THE REPUBLIC OF AZERBAIJAN

On the rights of the manuscript

Specialty: **3337.01- information-measuring and control systems**

Field of science: **Technical sciences**

Applicant: **Fatullaev Akif Allahverdi oglu**

ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

"New methods of meteorological measurements of the degree of pollution of the surface layer of the atmosphere"

Baku – 2021

The work was performed at Scientific Research Aerospace Informatics Institute.

Scientific supervisor (consultant): doctor of technical sciences,
Professor **Asadov Hikmet Hamid oglu**

Official opponents: doctor of technical sciences, professor
Gasımzade Tokay Murad oglu
doctor of technical sciences, professor
Rustamov Gazanfar Arastun oglu
doctor of technical sciences
Farzane Eldar Nadirovich

Dissertation council ED 2.41 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan Technical University.

Chairman of the Dissertation council:
doctor of technical sciences,professor **Vaqif Alijavad oglu Gasımov**

Scientific secretary of the Dissertation council:
doctor of technical sciences, dosent **Vahid Gara oglu Farhadov**

Chairman of the scientific seminar: doctor of technical sciences, dosent **Namig Tahir oglu Abdullaev**

INTRODUCTION

Relevance and degree of elaboration of the theme. The rapid development of industry is inextricably linked with environmental pollution and, in particular, the atmosphere. The presence of a temperature inversion, formed for various reasons in the lower atmosphere, leads to the accumulation of pollutants in the mixing layer under the inversion layer, which inevitably affects the ecological state of the entire surface layer of the atmosphere.

The most polluted part of the troposphere is the surface layer of the atmosphere, which is the lower boundary layer, extending from the earth's surface to a height of several tens of meters.

In the surface layer of the atmosphere, a sharp change in meteorological elements with height is observed: the vertical gradients of wind speed, temperature and moisture in the surface layer of the atmosphere are tens and hundreds of times higher than the corresponding values in the overlying layers, but decrease in absolute value with the size of the height.

From an ecological point of view, the pollution of the surface layer is closely related to the pollution of the entire boundary layer of the troposphere. A significant accumulation of water vapor, aerosol and small toxic gases is also observed in the boundary layer of the troposphere. All this shows the urgent need and urgency of meteorological measurements of aerosol pollutants in the boundary layer of the troposphere. The need for accurate measurement of water vapor also lies in the significant absorption of solar radiation energy by water vapor in the visible and near infrared range. The above confirms the relevance of the topic of dissertation research, which consists in the development of new methods and means of meteorological measurements of the degree of pollution of the lower layers of the troposphere.

To study the level of contamination of the lower level of the atmosphere, lidars, DOAS, radiosondes, and satellite microwave radiometers are used.

In several years, the last Japanese scientists Yoshi, Kuze, Shiraki, and others. An original method for studying the tropospheric surface layer was proposed, which consists in using an external emitter of high-altitude signal lamps used as safety lights in aviation. Solar photometers occupy a special place among meteor meter devices used to study the entire thickness of the atmosphere from the Earth to the Sun. Solar photometers installed on Earth make it possible to study aerosols, some small gases, and water vapor in the atmosphere. Solar photometers are also used to study clouds, ionospheric radiation, aerosol vents penetrating due to sandstorms, volcanic eruptions, etc.

Gas-filter correlation spectroscopy is also suitable for meteorological measurements in the lower troposphere. This is a relatively simple and reliable method, allowing for a relatively quick and selective discharge of various gases with sufficient safety. In this method, fluctuations in the light source, as well as changes in other gases, do not affect the measurement result. The gas-filter correlation method has been widely used in on-board meters since the 1960s.

At Chiba University (Japan), for the first time, a special type of DOAS spectrometer was proposed, in which a white signal lamp mounted on the roof of a high-rise object was used as a light source. These warning lights are usually intended for the safe operation of air transport.

In this dissertation work, further development of this method is proposed by replacing DOAS with a solar photometer, which also makes it possible to measure atmospheric aerosol. The paper proposes radial-difference and difference methods of meteorological measurement of the surface layer of the atmosphere, the theoretical foundations and applied issues of their implementation are developed.

The purpose and objectives of the research. The purpose of the thesis is to develop scientific and methodological foundations for the creation of highly effective methods and tools for meteorological measurements of the degree of pollution of the surface layer of the troposphere.

1. Investigation of the possibility of meteorological photometric measurement of the optical thickness of the surface layer of the troposphere using high-altitude signal lamps as an emitter and development of a new radial-difference method of photometric measurements, which makes it possible to exclude the temporal instability of the radiation intensity of high-altitude signal lamps and to determine the main direction of pollution of the surface layer of the atmosphere.

2. Development of a difference method for measuring the thickness of the tropospheric surface layer, which consists in carrying out two solar-photometric measurements at opposite boundaries of the investigated layer and further subtracting the measurement results.

3. Development of the following measurement, correction and optimization methods related to atmospheric aerosol:

- development of a method for measuring the low aerosol load of the atmosphere in the aerosol measurement network using the total and scattered radiation at low solar heights;
- development of an approximation method for determining the aerosol error correction coefficients for solar photometers when measuring the total amount of water vapor in the atmosphere;
- development of a method for finding the optimal values of optical thicknesses of fine and coarse dispersed components of atmospheric aerosol, ensuring the achievement of the minimum value of the correction signal for the influence of diffuse radiation.

4. Development of a mathematical model of the impact of soot on photolytic processes occurring in the border layer of the troposphere, taking into account the interaction of surface soot and ozone.

5. Development of an algorithm for increasing the accuracy of the photometric measurement method, the characteristics of which are subject to time drift due to the temporal instability of the characteristics of the opto-electronic path of the photometer.

6. Development of a variant of implementation of three-wave photo throwing, as a result of which a significant increase in

signal / noise at the output is achieved due to changes in some modes and an improved method of the Langley diagram used to calibrate solar photometers.

Research methods. In the process of solving the set scientific problems, the corresponding provisions of the theory of optical atmospheric measurements, mathematical analysis of signals, the theory of variational optimization, the theory of random processes, and the theory of atmospheric optics were used.

In order to confirm the results obtained, experimental-model studies of the optical indicators of the surface layer of the atmosphere were carried out.

The main provisions for the defense.

1. The proposed radial-difference method of meteorological measurements, which makes it possible to exclude the temporal instability of the radiation intensity of high-altitude signal lamps and to determine the main direction of pollution of the surface layer of the atmosphere.

2. The proposed difference method for meteorological measurements of the optical thickness of the tropospheric surface layer, which consists in carrying out two solar-photometric measurements - one with a ground-based photometer, the other with a photometer installed on the upper boundary of the surface layer and further subtraction of the obtained measurement results, in two versions.

3. New measurement, correction and optimization methods related to atmospheric aerosol:

- a method for measuring the low aerosol load of the atmosphere in the aerosol measurement network using the total and scattered radiation at low solar heights;

- an approximation method for determining the aerosol error correction coefficients for solar photometers when measuring the total amount of water vapor in the atmosphere;

- a method for finding the optimal values of optical thicknesses of fine and coarse dispersed components of atmospheric aerosol, ensuring the achievement of the minimum value of the signal for correcting the influence of diffuse radiation.

4. The constructed mathematical model of the impact of soot on photolytic processes occurring in the border layer of the troposphere, according to which: to ensure the receipt of a minimum amount of solar radiation on the border layer, a mutually inverse relationship between the concentrations of soot and ground-level ozone should be ensured.

5. The proposed algorithm for increasing the accuracy of the photometric method, changes in the characteristics of which are subject to drift due to the temporal instability of the characteristics of the optoelectronic path of the photometer, in two versions.

6. The proposed version of the construction of a three-wave photometer, in which a significant increase in the signal-to-noise ratio is achieved due to the simulation of photometric measurements at small values of the optical air mass in comparison with the real value of this indicator and the proposed improvement of the Langley diagram method used to calibrate solar photometers, consisting in the implementation of stabilization Langley charts by changing the wavelength to match the changing visibility on the Earth's surface.

Scientific novelty of research.

1. The possibility of meteorological photometric measurement of the optical thickness of the surface layer of the troposphere using high-altitude signal lamps as an emitter has been investigated. A radial-difference method of meteorological photometric measurements is proposed, which makes it possible to exclude the temporal instability of the radiation intensity of high-altitude signal lamps and to determine the main direction of pollution of the surface layer of the atmosphere.

2. A difference method for meteorological measurements of the optical thickness of the surface layer of the troposphere is proposed, which consists in carrying out two solar photometric measurements - one using a ground photometer, the other using a photometer installed on the upper boundary of the surface layer and

further subtracting the obtained measurement results. Two options for the implementation of the proposed method are proposed.

3. The following new methods of measurement, correction and optimization related to atmospheric aerosol have been proposed:

- a method for measuring a low aerosol load of the atmosphere in a network of aerosol measurements using the total and scattered radiation at low solar heights, in the implementation of which there is no need to measure direct solar radiation;
- an approximation method for determining the aerosol error correction coefficients for solar photometers when measuring the total amount of water vapor in the atmosphere;
- a method for finding the optimal values of the optical thicknesses of fine and coarse dispersed components of atmospheric aerosol, ensuring the achievement of the minimum value of the signal for correcting the effect of diffuse radiation under given restrictions on the minimum values of the optical thickness of the aerosol at three fixed wavelengths.

4. A mathematical model of the effect of soot on photolytic processes occurring in the near-boundary layer of the troposphere has been constructed. According to this model:

- there is a nature of the relationship between ground-level ozone and soot, which ensures the arrival of a minimum amount of solar radiation to the boundary layer of the lower troposphere;
- to ensure that a minimum amount of solar radiation reaches the boundary layer, a mutually inverse relationship between the concentrations of soot and the surface layer should be ensured;
- the appearance of a certain amount of soot leads to a decrease in solar radiation entering the boundary layer, which in turn leads to a decrease in the generated amount of ground-level ozone.

5. An algorithm is proposed for increasing the accuracy of the photometric method, the changes in the characteristics of which are subject to drift due to the temporal instability of the characteristics of the optoelectronic path of the photometer. Two ways of implementing the proposed algorithm are proposed.

6. A variant of constructing a three-wave photometer is proposed, in which a significant increase in the signal-to-noise ratio is achieved by simulating photometric measurements at low values of the optical air mass in the case of measurements in reality, at higher values of this parameter.

7. An improvement of the method of Langley diagrams used for calibrating solar photometers is proposed, which consists in the implementation of stabilization of Langley diagrams by changing the wavelength in accordance with the change in visibility on the Earth's surface.

The theoretical and practical value of research.

1. The method of meteorological photometric measurement of the optical thickness of the surface layer of the troposphere using signal lamps installed on high-rise structures as an emitter was further developed, first proposed by Japanese scientists, a radial-difference method of surface photometric measurements was developed, which significantly reduces the effect of temporal instability of the radiation intensity of high-altitude signal lamps on the measurement result and to determine the main direction of pollution of the surface layer of the atmosphere. The results obtained in this direction can be introduced into the practice of meteorological measurements to study the dynamics of aerosol pollution of the surface layer.

2. The developed difference method of meteorological measurements of the optical thickness of the surface layer of the troposphere, in two versions of its implementation, makes it possible to determine the altitude gradient of aerosol pollution of the surface layer and is most suitable for carrying out meteorological measurements in an urban environment.

3. The proposed methods for measuring, correcting and optimizing, taking into account the influence of atmospheric aerosol and ground-level ozone, including:

- a method for measuring the low aerosol load of the atmosphere in the aerosol measurement network using the total and scattered radiation at low solar heights;

- an approximation method for determining the aerosol error correction coefficients for solar photometers when measuring the total amount of water vapor in the atmosphere;

- a method for finding the optimal values of optical thicknesses of fine and coarse dispersed components of atmospheric aerosol, in order to achieve the minimum value of the signal for correcting the influence of diffuse radiation, it is possible to significantly reduce the inaccuracy of meteorological measurements of the indicators of pollution of the surface layer carried out using solar photometers.

4. The proposed mathematical model of the impact of soot on photolytic processes occurring in the near-boundary layer of the troposphere allows in practice to take into account the influence of the dynamics of changes in the quantitative parameters of aerosol and ozone in the lower layer of the atmosphere on solar radiation arriving at the Earth's surface.

5. The proposed method for increasing the accuracy of the photometric method, the measurements of which are subject to drift due to the temporal instability of the characteristics of the optoelectronic path of the photometer, makes it possible, in practice, to significantly increase the accuracy of serial meteorological measurements to study the dynamics of meteorological conditions.

6. The proposed version of the implementation of three-wave photometry, in which a significant increase in the signal-to-noise ratio is achieved due to photometric measurements, at simulated low values of the optical air mass, in practice, expands the potential possibilities of using three-wave solar photometers in terms of eliminating the residual effect of atmospheric aerosol on the result of the measurements.

7. The improved method of Langley diagrams, used to calibrate solar photometers, will make it possible in practice to significantly improve the calibration accuracy of solar photometers, and, as a result, the accuracy of solar photometric measurements.

Approbation and implementation of work. The main provisions and results of the dissertation research were reported and discussed at the following international republican conferences: V

Correspondence International Scientific and Practical Conference "Actual problems of ecology and labor protection". Kursk, 2014, 4th international interuniversity scientific and practical conference "Engineering design calculations and technological solutions in the creation of new applied areas in technology", Velikiye Luki. 2014. The main results of the dissertation work were implemented in the OKP "İşıqlanan obyektin (siqnal raketinin) uçuş hündürlüyünün ölçən qurğunun işlənilməsi" held in RIAI by order of the software "Radioquraşdırma - zavodu" MMC in 2013 -2014.

The name of the organization where the dissertation work was carried out. The dissertation work was carried out at the Research Institute of Aerospace Informatics of the National Aerospace Agency.

The total volume of the thesis, taking into account the volume of individual structural sections. The introduction consists of 21,000 characters, Chapter I of 52,000 characters, Chapter II of 50,000 characters, Chapter III of 52,000 characters, Chapter IV of 80,000 characters. The total volume of dissertations is 255,000 characters.

MAIN CONTENT OF WORK

In the introduction to the dissertation, the urgency of the problem is substantiated, its state is analyzed, the purpose of the work, the tasks of research and the provisions submitted for defense are formed.

The first chapter of the dissertation is devoted to the proposed new methods for studying the degree of pollution of the surface layer of the troposphere.

The presence of a temperature inversion, formed for various reasons on the lower (hereinafter, the lower layer means the boundary and surface layers) of the atmosphere, leads to the accumulation of pollutants in the mixing layer under the inversion layer, which inevitably affects the ecological state of the entire surface layer of the troposphere.

To study the degree of contamination of the lower troposphere, lidars, DOAS, radiosondes, and satellite microwave radiometers are usually used. In recent years, in a number of works by Japanese scientists Yoshi, Kuze, Shiraki, and others, an original method for studying the tropospheric surface layer was proposed, which consists in using high-altitude signal lamps as a DOAS emitter.

As noted in the work, a special kind of DOAS spectrometer was first proposed at Chiba University (Japan), in which a white signal lamp installed on the roof of a high-rise building was used as a light source; such signal lamps are usually intended for the safe operation of air transport. In Japan and in many other countries, there is a standard requiring the installation of a white signal lamp on the roof of high-rise buildings over 60 m high. The source is usually xenon lamps, which flash every 1.5 seconds. At the same time, the background in the form of a glow of the sky is very easy to take into account when analyzing the signal spectrum. The paper reports on the use of an element CCD receiver in the 2048 spectrometer in the wavelength range of 200 - 800 nm, which provided an average resolution of 0.3 nm / pixel. The measurement scheme using a high-altitude transmitter is shown in Fig. 1.

The magnitude of the signal for collimated light can be estimated as

$$I_1 = I_0 \, e^{-\alpha \cdot L \cdot C} , \qquad (1)$$

Where

I_1 - intensity of radiation at the input of the photometer;

I_0 - radiation intensity before absorption;

α - coefficient of adsorption;

L - path length;

C - idle gas mixing ratio.

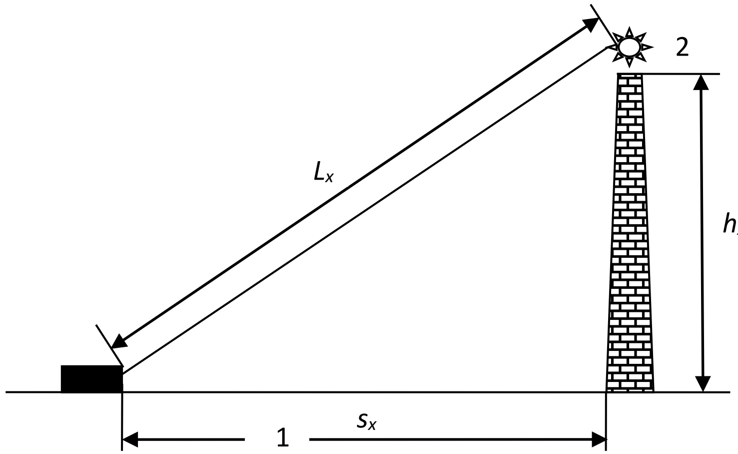

Fig. 1. Scheme of photometric measurements using a signal lamp: 1 - photometer; 2 - signal lamp

To measure the concentration of small gases in the troposphere, the values of the differential cross section $\Delta\alpha$ in several channels are pre-entered into the memory of the spectrometer. The following wavelengths were used to detect small gases: O_3:(265,7 – 304,4) nm; SO_2:(280,7 – 319,3) nm; NO_2:(406,2 - 444) nm.

According to the work, the optical thickness of NO_2 was measured using signal lamps installed at altitudes of 20 - 130 m. As noted above, model (1) is correct for a collimated light source. In a real case, the light of the signal lamp is non-collimated, and for this case, Allard's model is correct, mathematically expressed as follows

$$E(\lambda) = \frac{I_0(\lambda)}{L_x^2} e^{-L_x \delta}, \qquad (2)$$

Where

δ - specific optical density;

$E(\lambda)$ - energy illumination.

For this reason, further using formula (1), we mean that collimated light is used, i.e. the beam does not diverge radially. An example of such a source would be a laser, a searchlight beam, or any other suitable emitter.

To apply the above method, we write expression (2) for the case

$$L_x \cdot \delta << 1. \qquad (3)$$

Under condition (3), we have

$$E(\lambda) = \frac{I_0(\lambda)}{L_x^2} e^{-\delta \cdot L_x} = \frac{I_0(\lambda)}{L_x^2}\left(1 - \delta \cdot L_x\right). \qquad (4)$$

As can be seen from expression (4), to measure δ, the values of $E(\lambda)$, $I_0(\lambda)$, L_x must be known. Taking into account expression (2), the optical thickness can be calculated by the formula

$$\tau = L_x \delta = \ln\left(\frac{I_0(\lambda)}{E(\lambda) L_x^2}\right). \qquad (5)$$

To carry out measurements according to formulas (4) and (5), cumulative measurements using a photometer and a laser rangefinder must be given.

Thus, for an unknown value of L_x, the measurement algorithm for δ is as follows:

1. A laser rangefinder is measured L_x.
2. The photometer measures $E(\lambda)$ according to the formula (4).
3. By formula (5) δ is calculated.

Let us show that if $I_0(\lambda)$ has a temporal instability of the radiation intensity, such instability can be eliminated using the proposed method of radial-difference measurements.

The possibility of photometric measurement of the optical thickness of the lower tropospheric layer using high-altitude signal lamps as an emitter has been substantiated. A radial-difference method of photometric measurements is proposed, which makes it possible to exclude the temporal instability of the radiation intensity of high-altitude signal lamps and to determine the main direction of contamination of the surface layer of the troposphere. The scheme for carrying out radial-difference photometric measurements is shown in fig.2.

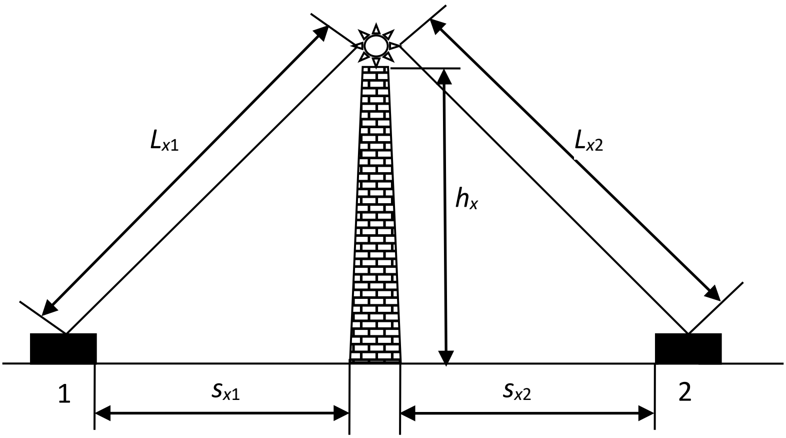

Fig.2. Scheme of radially - difference measurements.

The radial-difference measurement algorithm is as follows:

1. The positions of the photometer 1 and 2 are determined relative to the high-altitude radiator, where the conditions $L_{x_1} = L_{x\,2}$; $S_{x_1} = S_{x\,2}$ are satisfied.

2. Photometric measurement is carried out from position 1, according to the formula

$$\delta = \frac{1}{L_x} ln\left[\frac{I_0(\lambda)}{I(\lambda)}\right] \qquad (6)$$

as a result of which the optical $L_x$is determined as

$$\delta_1 = \frac{1}{L_x} ln\left[\frac{I_0(\lambda)}{I_1(\lambda)}\right] \qquad (7)$$

where $I_0(\lambda)$ is the initial intensity of the emitter; $I_1(\lambda)$ is the radiation intensity at the input of the photometer 1.

3. Photometric measurement is carried out from position 2, according to formula (6), as a result of which the optical thickness L_2 is determined as

$$\delta_2 = \frac{1}{L_x} ln\left[\frac{I_0(\lambda)}{I_2(\lambda)}\right] \quad (8)$$

where $I_2(\lambda)$ is the radiation intensity at the input of photometer 2.

Subtracting expressions (7) and (8) we obtain

$$\Delta\delta = \delta_1 - \delta_2 = \frac{1}{L_x} ln\left[\frac{I_2(\lambda)}{I_1(\lambda)}\right] \quad (9)$$

As can be seen from expression (4), with the radial-difference measurement method, it is possible to avoid temporal instability of the radiation intensity of high-altitude signal lamps.

As a result of carrying out radial - difference measurements, radial - difference diagrams of contamination of the surface tropospheric layer around the high-altitude transmitter are constructed.

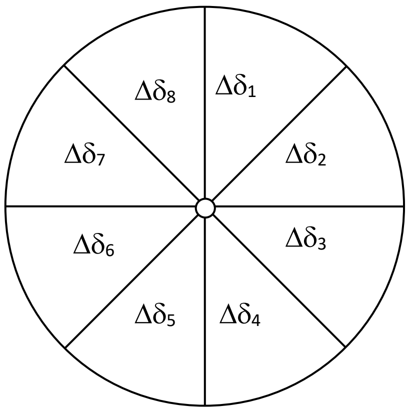

Fig.3. Radially differential conduction scheme photometric measurements

As shown in Fig.3, carrying out 4 pairs of photometric measurements allows dividing the entire circular area around the emitter into 8 segments and determining the directions in which the contamination of the lower troposphere is most severe. In conclusion of this section, we will consider the issues of calibrating photometric measurements using high-altitude non-collimated emitters. From expression (1.2.4) it is easy to obtain the following quadratic equation:

$$L_x^2 + \frac{I_0(\lambda)\cdot \delta L_x}{E_1(\lambda)} - \frac{I_0(\lambda)}{E_1(\lambda)} = 0. \qquad (10)$$

The solution to equation (10) has the following form:

$$L_x = -\frac{I_0(\lambda)\cdot \delta}{2E_1(\lambda)} + \sqrt{\frac{I_0^2(\lambda)\cdot \delta}{4E_1^2(\lambda)} + \frac{I_0(\lambda)}{E_1(\lambda)}}. \qquad (11)$$

Expression (11) allows us to propose the following algorithms for calibrating a photometric emitter:

1. A photometric measurement is carried out according to expression (5).

2. The value of L_x is calculated by the formula (11).

3. Comparison of the calculated value of L_x with the reading of the laser rangefinder is carried out.

Thus, the degree of calibration of the photometric meter can be estimated by the actual difference between the calculated and measured values of L_x. Exact coincidence of these values will mean a high degree of calibration of the meter.

In conclusion, we will formulate the main conclusions and provisions of the study:

1. The possibility of photometric measurement of the optical thickness of the lower tropospheric layer using high-altitude signal lamps as an emitter is shown.

2. A radial-difference method of photometric measurements has been proposed, which makes it possible to exclude the temporal instability of the radiation intensity of high-altitude signal lamps and to determine the main direction of contamination of the surface layer of the troposphere.

3. A method is proposed for calibrating a photometric emitter according to the degree of coincidence between the calculation results and the reference measurement of the distance to the emitter.

A method is proposed for varying the angle of observation of the signal lamp for the correction of temporal instability and radiation intensity. The mathematical substantiation of the advantage of the proposed method, which consists in ensuring a high value of the signal-to-noise ratio, is given.

A difference method for measuring the optical thickness of the surface layer of the troposphere is proposed, which consists in carrying out two solar-photometric measurements - one using a ground-based photometer, the other using a photometer installed on the upper boundary of the surface layer and further subtracting the obtained measurement results. Various options for the implementation of this method are considered. It is shown that with the proposed method for determining the low aerosol load, there is no need to measure the direct sunlight.

The second chapter of the thesis is devoted to model studies on the implementation of the radial - difference method for carrying out meteorological measurements of the surface layer of the atmosphere.

An approximation method for determining the correction coefficients in three-wave solar photometers is proposed. An example of using interpolation and extrapolation methods for calculating correction factors is shown.

A procedure is proposed for finding the optimal values of the optical thicknesses of fine and coarse dispersed components of atmospheric aerosol that ensure the achievement of the minimum value of the signal for correcting the effect of diffuse radiation on the values of the optical thickness of the aerosol at three fixed wavelengths. A geometric interpretation of the solution to the formulated optimization problem is given. It is noted that the proposed optimization procedure can be extended to the case of the presence of three or more dispersed components of atmospheric aerosol.

A mathematical model of the effect of soot on photolytic processes occurring in the near-boundary layer of the troposphere is proposed. According to the proposed model:

- there is a nature of the relationship between ground-level ozone and soot, which ensures the arrival of a minimum amount of solar radiation to the boundary layer of the lower troposphere;
- to ensure that a minimum amount of solar radiation reaches the boundary layer, a mutually inverse relationship between the concentrations of soot and the surface layer should be ensured;
- the appearance of a certain amount of soot leads to a decrease in solar radiation entering the boundary layer, which in turn leads to a decrease in the generated amount of ground-level ozone.

The third chapter of the thesis is devoted to model studies on the implementation of the difference method of meteorological measurements of pollution of the surface layer of the atmosphere.

An algorithm is proposed for increasing the accuracy of the photometric method for measuring water vapor in the atmosphere by eliminating the time drift of the characteristics of the optoelectronic path. Two ways of implementing the proposed algorithm have been developed.

As a result of solar photometric measurements with two optical air masses at a wavelength λ = 940 nm, we obtain

$$I(\lambda, m_1) = I_0(\lambda) \cdot exp[-a(m_1 W_1)^b], \quad (12)$$

$$I(\lambda, m_1) = I_0(\lambda) \cdot exp[-a(m_1 W_1)^b], \quad (13)$$

Where $m_1$and $W_i, i = \overline{1,2}$, respectively, are the optical air mass and the total amount of precipitated water; a and b are the constants of the opto-electronic path of the photometer. From expressions (12) and (13), respectively, we find

$$W_1 = \frac{1}{m_1} \sqrt[b]{\frac{1}{a} ln \frac{I_0(\lambda)}{I(\lambda, m_1)}}, \quad (14)$$

$$W_2 = \frac{1}{m_2} \sqrt[b]{\frac{1}{a} ln \frac{I_0(\lambda)}{I(\lambda, m_1)}}, \quad (15)$$

In the first method, a control measurement of water vapor is carried out using the Butler method. According to this method, the total amount of precipitated water can be calculated using the following expression.

$$W \approx \frac{P_0}{3T_0} \quad (16)$$

where P_0 is the partial pressure of water vapor on the earth's surface; T_0 is the surface temperature.

Thus, to implement the first version of the above algorithm, one should measure in parallel the values of W_1 and W_2 at optical masses m_1 and m_2 by the Butler method and then solve the system of equations (14), (15) for the coefficients a and b. Such a periodic comparison of the measurement results by the solar photometry and Butler methods will allow from time to time to correct the photometer readings due to the time drift arising from the degradation of the optoelectronic path and thereby increase the accuracy of photometric measurements.

The second embodiment of the above algorithm is related to measuring the total amount of precipitated water W. Using the relationship between the total amount of precipitated water W and zenith wet retention ZWD.

Similar to the first version of the above algorithm, in the second version of the implementation of this algorithm, parallel measurements of W_1 and W_2 are first performed using GPS at optical air masses m_1 to m_2, then the system of equations (14), (15) is solved with respect to the constants a and b.

An approximation method for determining the correction coefficients in three-wave solar photometers is proposed. An example of using interpolation and extrapolation methods for calculating correction factors is shown.

A procedure is proposed for finding the optimal values of optical thicknesses and coarse dispersed components of atmospheric aerosol, which ensure the achievement of the minimum value of the signal for correcting diffuse radiation by the values of the optical thickness of the aerosol at three fixed wavelengths. A geometric interpretation of the solution to the formulated optimization problem is given. It is noted that the proposed procedure can be extended to the case of the presence of three or more atmospheric atmospheric atmospheric aerosols.

A mathematical model of the effect of soot on photolytic processes occurring in the border layer of the troposphere is proposed. According to the proposed model:

- there is a nature of the relationship between ground-level ozone and soot, which ensures the arrival of a minimum amount of solar radiation to the boundary layer of the lower troposphere;

- to ensure that a minimum amount of solar radiation reaches the boundary layer, a mutually inverse relationship between the levels of soot and the surface layer should be ensured;

- the appearance of a certain amount of soot leads to a decrease in solar radiation entering the boundary layer, which in turn leads to a decrease in the amount of ground-level ozone.

The fourth chapter of the thesis is devoted to the development of new highly efficient methods and tools for remote sensing of the lower troposphere.

It is shown that in the existing variants of the implementation of the idea of three-wave photometry, the functionality can be found to significantly increase the signal-to-noise ratio due to similar measurements at low values of the optical air mass in the case of previous measurements at higher values of this parameter.

A new version of the construction of the photometer is proposed. The block diagram of the operational algorithm of the proposed version of the three-wave photometer is shown in Fig.4. The measured signals in the proposed version of the photometer with an optical air mass d·m, d = const, is calculated as:

$$I_n(\lambda_i, d_i) = I_{0_n}(\lambda_i, d_i) \cdot e^{-d_1 m[\tau_q(\lambda_i)+\tau_f(\lambda_i)+\tau_c(\lambda_i)]}, i = \overline{1,3}.3 \quad (16)$$

The parameter d_i; i $=\overline{1,3}$ determines the change in the optical air mass when measurements are taken at the wavelength λ_i, The parameter of the intermediate conversion in this case has the form:

$$z_2 = \frac{I_n^{k_3}(\lambda_1)\cdot I_n^{k_4}(\lambda_3)}{I_n(\lambda_2)} =$$

$$= \frac{I_{0_n}^{k_3}(\lambda_1)\cdot I_{0_n}^{k_4}(\lambda_3)}{I_{0_n}(\lambda_2)}\cdot exp^{-m\left[k_3 d_1 \tau_q(\lambda_1)+k_4 d_2 \tau_q(\lambda_3)-\tau_q(\lambda_2)+k_3 d_1 \tau_f(\lambda_1)+k_4 d_2 \tau_f(\lambda_3)-\tau_f(\lambda_2)+k_3 d_1 \tau_c(\lambda_1)+k_4 d_2 \tau_c(\lambda_3)-\tau_c(\lambda_2)\right]}.$$

(17)

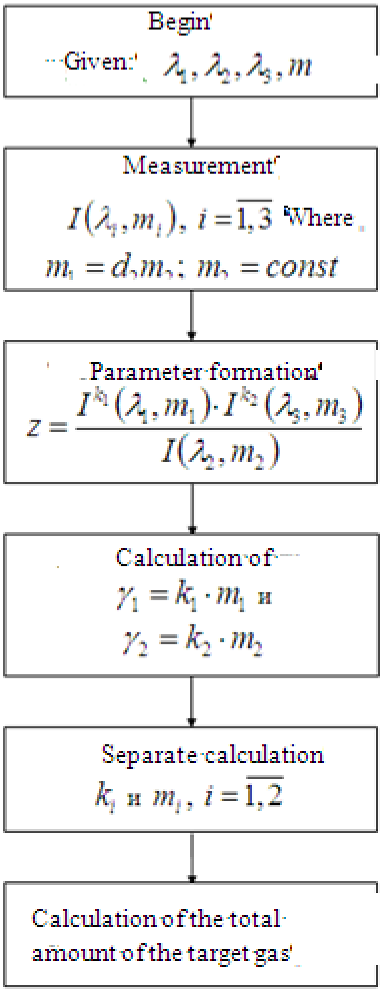

Fig.4. Block diagram of the operational algorithm of the proposed construction of a solar photometer.

The condition for compensation of dispersed components of atmospheric aerosol has the form

$$\begin{aligned} k_3 \cdot d_1 \tau_f(\lambda_1) + k_4 \cdot d_2 \tau_f(\lambda_3) = \tau_f(\lambda_2) \\ k_3 \cdot d_1 \tau_c(\lambda_1) + k_4 \cdot d_2 \tau_c(\lambda_3) = \tau_c(\lambda_2) \end{aligned} . \qquad (18)$$

Let us assume that the solution of the system of equations (18) gives a gain in increasing the estimated signal-to-noise ratios in the proposed device.

In the fourth chapter of the proposed method for measuring wavelength according to the visibility of the earth's surface during the calibration time. The theoretical, physical and mathematical foundations of the proposed method are stated. A functional diagram of the installation is proposed, with the help of which the proposed method can be implemented.

An improvement of the gas-filter method of radiometric measurements is proposed, which consists in replacing the block of correlation calculations with a multiplication block. Two ways of implementing the proposed improvement of the gas filter method of radiometric measurements are proposed. The errors of the proposed methods of implementing the gas-filter method of radiometric measurements are analyzed and a qualitative comparison of the results obtained is given.

Analysis of the existing factual material showed that, according to the results of the available experimental studies, the signals at the outputs of individual Landsat ETM + and MODIS channels or their combinations can have both positive and negative correlation with the results of ground-based radiometric measurements. It is shown that in the intercalibration and validation of the results of ground and onboard measurements, signals of those channels of onboard meters that have a positive correlation with the results of ground radiometric measurements should be used.

MAIN CONCLUSIONS

1. The conducted studies of the method of meteorological photometric measurements of the optical thickness of the surface layer of the troposphere using high-altitude signal lamps as an external emitter made it possible to propose a radial-difference method of photometric measurements, in which the temporal instability of the radiation intensity of high-altitude signal lamps is excluded and 19 it becomes possible to determine the main direction of surface pollution. layer of the atmosphere.

2. The conducted studies of the difference method of meteorological measurements of the optical thickness of the tropospheric surface layer, which consists in carrying out two solar-photometric measurements - one with a ground-based photometer, the other with a photometer installed at the upper boundary of the surface layer and further subtraction of the obtained measurement results allowed us to propose two a variant of the implementation of this method, the use of which makes it possible to more accurately determine the vertical gradient of the concentration of atmospheric aerosol and water vapor.

3. The developed methods of measurement, correction and optimization concerning the quantitative indicators of ozone and aerosol in the surface layer, including:

- a method for measuring the low aerosol load of the atmosphere in the aerosol measurement network at low solar heights,
- an approximation method for determining the aerosol error correction coefficients for solar photometers when measuring the total amount of water vapor in the atmosphere;
- a method for finding the optimal values of optical thicknesses of fine and coarse dispersed components of atmospheric aerosol, ensuring the achievement of the minimum value of the signal for correcting the effect of diffuse radiation, making it possible to increase the efficiency of using photometric methods for meteorological purposes and to correctly take into account the

peculiarities of the relationship between various atmospheric components of the lower layers of the atmosphere.

4. The developed mathematical model of the impact of soot on photolytic processes occurring in the near-boundary layer of the troposphere, which determines the nature of the relationship between ground-level ozone and soot, establishes the conditions for the entry of a minimum amount of solar radiation into the near-boundary layer of the lower troposphere.

5. The developed method for increasing the accuracy of the photometric method, by taking into account the temporal instability of the characteristics of the opto-electronic path of the photometer, makes it possible to increase the efficiency of using solar photometers for meteorological purposes.

6. The proposed version of the modification of three-wave photometry, where a significant increase in the signal-to-noise ratio was achieved by model implementation of measurements at low values of the optical air mass, as well as the developed version of constructing Langley diagrams for calibrating solar photometers, which consists in stabilizing Langley diagrams by changing the wavelength in accordance with with a change in visibility on the Earth's surface, they can significantly improve the meteorological indicators of complex photometers, which are widely used in the practice of meteorological measurements.

The following works of the author have been published on the topic of the dissertation.

1. Ибрагимов Э.А., Джавадов Н.Г., Фатуллаев А.А., Фатуллаев С.А. Способ повышения точности фотометрических измерений паров воды в атмосфере / Труды АзТУ, Баку, 2010, № 2, с. 61-63.

2. Агаев И.Х., Джавадов Н.Г., Фатуллаев А.А., Фатуллаев С.А. О возможности измерения малой аэрозольной нагрузки атмосферы с использованием прямой и рассеянной радиации при низких высотах Солнца / Труды АзТУ, Баку 2010, № 3, с. 91-93.

3. Джамалов А.Т., Фатуллаев А.А., Годжаева А.Ш., Мустафабейли Х.Ш. Калибровка результатов наземных и космических измерений показателей растительного покрова // Специальная техника, М., 2013, № 4, с. 24-27.

4. Фатуллаев А.А. Трехволновый солнечный фотометр для исследования приземного слоя тропосферы на основе высотных сигнальных ламп // Специальная техника, М., 2013, № 4, с. 45-54.

5. Фатуллаев А.А. Трехволновый солнечный фотометр с повышенным отношением сигнал/шум на выходе // Приборы, М., 2013, № 9, с. 8-12.

6. Фатуллаев А.А., Чалый Д.П. Оптимизация солнечного фотометрирования атмосферного аэрозоля с учетом влияния диффузной радиации / Сборник статей V Заочной Международной научно-практической конференции «Актуальные проблемы экологии и охраны труда». Курск, 2014, с. 163-167.

7. Фатуллаев А.А. Математическая модель влияния антропогенного аэрозоля на процессы генерации приземного озона / Материалы 4-й международной межвузовской научно-практической конференции «Инженерно-конструкторские расчеты и технологические решения в создании новых

прикладных направлений в технике» Выпуск 2. Великие Луки. 2014, с. 119-123.

8. Фатуллаев А.А. Вопросы солнечного фотометрирования атмосферного аэрозоля с учетом влияния диффузной техники // Специальная техника, М., 2014, № 3, с. 32-36.

9. Фатуллаев А.А., Асадов Х.Г. Вопросы использования газофильтрового радиометра на морских горизонтальных трассах для обнаружения углеводородных газовых скоплений // Специальная техника, М., 2014, № 4, с. 45-48.

10. Мамедбейли А.Г., Фатуллаев А.А. Новый метод фотометрического контроля аэрозоля приземного слоя атмосферы // Контроль. Диагностика. М., 2014, № 4, с. 24-27.

11. Фатуллаев А.А., Тахмазли М. Солнечные фотометры. Усовершенствование метода калибровки Ленгли // Фотоника, М., 2014, № 2 (44), с. 62-65.

12.Джавадов Н.Г.,Эминов Р.А., Мурсалов. Н.З., Фатуллаев А.А. Метод адаптивной оптимизации биоремедиации загрязненных нефтью и нефтепродуктами земляной массы. // Проблемы сбора, подготовки и транспорта нефти и нефтепродуктов, 2019, №1 с.144-153.

The defense will be held on « ***24*** » ***_january*** 2022 at _14^{00}__ at the meeting of the Dissartation council ED 2.41 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan Technical University.

Address: AZ 1073, Azerbaijan Republic, Baku, H.Javid ave.,25. AzTU.

Dissertation is accessible at the Azerbaijan Technical University Library.

Electronic versions of dissertation and its abstract are available on the official website of the Azerbaijan Technical University.

Abstract was sent to the required addresses on ***27 December*** 2021.

Signed for print:17.02.2021
Paper format:
(210x297)1\4Volume:
40006 simbol
Number of hard copies: 20