Arctic Sea Ice – Projections to 2050 and the consequences

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Introduction

The Arctic is regarded as one of the most vulnerable regions to climate change. It gathers the attention of both media and researchers, who take it as reference for how irreversible are the effects of climate change on the natural environment. More and more research has been focusing on monitoring the Arctic sea-ice, essential to the maintenance of the Arctic system.

This paper has two focuses, firstly it intends to provide a literature review on observed trends and projections for the Arctic sea ice extent, in order to find out whether a consensus exists on this matter. The main sources of uncertainties will be mentioned as the possible recovery mechanisms.

Secondly, possible consequences of the Arctic sea melt will be covered. Concerning the global matters the effects predicted on the carbon cycle are mentioned, according to the different views found in the literature.

Regarding local consequences, this paper refers to the effects on Polar Bear life, as an example of one element of the Arctic ecosystems, how the Inuit communities regard and perceive the effects of climate change, and also to the economic potential of the melting sea-ice.

Observed trends

Long-term records for Arctic sea ice extent do not exist. Only with the advent of microwave satellite technology in the early 1970s were accurate recordings of Arctic sea ice made. That said, **Figure 1** shows back-projections of arctic ice cover made by various methods, including the extrapolation of Arctic shipping records and measurements made at the Hadley Centre which date back to the 1860s. (Lemke et al, 2007)

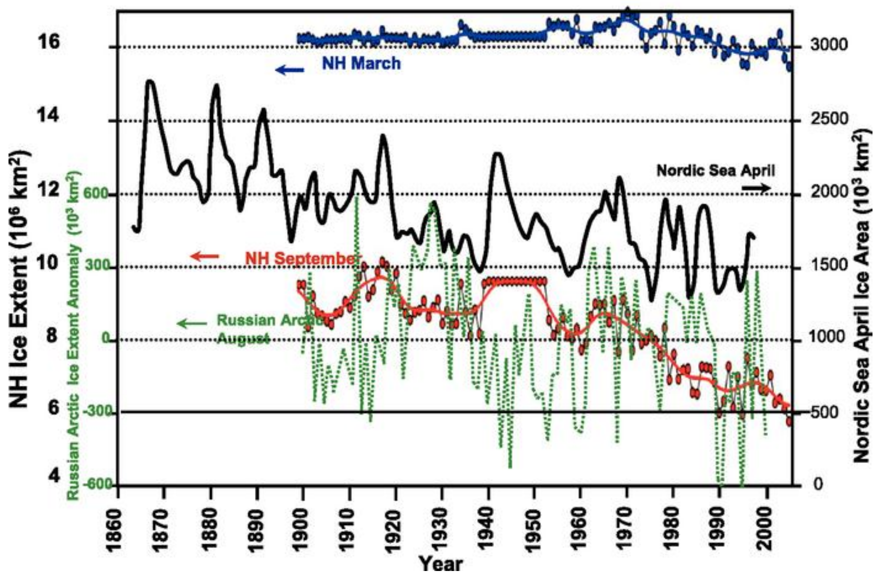

Figure 1. Time series of NH sea ice extent for March and September from the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) data set (the blue and red curves), the April Nordic Sea ice extent (the black curve) and the August ice extent anomaly (computed relative to the mean of the entire period) in the Russian Arctic seas – Kara, Laptev, East Siberian and Chukchi (dotted green curve). For the NH time series, the symbols indicate yearly values while the curves show the decadal variation (Lemke et al, 2007)

There has been a general decline in Arctic ice extent since the 1970s. This is also seen below, where sea ice has been measured to be decreasing by an average of 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade (IPCC, 2007). The smallest extent measured to date was 2007, although 2010 was also a near-record year and 2011 could prove to be so too, depending on weather conditions. (NSIDC, 2011)

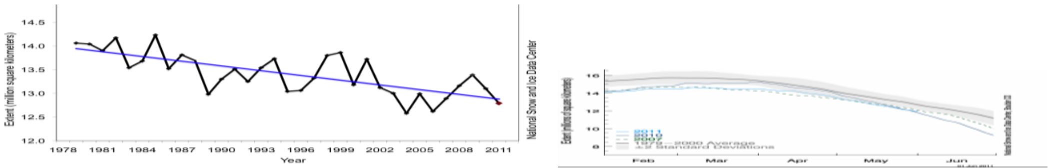

Figure 2. left, **Monthly May ice extent for 1979 to 2011. Right, daily Arctic sea ice extent as of June 1, 2011, along with daily ice extents for previous low-ice-extent years in the month of May. Light blue indicates 2011, dashed green shows 2007, dark blue shows 2010, and dark gray shows the 1979 to 2000 average. The gray area around the average line shows the two standard deviation range of the data. (NSIDC, 2011)**

Mean fluctuations of sea ice cover (sea-ice concentrations of more than 15%), for the period 1978 to present, range from a maximum of 16 million km^2 in March to a minimum of 7 million km^2 in September (Serreze et al., 2007). Observed minima in 2007, a record-breaking year for sea-ice shrinkage, were just 4.3 million km^2, while subsequent recorded September minima were 4.7 million km^2 in 2008 (meaning the average of these two years was 37% below the climatology of sea ice between 1980-1999 (Wang and Overland, 2009)), 5.4 million km^2 in 2009 and 4.9 million km^2 in 2010. 2011 predictions, from 19 responses for the pan-arctic (and 7 for the regional) outlook gives a median September minima of 4.7 million km^2, with values ranging from 4.0-5.5 million km^2. (SEARCH 2011)

Long-term Projections

The most up-to date IPCC report is the fourth assessment report (AR4). It tells us that global warming will not be uniform across the globe – polar regions are much more susceptible to climate change than areas close to the equator. In the A2 scenario, arctic air temperatures could increase by 8°C by 2100. That said, under all SRES scenarios, Arctic sea ice is projected to shrink, although only in the most severe scenarios was late-summer sea-ice predicted to disappear altogether by the end of the 21st century. (IPCC, 2007)

AR4 was published immediately before two sequential years of extreme summer minimum sea-ice coverage. As such, the predictions it makes are today seen as being somewhat conservative. For AR4, the IPCC ran 23 different climate models, producing results ranging from complete loss of summer ice in 2020 to only small losses by 2100. Wang and Overland (2009) refined these models by considering only the six which best reproduced the “ups and downs of sea ice area from summer to winter and back” (Kerr, 2009).

According to Wang and Overland (2009), the reductions in arctic sea-ice extent seen over the past 4-5 years has occurred 30 years before most predictions estimated it would happen. Using 6 models from phase 3 of the Coupled Model Intercomparison Project, CMIP3, and slightly adjusting the initial conditions, Wang and Overland were able to reproduce, reasonably accurately, the current observed situation. Their findings are shown in **Figure 3**. According to the report, “the first quartile of the distribution of time intervals for sea ice extent to drop from 4.6 to 1.0 million km^2 implies that a sea ice free Arctic in September may occur as early as the late 2020s… The uncertainty in timing of a summer sea ice free Arctic is largely due to both within-model contributions from natural variability and between-model differences.”

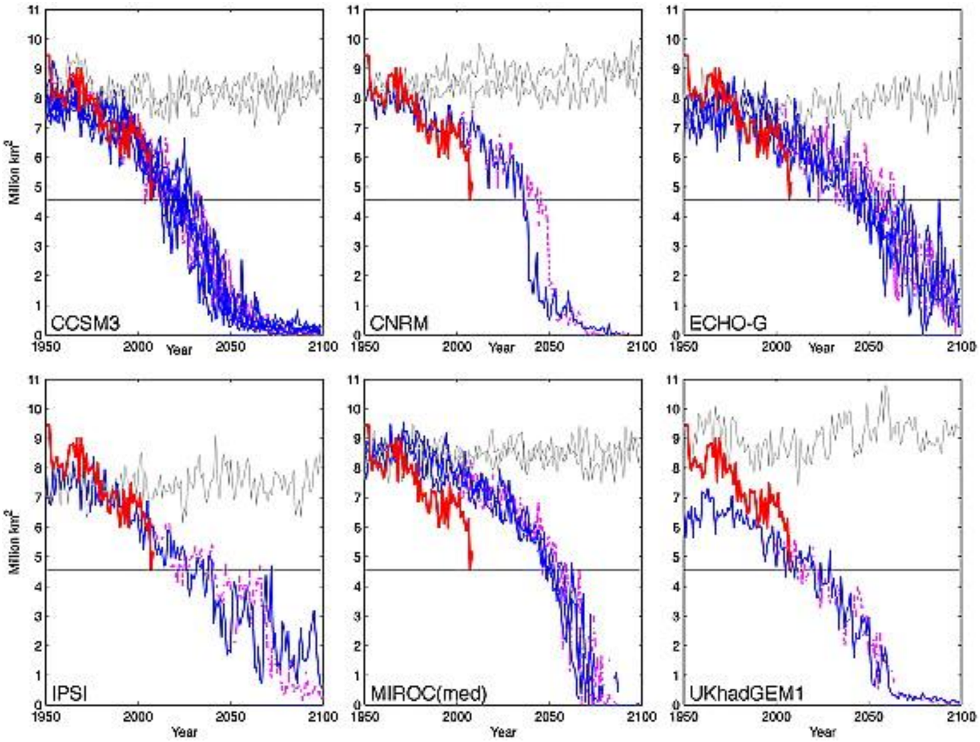

Figure 3. September sea ice extent as projected by the six models that simulated the mean minimum and seasonality with less than 20% error of the observations. The colored thin line represents each ensemble member from the same model under A1B (blue solid) and A2 (magenta dashed) emission scenarios, and the thick red line is based on HadISST analysis. Grey lines in each panel indicate the time series from the control runs (without anthropogenic forcing) of the same model in any given 150 year period. The horizontal black line shows the ice extent at 4.6 M km^2 value, which is the minimum sea ice extent reached in September 2007 according to HadISST analysis. All six models show rapid decline in the ice extent and reach ice-free summer (<1.0 M km^2) before the end of 21st century

Disagreement between the IPCC's AR4 and observations has led to greater acceptance of extreme claims, which only a few years ago were readily disregarded. In 2007, Wieslaw Maslowski of the US Postgraduate Naval School, stole the headlines when he predicted, using a linear regression of 1997-2004 trends, that Arctic Sea Ice could disappear completely by 2013. A more updated, and sophisticated, estimate was presented to the European Geosciences Union in April 2011, where the estimate was revised to near ice-free Arctic seas due to the summer melt by 2016 - plus or minus three years (Black, 2011). Meanwhile, Zhang et al. (2010) state that "summer ice volume may be more sensitive to warming while summer ice extent [is] more sensitive to climate variability." They predict that, under 4°C warming of the Arctic atmosphere, the ice extent will fall to low levels by 2025, and will continue above- (but near-) zero fluctuations into the 2040s (Zhang et al., 2010)

Whether this collapse will occur suddenly or gradually is still debated. Models have been unable to predict a 'tipping-point' for Arctic ice as they still simulate poorly a number of physical processes. The ice-albedo feedback, whereby a reduction in ice coverage decreases reflection of solar energy and thus the dark sea absorbs more energy, giving the possibility for a run-away process to occur is one such process. (Kerr, 2009). Eisenman and Wettlaufer (2009), however, seek to counteract the effects of the ice-albedo feedback by showing that thinner summer ice speeds up winter regrowth as the water is less insulated than previously. This mechanism, they predict, will "hold off a tipping point" and produce a gradual loss in sea ice over the next 25-30 years. (Kerr, 2009)

Uncertainties in Predictions

While AR4 held a huge range of predictions for Arctic sea ice, the possibility remained that effects on Arctic sea ice by 2100 could be minimal (under certain conditions and according to specific scenarios in select models). Just four years later, the consensus seems to be that September sea ice will disappear to zero, or at least reduce to minimum levels, sometime between 2016 and 2040. There are a number of reasons for this discrepancy. As stated above, many processes are poorly understood. There are also huge question marks about the feedback mechanisms at play in an unprecedented (in human time scales) ice-free arctic sea. What is more, there are also uncertainties in the observations, especially over time-scales of more than 10 years. According to Lemke et al. (2007) “the few available observations [made in the Arctic] are sparsely distributed in space and time and different data sets often differ considerably.” They continue, “few pan-arctic atmospheric Regional Climate Models (RCMs) are in use. When driven by analysed lateral and sea ice boundary conditions, RCMs tend to show smaller temperature and precipitation biases in the Arctic compared to Global Climate Models (GCMs), indicating that sea ice simulation biases and biases originating from lower latitudes contribute substantially to the contamination of GCM results in the Arctic. However, even under a very constrained experimental design, there can be considerable across-model scatter in RCM simulations. The construction of coupled atmosphere-ice-ocean RCMs for the Arctic is a recent development” and therefore remain unreliable.

As there are so many variables at play in these circumstances, it is very difficult to account for them all. For example, it has been claimed that the period 2030-2050 will see a new solar minimum which will counter the effects of human-induced climate change and will bring a new ‘mini ice age’ to northern Europe. These results have been widely contested, with Feulner and Rahmstorf (2010) showing that such solar effects are expected to produce a difference of no more than 0.3°C in the Arctic region during the period to 2100.

There are more factors at play with global warming than just an increase in temperature. It will also result in more severe weather and increased frequency and intensity of storms. According to Prof. David Barber, lead investigator of the Circumpolar Flaw Lead study at the University of Manitoba, "There are more storms now because there's more open oceans and those storms are having a dramatic impact on the sea ice." The storms drop precipitation, mostly snow, on the sea ice and the snow insulates the ice, keeping it from growing thicker. (Bowman, 2010)

As professor Barber points out, "We know we're losing sea ice. What you're not aware of is … what the consequences of this change are." Bowman, 2010)

Possible Recovery Mechanisms

Although the loss of Arctic sea ice is predicted as irreversible by some authors, there are studies on the possible recovery mechanisms of the Arctic sea ice in summer (Tietsche et al. 2010). This study arises from the runs of the atmosphere-ocean general circulation model (AOGCM) used in AR4. The runs for the near future show significant losses of Arctic summer sea ice followed by rapid temporary recovery, suggesting the existence of an equilibrium state that varies smoothly with climate forcing. Thus, the existence of recovery mechanisms that counteract the loss of sea ice is foreseen and studied by analysing the Arctic energy budget.

Using the model AOGCM ECHAM5/MPI-OM, and taking the initial conditions of an Arctic ice-free ocean during summer, the following conclusions were drawn::
- Sea-ice-free summer conditions cause the ocean to gain excess heat through the surface during summer, but they also cause enhanced heat *loss* through the surface during the following autumn and winter,when the insulating sea-ice cover is anomalously thin.
- This leads to an anomalously warm atmosphere, which in turn causes increased heat loss by longwave radiation at the top of the atmosphere and decreased heat gain by atmospheric advection from lower altitudes. A lasting impact of the ice–albedo feedback is not possible because the large-scale heat fluxes quickly adapt to release the excess oceanic heat from the Arctic.

Concluding, even dramatic perturbations of summer sea-ice cover in the Arctic are reversible on very short time scales of typically two years. This suggests that a so-called tipping point- the sudden irreversible loss of Arctic summer sea ice during warming conditions- is unlikely to exist (Tietsche et al. 2010). Allied to this, Eisenman and Wettlaufer (Science, 2009) report an under appreciated ice-thickness feedback that strongly opposes the ice-albedo feedback. When added summer heat thins the ice, the ice can grow back in winter all the faster because the ocean can lose heat faster through thinned ice.

Consequences

If the loss of sea ice might not be irreversible, the same cannot be said about the impacts this loss has on the Arctic's human population and on its biodiversity. Besides that, what would the consequences be in terms of the carbon cycle and of the global climate?

Regarding the global climate, results differ in different simulations, from increased precipitation in winter over western and southern Europe (Singarayer et al.) to reduced rainfall in the American West (Sewall and Sloan). In any case, it is consensual that winds become stronger from an ice-free ocean, resulting in more wave action and consequent coastal erosion (Serreze 2007).

Carbon cycle

The Arctic Ocean has a special role in the carbon cycle due to its specific characteristics:
- high primary production and air-sea fluxes of CO_2 when compared with the other oceans,
- deep water formation with the transport of organic and inorganic Carbon from surface to deep water, especially relevant for the sequestration of anthropogenic CO_2.

Therefore, the undergoing changes in the Arctic Ocean have a great potential to alter processes important to carbon exchange with the atmosphere (McGuire et al.2009).

However, in analyzing the literature, there is no consensus on whether the melt of sea ice will result in higher or lower sinking of carbon in the Arctic sea. According to Semiletov et al. (2004), sea ice melt ponds and open brine channels might act as spring/summer CO_2 sinks. However, Cai et al. (Nature 2010) argue that in a first period that might be the case, but in a second period the gradient of CO_2 existent between the air and the sea surface will decrease due to a shallow mixed-layer depth, strong surface-water stratification, surface warming, and low biological CO_2 fixation.
In order to assess which phenomenon will be dominant more research and monitoring are needed.

Polar Bears - an example

As in every ecosystem, there is in the Arctic a fragile balance between the natural environment and the fauna that lives there. Within the fauna, species are inter-connected and dependent upon a food-web. Thus, the effects of the loss of sea-ice on one species carries impacts in other species.

This paper focuses on the Polar Bear, often pictured by the media in a small piece of ice in the ocean to represent dramatic consequences of melting sea-ice, as an example of the climate change impact in the Arctic fauna.

Polar bears have a highly specialized nature, having diversified from the brown bear and adapted to the extreme conditions of Arctic environment through thousands of years. Their main prey are seals and they are highly dependent on arctic sea-ice to travel and hunt. Changes in sea-ice distribution, abundance or existence affects the their lives. The current trends of longer ice-free seasons means longer fasting seasons for polar bears, and by consequence, shorter hunting periods, in which they must store as much fat as possible to survive the following warm season.

Studies made by biologists in Canada (Derocher et al. 2004) indicate that there is a limit to female polar bear weight under which reproduction does not occur. This was estimated as 189 kg, while the mean for the period 1982-90 was 283 kg. As the polar bear is a long-lived species its population could continue for some years without a significant decline, even with low reproduction rates.

Other possible effects are (Derocher et al. 2004):
- changes in movement rates, since leads in ice are thought to appear more often, which would imply extra time to cross it swimming or to go around the lead.
- availability of prey, (mainly ringed and bearded seals), as the suitable sea ice habitats are reduced and these species are territorial during the breeding season their productivity will likely decrease.
- increasing human-bear interactions,

- increased exposure to pollutants,
- disruption of ice covered areas, used by Polar Bears, as shipping increases in the Arctic sea, etc.

The extent of the effects the loss of sea-ice will have on polar bears depends deeply on their behavioural plasticity and that of their prey, which has not been assessed so far. Long-term monitoring of existing populations is needed in order to better understand how and if the species are adapting to the changes in sea ice cover.

Inuit populations

The Inuit populations have acquired an extensive knowledge of the Arctic's dynamic of seasonal changes over vast periods of time. Although not using scientific methods or theories to assess it, the Inuit were deeply dependent on the accuracy of their knowledge for their survival. Thus, the stronger the understanding of the relations between sea-ice break-up, seasonal weather, availability of seals, etc. the better the chances of surviving in this place of extreme climate conditions.
It is interesting, therefore, to find out how the Inuit perceive the effects of global warming in their local environment. A paper by Laidler, G. (2004), further addressed, covers this topic based on research next to Inuit communities in North America.

An illustrative example of the intricate Inuit understanding of sea-ice is their vocabulary richness concerning that topic. In Figure 4, each square contains a Inuit word for a type of condition of sea-ice. For instance, *Akitkuit*, new ice is allowed to form from ice broken up by strong currents or waves, from the floe edge by strong currents or winds; *Apputainaq*, new cracks covered with snow, "false ice"; *Ikiarik,* forms when one piece of solid ice is pushed on top of another during a wind storm or spring tides; etc.

Laidler, G. (2004), through a literature review, gathered the general changes observed by Inuit in the last 20 years, regarding climate and sea-ice:

- Increased variability in weather events ;
- Fewer very cold days in early winter and fewer extended periods of extreme cold;
- Change in the pattern and rate of fall-to-winter transition;
- Increased number of summer storms/extreme events (especially the frequency of high wind events and lightning) and,
- Increased unpredictability, whereby changes are quick and the rate of change seems to be accelerating.

The sequence of effects of these changes in the Inuit communities daily life is schematized in **Figure 5**. In this scheme, the relationships between the physical, biological and socio-economic spheres are roughly exposed. The final consequences to Inuit life seem to be in hunting opportunities and success, sport hunting and tourism. Nevertheless even if, in the modern age, the communities can adapt to these changes just by converting to western life habits of buying food and clothes, instead of hunting for them, as is already the case to a certain extent, severe impacts are expected in their long-lived culture, sustained knowledge on local Arctic dynamics and traditions.

Other authors, however, alert to an exaggerated idea of the Inuit vulnerability to loss of sea-ice, argue that it can be partly mitigated by a range of factors including effective open water hunting technologies, and economic alternatives like participation in the wage economy, and that comparing to coastal urban populations the Inuit are less exposed to risks of increased inequality within their communities (Bravo 2009).

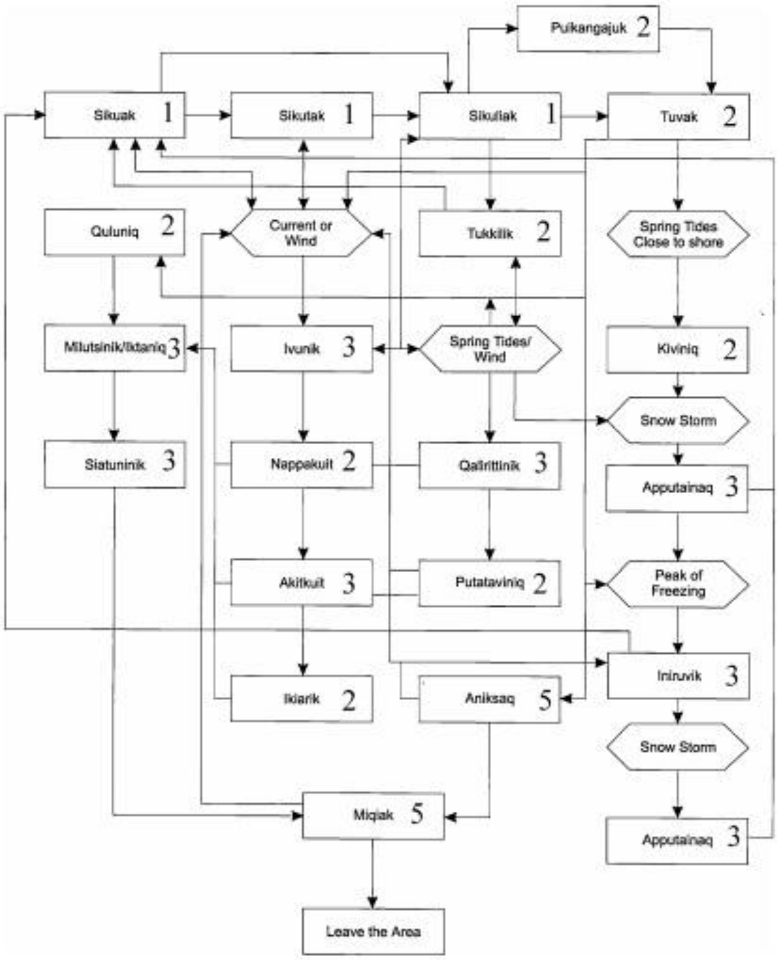

Figure 4. Inuit characterization of the effects of currents, spring tides, and wind on sea ice. Numbers in boxes refer to the stage of ice formation. Source:McDonald et al. (1997,16).

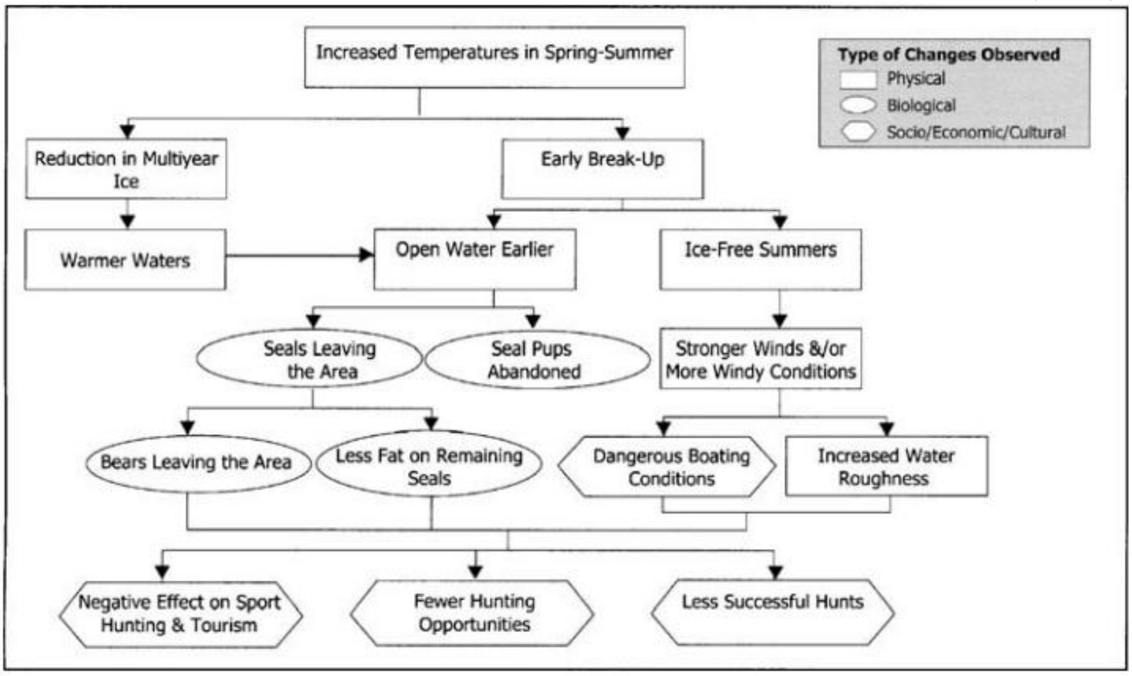

Figure 5. An example of Inuit perceptions of climate change influences on sea ice conditions and associated relationships – observations of seasonal change (spring and summer) in Sachs Harbour, NWT. Source: Nichols et al. (2004, 74).

Economic development

If for the ecosystem and for the cultural traditions of the Arctic native populations, the prospective of decreasing sea-ice does not present a bright future, for the oil companies of the Arctic countries the case is very different.

The United States Geological Survey has estimated that 90 billion barrels of undiscovered oil should exist in the region North of the Arctic Circle (Figure 6). As the world oil reserves are not expected to last for many more decades, this news, together with the facilitated exploration by the decreasing sea-ice, present prospects for high economic gains for Arctic nations. Norway and Russia have already agreed this year (BBC online 7 June 2011) on how to divide parts of the Arctic Barrents sea between them, for purposes of oil drilling. Yet, the drilling is only expected to start in 2015 in Russia, in a partnership between Rosneft-BP (Rianovosti 14 March 2011), while Norway extended the moratorium on oil production on the Arctic shelf until 2013.

In any case the further exploration of the Arctic oil reserves, although economically beneficial for the involved countries might lead to an acceleration of possible irreversible changes in the Arctic environment, which should therefore, be carefully considered.

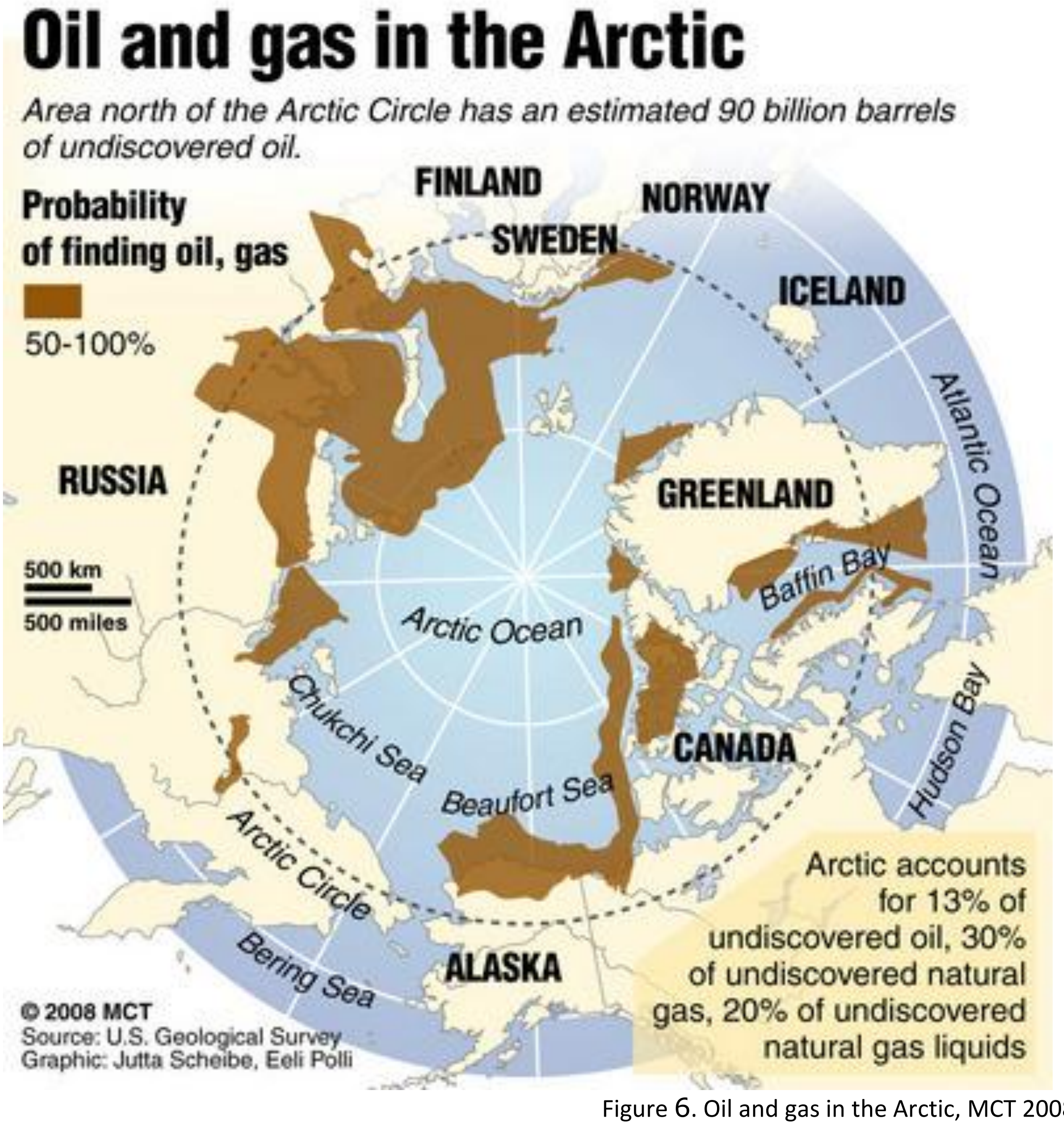

Figure 6. Oil and gas in the Arctic, MCT 2008

Conclusions

Despite all the remaining uncertainties it seems to be a consensus on the predictions of a September ice-free Arctic sea by 2016 -2025, which is earlier than previously expected.
Further research and monitoring Is needed In order to better understand possible feedbacks and to come up with better predictions.
The predicted consequences, also affected by uncertainties, have different ranges (local, global) and intensities and can even bring economic short-term economic benefits to Arctic nations, which might further intensify the damage of the ecosystems.
However, the extent of the impacts will also depend on the adaptation mechanisms and capabilities of the Arctic species and populations.
As they are, both fauna and human, highly adapted to the very dynamic system of the Arctic, if by acknowledging the increasing deviations from the Arctic balance, adaptation measures or mechanisms are taken faster than the pace of the changes, then there might be a chance for the Arctic societal and ecosystem.

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