Acta Avionica
Volume XX, 39 – No. 2, 2018

THE IMPACT OF TEMPERATURE CHANGES ON THE AIR TRAFFIC FLOW MANAGEMENT EFFECTIVENESS

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Summary. This article deals with the impact of the global climate changes, especially the impact of the temperature change on the operational and performance parameters of aircraft and consequently on the whole European aviation. The aim of this article is to do a research, study and analyse the influence of temperature changes on the aircraft performance and make an evaluation and conclusion for how they can affect the safety of the air traffic flow management. The theoretical part of the paper is focused on describing and analyzing weather, climate and meteorological elements and phenomena related to climate changes. The practical part of the thesis includes a system analysis of climate and temperature changes over selected International Slovak Airports – Kosice International Airport (LZKZ) and Milan Rastislav Stefanik Airport in Bratislava (LZIB), and also contains navigation calculations.

Keywords: Air temperature, air traffic flow management, ATCO, meteorology, meteorological elements and phenomena, aircraft performance and operation, a thunderstorm

1. INTRODUCTION

The article analyses and also characterizes the meteorological elements and phenomena, their risks and predictability. The main task of this thesis is to analyze, summarize and make an evaluation, conclusion and confirmation of the issue. The article has a theoretical and practical part. The theoretical part describes the meteorological elements related to climate changes such as a temperature and thunderstorm. The practical part of the article (Chapter 3) analyses the monthly temperature changes in years 2016 and 2017 at the Slovak International Airports, Kosice and Bratislava, and consequently describes how it could impact the aviation safety, security and the effectiveness of air traffic control.

2. METEOROLOGICAL ELEMENTS AND PHENOMENA RELATED TO CLIMATE CHANGES

Nowadays, the global climate changes is a very actual, important and disputabile topic in the whole world.
The climate on the Earth is gradually changing due to short-term (during months and years) and long-term (more than thousand years) changes. The causes of these changes lie in anthropogenic and natural factors. The natural factors are situated out of the climate system, like Earth´s orbit, the change of atmospheric aerosols depending on vulcanic eruptions with solar radiation interaction, the variation of the solar cycle including sunlight and sun eruptions. Milutin Milanković, a Serbian geophysicist and astronomer in 1920s introduced and described a collective effects of changes in the Earth´s movement on its climate over thousands of years – Milankovitch cycles. He hypothesized the variations in eccentricity, axial tilt and precession of the Earth´s orbit resulted in cyclical variation

in the seasonality of solar radiation reaching the Earth´s surface. These cycles directly influence the Earth´s climate system and thus the aircraft and air traffic flow management, too.
The first Milankovitch Cycle is the eccentricity – the measure of the Earth orbit shape´s deviation - where the path of the Earth´s orbit around the sun changes from a nearly circle to elliptical and back. One complete cycle of eccentricity lasts about 100 000 years. In a more ecliptical orbit there are two positions:

- aphelion – farther point from Sun and
- perihelion – closest point to Sun.

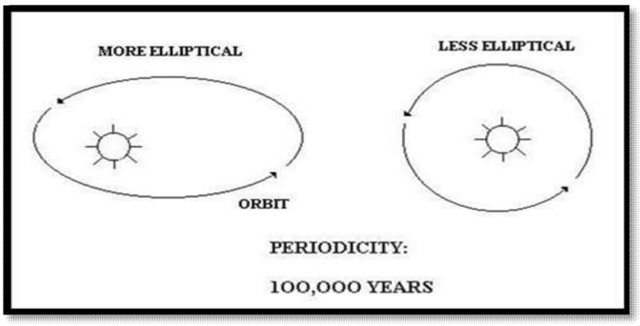

Figure 1 Eccentricity [7]

The second Milankovitch Cycle is the axial tilt or obliquity. The Earth is spinning around its own axis and it tilts at angles between 22.1 and 24.5 degrees and back. A complete axial tilt lasts about 41 000 years.

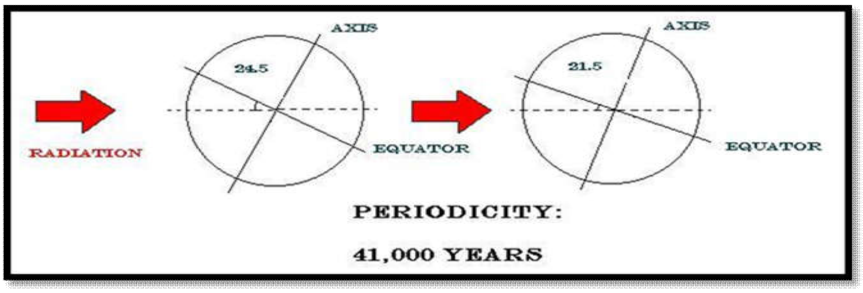

Figure 2 Axial tilt [7]

The last Milankovitch Cycle is the precession. It is a slow wobble as the Earth spins on axis. A complete precession periodicity is approximately 26 000 years.

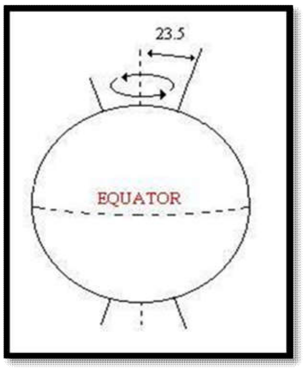

Figure 3 Precession [7]

These three Milankovitch Cycles can cause: that if summer is warmer on the northern hemisphere, that more ice is melted than it could be created in the previous year and the ice layer gradually thins.
The Earth gradually warms up and it leads to the fact that the climate changes and has a negative impact on aviation.
The natural factors, which can cause climate changes and global warming, are the radiation flows in the atmosphere. The Sun energy spreads into the space in the form of electromagnetic and corpuscular radiation. The sun behaves like a black emitter, where its radiation is a function of its surface absolute temperature. The following form of the black emitter´s luminous intensity law is:

$$E=\sigma T^4$$

where T is a temperature in Kelvin and σ is a Stefan-Boltzman constant.
The whole total power of the Sun is approximately 400 quadrillion W. It means that the sun power is arising in the central part of the Sun with a thermonuclear reaction. This is a merger of hydrogen nuclei onto the nuclei of helium and so energy arises. The consumption size of hydrogen is approximately a half billion tons per second.
The temperature in the atmosphere is not constant due to the unequal heating of the Earth surface. With periodical and nonperiodical changes the temperature differences are being compensated. The periodical changes are related to daily and yearly temperature running, and nonperiodical changes are related to horizontal movement of air mass.
For the aviation meteorological and navigation calculations a very important parameter is the vertical temperature gradient, which decreases at the rate of approximately 0,65 °C per 100 meters and 2 °C per thousand feet up to 36 000 feet.
The temperature is closely related to the air density and atmospheric pressure.
The density of air has a significant effect on the A/C´s performance. As air becomes less dense, it reduces the engine power, because the engine takes in less air; thrust, because the propeller is less efficient in thin air; and lift, because the thin air exerts less force on the airfoils.
Air density is increasing with decreasing temperature and decreasing at low air pressure and high temperature. Conversely, increasing the temperature the density decreases.
The density varies directly with pressure, and inversely with temperature.
The density altitude is the term for correlating aerodynamic performance in the nonstandard atmosphere. It is the altitude in the standard atmosphere corresponding to a particular value of air density – is a pressure altitude corrected for the nonstandard temperature.
As the density of the air increases, aircraft performance increases.
The density altitude is higher than pressure altitude if air mass is warmer than ISA. There is a rule that density altitude varies from pressure altitude about 118,8 ft for every 1 °C deviation from ISA temperature. This rule is illustrated on the picture (Figure 4).

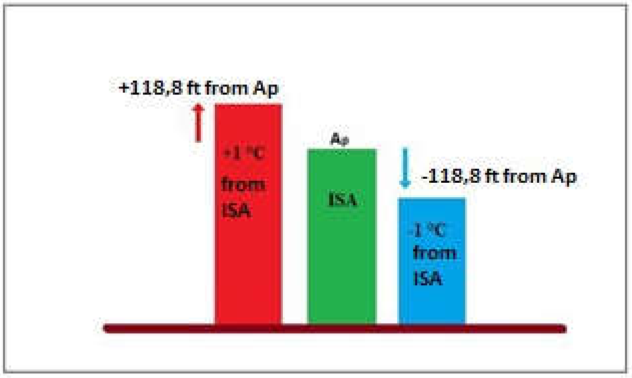

Figure 4 The density altitude based on ISA temperature deviation [4]

The mathematical formula is the following:

$$A_D = A_P \pm (118{,}8\ ft \times D_{ISA})$$

A_D = density altitude
A_P = pressure altitude
D_{ISA} = the deviation from ISA temperature in °C.
The practical example will be stated in Chapter 4.

The atmospheric pressure in aviation meteorology is the most important part of the weather elements which can affect the aviation safety. The pressure of the atmosphere varies with time and altitude. The standard pressure at a mean sea level is 1013,25 hPa. The pressure decreases by 1 hPa for every 27 ft. As an air density, the pressure relates to the temperature. It means, that in the colder air mass, which has bigger density by the same pressure than the warm air mass, the pressure decreases faster than in the warmer air mass. From this is clear, that air mass warmer than ISA is less dense and the air pressure deviation will be lower. In the practical usage it means: when the A/C will fly to the lower temperature heading its real height will decrease, if the aircraft flies a constant indicated height. (Figure 5)

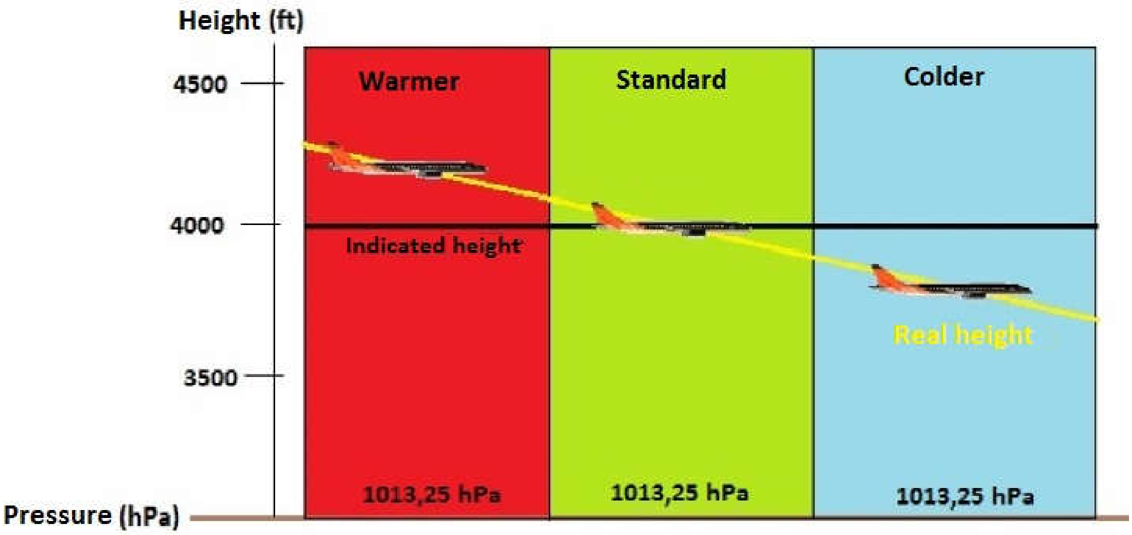

Figure 5 Real and indicated height [4]

The atmospheric pressure is one of the basic factors in weather changes, helps to lift the A/C, and actuates some of the most important flight instruments in the A/C (altimeter, ASI, the vertical speed indicator and the manifold pressure gauge).

The pressure altitude is the height above the SDP (a standard datum plane). If the altimeter is set for 1013,25 hPa SDP, the altitude indicated is the pressure altitude. So it means that the pressure altitude is the altitude in the standard atmosphere corresponding to the sensed pressure.

Above mentioned theoretical facts are very important, because they have a big impact on the aviation safety and on the air flow management affectivity.

The next chapters discuss the temperature changing during the last years and the impact on aviation.

3. TEMPERATURE CHANGES AT THE SLOVAK INTERNATIONAL AIRPORTS

The global climate is changed and with this the air temperature, too. In the practical aviation very important weather components, which have a considerable impact on the aircraft performance, are: air temperature, air pressure and a prevailing wind direction. In this article we will examine only a temperature and pressure effect without the wind components.

Firstly, we need to analyze a monthly temperature values and compare to the long-term average.
We have chosen 3 international airports – LZKZ, LZIB and LKPR to analyze.
The first airport is Kosice International Airport – LZKZ.

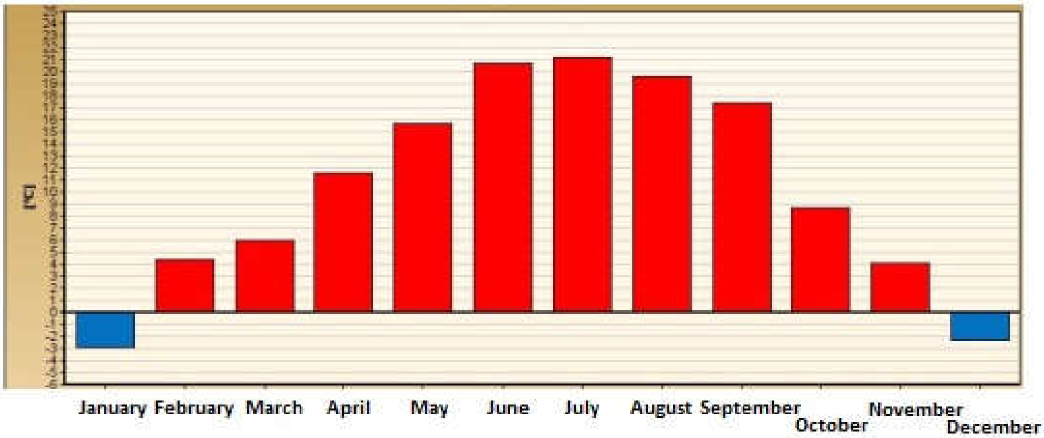

Figure 6 Average monthly air temperature at LZKZ in 2016 [5]

Figure 6 shows the average monthly temperature at LZKZ airport in the year 2016. It is noticeable, that temperature degrees with minus values are only in January and December. This fact shows the fact, that the climate changes. In January the average temperature rate is -3 °C degrees, but in February is above +4 °C degrees. In March the average temperature was + 6 °C degrees, in April + 11, 8 °C. June and July were the hottest months in 2016 at LZKZ airport with the average temperature + 20,8 °C and + 21,1 °C. The coldest months were January and December.

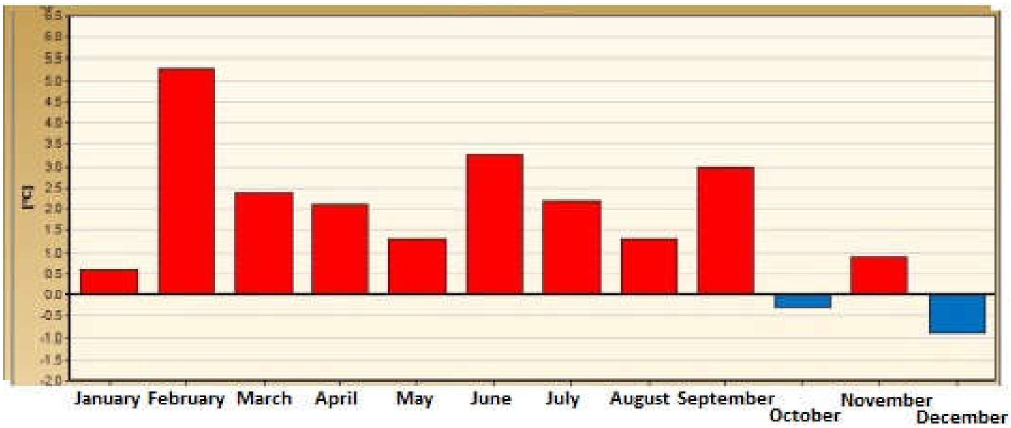

Figure 7 Deviation of the average monthly temperature from normal (1961-1990) in 2016 at LZKZ airport [5]

The greatest deviation of the average temperature from normal in 2016 was in February with a +5,3 °C value. Then followed by months – June (+3,5 °C), September (+3 °C), March (+2,4 °C), July (+2,2 °C), April (+2,1 °C), May and August (+1,3 °C), November (+0,9 °C) and January (+0,6 °C). Only in December and October were colder the average temperature in 2016 from normal. Compared to the previous chart where the average monthly temperature in January was -3 °C, the deviation of the average monthly temperature from normal was warmer by +0,6 °C.

Figure 9 Average monthly air temperature at LZIB in 2016 [5]

Figure 8 shows the average monthly temperature at LZIB airport in the year 2016. At LZIB minus temperature value was only in January, while at LZKZ were months October and December. The warmest months were at LZIB in 2016 - July (with average monthly temperature + 22,5 °C), Jun (+ 21 °C), August (+ 20,1 °C), September (+ 18, 9 °C) and May (+ 16,1 °C). Then followed by months: April (+ 11,3 °C), October (+ 10 °C), March (+ 6, 9 °C), February (+ 6,1 °C) and November (+ 4,9 °C). The two coldest months were December with the average monthly temperature + 0, 9 °C and January with the minus value of average monthly air temperature (- 0,5 °C).

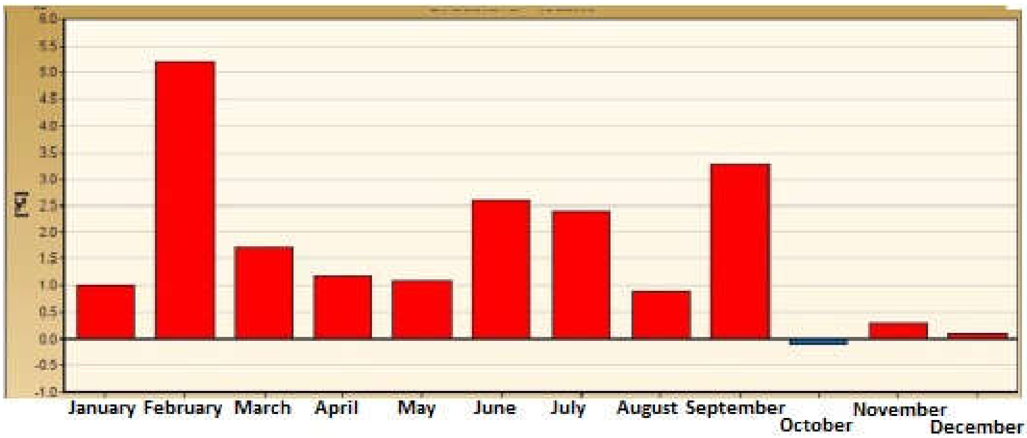

Figure 10 Deviation of the average monthly temperature from normal (1961-1990) in 2016 at LZIB airport [5]

The greatest deviation of the average temperature from normal in 2016 was in February (similarly as at LZKZ airport) with a + 5,3 °C value. Then followed by months: September (+ 3, 3 °C), Jun (+ 2,6 °C), July (+ 2,4 °C), March (+ 1,7 °C), April (+ 1,3 °C), May (+ 1,1 °C), January (+ 1 °C), August (+ 0,9 °C), November (+ 0,3 °C), December (+ 0,1 °C) and October (- 0,1 °C). The minimum value of air temperature deviation from normal (1961 – 1990) in 2016 at LZIB was in December and October.

Figure 10 discuss about the average monthly temperature at LZKZ in 2017. In 2017 minus temperature was only in January (-6,2 °C). The warmest month was August (+ 22 °C), Jun (+ 20,9 °C) and Jul (+ 20,1 °C). The coldest month was January and February and December with the same monthly average temperature (+ 0,9 °C).

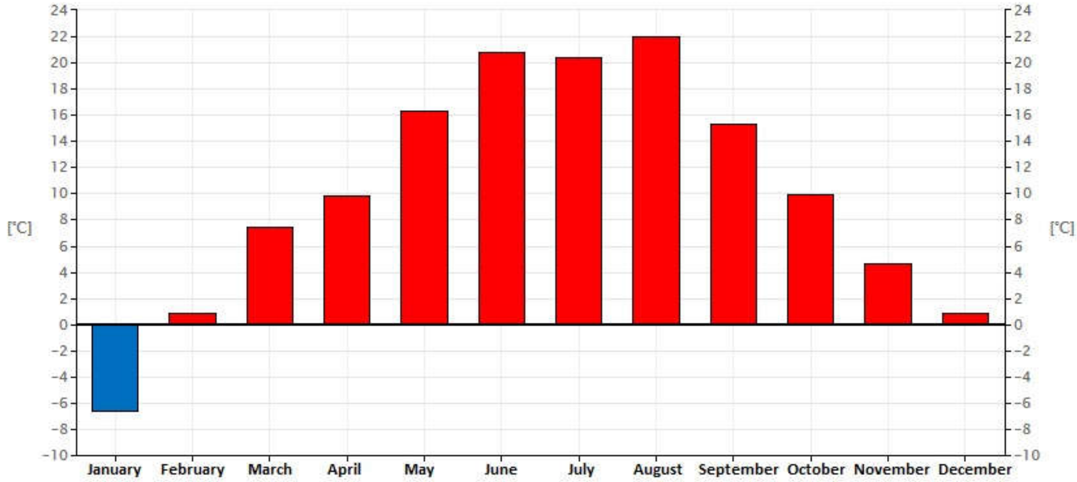

Figure 11 Average monthly air temperature in 2017, Kosice Airport [6]

The greatest deviation from the average monthly temperature from normal in 2017 was in January with a minus value (- 3,1 °C) and with the plus values March (+ 3,8 °C), August (+ 3,7 °C) and Jun (+ 3,4 °C). Then follows months December (+ 2, 3 °C), February (+ 1,8 °C), May (+ 1,9 °C), November (+ 1,5 °C), July (+ 1,4 °C). Months September and October had the same temperature values (+ 0,4 °C) and April has the smallest difference from the normal (+ 0,3 °C).

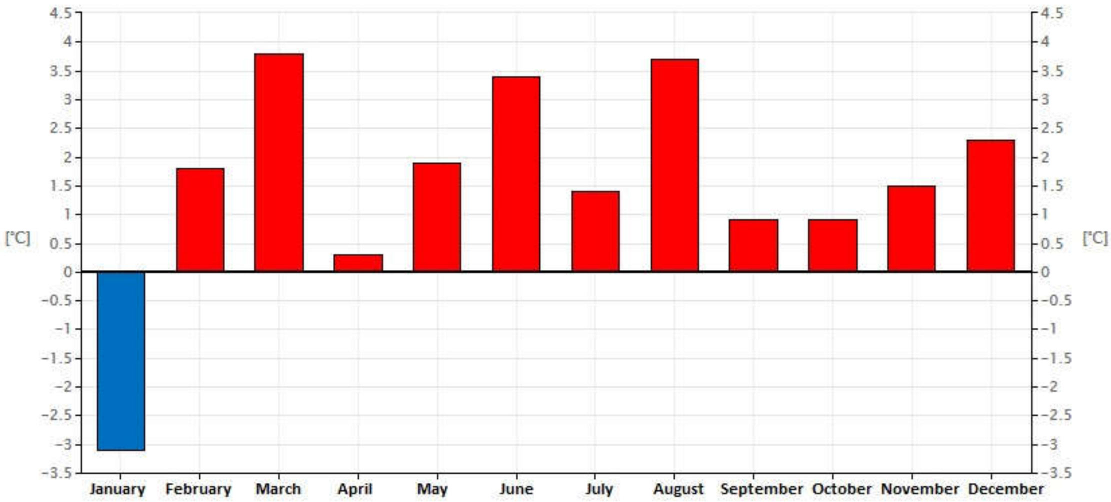

Figure 12 Deviation of average monthly air temperature in 2017 from the normal 1961 – 1990, Kosice Airport [6]

The average monthly air temperature at LZIB in 2017 was the following: the warmest month was August (+ 23,2 °C), Jul (+ 22,8 °C) and Jun (+ 22, 5 °C). The coldest month was January with a minus value (-4,1 °C). Only in January the temperature was minus. In comparison Bratislava

Airport to Kosice, the minus temperature in both cases was only in January and the warmest month was in August. In average, Bratislava Airport is warmer than Kosice Airport.

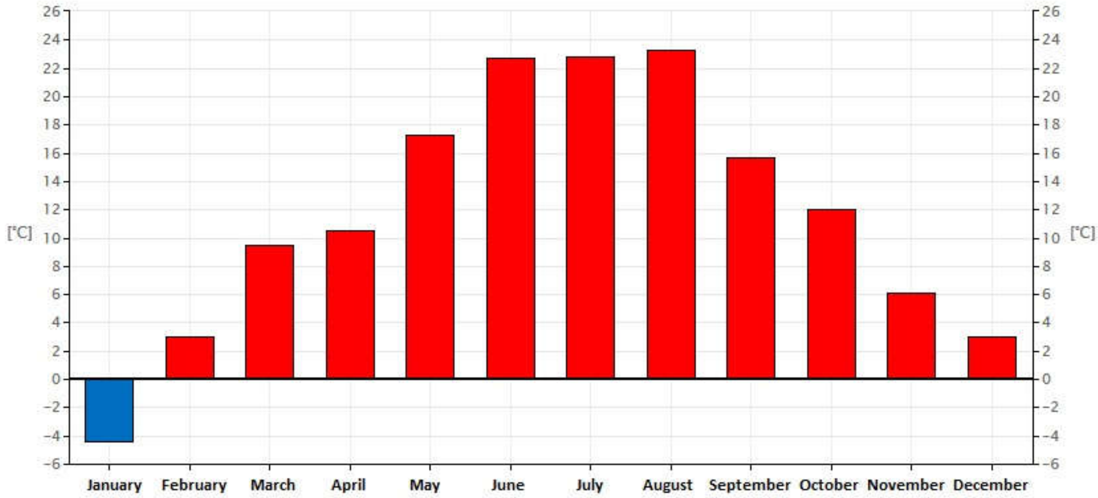

Figure 13 Average monthly air temperature in 2017, Bratislava Airport [6]

The greatest average temperature deviation from the normal in 2017 at Bratislava airport was in January with minus temperature (-3 °C), Marc with + 4,5 °C deviation from normal, Jun (+4,4 °C), and August (+ 4 °C). Figure 13 shows on the fact, that Bratislava airport had a big average temperature deviation from normal in 2017. From this Figure is clear that Bratislava airport had a greater temperature deviation than Kosice airport.

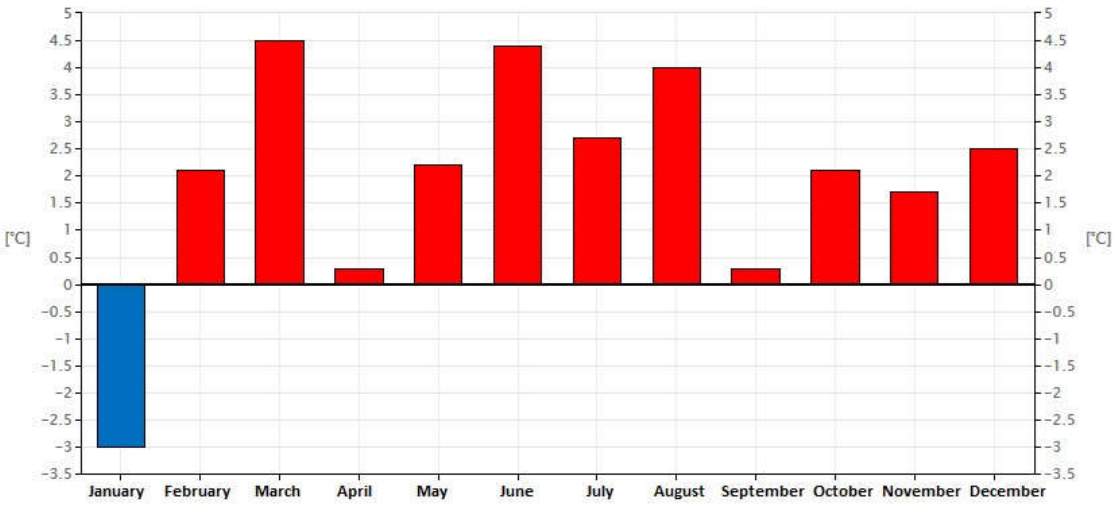

Figure 14 Deviation of average monthly air temperature in 2017 from the normal 1961 – 1990, Bratislava Airport [6]

From the above mentioned facts is clear that air temperature changes and gradually warms up. This change has a great impact on airports and operations of airports and A/C. A light increase of the mean temperature has no remarkable impact on airport usability and A/C performance, but the above mentioned facts have a great impact on deterioration of A/C engine performance and lift capabilities which can causes delays and cancellations, operational difficulties and with this, many other managements complications and safety problems (minimum safety clearance).

4. THE IMPACT OF THE TEMPERATURE CHANGE ON THE AIR TRAFFIC FLOW MANAGEMENT

The temperature changes can cause many adverse meteorological phenomena like a thunderstorm, which has a big impact on the aviation in the context of air traffic flow management, safety and economics. The temperature has a big impact on the operational parameters and on the performance of aircraft. When the A/C is taking-off or landing the warmer air slows the aircraft. It means that the A/C needs more time for taking off or landing and the ATCO has to count with more separating time between the aircraft. This situation causes more delays and contributes to an ineffective air traffic flow management. In the radar control the ATCO needs to keep a 5 NM horizontal and 1 000 ft vertical standard separation distance between the A/C.

The most dangerous meteorological phenomena is the thunderstorm. The cause of this phenomenon is a towering cloud – Cumulonimbus, which arises by convection. The convection is a messy, upward movement of air mass. Above the warmer surface the air is warmer and the lighter air mass starts a messy upward movement and mixes with another air mass. It can occur near the aerodrome or on the en-route track. The impulse of the air mass upward movement can cause factors like:

- different surface temperature limits (individual surfaces are heated unequally)
- local heat sources (fire, industrial equipment, cooling towers)
- impulses of motion (it can cause big vehicles like starting aircraft, which can release warm air from the runway)
- wind

The cumulus cloud developing process is the following:

1. Accumulating warm air mass at the surface, this consequently tears away from the surface and then starts an upward movement.
2. When the top of climbing stream reaches the condensation level a nebula will occur. This nebula evolves quickly, during 10 second till 1 minute.
3. The clouds grow, join each other and create a more distinctive and sharper edge. Where the climb is the strongest the tower is formulated.
4. The bottom of the cloud is the darkest, because it contains the most water droplets.
5. The cloud is growing until the supply of warm air mass is sufficient.

Pilots and controllers are able to recognize storms according to their shape and to forecast the next movement of the cloud and type of the precipitations (Figure 14).

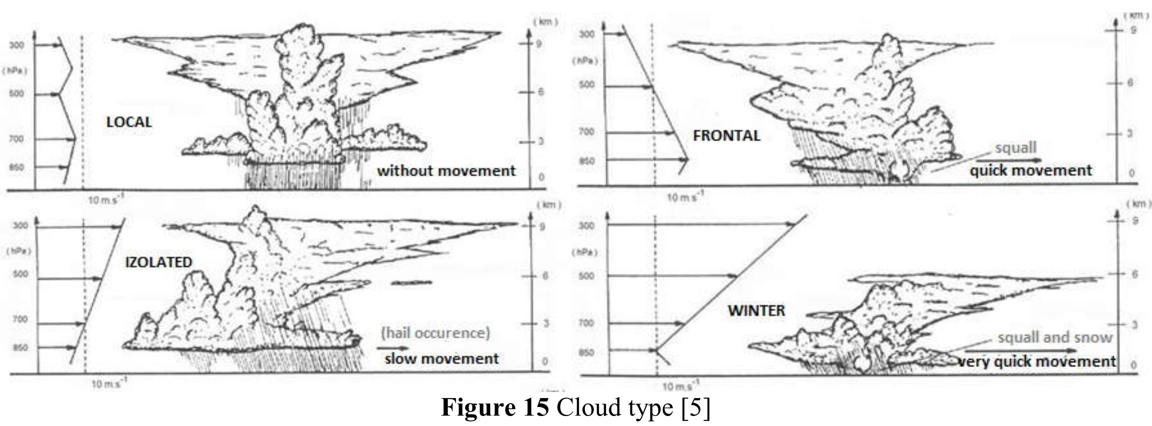

Figure 15 Cloud type [5]

If the thunderstorm occurs near the aerodrome, the aircraft on the APP have to join into the holding. The 30 min holding means more than 800 euro for full cost and also 30 min delays for one aircraft. If the thunderstorms occur on track, the aircraft can overfly or fly around. In the most cases the only option is to fly around the cloud and thunderstorm. This kind of manoeuvre can be plus more than 100 nm route and cost more than 400 Euros. The delay time in this case is more than 15 minutes. The delays of one aircraft cause a chain reaction and cause more delays for the next aircraft due to the separation.

4.1. Practical calculations related to air temperature, pressure and air density

In this chapter the impact of the air temperature and pressure on the aircraft performance and aviation safety via navigation and meteorological calculations is described.

Example 1 – The differences between the pressure and density altitude:

If the pressure altitude is 30 000 ft and a deviation of ISA temperature is + 7°C, in this case the density altitude will be 30 832 ft.

Calculation procedure:

A_P = 30 000 ft
D_{ISA} = +7°C

$$A_D = A_P + (118{,}8\, ft \times D_{ISA}) \qquad 1$$

$$A_D = 30\ 000\ ft + (118{,}8\ ft \times 7\ °C)$$

$$\boldsymbol{A_D = 30\ 832\ ft}$$

Example 2 – The true altitude height of the A/C above AD related to the temperature and pressure

The indicated altitude of the A/C on the altimeter is 4 000 ft by QNH – 1022 hPa. QFE at the nearest airport is 1005 hPa. The actual outside air temperature (T_{OAT}) in 4 000 ft is ISA +10. The question is what will be the true height of the A/C above the aerodrome?
Calculation procedure:
H = 4 000 ft
QNH = 1022 hPa
QFE = 1005 hPa
T_{OAT} in 4 000 ft = ISA+10
H_{true}= ?

1. Firstly, we need to find out the true height of the aircraft:

$$T_{ISA} = 15°C - \left(\frac{2°C \times H\,[ft]}{1\ 000}\right) \qquad 2$$

$$T_{ISA} = 15 - \left(\frac{2 \times 4\ 000\ ft}{1\ 000}\right) = 7\ °C$$

The ISA temperature at 4 000 ft will be + 7 °C. The difference (D_{ISA}) between the ISA and the actual OAT temperature is + 10 °C. It means that the T_{OAT} at 4 000 ft will be +17 °C.

$$4ft \times \frac{H\,[ft]}{1000\ ft} \times D_{ISA} = 4\ ft \times \frac{4\ 000\ ft}{1\ 000\ ft} \times 10°C = 160\ ft \qquad 3$$

Above mentioned formulas calculate the height correction of the airplane related to the actual temperature. The real height of the airplane with a temperature correction will be by 160 ft higher (4 160 ft) than indicated.

For the next calculation it is important to find out what is a height difference regarding to pressure altitude:

$$H_{dif} = (QNE - QNH) \times 27ft \qquad 4$$

$$H_{dif} = (1013\ hPa - 1022\ hPa) \times 27ft$$
$$= -243\ ft$$

The A/C altitude will be 243 ft lower by QNE than by QNH.

2. Secondly, it is necessary to compute the A/C position above AD:

$$H = (QNH - QFE) \times 27ft$$
$$H = (1022\ hPa - 1005\ hPa) \times 27ft = 459\ ft$$

The height of the aerodrome is 459 ft.

$$4\ 160\ ft - 459\ ft - 3\ 701\ ft$$

The aircraft will be 3 701 ft height above AD.

The air traffic flow management is closely related to the aviation safety. In the case of inadequate aircraft separation due to the temperature and pressure altitude deviations, the safety of the aircraft is threatened and the air traffic flow management affectivity degraded. For this, it is very important for pilots to listen carefully to the ATCO´s instructions and the controllers need to give proper and correct information for the pilots.

From the above mentioned is clear, that the meteorological elements like a temperature and thunderstorm can affect the aircraft performance and operation, consequently the air traffic flow management (also the ATCO) and the whole aviation operation system. We can´t affect meteorological elements and phenomena, but we can predict and forecast the possibility of occurrence and make a conclusion, measure and precaution.

5. CONCLUSION

The aim of this article is to point out the necessity to study how to use the theoretical knowledge and use it properly in the air traffic control practice.

The 3rd chapter shows the fact, that the temperature changes, warms up, which has a big impact on aviation. This impact is stated in the 4th chapter where we point out how the air temperature and meteorological phenomena and elements like thunderstorms and cumulonimbus clouds can affect the aircraft performance, and consequently the whole aviation. From the above mentioned, it is clear that air temperature raising and increasing cause more thunderstorm and cumulonimbus cloud occurrence and have a negative impact on the aircraft performance, the effective air traffic flow management and consequently on the whole aviation. Because of that, it is really important to know how to apply the theoretical knowledge in the practical situation and if it is possible, to adjust suitable economic measures for avoiding the dangerous situations.

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