

## Inter-annual variability of variations of ground and integrated atmospheric water vapor content in Europe

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**Abstract.** This paper presenting results of the seasonal, interannual mesoscale and synoptic variations of the surface and atmosphere integral moisture content variability analysis. More than 50 years of the meteorological network data and data from satellite navigation system receivers on Europe were analysed. The surface moisture content field in Europe decreases with increasing latitude and further from the coast. The intensity of variations in the partial pressure of water vapour, on the contrary, increases from northwest to southeast. It is shown, that the maximum contribution to the moisture content variability is given by seasonal variations. The predominant process of near ground and integrated atmospheric water content is year and half-year harmonics. In near ground and integrated atmospheric water content spectra the interannual variations were discovered. It is shown that the average annual values of the integral humidity, amplitude and phase of the annual and semiannual harmonics vary from year to year, as well as the intensity of the synoptic variations.

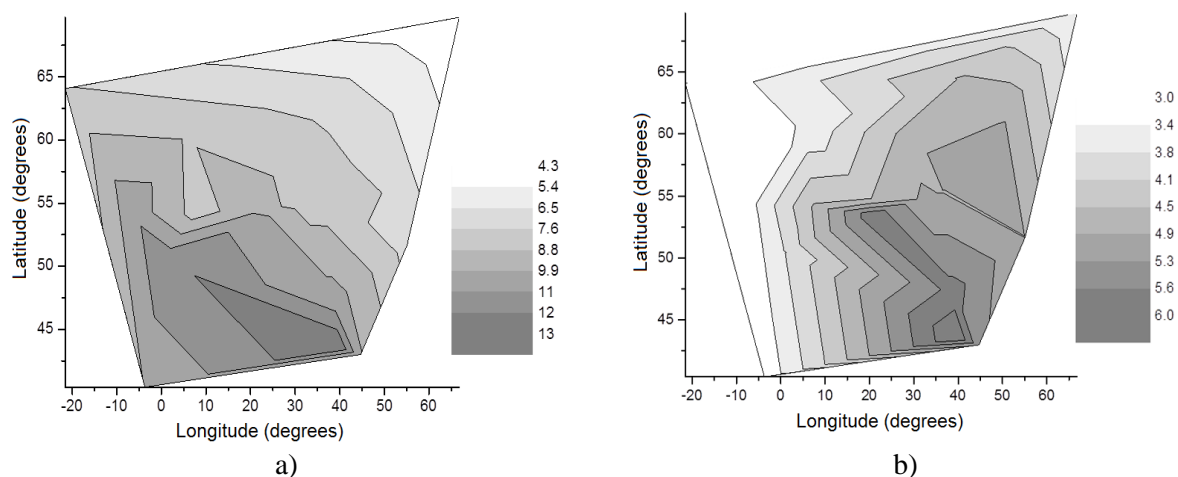
Last decades have shown a strong influence of climate variability on the main risks for the economy and ecology of the regions [1]. Temperature trends in different degrees are manifested in the regions of the Northern Hemisphere [2]. With increasing temperature, moisture content variability is often associated [3]. Water vapor plays a key role in the radiation balance of the Earth's atmosphere, as a result of which the water vapor content temporal and spatial variations at the interannual, synoptic and mesoscale level are closely interrelated with changes in the other meteorological fields and geophysical elements. In this case, one of the most important tasks is to search for the interannual regularities in the evolution of atmospheric moisture content variations.

In this work, long series of the atmosphere integral moisture content were constructed, calculated according to the GNSS receiver's every-second observations from the Kazan network [4] world service IGS GNSS in years of 2000-2016 [5]. The surface moisture content was estimated from the meteorological parameters [6] for years of 1966-2015. From the measurements of relative humidity and temperature, the partial pressure of water vapor was calculated  $e$ . The series of surface parameters are longer and allow the use of spectral analysis to highlight interannual variations. However, recently the development of the GPS – meteorology, which uses signals from global navigation satellite systems (GNSS) has been developed, which allows determining the integral moisture content (IWV) with high spatial-temporal resolution [4]. In Kazan, there is a network of receivers and it is shown that, according to GNSS receivers, it is possible to study temporal variations in atmospheric parameters over a wide range of time scales [7, 8].

Figure 1 shows the spatial cross sections of mean annual values of the partial pressure of water vapor and its standard deviation. Obviously, on the average, the surface moisture content field in



Europe decreases with increasing latitude and away from the coast. The intensity of variations in the partial pressure of water vapor, on the contrary, increases from northwest to southeast. The contribution to variance of variations in the partial pressure of water vapor yields all the processes from mesoscale to interannual.



**Figure 1.** a) Spatial dependence of mean annual values of the partial pressure of water vapor  $e$ , mbar; b) The spatial dependence of the value of the standard deviation of the partial pressure of water vapor  $\sigma_e$ , mbar.

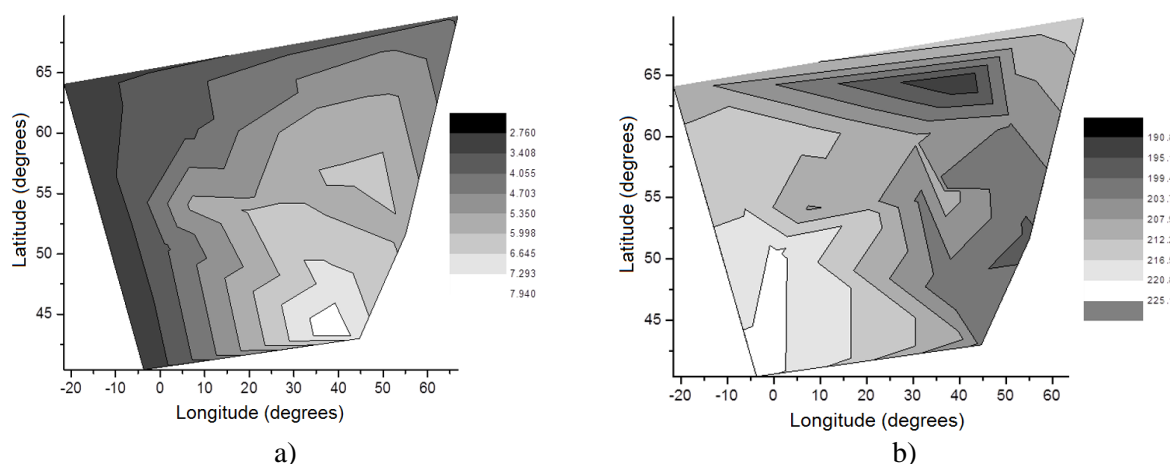
The strongest in the spectra of both the partial pressure of water vapor and the integral moisture content are seasonal variations. Their amplitudes for several points are given in table 1.

**Table 1.** Periods and amplitudes of significant periodicities in the series of surface partial pressure of water vapor.

Location	Murmansk 69.0 N 33.0 E	Moscow 55.8 N 37.6 E	Kaliningrad 54.7 N 20.5 E	Sochi 44.6 N 39.7 E
Mean value, mbar	5.8	8.3	9.0	12.8
12 month, amplitude mbar	1.0	2.9	1.2	1.6
6 month, amplitude mbar	0.3	0.5	0.2	0.3

Figure 2a shows the spatial dependence of the amplitude of the annual harmonic of surface water content in Europe. As can be seen from table 1 and figure 2a, the mean annual values of the partial pressure of water vapor have a strong latitudinal dependence, related both to the inflow of solar radiation and to the influence of moist air masses. Spatial variability in Europe is from 2 to 8 mbar on average over 50 years.

Figure 2b shows the spatial dependence of the maximum time of the annual harmonic of surface water content in Europe. The time lag of the maximum from the maximum of the solar radiation influx (170-180 days) characterizes the influence of the ocean, its spatial variability in Europe from 180 to 220 days on average over 50 years.

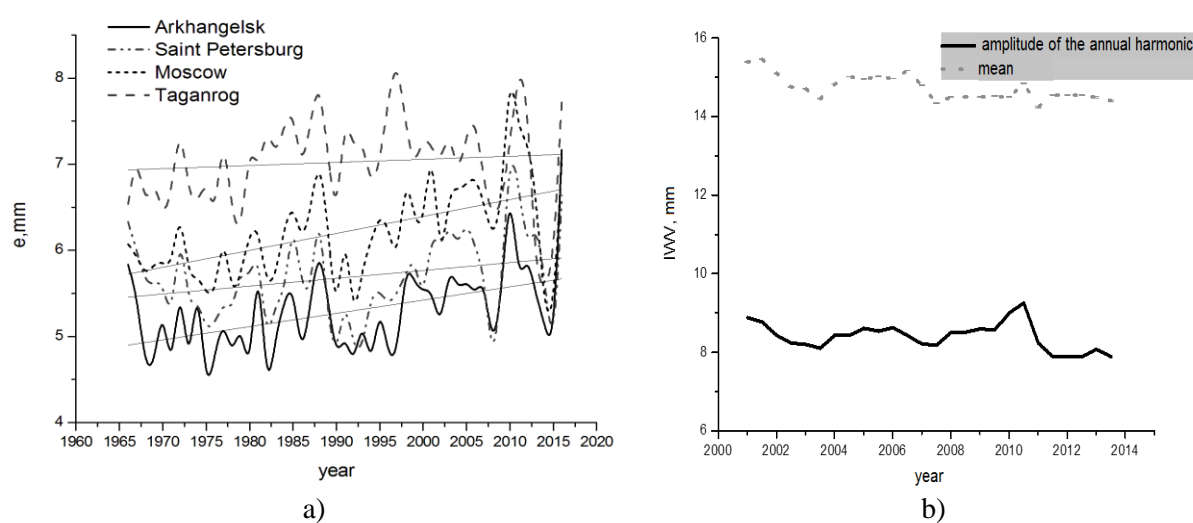


**Figure 2.** a) Spatial dependence of the amplitude of the annual harmonic of the surface moisture content, mbar; b) Spatial dependence of the maxima time of the annual harmonic of the surface moisture content, day.

Harmonic analysis of time series of surface moisture content in a sliding time window showed that both the mean annual values of the integral moisture content, so the amplitudes and phases of the annual and semiannual harmonics vary from year to year.

Figure 3a shows the interannual variations of the annual harmonic amplitudes for several points in the European territory of Russia and their linear trends. It can be seen that the amplitudes of the annual harmonic increase on average with time, but the angle of inclination of the trend is varies with the continentality index of the each site.

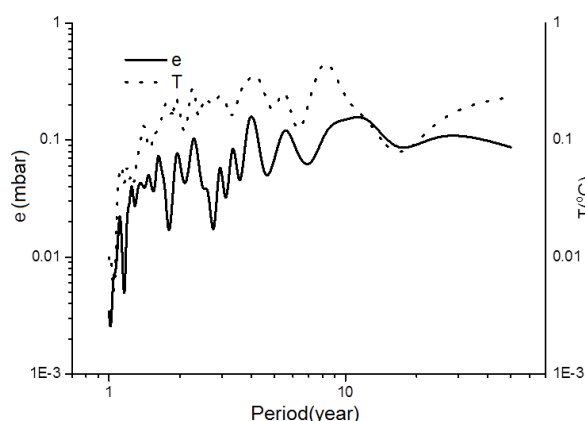
However, a detailed analysis shows that, since 2000, there has been no trend towards an increase in the amplitudes. The same effect can be seen in figure 3b, which shows the interannual variations of the mean annual values of the integral moisture content and the amplitude of the annual harmonic for the city of Potsdam (Germany).



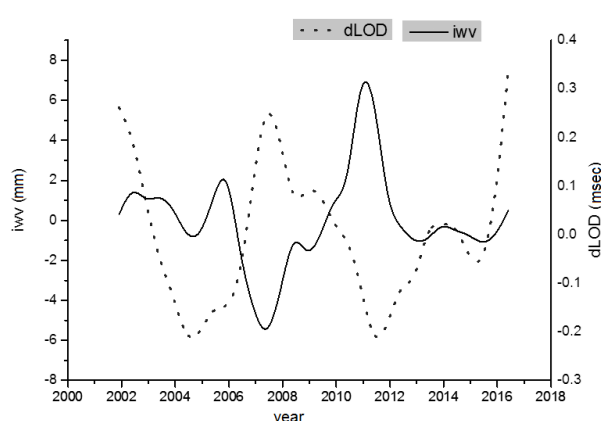
**Figure 3.** a) Interannual variations of the annual harmonic amplitudes for several points in the European territory of Russia and their linear trends. b) Interannual variations of the integral moisture content mean annual values, the amplitude of the annual harmonic for Potsdam (Germany).

To study the interannual variations in the atmospheric moisture content, Fourier analysis [7]. Fourier analysis of 50-year series of surface water content with preliminarily excluded linear trends revealed that in the spectra there are quasiperiodic processes with time scales of 4-5 years, 10 years, 20 years. Similar variations were observed in the series of surface temperature. Figure 4 shows the spectra of partial pressure series of water vapor and surface temperature in the city of Orenburg, Russia. For various sites of Europe periodicity in the spectra reveals similar facts, but the ratio of amplitudes for temperature and water vapor varies at different points.

Due to the fact that the length of the integral moisture content is less than 17 years, the slower variability was analyzed with the help of sliding smoothing of the time series within the annual time window with a step in half a year. Figure 4 shows the interannual variations of the integral moisture content (IWV) series in Olsztyn (Poland) and the variations in the duration of the day (dLOD) with excluded trends. Figure 5 shows that the interannual dynamics of the integral moisture content of the atmosphere and the parameters of the Earth's rotation change in antiphase, that is, the processes are connected. The communication mechanism requires additional research. Perhaps the advection of water vapor and the speed of Earth's rotation depend on the interhemispheric momentum exchange [10] Perhaps for each parameter a harmonica with a period of 18.6 years is allocated associated with the nutation of the earth's axis under the influence of the Moon [11]. Interannual variations and a strong seasonal course of moisture content are also noted from satellite data [12]. Spectra of the integral moisture content there are also harmonics with periods of 4-5 years and about 10 years.



**Figure 4.** Spectra of interannual variations of partial pressure series of water vapor and surface temperature in Orenburg.



**Figure 5.** Interannual variations of the series of integral moisture content (IWV) in Olsztyn city and variations in the duration of the day (dLOD) with excluded trends.

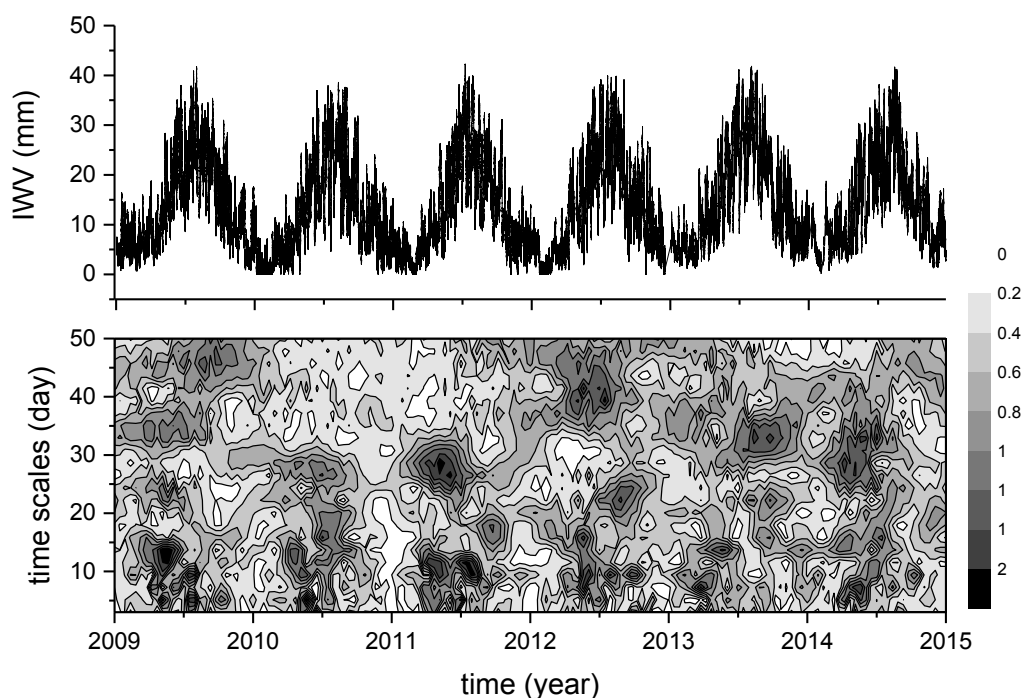
Interannual variations are also present in the variability of intensity of synoptic processes in atmospheric moisture content.

Figure 6 presents a fragment of the atmosphere integral moisture content and its wavelet spectrum for Kazan city (Russia) for 2009-2015 years. It illustrates that in the spectra of synoptic variations there are significant modes 3-4, 7-10, 11-14, 20-30 и 40-45 days.

According to figure 6, it is definite that the intensity of the synoptic variations for all the investigated parameters is modulated by the harmonics of the annual variation. It is determined that in the time series under study, wave variations predominate with periods of 3 to 10 days, which are characteristic of the Rossby waves. However, variations with periods of 15 to 45 days are more powerful, although less frequent. Amplitudes of the variations of integral water vapor during the summer grow from 1 to sometimes 4 mm of precipitated water.

It is shown that the maximum contribution to the variability of moisture content is given by seasonal variations. For Kazan city, with an average value of IWV equal to 13.4 mm of precipitated

water, the annual variation makes the greatest contribution to the overall dispersion; its share is 68%. The second for the contribution to the overall variance are the synoptic variations; their contribution in the dispersion is 20%. The average contribution of mesoscale variations to the overall variability of IWV in Kazan is 12%. Similar ratios of the contributions of different processes to the overall dispersion of variations are also characteristic of other series of integral moisture content in Europe.



**Figure 6.** Integral water content of the atmosphere and its wavelet spectrum by measurements of GNSS receivers in Kazan (Russia) 2009-2015.

Long series of surface and integral water vapor content of the atmosphere in Europe are analyzed. It is shown, that predominant process of near ground and integrated atmospheric water content is year harmonic. In near ground and integrated atmospheric water content mean value the interannual variations were found. Also synoptic and mesoscale processes make important contributions to variability of atmospheric moisture content. It is shown that the average annual values of the integral humidity, amplitude and phase of the annual and semiannual harmonics vary from year to year, as well as the intensity of the synoptic variations.

### Acknowledgments

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