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MODELLING OF ATMOSPHERIC DISPERSION WITH ARTM AND RODOS FOLLOWING THE ACCIDENT AT FUKUSHIMA DAIICHI NPP AND COMPARISON WITH MEASUREMENTS

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Abstract:
Results of the lagrangian particle model ARTM (Atmospheric Radionuclide Transport Model) and the gaussian puff model ATSTEP implemented in RODOS (Realtime Online Decision Support System for nuclear emergency management) for the spatial distribution of the total deposition of the radio nuclides Cs-134 and Cs-137 after the end of their release will be compared with each other and with results of aero gamma measurements of the deposition within the 80 km zone of Fukushima Dai-ichi NPP.

Calculations are performed using different meteorological information, firstly data as reported by TEPCO from measurements at the site of the NPP, and secondly re-analysed numerical weather prediction data from the German Weather Service (DWD), combined with a source term estimated by the Japanese Nuclear Safety Commission (NSC).

Both models – ARTM and RODOS – are employed at the BfS for the assessment of the radiological impact due to the release of radioactivity into the atmosphere, but with their focus on different release scenarios. ARTM is designed for long-term calculations in the vicinity of nuclear power plants (NPP) in routine operation, RODOS has its focus on emergency management in the case of a nuclear or radiological accident. With emissions over a relatively long period of nearly a month, atmospheric dispersion and deposition following the Fukushima accident can be simulated with both models.
For future decision making in radiological emergency management, knowledge of model performances and a validation of model results with measurements is of great importance.

Key words: *gaussian puff model, lagrangian particle model, radioactive release, ground deposition, Fukushima Dai-ichi*

INTRODUCTION
At the Federal Office for Radiation Protection, Germany (BfS) a number of models for atmospheric dispersion are employed for different applications. In emergency management model results are needed to support decision makers. Due to this dependency on model results for fast decision making, a strong wish for model validation with data preferably from dispersion experiments in the atmosphere exist. After the accident at Fukushima Dai-ichi NPP, a lot of measurements have been carried out in a zone up to 80 km around the NPP. For a model validation, an interesting result is the map of total caesium ground deposition in this 80 km zone. These aerogamma measurements have been carried out by MEXT and DOE between April 6 to 29 (MEXT, 2011). The results of these measurements are shown in Fig. 8.

MODEL DESCRIPTION
In this study, two models are used to simulate the measured ground deposition of caesium in the surrounding of Fukushima Dai-chi NPP.

ARTM (Atmospheric Radionuclide Transport Model) is a lagrangian particle model combined with a diagnostic wind field model to account for orography and a boundary layer flow model. It is designed to estimate the maximum dose that a reference person can receive during one year in the surrounding of a NPP. For this purpose, a post-processing dose module has been invented. Due to this purpose of regulatory estimations on a local scale in the vicinity of a NPP, only a single point input of the meteorological parameters wind speed, wind direction, precipitation and stability class on an hourly basis is possible. This data is usually provided by mandatory meteorological measurements at the site.

RODOS (Realtime Online Decision Support System) is an emergency management tool to help decision makers in the case of a nuclear accident with radioactive releases to the atmosphere. With RODOS the radiological impact and the effect of various countermeasures can be assessed in such an event. The implemented atmospheric dispersion model that has been used for this study is the gaussian puff model ATSTEP. The model area is typically 200 x 200 km². The meteorological information can be provided either as point measurements (up to 10000) or as 3D-NWP data, which are interpolated to the model grid.

INPUT DATA
As input data for the model runs, the source term and meteorological data are needed. For ARTM, also height information of the terrain are used with a resolution of 730 m (geoCOMMUNITY).

Source term
The source term is not available from direct measurements. In this study, the source term as published by the JAEA and NSC is used. It has been reconstructed from coupling environmental monitoring data with atmospheric dispersion simulations and thus doing a reverse estimation (Chino et al., 2011). This source term describes varying emissions during a period of 591 h, that is more than three and a half weeks. The emissions start at March 12, 8.00 am and end at April 5, 10 pm. From Tab.1 one can see, that the highest emission rates occurred during 6 hours on March 15. Another crucial information additional to the amount and release time interval is the release height. For the whole duration of the emission a release height of 30 m has

been assumed, which is roughly the height of the reactor buildings. The source term as proposed by Chino et al. additionally contains I-131, but this information is not considered since this study focuses only on the dispersion and deposition of caesium. The release of Cs-134 is derived from the release of Cs-137 assuming a constant ratio of 1:1.

Table 1. Sourceterm in Bqs^{-1} as constructed from the information given by Chino et al., 2011

Interval	Start	End	Cs-134 (Bqs^{-1})	Cs-137 (Bqs^{-1})
1	12.3.11 7:00	14.3.11 20:00	6.38E+08	6.38E+08
2	14.3.11 20:00	15.3.11 6:00	1.11E+10	1.11E+10
3	15.3.11 6:00	15.3.11 12:00	2.78E+11	2.78E+11
4	15.3.11 12:00	17.3.11 3:00	8.33E+08	8.33E+08
5	17.3.11 3:00	19.3.11 12:00	2.78E+09	2.78E+09
6	19.3.11 12:00	21.3.11 0:00	9.57E+09	9.57E+09
7	21.3.11 0:00	21.3.11 18:00	2.96E+08	2.96E+08
8	21.3.11 18:00	22.3.11 20:00	1.31E+09	1.31E+09
9	22.3.11 20:00	23.3.11 21:00	2.47E+09	2.47E+09
10	23.3.11 21:00	24.3.11 21:00	8.00E+08	8.00E+08
11	24.3.11 21:00	26.3.11 8:00	3.46E+07	3.46E+07
12	26.3.11 8:00	28.3.11 7:00	4.83E+07	4.83E+07
13	28.3.11 7:00	29.3.11 21:00	1.30E+09	1.30E+09
14	29.3.11 21:00	30.3.11 21:00	3.84E+10	3.84E+10
15	30.3.11 21:00	31.3.11 19:00	1.26E+09	1.26E+09
16	31.3.11 19:00	2.4.11 6:00	4.55E+08	4.55E+08
17	2.4.11 6:00	4.4.11 6:00	1.61E+08	1.61E+08
18	4.4.11 6:00	6.4.11 3:00	3.97E+07	3.97E+07

Meteorological data

Two types of meteorological data are available, meteorological observations from TEPCO at the site of Fukushima Dai-ichi and NWP data provided by the German weather service DWD especially for this study.

The meteorological observations of wind speed and wind direction are published by TEPCO as free downloads on their webpage. The measurements were carried out every ten minutes. From the description given with the data it is not clear, in which height the data had been taken. The very low wind speeds with a maximum of 6 ms^{-1} (Fig. 1) and the information, that the data had been taken from a monitoring car suggest, that a measurement height very close to ground level can be assumed. The TEPCO observations do not contain precipitation information.

The NWP data from DWD provide data on a grid of 25 x 25 points with 19 vertical layers, covering an area of 275 x 125 km² which includes the site of Fukushima Dai-ichi NPP. Additional to the profiles of wind speed (FF) and wind direction (DD) and other meteorological parameters, the precipitation intensity is given.

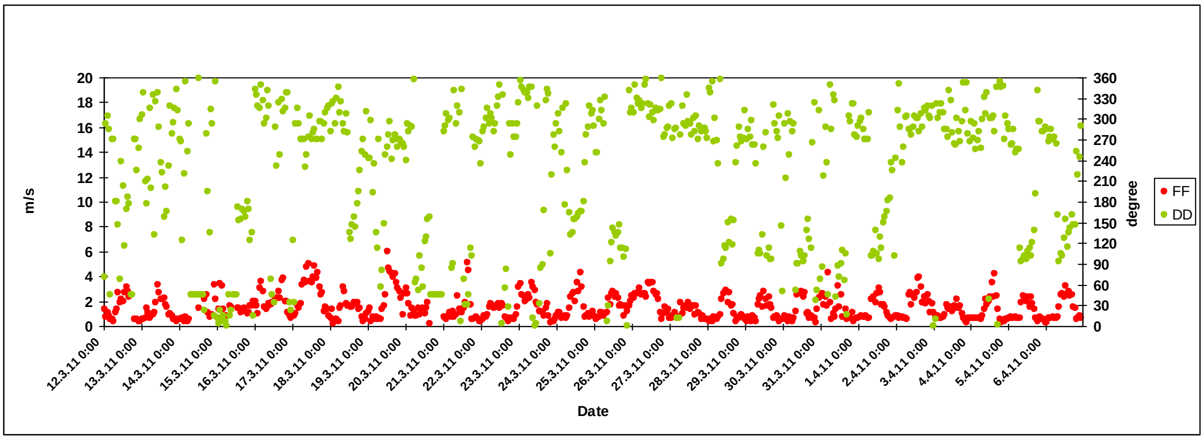


Figure 1. Time series of meteorological observations from TEPCO at the site of Fukushima Dai-ichi NPP. A measurement height close to ground level has been assumed for this data.

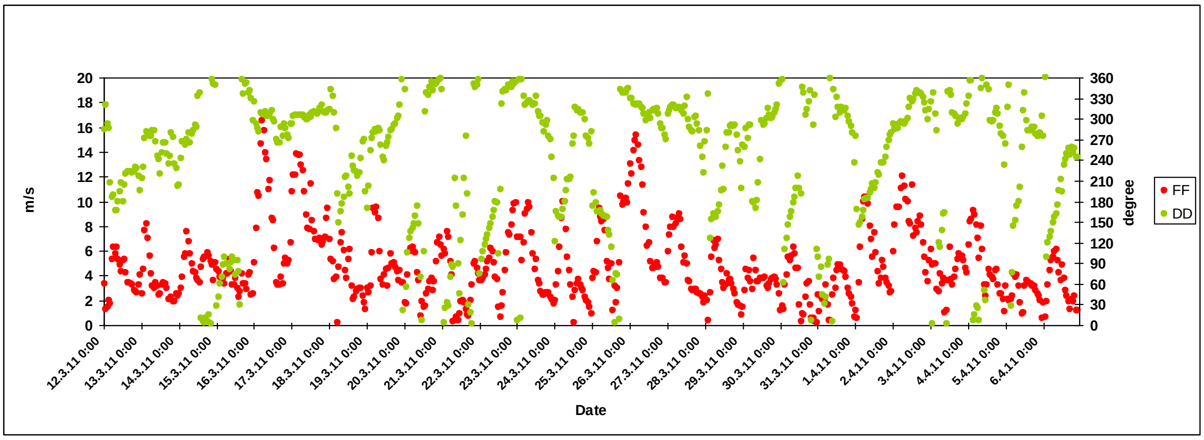


Figure 2. Time series of NWP data provided by the DWD near the site of Fukushima Dai-ichi NPP in a height of 10 m.

RESULTS

The first model runs presented use the single point information of wind speed and wind direction from the TEPCO observations. Both models employ the stability class for turbulence parameterisation. As there is no information available from which the stability class could be estimated, it is set to a constant value of class C, which describes neutral to slightly unstable conditions. The results for the total caesium ground deposition as calculated with ARTM and RODOS are shown in Fig. 3 and 4. These and all following modelled fields of caesium ground deposition are colour scaled exactly as the MEXT/DOE measurements in Fig. 8, for easy comparison. In the ARTM result, the ground deposition does not reproduce the measured contamination. The contaminated area to the south-west of the NPP is even more pronounced than that going to north-north-west, which is reverse in the measurement. RODOS and ARTM results agree fairly well, deviations are probably due to differences in grid resolution.

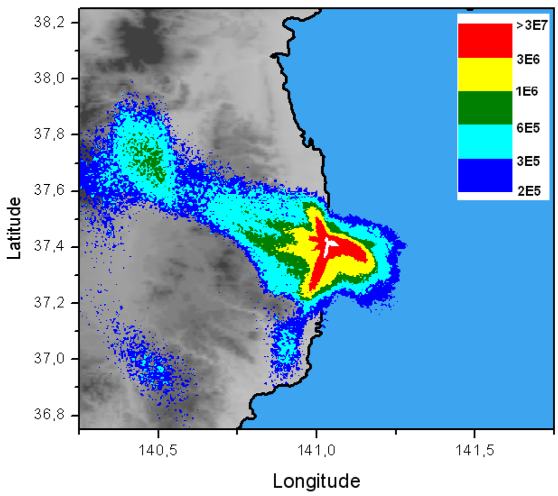


Figure 3. ARTM result of total Cs-137 and Cs-134 ground deposition in Bqm^{-2} with TEPCO single point input at the site

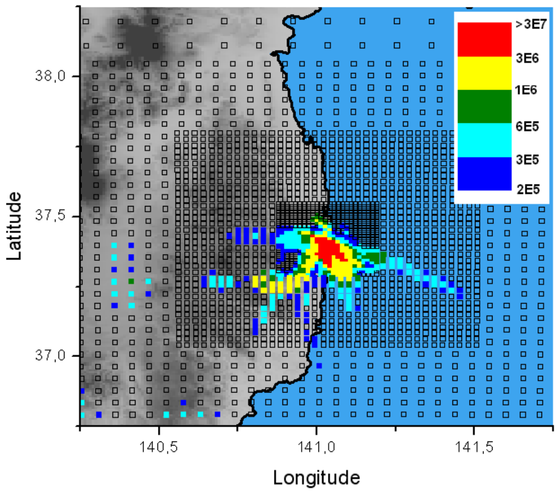


Figure 4. RODOS result of total Cs-137 and Cs-134 ground deposition in Bqm^{-2} with TEPCO single point input at the site

The second set of model runs is used to investigate, whether it is the quality of the TEPCO observations that leads to the failure of the models to reproduce the measured caesium ground deposition or a problem that comes with using only a single point measurement of meteorological parameters for this model area of 150 x 150 km². Additionally, the effect of precipitation on the intensity of ground deposition is studied. Fig. 5 shows the results of an ARTM run with single point meteorological input from NWP data next to the NPP in a height of 10 m. With this input, the highest intensity of ground deposition occurs straight to the west of the NPP, stretching even further than the measurements suggest. The second result (Fig. 6) is obtained with the same meteorological input, but precipitation intensity set to zero. The resulting field of ground deposition is then in intensity quite similar to that obtained with the TEPCO data. This comparison shows, how crucial information on precipitation intensity is, as wet deposition compared to dry deposition leads to an increase of deposition intensities of about a factor of ten or even more, depending on precipitation intensity and particle size. Another important factor can be the spatial and time distribution of precipitation intensity, which is quite variable in space as shown in Fig. 7. The variations are even higher, when the precipitation field at a certain time step is regarded. For the field of ground deposition as shown in Fig. 5, ARTM applied the precipitation intensity at each time step at the site of the NPP to the whole model area.

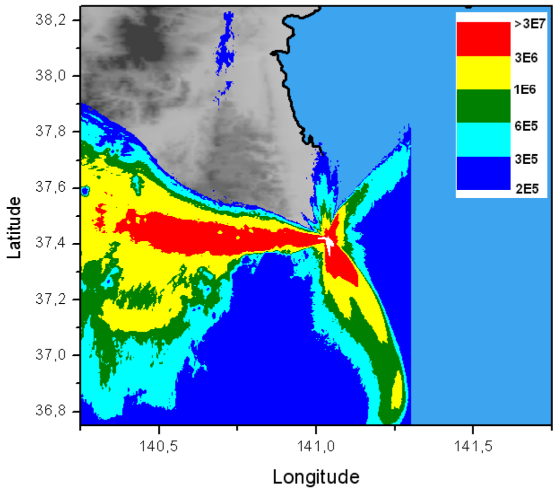


Figure 5. ARTM result of total Cs-137 and Cs-134 ground deposition in Bqm^{-2} with DWD single point input near the site

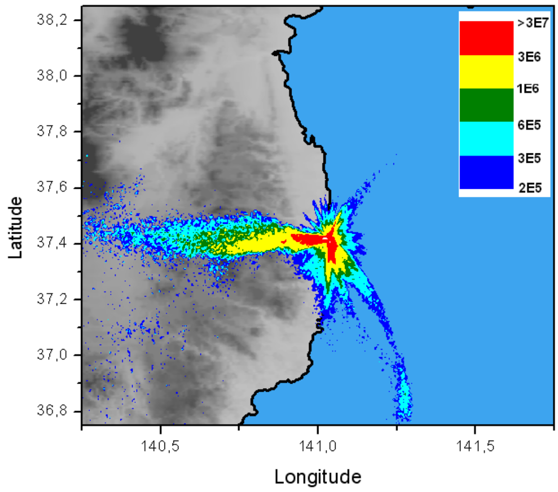


Figure 6. ARTM result of total Cs-137 and Cs-134 ground deposition in Bqm^{-2} with DWD single point input near the site, without precipitation

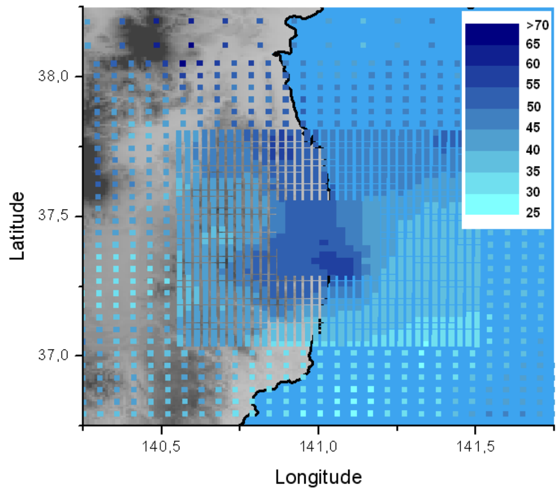
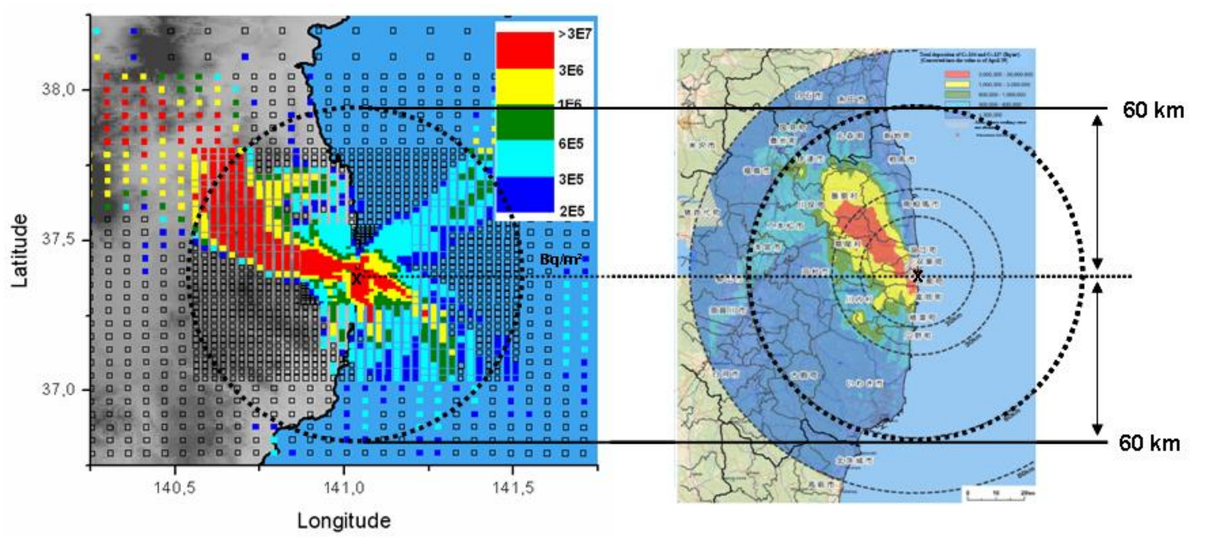


Figure 7. Sum of precipitation during the release interval in mm

The results shown in Fig.8 are obtained with RODOS, when all available information from the 3D-NWP data is used for the calculation. For better comparison with the measured ground deposition, both fields are put next to each other and the corresponding area of the 60 km zone around the site of Fukushima Dai-ichi NPP is indicated. It is clearly observable, that the magnitude of ground deposition with this model run is comparable to that obtained with ARTM and the single point meteorological input at the site of the plant, but the spatial distribution is modified. For the most effected region to the north-west of the NPP, emissions are still transported straight to the west near the NPP, but then the wind direction changes to a north-westerly direction. With the whole information contained in the 3D NWP data, the observed situation of ground deposition can be much better reproduced by this RODOS run than with any of the other runs. This clearly shows, how important a 3D meteorological input is for the model results, at least in a model area of these mesoscale dimensions. However, although the direction of the highly contaminated area is reproduced with an accuracy of about 10 degrees and contamination intensities and width of the contaminated area fit well at least up to 30 km from the NPP, this highly contaminated area stretches much further away from the plant than actually observed.



(Source: MEXT/DOE)

Figure 8. Comparison between the resulting Cs-137 and Cs-134 ground deposition in Bqm^{-2} from a RODOS run with 3D NWP data and the deposition map by MEXT and DOE

CONCLUSIONS

For an accurate reconstruction of measured ground deposition through model simulations in the case of the Fukushima Dai-ichi accident, a very good reconstruction of the time resolved source term and the meteorological field in the model area are necessary. Only an exact combination of wind direction, wind speed, precipitation and emission rate can make a simulated ground deposition fit the observations. There are still uncertainties in these input data, and up to now no reliable meteorological observations for cross checks with NWP data are available. Another deficiency is the need of a reverse estimation of the source term through atmospheric dispersion modelling, which again depends on the meteorological input.
With the data that is available now, the best results in our study are obtained by RODOS, because it can include the three dimensional meteorological field provided by the DWD and therefore account for changes in wind velocity in the mesoscale model area, which can not be achieved by the diagnostic wind field model employed in ARTM.

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