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Institute of Information Theory and Automation

RESEARCH REPORT

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Comparison of numerical weather prediction models for purposes of atmospheric dispersion modeling in case of an accident in a nuclear facility followed by a release of radionuclides into the atmosphere

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Abstract

This research report concerns numerical weather prediction models and their possible exploitation for purposes of atmospheric dispersion modeling within the grant project VG20102013018 provided by the Ministry of Interior of the Czech Republic. After brief description of numerical weather prediction systems MEDARD and ALADIN, their results are compared in terms of mutual agreement.

Contents

Chapter 1

Numerical weather predictions models

1.1 NWP MEDARD

1.1.1 Introduction

MEDARD is a regional weather prediction system for operational weather forecast and forecasts of concentrations of important pollutants, especially tropospheric ozone. The project has arisen in the Institute of Computer Science under support of the European Union (Project APPETISE) and the Czech Science Foundation. The weather forecast is based on the numeric weather prediction model MM5 (Mesoscale and Microscale, version 5). The forecasts of pollutant concentration is done with the help of the Chemistry transport model CAMx (Comprehensive Air quality Model with extensions). MM5 has been developed at the Pennsylvania State University (Penn State) and National Center for Atmospheric Research (NCAR), USA. The Comprehensive Air quality Model with extensions (CAMx) is a publicly available modeling system for the integrated assessment of photochemical and particulate air pollution. It has been developed by the ENVIRON International Corporation in the USA.

Energy-industry-oriented forecasting problems provided historically one of the main motivations for the development of the MEDARD system. The core of the MEDARD system consists of the numeric weather prediction (NWP) model WRF coupled with the chemical transport model CAMx. In addition to providing a weather and air quality forecast for the general public (*www.medard-online.cz*), it produces an archive of meteorological fields and hence it can serve as a genuine testbed for development of applications requiring meteorological variables as inputs.

1.1.2 Input and output data

Input and output data are the so-called meteorological fields; three-dimensional fields of values on a grid. The data fields available as input to the system MEDARD include terrain elevation, landuse/vegetation, land-water mask, soil types, vegetation fraction and deep soil temperature. The most important modeled values are:

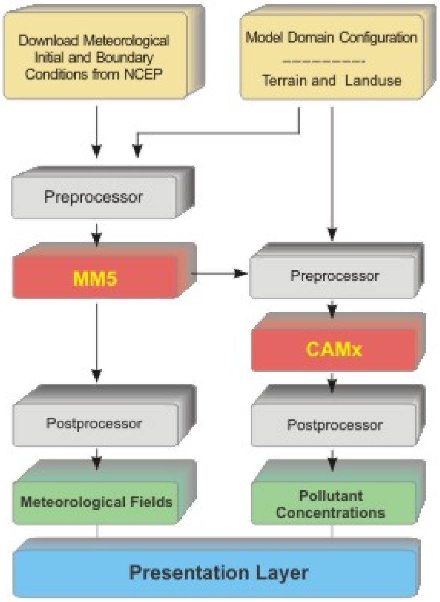


Figure 1.1: The MEDARD modeling system flow chart. (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*).

- Sea Level Pressure
- Air temperature
- Wind direction and velocity
- Relative humidity
- Precipitation
- Cloudiness (integrated cloud water)
- Turbulence

Other values such as measures of thunderstorm potential, boundary layer height and , soil layer temperatures can be derived and modeled for use in other applications (transport, environmental studies, agriculture, etc.). Terrain and landuse data are available from USGS (United States Geological Survey), with resolution of 30 sec, (cca 900m). Input data (initial and boundary conditions) used for the MM5 numerical model are routinely downloaded from the NCEP ftp server (National Center for Environmental Prediction, USA).

1.1.3 Model Orography and Landuse

The configuration of the MM5 modeling software works on two nested domains.

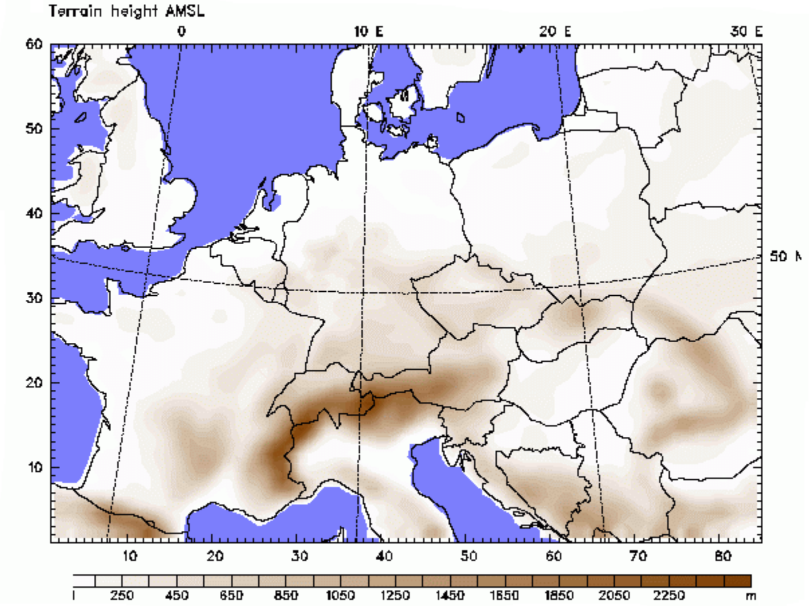


Figure 1.2: Domain 1: Terrain (Europe). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

Domain 1: The domain 1 covers an area larger than Central Europe, grid of dimensions 60x85 has resolution 27 km (see. Fig. 1.2–1.3).

Domain 2: The domain 2 covers the Czech Republic, grid of dimensions 70x70 has resolution 9 km (see. Fig. 1.4–1.5).

1.1.4 Data Assimilation Techniques - The use of measured meteorological data for improve weather and air quality forecasting

The analysis of actual meteorological situation is performed by means of data assimilation. Techniques of data assimilation try to integrate all available knowledge on the system, including observations and physical principles. Observations are provided by meteorological stations, radiosondes, satellites etc.

The model state is shifted towards observations with the help of different mathematical methods. This improves the agreement between model state and actual situation. Data assimilation was one of the factors which lead to great improvement of weather forecast in recent years. In a similar manner it is possible to use measurements of pollutant concentrations provided by emission monitoring stations (AIM - CHMI) and perform data assimilation in a chemistry transport model

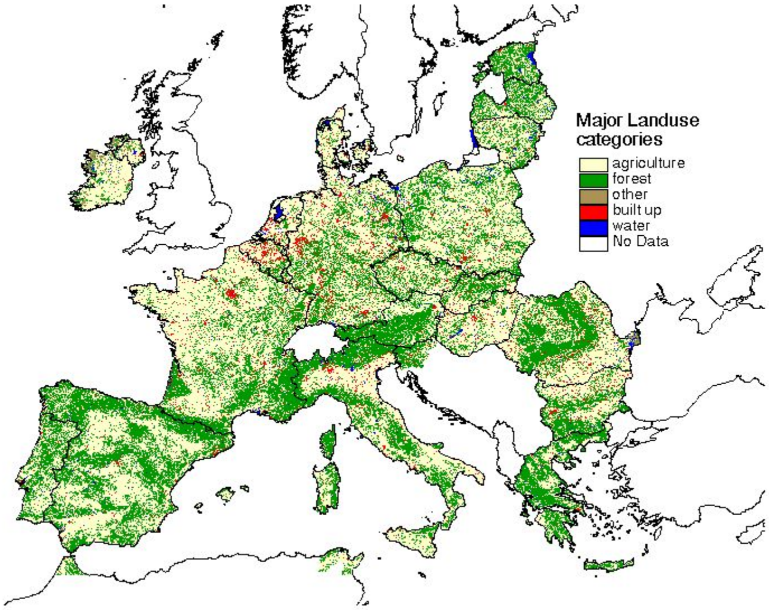


Figure 1.3: Domain 1: Landuse (Europe). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

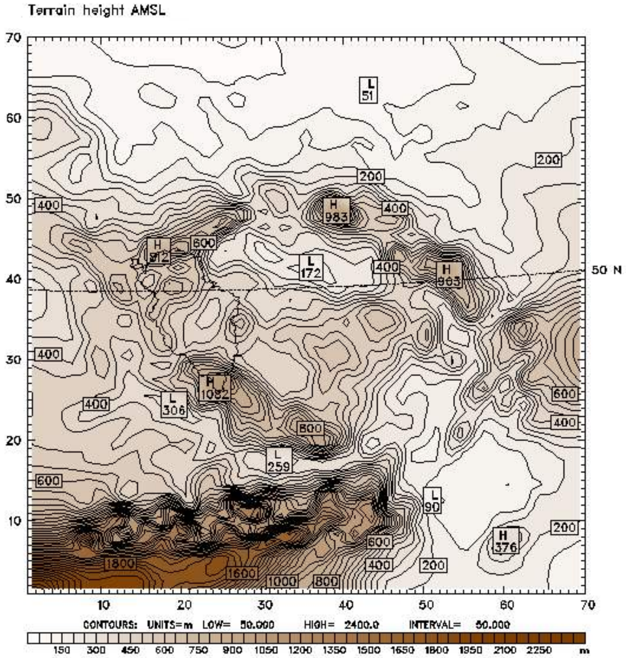


Figure 1.4: Domain 2: Terrain (Czech Republic). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

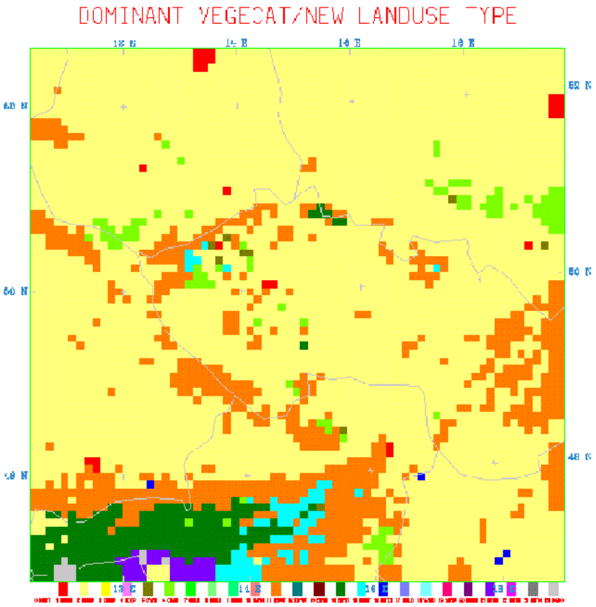


Figure 1.5: Domain 2: Landuse (Czech Republic). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

Figure 1.6: Measuring station AIM (Automated Air Pollution Monitoring), CHMI. (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

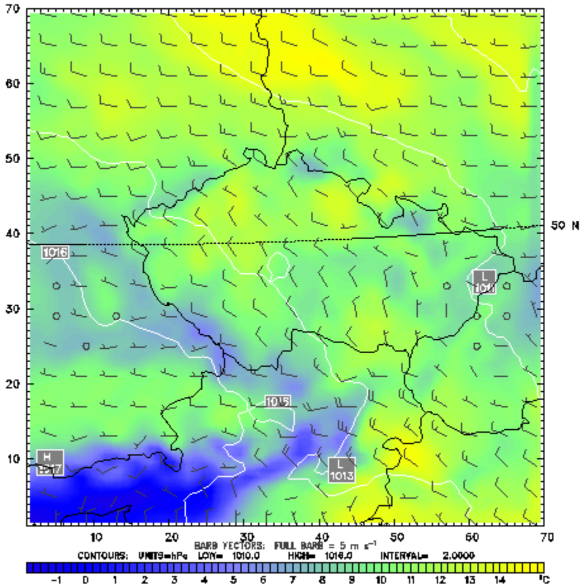


Figure 1.7: Sea level pressure, temperature. (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

1.1.5 Outputs of MM5

1.1.6 Outputs of CAMx

Energy-industry-oriented forecasting problems provided historically one of the main motivations for the development of the MEDARD system. The core of the MEDARD system consists of the numeric weather prediction (NWP) model WRF coupled with the chemical transport model CAMx. In addition to providing a weather and air quality forecast for the general public (*www.medard-online.cz*), it produces an archive of meteorological fields and hence it can serve as a genuine testbed for development of applications requiring meteorological variables as inputs.

1.1.7 Conclusions

One advantage of numerical models is their routine production of meteorological fields, which can be further processed automatically. The prediction can be issued four times daily. The model MM5 is one of the most popular numerical weather prediction models in the world. It is often used as generator of inputs for other applications. Currently a next generation model, namely, the WRF model, is being developed.

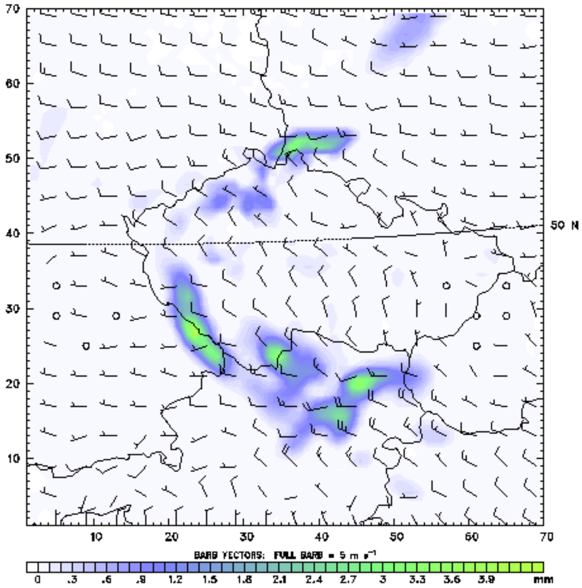


Figure 1.8: Precipitation. (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

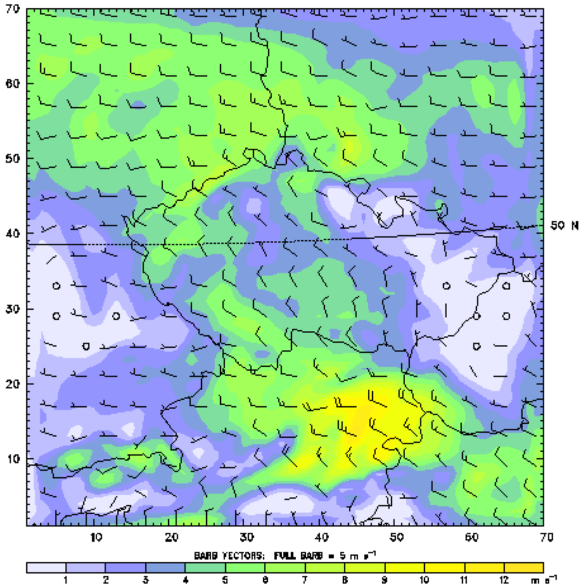


Figure 1.9: Wind velocity. (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

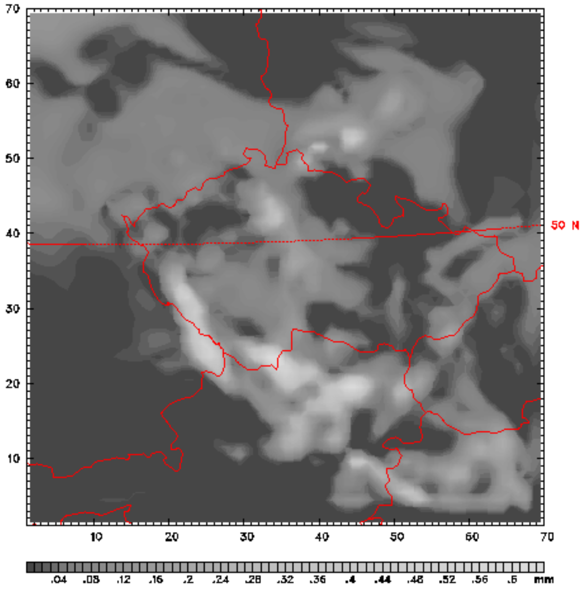


Figure 1.10: Cloudiness (integrated cloud water). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

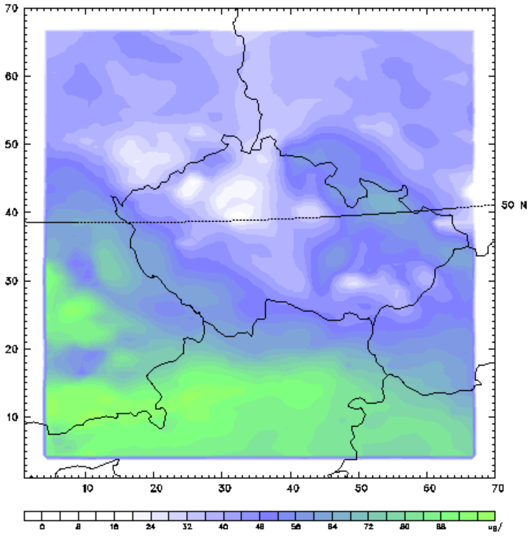


Figure 1.11: Ozone (O3). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

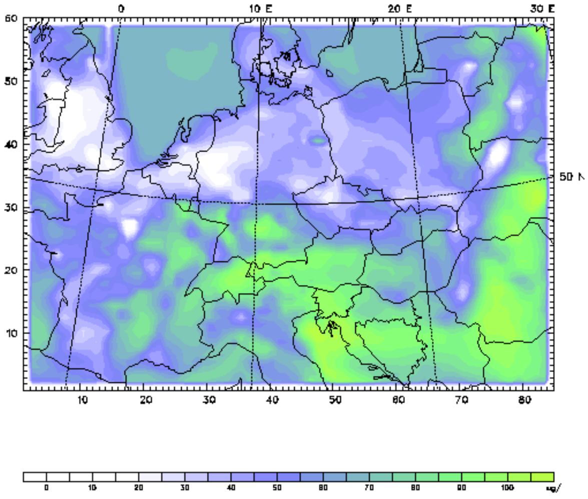


Figure 1.12: Ozone (O3) - Europe. (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

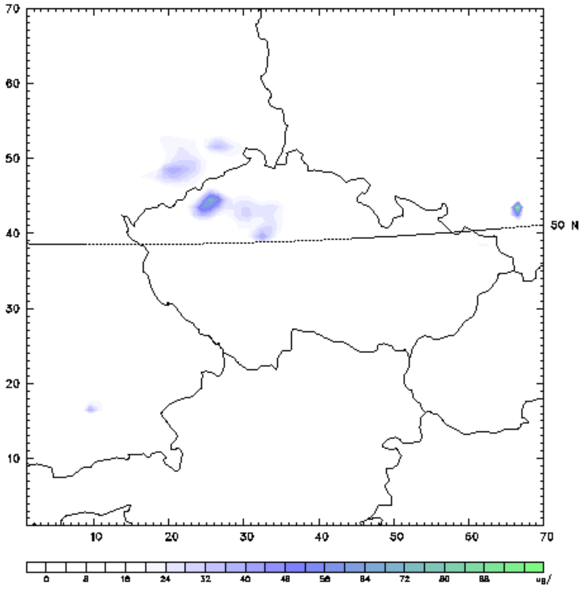


Figure 1.13: Nitrogen Oxide (NO). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

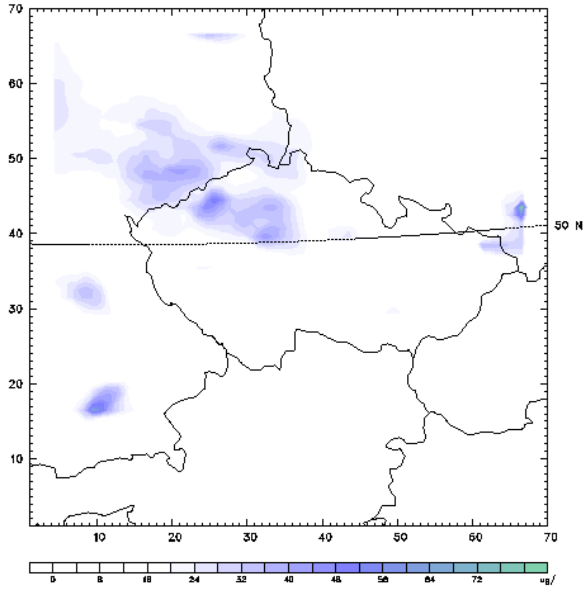


Figure 1.14: Nitrogen Dioxide (NO2). (Courtesy of Institute of Computer Science - Academy of Sciences of the Czech Republic, *http://www.uivt.cas.cz*)

1.2 NWP ALADIN

1.2.1 Introduction

This project was initiated in 1990 by Meteo-France with the aim of developing a limited area model (LAM) for numerical weather prediction purposes and today 15 countries are participating in the common work. Today, the prediction of local, mesoscale meteorological processes for the short range (up to 48 hours) is a basic task for the most of the meteorological services. Such predictions are provided by running limited area models (LAM). Limited area models give detailed, high resolution, forecasts for a relatively small geographical area. Joining the ALADIN project, the participating countries have an opportunity to take part in the development of the LAM ALADIN and also to run this model operationally for a convenient local domains. The local installation and operation is essential, because it gives freedom and flexibility, which is needed in order to satisfy the different requirements of the users. In the Czech Republic is ALADIN model operated by the Czech Hydrometeorological Service. The local operation gives the following advantages:

- Freedom in the choice of the geographical domain, horizontal and vertical resolution
- Freedom in the choice of the frequency of the model runs
- It is possible to define several model domains nested in each other

- Large choice of possible products with high frequency in time
- Freedom in modifying the local system
- Local practice and experience in modeling, possibility for education in this field

The LAM outputs are widely used. We list below the most important applications:

- Prediction of extreme weather events, warnings with high spatial resolution and high accuracy in time (accurate forecasts are highly beneficial in economy)
- Agricultural applications (frosts, hale, precipitation, etc.)
- Traffic applications (freezing, snow)
- Pollution prediction (tropospherical ozone concentration, diffusion of chemicals in case of industrial accidents)
- Aviation (thunderstorms, freezing, turbulence, fog, etc.)
- Hydrology (input for hydrological models, flood prediction)
- Energy sector (prediction of needed energy for heating and electricity in the function of the temperature)

For those who are interested in limited area modeling, it is worth to visit the HIRLAM web page, which presents a project similar to ALADIN considering its goals. It is important to mention that the leader committees of both projects (HIRLAM and ALADIN) decided to cooperate in the future and coordinate together their research and development activity.

The ALADIN products are more and more used in the operational forecasting at HMS. At the same time there are more and more products that are generated automatically from the raw model outputs. The number of users is increasing too. Consequently, the quality of the NWP products is a key issue in order to satisfy the demands with high quality information.

1.2.2 The main characteristics of the ALADIN model

- Spectral, hydrostatic limited area model.
- Application of fully harmonic functions (2 dimensional Fourier representation) for the horizontal spectral representation of the meteorological fields. The periodic extension of the functions is done using a so-called extension zone (see the figure below).
- Advanced parametrizations of atmospheric physical processes (radiation, convection, boundary layer processes, turbulence, microphysics, etc.)

- Lateral boundary conditions provided by the ARPEGE global model or a larger ALADIN version. The lateral boundary conditions ensure the propagation of meteorological information into the limited area domain from outside (coupling, relaxation). The relaxation zone (see the figure below) ensures the smooth transition of the meteorological parameters towards the lateral boundaries.
- The initial conditions of the model can be provided by running local data assimilation (3D-VAR, OI) or by interpolating the ARPEGE initial conditions onto the LAM grid.
- The initialization (the filtering of gravity waves from the initial conditions which are not consistent with the simplified model equations) is done by digital filtering.

1.2.3 Operative practice

In the every day operations a model run consists of the following steps:

- Interpolation of the lateral boundary conditions (and the initial conditions if there is no local data assimilation) onto the target LAM geometry.
- Subtraction of the orography and climatological information from an external "climatology file", which can be created by a configuration of the ALADIN model using raw information from US NAVY database. The climatology files have to be created only once for one domain for each month of the year.
- Initialization of the initial conditions (digital filter).
- Run the forecast.
- Interpolation of the output fields to a geographical coordinate system and perform file conversions according to the given application.

The ALADIN model is run twice a day starting from 00 and 12 UTC. It is important, that the forecast starts as soon as the lateral boundary conditions are available, in order to provide the information in time for the forecasters. The model is run by an automatic system (shell scripts, cron daemon), so basically it does not require any human intervention. However, in case of any technical problems or missing lateral boundary conditions, the model has to be run by direct intervention. Consequently, a control system has been set up which consists of 24 hour supervision of the model runs by operators. If the forecast fails, the operator calls the actual colleague from the NWP department being in shift who should connect the machine of HMS using a mobile phone and a laptop and should solve the problem.

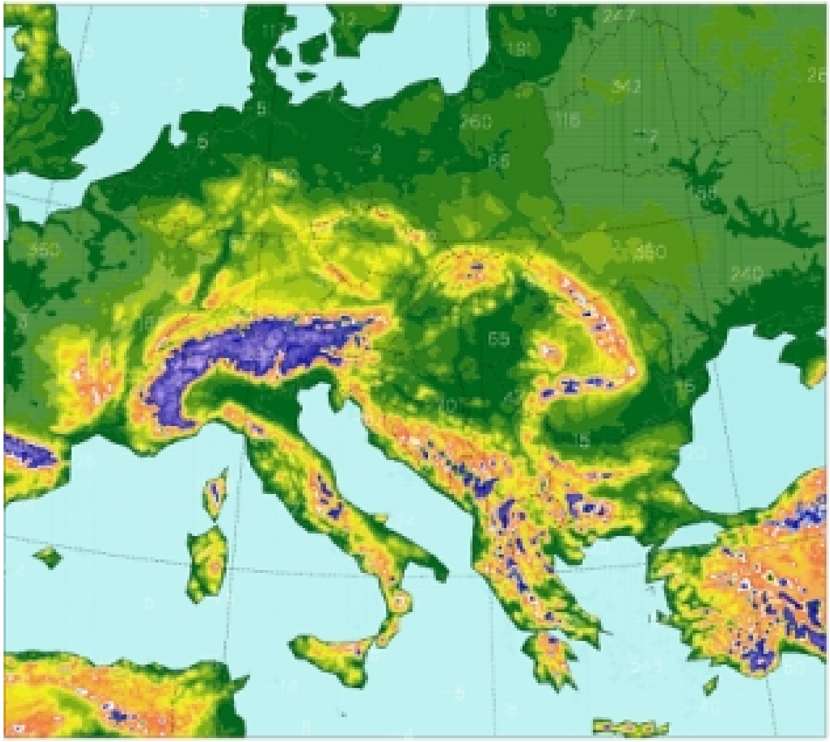
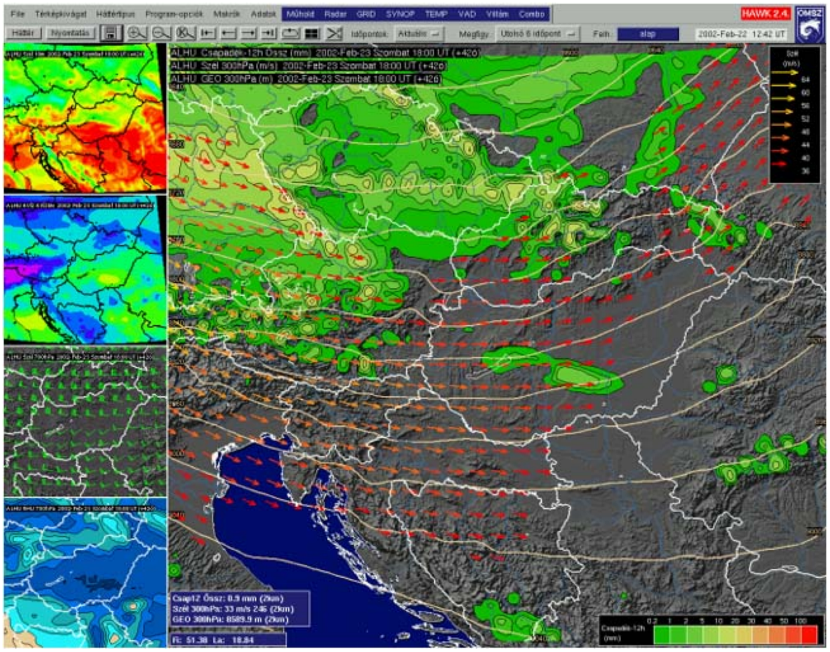


Figure 1.15: The ALADIN domain and orography. (Courtesy of Hungarian Meteorological Service, *http://www.met.hu*)

1.2.3.1 Visualization and post processing

Forecasters use a complex visualization system developed at HMS (HAWK-2) in order to interpret the NWP model's outputs. They also can combine the model fields with other information like radar or satellite observations with this system. Modern visualization systems make possible to modify the NWP prediction fields as well. Model outputs are post processed by statistical and dynamical adaptation methods as well for those meteorological fields, which are rather poorly represented by NWP models generally, due to the fact that such model's orography and surface characteristics are not perfect.



ALHU Csapadék-12h Össz (mm) 2002-Feb-23 Szombat 18:00 UT (+42ó)
ALHU Szél 300hPa (m/s) 2002-Feb-23 Szombat 18:00 UT (+42ó)
ALHU GEO 300hPa (m) 2002-Feb-23 Szombat 18:00 UT (+42ó)

Csap12 Össz: 0.9 mm (2km)
Szél 300hPa: 33 m/s 246 (2km)
GEO 300hPa: 8589.9 m (2km)

Fi: 51.38 La: 18.84

Figure 1.16: The visualization of ALADIN fields in HAWK2. (Courtesy of Hungarian Meteorological Service, *http://www.met.hu*)

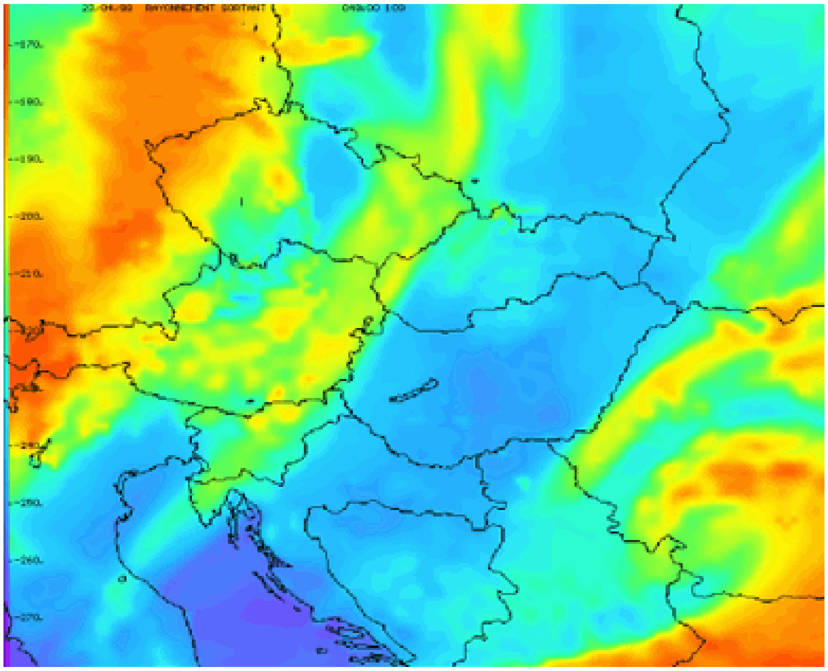


Figure 1.17: Forecasted pseudo satellite image. (Courtesy of Hungarian Meteorological Service, *http://www.met.hu*)

Chapter 2

Atmospheric dispersion model HARP: A Software Tool for Decision Support during Nuclear Emergencies

2.1 Brief description of the system

The HARP system is the application part of a grant project supported by the Grant Agency of the Czech Republic (period 2007–2009), which was solved in the Institute of Information Theory and Automation of the ASCR. The innovated version of the product is a complex software tool for purposes of modeling radiological consequences of radionuclide releases due to the normal and emergency operation of a nuclear facility. The system is designed for fast assessment of radiological consequences of accidental releases of radionuclides into the living environment. A special segmented Gaussian plume model is introduced, which can take into account both short-term meteorological forecast and release dynamics of discharged admixtures. The system offers various alternative options of input parameters definition of the release scenarios in their atmospheric, deposition, ingestion and dose parts. For that reason the software product can serve as a training tool enabling responsible staff to improve their knowledge and perception of the problem details. A special emphasis is laid on proper treatment of types of input parameter fluctuations in sense of differentiation between variability and uncertainty. Some model errors arising from the conceptual limitations can be roughly estimated on the basis of computations with alternative sub model options (atmospheric dispersion formulae for smooth/rough terrain, effect of near-standing buildings, influence of size of aerosol particles on dry deposition velocity, variability in Julian day of radioactive fallout, alternative semi-empirical expressions for time evolution of deposited radioactivity on terrain and some others). The options can be entered interactively from the screen and provide fast response for comparison.

Transport of radioactive harmful substances originally discharged into atmosphere and their radiological impact on population are treated. Accidental releases of passive pollutants into atmosphere are considered with duration of several hours or a few tens of hours. We are focused on radioactive discharges and their transport through the living environment towards human body. The model chain includes advection and dispersion of pollutants during its propagation in atmosphere, their deposition on terrain and subsequent transport through various food chains causing inner radioactivity activity intake into human body. The following pathways of irradiation are taken into account:

- External irradiation caused by cloudshine from radioactive plume drifted over the terrain according to weather characteristics.
- External irradiation from groundshine from radioactivity deposited on the terrain.
- Internal irradiation due to internal activity intake during inhalation of contaminated air.
- Internal irradiation due to internal activity intake during inhalation of air contaminated by resuspension of activity originally deposited on the ground.
- Ingestion pathway - internal irradiation due to consumption of contaminated food.

Complicated scenario of release dynamics have to be synchronized with available meteorological forecasts so that drifting of radioactive plume over the terrain can be satisfactorily modeled. We have used experience from various modifications of Gaussian model of admixtures dispersion in atmosphere [4, 5, 7]. For our purposes an approach of segmented Gaussian plume scheme has been adopted. We are utilizing short-term meteorological forecast being generated at point of release. Hourly changes of wind speed and direction, Pasquill class of atmospheric stability and precipitation are forecasted for the next 48 hours. Using assumption of activity conservation, the release dynamic is segmented into equivalent number of hourly segments. Each such segment is modeled in his all subsequent hourly meted phases when stepwise segment movement is driven by meteorological forecast for the corresponding hours. We shall mention here at least a basic approach how to determine stepwise radioactivity concentration in air, its time integral in the near-ground level and activity deposition on ground. Radioactive release from a nuclear facility should be treated as a mixture of several tens of the most important radionuclides. Each nuclide (possibly element) has its own decay constant, dose conversion factors, physical-chemical form of admixtures in the plume (noble gas, aerosol, elemental iodine, organic form) determining their deposition ability, release dynamics or environmental transport characteristics (e.g. soil-plant transfer factors for mobile and immobile chemical elements). For simplicity of mathematical notation the index of nuclide will be omitted in the following text. Nevertheless, the HARP system accounts for 132 nuclides and contains extensive database of all necessary nuclide/elements data.

Advanced data assimilation methods based on Bayesian filtering developed within the grant project are incorporated into the assimilation subsystem. It means, that the system offers a framework for embodiment of relevant information from different sources, such as measurements and expert judgements, in a statistically optimal way.

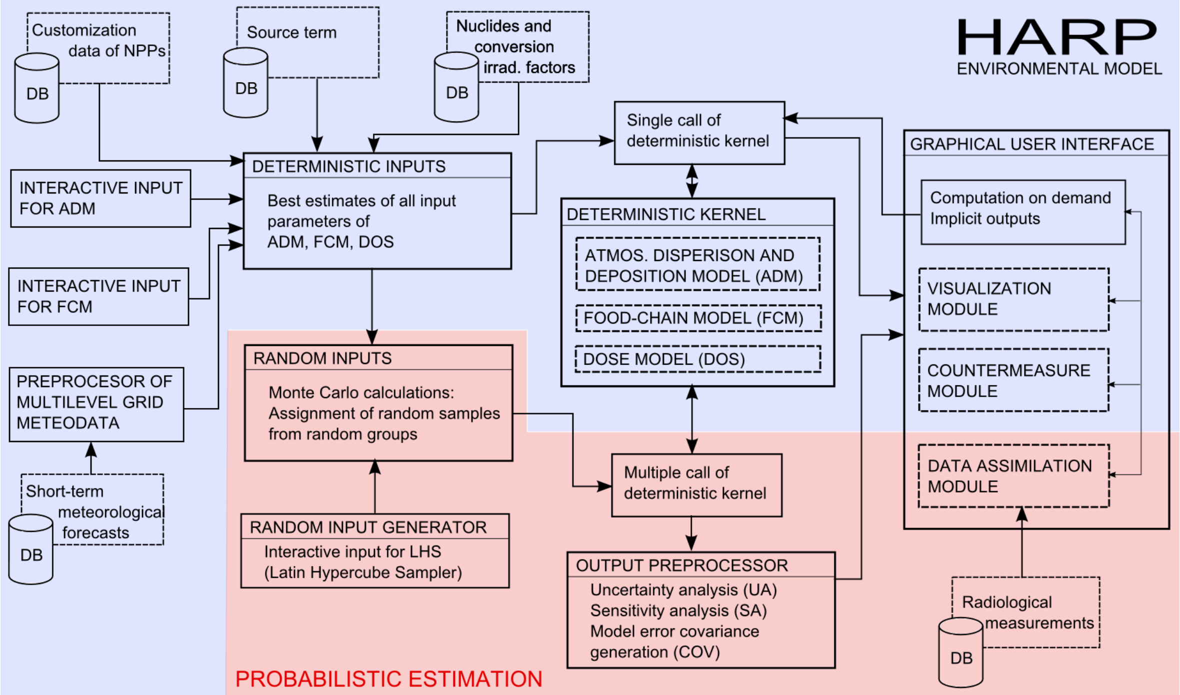


Figure 2.1: Flow-chart of architecture of the HARP system.

Provided that the system is connected to a monitoring network, it can be run in the on-line regime, where the subjectively chosen parameters regarding the release scenario (magnitude of release etc.) are iteratively re-estimated upon measurements. This assimilation methodology can be also used as a tool for testing of different topologies of a monitoring network and selection of the best one with regards to its functionality and economical and other constraints.

The HARP system is tuned and tested in cooperation with National Radiation Protection Institute of the Czech Republic in Prague, where the product is connected to a database server providing up to date short term meteorological forecasts on a three dimensional grid. Exploitation of detailed meteorological data further improves the reliability of embedded dispersion model.

Flow chart of architecture of the system is in Figure 2.1.

2.2 Meteorological inputs to the atmospheric dispersion model

Meteorological conditions are in the Gaussian atmospheric dispersion model of the HARP system parameterized using:

1. Wind speed and wind direction in altitude 10 meters above the ground:

In a Lagrangian trajectory puff/plume model the wind field determines the movement of the plume/puff over the terrain.

2. Pasquill's atmospheric stability category:

   Atmospheric stability category is a crucial input into Gaussian dispersion models. It parametrizes the amount of turbulence in the ambient atmosphere which has a major effect on the dispersion of air pollution plumes because turbulence increases the entrainment and mixing of unpolluted air into the plume and thereby acts to reduce the concentration of pollutants in the plume [4]. Besides the rate of turbulence, the atmospheric stability also determine the height mixing layer. Another physical process indirectly parametrized by the atmospheric stability is the rate of dry deposition which is the major process of puff/plume depletion.

2.2.1 Available meteorological data

Numerical data for purposes of modeling of releases from a nuclear power plants must be localized for a certain power plant. The data must cover sufficiently large surroundings of the source with an appropriate resolution, and must contain all the crucial meteorological quantities. Atmospheric dispersion model of HARP can process two kinds of input meteorological data. The desired forecast can be computed using:

1. Spatially varying gridded data related to a certain grid cell. This kind of data is produced using a numerical weather prediction models employing data assimilation. This kind of data must be transformed into the HARP format respecting its polar computational grid. This is performed in a meteorological pre-processor using a spatial interpolation (bi-linear, bi-cubic).
2. Spatially homogenized meteorological data related to the source of pollution. It is assumed, that the local meteorological conditions valid in vicinity of the source of pollution are also valid up to a given distance from the source (a few kilometers of tens of kilometers). This type of meteorological input is used only when the gridded data is no available, e.g. we have local meteodata observed at a location.

Currently, the data from two numerical weather prediction systems are available:

1. MEDARD data is available in two resolutions:
   (a) rectangular grid 9×9 km,
   (b) rectangular grid 3×3 km.

   Alignment of HARP polar grid and MEDARD 3×3 rectangular grid is in Fig. 2.2 and Fig 2.3.
2. ALADIN data is available on a rectangular grid with resolution 9×9 km. Alignment of HARP polar grid and ALADIN 9×9 km rectangular grid is in Fig. 2.4.

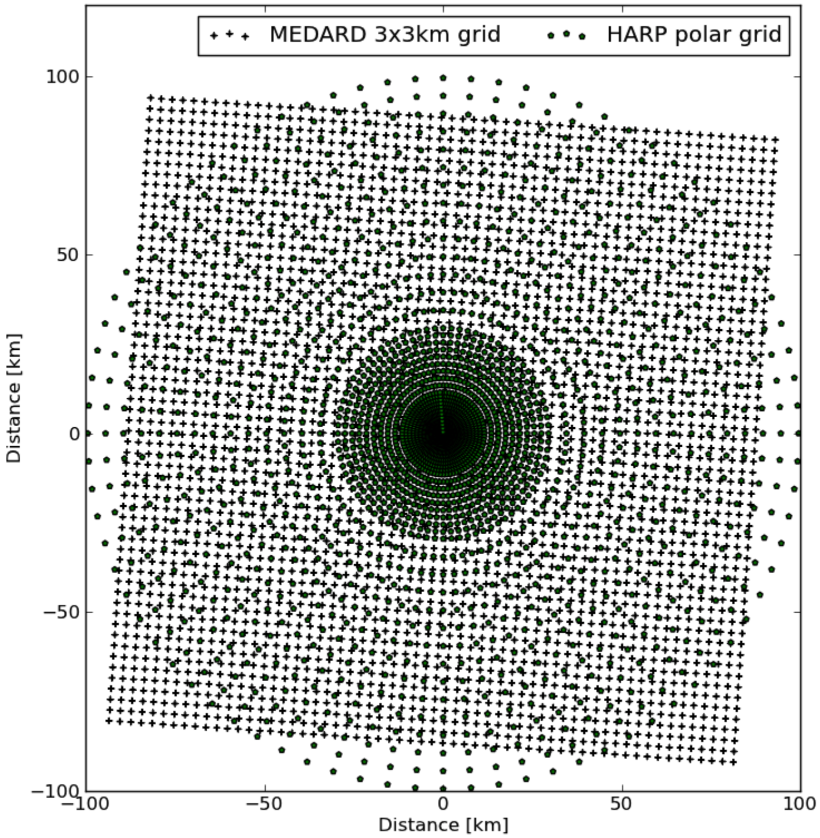


Figure 2.2: Visualization of alignment of HARP polar grid and MEDARD 3×3 km rectangular grid for site NPP Temelin.

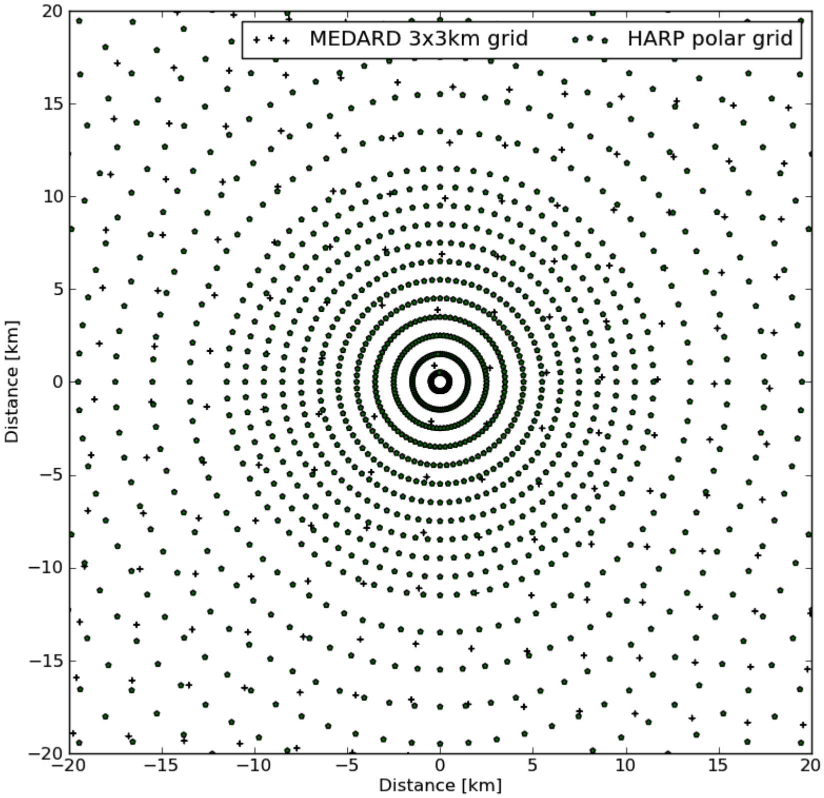


Figure 2.3: Visualization of alignment of HARP polar grid and MEDARD 3×3 km rectangular grid (detail) for site NPP Temelin.

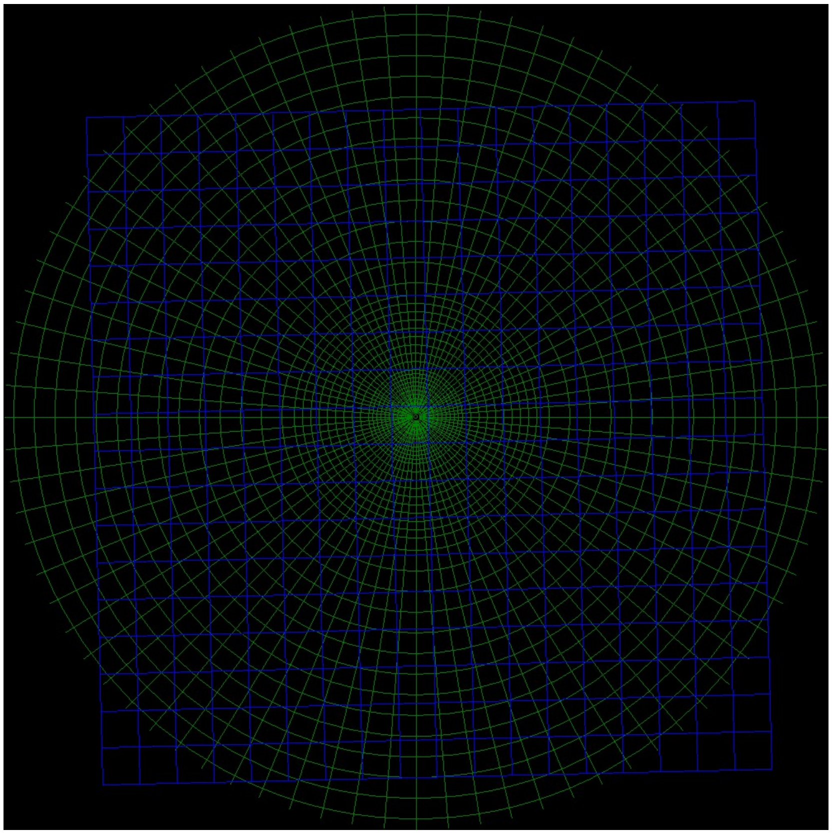


Figure 2.4: Visualization of alignment of HARP polar grid and ALADIN 9×9 km rectangular grid for site NPP Temelin.

Pasquill class	Conditions of the air	Lapse rate $[K/km]$	Std. of wind dir. $[deg]$
A	Very unstable	-17	25
B	Unstable	-15	20
C	Slightly unstable	-13	15
D	Neutral	-10	10
E	Stable	+5	5
F	Very stable	+25	2.5

Table 2.1: Pasquill's classification of the stability of the surface atmosphere, according to the degree of insolation and wind fluctuations.

Surface windspeed	Daytime incoming solar radiation			Nighttime cloud cover	
$[m/s]$	Strong	Moderate	Slight	>50%	<50%
<2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Table 2.2: Pasquill's classification of the stability of the surface atmosphere, according to the degree of insolation and wind speed.

2.2.2 Calculation of Pasquaill's atmospheric stability class

Variability of temperature with altitude influences the turbulence characteristics and thus the dispersion of pollutants. The temperature in the atmosphere is governed by incident solar radiation, prevailing wind velocity, and percentage of cloud cover. Depending on the magnitude of these parameters, [6] introduced the six stability classes named A, B, C, D, E, and F of the atmospheric turbulence. Class A denotes the most unstable or most turbulent conditions (the dispersion is higher), and class F the most stable or the least turbulent class (very low dispersion). Table 2.1 lists the six classes and Table 2.2 provides the meteorological conditions that define each class. Table 2.2 is used for determination of stability classes for purposes of HARP.

Besides the atmospheric stability category, dispersion coefficients are also dependent on travel time from the source and the type of terrain (urban, rural, etc.), e.g. [3]. The comprehensive review can be found in [4]. More advanced models apply Monin-Obukhov similarity theory and use the surface roughness length and the Monin-Obukhov length to determine the magnitude of dispersion, see [1, 2].

Chapter 3

Comparison of numerical weather prediction models

In this chapter we compare two specific meteorological sequences produced by MEDARD and ALADIN systems. Both the sequences are reanalyzed (retrospectively corrected forecasts using data assimilation of observations) 2-days meteorological forecasts. In order to compare performance of prediction systems under various conditions, the selected sequences are rather different:

Case 1:	Sequence with rather homogeneous wind field (both in wind direction and wind speed), higher wind speed (3-10m/s)
Case 2:	Sequence with calms (wind speed $< 1m/s$) and high fluctuations of wind direction

We compare basic meteorological quantities entering the dispersion model, namely:

1. wind speed in altitude 10m,
2. wind direction in altitude 10m,
3. Pasquill's atmospheric stability category evaluated using Table 2.2.

Forecasted values are point-wise compared with available observations of wind speed and wind direction, both in altitude 10m. The length of both sequences is 48 hours and the meteorological quantities are forecasted with time step of one hour.

3.1 Case 1 - homogeneous wind field

Comparison of numerical values of observed data and predicted data using MEDARD and ALADIN NWPs for Case 1 is in Table 3.1. Graphical representation is in Figure 3.1. Wind fields predicted MEDARD and ALADIN models are in Figure 3.2 and Figure 3.3, respectively. Finally, predictions of propagation of radionuclides computed by the

HARP system based on MEDARD and ALADIN NWPs are compared in Figure 3.4. The detailed view of the prediction in the zone of emergency planning, which is bounded by a circle of diameter 13km around the power plant, is in Figure 3.5. The visualized radiological quantity is the time integrated concentration (TIC) of radionuclide I-131.

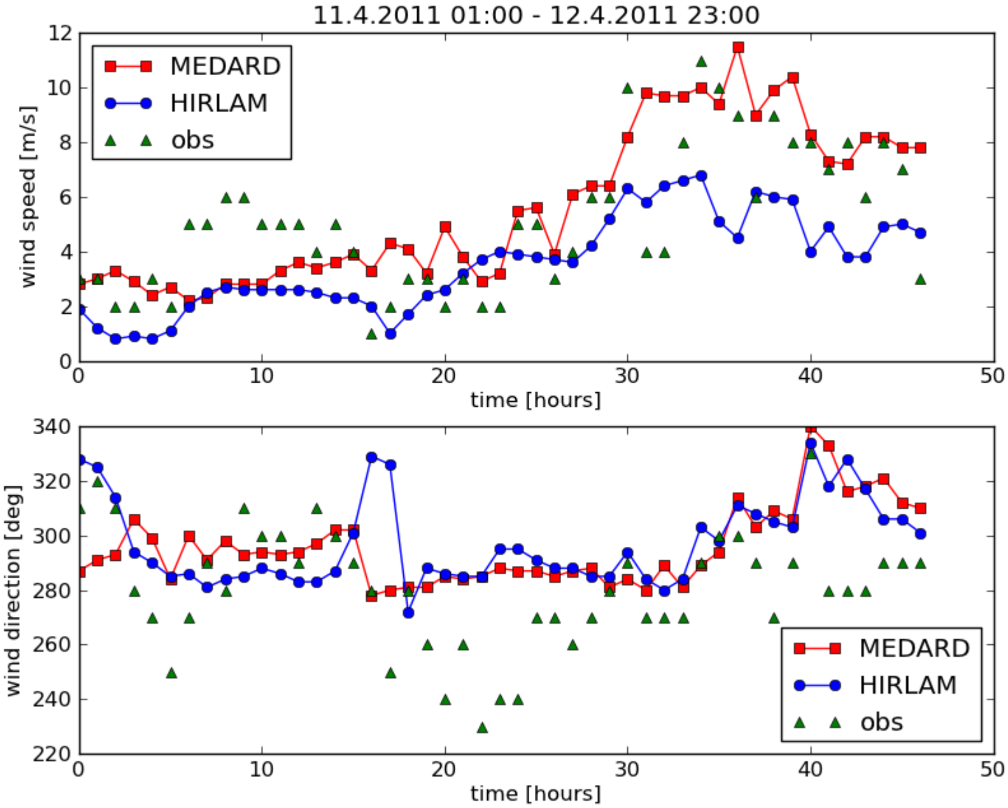


Figure 3.1: Case 1: 11.4.2011 1:00 - 12.4.2011 23:00, MEDARD vs. ALADIN vs. observations.

	Wind speed			Wind direction			Pasquill	
	MEDARD	ALADIN	obs.	MEDARD	ALADIN	obs.	MEDARD	ALADIN
11.4.2011 01:00	2.8	1.9	3	287	328	310	F	F
11.4.2011 02:00	3.0	1.2	3	291	325	320	F	F
11.4.2011 03:00	3.3	0.8	2	293	314	310	F	F
11.4.2011 04:00	2.9	0.9	2	306	294	280	D	F
11.4.2011 05:00	2.4	0.8	3	299	290	270	E	F
11.4.2011 06:00	2.7	1.1	2	284	285	250	C	F
11.4.2011 07:00	2.2	2.0	5	300	286	270	B	C
11.4.2011 08:00	2.3	2.5	5	291	281	290	B	A
11.4.2011 09:00	2.8	2.7	6	298	284	280	C	A
11.4.2011 10:00	2.8	2.6	6	293	285	310	C	A
11.4.2011 11:00	2.8	2.6	5	294	288	300	C	A
11.4.2011 12:00	3.3	2.6	5	293	286	300	C	A
11.4.2011 13:00	3.6	2.6	5	294	283	290	C	A
11.4.2011 14:00	3.4	2.5	4	297	283	310	C	A
11.4.2011 15:00	3.6	2.3	5	302	287	300	D	A
11.4.2011 16:00	3.9	2.3	4	302	301	290	D	C
11.4.2011 17:00	3.3	2.0	1	278	329	280	D	D
11.4.2011 18:00	4.3	1.0	2	280	326	250	D	F
11.4.2011 19:00	4.1	1.7	3	281	272	280	D	F
11.4.2011 20:00	3.2	2.4	3	281	288	260	D	E
11.4.2011 21:00	4.9	2.6	2	285	286	240	D	E
11.4.2011 22:00	3.8	3.2	3	284	285	260	D	D
11.4.2011 23:00	2.9	3.7	2	285	285	230	E	D
12.4.2011 00:00	3.2	4.0	2	288	295	240	D	E
12.4.2011 01:00	5.5	3.9	5	287	295	240	D	D
12.4.2011 02:00	5.6	3.8	5	287	291	270	D	D
12.4.2011 03:00	3.9	3.7	3	285	288	270	D	D
12.4.2011 04:00	6.1	3.6	4	287	288	260	D	D
12.4.2011 05:00	6.4	4.2	6	288	285	270	D	D
12.4.2011 06:00	6.4	5.2	6	281	285	280	D	D
12.4.2011 07:00	8.2	6.3	10	284	294	290	D	C
12.4.2011 08:00	9.8	5.8	4	280	284	270	D	C
12.4.2011 09:00	9.7	6.4	4	289	280	270	D	C
12.4.2011 10:00	9.7	6.6	8	281	284	270	D	C
12.4.2011 11:00	10.0	6.8	11	289	303	290	D	C
12.4.2011 12:00	9.4	5.1	10	294	298	300	D	C
12.4.2011 13:00	11.5	4.5	9	314	311	300	D	B
12.4.2011 14:00	9.0	6.2	6	303	308	290	D	C
12.4.2011 15:00	9.9	6.0	9	309	305	270	D	C
12.4.2011 16:00	10.4	5.9	8	306	303	290	D	D
12.4.2011 17:00	8.3	4.0	8	340	334	330	D	B
12.4.2011 18:00	7.3	4.9	7	333	318	280	D	C
12.4.2011 19:00	7.2	3.8	8	316	328	280	D	D
12.4.2011 20:00	8.2	3.8	6	318	317	280	D	D
12.4.2011 21:00	8.2	4.9	8	321	306	290	D	D
12.4.2011 22:00	7.8	5.0	7	312	306	290	D	D
12.4.2011 23:00	7.8	4.7	3	310	301	290	D	D

Table 3.1: Case 1: Comparison of measured values (obs.) and values forecasted by MEDARD and ALADIN.

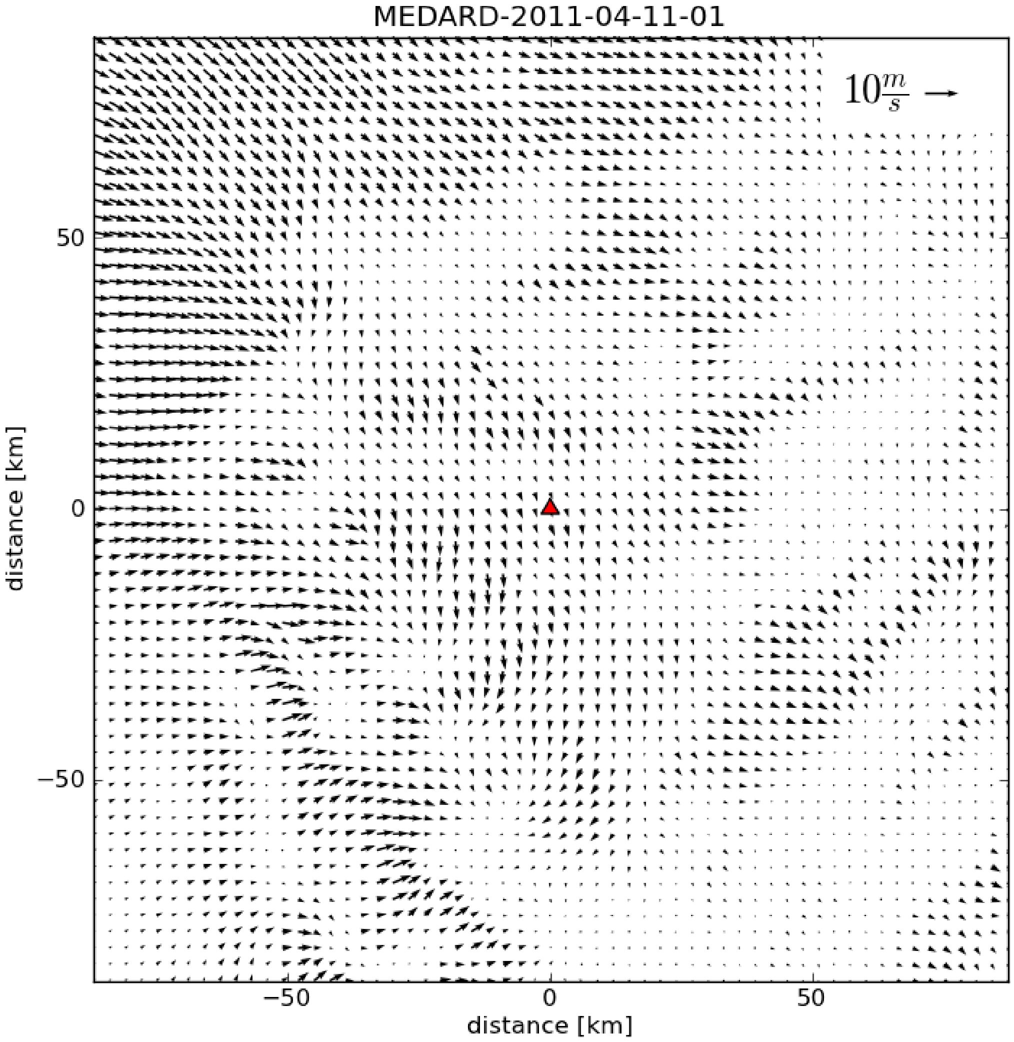


Figure 3.2: Case 1: Visualization of wind field given by MEDARD with time stamp 2011-04-11 1:00.

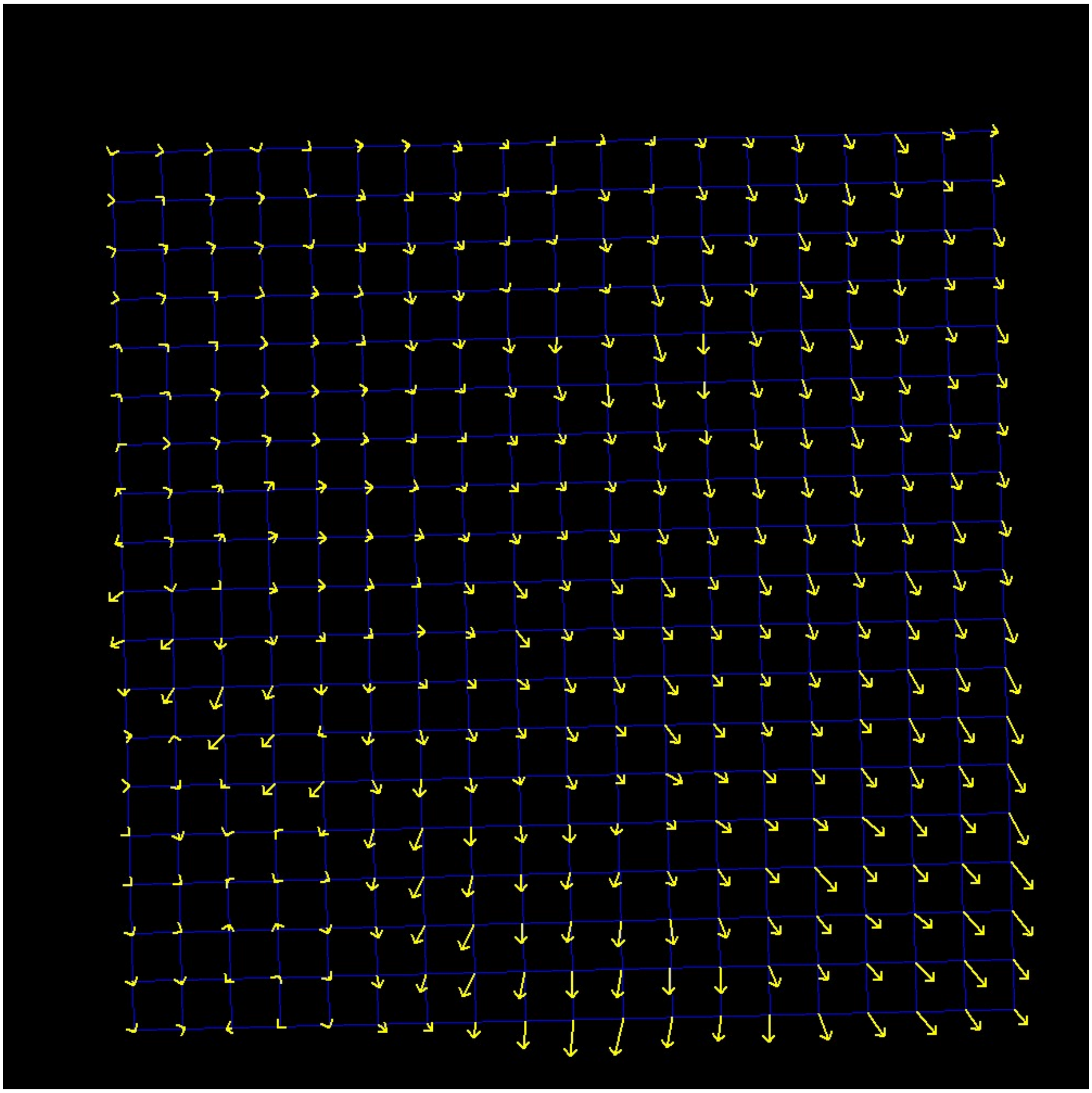


Figure 3.3: Case 1: Visualization of wind field given by ALADIN with time stamp 2011-04-11 1:00.

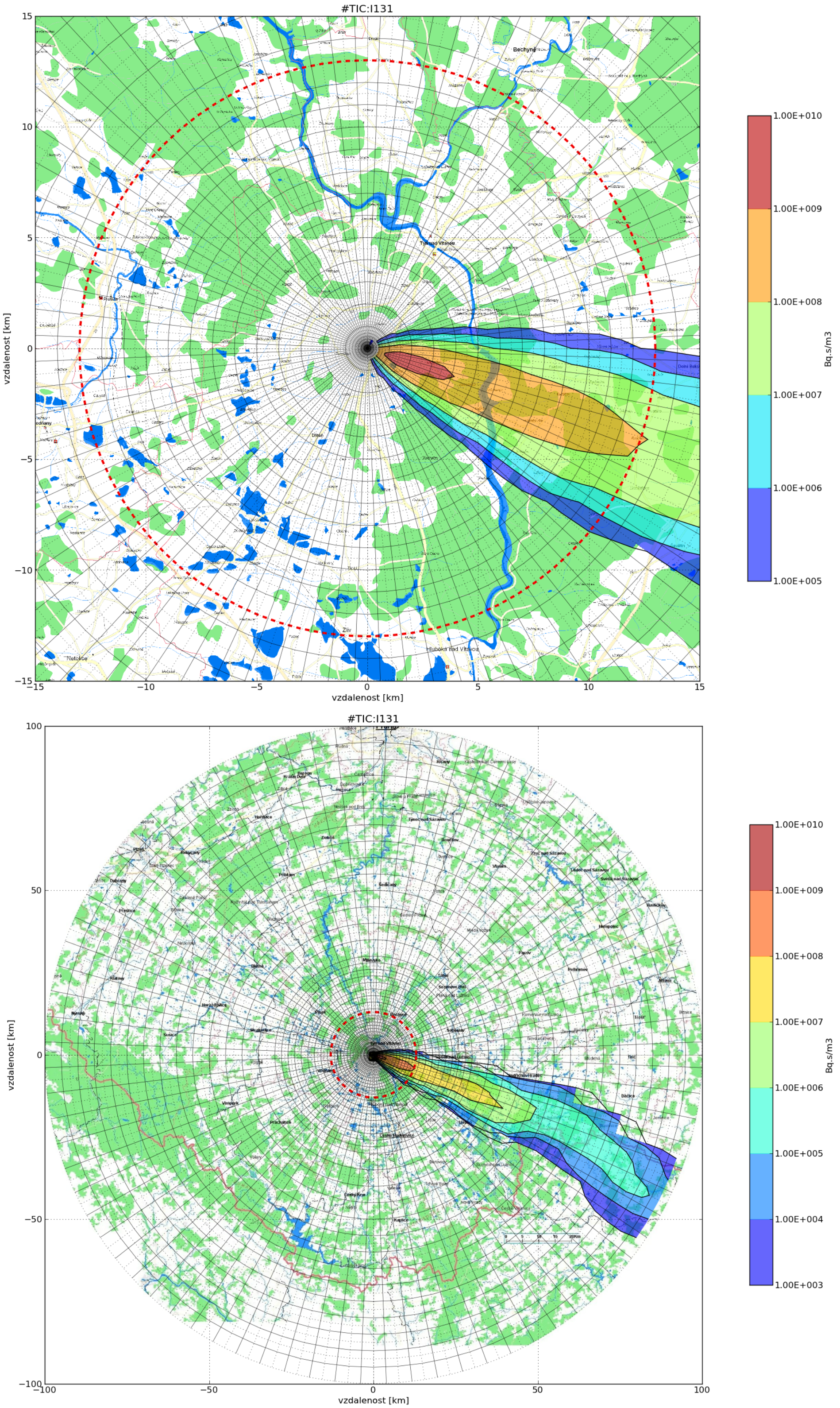


Figure 3.4: Case 1: Prediction of TIC I-131 evaluated using MEDARD meteorological data. Top: prediction up to 14km. Bottom: prediction up to 100km.

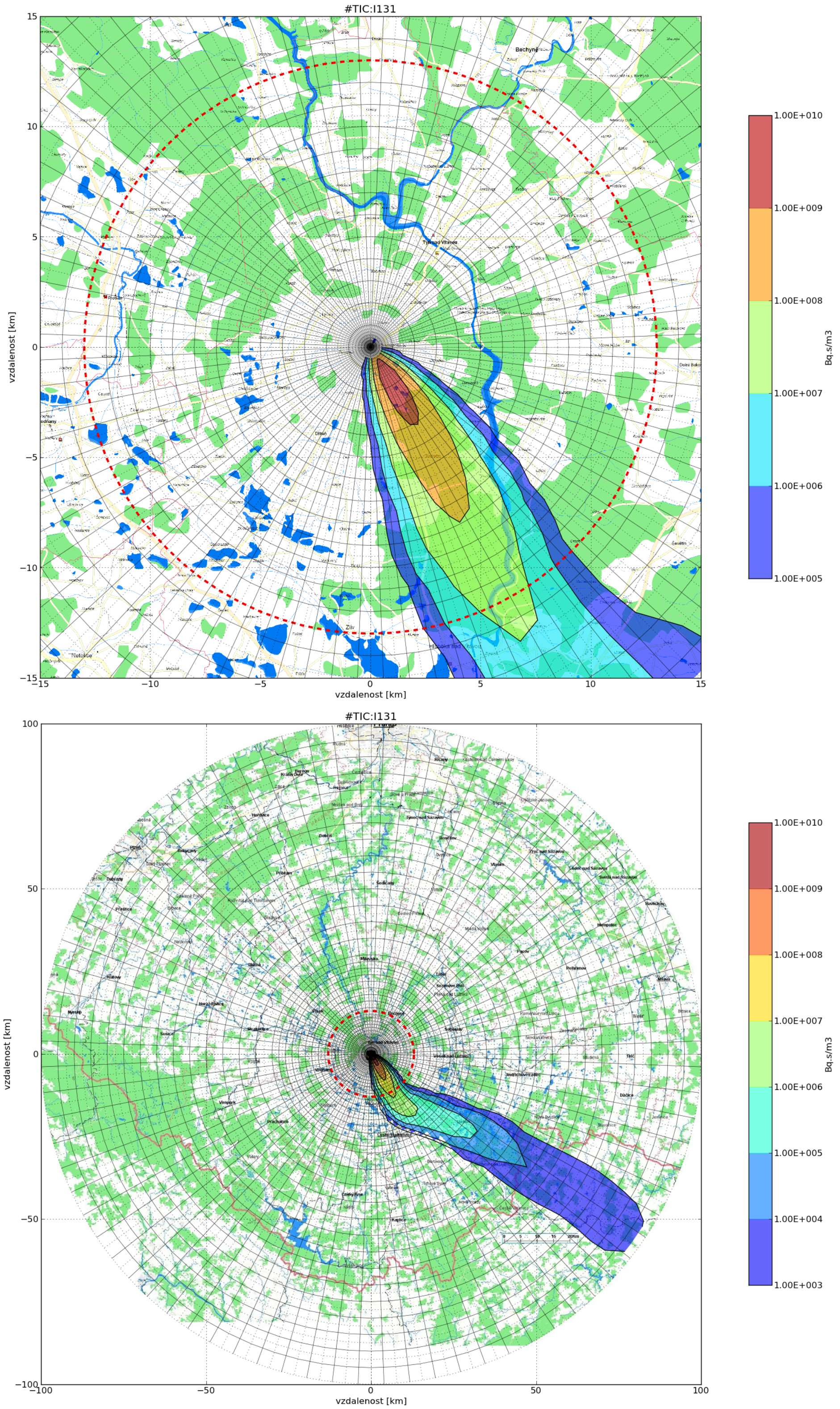


Figure 3.5: Case 1: Prediction of TIC I-131 evaluated using HIRLAM meteorological data. Top: prediction up to 14km. Bottom: prediction up to 100km.

3.2 Case 2 - calm conditions

Comparison of numerical values of observed data and predicted data using MEDARD and ALADIN NWPs for Case 2 is in Table 3.2. Graphical representation is in Figure 3.6. Wind fields predicted MEDARD and ALADIN models are in Figure 3.7 and Figure 3.8, respectively. Finally, predictions of propagation of radionuclides computed by the HARP system based on MEDARD and ALADIN NWPs are compared in Figure 3.9. The detailed view of the prediction in the zone of emergency planning, which is bounded by a circle of diameter 13km around the power plant, is in Figure 3.10. The visualized radiological quantity is the time integrated concentration (TIC) of radionuclide I-131. Due to the calm conditions valid during the propagation the plume did not leave the computational domain during the first 24 hours of the release.

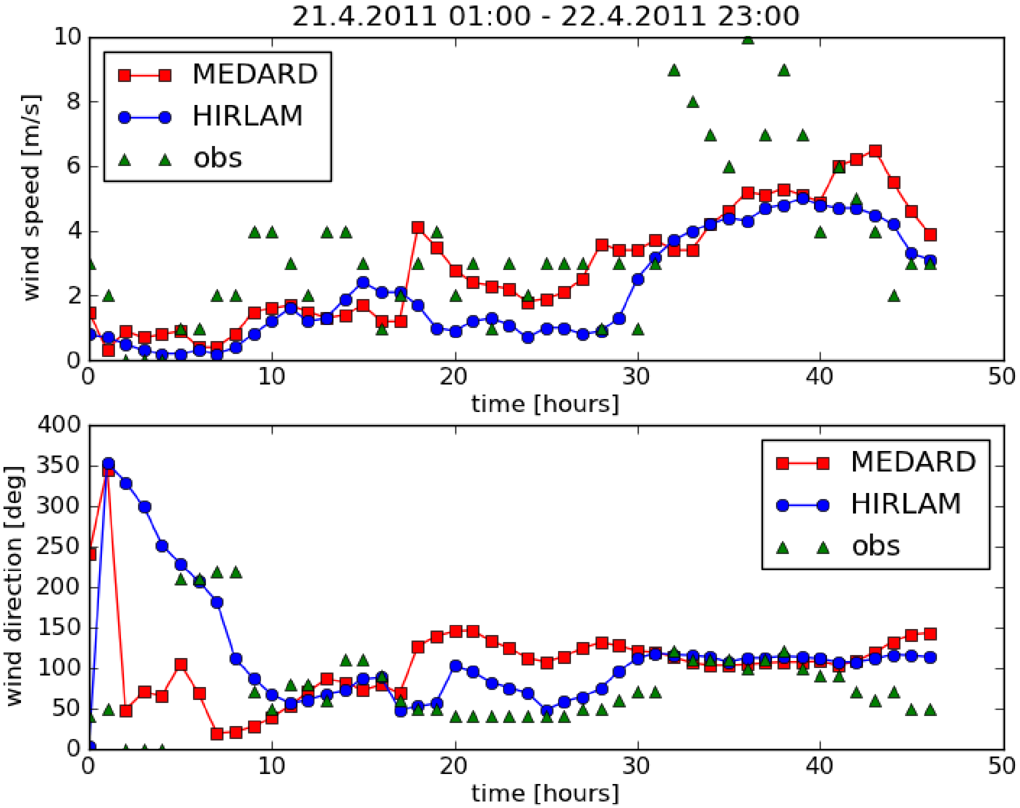


Figure 3.6: Case 2: 21.4.2011 1:00 - 22.4.2011 23:00, MEDARD vs. ALADIN vs. observations.

	Wind speed			Wind direction			Pasquill	
	MEDARD	ALADIN	obs.	MEDARD	ALADIN	obs.	MEDARD	ALADIN
21.4.2011 01:00	1.5	0.8	3	240	3	40	F	F
21.4.2011 02:00	0.3	0.7	2	344	354	50	F	F
21.4.2011 03:00	0.9	0.5	0	48	329	0	F	F
21.4.2011 04:00	0.7	0.3	0	70	299	0	D	F
21.4.2011 05:00	0.8	0.2	0	65	252	0	D	F
21.4.2011 06:00	0.9	0.2	1	105	228	210	B	F
21.4.2011 07:00	0.4	0.3	1	68	207	210	B	B
21.4.2011 08:00	0.4	0.2	2	19	182	220	B	A
21.4.2011 09:00	0.8	0.4	2	21	111	220	B	A
21.4.2011 10:00	1.5	0.8	4	27	87	70	A	A
21.4.2011 11:00	1.6	1.2	4	38	67	50	A	A
21.4.2011 12:00	1.7	1.6	3	53	56	80	A	A
21.4.2011 13:00	1.5	1.2	2	70	60	80	A	A
21.4.2011 14:00	1.3	1.3	4	86	67	60	B	A
21.4.2011 15:00	1.4	1.9	4	82	72	110	B	A
21.4.2011 16:00	1.7	2.4	3	72	86	110	C	B
21.4.2011 17:00	1.2	2.1	1	79	88	90	C	D
21.4.2011 18:00	1.2	2.1	2	68	48	60	E	E
21.4.2011 19:00	4.1	1.7	3	126	52	50	E	F
21.4.2011 20:00	3.5	1.0	4	139	56	50	E	F
21.4.2011 21:00	2.8	0.9	2	145	102	40	E	F
21.4.2011 22:00	2.4	1.2	3	146	95	40	E	F
21.4.2011 23:00	2.3	1.3	1	133	82	40	E	F
22.4.2011 00:00	2.2	1.1	3	124	75	40	F	F
22.4.2011 01:00	1.8	0.7	2	112	69	40	F	F
22.4.2011 02:00	1.9	1.0	3	107	48	40	F	F
22.4.2011 03:00	2.1	1.0	3	114	58	40	F	F
22.4.2011 04:00	2.5	0.8	3	124	64	50	D	F
22.4.2011 05:00	3.6	0.9	1	131	74	50	D	F
22.4.2011 06:00	3.4	1.3	3	127	96	60	C	F
22.4.2011 07:00	3.4	2.5	1	121	111	70	C	F
22.4.2011 08:00	3.7	3.2	3	119	118	70	C	B
22.4.2011 09:00	3.4	3.7	9	113	116	120	C	B
22.4.2011 10:00	3.4	4.0	8	106	115	110	C	B
22.4.2011 11:00	4.2	4.2	7	103	113	110	C	B
22.4.2011 12:00	4.6	4.4	6	103	107	110	C	B
22.4.2011 13:00	5.2	4.3	10	104	112	100	C	B
22.4.2011 14:00	5.1	4.7	7	106	112	110	C	B
22.4.2011 15:00	5.3	4.8	9	107	114	120	D	B
22.4.2011 16:00	5.1	5.0	7	107	113	100	D	B
22.4.2011 17:00	4.9	4.8	4	108	111	90	D	B
22.4.2011 18:00	6.0	4.7	6	103	107	90	D	D
22.4.2011 19:00	6.2	4.7	5	108	107	70	D	D
22.4.2011 20:00	6.5	4.5	4	119	111	60	D	D
22.4.2011 21:00	5.5	4.2	2	132	116	70	D	D
22.4.2011 22:00	4.6	3.3	3	141	115	50	D	D
22.4.2011 23:00	3.9	3.1	3	143	113	50	E	E

Table 3.2: Case 2: Comparison of measured values (obs.) and values forecasted by MEDARD and ALADIN.

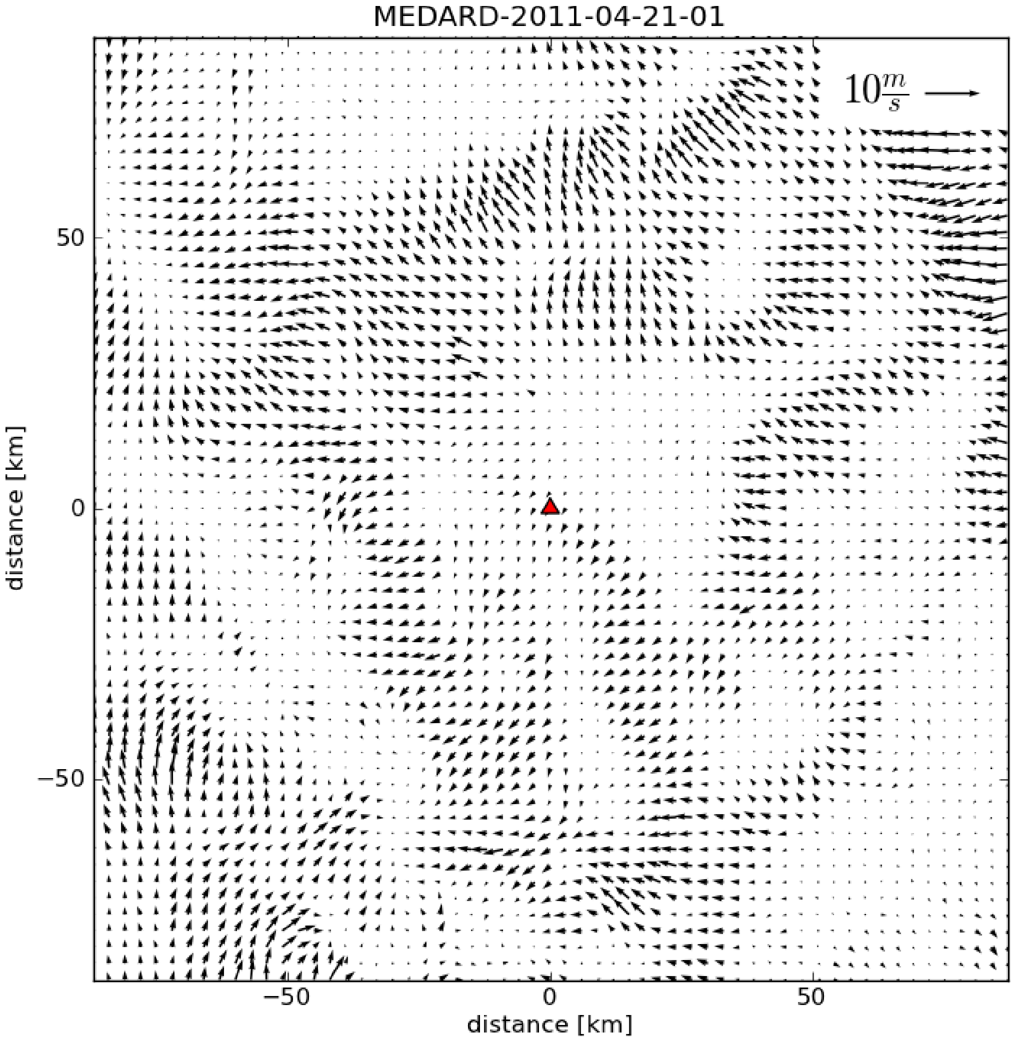


Figure 3.7: Case 2: Visualization of wind field given by MEDARD with time stamp 2011-04-21 1:00.

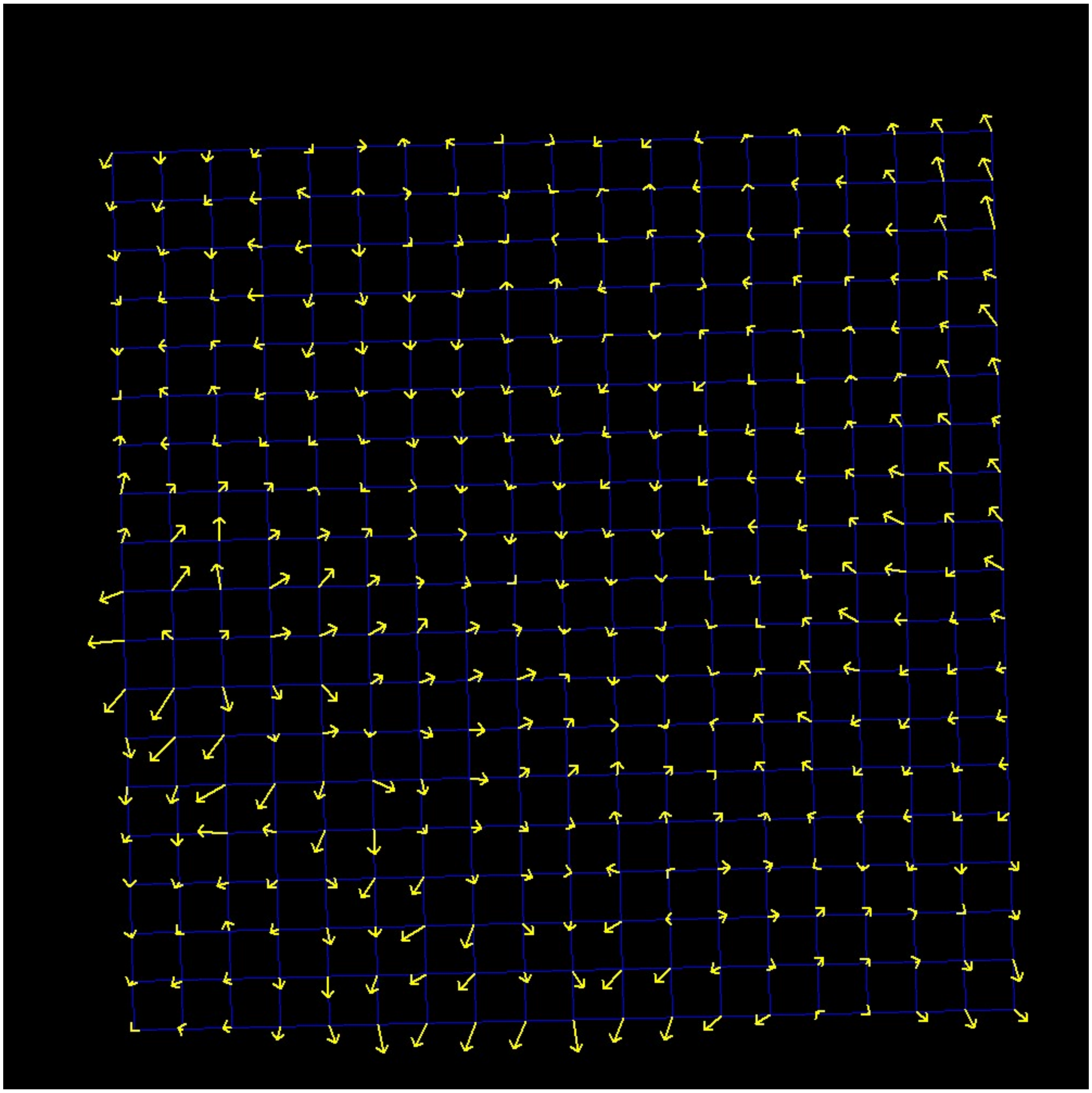


Figure 3.8: Case 2: Visualization of wind field given by ALADIN with time stamp 2011-04-21 1:00.

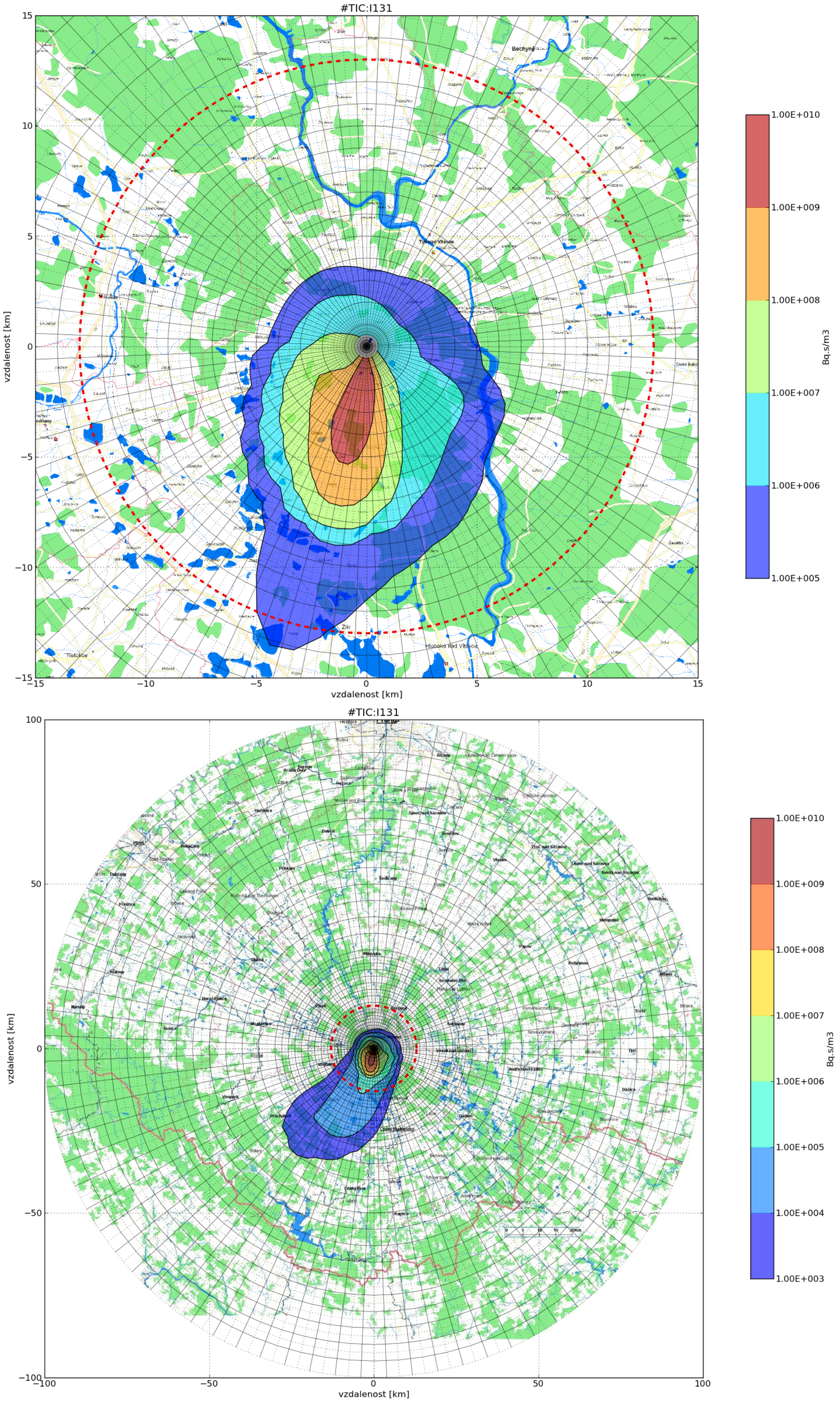


Figure 3.9: Case 2: Prediction of TIC I-131 evaluated using ALADIN meteorological data. Top: prediction up to 14km. Bottom: prediction up to 100km.

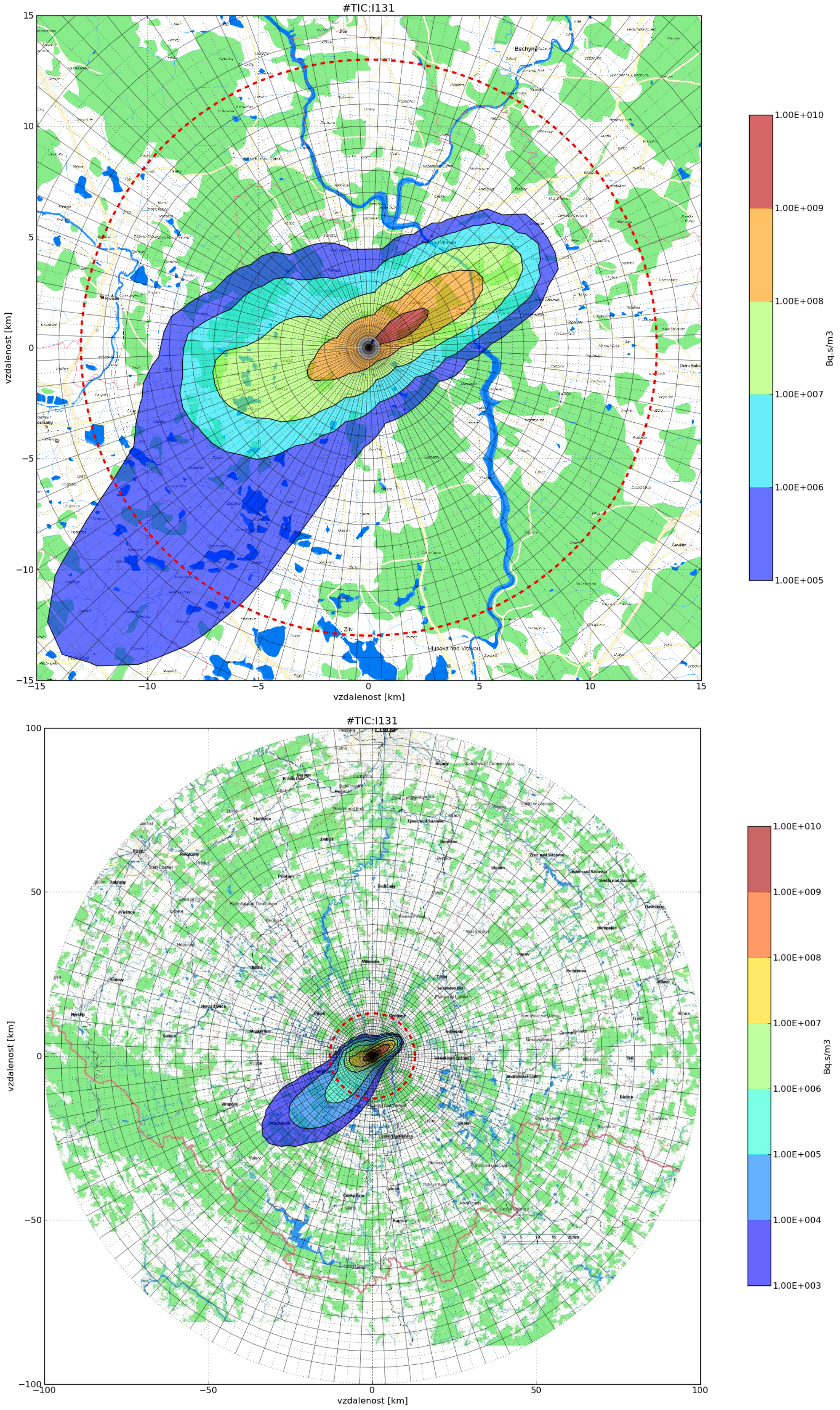


Figure 3.10: Case 2: Prediction of TIC I-131 evaluated using MEDARD meteorological data. Top: prediction up to 14km. Bottom: prediction up to 100km.

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