Retrospective Summary Comments SIO 2009 – AWI/FastOpt/OASys

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Please provide comments on the results of this year's outlook - all estimates this year came in below the September monthly average of 5.36 million square kilometers. Our projected error from last year was ~0.5 million square kilometers. Is this within the error tolerance? Or, was there something systematic or physical that contributed to lower projections or a higher observed value this year?

We think that the observed extent is within the error tolerance. Although we think that there is something systematic (or physical) which we explain in the following:

Our projections for the June/July/August outlook were 4.60/4.92/5.02 million square kilometers (Ensemble I - without data assimilation). The projections increase from the June to the August outlook.

Our technique assumes that the state of the sea ice-ocean system in spring/early summer determines at least partly the extent in September ((almost) all others methods assume that as well). We use no predictions of the summer atmosphere but assume that the atmosphere will stay most likely close to the atmosphere in the years 1989 to 2008. This gives us a mean value and a range of possible values. Even for the August outlook the range was pretty large. The atmosphere of 1996 gives a value of about 5.9 million square kilometers and the 2007 atmosphere a value of about 4.1 million square kilometer.

We interpret our increasing projections as follows: During the setup of our June projection (22nd of May) the sea ice thickness was relatively low (almost no multi-year ice). This leads to a mean projection of 4.60 million square kilometers. The July outlook was set up on July 2nd. The mean projection was considerably larger than a month before (4.92 million square kilometers). In our setting that means that the June 2009 atmosphere was less prone to reduce the sea ice (thickness) than the mean of the last 20 years. We set up the August outlook on July 11th. The August projection is again (slightly) larger than the July projection although the August outlook was initialized only 9 days after the July outlook. This suggests that the first days in July were also less prone to reduce the sea ice.

We are also interested in your thoughts and ideas on the following:
1. Factors driving the 2009 minimum.

We did no dedicated analysis.

2. Additional data or data products that would be useful for improving outlooks in the future, including any critical gaps in field observations.

Definitely ice thickness and snow thickness data, but we have not applied any quantitative analysis (network design/Observation System Simulation Experiment). See item 4.

3. Implications, based on this year's results, for the future state of arctic sea ice.

Looking at the September mean extent of 2007, 2008, and 2009, one gets the impression that the Arctic sea ice recovers slowly from the 2007 extreme event (see Fig1, http://www.arcus.org/search/seaiceoutlook/2008_outlook/downloads/monthly-reports/aug-sept/1979-2008-minimum.png). 2009 is pretty close to 2005 and pretty close to the decadal trend as well. This might imply that 2007 was really a singular event and that the ice cover in 2008 and 2009 returned to 'normal' values. However, we believe that the likelihood of '2007-events' is much higher now than a decade before and this is connected to the gradually reduced sea ice thickness.

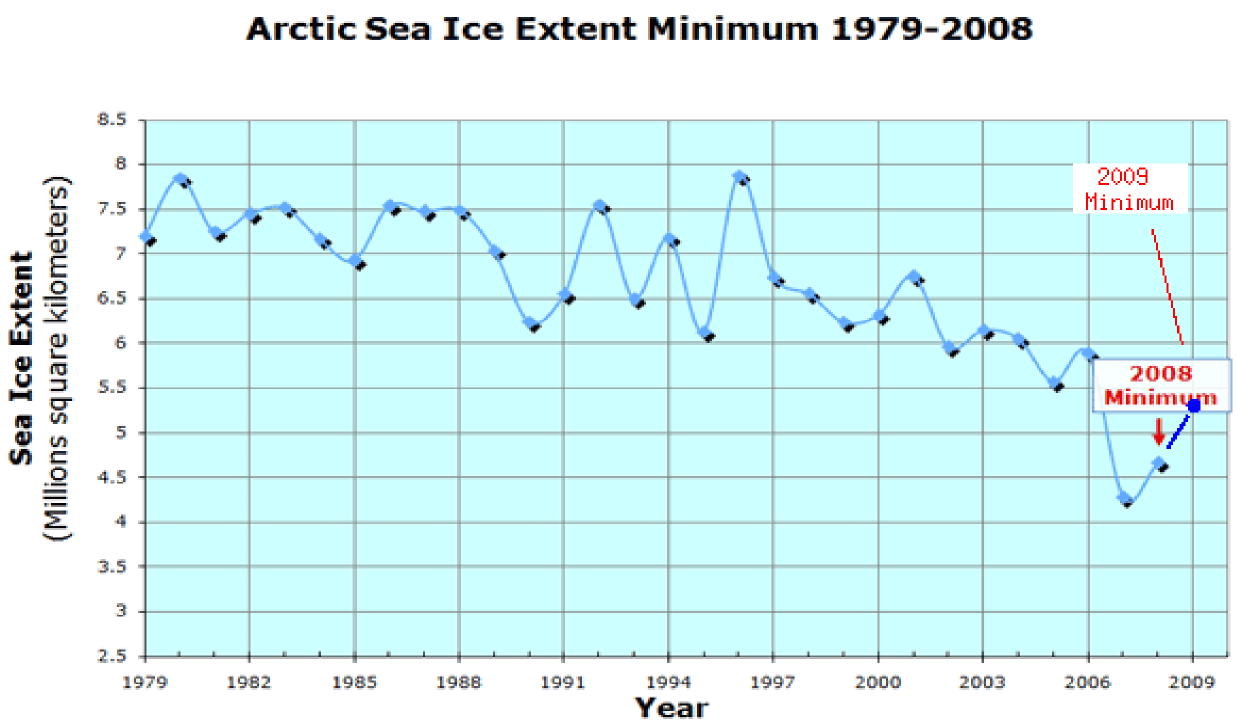

Fig 1: From http://www.arcus.org/search/seaiceoutlook/2008_outlook/downloads/monthly-reports/aug-sept/1979-2008-minimum.png. 2009 minimum added.

4. Any other "lessons learned" - including the usefulness of the Outlook as a community synthesis tool, suggestions for future outlook activities, or any other topic you want to comment on.

We used the outlook for a first test of our variational data assimilation system NAOSIMDAS under 'next -to-operational' conditions, even though the system is still under construction.

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For the projections which we called Ensemble I we used the sea ice-ocean model NAOSIM without any data assimilation. We know that NAOSIM tends to underestimate the September ice extent especially north of the Laptev Sea. We corrected for this bias by subtracting a constant.

The second set of projections (Ensemble II) uses an initial state of the sea ice-ocean system which has been optimzed with NAOSIMDAS. We hoped that this would avoid the bias in Ensemble I. The projections of Ensemble II for the June/July/August outlook were 4.30/4.42/4.43 million square kilometers. Compared to Ensemble I these values are considerably lower. In other words we failed even for the August outlook.

It was not until the August outlook that we noticed a problem in our setup of NAOSIMDAS. The sea ice-ocean model code used in NAOSIMDAS is not identical to the original code of NAOSIM. The latter has many code fragments which are not differentiable. For instance, to ensure that the ice concentration `a` is within the interval [0,1], non differentiable statements like `a=max(a,0)` and `a=min(a,1)` are used. Another more physical example is the use of two albedos for melting and freezing conditions, respectively. Depending on the air temperature an if-statement is used:

```
if (tair < 0.) then
  alb=alb_freeze
else
  alb=alb_melt
endif
```

This statement is not differentiable at `tair=0`. The sea ice-ocean model code used in NAOSIMDAS has been carefully analyzed for such code fragments and the code have been modified. Analytical functions like `atan` are employed to smooth these code fragments. In the example, this yields a small range around zero degree Celsius were a mixture of the freezing and the melting albedo is used. This range reflects the temperature variability within a model grid box. The value reflecting this variability is determined by comparing model runs with the 'smoothed' and the 'not smoothed' code. If the differences get too large the value is reduced.

Unfortunately it turns out, that these tests have been performed in summer and winter, respectively, but not in the seasons with largest melting and freezing rates. It was after delivering the August outlook, that we recognized large differences between the smoothed and not smoothed codes during these periods. The problem was easily resolved by decreasing one uncertainty parameter.

We re-ran the August outlook with the corrected NAOSIMDAS. We performed the optimization from May 1st to July 31th. Then we ran the model until July 11th and started the outlook. The corrected Ensemble II August value is 4.73 which is much closer to the corresponding Ensemble I values of 5.02 million square kilometers. NAOSIMDAS accomplishes this by perturbing the initial conditions at April 1st (start of assimilation window) (Fig. 2) and the surface boundary conditions in April to June (not shown). The largest perturbations are applied north of the Laptev Sea. Here the initial ice thickness is increased by up to 20 cm and the initial snow thickness is increased by about the same amount.

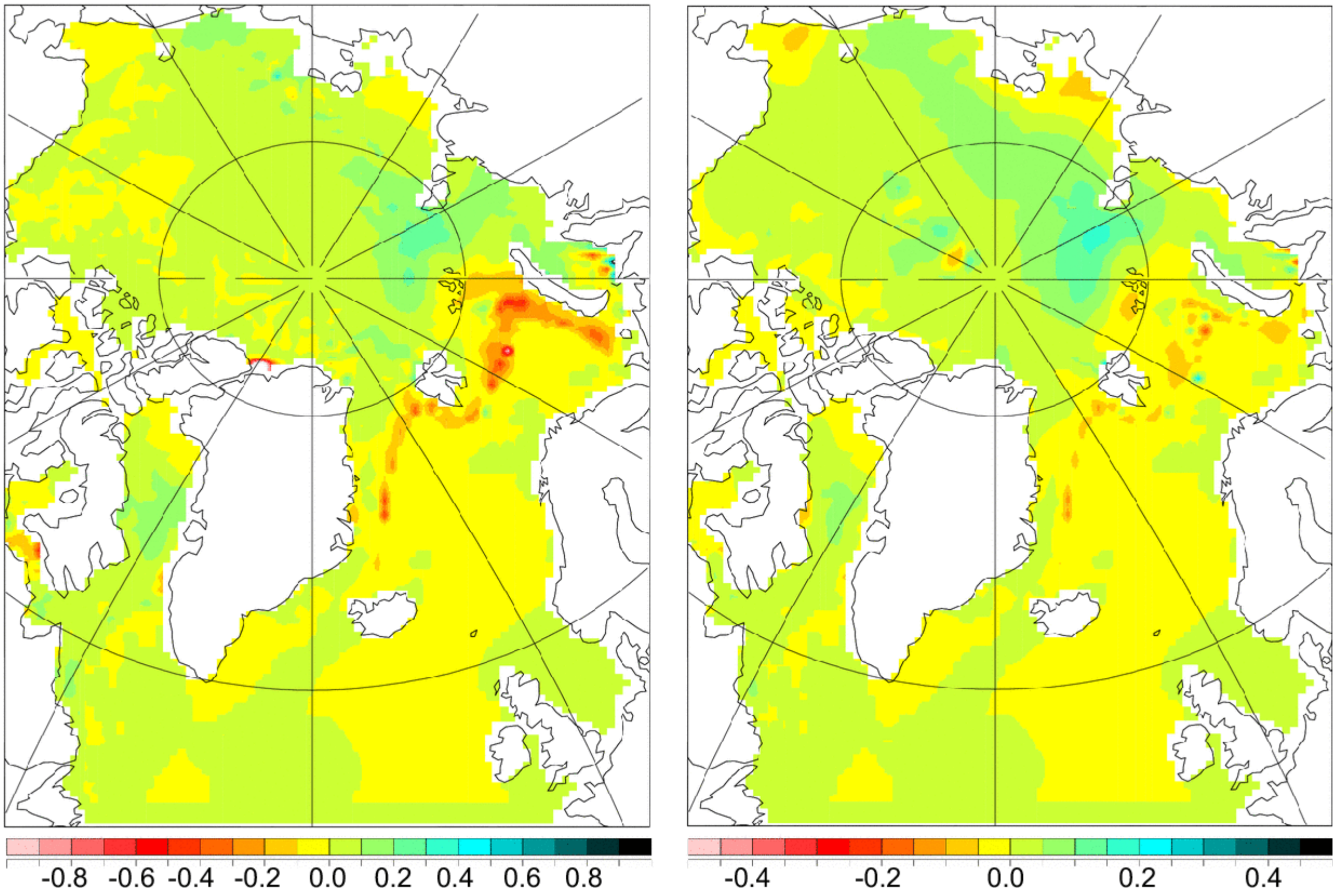

Fig 2: The perturbation applied on the initial ice thickness [m] (left) and the initial snow thickness [m] (right) at the beginning of the assimilation window (April 1 2009).

Fig. 3 shows the July 2009 mean ice thickness with and without data assimilation. North of the Laptev and Siberian Seas considerably more ice volume is visible in case of data assimilation. In the Beaufort Sea the data assimilation reduces ice volume. In September the extra ice volume north of the Laptev and Siberian Seas is responsible for the increased projected ice extent in September.

Note that we do not assimilate ice thickness observation north of the Laptev and Siberian Seas. The assimilation procedure increases the ice thickness there because the 'free' sea ice-ocean model underestimates the ice concentration with the start of the melting season in these areas. NAOSIMDAS corrects this by increasing the initial ice thickness and snow thickness (see Fig. 2) and by perturbation the surface boundary conditions (mainly the wind stress, not shown). The resulting ice thickness in July (Fig. 3) is now more consistent with the observed sea ice concentration and the hydrographic observations. This clearly demonstrates the strength of a variational data assimilation system.

Although NAOSIMDAS in the presented setup is able to produce more consistent sea ice thickness fields it would still be desirable to have ice thickness and snow thickness observations north of the Laptev and East Siberian Seas, or even better, Arctic wide. We hope that we have these data (or at least freeboard data) available for next year's outlook.

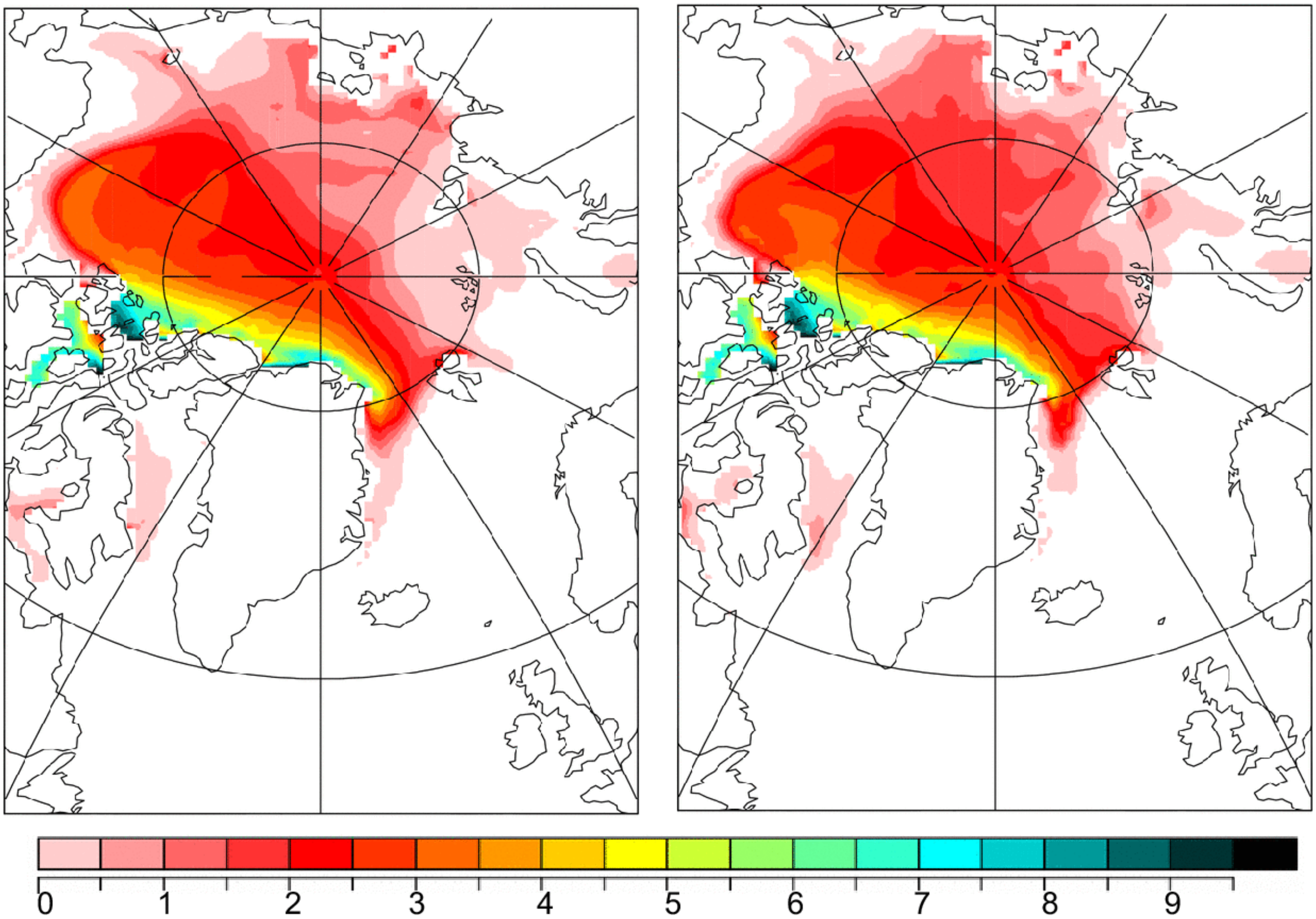

Fig 3: The July mean ice thickness [m] without (left) and with (right) data assimilation.