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IMPACT OF WEATHER ON OPERATIONS OF THE SLOVAK AIR FORCE

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Abstract: Atmospheric conditions are an important aspect of combat situations. They can facilitate, but also hinder, even make combat activities impossible. Weather have a significant impact on the course of all types of flights. Commanders and pilots must know in detail the activities of the meteorological service, as well as the effects of the weather, the state and development of the weather and, above all, dangerous weather phenomena. The aim of this article is to describe some dangerous weather phenomena in aviation and then to analyze the occurrence of fog at Sliač Airport. The article is also aimed at limiting the activities of the Air Force of the Slovak Republic. Based on the results of the analysis of 73 344 METAR (Meteorological Aerodrome Reports) and SPECI (Aerodrome special meteorological report), it is possible to create new models of predicted dangerous weather phenomena. By modernizing the means of the weather service, it is possible to increase the accuracy of the weather forecast, which significantly affects the safety of air transport.

Keywords: weather service, hazardous weather, fog, prediction

1. INTRODUCTION

An important factor that can decide on the implementation of military operations is the impact of visibility and fog, which significantly threaten the safety of aviation. Low visibility due to fog can affect not only the possibility of take-off and landing, but also the instrumentation and organizational measures at airports. There is currently a lot of research aimed at predicting dangerous weather phenomena in aviation, which is based on the introduction of modern approaches such as artificial intelligence and machine learning. All of these technologies are capable of increasing the quality of weather forecasting, which would have significant benefits for military aviation. It is therefore important that even within the Air Force, new modern technologies for the prediction of fogs and storms are introduced, which would significantly improve the level of forecasting techniques and the modernization of meteorological services.

A lot of research is currently underway with a focus on the prediction of dangerous weather phenomena. Bryan, G.H. and Morrison, H. in their research examine the micro-physical parameters affecting the development of storms. In their research, they evaluated simulated squall lines, where they found that these lines are sensitive to both microphysical and horizontal resolution. Simulations with larger Δx showed that they develop more slowly, produce more precipitation, and have higher cloud tops, leading to convective precipitation [1]. In their research, Bari, D., and colleagues discuss recent advances in the development of decision support systems and their fog forecasting components, and important advances in fog-related operational applications. The negative impact of fog occurrence is primarily financial loss. Better forecasts could mitigate these financial losses. Fog forecasts are currently very incomplete due to temporal and spatial scales [2]. As Castillo Boton, C., and colleagues say in their research, machine learning methods for fog prediction improve the accuracy of their prediction [3]. Gülne ̧se Ugurluel and colleagues argue in their research that fog events can lead to serious damage to airport operations and the economy due to low visibility conditions and interrupting transportation. This study aims to explain the characteristics of the fogs occurring at the airports of the Kars, Agrı, and Igdır cities where located in the northeast of Turkey and neighbouring Georgia, Armenia, Nakhchivan, and Iran, and evaluate fog

types [4]. Şeyda Tilev and the team in their research studied the fog events over Abu Dhabi International Airport, which is located at the northeastern coast of UAE, using METAR (2012 to 2022) and ERA5 data [5]. In their research, Rozerin Koyuncu and colleagues conducted a fog analysis at Ankara Esenboga International Airport conducted between 2011 and 2020. The data used in the fog analysis are taken from observations of aviation routine weather reports (METAR) and selected special aviation weather reports (SPECI) [6].
The aim of the work is to determine the impact of weather on the military operations of the Air Force of the Slovak Armed Forces. The work is focused on Sliač airport. An analysis of the occurrence of fog at the airport will be made from the 73 344 METAR and SPECI reports. Fog is one of the dangerous weather phenomena and therefore it is important to be able to predict this phenomenon. The idea of this work is to point out the need to introduce a fog prediction model. Therefore, it is necessary to ask research questions:
What is the effect of weather on Air Force aviation?
Which dangerous weather phenomena are dangerous for Sliač airport?
How does fog affect the operation of Sliač Airport?

2. METHODOLOGY OF RESEARCH

Several scientific methods are used in the research. This is mainly a statistical analysis, which will be used to evaluate the occurrence of fog at Sliač Airport. It will then be used to compare months of the year. The analysis of METAR reports is also important, because based on their decoding, it is possible to determine when fog occurred at a given airport. In this case, METAR reports with the FG code (fog) will be taken into account. A total of 73,344 METAR and SPECI reports were analyzed. METAR reports are made at Sliač Airport based on the airport regulations every hour. This means that there are 24 of them per day. If the conditions change during a given hour, a SPECI report will be made. In the past, there was also civil aviation at Sliač Airport. During this time, METAR reports were made every half hour, as is the case at other civil airports. From January 1, 2021 0600 UTC. METAR reports are made only once. per hour. METAR reports will be drawn from the archive of the Meteorological Office. The archive is made every month from 2018 to 2022. The analysis will include data on the number of days with fog in each month in a given time range [7].
Other methods used are empirical methods, where the Zverev diagram is used to predict fog based on air temperature and relative humidity, and the Berland method, which uses the differences between air temperature and dew point temperature. The research will also use comparative analysis, where we will compare traditional models with modern approaches such as artificial intelligence and machine learning, or consider their mutual combination.

3. VISIBILITY

One of the most important elements that is of essential importance for aviation activities is visibility. Visibility can be understood as the maximum distance at which it is possible to distinguish the contours of a black object observed against the sky in daylight and with normal characteristics of the human eye. In the case of weather protection of flight activities, it is necessary to distinguish between meteorological visibility and flight visibility [6], [8].
Meteorological visibility characterises the transparency of the atmosphere in the air layer just above the earth's surface. It is determined visually as the visibility of dark real landmarks or it can be measured by instruments that are based on the principle of the transparency of the atmosphere. Flight visibility represents the distance at which it is possible to observe objects on the surrounding background from the aircraft deck. Sometimes flight visibility is not considered horizontal flight visibility, but oblique flight visibility [6], [8].
In aviation practice, a distinction is made between:

- meteorological visibility (horizontal near the ground);
- flight visibility (horizontal during flight);
- oblique visibility (during flight, landing);
- vertical visibility (during flight or from the ground).

a. **Weather phenomena**

Weather phenomena that threaten the safety of flights or directly threaten aviation technology at airports are called dangerous weather phenomena. The most dangerous phenomenon for aviation is storm activity in the airport area or during flight. Flights are very dangerous in the area of storm activity due to strong turbulence, intense icing, electrical discharges and also the possibility of hail.
A storm is a very complex atmospheric phenomenon with electrical discharges in the form of lightning and thunder. During storms, intense showers with hail occur, which can impair visibility. The formation of storms is associated with the formation of cumulus clouds with great vertical strength. During flights, it is forbidden to fly into storm clouds and it is necessary to fly around them at a distance of at least 10 km. It is also possible to fly over storm clouds at least 1000 m above their upper limit [9].
Information about the distribution and direction of the progress of storm centres is of great importance in ensuring the safety of flying in areas with storm activity. It is important to gain knowledge from available ground and airborne radars. With their help, it is possible to find out the necessary data on the development of storm outbreaks accurately and on time. Weather forecasters at meteorological stations must know the aerological and synoptic conditions of the development of storms, the physical nature of the formation of storms, and also know how to correctly evaluate the probability of the occurrence of this phenomenon [9].
Storm activity is never created over the entire territory in a given area. Whether or not a storm occurs in a given area depends on the local peculiarities of the orography and topography of the place. But this dependence is strongly manifested in storms inside air masses and less so in frontal storms [10].

4. FOG FORECAST

Fog can also be called the accumulation of condensation products or sublimation products. It is an accumulation of water vapour directly above the earth's surface, where horizontal visibility decreases below 1 km. If the air is fogged with a visibility of 1 to 10 km, we call this phenomenon smoke. Fog is considered the most significant phenomenon impairing visibility. Fog makes it difficult to take off and makes it impossible for planes to land at airports not equipped with landing systems. During fog, it is impossible to fly with ground visibility, which makes it difficult to determine the position of the aircraft during the flight. During the flight, there is also a danger of aircraft collision [10].
Loss of direction during take-off, collision with an obstacle during take-off or during climb, landing in front of the runway, running out of the runway are mainly caused by fog. The weather service must perfectly know the physical nature of the fog formation process and also master practical methods of calculating the probability of the formation of different types of fog. Depending on the nature of the aerological and synoptic situation, we distinguish fogs inside air masses and frontal fogs [8].
Fogs inside air mass are divided into several types according to the conditions of their formation, according to the type of cooling:

Radiation fog is formed as a result of nighttime cooling of the air adjacent to the earth's surface from the subsoil. This subsoil is cooled by long-wave radiation. For the formation of fog, it is necessary that the turbulent transfer of heat is not too intense and that there is no mixing of an overly thick layer of air. The most favourable wind speed is 1 to 3 m/s. The air must be sufficiently humid. Radiation fog is usually 100 to 200 m thick. It usually forms in the second half of the night and during the morning it breaks up or turns into stratus with a height of 100 to 300 m. In winter, such fogs can last all day [6], [8].

Advection fog is formed when moist, warm air moves over the cold earth's surface. As it moves, the air layers from the cold surface cool down to the state of saturation. Advection fogs are extensive and exceed 20 m in the vertical direction. They can form throughout the day and can be accompanied by drizzle [6], [8].

a. **The effect of fog on flying**

The danger of fog for flying lies in the fact that it can form at any time of the day, can be very extensive in area and can last for a very long time. Advection fog is more dangerous for flying. It can occur at the same time at the operational and reserve airport. Flights above advection fog can only be carried out with the help of instruments, because landmarks cannot be seen through it. Less dangerous are radiation fogs, which occur only in certain weather, in a limited area and in certain orographically favourable areas. Radiation fog is densest near the ground. Basic fog forecasting methods include:
The Zverev diagram method, which is based on air temperature and relative air humidity at a certain time in the afternoon and expected cloudiness and wind at night. The results performed by the Zverev method yield good results if the temperature and humidity data are at the time of sunset. The advantage of this method is a small amount of input data and a quick result [9].
Among the decisive factors in the creation of the Zverev diagram are:
- dew point temperature, which can be expressed as [11]:

$$T_d = T - \left(\frac{100-RH}{5}\right) \qquad (1)$$

where:
- Td is the dew point temperature (°C);
- T is the current air temperature (°C);
- RH is relative air humidity (%) [11].

- relative air humidity is given by:

$$RH = \frac{e}{e_s} \times 100 \qquad (2)$$

where:
- RH is relative humidity (%);
- e is the current partial pressure of water vapour (hPa);
- es is the partial pressure of saturated water vapour at a given temperature (hPa) [11].

The change in saturated water vapour pressure with temperature is described by the Clausius-Clapeyron equation, which is defined as:

$$\frac{de_s}{dT} = \frac{Le_s}{R_v T^2} \qquad (3)$$

where:
- L is the latent heat of evaporation;
- Rv is the gas constant for water vapour;
- T is temperature (K) [11].

The calculation of the partial pressure of water vapour can be given by:

$$e = RH \times e_s \,/\, 100 \qquad (4)$$

where:
- e is the current partial pressure of water vapour (hPa);
- RH is relative humidity (%);
- es is the partial pressure of saturated water vapour (hPa) [11].

When creating the Zverev diagram, it is necessary to obtain current data on air temperature, relative humidity and pressure. Subsequently, it is necessary to calculate the dew point temperature. The change in saturated water vapour pressure with temperature can be expressed by the Clausius-Clapeyron equation. Subsequently, it is possible to create a diagram where the curves will represent the values of relative humidity and dew point [11].

Berland's method
The calculation consists in finding the air temperature at the time of fog formation and the minimum air temperature the following night. This method is based on observing the relationships between different meteorological elements that influence the formation of fog. When applying this method, the difference between temperature and dew point relative humidity is used [9].
In aviation meteorology, Berland's method is used to estimate visibility and conditions for landing and takeoff of aircraft. It is also often used as a supplement to numerical models. This method belongs to the empirical methods, thanks to which it can be effectively integrated into modern meteorological systems. The initial data for the calculation are:
- air temperature value and dew point temperature in the previous 24 hours;
- soil condition;
- expected amount of low, medium and high cloud cover;
- expected wind speed at the earth's surface;
- sunrise time [7].

5. AIRPORT SLIAČ

Sliač Airport or 81st Wing Sliač - Tri duby Airport is located in central Slovakia. Between the cities of Zvolen and Banská Bystrica. The town of Sliač is located in the Zvolen basin. Its altitude is 298m. The western part of the cadastral territory of the city consists of slightly undulating meadows passing into the foothills of the Kremnica hills, the deforested surroundings of the Hron stream and the western slopes of the Zvolen upland with a smoothly modelled surface of the ridges, which arose in the Tertiary plain on the eastern side of the city territory [7].

Figure 1 Hills around Sliač aiport

Figure 1 shows a map of Sliač airport with the surrounding hills. It is possible to see that the airport Sliač is located in the basin between them and the river Hron. It is also possible to see water streams from these hills, which flow into the hron river. The ground around the airport is wet, which can result in the formation of fog.

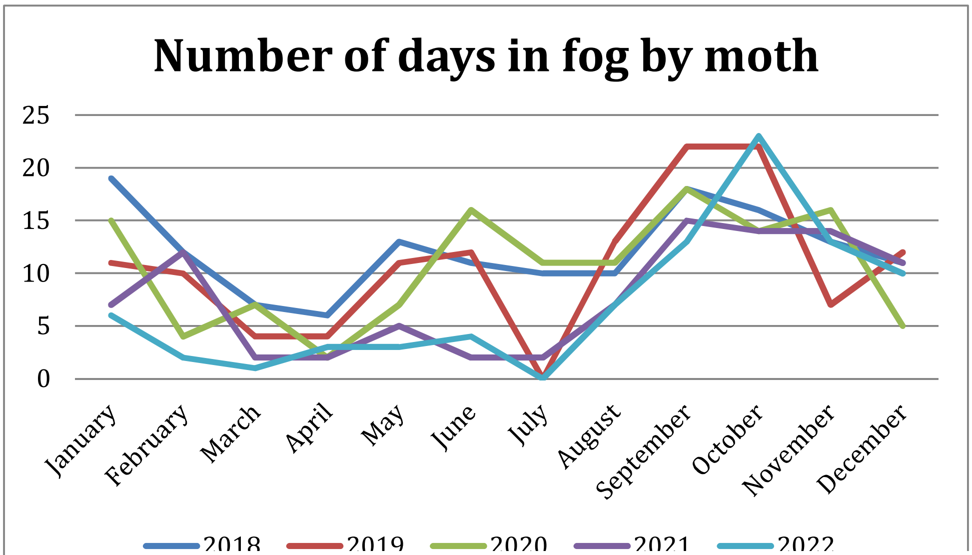

Figure 2 Number of days in fog by month, source: own

The method of statistical analysis and subsequent comparison of individual months was used in the evaluation of METAR and SPECI reports. These are issued regularly, every hour, and its format is fixed. The statistical analysis of the occurrence of dangerous weather phenomena was focused on fog. Orography significantly affects the development of fog at Sliač Airport. A total of 73 344 METAR and SPECI reports from Sliač Airport were analysed for the period 2018-2022.
Figure 2 shows curves with the occurrence of fog by month from 2018 to 2022. Figure 2 shows that fog at Sliač Airport occurs throughout the year. On average for the given period, it is 115 days, which represents 31% of days per year. The seasonal occurrence of fog can also be determined from graph 1. The fewest days with the appearance of fog are in the months of April and July. Conversely, the occurrence of fog is greatest in the winter months of September and October, which the graph shows for all analysed years. The most days with the occurrence of fog was October in 2022, namely 23 days of the month, which represents around 90%.
Based on the results of the analysis, fog forecasting is important, since the activity of up to 31% of days a year is limited by the presence of fog at Sliač Airport. The most common occurrence at Sliač airport is radiation fog, which is created by air cooling. This data could be used in the creation of new models to improve the accuracy of fog forecasts, which would contribute to increasing the safety of air transport.

6. NETWORKS OF METEOROLOGICAL STATIONS

The necessary data for the field of synoptic meteorology are obtained from meteorological and aerological observations. According to the measured data, which are coded into meteorological reports, the distribution of meteorological elements and phenomena in different geographical areas is determined.The density of stations is not uniform across the globe. Most weather stations are located in Europe and America. The exchange of weather information between stations within a state, between states and between continents is important. To facilitate the transfer of information between civilian components and the Slovak Armed Forces, the IMS is used, where coded reports on the meteorological situation are sent at regular intervals [8].

a. Air Force of the Slovak Republic

Part of the air force is Malacky Airport (LZMC), Sliač Airport (LZSL) and Prešov Airport (LZPW), which are also part of the network of meteorological stations in Slovakia. Continuous weather observation is carried out at military meteorological stations [12].
The Air Force is a component of the Armed Forces of the Slovak Republic and ensures the defence of the airspace and the sovereignty of the Slovak Republic. Correct and timely data on current and future weather developments are an integral part of the Air Force's combat capability. Accurate weather forecasts are very important to support the planning and execution of military air operations. Even in the past, during world wars, significant events were recorded due to the influence of weather [12].
Within Europe, there are around 35 000 air movements per day, which means that it is one of the busiest airspaces in the world. NATO (The North Atlantic Treaty Organization) also includes the United Air Force Command, which ensures the protection of Europe's airspace continuously 24/7. Specifically, it is the NATO integrated air and anti-missile defence system – NATINAMDS (NATO Integrated Air and Missile Defence System). In order to fulfil the main tasks within NATINAMDS, it is important to know the effects of weather on flying, which can have a negative impact on the execution of continuous airspace protection and defence [12].
Meteorological measurements are a very important activity for ensuring safe air traffic. In Slovakia, there is a network of synoptic stations where regular measurements of climatic conditions are carried out. The measured data are processed into meteorological reports and are sent to the IMS system by observers.Currently occurring dangerous weather phenomena are reported (coded) in METAR reports. In the case of military weather stations at airports, these reports are broadcast on an hourly basis. METAR reports include visibility, wind gusts, cloud cover, weather conditions, air temperature, dew point temperature and air pressure [13].
SPECI is a coded irregular meteorological report about the current weather at the airport. It is issued by the meteorological service in the event of a significant change in the weather, for example. The occurrence of a storm, a reduction in visibility, a change in the direction and speed of the wind. It is issued outside the METAR release date [13].
TAF (airport forecast) is a regular coded meteorological weather forecast for a given airport. It is issued at specified times for a specified period of validity. The TAF is valid for 9 hours and is renewed every three hours [13].

7. DISCUSSION AND RESULTS

Weather conditions have a significant impact on the operations of the Slovak Air Force. Analysis of METAR and SPECI reports from Sliač airport provides valuable information on the occurrence of fog and its impact on flight activities. Fog at Sliač airport is a very common phenomenon, also due to orography. Fog affects flight operations 31% of the year, which is about 115 days.
Reduced visibility represents a significant obstacle to flight activities. At Sliač airport, radiation fog occurs primarily, which is formed as a result of air cooling near the ground, especially in the morning or at night. Reduced visibility thus hinders take-off and landing in particular [6],[8]. The need to introduce new modern technologies for timely and accurate prediction therefore becomes necessary. The largest number of days with fog occurs in the months of October and November. In these months, it is necessary to expect greater restrictions on flight activities. The accuracy of fog forecasting can be increased by the introduction of new modern predictive models, which currently use artificial intelligence or machine learning. Such models can significantly help in planning and decision-making. Comparative analysis with methods such as the Zverev diagram and the Berland method points to potential improvements or increases in efficiency in prediction. The gradual introduction of advanced systems can minimize operational disruptions caused by fog, which will ultimately increase the safety

and reliability of air traffic. The results of this study are based on an extensive analysis of 73,344 METAR and SPECI reports from Sliač Airport for the period 2018 to 2022. The main findings can be considered:

Fog frequency: Fog occurs at Sliač Airport on average 31% of days per year, especially in the cold half of the year. The highest occurrence was recorded in October 2022, when fog occurred on 23 days per month.

Seasonal occurrence: The least fog occurrence was recorded in the months of April and July and the most in October and November.

Fog types: Radiation fog is the most common at Sliač Airport. Advection fog is less common, but poses a greater risk due to its longer duration and extensive coverage area.

Impact on operations: Flight operations at Sliač Airport are significantly affected by the occurrence of fog, especially during takeoff and landing. The need to introduce predictive models is justified by the high frequency of fog occurrence.

This study points to the need to introduce new predictive models to improve planning and decision-making in air operations. By adopting modern technologies and increasing the accuracy of weather forecasts, it is possible to reduce the effects of hazardous weather phenomena and increase the safety and efficiency of operations of the Slovak Armed Forces.

8. CONCLUSION

Weather has a significant impact on air traffic. The greatest emphasis is placed on the safety of air transport in civil aviation and also in the Slovak Air Force. Based on the analysis, it was found that visibility has the greatest impact on air traffic. It can be affected by dangerous weather phenomena such as storms, fog, precipitation, frost or wind. The research focused on fog, specifically at Sliač airport. Based on METAR and SPECI reports, it was found that the annual occurrence of fog at Sliač Airport is 31%. This percentage represents the average number of days with fog. This is almost 116 days a year when aviation activity is limited by fog. This percentage significantly affects aviation, as other dangerous phenomena are not included here. It is necessary for the Air Force of the Slovak Republic to introduce new forecasting models for fog prediction and thus prevent restrictions in connection with this phenomenon.

The results from the METAR and SPECI reports further analyse that the most common type at Sliač airport is radiation fog, which is created as a result of air cooling. The data used can be used in the development of new modern models to improve the accuracy of forecasts, thus contributing significantly to the safety of air traffic. It is necessary to trigger the need to introduce new technologies such as artificial intelligence and machine learning, which significantly helped in the prediction of dangerous weather phenomena. In the future, it is important to ensure the development of new modern forecast models, increase the availability of meteorological data at meteorological stations and also create archives. Continuous education of forecasters is very important. The introduction of these technologies would have enormous benefits not only for science, but especially for the safety of air traffic.

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