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# Assessment of Atmospheric Circulation Regimes in the Atlantic-Eurasian and Arctic Regions Using Climate Indices. The Perspectives of Applications in the Seasonal Weather Forecasts

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**Abstract:** Ocean-atmosphere interaction is a very important chain when considering the elements of general circulation of the atmosphere, which essentially defines the everyday weather that we experience. And climate index is one of the tools used to describe the state of ocean-atmosphere interaction. Between the known climate indices, significantly characterizing weather in the Atlantic-Eurasian region, we can name the North Atlantic Oscillation and Arctic Oscillation indices.

Polar air outbreaks from the Arctic can be categorically considered as extreme weather events because monthly temperature anomalies both in the Arctic and middle latitudes may exceed 20 degrees. It was found out that both the North Atlantic Oscillation and the Arctic Oscillation indices are not sensitive to the two completely different types of polar air outbreaks in terms of distinguishing them. The physical origins of polar air outbreaks were highlighted, and the classification of them was carried out. Based on this classification, a conclusion about the existence of the North Siberian anomaly was made. And, according to many features, this anomaly can be treated as the one more action center of the atmosphere. This finding has allowed us to introduce a new climate index, which was called as the Atlantic Arctic Oscillation index. It is related to the normalized difference of sea level pressure anomalies between Reykjavik (Iceland) and Ostrov Dikson (Russia) weather stations. This index permits us to identify the two types of polar air outbreaks with the high level of recognition probability.

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An interrelation between the new climate index and temperatures in the investigated (lat-lon) regions was analyzed. Summer season in the middle latitudes is becoming colder, while winter season in the Arctic is becoming warmer, and the Atlantic Arctic Oscillation index shows it.

One of the most important reasons of Arctic sea ice melting is related to the domination for the past 20 years of the second type of polar air outbreaks that cause high positive air temperature anomalies in the eastern sector of the Arctic. In contrast, during 1960s the first type of arctic air outbreaks prevailed.

**Key words:** climate index, Arctic, sea ice, season, polar air outbreaks, sea level pressure, surface air temperature, Atlantic Arctic Oscillation, Arctic Oscillation, North Atlantic Oscillation

## 1. Introduction

Long-term weather forecasts have the highest value from the economical point of view.

This research corresponds to the new WMO program S2S. In this program, specific attention is paid to the the seasonal weather forecasts and to the risk of extreme weather events.

There are many articles, where the interrelation between different climate indices and weather-forming meteotrological fields is considered. For example, see [1], [2], [3], [4]. In order to develop the methods of long-term weather forecasts, first of all, we need to establish the fundamental relationships in the climate system. Concerning these proplems, one can recommend the articles [5], [6], [7] and many others. There are many attempts to predict weather on a seasonal time-scale. But even state-of-the-art hydrodynamic models are still very sensitive to initial conditions; therefore, they cannot give a long-term weather forecast. A famous mathematician and meteorologist Edward Norton Lorenz discovered that slightly differing initial states can evolve into considerably different states. This phenomenon is also known as the butterfly effect. [8] We all have to underline that the accuracy of seasonal weather forecasts is still not at the very high level. For example, in the recent paper [9] a team of scientists notes that existing polar prediction systems do not yet meet users' needs.

The main goals of this research are to study as much as possible about polar air outbreaks from the Arctic, which are very important atmospheric circulation regimes, and to get a more detailed performance of climate change tendencies.

## 2. Methodology

*North Atlantic and Arctic Oscillation Indices (NAO and AO Indices)*

Between the known climate indices, characterizing weather in the Atlantic-Eurasian region, we can name the North Atlantic and Arctic Oscillations indices. But if we speak about Eurasia, the influence of the North Atlantic Oscillation is the most remarkable in Western Europe, already in European part of Russia it is essentially weaker and only during some years spreads to Siberia. As it is known, the Arctic Oscillation is very closely interrelated with the North Atlantic Oscillation, what is proven by the high correlation coefficients between the two time series. In fact, Arctic and North Atlantic Oscillations are different ways for describing of the same phenomena. See, e.g. [10], [11].

*Cold Air Outbreaks from the Arctic and Datasets*

Cold air outbreak is a quick propagation of polar air mass into lower latitudes that causes, first of all, rapid decreasing of temperature over large territories.

In this section the archive of the strongest polar air outbreaks to the European part of Russia for the last 30 years during the cold season is used to classify Arctic air outbreaks. This archive is provided by Vitaliy Stalnov, who is the acting member of Russian Geographical Society and association of researchers “Forecasts and Cycles”. (http://meteoweb.ru/ar055.php)

Monthly anomalies maps from NCEP/NCAR reanalysis dataset (http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl) and monthly sea ice concentrations anomalies from National Snow and Ice Data Center (http://nsidc.org/) were used as an instrument to represent different cases of polar air outbreaks in order to classify them.

From the analysis of the archive two absolutely different types of polar air outbreaks were found out.

*The First Type of Polar Air Outbreaks*

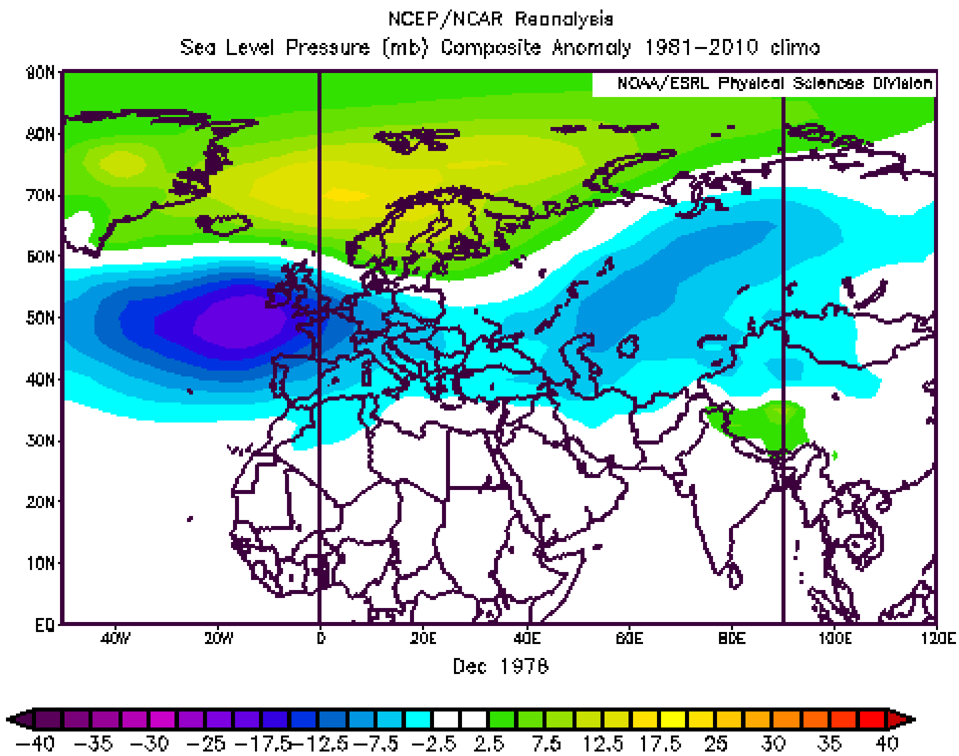


Figure 1 – Example of the First Type of Polar Air Outbreaks in Terms of SLP Anomalies Field

The first type of polar air outbreaks is presented in the figure 1. Its characteristic feature is positive SLP anomaly in the North Atlantic, which often spreads over significant part of eastern sector of the Arctic. At that type of polar air outbreak not rarely one can see a long band of low pressure extending from the Central North Atlantic to the Northern Siberia that only strengthens the movement of cold air from northeast to southwest.

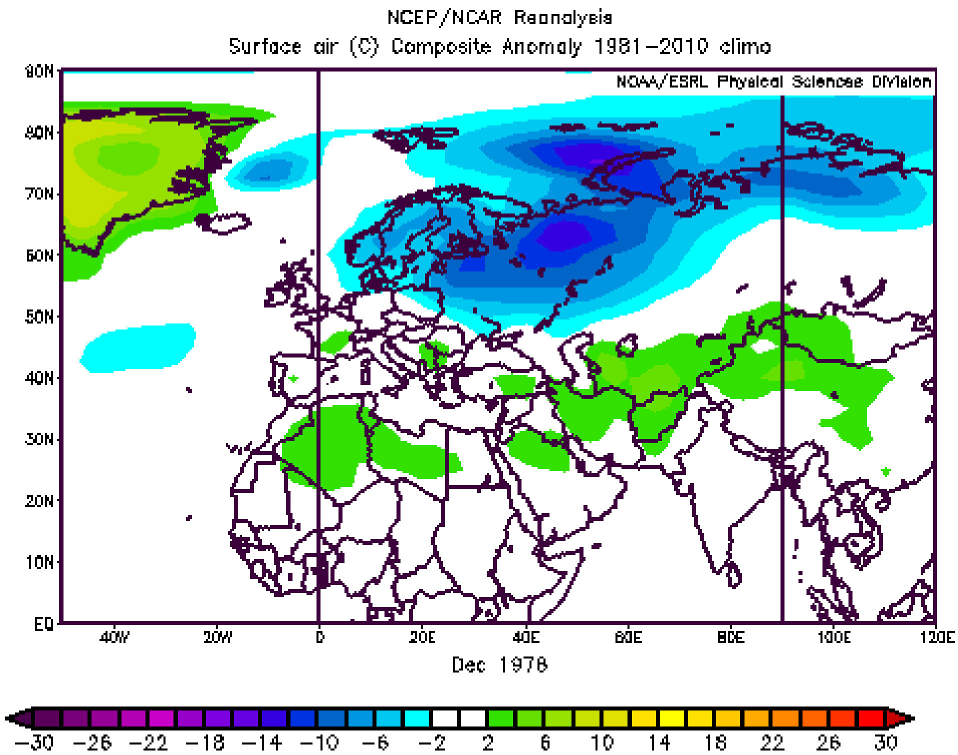


Figure 2 – Example of the First Type of Polar Air Outbreaks in Terms of Surface Air Temperature (SAT) Anomalies Field

As a consequence of such an atmospheric circulation (figure 2), high negative temperature anomalies are observed over most of European part of Russia and a series of European countries. At the same time over the territories where usually the Siberian high is located, we observe no negative temperature anomalies, instead we can see even positive ones. This is because over the southern periphery of negative SLP anomalies warm air is transported.

It is also very important to note that in the Arctic itself high negative temperature anomalies are observed.

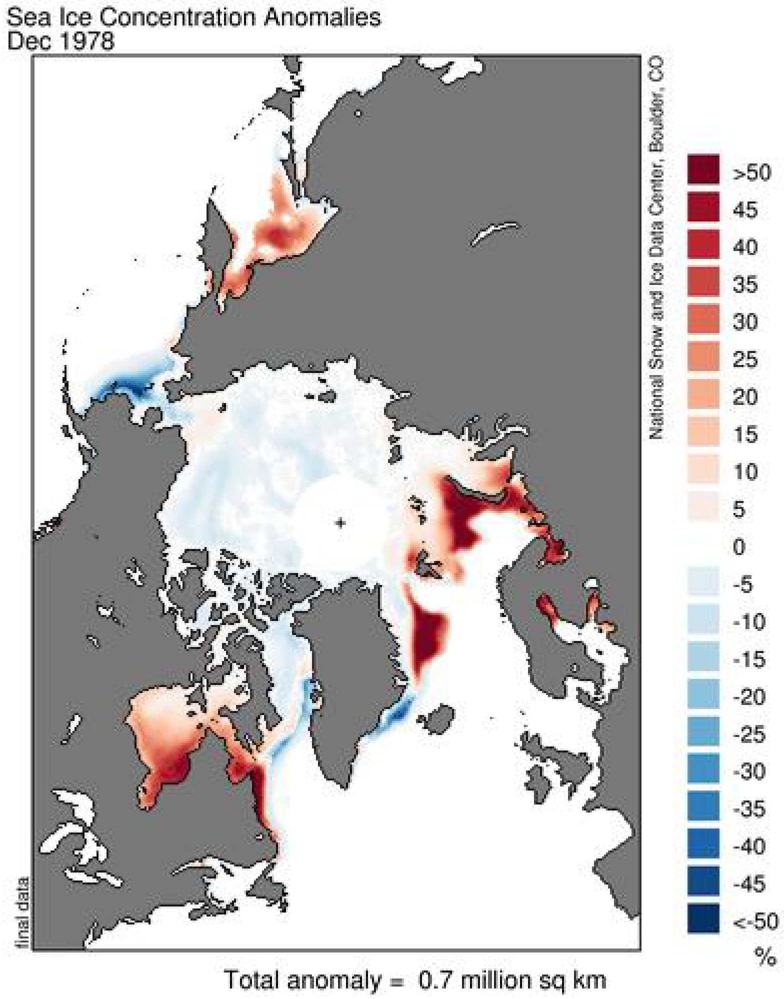


Figure 3 – Example of the First Type of Polar Air Outbreaks in Terms of Arctic Sea Ice

Therefore, one more characteristic feature of this type of polar air outbreaks is related to positive anomalies in concentration of sea ice presented in the figure 3.

So, we can conclude that the first type of polar air outbreaks is connected to series and strange anomalies because we have positive SLP anomalies near Icelandic low and negative SLP anomalies near Azores high and in Siberia, where typically also there is a maximum.

*The Second Type of Polar Air Outbreaks*

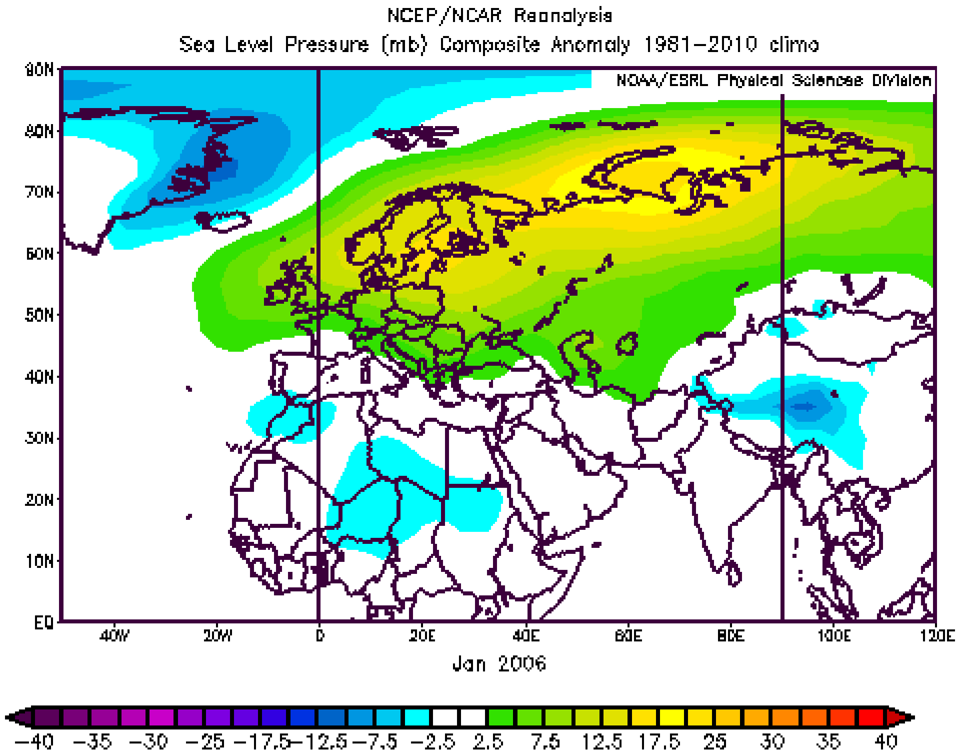


Figure 4 – Example of the Second Type of Polar Air Outbreaks in Terms of SLP Anomalies Field

The second type of polar air outbreaks is related to Arctic anticyclones. The region of their formation is the north of Siberia (very often the Kara Sea and Taimyr Peninsula).

This situation is presented in the figure 4. One can clearly note that the coupled effect of low pressure near Iceland and high pressure in the north of Siberia gives rise to very intense warm air outbreak in the eastern sector of the Arctic. The significant difference as compared to the first type of polar air outbreak is evident. There the north of Siberia experiences low pressure and the North Atlantic is under high pressure; here the situation is completely vice versa.

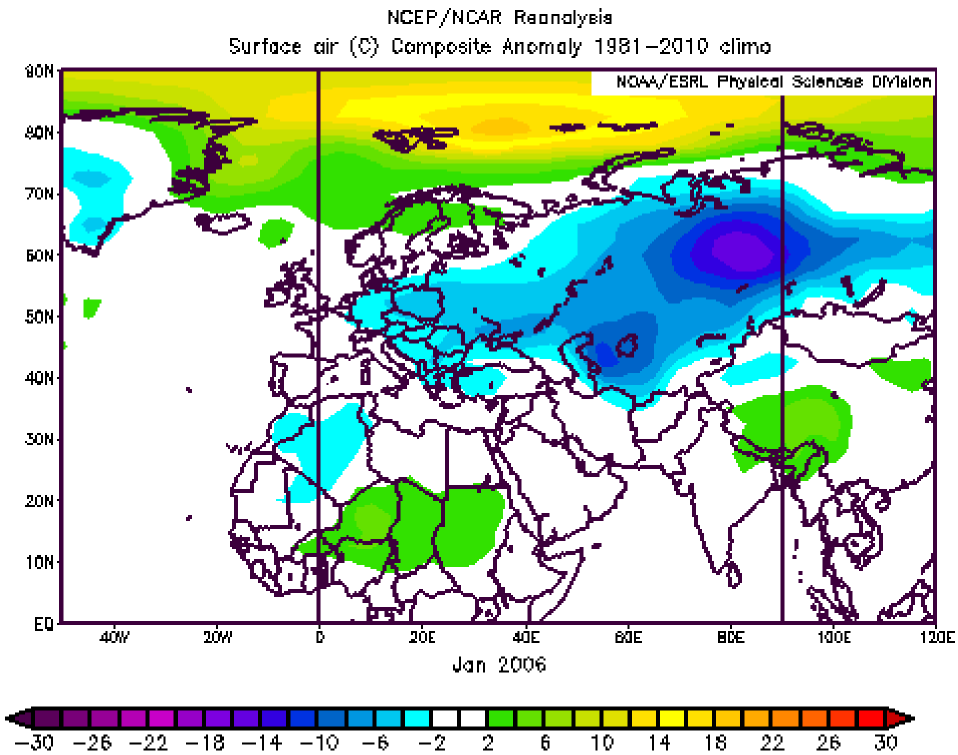


Figure 5 – Example of the Second Type of Polar Air Outbreaks in Terms of SAT Anomalies Field

Temperature anomalies, presented in the figure 5, speak for themselves. One more very important difference from the first type of polar air outbreaks is that negative anomalies move southward and already do not touch the Scandinavia. Also, we can note that as compared to the first type of polar air outbreaks, here the Central and Southern Siberia experience negative temperature anomalies. Between the Svalbard and Frantz Josef Land the positive temperature anomaly is about 20 degrees. And this anomaly is mean one for the whole month; therefore, one can suggest that it has an impact on the Arctic sea ice.

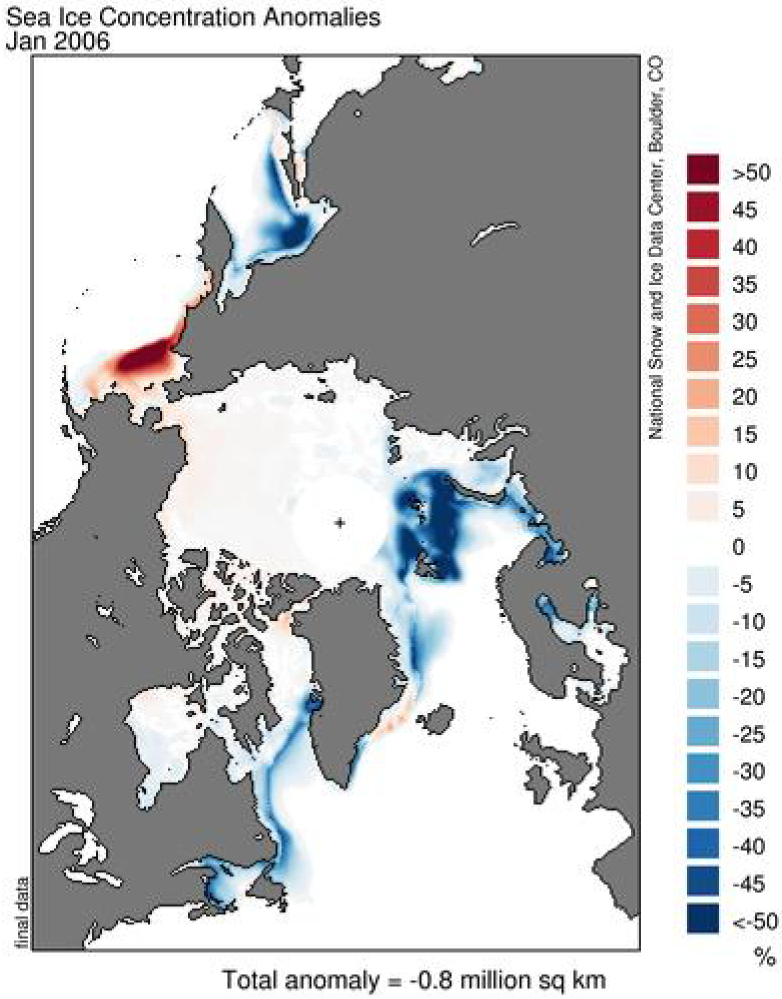


Figure 6 – Example of the Second Type of Polar Air Outbreaks in Terms of Arctic Sea Ice

Therefore, one more characteristic feature of this type of polar air outbreaks is related to negatie anomalies in concentration of sea ice (figure 6).

*Discussion*

As we have seen, the Northern Siberia and North Atlantic are key regions for the formation of described above situations. The conducted classification of polar air outbreaks has shown that there is the North Siberian anomaly and, according to many features, it can be treated as the one more action center of the atmosphere. So, we have the qualitative description of two physical mechanisms, inversely proportional to each other. Now, it is possible to introduce the corresponding quantitative characteristics. At that, the situation with climate indices for Central and Eastern Eurasia is very bad; they just do not exist.

*Atlantic Arctic Oscillation Index (AAO Index)*

In view of this a new climate index was established, named Atlantic Arctic Oscillation index. At that its monthly values are of the highest interest.

For the calculation of this index SLP data from two weather stations were used: Reykjavik (Iceland) and Ostrov Dikson (Russia). The international climate data were obtained from the Royal Netherlands Meteorological Institute (https://climexp.knmi.nl/selectstation.cgi?id=someone@somewhere). The missing values were filled up from NCEP/NCAR reanalysis dataset. In addition to the physical validity of the choice of these points, in the extreme conditions of the north the Ostrov Dikson station has the longest time-series. The derived index is the normalized difference of SLP anomalies between these stations. Normalization is used to avoid the series being dominated by the greater variability of the western station. Consider the derivation of this index through the example of January. We have interannual variability of SLP at both stations for this month. At first, the mean and standard deviation of the time-series were calculated. Then, from every SLP value the mean was subtracted, and the derived result was divided by the standard deviation. The same was done for both stations. And only after that the difference was found. The similar operation was made for all months.

To solve this task, a corresponding program in the modern high-level programming language MATLAB was written.

Positive values of this index characterize the second type of polar air outbreaks, whereas negative phase characterizes the first type of polar air outbreaks.

Table 1 – Example of the AAO Index Values

| Jan | Feb | March | April | May | June | July | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-3.22** | -2.16 | 0.40 | 0.06 | 3.01 | **0.32** | -1.34 | 0.79 | 0.22 | 1.38 | -0.96 | -1.99 | **1963** |
| **-1.85** | -0.16 | -0.24 | 1.12 | 1.88 | **-0.91** | 2.12 | -2.00 | -0.56 | 0.20 | -0.14 | 0.49 | **1964** |
| 0.01 | -1.91 | -1.31 | 1.89 | -1.09 | **0.31** | -2.16 | -0.02 | -0.66 | -0.34 | -0.78 | 0.84 | **1965** |
| **-1.01** | 0.14 | 0.87 | 2.54 | -0.16 | **0.37** | -0.76 | -2.35 | -2.05 | -1.33 | -0.56 | 3.08 | **1966** |
| **-2.04** | -0.03 | 0.45 | -1.20 | -0.29 | **1.07** | 1.94 | 1.39 | -0.82 | -0.29 | 0.29 | -1.78 | **1967** |
| -0.09 | 1.17 | -1.82 | 1.50 | 1.64 | **-0.80** | -2.01 | -1.48 | 3.73 | 0.77 | 0.65 | 0.83 | **2011** |
| **2.30** | 0.04 | 0.41 | -0.66 | -2.33 | **-0.39** | -2.20 | -1.57 | 1.52 | 0.53 | 1.14 | 1.21 | **2012** |
| **0.40** | -0.95 | -1.03 | 0.25 | 1.17 | **1.71** | 1.51 | 2.18 | 1.06 | -1.67 | -1.13 | 1.60 | **2013** |
| **2.40** | 2.85 | -0.61 | -1.46 | -0.79 | **-1.15** | 1.13 | -2.02 | -0.96 | 2.46 | -0.33 | 0.22 | **2014** |
| **0.61** | -0.09 | -0.13 | -0.54 | 2.04 | **-1.16** | -2.90 | 1.71 | 0.09 | 0.42 | 1.77 | 0.75 | **2015** |
| **1.76** | 0.25 | -0.42 | -0.90 | 0.04 | **0.57** | 0.77 | -0.99 | 3.39 | 1.40 | 1.19 | 0.67 | **2016** |

In the table 1 an example of the AAO index values is shown. Red colour is chosen to remember that this phase is related to positive temperature anomalies in the Arctic while blue colour is selected for representation of the first type of polar air outbreaks because they are associated with negative temperature anomalies in the Arctic.

And indicated years are chosen not by coincidence. One can clearly note that in January and June distributions of positive and negative phases are nearly inversely proportional to each other. Further analysis will show in detail the physical meaning of these distributions.

*Verification of AAO Index*

It should be pointed out that the archive of polar air outbreaks was filled up due to the AAO index. Originally the archive starts in 1978 and ends in 2006. But after the calculation of the new index, in length this archive depends upon the SLP time series at the two stations, namely, Reykjavik (Iceland) and Ostrov Dikson (Russia). So, the entire time series for the AAO index is from 1941 to the present.

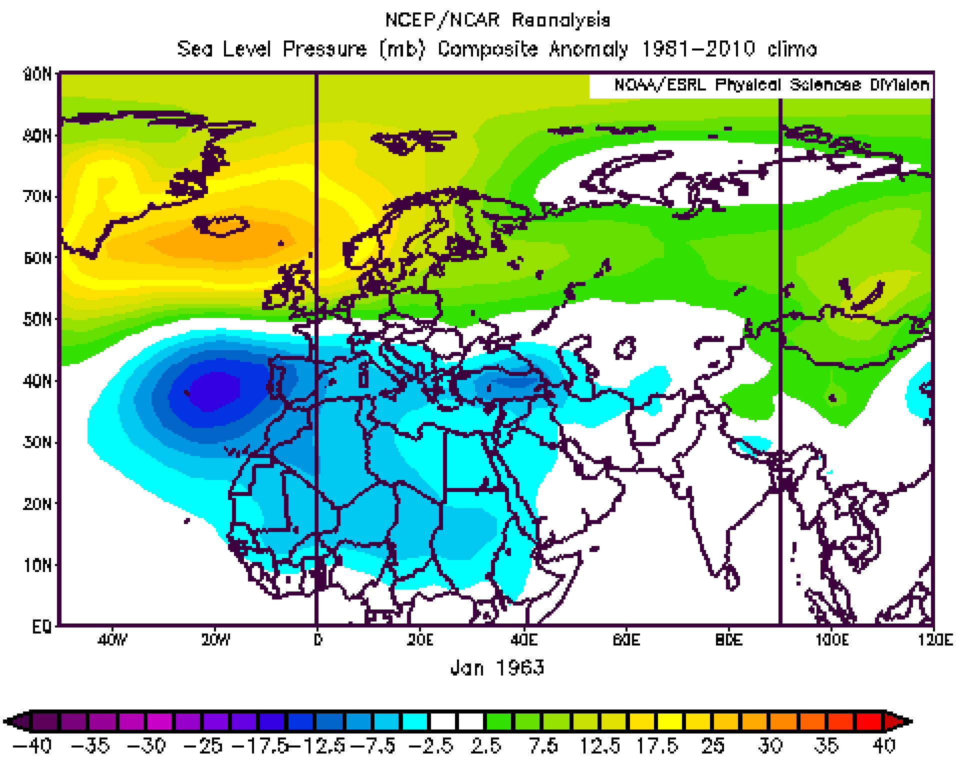


Figure 7 – SLP Anomaly in January 1963

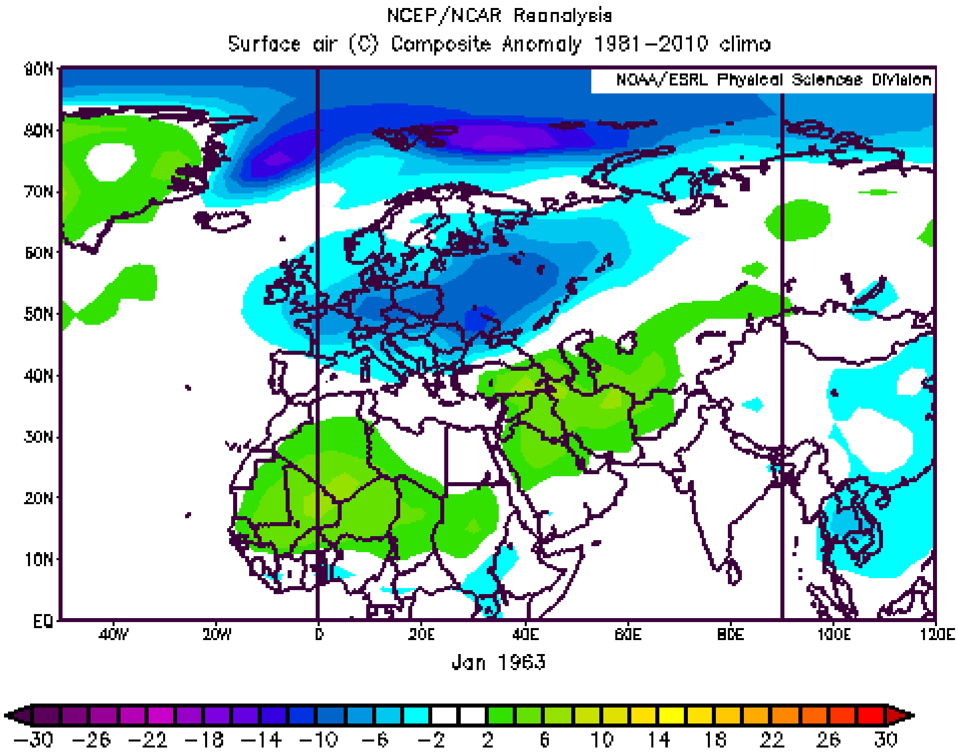


Figure 8 – SAT Anomaly in January 1963

SLP and SAT anomaly fields in the figures 7 and 8 correspond to the AAO index value equal to -3.22 that characterizes the first type of polar air outbreaks. This example proves that new climate index can be directly used to fill up the archive of polar air outbreaks.

*Interannual Variability of AAO Index*

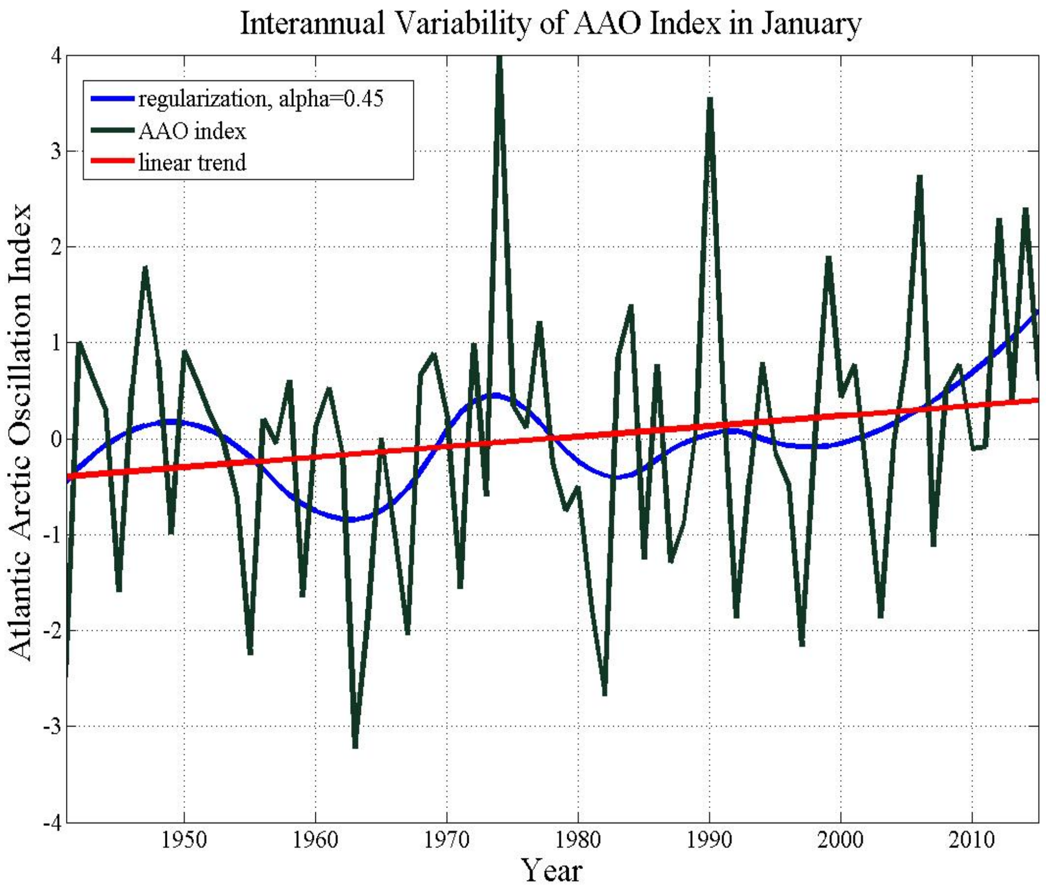


Figure 9 – Interannual Variability of AAO Index in January

In the figure 9 linear trend shows that there is the transition from negative phase to positive one. But the nonlinear smoothing, developed by O.M. Pokrovsky [12], is much closer to the reality because it reveals us a wave-like behavior of this oscillation, and due to this, e.g., we can see that in January in 1960s the first type of polar air outbreaks dominated. Another very important tendency is that for the last 20 years the second type of polar air outbreaks has been prevailing.

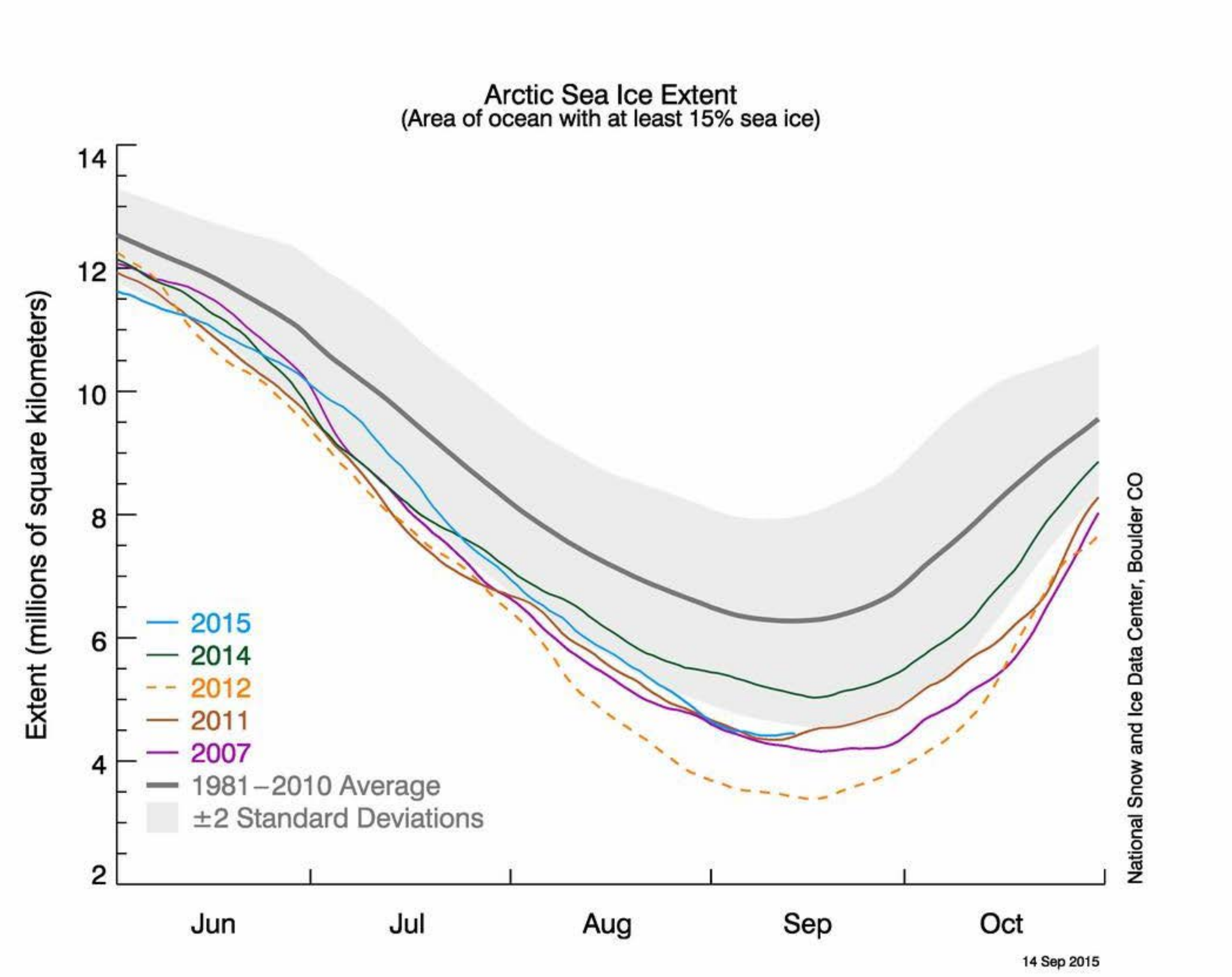


Figure 10 – Arctic Sea Ice Extent in Different Years

According to the National Snow and Ice Data Center report (figure 10), the Arctic sea ice extent had its minimum value in 2012. And till now ice extent is well below normal values. It is also can be explained by the domination of the second type of polar air outbreaks, which has produced a regular transportation of very warm air in the Arctic. This, in turn, gives rise to the not enough thick ice during winter, and in summer, multiyear ice is gradually decreasing. The impact of this process is cumulative, and in 2012 it gave rise to the lowest ice extent since regular satellite observations started.

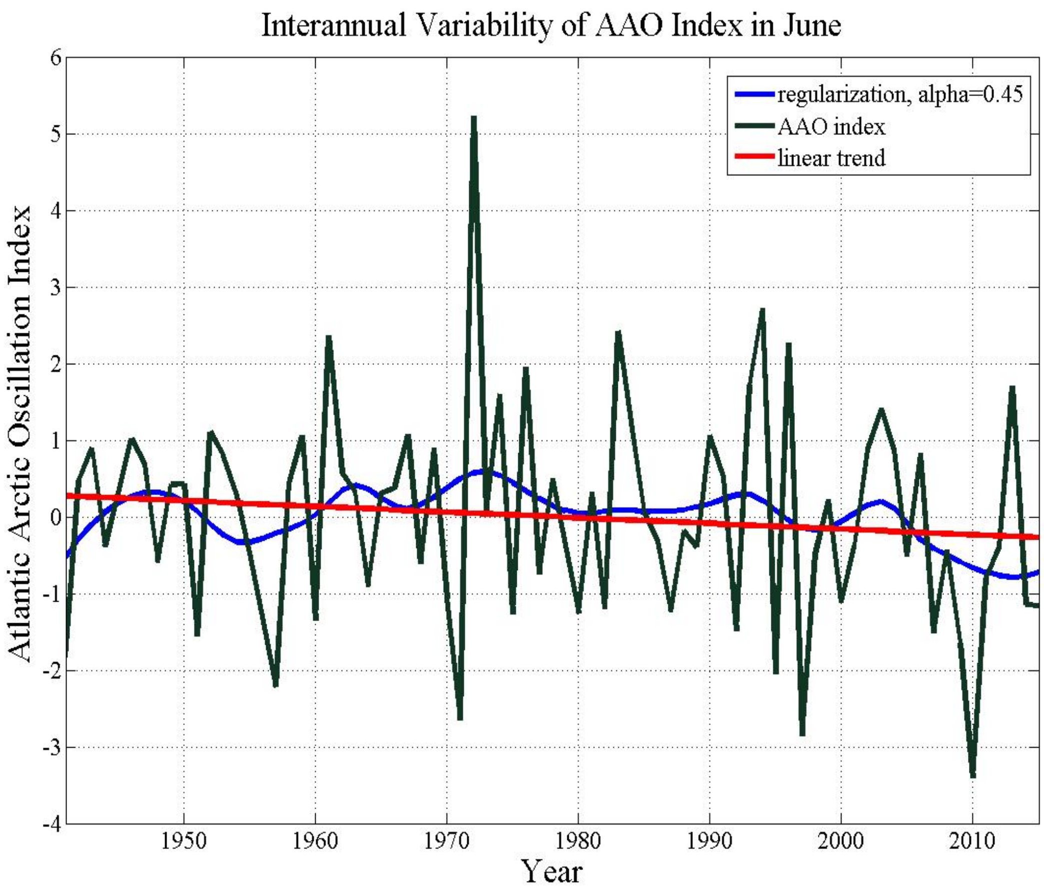


Figure 11 – Interannual Variability of AAO Index in June

In the figure 11 the smoothing shows very well that in June AAO index has quite low variability as compared to the situation in January. The physics of this index changes according to the season, that is in summer we should always keep in mind a high influence of solar radiation. Therefore, in summer we actually can speak only about the first type of arctic air outbreaks because the second type vanishes in terms of lower than normal temperatures.

Physically its negative phase means that for this month there is a higher probability for cold waves.

So, from this figure one can say that currently in June the strength and number of cold air outbreaks are increasing.

*Atlantic Arctic Oscillation and SAT in the Arctic. Advantages of the AAO Index over the NAO and AO Indices*

As we have seen, the most noticeable temperature anomalies in the Arctic are observed between the Svalbard and Frantz Josef Land. Therefore, it is interesting to assess the dependence of temperature concretely in this region on the AAO index.

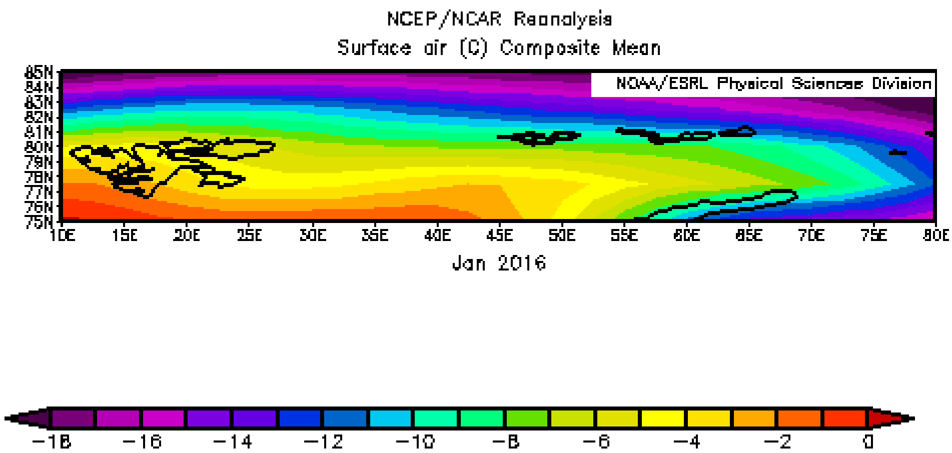


Figure 12 – The Region for which the Mean SAT Were Taken

For the region, presented in the figure 12, the time series of the mean surface air temperature from NCEP/NCAR reanalysis dataset were taken.

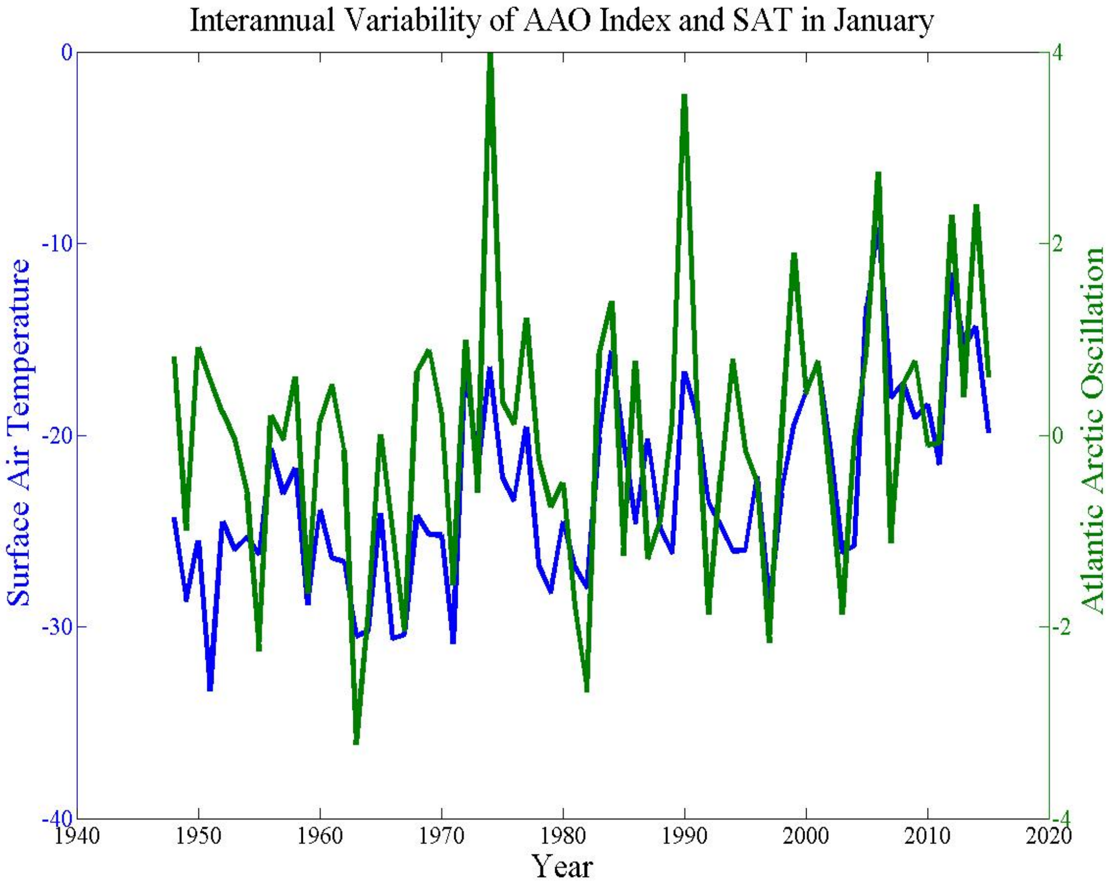


Figure 13 – Interannual Variability of AAO Index and SAT in January

In the figure 13 it is very good seen that in January between SAT and AAO the coherence is evident.

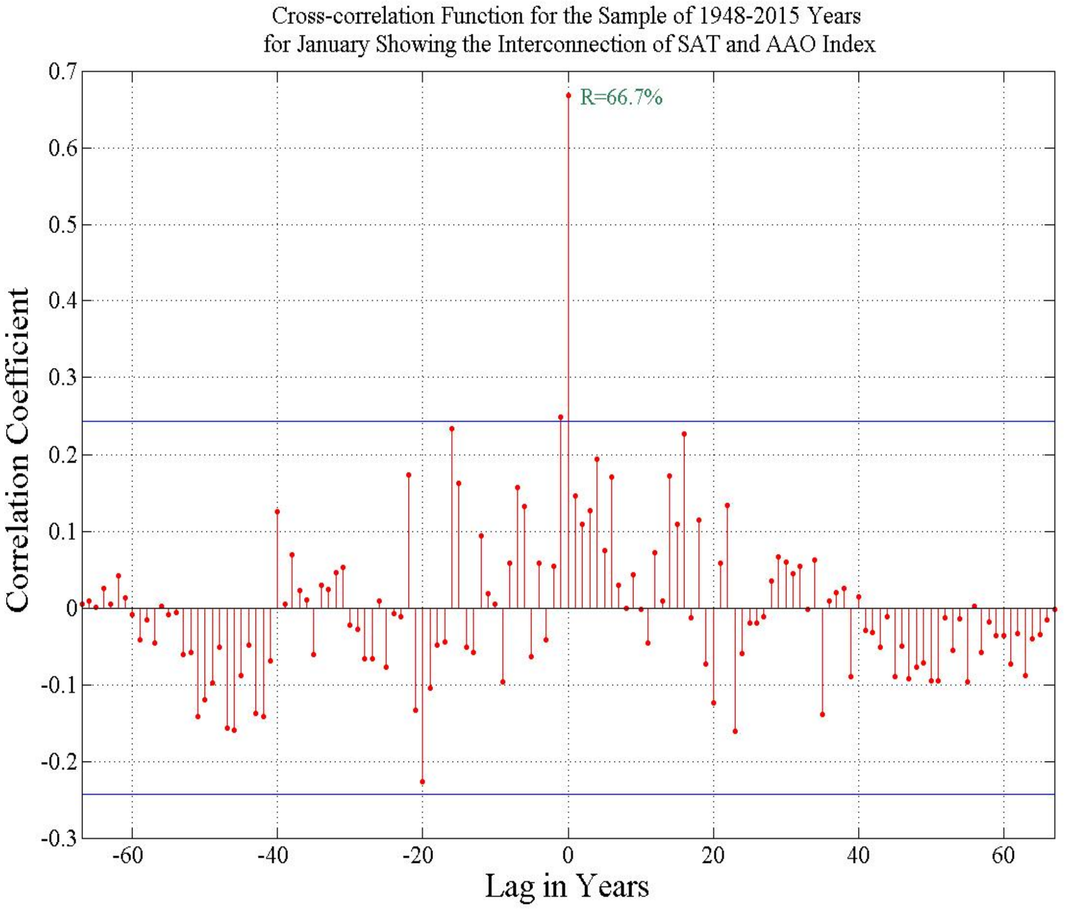


Figure 14 – Cross-correlation Function for the Sample of 1948-2015 Years for January Showing the Interconnection of SAT and AAO Index

And the cross-correlation function, presented in the figure 14, confirms the visual conclusion. The correlation coefficient between the two time series is nearly 67%.

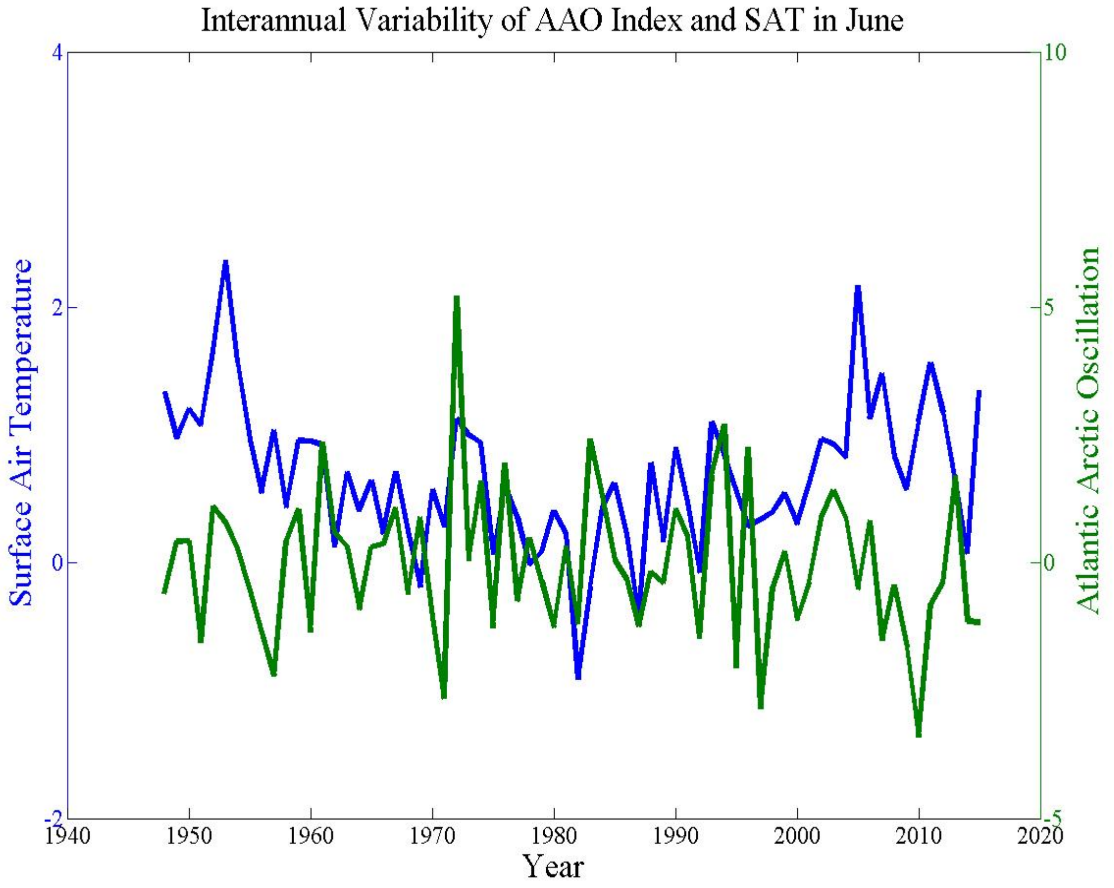


Figure 15 – Interannual Variability of AAO Index and SAT in June

An inverse situation is observed in June (figure 15). Already visually there is no perceptible interconnection.

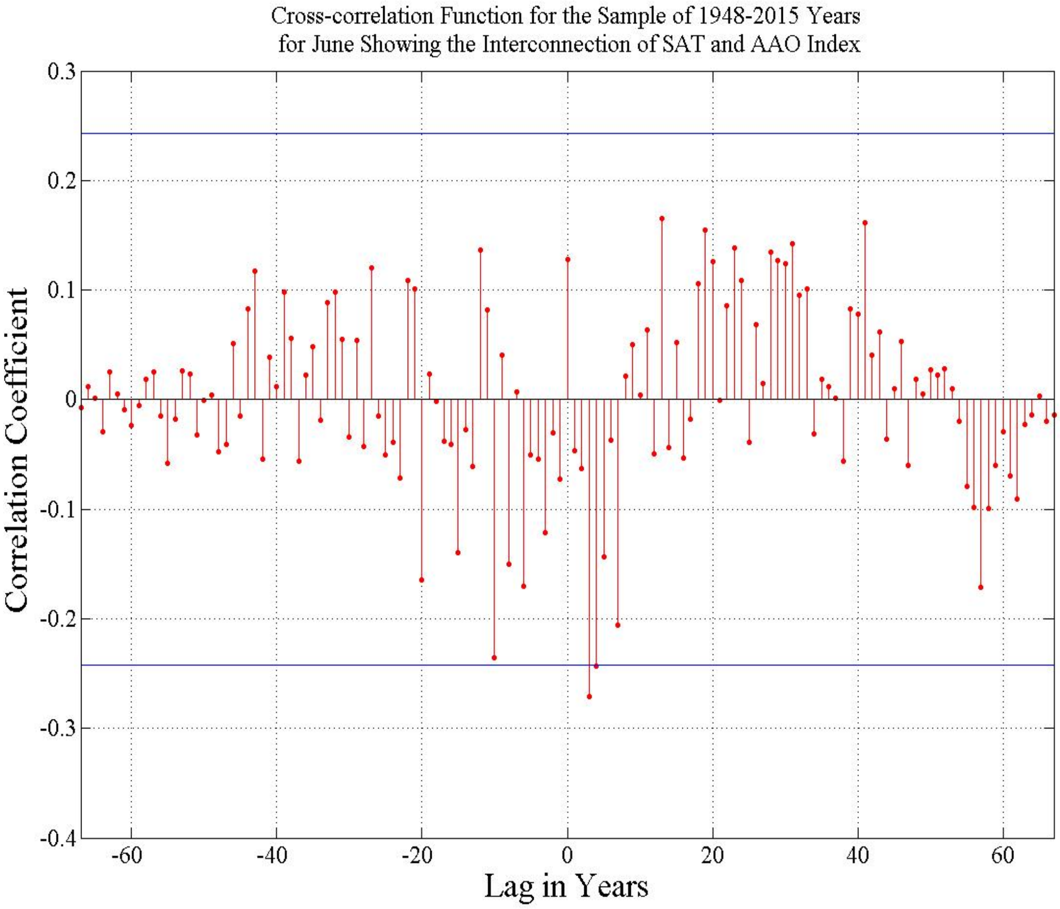


Figure 16 – Cross-correlation Function for the Sample of 1948-2015 Years for June Showing the Interconnection of SAT and AAO Index

And the correlation analysis, presented in the figure 16, confirms this statement.

Physically it is very easy to explain. Indeed, during the summer there is a very high influence from the Sun on the temperature regime in the Arctic. In winter the Sun is absent, and the temperature regime is significantly defined by the atmospheric circulation. And the introduced climate index is very well connected with SAT in January, which means that in this sector of the Arctic AAO index characterizes atmospheric circulation with the high accuracy.

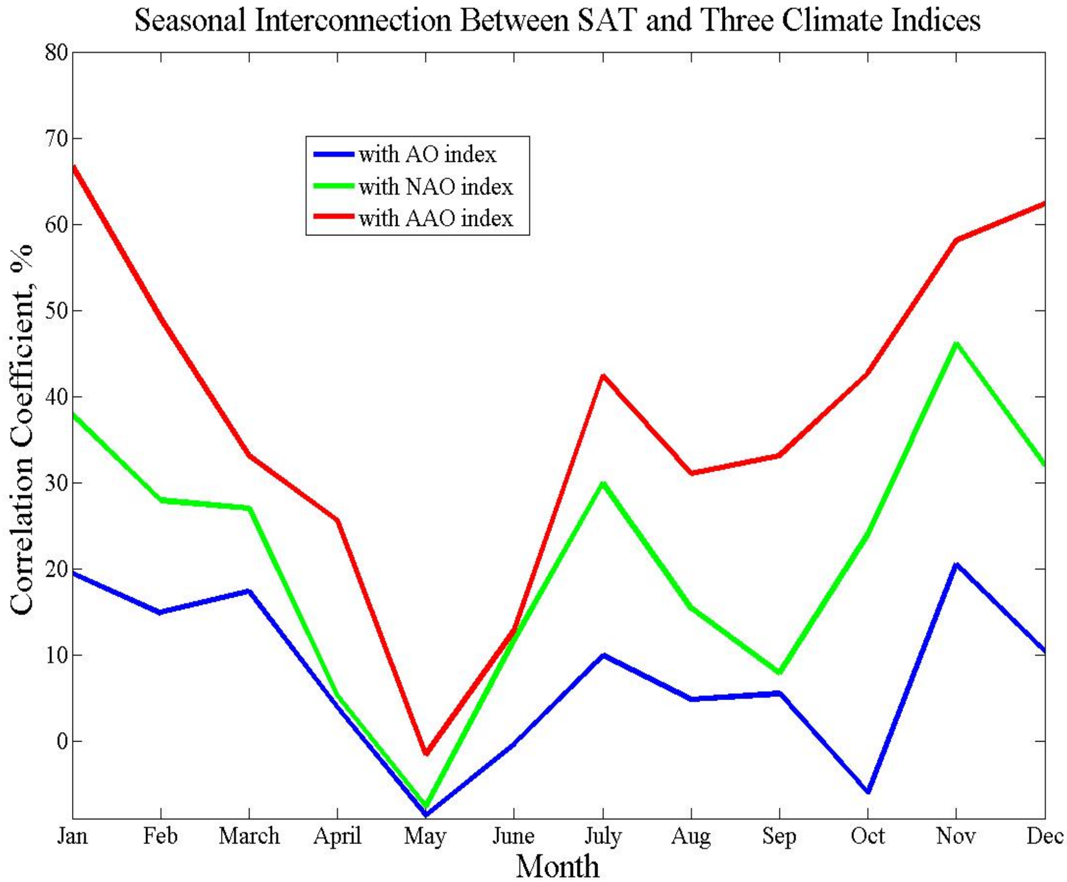


Figure 17 – Sesonal Interconnection Between SAT and Three Climate Indices

If we consider every month, then in the figure 17 we get the red curve, and it turns out that the maximum interconnection between AAO index and SAT is observed in January, while in May the correlation is about zero. In general, temperature regime during the winter season is well connected with Atlantic Arctic Oscillation. During the summer season, the situation is vice versa.

In order to find out the advantages of AAO index, we do the same with known climate indices and see that green and blue curves, representing the interconnection of SAT with NAO and AO indices, are significantly below the red curve.

Table 2 – Sensitivity of Three Climate Indices to the Cases with Polar Air Outbreaks

| Month, year | AO Index | | NAO Index | | AAO Index | |
|---|---|---|---|---|---|---|
| | I type | II type? | I type | II type? | I type | II type |
| **December, 1978** | **-0.98** | | **-2.34** | | **-0.87** | |
| **October, 1979** | **-1.24** | | **-0.67** | | | **1.81** |
| **March, 1980** | **-1.43** | | **-0.67** | | | **1.53** |
| **January, 1982** | | **0.88** | **-1.40** | | **-2.68** | |
| **November, 1984** | **-0.97** | | **-0.39** | | | **0.98** |
| **February, 1985** | **-1.44** | | **-1.28** | | | **1.31** |
| **February, 1986** | **-2.90** | | **-2.77** | | **-2.62** | |
| **January, 2012** | **-0.22** | | | **0.79** | | **2.30** |
| **January, 2016** | **-1.45** | | **-0.37** | | | **1.76** |

Another very important advantage of AAO index over NAO and AO indices is that it characterizes the two types of polar air outbreaks with the high accuracy.

In the table 2 a numerical proof of AO and NAO indices nonsensitivity to the two completely different types of polar air outbreaks is presented. The first column represents cases of polar air outbreaks, including their type (red colour indicates that the second type of polar air outbreaks was observed; blue colour corresponds to the first type of polar air outbreaks), and three others are monthly values of climate indices with the Atlantic Arctic Oscillation in the last column.

We see that Arctic and North Atlantic Oscillations are nearly of the same sign, whereas in reality different types of polar air outbreaks were observed. Moreover, their positive phases even do not imply any arctic air outbreaks; therefore, questions are put to the second type within NAO and AO indices.

In contrast, Atlantic Arctic Oscillation is very sensitive to both types of polar air outbreaks. And its phases do not only tell us about the type of polar air outbreaks, but also characterize the intensity of the corresponding anomalies. Physically this index shows the strength of meridional atmospheric circulation, and Arctic air outbreaks have a significant component of meridional motion. Therefore, there are more chances that this index will capture polar air outbreaks.

## 3. Conclusions

1) North Atlantic and Arctic Oscillations are not sensitive to the two completely different types of polar air outbreaks in terms of differentiating them.
2) Based on the conducted classification of polar air outbreaks, a conclusion about the existence of one more action center of the atmosphere over the north of Siberia was made.
3) A new climate index was introduced named Atlantic Arctic Oscillation, which characterizes the two types of arctic air outbreaks with the high accuracy. Also, the new index is much better interrelated with SAT in the Arctic than NAO and AO indices.
4) Currently in the middle latitudes summer season is getting colder, whereas in the Arctic winter season is getting warmer. And the new climate index identifies this phenomenon.
5) One of the most important reasons of Arctic sea ice melting is connected with the domination for the past 20 years of the arctic air outbreaks of the second type causing high positive air temperature anomalies in the eastern sector of the Arctic. In contrast, during 1960s the first type of arctic air outbreaks prevailed.

This research has shown that statistical analysis in combination with physical reasoning can reveal many important linkages and provide some advantages. It gives us a good starting point for the development of an alternative approach in the seasonal weather forecasting.

## Acknowledgements

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