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Development of a Complex Meteorological Support System for UAVs

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***Abstract*—**The sensitivity of UAVs to the atmospheric effects are apparent. All the same the meteorological support for the UAVs missions is often non-adequate or partly missing.

In our paper we show a new complex meteorological support system for different types of UAVs pilots, specialists and decision makers, too. The mentioned system has two important parts with different forecasts approach such as the statistical and dynamical ones.

The statistical prediction approach is based on a large climatological data base and the special analog method which is able to select similar weather situations from the mentioned data base to apply them during the forecasting procedure.

The applied dynamic approach uses the specific WRF model runs twice a day and produces 96 hours, high resolution weather forecast for the UAV users over the Hungary. An easy to use web-based system can give important weather information over the Carpathian basin in Central-Europe. The mentioned products can be reached via internet connection.

***Keywords*—**Aviation meteorology, statistical weather prediction, unmanned aerial systems, WRF.

I. INTRODUCTION

THE Unmanned Aerial Vehicles (UAVs) are playing more and more significant role in military and civil operations in Hungary, too. Aerial support for natural disaster management monitoring (such as earthquakes, floods and forest fire), government and private survey (such as cartography, precision agriculture, wild life monitoring, border control, geodesy, security and maintenance control for industrial companies, electricity cords network, gas and oil pipelines, etc.) may benefit from the on board instruments that might be the payload of such UAVs.

UAVs have an increasing number and applications worldwide so it is very important to recognize severe aviation weather situations and atmospheric processes which have a significant influence on flight safety and operational costs. Aviation meteorologists are supposed to give accurate information on actual and future weather in point of aerodromes and flight plans [1]. At the same time weather has different impacts on many UAVs due to their different structural and flight characteristics thus we have to know the behavior of this environmental impacts, well [2].

In order to know the rapidly changing meteorological variables we begun to develop a complex, aviation meteorological support system which is able to provide significant weather information for planning and operating UAV flights anytime, anywhere. Our work is mainly based on the freely available meteorological reports (METARs) and the WRF numerical weather model [3]. The mentioned support system uses aviation climatological calculations, different statistical methods, numerical weather prediction (NWP) model outputs and their post-processing, as well [4]. On the other hand we had some experiments to optimize flight paths for maximizing flight safety and reducing harmful weather impacts on UAVs, too.

In our study we show the structure and elements of the mentioned meteorological supporting system and some preliminary results in connection with its applicability are also going to be presented.

II. DATA BASE AND STATISTICAL APPROACHES

In order to apply any statistical approaches to make aviation meteorological weather predictions for UAVs we had to create an adequate data base with a useful data structures such as METARs. The data base contains all of the half hourly observed meteorological values and phenomena in the main airports of Hungary for the last eight years. The used data are the followings: wind direction, wind speed and gust, visibility, amount, height and type of clouds, temperature, dew point temperature, QHN air pressure and significant weather phenomena if they were able to observe at the given airport. The data were subjected to thorough some quality controls to

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the period from 2005 to 2012. Our records for the main airports are more than 98% complete. The present data base can easily be updated so its size and reliability is continuously growing in the future.

A. Aviation Climatological Products

The aviation climatological description contains the traditional or classical approaches, which classify the given places or zones of the world into climatological classes and the aviation specific information and statistics which basically refer to the given aerodrome or its vicinity [5]. In order to know the basic aviation climatological relationships which play an important role in our approach we had made detailed aviation climate descriptions for the main airports in Hungary such as Kecskemét (LHKE), Szolnok (LHSN) and Pápa (LHPA). In our present study we focus only some more interesting results because of size restriction so we represent some examples for Kecskemét (LHKE), only (Fig. 1).

Fig. 1 The location (A) of Kecskemét (LHKE) airport in Central Europe, Hungary. (source: Google Map)

In the aviation meteorology the visibility is one of the most important parameter may influence the feasibility of the missions if it is dedicated to reconnaissance purpose by detection in the visual or infrared ranges. For this reason, prediction of visibility and cloudiness (at least for the launching and target site) may be essential for the pre-flight briefing and during the whole mission, too.

It is practical to filter the conditional wind direction distributions for speed categories because the UAVs are well sensitive for higher wind speed. Because of its importance we show the relative frequency of wind directions in the LHKE airport in that case the wind speed is higher than 8 m/s and 12m/s, respectively (Fig. 2). As we can see the higher winds mainly have a well-defined direction of NW or 300º - 320º in the mentioned airport. This interval means that the predicted strong wind directions may vary in this very narrow range with high probability.

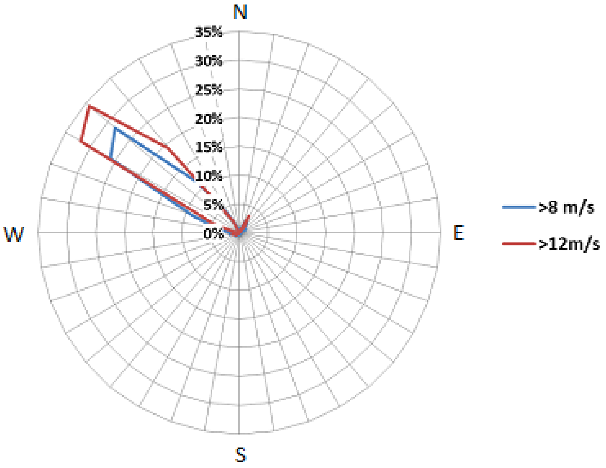

Fig. 2 Relative frequency of wind directions when the wind speed is over a given value in the LHKE airport during the last eight years

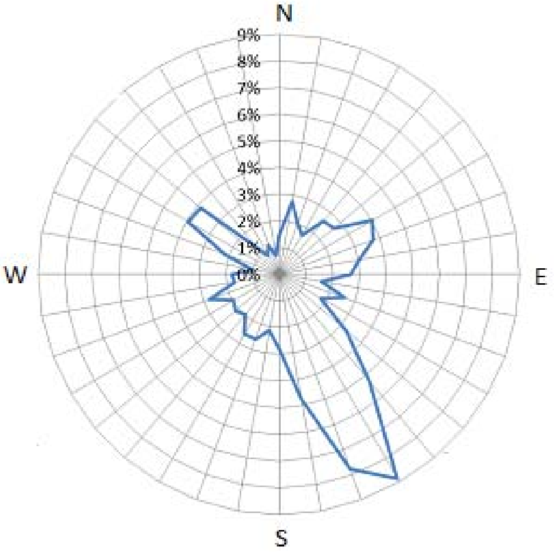

Fig. 3 Relative frequency of wind direction when the wind speed is over 3 m/s and fog occurs in LHKE airport during the last eight years

Fog, poor visibility and low ceilings are also dangerous factors in aviation with the special regards to UAVs. For example, Fig. 3 could be important during the advection fog forecasting procedure because we can determine the most probably directions in this case.

We can also calculate the usual successive variability of meteorological parameters build upon the database, if we are up in the initial conditions [6]. For example, Fig. 4 shows the successive relative frequency of different ceiling categories when the initial (t+0=23:45Z) category represents less than 150 meters ceilings.

Usually the diurnal changes of ceiling are in line with diurnal variations of temperature and dew point depression. Due to this fact the relative frequency of ceilings below 150 meters (red line) decreases and the relative frequency of ceilings between 150 and 300 meters (amber line) increases in the late night and morning hours. It should be noted that 12 hours after the relative frequency of ceilings below 300 meters is around 60%. On the other hand there is a 30% probability the ceiling will be 1500 meter or higher (or no ceiling) after 12 hours, as well (blue line).

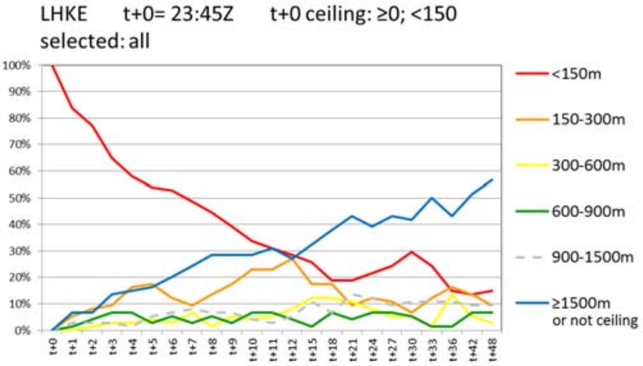

Fig. 4 Successive relative frequencies of different ceiling categories at the given initial condition in LHKE airport during the last eight years

B. Fuzzy-Logic Based Analog Forecasting

The basic principle of analog forecasting is to find similar weather situations in the past to the actual conditions and rank them according to the degree of their similarity in the interest of giving relevant information for weather forecasts. For a theoretical basis of an operational fuzzy logic-based analog forecasting system, the reader can refer to Hansen et al. [7]. When a UAV flight operation starts we can recognize the actual combination of different parameters by observing and measuring them. To find the most similar combinations in the database available we use our own supporting software which is based on a fuzzy similarity theory as we can found in earlier publications and our own test results, too [8].

We had defined the adequate similarity criteria system for each examined meteorological elements and we summed up of the individual similarity measures. This method can be averaging the individual values or choosing the minimal value of them. The overall similarity measure is appropriate for finding the nearest neighbor of effects that should be considered in the present discussion [9].

III. DYNAMIC MODEL SUPPORTING TO UAV OPERATIONS

In order to develop a proper meteorological support system for UAV operations we had to apply a suitable dynamical meteorological model because the above mentioned statistical approach cannot work properly in all cases. We had chosen the Weather Research Forecasting (WRF) model for this application since it is open source and freely available and suitable for using it in a broad range of applications [10], [11].

In order to achieve high resolution and accuracy model output that is suitable for the needs of the UAV meteorological needs we designated the resolution with several km in the target domain. Since global model (GFS) data for input as initial and boundary condition is available on a half degree horizontal resolution, and down scaling cannot be applied abruptly so the resolution of the first domain was 30 km. In order to avoid "sweeping" effect and boundary issues, we utilized two levels, telescoped two-way nests with horizontal resolution of 7.5 km and 1.875 km, for domains d02 and d03, respectively (Fig. 5).

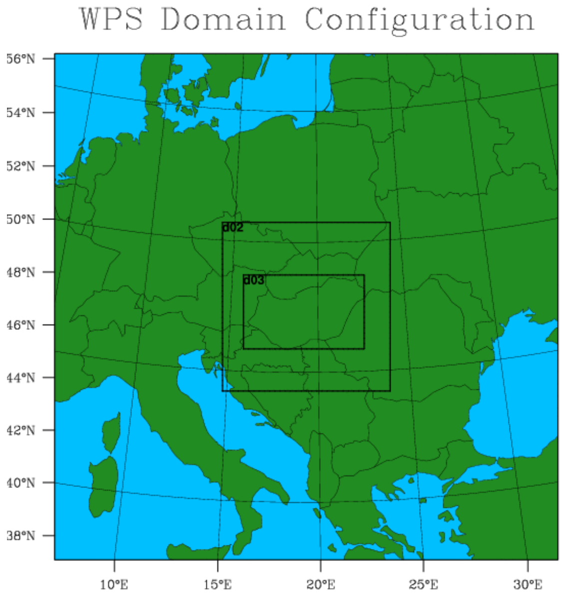

Fig. 5 The applied two-way nested WRF domain system with 7.5 km (d02) and 1.875 (d03) km horizontal resolutions

The model vertical grid (terrain following hydrostatic-pressure based σ-coordinate system) had also been modified to better resolve near surface features. Number of vertical levels had been increased to 20 in the bottom 200hPa, and decreased above the 300hPa level. Total numbers of vertical levels were 38.

Model calculations are performed two times every day. We make a 96 hours model runs which are based on the 0:00 UTC and 12:00 UTC global analysis by NCEP.

As we know most of the dangerous weather phenomena that affects flight operation are not directly predicted by meteorological models. For this reason the model outputs should be submitted to proper post-processing procedures. Scales of turbulence and icing processes are much below the resolution of a numerical meteorological model. Even smaller thunderstorms or the rotor flow associated with the mountain wave process are beyond the capabilities to be resolved by such mesoscale model. Visibility and low cloud are also pretty difficult to predict even from the outputs of a high resolution meteorological model.

The post-processed model outputs are posted a public web interface such as meteograms, maps and tables which can be accessed for authorized users with a simple web browser. The user can analyze them through custom speed animation map sequences of the different variables or she/he can select a location and download different meteograms of the selected location as well. The currently available numerical meteorological products are detailed in the next chapter.

IV. RESULTS AND DISCUSSION

To demonstrate the usefulness of our analog similarity-based method we show a case study situation in connection with another airport Szolnok, LHSN which is located very close to the LHKE airport. At 06:15UTC 23 January 2013 in Szolnok (LHSN) airport the weather situation was: 27005MPS 0800 +SN BKN005 OVC017 M02/M03 Q1006 NOSIG RMK AMB=. This means the visibility was poor with 800 m value and intensive snow was able to observe with low ceiling of 500 feet (underline in the presented METAR). We examined the ten most similar cases and averaging the values of each successive hour of the mentioned cases using our analog method mentioned earlier. After that we were able to make a prediction and could compare it with the observations.

It is well observed that the prognostic application of the mentioned method is significant because during the first six hours the predicted and the measured values are very close to each other (Fig. 6). The differences between the predicted and measured visibilities are smaller than 1000 m in the six hours interval but during the first four hours the same values are smaller than 500 m. If we can illustrate the n pieces of the most similar cases as usual in ensemble forecasting we can estimate the probability the given visibility categories, as well [12].

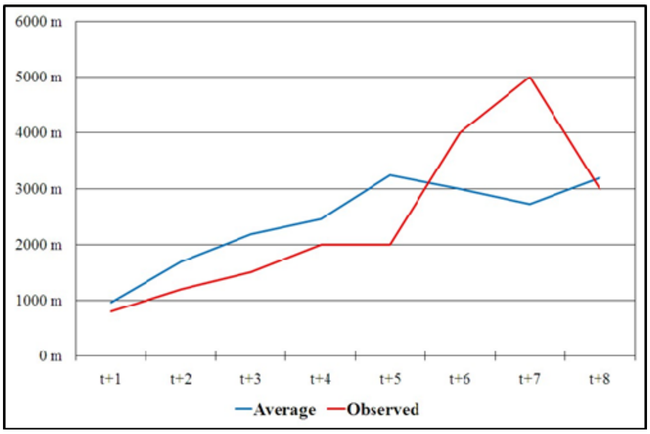

Fig. 6 Successive visibility values of the observed (05:45 UTC 23 January 2013) and the hourly average values of the ten most similar cases in Szolnok (LHSN) airport, Hungary

In order to give some proper meteorological information for UAV operations, we present the actual weather situation over Hungary via web. Our web system can present the actual visibility and ceiling categories which are predicted by post-processed WRF outputs. Because the NATO color code system which is based on the visibility and ceilings values an often used method to show the weather situation at a given airport we had applied it for the main airports in Hungary (Fig. 7).

As we can see the weather situation in 13 February 2013 was different in Hungary. In the western part of the country there was snow falling with low visibilities and ceilings but in the eastern part of Hungary the visibility and ceiling were so high with higher temperatures (Fig. 7). On the other hand the predicted NATO color codes were RED in the western region and were BLUE color codes in the eastern area of Hungary at the same time. In this case the forecast seems to be pretty good (Fig. 7).

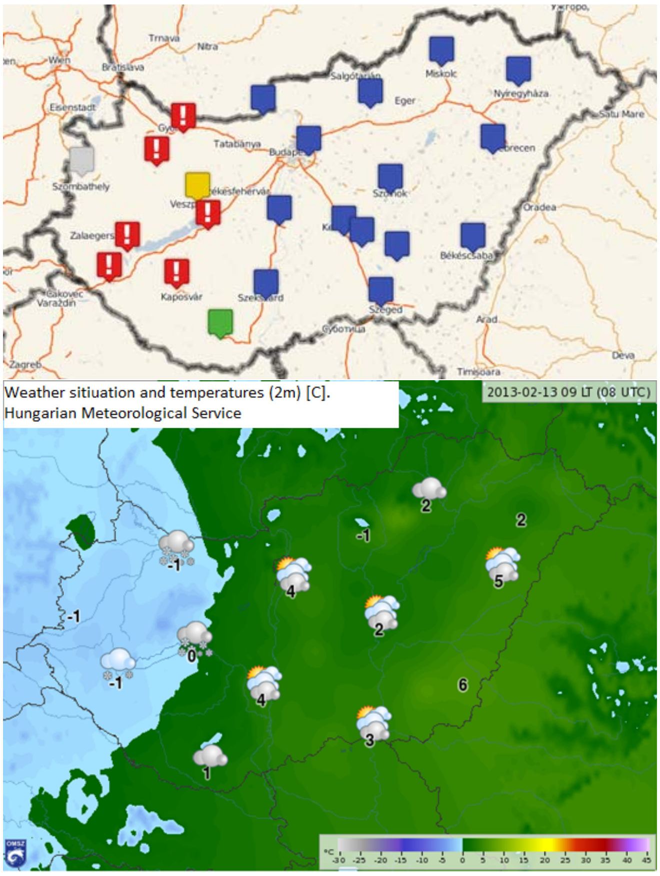

Fig. 7 The predicted weather situation (top) for Hungarian main airports applying the NATO color codes by WRF model and the same time measured weather situation (bottom) by Hungarian Meteorological Service

For the UAV operations we can present another WRF and post-processed numerical model product, too. It is very important to know how the weather will be changed at a given airport in time. In order to show this process we can make meteograms for the airports which represent the changing of the meteorological parameters in time during the prognostic time interval (Fig. 8). As it can be seen the given airport is LHKE, the sunrise and sunset time with the airport elevation are seen in the upper right corner. The horizontal axis represents the prognostic time interval (in this case from 00:00 UTC, 24 February 2013 until 24:00 UTC, 26 February 2013) and the vertical one represents the values of the predicted weather parameters such as amount and height of clouds, precipitation, temperatures, wind speed and directions and QNH pressures. As it can be seen well there are two periods of precipitations during the prognostic time interval: the earlier is between 08 UTC and 12 UTC in 23 February 2013 and the other is between 22 UTC 23 February 2013 and 02 UTC 25 February 2013. On the other hand the predicted temperature is higher than 0 ºC so the precipitation will be mainly rain or shower. The forecasted wind direction is about 90º (E) and from 25 February 2012 is mainly 0º - 30º (N-NE). The QNH pressure will increase at the LHKE airport (Fig. 8).

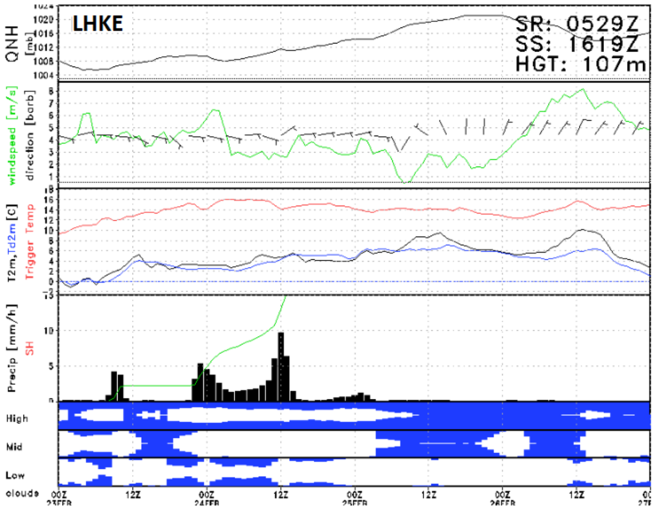

Fig. 8 Meteogram of the predicted meteorological parameters for the LHKE airport from 23 February 2013 until 26 February 2013

Of course the knowledge of the actual wind pattern in a given height is essential for the UAV pilots and operators, too. With the help of our complex meteorological system we are able to predict the wind field at the arbitrary levels as we can see it in the Fig. 9.

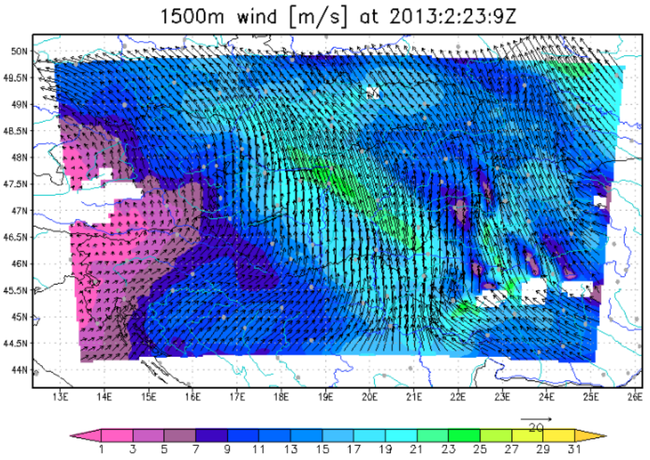

Fig. 9 The predicted wind speed and direction at 1500 m for the LHKE airport in 09 UTC, 23 February 2013. The colors and arrows represent the wind speed and the wind directions, respectively

The predicted wind field shows for the UAV pilots there is a high speed wind region at 1500 m high with the velocity of 23-25 m/s at 09 UTC, 23 February 2013 over middle Hungary. On the other hand over the northeastern part of Hungary the wind speed is 9-11 m/s, only. The predicted dominant wind direction is 150º - 180º over the whole country.

There is a possibility to make a special weather prediction for an arbitrary geographical position inside the model domains. For example we could make a relative humidity forecast for the φ=N47.70 and λ= E21.75 location (Fig. 10). This estimation respects to the lower troposphere (0-3 km height) and shows the changing the relative humidity inside this region. The high values (higher than 80% with dark green areas) of relative humidity means the possible clouds zones in time over the mentioned location. This information also will be crucial for UAV pilots and operators because some UAVs must not flight in cloud.

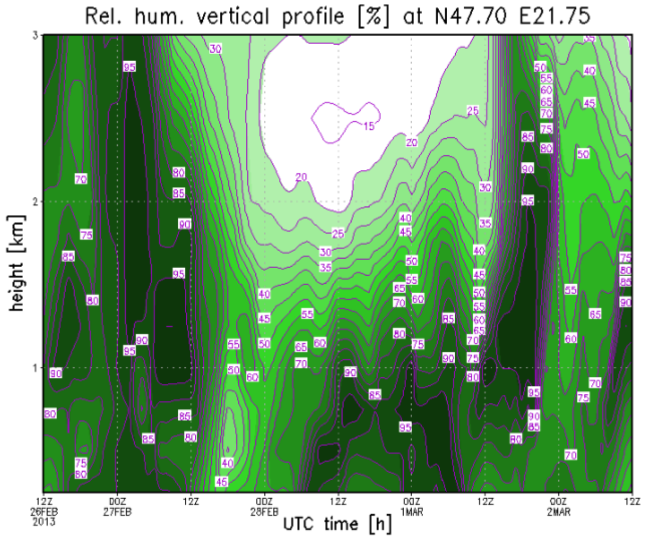

Fig. 10 The predicted relative humidity in the lower 3 km of the troposphere for the given location from 12 UTC, 26 February 2013 until 12 UTC, 02 March 2013. The dark green area represents the clouds (RH higher than 80%)

In the aviation meteorology the two most important parameters are the horizontal visibility and the height of ceiling. It follows we had to make prediction regarding them, too. At present we apply directly the WRF parameter values to prepare the visibility and ceiling forecasts as we can see in Fig. 11. As it can be seen there will be low ceiling (below 300 m) from 00 UTC 27 February 2013 until 10 UTC, 28 February 2013 at the given airport. The poor visibility (fog) will be observed with 100-200 m value between 20 UTC and 22 UTC 27 February 2013.

Nevertheless we would like to also apply other post-processing methods to predict these mentioned parameters more exactly because the present methods does not give enough good forecasting in all cases. We plan to use new statistical (as we present the analog method in this chapter) and other numerical approach to solve this problem well.

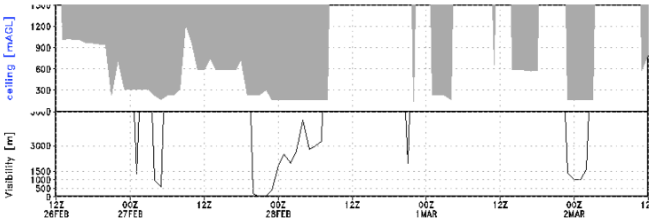

Fig. 11 The predicted ceiling (top) and visibility (bottom) in the LHKE airport from 12 UTC, 26 February 2013 until 12 UTC, 02 March 2013

On the other hand these presented products are also well usable during the UAV mission planning procedure because applying them we are able to decrease the weather caused risks during flight. In the near future we would like to develop a flight optimization method to create an optimal 3D flight path with the minimum risk of weather situation based on our complex meteorological support system for UAVs.

Most of the important aviation meteorology parameters can only be predicted with the help of significant local experience on a given site. Based on this recognition, the model outputs should be analyzed with respect to the weather situation and location. To be able to manage this challenge on the basis of a scientific approach, statistical analysis of the available historical weather data of some aerodromes in Hungary has been performed. The model output data should be analyzed parallel to the statistical archive data in a certain weather situation in order to yield the best forecast in a certain situation.

V. CONCLUSION

The proper, detailed and significant meteorological support is essential in the planning and executing phases of the UAV missions, too.

Our meteorological support for the UAV missions is based on the followings parts:

- an adequate data base of the main airports which contains the METAR data;
- the applied static and dynamic statistical methods can help us to give prognostic information for the UAV pilots and specialists;
- the WRF based numerical weather model which can give us high resolution weather prediction;
- the applied post-processing methods which are based on WRF products to predict some dangerous weather phenomena such as low visibility and ceiling, turbulence, wind shear, etc.;
- a special web site where we can access the adequate meteorological information in some graphical, text and other formats via (mobile) internet connection.

Nowadays the most important task is to link the statistical weather predictions with the numerical ones to give better combined approach in connection with the prediction of real weather situation for the UAV missions. On the other hand we develop a flight path optimization routine to minimize the weather hazards during the UAV flight.

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