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RESEARCH NOTE

Svalbard as a study model of future High Arctic coastal environments in a warming world

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Summary Svalbard archipelago, a high latitude area in a region undergoing rapid climate change, is relatively easily accessible for field research. This makes the fjords of Spitsbergen, its largest island, some of the best studied Arctic coastal areas. This paper aims at answering the question of how climatically diverse the fjords are, and how representative they are for the expected future Arctic diminishing range of seasonal sea-ice. This study uses a meteorological reanalysis, sea surface temperature climatology, and the results of a recent one-year meteorological campaign in Spitsbergen to determine the seasonal differences between different Spitsbergen fjords, as well as the sea water temperature and ice ranges around Svalbard in recent years. The results show that Spitsbergen fjords have diverse seasonal patterns of air temperature due to differences in the SST of the adjacent ocean, and different cloudiness. The sea water temperatures and ice concentrations around Svalbard in recent years are similar to what is expected most of the Arctic coastal areas in the second half of this century. This makes Spitsbergen a unique field study model of the conditions expected in future warmer High Arctic.

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1. Introduction

Arctic Ocean and the adjacent land masses are undergoing intensive climate change (IPCC, 2013). It is a region where temperature changes are 3—4 times greater than the average for the Northern Hemisphere, as evidenced both by observational (Serreze et al., 2009) and paleo-data (Miller et al., 2010). This phenomenon, called Arctic amplification (Manabe and Stouffer, 1980), which makes the Arctic climate change caused by any global radiative forcing greater than in other climate zones, is caused by albedo changes due to the decline in sea-ice extent and land snow cover, atmospheric and oceanic heat advection, as well as changes in cloud cover and water vapour (Serreze and Barry, 2011). This amplified warming continues unabated as evidenced by some parts of the Arctic Ocean up to +4°C warmer in August 2015 than the 1982—2010 August mean in these regions (Timmermans and Proshutinsky, 2015) and lands north of 60°N being +2.9°C warmer in the period of October 2014—September 2015 than in the beginning of 20th Century, being the warmest 12 month period in the observational record beginning in 1900 (Overland et al., 2015).

The increasing Arctic temperatures go hand-in-hand with the decline of the sea-ice extent, with trends negative in all months (Simmonds, 2015), the smallest magnitude in May (-30.45×10^3 km^2 year^{-1}), and the largest in September (-88.96×10^3 km^2 year^{-1}). These trends are expected to result in seasonal sea-ice or even all-year absence of ice over almost the whole Arctic Ocean before year 2100 (Stroeve et al., 2012) or even before 2040 (Wang and Overland, 2009, 2012) although different prediction approaches still leave a large uncertainty as to the date of the free of sea-ice summer in the Arctic (Overland and Wang, 2013). Even in a seasonal sea-ice mode, the Arctic Ocean is expected to be covered by ice for a decreasing amount of days per annum. According to recent estimates, the Arctic coastal waters will be covered with ice for only half of the year in most High Arctic coasts by 2015 and almost everywhere by 2070 (Barnhart et al., 2016).

Less sea-ice coverage will mean a more dynamic Arctic Ocean with larger waves (Thomson and Rogers, 2014), more intense storms (Long and Perrie, 2012) and more intensive vertical mixing within the water column (Zhang et al., 2013), which will increase the sea-ice retreat rate even further. All these changes will influence the ecology of the Arctic Ocean and the adjacent land masses (Post et al., 2009). The warming Arctic Ocean may also release large volumes of methane stored in the form of hydrates and permafrost within shallow marine sediments (Biastoch et al., 2011), creating a strong positive feedback of the global warming (DeConto et al., 2012), although the time scale of the involved processes is still poorly constrained (James et al., 2016).

Rapid warming of the Arctic has not omitted Spitsbergen, the main island of the Svalbard archipelago. The summer temperatures in 2015 were the highest in recorded history (Overland et al., 2015), including the composite Longyearbyen-Svalbard Airport record, which goes back to 1898 (Nordli et al., 2014). The Atlantic waters of the West Spitsbergen Current are getting warmer (Piechura et al., 2002; Walczowski et al., 2012), which in turn increases the calving rates of the Svalbard tidewater glaciers (Luckman et al., 2015). The glaciers are retreating (Błaszczyk et al., 2009), which expands the area of Svalbard fjords such as Horsund (Błaszczyk et al., 2013) in such a spectacular way that the misnamed fjord may become a real sound before 2035 (Ziaja and Ostafin, 2015).

This paper aims at answering the question, whether this easily accessible archipelago, a popular place for Arctic research (Research in Svalbard database, https://www.researchinsvalbard.no/, lists 413 ongoing projects) may already be a study model of the environment of High Arctic coastal areas as it is expected to become in the next decades of the 21st century.

2. Methods

For the values of climate-related fields in the region of Svalbard, I used NCEP/NCAR reanalysis (Kalnay et al., 1996). It is a lower resolution reanalysis (2.5° × 2.5°) than ERA-40 (Uppala et al., 2005), but it avoids the spurious Arctic temperature trends of ERA-40 (Screen and Simmonds, 2011). The low resolution also has the advantage of not introducing too many degrees of freedom to the temperature fields in a region sparsely and non-uniformly covered by data. For the sea surface temperatures (SST), I used a recent SST climatology, in situ merging and satellite data, created for the WMO recommended base for the period 1981—2010 (Xue et al., 2011), a 1° × 1° update of an earlier SST climatology (Xue et al., 2003), available at http://origin.cpc.ncep.noaa.gov/products/people/yxue/sstclim/. Because there is little long term temperature data from inland Spitsbergen for seasonal temperature averages available, I used results from a recent 12 month measurement campaign (Przybylak et al., 2014), involving 30 meteorological stations placed all over Svalbard. All figures were prepared using the R language (R Core Team, 2017).

3. Results and discussion

The NCEP/NCAR reanalysis provides fields of meteorological parameters which, although of low spatial resolution, are temporally homogeneous since mid-20th century in the Arctic (Screen and Simmonds, 2011). Svalbard is covered very sparsely with meteorological stations and most of them are placed on the warmer western side. I used the reanalysis node with a centre in South-West Spitsbergen (77.5°N, 15°E) to analyse the warming trend in Svalbard. This approach has an additional advantage, which is the possibility to check the trends against the neighbouring stations, the data from which has recently been analysed by Gjelten et al. (2016). The annual averages for the NCEP/NCAR near-surface atmospheric temperature time series (1950—2015) are shown in Fig. 1 together with the trend line and trend 95% confidence range. The linear trend for the annual average temperatures since 1950 is +0.60 K decade^{-1} (with uncertainty of ±0.17 K decade^{-1} at 95% confidence). This corresponds to a 3.9 K warming since 1950. The trend is over 4 times the global one, showing that Svalbard is a good study case of the Arctic amplification. Because the Gjelten et al. (2016) temperature trends are calculated for the period 1979—2015, I have also calculated the linear temperature trend for the same period. Its value is +0.89 K decade^{-1}

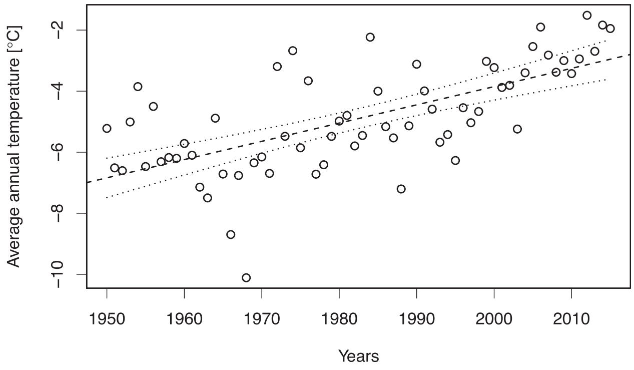


Figure 1 The annual near-surface air temperature averages, 1950—2015 from NCEP/NCAR reanalysis for South-West Spitsbergen. Linear trend and its uncertainty (95% confidence level) are marked with the dashed and the dotted line respectively.

(±0.32 K decade^{-1} at 95% confidence). This trend from the NCEP/NCAR reanalysis is lower than the station trends which are as follows: 0.96 K decade^{-1} for Ny-Ålesund, 1.03 K decade^{-1} for Hornsund, 1.06 K decade^{-1} for Barentsburg and 1.29 K decade^{-1} for the Svalbard Airport. The difference in the trends lies within statistical uncertainty, but it may also be caused by the larger spatial range of the reanalysis node covering also parts of the adjacent sea.

Fig. 2 shows the average near-surface atmospheric temperature data for all months since the year 1950. It presents 12 temperature graphs next to one another in a way that makes it possible to visually estimate the variability and trends for each month. The monthly averages in the recent years are similar to the locally measured ones (Cisek et al., 2017). It is clear from the figure that most of the warming since 1950 is confined to the coldest months, while the summers (especially June and July) have no warming trend. In fact the two months are the only ones with no statistically significant warming trend since 1950. The trends for the remaining ten months vary between +0.17 K decade^{-1} (±0.16 K decade^{-1} at 95% confidence) for May and +1.42 K decade^{-1} (±0.50 K decade^{-1} at 95% confidence) for January.

Recent temperature data measured at 30 Svalbard stations during a one-year campaign (Przybylak et al., 2014).

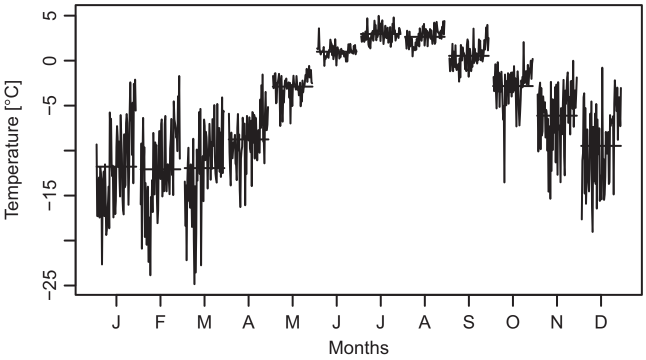


Figure 2 Near-surface air temperature averages for each month. Each month graph presents averages of each year in the range of 1950—2015 from NCEP/NCAR reanalysis for South-West Spitsbergen near Hornsund. Monthly means for the whole period are marked with horizontal lines.

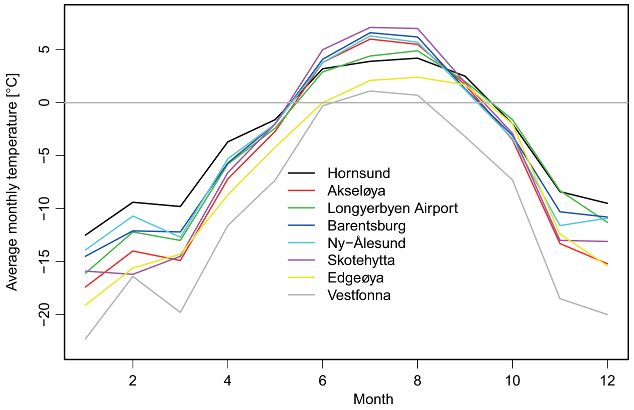
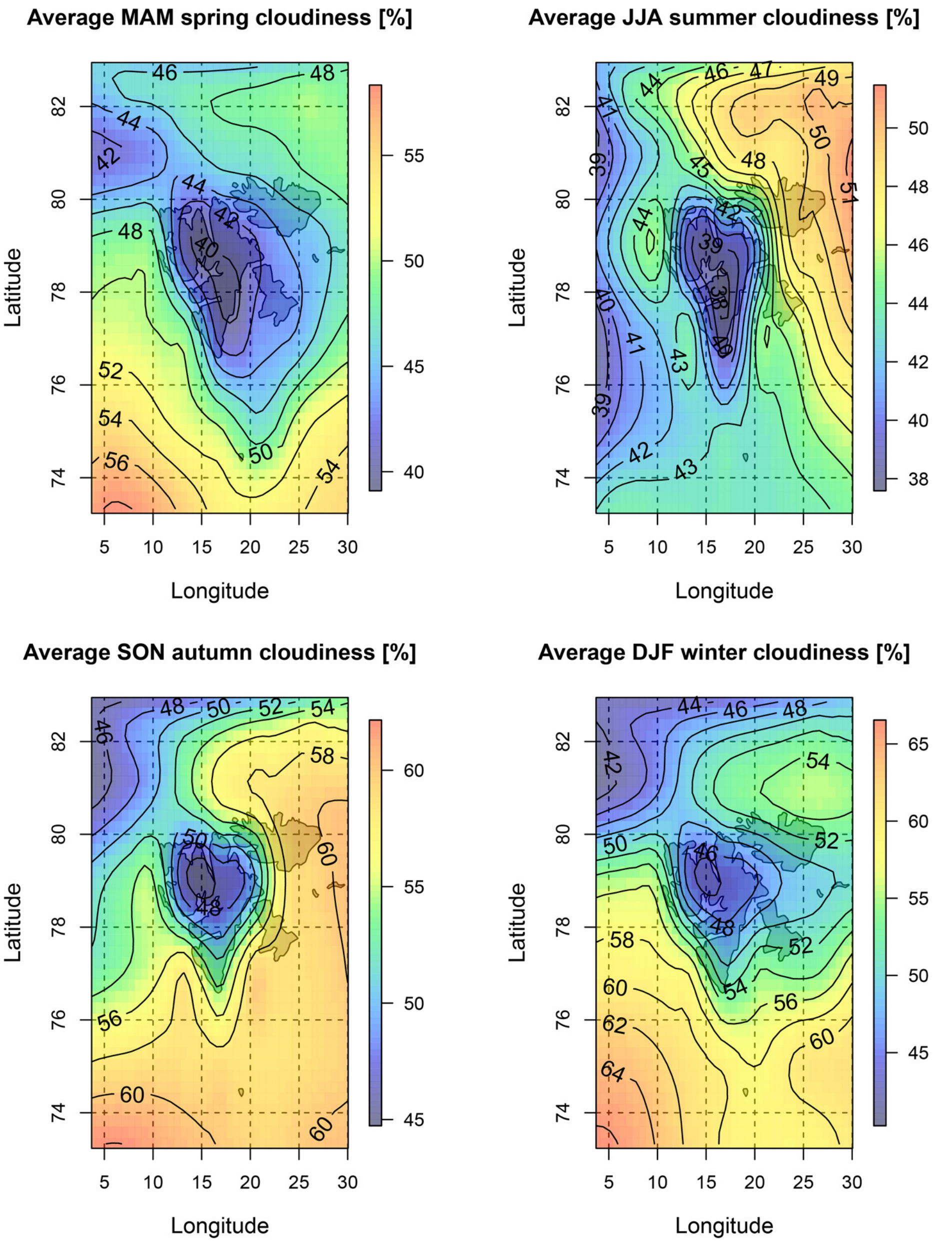


Figure 3 Monthly average near-surface temperatures recorded by meteorological stations in different Svalbard fjords from a one-year campaign of Przybylak et al. (2014).

Fig. 3 shows the monthly average temperatures from eight stations. Six of them are located in different Spitsbergen fjords, all close to sea-level to avoid the effect of altitude: Hornsund, Akseløya (in Bellsund), Longyearbyen Airport and Barentsburg (both in Isfjorden), Ny-Ålesund (in Kongsfjorden) and Skotehytta (near Pyramiden). The remaining two are placed on different islands, Edgeøya and Nordaustlandet (near Vestfonna glacier). Although the data is only from one year, the seasonal differences between Hornsund and Ny-Ålesund are similar to the ones derived from longer series (Cisek et al., 2017), which increases the confidence that the temperature range is representative for Svalbard fjords. The largest temperature differences are in winter (with the range of average January temperatures between −16.1 and −12.5°C (respectively for Akseloya and Hornsund) and in summer (from +3.9 to +7.1°C, respectively for Hornsund and Skotehytta). It is worthy of note that not the same fjords are warmest in summer and in winter (with Hornsund warmest in winter and coldest in summer). Coastal areas of Nordaustlandet island (represented by the Vestfonna station) are colder than all the coastal Spitsbergen stations during all seasons. Its annual monthly mean temperature variability if from −22.3°C in January to +1.1°C in July. This is caused by its north-eastern position and sea-ice coverage of adjacent ocean during most of the year. On the other hand, the Edgeøya station on an island east of Spitsbergen shows seasonal variability different than other stations with temperatures similar to the Spitsbergen coastal regions in autumn and winter while colder during the spring and summer. This shows the Svalbard fjords to be a diverse ensemble with different seasonal temperature patterns controlled by different processes.

One of the sources of differences in climate of different parts of Spitsbergen is the amount of clouds, influencing radiative fluxes. Fig. 4 shows the cloud coverage for the four seasons (averaged from the period 2010 to 2014) from NCEP/NCAR reanalysis. The cloudiness values from this product are underestimations of observed values, but they are useful for radiative forcing calculations (Weare, 1997) and no other analysis correlates better with satellite derived Arctic cloudiness on the time-scale of months (Liu and Key, 2016). In winter and spring, the largest cloudiness is over the warm waters of the West Spitsbergen Current and the


Average MAM spring cloudiness [%]

Average JJA summer cloudiness [%]

Average SON autumn cloudiness [%]

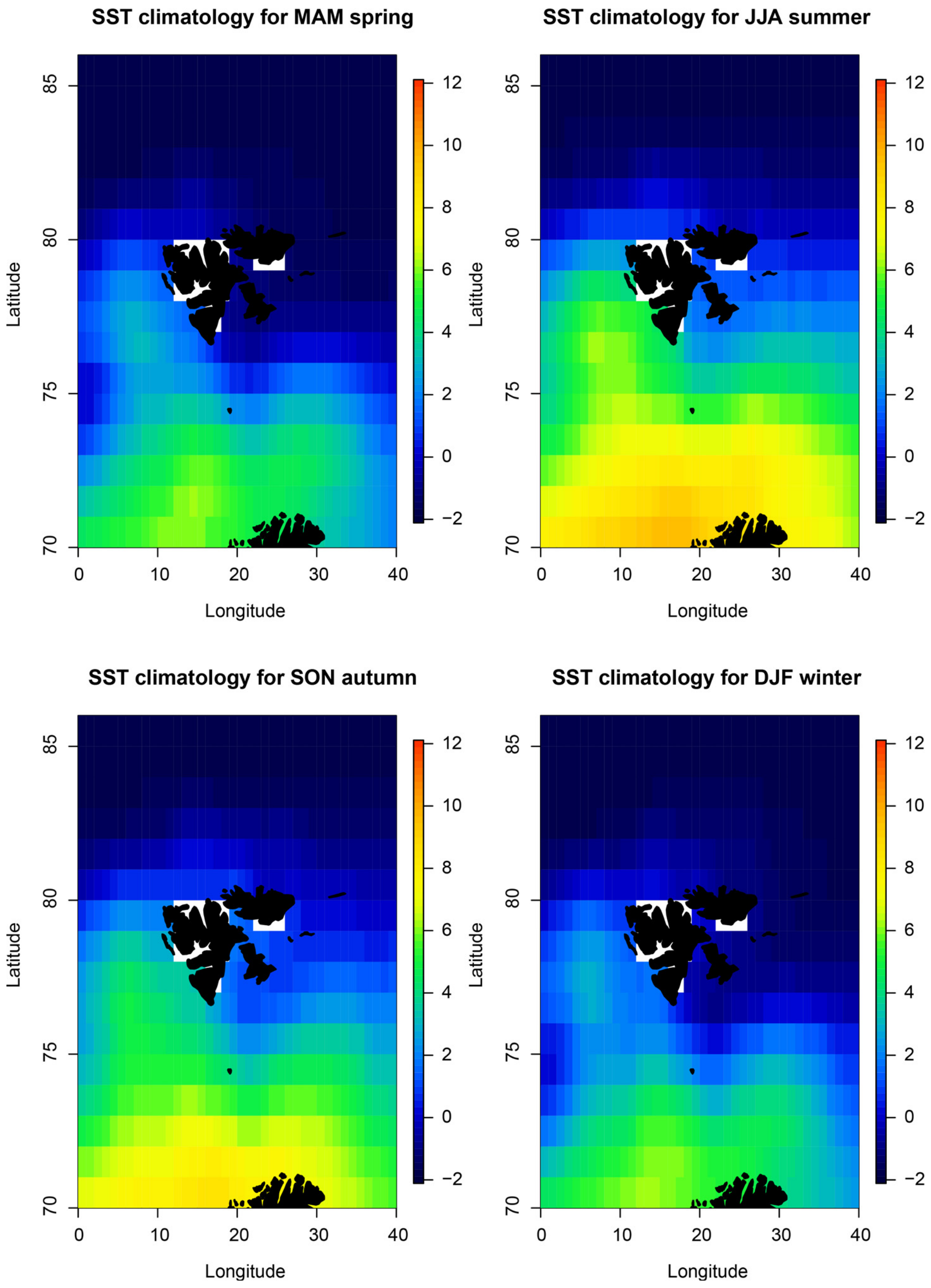
Average DJF winter cloudiness [%]

Figure 4 The average cloud coverage (2011—2015) for each season calculated from NCEP/NCAR reanalysis data.

south-eastern part of Svalbard, including Hornsund (a result confirmed by the local station data analysis from Hornsund and Ny-Ålesund in Cisek et al., 2017). In summer and autumn, the coastal areas both in the east and west of the island, have more clouds than the inland Spitsbergen. These patterns explain why Hornsund is warmest in winter when clouds have a warming forcing in the Arctic (Lubin and Vogelmann, 2006), while Skotehytta (the most inland station in Fig. 3) is warmest in summer. Arctic clouds work as a positive radiative forcing because the effect of blocking outgoing longwave radiation (the Arctic emits to space on average net 100 W m^{-2}) is more important than blocking incoming (solar) shortwave radiation during autumn and winter months of the "polar night" (Porter et al., 2010) and also, more surprisingly, during the spring (Francis and Hunter, 2007).

The cloud coverage is related to the SST, as the sea surface is the source of atmospheric water vapour (although other factors, such as wind direction, are also important). Fig. 5 shows the seasonal averages from a SST 1981 to 2010 climatology (Xue et al., 2011). The average sea surface temperatures to the west of Spitsbergen, in the Greenland Sea, are above zero in all months while to the east, in the Barents Sea, they are below zero for five months in the year (January—May). This East—West difference is larger then the South—North one along the Svalbard shores. The difference between the western part of the archipelago warmed by the West Spitsbergen Current (Walczowski and Piechura, 2011) and the cold eastern one, creates the large variability of environment in Svalbard, influencing the length of the snow-free and ice-free seasons, on the islands and in the adjacent seas respectively.

Fig. 6 presents the seasonal average sea-ice concentration for the period 2011—2015 calculated from the NCEP/NCAR reanalysis. It shows that Svalbard is recently practically free



SST climatology for MAM spring

SST climatology for JJA summer

SST climatology for SON autumn

SST climatology for DJF winter

Figure 5 The sea surface temperature seasonal averages calculated from SST 1981—2010 climatology (Xue et al., 2011). The climatology 1° × 1° grid data have not been interpolated. The white areas are grid nodes treated as land in the climatology.

of sea-ice in autumn. During the summer (JJA) sea-ice is sporadic in the north and east. On the other hand, winter and spring are the seasons in which the east coast of Svalbard is ice bound. The sea-ice reaches its maximum extent in May, when in the east of Svalbard, in the Barents Sea, it sometimes reaches Bjørnøya (Bear Island). This seasonal pattern means that the east and north coasts of Svalbard are ice-bound for about half a year, a state expected to be typical of the Arctic coastal areas only in about 50 years (Barnhart et al., 2016) while its West coast, with most of the easily accessible fjords, is already similar in to the ice-free conditions expected in the Arctic close to the end of the 21st century. The seasonal patterns of the sea-ice explain the SST patterns from Fig. 5, as sea water temperature cannot be positive with sea-ice present, therefore implying similar ones for the future High Arctic (IPCC, 2013). This makes Svalbard in general, and Spitsbergen fjords in particular, a natural laboratory of environmental changes expected in the future in the coasts of regions such as Greenland or the Canadian Arctic Archipelago.

4. Conclusions

Svalbard is an Arctic archipelago with warming trends exceeding the global average by at least four times with

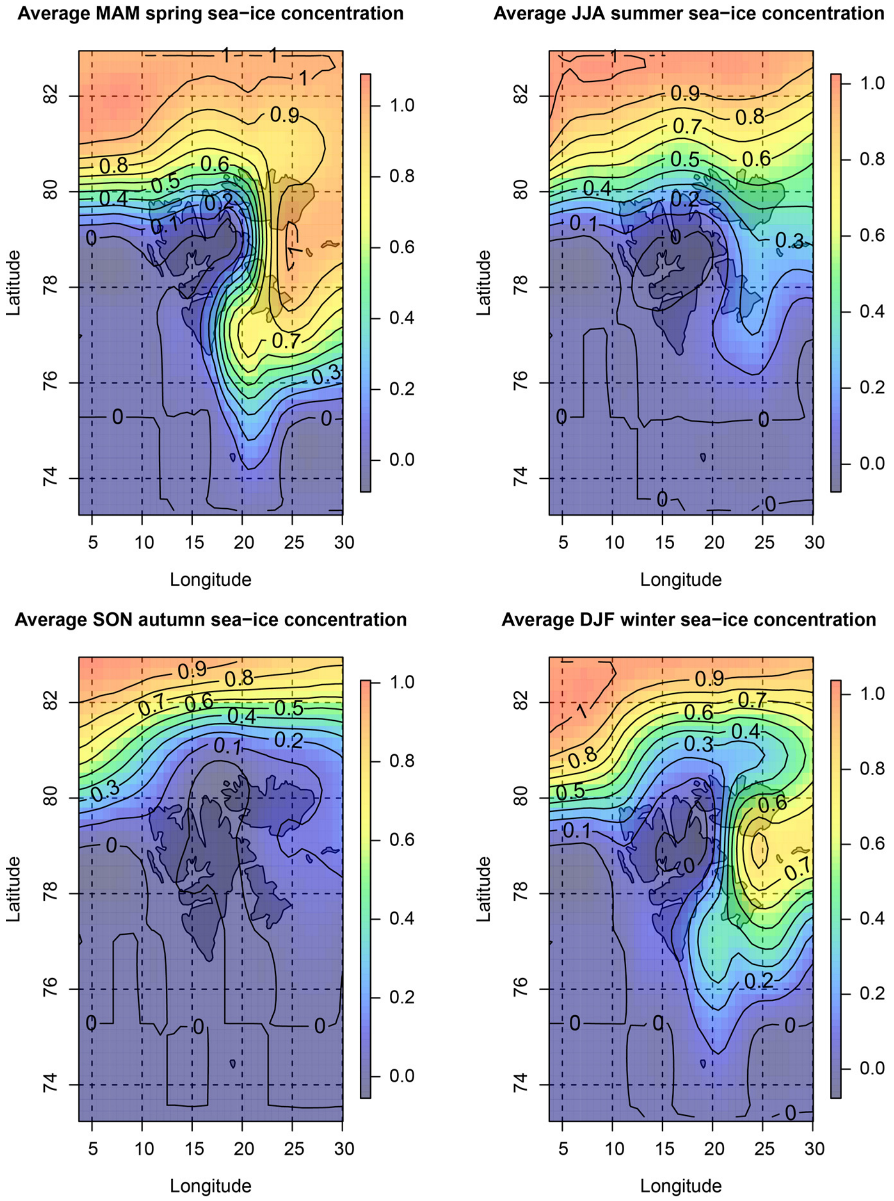


Figure 6 The average sea-ice concentration (2011—2015) for each season calculated from NCEP/NCAR reanalysis data.

most of the warming in the coldest months of the year. Its fjords represent diverse seasonal patterns of temperature due to some differences in the SST of the adjacent ocean, and the resulting different cloudiness. The sea water temperatures and ice concentrations in recent years are similar to what is expected in most of the Arctic coastal areas later this century. All this argues for using Svalbard as a model of future changes in the Arctic coastal ecosystems.

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