Chapter 9

Assessment of Atmospheric Circulation in the Atlantic-Eurasian Region and Arctic Using Climate Indices. The Possible Applications of These Indices in Long-Term Weather Forecasts

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Abstract 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. In this study, 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 their classification was carried out. Based on this classification, a conclusion about the existence of the North Siberian anomaly was made. According to its many features, this anomaly can be treated as one more action center of the atmosphere. This finding has allowed us to introduce a new climate index, which is called as the Atlantic Arctic Oscillation index. This index allows us to identify the two types of polar air outbreaks with a high level of recognition probability.

An interrelation between the new climate index and temperatures in the investigated 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.

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9.1 Introduction

Among the known climate indices that characterize the weather in the Atlantic-Eurasian region, the North Atlantic and Arctic Oscillations indices can be named. There are many articles, where the interrelations between different climate indices and weather-forming meteorological fields are considered, for example, (Pokrovsky 2007; Smith et al. 2016; Luo et al. 2016; Hurrell 1995). When speaking 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 spreads to Siberia only during certain years. It is also known that the Arctic Oscillation is very closely interrelated with the North Atlantic Oscillation. In fact, Arctic and North Atlantic Oscillations are different ways for describing the same phenomena although this issue is not completely agreed upon by researchers.

9.2 Two Types of Polar Air Outbreaks

Retrospective data on the strongest polar air outbreaks to the European part of Russia for the last 30 years during the cold season were used to classify arctic air outbreaks. The dataset was provided by Vitaliy Stalnov who is the acting member of Russian Geographical Society and association of researchers “Forecasts and Cycles” (Stalnov n.d.).

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 (<ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/>) were used as an instrument to represent different cases of polar air outbreaks in order to classify them.

From the analysis of the archives, two absolutely different types of polar air outbreaks were identified.

Characteristic features of polar air outbreaks are identified in the best manner by the sea level pressure (SLP) anomalies fields presented in the Fig. 9.1.

The main difference between these two types of polar air outbreaks is the temperature regime and sea ice conditions in the Arctic. During the first type of polar air outbreaks, in the eastern sector of the Arctic negative temperature anomalies are observed, which leads to the increased sea ice concentration. During the second type, this situation is reversed.

As seen, the Northern Siberia and North Atlantic are key regions for the formation of polar air outbreaks in the Atlantic-Eurasian region. 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.

9.3 Atlantic Arctic Oscillation Index (AAO Index)

9.3.1 Calculation of AAO Index

In the previous section, it was shown that there are two physical mechanisms that are inversely proportional to each other. At the same time, there are no climate indices for Central and Eastern Eurasia, which involve the action center of the atmosphere over the north of Siberia. In this view, a new climate index, entitled *Atlantic Arctic Oscillation*, was established.

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, the Ostrov Dikson station has the longest time-series in the extreme conditions of the north. 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. To solve this task, a corresponding program was written by using the modern high-level programming language MATLAB.

Positive phase characterizes the second type of polar air outbreaks, whereas negative phase characterizes the first type.

In the Table 9.1, an example of the AAO index values is shown. Attention should be paid especially to January and June: distributions of positive and negative phases are nearly inversely proportional to each other for the two different periods of time. Further analysis will show in detail the physical meaning of these distributions.

9.3.2 Interannual Variability of AAO Index

The linear trend in Fig. 9.2 shows that there is a transition from negative phase to a positive one. However, the nonlinear smoothing, developed by O.M. Pokrovsky (Pokrovsky 2010), is much closer to the reality because it reveals a wave-like behavior of this oscillation, and due to this, e.g., it is possible to see that in January in 1960s the first type of polar air outbreaks dominated. Another very important tendency is that during the last 20 years the second type of polar air outbreaks has been prevailing.

According to the National Snow and Ice Data Center Report (Beitler 2012), the Arctic sea ice extent had its minimum value in 2012, which can also be explained by the domination of the second type of polar air outbreaks that has produced a regular transportation of very warm air in the Arctic. This, in turn, causes the sea ice not to thicken enough during winter, and the multiyear ice extent is gradually decreasing in summer. Therefore, it is possible to conclude that the impact of this

Table 9.1 Example of the AAO index values

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

Fig. 9.2 Interannual variability of AAO index in January

process is cumulative, and as a consequence the year 2012 had the lowest ice extent since regular satellite observations started in 1979.

In June the situation is opposite, and currently the strength and number of polar air outbreaks of the first type is increasing. It should be pointed out that in summer the second type of polar air outbreaks vanishes in terms of lower than normal temperatures because of the high influence of solar radiation.

9.4 AAO Index and Surface Air Temperature in the Arctic. Advantages of the AAO Index Over the NAO and AO Indices

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 on the AAO index concretely in this region. For this purpose, the time series of the mean surface air temperature (SAT) from NCEP/NCAR reanalysis dataset were taken.

It is clearly visible from Fig. 9.3 that in January the coherence between SAT and AAO is evident. The cross-correlation function confirms the visual conclusion. The correlation coefficient between the two time series is nearly 67%.

If every month of the year is considered, this results to the red curve presented in the Fig. 9.4. The curve shows that the maximum interconnection between the AAO index and SAT is observed in January, while in May the correlation is about zero. In

Fig. 9.3 (a) Interannual variability of AAO index and SAT in January, (b) Cross-correlation function for the sample of 1948–2015 years for January showing the interconnection of SAT and AAO index

general, the temperature regime during the winter season is well connected with the Atlantic Arctic Oscillation. During the summer season, the situation is vice versa.

In order to find out the advantages of AAO index compared to the two other indices, the same analysis was done with NAO and AO indices. The resulting green and blue curves, representing the interconnection of SAT with NAO and AO indices, are significantly below the red curve.

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

Fig. 9.4 Seasonal interconnection between SAT and three climate indices

Table 9.2 Sensitivity of three climate indices to the cases with polar air outbreaks obtained from the retrospective data (Stalnov *n.d.*)

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

Table 9.2 presents the numerical proof of AO and NAO indices nonsensitivity to the two completely different types of polar air outbreaks. The first column represents cases of polar air outbreaks (the bold font corresponds to the second type of polar air outbreaks; the ordinary font corresponds to their first type), and three others are monthly values of climate indices with the Atlantic Arctic Oscillation in the last column.

It can be seen from the table that Arctic and North Atlantic Oscillations are nearly of the same sign, whereas in reality the different types of polar air outbreaks were observed. Moreover, from the physical point of view, their positive phases even do not imply any arctic air outbreaks; therefore, question marks indicate that in the table for the second type of polar air outbreaks by NAO and AO indices.

In contrast to NAO and AO, Atlantic Arctic Oscillation is a very sensitive index to both types of polar air outbreaks. 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 reflects the strength of meridional atmospheric circulation, of which the arctic air outbreaks are a significant component. Therefore, there are more chances that this index will be successful in capturing the polar air outbreaks.

9.5 Conclusions

1. A new climate index, entitled *Atlantic Arctic Oscillation (AAO)*, was introduced in this study. AAO characterizes the two types of arctic air outbreaks with a high accuracy. The new index is much better interrelated with SAT in the Arctic than NAO and AO indices.
2. 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.
3. North Atlantic and Arctic Oscillations are not sensitive to the two completely different types of polar air outbreaks in terms of differentiating them.
4. Based on the conducted classification of polar air outbreaks, a conclusion was made about the existence of one more atmospheric action center over the north of Siberia.
5. 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.

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