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Determination of Distribution of Ozone Content in Lower Troposphere and Atmospheric Aerosol Optical Thickness over Territory of Georgia Using Satellite Data and Ground Truth Measurements

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Abstract

Aerosol and ozone are very important parameters of the atmosphere. The data of these small constituents are required for the simulation of atmospheric processes, weather forecasting, study of climate variation, ecological appraisals and, etc. In the majority of studies is necessary the information above the large regions or continents. Ground-based study of these atmospheric parameters over the large area is difficult and expensive procedure. Furthermore, large changeability in the environment requires the rapid renovation of measurements. This circumstance requires the creation of the dense network of the ground stations of observations.

At present in the world there are several satellite systems for the operational global checking of the atmospheric parameters. These satellites are equipped with microwave and optical instruments for measuring the atmospheric parameters, such as the aerosol optical thickness of the atmosphere, the content of water vapor, ozone, greenhouse gases, carbon monoxide, nitrogen, sulfur, profiles of temperature, pressure and relative humidity, cloudiness and etc.

The relatively low accuracy of satellite measurements can be considerably improved by correction with the data of ground-based measurements. Work examines the methodology of the determination of the distribution of the ozone content in the lower troposphere and the aerosol optical thicknesses of the atmosphere above the territory of Georgia according to the data of satellite and ground-based measurements in Tbilisi.

For an example the schematic pictures of the 3D distributions of the ozone in the 2.5- km layer of the atmosphere, and also the aerosol optical thickness of the atmosphere above the territory of Georgia and contiguous countries for all days of observations, and also cloudless and not much cloud days are given.

Key words: atmospheric aerosol optical depth, tropospheric ozone, satellite data.

INTRODUCTION

In the last years the problem of the forthcoming climate change under the conditions of growing anthropogenic impact on the environment has been drawing an increasing attention. This problem acquires a particular importance for Georgia, where almost all climate types are encountered except of savannahs and tropical forests.

One of the main reasons for the modern climate change represents the human activity related to the energy consumption. Therefore a considerable attention was paid to the inventory of the anthropogenic emissions of the greenhouse gases and aerosols, having a direct effect on the climate formation, in Georgia [1].

The generalization by WMO of the opinions of the meteorological services from 50 countries enabled to classify the factors of the annual variability of the global climate: 1) ocean-atmospheric interactions; 2) destruction of forests, solar activity; 3) variability of the snow and ice cover; 4) others (urbanization, CO_2, aerosols, desertification, stratospheric aerosols, soil humidity). At a scale of decades the priority is given to: 1) CO_2; 2) destruction of forests; 3) urbanization, ocean-atmospheric interaction; 4) others (aerosols, solar activity, desertification, volcanic eruptions, stratospheric ozone, anthropogenic heat emissions, snow and ice cover) [2, 3].

Thus, changes in the global climate occurring at present are conditioned to a significant extent by the changes of the contents of radiatively active admixtures of an anthropogenic origin in the atmosphere. These admixtures are carbon dioxide (CO_2), methane (CH_4), nitrogen protoxide (N_2O), halocarbons (CFCs), tropospheric and stratospheric ozone and aerosols. Except of non soot aerosol particles and stratospheric ozone all other mentioned components play the role of heat accumulators in the formation of the energy level of the Earth.

CO_2, CH_4, N_2O, CFCs, tropospheric ozone together with water vapor, whose radiative properties are quite well studied [2], absorb long-wave radiation emitted by the Earth’s surface and create the “greenhouse” effect. Soot aerosols actively absorb solar radiation and warm the atmosphere by reemitting it. Nonsoot aerosol particles mainly scatter solar radiation thus diminishing its flux to the Earth’s surface. In addition aerosols interacting with clouds change their microphysical and electrical characteristics, which finally results in changing of the optical properties of these mixed aerodisperse systems. Considering that cloudiness represents one of the most important factors affecting the radiation and climate, the role of aerosols in indirect radiative effects in the atmospheric and Earth’s energy level formation turns out to be very significant.

The aerosol contents and ozone concentration are very important parameters of the atmosphere. These values are required for atmospheric processes simulation, weather forecasting, climate change research, environmental assessments, etc.

However, most studies need to know the atmosphere condition over a wide region or continent. A ground-based acquisition of the parameters of atmosphere within a large area is a difficult and expensive procedure. Moreover, a high variability in the atmosphere environment requires a quick update of measurements. This circumstance necessitates the establishment of a dense network of ground instrumentation stations.

Unfortunately at the moment in Georgia is not possible to organize fine-grid ground network for these observations. Therefore, the satellite measurements of the atmospheric minor constituents are especially relevant. So, preliminary results of ozone distribution in the lower troposphere and atmosphere aerosol optical thickness mapping over the territory of Georgia by satellite data and ground-based measurements are presented below.

METHOD AND DATA DESCRIPTION

Satellite systems for atmosphere remote sensing. The basic principle of the atmosphere remote sensing is the spectral radiance measurement in certain spectral bands to determine the physical parameters of atmosphere environment. This is possible due to the spectral absorption and emission or infrared and microwave radiation according to the Kirchhoff's law. Thus, the spectral irradiation passed through the atmosphere is a function of one's temperature and gas composition [4].

Modern satellite systems for Earth's atmosphere remote sensing are equipped with special optical or microwave sensors. The European Envisat (GOMOS, MIPAS and SCIAMACHY spectrometers) and MetOp (IASI, GOME-2 and HIRS/4 instruments), the American EOS (MOPITT, AIRS, OMI, TES infrared spectrometers, HIRDLS, MLS microwave radiometers), NPOESS (OMPS ultraviolet/visible spectrometer) [2] are well known among currently operating atmosphere remote sensing satellite systems, as well as the Japanese GOSAT one (TANSO infrared spectrometer) [6].

Main technical specifications of the onboard sensors for the Earth's atmosphere measurements of operational satellite systems are shown in table 1.

Table 1

Technical specifications of instruments for the atmospheric parameters measuring of operational satellite systems

Satellite system	Equipment	Spectral range, μm	Spectral resolution, μm
Envisat	GOMOS	0.25 – 0.95	0.17 – 0.20
	MIPAS	4.15 – 14.6	1.6 – 2.0
	SCIAMACHY	0.24 – 2.40	$0.2 \cdot 10^{-3}$– $0.5 \cdot 10^{-3}$
MetOp	IASI	3.62 – 15.5	$1.4 \cdot 10^{-3}$
	GOME-2	0.24 – 0.79	$0.135 \cdot 10^{-3}$
	HIRS/4	3.8 – 15.0	0.5 – 0.7
EOS	MOPITT	2.2 – 4.7	0.22 – 0.55
	AIRS	3.74 – 15.4	$4.9 \cdot 10^{-3}$
	OMI	0.27 – 0.5	$0.45 \cdot 10^{-3}$ – $1.0 \cdot 10^{-3}$
	TES	3.2 – 15.4	$2.9 \cdot 10^{-4}$ – $8.5 \cdot 10^{-4}$
	HIRDLS	6 – 18 mm	$4 \cdot 10^{-5}$ – $8 \cdot 10^{-5}$
	MLS	118 – 2250 GHz	400 – 510 MHz
NPOESS	OMPS	0.25 – 0.38	10^{-3}
GOSAT	TANSO	5.5 – 14.3	$6 \cdot 10^{-4}$ – $8 \cdot 10^{-4}$
Satellite system	**Swath, km**	**Spatial resolution, km**	**Atmospheric products**
Envisat	120	15 – 40	O_3, NO_2, NO_3, O_2, H_2O, aerosols
	150	3 × 30	O_3, NO, NO_2, HNO_3, N_2O_5, $ClONO_2$, CH_4
	960	32 × 215	O_3, NO_2, BrO, SO_2, HCHO, H_2O, CH_4, CO, CO_2, aerosols
MetOp	1066	12 – 18	O_3, aerosols

	960	80 × 40	O_3, NO_2, BrO, SO_2, HCHO
	2160	10 – 16	CO_2, O_3, N_2O
EOS	650	22	CO, CH_4
	1650	13.5 – 19.5	CO_2, CO, CH_4, O_3, SO_2, aerosols
	2600	13 × 24	O_3, NO_2, SO_2, HCHO, BrO, OClO, aerosols
	5.3 × 8.5	0.53 × 5.3	H_2O, O_3, CH_4, CO, HNO_3
	500	10 × 300	O_3, HNO_3, NO_2, N_2O_5, $CHClF_2$, CCl_2F_2
	300	1.5 × 3	H_2O, HNO_3, HCN, ClO, N_2O, O_3, SO_2, CH_3CN, CO, HCl, HOCl, BrO, CH_3CN
NPOESS	2800	50 – 250	O_3, BrO, HCHO, NO_2, OClO, SO_2
GOSAT	790	1.5 – 10.5	CO_2, CH_4, aerosols, clouds

Data processing. An aerosol optical thickness (AOT) and ozone column amount (OCA) over central and eastern Georgia for 2009-2011 was evaluated by EOS/OMI satellite spectrometer using in-situ ground-truth measurements. The OMI (Ozone Monitoring Instrument) is a joint development of the Netherlands Space Office, the Finnish Meteorological Institute and NASA. It is installed onboard the EOS Aura satellite and provides daily global monitoring of atmosphere condition in 270-500 nm band with 0.5 nm spectral resolution and 13×24 km/pixel spatial resolution. The measurement frequency is once per day. Aura satellite passes over Georgia is always around the same time: from 2 till 5 pm Greenwich mean time. The OMI L2G OMAEROG.003 Daily Level 3 Global Gridded Product was used for atmosphere condition initial mapping. Satellite data are available through the Mirador (http://mirador.gsfc.nasa.gov/) Earth Science Search Tool. Data selection, territorial segment clipping, and monthly values averaging were carried out through the Giovanni (http://disc.sci.gsfc.nasa.gov/giovanni/) Interactive Online Visualization and Analysis web-application.

As a result 390 monthly territorial segments of a regular grid data (Fig.1) was collected for each information product EOS/OMI.

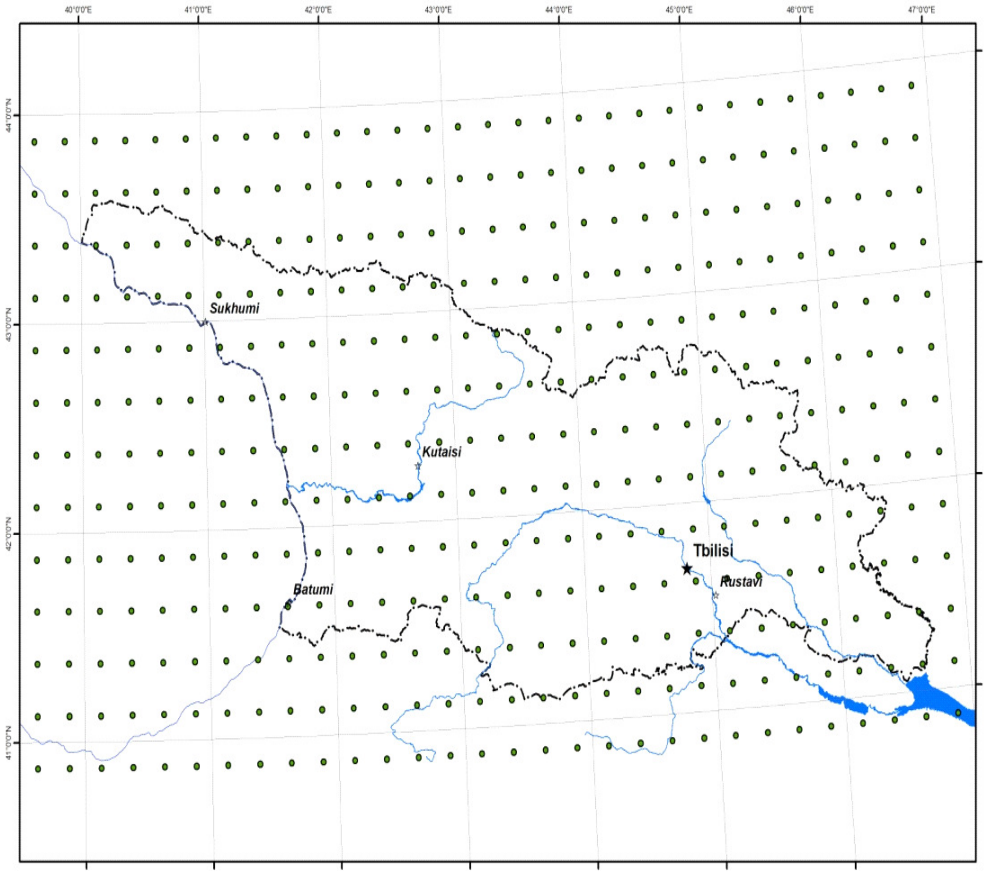

Fig.1. The atmosphere satellite measurements grid over Georgia

Total atmosphere column satellite measurements was recalculated to values for standard reference height H = 2500 m. The exponential dependence of p_{AOT} AOT relative value on height H proven for the territory of Georgia has been used which is shown in Fig.2 [7,8]. Using one it is possible to restore the relationship between w_{AOT} AOT accumulated fraction and current height in terms of the total atmosphere column amount.

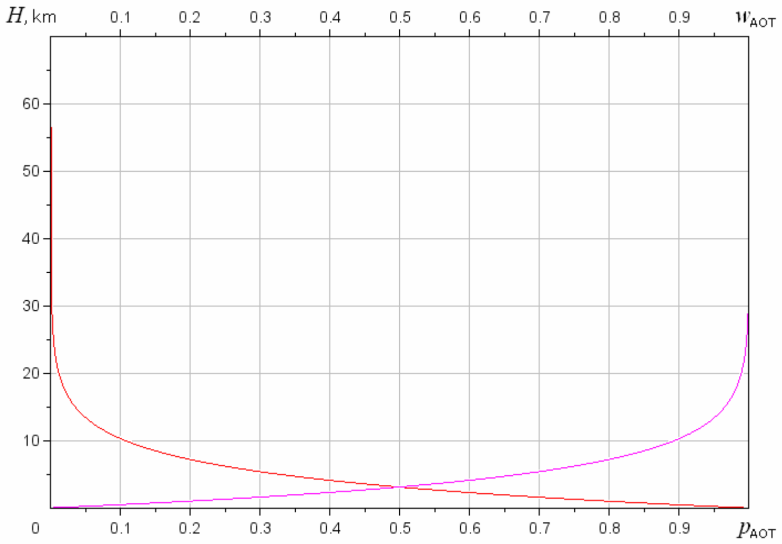

Fig.2. Vertical profiles of p_{AOT} AOT relative value and w_{AOT} AOT accumulated fraction

The dependence of n_{O3} ozone concentration on height is quite complicated, so the standard profile of the mid-latitudes summer atmosphere is used for average ozone concentration, shown in Fig.3 [9]. The relationship between w_{O3} ozone accumulated fraction and height is also restored using this profile.

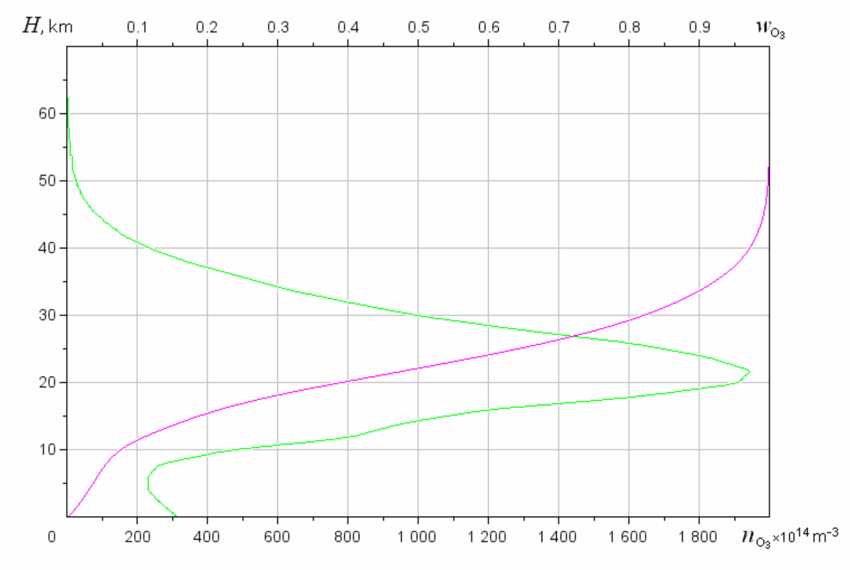

Fig.3. Vertical profiles of n_{O3} atmospheric ozone concentration and w_{O3} ozone accumulated fraction

Robust regressions of recalculated to lower atmosphere satellite measurements toward the near-surface truth data obtained at the M. Nodia Institute of Geophysics was found for 6 ground measurement stations of AOT inside the territory of Georgia (Fig.4) [2,7,8], as well as for measurements of ground-level ozone, aerosols and AOT in Tbilisi of late years (06.2009-12.2011) [10, 11]. Data on the total cloud cover in Tbilisi and elsewhere in Georgia and neighboring countries were taken from [11, 12] references.

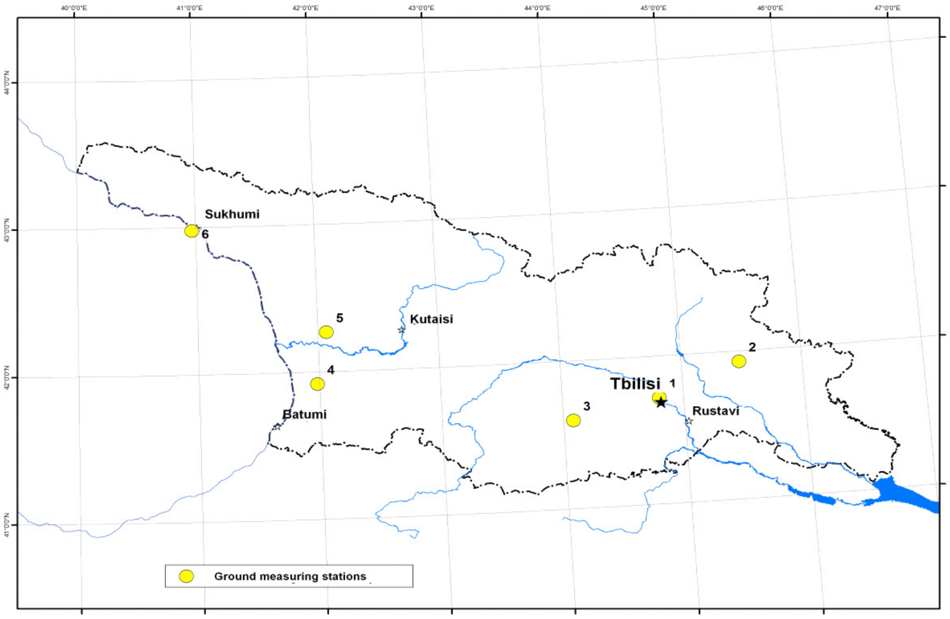

Fig.4. Ground measurement stations location on the territory of Georgia

Mentioned regression functions (separately for spring/winter and summer/autumn periods) are illustrated by Fig.5 and Fig.6 plots.

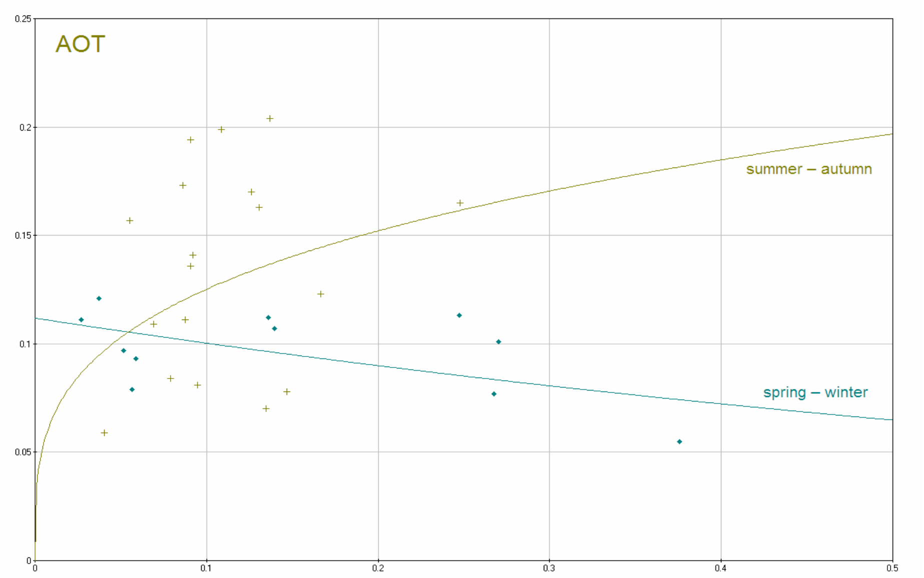

Fig.5. Regression curves between ground-based AOT values for sunny days and recalculated satellite measurements

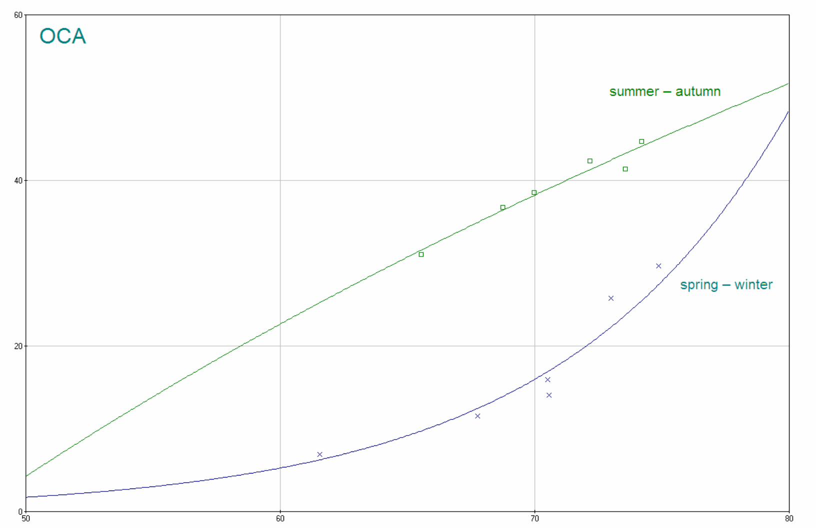

Fig.6. Regression curves between ground-based ozone concentrations in near-surface layer of atmosphere and recalculated satellite measurements

RESULTS

Collected satellite data were recalculated using regression dependences Fig.5 and Fig.6 into monthly series of near-surface AOT values and ozone concentrations on a regular grid Fig.1.

Next the analysis of time series of satellite measurements at each point was conducted. Periodic seasonal components was eliminated and linear trends was extracted. Maps of means and annual increments of AOT and ground-level ozone concentrations were developed by results of analysis. The preliminary results of these studies, which after some clarifications will be published soon, are presented in [13].

For example, schematic 3D plots of distributions of ozone concentrations in 2.5 km atmosphere layer, as well as AOTs over territory of Georgia and adjacent countries are listed below separately for all days of observations and for sunny and low cloud days only – see Fig.7-Fig.9.

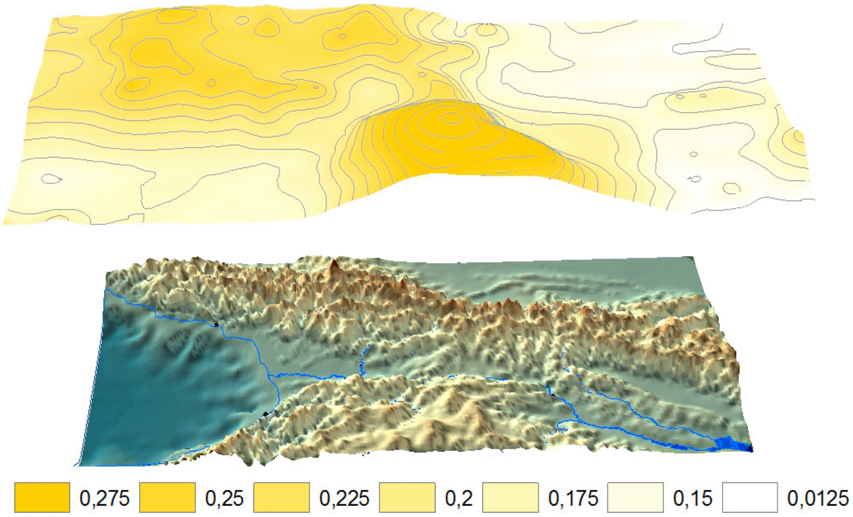

Fig.7. Schematic plot of the distribution of AOT means over territory of Georgia and adjacent countries for all days of observation (a darker tone corresponds to AOT higher values)

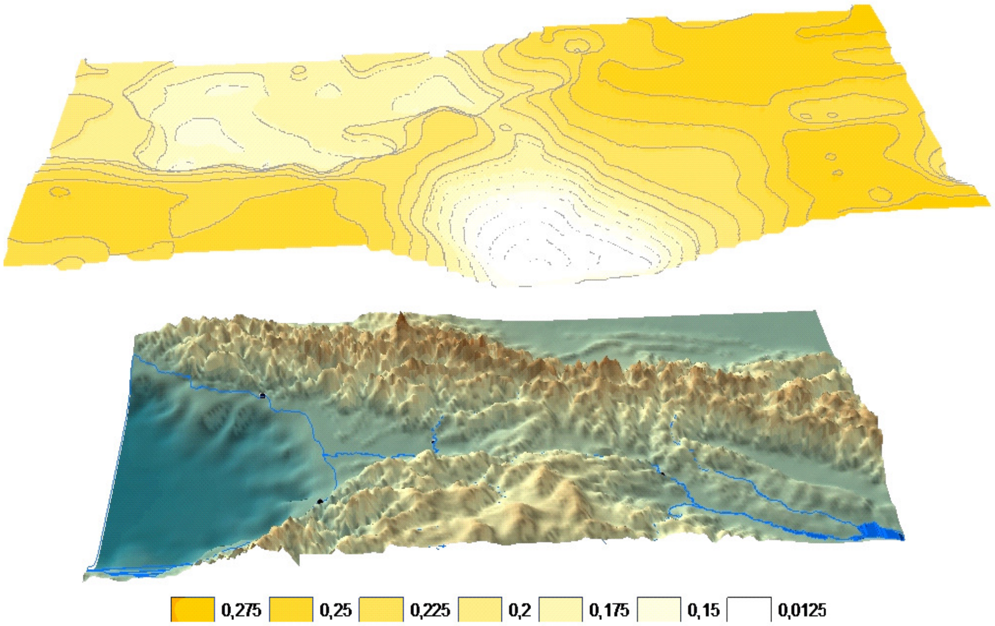

Fig.8. Schematic plot of the distribution of AOT means over territory of Georgia and adjacent countries for sunny and low cloud days of observation only (a darker tone corresponds to AOT higher values)

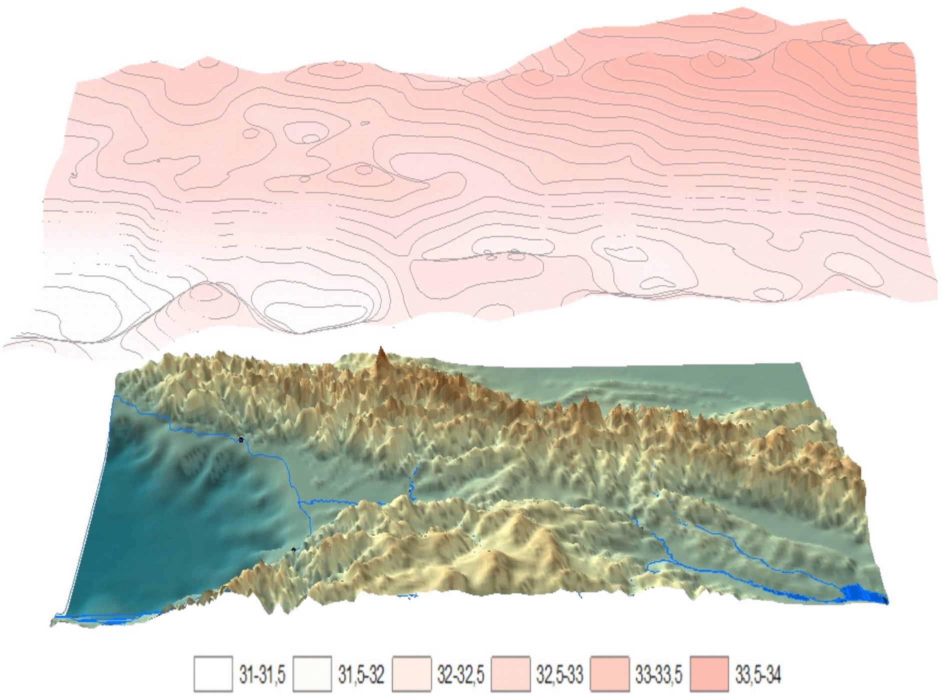

Fig.9. Schematic plot of the distribution of ozone concentrations in lower 2.5 km atmosphere layer over territory of Georgia and adjacent countries (a darker tone corresponds to higher values of ozone concentration)

As it follows from Fig.7 and Fig.8, the AOT distributions over the study area differ significantly from each other. In the first case (Fig.7) the AOT values over the ridges are greater than ones over the valleys. In the second case (Fig. 8) it is vice versa. This phenomenon can be explained by the presence of clouds, which, in addition to the direct visibility reduction, contribute to aerosols accumulation within near-cloud space [2, 14, 15].

Table 2

Total cloudiness over Georgia sites at 7 pm local time [17]

Site	Northern latitude	Eastern longitude	Elevation above sea level, m	Cloudiness, all data	Cloudiness, sunny days in Tbilisi at 1 pm
Aspindza	41°34'	43°15'	980	5.9	3,6
Ambrolauri	42°31'	43° 09'	544	6.1	4,0
Bolnisi	41°27'	44° 33'	534	6.8	4,3
Gori	41°59'	44°07'	612	6.2	3,8
Zugdidi	42°30'	41°51'	108	6.3	4,3
Mta-Sabueti	42°02'	43°29'	1245	7.3	5,5
Kutaisi	42°16'	42°38'	116	7.3	5,5
Pasanauri	42°21'	44°42'	1064	5.2	3,2
Tbilisi	41°42'	44°45'	425	6.3	4,1
Telavi	41°56'	45°23'	543	6.0	3,0
Khopa	41°23'	41°25'	33	6.7	5,5

Sochi	43°35'	39°46'	57	6.5	5,2
Shadzhatmaz	43°44'	42°40'	2056	8.9	8,7

For example, the vertical distribution of the number concentration of aerosols with sizes more than 0.35 μm in radius has been studied for various regions of Georgia. In particular it was shown that within the lower five kilometer atmospheric layer the size distribution of aerosols is quite steady and varies little with elevation and under the influence of cloudiness. However at days with cumulus clouds in comparison to cloudless days the mass of aerosols in the lower five kilometer layer increases approximately 1.4 times, while at days with clouds of various types including cumulus – 2.5 times [15]. In addition to this, the increased humidity of air in the layers of cloud formation, also contributes to increase of AOT [16].

For comparison, Table 2 shows the total cloud cover at 7:0 pm (the time of satellite pass over Georgia) for 10 observing stations in Georgia, 1 station in Turkey (Khopa, not far from Batumi) and 2 stations in Russia (Sochi-Razdolnoe, Shadzhatmaz) for all days of observations, as well as for the days when in Tbilisi in 1:0 pm (AOT measuring time) was clear of low cloud weather. In the first case (Fig.7), the AOT values are followed by the total cloud cover values. Overt the ridges the cloudiness is greater and, consequently, the AOT is greater too. Also we note that the overall vision of the AOT distribution over the study area as a whole is fitted good to earlier on the distribution of total cloud cover [17].

For sunny and low cloud days (Fig. 8) the classical distribution of AOT is observed – over the lowlands its value is higher than over the ridges [2,7,8].

CONCLUSIONS

The methodology of determination of distribution of ozone content in lower 2.5 km layer of atmosphere and aerosol optical thickness of the atmosphere above the territory of Georgia according to the data of satellite and ground-based measurements in Tbilisi is proposed. The obtained preliminary results indicate the prospect of the development of works in this direction. It is soon provided to present the more comprehensive data about the distribution of the indicated atmospheric parameters above territory of Georgia.

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ქვედა ტროპოსფეროში ოზონის შემცველობის და ატმოსფეროს აეროზოლური ოპტიკური სისქის განაწილების განსაზღვრა საქართველოს ტერიტორიის თავზე თანამგზავრული და მიწისპირა გაზომვების მიხედვით

ს. სტანკევიჩი, ო. ტიტარენკო, ა. ამირანაშვილი, ხ. ჩარგაზია

რეზიუმე

აეროზოლები და ოზონი ატმოსფეროს მნიშვნელოვან პარამეტრებს წარმოადგენს. ამ მცირე მინარევების ექსპერიმენტული მონაცემები აუცილებელია ატმოსფერული პროცესების მოდელირებისათვის, ამინდის პროგნოზირებისათვის, კლიმატის ცვლილების კვლევისთვის, ეკოლოგიური ექსპერტიზისათვის და სხვა.

უმრავლესი სახის კვლევებისათვის საჭიროა ინფორმაცია დიდი რეგიონებისა და კონტინენტების თავზე. ატმოსფეროს აღნიშნული პარამეტრების მიწისპირა კვლევები დიდ ფართობებზე რთული და ძვირადღირებული პროცედურაა. ამასთან, გარემოს დიდი ცვალებადობა ითხოვს გაზომვების სწრაფ განახლებას. ეს გარემოებები აუცილებელს ხდის მიწისპირა დაკვირვებების სადგურების კონცენტრირებული ქსელის შექმნას.

დღეისათვის მსოფლიოში არსებობს რამდენიმე სატელიტური სისტემა ატმოსფერული პარამეტრების გლობალური ექსპლუატაციური კონტროლისათვის. ეს თანამგზავრები აღჭურვილია მიკროტალღური და ოპტიკური ინსტრუმენტებით ისეთი ატმოსფერული პარამეტრების გასაზომად, როგორიცაა ატმოსფეროს აეროზოლური ოპტიკური სისქე, წყლის ორთქლის შემცველობა, ოზონი, სასათბურე აირები, ნახშირორჟანგი, აზოტი, გოგირდი, ტემპერატურის პროფილები, წნევა და ფართობითი ტენიანობა, ღრუბლიანობა და სხვა. თანამგზავრული გაზომვების შედარებით დაბალი სიზუსტე შესაძლებელია მნიშვნელოვნად გაუმჯობესდეს მიწისპირა გაზომვების მონაცემებით კორექციის საფუძველზე.

ნაშრომში განხილულია ქვედა ტროპოსფეროში ოზონის შემცველობის განაწილებისა და ატმოსფეროს აეროზოლური სისქის განსაზღვრის მეთოდოლოგია საქართველოს ტერიტორიის თავზე თანამგზავრული და ქ. თბილისში ჩატარებული მიწისპირა გაზომვების მონაცემების საშუალებით.

მაგალითისათვის მოყვანილია ატმოსფეროს 2.5 კმ სისქის შრისათვის ოზონის შემცველობის განაწილებისა და ასევე საქართველოს ტერიტორიის თავზე და მის მოსაზღვრე ქვეყნებისათვის ატმოსფეროს აეროზოლური ოპტიკური სისქის 3D სქემატური გამოსახულებები დაკვირვების ყველა დღისათვის როგორც უღრუბლო, ასევე მცირეღრუბლიანი დღეებისათვის.

Определение распределения содержания озона в нижней тропосфере и аэрозольной оптической толщи атмосферы над территорией Грузии по данным спутниковых и наземных измерений

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Резюме

Аэрозоли и озон - очень важные параметры атмосферы. Данные об этих малых примесях требуются для моделирования атмосферных процессов, прогнозирования погоды, исследования изменения климата, экологических экспертиз, и т.д.

В большинстве исследований необходима информация над большими регионами или континентами. Наземное исследование этих параметров атмосферы на большой площади - трудная и дорогая процедура. Кроме того, большая изменчивость в окружающей среде требует быстрого обновления измерений. Это обстоятельство требует создания плотной сети наземных станций наблюдений.

В настоящее время в мире есть несколько спутниковых систем для эксплуатационного глобального контроля параметров атмосферы. Эти спутники оборудованы микроволновыми и оптическими инструментами для измерения параметров атмосферы, таких как аэрозольная оптическая толща атмосферы, содержание водяного пара, озона, парниковых газов, окисей углерода, азота, серы, профилей температуры, давления и относительной влажности, облачности и т.д. Относительно низкая точность спутниковых измерений может быть значительно улучшена путем коррекции с данными наземных измерений.

В работе рассмотрена методология определения распределения содержания озона в нижней тропосфере и аэрозольной оптической толщи атмосферы над территорией Грузии по данным спутниковых и наземных измерений в Тбилиси.

Для примера приведены схематические картины 3D распределений содержания озона в 2.5-километровом слое атмосферы, а также аэрозольной оптической толщи атмосферы над территорией Грузии и сопредельных стран для всех дней наблюдений, а также безоблачных и малооблачных дней.