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INFLUENCE OF LAND USE CATEGORIES ON WRF FORECAST AND ITS ACCURACY

In this research analysis of possibilities and methods of correction or reclassification of land use and land cover data, obtained modeling effects of using more accurate land use and land cover data and estimations of improvements of surface meteorological parameters simulations by mesoscale numerical atmospheric prediction (NWP) model. For the Kyiv region area, it is shown that the default WRF land use and land cover datasets are not ideal and contain various types of inaccuracies. Thus, compared to USGS, MODIS IGBP is characterized by a better spatial resolution, more correctly describing the urban built-up territories, forest areas and the Dnipro riverbed, but MODIS IGBP does not display small settlements. Analysis of other researches had shown that most of the reviewed studies are based on the case study approach, namely on an analysis of a small number of specific simulations. The disadvantage of this approach is that the sample size from which conclusions can be drawn is insignificant, so it is useful to compare similar studies for the consistency of the obtained results. The most consistent conclusions regarding the simulation improvement by the land use and land cover modification in the WRF model are related to the parameters of air temperature and humidity. Thus, the usage of more accurate and up-to-date land use and land cover databases in WRF simulations made it possible to reduce bias of forecasts and improved the accuracy of minimum and maximum daily temperature forecasts. The most significant improvement in the performed forecasts concerns the night temperature. The second parameter that were most often able to predict better is relative humidity. Improvement of simulated wind parameters using another land use and land cover dataset in the WRF model may be possible in urban areas and near the coast, especially as improving description of breeze circulation by the model. Assessments regarding the possibility of improving WRF precipitation simulation by land use and land cover dataset modification are not definite, although some works have noted the influence of the heat island of urbanized areas on redistribution of precipitation. On the one hand, in most of the analyzed scientific works, land use and land cover changes did not allow to significantly improve precipitation forecasts using the WRF model. On the other hand, it can be assumed that the physical and geographical conditions of a simulation domain as well as available moisture in the atmosphere is playing a more significant role in precipitation modeling than land use and land cover.

Keywords: *Weather Research and Forecasting (WRF) Model, Land Use, Land Cover, Numerical weather prediction, Atmosphere Modelling, Accuracy.*

Introduction. The Earth’s surface features significantly affect air circulation in the atmosphere, micro- and mesoscale meteorological processes and phenomena [24]. Therefore, taking into account land surface properties is an important aspect in mesoscale atmospheric modeling. Description of land surface features in atmospheric models is implemented by splitting into small areas and conducting a subsequent classification of these areas. Modern LULC (land use and land cover) databases are built on the principle of a surface classification within geometrically equal areas of certain spatial resolution. The LULC definition includes two concepts — the type of land cover (LC) and the type of land use (LU) [22, 32]. Separately, the LC definition refers to the biophysical characteristics of the Earth's surface, including the distribution of vegetation, water, soil, etc. At the same time, LU refers to the way people use certain land area with an emphasis on the functional role of the land area for an economic activity [5, 25]. Given the current level of urbanization, these two concepts are usually combined and find their place in unified classification systems of the Earth's surface [3].

LULC is an important parameter that describes the properties of certain surface area and make possible to parameterize with some approximation the processes of heat and momentum exchange between surface and air, which in numerical models determine the calculation of meteorological parameters at the surface atmospheric boundary layer (ABL). Thus, change of LULC parameter in a certain part of the territory affect the accuracy of modeling atmospheric processes. Anthropogenic activity causes global changes of the Earth's surface. The land use and land cover change (LULCC) are considered, among others, as one of the drivers that has a significant impact on global climate changes, as well as on processes in ecosystems, biological cycles, biodiversity etc. [28]. Therefore, a significant amount of scientific research is devoted to the role of LULCC in modeling climate changes [30, 33, 44]. On the other hand, it is quite obvious that for the tasks of modeling atmospheric processes or weather forecasting the use of the most up-to-date LULC database plays an important role in increasing the accuracy of simulations.

The aim of the study is to analyze the scientific works on the methods of correction/reclassification of LULC data, obtained modeling effects of using more accurate LULC data and estimations of improvements of surface meteorological parameters simulations by mesoscale numerical atmospheric prediction (NWP) model.

The Ukrainian Hydrometeorological Institute of the State Emergency Service of Ukraine and the National Academy of Sciences of Ukraine have been working on the adaptation of the world's best samples of atmospheric models for various purposes and improvement for a long time [16, 35-37]. Thus, on the basis of the numerical mesoscale weather forecast model WRF (USA) [39], a forecasting system was created for the territory of Ukraine. The above has ensured providing forecasting meteorological fields with high spatial and temporal resolution as well as individual values at certain settlements for the needs of domestic consumers. Together with the use of other methods and models, it makes it possible to create specialized forecasting systems (forecasting of atmospheric phenomena, hydrological forecasting, forecasting of wind waves on the sea water area, etc.) and provides a modern level of hydrometeorological service [7].

The standard LULC database for all versions of the Weather Research and Forecasting (WRF) mesoscale meteorological model [39] is the USGS dataset named after developing institution – The United States Geological Survey [43]. The USGS LU data available for WRF simulations contain 24 land use categories and a grid spatial resolution of approximately 1 km. The dataset was obtained on the basis of the High Resolution Radiometer (AVHRR) images for the 12-month period, April 1992 - March 1993 [10]. The division into categories is based on the principle of a flexible structure of the database and the concepts of seasonal changes of the surface. Regions with a seasonal change of the land surface characteristics provide a basis for representing temporal and spatial models (patterns) of vegetation in the database. Such regions consist of relatively homogeneous land cover associations (e.g., similar floristic and physiognomic characteristics) that exhibit a distinct phenology (i.e., onset, peak, and duration of the growing season) [10]. According to some authors, the disadvantage of this dataset is that the classification principles were developed back in the 1970s [13].

The second standard LU database for WRF is the Collection 5 MODIS Global Land Cover Type [9]. This dataset was created by Boston University based on observational data processed by the 500 m MODIS Spectroradiometer Image covering the period of January to December 2001. The dataset is based on the classification developed by the International Geosphere-Biosphere Program (IGBP), consisting of 17 discrete categories. The actual dataset used for the WRF simulations is the 20-categories modified version of the IGBP MODIS dataset processed by NCEP [39]. In 2019, the revised Collection 6 MODIS Land Cover Type dataset was released [40]. The authors note that the land cover classification in the new dataset is more accurate owing to the redistribution of the categories of forests, shrubs, meadows, and agricultural land, and the share of misclassified grids has decreased.

An analysis of the LU USGS's and the MODIS IGBP's categories spatial distribution over the Kyiv region was carried out. An overlay of the USGS and MODIS categories and the current borders of urbanized areas is carried out using QGIS v. 3.22 [31] and Google Maps shown on the fig.1 and fig. 2 respectively.

The MODIS IGBP compared to the USGS data is characterized by a higher spatial resolution and a more correct depiction of urban, forest areas and the Dnipro riverbed. However, small settlements (which are available in USGS) are not displayed in MODIS IGBP. In general, for much accurate WRF simulations, at a minimum, a correction of the misclassified urban areas in both the USGS and MODIS IGBPs datasets is required.

Below we present a review of other researchers experience and some estimates of the received improvements in forecasts of meteorological parameters by using more accurate LULC data in the WRF model.

The studies [8, 12, 29] have shown that changes in LU during simulation using mesoscale atmospheric models can have a significant impact on the results of the simulation, for example, on the calculations of turbulent heat flows, which directly affect the daily cycle of meteorological parameters within the planetary boundary layer (PBL). One of the first works related to the modification of LU data for NWP models was the Grossman-Clarke's et al. study [12]. The authors replaced the standard USGS data used in the MM5 model with refined data obtained using LANDSAT satellite images of the Earth's surface produced in 1998. In particular, changes in the dataset were concerned urbanized areas, which were divided into 3 classes. The classes differed in terms of typical fractions of vegetation and non-natural surfaces, which were defined on the basis of ground-based information within the urban agglomeration of Phoenix, USA. The latter made it possible to describe variations in moisture availability for evaporation by soil cover class [12]. As a result, replacing the LULC data affects the forecasts, which was manifested, in particular, in the accuracy increase of the simulated diurnal temperature cycles, night-time temperature, maximum and minimum surface temperatures.

In work [8], the effect of refining LULC data in modeling meteorological conditions is shown in the example of a small domain that included the city of Houston and its suburbs, which have undergone significant urbanization in recent decades. The USGS dataset was changed to The Texas Forest Service (TFS) LULC database, obtained from LANDSAT imagery with a horizontal resolution of 30 m. These data more accurately describe the distribution of urban areas, residential areas, grassy vegetation, and forests. The use of TFS in combination with the Noah land surface model in the MM5 model made it possible to determine the effect of the refined LULC data on the diurnal cycles of air temperature (in particular, maximum temperature) and wind. It is also noted in [8] that the differences are clearly visible in synoptic processes with a weak pressure field and insignificant horizontal air flows. In this way, it was possible to simulate the effect of the asymmetrically elongated convergence zone of the heat island, which forms over Houston city and increases the strength of the sea breeze flow and changes the location of the onshore breeze front in the Gulf of Mexico, which could not be obtained when modeling using the USGS.

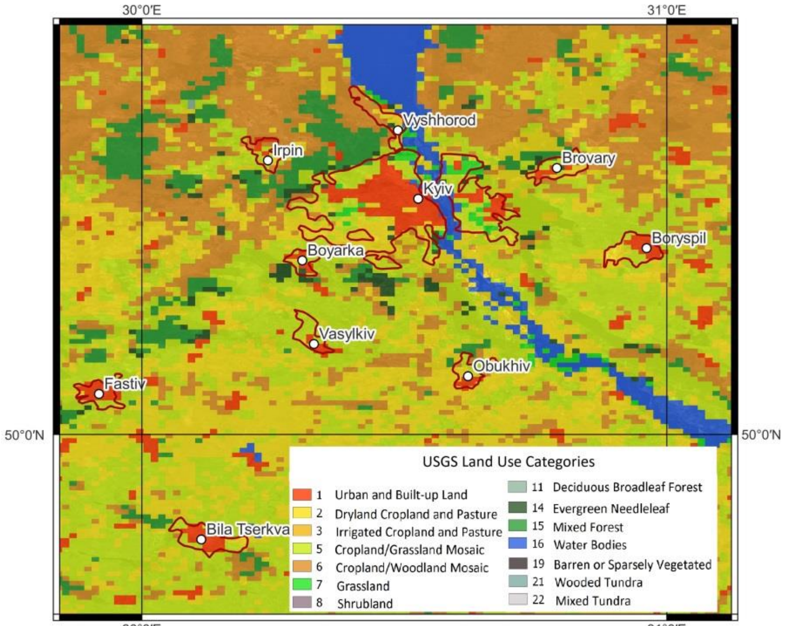

Fig. 1 **USGS Land Use Categories in Kyiv Region**

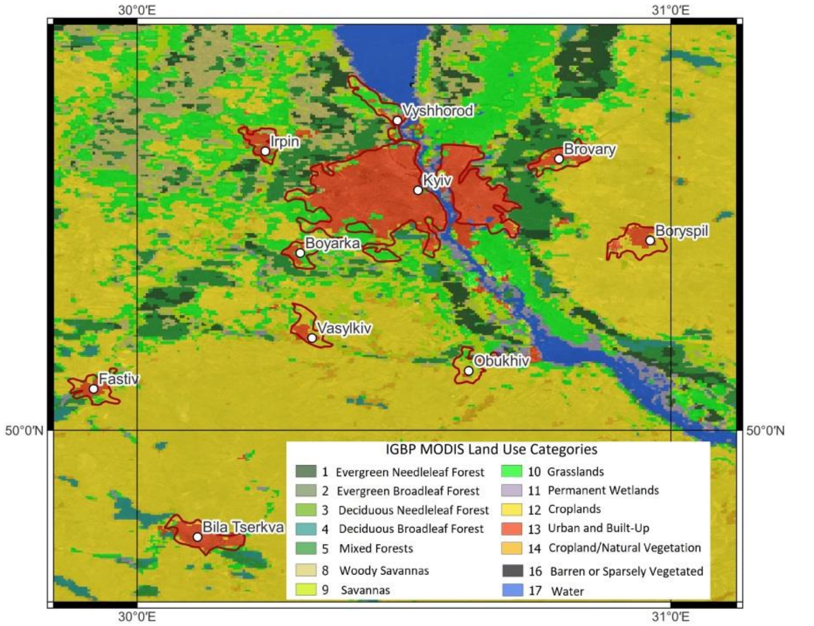

Fig. 2 **MODIS IGBP Land Use Categories in Kyiv Region**

The simulated precipitation and wind fields also undergo significant changes when using different LU data sets in work [6]. The authors used standard USGS and MODIS data, as well as additionally data based on the Syste`me Probatoire d'Observation de la Terre (SPOT) satellite system, 2007, which were interpreted and transformed into the LU database by the National Central University of Taiwan (NCU). As the authors noted, due to the overestimation of urban built-up area in the MODIS data, the WRF-MODIS simulation predicts overestimated daytime temperatures in western Taiwan. Conversely, the WRF-USGS coupling underestimates daytime temperatures. In contrast, the predicted temperature values obtained using the NCU data is set an intermediate position, with no significant bias. The WRF-MODIS combination over the coastal area off Taiwan simulates the strongest onshore sea breeze due to the increased land-sea temperature gradient, while the WRF-USGS simulation shows the weakest onshore breeze. WRF-USGS significantly overestimates the surface wind speed due to the lower roughness obtained from the coarser USGS data, while the surface wind speed estimated by WRF-NCU and WRF-MODIS are in better agreement with the actual observational data [6].

The use of datasets containing a different number of LULC categories comparing to the USGS or MODIS requires the adaptation of these datasets according to the standard classification with the appropriate codes, which will ensure the correct reading of the information from the appropriate files. For example, in work [13], the Corine Land Cover (CLC) data set was used, which contained 44 land use categories and was created based on 2006 satellite data of the European area. The horizontal resolution of the used images in this work is about 500 meters. The authors adapted the CLC LU categories to the USGS format using the reclassification methodology proposed in [29]. Statistical testing of temperature, humidity, and wind speed showed that CLC outperformed USGS. In general, using CLC for the WRF simulation results in higher predicted temperature values and lower moisture values than when using USGS. At the same time, wind speed has positive bias. In addition, CLC showed better statistical results in terms of root mean square error (RMSE). For example, RMSE for temperature are: 1.953 °C for USGS and 1.872 °C for CLC, for relative humidity 13.752% for USGS and 10.991% for CLC, for wind speed 1.498 m/s for USGS and 1.178 m/s for CLC. Besides, the updated dataset ensures a slightly higher correlation with actual observational data. In particular, it is noted that the forecasts have improved much more at meteorological stations in urban areas (higher temperature and lower relative humidity).

Also based on CLC data, but with a spatial resolution of 100 m, the study [38] is devoted to the assessment of the influence of high-resolution land use and topography (SRTM) data on the accuracy of WRF simulation in microscale modeling (with a step of 200 m) for the city of Warsaw. The results show that the effect of changing the default geographic data (MODIS and

GMTED2010) to higher resolution geographic data (CLC and SRTM) in most cases produced more accurate values of temperature and relative humidity at the 2 m level [38].

It is especially relevant to clarify land surface features in regions with a complex topography with steep slopes, where it is advisable to increase the resolution of the model grid [4]. Therefore, a significant part of the works devoted to the study of the effects of the use of different LULC datasets combines them with different digital relief models. For example, in [1], the WRF model was configured for six experimental configurations: using three land surface models (Noah, Rapid Update Cycle / RUC and TD) and two land use datasets (USGS and updated New Land Use / NLU). The result showed that the modeling of temperature and precipitation is sensitive to the combination of topography and LU data. The combination of NLU with RUC and TD resulted in a negative bias (0.27 ^{o}C) for 2 m maximum temperature and a positive bias (0.20 ^{o}C) in 2 m minimum temperature. The precipitation simulation result was better with NLU; especially the NLU and Noah configuration gave the lowest mean bias (2.39 mm/day) and RMSE (6.6 mm/day). All WRF experiments overestimated weak and heavy precipitation. Overall, the results showed that the application of updated land use data significantly improved the performance of the WRF model in simulating temperature and precipitation.

The land use data from the GLC2015 database were used in the WRF model by reclassifying land surface types [20]. The spatial resolution of GLC2015 is 300 m. The authors rescaled the data to a resolution of 1 km and adapted them to the USGS format. When verifying the model data, it was found that bias for surface air temperature was reduced by 2.54%, and RMSE was reduced by 1.48%. A 10.46% bias reduction and a 6.77% RMSE reduction for wind speed were also achieved using GLC2015. Though the simulation of the relative and absolute air humidity was reported to be less successful.

An evaluation of the obtained effect of using the North American Land Change Monitoring System (NALCMS) database in the WRF model in comparison with the standard USGS was carried out in work [23]. The experiment covered 120-hour forecasts for each day of January, April, July and September 2012. Verification was made for 120-hour forecasts of surface temperature, wind speed, and hourly precipitation. Statistical analysis revealed that the forecast of near-surface wind speed and temperature was improved with the updated and more accurate NALCMS dataset, especially in the 48- to 72-h forecasts. RMSE of mean wind speed reached a maximum decrease of 1.2 m/s, while surface temperature decreased to 0.6°C. The RMSE of the hourly precipitation is close in both cases, but there is some shift in precipitation spatial distribution.

Some works are devoted not only to a comparison of the standard datasets with updated ones but comparison with hypothetical reconstructed data for past periods. In [15] WRF modeling experiments were carried using the National Land Cover Database (NLCD) of 2006 and 1992 images, as well as a hypothetical (reconstructed) distribution of land cover of 1900 for the Las Vegas agglomeration. The heat island effect over the city turned out to be the most apparent when using modern LU data compared to data describing a less urbanized city.

Another example of a hypothetical assumption is the use of projections of climate changes and expected future changes in the distribution of different types of land use and urbanization [45]. In the study, the authors used WRF to simulate the regional climate with two different land-use scenarios: one with actual ground surface characteristics of 2005, and the other with projected future LULC. At the same time, the expected characteristics of LULC for the year 2050 are obtained by combining three different datasets under the most intensive urbanization scenario: 1) SLEUTH data – a set of geospatial data describing the future scenario of given trends of uncontrolled exponential growth of land use change in the year 2050 in the Santa Cruz watershed (Tucson area) using the SLEUTH model; 2) MAG (by the Maricopa Association of Governments) – raster images describing the future Arizona state urbanization scenario by the year 2050; 3) NALC - North American land area data (2005) classified using MODIS data (250 m) describing current LULC [45]. Experiments conducted on the meteorological data over a 10-year period showed a statistically significant increase in daily mean temperature over a more urbanized area (LULC_2050) compared to the actual one (LULC_2005). A notable feature is that daytime temperature does not change significantly, minimum (night-time) temperature over urban built-up areas is significantly increased. The authors of [45] explain such results by changes in the thermal properties of the surface, such as heat capacity and thermal conductivity. At the same time, it is worth noting that when conducting experiments, the authors used the non-hydrostatic WRF model with the involvement of an additional model to take into account the city streets profile (Urban Canopy Model, UCM). The UCM model estimates temperature and energy fluxes at roofs, walls, and road surfaces, which subsequently serve as lower boundary conditions for the atmospheric model [18, 42]. The authors of [45] did not get an unequivocal result regarding the impact of changing LULC data on precipitation modeling. A hypothetical reason for such uncertainty is the prevalence of relatively dry air masses over the research domain. In this case, the impact of urbanization on energy distribution on the surface does not lead to significant changes in precipitation because of a deficit of available specific humidity.

The work [19] is devoted to studying the influence of the land cover change in Tokyo city on precipitation within the urban built-up areas. The city location is characterized by rather high air humidity in summer. The authors experimented with replacing urbanized areas in the LULC dataset with a category describing predominant grass vegetation/pasture. The WRF simulation experiments estimated that growing urbanization cause increasing precipitation by 10-15% in coastal urban areas, with statistical significance levels of 95% and 99% in some areas. However, for hypothetical conditions, in some foothill areas, statistically significant negative precipitation anomalies have been identified, unlike actual urbanization. Similar conclusions for a precipitation redistribution over the territory were drawn in [21]. The authors associated this feature with the influence of large-scale urban areas development and resulting heat island.

The work [41] is focused on combining the most relevant data of LU parameters and the parameter describing the physical and hydraulic properties of the upper layer of the Earth's surface interacting with the atmosphere, which is soil type/soil texture (ST). For the territory of the United Arab Emirates, the authors updated the LULC and ST datasets. The use of more realistic ST and LULC data helps to reduce low temperature bias, mainly at the coastal and low elevation stations (< 200 m). However, the authors did not note a significant improvement in the simulation of relative humidity, wind speed, and precipitation. In the experiment with refined data, the accuracy of the WRF temperature simulation appears to be higher. Thus, for the territory of the Dubai International Airport, when rare vegetation is replaced by urban development, the bias with a negative sign (exceeds 3°C) in the average daily temperature is reduced to < 0.5°C. However, for stations at higher altitudes (> 200 m), the effect of more realistic land surface texture and LULC refinement is very small. This led the authors to conclude that other factors, such as the representation of local topography and deficiencies in physical schemes, may play a major role. Changes in the specified surface properties also affect the simulation of onshore and sea breezes, mainly in coastal areas. Changes in the simulation of moisture advection are also observed, which is manifested in the appearance of relative humidity bias [41].

As in the previous work, a similar approach of specifying LULC and ST data was used in work [27]. The authors investigated the data refinement factor using a WRF v4.1.3 simulation with a 1-km grid for a domain covering the São Paulo metropolitan area. Changes to standard data were made taking into account Brazilian national databases (MapBiomas, SoilGrids). Through such clarification, it was possible to obtain a significant difference in the simulated minimum and maximum air temperature, as well as air humidity.

Noteworthy is the use of the updated MODIS Land Cover Type Product (MCD12Q1) Collection 6 (C6) database to assess the impact of deforestation in West Africa on meteorological parameters in the region [2]. The authors in addition to the main task have evaluated the impact of the updated LULC MODIS on WRF simulation in the West Africa, compared to the default MODIS dataset. In particular, a slight improvement in the accuracy of the air temperature simulation was obtained, but for the precipitation simulation replacement of the initial data did not show a positive effect. This result is mostly due to the fact that the authors did not focus on the territory of large cities where the greatest changes in the type of LULC are observed.

Another example, when the effect of replacing LULC in WRF is studied not in the example of urban areas, is the work of [11]. Various datasets (Corine Land Cover, USGS, MODIS30, and MODIS15) were tested in experiments on modeling meteorological variables in a region with a complex topography (the Italian Alps). The authors concluded that a more detailed set of land use data significantly improves the description of the modeled area in complex terrain conditions. CLC data on land use is much more realistic compared to the default dataset, which, in particular, was reflected in the greater realism of the simulated daily cycles of energy flows (sensible heat flux). A similar study in the Austrian Alps allowed the authors to conclude about better performance of CLC over USGS, as well as better performance of MODIS over USGS in WRF simulations [34].

Table 1. ***Summary of some results of LULC modification in the WRF model***

LU title	Categories/ spatial resolution	The obtained effect
Corine Land Cover (CLC)	44 categories, 1km/500 m	Higher accuracy of forecasts of air temperature, relative humidity and wind speed [13, 14]
New land use (NLU)		The error of simulated temperature values (especially at night) is much lower than when using USGS. The effect of changing the elevation model in WRF was much higher than LULC, in particular, for the precipitation forecast, RMSE decreased by 0.33, 0.59, 0.09 mm/day in Noah, RUC and TD LSM, respectively [1]
GLC2015 (Global Land Cover, 2015)	24 categories, 300 m	Air temperature bias decreased by 2.54%, RMSE decreased by 1.48%, wind speed bias decreased by 10.46%, and RMSE decreased by 6.77% when using the updated dataset [20]
The Texas Forest Service (TFS)	30 m	Modeling showed better consistency of simulated meteorological conditions in "weak" fields, when the large-scale flow was weak [8]
North American Land Change Monitoring System (NALCMS)	19 categories, 30 m,	Reduction of RMSE for average wind speed to 1.2 m/s and for surface temperature to 0.6°C. Spatial redistribution of atmospheric precipitation was observed [23]
USGS, Modification, specification of urbanized areas	1 km, additional (3) subclasses for urbanized areas	The accuracy of daily temperature cycle simulations at 2 m has been significantly improved when modeling using MM5 model [12]
NCU based on 2007 Syste`me Probatoire d'Observation de la Terre (SPOT)	11 categories, reclassification	Wind speed: better agreement with observational data. Statistical analysis showed that the use of NCU in WRF outperforms other simulations [6]
National Land Cover Database (NLCD)	NLCD2006 - 16 categories NLCD1992 - 21 categories, reclassification	The heat island effect for the more modern (urbanized) state of the urban agglomeration is clearly demonstrated [15]
Combination of SLEUTH, NALC, MODIS (by 2050 projection)	250 m, 21 categories	Over urbanized areas, daily temperature did not change significantly, and the nighttime temperature increased significantly [45]
Modification USGS, MODIS	~1 km 21 categories	Precipitation increases by 10-15% in coastal urban areas, compared to the experimental replacement of urban areas with the category of pastures and grass vegetation [19]
Corine Land Cover (CLC)	44 categories, 100 m	More accurate modeling of temperature and relative humidity at 2 m level [38]
Modification (clarification) of standard MODIS data	~1 km	The use of a more up-to-date database of ST and LULC data reduced bias in the modeling of nighttime air temperature, mainly at coastal stations and stations at low altitudes (< 200 m) [41]
Collection 6 (C6) MODIS Land Cover Type Product (MCD12Q1)	500 m, 21 categories	A modest improvement in the accuracy of air temperature simulation was obtained, but for precipitation simulation, the replacement of the initial data did not show a positive effect [2]

It is worth noting that a significant part of research is devoted not so much to indirectly determining the role of improving LULC data in the accuracy of WRF modeling, but to finding the optimal combination of LULC factors and describing the relief and urban canopy layer by involving the Urban Canopy Model (UCM) module in WRF simulations. In [17], the authors managed to combine LULC modification, 4-dimensional data assimilation schemes (FDDA), a scheme for wind flow calculations (Topo-wind) and UCM, which in combination gave the best simulation results of surface wind speed and atmospheric pressure. For wind speed at 10 m, RMSE was reduced from 2.20 m/s to 1.67 m/s, and for atmospheric pressure from 6.76 Pa to 6.69 Pa, respectively. As a result, this allowed the authors to significantly improve the forecast of sulfur dioxide (SO_2) concentration and $PM_{2.5}$ particles in the air in the city of Beijing.

Anthropogenic activity causes not only an increase in urban areas but also a change of initial land use to other categories, for example, croplands. [28]. However, the classification of such LU category is a separate problem, since croplands are not stable from year to year due to a crop rotation. There are various methods of detecting such areas based on satellite images, for example, as in [26]. All of the above suggests that experiments with the modification of LULC datasets for WRF simulations will continue.

Conclusions. Most of the reviewed studies related to the comparison of WRF performances with default datasets and replaced/modified LULC datasets are based on the case study approach, namely on an analysis of a small number of specific simulations. The disadvantage of this approach is that the sample size from which conclusions can be drawn is insignificant, so it is useful to compare similar studies for the consistency of the obtained results.

The most consistent conclusions regarding the simulation improvement by the LULC modification in the WRF model are related to the parameters of air temperature and humidity. Thus, the usage of more accurate and up-to-date LULC databases in WRF simulations made it possible to reduce bias of forecasts and improved the accuracy of minimum and maximum daily temperature forecasts. The most significant improvement in the performed forecasts concerns the night temperature. According to the studies, the second parameter that were most often able to predict better after refining the LULC data is relative humidity. These two meteorological parameters are most often found in similar studies, and the effect of reducing their forecast bias is consistent between different studies.

Reports on the improvement of simulated wind parameters using another LULC dataset in the WRF model are less common in the works than for air temperature. It should be noted that it is most pronounced in urban areas and near the coast, where it is possible to improve description of breeze circulation by the model.

Assessments regarding the possibility of improving WRF precipitation simulation by LULC modification are not definite, although some works have noted the influence of the heat island of urbanized areas on redistribution of precipitation. However, it is also noted, for better confidence in the results, it is necessary to conduct more experiments in order to obtain a more representative sample. On the one hand, in most of the analyzed scientific works, LULC changes did not allow to significantly improve precipitation forecasts using the WRF model. On the other hand, it can be assumed that the physical and geographical conditions of a simulation domain as well as available moisture in the atmosphere is playing a more significant role in precipitation modeling than LULC.

Except for air temperature, assessment of heat fluxes, wind, precipitation, and relative humidity, assessments of other meteorological variables when LULC changes in the WRF model are practically not found in the scientific literature we reviewed.

In the case of using a LULC dataset that differs in the number of categories from the default dataset, it is necessary to carry out a reclassification by aligning the new dataset with the categories of standard LULC dataset (USGS or MODIS) to ensure the recognition of grid values and the correct operation of parameterizations in the WRF model.

In this article, based on the example of the Kyiv region area, it is shown that the default WRF LULC datasets are not ideal and contain various types of inaccuracies. Thus, compared to USGS, MODIS IGBP is characterized by a better spatial resolution, more correctly describing the urban built-up territories, forest areas and the Dnipro riverbed, but MODIS IGBP does not display small settlements.

Список літератури
References

1. Achenafi Teklay, Yihun T. Dile, Dereje H. Asfaw, Haimanote K. Bayabil, Kibruyesfa Sisay, Impacts of land surface model and land use data on WRF model simulations of rainfall and temperature over Lake Tana Basin, Ethiopia // Heliyon. 2019. Volume 5. Issue 9. https://doi.org/10.1016/j.heliyon.2019.e02469

2. Achugbu I.C., Olufayo A.A., Balogun I.A. et al. Modeling the spatiotemporal response of dew point temperature, air temperature and rainfall to land use land cover change over West Africa // Model. Earth Syst. Environ. 2022. Vol. 8. P. 173-198. https://doi.org/10.1007/s40808-021-01094-8

3. Alshari Eman A., Gawali Bharti W. Development of classification system for LULC using remote sensing and GIS // Global Transitions Proceedings. 2021. Vol. 2, Issue 1. P. 8-17. https://doi.org/10.1016/j.gltp.2021.01.002

4. Arnold D. et al. High Resolution Modelling in Complex Terrain. Report on the HiRCoT 2012 Workshop, Vienna, 21-23 February 2012.

5. Arsanjani J.J. Dynamic Land Use / Cover Change Modelling : Geosimulation and Agent-Based Modelling. Vienna: University of Vienna; 2011.

6. Cheng F.Y., Hsu Y.C., Lin P.L., Lin T.H. Investigation of the effects of different land use and land cover patterns on mesoscale meteorological simulations in the Taiwan area // Journal of Applied Meteorology and Climatology. 2013. 52(3), P. 570-587.

7. Doroshenko A. Numerical atmospheric models and their application in different areas of economics / Anatoliy Doroshenko, Vitalii Shpyg, Igor Budak, Kateryna Huda [In: Kvasniy L. And Tatomyr I. (eds) Ukraine in the context of global and national modern servisation processes and digital economy]: monograph. Praha: Oktan Print, 2020. – eBook ISBN 978-80-907863-4-9; Print ISBN 978-80-907863-3-2. – P. 155-171. DOI: 10.46489/UITCOG0909

8. Fang-Yi Cheng, Daewon W. Byun, Application of high resolution land use and land cover data for atmospheric modeling in the Houston–Galveston metropolitan area, Part I: Meteorological simulation results // Atmospheric Environment. 2008. Vol. 42, Issue 33. P. 7795-7811. https://doi.org/10.1016/j.atmosenv.2008.04.055

9. Friedl Mark A., Sulla-Menashe Damien, Tan Bin, Schneider Annemarie, Ramankutty Navin, Sibley Adam, Huang Xiaoman. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets // Remote Sensing of Environment. 2010. Vol. 114, Issue 1. P. 168-182. https://doi.org/10.1016/j.rse.2009.08.016

10. Global Land Cover Characteristics Data Base Version 2.0. URL: https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/GlobalLandCoverCharacteristicsDataBaseReadmeVersion2.pdf (date of access: 13 July 2022).

11. Golzio A., Ferrarese S., Cassardo C. et al. Land-Use Improvements in the Weather Research and Forecasting Model over Complex Mountainous Terrain and Comparison of Different Grid Sizes // Boundary-Layer Meteorology. 2021. Vol. 180. P. 319-351. https://doi.org/10.1007/s10546-021-00617-1

12. Grossman-Clarke S., Zehnder J.A., Stefanov W.L., Liu Y., Zoldak M.A. Urban Modifications in a Mesoscale Meteorological Model and the Effects on Near-Surface Variables in an Arid Metropolitan Region // Journal of Applied Meteorology. 2005. Vol. 44(9). P. 1281-1297. https://doi.org/10.1175/JAM2286.1

13. Jiménez-Esteve B., Udina M., Soler M., Pepin N., Mirò J. Land use and topography influence in a complex terrain area: a high resolution mesoscale modelling study over the Eastern Pyrenees using the WRF model // Atmos. Res. 2018. Vol. 202. P. 49-62. https://doi.org/10.1016/j.atmosres.2017.11.012

14. Jiménez-Esteve B. Land use influence in WRF model. A high resolution mesoscale modeling over Oriental Pyrenees. Master's thesis, Facultat de Física, Universitat de Barcelona, 2015.

15. Kamal S., Huang H., Myint S.W. The Influence of Urbanization on the Climate of the Las Vegas Metropolitan Area: A Numerical Study // Journal of Applied Meteorology and Climatology. 2015. 54(11). P. 2157-2177. https://doi.org/10.1175/JAMC-D-15-0003.1

16. Katsalova L.M., Shpyg V.M. The choice of optimal lag for Kriging interpolation of NWP model forecast // Meteorology, Hydrology and Water Management. 2016. Vol. 4, Issue 2. P. 23-28. DOI: https://doi.org/10.26491/mhwm/64292

17. Kun Wang, Yali Tong, Jiajia Gao, Chao Gao, Kai Wu, Tao Yue, Sida Qin, Chenlong Wang, Impacts of LULC, FDDA, Topo-wind and UCM schemes on WRF-CMAQ over the Beijing-Tianjin-Hebei region, China // Atmospheric Pollution Research. 2021. Vol. 12, Issue 2., P. 292-304. https://doi.org/10.1016/j.apr.2020.11.011 18. Kusaka H., Kimura F. Coupling a single-layer urban canopy model with a simple atmospheric model: Impact on urban heat island simulation for an idealized case // J. Meteor. Soc. Japan. 2004. Vol. 82. P. 67-80. https://doi.org/10.2151/jmsj.82.67

19. Kusaka H., Nawata K., Suzuki-Parker A., Takane Y., Furuhashi N. Mechanism of precipitation increase with urbanization in Tokyo as revealed by ensemble climate simulations // J. Appl. Meteor. Climatol. 2014. Vol. 53. P. 824-839. DOI: 10.1175/JAMC-D-13-065.1

20. Li H., Zhang H., Mamtimin A., Fan S., Ju C. A New Land-Use Dataset for the Weather Research and Forecasting (WRF) Model // Atmosphere. 2020. 11(4), 350. https://doi.org/10.3390/atmos11040350

21. Lin C.Y.,. Chen W.C., Chang P.L., Sheng Y.F. Impact of the urban heat island effect on precipitation over a complex geographic environment in northern Taiwan // J. Appl. Meteor. Climatol. 2011. Vol. 50. P. 339-353. DOI:10.1175/2010JAMC2504.1

22. Liping C., Yujun S., Saeed S. Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques – A case study of a hilly area, Jiangle, China // PLoS ONE. 2018. 13(7). e0200493. https://doi.org/10.1371/journal.pone.0200493

23. López-Espinoza E.D., Zavala-Hidalgo J., Mahmood R., Gómez-Ramos O. Assessing the Impact of Land Use and Land Cover Data Representation on Weather Forecast Quality: A Case Study in Central Mexico // Atmosphere. 2020. 11(11), 1242. https://doi.org/10.3390/atmos11111242

24. Manual on the Global Observing System (WMO No 544), Vol. I

25. McConnell W.J. Land Change: The Merger of Land Cover and Land use Dynamics A2 – Wright, James D. // International Encyclopedia of the Social & Behavioral Sciences (Second Edition). Oxford: Elsevier; 2015. p. 220-3.

26. Nguyen L.H., Joshi D.R., Clay D.E., Henebry G.M. Characterizing land cover/land use from multiple years of Landsat and MODIS time series: A novel approach using land surface phenology modeling and random forest classify // Remote Sens. Environ. 2020. 238, 111017.

27. Pedruzzi Rizzieri et al. Update of land use/land cover and soil texture for Brazil: Impact on WRF modeling results over São Paulo // Atmospheric Environment. 2022. Vol. 268, 118760. https://doi.org/10.1016/j.atmosenv.2021.118760

28. Pielke R.A., Sr., Pitman A., Niyogi D., Mahmood R., McAlpine C., Hossain F. et al. Land use/land cover changes and climate: modeling analysis and observational evidence // Wires Clim. Change. 2011. 2(6). P. 828-850. DOI: 10.1002/wcc.144

29. Pineda N., Jorba O., Jorge J., Baldasano J.M. Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model // International Journal of Remote Sensing. 2004. 25(1). P. 129-143.

30. Pongratz J., Schwingshackl C., Bultan S. et al. Land Use Effects on Climate: Current State, Recent Progress, and Emerging Topics // Curr. Clim. Change Rep. 2021. Vol. 7. P. 99-120. https://doi.org/10.1007/s40641-021-00178-y

31. QGIS.org, 2022. QGIS Geographic Information System. QGIS Association. http://www.qgis.org

32. Rawat J.S., Kumar M. Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India // The Egyptian Journal of Remote Sensing and Space Science. 2015. 18(1). P. 77-84. https://doi.org/10.1016/j.ejrs.2015.02.002

33. Santos M.J., Smith A.B., Dekker S.C. et al. The role of land use and land cover change in climate change vulnerability assessments of biodiversity: a systematic review // Landscape Ecol. 2021. Vol. 36. P. 3367-3382. https://doi.org/10.1007/s10980-021-01276-w

34. Schicker I., Arnold Arias D., Seibert, P. Influences of updated land-use datasets on WRF simulations for two Austrian regions // Meteorol. Atmos. Phys. 2016. Vol. 128. P. 279-301. https://doi.org/10.1007/s00703-015-0416-y

35. Shpyg V. et al. The application of regional NWP models to operational weather forecasting in Ukraine // CAS Technical Conference on “Responding to the Environmental Stressors of the 21st Century”: 18–19 November 2013: Conf. Materials. 2013. URL: https://www.researchgate.net/publication/312488806_The_Application_of_Regional_NWP_Models_to_Operational_Weather_Forecasting_in_Ukraine (date of access: 13 July 2022).

36. Shpyg V., Budak I. WRF reflectivity simulation and verification of thunderstorm forecast by radar and surface observation // 16th International Radar Symposium : 24-26 June 2015. Symposium Materials. Dresden, 2015. P. 610-615. DOI: 10.1109/IRS.2015.7226388

37. Shpyg V., Budak I. Estimation of effectiveness of thunderstorms observation and their forecast by the instability indices // 7th International Verification Methods Workshop. 03-11 May 2017, Berlin, Germany. Annalen der Meteorologie, 2017. Vol. 51. P. 81.

38. Siewert J., Kroszczynski K. GIS Data as a Valuable Source of Information for Increasing Resolution of the WRF Model for Warsaw // Remote Sensing. 2020. 12(11), 1881. https://doi.org/10.3390/rs12111881

39. Skamarock W.C. et al. A description of the Advanced Research WRF version 3. NCAR Tech. Note NCAR/TN-475+STR. 2008. 113 pp. https://doi.org/10.5065/D68S4MVH.

40. Sulla-Menashe Damien, Gray Josh M., Parker Abercrombie S., Friedl Mark A., Hierarchical mapping of annual global land cover 2001 to present: The MODIS Collection 6 Land Cover product // Remote Sensing of Environment. 2019. Vol. 222. P. 183-194. https://doi.org/10.1016/j.rse.2018.12.013

41. Temimi M. Assessing the Impact of Changes in Land Surface Conditions on WRF Predictions in Arid Regions // Journal of Hydrometeorology. 2020. 21(12). P. 2829-2853. https://doi.org/10.1175/JHM-D-20-0083.1

42. Tewari M., Chen F., Kusaka H. Implementation and evaluation of a single-layer urban canopy model in WRF/Noah // 7-th WRF Users' Workshop, Boulder, CO, NCAR, 2006. URL: http://www2.mmm.ucar.edu/wrf/users/workshops/WS2006/abstracts/Session05/5_6_Tewari.pdf (date of access: 13 July 2022)
43. USGS EROS Archive - Land Cover Products - Global Land Cover Characterization (GLCC). DOI: 10.5066/F7GB230D
44. Xuejie G., Yong L., Wantao L., Zongci Z., Giorgi F. Simulation of effects of land use change on climate in China by a regional climate model // Adv. Atmos. Sci. 2003. Vol. 20. P. 583-592. https://doi.org/10.1007/BF02915501
45. Zhaohui Yang (Joey), Dominguez Francina, Gupta Hoshin Vijai, Zeng Xubin and Norman Laura M. Urban Effects on Regional Climate: A Case Study in the Phoenix and Tucson "Sun Corridor" // Earth Interactions. 2016. Vol. 20. P. 1-25. https://doi.org/10.1175/EI-D-15-0027.1

Вплив категорій землекористування на прогноз WRF та його точність
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В даній роботі проведено аналіз щодо можливостей та способів коригування або рекласифікації даних щодо підстильної поверхні та категорій землекористування, отриманих у ході моделювання ефектів від застосування більш точних даних такого типу та оцінки ступеня покращення відтворення приземних метеорологічних величин в чисельній мезомасштабній атмосферній моделі. Для території Київської області за допомогою QGIS v. 3.22 та Google Maps було проведено аналіз баз даних USGS та MODIS IGBP. Отримано, що на даний момент обидві бази даних не є ідеальними і містять різного роду неточності. Так, MODIS IGBP у порівнянні із USGS більш коректно відтворює територію міст, лісових масивів та русла р. Дніпро, проте у MODIS IGBP не відображаються невеликі населені пункти. Аналіз інших досліджень показав, що більшість робіт, котрі стосуються порівняння успішності моделювання атмосферних процесів за допомогою моделі WRF при заміні даних щодо підстильної поверхні та землекористування засновані на «кейсовому підході», тобто на обробці результатів невеликої кількості специфічних симуляцій. Недоліком такого підходу є те, що вибірка, по якій можна робити висновки, є незначною, тому корисно проводити порівняння робіт на предмет узгодженості отриманих результатів. Використання більш точних та актуальних баз даних щодо підстильної поверхні WRF дає можливість зменшувати систематичну похибку прогнозів і покращували точність прогнозу мінімальної та максимальної добової температури. Найсуттєвіше покращення прогнозу має місце саме для нічної температури. Другою метеорологічною величиною, яку найчастіше вдається прогнозувати краще після коригування даних щодо підстильної поверхні є відносна вологість. Покращення змодельованих параметрів вітру найбільше проявляється на урбанізованих територіях та біля узбережжя, де вдається покращити відтворення бризової циркуляції моделлю WRF. Оцінки щодо можливості покращити моделювання опадів шляхом уточнення даних щодо підстильної поверхні та землекористування не такі однозначні, хоча в деяких роботах відзначено вплив острову тепла урбанізованих територій на перерозподіл опадів. З одного боку, в більшості проаналізованих наукових праць, коригування даних щодо підстильної поверхні та землекористування не дозволили суттєво покращити прогноз опадів за допомогою моделі WRF, з іншого боку, можна припустити, що важливу роль відіграють фізико-географічні умови території, для якої проводиться моделювання, та наявні запаси вологи в атмосфері.
Ключові слова: *модель Weather Research and Forecasting (WRF), землекористування, підстильна поверхня, чисельний прогноз погоди, атмосферне моделювання, точність*

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ВІДКЛАДЕННЯ ОЖЕЛЕДІ КАТЕГОРІЇ НЯ (НЕБЕЗПЕЧНА) ТА СГЯ (СТИХІЙНА) МАСОВОГО ХАРАКТЕРУ РОЗПОВСЮДЖЕННЯ НА ТЕРИТОРІЇ УКРАЇНИ ПРОТЯГОМ ДЕСЯТИРІЧ 1991-2000 рр., 2001-2010 рр., 2011-2020 рр.

Представлена робота присвячена дослідженню відкладень ожеледі категорії НЯ (небезпечна) та СГЯ (стихійна) масового характеру розповсюдження на території України протягом останнього 30-и річчя (1991-2020 рр.) по окремим десятирічним інтервалам. Показано особливості прояву таких випадків по території України в окремі місяці досліджуваних десятирічних інтервалів та виявлено роки в яких таких випадків було найбільше. Так, найбільша кількість таких випадків спостерігалась у 1998, 1999, 2009, 2013, 2014, 2018 рр. Встановлено, що у досліджувані десятиріччя найбільша кількість таких випадків було виявлено у зимові місяці (грудень-лютий), проте від десятиріччя до десятиріччя вони мали свою динаміку, а саме переважне їх збільшення у січні (відносно 1991-2000 рр.) та нестійка зміна у лютому та грудні (від