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Performance of GEM-LAM dichotomous forecast for selected weather phenomena
Sprawdzalność numerycznej prognozy dychotomicznej z modelu GEM-LAM dla wybranych zjawisk pogodowych

Key words: dichotomous forecast, frost, precipitation, verification scores, GEM meteorological model
Słowa kluczowe: prognoza dychotomiczna, przymrozek, opad, wskaźniki sprawdzalności, model meteorologiczny GEM

Introduction

Verification of forecasts is an essential part of every meteorological, operational or research forecasting system. Its results allow to track forecasts accuracy, identify errors and document improvements in the system (Ebert et al., 2013). Yet another important aim of verification is to provide information about quality of forecasts, that is useful from the point of view of specific end-user. Agriculture, road transport and aviation are the sectors of business activity especially weather-sensitive. Also managers of electricity companies, wind farms operators, as well as individual farmers and retailers take into account short- or long-term weather forecast, when planning their activities. In that case the forecast verification method should be tailored to the interests of specific users and provide results that help them make decision regarding whether to take particular actions and to estimate the value gained from the use of forecast product for a specific purpose (Casati et al., 2008).

This work presents the results of performance of GEM-LAM numerical model related to dichotomous forecast of two meteorological phenomena: frost and precipitation. In recent years this model has been used in many scientific studies, mainly focused on dispersion and transformation of air pollutants (Strużewska and Kamiński, 2008, 2012; Strużewska-Krajewska et al., 2014). However, its meteorological and air quality forecasts, issued currently in operational mode are available publicly via web portals (meteo.is.pw.edu.pl and www.ekoprognoza.pl) and can be of interest for some specific markets like power generation companies or agricultural sector. The performance of the model forecasts related to phenomena relevant to planning on-farm activities (as rain or frost) was not yet the subject of interest.

Data

Integrated system of numerical models, running at Warsaw University of Technology (WUT) has been created by Ecoforecast Foundation and Meteorology Division of WUT (Meteorology Team WUT, 2016) on a basis of operational model of Canadian Meteorological Center, Global Environmental Multiscale Model (GEM) (Côté et al., 1998) and its atmospheric chemistry extension, GEM-AQ (Kamiński et al., 2008). It consists of two configuration sets – global, with variable resolution numerical grid, covering the whole globe and focusing on Europe area with 15 km (0.135°) grid spacing and mesoscale (GEM-LAM), located over Poland, with 5 km (0.0625°) grid step. In mesoscale configuration the following physical parameterizations are used: for surface energy budget the force-restore equation (Deardorff, 1978); for turbulence parameterization the turbulent kinetic energy budget method, including statistical subgrid-scale cloudiness (Bélair et al., 2005) and the Bougeault–Lacarrere specification of the length scale (Bougeault and Lacarrere, 1989); for condensation processes the Kain–Fritsch scheme for deep convection (Kain and Fritsch, 1990, 1993) and Sundqvist scheme for non-convective clouds (Sundqvist, 1978); for solar and infrared radiation the schemes of Fouquart and Bonnel (1980) and Garand (1983) respectively and finally a modified McFarlane parameterization (McFarlane, 1987; McLandress and McFarlane, 1993) to take account for gravity wave drag effects.

The analysis covered GEM-LAM forecasts of precipitation and temperature at two heights: 2 m and at ground level. The results from model were compared with observations gathered at 15 meteorological stations from Poland (Table 1, Fig. 1), for one-year period (from June 2013 to May 2014). As for frost occurrence only forecasts issued in spring (March–May) and autumn (September–November) were evaluated.

Methodology

Frost forecast

In scientific literature one can find various criteria for frost occurrence. In this work definition referring to extreme temperatures, given by Woś (1999) was applied. It states that frost occurs when for a given day the minimum temperature is below 0°C and the maximum temperature is positive. Kossowska-Cezak (2003), Bielec-Bąkowska and Łupikasza (2009) and Tomczyk et al. (2015) have used the same rule in their research among others. The minimum temperature criterion for ground frost refers to grass minimum temperature, while for air frost it refers to minimum temperature measured in meteorological screen, usually at 1.25–2 m height. Regarding data obtained from model, the minimum temperature criterion was checked for

TABLE 1. Geographical coordinates of meteorological stations selected for analysis
TABELA 1. Współrzędne geograficzne stacji meteorologicznych wybranych do analizy

Station name Nazwa stacji	Longitude Dług. geogr. [°E]	Latitude Szer. geogr. [°N]	Height m.s.l. Wys. n.p.m. [m]
Koszalin	16,15	54,20	32
Ustka	16,87	54,58	6
Hel	18,82	54,60	1
Suwałki	22,95	54,13	184
Świnoujście	14,23	53,92	6
Resko	15,42	53,77	52
Mikołajki	21,58	53,78	127
Poznań	16,83	52,42	86
Warszawa	20,97	52,17	106
Leszno	16,53	51,83	91
Jelenia Góra	15,80	50,90	342
Kraków	19,80	50,08	237
Rzeszów	22,05	50,10	200
Zakopane	19,95	49,30	857
Przemyśl	22,77	49,80	279

FIGURE 1. Location of meteorological stations
RYSUNEK 1. Lokalizacja stacji meteorologicznych

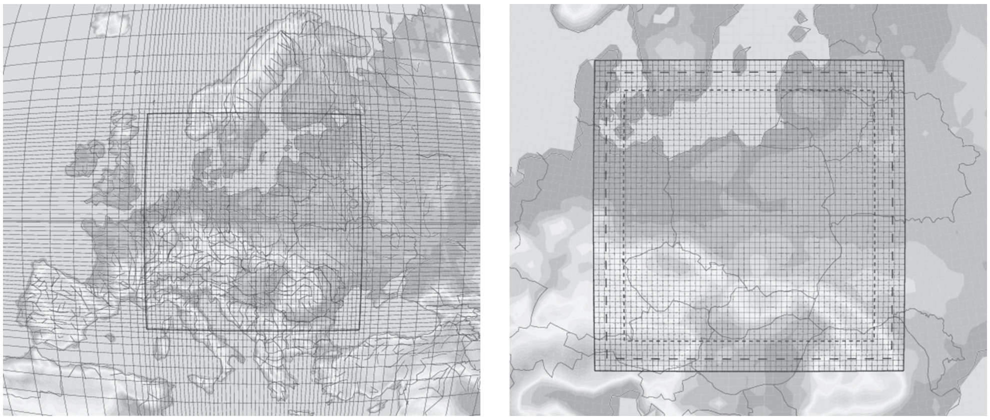

FIGURE 2. GEM-AQ computational domain configuration: global variable resolution grid with 0.135° resolution over Central Europe (left); nested grid with 0.0625° resolution over Poland (right) (Strużewska-Krajewska et al., 2014)
RYSUNEK 2. Konfiguracja siatki dla symulacji modelem GEM-AQ: siatka globalna o zmiennej rozdzielczości – 0.135° nad Europą Środkową (z lewej) i siatka zagnieżdżona dla Polski, o rozdzielczości 0,0625° (z prawej) (Strużewska-Krajewska i in., 2014)

values forecast for a time period from 18 to 06 UTC, while the positive temperature criterion was checked for the daytime values (06–18 UTC). As for observational data, the minimum and maximum temperature published in SYNOP reports at 06 and 18 UTC respectively were analyzed.

Precipitation forecast

For definition of precipitation event the threshold value of 1 mm for six-hour rainfall depth has been arbitrarily assumed. Although the accuracy of rainfall measurement is 0.1 mm, adoption of 1 mm value was dictated by the way the data are published in SYNOP reports. Regarding forecast data, from each model run time series of 24 values of accumulated rainfall were available and formed the basis for determination of precipitation event occurrence in six-hour time intervals.

Verification scores

For assessing the performance of precipitation and frost forecasts, verification and performance measures commonly used for dichotomous events has been used (Nurmi, 2003; Jolliffe, 2011): probability of detection (*POD*), success ratio (*SR*), frequency bias index (*FBI*) and critical success ratio (*CSI*). They are defined in terms of cell counts of contingency table (Table 2) using following formulas:

TABLE 2. Contingency table
TABELA 2. Tablica dwudzielcza

Event forecast Zdarzenie prognozowane	Event observed Zdarzenie obserwowane	
	Yes/Tak	No/Nie
Yes/Tak	a	b
No/Nie	c	d

$$POD = \frac{a}{a+c}; \quad SR = \frac{a}{a+b}$$

$$FBI = \frac{a+b}{a+c}; \quad CSI = \frac{a}{a+b+c}$$

where:
a – the total number of hits,
b – false alarms,
c – missed events.

Additionally, a modification of *CSI* score, Gilbert's skill score *GSS* (Schaefer, 1990) has been calculated in order to allow for the number of hits, that would have been obtained purely by chance and conditional miss rate *CMR* (Stephenson, 2000), which describes the reliability of negative forecast:

$$GSS = \frac{a - a_r}{a - a_r + b + c}$$

$$CMS = \frac{c}{c+d}$$

where:
a_r – number of hits for random forecast:

$$a_r = \frac{(a+b)(a+c)}{a+b+c+d}.$$

Results

Overall performance of frost and precipitation forecast

From the values of verification scores calculated using all the data collected (without any additional stratification) the overall predictability of numerical forecast from GEM model can be inferred (Table 3).

Probability of detection *POD* for both types of frost has similar value, slightly less than 0.5. It means, that more than 50% of observed frost events hasn't been correctly predicted. In this regard the forecast of precipitation is better, as *POD* reaches 0.64. Results for *SR* score show, that percentage of correct forecasts differ considerable between particular phenomena. The worst score, equal 0.47 has been obtained for precipitation. Such low value means that more than half of all forecast of that phenomenon was erroneous. In case of frost the results for success ratio are greater, especially for forecast of ground frost (*SR* = 0.75). Precipitation forecast is at an advantage in terms of *CMR* score, which amounts only to 0.04 for this phenomenon. It states, that less than 5% of forecast of non-occurrence of precipitation was wrong during analyzed year. Such a good result is mostly related to the tendency in the model to predict precipitation too frequently, as evidenced by the value of systematic error *FBI*, significantly greater than one (*FBI* = 1.38).

Scores of *POD*, *SR*, *FBI* and *CSI* can be presented together on the same diagram due to geometric relationship that exists between them (Roebber, 2009). For good forecast, they all approach

TABLE 3. Verification scores for forecast of particular phenomena
TABELA 3. Wartości wskaźników sprawdzalności prognozy dla poszczególnych zjawisk

Indicator/Wskaźnik	*POD*	*SR*	*FBI*	*CSI*	*GSS*	*CMR*
Ground frost/Przymrozek przy gruncie	0,49	0,75	0,66	0,42	0,35	0,12
Air frost/Przymrozek wysoki	0,47	0,64	0,75	0,37	0,33	0,07
Precipitation/Opad	0,64	0,47	1,38	0,37	0,32	0,04

unity, hence a perfect forecast lies in the upper right of the diagram. Deviations in a particular direction indicate the relative differences in *POD* and *SR*, and consequently bias and *CSI*. In this way the comparison of results for different forecasts is greatly facilitated. The distribution of points on Figure 3 shows that, although the values of *POD* and *SR* for precipitation and frost differ considerably, the performance of both forecasts in the sense of *CSI* (and *GSS* score) is similar. These two latter parameters are more versatile and useful for assessing or comparing predictability of various forecasts, as they simultaneously take into account false alarm errors (element "b" in Table 2, ignored when calculating *POD*) and missed event errors (element "c", omitted when calculating *SR*). From locations of square and triangle symbols on Figure 3, which depict the scores for ground and air frost respectively, it can be seen that the ground frost forecast has better performance (greater *SR* and *POD*, resulting in a higher *CSI* and *GSS*), although it is also more biased than forecast of air frost. In both cases *FBI* is much lower than 1, which means that the model clearly underpredicts the occurrence of frost.

Performance of forecast for spatially stratified data

In order to investigate the performance of forecast in different regions of Poland, verification scores were calculated separately for 15 considered locations. Results for frost forecast show

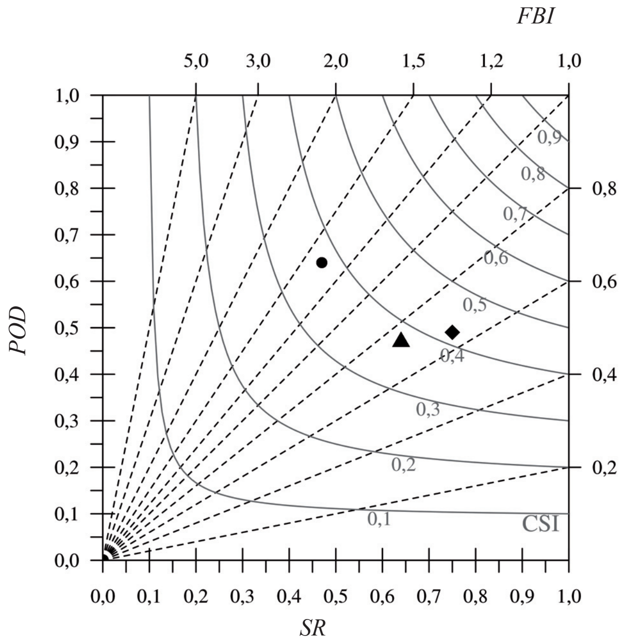

FIGURE 3. Performance diagram for the forecast of particular phenomena: square – ground frost, triangle – air frost, circle – precipitation
RYSUNEK 3. Diagram sprawdzalności dla prognozy poszczególnych zjawisk: kwadrat – przymrozek przy gruncie, trójkąt – przymrozek wysoki, koło – opad

significant variations between particular stations (Table 4, Fig. 4). The worst performances (*CSI* below 0.3) have forecasts issued for Hel, Resko, Świnoujście and Koszalin. The reason of this is their location – at the Baltic coast (Hel, Świnoujście and Koszalin) or at near proximity (Resko). Furthermore, another seaside resort – Ustka, although not mentioned above, has the *POD*, *SR* and *CSI* scores only slightly better than Świnoujście or Hel. Apart from the general tendency in the model for forecasting frost too rare, here the second factor – the problem with correct account for the impact of water reservoir on air temperature diurnal course in the vicinity, plays an important role. The current 5-km grid resolution of GEM-LAM setup seems to be insufficient to correctly reproduce the impact of such specific local conditions on development of frost. This primarily manifests by very low values of probability of detection score and *FBI* below 0.5.

The best results for frost forecast has been obtained for station located in the southern part of Poland: Zakopane (14), Jelenia Góra (11) and Przemyśl (15). Among these locations Zakopane stands out, characterized by the highest value of *POD* (0.83), *CSI* (0.70) and *GSS* (0.57). Moreover, at this station (as well as in Jelenia Góra) frost was observed the most frequently. From analysis of *GSS* values it is evident that performance of forecast

TABLE 4. Verification scores for ground frost forecast for particular stations
TABELA 4. Wartości wskaźników sprawdzalności prognozy przymrozków przy gruncie w podziale na stacje

No Lp.	Station/Stacja	Frost frequency Częstość przymrozków [%]	*POD*	*SR*	*FBI*	*CSI*	*GSS*	*CMR*
1	Koszalin	9	0,33	0,63	0,53	0,28	0,25	0,06
2	Ustka	9	0,33	0,83	0,40	0,31	0,29	0,06
3	Hel	17	0,25	0,78	0,32	0,23	0,19	0,13
4	Suwałki	28	0,52	0,69	0,75	0,42	0,30	0,17
5	Świnoujście	11	0,28	0,83	0,33	0,26	0,24	0,08
6	Resko	17	0,31	0,56	0,55	0,25	0,19	0,13
7	Mikołajki	23	0,51	0,80	0,64	0,45	0,37	0,13
8	Poznań	20	0,50	0,77	0,65	0,44	0,36	0,12
9	Warszawa	22	0,34	0,68	0,50	0,30	0,22	0,17
10	Leszno	29	0,41	0,91	0,45	0,39	0,31	0,20
11	Jelenia Góra	35	0,63	0,82	0,76	0,55	0,42	0,18
12	Kraków	17	0,57	0,57	1,00	0,40	0,32	0,09
13	Rzeszów	18	0,37	0,61	0,60	0,30	0,23	0,13
14	Zakopane	36	0,83	0,82	1,02	0,70	0,57	0,09
15	Przemyśl	16	0,55	0,79	0,70	0,48	0,42	0,08

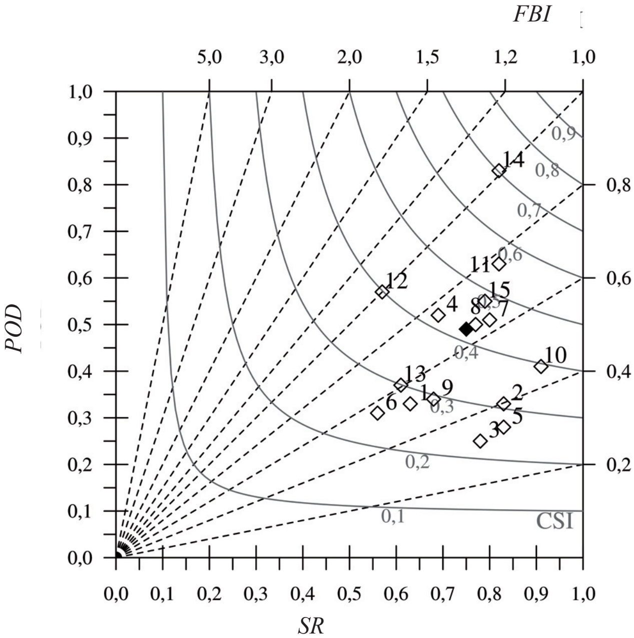

FIGURE 4. Performance diagram for the ground frost forecast for particular stations. Numbers correspond with station numbers from Table 4. Filled square – overall performance of ground frost forecast
RYSUNEK 4. Diagram sprawdzalności dla prognozy przymrozków przy gruncie w podziale na stacje. Numery odpowiadają numerom stacji z tabeli 4. Wypełniony kwadrat – wynik sprawdzalności bez podziału na stacje

for Przemyśl is the same as for Jelenia Góra (*GSS* = 0.42). However, the position of corresponding symbols (15 and 11) on Figure 4 is clearly different, with Przemyśl having lower value of *CSI* than Jelenia Góra. This discrepancy between *CSI* and *GSS* is related to the distinct values of precipitation frequency in both locations, with Jelenia Góra having twice higher value than Przemyśl. Schaefer (1990) pointed out, that this climatological characteristic determines how close the two scores are to each other. For a given *CSI*, the skill decreases as the forecast event becomes more frequent, which explains the greater decrease of skill in Jelenia Góra, when comparing to Przemyśl. Kraków (12) and Leszno (10) form another pair of stations that deserve attention. Despite nearly the same value of *CSI*, the performance of frost forecast regarding the *POD* and *SR* values is completely different: number of correct predictions of frost at Leszno is nearly 60% higher than for Kraków, while for the probability of detection score the situation is opposite – Kraków has 40% higher value than Leszno. Moreover, Kraków as well as Zakopane are the only locations with unbiased forecast.

The conditional miss rate for frost forecast is quite high, with value exceeding 0.1 at more than half stations. The worst *CMR* score has been obtained for Leszno (0.2), which on the other side has the best *SR* score (0.91). Therefore, for this location, contrary to others, the forecast of frost was correct more frequently than forecast of no frost occurrence. However, no clear association exists between the *CMR* and the values of other verification measures, for example the best results for conditional miss rate (0.06–0.09) have been noted either for locations having low values of *POD* or *CSI* (Ustka and Koszalin) as well as for Zakopane, that gained the highest value of these scores.

Unlike for frost, the results of performance of precipitation forecast (Table 5, Fig. 5) does not differ much between particular locations. There are two outliers however, having clearly better (Zakopane – 14) or worse (Przemyśl – 15) scores than others. The difference concerns mainly the probability of detection and critical succes index, and to a smaller extent success ratio. Przemyśl stands out negatively also in terms of *GSS* values (*GSS* = 0.18, that is almost twice lower than average). The highest value of this score belongs to Zakopane, however it does not mark off from other results, as in case of *CSI*.

The reasons of worst performance of forecast for Przemyśl can be attributed to the gaps and errors in the measurement data, i.e. incorrect coding of precipitation data in SYNOP reports. High values of *POD*, *CSI* and *GSS*, obtained for forecast issued for Zakopane are the result of coincidence of two facts – the over-

TABLE 5. Verification scores for precipitation forecast for particular stations
TABELA 5. Wartości wskaźników sprawdzalności prognozy opadu w podziale na stacje

No Lp.	Station/Stacja	Precipitation frequency Częstość występowania opadu [%]	*POD*	*SR*	*FBI*	*CSI*	*GSS*	*CMR*
1	Koszalin	10	0,66	0,47	1,41	0,38	0,33	0,04
2	Ustka	9	0,59	0,44	1,34	0,34	0,29	0,04
3	Hel	9	0,59	0,47	1,25	0,36	0,31	0,04
4	Suwałki	11	0,62	0,51	1,21	0,39	0,33	0,05
5	Świnoujście	9	0,64	0,43	1,47	0,35	0,30	0,04
6	Resko	7	0,73	0,44	1,64	0,38	0,34	0,02
7	Mikołajki	9	0,58	0,46	1,28	0,34	0,29	0,04
8	Poznań	10	0,63	0,50	1,26	0,39	0,33	0,04
9	Warszawa	10	0,60	0,49	1,22	0,37	0,32	0,04
10	Leszno	9	0,63	0,49	1,28	0,38	0,33	0,04
11	Jelenia Góra	11	0,71	0,45	1,59	0,38	0,32	0,04
12	Kraków	10	0,67	0,48	1,41	0,39	0,33	0,04
13	Rzeszów	9	0,72	0,45	1,60	0,38	0,33	0,03
14	Zakopane	16	0,81	0,50	1,62	0,45	0,36	0,04
15	Przemyśl	12	0,42	0,38	1,10	0,25	0,18	0,09

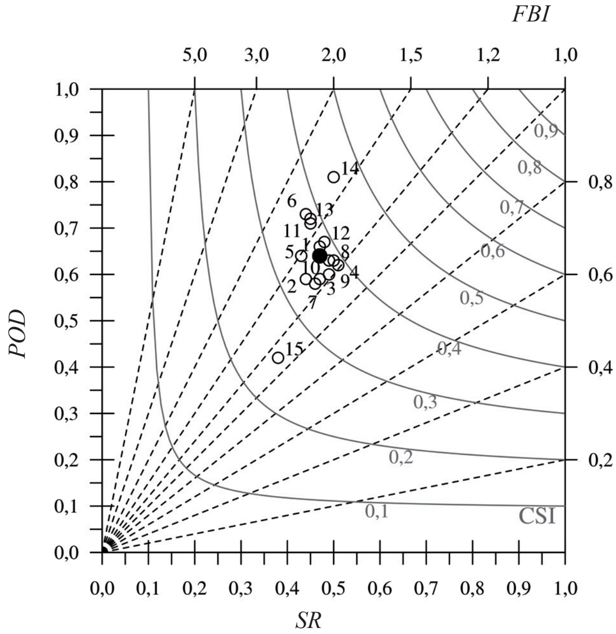

FIGURE 5. Performance diagram for the precipitation forecast for particular stations. Numbers correspond with station numbers from Table 5. Filled circle – overall performance of precipitation forecast
RYSUNEK 5. Diagramsprawdzalności dla prognozy opadu w podziale na stacje. Numery odpowiadają numerom stacji z tabeli 5. Wypełnione koło – wynik sprawdzalności bez podziału na stacje

all tendency in the model for forecasting precipitation too frequently (*FBI* >1 for all locations) and relatively high frequency of precipitation observed at this location. The first fact explains also, at least partially, why for all stations the probability that precipitation will be correctly forecast is greater than probability that forecast predicted precipitation is correct (*POD* > *SR*). Although only at most half of precipitation forecasts was accurate during the analyzed period, on the other side the probability of erroneous forecast of no precipitation (*CMR* score) was low at all locations. The best results were achieved for Resko (0.02) and Rzeszów (0.03), stations where precipitation also occurred the least frequently.

Discussion

In order to investigate the performance of frost forecast in a more detailed way, additional analysis, using different definition for frost occurrence was carried out. According to this new rule the frost occurred when for a given day the minimum temperature (T_{min}) was below 0°C and the mean daily temperature (T_d) was above 5°C. Adoption of such principle resulted in a significant decrease in a number of days with frost observed at particular locations, as 45 and 60% of all cases defined previously as ground and air frost respectively, were excluded from analysis. However, the omitted cases concerned mainly the situations observed in March and November, which are not so important for agricultural sector – the most harmful for plants are the late spring and early autumn cases (Radomski, 1968; Koźmiński, 1976).

The results obtained from this analysis are presented in Table 6. Probability of detection *POD* for both types of frost has a very low value – only 13 (7)% of observed ground (air) frost was correctly predicted. The values of *FBI* reveal that situations in which the calculated temperature changes during course of the day satisfied the conditions of T_{min} <0°C and T_d >5°C were predicted considerable too rarely, 5(9) times less frequently than observed for ground (air) frost. This also explains the low values of *CSI* and *GSS*. In contrast to this the SR scores are quite high, with value for ground frost slightly better than for air frost. It states that 2/3 of forecasts which warned of frost occurrence was correct. With regard to the negative forecast the better CMR score was achieved for air frost. Only 4% of forecasts of non-occurrence of frost were wrong during analyzed period.

TABLE 6. Verification scores for forecast of frost defined by T_d >5°C criterion
TABELA 6. Wartości wskaźników sprawdzalności prognozy dla przymrozków według kryterium T_d >5°C

Indicator/Wskaźnik	*POD*	*SR*	*FBI*	*CSI*	*GSS*	*CMR*
Ground frost/Przymrozek przy gruncie	0.13	0.67	0.20	0.12	0.11	0.10
Air frost/Przymrozek wysoki	0.07	0.62	0.11	0.07	0.06	0.04

From comparison of results collected in Tables 3 and 6 it is evident that performance of GEM-LAM model with regard to forecast of frost, defined using T_d >5°C criterion, is much worse than for frost using criterion of T_{max} >0. This issue is obviously related to the performance of temperature forecast. The quality of frost forecast, in the former case is much more sensitive to accuracy of predicted diurnal changes of temperature than in a latter case.

Summary and conclusions

The performance of dichotomous forecast can be studied with the help of various verification measures, which are based on counts expressing particular relations between forecast and observation i.e. hits, false alarms, misses and correct rejections. None of the calculated scores alone is capable to completely assess the quality of a forecasting system.

The results from verification of GEM-LAM numerical weather forecast indicate the existence of systematic errors – the frost is predicted too rarely while precipitation too frequently when compared with observations. Nonetheless, with regard to frost, nearly half of events observed in autumn and spring was correctly predicted (*POD* = 0.49 and 0.47 for ground and air frost respectively). As for precipitation, the score is better – 2/3 of the total, yearly amount of rain and snow incidents was properly forecast (*POD* = 0.64). From the point of view of specific end-users (e.g. farmers) more important than *POD* are the scores explaining how often the forecast of occurrence or non-occurrence of particular phenomenon is true. Three fourths of ground frost (2/3 of air frost) forecasts and only slightly less than half of precipitation forecast were true which means that in the context of *SR* score the forecast of frost is better than forecast of precipitation. The high quality of negative forecast is also very important, especially for frost, as the loss of the crops resulting from incorrect forecast of non-occurrence of frost conditions may be much greater than costs of unnecessary preventive action due to incorrect frost forecast. The values of *CMR* obtained in this study indicate that in case of negative forecast of ground frost there is still more than 10% probability that frost will occur.

In order to investigate the performance of forecast in different regions of Poland, verification scores were calculated separately for 15 considered locations. Only results for frost forecast show significant variations between particular stations. The worst scores were obtained for points located near the Baltic coast. This indicates the problem in the numerical model with correct account for the impact of water reservoir on development of frost in the vicinity. It is very probable that applied 5 km grid resolution is too coarse to properly reproduce the influence of such specific local conditions on frost formation.

The method of assessment of numerical weather forecast performance used in this study is oriented to the user needs, so it does not explain what are the reasons of erroneous forecasts. In case of frost, referring to criterion used, the cause may be related either to the prediction of too low temperature during the day or too high nighttime values. However it is also possible that both situations occur simultaneously. Errors in precipitation forecast could occur due to prediction of inaccurate rainfall amount or faulty timing of the event. Further studies, considering more specified criteria, as well as additional stratification of data according to synoptic situation types are needed to better understand circumstances in which errors arise.

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Summary

Performance of GEM-LAM dichotomous forecast for selected weather phenomena. In this study the performance of GEM-LAM numerical weather forecast focused on phenomena relevant to planning on-farm activities (i.e. frost and precipitation) is presented. Values from forecast were compared with observations gathered at 15 meteorological stations from Poland, for one year period. Based on data collected in contingency table, six verification scores were calculated. The results show that considerable bias exists – the model forecasts frost occurrence too rarely while precipitation events too frequently. However nearly half of frost cases and 2/3 of precipitation incidents were correctly predicted. As for success ratio *SR* score the frost forecast was more frequently correct (75 or 64%, depending on frost type) than forecast of precipitation (47%). The skill of negative forecast is high, especially for precipitation, where less than 5% of forecasts were erroneous. Analysis of verification scores calculated separately for each station shows, that regarding the forecast of frost, substantial differences in performance between particular locations exist. The worst results were obtained for stations located near the seaside which indicates that in the analyzed model the impact of water reservoir on frost formation is not correctly taken into account (at horizontal grid resolution of 5 km).

Streszczenie

Sprawdzalność numerycznej prognozy dychotomicznej z modelu GEM-LAM dla wybranych zjawisk pogodowych. W pracy przedstawiono analizę sprawdzalności prognozy numerycznej modelu GEM-LAM, dotyczącej wystąpienia dwóch zjawisk meteorologicznych ważnych z punktu widzenia potrzeb rolnictwa: przymrozku oraz opadu. Wartości prognozowane porównano z obserwacjami pochodzącymi z 15 stacji meteorologicznych z obszaru Polski, z okresu jednego roku. Na podstawie elementów tablicy dwudzielczej wyliczono wartości dla sześciu wskaźników sprawdzalności. Wyniki badań wskazują na istnienie znacznych błędów systematycznych – wystąpienie przymrozka prognozowane jest przez model zbyt rzadko, zaś opadu zbyt często. Tym niemniej blisko połowa przypadków wystąpienia przymrozka oraz 2/3 zaobserwowanych w ciągu roku zdarzeń opadu została poprawnie przez model przewidziana. Z kolei wartości wskaźnika sukcesu *SR* wskazują na częstsze sprawdzanie się prognozy przymrozka (75 lub 64% w zależności od rodzaju przymrozka) niż prognozy opadu (47%). Dla prognozy negatywnej sprawdzalność jest wysoka, zwłaszcza dla opadu, gdzie mniej niż 5% prognoz było błędnych. Analiza w podziale na stacje wykazała znaczne zróżnicowanie wartości wskaźników dla poszczególnych lokalizacji w odniesieniu do prognozy przymrozków. Najgorsze wyniki otrzymano dla stacji zlokalizowanych w pobliżu morza, co wskazuje na trudności z prawidłowym uwzględnieniem w modelu (w przyjętej rozdzielczości siatki obliczeniowej 5 km) wpływu zbiornika wodnego na zjawisko powstawania przymrozka.

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