SPECTRAL TRANSMITTANCE OF THE ATMOSPHERE OF BASIC SYNOPTIC OBJECTS

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This paper presents an analysis of relations existing between the variations of spectral transmittance of the atmosphere and synoptic conditions. This analysis enabled us to reveal certain regularities of its distribution in cyclones and anticyclones. As a result, we show that interrelation between the optical and synoptic conditions has a stable climatic character. The specific features of this interrelation manifestation in different regions of the former USSR are revealed that demonstrate the necessity of taking into account local factors when developing techniques for forecasting the atmospheric spectral transmittance.

Nowadays different optical systems which operate in the atmosphere and employ air as a working medium are widely used in science and technology. High variability of air physical properties causes undesirable transformation of radiation propagating through the atmosphere. Therefore, in order that these systems operate to advantage, information is needed about spatiotemporal distribution of air optical properties and their changes in the future. In this connection the optical radiation propagation in the atmosphere has been extensively investigated during the last years.[1,2] The results of these investigations indicate the advisability of developing the methods of optical weather forecast.

We shall not dwell on detail description of optical weather characteristics which are given in Ref. 2. It should be noted here that one of the basic element is the extinction of electromagnetic radiation which is characterized by a spectral coefficient of transmission or spectral transmittance. There too the conclusion was drawn[2] that one of possible methods of spectral transmittance forecast can be an opto–synoptic method based on relationship between variations of spectral transmittance and synoptic conditions.

It should be mentioned that this conclusion is not new, it can be found in the paper by Khromov,[3] however, to realize it there are no concrete results on relation between optical and synoptic objects. Therefore, the goal of our work is to found the relation between optical and synoptic conditions using spectral transmittance of the entire depth of the atmosphere as an example. It became possible due to a network of ozonometric stations developed in the Goskomgidromet (State Hydrometeorological Committee) system where spectral transmittance of the atmosphere is also measured.[4]

The aim to be sought can be attained by the method of superimposing synoptic and optical objects at the same time. The example of such superimposing for two spectral intervals $\lambda = 369$ and 572 nm is depicted in Figs. 1 and 2, where the ground synoptic maps of June 20, 1976 constructed using conventional synoptic symbols are shown. A field of spectral transmittance is projected onto the same map as dashed lines taking account of scale and geographic position. The optical objects with elevated and reduced spectral transmittance at the center are denoted as P_h and P_l, respectively.

Figure 1 represents the fields of optical transmittance at $\lambda = 572$ nm. This wavelength was chosen because the largest deviation of spectral behavior of atmospheric transmittance from the mean long–term conditions and the largest variability of spectral transmittance of the atmosphere during a year were observed at this wavelength.[5]

As seen from Fig. 1, several optical objects with different distribution of spectral transmittance over them can be separated out in the territory under study. The analysis of their relation with synoptic objects enables one to conclude that at $\lambda = 572$ nm the optical objects with low spectral transmittance at the center correspond to synoptic objects with higher pressure at the center (anticyclones). These are an object located over the Black Sea, the Caucasees, and Southern Ukraine and an optical object located over northern regions of Kazakhstan and south of West Siberia.

One more object with lower transmittance at the center was found over Sakhalin where an elevated background of pressure is also observed although there is no anticyclone outlined with closed isobars. And, finally, there is an object with lower transmittance at the center over mountain ranges of Middle Asia. Near this object no synoptic formations can be observed. This optical object is most likely to occur due to local processes caused by air stagnation in the mountain valleys where a great deal of aerosol might be stored.

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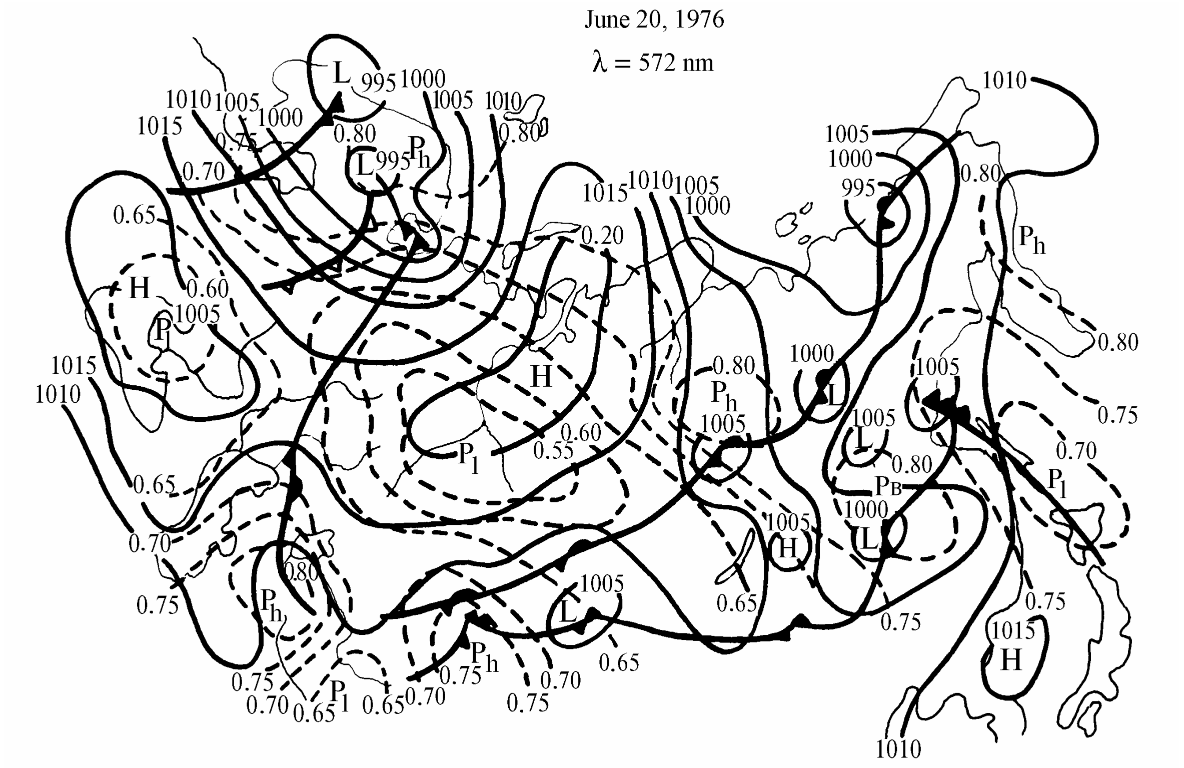

FIG. 1. Ground map of weather on June 20, 1976 and spectral transmittance of the entire depth of the atmosphere at λ = 572 nm.

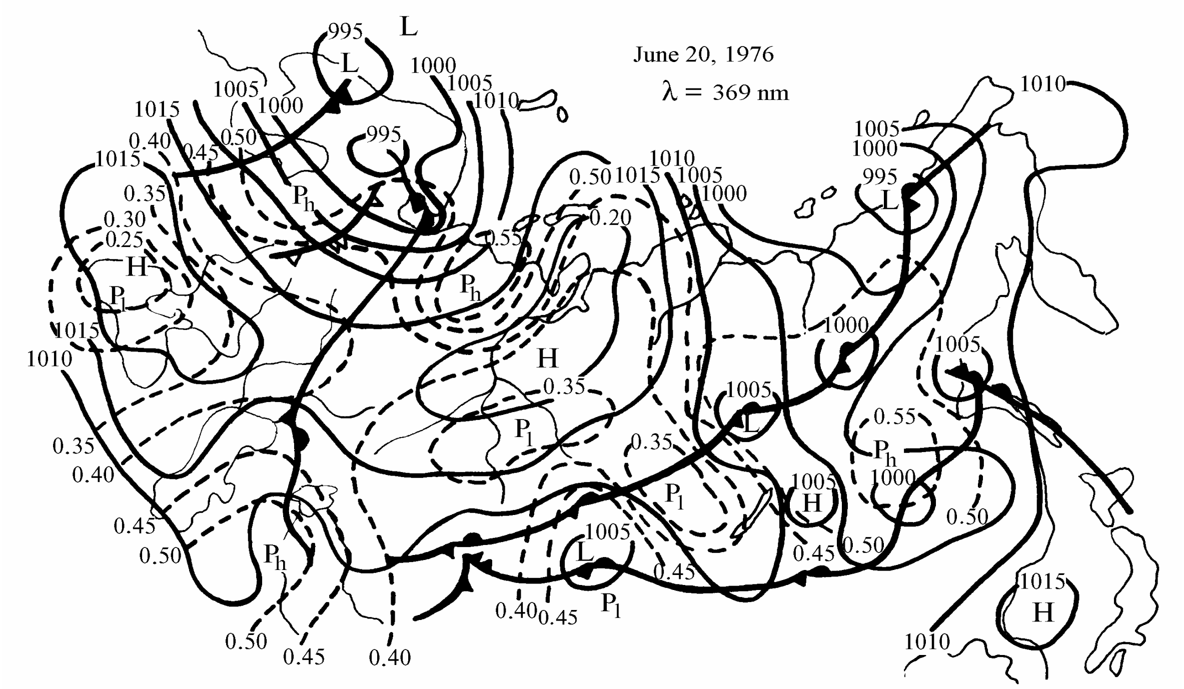

FIG. 2. Ground map of weather on June 20, 1976 and spectral transmittance of the entire depth of the atmosphere at λ = 369 nm.

The optical objects with elevated transmittance of the atmosphere are related to cyclones and atmospheric fronts. Figure 1 depicts two frontal boundary lines intersecting almost entire territory of the former USSR from west to east. Behind the frontal boundary lines, there are, as a rule, optical objects with elevated transmittance at the center. These are the objects located over the north of Scandinavian peninsula, Turkmenistan, southeastern regions of Kazakhstan, East–Siberian plateau, and Zabaikal'e.

Such interrelationship between synoptic and optical objects can be accounted for by an important role of atmospheric aerosol in extinction of electromagnetic radiation in an optical range and by the effect of moisture content of air masses.

It is common knowledge[3] that anticyclones are characterized by clear weather with explicit diurnal behavior of meteorological parameters. Two inversions are generally formed in them: the ground one of radiative cooling and the elevated one of sedimentation. Therefore, in an anticyclone, due to sharp decrease of intensity of turbulent exchange, the aerosol is stored under two blocking layers.

In contrast, in cyclones there is cloudy and rainy weather. As a consequence, aerosol is intensitively washed out that serves to decrease the extinction of electromagnetic radiation. The strongest washing out of aerosol occurs at frontal boundary lines: in front of a warm front and particularly behind a cold one, since after a cleaning trail of precipitation a cooler air mass with lower content of aerosol arrives. This was described by Khromov in 1948 using a factor of turbidity as an example.[3]

The radiation attenuation in the atmosphere is known to appear due to some factors: first, molecular and aerosol scattering and absorption. The contribution of every of them varies at the transition to other wavelength.

To check the aforementioned relations, we make the same analysis for the other spectral interval ($\lambda = 369$ nm). As seen in Fig. 2 at this wavelength, the relation between synoptic and optical objects holds too though there are some differences. Thus, e.g., a high–pressure ridge near Lake Baykal resulted in appearance of optical object with reduced transmittance at the center. An object with a reduced transmittance was also observed over eastern regions of Kazakhstan where an area with low pressure exists that somewhat contradicts the foregoing conclusion.

In our opinion, these variations in relations between synoptic and optical objects when transporting from one wavelength to the other are possible due to disruption of monotonous aerosol particle size distribution. As a result, the aerosol scattering coefficients are different at different wavelengths.

The analysis of several tens of similar maps reveals that the aforementioned relation between optical and synoptic objects is observed in all seasons over the entire territory under study, is of stable character, and, hence, it must manifest in climatic aspect.

However, the analysis of spectral transmittance distribution inside the synoptic object[6] indicates that the dependence of spectral transmittance on synoptic conditions is more versatile. This is supported by Figs. 1 and 2 and, primarily, by incomplete spatial coincidence of synoptic and optical objects.

Therefore, it is expedient to establish the dependence of the variations of spectral transmittance of the atmosphere on the location of measurement site in the synoptic object. It should be noted that the ozonometric stations are few and far between.[4] So we developed the method of such analysis.[7]

The essence of this method is that at different instants of time we determine a part of the synoptic object in which the chosen station is. The measurement results of spectral transmittance at the station are related to that part of the synoptic object where they were obtained.

The extent of dividing the synoptic position into individual objects and their parts can be different. The most voluminous classification is based on the theory of homogeneous air masses. As early as 1948, Khromov indicated that the atmospheric transmittance changes when proceeding from one air mass to the other.[3] The similar result was obtained by Shalamyanskii for total content of ozone.[8]

In Refs. 9 and 10 the authors attempted the more detailed classification of synoptic situations. In these papers a synoptic position is broken down into cyclonic and anticyclonic subtypes based on the nature of circulation. This classification turned out to be incomplete for establishing the relations between synoptic and optical objects since it was shown in Refs. 11–13 that the air transmittance as well as concentrations of optically active components of air depends on wind velocity inside the one and the same air mass. The same result, but for spectral transmittance, was obtained in Ref. 14.

Consequently, it is necessary to develop much more detailed classification of synoptic situations based on separation of individual elements of pressure field.

In Ref. 6 the authors attempted to divide the situation not only with respect to types of air masses and circulation character but also into zones depending on wind direction. The results derived in Refs. 6 and 14 showed that the main synoptic objects (cyclones and anticyclones) are, in turn, optically inhomogeneous. This formed the basis for developing the classification described below.

The classification of synoptic situations consists of several stages and levels.

The first level. All situations are divided with respect to genetic feature, i.e., origin of air mass determining the optical weather in the given physico–geographic region. Four types of air masses (arctic, moderate, subtropical, and tropical) are usually separated out for Russia and the states adjacent to it.[3] These types, in their turn, are divided into two subtypes (maritime and continental) depending on the region of their formation and subsequent transformation. Hence, at the first level of classification there are four types and eight subtypes which represent the most common differences in optical characteristics of synoptic objects.

The second level. The synoptic situations are divided with respect to circulation character. The main elements here are cyclones and anticyclones. As shown in Ref. 7, the elements at this level are small–gradient fields and contrast zones, appearing in the pressure field, and frontal divisions.

The third level. All of the objects of synoptic analysis are of three–dimensional character, therefore, in their individual parts we may observe deviations from the general characteristics. Thus, e.g., the frontal divisions are characterized by an inversion layer or more stable stratification as compared to the ambient air and serve as blocking layers for air admixtures. The inversion is observed at different altitudes due to different departure from the ground line of the front. In line with this fact the optical parameter distribution in the frontal zone changes. The precipitation zones which result in aerosol washing out and cleaning of the atmosphere are also related to the fronts. Therefore, the optical weather in the zone of atmospheric fronts must be highly changeable. To take into account this variability, such element as front must be divided at least into three zones:

prefrontal zone which is a space ahead of the ground front, over which the inversion appears;

frontal zone which is determined by the ground line of the front and the precipitation zone adjacent to it;

postfrontal zone where aerosol concentration decreases due to washing out.

Based on what has been said above the cyclones and anticyclones were divided into nine parts: N, NE, E, SE, S, SW, W, NW peripheries, and central portion.

The classification of synoptic situations provided 133 elementary subtypes: 16 small–gradient fields and contrast zones, 45 subtypes of situations for frontal divisions, 36 subtypes for cyclones, and 36 subtypes for anticyclones. At first glance it would seem that they are too numerous. However the experience on applying such classification for specific regions shows that a number of subtypes always decreases. Thus, e.g., in the region of Dikson there are no tropical air invasions which reduced the number of subtypes to 68. Moreover, the circulation peculiarities over the specific region can reduce this number. It should be noted that this classification has been developed for processes which usually cover not the entire troposphere but only its lower layers. When it is necessary to take into account the contribution due to overlying layers, this method must be amplified by the method of fixed parameters[15] for high–altitude frontal zones.

Let us describe here the analysis of variability of spectral transmittance of the atmosphere in the main synoptic objects which was carried out based on the data of the Goskomgidromet ozonometric network during 1972–1979 for different regions of the USSR using the foregoing method. It should be noted that in their analysis the local features must be taken into account since the geographic position of the region under study plays a very important role in the optical weather formation. It primarily depends on the presence of aerosol sources and sinks in the water vapor, anthropogenic pollution of the atmosphere, etc. in the given region, on preferential movement of synoptic objects, possibility of their stationarity, their origin, and destruction. Then we turn to the analysis of the obtained results.

Peculiarities of meteorological conditions of cyclones (the existence of frontal cloudiness over vast areas) reduce substantially a number of measurements of spectral transmittance of the atmosphere under the cyclonic conditions. The number of regions for which the analysis was made decreased because of the lack of statistical support on conditions of spectral transmittance in some regions. The spectral transmittance distribution in cyclones was considered only in 15 regions. However, even with limited quantity of data it was possible to draw some specific conclusions. Thus, all of the types of spectral transmittance distribution of the atmosphere in every of the 15 regions can be divided into three types depicted in Fig. 3.

For 10 regions incorporating Voronezh, Krasnoyarsk, Murmansk, Omsk, Petropavlovsk–Kamchatskii, Pechora, Sverdlovsk, Skovorodino, Yakutsk, and Nagaev Bay (Magadan region), a horizontal gradient from one periphery to the other is typical for cyclones (in Fig. 3 this is Murmansk). As a rule, in these regions the reduced transmittance is observed in eastern, northeastern, northern, or northwestern peripheries of cyclones, i.e., in its cold portion that can be accounted for by condensation processes. The three regions: Yakutsk, Magadan, and Nagaev Bay, do not fall into this category. The spectral transmittance gradient here is of opposite direction.

Over two regions adjacent to the coastal line (Leningrad and Vladivostok) the isolines of spectral transmittance in cyclones are almost symmetric to isobars (Fig. 3) but differ in the gradient direction. The transmittance at the center of cyclone is elevated over Leningrad and reduced over Vladivostok.

We failed to attain the substantial variations in atmospheric transmittance inside the cyclones over three regions in the south of the former USSR: Feodosiya, Chardzhou, and Bol'shaya Elan', despite of the fact that the transmittance distribution was obtained using several hundreds of measurements at each of these stations. Such situation can be created by implicit frontal processes almost always and, correspondingly, by weak effect of air cleaning from aerosol during precipitation. As a result, the cyclones over these regions are optically more homogeneous than those over the remaining ones.

The aforementioned peculiarities are observed over the entire spectral range under study that can be judged from the results for Petropavlovsk–Kamchatskii.

The clear weather in anticyclones was favorable for collecting much more voluminous statistical information for this type of synoptic objects. Therefore, we managed to analyze 29 regions.

For situations with anticyclone formation, as with cyclonic conditions, the following regions can be separated with respect to the spectral transmittance distribution:

1) the transmittance is with an explicit horizontal gradient from one periphery to the other (8 stations);
2) the transmittance isolines are parallel to isobars (2 stations);
3) the spectral transmittance changes unessentially inside the anticyclone (8 stations);
4) the transmittance is with multizonal distribution (11 stations).

It should be noted that the areas with elevated and reduced transmittance are, as a rule, at the periphery of anticyclone (Omsk in Fig. 3). Small–gradient distribution of transmittance in anticyclones is mainly observed over the southern regions where the differences between physical properties of air in different parts of the anticyclone become insignificant due to air heating.

The transmittance gradient is found where the anticyclones do not stay stationary but quickly move over the region under observation. In this case, the air entering the system of anticyclones has no time to transform, that influences the transmittance variability. In contrast, the multizonal distribution of transmittance is peculiar to those regions where anticyclones are frequently stationary, especially in winter. In this case the air is strongly transformed and, hence, more or less substantional variations in spectral transmittance are noted only at the anticyclone periphery. The regions with parallel distribution of transmittance isolines and isobars in anticyclones, as well as in cyclones, are found at the seacoast. It seems likely that this is specific feature of spectral transmittance distribution of the atmosphere in synoptic objects for oceanic regions. It should be noted that this conclusion must be put to the test.

The spectral transmittance distribution is also examined in a small–gradient field, contrast zone, and under the front passage. The results on spectral transmittance in the presence of cold and warm arctic fronts are given in Table I.

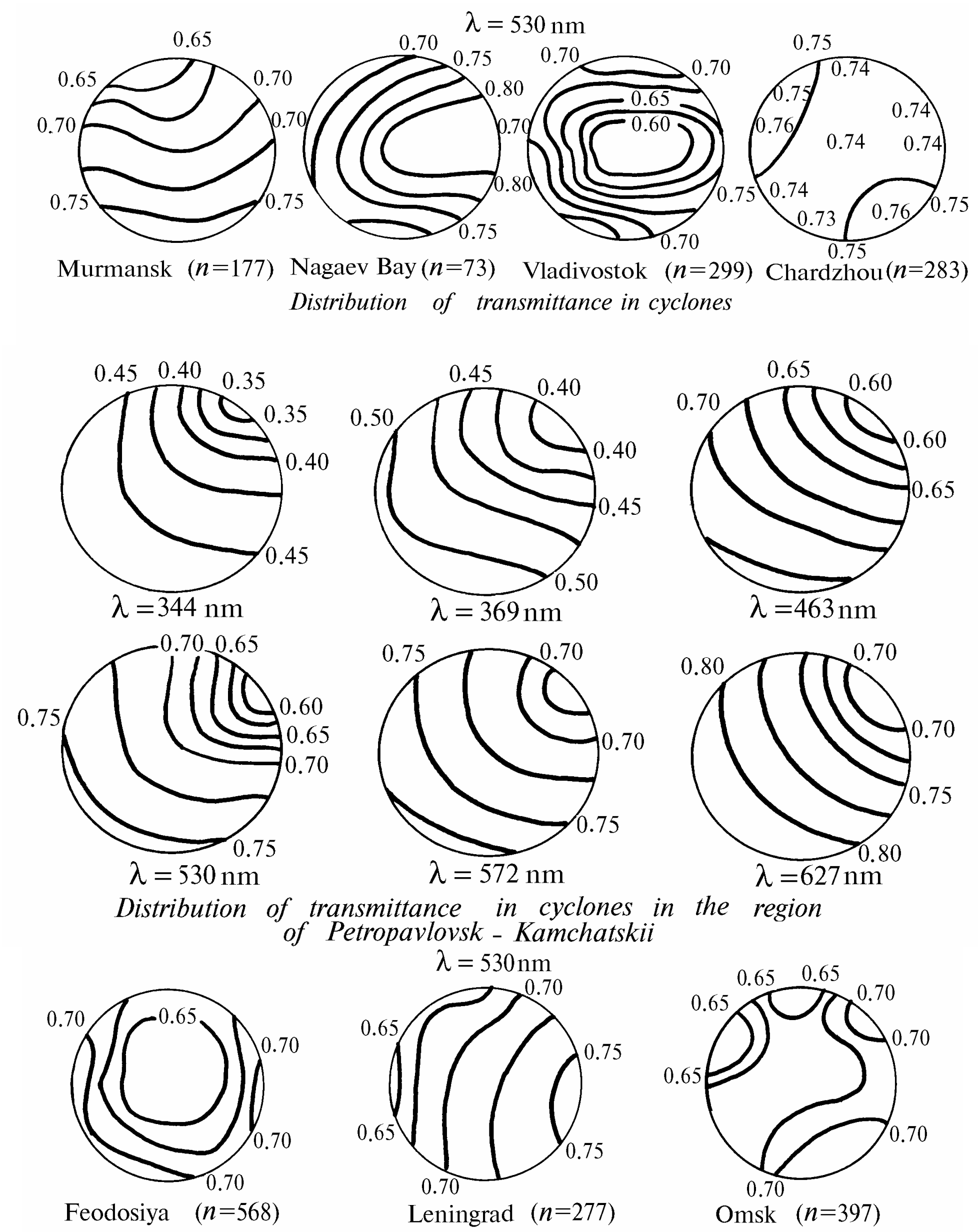

FIG. 3. Distribution of spectral transmittance in cyclones and anticyclones.

TABLE I. Variation of spectral transmittance of the atmosphere when the atmospheric fronts pass.

Front type	Measurement station position with respect to a front	Wavelength (nm)	
		344	572
Arctic cold front	ahead of a front	0.31	0.58
	inside a front zone	0.41	0.70
	behind a front	0.47	0.77
Arctic warm front	ahead of a front	0.45	0.72
	inside a front zone	0.48	0.75
	behind a front	0.36	0.68

The front passage through the observational station is accompanied with sharp variation of spectral transmittance no matter what the wavelength is. However, the nature of transmittance variation depends on the direction of the front movement. In the general case it depends on whether the cold air mas is changed for warmer one or not (in a cold air mass the spectral transmittance is, as a rule, higher). As a matter of fact, when a warm front passes, the transmittance in the zone of ground front somewhat increases as compared to prefrontal regions which is accounted for by a washing out role of precipitation. Then deeper in warm mass there occurs a sharp decrease of spectral transmittance.

Thus, a small–gradient field in the spectral transmittance distribution complies with its name, i.e., the transmittance gradients in it are small.

As to the regime of spectral transmittance in a contrast zone of pressure field, one must know what kind of its distribution was in synoptic objects whose interaction resulted in the formation of this zone, i.e., direction of horizontal gradients of spectral transmittance in cyclone and anticyclone. If the gradients are of the same sign, then in the contrast zone the spectral transmittance gradient has the same direction but larger absolute value. If in the cyclone and anticyclone the gradients are of opposite sign, then the spectral transmittance distribution in the contrast zone has a small–gradient nature.

Thus we can conclude that the spectral transmittance field of the entire depth of the atmosphere over Russia and adjacent states depends strongly on formation and movement regime of synoptic objects that can serve as a basis for developing the methods of forecasting large–scale variations in spectral transmittance. The transmittance gradients inside the synoptic objects make it possible to develop the methods of forecasting its mesoscale variations with an indispensable account of local peculiarities.

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