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Causes of November Cooling of the 1980s–1990s in European Russia

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Abstract—In the 1980s–1990s, a widespread November cooling occurred in European Russia against the background of global warming. Analysis showed that the observed cooling was caused by anomalous cold advection at the eastern edge of the area of positive sea-level pressure and geopotential anomaly centered over Scandinavia and the Gulf of Bothnia. This November circulation pattern is related to the positive phase of the Arctic Oscillation in the preceding winter. It is concluded that the observed November cooling was caused by the prevalence of the positive phase of the wintertime Arctic Oscillation and North Atlantic Oscillation in the last two decades of the 20th century.

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INTRODUCTION

European Russia (ER) has not avoided global warming. The most intense warming was observed in the last one-third of the 20th century in winter months [1, 2, 14]. Let us illustrate this by the temperature change in Moscow (VDNKh station) averaged over two decades, from the 1960s–1970s to 1980s–1990s. The annual temperature increased by 0.7°C, and the January mean temperature rose by 3.6°C. Against this background, an evident cooling before the beginning of winter is particularly strange: the Moscow November temperature decreased by 1.4°C during the same period. This decrease was observed everywhere in ER. Winter warming is explained mainly by the increase in the frequency of the positive phase of the Arctic (AO) and North Atlantic (NAO) oscillations, that is, by the increase in frequency and intensity of warm Atlantic air advection to ER [5, 11–13, 19, 20]. The causes of November cooling should also be looked for in the prevalence of some particular circulation patterns to which the cold air advection to ER is related. It is shown in [17] that only three monthly mean circulation patterns have a statistically significant influence on the annual air temperature averaged over northwestern Eurasia. Expectedly, it is the meridional dipole of atmospheric pressure anomalies over the North Atlantic in January and February connected with the AO and NAO, and, surprisingly, the zonal dipole of atmospheric pressure anomalies with centers of opposite sign over southern Scandinavia and the Labrador Sea in November. Later in [16], the author showed the relationship between the November circulation and zonal circulation in the preceding winter. In [16, 17], the annual air temperature averaged over northwestern Eurasia was studied along with an asynchronous relationship of the circulation patterns. This work is a development of the above-mentioned works; it focuses on November mean temperature in ER and explains the observed cooling.

DATA AND METHODS OF STUDY

The fields of air temperature, sea-level pressure, and 500-hPa geopotential height (H_{500}) were analyzed using the reanalysis [15] for 1950–2005 (56 years). The AO index for the same period was taken as interpreted by the National Centers for Environmental Prediction (NCEP), the United States, that is, as a projection of H_{1000} monthly mean anomaly onto the first EOF of H_{1000} monthly mean anomalies for all months. This index correlates well with the Thompson and Wallace index [19], which is not calculated anymore starting from 2002. The Barnston and Livezey index of teleconnections [8] is also taken in the NCEP interpretation, and the NAO index, in the Hurrell interpretation [13], as a principal component of the leading mode of the North Atlantic pressure anomaly expansion in EOFs.

The study is based on coupled modes of the variability of temperature field in ER in November and atmospheric pressure field in the Atlantic-European region. Analysis of maximum covariances based on the

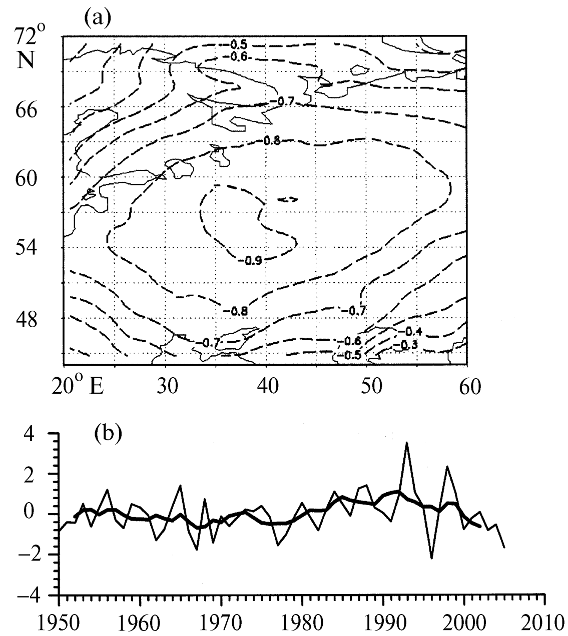

Fig. 1. (a) Loadings of the first EOF and (b) interannual cycle of the first principal component of air temperature in November, bold line is for 5-year running average.

singular decomposition of the cross-covariance matrix of the fields (vectors) is used. The method is described in detail in [3, 9]; it is now widely used in climatology. The statistical significance of coupled variability modes was determined using the Monte Carlo method described in [4].

The statistical significance of the correlation coefficients was estimated taking into account the series autocorrelation [10]. The significance of the results of principal component analysis was tested using the North criterion [18]. The composite analysis was used as an accompanying method. The Student t-test was used to determine whether the anomalies differed from zero statistically significantly and whether the composites are different.

ANALYSIS AND RESULTS

First, the variability structure of the November air temperature field was analyzed using principal components (empirical orthogonal components method). The first mode of temperature variability (Fig. 1) dominates absolutely. It describes more than 50% of the total temperature variance. The first empirical orthogonal function (EOF) is rather homogeneous with the same sign over the whole ER territory (Fig. 1a; hereinafter, dotted isolines indicate negative values, and solid lines show positive values and zero). There is a distinct maximum in the second half of the 1980s and the first half of the 1990s (Fig. 1b) in the multiyear time series of the first principal component (PC_1). This maximum corresponds (considering the EOF sign) to the above-mentioned cooling. This study considers only the first mode of temperature variability, since neither the PC_2, nor PC_3 have such distinct extremes, and their part of variance is much less (~20 and 10%, respectively). The PC_1 statistically significantly correlates (R = 0.51) with the East Atlantic–Western Eurasia teleconnection index. Other Barnston and Livezey's teleconnection indices [8] do not statistically significantly correlate with the PC_1. The correlation with the November AO is not significant either.

Being rather convenient for use, the circulation indices have a significant shortcoming. They strictly reflect a definite structure in the pressure or geopotential field, and even small deviations lead to considerable changes in relationship estimates. Therefore, analysis of maximum covariances between the fields of temperature T and pressure p and temperature T and H_{500} was chosen as the main method of study. The results for T and H_{500} were qualitatively similar to those for T and p, and the correlations obtained for H_{500} were somewhat higher than those for pressure. Thus, the results are presented for the pressure field alone since they are more restrictive.

Figure 2 shows the first coupled modes of variability of the temperature and pressure fields in November. The correlation of singular values (SV) of the first temperature and pressure modes is 0.68 (it is

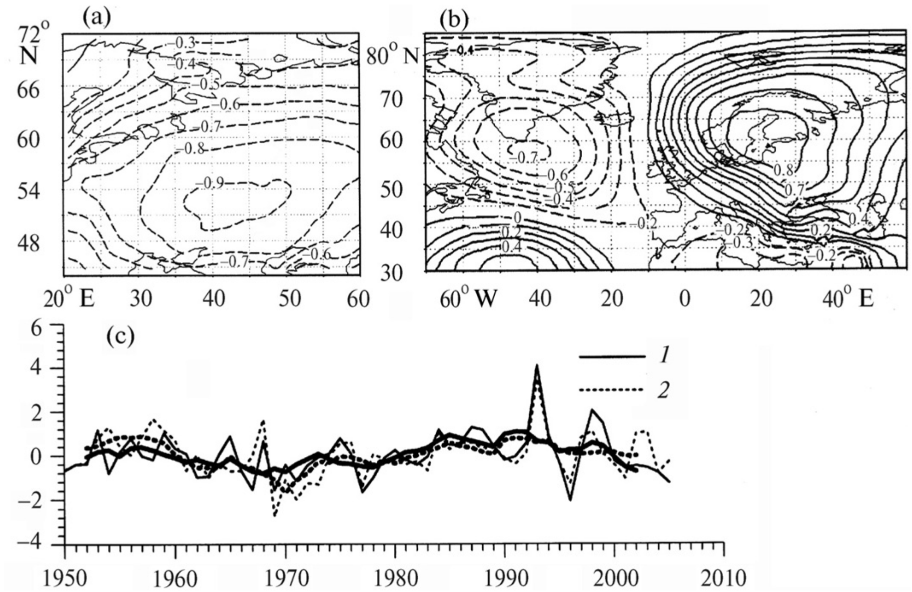

Fig. 2. First coupled singular vectors of (a) temperature and (b) pressure in November and (c) time series of corresponding singular values. (*1*) SV_1 of T_N and p_N, (*2*) SV_1 of p_N and T_N. Bold line is for 5-year running average, correlation coefficient $R = 0.68$.

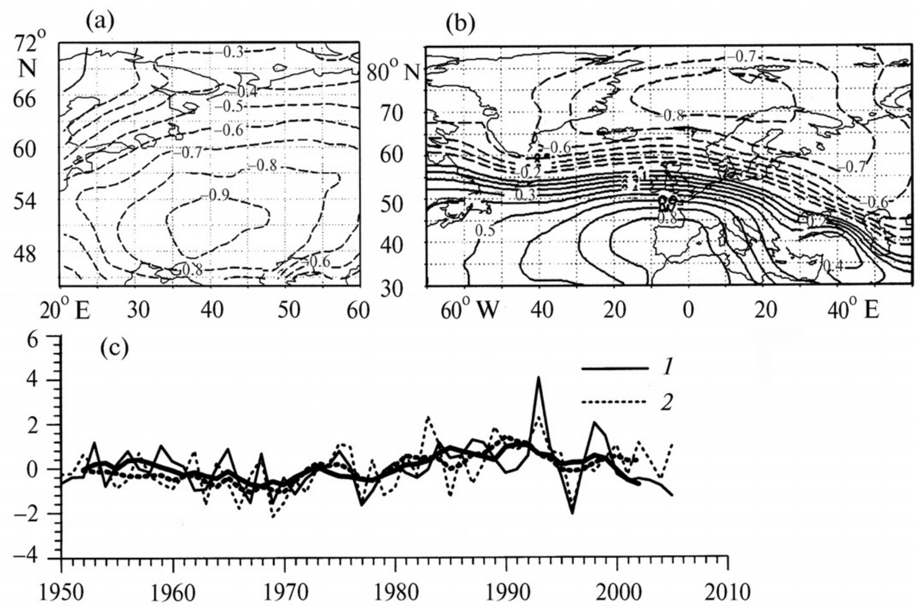

Fig. 3. First coupled singular vectors of (a) November temperature and (b) January pressure and (c) time series of corresponding singular values. (*1*) SV_1 of T_N, and p_J and (*2*) SV_1 of p_J and T_N. Bold line indicates five-year running average, $R = 0.42$.

0.77 for the SV_1 of temperature and H_{500}). The temperature singular vector (Fig. 2a) is almost similar to the first EOF of temperature and represents a one-sign field (the polarity of the modes is chosen so that the positive SV_1 corresponds to the cooling). The correlation between PC_1 and SV_1 is 0.95. The first singular pressure vector connected with temperature is a zonal dipole with a negative center over the Gulf of Bothnia and a positive center near the south end of Greenland (Fig. 2b). The most interesting detail of this pressure anomaly field is that it has two centers. There is an evident influence of its eastern (European) center on ER: the positive pressure anomaly over the Gulf of Bothnia initiates anomalous advection of the Arctic air to ER and the corresponding negative temperature anomaly.

Correlation coefficients between PC_1 and SV_1 of November temperature T_N and sea level pressure in November p_N and January p_J, index of the transatlantic oscillation in November (TAO_N), and the increase in the sea ice cover area in Artic from September to November ($dIC_{N\text{-}S}$)

Value	SV_1						TAO_N	$dIC_{N\text{-}S}$
	T_N and p_N	p_N and T_N	T_N and p_J	p_J and T_N	p_N and p_J	p_J and p_N		
$PC_1 T_N$	0.96	0.55	0.93	0.31	0.46	0.29	0.54	0.36
SV								
T_N and p_N		0.68	0.99	0.39	0.59	0.38	0.58	0.40
p_N and T_N			0.67	0.50	0.97	0.55	0.78	0.47
T_N and p_J				0.42	0.59	0.41	0.61	0.43
p_J and T_N					0.56	0.99	0.54	0.41
p_N and p_J						0.60	0.80	0.49
p_J and p_N							0.54	0.41
TAO_N								0.56

Note: All correlation coefficients are statisitcally significant at the 5% level; all correlation coefficients exceeding 0.4 are significant at the 1% level.

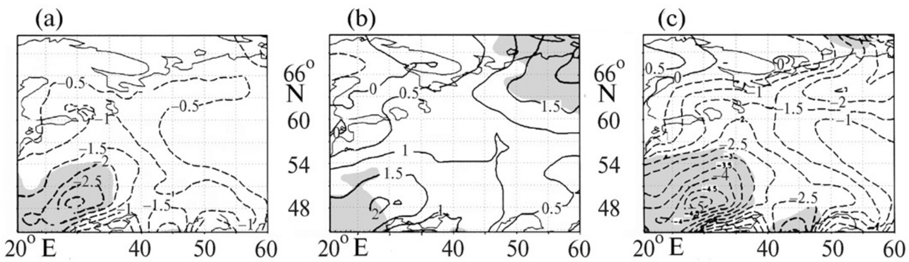

Fig. 4. Composites of temperature anomalies (°C) in November for (a) January NAO > 1 and (b) < 1 and (c) their difference. Shading is for anomalies and their differences at the 5% level.

The western (Greenland) center is not directly related to ER temperature, but it has proven to be an integral part of the dipole circulation; the correlation coefficient between central pressures of dipole is –0.41. Analysis of correlations between SVs and the Barnston and Livezey's teleconnection indices [8] showed that this pattern does not correspond to any of the teleconnections. The maximum correlation (0.57) is with the Scandinavia index. The correlation with other indices does not exceed 0.35. This pattern is related most closely (the correlation is 0.79) to the transatlantic oscillation, whose index was determined in [16] as a normalized difference of normalized pressure over southern Scandinavia and the Labrador Sea. The PC_1 and SV_1 of temperature correlate with this index with the coefficients of 0.55 and 0.58, respectively.

These results indicate that the November circulation pattern determines the interannual changes of the dominant temperature modes over ER in November. However, they do not explain the observed cooling or, what is the same, the observed prevalence of the positive phase of the pattern.

It was shown in [16] that the transatlantic oscillation in November is related to the AO (NAO) in the preceding winter. This relationship acts through the influence of winter circulation on the formation of the Arctic ice cover, summer ice extent, and conditions of the fall ice formation.

The singular values of the first modes and pressure field and the temperature fields in November statistically significantly correlate with the transatlantic index (table). Therefore, one can suppose that November temperature decreases are related to prevailing positive phases of the AO and NAO in the preceding winters. In fact, analysis of maximum covariances shows that the first singular vectors of atmospheric pressure in November connected with November temperature (Fig. 2b) and January pressure (not shown) are almost identical; the correlation of corresponding SVs is 0.97. At the same time, the first singular vectors of November temperature related to the November pressure field (Fig. 2a) and January (Fig. 3a) are also almost identical, the correlation between the corresponding SVs being 0.99.

Thus, both the dominant mode of November temperature variability and the November pressure mode that determines it are related to the same mode of pressure variability in the preceding winter. This mode

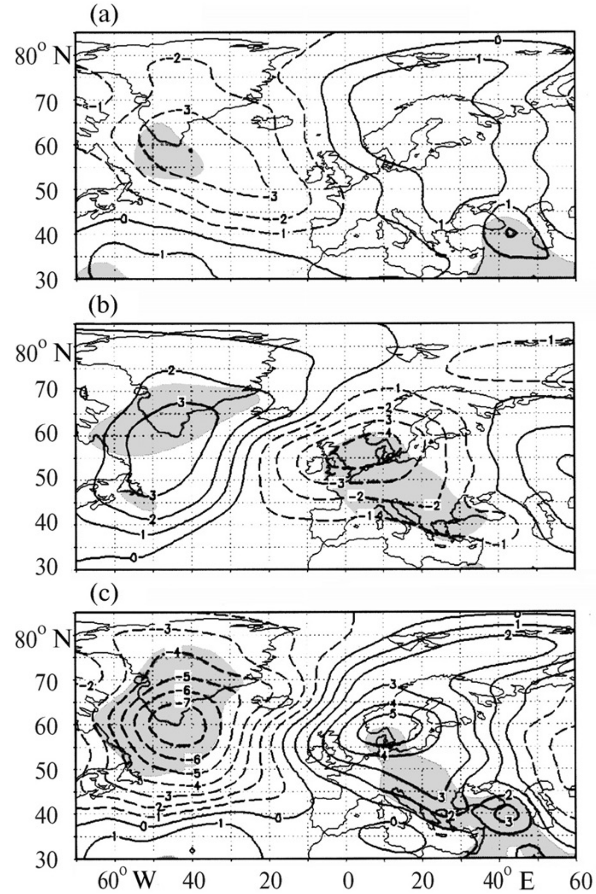

Fig. 5. As in Fig. 4 but for pressure anomalies (hPa).

represents a meridional dipole in the pressure field with centers over the Norwegian Sea and the Iberian Peninsula (Fig. 3b). Although it is not an exact copy of the AO in the Atlantic sector or the NAO, it is undoubtedly connected with it, the correlations being 0.87 and 0.82, respectively. In the 1980s–1990s, the positive AO and NAO phases prevailed in winter. In November during these twenty years, the positive pressure and geopotential anomaly was most frequent over the Scandinavian Peninsula and the negative temperature anomaly was most frequent in ER (5-year moving averages in Figs. 1b, 2c, and 3c). In the previous twenty years, especially in the 1960s, the AO and NAO phases were mainly negative. The 20th century minimum was observed in the winter of 1968/69 for both the AO and the NAO. In this period, the negative pressure anomaly in November determined the anomalous warm advection to ER and positive temperature anomaly.

Analysis of maximum covariances shows the linear relationship between the modes of variability of meteorological variables determining these modes according to the maximum correlation coefficient. It was found that the leading mode of November temperature variability is related to the mode of pressure variability in the preceding winter, which is close to the AO and NAO. To confirm these findings, direct relationships between November temperature, pressure, and precipitation and the AO and NAO indices in the preceding winter were analyzed. Figures 4–6 show the composites of temperature, pressure, and precipitation calculated for the January NAO index magnitude exceeding one standard deviation. The results of the composite analysis completely prove the conclusions of the analysis of maximum covariations. The positive pressure anomaly over Scandinavia and negative temperature anomaly in ER are most frequent when a high positive NAO index is observed. The pattern is inversed when the NAO index is significantly negative. The composite differences (Figs. 4c and 5c) are rather similar to the maps shown in Figs. 1a, 2a, 3a, and 2b, respectively, although they are more fine because they are based on another principle.

For high positive AO and NAO indices in winter, the negative pressure anomaly prevails over the northwestern North Atlantic in November and positive pressure anomaly prevails over central and eastern Europe (Fig. 5a). The negative temperature anomaly is observed over ER in this period corresponding to

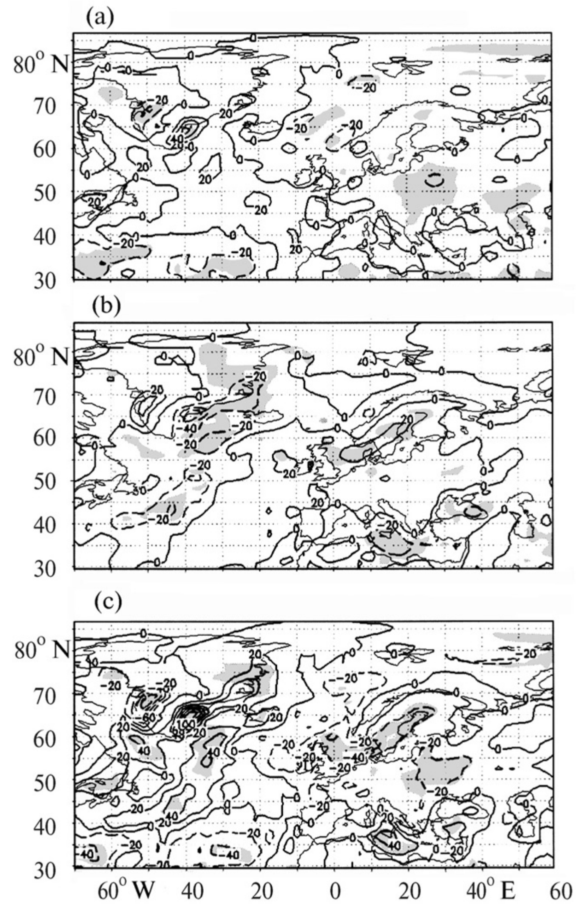

Fig. 6. As in Fig. 4 but for precipitation anomalies (mm).

the advection anomaly (Fig. 4a). There is an area of negative precipitation anomalies over ER (Fig. 6a), which also corresponds to the pressure anomaly field. The positive precipitation anomaly is located along the eastern coast of Greenland. This anomaly corresponds to the negative pressure anomaly over the northwestern North Atlantic. Such conditions prevailed in the last two decades of the 20th century.

When there are high negative indices of the AO and NAO in winter, the positive pressure anomaly is mostly observed over the northwestern North Atlantic in November, while the negative pressure anomaly prevails over the North Sea–Scandinavia (Fig. 5b). Precipitation anomaly is negative along the eastern coast of Greenland and over the Mediterranean Sea, while there is a positive precipitation anomaly stretching from southwest to northeast (Fig. 6b). Such a pattern of pressure and precipitation over Europe corresponds to the anomalously intense Skagerrak cyclogenesis at the polar front and to movement of Skagerrak cyclones northeastward along the front [7]. Advection of warm Atlantic air in warm cyclone sectors determines the positive ER temperature anomaly (Fig. 4b). Such conditions prevailed in the 1960s–1970s.

It should be noted that the results of composite analysis completely confirm the results of the analysis of maximum covariances: The periods of the prevalence of cold Novembers in ER are related to the periods when the positive AO and NAO phases prevailed in winter. Warm Novembers, on the contrary, are associated with negative AO and NAO phases.

CONCLUSIONS

The main result of this work is the following conclusion: Pressure anomalies over Scandinavia tend to be positive and temperature and precipitation anomalies in ER tend to be negative in Novembers following the winters with the prevalence of positive phases of the AO and NAO. On the contrary, Novembers following the winters with negative AO and NAO phases are characterized by a tendency toward negative pressure anomalies over Scandinavia and positive anomalies of temperature in ER and precipitation in northwestern ER.

The term "blocking" was not used intentionally in this paper. It means a particular climate (synoptic) formation in the pressure and geopotential fields, while the emphasis in the paper was on the fields of anomalies. Nevertheless, it should be noted that the development of a positive pressure and geopotential anomaly over Scandinavia can be considered as a tendency toward blocking formation. A negative pressure and geopotential anomaly in this region signifies an intensification of the westward transfer and westward–southwestward advection to ER.

Returning to the main topic of the paper formulated in the title, we can make a conclusion that November cooling in the 1980s–1990s was determined by prevailing anomalous cold advection at the eastern periphery of the area of positive pressure and geopotential anomaly with a center over Scandinavia–the Gulf of Bothnia. The high frequency of this circulation pattern is connected with the prevalence of positive AO and NAO phases in winter in the last two decades of the 20th century. This paper does not consider the question of how the signal of the winter AO and NAO persists until the fall and becomes apparent in November. In the previous works [16], the author assumed the possibility of signal transfer through the influence of winter circulation on the ice cover in Arctic, subsequent summer thawing, and, consequently, the conditions of the fall ice formation in this basin. In fact, the increase in the Arctic ice cover area from September to November statistically significantly correlates with the January and November circulation and November temperature (table). On the other hand, the signal can be transmitted through the sea surface temperature in the northeastern Atlantic and coastal seas of the Artic Ocean, which also conserves the "memory" about the winter circulation at least until the fall [6]. It seems that both inertial media, ice and water, can conserve and transmit the signal from winter to fall, but this should be the subject of further research.

It should be noted in conclusion that the author used other data and methods in the previous studies. Therefore, these results are not an artifact.

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