**June Report: Outlook Based on May Data**
**By: AWI / FastOpt / OASys**

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## Motivation: The Situation of Arctic Sea Ice

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

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

## Lessons learned from the 2008 Outlook and other recent work

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

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

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

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

## Experimental setup

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

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

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

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

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

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

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

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

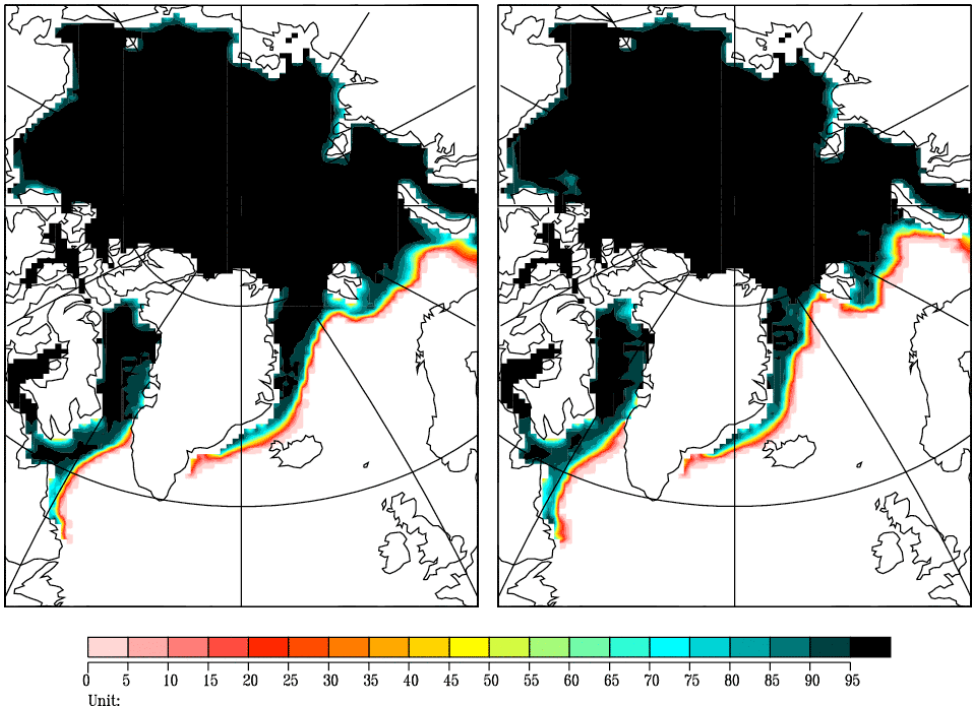


Fig. 1: April mean ice concentration from the free model run (left) and from the optimised model run (right).

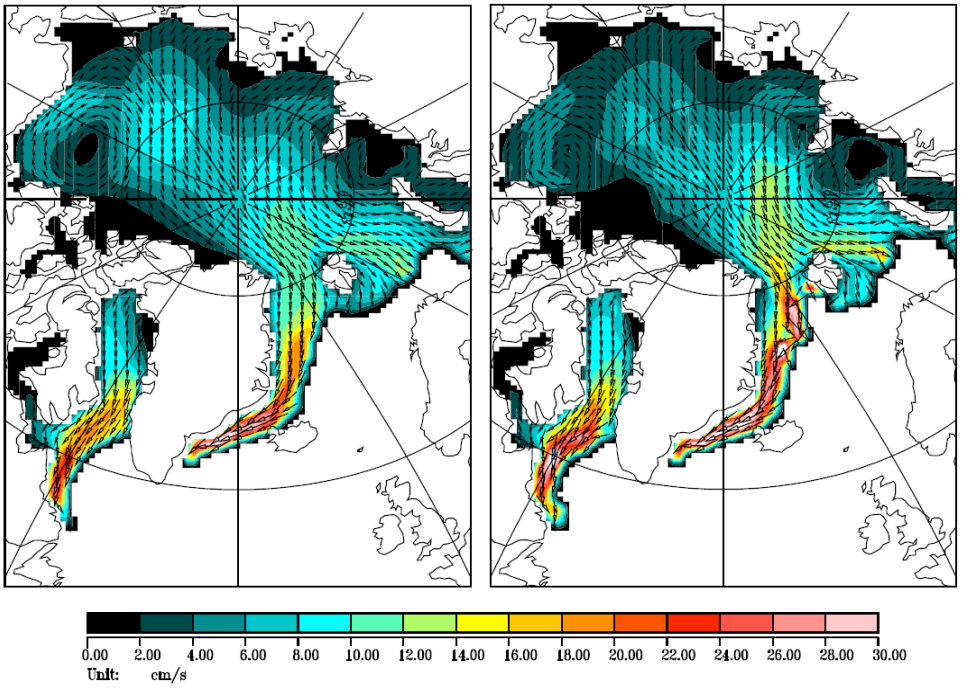


Fig. 2: April mean ice drift from the free run (left) and from the optimised model run (right).

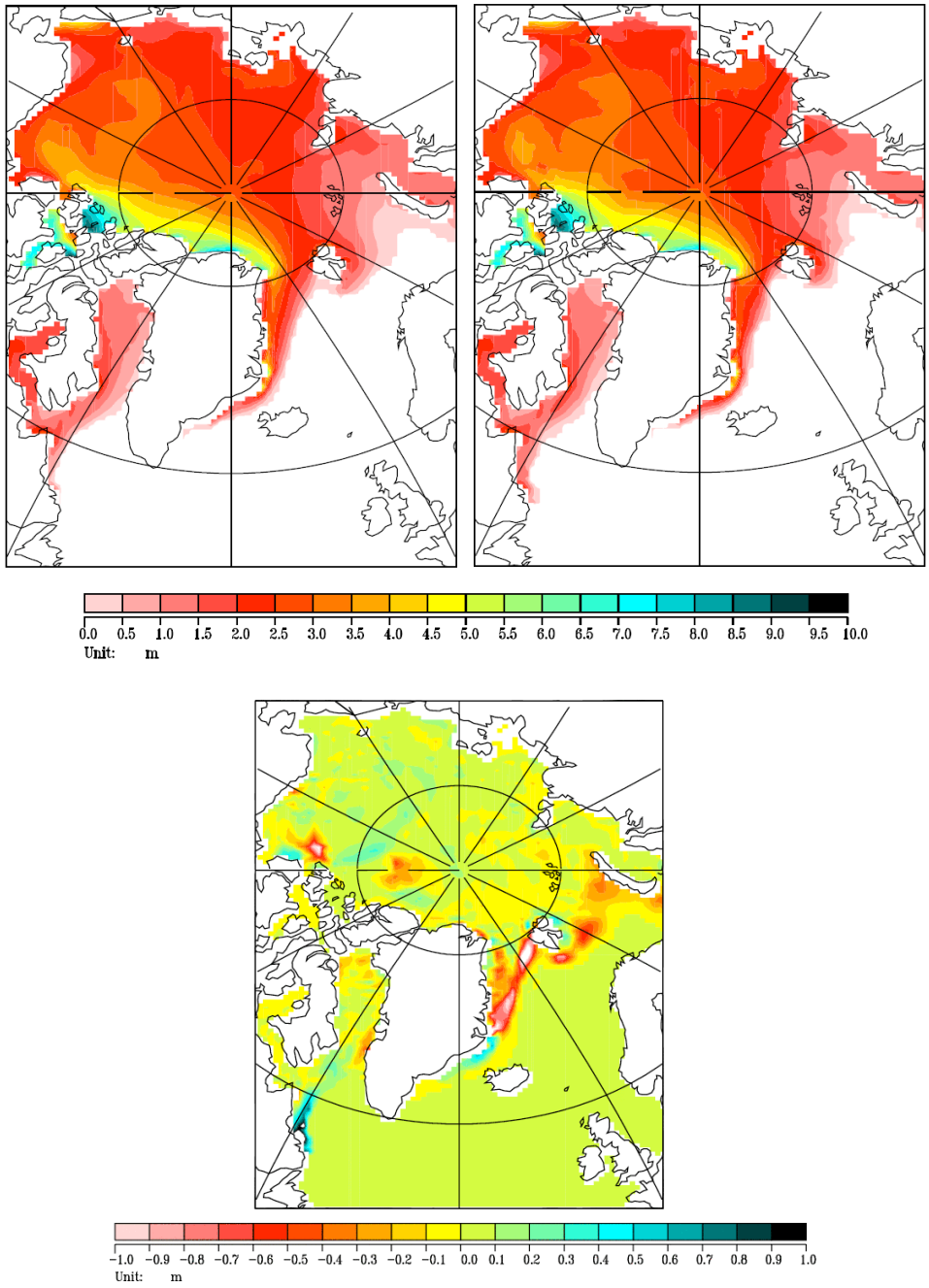


Fig. 3: April mean ice thickness from the free model run (left), from the optimised model run (right), and the difference of both (optimised minus free) (bottom).

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

## Mean September Ice Extent 2009

### Ensemble I

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

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

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

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

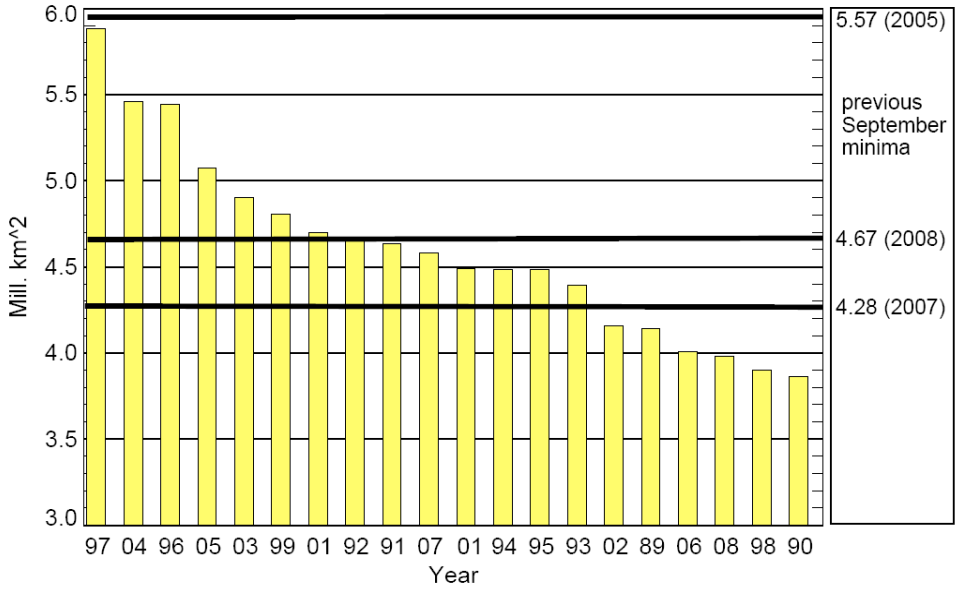


Figure 4: **Ensemble I** - Simulated mean September ice extent in 2009 [million km$^2$] when forced with atmospheric data from 1989 to 2008 (not optimised initial state on May 22$^{nd}$ 2009). Model derived ice extents have been adjusted assuming a systematic bias (see text). The thick black horizontal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

**Ensemble II (optimised initial conditions)**

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

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

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

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

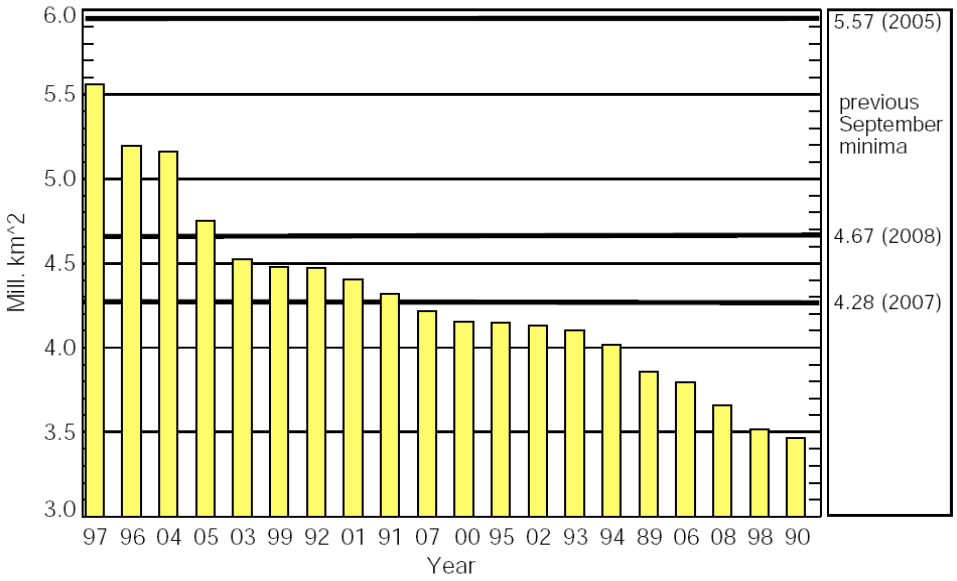


Figure 5: **Ensemble II** - Simulated mean September ice extent in 2009 [million km$^2$] when forced with atmospheric data from 1989 to 2008 from the optimised initial state on May 22$^{nd}$ 2009. The thick black horizontal lines display the minimum ice extent observed in 2005, 2007 and 2008.

**References:**

**Kauker, F., T. Kaminski, M. Karcher, R. Giering, R. Gerdes, and M. Voßbeck (2009)**, Adjoint analysis of the 2007 all time Arctic sea-ice minimum, Geophys. Res. Lett., 36, L03707, doi:10.1029/2008GL036323.

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**Zhang, J. and M. Steele, R. Lindsay, A. Schweiger, and Morison, J. (2008)**, Ensemble 1-Year predictions of Arctic sea ice for the spring and summer of 2008, Geophysical Research Letters, 35{8}, 2008.