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”

D1.42 – Monthly evolution of the FDD integrated all over the Arctic and redistributed over subarctic areas for each year

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

Deviation from Annex I:

- *The name of the report has been modified as follows 'Monthly evolution of the Freezing Degrees Days and Melting Degrees Days integrated all over the Arctic and redistributed over SubArctic areas for each year over the past 30 years' to include the data Melting Degrees Days (MDD) data.*
- *The dissemination level of this deliverable should be Confidential 'CO' and not Public 'PU' as stated in the DoW since the results haven't been published yet.*

Monthly evolution of the Freezing Degrees Days and Melting Degrees Days integrated all over the Arctic and redistributed over SubArctic areas for each year over the past 30 years.

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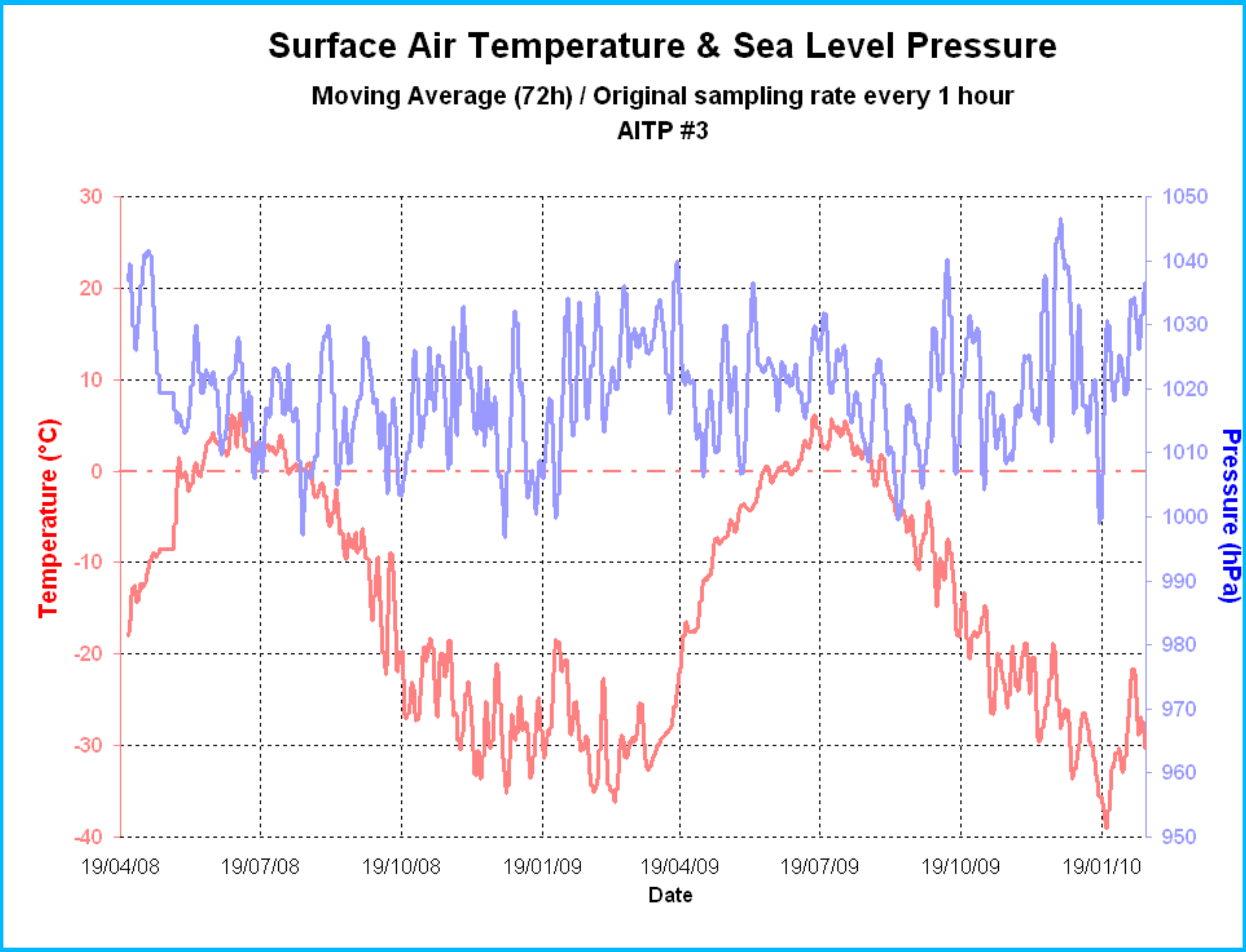

Figure 1 is representing a time series of surface air temperature and pressure obtained from a drifting buoy (AITP) anchored in sea-ice from April 2008 until January 2010 (DAMOCLES EU project). This buoy drifted in the Canadian Basin across the Beaufort Gyre and the Alpha ridge for almost two years (22 months) and reveals the annual cycle of surface air temperature in the Arctic Ocean extending from -30°C in winter up to +5°C in summer. In the following we will be calculating everywhere in the Arctic Ocean, the cumulative number of Freezing Degrees Days FDD during the period extending from September to June each year and the cumulative number of Melting Degrees Days MDD in summer extending from June to September each year. In fact the cumulative number of FDD and/or MDD is the integral of the surface air temperatures for temperatures below – 1.7°C (FDD) and above -1.7°C (MDD) during a one year cycle starting in September each year.

Freezing Degrees Days (FDD) and Melting Degrees Days (MDD) have been calculated using ERA Interim Reanalysis surface temperature at 2 metre height in the atmosphere for the past 30 years all over the Arctic Ocean . This work was accomplished in the context of ACCESS WP 1. FDD and MDD are simply a daily integration of 2 metre air surface temperature expressed in number of degrees of freezing or melting respectively below or above the sea water freezing temperature considered to be -1.7°C. The space resolution for the FDD and MDD calculation is identical to the ERA Interim resolution (*i.e. 0°75 in longitude and latitude*) and corresponds to about 1000 km^2 at 80°N. In this calculation, the resolution is 100 FDD and 10 MDD for a corresponding scale of 0 to 10 000 FDD and 0 to 1 000 MDD respectively. In both calculations only the sensible heat flux is considered as far as freezing of sea water and/or melting of sea ice is concerned.

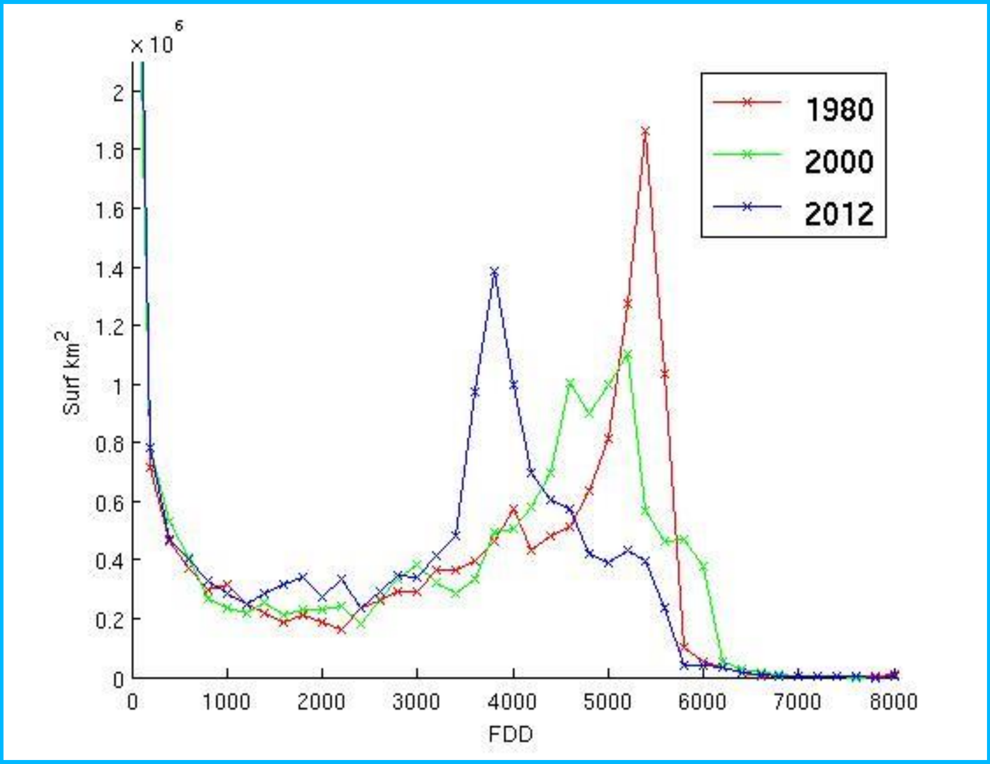

Figure 2: Freezing Degrees Days FDD calculated over the Arctic Ocean for 1980, 2000 and 2012.The curves represent the extent in km2 corresponding to any given FDD for a particular year.

It is clear that the number of FDD decreased significantly between 1980 and 2012 by more than 2 000 FDD which is equivalent to the sensible heat flux required to form more than a metre of sea-ice thickness. Direct observations of Arctic sea-ice revealed a decrease of about 1 metre of sea-ice thickness over the past 20 to 30 years. This is mainly due to successive winters being milder in recent years and therefore less and less capable of forming thicker ice.

The number of MDD increased significantly between 1980 and 2012, and doubled between 2000 and 2012 (Figure 3). This was mainly due to an increase in the duration of the melting season rather than due to an increase in temperatures above freezing. The opposite is true for freezing due mostly to a decrease in the strength of the cold (lower cold temperatures) during the winter-spring season rather than due to a decrease of the freezing period length. The surface impacted by melting due to MDD is rather stable and centred around the North Pole. This is in contrast with the surface impacted by freezing due to FDD which is centred above the Canadian archipelago and in the north of Canada and Greenland where the coldest average temperatures are dominant. While both FDD and MDD anomalies are impacting on sea-ice volume (or mass), FDD anomalies are impacting more on sea-ice thickness and MDD anomalies are impacting more on sea-ice extent.

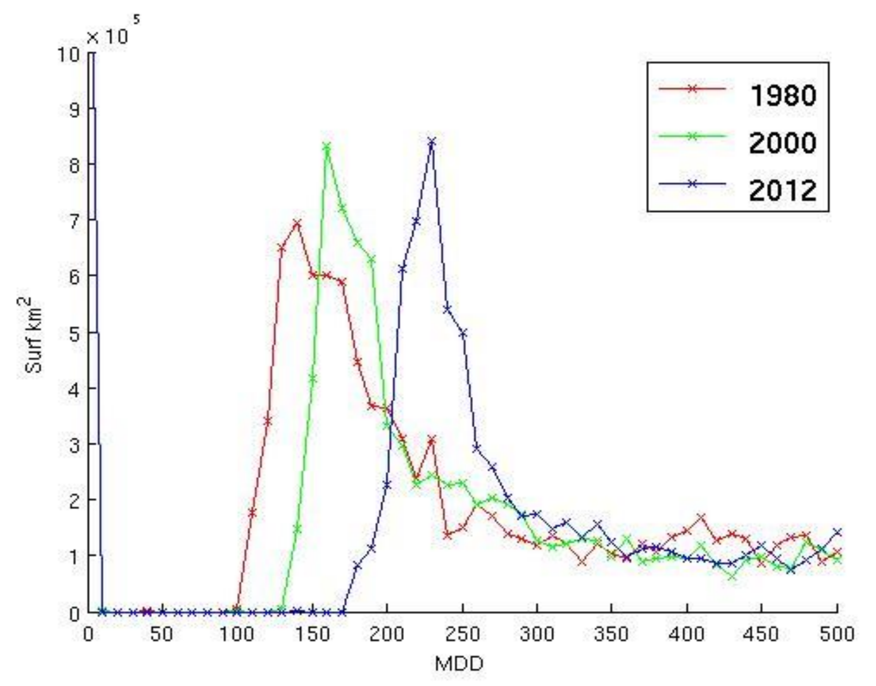

Figure 3: Melting Degrees Days MDD calculated over the Arctic Ocean for 1980, 2000 and 2012.The curves represent the extent in km2 corresponding to any given MDD for a particular year

The FDD and MDD anomalies appear to explain a large part of the Arctic sea-ice anomalies both in terms of sea-ice thickness and sea-ice extent. But what is the cause (or causes) of these anomalies? There are several potential causes. One might be an increase in the incoming short-wave solar radiation reaching sea-ice and the ocean surface due to a change in the transparency of the atmosphere (optical depth, albedo related to clouds and aerosols). Another factor might be an increase of long-wave downwards radiation due to an increase in greenhouse gases. Another driver might be an increase in warm air advection carrying more heat towards the pole and more cold air southwards. There is a strong need to differentiate local and regional temperature and sea-ice anomalies to attribute effects to specific causes. Another important aspect not treated in this calculation concerns the timing of the seasonal break-up and freeze-up events that are inevitably related to temperature anomalies. Last and not least Ocean heat flux to sea-ice is an important element in particular since lots of warm waters are advected from the North Atlantic Ocean to the Arctic through Fram Strait and the Barents Sea and from the North Pacific Ocean to the Arctic Ocean through Bering Strait.

On Figure 4 and 5, maps are indicating the area corresponding to a certain value of MDD and FDD respectively. On each maps, the magenta color represents the area covered by the most abundant MDD or FDD respectively. We noticed interesting and important features such as a clear and significant northward extension from 1980 until 2012 of the MDD characterized by the value 300 (bright yellow color) on figure 4. On figure 5 we noticed a net decrease of the highest FDD that occupied a major part of the Arctic Ocean (the area covered by the magenta color) in 1980 and still in 2000 (red color) and that almost disappeared by now (2012).

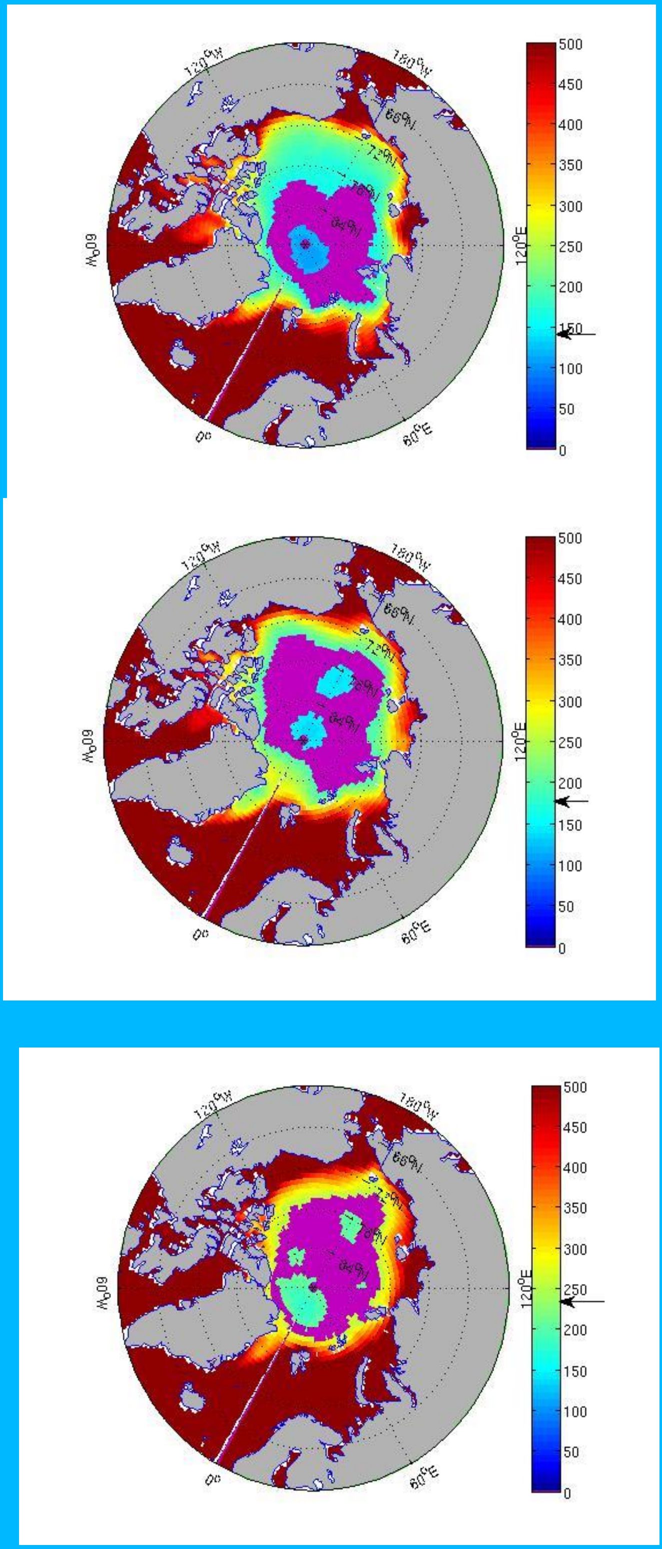

Figure 4. Melting Degrees Days in 1980, 2000 and 2012. The magenta colored area is representing the most abundant category of MDD which varied from 140 in 1980 up to 240 in 2012. There was an increase of 100 MDD between 1980 and 2012 (i.e. a 70% MDD increase) of the most abundant MDD category.

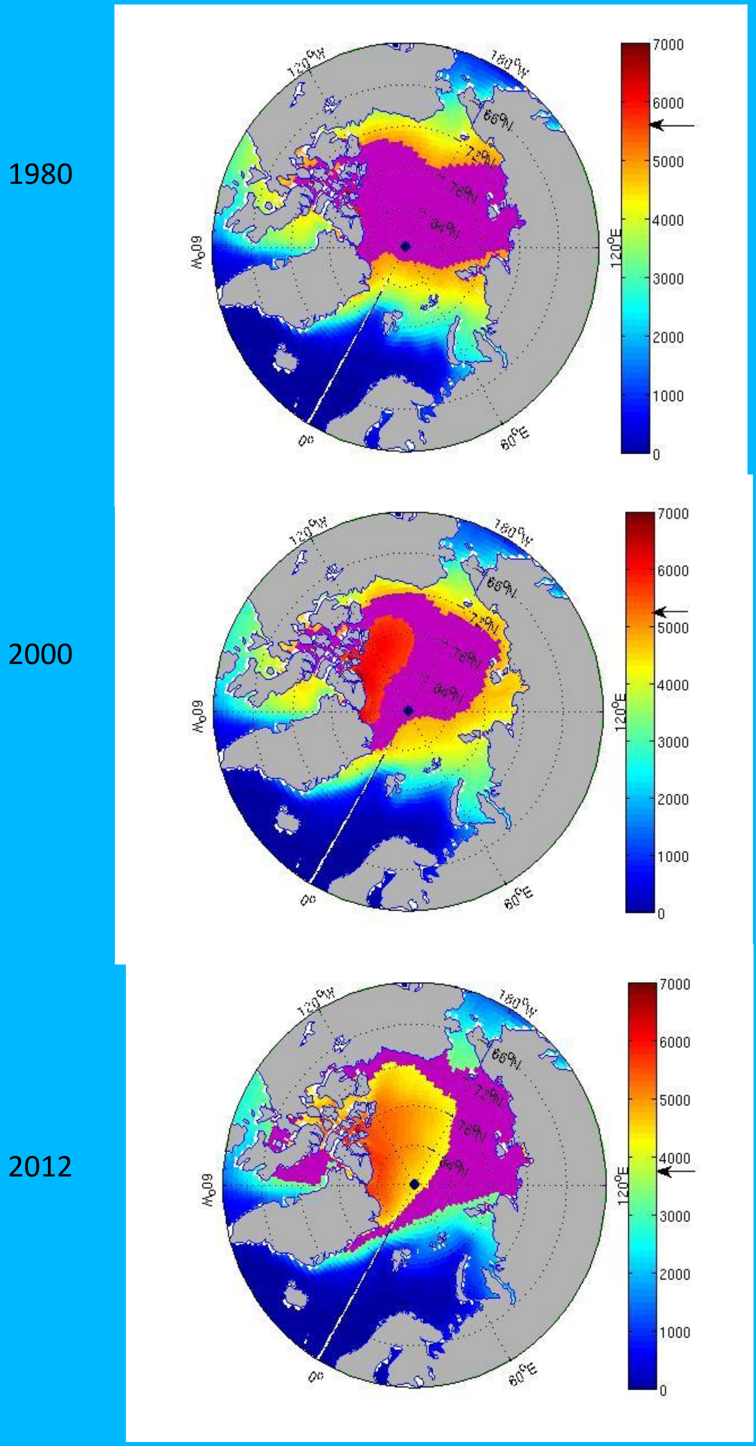

Figure 5. Freezing Degrees Days in 1980, 2000 and 2012. The magenta colored area is representing the most abundant category of FDD which varied from 5700 in 1980 to 3800 in 2012. There was a decrease of 1900 FDD from 1980 to 2012 (i.e. a 35% decrease in FDD) of the most abundant FDD category.

Applying the Stefan's Law and following Maykut (1986) for estimating sea-ice thickness H as a function of the cumulative number of Freezing Degrees Days (FDD) calculated from ERA Interim surface air temperatures all over the Arctic Ocean, we obtained the quadratic function by neglecting snow cover on top of sea-ice:

$$H^2 + 16.8H = 12.9\ \text{FDD}$$

From this formula we can now express FDD in H equivalent and combined with the extent of sea-ice for any given FDD one can calculate sea-ice volume. The results are presented on Figure 6.

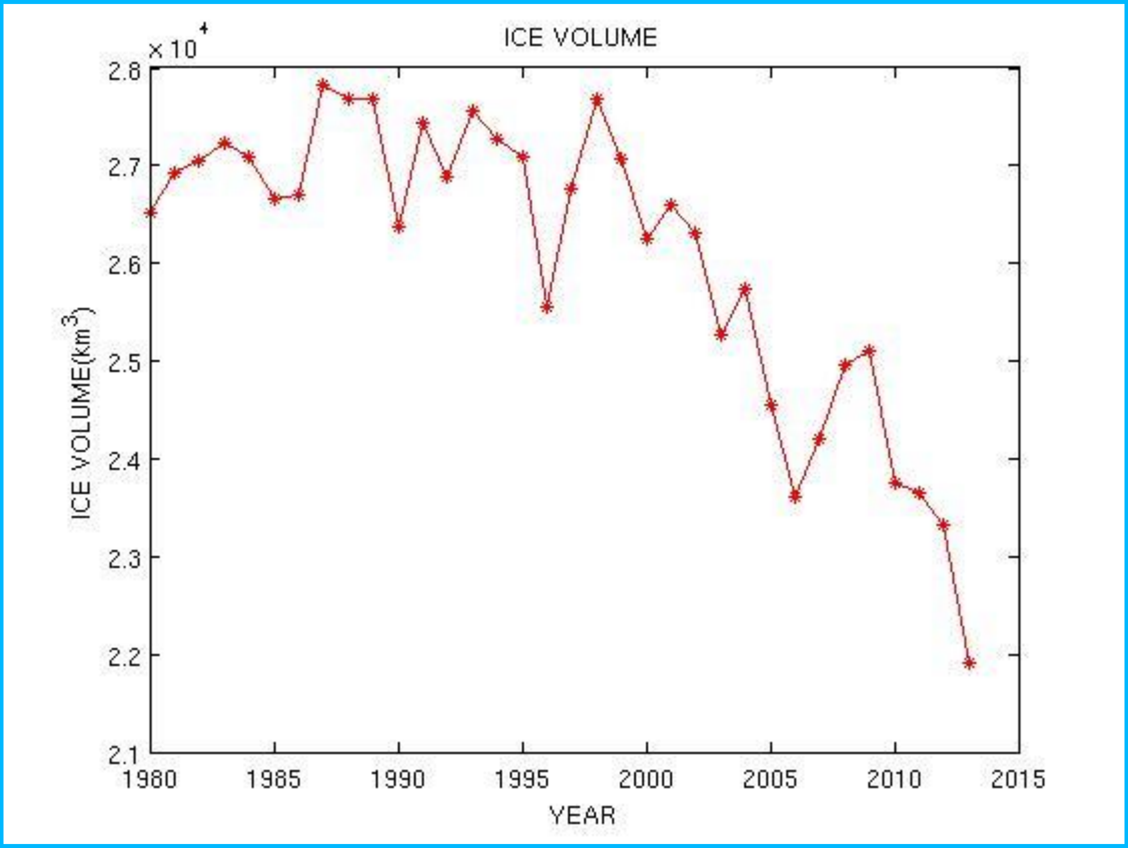

Figure 6. Sea-Ice volume in km3 corresponding to the Sea-Ice thickness calculated from a quadratic law relating Sea-Ice thickness newly formed during a freezing season to the number of Freezing Degrees Days during that season that extends from September to June (see Figure 1)

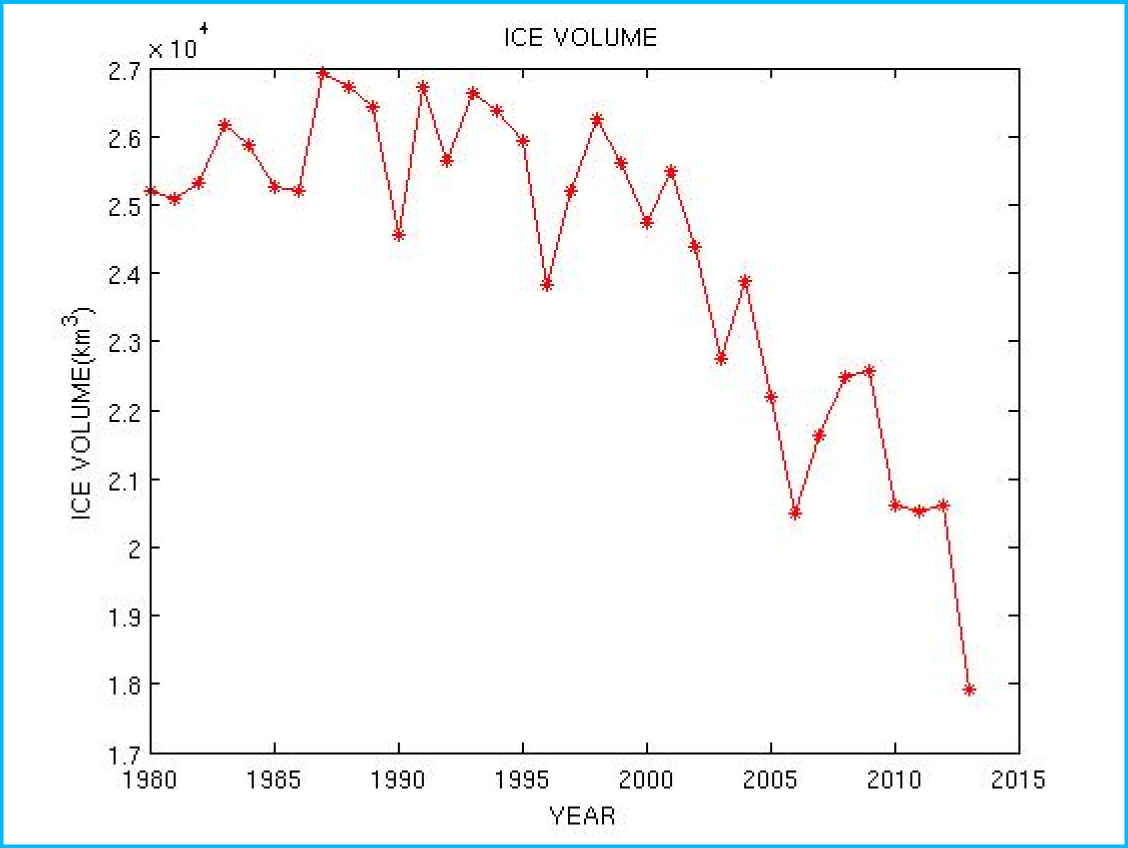

Figure 7. Sea-Ice volume in km3 corresponding to the Sea-Ice thickness calculated from a linear law relating Sea-Ice thickness newly formed during a freezing season to the number of Freezing Degrees Days during that season that extends from September to June (see Figure 1).

Figure 7 reveals a potential decrease of newly formed Sea-Ice related to atmospheric cooling from 27 000 km^3 to 17000 km^3 (i.e. 10000 km^3) mainly due to a decrease in Freezing Degrees Days from 5700 in 1980 down to 3800 in 2012 (i.e. 1900 FDD less). A decrease of 2000 FDD would correspond to about 1m of sea ice thickness over an area of about 10 million km^2 which is equivalent to about 10000 km^3 of sea-ice loss. This can be usefully compared to the estimation made by James Overland et al (2013 AGU Earth Future) based on the PIOMAS project who estimated the loss of sea-ice in September to be also 10000 km^3 over the past 30 years (from 16000 km^3 down to 6000 km^3) and which corresponds to a 27.8% decrease per decade quite comparable to the decrease in sea ice volume formed (or lacking) in winter that we observed.

We believe our estimation based on a quadratic relationshiop between newly formed Sea-Ice thickness and Freezing Degrees Days is more realistic. The decrease in sea-ice volume is slightly less (6000 km^3 from 28000km^3 down to 22000 km^3) than the estimation based on a linear relationship. Also the estimation for sea ice volume loss by Overland et al is taking into account the summer melting rather than the winter freezing and that is a significant difference. But obvioulsy melting sea-ice in summer would be easier if less sea ice would have been formed during the previous winter.

Our study is stressing attention onto the fact that Arctic sea-ice variability depends on both winter and summer processes. Also this study being limited to the contribution of atmospheric cooling and/or warming to sea-ice formation and/or melting, is not taking into account the effect from the Ocean which is particularly important for sea-ice melting through vertical heat fluxes. But it is important to be able to attribute correctly both freezing of the Ocean and melting of Sea-ice depending on Atmospheric versus Oceanic effects and this is this most important aspect this study is contributing to.

In order to deliver this deliverable as planned initially and well before the end of the ACCESS project we had to stop our investigation in 2012. But it would not be too much more work to extend this study up to the most recent years 2013 and 2014 before the end of the ACCESS project in 2015. The delay in postponing D1.42 from month 25 to month 36 is and was related to the fact that we decided to include an MDD analysis in this study which was not considered in the initial plan of ACCESS (only FDD). But we thought it was worthwhile to include MDD in addition to FDD for the benefit of ACCESS and related works.

It is important for ACCESS partners to merge deliverables D1.42 with D1.28 stressing attention on sea-ice variability analysed from remote sensing data (AMSR-E and SSMI) since there is naturally a strong coupling between sea-ice variability and surface air temperature. As we said before, surface air temperature is not the only driver for sea ice variability but it is an important one. A more complete study could and should also take into account orher elements of the atmospheric forcing such as winds in particular in the Marginal Ice Zone (MIZ) very sensitive to break up due to wind stress and wind fetch generating swell and waves in the MIZ. Needless to say the ocean is also a main driver for sea ice melting in addition to the atmospheric forcing. But this is another subject of strong interest for ACCESS.