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ACCESS NEWSLETTER

Arctic Climate Change
Economy and Society

Issue No. 9
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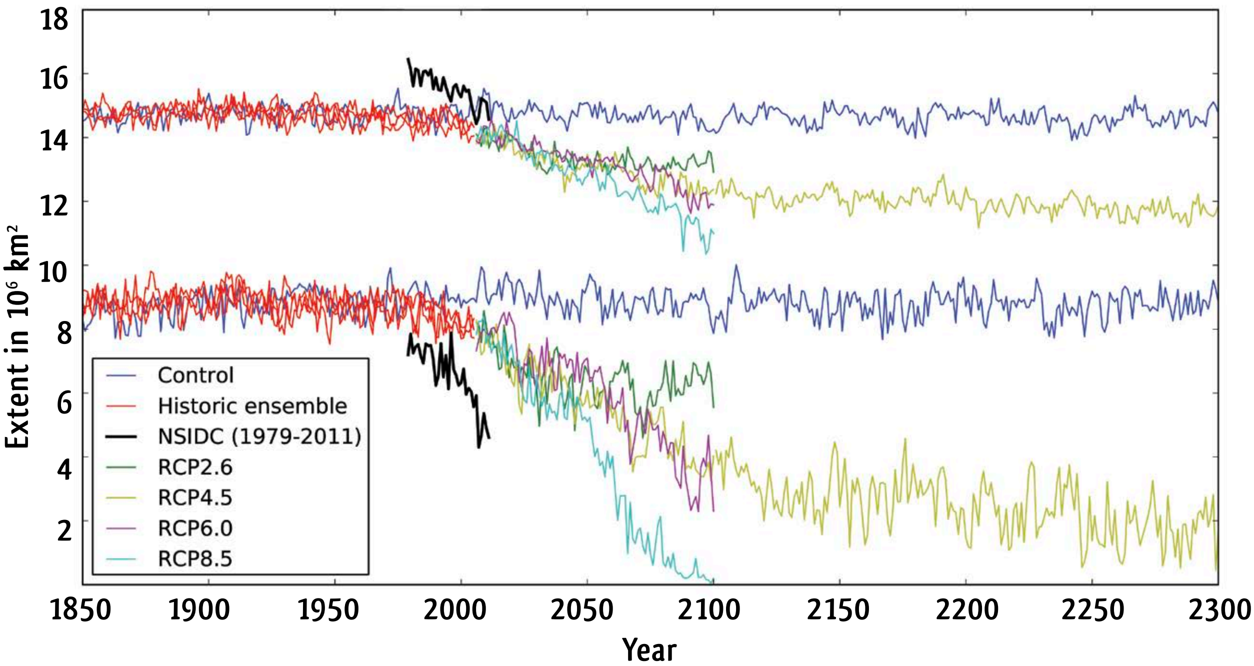
ACCESS Highlights



Modelled minimum and maximum Northern Hemisphere March and September mean sea-ice extent during the NorESM1-M simulations for 1850 to 2100 or 2300 (RCP: representative concentration pathway emission scenarios).

This newsletter is produced three times each year by a consortium of 27 partner organizations from 10 European countries in the 4-year Arctic Climate Change, Economy and Society (ACCESS) project. ACCESS is supported within the Ocean of Tomorrow call of the Seventh Framework Programme. Objectives of the ACCESS Newsletter are to facilitate international, interdisciplinary and inclusive information sharing of our research highlights about natural and human impact associated with sustainable development in the Arctic Ocean in the context of climate change.

SEVENTH FRAMEWORK PROGRAMME

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Editorial

Quantifying Climate Change Impacts on Economic Sectors in the Arctic

The ACCESS project will end early in 2015. Many tasks lay ahead, apart from finishing a number of research activities in the different work packages, an important objective is to develop a "synthesis" report of our results. We aim for a synthesis which is more than just an addition of the single research results, but one which focuses on cross-sectoral issues and the links between the different ACCESS research topics: natural sciences, social sciences, economy, governance, climate research, fisheries, shipping and natural resource exploitation. In ACCESS we facilitate research with a vast range of scientific branches on a range of economic and societal sectors. This means dealing with very different methods and even using different "languages", making the synthesis a challenge.

To help achieve this objective, ACCESS has planned and carried out a series of workshops in recent months, each dedicated to a particular aspect of the synthesis work. The first, Climate Change: The Arctic Outlook for the Next 30 Year: Synthesis of WP1 Work and Predictions is the focus of this newsletter. It reports on results discussed at the workshop organised by Work Package (WP) 1- Climate Change and the Arctic Environment, to set the scene for the upcoming workshops on the links between marine transportation, tourism, fisheries and oil and gas exploitation and indigenous peoples.

The workshop took place in June 2014 at the Laboratoire d'Océanographie in Villefranche-sur-Mer (LOV), France, organised by Martin Doble (LOV) and led by Peter Wadhams (University of Cambridge). It featured reports on the state of research in WP 1 and was enhanced by additional presentations and discussions of the implications of climate change-related results for other areas of research and sectors. This newsletter highlights some of its presentations and discussions.

Complementarity of the roles of observations and modelling in sea-ice prediction in the Arctic, both fields of intense research as a base for sectoral work in ACCESS, is the focus of the article by Peter Wadhams. Projected sea-ice cover in the Arctic as it results from coupled climate models that are part of the Intergovernmental Panel on Climate Change reports, and how to decide which may be the best ones to use for ACCESS purposes is the topic of an article by Kathrin Riemann-Campe and Rüdiger Gerdes (AWI). The intricacies of how to improve a climate model and how to interpret its sensitivities are featured in an article by Øyvind Seland and Jens Debernard (MET Norway). It is followed by a description of results on wide-scale Arctic sea-ice developments based on satellite observations provided by Jean-Claude Gascard (UPMC). Monitoring and forecasting of atmospheric data is most relevant for almost every commercial activity in the Arctic. The article by Harald Schyberg, Thomas Nipen and Roger Randriamampianina (MET Norway) describes the difficulties of forecasting in an area where routine observations are sparse. An article by Arne Eide (NOFIMA) addresses predictions of the distribution of the very important commercial fish species, cod in the Barents Sea, and the role climate change and management of fisheries play for the future development. In addition, we provide an example of how decision-makers could benefit from an advanced indicator system for sustainable development presented by Sebastian Petrick (IFW).

ACCESS Editorial Board

The Arctic Outlook for the Next 30 Years: Selected Highlights from Climate Change and the Arctic Environment Work Package

Overview

Climate change is strongly impacting both marine ecosystems and human activities in the Arctic, which in turn has important socio-economic implications. Arctic Climate Change Economy and Society (ACCESS) is evaluating the latest Arctic climate change scenarios and assessing their impacts on marine transportation (including tourism), fisheries and the extraction of hydrocarbons in the Arctic for the next three decades with particular attention to environmental sensitivities and sustainability. Understanding the socio-economic impacts of these changes on markets, economies and on European policy objectives along with their influence on Arctic governance are key areas of research within ACCESS.

ACCESS aims to better understand environmental changes in the Arctic and to quantify the impact of climate change on key economic sectors using an integrated and cross-sectoral approach. There are three general objectives of quantifying climate change impacts on economic sectors in the Arctic in the ACCESS research:

- To improve our understanding and the predictive capacity of how Arctic climate and marine ecosystems respond to a combination of natural and anthropogenic factors.
- To improve our understanding of how rapid environmental changes might affect human activity in the Arctic and impact on sectors and regions.
- To evaluate which risks to humans and the environment may result from projected economic changes and what measures could be developed to address these risks.

Based on these insights, it is possible to assess the related risks and opportunities in a broader context and to provide a foundation for the sustainable development of economic activities with a minimal impact on the sensitive Arctic environment.

The Arctic has experienced substantial changes in recent years. These changes are most likely caused by a combination of natural variability of the high-latitude climate system, anthropogenic changes in the radiation balance and subsequently in atmospheric and oceanic heat transports, and feedbacks of the air / sea-ice / ocean-coupled system triggered by thinning sea-ice cover. Climate scenarios and current models are unable to reproduce these recent changes. Sea-ice is vanishing faster than in all climate-coupled model scenario calculations. None of those calculations anticipated the 2007 and 2012 drastic sea-ice retreat events.

To improve scenarios and climate models, a number of measures are necessary. In ACCESS, we are monitoring the current status and variations of the Arctic sea-ice to provide a baseline against which to compare projected future changes and to maintain the critical measurements that are needed to confirm and determine the trends in ocean, ice and atmospheric variations. Outlooks and estimates of uncertainties for potential developments on time scales up to 30 years will be provided by ACCESS simulations. This includes regionally differentiated scenarios for the development of sea-ice and its variability; changes in the frequency, locality and intensity of extreme weather events; and potential changes in oceanic current systems that could result from increased economic activity. These will feed into earth system models to produce enhanced climate projections as a basis for policies and actions.

These analyses will feed directly into key sector assessments, namely maritime transport, fisheries and oil and gas extraction. ACCESS Work Package (WP) 1 - *the Arctic Environment in the Context of Climate Change* - is a point of departure for all the other activities of ACCESS.

Results of its research tasks are estimates of uncertainties in climate model projections and the identification of superior climate model results that can be used as input to evaluations in other work packages. So collaborating on findings and developing consensus views of the possible outlooks for the next three decades in the context of ACCESS objectives is critical. This was the focus of a two-day workshop, **Climate Change: The Arctic Outlook for the Next 30 Years a Synthesis of WP1 Work and Predictions** in early June 2014 at the Laboratoire d'Océanographie de Villefranche-sur-Mer. The first day covered selected research contributing to the 30-year outlook and discussions among the scientists and specialists. The second day considered the relevance of the outlook to other work packages and discussed the synthesis that features large in the compilation of the multitude of ACCESS investigations in this its final year. This newsletter presents selected highlights from the workshop.

Arctic Sea-ice Predictions: the Complementary Roles of Observation and Modelling

Peter Wadhams *- Department of Applied Mathematics and Theoretical Physics, University of Cambridge*

In recent years the Arctic has been transformed. A central ocean which was permanently ice-covered and where seasonal variations happened only in the sub-polar seas has changed with bewildering speed into an ocean where significant summer ice retreat occurs, exposing its wide continental shelves to the power of the sun. Soon the Arctic ice cover will resemble that of the Antarctic – extensive in winter, but almost non-existent in summer. A ship entering the summer Arctic today from the Bering Strait finds an ocean of open water. The top of the world now looks blue instead of white from space - a profound change. It is the summer changes which have created the potential for catastrophic feedback effects which may represent a serious threat to the planet.

Since the Industrial Revolution, the Arctic has been warming more rapidly than any other region of the globe (IPCC 2007, 2013; AMAP, 2011), with an amplification factor of 2-4 over the planet as a whole, which is increasing (Screen et al., 2012). Average air temperatures at 60-90 ° N have risen by 2 degrees Celsius (°C) since 1980. The rapid warming, combined with related factors such as ice-albedo feedback (Perovich and Polashenski 2012), and higher ocean heat flux (Shimada et al., 2006), are major contributors to a reduction in summer (September) sea-ice extent from 7 million square kilometres (km^2) in the 1970s to only 4.2 million km^2 in 2007. A brief recovery was followed by a further shrinkage in 2012 to 3.4 million km^2 with a further recovery in 2013 and 2014.

This summer retreat has been accompanied by a significant decrease in sea-ice extent in other seasons (Stroeve et al., 2012), also by changes in ice type, especially a dramatic reduction in multi-year ice (Comiso, 2012); a decline of more than 40 % in sea-ice mean thickness (Rothrock et al., 1999); a reduction of 73 % in pressure ridge frequency between 1976 and 1996 (Wadhams and Davis, 2000); and changes in ice dynamics (Rampal et al. 2009). Some coupled models predict an "ice-free" Arctic summer by 2040 (*e.g.* Holland et al., 2006; Wang and Overland, 2009), while others (Maslowski et al., 2012; Schweiger et al, 2012) predict an ice-free September within a very small number of years, before 2020 and possibly as early as 2015.

Analysis of thickness leads to greater alarm. The PIOMAS project (Pan-Arctic Ice-Ocean Modelling and Assimilation System) at University of Washington examined sea-ice volumes (making use of submarine data and interpolation rather than just ice extent), and found an "Arctic death spiral" (Figure 1) as the ice volumes at all seasons of the year spiral in towards zero (an ice-free Arctic). It should be noted that this is still a model, though an empirical one which extensive assimilation of extent and thickness data. An empirical extrapolation from these data show the September figure reaching zero in 2015 or 2016 and neighbouring months (July, August, October, November) set to follow not long afterwards. The reasons behind this dramatic loss of sea-ice are not fully understood, as the mechanisms involved are a complex interplay of atmospheric, sea-ice and ocean processes, with strong feedbacks. The Arctic sea-ice changes are associated with profound changes in the Arctic marine system, with increased periods and areas of

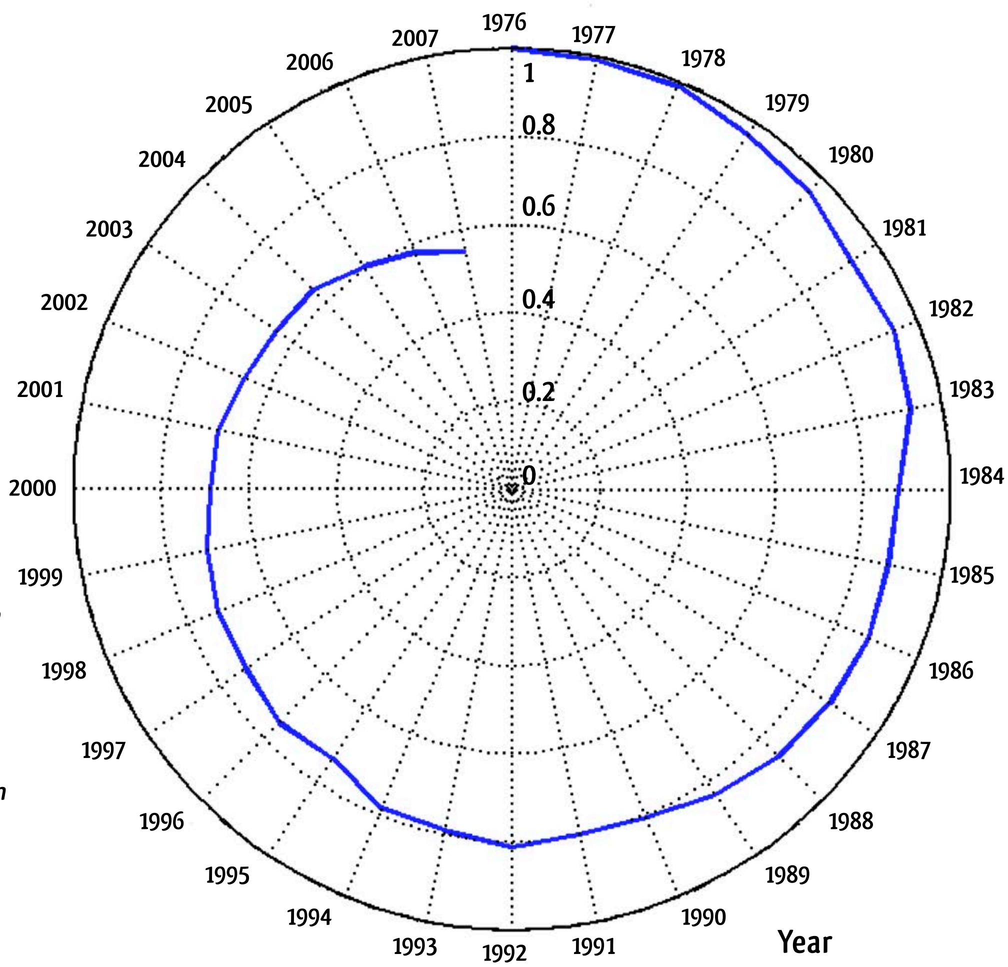

Figure 1 - Annual-averaged sea ice volume from 1976 to 2007, based on sea ice area derived from satellite data (NSIDC) and basin-wide mean thickness derived from UK submarine data interpolated by a technique described in Wadhams and Clancy (in press). The product shows a reduction in 2007 to 56% of the volume of 1976. It agrees with PIOMAS results but is based purely on observations with no recourse to a model.
Wadhams, P. and R. Clancy: Direct measurements of sea ice thickness and their implications for sea ice disappearance and feedbacks.

open water, increased fresh water input, increased input of solar radiation, increased surface ocean temperatures, an enhanced underwater light climate, an altered nutrient supply into the euphotic zone and a significant, but yet to be understood, change in ecosystem dynamics (Carmack, 2007; Wassmann et al., 2011).

The need for an accurate projection of sea-ice extent, particularly in summer, arises because a serious retreat of sea-ice leads to the coming into play of positive feedback loops, where a change in sea-ice extent initiates another undesirable or unexpected change. In the Arctic, we are already aware of at least two such loops. The albedo of open water of 0.1 compares to 0.5 - 0.7 for melting ice, and it has been recently estimated (Pistone et al., 2014) that the loss of area of summer sea-ice between the 1970s and 2012 has caused a global albedo decrease equivalent to one-quarter of the effect of all the carbon dioxide (CO_2) added to the atmosphere by man during that period. This is a "fast feedback" because its effect is immediate.

The sea-ice / albedo feedback is enhanced by faster spring snow melt in Arctic coastal lands as sea-ice recedes, probably due to warmer air masses moving over the coastal lands from the sea; already in 2012 we saw a 6 million km^2 negative area anomaly in June compared with 1980. This will itself create a feedback of similar magnitude to that discussed by Pistone et al., so if we put them together the overall sea-ice / snow-albedo feedback is adding 50 % to the direct global heating effect due to CO_2 addition, showing how the Arctic can become a driver of, rather than just a responder to, global change.

The second major feedback is the seabed methane (CH_4) feedback. So long as some ice was present in summer, however thin, the near-surface water temperature could not rise above 0 °C, since any warmer water would lose heat in melting ice. With the ice gone, the surface water can now warm up by several degrees in summer (satellites have shown 7 °C and shipborne surveys up to 7.5 °C, Bates et al., 2013), and over the shallow continental shelves (50 - 100 metres deep) this heat reaches down to the seabed. This melts offshore permafrost, frozen sediments which have lain there undisturbed since the last Ice Age. The thawing offshore permafrost triggers the release of plumes of methane gas from the disintegration of unstable solid methane hydrates which had been sealed into the sediment by the permafrost cap. Since the significant uncovering of the shelf seas started only in about 2005 this phenomenon is probably a new effect in the post-glacial history of our planet. This has been studied in the field by a US - Russian group (Shakhova et al., 2010a, 2010b, 2013).

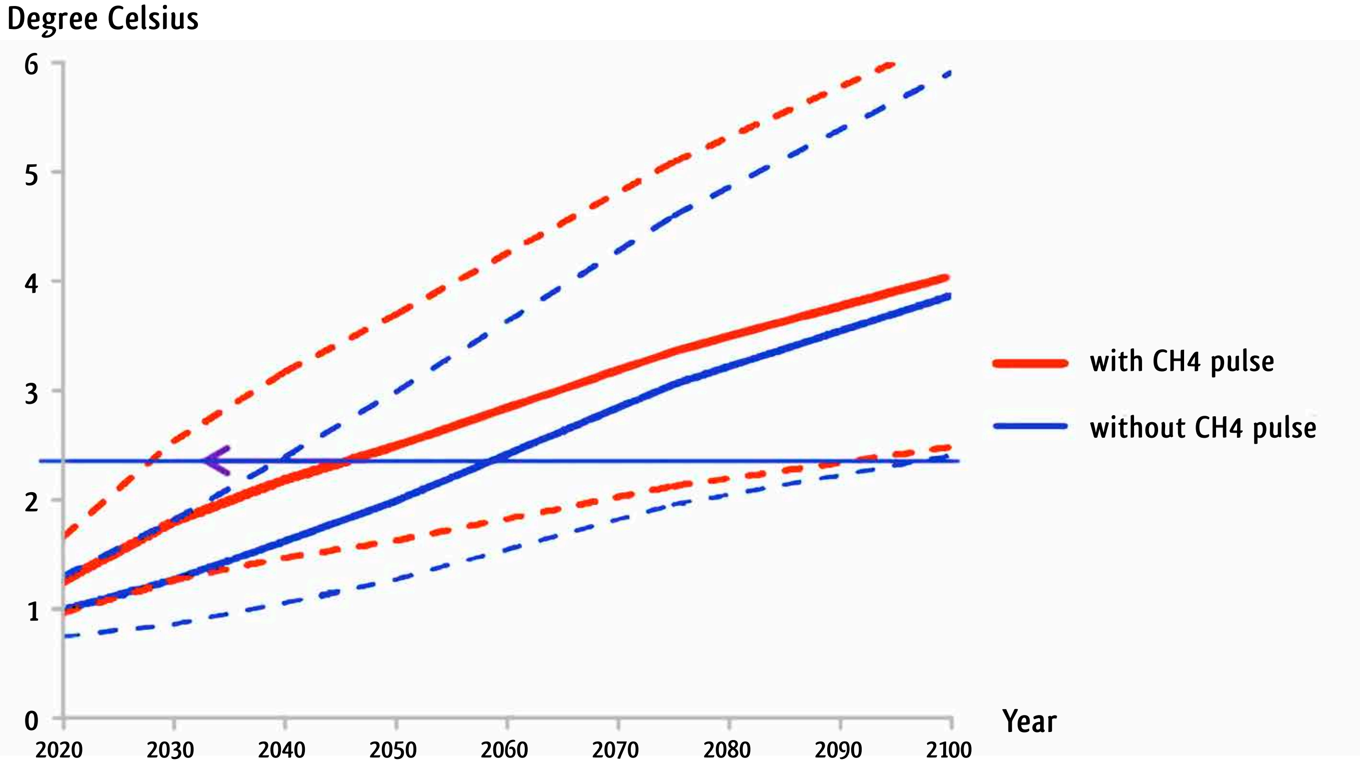

Figure 2 - Projected global temperature changes to 2100 as affected by a 50 gigatonne methane pulse taking place from 2015 to 2025. Solid line is a business-as-usual scenario, dashed lines are high and low emission scenarios.
Source: Based on Whiteman, Hope and Wadhams, 2013.

Despite its much lower concentration in the atmosphere than CO_2, methane makes a substantial addition to overall climate change because it is a much more powerful greenhouse gas. Latest IPCC estimates (2013) are that CH_4 contributes 0.97 W m^{-2} to radiative forcing while CO_2 contributes 1.68 W m^{-2}. Per unit mass, CH_4 is 23 times as powerful as CO_2 when measured over a 100 year period; this is called its global warming potential (GWP). Since methane persists in the atmosphere for only about

8 - 10 years after emission, its GWP when measured over this period is much greater than 23; figures of 100 - 200 have been quoted. It is clear that a sudden release of a large quantity of methane would have a huge, if short-lived, impact on climate. Whiteman, Hope and Wadhams (2013) undertook to estimate what this emission would mean in terms of global warming and economic cost to the world. Emissions of 50 gigatonnes (Gt) are assumed to take place over 2015 - 2025. The warming estimate was based on a standard model of response to CH_4 emissions and yielded a warming which peaks at 0.6 ° C in 2040 (Figure 2), a large increase in projected warming levels, especially as, in response to the nature of methane, the effect is concentrated in the years immediately after emission which are years in which CO^2 - induced warming is still gathering strength.

The economic analysis was based on the integrated assessment model that was used in the Stern (2007) review of climate change costs for the UK Government as well as for a more recent analysis conducted for the Asian Development Bank. The finding was that total costs (based on factors such as sea-level rise, changes in agricultural productivity, changes in transport and industrial practices) amount to US dollars (USD) 60 trillion over 100 years, an average exceeding USD 1 trillion per year.

These results are of enormous importance for two reasons: (1) They show the invalidity of arguments which point to the advantages of sea-ice retreat in terms of transport and oil exploration being easier; (2) They show that we must not imagine that future climate warming can be projected based only in a linear way on CO2 emissions. The reality is that new feedbacks come into play at certain critical points, which accelerate warming and may end up dominating the future pattern of global change.

In the ACCESS workshop, we explored the continuing gap between predictions based mainly on observations (the PIOMAS results) and those based on models. Our own models strive to bridge that gap.

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Arctic Sea-Ice in Climate Model Scenarios

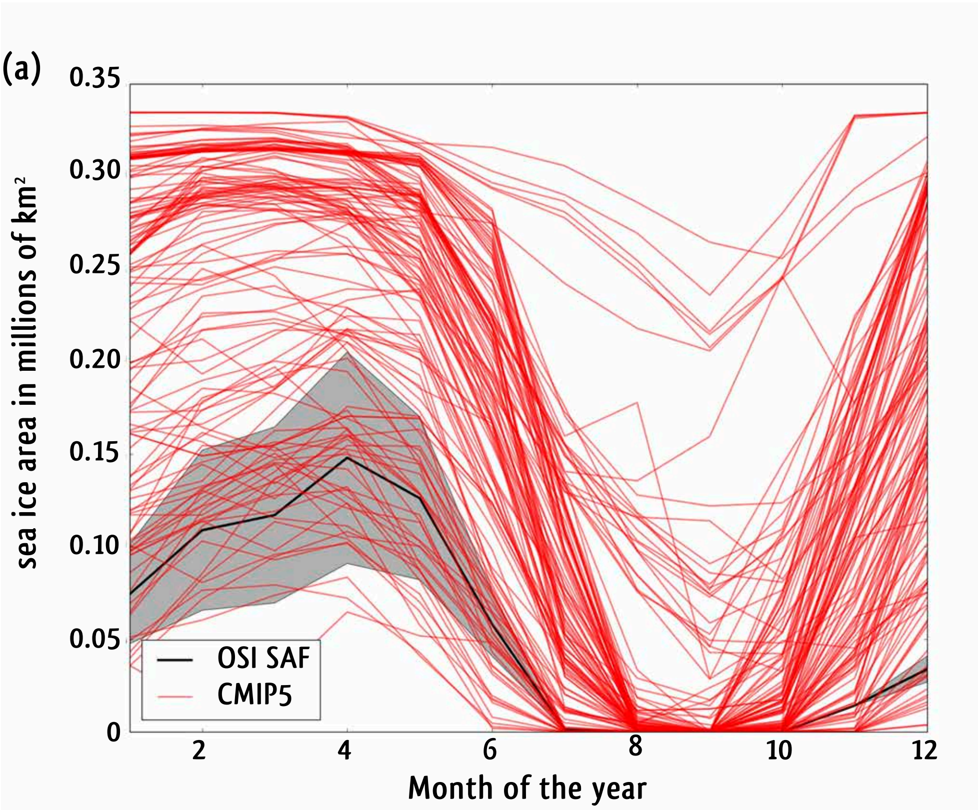
Kathrin Riemann-Campe and Rüdiger Gerdes - Alfred Wegener Institut

Global-coupled models are widely used to project future development of climate and its components in the decades ahead, e.g. Arctic sea-ice area and thickness. For the most recent Intergovernmental Panel on Climate Change Assessment Report No. 5 (IPCC-AR5) more than 30 global - coupled climate models carried out standardised experiments for present conditions and four greenhouse - gas emissions scenarios to assess the possible range of climate change in the future. These models are part of the Coupled Model Inter-comparison Project phase 5 (CMIP5) established by the World Climate Research Programme (WCRP) (Taylor et al. 2012). However, not all of these models are able to represent the past and present sea-ice conditions equally well. There are several reasons: one of them being that the winter sea-ice extent is strongly linked to the position of the North Atlantic current in the respective ocean part of the model. Many models have difficulties to simulate the correct position of this warm water current entering the Arctic and thus fail to simulate the sea-ice extent well in this respect.

Several studies have analysed the Arctic sea-ice distributions in CMIP5 models, including Stroeve et al. (2012) and Wang and Overland (2012) and identified individual models which simulate the distribution of sea-ice better than others. Depending on the analysis method, the list of the " better " models varies. Since in ACCESS we are interested in the Arctic as whole as well as specific sub-regions, we performed our own analysis of the CMIP5 models with a focus on these sub-regions. According to ACCESS partners dealing with resource extraction (Work Package [WP] 4), regions with potential for oil and gas exploitation are of special interest, namely the southern and northern Barents Sea, parts of the Kara Sea and off Greenland's west coast. Furthermore, we focus on coastal regions along the Northern Sea Routes, which are relevant for shipping activities in the Arctic, a topic dealt with in the marine transportation and tourism WP2.

To find out which CMIP5 models are performing better in the chosen regions as well as in the entire Arctic, we compare the mean seasonal cycle of monthly mean sea-ice concentration from the model experiments covering the 20th century with those derived from two different satellite products covering two time periods : OSISAF 1979-2005 (EUMETSTAT, 2011) and SSM/I 1992-2005 (SSM/I). The four best models with respect to past sea-ice concentrations according to this comparison are : MPI-ESM-LR, CCSM4, GFDL-CM3 and NorESM1-ME.

Development of the climate model simulations for future CMIP5 experiments are based on four different scenarios of potential greenhouse-gas concentrations in the atmosphere (leading to different radiative forcing for the atmosphere). These are the " representative concentration pathway " (RCP) emission scenarios (Moss et al., 2010). We chose to analyse two of those with an intermediate and a high concentration, respectively. By 2100 these scenarios reach a global change of radiative forcing relative to pre-industrial conditions of 4.5 W m^{-2} (watts per square metre) and 8.5 W m^{-2}. ACCESS research focuses on the 2010 to 2040 period in which the change in radiative forcing reaches approximately 3 W m^{-2} for the RCP 4.5 scenario and ~ 4 W m^{-2} for the RCP 8.5 scenario.



The models exhibit a large range of simulated sea-ice concentration in the southern Barents Sea for the period 1979 - 2005, as illustrated by the integrated sea-ice area (Figure 3a). Switching to the selected four "best" models, the range of sea-ice area is narrowed considerably (Figure 3b). Nevertheless, not all four models are within the range of one standard deviation of the OSI SAF satellite product and able to simulate the correct time of freeze-up in autumn. Each of the

Figure 3- Area integrated sea-ice concentration mean seasonal cycle in the southern Barents Sea:
(a) individual ensemble simulation of CMIP5 models (red) in comparison with OSI SAF (black) mean (line) and standard deviation (grey shading) during 1979-2005
(continued on following page)

selected models provides a number of simulations called "ensemble members", the difference of which indicate the model variability. For example, the GFDL-CM3 model has a larger variability within its five ensemble members than the CCSM4 with its six members. The change of the annual cycle of sea-ice as simulated by the selected models is shown in Figure 3 c. The mean of the period 1991 - 2005 (solid lines) is compared to the mean of 2025 - 2040 for the scenarios RCP 4.5 (dashed) and RCP 8.5 (dotted).

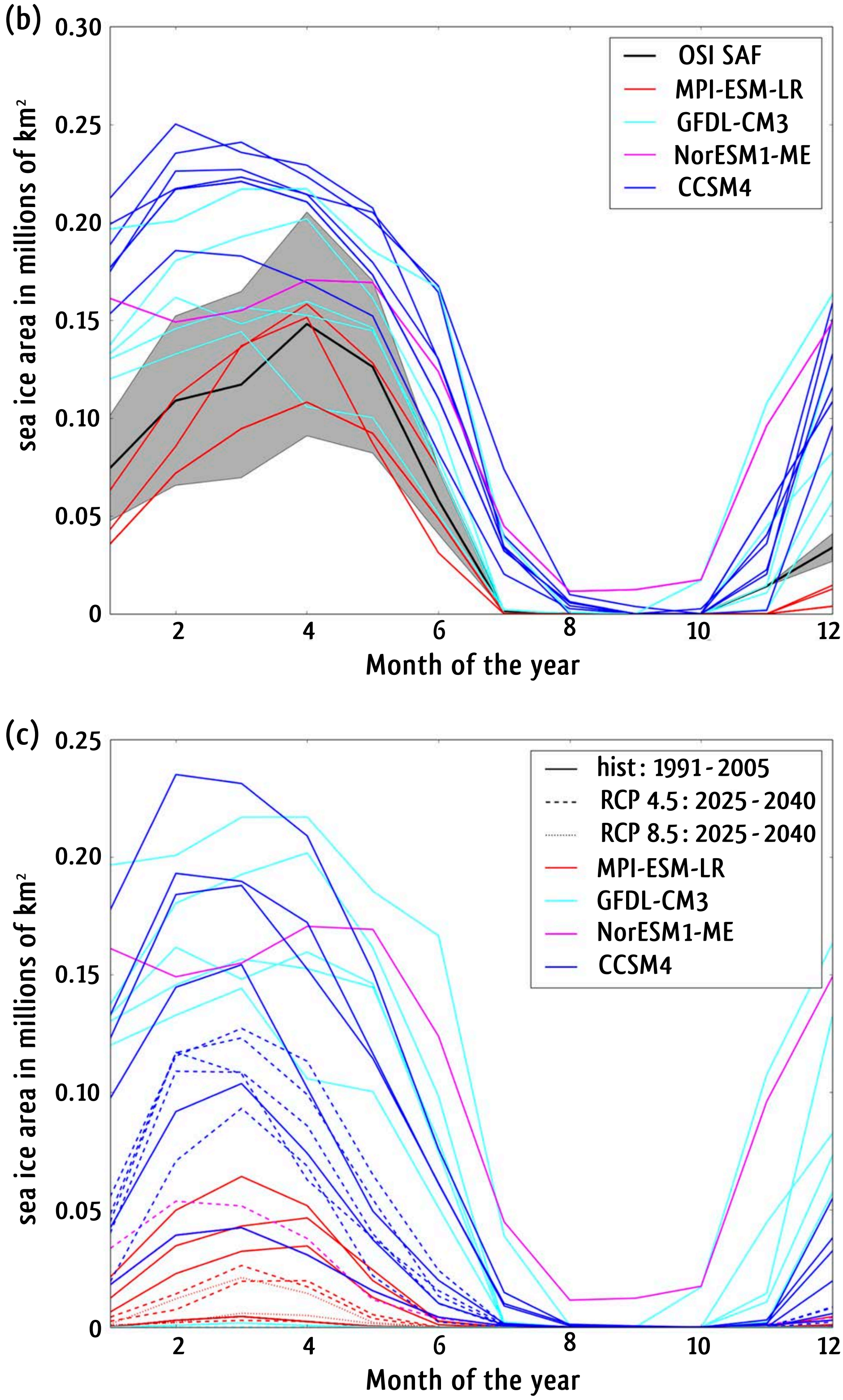


Figure 3 (continued) - Area integrated sea-ice concentration mean seasonal cycle in the southern Barents Sea:
(b) during 1979-2005 for four chosen models in comparison with OSI SAF (black) mean (line) and standard deviation (grey shading);
(c) historical run 1991-2005 (solid) versus future scenario (dashed, dotted) of mean sea-ice concentration for chosen models (coloured).

Despite using only the four best models, the simulated sea-ice conditions still vary considerably. Figure 3 shows the seasonal cycle of the sea-ice area. For April, it ranges from 3 to 22 millions of km² for the historical period 1991 - 2005 and from 0 to 12 millions of km² for the 2025 - 2040 period in the RCP 4.5 scenario (from 0 to 2 millions km² for the RCP 8.5 scenario, respectively). Furthermore, the mean 2025-2040 RCP 4.5 simulation of the CCSM4 produces more ice throughout the entire year than the MPI-ESM-LR during the mean 1991 - 2005.

The Arctic-wide decrease of sea-ice concentration in September in the 2025 - 2040 period compared with 1991 - 2005 also varies considerably between models (Figure 4). The sea-ice concentration in the GFDL-CM3 model, for example, retreats almost to the North Pole, whereas the sea-ice concentration in the other three models vanishes only along the coastal areas.

We summarise from this analysis that all models agree on a decrease in sea-ice concentration until 2040. Most models agree on a main decrease of approximately 30 % along the coast in September. However, the variability between ensemble members of one model as well as the range of results between the models is large. As a consequence, despite a general long-term downward tendency of sea-ice cover in the Arctic, estimates of future development in the economic sectors in the Arctic that depend on sea-ice conditions will still have to take into account the large uncertainty of sea-ice projections.

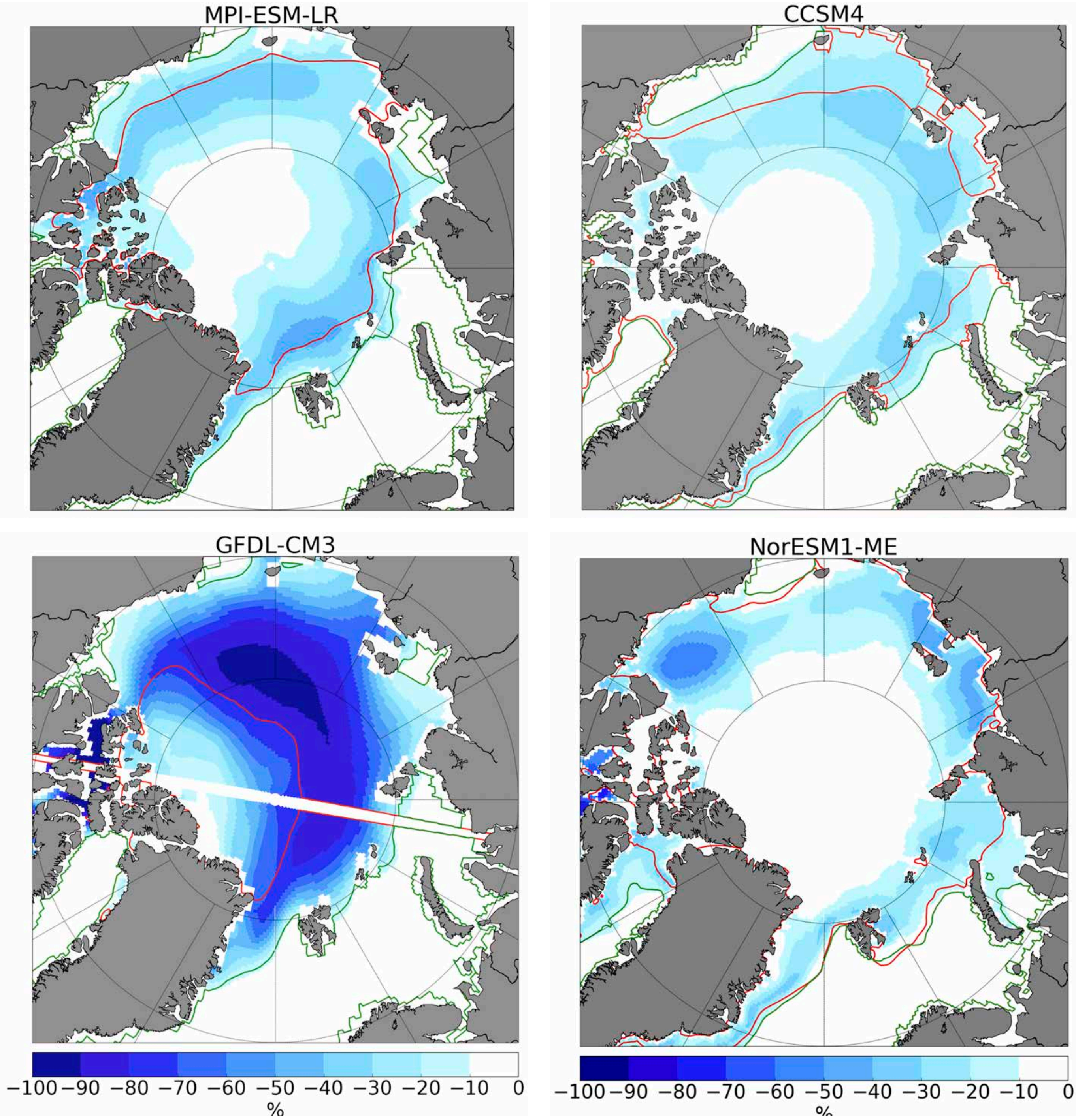


Figure 4 - Decrease of September mean sea-ice concentration from mean (1991-2005) to mean (2025-2040) in chosen models. The lines indicate the 15% contour line of the mean (1991-2005) in green and of the mean (2025-2040) in red.

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Sensitivities of Arctic Sea-ice in Climate Modelling

Øyvind Seland and Jens Debernard - Norwegian Meteorological Institute

There has been a downward trend of 3.8 % per decade over the period 1979 to 2012 in the annual average extent of sea-ice in the Arctic. The observed reduction in summer minimum sea-ice extent is even larger (11 % per decade) within the same period (IPCC AR5, 2013). The CMIP5 (Coupled Model Inter-comparison Project) models better simulate the observed trend of September Arctic sea-ice extent than the CMIP3 models. It has been suggested that in some cases model improvements, such as new sea-ice albedo parameterization schemes, have been responsible (IPCC AR5). In addition to physical processes, a possible explanation is also the relatively coarse resolution found in global models. Higher resolution may improve both the representation of large-scale circulation patterns, as well as geographical features, *e.g.* along the coastline.

NorESM (Norwegian Earth System Model), one of the CMIP5 models used in ACCESS WP 1, still has a delayed ice-melting compared to measurements (Bentsen et al. 2013). Figure 5 shows the modelled maximum and minimum northern hemisphere sea-ice area for the 20th century and for the four CMIP5 scenarios (Iversen et al. 2013.) We note periods with rapid reduction in modelled sea-ice area after year 2000, probable as a consequence of a thinner, more vulnerable ice cover.

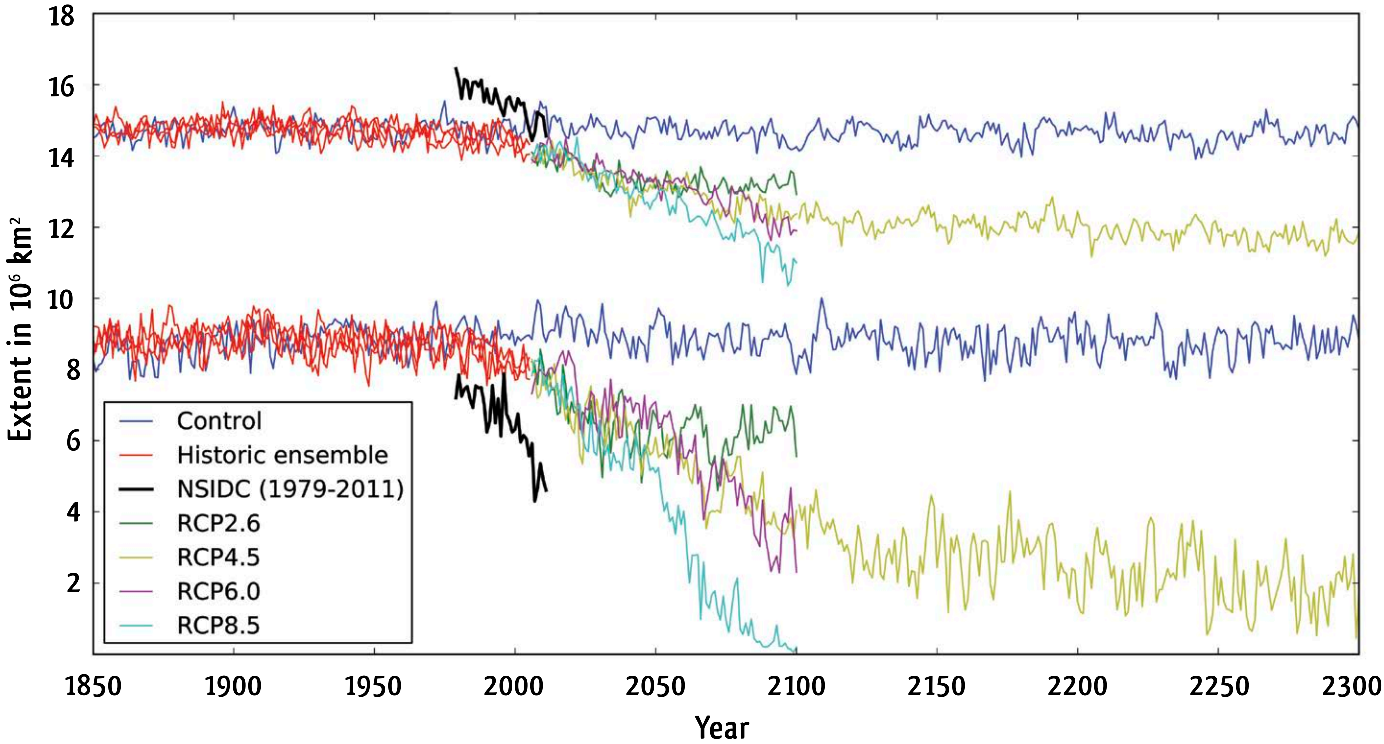
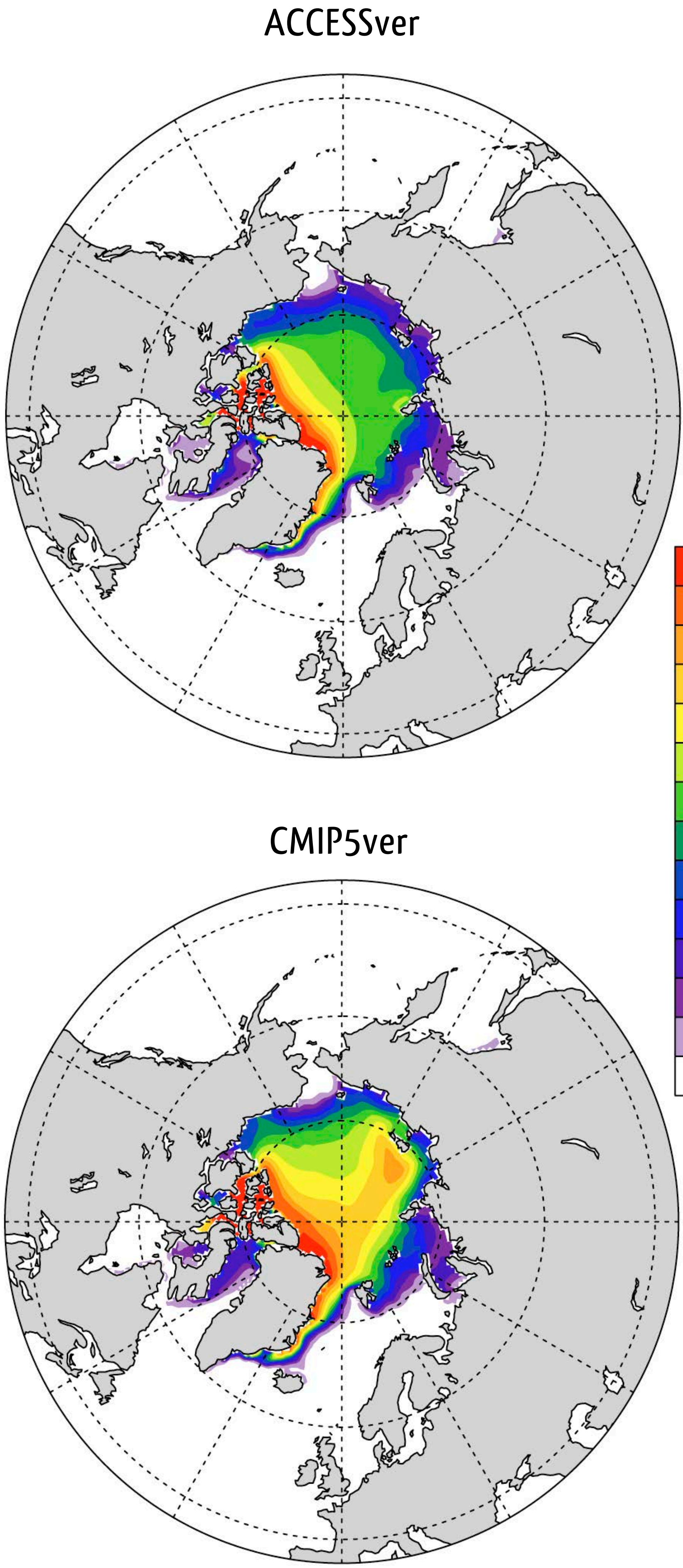


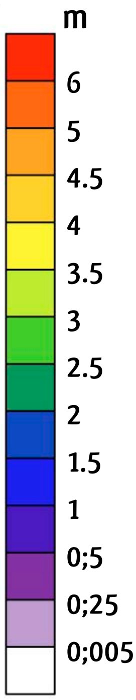
Figure 5 - Modelled minimum and maximum Northern Hemisphere March and September mean sea-ice extent during the NorESM1-M simulations for 1850 to 2100 or 2300.
Note: RCP = representative concentration pathway emission scenarios.

A focus of our research in ACCESS is to improve the modelling of Arctic sea-ice both through improving physics and resolution, where the themes addressed have been the effects of black carbon in the Arctic, the effects of increased model resolution, and effects of improving surface properties in the sea-ice model:

- In the Arctic, the light-absorbing properties of aerosols are of particular importance due to the natural high albedo of sea-ice, snow and glaciers. Regionally, soot and dust contribute to a shift in the radiative forcing towards positive values (warming). Emissions due to the increasing economic activities in the Arctic region are particularly potent. A particular focus on reducing soot emissions has been suggested as a mitigation strategy to reduce sea-ice loss in the near term.
- Experience from preliminary experiments indicates that systematic errors are considerably reduced when the resolution is doubled. This in itself provides a valid reason for doubled resolution for selected experiments. Many impact studies need data of higher geographical resolution, but the considerable uncertainty associated with sea-ice and snow cover renders regional down-scaling by dynamical or statistical methods of limited value.
- Melting processes on the sea-ice surface take place on a sub-grid scale and must be parameterized when they are taken into account in a large scale model. In ACCESS, the focus has been on the melting of snow on sea-ice and formation of melt-ponds in the ice.



Three published papers on the effects of black carbon in the Arctic build on this work and acknowledge NorESM and ACCESS. The focus has been on differences in climate response from black carbon in the Arctic compared with black carbon in lower latitudes. We find that black carbon emitted within the Arctic has an almost five-times larger Arctic surface temperature response (per unit of emitted mass) compared to emissions at mid-latitudes (Sand et al. 2013). Especially during winter, black carbon emitted in north Eurasia is transported into the high Arctic at low altitudes. A large fraction of the surface temperature response from black carbon is due to increased absorption when black carbon is deposited on snow and sea-ice, with associated feedbacks. Today there are few sources of black carbon within the Arctic, but these emissions are expected to grow due to increased human activity in the region. There is a great need to improve technologies to be less polluting for economic activities taking place and their expected expansion particularly since the Arctic has significantly higher sensitivity to black carbon emitted within the region compared with similar emissions at mid-latitudes. Studies related to the work to in ACCESS show that even relatively small and local emission sources, such as gas flaring, can have a noticeable impact in the whole Arctic basin



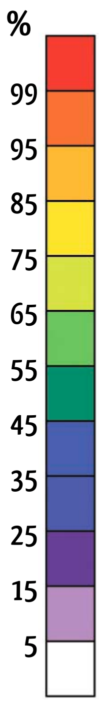
Generally first-year sea-ice has larger areas covered with melt-ponds than multi-year sea-ice early in the melt season. This is believed to be important for the rapid melting of first-year ice compared with multi-year ice. To include this effect in NorESM we have utilized a prognostic equation for the fractional area of first-year ice within a model grid cell. In addition, by using information from published in-situ measurements we have modified the relationship between melt pond depth and area fraction of melt-ponds to better describe melt-ponds on first-year ice. The previous description was only based on multi-year ice data.

Figure 6 - The effect on pre-industrial September sea-ice thickness (per unit surface area) of model changes done in ACCESS. Upper panel: New, improved model version. Lower panel: The CIMP5 version of NorESM.

Despite the fact that melt-ponds are found to be important for the melting of ice, we found only a small impact on sea-ice in the model when the differences between first-year and multi-year ice were introduced. Part of this problem may be that in NorESM1-M, we have too little melting of snow. To mitigate this problem in the model, we had to make the snow on sea-ice somewhat darker than observed in nature (a form of tuning).

The atmosphere model in the NorESM version used for CMIP5, CAM4-Oslo, has a fairly coarse resolution of 1.9 x 2.5° (~ 2°). We know from experiments at the National Center for Atmospheric Research (NCAR) done with the original CAM4 model, that there are improvements in Arctic circulation and sea-ice when the grid size is reduced to half, 0.9 x 1.25° (~ 1°). There is a drawback, however, and that is that the global temperature is around 0.2 K lower in the high resolution version (as can be seen at www2.cesm.ucar.edu). To combine the improvement of the sea-ice parameterization with the most promising model setup for the high resolution runs in order to improve representation of sea-ice and the Arctic climate, several experiments have been done with a shallow ocean configuration of NorESM, and with bias-correction of stand-alone atmospheric simulations with different resolutions. Experiments with increased atmospheric resolution show improvements in the large-scale circulation in the North Atlantic. However, there are challenges of how to properly bias-correct SST (sea surface temperature) and sea-ice in scenario runs. Therefore, in an attempt to improve the modelled Arctic climate in NorESM, we have opted for a full transient run from 1850 to 2100.

So far we have analysed the pre-industrial control, *i.e.* 1850 conditions. We did not need to retune the model, *i.e.* the cloud parameterizations are the same in the 2° version of the model. The 1° simulation was initialised with ocean and



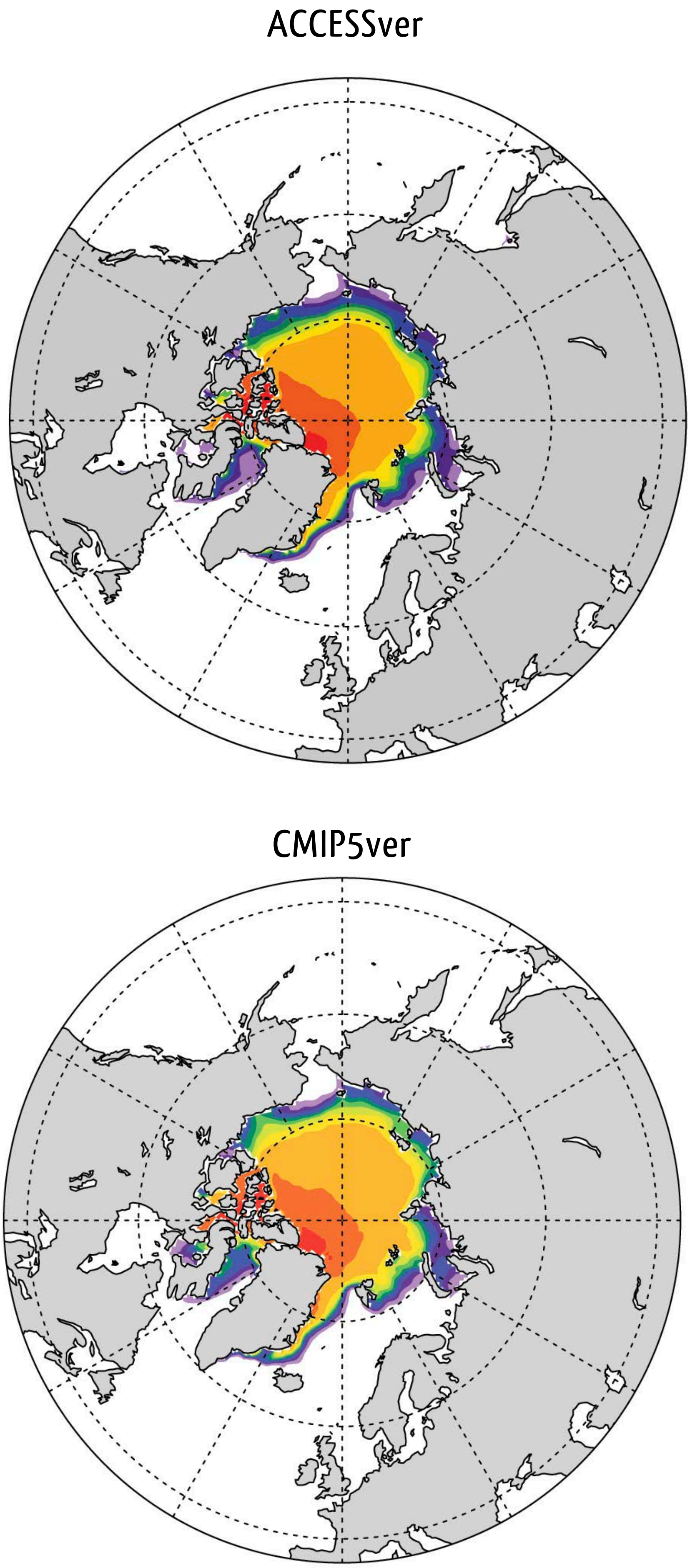
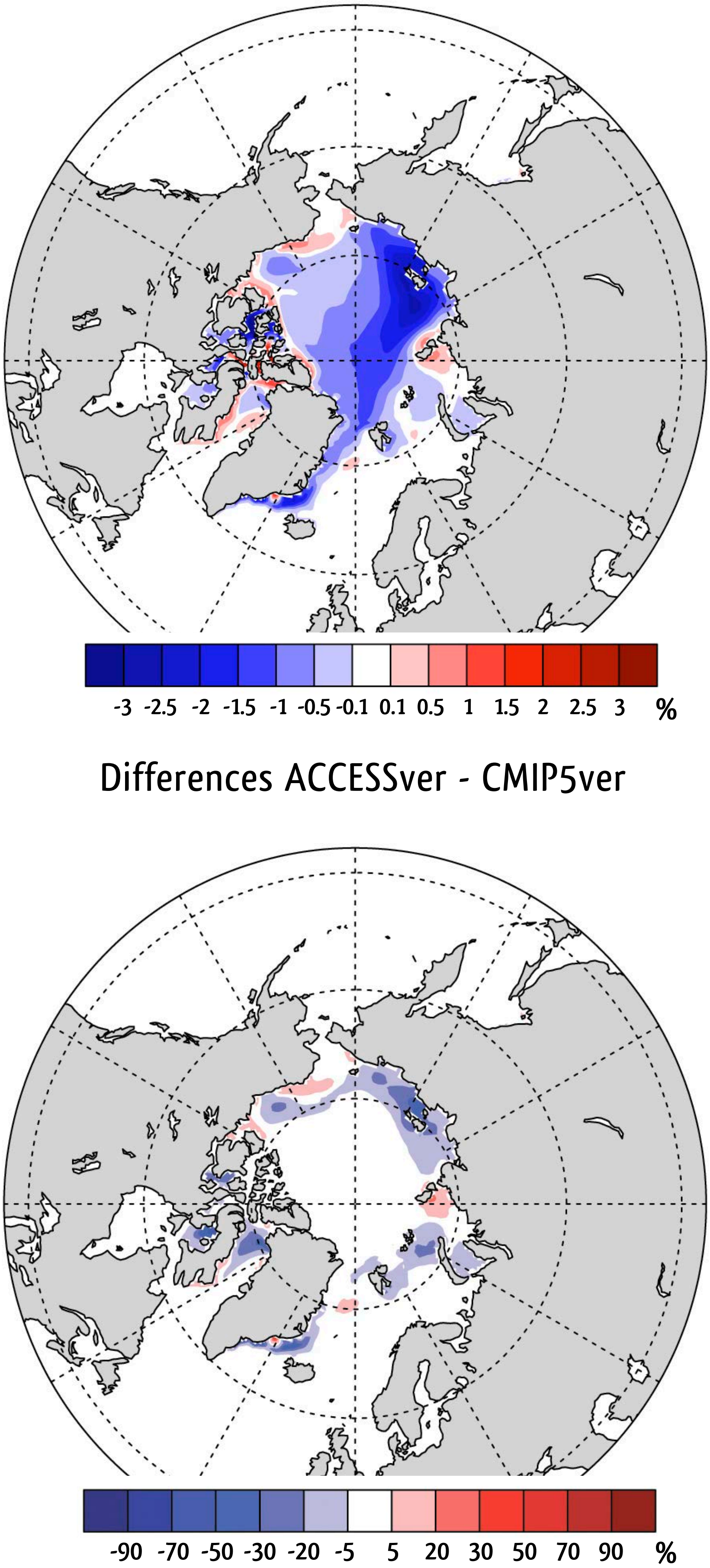


Figure 7 - The effect on pre-industrial September sea-ice concentration (area of sea-ice per unit surface area) of model changes done in ACCESS. Upper panel: New, improved model version. Lower panel: The CIMP5 version of NorESM



ice conditions from model year 700 of the CMIP5 spin-up. A typical feature of the sea-ice in NorESM is a too thick ice in the Siberian sector, in present day conditions and likely also in pre-industrial conditions. This structure is much weaker in the updated version of the model. Figure 6 shows the September average ice thickness over a thirty-year period in the updated version of the model (left), in the CMIP5 version (right) and the difference (below). The reduction of sea-ice cover is much smaller and mostly confined to near the edges (Figure 7). As found by NCAR for CAM4, the 1° version of NorESM also has a 0.2 K colder global mean temperature than the 2° version of the model. The model has also been run for historical conditions (1950-2005) and for the " representative concentration pathway " (RCP) 8.5 scenario (a rising radiative forcing pathway without mitigation actions), but these simulations have not yet been analysed. These simulations are also parts of the ACCESS work and should be ready late autumn 2014.

Figure 8 - The effect on pre-industrial September sea-ice thickness and sea-ice concentration of model changes done in ACCESS: difference between the new, improved model version and CIMP5 version of NorESM. Upper panel: sea ice thickness. Lower panel: sea-ice concentration

Citations:

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Iversen, T., Bentsen, M., Bethke, I., Debernard, J., Kirkevåg, A., Seland, Ø., Drange, H., Kristjansson, J., Medhaug, I., Sand, M., and Seierstad, I., 2013. " *The Norwegian Earth System Model, NorESM1-M – Part 2: Climate response and scenario projections* ". Geosci. Model Dev., 6, 389–415, doi:10.5194/gmd-6-389-2013.

Sand, M., Berntsen, T., Seland, Ø., and Kristjánsson, J., 2013. " *Arctic surface temperature change to emissions of black carbon within Arctic or mid-latitude* ". J. Geophys. Res. Atmos.,doi: 10.1002/jgrd.50613.33.

Arctic Sea-ice Variability at Seasonal, Inter-annual and Pan-Arctic Scale

Jean-Claude Gascard and Mehrad Rafizadeh - LOCEAN, Université Pierre et Marie Curie

A lot of attention is dedicated to Arctic sea-ice extent. This focus is, in particular, on the September sea-ice extent minimum to illustrate Arctic sea-ice variability and the long-term trend. The Arctic sea-ice September minimum is even taken by many as the major indicator for predicting Arctic sea-ice disappearance in years to come during the summer as well as a major indicator for Arctic sea-ice recovery by those who believe in Arctic sea-ice recovery when the September sea-ice minimum is not decreasing from year-to-year. The first group stresses attention on extreme Arctic sea-ice retreat events such as those occurring in September 2007 and September 2012. The second group puts attention on extreme events such as the one occurring in September 2013. The reality is different because of the importance of inter-annual variability. The critical factors are not only sea-ice extent and the September sea-ice minimum extent, rather, by far more importantly, the sea-ice mass (volume) depending on sea-ice extent and sea-ice thickness.

In this short note we would like to stress attention on important factors in the Arctic including sea-ice thickness and volume, and, in particular, sea-ice formation in winter in addition to the sea-ice melting in summer. The critical point is not only how much sea-ice can melt every year during summer, also how much sea-ice can be formed in winter. The importance is not only about sea-ice extent that is more and more difficult to predict since it is becoming thinner and thinner, but it is also sea-ice mass that includes both sea-ice extent and sea-ice thickness. The difficulty is that sea-ice extent is today much easier to observe and to measure with microwave radiometers installed on satellites than is sea-ice thickness using altimeters (Cryosat). That explains why there is such a bias (and controversy) in estimating the evolution of Arctic sea-ice and predicting the future disappearance or the future recovery of Arctic sea-ice.

Interestingly during DAMOCLES and the International Polar Year and now in the ACCESS project, we have estimated the number of freezing degrees-days (FDD) as a main element for Arctic sea-ice formation during winter and spring (*i.e.* during the freezing season) from September until May each year. Doing so over the past 30 years, we discovered several very interesting and important factors. The first is that the number of FDDs decreased substantially over the last 30 years

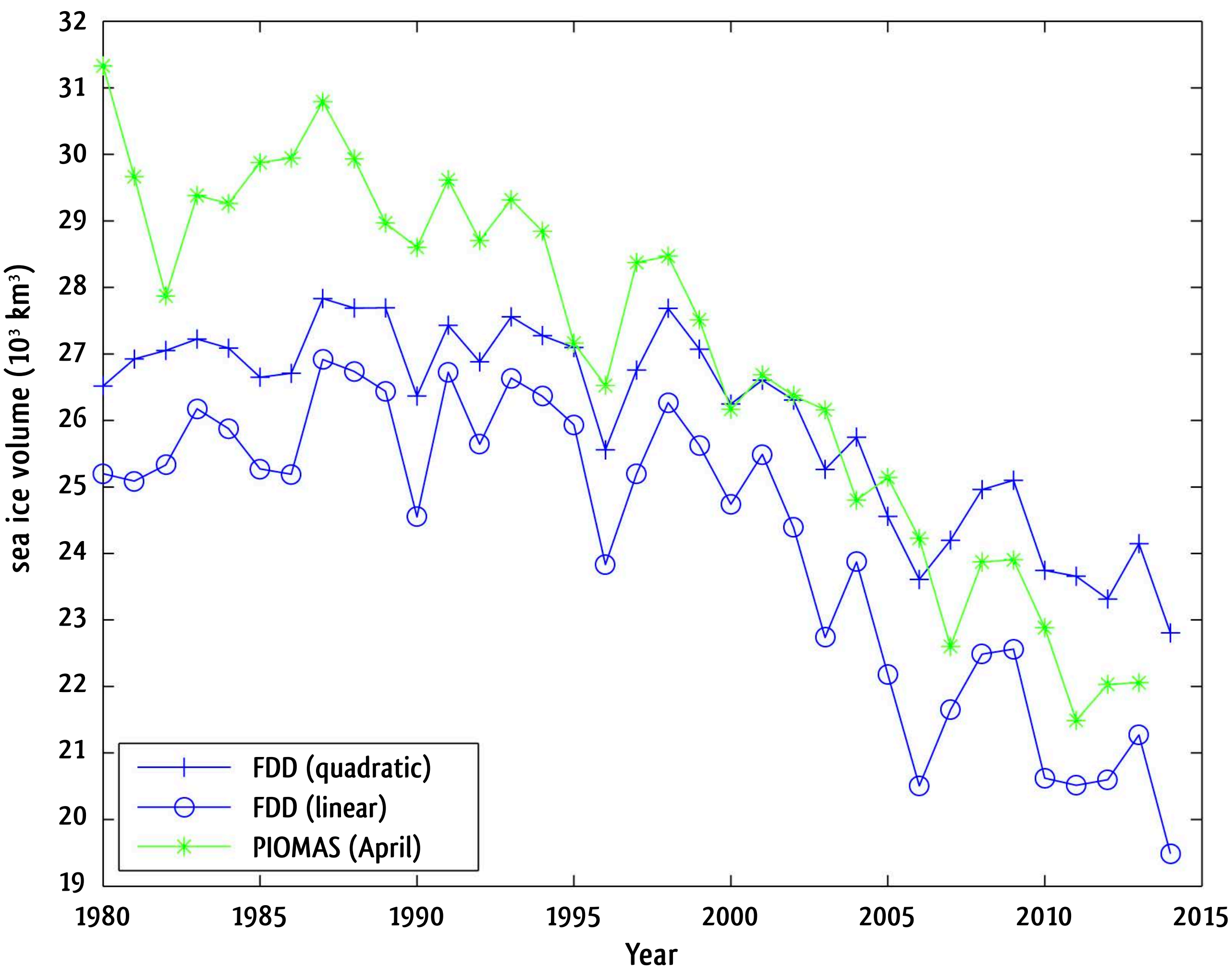

Figure 9 - Sea-ice volume calculated from FDD compared with PIOMAS, 1980 – 2014

in most parts of the Arctic Ocean. Over the three decades, the decrease in freezing degree-days was about 2 000 over more than 1 million km^2. Consequently the volume of sea-ice resulting from the FDD decrease has changed quite drastically from about 30 000 cubic kilometres (km^3) down to about 20 000 km3 in winter.

These results are remarkably similar to those deduced from the PIOMAS model as illustrated in Figure 9. The estimation of sea-ice volume formed in the Arctic is based on the number of freezing degree-days accumulated each winter-spring season from September to May for every year since 1980. We converted FDD in sea-ice thickness using a linear algorithm for thin ice and a quadratic algorithm for thick ice and compared the sea-ice volume deduced from PIOMAS in April each year since 1980. The sea-ice volume calculated from FDD in 2014 is the lowest ever. The linear algorithm looks very similar to PIOMAS with a systematic difference of about 1 000 km3 indicative of Arctic sea-ice becoming thinner. The similarities are also indicative of the fact the Arctic Ocean is dominated by first-year ice and the Arctic Ocean is becoming ice-free in summer.

It is important to note that the decrease of Arctic sea-ice mass in winter is very similar its decrease at the end of the summer (from 15 000 km^3 to 5 000 km^3) according to PIOMAS. It is notable that the winter of 2014 produced the minimum sea-ice volume over the period of the last 35 years. Also important to recognise is that a decrease of Arctic sea-ice thickness of about 50% combined with a decrease of Arctic sea-ice extent by about 50 % would result in an Arctic sea-ice volume decrease of 75 %. Today the sea-ice mass loss is relatively much larger than sea-ice extent decrease and this is why Arctic sea-ice mass is a more reliable and more relevant parameter to evaluate the state of Arctic sea-ice and to project the near-term evolution of Arctic sea-ice all year-long in summer as well as in winter.

Still Arctic sea-ice extent combined with its thickness, is an important factor directly impacting on ocean and atmospheric interactions with significant consequences on the environment and human activities. During DAMOCLES and ACCESS, we have analysed sea-ice extent deduced from Advanced Microwave Scanning Radiometers (AMSR) over the past decades. These observations yield several interesting and important features concerning the Arctic sea-ice break-up phase during the spring season and the sea-ice freeze-up phase during the autumn, plus winter and summer sea-ice extent maximum and minimum in different portions of the Arctic Ocean: the eastern versus the western Arctic and the Atlantic versus the Pacific Arctic in a limited band of latitudes (80° N to 90° N and 70° N to 80° N respectively).

Within the 70° N to 80° N latitude band, we observed a complete disappearance of Arctic sea-ice in the eastern Arctic as well as in the Atlantic sector of the Arctic Ocean in 2012. This vast area became entirely a seasonal Arctic sea-ice zone. The pole of the cold is more towards the western Arctic (north of Canada and Greenland). This explains why the Northwest Passage is more often obstructed with sea-ice than the Northern Sea Route. Another striking feature concerns the seasonal variability of the Pacific sector compared with the Atlantic portion of the Arctic Ocean: in this comparison the Pacific sector underwent larger (double) variations of sea-ice extent in a much shorter period (twice as short) as the Atlantic sector. Notably, all sectors of the Arctic Ocean are impacted by earlier sea-ice break up in the spring and later freeze-up during the autumn. Over the past 10 years we noticed a difference of about 15 days in the advance of the sea-ice break-up and a delay of about 10 days in the freeze-up period (equivalent to about 1 to 2 days per year respectively). This is one of the most important results since it impacts directly on the opening and closing dates of the transpolar sea routes and also on polar bear feeding habitats. Following a disappearance of sea-ice for some time during the summer period, one can anticipate the sea-ice break-up and freeze-up timing events will continue to evolve in the near-term all over the Arctic Ocean.

The northernmost region of the Arctic Ocean (80° N up to 90° N) has also been increasingly impacted by sea-ice retreat in summer during the past 10 years, but to a lesser degree than regions at lower latitudes, though this is not surprising. Noticeably it became more and more frequent to observe the ice edge moving up to 85° N in summer in the Atlantic sector of the Arctic Ocean as well as in the eastern Arctic over the last 10 year period.

All these results are part of the ACCESS project and will be included in appropriate sections of the ACCESS synthesis report, which is currently under development.

Monitoring and Forecasting: Short-Time Range in the Arctic

Harald Schyberg, Thomas Nipen, Roger Randriamampianina - Norwegian Meteorological Institute

Safety of operations in Arctic and managing weather-related risks depend on understanding the Arctic climate and likelihood of hazards. The capability of dealing with such risks also depends on forecasting capabilities to help short-range planning and provide advance warning of hazardous weather, ocean and ice conditions, or a combination of these elements. Forecasts from short-range Numerical Weather Prediction (NWP) models (timescale up to a few days) are the main tool in such forecasting. Work undertaken at MET Norway as a part of ACCESS has assessed the forecasting capabilities in the Atlantic sector of the Arctic by investigating the forecast performance of the global NWP model of the European Centre for Medium-Range Weather Forecasts (ECMWF) as well as the regional HIRLAM (High Resolution Limited Area Model) model run at MET Norway.

First, we analysed the inherent day-to-day pressure variability of the atmosphere at coastal observation points spanning the Norwegian mainland and Arctic island stations at a range of latitudes from 57° N to 80° N (Figure 10). This indicates the magnitude of the actual atmospheric variability which the model forecasts need to capture. We observe that there is a maximum in variability at 65° N, with generally decreasing variability north and south of that latitude. The position of the maximum pressure variability coincides roughly with the region of the average position of storm tracks on the polar front zone. The pressure on the Svalbard stations has comparably low day-to-day variability. One could think that the more dynamic variability found, as measured in this way, the more challenging would it be for the model to capture it.

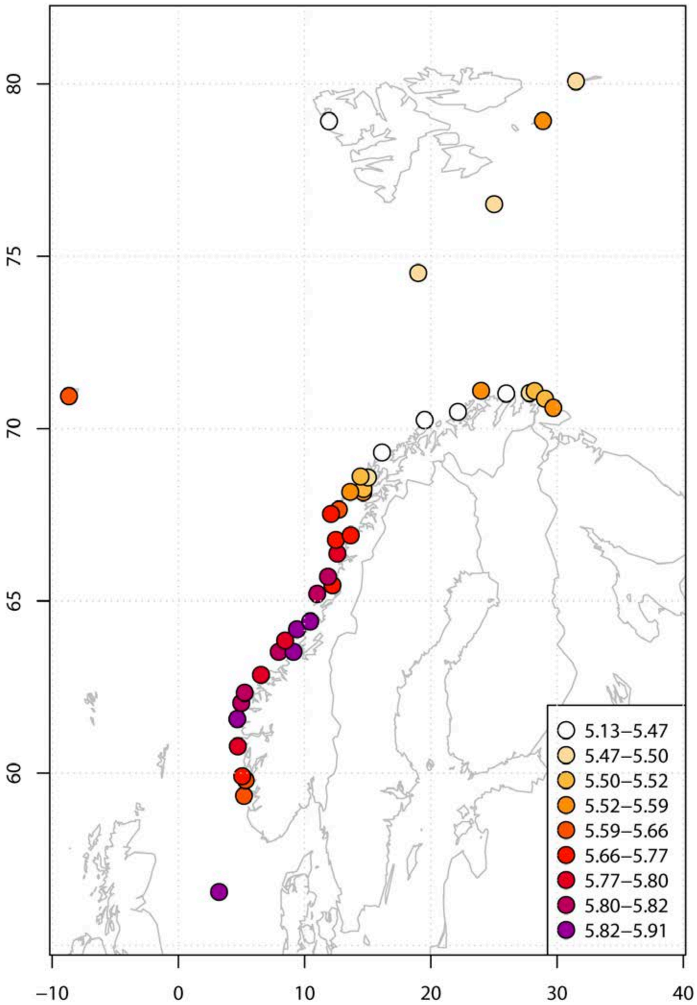

Figure 10 - Mean absolute day-to-day observed pressure (hPa) differences in the period January to September 2013

Figure 11 shows verification statistics for the same set of stations and the same time period in terms of root mean square errors for the ECMWF NWP model, and the same data plotted against latitude. The results are similar for the HIRLAM regional model (not shown here). For this sector of the Arctic, there is a striking general decrease in forecast quality when moving northwards. This is seen in spite of the fact that the day-to-day pressure variability is comparatively small at the highest latitude stations.

A candidate for explaining the decline in the quality towards the north would be the corresponding decrease in the observation density of the conventional meteorological observing network. For surface observation data, there is a general gap in pressure observations over parts of the sea-ice and parts of the ocean areas as there is only limited coverage from drifting buoys. There is almost no coverage of near-surface wind observations over sea-ice. The wind coverage over ocean is good due to satellite scatterometers and over populated continents due to conventional surface stations. Surface pressure gradient and near-surface winds are closely linked in the Arctic through the geostrophic relation. However, where only pressure gradient information is available through wind observations, the absolute value of the pressure field would need to be "anchored" with some coverage of surface pressure information.

Given the fact that a three-dimensional coverage is needed for the atmospheric state to be initialised in NWP, it is important that the atmosphere is covered with observations also above surface. The Arctic lacks conventional upper air data, but this is compensated by data from satellite sounding instruments. This requires that NWP assimilation systems are prepared to use them (ECMWF is using much more of these data than HIRLAM). It should be noted that it is difficult to use data from temperature sounding sensors in the lower troposphere because the signal will then have a surface contribution which is generally not well modelled. Also, atmospheric motion vectors and radio occultation do not give any coverage of winds or temperature profiles in the lowest part of the troposphere.

In summary there is a lack of both wind and temperature information in the lower troposphere in the remote ocean and ice areas in the Arctic (away from coasts and islands with radiosonde coverage), so this is likely to be a main reason for the geographical trend in the verification. But it is still possible

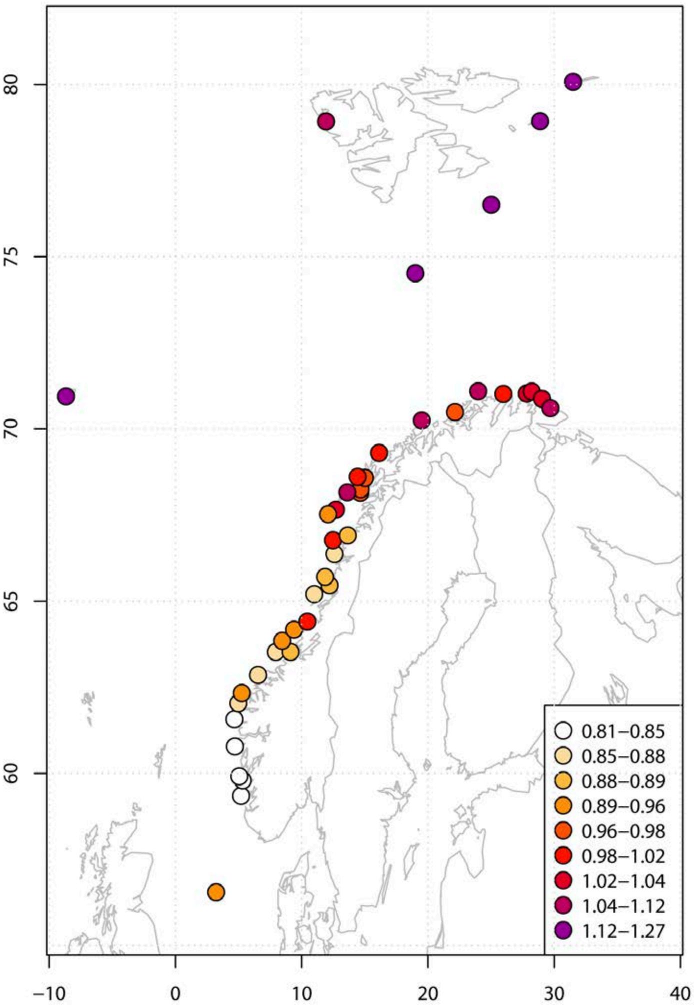

Figure 11 - Left: Root mean square errors in pressure (hPa) for forecasts in the range from 18 to 42 hours for the ECMWF global model.

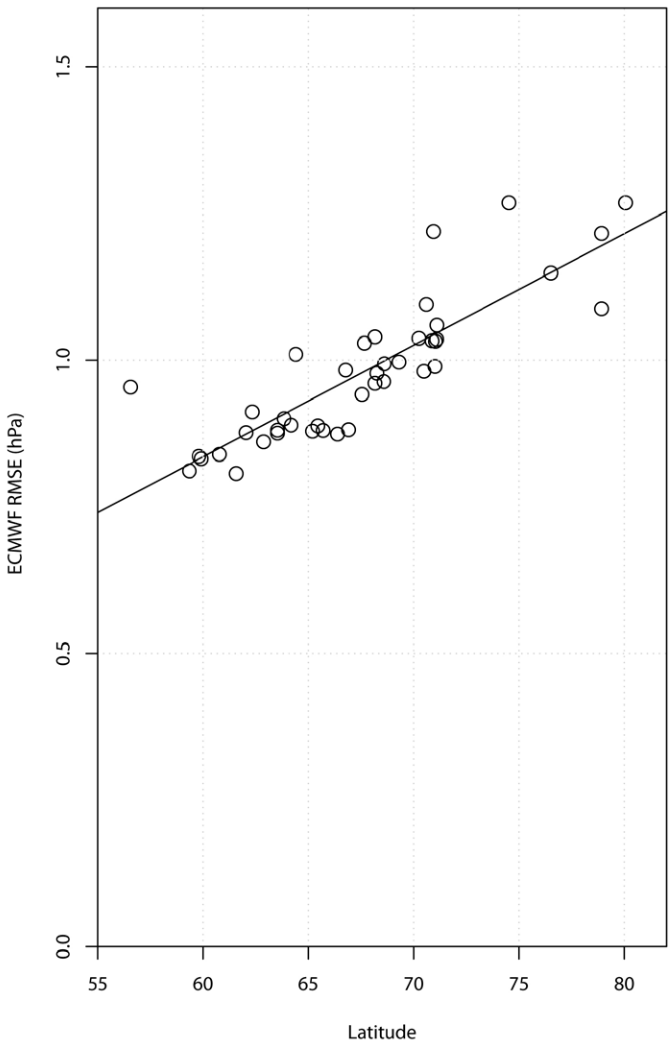

Figure 11 - Right: The same dataset with root mean square error in pressure for forecasts (hPa, vertical axis) plotted against latitude on the horizontal axis for the ECMWF model.

that other issues in our modelling capability of Arctic physical processes and surface conditions contribute, for instance inaccuracies in the description of the sea-ice concentration and surface description for sea-ice.

Some scenarios to improve the observing system have been defined and are now under study in this last phase of ACCESS. It is done in the framework of a state-of-the-art convection resolving regional NWP system covering a high-latitude area, the AROME-Arctic model. The assessment employs both experiments with the present observing system (observation data denial studies) as well as experiments with future extensions of the observing system through simulation studies ("Observing System Simulation Experiments"). Cost effectiveness and deploying observations at the right locations is critically important for planning the future evolution of the observing system. The analysis of these experiments will provide some ideas and guidelines for how to design observing network extensions for improving short-range Arctic forecasting.

Modelling Spatial Distribution of the Barents Sea Cod Fishery

***Arne Eide** - NOFIMA (Norwegian Institute of Food, Fisheries and Aquaculture Research) / University of Tromsø*

Climate change affects fisheries in a number of different ways. Physical and biological environmental changes influence growth, mortality and recruitment dynamics of a fish stock. The complex interactions of different species under varying environmental conditions are not even fully understood in its normal state, which also makes it difficult to predict the impact that climate change may have on marine ecosystems.

Climate change may also affect fisheries in more indirect ways. For example, market perturbations that affect price and availability of input factors in capture fisheries as well as the market prices of fish products, which are effected by the availability and price of alternative food options. Policy approaches to address climate change, for instance tax measures on bunker fuels, may affect the fisheries sector. Environmental concerns among consumers may affect fisheries policy and fisheries management in different ways.

Market effects and fisheries management responses to climate change may very well turn out to be the most important impact factors. Our study, however, targets the effects of physical and biological environmental changes in the most important sub-Arctic fishery — the Northeast Arctic (NEA) cod fishery in the Barents Sea. The annual harvest of NEA cod is currently about one million tonnes and the stock size today is approaching the levels in the initial years after World War II, the highest ever measured.

NEA cod is a benthic species (bottom dwelling). The distribution of benthic species is closely related to the availability of prey in shallow water areas. The Barents Sea is a shallow water area hosting a number of large benthic fish species, e.g. cod, haddock and saithe (pollock). These species are not found in the deep-water areas west and north of the Barents Sea shelf, while the distribution areas are constrained by sea temperatures and food availability in the east.

Simulation results based on the Intergovernmental Panel on Climate Change A1B scenario suggest that the distribution area of NEA cod may expand by 15% over the next 45 years (Figure 12). Corrected for expected food availability, calculated from the occurrence and distribution of zooplankton species during the same period, the total environmental carrying capacity of the NEA cod stock will increase by about 10% over the same period.

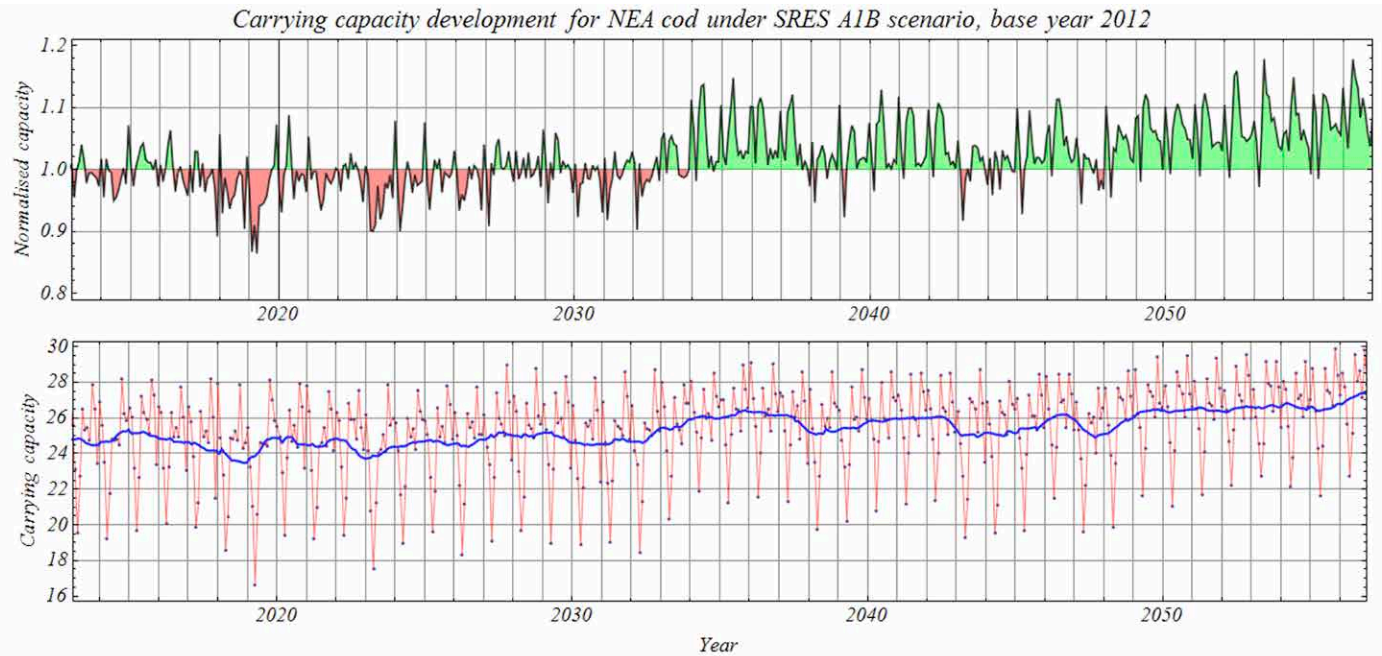

Figure 12 - The upper panel shows monthly environmental carrying capacities for Northeast Arctic (NEA) cod (2012-level equals 1) based on IPCC Special Report on Emissions Scenarios (SRES), the A1B scenario and initial distribution data from the FishExChange project (2004-2010).
The lower panel shows the corresponding monthly changes of total theoretical carrying capacities in terms of million tonnes of cod biomass. The red curve (connecting the dots) illustrates the monthly variation while the blue curve is the 12-month moving average of these numbers.

Citations:

Eide, A., 2014. "*Modelling Spatial Distribution of the Barents Sea Cod Fishery*". in Was, J., Sirakoulis, G. and Bandini, S. (eds.) : *ACRI 2014, Lecture Notes in Computer Science (LNCS).* 8751, pp. 288–299.

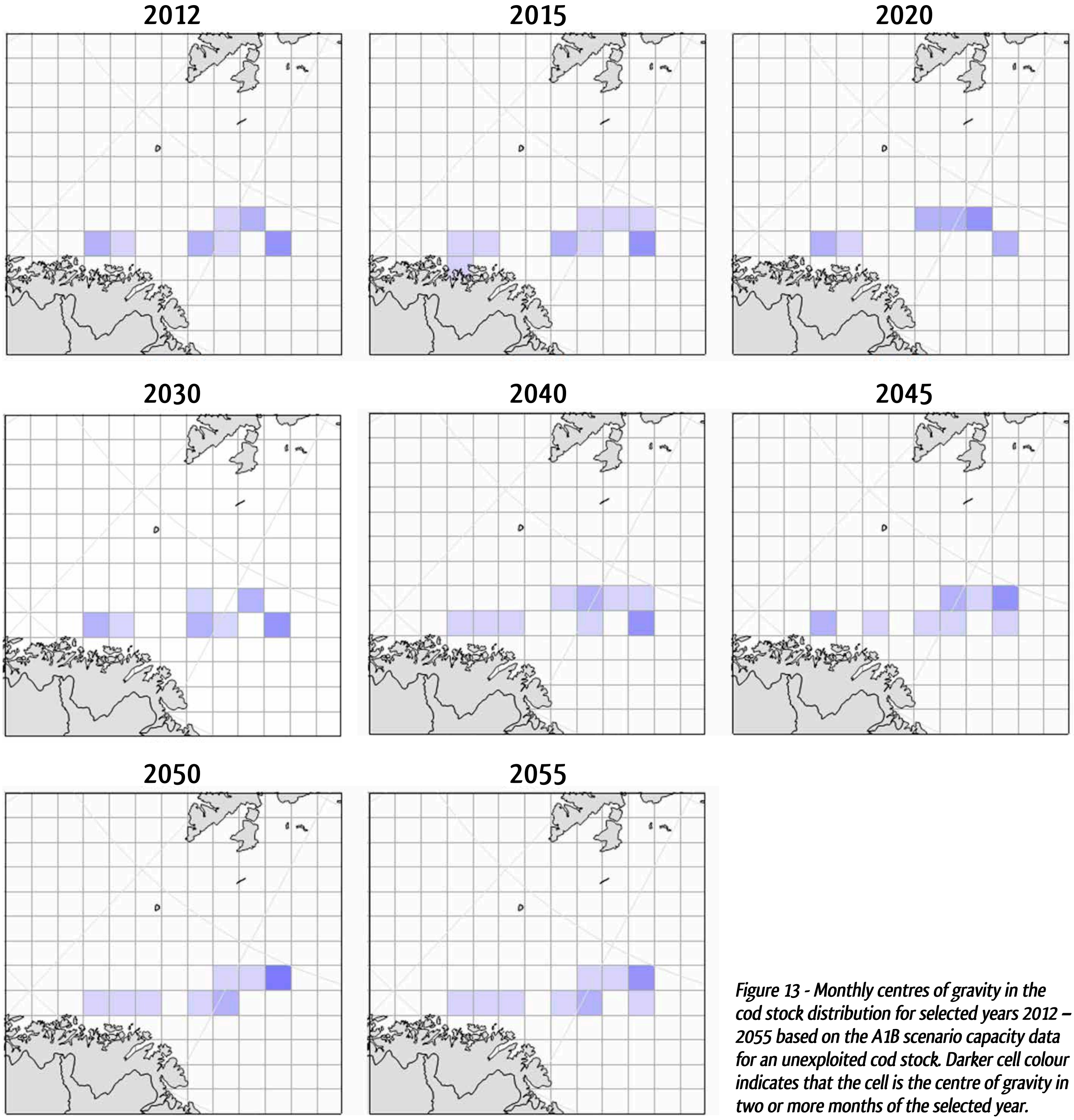

Figure 13 - Monthly centres of gravity in the cod stock distribution for selected years 2012 – 2055 based on the A1B scenario capacity data for an unexploited cod stock. Darker cell colour indicates that the cell is the centre of gravity in two or more months of the selected year.

Like most other fish species in the sub-Arctic, the NEA cod stock carries out long-distance seasonal migrations. NEA cod approach the north Norwegian cost for spawning during the first three months of each year before migrating for feeding in the central Barents Sea. The migratory pattern involves both physical and biological constraints. Our study concludes that the seasonal centres of gravity of the cod biomass seem to be fairly stable, even though the distribution area of the stock expands slightly (Figure 13). In biomass terms, the expansion is rather marginal.

From a fisheries management perspective, future climate-change effects represent similar challenges since today the knowledge of stock dynamics, distribution patterns and ecosystem interactions are limited. Management decisions have to be based on precautionary principles including an ecosystem perspective. Rather than changing this, climate change reinforces the importance of developing robust and safe management principles.

Informing Decision-makers on Arctic Change: ACCESS Develops Sustainable Development Indicator System

***Sebastian Petrick** - Kiel Institute for the World Economy - Contribution from Harald Schyberg, Norwegian Meteorological Institute)*

The Arctic Ocean is in a phase of changing environmental and climatic conditions as well as increasing human activity. ACCESS has been active in recent years to document these changes, their interactions and to analyse their causes and effects. Those who can benefit from the research results – policy-makers, businesses, Arctic communities, researchers unfamiliar with the region, among others – may find it challenging to make their way through the multitude of observations, predictions and assessments. To facilitate comprehension, ACCESS is developing a set of indicators as part of its synthesis of its broad range of research. The indicators aim to highlight the most relevant aspects of change and to provide a measure of the direction and sustainability of those changes in the Arctic Ocean. We aim for an effective trade-off between the richness of information and conciseness.

The indicators include sub-sets for each of the three economic sectors within the ACCESS scope : shipping and tourism ; fisheries ; and hydrocarbon extraction. In designing and compiling the indicator set, ACCESS is able to rely on the combined expertise of partners with Arctic knowledge from all three sectors. An indicator set for each sector is being developed that describes three dimensions of sustainable development as set out in the European Union Sustainable Development Strategy: environmental protection; social equity and cohesion and economic prosperity. The sector-specific information is complemented by information on the status and changes of the Arctic sea-ice, atmospheric circulation and ocean state, and projections for three decades; assessment of short-term forecasting capabilities in the Arctic; and plans for optimised observational systems that are being developed as part of ACCESS' overarching Work Package 1. A report on seafood production indicators has been published (*www.beijer.kva.se/discussions.php*). Other indicator reports will be released in the coming months.

Information on the weather is essential for many day-to-day operations in the Arctic such as maritime transport, fishing and the operation of offshore facilities. It is also critical for key activities like search-and-rescue and oil-spill response operations. All these activities have to manage weather-related risk for which they rely on weather forecasting capability in the Arctic. This capability is represented in the indicators.

To describe short-range forecasting capability, we use sea-level pressure as a representation of weather characteristics as it is a good indicator for assessing overall forecast capabilities because it is not influenced by local topography and surface characteristics. The European Centre for Medium-Range Weather Forecasts (ECMWF) has a leading model for global forecasts which is used as boundary data for many regional and local models. We chose to use the deviation of ECMWF forecasted versus observed pressure at a single observing station in Bjørnøya (Bear Island, position 74.5° N, 19.0° E).[1] We chose Bjørnøya for being a relatively remote, isolated location in the Arctic, yet with available measurements. We consider that the location has properties representative of high-latitude ocean areas — where there could be increased activities and operations in the future. Ideally a measure should cover a larger portion of the Arctic with more observing stations and more than one parameter, but that would increase the complexity involved and make it more difficult to establish a parameter which is defined in a consistent way to make it suitable for tracking forecast capabilities over time.

While the quality of weather forecasting in the Arctic has improved over time, it remains inferior to that at lower latitudes. This is not least because of gaps in the observing system. This capability should improve in the future driven by improvements in forecasting precision with more observations and enhanced modelling capability of processes in the Arctic. Monitoring the trend over time will give a view of how the forecasting capabilities evolve. Improved forecasting capability will in turn impact human activity in the Arctic and may lead, for example, to safer and faster navigation or less risky operation of energy production platforms. If forecasting capability does not improve as desired, this will show up in the indicator system. Such indications can provide a consistent data basis for informing decisions such as funding for measurements in high latitudes and better co-operation between various weather services.

The weather forecasting case shows how an indicator system can provide an efficient way to inform relevant actors simply by assembling existing information. Yet, its real strength lies in the combination of various indicators. For instance, with improved forecasting capability ship traffic (a specific indicator) may increase, but only in areas where navigators can rely on sufficient availability of protected ports (another specific indicator). This can highlight complementarities in investment decisions that need to be adequately taken into account.

Another scenario might be that as ship traffic increases, potentially related to better forecasting capability, pollution (an indicator in our system) increases in protected areas (also an indicator). The indicator system would point out the conflict in the economic development and environmental protection elements of the sustainable development framework. This case also underlines the thorny task of balancing that decision-makers grapple with between the favoured and the undesirable aspects that can be part of sustainable development. Indicator systems, such as the one developed by ACCESS, can highlight and track changes to better inform policy and decision-making.

1 -We calculate the root mean square value of the deviation of the ECMWF forecasts (18-42 hour range), averaged over one year.

Upcoming Arctic related events 2014-2015

2 – 4 December 2014

The Arctic Biodiversity Congress. Trondheim, Norway

The purpose of this Congress is to promote the conservation and sustainable use of Arctic biodiversity through dialogue among scientists, policy-makers, government officials, industry, civil society and indigenous peoples.

More information: *http://www.arcticbiodiversity.is/congress*

8 – 12 December

Arctic Change 2014. Ottawa, Canada

The international Arctic Change 2014 conference aims to stimulate discussion and foster collaborations among people with a vested interest in the Arctic and its peoples. Coinciding with the pinnacle of Canada's chairmanship of the Arctic Council and marking ArcticNet's 10th anniversary, Arctic Change 2014 welcomes researchers, students, Northerners, policy makers, and stakeholders from all fields of Arctic research and all countries to address the numerous environmental, social, economical and political challenges and opportunities that are emerging from climate change and modernization in the Arctic.

More information: *http://www.arcticnetmeetings.ca/ac2014*

18 – 23 January 2015

Arctic Frontiers 9th Annual Conference. Tromsø, Norway

The title is Climate and Energy. It will address three main themes:Arctic climate change – global implications; ecological winners and losers in future Arctic marine ecosystems; the Arctic's role in the global energy supply and security.

More information: *www.arcticfrontiers.com/2015-conference*

30 – 31 January 2015

Symposium on Law and Governance in the Arctic. Irvine, California, USA

This symposium will explore the effectiveness of existing governance in the Arctic region, strategies for improving effective implementation, and possible alternative governance regimes. A segment of the presented papers will be published in the UCI Law Review as a symposium.

More information:
www.law.uci.edu/academics/centers/cleanr/events/conferences.html

30 – 31 January 2015

Arctic Encounter Symposium. Seattle, Washington, USA

The second annual Arctic Encounter Symposium will challenge participants to tackle the shared interests and concerns of the United States and the global community about the Arctic. Leading experts, chief executive officers, and thought leaders from the science, technology, maritime, and energy sectors, will gather to challenge the status quo dialogue, critically address challenges to realizing the Arctic's full potential and collaborate on solutions. Participants will include key industry leaders, policy makers, and regional stakeholders.

More information: *www.law.washington.edu/events/ArcticEncounter*

2 – 4 February 2015

Community Earth System Model - Land Ice and Polar Climate Working Group Meetings. Obergurgl, Austria

For further information about the Polar Climate Working Group:
https://www2.cesm.ucar.edu/working-groups/pcwg

For further information about the Land Ice Working Group:
https://www2.cesm.ucar.edu/working-groups/liwg

24 – 26 February, 2015

ACCESS General Assembly. Universitat Politècnica de Catalunya in Vilanova, Spain

15 - 20 March 2015

2015 Polar Marine Science Gordon Research Conference. Lucca, Italy

The 2015 Polar Marine Science Gordon Research Conference (GRC) entitled "*Polar Shelves and Shelf Break Exchange in Times of Rapid Climate Warming*" will be held in Lucca, Italy from March 15-20, 2015. The GRCs provide an international forum for the presentation and discussion of frontier research in the biological, chemical, and physical sciences, and their related technologies.

More information: *http://www.grc.org/programs.aspx?id=12641*

23 – 27 March 2015

Dynamics of Atmosphere-Ice-Ocean Interactions in the High-Latitudes. Rosendal, Norway

The goal of this workshop is to summarize our fundamental understanding and description of small-scale processes in the coupled atmosphere-ocean-ice climate system at high latitudes in order to assess and reduce bias and uncertainties in weather prediction and climate models. The workshop will be limited to ca. 90 participants. Limited travel funding will be available to support a selection of early career scientists (Post-docs within 5 years of PhD and PhD students). *applications closed*

More information: *http://highlatdynamics.b.uib.no/*

23 – 30 April 2015

Arctic Science Summit Week (ASSW) 2015. Toyama International Conference Center, Toyama, Japan

The ASSW will include the final International Conference on Arctic Research Planning (ICARP III Conference and 4th International Symposium on Arctic Research (ISAR-4). The ICARP III aims to: identify Arctic science priorities for the next decade; co-ordinate various Arctic research agendas; inform policy makers, people who live in or near the Arctic and the global community; and to build constructive relationships between producers and users of knowledge.

More information:
http://icarp.iasc.info/images/articles/downloads/IASC_ProgressSpring_2014

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