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*Original Research*

# IMPACT OF FOG DISPERSION ON AVIATION AND ENVIRONMENTAL SAFETY

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## Abstract

*Fog is one of the most hazardous meteorological phenomena, significantly impacting aviation safety and the continuity and regularity of aviation operations, particularly in general aviation. It also causes substantial economic losses due to frequent operational disruptions and temporary airport closures. Moreover, fog remains one of the most complex atmospheric phenomena to forecast and observe with high accuracy.*

*The Vojvodina region, the focus of this study, is characterized by frequent fog, particularly during the colder part of the year. It hosts several small airports and airfields, which, despite their limited infrastructure, are regularly used and often operate without certified low-visibility landing systems. Under such conditions, fog dispersion techniques could serve as a potential supplementary operational approach for enhancing operational aviation safety. To illustrate the described meteorological conditions and their potential impact on aviation operations, this study analyzes the synoptic situation on 14 November 2025, during which an aircraft accident occurred at Subotica Airport (LYSU), resulting in severe injuries to the passenger and the death of the pilot.*

*This study provides a critical assessment of the potential to improve aviation safety at small airports and airfields in the Vojvodina region by applying fog dispersion methods, with particular consideration of their environmental implications. The study focuses on scenarios where certified low-visibility landing systems are not operationally available.*

**Keywords**: fog dispersion, aviation safety, low-visibility operations, environmental impact.

## INTRODUCTION

According to the International Civil Aviation Organization (ICAO) and the World Meteorological Organization (WMO), fog is defined as “a suspension of very small water droplets (and sometimes minute ice particles) in the atmosphere, reducing the horizontal visibility at the Earth’s surface to less than 1000 m.” [1]. Due to the substantial reduction in horizontal visibility, fog represents one of the most hazardous meteorological phenomena affecting aviation operations, particularly during approach and landing phases.

The Vojvodina region, characterized by flat terrain, extensive grassland areas, numerous water bodies, and high near-surface humidity, is conducive to frequent fog occurrence, especially during the colder part of the year. The region hosts several small airports and

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airfields with limited infrastructure and without certified low-visibility landing systems, primarily used for general aviation operations such as flight training, sport aviation, and private flying. Users of these small airports and airfields often lack access to locally relevant meteorological information and may rely on meteorological data and forecasts intended for larger airports or on observations from the nearest synoptic weather stations. These factors may adversely affect aviation safety at such locations.

In situations where landing operations under low-visibility conditions are not possible, it is relevant to consider methods for artificially improving visibility. One such approach is fog dispersion. According to the World Meteorological Organization, fog dispersion, or fog dispersal, is "a form of weather modification aimed at artificially improving visibility through the dissipation of fog."

The Serbian Center for Investigation of Accidents in Transport (CINS) initiated an official investigation into the accident at Subotica Airport (LYSU) on 14 November 2025. The final investigation report was not publicly available, and the probable cause of the accident is unknown at the time of writing [2]. However, multiple reports referenced poor visibility, fog occurrence, and difficulties in conducting the accident investigation due to unfavourable meteorological conditions.

## MATERIALS AND METHODS

### Fog dispersion methods and their effects

Fog dispersion methods depend primarily on the type of fog present [3,4]. Based on the temperature conditions under which fog forms, fog may be classified into three categories: warm fog, supercooled fog, and ice fog [3].

Warm fog (FG) consists of water droplets at temperatures above 0°C. This type of fog is highly stable, very common, and considered the most difficult to disperse artificially [5,6].

Supercooled fog or freezing fog (FZFG) forms at temperatures below 0°C but still consists partially or entirely of liquid water droplets due to the insufficient presence of ice-nucleating particles - INPs [5,6].

Finally, ice fog consists predominantly of ice crystals and most commonly occurs at temperatures below −30°C [5].

Based on the mathematical formulation of daytime visibility presented in [7], visibility can be most effectively improved by reducing the diameter of fog droplets. Additionally, considering the spatial scale required for effective fog modification at airports, the most practical and efficient approaches are air-mixing and air-replacement techniques, particularly evaporation-based and thermal fog dispersal methods, which have historically shown the greatest operational applicability in aviation fog dissipation [3,4].

The evaporation method consists of two main approaches: removing water vapor from the air and increasing the air's capacity to hold water vapor without condensation.

*Freezing fog* (FZFG) is considered one of the most hazardous fog types in aviation because it combines reduced visibility with icing conditions affecting aircraft, runways, and airport equipment [6,8]. Its greatest operational impact occurs during taxi, take-off, and landing phases [9,10]. Fog dispersion can be achieved through two approaches: homogeneous nucleation by locally cooling the air with liquid propane or dry ice, and heterogeneous nucleation by introducing ice-nucleating particles (INPs) into the atmosphere [3,11–13].

*Warm fog* dissipation can be achieved through direct heating, hygroscopic seeding, and mixing with drier air. Direct heating for localized fog dissipation may be achieved using hydrocarbon fuels or laser energy [3]. Recent research suggests that UV-C photolysis technology may potentially contribute to fog dissipation not only through localized heating but also by reducing the efficiency of cloud condensation nuclei (CCN) by approximately 35–45%, thereby potentially limiting fog reformation [14].

Currently, no satisfactory operational methods for effective *ice fog* dispersion have been identified; therefore, mitigation efforts are mainly focused on preventing or limiting ice fog formation [3,15,16].

According to the WMO Statement on Weather Modification [15] and recently published studies [17,18], commonly used seeding agents have generally not demonstrated significant adverse impacts on human health or the environment under standard operational conditions. However, the use of large quantities of such materials should still be approached with caution and careful environmental consideration.

According to [15], further progress in weather modification research requires high-quality observations, numerical modelling, well-designed experiments, and international collaborative efforts. Furthermore, significant social, ethical, environmental, and legal challenges remain important challenges with weather modification practices [15].

## RESULTS AND DISCUSSION

### Overview of Meteorological Data and LYSU Characteristics

This study analyzes the synoptic situation on 14 November 2025, with additional focus on the resulting weather conditions at Subotica Airport (LYSU).

As previously discussed, the effectiveness of fog dispersion methods is highly dependent on the spatial extent of the area being influenced. The runways at Belgrade Nikola Tesla Airport measure approximately 3.5 km × 45 m [19], while the runway at Subotica Airport is considerably smaller, with dimensions estimated at approximately 800 m × 30 m [20]. Additionally, the runway surface at Subotica Airport is grass-covered, unlike the concrete surfaces at Belgrade Airport. Grass-covered surfaces tend to retain near-surface moisture more efficiently, which may enhance local fog formation processes. Lake Palić is located approximately 6 km in a straight line from Subotica Airport and may represent an additional local source of atmospheric moisture.

Surface synoptic observations (SYNOP reports) from nearby meteorological stations were used to reconstruct the synoptic and local meteorological conditions during the event. SYNOP reports use a standardized WMO coding format for reporting surface meteorological observations at fixed synoptic hours [21]. The data include air temperature, dew point temperature, atmospheric pressure, pressure tendency, wind direction and speed, horizontal visibility, cloud cover, cloud type, present and past weather phenomena, precipitation amount, and additional information on atmospheric and surface conditions.

These observations are reported according to internationally standardized procedures, and each station is assigned a unique WMO station identifier [22]. The nearby stations considered in this study were Sombor (13160), Palić (13067), Kikinda (14117), Novi Sad – Rimski Šančevi (13168), Beograd Surčin (13272), Beograd Košutnjak (13275), and Szeged (12982), Hungary (Figure 1). For the sake of brevity, only the most relevant observations associated with the analyzed meteorological situation and study area are discussed and presented in this study. Beograd Surčin is also known as Belgrade Nikola Tesla Airport, with ICAO code LYBE [23]. Additionally, METAR (Meteorological Aerodrome Report) and TAF (Terminal Aerodrome Forecast) aviation weather reports were used in the analysis. TAF and METAR are standardized aviation weather observation and forecasting formats defined by ICAO and WMO [8,24]. METAR and TAF for LYBE, Batajnica Military Air Base (LYBT), Osijek Airport (LDOS), Pécs–Pogány Airport (LHPP), Budapest Ferenc Liszt International Airport (LHBP), Kecskemét Air Base (LHKE), Arad International Airport (LRAR), and Timișoara Traian Vuia International Airport (LRTR) were used in the analysis. Meteorological observations from nearby airports, combined with satellite imagery (Figure 1), were used to assess the spatial extent of fog occurrence over the Pannonian Basin.


***Figure 1*** *Locations of SYNOP stations (red), airport meteorological observation and forecast stations (green), Subotica Airport – LYSU (purple), and radiosonde measurement sites (blue) within the Vojvodina region. Source: adapted from Windy.com*

The satellite analysis was performed using Meteosat geostationary satellite imagery distributed by EUMETSAT [25].

Synoptic surface and upper-level analysis charts provided by the Deutscher Wetterdienst (DWD) were used to analyze the large-scale atmospheric conditions during the event [26].

Upper-air conditions were analyzed using radiosonde (upper-air sounding) data. Radiosonde measurements provide vertical profiles of temperature, relative humidity, pressure, and wind in the atmosphere [27] (Figure 1).

**Synoptic Situation Analysis**

An analysis of the surface pressure field indicated the presence of an anticyclone, *i.e.*, a weak pressure-gradient field associated with a high-pressure system over the Balkan Peninsula. The analysis of upper-air charts further confirmed the influence of the high-pressure system through a pronounced anticyclonic ridge extending across parts of Central, Southern, and Southeastern Europe, with its axis positioned over Serbia and the Balkan Peninsula (Figure 2a, c, and d).

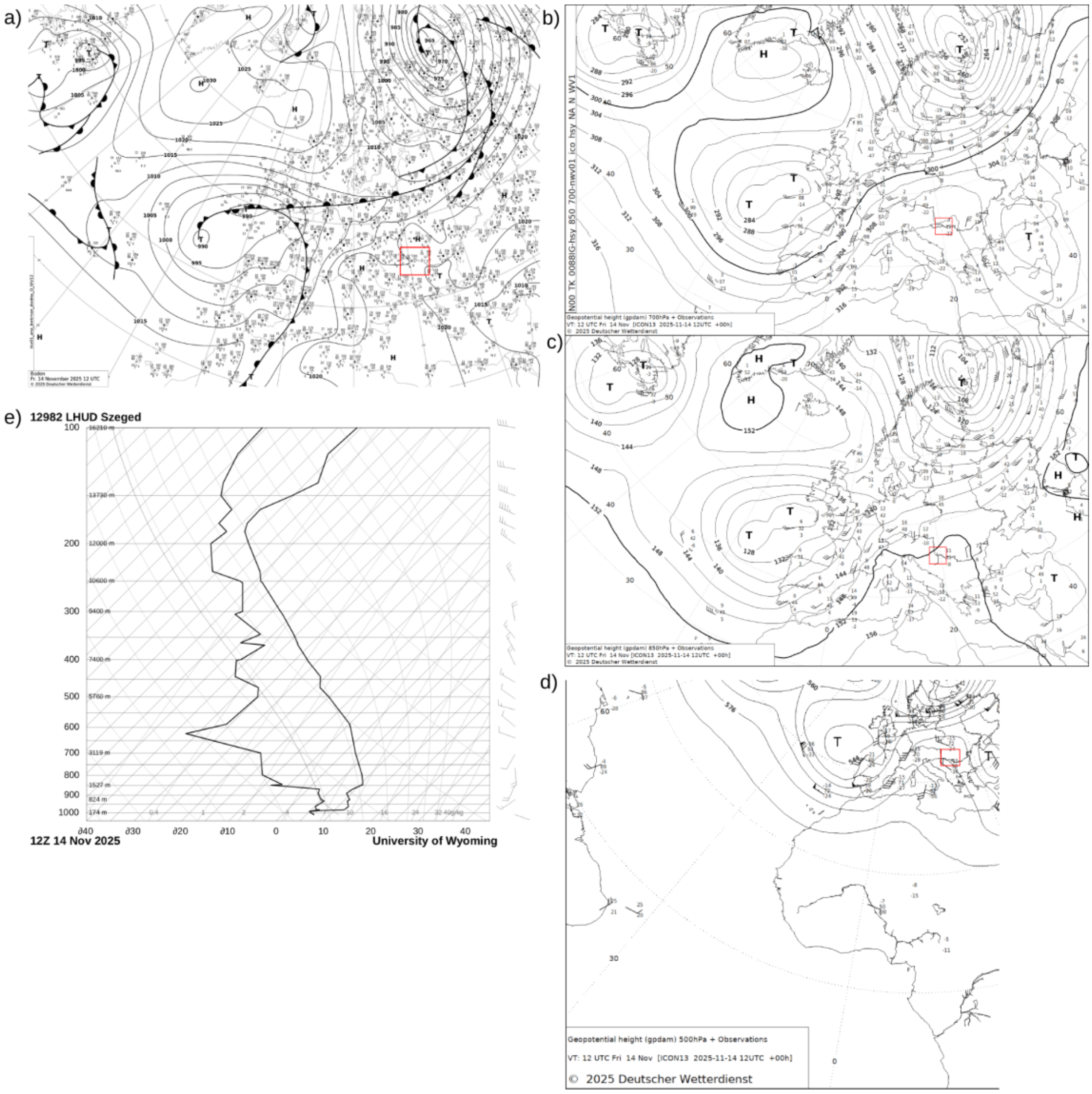


***Figure 2*** *Synoptic and upper-air meteorological conditions on 14 November 2025 at 12 UTC: (a) DWD surface synoptic analysis chart; (b–d) upper-level analysis charts at 700, 850, and 500 hPa; and (e) radiosonde (upper-air sounding) observations from Szeged. The red rectangle indicates the approximate location of Serbia within the analysis domain*

Radiosonde observations revealed a relatively warm and stable air mass for mid-November conditions, accompanied by a pronounced temperature inversion in the lower part of the vertical temperature profile. Surface observations also indicated weak near-surface winds, favoring nocturnal radiative cooling and fog formation (Figure 2b).

Satellite imagery revealed an extensive fog-covered area affecting most of the Vojvodina region during the night and early morning hours. Following sunrise (approximately 05:30 UTC), the spatial extent of the fog gradually decreased. By 09 UTC, the fog was primarily confined to areas north of Novi Sad. After 12 UTC, the fog remained largely limited to the northeastern part of Vojvodina.

As the dissipation process continued, around 13 UTC, a smaller fragmented portion of the fog field separated from the main area and persisted in the vicinity of the city of Subotica and Subotica Airport until approximately 14:30 UTC (Figure 3). The fragmented feature observed in satellite imagery may represent either residual fog or a transition toward low stratus cloudiness. After 14:30 UTC, the feature continued moving toward the northwest and had completely departed from the study area by 15 UTC according to available satellite observations.


***Figure 3*** *EUMETSAT satellite imagery showing fog distribution over the Vojvodina region at 14 UTC on 14 November 2025 [22]. The red rectangle indicates the approximate location of Subotica Airport (LYSU)*

SYNOP observations indicated that the Palić station reported fog-associated visibility reductions ranging from 0 to 600 m during the period from 06 to 18 UTC, when the station was operating in manual observation mode. Since air temperatures remained above 0 °C throughout the observed period, the event can be classified as warm fog.

Therefore, although satellite imagery indicated that the main fog-covered area had departed from the vicinity of Subotica by 15 UTC, surface observations continued to report reduced visibility conditions. This may indicate the persistence of a localized shallow fog layer or an area of restricted visibility that was not readily identifiable in the available satellite imagery.

According to the preliminary report issued by CINS, the accident occurred at approximately 15 LT (14 UTC). During this period, the fragmented feature identified in the satellite imagery was remained present within the study area.

From 13 UTC to 15 UTC, the main fog-affected area visible in satellite imagery extended northward toward Kecskemét Air Base (LHKE), where METAR observations reported reduced visibility due to fog, ranging from 200 to 350 m, accompanied by an overcast low stratus cloud layer with a cloud base at 200 ft (approximately 60 m).

## CONCLUSION

It can therefore be concluded that the area of Subotica Airport was affected by fog or very low stratus cloudiness at the time of the accident. However, whether these meteorological conditions directly contributed to the accident remains to be determined by the official investigation. Due to its relatively small runway dimensions and localized fog occurrence, Subotica Airport may represent a suitable case study for the potential application of fog dispersion methods. Since the analyzed event was characterized by warm fog conditions, recently proposed warm fog dispersion techniques described by [14] may be applicable in similar operational environments.

The application of fog dispersion techniques at similar small airports and airfields could potentially provide significant benefits for aviation safety under low-visibility conditions. However, further investigations are necessary, particularly regarding the environmental, operational feasibility, and effectiveness under real atmospheric conditions.

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