# JMA's Regional Atmospheric Transport Model Calculations for the WMO Technical Task Team on Meteorological Analyses for Fukushima Daiichi Nuclear Power Plant Accident

Kazuo Saito [*1], Toshiki Shimbori [*1] and Roland Draxler [*2]

**1 JMA Meteorological Research Institute, Japan *2 NOAA Air Resources Laboratory, USA*

## 1. Introduction

WMO convened a small technical task team of experts to produce a set of meteorological analyses that would be used to drive atmospheric transport, dispersion and deposition models (ATMs) for the UN Scientific Committee on the Effects of Atomic Radiation's (UNSCEAR) assessment of the Fukushima Daiichi Nuclear Power Plant accident. The primary aim of the group is to examine how the use of meteorological analyses could improve the ATM calculations.

The JMA's regional ATM (JMA RATM) for radionuclides has been developed at the Meteorological Research Institute (MRI), based on the JMA mesoscale tracer transport model (Shimbori et al., 2010) for the predictions of oxidant concentration and volcanic ash. The RATM shares its horizontal and vertical grid configurations with the JMA operational nonhydrostatic mesoscale model (NHM; Saito et al., 2006) and the JMA operational mesoscale 4D-VAR analysis. With reference to the JMA's global environmental emergency response model and others, dry deposition, wet scavenging, and gravitational sedimentation for light particles have been revised.

## 2. Mesoscale Analysis and Radar/rain gauge-Analyzed Precipitation of JMA

JMA provided their mesoscale analyses (MESO) fields to the WMO Task Team and UNSCEAR for the period 11 – 31 March 2011. The MESO analyses are produced by an operational JMA non-hydrostatic 4D-VAR system (JNoVA; Honda and Sawada, 2008), which assimilates a variety of local meteorological observations, including 31 wind profilers, total precipitable water vapor derived from 1,200 GPS stations, and JMA RAP data. All analysis fields including liquid and solid precipitation are produced by a three hour forecast of the outer-loop model of the incremental 4D-VAR with a horizontal resolution of 5 km.

JMA also provided the RAP dataset at 30 minute intervals, with a horizontal resolution of 45 seconds in longitude and 30 seconds in latitude covering a region from 118-150 degrees east longitude and from 20-48 degrees north latitude. JMA produces RAP by calibrating one-hour accumulated radar echo data with one-hour accumulated

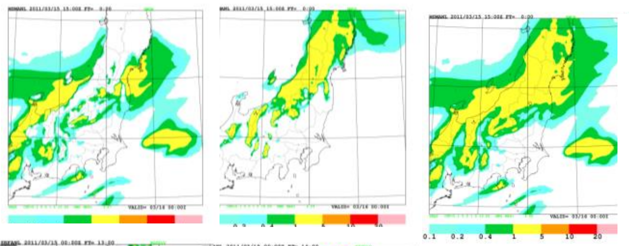

Fig. 1. Accumulated surface precipitation (mm per hour) by JMA-MESO for 1200-1500 UTC, 15 March 2011. Rain (left), snow (center) and total precipitation (right).

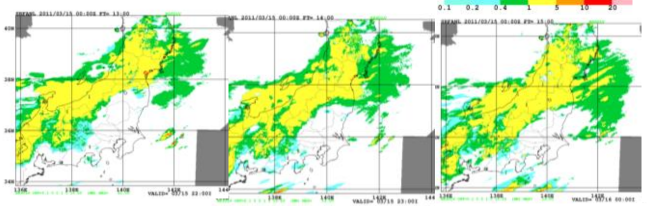

Fig. 2. Rainfall intensity (mm) by JMA RAP for 15 March 2011. 1200-1300 UTC (left), 1300-1400 UTC (center) and 1400-1500 UTC (right).

## 3. JMA Regional ATM

The JMA RATM is the mesoscale tracer transport Lagrangian model which is driven by the MESO analysis. For the prediction of radionuclides with RATM, the deposition schemes have been upgraded. Only washout processes are considered for wet deposition of light particles. The below-cloud scavenging rate is given by Kitada (1994):

$$\Lambda_w = AP^B \quad , \quad A = 2.98\times10^{-5}\mathrm{s}^{-1}, \quad B = 0.75$$

where P is the precipitation intensity [mm/h] given by the three-hour average of the accumulated precipitation from the MESO data or every 30 minutes from the RAP data. On the other hand, wet deposition for a depositing gas is considered only as a rainout process. The in-cloud scavenging rate is given by Hertel et al. (1995):

$$\Lambda_r = \frac{1}{(1-\mathrm{LWC})/HRT_a + \mathrm{LWC}} \frac{P}{Z_r}$$

where LWC is the liquid water content, T is the temperature [K], and $Z_r$ is cloud thickness defined by the MESO data.

Wet deposition is applied to tracer particles or gases under the height of about 3000 m in the original RATM. Dry deposition is simply computed from the following deposition rate (Iwasaki et al., 1998):

$$\Lambda_d = \frac{V_d}{Z_d}$$

where $V_d$ is the dry-deposition velocity and Zd is the depth of surface layer. The value of $V_d$ is set to $1\times10^{-3}$ m/s for light particles or $1\times10^{-2}$ m/s for depositing gas (Draxler and Rolph, 2012), and $Z_d$ is 100 m for both tracer types.

Furthermore, gravitational settling is considered for light particles in the vertical advection step. These tracer particles follow the Stokes' law with the Cunningham correction coefficient. The grain-size distribution assumes a log-normal with mean diameter of 1 μm and standard deviation of 1.0 (upper cutoff: 20 μm), and a uniform particle density of 1 g/cm$^3$.

Table 1. Specifications of JMA RATM (preliminary version).

| | |
|---|---|
| Meteorological Field | 3 hourly outputs of JMA MESO analysis |
| Grid Size | 5 km |
| Number of Tracers | 100,000/3 hr |
| Horizontal Diffusion | Gifford (1982) |
| Vertical Diffusion | Louis et al. (1981) |
| Dry Deposition | Ngas: None, Dgas: $V_d$=1x10$^{-2}$ m/s<br>Lpar: $V_d$=1x10$^{-3}$ m/s |
| Wet Scavenging | Ngas: None, Dgas: Hertel et al. (1995) with Henry's constant=0.08<br>Lpar: Kitada (1994) with accumulated liquid precipitation analysis |
| Gravitational Settling | Ngas: None, Dgas: None<br>Lpar: Stokes' law with Cunningham correction |

Ngas: Noble gas, Dgas: Depositing gas, Lpar: Light particle

The motion of tracer particles in RATM is calculated in the same coordinate system as the MESO analysis. From the point of view of the wet deposition process, due to the restriction of the treatment of the ice phase in the previous RATM, only liquid rain (left panel of Fig.1) was considered in the calculation, not the total precipitation (right panel of Fig. 1). When using the RAP data, instead of the 3-hourly accumulated precipitation by MESO, the RAP precipitation intensity at each MESO grid point (5-km horizontal resolution) is calculated from the spatial average of the surrounding 25-grid cells of RAP (1-km resolution) every 30 minutes. Since RAP does not distinguish rain and snow, all RAP precipitation was considered to be liquid rain in the calculation.

As previously mentioned, the JMA MESO analysis is produced by a three hour forecast of the outer-loop model of 4DVAR. Because instantaneous vertical motion is affected by gravity waves, simple time interpolation of updrafts between the 3 hourly analysis fields yielded an overestimation of the vertical advection of the air parcel. To compensate for the above situation, in the revised version of RATM, the vertical advection is calculated using a spatially-averaged (9-grid cells) value of the MESO vertical velocity and the vertical motion is assumed to be terrain-following (w*=0) at the lowest model level (40 m).

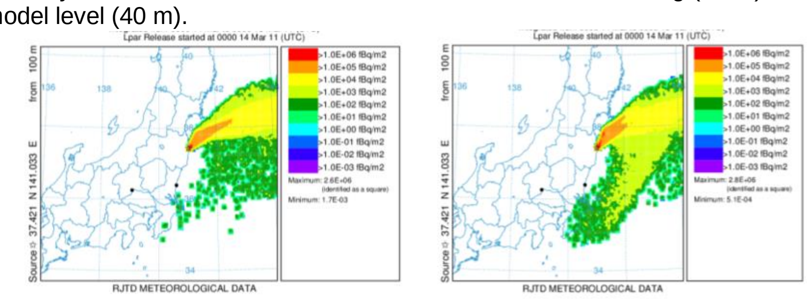

Fig. 3. Lpar accumulated deposition for unit release at 0000-0300 UTC, 14 March 2011. RAP is used for precipitation. Left) No adjustment for vertical motion. Right) 9-grid average and w*=0 at the lowest level.

In the preliminary version of RATM, wet scavenging was assumed to occur below about 3,000 m ASL, but deposition over Miyagi prefecture was overestimated. In the revised RATM, this overestimation was ameliorated by reducing the level of wet scavenging to below about 1,500 m. Some improper treatments of horizontal and vertical interpolations of the kinematic fields were found in the preliminary version of RATM. These computational bugs were also corrected in the revised version. Also the number of tracer particles was increased from 100,000/3 hr to 300,000/3 hr, but the impact was almost negligible (figure not shown).

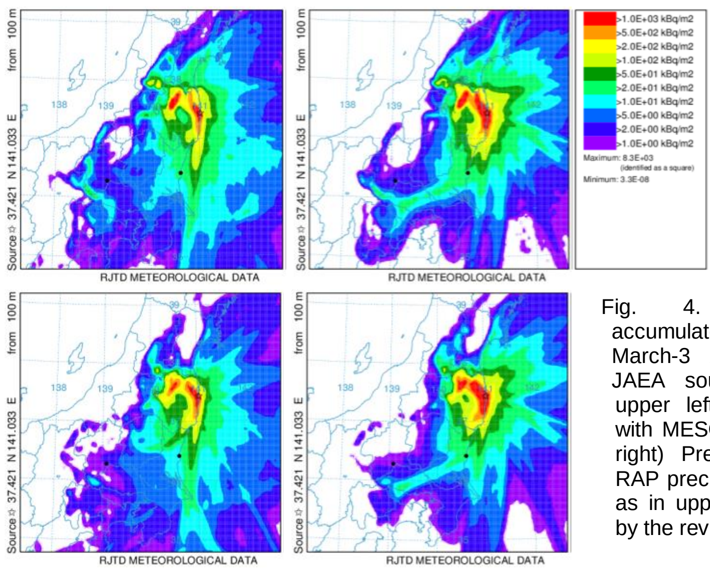

Fig. 4. Lpar (Cs-137) accumulated deposition for 11 March-3 April 2011using the JAEA source.
upper left) Preliminary RATM with MESO precipitation. upper right) Preliminary RATM with RAP precipitation. lower) Same as in upper figures but results by the revised RATM.

## 4. Verifications against observation

The Cs-137 deposition patterns and the time series of low level air concentrations at Tokai (JAEA) were verified against observed deposition from ground and aerial measurements. Two sets of calculations were examined, where the precipitation was given by the MESO or the RAP data. Performance of the revised RATM is significantly improved compared with the preliminary version of RATM for almost all evaluation parameters and rank metrics. Use of RAP data for precipitation improves the correlation coefficients, but rank metrics become slightly worse. As for the statistics for Cs-137 concentration at the JAEA observation site, performance of revised RATM using MESO precipitation slightly improves in terms of the rank metrics, while the revision does not improve the metrics when the RAP data were used for precipitation.

Table 2. Statistics of JMA RATMs. Cs-137 deposition using the JAEA source.

| RATM | R | FB | FMS | FOEX | %FA2 | KSP | METRIC |
|---|---|---|---|---|---|---|---|
| Preliminary MESO | 0.45 | -0.02 | 100.00 | -0.46 | 51.01 | 10.0 | 3.09 |
| Preliminary RAP | 0.77 | 0.54 | 100.00 | 9.67 | 41.99 | 11.0 | 3.22 |
| Revised MESO | 0.70 | -0.04 | 99.63 | -0.83 | 37.94 | 10.0 | 3.37 |
| Revised RAP | 0.84 | 0.56 | 99.08 | 9.12 | 35.73 | 13.0 | 3.28 |

R is the correlation coefficient, FB the fractional bias, FMS the Figure of Merit in Space, FOEX the factor of exceedance, %FA2 the percentage within a factor of two, and KSP the Kolmogorov-Smirnov parameter. METRIC means a rank evaluated by the above parameters.

***Reference***

Saito, K, T. Shimbori and R. Draxler, 2015: JMA's Regional ATM calculations for the WMO Technical Task Team on meteorological analyses for Fukushima Daiichi Nuclear Power Plant accident. *J. Environ. Radioact.*, **139**, 185-199.

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