Decision support software for weather forecast powered by machine learning, data fusion and data mining techniques applied on remote sensing data

Scientific and technical report 2026

- SUMMARY -

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PHASE SUMMARY

According to the World Meteorological Organisation, many natural disasters that cause damage and loss of life are due to weather, and especially severe weather. Most of the meteorological decision-making processes rely to a great extent, at least at the national level, on the experience of operative meteorologists, but due to the chaotic character of the atmosphere, effectively and accurately analyzing a large volume of meteorological data is a difficult task for meteorologists. WinDMiL project aims to contribute to improving meteorological decision support at the national level in terms of faster decision times and higher precision, providing a laboratory scale working prototype of a software solution for remote sensing data mining and assisting decision-making processes in meteorology. The direct beneficiary of WinDMiL is the Romanian National Meteorological Administration. WinDMiL integrates data mining methods for fast and precise remote sensing data analysis, machine learning methods for weather forecast and a component for visualizing the results of the mining, easily readable for meteorologists and aimed to facilitate meteorological decision-making.

The main objective of the project is to improve the meteorological decision-making processes by use of data mining (DM) techniques applied on remote sensing data, with a specific target on combining radar and satellite data. The focus is on providing meteorologists relevant information from past similar situations and assisting them in various decision-making tasks (e.g., predicting the areas affected by severe meteorological phenomena, precipitation and hail forecasting, short term quantitative precipitation forecast) and for various climatological analysis. The project's main goal is to create the WinDMiL data mining software for assisting operational meteorologists in their daily tasks by offering them easily readable visualizations of the mining results.

The project results are: **(1)** Software modules (integrated into the WinDMiL system) implementing the machine learning models developed for data analysis, **(2)** Scientific publications for disseminating the obtained scientific results, and **(3)** Scientific and technical reports documenting the original data mining and machine learning methods developed for the analysis of meteorological data.

The current report presents the original results obtained during the research carried out within the WinDMiL project for achieving the scientific and technical objectives proposed in the project plan for 2026. The report highlights the current status of the project implementation, the way in which the activities undertaken in the work plan were carried out and how the results obtained in the current project phase (2026) were disseminated. To summarize, the results obtained within the WinDMiL project in 2026 are:

- Data mining techniques for the analysis of meteorological data.
- Software module for data analysis.
- Project website (https://www.cs.ubbcluj.ro/windmil/) and WeADL 2026 workshop organisation (https://www.cs.ubbcluj.ro/weadl/).
- 6 scientific papers: 3 published papers, 2 papers in press, 1 paper submitted for publication (under review). Among these papers: 1 paper is published in the proccedings of a WoS indexed international conference (C-ranked according to CORE classification), 1 paper is published in the proccedings of a WoS indexed international conference (B-ranked according to CORE classification), 1 paper is published in a WoS - Proceedings Citation Index (CPCI) indexed journal; 1 paper is in press for publication in a journal indexed in Scopus and WoS-CPCI; 1 paper is in press in the proccedings of a WoS indexed, D-ranked international conference; 1 paper is submitted to a WoS indexed, C-ranked international conference.

The project objectives for 2026 have been achieved, as highlighted by the annual report for 2026. The planned objectives, together with the related activities have been totally fulfilled and carried out according to the project implementation plan. The minimum performance criteria regarding the results dissemination for 2026 (at least 2 publications in journals/conferences) has been accomplished.

1. INTRODUCTION

1.1 WINDMIL PROJECT

The WinDMiL project aims to contribute to the improvement of decision-making processes in meteorology, as well as to provide a laboratory scale functional prototype of a software system for the analysis of meteorological data and the support of meteorological decision-making. The direct beneficiary of WinDMiL is the National Meteorological Administration (ANM) of Romania. WinDMiL will integrate methods for extracting knowledge from remote-sensing and reanalysis data for their rapid and accurate analysis, machine-learning methods for weather forecasting, and a component for visualizing the results in a way that is easy for meteorologists to interpret, intended to facilitate meteorological decision-making.

1.2 SCIENTIFIC AND TECHNICAL OBJECTIVES

The main objective of the project is to improve the decision-making process in meteorology by using machine learning techniques and knowledge discovery from meteorological data (remote sensing, reanalysis), with a specific focus on combining reanalysis data with radar data and satellite imagery. The goal is to provide meteorologists with relevant information from similar past situations and to assist them in decision-making (for example, predicting areas affected by severe weather events, forecasting precipitation and hail, short-term quantitative precipitation forecasting) as well as in conducting climatological analyses. The WinDMiL software system envisioned in the project will assist operational meteorologists in their daily tasks by providing them with relevant visualizations of the DM techniques' results. This project is applied and interdisciplinary, having two main scientific and technical objectives:

O1. Development and scientific validation of new DM techniques specially designed for remote sensing data analysis, with a specific emphasis on radar and satellite data fusion. Following our previous scientific results in the unsupervised learning based analysis of meteorological data, as well as in deep learning (DL)-based weather nowcasting, methods such as deep k-nearest neighbor (kNN), deep case-based reasoning, deep convolutional autoencoders and deep recurrent encoder-decoder architectures specially tailored for remote sensing data will be targeted as DL models for components of the WinDMiL software.

O2. Development and user evaluation of the WinDMiL system for descriptive and predictive DM and for graphical visualization of the mining results. This objective will be achieved using the methods developed as part of O1 and is expected to support meteorological decision-making.

O3. Contribution to the development of scientific knowledge by disseminating the obtained theoretical and applicative scientific results through scientific publications.

2 DISSEMINATION

2.1 WEADL WORKSHOP

To disseminate the results obtained within the project and present recent research developments in meteorology and deep learning, the fifth edition of the WeADL Workshop (*Workshop on Applied Deep Learning*) was organised as part of the WinDMiL project on the 5th of June 2026. The workshop's main objective was to raise awareness within the scientific community of the challenges associated with deep learning, machine learning, and artificial intelligence-driven scientific research in interdisciplinary fields, with a particular focus on machine learning and knowledge discovery techniques applied to meteorological data. The event took place via the Microsoft Teams platform, with the programme and recorded discussions

subsequently made available on the workshop website. More than 20 participants attended the event, 9 of whom delivered presentations. Participants included researchers in the field, doctoral and master's students, as well as scientists representing the project partner.

2.2 Scientific Publications And Presentations

Tables 1 and 2 present the list of scientific publications and presentations obtained during the second phase (2026) of the WinDMiL project.

[L1]	Orășan Paul-Dumitru, Czibula Gabriela, Albu Alexandra-Ioana, *Using diffusion models for enhancing the performance of semi-supervised image classifiers*, Lecture Notes in Artificial Intelligence, volume 16516, pp 515–537, 2026 (WoS - Clarivate Analytics, Conference Proceedings Citation Index)
[L2]	Ștefan Alexandrescu, Gabriela Czibula, Alexandra-Ioana Albu, Eugen Mihuleț, *X-CViT: An explainable vision transformer architecture for classification of cloud images*, 15th International Conference on Pattern Recognition Applications and Methods (ICPRAM 2026), pages 175-186 (C-ranked, indexed WoS)
[L3]	Gabriela Czibula, Andrei Mihai, Sîrbu Alexandru-Gabriel, Istvan Gergely Czibula, Eugen Mihuleț, Ioan-Ștefan Gabrian, *GEM-Qt: Generating embeddings for meteorological reanalysis data using a quadtree-based approach*, ENASE 2026, pp. 1149-1157 (B-ranked, indexed WoS)
[L4]	Ștefan Alexandrescu, Gabriela Czibula, Eugen Mihuleț, *The impact of data representations for enhancing the performance of photovoltaic energy forecasting*. 2026 IEEE 22nd International Conference on Intelligent Computer Communication and Processing (ICCP), in press (D-ranked, indexed WoS)
[L5]	Gabriela Czibula, Andrei Mihai, Sîrbu Alexandru-Gabriel, Răzvan Romulus Andro, Istvan Gergely Czibula, Eugen Mihuleț, *An empirical study on evaluating meteorological reanalysis data embeddings for classification of atmospheric circulation*, ICPRAM 2026, submitted (C-ranked, indexed WoS)
[L6]	Gabriela Czibula, Ștefan Alexandrescu, Alexandra-Ioana Albu, Eugen Mihuleț, *On using vision transformer-based models and generative learning for classification of cloud images*, Lecture Notes on Computer Science (LNCS), 2026, in press **(**indexed WoS - Clarivate Analytics, Conference Proceedings Citation Index)

Table 1 - List of scientific publications obtained during the second phase of the WinDMiL project

Ștefan Alexandrescu, *X-CViT: An explainable vision transformer architecture for classification of cloud images*, 15th International Conference on Pattern Recognition Applications and Methods (ICPRAM 2026), March 2, 2026 [link]
Andrei Mhai, *GEM-Qt: Generating embeddings for meteorological reanalysis data using a quadtree-based approach*, ENASE 2026, May 22, 2026 [link]
Raluca Gabrian, *MTG-I1 Lightning Imager NWC SAF Products: overview, algorithm and its applications*, 6th Workshop on Applied Deep Learning, WeADL 2026, June 5, 2026 [link]
Ioan-Ștefan Gabrian, *ICON-LAM Model Configuration: Sensitivity Tests*, 6th Workshop on Applied Deep Learning, WeADL 2026, June 5, 2026 [link]
Andrei Mihai, *GEM-Qt: Generating embeddings for meteorological reanalysis data using a quadtree-based approach*, 6th Workshop on Applied Deep Learning, WeADL 2026, June 5, 2026 [link]

Table 2 - List of presentations during the second phase of the WinDMiL project

3 Conclusions

This report presented the original results obtained from the research carried out within the project in order to meet the scientific and technical objectives proposed in the implementation plan for 2026 (Phase 2). For

each partner (UBB and ANM) the report indicates the way in which the activities from the project plan were accomplished. We summarize the results obtained within the project for 2026 as follows: **(1)** data mining techniques for (remote sensing) data analysis; **(2)** software module for data analysis; **(3)** project website (https://www.cs.ubbcluj.ro/windmil/) and the organisation of **WeADL 2026** workshop (https://www.cs.ubbcluj.ro/weadl/); and (4) scientific articles disseminating the original results obtained in Phase 2 of the project implementation.

The dissemination of the results obtained within the project in 2026 was achieved by 5 published papers and 1 publication under review, as follows: 1 paper is published in the proccedings of a WoS indexed international conference (C-ranked according to CORE classification), 1 paper is published in the proccedings of a WoS indexed international conference (B-ranked according to CORE classification), 1 paper is published in a WoS indexed journal, Proceedings Citation Index (CPCI); 1 paper is in press for publication in a journal indexed in Scopus and WoS-CPCI; 1 paper is in press in the proccedings of a WoS indexed, D-ranked international conference; 1 paper is submitted to a WoS indexed, C-ranked international conference.

Consequently, the minimum performance criteria provided (at least two papers published in a journals/conferences) was met. Furthermore, the project objectives for 2026 have been met, and all associated activities have been completed and carried out in accordance with the project implementation plan.