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About the need to develop the data assimilation procedures for the meteorological pre-processors of the emergency response systems

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Abstract – The need to develop and use data assimilation procedures in the emergency response systems (ERS) dealing with the atmospheric dispersion of pollutants is discussed.

Keywords: atmospheric dispersion, RODOS

Introduction

Atmospheric Dispersion Models (ADMs) play a key role in the sequence of model components of real-time emergency response systems (ERS) like RODOS (the **R**eal-time **O**n-line **D**ecisi**O**n **S**upport system for nuclear emergency management in Europe (J. Ehrhardt, 1997). Performance of the ADMs is highly sensitive to the quality of the meteorological fields produced by the diagnostic wind models (meteorological pre-processors - MPPs), which act as interface between the ADMs and the incoming meteorological data. The meteorological data can be measurements from one or more stations in the area of interest or prognostic data from synoptic- or meso-scale Numerical Weather Prediction (NWP) models. The existing ERSs are usually linked to both the results of meteorological measurements and the results of the NWP models operated externally. The MPPs of the most current ERSs use either measurements or the NWP data to calculate the meteorological fields for the ADMs. The problem of the simultaneous use of meteorological measurements and NWP data in the MPPs of ERSs was addressed by Kovalets et al. (2004), where the development and evaluation of data assimilation procedures for the MPP of RODOS has been presented. The developed methodologies were statistical three-dimensional data assimilation procedures (3DDA). During the discussions of the developed methodologies (Kovalets et al., 2003) questions were raised based on the fact that in case of real emergency, it is the official NWP simulations from the national weather services, with full prognostic capacity, including data assimilation of available

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measurements that are used by authorities in order to draw emergency plans. Another issue concerned the specific characteristics of the 3DDA methods for the meteorological pre-processors in view of the fact that the development of the 3DDA methods for the NWP models is ongoing in all the weather services of the world (Courtier et al., 1998, Barker et al., 2003). The present research note presents some additional results obtained with the methodologies described by Kovalets et al. (2004) together with some new results obtained from the pre-operational use of RODOS. At the same time it attempts to address the abovementioned questions on the basis of these results.

Results and discussion

The need to use data assimilation procedures in the MPP of the RODOS system comes from the fact that usually to the end users of the RODOS system additional measured meteorological information is available to that already used for the calculations of the weather forecast by the National Weather Service. Thus, without the use of the data assimilation procedures in the MPP that additional data can be lost.

However, this is not the only reason for the use of the DA procedures in the MPP. Another reason noted in Scire (2000), comes from the fact that the scales of the atmospheric movements resolved by the NWP model and the MPP are significantly different because the grid scale of the MPP is usually 3-10 times finer than the grid of the NWP model. Hence, the small-scale movements present in the measurements that are treated as “noise” when used in the NWP model are to be resolved by the MPP. Thus, even if some particular meteorological observations were already used for the calculation of the NWP forecast, they should be used *again* if these forecasts are being pre-processed on the finer grid of the MPP.

The above can be demonstrated by the results of the use of the RODOS system, previously implemented in Ukraine (Zheleznyak et al., 2003), during the National training on off-site emergency management of Zaporizhje Nuclear Power Plant (ZNPP) in August 2002. During these trainings, the atmospheric dispersion of the radionuclides in the consequence of a hypothetical emergency situation at the ZNPP was calculated with the RODOS system. Two kinds of calculations were performed: in the first run the input meteorological data to the RODOS system were taken from the on-line meteorological data measured locally near the point of hypothetical release. In the second run the forecast data were used from the MM5 NWP model.

The MM5 NWP model was operated in three nested domains. The first (coarsest) domain was centred on (49.0° N, 32.0° E), and covered most part of Europe with spatial resolution of 81 km, and with 37x37 nodes in X and Y directions. The second nested domain covered all Ukraine and the Black Sea. It had 73x73 nodes in X and Y directions and spatial resolution 27 km. The third nested domain, which is presented in Figure 1 covered a region of 180x180 km^2 around the ZNPP (34.6333° N, 47.48° E) with 9 km grid resolution and 22x22 nodes. The number of the vertical levels in all nested domains was 31. Initial and boundary conditions were prepared on the basis of the forecast data of the German meteorological centre Offenbach (DWD) and operational data from Ukrainian meteorological stations processed by Ukrainian Hydrometcenter. The forecast data, obtained from DWD cover the area from 0° to 90° W and from 0° to 90° N with grid resolution of 1.5°. The measurement data, used in the data assimilation during calculations in the 3rd domain were data of the surface meteorological stations, operated by UkrHydrometcenter “Zaporizhia” (47.80 N 35.02 E), “Pryshyb” (47.27 N 35.31 E), “Kryvyi Rih” (48.03 N 33.22 E), “Nikopol” (47.58 N 34.45 E), shown in Figure 1 by triangles. The nearest to the ZNPP meteorological station is “Nikopol”, situated on the other bank of the water pond in approximately 15 km from ZNPP. The ZNPP had its own meteorological station, operating at the territory of ZNPP. Its location is shown in Figure 1 by square. Its data were used as a meteorological input for the first set of calculations but were not used in data assimilation procedure.

The source term in both calculations was identical and generated by the responsible users of RODOS. The meteorological conditions measured at the point of release were as follows: wind speed – 3-4 m/s, wind direction – 300 deg, stability category – D. The main results of these two runs together with the NWP wind field calculated by the MM5 for the corresponding time moment are shown in Figure 1. As it can be seen from this Figure, significant discrepancy exists between the two runs results. As the first run represents the calculations performed using only the meteorological measurement at the point of release, they can’t be treated as more “true” then those obtained using the NWP data. On the other hand it is obvious that the forecast model fails to predict well the local velocity at the point of release, in spite of using the nearby measurement (“Nikopol”) in its own data assimilation procedure. This model error can be explained by the influence of the nearby water pond on the wind field around it. However, as it is shown in Figure 1-(c) the wind vector predicted by the NWP model near the ZNPP quickly changes its direction, so that the calculated value of the wind direction near the point of release is very sensitive to the distance from that point. This justifies the necessity of using the additional measured wind information through 3DDA when the results of the NWP forecast are interpolated on the finer grid of the MPP. In this context especially valuable would be incorporating of the meteorological measurement at ZNPP (which in operational practice is not available to the NWP model) in the process of calculations of the MPP.

In Kovalets et al. (2004) 3-dimensional data assimilation procedures were verified against the meteorological data measured during the ETEX campaigns (Gryning et al., 1998). The effect of the data assimilation procedures was shown through of the improvement of the meteorological fields calculated by the MPP using both meteorological measurements and the ECMWF NWP data in comparison to those obtained using only the ECMWF NWP data. While the grid scale of the ECMWF model was approximately 50 km, the grid scale of the MPP was approximately 5 km. The domain size was 300x300 km^2, the number of measurements used for the data assimilation was 6, the number of measurements used for comparisons 43, and the number of time levels at which calculations were performed was 32, covering the time intervals of the ETEX1 and ETEX2 campaigns. In Table 1 results of the above comparisons are shown for the case of ETEX1 experiment. The method of optimal interpolation (OI) was used for data assimilation, previously described in Kovalets et al., 2004. Data, presented in columns 1-2 of the Table 1 are those obtained using the *analysed* ECMWF data instead of the prognostic ECMWF data.

In spite of the fact that the *analysed* ECMWF data had already utilized the available meteorological measurements in its own data assimilation scheme, significant improvement of the calculated by the MPP meteorological fields under the influence of data assimilation can be observed. Also interesting is that the statistical characteristics of the errors of background field, calculated from the prognostic ECMWF data are better than those calculated from the analysed ECMWF data. This can be connected with the physical inconsistency of the wind fields (i.e. not satisfying continuity and momentum equations) introduced by the optimal interpolation, which was used in the ECMWF model (ECMWF, 1995) for the calculation of the analyses.

Until now several advanced 3DDA methodologies have been developed for the initialisation of the NWP models, based on the variational principles (Barker et al., 2003, Courtier et al., 1998). But the known 3DDA schemes developed for the NWP models are not concentrated on the adequate representation of the ABL processes. For instance in the variational 3DDA scheme of the MM5 and WRF NWP models (Barker et al., 2004) the balance constraints imposed are only the mass balance, "weak geostrophic" and hydrostatic relationships. In literature no other 3DDA methods exist, where the processes in the ABL are taken into account in a more specialised way exist. The difference of the 3DDA methods applicable for the MPPs of the ERSs should originate from the fact that the small-scale characteristics of the atmospheric surface and boundary layers are of primary importance for the purposes of the local-scale ADMs of the ERSs. Hence, further development of the 3DDA for the MPPs should combine the advanced meteorological parameterisations of the ABL under various conditions and the simplified diagnostic equations of the wind flow in the ABL (as those in Dunkerley et al., 2001) with the statistical and/or variational approaches of data assimilation.

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Figure 1. Example of RODOS calculations during nuclear emergency trainings on Zaporizzhe NPP 22.08.2002; a) time-integrated concentrations of ^{131}I in air calculated on the basis of the wind measurements at the release point; b) time-integrated concentrations of ^{131}I in air calculated on the basis of forecast data of MM5; c) wind streamlines calculated by the MM5-IMMSP for 28 August 2002, 11-00 UTC ;"□" – location of the source of release and of the meteorological station at ZNPP; "△" – location of the meteorological stations, used for data assimilation in MM5 calculations.

Tables

Variable	Background field *analysed*	Data assimilation (OI).	Background field *prognostic*	Data assimilation (OI)
rmsu, m/s	3.19	2.52	2.57	2.44
biasu, m/s	1.06	0.25	0.67	-0.08
rmsd, dec. degree	31	31	33	33
biasd, dec.degree	9.55	4.26	10.3	5.5

Table 1 Root mean square errors of the magnitudes of wind velocity and wind direction (rmsu, rmsd), and absolute errors of the magnitudes of wind velocity and wind direction (biasu, biasd), calculated by the MPP for the case of ETEX1 experiment with the use of the analysed ECMWF data only (background field) and subsequently corrected with data assimilation procedure (columns 1, 2) and with the use of the *prognostic* ECMWF data and with data assimilation (columns 3, 4). Data in columns 3 and 4 are taken from Kovalets et al., 2004.

Figure 1