Emergency Meteorological Data Preparation for Artillery Operations

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Abstract: The article discusses a research project focused on new approaches to the meteorological preparation of artillery units. As can be observed in the current conditions of the war in Ukraine, artillery is a key component of both warring parties. The effectiveness of artillery is based on the accuracy of its fire. However, in order for the artillery to fire accurately, it is necessary to compensate for all the influences that may affect the shell flight. The main component of influencing factors are meteorological conditions, which the artillery determines by upper air sounding of the atmosphere. However, currently used methods are very susceptible to enemy activity and artillery must therefore be able to obtain meteorological data at any level of degradation of its capabilities. This article describes the research project which is aimed to create an aggregated predictive model based on historical meteorological data. Using this model, it would be possible to obtain meteorological data autonomously, without the need for complex sounding of the atmosphere or obtaining data from external sources. The article describes the proposed approaches to the solution of the project and the creation of an aggregated predictive model for the use of artillery units.

1 INTRODUCTION

Although many statements predicted the gradual decline of artillery in modern conflicts, the opposite is true. Currently, as we can unfortunately see, especially in the conditions of the war in Ukraine, the artillery is an absolutely key component providing fire support to combat units. However, the degree of effectiveness of artillery must be seen in the broader context of its operation and through the lens of all the data and technologies that artillery uses in order to be able to fire accurately and efficiently.

Unlike other types of combat support and combat security forces, which include, for example, chemical, anti-aircraft, logistics and engineering forces, artillery is one of the oldest components of the armed forces, whose principles and principles of operation have undergone fundamental changes in the course of modern history. These changes have become more or less reflected in the character they operate on the battlefield (Rolenec and others, 2021).

Artillery is a technical branch of military whose main purpose is to provide fire support to combat units. However, this general definition, which can be found in all sources, must be seen in a clear context. Providing artillery support to combat units in detail means providing those units with an effect that they are unable to achieve with their weapons at distances that their weapons cannot fire at. In addition to the size of the effect, there is another aspect to be seen in the background of the general definition, which is accuracy. Therefore, if we should mark the clear pillars of artillery activity, it is accuracy combined with long range, because these two parameters clearly define the effectiveness of artillery fire. Thus,

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throughout history, the vast majority of innovations have been aimed at increasing artillery capabilities in the area of accuracy and range.

In order to understand the issue of how modern artillery improves its accuracy by using meteorological data, it is first necessary to describe the basics of artillery fire control and the methods of supplying meteorological data.

2 ARTILLERY FIRE CONTROL

Artillery is a multidisciplinary, technical type of branch that is quite specific in how comprehensive data it needs for its operations. In general, artillery consists of four sub-groups:

1) weapon and ammunition systems,
2) sensors,
3) fire control,
4) supporting means.

Effectors are the most visible part of the artillery, because they stand at the very end of the entire chain. In the artillery environment, effectors are cannons (howitzers), mortars, and rocket launchers. Effectors are artillery tools, the purpose of which is to deliver the ammunition, which is the carrier of the effect on the target. For the effective function of effectors, firing data is necessary, because they accumulate positional and ballistic data about the effector, and the ammunition used by it, as well as the meteorological data informing about meteorological conditions that may affect the flight path of the shell. The firing data are determined within fire direction centers, with information from the supporting means and other sources being used to determine them.

Sensors are another combat components of artillery, which are still necessary even in modern conditions, because they are the means that allow the observation of the target, its localization, identification and subsequent cooperation on fire control. Fire control cooperation consists in the fact that the sensors observe the shell impacts and provide the fire direction centers with their position data, based on which corrections are made to the firing data so that the target is hit. Modern sensors can take many forms and are typically based on optical, optoelectronic or radar instruments positioned on self-propelled ground platforms, or aircrafts.

Fire control is one of the main components of artillery, it is a process that involves planning, coordinating, preparing and directing the firing of artillery effectors. Its main objective is to achieve maximum effect in the target, taking into account the needs of the operational environment and the tasks of the supported unit. Generally, artillery fire control is divided into tactical fire control and technical fire control.

Tactical fire control is part of the broader fire control process and focuses on planning and conducting fire at the tactical level within a specific combat deployment. Typical tasks of tactical fire control are the selection of the most suitable fire unit to meet the objective according to combat effectiveness, ammunition supply, position and other metrics. (Świętochowski, 2019)

Technical fire control is the process of converting the characteristics of weapon sets and ammunition (ballistic firing conditions), the location of weapon sets and targets (conditions of topographic-geodetic connection) and meteorological conditions into firing data. To put it simply, technical fire control deals with the calculation of the firing data, which are set on the effector sights. (Blaha and others, 2016)

Currently, technical fire control is an activity that can be performed by a human entity or automated tool using specialized software (fire control system or ballistic computer). The method of performing technical fire control is thus divided into manual and digital gunnery.

Supporting means are a specific components whose goal is to supply artillery units with all the data necessary to fire. This is mainly the delivery of navigation data for effectors and sensors (artillery survey) and upper air sounding of the atmosphere, the aim of which is the delivery of actual meteorological data.

3 METEOROLOGICAL TECHNIQUES

Meteorological techniques and preparation is a key component of artillery fire control and artillery target acquisition. The reason for this is that meteorological conditions significantly affect the flight path of the shell. The firing data must compensate for these conditions in order to adjust the flight path of the shell to hit the target. Approaches to technical fire control and the inclusion of meteorological data vary across individual states. However, in general, when determining the firing data, corrections are included that adjust the flight path of the shell for the effect of:

- air temperature,
- air density,
- air pressure,
- air humidity,
- wind speed and direction.

The inclusion of current meteorological conditions in the firing data allows the artillery to conduct fires for effect without prior adjustment, which significantly increases the level of surprise and the resulting effectiveness of artillery fire (Němec and others, 2022).

The assessment of current meteorological conditions can also have a major influence on the planning of the routes of movement of artillery units on the battlefield. Patency, security and concealment are the main requirements for the routes of movement between non-combat deployment areas, hiding areas and firing positions. With regard to the increasing dynamics of conflicts, it is necessary to plan the routes of movement for artillery reconnaissance means, fire support means, as well as logistic units bringing supplies quickly and automatically (Nohel and Others, 2019, 2022).

3.1 Ascertaining of Meteorological Conditions

Meteorological conditions can be detected in different ways. Currently, the most widely used method is the upper air sounding of the atmosphere, which is carried out by specialized artillery units, which are equipped with specific technical means for this purpose.

In the conditions of the artillery of the Czech Army, the upper air sounding of the atmosphere is carried out using the newly developed PODTEO vehicle. This vehicle consists of a modified wheeled M65E19WM 4×4 LMV Chassis Cab complete with a CL 35ARM PODTEO trailer (Figure 1).

Figure 1: PODTEO vehicle.

PODTEO vehicle is equipped with:

- meteorological computer Marwin MW32,
- radiotheodolite RT20,
- CG31 antenna set,
- surface station MAWS201M Tacmet.

The operation of this vehicle is based on the ability to perform the upper air sounding and surface observations and measurements. Upper air sounding is realized by releasing meteorological balloons filled with hydrogen, on which Vaisala RS92-SGP, RS41-SGP or RS92-D radiosondes are attached (Figure 2a).

(a) (b)

Figure 2: Radiosonde and radiotheodolite RT-20.

These radiosondes transmit meteorological data to the RT20 radiotheodolite (Figure 2b). Upper air sounding can be characterized as the main component, because its goal is to find out the meteorological conditions at individual heights, in which artillery shells fly, and thus it is possible to accurately determine the influence of meteorological conditions on the flight of the shell.

However, surface observations and measurement is also important, which is carried out using the MAWS201M Tacmet surface weather station. The data detected by upper air or surface measurements are sent to the Marwin MW32 computer, which compiles meteorological messages based on them, and then distribute them to the fire direction centre, automated fire control system, ballistic computer and/or sensors.

3.2 Meteorological Messages

Meteorological messages represent the main output of upper air sounding, as meteorological data are transmitted by them. These data are:

- surface air pressure,
- surface virtual air temperature,
- surface wind direction and speed,
- mean changes in air density,
- mean changes in virtual air temperature,
- mean wind direction and speed,
- direction data and wind speeds in the lower atmosphere,
- air density values and other data.

Meteorological messages take the form of a system of alphanumeric characters - data about the state of the atmosphere in the vicinity of the meteorological unit that detected these data, up to a specified height. The determined data are presented in the meteorological message in two-digit and multi-digit groups. Individual places in groups have a predetermined and unchanging meaning. The groups are sorted in a fixed way and their order does not change. This guarantees that the placement of a certain number in a group clearly determines its meaning, and the order of the group in the report determines the name of the fact that the data in the group describes.

Artillery uses following types of meteorological messages:

- Meteo 11,
- METCM,
- METGM,
- METB3
- others.

These messages are passed directly to software tools or, in the case of manual calculation of firing data, they are de-rooted and the individual data used in an analytical calculation. Without the supply of meteorological data in the form of a meteorological message, the artillery cannot fire with such accuracy that it does not have to adjust the fire. (Blaha and others, 2018) The ability to create and deliver them is thus absolutely crucial for the element of surprise and the resulting effectiveness of artillery fire.

3.3 Identified Downsides

Upper air sounding is advantageous in fact that it provides up-to-date meteorological data for a given area, such as an artillery emplacement. However, this method of determining meteorological data has several fundamental negatives. The first negative is the spatial limitation on which the data obtained in this way can be used. Another negative is the active radiation of individual devices and the consequent possibility of locating the meteorological station and its subsequent destruction. This lack of upper air sounding of the atmosphere is often observed in the war in Ukraine, where meteorological assets are targeted and destroyed so that the artillery does not have meteorological data available and its fire is not accurate. (Hrnčiar and Kompan, 2023)

The last of the main shortcomings is related to the possibility of destruction or malfunction of sounding devices. Considering that these are highly specific means, the availability of which, as well as the availability of specially trained personnel - their loss (caused by any reason) is very noticeable. As a result of the unavailability of meteorological data, in addition to reducing the accuracy of fire control and the resulting efficiency of artillery activity, it will be reflected in an increase in the consumption of ammunition, which is actually a commodity that, with the prolongation of the war in Ukraine, is proving to be absolutely crucial. The lack of metrological data can thus have strategic consequences (Šlouf and Others, 2023).

For the stated reasons, the effort is to replace the upper air sounding of the atmosphere with other methods, which will not be so materially (personaly) demanding and thus will not be so sensitive to detection. One of these ways is the acquisition of gridded meteorological data from multiple sources within the World Area Forecast Center (WAFC). This method is advantageous in fact that it is not based on the discharge of a meteorological radiosonde, and thus the negatives associated with this means are eliminated. Even so, this method has shortcomings, which paradoxically revealed themselves during the COVID-19 pandemic. One of the main sources on which this method is based is the data detected by aerial platforms flying at different altitudes. At the time of the pandemic, when air traffic was enormously suppressed, this was reflected in a fundamental lack of data for compiling meteorological messages. Although it was a non-war reason, it can also be expected in the event of armed conflicts, when civilian air traffic will not be operated and military platforms will fly only in selected areas with a lower level of risk from air defense. These areas can be significantly far from the artillery deployment areas and the obtained meteorological data will not be as accurate as needed. The availability of data obtained in this way can be quite fundamentally limited even in armed conflicts.

The last of the main limitations is the ability to distribute the detected meterological data in the form of meteorological messages. (Blaha and Brabcová, 2010) In the current war in Ukraine, it is possible to observe a significant capability of electronic warfare, which is able to effectively disrupt electromagnetic transmissions. Both the distribution of data from the radiosonde to the ground station and the distribution of data from the WAFC can be significantly difficult, if not impossible. For these reasons, it is necessary to look for methods that are not based on active transmission, remote data download and will be usable even with various degradation of capabilities so that, even from the point of view of meteorological preparation, the artillery is autonomous and can thus fire accurately even in the unavailability of any components of meteorological preparation.

4 EMERGENCY METEOROLOGICAL DATA PREPARATION PROJECT

Based on the analysis of the current situation and findings from the war in Ukraine, two key facts regarding the meteorological preparation of artillery were identified. Specifically, it is the fact that meteorological preparation continues to be an absolutely necessary part providing key data for artillery, without which it is not and will not be possible to fire accurately in the future. The second fact is that the current methods of obtaining meteorological data have a number of shortcomings, which can very easily cause the non-delivery of this vital data for any reason.

Based on the evaluation of the current situation, the research team defined a new project, called Emergency METEO, whose goal is to ensure the availability of meteorological data for the needs of artillery fire control in case of degradation of the capabilities of artillery meteorological units or other sources from which artillery units obtain meteorological data.

4.1 Overall Project Concept

The basis of the project is set on the intention of obtaining an autonomous ability to generate meteorological data (and from them to create meteorological messages of any format) without the need for sounding.

One of the initial insights that the research team brought to the possibility of autonomous determination of meteorological data was work with fire control systems. Some of these software tools make it possible to generate overall reports, for example, for a climate zone and a season, if an actual meteorological message is not available. Determining firing data based on meteorological messages generated in this way can generally be better than working with basic (tabular) values. However, the errors that arise when using such a message can also be very large, and therefore it will be necessary to always conduct fire adjustment. The applicability of this method is thus close to zero, because on the basis of the firing data determined in this way, it will not be possible to conduct accurate fire in the form of effective fire.

For this reason, the research team came up with the idea of working on a similar basis of generating meteorological data based on spatial and temporal conditions, but with a significantly greater degree of detail of the underlying data, which will allow the generation of meterological messages with greater accuracy, which will already allow firing without adjustment.

Historical data was identified as the main source of information, based on which the research team would like to define a predictive (statistical) model from which future meteorological data (meteorological messages) would be generated.

The first step in the research is therefore to determine the initial demands on the spatial and temporal scale for the intended predictive model.

4.1.1 Spatial Scale

In the introductory part, the intention is to create a predictive model that would cover the entire territory of the Czech Republic.

In order to achieve this spatial coverage, it will be necessary to obtain historical meteorological data from the largest possible portfolio of measuring stations, which would adequately cover the entire territory of the Czech Republic. In this area, the first problematic aspect arises regarding the requirements of artillery for meteorological data and the resulting requirements for character of sounding from a given measuring station. One problematic part is the maximum height from which meteorological data is collected. The research project is primarily aim for the firing of 155 mm effectors, which allow firing at distances of up to 40 kilometers. As the distance increases, so does the height that the shell reaches during flight, and thus the height for which meteorological data must be known. In the case of 155 mm effectors, it is necessary to work with height parameters also related to shooting at a high angle, when individual projectiles reach greater heights than when shooting at a low angle (Balon and Komenda, 2006).

According to the basic data on the height scale of 155 mm shells, it is therefore necessary that only those stations that carried out upper air sounding of the atmosphere up to a height of 20,000 meters AGL are selected for the collection of historical data. (Figure 3) The reason why this fact is problematic is that this type of sounding is carried out by only a limited number of meteorological stations on the territory of the Czech Republic. With a smaller number of meteorological stations, the coverage and therefore the accuracy of the predictive model decreases. The further away the place of application of the aggregated meteorological data would be from the meteorological station, the greater the error rate of the predictive model will be.

It is this area that is a possible point of conflict on which the research team plans to work so that it is possible to find ways to also use data from meteorological stations that carry out sounding, for example by ground measurements or at lower altitudes, which would increase the spatial coverage.

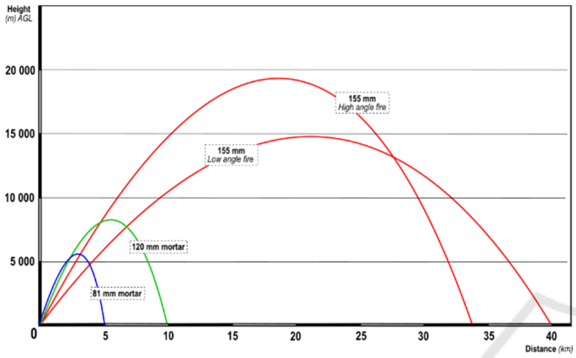

Figure 3: Maximum heights of artillery ammunition flight path.

4.1.2 Temporal Scale

Another addressed area is the temporal scale for which it will be possible to determine data from the predictive model. As already mentioned, the artillery needs to work with the most accurate data possible. The intention of the research team is thus to prepare a framework prediction of the meteorological situation for individual days of the year, with the fact that this general framework will be refined for sub-parts of the given calendar day.

The output will be a predictive model within which artillery specialists will be able to generate a meteorological message for their position and a specific part of the day of the year. Dividing the day into individual time stages will be a separate area of solution, because during the day we will find time periods with higher weather stability and time periods where changes occur (for example, sunrise and sunset, noon, etc.).

4.2 Project Workflow

It is already clear that the creation of such a model will take a large amount of time and work, as it will primarily involve working with a large amount of historical data, which must be analyzed, sorted and aggregated into a predictive model that can be further used in specific applications. The research team has currently defined the successive steps of work on the new project, which they would like to implement in the short, medium and long term horizon.

4.2.1 Phase 1 (Short Term Horizon)

The first phase is primarily aimed at finding out whether the proposed concept of emergency determination of meteorological messages is applicable in terms of accuracy, which means whether the output meteorological data in the form of a meteorological message is accurate.

Therefore, the predictive model in this phase will be processed only for one measuring station (Prague) and a retrospective time horizon of 20 years. The meteorological station in Prague was chosen for the reason, because it meets all the initial requirements, it performs measurements up to the maximum height (30-35 km) and the measured data is stored for further use. For this station, it is thus possible to find historical data up to 49 years back (since 1974). However, the research team defined a limit of 20 years back, which is the time horizon of measurements from which the predictive model will be created.

Complex soundings of the atmosphere at this measuring station take place three times a day (at 0, 6 and 12 hours UTC), outside these dates on request. The predictive statistical model will thus be based on the average values at the height corresponding to the meteorological situation on the ground to determine the meteorological conditions of individual days of the year. This similarity will be defined by the so-called typification of the synoptic situation. Within Phase 1, the biggest challenge will be the processing of a large volume of meteorological data and their interpretation. One of the biggest problems identified will be defining the average weather value for each day of the year.

Approaches to defining the mean value vary, with the research team intending to involve statistical specialists in addition to experts in meteorology and artillery to analyze the data and define the mean value. In general, the biggest crisis point is the determination of extreme values on individual days, which can then affect the mean value. A typical example of this can be, summer storms with hail, which can significantly reduce the air temperature and change the direction and speed of the wind. The exclusion of such values will therefore have to be implemented not only by the professional consensus of artillery experts and meteorologists, but must also be assessed from the point of view of mathematical and statistical methods.

The main goal of this part will be to find out whether it is possible to create an applicable predictive model for artillery and whether it is worth continuing the research. To achieve this goal, a predictive meteorological model will be created for the Prague area. This model will then be verified by a practical experiment. This experiment will consist in the fact that the output from the predictive model is compared with the result from a real upper air sounding of the atmosphere.

If the results of the experiment are satisfactory, the research will continue in phase 2. If not, the research team will look for critical points and try to eliminate them.

At the moment, the research team is already working on phase 1, when it analyzes classified data from the meteorological station in Prague. The intention of the research team is to obtain the first outputs for the processing of the predictive model already in the fall of this year.

4.2.2 Phase 2 (Mid Term Horizon)

If the predictive model is applicable, the research will enter the second phase, the aim of which will be to extend its validity to the entire territory of the Czech Republic. This is a rather challenging part because in phase 1 the predictive model will be defined for only one meteorological station and will be checked for validity at its location. The extension of the predictive model to the entire territory of the Czech Republic, however, brings further challenges that will have to be overcome.

First of all, it is mainly about the fact that it will be necessary to analyze and process meteorological data from other meteorological stations. However, the main problem will be the design of approaches for aggregating the model to spaces outside the source meteorological station so that the predictive model still provides valid data.

In this case, it will be necessary to work with the variability of the terrain, which will influence the station from which the primary data will be obtained, which interpolation method of height data will be chosen, or which numerical model to use and also how the model will eventually compare data between multiple stations according to the position of the firing position, for which meteorological data will need to be determined.

The output of this part should be a predictive meteorological model that will be applicable on the entire territory of the Czech Republic. The verification of its applicability will be realized by two practical experiments. The first experiment will be identical to the experiment based on the comparison with the real upper air sounding of the atmosphere. However, as part of phase 2, this sounding will be carried out by the PODTEO vehicle, which will carry it out in a selected area on the territory of the Czech Republic, outside the stationary meteorological stations.

The second experiment will be based on the use of aggregated data during live artillery fire. In this case, effective fires will be conducted with firing data incorporating meteorological data from the upper air sounding and predictive model. The difference in data will then be compared, as will the accuracy of the resulting fire.

4.2.3 Phase 3 (Long Term Horizon)

The long-term vision of the research implementation is the advanced use of meteorological data and the creation of a progressive version of a predictive statistical model, which would not only determine the meteorological report for a given part of an individual day, but also work progressively with the measured data view of the outlook for the next hours, days to weeks.

By analyzing the measured data, it will be possible to monitor their development over the years, and the goal of the research team is thus to determine the curve of the development of the meteorological situation and the resulting ability to refine the meteorological predictive model in the form of an outlook for the next hours, days or weeks.

5 CONCLUSION

The Emergency METEO project is based on current findings from the war in Ukraine, in which both the benefits and negatives of modern technologies are fully manifested. From the artillery point of view, we can observe that modern technologies significantly advance the capabilities and effectiveness of artillery. It can be observed that accuracy and long range are the absolute basis that define the final effect of an artillery fire. At the same time, we can see how the accumulation of fire is gradually abandoned and the mass deployment of artillery as it was before is already a thing of the past.

As artillery moves from mass deployment to precision target engagements, providing supporting data for fire control support is critical. The ability to deliver meteorological data is thus absolutely essential. However, the environment of modern conflicts is very demanding in terms of capability degradation, where many modern technologies are very sensitive to enemy activity or harsh conditions on the battlefield. The Emergency METEO project thus aims precisely at preserving the ability to supply meteorological data in the event of a degradation of this ability, which can have major consequences.

The intention is to create an aggregated predictive meteorological model based on historical data, with the use of which it would be possible to compile meteorological messages without the need for upper air sounding of the atmosphere or obtaining meteorological data from other, external sources. The solution to the research project is currently in the initial phase when, after defining the content of the project, the research team is developing possible approaches to data evaluation. The initial design works with the hypothesis that data from a predictive weather model will be accurate and applicable to artillery fire. The current phase of developing the predictive model is intended to confirm or refute this hypothesis, or to help identify problematic nodes.

If the research is successful and the predictive meteorological model provides accurate data, it will be a major step towards artillery autonomy. Artillery units of the NATO armies will thus be able to fulfill the tasks of the main type of branch with an expanded capability.

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