CONSIDERATIONS ON SEVERE METEOROLOGICAL PHENOMENA FOR AIRCRAFT FLIGHTS IN ROMANIA

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Abstract: *Weather conditions and events have a significant impact on the flight of civil or military manned or unmanned aircraft (UAV/UAS). Adverse and/or dangerous weather conditions force flights to be delayed, diverted, canceled or may cause events with undesirable consequences due to their influence on both aircraft and pilots through biometeorological implications.*

This paper presents meteorological phenomena hazardous to aircraft flight and the human factor from the perspective of methods and instruments used to detect atmospheric and environmental phenomena.

Keywords: *severe meteorological phenomena, detection methods, meteorological instruments, meteorological radar, biometeorological indicators*

Acronims

ATC	*Air traffic control*	*ESWD*	*European Severe Weather Database*
THI	*Temperature humidity index*	*HSI*	*Heat stress index*

1. INTRODUCTION

Hazardous weather conditions and events can significantly influence the evolution of an aircraft on its flight path, causing delays, diversions, cancellations of flights or the occurrence of events with serious consequences.

The most common severe weather phenomena are: severe weather that includes thunderstorms, hail, tornadoes, hurricanes and sandstorms, they can cause severe turbulence, reduced visibility, downdrafts, hail and lightning; ice and sleet deposited on aircraft structural elements can significantly reduce aerodynamic performance and loss of maneuverability, and sleet on the moving surfaces of airport bridges leads to loss of landing gear grip; fog reduces visibility and increases the risk of ground and mid-air collisions of aircraft with other aircraft or ground obstacles.

Adverse weather conditions include: strong winds that can significantly affect the trajectory and speed of the aircraft (increases the take-off/landing distance) or can affect the maneuverability of the aircraft during the flight; turbulence caused by updrafts can cause uncontrolled movements of aircraft sometimes with undesirable consequences; low-visibility clouds can significantly reduce visibility with direct implications for collision risk; heavy precipitation in the form of torrential rain or heavy snow can reduce visibility and affect aircraft flight performance including hydroplaning when landing on airport movement surfaces.

Specialized resources indicate a relevant impact of adverse weather conditions on the human body by quantifying biometeorological indicators with implications for human performance that implicitly affect aircraft performance. Adverse weather conditions can also significantly influence the physical and mental state of pilots with direct and relevant implications on flight safety and performance. The measured biometeorological indices can reveal approaches regarding the implementation of appropriate risk prevention measures. Here is a brief exposition of the most relevant biometeorological index:

- *temperature humidity index (THI), [1]*
- *the wind chill index (wind chill index), [2]*
- *the solar radiation index, [3]*
- *UV index, [4]*
- *thermal stress index / heat stress index (HSI), [5]*

Flying aircraft in adverse/hazardous weather conditions requires careful planning and continuous and constant monitoring of the weather conditions along the flight path. This uses both the consultation of weather maps and forecast charts to identify and avoid risk areas and effective communication with air traffic authorities (ATC) for emergency assistance.

2. CLIMATOLOGICAL ASPECTS OF SEVERE WEATHER IN ROMANIA

Climate data all over the world indicate that incidence of severe weather is gradually increasing in frequency and intensity. As global warming is advancing towards a hotter world, most of the climate variables are significantly changing. These changes imply diverse effects on human society. One of the most affected sectors is aviation where among leading causes of flight delays and accidents are dangerous weather phenomena.

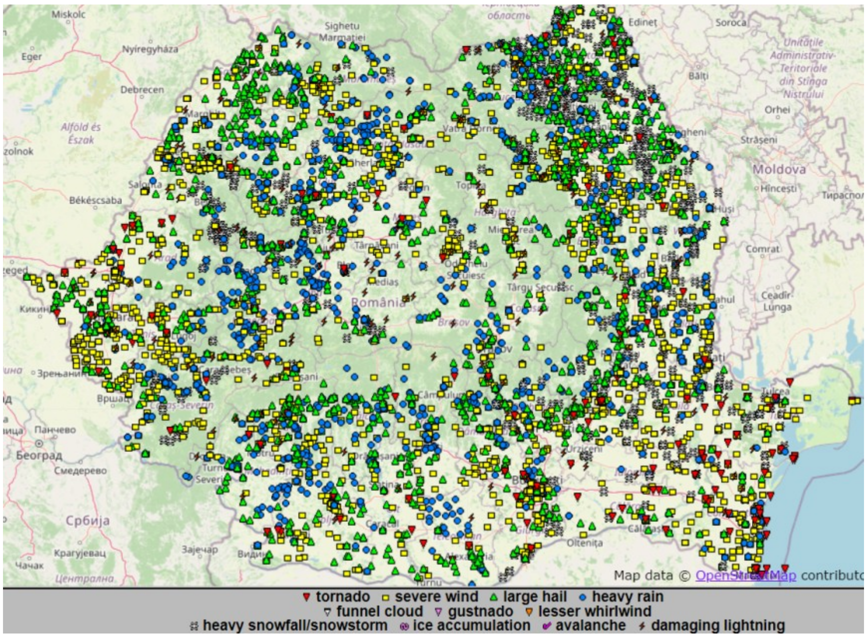


FIG. 1. Severe weather reports in Romania (1994-2023)[6]

European Severe Weather Database (ESWD) operated by European Severe Storms Laboratorycollects relevant information in respect to severe weather in Europe. In Romania, severe weather reports in the last three decades (1994-2023) indicate that northeastern Romania is the most affected area by such weather (Fig. 1).

Eastern Carpathians, Southern Carpathians and Danube Delta had the lowest cases of severe weather reports due to low population density.

Tornadoes reports indicate that the highest frequency of these events was recorded in the southern areas of Romania. The highest numbers of cases with severe winds were reported in western Romania. Extra-Carpathian and Sub-Carpathian regions were the most affected areas by large hail, while the lowest number of cases was reported in southeastern Romania.

The risks of flying through severe weather events which include severe turbulence, wind shear, downbursts, icing, lightning and hail could be extremely dangerous for flight safety [7].Therefore, the avoidance of such events is crucial for flight safety. However, diverting, postponing or flight canceling can result in considerable disturbances and interruption to air traffic.

Even mild weather events related to atmospheric convection or slow-release phenomena such as heat and cold waves, can lead in flight disturbances and delays. Higher temperature maxima at the surface level is significantly decrease air density which impacts the lifting force of the aircraft on the process of taking-off [8]. Civil aviation is highly sensitive to severe weather. Even minor disruption in the flight management plans can induce large interruptions throughout an entire continent [9, 19].

Winter-specific phenomena can also severely affect aircraft flights. For instance, snow can have multiple negative effects on aviation. It can affect visibility through precipitation and increase the risk of fog formation by melting on the surface and increasing the humidity in the lower layer [10]. On the other hand, accumulation of snow on the aircrafts and runways can induce serious delays of flights [11].

3.WEATHER FORECAST TECHNOLOGIES AND TOOLS

The monitoring of dangerous flight phenomena is carried out by terrestrial, aerial and satellite observation systems. In what follows, we present a series of technologies and software tools used to monitor meteorological phenomena for the acquisition of specific data necessary to maintain aircraft flight safety.

3.1. On-board panoramic radar

The on-board panoramic radar is used to find and determine the elements used in air navigation, display the shape of the land surface and a weather regime to display thunderstorm formations according to size and alert level. In the work in front of us, we will refer only to the weather regime, in which the principle of operation is that of primary radar. The transmitting part through the Antenna emits signals of determined duration, wavelength or frequency and power – the desired objective.

Weather radars are generally based on the operating principle centered on the Doppler effect, also applied to electromagnetic waves reflected from a moving target. [12] The radar emits short, high-intensity electromagnetic pulses, and a frequency-Doppler frequency difference occurs between the frequency of the sounding signal emitted and that of the reflected signal (echo) received. The value of this frequency is given by the well-known formula:

$$f_D = \frac{v}{2\lambda},$$

where:

f_D = Doppler frequency, v = radial velocity of the target,

λ = wavelength of the sounding signal emitted

The ranges of wavelengths (λ) most used in meteorological radar technology are in Table 1:

Table 1. [13]

Band	λ=wavelength	f =frequency, $f=\frac{c}{\lambda}$, $c = 3x10^8$ m/s	remarks
W	0.3 ÷ 0.8 cm	35 ÷94 GHz	for middle latitudes
K	0.8 ÷ 2 cm	14 ÷35 GHz	
X	3 cm	10 GHz	
C	5 cm	5 GHz	especially for rain
S	10 cm	3 GHz	

For the pilot the image of the data provided by the radar is essential and the experience and insight of the pilot can make the difference between a dangerous flight and a peaceful one. Below in Fig. 2 we have the weather situation displayed with the dimensions of the thunderstorm formations as indicated by the colors and their danger level, in accordance with the specific characteristics in Table no. 2. [12, 17]

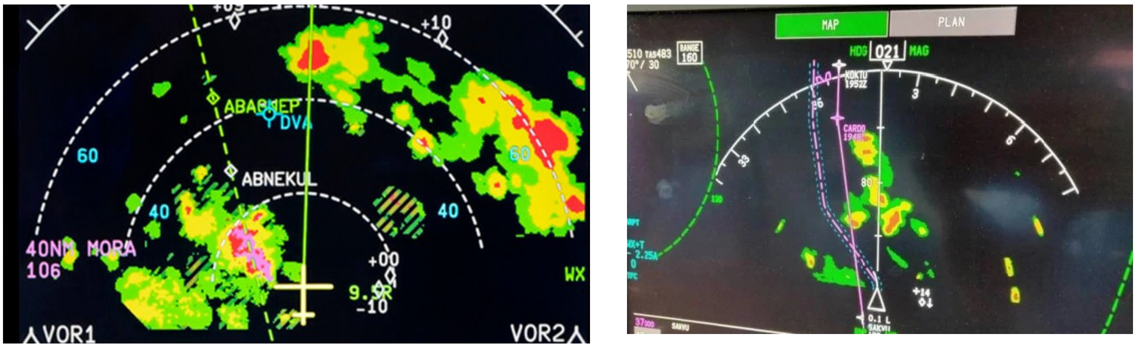


FIG. 2. On-board weather radar indicator [14, 15, 17]

Can be seen the possibility offered by the aerial radar image that the pilot can find solutions to avoid dangerous areas, with minimal deviations from the path.

Table 2. [12]

Level display	Category the storm	Remarks
Magenta	Extreme	Severe turbulence, large hail, electrical discharges, widespread wind gusts (blizzards) and turbulence
	Intense	Severe turbulence, electrical discharges, areas with squalls, possible hail
Red	Very strong	Possible severe turbulence, electric shocks.
	Strong	Severe turbulence, possible electric shocks.
Yellow	Moderate	Light to moderate turbulence possible with electrical discharges
Green	Low	Light to moderate turbulence, possibly with electrical discharges
Black		

The weather regime presents a series of information, such as:

a) Determination and analysis in space of the shapes, types, consistency of cloud formations, their location and their cataloging as a level of danger to the flight;

b) Makes it possible to discover other aircraft flying in the forward area, ensuring risk assessment in preventing approaches;

c) Provides the possibility of displaying the relief with the determination of the safety height in the high regions.

The safety of flying in the area with radar echoes depends on the intensity of the echoes, the distance between them, and the capabilities of the aircraft and the experience of the pilot. Weather radars are constantly developing, they practically determine the concentration of humidity, therefore the pilot must have thorough knowledge of meteorology because atmospheric disturbances do not only come from the area of increased humidity in the form of rain / hail, but also from the strong currents that I take care forms within these stormy formations.[14]

Below is an unpleasant situation with potentially catastrophic consequences of a transport aircraft interacting with a hail formation.

Austrian Airlines Flight OS434 (Fig. 3) sustained considerable hail damage while on approach to land. The aircraft was caught in a severe storm, which resulted in damage to the outer skins and especially the cone. [16]

FIG. 3. Austrian Airlines Mayday after severe hail damage [5]

In conclusion, the weather radar is an electronic device used to locate types of precipitation (rain, snow, sleet, etc.), to determine their trajectories and to predictably calculate the future position and intensity of atmospheric phenomena.

3.2.Automatic weather stations

The best-known technologies and analysis tools are automated weather stations that collect online data on a range of atmospheric parameters such as: temperature, precipitation, wind speed, humidity, atmospheric pressure, cloud ceiling and lightning presence, as examples Vaisala TacMet MAW 201M (Fig. 4a) and Davis Instruments Vantage Pro2 (Fig. 4b). [21, 22]

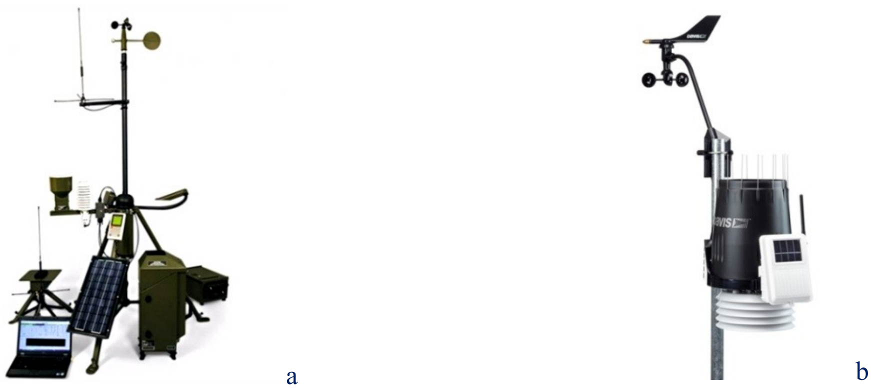
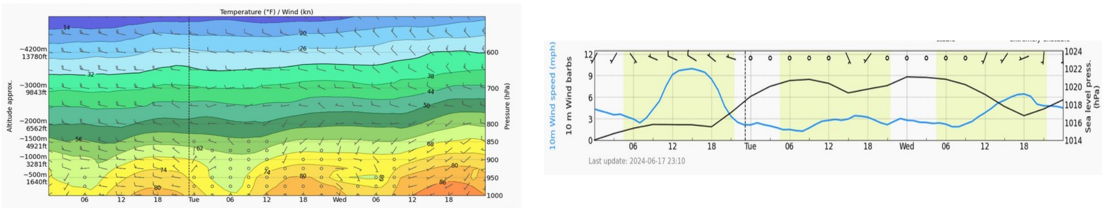


FIG. 4. Automatic weather stations

3.3. Online software. Meteoblue

Offers a free online tool for providing weather information and forecasts on: temperature, precipitation, wind speed and direction, cloud cover, humidity, visibility and air quality. The services offered can be accessed from a number of IT platforms with various operating systems by individuals, legal entities, specialists, meteorologists and researchers who need detailed specialized meteorological data for analysis and research activities. The features of the data provided are: high-resolution data, long-term forecasts, customized data, graphical visualizations. [18]

A series of exposures regarding data specific to the aeronautical field, data valid for the Brașov region are recorded in Fig. 5. and Fig. 6.



a b

FIG.5. Meteorological data –Meteoblue, a. wind-temperature, b.pressure

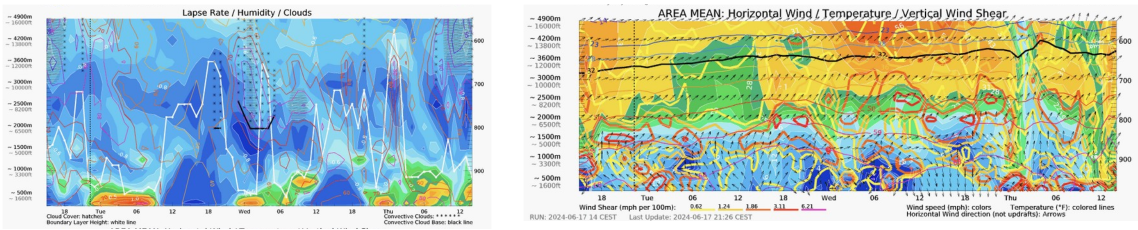


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FIG.6. Meteorological data –Meteoblue, a.laps rate/humidity/clouds, b. horizontal wind/temperature/vertical wind shear

This online software provides relevant data on meteorological phenomena in the area of interest necessary for specific flight activities.

3.4.Offline software. Supercell Wx

Supercell Wx is a freeware, open source tool used to view live NEXRAD level 2 and level 3 data and severe weather alerts. It displays continuously updating weather data overlaid on responsive maps, providing the ability to monitor weather events using reflectivity, velocity and other products. The software tool also provides extended functionality such as weather reports and specific lightning data see Fig. 7.

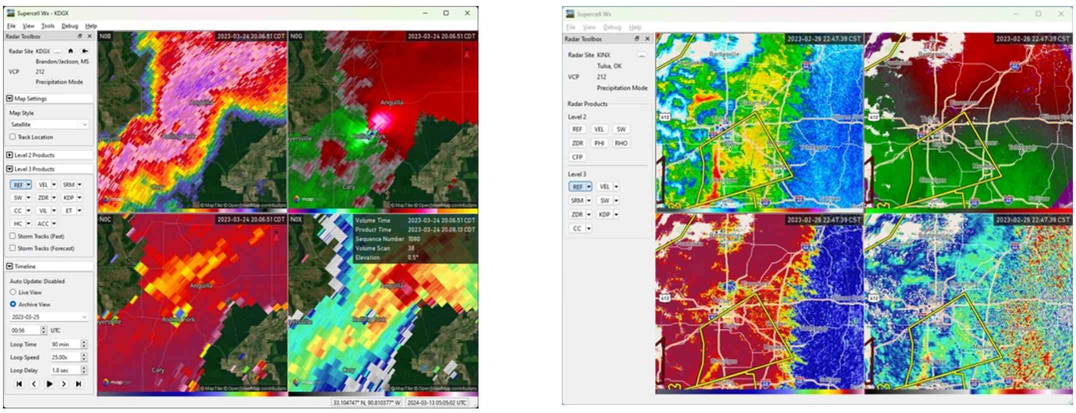

FIG. 7. Supercell Wx, [20]

Data visualization for NEXRAD level 2 offers over 200 graphic and numerical products, including: reflectivity, wind profile, storm velocity, tornado vortex, velocity display, hail index, icing level, hydrometeor classification, [20]

4. CONCLUSIONS

The factors that contribute to aviation accidents can be classified into four categories, such as: human errors / the human factor through lack of relevant training or experience, technical failures can increase the risk of an accident, unpredictable weather conditions that can be difficult to forecast can put pilots in dangerous situations, inadequate procedures and regulations necessary to manage aeronautical activities can favor the risk of accidents.

Lessons learned may focus on the following aspects: the importance of aircrew training, the need to equip aircraft and ground systems with advanced weather forecasting equipment for detailed and up-to-date data, the implementation of procedures and regulations, the development of early warning systems for the occurrence of hazardous weather conditions and cultivating a culture of safety in aviation.

For future studies, it is considered to focus on the statistical analysis of aeronautical accidents caused by dangerous meteorological phenomena, multicriteria analysis classified by types of aircraft and types of phenomena.

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