C. JMA data and meteorological analyses

C-1. Observation data of JMA[1]

This subsection describes the observation network for Meso-scale NWP system at JMA based on the documents presented at the first Task Team meeting held at Geneva in 2011 (Section B-2-1).

C-1-1. Upper air observations

Figure C-1-1 shows the upper air observation network of JMA as of March 2011. It consists of 31 wind profilers so-called WINDAS (wind profiler data acquisition system) and 16 radiosonde stations. These data are collected at the control center in the headquarters of JMA through the Automated Data Editing and Switching System (ADESS) in real time, and assimilated by the Mesoscale analysis (see C-2).

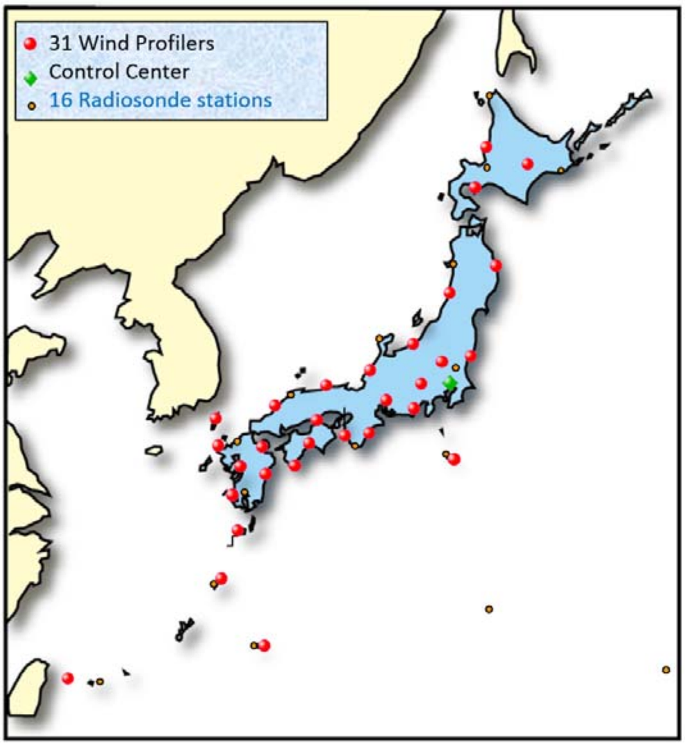

Fig. C-1-1. Upper air observation network of JMA. Large red circles indicate wind profilers, and small orange circles show raidosonde stations. After Saito et al. (2015).

C-1-2. Surface observations

Figure C-1-2 shows the surface observation network of JMA as of March 2011. JMA has totally 1,579 surface observation stations which consist of 156 manned and special automated weather stations (AWSs), and an AWS network so-called AMeDAS (Automated Meteorological Data Acquisition System). In AMeDAS, there are four types of AWSs. They

[1] K. Saito and K. Nagata

are 686 AWSs for precipitation, temperature, wind, and sunshine duration, 79 AWSs for precipitation, temperature and wind, 356 AWSs for precipitation, and 302 AWSs for snow depth. The right figure of Fig. C-1-2 is the enlarged view over East Japan, where averaged horizontal distance of AMeDAS is about 17 km for precipitation. These precipitation data are used for precipitation analysis (section C-4) and the analysis data are assimilated in Meso-scale 4D-VAR Analysis (section C-8).

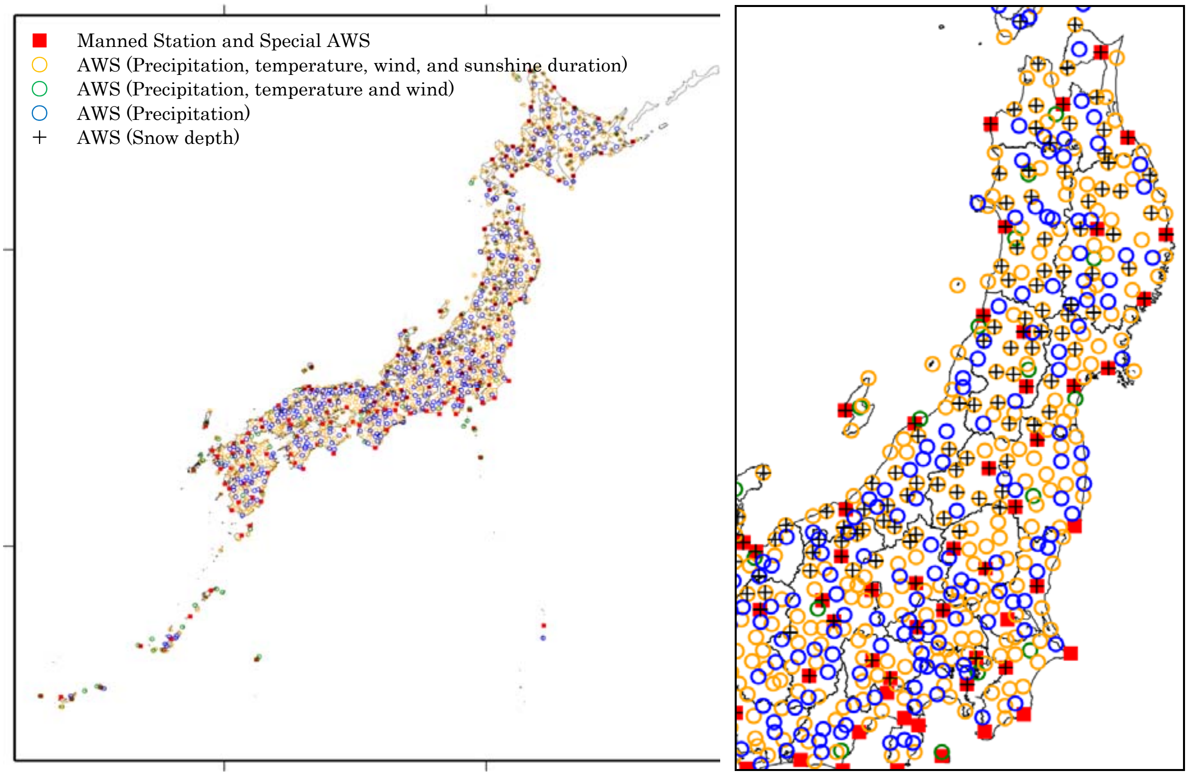

Fig. C-1-2. Left) Surface observations of JMA. Solid squares indicate manned and special AWS station. Red (green, blue) circles indicate AWS. Right) Enlarged view over East Japan.

C-1-3. Radar network

Figure C-1-3 shows the radar network of JMA. As of March 2011, JMA has 20 C-band operational meteorological radars, and 16 of them are Doppler radars[2]. Radar reflectivity data are calibrated and composited by the surface rain gauge data as the precipitation Nowcasting (Fig. C-1-4). Precipitation Nowcasting provides precipitation intensity forecasts of swiftly growing convections with a spatial resolution of 1 km up to an hour ahead to assist disaster prevention activities. Radial winds observed by these Doppler radars and Doppler Radars for Airport Weather are assimilated in Mesoscale 4D-VAR (section C-8).

[2] JMA's all 20 C-band operational radars have been Doppler radar since March 2013.

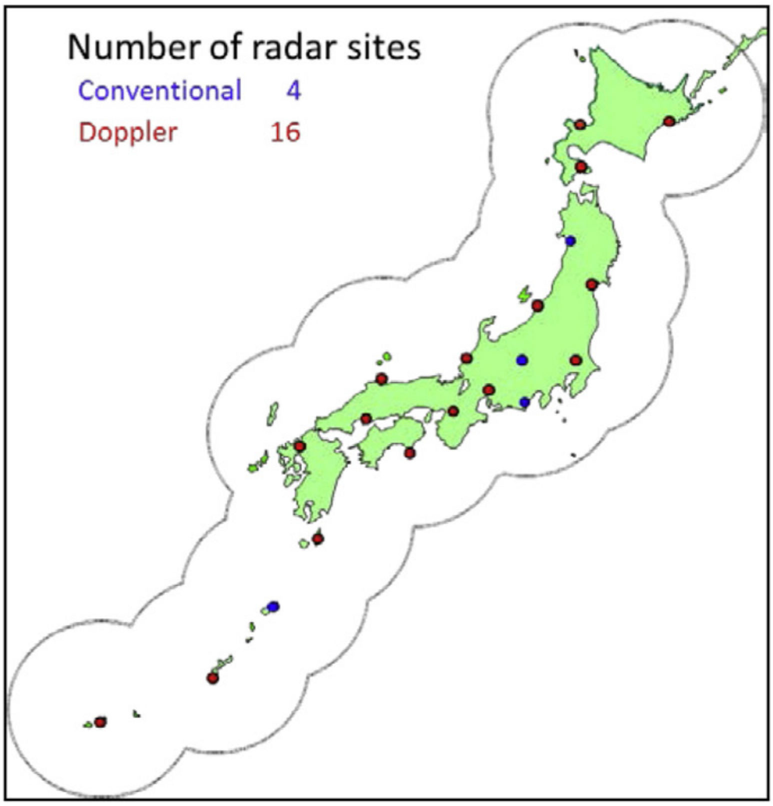

Fig. C-1-3. Weather radar network of JMA as of March 2011. Red circles indicate the Doppler radars and blue circles indicate the conventional radars. Doppler Radars for Airport Weather are not indicated.

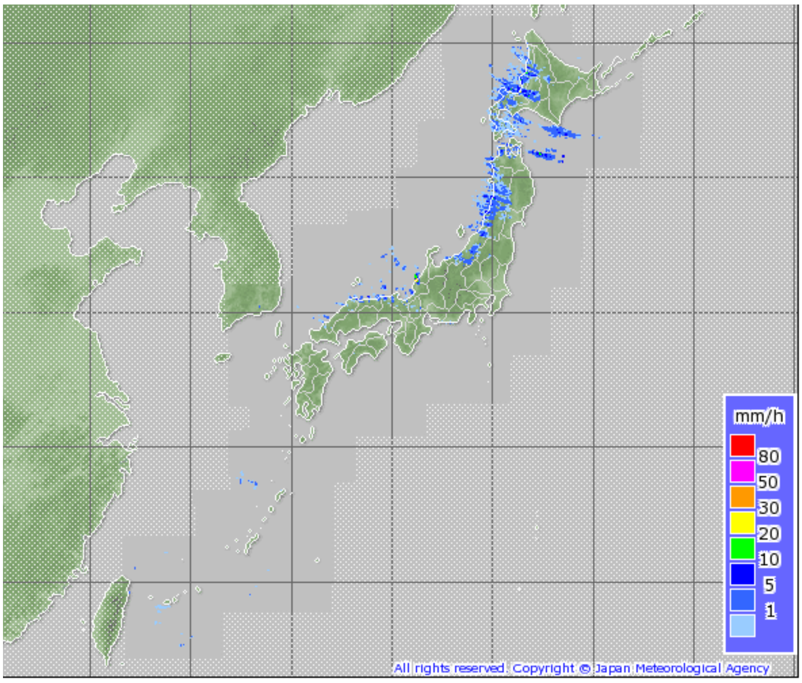

Fig. C-1-4. Example of radar composite precipitation Nowcasting of JMA. .

C-1-4. GPS network

Figure C-1-5 shows GPS ground receiver network by the Geospatial Information Authority of Japan, so-called GEONET. GEONET was originally deployed to obtain geospatial information in Japan, while total precipitable water vapor (TPW) information is analyzed by JMA in real time (Shoji, 2009). There are about 1,200 GPS stations in GEONET, and GPS-derived TPW data have been assimilated in Meso-scale Analysis since October 2009 (section C-8).

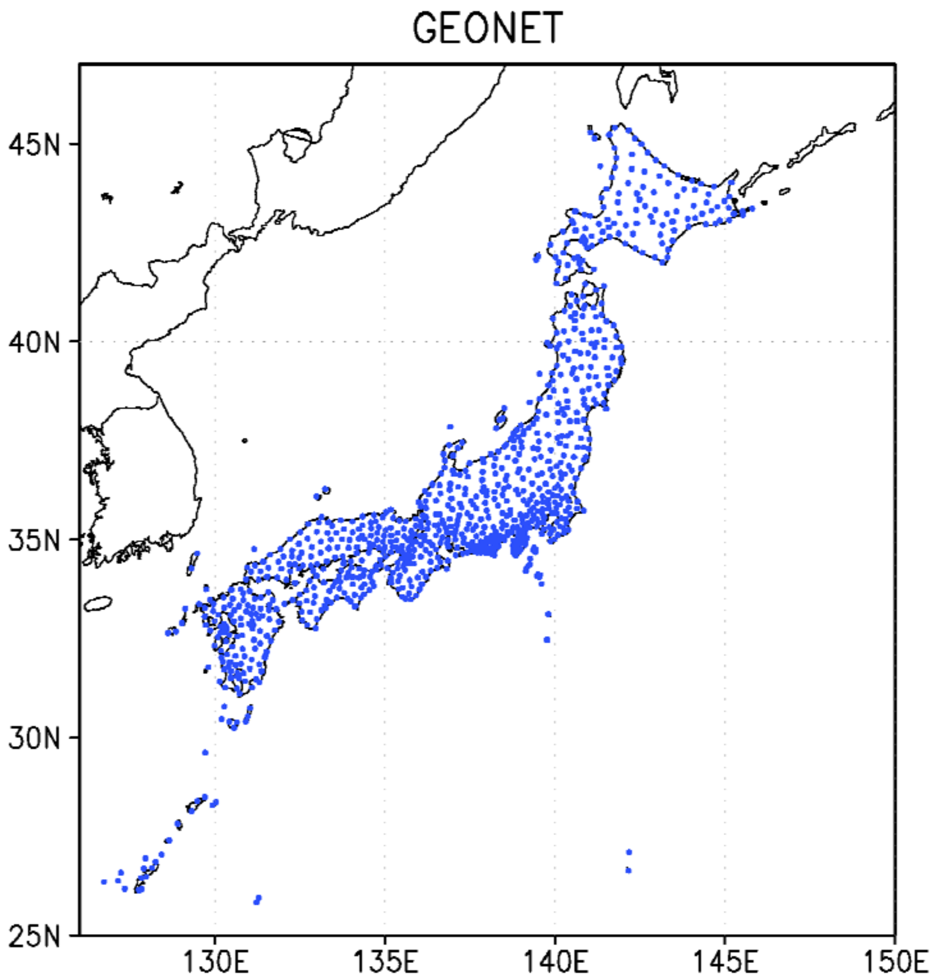

Fig. C-1-5. GPS network by Geospatial Information Authority of Japan.

C-2. NWP system at JMA[1]

This subsection describes operational NWP systems at JMA based on the documents presented at the first Task Team meeting held at Geneva in 2011 (Section B-2-1).

C-2-1. JMA deterministic NWP systems

Table C-2-1 shows deterministic NWP systems of JMA as of March 2011[2]. Two NWP systems are operated in JMA to support its official forecasting. The main objective of the Meso-scale NWP system is to support JMA's short range forecast for disaster prevention. The forecast model operated in the Meso-scale NWP system is the JMA nonhydrostatic model with a horizontal resolution of 5 km (MSM: Meso-Scale Model; Saito et al., 2007; JMA, 2013). Lateral boundary condition is given by the forecast of the JMA global spectral model (GSM). Initial condition of MSM is prepared by Meso-scale Analysis, which employs the JMA nonhydrostatic 4D-VAR system (Section C-8).

Table C-2-2 lists observations used in JMA NWP systems as of March 2011. Here. G means that the data are used in the Global Analysis, M in the Meso-scale Analysis (MESO), L in the Local Analysis, and Q in the hourly analysis. The observations described in C-1 are included in the table (shown in red letters).

Table. C-2-1. Deterministic NWP systems of JMA as of March 2011.

		Global NWP System	Meso-scale NWP System
	Objectives	Short and Medium range forecast	Short range forecast for disaster mitigation
	Forecast Domain	The whole globe	Japan and its surroundings (3600km x 2880km)
NWP Model	NWP Model	Global Spectral Model (GSM)	Meso-Scale Model (MSM)
	Horizontal Resolution	T_L959 (0.1875deg., ~20km)	5km
	Vertical Levels	60 Levels, up to 0.1 hPa	50 Levels, up to about 22km
	Forecast Hours (Initial Times)	084 hours (00, 06, 18UTC) 216 hours (12UTC)	15hours(00,06,12,18UTC) 33hours (03,09,15,21UTC)
Data Assimilation System	Data Assimilation System	Global Analysis (GSM 4D-Var)	Meso-scale Analysis (JNoVA 4D-Var)
	Horizontal Resolution	TL319 (0.5625deg., ~60km)	15km
	Vertical Levels	60 Levels, up to 0.1 hPa	40 Levels, up to around 22km
	Data Cut-Off	+02h20m [Early Analysis]	+50min
		+05h25m (06/18UTC) +11h25m (00/12UTC) [Cycle Analysis]	
	Assimilation Window	-3h~+3h	-3h~0

[1] K. Saito and Y. Honda

[2] JMA has been operating local forecast model (LFM) with a horizontal resolution of 2 km since 2013. Specifications of global and Meso-scale NWP systems have also been enhanced in the following years (JMA, 2013).

Table. C-2-2. Observations used in JMA NWP systems as of March 2011.

	Kind	P	T	UV	RH	IPW	RR	Doppeler Velocity	Radiance	Refractivity
Direct Observations	Land Surface Observations	GM	L	L						
	Automated Weather Stations		LQ	LQ						
	Sea Surface Observations	GM	GM							
	Aircraft Observations		GMLQ	GMLQ						
	Upper Air Sounding	GM	GM	GM	GM					
	Upper Air Wind Profiles	GM		GM						
Remote Sensing	Wind Profiler			GMLQ						
	Doppler Radar							MLQ		
	Radar/Raingauge-Analyzed Precipitation						M			
	Radar Reflectivity				M					
	Ground-Based GPS					ML				
Bogus	Typhoon Bogus	GM		GM						
GEO Satellite	Atmospheric Motion Vector			GMQ						
	Clear Sky Radiance								GM	
LEO Satellite	Polar Atmospheric Motion Vector			G						
	Microwave Sounder								GM	
	Microwave Imager						M		GM	
	Scatterometer			G						
	GPS Radio Occultation									G

C-2-2. History of operational Meso-scale NWP system at JMA

The first operational Meso-scale NWP system at JMA started in March 2001 using a spectral hydrostatic model. The horizontal resolution was 10 km, the number of vertical levels was 40, and the forecast was conducted every six hours. The forecast model was replaced by the JMA nonhydrostatic model in 2004 (Saito, 2006) and the model resolution, vertical model levels, and operation time interval were enhanced to 5 km, 50 levels, and 3 hour in 2006, respectively. Fig. C-2-1 shows the model domain of MSM as of March 2011, which covers Japan and its surrounding areas with grid numbers of 721x577 (3,600 km x 2,890 km)[3]. The main purpose of the Meso-scale NWP system is to support short-term weather forecast for disaster prevention, while its forecasts are used for very short range precipitation forecast and forecast for aviation (Terminal Area Forecast, TAF).

[3] The model domain of MSM has been enlarged to 4,320 km x 3,300 km since March 2014 (JMA, 2014).

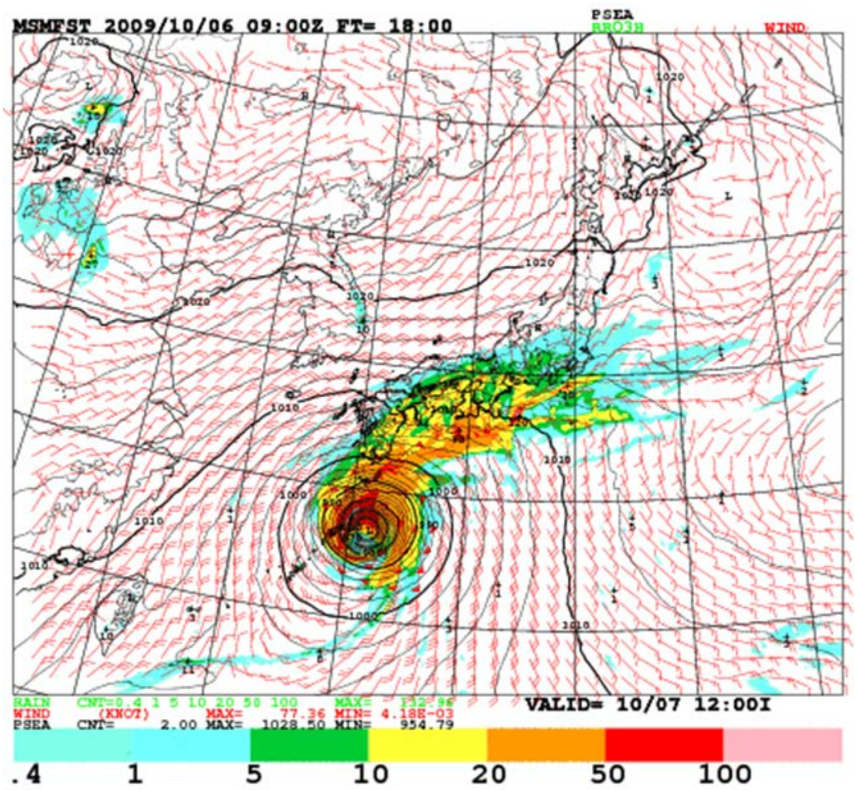

Fig. C-2-1. Domain of MSM (as of 2011) and an example of its forecast.

Several modifications have been done to Meso-scale NWP system since its start of 2001. Table C-2-3 lists the main modifications added to the operational Meso-scale NWP system at JMA from 2001 to 2011. It includes the modifications of the data assimilation system and the use of observation data, such as the implementation of JMA nonhydrostatic 4DVAR in 2009 (Section C-9),introduction of the global positioning system (GPS)-derived total precipitable water vapor (TPWV) data in 2009 (Ishikawa, 2010), and introduction of 1D-Var retrieved water vapor data from radar reflectivity in 2011 (Ikuta and Honda, 2011).

These modifications have contributed to the remarkable improvement of the QPF performance of MSM (Fig. C-2-2).

Table. C-2-3. Modifications for operational Meso-scale NWP system at JMA up to 2011. After Saito (2012).

Year. Month	Modification
2001. 3	Start of Meso-scale NWP system (10kmL40+OI)
2001. 6	Wind profiler data
2002. 3	Meso 4D-Var
2003. 10	SSM/I microwave radiometer data
2004. 7	QuikSCAT Seawinds data
2004. 9	Nonhydrostatic model
2005. 3	Doppler radar radial winds data
2006. 3	Enhancement of model resolution (5kmL50)
2007. 5	Upgrade of physical processes
2009. 4	Nonhydrostatic 4D-Var
2009. 10	GPS total precipitable water vapor (TPWV) data
2011. 6	Water vapor data retrieved from radar reflectivity

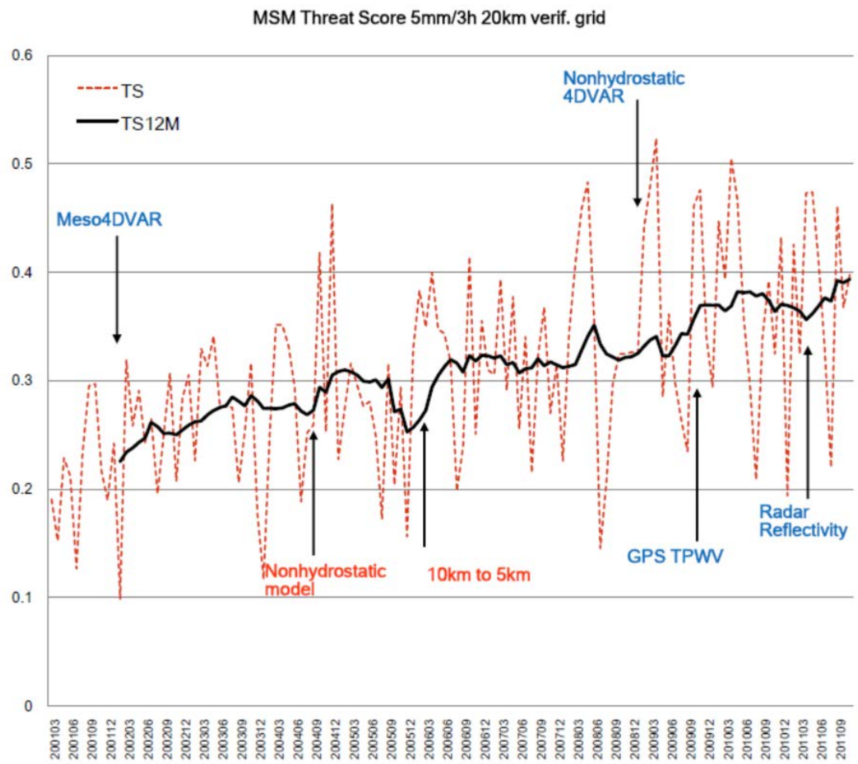

Fig. C-2-2. Domain Threat score of MSM for three-hour precipitation averaged for FT = 3 h to 15 h with a threshold value of 5 mm/3 hour from March 2001 to November 2011. The red broken line denotes the monthly value, while the black solid line indicates the 12-month running mean. After Saito (2012).

C-3. Data configurations of JMA mesoscale analysis[1]

For the task team, the 4D-VAR mesoscale analysis (MA) data in the GRIB2 format, bit-oriented data exchange format standardized by the World Meteorological Organization (WMO) Commission for Basic Systems (CBS) were provided in May 2012. Data configurations of provided data are described as follows:

Horizontal grid numbers: 719 in an x-direction and 575 in a y-direction,

Horizontal resolution: 5 km,

Vertical layers: 48 with the terrain following hybrid vertical coordinate,

Model top height: 21.801km,

Map projection: Lambert conformal conic projection with standard latitudes of 30°N and 60°N, and standard longitude of 140°E, and grid point of (488, 408) corresponds to 30°N and 140°E.

Here grid point of (1, 1) is located at the northwestern edge. Three kinds of files in the GRIB2 format were provided, found in detail in Table C-3-1; the first is model plain data including atmospheric elements such as winds, temperature and hydrometeors, the second is surface land data, and the last is sea surface temperature data.

For the scientific basis of JMA 4D-VAR mesoscale analysis, see C-8.

[1] T. Kato, T. Hara and N. Nemoto

Table C-3-1. Mesoscale analysis (MA) data in the GRIB2 format provided by JMA.

Model plain data of JMA mesoscale analysis

File name: jma_ma_met_hybrid-coordinate_yyyyMMddhhmm.grib2bin

Element		Unit	Layer	Grib code
U	x-wind speed on Lambert projection	m/s	1,2,--,48	0,2,2
V	y-wind speed on Lambert projection	m/s	1,2,--,48	0,2,3
W	z-wind speed	m/s	1,2,--,48	0,2,9
Z	height *	m	surface 1,2,--,48	0,3,5
PT	potential temperature	K	1,2,--,48	0,0,2
QV	water vapor mixing ratio (specific humidity)	kg/kg	1,2,--,48	0,1,2
QC	cloud water mixing ratio	kg/kg	1,2,--,48	0,1,22
QR	rain water mixing ratio	kg/kg	1,2,--,48	0,1,24
QCI	cloud ice mixing ratio	kg/kg	1,2,--,48	0,1,23
QS	snow mixing ratio	kg/kg	1,2,--,48	0,1,25
QG	graupel mixing ratio	kg/kg	1,2,--,48	0,1,32
P	pressure	Pa	surface 1,2,--,48	0,3,0
PSEA	sea level pressure	Pa	surface	0,3,1
RAIN	previous 3-hour accumulated precipitation amount	kg/m^2	surface	0,1,8

*) Terrain height of model is stored as surface in Z.

Surface land data of JMA mesoscale analysis

File name: jma_ma_land-surface_yyyyMMddhhmm.grib2bin

Element		Unit	Grib code
TUGD	soil temperature (4 layers) *	K	2,0,2
KIND	surface kind (1-4) **		2,192,0

*) depth of layers from the surface: 0.02m, 0.115m, 0.39m, 0.89m

**) 1: no snow on land, 2: no ice over the sea, 3: snow on land, 4: ice over the sea

Surface ocean data of JMA mesoscale analysis

File name: jma_ma_ocean_sst_yyyyMMddhhmm.grib2bin

Element		Unit	Grib code
SST	sea surface temperature	K	10,3,0

C-4. Quantitative Precipitation Estimation (QPE) and Quantitative Precipitation Forecasting by JMA[1]

Radar/Rain gauge-Analyzed Precipitation (referred to here as “R/A”) is a QPE product of JMA (see Fig. C-4-1). It shows one-hour cumulative rainfall with a spatial resolution of 1 km, and is issued every 30 minutes.

JMA collects data from about 10,000 rain gauges operated by JMA (see Fig. C-1-2), the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and local governments every ten minutes or every hour (rain gauges are located in every 7-km grid square on average) and data from 46 C-band radars operated by JMA (see Fig. C-1-3) and MLIT with a spatial resolution of 1 km every five minutes. Each radar covers an area of 500 km × 500 km. All of these data are used for producing the R/A.

The R/A data are produced with the following steps. First, echo intensity data obtained every five minutes are accumulated. If echoes move too fast, one-hour accumulated echo intensities sometimes show an unnatural striped pattern. To avoid such unnatural patterns, accumulation is conducted taking account of echo movements.

Second, to produce accurate R/A, calibration of one-hour accumulated radar data is performed to fit the distribution of one-hour accumulated rain gauge data. Calibration is conducted in two steps. First, each piece of radar data is calibrated to fit averaged rain gauge data within the relevant observation range. Then, detailed calibration of radar data over land is conducted to fit rain gauge data on local scales.

After the above calibration, R/A is produced using the calibrated accumulation of echo intensities by transforming the coordination from zenithal projection into latitude-longitude grids with equidistant cylindrical projection. Nagata (2011) which explains how to produce R/A in detail is carried in the following pages. Further, JMA has issued “High-resolution Precipitation Nowcasts” since August 2014.

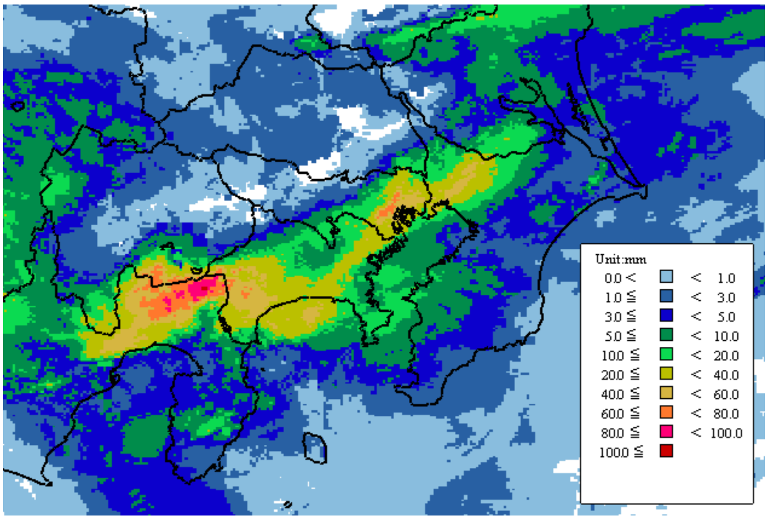

Fig. C-4-1. Sample of R/A product (06 UTC, 8 Sep. 2010).

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[1] K. Nagata

Quantitative Precipitation Estimation and Quantitative Precipitation Forecasting by the Japan Meteorological Agency

Kazuhiko NAGATA
Forecast Division, Forecast Department
Japan Meteorological Agency

1. Introduction

Typhoons sometimes hit countries in East Asia and Southeast Asia, and may bring various hazards including sediment-related disasters, flooding and inundation. To prevent and mitigate damage from such disasters, analysis and forecasting of precipitation amounts is very important. Analysis relating to the distribution of rainfall amounts is called Quantitative Precipitation Estimation (QPE), and that relating to forecasting is called Quantitative Precipitation Forecasting (QPF). The Japan Meteorological Agency (JMA) developed QPE and QPF products as well as QPE/QPF-induced products using radar data, rain gauge data and numerical weather prediction (NWP) output. Figure 1 shows the relationships that link these various data and products, including QPE and QPF.

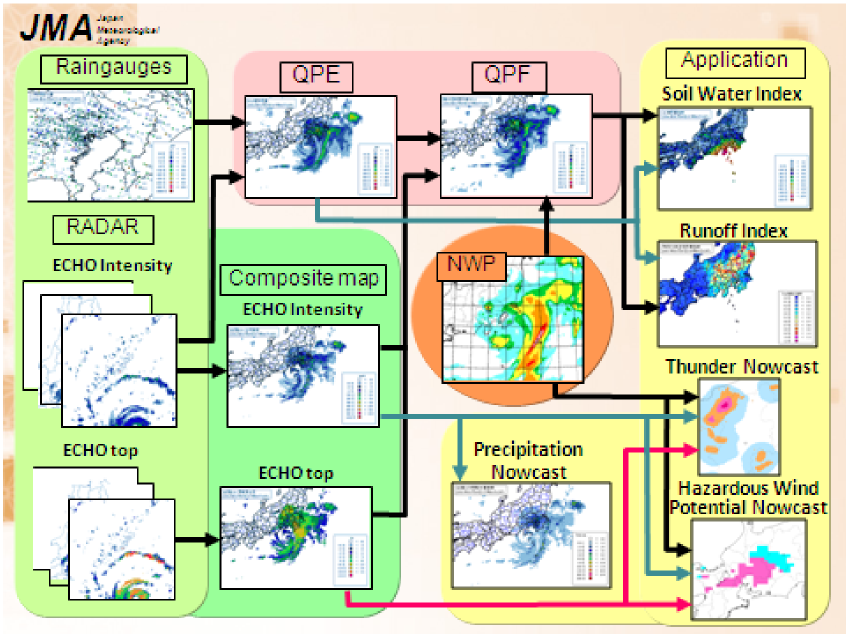


Fig. 1 Various precipitation products derived from rain gauge and radar data

2. Radar/Rain gauge-Analyzed Precipitation

Radar/Rain gauge-Analyzed Precipitation (referred to here as “R/A”) is a QPE product of JMA. It shows one-hour cumulative rainfall with a spatial resolution of 1 km, and is issued every 30 minutes. Figure 2 shows a sample.

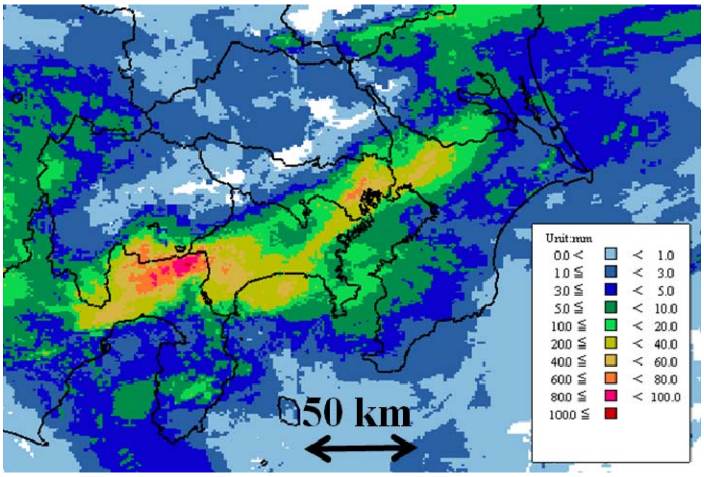


Fig. 2 Sample of R/A product (06 UTC, 8 Sep. 2010)

2.1 Observation data used to produce R/A

Both rain gauge and radar data are used to produce R/A. Although rain gauges measure precipitation amounts with satisfactory accuracy, they can observe only at a single point. Conversely, radars can observe large areas at the same time with a higher spatial resolution than the rain gauge network, but may produce readings different from those obtained with a ground-based rain gauge as they measure amounts of rain overhead. Their accuracy is also not as reliable as that of rain gauges because they are remote sensing instruments. For monitoring and prediction of sediment-related disasters, flooding and inundation, the rain gauge network is too rough and radar observation lacks sufficient accuracy. For this reason, JMA produces R/A 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 by JMA, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and local governments every ten minutes or every hour (rain gauges are located in every 7-km grid square on average) and data from 46 C-band radars operated by JMA and MLIT with a spatial resolution of 1 km every five minutes. Each radar covers an area of 500 km × 500 km.

2.2 R/A algorithms

The procedure for producing R/A involves the following three steps:

1. Accumulation of radar intensity data
2. Calibration of radar data
3. Composition of calibrated radar data

This section briefly describes each process.

2.2.1 Accumulation of radar intensity data

First, echo intensity data obtained every five minutes are accumulated. If echoes move too fast, one-hour accumulated echo intensities sometimes show an unnatural striped pattern (see the image on the left of Fig. 3). To avoid such unnatural patterns, accumulation must be conducted taking account of echo movements (see the image on the right of Fig. 3). In this process, the observed echoes are divided into pieces and traced every five minutes. Then, by summing up the echo intensities passing a grid, the one-hour accumulated echo intensity of the grid is estimated. Quality checking of echo intensities is also conducted at this stage.

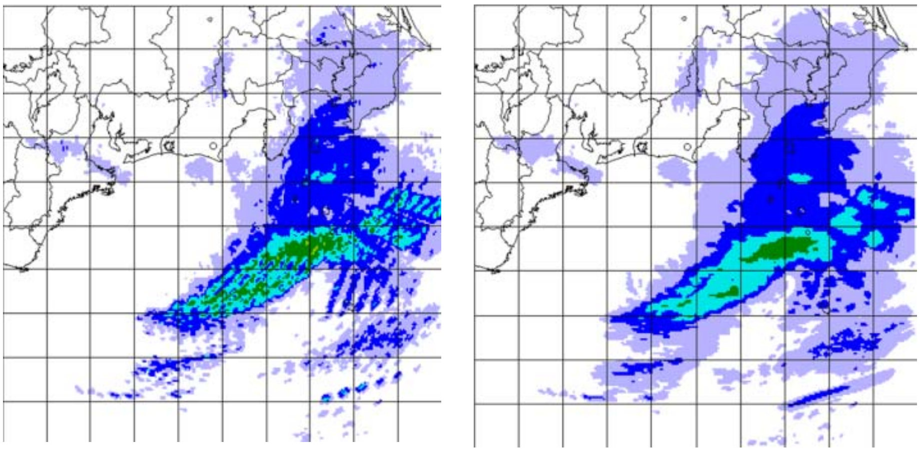


Fig. 3 Accumulation of radar intensity data
Left: one-hour accumulated echoes; right: as per the figure on the left, but with consideration of echo movements

2.2.2 Calibration of radar data

To produce accurate QPE, calibration of one-hour accumulated radar data is performed to fit the distribution of one-hour accumulated rain gauge data. Calibration is conducted in two steps. First, each piece of radar data is calibrated to fit averaged rain gauge data within the relevant observation range. Then, detailed calibration of radar data over land is conducted to fit rain gauge data on local scales.

2.2.2.1 Calibration over the whole radar observation range

Values of one-hour precipitation estimated from the accumulation of radar echo intensities in a certain grid are generally different from observation values from a rain gauge in the grid. As rain gauge measurement is more reliable, the accumulation of radar echo intensities is calibrated with rain gauge observations within the radar observation range to meet the following two conditions:

(1) The average of the calibrated accumulation for radar echo intensities over a certain domain should be equal to that of all other radars observing the same domain.
(2) The average of the calibrated accumulation for radar echo intensities over a certain grid should be equal to the average of the rain gauge observations.

Figure 4 shows a sample of this calibration. The figure on the left shows one-hour precipitation estimated from the accumulation of radar echo intensities; the central figure shows one-hour precipitation after calibration to meet the two conditions outlined above; and the figure on the right shows the one-hour precipitation observed by rain gauges. The original accumulation of radar echo intensities (left) in a certain grid is less than the rain gauge observation in the same grid (right). Due to calibration, the central figure shows more precipitation than that on the left. The figure on the right is closer to the central figure than the left figure.

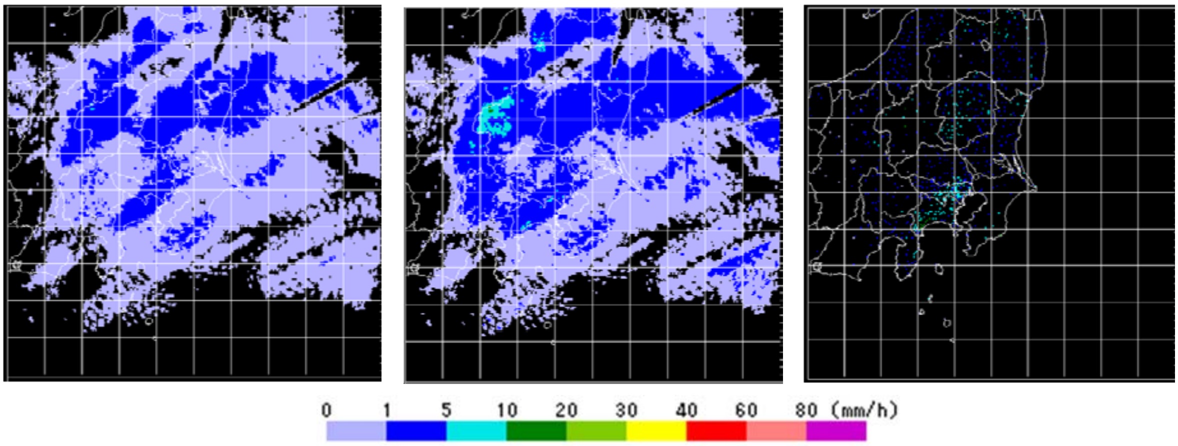


Fig. 4 Left: sample of one-hour precipitation estimated by accumulating echo intensities; center: after calibration; right: from raingauge observations

2.2.2.2 Calibration over land

The calibrated echo intensities explained above are further calibrated to enable expression of more detailed patterns of precipitation on local scales (Makihara, 2000). For example, the calibrated accumulation of echo intensities for a certain grid g derived using the method described in 2.2.2.1 is calibrated again using data from rain gauges within about 40 km of that grid. A calibration factor for grid g is calculated with weighted interpolation of the calibration factors of the surrounding grids that contain rain gauges within 40 km of the grid. Here, the calibration factor for the grid is defined as the ratio of rain gauge observation values to the calibrated accumulation of radar echo intensities in the grid using the method outlined in 2.2.2.1. The following factors are taken into account to calculate the weight of interpolation:

(1) Distances between grid g and rain gauges
(2) Differences between echo intensity for grid g and those for grids containing rain gauges
(3) Beam attenuation rate for precipitation
(4) Uniformity of rain gauge distribution

Multiplying the calibrated echo intensities by the calibration factor as determined above gives the estimated precipitation for grid g.

Figure 5 shows a sample of this calibration. The figure on the left shows calibrated accumulation of radar echo intensities calculated using the method outlined in 2.2.2.2, and that on the right shows one-hour rain gauge data (in the same way as the image on the right of Fig. 4). The figure on the left matches the rain gauge data better than the central image in Fig. 4.

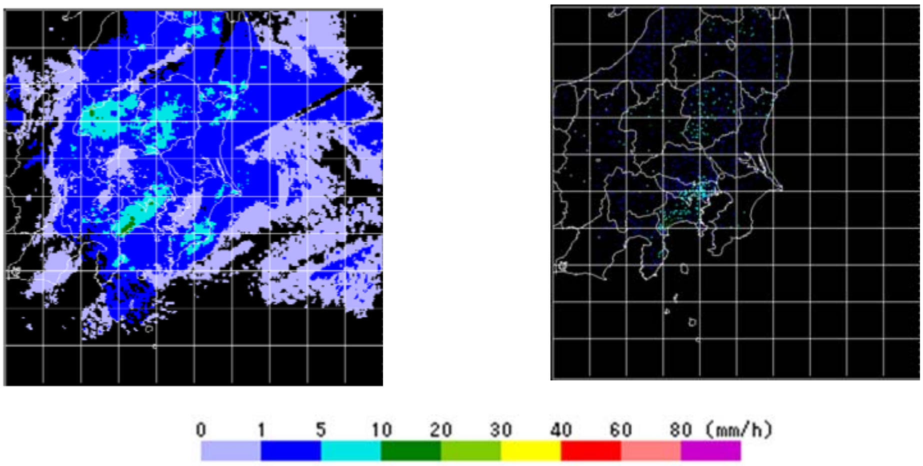


Fig. 5 Left: sample of one-hour precipitation after calibration over land; right: the corresponding raingauge observations (as per the image on the right of Fig. 4)

2.2.3 Composition of calibrated radar data

After the above calibration, a composite precipitation map is produced using the calibrated accumulation of echo intensities calculated using the method outlined in 2.2.2.2 from 46 radars located around the country by transforming the coordination from zenithal projection into latitude-longitude grids with equidistant cylindrical projection. If two or more radars observe the same grid, the greater value is selected. Figure 6 shows calibrated echo intensities covering each region and a composite precipitation map of the country.

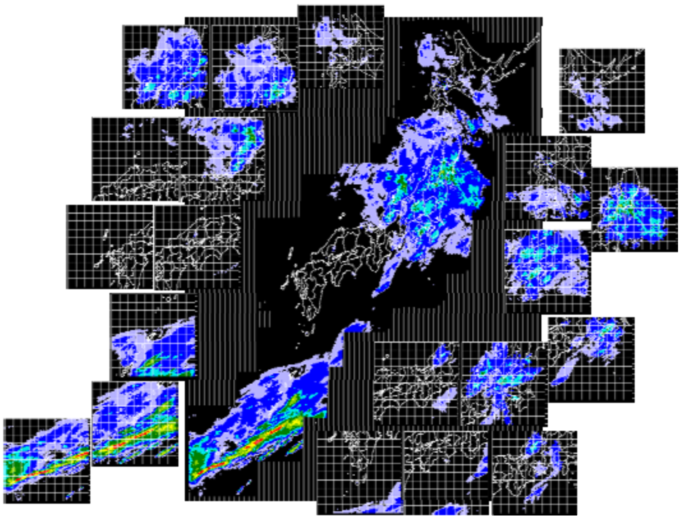


Fig. 6 Radar data covering each region and a composite precipitation map

2.3 Accuracy of R/A

To assess the accuracy of R/A, experimental R/A data for verification excluding rain gauge data at about 200 observing points were prepared, and were compared with the excluded rain gauge data. Rain gauge observation values were compared with R/A values for nine grids (a central grid and the eight grids surrounding it) considering location errors equivalent to the dimensions of one grid (i.e., 1 km) stemming from wind-related advection of raindrops before their arrival at ground level, and/or errors resulting from coordinate transform.

Figure 7 shows a scatter plot comparing hourly R/A values and corresponding rain gauge measurements taken over a period of four months during the warm season (from August to November of 2009). Only the best R/A values out of the nine grids are plotted. The figure shows close agreement between R/A values and rain gauge measurements.

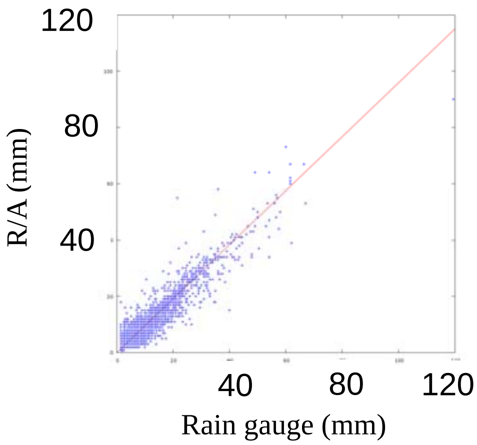


Fig. 7 Scatter plot of R/A and rain gauge data with a regression line (red) (R/A = 0.96 × Raingauge)

3. Very-short-range Forecasting of Precipitation

Very-short-range Forecasting of Precipitation (referred to here as “VSRF”) is a QPF product of JMA. It provides hourly precipitation forecasting up to six hours ahead with a spatial resolution of 1 km. VSRF is calculated by merging the forecast precipitation with values from JMA’s mesoscale model (MSM) and the extrapolated composite echo intensity. Figure 8 shows a sample of VSRF. An outline of the procedures for producing VSRF is given below.

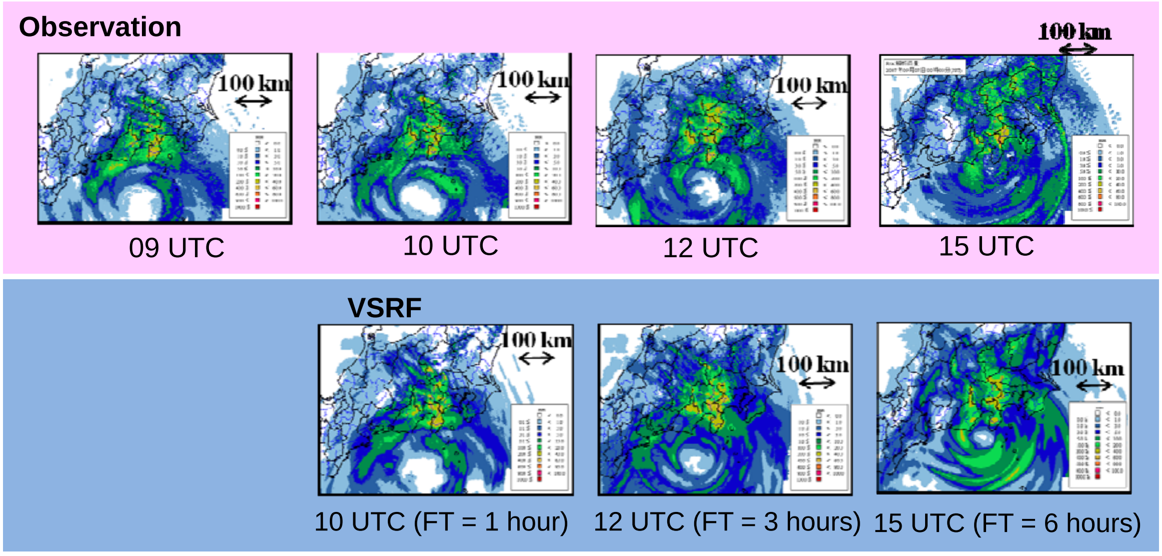


Fig. 8 Sample of VSRF (initial time: 09 UTC, 6 Sep. 2007)

3.1 VSRF algorithms

Generally, extrapolation is the best method of precipitation forecasting for a time frame within a few hours from the present. However, a numerical model gives better performance gradually over time. JMA therefore conducts VSRF by both using extrapolation and merging model output. The procedure for producing VSRF consists of two parts:

1. The extrapolation method
2. The merging method

3.1.1 Extrapolation method

3.1.1.1 Movement vectors

First, the area over Japan is divided into 50-km grid squares. Then, the movement vectors of precipitation systems are estimated for every 50-km grid using a pattern matching method, which indicates the systems' direction and speed of movement. In order to avoid any adverse influence from orographic effects on this estimation[1], time subtractions of R/A are used. Thirty candidates for movement vectors in the grid with the highest matching scores are obtained accordingly using the differences among R/A (t = 0 h), R/A (t = -1 h), R/A (t = -2) and R/A (t = -3 h). Then, the most suitable candidate vector is selected in consideration of time-space smoothness. Movement vectors gradually approach the speed of 700-hPa winds of the MSM as the forecast time increases. Figure 9 shows a sample of a movement vector (left) and the one-hour accumulated precipitation forecast with this movement vector (right).

[1] Orographic effects in a grid cause precipitation systems to look static or appear to move more slowly than they actually do.

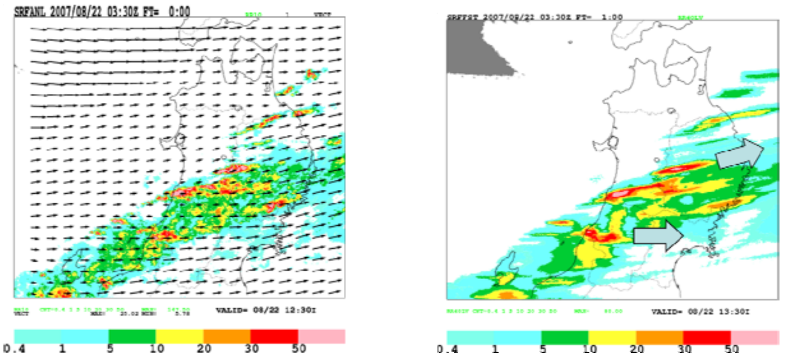


Fig. 9 Sample of movement vectors and forecast one-hour accumulated precipitation
Left: initial echo intensity (shading) and movement vectors (arrows); right: forecast one-hour accumulated precipitation. The block arrows show precipitation system direction of movement.

3.1.1.2 Orographic effects

Precipitation caused by orographic enhancement is sometimes seen to be stationary over the windward side of mountains. The algorithm follows the concept of the seeder-feeder model (Browning & Hill, 1981). Rainfall passing through a feeder cloud generated by orographic effects becomes enhanced due to water droplets in the feeder cloud.

Precipitable water, which is estimated using data for temperature, relative humidity and wind from the surface to 850 hPa in the MSM, is used to judge whether feeder clouds are generated. If so, precipitation is enhanced depending on the amount of rainfall from the seeder cloud. Figure 10 shows orographic enhancement of precipitation.

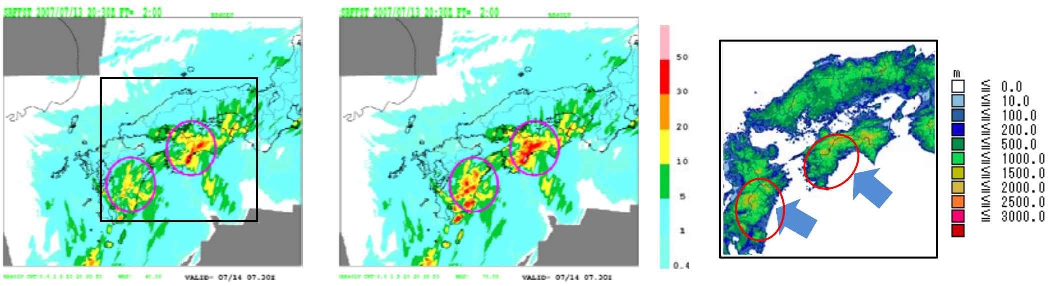


Fig. 10 Orographic enhancement (inside the circles of the figures to the left and center)
Left: forecast one-hour accumulated precipitation without orographic effects; center: as per the image on the left, but with orographic effects; right: altitude map showing the square area from the figure on the left. The block arrows show precipitation system direction of movement.

The dissipation of echo on the lee side of mountains is also considered. This occurs when the echo top is low, the angle between the directions of mid- and low-level winds is small, and no echoes are present in the dissipation area. Echo dissipation is clearer when echo intensity is stronger and the travel time from the mountaintop to the dissipation area is longer. Echo dissipation is estimated statistically from 700-hPa winds, 900-hPa winds and the relative humidity of the MSM. Figure 11 shows a case of echo dissipation.

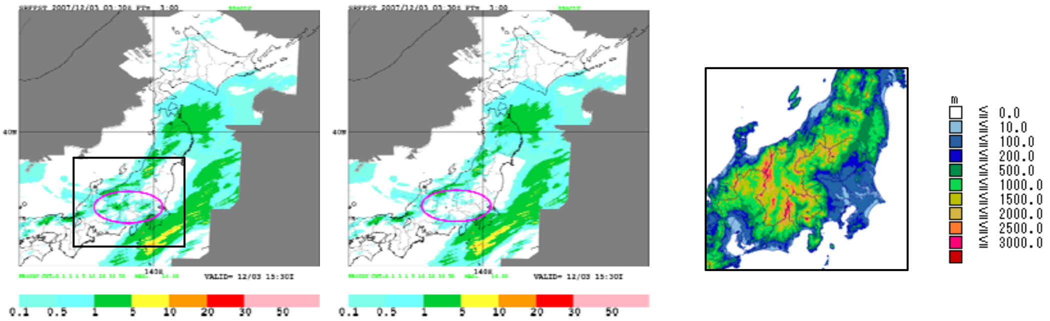


Fig. 11 Echo dissipation (inside the circles of the figures to the left and center)
Left: forecast one-hour accumulated precipitation without orographic effects; center: with orographic effects; right: topographic map with altitude showing the square areas from the figures to the left and center.

3.1.1.3 Accumulation of forecast intensity

The initial field used for VSRF is a composite echo intensity field obtained in the process of making R/A. The echo intensity field is shifted along the movement vector with a time step of two or five minutes. One-hour precipitation at a particular point is calculated as the sum of the echo intensities passing that point. In the process, enhancement and dissipation of precipitation due to orographic effects are considered.

3.1.2 Merging of extrapolation method and MSM

The performance of the conventional extrapolation method is satisfactory up to three to four hours from the initial time. For forecast times of more than six hours, the results of the MSM are considered superior to those of the extrapolation method. It is expected that four- to six-hour forecasts can be improved by merging the results of the extrapolation method and those of the MSM with a different blending ratio over time. The blending ratio is estimated from the accuracy levels of the extrapolation method and the MSM over the past few hours (Araki, 2000). VSRF is the output of this merging process, for which a sample is shown in Figure 12. The precipitation in the red circle for VSRF is from an extrapolation method forecast, and that in the blue circle is from the MSM. R/A more closely corresponds to VSRF than to extrapolation method forecasting and the MSM due to the merging of the extrapolation method forecast and the MSM.

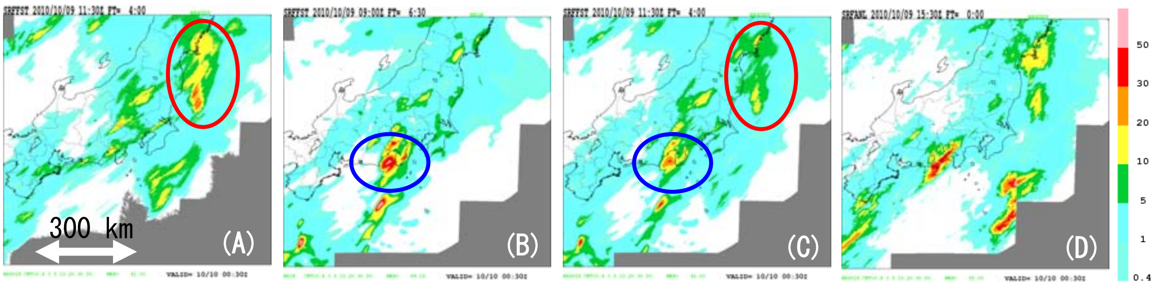
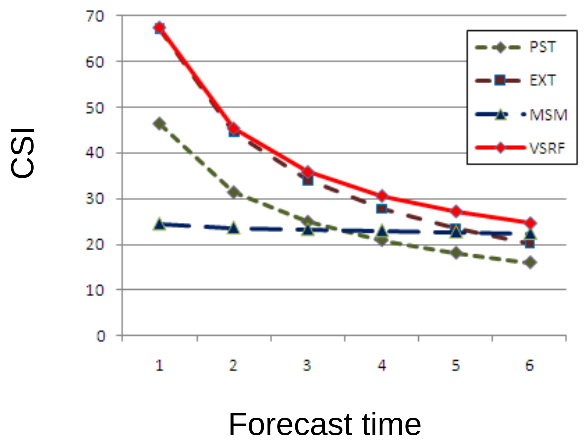


Fig. 12 Merging process

Forecasting with (A) the extrapolation method, (B) the MSM and (C) VSRF for 1530 UTC on 9 Oct., 2010, and (D) R/A for the same time. The initial time of (A) and (C) is 1130 UTC (FT = 4), and that of (B) is 0900 UTC (FT = 6.5). Precipitation in the red circle for VSRF originates from the extrapolation method, and that in the blue circle originates from the MSM. The amount of precipitation depends on the blending ratio.

3.2 Accuracy of VSRF

Critical Success Index (CSI) values for VSRF, the extrapolation method (EXT), the MSM and the persistent forecast (PST) for averaged hourly precipitation from June to August 2010 are shown in Fig. 13. Here, the region over Japan was divided into 20-km grid squares. The threshold of rainfall is 1 mm/hour. The figure shows that VSRF exhibits superior performance over the whole forecast time.



		Event observed	
		Yes	No
Event forecast	Yes	A	B
	No	C	D

CSI = A / (A + B + C) × 100

Fig. 13 CSI of VSRF, the extrapolation method (EXT), the MSM and the persistent forecast (PST) verified from June to August 2010

4. Applications of QPE/QPF

Precipitation figures alone do not provide enough information for forecasters to monitor and forecast sediment-related disasters because such events are closely linked to the amount of moisture in the soil. JMA uses the Soil Water Index to monitor and forecast sediment-related disasters.

Precipitation figures alone also provide insufficient information for forecasters to monitor and forecast flood disasters because such events are closely linked to the amount of water outflow to rivers as well as the time lag of water as it moves along river channels. JMA uses the Runoff Index to monitor and forecast flood disasters.

4.1 Soil Water Index

The Soil Water Index (referred to here as the “SWI”) is calculated up to six hours ahead with a spatial resolution of 5 km showing the risk of sediment-related disasters (debris flow, slope failure, etc.) caused by heavy rain. Figure 14 shows a sample of the SWI.

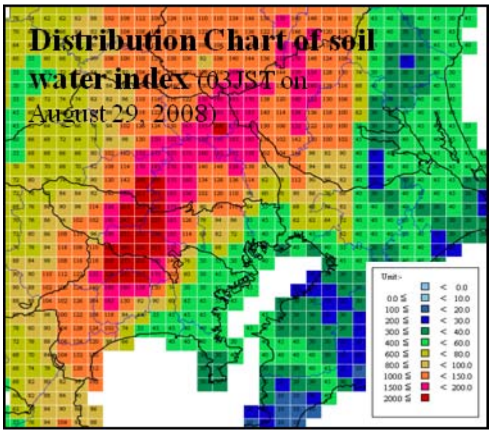
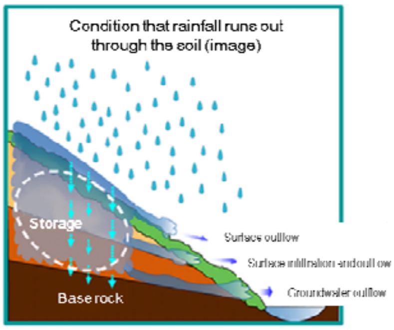


Fig. 14 Soil Water Index distribution chart

The risk of sediment-related disasters caused by heavy rain becomes higher when the amount of moisture in soil increases. Such disasters may sometimes be caused by rainfall from several days before.

The amount of moisture in the soil is indexed using the tank model method to indicate how much rainwater is contained in soil based on rainfall analysis (see Fig. 15). R/A and VSRF are used as input for the tank model.



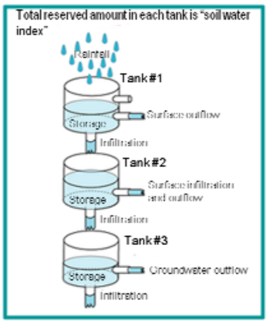


Fig. 15 Outline of tank model

Left: Condition in which rainfall runs out through soil; right: The total reserved amount in each tank is used to form the Soil Water Index.

Sediment-related disasters frequently occur in areas with high SWI values. Figure 16 shows a time-sequence representation of the SWI in a grid where a sediment-related disaster actually occurred. Its timing approximately coincided with the peak SWI value.

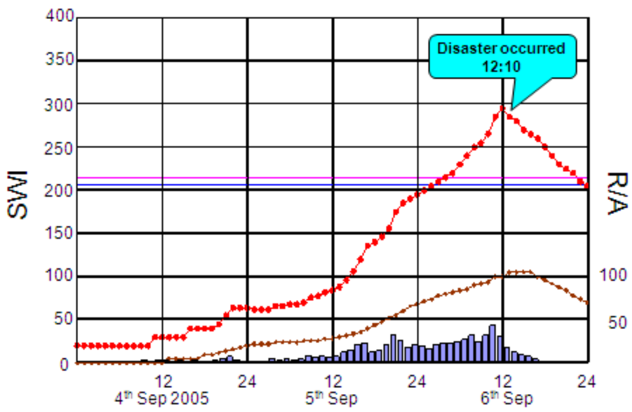


Fig. 16 Time-sequence representation of SWI and rainfall amounts in a grid where a sediment-related disaster occurred. The red line shows the SWI, the brown line shows 24-hour cumulative rainfall, and the bars show 1-hour cumulative rainfall.

Since May 2010, the SWI has been used by forecasters at JMA's meteorological observatories when issuing heavy rain warnings/advisories to call attention to the risk of sediment disasters.

4.2 Runoff Index

The Runoff Index (referred to here as the "RI") is calculated up to six hours ahead with a spatial resolution of 5 km showing the risk of flooding for individual rivers in the country. The amount of rainfall is not directly linked to the risk of flooding for the following two reasons:

1. There is a time difference between the occurrence of rainfall and increased water levels in rivers.
2. It takes time for water to run down river channels.

Accordingly, when monitoring and forecasting flood risk, the above two effects should also be carefully considered in addition to accurate QPE/QPF (see Fig. 17).

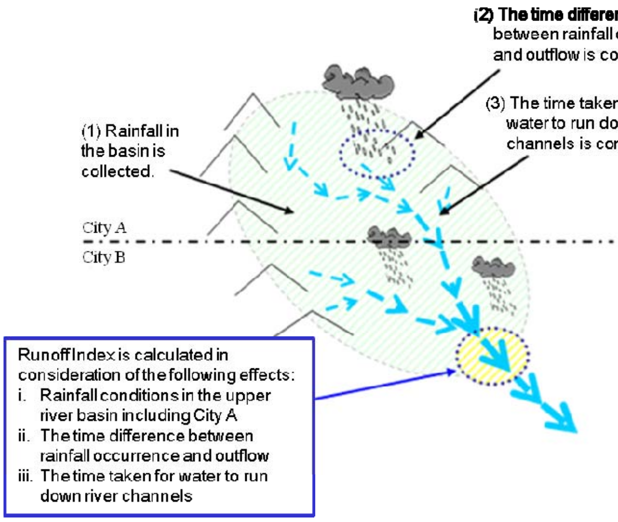


Fig. 17 Three effects to be considered in evaluating flood risk

In the RI, the tank model is used to estimate outflow, and includes the processes of water flowing down the slopes of the basin (covering an area of about 5 km × 5 km) to the river, and then down the river channel. The RI is calculated targeting rivers with a length of 15 km or more. R/A and VSRF are used as inputs for the tank model. Figure 18 shows a sample of the RI.

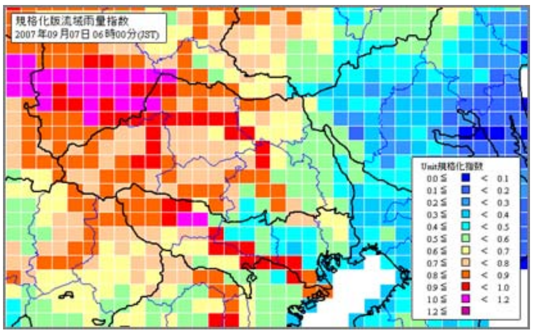


Fig. 18 Sample of the RI shown in 5-km grids

Floods frequently occur in areas with high RI values. Figure 19 shows a time series representation of the RI and water levels in a grid where actual flooding occurred. The time series corresponds closely to the water level of the river.

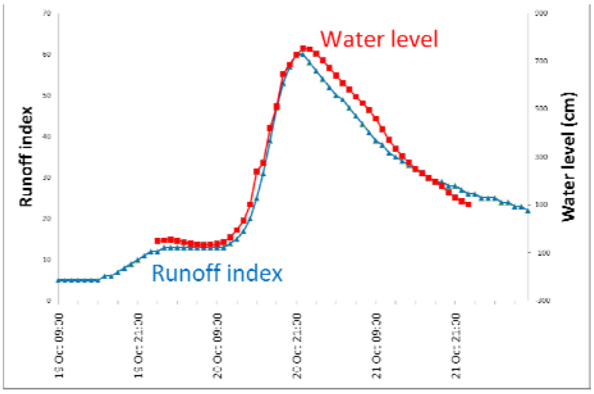


Fig. 19 Time series of the RI and water levels for a grid in which flooding occurred. The red line shows the water level, and the blue line shows the RI.

Since May 2010, the RI has been used by forecasters at JMA's meteorological observatories when issuing flood warnings/advisories to call attention to the risk of flooding.

References

Araki, K., 2000: Six-hour forecasts of precipitation. Reports of the Numerical Prediction Division, **47**, 36 – 41 (in Japanese).

Browning, K. A., F. F. Hill, 1981: Orographic Rain. Weather, **35**, 326 – 329.

Makihara, Y., 2000: Algorithms for precipitation nowcasting focused on detailed analysis using radar and raingauge data, Study on the Objective Forecasting Techniques, Technical Reports of the Meteorological Research Institute, **39**, 63 – 111.

C-5. GRIB2 templates for JMA Radar/Rain gauge-Analyzed Precipitation data[1]

FM 92 GRIB (Gridded Binary) is a standard data format for storing grid data, defined by WMO (World Meteorological Organization). It is a container format made from eight kinds of sections to hold various types of data structure, by selecting templates for grid definition (section 3), product definition (section 4), and data representation (section 5). Each template is identified by 16 bit numbers and is called like DRT (Data Representation Template) 5.200 for example.

The JMA Radar/Rain gauge-Analyzed Precipitation data is stored in GRIB format using two uncommon templates: PDT (Product Definition Template) 4.50008 (R/A product metadata) and DRT 5.200 (run-length encoding). PDT 4.50008 is JMA's local extension, not to be described in the WMO Manual on Codes[2]. DRT 5.200 is an agreed international standard, but the Manual does not contain a description of the compression algorithm for historical reason. Documentation for those templates has been provided in Japanese language only (JMA, 2006).

An English version of the documentation was prepared for the task team activity, and is included in this section for future reference.

[1] E. Toyoda

[2] https://www.wmo.int/pages/prog/www/WMOCodes.html

GRIB2 templates for JMA Radar/Rain gauge-Analyzed Precipitation data: PDT 4.50008 and DRT 5.200

June 27, 2012 (rev5)
TOYODA Eizi
Japan Meteorological Agency

Introduction

Radar/Rain gauge-Analyzed Precipitation (hereafter called R/A) data of Japan Meteorological Agency (JMA) is grid data of precipitation. It is given in standard WMO Code FM92 GRIB Edition 2, but it includes templates not described in WMO Manual on Codes. This document supplements WMO Manual to decode that dataset.

PDT 4.50008

Product definition template (PDT) 4.50008 is locally modified version of PDT 4.8 defined by JMA. This template is identical to standard PDT 4.8 (average, accumulation and/or extreme values or other statistically-processed values at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval) until octet 58, and the rest is additional fields for quality-control purpose.

Octet	Type	Contents	Actual Value
10	Code table 4.1	Parameter category	1 (Humidity)
11	Code table 4.2	Parameter number	200 [Note 1]
12	Code table 4.3	Type of generating process	0 (analysis)
13	Local code	Background generating process identifier	150 (very short range forecast)
14	Local code	Analysis or forecast generating process identifier	255 (missing)
15-16	Integer	Hours after reference time of data cutoff	0
17	Integer	Minutes after reference time of data cutoff	0

18	Code table 4.4	Indicator of unit of time range	0 (minutes)
19-22	Integer	Forecast time in units defined by octet 18	variable
23	Code table 4.5	Type of first fixed surface	1 (surface)
24	Integer	Scale factor of first fixed surface	255 (missing)
25-28	Integer	Scaled value of first fixed surface	$2^{32} - 1$ (missing)
29	Code table 4.5	Type of second fixed surface	255 (missing)
30	Integer	Scale factor of second fixed suraface	255 (missing)
31-34	Integer	Scaled value of second fixed surface	$2^{32} - 1$ (missing)
35-36	Integer	Year — end of overall time interval	variable
37	Integer	Month — end of overall time interval	variable
38	Integer	Day — end of overall time interval	variable
39	Integer	Hour — end of overall time interval	variable
40	Integer	Minute — end of overall time interval	variable
41	Integer	Second — end of overall time interval	variable
42	Integer	Number of time range specifications used in statistical process	1
43-46	Integer	Total number of data values missing in statistical process	0
47	Code table 4.10	Statistical process	1 (Accumulation)
48	Code table 4.11	Type of time increment between successive fields used in statistical process	2 (Same reference time, forecast time incremented)
49	Code table 4.4	Unit of time for time range over which statistical processing is done	0 (minutes)
50-53	Integer	Length of the time range over which statistical processing is done	60
54	Code table 4.4	Unit of time for time increment between the successive fields used	0
55-58	Integer	Time increment between successive	0 (continuous)

		fields	
59-66	Two-bit fields	Radar status block 1 [Note 2]	
67-74	Two-bit fields	Radar status block 2 [Note 2]	
75-82	Flag table	Rain gauge availability [Note 2]	

Notes:

[1] parameter number 200 is used for one-hour precipitation (water equivalent) [mm] with RLE packing scheme (DRT 5.200). Theoretically it should be 52 (Total precipitation rate [kg.m-2.s-1]), since GRIB regulation 92.6.2 discourages use of parameter names not orthogonal to other parts of PDT/DRT. Unfortunately the parameter has tradition much longer than the regulation, thus it cannot be changed for compatibility reasons.
[2] octets 59-82 describe availability and operation status of data sources. Officially the template only describes this blocks as “defined by data producing centre”. Details are given below for informational purpose, but Japan’s National Focal Point for Codes and Data Representation Matters to WMO (not me) may not be aware of recent changes and hence cannot be responsible to different practices.

Radar status block 1 (informational)

Block 1 describes operation status of data sources, mostly radar sites operated by JMA. Place names in capital letters are registered to WMO Publication No.9 Volume A, and number (starting from 47) is station index.

Bits	Type	Description
1-2	R	47415 SAPPORO/KENASHIYAMA
3-4	R	47419 KUSHIRO/KOMBUMORI
5-6	R	47432 HAKODATE/YOKOTSUDAKE
7-8	R	47590 SENDAI
9-10	R	47582 AKITA
11-12	R	47572 NIIGATA/YAHIKOYAMA
13-14	R	47695 TOKYO/KASHIWA
15-16	R	47611 NAGANO/KURUMAYAMA
17-18	R	47659 SHIZUOKA/MAKINOHARA

19-20	R	47705 FUKUI/TOJIMBO
21-22	R	47636 NAGOYA
23-24	R	47773 OSAKA/TAKAYASUYAMA
25-26	R	47791 MATSUE/MISAKAYAMA
27-28	R	47792 HIROSHIMA/HAIGAMINE
29-30	R	47899 MUROTOMISAKI
31-32	R	47806 FUKUOKA/SEFURISAN
33-34	R	47869 TANEGASHIMA/NAKATANE
35-36	R	47909 NAZE/FUNCHATOGE
37-38	R	47937 NAHA/ITOKAZU
39-40	R	47920 ISHIGAKIJIMA/OMOTODAKE
41-42	R	47909 NAZE/FUNCHATOGE, in special operation
43-44	R	47937 NAHA/ITOKAZU, in special operation
45-46	B	Gauges in AMeDAS network used
47-48	B	Other raders used
49-50	B	Other rain gauges used
51-60		reserved
61-62	M	Modelling data
63	bit	OOM is used in forecast
64	bit	MSM is used in forecast

Notes:
(1) This table is taken from documentation dated November 2006. Later changes may exist.
(2) Bits are counted as in BUFR. Bit 64 is the most significant bit of the first octet of the block. Bit 1 is the least significant bit of the last octet of the block.

Each two-bit pair represents operation status of data source (radar or gauge).

Upper bit	Lower bit	Type R	Type M	Type B

(#2)	(#1)			
0	0	No data (bulletin missing)	Not used	Unused
0	1	Observation done, echo presents	Latest run used	Used
1	0	Observation done, echo absent	Second-latest run used	reserved
1	1	No operation	reserved	reserved

Radar status block 2 (informational)

Block 2 covers radar sites *not* operated by JMA. Each two-bit pair is operation status encoded in the same way as in block 1.

Bits	Description
1-2	Pinneshiri [Pinne Yama*]
3-4	Otobe Dake*
5-6	Muri Yama
7-8	Hako Dake*
9-10	Monomi Yama*
11-12	Shirataka Yama*
13-14	Nishi Dake
15-16	Hōdatsu Zan*
17-18	Yakushi Dake*
19-20	Hijiri Kōgen
21-22	Akagi San*
23-24	Mitsutōge Yama
25-26	Ōgusu Yama
27-28	Takasuzu Yama*
29-30	Gozaisho Yama*

31-32	Jatōge
33-34	Miyama
35-36	Jōgamoriyama
37-38	Rakansan [Osorakan Zan*]
39-40	Ōwasan
41-42	Myōjin San*
43-44	Takashiro Yama
45-46	Shakadake [Shakagadake*]
47-48	Kunimi Yama*
49-50	Happongi Yama (Gotō Shi)
51-52	Yae Dake*
53-64	reserved

Notes:
(1) This table is translated from documentation dated November 2006. Later changes may exist.
(2) Name of radar sites may have different spelling, as they are not registered to WMO. Names marked with asterisk (*) are found in "Gazetteer of Japan" (2007, http://www.gsi.go.jp/ENGLISH/pape_e300284.html).

Flag table for rain gauge availability

Availability of each data source (mostly rain gauges in a prefecture) is indicated by a bit each.

Bit	Data source
1	gauges in AMeDAS network
2	gauges operated by Water and Disaster Management Bureau, MLIT (Ministry of Land, Infrastructure, Transport and Tourism)
3	gauges operated by Road Bureau, MLIT
4-17	reserved
18	gauges in Hokkaido (hereafter proper name is prefecture of Japan)
19	gauges in Aomori

20	gauges in Akita
21	gauges in Iwate
22	gauges in Miyagi
23	gauges in Yamagata
24	gauges in Fukushima
25	gauges in Ibaraki
26	gauges in Tochigi
27	gauges in Gunma
28	gauges in Saitama
29	gauges in Tokyo
30	gauges in Chiba
31	gauges in Kanagawa
32	gauges in Nagano
33	gauges in Yamanashi
34	gauges in Shizuoka
35	gauges in Aichi
36	gauges in Gifu
37	gauges in Mie
38	gauges in Niigata
39	gauges in Toyama
40	gauges in Ishikawa
41	gauges in Fukui
42	gauges in Shiga
43	gauges in Kyoto
44	gauges in Osaka
45	gauges in Hyogo

46	gauges in Nara
47	gauges in Wakayama
48	gauges in Okayama
49	gauges in Hiroshima
50	gauges in Shimane
51	gauges in Tottori
52	gauges in Tokushima
53	gauges in Kagawa
54	gauges in Ehime
55	gauges in Kochi
56	gauges in Yamaguchi
57	gauges in Fukuoka
58	gauges in Oita
59	gauges in Nagasaki
60	gauges in Saga
61	gauges in Kumamoto
62	gauges in Miyazaki
63	gauges in Kagoshima
64	gauges in Okinawa

Note: translated from documentation dated November 2006. Later changes may exist.

DRT 5.200: Run-length packing

Data representation template (DRT) 5.200 is an international standard registered in WMO Manual on Codes. The structure of data section (section 7) is, unfortunately, not described enough to implement software.

Data Representation Section (Sec5) Structure

Taken from WMO Manual, with modification of words for ease of understanding.

Octet	Type	Contents
12	Integer	Number of bits used for each packed value in the run length packing with level values (only 8 has been used at the time of writing)
13-14	Integer	*MV* - Maximum value within the levels that is actually used in this GRIB message
15-16	Integer	*MVL* - Maximum value of level (predefined)
17	Integer	Decimal scale factor of representative value of each level
18 ... 19+2*(*MVL*-1)	Integer[*MVL*]	List of scaled representative values of each level from 1 to *MVL*

Data Section (Sec7) Structure

Octet	Type	Contents
1-4	Integer	Length of the section
5	Integer	Number of the section (7)
rest	(described below)	Packed grid data

Run length encoding (RLE) is a technique that compresses data into a series of pair of repeated element and repetition count. There are lots of specific encodings of the name in the information technology industry. Microsoft DIB (bitmap) format is famous one, but is differnt from JMA's.

Firstly, in lexical (small-scale) viewpoint, packed grid data is considered as a sequence of **bytes.** The size of byte is given at octet 12 of data representation section. It may not be eight, but as far as I know, all implementations uses 8 bits per byte (hence it's same as octet).

Switching to syntax (large-scale) viewpoint, **Packed grid data** is a sequence of sets, each of which represents a consecutive grid points with the same value. A **set** consists of a **data byte** (value equals to or less than *MV*) and an optional repetition count sequence (hereafter called **RCS**) that is a sequence of **digits**, each of which is bytes with value more than *MV*. The structure in BNF is as follows:

packed_grid_data := *(set)
set := data_byte rcs
data_byte := <any byte whose value is *MV* or less>
rcs := *(digit)
digit := <any byte whose value is more than *MV*>.

RCS describes number of consecutive grid points in the set. The number is decremented by one, and then expressed in positional notation with base B = 255 - MV (note: each digit may take value one of B possibilities between MV + 1 and 255) and digits are sorted in little-endian order. Thus the number of consecutive grid points R is given as follows:

$$R = 1 + \sum_{i=1}^{N} B^{(i-1)}[a_i - (MV + 1)],$$

where N is the number of bytes in repetition count sequence and a_i is i-th byte in the sequence. When RCS is missing in a set, that means R = 1.

Value of the “data byte” is different from that of original data described by the parameter. The byte value is called **level**, which is an index to the list of “representative value” at the end of data representation section. Each value in the table is scaled by the decimal scale factor (octet 17 of DRS). The original data Y is given by a similar formula to regulation 92.9.4:

$$Y \cdot 10^D = X = table[L],$$

where D is the decimal scale factor, X scaled value, L level, and *table*[L] is L-th (1-starting) entry in the table. The idea of level is something like Beaufort’s scale giving approximate value of wind speed. “Maximum value of level” *MVL* in Section 5 is the number of these levels, which is fixed number 98 for current R/A. Note that *MV* is often less than *MVL* (*MV* cannot be more than *MVL*).

Note that the “level zero” is defined to mean missing value, hence the list of levels in DRS does not include an entry for zero. As far as I know, JMA never used the standard bit-map (GRIB2 Section 6) with run length packed data. Bit-map octets cannot be shorter than one-eighth of grid point counts, but this run length packing can be as short as a single set if almost entire field is zero.

A compact algorithm can decode this data structure, as shown in Appendix.

Appendix: decoding algorithm

Following code in C is only for clarification of algorithm. There is no warranty.
It assumes that a byte in RLE has eight bits, and also C type “`char`” has exactly eight bits.
Bit-map processing is to be done after `decode()` function, although JMA doesn’t use bit-map with run-length packing.

```
#include <stdlib.h>
#include <math.h>

	unsigned
get_uint2(unsigned char *p)
{
	return (p[0] << 8) | p[1];
}

	unsigned long
get_uint4(unsigned char *p)
{
	return (p[0] << 24) | (p[1] << 16) | (p[2] << 8) | p[3];
}

	int
decode(const unsigned char *drs, /* SECTION 5 */
	const unsigned char *ds, /* SECTION 7 */
	double *buf, /* RESULT */
	unsigned long buflen)
{
	unsigned long i, ib, npixel, iend, nrepeat, mv, ir;
	double scale_factor, decimal_factor, xlated;
	scale_factor = (drs[16] & 0x80) ? -(drs[16] & 0x7F) : drs[16];
	decimal_factor = pow(10.0, scale_factor);
	if (drs[11] != 8) { return -1; } /* BYTE SIZE IS NOT 8 */
	npixel = get_uint4(drs + 5);
	if (buflen < npixel) { return -1; }  /* OVERRUN */
	iend = get_uint4(ds) - 1;
	mv = get_uint2(drs + 12);
	ib = npixel - 1;
	nrepeat = 0;
	for (i = iend; i >= 5; i++) {
		if (ds[i] > mv) {
			nrepeat *= (255 - mv);
			nrepeat += (ds[i] - mv - 1);
		} else {
			if (ib < ++nrepeat) { return -1; }  /* OVERRUN */
			if (ds[i] == 0) {
				xlated = -1.0;  /* MISSING VALUE */
			} else {
				xlated = get_uint2(drs + 17 + 2 * (ds[i] - 1))
				* decimal_factor;
			}
			for (ir = 0; ir < nrepeat; ir++) {
				buf[--ib] = xlated;
			}
			nrepeat = 0;
		}
	}
	if (ib > 0) { return -1; } /* UNDERRUN */
	return 0;
}
```

C-6. Radar / Rain gauge-Analyzed Precipitation Dataset by JMA[1]

For the task team, the Radar / Rain gauge-Analyzed Precipitation dataset was provided by JMA in GRIB2 format. It gives the most reliable and finest precipitation analysis fields and is to be used with the atmospheric transfer models for computing rain wash. Details of the data set including data configuration and format are described in a pdf document file (the following pages) and shared along with the dataset as the contribution of JMA among the Task Team members.

[1] T. Fujita and N. Nemoto

Radar / Rain gauge-Analyzed Precipitation Dataset by JMA

This document describes basic information needed to handle the Radar / Rain gauge-Analyzed Precipitation Dataset (RA) by the Japan Meteorological Agency (JMA), which is provided to the WMO Technical Task Team on Meteorological Analyses for Fukushima Daiichi Nuclear Power Plant Accident. Since the concept and overview of the data are mostly given in Nagata (2011)[1], the data description given below is rather limited: the file format, data area, and so on.

1. File names of the Radar / Rain gauge-Analyzed Precipitation dataset

The generic file names of the RA dataset are specified as follows:

```
Z__C_RJTD_yyyyMMddhhmmss_SRF_GPV_Ggis1km_Prr60lv_ANAL_grib2.bin
```

where two consecutive underscores are given between the first Z and C, while a single underscore is used in other places. The specific character string ‘`yyyyMMddhhmmss`’ should properly stand for the year in four digits, month, day, hour, minute, and second in two digits in Coordinated Universal Time (UTC) at observation, while the observation time shows the end of accumulation period. For example, the one hour accumulated analyzed rainfall amount data from 1000 UTC to 1100 UTC on March 12, 2011 is stored in:

```
Z__C_RJTD_20110312110000_SRF_GPV_Ggis1km_Prr60lv_ANAL_grib2.bin
```

Note that the minutes are `00` or `30` since the data is given every thirty minutes, and the seconds are always assumed to be `00`.

2. Grid alignment and the number of grids

The horizontal resolution of the data is 45 seconds in longitude and 30 seconds in latitude. The entire area streches from 118 degree to 150 degree in East, and from 20 degree to 48 degree in North (Fig. 1), in a way that each tiny region of 45 seconds by 30 seconds is arranged within the entire region without any overlap nor gap, which means tiny regions of total 2560 by 3360 are defined in the area.

---

1 <http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/techrev/text13-2.pdf>

3. File format

The data is encoded and formatted in the form of FM92 GRIB Edition 2 (WMO, 2011)[2] with specific extensions for this usage. The sizes of the data files vary from 100 kB to 500 kB or more depending on the meteorological condition at the observation time. Users should refer to the Appendix for more detail in addition to WMO (2011).

Discrete level values of precipitation intensity are compressed in a run length encoding, and set into the sixth octet and after in the seventh section. Note that the maximum value of the data in one file, which naturally differs file by file, is referred to as the standard value for the run length compression of the data in the file (MV, octets 13-14 in the fifth section), and that once the RA dataset is processed by the program mentioned in the next section, the compressed data is re-encoded in the simple compression and the run length rule is not applied anymore.

4. Data Handling Program

A data conversion program `conv_jma_grib2` is prepared by JMA for the users' convenience. The program is originally designed to convert the JMA Meso-analysis data, but also usable to convert the RA dataset. Users should refer to the User's Manual (JMA, 2012) on the `conv_jma_grib2` program for the details.

APPENDIX GRIB2 Format for the Radar / Rain gauge-Analyzed precipitation

The GRIB2 files for the Radar / Rain gauge-Analyzed precipitation (R/A) employ a template of local use 4.50008 in section 4. It is almost identical to the template 4.8 with n = 1 (octet 42), but the following records are additionally placed:

(1-58 same as the template 4.8 with n = 1)

59-66 Flags on radar operations PART1

67-74 Flags on radar operations PART2

75-82 Flags on rain gauge operations

---

[2] <ftp://ftp.wmo.int/Documents/MediaPublic/Publications/CodesManual_WMO_no_306/WMO306_Vol_I.2_2011_en.pdf>

The flags above indicate which radar or rain gauge sites are in operation to analyze the precipitation intensity, however, the details are not shown here because the information is longish and considered unimportant for the task teams' work. Toyoda (2012) provides full details on the extensions defined by JMA.

Discrete level values of precipitation intensity (lv), parameter category 0 (moisture) and number 200 (local use) specified in section 4, are stored in section 7 with the run length packing, as section 5 describes that the template 5.200 is used. The level values should be interpreted to precipitation intensity with a table stored in section 5 (List of MVL scaled representative values of each level from lv=1 to MVL). lv= 0 means no observation (missing).

REFERENCES

JMA, 2012: conv_jma_grib2 － a tool to convert GRIB2 provided for UNSCEAR by JMA — Users' Manual by the Japan Meteorological Agency, 7 p.

Nagata, K., 2011: Quantitative Precipitation Estimation and Quantitative Precipitation Forecasting by the Japan Meteorological Agency. , RSMC Tokyo - Typhoon Center Technical Review No.13, 37-50.

Toyoda, E., 2012: GRIB2 templates for JMA Radar/Rain gauge-Analyzed Precipitation data: PDT 4.50008 and DRT 5.200, a document submitted to WMO Inter-Programme Expert Team on Data Representations and Codes. http://goo.gl/Y6JMh

WMO, 2011: Manual on Codes – International Codes, Part B -Binary Codes. WMO Publication No.306 Volume I.2, Geneva, Switzerland.

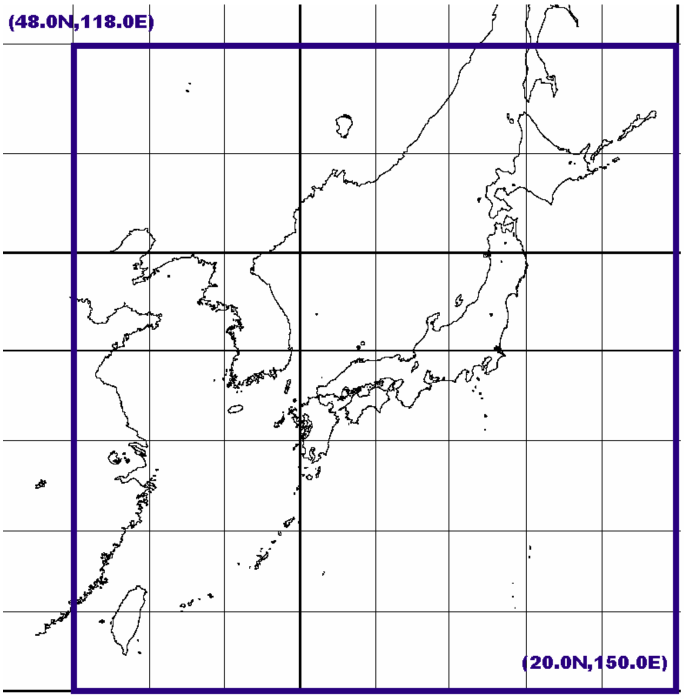


Fig. 1 Area of the RA dataset.

C-7. File converter tool[1]

Following an agreement reached by the task team, JMA offered the Radar/Rain Gauge analyzed precipitation (R/A) fields (see C-4) and the 4D-VAR mesoscale analysis (MA) fields (see C-3 and C-8) in the GRIB2 format, bit-oriented data exchange format standardized by the World Meteorological Organization (WMO) Commission for Basic Systems (CBS). However, a horizontal coordinate such as the Lambert conformal conic projection, the terrain following hybrid vertical coordinate, and the run length encoding (RLE) used in the provided datasets might not be familiar to some members of the task team. Moreover, decoding data described in the GRIB2 often requires special technics and knowledge.

In order to help members' work, JMA also provided a converter tool (called "conv_jma_grib2") to process the offered data. Its functions are schematically displayed in Fig.C-7-1. The "User Manual" of the tool distributed to the task team members is shown from the following page, which describes details of its functions, usages (compiling and running) and some examples in use. The tool was written fully in C programing language from scratch, and scripts to generate compiling environment depending on various users' system was attached, which helped the tool available on many systems. Only one small bug was fixed just after it was released to the members, but no further defects have been reported.

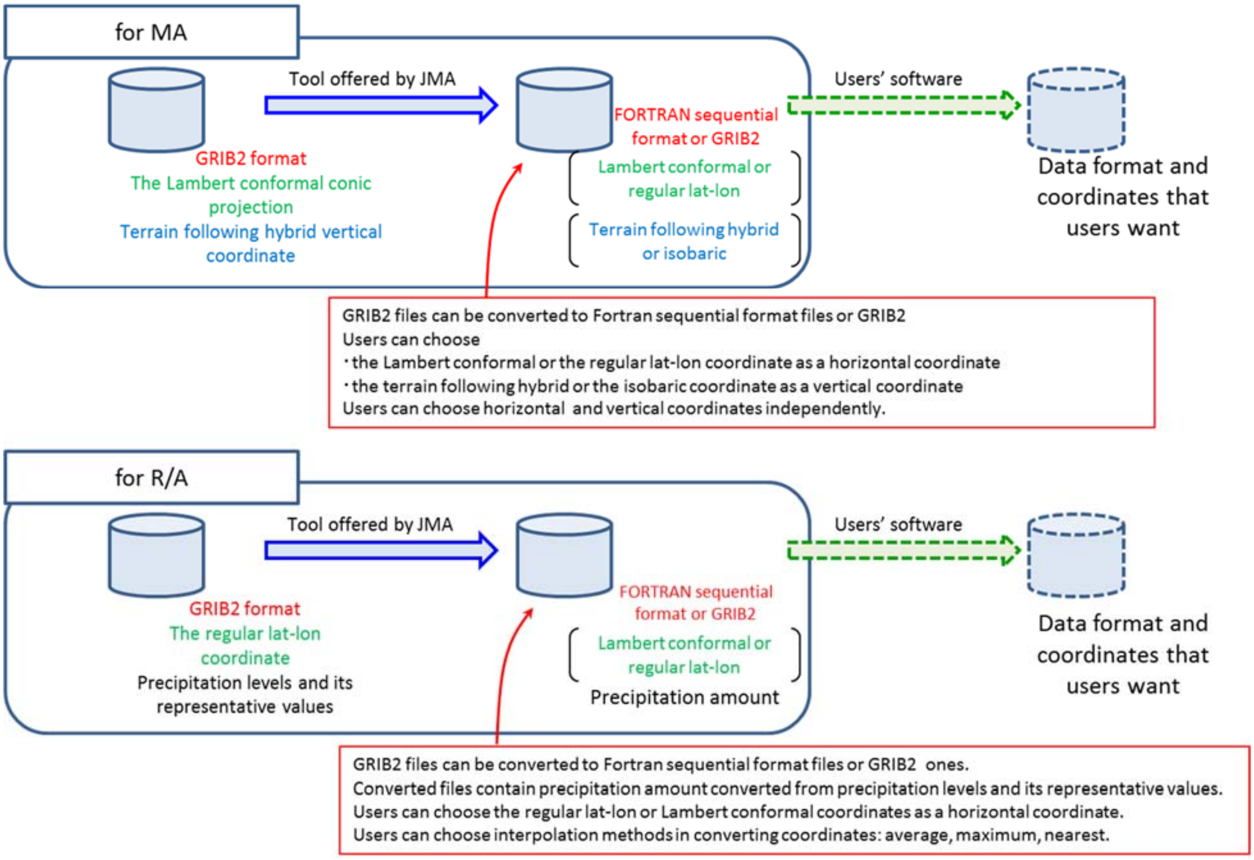


Fig. C-7-1. A schematic figure showing functions of the converter tool provided by JMA.

[1] T. Hara

conv_jma_grib2

— a tool to convert GRIB2 provided for UNSCEAR by JMA —
Users' Manual

by the Japan Meteorological Agency

1 Introduction: what does the tool do?

The Japan Meteorological Agency (JMA) has provided the operational mesoscale analysis (MA) in the GRIB2 format to members of the task team. MA employs the Lambert conformal conic projection as a horizontal coordinate, but it has been revealed that the projection might not be familiar to some people. In addition, a terrain following hybrid coordinate adopted by MA could be another factor to hamper members' work.

Furthermore, while the GRIB2 format is regulated by the WMO and established as a common format to exchange meteorological data, it might not an easy task to decode and process them.

Considering the situation, JMA has decided to provide a tool to convert horizontal and vertical coordinates as well as the data format. The tool provides functions

- to convert the GRIB2 format to the FORTRAN sequential format which is much more familiar and can be visualized by the GrADS, a popular tool in the meteorological society.
- to re-project data in the GRIB2 to other projection.
- to convert the terrain following hybrid vertical coordinate to the isobaric coordinate with arbitrary pressure planes.

The tool is applicable for the following GRIB2 files provided to the UNSCEAR task team.

- `jma_ma_met_hybrid-coordinate_201103DDHH00.grib2.bin`
  (MA for the atmosphere)
- `jma_ma_land-surface_201103DDHH00.grib2.bin`
  (MA for the land surface)
- `jma_ma_ocean_sst_201103DDHH00.grib2.bin`
  (MA for the sea surface temperature)
- `Z__C_RJTD_201103DDHHMN00_SRF_GPV_Ggis1km_Prr60lv_ANAL_grib2.bin`
  (Radar/Raingauge analyzed precipitation)

2 Setup

The source codes described in C can be complied as the following.

```
$ tar xvzf conv_jma_grib2-1.00.tar.gz
$ cd conv_jma_grib2-1.00
$ ./configure
$ make
```

After the compilation finishes successfully, the executable file `conv_jma_grib2` is generated in the current directory. You can copy the executable to another directory you like.

The `configure` script automatically determines endian of your computer and the executable built is compatible to your computer.

Note that `makedepend` (a tool to generate dependencies automatically) is used in the compilation. Even if `makedepend` is not installed in your computer, the codes are compiled successfully using the prescribed dependencies in `src/.depend.default` as long as no modifications are added into the codes. If you are going to add some modifications but `makedepend` is not installed, you might need to update the dependencies by hand, which `makedepend` automatically does. `config.log` generated after running `configure` tells you whether `makedepend` is installed in your computer and used in compiling them.

3 Basic Usage

As the first practice, just type as follows with a GRIB2 file provided by JMA.

```
$ conv_jma_grib2 grib2_file
```

You obtain a converted file in the FORTRAN sequential format with a GrADS ctl file. The converted file is put with a file name combined the original GRIB2 file name (including a directory path) and "`.dat`" and "`.ctl`", that is, if your GRIB2 file is named as `/home/john/sample.grib2`, file names of the converted ones are `/home/john/sample.grib2.ctl` and `/home/john/sample.grib2.dat`. If `-o output_file` is added to the option line, the output file name can be altered to `output_file`.

You can see what elements are stored by looking at the ctl file. This operation just converts file formats and no coordinate transformations are done. By opening the ctl file with GrADS, you can draw elements stored in the file. In the case of converting GRIB2 files of the Radar/Raingauge-Analyzed Precipitation (R/A), converted files contain precipitation intensity (parameter category:1, number:8), while discritized levels of precipitation intensity (parameter category:1, number:200) is stored in the original GRIB2 files. It is also the case when you convert the original GRIB2 to the GRIB2 again with `-g` option.

Note that converted FORTRAN sequential files are described in the big endian even if the byte order of your computer is the little endian. While the GrADS can recognize the endian because the endian is specified in a "OPTION" line in the ctl file, take care of that when you try to read the file by your own programs (FORTRAN compilers usually have a "big endian" mode, with which `read/write` statement in FORTRAN read/write sequential files in the big endian even on little-endian machines).

Furthermore, the first point of the GRIB2 is at the northwest edge (j increases from north to south), however, converted files in the FORTRAN sequential format have the first point at the southwest edge (j increases from south to north). That is why no "`yrev`" option is placed in the OPTION line in ctl files.

By default, ctl files for GrADS assume a linear grid even if the Lambert projection is employed. The generated ctl file should be like the following:

```
#pdef 719 575 LCCR 30.000 140.000 487.977067 168.019156 30.000 60.000 140.000 5000.000 5000.000
#xdef 963 linear 107.000000 0.051922
#ydef 668 linear 19.000000 0.044966
xdef 719 linear 1.000000 1.000000
ydef 575 linear 1.000000 1.000000
```

Although the GrADS ignores lines starting with `#`, parameters related to the Lambert projection is written down in a `pdef` statement. In this case, the numbers of grids specified by `xdef` and `ydef` is real grid numbers. You can draw this file with GrADS but map drawn is not correct.

If `-c` option is specified, the parameters in the ctl files will be

```
pdef 719 575 LCCR 30.000 140.000 487.977067 168.019156 30.000 60.000 140.000 5000.000 5000.000
xdef 963 linear 107.000000 0.051922
ydef 668 linear 19.000000 0.044966
#xdef 719 linear 1.000000 1.000000
#ydef 575 linear 1.000000 1.000000
```

This time, the GrADS interprets the `pdef` statement, and draw figures interpolating the Lambert projected grids to linear Latitude/Longitude coordinate. Real grid numbers are appeared in the `pdef` statement, but numbers specified by `xdef` and `ydef` are not related to the real grid numbers (they are adjusted so that the entire domain can be drawn).

4 Coordinate transform

This tool has a function to transform horizontal and vertical coordinates.

All options explained in the Section 3 are also available when options for a horizontal and/or vertical coordinate transform are specified.

Of course, the vertical transform is valid only for the atmospheric analysis (not for land, sst, and R/A analysis).

4.1 Horizontal transform

If you are going to change a horizontal coordinate of the provided GRIB2 data, you should create a configuration file describing parameters of the destination projection. The configuration file is put as an option in the command line with `-h` like

```
$ conv_jma_grib2 -h config_h.txt grib2_file
```

4.1.1 Converting to the Latitude/Longitude coordinate

When converting data in the GRIB2 to those on the Latitude/Longitude coordinate, an example of the configuration file content, saved as `config_sample/config_h_ll.txt`, should be like the following:

```
proj = LL
nx = 201
ny = 201
dx = 0.05
dy = 0.05
xlat = 40.0
xlon = 130.0
xi = 1.0
xj = 1.0
```

- `proj` must be `LL` (Latitude/Longitude)
- `nx`, `ny`: the numbers of grids of x- and y-direction.
- `dx`, `dy`: grid spacing of x- and y- direction. (unit: degree)
- `xlat`, `xlon`, `xi`, `xj`: (`xi`, `xj`) on the coordinate corresponds to the point identified by `xlat` and `xlon`. In the coordinate the configuration file assumes, a point of (1, 1) is located at the northwest edge and `xj` increases from north to south (the coordinate value of the first point is 1, not 0).

  When a coordinate you want to convert to is the Latitude/Longitude, it is easy and understandable to set the latitude and longitude of the first point (i.e. the most northwestern point) to `xlat` and `xlon`, and `xi` = `xj` = 1.0.

4.1.2 Converting to the Lambert Coordinate

When you are going to convert the JMA GRIB2 data (ex. Radar/Raingauge Analyzed Precipitation) to those on the Lambert coordinate, a configuration file on parameters for the target coordinate is required. An example of what should be described in the configuration, saved as `config_sample/config_h_lm.txt`, is as follows.

```
proj = LMN
nx = 719
ny = 575
dx = 5000.0
dy = 5000.0
xlat = 30.0
xlon = 140.0
xi = 488.0
xj = 408.0
slat1 = 30.0
slat2 = 60.0
slon = 140.0
```

The format of the configuration file is similar to that for converting to the Latitude/Longitude coordinate, mentioned in the previous subsection. This time, `proj` must be `LMN` (Lambert North). In addition to parameters used also for the Latitude/Longitude coordinate, two standard latitude and a standard longitude must be set to `slat1`, `slat2` and `slon` in degree. Along the standard latitudes and longitude, no expansion or shrink occurs in the projection from the Earth sphere to the plane. It is strongly recommended that when you would like to use the Lambert projection, `slat1` = 30, `slat2` = 60 and `slon` = 140. In the case of the Lambert projection, `dx` and `dy` mean grid spacings at the standard latitude and longitude at the points identified by `slat1`, `slat2` and `slon`. (Parameters in the example shown above is used in the JMA meso analysis).

Wind components u and v in the GRIB2 depict x- and y- direction winds on the Lambert projection, respectively (not zonal and meridional winds). When the Lambert coordinate is converted to the Latitude/Longitude one, u and v are rotated so that the rotated winds u' and v' can be interpreted as zonal and meridional winds. The details of the rotation are described in Appendix A.

Note that conversion of the original MA GRIB2 described in the Lambert projection to another Lambert projection with different parameters (ex. smaller region) is also possible.

The original domain is expected to cover the entire domain of the converted one. If the tool finds a point on the target coordinate locating out of the original domain, it abnormally halts with an error message by default. However, adding `-d` to the command line option allows you to include points which are not covered by the original coordinate. MISSING (`undef` in GrADS) are stored into these points.

For almost elements in the GRIB2, the tool calculated values on the target coordinate by the linear interpolation of values on four adjacent points on the original coordinate. There are two exceptions.

1. In converting `KIND` (surface kind such as land, sea, land covered by snow, sea covered by ice) stored in the land surface analysis, the tool uses a value on the nearest point selected from the four adjacent points (because a fractional "`KIND`" obtained by the linear interpolation as the other elements is meaningless.)
2. In converting Radar/Raingauge Analyzed precipitation originally on the Latitude/Longitude coordinate to other coordinate, three options for the interpolation are available. The following characters should be placed in the command line after `-r`.
   - `m`: averaged values over grids on the original projection which are covered by the grid on the target projection are adopted.
   - `x`: maximum values over grids on the original projection which are covered by the grid on the target projection are adopted.
   - `n`: values on the nearest grids on the original projection is adopted.

4.2 Vertical transform

When you are going to transform the original terrain following hybrid coordinate of MA to the isobaric coordinate, the configuration file describing a list of pressures of the isobaric planes is required like the following, saved as `config_sample/config_v.txt`.

```
pout = 1000.0, 950.0, 925.0, 850.0, 700.0, 500.0, 300.0, 250.0, 200.0, 100.0
```

Each value in the list is separated by a comma, and the unit of pressure is hPa. No line breaks should be inserted. Pressures in the list should be in descending order. Arbitrary pressure (but note that the top of MA is located around 40hPa) can be specified as long as the number of pressures in the list is less than 100.

With the configuration file describing a list of pressures, you can run the tool like

```
$ conv_jma_grib2 -v config_v.txt grib2_file
```

If surface pressure of one point on one isobaric plane is less than that of the isobaric plane, it means that the point is located underground. Because extrapolated (physically meaningless) values are stored to underground points by default, you should determine validness of each point by comparing surface pressure and that of a isobaric plane. If `-u` is added in the command line, values on underground points are set to MISSING (`undef`) instead of the extrapolated values.

When converting to the isobaric coordinate, temperature is stored instead of potential temperature in the original GRIB2.

Note that you would like to transform horizontal and vertical coordinate simultaneously, both `-h config_h` and `-h config_v` should be placed in the command line. If the both are requested, the vertical coordinate is transformed before the horizontal one.

5 Other Command line options

-l

If `-l` is specified in the command line, a file containing values of latitudes and longitudes of all points in the domain is generated in the GrADS format with a ctl file.

-p

If `-p` is specified in the command line, records in the GRIB2 are printed. After printing them, the tool exits. No files are generated besides the printed information.

6 Quick reference

```
conv_jma_grib2 grib2_file [-h config_h_file] [-v config_v_file] [-o output_file]
               [-g] [-p] [-d] [-r m|x|n] [-l] [-c] [-u]
      -g: output in GRIB2 format
      -p: only print records in grib2_file
      -d: allow out of domain in coordinate conversion
      -c: use pdef in GrADS ctl files
      -u: set MISSING to values located underground
      -r: RA interpolation option
          m: mean
          x: max
          n: nearest
      -l: output lat and lon in GrADS format
```

The identical explanation can be obtained by just executing the tool without any arguments.

One or more options can be specfied in general.

7 Examples

1. Just convert the GRIB2 file format to the GrADS one.

```
$ conv_jma_grib2 /home/john/jma_ma_met_XXXX.grib2.bin
```

The tool generates `jma_ma_met_XXXX.grib2.bin.dat` and `jma_ma_met_XXXX.grib2.bin.ctl` in a directory `/home/john`.

2. Just convert the GRIB2 file format to the GrADS one, but a file name of outputs is specified.

```
$ conv_jma_grib2 /home/john/jma_ma_met_XXXX.grib2.bin -o after
```

Files named `after.dat` and `after.ctl` in the current directory.

3. The original GRIB2 files for R/A depict precipitation intensity with discrete integer level values. The following operation produces a GRIB2 file again, but the discrete level values are interpreted to real-number values using the conversion table in the original GRIB2 files. The generated GRIB2 files do not employ any local-use templates, while the original ones use some of them.

```
$ conv_jma_grib2 /home/john/Z__C_RJTD_XXXX_Prr60lv_ANAL_grib2.bin -g
```

A GRIB2 file containing real-number precipitation intensity is created with a name `/home/john/Z__C_RJTD_XXXX_Prr60lv_ANAL_grib2.bin.grib2.bin`.

4. Convert a horizontal coordinate following a configuration file

```
$ conv_jma_grib2 /home/john/jma_ma_met_XXXX.grib2.bin -h config_h.txt
```

where `config_h.txt` should be prepared in advance.

The tool generates `jma_ma_met_XXXX.grib2.bin.dat` and `jma_ma_met_XXXX.grib2.bin.ctl` in a directory `/home/john`.

```
$ conv_jma_grib2 /home/john/jma_ma_met_XXXX.grib2.bin -h config_h.txt -d
```

By adding `-d` in the command line, points which the original data do not contain is fulfilled by `undef` instead that the tool abnormally aborts.

```
$ conv_jma_grib2 /home/john/jma_ma_met_XXXX.grib2.bin -h config_h.txt -g
```

this operation generates a GRIB2 file `jma_ma_met_XXXX.grib2.bin.grib2.bin` instead of the file in the GrADS format.

```
$ conv_jma_grib2 Z__C_RJTD_XXXX_Prr60lv_ANAL_grib2.bin -h config_h.txt -r n
```

Transform a coordinate of R/A following a configuration file `config_h.txt`. In interpolating, values on the nearest grids on the original projection is adopted.

5. Convert a vertical coordinate following a configuration file

```
$ conv_jma_grib2 /home/john/jma_ma_met_XXXX.grib2.bin -v config_v.txt
```

A rule to name files are the same as former examples.

```
$ conv_jma_grib2 /home/john/jma_ma_met_XXXX.grib2.bin -v config_v.txt -u
```

Values located underground in the generated file is set to `undef`.

6. Convert horizontal and vertical coordinate simultaneously

```
$ conv_jma_grib2 jma_ma_met_XXXX.grib2.bin -h config_h.txt -v config_v.txt
```

A Lambert conformal conic projection

Coordinates x and y on the projected rectangular plane are given by:

$$
\begin{aligned}
(x - x_0)D_X &= \rho(\phi)\sin[\alpha(\lambda - \overline{\lambda})] - \rho(\phi_0)\sin[\alpha(\lambda_0 - \overline{\lambda})], \\
(y - y_0)D_Y &= \rho(\phi)\cos[\alpha(\lambda - \overline{\lambda})] - \rho(\phi_0)\cos[\alpha(\lambda_0 - \overline{\lambda})]
\end{aligned}
$$

where

$$
\begin{aligned}
&\rho(\phi) = \frac{R\cos\phi_1 U(\phi)^\alpha}{\alpha U(\phi_1)^\alpha}, \quad (R = 6371000 \text{ m: Radius of the Earth}) \\
&\alpha = \frac{\ln(\cos\phi_1) - \ln(\cos\phi_2)}{\ln U(\phi_1) - \ln U(\phi_2)} \\
&U(\phi) = \tan\left(45^\circ - \frac{\phi}{2}\right), \\
&D_X, D_Y : \texttt{dx}, \texttt{dy}, \\
&\phi_1, \phi_2 : \texttt{slat1}, \texttt{slat2}, \\
&\overline{\lambda} : \texttt{slon}, \\
&\phi_0, \lambda_0 : \texttt{xlat}, \texttt{xlon}, \\
&x_0, y_0 : \texttt{xi}, \texttt{xj}.
\end{aligned}
$$

The symbols used above (`dx`, `dy`, `slat1`, `slat2`, `slon`, `xlat`, `xlon`, `xi` and `xj`) are explained in Section 4.1.2.

When you would like to convert x- and y- direction winds on the Lambert projection to zonal and meridional winds, you should rotate the wind vectors by the following angle θ ($\theta > 0$: clockwise rotation)

$$\theta = \alpha(\lambda - \overline{\lambda}),$$

where λ is the longitude of the point. Under the usual and recommended condition (`slat1` $= 30^\circ$, `slat1` $= 60^\circ$ and `slon` $= 140^\circ$), $\alpha \simeq 0.715$.

C-8. JMA Meso-scale 4D-VAR analysis[1]

JMA operates a data assimilation system for Meso-scale Analysis to initialize MSM (Section C-2-1). As of March 2011, the Meso-scale Analysis adopted a 4D-VAR data assimilation system, which employs JMA-NHM as a time integration operator, named the "JMA Nonhydrostatic model"-based Variational Analysis Data Assimilation (JNoVA; Honda et al. 2005, Honda and Sawada, 2008, 2009).

The analysis of 4D-VAR is obtained by minimizing a cost function in an iterative process. JNoVA adopts the incremental approach (Courtier et al. 1994) to reduce the computational cost for operational use. In the incremental approach, a low-resolution model is used in the iterative process called the "inner loop" to obtain an analysis increment while a high-resolution model is used to obtain an analysis. The minimization process is carried out as follows (ordinal numbers correspond to those in Fig. C-8-1):

1. Initialized with the previous Meso-scale Analysis, run the high-resolution (5km) forecast model within the data assimilation window (0 to 3-hours) to obtain the first guess.
2. Perform quality-control of observations (see Section 2.3 for details) and calculate deviations of the observations from the first guess.
3. Execute the JNoVA to assimilate the quality-controlled observations on a low-resolution (15km) space. This step is iterated to minimize the cost function until pre-defined criteria is satisfied. At the end, analysis increments at the beginning of the data assimilation window are obtained.
4. Add the analysis increments (on the low-resolution space) to the (high-resolution) first guess at the beginning of the data assimilation window through an interpolation process, and make an initial condition for the next step.
5. With the initial condition made in the previous step, run the high-resolution (5km) forecast model within the data assimilation window to obtain an analysis at the end of the data assimilation window.

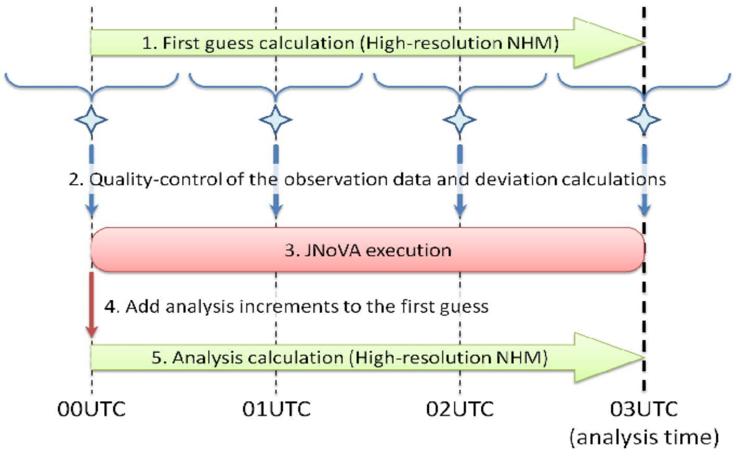


Fig. C-8-1. Schematic procedure of the Meso-scale Analysis (an example of 03UTC analysis).

[1] Y. Honda

Table C-8-1. Specification of MSM, NLM and ADM used in JNoVA.

	MSM	NLM	ADM
Resolution	5km, 50layers	15km, 40layers	15km, 40layers
Horizontal advection	Flux form fourth-order with advection correction	Flux form fourth-order with advection correction	Flux form fourth-order
Solver of pressure equation	HE-VI	HE-VI	HE-VI
Targeted moisture diffusion	Considered	Considered	Not considered
Moist physics	3-ice bulk microphysics	Large scale condensation	Large scale condensation
Convection	Modified Kain-Fritsch	Modified Kain-Fritsch	None
Turbulence	Mellor-Yamada -Nakanishi-Niino level 3	Deardorff	Deardorff
Surface flux	Beljaards and Holtslag	Louis (land) and Kondo (sea)	Louis (land) and Kondo (sea)
Ground temperature	Four-layer thermal diffusion	Four-layer thermal diffusion	Four-layer thermal diffusion
Radiation	Considered	Considered	Not considered

In JNoVA, a simplified nonlinear version of the JMA-NHM (NLM) is used in the inner loop to provide trajectories at every iteration instead of the tangent linear model (TLM) of the NLM due to discontinuity and nonlinearlity of the JMA-NHM. In addition, the adjoint model (ADM) of the NLM is used to provide gradient information of the cost function. The specification of these inner models, NLM and ADM, as well as MSM is briefly listed in Table C-8-1.

JNoVA is capable of assimilating variety of observational data from conventional data to satellite data. The observation used in Meso-scale Analysis as of March 2011 is listed in Table C-2-2. One of the unique characteristics of Meso-scale Analysis is the direct assimilation of precipitation, which is crucial for reproducing the realistic precipitation in the analysis.

In April 2009, JNoVA was introduced in Meso-scale Analysis by replacing a previous 4D-Var system. Before its introduction, twin experiments were conducted under almost the same conditions as the operational system in summer (2006/7/16 – 8/31) and in winter (2007/12/23 – 2008/1/23) to compare the performance of JNoVA with that of a previous 4D-Var based on a limited-area hydrostatic spectral model. The quantitative precipitation forecast (QPF) of JNoVA is better than that of the previous 4D-Var for all thresholds according to the equitable threat score (ETS) of three-hourly accumulated precipitation forecasts (Fig. C-8-2). Upper-air verification reveals that the analysis of JNoVA is better than that of the previous 4D-Var, although the impact on the forecast is quite limited (not shown). From surface verification, it is found that the root mean square errors (RMSEs) of the surface temperature in summer and the surface wind in winter are reduced, and that the scores of other

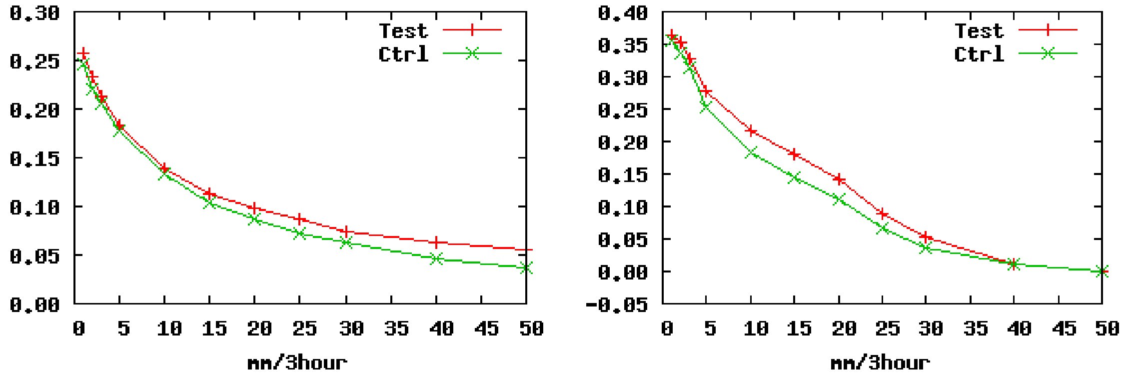


Fig. C-8-2. Equitable threat scores of three-hourly accumulated precipitation forecasts in summer (right) and winter (left). The red and green lines show the results of JNoVA (Test) and the previous 4D-Var (CTRL), respectively. The horizontal axis is the threshold value of the rainfall amount.

surface variables are neutral (not shown). In the case of Typhoon Wukong (T0610), its typhoon track forecast as well as precipitation forecast was improved by JNoVA (Fig. C-8-3). More figures are found in Honda and Sawada (2009).

Further detailed information on Meso-scale Analysis and JNoVA can be found in Section 2.6 of JMA (2013).

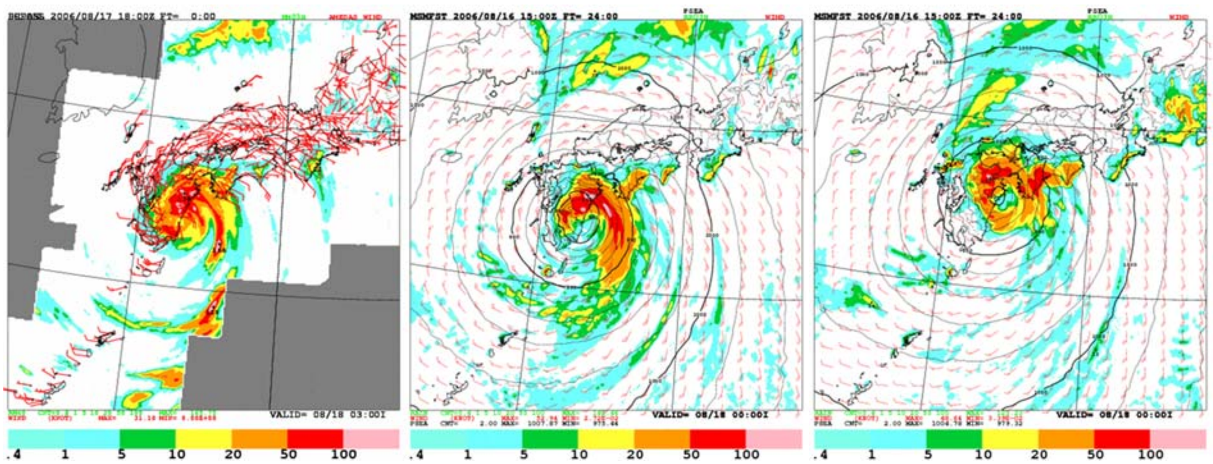


Fig. C-8-3. Three-hourly accumulated precipitation of 24-hour forecasts from 17 Aug. 2006 at an initial time of 15 UTC. From the left, RA, the forecast of JNoVA and that of the previous 4D-Var are shown

C-9. Meteorological Field[1]

Before the hydrogen explosions of Fukushima Daiichi nuclear power plant, two weak low pressure troughs accompanying a low pressure system passed over the Japanese Islands between 9 and 11 March 2011, bringing light rain over wide areas of eastern Japan (not shown). On 12 March, a high pressure system covered the main island of Japan, and moved to the Pacific Ocean about 1000 km east of the island on 13 March; however it continued to cover eastern Japan. The wind direction was from the south below a height of 1 km and from the west above the height in the afternoon of 12 March, the time of the hydrogen explosion of No.1 reactor (Fig. C-9-1a). During the daytime of 14 March, the time of the hydrogen explosion of No.3 reactor, south-southwesterly (westerly) winds dominated below (above) a height of 1 km (Fig. C-9-1b).

Between 12 and 15 March, a weak low pressure system (hereafter Low A) formed north of Taiwan and moved eastward off the southern coast of the main island of Japan (Fig. C-9-2). After 15 March the system moved toward the northeast while developing rapidly. Light rain was observed over eastern Japan from the afternoon of 15 March to the morning of 17 March, while less rain was observed there until the morning of 15 March (Fig. C-9-4). In particular, rain was observed in the Fukushima prefecture during the night from 1700 JST 15 to 0400 JST 16 March (e.g., Fig. C-9-5), a time corresponding with significant emissions. Weak precipitation intensity was observed over most areas of the Fukushima prefecture, and the precipitation systems had low vertical structures (Fig. C-9-6).

North-northeasterly low-level winds dominated during the morning of 15 March. In particular, the wind speed exceeded 10 m s^{-1} over south areas of the Ibaraki prefecture at the time of the container burst of No. 2 reactor. In the afternoon, the wind direction rotated clockwise and gradually changed to south over the Fukushima prefecture (Fig. C-9-7). This wind change was caused by another low pressure system (Low B) that formed over the Kanto Plain, east of Low A (Fig. C-9-3). Chino et al. (2011) estimated that the maximum I-131 emissions occurred between 0900-1500 JST (0000-0600 UTC), 15 March. During that period the winds had the eastward component (cold color) below a height of 1 km and westerly winds (warm color) dominated above the height (Fig. C-9-1c). The low-level easterly component was brought from the circulation of Low A located over the ocean southeast of Ibaraki prefecture (Fig. C-9-2). After 1500JST southeast winds appeared associated with Low B around a height of 1 km and lasted until 0200JST next day (Figs. C-9-1c and 1d).

Between 18 and 19 March, a high pressure system covers widely the Japanese Islands (middle-row panels in Fig. C-9-2), and winds were generally from the west. Then, a low pressure system passed over the main island of Japan from 20 and 22 March (bottom panels in Fig. C-9-2), bringing moderate rain over the Kanto area (bottom panels in Fig. C-9-4).

[1] T. Kato

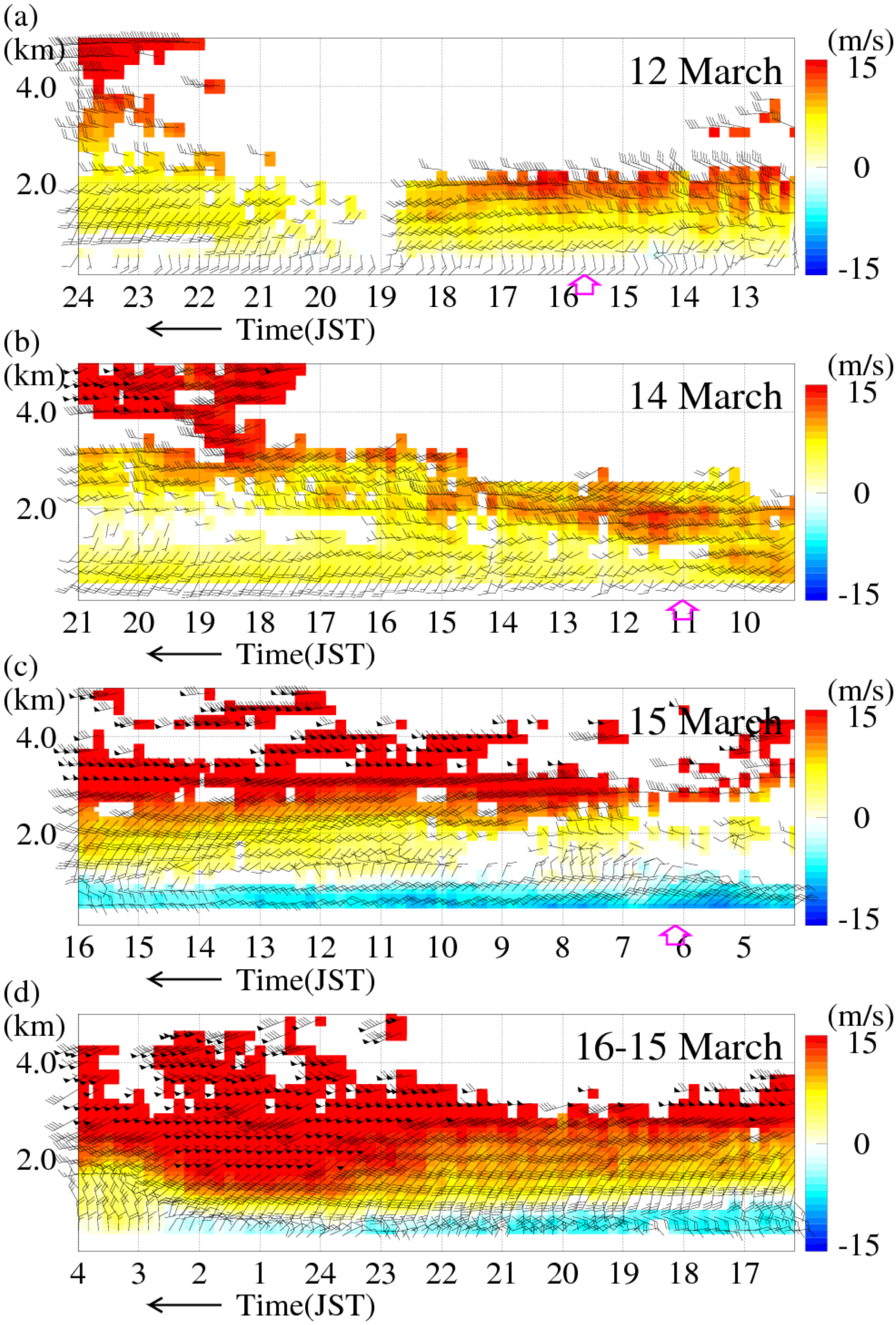


Fig. C-9-1. Time series of horizontal winds (arrows) and zonal wind speed (color shade) below a height of 5 km observed by a JMA wind profiler at Mito (See its location in Fig.C-9-7). (a) From 1210 JST to 2400 JST, March 12. (b) From 0910 JST to 2100 JST, March 14. (c) From 0410 JST to 1600 JST, March 15. (d) From 1610 JST, March 15 to 0400 JST, March 16. Pink arrows show the times of hydrogen explosion of No. 1 reactor for (a) and No.3 reactor for (b) and that of container burst of No.2 reactor for (c). Full and half barbs denote 5 m s^{-1} and 2.5 m s^{-1}, respectively, and pennants denote 25 m s^{-1}.

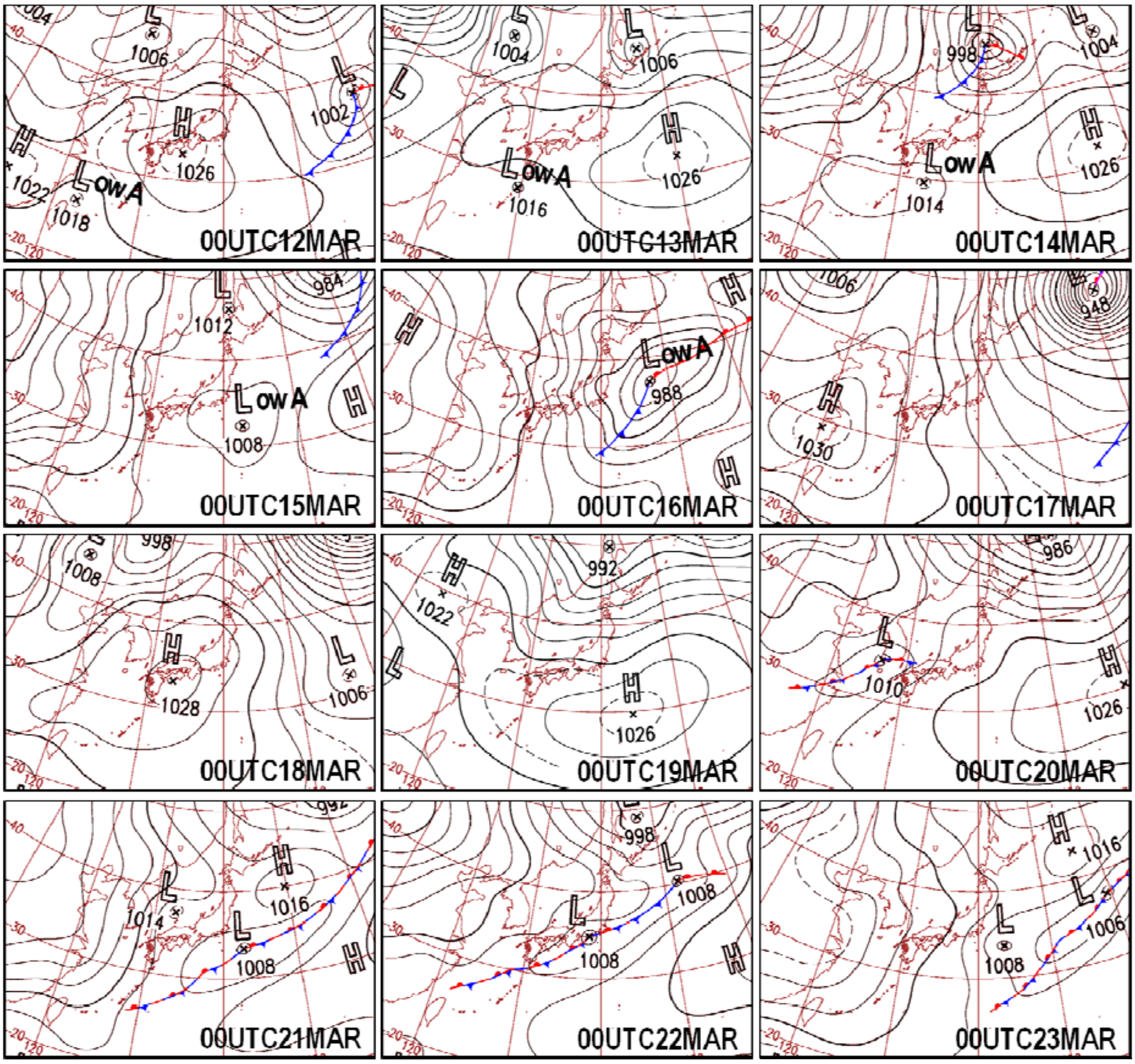


Fig. C-9-2. Surface weather charts at 00UTC (09 JST) from 12 to 23 March, 2011.

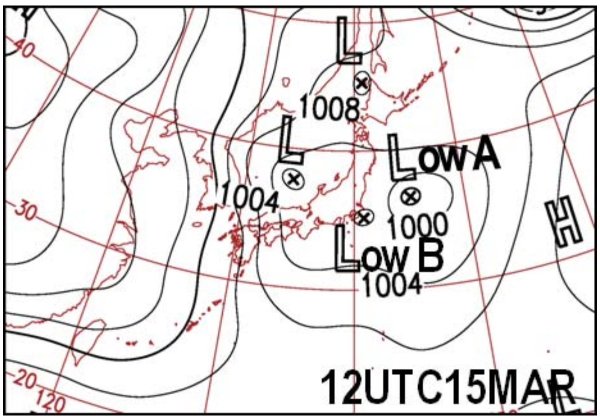


Fig. C-9-3. Surface weather charts at 12UTC (21 JST) 15 March 2011.

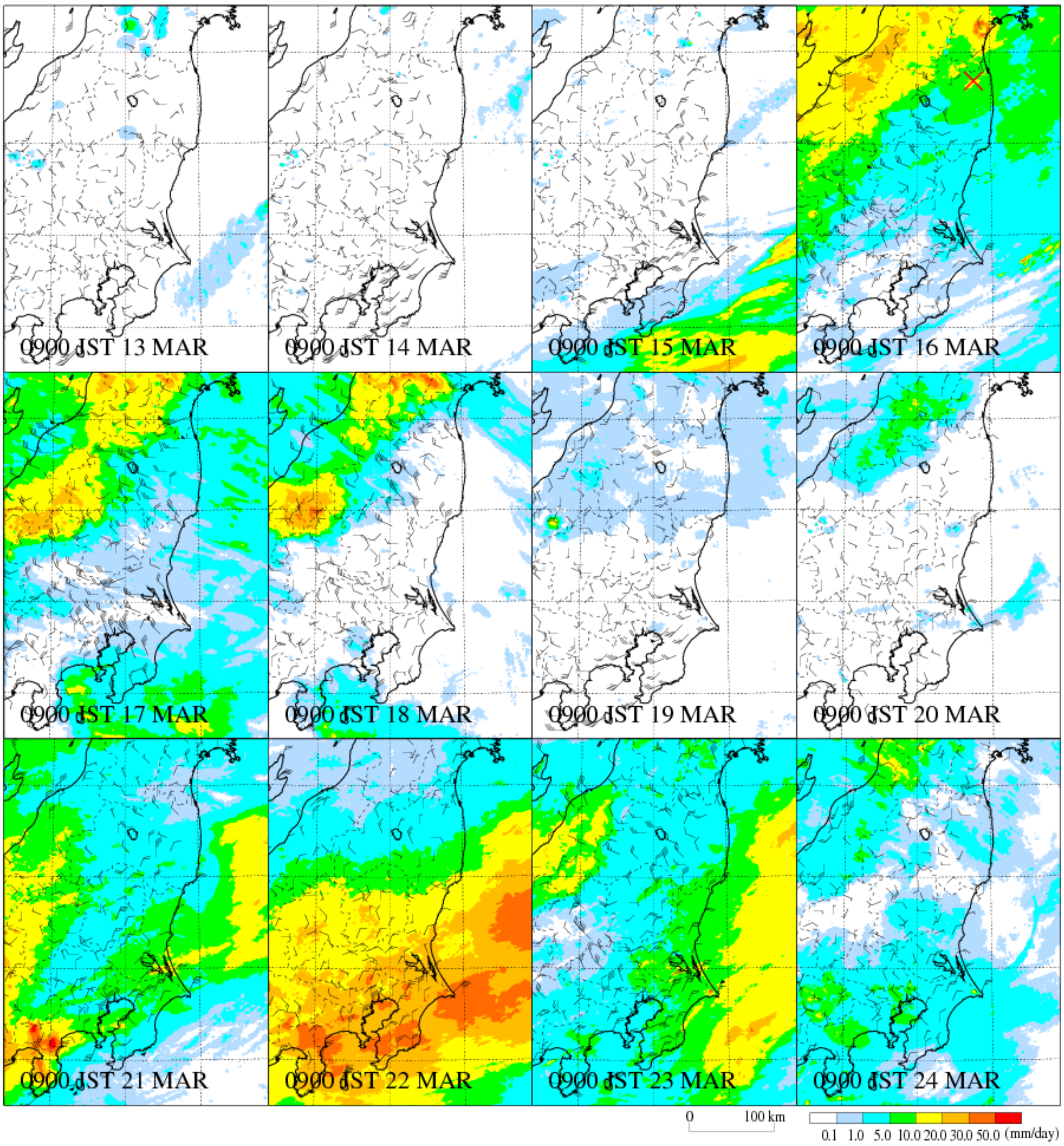


Fig. C-9-4. Horizontal distributions of 24-hour accumulated precipitation amounts and observed surface winds at 0000 UTC (0900 JST) between 13 and 24, March 2011. Red cross on the left-top panel shows the location of Iidate.

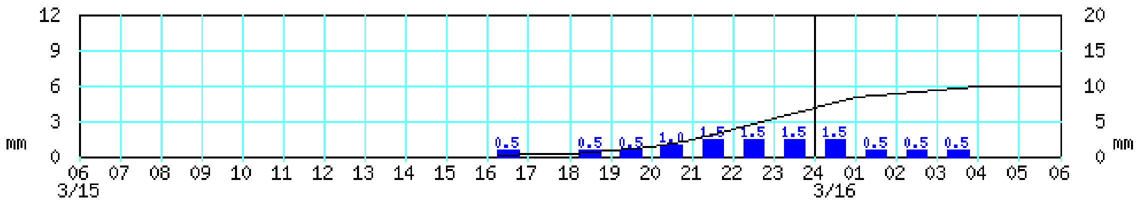


Fig. C-9-5. Time series of hourly accumulated precipitation amounts (bar) and total amount (line) at Iidate (See its location in the left-top panel of Fig.C-9-4) between 0600 JST 15 and 0600 JST 16, March 2011.

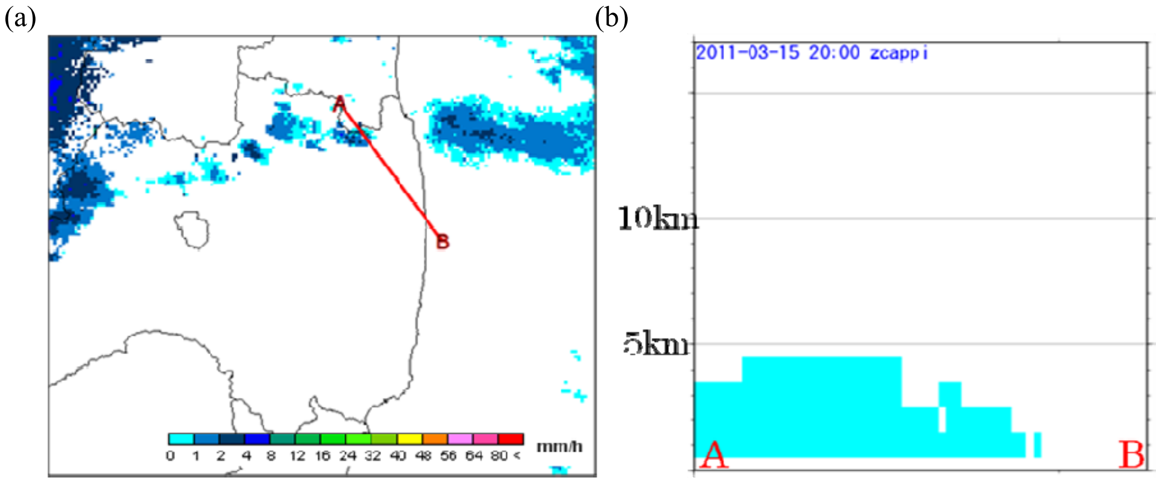


Fig. C-9-6. (a) Horizontal distribution of precipitation intensity estimated by JMA radar at 2000 JST 15 March 2011, and (b) vertical cross section of red line in (a).

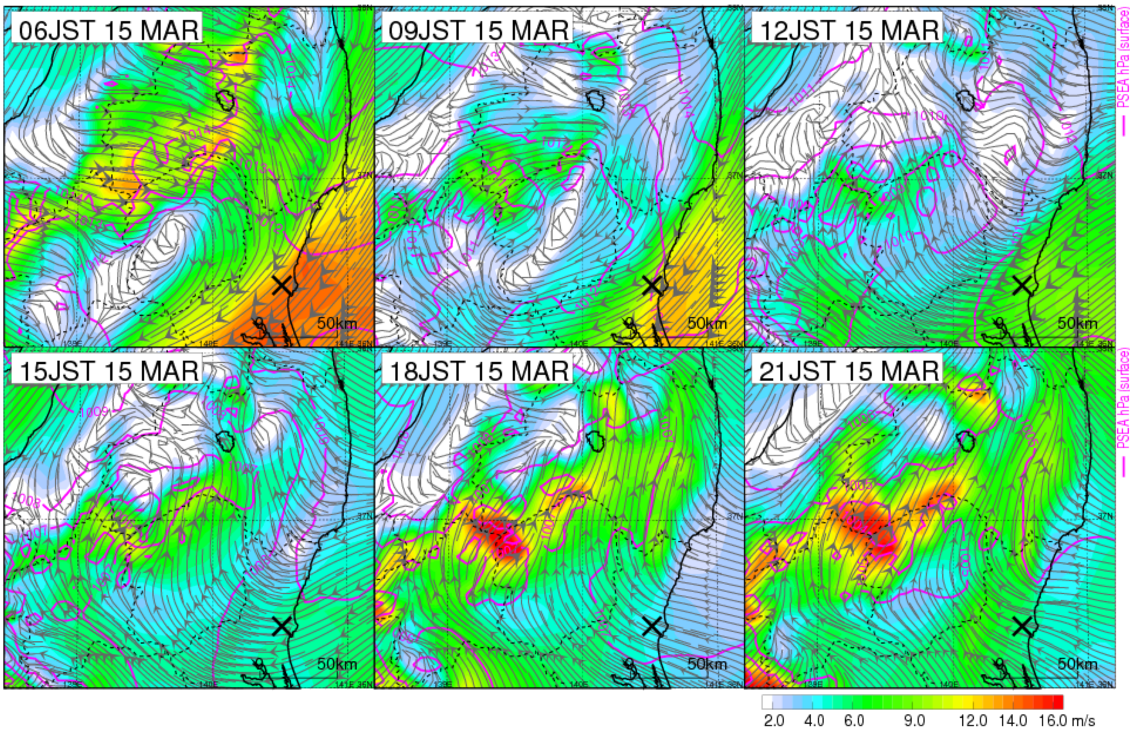


Fig. C-9-7. Horizontal winds at about a 540 m height above the model surface (stream lines), their speed (color shade) and sea level pressure (pink contours) depicted from mesoscale analysis of JMA between 2100 UTC, 14 (0600 JST, 15) and 1200 UTC (2100 JST), 15 March 2011. Black crosses show the location of Mito.