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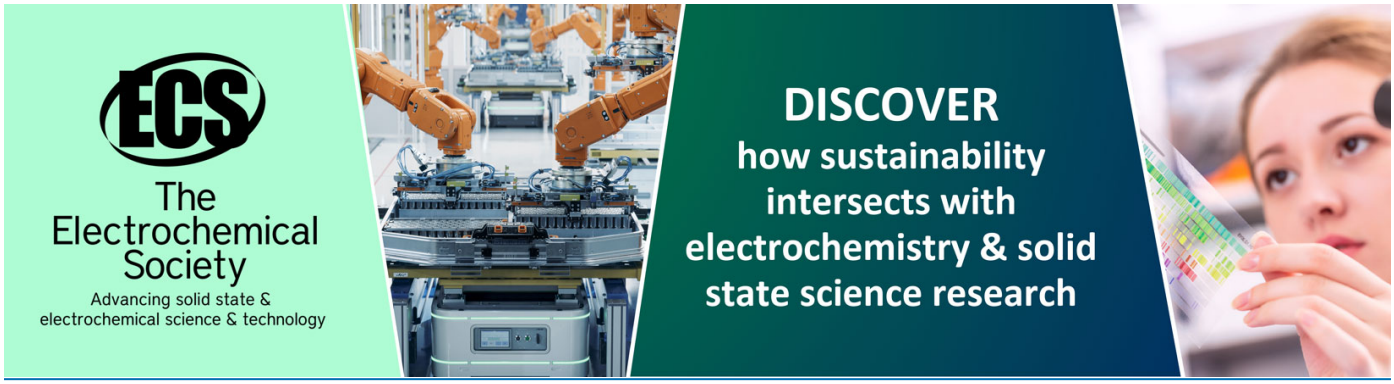

Comparing the «*earlier*» and the «*modern*» warming in West Arctic on example of Svalbard

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Abstract. The article analyzes the common features and differences of "*earlier*" and "*modern*" warming observed. The longest-period series of meteorological observations made on the Svalbard archipelago are used. The phases of growth of surface air temperature are studied. It has been shown that "*earlier*" warming was more significant in comparison with "*modern*" warming. The most significant anomalies are observed in the winter months in "*early*" warming, while "*modern*" warming is recorded throughout the year.

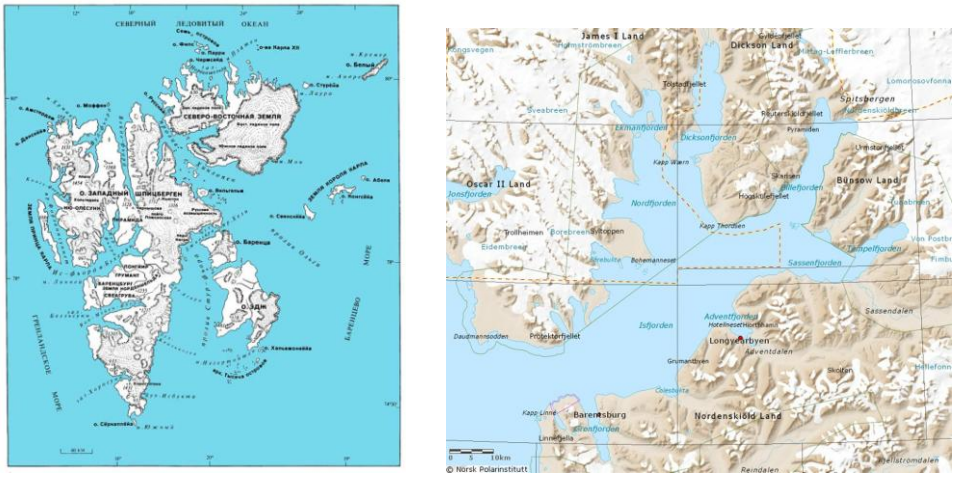
1. Introduction

In recent decades, the climate of our planet is undergoing major changes, with the most noticeable climatic changes observed in the Arctic region. For example, it is a record decrease in the area of ice cover in 2007 and 2012, increasing the temperature of the Atlantic water (AW) and surface air temperature (SAT). Taken together, this indicates a significant change observed in the Arctic in recent decades of XX century and the first decade of XXI century. Similar processes have taken place in the first half of the XX century and aroused great scientific interest, which was reflected in the formation of a number of hypotheses about the causes of the observed phenomena. The Arctic is an important part of the planetary climate system associated with the other part by means of the transfer of heat and moisture in the atmosphere and the ocean [5,16]. Observed climate change in the Arctic, taking place in last decades, against a background of global warming, caused great interest among the experts-climatologists. We tried to analyze the views of a number of modern Russian and foreign scientists about the basic climate changes (climate trends) observed in the Arctic region for the period of XX and the first decade XXI centuries on example of the Svalbard (West Arctic area). To assess changes in global and regional climate is most often used information about SAT [5,11]. Fluctuations of SAT on Svalbard for the century-long period of measurements indicate the two main periods of warming: 1920 – 1940, and 1980 – present time (p/t) [5,6,10,17,18]. It should be noted that the so-called "*earlier*" warming (1920-1940) caught the attention of researchers in the first half of the last century. This period is considered as the most powerful in its size climatic fluctuations recorded at that moment with the help of regular meteorological observations, thus increasing the SAT was observed not only in the cold season, but also in average for the year [24]. The author concludes that the Arctic warming was caused by strengthening of the general circulation of the atmosphere, intensification of the most important centers of atmospheric activity in the northern hemisphere (the Icelandic minimum, Siberian maximum). The scientists from Arctic and Antarctic research institute [8,9,12,13,14] are use the V.Y. Viese hypothesis as a base, which considers the intensification of atmospheric circulation and solar activity the main causes of the "*earlier*" warming. A number of studies [1,4] discuss the climate changes in the Arctic, taking place during the "*modern*" warming (1980s – p/t). It is noted that at this period is the sharp reduction in the area occupied by the sea ice at the end of the summer period, as well as dissemination of positive anomalies of water temperature in the intermediate layer of AW. The

sharp increase in the average values of SAT was observed in winter (since 1998) and summer (since 1996) months, the maximum values were recorded in 2012. A significant role in amplifying warming in the Arctic is given to meridional transport. The intensification of meridional transport contributes significantly to the observed positive trend in the average SAT during modern period [1]. By the way, the low-frequency oscillations of the climate system with a period of 50 - 80 years are considered as one of the causes of the two warming phases, as well [20]. A large number of Russian and foreign publications devoted to the study of climate itself Svalbard. They analyzed changes in the various components of the Svalbard climate system during the XX century and the first decade of XXI century [15,27,17,18,23,10]. So increasing the SAT in the XX century was 2,6 degrees in terms of a linear trend [17]. Positive anomalies were observed in the other constituent parts of the climate system of the archipelago. For example, a noticeable mitigates of the ice conditions are observe in the Grønfjorden Bay, where the Russian mining community Barentsburg is locate [27]. This is manifested in the absence of a sustainable ice cover (land-fast ice) in most winters and after 2012. A stable trend towards mitigate the climate in the area of Svalbard corresponds to the well-known concept of "*rapid warming*" of the Arctic for the period 1980 - 2015 [1,2,25,26,19,6].

2. Data and Methods

We used data from the Norwegian Meteorological Institute [10,15,17,18] for Longyearbyen (1898-2014, West Spitsbergen Island, Isfjorden Bay), which include average monthly values of SAT (Fig. 1).



(a) (b)

Figure 1 – Svalbard – West Spitsbergen Island (a) and Isfjorden Bay – (b)

This climate series was obtained by combining the observations carried out strictly in Longyearbyen and temporary observation points (expedition of hunters, geologists, etc.) at the nearest part of the archipelago. The series was formed by using specific interpolation methods [17]. However, the period from 1889 to 1900 was excluded from the original series, since there is no reliable information about the measurement procedure, the instruments used, their accuracy class, etc. for this period. SAT anomalies were calculated to analyze the long-period variability (relative to the average for the entire time series) and used modern methods of regression analysis [21]. To reveal of long-term trends in the time series, presented as an average for the year or the month values, the method of moving average with the step of 11 years was used. The choice of such step is due to the existence of a well-known cycle of solar activity changes. Using the filter is due to significant SAT interannual variability and the need to reveal regularities of long-term temporal variability of interest to us, except for "*high-frequency*" oscillations with a smaller period.

3. The analysis of SAT temporal variability in area of Svalbard

Figure 2 shows graphs of temporal variability of average and smoothed values of SAT.

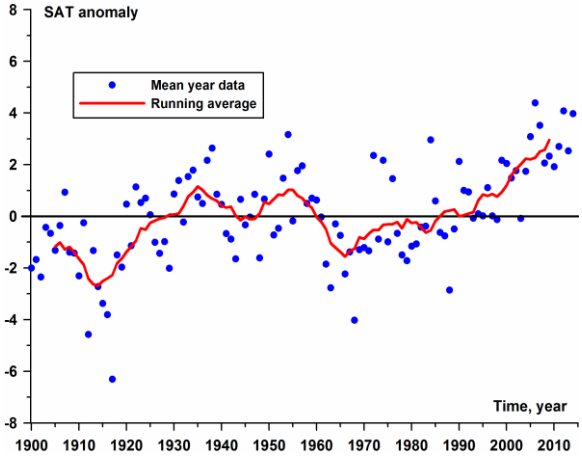


Figure 2 - Variability of the average annual values SAT anomalies for the period from 1900 to 2014

The most intensive increase of SAT is observed approximately from the 1915 to 1935 (phase of growth for "*earlier*" warming) and from mid of 1980s.. The second one is so-called "*modern*" warming, coinciding with the period of the well-known "*Arctic amplification*" which is understood a significant increase of SAT since 1980 across the entire Arctic [22]. Calculation of the linear trend showed that warming occurred on average at a rate of 0.026 deg/year and amounted approximately to 2.9 degrees over the entire observation period (Tab. 1). In terms of deviations from the mean "*modern*" warming it is more powerful in compare with the "*earlier*" (Fig. 1b). This growth phase marked in this figure on the smoothed curves of SAT (1915-1935 and 1980-2009). The maximum deviation of the average annual values of SAT (not smooth) were 4.4 and 4.1^{o}C (2006 and 2012) for the period of "*modern*" warming. Similar values for the period of the "*earlier*" warming is significantly lower – 2.7 and 3.2 degrees (1938 and 1954). The values of warming have also been analyzed for each month of the year individually. The results are shown in Table 1. Maximum warming observed in February, March, April and November. SAT increasing for these months was 4-5 degrees for the whole series. These linear trends are statistically significant at P <0,05. The exceptions are the trends for January and December, which is statistically significant at P <0,15.

Table 1. The values of warming for individual month

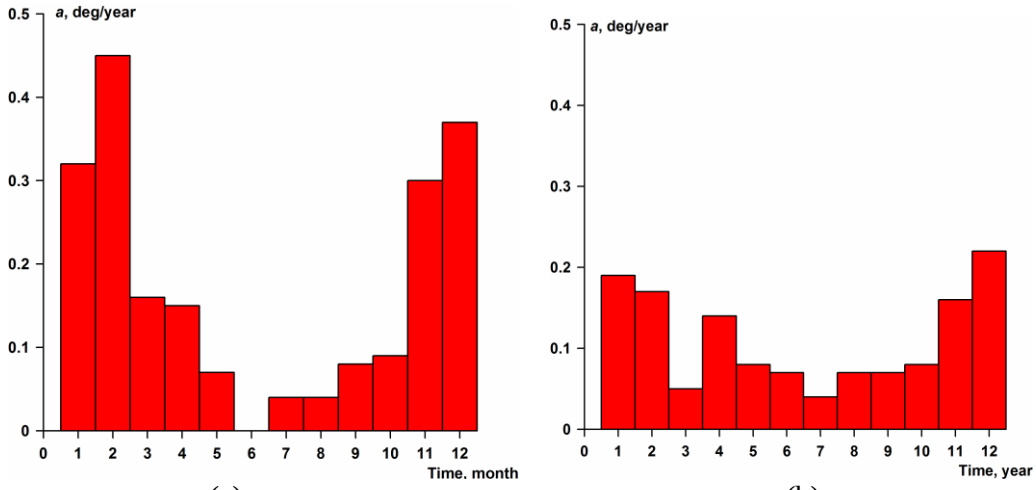
Month	deg/year
January	0.021
February	0.052
March	0.048
April	0.038
May	0.029
June	0.009
July	0.015
August	0.011
September	0.020
October	0.016
November	0.040
December	0.019
1900-2014	2.9

Separate analysis and comparison of the intensity of the allocated warming phase was performed. The results are shown in Table 2. Calculation of the corresponding linear regression equations was held for the smoothed series. Comparing the results obtained for the mean year values, it can be argued that for the both warming observed more intensive increase of the SAT, than as a whole for the entire period (1900 - 2014). Linear trend coefficient is 0.17 deg/year for the "earlier" warming and 0.11 deg/year for "*modern*". Thus, both warming occurs at a rate close to, but much larger than in the whole for the entire period of instrumental observations (0.026 deg/year).

Table 2. Comparison of two warming periods for Svalbard

Month	deg/year	
	«*earlier*	«*modern*»
January	0.32	0.19
Fabruary	0.45	0.17
March	0.16	0.05
April	0.15	0.14
May	0.07	0.08
June	0.00	0.07
July	0.04	0.04
August	0.04	0.07
September	0.08	0.07
October	0.09	0.08
November	0.30	0.16
December	0.37	0.22
Year	0.17	0.11

Figure 3 shows a comparison of manifestations of warming in certain months. The most significant speed of the SAT change is observed in the period from November to April for both warming. The absolute maximum was recorded in February for the period of the "*earlier*" warming – 0.45 deg/year. Overall, on the basis of monthly estimates, we can single out two characteristic periods: "*warm*" (May - October) and "*cold*" (November - March). For the "*cold*" period, the values of the rate of SAT changes in the "*earlier*" warming exceed the corresponding values for the "*modern*" period in 1.5-2 times.



(a) (b)

Figure 3 – The line trend coefficient of mean month SAT for Svalbard area for "*earlier*" (a) and "modern" (b) warming

It should be noted that the period of "*modern*" warming on most parts of the Russian Arctic was characterized by positive values of linear trend coefficients both in the average for the year and for individual seasons (Assessment Report ..., 2008). A comparison of the rates of SAT changes in absolute value showed that "*modern*" warming is occurring with greater intensity on Svalbard. For example, warming for the area of the Kola Peninsula is happened at a rate of 0.6 – 0.7 deg/10 years, and for Svalbard 1.1 deg/10 years (on annual average). Something early, comparison of the two warming periods was carried out according to the data of 30 meteorological stations located north of 60 north latitude [5,6]. Analysis was carried out for the separate seasons of the year («*summer*»: June – August and «*winter*»: November - March), as well as for annual averages 1921-1941 and 1978-1998. The authors of this article compared the values of the linear trend coefficients calculated for time intervals corresponding to the SAT growth phases for the indicated warming periods. It turned out that earlier warming developed faster on average over the year, as well as during the winter and summer seasons, especially in the Greenland Sea region. The rate of warming was estimated by linear trends for the indicated periods. On the basis of this analysis conclusion about more rapid development of "earlier" warming was done. Thus, our results are generally consistent with those obtained for other regions of the Arctic.

4. Conclusion

The following base conclusions can be drawn in frame of the analysis:

- revealed SAT increase on 2.9 degrees over the entire period of instrumental observations on Svalbard. The most significant SAT increase is observed in November, February, March, April, and is 4 - 5 degrees per century.
- the rate of SAT increase during the "*earlier*" warming was 0.17 deg/year and in the period of "*modern*" – 0.11 deg/year. Analysis of the SAT rate changes for the individual months of the year showed that the most intensive SAT growth accounted in February during the "*earlier*" warming – 0.45 deg/year, that in 2.5 times in compare with the average annual values.

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