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Use of the numerical simulations with weather forecast model WRF as a proxy to atmospheric soundings

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The present study aims to check the ability of numerical weather forecast models to represent the vertical structure in the atmosphere and thus to serve as an approximation of the in-situ atmosphere sounding. The advantage of using such proxy is the better resolution in both time and space and therefore the lack of measurement would be no longer a problem. The numerical model, used here is the model system Weather Research and Forecasting WRF. The model domain covers the whole territory of Bulgaria and by means of double nesting approach resolves the area with spatial resolution of 1.8 km. Several numerical experiments are performed to configure and tune the model parameters in order to obtain adequate model results. The data from atmosphere sounding in Sofia meteorological station are compared with the data coming from the Doppler channel of meteorological radar Gematronik c360, located in Sofia airport. The simulated vertical profiles of the temperature, humidity and wind are validated using available measurements from atmosphere sounding. Conclusions about the usability of numerical simulations as a proxy of atmosphere sounding are derived. A real application of this method, a case when the model gave useful information, is demonstrated.

Key words: numerical weather forecast, vertical atmosphere sounding, radar meteorology

INTRODUCTION

The need of information about the vertical distribution of the meteorological elements (temperature, humidity, wind speed and direction, dewpoint temperature) in the troposphere is getting more and more important and expressed. Several problems related to the weather forecast, like for example severe convections and storm events alarm, aviation safety, hail protection, require such type of information. Unfortunately the measurements from atmosphere sounding are very expensive and therefore limited in space and time. In Bulgaria sounding is performed once per day in 12 UTC in the meteorological station in Sofia. In general this is not representative for the whole Bulgarian territory having in mind the diurnal cycle, complex relief and different climatic characteristics in Bulgaria. The other remote sensing approach to obtain data are the meteorological radars, which give rich information about the distribution of hydrometeors in the air. The radar data from the Doppler channel could be used to calculate the wind vertical profile, but the ability is limited.

The lack of information about the vertical profile of the main meteorological elements with fine resolution could be partially compensated by the data from numerical weather forecast model. This method is shown further. An example of a real case with an airplane accident in the region of town Tran on 7.05.2014 is described, where the numerical simulation has given a useful information and has helped the investigation of the accident.

NUMERICAL MODEL CONFIGURATION

In this study the Advanced Research WRF (ARW) versionof the model system WRF 3.4.1, implemented in the National Center for Atmospheric Research (NCAR) and the National Centers for Environmental Prediction (NCEP) in United States is used [1]. The initial and boundary conditions for the air temperature, wind speed humidity, pressure and total cloud cover come from the operational global forecast system (GFS) distributed by NCEP with a spatial resolution of 0.5 deg. The model configuration uses the non-hydrostatic approximation. The model domain is resolved by a grid in Lambert Conformal Projection with three nests correspondingly with spatial resolution of 15:5:1.8 km (Fig. 1).

domain covers Bulgaria and adjacent regions, and the third domain with finest resolution is selected in a way to cover the mountain chains in the weather part of the country, and the center is located in Sofia, where the atmosphere sounding is performed every day. The third domain topography is shown in Fig. 2 and one could well identify the Balkan, Vitosha and

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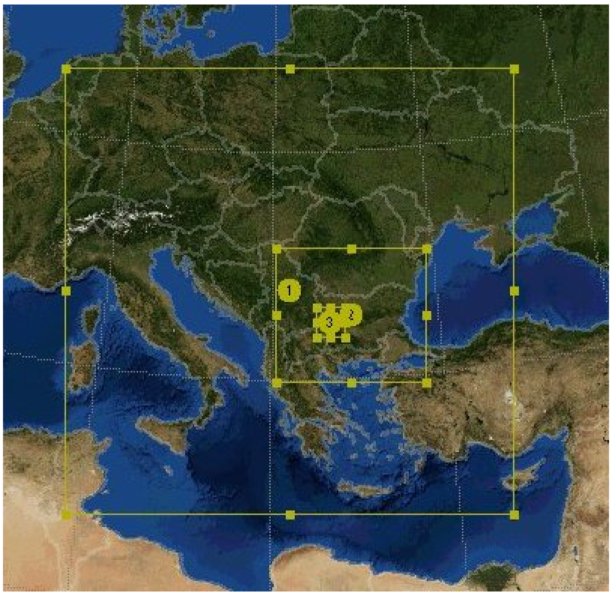


Fig. 1. Three nested model domains.

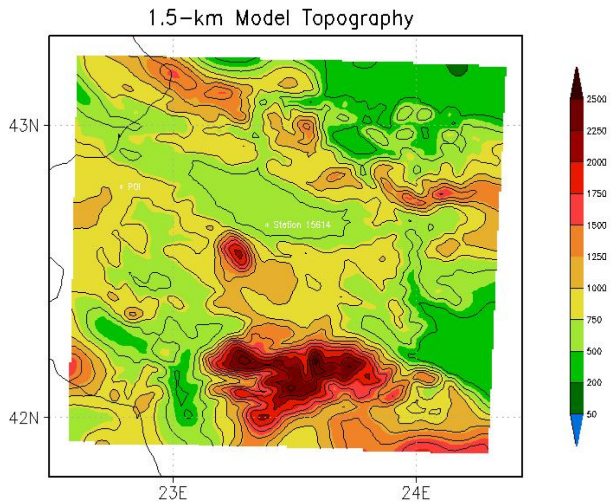


Fig. 2. Third domain topography 1.8 km resolution.

Rila mountains. The vertical coordinate system is sigma – terrain following with 65 levels. Several numerical experiments are performed to configure and tune the model parameters in order to obtain adequate model results. The most important parameters are related to the parameterization of the subgrid physics processes [2].

The following parameterization schemes are used in the model:

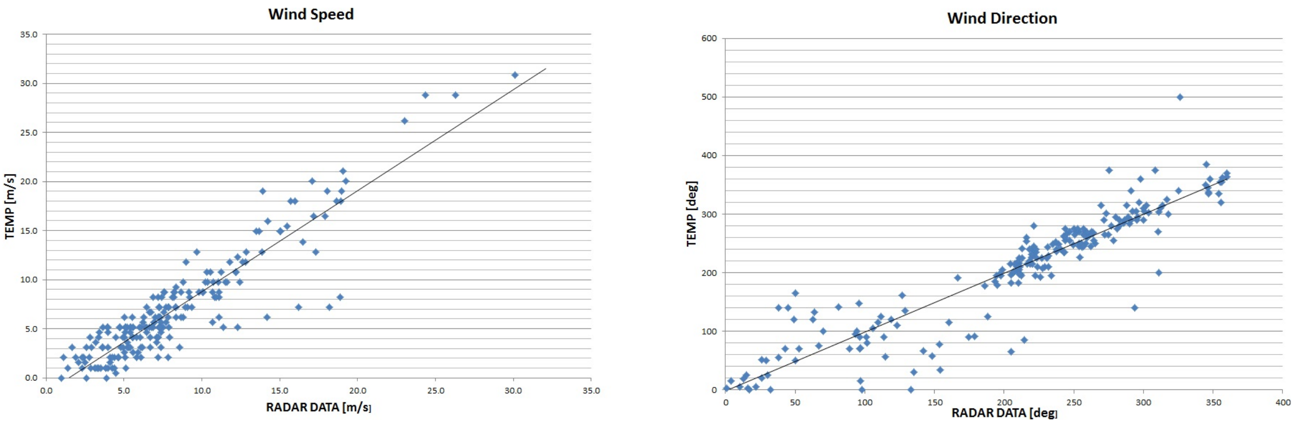
- For microphysical processe in the clouds: WRF Double-Moment 6 class scheme ([9])
- Longwave radiation processes: RRTM (Rapid Radiative Transfer Model) ([7])
- Shortwave radiation processes: Dudhia scheme ([8])
- Air-surface exchange processes: Noah Land Surface Model
- Planetary boundary layer parameterization: Yonsei University scheme
- Convective processes parameterization: Kain-Fritsch scheme ([6]). Note that this scheme is used only in first and second domains, in the third domain with resolution 1.8 km, the convection is not parameterizied.

The model simulation starts at 12:00UTC on 06 May 2014 and the integration is for 24 hours. The interesting period for the airplane accident investigation is around 06:00UTC on 07 May, thus the model spinup time is sufficient.

AVAILABLE DATA TO VALIDATE THE MODEL RESULTS

The simulated vertical profiles of the main meteorological elements could be compared with the data from atmosphere sounding. Such a comparison is performed for example by [3]. This study demonstrates very good positive correlation coefficient between model and sounding data ($r = 0.91$ for the temperature and $r = 0.7$–0.8 for humidity). The authors however show that for the wind the correlation is not so good especially in the low atmopheric layers. We are especially interested in the wind that is why in this chapter we concentrate on that element.

Another approach to validate the model results is the comparison with the wind field calculated from the radar data. A Doppler meteorological radar Gematronic C360 operates on Sofia airport, which is very near to the place of meteorological ballon sounde launching. The radar identifies the hydrometeors in th air and the special algorithm VVP (Volume Velocity Processing) calculates the wind on different vertical levels using the hydrometeors displacement. The output is a product which gives the horizontal wind speed and direction in the vertical column above the radar location. In fact this velocity is representative average for a circle with radi of 25 km. This means that one could expect the vertical wind profile to be smoothed. Another limitation is that the result is usable only in the presence of sufficient quantity of hydrometeors, which are used as indirect passive tracers. So in the clear sky days, the method would not work good. Nevertheless, the temporal resolution is very good (about 5 min) and gives the opportunity to follow fine processes evoluton and the data could give



a) b)

Fig. 3. Comparison of the wind vertical profiles from radar and sounding: a) speed b) direction.

very useful information when validating the model results. Our first objective is to compare the wind measurements from the atmosphere sounding and the radar aiming to quantify the usability of radar data. The period for which we have data is 1-20 May 2014.

The atmosphere sounding data are taken from University of Wyoming data base: http://weather.uwyo.edu/upperair/sounding.html for station 15614, coordinates 42.65N and 23.38E, elevation of 595m. The meteorological radar MRL is located on 530 m elevation and the data are made kindly available to us by the Bulgarian Air Traffic Services Authority. The radar data product gives the wind speed and direction on levels with 200 m step, reaching 10 km height. However, the information is nor regular, some levels are missing in the reports, as the data quality depends on the hydrometeors concentration and the algorithm sensitivity. In order to compare with the sounding data at midday, only the radar data in 12:01 UTC are taken. As the vertical levels differ in both sources of data, linear interpolation of sounding data to radar vertical levels is performed.

The results from the above described comparison are summarized in Fig. 3 a and b, and the main statistics are calculated in Table 1 for the wind speed and Table 2 for the wind direction. The good correlation between sounding and radar is evident ($r = 0.9$). The Root Mean Square Error (RMSE) for the wind speed is calculated following [4]. Very interesting is to check the correlation and RMSE in the different vertical heights, it is seen that better correlation is observed in the free atmosphere. The difference in the wind velocity is about 2 m/s. However, some of the differences are systematic errors, coming from

Table 1. Statistics about the comparison of wind speed in radar and atmosphere sounding

	600m	800m	1400m	1600m	All levels
RMSE	2.1	2.2	2.5	2.4	2.5
Correlation	0.67	0.82	0.79	0.75	0.91

Table 2. Statistics about the comparison of wind direction in radar and atmosphere sounding

	600m	800m	1400m	1600m	All levels
Correlation	0.69	0.87	0.88	0.89	0.88

the specific device functioning. A problem is also the limited sample (only 19 days). For example one of the days the radar observations show twice higher wind speed than the sounding.

The comparison in this chapter was done in order to assure that the data for the wind speed and direction calculated from the meteorological radars could be used for numerical model verification. As the midday sounding is not representative for each moment of the day the radar data could be used as a substitution when verifying the model simulated vertical wind profiles. However, this evaluation should be further extended to all seasons and more sample data, thus the conclusions made should be consider as an initial estimate.

NUMERICAL SIMULATION OF THE VERTICAL DISTRIBUTION OF THE METEOROLOGICAL ELEMENTS ON 07.05.2014

The period of the model integration in this study is chosen on purpose. On 07.05.2014 about 0600 UTC an agricultural airplane had to land emergently

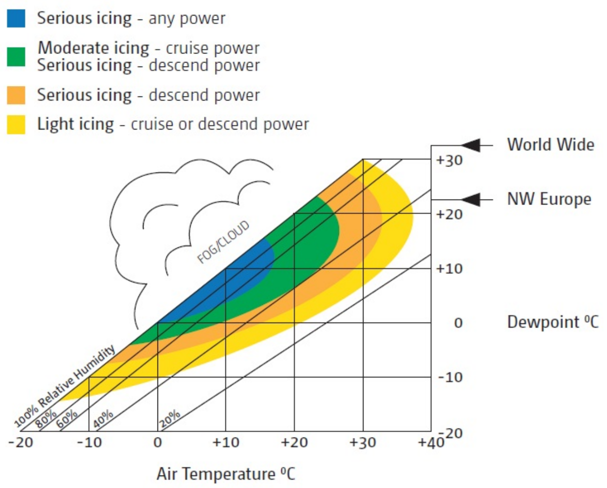


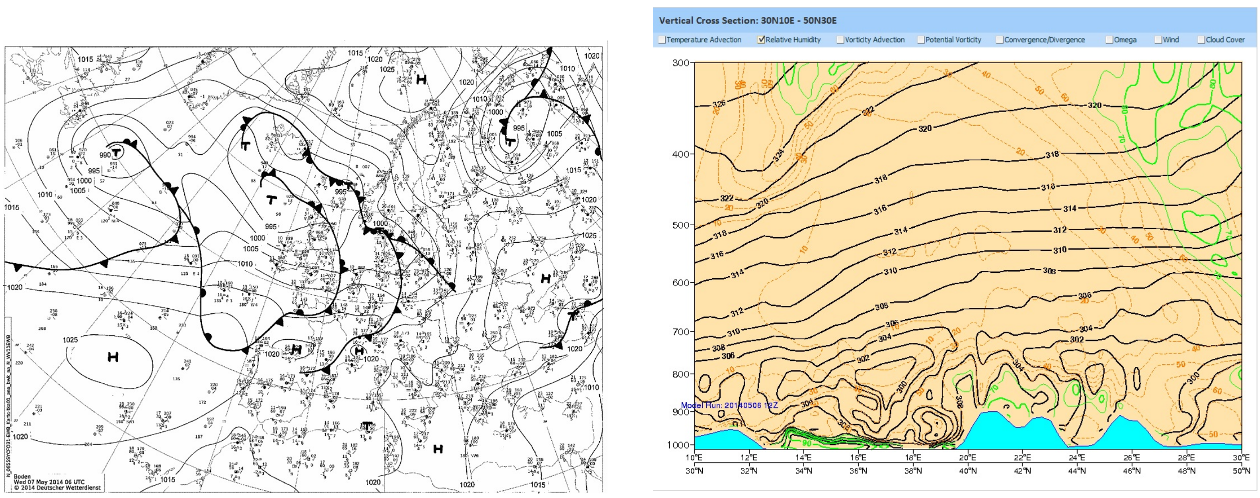
Fig. 4. Icing conditions.

because of the damage in the airplane engine. The landing was near the town Tran and the accident occurred in the location 42,65N and 23,38E, on 1000 m height above the ground. The pilot reported that the reason to cause the accident is a sudden and fast engine carburetor icing. The investigation of the case needed reliable meteorological information about the vertical profiles of temperature for this location. The place and time of the accident are very far from the nearest available atmosphere sounding and no radar data exist for the place. According to the Aeronautical Information Circular AIC: P 077/2009 [5] an engine icing initiates when the air temperature is above 0ºC and the relative humidity exceeds 60% Fig. (4).

The important for the investigation was to know whether there were favorable condition for engine icing. As radar and sounding data are not useful in this case, only the surface synoptic measurements of the near high locations could be of help. These are the meteorological stations in Dragoman, Sofia, Kiustendil and Cherni vryh. In this case the numerical model approach proved to be very helpful.

The synoptic observations for the date of the accident are shown in Fig. 5a and Fig. 5b gives the vertical cross-section from the prognostic analysis of the European Center for Medium range weather forecast (source http://eumetrain.org/). The two analysis show that Bulgaria was in the periphery of a large anticyclone centered over Russia. This situation is favorable for formation of temperature inversion in the planetary boundary layer and the air mass was humid. The estimate of the weather conditions is only qualitative and more precise quantitative estimate is not possible based only on this data. That is why we used the described in Chapter 2 configuration of WRF model. The numerical experiment provided 3D fields of temperature, humidity and wind for the moment of the accident with a spatial resolution of 1.8km. The simulated vertical profiles for the temperature and relative humidity in the location of the accident in 0600 UTC are given in Fig. 6.

From the plots in Fig. 6 one can see that on level 820hPa, which correspond approximately to 900 m the values for the temperature is 3.5ºC and the relative humidity of 63%. These are favorable conditions for icing and it could occur according to [5].



a) b)

Fig. 5. a) Synoptic maps of Europe for 7.05.2014 from wetterzentrale.de and b) ECMWF prognostic analyses cross-section from eumetrain.org.

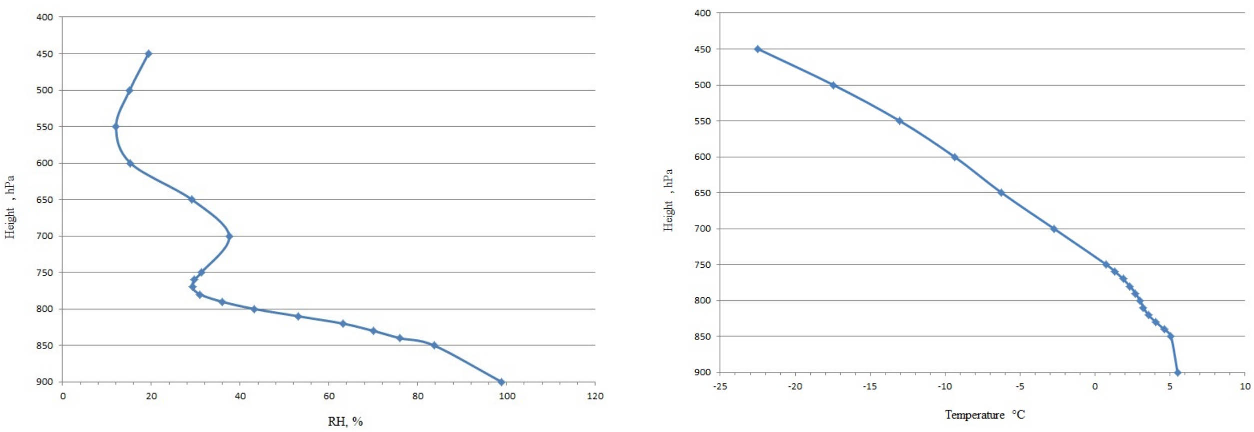


Fig. 6. Simulated vertical profiles for the temperature and relative humidity in the location of the accident.

MODEL RESULTS VERIFICATION

The model results confirm the pilot report plausible. But the question is whether the model results are reliable. Unfortunately this day the meteorological radar in Sofia airport did not produce a good wind profile that is why we can use only the available atmosphere sounding in Sofia at 12 UTC to validate the model results.

The taken model data refer to 1200Z on 7.05.2014. The comparison with the sounding data is shown in Fig. 7 in the form of aerological diagrams: the sounding temperature, relative humidity and wind profile on the left plot, and the corresponding model profiles - on the right. One can note the good agreement between the two sources of data. The layer of temperature inversion between 500 and 350 hPa is represented well by the model, the tropopause height at about 250 hPa coincides as well. The agreement between model and sounding wind profiles is excellent especially in the free atmosphere. The vertical variations of dewpoint temperature match also well, larger differences could be seen in low troposphere and the reason for that is the parameterized boundary layer processes and the discreet resolution in vertical.

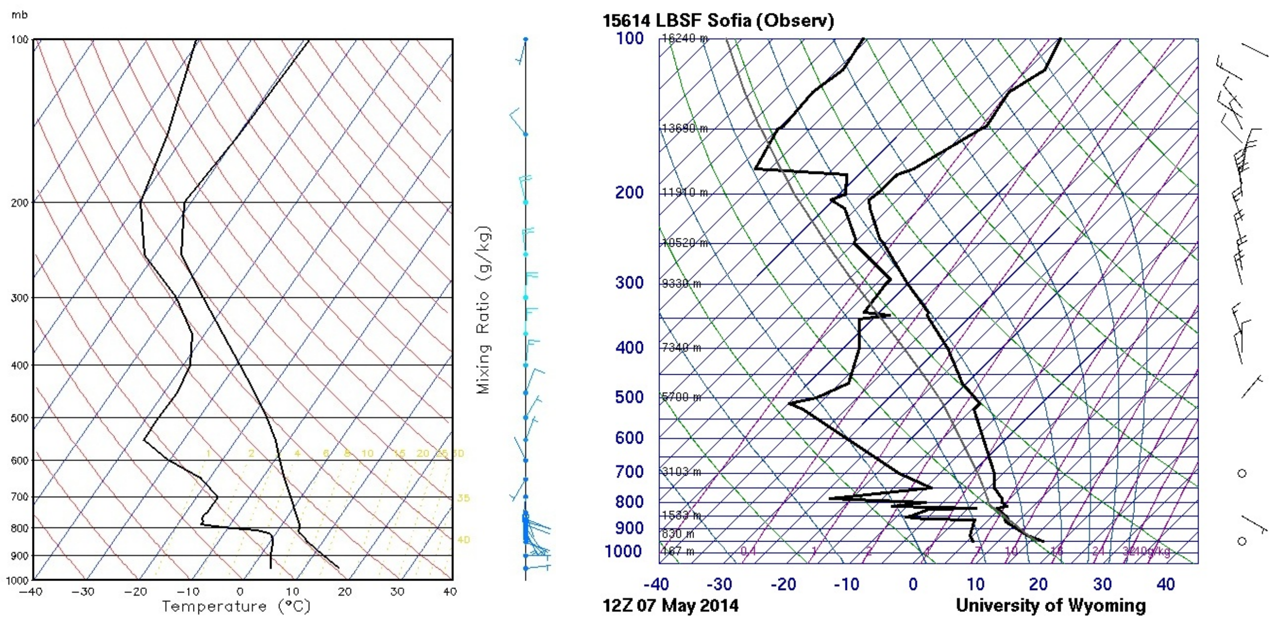
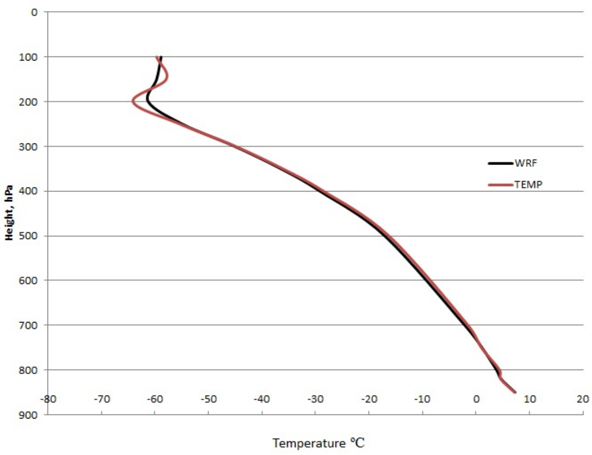


Fig. 7. Simulated vertical profiles for the temperature and relative humidity in the location of the accident.



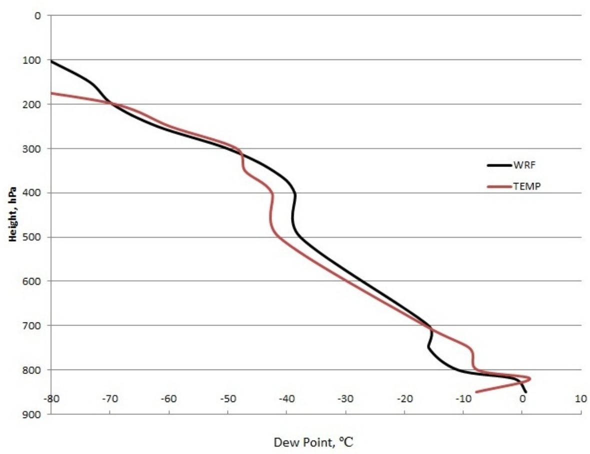
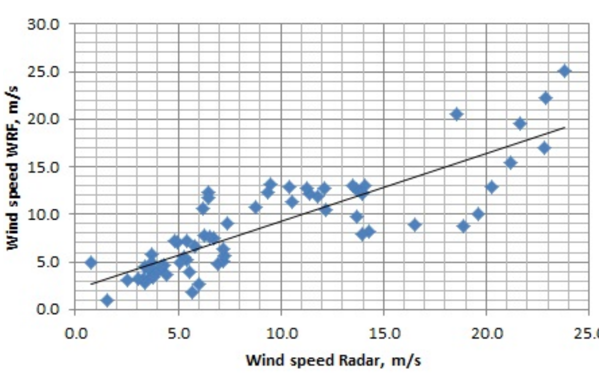


Fig. 8. Comparison between vertical profiles from sounding and WRF model for air (left) and dewpoint (right) temperature.

In order to better demonstrate the agreement between sounding data and model results we show in Fig. 8 the superimposed curves of the measured and simulated air temperature (the left plot) and dewpoint temperature (the right plot). The agreement is almost complete for the temperature in the lower and middle troposphere. The correlation coefficioent between the curves in the left plot is 0.99, and the RMSE about 1 deg C. Regarding the dewpoint temperature the differences are mainly in the layers between 800-700 hPa and 500-400 hPa and is related most probably to cloud formation. Nevertheless the correlation coeficient is 0.9, indicating good agreement.

The place of the airplane accident is situated about 50 km from Sofia. Thus, in principle, the meteorological radar at Sofia airport covers this area and the radar data are rather representative. As stated in Chapter 3, these data are also useful for model results validation. Unfortunately, the radar data for 7.05.2014 are not good quality so we had to take other dates for comparison of model and radar wind.

For this purpose, several other experiment for the period of the airplane accidents were run. Seven dates with valid radar wind profiles for 6h are chosen and the described in Chapter 2 model configuration was integrated for a 12 hours period starting at 0h on the corresponding date. The Fig. 9 shows the results from comparison between simulated and radar wind profiles, the speed is on the left plot and the direction - on the right. The data agree well, the correlation coefficient is calculated to 0.85 both for wind speed and direction which indicates very good positive correlation.



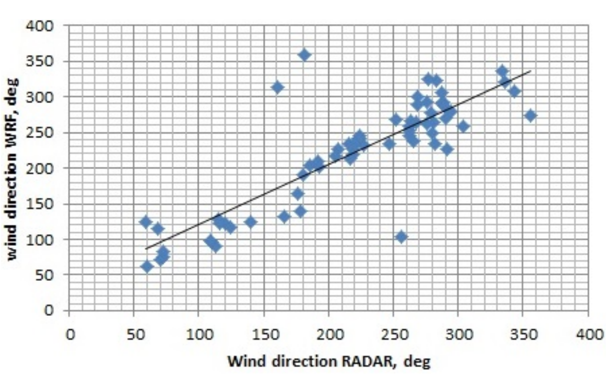


Fig. 9. Comparison between atmosphere sounding and meteorological radar data for wind speed (left) and direction (right).

CONCLUSIONS

Numerical simulations could present very useful source of data in cases when the information about vertical profiles of the meteorological element is needed. The advantage of these numerical data is the fine resolution both in time and space. In this study we have compared data from available atmosphere sounding and meteorological radar with the model simulated vertical profiles of temperature humidity and wind. The model used is in the study is the ARW version of the weather forecast model system WRF.

As a first step we have compared the measured sounding wind data and the calculated from the meteorological radar images wind speed and direction. The results present good positive correlation between two sources of data and demonstrated that the radar data can be used for model validation. The sounding data are more precise and reliable data source but the main advantage of the radar data is the very fine temporal resolution and the good sensitivity.

This study was motivated by the investigation of an airplane accident in the area of town Tran on 7.05.2014, which was caused most probably by engine carburetor icing. The necessary information about the vertical profiles of air temperature, humidity and wind for the place of the accident could be obtained only by numerical model, as the atmosphere sounding data are not available in this moment of time and location. The comparison between the model simulations and the aerological diagram further in the day of the accident demonstrated that the simulated model profiles agree well with the atmosphere sounding thus indicating that the model results could be used successfully as a proxy of the measured vertical profiles. The differences between model and measurements are mainly in the planetary boundary layer due to the model limitation to parameterize the subgrid physics processes. The model results for 6h on 7.05.2014 confirm the pilot report for airplane engine icing as plausible thus giving very useful information.

To conclude, the results presented in this study should be considered as preliminary because they refer only to May 2014. More detailed investigation on the relationship between data coming from atmosphere sounding or meteorological radar and obtained with numerical model should be performed for several seasons and years in order to confirm the good correlation and the usability of the model simulations. This is a motivation for the authors for future studies.

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ЧИСЛЕНА АПРОКСИМАЦИЯ НА ПРОФИЛИ ОТ АЕРОЛОГИЧНИ СОНДАЖИ С ПОМОЩТА НА ЧИСЛЕНИЯ МОДЕЛ ЗА ПРОГНОЗА НА ВРЕМЕТО WRF

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(Резюме)

Нуждата от информация за вертикалното разпределение на метеорологичните елементи (температура, влажност, скорост и посока на вятъра, точка на оросяване) в тропосферата е несъмнена и все по-изразена. Редица задачи, свързани с прогноза на времето, като например предупреждения за опасни конвективни явления, метеорологичното осигуряване на авиацията, борбата с градушките, изискват такъв тип информация. За съжаление данните от измервания посредством аерологични сондажи са скъпи и поради това твърде ограничени, както по пространство, така и по време. За България например, измерванията са веднъж дневно в 12UTC в метеорологична станция София. Това е недостатъчно, като се имат предвид климатичните характеристики, денонощната изменчивост и разнородния релеф на страната.

Настоящето изследване цели да провери, доколко резултатите от числени симулации могат да се използват като заместител (апроксимация) на аерологичния сондаж в дадена точка и момент от времето. Предимството е, че така се решава проблемът с недостатъчните данни от измервания. Численият модел, който се използва е на базата на моделната система Weather Research and Forecasting WRF [1]. Моделната конфигурация покрива територията на България с двойна нестинг-процедура, като достигнатата разрешаващата способност по пространство за част от страната е 1,8 км. Извършени са серия от числени експерименти за конфигуриране и настройка на моделните параметри с цел постигане на адекватни числени резултати [2]. Численo симулираните вертикални профили на температура, влажност и вятър са сравнени с наличните данни от аерологичния сондаж в София. Направени са изводи за достоверността на тази апроксимация. Показан е реален случай, в който така описаната процедура е дала полезна информация и реално приложение.

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