European temperature anomalies in the cold period associated with ENSO events

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Abstract. El Niño (EN) and La Niña (LN) manifestations in the air surface temperature fields over the Europe are studied in present paper using pan-European E-OBS 19.0e gridded data for 1950-2018 and 20CRv2c reanalysis data for 1870-2014. Particular accent was put on winter severity in the Azov Sea region. Taking into account the Eastern and Central types of both EN and LN events sorted out previously, composites of monthly and ten-day air temperature anomalies were obtained for each type of events. The anomalies of each month from October “0” year (the year when event began) to April “+1” year (the year following “0” year) were analyzed. The typical features of statistically significant manifestations in European air temperature for the Eastern and Central types of EN and LN events were described.

1. Introduction
In the early 2000s, the scientific community established an opinion about the heterogeneity of El Niño (EN) characteristics during their evolution. That led to revealing of a large number of EN classifications. Some later the La Niña also began to be classified [1–8]. Recently, spatial classifications have been most widely used. As a result, both El Niño [1–5] and La Niña are divided into the eastern and central types [6–8] according to criterion of their sea surface temperature anomalies (SSTA) localization in the maximum phase of events development.

Maximum phase of Eastern EN type is characterized by the positive SSTA localization in the area from the South American coast till the central equatorial Pacific while its Central type is characterized by the warm SSTA localization only in the central equatorial part. The classification is validated using the decomposition of more than 100 years SST fields into empirical orthogonal functions [1,2] and other methods of spatial classifications [3–5]. Similarly to El Niño, the La Niña also are revealed in two types according to the criterion of localization of negative SSTA in the maximum phase of the events development [6–8].

ENSO is the most important global interannual signal in the ocean-atmosphere system. Its manifestations in the weather-climate anomalies are noted by number of authors [9–11] not only over the tropical zone, but also in extratropical latitudes over the globe. Such a long-range interaction of the Pacific anomaly is due to feedbacks in the ocean-atmosphere system and is governed by the duration and intensity of SST anomalies [11].

Let us briefly outline the impact of extreme ENSO events on the Atlantic-European region. It is known from [12] that in winter during the El Niño years, sea level pressure decreases over the Southern and Central Europe and increases over Northern Europe, Iceland and Greenland. As a result, zonal circulation over Europe is weakening, which leads to abnormally cold winters over Northern
Europe. In [13, 14], it was shown that the warm and cold ENSO phases significantly affect the North Atlantic Oscillation (NAO) and the Arctic circulation, which play a crucial role in the European and the North Atlantic climate variability. The EN and LN events in the cited works were considered without taking into account their classification. Accounting for the EN and LN types can significantly clarify the climate manifestations in the mid-latitudes of the North Atlantic and Europe.

It is known that the strong EN and LN events are more pronounced in the Atlantic-European region in the cold season than in the warm one [8,12,13]. This is due to the fact that the maximum phases of opposite sign events occur mainly in October, November and December, and taking into account the inertness of the atmosphere, their manifestations are observed some later (1-3 months lag). At the same time, it is known that winter Northern Hemisphere atmospheric circulation is more intense than in summer, due to which the responses to ENSO events are more pronounced.

The study of ENSO events climate manifestations in the Atlantic-European region is really important because weather and climatic anomalies (in part, abnormal cold in winter and spring frosts) lead to economic losses in various fields of human activity.

One of sufficiently important task for South of Russia sustainable development is the climate forecast of the ice conditions in the Sea of Azov. Early prediction of freeze up will protect the transport connection in the region, including the Crimea Bridge. The dynamics of ice formation in winter (increase of thickness and ice quantity) depends primarily on two main factors: air temperature and wind conditions. The total ice accumulation by a certain date is provided by the sum of below zero air temperatures integrated over the time interval started from the first day when the air temperature falls below 0 °C [14]. The sea ice extent of the Azov Sea strongly correlates with the sum of mean daily negative air temperatures during the ice season [14]. Possible impact of ENSO episodes on the Azov basin will be of particular interest here.

Therefore, the aim of present study is to analyze EN and LN types manifestation in the extreme temperature fields during the cold season in the Atlantic-European region, including the Sea of Azov.

2. Data and methods

For analyze climatic anomalies, the daily data arrays on the mean temperature from the E-OBS 19.0e database with the spatial grid of 0.1° × 0.1° in 1950–2018 were used. Additionally, longer series of 20 Century Reanalysis v2c (20CRv2c or 20CR) data with the spatial grid of 2° × 2° in 1870-2014 were used. The analysis of accumulated mean daily temperatures on the coast of the Sea of Azov was carried out by the data of 5 coastal stations (Mariupol, Berdyansk, Genichesk, Opasnoe and Mysovoe) for 1950-2013.

The authors used the classification previously obtained taking into account spatio-temporal features [5] for analyze response to El Niño events. This classification is based on hierarchical cluster analysis (Ward’s method). In this classification the fields of Pacific tropical SSTA from April “0” year (the year when event began) to January “+1” year (the year following “0” year) were using as input data. Every El Nino event were normalized to the standard deviation calculated for the months of each individual event. A measure of the distance between clusters was chosen Euclidean distance. As a result, two types are found: spring-summer eastern (or eastern) and autumn central (or central). The selected classification is generally consistent with common accepted classifications [1,4]

The spring-summer eastern type (CT) is characterized by the intensification of SSTA off the coast of South America and next the anomalies propagate to the central equatorial Pacific. The beginning of these events is observed in April, May and July. They reach their maximum phase in October - December. To this type in 1900-2018 relate 21 EN ET events (1877–1878, 1888–1889, 1896–1897, 1899–1900, 1902–1903, 1904, 1905–1906, 1918–1919, 1925–1926, 1930–1931, 1951, 1957–1958, 1963–1964, 1965–1966, 1969–1970, 1972–1973, 1976–1977, 1982–1983, 1997–1998, 2006–2007, 2015–2016). In the period 1950–2018, only 11 events are included.

The second - the autumn central type (CT). This type is characterized that in the center of the Pacific Ocean both the occurrence of warm SSTA and the localization of this anomaly in the maximum phase development are noted. The begin of the events be in the autumn, mainly in October,
and the maximum phase is reached between November and January. The autumn central type includes 11 events and 12 corresponding years with an observed characteristic anomaly SST (1885–1886, 1911–1912, 1940–1941, 1968–1969, 1977–1978, 1986–1987, 1987, 1991–1992, 1994–1995, 2002–2003, 2009–2010, 2018-2019). For 1950–2018, there are only 9 events associated with the EN CT.

Spatial classification of these events was used for analyze responses to La Niña events [8]. As for El Nino, the classification was carried out on the basis of hierarchical cluster analysis by the Ward’s method. The Euclidean distance was chosen as a measure of cluster proximity. The input to the classifier was the SSTA fields observed in the maximum phase of La Niña (from November to January). The classifier singled out the presence of two types of La Niña, called in the work eastern and central.

La Niña of the eastern type (ET) in the maximum phase is localized in the Nino3 region (5 ° N – 5 ° S, 150 ° W – 90 ° W). In this type, for the analysis period, there were about 14 events of LN ET (1903-1904, 1909–1910, 1916–1917, 1924–1925, 1938–1939, 1942–1943, 1954–1955, 1955–1956, 1964–1965, 1967–1968, 1970–1971, 2005–2006, 2007–2008, 2017–2018). Only 8 events are noted for the period 1950–2018.

The central type (CT) of La Niña in the maximum phase is characterized by the localization of SSTA in the Nino4 region (5 ° N -5 ° S, 160 ° E -150 ° W). In 1900–2018, 13 events and 14 years of relate into this type (1910–1911, 1933–1934, 1949–1951, 1973–1974, 1975, 1983–1984, 1984–1985, 1988–1989, 1998–1999, 1999–2000, 2010–2011, 2011–2012, 2016–2017). The 11 events are noted for the period 1950–2018.

It’s useful to note, that the long-term events of El Niño and La Niña, the duration of which was about 2 years, were analyzed as 2 separate when calculating the responses.

The ten-day composite maps of minimum temperatures for each type were constructed using detailed E-OBS data for analyze the responses in the Atlantic-European region to ENSO events that were evaluated for the cold period, from October “0” year to April “+1” year of the event. Additionally, monthly average composite maps were constructed using a less detailed but longer reanalysis of 20CR. For each ten-days individually and every month, a multi-year trend and seasonal variability were excluded.

The statistical significance of El Niño and La Niña impacts was assessed independently for each type. For this purpose, air temperature values for each grid of the dataset and for each EN/LN type were sampled. For each grid standard two-sample t-test was applied to the sample EN/LN mean and the mean annual value (calculated notwithstanding sample values) assuming samples were taking from the population with unknown variance. The Student's t-test statistic value was calculated using the following formula:

$$t = \frac{|\bar{x} - \bar{y}|}{\sqrt{\frac{n_x D_x + n_y D_y}{n_x + n_y}}} \sqrt{\frac{n_x n_y (n_x + n_y - 2)}{n_x + n_y}},$$

where $D_x$ and $D_y$ are variances of the two samples; $n_x$ and $n_y$ are samples’ sizes. For convenience, all insignificant differences $|\bar{x} - \bar{y}|$ (at the 5% level) were assumed to be zero.

In addition, frequency of the type of anomaly (positive/negative) was estimated at each grid of the domain as follows. If the sign of an anomaly coincided with the composite sign and its absolute value exceeded 0.5°C, the number of matches was calculated and divided by the number of events of the type under analysis. Dark dots on composite maps mark grids with more than 80% of frequency and light dots, if it exceeds 66%.

In this study validity of composite analysis of E-OBS 19.0e data was tested as follows. 100 artificial composite fields consisting of 8, 9 and 11 fields of ten-day temperature were randomly generated (the number of maps corresponds to the number of El Niño and La Niña events of different types observed in 1950-2018). These artificial composites were tested to have areas of “significant” grid points where the frequency of anomaly occurrence was more than 66%. The areas were differentiated on small areas less than 500,000 km² and large areas - more than 500,000 km². An error
probability was evaluated for the ten-day temperatures of January. The results of the assessment for different types of El Niño and La Niña are shown in Table 1.

**Table 1.** The error probability about composite air temperature anomaly maps associated with ET and CT Nino (EN) and La Niña (LN). S is the area of the region of a homogeneous anomaly. The number of CT EN events is indicated by “/”, because E-OBS data is available only until December 2018, and the last CT EN event began in 2018.

| ENSO events | mean ten-day air temperatures | S<500,000 km² | S>500,000 km² |
|-------------|-------------------------------|---------------|---------------|
| ET EN (11)  | 12 %                          | 1 %           |
| CT EN (8/9) | 37 / 28 %                     | 13 / 9 %      |
| ET LN (8)   | 37 %                          |               |
| CT LN (11)  | 12 %                          | 1 %           |

3. Results and discussion

In this paper, we studied the manifestations of two different El Niño and La Niña types in the Atlantic-European region during October-April period. Let’s characterize the most pronounced and significant of them in air temperature anomalies fields.

**Eastern type of El Niño.** Its features are manifested as follows. The third ten-day of November is characterized by positive anomalies in the air temperature fields over the North European part of Russia (EPR). In the next ten-day positive anomaly spreads also over the central and eastern parts of Europe (fig. 1a). A similar pattern is also observed in the third ten-day of December and the first ten-day of January. The maximum anomaly exceeds +4°C in December in the EPR. However the analysis of composite fields using 20CR over a longer period showed that the air temperature anomalies of December are generally insignificant and their repeatability is less than 66%. The next important manifestation was observed in February. In this month is characterized by a stable structure of air temperature field with positive anomalies in the Center and Southeast of Europe and negative one in its Northern part. At the same time, the most striking anomalies arise in the second ten-day of February. They are 3-5°C higher than climatic norm in Southern and Central Europe and have an epicenter in the Krasnodar Krai (a positive anomaly exceeds +4°C). There are negative anomalies (less than –3°C) in its Northern Europe but the repeatability of it does not always exceed 66% (Fig. 1b). A similar pattern is confirmed by the result of calculations using of 20CR data sets (fig. 1c). The repeatability of anomalies fields exceeds 66% for 20 cases of ET EN. The error probability about on the correct anomalies existence does not exceed 1% (table 1).

**Central type of El Niño.** It characterizes by a positive temperature anomaly of up to + 3 °C throughout the Europe except its South-Western part in the third ten-day of November. However, this

![Figure 1. Composite maps of air temperature anomalies in the European region associated with ET EN for the first ten-day of December (a) and the second ten-day of February (b) calculated by E-OBS data set and for the February(c) calculated by 20CR. Light nodal points – repeatability greater than 66%, dark – 80%.](image-url)
anomaly does not last long. Just in the first ten-day of December a negative air temperature anomaly appears in the Center and in the South EPR. Its repeatability exceeds 66%. At the same time, there are positive temperature anomalies up to +4 °C (repeatability 80%) over Scandinavia. In the second ten-day of December, the negative anomaly intensifies and spreads to central Europe. Its minimum locates in the Volgograd and Rostov regions of Russia and reaches –5 °C less than climate norm (fig.2a). The December negative anomaly is also confirmed by the composite maps (11 events), calculated on the basis of 20CR (fig.2d). In January second ten-day the negative air temperature anomalies is observed over the Central and Eastern Europe (fig. 2b), and in the third ten-day it moves to the South and reaches –2...–4°C. A negative anomaly in January is also demonstrated the results of the same calculations using 20CR data (fig. 2e). The another typical feature of CT EN is manifests in a –2 °C decrease of the minimum daily air temperature of April in the Black Sea and Adriatic regions in the second ten-day. Next, in the third ten-day of April, negative anomalies are in the Northern and Eastern Europe (fig. 2c). These April anomalies are confirmed by monthly air temperature composite fields from 20CR data (fig. 2f). The ten-days composite maps have the error probability is 9% for November and December, and 13% for January and April (table 1).

![Figure 2](image)

**Figure 2.** Composite maps of air temperature anomalies in the European region associated with CT EN for the second ten-day of December (a), the second ten-day of January (b) and the third ten-day of April (c) calculated by E-OBS data set and monthly December (d), January (e) and April (f) calculated by 20CR. Light nodal points – repeatability greater than 66%, dark – 80%.

**Eastern type of La Niña.** The temperature anomaly in the first ten-day of October is positive in the north of Europe. In the second ten-day, its spreads to the East Europe too. The maximum anomaly reaches +2...+3°C in the third ten-day of October in the eastern of Europe and the Black Sea region (fig. 3a). A positive October anomaly is confirmed on more complete composites (13 ET LN events) by 20CR (fig. 3b). A similar pattern of positive air temperature anomalies is also observed in the second ten-day of November. Next climatic responses to ET LN are observed in February. In the third ten-day of February and in the first ten-day of March an intense negative air temperature anomalies are obtained practically all over the Europe (except Turkey and Georgia). The minima of temperature anomalies less than –6 °C occupies the territory of Finland (fig. 3c). In the Scandinavian region stable cold conditions have –4...–5 °C anomalies and repeat in the second and third ten-days of March and the first ten-day of April. Using 20CR in the March the these negative anomalies field is confirmed
only over the West Europe. The error probability calculated on the basis of E-OBS reconstruction data set is 13%.

Figure 3. Composite maps of air temperature anomalies in the European region associated with ET LN for the third ten-day of October (a) and the first ten-day of March (c) calculated by E-OBS data set and monthly October (b) calculated by 20CR. Light nodal points – repeatability greater than 66%, dark – 80%.

Central type of La Niña. The field of negative temperature anomalies (minimum of up to –3 °C) during the CT LN in the second and third ten-days of November is located in the central and Eastern Europe. The repeatability of this anomaly is mainly 66% (Fig. 4a). This anomaly is partially confirmed in the monthly average composite field of air temperature anomalies calculated using 20CR data (Fig. 4b). In the third ten-day of December and the first and second ten-days of January, steadily warm weather locates in the Baltic region and in Great Britain. Their maximum values are +2..+3°C. A similar pattern also corresponds to ten-day anomalies in the third ten-day of February (Fig. 4c). The third ten-day of March and the first ten-day April are also characterized by positive air temperature anomalies (on average + 2 °C) in the East Europe (covering Ukraine, Poland, Belarus and the Baltic countries). In general, the cold anomalies in winter and spring of “+1” year are not typical manifestation for CT of La Niña. The error probability about the obtained anomalies does not exceed 1%.

Figure 4. Composite maps of air temperature anomalies in the European region associated with CT LN for the third ten-day of November (a) and third ten-day of February (b) calculated by E-OBS data set and monthly November (b) calculated by 20CR. Light nodal points – repeatability greater than 66%, dark – 80%.

Particular study on severity of winter in the Azov Sea region depending on the EN and LN types was carried out. Computations were made for the period 1950-2013 based on the data of five meteorological stations located at the coast of the Azov Sea (Mariupol, Berdyansk, Genichesk, Opasnoye and Mysovoye). Magnitude of winter severity was estimated using standard methodology [15] which assumes summation of negative values of the mean daily air temperature for October to April period. The sum below -400°C indicates severe winter, for temperate winter this sum is within -200 – -400°C, for mild winters – above -200°C.
The analysis showed that severe winters for the Azov region are typical for 13% of cases, temperate ones - for 36% and mild winters - for 52% (Table 2 and Fig. 5). At the same time the number of mild winters associated with ET EN is 66%, while there are 30% of temperate winters and only 4% of the severe ones. The characteristic of CT EN is the increase of temperate and severe winters number by 5 and 17% relative to the average, which corresponds to 41 and 29%. It needs to note that the results for both ET and CT El Niño are in good agreement with the composite fields of temperature anomalies in the E-OBS and 20CR data sets. It can be explained by the uniformity of responses during cold periods for different types of phenomena. For CT LN, the number of severe winters does not change, but temperate becomes more (45%), and less mild (42%). Winters in the CT LN years are of about the climatic norm. In general, the La Niña events manifestations in winter conditions over the Azov region is weakly expressed, and in the case of the Central type, it is completely absent.

Thus, the features of regional and local manifestations of different types of El Niño and La Niña on Europe and the Sea of Azov are shown.

Table 2. Climatic responses of different types El Niño and La Niña to the frequency of severe, temperate and mild winters in the Azov Region

| Events | Mild | Temperate | Severe |
|--------|------|-----------|--------|
| All (1950-2013) | 51,7 | 35,6 | 12,7 |
| ET EN | 66,0 | 29,8 | 4,3 |
| CT EN | 29,4 | 41,2 | 29,4 |
| ET LN | 41,9 | 45,2 | 12,9 |
| CT LN | 51,0 | 34,7 | 14,3 |

Figure 5. Climatic responses of different types El Niño and La Niña to the frequency of severe, temperate and mild winters in the Azov Region and comparison with the climate period 1950-2013

4. Conclusion
As a result of the analysis of 10-days composite maps of daily temperature, the significant typical climate temperature anomalies in the Atlantic-European region and in the level of winters severity in the Sea of Azov area the associated with EN and LN were revealed.

ET EN is accompanied by a temperature increase by 3 °C in the third ten-day of November in the North of European territory of Russia, and in the next ten days - in the its Center, in the East and North of Europe. A similar situation is repeated in the third ten-day of December and the first ten-day of January, but their maximum anomaly is more than +4 °. In February, especially in the second ten-day, more than +4 °C anomalies are typical for the Central and Southern Europe (except for the territory of Spain and Portugal).

In the third ten-day of November, CT EN is characterized by a positive temperature anomaly of up to +3 °C in most of Europe, except its South-West. In the first ten-day of December, a negative anomaly (which reaches −5 °C) arise in the Center and South of the European Russia, and next, in the
second ten-day of December in South-Eastern Europe. In the second ten-day of January, a negative anomalies of $-2$–$-4$ °C are over the Central and Eastern European Russia are typical, and in the third ten-day period the anomalies move to the South. A temperature decrease by $-2$ °C less than normal in the second and third ten-days of April are typical for the Black Sea and Adriatic regions, as well as in the northern and eastern parts of Europe.

ET LN is accompanied by persistent positive temperature anomalies from the first ten-day of October to the second ten-day of November in the Eastern and Northern Europe. In late February and early March, pronounced negative temperature anomalies are located throughout Europe, except Turkey and Georgia. Minimum anomaly of $-6$ °C is in the Northern Europe is still existed until the first ten-day of April.

CT LN. The second and third ten-days of November are characterized by a negative temperature anomalies field. Its minimum is of $-3$ °C in Central and Eastern Europe. From the third ten-day of December till the second ten-day of January, as well as in the third ten-day of February, there is steadily positive temperature anomaly (of $+2$ - $+3$ °C) in the Baltic States and Great Britain is typical. The third ten-day of March and the first one of April are characterized by positive temperature anomalies (average $+2$ °C) too in eastern Europe, including Ukraine, Poland, Belarus and the Baltic countries.

As for the Azov Sea, mild winters was found to be likely occur (66%) after the ET EN than temperate winters (30%). Occurrence of severe winters after the ET EN is only 4%. In contrast, probability of severe winter after the CT EN is significantly higher – 30%, for temperate winter - 41%, while mild winters has only 29% of occurrence. La Niña types do not have a significant impact on winter severity in the Azov Sea region. These features indicate its potential to be a long-range predictor for ice formation in the Azov Sea.

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