ON THE CONDITIONS FOR THE APPEARANCE OF ANOMALIES IN THE AEROSOL EXTINCTION OF UV RADIATION IN A CLEAR ATMOSPHERE

V.L. Krauklis, G.A. Nikol'skii, M.M. Safronova, and E.O. Shul'ts

Leningrad State University

Received September 26, 1989

Comprehensive spectral, actimetric, and meteorological data, obtained during a period of high solar activity (1981 and 1988) in order to determine how the effect of solar emissions is transmitted to the troposphere, are studied. The ability of water vapor to transform reversibly from the free state into a bound state (association in clusters) under the action of microwave and, as auxiliary factors, ultraviolet and corpuscular radiations has been observed experimentally for the first time.

When water vapor molecules a bound state the spectral optical thickness in the visible, near-IR, and IR regions of the spectrum decreases, and cluster absorption bands appear and deepen in the regions 330–340 nm, 365, and 380–390 nm. In the region 330–340 nm the spectral thickness of the cluster absorption can exceed 1.0.

It is affirmed that the anomalous transmission is caused by clusters and is realized under the conditions determined by S.F. Rodionov.

The measurements of the optical and meteorological parameters of the atmosphere under mountain conditions (3100 m, Cheget Peak) begun in 1979 were aimed at determining the variability of the content of optically active components in the atmosphere in connection with the effect of solar activity on the lower stratosphere and troposphere. Initially the measurements were performed next to a neutron monitor; this made it possible to monitor continuously the variations in the intensity of cosmic rays in expectation of the Forbush decreases. Indicating intrusion of high-energy solar protons. However strong Forbush decreases did not occur in either the period of investigations in 1979 or in 1980. Difficult weather conditions during these years had a significant effect on the results of the measurements, because the spectrometric and recording apparatus were located in the open and, in spite of the measures taken to shield them, they were subjected to destabilizing perturbations. Experience in working at Cheget showed that the measurements will have the required accuracy only if the apparatus operates under conditions characteristic for laboratory enclosures. Since the measurements must cover the period from sunrise to sunset, it is obvious that they must be performed from a rotating laboratory, whose front wall is equipped with illuminators and is always directed toward the sun. It took several years to set up this project.

In the meanwhile, comprehensive measurements under mountain conditions continued, but now they were performed under milder environmental conditions, since the measurements in 1981 and subsequent years were performed only at an altitude of 2100 m (at the High-Altitude Astronomical Station of the Main Astronomical Observatory of the Academy of Sciences of the USSR ($\varphi \sim 43.8$ n.l.). In 1981 the measurements were begun in a period of quite high solar activity. In the periods from July 25 to July 29 and October 11 and 12 a large number of chromospheric flares were observed in observations of the H_a line and in the radio frequency-range (2, 3, and 5 cm). On these days the weather conditions were favorable for performing spectrometric measurements using the instrumentation system.

The measurement were performed, when possible, from sunrise to sunset and consisted of the following: 1) measurements of the spectral transmission from 300 to 520 nm (UV spectrometer); 2) measurements of the intensity of scattered radiation from the aureole zone and the almucantar (universal filter photometer with a viewing angle of 1.5°) in eight narrow sections of the spectrum from 390 to 650 nm; 3) measurements of fluxes in wide spectral regions and integrated solar radiation making it possible to determine the turbidity of the atmosphere and the total content of water vapor; and, 4) measurements of the total content of water vapor (IR hygrometer). Complex measurements of this type made it possible to follow the effect of intrusions of solar protons and solar ratio waves on the composition (total content of optically active components) and meteorological parameters (using radiosonde data) of the troposphere and lower stratosphere.

Combined analysis of the data revealed a relationship between phenomena occurring on the sun (chromospheric flares and radio bursts) and changes at the altitudes of the isobaric surfaces 200, 300, and 500 hPa, changes in the temperature and wind velocity and direction at the same altitudes and intensification of the downwards motion of air masses in the troposphere (above the sounding region), and sharp changes in the total content of water vapor and the spectral transmission of the atmosphere.

0235-6880/90/03 201–13 $02.00

1. HEATHER CONDITIONS DURING THE OBSERVATION IN 1981

The meteorological conditions during the period of observations from July 25 to 29 and the observations on October 1 and 11–12, 1981 were characterized by stable weather with few clouds. On the days when the effect of solar flares was especially noticeable – July 27 and 28 and October 11–12 – there were no clouds. The radiosonde data show the changes occurring in the meteorological conditions in the period from July 25 to 28 are characteristic for a heated uniform air mass and should cause this air mass to become turbid, but in reality the integrated transmission of the atmosphere increased substantially from 0.66 on July 25 to 0.81 on July 28. This phenomenon can be best explained by suppression of the upward turbulent motion of heated masses of air near the ground by the downwards motion of air from the lower stratosphere which intensified up to July 28, 1981 up to 6 cm/sec.

The total content of water vapor (W, cm) in the atmosphere on July 28, 1981 was very low compared with that observed before and after this date. It varied from 0.45 to 0.15 cm of precipitated water from 7 to 11 am. This can be compared with the following data. On July 27, during the same hours, W changed from 0.4 to 1.0 cm auid on July 29 the total water-vapor content increased from 0.5 to 1.8 cm of precipitated water. The radiosonde data for July 28, 1981 showed that around 9 h local time the absolute humidity decreased at all altitudes in the troposphere. It is obvious that during these hours the tropospheric air mass settled on the 800 hPa surface; this is confirmed also by the corresponding measurements of the wind-direct ion profile. Here it is pertinent to note that the aerological data indicate that in the second half of July a uniform air mass, extending up to the tropical tropopause at an altitude of 17 km, was present above the region of the measurements. There were no Indications of the presence of the polar tropopause.

2. INTRODUCTION OF AEROLOGICAL DATA

Although the main optical observations during the summer of 1981 were performed In the period from July 26 to July 30, data over a longer period of time, from July 14 to August 2 – were introduced in order to get an idea of the preceding and subsequent states of the troposphere in the region of the observations. Figure 1 shows, aside from the changes in the altitudes of the isobaric surfaces 850, 700, 500, 300, and 200 hPa, the variations in the temperature T and the direction D and velocity V of the wind at the altitude of the 20 hPa surface during the periods of radiosonde observations.

Analysis of the aerological data over the period from July 14 to August 2, 1981, obtained by radiosonde observations at the airport in Mineral'nye Vody, shows that during this period the change in the altitudes of the lsobaric surfaces 200, 300, and 500 hPa occurred in a similar manner, but with a decrease in the amplitude with the transition from the 150 hPa surface to the 100 hPa surface and from the 300 hPa surface to lower altitudes. This fact can apparently be interpreted from the viewpoint of the changes brought about by the effect of the fluxes of cosmic particles in the altitude of the isobaric surfaces, the air temperature, and the changes in the velocity and direction of the wind. This explanation of the events is consistent with the results obtained by other investigators (for example, Schuurmans and Oort[1]). At lower altitudes (700 and 850 hPa) synchronism differing from the synchronism observed in the changes at the three top levels Is already observed.

At the beginning of the period only single geoeffective flares occurred on the sun, and for this reason the consequences of such flares could be observed at the levels 200, 300, and 500 hPa. The absence of trends in the meteorological parameters H, T, V, and D as a function of time on July 15 and 16 also helps to reveal this effect. At the geoeffective longitudes the 1N flares (the number 1, 2, 3, and 4 indicate the areas of the flares according to a five point system S and F, N, and B denote weak, average, and bright flares, respectively) on July 14, 15, and 16 were apparently responsible for the perturbations in the values oh H near the corresponding times (for example, at 18 h on July 14 and 6 h on July 16). The increases in H (for 200 hPa) on July 14–16 occurred against the background of the average value $H = 12370$ m and reached 40–50 m, but the flare on July 17 (2N) apparently had a stronger effect on the pressure field in the upper troposphere – the 200 hPa level dropped to 130 m over the course of that day. The decrease in the temperature to ~ 2°C was also significant, but it started and ended with a delay of 6 h. The wind velocity, which dropped by 30 m/s, reacted with an additional delay of 6 h. The wind direction on July 18 changed from 250° to 320°. The wind finally returned to the direction ~ 250° only on July 29. The wind velocity V after the minimum on July 18 at 12 h, Greenwich time, started to increase and increased over a period of two days up to 42 m/sec, but the flares 1N and 1B on July 21 led to the appearance of asynchronous changes in H and V; H continued to increase, and V decreased form 37 to 23 m/sec. The asynchronism appearing in the behavior of H and V continued to exist until the end of the period, and reached a maximum on July 28 and 29. During the asynhronous wave-like behavior H and V simultaneously assumed extreme values – ΔH reached 225 m and V dropped to 7 m/sec. The change in the altitude of the 300 hPa level was also very significant, $\Delta H = 220$ m.

As one cam see from Fig. 1, a sharp drop in temperature, equal to 5.5°C, occurred on July 18 at the 200 hPa level. On subsequent days the air temperature increased. By July 25 the temperature increased up to –44.5°C and on subsequent days it remained near –(46–47)°C.

Comparing the details of the time dependence of H, T, V, and D gives the same sequence of their responses to the disturbance of the atmosphere after the solar flare. The response of the parameters is divided into six-hour periods, determined by the periods of radiosonde observations. The real leading-lagging intervals cam apparently change by ±3 h. The obtained sequence of responses is observed over the course of 6–30 h. However we are interested in the changes in H, T, and V on time scales of the order of 2–8 days (wave-like behavior) and the coupling realized in the process.

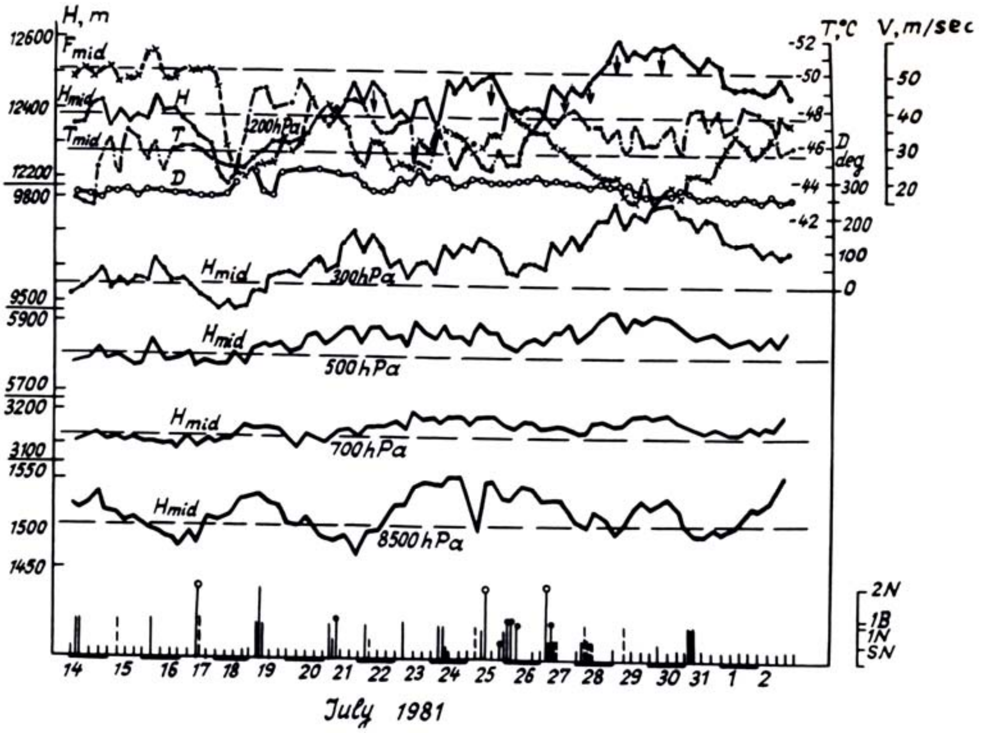

FIG. 1. The change in the altitude of the isobaric surfaces 850, 700, 500, 300, and 200 hPa and the change in temperature and wind velocity and direction on the 200 hPa surface from July 14 to August 2, 1981, based on radiosonde data obtained above Mineral'nye Vody. The times and intensities of the flares are presented in a relative scale above the abscissa axis. The relative scale of intensity of the flares is shown on the right.

Noting the rapid change in the parameters H, T, and V on July 17 it is obvious that the changes in H extended down to the same isobaric surfaces (300 and 500 hPa) as in the case of the disturbances in H on July 14 and 16. This suggests that the changes in H, T, and V on July 17 can also be attributed to the effects of the solar flares. Tracing the variations in H on the isobaric surfaces 200, 300, and 500 hPa gives a basic for the assertion that the response of the troposphere to the flares on July 16 and 17 is permanent.

Having interpreted, to a first approximation, the process occurring in the upper troposphere on July 15 to 19, we shall now consider the consequences of the new series of flares starting on July 21 and reaching a maximum on July 25–27 (see the graphical distribution of the flames in time at the bottom of Fig. 1). Looking at H and V we cam see that on July 21–23, 24–25, and 27–31 they seemingly form three antinodes, within which the wind velocity diminishes and the pressure increases. This means that downwards fluxes, carrying drier air into lower layers and preventing the development of upwards turbulent fluxes of moist air from mountain valleys and canyons, should arise.

According to Refs. 1 and 2, the effect of a solar flare of intensity 2 and higher is manifested as a change in the pressure in the middle and upper troposphere over a period of 6 hours after the flare. At middle latitudes the effect of the flames is of a focal character, and in most cases it results in an increase of the pressure and therefore a dropping of the air masses at locations where the flare has the maximum effect. The disturbance is also manifested in the change in temperature and wind velocity and direction. The maximum change in the air temperature, equal to +1.1, was observed at the isobaric surface 500 hPa, while at 200 hPa the temperature dropped by 1.8°C.[2] It is obvious that the largest changes in the wind velocity occur at the levels 300–500 hPa. In the period studied (see Fig. 1) the temperature changes reached –2.5°– -4°C, which is much greater than the published data (–1.8°C), since during the summer period and at a lower latitude (43.8) the effect of the flares should be weaker.[1] Above Mineral'nye Vody near the isobaric surface 200 hPa, where the Pfotzer maximum of Ionization of air by cosmic rays is found, the same large (~ 220 m), as at 300 hPa, increase in the altitude of the isobaric surface was observed.

There can arise some doubt in the fact that the changes found ΔH, ΔT, and ΔV refer to the air mass transformed by solar cosmic rays and did not appear as a result of the arrival of a crest in the high-pressure field. However the comparisons, made above, of the variations based on concrete aerological data with the data taken from Refs. 1 and 2 show that the effect of solar flares on the atmospheric parameters in the results obtained is quite reliable. This is confirmed by data from optical sounding of the thickness of the atmosphere at altitudes above the observational station.

3. RESULTS OF OPTICAL OBSERVATIONS

As mentioned above, in 1981 measurements of the spectral optical densities of the thickness of the atmosphere were limited to the region of the spectrum from 400 to 650 nm and were accompanied by measurements of the total content of water vapor (IR hygrometer), and the transmission and turbidity of the atmosphere. Figures 2 and 3 shows the success sive Intensifications of the process of transformation of the total water-vapor content W and the spectral optical thicknesses under the action of increasing frequency and power of solar flares in the periods July 26 to 28 and October 11 and 12, 1981. Figure 2 shows daytime behaviors (for the period July 26–29) of discrete collections of the measured parameters and the parameters used for analysis, whose components demonstrate the coupling between the optical and microphysical phenomena and the solar-cosmic factors, including the results of hourly counting of the neutron component on the cosmic-ray (Cr) monitor in Tbilisi, the time sequence of the solar flames (2*N*, 1*B*, 1*H*, *SF*, *SN*) and the strongest radio bursts (RBs). It is easy to see that there is a quite strong correlation between the behavior of the cosmic-ray intensity (CRI) as a function of time and the behavior of the values of the total water-vapor content W at altitudes above the level of the station. The residual (molecular scattering subtracted out) spectral optical thicknesses τ_{411}, τ_{471}, and τ_{557} (λ = 411, 471, and 557 nm) are in quite good agreement with one another and with W. It is obvious that the greatest variations in the amplitude are characteristic for W and that they are caused by solar flames and radio bursts at frequencies of 2950–15000 MHz.

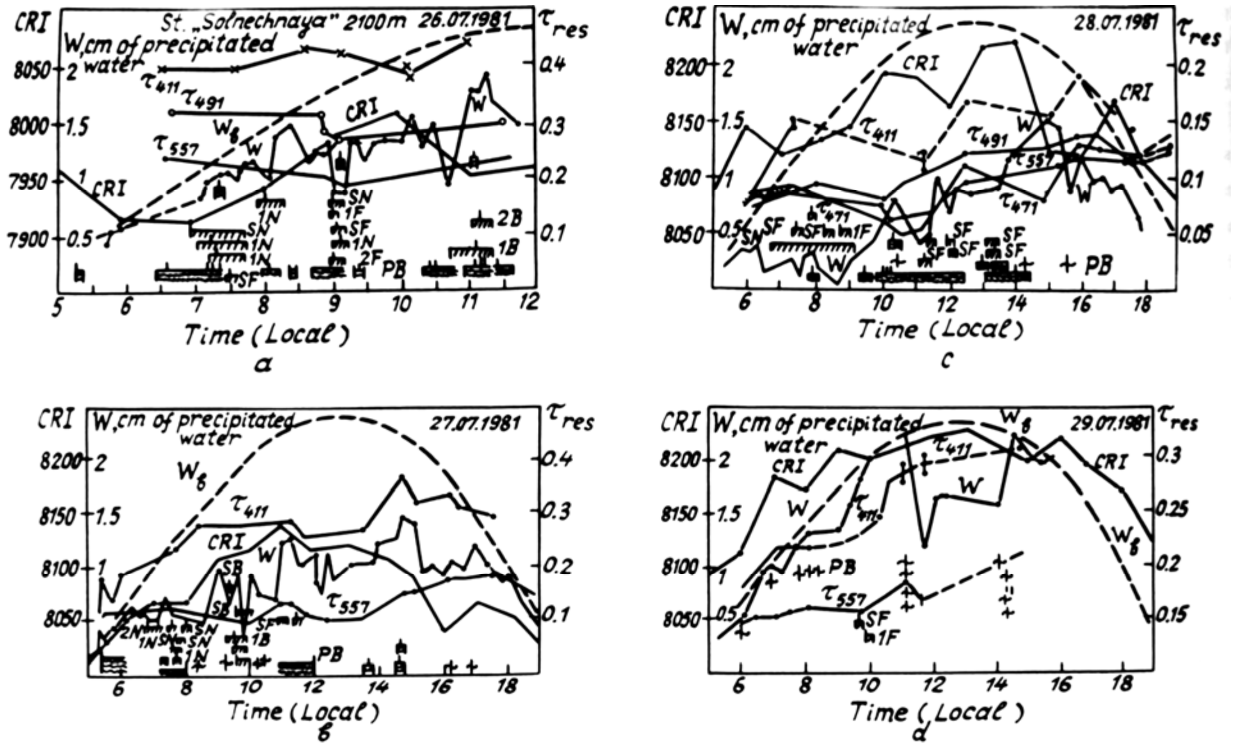

FIG. 2. Daytime behavior of the spectral residual thickness at wavelengths of 411, 471 and 557 nm *and the total water-vapor content above* 2.1 km *compared with the daytime behavior of the hourly sums of the cosmic ray intensities, based on data obtained from the neutron monitor in Tbilisi: a) July* 26, 1981*: b) July* 27. 1981; *c) July* 28, 1981; *d)* July 29, 1981. *The duration and intensity of the flares and radio bursts (RBs) on the sum are presented at the bottom of the figures.*

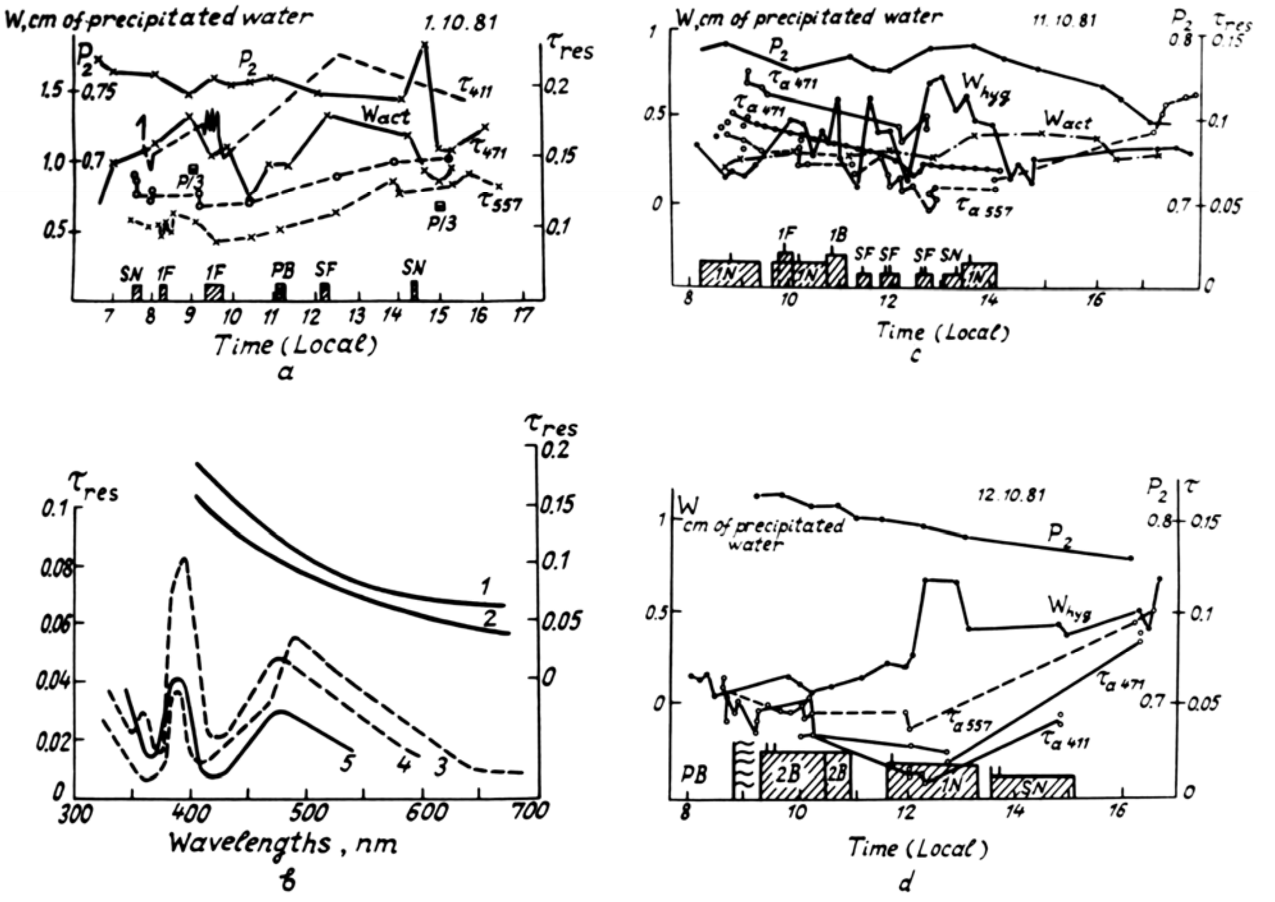

FIG. 3. *The daytime behavior of the spectral residual thicknesses at the wavelengths* 411, 471, *and* 557 nm, *the integrated transmission* P_2, *and the total water vapor content* W_{act} *based on wide band filter actionometry. Observations were performed on October* 1, 1981 *(a), October* 11, 1981 *(c), and October* 12, 1981 *(d). The flares and radio bursts are shown on the abscissa axis. The spectral behavior of the residual thickness of a layer of the atmosphere above* 2.1 km *is shown in b: 1)* 9 h, *October* 1, 1981*; 2)* 10 h, *October* 1, 1981*; 3) based on measurements at the station Solnechnaya,* 1986–1987*; 4) based on measurements on the station on Mt. Wilson,* 1920*; 5) based on Measurements on the station Kalama,* 1920, *southern hemisphere. The difference between the curves* 1 *and* 2 *is connected with the rapid drop in W (see 3a).*

It is interesting to trace the difference in the quantities W and W_b, the latter of which predicts the daytime behavior of the total water-vapor content under background conditions during clear summer (July) weather in the absence of the distributing factors. In the period when there are no flares and radio bursts, for example, from 9 h 10 min to 9 h 30 min on July 29 W increases rapidly toward the level W_b corresponding to that moment in time. On July 27 a similar attempt "worked" only at 18 h. Throughout virtually the entire day $W \sim W_b/2$ (from 6 h 30 min to 17 h 30 min).

It should be noted that not only proton flares (1*B* and 2*B*) but also ejections of fast electrons accompanyied by radio bursts – sharp and powerful increases in microwave radiation from active regions, which also result in changes in W and τ_{res} – apparently have a direct and rapid effect on the atmosphere. This is confirmed by the events on July 29, which, in our opinion, are extremely important based on the fault that independent measurements revealed a striking synchronization of the appearance of a series of radio bursts on the sun and significant changes in the total water-vapor content near 11 and 14 h. The spectral thickness τ_{557} reacted very clearly to the 11-hour radio bursts, more accurately, to the subsequent decrease in W. On the preceding days one cam also see a series of obvious effects of the flares and radio bursts on the behavior of W and τ_λ. Thus on July 26 W and τ_{491} responded sharply to a series of flares and radio bursts (around 9 h). We note, by the way, that other values of τ_λ also responded to the events, but the measurements were performed systematically in 8 channels, out of which in only one the event under study was reliably recorded. Two analogous events occurred on July 27 (around 8 and 10 h). We shall now consider the events on July 28, when the effect of the disturbances reached a maximum. Indeed, the water-vapor content in the morning (with the same type of weather) turned out to be extremely low, around 0.2 cm of precipitated water. There is no doubt that such a decrease in W is unusual, even during intense downwards motion in an anticyclone. By the morning of July 28 the velocity of the downwards motion of the air mass in the lower stratosphere and upper troposphere reached its maximum value — 6 m/sec. Apparently the vertical motion was accentuated by the action of the solar flares.

The observations on July 29 (Fig. 2d) were performed at a time of significantly lower solar activity. During the day there were only two flares of low intensity (about 10 h) and, apparently, with weak geoeffectiveness. The behavior of W up to 11 h had only 1 and not very strong disturbance, which can be attributed to the radio bursts at 8 h 20 min. But soon after 11 h the usual daytime behavior of W was disrupted. The water-vapor content, having dropped rapidly from 2.2 cm precipitated water, reached the level 1.6 cm, at which it remained up to 14 h. Over the next 30 min W rose to the maximum value on that day — 2.2 cm. The changes in W in the period from 10 h up to 13 h are quite synchronously repeated in τ_{557}- Analysis of the summary of the events occurring on the sun[3] showed that the onset of the drop and the rise in W definitely correspond to separate series of strong radio bursts at 11 h 06 min (8 h 06 min UT) and 14 h 13 min (11 h 13 min UT). The period of the drop corresponds to radio bursts at wavelengths of 2–5 cm, while the freeing of H_2O molecules from clusters corresponds to bursts at 3–10 cm.[3]

The second period of observations from October 1 to 12, 1981 was also rich in flares and radio bursts. The data for October 1, 11, and 12, containing the most important information, are combined in Fig. 3. Figures 3a and b present data for the first of September in the form of the daytime (3a) and spectral behavior of the residual thicknesses (3b). The integral transmission P_2 and the total content of water vapor according to the device with the wide-band filters (W_{act}) are also shown in the figure as a function of the time of day. The low transmission of the atmosphere occurs as a result of the comparatively high values of W, which fluctuate around the average value of 1 cm of precipitated water. The specific oscillations and decrease in τ_{411}, maintained by the decrease in W and τ_{471} and τ_{557} in the period from 9 h 30 min and 10 h 30 min are interesting. There is no doubt that these changes occur in connection with the 1F flare. The corresponding change in W was equal to $\Delta W = 0.36$ cm of precipitated water. The curves 1 and 2 in Fig. 3b demonstrate the shift in the spectral behavior of the optical thicknesses between 9 and 10 h as a result of the effect of the not very intense flare (1F) on the optical thicknesses of tropospheric air. The decrease in τ_{res} was equal to 0.013 at $\lambda = 500$ nm, 0.02 for $\lambda = 650$ nm, and 0.03 for $\lambda = 411$ nm.

We shall return again to the dependences 3, 4, and 5 in Fig. 3b, but now we shall study the data for October 11 and 12, which demonstrate an even stronger effect of the flares and radio bursts on the troposphere than on July 27–28. The low values and sharply irregular behavior of W on October 11, 1981 are closely related with the large number and nonrhythmic sequence of the flares. All characteristic features of the actions can be clearly traced after each group of flares not only in W (rapid drops and attempted rises) but also in τ_λ. The fact that τ_{557} was recorded more frequently makes it possible to trace the response of τ_λ to each group and even to separate flares.

The data for October 12, which indicate a very strong perturbation of the active components of the troposphere and, naturally, its optical characteristics, are extremely interesting. The combined effect of strong flares (2B and 3B) and numerous and powerful bursts engendered anomalies in the characteristics of the troposphere. Before noon the total water-vapor content remained at the level 0.15 cm of precipitated water. An especially impressive phenomenon, which was never encountered earlier in the measurements, is the reverse order of τ_{411}, τ_{471}, τ_{557} on the scale of residual (aerosol) optical thicknesses and the extremely low values of τ_{411} (~ 0.01) and τ_{471} at noon. This super anomalous UV transmission should be connected either with the virtually complete removal of the submicron fraction of the aerosol from the thickness of the atmosphere or a 20% burst of the solar UV radiation. In connection with the latter proposition the jump in W between 12 h and 13 h is especially interesting, but this aspect requires a separate investigation.

We shall now return to Fig. 3b. The curves 3, 4, and 5 characterize the spectral behavior of the residual thickness under conditions of high transmission at a high altitude location. The curve 3 was constructed from the results of our measurements in 1980 and 1986. The curve 4 was obtained from data for the period 1918–1920 at the station on Mt. Wilson, while the curve 5 was constructed from data on the station Kalama (southern hemisphere, same period). It is obvious that in these cases very characteristic spectral dependences τ_{res}, having a high degree of similarity, were obtained. The sharp changes in τ_{res} indicate that the maxima of the attenuation in the regions 480, 390 , 360, and 340 nm are related with absorption, and not with scattering. The analogy in the structure of the attenuation indicates that the observed spectral dependences, characteristic for the background conditions of the atmosphere high in the mountains, are common.

The cases when attenuation bands (20% of the observations) with maxima near 330, 360, and 380 nm appeared were noted at the beginning of the 1980s by C.A. Alekseeva (Main Astronomical Observatory). The data from numerous observations of the spectral transmission, performed high in the mountains using standard stars, revealed that the appearance, intensity, and width of the bands depend strongly on the water vapor content above the point of observation. We relate these attenuation (absorption) bands and the band near 480 nm with the existence of cluster complexes in the troposphere (not only under nightime but also under daytime conditions).

4. ON THE MECHANISMS OF THE EFFECTS

The process of transformation (association) of water—vapor molecules in the middle and upper troposphere (4–14 km) caused by the high-energy ionizing component of solar corpuscular radiation (SCR) can proceed according to the following scheme (proposed for the mesosphere by F. Fehsenfeld and E. Ferguson in 1969 (Ref. 5) and extended to the stratosphere by P. Vinogradov et al. in 1960 (Ref. 6):

$$N_2^+ + O_2 \rightarrow O_2^+ + N_2, \quad O_2^+ + O_2 + M \rightarrow O_2^+O_2 + M.$$

$$O_2^+O_2 + H_2O \rightarrow O_2^+H_2O + O_2.$$

$$O_2^+H_2O + H_2O \rightarrow H_3O^+ + HO + O_2.$$

$$H_3O^+ + H_2O + M \rightarrow H_3O^+H_2O + M.$$

With a further increase in the degree of association, determined by the temperature of air and the concentration of water vapor in the layer of absorption of SCR, we have

$$H_3O^+(H_2O)_{n-1} + H_2O + M \rightarrow H_3O^+(H_2O)_n + M.$$

If it is assumed that close numbers of H_2O molecules are concentrated in two ensembles of negative ionic clusters $HCO_3(H_2O)_{m_1}$ and $NO_3^-(H_2O)_{m_2}$, i.e., $m_1 + m_2 \simeq n$, then the number of associated H_2O molecules will be equal to $2n \cdot p$, where p is the number of ionization acts. From recent investigations it became clear that the degree of association of water clusters in some cases reaches $n = 70$. Because of this and for convenience in making further estimates, we shall assume $n = 50$.

In connection with the fact that association with H_2O molecules occurs on a 10 km path and the average lifetime of the ions is estimated to be about 150 sec, $8 \cdot 10^{17}$ ionization acts must occur per 1 sec in a column of the atmosphere with unit cross section (between 4 and 14 km) in order to combine into complexes $1.2 \cdot 10^{22}$ H_2O molecules (0.36 cm of precipitated water; the case of October 1, 1981). Since the average ionization potential of air molecules is equal to 35 eV the total energy of fast SCR must be equal to $3.5 \cdot 10^{19}$ eV (taking into account the fact a fast particle gives up about 80% of its energy to ionization of molecules). Thus transformation of water vapor could have been caused by particles with total energy of $3.5 \cdot 10^{19}$ eV, traversing in the lower stratosphere individual areas of 1 cm^2 every second. The simplest approach — the small number of high-energy particles — may seem to be most attractive for explaining the transformation of water vapor, but, as follows from measurements on the SHAL setup in Yakutsk,[7] the number of particles with energies of 10^{17}–10^{19} eV is extremely small and not one of these particles is connected with the sun. In a number of works, for example. Ref. 8, it is pointed out that the energy of the SCR (protons) even in the limiting cases does not exceed several tens of glgaelectron volts. Thus the solar corpuscular component does not have the required flux density in order to initiate the physical mechanism of the observed phenomenon of transformation of water vapor, though rocket and satellite data indicate that after a powerful chromospheric flare the earth's magnetosphere is flooded with particles with energies of 0.1–1 GeV. However the ten orders of magnitude in the total energy necessary for ionization of a large enough number of nitrogen molecules owing to an increase in the number of the particles participating in ionization processes is evidently not covered.

We shal1 return now to the data presented in Fig. 2d. These data could indicate that solar centimeter-wavelength radio waves play a special role in the microphysical state of the molecules of water vapor. The events observed in the daytime behavior indicate that the radio bursts apparently control the state of a significant part of the water vapor in the middle and upper troposphere and in the lower stratosphere. As already mentioned above, the period of decay of κ corresponds to bursts of radio waves at wavelengths ranging from 2 to 5 cm, while the period during which the H_2O molecules return to the free state correspond to radio bursts in the range 3–10 cm.

Recent investigations of the spectrum of radio bursts in the range of frequencies from 1 to 18 GHz have shown[9] that in 80% of the cases the radio bursts have in the frequency spectrum several peaks simultaneously, whose positions on the frequency scale remain virtually unchanged throughout the lifetime of the radio burst. Taking these factors into account, there is hope that the radio bursts can have a perturbing effect owing to the presence of two or more components with close and fully determined frequencies. The phenomenon of wide-band excitation, observed by A.V. En'shin and S.D. Tvorogov[10] when working with laser sources of biharmonik radiation makes it possible to view the interaction of microwave radiation with the medium in a new way.

It should be noted that the synergism in the actions of solar emissions on the microphysical state of water vapor, as studied here, is apparently not limited only to the effect of radio bursts, but it is also maintained by bursts of UV radiation, accompanying the solar flares.

The fact that the process of transformation of water lasts for 15–20 min after the event on the. sun is recorded suggests that both quasirelativistic protons and neutrons from the sun also can participate in the observed relatively rapid change in the water vapor concentration in the upper troposphere and, as a consequence, the rapid change in the optical characteristics of the atmosphere in the UV, visible, and IR regions of the spectrum.

5. ON THE NATURE OF THE ANOMALOUS EXTINCTION IN THE ULTRAVIOLET

Aside from the external reasons for the appearance of anomalies in the extinction of solar radiation, is also necessary to consider the local meteorological conditions, which favor the appearance of strong anomalies in the extinction of UV radiation. In addition to the results published in Ref. 11, in 1988 convincing evidence was obtained for the cluster nature of the anomalous extinction in the region of the spectrum 330–400 nm.

In one of the main works of S.F. Rodionov[12] on the investigation of the anomalous transmission (for $\lambda < 330$ nm) and the phenomenon of anomalously high extinction in the near-UV region that usually accompanies this effect indicates that the effect appears (during good optical weather) on 80% of the observation days, and necessarily when the moisture content of the air in the middle and lower troposphere is high enough. We should apparently recall that S.F. Rodionov performed spectrometric measurements on the peak Terskol and Priyut-11, i.e., practically on the slope of the Elbrus. It is possible that the local meteorological conditions favored higher repeatability of the anomalous transmission.

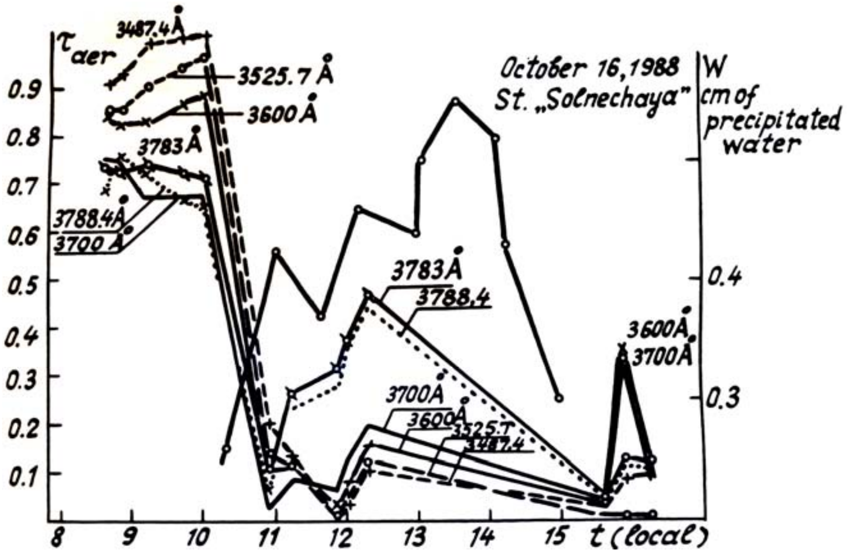

FIG. 4. The daytime behavior of the spectral residual thicknesses (aerosol) τ_a *and the total content of water vapor W. The observations were conducted on October* 16, 1988*. The wavelengths are given in angstroms (*Å*).*

Commenting on the possibility and conditions for the appearance of the effect, G.P. Gushchin[13] presents the spectral behavior of the extinction in the region 300–400 nm, calculated from the measurements of Rodionov. The curve has a maximum near 380 nm ($\tau_a \simeq 1.84$) and a sharp drop for $\lambda < 330$ nm. In the 1960s G.P. Gushchin and G.V. Rozenberg explained the anomalous transmission as being due to the multiply scattered light entering the aperture of the apparatus after repeated scattering by molecules and particles in the atmosphere. In one of his latest works G.V. Rozenberg'[4] acknowledged that anomalous transmission can exist, but G.P. Gushchin does not relinguish his previous beliefs, though in the same work (Ref. 13, p. 92, Fig. 3.16) he presents data on the fact that multiple scattering is manifested for atmospheric masses $m > 15$ (with an aperture $\omega = 5'$) and for masses $m > 6$ (for $\omega \simeq 30'$). In our opinion, these conditions give the effect of anomalous transmission a great deal of freedom for self expression, if the masses $m < 6$. Turning now to the data of Ref. 13, we can confirm without difficulty the existence of the effect for the region of the spectrum with $\lambda \leq 330$ nm.

TABLE I.

The absorption cross section of Large water clusters in the region of the spectrum 330–380 nm (estimate)

λ, nm	$\sigma \times 10^{21}$	λ, nm	$\sigma \times 10^{21}$	Remark
331	4.0 ∓ 2.5	352	3.4 ∓ 2.5	It was assumed that $n = 50$
333	4.3 ∓ 2.5	360	3.1 ∓ 2.0	
336	4.1 ∓ 2.5	370	3.0 ∓ 2.0	
340	3.9 ∓ 2.5	380	2.4 ∓ 2.0	
347	3.7 ∓ 2.5			

The results of the measurements performed on October 16, 1988, which we obtained on the station Solnechnaya (Fig. 4), clearly demonstrate not only the effect of anomalous extinction in the region of the spectrum 330–380 nm but also the dynamics of the motion of the spectral maximum of extinction in the course of the day. We attribute the sharp drop in the spectral thickness accompanying the rapid increase in the total water-vapor content between 10 h and 11 h to the decay of clusters with high degree of association. This makes it possible to estimate the absorption cross section of large clusters in the wavelength range 330–380 nm (Table I).

In the period from 11 h 30 min to 13 h 00 min the increase in extinction with a maximum near 12 h 20 min occurs in phase with the change in W. This can be explained by the quite large inflow of water vapor into the atmosphere accompanying the sublimation of a thick layer of frost covering all objects and vegetation. Unfortunately, the lack of spectral data between 12 h 30 min and 15 h 30 min made it impossible to trace the variations of the extinction in the period when W approaches the maximum value and subsequently decreases.

The appearance of anomalies in the magnitudes and daytime behavior of the extinction of solar radiation on October 16, 1988 is definitely connected with the meteorological situation on this day. For high transmission in the visible and IR regions of the spectrum (high integrated fluxes) and with negative air temperature in the morning the flow of additional quantities of water vapor from the surface created ideal conditions for development of large clusters in the early morning, decomposition of these clusters before noon, increase in the mass of the clusters with smaller degree of association after noon, and the appearance at about 16 h of a third maximum of extinction, which has its own spectral peculiarities.

CONCLUSIONS

It has been found for the first time that solar activity affects the radiation fields in the troposphere primarily through the processes in which some of the water vapor molecules (30% and more) are transferred from the free state into a bound state and back into the free state. In these processes their contribution to the transfer of solar radiation in the ultraviolet, visible, and infrared regions of the spectrum as well as the transfer of long-wavelength radiation by the earth's surface and atmosphere changes significantly.

It was confirmed that 1) the effects of anomalous transmission and anomalous selectivity Eire related with the same processes of clusterization of water-vapor molecules; 2) all of S.F. Rodionov's conclusions regarding the appearance of anomalous transmission under conditions of high transmission, adequate humidity, and low air temperatures are correct. The only feature, necessary for clarifying the conclusions drawn by S.F. Rodionov, is the replacement of submicron aerosol (as an active factor) by water clusters.

REFERENCES

1. C.J.E. Schuurmans and A.H. Oort, Pure Appl. Geophys. **75**, No. 4, 233–246 (1969).
2. D.G. German and R.A. Goldberg, *The Sun, Weather, and Climate* [in Russian], Gidrometeoizdat, Leningrad, (1981), p. 178.
3. *Solar Data*, Bulletin [in Russian], Nauka, Leningrad (1981), No. 7, p. 119.
4. G.A. Alekseeva, *Studies of the Spectral Atmospheric Extinction from Stellar Electrospectrophotometric Observations,* Candidates Dissertation in Physical Mathematical Sciences, Main Astronomical Observatory, Akad. Nauk SSSR, (1982).
5. F.C. Fehsenfeld and E.E. Ferguson, J. Geoph. Res. **74**(9), 2217–2222 (1969).
6. P.S. Vinogradov, I.K. Larin, A.I. Poroikova, and V.A. Talrose in: *Proceedings of the All-Union Ozone Conference* [in Russian], Nauka, Moscow (1987).
7. N.N. Efimov. D.D. Krasil'nikov, S.I. Nikol'skii, et al. in: *Problems in Cosmic Rays Physics* [in Russia], Nauka, Moscow (1987).
8. E.V. Gorchakov in: *Problems in Cosmic Rays Physics* [in Russian], Nauka, Moscow (1987).
9. M. Stähli, D.E. Gary, and C.J. Hurford, Bull. Amer. Astron. Soc. **20**, No. 2, 678 (1988).
10. A.V. En'shin and S.D. Tvorogov, Atmos. Opt. **2**, No. 5, 456–461 (1989).
11. G.A. Nikol'skii, M.M. Safronova, and E.O. Shul'tz, *Propagation of Optical Radiation in the Atmosphere and Adaptive Optics* [in Russian], Tomsk. (1988), pp. 71–78.
12. S.F. Rodionov, *Electrophotometric Studies of the Atmosphere on the Elbrus* [in Russian), Gidrometeoizdat, Leningrad (1970).
13. G.P. Gushchin and N.N. Vinogradova, *Total Ozone Content in the Atmosphere* [in Russian], Gidrometeoizdat, Leningrad (1983).
14. G.V. Rozenberg *Problems in Atmospheric Optics* [in Russian], Leningrad State University, Leningrad (1979).