THUNDERSTORM OCCURENCE AND ASSOCIATED FLIGHT HAZARDS IN THE SOUTHERN PART OF ROMANIA

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Abstract: *This research work evaluates the thunderstorm occurrence and associated flight hazards in the southern part of Romania. This study focused on the monthly and annual occurrence, the trend of this flight hazard during the past six years. The statistical analyses employed were Simple and Multiple bar charts and correlations. It was observed from the analysis that thunderstorms occur mostly between March and October with an increasing trend of 71% for 2010 and 2014, and with a lower rate, between 10%-33% for 2011, 2012 and 2015, probably associated with the global warming. The monthly peak was registered in June, but August also became a month with a high probability of thunderstorm formation. A significant decrease with 28%-89% was also revealed for September.*

The study concluded that the thunderstorms occurrence in the studied area has significantly increased and it has more impact on delays than on diversions, but it is not the root cause of any incident/accident.

Keywords: *thunderstorm, occurrence, flight hazard*

1. INTRODUCTION

One of the most important flight hazard is the thunderstorm. When assessing accidents related with thunderstorms and other related impacts, it became obvious that the flight hazards associated where not always identified by the aviators. This weather phenomena significantly influence the safety and the operational activity of air traffic, particularly at the terminal areas. The serious consequences are excepting accidents, delays, diversions and sometimes cancellations of flights. The thunderstorms can be devastating as a typhoon, hurricane, tropical cyclone or a tornado. It is estimated that there are as many as 40,000 thunderstorm occurrences each day world-wide. A single cell of thunderstorm affects an area of 8 km. According to NTSB Aviation Accident and Incident Data Base [3, 8] most of the weather factors that caused or contributed to weather-related accidents are thunderstorms or weather phenomena associated with them.

Therefore, a good knowledge of this flight hazard becomes very important to aviators, in order to increase the flight safety and reduce the risks to a minimum.

As such, the purpose of this study is to determine the occurrence of thunderstorms in the southern part of Romania and the comparison with previous statistical data.

In order to achieve this aim, the following objectives were pursued to:

1. Determine the annual and monthly occurrence of thunderstorm over the southern part of Romania.
2. Analyze the variability/trend of thunderstorm occurrence in southern part of Romania.
3. Correlate with the global climate changes in the last years.
4. Determine the influence of thunderstorm on flight safety and operations.

2. ATMOSPHERIC PARAMETERS NECESSARY FOR THUNDERSTORM DEVELOPMENT

2.1 High relative humidity (sufficient water vapour to form and maintain the cloud). The amount of water vapour in the atmosphere plays an important part in the development of thunderstorm. In order to calculate the amount of water vapour in the atmosphere [1] the partial pressure of the water vapour , maximum water vpour pressure E and relative humidity RH are used.

$$RH = \frac{e}{E}100 \tag{1}$$

The saturation corresponds to a relative humidity of 100%. The empirical relation between E and temperature, t is as follows[3]:

$$E = 6.107\left(\frac{7.6326t}{10^{241.9+t}}\right) \tag{2}$$

For practical aviation purposes dew point temperature is used, τ, which is the temperature at which the relative humidity reaches 100%, by cooling at a constant pressure and maintaining the water vapour quantity constant. Its values may be determined using the formula [3]:

$$\tau = \frac{241.9 \ln \frac{e}{6.107}}{7.6326 - \ln \frac{e}{6.107}} \tag{3}$$

Using a simple approximation [3] we may conclude that the temperature dew point is

$$\tau \approx t - \frac{100 - RH}{5} \tag{4}$$

or

$$RH \approx 100 - 5(t - \tau) \tag{5}$$

2.2 Atmospheric instability.

The Environmental Lapse Rate, γ value gives a clear indication [3] regarding the stability state of the atmosphere and can be written as function of temperature, t and altitude, z:

$$\gamma = -\frac{\partial t}{\partial z} \tag{6}$$

The conditional instability occurs if:

$$\gamma_S \prec \gamma \prec \gamma_D \tag{7}$$

The absolute instability occurs if:

$$\gamma \succ \gamma_D \tag{8}$$

where $\gamma_S = 1.8°C/1000ft$ is Saturated Adiabatic Lapse Rate and $\gamma_D = 3°C/1000ft$ is Dry Adiabatic Lapse Rate.

2.3 Indices used for TS determination

K_{index} is derived arithmetically as:

$$K_{index} = (t_{850mb} - t_{500mb}) + \tau_{850mb} - (t_{700mb} - \tau_{700mb}) \tag{9}$$

The difference between t_{850mb} and t_{500mb} is used to parameterize the vertical temperature lapse rate, γ. The temperature dew point at 850 mb, τ_{850mb} provides information on the moisture content in the lower level of the atmosphere. The vertical extent of the moist layer is represented by the difference between t_{700mb} and τ_{700mb} [1, 2].

TS probability (P_{TS})may be calculated using the formula:

$$P_{TS} = 4(K_{index} - 15) \tag{10}$$

Table1. Correlation between K_{index} and P_{TS}

K_{index} value	TS probability(P_{TS})
Less than 20	None
20 to 25	Isolated thunderstorms
26 to 30	Widely scattered thunderstorms
31 to 35	Scattered thunderstorms
Above 35	Numerous thunderstorms

2.3 Triggering action. The triggers or lifting forces are [4] convection, orographic uplift, convergence and frontal uplift. The source of lift (upward) is caused by the difference in air density and it is accomplished by several methods: differential heating, fronts, terrain.

3. THUNDERSTORM (TS) DEVELOPMENT

3.1 Types of thunderstorms. Thunderstorms are classified [4] as heat, or air mass thunderstorm (more common in summer) and frontal thunderstorm (more common in winter). Heat thunderstorms are isolated, most frequent over land in summer, formed by day, clear by night and associated with cols and weak lows. Frontal type thunderstorms are most frequent in winter, formed over land or sea, by day or by night, usually formed in a line at a cold front or occlusion, found in depressions or troughs, often accompanied by a squall line.

3.2 Life cycle of a thunderstorm. The life cycle of a thunderstorm cell lasts about 15-20 minutes for the initial and mature stages, and about 1.5 to 2.5 hours for the dissipating stage. During the initial stage, the currents are up draughts.

The second stage of development is the mature stage or Towering Cumulus stage and the currents are strong vertical up draughts and down draughts. In this stage, microbursts may appear, in a region with a diameter of 1 km to 4 km and a duration of 1 minutes to 5 minutes. The precipitations start to fall in this mature stage. Rising and falling water droplets will produce a considerable build-up of static electricity, usually of positive charge at the top of the cloud and negative at the bottom. The build-ups eventually lead to lighting discharge and thunder.

The third stage is the dissipating stage[3, 4], which is characterized by down draughts. The Cumulonimbus cloud usually reaches the tropopause and in the upper part of the cloud there will appear the anvil. Large variations in static charge in and around the cloud cause discharge in the form of lighting, which can appear in the cloud, from the cloud to the ground, or from the cloud to the air alongside.

3.3 Supercell thunderstorms (Severe local storms). Supercell thunderstorms are more common over continental land masses than over the maritime areas. Thunderstorms over mid-vest states of USA, north of Africa and west of Europe producing tornadoes are good examples.

3.4 Movement of a thunderstorm. The movement of a thunderstorm may be calculated using the following formula, during the winter:

$$v_{TS} = 0.80 v_{700mb} \tag{11}$$

and using the following formula for summer:

$$v_{TS} = 0.50 v_{500mb} \tag{12}$$

where v_{TS} = thunderstorm movement velocity, v_{700mb} = wind velocity at 700 mb and v_{500mb} = wind velocity at 500 mb.

Forecasting the occurrence of thunderstorm will be largely a matter of assembling the conditions necessary for the formation and the triggers. A combination of this two groups will indicate the probability of thunderstorms. Satellite images and computer modeling are used to predict this occurrence.

4. THUNDERSTORM HAZARDS

4.1 Turbulence. Turbulence can be severe both within cloud and their sides. Turbulence may be dangerous below the cloud, during take-off and landing and wind shear may also appear.

4.2 Hail. Hail may be expected at any height in the cloud, also below the cloud and below the anvil. Damaging hail can occur up to a height of 45,000 ft.

4.3 Icing. This weather phenomena may occur at all heights in the cloud, where the temperature is between 0°C and -40°C. Due the fact that Cumulonimbus cloud is a cumuliform cloud [4], inside the cloud there is a high concentration of large supercooled water droplets, which may result in severe clear icing.

4.4 Lightning. Lightning is most likely to occur within 5,000 ft of the freezing level. There are 3 effects that may be expected:

- It may cause a pilot temporarily blinded.
- Compasses may become totally unreliable.
- Some airframe damage may be caused, particularly with composite aircraft.

4.5 Static. This causes interference on radio equipment in the LF, MF, HF and VHF frequencies. St Elmo’s fire may be caused by static and it results in purple rings of light, especially around the wing tips. This indicates[2, 4] that the air is electrically charged and lightning is probable, but it does not represent a hazard for flight.

4.6 Pressure variation. Local pressure variation may determine inaccurate altimeter readings as much as ±1000 ft at all heights.

4.7 Microburst. These are strong vertical down draughts [4, 9] in the cloud, which also move outwards by reaction from the ground. They are largely caused by descending raindrops, which cools the surrounding air by evaporation, the higher density accelerating the down draught still further. They have a horizontal development between 1km and 4 km and have a lifetime of about 4 minutes. They may cause severe turbulence and severe wind shear conditions. A warning sign of this weather phenomena is virga.

4.8 Water ingestion. If up draught speed approaches or exceeds the terminal velocity of raindrops which are falling, the resulting high concentrations of water can exceed the design limits for water ingestion in some turbine engine. That may cause engine flame-out and/or structural failure. Water ingestion may also affect Pitot heads.

4.9 Tornados. These are usually associated with severe thunderstorm and Tropical Revolving Storm [4], which often occur in the mid-west of USA, west of Europe and north of Africa.

5. DATA PRESENTATION AND ANALYSIS

5.1 Data presentation. The studied area is located between 44°N and 45°N, 24°E and 27°E and the analyzed data set includes parameters used to forecast the significant weather phenomena for aviation purposes. The analyzed period consists of six years (from 2010 to 2015).

The table 2. shows the total yearly frequency of TS occurrences during the last six years over the southern part of Romania and fig. 1 depicts the graphic representation of statistical data.

Table 2. Number of days with TS

Year	Total days number with TS
2010	51
2011	26
2012	32
2013	43
2014	53
2015	26

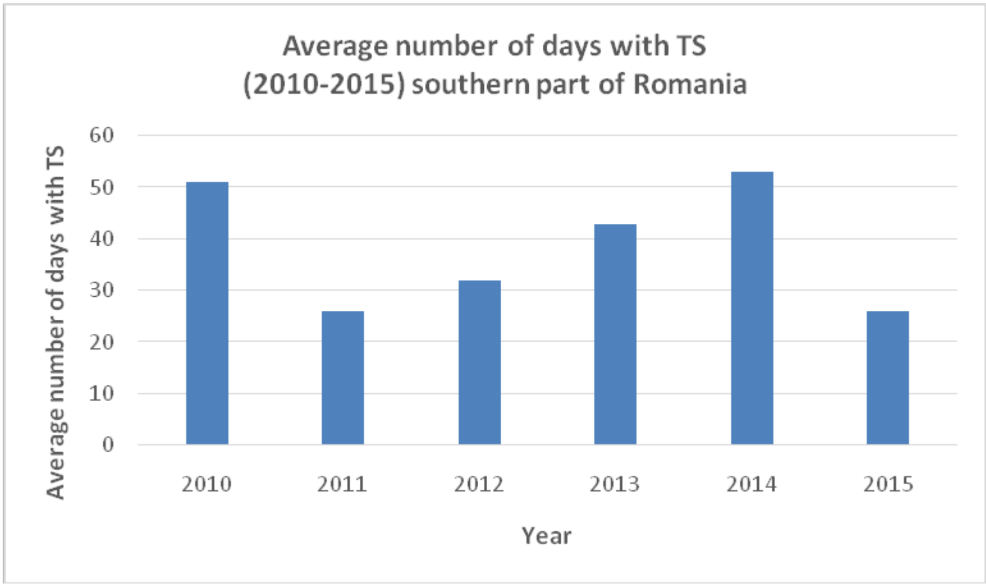

FIG. 1. Average number of days with TS in the southern part of Romania

In this area are three international airports that reported thunderstorms as follows:

- the table 3. shows the total yearly frequency of TS occurrences during the last six years at LROP and LRBS.

Table 3. Monthly frequency of TS occurrences for LROP and LRBS

Month	2010	2011	2012	2013	2014	2015
March	0	0	1	0	0	1
April	2	0	4	0	2	1
May	10	14	8	8	9	6
June	10	9	8	13	12	6
July	16	5	5	9	15	5
August	8	3	4	6	6	7
September	3	1	0	1	2	3
October	0	0	0	2	0	0
November	2	0	0	0	0	0
December	0	0	0	0	1	0

- the table 4. shows the total yearly frequency of TS occurrences during the last six years at LRCV.

Table 4. Monthly frequency of TS occurrences for LRCV

Month	2010	2011	2012	2013	2014	2015
March	0	0	1	0	0	1
April	2	0	4	0	2	1
May	10	14	8	8	9	6
June	10	9	8	13	12	6
July	16	5	5	9	15	5
August	8	3	4	6	6	7
September	3	1	0	1	2	3
October	0	0	0	2	0	0
November	2	0	0	0	0	0
December	0	0	0	0	1	0

The graphic representations of statistical data for LROP, LRBS and LRCV are depicted in Fig. 2 and Fig. 3.

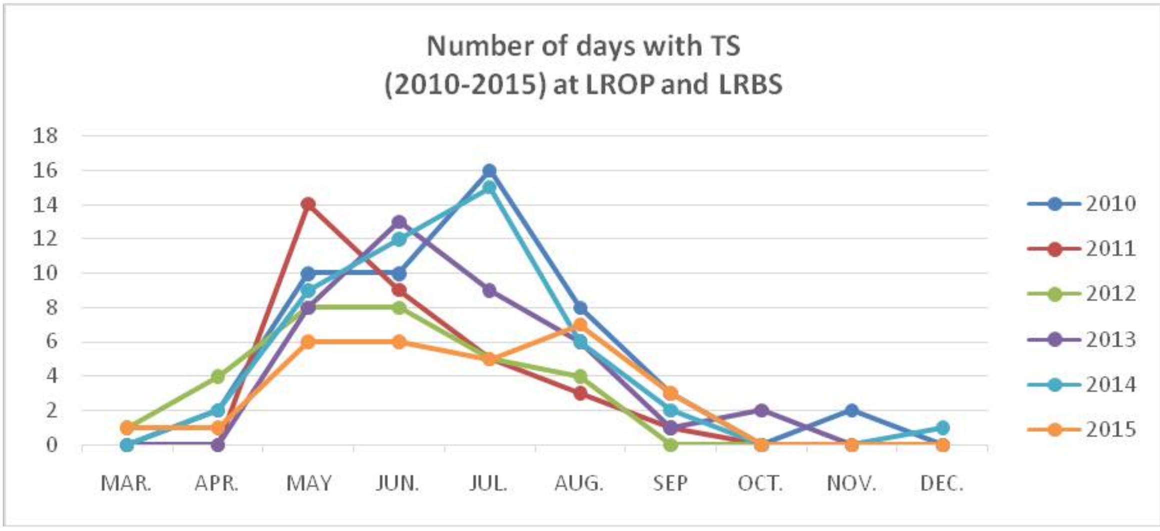

FIG. 2. Number of days with TS at LROP and LRBS

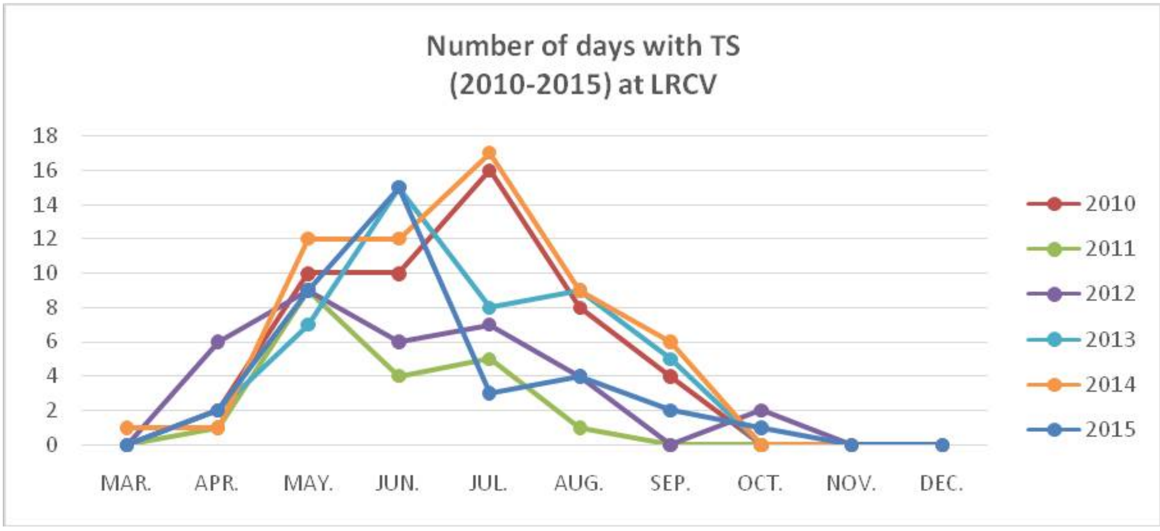

FIG. 3. Number of days with TS at LRCV

The graphic representations of percentages for LROP, LRBS and LRCV are depicted in Fig. 4 and Fig. 5.

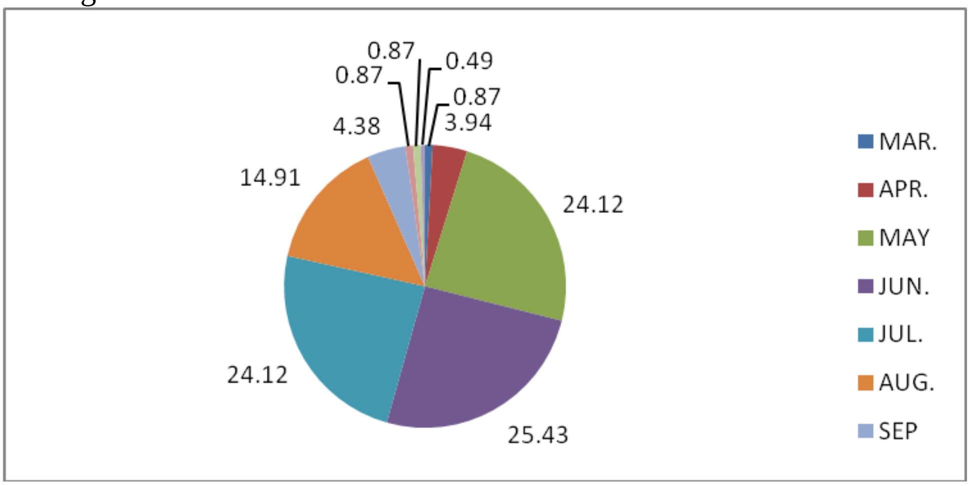

FIG. 4. Percentages of days with TS by months at LROP

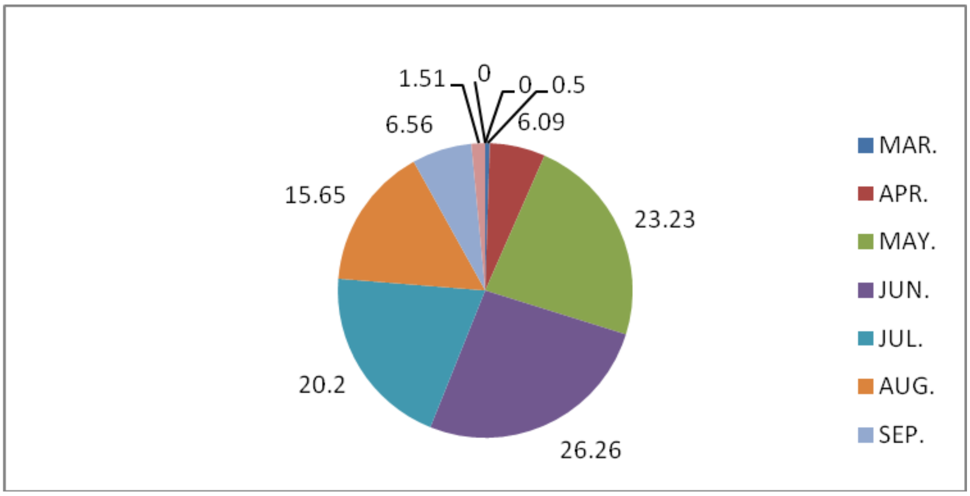

FIG. 5. Percentages of days with TS by months at LRCV

5.2 Data analyses. Statistical data indicate that thunderstorms form in the southern part of Romania mostly between March and October, and only in exceptional cases during December. Thunderstorms have not occurred during January and February within the studied period. The number of days with thunderstorms revealed by the study has increased by 71% for 2010 and 2014. A lower rate of increasing was recorded for 2011, 2012 and 2014.

The monthly peak was recorded in June, but August became a month with a high probability of thunderstorm formation, instead of September as previous studies depicted. The percentages decreasing for September vary between 29% and 89%. July also has become a month with a high number of thunderstorms. The presence of thunderstorms in the southern part of Romania has caused delays and even cancelations of flights, but never incidents/accidents. When thunderstorms have been reported within the southern part Bucharest FIR, the most common method to avoid the associated flight hazards was to divert.

CONCLUSIONS

The study indicates that in the last six years the number of days with thunderstorms has increased by almost 71%, during 2010 and 2014 and with smaller percentages between 10%-33% in 2011, 2012, 2013 and 2015, compared to previous studies. The study revealed that the peak of days number associated with thunderstorm was in 2010 and 2014. The monthly peak was registered in June, but also the fact that August became a month with a high probability of thunderstorm formation. A significant decrease with 28%-89% was also revealed for September.

This trend for TS occurrence is a general one for the central and eastern part of Europe. The growth may be connected with the global changes of climate. The observed trend of temperature and of the greenhouse gases concentrations may be the cause of this perturbation.

The presence of TS influences the flight safety, especially on the final approach causing delays, in some situations the alternate airport being used. During the other phases of flight the aviators use diversion, in order to avoid TS areas and the associated flight hazards. The operational activity was seriously affected during the days with TS, but no incident/accident related with this weather phenomena was registered in the southern part of Romania.

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