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Arctic Sea Ice in summer 2008 - an outlook

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Motivation: The Situation of Arctic Sea Ice

The area of the ocean covered by ice is an important climate parameter. A smaller ice cover means less reflection of sunlight and more storage of heat in the ocean. Both effects contribute to local warming which may further reduce the ice-covered area. The annual Arctic sea ice extent minimum occurs in September, at the end of the melting season. The Arctic sea ice extent minimum has a downward trend from about 7 million km^2 in the early 1980s to about 5.5 million km^2 in 2006.

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.

In September 2007 the sea-ice extent in the Arctic Ocean reached a new record minimum of 4.3 million km^2, 1.3 million km^2 below the old record minimum of September 2005.

Following this event there has been an intense scientific discussion on the cause of this sudden drop, basically whether this was a consequence of climate change or due to natural variability, or a mixture of both.

At present there is evidence that indeed there was interplay of both factors. There are indications for a sea ice thickness decrease in the last decade, accompanying the decrease of sea ice extent. The area covered by older, thicker ice has decreased to make space for younger, thinner ice. This has led to a larger vulnerability of the ice cover, since thinner ice can melt faster and offers less resistance to wind forcing. In addition to this long-term trend, for several months in 2007 unusual wind patterns occurred, which pushed ice from the Chukchi area north of the Bering Strait to the North and West. A larger area of open water evolved, and the extent of sea ice was drastically reduced.

Favourable winds acting on a rather thin, low concentration ice cover, made the transpolar drift from the ice production areas north of Siberia to the exit of sea ice through Fram Strait much faster than during earlier decades. The schooner TARA, an expedition vessel that was frozen into the drifting sea ice as part of DAMOCLES research project, experienced a drift velocity about twice as large as expected.

Triggered by the rising concern about the future development of the Arctic sea ice and as a contribution to the DAMOCLES project, scientists from AWI and OASYS have employed a technique called 'ensemble simulations' to predict the likeliness of certain sizes of the sea ice extent for September 2008. The method uses simulations with the coupled ice-ocean model NAOSIM, developed at AWI

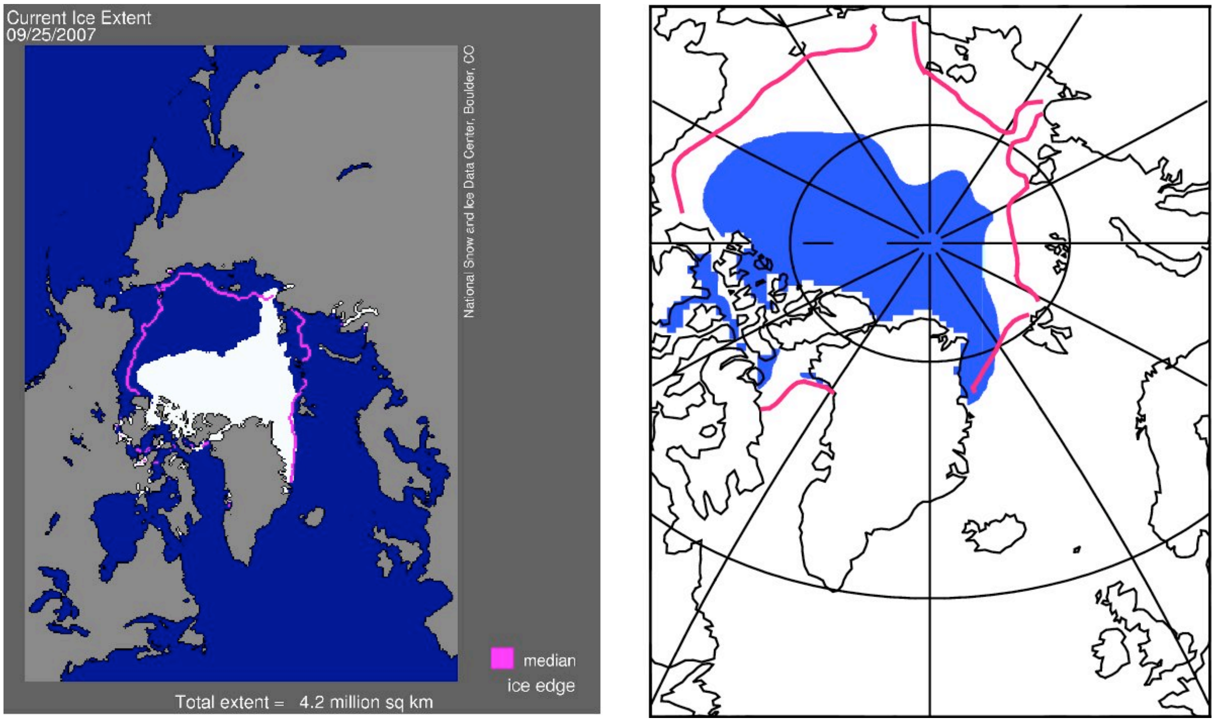

Figure 1: Area within the 15% sea-ice margin on 09/25/2007 as deduced from satellite data (left, white) (www.nsidc.org/arcticseaicenews) and computed by NAOSIM (right, blue). The magenta lines display the long-term September mean for 1988 to 2007.

<u>The Concept of 'Ensemble Simulations'</u>

While the sea ice state at the beginning of the melt season is important, the development until September depends strongly on the actual atmospheric conditions, especially the wind, cloudiness, and surface temperatures. The strong variability of the high latitude atmosphere is responsible for large fluctuations of sea ice extent from year to year. To actually predict sea ice extent in September, we thus would need to know the development of the atmospheric state over several months in advance. Such long-term weather forecasts are not available or have little skill. Thus, we can only make a probabilistic forecast: Given a certain range of atmospheric variability and the known conditions at the beginning of the melt season, how large is the probability that sea ice extent will fall below a certain value? To this end, we employ a technique named 'ensemble simulation' where we prescribe atmospheric conditions from the years 1988 through 2007 to force an ocean-sea model.

The ocean-sea ice model NAOSIM calculates oceanic circulation, temperature, and salinity as well as sea ice drift, thickness, and concentration among other variables. The model incorporates the basic dynamical and thermodynamic equations that govern ocean and sea ice. Thus, it is able to reconstruct, starting from given initial conditions, the history of ocean and sea development through time. Input to the model are several atmospheric quantities that are necessary to calculate the heat, water and momentum exchanges between the different media. We say that the model is "forced" by these atmospheric data.

The coupled ice-ocean model NAOSIM is forced with atmospheric surface data from January 1988 to the end of June 2008. This atmospheric forcing has been taken from the "NCEP reanalysis". These data are no observations but the output of a global atmospheric model constrained by observations. This is similar to the first step in numerical weather prediction, where all available atmospheric data are gathered and interpolated to a regular grid using an atmospheric model to incorporate the atmosphere dynamics. Reanalysis data are not without errors, especially in the sparsely observed Arctic.

Figure 1 displays the ice extent on 09/25/2007 as deduced from satellite-data and as simulated by NAOSIM. The model is able to reproduce the large ice-free areas in the central Arctic Ocean. Some discrepancies compared to the observations are visible, partly reflecting unavoidable shortcomings of resolution and representation of physical processes in the model. However, it is not possible to determine if these discrepancies are due to inadequate atmospheric forcing data or due to flaws in the ice ocean model. As in the observations the model simulates an all-time minimum ice extent in September 2007 (Fig. 2). These results (and many more that were used to validate the model in the past) convince us that the model simulations are suitable for the task.

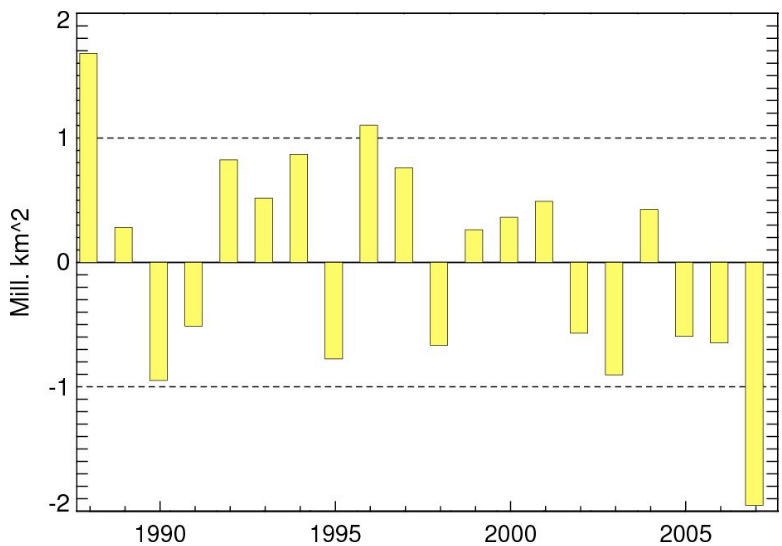

***Figure 2**: The simulated September sea-ice extent anomaly [Mill. km^2] for the years 1988 to 2007.*

For the coming summer 2008 the atmospheric situation is unknown. However, we can use end of June to September atmospheric data from the past years 1988 to 2007 to get an estimate of the possible range of minimum sea ice extent. The model experiments all start from the same initial conditions on the 27th June 2008. We thus obtain 20 different realizations of the possible sea ice development from July through September 2008. We use this ensemble of realizations to derive probabilities of specific sea-ice extent values to be expected as minimum in the summer 2008. The method also provides the probability for reaching a new record minimum below the 2007 value.

Results

Minimum Ice Extent 2008

The summer minimum sea ice extent for all 20 realizations is shown in Figure 3, ordered by the magnitude of ice extent. With the atmospheric forcing from the extraordinary year 2007, the minimum sea ice extent occurring in September 2008 comes out even lower than it was in 2007 by 0.22 million km^2. The ensemble mean value for the 20 summers is 4.43 million km^2. This is the most likely value under the assumption that the atmospheric conditions in the remaining months of summer 2008 do not fall out of the range of the previous 20 years. The standard deviation of the ensemble is 0.21 million km^2. Assuming a Gaussian distribution we are now able to state the probabilities that sea ice extent will fall below a certain value.

The probability that in 2008 the ice extent will fall below the minimum from September 2007 is about 8%, the probability to fall below the minimum of 2005 (second lowest value in the last 20 years) is practically 100%. With a probability of 80% the minimum ice extent in 2008 will be in the range between 4,16 and 4.70 million km^2.

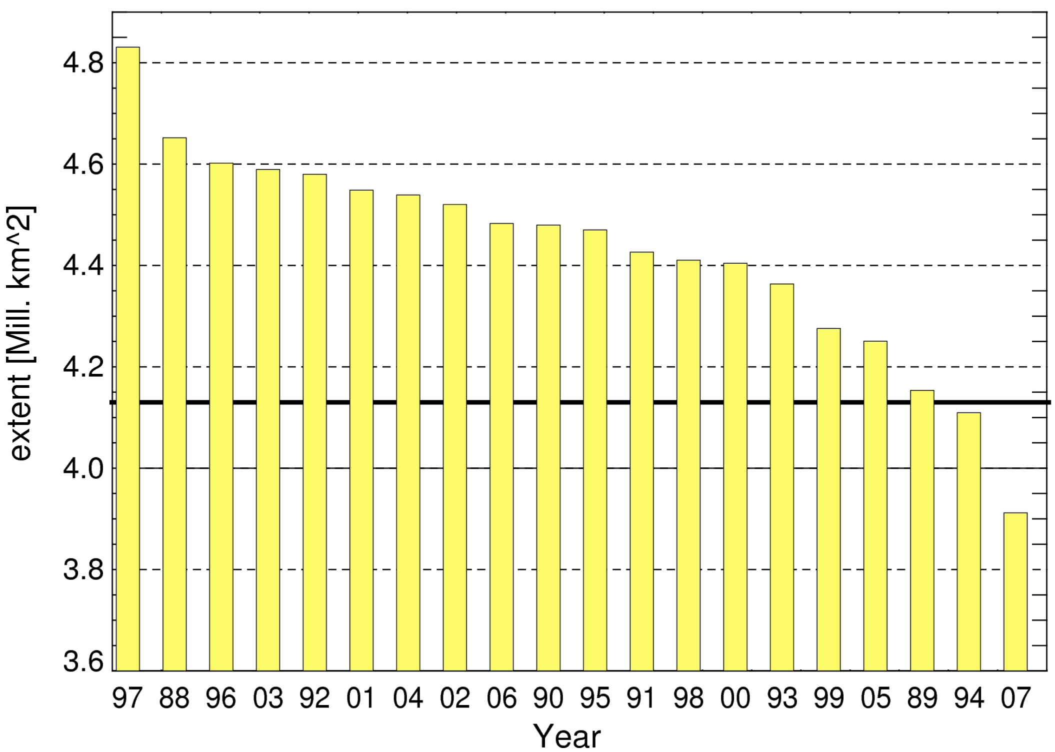

Figure 3*: Simulated minimum sea-ice extent in 2008 [Mill. km^2] when forced with atmospheric data from each year between 1988 and 2007 from the initial state of June 27, 2008. Model derived ice extents have been adjusted with a constant offset to account for discrepancies with satellite-derived ice extents. The thick black horizontal line displays the minimum ice extent observed in 2007.*

Influence of previous winter conditions

For an improvement of seasonal sea ice outlooks in the future it is important to know which of the data that we can observe at the end of the winter season have the largest influence on the sea ice extent in September.

Our model experiments reveal that especially the ice thickness at the end of winter has a big influence on the following September ice extent. In March 1988 for example, the ice thickness was much larger than in 2007 or 2008. When performing the ensemble simulation for the atmospheric forcing of all years from 1988 to 2007, atarting from the initial ice conditions in March 1988, the smallest of the September sea ice extents from the ensemble members is almost 2 Mio km^2 larger than with initial ice conditions from March 2007. The largest of the September mean sea ice extents occurring for the ensemble simulation is 1 Mio km^2 above the one starting in March 2007. The ensemble mean ice extent of September for starting in March 1988 is 0.73 Mio km^2 higher than the corresponding value for starting in March 2007.

<u>We can therefore conclude that the initial ice conditions in March are responsible for a difference of 1-2 Mio km^2 in the monthly mean September sea ice extent.</u>

The strong reduction of ice extent in 2007 left large areas to form new ice in winter 2007/2008. Comparatively large areas of rather thin, young ice therefore characterize the situation at the beginning of the melt season in spring 2008. This can be seen in satellite derived first-year ice fractions, e.g. from NIC (see www.nsidc.org/arcticseaicenews/), as well as in the model results. <u>Therefore, a model run driven with atmospheric data from 2007 which is started from spring ice conditions in 2008 instead of 2007 leads to even smaller ice extent.</u>