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THE EFFECT OF CLIMATE CHANGE ON THE APPLICATION, OPERATION, REPAIR, MAINTENANCE AND LIFECYCLE OF TECHNICAL EQUIPMENT[2]

In the past period mankind had to face challenges representing more and more burden because of climate change. Global warming, water shortage and desertification cause problems that render the life of people affected impossible on the one hand, and restrict the application of technical equipment on the other. My goal with this study is to present the challenges arising in connection with climate change in their complexity and the security risks which fundamentally determine the future activities and duties of the armies. Hopefully I could draw the attention to the fact that climate change will inevitably influence the application of military forces and technical equipment. It will have an effect on the operation, repair, maintenance and lifecycle of technical equipment.

AZ ÉGHAJLATVÁLTOZÁS HATÁSA A TECHNIKAI ESZKÖZÖK ALKALMAZÁSÁRA, AZOK MŰKÖDÉSÉRE, JAVÍTÁSÁRA, KARBANTARTÁSÁRA, ÉLETCIKLUSÁRA

Az elmúlt időszakban – az éghajlat változás okán – az emberiségnek egyre nagyobb teherrel járó kihívásokkal kell szembenéznie. A globális felmelegedés, a vízhiány, az elsivatagodás olyan problémákat okoz, melyek egyrészről ellehetetlenítik az általuk sújtott emberek életét, másrészről pedig korlátozzák a technikai eszközök alkalmazását. Jelen tanulmány megírásával az a célom, hogy komplexitásában mutassam be a klímaváltozás kapcsán felmerülő kihívásokat, illetve azon biztonsági kockázatokat, melyet alapjaiban határozzák majd meg a hadseregek jövőbeni tevékenységeit/feladatköreit. Reményeim szerint sikerül rámutatnom, hogy a klímaváltozás elkerülhetetlenül fogja befolyásolni a katonai erők és technikai eszközök alkalmazását. Hatással lesz a technikai eszközök működésére, javítására, karbantartására, életciklusára.

INTRODUCTION

The Earth's population has to face and endure effects of nature that have negative impact on its quality of life. Different regions of our Earth are hit by different kind of natural disasters. While lengthy droughts emerge in certain areas other regions face the difficulties caused by floods and torrential rain. Problems caused by rivers and wells drying up are experienced simultaneously with mudslides crashing down on mountainsides slackened by rainfall.

The continuous increasing average temperature determines the climatic conditions of our Earth labelled as global warming dealing with this topic [1]. Several problems determine our existence have arisen as a result of global warming. The decline of the volume of agricultural production and the deterioration of the quality of produced agricultural goods should be

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mentioned here. The aggregate of these two effects may have led to substantial famines.

As an effect of global warming heat waves sweep through for instance the European continent that practically "paralyse" people who are used to the effects of continental climate in their physical work. As a consequence of warm up glaciers started to melt; glaciers that provide water for almost one and a half billion people.

The size of the problem can be understood when one is aware of the fact that only 2% of the water resources of the Earth is freshwater useful for man and 70% of it originates in glaciers.

It will undoubtedly lead to enormous problems if billions of the Earth's population face the challenges of famine and water shortage.

Global warming is the joint result of several human activities. Among the most significant ones are the increased air pollution emerging in connection with electric energy generation, the keeping of farm animals (large-scale meat production), carbon dioxide emission originating from the use of vehicles, overconsumption, lumbering and warfare in connection with which huge volumes of fossil fuel is burnt[2].

THE CONCEPT OF CLIMATE CHANGE

Climate change means the permanent and considerable change of the climate at a local or global scale. The change may extend to the average temperature, the amount of average precipitation and its regional distribution or wind conditions. When looking at the last period of human history it can be stated that climate change would be a relatively fast environmental process which can take about a few decades only. Climatic change can happen as a consequence of natural processes of the Earth (e.g. tectonic movement of continents), external impacts on the planet (e.g. changes in the orbital parameters of the Earth or collision of a meteorite etc.) or even by virtue of human activities (e.g. the production of greenhouse gases). In everyday use expression 'climate change' often refers to the changes of the climate taking place in our days.

According to the most common definition climate change refers to the long term and permanent change of the climate regardless of its reasons. This expression is frequently used to describe the relatively fast changes caused by human beings as opposed to natural processes. In this sense and in policy disputes climate change can be used as a synonym of global warming. From a scientific aspect global warming only refers to temperature changes while climate change also includes other changes caused by greenhouse gases.

Climate change is a natural process. Scientists already pointed out that the average weather features of a certain area constantly change over time. However, scientific researches and examinations related to the phenomena and consequences of climate change indicate that global warming, have continuously accelerated since the industrial revolution – and it is a significant consequence of human activities (e.g. mostly the combustion of fossil fuels such as coal, oil and natural gas).

According to the climate change the global average temperature and the mean temperature of the European region increased by 0.6 °C and 1 °C in the past century, respectively. Nowadays, the temperature of our planet is higher by more than 2 °C than before

industrialisation. This warming would become irreversible and will have serious consequences in the future.

Global warming experienced on the Earth is related to the change (increase) of the concentration of greenhouse gases in the atmosphere. Practically it can be stated that – based on the domino effect – this is the cause of several negative effects which will be set forth in the following.

THE EFFECTS OF GREENHOUSE GASES ON THE CLIMATE OF THE EARTH

The large part of ingoing shortwave radiation originate from the Sun are mainly absorbed by Earth surface, thus the Earth (like a lower temperature orbit) produces a well-known infrared radiation fluxes toward the space. This long wave radiation can be absorbed by the greenhouse gases in the atmosphere and reflected back towards the earth's surface by them. This phenomenon is called as "Greenhouse effect", which can lead to an ever-increasing average atmospheric global temperature near the similar or higher anthropogenic production of greenhouse gases (Fig. 1).

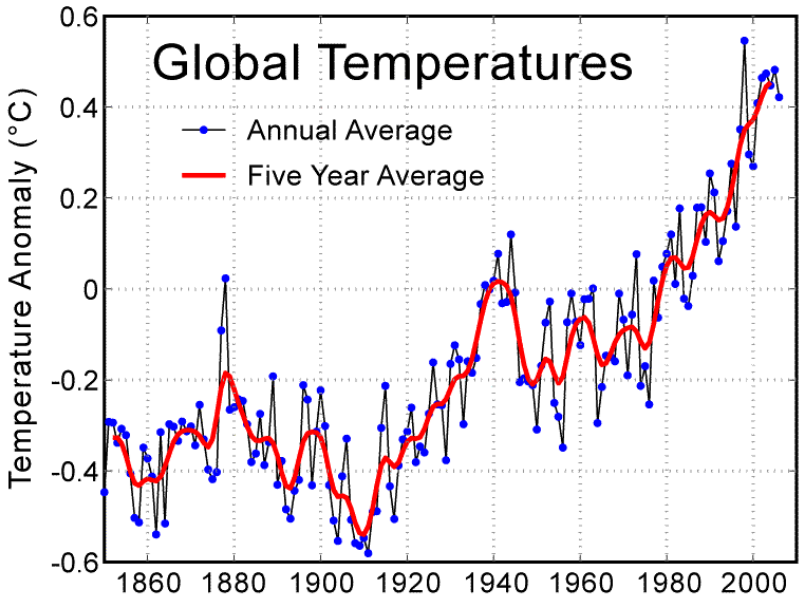

Fig. 1. The changes of the average temperature of the Earth atmosphere in the last 150 years.

According to the data of IPCC[3] the average temperature of the air in the troposphere[4] increased by 0,74 ± 0,18 °C between 1905 and 2005 [1]. In the opinion of the Panel the main reason for that is the increase of the concentration of greenhouse gases released into the atmosphere since the middle of the 19th century. According to the climate models accepted by IPCC the temperature of Earth's surface is expected to increase by 1.1-6.4 °C between 1990 and 2100 and it is very likely that it would increase further. The reason for this lies in the fact that the

[3] IPCC: International Panel on Climate Change.

[4] The troposphere is the bottom layer of the atmosphere where the majority of weather phenomena take place. Troposphere extends to a height of 16-18 km from the Earth's surface in the tropics while only to 10 km at the polar circles. This layer includes 80% of the mass of the atmosphere.

decomposition period of greenhouse gases concentrated in the atmosphere is quite extended.

Temperature increase at global scale leads to environmental changes such as:

- rise of the sea level,
- change of amount of precipitation and its spatial distribution,
- the formation of extreme weather conditions[5].

In connection with global warming the production capacity of agriculture obviously changes. This has a considerable effect on national economies as it either increases or decreases gross national product.

It can be expected that some of the surface waters dry up, glaciers melt, hurricanes and typhoons become more frequent, bigger and more devastating – and in the meantime damages caused by frost and in general cold will reduce significantly. Changes in different areas of the Earth can be different.

According to the linear trend applied to the average surface temperature of the Earth it increased by 0.74 ± 0.18 °C between 1990 and 2000. In the 20th century the rate of warming was twice higher than it was in the second half of the 19th century. On the other hand, the globally changes of the temperature are not distributed uniformly. Since 1979 the warming of the atmosphere was twice faster than the oceans'[6] [2]. The reasons for that are the higher effective thermal capacity[7] of the oceans and the rate of heat loss occurring together with evaporation.

As a result of the melting of the ice cover the rise of sea level can be predicted. The main reasons for that are the seawater warming (oceans have larger volume) and the non-floating (continental) ice melting. According to the Hadley Centre[8] (one of the leading institutions of climate modelling), sea level will rise by 40 cm until 2080 if the restriction of the emission of greenhouse gases fails. This means for example, that contrary to the present 13 million people in the future 94 million people will be threatened by annual floods.

Among the negative effects of global warming the appearance of long lasting droughts and the tendency of desertification must be mentioned. The existence of water in adequate volume and of course cleanness forms the basis of preserving human existence. Climate change can be blamed for problems occurring recently at an increasing rate and in more and more areas that refer to water shortage. Researchers determined that the proportion of the continental area of the Earth affected by severe drought more than doubled from the 1970's till the beginning of the 2000's [3]. When examining the droughts affecting the Earth globally we can see that currently 1.1 billion people don't get safe drinking water because of droughts [4].

[5] These phenomena can be e.g. extreme temperature conditions, hurricanes, tsunamis.

[6] Contrary to the average temperature increase of the atmosphere of 0.25 °C/decade the warming experienced with oceans was 0.13 °C in the same period.

[7] It expresses that for the same temperature change more heat is necessary in case of water.

[8] Royal Meteorological Institute.

It is beyond doubt that the extreme weather due to the effect of climate change and the extreme climatic conditions have an effect on military operations as well.

Besides influencing the efficiency of the soldiers negative effects substantially spoil the applicability of technical equipment.

On the effect of droughts desertification increasingly affects the Earth. By the increase of the area of desertified land the concentration of airborne dust in the air space increases. If we only consider the theatres of war significant from a military aspect in the recent past and present[9], it is clear that the armed forces of the allied nations were facing the problems caused by sand and dust to a great extent, with the problems that have negatively influenced the applicability and calculated lifecycle of their military equipment. I will present these problems below.

If we think on the Iraq war when examining the limitations of applicability we have to remember the practically everyday sandstorms (Fig. 2) that actually paralysed the targeting of the laser-guided bombs of the allied forces.

Fig. 2. Sandstorm over Baghdad

Laser-guided bombs are guided aerial bombs where the bomb is guided by illuminating the target with laser. The laser beam used for marking (designation) scatters to a very small extent under optimal atmospheric conditions.

Because of the small scattering of the laser beam on the one hand targets at distances of several tens of kilometres can be marked, and on the other hand the target can be marked relatively accurately[10]. However, the disadvantage of laser guidance becomes apparent primarily in its sensitivity to the weather. Laser beam scatters[11] in an air layer polluted with grains of sand. It is

[9] Iraq and Afghanistan.

[10] As a result of continuous development the circular dispersion that can be achieved by the most advanced laser-guided bombs is 80-100 cm.

11 It should be noted that over and above suspended particulate matter high humidity further restricts laser guidance. Water vapour and drops cause the dispersion of the laser beam.

clear therefore that the target has to be continuously illuminated during the flight of the laser-guided bomb (Fig. 3), the aircraft may not perform significant flight manoeuvres during this time and nothing may distract its attention from performing the mission.

Fig. 3. GBU-28 laser-guided bomb, and its release from an F-15 of the U.S. Air Force[12]

As targets are marked by laser designators installed in the aircraft or suspended from one of the weapon suspension stations as a separate pod (targeting pod) therefore it is essential that the target is clearly visible. If clear view ceases – e.g. because of the dust pollution of the air – the applicability of laser-guided bombs is practically reduced to zero.

In order to reduce the negative effects of sandstorms becoming more and more frequent due to climate change the role of aerial target designation is increasingly taken over by ground-based target designation options. Instead of illuminating using on-board targeting pods through a dust polluted air space from a long distance, forward air traffic controllers[13] carry out laser target illumination these days. The forward air traffic controllers approach the target area by ground combat vehicles, select the target to be destroyed and designate it. These soldiers are a lot closer to the target therefore they have to illuminate through a lot smaller dust polluted layer of air. However, this is obviously a compromise; a solution where target designation and the guidance to target becomes independent from the destruction ability thus increasing error possibilities due to the human factor twofold.

It is typical of the atmospheric conditions of desertified land that suspended sand(grains) are continuously present in the air. Sand can significantly reduce the performance and lifetime of turbine engines.

Turbine engines are internal combustion engines where air is compressed by a compressor rotated by a gas turbine. As a matter of fact the turbine engine is a heat engine that transforms thermal energy obtained by fuel combustion to mechanical energy which is then utilised as the kinetic energy of escaping gas or with consumers driven by the work taken off from rotating shafts. Thermal energy is transformed to mechanical work in a certain cycle. By reducing the blade height of the compressor and the turbine the efficiency of the stages of the engine also decreases which reduces the effective efficiency of the gas turbine and the maximum efficiency related to the optimal pressure conditions. In plain language this means

[12] The targeting pod AAQ–14 LANTIRN that guides the bomb to the target can be seen under the fuselage.
[13] The denomination according to the NATO terminology is JTAC (Joint Terminal Air Controller).

that if the length of the gas turbine blades gets shorter as a result of an external impact than the efficiency of the engine decreases as the compression ratio decreases.

The question might arise: what causes the reduction of blade length[14]? The main reason is the sand (grains of sand) sucked into the engine (Fig. 4).

Fig. 4. Operation of aircraft gas turbines under desert conditions

The major problem is caused by the fact that sand is a mineral with a crystal structure that is able to erode the hardest alloys[15]. Practical experience shows that the technical lifetime of aircraft engines operated in deserts or desertified land is 30-35% lower that those operating under continental climatic conditions. Furthermore, the grains of sand sucked in cause damages on the surface coating of the blades as well.

Engineers designing engines have developed several technical solutions in order to maintain engine efficiency. Among them are dust separators applied specifically on helicopters (Fig. 5).

Fig. 5. PZU dust separator on Mi-17 transport helicopter

This equipment absorbs the dust sucked in by the operating engine from surrounding air and internally spins it (along its internal superficies). As an effect of the centrifugal force the dust and sand crystals deposit on the superficies. The deposited contamination is “blown out” from the equipment by the high pressure air coming from the engine.

[14] The reduction of blade length shall be understood as blade abrasion.

[15] When talking about engines titanium alloys must be considered.

In order to maintain and increase the thermal load capacity of the blades scientist in Ohio [5] are experimenting with coatings that – besides their heat resistance – are able to withstand load caused by friction. Experiments have pointed out that a coating containing zirconia-aluminium-titanium could be the solution for tolerating loads caused by dust and sand. This is the only coating able to change shape proportionate to blade expansion.

Rotorcraft flights above deserts that have developed due to droughts have an additional negative segment. The negative effect of airborne dust have become increasingly important during take-off and landing. The thick dust stirred up by the rotary wings of helicopters makes it difficult (and in extreme cases prevents) safe take-off and landing because the pilot looses ground vision during these manoeuvres. At close to the ground altitudes[16] spatial orientation of the helicopter is only possible by using flight instruments but the slightest error in steering leads to crashing into the ground. It can therefore be stated that from the aspect of aviation safety airborne dust substantially restricts the applicability of helicopters during take-off and landing.

Currently extensive research work is carried out in the United States to use on-board radars to help helicopter pilots under reduced visibility. As a result of current development of the American Sierra Nevada Corporation (hereinafter: SNC) the first prototype of the so-called Helicopter Autonomous Landing System (HALS[17]), operating at 94 GHz frequency and able to provide 3 dimension imagery of the ground surface even in dense dust [6] has been constructed.

The equipment "projects" the basic information[18] into a digitally displayed space which information is vital for performing safe flight manoeuvres[19].

According to the report of IPCC[1] the volume of precipitation falling on continents in the 20th century has shown an increase by the fact that the volume of atmospheric vapour has increased as a result of global warming and in accordance with the Clausius-Clapeyron law[20]. On the effect of increased precipitation the extent as well as the extremity of the average precipitation volume has increased both from territorial and from quantitative aspects.

As humidity of the air increases challenges related to the corrosion of metals[21] come to the front more and more. When examining the effects of moisture on combat vehicles we have to discuss the corrosive effect exerted on parts and equipment and the relevant protection and prevention as the most important factors.

Corrosion and rusting caused by humidity attacks and destructs emphatically the external

[16] During landing and take-off the altitude of maximum 2 metres from the surface should be considered as close to the ground altitude.

[17] HALS = Helicopter Autonomous Landing System.

[18] These parameters are the following: Flight altitude above ground, forward speed, artificial horizon required for the orientation of the helicopter, vertical speed indicator.

[19] These are low speed operations performed mostly close to the ground.

[20] Clausius-Clapeyron law: The vapour pressure of all substances increases exponentially with temperature thus the water absorption capacity of the atmosphere increases when the temperature of the air increases.

[21] Corrosion is destruction generated by chemical or electrochemical changes, which starts from the surface of metals and advances towards the centre of the metal. It must be taken into account that the corrosive effect of rainwater is stronger than that of clean (distilled) water as dissolved substances present in rainwater increase conductivity.

surface of combat vehicles. There are several options available to protect the metal surfaces of combat vehicles against corrosion. These are passive and active corrosion protection methods. The best known type of passive corrosion protection is to cover metal surface with various coatings[22].

Corrosion protection coatings can be various lacquers, plastics or enamels. The disadvantage of this method is that these coatings provide protection only until they get damaged. Coatings resistant to damages are relatively expensive but the costs are negligible compared to the value of the combat vehicle. Naturally the damages of the coatings can be removed by continuous maintenance but punctiform corrosion damages spreading perpendicularly to the surface may develop where damages had occurred which reduce the strength of the coat. Another also passive procedure is that certain parts and components of combat vehicles are manufactured of materials greatly resistant to corrosion. In case of aircraft it is fortunate that light composite materials that better withstand corrosion and aluminium alloys are more widely used by aircraft manufacturers. The essence of the active corrosion protection procedures is that metal exposed to increased corrosion is protected by another metal that is more reactive to corrosion (generally magnesium). In this case the two materials are in metallic contact with each other. When the effect of corrosion appears the metal more reactive to corrosion starts to dissolve by oxidising and the metal to be protected remains undamaged. This procedure has the advantage that even steel alloys without coating can be protected safely but its disadvantage is that the reactive metal must be supplemented at certain intervals.

The most efficient method of corrosion protection is the combined application of passive and active procedures. In this case the surface of the metal to be protected is coated with the material more reactive to oxidation.

These coats provide complete protection because on the one hand, the contiguous coating applied on the metal surface completely isolates the metal from its environment, and on the other hand metallic contact between the surface and its coating remains even in case of a surface damage. If the insulating coating gets damaged the more reactive coat would continue to become oxidised due to the metallic contact of the two materials, thus protecting the metal from damage.

Besides the external cover and the frame of combat vehicles high humidity has a harmful effect on the engine and systems of combat vehicles[23], specifically when maintenance is inappropriate.

In the ideal case the engines (closed system combustion engines or diesel engines) of well maintained combat vehicles, if properly sealed, are exposed to small corrosion effects. Because of leakproofness and the relatively high surface temperature of the engines moisture

[22] This procedure is called sintering.

[23] Especially the turbine engines of aircraft are exposed to the effects of precipitation because it enters the engine easily during the flight and because of the high forward speed the volume of precipitation flowing in can also be considerable. Large volumes of precipitation could even decrease the performance of the engines because the large volume of water flowing in cools down the hot air driving the turbines.

can get into the interior of the engines only in a negligible volume.

It should be noted however, that in case the system is not properly maintained/sealed or if the operation of the engine cannot be regarded as continuous, furthermore if the engine compartment or the engine bay is not properly protected from precipitation than the effect of corrosion is significant (Fig. 6).

Fig. 6. Corrosion on the cylinder head of a combustion engine

Although it is true that a slight performance increase can be observed through the pressure increase in connection with the evaporation of the moisture in the combustion engine when the engine is operating – based on the principle of water injection systems – the disadvantages are enormous compared to this minor advantage. Contrary to water injection systems it is not us who determine the time of moisture entering/leaking into the cylinders of engines with defective tightness thus the corrosive load in the section between the place of leakage and the combustion zone of the engine is very high.

Over and above corrosion moisture can cause disastrous defects in the electronic systems of combat vehicles because of electric short circuits[24]. Over and above the discharge of electric equipment these defects may lead to the combat vehicle catching fire or its possible complete destruction.

In order to protect the electric equipment of combat vehicles and to increase their lifetime it is vital that insulation of appropriate quality is used especially in areas where humidity is high.

If high temperature conditions subsist permanently problems will occur also with the batteries of combat vehicles. When operating at high temperature conditions chemical reactions within the battery accelerate and as a result battery liquid[25] evaporates from the battery cells much faster than under normal temperature circumstances. If the electrolyte that ensures the chemical processes of the battery evaporates the operation of the equipment stops. Therefore in case of high temperatures increased attention must be paid to the maintenance of the batteries (unless they are maintenance free batteries) and to regularly fill them up with liquid.

In addition to the above as a result of permanent high temperature conditions the plastic and

[24] Electric short-circuit develops where the resistance between two given circuit points is very small or negligible.

[25] The aqueous solution of sulphuric acid is used as electrolyte.

rubber pipes transporting the liquids of the engine and air cooler as well as the oil and fuel systems age at around 70% of their total lifetime.

Early ageing is most apparent at the connections where metal or plastic rings press these pipes to the inlet and outlet orifices of the equipment. If these cooling and lubricating systems break down this could lead to the fatal overheating and failure of the engine/motor. If high temperature conditions permanently subsist special attention should be paid to the periodic inspection of the plastic and rubber pipes transporting the liquids of the engine and air cooler as well as the oil and fuel systems and their replacement in due time.

It is important to note that the deployability of the operators of military equipment has a large effect on the applicability of these assets. High temperature conditions influence the ability to concentrate and the reaction time of soldiers (who deploy the assets of armament technology) negatively. High air humidity[26] just increases this negative effect.

In the tactical aircraft and helicopter corps of the air force service, specifically for aircraft and helicopter pilot staff, special emphasis is placed on determining the temperature limit above which flights must be restricted. The reason for that is that the reduction of pilots' performance may lead to fatal aviation incidents. In aviation this temperature is called "comfort temperature". The rate of the comfort temperature is determined by the outside air temperature, air humidity and the current speed of the wind. The comfort temperature, the rate of which may not exceed the 25 °C limit, is calculated by using these values in a formula.

When reaching the comfort temperature a decision is made whether the mission can be executed. If the pilot executes a training type mission and postponement does not endanger state of alert than it is prohibited to continue flying. If the execution of the mission is of operational nature[27], it should obviously be executed. By increasing the comfort temperature the load of the pilots increases exponentially. Restrictions to deploy the assets of armament technology increase.

In order that the body endures the negative effects exerted on it armies demand increased physical preparedness/conditions from pilots. This is the same in the Hungarian Army also where pilots have to meet the highest standards of physical condition [7].

CONCLUSION

Based on the trends the negative effects due to climate change will increase in the future.

Currently scientist specialised in this issue are able only to estimate the extremities concerning the expected temperature limits, sea level rise due to melting, the rate of desertification and the increase of the volume of moisture participating in the hydrologic cycle. Although forecasts based on estimates show certain standard deviation regarding limit values, one thing is common in them: All point to extremities.

[26] The higher the humidity of the air, the more intense the temperature sensation. Which means, that high temperature is more unbearable.

[27] E.g. duties related to defence and alliance obligations laid down in the constitution.

If we accept the forecasts of scientists we can state that we have to "make arrangements" to endure/manage the negative effects of climate change for the long term. The only question is how quickly these negative effects would arise. The quicker the change into the negative direction the less time remains to implement measures inhibiting the effects of the processes, and the higher effect will society have to suffer, respectively. We can understand that recently we already had to face these problems if we consider how sandstorms restricted the deployment of military equipment in Iraq or how these storms hindered the fuelling of military equipment[28] [8].

The maintenance of military equipment in areas hit by extreme weather effects due to climate change requires increased attention from the operators. The lifecycle of military equipment shortens as a consequence of increased weather load. In order to keep the desired deployment indexes sustainable increased investment of financial and other resources is required [9].

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[28] Several operations had to be postponed or cancelled in the Iraq war because of sandstorms; the lifetime of technical equipment decreased and repair costs increased significantly. Sandstorms made the transport of reserves more difficult which primarily jeopardized fuel supplies. In a war where 9 million litres of fuel was moved on the theatre of war every weather anomaly endangered the success of operations.

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