Evaluation Approaches for an Aggregated Meteorological Model for Artillery Operations

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Abstract: This article presents a research initiative focused on developing innovative methods of meteorological preparation for artillery units. The ongoing conflict in Ukraine has underscored the pivotal role of artillery for both sides, with its effectiveness hinging on fire accuracy—requiring compensation for multiple variables affecting projectile trajectory. Among these variables, meteorological conditions are paramount and have traditionally been assessed via upper-atmosphere sounding. However, current methods are susceptible to enemy interference, necessitating the autonomous acquisition of meteorological data by artillery units, even under degraded operational conditions. This research project proposes the development of an integrated predictive model that leverages historical meteorological data. Using this model, artillery units would be able to independently generate meteorological insights, eliminating the need for complex atmospheric sounding systems or reliance on external data sources. The article also outlines a proposed method for evaluating the model's effectiveness, based on the General Preparation procedure used in artillery fire control.

1 INTRODUCTION

Although some military theorists forecasted a gradual decline in the tactical relevance of artillery, contemporary conflict dynamics suggest otherwise. The ongoing war in Ukraine clearly illustrates that artillery remains a critical element of force projection, ensuring sustained and effective fire support for maneuver units. This reality invites a nuanced assessment of artillery's operational effectiveness, which is increasingly tied to the integration of supporting technologies and data streams that govern precision targeting and fire planning.

In contrast to other combat support branches such as air defence, engineering, or logistics artillery represents one of the oldest and most continuously evolving military capabilities. Its doctrinal functions and technical applications have undergone multiple transformations in response to changes in warfare, battlefield requirements, and advancements in weapon systems.

Fundamentally, artillery is designed to deliver fire support defined as the provision of fire effects that exceed the direct engagement capabilities of supported units, particularly at extended ranges. Within this framework, precision and reach emerge as the essential factors underpinning artillery utility. Consequently, most historical improvements in artillery technology have centered around enhancing these two attributes (Rolenec et al., 2021).

The present article builds upon prior research presented at ICINCO 2023 (Ivan et al., 2023), offering a significantly enriched contribution. This paper proposes a new approach based on the statistical processing of 20 years of historical atmospheric sounding data from selected meteorological stations, aimed at generating predictive meteorological messages. The proposed method is directly linked to artillery fire control and includes a model evaluation using General

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Preparation methodology. It deepens the theoretical foundation, introduces a rigorous evaluation methodology grounded in the General Preparation procedure, and elaborates on spatial and temporal model structuring relevant to complex operational environments where data acquisition is compromised.

To fully understand how contemporary artillery leverages meteorological information to improve fire accuracy, it is necessary to examine the principles of artillery fire control and the systematic integration of atmospheric data within this process.

2 ARTILLERY FIRE CONTROL

Artillery represents a technically advanced and multi-domain branch of the armed forces, characterized by its demand for a wide spectrum of input data to operate effectively. The artillery system can generally be divided into four fundamental components: weapon–ammunition subsystems, sensor units, fire direction capabilities, and auxiliary or support technologies.

At the forefront of the system are the effectors, which are the terminal platforms responsible for delivering kinetic effects. These include tube artillery (howitzers and cannons), mortars, and multiple launch rocket systems (MLRS). For these weapon systems to function with the required precision, they must be supplied with reliable firing data. This data set comprises spatial orientation and position of the firing unit, ballistic characteristics of the selected ammunition, and environmental factors - primarily meteorological conditions - that influence projectile behavior during flight.

The computation and provision of this firing data falls under the responsibility of fire direction centers. These command nodes integrate data streams from supporting assets and sensor systems to calculate firing solutions. Sensors, which are critical for observing impacts and facilitating corrections, may include electro-optical devices, laser rangefinders, radar systems, or UAV-mounted platforms. Their purpose is to relay observed point-of-impact information back to fire control units, enabling real-time corrections.

Fire control itself forms the operational core of artillery employment. It encompasses a coordinated sequence of tasks: planning, fire mission allocation, preparation, and direction of fires in alignment with mission intent. The primary objective is to maximize destructive or suppressive effects on designated targets.

Artillery fire control is structured into two distinct but interdependent domains:

Tactical fire control operates at the mission planning level. It involves choosing the optimal firing unit based on current battlefield conditions, logistical status, ammunition availability, and the overall tactical picture (Świętochowski, 2019). This layer aligns artillery effects with maneuver elements and broader operational goals.

Technical fire control deals with precise adjustment of firing parameters. These include calculations for azimuth, elevation, and propellant settings based on weapon configuration, ballistic tables, and environmental corrections (Blaha et al., 2016). The process may be executed manually by trained personnel or through automated means using digital fire direction systems and ballistic software. Depending on the level of technological integration, technical fire control is categorized as either manual (human-calculated) or automated (computer-assisted).

3 METEOROLOGICAL TECHNIQUES

Meteorological support constitutes an essential pillar of effective artillery fire control and target engagement procedures. The ballistic path of an artillery projectile is inherently sensitive to a variety of atmospheric parameters, which must be accurately accounted for when generating firing solutions. Without proper environmental compensation, the likelihood of first-round target effects is significantly reduced.

Although specific methodologies for integrating meteorological data into fire control vary from country to country, there is a common operational consensus regarding the core atmospheric variables that influence projectile trajectory. These typically include:

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

By incorporating real-time or highly relevant meteorological inputs into the fire direction process, artillery units gain the ability to engage targets without the need for prior adjustment salvos. This capability enhances operational tempo, supports rapid fire missions, and contributes to achieving tactical surprise, thereby increasing the lethality and effectiveness of indirect fire (Němec et al., 2022).

Meteorological considerations also play a key role in the operational mobility of artillery assets. The selection and planning of movement corridors linking concealment zones, firing positions, and logistical resupply points must reflect not only tactical and terrain-based factors but also prevailing and forecasted weather conditions. Ensuring mobility, safety, and minimal exposure during transit is particularly critical in dynamic combat scenarios where the tempo of operations requires fast and often pre-programmed route selection for reconnaissance vehicles, fire support platforms, and logistic convoys (Nohel et al., 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.

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 (Fig. 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 (Fig. 2).

These radiosondes transmit meteorological data to the RT20 radiotheodolite (Fig. 3). 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.

Figures 2 and 3: Radiosonde and radiotheodolite RT-20.

3.2 Meteorological Messages

Meteorological messages represent the fundamental output derived from upper-atmosphere soundings, providing artillery and other combat elements with vital environmental parameters. These reports encapsulate a variety of atmospheric metrics, such as surface-level pressure, virtual temperature, ground-level wind vectors, and aggregated indicators like average air density and temperature gradients, wind profiles across selected altitudinal bands, and other parameters relevant to ballistic computations.

The structure of these messages follows a strict alphanumeric coding scheme. Data are encoded into specific two and multi-digit numeric groups, where each digit within a group conveys a predefined physical quantity or state. The group positions are fixed within the message format, allowing the decoding software or operator to reliably extract and interpret environmental data from the positional context of each number. The sequential arrangement of these groups in the message further denotes the type and relevance of each dataset.

In practical artillery application, several variants of meteorological messages are in routine use, such as Meteo 11, METCM, METGM, METB3, and METBK, depending on national doctrine and equipment. These formats are either directly processed by automated fire control systems or manually interpreted to derive necessary corrections for computing firing parameters.

Having access to these encoded meteorological datasets is essential to achieving first-round target effects without requiring bracketing or correction salvos. The operational ability to autonomously produce and disseminate these reports is therefore critical to preserving the initiative, enhancing the element of surprise, and ensuring accurate and lethal artillery engagement (Blaha et al., 2018).

3.3 Identified Downsides

Upper air sounding represents a well-established technique for acquiring current atmospheric profiles in proximity to deployed artillery assets. Its principal advantage lies in the ability to collect real-time meteorological parameters at the location of interest. However, despite its operational utility, this method exhibits several critical limitations that restrict its broader application on the modern battlefield.

One of the key disadvantages is the limited spatial validity of the collected data. Meteorological information obtained via radiosonde release is highly localized, making it less applicable for dispersed or maneuvering fire units. Moreover, the method's reliance on active signal transmission exposes the meteorological system to detection, geolocation, and subsequent kinetic targeting by adversaries. This vulnerability has been repeatedly observed in the context of the Ukraine conflict, where hostile forces prioritize the neutralization of meteorological capabilities to degrade artillery accuracy (Hrnčiar & Kompan, 2023). These vulnerabilities have been confirmed in operational scenarios where adversaries employed electronic warfare and long-range fires to suppress meteorological units, thereby degrading the accuracy of artillery fire. This highlights the urgent need for methods resilient to enemy interference, including passive and autonomous solutions.

A further drawback stems from the logistical and personnel dependencies associated with upper air sounding. Radiosonde operations require specialized hardware and trained operators. Any disruption—whether through equipment failure, attrition, or operational constraints—can render the meteorological support function inoperable. The absence of atmospheric correction data reduces the effectiveness of artillery fire missions, increasing ammunition expenditure and logistical strain—factors that carry growing strategic weight in prolonged high-intensity conflicts (Šlouf et al., 2023).

In response to these limitations, alternative data sources have been explored, including the use of gridded meteorological fields generated by the World Area Forecast Center (WAFC). These datasets offer broader spatial coverage and eliminate the need for on-site radiosonde launches. However, the geographic distance between WAFC sampling grids and actual artillery positions can result in data inaccuracies. Furthermore, in active conflict zones, reliability of data transmission becomes problematic due to adversarial electronic warfare capabilities.

A notable operational challenge lies in the distribution of meteorological messages. In contemporary conflicts such as that in Ukraine, advanced electronic attack systems have demonstrated the capacity to jam or intercept electromagnetic signals. This affects both the uplink from airborne sensors and the downstream dissemination of WAFC products. Consequently, reliance on transmission-based meteorological support may prove untenable under degraded conditions (Blaha & Brabcová, 2010).

Given these constraints, it becomes imperative to explore passive, autonomous meteorological solutions that are independent of real-time sensing and communication. Such systems must be resilient to electronic disruption and capable of supporting artillery fire control even under conditions of partial or total sensor denial.

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

Project is based on the previous research areas which dealt with artillery survey and meteorological units (Ivan et al., 2023; Ivan et al., 2022) The core objective of the project revolves around achieving autonomous generation of meteorological data and subsequent creation of meteorological messages, eliminating the dependency on traditional sounding methods.

Initially, the research team recognized the potential for autonomously determining meteorological data through their work with fire control systems.

Some of these software tools enable the generation of comprehensive reports for specific climate zones and seasons, even in the absence of actual meteorological messages. While deriving firing data from such generated messages may generally yield better results than relying solely on basic tabular values, the margin of error can still be significant, often necessitating subsequent fire adjustments. Consequently, the practical feasibility of this method is minimal, as it does not guarantee accurate fire effectiveness.

In response, the research team proposed a more detailed approach to generating meteorological data based on spatial and temporal conditions. This enhanced method aims to utilize a richer dataset to produce meteorological messages with greater precision, facilitating firing without the need for subsequent adjustments.

The team identified historical data as the primary information source to develop a predictive (statistical) model for generating future meteorological data (meteorological messages). The initial phase of the research focuses on defining the spatial and temporal scales required for the intended predictive model. This step lays the groundwork for subsequent model development and refinement.

4.2 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.

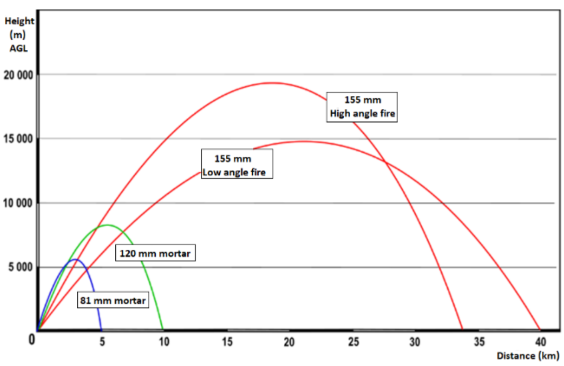

Figure 4: Maximum heights of artillery ammunition flight path.

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. (Fig. 4) 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.

4.3 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.).

4.4 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.

4.5 Phase 1 (Short Term Horizon)

The primary objective of the first phase is to assess the feasibility and accuracy of the proposed emergency determination of meteorological messages. This involves verifying whether the generated meteorological data accurately reflect the conditions, particularly in terms of their representation within meteorological messages.

During this initial phase, the predictive model will focus solely on data from one measurement station, specifically Prague, spanning a retrospective period of 20 years. Prague was chosen due to its adherence to initial requirements, including comprehensive measurements up to maximum altitudes (30-35 km) and data storage capabilities dating back to 1974. However, for model creation, only data from the last 20 years will be utilized. At the Prague station, atmospheric soundings occur thrice daily (at 0, 6, and 12 hours UTC), with additional soundings available upon request.

The primary aim of this phase is to ascertain the feasibility of creating an applicable predictive model for artillery purposes, with a practical experiment planned to validate the model's accuracy against real upper air sounding data. Successful results will pave the way for phase 2, while any shortcomings will prompt critical analysis and refinement.

4.6 Phase 2 (MID Term Horizon)

If the predictive model proves effective, the research will advance to the second phase, aimed at expanding its applicability to the entire Czech Republic. This phase poses significant challenges as the initial model, developed in phase 1 for a single meteorological station, must now be extended to cover the entire country.

One major challenge involves analyzing and processing meteorological data from multiple stations across varied terrain. Aggregating the model to areas beyond the source station requires careful consideration of terrain variability, selection of interpolation methods for height data, choice of numerical models, and comparison of data from multiple stations relative to firing positions.

The objective of this phase is to produce a predictive meteorological model applicable across the Czech Republic.

4.7 Phase 3 (Long Term Horizon)

The overarching goal of the research implementation is to advance the utilization of meteorological data by developing an enhanced version of a predictive statistical model. This progressive model aims not only to generate meteorological messages for specific times within a day but also to forecast outlooks for the upcoming hours, days, and even weeks.

The ultimate objective is to discern the trajectory of meteorological patterns over time, enabling the refinement of the predictive model to provide increasingly accurate forecasts for various time frames, ranging from hours to weeks ahead.

5 APPROACH TO MODEL EVALUATION

Apart from the creation of the meteorological model, it was necessary to define the method of its evaluation. Considering that this is a meteorological model initially defined for use with artillery units, the methodology of its evaluation was defined following its direct use in determining the firing data. For the evaluation of the model, the evaluation method was determined in the first phase in the sense of the method of determining the firing data - specifically, the General preparation of the firing data was chosen. This method of determining the firing data was chosen because it is a method in which the firing data are determined for actual meteorological, ballistic and geophysical influences. General preparation thus applies all measurable effects of both the weapon and the surrounding environment to the firing.

5.1 Phase 1 (Short Term Horizon)

General preparation is one of the main ways of firing data preparation in the artillery of the Czech Army. This method of firing data preparation is used, with partial differences, by most of the artillery of various armies around the world. The main purpose of the general preparation is to determine all possible measurable influences with effect on the artillery shell and thereby changing its trajectory. Within artillery, there are always defined tabular firing conditions. If the real conditions are different, the trajectory of the shell deviates. As part of the general preparation, the main purpose is to find out the changes in the real conditions compared to the tabular values, and for these changes to clearly define the variation in the trajectory of the shell in direction and distance. The general preparation of firing data generally works with three groups of effects causing the variation of the trajectory of the shell for which it determines the corresponding distance (ΔD) and deflection (ΔS) corrections for meteorological, ballistic and geophysical effects according to equations (1) and (2).

$$\Delta D = \Delta DM + \Delta DB + \Delta DG \quad (1)$$

$$\Delta S = \Delta SM + \Delta SB + \Delta SG \quad (2)$$

Where:

ΔD is total range correction for actual conditions

ΔS is total deflection correction for actual conditions

$\Delta DM/\Delta SM$ is range (direction) correction for changes in meteorological conditions

$\Delta DB/\Delta SB$ is range (direction) correction for changes in ballistic conditions

$\Delta DG/\Delta SG$ is range (direction) correction for changes in geophysical conditions

Meteorological Conditions.

Meteorological conditions include effects that affect the distance and deflection of the firing after the shell leaves the barrel. The influence of meteorological conditions was sufficiently described in the previous parts of this article. Changes in meteorological conditions are obtained from the meteorological message METEO 11. Using data from this meteorological message distance corrections will be calculated for the following influences (Equation 3):

- change in ground air pressure at the altitude of the firing position;
- change in air temperature at standard meteorological altitudes;
- direction of ballistic wind;
- ballistic wind speed.

$$\Delta DM = \Delta D\Delta H + \Delta D\Delta T + \Delta D\Delta W \quad (3)$$

Where:

ΔDM is range correction for changes in meteorological conditions

$\Delta D\Delta H$ is range correction for change of barometric pressure

$\Delta D\Delta T$ is range correction for change of air temperature

$\Delta D\Delta W$ is range correction for range wind

As part of the calculation, the individual components of the influences defined by equations (4) to (8) are followed.

$$\Delta D\Delta H = \Delta HB \times 0{,}1 \times \Delta XH \quad (4)$$

Where:

$\Delta D\Delta H$ is range correction for change of barometric pressure

ΔHB is actual change of surface barometric pressure

ΔXH is unit range correction for barometric pressure change of 10 Torr

The individual measured variables must be expressed as a difference from the tabular values as part of the calculation of total corrections in distance and deflection. The exact difference values from the tabular values are determined by the following equations.

$$\Delta HMDP = H - 750 \quad (5)$$

Where:

$\Delta HMDP$ is change in surface barometric pressure

H is actual barometric pressure in altitude of meteorological unit

750 is tabular barometric pressure value (750 Torr)

$$\Delta D\Delta T = \Delta\tau \times 0{,}1 \times \Delta XT \quad (6)$$

Where:

$\Delta D\Delta T$ is range correction for change of air temperature

Δτ is actual change of air temperature in selected altitude

ΔXT is unit range correction for air temperature change of 10 °C

$$\Delta T = T - 15{,}9 \quad (7)$$

Where:

ΔT is change in air pressure

T is actual air temperature in altitude of meteorological unit

15,9 is tabular air temperature (15,9 °C)

$$\Delta Dwx = wx \times 0{,}1 \times \Delta Xwx \quad (8)$$

Where:

ΔDwx is range correction for range wind

wx is actual value of range wind

ΔXwx is tabular correction for range wind of 10 m.s-1

Using data from this METEO 11 meteorological message, deflection corrections calculated for the transverse component of the ballistic wind will be determined (Equation 9)

$$\Delta SM = \Delta SW \quad (9)$$

Where:

ΔSM is total deflection correction for changes in meteorological condition

ΔSW is deflection correction for cross wind

$$\Delta Sw = wz \times 0{,}1 \times \Delta Zwz \quad (10)$$

Where:

ΔSw is deflection correction for cross wind

wz is actual crosswind value

ΔZwz is tabular correction for cross wind of 10 m.s-1

Ballistic wind is a specific term that describes how much wind, defined by direction and speed, affects the flight of the shell. Depending on the direction in which the ballistic wind affects the flight of the shell, we decompose the range and cross wind vector. For the distribution into individual vectors, it is first necessary to determine the angle of wind according to equation (5).

$$Aw = \alpha S - \alpha w \quad (11)$$

Where:

Aw is angle of wind

αS is direction of fire

αw is direction of wind

Individual vectors are then determined according to equations (6) and (7).

$$wx = w \times \cos Aw \quad (12)$$

$$wz = w \times \sin Aw \quad (13)$$

Where:

wx is actual value of range wind

wz is actual value of cross wind

w is actual value of wind speed

Aw is angle of wind

Ballistic conditions.

Ballistic firing conditions are determined during a process known as ballistic preparation. Ballistic conditions include those influences that affect the distance and deflection of the firing and are active mainly until the moment when the shell leaves the barrel and partially also on the flight path of the shell. Ballistic effects depend on the type and construction of the effector and the type of used ammunition. For the purposes of evaluating the meteorological model, the firing data will be prepared for the standard effector of the Army of the Czech Republic, namely the 152mm SPG M-77 DANA.

The purpose of the ballistic preparation is to determine the changes in the ballistic characteristics of the effector and ammunition against the tabular values. Based on the identified changes from the tabular values, distance and direction corrections for ballistic firing conditions are then prepared (Equations 14 and 15).

$$\Delta DB = \Delta Dv0 + \Delta DCT + \Delta DCh + \Delta DCol \quad (14)$$

Where:

ΔDB is total range correction for changes in ballistic conditions

$\Delta Dv0$ is range correction for change in muzzle velocity

ΔDCT is range correction for change in charge temperature

ΔDCh is range correction for change in used charge type

$\Delta DCol$ is range correction for change in unpainted shell body

For the evaluation of the proposed meteorological model, all ballistic effects listed above will be evaluated as tabular. This solution was chosen in order to distance and deflection corrections caused by changing meteorological conditions stand out clearly. Simply said, the values inserted into equation (14) will be zero.

In the case of direction correction, the only influence considered is spin drift, which is the lateral (directional) deviation of the shell caused by the rotation of the shell (Equation 15). This phenomenon is caused by rotational stabilization, which helps to direct and thus improve the accuracy of the shell's flight. The rotational movement is given to the shell by the bore of the barrel. Spin drift is thus a phenomenon that manifests itself in all guns with a grooved barrel bore. It is obvious that this phenomenon is negligible for small caliber weapons. However, with increasing firing distance, the lateral deviation of the shell increases, and if the firing was not compensated for spin drift, the target would not be hit. This is especially evident with artillery weapons, which can fire at a distance of several dozens of kilometers.

$$\Delta SB = Z \quad (15)$$

Where:

ΔSB is total deflection correction for change in ballistic conditions

Z is tabular deflection correction for spin drift

Spin drift values are clearly defined in the firing tables for each distance, and it is thus possible to quantify them precisely. Unlike ballistic influences affecting the distance, the spin drift will not be zero, but will correspond to precisely selected distances.

Geophysical Conditions.
Geophysical conditions can have a large effect on the direction of artillery fire. In particular, the direction and speed of the Earth's rotation have significant consequences for the artillery fires.

A crucial variable is the Coriolis Effect: Due to the Earth's rotation, a shell moving on the Earth's surface has an apparent deflection due to the Coriolis Effect. This effect is caused by a combination of the Earth's rotation and the forward motion of the shell. In the Northern Hemisphere, the influence of the Coriolis effect is such that shells seem to deflect to the right, while in the Southern Hemisphere the deflection is to the left. This variation is most noticeable with long-range shells or shells fired on long distances.

Another necessary variable is the speed of the Earth's rotation. The speed of the Earth's rotation also affects artillery fire, especially when it comes to variations caused by the Corio-press effect. At locations with a higher rotational speed of the Earth, such as the equator, the deviations caused by the Coriolis effect are more significant than at locations with a lower rotational speed, such as the poles.

Consider these geophysical phenomena is necessary for accurate calculation of firing data and effective target engagement, especially in long distances fires or in different geographical areas. The rules of firing and fire control in the Czech Army assess the geophysical effects during artillery fire at distances of less than 25 km as negligible. Due to the fact that for the evaluation of the model, the effector will be 152mm SPG M-77 DANA, whose maximum range is around 20 kilometers, geophysical influences will be considered as zero for the evaluation of the meteorological model.

5.2 Initial Conditions for Model Evaluation

The general preparation of firing data for artillery fire has clearly established conditions of its execution. These conditions relate to the spatial validity of distance and direction corrections, requirements for the distance of the meteorological station from the firing position, etc.

From the point of view of the verification of the meteorological model, these conditions had to be modified in such a way that its applicability could be qualitatively evaluated. From the point of view of spatial validity, it was first of all necessary to define for which firing directions and distances the meteorological model will be evaluated, while the basic principle applied by the authors in the evaluation proposal was complexity. For this reason, 4 main directions of distance were defined, which are identical with the cardinal directions, i.e. North, South, East and West. In the first instance, the author's collective assessed a more detailed distribution of the firing directions as inexpedient. However, the situation is different in the case of the distance of the firing. In this case, the authors' effort was to comprehensively divide the maximum firing distance of the 152mm SPG M-77 so that all individual layers of the meteorological report were covered, and the model thus comprehensively covered both the firing distance and equally divided meteorological sounding altitudes. For this reason, the firing data were calculated for the distance of 6, 7.8; 10; 10.4; 12.2; 13; 13.8; 14.8; 17.1 and 18 kilometers. One of the main aspects of the evaluation is that, unlike the standard use of a meteorological station, the process will be set up so that the meteorological station is placed in exactly the same position as the firing unit, which is the location for which the firing data will be calculated (Fig. 5).

The evaluation process itself will then be based exclusively on the basis of comparative analysis, when the total range and deflection correction calculated by the general preparation method using the meteorological message compiled using the meteorological model and the real meteorological message obtained from real measurements will be evaluated against each other. Overall, the meteorological model will be evaluated by a comparative analysis of the General Preparation calculated for all indicated directions and all distances. In total, there will be 44 results of general preparation calculated according to the meteorological model and 44 results of general preparation calculated according to the real meteorological report.

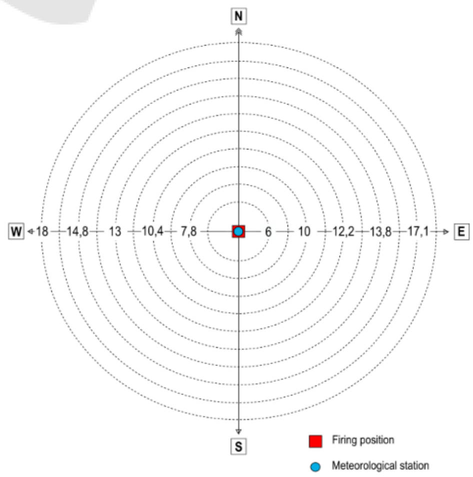

Figure 5: Positional chart for comparative calculation of general preparation.

However, such an evaluation would lack a time variable. For this reason, the same calculation/comparison process will be performed for four different times. Specifically, it will be real meteorological reports obtained in each quarter of the year.

The own evaluation of the comparative data will also be a separate variable. Due to the circularity of the network (Fig. 5) and the change in time data, the author's team is considering the application of the Rose diagram method.

6 CONCLUSION

The Emergency METEO project originates from recent observations in the conflict in Ukraine, where the impact of modern technologies on warfare, both positive and negative, has become evident. In terms of artillery, modern technologies significantly enhance its capabilities and effectiveness. Accuracy and long range are fundamental factors determining the outcome of artillery fire, leading to a shift away from mass deployment towards precision targeting.

In this evolving landscape, providing meteorological data for fire control support becomes crucial. However, modern conflict environments pose challenges such as capability degradation due to enemy activity or harsh battlefield conditions. The Emergency METEO project aims to safeguard the supply of meteorological data in such scenarios, recognizing its critical importance.

The project's goal is to develop a predictive meteorological model based on historical data. This model would enable the generation of meteorological messages without relying on upper air sounding or external sources. Currently in its initial phase, the research team is exploring various approaches to data evaluation. The project's hypothesis is that data from a predictive weather model will be accurate and applicable to artillery fire. The ongoing development phase aims to validate this hypothesis and identify any potential issues.

One of the key elements of model development is its evaluation. This evaluation must be complex and precise enough, to discover all possible inaccuracies. Because of this, it is essential to conduct the evaluation in a way that corresponds to calculation of firing data since the model is created mainly for artillery. Evaluation done in a proposed way will ensure that all minor flows would be discovered and ensures whether it is possible to continue in development process and research itself.

The model's usefulness will be explicitly evaluated by comparing corrections derived from the predictive data to those based on real atmospheric soundings across 44 scenarios and 4 seasonal periods, offering a statistically grounded measure of operational applicability.

Success in this research would represent a significant advancement towards artillery autonomy. NATO artillery units would gain expanded capabilities, allowing them to fulfill their primary tasks more effectively.

Although current results are preliminary, future phases of the project will focus on structured evaluation of model output using archived METB3 data and firing-table-derived indicators of ballistic accuracy.

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