September 2010 Sea Ice Outlook: July Report

Community Contributions

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Public Contributions

July Outlook for 2010 September Arctic Sea Ice Extent Minimum

Todd Arbetter[1], Sean Helfrich, Pablo Clemente-Colón
Science and Applied Technology Division
North American Ice Service/National Ice Center
Suitland, Maryland

[1]Todd Arbetter, UCAR Visiting Scientist, *todd.arbetter@noaa.gov*

As in the June 1 Outlook, we used the most recent data available to produce a full forecast for the remainder of the summer. In this case we use week 25 data, 8 weeks later than previous forecast. As in previous forecasts, we use NASA Team sea ice concentration, NCEP 2-meter air temperature, and NCEP Sea Level Pressure as predictors, and ice extent/concentration as the predictand. We find that the new projected summer minimum ice extent is significantly lower, at 4.27 million km2 (compared to 4.85 million km2), and lower values are predicted for weeks 29 and 33 as well (figure 1). Curiously, the week 17 ARIFS run predicted a lower value for both ice extent and ice area for week 25 than was actually observed, but the week 25 run predicts lower values for all further weeks in the summer than the week 17 values. The low predicted value in week 25 could be due in part to the lack of prediction capability for the Canadian Arctic Archipelago (CAA): we held the model capabilities constant to be able to directly compare its predictive ability, but there will be a low bias for prediction versus actual because the missing area in the CAA is not accounted for.

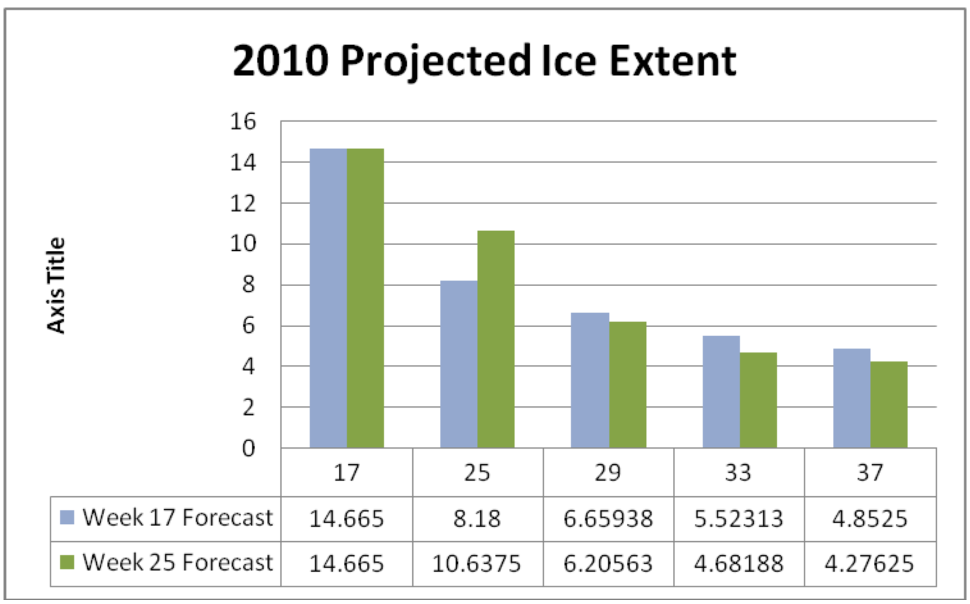


Figure 1: Projected Arctic Sea Ice Extent over summer 2010, based on Week 17 conditions (blue) and week 25 conditions (green). While the observed value for week 25 is higher than predicted in week 17, future summer conditions are projected to be lower using week 25 conditions than they are with week 17 conditions.

Figure 2 compares predicted and observed conditions for week 25 and shows that there are noticeable differences in the ice conditions beyond the missing CAA forecast; in reality, there is a larger open water area is evident in the Laptev Sea. Meanwhile, some ice is beginning to retreat from the eastern Beaufort Sea while the forecast shows light ice (1-3/10) all the way to the shore. Differences in mid-September conditions are provided in Figure 4.

While we have the benefit of hindsight to assist with evaluating ARIFS for the summer season, it is our goal to implement this system operationally for the use of the Navy, Coast Guard, and our partners in the North American Ice Service (Canadian Ice Services, USCG International Ice Patrol).

The simple linear regression model (Helfrich and Arbetter Regression Model, or HARM) performed in the first outlook was not updated in time for this outlook, but will be done in time for the next update.

(CAVEAT: This is not an official National Ice Center forecast and should not be interpreted as advice for navigation. Only ice-capable ships with experienced ice pilots should attempt navigation in the Arctic, and should consult with local authorities for current ice conditions and navigational restrictions.)

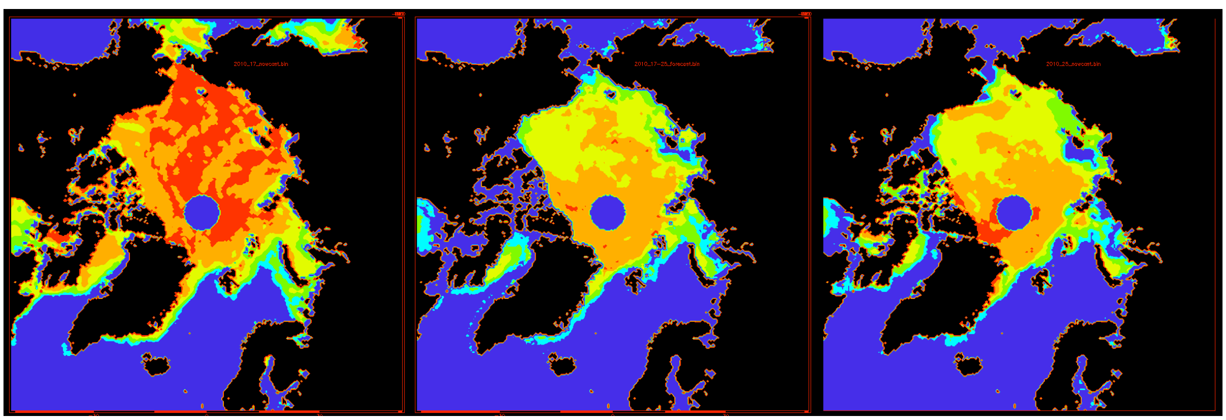


Figure 2: Sea ice extent and concentration for 2010, end of April conditions (left), projected conditions for 2010, mid-July conditions (right), and actual mid-July conditions (right). The blue area in the center (surrounding the North Pole) is the SSM/I blind spot; no projections are done for this region. WMO color codes are given in Figure 3.

Figure 3: WMO Sea Ice Color codes for Ice Concentration.

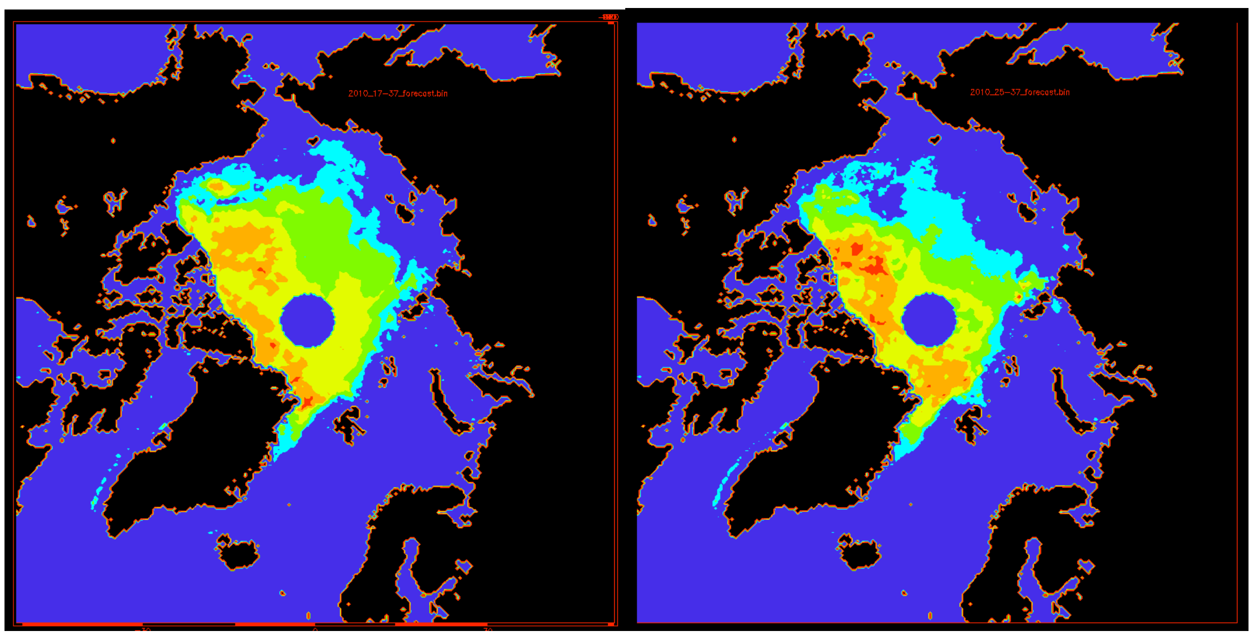


Figure 4: Mid-September Arctic ice extent, as projected from mid-April conditions (left) and mid-July conditions (right). While both projections show large retreat in the Siberian and Laptev Seas, the mid-July projections suggest the 15% ice edge will be further back and ice retreat in the Beaufort Sea will be more severe. The Nothern Sea Route is likely to be navigable, but the model does not predict sea ice conditions in the Canadian Archipelago, so no direct conclusions can be drawn about the Northwest passage.

References

Drobot, S. D., J. A. Maslanik, and M. R. Anderson, 2008: Interannual variations in the opening date of the Prudhoe Bay shipping season: links to atmospheric and surface conditions. *International Journal of Climatology*, **29** (2), 197-203.

Sea ice outlook 2010

Lars Kaleschke[1], Gunnar Spreen[2]
[1]Institute for Oceanography, KlimaCampus, University of Hamburg
[2]Jet Propulsion Laboratory, California Institute of Technology
Contact: `lars.kaleschke@zmaw.de`, Tel. ++49 40 42838 6518

July 14, 2010

1 Extent Projection

We estimate a September 2010 monthly mean extent of **5.2 ± 0.1 million square kilometers**.

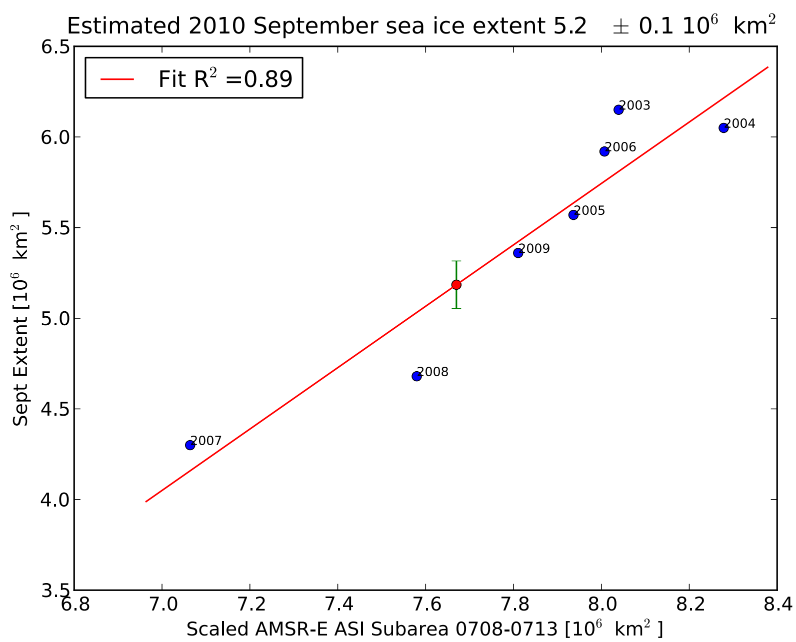


Figure 1: September 2010 sea ice extent estimate. Daily updates are available at `ftp://ftp-projects.zmaw.de/seaice/prediction/`

2 Methods and Techniques

The estimate is based on AMSR-E sea ice concentration data on a 6.25 km grid derived using the ARTIST sea ice (ASI) algorithm (Spreen et al., 2008; Kaleschke et al., 2001). We used two different sea ice concentration data sets, one based on the reprocessed gridded level 3 AMSR-E brightness temperatures for the years 2003-2010 (`ftp://ftp-projects.zmaw.de/seaice/AMSR-E_ASI_IceConc/`), the other is based on near-real-time AMSR-E level 1b brightness temperatures. Because the level 3 data is available only with some delay the level 1 data are used for the most recent year.

A five day median filter is applied on the data to reduce the atmospheric influence and coastal spillover effects (Kern et al., 2010; Maaß et al., 2010). Thus, any dates given below are not exactly for the individual day but include the previous four days.

To obtain an estimate we regress the ice area from the Arctic subregion shown in Figure 2 with the previous years and their September mean extents. As shown in Figure 2 the considered region contains the central Arctic and some of the Arctic marginal seas but excludes the multiyear sea ice region north of Greenland and the North Pole. To be able to regress the original AMSR-E sea ice area with the mean September sea ice extent two scalings are applied. First the 11-15 September five day median filtered sea ice area of the Arctic subregion for years 2003 to 2009 are regressed with the according mean September sea ice extent taken from NSIDC (Fetterer et al., 2002, updated 2009) (Figure 3). And second the near real time and reprocessed AMSR-E ice concentrations are scaled to each other to account for the small differences between the two datasets (Figure 4). Using these scalings the mean September sea ice extent is estimated from the current five day median sea ice area and the sea ice area of the same five day period of years 2003 to 2009 (Figure 1).

3 Rationale

Our assumption is that the Arctic sea ice is on decline with a constant trend over the last few years. In addition there is interannual variability due to the weather.

A hindcast experiment for last year was conducted to test the performance of the new method. The correlation between September mean extent and the selected training area increases as the time difference decreases. In 2009 the correlation R^2 increased from insignificant values earlier in Spring to values around $R^2 \approx 0.5$ at the the end of May (Figure 5).

The standard error of the prediction σ dropped from ± 4 million square kilometers to values below ± 1 million square kilometers after June 10 (Figure 6). As the deviation from the observed value is signifcantly smaller than the standard error we define its half as our uncertainty.

The prediction skill depends on the selected training area. The skill increased when we removed some of the seasonal ice covered areas in our analysis (Figure 6).

From this hindcast experiment we deduce that reliable forecasts seem to be possible in mid-June. Some predictive skill exists already at the end of May.

With the additional processing steps we considerably reduce the observational noise and improve the prediction skill as compared to our last years attempts using SSM/I data. The higher spatial resolution of AMSR-E compared to SSM/I allows to better resolve small scale sea ice openings like coastal polynyas. The size and number of these openings might inhere some predictive capability for the sea ice minimum. Which could explain parts of the improvement achieved in comparison to using SSM/I data.

4 Executive Summary

Our outlook is based on statistical analysis of satellite derived sea ice area. We introduced following improvements: high resolution (AMSR-E) sea ice concentration data, a time-domain filter that reduces observational noise, and a space-domain selection that neglects the outer seasonal ice zones. Thus, small scale sea ice openings like coastal polynyas that might inhere some predictive capability for the sea ice minimum can be better utilized.

References

Fetterer, F., K. Knowles, W. Meier, and M. Savoie (2002, updated 2009). *Sea Ice Index*, 1972-2009. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Kaleschke, L., C. Lüpkes, T. Vihma, J. Haarpaintner, A. Bochert, J. Hartmann, and G. Heygster (2001). SSM/I Sea Ice Remote Sensing for Mesoscale Ocean-Atmosphere Interaction Analysis, *Can. J. Rem. Sens.*, 27(5), 526-537.

Spreen, G., L. Kaleschke, and G. Heygster (2008). Sea ice remote sensing using AMSR-E 89-GHz channels, *J. Geophys. Res.*, 113, C02S03, doi:10.1029/2005JC003384.

Kern, S., L. Kaleschke, and G. Spreen (2010). Climatology of the Nordic (Irminger, Greenland, Barents, Kara and White/Pechora) Seas ice cover based on 85 GHz satellite microwave radiometry: 1992-2008.Tellus A, Published Online: Apr 19 2010, DOI: 10.1111/j.1600-0870.2010.00457.x

Maaß N., and L. Kaleschke (2010). Improving passive microwave sea ice concentration algorithms for coastal areas: applications to the Baltic Sea. Tellus A, Published Online: Apr 1 2010, DOI: 10.1111/j.1600-0870.2010.00452.x

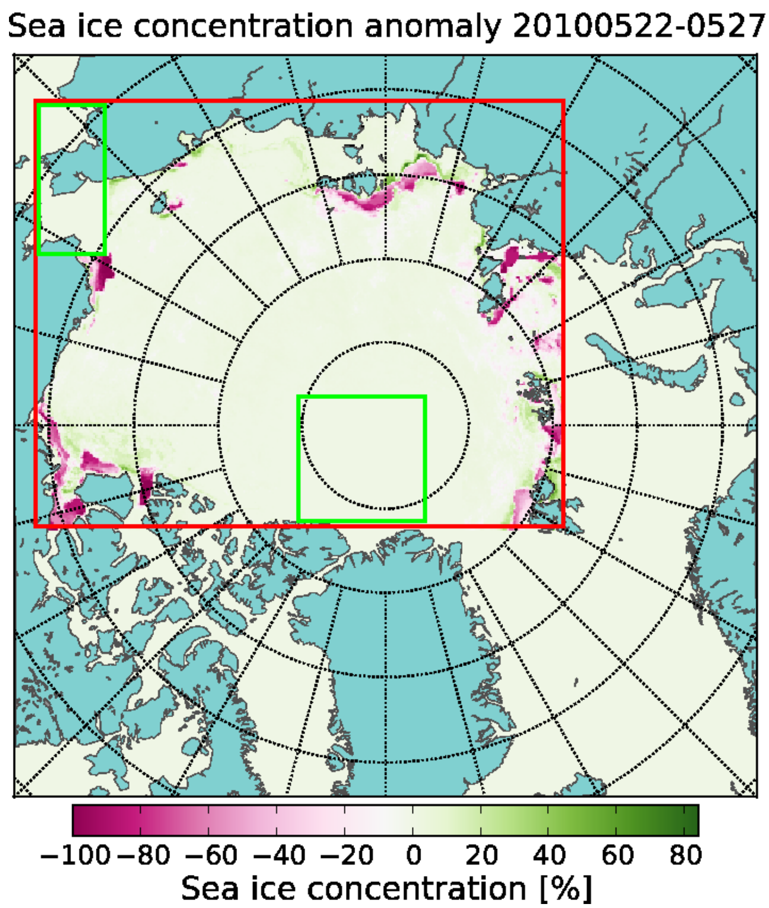


Figure 2: 2010 sea ice concentration anomaly derived from AMSR-E ASI data. The anomaly is calculated with respect to the years 2003–2009. The red rectangle indicates the subset for calculation of the ASI AMSR-E sea ice area. The green rectangles indicates areas that are not taken into account.

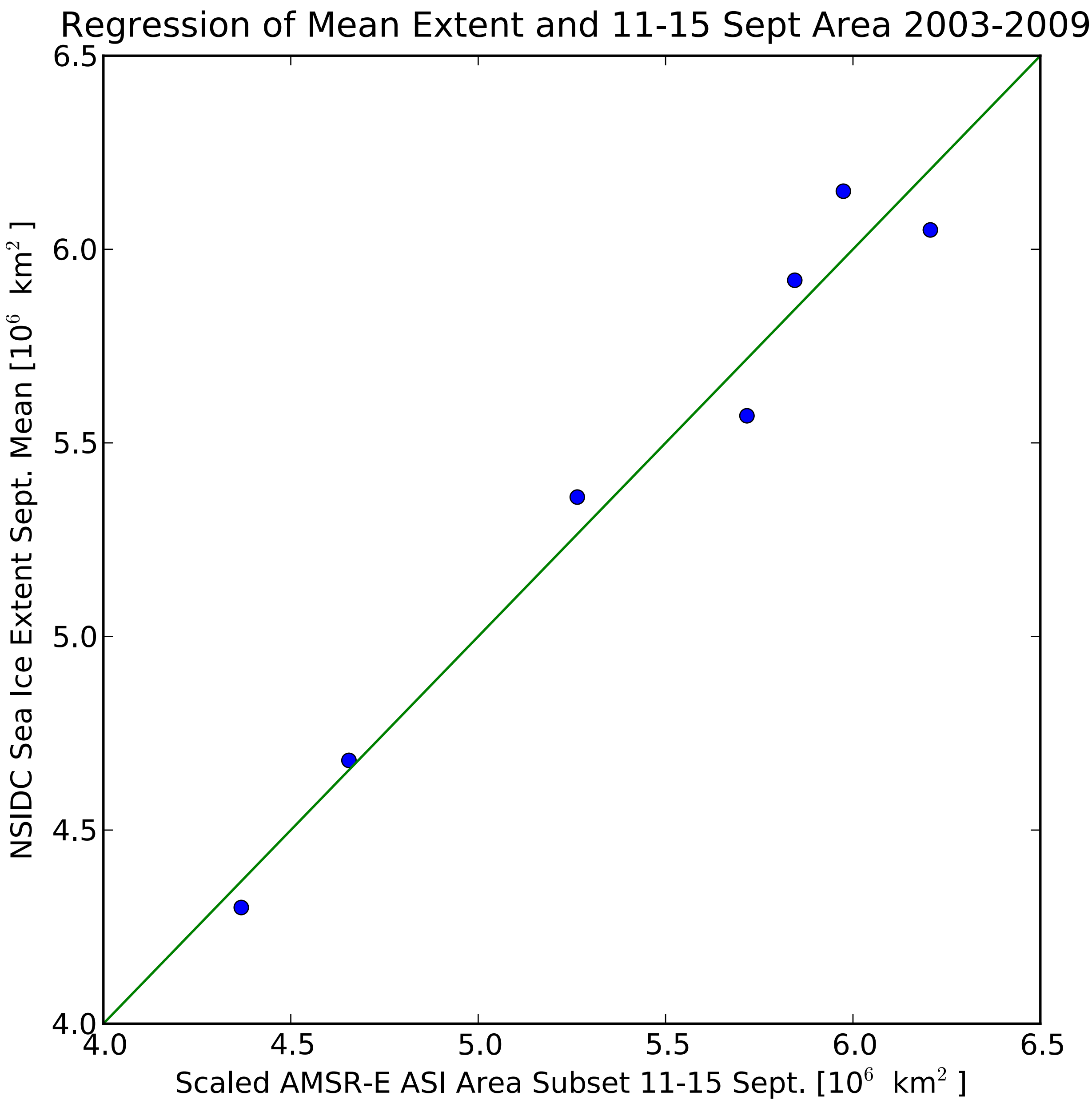


Figure 3: Regression of regional (region shown in Fig. 2) five-day median filtered AMSR-E ASI area and total NSIDC September mean extent.

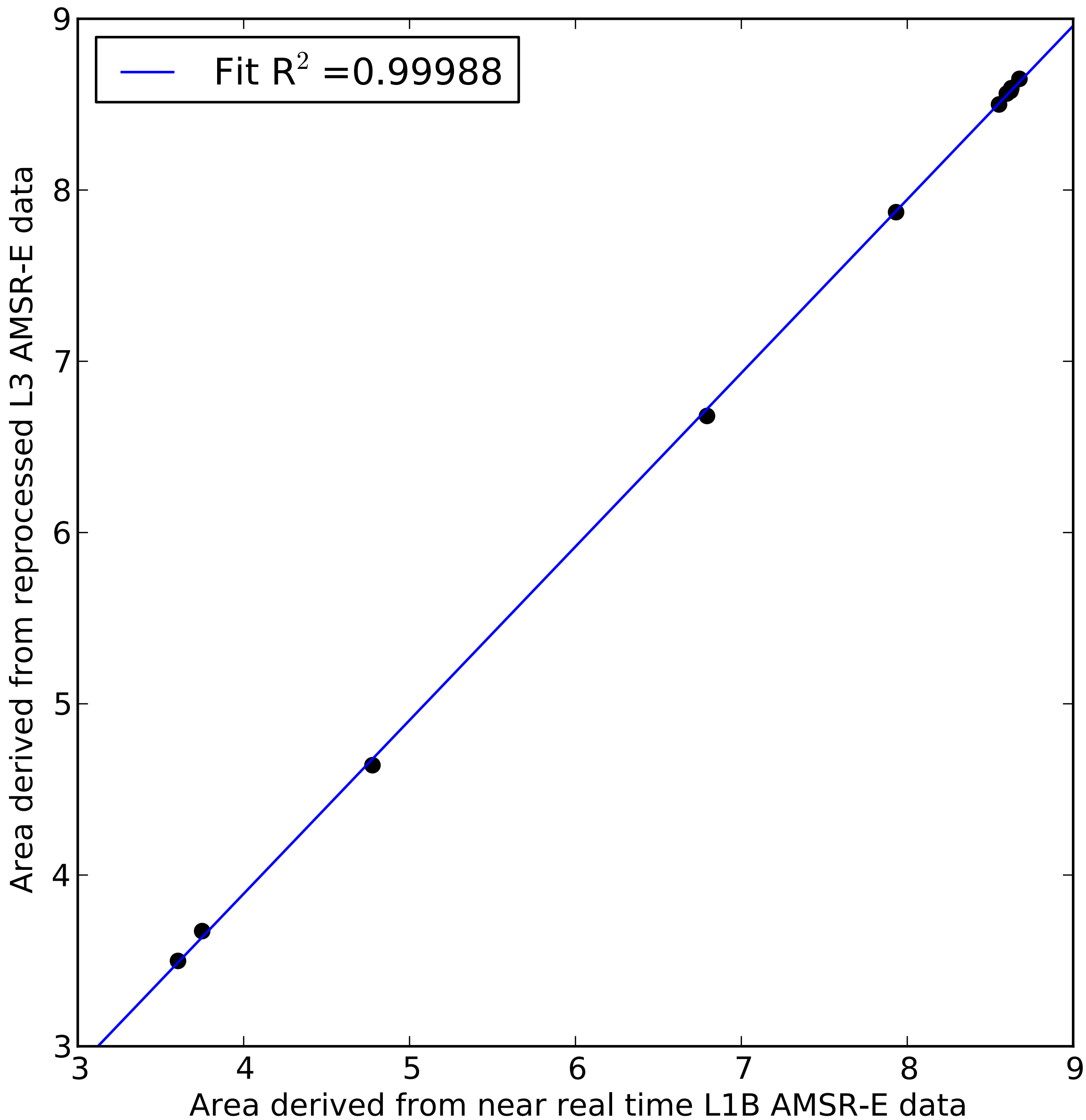


Figure 4: Regression of near real time and reprocessed data.

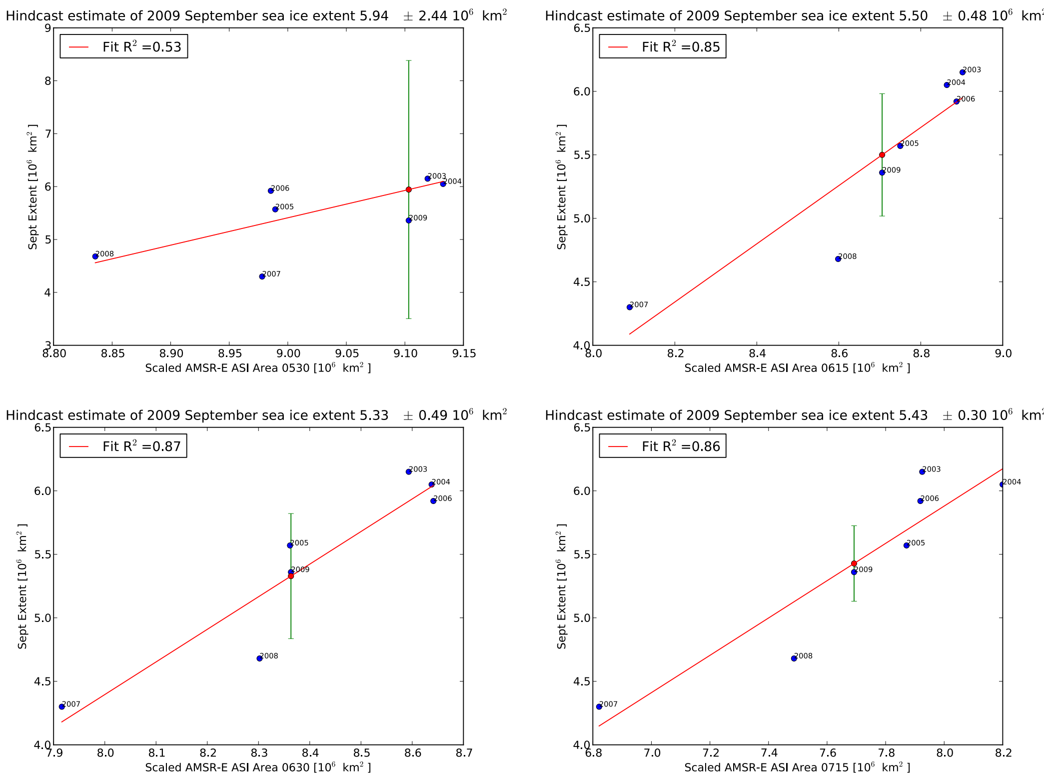


Figure 5: Hindcast prediction for September 2009.

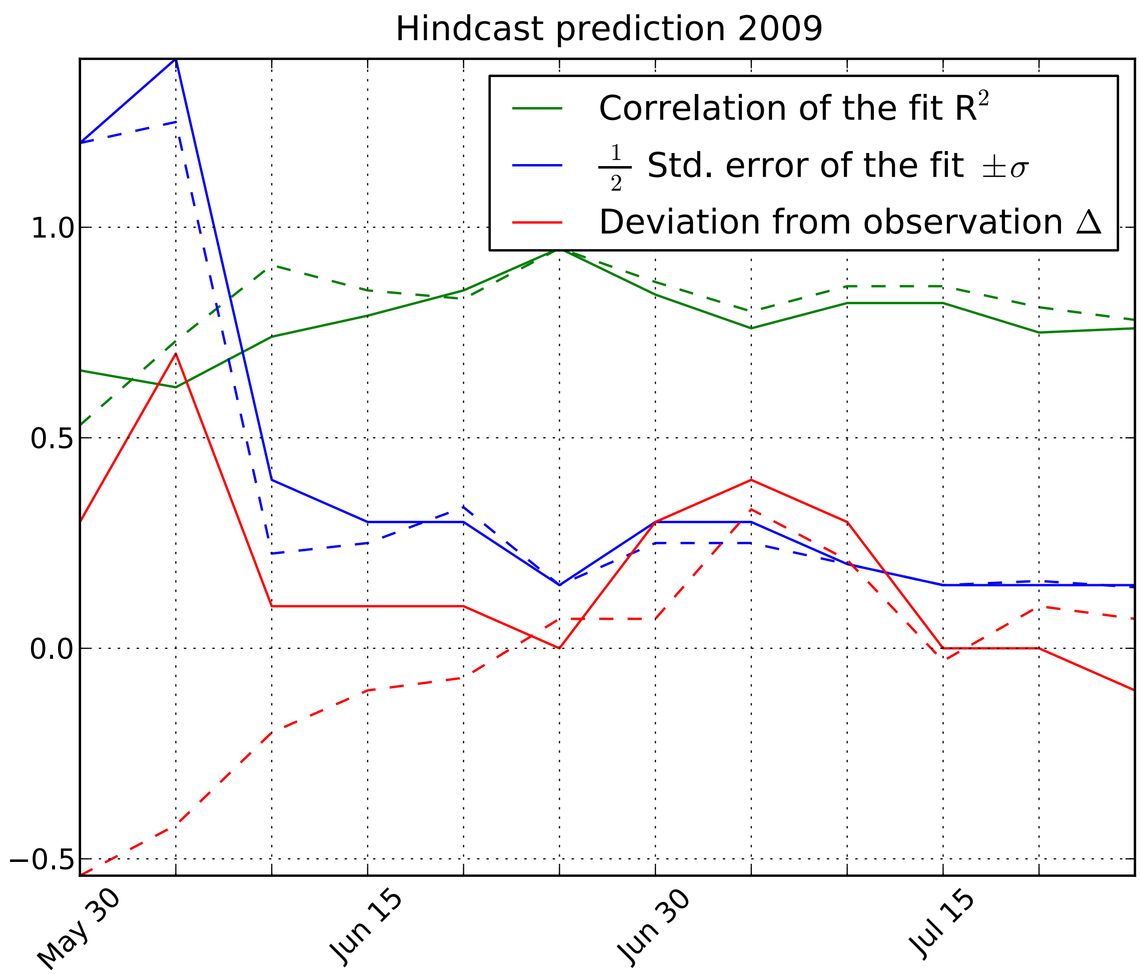
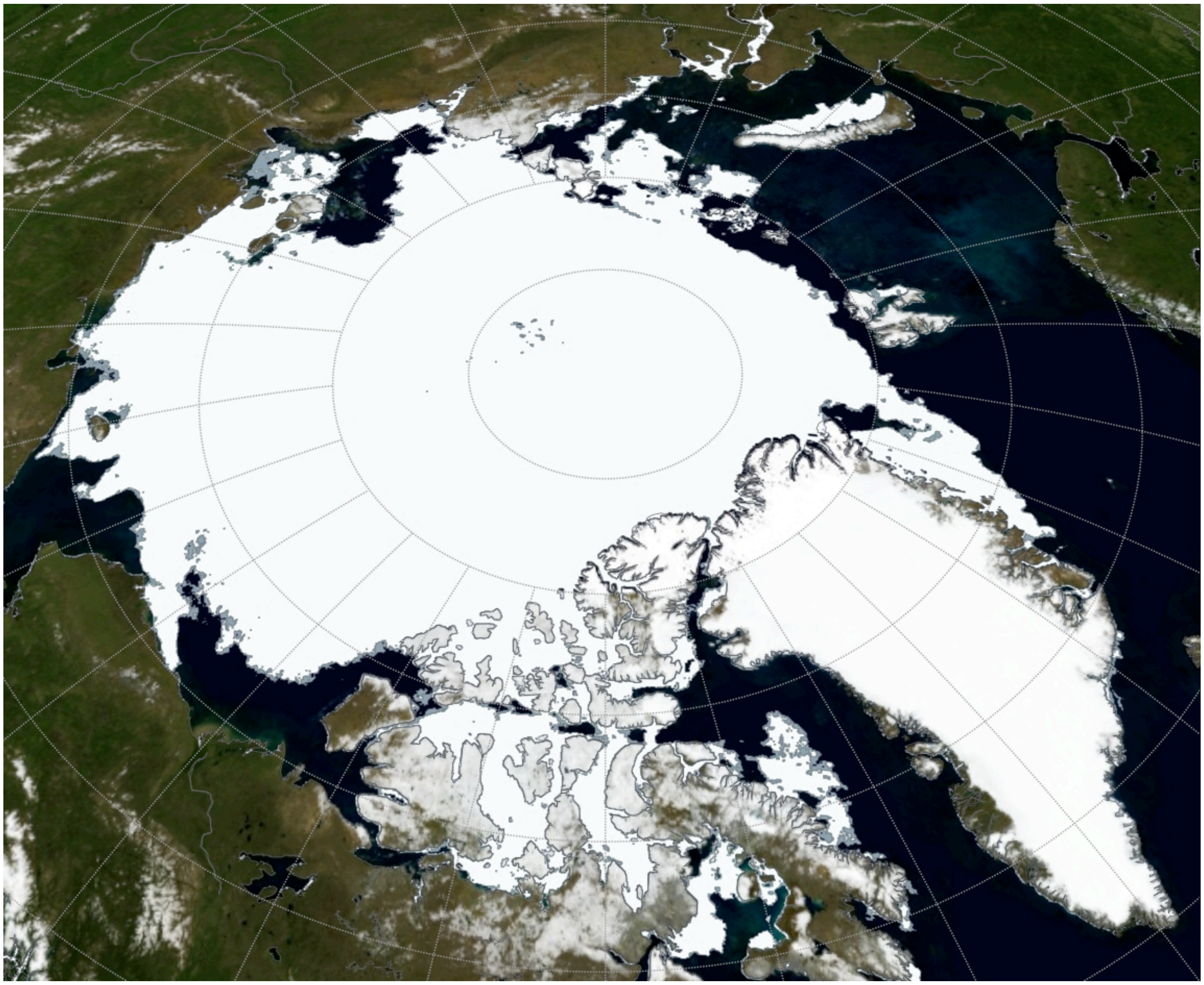


Figure 6: Hindcast prediction for September 2009. The results for the solid and dashed lines are for different training areas (see 2).



Recent AMSR-E map.

July 2010 Sea Ice Outlook – AWI/FastOpt/OASys contribution

F. Kauker[a,b], R. Gerdes[a], M. Karcher[a,b]

T. Kaminski[c], R. Giering[c], M. Vossbeck[c]

July, 2010

[a] Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany
[b] O.A.Sys - Ocean Atmosphere Systems, Hamburg, Germany
[c] FastOpt, Hamburg, Germany

As for the SIO of June 2010 we make use of the 4DVar data assimilation system NAOSIMDAS to perform an additional set of ensemble experiments starting from an initial state determined via data assimilation.

Experimental setup

For the present outlook the coupled ice-ocean model NAOSIM has been forced with atmospheric surface data from January 1948 to June 26th 2010. This atmospheric forcing has been taken from the NCEP/NCAR reanalysis (Kalnay et al., 1996). We used atmospheric data from the years 1990 to 2009 for the ensemble prediction. The model experiments all start from the same initial conditions on June 26th 2010. We thus obtain 20 different realizations of sea ice development in summer 2010. We use this ensemble to derive probabilities of ice extent minimum values in September 2010.

As in the June 2010 outlook two ensemble experiments with different initial conditions on June 26th 2010 were performed:

Ensemble I starts from the state of ocean and sea ice taken from a forward run of NAOSIM driven with NCEP/NCAR atmospheric data from January 1948 to June 26th 2010.

Ensemble II starts from an optimised state derived by NAOSIMDAS with an assimilation window from March 1, 2010 to June 26th 2010. The following observational data streams were assimilated:

- 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 spatial resolution of 10 km.

- Two-day mean ice displacement data for March to April 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 assimilation minimizes the difference between observations and model analogues, by variations of the model's initial conditions on March 1st and the surface boundary conditions (wind stress, scalar wind, 2m temperature, dew-point temperature, cloud cover, precipitation) from March 1st to June 26th 2010.

Brief comparison of 'free' versus 'optimized' initial state

Figure 1 displays the modeled ice concentration on June 26th 2010 for the "free" run and the run with data assimilation. As for the June outlook differences can be mainly seen next to the ice margin especially in the Barents Sea. We have expected that the benefit of the data assimilation will become more obvious in the July outlook (see June report) but this is not the case. The ice thickness on June 26th 2010 (Fig. 2) exhibits some differences at the ice edge but also some minor differences in the Canadian basin. We assume that this is driven by a slight weakening of the Beaufort gyre in case of data assimilation (see June report).

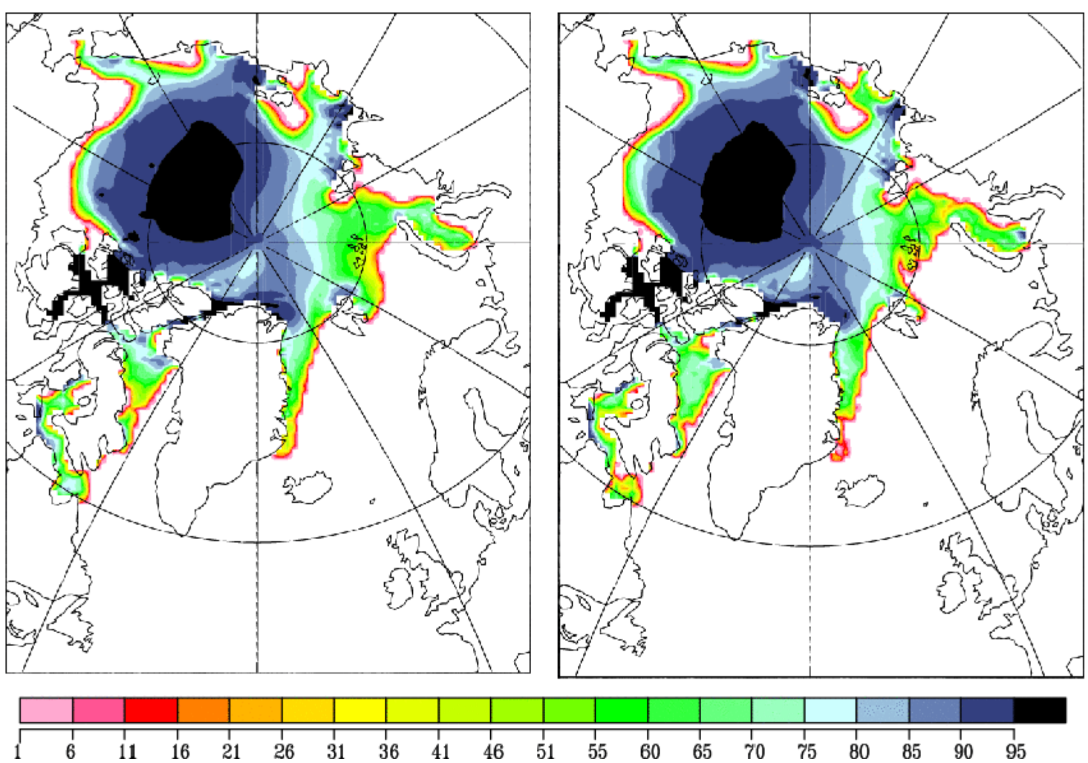


Fig. 1: The ice concentration [%] at the 26th of June 2010 in case of the "free" run (left) and in case with data assimilation (right).

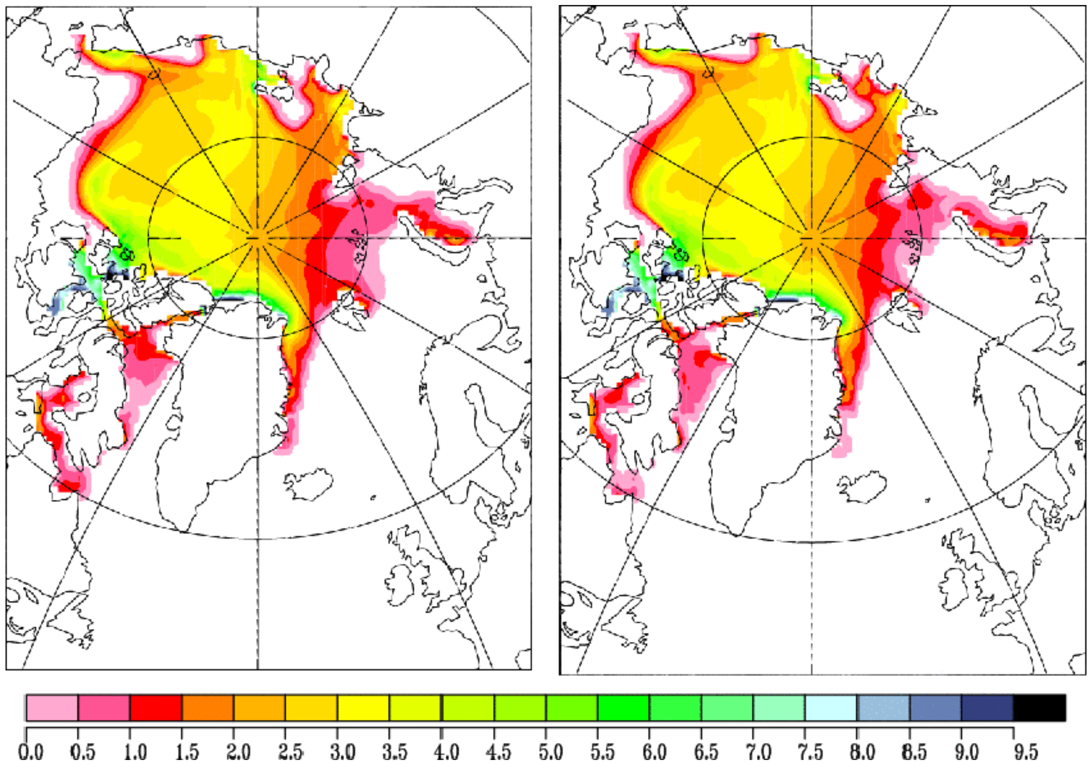


Fig. 2: The ice thickness [m] at the 26th of June 2010 in case of the "free" run (left) and in case with data assimilation (right).

Mean September Ice Extent 2010

Ensemble I (no assimilation)

The result for all 20 realizations ordered by the September ice extent is shown in Figure 3. Since the forward simulation underestimates the September extent compared with the observed extent minima in 2007, 2008, and 2009 by about 0.49 million km^2 (in the mean), we added this bias to the results of Ensemble I (see our June outlook).

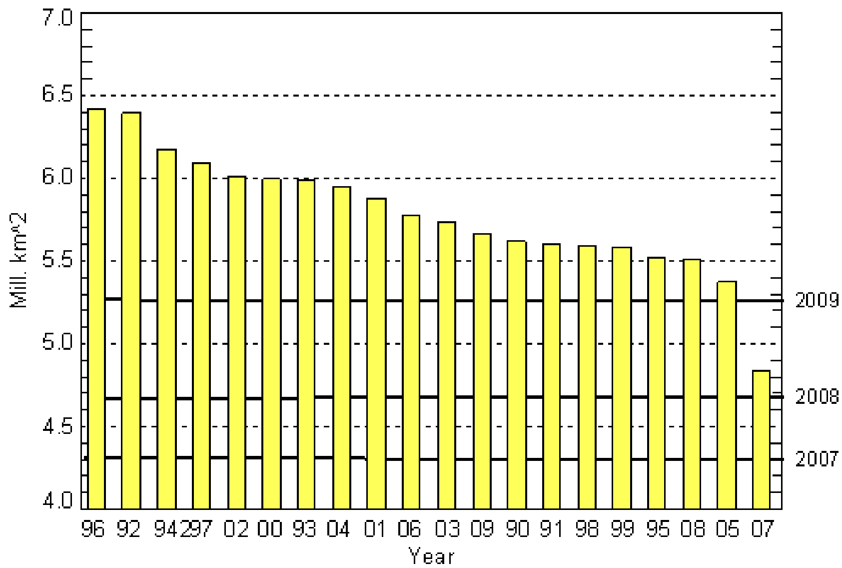


Figure 3: ***Ensemble I*** *- Simulated mean September ice extent in 2010 [million km^2] when forced with atmospheric data from 1990 to 2009 (initial state on June 26th 2010). Model derived ice extents have been adjusted assuming a systematic bias (see text). The thick black horizontal lines display the minimum ice extent observed in 2007, 2008 and 2009.*

The Ensemble I mean value is 5.78 million km² (bias included). The standard deviation of Ensemble I is 0.37 million km^{2}. Assuming a Gaussian distribution we are able to state probabilities (percentiles) that the sea ice extent in September 2010 will fall below a certain value.

The probability deduced from **Ensemble I** that in 2010 the ice extent will fall below the three lowest September minima:

probability to fall below 2007 (record minimum) is below 1%,
probability to fall below 2008 (second lowest) is below 1%,
probability to fall below 2009 (third lowest) is about 12%.

With a probability of 80% the mean September ice extent in 2010 will be in the range between 5.3 and 6.3 million km^2.

Ensemble II (initial state from data assimilation)

The mean September sea ice extent for all 20 realizations starting from optimized initial conditions is shown in Figure 4. In this setup we expect the observations to correct the bias that was present in the free run. Therefore in ensemble II, in contrast to ensemble I, we do not explicitly correct for a bias. We expect the observations to have a larger impact in the upcoming outlooks.

The Ensemble II mean of 5.33 million km^2. The standard deviation of Ensemble II is also 0.37 million km^2.

The probability deduced from **Ensemble II** that in 2010 the ice extent will fall below the three lowest September minima:

probability to fall below 2007 (record minimum) is below 1%,
probability to fall below 2008 (second lowest) is about 3%,
probability to fall below 2009 (third lowest) is about 50%.

With a probability of 80% the mean September ice extent in 2010 will be in the range between 4.9 and 5.8 million km^2.

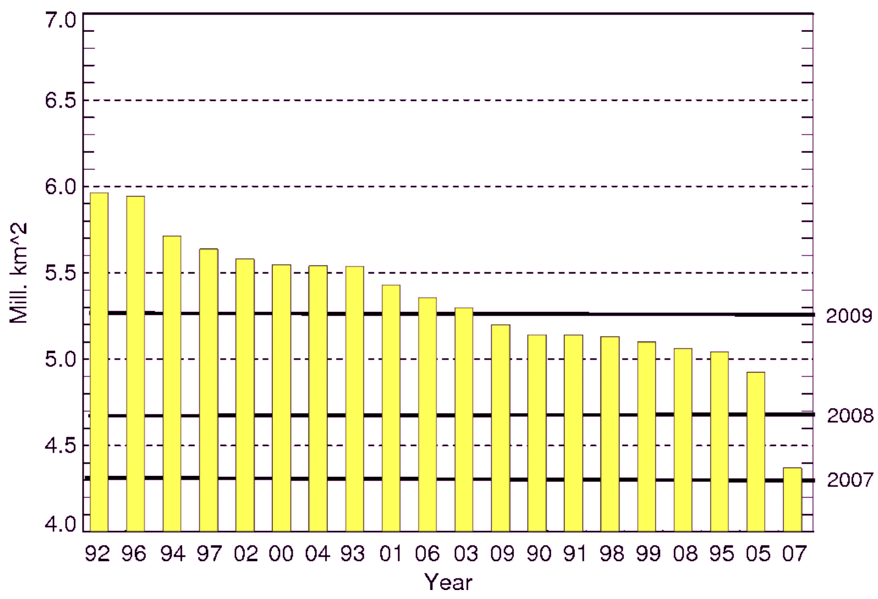


Figure 4: ***Ensemble II*** *- Simulated mean September ice extent in 2010 [million km^2] when forced with atmospheric data from 1990 to 2009 from the initial state on June 26th 2010 with data assimilation. The thick black horizontal lines display the minimum ice extent observed in 2007, 2008 and 2009.*

Discussion – back to before 2007 situation?

With respect to the June outlook the July prediction has even increased slightly (about 0.2 million km^2). In previous analyses we showed the importance of the initial ice thickness distribution for the ensemble prediction. A comparison of the modeled ice thickness on July 1st 2007, 2008, and 2009, and the initial ice thickness on June 26th 2010 reveals, as for the June outlook, considerably larger ice thickness mainly in the East Siberian Sea, north of the East Siberian Sea, and in the vicinity of the North Pole in 2010 compared to the years 2007 to 2009 (Fig. 5). The 'observed' ice concentration on June 25th 2010 (Fig. 6) shows still a large ice concentration in the areas where large ice thicknesses are modeled, i.e. there is no obvious contradiction between the two fields.

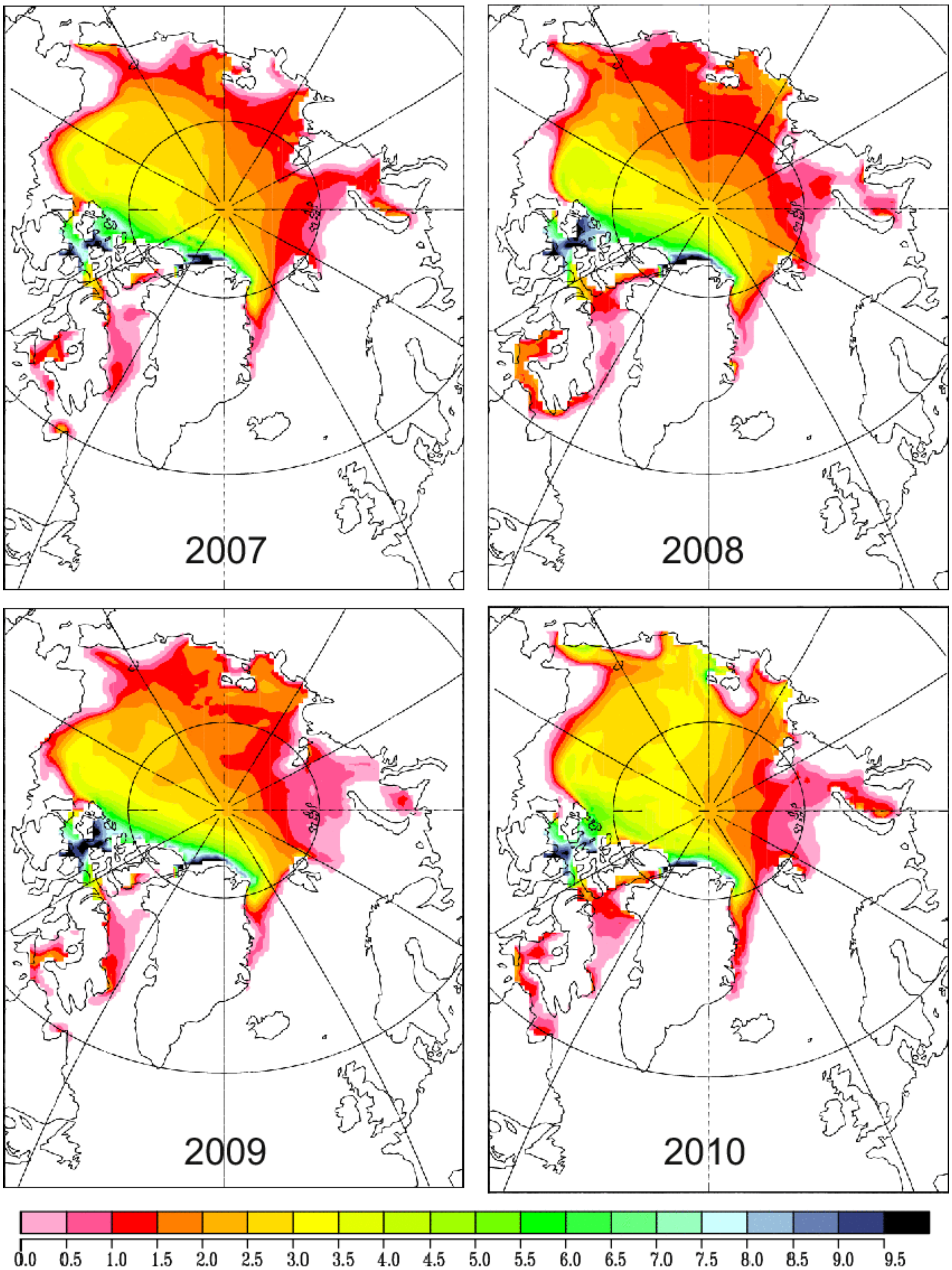


Figure 5: The ice thickness [m] at end of June 2007, 2008, 2009, and at the 26th of June 2010 (equal to Fig. 2 left).

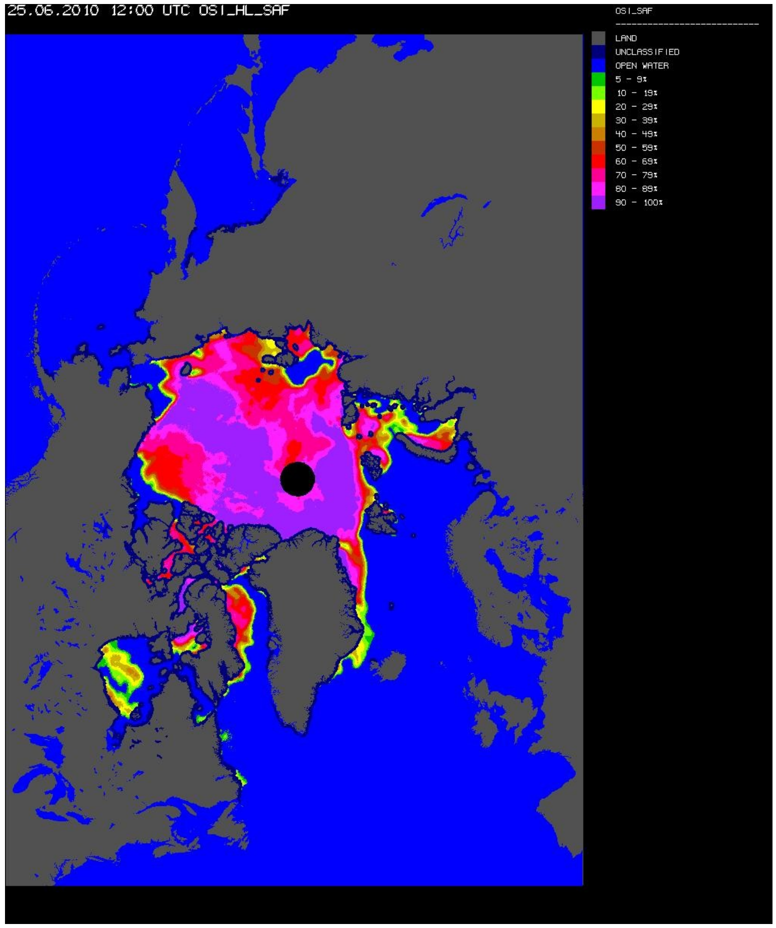


Figure 6: The 'observed' ice concentration on June 25th 2010 (courtesy OSI-SAF).

References:

Kalnay et al. (1996), The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc., 77, 437-470.

2010 Sea Ice Outlook
July Report

Jennifer Kay, Marika Holland, David Bailey
University Corporation for Atmospheric Research (UCAR)

1. Extent Projection
Provide a sea ice projection for the September monthly mean arctic sea ice extent (in million square kilometers). For reference, the arctic sea ice monthly mean extent for September 2009 was 5.36 million square kilometers, the third lowest in the satellite record.

4.89 million sq. km. (stdev. 0.5, min. 4.0, max. 5.8)

2. Methods / Techniques
Provide the type of estimate (heuristic, statistical, ice-ocean model ensemble runs, etc.).

The method is an informal inquiry of 19 climate scientists on June 1, 2010. While some people used statistics to inform their estimate, most predictions were based on information provided by the organizer about recent sea ice conditions and lunch time discussions.

3. Rationale
Include a short paragraph on the physical rationale for the estimate.

This is the third year that I have assembled estimates for the September ice extent motivated by lunch-time discussion amongst climate scientists working at NCAR. Our discussion generally include both researchers intimately involved in sea ice research, and researchers who have no specific knowledge of sea ice processes but experience in climate research.

Discussion this year has focused on the vulnerability of the ice pack due to long-term thinning, the record-low ice extent minima of the past three years, this year's strong negative AO and its influence on ice export and winter temperatures, the fast pace of the ice loss in May 2010, and on the importance of the unpredictable summer weather conditions.

Although our methods are very different than those used for other groups participating in the sea ice outlook, we think that they provide an interesting contrast and emphasize that there are many unpredictable factors in seasonal sea ice prediction that make a reasoned guess of the mean September Arctic ice extent competitive with much more sophisticated methods.

For example, in 2009, we were all pretty pessimistic and over-predicted the seasonal ice extent loss. Only 3/19 entrants predicted a greater September 2009 ice extent than what was observed. But, we were in good company. Our average guess was well within ARCUS sea ice outlook efforts to predict sea ice conditions using statistical, modeling, and heuristic techniques.

4. Executive Summary
Provide a short paragraph that summarizes your outlook contribution in two or three sentences.

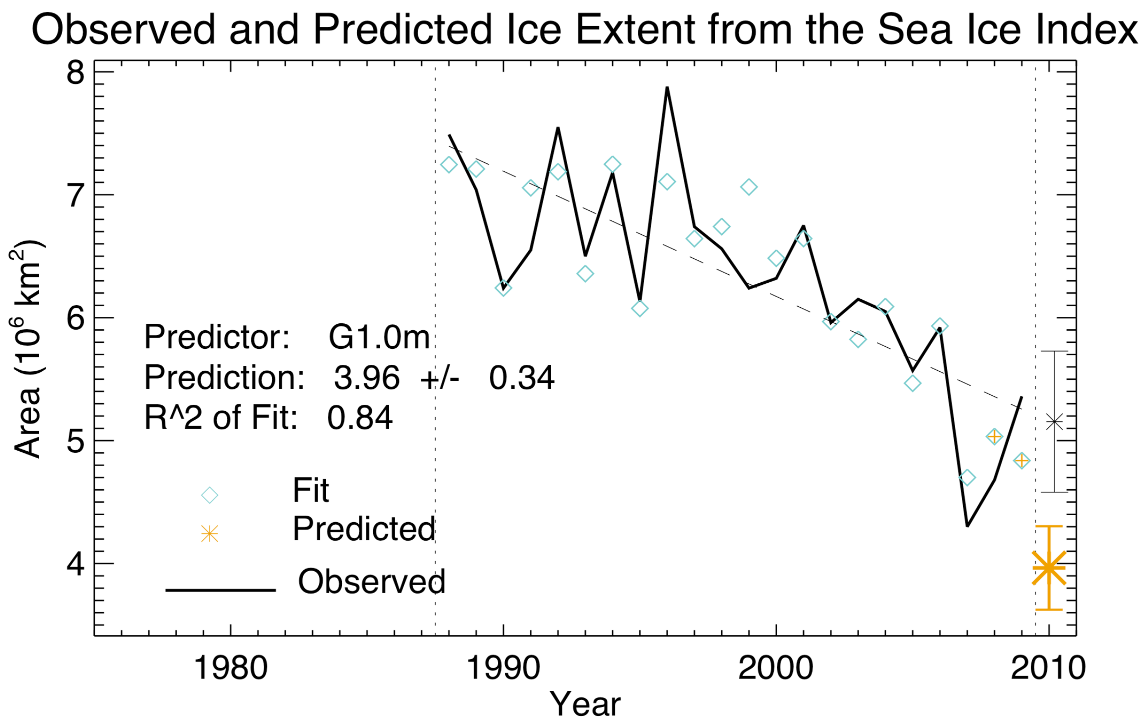
An informal pool of 19 climate scientists on June 1, 2010 estimates that the September 2010 ice extent will be 4.89 million sq. km. (stdev. 0.5, min. 4.0, max. 5.8). In 2007, 2008, and 2009, our informal pool estimate of the mean September ice extent was competitive with much more sophisticated prediction efforts based on statistical methods and ice-ocean model ensemble runs.

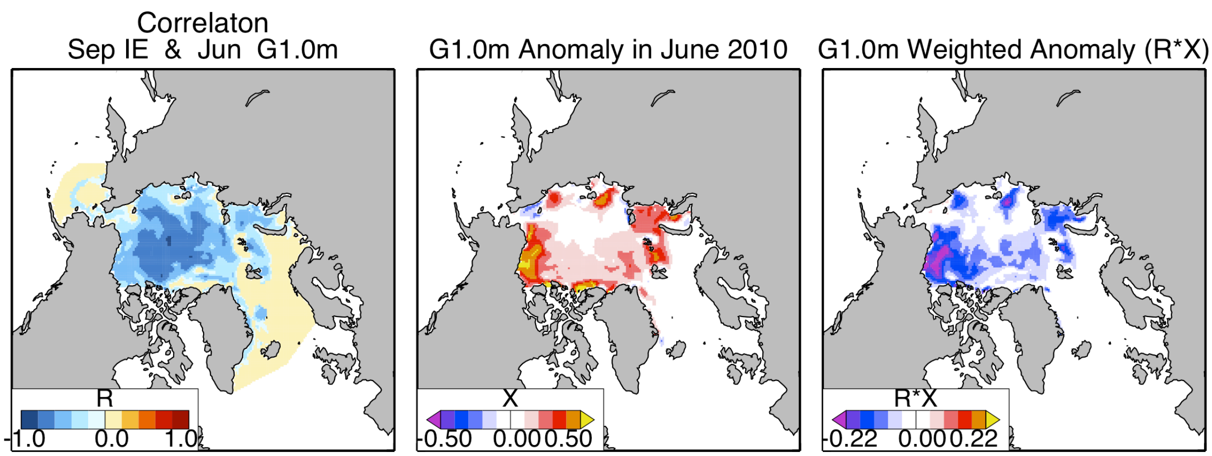
2010 Sea Ice Outlook
July Report

Ron Lindsay and Jinlun Zhang
Applied Physics Laboratory, University of Washington

End of June: According to our model retrospective simulations, the ice in the Arctic has continued to thin at a remarkable rate. The statistical method based on the PIOMAS model analysis now is projecting a new record low ice extent. The best predictors are G1.0 (area with less than 1.0 m of ice) and G0.4 (area with less than 0.4 m of ice) which give nearly identical results. Using the same one as last month (G1.0) **the predicted extent is 3.96 +/- 0.34 million square kilometers**. The R2 value for this predictor is 0.84, which now indicates a high degree of skill in the forecast. Here is the diagnostic plot for this month:

Predictions for September 2010 from June





Sea ice outlook in 2010: Atmospheric forcing and sea ice extent

July Report

Jennifer V. Lukovich[1], Matthew G. Asplin[1], David G. Barber[1]

[1]CENTER FOR EARTH OBSERVATION SCIENCE, FACULTY OF EARTH, ENVIRONMENT AND RESOURCES, UNIVERSITY OF MANITOBA, WINNIPEG, MB, CANADA

1) Extent projection

Estimate for sea ice extent for September, 2010; less than the value for the 2007 minimum in sea ice extent , with a value on the order of $\sim 4.0 \cdot 10^6 km^2$.

2) Methods/Techniques

A heuristic assessment of the surface, stratosphere and ice conditions in 2010 relative to 2007 atmospheric and ice conditions in June provides the basis for a projection of sea ice extent less than the record minimum in ice extent encountered in September, 2007. Comparison of SAT and SLP anomalies, in addition to temperature anomalies at 850 mb for 2007 and 2010 relative to the 1979 – 2010 climatological mean highlight differences in near-surface atmospheric conditions leading up to the minimum in summertime ice extent. Upper atmospheric contributions to sea ice extent are examined in the context of relative vorticity to highlight variations in wintertime preconditioning events when the cold core polar vortex governs surface phenomena (Hare, 1968; Overland, 2009). Examined in particular are the stratospheric (10 mb) relative vorticity fields in 2007 and 2010 for March and April during the breakup of the wintertime polar vortex. Monthly means of ECMWF ERA-Interim relative vorticity used in this study were obtained from the ECMWF data server.

Stratospheric winds for March and April are also examined and compared with composites for years characterized by minima in sea ice extent, as presented in the 2009 June and July SIO submissions, and additional information may be found therein (Lukovich and Barber, 2009). Stratospheric winds were once again obtained from the NCEP reanalysis dataset provided by the NOAA/ESRL Physical Sciences Division. Revised composites (relative to the 2009 SIO outlook submission) based on record minima in sea ice extent in September include the years 2002 - 2009, in accordance with time series for monthly records of sea ice extent (http://earthobservatory.nasa.gov/Features/WorldOfChange/sea_ice.php).

Zonal and meridional surface wind anomalies, composites for vector surface winds and SLP for years associated with record lows in ice extent for June also provide an indication of anticipated dynamical properties at the surface during years characterized by record minima in ice extent. Differences in patterns for surface winds and in record minimum composites for SLP minimum in June provide a reference for regional differences in advection and convergence/divergence properties that will accelerate or inhibit summertime sea ice decline. A comparison of ice extents for June, 2007 and June, 2010 is also presented to illustrate regional differences in ice conditions leading up to the September minimum in ice extent.

Figures

1. SAT, SLP and 850 mb temperature anomalies relative to the 1979 – 2010 climatological mean.
2. Stratospheric relative vorticity in March and April for 2007 and 2010
3. Vector stratospheric winds in March for 2007, 2010, and years characterized by minima in sea ice extent.
4. Zonal surface wind anomalies and composites in June
5. Meridional surface wind anomalies and composites in June
6. Vector surface wind composites for minima in sea ice extent. Minima in sea ice extent and dipole anomaly pattern.
7. SLP composites and differences for 2007 and 2010
8. Sea ice extent in June, 2007 and June, 2010.

3) Results and Rationale

SLP and SAT anomalies for 2007 and 2010

Positive surface air temperature anomalies in 2010 are spatially comparable to those found in 2007, with the exception being the presence of positive temperature anomalies over much of the Canadian Archipelago and Hudson Bay in 2010. Considerable breakup of fast ice in Parry Channel and McClure Strait has been observed in June 2010 (more so than 2007), and sea ice cover is rapidly being removed within Hudson Bay. It is therefore expected that the Northwest Passage will be navigable by icebreakers (using satellite and helicopter reconnaissance) as early as late July, and by any vessel by mid-August.

A dipole structure in mean sea level pressure is present for both June 2007 and 2010, with low (high) pressure anomalies over central Siberia (the North pole). A stronger pressure gradient is indicated in 2010 versus 2007, which suggests stronger surface winds, and temperature advection which may enhance both sea ice motion and sea ice decay. The prevalence of high pressure over much of the Arctic pack ice during June 2010 maintained lower amounts of cloud cover, having a net positive effect on the radiation balance of the sea ice surface.

The state of the El Nino Southern Oscillation and the Arctic Oscillation play an important role on winter atmospheric circulation in the Northern hemisphere. Winter 2009/2010 was characterized by a moderate El Nino, resulting in a deepened westward-shifted Aleutian Low, and a split jet stream. Although the El Nino event has now subsided in the tropics, meridional circulation patterns have persisted in the Northern hemisphere into

June. This has resulted in deepened ridges and troughs persisting over North America and Eurasia into June, and has resulted in numerous warm air intrusions into the High Arctic. The Arctic oscillation was strongly negative, and is attributed to cold air outbreaks in Europe, and a deepened Icelandic Low. Meridional temperature advection is observed at the 850mb level. 850mb air temperature anomalies are somewhat less in magnitude than in 2007, but describe the advection of warm air aloft into the ridge of high pressure that is centred over the North Pole, which helps maintain the surface high pressure zone.

The frequency and intensity of summer cyclones will place a key role in the reduction of sea ice cover this summer, particularly if large areas of open water characteristic in the past 3 years are present. Summer storms can form over Eurasia and track into the Arctic Basin, increasing winds and subsequent divergence in the sea ice cover. Storms that are maintained by deep upper-level lows can persist for weeks, and even cause the Beaufort Gyre to reverse direction (McLaren et al., 1986; LeDrew et al., 1991). These summer reversals have become more frequent in recent years, with an increase in mobility of the ice pack that accompanies decreased summer sea ice coverage (Lukovich and Barber, 2006; Asplin et al., 2009). Reversals of the BG lead to ice divergence, lower sea ice concentrations, and lead to increased export of multi-year ice through Fram Strait.

Stratospheric relative vorticity fields

Stratospheric (10mb) relative vorticity fields in March of 2007 exhibit a pattern comparable to the dipole anomaly presented in studies by Wang et al. (2009), with predominantly anticyclonic (cyclonic) circulation over the western (eastern) Arctic Ocean (Figure 2a), as noted in previous sea ice outlook submissions (Lukovich and Barber, 2009). A similar, albeit less distinctive pattern in relative vorticity is observed in March of 2010 (Figure 2b). The transition from positive to negative vorticity, or between cyclonic and anticyclonic circulation in April is oriented parallel to Fram Strait and over the transpolar drift stream in 2007 (Figure 2c). The transition from cyclonic to anticyclonic circulation is however shifted westward in 2010 and oriented over Baffin Bay, suggesting differences in zonal and meridional stratospheric dynamical contributions and their anomalies to surface preconditioning phenomena in late winter.

It is also interesting to note that relative vorticity fields in April, 2010 resemble those in March, 2007. Moreover, patterns in SLP fields in June, 2007, reflect the reversal in relative vorticity fields in April, 2007; east-west asymmetry in the SLP low (high) in the western (eastern) Arctic in June is also apparent in the stratospheric anticyclonic (cyclonic) circulation in the western (eastern) Arctic in April.

Stratospheric winds in March and April

Stratospheric (10 mb) winds and composites for years associated with minima in sea ice extents in March 2007 exhibit maximum wind speeds in the western Arctic in a manner similar to composites for vortex displacement events noted in previous SIO submissions (Figure 3). As noted by Hare (1968) and Overland (2009) the cold core polar vortex governs surface winter conditions; as described in the June, 2009 submission, a similarity in composites for years associated with vortex displacements and minimum sea ice extent may be attributed to coherent deformation of the vortex during vortex displacement events, in contrast to vortex splitting events where cyclonic remnants erode stratosphere-surface connections in late winter. Differences between 2010 and 2007 and composite stratospheric winds in March and April (Figure 3b) and Figure 3e) compared to Figure 3c) and Figure 3f)) suggest that wintertime preconditioning events due to stratospheric dynamical phenomena in 2010 will not contribute to accelerated ice loss and retreat in summer due to dynamical phenomena in winter, relative to ice loss and retreat in 2007.

Surface zonal and meridional wind anomalies in June

Surface zonal wind anomalies in June, 2007 and 2010 indicate strong easterlies in the Beaufort Sea region relative to the 1979 – 2010 climatological mean, indicating enhanced advection of sea ice out of this region throughout summer (Figure 4a) and Figure 4b). Similarity between the spatial patterns in surface zonal wind anomalies in June, 2007, 2010 and sea ice minimum composite (Figures 4 a), b), and e) suggests a continued decline in sea ice due to dynamic contributions associated with advection.

Similarity in spatial patterns for meridional wind anomalies in June, 2007, 2010 and for the difference between the climatological mean and sea ice minimum composite (Figures 5 a), b) and e) indicate advection and entrainment associated with northerly flow to the west of Banks Island in 2010, in addition to enhanced export through Fram Strait due to stronger northerly flow. Also of interest is the maximum in southerly winds over the Laptev Sea which, if sustained during the summer, could lead to enhanced ice retreat in this region. Increased northerly flow to the west of Banks Island and decreased southerly flow in the southern Beaufort Sea for 2010 (Figure 5b) also indicates dynamical contributions to a decline in sea ice due to advection, rather than advanced retreat from the coastline, depending on ice conditions and the persistence of meridional winds in this region.

Surface wind anomalies for June

Surface vector winds for June, 2007, 2010, sea ice minima composites and the difference between 2010 and sea ice minima composite summarize spatial patterns from zonal and meridional wind anomalies (Figure 6). Noteworthy in particular is the aforementioned eastward shift in maxima and enhanced southerly flow in the Laptev Sea region (Figure 9d), indicating contributions to enhanced ice retreat due to southerly flow in this region.

SLP composite and differences for June

Information on regions of convergence and divergence associated with SLP highs and lows (and associated anticyclonic and cyclonic circulation) is illustrated, and regional differences highlighted, through investigation of the SLP composites and differences for June (Figure 7). East-west asymmetry in high and low SLP in the eastern and western Arctic region evident during vortex displacement events and minimum ice extent components in June (as noted in a previous SIO submission) is also apparent in June of

2007 and 2010 (Figures 7a) and 7b)). Noteworthy is the difference field for 2010 – 2007 in Fram Strait compared to the difference field for 2010 and the sea ice minimum composite, indicating export through Fram Strait comparable to that encountered in 2007. SLP patterns in the Beaufort Sea region are also similar in 2007 and 2010, with an eastward and poleward shift in the SLP high for 2010.

Recent studies have noted the role of persistent SLP over the Beaufort Sea during July, August and September and strong meridional flow in the retreat of, and record reduction in, sea ice in the summer of 2007 (Kwok, 2008; Ogi et al., 2008). Comparison of SLP for 2010 with sea ice minimum composites illustrates a strengthened SLP high in the Beaufort Sea region and raises the question as to whether June conditions will now play a role due to the earlier onset of ice melt, and act as a dynamical predictor for ice retreat in September.

Ogi et al. (2008) also highlighted in their assessment of the record reduction in sea ice in 2007 the role of free drift conditions in ice retreat. In particular, buoys will travel to the right of the surface winds and towards the centre of an anomalous anticyclone if in a state of free drift. Also of interest is convergence/divergence of the ice pack depending on free drift conditions of sea ice and ice thickness. Recent updates of ice conditions in the Arctic have indicated a reduction in ice loss due to a filament of multi-year (two- to three-year) ice that may inhibit Ekman drift towards the centre of the SLP high and further ice retreat

Sea ice extent for June 2007 and 2010

The occurrence of large areas of open water during the summer months (July – August) represent large areas of fetch distance, where persistent winds from cyclones may churn up long period waves that can propagate across the open water, and into the pack ice where they cause large ice floes to fracture (Figure 8). Such an event was observed in situ by the authors in September 2009. A longwave swell of period 16s with wavelength 200m was observed to cause flexural failure in large multi-year floes (5km+ diameter) approximately 250nm from the ice edge (Asplin et al., 2010 *in prep*). Furthermore, heavily decayed (rotten) first-year ice, interspersed with small old ice floes were observed in the Beaufort sea during the same cruise (Barber et al., 2009). The effects of flexural fracture in the old ice, and remnant rotten ice may have resulted in a weaker ice cover in 2010. Although speculative, it could prove to be a critical factor this year as much old ice was observed in the Southern Beaufort and Chukchi seas in April 2010, and will be more resistant to melting. It will be very interesting to observe this sector of the Arctic Basin as the surrounding first-year ice decays, leaving predominantly old ice to persist later into the summer.

4) Executive Summary

Similarity in the surface air temperature (SAT) and sea level pressure (SLP) fields in June 2007 and 2010, with increased temperatures over Hudson Bay and the Canadian Archipelago, and stronger winds associated with a strengthened SLP high over the western Arctic indicate that sea ice decline will exceed the 2007 record minimum in ice extent. Differences in wintertime stratospheric dynamical phenomena in late winter between 2007 and 2010 suggest that dynamic contributions to ice loss will not be as significant in September 2010 as in 2007. June conditions of surface meridional anomalies however highlight the possibility of enhanced ice loss due to advection out of the Beaufort Sea region and through Fram Strait, and ice retreat in the Laptev Sea region. Further investigation of ice thickness and free ice drift conditions, in addition to persistence of SLP maxima will provide further insight as to whether convergence (divergence) of sea ice associated with SLP highs (lows) will give rise to increased ice retreat in the Arctic and the Beaufort Sea region in particular.

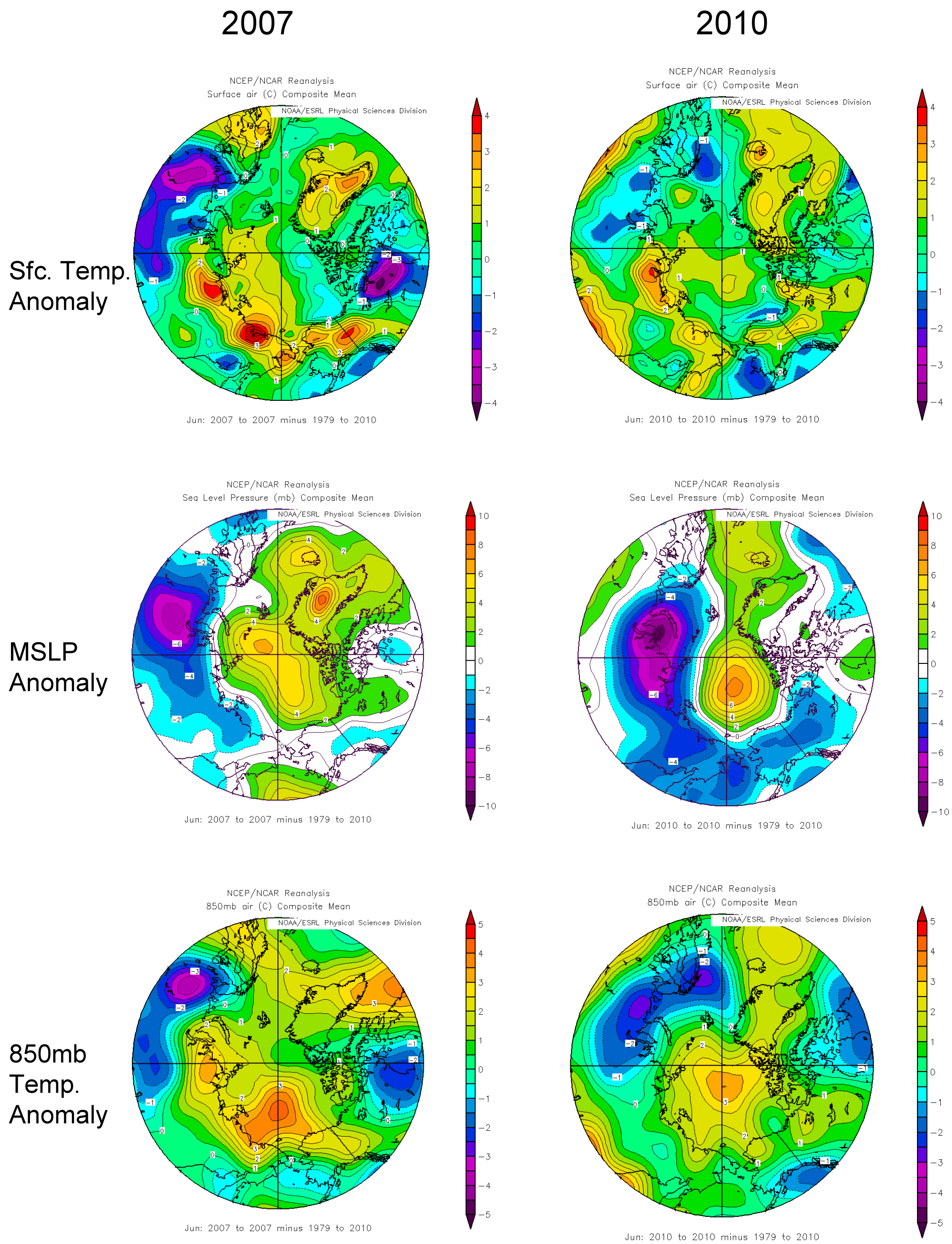


Figure 1. SAT, SLP and 850 mb temperature anomaly for 2007 (left column) and 2010 (right column). Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/

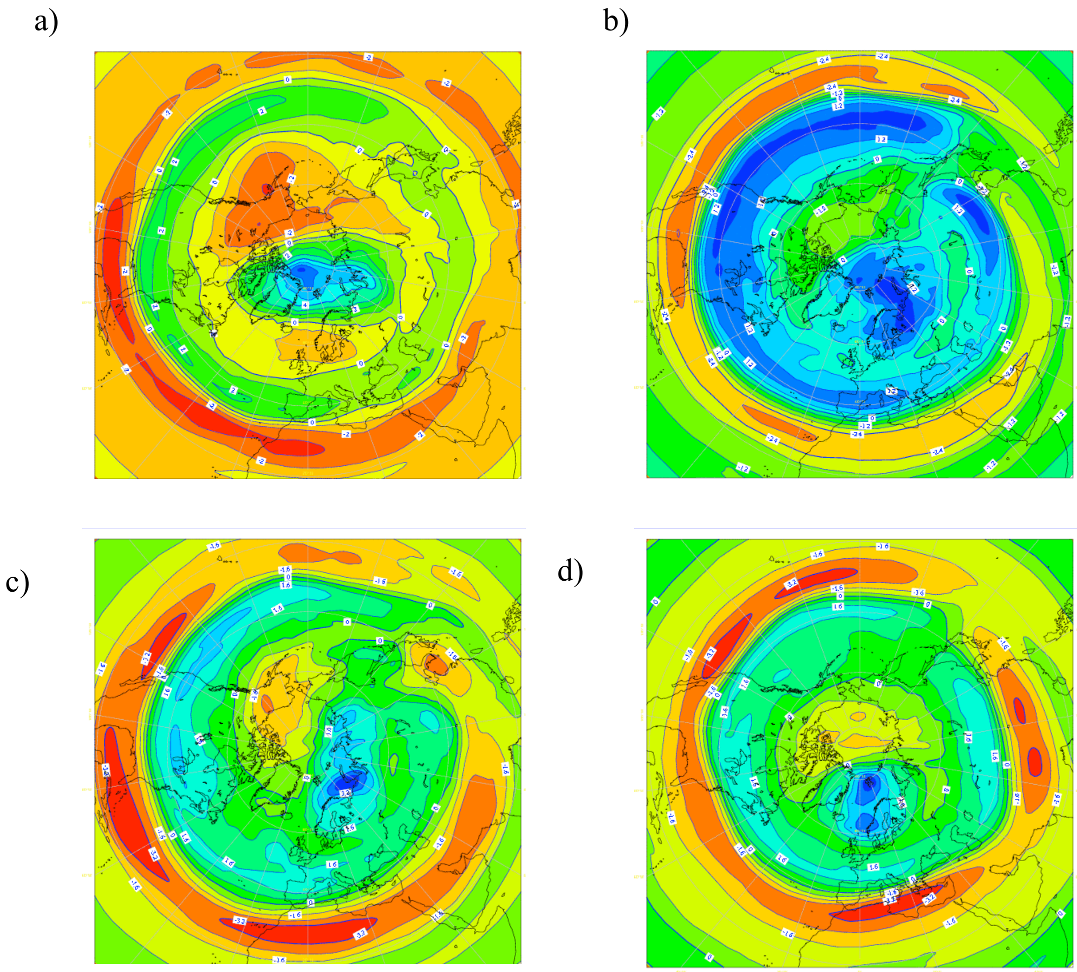


Figure 2. Stratospheric (10 mb) relative vorticity fields for March in a) 2007 and b) 2010, and April in c) 2007 and 2010 d). Anticyclonic activity (negative relative vorticity) is depicted by red shading. Image provided by the ECMWF ERA-Interim data portal at http://data-portal.ecmwf.int/data/d/interim_moda/levtype=pl/.

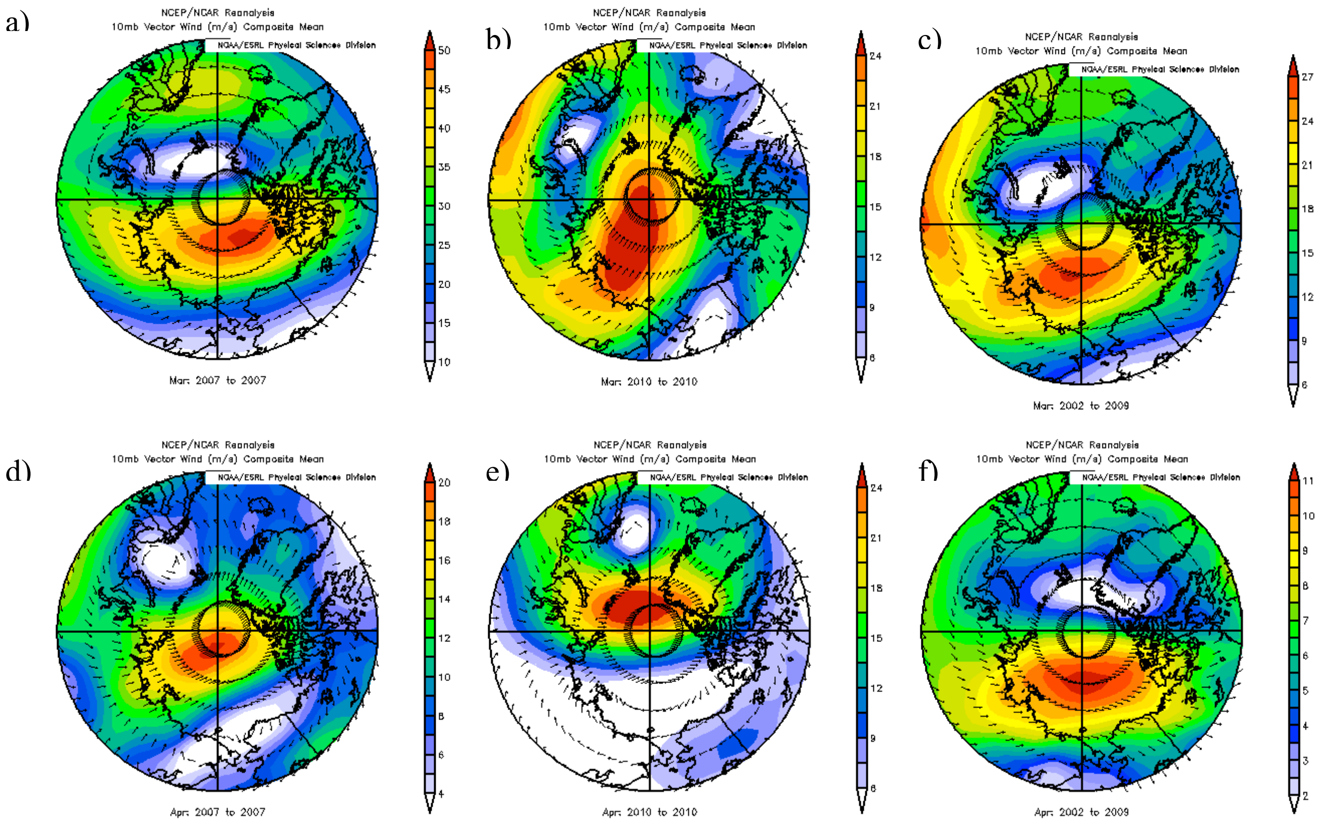


Figure 3. Stratospheric winds in March in a) 2007, b) 2010 and for minima in sea ice extent, and in April in d) 2007, e) 2010, and f) for minima in sea ice extent. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/

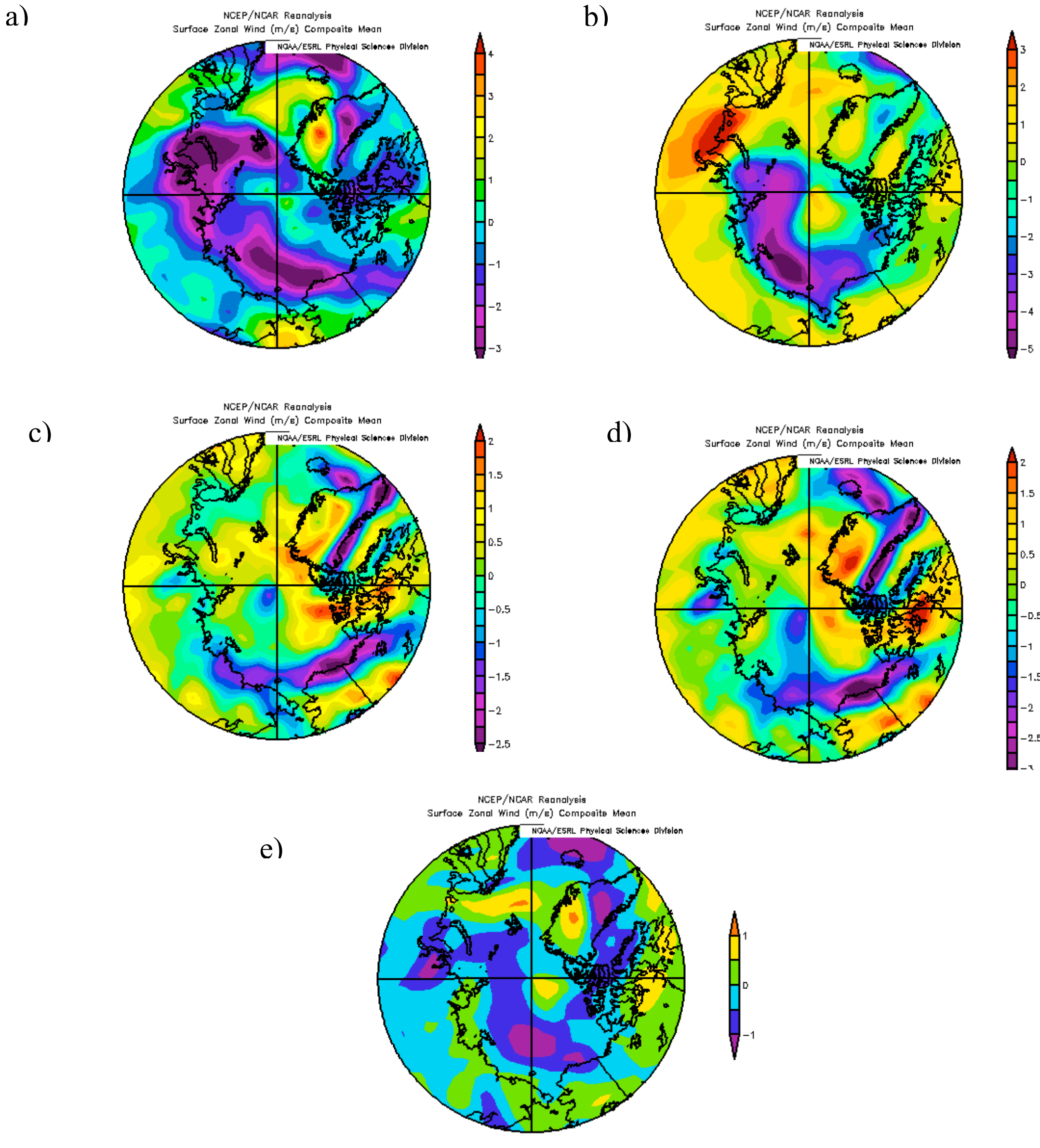


Figure 4. Surface zonal wind anomalies in June in a) 2007 and b) 2010, and c) average zonal winds from 1979 – 2010 c), d) composites for minima in sea ice extent and e) difference between composite and climatology. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/

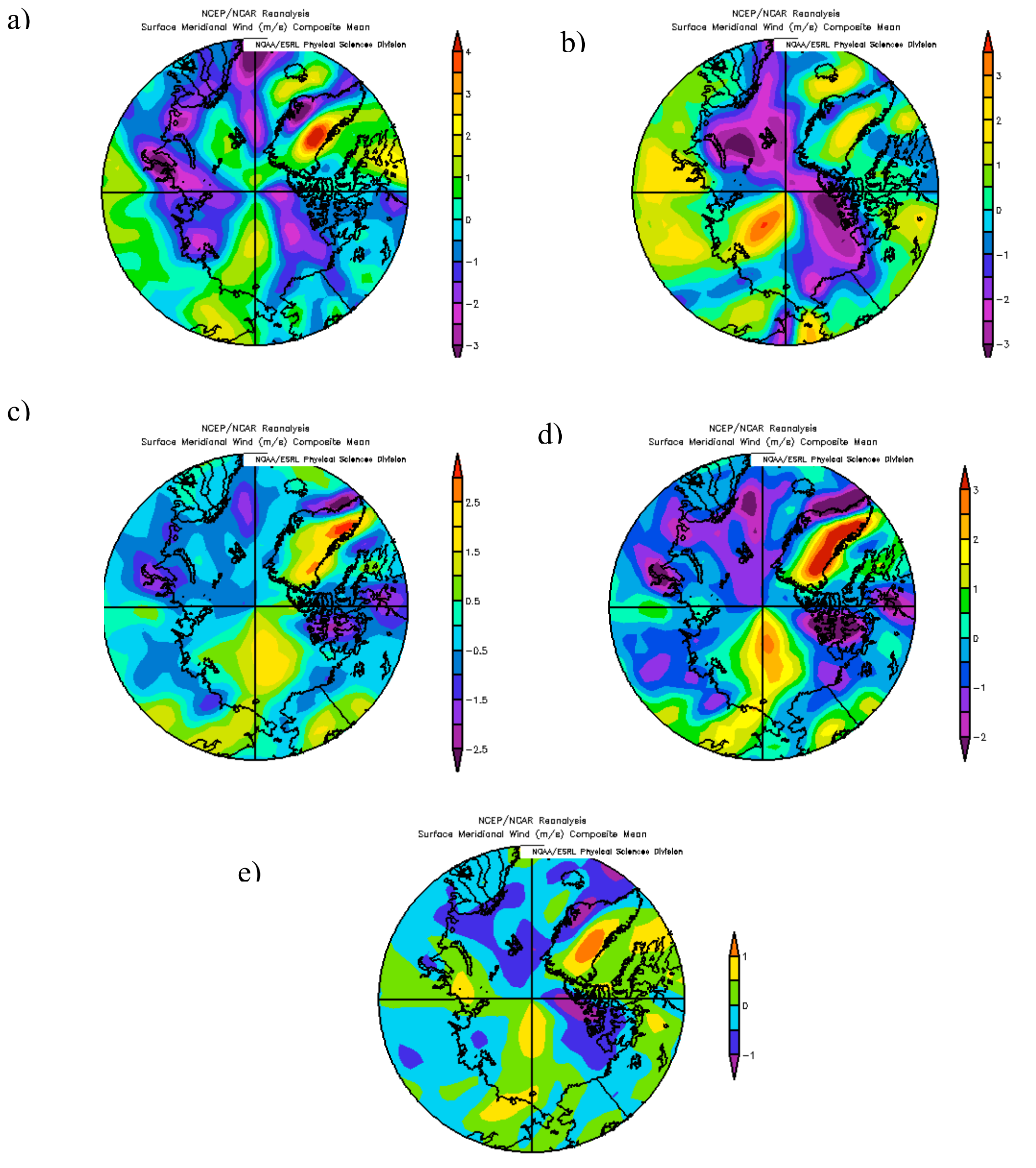


Figure 5. Meridional wind anomalies in June in a) 2007, b)2010 and mean meridional winds from c) 1979 – 2010, and d) composite for years associated with minima in sea ice extent.

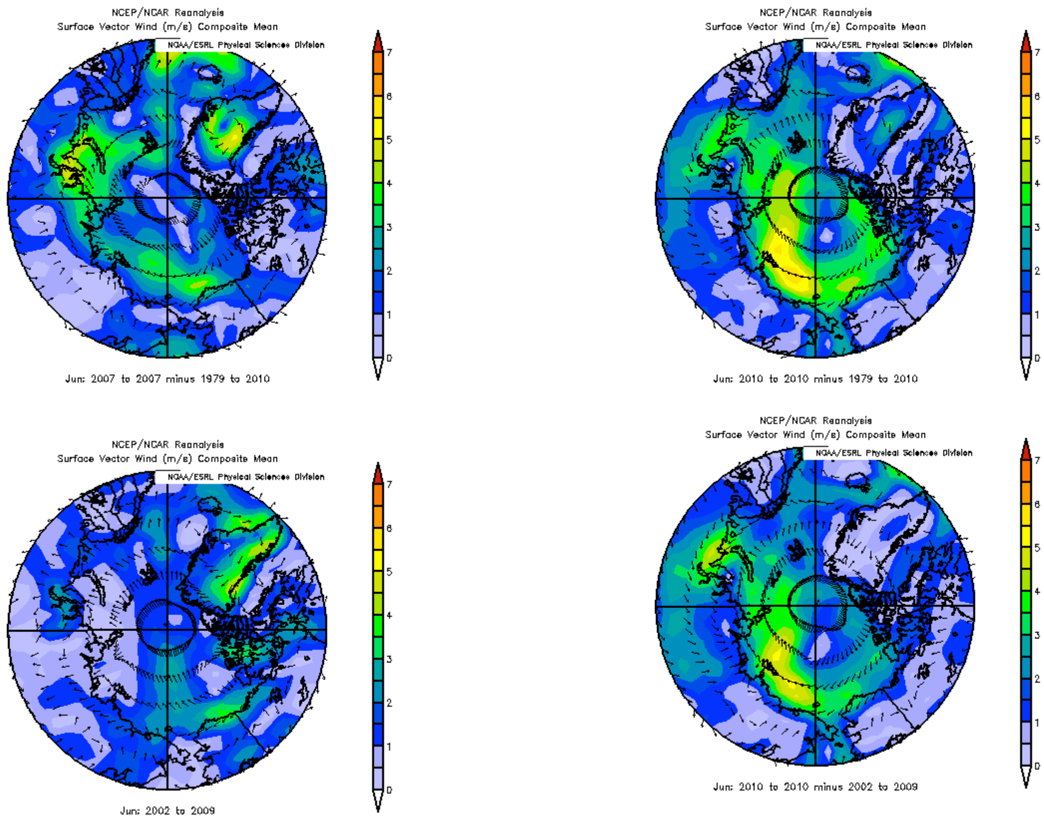


Figure 6. Vector winds for June in a) 2007, b) 2010, c) sea ice extent minimum composite for 2002 to 2009 and d) difference between June, 2010 and sea ice extent composite. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/.

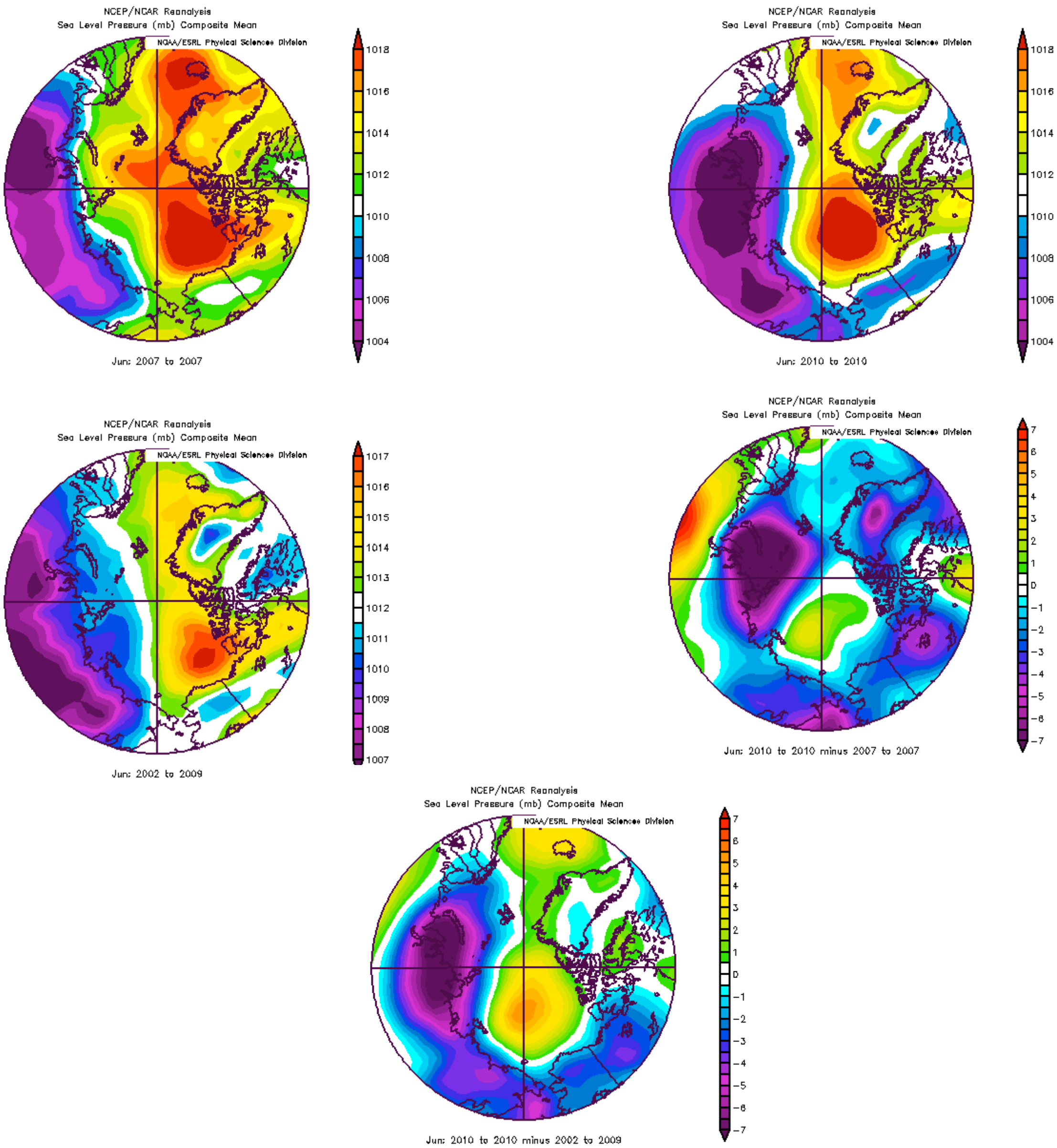


Figure 7. SLP for June in a) 2007, b) 2010, c) sea ice minimum composite from 2002 to 2009, d) difference between 2010 and 2007, and e) difference between 2010 and sea ice minimum composite.

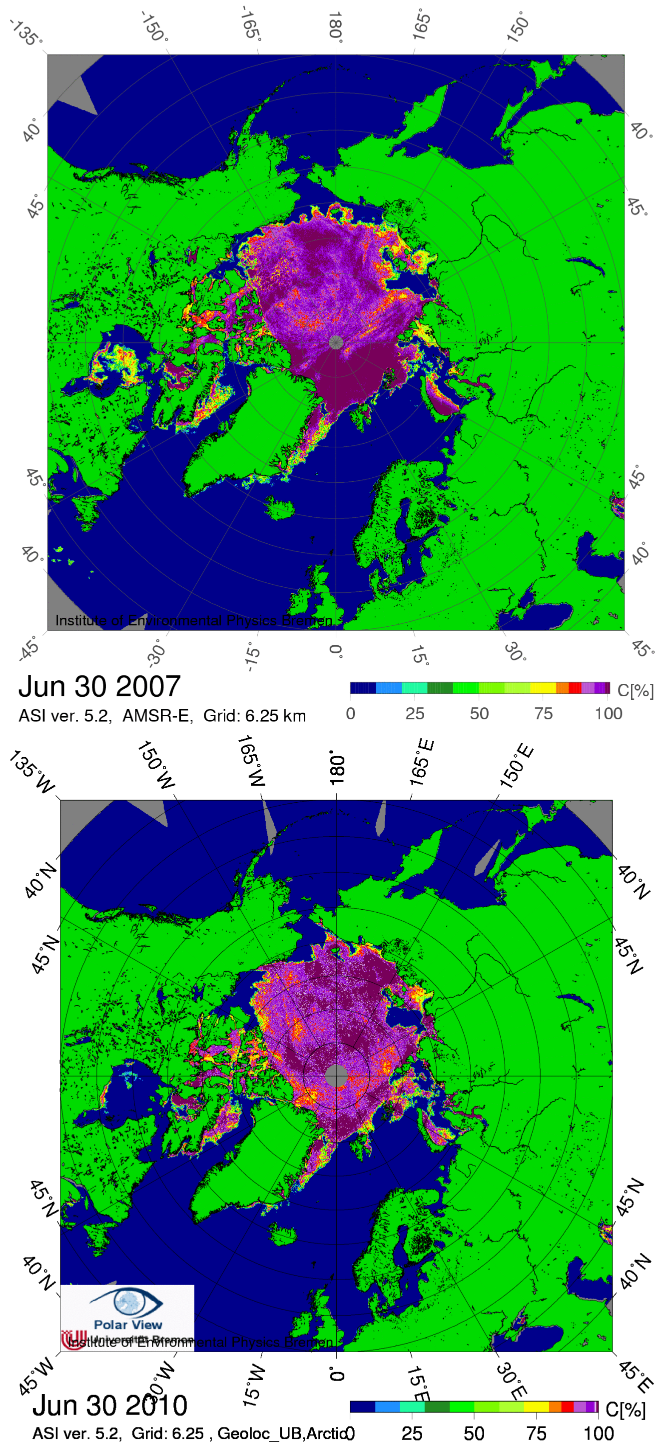


Figure 8. Sea ice extent and ice concentrations for a) June 30, 2007 and b) June 30, 2010. Source: http://www.iup.uni-bremen.de:8084/amsr/

2010 Sea Ice Outlook Projections as of 14 July 2010

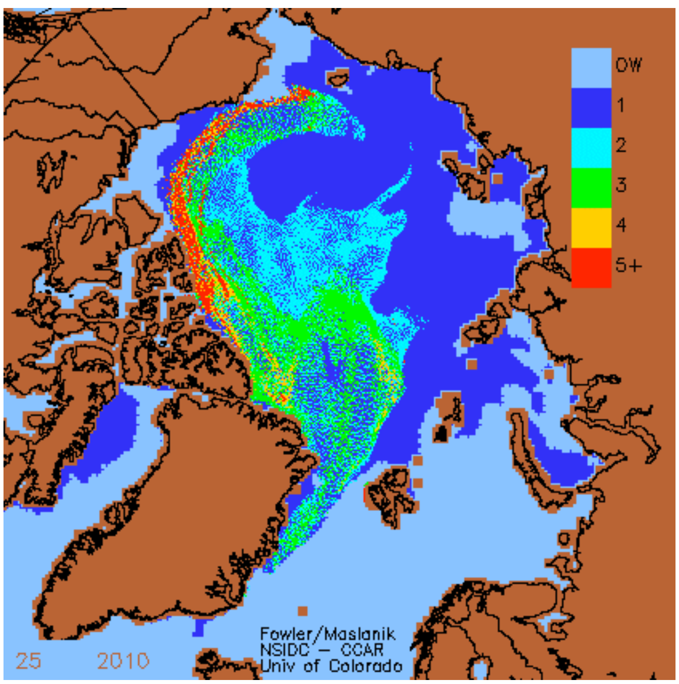
J. Maslanik
University of Colorado

1. Extent Projection

Our overall projection for minimum ice extent remains unchanged from last month. That estimate is that the end-of-summer ice extent will be 4.5 x 10^6 km^2 , with the possibility of 3.8 x 10^6 km^2 depending on atmospheric circulation.

2. Methods/Techniques

The following is based on subjective analyses based on various data sets and historical patterns. This includes assessment of U. of Colorado satellite-derived (Lagrangian drift) sea ice age and ice drift in the context of conditions in previous years, along with review of atmospheric fields and a variety of other data sets.



3. Rationale

Our projection is based on the following rationale:

Comparing our latest ice age data (for 21 June 2010; left) to current (14 July) ice extent data shows that the pack edge has retreated back to the multiyear ice edge in the eastern Arctic and in the Beaufort and Chukchi seas. (It is important to emphasize that since we use a 40% concentration cutoff, this means that ice still could be present in areas where we show "open water" in these maps.) Further retreat may therefore be delayed in those areas, which might account for the decrease in the previously rapid rate of ice loss seen in the total ice extent plot on NSIDC's Sea Ice Index page. Ice remains extensive in the East Siberian and Laptev seas, consistent with wind patterns that have favored westward and southward drift into those areas during June. Over the first part of July however, low pressure has become more dominant in the central Arctic, which could set up northward drift along with warm air transport in those areas. This pattern would be consistent with mean pressure fields for July-September. The result could be a rapid retreat of the first-year ice cover in the Siberian seas and Canada Basin and accelerated decrease in total extent. We still anticipate some retreat of the second-year (light blue) ice in the central Arctic and persistence of the older ice into late summer.

Beaufort and Chukchi seas:

As noted in the pan-Arctic outlook discussion, the 40% concentration ice edge has retreated to the edge of the band of the several-year-old multiyear ice in the Beaufort and Chukchi seas. Since our data show this multiyear ice as being close to shore near Barrow, it is likely that ice will persist in that area relatively late into the melt season. Some offshore, northward drift of this strip of ice is likely, particularly in the Chukchi Sea if typical summer circulation patterns occur.

We anticipate that the ice further north, beyond the oldest ice (yellow and red) will melt out first, perhaps leaving a narrow strip of multiyear ice but with a semi-enclosed "polynya" opening up in the western Canada Basin.

East Siberian and Laptev seas:

As noted above, we think it likely that the first-year ice persisting in these areas will melt or retreat rapidly through the rest of July and August.

4. Executive Summary

We anticipate that the end-of-summer ice extent will be 4.5 x 10^6 km^2 . A larger decrease to 3.8 x 10^6 km^2 is possible depending on atmospheric ciculation patterns. Ice extent is likely to retreat rapidly in the East Siberian and Laptev seas, with thick multiyear ice persisting in the southern Beaufort Sea and eastern Chukchi Sea. Overall, we expect the loss of ice extent to accelerate, following the slow-down seen over the last few weeks.

September 2010 Sea Ice Outlook
July Report

A. McLaren, H. Hewitt, A. Maidens, A. Arribas and D. Peterson
Met Office Hadley Centre

Caveat: This is an experimental projection, not an official Met Office forecast

Extent Projection

5.5 million square kilometres.

Method (Coupled atmosphere-ice-ocean model ensemble runs)

This projection is an experimental model prediction from the Met Office Hadley Centre seasonal forecasting system (GloSea4). GloSea4 is an ensemble prediction system and became operational in September 2009 (Arribas *et al*., 2010). It uses the same coupled model as the latest Hadley Centre coupled climate model (Hewitt *et al.*, 2010) consisting of the following model components:

- atmosphere = UM (Met Office Unified Model; Davies *et al.*, 2005)
- ocean = NEMO (Nucleus for European Modelling of the Ocean; Madec, 2008)
- sea ice = CICE (Los Alamos sea ice model; Hunke and Lipscomb, 2010)
- land surface = MOSES (Met Office Surface Exchange Scheme; Essery *et al.*, 2003).

The GloSea4 system has a real-time forecasting component, together with an accompanying set of hindcasts (or historical re-forecasts) which are used for bias correction and skill assessment. The forecasts and hindcasts differ only by their initial conditions and are typically run for 6 months. The hindcasts are currently done for the period 1989-2002.

The ocean is initialised using an ocean data assimilation scheme (Martin *et al.*, 2007) which assimilates ocean SST (in-situ and satellite) and ocean profiles (temperature and salinity). The atmosphere initial conditions are provided by the Met Office operational numerical weather predition analyses for the forecast run and from ERA-interim (ECMWF, 2009) reanalysis for the hindcast runs. Currently sea ice is initialised from a previous coupled model climatology (HadGEM1 under pre-industrial conditions). This is a major limiting factor in our ability to attempt to forecast the sea ice over a timescale of months. Work is ongoing to assimilate sea ice concentration observations into the ocean data assimilation scheme, which should become operational within the next year.

Both GloSea4 and the coupled model are under continual development. For example, work is currently being done to improve the Arctic ice thickness distribution which is not as realistic as the previous Hadley Centre climate models (HadGEM1 and HadGEM2). This is also the first time that the sea ice in the GloSea4 system has been investigated, as the focus for seasonal forecasts has generally been looking at ENSO and its teleconnections. Given these issues and the lack of realistic sea ice initial conditions, the September sea ice extent prediction is given here with low confidence as a prediction, but more as an illustration of our potential to provide such estimates in the future. It will also act as a useful benchmark for assessing the impact of future developments.

Further information on GloSea4 is available on the Met Office website:
(http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/glosea4).

Hindcast Results and the Summer 2010 Forecast

September ice extent anomalies for 1989-2002 from the May hindcast ensemble are shown in figure 1. The ensemble for each year consists of 9 model runs (3 different start dates each used for 3 runs with different physics perturbations). The correlation of the ensemble mean with the observational data set HadISST (Rayner *et al.*, 2003) is low (0.31) which is probably to be expected given the issues discussed above.

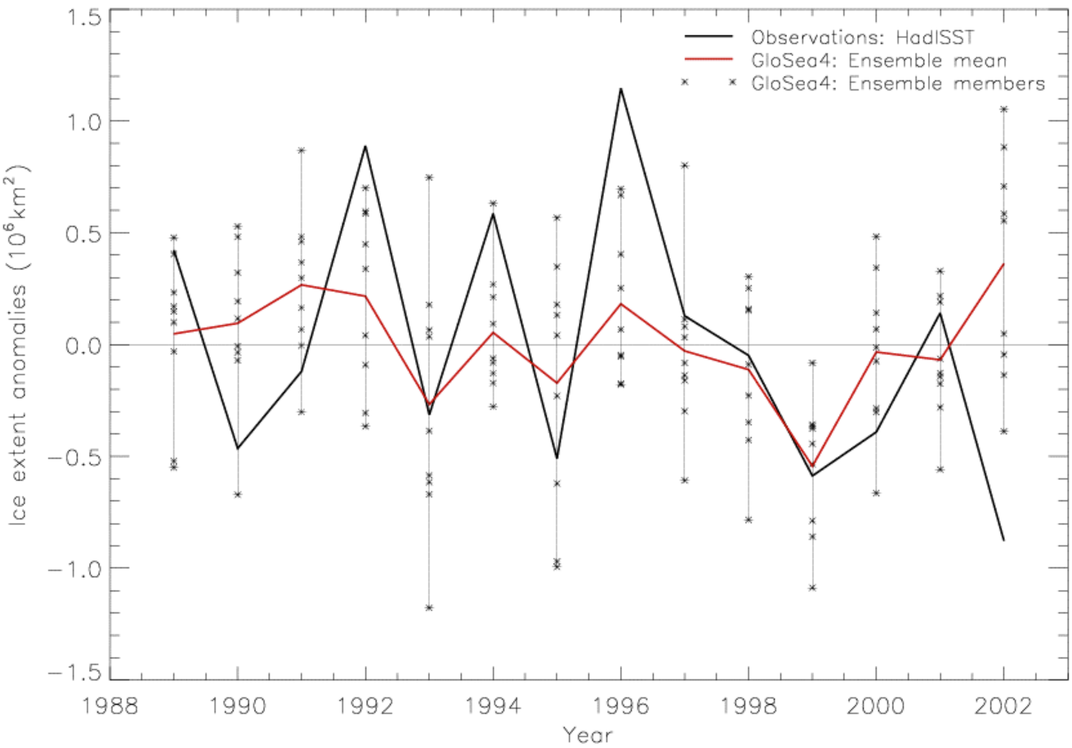


Figure 1: Arctic ice extent anomalies of the September monthly mean for the HadISST observational data set (Rayner *et al.*, 2003) (red line) and the GloSea4 hindcast ensemble mean (thick black line) for 1989-2002. Observed (model) anomalies are relative to the observed (model) climatology for 1989-2002. Results from the individual ensemble members are shown by the asterisks.

The September 2010 prediction uses the ensemble mean from 42 runs (3 different start dates each used for 14 runs with different perturbed physics) starting in May. The ice extent anomalies for the different ensembles are shown in figure 2, relative to the hindcast 1989-2002 climatology. The ensemble mean anomaly is then added to the HadISST dataset 1989-2002 climatology to give a prediction for September 2010 of 5.5 million square kilometres. Despite the known model deficiencies, it is encouraging that this estimate lies in the range of the June Outlook report projections.

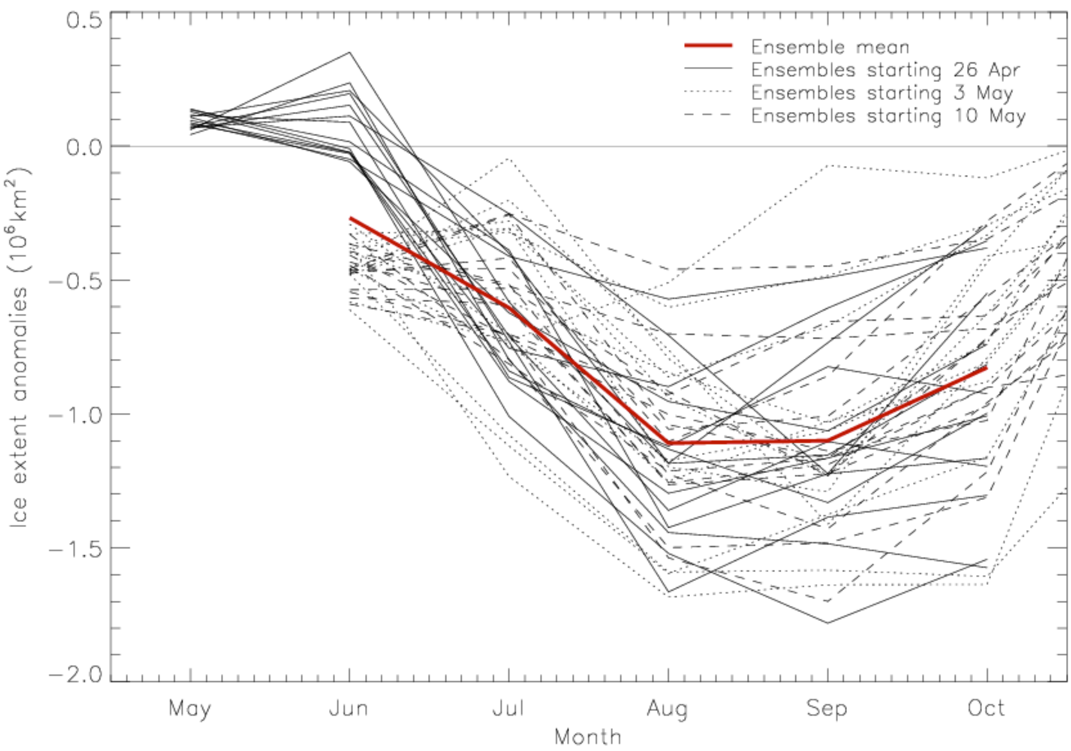


Figure 2: GloSea4 forecast for summer 2010 Arctic sea ice extent anomaly relative to the model climatology for the hindcast period 1989-2002. The ensemble mean (red line) is shown together with the 42 ensemble members (black lines).

Executive Summary

The September monthly mean sea ice extent for the Arctic is predicted to be 5.5 million square kilometres.

This experimental estimate is from the Met Office Hadley Centre seasonal forecasting system (GloSea4). GloSea4 is an ensemble prediction system that uses the same atmosphere-ice-ocean coupled model as the latest Hadley Centre climate model. Both the system and the model are under continuous development; for example the sea ice in the seasonal forecast is currently initialised with a model climatology, but this will be improved to use assimilated ice concentration observations soon. Hindcast runs indicate that there is little skill in our *current* system for predicting September ice extent. Therefore the 2010 prediction is given with low confidence, but illustrates our methods and our potential to provide improved model estimates in the future.

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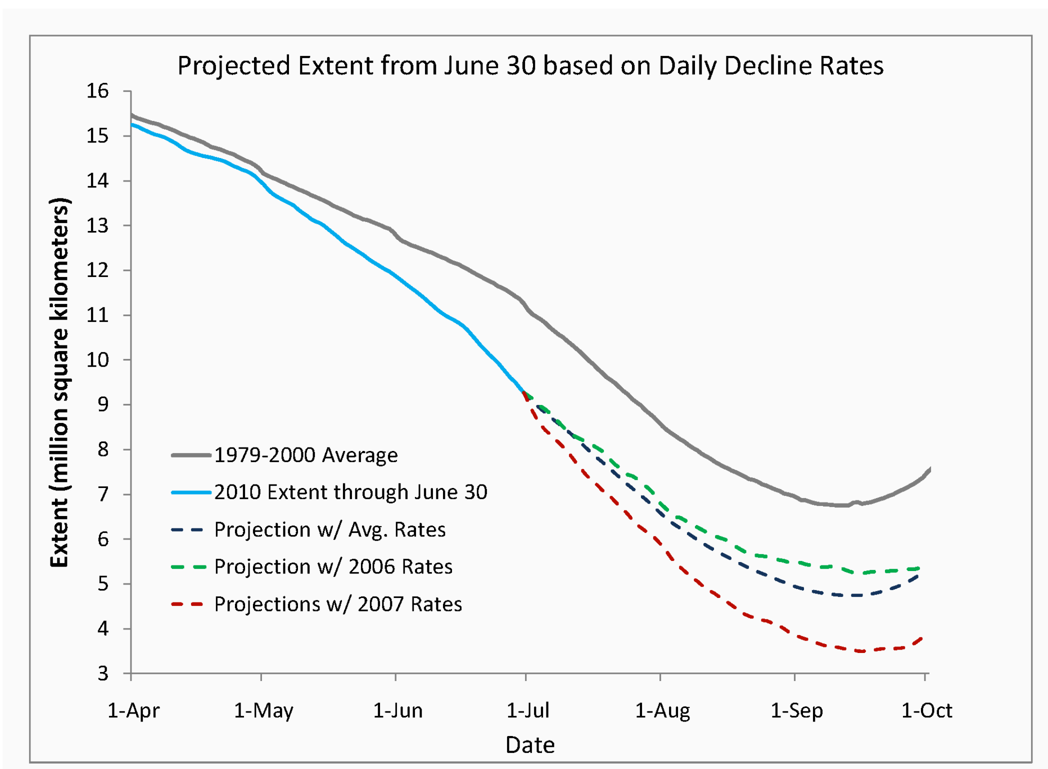
2010 Sea Ice Outlook, June Report

Walt Meier, Julienne Stroeve, Mark Serreze, Ted Scambos
National Snow and Ice Data Center (NSIDC)

<u>*Summary*</u>

NSIDC's first outlook for May based on survival rates of different ice age classes from the end of March, designated as Stroeve et al. This yielded a range between 5.21 and 5.76 million square kilometers based on average survival rates for 2005-2009 and 2000-2009 respectively, with an average estimate of 5.5 million square kilometers. This estimate is unchanged. See the previous report for details of this method.

Here was also implement an alternative NSIDC method, by Meier, Stroeve, Serreze, and Scambos. This is based on daily decline rates from July 1 until the minimum extent is reached. Using average daily decline rates from 1979-2000, the minimum extent is estimated to be 4.74 million square kilometers. To provide a range, we estimate the minimum based on decline rates for two recent years. Using 2006 rates, when the decline through July, August, and September was slower than normal, yields a minimum estimate of 5.23 million square kilometers. Using 2007 rates, when the summer decline was rapid, yields a minimum estimate of 3.49 million square kilometers. We note here that rates have slowed since the June 30 cutoff for data. Thus, at the time of submission (14 July) it is more likely that the final extent will be closer to 2006 and than to 2007.



Projected timeseries of extent starting July 1, 2010 through October 1, 2010 using decline rates from: (dark blue) 1979-2000 average, (green) 2006 rates, and (red) 2007 rates. The light blue line is the observed data through June 30. The gray line is the 1979-2000 average extent.

Details of Method

After the solstice, the melt rate and hence rate of extent loss starts to become more and more constrained as the incoming solar energy decreases. The extent loss rates from different years essentially represent the effect of weather variations during the remainder of the summer with the observations representing initial conditions. Our method projects a minimum daily extent by simply stepping forward day-by-day using a rate from a given year or average of years for each day.

Simply using **climatological daily rates** from 1979-2000, we obtain an estimate of **4.74 millions square kilometers**. Rates from different individual years can provide a range. Here we selected two recent years, 2006 and 2007, to provide a range around the climatological average. Both 2006 and 2007 both have relatively less multiyear ice than during the earlier part of the record and thus are more consistent with the initial thickness character of the ice in 2010. However, the evolution of the extent loss differed greatly between the two years due to different weather conditions. In 2006, the summer loss was quite slow, while 2007 experienced the most rapid decline in the satellite record. In 2006, extent rarely declined by more than 100,000 square kilometers per day and even in early July, decline rates were around 50,000 square kilometers per day. However, in 2007, there were some days in early July where 200,000 square kilometers of ice was lost and rates remained at or near 100,000 square kilometers per day through most of July and into early August. Using **2006 rates**, we obtain a 2010 estimate of **5.23 million square kilometers**; for **2007 rates**, we obtain an estimate of **3.49 million square kilometers**.

There are important issues to keep in mind. First, the weather may differ significantly from other years or the climatological average. In addition, the initial extent (June 30) for this year is different from other years or climatology on which the rates are determined. In other words, the rate of extent loss is a function not only of the weather conditions through the summer, but also the starting extent. Conditions exactly like 2006 would not necessarily result in the same daily decline rate if the starting extent was some other value than the June 30, 2006 extent. Not only the total extent, but the distribution of ice within the Arctic and, as mentioned above, the thickness distribution (e.g., multiyear vs. first-year), will also affect the decline rates.

Addendum since June 30

We base our estimates here on data through June 30 as stipulated in the Sea Ice Outlook guidelines. However, we note that between the June 30 cut-off date and the submission date (July 14), the decline rate has slowed significantly, at least for the time being. Each day of slower than normal melt means that a lower minimum becomes less likely (because there is one less day of melt remaining and the extent hasn't decline much), because a few days of slow decline can substantially change projections.

The slowdown has been caused by a change in the sea level pressure, where high pressure that dominated over much of the Arctic through June has been replaced by a succession of low pressure systems. The low pressure systems bring more clouds, reducing solar insolation. Low pressure also results in divergence of the ice pack, opening up ice-free areas within the ice pack. These unconsolidated ice regions will be more prone to melt through the summer. Thus we expect decline rates to increase. However, with over a week already of slower rates, it seems a record minimum extent is unlikely, even if decline rates pick back up to 2007 levels. Much still depends on how the weather plays out through the rest of the summer, but as sun begins to set, the end of the melt season is on the horizon and the potential range for minimum extent begins to narrow more and more.

PAN-ARCTIC OUTLOOK As of July 13, 2010

J. Morison and N. Untersteiner
University of Washington

1. Extent Projection
5.6 million square kilometers

2. Methods / Techniques
Heuristic: judgment based on recent observations, e.g., previous winter AO, ice conditions observed during NPEO hydro surveys, atmospheric and ice surface conditions observed with the NPEO buoys and Web Cams, recent ice trajectories.

3. Rationale
- The winter AO was negative, which we feel contributed to the relatively great amount of deformed ice we directly observed in the central Arctic Ocean in April. Consequently, we think the central Arctic ice, in spite of still being predominately young, tends to be thicker than in recent years.
- Recent buoy trajectories in the central Arctic Ocean also have a more anticyclonic, export adverse, trajectory than in recent years, and our buoys don't appear to be crossing towards Fram Strait as fast.
- Our NPEO Web cams show more melt ponds than last year, but less than in other recent years. This is in spite of there having been more snow in April 2010 than the previous 2 springs. For the most part, the ice at both 2010 Web Cam locations looks fairly well drained, presumably contributing to increased albedo
- As evidenced by the number of times we have seen the 2010 melt ponds freeze over already, we think the early summer input of heat to the ice from the atmosphere is less than average.
- Based on some AXCTD drops done in May, we think there is some ocean heat from 2009 directly below the mixed layer in the Beaufort Sea. However, the mixed layer was reasonably deep (40-50 m) this spring so if there has been enough melt in quiet to normal wind conditions, a new shallower seasonal pycnocline may be established and the ocean heat may be trapped for the rest of this summer.

4. Executive Summary
Last month's estimate of 5.3 million square kilometers was based on considering the 2009-2010 winter AO and ice conditions observed in the field in April. The conditions observed with the Web Cams, buoy trajectories, and the present trends in ice extent have prompted us to raise our estimate to 5.6 million square kilometers, recognizing that the Arctic weather in the next couple of months will trump all.

2010 PAN-ARCTIC OUTLOOK
July Outlook

Chris Petrich - Geophysical Institute, University of Alaska Fairbanks

1. Extent Projection

The projected sea ice extent for September 2010 is 4 Mm^2, with a possible range of 3.4 to 5.4 Mm^2, and most likely range of 3.4 to 4.9 Mm^2.

2. Methods / Techniques:

heuristic, statistical

It is assumed that the mean sealevel pressure in June in the Pacific sector of the Arctic and sub-Arctic (90E to 270E and 45N to 90N) is a useful indicator for the inter-annual change of September sea ice extent. June mean sealevel pressure is calculated from the NCEP/NCAR reanalysis product, and individual years are visually compared to 2010. The pressure distribution in June 2010 resembles the situation of 1997 most closely and is in tune with many years that showed a considerable decrease in ice extent with respect to the previous year. However, it also resembles 1965 which was most likely a year like any other. Sea ice extent anomalies were kindly provided by Walt Meier, NSIDC, and are based on the NASA Team algorithm from SMMR-SSM/I (1979-present) and Hadley ISST dataset, with monthly extents adjusted to be consistent with the SMMR-SSM/I data (1953-1979).

The best estimate is based on the 1.4 Mm^2 reduction observed from 1996 to 1997. The bounds are based on the 2006 to 2007 and 1964 to 1965 reductions of 2 Mm^2 and 0 Mm^2, respectively.

3. Rationale

Sealevel pressure is related to both surface winds and clouds (and hence insolation) which are known to drive Arctic ice reduction in summer. The mean sealevel pressure of June is used as a proxy for September sea ice extent reduction because the association appears to be stronger than for any other month.

4. Executive Summary

The June sealevel pressure distribution is used as proxy for the inter-annual change in sea ice extent. September 2010 is most likely to see a lower sea ice extent than September 2009, potentially even less than in 2007.

2010 PAN-ARCTIC OUTLOOK
JULY REPORT

Prepared by Oleg Pokrovsky
Main Geophysical Observatory, Russia

1. Extent Projection
Sea ice projection for the September monthly mean arctic sea ice extent – 4.9 (in million square kilometers)
2. Methods / Techniques
Statistical analysis of the AMO, PDO and AO time series based on specific regression model

3. Rationale

Substantial bias in previous sea ice projection for the September was obtained because of principal change in atmospheric circulation over Asia and Eastern part of European Russia, which was found in recent monthly SLP fields (fig.1). It is in contrast to Jan-Apr average wind field (fig.2). Southward flow direction was turned in Northward. The reason of this change is related to increasing of SST in North-East Atlantic domain (fig.3) and development of considerable SLP low anomaly. As a result hot air masses from South Asia and Africa have arrived in Siberia and Russian Arctic (fig.4). Relatively thin ice cover will be subjected to rapid melting due to the SAT substantial increasing in Russian Arctic and in North East of Canada.

4. Executive Summary

Future SIE estimates in Arctic might be obtained by joint analysis of time series of three climate indicators: AMO, PDO, AO for last thirty years. I used a modified regression analysis approach.

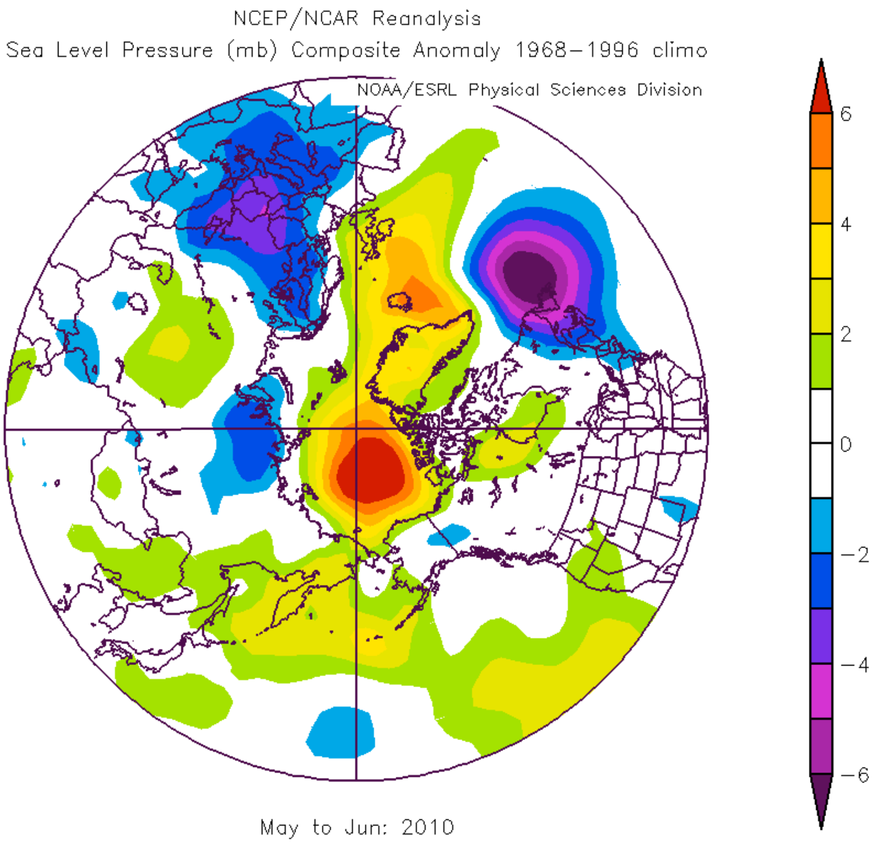


Figure 1. May-June SLP field

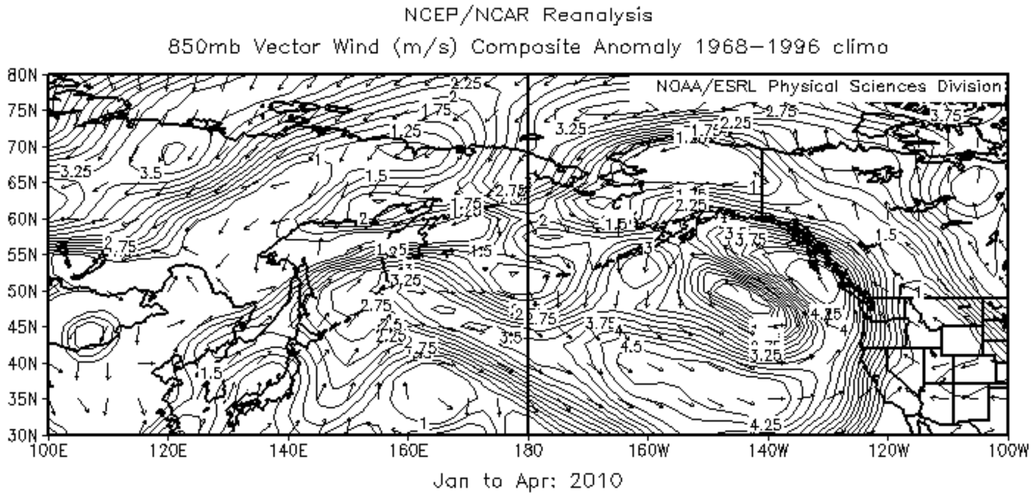


Figure 2. Jan-April vector wind field

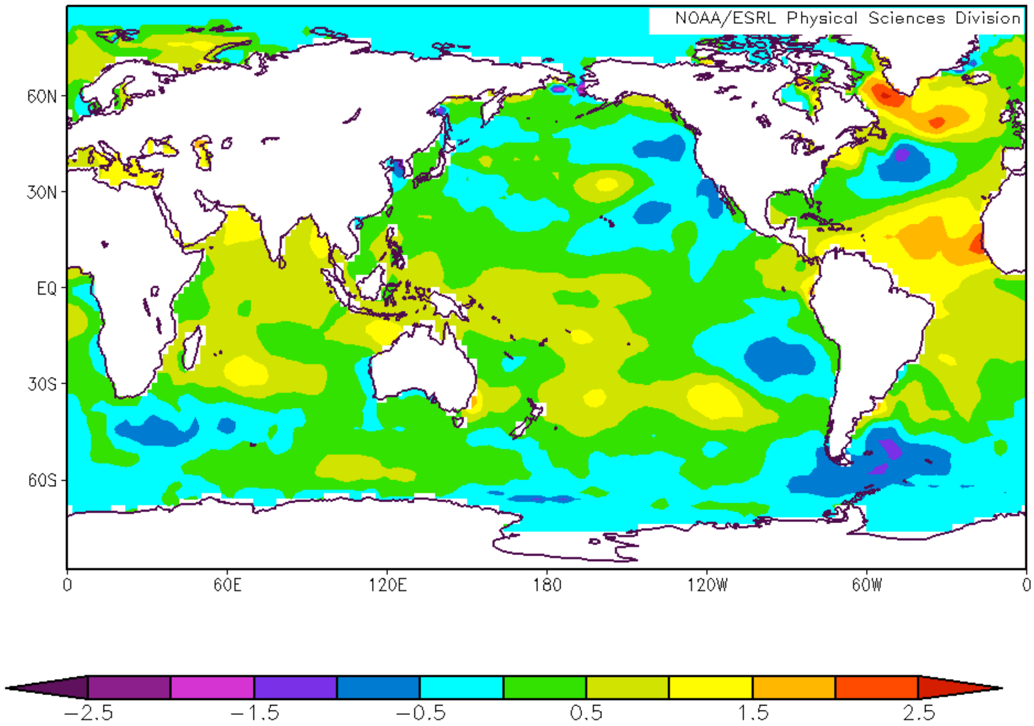


Figure 3. May-June SST field

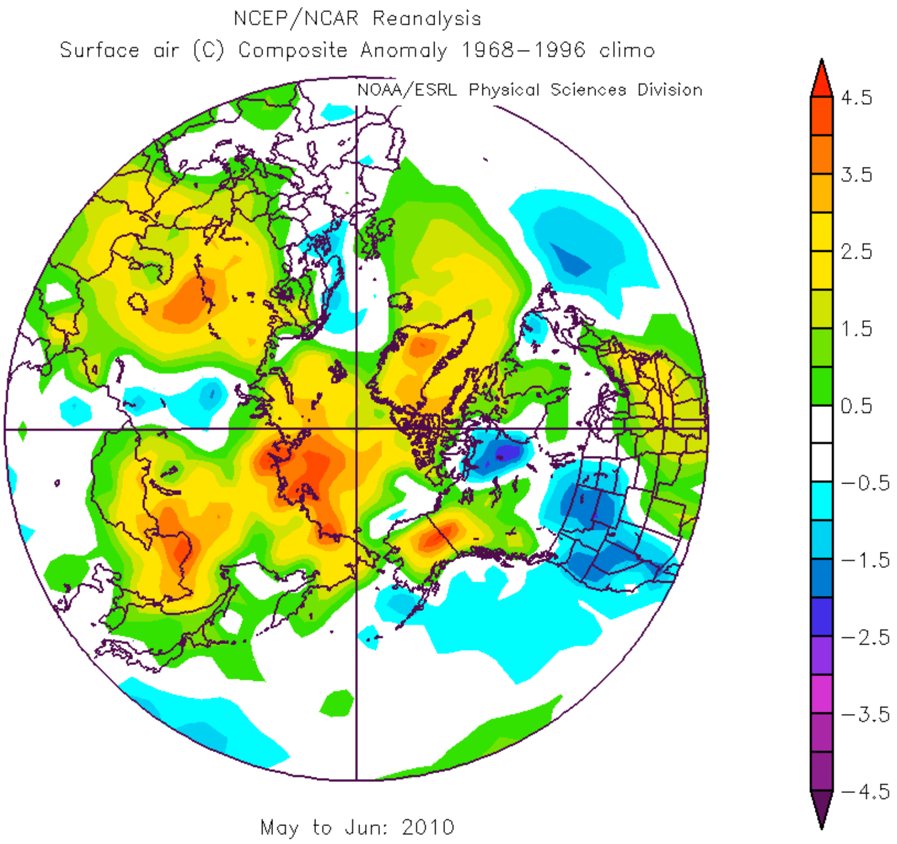


Figure 4. May-June SAT field

Sea Ice Outlook for September 2010 (July Report Based on June Data)

Ignatius G. Rigor[1], Son V. Nghiem[2], Pablo Clemente-Colón[3]
[1]Polar Science Center, Applied Physics Laboratory, University of Washington (UW)
[2]Jet Propulsion Laboratory, California Institute of Technology
[3]Naval/National Ice Center

1. Extent Projection

   5.4 million sq. km. We estimate that the September 2010 mean sea ice extent will remain below the mean September sea ice extent (1979 – 2009).

2. Methods and Techniques

   This estimate is based on the prior winter AO conditions, and the spatial distribution of the sea ice of different ages as estimated from a Drift-age Model (DM), which combines buoy drift and retrievals of sea ice drift from satellites (Rigor and Wallace, 2004, updated). The DM model has been validated using independent estimates of ice type from QuikSCAT (e.g. Fig. 1 left; and Nghiem et al. 2007), and *in situ* observations of ice thickness from submarines, electromagnetic sensors, etc. (e.g. Haas et al. 2008; Rigor, 2005). For this analysis, we used the NCEP operational SIC analysis to determine which areas of sea ice survived in Sept. 2009, but the Bootstrap SIC analysis for previous years.

3. Rationale

   Figure 1 shows the estimated age of sea ice this spring. The average age of sea ice has been increasing since the record minimum ice extent in September 2007. There is more second year ice this spring, compared to last spring. This increase in the basin wide average age of sea ice was a result of extremely low Arctic Oscillation (AO) conditions during the winter of 2009/2010 (L'Heureux et al. 2010, and www.cpc.noaa.gov), which sequestered sea ice the larger Beaufort Gyre (e.g. Fig. 2; and Rigor et al. 2002), and compacted sea ice into the East Siberian Sea. However, these conditions are still far younger and thinner than the condition of sea ice prior to the 1990's, and it would take a few years of similar conditions to allow sea ice to recover (Rigor 2005).

   Regionally, we expect alternating areas of faster and slower retreats of sea ice due to the extreme low AO conditions during the past winter. Figure 2 shows the regression map of summer sea ice concentration and winter ice motion on the winter AO index. Note that the areas where sea ice extent is currently retreating (e.g. Banks Island, west of Barrow, and east coast of the Laptev Sea), are areas of much younger, thinner first-year ice where the low AO conditions blew sea ice away during the past winter. We realize that the current sea ice extent is 0.5 million sq. km. below the pace of 2007, but we also note that much of these decreases are primarily in the lees of the coast and fast ice, where the younger, thinner sea ice simply does not have enough mass to survive the onset of summer. In the East Siberian Sea and east of Barrow, where sea ice has been packing into the coast we expect sea ice to hold out longer and thus slow the overall retreat of Arctic sea ice extent.

4. Executive Summary

Our outlook based on June data has not changed from May. As hypothesized in our outlook based on May data, the retreat of sea ice extent has slowed and is now behind the pace of the record minimum in 2007. The winds during the past two weeks have reversed the flow of the buoys and sea ice in the Beaufort Gyre and Transpolar Drift Stream, slowing export, and sequestering sea ice in the Arctic (Fig. 3). We continue to expect the September sea ice extent just above the minimum in 2009.

Figures

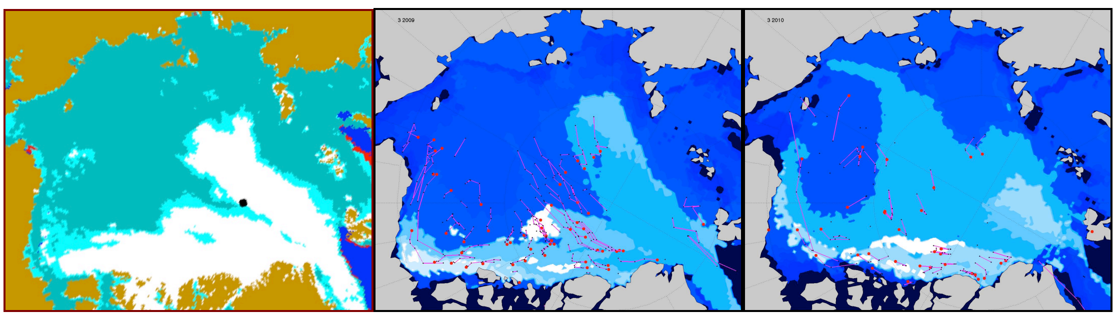


Figure 1. Maps of Arctic sea ice distribution based on QuikSCAT (QS) for March 2009 (left), and the age of sea ice based on the Drift-Age Model (DM) for each March 2009 and March 2010 (middle and right). The colors on the QS map shows perennial ice (white), mixed ice (aqua), seasonal ice (teal). The red dots on the DM maps show the current positions of buoys, while the black dots behind these show the positions of the buoys during the previous 6 months.

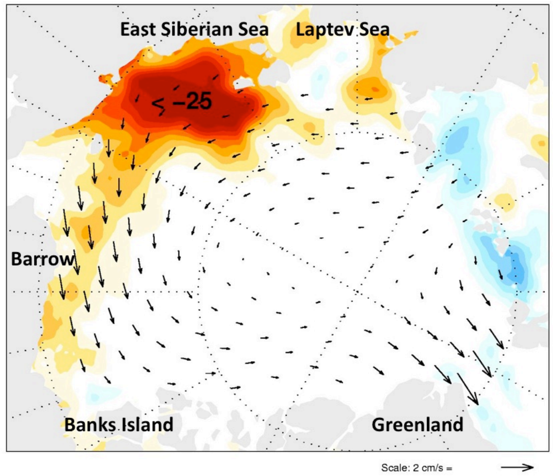


Figure 2. Regression map of summer sea ice concentration and prior winter sea ice motion on the prior winter Arctic Oscillation index. After low AO winters, the reds imply that sea ice concentrations should be higher I these areas, while blues imply lower that normal sea ice concentrations during the following summer. Based on Rigor et al. 2002.

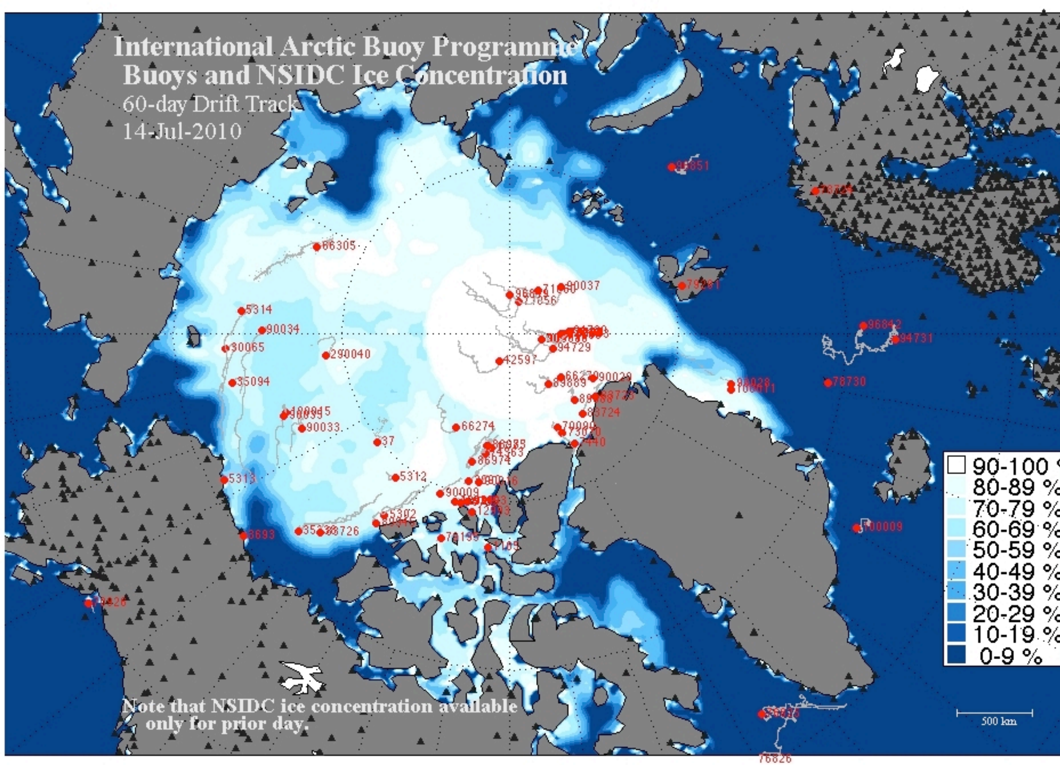


Figure 3. Map of buoys drifting on the Arctic Ocean. The red dots show the current position of the buoys, while the grey tails behind these dots show how the buoys have drifted during the last 60 days. Note how the buoys in the Beaufort Gyre are drifting counter-clockwise, and near the pole they have turned away from Fram Strait driven by a deep low in Sea Level Pressure over the central Arctic. This wind and ice drift pattern slows the export of sea ice from the Arctic Ocean. Source http://iabp.apl.washington.edu.

2010 Sea Ice Outlook
July Report

Adrienne Tivy
International Arctic Research Center, University of Alaska Fairbanks

Prediction - 5.7 million sq km

The prediction is statistical, it is based on a simple regression where the predictor is the previous summer (May-June-July) sea surface temperature in the North Atlantic and North Pacific oceans near the marginal ice zone. Warmer (colder) than normal SST is associated with a reduction (increase) in ice extent.

Outlook of 9/2010 Arctic sea ice from 7/1/2010

Jinlun Zhang
Polar Science Center, Applied Physics Lab, University of Washington

The predicted September 2010 ice extent is **4.8 million square kilometers**. This is based on ensemble predictions starting on 7/1/2010. The ensemble predictions are based on a synthesis of a model, NCEP/NCAR reanalysis data, and satellite ice concentration data. The model is the Pan-arctic Ice-Ocean Modeling and Assimilation System (PIOMAS), which is forced by NCEP/NCAR reanalysis data. It is able to assimilate satellite ice concentration data. The ensemble consists of seven members each of which uses a unique set of NCEP/NCAR atmospheric forcing fields from recent years, representing recent climate, such that ensemble member 1 uses 2003 NCEP/NCAR forcing, member 2 uses 2004 forcing, …, and member 7 uses 2009 forcing. Each ensemble prediction starts with the same initial ice–ocean conditions on 7/1/2010. The initial ice-ocean conditions are obtained by a retrospective simulation that assimilates satellite ice concentration data. No data assimilation is performed during the predictions. More details about the prediction procedure can be found in Zhang et al. (2008) http://psc.apl.washington.edu/zhang/Pubs/Zhang_etal2008GL033244.pdf. Additional information can be found in http://psc.apl.washington.edu/zhang/IDAO/seasonal_outlook.html.

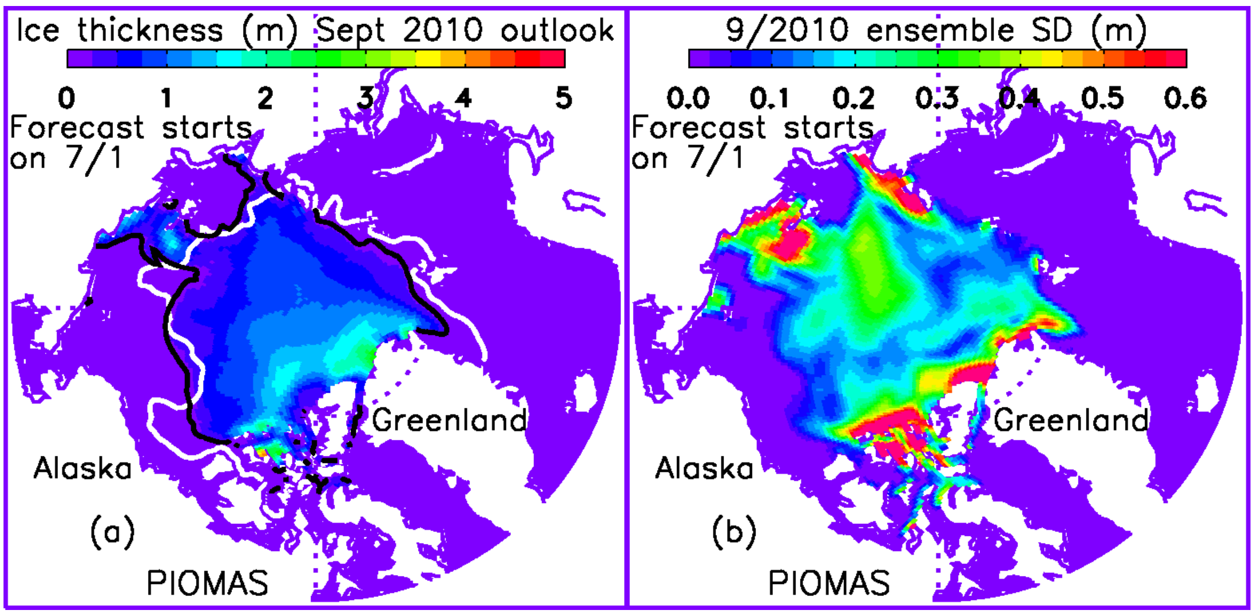


Figure 1. (a) Ensemble prediction of September 2010 sea ice thickness and (b) ensemble standard deviation (SD) of ice thickness which shows the uncertainty of the prediction. The white line represents satellite observed September 2009 ice edge defined as of 0.15 ice concentration, while the black line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

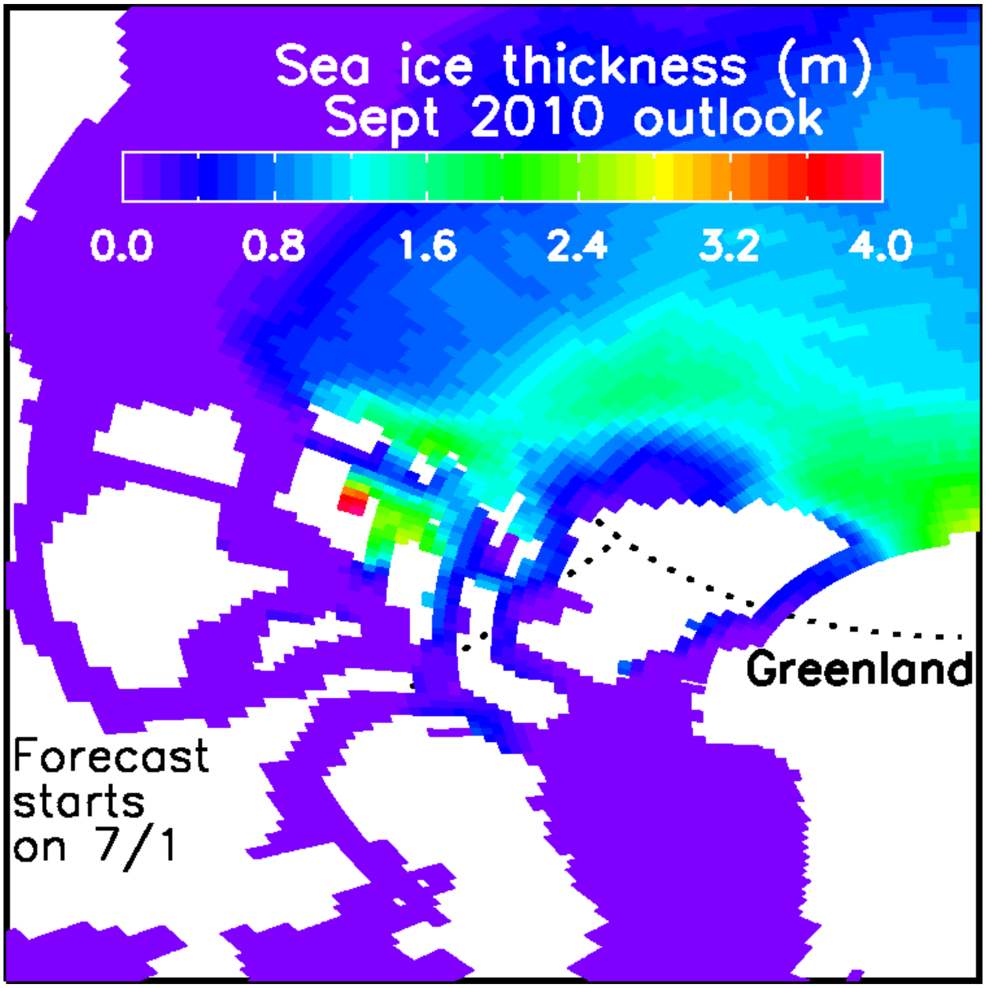


Figure 2. Ensemble prediction of September 2010 sea ice thickness in the Northwest Passage (NWP) region. Most of the NWP is ice free except some thin ice in the Lancaster Sound.

Public Contribution

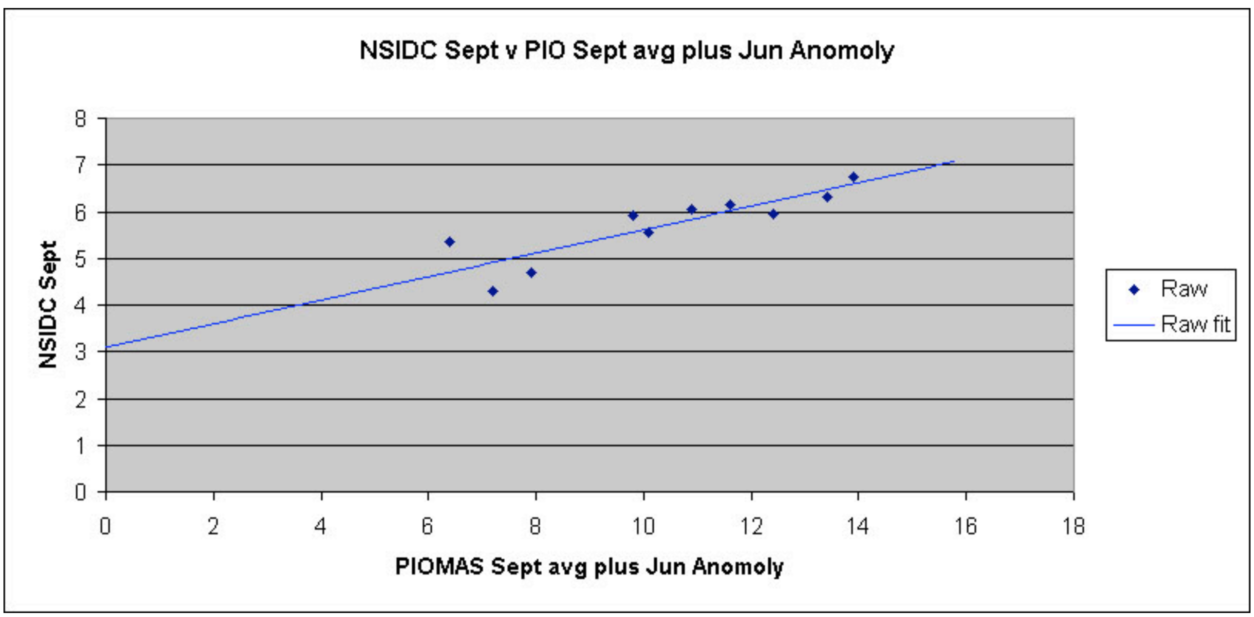
2010 Sea Ice Outlook
July Report

Greg Wellman
Princeton Consultants

Extent Projection
4.2 Million square kilometers for the 2010 September average.

Method
I plotted the NSIDC September average extent against the Spring/Early Summer PIOMAS volume anomaly for each year 2000 to 2009. This produced, a scatter plot with 10 points that strongly suggested the possibility of a linear fit. Taking a linear fit and extrapolating to the 2010 PIOMAS volume anomaly, gave 4.2 million km2.

It should be noted that while the NSIDC numbers were easily available, I unfortunately eyeballed the PIOMAS values off their public volume anomaly vs time graph. That could introduce error, particularly when the modeled volume is changing rapidly. There are other possible sources of error or different ways to treat the data that I'll discuss under Rationale, but I ultimately decided that the simple linear fit was the most justified.



In the plot, the PIOMAS anomaly has had 14.4 (thousand km3) added to each point, which is basically estimating the September volume assuming the anomaly remains at the June level.

Rationale
The rationale is that pre-conditioning is the most important factor in September ice extent. PIOMAS appears to be the best estimate of pre-conditioning available.

Possible sources of error: Not correlating against other variables like total solar irradiance (TSI), various current strengths (e.g. East Greenland current), surface water temperature, etc. Each of those has real physical effects on melt rates. However I was going for something simple.

Probable systematic error: It is generally agreed that the weather patterns of 2007 were statistically unusual in that the arctic had less cloud cover and persistent warm winds from Asia. Arguably then, the 2007 data point in my scatter plot should be given less weight. But I had no rationale for any given weighting so I left all weightings equal. As it stands 2007 and 2009 are roughly equal and opposite outliers.

Other possible data treatments
1. Including data earlier than 2000 would probably reduce the slope of the fitted line. Including enough such data would appear to give a curved fit rather than a straight line. Ultimately I decided that going further back was to enter a different regime from the present.
2. Forcing a "zero intercept". That is to say that one would expect that a PIOMAS anomaly of -14.4 (thousand km3) should lead to zero ice extent as 14.4 is the baseline September volume in that model. However, again, I consider that a different regime. The approach to zero volume may be very non-linear with respect to extent, as the ice appears to thin out faster than it shrinks in area.
3. Fitting a pre-chosen power law. Naively one might expect area to scale as volume to the 2/3 power. But in practice that does not appear to be the case.

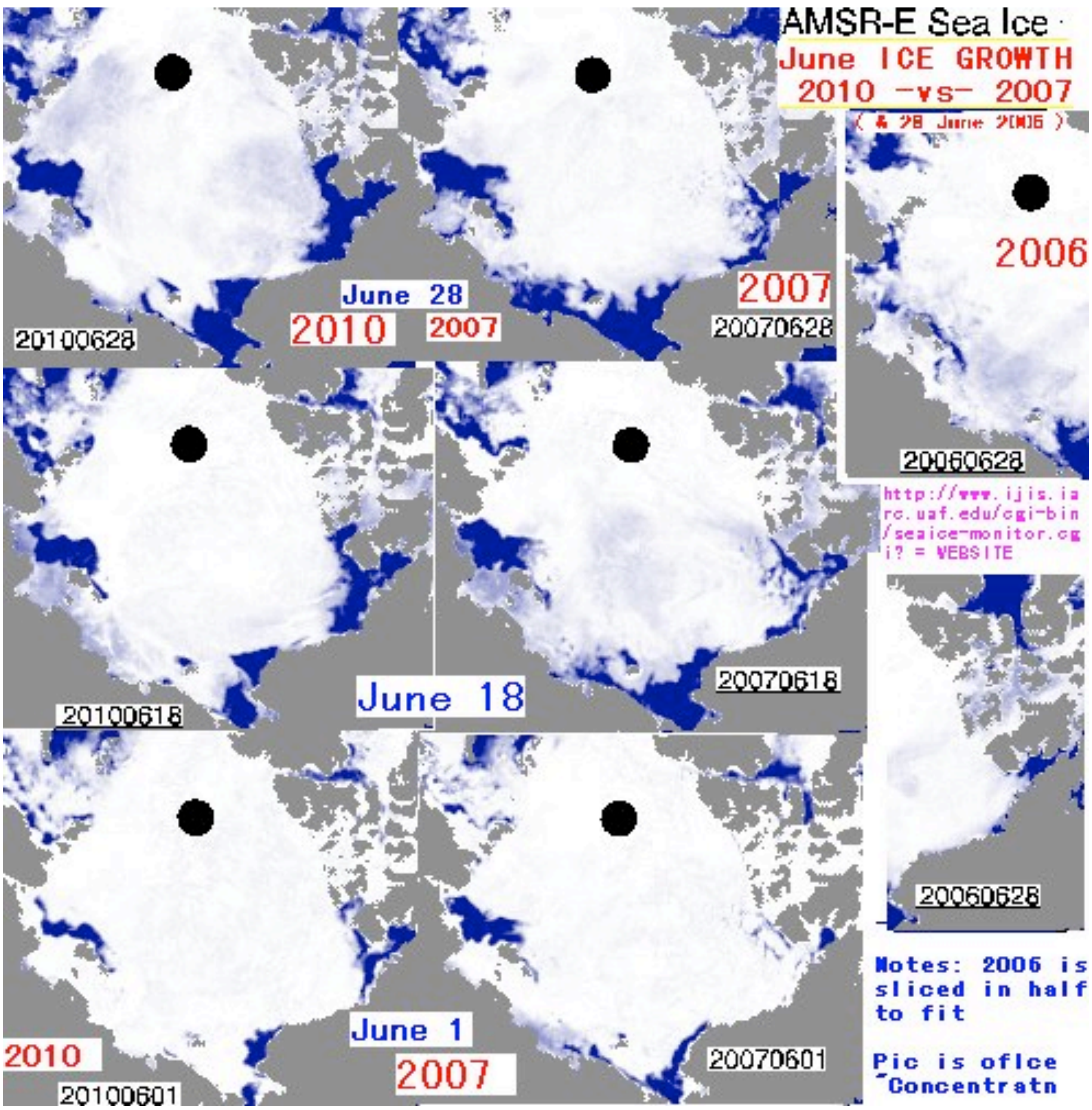
Public Contribution

2010 Sea Ice Outlook
July Report

Charles Wilson

Charles Wilson: Prediction 1 million Sq. Km.
The El Nino of this year was the entire basis of my Prediction - - that is, that the EXTREME year of 2007 would be repeated - - and even More strongly.

As such, note NOT ONLY the fact that Ice-Loss has rapidly caught up with the 2007 pace & gone into record Low Territory in All extent & Area indexes (Jaxa, Bremen, NSIDC, Norsex's 4 Charts) & Piomas's Volume - - but that the Open water Polynnya are at the same 3 PLACES.as in 2007. The Fall in Indexes could be just Luck. This is like a Fingerprint.



Public Contribution

I think PIOMAS is showing a near constant Acceleration that may be from the Ice-to-Water Albedo-Feedback effect.

My figures below are from superimposing the PIOMAS charts for Current Anomaly & the Verification Chart that showed the ICESAT's exact measurements. (Both at the Polar Ice Center). From November 1st Icesat data I infer a September Minimum by simply subtracting the same amount Piomas decreased in that time-span.

Figures are in km3 Ice "LEFT" i.e. above "Zero Ice" (exception: Piomas Coordinates measure: Down from Average) P+I refers to Piomas + ICEbridge:

------------------- ICESAT / PIOMAS Current Piomas Chart Reads:
'06-7 Change: 4000 --- ---- 2700 P
2007 Sept.___ 5050d ------ 6350 P
2007 Nov. ___ 6000 --- ---- 7300 P - 8200 Icesat / - 6900 Piomas
2009 Sept. - -- - ? -- -- -- -- 5800 P+I
2010 17 Apr. - - - - - - - = 6400 P+I -7800 Anomaly
2010 18 June - - - - - - = 3500 P -10700 Anomaly
Zero Ice at -14200 Anomaly -14,200 Anomaly
The loss rate for 2010 from 17-April to June = 62-days = for a fall from 6400 km3 LEFT to 3500 = LOSS OF 2900 km3 = LOSS RATE of 327.4 km3 lost/week = 10.7 weeks left until hit Zero, roughly the start of September.