METEO11 Meteorological Message gained from the METB3, METCM or Abstract of Measured Meteorological Data

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ABSTRACT

Artillery of some NATO armies, especially of the former Eastern bloc states, still use the non-standard METEO11 meteorological messages for firing data calculations. If these countries are unable to carry out comprehensive meteorological soundings, the other states in the multinational task forces can distribute them the METB3 and METCM meteorological messages, standardized in NATO. There is a problem that they do not have adapted their fire control systems for using the METB3 or METCM meteorological messages and therefore they cannot be adequate partners for other NATO countries. This long-term incompatibility is caused by different model of tabular atmosphere and non-standard firing tables. In order for these countries to become fully interoperable partners in NATO, it was necessary to carry out a research to compile the METEO11 meteorological message from standardized meteorological products available to all NATO partner states. The paper summarizes the results of this research and analyses the accuracy of developed METEO11 alternative methods. Solving of the problem lies on the ability to compose METEO11 meteorological message according to an abstract of a measured meteorological data and in the ability to carry out conversions of the METB3 or METCM meteorological messages. Authors had derived all needed mathematical models, which they implemented into the new software "METEO11 MAKER" and "METCM & METB3 to METEO11".

Keywords: Artillery, Meteorological Message, METEO11, METCM, METB3, Artillery Fire Control System, GOST 4401-48, ICAO, METEO11 MAKER, METCM & METB3 to METEO11.

1. INTRODUCTION

Within the NATO, there has been a long-term effort to unify the artillery caliber of all member countries and to standardize processes in automated fire control systems [1]. Unified caliber will streamline the supply of artillery ammunition in the future and a unified concept of automated artillery fire control systems will enable cooperation, data exchange and eventual a centralization of NATO artillery control. However, some states cannot afford purchase of new NATO standard-caliber weapon systems and develop or purchase of a new automated artillery fire control system for financial or other reasons.

The non-standard caliber is related to another concept of artillery firing data preparation, based on a different standard atmosphere model, input data or physical units [2], [3], [4]. The differences are evident especially in the field of meteorological preparation process of the weapon systems manufactured in the past by the former Eastern Bloc countries. These states must use a METEO11 non-standardized meteorological message format to calculate firing data of their weapon systems. Therefore, their artillery cannot be a full-featured partner to Western Alliance states. For this reason, a research has been carried out to determine the mathematical models of alternative compilation methods of the METEO11 meteorological message and the development of the application support, which implemented defined mathematical models. Derived calculation procedures and developed software can now provide interoperability of countries using METEO11 with other NATO countries in the field of meteorological preparation process.

2. ENSURING AN INTEROPERABILITY IN THE FIELD OF THE ARTILLERY METEOROLOGICAL PREPARATION PROCESS

The non-standardized format of the METEO11 meteorological message comes out from the non-standardized concept of firing tables and the atmosphere model, based on the state standard of the former USSR, labeled GOST 4401-48. The NATO standard atmosphere model is based on the model of the International Civil Aviation Organization (ICAO) model, described in STANAG 4044 [2]. Standard meteorological message formats in NATO include, in particular, METCM [4] for computer processing, and METB3 [5] used in manual calculations.

The significance of data in the METB3 [5] and METCM [4] meteorological messages, compiled according to the ICAO atmosphere model [2] and for use with STANAG 4119 [6] firing tables, is completely different from that of the METEO11 meteorological message [5]. Also different is the system of artillery firing data preparation methods.

The solution of the introduced problem in the interoperability between former Eastern Bloc and other NATO countries lies in the ability to:

- Compile a meteorological message in the METEO11

format on the basis of other data that can be obtained from foreign meteorological units;
- Convert meteorological message from the METB3 or METCM to the METEO11 format with adequate accuracy.

Converting the METB3 or METCM meteorological messages to the METEO11 format will always be influenced by errors due to differences in the meaning of particular data and ways of determining the data in the each type of the meteorological messages, the differences between the standard atmosphere models and the need to perform numerous interpolation of data between large height ranges. The most efficient and most accurate way to gain a METEO11 meteorological message is based on the abstract of a measured meteorological data that can be generated by the MARWIN MW32 meteorological set of any NATO state. If abstracts of the measured meteorological data cannot be retrieved, artillery should be able to convert the meteorological messages METB3 and METCM (less accurate method).

3. METEO11 MAKER SOFTWARE

The METEO11 meteorological message calculation system according to abstract of a measured meteorological data was presented at the conference ICMT 2017 [7]. The characterized calculation procedure [7] was implemented into a new application (figure 1), which allows the OriginalMetData file (generated by MARWIN MW32 meteorological set) to be loaded and then to compile the METEO11 meteorological message.

Figure 1 - Example of the METEO11 meteorological message composed by the METEO11 MAKER

The METEO11 MAKER software calculates the medium values of meteorological elements up to the 12 000 meters standard height (SH), while also checking that there is enough data in the OriginalMetData file needed to compose the METEO11 meteorological message. If the meteorological sounding has not been carried out at a minimum of 12 kilometers, the program will only compose the METEO11 meteorological message for the SHs for which it has sufficient information from the meteorological sounding and will warn the user.

4. METCM & METB3 TO METEO11 SOFTWARE

The mathematical model of the METB3 meteorological message conversion to the METEO11 format was published at the conference ICMT 2017 [8]. The first METCM meteorological message conversion to the METEO11 was published in the journal [9]. The conversion process described in journal [9] is based on the calculations of meteorological data after 50 meters of altitudes above the artillery meteorological station (unit). Carried out interpolations of meteorological data during conversion and including differences between standard atmosphere models and physical units basically simulates meteorological soundings by radiosonde, during which meteorological data are collected after 50 meters, and after that the medium meteorological data of the METEO11 meteorological message are calculated.

When the METCM & METB3 to METEO11 software was developing, authors reworked the mathematical model of the conversion published in the journal [9]. The modified method of the METCM conversion to the METEO11 format allows more accurate calculations of the medium meteorological data than the first method [9], especially in the higher SHs of the METEO11. The original mathematical model was limited to the SH of 3 000 meters in the METEO11 meteorological message and to the wind changes from the 00 zone to the 07 zone of maximum 3200 mils (mil – former Eastern Bloc artillery angular rate: $1°=16.6\overline{6}$ mils, $3.6'=1$ mil, 1 circle =6000 mils). The new conversion model lets us convert the METCM up to the METEO11 SH of 12 000 meters.

The METCM & METB3 to METEO11 software allows generating the METEO11 meteorological message according to the inserted METCM or METB3 meteorological message. The software allows maximum intuitive manipulation, even without a manual for use. The individual controls are hidden from the user until they can be used. Required user inputs are minimized as much as possible in the software.

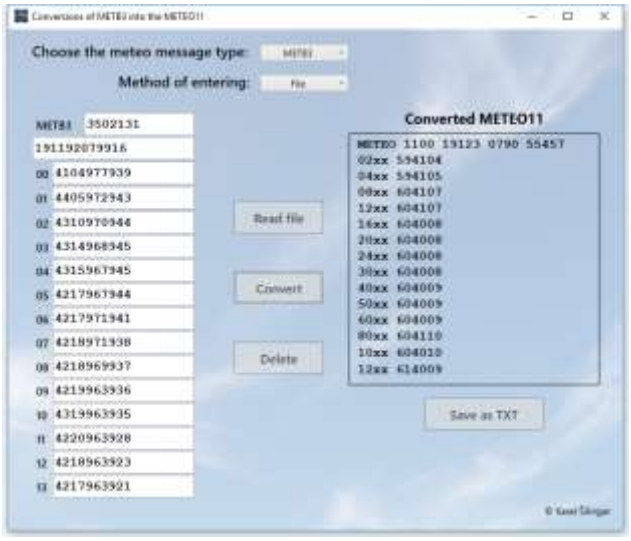

Figure 2 - METCM & METB3 to METEO11 software

5. GENERAL CONCLUSIONS OF THE METEO11 ALTERNATIVE COMPILATION METHODS ANALYSIS

The analysis of the METEO11 meteorological message alternative compilation methods accuracy was carried out using METEO11 meteorological messages, abstracts of the measured meteorological data files (OriginalMetData files) and METB3 and METCM meteorological messages, which were available from the complex meteorological soundings conducted by the artillery regiment, which cooperated in the research (i.e. from the 13th artillery regiment of the Czech Army Forces).

The METEO11 meteorological messages were generated by the METEO11 MAKER software according to the abstracts of the measured meteorological data and by the METCM & METB3 to METEO11 software were converted the METEO11 from the METCM and METB3 meteorological messages. According to the original METEO11 meteorological messages (generated by the MARWIN MW32 from the same meteorological sounding) and METEO11 meteorological messages from the METEO11 MAKER and METCM & METB3 to METEO11 software errors were calculated. The detected errors were the differences between the partial values in the original METEO11 and in the METEO11 compiled by the METEO11 MAKER and METCM & METB3 to METEO11 software. They were used to perform a subsequent statistical evaluation of the calculation methods accuracy.

To analyze the accuracy of the METEO11 meteorological message alternative compilation methods, the error values with signs and their absolute expressions were used. The error values with signs were used to characterize probability divisions of the error patterns. The relation of the selected statistical characteristics to the absolute values of the errors made it possible in particular to characterize the greatest impacts on the artillery shooting errors (deviations) due to the nature of the manual calculations concept of the total repairs. If the calculated meteorological data is used for manual calculations of distance and direction corrections for meteorological conditions, the error sign will only indicate whether the deviation of the artillery shell impact point occurs before or behind the point that would be obtained by shooting with firing data calculated using the original METEO11 meteorological message from the MARWIN MW32, respectively to the right or left of this point.

The signs of the errors did not have a regular course, and were often based only on the way in which the MARWIN MW32 rounded off the values when compiling the actual METEO11 meteorological message. In manual calculations of artillery firing data, it is always based on one SH, whose data is considered as average for the whole ballistic curve, and therefore some statistical characteristics were related to the absolute values of partial data calculation errors in the METEO11 meteorological message. The signs of partial errors can also mean a mutually excluding of errors, which results from the scalar product of the missile motion vector on the ballistic curve, the wind vector acting on the missile and the vector of the influence of the air temperature on the distance of the firing. In the most unfavorable cases, partial errors will affect the overall error of determining a total correction for meteorological conditions in the same sense.

In order to assess the accuracy of the individual methods of alternative compilation of the METEO11 meteorological message, the selected basic statistical attributes were calculated, which allowed to construct inductive conclusions on the accuracy of individual methods. The arithmetic means of errors, average error deviations from the arithmetic means of errors and the sample standard deviations were gradually calculated from the errors detected in the each SH of the METEO11 meteorological messages. The average error deviations indicate an error variability with respect to the arithmetic means of errors (averages) and represent their average differences. The sample standard deviations allow for the estimation of statistical variability of the errors and a better idea of the probability functions courses of the errors in the each SH of the METEO11 meteorological message. Probable error functions in the each SH will further become symmetrical by zero or close to zero (considering the sign values), and the values of the slope coefficients and spikes of these functions will also be close to zero with respect to the probability distribution model.

In this paper the values of calculated selected statistical characteristics are presented in the following tables. For better clarity of defined conclusions, average errors are presented in charts. Values of statistical attributes using absolute values are not presented.

The medium changes of the virtual air temperature

The arithmetical means of errors (arithmetical means), average error deviations (mean deviations) and sample standard error deviations in the calculation of the medium changes of the virtual air temperature in the each SH of the METEO11 meteorological message are presented in the Table 1. Cells with calculated values of statistical characteristics contain data streams that help to estimate the course of the values in the Table columns. The values in the Table 1 are in degrees of Celsius.

Virtual air temperature									
Stand. height [m]	Arithmetic means			Mean deviations			Sample stand. error deviation		
	Abstract	METB3	METCM	Výpis	METB3	METCM	Výpis	METB3	METCM
200	0.36	0.39	0.38	0.46	0.48	0.51	0.49	0.50	0.55
400	0.24	0.26	0.26	0.37	0.39	0.39	0.44	0.45	0.45
800	0.24	0.39	0.32	0.41	0.48	0.48	0.50	0.50	0.53
1200	0.34	0.22	0.21	0.45	0.48	0.33	0.48	0.60	0.41
1600	0.34	0.30	0.26	0.49	0.54	0.39	0.55	0.63	0.45
2000	0.34	0.09	0.15	0.49	0.33	0.31	0.55	0.53	0.44
2400	0.19	0.09	-0.06	0.36	0.33	0.17	0.47	0.53	0.35
3000	0.22	0.05	-0.03	0.44	0.35	0.18	0.55	0.65	0.39
4000	0.06	-0.09	-0.24	0.18	0.33	0.37	0.35	0.53	0.44
5000	0.09	-0.05	-0.33	0.28	0.26	0.44	0.47	0.49	0.48
6000	0.06	0.23	-0.39	0.18	0.60	0.48	0.36	0.87	0.50
8000	0.03	0.68	-0.48	0.06	0.68	0.53	0.18	0.78	0.57
10000	0.04	0.85	-0.78	0.07	0.90	0.36	0.19	1.14	0.51
12000	-0.04	0.67	-0.84	0.17	1.52	0.27	0.37	1.75	0.37

Table 1 Selected statistical characteristics – medium changes of virtual air temperature

The red frames in the Table 1 represent the average errors of the virtual air temperature (arithmetical means of errors) that are greater than 0.5. If the average error is less than 0.5, then the calculated values (after rounding) will in most cases coincide the actual ones. The greatest emphasis is for the virtual air temperature calculation because its influence is the largest of the meteorological data used when calculating the artillery firing data.

If the sum of the absolute value of the average error and the absolute value of the mean deviation is greater than 1, it can be assumed that the calculated values of the medium change of the virtual air temperature will in most cases be different by one or

more degrees of Celsius. Such values of mean deviations are highlighted in Table 1 with green frames.

If the sum of the average error and the sample standard error deviation (in absolute terms) is greater than 1, it can be assumed that 68 % of the most accurate results of the medium changes of the virtual air temperature calculations will not achieve a better accuracy than 1 degree of Celsius. These values of the sample standard error deviations are represented by purple frames. 95 % of the calculated medium changes of the virtual air temperature in these SHs will be scattered around their average errors within a range of two times of the sample standard error deviation values.

For the artillery firing data calculations should be used only the values of the medium changes of the virtual air temperature from the alternatively compiled METEO11 meteorological message (from its SHs) for which the sums of the average error with the mean deviation and the sum of the average error with the sample standard error deviation are less than 1. These SHs will then obtain the medium changes of the virtual air temperature that will typically (after rounding) differ to one degree of Celsius compared to the data that would be obtained from the METEO11 meteorological message compiled by the MARWIN MW32.

The absolute values of the average errors, which occur in calculations of medium changes of the virtual air temperature, are expressed in the Figure 3.

Figure 3 - Average errors – medium changes of the virtual air temperature

Medium wind direction

An analysis of the errors that occurred in the medium wind direction calculations was performed analogously to the medium change of the virtual air temperature. The values given in the Table 2 are in hundreds of mils.

Highlighting the color frames in the Table 2 is analogous to evaluating the accuracy of the medium changes of the virtual air temperature calculations. The green and purple frames highlight the values (green – sums of the average error and the mean deviation, purple – sums of the average error and the sample standard error deviation; all in absolute terms) greater than 2, as lower accuracy of calculations can be accepted for the wind direction than for the virtual air temperature. The medium wind direction is decomposed into the cross-sectional and longitudinal components (based on the medium wind speed) when calculating artillery firing data. The error in calculating the medium wind direction is therefore further broken down into two partial errors (the smaller, the smaller is medium wind speed).

Wind direction									
Stand. height [m]	Arithmetic means			Mean deviations			Sample stand. error deviation		
	Abstract	METB3	METCM	Výpis	METB3	METCM	Výpis	METB3	METCM
200	-0.55	-0.17	0.15	0.99	0.50	0.46	1.28	0.65	0.66
400	-0.36	0.09	0.09	0.73	0.40	0.48	0.93	0.60	0.67
800	-0.09	0.26	-0.53	0.22	0.51	1.01	0.38	0.62	1.40
1200	-0.03	0.22	-0.44	0.24	0.48	0.74	0.54	0.67	0.99
1600	0.00	-0.26	0.09	0.31	0.80	0.72	0.67	1.05	1.14
2000	0.06	-0.23	0.03	0.23	0.79	0.78	0.44	1.11	1.38
2400	0.25	-0.55	0.30	0.38	0.83	0.98	0.44	0.96	1.47
3000	0.31	-0.55	0.52	0.47	1.01	1.05	0.54	1.30	1.42
4000	0.19	-0.23	0.45	0.36	0.56	0.85	0.47	0.69	1.09
5000	0.22	-0.05	0.12	0.34	0.52	1.18	0.42	0.79	1.82
6000	0.26	-0.68	0.06	0.48	1.60	1.23	0.58	2.50	2.12
8000	0.13	-0.95	0.97	0.41	2.58	1.19	0.68	3.48	1.83
10000	0.04	0.35	0.85	0.21	1.09	1.40	0.44	1.39	2.20
12000	0.35	0.28	1.12	0.45	0.43	1.28	0.49	0.57	2.01

Table 2 Selected statistical characteristics – medium wind direction

The absolute values of the average errors, which occur in calculations of the medium wind direction, are expressed in the Figure 4.

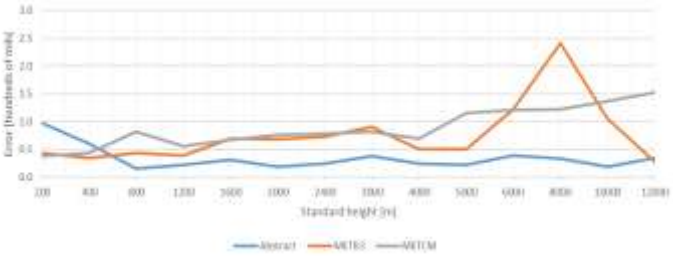

Figure 4 - Average errors – medium wind direction

Medium wind speed

The selected statistical characteristics of the errors generated by the medium wind speed calculations in the each SH of the METEO11 meteorological message are given in the Table 3 and in the graph in the Figure 5. The values in the Table 3 are in units of meters per second.

Wind speed									
Stand. height [m]	Arithmetic means			Mean deviations			Sample stand. error deviation		
	Abstract	METB3	METCM	Výpis	METB3	METCM	Výpis	METB3	METCM
200	0.24	0.52	0.41	0.66	0.50	0.48	0.90	0.51	0.50
400	0.12	0.39	0.29	0.43	0.48	0.46	0.65	0.50	0.52
800	0.00	0.22	0.26	0.18	0.41	0.45	0.43	0.52	0.57
1200	0.00	0.00	0.35	0.19	0.43	0.59	0.44	0.67	0.69
1600	-0.13	0.17	0.41	0.27	0.50	0.54	0.42	0.65	0.61
2000	0.00	0.05	0.42	0.19	0.17	0.57	0.44	0.38	0.66
2400	-0.03	0.00	0.42	0.18	0.09	0.57	0.40	0.31	0.66
3000	0.03	0.18	0.42	0.06	0.37	0.55	0.18	0.50	0.61
4000	0.00	0.18	0.55	0.06	0.37	0.56	0.25	0.50	0.62
5000	0.06	0.32	0.61	0.18	0.56	0.51	0.35	0.65	0.56
6000	-0.10	0.18	0.73	0.29	0.30	0.53	0.47	0.39	0.63
8000	-0.17	0.91	1.55	0.33	1.00	1.27	0.46	1.41	2.03
10000	-0.04	0.25	1.19	0.14	1.03	1.00	0.34	1.41	1.49
12000	-0.04	0.06	0.72	0.17	0.53	1.01	0.37	0.87	1.59

Table 3 Selected statistical characteristics – medium wind speed

The highlighted by the color frames in the Table 3 is analogous to the evaluation of the accuracy of medium changes of the virtual air temperature calculations and the medium wind directions calculations. The accuracy of the medium wind speed calculation is acceptable (with respect to the variability of this meteorological variable with increasing height and with respect to the distance and direction correction values while calculating the artillery firing data) if the average error of its calculation is lower than one unit (red frames) and if the sum of absolute average error value and the mean deviation up to 1.5 (green boxes, both in absolute terms). The sample standard deviation

for which its sum with the average error is greater than 1.5 is highlighted by purple frame.

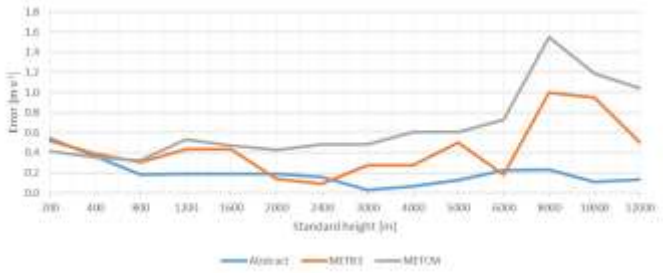

Figure 5 - Average errors – medium wind speed

Discussion

The accuracy of the individual METEO11 meteorological message alternative compilation methods follows from the background used to build these messages. The accuracy of the partial data in the compiled METEO11 meteorological message is primarily affected by the details of the data in the source document (abstract, meteorological message). If a different meteorological message format is used (METCM or METB3) to compile the METEO11 meteorological message, the accuracy of the calculated data is affected especially by the similarity of the purport of the data in the initial message with the meaning of the data in the METEO11 meteorological message.

On the basis of the calculated statistical characteristics of the errors that may arise in the alternative calculation of the METEO11 meteorological message, it is desirable to adopt appropriate limitations to their use for the complete preparation of the artillery firing data. The analysis shows that artillery units should endeavour to obtain the abstracts of the measured meteorological data from the meteorological unit, which provides their meteorological support for the multinational task forces they are assigned to. The use of the METEO11 meteorological message compiled according to the abstract of the measured meteorological data is not necessary to limit due to the probable errors of the calculated meteorological data in the SHs.

When converting the meteorological messages METB3 and METCM to the METEO11 format, the growing SH spreads the probability of the error distribution, and individual values are more scattered around their average error. Calculated meteorological data is appropriate for the different meteorological variables and various source messages to limit for the complete preparation of the artillery firing data into the different SHs. A summary of the individual recommendations based on the analysis is given in the Table 4. Based on the individual recommendations, the overall conclusions are drawn for the use of the alternative gained METEO11 meteorological message for the complete preparation of the artillery firing data. The overall conclusions are determined with regard to the possibility of using all partial meteorological variables in the relevant SHs.

Stand. height [m]	Medium change of virtual air temperature			Medium wind direction			Medium wind speed			General conclusions		
	Abstract	METB3	METCM	Abstract	METB3	METCM	Abstract	METB3	METCM	Abstract	METB3	METCM
200	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
400	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
800	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1200	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1600	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2000	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2400	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3000	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4000	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5000	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6000	✓	⛔	✓	✓	⛔	⛔	✓	✓	✓	✓	⛔	⛔
8000	✓	⛔	⛔	✓	⛔	⛔	✓	⛔	⛔	✓	⛔	⛔
10000	✓	⛔	⛔	✓	⛔	⛔	✓	⛔	⛔	✓	⛔	⛔
12000	✓	⛔	⛔	✓	⛔	⛔	✓	⛔	⛔	✓	⛔	⛔

Table 4 Recommendations based on the analysis

The table 4 shows that the METEO11 meteorological message compiled according to an abstract of the measured meteorological data can be used without any limitation. The converted METEO11 meteorological messages from the METB3 or METCM need to be limited for the use in the complete preparation of the artillery firing data (without adjustment of fire) to the SH of 5 000 meters. Higher-layer meteorological data (higher SHs) may also be used when calculating complete preparation of the artillery firing data, but prior to effective firing, it is necessary to shoot one control round by the lead gun and then to count necessary repairs (adjustments). Meteorological data in the converted METEO11 meteorological message from the SH of 6 000 meters would be used primarily in the preparation of the artillery firing data for steep angles of ballistics curves, which are used seldom.

6. CONCLUSION

The METEO11 MAKER and METCM & METB3 to METEO11 software represent a set of applications to solve the incompatibility of artillery of former Eastern Bloc with other NATO armies in part of the meteorological preparation process. These countries can now compile the METEO11 meteorological message according to an abstract of the measured meteorological data or convert standardized METCM and METB3 meteorological messages. The ability to obtain an METEO11 meteorological message alternate will allow the artillery to fire without the need to adjust or register fires, which are time consuming and can reveal the artillery battery position to the enemy.

The application support to ensure the interoperability of the artillery of some NATO countries within the meteorological preparation process is designed to be as intuitive as possible and without the need for prior study of the instructions. To develop the software METEO11 MAKER and METCM & METB3 to METEO11, it was necessary to:

- define mathematical models of calculations;
- make complex designs of application structures;
- make an analysis of the individual METEO11 meteorological message alternative compilation methods.

Due to the accuracy of the individual METEO11 meteorological message alternative compilation methods, it is necessary to perform primarily METEO11 compilation according to the abstract of measured meteorological data in the OriginalMetData format. If the abstracts of measured

meteorological data cannot be obtained within the international task forces for various reasons, then artillery units should convert meteorological message METB3 or METCM.

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