SPECTRAL AND TEMPORAL VARIATIONS OF THE RESIDUAL EXTINCTION IN THE NEAR–UV

G.A. Nikolskii and E.O. Shul'ts

Leningrad State University
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The data of high–mountain observations of variabilities of the optical spectral thickness in the wavelength range 320–430 nm *and of the total ozone and water vapor contents, obtained during the maxima and minima of current and preceding cycles of solar activity, are analyzed. The optical properties of both the atmospheric and stratospheric air masses are concluded to be continuously controlled by microwave and corpuscular solar radiation. The corpuscular radiation affects the troposphere at mid–latitudes after bright solar flares solely. Microwave solar radiation in the centimeter and millimeter wavelengths directly affects the microphysical state of the molecules of water vapor thereby altering the radiative and thermal regimes of these atmospheric layers. The possibility of formulation of the basic weather and climate mechanisms for how the sun affects the troposphere is offered.*

The set of the spectral data obtained in the 1980's at the Mountain Astronomical Station of the Main Astronomic Observatory (MAO) of the Academy of Sciences of the USSR covers the period incorporating two maxima (1981 and 1989) and the intermediate minimum (1985–1986) of solar activity (SA). Measurements of the atmospheric spectral optical thickness in the wavelength range 300–530 nm were accompanied by those of the total (spectroscopic) water vapor content (as retrieved from the 940 nm band measurements), of the spectral intensities of the solar aureole, and of the meteorological parameters of the atmosphere.

These studies were aimed at identifying the atmospheric component sensitive to the pulsed action of solar emissions, which certainly accompany the bright solar chromospheric flares. This component would "switch on" the mechanism of transformation of the latent energy of tropospheric air masses into changes of mesoscale circulation. Such a component was indeed identified and appeared to be atmospheric water vapor whose molecules were capable of transformation from the free state into bound state under the action of corpuscular and microwave solar radiations, i.e., these molecules associate into clusters and further produce the microdispersed water droplet fraction of tropospheric aerosol. This process is accompanied by the release of heat, which may stimulate, provided the process occurs on a sufficiently large scale, the development of temperature inversions or of various other thermodynamic phenomena. In the case of the stable state of the atmospheric layer being considered, the initial water vapor content may either be recovered spontaneously or under the action of the solar microwave radiation in the frequency range that differ from the frequency range responsible for association of vapor molecules into clusters.

The translation of water vapor molecules into their bound state entails a decrease of the spectral optical thickness in both the visible and the near IR as well as appearance and deepening of cluster absorption bands in the wavelength ranges 320–330, 360, 380–390, 410, and 480 nm.

We have found from the results of observations of numerous responses of the atmosphere to solar flares and to burst of the solar microwave emission that the change in the spectroscopic water vapor content (*W*, cm of precipitated water) depends on the power and duration of action of solar "disturbance". If solar events remain weak, short, and separated by long time intervals, the change in W caused by such an event amounts to a tenth of per cent, or to a few per cent. The phase of the maximum depletion of water vapor content is reached in 15–20 min after the flare occurs at the solar disk in the visible or after the beginning of the microwave radio burst recorded by solar radio telescopes.

Molecules of H_2O associate quite efficiently only in the case which the maximum of the spectral intensity of radio burst is reached within the band $3 < \lambda < 12$ cm. Radio bursts with maximum emission in this band apparently give rise to the process of cluster dissociation and recovering of either preceded or predicted value of *W*.

These conclusion were drawn from the data obtained under conditions without a series of bright flares radio bursts when the latter were sufficiently separated in time. Then the microphysical and optical responses of the troposphere could be confidently attached to the solar events. An example of such a situation is shown in Fig. 1 (see Ref. 1, Fig. 2*d*).

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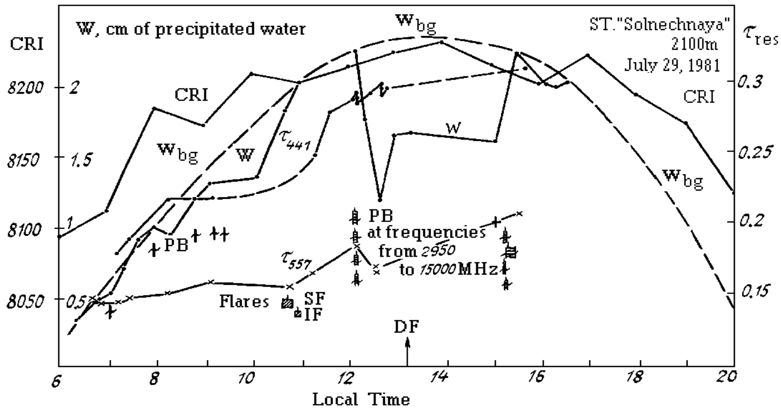

FIG. 1. The daytime behavior of the spectral residual optical thickness at wavelength of 411 *and* 557 nm *and the total water vapor content above* 2.1 km *in comparison with the daytime behavior of the hourly sums of cosmic ray intensity (a neutron monitor in Tbilissi on July 29, 1981).* W_{bg} *is the retrieved daytime behavior of W under background condition (without perturbing factors). Duration and intensity of flares (DF and IF) and radio burst (RB) are indicated at the bottom of the figure.*

Variations of the residual optical thickness at wavelength of 411 and 557 nm and of the total water vapor content for the most part of the day on July 29, 1981 clearly show the response of these parameters to practically every radio burst. Extremely important evidences in favour of this mechanism were obtained from tracking the effect of the two series of radio burst around 11:00 and 14:00, local time (LT). Measurements in October, 1981 have also demonstrated much evidence enough to present numerous illustration of quick and direct response of tropospheric parameters to solar events, incorporating several bright flares with accompanying radio bursts. Having occurred around 10 h LT, the flares on October 12, 1981 very strongly affected the microphysical and optical parameters of the troposphere. During the morning hours the total water vapor content approached zero, and the residual optical thickness at a wavelength of 411 nm dropped practically to zero at noon. Apparently, such strong anomalies in the tropospheric parameters cannot be explained only by direct effects of flares on the lower troposphere. Calculations of the rates of downward motion of dry air from the upper troposphere and the lower stratosphere supported our assumption that the downward movement of the dry upper tropospheric air mass in a crest of the high–pressure field over Northern Caucasus was intensified under the action of the high–intensity corpuscular and microwave emissions, thereby forcing the humid lower tropospheric air to be carried out of the Kislovodsk region, which was subsequently filled with dry air.

Thus, the combined effect of direct and indirect actions of solar emissions significantly change the total water vapor content and the optical thickness of the atmosphere in all spectral regions, and this effect lasted for 10 hours and more. Such a long duration of the tropospheric response was, apparently, triggered by a series of preceding solar events, which formed an almost continuous series of actions on the atmosphere (see Ref. 1).

A number of examples are available, showing the response W to individual but comparatively strong solar events. In such cases the decrease of *W* lasts for 60–70 min, and the recovery process may take as much as 90 min. The more quick recovery of *W* from 0.5 to 1.0 cm of precipitated water took 30 min.

Measurements at the beginning of the solar activity (1989) confirmed unambiquously our previous conclusions about both the character and limits of the established responses of the tropospheric air masses over Northern Caucasus to solar events. Valuable data on the response of the troposphere to solar flares were obtained from tracking the action of the series of solar flares from October 20 to October 27, 1989. The brightest flare in that series (4B) occurred on October 19, 1989, at 12:29, Greenwich time. The number 4 indicates the area of this flare according to a five–point system (S, 1, 2, 3, and 4) and B denotes the bright flare.[1] Because of the local weather conditions observations began only in the morning of October 20, so that the quick response of the atmosphere to the radio burst turned out to be unavailable for our observations. However, the most intensive flux of relativistic solar protons during these events intruded the atmosphere on October 20, and it was recorded by the neutron monitors positioned at higher latitudes of Northern Hemisphere.

Of primary importance were the data of spectral observations of the rapid response of the troposphere to the burst of flux of high energy solar protons. The response of the troposphere to them extended 70 minutes over Northern Caucasus. The minimum values of W were recorded at 7:26, Greenwich time and the maximum residual optical thicknesses in the wavelength range 360–430 nm were recorded at 7:30 Greenwich time. As a result of the effect of this corpuscular flux, the optical thickness increased from 0.4 to 0.9 in the wavelength range 380–390 nm, while the value *W* dropped from 0.73 to 0.44 cm of precipitated water.

Figure 2 shows the family of curves illustrating the spectral behavior of the residual optical thickness at different time including not only the time of response of the troposphere to the effect of intrusions of these corpuscles, but also some responses to solar events preceding and following them.

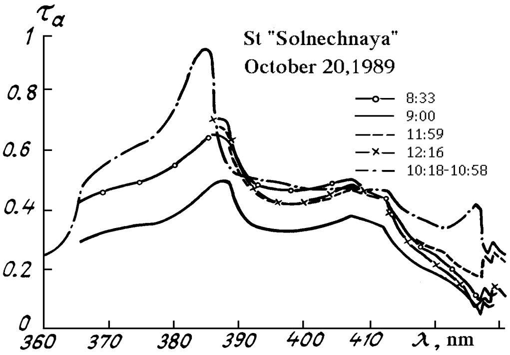

FIG. 2. Spectral behavior of the residual optical thickness, October 20, 1989. (Measurements at the Mountain Astronomical Station of the Main Astronomical Observatory of the Academy of Sciences of the USSR).

As can be seen from Fig. 2, the minimum value of the aerosol optical thickness, τ_a were detected around 09:00, LT (06:00, Greenwich time). This spectrum refers to a time period, when no noticeable responses to any external or internal atmospheric disturbances were recorded. The average value of optical thickness for the wavelength region 378–407 nm was $\tau_a \approx 0.35$ from 9:00 to 9:55, LT. Such a value of τ_a was quite typical for the periods of the maximum solar activity.

The spectral behavior of τ_a at 08:33, LT characterizes a situation of a somewhat larger extinction, which should be attributed to the effect of flare and of radio burst, which have occurred between 08:10 and 08:30, LT. Note the neutral behavior of the radiation extinction, which appeared because of the rapid response of the troposphere to the action of solar emission between 08:10 and 08:30, LT. Between 10:00 and 11:00, LT quite different behavior of the atmospheric extinction spectrum is manifested upon the action of high–energy corpuscles. One can clearly see the selective character of that component of extinction of solar radiation, which appears in the course of response in the wavelength regions 365–385 and 415–425 nm. One may conclude that the maxima already existing in the selected structure of spectral behavior of extinction are intensified and shifted toward shorter wavelengths: from 388 to 385 nm and from 428 to 426.5 nm. The optical thickness increases from 0.5 to 0.95 in the wavelength region 385–388 nm as a response on the effect of intrusions of corpuscular flux (in comparisin with the spectrum taken at 09:00, LT) and increases by about a factor of five around 427 nm.

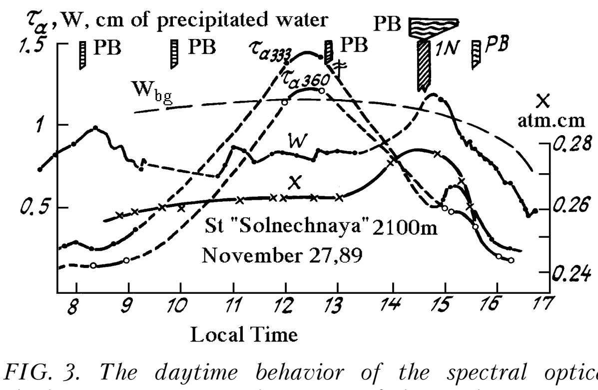

FIG. 3. The daytime behavior of the spectral optical thickness at $\lambda = 333$ *and* 360 nm, *of the total water vapor content (W), and of the total ozone content on (X) October 27, 1989. The beginnings of solar flares (IF) and of radio bursts are indicated at the top of the figure.*

Conclusions about the response of the troposphere and stratosphere to the effect of radio bursts and of flare on October 27, 1989 may be very interesting. Figure 3 shows the daytime behavior of the principal components of extinction of solar radiation. In the context of our discussions of the anomalous UV extinction, considerable attention must be devoted to the extremely large noon values of τ_a in the wavelength region 320–330 nm ($\tau_{a333} = 1.45$). The value of τ_a started to increase simultaneously with Ω decreasing around 08:20 h, LT soon after the radio burst at 08:05 LT. The effect of the radio burst at 09:50, LT, was not traced because of the interruption in the observations. The maximum of the microwave flux at 8:05, LT was recorded at 2.8 GHz. The third radio burst on that day was recorded at 12:46, LT with maximum intensity at a frequency of 5.9 GHz. As can be seen from Fig. 3, the values of τ_{a333} and τ_{a360} then started to decrease. To our mind, this was the result of the effect of radio bursts.

During the morning hours the total ozone content (X) did not react in any way on the seldom solar events, but after the fourth radio burst (at 13:01, LT) the value of X started to increase, reaching its maximum of 0.277 atm·cm by the moment of the beginning of the flare (*1N* flare at 14:31, LT) and by the maximum of the fifth radio burst (at 14:36, LT), when microwave flux of high intensity $F > 1500$ solar flux units (1 s. f. u. = 10^{-22} W m^{-2} Hz^{-1}) was found to occur at frequencies from 2.85 to 15.4 GHz. This flux exceeded 4000 s.f.u. at a frequency of 9.3 GHz and was only a little bit lower at a frequency of 15.4 GHz (3900 s.f.u.). The responses of all four monitored components of radiation extinction to the fifth radio burst were quite obvious: W increased by 0.25 cm of precipitated water, X increased by 6%, and τ_{a333} and τ_{a360} also reacted to a radio burst, although with a time delay of about 20 m, because of the changes in the value of Ω with the accompanying phase transformations. So far the question remains unsolved: whether these components reacted only to that radio burst or to *1N* flare at 14:31, LT (at 11:31, Greenwich time). Note that although that flare was accompanied by an X–ray burst, it was average, because the energy of the emitted protons did not reach several hundreds of MeV and the main portion of flux of particles can not reach relativistic velocities. Hence the flare has insignificant effect on the middle and lower troposphere at mid–latitudes.

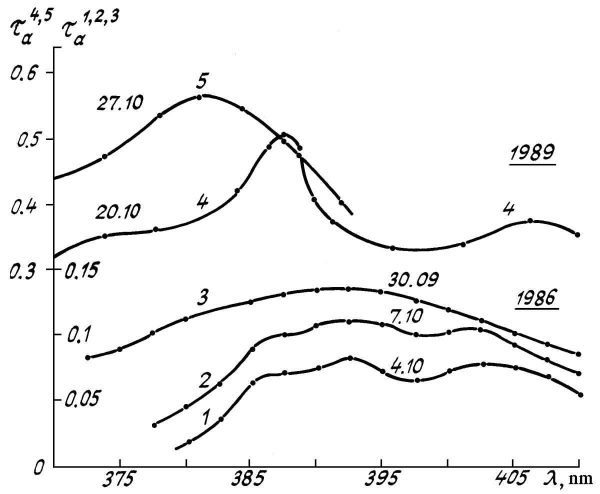

FIG. 4. Spectral dependence of the residual optical thickness typical for the period of minimum (curves 1, 2, and 3), and maximum (curves 4 and 5) of the solar activity in 1989.

Now we consider variation of the spectral optical thickness associated with the transition from the minimum to the maximum of solar activity. Figure 4 shows five spectral dependences of the residual spectral thickness, characterizing the range of variation of the extinction of solar radiation in the near–UV, which is related to solar activity. Curves *4* and *5*, obtained in 1989, demonstrate that the spectral extinction during that period was about four times as high as it had been under the same weather conditions during the period of low solar activity (curves *1*, *2*, and *3*, lower scale).

Looking at the changing spectral selectivity in the presented curves one may note that when τ_a increases, the spectral maximum tends to shift toward shorter wavelengths, with the minimum of extinction mostly to be found around 360 nm, thereby testifying that the phenomenon of anomalous transparency actually takes place. Without presenting data for the wavelength range around 300 nm, we may note, however, that the anomalous behavior of extinction is often observed there (τ_a decreases at wavelengths shorter than 310 nm).

The presented data are good reasons to believe that the solar microwave radiation actually controls the optical characteristics of the tropospheric air mass, thereby immediately affecting the microphysical state of the molecules of water vapor and resulting in variations of the optical parameters of the tropospheric air column in the UV, the visible, and the near–IR.

REFERENCES

1. V.L. Krauklis, G.A. Nikolskii, M.M. Safronova, and E.O. Shul'ts, Atm. Opt. **3**, No. 3, 201–213 (1990).