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ASSESSMENT OF THE ACCURACY OF METEOROLOGICAL DATA OBTAINED FROM VIRTUAL AND AUTOMATIC WEATHER STATIONS FOR THE CONDITIONS OF UKRAINIAN POLISSYA

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Abstract. *The article presents a comprehensive assessment of meteorological data obtained from the virtual Visual Crossing Weather Data (VCWD) and the automatic (iMetos Base) meteorological station for the Polissya region of Ukraine. For this purpose, were selected the meteorological data which are included in the formula for calculating the reference evapotranspiration (ET_0) according to the Penman-Monteith method (FAO56-PM), namely average (Tmean), maximum (Tmax) and minimum (Tmin) air temperature, dew point temperature (Tdew), average relative humidity (Rhmean), average water vapor pressure deficit (Damean), total solar radiation (Rs), average wind speed at a height of 2 m (u_2) and daily precipitation (P). The results of the regression analysis and the calculation of the mean absolute percentage error (MAPE), root mean square error (RMSE), and standard error (SEE) demonstrate that the data on mean and maximum air temperature, as well as dew point temperature, were obtained with a high degree of accuracy from the virtual VCWD weather station. The MAPE errors are 5,6, 2,8, and 8,3 %, respectively (MAPE < 10 %). For the minimum air temperature and average relative humidity, good accuracy is inherent, with MAPE errors of 20,0 and 13,6 %, respectively (MAPE =10-20 %). The data on solar radiation and water vapor pressure deficit were obtained with satisfactory accuracy, with MAPE errors of 25,0 and 45,2 %, respectively (MAPE = 20–50 %). The data on wind speed at a height of 2 m, total monthly and daily precipitation were obtained with unsatisfactory accuracy, with MAPE errors of 62,3, 52,6, and 40103 % (MAPE >50 %), respectively. It has been established that the values of daily precipitation (RMSE = 6,0 mm) obtained from VCWD are not accurate. It is possible to use only the total precipitation for the month (RMSE = 11,6 mm) or its annual values (RMSE = 47,9 mm). The application of a correction factor to the obtained meteorological data increases their accuracy and reduces the errors of MAPE, RMSE and SEE. The use of various errors made it possible to comprehensively verify the obtained meteorological data. For example, the MAPE error calculates the accuracy of the meteorological indicator, while the RMSE and SEE errors indicate how the obtained value differs from the average value. In the future, the obtained meteorological indicators from the Visual Crossing Weather Data virtual meteorological station will be used to calculate the reference and actual evapotranspiration using the Penman-Monteith method (FAO56-PM) in the conditions of Polissya of Ukraine.*

Keywords: *virtual weather station, meteorological data, air temperature, precipitation, accuracy, MAPE, RMSE and SEE errors*

Relevance of the study. Meteorological data are useful for a variable applications, such as weather and climate forecasting, landscape planning, and disaster management. However, the availability of these data requires a good network of stationary meteorological stations and other supporting systems for their collection, recording, processing, archiving, communication, and dissemination [1]. Weather-based forecasting models play an important role in agricultural decision support systems, but they are usually computed at the regional level due to the limited number of weather stations. Farmers have to contact the nearest weather station, but the recommendations are not always adapted to their situation [2, 3]. Currently, virtual weather stations (VWS) are widely used [2, 4] and the demand for spatial climate data in digital form has increased [5]. A VWS is the integration of algorithms for downloading meteorological data, processing it, and using it to obtain data in the nearest places where there are no meteorological stations. To develop a VWS, it is necessary to evaluate the accuracy of various interpolation methods and the original meteorological data [2, 4]. Evaluation of meteorological data obtained from different sources is a fundamental task of meteorological analysis [6]. Studies conducted in Kenya [1], Belgium [2], the United States [3], Ecuador [7, 8], New Zealand [9], Brazil [10], Albania [11], Poland [12], Canada [13], and Ukraine [14] determined the accuracy of available meteorological data for individual points of the landscape obtained from the Virtual Climate Station Network by comparing them with measurements at independent meteorological stations.

To establish the accuracy of meteorological data obtained from virtual weather stations, we chose Visual Crossing Weather Data (VCWD). VCWD provides easy access to hourly or daily climate data for the entire world, including forecast data for the next 15 days. Its archive includes more than 50 years of global weather history. In addition to the usual meteorological indicators, such as temperature and relative humidity, wind speed and precipitation, powerful features such as solar radiation and energy, degree days, evapotranspiration reference and weather forecast are available. All data from the site is available for download via the weather data request page and the weather API. The datasets are displayed in a table, which is available in several formats. One of the powerful features of VCWD is the ability to import data into most business intelligence systems, including Excel, for further processing [18].

Although meteorological parameters are measured regularly and are widely available on weather forecasting services on the Internet, they need to be checked for accuracy in each region separately. Previous studies have examined one or more meteorological indicators. № comprehensive verification of all meteorological data measured by an automatic weather station has yet been conducted. Therefore, this study was conducted to verify the accuracy and quality of the meteorological data obtained from the virtual climate station for the conditions of Polissya in Ukraine.

Analysis of recent research and publications. Studies conducted around the world confirm the reliability of meteorological data obtained from virtual weather stations (VWS) [2, 9, 13]. As stated in [2, 4, 5], in order to develop VWS and GIS-compatible climate maps, it is necessary to evaluate the accuracy of various interpolation methods and source meteorological data. To validate VWS, a randomly selected weather station is removed from daily datasets and the interpolated values are compared to the actual values. From a practical point of view, the meteorological data obtained from VWS can be used to control crop irrigation. To develop the VWS in the United States, the authors of [15] used the PRISM (Parameter-elevation Relationships on Independent Slopes Model) interpolation method, which was compared with the WorldClim and Daymet climate data sets. The comparison showed that the use of a relatively dense set of station data and the PRISM interpolation method led to a significant improvement in climate data compared to WorldClim and Daymet.

Often, meteorological data are not used independently, but as input data in various climate models, so their quality affects the accuracy of calculations [17]. Many studies have been devoted to the statistical comparison of meteorological data, some of which are more than 100 years old [16]. Studies by the authors of [7, 8] demonstrate the importance of using high-quality meteorological data to calculate the reference evapotranspiration. The verification of the results of meteorological data obtained from VWS and automated weather stations (AWS), which was performed by the authors of [3] in the western United States, showed their reliability and they can serve as input data for landscape environmental modeling. Studies conducted in New Zealand [9] determined the accuracy of available meteorological data for individual points of the landscape obtained from the Virtual Climate Station Network (VCSN) by comparing them with measurements at independent meteorological stations. It was found that the average monthly global radiation, average daily maximum and minimum air temperature are obtained from the VCSN with reasonable accuracy and a small margin of error. However, the amount of precipitation was calculated inaccurately. The authors' research [12] on air temperature observations in Warsaw (Poland) showed that the statistical ML (machine learning) model can serve as an alternative approach to traditional kriging and numerical modeling, characterized by lower complexity and higher computing speed in the field of urban meteorological research (RMSE = 1,06 °C and R^2 = 0,94, compared to AWS). The authors of [13, 17] note that air temperature obtained from

VWS is an attractive source of data for predicting water temperature due to the reduced cost of instrumental equipment and the availability of long-term historical records over large areas of North America.

Studies conducted in Brazil (Paraíba State) [10] comparing global horizontal irradiation obtained from automated meteorological stations and satellite images showed good correlation of data. It was confirmed that the calculated data from satellite images slightly exceed those obtained by ground-based meteorological stations. Comparison of solar radiation data provided by NASA's Solar Radiation Database with available ground measurements in Albania [11] shows that the ground-based solar radiation data are in all cases underestimated compared to the data provided by the NASA database. The conversion factor is 1,149. Work [14] compared the average daily air temperature in the Odesa region obtained from a field monitoring station with data from the weather forecasting service (Meteo.Farm) and the weather site of the Odesa State Agricultural Station of the Institute of Food and Agriculture of the National Academy of Agrarian Sciences of Ukraine. The standard deviations showed the closeness of the air temperature data between all three data sources: RMSE (weather site) = 1,38 °C and RMSE (weather site) = 1,63 °C.

The purpose of the research was to conduct a comprehensive verification of meteorological data obtained from the virtual (Visual Crossing Weather Data) and automatic (iMetos) meteorological stations for the conditions of Polissya in Ukraine.

Materials and methods. The daily meteorological data for this study were obtained from VWS Visual Crossing Weather Data (VCWD) [18] for the period May-September 2023-2024 and from the iMetos Base weather station from Pessl Instruments [19], which is located at the experimental site in LLC "Agrofirma Kyivska", Makovyshche village, Bucha district, Kyiv region (50.4574°, 29.8949°).

For the comprehensive verification, we selected meteorological data that are included in the formula for calculating the reference evapotranspiration (ET) according to the Penman-Monteith method (FAO56-PM) [20], namely, mean (Tmean), maximum (Tmax) and minimum (Tmin) air temperature, dew point temperature (Tdew), average relative humidity (Rhmean), average water vapor pressure deficit (Damean), total solar radiation (Rs), average wind speed at a height of 2 m (u_2), and daily precipitation (P).

To verify the obtained meteorological data, we used regression analysis and the graph analytical method, for which the actual values obtained from AWS iMetos were plotted on the abscissa axis and the actual values obtained from VWS Visual Crossing Weather Data on the ordinate axis. The resulting linear relationship was compared with a 1:1 line [1, 7]. To assess the accuracy of the obtained meteorological data, the mean absolute percentage error MAPE [21, 22], root mean square error RMSE [23], and standard error of estimate SEE [24] were determined:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{x-y}{x}\right|\cdot 100\% . \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x-y\right)^2} . \quad (2)$$

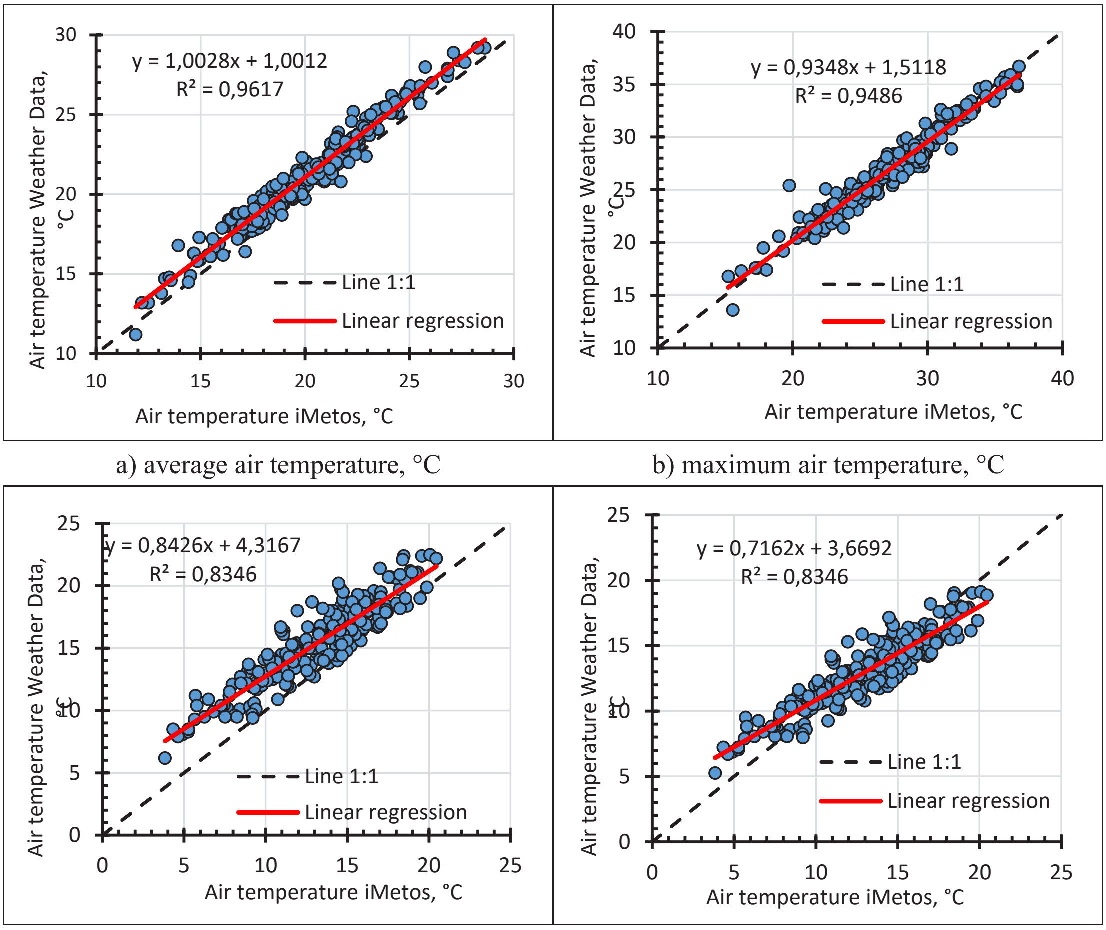
$$E = \sqrt{\frac{1}{(n-2)}\left[\left(y-\bar{y}\right)^2 - \frac{\left[\Sigma\left(x-\bar{x}\right)\left(y-\bar{y}\right)\right]^2}{\Sigma\left(x-\bar{x}\right)^2}\right]} \quad (3)$$

where x – the value of the meteorological indicator obtained from AWS iMetos; y – from VWS VCWD; $\bar{x}$. – is the average value of the meteorological indicator obtained from AWS iMetos; $\bar{y}$ – from VWS VCWD; n – sample size ($n = 306$).

The use of various errors makes it possible to comprehensively verify the obtained meteorological data. For example, the MAPE error calculates the accuracy of the meteorological indicator. The RMSE and SEE errors indicate how the obtained value differs from the average value. The lowest errors indicate the best accuracy of the obtained meteorological indicator.

Research results and discussion. According to the results of a comprehensive check of air temperature, which was obtained from VMS Visual Crossing Weather Data and from the iMetos automatic meteorological station, it was found that the most reliable data are obtained for the average and maximum air temperature. As can be seen from the graph (Fig. 1a, 1b), the obtained linear dependencies almost coincide with the 1:1 line, and the coefficients of determination are 0,9617 and 0.9486, respectively. Less accurate data are obtained for the minimum air temperature, the linear dependence is above the 1:1 line (Fig. 1c), and the coefficient of determination is 0,8346. This indicates an overestimation of the minimum air temperature relative to the actual temperature.

The results of the error calculations (Table 1) also confirm that the most reliable data are obtained for the average and maximum air temperature. For example, for the maximum air temperature, on average over the years of research, the errors of MAPE, RMSE, and SEE



a) average air temperature, °C b) maximum air temperature, °C

c) minimum air temperature, °C d) minimum specified air temperature, °C

Fig. 1. Regression analysis for checking air temperature

were 2,8 %, 1.0, and 0,9 °C, respectively, which corresponds to the high accuracy of the result [22]. For 2023–2024, the MAPE, RMSE, and SEE errors for the maximum air temperature were 2,4–3,1 %, 0,8–1,1, and 0.75–1.04 °C, respectively. In terms of months of research, the errors of MAPE, RMSE, and SEE for the maximum air temperature were within 2,6–3,4 %, 0,8–1,1, and 0,66-1,00^0 C, respectively. The minimum error values were observed in May, and the maximum in July and September. Such a small range of errors indicates their stability over time.

For the minimum air temperature, the errors of the MAPE, RMSE, and SEE were 20,0 %, 2,6, and 1,29 °C, respectively, which corresponds to the good accuracy of the result [22]. To improve the accuracy of the minimum air temperature, we calculated the ratio of the actual minimum temperature to the one obtained from VCWD, which averaged 0.85 over the years of research. Multiplying the obtained minimum air temperature data by the correction factor of 0,85, we obtained the revised minimum air temperature. As a result, the errors of the MAPE, RMSE, and SEE decreased and amounted to 10,4 %, 1,5, and 1,10 °C, respectively (Table 1), which corresponds to the high accuracy of the result (Fig. 1d).

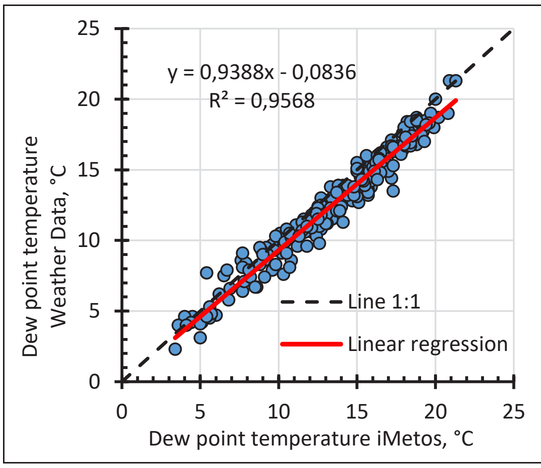
According to the analysis of the graph (Fig. 2a), it was found that the obtained linear dependence for the dew point temperature almost coincides with the 1:1 line, and the coefficients of determination are 0.9568, which indicates the high accuracy of the results [24].

The results of the error calculations (Table 2) also confirm the high accuracy of the dew point temperature obtained from VCWD. Thus, on average, over the years of research, the errors of MAPE, RMSE, and SEE, respectively, were 8,3 %, 1,2, and 0,79 °C, which corresponds to the high accuracy of the result [22]. For the years 2023–2024, the errors of MAPE, RMSE, and SEE were 6,8–9,7 %, 0,9–1,5, and 0,68–0,72 °C, respectively. In terms of months of research, the errors of MAPE, RMSE and

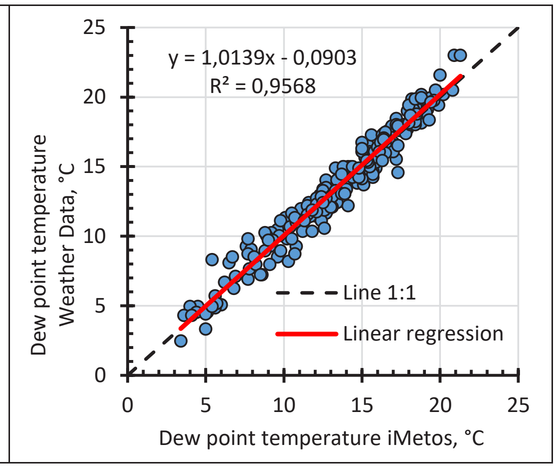
1. MAPE, RMSE and SEE errors for air temperature, °C (by observation periods)

Observation period	Air temperature, °C											
	aver	max	mine	min*	aver	max	mine	min*	aver	max	mines	min*
	MAPE error				RMSE error				SEE error			
average	5,6	2,8	20,0	10,4	1,2	1,0	2,6	1,5	0,63	0,90	1,29	1,10
2023	5,5	2,4	20,0	9,3	1,2	0,8	2,4	1,2	0,57	0,75	1,07	0,91
2024.	5,6	3,1	20,1	11,4	1,3	1,1	2,8	1,7	0,69	1,04	1,42	1,21
May	4,6	2,6	25,3	13,3	0,9	0,8	2,3	1,4	0,67	0,66	0,77	0,65
June	4,7	2,6	12,5	8,3	1,1	0,8	1,7	1,3	0,57	0,80	0,97	0,82
July	5,4	2,9	17,2	7,4	1,3	1,1	2,6	1,3	0,59	1,00	1,15	0,98
August	6,1	2,4	22,6	8,5	1,4	0,9	3,2	1,4	0,43	0,77	1,06	0,90
September	6,5	3,4	28,7	18,9	1,3	1,0	2,8	1,9	0,67	0,85	1,08	0,92

min* – specified minimum air temperature.



a) dew point temperature



b) specified dew point temperature

Fig. 2. Regression analysis to check the dew point temperature

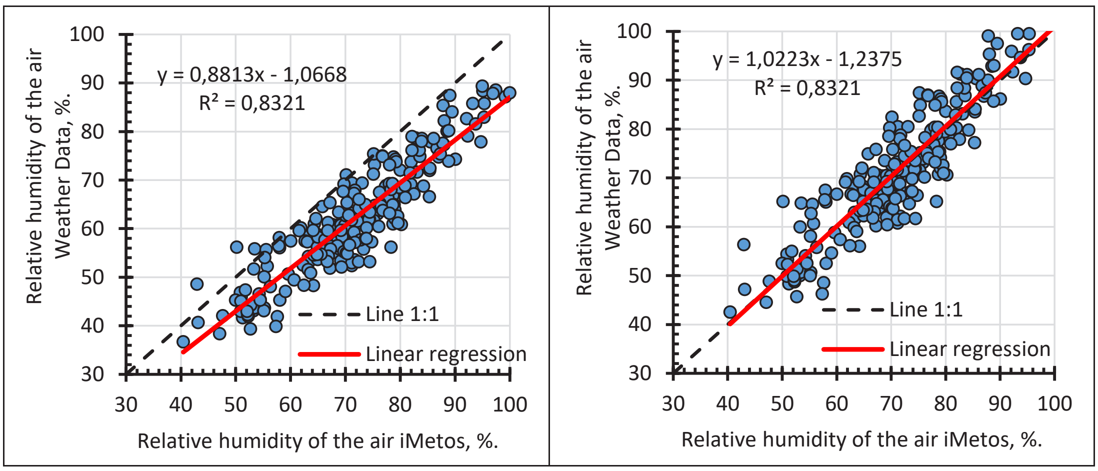
SEE for dew point temperature were in the range of 11,4–7,1 %, 1,4–0.9 and 0,93–0,53 °C, respectively. The minimum error values were observed in the summer months, and the maximum in May and September. To improve the accuracy of the dew point temperature, we calculated the ratio of the actual dew point temperature to the one obtained from VCWD, which averaged 1.07 over the years of research. Multiplying the obtained dew point temperature data by the correction factor of 1,07, we obtained the corrected dew point temperature. As a result, the MAPE and RMSE errors decreased by 2,5 % and 0,3 °C, and the SEE error increased by only 0,06 °C. The refined dew point temperature also corresponds to the high accuracy of the result (Fig. 2b).

According to the analysis of the graph (Fig. 3a), it was found that the obtained linear dependence for relative humidity is below the 1:1 line, the coefficients of determination of the obtained dependence are 0,8321. This indicates that the relative humidity is underestimated relative to the actual one.

On average, over the years of research, the MAPE, RMSE, and SEE errors for relative humidity obtained from VCWD were 13.6 %, 10.7 %, and 4.62 %, respectively (Table 3), which corresponds to the good accuracy of the result [22]. For the years 2023–2024, the errors of the MAPE, RMSE, and SEE were 11,5–15,7 %, 9.0–12.1, and 4,24–4,39 %, respectively. In terms of months of research, the errors of MAPE, RMSE and SEE for relative humidity were in the range of 16,1–8,9 %, 12,2–5,6 and 4,38–2,39 %, respectively. The minimum error values were observed in May, and the maximum – in the summer months. To improve the accuracy of relative humidity, we calculated the ratio of actual relative humidity to that obtained from VCWD,

2. Errors of MAPE, RMSE and SEE for dew point temperature, °C (by observation periods)

Observation period	Dew point temperature, °C					
	average	refined	average	refined	average	refined
	MAPE error		RMSE error		SEE error	
average	8,3	5,8	1,2	0,9	0,79	0,85
2023	6,8	6,5	0,9	0,8	0,68	0,74
2024	9,7	5,2	1,5	0,9	0,72	0,78
May	11,4	15,8	0,9	1,2	0,93	1,00
June	7,1	4,7	1,1	0,7	0,62	0,67
July	7,1	4,3	1,4	0,9	0,77	0,83
August	7,8	4,0	1,3	0,7	0,53	0,58
September	10,9	8,4	1,2	1,0	0,76	0,83



a) relative humidity b) clarified relative humidity

Fig. 3. Regression analysis for checking relative humidity

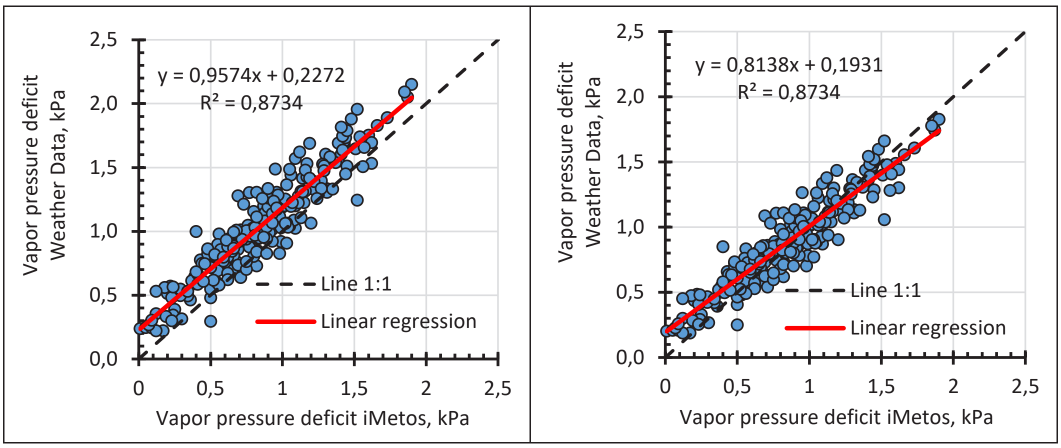
which averaged 1.16 over the years of research. Multiplying the obtained relative humidity data by the correction factor of 1,16, we obtained the corrected relative humidity. As a result, the MAPE and RMSE errors decreased by 7,4 % and 5,3 %, and the SEE error increased by 0,74 %. The accuracy of the result of the refined relative humidity increased to high (Fig. 3b).

Based on the analysis of the graph (Fig. 4a), it was found that the obtained linear dependence for the water vapor pressure deficit is above the 1:1 line, the R^2 of the obtained dependence is 0,8734. This indicates an overestimation of the water vapor pressure deficit relative to the actual values.

On average, over the years of research, the MAPE, RMSE, and SEE errors for the water vapor pressure deficit obtained from VCWD were 45,2 %, 0,24, and 0,14 kPa, respectively (Table 4), which corresponds to satisfactory accuracy [22]. For the years 2023–2024, the errors of MAPE, RMSE, and SEE, respectively, were 47,8–42,6 %, 0.21–0,26, and 0,14–0,13 kPa. In the context of months of research, the errors of MAPE, RMSE, and SEE for the water vapor pressure deficit were in the range of 82,7–9,8 %, 0,28–0,13, and 0,14–0,07 kPa, respectively. The minimum error values were observed in May, and the maximum in the summer months. It should be noted that the MAPE error in July was very high, amounting to 82,7 %, which corresponds to the unsatisfactory accuracy of the result [22]. To improve the accuracy of the water vapor pressure deficit, we calculated the ratio of the actual water vapor pressure deficit to the one obtained from VCWD, which averaged 0,80 over the years of research. Multiplying the obtained data on the water vapor pressure deficit by the correction factor of 0,80, we obtained the refined water vapor pressure deficit. As a result, the errors of MAPE, RMSE, and SEE decreased by 7,4 %, 0,1, and 0,03 kPa. The accuracy of the result of the refined water vapor pressure deficit remained satisfactory (Fig. 4b). In July, the MAPE error

3. Errors of MAPE, RMSE and SEE for relative humidity, % (by observation periods)

Observation period	Relative air humidity, %.					
	average	refined	average	refined	average	refined
	MAPE error		RMSE error		SEE error	
average	13,6	6,2	10,7	5,4	4,62	5,36
2023	11,5	6,2	9,0	5,3	4,24	4,92
2024	15,7	6,2	12,1	5,4	4,39	5,09
May	8,9	11,7	5,6	7,4	2,39	2,77
June	11,6	6,2	9,5	5,7	4,38	5,08
July	14,4	5,3	11,6	5,1	4,12	4,77
August	16,1	5,3	12,2	4,6	4,35	5,05
September	13,4	6,7	9,9	5,2	2,76	3,20



a) water vapor pressure deficit   b) specified water vapor pressure deficit

Fig. 4. Regression analysis for checking the water vapor pressure deficit

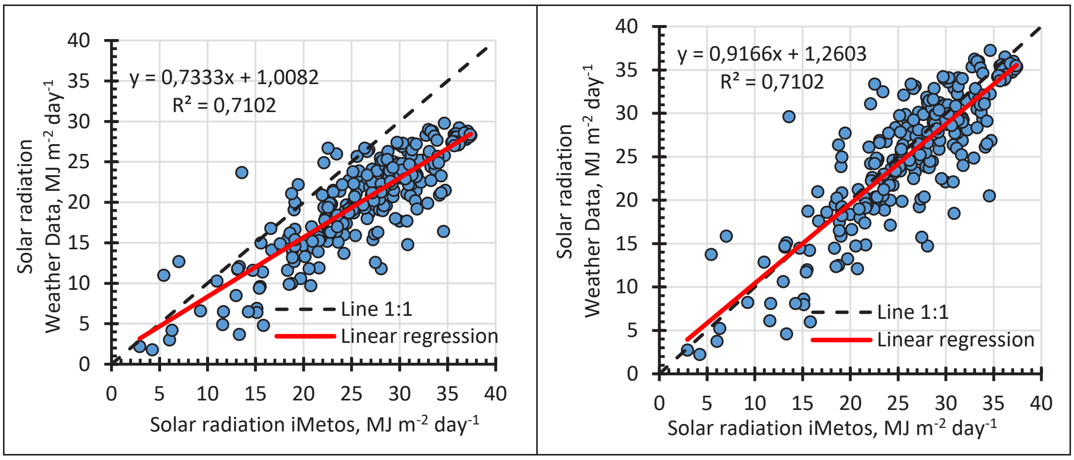
4. MAPE, RMSE and SEE errors for water vapor pressure deficit, kPa (by observation periods)

Observation period	Water vapor pressure deficit, kPa					
	average	refined	average	refined	average	refined
	MAPE error		RMSE error		SEE error	
average	45,2	27,7	0,24	0,14	0,14	0,11
2023	47,8	32,2	0,21	0,15	0,14	0,11
2024	42,6	23,3	0,26	0,14	0,13	0,11
May	9,8	17,0	0,13	0,22	0,07	0,05
June	40,3	22,8	0,23	0,13	0,14	0,11
July	82,7	53,8	0,28	0,14	0,14	0,12
August	34,7	16,6	0,25	0,14	0,09	0,07
September	26,9	17,4	0,19	0,14	0,11	0,09

decreased to 53,8 %, which brings the accuracy of the results obtained in this month almost to satisfactory.

Based on the analysis of the graph (Fig. 5a), it was found that the obtained linear dependence for solar radiation is below the 1:1 line, the coefficients of determination of the obtained dependence are 0,7102. This indicates an underestimation of solar radiation values relative to the actual ones.

On average, over the years of research, the errors of MAPE, RMSE, and SEE for solar radiation obtained from VCWD were 25,0 %, 7,0, and 3,26 MJ/m^2 /day, respectively (Table 5), which corresponds to the satisfactory accuracy of the result [22]. For 2023–2024, the errors of



a) solar radiation b) refined solar radiation

Fig. 5. Regression analysis to check solar radiation

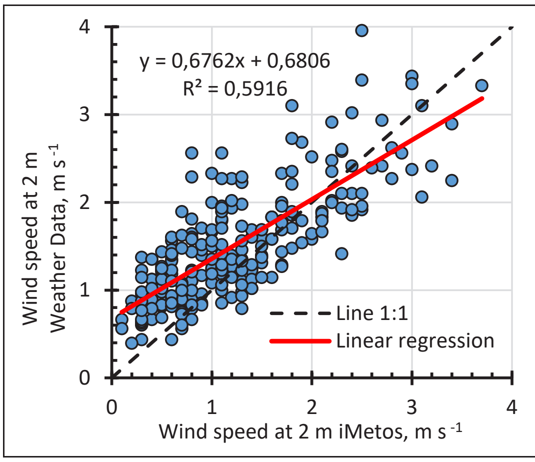
MAPE, RMSE, and SEE, respectively, were 24,5–25,6 %, 6,7–7,3, and 3,49–2,99 MJ/m^2/day. In the context of the study months, the errors of MAPE, RMSE and SEE for solar radiation were in the range of 28,9–22,7 %, 7,3–6,0 and 7,48–1,97 MJ/m^2 /day, respectively. The minimum values for the MAPE error were observed in the summer months, and the maximum values were observed in May and September. For the RMSE error, on the contrary, the maximum values were observed in the summer months, and the minimum values were observed in May and September. The maximum values of the SEE error were in May and the minimum values were in September. To improve the accuracy of solar radiation, we calculated the ratio of actual solar radiation to that received from VCWD, which averaged 1,25 over the years of research. Multiplying the obtained solar radiation data by the correction factor of 1,25, we obtained the corrected solar radiation. As a result, the MAPE and RMSE errors decreased by 10,5 % and 2,8 MJ/m^2 /day, and the SEE error increased by 0,82 MJ/m^2/day. The accuracy of the result of the refined solar radiation increased to good (Fig. 5b).

The largest deviations of the obtained meteorological data from the actual ones were found for wind speed, with a determination coefficient of 0,5916 for the established dependence (Fig. 6a). According to the analysis of the graph, it was found that the obtained linear dependence for wind speed crosses the 1:1 line at the point 2.1. Up to the value of 2,1, the linear dependence passes above the 1:1 line, and after crossing it, it passes below. This indicates that the wind speed is overestimated up to a value of 2.1 m/s, and then it is underestimated.

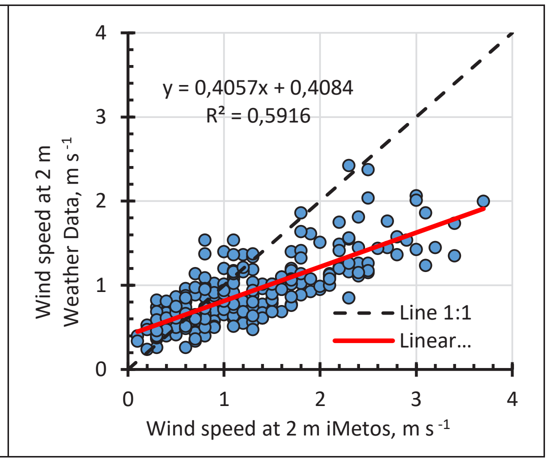
On average, over the years of research, the MAPE, RMSE, and SEE errors for the wind speed at a height of 2 m obtained from VCWD were 62,3 %, 0,56, and 0,43 m/s, respectively (Table 6), which corresponds to the unsatisfactory accuracy of the result [22]. For the years 2023–2024, the errors of the MAPE, RMSE,

5. MAPE, RMSE and SEE errors for solar radiation, MJ/m^2 /day (by observation periods)

Observation period	**Solar radiation, MJ/m /day²**					
	total	**refined**	**total**	**refined**	**total**	**refined**
	MAPE error		**RMSE error**		**SEE error**	
average	25,0	14,5	7,0	4,2	3,26	4,08
2023	24,5	15,0	6,7	4,4	3,49	4,36
2024	25,6	14,0	7,3	4,0	2,99	3,74
May	26,1	19,5	6,6	5,3	7,48	9,35
June	24,5	17,5	7,3	4,8	3,82	4,77
July	24,9	14,5	7,6	4,4	3,27	4,09
August	22,7	10,4	6,9	3,7	2,72	3,40
September	28,9	14,4	6,0	3,1	1,97	2,46



a) wind speed



b) updated wind speed

Fig. 6. Regression analysis to check wind speed

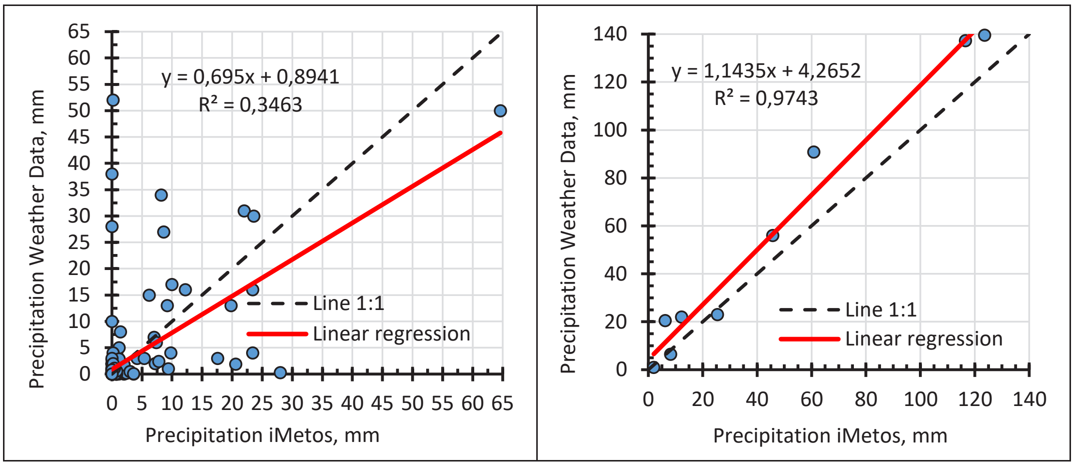
and SEE, respectively, were 25,8–98,7 %, 0,36–0,71, and 0,32–0,45 m/s. In the context of the study months, the MAPE, RMSE, and SEE errors for wind speed were in the range of 124,3–23,6 %, 0,68–0,35, and 0,39–0,27 m/s, respectively. The minimum values for the errors were observed in May and June, and the maximum values were observed in July and August. It is worth noting the very high error of the MAPE in August, which amounted to 124,3 %. To improve the accuracy of wind speed determination, we calculated the ratio of the actual wind speed to the one obtained from VCWD, which averaged 0,6 over the years of research. Multiplying the obtained wind speed data by the correction factor of 0,6, we obtained the refined wind speed. As a result, the MAPE and SEE errors decreased by 23,3 % and 0,19 m/s, and the RMSE error increased by 0,05 m/s. The accuracy of the data obtained increased to satisfactory (Fig. 5b). At the same time, despite the decrease in average errors over the years of research, in May and June, the MAPE and RMSE errors increased. Thus, in May, these errors increased by almost 2,5 times.

Based on the results of comparing the daily precipitation obtained from the VCWD and the actual values, a moderate relationship between them was established [24], with a determination coefficient of 0,3463 (Fig. 7a). The obtained linear dependence for daily precipitation falls below the 1:1 line. Based on the analysis of total precipitation for the month obtained from VCWD and actual precipitation, a close relationship between them was established. The coefficients of determination are 0,9743 (Fig. 7b). The resulting linear relationship for total precipitation per month is above the 1:1 line. This indicates an overestimation of total precipitation for the month relative to the actual precipitation.

On average, over the years of research, the errors of MAPE, RMSE, and SEE for daily precipitation obtained from VCWD were 40103 %, 6,0, and 5,7 mm/day, respectively (Table 7), which corresponds to a very unsatisfactory accuracy of the result [22]. Such high error values are observed

6. MAPE, RMSE and SEE errors for wind speed, m/s (by observation periods)

Observation period	**Wind speed, m/s**					
	average	**refined**	**average**	**refined**	**average**	**refined**
	MAPE error		**RMSE error**		**SEE error**	
average	62,3	39,0	0,56	0,61	0,43	0,26
2023	25,8	38,0	0,36	0,72	0,32	0,19
2024	98,7	40,0	0,71	0,48	0,45	0,27
May	18,6	50,2	0,48	1,13	0,39	0,23
June	23,6	36,7	0,35	0,77	0,25	0,15
July	48,3	31,3	0,55	0,58	0,33	0,20
August	124,3	53,8	0,68	0,35	0,27	0,16
September	63,1	28,1	0,67	0,37	0,25	0,15



a) daily b) the amount for the month

Fig. 7. Regression analysis for precipitation verification

7. Errors of MAPE, RMSE and SEE for precipitation, mm (by observation periods)

Observation period	Precipitation, mm					
	daily	amount for the month	daily	amount for the month	daily	amount for the month
	MAPE error		RMSE error		SEE error	
average	40103	52,6	6,0	11,6	5,7	-
2023	18295	72,7	6,4	12,6	6,3	-
2024	61912	32,5	5,4	10,7	5,1	-
May	4367	50,0	5,0	10,0	4,8	-
June	52911	33,5	6,2	25,3	6,0	-
July	74467	17,6	9,9	13,1	9,0	-
August	23264	120	2,8	8,3	2,7	-
September	10941	50,5	4,4	9,8	4,3	-

both by years of research and by months, which indicates that it is impossible to use the obtained values of daily precipitation from VCWD [9].

Based on the analysis of total monthly precipitation obtained from VCWD, their unsatisfactory accuracy was found. Thus, on average, over the years of research, the MAPE and RMSE errors for the amount of precipitation per month were 52,6 % and 11,6 mm/month, respectively (Table 7). For the years 2023–2024, the MAPE and RMSE errors were 72,7–32,5 % and 12,6–10,7 mm/month, respectively. In terms of months of research, the MAPE and RMSE errors for the amount of precipitation per month were in the range of 120,0–17,6 % and 25,3–8,3 mm/month, respectively. The minimum values for the MAPE error were observed in July, and the maximum values were observed in August. For the RMSE error, the minimum values were observed in August, and the maximum values were observed in June.

For the amount of annual precipitation obtained from VCWD, their satisfactory accuracy was found (MAPE = 23,9 %, RMSE = 47,9 mm/year). For 2023–2024, the errors of the MAPE and RMSE were 28,7–19,2 % and 57,6–38,3 mm/year, respectively.

Conclusions.

1. Based on the results of the analysis of meteorological data obtained from the Visual Crossing Weather Data virtual meteorological station, their accuracy was established. Thus, the data on the average, maximum air temperature and dew point temperature are received with high accuracy, with the MAPE errors of 5,6, 2,8 and 8,3 %, respectively (MAPE < 10 %). The minimum air temperature and average relative humidity are characterized by good accuracy, with the MAPE errors of 20,0 and 13,6 %, respectively (MAPE = 10–20 %). The data on solar radiation and water vapor pressure deficit are obtained with satisfactory accuracy, with MAPE errors of 25,0 and 45,2 %, respectively

(MAPE = 20–50 %). Data on wind speed at a height of 2 m, total monthly and daily precipitation were obtained with unsatisfactory accuracy, with MAPE errors of 62,3, 52,6, and 40103 % (MAPE > 50 %), respectively.

2. According to the results of the research, it was found that the values of daily precipitation (RMSE = 6.0 mm) obtained from VCWD are not correct. It is possible to use only total monthly precipitation (RMSE = 11,6 mm/month) or annual values (RMSE = 47,9 mm/year).

3. The application of the correction factor to the obtained meteorological data increases their accuracy and reduces the errors of MAPE, RMSE and SEE.

4. In the future, the meteorological data obtained from the Visual Crossing Weather Data virtual meteorological station will be used to calculate the reference and actual evapotranspiration using the Penman-Monteith method (FAO56-PM) in the Polissya region of Ukraine.

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УДК 631.67

ОЦІНКА ТОЧНОСТІ МЕТЕОДАНИХ, ОТРИМАНИХ З ВІРТУАЛЬНОЇ ТА АВТОМАТИЧНОЇ МЕТЕОСТАНЦІЙ ДЛЯ УМОВ ПОЛІССЯ УКРАЇНИ

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Анотація. *У статті проведено комплексне оцінювання метеорологічних даних, отриманих з віртуальної Visual Crossing Weather Data (VCWD) та автоматичної (iMetos Base) метеорологічної станції для умов Полісся України. З цією метою було обрано метеорологічні дані, які входять до формули розрахунку еталонної евапотранспірації (ET_0) за методом Пенмана-Монтейта (FAO56-PM) а саме: середня (Tmean), максимальна (Tmax) та мінімальна (Tmin) температури повітря, температура точки роси (Tdew), середня відносна вологість повітря (Rhmean), середній дефіцит тиску водяної пари (Damean), сумарна сонячна радіація (Rs), середня швидкість вітру на висоті 2 м (u_2) та щодобові опади (P). На основі регресійного аналізу та розрахунку середньої абсолютної відсоткової похибки (MAPE), середньоквадратичної похибки (RMSE) та стандартної похибки (SEE) обґрунтовано, що з високою точністю з віртуальної VCWD-метеостанції отримано дані щодо середньої та максимальної температури повітря, а також температури точки роси. Похибки MAPE відповідно* *становлять 5,6, 2,8 та 8,3 % (MAPE < 10 %). Для мінімальної температури повітря та середньої відносної вологості повітря притаманна добра точність, похибки MAPE яких відповідно становлять 20,0 та 13,6 % (MAPE = 10 – 20 %). Із задовільною точністю отримано дані про сонячну радіацію та дефіцит тиску водяної пари, похибки MAPE яких відповідно становлять 25,0 та 45,2 % (MAPE = 20 – 50 %). Дані про швидкість вітру на висоті 2 м, сумарні місячні та щодобові опади отримано з незадовільної точністю, похибки MAPE яких відповідно становлять 62,3, 52,6 та 40103 % (MAPE > 50 %). Встановлено, що значення щодобових опадів (RMSE = 6,0 мм), отриманих з VCWD використовувати не коректно. Можливо використовувати тільки сумарні опади за місяць (RMSE = 11,6 мм) або їх річні значення (RMSE = 47,9 мм). Застосування коригуючого коефіцієнту до отриманих метеорологічних даних підвищує їх точність, та зменшує похибки MAPE, RMSE та SEE. Застосування різних похибок дало можливість комплексно перевірити отримані метеорологічні дані. Так, за допомогою похибки MAPE розраховується з якою точністю отримується метеорологічний показник, похибки RMSE та SEE вказали наскільки отримана величина відрізняється від середнього значення. Надалі отримані метеорологічні показники з віртуальної метеорологічної станції Visual Crossing Weather Data будуть використані для розрахунку еталонної та фактичної евапотранспірації за методом Пенмана-Монтейта (FAO56-PM) в умовах Полісся України.*

Ключові слова: *віртуальна метеостанція, метеорологічні дані, температура повітря, опади, точність, похибки MAPE, RMSE та SEE*