WIND SHEAR ASSOCIATED WITH MEDITERRANEAN CYCLONES ACTIVITY AND THE IMPACT ON FLIGHT SAFETY DURING WINTER OPERATIONS AT HENRI COANDA OTOPENI AND AUREL VLAICU BANEASA AIRPORTS

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Abstract: *The regulated airspace in which aircraft flights take place is part of the Earth's atmosphere. At the same time, the same airspace is the seat of meteorological process and phenomena that have no borders and whose activity is not regulated, but whose evolution in time and behavior is governed by their own laws.*

This study presents, in a descriptive manner, low level dangerous weather conditions associated with wind shear also called the invisible killer. The phenomenon can occur locally, extremely rarely (3-4 times per year) during winter operations, mainly in January, under the activity of Mediterranean cyclones and its uniqueness consists in duration and intensity. To highlight the impact on flight safety in winter operations, especially in the current context of global warming, the reference and analysis periods applicable to this study are indissolubly reduced to days and minutes. When we talk about flight safety, the immediate application of corrective actions by pilots, the reference period is indissolubly reduced to seconds, those seconds that can make the difference between life and death.

Keywords: *Wind shear, Mediterranean cyclones, flight safety, runway, winter operations*

Acronyms and symbols

LLWS	*Low-level wind shear*	*ASOS*	*Automated Surface Observing Systems*
METAR	*Meteorological aerodrome reports*	*NOAA*	*National Oceanic and Atmospheric Administration*
WMO	*World Meteorological Organization*	*RVR*	*Runway Visual Range*
LLJ	*Low level jet*	*QNH*	*Air pressure measured at the airport meteorological station and reduced to Mean Sea Level from International Standard Atmosphere*

1. INTRODUCTION

The significance of wind shear to aviation lies in its effect on aircraft performance and hence its potentially adverse effects on flight safety. The response of aircraft to wind shear is extremely complex and depends on many factors including the type of aircraft, the phase of flight, the scale on which the wind shear operates relative to the size of the aircraft and intensity and duration of wind shear encountered [1].

Although it may be present at all levels in the atmosphere, the occurrence of wind shear in the lowest 500 m is of particular importance to aircraft landing and taking off.

During the initial climb-out and approach phases, aircraft fly at low heights and near critically low airspeeds, therefore being especially exposed to the most adverse effect of wind shear: sharp variations of lift force [5].

Low-level wind shear at the airports or in their vicinity has been cited in a number of aircraft accidents/incidents and is considered by the aviation community be one of the major technical problems facing aviation [1, 5].

This study can be a useful guide for pilots applicable in exceptionally wind shear situation, a briefing about winter operations under Mediterranean cyclones activity at Henri Coanda Otopeni and Aurel Vlaicu Baneasa Airports, a briefing based on analysis of real meteorological situations reported in METAR in the last 10 years. This study aims to be a briefing for the immediate recognition and awareness of the associated hazards that may occur locally when aircraft experience shear conditions on the runway and/or during the take-off and landing procedure.

2. MATERIALS AND METODS

The meteorological situations analyzed are based on the information in database from archive of automated airports weather observations available on the website of The Iowa Environmental Mesonet (IEM), network Romania ASOS, [12].

The Automated Surface Observing Systems (ASOS) serves as the nation's primary surface weather observing network. ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities [17].

The primary concern of the aviation community is safety, and weather conditions can threaten that safety. A basic strength of ASOS is that critical aviation weather parameters are measured where they are needed most: airport runway touchdown zone(s) [17]. Taking into account this consideration, the Romania ASOS data archive was chosen as the main data source for the analysis of this meteorological phenomenon.

For a more accurate interpretation in scientific purpose of the meteorological data from archives available on the website mentioned above, was used simultaneously the database, graphs and charts from the archives available on https://weatherspark.com (the archive that is based on records obtained from NOAA's Integrated Surface Hourly data set), [13, 19 and 21].

The comparative analysis of the meteorological situations at the two airports from the last 10 years, from January 1, 2011 to December 31, 2020, highlights the fact that, in the context of global warming, there are significant differences between the theoretical aspects known about the low level wind shear phenomenon and the real manifestation of the phenomenon not negligible when talking about flight safety.

3. RESULTS AND DISCUSSIONS

Processing data from meteorological observations over a period of several years (e.g., 10 years) is essential for understanding the climate system to which both airports belong. The climatological particularities give only an overview in terms of the appearance, duration and evolution of the weather in general.

The meteorological conditions specific to each season (winter and summer) play an essential role in terms of scheduling flights. In each season, the weather factor is predominantly favorable for the aeronautical activities according to the schedule. Sudden changes in the weather are what disrupt air traffic at an airport.

Even reported and/or forecasted these sudden changes of the weather in the last 10 years by the way of manifestation at the airport sometimes surprised pilots with great flight experience.

We are not referring here to the effect on attitude of the aircraft and the variation of the flight parameters, but of the way in which these meteorological phenomena manifested themselves at the airport and at low levels, at their duration and intensity, aspects that are not properly known increase the chances that the flight safety is endangered.

In order to identify the effects of global warming on local shear and flight safety, meteorological data recorded and coded in METAR messages issued by the two airport weather stations in the last 10 years were processed, a period that WMO characterized as *the warmest decade on record, the warmest six years since 2015* [17] (FIG. 1).

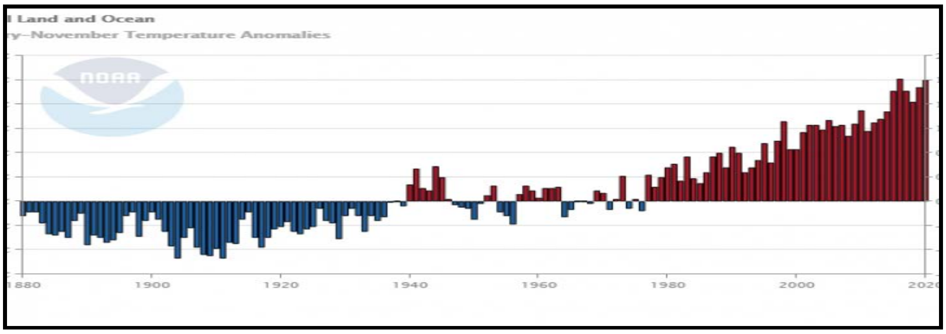


FIG. 1. Temperature anomalies 1880 - 2020

In order to present completely and in detail the unfavorable changes in the evolution of the weather for short periods of time (days, hours, and minutes) and to highlight the shearing reported in the period 24 – 26 January, 2014.

3.1. Comparison of the average weather at Henri Coanda International Airport (LROP) and Bucharest Baneasa Aurel VlaicuI International Airport (LRBS) (1 jan 2011 – 31 dec 2020)

The graphics included in this section (FIG. 2 – FIG. 9) depicts the typical weather for Henri Coanda International Airport and Bucharest Baneasa Aurel Vlaicu International Airport, based on a statistical analysis of historical hourly weather reports and model reconstructions from January 1, 2011 to December 31, 2020. From climatic point of view, the two airports are located in mid-latitudes where the climate is temperate continental with a transitional character.

As reference Influence of meteorological phenomena on worldwide aircraft accidents, 1967–2010 the weather is characterized by low-pressure systems and large-scale synoptic fronts [7]. The climatic and meteorological differences between the two airports are given first of all by the particularities of the active surface (Baneasa is included in the urban perimeter; Otopeni is in the plain and less by the elevation difference (17ft) between them.

Located in the central part of the Romanian Plain, on the background of the general circulation of air masses, specific to the middle latitudes, the interference of the western and eastern atmospheric circulation is noticeable, an effect that is reflected primarily in the direction of runways (080^0-260^0 Otopeni Airport, 070^0-250^0 Baneasa Airport). The meteorological phenomena that accompany wind shear and that have a significant role in reducing visibility below the limits of operation at the airport appear in winter on the predominant wind directions (FIG. 2).

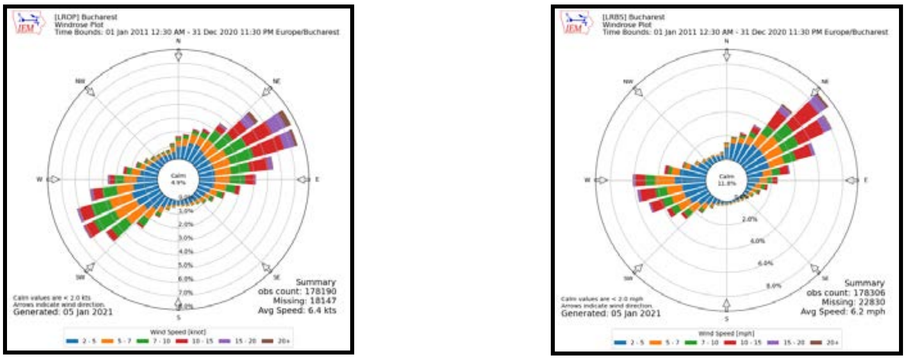


FIG. 2. Wind roses, left Otopeni airport-LROP, right Băneasa airport-LRBS

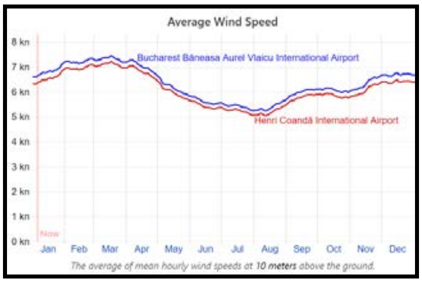


FIG. 3. Average Wind Speed

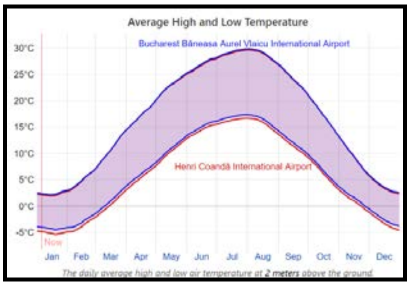


FIG. 4. Average Temperature High and Low

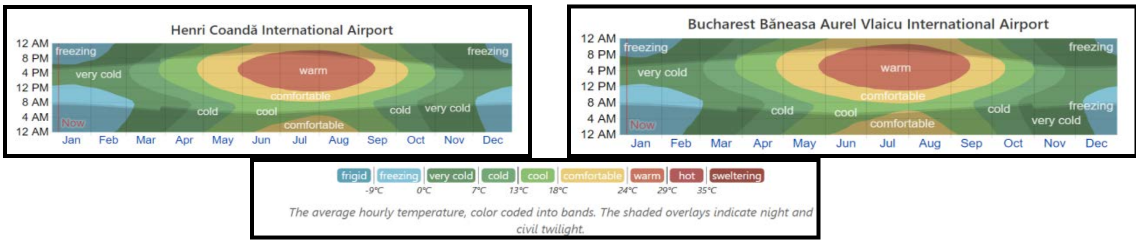


FIG. 5. Average HourlyTemperature

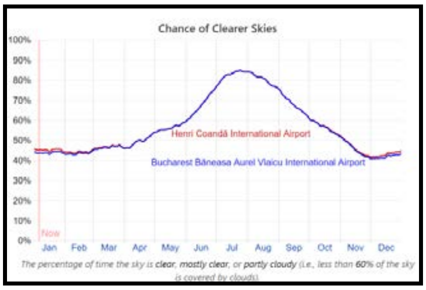


FIG. 6. Chance of Sky Clear

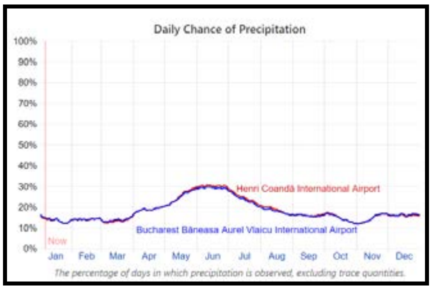


FIG. 7. Daily Chance of Precipitation

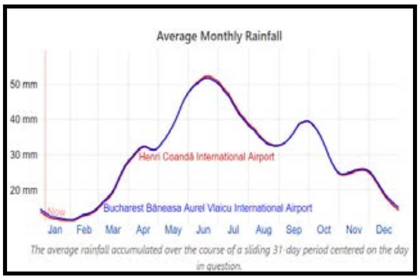


FIG. 8. Average Montly Rainfall

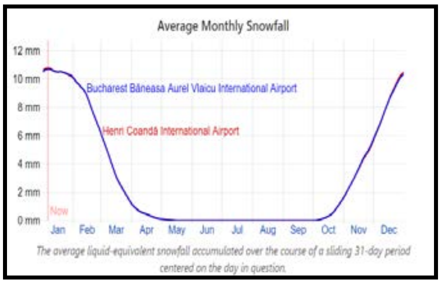


FIG. 9. Average Montly Snowfall

During winter operations the analyzed shear situations associated with low visibility are mainly due to freezing drizzle, moderate snow, fog, usually freezing fog and exceptionally with freezing rain. Specific to both airports is wind shear accompanied by moderate snow. These associated phenomena are due to the prevalence of large-scale synoptic fronts. They not only reduce the values of horizontal visibility, vertical visibility and RVR below the operating limits but also have the greatest contribution to the runway contamination, to the decrease of the friction coefficient and the decrease of the braking action. The lowest values of horizontal visibility and visibility along the runway occur when shearing is accompanied by moderate snow and blowing snow associated with fog:

LROP 251130Z 05030G40KT 0050 R08R/0175N R26L/0150N R08L/0375V0550N R26R/0175N SN BLSN BKN005 OVC021 M07/M07 Q1009 WS ALL RWY 58450294 08450294 NOSIG

Through their action, the Mediterranean cyclones that cross in the cold season (October - March) these two airports have the greatest negative impact on flight safety both on the ground and on takeoff and landing operations.

3.2 Impact of wind shear as extreme weather phenomena on flight safety during winter operations

Wind shear is a change in wind speed and/or direction over a short distance, which results in a tearing or shearing action. If the change occurs gradually (slowly) the effect would be negligible but when the change occurs within a few seconds, the flight crew would have to make rapid, positive inputs to maintain control of the aircraft.

Although wind shear can occur at any altitude, it is particularly hazardous when it happens over a short period of time and within 2,000 feet of the ground, during takeoff or landing. During takeoff phase, the aircraft operates only slightly above stall speed, and a major change in wind velocity can lead to a loss of lift. If the loss is great enough that power response is inadequate, it results in a steep descent [5, 16] .

The altitude at which the encounter occurs, pilot reaction time, and airplane response capability determine if the descent can be altered in time to prevent an accident [16]. To reduce the risk of LLWS affecting operations at LROP by increasing its probability of detection, ROMATSA (the Romanian national Air Navigation Services provider) is currently deploying a wind monitoring and wind shear detection system based on the use of a scanning Doppler Lidar system and of a Doppler Sodar system[4].

The time dependency of significant low-level wind shear can best be illustrated through example. In this study was analyzed the *reported wind shear (on all runways)* produced during the Mediteranean cyclons activities, between 24 - 26 January 2014.

In order to demonstrate the negative impact that low level wind shear and awareness of risks on flight safety, more arguments were introduced: meteorological messages, meteorological maps, atmospheric soundings and low level wind shear maps.

Following the average monthly situations of the atmospheric pressure distribution over Europe, it is found that these cyclones form in October and disappear at the end of March. During this period above the Mediterranean Sea, by advection of the polar air on Central and Western Europe, a permanent front is formed, front which separates the polar air from the north from the tropical air from the south.

Behind these cyclones, in their western sector, cold and dense air penetrations from the Siberian or Greenlandic Anticyclone take place, which causes wind intensifications, low ceilings, sudden and pronounced decreases in air temperature and sometimes violent snowstorm (blowing snow).

The wind shear associated with the Mediterranean cyclones activity at the two airports is generated by the existence of large horizontal baric gradients that determine the intensification of the wind speed and the appearance of gusts (FIG. 10 - 21 and Annex 1).

Practically, during winter operations when the wind shear is associated with advection of warm air, the weather conditions at both airports can have a negative impact on flight safety.

From the processing of the data included in the METAR messages issued by the meteorological stations of the airport, it results that in the last 10 years, at Otopeni airport (LROP) the shear phenomenon has a frequency 4 times higher than in Băneasa airport (Table 1).

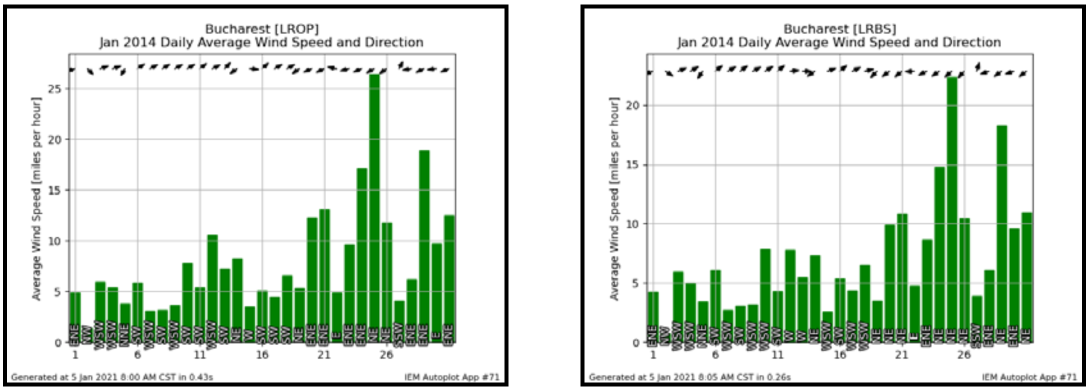


FIG. 10 Average Wind Speed and Direction – January 2014

Table 1. Reported wind shear on all runways

Airport	*The start of period (from) 2011-01-01 00:00Z*	*The end of period 2020-12-31 23:30Z(till)*	*Total number of METAR messages issued during analyzed period*	*WS reported in METAR*	*% from total number of METAR messages*
LRBS	2011-01-01 00:00Z	2020-12-31 23:30Z	178.259	445	0,25%
LROP	2011-01-01 00:00Z	2020-12-31 23:30Z	178.143	1803	1,01%

Practically, in the context of global warming, during the winter, the local particularities of the manifestation of the wind shear associated with the Mediterranean cyclones prove once again that nature works according to its own laws. Although the horizontal distance is very small, only 9 km, due to the duration, intensity and meteorological phenomena of significant weather associated, the wind shear manifests itself differently at the two airports.

In order to describe as completely possible the influence on the flight safety during winter operations using the method of comparative analysis the meteorological situation was analyzed following three sequences:

- before the occurrence of the phenomenon of shearing at the airport (before)
- during the manifestation of the shear phenomenon at the airport (during)
- after the phenomenon no longer appears reported in METAR (after).

The three meteorological sequences are analyzed through the prism of the following aviation weather information: wind, visibility and RVR (Runway Visual Range), weather phenomena, cloud coverage/vertical visibility, temperature, QNH and runway state code (SNOWTAM).

Table 2. The start of the reported wind shear in METAR and SNOWTAM (Runway State Code)

A/P	Date/Time of issued	Wind	Meteorological (horizontal) visibility	Present weather	Sky cond. (100s ft)	OAT/DP	QNH	Supplementary information Reported wind shear
LROP	241800Z	06020KT	2500	-FZDZ BR	SCT004 OVC005	M05/M06	Q1018	
	241830Z	05019KT	4000	-FZDZ BR	FEW004 OVC005	M05/M06	Q1017	**WS ALL RWY**
LRBS	251900Z	05021G31KT	5000	-SN BLSN	FEW011 SCT014 OVC021	M07/M09	Q1012	
	251930Z	05019KT	7000	-SN BLSN	SCT012 SCT016 OVC021	M07/M09	Q1012	**WS ALL RWY**

SNOWTAM	A/P	Date/Time of issued	SNOWTAM
	LROP	241800Z	58750094 08750094
		241830Z	**58750094 08750094**
	LRBS	251900Z	07490293
		251930Z	**07490293**

Table 3. The end of the reported wind shear in METAR and SNOWTAM (Runway State Code)

A/P	Date/ Time of issued	Wind	Met. (horizont.) visibility	RVR	Present weather	Sky cond. (100s ft)	OAT/DP	QN H	Supplem. Inform. Reported wind shear
LROP	**260600Z**	05010KT	0800	R08R/P2000 R26L/1700N R08L/1600N R26R/1900U	SN DRSN FG	SCT004 BKN005 OVC034	M06/M07	Q10 12	**WS ALL RWY**
	260630Z	05011KT	0800	R08R/P2000 R26L/1300D R08L/1400D R26R/1500D	SN DRSN FG	BKN005 OVC043	M06/M06	Q10 12	
LRBS	**261900Z**	0000KT	0600	R07/1900VP2000U R25/1300U	SN FZFG	FEW004 OVC015	M06/M07	Q10 11	**WS ALL RWY**
	261930Z	00000KT	0800	R07/2000U R25/1300D	-SN FZFG	OVC015	M06/M07	Q10 11	

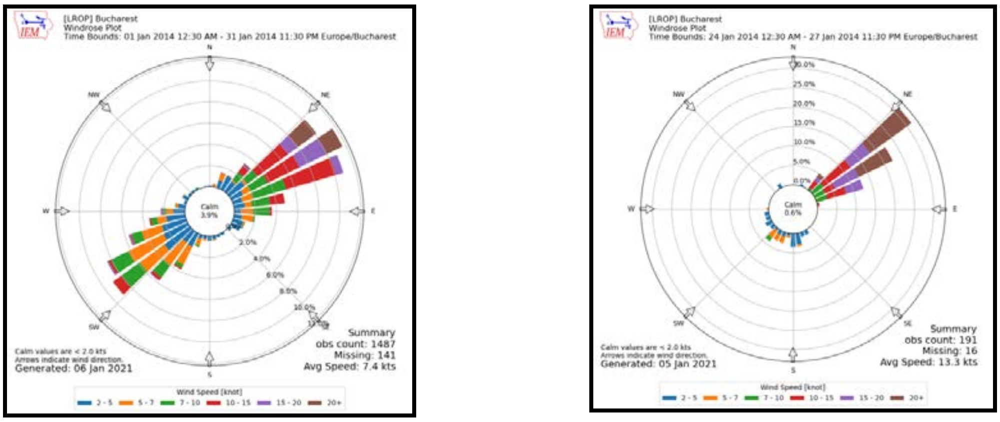
SNOWTAM	A/P	Date/Time	SNOWTAM
	LROP	**260600Z**	**58450394 08450394**
	LRBS	**261900Z**	**07490293**

This graphically presentation (local time) illustrates the historical weather reports recorded by the weather stations at Otopeni and Baneasa Airport, in January 2014, with special 24 - 27 January 2014.

Table 4. The start and the end of the reported wind shear Period (from-till)

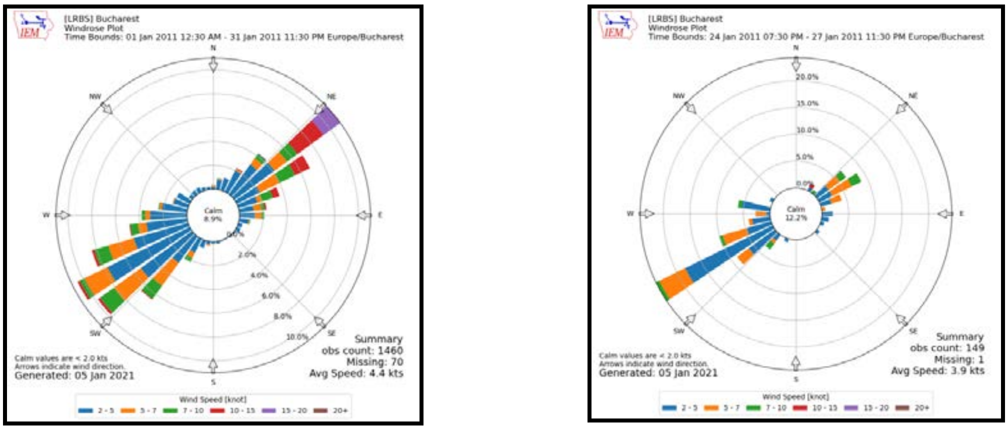
A/P	Date/Time – START FROM(FM)	Date/Time – FINISH TILL(TL)	PERIOD
LROP	241830Z	260600Z	36 hours
LRBS	251930Z	261900Z	24 hours

It can be seen from the graphs (FIG. 10 - 12) that when installed of wind shear at the airport is marked by the backing rotation of the wind direction, typical behavior of cyclonic air masses, sudden increases in wind speed, with values almost double compared with the previous period (FIG. 13).



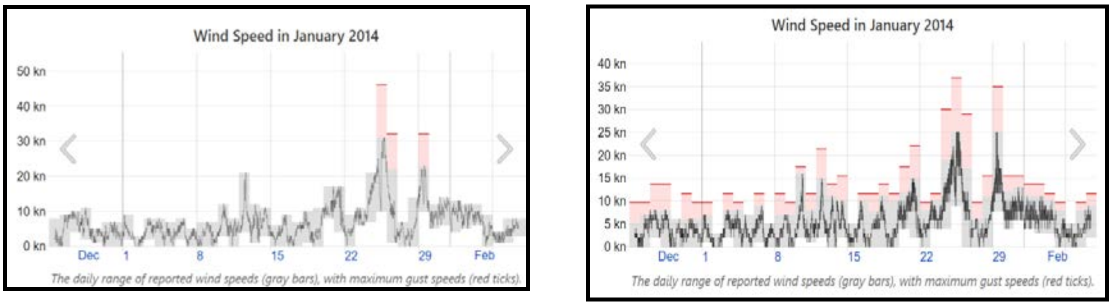
1 – 31 Jan 2014 24 – 27 Jan 2014

FIG. 11. Wind roses - Henri Coandă Otopeni Airport (LROP)



1 – 31 Jan 2014 24 – 27 Jan 2014

FIG. 12. Wind roses - Aurel Vlaicu Baneasa Airport (LRBS)



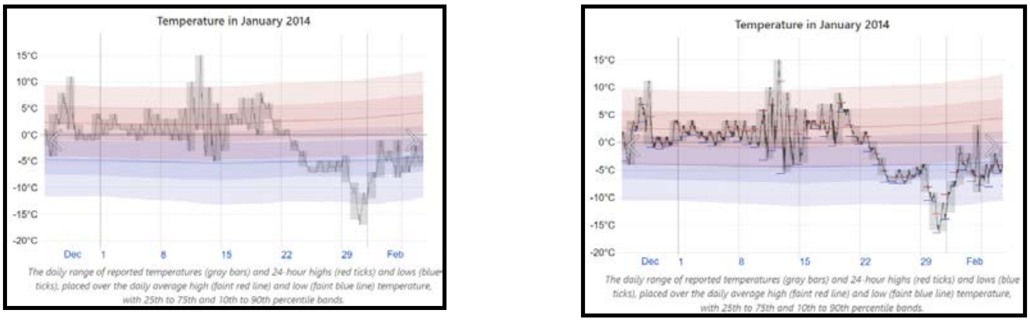
LROP LRBS

FIG. 13. The daily range of reported winds speeds (grey bars), with maximum gust speeds (red ticks)

Sudden decreases in air pressure are shown in FIG. 14. The air pressure decreases in the first 24 hours with 13 mb, from 1021mb (January, 24 -12:00PM) to 1008mb (January, 25 – 03:00PM). Normally pressure variation for mid-latitude is 3mb on 24 hours. The outside air temperature (FIG. 15 - 16) decrease before as wind shear to appear at the airport and after remain constantly (-6^{0}C - 7^{0}C) through period when wind shear is reported.

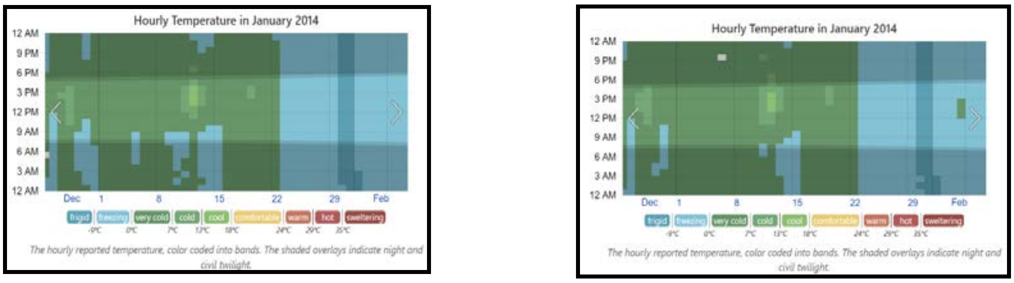
LROP LRBS

FIG. 14. The daily range of atmospheric pressure (grey bars), as measured by altimeter setting reported



LROP LRBS

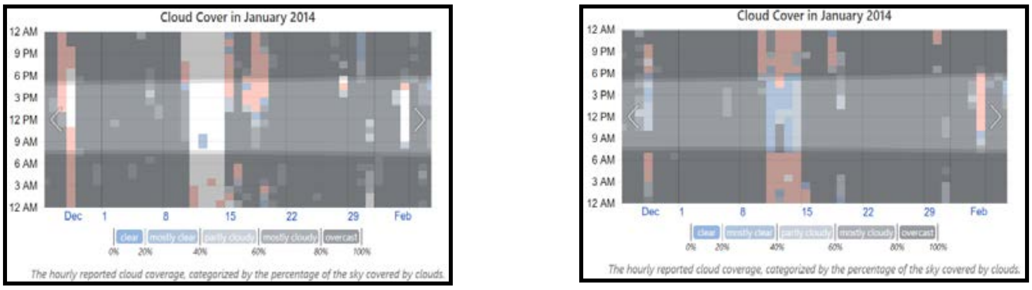
FIG. 15. Average Temperature (gray) and average 24-hours highs (red line) and lows (blue line)



LROP LRBS

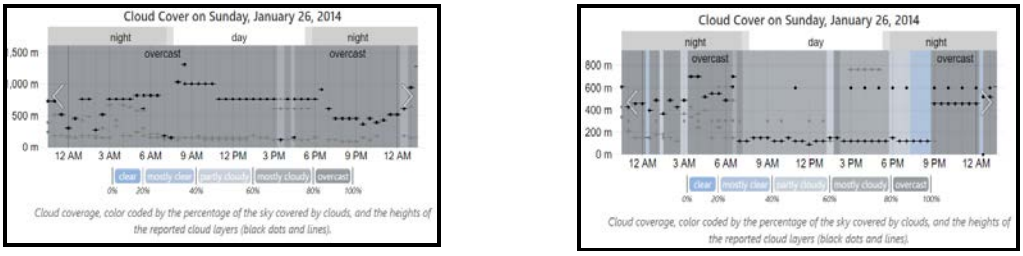
FIG. 16. The hourly reported temperature color into bands

During period when wind shear is reported to the airport, cloud coverage (FIG. 17, FIG. 18) increase from broken to overcast, and the height of cloud base decrease significantly from above 600 m during day to below 200 m during night.



LROP LRBS

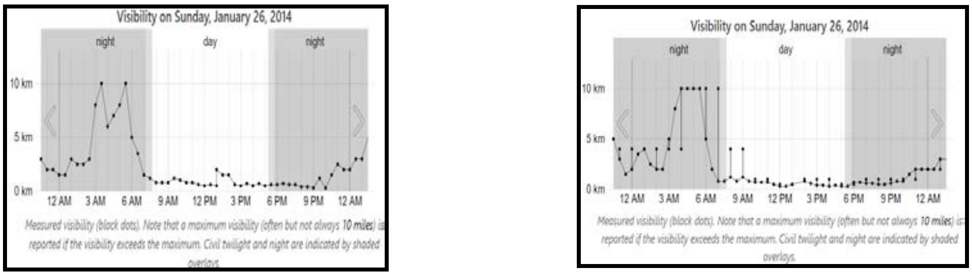
FIG. 17. The hourly reported cloud coverage, categorized by percentage of the sky covered by clouds



LROP LRBS

FIG. 18. Cloud coverage, color coded by the percentage of the sky covered by clouds

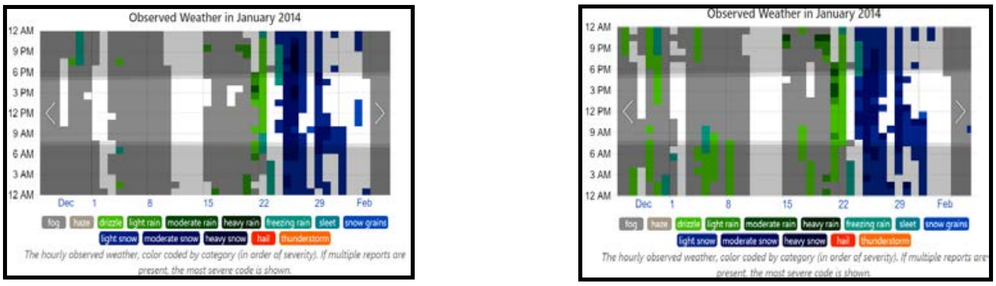
Before reporting wind shear, visibly decreases suddenly, next remains low or improves slightly while maintaining wind shear and, after the phenomenon ceases, visibility begins to increase slowly (FIG. 19). At Bucharest Henri Coanda (OTP) international airport, Low Visibility Procedures are applied when visibility is less than 600 m (2,000 feet) or the ceiling is below 60 m (200 feet) [6].



LROP LRBS

FIG. 19. Measured visibility

At both airports, before of the wind shear reported, the meteorological phenomena (FIG. 20) have low intensity (sleet, freezing rain, snow), during the intensity becomes moderate, intensity that is maintained in the next 24 hours. Fog appears a few hours before the shearing stops.



LROP LRBS

FIG. 20. The hourly observed weather, color coded by category(in order to severity)

All maps display included in FIG. 21 shown the forecast low level wind shear in the 0-.6 mi (above ground) layer during period January,24 08:00PM (06:00Z) - January,26 05:00PM (15:00Z). Wind shear is calculated by taking the wind vector at the surface and subtracting it from the wind vector 0.6 miles (1500 ft) above the surface [13]. The higher shear value (magnitude of 50-60 kt) appear above Bucharest at 11:00 AM (09:00Z) January,25.

Wind gusts appear on the ground reported in METAR messages when in this air layer the magnitude of the wind shear exceeds 30-35 kt and ceases when the magnitude drops below 15 kt. At Otopeni Airport maximum wind speed reported during gust of was 46 kt on January,25 at 1700Z (06030G46KT) and to Baneasa Airport was 35 kt (05021G35KT reported approximately 3 hours later (252030Z).

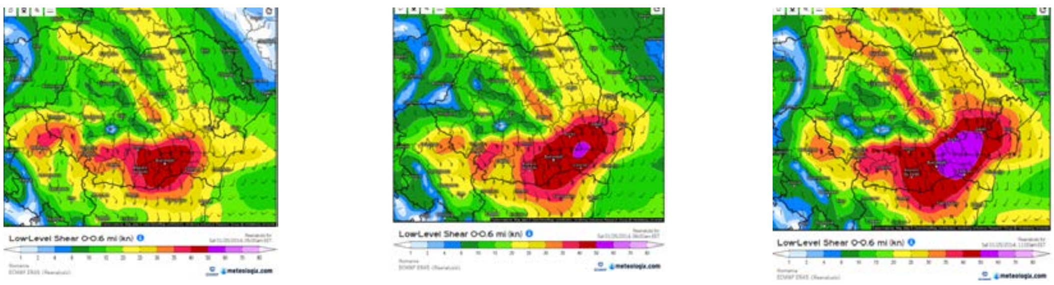


FIG. 21. Low level wind shear January,24 08:00PM (06:00Z) - January,26 05:00PM (15:00Z) 2014

CONCLUSIONS

Practically, in the context of global warming, during the winter, the local particularities of wind shear (the duration, intensity meteorological phenomena of significant weather associated) prove once again that nature works according to its own laws. During winter operations, the most dangerous conditions for flight safety are when the wind shear appears after sunset, ceases before sunrise, reason for which this case was selected. The wind shear which forms in these meteorological conditions (thermal inversion with low level jet above) has the average duration of maintain at the Otopeni Airport 36 hours, comparably with Baneasa Airport where is of 24 hours (Table 4). As reference M. Balmez, F. Georgescu[2, 3], the mechanism that leads to the low-level jet formation (type I) is the baroclinicity induced by the development of a Mediterranean cyclone.

Warm-frontal wind shear may persist 6 hours or more ahead of the front, in cold air mass, because of the fronts shallow slope and slow movement [16]. Strong winds aloft, associated with the warm front (advection of warm air mass at ground level), may cause a rapid change in wind direction and speed where the warm air overrides the cold, dense air near the surface. During the winter, on the background of an accentuated radiative cooling and of the anticyclonic conditions if in the radiosonde profile a thermal inversion appears (Annex A) with thickness of 100 and 500 meters above ground level, 24 hours later a current jet appears with speeds of 50-55 kt, identified at an altitude of about 1000 meters. When the speed of the jet stream from the altitude drops below 40 kt, about 6 hours later than the time when the thermal inversion reaches the maximum vertical extension, the shear phenomenon is reported at the airport.

The most important changes in wind speed at the airport are maintained as long as the thermal inversion is associated with low level jet when the average wind speed exceeds 30 kt, and in gusts it can reach 46 kt (25 January 1700 UTC 46KT). There are mainly fluctuations in wind speed and less in direction. Sometimes these large fluctuations in wind speed are suddenly reduced and calm settles at the airport. When low-level jet (LLJ) it stops at ground level wind speed decreases.

As a rule for both airports, whenever a radiation inversion occurs above the airport and is accompanied by a low level jet at the top, shear is reported on all runways, usually first at Otopeni and few hours laters to Baneasa. When an aircraft departing from the airport ascends and enters the low-level jet, it experiences increasing headwind and lift.

As it departs the jet, however, the headwind and lift decrease and require timely and appropriate corrective action by the pilot. It is vital that such conditions should be quickly recognised if they are encountered, and that pilot response should be immediate and correct. Through a detailed analysis of the meteorological conditions associated with wind shear produced by Mediterranean cyclones during winter operations, *this study is the lesson that wind shear itself offers us for learning through its own manifestation and evolution:*

- *The lesson learned from reported wind shear on all runways (WS ALL RWY) at both airports, when pilots receive information by meteorologists.*
- *The lesson learned from the atmosphere, from real weather situations when, in the context of global warming, the pilot can suspect and report wind shear on all runways and during take-off.*

A decision taken correctly another time, in the same meteorological conditions, in the current context of global warming, when the manifestation of the phenomenon can surprise by intensity and duration, the risk of an incident, respectively aviation accident can increase significantly.

In conclusion, precisely so that pilots are not surprised by the real manifestation of this phenomenon in global warming, this analysis has primarily a preventive role, thus avoiding the application of corrective actions even with a delay of few seconds. Let's not forget: these seconds can make the difference between life and death.

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