JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2013

Japan Meteorological Agency

1. Summary of highlights

(1) The forecast range of the Global Spectral Model (GSM) and the One-week Ensemble Prediction System (EPS) at 12 UTC was extended from 9 days to 11 days in March 2013 (see 4.2.2.1(1) and 4.2.5.1). Improvement of the Radiation Parameterization Scheme was introduced into the GSM in April 2013 (see 4.2.2.1(1)).

(2) The domain of the Meso-scale Numerical Weather Prediction (NWP) system was expanded in March 2013 (see 4.3.1.1 (1) and 4.3.2.1 (1)). The forecast range of the Meso-Scale Model (MSM) was extended to 39 hours for all initial times in May 2013 (see 4.3.2.1 (1)).

(3) The domain of the Local NWP system was expanded to enable coverage of Japan along with its surrounding areas and the update frequency was enhanced to an hourly basis in May 2013 (see 4.3.1.1 (3) and 4.3.2.1 (2)).

(4) Clear sky radiance data from the Global Change Observation Mission 1st – Water (GCOM–W1)/Advanced Microwave Scanning Radiometer 2 (AMSR2) imager were introduced into the Global and Meso-scale NWP systems in September 2013 (see 4.2.1.2 (2) and 4.3.1.2 (1)).

(5) Observational and retrieval data derived from sensors on board the Meteorological Operational Satellite Programme (Metop)-B satellite were introduced into the Global and Meso-scale NWP systems in November 2013 (see 4.2.1.2 (3) and 4.3.1.2 (2)).

(6) AMVs derived from composite satellite imagery using geostationary (GEO) and polar-orbit (LEO) images (LEO-GEO AMVs) and AMVs derived from Advanced Very High Resolution Radiometer (AVHRR) images (AVHRR AMVs) were introduced into the Global NWP system in July 2013 (see 4.2.1.2 (4)).

(7) The second long-term reanalysis project (JRA-55) was completed in March 2013 (see 4.6.1.2).

2. Equipment in use

On 5 June, 2012, an upgraded version of the computer system used for numerical analysis/prediction and satellite data processing was installed at the Office of Computer Systems Operations in Kiyose, which is about 30 km northwest of JMA’s Tokyo Headquarters. The office in Kiyose and JMA’s Headquarters are connected via a wide-area network. The computer types used in the system are listed in Table 2-1, and further details are provided in Narita (2013).

Table 2-1 System computer types

Supercomputers (Kiyose) Hitachi: SR16000 model M1

Number of subsystem	2
Number of nodes	54 physical nodes per subsystem
	432 logical nodes per subsystem
Processors	3,456 IBM POWER7 processors (32 per node)
Performance	423.5 TFlops per subsystem (7.84 TFLOPS per node)
Main memory	55.296 TiB per subsystem (128 GiB per node)
High-speed storage*	Hitachi AMS2500 (138 TB for primary, 210 TB for secondary)
Data transfer rate	96 GiB/s (one way) (between any two nodes)
Operating system	IBM AIX Version 7.1

* Dedicated storage for supercomputers

Primary Satellite Data Processing Servers (Kiyose): Hitachi EP8000/750

Number of servers	3
Processor	IBM POWER7 (3.0 GHz)
Main memory	128 GiB per server
Operating system	IBM AIX Version 6.1

Secondary Satellite Data Processing Servers (Kiyose): Hitachi EP8000/750

Number of servers	6
Processor	IBM POWER7 (3.0 GHz)
Main memory	128 GiB per server
Operating system	IBM AIX Version 6.1

Foreign Satellite Data Processing Servers (Kiyose): Hitachi HA8000/RS220AK1

Number of servers	6
Processor	Intel Xeon X5670 (2.93 GHz)
Main memory	32 GiB per server
Operating system	Linux

Division Processing Servers A (Kiyose): Hitachi BS2000

Number of servers	16
Processor	Intel Xeon E5640 (2.66 GHz)
Main memory	48 GiB per server
Operating system	Linux

Division Processing Servers B (Kiyose): Hitachi EP8000/520

Number of servers	2
Processor	IBM Power6+ (4.7 GHz)

Main memory	32 GiB per server
Operating system	IBM AIX Version 6.1

Decoding Servers (Kiyose): Hitachi EP8000/750

Number of servers	2
Processor	IBM Power7 (3.70 GHz)
Main memory	64 GiB per server
Operating system	IBM AIX Version 6.1

Mass Storage System (Kiyose)

Shared storage**	Hitachi VFP500N and AMS2500 (754 TB total, RAID 6)
Data bank storage**	Hitachi VFP500N and AMS2500 (2932 TB total, RAID 6)
Backup tape storage	Hitachi EP8000 and L56/3000 (1520 TB total)

** Shared by supercomputers and servers

Wide Area Network (between HQ and Kiyose)

Network bandwidth	200 Mbps (two independent 100-Mbps WANs)

3. Data and Products from GTS and other sources in use

3.1 Observation

A summary of data received through the GTS and other sources and processed at JMA is given in Table 3-1.

Table 3-1 Number of observation reports in use

SYNOP/SHIP	84,000/day
BUOY	34,000/day
TEMP-A/PILOT-A	1,700/day
TEMP-B/PILOT-B	1,700/day
TEMP-C/PILOT-C	1,300/day
TEMP-D/PILOT-D	1,300/day
AIREP/AMDAR	621,000/day
PROFILER	6,800/day
AMSR2	14,000,000/day
AIRS/AMSU	210,000/day
NOAA/AMSU-A	1,280,000/day
Metop/AMSU-A	644,000/day
NOAA/AMSU-B	620,000/day
NOAA/MHS	5,790,000/day
Metop/MHS	2,920,000/day
Metop/ASCAT	4,660,000/day
GOES/CSR	1,430,000/day
MTSAT/CSR	130,000/day
METEOSAT/CSR	1,250,000/day

GPSRO	310,000/day
AMV	3,400,000/day
SSMIS	20,300,000/day
TRMM/TMI	4,730,000/day
GNSS-PWV	700,000/day
AMeDAS	232,400/day
Radar Reflectivity	4,200/day
Radial Velocity	4,200/day
Typhoon Bogus	12/day

3.2 Forecast products

Grid Point Value (GPV) products of the global prediction model from ECMWF, NCEP, UKMO, BOM, CMS, DWD and CMA are used for internal reference and monitoring. The products of ECMWF are received via the GTS, and the other products are received via the Internet.

4. Forecasting systems

4.1 System run schedule and forecast ranges

Table 4.1-1 summarizes the system run schedule and forecast ranges.

Table 4.1-1 Schedule of the analysis and forecast system

Model	Initial time (UTC)	Run schedule (UTC)	Forecast range (hours)
Global Analysis/Forecast	00 06 12 18	0225 – 0330 0825 – 0930 1425 – 1530, 1715 – 1800 2025 – 2130	84 84 264 84
Meso-scale Analysis/Forecast	00 03 06 09 12 15 18 21	0055 – 0205 0355 – 0505 0655 – 0805 0955 – 1105 1255 – 1405 1555 – 1705 1855 – 2005 2155 – 2305	39 39 39 39 39 39 39 39
Local Analysis/Forecast	00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21,	0035 – 0100, 0135 – 0200, 0235 – 0300, 0335 – 0400, 0435 – 0500, 0535 – 0600, 0635 – 0700, 0735 – 0800, 0835 – 0900, 0935 – 1000, 1035 – 1100, 1135 – 1200, 1235 – 1300, 1335 – 1400, 1435 – 1500, 1535 – 1600, 1635 – 1700, 1735 – 1800, 1835 – 1900, 1935 – 2000, 2035 – 2100, 2135 – 2200,	9

	22, 23	2235 – 2300, 2335 – 2400	
Typhoon Ensemble Forecast	00 06 12 18	0305 – 0350 0905 – 0950 1505 – 1550 2105 – 2150	132 132 132 132
Ocean Wave Forecast	00 06 12 18	0330 – 0350 0930 – 0950 1530 – 1550, 1840–1850 2130 – 2150	84 84 264 84
Storm Surge Forecast	00 03 06 09 12 15 18 21	0200 – 0225 0505 – 0525 0800 – 0825 1105 – 1125 1400 – 1425 1705 – 1725 2000 – 2025 2305 – 2325	39 39 39 39 39 39 39 39
One-week Ensemble Forecast	12	1605 – 1835	264
One-month Ensemble Forecast	12	1855 – 2015 (every Wednesday and Thursday)	816
Seasonal Ensemble Forecasts	00	2205 – 2315 (every 5 days)	(7 months)

4.2 Medium-range forecasting system (4 – 10 days)

4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation

(1) Global Analysis (GA)

A four-dimensional variational (4D-Var) data assimilation method is employed in analysis of the atmospheric state for the Global Spectral Model (GSM). The control variables are relative vorticity, unbalanced divergence, unbalanced temperature, unbalanced surface pressure and the natural logarithm of specific humidity. In order to improve computational efficiency, an incremental method is adopted in which the analysis increment is evaluated first at a lower horizontal resolution (TL319) and is then interpolated and added to the first-guess field at the original resolution (TL959).

The Global Analysis (GA) is performed at 00, 06, 12 and 18 UTC. An early analysis with a short cut-off time is performed to prepare initial conditions for operational forecasting, and a cycle analysis with a long cut-off time is performed to maintain the quality of the global data assimilation system.

The specifications of the atmospheric analysis schemes are listed in Table 4.2.1-1.
A reduced Gaussian grid system was implemented for the GA in August 2008.

The global land surface analysis system has been in operation since March 2000 to provide the initial conditions of land surface parameters for the GSM. The system includes daily global snow depth analysis, described in Table 4.2.1-2, to obtain appropriate initial conditions for snow coverage and depth.

Table 4.2.1-1 Specifications of the GA

Analysis scheme	Incremental 4D-Var
Data cut-off time	2.3 hours for early run analysis at 00, 06, 12 and 18 UTC 11.8 hours for cycle run analysis at 00 and 12 UTC 7.8 hours for cycle run analysis at 06 and 18 UTC
First guess	6-hour forecast by the GSM
Grid form, resolution and number of grids	Reduced Gaussian grid, roughly equivalent to 0.1875˚ [1920 (tropic) – 60 (polar)] x 960
Vertical levels	60 forecast model levels up to 0.1 hPa + surface
Analysis variables	Wind, surface pressure, specific humidity and temperature
Observation (as of 31 December 2013)	SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, AMDAR; atmospheric motion vectors (AMVs) from MTSAT-2, GOES-13, 15, METEOSAT-7, 9; MODIS polar AMVs from Terra and Aqua satellites; AVHRR polar AMVs from NOAA and Metop satellites; LEO-GEO AMVs; ocean surface wind from Metop-A, B/ASCAT; radiances from NOAA-15, 16, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP-F16, 17, 18/SSMIS, TRMM/TMI, GCOM-W1/AMSR2; clear sky radiances from the water vapor channels (WV-CSRs) of MTSAT-2, GOES-13, 15, Meteosat-7, 10; GNSS RO refractivity data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A/blackjack, TerraSAR-X/IGOR, C/NOFS/CORISS
Assimilation window	6 hours

Table 4.2.1-2 Specifications of snow depth analysis

Methodology	Two-dimensional Optimal Interpolation scheme
Domain and grids	Global, 1˚ × 1˚ equal latitude-longitude grids
First guess	Derived from previous snow depth analysis and USAF/ETAC Global Snow Depth climatology (Foster and Davy 1988)
Data used	SYNOP snow depth data
Frequency	Daily

(2) Typhoon bogussing in the GA

For typhoon forecasts over the western North Pacific, typhoon bogus data are generated to represent typhoon structures accurately in the initial field of forecast models. These data consist of information on artificial sea-surface pressure and wind data around a typhoon. The structure is axi-asymmetric. First, symmetric bogus data are generated automatically based on the central pressure and 30-kt wind speed radius of the typhoon. Axi-asymmetric bogus data are then generated by retrieving asymmetric components from the first-guess field. Finally, these bogus profiles are used as pseudo-observation data for the GA.

4.2.1.2 Research performed in the field

(1) Hybrid 4D-Var/EnKF data assimilation

The usage of flow-dependent background error covariance from the ensemble Kalman filter in 4D-Var has been tested for the GA, and ensemble-based background error information has been incorporated into the variational data assimilation framework using extended control variables. The local ensemble transform Kalman filter (LETKF) is used as an ensemble update scheme. The horizontal resolution is TL319 (about 55 km, which is the same as the resolution of the inner model used in 4D-Var), and there are 50 ensemble members. One-month cycled analysis and forecast experiments for both winter and summer have been performed, with preliminary results suggesting general improvements regarding forecast error in the troposphere and tropical cyclone track forecasting. Further research activities such as seeking the optimal ensemble configuration and investigating analysis quality for the stratosphere need to be conducted. (Y. Ota and T. Kadowaki)

(2) Assimilation of GCOM-W1/AMSR2 radiance data into the Global NWP system

The Global Change Observation Mission 1st – Water (GCOM–W1)/Advanced Microwave Scanning Radiometer 2 (AMSR2) imager is the successor to the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E). Clear sky radiance data from microwave imagers are assimilated into the Global NWP system, in which AMSR2 radiance data have been assessed. The quality of bias-corrected AMSR2 radiance data is comparable to that of data from AMSR-E and other microwave imagers. To investigate the related impact on analysis and forecasts in data assimilation experiments, AMSR2 radiance data were incorporated in addition to the currently used microwave imager data. Experiments with the Global NWP system demonstrated improvements in humidity fields. AMSR2 radiance data assimilation was operationally introduced on 12 September 2013. (M. Kazumori and T. Egawa)

(3) Assimilation of Metop-B data into the Global NWP system

JMA began to utilize observational and retrieval data derived from sensors on board the Metop-B satellite in the Global NWP system on 28 November 2013. The assimilation targets are the Advanced Microwave Sounding Unit-A (AMSU-A), the Microwave Humidity Sounder (MHS), the GNSS Receiver for Atmospheric Sounding (GRAS) and the Advanced Scatterometer (ASCAT) data along with one set of retrieval data (atmospheric motion vector (AMV) information) from the Advanced Very High Resolution Radiometer (AVHRR). These data from Metop-A have been utilized in the Global NWP system since 2007. Statistical research based on the mean and standard deviation of differences between observations from Metop-B and related GSM simulations showed that the quality of Metop-B data was comparable to that of Metop-A data. Observing system experiments (OSEs) conducted for the month of August 2013 showed improvement of typhoon track predictions as well as forecast indices such as temperature at 850hPa and geopotential height at 500hPa. (M. Moriya)

(4) Usage of LEO-GEO and AVHRR Polar Atmospheric Motion Vectors (AMVs)

To improve polar region coverage, LEO-GEO and AVHRR AMVs were introduced into the Global NWP system on 1 July 2013. LEO-GEO AMVs are derived in the latitudinal zone from approximately 60° to 70° using composite satellite imagery (a combination of geostationary (GEO) and polar-orbit (LEO) images). AVHRR (Advanced Very High Resolution Radiometer) polar AMVs (AVHRR AMVs) are estimated using AVHRR sequential images for areas over polar regions. A specific quality control (QC) system was developed to enable the use of the new AMVs for the GA. Three-month observing system experiments (OSEs) for these new AMVs were performed with the GA using the QC system in the summer and winter of 2012. Positive impacts on the analysis and forecast values of major physical elements and heights were seen for the summer and winter of 2012. More details are provided in Yamashita (2014a). (K. Yamashita)

(5) Impact of NASA TERRA MISR AMV assimilation

MISR is the Multi-angle Imaging SpectroRadiometer on board the National Aeronautics and Space Administration's (NASA's) Terra satellite, and MISR AMVs are produced by NASA's Jet Propulsion Laboratory (JPL) using the MISR Level 2 Cloud product (Muller et al. 2012). To investigate the quality of MISR AMVs, a statistical comparison of these data against collocated first-guess values of the GSM was conducted. OSEs assimilating these AMVs in the global atmosphere were also subsequently performed on a trial basis using data from July 2012. Most AMV data are distributed in low vertical layers (LL, below 700 hPa) and have positive biases against first-guess values of the GSM in all layers. AMVs in the LL region have larger standard deviations for wind speed departure from first-guess values than those of geostationary satellite AMVs. The results of the OSEs showed large differences in the mean analyzed field all over the globe, especially at geopotential heights of around 700 hPa. Although negative impacts of major components (500 hPa geopotential heights etc.) are seen in two-day forecasts (especially in the tropics and the Southern Hemisphere), positive impacts are seen on three-day forecasts in the Northern Hemisphere. Further research is required on the usage of MISR AMVs and other AMVs. More details are provided in Yamashita (2014 b). (K. Yamashita)

4.2.2 Model

4.2.2.1 In operation

(1) Global Spectral Model (GSM)

The specifications of the operational Global Spectral Model (GSM1304; TL959L60) are summarized in Table 4.2.2-1.

JMA runs the GSM four times a day (at 00, 06 and 18 UTC with a forecast time of 84 hours and at 12 UTC with a forecast time of 264 hours).

The forecast range of the GSM at 12 UTC was extended from 9 days up to 11 days in March 2013. Improvement of the Radiation Parameterization Scheme was introduced in the GSM in April 2013.

Table 4.2.2-1 Specifications of the GSM for 11-day forecasts

Basic equations	Primitive equations
Independent variables	Latitude, longitude, sigma-pressure hybrid coordinates, time
Dependent variables	Surface pressure, winds (zonal, meridional), temperature, specific humidity, cloud water content
Numerical techniques	Spectral (spherical harmonic basis functions) in horizontal, finite differences in vertical Two-time-level, semi-Lagrangian, semi-implicit time integration scheme Hydrostatic approximation
Integration domain	Global in horizontal, surface to 0.1 hPa in vertical
Horizontal resolution	Spectral triangular 959 (TL959), reduced Gaussian grid system, roughly equivalent to 0.1875˚ × 0.1875˚ lat-lon
Vertical resolution	60 unevenly spaced hybrid levels
Time step	10 minutes
Orography	GTOPO30 dataset, spectrally truncated and smoothed
Gravity wave drag	Longwave scheme (wavelengths > 100 km) mainly for stratosphere Shortwave scheme (wavelengths approximately 10 km) only for troposphere
Horizontal diffusion	Linear, fourth-order
Vertical diffusion	Stability (Richardson number) dependent, local formulation
Planetary boundary layer	Mellor and Yamada level-2 turbulence closure scheme Similarity theory in bulk formulae for surface layer
Treatment of sea surface	Climatological sea surface temperature with daily analyzed anomaly Climatological sea ice concentration with daily analyzed anomaly
Land surface and soil	Simple Biosphere (SiB) model
Radiation	Two-stream with delta-Eddington approximation for shortwave (hourly) Table look-up and k-distribution methods for longwave (every three hours)
Convection	Prognostic Arakawa-Schubert cumulus parameterization
Cloud	PDF-based cloud parameterization

4.2.2.2 Research performed in the field

(1) Update of climatology of the total-column aerosol optical thickness

The GSM's radiation scheme involves the use of the climatology for total-column aerosol optical thickness based on satellite observations. In April 2013, new aerosol optical depth distribution was introduced to improve radiative heating and fluxes. According to the verification with sun-photometer observation, the accuracy of the updated climatology improved as a result of following improvements: (1) The statistical averaging time period was extended to 104 months from 67 months. (2) New satellite observations such as those of Terra/MISR and Aura/OMI were introduced in addition to those of Aqua/MODIS and Terra/MODIS. (3) Alternative values for areas where satellite observation data were missing around polar regions were improved from estimated values of the Earthprobe/TOMS aerosol index to observations made at Antarctica's Showa Station. As a result, the mean error of shortwave radiation flux at the top of the atmosphere was reduced, and the mean error against radiosonde observation around the Antarctic was improved. (H. Yonehara)

(2) Improvement of a shortwave radiation scheme

In the GSM's shortwave radiation scheme, near-infrared water vapor absorption is calculated using a method known as exponential sum fitting of transmissions (Wiscombe and Evans 1977). In April 2013, water vapor absorption coefficients were updated with improved values suggested by Collins et al. (2006) to reduce the deficiency of shortwave heating in the troposphere. The low temperature bias in the upper troposphere was reduced as a result of this improvement. (H. Yonehara)

(3) Upgrade of the GSM

JMA plans to upgrade the GSM with more vertical levels and a higher top level in March 2014. The parameterization schemes for variables such as the boundary layer, radiation, non-orographic gravity waves and deep convection will also be revised to improve the representation of atmospheric characteristics. The number of vertical layers will be increased from 60 to 100, and the pressure of the top level will be raised from 0.1 to 0.01 hPa. In a trial run, overall improvement was found in forecasts of various elements including geopotential height, mean sea level pressure and 850/250-hPa vector winds in the extratropics. (H. Yonehara)

4.2.3 Operationally available NWP products

The model output products shown below from the GSM are disseminated through JMA's radio facsimile broadcast (JMH) service, GTS and the Global Information System Centre (GISC) Tokyo website.

Table 4.2.3-1 List of facsimile charts transmitted via the GTS and JMH

The contour lines (upper-case letters) are: D: dew-point depression (T - T_d); E: precipitation; H: geopotential height; J: wave height; O: vertical velocity (ω); P: sea level pressure; T: temperature; W: isotach wind speed; Z: vorticity; δ: anomaly from climatology; μ: average over time.

The other symbols are: a: wind arrows; b: observation plots; d: hatch for dewpoint depression < 3 K; g: arrows for prevailing wave direction; j: jet axis; m: wave period in digits; t: temperature in digits; x: streamlines.

The subscripts in the table indicate: $_{srf}$: surface; $_{trp}$: tropopause; digit (ex. $_{500}$) pressure in hPa.

The superscripts indicate dissemination channels and time: ^{G}: sent to GTS; ^{J}: sent to JMH; ^{12}: for 12 UTC only; ^{5}: statistics for pentad sent once per five days for 00 UTC; ^{m}: statistics for the month sent monthly for 00 UTC.

Model	Area	Forecast Time [h]						
		Analysis	12	24	36	48 72	96 120	144 168 196
GSM	Asia	HZ_{500}^{G} $T_{850}O_{700}^{G}$		HZ_{500}^{GJ} $T_{500}D_{700}^{GJ}$ $Ta_{850}O_{700}^{GJ}$ PE_{srf}^{GJ}				
	East Asia	$HWtab_{300}^{GJ}$ $HTab_{500}^{G}$ $HTbd_{700}^{G}$ $HTbd_{850}^{GJ}$		PE_{srf}^{G}		HZ_{500}^{G} $Ta_{850}O_{700}^{GJ12}$ PE_{srf}^{GJ}	PE_{srf}^{J12}	
	Asia						HZ_{500}^{G12} $P_{srf}T_{850}^{G12}$	
	Asia-Pacific	$HWtaj_{200}H_{trp}^{G}$ $HWta_{250}^{G}$		$HWta_{250}^{G}$ $HWta_{500}^{G}$				
	NW Pacific	x_{200}^{G} x_{850}^{G}		x_{200}^{G} x_{850}^{G}				
	N Hem.	HT_{500}^{G}						
Ocean Wave	Japan	$Jbgm_{srf}^{GJ}$						
	NW Pacific	$Jbgm_{srf}^{GJ}$	Jgm_{srf}^{J}			Jgm_{srf}^{J}		
JCDAS	N Hem.	$\mu H\delta H_{100}^{G5}$, $\mu H\delta H_{500}^{G5}$, $\mu H\delta H_{500}^{Gm}$, $\mu P\delta P_{srf}^{Gm}$						

Table 4.2.3-2 List of GPV products (GRIB2) distributed via the GISC Website

Symbols: H: geopotential height; U: eastward wind; V: northward wind; T: temperature; R: relative humidity; O: vertical velocity (ω); Z: vorticity; X: stream function; Y: velocity potential; P: pressure; Ps: sea-level pressure; E: rainfall; N: total cloud cover; Ch: high cloud cover; Cm: middle cloud cover; Cl: low cloud cover.

Model	GSM
Area and resolution	Whole globe, Region II 0.25° × 0.25° (surface) 0.5° × 0.5° (surface, isobar level)
Levels	10 hPa, 20 hPa, 30 hPa, 50 hPa, 70 hPa, 100 hPa, 150 hPa, 200 hPa, 250 hPa, 300 hPa, 400 hPa, 500 hPa, 600 hPa, 700 hPa, 800 hPa, 850 hPa, 900 hPa, 925 hPa, 950 hPa, 975 hPa, 1,000 hPa, surface
Elements	Surface: U, V, T, R, Ps, P, E, N, Ch, Cm, Cl 200 hPa: U, V, T, R, H, O, X, Y 500 hPa: U, V, T, R, H, O, Z 850 hPa: U, V, T, R, H, O, X, Y Other levels: U, V, T, R, H, O
Forecast	0 – 84 every 3 hours,

hours	90 – 264 every 6 hours (12 UTC)
Initial times	00 UTC, 06 UTC, 12 UTC, 18 UTC

Table 4.2.3-3 List of GPV products (GRIB) distributed via the GISC website and the GTS

Symbols: D: dew-point depression; E: precipitation; G: prevailing wave direction; H: geopotential height; J: wave height; M: wave period; O: vertical velocity (ω); P: sea level pressure; R: relative humidity; T: temperature; U: eastward wind; V: northward wind; X: stream function; Y: velocity potential; Z: vorticity;
The prefixes μ and σ represent the average and standard deviations of ensemble prediction results, respectively. The symbols °, *, ¶, §, ‡ and † indicate limitations on forecast hours or initial times as shown in the notes below.

Model	GSM	GSM	GSM
Destination	GISC	GTS, GISC	GTS, GISC
Area and resolution	Whole globe, 1.25° × 1.25°	20°S – 60°N, 60°E – 160°W 1.25° × 1.25°	Whole globe, 2.5° × 2.5°
Levels and elements	10 hPa: H, U, V, T 20 hPa: H, U, V, T 30 hPa: H, U, V, T 50 hPa: H, U, V, T 70 hPa: H, U, V, T 100 hPa: H, U, V, T 150 hPa: H, U, V, T 200 hPa: H, U, V, T, X, Y 250 hPa: H, U, V, T 300 hPa: H, U, V, T, R, O 400 hPa: H, U, V, T, R, O 500 hPa: H, U, V, T, R, O, Z 600 hPa: H, U, V, T, R, O 700 hPa: H, U, V, T, R, O 850 hPa: H, U, V, T, R, O, X, Y 925 hPa: H, U, V, T, R, O 1,000 hPa: H, U, V, T, R, O Surface: P, U, V, T, R, E†	10 hPa: H, U, V, T 20 hPa: H, U, V, T 30 hPa: H, U, V, T 50 hPa: H, U, V, T 70 hPa: H, U, V, T 100 hPa: H, U, V, T 150 hPa: H, U, V, T 200 hPa: H§, U§, V§, T§, X, Y 250 hPa: H, U, V, T 300 hPa: H, U, V, T, D 400 hPa: H, U, V, T, D 500 hPa: H§, U§, V§, T§, D§, Z 700 hPa: H§, U§, V§, T§, D§, O 850 hPa: H§, U§, V§, T§, D§, O, X, Y 925 hPa: H, U, V, T, D, O 1,000 hPa: H, U, V, T, D Surface: P¶, U¶, V¶, T¶, D¶, E¶	10 hPa: H*, U*, V*, T* 20 hPa: H*, U*, V*, T* 30 hPa: H°, U°, V°, T° 50 hPa: H°, U°, V°, T° 70 hPa: H°, U°, V°, T° 100 hPa: H°, U°, V°, T° 150 hPa: H*, U*, V*, T* 200 hPa: H, U, V, T 250 hPa: H°, U°, V°, T° 300 hPa: H, U, V, T, D*‡ 400 hPa: H*, U*, V*, T*, D*‡ 500 hPa: H, U, V, T, D*‡ 700 hPa: H, U, V, T, D 850 hPa: H, U, V, T, D 1,000 hPa: H, U*, V*, T*, D*‡ Surface: P, U, V, T, D‡, E†
Forecast hours	0 – 84 every 6 hours and 96 – 192 every 12 hours † Except analysis	0 – 84 every 6 hours § Additional 96 – 192 every 24 hours for 12 UTC ¶ 0 – 192 every 6 hours for 12 UTC	0 – 72 every 24 hours and 96 – 192 every 24 hours for 12 UTC ° 0 – 120 for 12 UTC † Except analysis * Analysis only
Initial times	00 UTC, 06 UTC, 12 UTC, 18 UTC	00 UTC, 06 UTC, 12 UTC, 18 UTC	00 UTC, 12 UTC ‡ 00 UTC only

Model	One-week EPS	Ocean Wave Model
Destination	GISC	GISC
Area and resolution	Whole globe, 2.5° × 2.5°	75°S – 75°N, 0°E – 358.75°E 1.25° × 1.25°
Levels and elements	250 hPa: μU, μV, σU, σV 500 hPa: μH, σH 850 hPa: μU, μV, μT, σU, σV, σT 1,000 hPa: μH, σH Surface: μP, σP	Surface: J, M, G
Forecast hours	0 – 192 every 12 hours	0 – 84 every 6 hours, 96 – 192 every 12 hours
Initial times	12 UTC	00 UTC and 12 UTC

4.2.4 Operational techniques for application of NWP products

(1) Forecast guidance

The application techniques for both the medium- and short-range forecasting systems are described in 4.3.4.1 (1).

4.2.5 Ensemble Prediction System (EPS)

4.2.5.1 In operation

Presently, JMA operates the One-week EPS once a day from a base time at 12 UTC with a forecast range of eleven days. The specifications of the EPS are shown in Table 4.2.5-1. It is composed of one control forecast and fifty perturbed forecasts. Initial perturbations are generated using the singular vector (SV) method (Buizza and Palmer 1995). The tangent-linear and adjoint models used for SV computation are lower-resolution versions of those used in the four-dimensional variational data assimilation system for the GSM until October 2011. The moist total energy norm (Ehrendorfer et al. 1999) is employed for the metrics of perturbation growth. The forecast model used in the EPS is a low-resolution version of the GSM (see 4.2.2.1). Accordingly, the dynamical framework and physical processes involved are identical to those of the GSM except for the horizontal resolution. A stochastic physics scheme (Buizza et al. 1999) is used in the One-week EPS in consideration of model uncertainties associated with physical parameterizations.

Unperturbed analysis is prepared by interpolating the analyzed field in global analysis (see 4.2.1.1). The sea surface temperature analysis value is used as a lower boundary condition and prescribed using the persisting anomaly, which means that the anomalies shown from analysis for the initial time are fixed during the time integration. The sea ice concentration analysis value is also prescribed using the persisting anomaly.
JMA extended the forecast range of its One-week EPS from 9 days up to 11 days in March 2013.

Table 4.2.5-1 Specifications of the One-week EPS

Integration	Start of operation	March 2001
	Ensemble size	51
	Initial time	12 UTC
	Forecast range	11 days
EPS model	Model type	GSM
	Horizontal resolution	TL319 reduced Gaussian grid system roughly equivalent to 0.5625° × 0.5625° (55 km) in latitude and longitude
	Vertical resolution (model top)	60 levels (0.1 hPa)
	Model ensemble method	Stochastic physics scheme

<table>
<tr><td rowspan="7">Initial perturbation (Initial ensemble generator | Singular vector method)</td><td>Inner-model resolution</td><td colspan="3">Spectral triangular truncation 63 (T63), 40 levels</td></tr>
<tr><td>Norm</td><td colspan="3">Moist total energy</td></tr>
<tr><td>Targeted area</td><td>Northern Hemisphere (30°N – 90°N)</td><td>Southern Hemisphere (90°S – 30°S)</td><td>Tropics (30°S – 30°N)</td></tr>
<tr><td>Physical process</td><td colspan="2">*Simplified physics</td><td>**Full physics</td></tr>
<tr><td>Optimization time</td><td colspan="2">48 hours</td><td>24 hours</td></tr>
<tr><td>Evolved SV</td><td colspan="3">Used</td></tr>
<tr><td>Number of perturbations</td><td colspan="3">25</td></tr>
</table>

*Simplified physics: initialization, horizontal diffusion, surface fluxes and vertical diffusion

**Full physics: as per simplified physics with the addition of gravity wave drag, large-scale condensation, long-wave radiation and deep cumulus convection

4.2.5.2 Research performed in the field

(1) Improvement of One-week EPS

JMA plans to improve the One-week EPS (WEPS) in March 2014. The work will include enhancement of the forecast model's horizontal resolution from TL319 to TL479 and revision of its physical processes, such as the stratocumulus and radiation schemes. It will also include increased frequency of operation from once a day to twice a day and an approximate halving of each ensemble size from 51 to 27 so that the total ensemble size will be 54/day instead of 51/day. An experiment was conducted for the periods from December 2011 to February 2012 and from July to September 2012 on the improved WEPS. The results showed that the anomaly correlation coefficients for the 500-hPa geopotential height of the ensemble mean forecast for the Northern Hemisphere extra-tropics as determined using the improved WEPS were higher than those of the operational WEPS up to about ten days ahead, indicating that the improved WEPS is superior to the operational version for almost the whole forecast range. (H. Yamaguchi, M. Higaki and M. Kyouda)

4.2.5.3 Operationally available EPS products

See 4.2.3.

4.3 Short-range forecasting system (0 – 72 hrs)

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

(1) Meso-scale Analysis (MA)

A 4D-Var data assimilation method has been employed since 19 March, 2002, for mesoscale analysis of atmospheric conditions (Meso-scale Analysis, or MA). The MA was replaced with a new 4D-Var called the JNoVA (Honda et al. 2005) in April 2009. The JNoVA is based on JMA's non-hydrostatic model (JMA-NHM; Saito et al. 2006), which is a current mesoscale forecast model (the Meso-Scale Model, or MSM). The analysis domain was expanded in March 2013. The specifications of the MA are detailed in Table 4.3.1-1.

Table 4.3.1-1 Specifications of the MA

4D-Var formulation	Incremental 4D-Var using a nonlinear forward model in the inner step with low resolution
Data cut-off time	50 minutes for analysis at 00, 03, 06, 09, 12, 15, 18 and 21 UTC
Observation (as of 31 December 2013)	SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR; AMVs from MTSAT-2; radiances from NOAA-15, 16, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP/SSMIS-F16, 17, 18, TRMM/TMI, GCOM-W1/AMSR2; WV-CSR of MTSAT-2; radar-raingauge analyzed precipitation; precipitation retrievals from TRMM/TMI, DMSP-F16, 17, 18/SSMIS, GCOM-W/AMSR2; total Precipitable Water Vapor from ground-based GNSS
First guess	3-hour forecast produced by the MSM
Domain configuration	(Outer step) Lambert projection; 5 km at 60°N and 30°N, 817 × 661 Grid point (1, 1) is at the northwest corner of the domain. Grid point (565, 445) is at 140°E, 30°N. (Inner step) Lambert projection; 15 km at 60°N and 30°N, 273 × 221 Grid point (1, 1) is at the northwest corner of the domain. Grid point (189, 149) is at 140°E, 30°N.
Vertical levels	(Outer step) 50 levels up to 22 km (consistent with the forecast model setting) (Inner step) 40 levels up to 22 km
Analysis variables	Wind, potential temperature, surface pressure and pseudo-relative humidity
Assimilation window	3 hours

(2) Typhoon bogussing of the MA

The method employed is the same as that in the GA (see 4.2.1.1 (2)).

(3) Local Analysis (LA)

Local Analysis (LA), which was introduced in August 2012, produces initial conditions for the Local Forecast Model (LFM) at a horizontal resolution of 2 km. For the provision of initial conditions to the high-resolution forecast model targeting small-scale severe weather events, the LA is designed to allow rapid production and frequent updating of analysis at a resolution of 5 km. An analysis cycle with hourly three-dimensional variational (3D-Var) data assimilations is executed each time for the previous three-hour period to incorporate information from newly received observations in each case. High-resolution NWP's capacity to capture small-scale variations in topography is expected to help a reduction of representativeness errors in surface observation assimilation. In association, the LA also assimilates automated surface station (AMeDAS) data ahead of other operational data assimilation systems at lower resolutions to appropriately reflect the effects of local-scale environments near the surface. The analysis domain was expanded so that the Japan and its surrounding areas can be covered and the update frequency was enhanced to every hour in May 2013. The specifications of the LA are detailed in Table 4.3.1-2.

Table 4.3.1-2 Specifications of the LA

Analysis cycle	The three-hour analysis cycle repeats hourly assimilation with 3D-Var and one-hour forecasts.
Data cut-off time	30 minutes for analysis at 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23 UTC
Observation (as of 31 December 2013)	SYNOP, SHIP, BUOY, AMeDAS, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR and total Precipitable Water Vapor from ground-based GNSS
First guess	Initial fields produced by the latest MSM
Domain configuration	Lambert projection; 5 km at 60°N and 30°N, 633 × 521 Grid point (1, 1) is at the northwest corner of the domain. Grid point (449, 361) is at 140°E, 30°N
Vertical levels	50 levels up to 22 km
Analysis variables	Wind, potential temperature, surface pressure, pseudo-relative humidity and ground potential temperature

4.3.1.2 Research performed in the field

(1) Assimilation of GCOM-W1/AMSR2 radiance data into the Meso-scale NWP system

Based on assessment in the Meso-scale NWP system, the quality of bias-corrected AMSR2 radiance data is comparable to that of data from AMSR-E and other microwave imagers. To investigate the related impact on analysis and forecasts in data assimilation experiments, AMSR2 radiance data were incorporated in addition to the currently used microwave imager data. In experiments with the Meso-scale NWP system, increases in the analysis increment of humidity with AMSR2 radiance data assimilation were found along with significant improvements in precipitation forecasting. AMSR2 radiance data assimilation was operationally begun on 12 September 2013. (M. Kazumori and T. Egawa)

(2) Assimilation of Metop-B data into the Meso-scale NWP system

JMA assimilated observational data derived from sensors on board the Metop-B satellite into the Meso-scale NWP system on 28 November 2013. The assimilation targets are the Advanced Microwave Sounding Unit-A (AMSU-A) and the Microwave Humidity Sounder (MHS). Data from Metop-A had previously been utilized in the Meso-scale NWP system since 2008. Statistical research based on the mean and standard deviation of differences between observations from

Metop-B and related MSM simulations showed that the quality of Metop-B data was comparable to that of Metop-A data. OSEs for each one-week period in August and February 2013 showed an almost neutral impact in terms of forecast scores relating to precipitation and elements such as temperature and wind vectors. (M. Moriya)

4.3.2 Model

4.3.2.1 In operation

(1) Meso-Scale Model (MSM)

JMA has operated the MSM since March 2001. Its main roles are disaster prevention and aviation forecasting. The JMA-NHM was adopted as the MSM in September 2004, and 15- or 33-hour forecasts have been provided every 3 hours, i.e., 8 times a day, since May 2007. The forecast domain was expanded in March 2013. The forecast range at all the initial times was extended to 39 hours in May 2013.The specifications of the MSM are listed in Table 4.3.2-1.

Table 4.3.2-1 Specifications of the MSM

Basic equations	Fully compressible non-hydrostatic equations
Independent variables	Latitude, longitude, terrain-following height coordinates, time
Dependent variables	Momentum components in three dimensions, potential temperature, pressure, mixing ratios of water vapor, cloud water, cloud ice, rain, snow and graupel, number concentration of cloud ice
Numerical techniques	Finite discretization on Arakawa-C-type staggered coordinates, horizontally explicit and vertically implicit time integration scheme, fourth-order horizontal finite differencing in flux form with modified advection treatment for monotonicity
Projection and grid size	Lambert projection, 5 km at 60°N and 30°N
Integration domain	Japan, 817 × 661 grid points
Vertical levels	50 (surface to 21. 8 km)
Forecast times	39 hours from 00, 03, 06, 09, 12, 15, 18 and 21 UTC
Initial fields	4D-Var analysis with mixing ratios of cloud water, cloud ice, rain, snow and graupel derived from preceding forecasts considering consistency with the analysis field of relative humidity The MSM runs three hours before the initial time for spin-up.
Lateral boundary	00–45 hour forecasts by the GSM initialized at 00/06/12/18 UTC for (03, 06)/(09, 12)/(15, 18)/(21, 00) UTC forecasts
Orography	Mean orography smoothed to eliminate shortest-wave components
Horizontal diffusion	Linear, fourth-order Laplacian + nonlinear damper Targeted moisture diffusion applied to grid points where excessive updrafts appear
Convection	Kain-Fritsch convection scheme
Cloud	Three-ice bulk cloud microphysics Lagrangian treatment for rain and graupel precipitation
Radiation (short wave)	Two-stream with delta-Eddington approximation (every 15 minutes)

Radiation (long wave)	Table look-up and k-distribution methods (every 15 minutes)
Cloudiness	Cloud water and cloud cover diagnosed using a partial condensation scheme
Gravity wave drag	No parameterization scheme included
PBL	Improved Mellor-Yamada Level 3 scheme Similarity theory adopted for surface boundary layer
Land surface	Ground temperature predicted using a four-layer ground model Evaporability predicted initialized by climatological values depending on location and season
Surface state	Observed SST (fixed during time integration) and sea-ice distribution Climatological values of evaporability, roughness length and albedo Snow cover over Japan analyzed daily

(2) Local Forecast Model (LFM)

Making use of the new powerful supercomputer system installed in June 2012, operation of a forecast model called the LFM with an even higher resolution was launched in August 2012 along with LA. The new model has 2-km horizontal grid spacing and 60 vertical layers up to a height of approximately 20.2 km above the surface, and is designed to produce more detailed forecasts with emphasis on predicting localized and short-lived severe events. The LFM is specifically intended to provide very short-range forecasts for the period of nine hours ahead and other periods, and to allow rapid and frequent forecast updates based on initial conditions with the latest observations assimilated by the LA. The forecast domain was expanded so that the Japan and its surrounding areas can be covered and the update frequency was enhanced to every hour in May 2013.The specifications of the LFM are listed in Table 4.3.2-2.

Table 4.3.2-2 Specifications of the LFM

Basic equations	Fully compressible non-hydrostatic equations
Independent variables	Latitude, longitude, terrain-following height coordinates, time
Dependent variables	Momentum components in three dimensions, potential temperature, pressure, mixing ratios of water vapor, cloud water, cloud ice, rain, snow and graupel
Numerical techniques	Finite discretization on Arakawa-C-type staggered coordinates, horizontally explicit and vertically implicit time integration scheme, fourth-order horizontal finite differencing in flux form with modified advection treatment for monotonicity
Projection and grid size	Lambert projection, 2 km at 60°N and 30°N
Integration domain	Japan, 1531 × 1301 grid points
Vertical levels	60 (surface to 20. 2 km)
Forecast times	9 hours from 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23 UTC
Initial fields	The LA produces initial conditions through the three-hour analysis cycle based on hourly assimilation with 3D-Var and one-hour forecasts.
Lateral boundary	00–13 hour forecasts produced by the latest MSM
Orography	Mean orography smoothed to eliminate shortest-wave components

Horizontal diffusion	Linear, fourth-order Laplacian + nonlinear damper Targeted moisture diffusion applied to grid points where excessive updrafts appear
Convection	No parameterization scheme included
Cloud	Three-ice bulk cloud microphysics Lagrangian treatment for rain and graupel precipitation
Radiation (short wave)	Two-stream with delta-Eddington approximation (every 15 minutes)
Radiation (long wave)	Table look-up and k-distribution methods (every 15 minutes)
Cloudiness	Cloud water and cloud cover diagnosed using a partial condensation scheme
Gravity wave drag	No parameterization scheme included
PBL	Improved Mellor-Yamada Level 3 scheme Similarity theory adopted for surface boundary layer
Land surface	Ground temperature predicted using a four-layer ground model Evaporability predicted initialized by climatological values depending on location and season.
Surface state	Observed SST (fixed during time integration) and sea-ice distribution Climatological values of evaporability, roughness length and albedo Snow cover over Japan analyzed daily

4.3.2.2 Research performed in the field

4.3.3 Operationally available NWP products

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

(1) Forecast guidance

Forecast guidance is utilized to issue warnings, advisories, information and weather forecasts. Four operational techniques are routinely used to derive guidance from NWP model output. The first involves the use of the Kalman filter, the second involves an artificial neural network, the third is based on logistic regression, and the last is a diagnostic method. These techniques are applied to grid-point values from the GSM (20-km grid squares, 0 – 84 hour forecasts) and the MSM (5-km grid squares, 0 – 39 hour forecasts) in order to reduce systematic forecast errors and enable the extraction of useful information such as probability data and categorical/diagnostic values.

The Kalman filter technique is used to derive data on the probability of precipitation, average precipitation amounts, maximum/minimum temperatures, time-series temperature, maximum wind speed/direction, maximum instantaneous wind speed/direction, time-series wind speed/direction, average and minimum visibility, and the probability of minimum visibility values being less than 5,000 or 1,600 meters. The gust speed and direction values have been used since November 2012. Maximum wind speed/direction and time-series wind speed/direction guidance were improved in June 2013.

The artificial neural network technique is used to derive data on sunshine durations, minimum humidity, cloud amounts, cloud base heights and point-type maximum snowfall depths. The maximum precipitation guidance is derived by multiplying the average precipitation amount for each grid square by an optimum ratio derived using the artificial neural network. The probability of gusting (PoG) values has been used since November 2012. The maximum 24-hour cumulative precipitation guidance was also improved in March 2013. To derive the ratio of average precipitation to maximum precipitation, the multiple linear regression method is used in place of the artificial neural network. The point-type maximum snowfall depths guidance was improved in November 2013.

The logistic regression technique is used to derive data on the probability of thunderstorms and particular cloud base heights. The Lagged Average Forecast (LAF) method has been applied to determine the probability of thunderstorms since May 2008. The logistic regression technique is also applied to turbulence index values for area forecasts. The turbulence index (also known as the TBindex (Kudo 2011)) is constructed from a number of other turbulence indices used to comprehensively predict various kinds of turbulence. It has been in operation since February 2010, and was upgraded in June 2010.

The diagnostic method is used to derive data on grid-type maximum snowfall depths, weather categories and visibility distribution guidance, which is determined using extinction coefficients for raindrops, snowfall, cloud water and humidity. Visibility distribution guidance has been provided since March 2011. The diagnostic method is also applied to the CB cloud amount, the CB top height and the aircraft icing index for area forecasts. The CB cloud amount and top height are derived based on the technique to discriminate deep convection used in the Kain-Fritsch convective scheme, in which cloud top and base heights are estimated from the surrounding temperature, humidity and updraft conditions. CB cloud forecasting has been performed since 2007, and was upgraded in 2009. The icing index is constructed by multiplying a distribution function of icing for temperature and dewpoint depression based on the results of statistical research performed for the area around Japan. To support marine warnings, the visibility distribution guidance derived from the GSM has been used since November 2012.

(2) Hourly Analysis

JMA Hourly Analysis involves three-dimensional evaluation of temperature and wind fields with a grid spacing of 5 km to provide real-time monitoring of weather conditions. The latest MSM forecast is used as the first guess, and observational information is added through assimilation. The three-dimensional variational data assimilation method is adopted as the analysis technique. The hourly product is made within 30 minutes of the end of each hour, and is provided to operational forecasters and aviation users. The specifications of the Hourly Analysis schemes are listed in Table 4.3.4-1.

Table 4.3.4-1 Specifications of the Hourly Analysis

Analysis scheme	3D-Var
Data cut-off time	20 minutes
First guess	2, 3 or 4-hour forecast by the MSM
Domain configuration	Lambert projection, 5 km at 60°N and 30°N, 721 × 577 grid points Grid point (1, 1) is at the northwestern corner of the domain. Grid point (489, 409) is at 140°E, 30°N.
Vertical levels	50 forecast model levels
Analysis variables	Wind, temperature, surface wind and surface temperature
Observation (as of 31 December, 2013)	AMeDAS, Wind Profiler, Weather Doppler radar (radial velocity), AIREP, AMDAR, and AMVs from MTSAT-2
Post-processing	Surface filtering (followed by adjustment of the increment within the PBL)

4.3.4.2 Research performed in the field

(1) Forecast guidance

The maximum wind speed and direction guidance has been developed to support wind information for one-week forecasts. The Kalman filter and the frequency bias correction techniques are applied to each ensemble member of the one-week EPS.

Maximum snowfall amount guidance has been developed to support snowfall information for one-week forecasts. The diagnostic method is used to derive the maximum snowfall amount for each ensemble member of the one-week EPS.

Maximum/minimum temperatures and time-series temperature guidance will be improved in 2014. To enhance forecast accuracy, new predictors have been introduced. In addition, Kalman filter system error covariances have been introduced for warm and cold seasons.

4.4 Nowcasting and Very-short-range Forecasting systems (0 – 6 hrs)

Since 1988, JMA has routinely operated a fully automated system of precipitation analysis and very short-range forecasting to monitor and forecast local severe weather conditions. In addition to these, JMA has issued Precipitation Nowcasts since June 2004, Thunder Nowcasts since May 2010 and Hazardous Wind Potential Nowcasts since May 2010.

The system is used to output the five products outlined below.

(1) Precipitation Nowcasts, which are forecasts of 10-minute cumulative precipitation and 5-minute-interval precipitation intensity based on extrapolation covering up to 60 minutes ahead.
(2) Thunder Nowcasts, which are forecasts of thunder and lightning activity based on lightning detection network system observation covering up to 60 minutes ahead.
(3) Hazardous Wind Potential Nowcasts, which are forecasts of the probability of hazardous wind conditions such as tornadoes covering up to 60 minutes ahead.
(4) Radar/Raingauge-Analyzed Precipitation (R/A)*, which shows one-hour cumulative precipitation based on radar observation calibrated half-hourly using raingauge measurements from JMA's Automated Meteorological Data Acquisition System (AMeDAS) and other available data such as those from rain gauges operated by local governments.
(5) Very-Short-Range Forecasts of precipitation (VSRFs), which are forecasts of one-hour cumulative precipitation based on extrapolation and prediction by the MSM and LFM (see 4.3.2.1) and covering the period from one to six hours ahead.

*Referred to before 15 November, 2006, as *Radar-AMeDAS precipitation*.

4.4.1 Nowcasting system (0 – 1 hrs)

4.4.1.1 In operation

(1) Precipitation Nowcasts

Precipitation Nowcasts predict 10-minute accumulated precipitation and 5-minute-interval precipitation intensity by extrapolation up to one hour ahead. Initial precipitation intensity distribution is derived from radar data obtained at 5-minute intervals, and is calibrated by raingauge observation. Using estimated movement vectors, these forecasts predict precipitation distribution by extrapolation within three minutes of radar observation. The specifications are summarized in table 4.4.1-1.
Precipitation Nowcasts are provided to local weather offices and to the public to help clarify precipitation transition and to support disaster prevention activities.

Table 4.4.1-1 Specifications of the Precipitation Nowcast model

Forecast process	Non-Linear motion/intensity extrapolation including the generation and lifecycle estimation of storm cells as well as orographic rainfall trend prediction
Movement vector	Precipitation system and/or cell motion estimated using the cross-

	correlation pattern matching and discrete interpolation
Time step	5 minutes
Grid form	Cylindrical equidistant projection
Resolution	Approx. 1 km
Number of grids	2,560 × 3,360
Initial	Calibrated radar echo intensities
Forecast time	60 minutes ahead, updated every 5 minutes

(2) Thunder Nowcasts

Thunder Nowcasts predict thunder and lightning activity up to one hour ahead. Initial activity distribution is derived from lightning detection network system observations obtained at 10-minute intervals. Using estimated movement vectors, these forecasts predict activity distribution by extrapolation within three minutes of radar observation. The specifications are summarized in table 4.4.1-2.

Thunder Nowcasts are provided to local weather offices and to the public. They are utilized to understand thundercloud transfer and to advise people to stay in or go to safe places in order to avoid lightning strikes.

Table 4.4.1-2 Specifications of Thunder Nowcast model

Forecast process	Extrapolation
Movement vector	As per the Precipitation Nowcast system
Grid form	Cylindrical equidistant projection
Resolution	Approx. 1 km
Number of grids	2,560 × 3,360
Initial	4-level activity of thunder and lightning based on lightning detection network system observation
Forecast time	60 minutes ahead, updated every 10 minutes

(3) Hazardous Wind Potential Nowcasts

Hazardous Wind Potential Nowcasts predict the probability of hazardous wind conditions such as tornadoes up to one hour ahead. Initial probability distribution is established using radar measurements including Doppler radar data obtained at 10-minute intervals and severe weather parameters calculated from Numerical Weather Prediction. Using estimated movement vectors, these forecasts predict probability distribution by extrapolation within three minutes of radar observation. The specifications are summarized in table 4.4.1-3.
Hazardous Wind Potential Nowcasts are provided to local weather offices and to the public. They are utilized to understand potential hazardous wind transfer and to call attention to hazardous wind conditions.

Table 4.4.1-3 Hazardous Wind Potential Nowcast model

Forecast process	Extrapolation
Movement vector	As per the Precipitation Nowcast system

Grid form	Cylindrical equidistant projection
Resolution	Approx. 10 km
Number of grids	256 × 336
Initial	2-level presumed hazardous wind probabilities
Forecast time	60 minutes ahead, updated every 10 minutes

4.4.1.2 Research performed in the field

(1) Development of High-Resolution Precipitation Nowcasts

JMA has developed High-Resolution Precipitation Nowcasts which predict five-minute cumulative precipitation, five-minute-interval precipitation intensity and estimated forecast error with a resolution of 250 meters up to 30 minutes ahead. The product is scheduled to become operational in the summer of 2014.

a. Analysis

- Three-dimensional analysis of storm cells is conducted using radar echo intensity and Doppler velocity data as well as vertical profiles of the atmosphere derived from radiosonde and wind profiler observation.
- Precipitation intensity is calibrated based on raingauge observation.

b. Forecasting

- Large-scale distribution of precipitation is predicted based on non-linear motion/intensity extrapolation.
- The life cycle of strong storm cells is evaluated using a one-dimensional vertical convective model.
- Generation of convective clouds triggered by convergence is considered.

4.4.2 Models for Very-short-range Forecasting Systems (1 – 6 hrs)

4.4.2.1 In operation

(1) Radar/Raingauge-Analyzed Precipitation (R/A)

Radar/Raingauge-Analyzed Precipitation (R/A) is a type of precipitation distribution analysis with a resolution of 1 km, and is derived on a half-hourly basis. Radar data and raingauge precipitation data are used to make R/A. The radar data consist of intensity data from 46 weather radars operated by JMA and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), and the raingauge precipitation data are collected from more than 10,000 raingauges operated by JMA, MLIT and local governments.

After collecting this information, the radar intensity data are accumulated to create one-hour accumulated radar precipitation data. Each set of this data is calibrated with the one-hour accumulated raingauge precipitation data. R/A is a composite of all calibrated and accumulated radar precipitation data. The initial field for extrapolation forecasting is the composite of the calibrated radar intensity data.

(2) Very-Short-Range Forecasts of precipitation (VSRFs)

The extrapolation forecast and precipitation forecast from the MSM and the LFM (see 4.3.2.1) are merged into the Very-Short-Range Forecast of precipitation (VSRFs). The merging weight of the MSM/LFM forecast is nearly zero for a one-hour forecast, and is gradually increased with forecast time to a value determined from the relative skill of MSM/LFM forecasts. The specifications of the extrapolation model are detailed in table 4.4.2-1.

Table 4.4.2-1 Specifications of extrapolation model

Forecast process	Extrapolation
Physical process	Enhancement and dissipation
Movement vector	Precipitation system movement evaluated using the cross-correlation method
Time step	2 – 5 minutes
Grid form	Oblique conformal secant conical projection
Resolution	1 km
Number of grids	1,600 × 3,600
Initial	Calibrated radar echo intensities
Forecast time	Up to six hours from each initial time (every 30 minutes = 48 times/day)

VSRFs products are issued about 20 minutes after radar observation to support local weather offices that issue weather warnings for heavy precipitation, and are used for forecast calculation of applied products such as the Soil Water Index and the R/A Runoff Index.

4.4.2.2 Research performed in the field

(1) Radar/Raingauge-Analyzed Precipitation (R/A)

- Mitigation of upper-altitude radar echo impacts will be applied in 2014.

(2) Very-Short-Range Forecasts of precipitation (VSRFs)

- The LFM (see 4.3.2.1) was merged to support prediction of precipitation in October 2013.
- Several improvements are planned for 2014, including:
  - Derivation of mid-term movement vectors based on a large-scale precipitation system

- Estimation of storm cell life cycles from trends of precipitation intensity calculated using numerical weather prediction models

4.5 Specialized numerical prediction

4.5.1 Assimilation of specific data, analysis and initialization (where applicable)

4.5.1.1 In operation

(1) Global Ocean Data Assimilation System

The Global Ocean Data Assimilation System (named MOVE/MRI.COM-G; Usui et al. 2006) developed by the Meteorological Research Institute of JMA is in operation at JMA. Its specifications are shown in Table 4.5.1-1.

Table 4.5.1-1 Specifications of the Global Ocean Data Assimilation System

Basic equations	Primitive equations with free surface
Independent variables	Lat-lon coordinates and σ-z hybrid vertical coordinates
Dependent variables	u, v, T, S, SSH
Numerical technique	Finite difference both in the horizontal and in the vertical
Grid size	1˚ (longitude) × 1˚ (latitude, smoothly decreasing to 0.3˚ toward the equator) grids
Vertical levels	50 levels
Integration domain	Global oceans from 75°N to 75°S
Forcing data	Heat, water and momentum fluxes are calculated using data from the JMA Climate Data Assimilation System (JCDAS).
Observational data	Sea-surface and subsurface temperature and salinity and sea surface height
Operational runs	Two kinds of run (final and early) with cut-off times of 33 days and 2 day, respectively, for ocean observation data

Outputs of MOVE/MRI.COM-G are used to monitor and diagnose tropical ocean status. Some figures based on MOVE/MRI.COM-G output are published in JMA's *Monthly Highlights on Climate System* and provided through the Tokyo Climate Center (TCC) website (http://ds.data.jma.go.jp/tcc/tcc/index.html). The data are also used as oceanic initial conditions for JMA's coupled ocean-atmosphere model (JMA/MRI-CGCM).

(2) High-resolution sea surface temperature analysis for global oceans

High-resolution daily sea surface temperatures (SSTs) in global oceans are objectively analyzed on a 1/4˚ × 1/4˚ grid for ocean information services and to provide boundary conditions for atmospheric short-range prediction models and North Pacific Ocean models. SSTs obtained from polar-orbiting satellites (AVHRRs on Metop, AVHRRs on the NOAA series, and AMSR2 on GCOM-W1) are used together with in-situ SST observations. The analysis data are available on the NEAR-GOOS Regional Real Time Data Base (http://goos.kishou.go.jp).

4.5.2 Specific models

4.5.2.1 In operation

(1) Typhoon Ensemble Prediction System (Typhoon EPS)

JMA routinely operates the Typhoon EPS to support the issuance of five-day tropical cyclone (TC) track forecasts. This EPS consists of 11 forecasts run up to four times a day from base times at 00, 06, 12 and 18 UTC with a forecast range of 132 hours. The system is operated when any of the following conditions is satisfied:

- A TC of tropical storm (TS*) intensity or higher is present in the RSMC Tokyo - Typhoon Center's
- area of responsibility (0°–60°N, 100°E–180°).
- A TC is expected to reach TS intensity or higher in the area within the next 24 hours.
- A TC of TS intensity or higher is expected to move into the area within the next 24 hours.

* A TS is defined as a TC with maximum sustained wind speeds of 34 knots or more and less than 48 knots.

The specifications of the Typhoon EPS are shown in Table 4.5.2-1. A low-resolution version of the GSM is used in the Typhoon EPS as well as the One-week EPS (see 4.2.5.1). Accordingly, the dynamical framework and physical processes involved are identical to those of the GSM except for the horizontal resolution. The unperturbed analysis is prepared by interpolating the analyzed field in the GA. The sea surface temperature analysis value is used as a lower boundary condition and prescribed using the persisting anomaly, which means that the anomalies shown by analysis for the initial time are fixed during the time integration. The sea ice concentration analysis value is also prescribed using the persisting anomaly. As with the One-week EPS, initial perturbations are also generated using the SV method, but the configurations are different.

Table 4.5.2-1 Specifications of the Typhoon EPS

Integration	Start of operation	February 2008
	Ensemble size	11
	Initial time	00, 06, 12 and 18 UTC
	Forecast range	132 hours
EPS model	Model type	GSM
	Horizontal resolution	TL319 reduced Gaussian grid system roughly equivalent to 0.5625° × 0.5625° (55 km) in latitude and longitude
	Vertical resolution (model top)	60 levels (0.1 hPa)

<table>
<tr><td></td><td>Model ensemble method</td><td colspan="2">Stochastic physics scheme</td></tr>
<tr><td rowspan="7">Initial perturbation (Initial ensemble generator | Singular vector method)</td><td>Inner-model resolution</td><td colspan="2">Spectral triangular truncation 63 (T63), 40 levels</td></tr>
<tr><td>Norm</td><td colspan="2">Moist total energy</td></tr>
<tr><td>Targeted area</td><td>Northwestern Pacific
(20°N – 60°N, 100°E – 180°)</td><td>Vicinities of up to 3 TCs in the Typhoon Center’s area of responsibility</td></tr>
<tr><td>Physical process</td><td>Simplified physics</td><td>Full physics</td></tr>
<tr><td>Optimization time</td><td colspan="2">24 hours</td></tr>
<tr><td>Evolved SV</td><td colspan="2">Not used</td></tr>
<tr><td>Number of perturbations</td><td>10</td><td>10 for each TC</td></tr>
</table>

(2) Environmental emergency response system

JMA acts as a Regional Specialized Meteorological Center (RSMC) for Environmental Emergency Response in WMO Regional Association (RA) II, and is responsible for the preparation and dissemination of transport model products on exposure and surface contamination involving accidentally released radioactive materials. An operational tracer transport model is run at the request of National Meteorological Services in RA II and the International Atomic Energy Agency (IAEA) to offer RSMC support for environmental emergency response.

A Lagrangian method is adopted for the transport model, and large numbers of tracers are released at certain times and locations in line with pollutant emission information provided as part of related requests. Effects on three-dimensional advection and horizontal/vertical diffusion, dry and wet deposition and radioactive decay are computed from three-hourly outputs of the high-resolution global model (TL959L60). The standard products of the RSMC involve maps on trajectories, time-integrated low-level concentrations and total deposition up to 72 hours ahead.

As part of the CTBTO-WMO Backtracking Response System, JMA is responsible for providing atmospheric backtracking products to the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) in its role as a Regional Specialized Meteorological Center. JMA developed an atmospheric backtracking transport model and built up a response system that receives e-mail notifications from CTBTO, executes backtracking calculations and provides the resulting products in line with the procedure defined in WMO no. 485. JMA began operation of the backtracking system in December 2009. The backtracking up to 50 days (as requested by CTBTO at a 2011 meeting of the Coordination Group for Nuclear Emergency Response Activities (CG-NERA)) can be provided on an operational basis.

(3) Ocean-wave forecasting models

JMA operates three numerical wave models: the Global Wave Model (GWM), the Coastal Wave Model (CWM) and the Shallow-water Wave Model (SWM), all of which are classified as third-generation wave models. The GWM and the CWM are based on the MRI-III, and were developed at JMA's Meteorological Research Institute and updated to create new versions in May 2007. The models' specifications are given in Table 4.5.2.1 (3)-1.

An assimilation scheme developed by JMA for wave models was incorporated into the GWM and the CWM in October 2012.

The SWM is based on the WAM, which was modified at the National Institute for Land and Infrastructure Management of MLIT and put into operation under a cooperative framework with MLIT's Water and Disaster Management Bureau. The target area is limited, and is currently being expanded. The models' specifications are given in Table 4.5.2.1 (3)-2.

Table 4.5.2.1 (3)-1 Specifications of the ocean-wave prediction model

Model name	Global Wave Model	Coastal Wave Model
Model type	Spectral model (third-generation wave model)	
Spectral components	900 (25 frequencies from 0.0375 to 0.3 Hz and 36 directions)	
Grid form	Equal latitude-longitude grid on spherical coordinates	
Grid size	0.5° × 0.5° (720 × 301)	0.05° × 0.05° (601 × 601)
Integration domain	Global 75°N – 75°S	Coastal Sea of Japan 50°N – 20°N, 120°E – 150°E
Time step	Advection term: 10 minutes Source term: 30 minutes	Advection term: 1 minute Source term: 3 minutes
Forecast time	84 hours from 00, 06 and 18 UTC 264 hours from 12 UTC	84 hours from 00, 06, 12 and 18 UTC
Boundary conditions	-	Global Wave Model
Initial conditions	Hindcast	
Wind field	Global Spectral Model (GSM)	
	Bogus gradient winds (for typhoons in the western North Pacific)	

Table 4.5.2.1 (3)-2 Specifications of the ocean-wave prediction model

Model name	Shallow-water Wave Model		
Model type	Spectral model (third-generation wave model)		
Spectral components	1,260 (35 frequencies from 0.0418 to 1.1 Hz and 36 directions)		
Grid form	Equal latitude-longitude grid on spherical coordinates		
Grid resolution	1' × 1'		
Areas	Domain name	Grid size	Integration domain
	Tokyo Bay	37 × 43	35.05°N – 35.75°N 139.55°E – 140.15°E
	Ise Bay	61 × 43	34.35°N – 35.05°N 136.45°E – 137.45°E
	Harima-Nada Osaka Bay	79 × 49	34.05°N – 34.85°N 134.15°E – 135.45°E
	Ariake Sea	43 × 49	32.45°N – 33.25°N 130.05°E – 130.75°E
	Off Niigata	55 × 37	37.80°N – 38.40°N 138.35°E – 139.25°E
	Sendai Bay	37 × 43	37.75°N – 38.45°N 140.90°E – 141.50°E
	Off Tomakomai	121 × 43	42.00°N – 42.70°N 141.00°E – 143.00°E

	Suo-Nada Iyo-Nada Aki-Nada	109 × 67	33.30°N – 34.40°N 131.00°E – 132.80°E
	Hiuchi-Nada	103 × 73	33.60°N – 34.80°N 132.60°E – 134.30°E
	Off Shimane	67 × 31	35.25°N – 35.75°N 132.55°E – 133.65°E
Time step	Advection term: 1 minute Source term: 1 minute		
Forecast time	39 hours from 03, 09, 15 and 21 UTC		
Boundary conditions	Coastal Wave Model		
Initial conditions	Hindcast		
Wind field	Meso-Scale Model (MSM)		
	Bogus gradient winds (for typhoons in the western North Pacific)		

Wave model products are adopted by various domestic users (such as governmental organizations and private weather companies) via the Japan Meteorological Business Support Center (JMBSC), whereas SWM products are only used within JMA and MLIT's Regional Development Bureaus. GWM products are available within JMA's WMO Information System for National Meteorological and Hydrological Services (NMHSs), and are also disseminated to several countries via GTS.

(4) Storm-surge model

JMA operates a numerical storm surge model to predict storm surges in coastal areas of Japan using sea-surface wind and pressure fields inferred by the MSM. In the case of tropical cyclones (TCs), storm surges for six scenarios are predicted in consideration of TC track forecast errors. In addition to the MSM, TC bogus data corresponding to five tracks (center, faster, slower and rightmost/leftmost of the TC track forecast) are used for each scenario. Data on astronomical tides are required for the prediction of storm tides (i.e., the sum of storm surges and astronomical tides). Astronomical tides are estimated using an ocean tide model and added linearly to storm surges. The model's specifications are given in Table 4.5.2.1 (4)-1.

Table 4.5.2.1 (4)-1 Specifications of the numerical storm-surge model

Basic equations	Two-dimensional shallow-water equations
Numerical technique	Explicit finite difference method
Integration domain	Coastal areas of Japan (117.4°E – 150.0°E, 20.0°N – 50.0°N)
Grid size	Adaptive Mesh Refinement (AMR) method 45 seconds (longitude gradually doubling to 12 minutes toward offshore areas) × 30 seconds (latitude gradually doubling to 8 minutes toward offshore areas)
Boundary conditions	Modified radiation condition at open boundaries and zero normal flows at coastal boundaries
Forecast time	39 hours
Forcing data	Meso-Scale Model (MSM)
	Bogus data for TCs around Japan

Astronomical tides	Ocean tide model (Egbert and Erofeeva 2002) and data assimilation of harmonic constants at tide stations using the ensemble transform Kalman filter (ETKF)

JMA developed a storm surge model for the Asian region in 2010 in collaboration with Typhoon Committee Members providing tidal observation and sea bathymetry data. Since 1 June, 2011, horizontal maps of predicted storm surges have been published on JMA's Numerical Typhoon Prediction website. Since 5 June, 2012, three time-series charts of predicted storm surges have been published. The storm surge model uses the GSM for meteorological forcing. In the case of TCs, storm surges are predicted up to 72 hours ahead using a simple parametric TC track (center) in addition to the GSM. The model's specifications are given in Table 4.5.2.1 (4)-2. JMA expanded the forecast region and added seven stations for time-series charts in 2013. JMA plans to add 35 stations in 2014.

Table 4.5.2.1 (4)-2 Specifications of the Numerical storm-surge model (Asian region)

Basic equations	Two-dimensional linear shallow-water equations
Numerical technique	Explicit finite difference method
Integration domain	Coastal areas of Asia (95.0°E – 160.0°E, 0.0°N – 46.0°N)
Grid size	2 minutes × 2 minutes
Boundary conditions	Modified radiation condition at open boundaries and zero normal flows at coastal boundaries
Forecast time	72 hours
Forcing data	Global Spectral Model (GSM)
	Bogus data for TCs (center)
Astronomical tides	Not included

(5) Ocean data assimilation system for the North Pacific Ocean

An ocean data assimilation system for the North Pacific is operated to represent ocean characteristics such as the movement of the Kuroshio current in the mid/high latitudes of the North Pacific with the specifications shown below. Data on ocean currents and several layers of subsurface water temperatures (products of this system) are available on the NEAR-GOOS Regional Real Time Database (http://goos.kishou.go.jp).

Table 4.5.2.1 (5)-1 Specifications of the ocean data assimilation system for the North Pacific Ocean

Basic equations	Primitive equations with free surface
Independent variables	Lat-lon coordinates and σ-z hybrid vertical coordinates
Dependent variables	u, v, T, S, SSH
Numerical technique	Finite difference both in the horizontal and in the vertical with a three-dimensional variational (3D-Var) data assimilation system
Grid size	(1) Western North Pacific model 0.1° longitude × 0.1° latitude in the seas off Japan, decreasing to 0.166° toward the northern and eastern boundaries with the North Pacific model

	(2) North Pacific model 0.5° longitude × 0.5° latitude
Vertical levels	54
Integration domain	(1) Western North Pacific model From 15°N to 65°N between 115°E and 160°W (2) North Pacific model From 15°S to 65°N between 100°E and 75°W
Forcing data	Heat, water and momentum flux driven from the JMA Climate Data Assimilation System (JCDAS) and from a low-resolution version (TL319) of the operational GSM
Observational data	Sea-surface and subsurface temperature/salinity, sea surface height, sea ice concentration
Operational runs	10-day assimilation and 30-day prediction are implemented every day

(6) Sea-ice forecasting model

JMA issues information on the state of sea ice in the seas off Japan. A numerical sea-ice model has been run to predict sea ice distribution and thickness in the seas off Hokkaido (mainly in the southern part of the Sea of Okhotsk) twice a week in winter since December 1990 (see Table 4.5.2.1 (6)-1).

Table 4.5.2.1 (6)-1 Specifications of the numerical sea-ice prediction model

Dynamical processes	Viscous-plastic model (MMD/JMA 1993) – considering wind and seawater stress on sea ice, Coriolis force, force from the sea surface gradient and internal force
Physical processes	Heat exchange between sea ice, the atmosphere and seawater
Dependent variables	Concentration and thickness
Grid size and time step	12.5 km and 6 hours
Integration domain	Seas around Hokkaido
Initial time and forecast time	168 hours from 00 UTC (twice a week)
Initial condition	Concentration analysis derived from MTSAT and NOAA satellite imagery and thickness estimated by hindcasting

Grid-point values of the numerical sea-ice model are disseminated to domestic users. Sea ice conditions for the coming seven days as predicted by the model are broadcast by radio facsimile (JMH) twice a week.

(7) Marine pollution transport model

JMA operates the numerical marine-pollution transport model in the event of marine-pollution accidents. Its specifications are shown in Table 4.5.2.1 (7)-1. The ocean currents used for the model’s input data are derived from the results of the ocean data assimilation system for the North Pacific Ocean.

Table 4.5.2.1 (7)-1 Specifications of the marine pollution transport model

Area	Western North Pacific
Grid size	2 – 30 km (variable)
Model type	3-dimensional parcel model
Processes	Advection caused by ocean currents, sea surface winds and ocean waves Turbulent diffusion Chemical processes (evaporation, emulsification)

(8) Aeolian dust prediction model

JMA has operated an Aeolian dust prediction model to forecast Aeolian dust distribution since January 2004. The model is directly coupled with a low-resolution version of the GSM, and makes use of several GSM parameters without temporal or spatial interpolation (Tanaka et al. 2003). The model's specifications are given in Table 4.5.2.1 (8)-1.

The 3D semi-Lagrangian transport scheme was updated in February 2010 to enable appropriate handling of dust advection.

Table 4.5.2.1 (8)-1 Specifications of the Aeolian dust prediction model

Basic equations	Eulerian model coupled with the Global Spectral Model
Numerical technique	3D semi-Lagrangian transport and dust emission calculation from surface meteorology
Integration domain	Global
Grid size	T106 (1.125°)
Vertical levels	20 (surface – 45 hPa)
Initial time and forecast time	96 hours from 12 UTC (once a day)
Boundary conditions	Similar to those of the Global Spectral Model
Forcing data (nudging)	Global analysis (GA) and forecasts of the Global Spectral Model (GSM)
	Snow depth analysis

(9) Ultraviolet (UV) index prediction system

JMA has operated a UV-index prediction system since May 2005. It consists of a chemical transport model (CTM) that is directly coupled with a low-resolution version of the GSM (Shibata et al. 2005) and the radiative transfer model (Aoki et al. 2002). The models' specifications are given in Tables 4.5.2.1 (9)-1 and 2.

The UV index is calculated using the radiative transfer model in the area from 122°E to 149°E and from 24°N to 46°N with a grid resolution of 0.25° × 0.20°. The Look-Up Table (LUT) method is adopted in consideration of the computational cost involved. The basic parameters of LUT are the solar zenith angle and the total ozone predicted by the CTM. The clear sky UV index is corrected for aerosols (climatology), distance from the sun, altitude and surface albedo (climatology). The forecast UV index is also corrected for categorized weather forecasting.

Table 4.5.2.1 (9)-1 Specifications of the chemical transport model in the UV index prediction system

Basic equations	Eulerian model coupled with the Global Spectral Model
Numerical technique	3D semi-Lagrangian transport and chemical reaction
Integration domain	Global
Grid size	T42 (2.8125°)
Vertical levels	68 (surface – 0.01 hPa)
Initial time and forecast time	48 hours from 12 UTC (once a day)
Boundary conditions	Similar to those of the Global Spectral Model
Forcing data (nudging)	Global analysis (GA) and forecasts of the Global Spectral Model (GSM)
Observational data	Column ozone from OMI/NASA

Table 4.5.2.1 (9)-2 Specifications of the radiative transfer model in the UV index prediction system

Basic equations	Radiative transfer equations for multiple scattering and absorption by atmospheric molecules and aerosols
Numerical technique	Doubling and adding method
Spectral region and resolution	280 – 400 nm and 0.5 nm

(10) Photochemical oxidant information advisory service

JMA has issued photochemical oxidant information advisory service since August 2010. The information is produced by combining a global chemistry-climate model (MRI-CCM2; Deushi and Shibata 2011) incorporating chemical transport processes of photochemical oxidants in the troposphere/stratosphere and statistical guidance induced from model outputs associated with past events. The latter is prepared by performing verification of the model's output against observations to enable quantification of oxidant levels for operational forecasters.
The models' specifications are given in Tables 4.5.2.1 (10)-1.

Table 4.5.2.1 (10)-1 Specifications of the global chemistry-climate model for the photochemical oxidant information prediction system

Basic equations	Eulerian model coupled with the Global Spectral Model
Numerical technique	3D semi-Lagrangian transport and chemical reaction
Integration domain	Global
Grid size	T106 (1.125°)
Vertical levels	48 (surface – 0.01 hPa)
Initial time and forecast time	72 hours from 12 UTC (once a day)
Boundary conditions	Similar to those of the Global Spectral Model
Emission inventories	EDGAR, GEIA (for Global) and REAS (for East-Asia)
Forcing data (nudging)	Global analysis (GA) and forecasts of the Global Spectral Model (GSM)

(11) Mesoscale air pollution transport model

JMA issues photochemical oxidant information for relevant prefectures on days when high oxidant concentration is expected. This information is based on statistical guidance for oxidant concentration using weather elements and pollutant observation data as input. In addition to this statistical guidance, a mesoscale atmospheric transport model (Takano et al. 2007) is applied to oxidant concentration forecasting with a grid interval of 10 km, in which MSM output is used to calculate the transport of highly concentrated pollutant masses in the air. Using the oxidant forecast from the atmospheric transport model with the initial time at 03 UTC, photochemical oxidant information is issued hourly for 04 – 09 UTC for the northern part of the Kyushu region and the Kanto region including the Tokyo metropolitan area.

(12) Regional Atmospheric Transport Model (RATM) for volcanic ash

JMA introduced the volcanic ash fall forecast in March 2008 (Shimbori et al. 2009). This is a six-hour prediction of areas where ash is expected to fall as a result of volcanic eruptions in Japan, and is issued in principal when an ash plume reaches a height of 3,000 m above the crater rim or when the JMA Volcanic Alert Level is three or higher. The specifications of the volcanic ash transport model, for which the outputs of the MSM are used, are given in Table 4.5.2.1 (12)-1. Quantitative forecasting of ash-fall depth has been developed and is currently under trial operation.

Table 4.5.2.1 (12)-1 Specifications of RATM for volcanic ash

Model type	Lagrangian description
Number of tracer particles	100,000
Time step	3 minutes
Forecast time	6 hours from the time of eruption
Initial condition	Eruption column based on observational reports including eruption time and plume height, and continuance of volcanic-ash emissions
Meteorological field	Meso-Scale Model (MSM)
Processes	3D advection, horizontal and vertical diffusion, volcanic-ash fallout, dry deposition and washout

(13) Global Atmospheric Transport Model (GATM) for volcanic ash

Since 1997, JMA has been providing information on volcanic ash clouds to airlines, civil aviation authorities and related organizations in its role as the Volcanic Ash Advisory Centre (VAAC) Tokyo. JMA introduced the Global Atmospheric Transport Model (GATM) in December 2013 as an 18-hour prediction of areas where ash clouds are expected in the relevant region as a result of volcanic eruptions. The forecast is normally updated every six hours (00, 06, 12 and 18 UTC) for as long as ash clouds are identified in satellite imagery.

The specifications of the GATM are given in Table 4.5.2.1 (13)-1.

Table 4.5.2.1 (13)-1 Specifications of GATM for volcanic ash

Model type	Lagrangian description
Number of tracer particles	40,000
Time step	10 minutes
Forecast coverage	18 hours from the time of MTSAT-2* observation * Scheduled for replacement by Himawari-8 in mid-2015
Initial condition	Location of volcanic ash particles based on the area and maximum altitude of volcanic ash cloud observed by satellite
Meteorological field	Global Spectral Model (GSM)
Processes	3D advection, (horizontal and vertical diffusion,) volcanic-ash fallout, dry deposition and washout

4.5.2.2 Research performed in the field

(1) Storm surge model

Wave setup sometimes plays a predominant role in storm surges at Japanese ports facing the open ocean, but this effect is not included in the current storm surge model. JMA is currently evaluating a number of methods that can be operationally used to estimate sea-level rises caused by wave setup using wave conditions predicted in wave model products.

(2) Sea-ice forecasting model

A new ocean forecast model and a new ocean data assimilation system for the North Pacific Ocean have been developed (see 4.5.2.1 (5)). JMA introduced ocean current data produced as a result of these two developments into the sea-ice forecast model in March 2011, and is currently verifying calculated sea ice data against observation data.

(3) Aeolian dust prediction model

The Meteorological Research Institute is developing an earth-system model (MRI-ESM1) that contains aerosols for the prediction of global warming (Yukimoto et al. 2011), and JMA plans to update the Aeolian dust prediction model based on MRI-ESM1 in autumn 2014. A data assimilation system with the local ensemble transform Kalman filter (LETKF) for aerosols (Sekiyama et al. 2010) has also been developed. Verification and improvement of the system will be carried out toward operational application.

(4) UV index prediction system

The Meteorological Research Institute is developing the global chemistry-climate model MRI-CCM2 (Deushi and Shibata 2011), which is a part of the MRI-ESM1 earth-system model (Yukimoto et al. 2011). JMA plans to update the UV index prediction system based on the MRI-CCM2 in autumn 2014. The horizontal resolution of the model will be enhanced from T42 to TL159. A data assimilation system with the LETKF for stratospheric ozone has also been developed (Sekiyama et al. 2011; Nakamura et al. 2013), and is scheduled to enter operation in 2017.

(5) An ensemble forecast system for ocean waves

JMA has embarked on the development of an ensemble wave forecast system in response to demand for stochastic wave forecasts up to a week ahead. A prototype of the system has been developed, and further verification and improvement will be carried out. JMA began running the system in quasi-operational mode on 29 May 2013. Verification and further improvement will be carried out in 2014, and week-range wave forecasts are scheduled for issuance in 2015.

(6) Regional chemical transport model

JMA plans to improve the photochemical oxidant information advisory service by introducing a high-horizontal-resolution regional chemical transport model developed by the Meteorological Research Institute (Kajino et al. 2012). The system will be put into operational mode in spring 2015.

(7) Typhoon EPS

JMA plans to improve the Typhoon EPS (TEPS) in March 2014. The improvement will include enhancement of the horizontal resolution of the forecast model from TL319 to TL479, revision of its physical processes (such as the stratocumulus and radiation schemes), and an ensemble size increases from 11 to 25.

A preliminary experiment involving the use of TEPS with the TL479-version model was conducted to investigate the impact of a higher-horizontal-resolution model on typhoon forecasting. The results showed that the higher-resolution TEPS supported sharper representation of tropical cyclones (TCs) than the current TEPS not only for typhoon-category storms but for all tropical depressions. The error of TC tracks predicted using the higher-resolution TEPS was also smaller than that of the current TEPS, mainly due to the reduction of systematic biases.

In order to investigate the impact of a larger ensemble size on probabilistic TC track forecasting, another experimental configuration in which the ensemble initial conditions were increased from 11 to 25 was tested. Comparison of Brier skill scores for TC strike probabilities showed higher values from the experiment than for the current TEPS, indicating that the ensemble size increase in the order of a dozen was associated with a higher level of skill. However, the increase produced an excessive ensemble spread, causing negative impacts on ensemble TC track forecasting such that the initial ensemble spread needed to be reduced. Accordingly, initial perturbation with a reduced amplitude was applied to TEPS to restrict the excessive ensemble spread. The results of another experiment conducted after the revision indicated that the reduced amplitude provided better performance in combination with the increased ensemble size.

(8) Volcanic ash concentration forecast

Despite the importance of volcanic ash concentration forecasting in the world of aviation, no the method for such prediction has yet been developed. JMA is currently evaluating a forecast method involving calculation with weight coefficients for individual particles, based on the comparison of actual results with observation data for past eruptions.

4.5.3 Specific products operationally available

(1) Numerical storm surge prediction products

Time series representations of predicted storm tides/astronomical tides and forecast time on predicted highest tides for the coastal area in Japan are disseminated to local meteorological observatories. This information is used as a major basis for issuing storm surge advisories and warnings.

(2) Aeolian dust products operationally available

Predicted distributions of the surface concentration and total amount of Kosa in eastern Asia are provided online (http://www.jma.go.jp/en/kosa/index.html) once a day.

(3) UV index products operationally available

Distributions and time series representations of predicted UV index information are provided online (http://www.jma.go.jp/en/uv/index.html) twice a day.

4.6 Extended-range forecasts (ERFs) *(*10 – 30 days*)*

4.6.1 Models

4.6.1.1 In operation

JMA operates One-month Ensemble Prediction System (One-month EPS) once a week. The numerical prediction model applied for this system is a low-resolution version (TL159) of the GSM (Table 4.6.1.1-1). For the lower boundary condition of the model, initial COBE-SST (Ishii et al. 2005) anomalies are fixed during the 34-day time integration. Soil moisture, soil temperature and snow depth are predicted by the model, and their initial states are provided by the land data assimilation system.

An ensemble consists of 50 members per week – 25 member runs for each of the 34 days of ensemble prediction from two consecutive days. Thus, initial perturbations are produced by combining the breeding of growing mode (BGM) method and the LAF method.

Table 4.6.1.1-1 Specifications of the one-month EPS

Atmospheric model	GSM1103C
Integration domain	Global, surface to 0.1 hPa
Horizontal resolution	TL159 (reduced Gaussian grid system, approx. 1.125º Gaussian grid, 320 × 160 – 120 km)
Vertical levels	60 (surface to 0.1 hPa)
Forecast time	816 hours from 12 UTC
Ensemble size	50 members
Perturbation generator	Combination of breeding of growing mode (BGM) method and lagged averaged forecast (LAF) method
Perturbed area	Northern Hemisphere (20ºN – 90ºN) and tropics (20ºS – 20ºN)

4.6.1.2 Reanalysis project

In March 2013, JMA completed the second Japanese global reanalysis, known formally as JRA-55 and informally as JRA Go! Go! (as "go" is the Japanese word for "five"), to provide a comprehensive atmospheric dataset suitable for the study of climate change and multi-decadal variability. The data cover a period of 55 years extending back to 1958 when regular radiosonde observations became operational on a global basis. The data assimilation system for JRA-55 is based on the TL319 version of JMA's operational data assimilation system as of December 2009, which has been extensively improved since the JRA-25 dataset was produced. JRA-55 is the first global atmospheric reanalysis in which four-dimensional variational assimilation (4D-Var) was applied to the last half century including the pre-satellite era. Its production also involved the use of numerous newly available and improved past observations. The resulting reanalysis products are considerably better than those based on the JRA-25 dataset. Two major problems with JRA-25 were a lower-stratosphere cold bias, which has now been reduced, and an Amazon basin dry bias, which has been mitigated. The temporal consistency of temperature analysis has also been considerably improved. Details of JRA-55 are provided in the JRA-55 comprehensive report (submitted to the Journal of the Meteorological Society of Japan). JMA continues the production of JRA-55 dataset information on a near-real-time basis with the data assimilation system used for this dataset.

The near-real-time base climate data assimilation system (JCDAS) will be replaced with a set-up based on JRA-55 in 2014. The new near-real-time product is also called JRA-55.

4.6.2 Operationally available NWP model and EPS ERF products

A model systematic bias was estimated as an average forecast error calculated from hindcast experiments for the years from 1981 to 2010. The bias is removed from forecast fields, and grid-point values are processed to produce several forecast materials such as ensemble means and spreads.

Gridded data products for one-month forecast are disseminated on the Tokyo Climate Center (TCC) website (http://ds.data.jma.go.jp/tcc/tcc/index.html). Details of these products are shown in Table 4.6.2-1, and map products disseminated through TCC are shown in Table 4.6.2-2.

Table 4.6.2-1 Gridded data products (GRIB2) for one-month forecasts disseminated through the TCC

Details		Level (hPa)	Area	Base time & forecast times
Ensemble mean value of forecast members	Sea-level pressure and its anomaly, rainfall amount and its anomaly	-	Global 2.5˚ × 2.5˚	Base time: 00 UTC of Thursday 1-day Forecast time :2,3,4…,31,32 days from later initial time
	Temperature and its anomaly	Surf, 850, 700		
	RH, wind (u, v)	850		
	Geopotential height and its anomaly	500, 100		
	Wind (u, v)	200		
	Stream function and its anomaly	850, 200		
	Velocity potential and its anomaly	200		

Table 4.6.2-2 Map products for one-month forecasts disseminated via the TCC

	Forecast time	Parameter
Ensemble mean	Averages of days 2 – 8, 9 – 15, 16 – 29, 2 – 29	Geopotential height and anomaly at 500 hPa, temperature and anomaly at 850 hPa, sea-level pressure and anomaly, stream function and anomaly at 200hPa and 850hPa, velocity potential and anomaly at 200hPa, precipitation and anomaly, temperature and anomaly at 2m, sea surface temperature (prescribed)

4.7 Long range forecasts (LRF) (30 days up to two years)

4.7.1 Models

4.7.1.1 In operation

JMA operates Seasonal Ensemble Prediction System (Seasonal EPS) using an atmosphere-ocean coupled model (JMA/MRI-CGCM; Yasuda et al. 2007) for three-month, warm/cold season and El

Niño outlooks. The 51-member ensemble is used for the three-month forecast issued every month and for the warm/cold season forecasts issued five times a year (in February, March, April, September and October). The El Niño outlook is also issued based on the same model results.
The JMA/MRI-CGCM was developed by the Meteorological Research Institute and the Climate Prediction Division of JMA. Its specifications are shown in Table 4.7.1-1. The model is initialized with atmospheric and oceanic analysis using the JMA Climate Data Assimilation System (JCDAS) and MOVE/MRI.COM-G, respectively. Land surface climatological conditions are used as the initial values for the CGCM, and a land surface model coupled to the AGCM is used for the prediction of land surface conditions. The climatological distribution of sea ice is used as the lower boundary condition. The EPS adopts a combination of the LAF method and the initial perturbation method described below. Nine-member ensemble predictions are made every five days, and atmospheric initial perturbations for each initial date are obtained using the BGM method. Oceanic initial perturbations are obtained with MOVE/MRI.COM-G (see 4.5.1.1 (1) for details) forced by the surface heat and momentum fluxes of atmospheric initial perturbation fields using the BGM method.

Table 4.7.1-1 Specifications of the seasonal EPS

Model	JMA/MRI-CGCM (Yasuda et al. 2007)	
Oceanic component	Identical to the model for MOVE/MRI.COM-G	
Atmospheric components	Basic equations	Primitive equations
	Domain	Global
	Resolution	TL95, 40 vertical levels
	Convection scheme	Arakawa-Schubert
	Land surface processes	SiB of Sellers et al. (1986)
Coupling	Coupling interval	1 hour
	Flux adjustment	Monthly heat and momentum flux adjustment
Forecast period	7 months	
Model run frequency	Once every 5 days	
Perturbation generator	Combination of the breeding of growing mode (BGM) method and the LAF method	

4.7.2 Operationally available EPS LRF products

A model systematic bias was estimated for use as an average forecast error calculated from hindcast experiments for the 30 years from 1981 to 2010. The bias is removed from forecast fields, and grid-point values are processed to produce several forecast materials such as ensemble means and spreads.

The following model output products (Table 4.7.2-1) for three-month forecast are disseminated through the Tokyo Climate Center (TCC) website (http://ds.data.jma.go.jp/tcc/tcc/index.html).

Table 4.7.2-1 Gridded data products(GRIB2) and maps for three-month forecast disseminated through TCC

Details		Level (hPa)	Area	Initial time & forecast time
Ensemble members, their ensemble mean and spread (standard deviation) values of forecast members averaged for each one-month and three-month period during the forecast time range	Rainfall amount, surface temperature at 2 m, sea surface temperature, sea-level pressure, and their anomalies	-	Global 2.5˚ × 2.5˚	Initial time: 00 UTC around the 15th day of each month Forecast times: Each one-month and three-month average
	Temperature and its anomaly	850		
	Geopotential height and its anomaly	500		
	Wind (u, v) and its anomaly	850, 200		

The following model output products (Table 4.7.2-2) for warm/cold season prediction are disseminated through the Tokyo Climate Center (TCC) website (http://ds.data.jma.go.jp/tcc/tcc/index.html).

Table 4.7.2-2 Gridded data products (GRIB2) and maps for warm/cold season forecast disseminated through TCC

Details		Level (hPa)	Area	Initial time & forecast time
Ensemble members, their ensemble mean and spread (standard deviation) values averaged for each one-month and three-month period during forecast time range	Rainfall amount, surface temperature at 2 m, sea surface temperature, sea-level pressure, and their anomalies	-	Global 2.5˚ × 2.5˚	Initial time: 00 UTC around the 15th day in Feb., Mar., Apr., Sep. and Oct. Forecast times: Each one-month and three-month average
	Temperature and its anomaly	850		
	Geopotential height and its anomaly	500		
	Wind (u, v) and its anomaly	850, 200		
	Relative humidity and its anomaly	850		

5. Verification of prognostic products

5.1 Annual verification summary

5.1.1 NWP prognostic products

Objective verification of prognostic products is operationally performed against analysis and radiosonde observations according to WMO/CBS recommendations. The results of monthly verification for 2013 are presented in Tables 5.1.1-1 – 5.1.1-20. All verification scores are only for prediction from 1200 UTC initials.

Table 5.1.1-1 Root mean square errors of geopotential height at 500 hPa against analysis (m)

Northern Hemisphere (20–90˚N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	8.3	7.4	7.6	7.2	6.8	6.6	5.9	5.8	6.3	6.5	7.1	7.6	6.9
72	28.4	23.0	25.3	23.7	21.5	21.4	18.4	18.4	21.3	20.9	24.8	25.3	22.7
120	55.2	43.9	51.1	46.1	45.3	41.3	37.3	35.5	44.2	42.7	51.5	50.0	45.3

Table 5.1.1-2 Root mean square errors of geopotential height at 500 hPa against analysis (m)

Southern Hemisphere (20–90˚S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	8.0	8.2	8.3	8.9	9.1	9.7	9.8	9.6	9.9	9.0	8.4	7.4	8.9
72	24.7	25.4	28.0	31.5	30.8	33.9	33.2	33.2	34.4	28.8	27.9	22.8	29.6
120	45.8	48.3	53.5	61.0	61.1	65.7	62.9	63.7	62.6	54.7	56.4	46.4	56.8

Table 5.1.1-3 Root mean square errors of geopotential height at 500 hPa against observations (m)

North America

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	12.6	12.8	12.4	12.1	10.5	11.1	9.6	9.4	10.2	11.3	12.1	12.0	11.3
72	35.9	27.7	30.2	23.8	21.5	21.7	17.4	16.4	19.7	21.4	27.4	28.0	24.3
120	68.1	49.4	52.4	44.3	43.1	36.3	32.1	29.6	37.1	42.9	58.7	54.6	45.7
ob. num.	93	92	92	92	91	93	94	94	94	93	93	92	92.8

Table 5.1.1-4 Root mean square errors of geopotential height at 500 hPa against observations (m)

Europe/North Africa

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	14.8	12.8	11.3	12.6	12.7	11.7	9.7	10.2	11.3	11.4	13.3	15.1	12.2
72	32.0	25.2	24.8	25.8	25.6	21.4	17.8	20.0	25.6	22.5	31.4	28.3	25.0
120	60.2	49.5	42.3	49.4	52.7	40.0	31.9	37.6	53.5	46.4	63.1	57.4	48.7
ob. num.	57	57	57	58	58	58	58	59	60	60	60	59	58.4

Table 5.1.1-5 Root mean square errors of geopotential height at 500 hPa against observations (m)

Asia

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	13.3	13.7	12.4	12.2	11.5	11.4	10.6	10.3	10.4	10.7	12.0	12.5	11.8
72	23.3	20.2	23.2	22.8	20.4	21.5	19.6	17.1	18.6	19.7	20.4	24.2	20.9
120	38.3	31.6	42.8	35.4	34.0	31.4	29.8	24.6	29.6	32.2	38.3	40.6	34.1
ob. num.	87	86	88	90	90	97	103	103	104	104	105	106	96.9

Table 5.1.1-6 Root mean square errors of geopotential height at 500 hPa against observations (m)

Australia/New Zealand

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	13.8	13.7	13.8	12.4	13.4	12.7	12.9	13.4	13.6	15.4	12.7	14.1	13.5
72	20.6	20.8	21.6	21.2	26.9	23.7	23.5	24.1	24.8	23.4	20.4	20.6	22.6
120	41.2	31.4	38.0	38.5	52.2	44.7	47.1	39.3	42.3	34.1	37.4	33.4	40.0
ob. num.	14	13	13	12	11	13	13	12	12	12	13	12	12.5

Table 5.1.1-7 Root mean square errors of geopotential height at 500 hPa against observations (m)

Northern Hemisphere (20–90˚N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	13.8	13.6	12.9	13.0	12.0	12.3	11.0	10.9	11.4	11.7	12.6	13.1	12.4
72	31.7	25.1	27.4	25.3	23.4	23.0	20.0	19.7	22.8	22.6	27.7	27.6	24.7
120	58.4	45.4	50.5	46.4	44.7	39.3	35.9	34.0	44.7	44.0	55.9	52.2	45.9
ob. num.	325	324	327	330	332	343	350	349	354	353	351	351	340.8

Table 5.1.1-8 Root mean square errors of geopotential height at 500 hPa against observations (m)

Southern Hemisphere (20–90˚S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	12.6	12.1	13.2	13.8	13.5	13.2	14.5	14.5	14.3	14.0	12.9	12.4	13.4
72	20.7	21.8	22.8	26.8	27.6	28.7	29.6	29.8	28.2	25.1	24.1	19.6	25.4
120	38.6	37.4	39.2	46.6	50.0	53.5	54.9	49.3	51.0	41.1	45.1	33.8	45.0
ob. num.	38	38	37	37	37	40	39	39	39	39	40	40	38.6

Table 5.1.1-9 Root mean square of vector wind errors at 250 hPa against analysis (m/s)

Northern Hemisphere (20–90˚N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	3.5	3.5	3.5	3.5	3.5	3.5	3.4	3.5	3.4	3.2	3.3	3.4	3.4
72	8.3	7.4	8.0	8.1	8.1	8.6	8.2	8.2	8.3	7.7	8.0	8.3	8.1
120	13.5	11.8	13.1	13.1	13.5	13.1	12.7	12.5	13.6	12.6	14.0	13.5	13.1

Table 5.1.1-10 Root mean square of vector wind errors at 250 hPa against analysis (m/s)

Southern Hemisphere (20–90˚S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	3.3	3.4	3.4	3.5	3.5	3.6	3.5	3.4	3.5	3.4	3.4	3.2	3.4
72	8.4	8.3	8.9	8.9	9.0	9.4	8.7	8.6	8.9	8.2	8.5	7.9	8.6
120	13.0	13.3	14.3	14.8	15.1	15.7	14.3	14.0	14.3	13.4	14.5	13.2	14.2

Table 5.1.1-11 Root mean square of vector wind errors at 250 hPa against observations (m/s)

North America

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	6.0	6.0	5.5	5.9	5.9	6.1	5.4	5.8	5.5	5.6	5.4	5.7	5.7
72	12.1	9.8	9.7	9.5	9.5	10.3	9.0	9.1	9.2	9.0	9.6	10.1	9.7
120	18.4	14.8	15.0	15.1	14.2	13.9	13.0	12.6	14.2	14.2	16.4	16.0	14.8
ob. num.	91	90	91	91	90	91	93	92	93	91	91	90	91.2

Table 5.1.1-12 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Europe/North Africa

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	5.2	4.6	5.0	5.0	5.4	5.0	4.7	5.2	5.2	5.5	5.6	5.4	5.2
72	9.1	8.2	8.7	8.3	9.7	9.2	8.4	9.9	10.2	9.2	10.3	9.4	9.2
120	16.9	13.5	12.5	15.1	16.0	14.5	12.7	15.9	17.0	14.6	18.4	15.9	15.3
ob. num.	58	59	60	61	62	62	63	62	64	63	62	62	61.5

Table 5.1.1-13 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Asia

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave

24	5.1	5.3	6.1	6.3	6.4	6.0	6.0	5.4	5.2	4.8	4.5	4.9	5.5
72	8.1	7.3	9.4	9.4	10.4	10.3	9.7	8.8	8.3	7.7	7.2	8.3	8.7
120	11.0	10.1	13.2	12.5	14.3	13.7	12.9	11.9	11.5	11.2	11.3	11.5	12.1
ob. num.	135	133	135	136	136	140	140	141	141	141	141	140	138.3

Table 5.1.1-14 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Australia/New Zealand

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	5.8	5.5	5.3	5.5	5.6	5.5	5.5	4.9	5.4	5.2	5.4	6.1	5.5
72	8.2	8.4	8.0	9.1	9.2	8.7	7.9	7.3	7.9	7.4	8.1	8.4	8.2
120	11.7	12.1	11.8	13.9	14.7	12.9	12.5	10.9	12.3	10.5	12.5	11.7	12.3
ob. num.	22	24	22	21	18	21	21	20	19	21	21	19	20.8

Table 5.1.1-15 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Northern Hemisphere (20–90˚N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	5.2	5.2	5.5	5.6	5.7	5.6	5.4	5.4	5.2	5.0	4.9	5.1	5.3
72	9.4	8.1	9.1	9.0	9.7	9.8	9.2	9.3	9.2	8.5	8.7	9.0	9.1
120	14.8	12.1	13.6	14.1	14.5	13.9	13.2	13.4	14.1	13.3	14.7	14.0	13.8
ob. num.	388	385	389	393	395	399	399	396	401	398	399	393	394.6

Table 5.1.1-16 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Southern Hemisphere (20–90˚S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	5.7	5.7	5.6	5.8	5.9	6.2	5.7	5.5	6.3	6.0	5.6	5.8	5.8
72	8.6	8.9	8.7	9.4	10.0	9.9	8.9	8.9	9.7	9.0	8.7	8.0	9.1
120	12.4	12.9	12.8	14.0	15.1	14.9	13.8	13.5	14.4	12.6	13.5	11.6	13.5
ob. num.	45	46	43	43	43	45	44	46	43	45	46	45	44.5

Table 5.1.1-17 Root mean square of vector wind errors at 850 hPa against analysis (m/s)

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	1.6	1.5	1.5	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
72	3.0	2.8	2.7	2.6	2.7	2.7	2.7	2.8	2.8	2.9	2.6	2.7	2.8
120	3.9	3.6	3.4	3.3	3.3	3.4	3.5	3.6	3.6	3.7	3.3	3.5	3.5

Table 5.1.1-18 Root mean square of vector wind errors at 250 hPa against analysis (m/s)

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	3.4	3.4	3.3	3.1	3.1	3.2	3.1	3.1	3.1	3.0	3.0	3.2	3.2
72	6.1	6.1	6.1	5.8	5.6	5.8	5.7	5.7	5.7	5.6	5.6	6.0	5.8
120	7.8	7.6	8.0	7.7	7.3	7.6	7.3	7.3	7.2	7.1	7.4	7.7	7.5

Table 5.1.1-19 Root mean square of vector wind errors at 850 hPa against observations (m/s)

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	3.8	3.7	3.6	3.4	3.2	3.3	3.4	3.4	3.5	3.5	3.5	3.4	3.5

72	4.3	4.2	4.2	3.7	3.6	3.8	3.9	4.0	4.0	4.1	4.1	3.9	4.0
120	4.9	4.5	4.5	4.1	3.9	4.2	4.5	4.6	4.4	4.7	4.6	4.2	4.4
ob. num.	62	65	69	65	62	65	62	59	60	67	66	68	64.2

Table 5.1.1-20 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	5.3	5.2	5.0	4.7	4.8	4.9	4.7	4.9	4.9	4.6	4.8	5.0	4.9
72	6.9	6.9	6.7	6.3	6.2	6.7	6.4	7.2	7.0	6.2	6.3	6.7	6.6
120	8.0	7.8	8.0	7.9	7.4	8.1	8.0	8.9	8.4	7.2	7.9	7.6	7.9
ob. num.	63	67	71	64	61	64	61	56	60	66	65	66	63.7

Verification for One-week EPS is performed against analysis according to the Manual on GDPFS (WMO-No. 485). The Brier Skill Score (BSS) for seasonal (DJF: December-January-February), MAM: March-April-May, JJA: June-July-August, SON: September-October-November) and annual averages in 2013 (December in 2012) are shown in Tables 5.1.1-21 - 5.1.1-26.

Table 5.1.1-21 BSS for geopotential height at 500 hPa over the Northern Hemisphere (20–90˚N)

Hour	Z500 anomaly +1.0 standard deviation					Z500 anomaly +1.5 standard deviation					Z500 anomaly +2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.914	0.912	0.873	0.898	0.899	0.900	0.907	0.854	0.891	0.888	0.872	0.889	0.844	0.882	0.872
72	0.783	0.762	0.661	0.729	0.734	0.751	0.738	0.615	0.697	0.700	0.704	0.695	0.570	0.681	0.662
120	0.608	0.579	0.442	0.527	0.539	0.568	0.536	0.371	0.480	0.489	0.495	0.468	0.287	0.471	0.430
168	0.422	0.394	0.258	0.323	0.349	0.365	0.343	0.189	0.288	0.296	0.280	0.265	0.159	0.275	0.244
Hour	Z500 anomaly -1.0 standard deviation					Z500 anomaly -1.5 standard deviation					Z500 anomaly -2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.888	0.898	0.850	0.888	0.881	0.868	0.873	0.830	0.857	0.857	0.824	0.849	0.801	0.830	0.826
72	0.715	0.729	0.622	0.699	0.691	0.658	0.679	0.573	0.640	0.637	0.571	0.613	0.516	0.572	0.568
120	0.515	0.535	0.403	0.477	0.483	0.445	0.471	0.352	0.406	0.418	0.344	0.385	0.292	0.319	0.335
168	0.335	0.350	0.222	0.255	0.291	0.262	0.287	0.169	0.188	0.226	0.152	0.210	0.131	0.129	0.155

Table 5.1.1-22 BSS for temperature at 850 hPa over the Northern Hemisphere (20–90˚N)

Hour	T850 anomaly +1.0 standard deviation					T850 anomaly +1.5 standard deviation					T850 anomaly +2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.800	0.791	0.736	0.779	0.776	0.768	0.757	0.695	0.740	0.740	0.730	0.708	0.654	0.693	0.697
72	0.624	0.614	0.511	0.594	0.586	0.567	0.552	0.443	0.536	0.525	0.523	0.496	0.382	0.464	0.466
120	0.458	0.440	0.336	0.423	0.414	0.401	0.387	0.266	0.365	0.355	0.332	0.328	0.205	0.292	0.289
168	0.306	0.289	0.197	0.261	0.264	0.249	0.234	0.144	0.218	0.211	0.178	0.169	0.101	0.169	0.154
Hour	T850 anomaly -1.0 standard deviation					T850 anomaly -1.5 standard deviation					T850 anomaly -2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.812	0.826	0.720	0.779	0.784	0.766	0.786	0.664	0.719	0.734	0.678	0.719	0.608	0.649	0.664

72	0.636	0.655	0.478	0.574	0.586	0.570	0.587	0.385	0.473	0.504	0.465	0.486	0.246	0.349	0.386
120	0.461	0.483	0.294	0.386	0.406	0.388	0.399	0.204	0.284	0.319	0.311	0.289	0.086	0.143	0.207
168	0.290	0.306	0.158	0.219	0.243	0.219	0.231	0.087	0.132	0.167	0.154	0.143	-0.009	0.025	0.078

Table 5.1.1-23 BSS for geopotential height at 500 hPa over the Tropics (20˚S–20˚N)

Hour	Z500 anomaly +1.0 standard deviation					Z500 anomaly +1.5 standard deviation					Z500 anomaly +2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.780	0.762	0.722	0.729	0.748	0.766	0.726	0.655	0.680	0.707	0.746	0.671	0.532	0.612	0.640
72	0.604	0.577	0.475	0.525	0.545	0.581	0.543	0.413	0.500	0.509	0.526	0.454	0.345	0.438	0.441
120	0.460	0.406	0.267	0.354	0.372	0.434	0.395	0.220	0.312	0.340	0.378	0.321	0.152	0.213	0.266
168	0.293	0.224	0.132	0.216	0.216	0.303	0.223	0.100	0.177	0.201	0.300	0.165	0.056	0.116	0.159
Hour	Z500 anomaly -1.0 standard deviation					Z500 anomaly -1.5 standard deviation					Z500 anomaly -2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.703	0.724	0.611	0.726	0.691	0.692	0.706	0.548	0.714	0.665	0.668	0.727	0.479	0.679	0.639
72	0.414	0.513	0.254	0.535	0.429	0.308	0.477	0.114	0.492	0.348	0.287	0.491	0.021	0.406	0.301
120	0.212	0.275	0.018	0.301	0.202	0.071	0.219	-0.110	0.211	0.098	0.063	0.224	-0.179	0.099	0.052
168	-0.104	-0.002	-0.311	0.017	-0.100	-0.409	-0.061	-0.503	-0.130	-0.276	-0.454	-0.016	-0.604	-0.173	-0.312

Table 5.1.1-24 BSS for temperature at 850 hPa over the Tropics (20˚S–b 20˚N)

Hour	T850 anomaly +1.0 standard deviation					T850 anomaly +1.5 standard deviation					T850 anomaly +2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.638	0.591	0.563	0.597	0.597	0.607	0.533	0.502	0.533	0.544	0.553	0.471	0.431	0.468	0.481
72	0.416	0.368	0.339	0.372	0.374	0.385	0.305	0.281	0.311	0.320	0.327	0.246	0.222	0.241	0.259
120	0.288	0.240	0.223	0.259	0.252	0.268	0.191	0.172	0.205	0.209	0.218	0.145	0.122	0.147	0.158
168	0.214	0.146	0.136	0.180	0.169	0.201	0.119	0.093	0.142	0.139	0.151	0.093	0.053	0.100	0.099
Hour	T850 anomaly -1.0 standard deviation					T850 anomaly -1.5 standard deviation					T850 anomaly -2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.588	0.570	0.569	0.598	0.581	0.536	0.520	0.528	0.541	0.531	0.486	0.467	0.477	0.484	0.479
72	0.300	0.310	0.322	0.363	0.324	0.232	0.234	0.283	0.298	0.262	0.184	0.174	0.233	0.243	0.208
120	0.171	0.188	0.202	0.251	0.203	0.123	0.117	0.169	0.183	0.148	0.093	0.070	0.133	0.137	0.108
168	0.082	0.101	0.120	0.176	0.120	0.042	0.055	0.101	0.106	0.076	0.015	0.022	0.071	0.059	0.042

Table 5.1.1-25 BSS for geopotential height at 500 hPa over the Southern Hemisphere (20–90˚S)

Hour	Z500 anomaly +1.0 standard deviation					Z500 anomaly +1.5 standard deviation					Z500 anomaly +2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.895	0.913	0.920	0.905	0.908	0.882	0.888	0.910	0.892	0.893	0.861	0.867	0.891	0.860	0.870
72	0.725	0.738	0.761	0.738	0.741	0.699	0.698	0.722	0.703	0.705	0.643	0.654	0.688	0.630	0.654
120	0.540	0.546	0.571	0.544	0.551	0.485	0.495	0.513	0.484	0.494	0.396	0.415	0.452	0.357	0.405

168	0.347	0.353	0.377	0.357	0.359	0.286	0.293	0.323	0.272	0.294	0.184	0.196	0.255	0.180	0.204
Hour	Z500 anomaly -1.0 standard deviation					Z500 anomaly -1.5 standard deviation					Z500 anomaly -2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.888	0.890	0.896	0.892	0.891	0.871	0.870	0.877	0.871	0.872	0.849	0.843	0.837	0.841	0.843
72	0.704	0.689	0.705	0.698	0.699	0.659	0.645	0.654	0.648	0.652	0.607	0.592	0.584	0.580	0.591
120	0.492	0.464	0.485	0.485	0.482	0.425	0.399	0.415	0.420	0.415	0.357	0.340	0.317	0.340	0.339
168	0.311	0.265	0.287	0.295	0.290	0.244	0.208	0.207	0.237	0.224	0.180	0.157	0.103	0.163	0.151

Table 5.1.1-26 BSS for temperature at 850 hPa over the Southern Hemisphere (20–90˚S)

Hour	T850 anomaly +1.0 standard deviation					T850 anomaly +1.5 standard deviation					T850 anomaly +2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.824	0.828	0.822	0.828	0.826	0.785	0.782	0.788	0.790	0.786	0.762	0.737	0.750	0.743	0.748
72	0.622	0.615	0.614	0.631	0.620	0.557	0.539	0.559	0.568	0.556	0.509	0.455	0.504	0.491	0.490
120	0.451	0.428	0.423	0.442	0.436	0.385	0.345	0.367	0.378	0.369	0.345	0.262	0.309	0.309	0.306
168	0.294	0.264	0.260	0.273	0.273	0.233	0.200	0.213	0.217	0.216	0.194	0.141	0.160	0.168	0.166
Hour	T850 anomaly -1.0 standard deviation					T850 anomaly -1.5 standard deviation					T850 anomaly -2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.837	0.822	0.835	0.849	0.836	0.837	0.789	0.793	0.829	0.812	0.863	0.747	0.736	0.789	0.784
72	0.656	0.608	0.632	0.660	0.639	0.666	0.563	0.568	0.634	0.608	0.728	0.505	0.489	0.578	0.575
120	0.502	0.411	0.433	0.477	0.456	0.539	0.352	0.367	0.452	0.428	0.633	0.295	0.303	0.414	0.411
168	0.376	0.243	0.267	0.322	0.302	0.436	0.197	0.201	0.300	0.284	0.560	0.159	0.151	0.282	0.288

6. Plans for the future (next 4 years)

6.1 Development of the GDPFS

6.1.1 Major changes expected in the next year

(1) The vertical resolution of the GSM will be enhanced from 60 to 100 layers, and the model's top height will be raised.

(2) The horizontal resolution of both the One-week EPS and the Typhoon EPS will be enhanced from TL319 to TL479.

(3) The update frequency of the One-week EPS will be increased from once a day to twice a day.

(4) The ensemble size of the Typhoon EPS will be increased from 11 to 25.

(5) Hyper-spectral infrared sounding data from Aqua/AIRS and Metop/IASI will be assimilated.

(6) A new framework consisting of a regional forecast model and a data assimilation system (ASUCA and ASUCA-Var) will be installed in the Local NWP system.

(7) The off-line simple biosphere model (SiB) will be introduced for land surface analysis.

(8) The horizontal resolution of the one-month prediction system will be enhanced from TL159 to TL319.

6.1.2 Major changes expected in the next four years

(1) The vertical resolution of both the One-week EPS and the Typhoon EPS will be enhanced from 60 to 100 layers.
(2) The vertical resolution of the MSM will be enhanced.
(3) A SiB will be incorporated into the MSM.
(4) An urban canopy will be incorporated into the SiB of the MSM.
(5) Surface observation data will be assimilated into the MA.
(6) A new framework consisting of a regional forecast model and a data assimilation system (ASUCA and ASUCA-Var) will be installed in the Meso-scale NWP system.
(7) The horizontal resolution of the Aeolian dust and global chemistry-climate models will be enhanced.
(8) A data assimilation system with the local ensemble transform Kalman filter will be introduced in aerosol and stratospheric ozone analysis.
(9) A regional chemical transport model for photochemical oxidant information will be introduced.
(10) The UV index prediction model will be improved via the introduction of a new global chemistry-climate model (MRI-CCM2).
(11) Improvements to the Seasonal EPS will include enhancement of the horizontal and vertical resolutions of the atmospheric model from TL95 to TL159 and from 40 to 60 levels, respectively, expansion of the target area to the whole globe in the oceanic model, and introduction of a sea-ice model.

6.2 Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

6.2.1 Planned Research Activities in NWP

6.2.2 Planned Research Activities in Nowcasting

(1) Application of rapid scan observation by the Geostationary Meteorological Satellite to improve Thunder Nowcasts (see 4.4.1.1).
(2) Detection of mesocyclones using radar data with a resolution of 250 meters to improve Hazardous Wind Potential Nowcasts (see 4.4.1.1).

6.2.3 Planned Research Activities in Long-range Forecasting

6.2.4 Planned Research Activities in Specialized Numerical Predictions

(1) Probability forecasts for volcanic ash

JMA is currently exploring methods to meet the needs of probability forecasts for volcanic ash as described in the International Airways Volcano Watch (IAVW) roadmap.

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