

# On Some Signs of a Recurrent Climate Scenario Advent

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**Abstract**—Since atmosphere pressure field is an actual envoy of climatic signal the atmospheric Highs and Lows should be attributed to the key active focal points within the ocean-atmosphere interplay system. Here we were set a task to determine how the dynamics of those centres of action relates to the climate change both on regional and global scales. For this target the near-surface temperature and atmospheric pressure differences between the Icelandic Low and the Azores High were considered. The secular term of phase states of the system under consideration was found divided into three nonintersecting subsets. Each of that was put in consequence with one of three climatic scenarios related to the periods of 1905-1935 (relatively warm phase), 1940-1970 (cold phase) and 1980-2000 (warm phase).

**Keywords**—Climate change, climatic scenario, fields of environmental characteristics, North Atlantic region.

## I. INTRODUCTION

ONE of the goals of the climate diagnosis [9], covered in our work, is the search for an independent confirmation of the earlier hypothesis of a substantial nonlinear nature of the climate change process in the modern secular scale [6]. The results of multiple works showing the quasi-cyclic intermittence of the ocean and the atmosphere climate characteristics variability processes during the last 100-150 years had served us the natural basis for this hypothesis.

It can be noted that, notwithstanding the observed apparent climate chaos of the current epoch, using the methods of random signals frequency filtering and their standard statistic processing, one can pinpoint not only the linear trends of the climate system evolution, but also some kind of a alternating sequence of its relatively determined phase states. To describe the complex of various signs, featuring every such separate state, the word-combination ‘climate scenario’ is considered usually in modeling practice. Since this notion is often used in the further contents of the paper, it needs a more precise commentary.

A climate scenario term is usually interpreted as a certain aggregate of climate events within a certain time scale, described by appropriate numerical models. We presume that for the sake of reasonable brevity and the convenience of apprehending the results of similar type of studies, it is quite

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feasible to widen this notion, expanding it on the spectrum of thermodynamic states of the real climate system in a certain phase space, limited by some time scale.

To substantiate this interpretation, let us assume that a multitude of the climate system phase states  $\Omega\{\hat{\zeta}_i(\varphi, \lambda, z, t)\}$  exists within the time scale  $\mathcal{T}$ , where  $\{\hat{\zeta}_1(\varphi, \lambda, z, t), \hat{\zeta}_2(\varphi, \lambda, z, t), \dots, \hat{\zeta}_n(\varphi, \lambda, z, t)\}$  are the climate parameters, e.g., atmospheric pressure, temperature, moisture, etc. Here:  $\varphi$  – latitude,  $\lambda$  – longitude,  $z$  – vertical coordinate,  $t$  – time, symbols  $\sim$  and  $\wedge$  indicate, correspondingly, temporal and spatial averaging used for the climate signal extraction.

The climate scenario in the episode  $\tau_j$ ,  $\tau_j \in \mathcal{T}$ ,  $\tau_j \gg \tau_c$  ( $\tau_c$  - the longevity of the existence of a large scale synoptic process, e.g., atmospheric cyclone) would be assumed as the sub-aggregate of the climate system phase states  $\Omega_j\{\hat{\zeta}_{ij}(\varphi, \lambda, z, t)\} \in \Omega\{\hat{\zeta}_i(\varphi, \lambda, z, t)\}$  which do not deviate from one another more than by small positive values  $\{\varepsilon_{ij}\}$ , i.e. they meet the criterion

$$\left| \hat{\zeta}_{ij}(\varphi, \lambda, z, t) - \bar{\zeta}_{ij}(\varphi, \lambda, z, t) \right| \leq \frac{\varepsilon_{ij}}{2}, \quad -\frac{\tau_j}{2} \leq t \leq \frac{\tau_j}{2} \quad (1)$$

where  $\bar{\zeta}_{ij}(\varphi, \lambda, z, t)$  – the average state by the sub-aggregate  $\Omega_j$ . In this case various climate scenarios shall have their corresponding non-overlapping sub-aggregate phase states, for which the condition (1) is violated. It is natural that each scenario would be characterized by its inherent climate peculiarities as on the regional level, so, by all probability, on the global scale.

Hence, various climate scenarios, by definition, are matched by time intervals  $\tau_j$ , where the parameters  $\xi_i(\varphi, \lambda, z, t - \tau)$  are forming the non-overlapping aggregates, by criterion (1); at that, the duration of these intervals will considerably exceed the time of transition from one scenario to another, let’s say, by an order.

Addressing the history of studying this problem, we shall note that, according to certain data [1], [13]-[16], in the middle of the XX century a process somewhat similar to the

changeover of a successive climate scenario has been taking place. Moreover, certain results of the analysis of the commonly accessible hydro-meteorological survey banks [2], [3] afford the ground to assume that, probably, several changeovers had occurred during the last 100-150 years.

Since the independent check of the supportability of these assumptions would have a doubtless scientific interest and an evident practical meaning, these factors became the major incentive for the current investigation. We bore in mind also that the identification of individual scenarios would demand the determination of the distinguishing features of each one of them, the evaluation of their duration and time interval, during which the transition from one scenario to another is taking place.

Energetically active zones of the Global Ocean and the planetary centers of the atmospheric activity, located as a rule above the oceans, deserve a special attention as the informational regions featured by a most noticeable manifestation of the climate variability signals. The following centers should be named among the latter: Icelandic Low and Azores High of the atmospheric pressure, which are affecting the North Atlantic oceanic region and vast adjacent land areas. What concerns the Pacific Ocean, these are correspondingly the Aleutian Low and Hawaiian High. In the Southern hemisphere, similar quasi-stationary atmospheric activity centers locate over the Atlantic, Indian and Pacific oceans. As the most robust atmospheric activity centers on the Eurasian continent, the Siberian High can be identified, as well as the atmospheric pressure minimum on the Hindustan peninsula.

## II. THE DATA AND METHODS

To analyze the spatio-temporal structure of climate signal variability in some of above mentioned centers, we used the monthly average atmospheric pressure fields at sea level [2] and the near-surface temperature [3] on the nets  $5^\circ \times 5^\circ$  prepared by the British Met Office Hadley Center, the materials of which are freely accessible on their web-site for any requiring users (<http://hadobs.metoffice.com/>).

On the base of these data the mean atmospheric pressure values for every cell ( $5^\circ \times 5^\circ$ ) in the Northern Hemisphere for the period 1900-2012 were calculated and corresponding chart of long-term mean pressure field was constructed. In the beginning we decided to concentrate our attention on the Atlantic Ocean with its two main centers – Icelandic Low and Azores High (Fig. 1). On Fig. 1 the regions around the mean position of these centers were marked by the squares ( $20^\circ \varphi \times 20^\circ \lambda$ ) having approximately the same areas as a cyclone with character radius equal 1000 km.

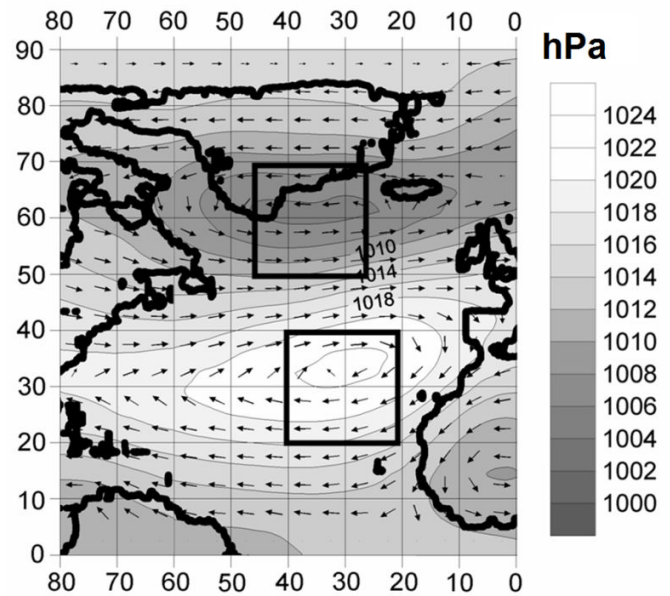


Fig. 1 Average (1900-2012) field of atmospheric pressure at a sea level in Northern Atlantic and a field of a geostrophic wind. The sites of two “squares” allocate areas of the Azores High (20-40°N; 40-20°W) and the Icelandic Low (50-70°N; 45-25°W)

For determination the current climate state the averaging the atmospheric pressure and near-surface temperature fields within the limits of these squares has been done by the following procedure:

$$\hat{\zeta}_i^k(\varphi_j, \lambda_j, z_0, t) = \frac{1}{\tau_0 \cdot \Delta\varphi \cdot \Delta\lambda} \cdot \int_{-\tau_0/2}^{+\tau_0/2} \int_{-\Delta\varphi/2}^{+\Delta\varphi/2} \int_{-\Delta\lambda/2}^{+\Delta\lambda/2} \zeta_i^k(\varphi_j + r_1, \lambda_j + r_2, z_0, t + \tau) dr_1 dr_2 d\tau \quad (2)$$

where  $\varphi_j, \lambda_j$  – latitude and longitude of the (k) atmospheric activity center (Fig. 1),  $z_0$  – vertical coordinate (sea surface level),  $t$  – time,  $\tau_0$  – moving time average-out scale,  $\zeta_i$  – a certain climate parameter, e. g., temperature ( $i=1$ ), atmospheric pressure ( $i=2$ ), etc. The scales of averaging were ( $\Delta\varphi=20^\circ, \Delta\lambda=20^\circ$ ) and ( $\tau_0=11$  years) consequently.

## III. THE CLIMATE SCENARIOS

Further, it was possible to trace the evolution of these characteristics in the XX century by analyzing the pressure and temperature temporal variability  $\hat{T}(z_o, t)$  and  $\hat{P}(z_o, t)$  in the atmospheric activity centers – Icelandic Low and Azores High (Fig. 2, 3). For the center of the Azores High (Fig. 2), several periods of increase and decrease of atmospheric pressure should be determined, which can, possibly, testify to the corresponding intermittence of

intensification and weakening phases of the Hadley meridional circulation between low and middle latitudes. The atmospheric pressure in the Icelandic Low evolves quasi-synchronously, though in the anti-phase; at that, the periods of its deepening indicate that at this time the Ferrell cell circulation became more active showing an intensification of the air masses exchange between the moderate and high latitudes. Hence, one might come to a conclusion that during the XX century the inter-decadal large-scale atmospheric pressure field excitations in the Northern Atlantic region had quite a coherent nature pointing at their evident phase structure. The same tendency was also traced in the graphs of the surface mean multiyear sea temperature variability in the regions of the High and Low under consideration. It is seen in Fig. 3, that the inter-decadal temperature fluctuation variability within the limits of these centers (see squares on Fig. 1) occurred quasi-synchronously and practically coincided by the phase.

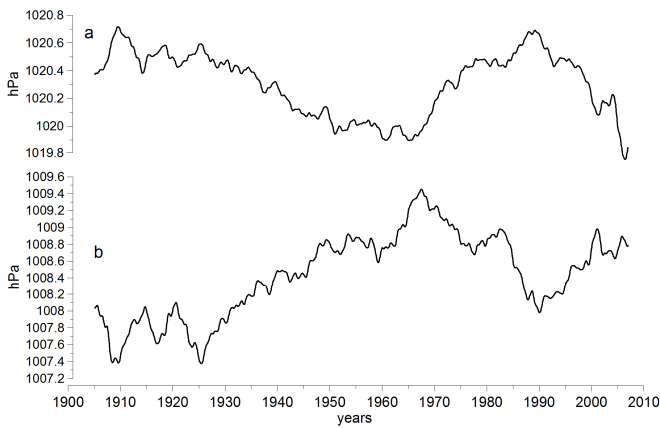


Fig. 2 Secular course of atmospheric pressure in (a) Azores High and (b) Icelandic Low

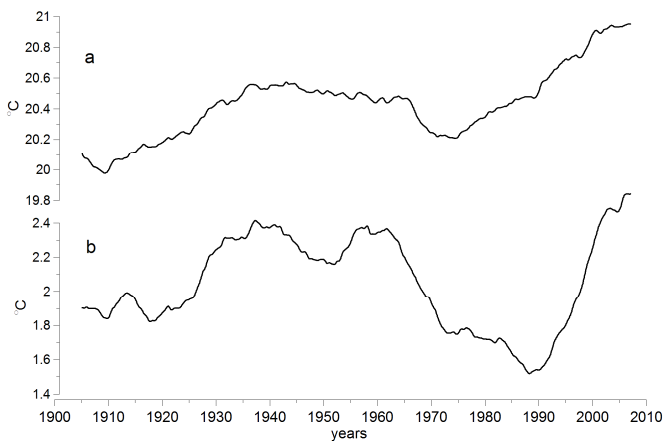


Fig. 3 Secular course of sea surface temperature in (a) Azores High and (b) Icelandic Low

Thus, the main preliminary result of this work sounds like there is an evident signs of existence of severers phase states in the spatial-temporal structure of the North Atlantic climate system variability.

It should be underlined that for studying such kind of

variability it was decided to use the two-way state parameter (SP) of some kind of the North Atlantic Oscillation index [4], in the form of the atmospheric pressure at sea level  $\delta\hat{P}(z_o, t) = \hat{P}_{AZ}(z_o, t) - \hat{P}_{IS}(z_o, t)$  and near-surface temperature differences  $\delta\hat{T}(z_o, t) = \hat{T}_{AZ}(z_o, t) - \hat{T}_{IS}(z_o, t)$ , between two main atmospheric activity centers in Atlantic sector of Northern hemisphere. As a result, it was found out that this choice turned out to be quite essential, since this parameter allowed to formalize the most adequately the major inter-decadal climate variability factors in the region and to obtain its adequate visual presentation.

Fig. 4 shows the phase trajectory of the SP on the coordinate plane  $\left(\delta\hat{P}(z_o, t), \delta\hat{T}(z_o, t)\right)$  throughout the whole sequence of data processed for 1900-2012. A noticeable localization of three major clusters of the indicated thermo-baric parameter appears to confirm our previous conclusion about the existence of the phase structure of the climate variability in the region under consideration during the XX century which, according to criterion (1), where  $\mathcal{E}_T \approx 0.15^\circ\text{C}$ ,  $\mathcal{E}_p \approx 0.65 \text{ hPa}$ , has divided into three sequential scenarios.

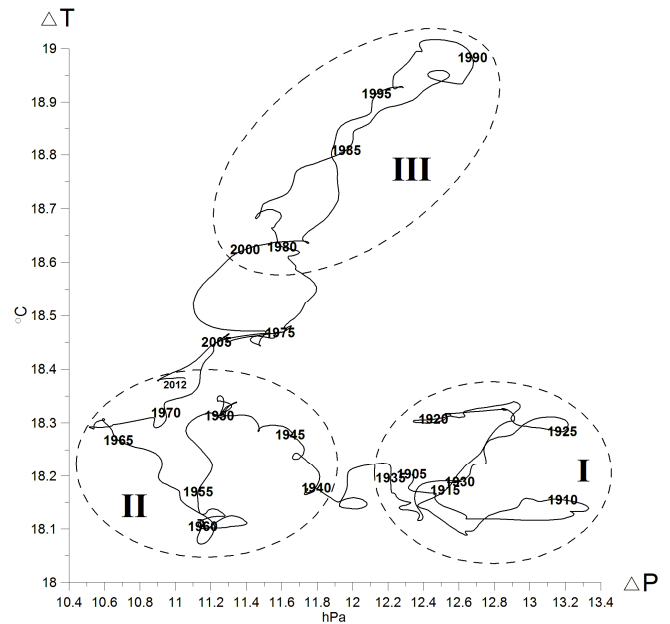


Fig. 4 Phase trajectory of thermo-baric parameter (differences of temperature and pressure between Azores High and Icelandic Low). Ovals allocate the phase subsets of SP corresponding to various scenarios of a climate: 1) 1905-1935, 2) 1940-1970, 3) 1980-2000 years

The first of them manifested itself in the beginning of the XX century (1905-1935), when the meridional temperature contrast between the centers was minimal (18.2 °C), and the atmospheric pressure difference was of relatively high level (12.7 hPa). As a consequence, the regional atmospheric

circulation structure in that period was distinguished by the intensely developed westerlies transferred the warm and moist air masses from the Atlantic region towards Europe and further to the East. The results of the analysis show that the near-surface temperature in both the atmospheric activity centers was abnormally low at that time (Fig. 3) – the ocean was apparently losing heat, giving it to the atmosphere. At that scenario the climate conditions on the European continent, as known, were noted by a higher as near-surface temperature so air moisture, followed by enlargement of rivers discharge, the Volga in particular the Caspian Sea level up-rise [11], [12] etc.

In 1940-1970, the new scenario substituted the previous climate phase in the region (Fig. 4) with a noticeable decrease of the meridional atmospheric pressure difference (11.2 hPa), which was followed by weakening of the zonal transport, lowering of the cyclogenesis intensiveness, and at least to shortening the warm and moisture flows from the Atlantic to the Western and Eastern Europe. The Volga discharge in this period perceptibly fell down, and the Caspian Sea level lowered sharply. During the second scenario an increase of the near surface temperature was noted in both centers (Fig. 3), which was accompanied in all appearances with the heat accumulation by the upper active ocean layer. The ocean surface temperature difference between the atmospheric activity centers in both that climate phases remained relatively low (18.2 °C).

Further, in 1980-2000, the third scenario came on stage, with higher meridional differences as the atmospheric pressure (12.0 hPa) so the ocean surface temperature (18.8 °C). Moreover, in the first half of this scenario – until 1990 – the variations of the said features were growing noticeably, and then were decreasing until its complete end. The characteristic feature of this climate phase was the cyclogenesis intensification with the strengthening of the western air mass transport, and also the increase of the ocean heat irradiation into the atmosphere with all the accompanying consequences of this process.

The first and the third scenarios were found to be qualitatively similar. The zonal transport during both these climate phases in the North Atlantic region was quite intensive, and the warm and moist air masses transfer from the ocean area to Europe was occurring. Meanwhile, this process was accompanied by lowering of the ocean surface temperature within the atmospheric activity centers. At the same time, it should be noted a more significant cooling of the ocean surface in the Icelandic region (Fig. 3) during the period of third scenario. The phases of strengthening and weakening of the meridional atmospheric circulation in the Northern Atlantic caused by certain behavior of the atmospheric pressure difference between two centers (Fig. 3), are well correlated with the inter-decadal variations of the ocean surface temperature anomalies in the tropical oceanic area, called the Atlantic multi-decadal oscillations (AMO), which in their turn are connected with the thermohaline circulation fluctuations [10].

Fortunately it was found that above mentioned results do not contradict the data of the independent field studies. Thus,

in particular, the specialized observations of the thermodynamic characteristics of the Northern Atlantic (Russian Program “ATLANTEX-90”), that coincided in time with the third climate scenario phase, showed that during this period the Newfoundland energetically active zone was in the abnormal state, the trans-frontal exchange across Gulfstream between cold and desalted polar waters and the Central Atlantic warm and salt water mass was intensified, and the transport of the North Atlantic Current reached its maximum value (100 Sv) [5].

Final results of the study revealed that in the beginning of the XXI century climate system showed an abrupt transition to the state, which by its thermo-baric parameters corresponds approximately with what was observed in the 40-60-years of the last century [7], that is during the second scenario, by our classification. This might mean the onset of the inter-system heat redistribution next phase, accompanied by heat accumulation in the ocean and the corresponding decrease of the mean temperature of the near surface air on land.

Something similar to what was described above inherently to the North Atlantic climate variability can be detected by same analysis of the corresponding hydro-meteorological fields related to other regions of the Earth. Thus, for instance, the thermo-baric phase trajectories, featuring the dynamics of the regional climate in Eurasia, also shows the hints of three scenarios presence, related to the periods of 1905-1935, 1940-1970 and 1980-2000 consequently. In this particular assessment the Siberian High and the depression on Hindustan peninsular were assumed as the regional key atmospheric activity centers.

Hence, we have the grounds to suppose that mentioned above the short-period inter-decadal excitations of the modern climate have a global nature and are manifested everywhere.

#### IV. CONCLUSION

The behavior of the sea surface atmospheric pressure and sea surface temperature for the 1900-2012 period in the regions of Icelandic Low and Azores High within the spatial-temporal average-out (20° latitude, 20° longitude and 11 years) was analyzed. The set of the ocean-atmosphere system thermodynamic states was found to be splitting into three clusters, each of that can be treated as the individual climate scenario. A life time of such a scenario constituted about 20-35 years, and the transition from one scenario to another covered 2-3 years, i.e. it run comparatively quickly.

The revealed non-overlapping sub-aggregates of the thermodynamic parameters related to particular climate scenario give an idea to follow the circulation peculiarities and the interrelated temperature differences within the limits of the Northern Atlantic ocean-atmosphere regional system. The results of this analysis bear evidence that the most probable intermittent strengthening and weakening of Hadley and Ferrell circulations [8] occurred there in same phase. Therefore, in the beginning of the XX century (1905-1935) and its last quarter (1980-2000) a significant intensification of these general meridional circulation cells took place. Their weakening was traced in the middle of the last century (1940-

1960), and can be also noticed in the beginning of the present century.

The phases of strengthening and weakening of the atmospheric circulation longitudinal component in the Northern Atlantic are well correlated with the inter-decadal variations of the sea surface temperature in the tropical ocean area, which are, apparently, connected with the corresponding fluctuations of its thermohaline circulation [10].

The analogous character of the climate system behavior was also detected in some other regional atmospheric activity centers that can be considered as a witness on the global nature of the detected phase type of modern climate inter-decadal variability.

Finally, the attention should be paid to the fact that at the beginning of XXI century the thermodynamic state of the Northern Atlantic regional climate system shows a tendency to face towards the situation, similar to the scenario of the 40-60s.

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