Arctic sea ice in IPCC climate scenarios in view of the 2007 record low sea ice event

A comment by Ralf Döscher, Michael Karcher and Frank Kauker

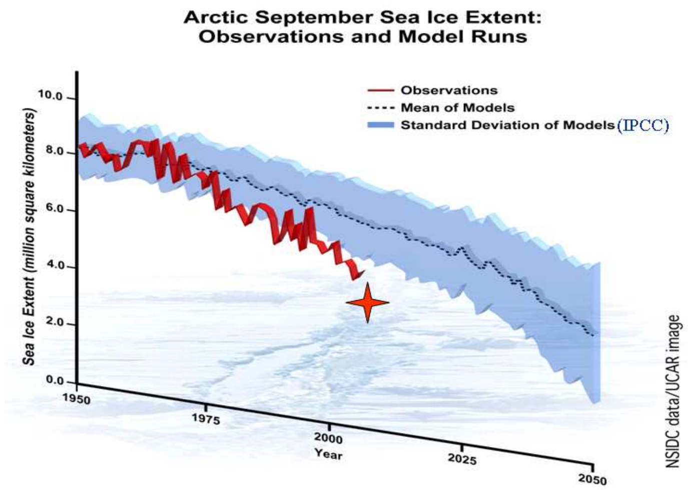

Fig. 1: Arctic September sea ice extent in observations (red), and IPCC AR4 'model ensemble' (blue). The figure originates from UCAR with data from NSIDC. The red star for the 2007 September sea ice extent is added for this article.

In September 2007, the Arctic sea ice extent reached a new record low of 4 million km^2, about 1 million km^2 lower than the preceding record low in 2005. The 2007 event is unprecedented in observed history. Here we try to summarize the current state of the discussion regarding the causes of this event and to which extent a prediction of such extreme events by models can be expected.

Realization of present day Arctic sea ice extremes by the IPCC models

The 4th assessment report (AR4) of the IPCC (IPCC, 2007) has compiled projections of Northern hemisphere sea ice extent from future climate scenarios calculated with global coupled climate models. The results of these experiments exhibit a persistent decrease of summer sea ice extent as seen in *the 'model ensemble mean' of 19* climate models, i.e. the average of all 19 model applications (Fig. 1). However, after 1996 the observed sea ice extent curve lies outside of one standard deviation of the AR4 '*model ensemble*', i.e. outside of the range in which 66% of all model realizations fall (assuming a Gaussian normal distribution within the ensemble). The ice extent during the summer event in 2007 falls 2.75 million km^2 below the mean extent of the years 1980-2000. Considering these figures in isolation, it is apparently justified to call the AR4 '*ensemble mean'* projection of Northern Hemisphere sea ice extent "too conservative". However, an important part of the story is missing: While we may compare long term change in nature with ensemble means, we may not compare short-term natural changes with an ensemble mean.

It is necessary to be aware of an important difference between the observed data and climate model results as they typically are published. Mostly, as is the case in Fig. 1, the presented climate model results are ensemble means. In this context an ensemble is a number of model experiments which differ from each other, e.g. by changed initial (starting) conditions and in the case of AR4 by different model formulations. In coupled climate models small initial differences may grow large as a consequence of the non-linearity and chaotic behavior of the climate system (the famous butterfly effect) and due to different model sensitivities. The use of ensembles instead of just one experiment provides a range of possible realizations of the climate system under given external forcing. It is evident that the ensemble mean provides a more robust picture on the system's long term response to the external forcing than any single ensemble member. On the other hand the ensemble mean has a reduced variability and less extreme events than any single member. For a test whether the IPCC models are 'too conservative' in comparison to observations, we should compare the observed 'realization' with single realizations of the ensemble models.

Only little has been published on the behavior of sea ice in single members of the AR4 experiments members. An exception is Holland et al. (2006) show results from an AR4 member calculated with the CCSM3 model. In this experiment the northern hemisphere sea ice extent exhibits a rapid decrease event over a 10 year period starting in 2023. Other CCSM3 realizations which had not been used for the IPCC AR4 are documented in the paper as well (Fig. 2) Those model versions differ from the AR4 ensemble member in spatial resolution and details of parameterizations. All the CCSM3 model experiments show considerable interannual and interdecadal variability with rapid change events of 5-10 years length, the first one starting as early as 2013. Here we have an example that CCSM3 as one of the IPCC models is principally able to generate rapid decrease events of similar amplitude as the sea ice extent reduction event observed in 2007. It is important to notice, that with respect to coupled climate models there is a difference between the ability to generate a specific type of behavior (e.g. a fast sea ice reduction event) on one hand and the concrete ability to 'predict' such an event correct in time on the other hand. Even a 'perfect' model would not be able to perform a 'perfect prediction'. One reason is our limited knowledge on the current state of the ocean which is not well enough observed, so that assumptions must be made to start model runs. Another reason is the non-linear character which leads to different large scale variability and Arctic-internally generated variability. The latter contributes substantially to the overall Arctic variability (as indicated by e.g. Mikolajewicz et al. (2005) and current DAMOCLES results by Döscher et al., pers. comm..). Both phenomenon can potentially influence the onset time of rapid ice change event. As a result, we see no common timing for the rapid decrease events in the varying scenario runs. The first occurrence of a rapid event is spread between 2013 and 2045 in the different CCSM3 model versions.

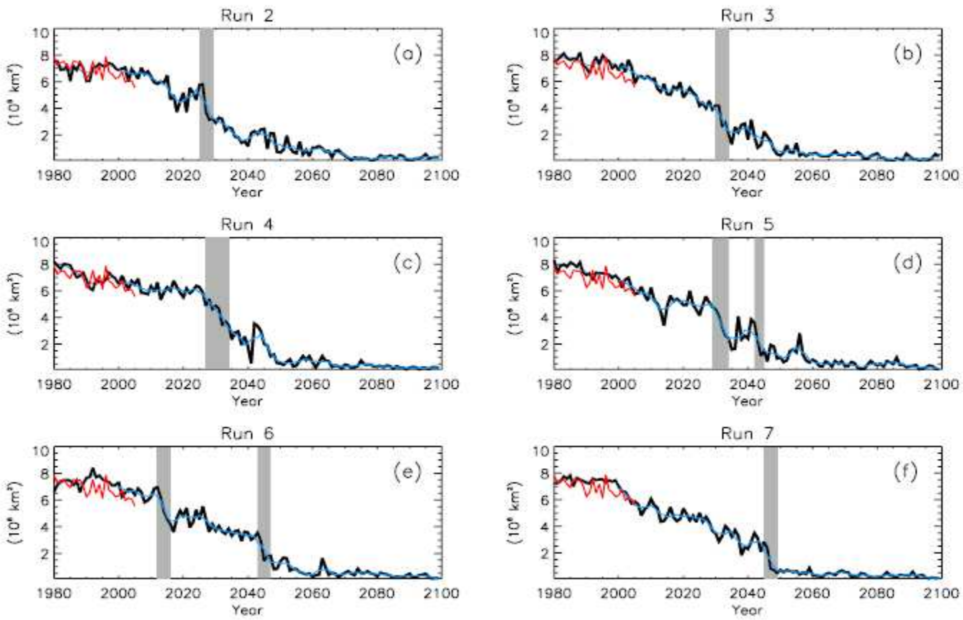

Fig. 2: The northern hemisphere sea ice extent from six additional CCSM3 A1B ensemble members. The five-year running mean (blue)and observed extent (red) are also shown. Grey shading inicates an abrupt transition. (figure by courtesy of Holland et al., 2006).

Other AR4 models are less well documented with respect to sea ice performance than CCSM3. However it is clear from IPCC related publications (e.g. Zhang and Walsh, 2006), that the interannual variability differs among the models. A model with low interannual variability is less prone to generate triggering events with associated ice reductions in the Arctic. The stronger interannual variability is in a model, the more likely are events capitalizing on the highly non-linear nature of the Arctic climate system and feedback mechanisms such as sea ice-albedo feedbacks, ice age feedbacks or interaction between sea ice and atmospheric circulation changes. The different representation of processes and the different sensitivity leads to a range of different amplitudes of interannual variability.

In the following we will attempt to compare rapid change events documented for the single members of the CCSM3 experiments with the observations of the 2007 record low sea ice cover. Since observations from 2007 are not yet published, unpublished preliminary results from the DAMOCLES project, as well as from scientific conferences give us impressions on the 2007 event

The 2007 record low sea ice event

A major feature of the 2007 summer was a pronounced SLP (Sea Level Pressure) anomaly over the coasts of northern Alaska and Canada, advecting warm air from the Pacific into the central Arctic and forcing sea ice transport towards the Northern Greenland coast and southwards through Fram Strait. Fig 3 shows the SLP anomaly in summer 2007 with respect to the mean summer SLP for the period 1980-2000. At about the same time cloud coverage was lower than normal (pers. comm. Kay). The consequentially increased downwelling radiation must have supported sea ice melting.

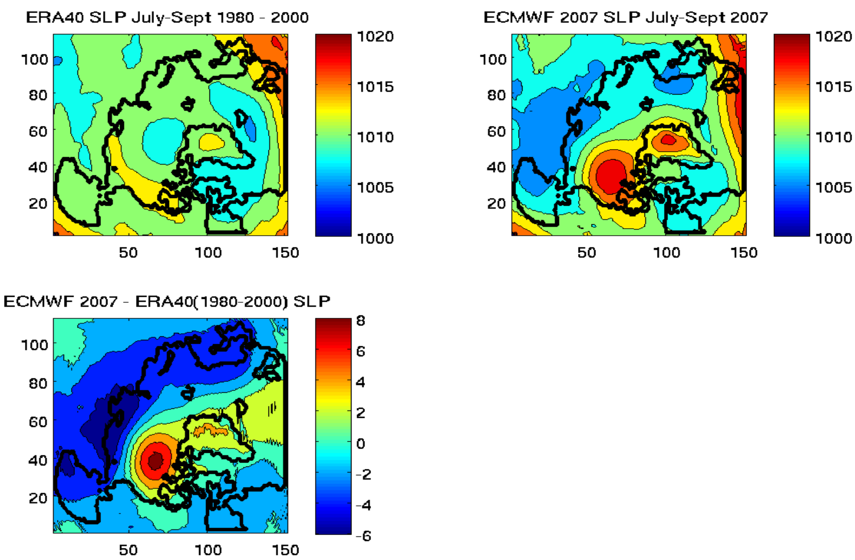

Fig. 3: July-September sea level pressure (SLP) for 1980…2000 in the ERA-40 reanalysis (upper left), for July-September 2007 in the ECMWF analysis (upper right), and the difference 2007 – (1980…2000) (lower).

A general thinning of sea ice during the last decades has been shown by submarine-based observations (e.g. Rothrock et al, 1999), supported by in-situ measurements in different local areas. Haas et al (Fig.4, personal communication) shows a persistent move of the peak of thickness distribution from about 2.5 m in 1991 to 1 m in 2007 for the local area just north of Fram Straits. The development after 2004 (from about 2 m to 1 m) appears especially pronounced. Since the thinner ice is much less able to resist strong winds, rapid ice movement as a response to strong winds moving ice out of Fram Strait was made easy in 2007.

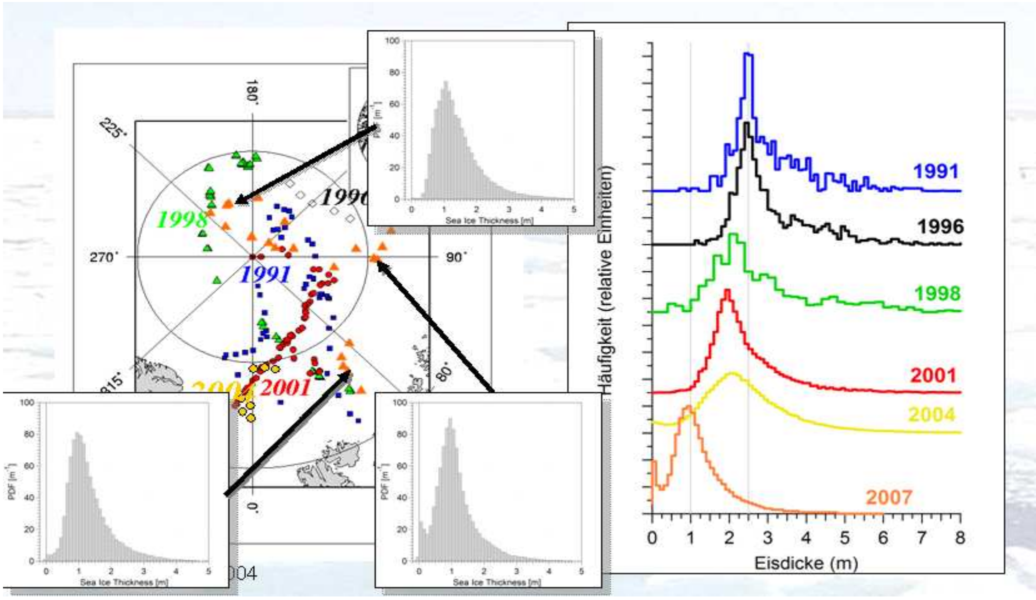

Fig. 4: Sea ice thickness observations in the area north of Fram Straits (Haas et al., 2007, pers. comm..). The right hand side figure displays sea ice thickness (x-axis) and probability of occurrence (y-axis).

TARA, a ship frozen into the Arctic sea ice as part of the DAMOCLES project in 2007 was drifting on a trans-polar track, similar to the FRAM expedition starting 1894. However, for Tara, the journey took 507 days, compared to 1055 days for the FRAM expedition a century ago. The extraordinarily fast drift of TARA confirmed the fast ice movement from the eastern Eurasian Basin to Fram Strait. Interestingly, as a result of the intense ice drift towards Fram Strait the ice coverage inside the Strait was anomalously high during summer 2007, contrasting the large ice free areas in the Canadian and eastern Eurasian basins in summer 2007.

Other components of the extreme 2007 event have been suggested. It is speculated on increased basal melting due to increase turbulent mixing in ice leads, increased fraction of melt ponds supporting surface melting and increased influence of warm inflows from the Atlantic and Pacific Ocean.

For the aforementioned CCSM3 experiments Holland et al. (2006) report rapid sea ice reduction events to be dominated by thermodynamic forcing, strong ice thinning, active sea ice –albedo feedback and a strong role of northward ocean heat transport. While ice thinning, increased shortwave radiation and sea ice – albedo feedbacks seem to be important ingredients in the real 2007 event, too, a dominating role for thermodynamic forcing without dynamic influences, or for ocean heat transports are not evident for the 2007 event. The mechanisms documented as dominant for the ice reduction events in the CCSM3 experiments therefore differ from the likely causes of the 2007 event.

What do we learn from this quick comparison? Despite partly different mechanisms, the GCM is sufficiently robust to generate ice reduction events with similar amplitudes as the observed 2007 event. However it is not clear at this time (February 2008) to what extent the observed 2007 event will recover and possibly is not at all comparable to the simulated events in CCSM3, which mostly initiate a permanent step towards less ice. Already for the next round of IPCC scenario projections (AR5), participating models will be required to pass certain tests under discussion. For the Arctic, the ability to generate rapid ice reduction events should be an important criterion. Clearly more work on model improvement and representation of mechanisms is a useful and permanent task.

Prediction capability in the Arctic

Regional Arctic ocean-sea ice hindcast simulations forced with 2007 operational atmospheric analyses from ECMWF or NCEP generally reproduce a record low summer (Köberle, Gerdes, Hacker, , pers.comm; Meier, pers. comm.; see also the animation of Zhang (APL) http://psc.apl.washington.edu/zhang/IDAO/summer2007_arctic_seaice.gif), although with varying ice extent shape. Remaining problems with respect to an Arctic seasonal and decadal sea ice forecast are better estimates of se ice thickness, a skilled large scale atmospheric circulation, and to an extent, simulated multi-annual records of ocean inflow and at least the seasonal sea ice history in terms of concentration and thickness. The large scale atmospheric part requires a global prediction system, and the latter two items require careful adjustment and continued improvement of Arctic coupled models or of the Arctic representation of global models. Thereby Arctic feedbacks play an important role. E.g is the Arctic atmospheric circulation affected by the evolving geographical distribution of ice cover. First regional coupled ocean-ice-atmosphere simulations of 2007 give very different summer air circulations, depending on the initial states of sea ice during winter 2006/2007 (Döscher, pers. comm.)

Projects on better seasonal and decadal prediction systems are on the way. In order to improve forecast capabilities on these time scales, observations of the state of ocean circulation and sea ice are indispensable. These needs are addressed by observation projects such as DAMOCLES, RAPID (monitoring of the Atlantic overturning circulation at 25^{o}N) and ARGO (a global program with 3000 profiling floats). Especially for polar areas, ice thickness information is required (CRYOSAT-2, expected during 2009, unmanned aircraft surveys). These observations will have to be combined with appropriate model initialization methods, which are currently explored. A large role can be expected for data assimilation in this context.

This effort might take years before skilled seasonal-to-decadal projections of the Arctic climate systems might be possible. DAMOCLES is contributing by developing Arctic observational systems, improved regional models and advanced data assimilation methods for reanalysis and model initialization

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