Seasonal and interannual changes in optical thickness of the atmosphere in the Yakutsk array region

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Abstract. The analysis of the atmospheric optical thickness is given. Atmospheric optical thickness is obtained from spectral transparency of the atmosphere by CE318 radiometer. In the paper features of seasonal and interannual AOT of the atmosphere in the period 2004-2014 are discussed. It is noted that AOT measured at the Yakutsk sensitive to restructure of the atmosphere from winter to summer, passage of storm fronts in summer and large-scale wildfires.

1. Introduction

The formation of weather and climate in the regions is played by: microclimate, frequency of air travel (cyclones and anticyclones), including such factors as technogenic catastrophes - active volcanic activity, global forest fires and for the northern latitudes of the greenhouse effect. To monitor the changes in atmospheric parameters, a network of stations was established, located on all continents. The main goal of this project was global monitoring of the atmosphere and detection of changes that could affect the Earth’s climate as a whole. Yakutsk is one of the items in the global chain of stations that supplies such information [1, 2].

At present, data on the optical thickness of the atmosphere (AOT) are analyzed in the context of long-term observations

2. Features of the atmosphere in the central Yakutia

The change in temperature conditions and the micro and macroscopic aerosol characteristics of the atmosphere affect the formation of local weather, and, with prolonged exposure to climatic conditions, as a whole. This is clearly seen from data collected over a 10-year period in the vicinity of Yakutsk. For example, an analysis of the statistical series of observations of air temperature in the surface layers of the atmosphere carried out in [3, 4], using data collected from the extensive air showers (EAS) collected over 40 years at the Yakutsk array, revealed a winter upward temperature trend with a gradient of $\Delta t / 10 = + 0.6^\circ$ (Fig. 1).

The air shower measuring array is in the valley of the Lena River 50 km south-west of Yakutsk and is located at an altitude of 100 m above sea level [5]. According to its geographical coordinates, the facility belongs to central Yakutia. The climate of central Yakutia is extreme continental: in July, air temperature often reaches 35 $^\circ$C, and in winter it drops to -55 $^\circ$C. In the area of the array, the wind prevails in the west and north-west directions. The average annual precipitation is 247 mm. In winter, especially during frosts below -40 $^\circ$C, there is an ice fog
Figure 1. Interannual trend of surface air temperature near Yakutsk.

Figure 2. Vertical profile of air temperature distribution for different moments in time. The green curve (shower from 070589) was obtained in the spring period and corresponds to the standard form.

spreading through the valley. The thickness of a dense layer of the fog does not usually exceed 5-50 m from the surface of the earth. The period with low temperatures at night in the area of the test site lasts more than 6 months, beginning in October and ending in May. At winter time, there is also little precipitation, usually small needle ice crystals.

In winter, the temperature variation in altitude differs significantly from the standard distribution, and a stable temperature inversion is observed in the lower part of the atmosphere. Fig. 2 shows the distribution of air temperature in height. Individual measurements obtained with the help of atmospheric probes in the vicinity of Yakutsk are given. It can be seen from this figure that the dependence of the temperature distribution on height in the winter months is complex. In the winter, there is a gradual increase in temperature from the ground level to heights of 2000-3000 m above sea level, and above, there is a monotonous decrease to extremely low values at heights of 9000 -11000 m.

In the spring and autumn seasons, the temperature distribution in the atmosphere does not differ from the standard, i.e. the fall starts from the ground level. This difference in the temperature distribution over the height in different time periods reflects the distribution of the air density and the passage of optical waves through the troposphere.

3. Observations

Regular observations of the state of the atmosphere at the Yakutsk array began in 1970 and continuous to the present day. An automatic mini station measures the temperature, pressure and humidity of the air. Particular attention was paid to the winter period of observations, since observations of the Cherenkov radiation in the optical wavelength were conducted at the Yakutsk array, and for this reason an estimate of the state of the atmosphere was required [6]. Since 2004, a laser at a wavelength of 532 nm and a radiometer of CE 318 have been used to monitor the atmosphere [7]. On the basis of these measurements, a database on the state of the atmosphere in the area of the Yakutsk EAS installation continued to be formed.

3.1. Seasonal variations of AOT in Yakutsk region

The optical properties of the atmosphere are related to the content of aerosol particles of natural and artificial origin. Usually, observations are made between April and November in automatic
mode. The following characteristics were restored: AOT, albedo of single scattering of aerosol and volume distribution of particles by size.

Within the annual measurements, AOT data were averaged by monthly blocks and then summed over the entire observation period. The result is shown in Fig. 3.

It follows from the data that, in general, the AOT values in the Yakutsk region are small. As can be seen, from Fig. 3, starting from May and August, the average values of AOT in the Yakutsk region are $0.18 \pm 0.02$ and tend to decrease to $0.11 \pm 0.02$ in September-November. In winter, AOT measurement by this method is not carried out at the installation due to a short light day and low sun at the zenith ("polar night"). It can be assumed that the AOT value remains at the same level or even slightly below the average value (equal to $0.08 \pm 0.02$) due to the freezing of a part of the water vapor at very low temperatures. According to observations over a ten-year period of time, there are no noticeable variations of AOT in the data, except for some years, for example, 2012, when long-term and large-scale forest fires took place in the territory of central Yakutia. For this reason, the AOT values in the summer months were 1.5-2.0 times higher than in the autumn - winter and spring periods. This circumstance, as can be seen from Fig. 3, influenced the distribution of AOT in the annual block of observations. If we take into account the abnormal years (with fires), the distribution of AOT by months in the monitoring area will not have a pronounced seasonal course.

3.2. Interannual changes in AOT
Central Yakutia is located in an area with a extreme continental climate, when the air temperature in winter can reach $-55^\circ$, and in summer $+35^\circ$. Such a sharp restructuring of the atmosphere is accompanied in the winter months by a temperature inversion, which leads to an increase in air density in the surface layers of the atmosphere, and this often leads to an increase in AOT and frost fogs [8, 9]. In the summer months, due to high temperatures and low rainfall, frequent forest fires are caused by dry thunderstorms. In this period of time, too, there is an increase in AOT due to the smoke of the atmosphere. Fig. 3 shows data on the parameter AOT, averaged over monthly blocks for observation periods, starting from 2004 to 2013. There is no regularity in the distribution of AOT over the years. It is only necessary to note the abnormal emissions in 2012, the cause of which is discussed below.

In the spring-summer periods with different intensity in Yakutia, forest fires are observed, which significantly affect both the average monthly and annual AOT values. This - above all, refers to the Southern and Central Yakutia, including the city of Yakutsk. As can be seen from
the data shown in Fig. 4, the interannual value of AOT varies from 0.1 in quiet years, to 0.3 in years with an abnormally large number of forest fires. According to [10] large-scale forest fires were noted in 2012, which affected the annual AOT, the average value, which reached the value equal to 0.29±0.25 in 2012. 2012 is allocated, when the AOT value was three times higher than the average values for the relatively successful fire season.

4. Conclusion

Central Yakutia occupies a vast territory, has large tracts of taiga and the absence of large industrial enterprises. Therefore, the atmosphere in this area is cleaner than in regions with a developed industrial structure [11].

Nevertheless, the global warming has affected Yakutia. This is evident from Fig. 1, the data of which indicate a significant change in the mean annual temperature, and this can be traced practically throughout the entire territory of Yakutia, including the circumpolar zones. Subsequent to this, the atmosphere that responds not only to geophysical phenomena in the upper layers of the stratosphere, but also to frequent natural and anthropogenic anomalies, is gradually being rebuilt. As we can see, one of the significant factors of the interannual variability of AOT during the observation period is large-scale forest fires, as a result of which a large amount of fine-dispersed smoke aerosols enter the atmosphere. Fig. 4 shows that in the Yakutsk region for this reason, an almost threefold increase in AOT (\(\sim 0.3\)) relative to the multi-year rate (\(\sim 0.11\)) occurred.

Thus, the main role in the interannual variations of AOT in Central Yakutia, in addition to the seasonal circulation of air masses, is played by a finely dispersed aerosol from large forest fires, which significantly affects the average annual value of AOT.

Acknowledgments

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