Operational forecasts for air dispersion of hazardous pollutants based on results of the COSMO model.

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1 Introduction

The project developed at the IMWM-NRI is intended to help in determining the response to the occurrence of a potential danger to Poland, related to at least two types of threats:

1. anthropogenic threats, resulting mainly from incidents in nuclear power plants (NPPs – cf. Fig. 1) in neighboring countries, as well as other disasters or accidents of the nature of emission incidents, causing contamination of the environment with toxic (more generally: dangerous) substances ;
2. natural threats, such as volcanic eruptions and eruptions, and their impact on broadly understood safety, including e.g. the safety of air transport.

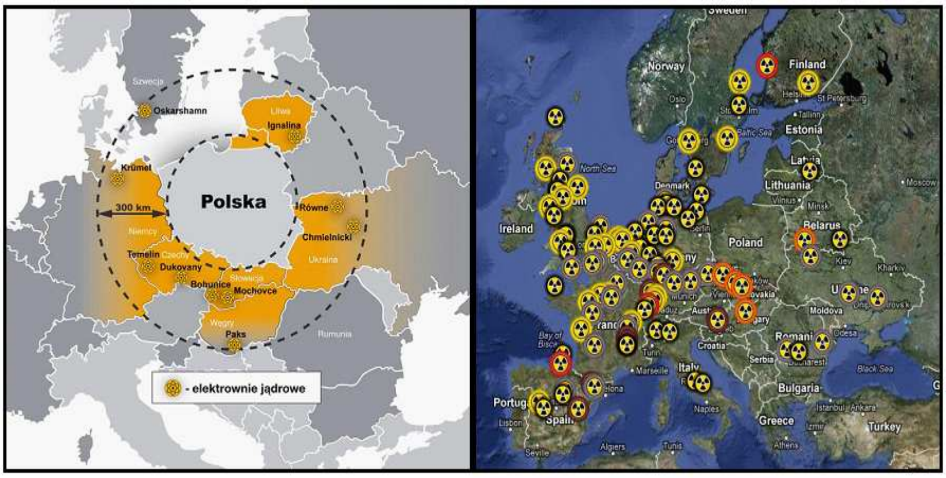

Figure 1: Left – NPP within 300 km from Poland (Mazur, 2015). Right – High-risk reactors in Europe. Red – the type used in Fukushima; Orange – inadequate security; Yellow – older than 30 years; Brown – seismically active region. Other: Gray – under construction; Black – turned off (status – end of 2015 yr.)

In terms of safety, the key issue is information – including forecasts – if/how the territory of Poland may be endangered as a result of a hypothetical accident in selected NPP(s) or of a release of another contamination.

At IMWM-NRI a system for forecasting – in operational mode – the dispersion of pollutants from locations in the COSMO model domain has been prepared. Two models (Lagrangian – trajectory and Eulerian – field) are complementary in terms of information on dispersion of pollutants. 1. The Lagrangian model: three-dimensional trajectory calculated as a solution for the following set of equations (Potter, 1979):

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$$\frac{dx}{dt} = u(x;t)$$

where x=x(t) – 3D coordinates of the trajectory point; u – 3D windspeed field.
Solution, understood as a change of point's location is given by the following procedure:

$$\Delta x_0 = u(x_0;t_0) \cdot \Delta t$$

With iterative correction and iteration index i=1,3:

$$\Delta x_i = \frac{\Delta x_0 + u(x_0 + \Delta x_{i-1}; t + \Delta t) \cdot \Delta t}{2}$$

Finally (for i=N=3):

$$x(t + \Delta t) = x(t) + \Delta x_N$$

2.Eulerian model

General equation of dispersion (including horizontal advection and vertical diffusion) of contamination concentration c may be written as:

$$\frac{\partial c}{\partial t} + \frac{\partial uc}{\partial x} + \frac{\partial vc}{\partial y} = \frac{\partial}{\partial z}\left(K_v \frac{\partial c}{\partial z}\right) + G$$

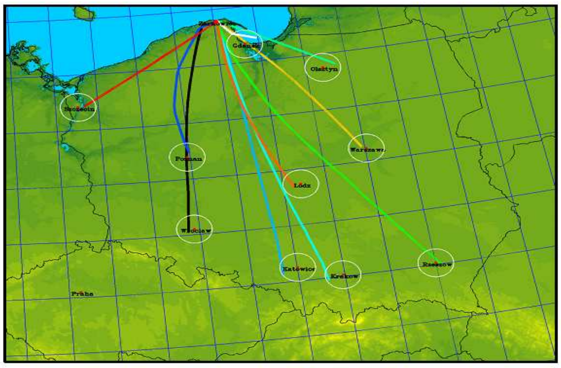
where u, v – 2-D windspeed field; Kv – tensor of turbulent diffusion (vertical component), G – contamination's emission and removal (wet- and dry deposition). Solution is calculated separately for horizontal advection – with Flux Correction method (class of AFP – Area Flux Preserving approaches), vertical diffusion – with semi-explicit Crank-Nicholson's method (cf. Bott, 1989, Potter, ibid.). Both types of models are used in the system, giving complementary information.

2 Concept, goals and results

Main general goal of the work was to increase an overall level of Poland's safety in the context of nuclear installations located in neighboring countries, safety and fluency of air traffic over Poland in the event of volcanic eruptions (introduction of a periodic ban on flights over Poland), the possibility of reacting to the occurrence of other releases of hazardous, toxic substances, etc.

The effect of implementation became a system for forecasting and informing about the possible effects of incidents related to nuclear accidents of a wide scale of intensity or volcanic eruptions located throughout Europe, which may result e.g. in the introduction of a flight ban over selected areas of the continent, including Poland, or any other release of dangerous or toxic substances into the atmosphere.
The results may be used to determine actions and responses for events of this kind. In Figure 2 an example of the results is presented.

City	ETA
Gdańsk	0.1
Olsztyn	1.1
Szczecin	2
Poznań	2.3
Warsaw	2.5
Łódź	2.5
Wrocław	3.9
Katowice	4
Kraków	4.3
Rzeszów	4.9



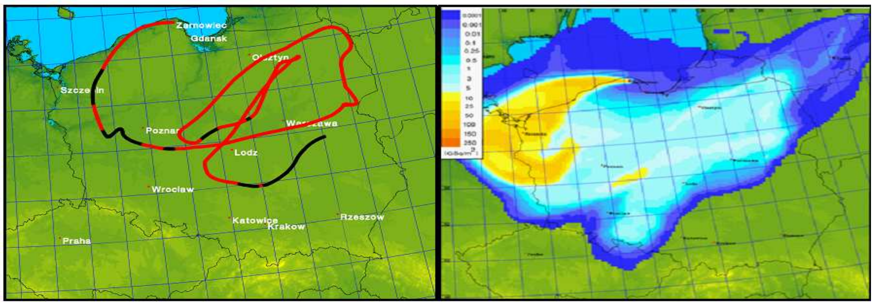


Figure 2: Assessment of the impact of the future Polish NPP; climatological data 2001-2010 (Mazur, ibid.). Upper left – estimated fastest times of arrival (ETA, hours) of contamination cloud to main Polish cities. Upper right – paths of fastest trajectories, as computed with Lagrangian model. Lower left – the trajectory with the longest course over the territory of Poland. Lower right – results of Eulerian model for the case of the release for longest trajectory.

Another example was an assessment of the impact from Chernobyl NPP with climatological data 2001-2010, as shown in Figure 3. The results showed that the "real case" of 25-26 of April 1986 was a special not only because of the catastrophic intensity of the release, but also because of spatial scale and range of the atmospheric dispersion. From climatological data (2001-2010), the probability of impact (Figure 3, left) was relatively much smaller for western Europe then for western part (or eastern Europe) of USSR. Yet, the mean estimated time of arrival (ETA again) was in general in line with reality. For example, contamination cloud came to Poland within 24 hours, as modeled.

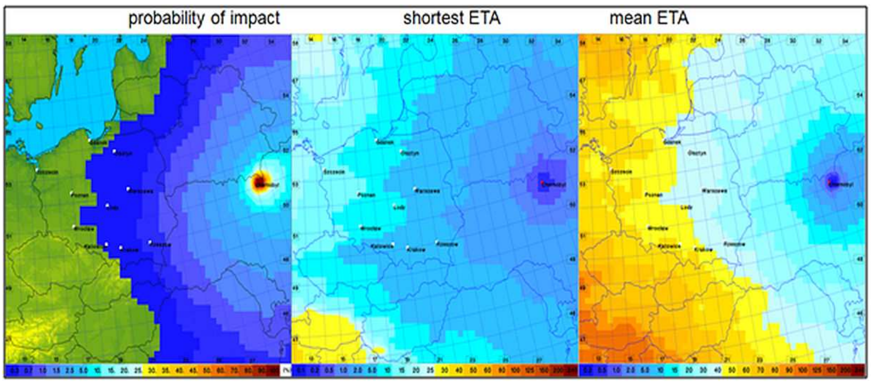


Figure 3: Assessment of the impact from Chernobyl NPP; climatological data 2001-2010, see explanations in text (Mazur, ibid.).

In basic setup, operation forecasts of air dispersion of pollutants was computed over a domain centered over Poland with spatial resolution of 7km, 385x321 grid points, as shown e.g. in Figure 4.

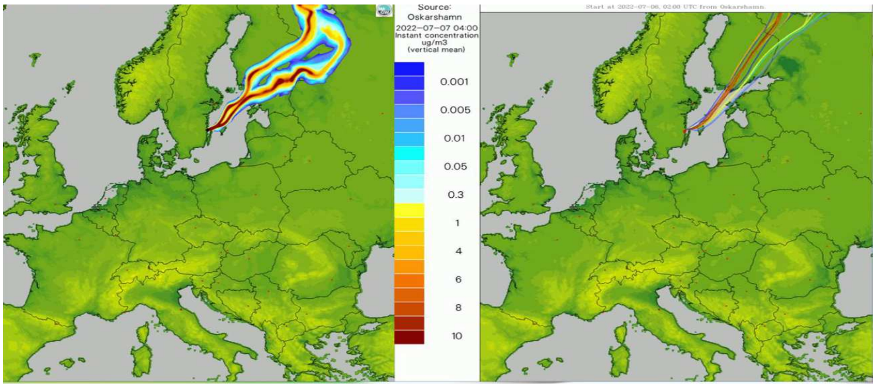


Figure 4: Domain for basic operational setup – an example of operation forecast of air dispersion of nuclear cloud from NPP in Oskarshamn, Sweden. Left – vertical mean of instant concentration (ug/m3), calculated with Eulerian model. Right – respective trajectories computed with Lagrangian model.

Due to the ongoing war in Ukraine, and especially situation with Ukrainian NPPs, the domain had to be extended by about 20 at least in the eastern direction, as shown in Figure 5. The extended domain covers the entire territory of Ukraine and its closest vicinity.

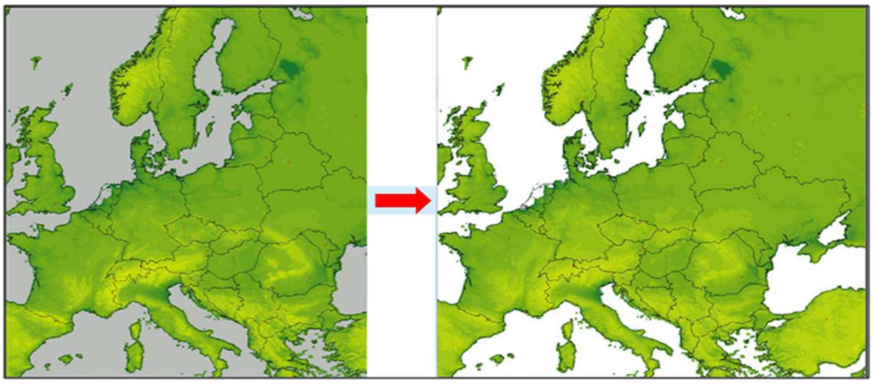


Figure 5: Extension of domain due to war in Ukraine and situation in nuclear power plants.

In Figure 6 the example results of calculation for special case – emission (or release) from NPP In Enerhodar, east of Ukraine.

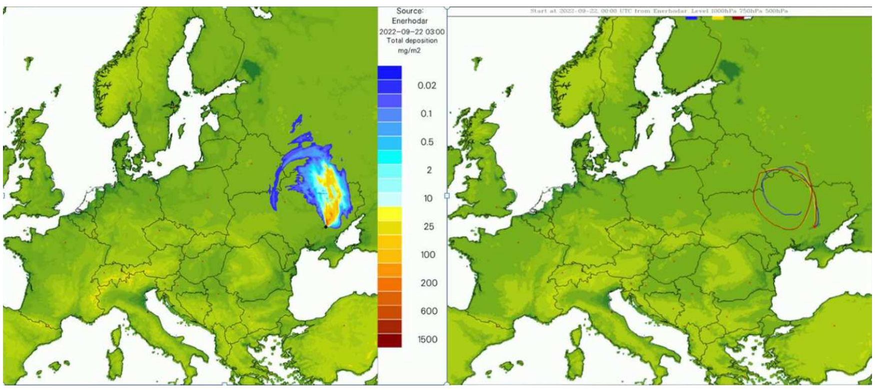


Figure 6: Domain for modified operational setup – an example of operation forecast of air dispersion of nuclear cloud from NPP in Enerhodar, Ukraine. Left – total deposition (mg/m2), calculated with Eulerian model. Right – respective trajectories computed with Lagrangian model

3 Summary

The entire history of mankind is full of emission incidents or even disasters, both resulting from military and peaceful uses, both anthropogenic and natural. Below are provided some examples (cf. Mazur, ibid.).

- October 1957, accident in Windscale reactor (UK): contaminated 500 km2 of the area around the NPP; similarly to the Chernobyl accident – a result of an unfortunate combination of many factors;
- April 1986, explosion and fire of Chernobyl reactor; commonly believed – a catastrophe on a global scale both in terms of the amount of the release and of it spatial extent;
- April 2010, eruption of Eyjafjallajökull volcano in Iceland, flight bans, threat to air traffic over Europe;
- March 2011, the disaster at the Fukushima NPP – the result of an earthquake, the impact of the tsunami wave and a confluence of unfortunate circumstances and human errors;
- September to December 2021, Cumbre Vieja volcano eruption – a hundred days of emission of volcanic ashes/sulfur compounds.

This list is definitely not complete. That is why there is a need for efficient systems that would respond to a crisis situation – a threat to the natural environment or human activity. It is important to prepare tools that allow to react and/or minimize the negative effects of possible accidents/releases. Such systems (Bartzis et al., 2000; Hoe et al., 2009) are to provide support – an information on the further development of events, the forecasted state of the environment and the negative impact of various factors on human society within the range of such impact.

The motto for this work was a Latin maxim: *"Si vis pacem, para bellum!"*. It means that we should be prepared for various difficult situations, even if they never happened.

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