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Manifestation of Equatorial Processes in Water Vapor Variations Over Europe

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Abstract—We studied the variations in time series of the near-surface water vapor partial pressure on the territory of Europe over a multiyear period. It is found that the contribution of fluctuations on time scales from 2 to 5 years is from 35 to 60% of the variance of the interannual variations. The spatial dependences of the local coherence between harmonics on 2–4 scales of Niño3.4 index and the water partial pressure in Europe are determined. We determined that the correlation of these variations reaches 0.7–0.9. It is shown that westward-propagating planetary waves play a significant role in energy transfer from equatorial regions to midlatitudes. This energy begins to increase in the winter of an El Niño year and reaches the maximum a year later.

Keywords: near-surface water vapor partial pressure, El Niño – Southern Oscillation, planetary waves

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Water vapor plays an important role in the thermodynamics of the atmosphere and in the physics of atmospheric aerosol [1]. As estimated in [2], its percentage of the greenhouse effect is up to 50%, and the percentage of clouds, also associated with the atmospheric water vapor content, is 25%. Like temperature and precipitation trends [5], the variations in water vapor also characterize climate changes [3, 4].

In [6] it is shown that the variations in the integrated water vapor content and water vapor partial pressure are coherent and related to macrocirculation processes. The authors hypothesized that the interannual variations in atmospheric water vapor content depend on atmospheric dynamics, the most prominent manifestation of which is considered to be the El Niño – Southern Oscillation (ENSO). Alternation between warm conditions of El Niño and cold conditions of La Niña represents the strongest interannual oscillation of the global climate system. El Niño events are characterized by surface heating in the tropical part of the Pacific Ocean and the weakening of equatorial trade winds, occurring every few years. These conditions are accompanied by changes in the atmospheric and oceanic circulations, influencing the global climate and marine and ground ecosystems. In particular, El Niño influences substantially the mid- and high-latitude atmospheric dynamics [7, 8].

In this work we will try to identify the possible manifestations of equatorial processes in the variations of the atmospheric water vapor content over Europe.

The Nino3.4 index of temperature anomalies on the ocean surface is usually used as an ENSO characteristic. Monthly indices are available from 1950 to the present [9]. The index represents anomalies of the average sea surface temperature (SST) in the region bounded by −5 and 5° S and 170 and 120° W. This index is highly variable on the El Niño timescales [8]. The El Niño/La Niña event is considered to have happened if the five-month sliding average of the Nino3.4 index exceeds +0.4°C for El Niño or −0.4°C for La Niña for at least six consecutive months.

In [6] we compiled long time series of near-surface water vapor content over Europe that was determined from meteorological parameters. The eight-time measurements of the relative humidity and temperature were used to estimate the water vapor partial pressure e. We employed data from different European meteorological services [10] and Rosgidromet archive for the territory of Russia [11].

The ENSO energy is considered to be mostly in the range of 2–7 years [7, 12]. Bandpass filtering of time series of water vapor partial pressure was used to determine the contribution of fluctuations in this time interval, found to be from 35 to 60% of the variance of the annual average e values, depending on the observation site; this is comparable to the contribution from the linear trend, usually applied in analysis of interannual variations [5].

We sought coherent events on the same timescales in time series of water vapor content and Nino3.4

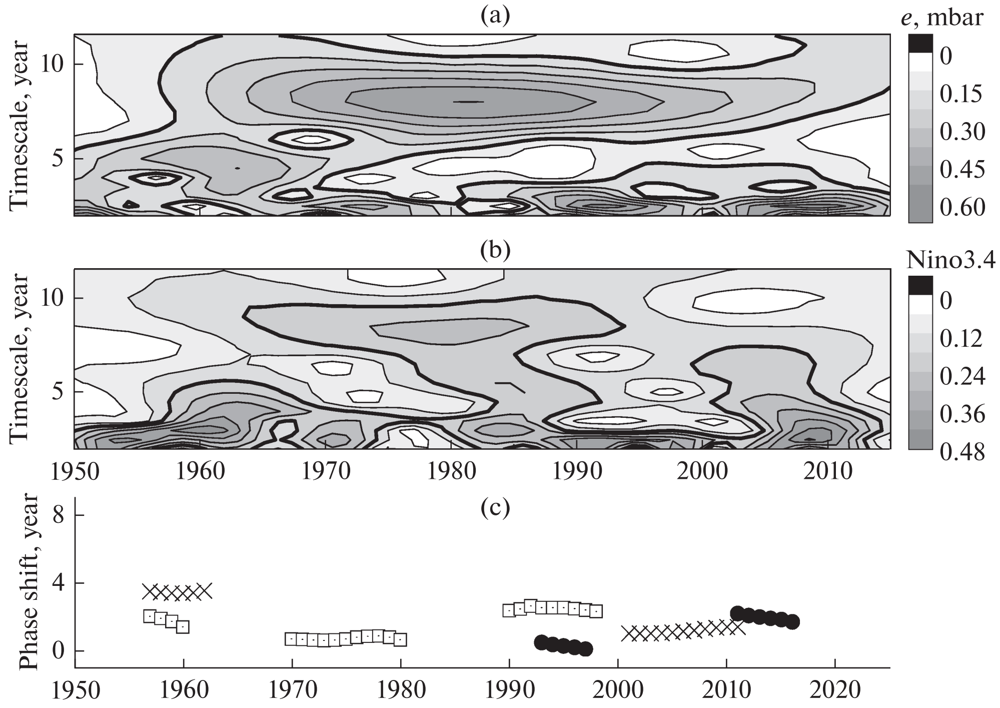

Fig. 1. Amplitude wavelet spectra (90%-significance level is shown by semibold line): of (a) water vapor partial pressure (Norway); (b) Nino3.4 index; and (c) their phase cross-spectrum for oscillations significant at 90% probability on timescales of 2.5 (□), 3 (●), and 4 (×) years.

index by analyzing their wavelet spectra. The wavelet spectrum, obtained using the Morlet parent function, extracts a quasi-periodic signal on a required timescale and localizes its amplitude and phase in time (the method was developed in [13] to search for coherent variations in time series of atmospheric parameters and admixtures). In these wavelet spectra, referenced to a single period of time, we selected significant (at no less than 90% probability) disturbances, identified simultaneously in time series of the water vapor content and Nino3.4 index. It is well known that, when a periodic process is present, its phase does not change in time [14]. The main criterion in selecting coherent variations, i.e., the distribution of the difference between phase spectra for a given timescale, has a narrow maximum during the time when the amplitude spectra exceed the 90%-significance level. The significance level was estimated in [15] according to the chi-squared test using the white noise model. The constancy of phase characteristics indicates that processes are coherent, with the wavelet transform localizing these processes in time. The timescales of variations and their amplitudes and time referencing were determined in such a way.

Figure 1 presents an example of amplitude wavelet spectra of water vapor partial pressure (Norway) and Nino3.4 index together with their phase cross-spectrum for oscillations significant at 90% probability on timescales of 2.5, 3, and 4 years.

A wavelet transform of a time series shows that water vapor content, like the Nino3.4 index, contains significant quasi-periodic variations on timescales of 2–5 and 6–8 years. It can be seen that the variations on timescales of 2–3 years are more intense; however, they are not constant, but occur and decay, sometimes in the form of a few modes simultaneously. Analogous synchronous variations were detected in time series of the near-surface temperature on the entire territory of Europe. Meteorological parameters on the territory of Europe vary coherently with the Nino3.4 index in an irregular fashion: the coherence appears, continues for a few years, and then disappears.

To estimate the level of the linear interrelation between these quasi-periodic variations in time series of water vapor content in separate periods of time, we studied the local wavelet correlation [16] between variations (on timescale of 2–4 years) in the Nino3.4 index and water vapor partial pressure on the European territory of Russia. The water vapor data, homogeneous in quality and time coverage, and obtained at a dense network of stations, made it possible to construct the spatial dependences of phase and correlation characteristics of the link between water vapor content and the Nino3.4 index. Unfortunately, the available long time series of water vapor content over western Europe are much more sparsely spaced and, as such, could not be included in the analysis.

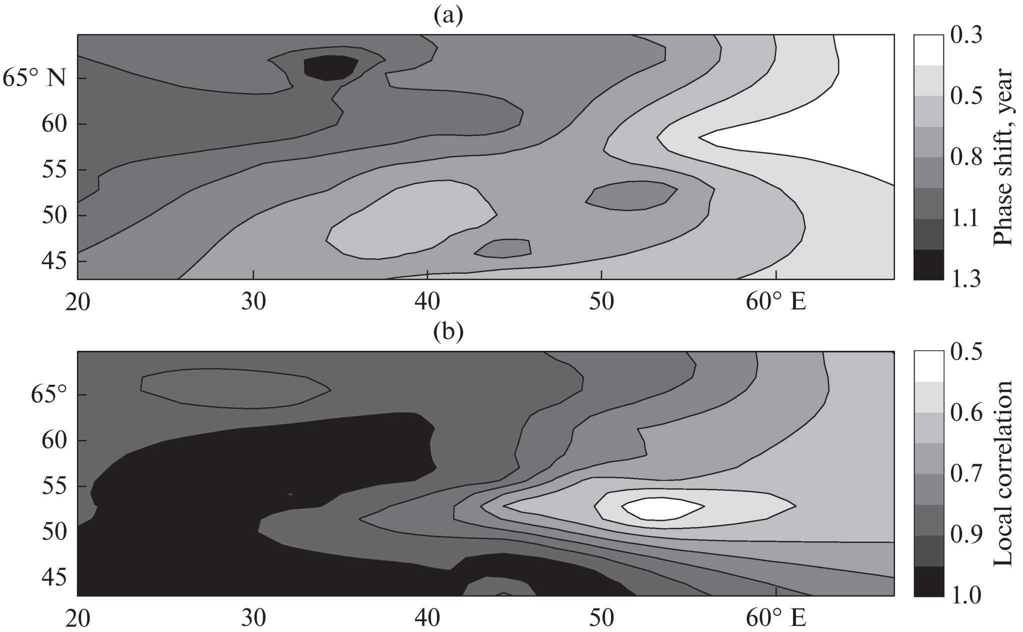

Fig. 2. Spatial dependence of (a) the cross-spectral phase shift and (b) and local wavelet correlation between 3-year periodicity of the Nino3.4 index and near-surface water vapor partial pressure on the European territory of Russia during 2008–2016.

It was found that, during the periods when variations on each timescale are significant, the correlation between these variations is 0.7–0.9 at the 95%-significance level. The phase cross-spectrum in all events indicated that these variations propagated from east to west. A characteristic example of how local wavelet correlation and cross-spectral phase shift (of variations on three-year timescale) of the Nino3.4 index and water vapor partial pressure are distributed in space during 2008–2016 is presented in Fig. 2.

In [17] it was concluded that ENSO had influenced the North Atlantic Oscillation in the second half of the twentieth century and at the beginning of the twenty-first century, characterized by about two-year delay. No opposite effect with a similar degree of reliability was found. Hence, the variations in atmospheric circulation will also determine the field of water vapor content in Europe.

We will discuss how ENSO energy is transferred to midlatitudes. In [18] it is suggested that the ENSO energy is transferred to high latitudes via planetary waves and, in particular, with the participation of Kelvin waves. In work [7] it is argued that the energy of El Niño events is transferred to middle and high latitudes by Rossby waves. In [19] the wintertime (November–March) ERA-Interim reanalysis data for geopotential in the troposphere and stratosphere from 1979 to 2016 are used to analyze the spectra of wave disturbances with zonal numbers $1 \le k \le 10$. It is found that the energy of eastward-propagating waves may be a factor of 1.5–2 larger in El Niño than La Niña years in the tropical and subtropical troposphere and in the subtropical lower stratosphere.

It was shown earlier that waves with characteristics close to those of Kelvin waves are found in midlatitudes; they propagate westward and have periods of 10–60 days [20]. That is, Kelvin waves can be identified at midlatitudes; and the variance of synoptic-scale fluctuations in pressure may serve as a measure of their intensity. In order to determine how the intensity of wave activity is related to the ENSO in the range of Kelvin waves, we applied bandpass filtering to time series of the near-surface pressure and obtained time series of the variance of pressure fluctuations in a band from 10 to 60 days on the territory of Europe and compared the average fluctuations in El Niño and La Niña years.

It is found that, in contrast to La Niña years, in wintertime of El Niño years the wave activity of fluctuations in near-surface pressure with periods of 10–60 days increases on average by 12% relative to multiyear average wintertime levels, and decreases, on average, by 25% in summertime. We note that the variance of synoptic-scale fluctuations of pressure is a factor of 2–4 larger in winter than summer, making the summertime reduction of wave activity insignificant. This effect persists into the next year: a year after El Niño the wave activity with the periods of 10–60 days is, on average, 15% higher as compared to La Niña years.

We estimated the intensity of wave processes as anomalies in the variance of synoptic-scale variations in the near-surface pressure relative to the multiyear average level for each month. In all time series of pressure fluctuation anomalies we detected variations synchronous with the Nino3.4 index on the same timescales as in time series of near-surface temperature and near-surface water vapor partial pressure. The local wavelet correlation between pressure fluctuation anomalies and the Nino3.4 index, when these fluctuations exist, reaches 0.8–0.9 at no lower than the 95%-significance level. The spatial maps of the phase cross-spectrum indicate that these variations propagate from east to west; the maximum of the pressure fluctuation anomalies lags the maximum of the Nino3.4 index by about 1 year in all cases.

It can be concluded that the El Niño – Southern Oscillation makes a significant contribution to the interannual variations in water vapor content on the territory of Europe, with an important role in the ENSO energy transfer being played by westward-propagating planetary waves. The energy of these waves starts to increase during winter of an El Niño year and reaches a maximum a year later.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. M. V. Panchenko, S. A. Terpugova, V. S. Kozlov, V. V. Pol'kin, and E. P. Yausheva, "Annual behavior of the condensation activity of submicron aerosol in the atmospheric surface layer of Western Siberia," Atmos. Ocean. Opt. **18** (8), 607–611 (2005).
2. G. A. Schmidt, R. A. Ruedy, R. L. Miller, and A. A. Lacis, "Attribution of the present day total greenhouse effect," J. Geophys. Res. **115** (D20106), 1–6 (2010).
3. V. N. Malinin, S. M. Gordeeva, and L. M. Naumov, "Total precipitable water of the atmosphere as a climate forcing factor," Sovremennye Problemy Distantsionnogo Zondirovaniya Zemli Kosmosa **15** (3), 243–251 (2018).
4. J. Morland, CoenM. Collaud, and K. Hocke, "Tropospheric water vapor above Switzerland over the last 12 years," Atmos. Chem. Phys. **9**, 5975–5988 (2009).
5. Yu. P. Perevedentsev, A. A. Vasil'ev, K. M. Shantalinskii, and V. V. Gur'yanov, "Long-term variations in surface air pressure and surface air temperature in the Northern hemisphere mid-latitudes, Rus. Meteorol. Hydrol. **42** (7), 461–470 (2017).
6. O. G. Khutorova, V. E. Khutorov, and G. M. Teptin, "Interannual variability of surface and integrated water vapor and atmospheric circulation in Europe," Atmos. Oceanic Opt. **31** (5), 486–491 (2018).
7. I. Herceg-Bulic, B. Mezzina, F. Kucharski, P. Ruggieri, and M. P. King, "Wintertime ENSO influence on late spring European climate: The stratospheric response and the role of North Atlantic SST," J. Climatol. **37** ((S1)), 87–108 (2017).
8. A. Timmermann, An Soon-Il, Jong-Seong Kug, Fei-Fei Jin, WenjuCai, A. Capotondi, Kim M. Cobb, M. Lengaigne, M. J. McPhaden, M.F. Stuecker, K. Stein, A. T. Wittenberg, Kyung-Sook Yun, T. Bayr, HanChing Chen, YChikamoto., B. Dewitte, D. Dommenget, P. Grothe, E. Guilyardi, Yoo-Geun Ham, M. Hayashi, S. Ineson, DaehyunKang, SunyongKim, WonMooKim, June-Yi Lee, Tim Li, Jing-Jia Luo, S. McGregor, Y. Planton, S. Power, H. Rashid, Hong-Li Ren, A. Santoso, K. Takahashi, A. Todd, GuominWang, GuojianWang, Ruihuang Xie, Woo-HyunYang, Sang-WookYeh, JinhoYoon, E. Zeller, XuebinZhang, "El Niño—Southern Oscillation complexity," Nature **559**, 535–545 (2018).
9. http://origin.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml#history.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php (Cited November 25, 2018).
10. www.ecad.eu (Cited November 25, 2018).
11. http://meteo.ru/data/163-basic-parameters (Cited November 25, 2018).
12. P. Llamedo, R. Hierro, A. de la Torre, and P. Alexander, "ENSO-related moisture and temperature anomalies over South America derived from GPS radio occultation profiles," J. Climatol. **37**, 268–275 (2017).
13. O. G. Khutorova and G. M. Teptin, "An investigation of mesoscale wave processes in the surface layer using synchronous measurements of atmospheric parameters and admixtures," Izv., Atmos. Ocean. Phys. **45** (5), 549–556 (2009).
14. G. Dzhenkins and D. Vatts, *Spectral Analysis and Its Applications*. Vol. 1 and 2 (Mir, Moscow, 1971) [in Russian].
15. G. Torrence and G. P. Compo, "A practical guide to wavelet analysis," Bull. Am. Meteorol. Soc. **79** (1), 61–78 (1998).
16. V. A. Bezverkhnii, "Development of the wavelet-transform method for the analysis of geophysical data," Izv. Akad. Nauk. Fiz. Atmos. Okeana. **37** (5), 630–638 (2001).
17. I. I. Mokhov and D. A. Smirnov, "Study of the mutual influence of the El Niño-Southern Oscillation processes and the North Atlantic and Arctic Oscillations," Izv., Atmos. Ocean. Phys. **42** (5), 598–614 (2006).
18. S. Jevrejeva, J. C. Moore, and A. Grinsted, "Oceanic and atmospheric transport of multiyear El Nino—Southern Oscillation (ENSO) signatures to the polar regions," Geophys. Rev. Lett. **31**, L24210 (2004).
19. V. V. Gur'yanov, A. V. Eliseev, I. I. Mokhov, and Yu. P. Perevedentsev, "Wave Activity and Its Changes in the Troposphere and Stratosphere of the Northern Hemisphere in Winters of 1979–2016," Izv., Atmos. Ocean. Phys. **54** (2), 114–126 (2018).
20. O. G. Khutorova and G. M. Teptin, "Local and planetary scales of wave disturbances for synchronous measurements of atmospheric admixtures," Dokl. Earth Sci. **400** (1), 89–91 (2005).

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