The new technique and instruments for Roshydromet ozone network

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The total ozone network of Roshydromet is the only source of regular information about the ozone layer above Russian territory. 28 stations are equipped with filter ozonometers M-124. Its are exploited for the field operation more than 30 years and needed the replacement by the modern automated equipment. The new equipment should operate under all weather conditions on the Russian vast territory. Moreover, in accordance with modern requirements, ozone network should measure also incoming UV radiation.

Specialists of the Main Geophysical Observatory (MGO) and of some optical organizations in St. Petersburg created a new instrument - ultraviolet ozone spectrometer (UVOS) on the basis of polychromator (diffraction grating + CCD line).

The UVOS spectral range is 290-400 nm, spectral resolution - about 1 nm, the time of recording of the spectrum - from 2 ms up to 2 s. The instrument detects the spectra of UV radiation from the hemisphere and from the zenith of clear and cloud sky.

The unique technique is used for the measurement of total ozone up to 85^{o} zenith angle, including measurements for fast-changing cloudy condition. UVOS satisfies the WMO requirements for total ozone measurements and UV spectra measurements.

UVOS advantages are the ability to perform measurements of total ozone at any cloudiness, simplicity of design with no moving parts, small weight and dimension, easiness of operation. The instrument is capable to work in the Russia territory in any range of astronomical and weather conditions.

Monitoring of the ozone layer state over the Russia territory and adjacent countries is carried out at 28 ozone stations of RF and 5 stations of Kazakhstan. The measurements are made by filter ozonometers M-124 (maximum wave-lengths of two filters - 302 and 326 nm, half-width - 20 nm). The ozonometers M-124 are calibrated every 2 years against standard - the Dobson ozone spectrophotometer № 108, which in turn every 4 years is calibrated on regional WMO standard in Germany.

Simple instruments provide reliable total ozone measurements on the ozone stations from 80ºN (Island Heis) to 80ºS (Vostok). The peculiarity of the method of measurement is the obligatory use of zenith observations for clear sky and for any cloudy sky (except for precipitation).

For calculating the total ozone from zenith clear sky observations the equation for direct sun is used with the additional empirical coefficients. For calculating the total ozone from cloudy sky observations the optical density of the clouds is visually determined and the suitable empirical coefficient (five gradations) is introduced in equation.

Using of the cloudy sky observations is the M-124 evident advantage. Zenith measurements are practically bridge gaps in observations. The measurements can be carried out up to zenith angle of 85º, that ensures practically continuous operation of Northern stations.

Dobson and Brewer instruments use mainly the direct sun observations, while zenith sky measurements, especially for cloud sky, are considered only as an additional, and not sufficiently accurate.

UV-Visible spectrophotometer SAOZ also uses the zenith-sky algorithm for total ozone measurements. But really SAOZ can measure total ozone at sunrise and sunset solely. A significant limitation of this method is the lack of total ozone measurements during the day, when UV radiation at low ozone can be dangerous.

As to the accuracy of M-124 measurements, according to the Assessment 2010 estimate (WMO Global Ozone Research and Monitoring Project—Report No. 52) "*Dobson, Brewer ozone spectrophotometers, and filter instruments provide long-term ground-based total ozone time series. The standard deviation of monthly differences is on average about 1.5% and within 0.6–2.6% for 90% of Dobson and Brewer network stations and on average about 2% and within 1.5–3.5% for 90% of stations with filter instruments M-124.*"

It should be noted that the most of the M-124 total ozone measurements are made under a cloudy sky. All-weather measurements exclude the gaps in long-term time series.

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The successful experience of the M-124 zenith measurements became the basis for the development of the method and for design of the automated equipment.

Specialists of the Main Geophysical Observatory (MGO) and of some optical organizations in St. Petersburg have created a new instrument - Ultraviolet Ozone Spectrometer (UVOS) on the basis of polychromator (diffraction grating + CCD line).

The technical characteristics of UVOS (Table 1) completely agree with the requirements of WMO for the spectral instruments for total ozone and UV radiation measurements.

Table 1. UVOS specification.

Parameter	**units**	**Value**
Spectral range	nm	290÷400
Spectral resolution	nm	< 1
Minimum spectrum recording time	m**sec**	2
UVR spectral density range	mWt/m^2*nm	$0.5÷1.5x10^3$
UVR measurements error	%	не более 10
Total ozone measurements range	atm-cm	0,1 ÷ 0,6
Sun heights range for total ozone measurements	degree	5÷70
Total ozone measurements error	%	<= 5
Optical block weight	kg	<= 9
Dimensions	mm	400x140x380
Power supply	V, (Hz)	220 (50)

The UVOS optical unit (Fig.1) may be installed on the meteorological site or on the roof of the station, where horizon is closed not more than 5°. The UVOS personal computer is installed indoors and is connected with the optical unit with a cable or radio modem.

The entrances of two optical channels are situated on the top plane of the optical block. The scattered radiation from the zenith sky comes in the first channel and the radiation from the hemisphere of the sky (the angle of 176°) comes through the diffuser in the second channel.

The each measurement registers two UV spectra at the range from 290 to 400 nm with a resolution of about 1 nm and exposure time varies from 2 ms to 2 s.

Channel switching is performed by the shutter, which controlled by PC, opening in turn two channels "Zenith" and "Hemisphere", and also closes both channels to measure dark current. (The shutter is the single moving part of the device).

"Zenith" and "Hemisphere" radiation in turn through the optical fibre falls on the entrance slit of polychromator. The mirror of polychromator directs the radiation to the concave diffraction grating (800 stroke/mm). Formed spectrum goes to the CCD line. The signals array after amplifying is converted by ADC, then is read by the internal controller and is transferred to the PC via cable or radio modem.

On the polychromator housing the heater is mounted, which in combination with Peltier element keeps the internal temperature 20º±2ºC, when the outside temperature is changed from -50º to +50ºC.

Flexible software uses individual stations parameters (like a geographical coordinates, period of measurements et. al.).The exposure is automatically selected in the course of measurements. Total ozone, UV spectra and the level of UV radiation in the ranges of UV-A and UV-B radiation are calculated and regularly will be sent throw the Internet to the information-analytical center.

The method of total ozone determining is similar to the method of total ozone calculating by Dobson for direct sunlight [Report GAW WMO No 183]. For the transition to the zenith blue sky light in equation (1) the empirically obtained coefficient Kzb is used, and for taking into account the influence of aerosol and clouds the additional coefficient Kzc is introduced in the process of observation.

Fig. 1 Ultraviolet ozone spectrometer (UVOS). Voeikovo station.

Zenith radiation in the UV spectrum from 290 to 400 nm is used to calculate total ozone.(Fig.2). To determine ozone two wavelengths $I_{\lambda1}$, $I_{\lambda2}$ are selected in the absorption band of ozone. To exclude the impact of atmospheric aerosol or clouds on the ratio $I_{\lambda1}/I_{\lambda2}$ .another two wavelengths $I_{\lambda3}$ and $I_{\lambda4}$ are selected in spectrum outside the absorption bands of ozone.

This method is expressed by formula

$$X = \frac{\lg(S_{0\lambda1}/S_{0\lambda2}) - \lg(I_{\lambda1}/I_{\lambda2}) \cdot Kzb - \Delta\beta_{\lambda12} m - Kzc(I_{\lambda3}/I_{\lambda4})}{\Delta\alpha_{\lambda12}\mu} \qquad (1)$$

Where

X = total amount of ozone expressed in Dobson Units;

$S_{0\lambda1}$ and $S_{0\lambda2}$ = intensities outside the atmosphere of solar radiation at the short and long wavelengths, respectively, of the wavelength pair;

$I_{0\lambda1}$ and $I_{0\lambda2}$ = measured intensities at the ground of solar radiation at the short and long wavelengths, respectively;

β and $\beta_{\lambda2}$ = Rayleigh scattering coefficients of air at the short and long wavelengths, respectively;

m = ratio of the actual and vertical paths of solar radiation through the atmosphere, taking into account refraction and the earth's curvature: airmass;

$ά_{\lambda1}$ and $ά_{\lambda2}$ = absorption coefficients of ozone at the short and long wavelengths, respectively;

μ = ratio of the actual and vertical paths of solar radiation through the ozone layer, the mean height of the ozone layer being 22 km if not approximated by latitude of the station: ozone mass.

Kzb = f(x,μ) zenith coefficient for clear sky which is determined empirically from observations$

Kzc = $f(I_{\lambda3}/I_{\lambda4})$ zenith for cloud sky, where $I_{\lambda3}$ и $I_{\lambda4}$ measured intensities at the short and long wavelengths outside the ozone absorption bands.

The pairs of wavelengths $I_{\lambda 1}/I_{\lambda 2}$ and $I_{\lambda 3}/I_{\lambda 4}$, are registered in the UV spectrum at one time. Changing of ratio $I_{\lambda 3}/I_{\lambda 4}$ in the area outside ozone absorption is associated with the influence of aerosol and clouds to ratio $I_{\lambda 1}/I_{\lambda 2}$ in the absorption band of ozone even with the rapidly changing clouds.

Fig.2. Example of Zenith scattered radiation spectrum. Frounhofer's lines in region 390nm are well separated

The advantages of UVOS are obvious. These are the ability to perform measurements of total ozone at any cloudiness (Fig.3), wide sun heights range, a lack of moving parts, the small weight and dimension, the easiness of operation. Another quality of the instrument is essentially for field measurements. The presence of Fraunhofer's lines in the spectrum allows constantly to check the wavelength scale of UVOS and, when it is necessary, to correct the scale.

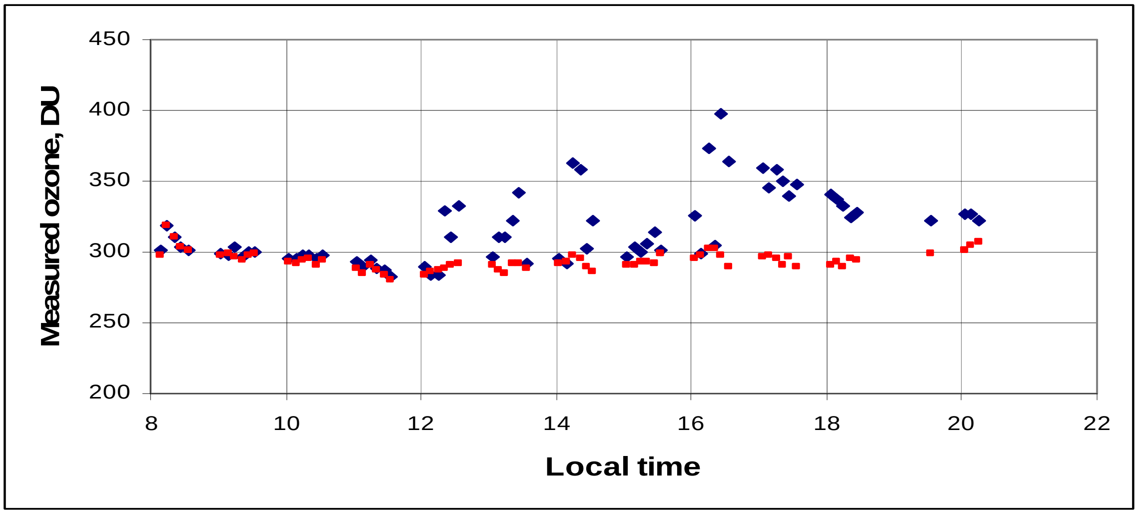

Fig.3. UVOS total ozone measurements for 15.09.2013. Cloudy conditions. Blue points- uncorrected data, red points – values corrected for cloudy. Mean values: UVOS - 294 D.u, Dobson spectrophotometer No108 - 293 D.u.

The UVOS is capable to measure total ozone over the Russia territory in any range of weather conditions.

UVOS also registers the UV spectrum from the hemisphere of the sky from 290 to 400 nm and it accordingly allows to measure radiation in the range of UV-A, UV-B and erythema-active radiation.

Now 14 devices UFOS were manufactured by the firm “Laser Centre ITMO” and after calibration in MGO will be installed on Roshydromet ozone network.