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MODELLING THE REGIONAL AND LONG-RANGE DISPERSION OF RADIOACTIVITY FROM THE FUKUSHIMA NUCLEAR DISASTER AT THE AUSTRIAN WEATHER SERVICE: ESTIMATE OF RELEASE RATES AND FIRST MODEL VALIDATION BASED ON CTBTO MEASUREMENT DATA

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Abstract: On March 12, 2011 at approximately 06:30 UTC an explosion occurred at Unit 1 of the Fukushima Daiichi nuclear power plant in Japan. As soon as the event was disclosed, the Meteorological and Geophysical Service of Austria (ZAMG) set-up and run its transport modelling system to perform dispersion computations (forecasts) of the radioactive cloud. The Lagrangian Particle Diffusion model FLEXPART was used, driven by input data from the European Centre for Medium-Range Weather Forecasts (ECMWF). The computations were made regarding the most important radionuclides already known from the Chernobyl nuclear disaster, namely ^{131}I, ^{137}Cs and ^{133}Xe.

ZAMG also hosts the Austrian National Data Centre (NDC) for the verification of the Comprehensive Nuclear Test Ban Treaty (CTBT) and thus has real-time access to the global radioactivity measurements of the CTBT Organization. CTBTO stations are distributed all over the globe and measure radioactive particles as well as Xenon gases with a very high accuracy.

These data were used to validate the model simulation, and to estimate the source terms of ^{131}I, ^{137}Cs and ^{133}Xe. First results show that the model worked well regarding transport, but underestimated the concentrations of ^{131}I transported towards Europe. Furthermore, it was demonstrated that significant amounts of ^{131}I, ^{137}Cs and ^{133}Xe were already set free during the first hours and days of the accident, exceeding initial estimates by orders of magnitude.

The Fukushima case furthermore revealed uncertainties in transport modelling related to physical processes, most prominently wet deposition. Since exact release rates from Fukushima are still largely unknown, a validation of these processes based on monitoring data is not possible. To check and improve the parameterization of physical processes, controlled tracer experiments are needed. Such large-scale experiments were not conducted since more than a decade. New tracer experiments should include tracers that are subject to wet deposition.

Key words: *long-range transport modelling, emergency response activities, source term estimation, model validation, nuclear accident.*

INTRODUCTION

The emergency response forecast system, including long-range transport and dispersion modelling, was built up at the Austrian National Weather Service (ZAMG) after the Chernobyl accident in 1986 (Pechinger et al., 2001). The system is operated on a routine basis to support the Austrian emergency response management. The models FLEXTRA (Stohl et al., 1995; Stohl and Seibert, 1998) and FLEXPART (Stohl et al., 1998; Stohl et al., 2005) are used for transport modelling in the emergency response modelling system driven by regional-scale or global-scale weather analyses and forecasts fields available at ZAMG. Since July 2011, ZAMG is furthermore Regional Specialized Meteorological Centre (RSMC) for Atmospheric Transport Modelling (backtracking) of the WMO and supports the Comprehensive Nuclear Test Ban Treaty Organisation (CTBTO; Hoffmann et al., 2000) with long-range dispersion modelling in back-tracking mode.

On March 11, 2011 at 05:56 UTC an earthquake of magnitude 9.0 occurred near the shorelines of Honshu, Japan at 24km depth. Immediately thereafter, Blocks 1 to 3 of the Fukushima-Daiichi Power plant were automatically shut down. Blocks 4 to 6 were not in operations during the earthquake. At 07:00 UTC the Power plant was hit by a tsunami, which destroyed the emergency cooling and electricity backup system. On March 12, 2011 at 06:36 UTC a hydrogen explosion occurred at Unit 1 of the Fukushima Daiichi nuclear power plant. Further explosions followed in units 3 and 2 on March 14, 2011 at 02:01 UTC and 21:14 UTC, respectively. Fire occurred at unit 4 on March 14, 2011 at 23:54 UTC. In the course of the events, at least partial core melt downs were reported by the NPP operators in blocks 1 to 3.

Only minutes after the event was disclosed, the first model simulation of the emergency response system was initiated at ZAMG on March 12, 2011 at 09:00 UTC with a first-guess release starting on March 12, 2011 at 08:30 UTC. In this case, the Lagrangian Particle Diffusion model FLEXPART (Version 8) was used, driven by input data (weather analyses and forecasts) from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Results of the model simulations based on a first-guess release rate are presented in the following. ZAMG is the Austrian National Data Centre for the verification of the Comprehensive Nuclear Test Ban Treaty and thus has real-time access to the global radioactivity measurements of the CTBTO (Schulze et al., 2000). The improved model runs are evaluated in comparison to these observational data.

METHODOLOGY

For the simulation of the dispersion of the radioactive cloud, released by the accident site at Fukushima Daiichi, the Lagrangian particle diffusion model (LPDM) FLEXPART version 8 (Stohl et al., 2005) was used. The LPDM is driven with global numerical weather predictions of the European Centre for Medium Range Weather Forecasts (ECMWF) on a latitude/longitude grid with 1 degree horizontal resolution and 3 hourly temporal resolution and 91 ECMWF model levels. Air concentration and deposition fields are calculated on an output grid with 0.5° horizontal resolution and 10 vertical levels. Results are displayed for the lowest level, between 0 and 500 m above ground.

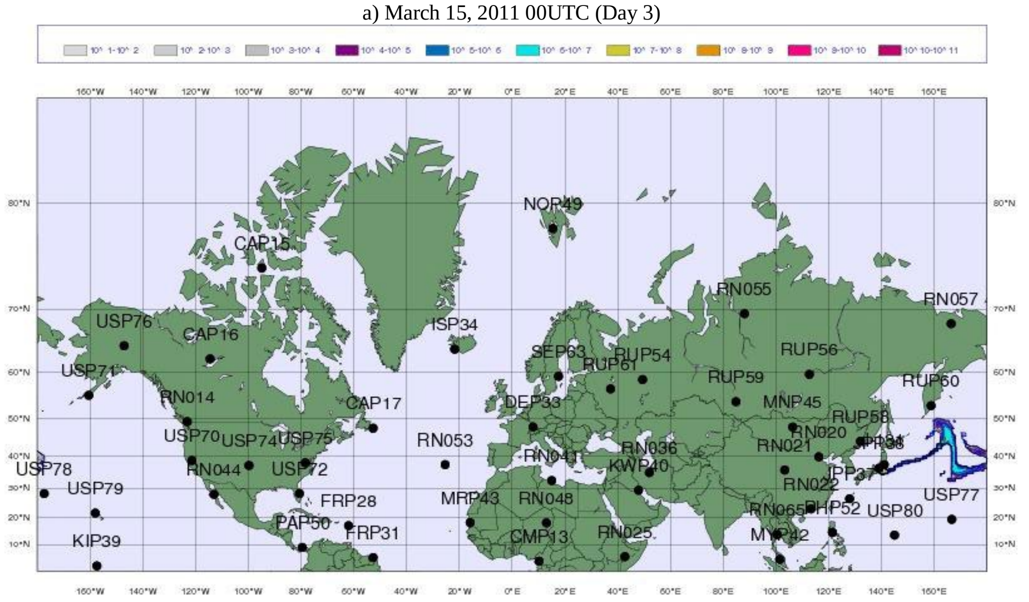
The simulated species were ^{131}I, ^{137}Cs and ^{133}Xe. Dry and wet depositions as well as radioactive decay were considered in the model simulation for ^{131}I and ^{137}Cs. The noble gas ^{133}Xe is an inert tracer and not subject to deposition, but to radioactive decay. The first-guess source term was estimated based on experiences from the Chernobyl accident, postulating a continuous release rate of 10^{17} Bq ^{131}I per day, 10^{16} Bq ^{137}Cs and 10^{19} Bq ^{133}Xe (RUN1, selected results in Fig.1).

Data from the global radioactivity measurements of the CTBT Organization (CTBTO; Schulze et al., 2000) are used to validate the model simulations. CTBTO stations are distributed all over the globe (sites indicated in Figure 1) and measure radioactive particles as well as Xenon gases with a very high accuracy of approximately 1 μBqm^{-3} for ^{131}I and ^{137}Cs and 0.1 mBqm^{-3} for ^{133}Xe.

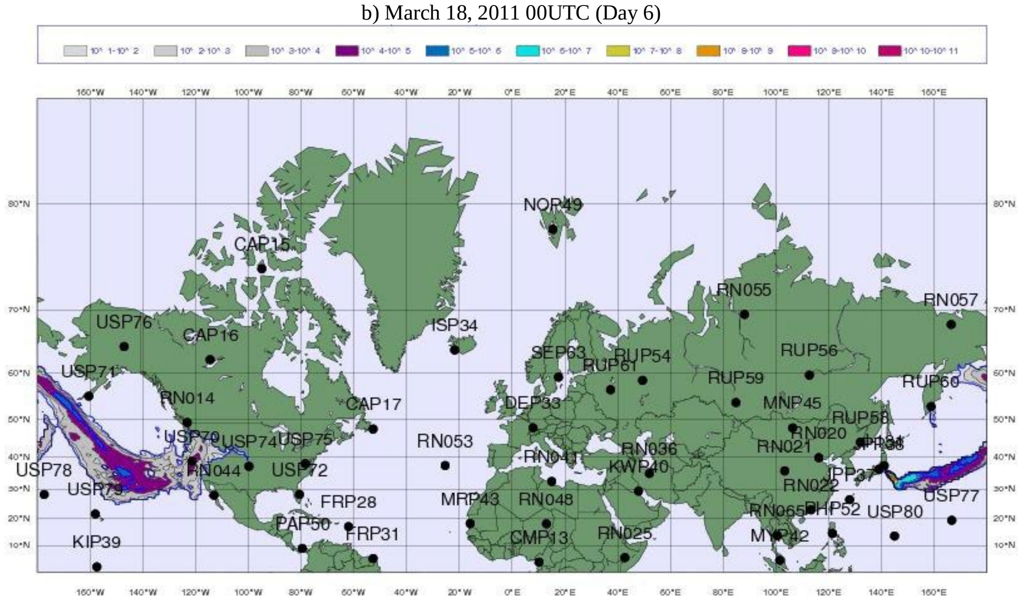
RESULTS
Selected model results for ^{131}I near-surface concentration fields due to the first-guess continuous release rate of 10^{17} Bq ^{131}I per day are depicted in Figure 1. The plume left Japan and was transported to the northwest over the Pacific Ocean within the first three days after the first explosion at Fukushima power plant on March 12, 2011 (Figure 1a). The plume has reached the western coast of North America on March 18, 2011, 6 days after the on-set of the release (Figure 1b). The model results in Figure 1c and Figure 1d indicate radioactive concentration values less than 10^4 Bqm^{-3} ^{131}I over the North American Continent on March 21, 2011 and over the Caribbean Sea and – to a minor degree – over Europe on March 24, 2011. Starting March 28, somewhat higher radioactivity levels reached Europe (see Masson et al., 2011).

The times of arrival of the plume at North America (e.g. Fig. 2b) and at Europe (e.g. Fig.2c) were in general well reproduced by the model. Of course, some comparisons of measurements and model results reveal somewhat less agreement, e.g. the arrival of the plume at Hawaii was forecasted one day late (Fig. 2d). At most sites, the radioactivity measurements were slightly higher than the modelled values. Especially the modelled concentration values in Europe were somewhat lower than observed (e.g. Fig. 2c).

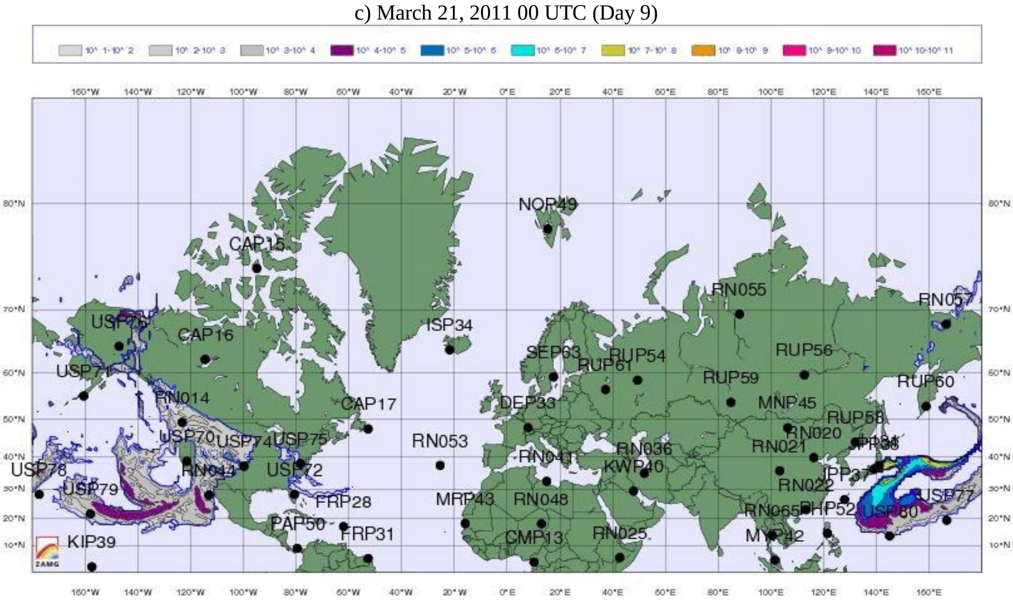
a) March 15, 2011 00UTC (Day 3)



b) March 18, 2011 00UTC (Day 6)



c) March 21, 2011 00 UTC (Day 9)



d) March 24, 2011 00 UTC (Day 12)

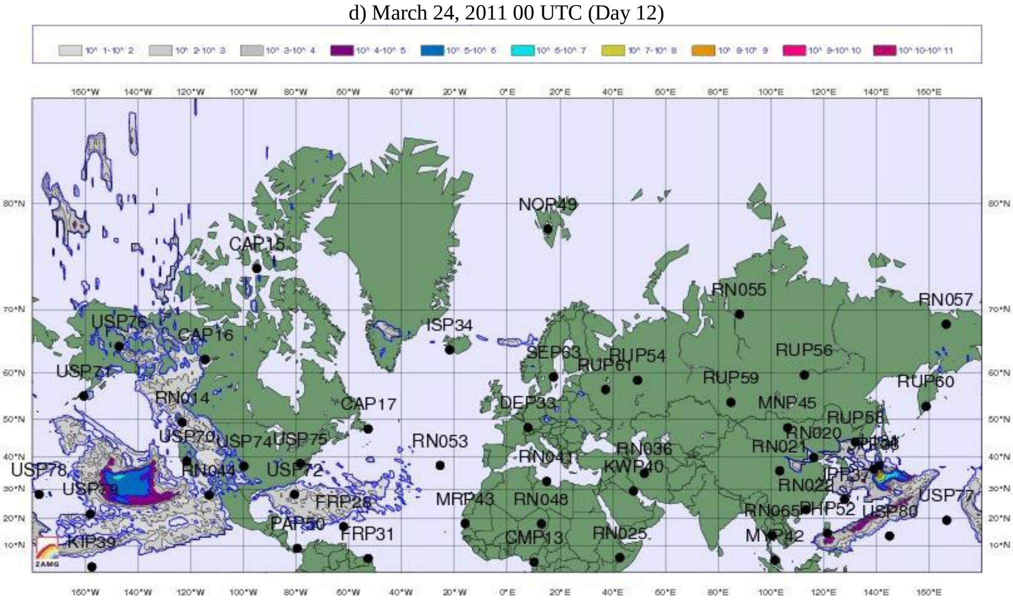


Figure 1: Modelled near surface air concentration fields for ^{131}I in Bqm^{-3} a) on March 15, 2011 00 UTC (Day 3) b) on March 18, 2011 00 UTC (Day 6) c) on March 21, 2011 00 UTC (Day 9) d) on March 24, 2011 00 UTC (Day 12). Symbols indicate station sites of the CTBTO radioactivity observational network.

Some indication is found that significant amounts of ^{131}I, ^{137}Cs and ^{133}Xe were already set free during the first days of the accident, exceeding initial estimates by orders of magnitude: At the Californian coast, twice as much radioactivity was measured on March 16, 2011, when the large-scale flow over the Pacific Oceans turned from south-west to north-west and the plume reached the North American Coast for the first time (Fig. 2c). These findings could also be due to a too high wet deposition in the model run. There was precipitation in the crisis region as well as over the Pacific during the first days.
Based on the model simulations and the available CTBTO measurements, ZAMG was the first institution world-wide that estimated a release rate of ^{131}I and ^{137}Cs. The estimate amounted to about $4{\cdot}10^{17}$Bq for ^{131}I and $4{\cdot}10^{16}$ Bq for ^{137}Cs (ZAMG, 2011). Similar release rates were reported by the French Radiation Protection Institute a few hours later (IRSN, 2011) and later on by the Japan Nuclear Safety Commission and Japan Atomic Energy Agency (Chino et al., 2011).

CONCLUSIONS AND OUTLOOK

Evaluation of model runs against radioactivity measurements reveal that the model worked well regarding the progress and position of the plume, but underestimated the concentrations of ^{131}I transported towards Europe. Indication is found that significant amounts of ^{131}I, ^{137}Cs and ^{133}Xe were already set free during the first days of the accident, exceeding initial estimates by orders of magnitude. One of the complicating factors was the high amount of ^{131}I that was emitted as gas, and was thus slower deposited than radioactive particles (see Masson et al., 2011), facilitating hemispheric-scale transport.

More detailed investigations of the radioactive emissions to air in the course of the Fukushima event meanwhile become available. Re-calculation of the Fukushima case based on these emission rates will be undertaken in order to minimize the impact of uncertainties in source term estimation on the result of model validation against the monitoring data. ZAMG will also publish improved source estimates in due course, based on inverse modelling.

The Fukushima case revealed uncertainties in transport modelling related to physical processes, most prominently wet deposition. To check and improve the parameterization of physical processes, controlled tracer experiments are needed. Such large-scale experiments were not conducted since more than a decade. New tracer experiments should include tracers that are subject to wet deposition (Galmarini et al., 2011).

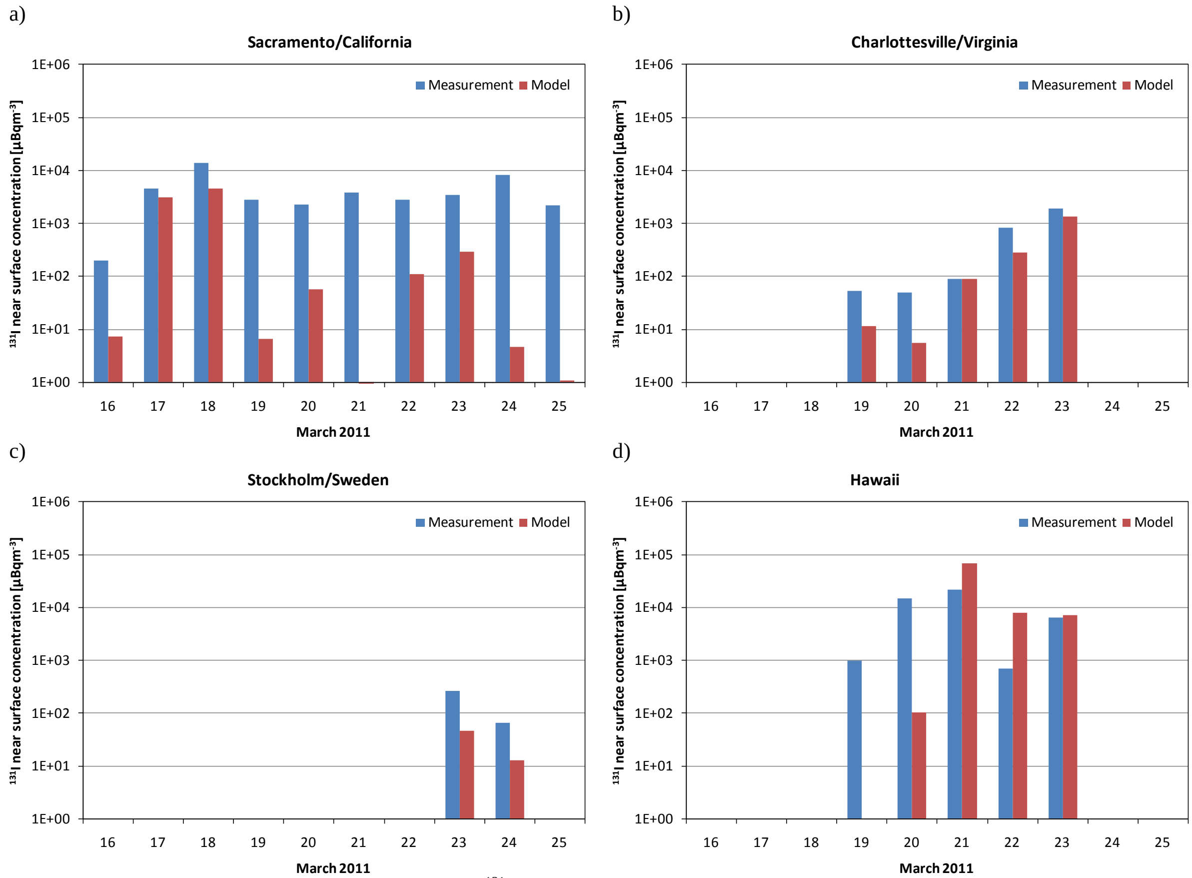


Figure 2: Comparison of measured and modeled ^{131}I concentrations at CTBTO measurements sites on March 16 to 25, 2011.

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