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The Influence of Climate Change on the Integral Function of Distribution of Horizontal Minimum Visibility Distance

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***Abstract*—Modern telecommunication systems widely use broadband high-speed communication channels, especially in the "last mile." One possible implementation of such channels is Free Space Optics (FSO) systems. Like fiber-optic systems (FTTH), FSO enables broadband data transmission using infrared (IR) wavelengths, which is why it is also referred to as "fiberless optics" or "wireless optical communication". In FSO, IR waves propagate through the atmosphere, and their energy attenuation depends on atmospheric conditions. It is generally assumed that the attenuation process consists of two components: a constant component and a variable component, which depends on atmospheric transparency determined by the current meteorological conditions in a given region. The value of the constant component for a specific region is usually known, while the variable component must be determined, as it depends on changes in atmospheric transparency due to aerosols. Thus, the main challenge in FSO design is determining the integral distribution function of kilometer attenuation (IDFKA) of IR waves. Therefore, experimental measurements of statistical data on optical wave attenuation during atmospheric propagation are conducted worldwide for different climate regions. Similar measurements have been carried out for the Tashkent region (as reported in). However, due to significant climate changes, previously conducted calculations may no longer correspond to the current atmospheric conditions. This study presents new measurement data to determine the changes in the integral distribution function of kilometer attenuation (IDFKA) of IR waves.**

Keywords*— *Climate change, integral distribution function of MVD, airport, Free Space Optics (FSO)

I. Introduction

To meet the growing societal demand for a diverse range of telecommunications services, high-speed broadband communication channels are needed for the "last mile." One of the most obvious solutions to this issue is the use of Fiber to the Home (FTTH) technology, which allows for the transmission of large amounts of information over significant distances. However, the drawbacks of this solution include the complexities and time-consuming processes involved in establishing FTTH channels (such as obtaining permits for optical cable installation, conducting excavation work, and so on) [1, 2].

As an alternative, Free Space Optics (FSO) technology can be considered. Like fiber-optic systems (FTTH), FSO uses infrared (IR) wavelengths and does not lag behind in terms of wide bandwidth transmission capabilities. This is why it is also referred to as "fiberless optics" or "wireless optical" communication [3, 4].

II. Problem Statement

In Free Space Optics (FSO), infrared (IR) waves propagate through the atmosphere, and the process of energy attenuation is divided into two components: a constant and a variable component. The variable component depends on atmospheric transparency, which is determined by the current meteorological conditions in the selected region. The magnitude of the constant component is typically known for a given area, while the variable component needs to be determined, as it is influenced by changes in atmospheric transparency due to the presence of aerosols. Therefore, the primary challenge in designing FSO systems is determining the integral distribution function of kilometer-scale attenuation (IDFKS) of IR waves. Consequently, experimental measurements of statistical data regarding optical wave attenuation in the atmosphere have been conducted worldwide for various climatic regions (as referenced in) [5, 6].

When designing an FSO system, the value of the IDF_{KS} is aligned with the energy resources allocated in the

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selected FSO equipment. Furthermore, by utilizing statistical data on optical wave attenuation in the atmosphere of the region where the atmospheric channel (AC) will be established, the channel readiness coefficient (AC_{RC}) can be determined [7, 8].

Recently, however, there has been increasing discussion regarding climate change and its consequences, manifested in abnormal weather patterns. Global temperatures are rising, ice and snow volumes are decreasing, and sea levels are rising. The primary cause of climate change is considered to be the increase in greenhouse gases in the atmosphere, which trap heat at the Earth's surface, causing warming. This increase is primarily due to the burning of fossil fuels (oil and gas), deforestation, decomposition of organic waste in landfills, and agricultural activities (cows and sheep produce methane during digestion, and the use of certain fertilizers raises nitrous oxide concentrations) [9, 10].

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III. Consequences of Rapid Climate Change

The impacts of abrupt climate change are numerous, with weather gradually becoming warmer, leading to shifts in climate zones. Results from previous experimental measurements of optical wave attenuation in various climatic regions [1-5] may not reflect the current state of the atmosphere. Therefore, it is essential to conduct repeat measurements to determine the changes that have occurred, so that the obtained data can be used in the design of Free Space Optics (FSO) systems.

IV. Problem Solution

As noted earlier, the attenuation of infrared waves in atmospheric channels (AC) directly depends on atmospheric transparency, which is regularly measured by meteorological networks at airports worldwide, necessary for the normal operation of airport runways. According to the requirements of the International Civil Aviation Organization (ICAO), measurements must be conducted with an accuracy of no more than ±5%.

The measured data on atmospheric transparency are converted into meteorological visibility distance (MVD) (Sm) using Kosmider's relations [11, 12]. Consequently, to determine the integral distribution function of kilometer-scale attenuation (IDFKC), it is necessary to gather and process statistical data on MVD for the corresponding geographical regions (GR).

According to the climate zoning by the Hydrometeorological Center for the Central Asian region (since 1966), the territory of Uzbekistan is divided into the following geographical regions:

1. Karakalpakstan and Khorezm region.
2. Bukhara and Navoi regions.
3. Samarkand, Jizzakh, Syrdarya, and Tashkent regions.
4. Fergana Valley.
5. Kashkadarya and Surkhandarya regions.
6. City of Tashkent.

In each of these geographical regions, meteorological stations with continuous MVD measurements are installed to ensure the proper functioning of the airport. Given the airport's considerable area, it can be asserted that averaged conditions for the specific region are established there.

The authors have collected and processed statistical data on MVD in accordance with the zoning of Uzbekistan from the meteorological stations of the airports in Urgench, Bukhara, Samarkand, Karshi, Fergana, and Tashkent for the years 2004-2008 [13, 14].

As an example, we will consider the statistical data collected from the meteorological station at Tashkent Airport (the observation years were randomly selected from the last decade, specifically 2001-2010, from the archive of the Hydrometeorological Center of Uzbekistan) [7]. The total volume of processed data (total observation time) amounted to 26,280 hours (3 years). In accordance with ICAO recommendations, MVD values were selected from 11 intervals: 0-0.45; 0.45-0.7; 0.7-1.1; 1.1-1.3; 1.3-1.5; 1.5-2.2; 2.2-3.0; 3.0-3.5; 3.5-4.1; 4.1-7.0; 7.0-10.0. The selection of intervals is sufficient, and the frequency of collected data is acceptable for practical calculations assessing the impact of atmospheric transparency on FSO performance [15, 16].

Next, the probability of Sm falling within the corresponding interval throughout the year was determined, and then averaged over the entire observation period (see Table 1).

Table 1 Statistical Data on MVD for Tashkent for 2004/2008

Years	T-2004	T-2006	T-2008	T-average.
L(м)	L=F($T_{\%}$)	L=F($T_{\%}$)	L=F($T_{\%}$)	L=F($T_{\%}$)
10000	0,819	0,814	0,745	0,793
7000	0,902	0,863	0,828	0,864
4100	0,907	0,866	0,839	0,870
3500	0,967	0,937	0,918	0,940

3000	0,969	0,943	0,926	0,946
2200	0,971	0,945	0,933	0,950
1500	0,974	0,945	0,933	0,951
1400	0,977	0,965	0,973	0,972
1300	0,985	0,978	0,980	0,981
1100	0,985	0,978	0,998	0,981
1000	0,986	0,978	0,998	0,983
800	0,986	0,979	0,998	0,987
700	0,986	0,994	0,998	0,992
450	0,999	0,999	0,999	0,999

According to the statistical data provided above, the acceptable failure-free operation of FSO is approximately 0.98 at a communication range of around 1250 meters, which is satisfactory and suitable only for certain communication channels.

Now, let's examine the values of the integral distribution functions of atmospheric turbulence at the present time. For this, we will use historical weather data from Tashkent for the years 2021-2024, as published by "Tashkent Meteorological Station (meteorological station), Uzbekistan, WMO_ID=38457, Encoding: UTF-8. Information provided by the website 'Weather Schedule', rp5.kz" [17, 18].

Measurements at the meteorological station are conducted daily, continuously every 3 hours under relatively stable weather conditions and every 0.5 hours under extreme conditions.

As an example, Table 2 presents data recorded at the Tashkent Meteorological Station on the occurrence of atmospheric turbulence falling within the corresponding interval Sm for each day of January 2024, which was then summed up for the entire month.

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As an example, Table 2 presents data recorded at the Tashkent Meteorological Station on the occurrence of atmospheric turbulence falling within the corresponding interval Sm for each day of January 2024, which was then summed up for the entire month [18, 19].

TABLE 2. SUMMARY DATA ON MIA OF TASHKENT" (MDV STANDS FOR - MINISTRY OF INTERNAL AFFAIRS)

	T (2004-2008) average	T(2021-2024) average
L(м)	L=F(T%)	L=F(T%)
10000	0,793012	0,871
7000	0,864011	0,903
5000	-	0,937
4000	0,870013	0,962
3500	0,940021	-
3000	0,946009	0,969
2000	0,950006	0,983
1500	0,951015	-
1400	0,972011	-
1100	0,981013	-
1000	0,983011	0,993
800	0,987015	-
700	0,992016	-
500	0,999010	1,000
100		-

The data collected for all months from 2021 to 2024 have been summarized and presented in Tables 3, 4, and 5.

TABLE 3. DATA ON ATMOSPHERIC TURBULENCE (МДВ) FOR ALL MONTHS OF 2021 OBTAINED FROM THE TASHKENT METEOROLOGICAL STATION

L/мес.	1	2	3	4	5	6	7	8	9	10	11	12	Σ	T%	L=F(T %)
10000	486	376	636	616	735	698	726	682	618	368	486	462	6889	0,.786	0,786
9000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7000	-	85	-	33	-	16	-	34	50	133	-	-	351	0,040	0,826
6000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5000	-	37	-	12	-	2	-	1	7	40	-	-	99	0,011	0,837
4500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4000	111	123	90	56	6	4	15	27	45	192	126	177	972	0,112	0,949
3500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3000	-	28	-	2	-	-	-	-	-	11	-	-	41	0,005	0,954
2500	-	-	-	-	-	-		-	-	-	-	-	-	-	-
2000	78	11	12	-	3	-	3	-	-	-	39	66	212	0,024	0,978
1500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1000	57	9.5	3	1	-	-	-	-	-	-	18	27	115,5	0,013	0,991
500	12	2.5	3	-	-	-	-	-	-	-	51	12	80,5	0,009	1,000
Σ	744	672	744	720	744	720	744	744	720	744	720	744	8760	Σ1	

TABLE 4. DATA ON ATMOSPHERIC TURBULENCE (МДВ) FOR 2023-2024 OBTAINED FROM THETASHKENT METEOROLOGICAL STATION

L/мес.	1	2	3	4	5	6	7	8	9	10	11	12	Σ	T%	L=F(T%)
10000	498	582	546	708	720	717	744	744	720	654	519	387	7539	0,861	0,861
9000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4000	90	63	126	12	24	3	-	-	-	54	141	207	720	0,082	0,943
3500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2000	88	24	45	-	-	-	-	-	-	30	12	75	274	0,032	0,975
1500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1000	28	3	12	-	-	-	-	-	-	-	33	42	118	0,013	0,988
500	40	-	15	-	-	-	-	-	-	6	15	33	109	0,012	1,000
Σ	744	672	744	720	744	720	744	744	720	744	720	744	8760	Σ1	

TABLE 5. STATISTICAL DATA ON ATMOSPHERIC TURBULENCE FOR TASHKENT FOR 2021-2024.

	T-2021	T-2022	T-2023/24	T-average
L(м)	L=F(T%)	L=F(T%)	L=F(T%)	L=F(T%)
10000	0,786	0,861	0,968	0,871
7000	0,826	-	0,980	0,903
5000	0,837	-	-	0,837
4000	0,949	0,943	0,993	0,962
3000	0,969	-	-	0,969
2500	-	-	0,000	-
2000	0.978	0,975	0,996	0,983
1000	0,991	0,988	1,000	0,993
500	1,000	-	-	1,000

Now, let us consider what the integral distribution functions of MVD will be at the present time. To do this, we will use the weather archive data from Tashkent for the period from September 1, 2023, to August 31, 2024, obtained from the "Tashkent Meteorological Station (WMO_ID=38457, UTF-8 encoding). Information provided by the website 'Weather Schedule', rp5.kz". Measurements are taken daily, round-the-clock, every 0.5 hours.

As an example, Table 2 presents the data recorded at the summary data on mia of Tashkent, summed up for the entire month.

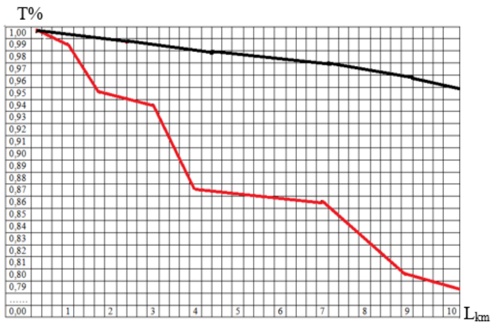

Fig. 1. Diagrams of the integral functions of distribution of minimum visibility distance (mvd) in tashkent for 2004-2008 and 2023-2024.

From the figure, it is evident that climate change has significantly influenced the integral distribution function of MVD, resulting in a positive trend. The Conclusion

V. CONCLUSIONS

Climate change, which has been frequently discussed lately, poses a serious threat to Uzbekistan. The country is among the most vulnerable to climate change in Eurasia. The average warming rates in Uzbekistan exceed global averages, leading to intense glacier melting, a reduction in water resources, and an increase in extreme weather events such as mudslides, avalanches, and droughts. These processes cause significant harm to the country's economy and the livelihoods of its population.

VI. ACKNOWLEDGEMENTS

Most publications primarily discuss the negative consequences of climate change, which are indeed numerous, but there are also some positive aspects that are often overlooked.

As demonstrated by the conducted research, the results (shown in Figure 2) indicate that the curve corresponding to the integral distribution function of visibility distance (MVD) for 2023-2024 is much straighter and positioned higher than that for 2004-2008. This suggests that fluctuations in atmospheric conditions have become less significant, and transparency has remained more consistent and clearer than in previous years.Such changes in the atmosphere of Tashkent suggest that the application of Free Space Optics (FSO) in telecommunications networks isbecoming more feasible. In particular, in the currently deployed 5G networks, preference can be given to transport networks built on the basis of FSO.

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