

Interannual climate anomalies in the Atlantic-European region associated with La-Nina types

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Abstract. La Nina manifestations in the meteorological fields of the Atlantic-European region are studied in the paper taking into account its classification based on spatial and temporal features. Monthly global data on sea surface temperature (SST) from COBE SST2 and HadISST data sets in 1900 – 2014, air temperature and sea level pressure from 20th Century Reanalysis V2c were used. Two La Nina types differing one from another in character of SST cold anomaly propagation over the equatorial Pacific region were classified. It is shown that interannual ocean-atmosphere anomalies manifest in the Atlantic-European region mostly in winter due to teleconnection mechanism. Additionally, the role of North Atlantic Oscillation and East Atlantic Oscillation in the level of La Nina types manifestation are analyzed too.

1. Introduction

El Nino — Southern Oscillation (ENSO) is a quasi-periodic (two to seven years) signal of the air-sea interaction in the equatorial Pacific [1]. It characterizes by two episodes – the warm (El Nino) and cold (La Nina) ones.

ENSO provokes great interest of world leading scientists and experts due to its global climate manifestations in the environment especially its negative consequences [2]. Investigation of the ENSO influence on the regional hydrometeorological anomalies around the Globe is one of the most important issues of the study within the principal world and regional climate projects since the late second half of XX century. ENSO manifestations in the Atlantic-European region is an important problem within lot of international programmes such as CLIVAR, EUROMED, etc. The El Nino and La Nina impacts on the atmospheric circulation in the Atlantic-European region was generally studied in [3-6]. The authors [4, 6] emphasized that atmospheric circulation variability in the Atlantic-European region is more prominent in La Nina years than in El Nino years.

As a rule, La Nina events are characterized by an extreme SST drop, growth of Southern Oscillation index and trade wind strengthening in the equatorial Pacific Ocean. Unlike El Nino, the La Nina events gained the scientific interest some later. For a long time La Nina was considered as El Nino feature [7]. Only in late 1990s after 1998 – 2000 La Nina events, which led to catastrophic consequences around the Globe, researchers began to investigate this event more carefully [8].

Nowadays, taking into account different approaches El Nino events are classified into two to three types [9-12]. However, the question of La Nina classification is still open for discussion. Some authors have shown that the zonal location of maximum cold SST anomalies in the central Pacific does not reflect obvious character of each individual La Nina event [11, 13, 14]. On the other hand, there are the publications which confirm the existence of two La Nina types [15, 16]. The results of papers [6, 16, 17] show that different La Nina types have different climatic responses in anomalies of precipitation, surface wind direction and surface air temperature in the lower atmosphere both in the



tropical and non-tropical regions. Nevertheless, the mathematical confirmation of La Nina differences has not been obtained yet, thus there is no generally recognized classification at the moment. Therefore, the aim of this paper is to clarify the preliminary La Nina classification and then study the pattern of the each La Nina type manifestation in climatic anomalies in the Atlantic-European region in 1900 - 2014.

2. Data and methods

Monthly SST data sets from Met Office Hadley Centre (HadISST) [18] and Japan Meteorological Agency (COBE SST2) [19] of 1° space resolution from 1900 to 2014 are used in this study. Besides this, Southern Oscillation index (SOI) obtained for 1856 – 2013 in the University of East Anglia Climatic Research Unit is used too [20]. To remind, SOI index is calculated as a normalized difference of sea level pressure (SLP) between the Darwin and Tahiti in the Pacific. At the same time, Nino3.4 index was calculated as SST anomaly in Nino3.4 region (5 °N- 5 °S, 170 °W-120 °W) using HadISST and COBE SST2 data sets. The time series (SOI and Nino3.4) were detrended and tested for Gaussian distribution.

Sea level atmospheric pressure (SLP) and air temperature (T_a) from the 20th Century Reanalysis V2c with 1° space resolution in 1900 – 2014 [21] were analyzed as the main parameters to study La Nina manifestations in the Atlantic-European region. At the same time, North Atlantic Oscillation (NAO) index and Eastern Atlantic Oscillation (EA) indices were used too.

Seasonal variability was filtered from all data sets. In order to assess seasonal variability the average monthly values of $\tilde{F}(\varphi, \lambda, z_0, \tau)$ were calculated for all time series for the each month:

$$\tilde{F}(\varphi, \lambda, z_0, \tau) = \frac{1}{n} \sum_{i=0}^{n-1} F(\varphi, \lambda, z_0, \tau + 12i), \quad (1)$$

where φ is latitude, λ - longitude, z_0 - depth, τ - 1, 2, ..., 12 months, and n – number of observation years (in our case 114). Then monthly anomalies $\delta\tilde{F}(\varphi, \lambda, z_0, t)$ of the obtained seasonal variability and linear trend

$$T(\varphi, \lambda, z_0, \tau) = a + bX, \quad (2)$$

were calculated: $\delta\tilde{F}(\varphi, \lambda, z_0, t) = F(\varphi, \lambda, z_0, \tau) - \tilde{F}(\varphi, \lambda, z_0, \tau) - T(\varphi, \lambda, z_0, \tau)$, where X is a serial value of SST, SLP or T_a time series, a and b are linear trend coefficients.

Thus anomalies for the each grid point were calculated relative to 1900-2014 period for monthly SST, SLP and T_a series after removing linear trend and seasonal variability.

La Nina classification was made on the basis of cluster analysis (hierarchical method). As a measure of relationship between clusters the Euclidean distance was chosen which is the most popular metric in cluster analysis representing a geometric distance in the multidimensional space. It is determined by the formula:

$$d_{E_y} = \sqrt{\sum_{k=1}^m (x_{ik} - x_{jk})^2} \quad (3)$$

where x_{ik} and x_{jk} are values of the k variable at i and j distance, m is a number of characteristics. Two variables were applied for La Nina geographic coordinates and values of SSTA in October-December (La Nina events reach of the mature phase in these months in 80% cases).

Composite analysis [22] was used to study the patterns of La Nina type manifestations in the meteorological fields associated with the mature phase of event. Spatially averaged strongest negative monthly SST anomalies were chosen to define the La Nina mature phase and a 3 months period was a time criterion for composites [16]. Composites of SLP and T_a anomalies associated with different La Nina types were calculated for the each month from December of the La Nina onset («0») year to November of the next («+1») year for the 1900 – 2014 interval. Statistical significance of the composites was assessed by the Student's test.

Using the Atlas of Extratropical Storm Tracks for 1961-1998 from the NASA GISS web page (<http://data.giss.nasa.gov/stormtracks/>) composite schemes of winter storm tracks were obtained.

3. La Nina spatial classification

The initial task of this study is to identify La Nina events on the basis of specific criteria. The list of operational definitions and indices of La Nina and El Nino suggested by 26 member-countries of the World Meteorological Organization (WMO) is published [23]. And it is noted that the researcher is responsible for criteria choice to identify the cold and warm ENSO episodes.

Similar to El Nino, the La Nina is usually identified by Nino3.4 index (see above). In present paper Nino3.4 index was calculated for the period 1900-2014. Criterion chosen to identify La Nina events was a cold SST anomaly (SSTA) with -0.5°C threshold and minimum duration (D) of 5 months as follows:

$$\begin{aligned} \text{SSTA in Nino3.4} &\leq -0.5^{\circ}\text{C}, \\ D &\geq 5 \text{ months.} \end{aligned}$$

However, one primary criterion is not enough to provide the complete selection of cold episodes of ENSO. Accordingly, we also involved the Nino1+2 index (SST anomaly of -0.75°C in the region limited by coordinates 0° - 10°S and 90° - 80°W). This permitted us to make sure that the selected event is really La Niña, but not just a period with a fall of average SST in the Pacific during 5 months. The cold anomaly can progress in the Eastern equatorial Pacific (Nino1+2), but it stay weak in the Central equatorial Pacific (Nino3.4). To check the La Nina occurrence and clearly illustrate the intensity and spatial scales of anomalies, the maps of the cold SST anomalies during the mature La Nina phase were built.

Thus, using both HadISST and COBE SST2 data sets and the abovementioned criteria 21 La Nina events were selected within 114 years period: in 1909-1910, 1916-1917, 1924-1925, 1933-1934, 1938-1939, 1942-1943, 1949-1951, 1954-1956, 1964-1965, 1967-1968, 1970-1971, 1973-1974, 1975-1976, 1983-1984, 1984-1985, 1988-1989, 1995-1996, 1998-2000, 2007-2008, 2010-2011, 2011-2012. Long-lasting La Nina events, such as 1954-1956, 1949-1951 and 1998-2000, were considered as two different La Nina events in spatial classification because they have two significant SSTA maxima with a 12 month periodicity. Note, that such events were identified by some authors [6, 16, 17], however, using much shorter time series, in particular from 1950 to 2013.

The analysis of all monthly maps revealed the following. Some La Nina events are characterized by the occurrence and development of cold SST anomaly in the central equatorial Pacific, while the others – in its eastern part, near Peru and Ecuador coast. The similar feature is described in [6, 16, 17].

To get the objective La Nina classification, the hierarchical cluster analysis was applied to both HadISST and COBE SST2 data sets. The results shown in the form of a dendrogram in figure 1 indicate the presence of two clusters. Accordingly, 12 La Nina years with the lowest SSTA values in the east are in the first cluster named the East Pacific La Nina type (EP), and 12 La Nina years with the most negative SSTA values in the central equatorial Pacific belong to the second cluster named the Central Pacific type (CT).

Figure 2 illustrates a clear difference between the two La Nina types in location of the most negative SSTA during its mature phase in October-December. Maps were obtained for the each identified type of events on the basis of HadISST (figure 2 a, b) and COBE SST2 (figure 1 c, d) data sets. Two independent data sets produce identical results, and this additionally demonstrates the significance of our results. Composites of SSTA spatial distribution during the mature La Nina phase in October-November for the EP La Nina type are shown in figure 2 a and b and CP La Nina type – in figure 2b and d. However, it does not mean that cold anomalies occur in the same places. The main feature of the CP La Nina type is the location of the most negative SSTA in the equatorial Pacific during the mature phase, and accordingly as for the EP La Nina type it is in the East Pacific, near the western coast of South America. So the results of cluster analysis in figure 2 show the place of typical location of the most negative SST anomalies during mature phase of La Nina. It is important for the subsequent study of atmospheric and oceanic responses.

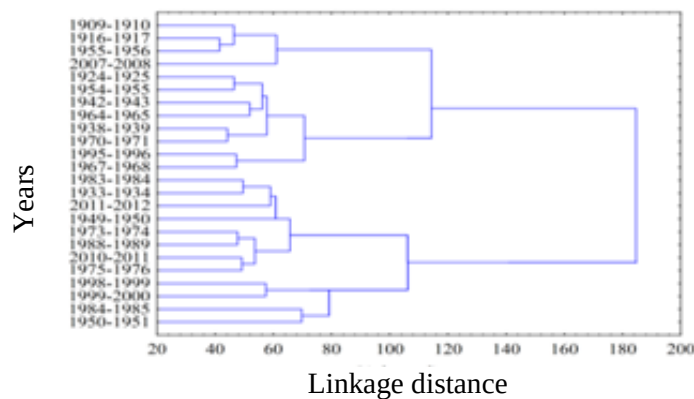


Figure 1. Dendrogram of cluster analysis of classification of La Nina events for 1910-2014 taking into account two criteria: geographic coordinates and values of SSTA in October-December during the mature phase of La Nina.

The Student's test (t) estimations of statistical significance of mean values of the composites ($\bar{x}$) were used to confirm the correctness of classification. To solve this task, two hypotheses were stated: $H_0: \bar{x}_1 \neq \bar{x}_2$ and $H_1: \bar{x}_1 = \bar{x}_2$. Then the empirical Student criterion (t) and critical criterion (t_{cr}) were estimated. H_0 was rejected if $t > t_{cr}$, therefore the difference between the average values of the elements in the same composite was too large and not statistically significant. H_0 was adopted if $t < t_{cr}$, therefore the difference between the average values of the elements in the composite was acceptable and statistically significant. The 95% statistically significant areas of the composites are dotted in figure 2.

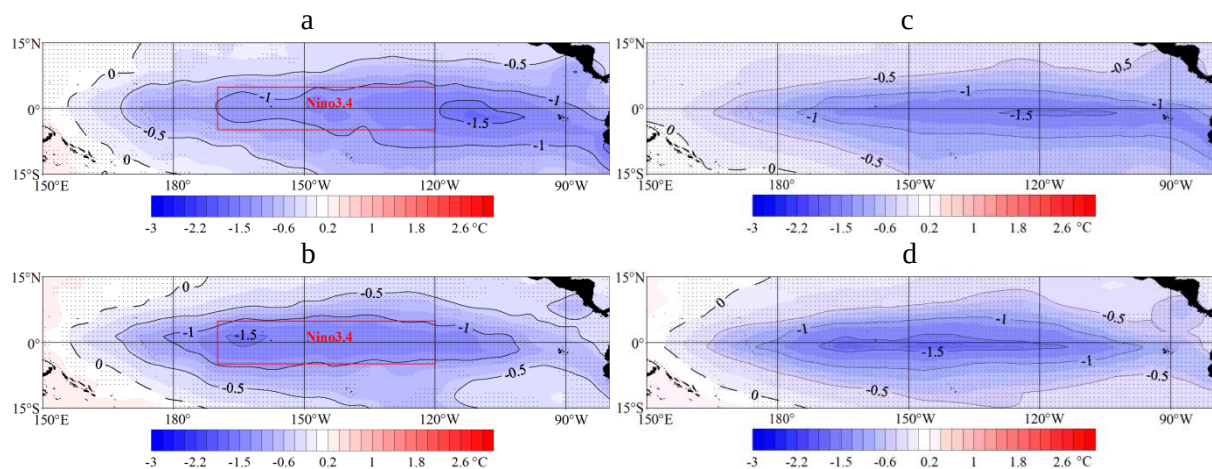


Figure 2. Composites of SSTA spatial distribution by HadISST (a, b) and COBE SST2(c, d) data sets during the mature La Nina phase in October-November in 1900 – 2014 for the EP La Nina type (a, c) and CP La Nina type (b, d). The areas with 95% statistical significance are dotted.

The average composite anomaly during the CP La Nina type is approximately $-1.3\text{ }^{\circ}\text{C}$, while the most negative anomaly reached $-2.22\text{ }^{\circ}\text{C}$ in 1988-1989. The CP events usually start in summer, while the period of their mature phase is mostly in November-January. The typical maximum SOI index for 12 CP La Nina events is about 2.69. As for the EP La Nina type, the average anomaly is $-1.10\text{ }^{\circ}\text{C}$ which is less than during EP La Nina events. Some of them occur both in summer and autumn, but all of them reach their maxima in autumn-winter. Their mature phase falls on October-December at 0.9 probability level. The typical maximum value of the SOI index for EP La Nina events is about 1.71 which is about a unit less than the typical SOI value for the CP La Nina events. This considerable difference in the atmospheric pressure index allows to assume that the atmospheric processes play an important role in the EP La Nina development.

4. Manifestations of La Nina types

Two main meteorological characteristics – SLP and T_a in the Atlantic-European region were studied for each month from December «0» to November «+1» La Nina years for 12 EP and 12 CP events in 1900 – 2014. The strongest signal in the Atlantic-European region during La Nina years was noted in winter from December to March. The maximum La Nina response in the North Atlantic is usually in January.

As a rule, the mature phase of EP La Nina type is in October-December, while in the case of CP type it is in November-January. Due to lagged teleconnection La-Nina manifestations in the Atlantic-European region is observed 1-2 month later after its most negative SSTA in the Pacific Ocean. La Nina influence manifests in changes of the North Atlantic Oscillation (NAO) and the East Atlantic (EA) oscillation. CP type is followed by the positive NAO index in that winter, while the EP La Nina type – by the negative one. At the same time, the EA index is negative during both the EP and CP La Nina types, but it is more intense for the EP type.

The composite maps of SLP and T_a in January and February associated with EP La Nina type (12 events) and CP La Nina type (12 events) based on the 20th Century Reanalysis V2c data sets are shown in figure 3. Statistically significant negative SLP anomaly related to EP La Nina years (figure 3 a, b, e, f) is observed in December-February over subtropics and temperate latitudes in the North Atlantic. At the same time positive SLP anomaly is located in the North-East of the Atlantic-European region. This structure of the SLP field corresponds to the negative EA pattern. The analyses of all monthly composites shows that EP La Nina years are accompanied by EA negative phase strengthening, which causes cold winters in the Eastern Europe (figure 3 b, f) and late spring throughout the European region.

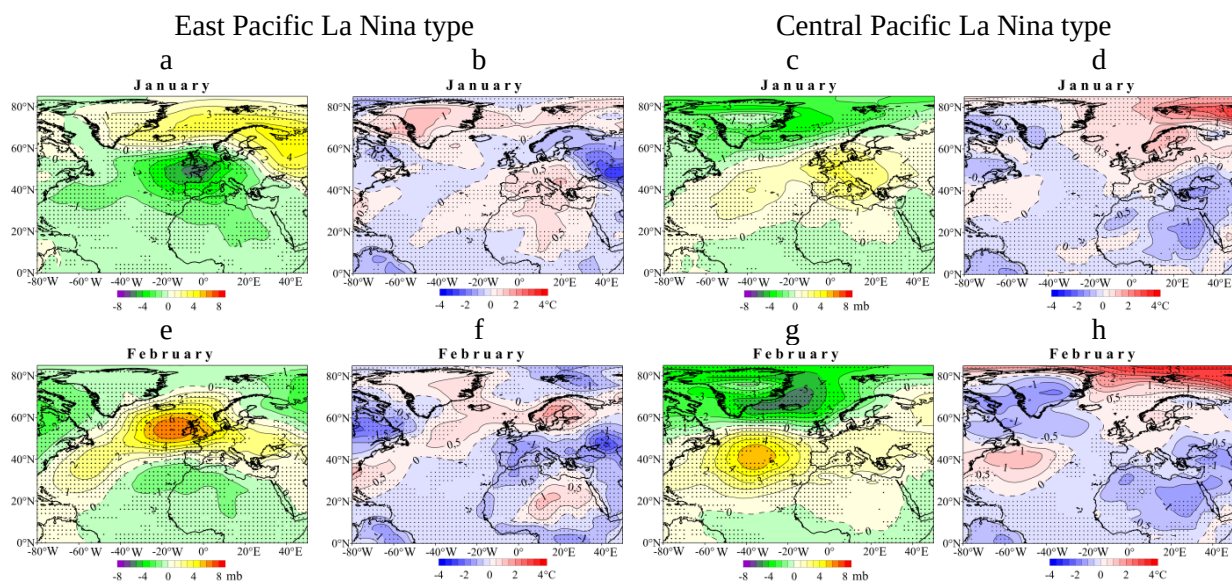


Figure 3. Composites of sea level pressure anomalies (a, e), air temperature anomalies (b, f) during the EP La Nina type (12 events) and composites of sea level pressure anomalies (c, g) and air temperature anomalies (b, d) during the CP La Nina type (12 events). The areas with 95% statistical significance are dotted.

CP La Nina type (figure 3 c, d, g, h) is characterized by the opposite spatial structure of anomalies relative to the EP type. In winter, a positive SLP anomaly is observed in the temperate latitudes (40–60 °N) over the North Atlantic. A negative SLP anomaly is in high latitudes and reaches -6 mb (figure 2 c, g). This structure corresponds to the positive phase of the North Atlantic Oscillation. In this case the trajectories of the North Atlantic cyclones shift about 200–400 km to the North and bring a positive temperature anomaly to the Western and Northern Europe (figure 3 d, h). The characteristic feature is

that due to cyclonic activity a significant positive air temperature anomaly occurs in the Barents Sea region in December - March during the CP La Nina type.

Thus, the La Niña classification implemented in this paper has permitted to find the features of two La Nina types associated with the global processes in the ocean-atmosphere system and their manifestations in the fields of meteorological anomalies by the means of strengthening or weakening of the EA and NAO.

Composites of winter storm tracks during the mature phase (+1 year) of La Nina were obtained. In connection with the limitation of the data set 8 events were considered: 4 of them for are CT and 4 for the ET La Nina types. Composite schemes of storm tracks in January and February calculated for each type of La Nina (figure 4) agree with the composite structure of SLP and air temperature anomalies shown above. North Atlantic storm tracks are more spreaded toward the South during the EP La Nina type (figure 4 a, c) as well as for the negative EA oscillation phase and more concentrated northward for the CP type (figure 4 b, d) as well as for the positive NAO phase. In the result cyclonic activity over the Central Europe and Mediterranean basin intensifies during the EP La Nina type.

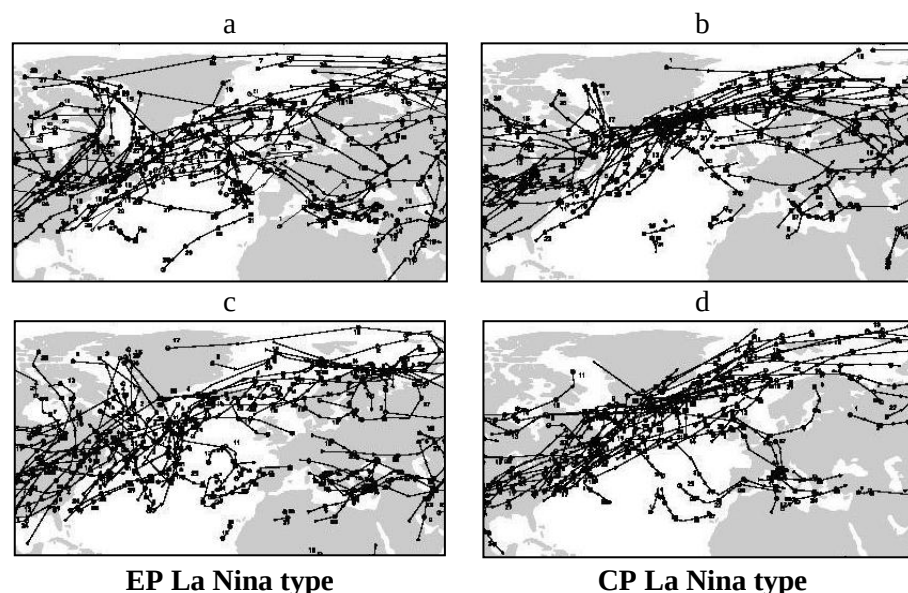


Figure 4. Composite schemes of storm tracks in January (a, b) and February (c, d) in “+1” year of the (a, c) Eastern Pacific La Nina type (1965, 1968, 1971, 1996) and (b, d) Central Pacific La Nina type (1974, 1976, 1984, 1989).

5. Conclusions

On the basis of HadISST and COBE SST2 data sets in 1900 - 2014 using the criteria of -0.5°C SST anomaly and its duration for no less than 5 months in the Nino3.4 region, the La-Nina events were selected and analyzed. It was found that the La Nina contribution in the total variance of the ENSO variability is 48.5%.

Two La Nina types (East Pacific and Central Pacific) were detected using the hierarchical cluster analysis method taking into account the most negative SSTA values and their spatial location in the mature La Nina phase. It was shown that the CP La Nina events are more intense than the EP La Nina events estimated by the SSTA and SOI values. This result confirms the important role of the atmospheric processes in formation of the CP type of La Nina.

The manifestations of the two La Nina types were shown in the meteorological fields of the Atlantic-European region. The EP La Nina years are characterized by the strengthening of the negative

EA phase causing the cold winters in eastern Europe, including the Azov-Black Sea region, with anomalies reaching -2.5°C in January and February. The CP La Nina type manifests in the strengthening of the NAO positive phase which causes a positive air temperature anomaly in western and northern Europe. There is a significant positive air temperature anomaly in the Barents Sea region during the CP La Nina type from December to March due to the cyclonic activity over the region.

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