Ice extent: 1.920 million km^2
Ice area: 1.825 million km^2
Avg concentration: 95.1%
MYI Extent: 1.920 million km^2
MYI Area: 1.493 million km^2
Avg concentration: 77.8%

As was the case last year, the charts represent the *parcels* of ice that we believe will survive the summer. However it *does not* represent their final location. Drift due to wind and water will transport along the Beaufort Gyre out of the Beaufort and Chukchi Seas. Some ice in the Amundsen Basin will be transported out into the Barents Sea. The picture of the ice in September 2009 will be somewhat different than the current (May 29) conditions.

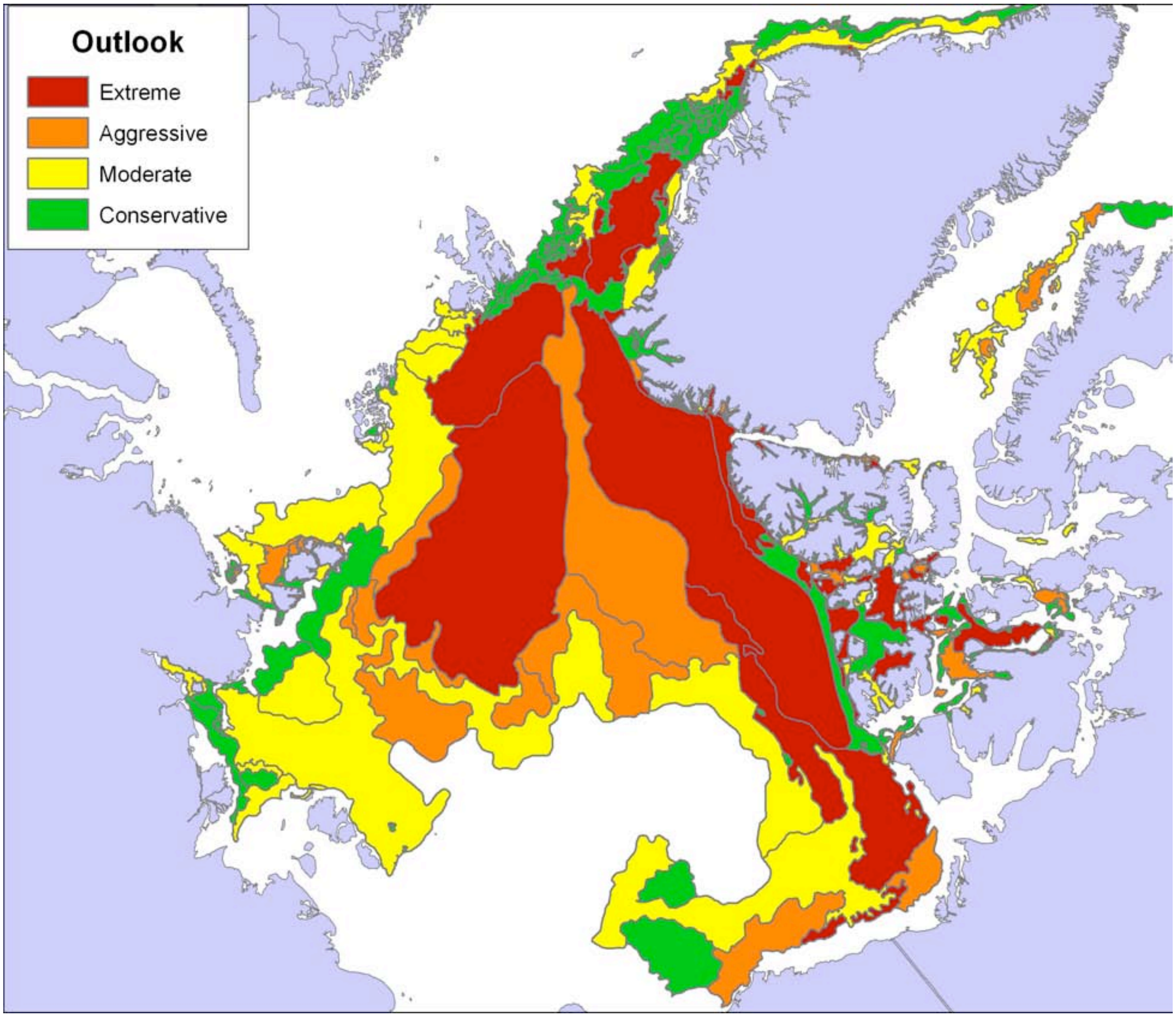

Figure 2: Surviving ice parcels. Extreme = red, Aggressive= red + orange, Moderate= red + orange + yellow, Conservative=red + orange + yellow + green.

From the spread of prognostications, we believe the Moderate case (4.763 million km^2) is the most likely, although at this point it is too early to tell. NIC is also working on an Arctic minimum sea ice outlook index which should strengthen the confidence we have in a particular outlook. Preliminary results of the index favor the Conservative estimate, but further refinement is required before the index will be considered in our outlook.

September 2009 Sea Ice Outlook: June Report
Canadian Ice Service

The Canadian Ice Service (CIS) is predicting the minimum Arctic sea ice extent to be near 5 million square kilometres in September, 2009, which will make it the third lowest in the 1979-2009 record. This value is slightly greater than that observed in September, 2008, but still lies well below the average extent for 1979-2008 (which is equal to 6.67 million square kilometres, based on the SMMR- and SSM/I-derived data available on the NSIDC web site).

The CIS value was derived empirically, based on the following two factors: 1) the amount of multi-year ice remaining in the Arctic Ocean at the end of May, 2009, which was similar to but slightly less than the amount remaining at the end of May, 2008; and 2) the unexpected formation of a large area of second-year ice over the pole at the end of the 2008 melt season, and the new uncertainties associated with this. Predictions for first-year sea ice loss in summer 2008 were for the most part overestimates (especially near the pole, where the large area of second-year ice now exists), leading to new reservations regarding the potential rate of ice loss in summer 2009. Taking the above into consideration, the operational staff at CIS are predicting a summer sea ice minimum extent similar to but slightly greater than that of 2008.

CIS is also currently testing two models for long-range sea ice prediction. A Multiple Linear Regression model, based on atmospheric inputs alone, predicts a September, 2009, Arctic sea ice extent of 5.5 to 5.8 million square kilometres. An Optimal Filtering model, based on ice inputs alone, predicts 4.2 million square kilometres. So the above value of ~5.0 million square kilometres also represents an average of these *very* experimental model predictions. CIS will be conducting verification studies of the predictions produced by these models in the coming years.

September 2009 Sea Ice Outlook: June Report
By: Charles Fowler, Sheldon Drobot, and James Maslanik

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1A. Extent Projection

Predicted minimum extent based on data to date is 4.89 million sq. km. Estimated confidence interval for this estimate is +/- 0.39 million sq. km.

As noted below, the potential exists for more extensive ice loss if the large expanse of 2nd.-year ice in the central Arctic does not survive or if substantial amounts are transported northward toward the Canadian Archipelago or through Fram Strait. This is in part due to the fact that so little of the older, thicker multiyear ice exists at present in the Arctic Basin compared to previous years.

2A. Method

This estimate is based on a statistical regression model that uses passive microwave derived sea-ice concentrations, and estimates of ice age and thickness regressed against the minimum ice extents over the past 26 years. The ice age and thickness information used are derived from Lagrangian tracking of ice regions, with a different mean ice thickness assigned to each ice age category of multiyear ice, for 2nd.-year through 10th.-year ice. This is combined with a simple temperature-driven ice growth model and melt parameterization to estimate first-year ice thickness. In this implementation, "open water" is defined as less than 40% ice concentration.

3A. Rationale

The approach assumes relationships between ice disappearance and concentration, age, and thickness. In this approach, the model does not directly factor in the removal of ice due to transport. Instead, the parameters relate mostly to ice melt. To the degree that the parameters influence susceptibility to transport though, the statistical model probably captures some of these indirect affects. For example, assuming that thinner ice and/or first-year ice is more affected by ice kinematics and transport, then the model would include such effects indirectly.

A key driver for the prediction is extent of ice of different ages. Figure 1 shows our estimate of ice age at the end of April, 2009 (panel 4) along with the ice age coverage at the end of April for the three previous years. The main points to take from these maps are the relatively small coverage of the older, thicker age classes, and the extent of 2nd.-year ice within the central Arctic Basin. This ice is less susceptible to melt than first-year ice but still presumably more susceptible to loss than the older ice classes. In addition, our data suggest a considerable amount of first-year ice mixed in with the 2nd.-year ice in this area, perhaps predisposing the region toward greater melt and convergence.   A switch to positive NAO wind patterns could also drive this 2nd.-ice northward, exposing more open water within the central Arctic Ocean, perhaps extending to the vicinity of the North Pole.

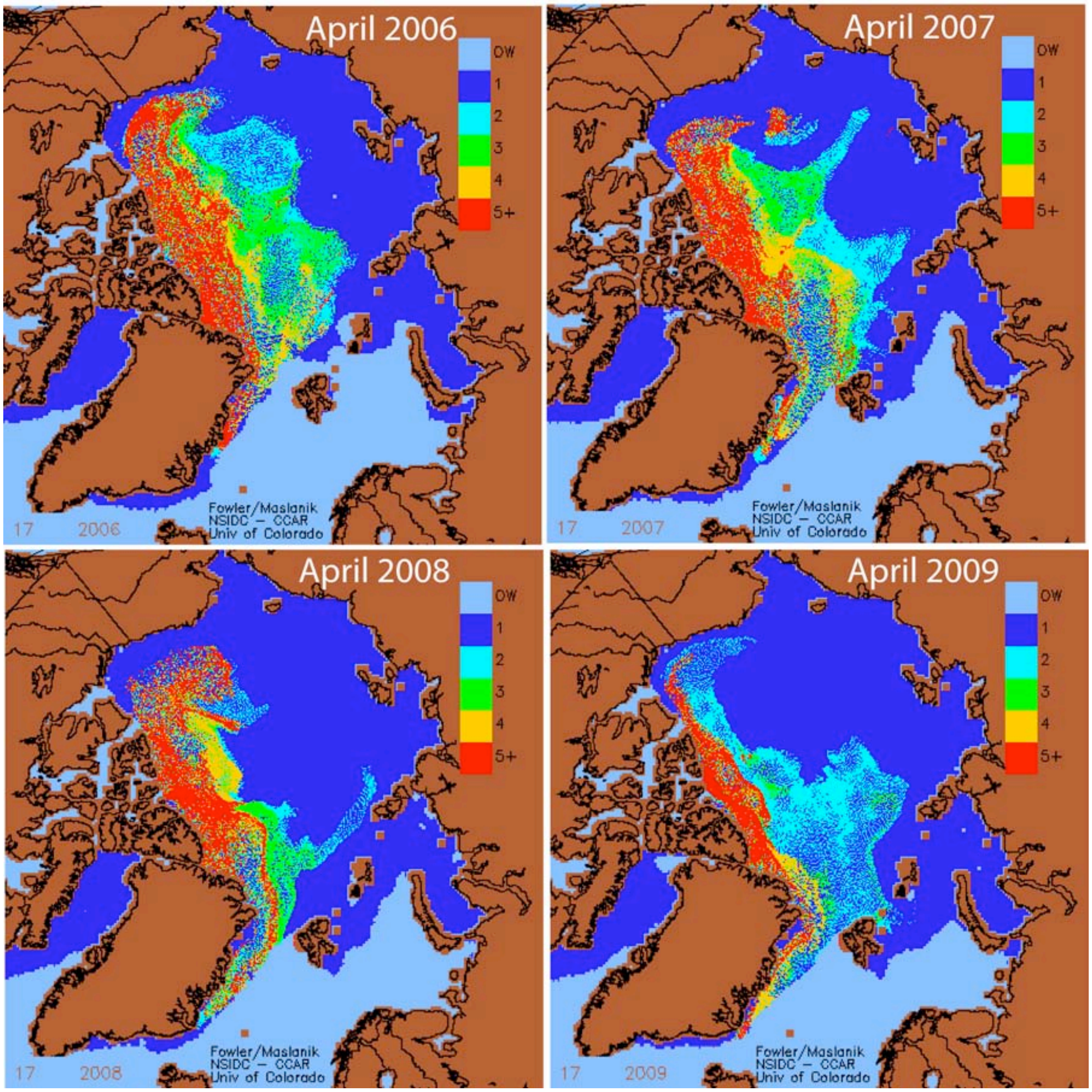

Figure 1.   Estimated ice age for the end of April for 2006-2009.

1B.   Estimates of Ice Conditions in Specific Regions

Two discussions are provided.   The first draws from ice-pack opening dates that we have estimated for each 25km grid cell in the Arctic.   Here, we limit the opening-date results to the Beaufort and Chukchi seas. The full grid of opening dates is available, but our confidence in performance for other areas is considerably less.   The second discussion addresses distributions of multiyear ice of different ages and the possible effects on ice conditions through summer.

1B. 1. Opening Dates in the Beaufort and Chukchi Seas

Estimated opening dates are shown in Figure 2.

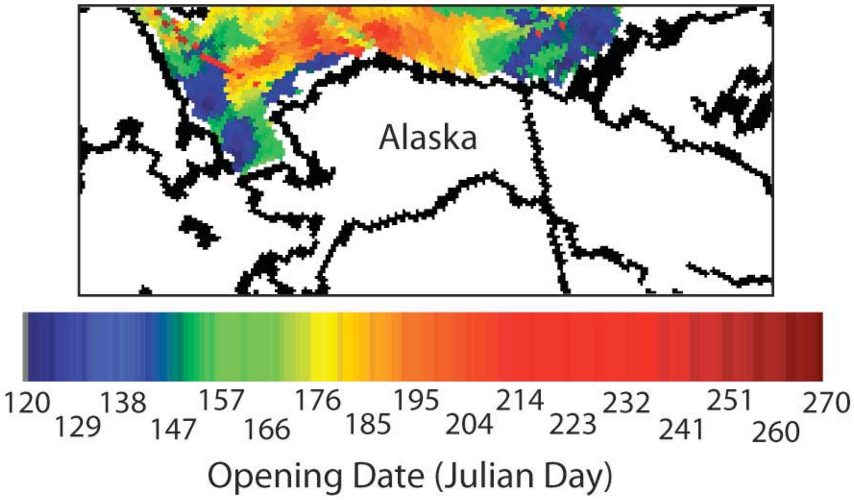

Figure 2. Estimated opening dates in the western Arctic.

At the time of this writing (end of May), open water has formed in the southern Chukchi Sea – reasonably consistent with the dates in Figure 2. The eastern Beaufort Sea is still mostly ice covered (albeit with reduced concentration), so the our estimated opening dates for that area were too early.

1B.2. Distribution of Multiyear Ice Types

Beaufort and Chukchi seas

As indicated in Figure 1, the most recent ice age map suggests that some multiyear ice is present further south in the Beaufort Sea than during the past 2 years. However, this ice appears to be predominantly 2nd.-year ice, in contrast to previous years (including years earlier than those shown in Figure 1) when the multiyear ice in the Beaufort Sea was some of the oldest and presumably thickest ice in the Arctic Basin (as a result of ice transport from the Canada Basin and central Arctic). The mixture of 2nd.-year and first-year ice is also more diffuse than previously, so as melt progresses through summer, it seems likely that scattered, isolated multiyear floes will persist, but within otherwise open-water areas. It is also likely that the remaining 2nd.-year floes will disappear faster due to melt than was the case in summer 2008, when multiyear ice persisted in small bands, particularly north of Barrow. Last year's multiyear ice was likely to have been older, thicker ice though, as noted above, so this summer's multiyear ice in the area may not last as long. As in recent years, we expect that the remaining multiyear ice in the Beaufort Sea will melt out as in moves westward into the Chukchi Sea, with virtually none of this ice recirculating into the Canada Basin to replenish the loss of multiyear ice due to melt.

High Arctic (Central Arctic/Canada Basin)

Our data show the western sector of the High Arctic (along with most of the Canada Basin) region to be covered nearly entirely by first-year ice, unlike any previous spring over the 1979-present satellite record. We anticipate that most of this area will become ice free by the end of summer. The High Arctic areas adjacent to the Canadian Archipelago continues to experience reductions in coverage of the oldest ice types, with the remaining oldest ice compacted against the Archipelago coast.

The remainder of the High Arctic north of 85 deg. is covered by predominantly multiyear ice, but this ice is mostly 2nd-year ice. Based on climatological conditions though, it is unlikely that under "normal" conditions, this ice would melt out, so heavy ice may remain in this area throughout summer. The most likely scenario for a retreat of this multiyear ice edge would be if atmospheric circulation produces persistent and strong southerly winds that reduce ice extent through ice transport.

Northeast Passage

Also depending on ice transport patterns (for example, if the ice is pushed northward), the potential exists for the remaining first-year ice to melt out along the Northeast Passage. (Caution: As noted above, our definition of "open water" is an ice coverage of 40% or less. So, there may be ice present even in areas that we describe as open – a significant distinction for operations in areas that satellite products such as ours define as "open water.")

Other

More multiyear ice is present along the northeastern Svalbard coast than is typical. Ice free dates may therefore be delayed in this area, although wind patterns will probably be the main factor affecting the date due to the relatively short distances the ice edge needs to retreat to free the Svalbard coast.

2B. Methods

The opening dates are estimated by regressing the opening dates for the past 10 years against the above-described ice thickness/age conditions and 2-m air temperatures for the end of April 2009.

The discussion of the location and significance of multiyear ice types is based on the ice age data noted above.

3B. Rationale

The basis for the opening date results is the same as for the extent prediction above. For the discussion of multiyear ice, we rely on subjective interpretations of conditions in previous years and on general knowledge of ice behavior in different locations.

September 2009 Sea Ice Outlook: June Report

By: Robert Grumbine

1) My projection is 4.92 million km^2, with a standard error estimate of 0.47.

2) Statistical based on the rationale in 3

3) I'm viewing the problem as one of growth of open water, rather than decline of ice cover. From this view, ice-albedo feedback is a problem in population growth. The more open water, the more the population of open water grows. As with biological populations, there is a limit to the growth, in that the area of open water can't exceed the area of ice cover before the growth began. In constructing the statistical estimate, I estimated the 'normal' ice extent (7.39 million km^2), computed the open water each year by subtracting the observed cover from 7.39, and then found a best fit exponential curve to this open water value. Since we're still on the early part of the growth curve, exponential is a fair approximation. Finishing out the full fit to the sigmoid will take more time.

As an eyeball issue, model projections and ensembles of coverage have seemed to me to be following a sigmoid. With only the exponential part of the curve, I'm estimating zero cover for September in 2022. Since I do believe the sigmoid term is present and ultimately important, 2022 is an early bound, using only extent information.

September 2009 Sea Ice Outlook: June Report
By: Christian Haas and Stefan Hendricks

Arctic multiyear ice thickness at the onset of the 2009 melting season

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Discussions among experts of the international 2008 SEARCH Sea Ice Outlook repeatedly stated a lack of ice thickness data as one main gap in our understanding and prediction of Arctic sea ice coverage. In April 2009, a team of the University of Alberta (Canada) and Alfred Wegener Institute for Polar and Marine Research (AWI, Germany) obtained an almost pan-Arctic airborne ice thickness snapshot of some of the key multiyear ice regions of the Arctic Ocean. The wide regional coverage was possible because for the first time ice thickness surveys using electromagnetic sounding could be performed from a fixed-wing aircraft, a Basler BT67/DC3 owned by AWI. A state-of-the-art towed ice thickness sensor (an "EM bird") was operated on an 80 m long cable below the plane, 20 m above the ice, and was winched under the belly of the plane for take-off and landing. Surveys were performed north of Svalbard, Greenland and Ellesmere Island, and in the Beaufort and Chukchi Seas, and included a visit of the Russian Drifting Station NP-36. Results show prominent thickness gradients in all regions as surveys crossed ice regimes of different age and origin. Individual profiles show marked differences as a result of their variable deformational and thermodynamic history. Data are available for comparison with results from satellite measurements and to validate or initialize numerical models. Comparisons with results from previous, regional surveys are still ongoing. However, preliminary findings indicate that modal ice thicknesses were similar or slightly larger than in recent years. This, together with a slight increase in the overall multiyear-ice coverage, may lead to speculations about a temporary recovery of the Arctic sea ice cover to more normal, though slowly declining conditions, at least for the summer of 2009. However, little information is available about the thickness of the vast first-year ice regions, which may be the most vulnerable to rapid mass loss during the summer. The figure shows mean ice thickness of 20 km segments of all profiles.

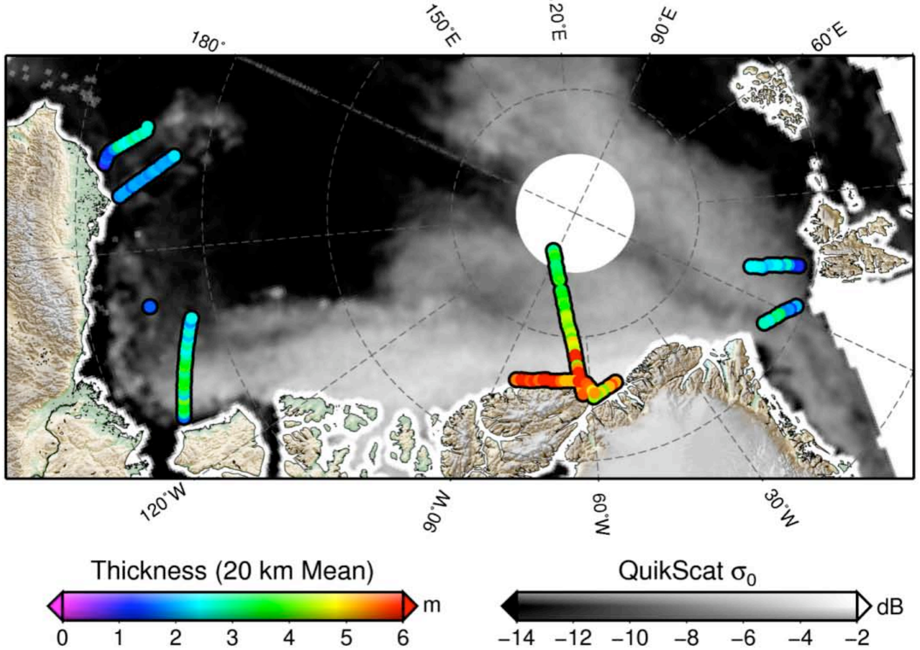

Figure: Mean ice thickness of 20 km segments of all profiles surveyed in April 2009. Backscatter (σ_0) information shows the approximate distribution of first-year (dark) and older ice (brighter).

September 2009 Sea Ice Outlook: June Report

By: Masahiro Hori, Kazuhiro Naoki, Keiji Imaoka, Japan Aerospace Exploration Agency (JAXA)

1. Extent Projection
5 million square kilometers

2. Methods/Techniques
A diagnosis based on the analysis of remote sensing (AMSR-E) data within the past 7 years

3. Rationale
Multi-year ice fraction was estimated from AMSR-E brightness temperature data. Also, AMSR-E sea-ice concentration was used for estimating sea-ice extent which is available at http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=e.

The fraction of multi-year ice seems to be the smallest this spring within the last 7 years, although the spring sea-ice extent itself became the largest this May due to the cooler air temperature. Thus, the spring sea-ice condition is in a good position to melt similarly to what we saw in 2007 and 2008. However, at this moment, it is difficult to estimate how much summer weather patterns will accelerate the melting.

4. Supplemental images

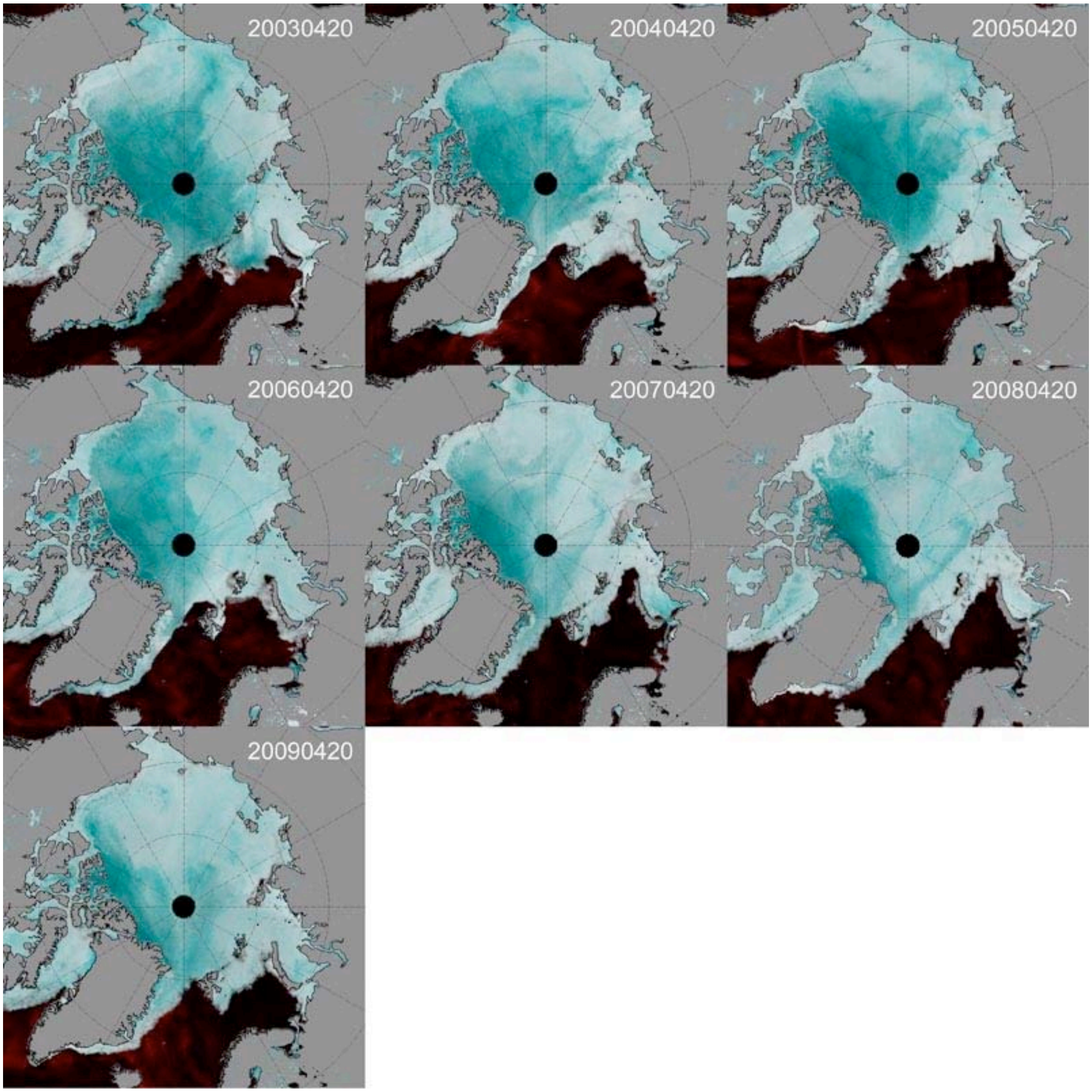

Fig.1 RGB color composite images of AMSR-E brightness temperatures at the 36GHz-V and 18GHz-V channels captured on April 20 during 2003 to 2009 which indicate rough estimates of the spatial distribution of the sea ice thickness (thick multi-year ice is shown in dark blue, and thin young ice in light blue).

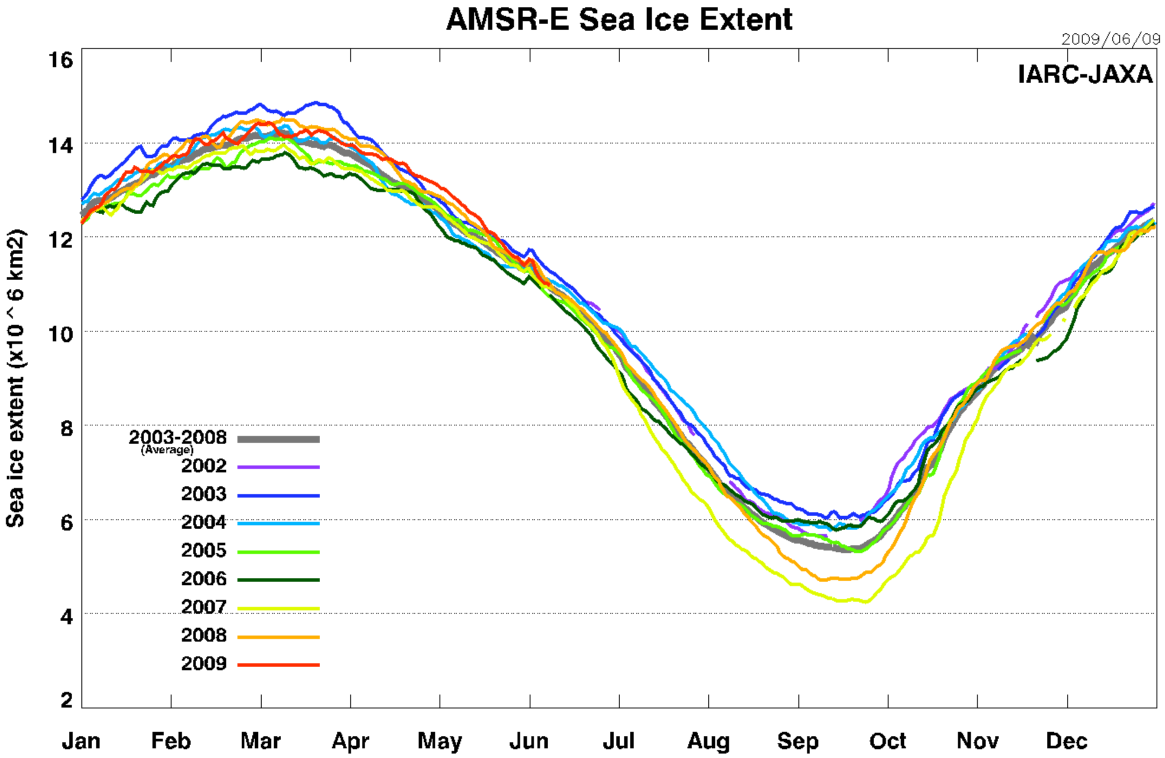

Fig.2 Seasonal variations of the Arctic sea ice extent during recent 7 years.

Sea Ice Outlook - May 2009

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June 3, 2009

2009 September Extent

Our forecast is 4.92 ± 0.43 Mio. km^2

Methods and Techniques

The estimate is based on a quadratic extrapolation of the measured September sea ice extent time series (Fig. 1)

Physical Rationale

The estimate is based on an assessment of different statistical forecast methods. We investigated three different techniques and a combined method in a hindcast experiment. The different techniques are:

- extrapolation of the september minimum timeseries,
- correlation of previous winter surface air temperature
- correlation of May ice extent anomaly
- a combination of the three methods above.

Extrapolation of the sea ice extent time series

We extended the Cavalieri et al. (2003) dataset with the NSIDC Sea Ice Index (Fetterer et al., 2002) to a homogeneous 37 year long time-series of the sea ice extent. The September minimum was extrapolated using a linear and quadratic fit (Fig. 1). Since the quadratic prediction better represents the observations it was used for the forecast. The 2009 forecast based on this method is 4.92 ± 0.43 Mio. km^2.

Northern hemispheric winter surface air temperature

The surface air temperature was obtained from NCEP reanalysis data. Zonal means of temperature correlated with September minimum showed statistical significant relation in the northern hemisphere from about 27.5N to 90N (Fig. 3). Ice growth during winter has an impact on the amount and extent of ice left after summer melting. The forecast calculated from the average of 27.5N to 90N from December to April air temperature is 6.0 ± 0.4 Mio. km^2.

Correlation of May with September extent

Correlation of the actual extent anomaly with the September anomaly depends on the time of year. The correlation is not significant for the May average extent, but will get better with each month when approaching September. Since the DMSP-F13 SSM/I has serious problems, we extrapolated the daily ice extent data from NSDIC seaice index and obtained three scenarios of the mean may extent: 13.075, 12.925 and 12.825 Mio km^2. Fig.4 shows that this difference does not have a very high impact on the September anomaly. Since there is no significant statistical relation this forecast is not used in the present prediction. The technique will become important in the following months. As you can see in Fig.5 the significance rapidly increases with the start of June and is not significant in previous months. Fig.5 also shows the impact of the 2007 and 2008 extreme minima on the correlation. Statistical significance of correlation coefficients was determined by permutation tests.

Combination of different forecasts

The inverse of the standard error of estimate is used to weight the seperate forecasts and make a combined prediction. The combined forecast $\bar{F}$ is calculated from the seperate forecasts F_k

$$\bar{F} = \frac{1}{S} \sum_{k=1}^{n} \frac{1}{\sigma_k} F_k$$

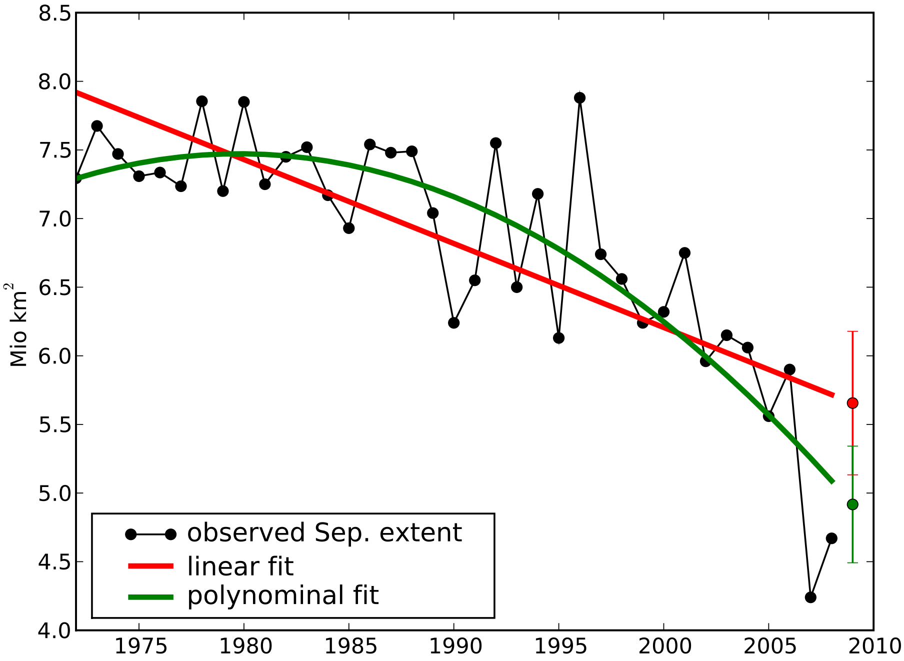

Figure 1: Extrapolation of September time series, correlation coefficients $r_{lin} = 0.78$ and $r_{poly} = 0.86$

with $S = \sum_{k=1}^{n} \frac{1}{\sigma_k}$ being the sum of all weights. The estimated error $\Delta\bar{F}$is calculated using:

$$\Delta\bar{F} = \sum_{k=1}^{n} \frac{\partial\bar{F}}{\partial F_k}\sigma_n$$

The combined forecast is 5.5 ± 0.5 Mio. km^2.

Assessment of the forecast methods

The four different methods are compared in a hindcast experiment (Fig. 6) for the nine years from 2000 to 2008. The total error is smallest for the quadratic extrapolation of the time series. The largest error occurs for the prediction based on the May extent. The combined method yields in average better results than the predictions based on air temperature and on the May extent but also suffers from their larger errors as compared to the extrapolation. Thus, the combined method is not the most suitable approach.

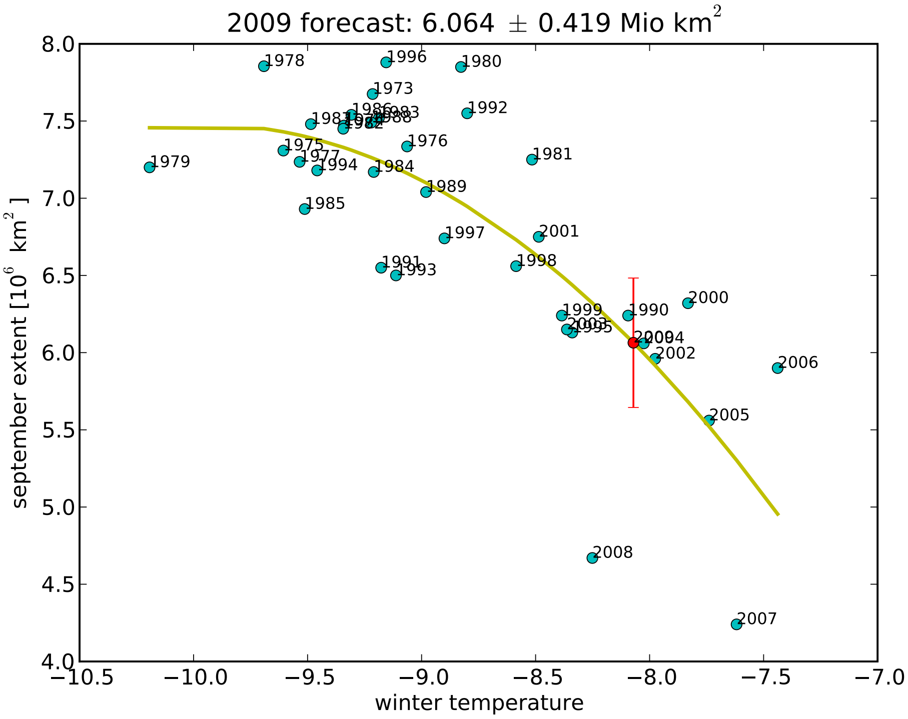

Figure 2: Northern hemispheric winter temperature and September ice extent with 2009 prediction.

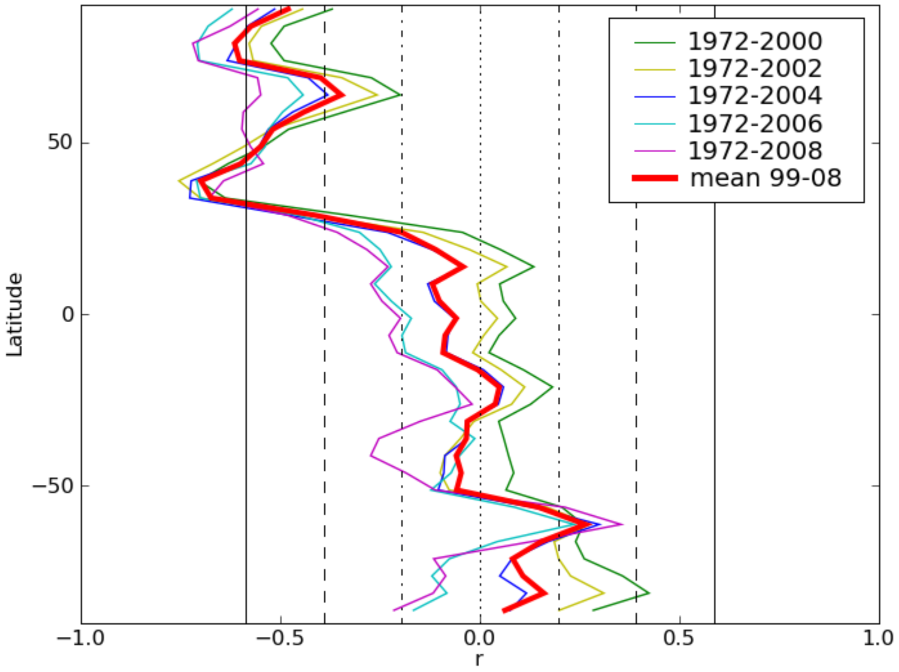

Figure 3: Correlation coefficient r of zonal mean air temperature with September extent; the black lines show 68%, 95% and 99% significance levels

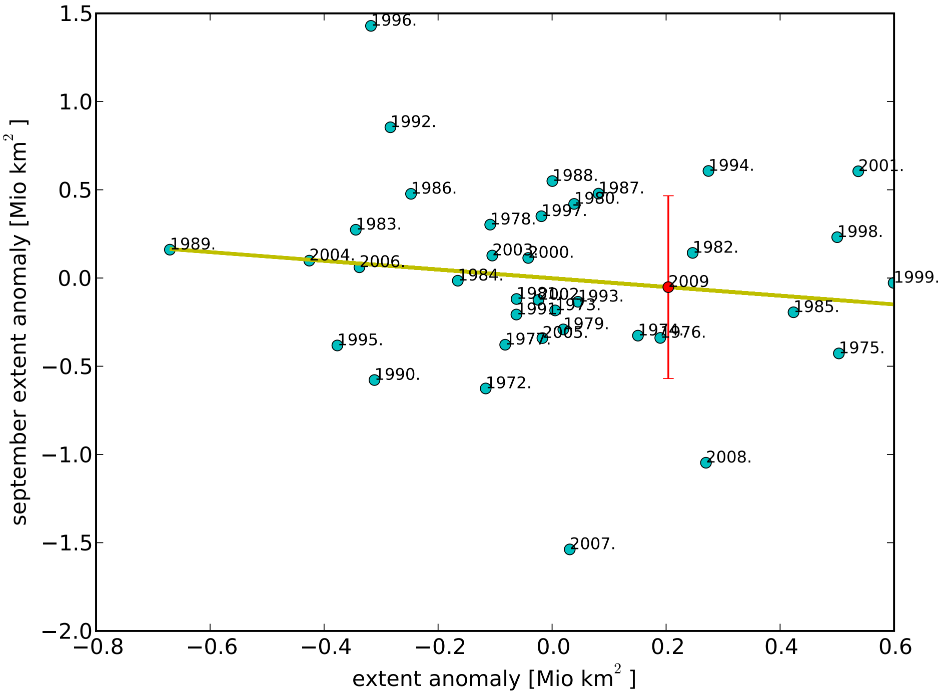

Figure 4: Correlation of May extent anomaly with September extent anomaly, $r = -0.1$

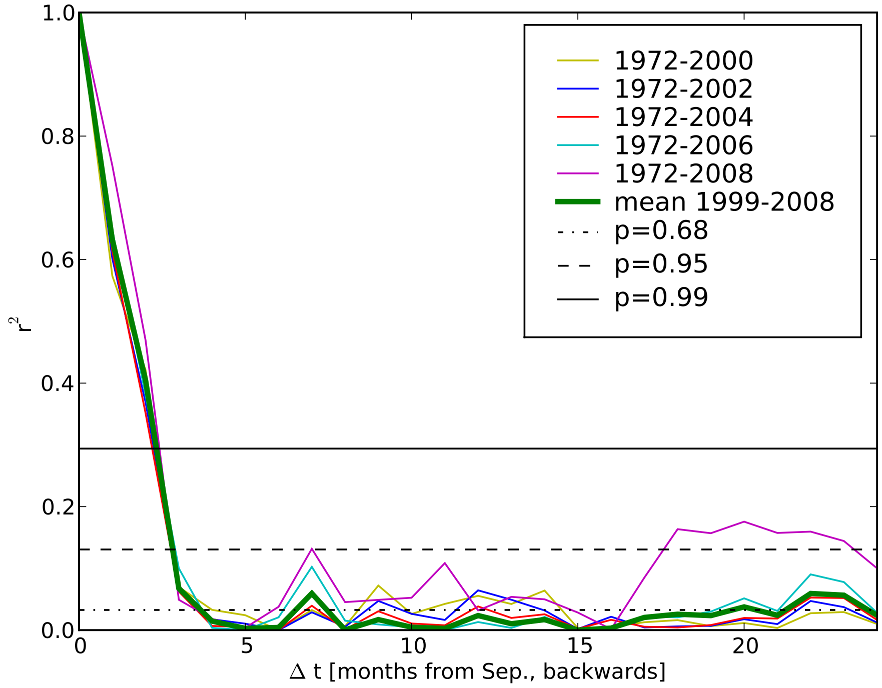

Figure 5: Correlation coefficients of september extent anomaly with previous months, black lines are significance levels, timeseries was cut off in 2-year steps to show the impact of 2007 and 2008 minima

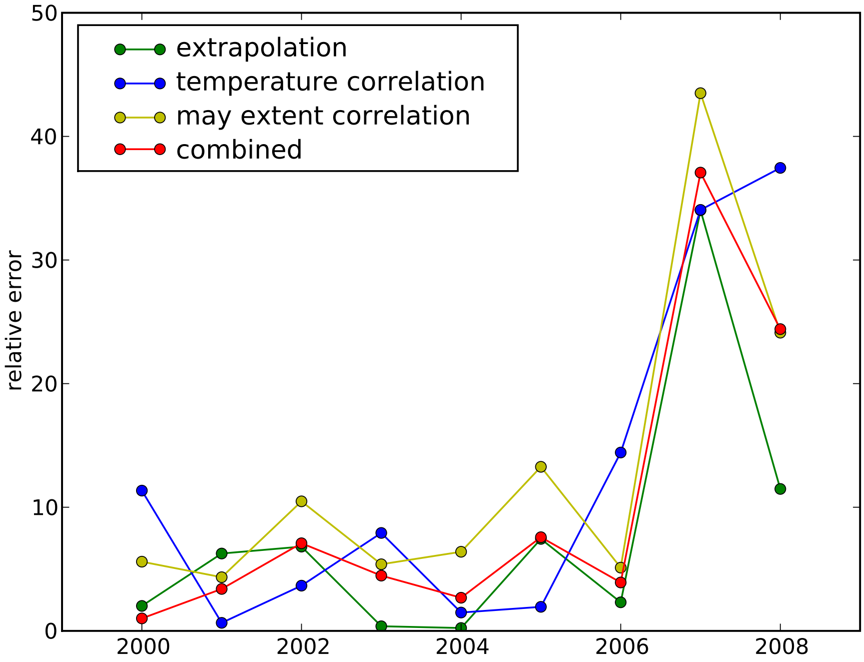

Figure 6: Prediction error hindcast experiment. The methods described in the text are used to predict the September minimum for the years 2000 to 2008. The relative deviation of the prediction to the actual sea ice extent are shown. The averaged errors are 8%, 10%, 12% and 13% for the extrapolation, combined method, correlation with temperature and May extent, respectively.

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September 2009 Sea Ice Outlook: June Report

By: AWI / FastOpt / OASys

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June[1], 2009

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Motivation: The Situation of Arctic Sea Ice

The annual Arctic sea ice extent[1] minimum occurring in September, at the end of the melting season, has exhibited a downward trend from about 7 million km^2 in the early 1980s to about 5.5 million km^2 in 2006. After a new record minimum of 4.28 million km^2 in September 2007 the sea-ice extent in the Arctic Ocean barely missed this record in the following year 2008, with an extent of 4.67 million km^2.

In 2009, as in the previous year, AWI and OASys participate in the S4D Sea Ice Outlook (SIO), this time joined by FastOpt. The basic approach remains. We perform ensemble simulations with the coupled sea ice-ocean model NAOSIM, driven with summer atmospheric forcing from the past 20 years, each starting from the same initial conditions. This provides a range of different ice cover developments over the summer and allows for probability estimates of the minimum ice extent.
This time, however, we will add a set of ensemble simulations which start from an initial state which is optimized by the use of the 4DVar data assimilation system NAOSIMDAS, incorporating observed ice concentration, ice motion and ocean hydrography.

Lessons learned from the 2008 Outlook and other recent work

For the three successive ice outlooks for 2008 we had used a set of ensemble simulations with atmospheric summer conditions of the past 20 summers (1988 to 2007) from the NCEP/NCAR reanalysis. The simulations were initialized on June 1st, June 27th, and August 8th, respectively, and then run until the end of September 2008 (http://www.damocles-eu.org/research/Little_ice_but_no_record_low_578.shtml).
In agreement with a similar study by Zhang et al., (2008) we found that ensemble mean and the standard deviation of the predicted summer minimum ice extent depend significantly on the initial state of ice and ocean. The uncertainty of the prediction was halved when starting at the end of June instead of the end of May. This result is reinforced by an adjoint sensitivity study (Kauker et al., 2009) that showed that about 2/3 of the September ice extent anomaly in 2007 was determined at the end of June 2007.

To better estimate the effect of the initial conditions we repeated the ensemble experiment with initial conditions from June 1st 1988, a year with much larger Arctic ice volume than 2008. The ensemble mean ice extent prediction for September was dramatically higher (~2 million km^2) in this experiment,

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[1] The ice extent is defined by the outer edge of the ocean surface covered with sea ice. In practice, sea ice concentration (the fraction of area covered by sea ice) is measured from satellites and the 15% concentration contour is taken as the sea ice edge.

even when forced with 2007 atmospheric conditions. This highlights the importance of the knowledge of the initial ice thickness distribution in early summer for the prediction of the September ice conditions in the Arctic. For the SIO 2009 we therefore make use of the 4DVar data assimilation system NAOSIMDAS to perform an additional set of ensemble experiments starting from an optimized initial state.

Experimental setup

For the present outlook the coupled ice-ocean model NAOSIM has been forced with atmospheric surface data from January 1948 to May 22nd 2009. This atmospheric forcing has been taken from the NCAR/NCEP- reanalysis.
Since for the coming summer the atmospheric situation is unknown, we used atmospheric data from the years 1989 to 2008. The model experiments all start from the same initial conditions on May 22nd 2009. We thus obtain 20 different realizations of sea ice development in summer 2009. We use this ensemble to derive probabilities of ice extent minimum values in September 2009.

Two ensemble experiments with different prescriptions of the initial conditions on May 22nd 2009 were performed:

Ensemble I starts from the state of ocean and sea ice as it is calculated by a forward run of NAOSIM driven with NCEP atmospheric data from January 1948 to 22nd May 2009.

Ensemble II starts from an optimised state derived by applying NAOSIMDAS for April 2009, followed by a short forward integration (with NCEP May 2009 data) until May 22nd 2009. NAOSIMDAS has been developed (and is still developed further) in the EU FP6 project DAMOCLES (http://www.damocles-eu.org). Observational data used include:

- Hydrographic data from Ice Tethered Platform profilers (http://www.whoi.edu/page.do?pid=20756) which have been deployed as part of several IPY initiatives, covering part of the central Arctic Ocean
- Hydrographic data from ARGO profilers provided by the CORIOLIS data center (http://www.coriolis.eu.org/cdc/default.htm) mostly covering the Nordic Seas and the northern North Atlantic Ocean
- Daily mean ice concentration data from the MERSEA project, based on multi-sensor SSM/I analysis, kindly provided by Steinar Eastwood (OSI-SAF, met.no), with a spacial resolution of 10 km.
- Two-day mean ice displacement data from merged passive microwave (SSM/I, AMSR-E) or scatterometer (e.g. ASCAT) signals, which were kindly provided by Thomas Lavergne (OSI-SAF, met.no), with a spatial resolution of 62.5 km.

The 4DVar optimisation minimises the difference between observations and model analogues, by variations of the models initial conditions on April 1st and the surface boundary conditions (wind stress, scalar wind, 2m temperature, dew-point temperature, cloud cover, precipitation) in April 2009.

A comparison of 'free' versus 'optimised' initial conditions

To be able to interpret the differences in the two ensemble simulations starting from free and optimised initial states on May 22nd 2009, we display monthly mean April 2009 ice concentration, ice thickness and ice drift.

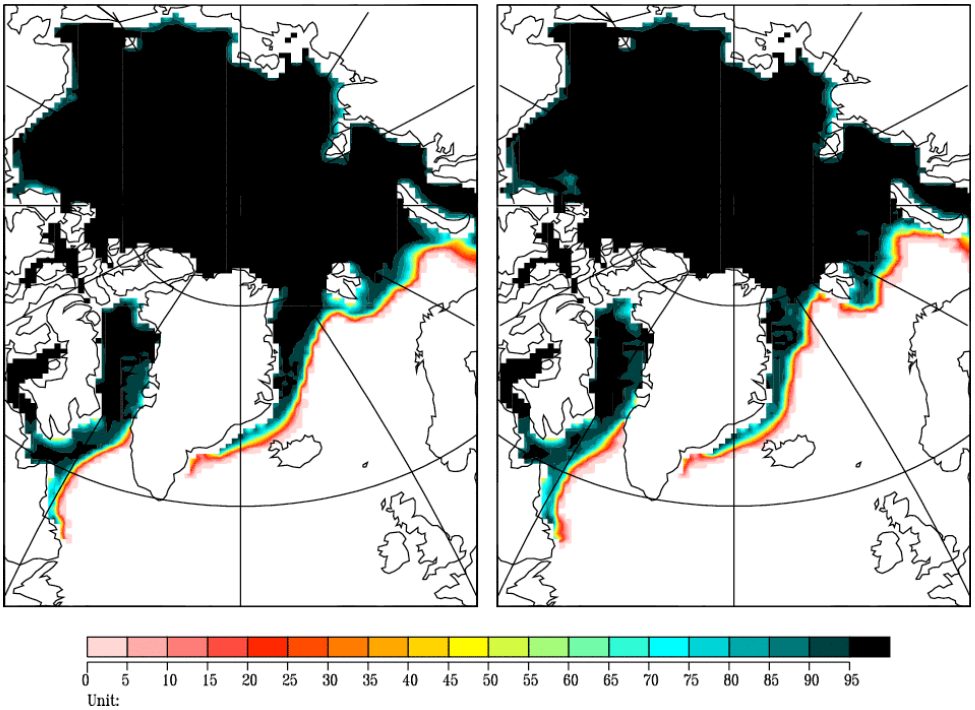

Fig. 1: April mean ice concentration from the free model run (left) and from the optimised model run (right).

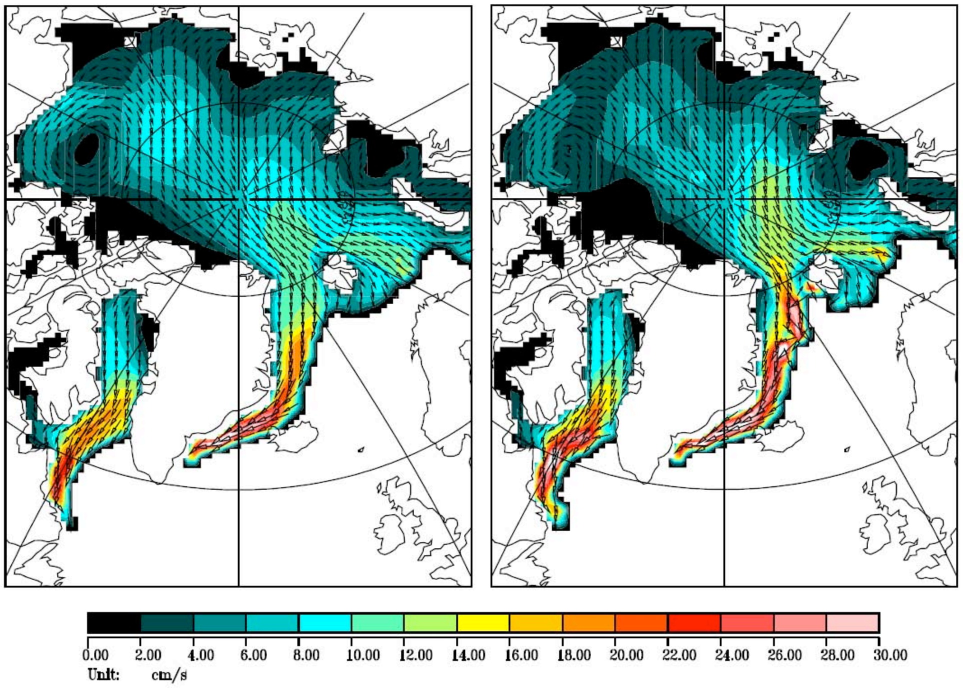

Fig. 2: April mean ice drift from the free run (left) and from the optimised model run (right).

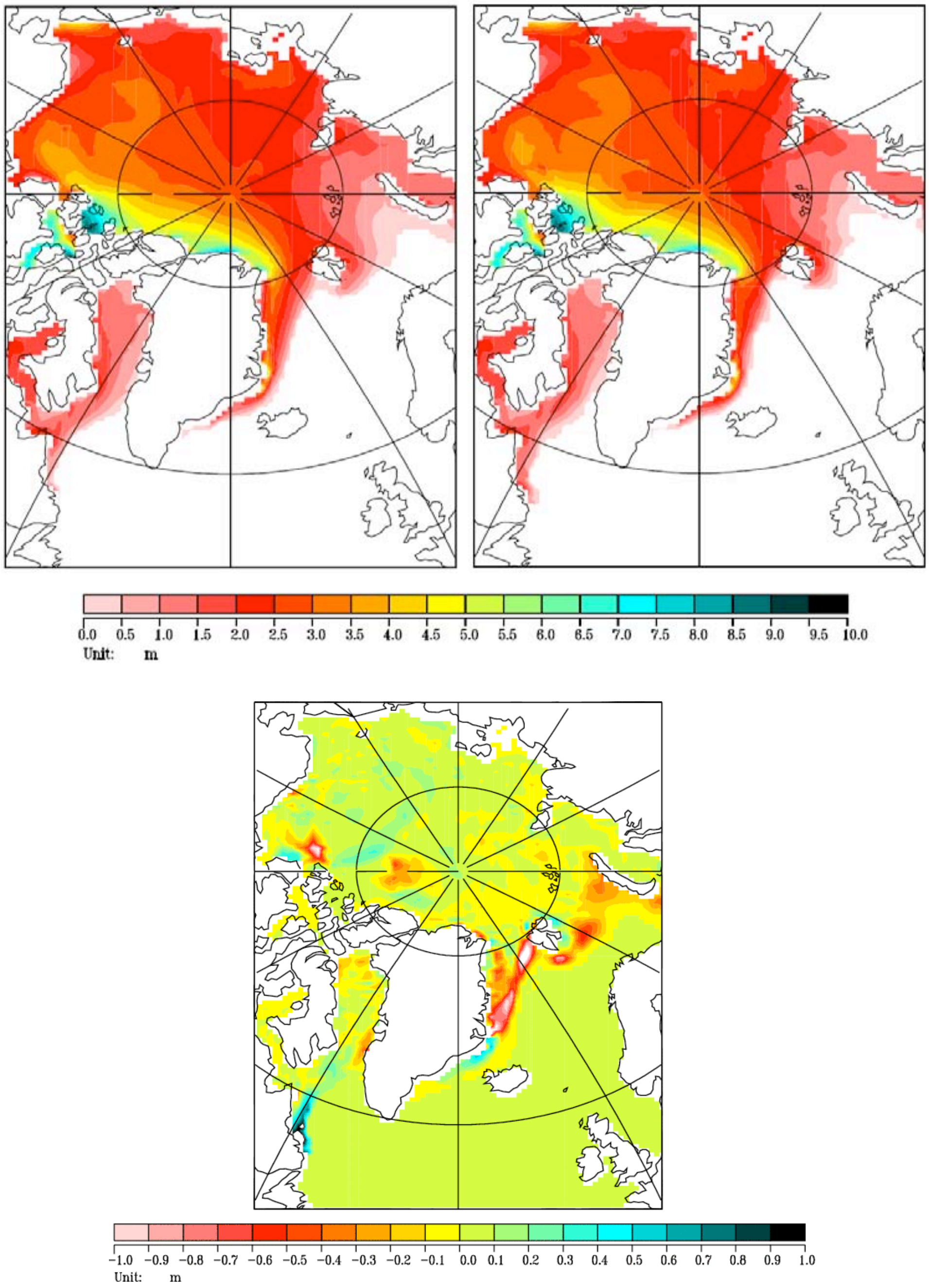

Fig. 3: April mean ice thickness from the free model run (left), from the optimised model run (right), and the difference of both (optimised minus free) (bottom).

The ice concentration (Fig. 1) from the optimised model run is characterised mainly by an ice edge in the Barents and Nordic Seas that is slightly more structured and shifted northward. For the ice drift (Fig. 2), the optimised April mean exhibits a weaker Beaufort Gyre circulation and stronger southward motion in the Transpolar Drift. In Fram Strait, the tendency of the model to exhibit fast sea ice motion close to the Greenland coast is reduced in the optimised run, leading to a more realistic velocity profile in the East Greenland Current (Spreen, 2008). The optimised sea ice thickness for April 2009 (Fig. 3 right) is slightly thicker in parts of the Canadian basin, while thinner ice can be found in the Barents and Nordic Seas.

Mean September Ice Extent 2009

Ensemble I

The result for all 20 realizations ordered by the September ice extent is shown in Figure 4. Since the forward simulation underestimates the September extent compared with observed extent minima in 2007 and 2008 by 0.40 million km^2, we added this systematic bias to the results of Ensemble I.
The Ensemble I mean value is 4.60 million km² (bias added). This is the most likely value under the assumption that the atmospheric conditions in the remaining months of summer 2009 stays within the range of the previous 20 years. The standard deviation of Ensemble I is 0.55 million km^2, which is larger than the uncertainty of last years first AWI/OASys outlook that was initialized on June 1st (0.40 million km$^{2.}$). Assuming a Gaussian distribution we are able to state probabilities (percentiles) that the sea ice extent in September 2009 will fall below a certain value.

The probability deduced from **Ensemble I** that in 2009 the ice extent will fall below the three lowest September minima is:

probability to fall below 2007 (record minimum)	is about 28%,
probability to fall below 2008 (second lowest)	is about 55%,
probability to fall below 2005 (third lowest)	is about 96%.

With a probability of 80% the mean September ice extent in 2009 will be in the range between 3.9 and 5.3 million km^2.

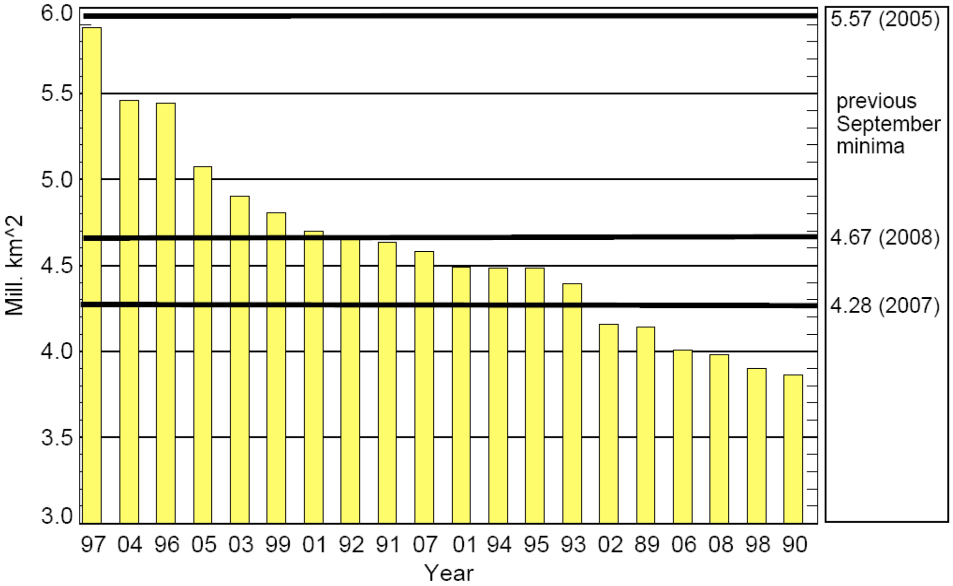

Figure 4: **Ensemble I** - Simulated mean September ice extent in 2009 [million km^2] when forced with atmospheric data from 1989 to 2008 (not optimised initial state on May 22nd 2009). Model derived ice extents have been adjusted assuming a systematic bias (see text). The thick black horizontal lines display the minimum ice extent observed in 2005, 2007 and 2008.

Ensemble II (optimised initial conditions)

The mean September sea ice extent for all 20 realizations starting from optimised initial conditions is shown in Figure 5. The closer we will come to the summer minimum in the upcoming July and August outlooks, the more we expect the optimisation of the initial state to correct the systematic (summer) bias we added in Ensemble I. Therefore, for Ensemble II we applied no (summer) bias correction. Hence, the Ensemble II mean of 4.30 million km^2 is somewhat lower than the mean of Ensemble I (note that the optimization increases the predicted mean by 0.1 million km² compared to the uncorrected Ensemble I mean of 4.20 million km^2). As for Ensemble I the standard deviation of Ensemble II is 0.55 million km^2.

The probability deduced from **Ensemble II** that in 2009 the ice extent will fall below the three lowest September minima is:

probability to fall below 2007 (record minimum) is about 49%,
probability to fall below 2008 (second lowest) is about 75%,
probability to fall below 2005 (third lowest) is about 99%.

With a probability of 80% the mean September ice extent in 2009 will be in the range between 3.6 and 5.0 million km^2.

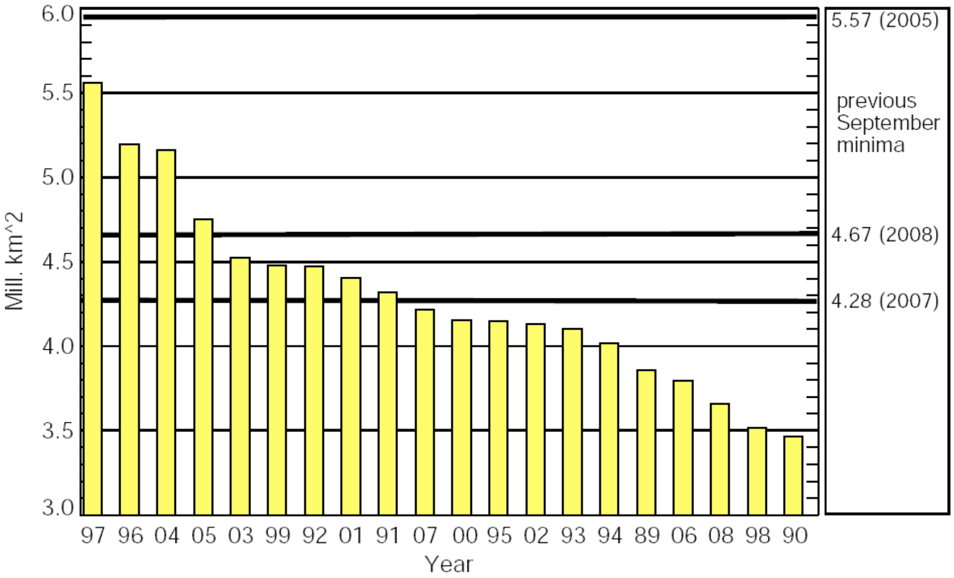

Figure 5: **Ensemble II** - Simulated mean September ice extent in 2009 [million km^2] when forced with atmospheric data from 1989 to 2008 from the optimised initial state on May 22nd 2009. The thick black horizontal lines display the minimum ice extent observed in 2005, 2007 and 2008.

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September 2009 Sea Ice Outlook: June Report

By: Ron Lindsay, Jinlun Zhang, Harry Stern, and Ignatius Rigor

Our Outlook forecast of the September mean total ice extent in the Arctic calls for conditions nearly the same as seen in 2008. It is based on model estimates of the mean ice conditions for the month of May and a linear regression model fit to the years 1987 through 2008.

Predicted extent: 4.90 million sq km
RMS error of the fit: 0.40 million sq km

Best predictor variable: G1.0, the fractional area of water and ice less than 1.0 m thick
R^2 for the fit: 0.78

The region most influential in making the prediction is in the Beaufort Sea, which shows substantially thinner ice than normal in the model simulation.

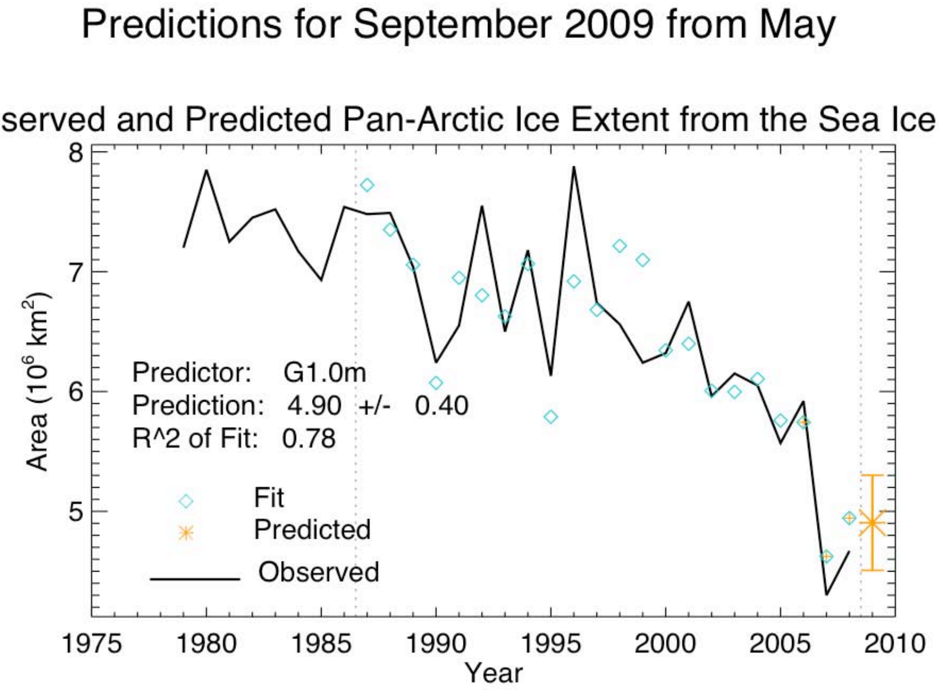

Figure 1: Time series of the September mean total ice extent from the Sea Ice Index (black), the extent predicted by the fit in past years (blue), and the predicted ice extent for 2009 with error bars (orange).

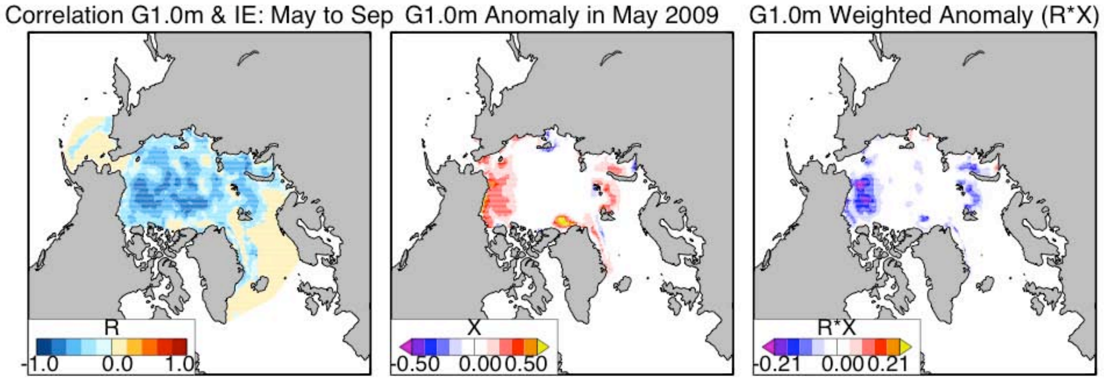

Figure 2: The maps show 1) the correlation of the G1.0 variable in May with the September ice extent for 1987-2008; 2) the anomaly of G1.0 in May 2009; and 3) the product of the anomaly and the correlation. The integral of the last map gives the predictor value for 2009 and it shows where the anomaly and the correlation most strongly align... in this case in the Beaufort Sea, but also a little in the Barents Sea.

Observations of the Decline of Arctic Sea Ice

S. V. Nghiem[1], I. G. Rigor[2], P. Clemente-Colón[3], D. K. Perovich[4], and G. Neumann[1]
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[2]University of Washington, Seattle, Washington, USA
[3]National Ice Center, Suitland, Maryland, USA
[4]Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, USA

The decline of Arctic sea ice in the last half century is reviewed together with the latest observations in 2009. Maps of sea ice classes derived from QuikSCAT (QS) scatterometer data and ice age derived from buoy observations showed that the extent of perennial sea ice (in March) rapidly reduced at a rate of 1.5×10^6 km^2 in this decade, triple the reduction rate during the three previous decades (1970-2000) (Nghiem et al., *Geophys. Res. Lett.*, vol. 34, 2007).

A record was set in the reduction of Arctic perennial ice extent in winter 2008, while the winter total sea ice extent has been stable compared to the average over the decade of the QS data record (1999-2009). By 1 March 2008, the extent of perennial sea ice was reduced by one million km^2 compared to that at the same time in 2007, which continued the precipitous declining trend observed in this decade. Beyond the QS satellite data time-series, the perennial sea ice pattern change was deduced by using the buoy-based estimates computed with 50 years of data from drifting buoys and measurement camps to track sea ice movement around the Arctic Ocean. The combination of the satellite and surface data records confirms that the reduction of winter perennial ice extent broke the record in 2008 compared to data over the last half century.

In the 2007-2008 ice season, perennial ice extent reduced by 1.2×10^6 km^2 between 10/1/2007 and 5/1/2008. Updated observations from QS data showed that perennial ice extent was 0.5×10^6 km^2 larger on 10/1/2008 compared to the same date in 2007 due to more plentiful survival of sea ice after summer 2008. Nevertheless, between 10/1/2008 and 5/1/2009, the reduction of sea ice extent was 50% more rapid than the reduction rate in the same period between 2007 and 2008. On 5/1/2009, perennial ice extent has reduced to 2.1×10^6 km^2, which is a virtual tie to 2.2×10^6 km^2 of perennial ice extent on 5/1/2008 given the uncertainty of $\pm0.2\times10^6$ km^2 in QS measurements. Although the extent of perennial ice extent is similar, its distribution is quite different between the two years with a significant perennial ice pack in the Beaufort Sea in 2008 while there is a large perennial ice pack in the path of the Transpolar Drift Stream (TDS) in 2009 (Figure 1). The continuing drastic reduction of Arctic perennial ice significantly decreases the overall surface albedo resulting in enhanced solar heat absorption in spring and summer, which further decreases the Arctic ice pack through the ice-albedo feedback mechanism.

There is an imminent need for accurate mapping of the ocean floor (bathymetry) especially in the region around the North Pole (NP). Thus, the method to map sea ice using satellite scatterometer data is advanced to enable observations of Arctic sea ice classes as close as 42 km to the NP, which mitigates the problem of the NP data-blind area in other satellite datasets for operational applications. Results reveal a historical fact that the boundary of perennial sea ice already crossed the NP in February 2008, leaving the area around the NP occupied by seasonal sea ice. New QS observations in 2009 suggest a split between two main perennial ice packs (Figure 1), the TDS perennial ice pack and the north Greenland perennial ice pack, extending from the NP to Fram Strait, which may impact the rate of ice export in 2009 and, consequently, the overall state of Arctic sea ice in the coming summer season.

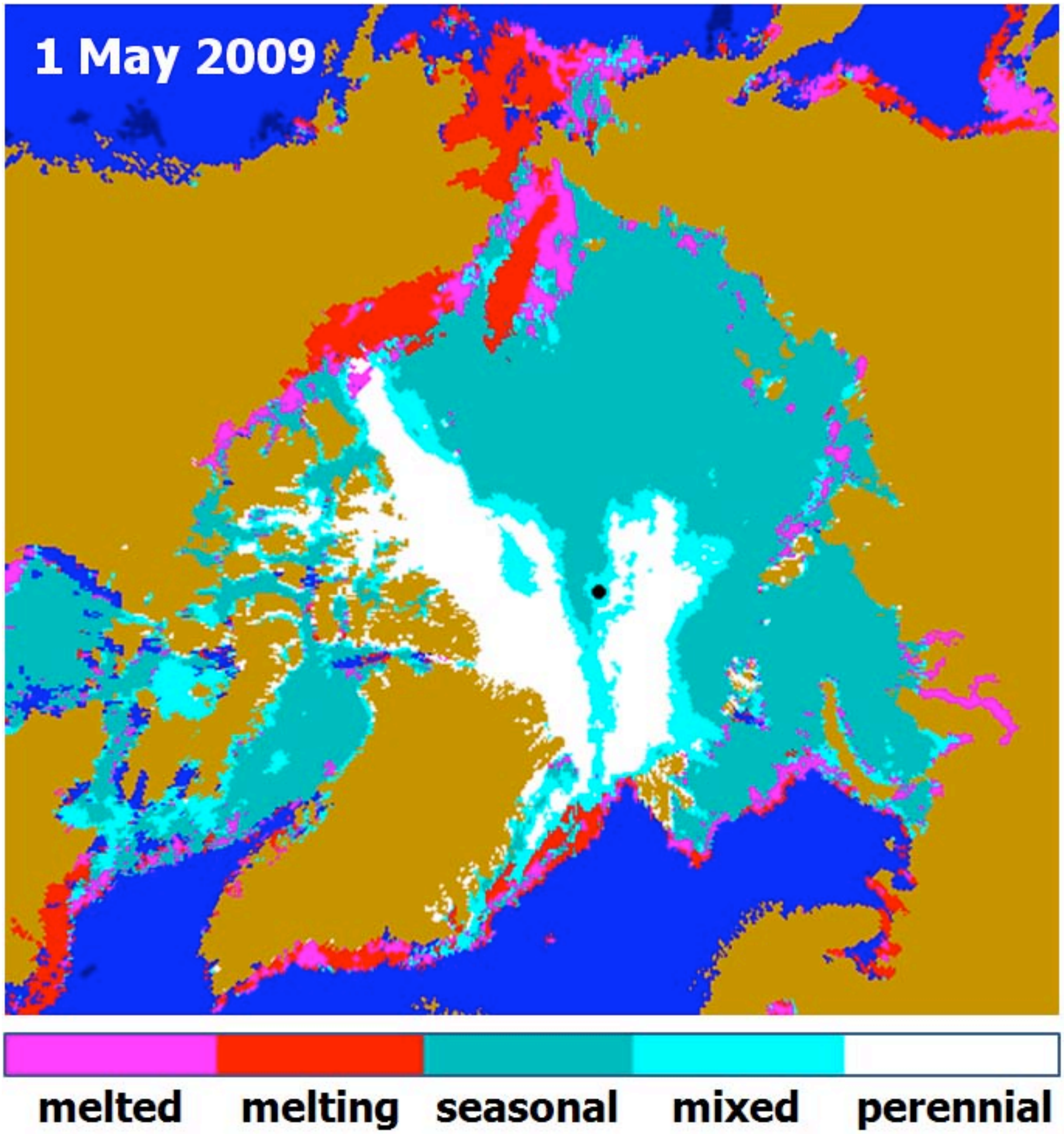

Figure 1. Arctic sea ice distribution for perennial ice (white), mixed ice (aqua), seasonal ice (teal), ice with current melting surface (red), and ice with melted surface within the previous ten days (magenta). Blue is for open water and brown for land. The extent of perennial ice was about the same on 1 May 2009 and 1 May 2008, while there is more second year ice in 2009 due to more ice survived summer 2008. Springtime perennial ice extent was the lowest in 2008 as observed by QuikSCAT data in the decade of 2000s and by the buoy-based estimates in the last half century. In winter and spring, not only the rapid reduction rate but also the temporal characteristics are similar in this year and in 2007 when the drastic decrease of perennial ice preconditioned the record low of the total ice extent in summer 2007. Extensive areas of melt occurred on 1 May (red) as well as early melt in April (magenta) leading to lower ice albedo and more solar heat absorption.

Sea-ice Outlook for Summer 2009

An T. Nguyen, Ronald Kwok, Dimitris Menemenlis
JPL/Caltech

1 Extent Projection

Our first guess of the September monthly mean Arctic sea-ice extent is 4.9 ± 0.5 millions km^2.

2 Methods / Techniques

The 2009 sea-ice extent is estimated using a Pan-Arctic configuration of the Massachusetts Institute of Technology general circulation model (MITgcm) and atmospheric surface boundary conditions from the Japanese 25-year Reanalysis Project (JRA-25) [Onogi et al., 2007]. The model has 18km horizontal grid spacing and 50 vertical levels. The K-Profile Parameterization (KPP) scheme is used for vertical mixing [Large et al., 1994]. Lateral boundary conditions are monthly and are taken from the Estimating the Circulation and Climate of the Ocean, Phase 2 (ECCO2) global optimized solution (http://ecco2.jpl.nasa.gov, [Menemenlis et al., 2008]). Initial hydrographic conditions are from the World Ocean Atlas 2005 [Antonov et al., 2006; Locarnini et al., 2006] starting in January 1992. Initial sea-ice condition is from Zhang and Rothrock [2003]. No climate restoring is used. The forward integration period is Jan 1992 to Feb 2009. On March 1, 2009, we re-initialize sea-ice thickness with preliminary thickness from ICESat [Kwok et al., in press] and then integrate the model forward until the end of the available JRA25 reanalysis (May 2009). For summer 2009, predictions are performed using JRA25 surface atmospheric conditions from 2006 to 2008.

3 Rationale

The 2006-2008 forcing period covers the extreme 2007 summer condition with anomalously clear sky and wind patterns, which resulted in a large retreat of the Arctic sea-ice cover [Drobot et al., 2008]. Thus, we use atmospheric conditions from the last three years (2006-2008) to estimate upper/lower bounds of the Arctic sea-ice extent.

Using preliminary mid-February-to-mid-March ICESat-derived thickness as initial sea-ice thickness conditions, our solutions for September monthly mean sea ice extent are either 4.4 millions km^2 for 2007 atmospheric conditions or 5.5 millions km^2 for 2006 and 2008 atmospheric conditions. Our first guess of the monthly mean sea-ice extent for September of 2009 is $4.9 \pm 0.5 \times 10^6 km^2$, that is, the median of these experiments and their spread.

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September 2009 Sea Ice Outlook: June Report

By: Oleg Pokrovsky

1. *A sea ice projection for the September monthly mean arctic sea ice extent (million square kilometers),* **4.6**

2-*The type of estimate:* heuristic, and statistical

3-*The physical rationale for the estimate.*

There is opinion among Russian scientists that anomaly low sea ice extent (SIE) in September 2007 was occurred primarily due to rare circulation atmospheric regime held on in summer

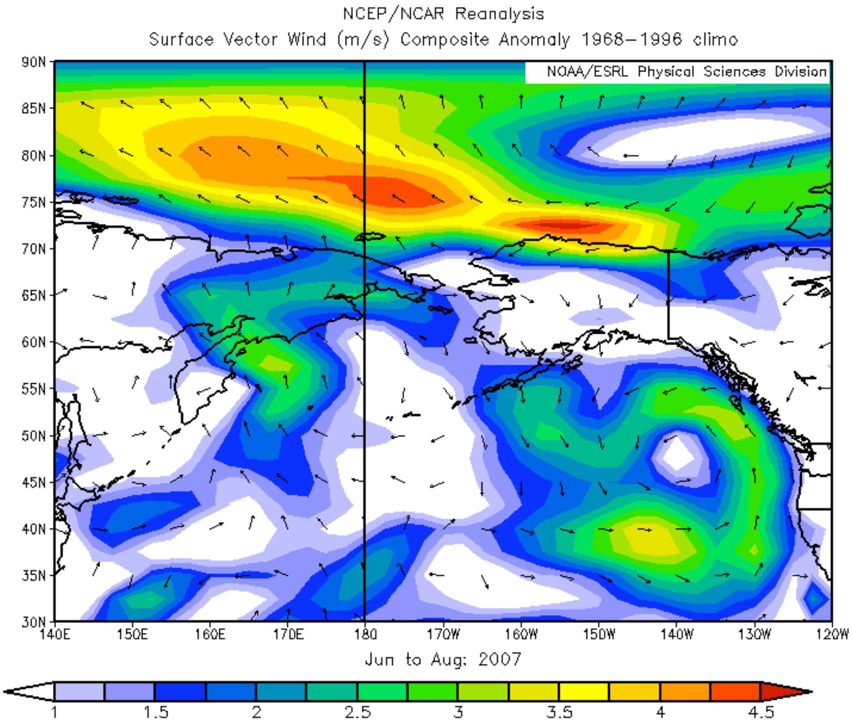

Figure 1. Surface vector wind field for summer 2007

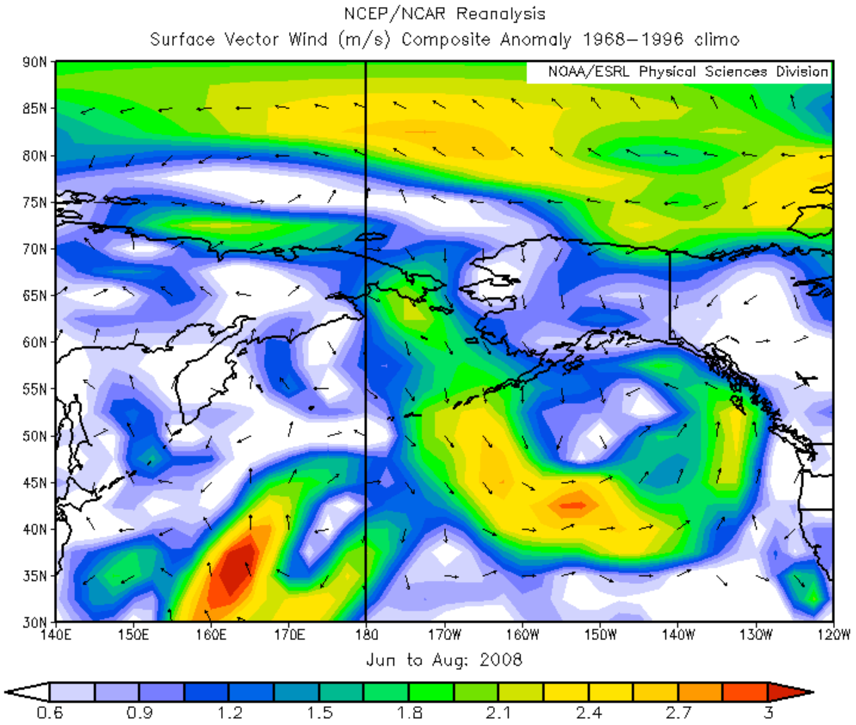

Figure 2. Surface vector wind field for summer 2008

(see fig.1). There is an opinion that extremely low Arctic sea ice extent (ASIE) magnitude was observed in 2007 due to strong eastward wind, which destroyed thin ice cover in Pacific (especially in Alaska and Canadian) sector of Arctic melted by warm air masses inflow from low latitudes. The wind field last (2008) year (fig.2) has been distinguished by strong north wind occurred in Siberia. As a result September ASIE in 2008 was partly recovered with account to 2007.

Wind field anomalies are generated partly by SST occurred in previous months. Our main attention should be drawn to North Pacific (NP) area. Spring field of SST (fig.3) reveals negative anomaly in eastern part of NP and significant temperature contrast between the east and west parts. That led to generation of atmospheric high in eastern part of NP and rapid transport of warm air from south. The SST field in 2009 (fig.4) demonstrates quite opposite SST anomaly. That suggests a different regime of air circulation in summer months 2009. Thus the ASIE in Pacific sector is expected to be close to last year value.

The ASIE in Atlantic sector is regulated mainly by temperature of Atlantic inflow waters. Most important indicator is a temperature of Atlantic waters at 300 m core depth. Unfortunately, the SST is only available indicator to be used. Thus there is some uncertainty, based only on the SST fields. Nonetheless, the SST field is a valuable source of data to predict ASIE in western Arctic (I mean Nordic, Barents, and Kara seas). The difference between January-April SST fields 2009 and 2007 (fig.5) shows that this year Atlantic water inflow is much cooler than those in 2007. So, we expect that the ASIE value in this area will be higher 2007 magnitude.

April ASIE value is more close to those of 2008 and higher than those of 2007. Thus, we can expect that September ASIE value of 2009 will be close to those of 2008: **4.6**.

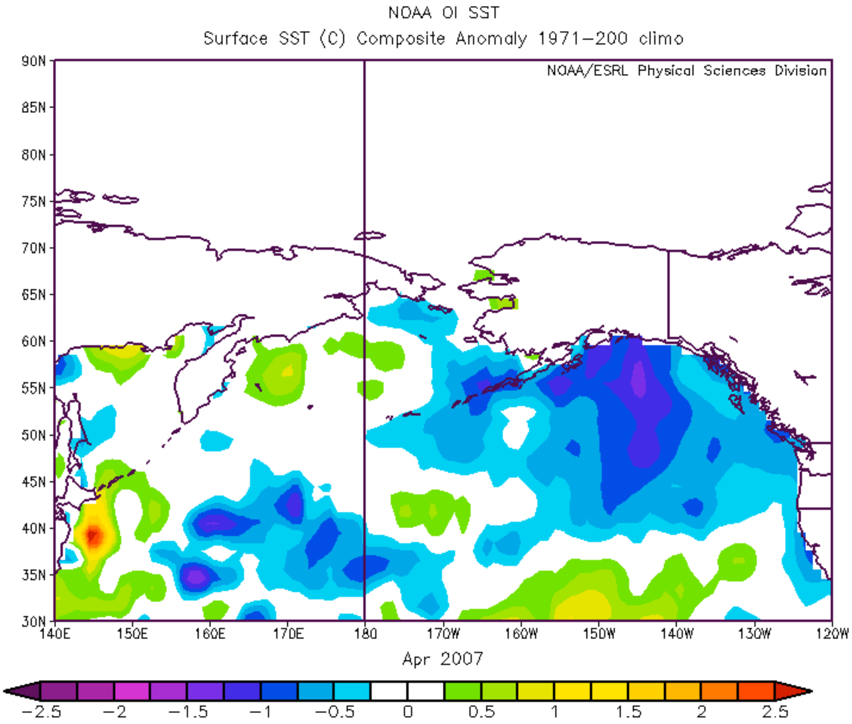

Figure 3. SST field anomaly in NP for April 2007

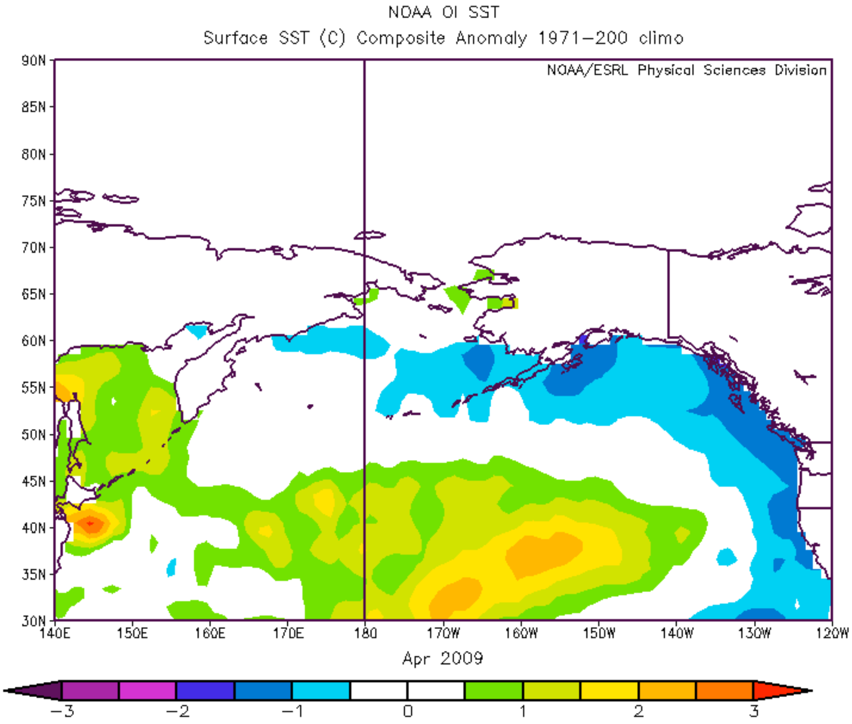

Figure 4. SST field anomaly in NP for April 2009

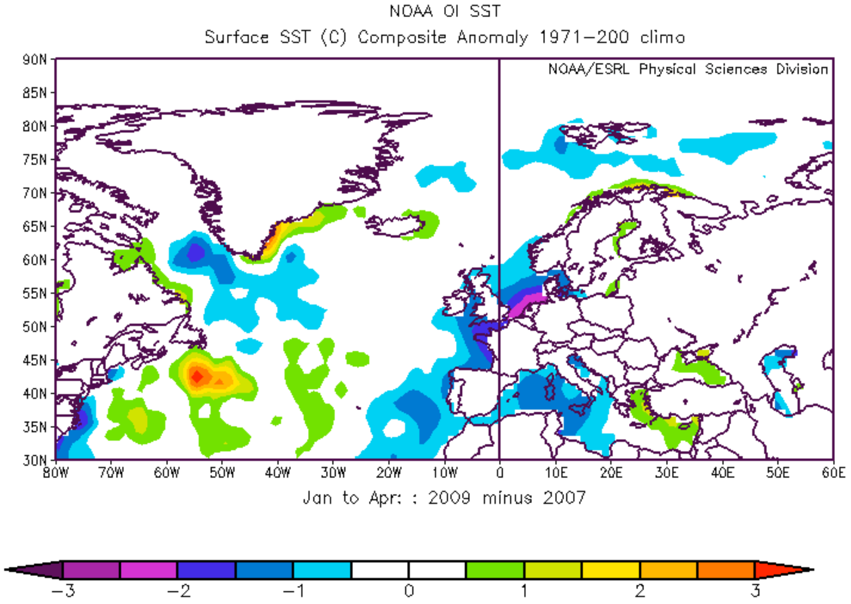

Figure 5. The difference between January-April SST fields 2009 and 2007.

September 2009 Sea Ice Outlook: June Report
By: Harry Stern

Sea ice extent: 4.67 million sq km.
Standard deviation: 0.42 million sq km.

Type of estimate:

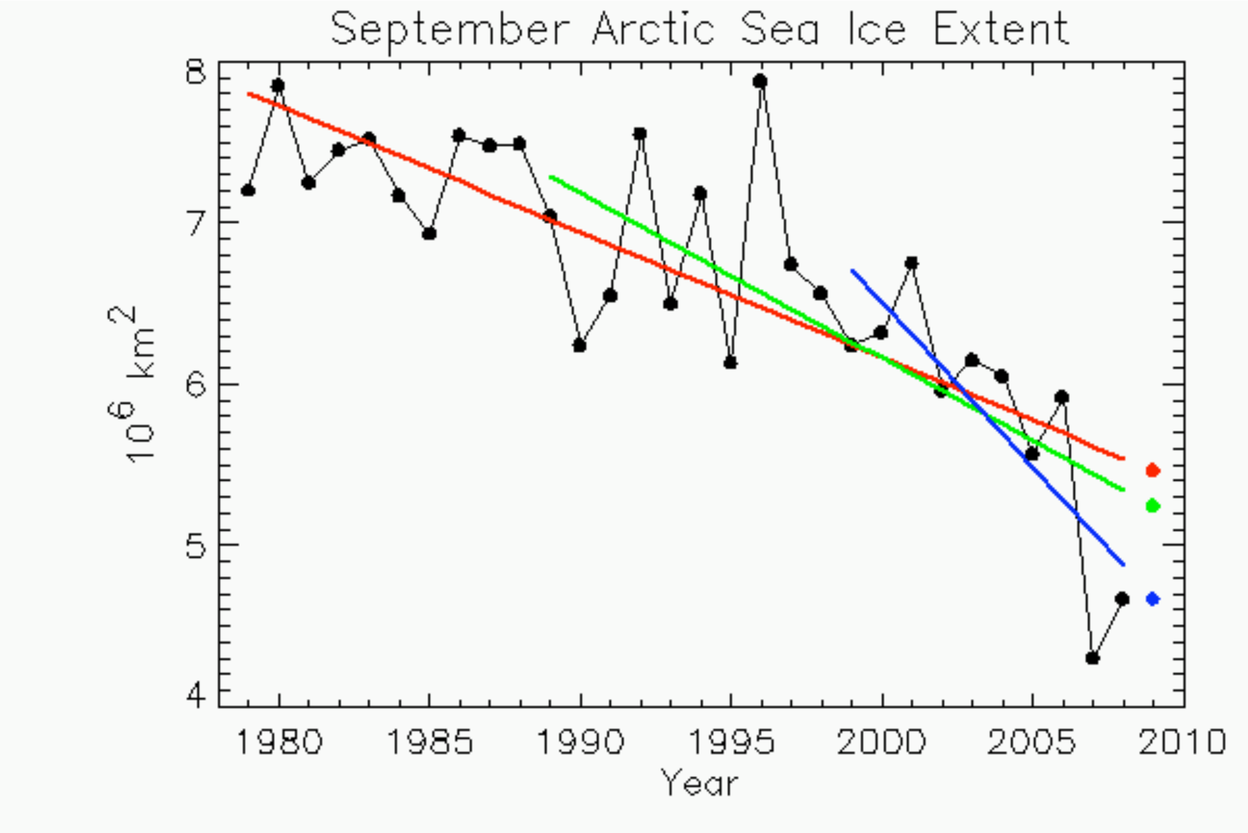

Figure 1: The red line is a linear least squares fit over the past 30 Septembers, 1979-2008, with a red dot indicating the projection for 2009. The green line is a fit over the past 20 Septembers, 1989-2008, with a green dot indicating the projection for 2009. The blue line is a fit over the past 10 Septembers, 1999-2008, with a blue dot indicating the projection for 2009.

My estimate for September 2009 is the blue dot, i.e. it is based on a linear least squares fit of the past 10 Septembers. The standard deviation of the residuals of the fit is 0.42 million sq km. The squared correlation (R^2) is 0.67.

Physical rationale for the estimate:
This is a purely statistical estimate with no physical factors contributing to it. I believe it's important to include in the Outlook a crude linear extrapolation that can serve as a benchmark against which to compare other, more sophisticated estimates.

Last year I also submitted an estimate based on a 10-year linear trend (1997-2006), purposely excluding 2007 because it appeared to be an extreme outlier. However, the sea ice extent in September 2008 turned out to be relatively close to that of 2007. Therefore I don't believe 2007 is an outlier, and I have included it in this year's linear fits.

Interestingly, the estimate of 4.67 million sq km, based on the 10-year linear trend, is exactly the same sea ice extent as observed in September 2008. In other words, the trend estimate is the same as simple persistence.

Finally, it is interesting to look at the 10-year trends of September sea ice extent for the three 10-year periods of sea ice observations during the satellite era:

Period	**Mean**	**Trend**	**R^2**
1979-1988	7.39	-0.0027	0.0010
1989-1998	6.84	+0.014	0.0053
1999-2008	5.79	-0.20	0.67

Table 1: The mean is in units of millions of sq km, the trend is millions of sq km per year, and R^2 is the squared correlation of the fit.

Within each of the first two decades there was virtually no trend, although the mean did decrease from the first decade to the second. In the third decade, the trend has been dramatic and significant.

September 2009 Sea Ice Outlook: June Report

By: Julienne Stroeve, Walt Meier, Mark Serreze, Ted Scambos

Extent Projection: 4.6 million sq-km
Method: Statistical, based on ice age survivability

Rationale

The ongoing transition from a spring ice pack characterized by a high percentage of old thick ice to one with younger and thinner ice is a key driver of the strong downward trend in September ice extent. This is because a thinner spring ice pack tends to be more fractured (more leads) and requires less energy to completely melt. Dark open water areas develop earlier in the melt season than they used to. These dark areas readily absorb solar energy, warming the upper ocean and promoting even more melt. .

However, as pointed out by many scientists, September ice extent in a given year is also strongly determined by summertime patterns of atmospheric circulation. As is now well known, the circulation during the summer 2007, featuring high pressure over the central Arctic Ocean and low pressure over Siberia, promoted especially strong summer melt, working in tandem with thin spring ice to yield a record low monthly September ice extent of 4.28 million sq-km. While the 2009 melt season started out more thin ice than observed in the last several decades, making it highly likely that ice extent in September will be well below average, whether or not a new record low is set depends critically on the circulation patterns that set up over the next few months.

One way to estimate the end-of-summer ice extent is to examine survival rates of ice of different ages in the Arctic. In the May 2008 blog entry at NSIDC's Arctic Sea Ice News and Analysis web site(http://nsidc.org/arcticseaicenews/2008/050508.html), survival rates of different ice age classes based on ice age data from (Maslanik et al., 2007) were used to estimate the 2008 September ice extent. This method predicted a new record low would be set in September 2008 since 73% of the Arctic basin was covered by first-year ice in spring 2008, of which typically 60% melts out each summer. However, this method did not account for the fact that at more northern latitudes it is likely that the survival rates will be higher.

Using the same method but breaking up the survivability analysis into 2 degree latitude bins would have given an estimate for September 2008 of 4.77 million sq-km, which was close to the observed value of 4.67 million sq-km.

For 2009 the same method predicts an average monthly mean September ice extent of 4.57 million sq-km (see Figure). Note however, that if survival rates from the last few years are used, the 2007 record minimum would be broken in 2009. The last several years have seen persistent summer high pressure patterns, a pressure pattern that is favorable for ice loss. If this pressure pattern were to continue again in 2009, it is possible a new record low would occur given the fact that the ice is even thinner, and, on average, younger this year than in the previous two years.

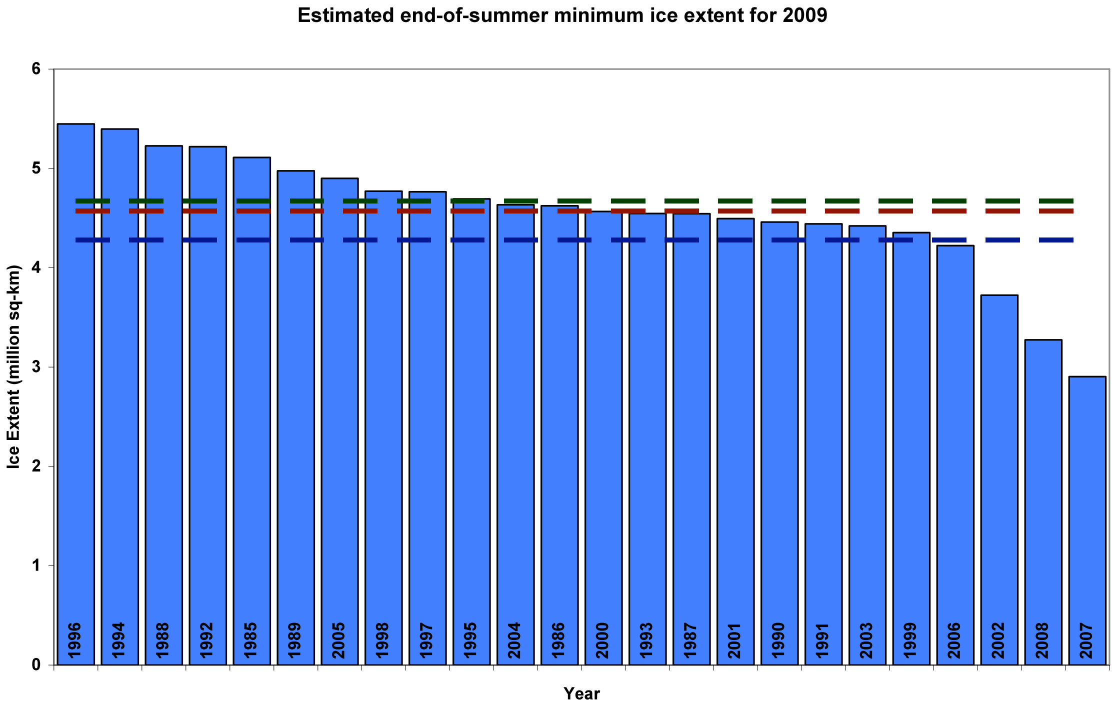

Figure 1. This bar plot shows estimates of monthly mean sea ice extent for September 2009 based on known ice survival rates derived at discrete 2 degree latitude bins. The blue dotted line indicates the record-breaking minimum extent of 2007; the green dotted line shows the minimum extent of 2008; and the red dotted line shows the mean estimate based on all years between 1983 and 2008.

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Outlook of 9/2009 Arctic sea ice from 6/1/2009

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The predicted September 2009 ice extent is **4.2 million square kilometers**. This is based on ensemble predictions starting on 6/1/2009. 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 2002 NCEP/NCAR forcing, member 2 uses 2003 forcing, …, and member 7 uses 2008 forcing. Each ensemble prediction starts with the same initial ice–ocean conditions on 5/1/2009. The initial ice-ocean conditions are obtained by a retrospective simulation that assimilates satellite ice concentration data. Of course, 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

See three figures below.

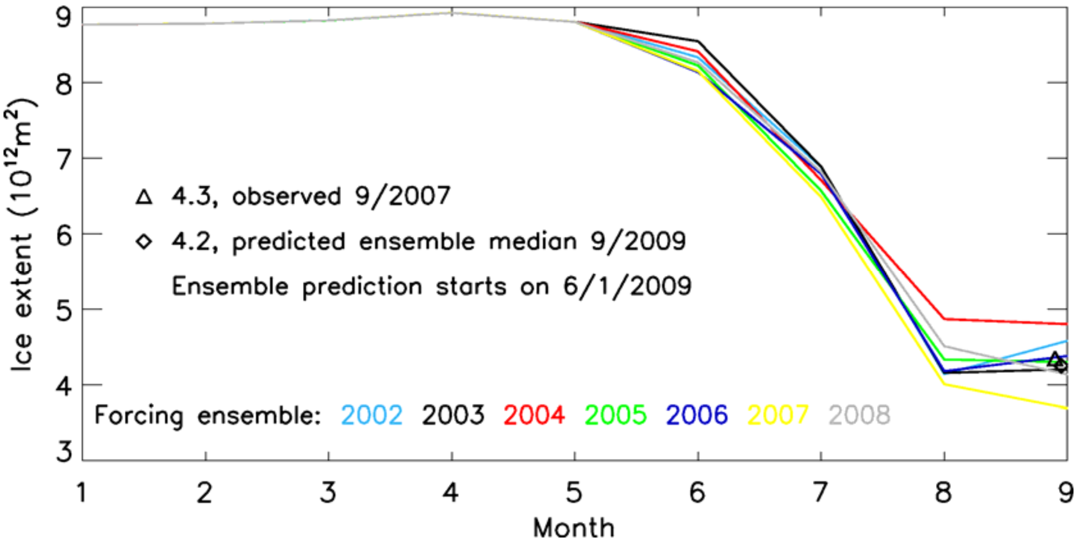

Figure 1. Monthly ice extent over January–September 2009 from seven ensemble members and their ensemble median for September 2009. Results for January–May are from the retrospective simulation and results for June–September are from the ensemble predictions (prediction range is 6/1 – 9/30/2009). The ensemble median is considered to have a 50% probability of occurrence and the ensemble median ice extent for September 2009 is 4.2 million square kilometers, slightly lower than that in September 2007 at 4.3 million square kilometers.

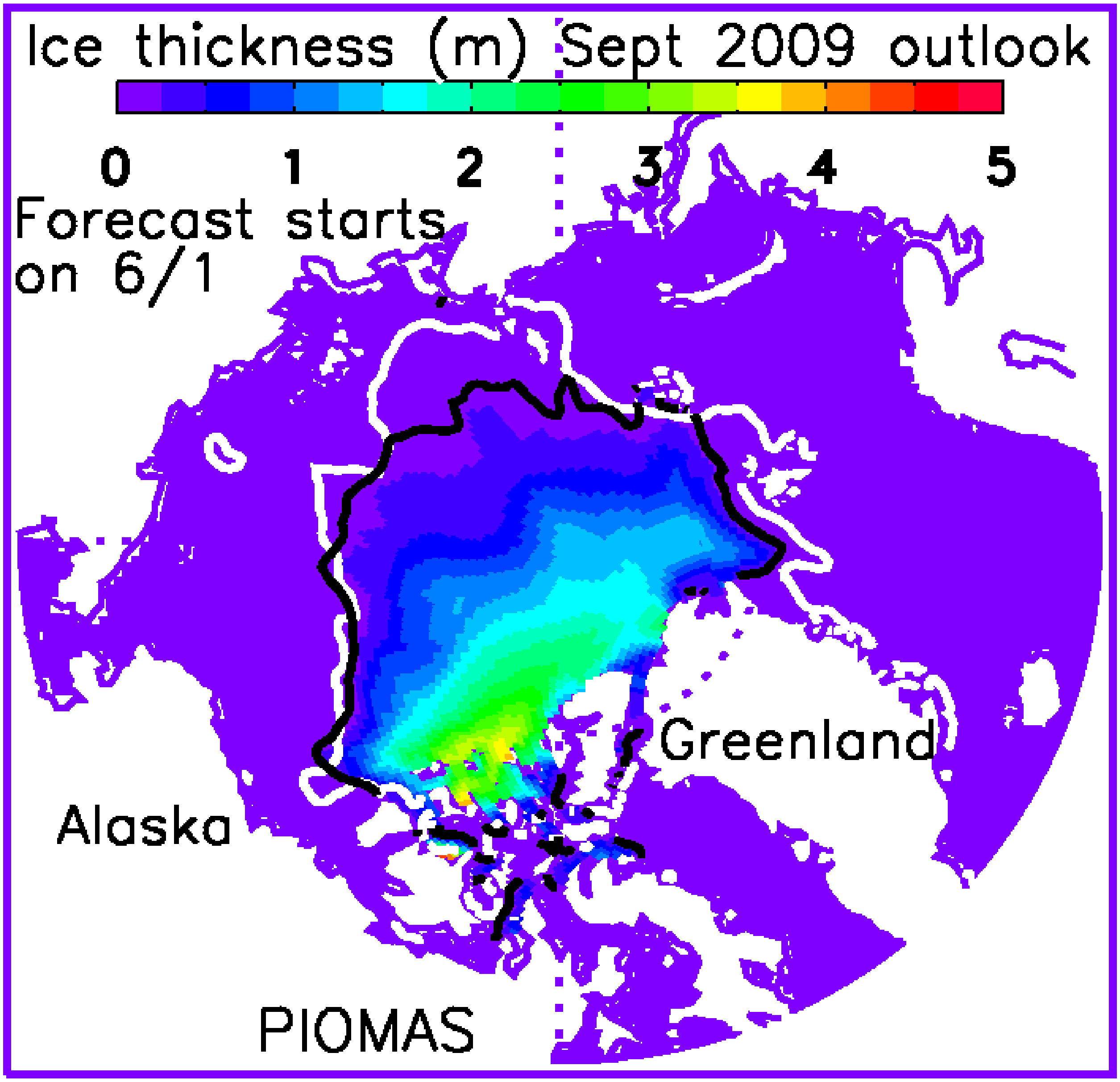

Figure 2. Ensemble prediction of September 2009 sea ice thickness. The white line represents satellite observed September 2008 ice edge defined as of 0.15 ice concentration, while the black line model predicted September 2009 ice edge.

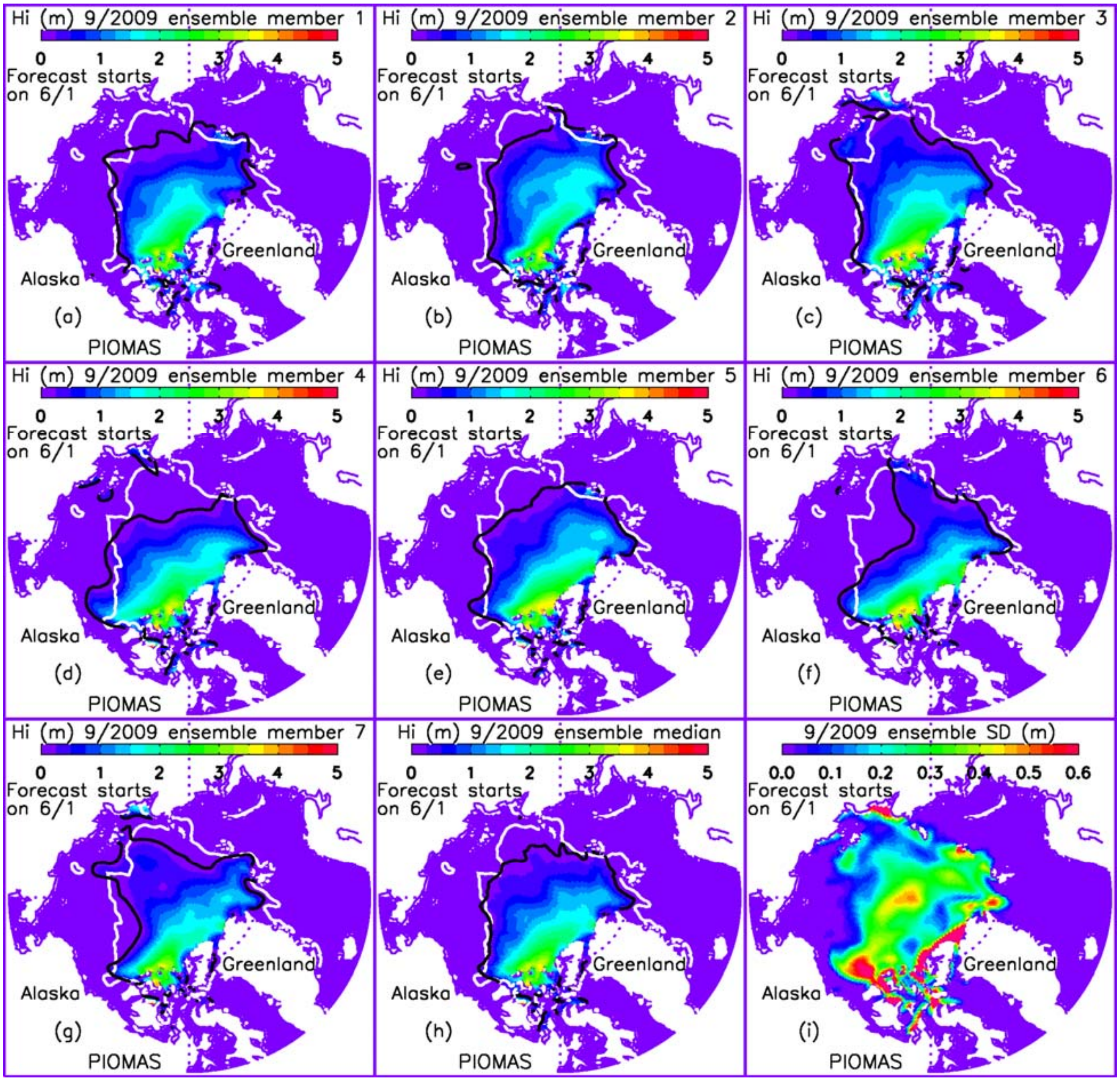

Figure 3. September 2009 sea ice thickness predicted by seven individual ensemble members, ensemble median ice thickness, and ensemble standard deviation (SD) of ice thickness. The spatial ensemble median ice thickness distribution (Figure 3h, the same as Figure 2) is most likely to occur in September 2009.