Project no. 265863

ACCESS

Arctic Climate Change, Economy and Society

Instrument: Collaborative Project
Thematic Priority: Ocean.2010-1 "Quantification of climate change impacts on economic sectors in the Arctic"

D1.28 – Regional distribution of melt onset and freeze up on an annual basis

Due date of deliverable: **30/06/2013**

Actual submission date: **14/03/2014**

Start date of project: **March 1st, 2011** Duration: **48 months**

Organisation name of lead contractor for this deliverable: **UPMC**

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	
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The Arctic sea-ice appears to be one of the most important elements of the Earth environment subjected to large fluctuations in the context of climate change. Every summer since the early 2000s drastic sea-ice retreat occurred all over the Arctic Ocean. Summer 2007 was one of the most remarkable events with a sea-ice retreating to almost 4 million km2, i.e. 2 million km2 below the 1979-2000 average. Summer 2012 went even more extreme with a sea-ice retreating down to approximately 3 million km2, i.e. half of what it used to be 20 years ago. Combining a 50% sea-ice thinning together with a 50% sea-ice extent decrease, would correspond to a 75% sea-ice volume (or mass) loss. This is similar to PIOMAS model estimation. Due to uncertainties about sea-ice thickness distribution, there is a general agreement for actually estimating a 60% decrease of sea-ice mass at least during the past 20 years. An important aspect to remember deals with the fact that sea-ice thickness was the first prime sea-ice parameter to be observed to decrease during the mid 90s based on US submarine patrolling under sea-ice with upward looking sonars measuring sea-ice draft. The sea-ice extent (another prime sea-ice parameter) was observed to decrease during the 2000s, lagging ten years after sea-ice thickness was reported to decrease. This is important for attributing a cause to the drastic sea-ice retreat observed during the past 20 years.

Mainly based on AMSR-E remote sensing data providing daily maps of the Arctic sea-ice extent as defined by the 15% sea-ice concentration limit, we are presenting on figure 1 the evolution of the Arctic sea-ice extent during the past 10 years (2003-2012) on a yearly basis. Due to a failure of the AMSR-E on October 4, 2011, we included data issued from the SSMI for the last year 2011-2012.

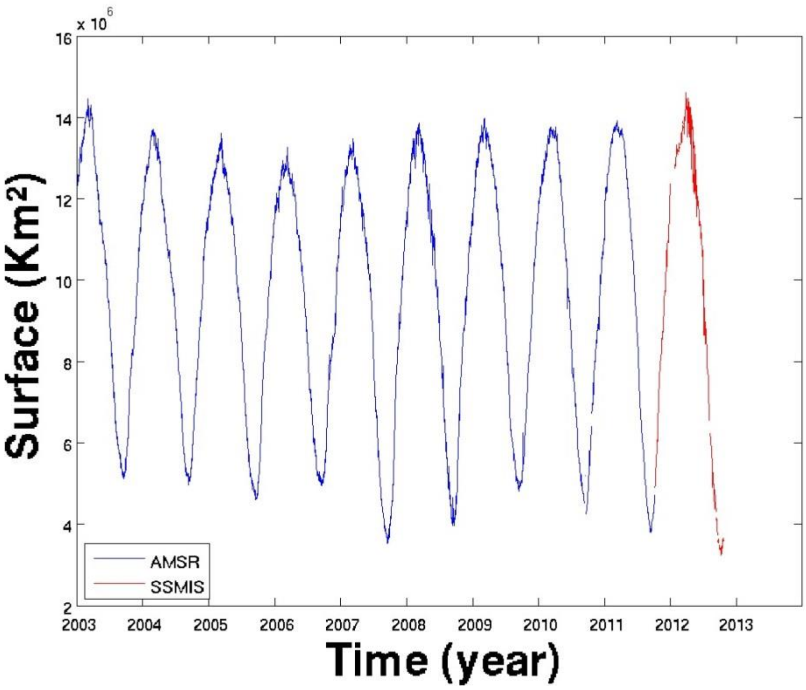

Figure 1. The annual cycle of the Arctic sea-ice expressed in million km2 over the past 10 years as observed with the AMSR-E and the SSMI passive microwave radiometers. Most of the data are issued from AMSR-E until October 4, 2011 when the AMSR-E failed. The last year (October 2012 – September 2013) is issued from the SSMI corrected data.

It is remarkable to realize that most of the sea ice variability did occur in an area extending from 70°N up to 80°N as shown on figure 2 when comparing the total sea ice extent (in blue) with the sea ice extent restricted to the 70°N to 80°N latitudinal range (in red) during the break up (melting) season on July 15 of each year.

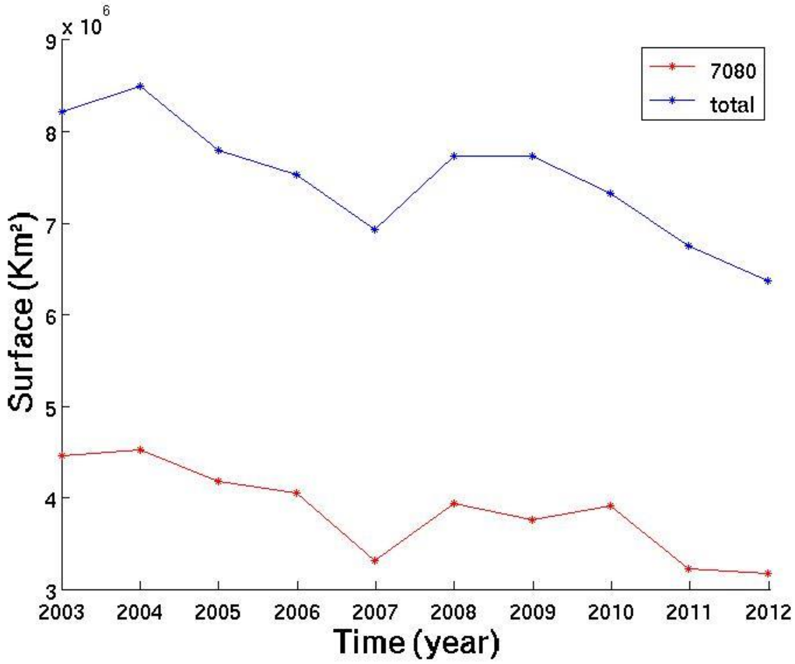

Figure 2. The total Arctic sea-ice extent (blue curve) estimated from AMSR-E in million km2 every year on July 15 from 2003 until 2012 compared with the sea-ice extent estimated within the 70°N -80°N band of latitudes (red curve).

Comparing two extreme years 2007 and 2012, most of the Arctic sea-ice disappeared in summer 2012 in a band of latitudes extending from 70°N up to 80°N (figure 4) in contrast with sea-ice extending over a band of latitudes from 80°N up to 90°N (figure 3) where sea ice extent remained just about the same during both years. During summer 2007 approximately 1 million km2 remained in the 70°N -80°N band of latitudes. The area extending from 70°N up to 80°N is now typically considered as the Arctic seasonal sea-ice zone characterized by a complete melting of sea-ice during summer months. This is an important area that includes both the North East and the North West passages. The area extending from 80°N up to the North Pole is the last area resisting to the summer melt in the entire Arctic. In this domain summer melt is affecting 25% of the area since sea-ice extent varies from 3.3 million km2 (100% cover) in winter time down to a 2.4 million km2 in summer time.

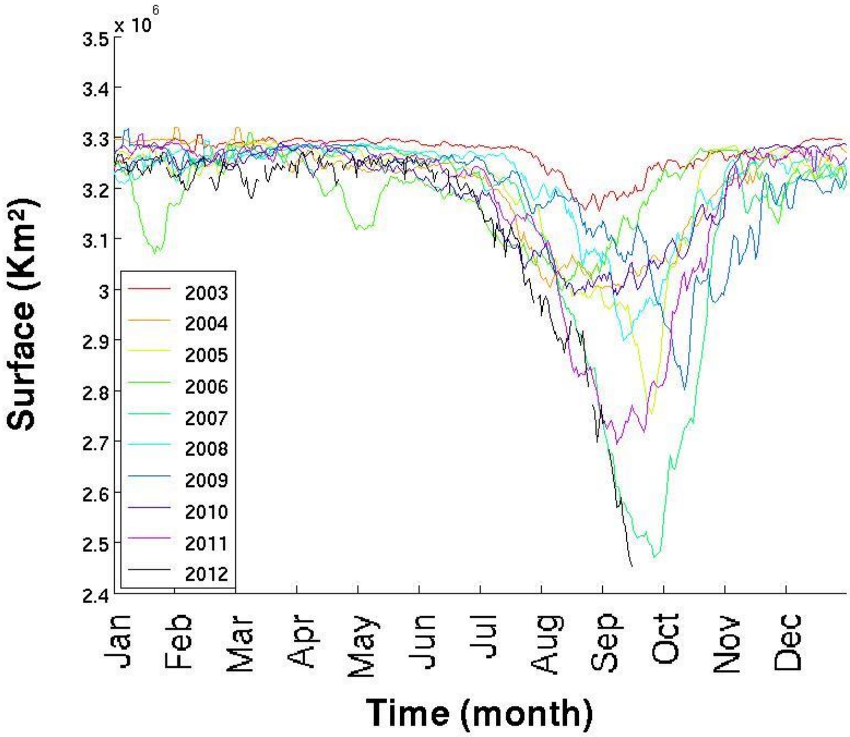

Figure 3. The Arctic sea-ice extent annual cycle in million km2 within the 80°N -90°N band of latitudes for the past 10 years.

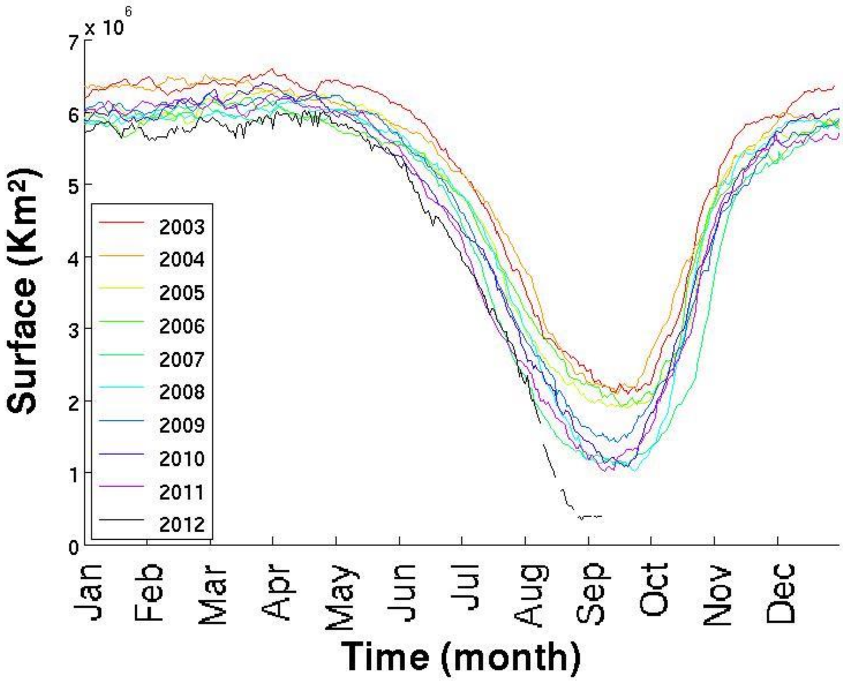

Figure 4. The Arctic sea-ice extent annual cycle within the 70°N – 80°N band of latitudes for the past 10 years expressed in million km2.

Splitting the Arctic Ocean in two parts along the 90°E-90°W meridians (black bold lines on figure 5), the Atlantic and Pacific Arctic sectors of the Arctic Ocean were arbitrarily defined within the 70°N to 80°N range of latitudes. The so-called Atlantic sector of the Arctic Ocean, includes Baffin Bay, the Greenland Sea, the Barents Sea and the Kara Sea. The so-called Pacific sector of the Arctic Ocean includes the Beaufort Sea, the Chukchi Sea, the East Siberian Sea and the Laptev Sea. The North West and North East passages are entirely included in these two sectors which correspond mainly to the Arctic seasonal sea-ice zone.

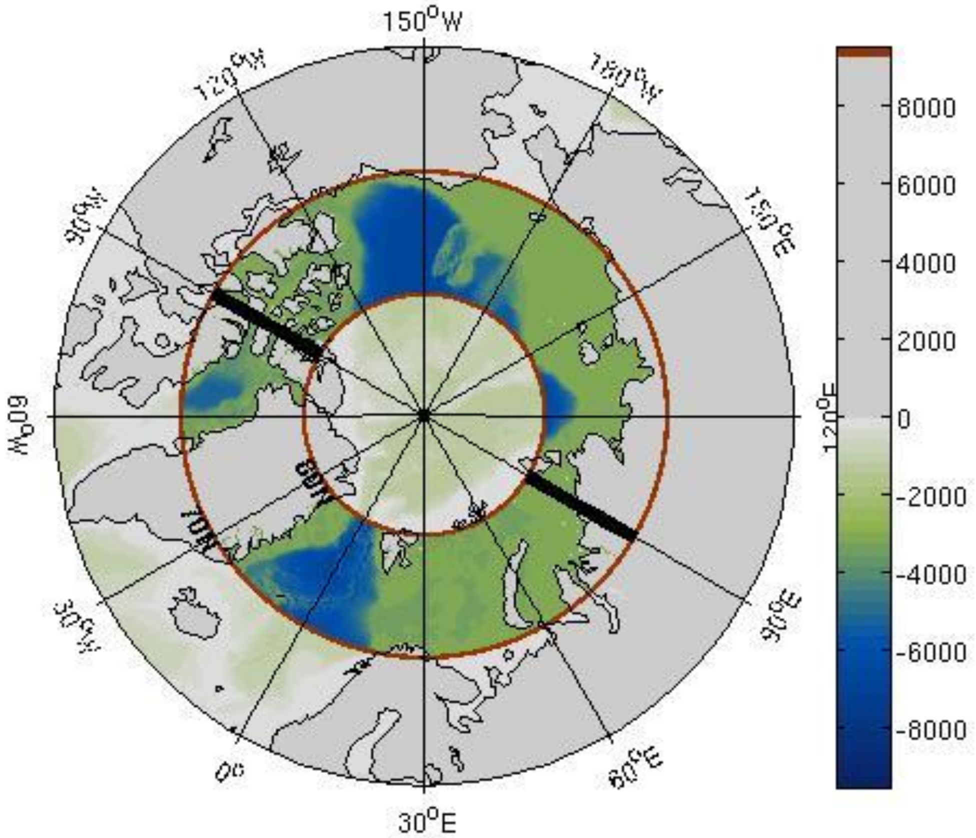

Figure 5. The Arctic Ocean polar stereo-projection showing the 70°N-80°N and 80°N-90°N band of latitudes and the bold line (black) stretched along the 90°W and 90°E meridians and separating the Arctic Atlantic sector from the Arctic pacific sector arbitrarily

Two very distinct modes of variability characterized the seasonal evolution of the Arctic Sea-Ice: the so-called Atlantic versus the Pacific mode (figure 6). The Atlantic mode appeared to be characterized by a much longer time evolution with a break up melting season starting in May and reaching a peak in June-July, one month earlier than the Pacific Arctic sector which revealed a much faster time evolution and larger spatial amplitude of the Arctic sea-ice cover. The Atlantic Arctic sector sea-ice break up was consistently preceding the Pacific Arctic sector sea-ice break up by more than one month. Figure 6 shows the same as figure 4 but after separating the Atlantic Arctic sector from the Pacific Arctic sector as defined previously.

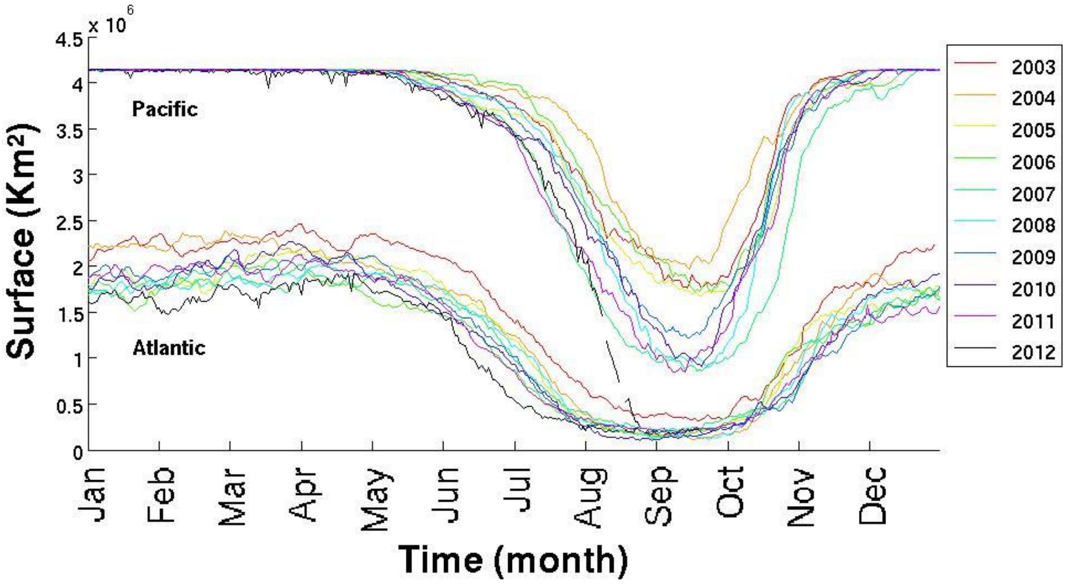

Figure 6. The Arctic sea-ice extent annual cycles within the 70°N-80°N band of latitudes in million km2 for the past 10 years divided between the Arctic Atlantic sector and the Arctic Pacific sector

Interesting results appear on Figure 6 when comparing the so called Atlantic Arctic sector to the Pacific Arctic sector in terms of sea-ice extent (sea-ice concentration >15%) within the 70°N to 80°N range of latitudes. As far as the Pacific sector is concerned, we observed a saturation of the sea-ice extent in winter slightly above 4 million km2 indicating that the total area was frozen during the winter season. During the summer sea-ice retreat, sea-ice extent with sea-ice concentration above 15%, is retreating to about 1 million km2 in the Pacific Arctic sector between 70°N and 80°N. Within the Atlantic Arctic sector the amplitude of the change was not only twice smaller (from about 2 million km2 to almost 0) but it occurred over a much longer time period including the fact the melt season and the sea-ice break up started much earlier than within the Pacific Arctic sector. As a consequence the seasonal evolution of the Arctic sea-ice extent within the70°N up to 80°N range of latitudes exhibits a double dip resulting from a first acceleration of the sea-ice retreat due to the Atlantic Arctic sector melting period reaching its peak in June-July followed by a second acceleration of the sea-ice retreat one or two months later due to the Pacific Arctic sector melting period reaching its peak in July- August each year. There was also a smaller delay between the two sectors of the Arctic Ocean during the freeze up.

The summer of 2012 is a clear illustration of this phenomenon. Most of the Arctic sea-ice retreat during the first part of the 2012 summer season (June and July) occurred in the Atlantic sector. Early on August 2012 a deep cyclonic low pressure system invaded most of the central Arctic

Ocean and coincided with the second phase of the melting season involving the Pacific Arctic sector to explain the Arctic sea-ice double dip retreat. It is more likely that the Low pressure system that invaded the whole central Arctic Ocean from August 4 to 8, 2012, contributed to the second phase of the Arctic sea-ice melting largely influenced by the Pacific Arctic sector.

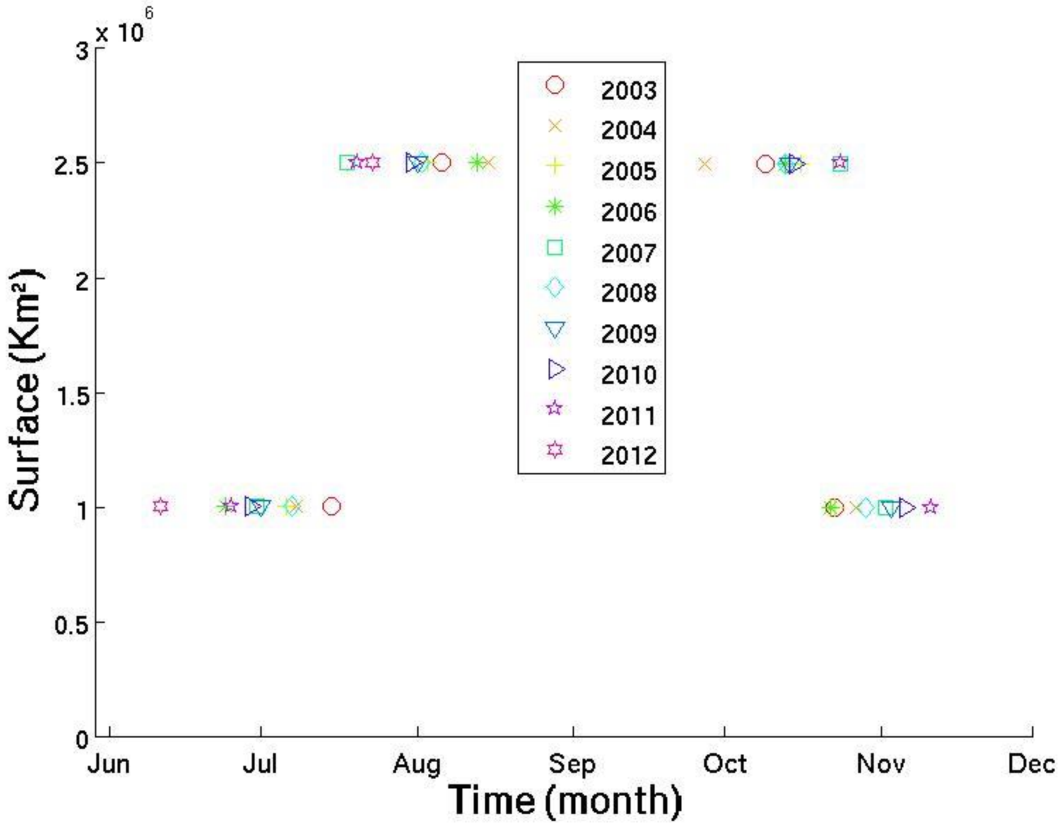

Figure 7. Estimated time period (in days) for the break up (max melting rte) and the freeze up (max freeze rate) calculated when sea-ice extent reached 1 million km2 for the Arctic Atlantic sector and 2.5 million km2 for the Arctic Pacific sector respectively within the 70°N-80°N band of latitudes over the past 10 years.

Both sectors of the Arctic Ocean are characterized by an advance of the melt onset-break up season by 1.5 days from one year to the next and a delay of the freeze up season by 1 day per year on average over the past 10 years. The broadening of the melting season of Arctic Sea-Ice extending from the Spring break up to the Fall freeze up, increased by more than a month over the past 10 years. The important factor is not only that the Arctic sea-ice extent minimum characterizing the Arctic sea-ice retreat each year in summer (around mid-September) decreased by 1 or 2 million km2 but it is also that the melting period was steadily increasing by few days every year since the early 2000s.

Consequently, In addition to the seasonal variability of the Arctic sea-ice extent involving the two modes of variability (Atlantic first and Pacific second) wefirst described, there is an important and significant inter-annual variability component contributing to the broadening of the Arctic sea-ice melting season by a couple of days every year. Comparing early years during the 2000s with more recent years we observed an increase of the Arctic melting season by almost one month in less than 10 years.

In addition to the Arctic sea-ice minimum extent decreasing significantly and steadily every year, it is important for modeling prediction to take into account the broadening of the Arctic melting season that will continue at a time the whole seasonal sea-ice would have melted away at the end of each summer. It is essential for the predictive modeling to reproduce the double dip mode typical of the Arctic sea-ice melting and Arctic sea-ice extent retreat due to the Atlantic Arctic and Pacific Arctic influences respectively. Our ability to better predict these modes of variability, is essential for economic sectors such as marine transportation at high latitudes along the Northern Sea Route and/or the North West Passage, oil and gas extraction and exploitation in Arctic regions as well as fisheries. In this paper it was not intended to attribute the cause of the Arctic sea-ice variability to any specific processes but at present it might be useful to indicate that a shift of 1 to 2 days per year during the past 20 years was also reported for long wave downward solar radiation and snow melt onset. But other effects such as sea-ice thickness reduction, and/or increasing sea-ice drift velocity need also to be considered as well as the number of freezing degree days contributing to the formation of sea-ice in winter and melting degree days contributing to the sea-ice melting in summer. Last and not least oceanic heat advection both from the Atlantic and the Pacific Oceans into the Arctic Ocean is a critical element that models will need to take into account carefully to improve predictive capabilities of future evolution of Arctic sea-ice. A prerequisite for better modeling prediction of Arctic sea-ice evolution will be to take precisely into account the double dip mode of Arctic sea-ice seasonal variability as well as the inter-annual variability leading to an expansion of the melting season in the Arctic.

A linear projection based on the last 4 years sea-ice extent minimum would lead to an ice free Arctic Ocean by 2020 (figure 8). A root mean square extrapolation based on the last 10 years sea-ice minimum extent taking into account the interannual sea-ice variability would lead to an ice free Arctic Ocean by 2035 (figure 8). None of these two extrapolations are satisfactory. We demonstrated the whole area extending from 70°N up to 80°N is now part of the seasonal sea-ice zone since it is almost entirely melting away every summer except sea-ice drifting away in the east Greenland Current and covering a total of 100000 km2 to 200000 km2 for the Atlantic sector and a similar area North of the Canadian Archipelago for the Arctic Pacific sector (along the northern shore of Banks and Ellesmere Islands). Consequently the most important issue for predicting an ice free Arctic Ocean, concerns the area extending from 80°N up to the North Pole that is still mainly covered (75%) by sea-ice at the end of summer season (i.e. 2.4 million km2 in summer compared to 3.3 million km2 in winter). It represents less than half of the sea-ice found typically in the Arctic Ocean at the end of each summer 20 years ago. This is certainly true as far as sea-ice extent is concerned but even more striking for sea-ice mass or volume that melted away each summer since. Today the area extending between 80°N and the North Pole, is the last sea-ice area of the Arctic Ocean still partly resisting to summer melt. Our predictive capability regarding the resilience of the last sea-ice area of the Arctic Ocean would entirely depend on our ability for taking into account several important factors. One concerns the advection of the warm and salty Atlantic water masses into the Arctic Ocean. As recently demonstrated by R. Speilhagen et al. in Science, the Atlantic water inflow through Fram Strait has never been so warm during the past 2000 years than today. The Atlantic inflow is the most important source of heat and salt for the Arctic Ocean. It is more likely the Atlantic inflow North of Svalbard and Franz Josef Land that was and is responsible for a significant northward retreat of the ice edge in that region like it was responsible for maintaining Whalers Bay sea-ice free all year long for a long time.

A second factor dealing with the last sea-ice area North of 80°N concerns the main drift of the Arctic Sea-ice influenced by the transpolar sea-ice drift in the Arctic Atlantic sector and the Beaufort anticyclonic gyre in the Arctic Pacific sector. Both are contributing to carry on sea-ice North of 80°N across the North Pole region and towards the northern shores of Greenland and Canada. This area is strongly dependent on meteorological conditions and extreme weather events as shown during the summer of 2012 (early August).

Last and not least a third important factor concerns the intensity of the freezing that can be quantified in terms of Freezing Degrees Days (FDD) accumulated during the winter-spring period and the intensity of the melting that wan be quantified in terms of Melting Degrees Days (MDD) accumulated during the summer season. By in large this warming effect can be largely attributed to long wave downward solar radiation but also to more invasive warm air masses advected from the South in contrast with Cold Air Outbreaks advecting cold air to the South and related to Sudden Stratospheric Warming events (SSW). This seems to be favorable for atmospheric blocking creating more extreme weather events such as the 2012 perfect storm extending all over the Arctic Ocean and enhancing meridional heat transfer at the expense of hemispheric zonal heat transfer by westerlies at mid latitudes and at the periphery of the Arctic.

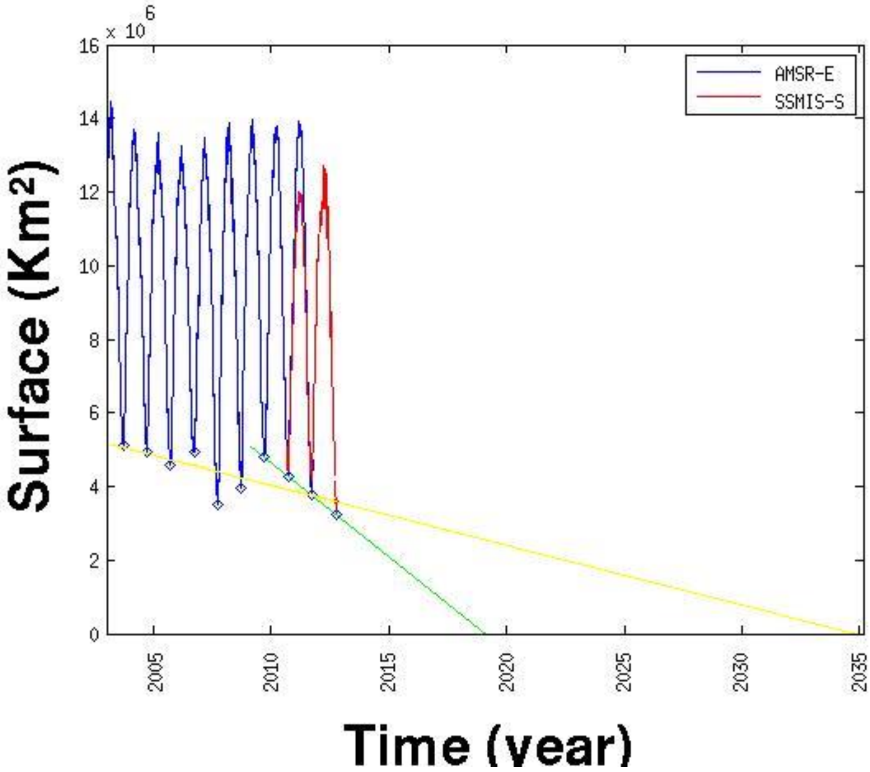

Figure 8. Estimated time period (in year) for an ice free Arctic Ocean in summer time. A first linear extrapolation based on the past 4 years would lead to an ice free Arctic Ocean in summer 2020. A second linear extrapolation (root mean square) taking into account the inter-annual variability over the past 10 years would lead to an ice free Arctic Ocean in summer 2035.

Due to uncertainties in sea-ice thickness distribution, an estimated 66% up to 75% of sea-ice mass or volume melted away during recent summers compare to the situation twenty to thirty years ago. How long would it take to melt away the 1/3 or 1/4 of Arctic Sea-ice left in summer (approximately 2.5 million km2) that remain trapped in the northernmost sea-ice area extending from 80°N to the North Pole?