6.2 JMA'S REGIONAL ATM CALCULATIONS FOR THE WMO TECHNICAL TASK TEAM ON METEOROLOGICAL ANALYSES FOR FUKUSHIMA DAIICHI NUCLEAR POWER PLANT ACCIDENT

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1. INTRODUCTION

The World Meteorological Organization (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 Japan Meteorological Agency's regional ATM (JMA RATM) for radionuclides has been developed at the Meteorological Research Institute (MRI), based on the JMA mesoscale tracer transport model (Seino et al., 2004; Takano et al., 2007; 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; 2007; Saito, 2012) and the JMA operational mesoscale 4D-VAR analysis. With reference to the JMA's global environmental emergency response model, dry deposition, wet scavenging, and gravitational sedimentation for light particles have been revised.

Preliminary and revised calculations of the JMA RATM were conducted according to the task team's agreed standard with a horizontal resolution of 5 km using a unit source emission rate. The simulations were conducted for the period 11 through 31 March 2011. The mesoscale analysis data of JMA were used to drive the ATM, while the JMA's Radar/Rain gauge-analyzed precipitation data were employed to evaluate the wet scavenging.

Several modifications were made to the JMA RATM. Results of the RATM calculation were verified against the observed Cs-137 deposition pattern and the air concentration time series. The performance of the ATM was significantly improved by the revisions, especially for the Cs-137 deposition.

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2. JMA'S CONTRIBUTIONS TO WMO TASK TEAM

2.1 WMO Task Team Meetings

In 2011, WMO convened a small technical task team of experts from five countries (Austria, Canada, Japan, United Kingdom, and the United States) to produce a set of meteorological analyses that would be used to drive ATMs for UNSCEAR Group B estimates of the dispersion and deposition of radionuclides released to the atmosphere from the Fukushima Daiichi Nuclear Power Plant accident. The primary aim of the team is to examine how the use of meteorological analyses could improve the ATM calculations.

At the 1st Task Team meeting (Geneva, 30 November - 2 December, 2011) JMA agreed to reprocess 4D-VAR mesoscale (MESO) analysis and Radar/Rain gauge-Analyzed Precipitation (RAP) data from their internal archive format to GRIB2. At the 2nd Task Team meeting (London, 1 - 3 May, 2012), JMA presented an offer to provide a software tool to convert these files to a latitude-longitude grid, either retaining the vertical hybrid terrain-following grid or converting these data to pressure-level surfaces. At the 3nd and final Task Team meeting (Vienna, 3 - 5 December, 2012), JMA and WMO agreed to make the MESO analysis and RAP data available to the scientific community for research purposes via the WMO ftp server. For more detailed information of the task team activities, see WMO website:
(http://www.wmo.int/pages/prog/www/CBS-Reports/DPFSERA-index.html).

2.2 MESO Analysis of JMA

To assist in the regional ATM calculations, JMA provided their mesoscale analyses fields to the WMO Task Team and UNSCEAR for the period 11 – 31 March 2011, at three-hourly intervals and at a 5-km horizontal resolution. The MESO analyses are produced by an operational JMA non-hydrostatic 4D-VAR system (JNoVA; Honda et al., 2005; 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. The MESO output covered 719 (x-direction) by 575 (y-direction) grid points on a Lambert Conformal projection (30N and 60N at 140E), up to about 21 km above ground level (AGL). There are in total 50 levels, including 11 levels below 1 km AGL.

Figure 1 shows the one hour average of surface precipitation by JMA-MESO for 1200-1500 UTC, 15 March 2011, one of the critical deposition episodes. Most of surface precipitation over northern Japan during this period was in the form of snow (center panel) except in some of the coastal areas.

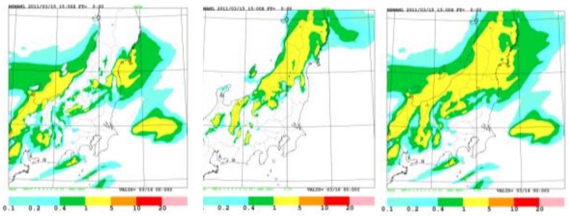


Fig. 1. Accumulated surface precipitation (mm per hour) by JMA-MESO for 1200-1500 UTC, 15 March 2011. Rain (left), snow (center) and total precipitation (right).

2.3 Radar/Rain Gauge-Analyzed Precipitation (RAP)

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 (2560 by 3360 grid points). JMA produces RAP by calibrating one-hour accumulated radar echo data with one-hour accumulated rain gauge precipitation data. It collects data from 10,000 rain gauges operated in Japan and data from 46 C-band radars operated by JMA and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). A detailed description of RAP is found in Nagata (2011).

RAP intensities at 1 hour intervals for 1200-1500 UTC, 15 March 2011 are shown in Fig. 2. This illustrates a good agreement of RAP with the JMA-MESO total precipitation (Fig. 1). A circle-shaped small intense precipitation area is seen around the radar site at Sendai (38.3N, 140.9E) for 1200-1300 UTC (left), which is due to a bright-band observed by the Sendai radar.

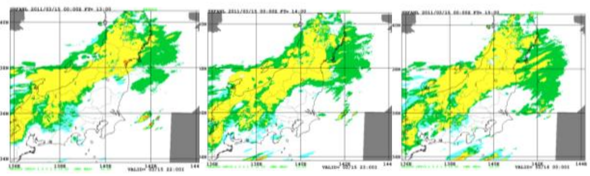


Fig. 2. Rainfall intensity (mm) by JMA RAP for 15 March 2011. 1200-1300 UTC (left), 1300-1400 UTC (center) and 1400-1500 UTC (right).

2.4 File Converter Kit and WMO Ftp Site

JMA provided the MESO and RAP data in the JMA provided the MESO and RAP data in GRIB2 format to members of the Task Team and UNSCEAR. The MESO data are on a Lambert conformal projection in the horizontal coordinate and a terrain-following hybrid vertical coordinate. Furthermore, while the GRIB2 format is regulated by WMO as a common format to exchange meteorological data, it might not an easy task to decode and process GRIB2. Considering the situation, JMA decided to provide a tool to read and process the MESO and RAP data. The tool provides the following three functions;

i) to convert the GRIB2 format data to the FORTRAN sequential binary format data (GrADS),

ii) to re-project data from the Lambert conformal projection to a regular latitude-longitude projection,

iii) to covert data from terrain-following hybrid vertical coordinate to an isobaric coordinate at arbitrary pressure planes.

Both the JMA MESO and RAP data were made available to the UNSCEAR community through a WMO hosted password protected FTP site with read instructions and the previously described file converter kit. The data are also available on the WMO web server (http://wmo.int/metadata1) to the scientific community for research purposes with acknowledgement to JMA as the data source. For access to the password, researchers should contact WMO (dpfsmail@wmo.int).

3. JMA REGIONAL ATM

3.1 Brief Description of RATM

The JMA RATM is the mesoscale tracer transport Lagrangian model which is driven by the MESO analysis. The JMA operational products of RATM are the photochemical oxidant information and the volcanic ash fall forecast in Japan. RATM was not previously applied in predicting the dispersion and deposition of radionuclides. The details of RATM are described by Shimbori et al. (2010).

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):

$$\Lambda_w=2.78\times10^{-5}\ P^{0.75}\ [1/s],$$

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):

$$\Lambda_r=P/\{[(1-LWC)/6.56\times10^{-3}T+LWC]Z_r\},$$

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):

$$\Lambda_d = V_d / Z_d,$$

where V_d is the dry-deposition velocity and Zd is the depth of surface layer. The value of V_d is set to 1×10^{-3} m/s for light particles or 1×10^{-2} m/s for depositing gas (Sportisse, 2007; 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. Note that if a tracer particle moves under the model surface in the vertical advection or diffusion step, it is forcibly reflected to the mirror symmetric point above the surface.

Specifications of preliminary version of JMA RATM are listed in Table. 1.

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 Lpar: V_d=1x10^{-3} m/s
Wet Scavenging	Ngas: None Dgas: Hertel et al. (1995) with Henry's constant=0.08 Lpar: Kitada (1994) with accumulated liquid precipitation analysis
Gravitational Settling	Ngas: None Dgas: None Lpar: Stokes' law with Cunningham correction

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

3.2 Use of MESO and RAP Data

The motion of tracer particles in RATM is calculated in the same coordinate system as the MESO analysis (Lambert conformal in the horizontal and a terrain-following hybrid in the vertical). From the point of view of the wet deposition process, due to the restriction of the treatment of the ice phase in the current 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. Due to the restriction of the current RATM's treatment of the ice phase, all RAP precipitation was considered to be liquid rain in the calculation.

3.3 Revision of RATM

As previously mentioned, the JMA MESO analysis is produced by a three hour forecast of the outer-loop model (NHM with a horizontal resolution of 5 km) of 4DVAR. These are not averaged values in the assimilation window but instantaneous values predicted by the outer loop model at the analysis time (end of the 3-hour assimilation window) and stored as the analysis field. Because instantaneous vertical motion is affected by gravity waves, simple time interpolation of updrafts between the 3 hourly analysis fields may yield an overestimation of the vertical advection of the air parcel, even if the magnitude of updraft is small.

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).

Figure 3 compares 24-hour Lpar accumulated deposition for unit release at 0000-0300 UTC, 14 March 2011. Difference is seen in the deposition over the sea off the east coast of the Kanto Plain.

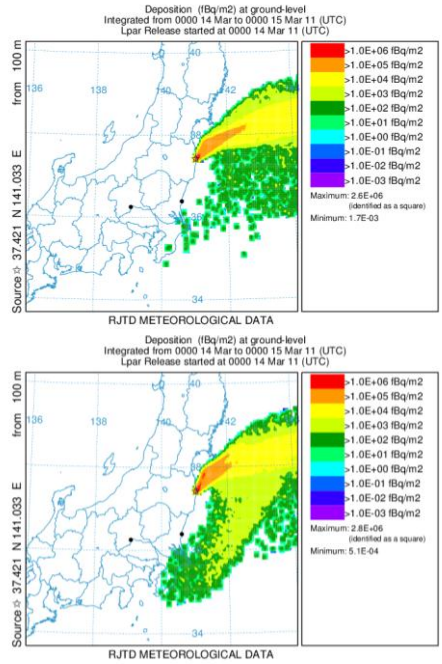
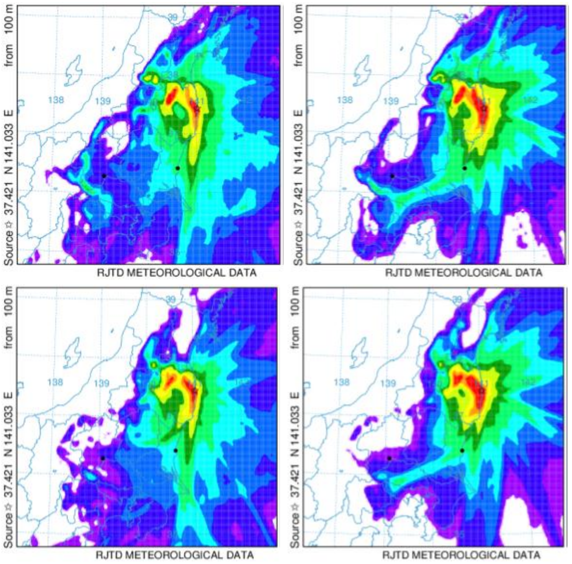


Fig. 3. Lpar accumulated deposition for unit release at 0000-0300 UTC, 14 March 2011. RAP is used for precipitation. upper) No adjustment for vertical motion. lower) 9-grid average and w*=0 at the lowest level.

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).



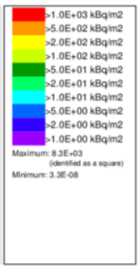


Fig. 4. Lpar (Cs-137) accumulated deposition for 11 March-3 April 2011using the JAEA source. upper left) Preliminary RATM with MESO precipitation. upper right) Preliminary RATM with RAP precipitation. lower) Same as in upper figures but results by the revised RATM.

Figure 4 compares Cs-137 accumulated deposition for 11 March-3 April 2011 using the JAEA release rates. Overestimation of deposition over Miyagi prefecture and west Kanto in the preliminary RATM (upper figures) is ameliorated in the revised RATM (lower figures). When RAP data is used for precipitation, a dense deposition area in the northwest of Fukushima Daiichi Nuclear Power Plant is more distinctly reproduced (right figures).

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 (Fig. 5 of Draxler et al., 2013). The statistical metrics used in Draxler et al. (2013) was applied to the results of the preliminary and revised RATMs. The release rates estimated by JAEA are used for the calculations. Two sets of calculations were examined, where the precipitation was given by the MESO or the RAP data.

Table 2 shows verification statistics by RATMs for Cs-137 deposition. Here, 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 1-4 mean rank metrics evaluated by the above parameters. For more detail, see Section 8 and Appendix A of Draxler et al. (2013). 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.

Table 3 is 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 by NOAA verification tools. Cs-137 deposition using the JAEA source.

RATM	R	FB	FMS	FOEX	%FA2	KSP	METRIC 1	METRIC 2	METRIC 3	METRIC 4
Preliminary MESO	0.45	-0.02	100.00	-0.46	51.01	10.0	3.09	2.60	4.08	4.59
Preliminary RAP	0.77	0.54	100.00	9.67	41.99	11.0	3.22	2.63	4.02	4.44
Revised MESO	0.70	-0.04	99.63	-0.83	37.94	10.0	3.37	2.75	4.35	4.73
Revised RAP	0.84	0.56	99.08	9.12	35.73	13.0	3.28	2.65	4.10	4.46

Table 3. Statistics of JMA RATMs by NOAA verification tools. Cs-137 concentration using the JAEA source.

RATM	R	FB	FMS	FOEX	%FA2	KSP	METRIC 1	METRIC 2	METRIC 3	METRIC 4
Preliminary MESO	0.51	-0.82	80.00	-21.43	21.43	43.0	2.22	1.63	2.79	3.01
Preliminary RAP	0.59	-1.66	57.50	-45.24	4.76	64.0	1.46	0.93	1.55	1.60
Revised MESO	0.39	-0.40	77.5	-19.05	14.29	43.0	2.30	1.67	2.92	3.06
Revised RAP	0.07	-1.68	62.5	-42.86	9.52	67.0	1.12	0.59	1.26	1.36

5. SUMMARY AND REMARKS

JMA provided MESO analysis and RAP data with a file converter kit to the WMO Task Team and UNSCEAR. These data are available to the research community. JMA RATM was modified for radionuclides. Verification against observations shows that the performance of RATM was significantly improved by the revision. Use of RAP data improved the Cs-137 deposition pattern while degraded the time series of concentration at the JAEA observation site. A similar tendency was found in the verification of other ATM calculations in the Task Team (Draxler, et al., 2013). The reason is not clear at this stage.

The results suggest several topics for future research and in particular the treatment of wet scavenging of light particles. The current version of RATM only uses liquid precipitation at surface with the MESO data, but total precipitation should be used. Also the implementation of different scavenging treatments for snow and graupel is required. To further improve the RATM, the use of the 3-dimensional distribution of water substances is required in the scavenging computation.

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