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

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As for the SIO 2009 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 May 28nd 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 May 28nd 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 2009 two ensemble experiments with different initial conditions on May 28nd 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 28nd May 2010.

Ensemble II starts from an optimised state derived by NAOSIMDAS with an assimilation window from March 2010 to May 28th 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 May 28th 2010.

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

Figure 1 displays the modeled ice concentration on May 28th 2010 for the “free” run and the run with data assimilation. Differences can be mainly seen next to the ice margin especially in the Barents Sea. We have not expected large differences this early in the melting season because we know that NAOSIM is able to simulate the ice concentration during the winter season with some accuracy. We expect that the benefit of the data assimilation will become more obvious in the July and August outlooks. The ice thickness on May 28th 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 as illustrated by the mean March 2010 ice drift and it's difference with the “free” run (Fig. 3).

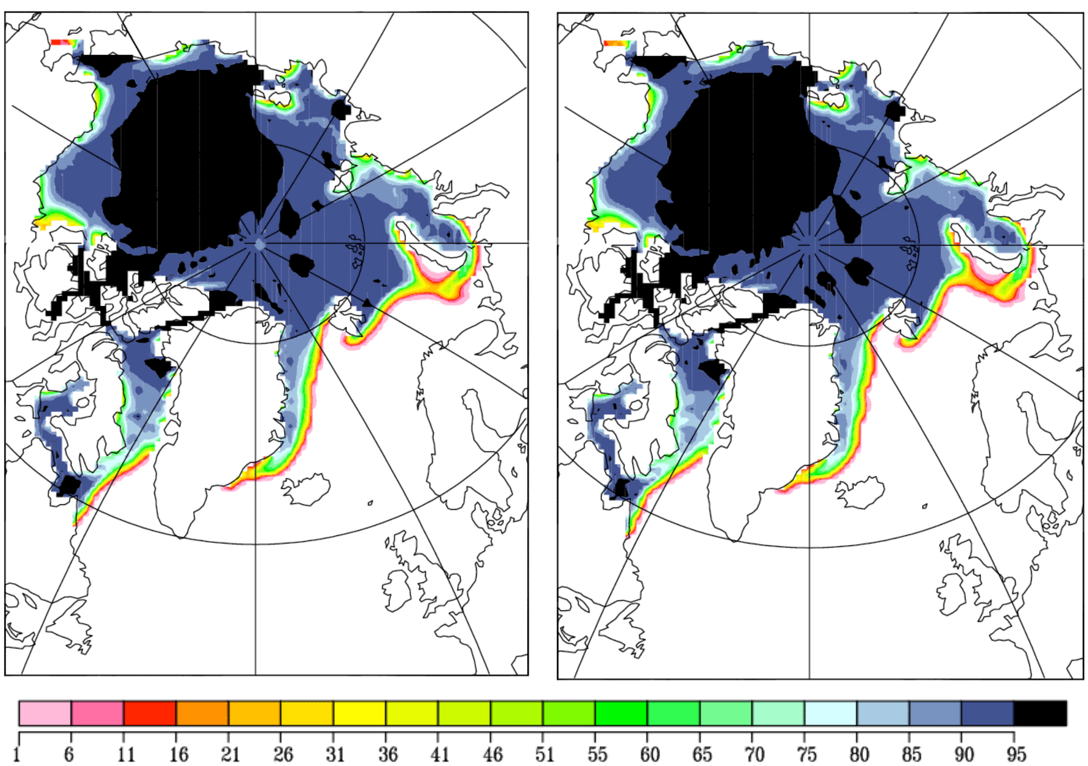

Fig. 1: The ice concentration [%] at the 28th of May 2010 in case of the “free” run (left) and in case with data assimilation (right).

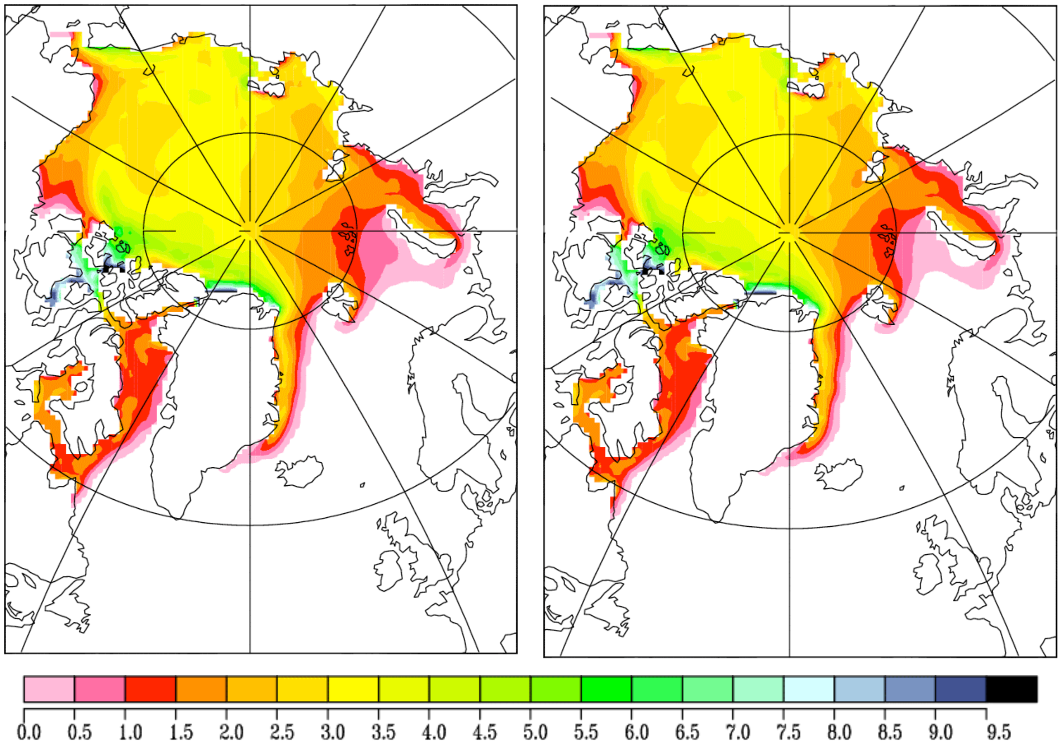

Fig. 2: The ice thickness [m] at the 28th of May 2010 in case of the "free" run (left) and in case with data assimilation (right).

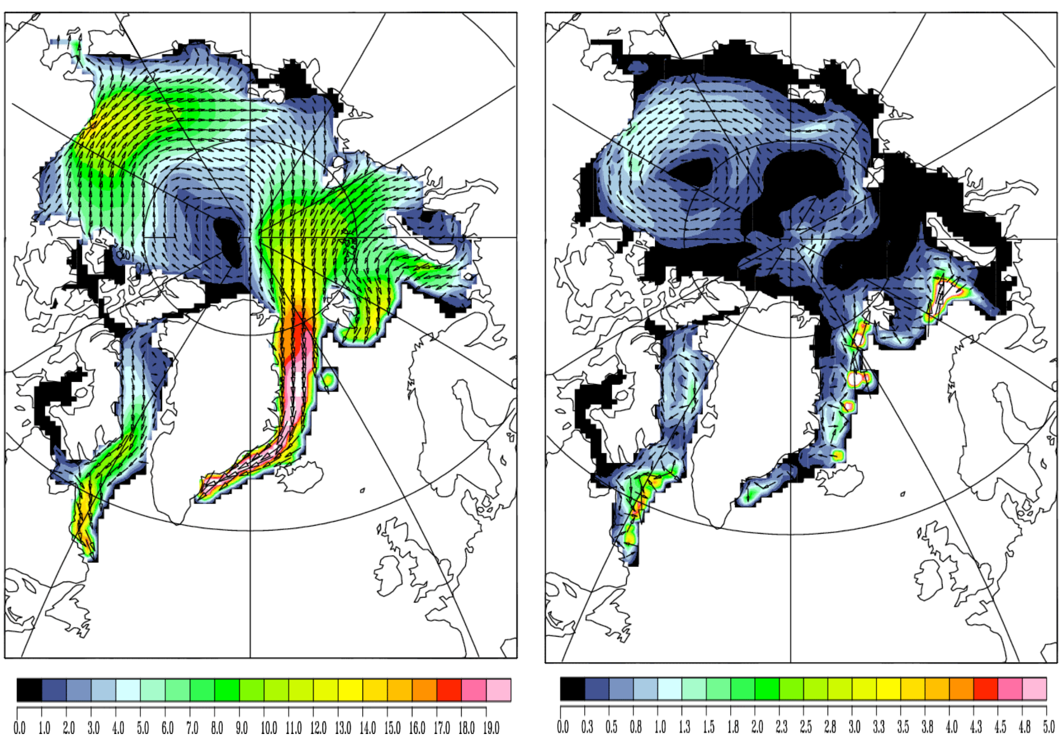

Fig. 3: The mean March 2010 ice drift [cm/s] in case of data assimilation (left) and the difference to the "free" run (right).

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 4. 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 systematic bias to the results of Ensemble I. We are not able to say whether the bias is caused by a imperfect sea ice-ocean model or by imperfect initial or boundary conditions. Fig. 5 shows the mean September ice extent for 1989 to 2009 for hindcasts performed with the same model but with three different sets of surface boundary conditions. Black bars denote the hindcast performed with the NCEP/NCAR reanalysis (Kalnay et al., 1996), green bars the hindcast driven with JRA25 (Onogi et al., 2007), and blue bars the hindcast driven by the ERA interim (Berrisford et. al, 2009) reanalysis. To eliminate effects associated with the cold start the JRA-25 experiment was initialized with fields from the NCEP/NCAR driven experiment on 1st of January 1979 and the ERA interim experiment was initialized with fields from the NCEP/NCAR driven experiment on 1st of January 1989.

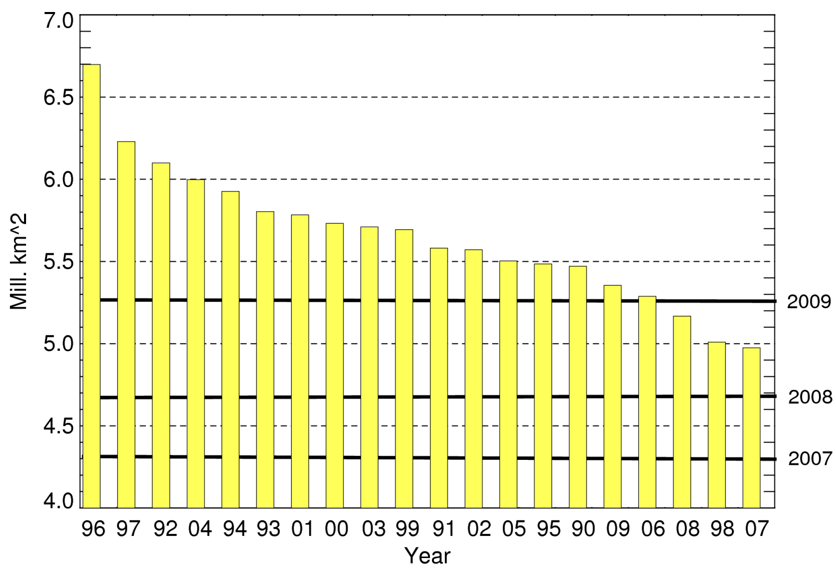

*Figure 4: **Ensemble I** - Simulated mean September ice extent in 2010 [million km^2] when forced with atmospheric data from 1990 to 2009 (initial state on May 28nd 2010). Model derived ice extents have been adjusted assuming a systematic bias (see text). The thick black horizontal lines display the minimum ice extent observed in 2007, 2008 and 2009.*

The results of the NCEP/NCAR experiment and the JRA-25 experiment are similar (especially for 2007, 2008, and 2009) but both underestimate the ice extent. The ERA interim experiment, on the other hand, overestimates the extent by about a million km^2. The reasons for this mismatch are unclear and currently being investigated. This demonstrates that errors in the surface boundary conditions are one possible origin of the bias. The 4DVar data assimilation used for ensemble II includes the surface boundary conditions in the set of control variables, i.e. the set of variables to be adapted to match the observations.

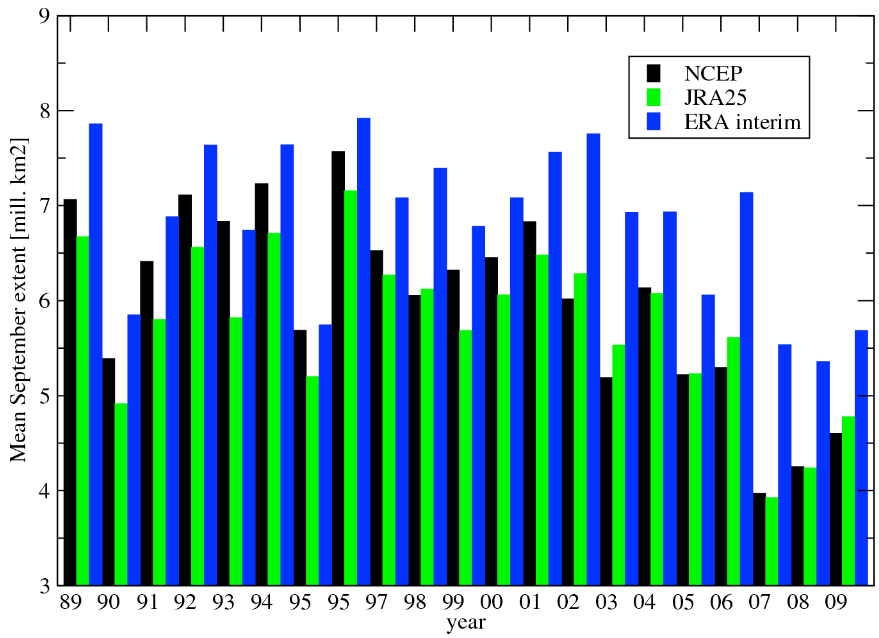

Fig 5: The mean September ice extent [million km^2] as simulated with the NCEP reanalysis (black bars), the Japanese (green bars) and the ERA interim reanalysis (blue bars).

The Ensemble I mean value is 5.61 million km² (bias included). The standard deviation of Ensemble I is 0.41 million km^2 (2008: 0.55; 2009: 0.40). 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 27%.

With a probability of 80% the mean September ice extent in 2010 will be in the range between 5.1 and 6.1 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 6. 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 5.19 million km^2 is somewhat lower than the mean of Ensemble I (note that the optimization increases the predicted mean by about 0.07 million km² compared to the uncorrected Ensemble I mean of 5.12 million km^2). As for Ensemble I the standard deviation of Ensemble II is 0.41 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 about 1%,
probability to fall below 2008 (second lowest) is about 10%,
probability to fall below 2009 (third lowest) is about 72%.

With a probability of 80% the mean September ice extent in 2010 will be in the range between 4.67 and 5.71 million km^2.

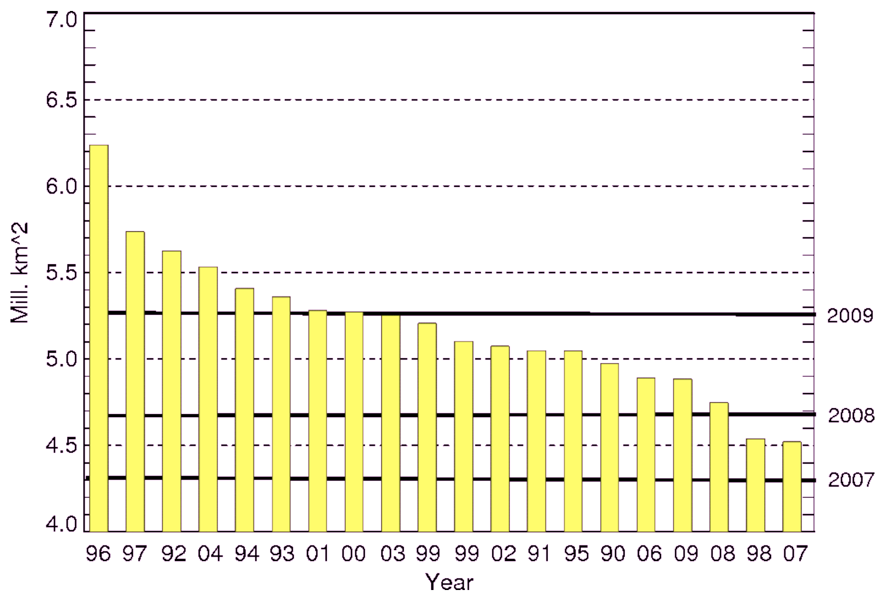

*Figure 6: **Ensemble II** - Simulated mean September ice extent in 2010 [million km^2] when forced with atmospheric data from 1990 to 2009 from the initial state on May 28th 2010 with data assimilation. The thick black horizontal lines display the minimum ice extent observed in 2007, 2008 and 2009.*

Discussion – back to before 2007 situation?

The ensemble I prediction of September 2010 looks similar to the situation before 2007.

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 June 1st 2007, 2008, and 2009, and the initial ice thickness on May 28th 2010 reveals 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. 7).

An adjoint sensitivity analysis (Kauker et al., 2009) of the causes of the modeled difference in ice area in September 2007 and September 2005 pointed out the importance of wind stress anomalies which redistributed the ice in the inner Arctic. May and June wind stress anomalies were found to cause about

50% of the September difference between 2007 and 2005 of about 1 million km^2. Therefore we calculated the March to May mean ice drift for the years 2007 to 2010 (Fig. 8).

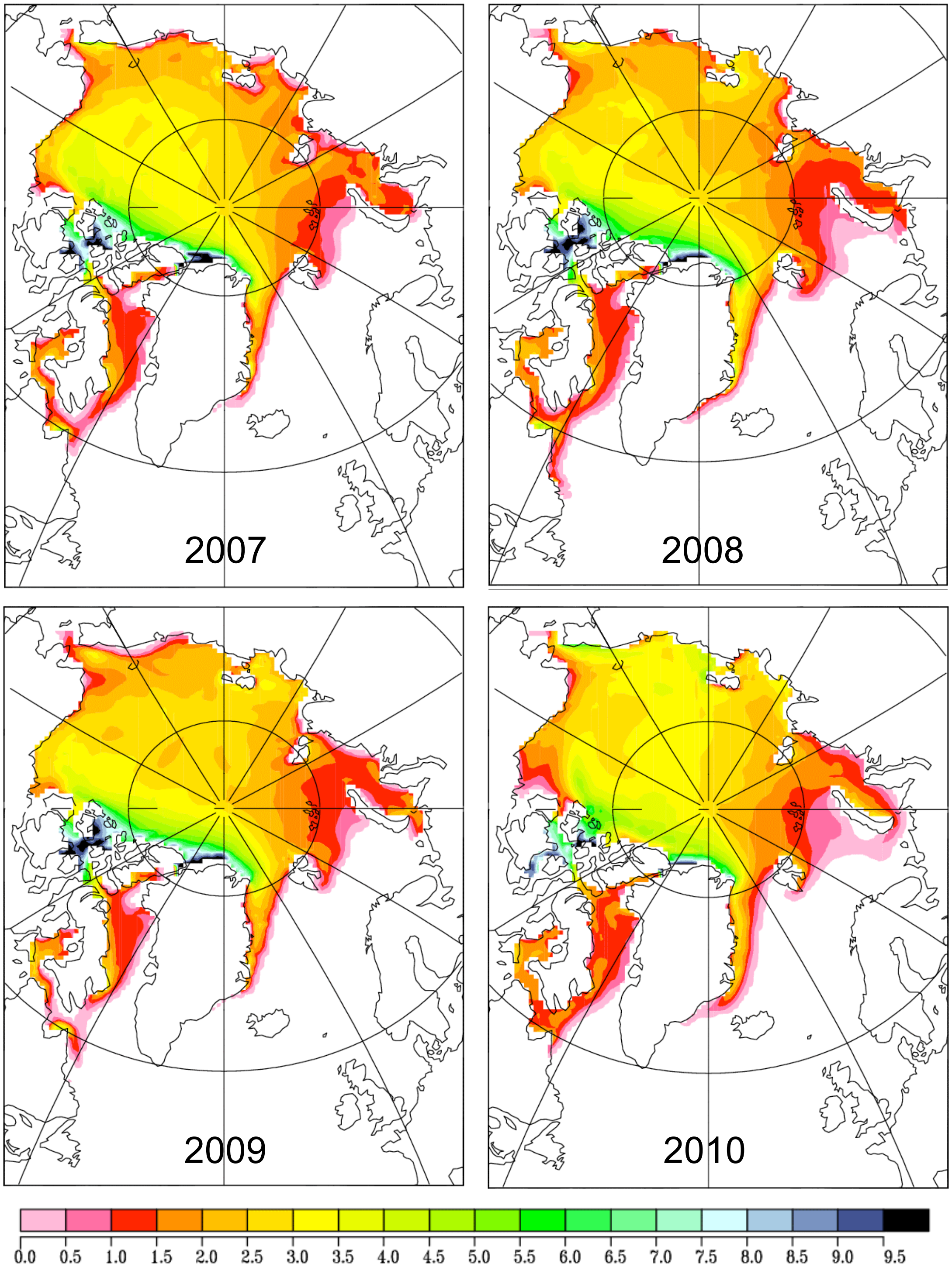

Figure 7: The ice thickness [m] at end of May 2007, 2008, 2009, and at the 28th of May 2010 (equal to Fig. 2 left).

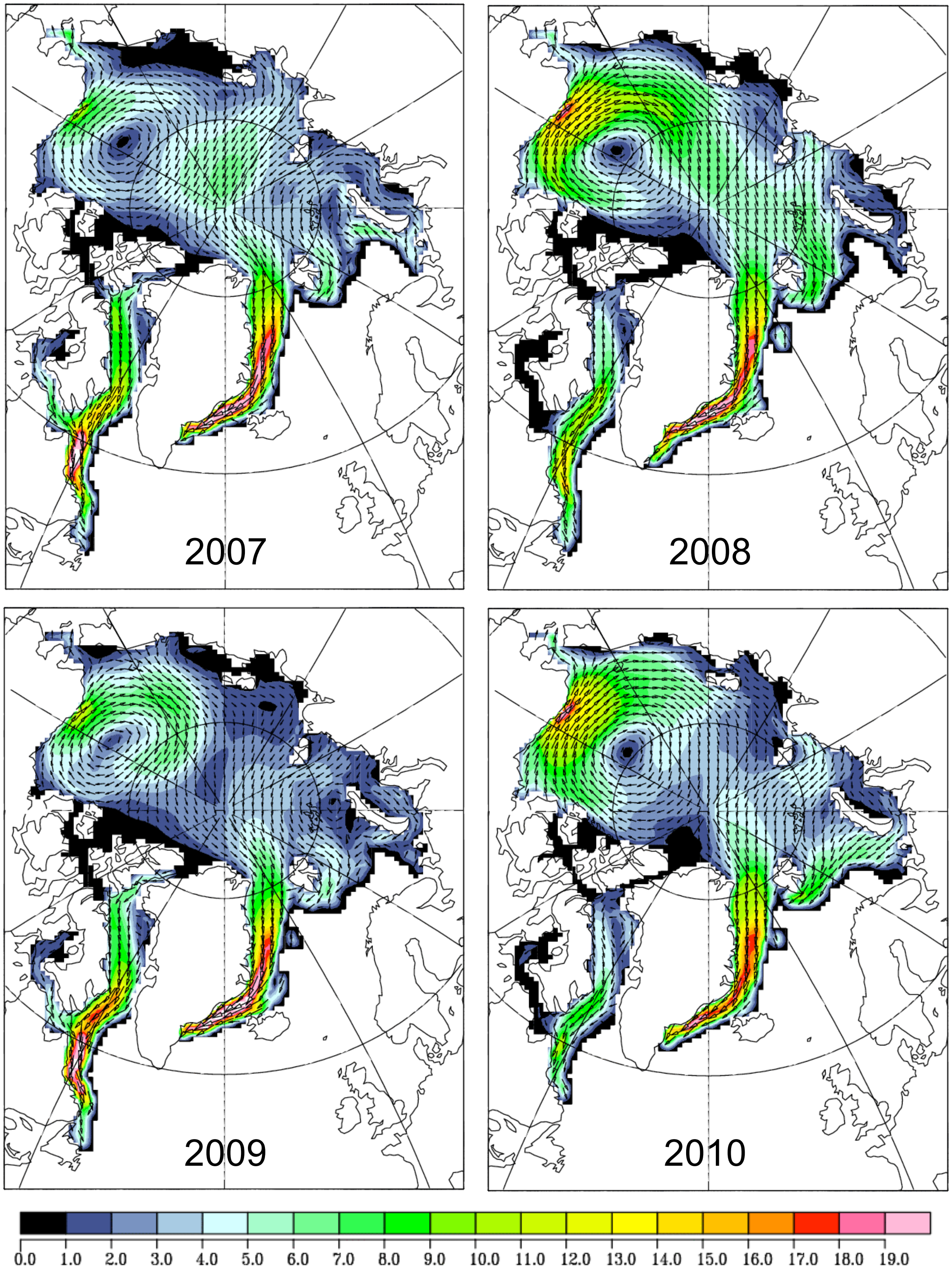

Figure 8: The mean March to end of May ice drift [cm/s] of 2007, 2008, 2009, and 2010 (until 28th of May).

In contrast to the years 2007 and 2009 which showed a relatively weak Beaufort gyre, in 2009 and in 2010 a strong Beaufort gyre is present. While in 2009 also the Transpolar Drift was strong, in 2010 the Transpolar Drift is weak. This suggests that the strong Beaufort gyre and the weak Transpolar Drift are at least partly responsible for the large ice thickness in the Beaufort Sea and north of it through anomalous ice advection. This hypothesis is supported by ice age observations. Fig. 9 displays the ice age distribution estimated by satellite data for end of April 2009 and 2010. In 2010 a much stronger Beaufort gyre is suggested. However, no multi-year ice is visible in the east Siberian Sea at the end of April 2010.

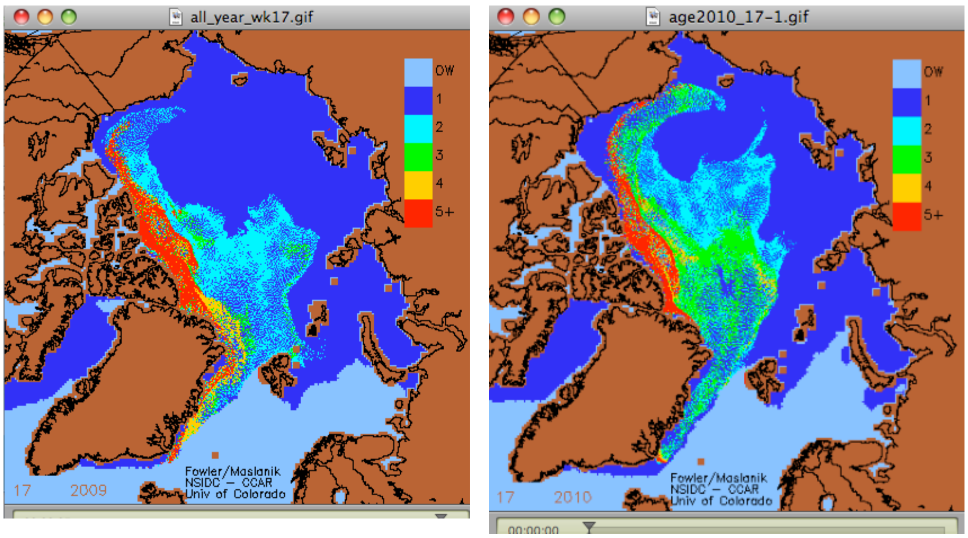

Figure 9: The observed ice age distribution at end of April 2009 (left) and end of April 2010 (right) (taken from the presentation of J. Overland at the final DAMOCLES GA in Tromso, Norway, 27th of May, 2010; courtesy Chuck Fowler and Jim Maslanik).

References:

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