Interannual globally synchronized variations in the climate system and their predictability

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Abstract. The predictability of the widely known phenomenon of El Niño is investigated. For this, the recently found Global Atmospheric Oscillation (GAO) is considered as the main mode of the short-term climatic variations because GAO includes the El Niño – Southern Oscillation process within itself. Three indices characterizing dynamics and interrelation of the extratropical and tropical components of GAO are defined. Among these indices there is one by means of which it is possible to predict El Niño with the lead time of about one year. Generally, it is more, than the lead times of present day hydrodynamical and statistical methods of the El Niño successful forecasting. Then, by means of wavelets, a range of time scales is cleared up in which the closest crosscorrelations exist of this index with an index characterizing El Niño itself.

1. Introduction
It was found already many times ago that there are many peaks of the spectral density in the range of time scales of spectra of climatic variations from one to about ten years. First of all, such peaks were found for the processes of El Niño – Southern Oscillation (ENSO) developing in tropics of the Pacific Ocean. The origin of these peaks long time was a subject of a hot debate. Many researchers considered that these peaks, being found on quite short series of instrumental meteorological observations, are insignificant from the statistical point of view, i.e. they arise by a random chance, and so will disappear at longer observations.

There were also those who recognized reality of these peaks and connected them with some processes in the atmosphere excited by some periodic external forces. Among these researchers it is necessary to mention N.S. Sidorenkov. He considered that Luni-solar tidal effects and some peculiarities of the Earth rotation are guilty in the emergence of the ENSO spectral peaks [1]. Some foreign scientists also held a similar opinion for a long time [2].
The point of view of Sidorenkov was subjected to verify in [3-5]. Carefully verified series of instrumental meteorological observations available now were used for this purpose. As a result, all main peaks of a spectral density in the range of time scales from one year to about decade were attributed to three external periodic forces affecting the global climate system: 1) the Chandler wobble in the Earth’s pole motion (the main period of about 1.2 year); 2) the Luni-Solar nutation of the Earth’s rotation axis (the main period of about 18.6 years); 3) the solar activity cycle (the main period of about 11.5 years) [6-7]. It is important to stress that the main periods indicated are incommensurate to each other for certain. As a result, these forces affect the climate system at “improper time moments”. As a result, these forces generate very complex, apparently chaotic, but, actually, internally ordered variations among which “rhythms” of ENSO are most known.

So far as the above-stated main force periods are really incommensurable, to appropriate test a hypothesis that the mathematical template of the short-term climatic variations is the strange nonchaotic attractor (SNA) found by mathematicians at the end of the XXth century in solutions of some simple nonlinear dynamical systems affected by two external forces which periods are “very incommensurable” with each other (the ratio of two force periods usually considered to be equal to the so-called “golden mean” – the irrational which is most bad approximated by sequences of rationals). The SNA hypothesis is attractive because it allows prediction of future behavior of the considered dynamical system with no limit, at least, in principle.

The analysis made in [4-5], showed that peaks in the ENSO spectra and even in spectra of some meteorological processes developing in extratropics really have some properties inherent to the SNA dynamics. The first property consists that the magnitudes of the logarithms of the main peak amplitudes are connected by a linear relationship with the magnitudes of these peak serial numbers. The second property consists that the accumulated sum of the squared temporal autocorrelations of the ENSO decreases linearly in the log–log scale plot.

The aim of this paper is to show that, thanks to the SNA character of the short-term climatic variations, El Niño can be predicted with the lead time of about one year. In general, it surpasses the predictability limit of present-day methods of the El Niño successful forecasting.

2. Materials of the study

The global monthly mean sea level pressure (SLP) fields used in the analysis were taken from the following sources: NCEP/NCAR Reanalysis on a 2.5°x2.5° grid over 1948-2017 [8], Met Office Hadley Center HadSLP2 on a 5°x5° grid over 1850-2017 [9], NOAA-CIRES 20th Century Global Reanalysis Version 2c on a 2°x2° grid over 1851-2014 [10], ECMWF ERA-20C on a 1°x1° grid over 1900-2010 [11], and JMA JRA-55 on a 1.25°x1.25° grid over 1958-2013 [12].

The global monthly mean values of sea surface temperature (SST) were taken from the following sources: Met Office Hadley Center HadISST on a 1°x1° grid over 1870-2017 [13], JMA COBE SST2 on a 1°x1° grid over 1850-2016 [14] and NOAA ERSST V5 on a 2°x2° grid over 1854-2017 [15]. The global monthly mean data of the near-surface temperature of Met Office Hadley Center HadCRUT.4.6 on a 5°x5° grid over 1850-2017 [16] and the global monthly mean data of the surface air temperature (SAT) from the above-mentioned re-analyses (NCEP/NCAR, 20thC_ReanV2c, ERA-20C and JRA-55) have also been analyzed.

The obtained results are very similar for the above sources, so we show calculations based on the NCEP/NCAR Reanalysis data for the most reliable 70-years period 1948-2017, and from Met Office Hadley Center HadSLP2 and HadCRUT.4.6 for more longer period 1880-2017.

3. Results

3.1. Synchronization in the tropical and extratropical processes of the Global Atmospheric Oscillation

The basis for a possibility of prediction of El Niño is that it is not an isolated regional phenomenon though it can be characterized by the Niño1+2, 3 and 4 indices which values are defined by SST within some restricted regions of the near-equatorial strip of the Pacific Ocean. In this work a new
index is used. This index has been called the Extended Oceanic Nino Index (EONI). EONI represents the SST averaged over the full near-equatorial strip of the Pacific Ocean (5°S-5°N, 170°-80°W) including the regions of Niño2, 3 and 3.4 (green rectangle at figure 1a).

**Figure 1.** The mean difference of monthly anomalies of the surface air temperature (a) and sea level pressure (b) taking place at events of El Niño and events opposite to them – La Niña (positive and negative phases of the Global Atmospheric Oscillation), estimated from NCEP/NCAR Reanalysis for 1948-2017. “Asterisks” identify points which are used to define the GAO indices.

It has been shown in [17-20] that El Niño is a component of a certain global-scale process called the Global Atmospheric Oscillation (GAO) for this reason. The GAO-field was defined as the mean difference in monthly anomalies SLP fields taking place at events of El Niño and events opposite to them – La Niña (figure 1b). Two largest features of the GAO-field are an area of positive differences covering all tropical zone of the Earth from Indonesia to eastern coast of South America, and an X-shaped area of the negative differences which crossing takes place within the classic region of the El Niño observation, and which branches envelope the above-mentioned area of positive differences from all directions. In the tropical part the GAO-field is very similar to the field, constructed many years ago by H.P. Berlage (see figure 4 in [21]) and called the Southern Oscillation (SO).
GAO can be characterized by the GAO1 index which is calculated as the sum of the normalized values of SLP-anomalies in ten geographical areas (“asterisks” at figure 1b) coinciding with extrema (maxima and minima) in the field of GAO: 

\[(5°S-5°N, 35°-25°W) + (5°S-5°N, 55°-65°E) + (55°-65°N, 95°-85°W) + (65°-55°S, 95°-85°W) + (5°S-5°N, 145°-155°E) - (45°-55°N, 175°-165°W) - (45°-55°N, 15°-5°W) - (55°-45°S, 15°-5°W) - (55°-45°S, 175°-165°W) - (5°S-5°N, 95°-85°W).\]

This index is positive during El Niño, and it is negative during La Niña. It turned out that temporal variations of GAO1 and EONI occur synchronously. The crosscorrelation between these indices surpasses 0.9 at zero temporal shift between them (see the black line in figure 2a).

![Figure 2](image)

**Figure 2.** Temporal crosscorrelation functions of the pairs GAO1 – EONI (a black curve), GAO2 – EONI (a blue curve) and GAO3 – EONI (a red curve) indices after band-pass filter for years 2 to 7 (a), coherence and phase (°) between GAO2 – EONI (b) and GAO3 – EONI (c) for 1948-2017.

In order to be convinced that GAO and SO nevertheless are not identical, one more GAO2 index is useful. This index differs from GAO1 in the fact that at its calculation the SO-regions with coordinates 

\[(5°S-5°N, 145°-155°E)\]

and 

\[(5°S-5°N, 95°-85°W)\]

are excluded from consideration (more dark “asterisks” at figure 1b). The synchronous crosscorrelation between GAO2 and EONI is also very high (> 0.8) (see the blue line in figure 2a), the coherence is higher than 0.8 at periods 3-6 years with phase near 0° (figure 2b). It means that there is a close synchronous coupling between El Niño – Southern Oscillation (ENSO) occurring in tropics and some extratropical processes.
A crosswavelet transformation (CWT) of a GAO2 and EONI time series allows to find out what variations of temporal scales determine the above synchronous coupling between these processes. The technique of the CWT calculation is described in [22, 23]. Figure 3 shows wavelet coherence and phase on the time plane (in years) – the time scale of the wavelet transformation (in years) for a time frame of 1948-2017 when most reliable input data of the NCEP/NCAR Reanalysis were used for estimations of the GAO2 and EONI indices.

Figure 3. The wavelet coherence and phase between GAO2 and EONI for 1948-2017 (above), and their time series after band-pass filter for years 2 to 7 (below). Phase from the wavelet cross-spectrum is indicated by arrows oriented in a particular direction to indicate the relative lag between coherent components in regions of the time-frequency plane where coherence exceeds 0.7. The white dashed line shows the cone of influence where edge effects become significant (95%).

It is visible in figure 3 that the wavelet coherence is painted over by shades of yellow color (exceeds 0.7) within the scales 2-7 years, and corresponding phase-arrows oriented in 0° direction. It indicates that there is an almost complete coincidence of the GAO2 and EONI phases in these scales.

The wavelet coherence for scales 3-6 years is very high (> 0.8). Taking into account that input meteorological data are burdened by errors of observations for certain, it is possible to assume that there exists a functional one-to-one interrelation between variations of GAO2 and EONI in these scales. Exceptions are 1950th when in the wavelet coherence rather larger blue sites are visible within
the considered scales. It says about the absence of the synchronization between variations of GAO2 and EONI during these calendar years. Perhaps, the absence of the synchronization is obliged to errors of meteorological observations.

The wavelet coherence is a little less (about 0.7) for the scales of 2-3 years. Thus, variations of GAO2 and EONI also are synchronous in a very good degree within these scales. But sometimes, the share of the areas which are painted over in blue color increases. So, the synchronization is more non-uniform in these scales. Near the scale of 8 years a horizontal strip of mainly green areas is visible in the wavelet coherence (especially in the range of the 1970th – the 1990th calendar years). It demonstrates to lack of the synchronization of variations of GAO2 and EONI. The wavelet coherence decreases to about 0.6 here. Many climatologists consider the 1976/77 and 1998/99 years to be the times of special "climatic shifts" [24-26]. Perhaps, the destroying and restoring of the synchronization are a reflection of these shifts.

Yellow areas prevail again within the scales more than 10 and up to about 20 years. These yellow areas make two almost horizontal strips for almost all calendar years shown in the wavelet coherence. One of the strips is aligned near the scale of 11.5 years. This scale well coincides with the period of the well-known Sun spot cycle. The second strip coincides with the 18.6-year period of the Luni-Solar nutation. The wavelet coherence reaches 0.8 for both of these strips. In contrast, blue areas sharply prevail in scales more than 20 years. The wavelet coherence reduces here practically to zero (around 0.1). It demonstrates an out-of-links behavior of the GAO2 and EONI variations within this scale.

It is possible to conclude from everything told that the behavior of extratropical components of GAO represented by GAO2 index and the behavior of tropical processes represented by EONI index, are not identical. These processes are very similar in the range of temporal scales from about 2 years to about 2 decades. However, there is some disparate between these indices near the scale of 8 years. Variations of GAO2 and EONI within the 2 decade and more scales look to be in out-of-phase.

3.2. Global Atmospheric Oscillation as a predictor for El Niño

The Chandler wobble in the Earth’s pole motion is one of the external drivers of the climate system. It was established in the second half of the XXth century [27, 28] that this wobble excites tides propagating eastward in the extratropical atmosphere and oceans. The phases of these tides are opposite in the Northern and Southern hemispheres. Recently, it has been shown [3] that the oceanic pole tide in the North Pacific excites a positive SST anomalies in the near-equatorial strip of the Pacific Ocean after the reflection of this tide from west coasts of North America. It is just positive SST anomalies of El Niño which is a component of ENSO.

As for the atmospheric pole tide, continents are not for them an absolute obstacle. Therefore, a general eastward propagation must be a property inherent to the GAO-field. And the spatial structure of GAO as a whole propagates eastward. This propagation can be seen (figure 4) in a sequence of grid-point cross-correlations between GAO2 index and the monthly-mean SLP anomalies. There is a lag of -21 to +21 months since 42 months is the mean interval between subsequent El Niño events in the data used in our study. First (at the month “-21” that corresponds to La Niña) the X-shaped structure on Pacific is formed by positive SLP anomalies, and the tropical elliptic-shaped structure is formed by negative SLP anomalies. Then both structures move eastward to the American continent and West Pacific respectively. At about the month “-14” these structures start to transform themselves into their opposites, i.e. the X-shaped structure becomes to be more similar to the elliptic-shaped structure, and the elliptic-shaped structure becomes to be similar to the X-shaped one. These transformations end at the month “0” which corresponds to the maximum of El Niño event. Analogous eastward movements and transformations take place during the subsequent months up to the month “+21” which corresponds to the maximum of La Niña event. It is worth noting that the GAO spatial structure does not propagate eastward in the near-surface temperature (NST) anomalies, and appears as standing wave. The eastward propagation in the SLP-field tropical dynamics as well as the standing nature of the NST-field tropical dynamics are well known. In particular, many Hoffmoeller diagrams published during the latest decades also confirm these facts (for example [29]).
Figure 4. The sequence of grid-point lag crosscorrelations maps with the lags from -21 to +21 months (given at intervals of 3 months) between GAO2 index, calculated as the next combination of the sea level pressure (SLP) anomalies: \(P(0^\circ, 30^\circ W) + P(0^\circ, 60^\circ E) + P(60^\circ N, 90^\circ W) + P(60^\circ S, 90^\circ W) - P(50^\circ N, 170^\circ W) - P(50^\circ N, 10^\circ W) - P(50^\circ S, 10^\circ W) - P(50^\circ S, 170^\circ W)\), and the SLP-anomalies from HadSLP2 for 1880-2017 period, that show a sequence of the GAO development over 21 months before and after an El Niño events. The El Niño leads SLP anomalies at 21 months is defined as “−21 mon”, the zero-lag as “0 mon”, and the El Niño lags SLP anomalies at 21 months - as “+21 mon”.

Characteristic areas for the computation of the GAO3 index were chosen to represent the most peculiar features of the eastward propagation of GAO at the time of the reciprocal transformation of the X- and elliptic-shaped structures. To this end, a comprehensive crosscorrelation analysis of SLP and NST anomalies with the EONI index was carried out, and areas showing a certain advanced link with this index were selected (figure 5). A total of 15 following regions were selected to calculate GAO3. GAO3 = \(T(20^\circ N-50^\circ N, 160^\circ W-130^\circ W) + T(35^\circ S-25^\circ S, 160^\circ W-80^\circ W) + T(65^\circ S-45^\circ S, \)
150°E-160°W) + T(65°S-45°S, 60°W-0°) + T(40°N-70°N, 90°E-180°) − T(30°S-30°N, 60°W-180°) − T(60°S-31°S, 90°E-120°E) − T(31°N-60°N, 100°W-40°W) + P(50°N-70°N, 170°E-120°W) + P(70°S-50°S, 170°E-120°W) + P(60°S-20°N, 40°E-80°E) + P(30°S-30°N, 70°W-10°W) − P(0°-40°N, 120°E-120°W) − P(45°S-25°S, 120°E-60°W) − P(50°N-70°N, 50°E-90°E), where P and T are the pressure and temperature anomalies divided by their standard deviations.

Figure 5. The sea-level pressure (a) and near-surface temperature (b) maps of GAO for the moment of 14 months before an El Niño event when the spatial structure of GAO starts to transform itself into the opposite phase, i.e. the X-shaped structure becomes to be more similar to the elliptic-shaped structure, and the elliptic-shaped structure becomes to be similar to the X-shaped one. Data from HadSLP2 and HadCRUT.4.6 for 1880-2017 period.

The time series of GAO3 and EONI after band-pass filter for years 2 to 7 are shown in figure 6. It is possible to see that the main extrema of the GAO3 series lead the main extrema of the EONI series approximately for one year. The crosscorrelation between GAO3 and EONI is high (~0.8) with time.
lag about 12-14 months (see the red line in figure 2a), the coherence is higher than 0.8 at periods 4-6 years with phase near 90° (figure 2c). So, apparently, GAO3 can be used for prediction of EONI with the lead time of about one year.

Addressing to the wavelet coherence and phase between the GAO3 and EONI time series shown in figure 6, it is possible to see that this picture, in its main features, reminds the CWT-pattern of the GAO2 and EONI shown in figure 3. However, these patterns strongly differ in their details. So, at figure 6 in the range of the scales from 4 to 6 years almost all areas are marked by phase-arrows oriented in approximately 90° direction. It means that variations of GAO3 lead corresponding variations of EONI about 1/4 of current periods (~ 14 months).

Figure 6. The wavelet coherence and phase between GAO3 and EONI for 1948-2017 (above), and their time series after band-pass filter for years 2 to 7 (below). Phase from the wavelet cross-spectrum is indicated by arrows oriented in a particular direction to indicate the relative lag between coherent components in regions of the time-frequency plane where coherence exceeds 0.7. The white dashed line shows the cone of influence where edge effects become significant (95%).

In the range of the scales 2-4 years phase-arrows oriented in approximately 135° direction (GAO3 leads EONI about 3/8 of current periods ~ 14 months). Also the CWT-patterns of figures 3 and 6 are
similar with each other in the scales from 8 to about 16 years. In both patterns an almost horizontal strip exists in these scales. The wavelet coherence corresponding to this strip are similar though they are slightly less for the pair GAO3 – EONI in comparison with the pair GAO2 – EONI. However, in scales more than 16 and up to about 20 years the CWT-patterns are completely different. For the pair GAO2 – EONI, as it was specified earlier, there exists another almost horizontal strip of yellow areas, i.e. variations of GAO2 and EONI occur links in these scales. But, all these areas are almost blue for the pair GAO3 – EONI, i.e. the corresponding variations occur out-of-links. The wavelet coherence is low (about 0.2) for these variations.

4. Conclusions
The interannual scales are considered in this paper, and the predictability of the well-known phenomenon of El Niño is investigated. For this purpose, the so-called Global Atmospheric Oscillation (GAO) is considered which has been recently recognized by climatologists. GAO represents a synchronized integrity of the well-known processes in tropics connected with El Niño, and some extratropical processes, that have eastern propagation.

At ENSO time scale range (2-7 years) the received almost complete coincidence of the CWT-pattern of the GAO3 series with the CWT-pattern of the EONI series with the lead time of about 14 months means that it is possible to well forecast EONI using the GAO3 index. Generally, it is significantly more, than the lead times of hydrodynamic and statistical successful forecasts of El Niño used in the present-day operational practice. Let's remind that all present-day forecasts of El Niño suffer from the so-called spring barrier of predictability, and so their practical predictability is limited to the lead time of about one half of year. Thus, eastern propagation of GAO can help to predict strong El Niño and La Niña events with the lead time of about one year.

Acknowledgments
This work was partly supported by the Russian Science Foundation (project no. 14-50-00095).

References
[1] Sidorenkov N.S 2009 The interaction between Earth's rotation and geophysical processes (Weinheim: Wiley-VCH & Co. KCaA) p 305
[2] Treloar N.C 2002 Luni-solar tidal influences on climate variability International Journal of Climatology 22 pp 1527–1542
[3] Serykh I.V, Sonechkin D.M 2016 Confirmation of the oceanic pole tide influence on El Niño Sovremennye problemy distansionnogo zondirovaniya Zemli iz kosmosa 13 2 pp 44–52
[4] Serykh I.V, Sonechkin D.M 2017 Manifestations of motions of the Earth’s pole in the El Niño – Southern Oscillation rhythms Doklady Earth Sciences 472 2 pp 256–259
[5] Serykh I.V, Sonechkin D.M 2017 Chaos and order in atmospheric dynamics: Part 2. Interannual rhythms of the El Niño – Southern oscillation Izvestiya Vysshih Uchebnykh Zavedeniy. Prikladnaya Nelineynaya Dinamika 25 5 pp 5–25
[6] Vakulenko N.V, Sonechkin D.M 2011 Evidence of the solar Activity’s effect on El Nino Southern Oscillation Oceanology 51 6 pp 935–939
[7] Serykh I.V 2017 A comparison of the structure and dynamics of Global atmospheric oscillation in reality and in the CMIP5 climate models IOP Conference Series: Earth and Environmental Science 96 012006
[8] Kalnay E, Kanamitsu M, Kistler R et al 1996 The NCEP / NCAR 40-year reanalysis project Bull. Amer. Meteor. Soc. 77 pp 437–471
[9] Allan R.J, Ansell T.J 2006 A new globally-complete monthly historical gridded mean sea level pressure data set (HadSLP2): 1850-2004 J. Climate 19 pp 5816–5846
[10] Compo G.P, Whitaker J.S, Sardeshmukh P.D et al 2011 The Twentieth Century Reanalysis Project Quarterly J. Roy. Meteorol. Soc. 137 pp 1–28
[11] Stickler A, Brönnimann S, Valente M.A et al 2014 ERA-CLIM: Historical Surface and Upper-
Air Data for Future Reanalyses Bull. Amer. Meteor. Soc. 95 9 pp 1419–1430
[12] Kobayashi S, Ota Y, Harada Y et al 2015 The JRA-55 Reanalysis: General Specifications and Basic Characteristics J. Met. Soc. Jap. 93 1 pp 5–48
[13] Rayner N A, Parker D E, Horton E B et al 2003 Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century J. Geophys. Res. 108(D14) 4407
[14] Hirahara S, Ishii M, Fukuda Y 2014 Centennial-scale sea surface temperature analysis and its uncertainty J. of Climate 27 pp 57–75
[15] Huang B, Banzon V F, Freeman E et al 2015 Extended reconstructed sea surface temperature version 4 (ERSST.v4). Part I: Upgrades and intercomparisons J. Clim. 28 3 pp 911–930
[16] Morice C P, Kennedy J J, Rayner N A and Jones P D 2012 Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 dataset J. Geophys. Res. 117 D08101
[17] Bychev V I, Neiman V G, Romanov Yu A and Serykh I V 2012 El Niño as a consequence of the global oscillation in the dynamics of the Earth’s climatic system Doklady Earth Sciences 446 1 pp 1089–1094
[18] Bychev V I, Neiman V G, Romanov Y A and Serykh I V 2012 On El Niño's impact upon the climate characteristics of the Indian monsoon Oceanology 52 2 pp 147–156
[19] Bychev V I, Neiman V G, Ponomarev V I, Romanov Yu A, Serykh I V and Tsyrkova T V 2014 The Influence of Global atmospheric oscillation on formation of climate anomalies in the Russian Far East Doklady Earth Sciences 458 1 pp 1116–1120
[20] Bychev V I, Neiman V G, Romanov Yu A, Serykh I V and Sonechkin D M 2016 Statistical significance and climatic role of the Global Atmospheric Oscillation Oceanology 56 2 pp 165–171
[21] Bjerknes J 1969 Atmospheric teleconnections from the equatorial Pacific Mon Weather Rev. 97 pp 163–172
[22] Torrence C, Compo G P 1998 A Practical Guide to Wavelet Analysis Bull. Amer. Meteor. Soc. 79 pp 61–78
[23] Torrence C, Webster P 1999 Interdecadal changes in the ESNO-Monsoon System J.Clim. 12 pp 2679–2690
[24] Bychev V I, Neiman V G, Romanov Yu A and Serykh I V 2009 On the spatial nonuniformity of some parameters of global variations in the recent climate Doklady Earth Sciences 426 4 pp 705–709
[25] Bychev V I, Neiman V G, Anisimov M V, Gusev A V, Serykh I V, Sidorova A N, Figurkin A L and Anisimov I M 2017 Multi-decadal oscillations of the ocean active upper-layer heat content Pure and Applied Geophysics 174 7 pp 2863–2878
[26] Serykh I V 2016 Influence of the North Atlantic dipole on climate changes over Eurasia IOP Conference Series: Earth and Environmental Science 48 012004
[27] Maksimov I V 1955 "Polar tide" in the sea and the Earth's atmosphere Trudy instituta okeanologii AN SSSR 8 pp 92–118
[28] Maksimov I V 1956 Notation standing wave in the ocean and its geographical investigation Izvestiya Akademii nauk SSSR, ser. geograficheskaya 1 pp 14–34
[29] Peng J B, Chen L T, Zhang Q Y 2014 The relationship between the El Nino/La Nina cycle and the transition chains of four atmospheric oscillations. Part II: The relationship and a new approach to the prediction of El Nino Adv. Atmos. Sci. 31 3 pp 637–646