WIND CONDITIONS AT THE HEYDAR ALIYEV BAKU AND SHOTA RUSTAVELI TBILISI INTERNATIONAL AIRPORTS IN 2015–2024

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Abstract

Meteorological conditions, including surface wind speed and direction, have a significant impact on aviation. They play an important role in both aviation accidents and ensuring the safe operation of aircraft. Consequently, there is a focus on the continuous monitoring of weather conditions at airports, as well as the scientific analysis of this monitoring data, worldwide, including in Azerbaijan and Georgia. This study examines wind conditions at Heydar Aliyev Baku and Shota Rustaveli Tbilisi international airports between 2015 and 2024. Data on mean wind speed (F) and gusty wind speed (G) for different wind directions were obtained from [https://rp5.ru]. Period of record: 2015–2024; observation interval: 30 min. Wind direction sectors: 22.5° each (total: 18 sectors). Statistical analysis was performed on the following amount of data: Baku: F: 166,825 measurements and G: 12,245 measurements; Tbilisi: F: 166,704 measurements and G: 7,533 measurements. The following results were obtained in particular. The mean gusty wind speed at Baku airport is 0.4 m/s higher than at Tbilisi airport (5.3 and 4.9 m/s, respectively). The mean gusty wind speed in Baku is 2.0 m/s lower than in Tbilisi (17.2 and 19.2 m/s, respectively). The maximum values of F and G in Baku are lower than in Tbilisi (23 and 31 m/s and 26 and 33 m/s, respectively). The number of gusts in Baku is significantly higher than in Tbilisi (1,225 and 753 cases per year, respectively). The repeatability of the mean and gusty wind speeds at the two airports is similar: unimodal for F and bimodal for G. The correlation between F and G values is very high for both airports (R = 0.97). The maximum repeatability of mean wind speed is in the north-northwest direction in Baku (20.2%) and in the north-west direction in Tbilisi (28.3%). As in the previous case, the maximum repeatability of wind gust speed in Baku and Tbilisi occurs in the same direction: 56.1% in Baku and 72.4% in Tbilisi. The maximum number of cases per year with wind speeds of ≥15 m/s (count ≥15 m/s) in Baku is 95 in the North-Northwest direction and 290 in the North-West direction in Tbilisi. The maximum number of counts of wind speeds of at least 15 m/s in Baku for G is 661, and for Tbilisi it is 529 (the same directions as in the previous case for both airports). The indicated values of the number of cases per year with wind speeds of ≥15 m/s at both airports coincide well with the direction of aircraft take-off and landing. In Baku, there are 10 cases per year of crosswinds and winds close to it with a speed of ≥15 m/s, whereas in Tbilisi there are none.

Keywords: aviation meteorology, wind speed, wind direction, risk estimation, statistical analysis

I. Introduction

It is known that meteorological conditions have a significant impact on aviation and play an important role in aviation accidents and also ensuring the safe operation of aircraft. Wind, visibility, precipitation intensity and amount, weather phenomena, etc. are the most important meteorological parameters that affect the working of aerodromes [1]. Therefore, continuous monitoring of weather conditions at airports, as well as scientific analysis of this monitoring data, are given special attention worldwide [2-6], including in Azerbaijan and Georgia [7-11]. These studies are also important for assessing the role of climate change on the expected variability of meteorological conditions at airports.

In particular, the article [2] presents a systematic review of the growing but somewhat dispersed academic literature on climate change impacts and adaptation in the aviation sector. Information was synthesised from 131 studies (published between January 2000 and November 2022) on eleven climate change effects and the associated impacts and potential adaptation measures. Six areas for action to address knowledge, awareness and implementation gaps were identified: (i) to broaden geographical coverage, particularly to address the current lack of studies addressing climate risks and responses in Central and South America, Africa and the Middle East; (ii) to extend knowledge of physical impacts; (iii) to address known-unknowns such as the risks associated with unprecedented or compound extreme events; (iv) to extend knowledge of adaptation including cost–benefit analysis and consideration of integrated mitigation and adaptation; (v) to identify and apply other relevant research; and (vi) for sector bodies to support and facilitate collaboration between researchers and practitioners to co-develop accessible user-oriented climate adaptation services.

The paper [3] presents a detailed analysis of ten years of data (2011-2020) on wind speed and direction at Minangkabau international airport. It was found that, the condition of the overall average wind direction and speed at this airport was in the safe category for the takeoff and landing process. In the work [4] it is noted that weather is considered a causal factor in about 30% of all US aviation accidents. The author reports that fatal aviation accidents data related to ceiling, fog, and wind are estimated at 20%, 14%, and 10%, correspondingly. It is indicated that knowing weather conditions can help to improve operational planning, including fuel consumption and people safety. In the article [5] deals with the occurrence of storms and their associated dangerous phenomena at Slovakia's international airports which are located in different orographic conditions of the country in 2018-2023. This paper provides a valuable insight into the safety of airport operations, the safety of the flight itself.

In the work [6] authors provide a comprehensive spatiotemporal analysis of fatal weather-related general aviation accidents from 1982 through 2013 using data culled from the United States National Transportation Safety Board (NTSB). Weather was a cause or contributing factor in 35% of fatal general aviation accidents, of which 60% occurred while instrument meteorological conditions were present. Fatal weather-related general aviation accidents occur most frequently between October and April, on weekends, in early morning and evening periods, and along the West Coast, Colorado Rockies, Appalachian Mountains, and the Northeast. There has been a long-term reduction in weather-related general aviation accidents and fatalities since the 1980s; nonetheless, these accidents are still responsible for nearly 100 fatalities/year in the United States. This study provides pilots, academics, the Federal Aviation Administration, the NTSB, and other aviation organizations with information to advance mitigation efforts aimed at reducing future aviation-related accidents in the United States.

The paper [7] presents the results of studies of changes in the surface air temperature regime and its possible impact on the conditions of takeoff and landing of aircraft in the Ganja-Gazakh region (Azerbaijan). In paper [8] regularity of distribution of precipitation at the airdromes of Azerbaijan was studied.

In papers [9,10] the results of study of characteristics of fogs in the airport of Tbilisi city are presented.

Detailed data on meteorological elements (visibility, wind speed and direction, air temperature, dew point and humidity, absolute and mean atmospheric pressure, weather phenomena, rainfall) at Georgian aerodromes (Tbilisi, Kutaisi, Batumi) in [11] are presented. Period of record: 2010-2016, observation interval: 30 min. Wind direction sectors - 30° each (12 sectors).

This work is a continuation and addition to the previously conducted studies. It presents some results of the studies of wind conditions at the Heydar Aliyev Baku and Shota Rustaveli Tbilisi international airports in 2015–2024.

II. Study area, material and methods

Study area: Heydar Aliyev Baku international airport (Baku airport, or Baku) and Shota Rustaveli Tbilisi international airport (Tbilisi airport, or Tbilisi). In Fig 1,2 images of these airports against the background of a wind rose contour (Table 1) are presented.

Figure 1: *Image of Baku airport against the background of a wind rose contour.*

Figure 2: *Image of Tbilisi airport against the background of a wind rose contour.*

Table 1: *Wind direction list.*

Wind blowing from	Abr.	Degree	Wind blowing from	Abr.	Degree
North	N	0	South	S	180
North-Northeast	NNE	22.5	South-Southwest	SSW	202.5
North-East	NE	45	South-West	SW	225
East-Northeast	ENE	67.5	West-Southwest	WSW	247.5
East	E	90	West	W	270
East-Southeast	ESE	112.5	West-Northwest	WNW	292.5
South-East	SE	135	North-West	NW	315
South-Southeast	SSE	157.5	North-Northwest	NNW	337.5
Variable wind direction	VD		Calm, no wind	Calm	

Baku Airport (METAR UBBB) has two almost parallel runways about 4 km and 3.2 km long. Tbilisi Airport (METAR UGTB) has one operational runway 3 km long. Both airports accept all types of passenger and cargo aircraft, including the world's largest Airbus A380 and An-225 (Mriya) [https://www.biletik.aero/handbook/pomoshch/perelet/chem-opasen-silnyy-veter-pri-posadke-samolyeta/]

In the work data of [https://rp5.ru/Weather_archive_in_Baku,_Heydar_Aliyev_(airport) and https://rp5.ru/Weather_archive_in_Tbilisi_(airport),_METAR] on mean wind speed (F, m/sec), and gusty wind speed (G, m/sec), for different wind directions are used. Period of record: 2015-2024, observation interval: 30 min. Wind direction sectors – 22.5° each (18 sectors, Table 1).

In fact, take-off and landing are the only times during a flight when high winds can result in flight delays—almost every flight deals with high winds at some point during its climb or descent. With this in mind, horizontal winds (also known as "crosswinds") in excess of 15 m/sec are generally prohibitive of takeoff and landing most types of aircraft [https://www.skyscanner.com/tips-and-inspiration/what-windspeed-delays-flights].

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [12].

The following designations except those specified above will be used below: Mean – average values; Min - minimal values; Max - maximal values; Range – Max - Min; St Dev - standard deviation; C_v – coefficient of variations (C_v = 100· St Dev/ Mean, %); Count - number of measuring; Count, ≥15 m/sec - number of cases in year with wind speed ≥15 m/sec; R^2 – coefficient of determination; R – coefficient of linear correlation; difference between mean values was produced with the use of Student's criterion with the level of significance α not worse than 0.01. The degree of correlation was determined in accordance with [12]: very high correlation ($0.9 \le R \le 1.0$); high correlation ($0.7 \le R < 0.9$); moderate correlation ($0.5 \le R < 0.7$); low correlation ($0.3 \le R < 0.5$); negligible correlation ($0 \le R < 0.3$).

III. Results and discussion

Results in Tables 2,3 and Fig. 3 – 8 are presented.

Table 2 presents statistical characteristics of mean and gusty wind speed at Baku and Tbilisi airports for all observation data from 2015 to 2024.

Table 2: *Statistical characteristics of mean and gusty wind speed at Baku and Tbilisi airports.*

Location	Baku		Tbilisi	
Parameter	F	G	F	G
Mean	5.3	17.2	4.9	19.2
Min	0	8	0	7
Max	23	31	26	33
Range	23	23	26	26
St Dev	3.2	2.6	3.8	3.5
C_v (%)	60.1	15.1	78.4	18.3
Count	166825	12245	166704	7533

As follows from this Table mean value of F in Baku airport is on 0.4 m/sec higher than in Tbilisi airport (5.3 and 4.9 m/sec respectively). At the same time mean value of gusty wind speed in Baku is on 2.0 m/sec lower than in Tbilisi (17.2 and 19.2 m/sec respectively). Max values of F and G in Baku are lower than in Tbilisi (23 and 31 m/sec and 26 and 33 m/sec respectively). It is important to note that number of gusty wind in Baku is significantly more than in Tbilisi (1225 cases at 30 min intervals per year and 753 cases respectively).

Repeatability of mean and gusty wind speed at Baku and Tbilisi airports have the same appearance: for F - unimodal, for G – bimodal (Fig. 3). The max repeatability of mean wind speed in Baku falls on 3 m/sec (13.9 %), and in Tbilisi - on 2 m/sec (19.9%).

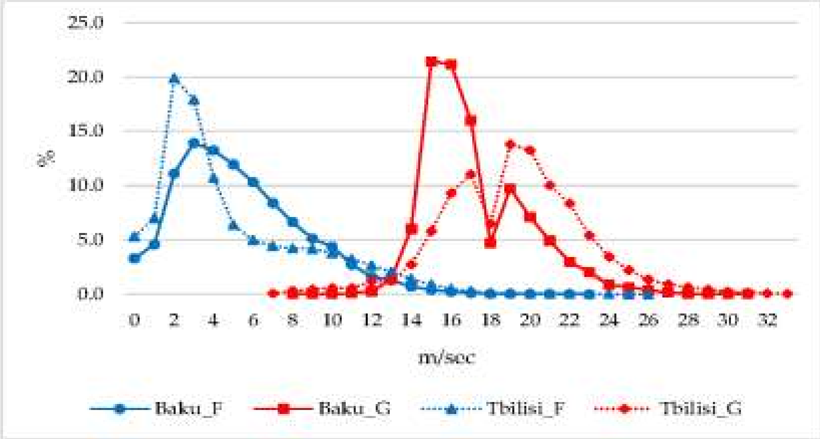

Figure 3: *Repeatability of mean and gusty wind speed at Baku and Tbilisi airports.*

The first extreme of wind gust repeatability in Baku falls on 15 m/sec (21.5%), and in Tbilisi - on 17 m/sec (11.1%). The second extremes of these repeatabilities at both airports falls on the same wind speed - 19 m/sec (Baku - 9.75%, Tbilisi - 13.8%).

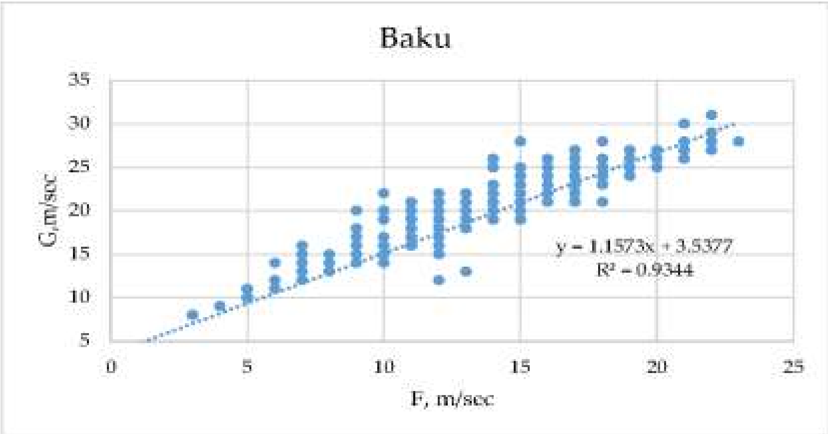

Figure 4: *Linear correlation and regression between of mean and gusty wind speed at Baku airport.*

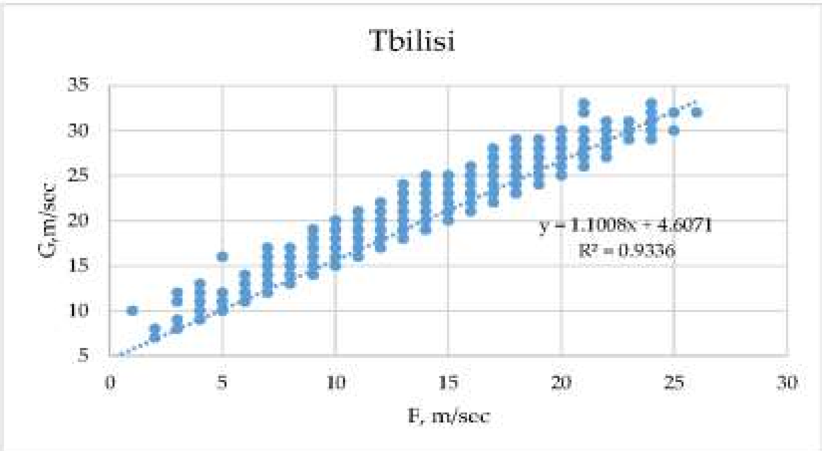

Figure 5: *Linear correlation and regression between of mean and gusty wind speed at Tbilisi airport.*

Fig. 4 and 5 show graphs of linear correlation and regression between mean and gusty wind speeds at Baku and Tbilisi airports. For both airports, the correlation between F and G values is very high (R = 0.97).

Fig. 6 and 7 presents data about repeatability of mean and gusty wind speed at Baku and Tbilisi airports for different wind directions.

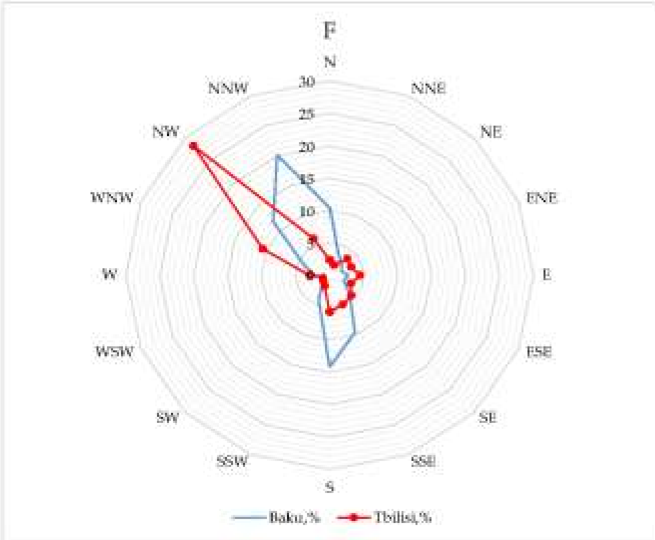

Figure 6: *Repeatability of mean wind speed at Baku and Tbilisi airports for different wind directions.*

As follows from Fig. 6, the max repeatability of the mean wind speed in Baku is in the NNW direction (20.2%), and in Tbilisi – in the NW (28.3%). Note that in Baku the repeatability of variable wind direction is 1.72%, and in Tbilisi – 8.65%. The repeatability of cases with calm in Baku is 3.28%, and in Tbilisi – 5.3%.

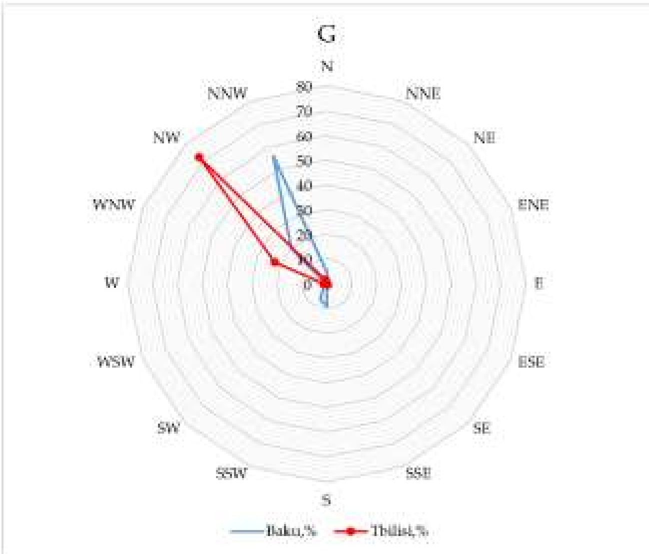

Figure 7: *Repeatability of gusty wind speed at Baku and Tbilisi airports for different wind directions.*

It follows from Fig. 7 that, as in the previous case, the max repeatability of wind gust speed in Baku and Tbilisi falls on the same direction (NNW and NW, respectively). In Baku, this repeatability is 56.1%, and in Tbilisi – 72.4%. In the studied period of time, cases with VD for G were observed only in Tbilisi – 0.4% of all measurement cases.

In Table 3 statistical characteristics of mean and gusty wind speed at Baku and Tbilisi airports for different wind directions are presented. The same Table presents the data about number of cases in year with wind speed ≥15 m/sec for both airports at different wind directions.

Table 3: *Statistical characteristics of mean and gusty wind speed at Baku and Tbilisi airports for different wind directions.*

Parameter	Direct.	Baku		Tbilisi		Direct.	Baku		Tbilisi	
		F	G	F	G		F	G	F	G
Mean	N	6.1	17.0	2.9	11.5	S	5.8	15.7	2.9	11.0
Min		1	9	1	7		1	10	1	8
Max		20	25	14	14		16	23	9	14
Count, ≥15 m/sec		5.5	55.5	0	0		1.3	91.8	0	0
Mean	NNE	4.8	14.8	2.7	16.6	SSW	6.1	15.9	2.6	12.0
Min		1	9	1	14		1	11	1	11
Max		13	19	13	19		20	26	8	13
Count, ≥15 m/sec		0	0.8	0	0.4		3.2	64.7	0	0
Mean	NE	4.4	12.5	2.9	13.4	SW	4.5	15.7	2.5	12.2
Min		1	10	1	10		1	12	1	9
Max		11	17	13	20		21	26	11	14
Count, ≥15 m/sec		0	0.2	0	0.2		0.8	14.4	0	0
Mean	ENE	3.9	8.5	2.9	12.8	WSW	3.2	16.2	2.6	14.9
Min		1	8	1	10		1	12	1	10
Max		10	9	12	19		21	26	13	21
Count, ≥15 m/sec		0	0	0	0.1		0.3	4.6	0	0.3
Mean	E	3.7	13.0	3.3	12.1	W	2.6	16.3	3.3	15.1
Min		1	11	1	1		1	12	1	8
Max		10	14	10	10		15	21	14	23
Count, ≥15 m/sec		0	0	0	0.2		0.1	1.8	0	4.8
Mean	ESE	3.6	13.0	3.3	12.1	WNW	3.0	16.2	6.8	18.3
Min		1	13	1	9		1	12	1	9
Max		11	13	11	15		17	28	23	31
Count, ≥15 m/sec		0	0	0	0.3		0.2	2.9	38.9	154
Mean	SE	4.3	14.3	3.2	10.5	NW	5.7	17.4	8.7	19.7
Min		1	11	1	8		1	9	1	10
Max		13	16	11	14		23	31	26	33
Count, ≥15 m/sec		0	0.4	0	0		33.8	227.7	289.5	529.3
Mean	SSE	4.7	15.7	3.1	10.0	NNW	7.6	17.6	5.5	18.2
Min		1	13	1	7		1	12	1	9
Max		14	19	8	14		22	30	21	27
Count, ≥15 m/sec		0	3.3	0	0		95.3	661	8.7	10.5
Mean	VD	1.0	0			VD			1.6	8.6
Min		1	0						1	7
Max		2	0						7	12
Count, ≥15 m/sec		0	0						0	0

In particular, as follows from Table 3, for different wind direction mean values of F in Baku varied from 2.6 m/sec (W wind) to 7.6 m/sec (NNW wind) and in Tbilisi varied from 2.5 m/sec (SW wind) to 8.7 m/sec (NW wind). Mean values of G in Baku varied from 8.5 m/sec (ENE wind) to 17.6 m/sec (NNW wind) and in Tbilisi - from 10.0 m/sec (SSE wind) to 19.7 m/sec (NW wind). For different wind direction max values of F in Baku varied from 10 m/sec (ENE and E wind) to 23 m/sec (NW wind) and in Tbilisi varied from 8 m/sec (SSE wind) to 26 m/sec (NW wind). Max values of G in Baku varied from 9 m/sec (ENE wind) to 31 m/sec (NW wind) and in Tbilisi - from 10 m/sec (E wind) to 33 m/sec (NW wind).

In Baku mean values of F for variable wind direction is 1.0 m/sec, and of G – 0. For VD in Tbilisi mean values of F is 1.6 m/sec, and of G – 8.6 m/sec; max values of F is 7 m/sec, and of G – 12 m/sec (Table 3).

Max number of cases in year with wind speed ≥15 m/sec in Baku for F is 95 (NNW wind) and for Tbilisi - 290 (NW wind). Max number of cases in year with wind speed ≥15 m/sec in Baku for G is 661 (NNW wind) and for Tbilisi - 529 (NW wind). Note that the indicated values of count, ≥15 m/sec in the direction at both airports coincide well with the direction of takeoff and landing of aircraft.

The number of cases per year with crosswinds and winds close to it with a speed of ≥15 m/sec in Baku is 10 cases, and in Tbilisi it is absent.

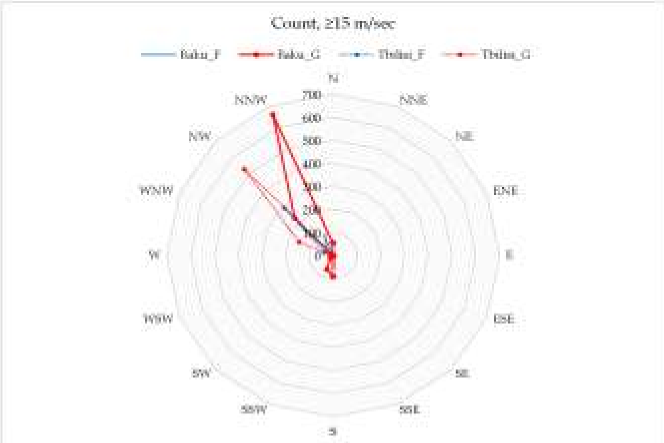

Fig. 8: *Number of cases in year with wind speed ≥15 m/sec at Baku and Tbilisi airports for different wind directions.*

Finally, for clarity, Fig. 8 shows a diagram of the dependence of the number of cases per year with a wind speed of ≥15 m/sec at the airports of Baku and Tbilisi on different wind directions.

V. Conclusion

A study of wind conditions at the Heydar Aliyev Baku and Shota Rustaveli Tbilisi international airports in 2015–2024 was conducted. Data on mean wind speed (F), gusts (G) and directions at both airports were compared.

The statistical characteristics of the specified parameters were studied. In particular, comparison made repeatability of mean and gusty wind speed at Baku and Tbilisi airports; linear correlation and regression relationships between F and G values were established for both airports; repeatability of mean and gusty wind speed at Baku and Tbilisi airports for different wind directions were installed; statistical characteristics of mean and gusty wind speed at both airports for different wind directions are studied; data about number of cases in year with wind speed ≥15 m/sec for both airports at different wind directions are presented.

In the near future, we plan to conduct similar studies for individual months of the year. In addition, it is planned to study other meteorological characteristics related to the safe operation of airports (visibility, atmospheric phenomena, thermal conditions, etc.). It is also planned to conduct the above studies for other airports in Azerbaijan and Georgia.

Such studies can be useful from both a scientific and practical point of view (improving knowledge in terms of regional climate study, using research results to climate change modeling, using the information obtained in training flight crews and maintenance personnel, as well as improving their qualifications, etc.).

CONFLICT OF INTEREST.
Authors declare that they do not have any conflict of interest.

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