Community Submissions for 2008 Sea Ice Minimum Summary Report

10 October 2008

Table of Contents

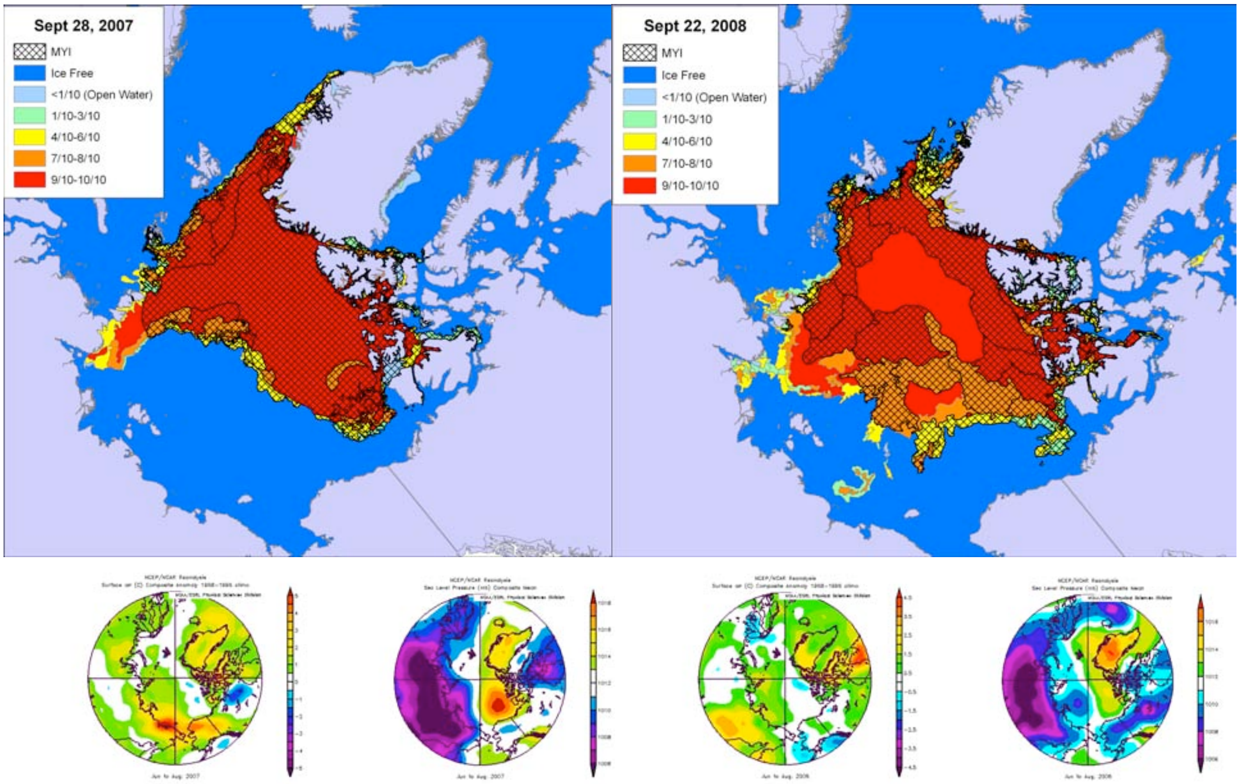
Todd Arbetter, S. Helfrich, Pablo Clemente-Colón, and Ignatius Rigor
National Ice Center
2008 Sea Ice Minimum Summary Report

The 2008 Arctic sea ice extent minimum did not surpass the record set in 2007, but did approach it, and 2008 is now the 2nd-lowest ice extent since NIC monitoring began in 1972 (4.598 million km^2 as of Sept 22, 2008). Because of the excessive melt and export in 2007, 2008 did see the lowest ever recorded extent of multiyear ice (3.226 million km^2). Because much of the ice in the Arctic was first-year ice, it was expected to melt more readily. In a typical year, most first-year ice does not survive the summer, while the multiyear, or perennial ice, remains intact. But 2008 was far from typical.

The summer of 2007 was characterized by a strong Siberian low and a Strong Beaufort Gyre (high), which set up a condition labeled the "Transpolar Express". Ice drift was strong from the East Siberian Sea across the North Pole and out Fram Strait into the Greenland Sea. Surface air temperatures were warmer than normal, especially in the Beaufort and Chukchi Seas, which contributed to the strong melt, particularly as ice concentrations decreased. Because of this, there was a sharp, well-defined ice edge by the end of the melt season.

In 2008, while the strong Siberian low persisted, the Beaufort Gyre was weakened. Transpolar drift was diminished, and less ice was exported through Fram Strait. Surface temperatures were closer to average. Lacking strong transport, most the the Arctic ice remained within the basin. In early July, the Beaufort Sea experienced a period of anomalously warm temperatures coupled with a strong low over the western Canadian Archipelago. This event cleared ice out of Amundsen Gulf and the southern Beaufort Sea. By August 21, the southern route of the Northwest Passage was open. An easterly wind along the northern Siberian coast, along with warmer than average temperatures, cleared ice from the coast and pushed it west toward the Taymyr Peninsula in the Laptev Sea. The ice pack remained consolidated here long after points east had cleared. It wasn't until September 5 that an open water path appeared allowing access from the Lapteve Sea to the Vilkitsky Strait and Kara Sea; this signified the opening of the Northern Sea Route. This was the first time both the Northwest Passage and Northern Sea Route were simultaneously open since ice charting began. Both routes were closed by September 22, 2008.

Summer 2008 is also notable by how much of the region was dominated by first year ice, and by how much of this survived the summer melt season. NIC analysts identify stage of development over the course of the winter according to WMO definitions. The stage of development is carried over the summer regardless of the actual thickness of the ice. Thus, much of the ice was classified as "thick first year ice" or "medium first year ice", although the actual thicknesses were decreasing due to melt. Typically, most of the first year ice does not survive the summer. But the central Arctic, which is usually 80-90% MYI, was mostly or totally FYI. The fact that the ice extent did stay above the all-time record low is due to weakened transport and average or lower temperatures over the Canadian side of the basin (where ice is typically thickest). Had a stronger Beaufort Gyre existed, more ice would have been transported out via Fram Strait. If the temperatures had been above average, there would have been more surface melt and heating of the ocean surface layer; this would have accelerated the melt rate of the ice.



Left: Sea ice conditions for September 28, 2008 (top), with 2007 June-July-August NCEP surface air temperature (SAT) anomalies (bottom left) and mean sea level pressure (bottom right).
Right: Sea ice conditions for September 15, 2007 (top), with 2008 June-July-August NCEP SAT anomalies (bottom left) and mean SLP (bottom right).

(NCEP images provided by the NOAA Earth Systems Research Laboratory, Boulder, Colorado, http://www/cdc.noaa.gov)

Hajo Eicken
2008 Sea Ice Minimum Summary Report

Alaska regional outlook
In the Alaska Arctic sector (Bering, Chukchi and Beaufort Sea), ice retreat in the summer of 2008 progressed somewhat less rapidly over the months of June and July than in 2007. In the absence of strong southerly flow, both melt and advective transport were not as pronounced, although ice retreat late in the season rivalled or exceeded that of 2007 in the Beaufort Sea. A key difference for local communities and marine mammals was the fact that ice lingered much longer in coastal regions and over the Chukchi shelf, allowing hunters access to walrus and seals, while in turn allowing walrus to feed off the ice platform. In 2007, in contrast, rapid ice retreat made for a very poor hunting season and forced walrus onto shore for lack of ice as the summer progressed.

A key factor in controlling ice retreat in this sector of the Arctic is advection of thick multiyear ice from the high Canadian Arctic into the southern Beaufort and Chukchi Sea. Despite the retreating summer ice edge, multiyear ice still makes it into these regions as a result of higher winter drift velocities. The greater thickness of this ice appears to significantly delay ice retreat relative to first-year ice. While our ice thickness data clearly show the importance of this advection of old ice for the ice mass budget, and while simple models of ice melt indicate its impact on delaying rates of ice retreat, what is needed is a more systematic way of integrating data on the thickness distribution of this ice into models that forecast regional ice conditions and their impact on ice ocean interaction. Certainly 2008 demonstrated that despite the preconditioning of 2007, high rates of advection still allowed for multiyear ice to persist in the Alaskan Arctic in early spring and summer. From a regional perspective, our comparison with ground-based observations by Iñupiat ice experts demonstrates that standard remote-sensing products used to assess ice extent on the pan-Arctic scale (passive microwave data) are not always useful in helping assess or predict the conditions at the local level. Pond formation and small floe sizes in dispersed ice (and coastal effects on the radiometer signal) contribute to substantial biases in the derived ice concentration data.

Jean-Claude Gascard
2008 Sea Ice Minimum Summary Report

Visual in situ Sea-Ice Observations taken during the Chinare 2008 expedition on board the Chinese icebreaker Xuelong (PRIC)
These observations occurred during the period extending from mid-August until early on September 2008 north of the Beaufort Sea (80 to 86°N and 135°W to 160°W approximately).

Most of the sea ice observations were taken during the Ice camp starting on August 22 and ending on August 29 located at about 85°N and 145°W in an area of strong drift (30 miles northwards in one week). During this whole period we received daily sea ice AMSR-E image processed by the University of Bremen and the Polar View consortium and were able to compare with the situation in the area surveyed by Xuelong during this period. Many observations were taken using EM31 hanging on portside of Xuelong during the whole cruise and also radiometers posted at an angle on portside like EM31 (cf Kazu report).

Thanks to AMSR-E images Xuelong was making good progress sailing northwards in a significantly less sea ice concentration area than the surroundings at the same latitude.

We also collected good information from IMBs (CRREL) deployed during the spring together with Met buoys and Acoustic Ice Tethered Platforms for Damocles. The main results being a/ that the region located north of the Beaufort Sea exhibited a strong drift towards the north (similar to the Xuelong drift already mentioned) and b/ a strong inhomogeneity in surface and bottom melt of sea ice both in time and space. However during that time bottom melt never exceeded 1m and never reached 2m like recorded in 2007 (Don Perovich).

One of the most fascinating observations from Xuelong concerned the melt ponds. In general melt ponds concentration was of the order of 5/10 but there were 2 kinds of melt ponds 1) mainly those characterized by blue turquoise water indicating sea ice bottom still trapping melted water above the ice and 2) those characterized by no bottom and filled up with sea water looking very dark compare with the other ponds. An interesting feature concerns the geometry of these dark holes (not ponds anymore in fact). A typical geometry appeared like an elongated shape of about 50 to 100m long and a more restricted width of about 10 to 2m. This resulted from the surface topography of sea ice before entering into the summer melt season. Of course passive microwave radiometers did not reach any resolution of that size but it would be interesting to see how the melt ponds evolution with black holes replacing the turquoise blue waters, might affect the backscattering signals captured by radiometers. In almost all cases the bottom of the melt ponds was reaching an ultimate stage of deterioration before disappearing by exhibiting this typical ice coral reef aspect quite noticeable when reaching the surface after being released and detached from the sides of the ponds naturally (buoyancy) or under the effect of the icebreaker when progressing into the sea ice. An important point to mention concerns the sea ice thickness that was very small (few tens of centimeters and less) over large areas indicated like solid ice by AMSR. No smart polar bears dared venturing into this region.

Although the past winter was significantly colder than the previous winter and more ice was formed and summer was not as long as the previous summer, it looks like the 2008 summer minimum sea ice extent would get pretty close to the previous minimum reached last year (septemnber 2007) with some differences notably in the western Arctic (Chukchi and Beaufort Seas). There was much less ice in the Beaufort Sea and north of the Mackenzie sector of the Arctic compare with last year. For most of the summer there was a persistent tongue of ice in the Chukchi Sea (north of Wrangel island) that finally disappeared at a later stage. Both north-west and north-east passages opened at about the same time early on August.

Even if the 2008 summer sea ice minimum extent appeared to be slightly above the 2007 all time record minimum according to passive radiometers, it does not seems like the ice mass budget would be significantly different in 2008 compare with 2007. The lower sea ice concentration observed north of the Beaufort Sea in the area and explored during Chinare 2008 with Xuelong seems to have been preconditioned by a strong and persistent northwards sea ice drift that lasted for several months from spring (April 2008) when ice stations were deployed north of the Canadian polar station Eureka, to well into the summer. Very early in the season this whole area already exhibited a significantly lower sea ice concentration that accentuated throughout the summer season. There was a remarkable persistent and strong shear zone north of Eureka well documented by ice platforms deployed overthere during spring time for Damocles. It seems like sea ice drift speed is an important parameter related to sea ice summer minimum extent and that seems quite logical. Why is sea ice drifting so more rapidly to day than before?

Masahiro Hori
2008 Sea Ice Minimum Summary Report

This summer at least shortwave forcing by cloudiness anomaly is considered to be weak compared with the preconditioning in winter to spring. Summer cloudiness over the Arctic Ocean in 2008 was relatively high compared with the anomalous low cloudiness seen in 2007.

On the other hand, the fraction of multi-year ice was smaller in the spring of 2008 than in 2007. The latter thinning of sea ice seems to promote the unexpected melting of sea ice seen in this August to September.

Regarding the prediction, I have no idea, although spring condition must be one of important indicators for predicting summer melt.

By taking advantage of higher resolution images by "AMSR-E" and its successor "AMSR2" to be launched in around 2012, we would be able not only to monitor sea ice concentration but also to track summer sea ice motion more precisely, which might be useful for getting a better OUTLOOK in near future. JAXA's AMSR/-E web:
http://sharaku.eorc.jaxa.jp/AMSR/index_e.htm SIC monitor by IARC-JAXA:
http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=e

Stephen Howell and Claude Duguay

2008 Sea Ice Minimum Summary Report

Interdisciplinary Centre on Climate Change (IC^3)
University of Waterloo, 200 University Avenue West
Waterloo, Ontario, Canada N2L 3G1

Sea Ice within the Northwest Passage: What Happened in 2008?

The Western Parry Channel region of the Northwest Passage did not open this year because it was subject to import of multi-year ice (MYI) from the Queen Elizabeth Islands, predominately via Byam-Martin Channel. This was the fundamental difference between 2007 and 2008.

Pre-conditioning is very important because MYI within this region is cyclical in nature. When this region is dominated by MYI that experiences a slower (sometimes not at all) breakup, this limits the drift of MYI from the QEI into the region. However, when the region contains seasonal first-year ice (FYI) that completely breaks up, this provides an area of open water where MYI then drifts into. This process gradually “fills up” this region of the Northwest Passage with MYI over a period of 3-5 years, only to subsequently re-initialize. In 2007, this region contained appreciable amounts of MYI at the start of the melt season restricting the flow of MYI from the QEI. When warm August temperatures rapidly removed the MYI in 2007, import did occur, just later in the season (mid-September to October). In 2008, the region was predominately FYI which allowed MYI from the QEI to immediately enter the region during breakup. Considerable amounts of MYI have since been flushed into this region of the Northwest Passage which may make its clearing difficult in 2009. One facet that continued in 2008 however, was the lack of FYI surviving the melt season within the region.

Jennifer Hutchings
2008 Sea Ice Minimum Summary Report

Comments, in Retrospect, on the 2008 Arctic Summer Sea Ice Outlook


Example of ice observed at 83N and 150W, September 5th 2008. Photograph was taken by Alice Orlich.

2008 saw the lowest ever ice extent in the Beaufort Sea. Alice Orlich on the Louis S. St. Laurent, in July and August 2008, observed a heavily melted ice pack up to 83N along 150W (the furthest north the ship achieved this summer).

The preconditioning of the ice pack in the previous winter, and the 10 years prior, probably played a role in this event. The Beaufort ice pack has been getting younger, and therefore thinner, since the 1990s. A shift in the Beaufort Gyre, towards less recirculation of ice within the Arctic Basin is partly responsible for the younger pack in the southern and western Beaufort Sea.

At the start of summer I predicted that the ice was preconditioned for an exceptionally low end of summer ice extent. We saw that ice was retreating early from the regions close to Banks Island, which was the forbearer of a much reduced ice pack in this region. We anticipated that the northward transport of ice from the Beaufort during winter 2007-2008 would create a younger and therefore more vulnerable to melt ice pack in the Beaufort. As predicted, we did see an exceptionally low end of summer ice extent in the Beaufort. I did extend this prediction to the rest of the Arctic, as the ice drift patterns over the last 3 years have been anomalous, pushing ice towards the Canadian Archipelago and into the Transpolar Drift, and increasing the extent of young first, second and third year ice in the Siberian Arctic. It appears that this preconditioning was not so important for predicting the end of summer ice extent in the Siberian Arctic.

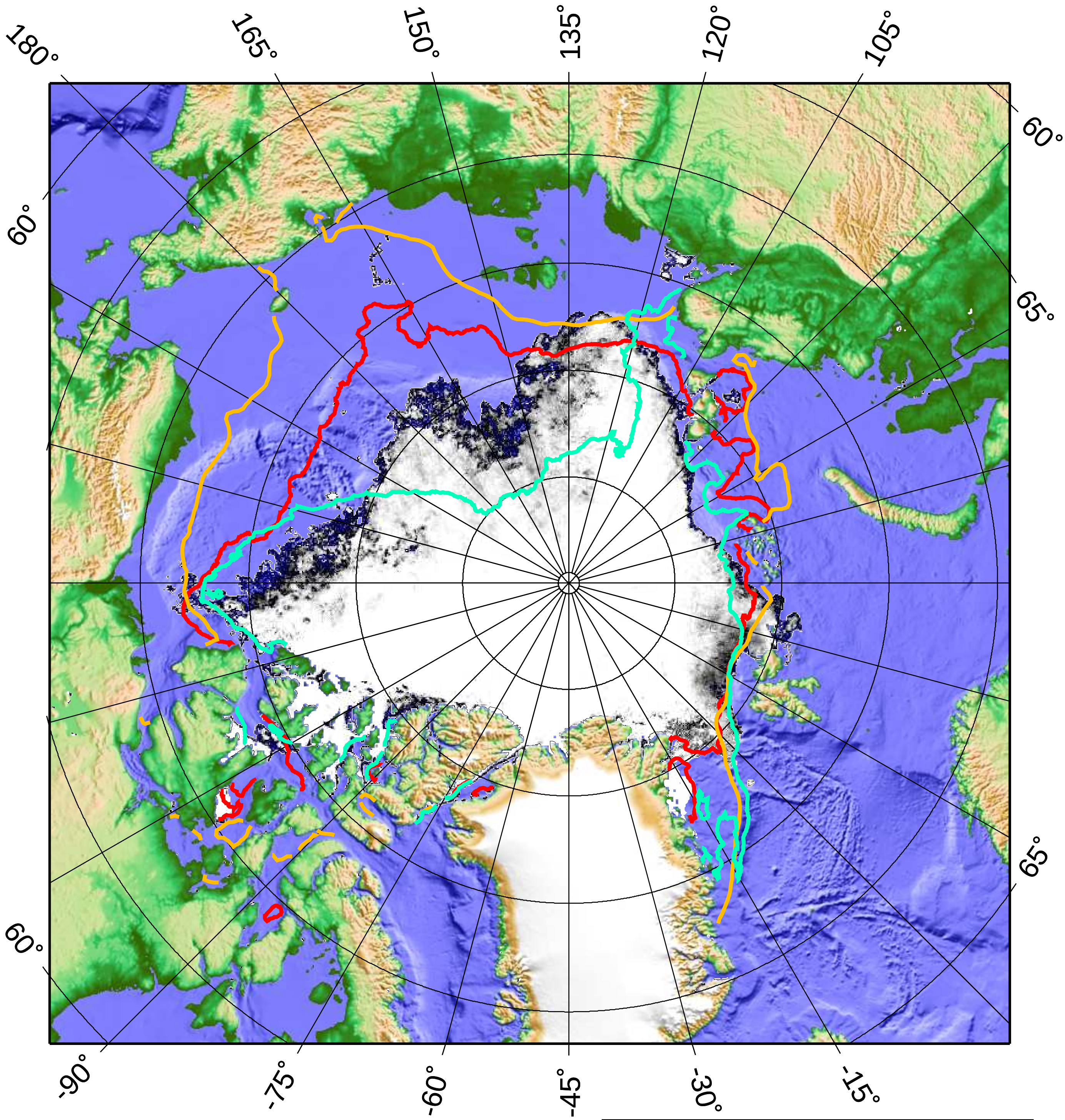
Although the winter (and previous summer) preconditioning of the ice pack in the Beaufort is important for predicting end of summer conditions, I would like to point out that extended weather forecasts during summer are important for predicting ice drift that may interfere with shipping. Northerly winds this summer pushed the eastern tongue of old ice into the south-eastern Beaufort. Such drifts of ice are an impediment to shipping in the region. In terms of the utility of an ice forecast for enhancing shipping operations, medium range (one to two weeks out) forecasts that employ numerical weather prediction models might be a good place to focus some effort.

Summer ice conditions in the Beaufort are clearly dependent on the decadal history of ice drift, deformation and summer melt in the region. Hence support of sea ice monitoring is imperative in the preparation of accurate summer forecasts. Satellite passive microwave does not provide information about the age and thickness of ice, so is not useful by itself in a monitoring system, or in analysis of the state of the Arctic ice pack. Ice drift must be monitored. Ice thickness information, either from satellite or in-situ observations is useful, though this should resolve the ice thickness distribution as the thinner ice melts out sooner and can accelerate summer melt. A goal for accurate summer forecasts should be an accurate map of ice type, age, thickness distribution and ridging at the end of winter. There are several tools that could be developed to provide this, though each has its limitations. Models require validation, and hence a supporting monitoring system. Blended data-modeling methodologies require data that resolves ice drift and type adequately. Building maps from observations requires skilled ice observers and a high density of data. Sea ice monitoring is the foundation of any forecast system. The monitoring system will be a blend of remote sensing, autonomous data stations (drifting buoys), in-situ, airborne and under-ice data.

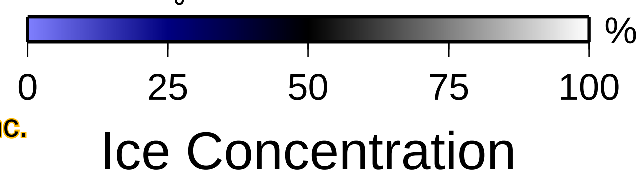
Lars Kaleschke
2008 Sea Ice Minimum Summary Report

The preconditioning—very likely, a thinner sea ice cover—was the reason for the false statistical prediction of the sea ice minimum. The last two years clearly fall out of the statistical cluster of the years before. The anomalous rapid retreat of the ice area in August could not be explained by the summer—nor by the wintertime atmospheric forcing. In September 2008, the sea ice area minimum was less than 5% larger than the September 2007 sea ice area minimum as derived from AMSR-E 89 GHz data. The absolute difference is so small that only a few days with different forcing could have put 2008 for another record. Passive microwave observations of the sea ice area are well validated and reliable. The largest uncertainties arise from the melted ice surface and research should be prompted in the investigation and quantification of this error source. The greatest unknown is sea ice thickness. More ice mass balance buoys should be deployed and extensive EM measurements should be conducted. The new satellite altimeter systems such as ICESAT and CRYOSAT offer the possibility of ice thickness measurement from space. The development of a fully coupled ocean-ice-atmosphere prediction system is a key issue for a better outlook and for climate predictions on a decadal time scale. The problem of the initialization is only one of the fundamental challenges towards such a system.

2008 Minimum Sea Ice Extent



AMSR-E ASI 2008-09-18



orange: Sep 1979-1983 SMMR Bootstrap 50% ice conc.

red: Sep 2002-2006 AMSR-E ASI 50% ice conc.

green: Sep 2007 AMSR-E ASI 50% ice conc.

Ronald Kwok
2008 Sea Ice Minimum Summary Report

Preconditioning and forcing of the summer ice cover:
1. This past winter and summer was cooler than the year before. In addition, even though the seasonal ice cover was formed later in the fall of 2007, the mean thickness of the seasonal ice cover at the end of March was comparable to that of the previous two seasons. This can be attributed to the shallower snow depth (only slightly more than half of previous year) leading to faster growth i.e., higher ice production. This allowed the seasonal ice to survive the summer of 2008. So we expect some replenishment of the multiyear ice area this summer.

2. Except for higher than average ice export (at the Fram Strait) in June, the rest of the summer had been about average, i.e., low. During June, the Transpolar drift was tilted towards the Beaufort Sea partially explaining the larger than normal retreat/melt of the ice edge north of the Alaskan Coast/Beaufort Sea. Again, ice advection plays a role in removing ice coverage, exposing more of the ocean to the input of heat from the atmosphere, and adding to the ice albedo feedback. The export through the Nares Strait was comparable to last year (i.e., higher than usual), which also served to remove thick ice from the Arctic Ocean.

Ronald Lindsay
Polar Science Center, Applied Physics Lab, University of Washington
2008 Sea Ice Minimum Summary Report

Recap of Predictions of September 2008 Arctic Sea Ice Extent
Our method uses estimates of ice thickness from a coupled ice-ocean model as predictors for a statistical forecast of the minimum ice extent in September. Fields of ice thickness (H), ice concentration (IC), area with less than 0.66 m thick ice (G1), and area with less than 1.94 m thick ice (G2) are the predictors considered in this forecast. The method is described in Lindsay et al (2008a). The model fields are collapsed to scalar time series by weighting each field with its correlation to the September ice extent (Drobot, 2006). A statistical model is then fit for the years 1987–2007. The performance of each predictor at each lead time is shown in Figure 1.

In retrospect the mean thickness H was the best predictor from almost all months but the error standard deviation of the prediction equation using H in past years was larger than for the G1 or G2 predictors. Ice concentration was a poor predictor in every month except August. The predictions from both G1 and G2 were correct to nearly within the error bars every month and one of the two was the best predictor each month. As might be expected, the area with less than 0.66 m of ice, G1, was the best predictor at shorter intervals, 1 to 3 months, while the area with less than 1.94 m of ice, G2, was better for longer intervals.

The main reason the ice extent was quite low in 2008 was that there were large areas of thin ice. Figure 2 shows the time series of each of the four predictors in March and August, along with the trend lines. There are two reasons why 2008 didn't quite match the ice record low extent of 2008: 1) thin ice was more extensive in the spring of 2007 than in 2008 and 2) the unusually persistent winds from the Pacific side of the basin that blew much of the ice to the opposite side in 2007 were absent in 2008. Note that, relative to the trend line, the March H, IC, G1, and G2 values all fully recovered during the winter from the extreme 2007 values.

As discussed in Lindsay et al (2008b) the linear trend accounts for much more of the variance of the mean ice thickness than for the variance of either the mean ice concentration or ice extent. The mean ice thickness in 2008 was nearer the linear trend line (1987–2007) than in 2007. So while the thickness in 2008 was the thinnest in the record except for 2007, it was quite consistent with the downward trend in the mean ice thickness in the basin over the last 21 years. The fact that 2008 sea ice extent did not establish another record minimum is thus consistent with our understanding that the 2007 sea ice record anomaly was established by a combination of long-term thinning and unusual wind patterns (Maslanik et al., 2007; Lindsay et al., 2008b; Zhang et al, 2008)

To improve predictions using a statistical approach such as the one we used would require a longer and more accurate record of the seasonal changes in the ice thickness distribution. Unfortunately that is only obtainable through models. New observations can't help much except for driving improvements in the models because they can't give a consistent record of the past behavior of the system. Perhaps a more problematic issue is that the statistical relationships between elements of the system are changing rapidly. Until a new stable regime is established and we can get an adequate number of sample years of this new regime, statistical methods of prediction will be limited in their accuracy. With nonstationary statistics the standard error of the fit over past years is not a good measure of the uncertainty in the prediction. Here the trend is our friend. It allows us to obtain some skill relative to climatology. The harder part is to predict the increasingly large deviations about the trend and to know when the trends are changing.

As the September ice extent and ice thickness decrease, they will be more subject to variable and unpredictable wind patterns earlier in the season, making the total ice extent more difficult to predict. More importantly, the summer ice extent in particular regions (where individuals can actually use the predictions for planning purposes) will be even harder to predict beyond what the trends suggest.

The 2008 observations reinforce our contention (Lindsay et al., 2008b) that the record minimum of 2007 was less just the damage left by a perfect storm of unusual winds, but more the result of a gradual erosion of the mean sea ice thickness over the past 20 years and the increasing abundance of thin young ice at the beginning of the melt season.

References

Drobot, S. D., J. A. Maslanik, and C. F. Fowler (2006), A long-range forecast of Arctic summer sea-ice minimum extent, *Geophys. Res. Lett*., 33, L10501, doi:10.1029/2006GL026216

Lindsay, R. W., J. Zhang, A. J. Schweiger, and M. A. Steele, 2008a: Seasonal predictions of ice extent in the Arctic Ocean*, J. Geophys. Res*., 113, C02023, doi:10.1029/2007JC004259.

Lindsay, R. W., J. Zhang, A. J. Schweiger, and M. A. Steele, and H. Stern, 2008b: Arctic sea ice retreat in 2007 follows thinning trend. *J. Clim*., in press.

Maslanik, J., C. Fowler, J. Stroeve, S. Drobot, J. Zwally, D. Yi, and W. Emery, 2007: A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss, *Geophys. Res. Lett.,* 34, L24501, doi:10.1029/2007GL032043.

Zhang, J., R. Lindsay, M. Steele, A. Schweiger, 2008: What Drove the Dramatic Retreat of Arctic Sea Ice During Summer 2007? *Geophys. Res. Lett*., 35, L11505, doi:10.1029/2008GL034005.

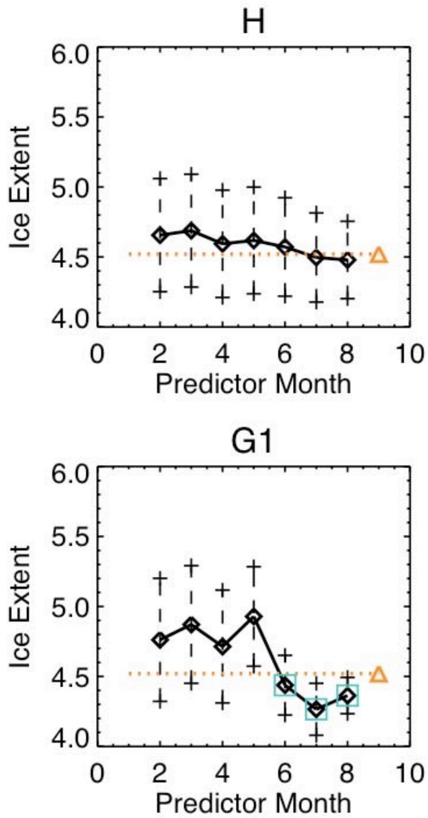


Figure 1. The performance of each predictor in 2008 in predicting the September minimum ice extent (in million sq km). The black lines show the prediction based on each of the four variables for each predictor month back to February. The dashed lines are the prediction uncertainties—the error standard deviations of the linear regression fit. The blue squares in the G1 and G2 plots show which variable of the four had the minimum prediction uncertainty in each month and hence the value chosen for the prediction at the end of each month. The orange triangle and dotted line is the observed minimum September ice extent (4.52 million sq km) from the NSIDC web site.

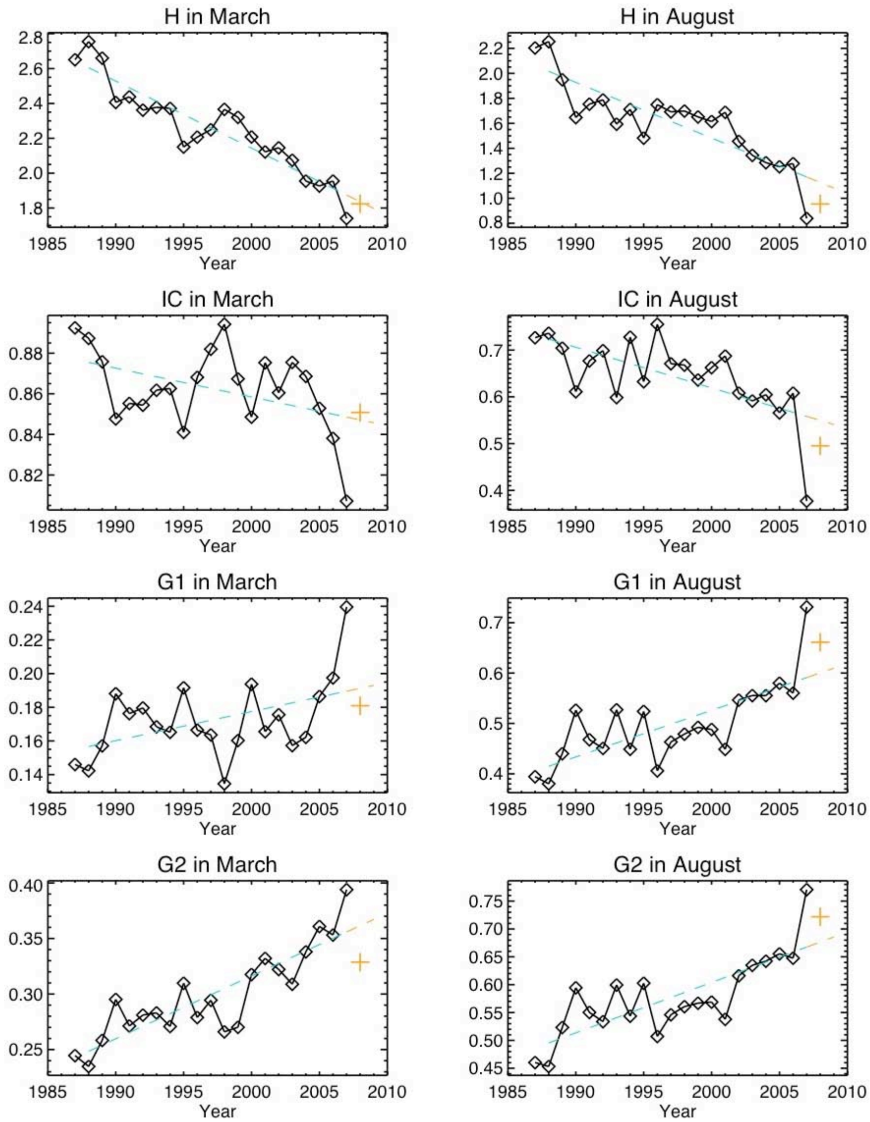


Figure 2. The simulated mean ice thickness H, ice concentration IC, area with less than 0.66 m thick ice, G1, and area with less than 1.94 m ice, G2, for the Arctic Ocean in March and August. The trend lines are computed for 1987–2007 and the extension of the trend is shown in orange along with the estimates for 2008 as an orange cross.

Jim Maslanik, Sheldon Drobot, Chuck Fowler
University of Colorado
2008 Sea Ice Minimum Summary Report

In our last estimate of minimum ice extent, we provided two estimates; one based on our probabilistic model and a second based on empirical analysis that combined a variety of information, past history and experience. The model yielded an estimate of 4.86 million sq. km. The empirical estimate was 4.4 million sq. km. The observed minimum turned out to be 4.52 sq. km. Our two methods of estimation thus bracketed the actual minimum quite closely.

How important was preconditioning versus anomalous meteorological forcing in giving the 2008 September minimum?
Our opinion is that preconditioning was the key factor driving the ice reduction this summer. As others have noted, atmospheric conditions through much of spring and summer favored the survival of ice. When conditions shifted to wind patterns more conducive to reductions in ice extent due to ice transport, we believe that preconditioning in the form of relatively thin first-year ice vs. multiyear ice that resulted in reduced ice concentration and weaker ice within the interior pack, facilitated reduction of ice extent.

How was 2008 different than 2007?
With the exception of conditions during late summer, atmospheric circulation and air temperatures (Figures 1 and 2) in 2007 was, as least subjectively, more favorable to ice loss than appears to have been the case in 2008. Spring and summer in both years showed a general dipole pressure pattern that has been linked to reduced ice extent in the Pacific sector of the Arctic. However, this pattern was stronger and more persistent in 2007, with the pattern persisting through late summer. Southerly winds in the Beaufort, Chukchi and East Siberian seas were more common in 2007, resulting in higher temperatures in the region and northward ice transport. In contrast, winds were weak and variable north of Alaska in late summer 2008, which helped ice to persist in that area longer than usual. The persistence of the well-defined high pressure area in the Beaufort Sea and Canada Basin in 2007 also resulted in unusually cloud-free conditions and thus more solar warming compared to 2008. The center of the high pressure area in 2008 produced strong east to west ice transport in the Beaufort Sea in 2008 rather than the more northward transport in 2008. Low pressure in the Siberian Arctic was shifted southward in 2008. Closed low pressure areas in the Laptev/East Siberian Sea areas produced southward drift of ice into the region compared to the cross-Arctic drift in 2007. Overall, the 2007 patterns also favored increased ice export through Fram Strait compared to 2008.

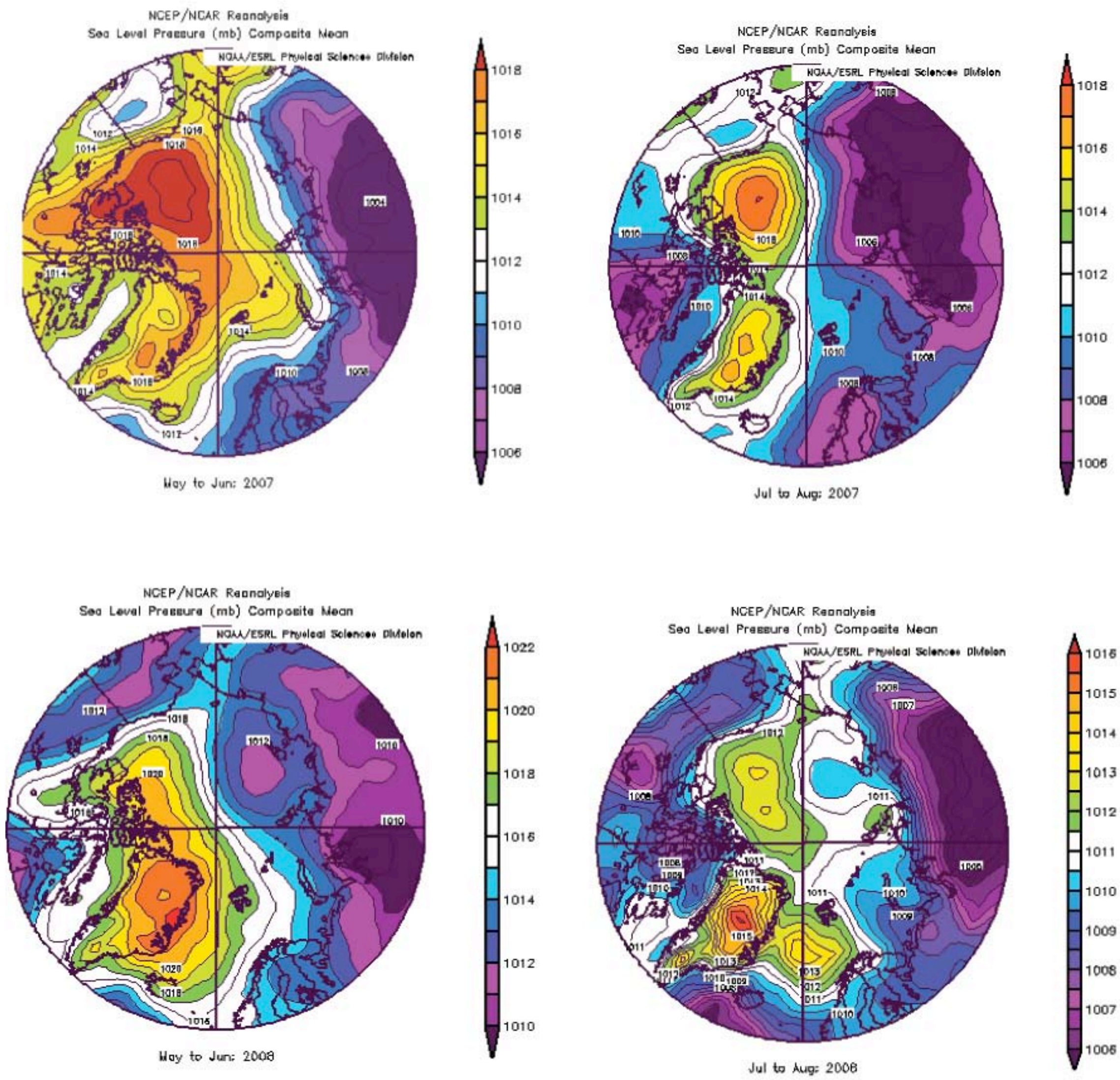


Figure 1. Mean sea level pressure for May-June and July-August 2007 (top) and 2008 (bottom).

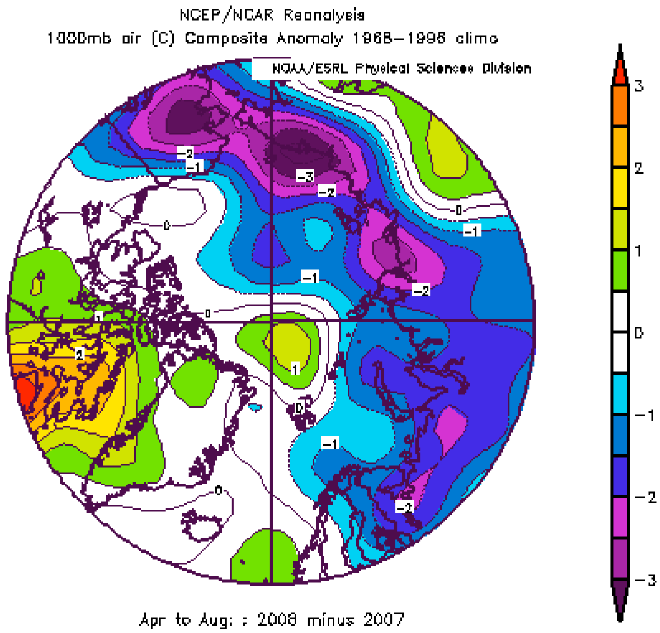


Figure 2. Mean surface air temperature for April – August 2008 minus April – August 2007.

If end of spring sea ice conditions were a major factor, does this give some skill in summer projections, even if the meteorological conditions cannot be predicted?

Yes. Our relatively accurate forecasts, which make use of ice age and ice type, demonstrate this.

What would be needed to provide a better OUTLOOK, e.g., improved passive microwave data interpretation, data assimilation in sea ice models, or ??

We think that the key parameters to improve the forecasts are ice thickness and snow depth, generated from observations and/or models.

Walt Meier, Mark Serreze, and Julienne Stroeve
NSIDC Analysis
2008 Sea Ice Minimum Summary Report

The summer 2008 melt season offered several surprises. As the melt season began, the Arctic was covered by a record areal-proportion of first-year ice. Since first-year ice, being rather thin, is more likely to melt out during summer than older and generally thicker ice, this suggested a very low, quite possibly another record, minimum extent.

However, as the melt season progressed into July, the seasonal decline did not accelerate as it had in 2007. This was primarily due to comparatively cooler conditions. Early July of 2007 saw the onset of persistent high atmospheric pressure (an anticyclone) over the Beaufort Sea and low pressure over eastern Siberia. This led to warm southerly winds north of Siberia. Clear skies under the anticyclone near the summer solstice contributed further to rapid melt. July of 2008 saw a different atmospheric pattern not as conducive to strong melt

By the end of July, the 2008 extent was well above that for 2007, though still far below normal. However, while August is generally a time when the decline rate begins to slow in response to decreasing solar radiation, this year the extent decline actually accelerated. The strong ice loss for August appears to have reflected the melt out of large regions of first-year ice, especially north of Siberia where a shift in atmospheric circulation led to fairly warm conditions.

The seasonal minimum of 4.52 million square km occurred on September 14. This is only about 9% higher than the value of 4.13 million square km that was measured on September 16 of 2007. However, in examining ice area – the extent weighted by concentration – the seasonal minimum in 2008 was nearly identical to that of 2007. Put differently, the 2008 melt season ended with a more dispersed (lower concentration) ice pack than in 2007. This appears to be at least partly due to differences in winds. Toward the end of the 2007 melt season, strong northward winds resulted in convergence of sea ice and a more tightly-knit ice pack. The ice motion late in the 2008 melt season was variable and did not result in strong convergence.

The 2008 melt season ended with a large amount of first-year ice remaining. This was due to cooler conditions, as well as the fact that so much first-year ice was found at far northern latitudes where, compared to lower latitudes, the surface receives less solar radiation over the summer season.

This first-year ice that has survived the summer will become second-year ice and will thicken through the winter. Depending on conditions through this winter and next summer, this thicker second-year ice could be more resilient and less likely to melt. This may result in a stabilization of the ice extent for a few years with summer minimums staying in the range of 4.0 to 4.5 million square kilometers. Much will depend on conditions through the winter and the following melt season. Regardless, with a growing radiative forcing, an eventual transition to ice-free summers seems inevitable.

Martin Miles
2008 Sea Ice Minimum Summary Report

The physics that appear to have played a role in the near-record minimum September sea ice this year are: The predominantly first-year ice that comprised the ice cover preconditioned it to be more vulnerable to melt through the summer, even in August when the major radiative/thermodynamic effects are generally less than in June and July; The atmospheric patterns were less conducive to melt and (apparently) ice export than in 2007, so a new record was averted. The preconditioning and the state of ice cover in spring is clearly useful for prediction, even if we can't predict the weather patterns. However, it appears that slightly more of this first-year ice managed to survive than would be predicted solely on survival rates based on previous years, so more can be done here.

Leif Toudal Pedersen, Gorm Dybkjær and Rasmus Tonboe
(Danish Meteorological Institute) DMI
2008 Sea Ice Minimum Summary Report

Preconditioning vs. weather
The main preconditioning considered in our outlook is the area of robust multiyear ice in spring (April-May), the thickness of the FY ice as determined by the number of freezing degree days during winter/spring and the winter/spring total ice extent at the time of issue of the outlook. In our regression we represent these parameters by multiyear ice area determined from QuickSCAT scatterometer data, North Pole freezing degree days and the winter or spring ice extent. The weather conditions during spring and summer are not part of our regression though we acknowledge that the summer weather is very important. We experimented with using e.g. the melt onset date which is important for the snow albedo and radiation balance as a proxy but found insufficient correlation. The uncertainty in the long term development of the Summer weather is a severe weakness in our model and explains why our predictions are only accurate when the summer has started and affected the early summer ice extent. Also, we do not consider long term trends in the ocean which may effect the heat flux from the ocean to the ice.

Multiyear ice is fairly robust to summer melt in the Arctic Ocean. However, during the last 6 years the area covered by multiyear ice has shrunk due to melt and export. During winter this lost multiyear ice has been replaced by thinner first-year ice. This means that the sea ice cover is more sensitive to weather forcing than it was before (>6 years ago). A warm summer like 2007 gives a significant reduction in sea ice extent while a later than normal melt onset date (e.g. a colder than normal summer) like the situation in 2008 results in some replenishment of the MY ice (survival of some of the FY-ice).

How did 2007 and 2008 differ?
- We had less multiyear ice in 2008 than 2007.
- The number of North Pole freezing degree days were larger in 2008 than 2007.
- The winter ice extent was larger in 2008 than in 2007.

Prediction skill
A smaller multiyear ice area in the Arctic Ocean means that the sea ice summer extent is more sensitive to weather conditions during summer. This makes it more difficult to predict using statistical regression analysis. In the spring 2008 it looked like another minimum extent record with very high retreat rates and our first prediction in May (3.66mill. km^2) and second in June (3.41mill. km^2) was below the 2007minimum. Our third prediction in July (4.46mill km^2) when the summer melt had started was about the same as last year and quite close to the actual 2008 extent (4.52mill km^2).

Needed for better outlook
Long range (seasonal) weather forecasts.
State of the ocean at the beginning of the Summer.

Oleg Pokrovsky
2008 Sea Ice Minimum Summary Report

Final Remarks on the Arctic ice extent outlook for September 2008

There two major impact factors and mechanisms:

- SST fields
- SLP and wind velocity forcing

When compare summer SST fields (fig.1,2) for 2007 and 2008 one can see that there were a more strong positive anomaly in 2008's North-Western Pacific SST and more strong negative one in 2007's North-Eastern Pacific SST. In contrast, the 2008's Nordic Seas was colder than 2007's field as well as all Russian margin Seas. As a result, in 2007 one can observe northward inflow of warm air to Eastern Arctic through Russian Far East area (fig.3), and in 2008 – similar inflow via high latitude domain of North America (fig.4). Thus the most free of ice areas at this September are located in Chukchi and Beaufort Seas, but in 2007 those were in Russian sector of Arctic. The Atlantic sector of Arctic was more ice covered as it was impacted by more cold incoming Atlantic water in 2008 with account to those for 2007. Lower SLP in summer 2007 was a causal of more intensive transport of warm Atlantic water in last year summer, which impact on more intensive ice melting in Kara and Barents Seas. That was a major motivation to predict a significant positive shift in Arctic ice extent for this September.

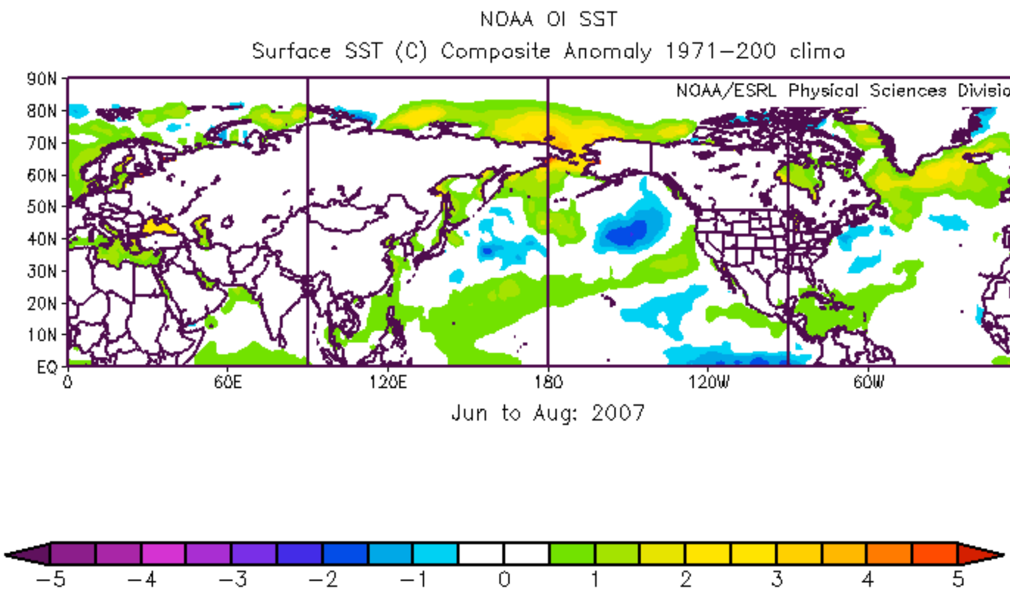


Figure 1. The SST anomaly field for summer 2007

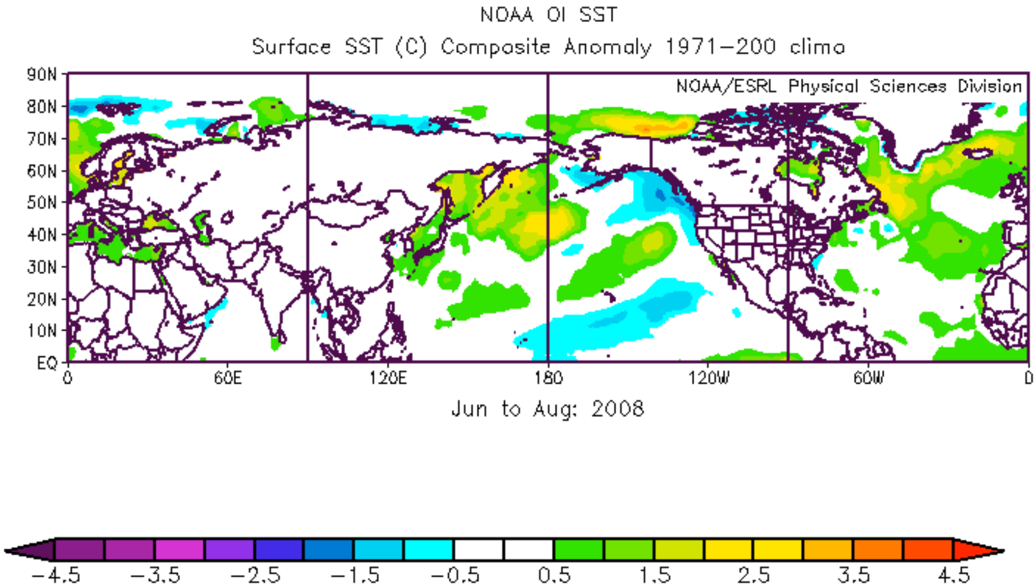


Figure 2. The SST anomaly field for summer 2007

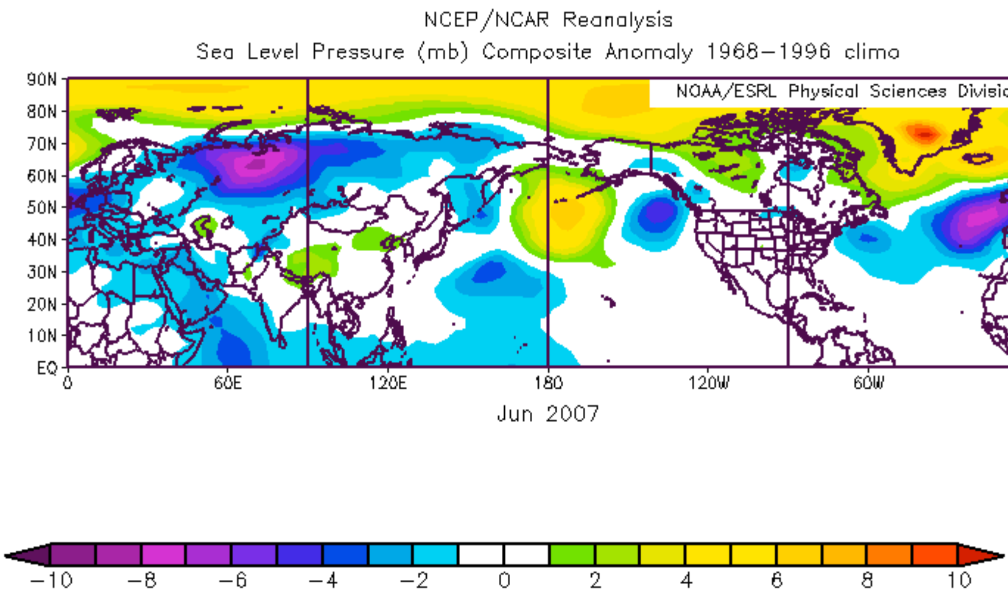


Figure 3. The SLP anomaly field for summer 2007

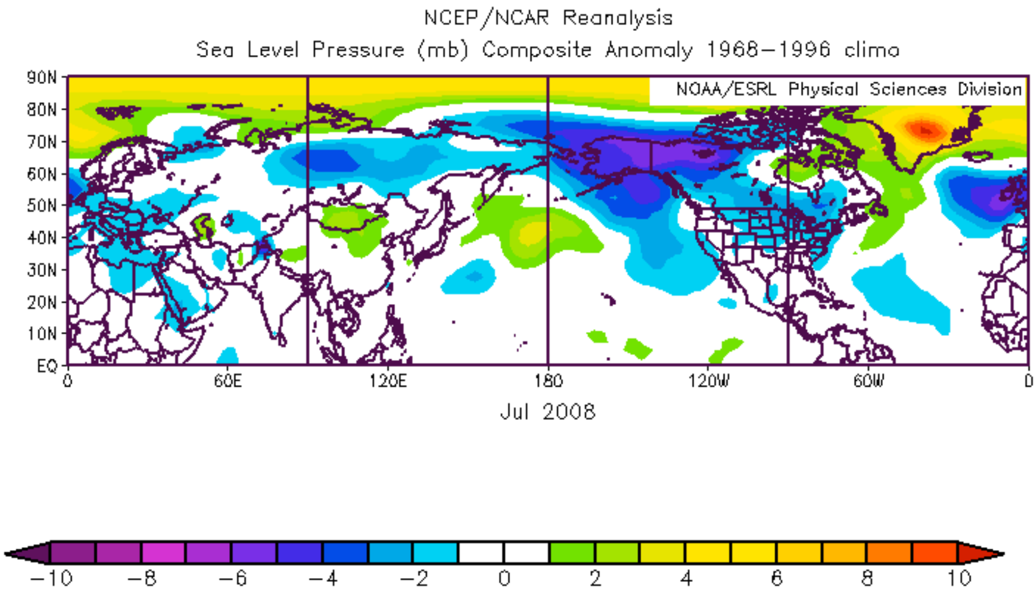
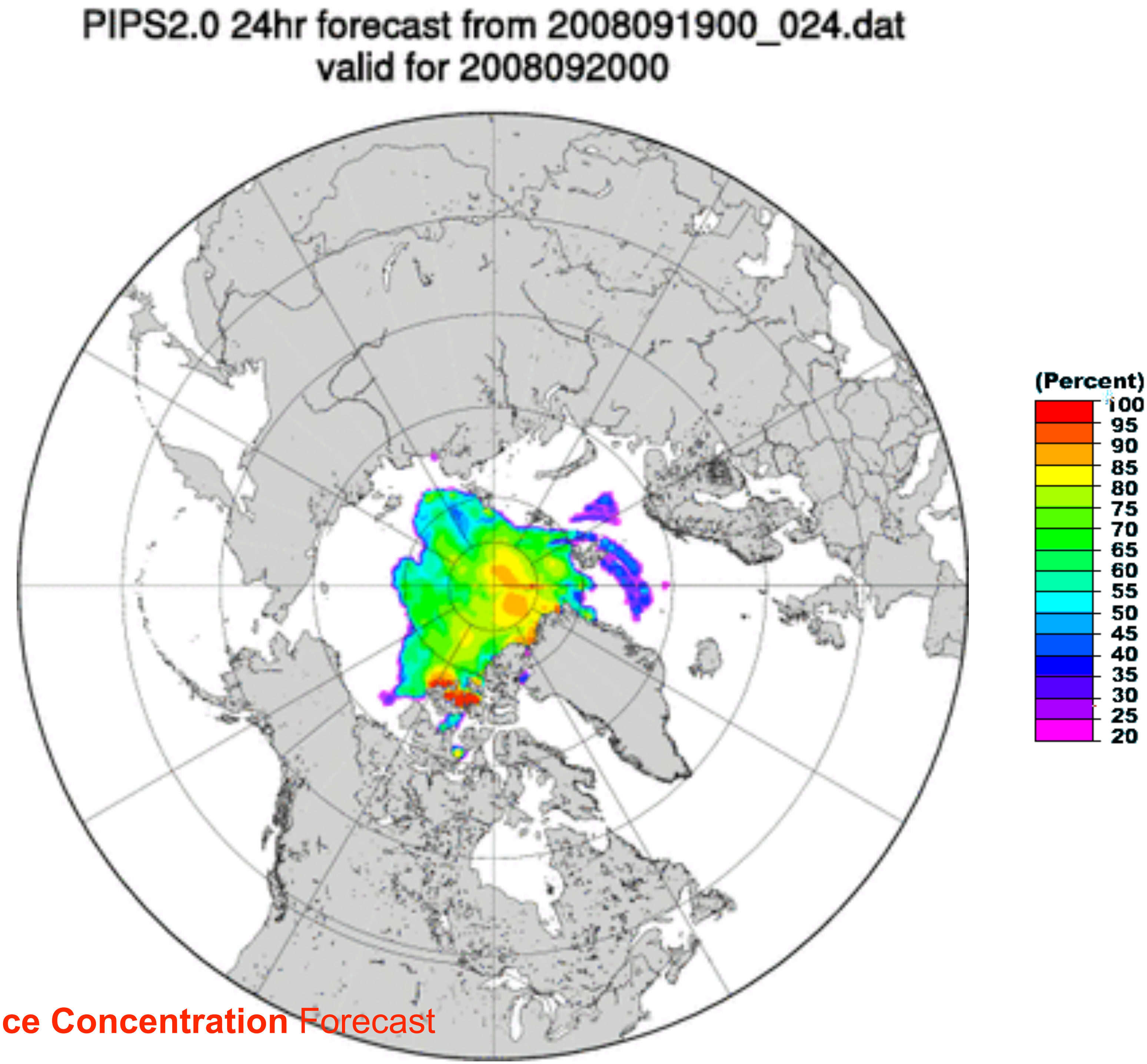


Figure 4. The SLP anomaly field for summer 2008

Simon Prinsenberg
2008 Sea Ice Minimum Summary Report

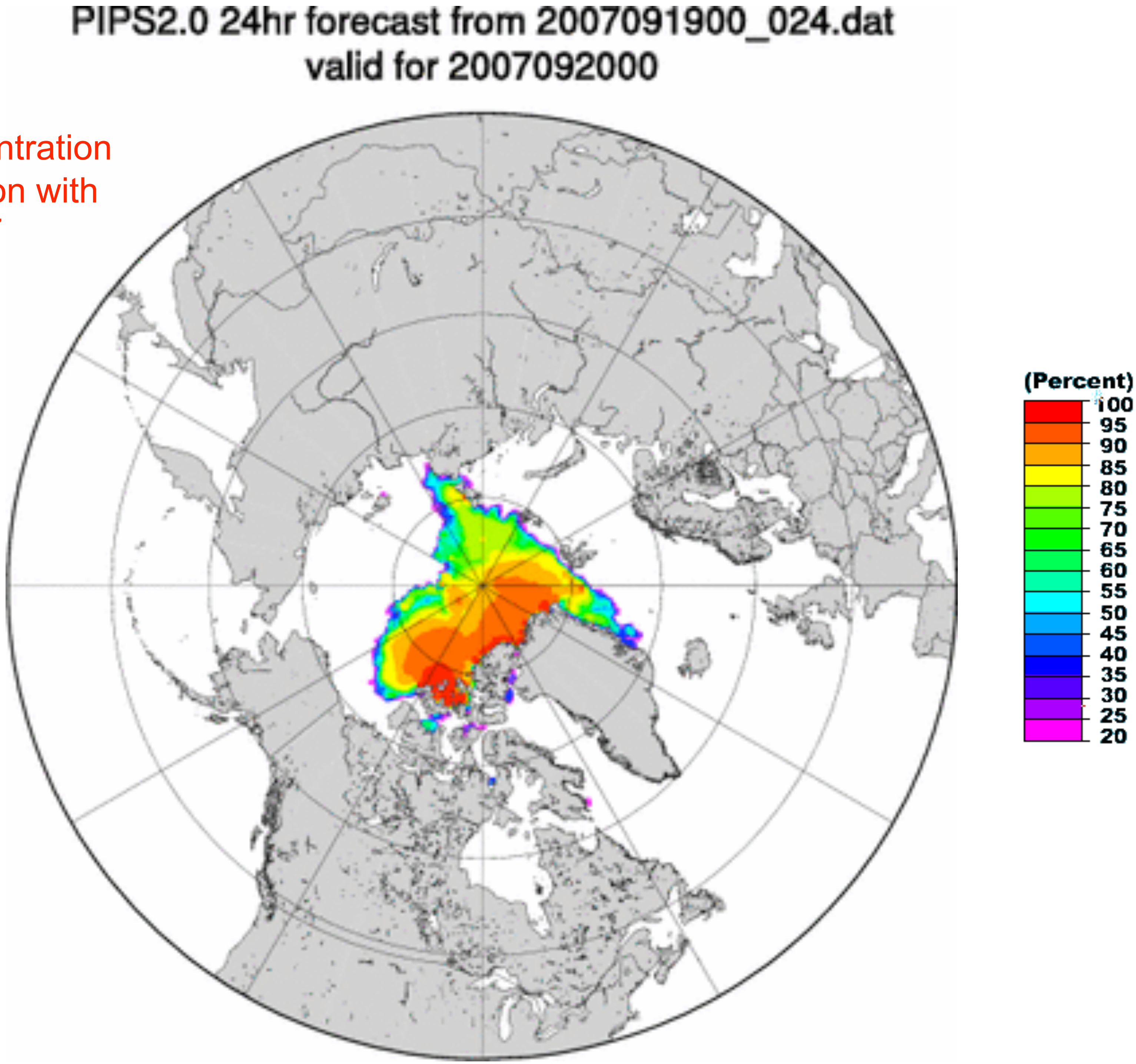
- The ice extent does not tell the complete story of sea ice loss; in 2008 we lost more Arctic ice in total and more of the thicker ice beyond 2007. Most of the ice shelf along the northern coast of the Canadian Arctic Archipelago is gone.

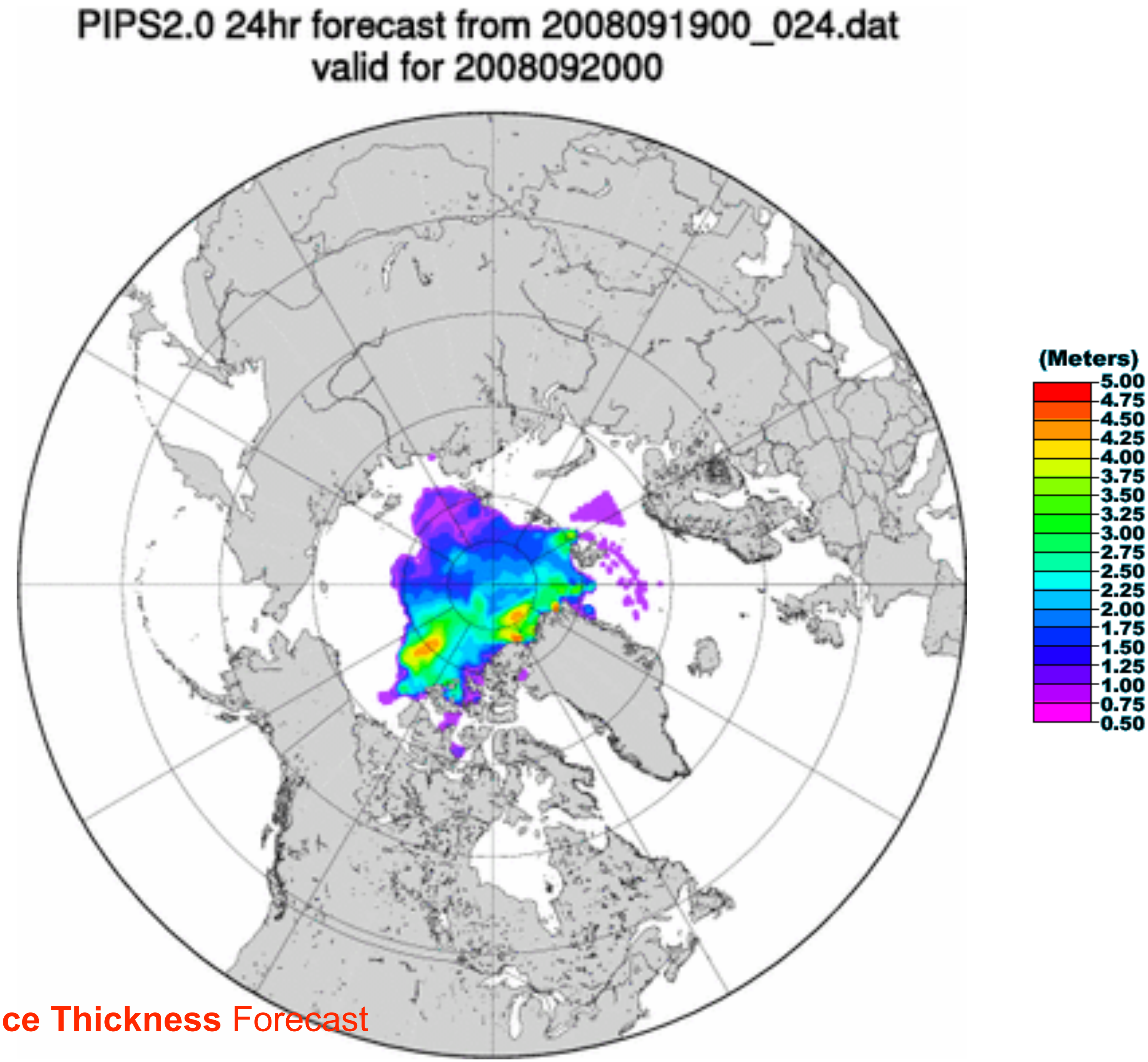
Ice debriefing sub-slides of CCG ice debriefing September 2007, Icebreaking Program Canadian Coast Guard by Andy.Maillet@dfo-mpo.gc.ca



Tomorrow's **Ice Concentration** Forecast

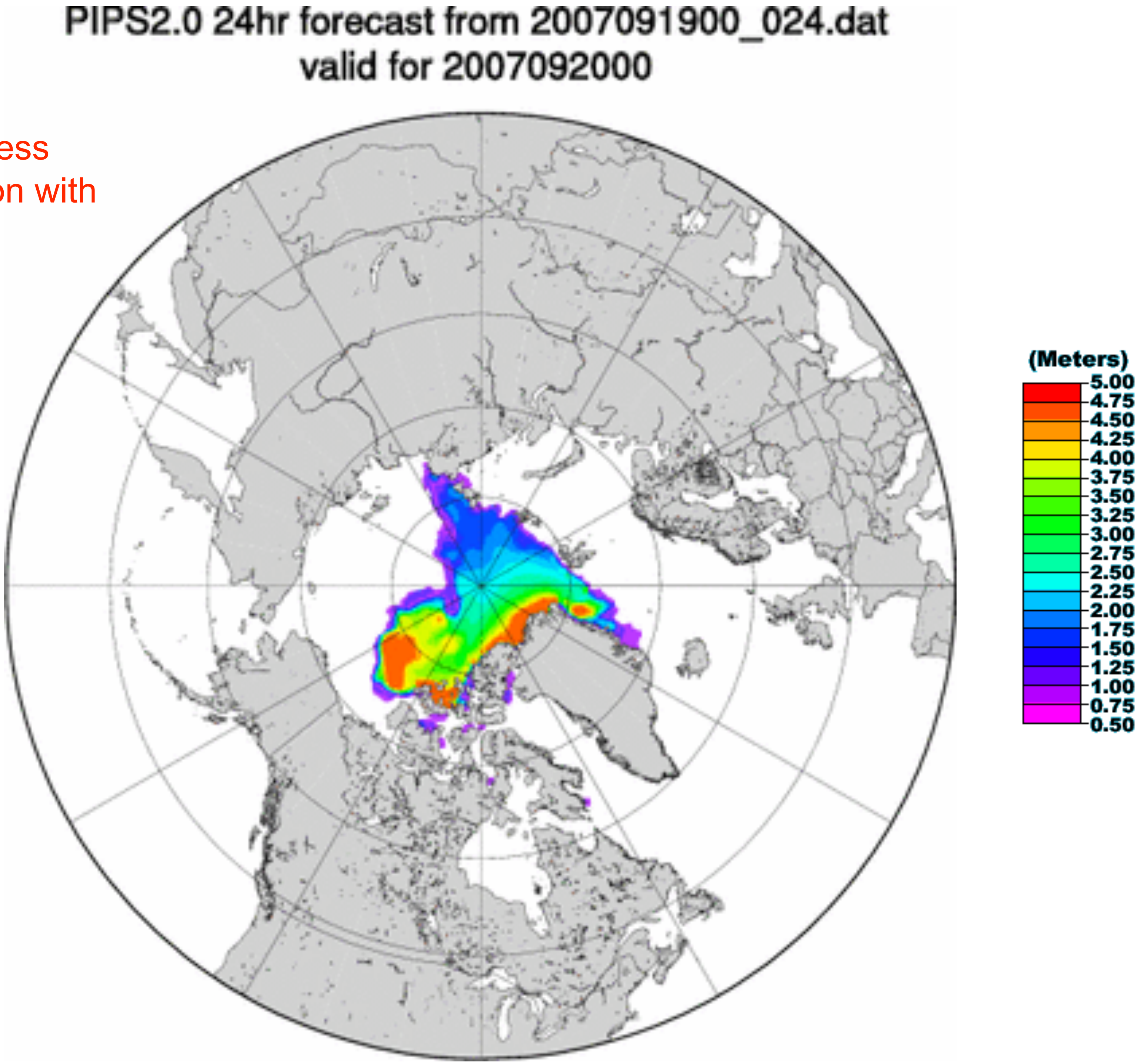
Ice Concentration Comparison with 2007





Tomorrow's **Ice Thickness** Forecast

Ice Thickness Comparison with 2007



Ignatius G. Rigor[1,2], Pablo Clemente-Colón[3], Son V. Nghiem[4], James Brinkley[3], and Todd Arbetter[3]

2008 Sea Ice Minimum Summary Report

[1] *Polar Science Center, Applied Physics Laboratory, University of Washington*
[2] *NOAA/UW Joint Institute for the Study of the Atmosphere and Ocean (JISAO)*
[3] *Naval/National Ice Center*
[4] *Jet Propulsion Laboratory, California Institute of Technology*

Recap of Summer 2008 Outlook: How important was preconditioning versus anomalous meteorological forcing in giving the 2008 September minimum? If end of spring sea ice conditions were a major factor, does this give some skill in summer projections, even if the meteorological conditions cannot be predicted? How was 2008 different than 2007?

Our outlook emphasized the importance of preconditioning in making a summer outlook, i.e., spatial distribution of ice thickness (or age of ice as a proxy for thickness). We expected an extensive retreat of sea ice this summer given that we had more FY ice in the Spring than ever observed, and regionally we expected extensive retreats of sea ice along the Eurasian coast driven by high-AO conditions during the previous winter, and extensive retreat in the Beaufort and Chukchi seas given the fracturing of what remained of the older, thicker ice areas during early winter, which left extensive areas of younger, thinner ice interspersed between the patches of old ice.

In retrospect, our overall outlook of setting a new record minimum based on the vast amount of FY ice should have been tempered by the fact that the FY ice over the pole should be thicker since it was the first ice to grow last fall and the north pole is also colder than the Eurasian and Alaskan coasts, and during summer this ice is subject to less incident sunlight. Although we did not set a new record minimum as we expected, the ice did retreat considerably in the Beaufort, Chukchi, East Siberian and Laptev seas as we expected despite what may have been a cooler summer than 2007, and the fact that the winds during summer tended to export less sea ice from the Arctic Ocean.

Harry Stern
2008 Sea Ice Minimum Summary Report

When you ask us for predictions of future sea ice extent, we are free to try many different things—running complicated models, doing statistical analysis, or just making a seat-of-the-pants guess. When you ask us what actually happened in September 2008, we are not free to improvise—there IS a right answer. Finding the right answer requires digging into data and making comparisons between years. I have not done that with sufficient rigor to give definitive answers to your questions. Others are working on it—see Ron Lindsay's submission for example. The best I could do would be to reiterate what others have found, but that would not be an independent result for your survey, so I'll refrain.

What I can do is address the success or failure of the estimate that I made for September 2008 back in May and June. I used linear extrapolation of September 1997–2006 to estimate September 2008 at about 5.5 million sq km with standard deviation about 0.2 million (that's the standard deviation of the residuals of the linear fit of 10 Septembers). This is a purely statistical method, and my prediction did not use September 2007 in the regression because it appeared to be an "outlier." Note also that my prediction was for the September MONTHLY AVERAGE ice extent, not the absolute minimum daily extent. The monthly average will come in somewhere between 4.5 million and 5.0 million. So, what can I conclude...?

1. My estimate was at least 3 standard deviations too high, i.e., very wrong, way too high.

2. September 2007 was not an "outlier," in the sense that September 2008 did not bounce back to the trend line. This is also supported by CC's statistical prediction. She fit a quadratic to all Septembers, back to 1979 and including 2007, and came up with an extrapolated value of 5.3 million for September 2008, which is also way too high (although I don't know how many standard deviations too high, as she did not report the standard deviation of the residuals).

3. Therefore it appears that year-to-year persistence has an effect—September 2008 was low partly because September 2007 was low.

4. The factors that lined up to create the September 2007 minimum did not all line up again in September 2008 (winds in particular), hence the slight upward bounce from 2007 to 2008. Note that we have still never had 2 record minima in consecutive years. This is not surprising for a process that is at least partly random (i.e., short-term weather conditions).

5. To speculate on your last two questions:
Yes, some skill in predictability is possible based on the sea ice thickness distribution in spring. To make use of that potential we would need good estimates of sea ice thickness such as might be obtained from ICESat or CryoSat (i.e., complete spatial coverage).

Jinlun Zhang
2008 Sea Ice Minimum Summary Report

Ensemble Predictions of September 2008 Arctic Sea Ice Conditions (Summary)
Recommended by an international workshop supported by the US SEARCH and the European DAMOCLES program, a community-wide Arctic Sea Ice Outlook for September 2008 was being initiated (http://www.arcus.org/search/seaiceoutlook/). We participated in this initiative by conducting ensemble seasonal predictions of arctic sea ice extent and spatial distribution of ice thickness and concentration. We have also set up a web page to support this activity (http://psc.apl.washington.edu/zhang/IDAO/seasonal_outlook.html). 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, Zhang et al., 2008), which is forced by NCEP/NCAR reanalysis data and assimilates 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 2001 NCEP/NCAR forcing, member 2 uses 2002 forcing, …, and member 7 uses 2007 forcing. Each ensemble prediction starts with the same initial ice–ocean conditions at a given starting date of prediction before September 2008. The initial ice-ocean conditions are obtained by a retrospective simulation that assimilates satellite ice concentration data. More details about the prediction procedure can be found in Zhang et al. (2008).

The September 2008 sea ice extent was predicted to be 4.5/4.6/5.1 million square km in May/June/July, based on the ensemble median of the 7 ensemble members. The NSIDC reported that the minimum summer 2008 ice extent is **4.52** million square km. To illustrate the results, the September 2008 sea ice conditions predicted in June are presented, followed by a summary.

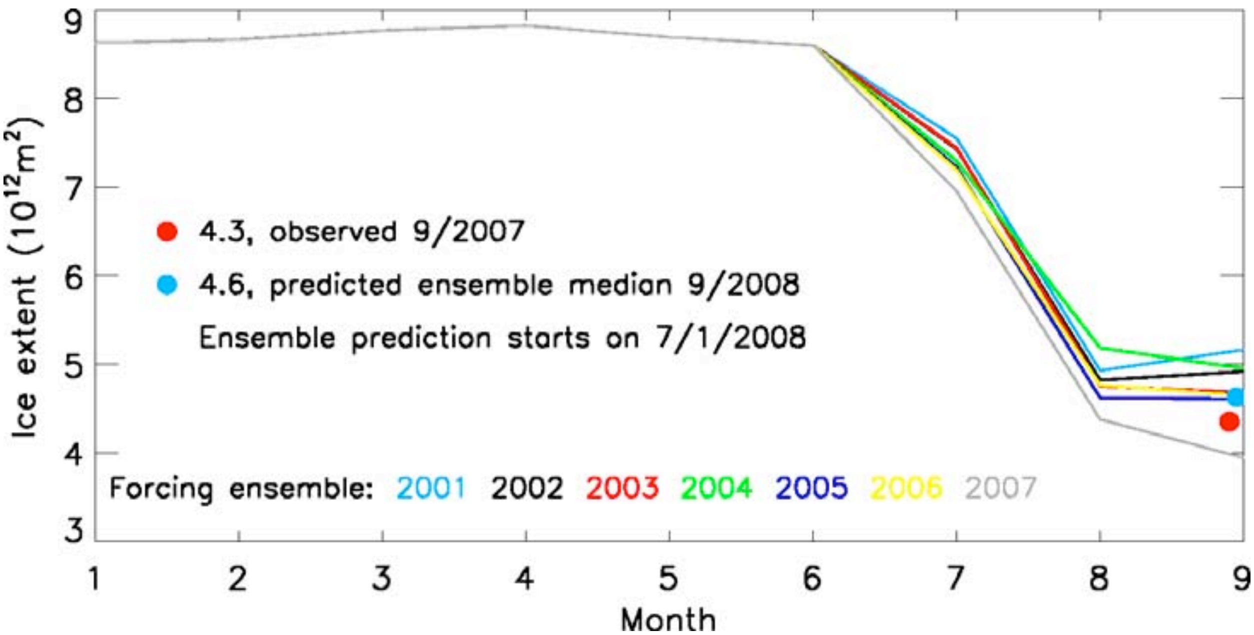


Figure 1 shows the monthly variations of ice extent over January–September 2008 from these seven ensemble members and their ensemble median. Results for January–June are from the retrospective simulation and results for July–September are from the ensemble predictions (prediction range is 7/1—9/30/2008). The ensemble median is considered to have a 50% probability of occurrence and the ensemble median ice extent for September 2008 is **4.6** million square km, slightly greater than that in September 2008 at **4.52** million square km.

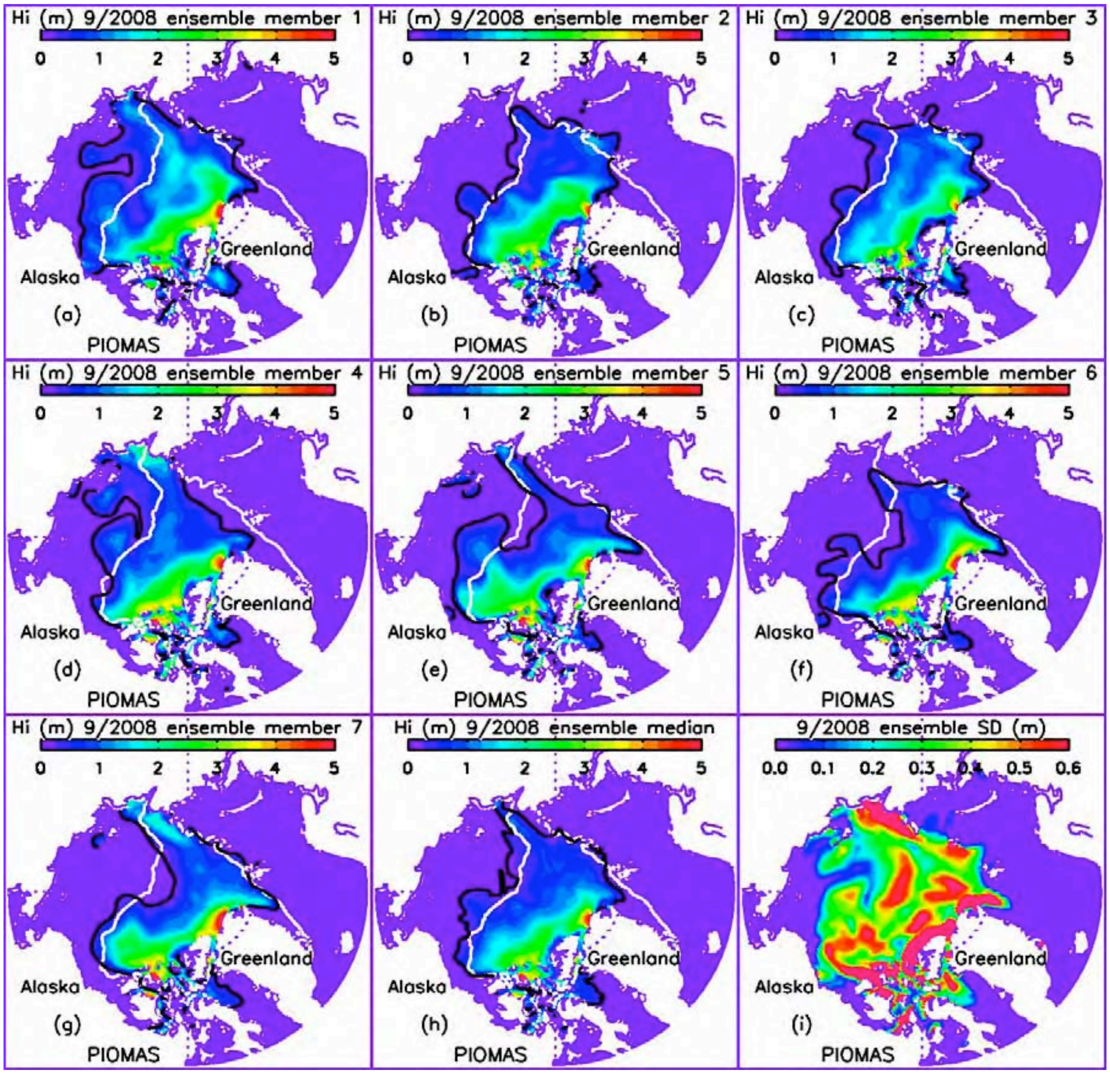


Figure 2 shows the predicted September 2008 ice thickness from these seven ensemble members and ensemble median and standard deviation (SD). The white line represents the satellite observed September 2007 ice extent and the black line the predicted September 2008 ice extent. The predicted spatial ensemble median ice thickness distribution (***Figure 2h***) is most likely to occur in September 2008, and the predicted ensemble median ice extent (***Figure 2h***) is rather close in shape to the satellite observation of September 2008 ice extent. Figure 2g suggests that if the wind and thermal forcing in July–September 2008 is close to that in 2007, the North Pole would be close to ice free.

Summary

(1) Preconditioning and anomalous meteorological forcing are all important. Whether they are equally important or not is not yet known. It has become obvious that if the initial ice-ocean conditions come from a heavy ice year, more ice will be predicted in September. On the other hand, the difference in the ice thickness fields predicted by the 7 ensemble members (Figure 2) highlights the importance of meteorological forcing.

(2) The ensemble predictions demonstrate certain skills in estimating both ice extent and its shape, in comparison with observations. However, they do not show improved accuracy with decreasing prediction range. It is not yet known why.

(3) Assimilation of satellite ice concentration improves the predictions.

(4) In comparison with 2007, 2008 started with much less ice, grew more ice in winter and spring because of thinner ice, and retained more ice in summer in the Pacific sector of the Arctic Ocean because of weaker southerly winds in that region.

(5) Although summer 2008 has slightly larger sea ice extent than summer 2007, the ice is thinner in a large area in the western Arctic, according to PIOMAS.

Reference

Zhang, J., M. Steele, R.W. Lindsay, A. Schweiger, and J. Morison, Ensemble one-year predictions of arctic sea ice for the spring and summer of 2008. Geophys. Res. Lett., 35, L08502, doi:10.1029/2008GL033244, 2008.
(http://psc.apl.washington.edu/zhang/Pubs/Zhang_etal2008GL033244.pdf)