JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2016

Japan Meteorological Agency

1. Summary of highlights

(1) Himawari-8 Atmospheric Motion Vector (AMV) data were incorporated into the Global, Meso-scale and Local NWP systems and Hourly analysis in March 2016 (4.2.1.2 (1)).

(2) Himawari-8 Clear-Sky Radiance (CSR) data were incorporated into the Global and Meso-scale NWP systems in March 2016 (4.2.1.2 (2)).

(3) GPM Microwave Imager (GMI) data were incorporated into the Global and Meso-scale NWP systems in March 2016 (4.2.1.2 (3)).

(4) Typhoon bogus data assimilation scheme for Global Analysis was upgraded in September 2016 (4.2.1.2 (4)).

(5) The GSM parameterization schemes were upgraded in March 2016 (4.2.2.2 (1)).

(6) GPM Dual-frequency Precipitation Radar (DPR) data were incorporated into the Meso-scale NWP system in March 2016 (4.3.1.2 (1)).

(7) GNSS Radio Occultation (RO) data were incorporated into the Meso-scale NWP system in March 2016 (4.3.1.2 (2)).

(8) JMA high-resolution radiosonde observation data were incorporated into the Meso-scale NWP system in March 2016 (4.3.1.2 (3)).

(9) The operational atmospheric transport, dispersion and deposition model for EER was updated in October 2016 (4.5.2.1 (2)).

(10) A global Wave Ensemble System (WENS) with a 1.25-degree grid resolution covering most global regions entered operation in June 2016. The system is run once a day at 12 UTC to predict ocean wave conditions up to 264 hours ahead with 27 members (4.5.2.1 (3)).

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 (980 GFLOPS 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/SYNOP MOBIL	200,000/day
BUOY	45,000/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	1,200/day
AIREP/AMDAR	1,000,000/day
PROFILER	8,000/day
AMSR2	13,000,000/day
AIRS/AMSU	320,000/day
NOAA/AMSU-A	960,000/day
Metop/AMSU-A	640,000/day
NOAA/MHS	5,800,000/day
Metop/MHS	5,800,000/day
Metop/ASCAT	4,900,000/day
GOES/CSR	1,300,000/day
Himawari/CSR	1,180,000/day
METEOSAT/CSR	1,800,000/day
GPSRO	510,000/day

AMV	11,000,000/day
SSMIS	16,900,000/day
GNSS-PWV	460,000/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,	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 –	9

	20, 21, 22, 23	2100, 2135 – 2200, 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 0500 – 0525 0800 – 0825 1100 – 1125 1400 – 1425 1700 – 1725 2000 – 2025 2300 – 2325	39 39 39 39 39 39 39 39
One-week Ensemble Forecast	00 12	0310 – 0500 1510 – 1845	264 264
One-month Ensemble Forecast	12 12	1855 – 2015 (every Tuesday and Wednesday) 1855 – 2015 (every Saturday and Sunday)	816 432
Seasonal Ensemble Forecasts	00	1730 – 1910 (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.

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 GA specifications

Analysis scheme	Incremental 4D-Var
Data cut-off time	2 hours and 20 minutes for early run analysis at 00, 06, 12 and 18 UTC 11 hours and 50 minutes for cycle run analysis at 00 and 12 UTC 7 hours and 50 minutes 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	100 forecast model levels up to 0.01 hPa + surface
Analysis variables	Wind, surface pressure, specific humidity and temperature
Observation (as of 31 December 2016)	SYNOP, METAR, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, AMDAR; atmospheric motion vectors (AMVs) from Himawari-8, GOES-13, 15, Meteosat-7, 10; 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, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP-F17, 18/SSMIS, GCOM-W/AMSR2, GPM-core/GMI, Megha-Tropiques/SAPHIR, Aqua/AIRS, Metop-A,B/IASI; clear sky radiances from the water vapor channels (WV-CSRs) of Himawari-8, GOES-13, 15, Meteosat-7, 10; GNSS RO bending angle data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A, B/blackjack, TerraSAR-X/IGOR, zenith total delay data from ground-based GNSS
Assimilation window	6 hours

Table 4.2.1-2 Snow depth analysis specifications

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 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. Symmetric bogus profiles are first generated automatically based on the central pressure and 30-kt wind speed radius of typhoons. Asymmetric components are then retrieved from the first-guess fields and added to these profiles. Finally, the profiles are used as pseudo-observation data for GA.

4.2.1.2 Research performed in the field

(1) Assimilation of Himawari-8 Atmospheric Motion Vector (AMV) data into the Global NWP system

JMA launched its new-generation Himawari-8 operational meteorological geostationary satellite on 7 October 2014, and Himawari-8 atmospheric motion vector (AMV) data have been operationally provided to the NWP community since 7 July 2015 (Bessho et al. 2016). To support the effective use of Himawari-8 AMVs, the AMV pre-processing system was updated in three main ways: (1) the quality indicator (QI, Holmlund 1998) thresholds for low-quality AMV rejection were revised; (2) climatological checking was revised to involve the use of more AMVs in the middle troposphere; and (3) a 100-km super-observation technique (Yamashita 2014) was introduced into the Global NWP system for Japan and surrounding areas. Observation System Experiments (OSEs) for a three-month period covering summer 2015 showed that the assimilation of Himawari-8 AMVs with the revised pre-processing system reduced wind speed differences between observation and first-guess values over the Himawari-8 observation area (especially around Japan) and also significantly improved wind speed fields at 850 hPa up to a two-day forecast time frame. More detailed OSE results are reported by Yamashita (2016). In addition, the mean positional errors for ten summer 2015 typhoons were reduced. The revised pre-processing system was introduced and assimilation of Himawari-8 AMVs into the Global NWP system, the Meso-scale system, the Local NWP system and Hourly Analysis was commenced in March 2016. (K. Yamashita)

(2) Assimilation of Himawari-8 Clear-Sky Radiance (CSR) data into the Global NWP system

Clear-sky radiance (CSR) data from Himawari-8 have been operationally provided to the NWP community since 7 July 2015. Such data from three water vapor absorption bands (6.2, 6.9 and 7.3 micrometers, referred to as bands 8, 9 and 10, respectively) contain observational information on upper-tropospheric water vapor in clear-sky conditions (Bessho et al. 2016). Improved cloud detection in CSR data production at JMA’s Meteorological Satellite Center increases the number of available CSR data, especially over land. Further cloud detection in the preprocessors of data assimilation (DA) systems is based on the clear-pixel ratio of Himawari-8 band 13 (10.4 micrometers). Overall, Himawari-8 CSR data quality is superior to that of MTSAT-2. These enhancements contribute to improved water vapor analysis in DA systems, with the area of improvement corresponding to that covered by Himawari-8 observation. Enhanced water vapor analysis is crucial for accurate prediction of severe weather phenomena such as tropical cyclones and heavy precipitation caused by stationary fronts in East Asia. More detailed OSE results are reported by Kazumori (2016 a). Assimilation of Himawari-8 band 8, 9 and 10 CSR data into the Global NWP system and the Meso-scale NWP system was commenced in March 2016. (M. Kazumori)

(3) Assimilation of GPM Microwave Imager (GMI) data into the Global NWP system

A new core observatory satellite of the Global Precipitation Measurement (GPM) mission was launched by NASA and JAXA in February 2014, and data from the GPM microwave imager (GMI) (the successor to the TRMM microwave imager) have been available since March 2014. OSEs on GMI radiance data, which is clear-sky radiance information from the GMI's 19, 23, 37 and 89 GHz vertical polarized channels and the new 183+3, 183+7 GHz channels, were conducted using the Global NWP system for the periods of January 2015 and July 2014. Removal of cloud-affected radiance for 183 GHz channels was based on the GMI window channel's (166 GHz) first-guess departure (observed radiance minus simulated radiance), while data for other channels were assimilated as with other microwave imager information. The OSE results indicated improvements in the lower-tropospheric water vapor and temperature fields. Detailed OSE results are reported by Kazumori (2016 b). Assimilation of GMI data was commenced in March 2016 along with assimilation into the Meso-scale NWP system. (M. Kazumori)

(4) Upgrade of typhoon bogus data assimilation scheme for Global Analysis

Observation errors in sea-surface pressure and wind elements of typhoon bogus data in data assimilation were updated for suitability to the latest Global NWP system, and the method of sea-surface pressure and wind data deployment was revised. In the old scheme, bogus sea-surface pressure observations were given at six positions: the typhoon center in the first-guess field, that fixed by forecasters, and four positions on the periphery of a circle with a radius of 200 km from the typhoon center fixed by forecasters. At these positions, bogus upper-air wind observations were given for 1,000, 925, 850, 800, 700, 600, 500, 400 and 300 hPa. In the revised scheme, bogus sea-surface pressure and wind observations at 850 and 300 hPa are given from 13 grids uniformly deployed within a square with a 400-km diagonal. OSEs on the new typhoon bogus data for summer 2015 showed that typhoon track prediction errors were reduced in the range from initial to 84-hour forecast lead times. (I. Okabe, Y. Ota and Y. Kosaka)

4.2.2 Model

4.2.2.1 In operation

(1) Global Spectral Model (GSM)

The specifications of the operational Global Spectral Model (GSM1603; TL959L100) 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).

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

1. System	
Model (version)	Global Spectral Model (GSM1603)
Date of implementation	24 March 2016
2. Configuration	
Horizontal resolution (Grid spacing)	Spectral triangular 959 (TL959), reduced Gaussian grid system, roughly equivalent to 0.1875 × 0.1875˚ (20 km) in latitude and longitude
Vertical resolution (model top)	100 unevenly spaced hybrid levels (0.01 hPa)
Forecast length (initial time)	84 hours (00, 06, 18 UTC) 264 hours (12 UTC)
Coupling to ocean/wave/sea ice models	--
Integration time step	400 seconds
3. Initial conditions	
Data assimilation	Four-dimensional variational (4D-Var) method
4. Surface boundary conditions	
Treatment of sea surface	Climatological sea surface temperature with daily analysis anomaly Climatological sea ice concentration with daily analysis anomaly
Land surface analysis	Snow depth: two-dimensional optimal interpolation scheme Temperature: first guess Soil moisture: climatology
5. Other details	
Land surface and soil	Simple Biosphere (SiB) model
Radiation	Two-stream with delta-Eddington approximation for short wave (hourly) Two-stream absorption approximation method for long wave (hourly)
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
Planetary boundary layer	Mellor and Yamada level-2 turbulence closure scheme Similarity theory in bulk formulae for surface layer
Convection	Prognostic Arakawa-Schubert cumulus parameterization
Cloud	PDF-based cloud parameterization
Gravity wave drag	Longwave orographic drag scheme (wavelengths > 100 km) mainly for stratosphere Shortwave orographic drag scheme (wavelengths approx.. 10 km) for troposphere only Non-orographic spectral gravity wave forcing scheme
6. Further information	
Operational contact point	globalnwp@naps.kishou.go.jp
System documentation URLs	http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2015_Japan.pdf
Product list URLs	http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2015_Japan.pdf

4.2.2.2 Research performed in the field

(1) Upgrade of the GSM

JMA plans to upgrade its Global Spectral Model (GSM) in 2017 by revising its parameterization schemes (such as land surface processes, deep convection, cloud, radiation and sea ice). The results of an experiment conducted for the periods from December 2015 to February 2016 and from July to September 2015 showed overall improvement in forecasts of elements such as geopotential height and wind. (H. Yonehara et al.)

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 hours	0 – 84 every 3 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	GTS, 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	GTS, GISC
Area and resolution	Whole globe, 2.5° × 2.5°	75°S – 75°N, 0°E – 359.5°E 0.5° × 0.5°
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 for 12 UTC
Initial times	00 UTC and 12 UTC	00 UTC, 06 UTC, 12 UTC, 18 UTC

4.2.4 Operational techniques for application of NWP products

4.2.4.1 In operation

(1) Forecast guidance

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

4.2.4.2 Research performed in the field

4.2.5 Ensemble Prediction System (EPS)

4.2.5.1 In operation

JMA operates the One-week EPS (WEPS) to support one-week forecasts. The specifications of the EPS are shown in Table 4.2.5-1. It is composed of one control forecast and 26 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 4D-Var 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 GSM1304. Accordingly, the dynamical framework and physical processes involved are identical to those of the previous version of GSM except for the horizontal resolution. A stochastic physics scheme (Palmer et al. 2009) 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.

Table 4.2.5-1 One-week EPS specifications

1. Ensemble system	
Ensemble (version)	One-week EPS (WEPS)
Date of implementation	March 2001
2. EPS configuration	

Model (version)	Global Spectral Model (GSM1304)
Horizontal resolution/grid spacing	Spectral triangular 479 (TL479), reduced Gaussian grid system, roughly equivalent to 0.375 × 0.375° (40 km) in latitude and longitude
Vertical resolution (model top)	60 unevenly spaced hybrid levels (0.1 hPa)
Forecast length (initial time)	11 days (00, 12 UTC)
Members	1 unperturbed control forecast and 26 perturbed ensemble members
Coupling to ocean/wave/sea ice models	--
Integration time step	720 seconds
Additional comments	
3. Initial conditions and perturbations	
Initial perturbation strategy	Singular vectors (SVs)
Optimization time in forecast	Among three targeted SV areas: 48 hours for Northern Hemisphere (30 − 90°N) 24 hours for Tropics (30°S − 30°N) 48 hours for Southern Hemisphere (90 − 30°S)
Horizontal resolution of perturbations	Spectral triangular 63 (T63), quadratic Gaussian grid system, roughly equivalent to 1.875 × 1.875° (180 km) in latitude and longitude
Initial perturbation area	Global
Data assimilation method for control analysis	Four-dimensional variational (4D-Var) for Global Analysis (GA) Control analysis based on interpolation of high-resolution GA (TL959)
Initial conditions for perturbed members	Addition of perturbations to control analysis (SV-based components in +/- pairs)
Additional comments	
4. Model uncertainty perturbations	
Model physics peturbations	Stochastic perturbation of physics tendency
Model dynamics peturbations	--
Additional comments	• Identical model versions for all ensemble members • Above model uncertainty perturbations not applied to control forecasting
5. Surface boundary perturbations	
Sea surface temperature peturbations	--
Soil moisture peturbations	--
Surface wind stress/roughness peturbations	--
Other surface perturbations	--
Additional comments	
6. Other model details	
Surface boundary conditions	
Treatment of sea surface	Climatological sea surface temperature with daily analysis anomaly Climatological sea ice concentration with daily analysis anomaly
Land surface analysis	Snow depth: two-dimensional optimal interpolation scheme Temperature: first guess Soil moisture: climatology
Model dynamics and physics	
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)
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
Planetary boundary layer	Mellor and Yamada level-2 turbulence closure scheme Similarity theory in bulk formulae for surface layer
Convection	Prognostic Arakawa-Schubert cumulus parameterization
Cloud	PDF-based cloud parameterization
Gravity wave drag	Longwave scheme (wavelengths > 100 km) mainly for stratosphere Shortwave scheme (wavelengths approx. 10 km) for troposphere only
7. Products	
Method of calculation (if not unique)	
Other specifications as necessary	
8. Further information	
Operational contact	globalnwp@naps.kishou.go.jp
System documentation URLs	http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2015_Japan.pdf
Product list URLs	http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2015_Japan.pdf

4.2.5.2 Research performed in the field

(1) Improvement of One-week EPS

JMA plans to improve the One-week EPS (WEPS) and unify WEPS and the Typhoon EPS (TEPS) in 2017. Changes will include increasing the number of forecast model vertical levels from 60 to 100 and raising the pressure of the top level from 0.1 to 0.01 hPa, as well as a revision of the model's physical processes (including those of the boundary layer, radiation, non-orographic gravity waves, land surface, multi-layer sea ice and deep convection). The improvement will also involve consideration of sea surface temperature perturbations as boundary conditions for the atmospheric model and incorporation of an ensemble Kalman filter for the generation of initial perturbations. The results of experiments conducted for the periods from July to September 2015 and from December 2015 to February 2016 showed related improvements in typhoon track forecasting, precipitation forecasting over Japan and other forecast elements such as geopotential height. (K. Ochi, Y. Ota and H. Yamaguchi)

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 MA specifications

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 2016)	SYNOP, METAR, SHIP, BUOY, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR; AMVs from Himawari-8; ocean surface wind from Metop-A, B/ASCAT; radiances from NOAA-15, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP-F17, 18/SSMIS, GCOM-W/AMSR2, GPM-core/GMI; WV-CSR of Himawari-8; radar-raingauge analyzed precipitation; precipitation retrievals from DMSP-F17, 18/SSMIS, GCOM-W/AMSR2; GPM-core/GMI; GPM-core/DPR; GNSS RO refractivity data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A, B/blackjack, TerraSAR-X/IGOR, TanDEM-X/IGOR; 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) 48 levels up to 22 km (consistent with the forecast model setting) (Inner step) 38 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 essentially as per that used for 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. A new system based on ASUCA and ASUCA-Var was implemented in the operational LA in January 2015, replacing the previous one based on JMA-NHM and JNoVA. The specifications of the LA are detailed in Table 4.3.1-2.

Table 4.3.1-2 LA specifications

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 2016)	SYNOP, SHIP, BUOY, AMeDAS, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR, AMVs from Himawari-8 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	48 levels up to 22 km
Analysis variables	Wind, potential temperature, surface pressure, pseudo-relative humidity, skin temperature, ground temperature, soil moisture

4.3.1.2 Research performed in the field

(1) Assimilation of GPM Dual-frequency Precipitation Radar (DPR) data into the Meso-scale NWP system

The Dual-frequency Precipitation Radar (DPR) on board the GPM core satellite incorporates Ku-band precipitation radar (KuPR) and Ka-band precipitation radar (KaPR), which are used to observe vertical profiles of reflectivity in the mid-latitude region between 65°S and 65°N. In DPR assimilation, relative humidity (RH) data retrieved from the DPR reflectivity profile using Bayesian theory are assimilated on the basis of 4D-VAR (Ikuta 2014). Only the liquid phase of DPR is used in data assimilation. An OSE on DPR confirmed that DPR assimilation improved precipitation forecasts even with a lead time of 33 hours despite the narrow swathes of KuPR and KaPR (250 and 150 km, respectively). Statistical evaluation of precipitation forecasting for around a one-month period in summer 2015 showed improvement at values over 10 mm/3 h. The impact in winter was low because ice-phase data were not used. Detailed OSE results are reported by Ikuta (2016). Assimilation of DPR data into the Meso-scale NWP system was commenced in March 2016. (Y. Ikuta)

(2) Assimilation of GNSS Radio Occultation (RO) data into the Meso-scale NWP system

Global Navigation Satellite System (GNSS) Radio Occultation (RO) data exhibit fairly uniform distribution worldwide, in contrast to data from radiosondes and aircraft, producing vertical profiles of atmospheric parameters that can be assimilated into numerical weather prediction (NWP) systems without bias correction. JMA began using GNSS RO refractivity data in its Meso-scale NWP system in March 2016. In this system, RO data from GRACE-A, GRACE-B, Metop-A, Metop-B, COSMIC, TerraSAR-X and TanDEM-X are assimilated after application of gross-error quality checking. The one-dimensional observation operator in the Radio Occultation Processing Package (ROPP) is used for data assimilation, and the system's model top is at about 40 hPa. Comparison of experiment results regarding assimilation of RO refractivity and RO bending-angle data showed slightly better improvement with the former, while improved first-guess temperature profiles were seen with both, especially in the upper troposphere. These results suggest that the upper-layer information of the current mesoscale model may be insufficient for bending-angle assimilation due to the limited model-top height. Accordingly, RO refractivity data have been assimilated into the Meso-scale NWP system. (Y. Hirahara, H. Owada and M. Moriya)

(3) Assimilation of JMA high-resolution radiosonde observation data into the Meso-scale NWP system

In recent years, JMA has introduced GPS radiosondes for all its radiosonde stations. This has enabled atmospheric observation at intervals of a few seconds (representing several thousand altitudes in total) along with collection of positional information and storage of the results in high-resolution data (HRD) format. JMA also developed a new quality control procedure to determine the appropriateness of observation values and positions along with a data selection algorithm for thinning with appropriate height intervals to remove data correlation. OSEs conducted for two months in summer 2015 and in winter 2014 – 2015 showed that the assimilation of JMA's HRD with this quality control and data selection improved quantitative precipitation forecasts in summer, although the impacts in winter were rather neutral. Forecasts of variables such as surface temperature and surface wind (in summer) and sea-level pressure (in both summer and winter) were also slightly improved. More detailed information is reported by Sako (2016). JMA began to assimilate HRD into the Meso-scale NWP system in March 2016 using the new algorithm. (H. Sako)

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 MSM specifications

1. System	
System	Meso-scale model (forecast model: JMA-NHM)
Date of implementation	1 Mar. 2001 (JMA-NHM: 1 Sep. 2004)
2. Configuration	
Domain	Japan, Lambert projection, 817 × 661 grid points
Horizontal resolution	5 km at 60 and 30°N (standard parallels)
Number of model levels	48
Model top	21.8 km
Forecast length	39 hours
Runs per day (times in UTC)	8 (00, 03, 06, 09, 12, 15, 18 and 21 UTC)
Coupling to ocean/wave/sea ice models	None
Integration time step	20 seconds
3. Initial conditions	
Data assimilation method	4D-Var analysis with mixing ratios of cloud water, cloud ice, rain, snow and graupel derived from preceding forecasts in consideration of consistency with the analysis field of relative humidity The MSM runs three hours before the initial time for spin-up.
4. Surface boundary conditions	
Sea-surface temperature	Observed SST (fixed during time integration) and sea-ice distribution
Land surface analysis	Climatological values of evaporability, roughness length and albedo Snow cover analysis over Japan using a land surface model
5. Lateral boundary conditions	
Model providing lateral boundary conditions	GSM
Lateral boundary condition update frequency	4 times/day 00 – 45-hour GSM forecasts initialized at 00/06/12/18 UTC for (03, 06)/(09, 12)/(15, 18)/(21, 00) UTC forecasts
6. Other model details	
Soil scheme	Ground temperature prediction using a four-layer ground model Evaporability prediction initialized using climatological values depending on location and season
Radiation	Short wave: two-stream with delta-Eddington approximation (every 15 minutes) Long wave: table look-up and k-distribution methods (every 15 minutes)

Large scale dynamics	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 Fully compressible non-hydrostatic equations
Boundary layer	Improved Mellor-Yamada Level 2.5 scheme Similarity theory adopted for surface boundary layer
Convection	Kain-Fritsch convection scheme
Cloud/microphysics	Three-ice bulk cloud microphysics Lagrangian treatment for rain and graupel precipitation Cloud water and cloud cover diagnosed using a partial condensation scheme
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
Gravity wave drag	None
7. Further information	
System documentation URLs	http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2015_Japan.pdf

(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. This model has 2-km horizontal grid spacing and 58 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 ASUCA forecast model was introduced in January 2015, replacing the previous JMA-NHM model. The specifications of the LFM are listed in Table 4.3.2-2.

Table 4.3.2-2 LFM specifications

1. System	
System	Local Forecast Model (ASUCA)
Date of implementation	30 Aug. 2012 (ASUCA: 29 Jan. 2015)
2. Configuration	
Domain	Japan, Lambert projection, 1,531 × 1,301 grid points
Horizontal resolution	2 km at 60 and 30°N (standard parallels)
Number of model levels	58
Model top	20.2 km
Forecast length	9 hours
Runs per day (times in UTC)	24 (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)
Coupling to ocean/wave/sea ice models	None
Integration time step	50/3 seconds (3-stage Runge Kutta method)
3. Initial conditions	
Data assimilation method	The LA produces initial conditions via a three-hour analysis cycle based on hourly assimilation with 3D-Var and one-hour forecasts.
4. Surface boundary conditions	

Sea-surface temperature	SST (fixed during time integration) and sea-ice distribution from MSM
Land surface analysis	Climatological values of evaporability, roughness length and albedo Snow cover analysis from MSM
5. Lateral boundary conditions	
Model providing lateral boundary conditions	MSM
Lateral boundary condition update frequency	8 times/day 00 – 13-hour forecasts using the latest MSM information
6. Other model details	
Soil scheme	Ground temperature prediction using a four-layer ground model Evaporability prediction initialized using climatological values depending on location and season
Radiation	Short wave: two-stream with delta-Eddington approximation (every 15 minutes) Long wave: table look-up and k-distribution methods (every 15 minutes)
Large-scale dynamics	Finite volume method on Arakawa-C-type staggered coordinates, horizontally explicit and vertically implicit time integration scheme, combined third- and first-order upwind horizontal finite difference schemes in flux form with a limiter by Koren (1993) in advection treatment for monotonicity Fully compressible non-hydrostatic equations
Boundary layer	Improved Mellor-Yamada Level 3 scheme Similarity theory adopted for surface boundary layer
Convection	Convective initiation
Cloud/microphysics	Three-ice bulk cloud microphysics Time-split treatment for rain and graupel precipitation Cloud water and cloud cover diagnosis using a partial condensation scheme
Orography	Mean orography smoothing to eliminate shortest-wave components
Horizontal diffusion	None
Gravity wave drag	None
7. Further information	
System documentation URLs	http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2015_Japan.pdf

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 for the issuance of warnings, advisories, information and weather forecasts. Five operational techniques are routinely used to determine guidance from NWP model output: Kalman Filter (KF), Artificial Neural Network (ANN), Multiple Linear Regression (MLR), Logistic Regression (LR), and Diagnostic Methods (DM). These approaches are applied to grid-point values from the GSM, the MSM and the LFM in order to reduce systematic errors in NWP models and extract useful information such as probabilities and categorical/diagnostic values. The specifications of weather forecast and aviation forecast guidance are listed in Table 4.3.4-1 and 4.3.4-2, respectively.

Table 4.3.4-1 Weather forecast guidance specifications

Guidance based on the GSM is provided every 6 hours with forecast times between 3 and 84 hours every 3 hours. Guidance based on the MSM is provided every 3 hours with forecast times between 3 and 39 hours every 3 hours.

Element	Details	Type	NWP	Statistical tool
Average precipitation	3-hour cumulative precipitation (grid average)	Grid (20 * 20 km for GSM, 5 * 5 km for MSM)	GSM, MSM	KF
Maximum precipitation	1-, 3- and 24- hour cumulative precipitation (maximum value within each grid square)			ANN (1, 3 hours), MLR (24 hours)
Probability of precipitation	Probability of precipitation totaling 1 mm or more over 6 hours			KF
Weather	Categorization (including sunshine duration and precipitation type)			ANN (sunshine duration), DM (precipitation type)
Visibility	Minimum visibility			DM
Maximum snowfall	3-, 6-, 12- and 24-hour snowfall depths (maximum value within each grid square)	Grid (5 * 5 km)		DM + LR
Snowfall	6-, 12- and 24-hour snowfall depths	Point (323)		ANN
Temperature	Maximum, minimum, time-series temperature	Point (928)		KF
Wind	Maximum, time-series wind speed/direction	Point (928)		KF
Humidity	Minimum humidity, time-series humidity	Point (154)		ANN (minimum), KF (time series)
Probability of TS	Probability of thunderstorms	Grid (20 * 20 km)		LR

Table 4.3.4-2 Aviation forecast guidance specifications

Guidance based on the MSM is provided every 3 hours with forecast times between 1 and 39 hours every hour. Guidance based on the LFM is provided every hour with forecast times between 1 and 9 hours every hour.

Element	Details	Type	NWP	Statistical tool
Visibility	Minimum and mean visibility	Point (91 airports)	MSM	KF
Probability of visibility	Probability of visibility less than 5,000 and 1,600 m			KF
Cloud	Cloud amount and height of lower 3 layers			ANN

Probability of ceiling	Probability of ceiling below 600 and 1,000 ft			LR
Wind	Time-series, maximum wind speed/direction			KF
Gust	Gust speed/direction			KF
Probability of gusts	Probability of gusting			LR
Weather	Categorized weather			DM
Temperature	Maximum, minimum and time-series temperature			KF
Turbulence	Turbulence index	Grid (40 * 40 km and 28 layers for MSM, 10 * 10 km and 45 layers for LFM)	GSM, MSM, LFM	LR
Icing	Icing index		MSM, LFM	DM
CB	CB cloud amount and CB top height		GSM, MSM, LFM	DM
Visibility	Minimum visibility		LFM	DM

(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 3D-Var 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 4.3.4-3.

Table 4.3.4-3 Hourly Analysis specifications

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	48 forecast model levels
Analysis variables	Wind, temperature, surface wind and surface temperature
Observation (as of 31 December, 2016)	AMeDAS, Wind Profiler, Weather Doppler radar (radial velocity), AIREP, AMDAR, and AMVs from Himawari-8
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

Icing index values based on the GSM will be operationally introduced in 2017. DM approaches are used to determine these values.

Guidance on precipitation based on the GSM/MSM and CB top height based on the GSM will be improved in 2017.

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. High-resolution Precipitation Nowcasts (JMA's latest nowcasting product) were introduced in August 2014.

The products are listed below.

(1) High-resolution Precipitation Nowcasts (incorporating forecasts of 5-minute cumulative precipitation, 5-minute-interval precipitation intensity and error range estimation based on extrapolation and spatially three-dimensional forecasting covering the period up to 60 minutes ahead)
(2) Precipitation Nowcasts (incorporating forecasts of 10-minute cumulative precipitation and 5-minute-interval precipitation intensity based on extrapolation covering the period up to 60 minutes ahead)
(3) Thunder Nowcasts (incorporating forecasts of thunder and lightning activity based on lightning detection network system observation covering the period up to 60 minutes ahead)
(4) Hazardous Wind Potential Nowcasts (incorporating forecasts of the probability of hazardous wind conditions such as tornadoes covering the period up to 60 minutes ahead)
(5) Radar/Raingauge-Analyzed Precipitation (R/A)* (incorporating 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)
(6) Very-Short-Range Forecasts of precipitation (VSRFs) (incorporating 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) High-resolution Precipitation Nowcasts

High-resolution precipitation nowcasts (HRPNs) provide five-minute-interval precipitation intensity and cumulative precipitation data up to an hour ahead. Initial precipitation intensity distribution is determined via three-dimensional analysis of storms using radar echo intensity, Doppler velocity, raingauge, surface and upper-air observation data.
Data on vertical atmospheric profiles is part of input data for prediction generation. The initial values for such data are based on upper-air observation data, and are updated via comparison of cumulonimbus cloud profiles (echo top rising speed, ceiling height, lightning count and rainfall amount) between radar/radio-based observation and calculation using the Vertically One-dimensional Convective Model (VOCM). Thus, HRPNs are multi-observing-system-based nowcasting products beyond radar-based data with concentration on various observation data application technologies.

Two HRPN prediction processes are adopted: (1) high-resolution three-dimensional prediction generated by extrapolating the three-dimensional distribution of water content and using VOCM data relating to notable heavy rain regions; and (2) low-resolution three-dimensional prediction generated with a longer time step and reduced vertical calculation for areas outside high-resolution prediction regions. Data processing functions are designed for prediction using a dynamical estimation approach suitable for forecasting of rain phenomena that develop widely and rapidly based on a kinetic approach involving the extrapolation of phenomenon movement trends. Generation of data on convective cloud initiation triggered by three phenomena is also considered. HRPN distribution data contain information on prediction uncertainty in the form of predictions regarding the magnitude of errors included in forecast rainfall. Knowledge of this uncertainty is considered useful in applications such as river water level prediction.
The specifications are summarized in Table 4.4.1-1.
High-resolution Precipitation Nowcasts are provided to local weather offices and to the public in order to enable close monitoring of heavy rain areas and support disaster prevention activities.

Table 4.4.1-1 High-resolution Precipitation Nowcast model specifications

Forecast process	• Kinetic: non-linear motion/intensity extrapolation • Dynamic: vertically one-dimensional convective model enabling calculation relating to raindrop generation, precipitation and evaporation • Convective Initiation: three triggers: (1) downflow caused by heavy

	rainfall, (2) temporal variation of surface temperature and water vapor, (3) intersection of arch-shaped thin echo
Movement vector	• Precipitation system, cell and rain intensity trend motion vectors estimated using cross-correlation pattern matching and discrete interpolation • Dual-Doppler wind
Time step	5 minutes (low-resolution three-dimensional prediction) 1 minute (high-resolution three-dimensional prediction) 1 second (vertically one-dimensional convective model)
Grid form	Cylindrical equidistant projection
Resolution and forecast time	Approx. 250 m over land and coasts 00 ー 30 minutes ahead 1 km over land and coasts 35 ー 60 minutes ahead 1 km from the coasts 00 ー 60 minutes ahead
Number of grids	16,660,800 for distribution data, with up to 51,840,000 for internal calculation of high-resolution three-dimensional prediction
Initial	• Analyzed precipitation distribution determined from radar, raingauge and upper-air observation • Vertical atmospheric profiles based on radiosonde and cumulonimbus cloud features
Update interval	Every 5 minutes

(2) 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 on the basis of extrapolation within three minutes of radar observation. These processes are planned to be replaced with smoothing the output of High-resolution Precipitation Nowcasts. The specifications are summarized in Table 4.4.1-2.

Precipitation Nowcasts are provided to local weather offices and to the public to help clarify precipitation transition and to support disaster prevention activities.

Table 4.4.1-2 Precipitation Nowcast model specifications

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

(3) 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 on the basis of extrapolation within three minutes of radar observation. The specifications are summarized in Table 4.4.1-3.

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 4.4.1-3 Thunder Nowcast model specifications

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

(4) 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 on the basis of extrapolation within three minutes of radar observation. The specifications are summarized in Table 4.4.1-4.
Hazardous Wind Potential Nowcasts are provided to local weather offices and to the public. They are utilized to understand the transition of high potential areas for hazardous wind and to call attention to hazardous wind conditions.

Table 4.4.1-4 Hazardous Wind Potential Nowcast model specifications

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) Improvement of Thunder Nowcasts (4.4.1.1 (3))

The method for analysis of potential lightning areas (activity level 1) was improved in December 2016 to avoid excessively large level-1 areas as follows:

- A new algorithm for radar echo classification to evaluate the possibility of lightning within the next hour was introduced with consideration of three-dimensional factors such as hailstone layer depth and distribution of vertical echo intensity.
- Additional parameters calculated from NWP for consideration of likely lightning conditions were applied for classified radar echoes.

(2) Improvement of Hazardous Wind Potential Nowcasts (4.4.1.1 (4))

The use of Doppler radar data produced from the X-band multi-parameter radar network system operated by the Ministry of Land, Infrastructure, Transport and Tourism was started for better identification of precursors to hazardous wind.

New severe weather parameters developed in consideration of the energy conservation law and vertical wind shear data for identification of hazardous wind conditions were introduced in December 2016 to increase the probability of detection and reduce the false alert ratio.

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 Extrapolation model specifications

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 Runoff Index.

4.4.2.2 Research performed in the field

(1) Very-Short-Range Forecasts of precipitation (VSRFs) (4.4.2.1 (2))

The method of merging extrapolating forecasts and MSM/LFM forecasts was improved in November 2016.

4.5 Specialized numerical predictions

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

4.5.1.1 In operation

(1) Global Ocean Data Assimilation System

JMA's global ocean data assimilation system was upgraded in June 2015 to the MOVE/MRI.COM-G2 version (Toyoda et al. 2013) developed by its Meteorological Research Institute. Its specifications are shown in Table 4.5.1-1.

Table 4.5.1-1 Global Ocean Data Assimilation System specifications

Basic equations	Primitive equations with free surface
Independent variables	Lat-lon coordinates and σ-z hybrid vertical coordinates
Dependent variables	Zonal and meridional velocities, temperature, salinity and sea surface height
Analysis variables	Sea-surface and subsurface temperature and salinity
Numerical technique	Finite difference both in the horizontal and in the vertical
Grid size	1˚ (longitude) × 0.5˚ (latitude, smoothly decreasing to 0.3˚ toward the equator) grids
Vertical levels	52 levels with a bottom boundary layer
Integration domain	Global oceans
Forcing data	Heat, water and momentum fluxes calculated using data from the JRA-55 Reanalysis
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-G2 are used to monitor and diagnose tropical ocean status. Some figures based on MOVE/MRI.COM-G2 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-CGCM2).

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

Objective analysis is conducted to produce high-resolution data on daily sea surface temperatures (SSTs) in global oceans on a 1/4˚ × 1/4˚ grid for ocean information services. These data are also used to provide boundary conditions for short- to medium-range NWP models and the ocean data assimilation system for the North Pacific Ocean. SST data obtained from polar-orbiting satellites (AVHRRs on the NOAA series and Metop; Windsat on Coriolis; and AMSR2 on GCOM-W) are used together with in-situ SST observation data. The analysis data are available on the NEAR-GOOS Regional Real Time Database (http:// ds.data.jma.go.jp/gmd/goos/data/database.html).

4.5.1.2 Research performed in the field

4.5.2 Specific models

4.5.2.1 In operation

(1) Typhoon Ensemble Prediction System (Typhoon EPS)

JMA operates the Typhoon EPS to support five-day tropical cyclone (TC) track forecasts. The system involves 25 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, and 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 GSM1304 is used in this EPS and in the One-week EPS (see 4.2.5.1). Accordingly, the dynamical framework and physical processes involved are identical to those of the previous GSM except for horizontal resolution. Unperturbed analysis is conducted by interpolating the target field in GA. The results of sea surface temperature and sea ice analysis are referenced for the lower boundary condition, and the initialized condition is prescribed using the persisted anomaly. Accordingly, anomalies shown based on analysis for the initial time are fixed during time integration. 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 Typhoon EPS specifications

<table>
<tr><td rowspan="4">Integration</td><td>Start of operation</td><td colspan="2">February 2008</td></tr>
<tr><td>Ensemble size</td><td colspan="2">25</td></tr>
<tr><td>Initial time</td><td colspan="2">00, 06, 12 and 18 UTC</td></tr>
<tr><td>Forecast range</td><td colspan="2">132 hours</td></tr>
<tr><td rowspan="4">EPS model</td><td>Model type</td><td colspan="2">GSM1304</td></tr>
<tr><td>Horizontal resolution</td><td colspan="2">TL479 reduced Gaussian grid system roughly equivalent to 0.375° × 0.375° (40 km) in latitude and longitude</td></tr>
<tr><td>Vertical resolution (model top)</td><td colspan="2">60 levels (0.1 hPa)</td></tr>
<tr><td>Model ensemble method</td><td colspan="2">Stochastic physics scheme</td></tr>
<tr><td rowspan="4">Initial perturbation (Initial ensemble generator | Singular</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>
</table>

vector method)	Optimization time	24 hours	
	Evolved SV	Not used	
	Number of SVs	10	10 for each TC

(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 (TL959L100). The standard products of the RSMC involve maps on trajectories, time-integrated low-level concentrations and total deposition up to 72 hours ahead. In October 2016, JMA updated its operational atmospheric transport, dispersion and deposition model. Time-integrated concentration and deposition have been calculated at 0.5-degree intervals since then. The number of tracer particles was increased to one million and the horizontal diffusion treatment proposed by Gifford (1982) was introduced.

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. Backtracking over a period up to 50 days can be provided on an operational basis.

(3) Ocean-wave forecasting models

JMA operates four numerical wave models: the Global Wave Model (GWM), the Coastal Wave Model (CWM), the Wave Ensemble System (WENS), and the Shallow-water Wave Model (SWM). The GWM, CWM and WENS are based on MRI-III, which was developed at JMA's Meteorological Research Institute (MRI), and a major update was made to the current version in May 2007. The WENS has been operational since June 2016. The specifications of the models 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. JMA began calculating wave components (windsea and swell) for the GWM and CWM on July 20 2016.

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 model is applied to *22 bay/limited sea*. The models' specifications are given in Table 4.5.2.1 (3)-2.

Table 4.5.2.1 (3)-1 Ocean-wave prediction model specifications

Model name	Global Wave Model	Coastal Wave Model	Wave Ensemble System
Model type	Spectral model (third-generation wave model)		
Date of implementation	May 2007	May 2007	June 2016
Grid form	Equal latitude-longitude grid on spherical coordinates		
Grid interval	0.5° × 0.5° (55 km)	0.05° × 0.05° (5 km)	1.25° × 1.25° (140 km)
Calculation area	Global 75°N – 75°S	Coastal Sea of Japan 50°N – 20°N, 120°E – 150°E	Global 75°N – 75°S
Grids	720 × 301	601 × 601	288 × 121
Spectral components	900 (25 frequencies and 36 directions) Frequency: 0.0375 – 0.3 Hz; logarithmically divided direction: 10° intervals		
Forecast cycle	4 times a day (every 6 hours)		Once a day
Forecast length (12 UTC) (00/06/18 UTC)	264 hours 84 hours	84 hours 84 hours	264 hours
Forecast time interval	Every 3 hours	Every 3 hours	Every 6 hours
Time step	Advection term: 10 minutes Source term: 30 minutes	Advection term: 1 minute Source term: 3 minutes	Advection term: 30 minute Source term: 60 minutes
Assimilation	Wave height analyzed using the Objective Wave Analysis System Initial conditions modified using analysis wave height		
Surface forcing	Global Spectral Model (GSM) (20 km grid) Winds inside typhoons modified using ideal gradient wind values (– 72 hours)		One-week Ensemble Prediction System (WEPS) 27 members
Lateral boundary	Sea ice: analysis area regarded as land	Sea ice: analysis area regarded as land GWM prediction used for boundary spectrae	Sea ice: analysis area regarded as land
Shallow-water effects	No	No	No

Product	Significant wave height, wave period and mean wave direction Wave components (windsea and two swells) also calculated

Table 4.5.2.1 (3)-2 Ocean-wave prediction model specifications

Model name	Shallow-water Wave Model		
Model type	Spectral model (third-generation wave model)		
Grid interval	1' × 1' (1.7 km)		
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		
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 Shiranui Sea	43 × 73	32.05°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
	Ishikari Bay	49 × 43	43.10°N – 43.80°N 140.70°E – 141.50°E
	Off Ishikawa	49 × 67	36.20°N – 37.30°N 136.00°E – 136.80°E
	Off Nemuro	85 × 49	43.20°N – 44.00°N 145.00°E – 146.40°E
	Off Miyazaki	31 × 73	31.50°N – 32.70°N 131.30°E – 131.80°E
	Tsugaru Strait	61 × 67	40.75°N – 41.85°N 140.35°E – 141.35°E
	Off Ibaraki Off Boso	49 × 103	35.00°N – 36.70°N 140.20°E – 141.00°E
	Genkai-Nada	83 × 43	33.40°N – 34.10°N, 129.55°E – 130.95°E
Forecast cycle	4 times a day (every 6 hours) at initial times of 03, 09, 15 and 21 UTC		
Forecast length	39 hours		
Forecast step interval	Hourly		
Integration time step	Advection term: 1 minute		

	Source term: 1 minute
Assimilation	No (hindcast)
Surface forcing	Meso-Scale Model (MSM)
	Bogus gradient winds (for typhoons in the western North Pacific)
Lateral boundary	Sea ice: analysis area regarded as land CWM prediction used for boundary sprectrae
Shallow-water effects	Refraction and bottom friction
Product	Significant wave height, wave period and mean wave direction

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 Numerical storm-surge model specifications

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, 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. JMA began providing daily storm surge predictions associated with the winter monsoon and synoptic eddies in January 2016. A multi-scenario prediction method was incorporated into the model in June 2016 to support the provision of more useful risk management information. The model's specifications are given in Table 4.5.2.1 (4)-2. JMA added 10 stations for time-series charts in 2016, bringing the total to 78.

Table 4.5.2.1 (4)-2 Numerical storm-surge model (Asian region) specifications

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), Typhoon EPS (TEPS)
	Bogus data for TCs (center)
Astronomical tides	Not included

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

A 3D-Var 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 in Table 4.5.2.1 (5)-1. 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://ds.data.jma.go.jp/gmd/goos/data/database.html).

Table 4.5.2.1 (5)-1 Specifications of the 3D-Var 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	Zonal/meridional velocities, temperature, salinity and sea surface height
Analysis variables	Sea-surface/subsurface temperature and salinity
Numerical technique	Finite difference both in the horizontal and in the vertical
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 (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 fluxes from the Japanese 55-year Reanalysis (JRA-55) and from the control run of One-month Ensemble Prediction System
Assimilation scheme	3D-Var with 5-day windows
Observational data (as of 31 December 2016)	Sea-surface and subsurface temperature/salinity, sea surface height (Jason-3), 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 Numerical sea-ice prediction model specifications

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 Himawari-8, NOAA and Metop satellite imagery; 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 Marine pollution transport model specifications

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 since January 2004 to enable forecasting of Aeolian dust distribution. In November 2014, the model was updated to a new version based on an Earth-system model (MRI-ESM1; Yukimoto et al. 2011; Yukimoto et al. 2012) for global climate change research. The model consists of an atmospheric general circulation model (AGCM) called MRI-AGCM3 and a global aerosol model known as MASINGAR mk-2, which are linked with a coupler library called Scup (Yoshimura and Yukimoto 2008). The method of dust emission flux calculation was updated to encompass the scheme of Tanaka and Chiba (2005). The model is coupled with a low-resolution version of the AGCM, and involves the use of several AGCM parameters without temporal or spatial interpolation. The model's specifications are given in Table 4.5.2.1 (8)-1.

Table 4.5.2.1 (8)-1 Aeolian dust prediction model specifications

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	TL159 (1.125°)
Vertical levels	40 (surface – 0.4 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)
	Sea surface temperature (MGDSST)

(9) Ultraviolet (UV) index prediction system

JMA has operated a UV-index prediction system since May 2005. The UV index is calculated using a chemical transport model that predicts the global distribution of ozone and a radiative transfer model. In October 2014, the ozone chemistry model was updated to a new version of the chemistry-climate model (MRI-CCM2; Deushi and Shibata 2011), which is part of MRI-ESM1. The model's components are coupled with Scup, and its horizontal resolution has been enhanced from T42 to T106 (see Table 4.5.2.1 (9)-1 for model specifications).

The radiative transfer model (Aoki et al. 2002) calculates the UV index 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 total ozone predicted using 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. The specifications of the radiative transfer model for the UV index are given in Table 4.5.2.1 (9)-2.

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	T106 (1.125°)
Vertical levels	64 (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) Regional chemical transport model for photochemical oxidants

JMA provides prefectural governments with photochemical smog bulletins as a basis for related advisories. The bulletins are produced by combining numerical model prediction of tropospheric photochemical oxidant distributions for the same day or the following day and statistical guidance derived from model outputs associated with past events.

Since March 2015, numerical model prediction of photochemical oxidants has been carried out using the NHM-Chem regional chemical transport model with finer spatial resolution (Kajino et al. 2012) driven with meteorological fields predicted using JMA-NHM offline. The related lateral boundary conditions for chemical species are given by MRI-CCM2 as described in 4.5.2.1 (9). The specifications of the regional chemical transport model are given in Table 4.5.2.1 (10)-1.

Table 4.5.2.1 (10)-1 Specifications of the regional chemical transport model for photochemical oxidants

Model type	3-dimensional Eulerian chemical transport model
Area	East Asia
Grid size	20 km
Vertical layers	18 (surface – 10 km)
Forecast time	72 hours (initial time 12 UTC)
Emission inventories	REAS1.1, GFED3 and MEGAN2
Meteorological fields	JMA-NHM output constrained and initialized using Global Analysis (GA) and Global Spectral Model (GSM) forecasts

(11) Mesoscale air pollution transport model

JMA also issues very-short-term photochemical smog bulletins on days when high oxidant concentration is expected. The bulletins provide an outlook on photochemical smog for the same day based on statistical guidance for oxidant concentration using data on 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 very-short-range forecasting of oxidant concentrations with a grid interval of 10 km, with MSM output used to calculate the transport of highly concentrated pollutant masses in the air. Based on the oxidant forecast from the atmospheric transport model with an initial time of 03 UTC, photochemical smog bulletins show the hourly potential of smog occurrence for 04 – 09 UTC in the northern part of the Kyushu region and the Kanto region, where the Tokyo metropolitan area is located.

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

JMA introduced the Volcanic Ash Fall Forecast (VAFF) based on the Regional Atmospheric Transport Model (RATM) in March 2008 (Shimbori et al. 2009) and updated it in spring 2015 (Hasegawa et al. 2015). Three types of forecasts are sequentially provided: VAFFs (Scheduled) are issued periodically based on an assumed eruption for active volcanoes, VAFFs (Preliminary) are brief forecasts issued within 5 ー 10 minutes of an actual eruption, and VAFFs (Detailed) are more accurate forecasts issued within 20 ー 30 minutes of an actual eruption. The updated VAFFs provide information on expected ash/lapilli fall areas and/or amounts based on the RATM with LFM or MSM outputs. The specifications of RATM are given in Table 4.5.2.1 (12)-1.

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

Model type	Lagrangian description
Number of tracer particles	100,000 (Scheduled, Preliminary) 250,000 (Detailed)
Time step	1 minute (Preliminary)

	3 minutes (Scheduled, Detailed)
Forecast time	18 hours from the time of assumed eruption (Scheduled) 1 hour from the time of eruption (Preliminary) 6 hours from the time of eruption (Detailed)
Initial condition	Eruption column based on observational reports including eruption time and plume height, and continuance of volcanic-ash emissions
Meteorological field	Local Forecast Model (LFM) or 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 area of responsibility 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. In July 2014, GATM was extended to provide 24-hour prediction on a trial basis for verification of 24-hour forecast efficacy in areas with volcanic ash clouds.

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*[1] from the time of satellite observation *1 24 hours on a trial basis (18 hours for regular operation)
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

A data assimilation system with a local ensemble transform Kalman filter (LETKF) (Sekiyama et al. 2010; Yumimoto et al. 2015) and a two-dimensional variational (2D-Var) data assimilation method for aerosols using satellite sensors has been developed. Verification and improvement of the system will be carried out toward operational application.

(4) UV index prediction system

A data assimilation system with LETKF for stratospheric ozone has been developed (Sekiyama et al. 2011; Nakamura et al. 2013), and is scheduled to enter into operation in 2018.

(5) Regional chemical transport model

A nudging technique for surface ozone data assimilation has been applied to the regional chemical transport model. JMA is currently evaluating this application for the photochemical oxidant information advisory.

(6) Volcanic ash concentration forecast

Despite the importance of volcanic ash concentration forecasting in the world of aviation, no 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.

(7) Time of Arrival (ToA) product experiments for environmental emergency response services

Based on discussions held at a 2013 meeting of the Expert Team on Emergency Response Activities (ET-ERA), a JMA expert took part in joint-RSMC Time of Arrival (ToA) product experiments conducted in June and October 2015. ToA products are designed to present users with arrival times along with specific contamination values to support environmental emergency response services. Specifications and procedures for the ToA delivery system have not yet been established among related RSMCs. ToA product experiments will be continued as discussed at a 2015 ET-ERA meeting.

(8) Inclusion of information on rough sea areas in Wave Forecast Charts

Rough sea areas, which may be challenging for navigation, will be included in future Wave Forecast Charts. The new information will indicate areas of 1) crossing waves, and 2) rough waves against currents, which make seas complex, high and chaotic. Such areas will be indicated on Wave Forecast Charts (FWPN/FWJP) and directly issued to navigators via radio facsimile.

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

A 4D-Var ocean data assimilation system has been quasi-operational since March 2016 with the same integration domain, grid size and vertical levels as those of the 3D-Var system (Table 4.5.2.1 (5)-1). With the Global Spectral Model (GSM) used for forcing data, 10-day assimilation and 11-day prediction are implemented on a daily basis. This 4D-Var system is part of a prototype for the future operational analysis/forecasting system (MOVE/MRI.COM-JPN) being developed by JMA's Meteorological Research Institute (see 6.1.2). Its output is used as reference for the development of the next operational system.

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 surface concentration and the total amount of Aeolian dust 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 and the current system was upgraded in March 2014.

The specifications of the One-month EPS are shown in Table 4.6.1.1-1. The numerical prediction model applied for this system is a low-resolution version (TL319) of the GSM. For the lower boundary condition of the model, initial SST anomalies which are estimated using the high-resolution daily SSTs (see 4.5.1.1(2)) 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. A stochastic physics scheme (Buizza et al. 1999), which is same as in the One-week EPS (see 4.2.5.1), is used in consideration of model uncertainties associated with physical parameterizations.

Table 4.6.1.1-1 One-month EPS specifications

Atmospheric model	GSM1304
Integration domain	Global
Horizontal resolution	TL319 reduced Gaussian grid system roughly equivalent to 0.5625 × 0.5625° (55 km) in latitude and longitude
Vertical levels (model top)	60 levels (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)
Model ensemble method	Stochastic physics scheme

4.6.1.2 Reanalysis project

In March 2013, JMA completed the second Japanese global reanalysis, known formally as JRA-55 (Kobayashi et al. 2015) 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 (Onogi et al. 2007). 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 a dry bias in the Amazon basin, which has been mitigated. The temporal consistency of temperature analysis has also been considerably improved. JMA continues the production of JRA-55 dataset on a near-real-time basis with the data assimilation system used for this dataset.

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 provided via 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 provided via the TCC are shown in Table 4.6.2-2.

Table 4.6.2-1 Gridded data products (GRIB2) for one-month forecasts provided via the TCC website

Details		Level (hPa)	Area	Base time & forecast times
Ensemble mean value of forecast members	Sea level pressure* and its anomaly	-	Global 2.5˚ × 2.5˚	Base time: 00 UTC of Wednesday Forecast time:2,3,4…,31 ,32 days from base time
	Rainfall amount and its anomaly	-		
	Temperature and its anomaly	Surf, 850, 700		
	Relative humidity	850		
	Geopotential height and its anomaly	500, 100		
	Wind (u, v)	850, 200		
	Stream function and its anomaly	850, 200		
	Velocity potential and its anomaly	200		
Individual ensemble	Sea level pressure*	-		Base time : 00UTC of
	Rainfall amount	-		

members	Temperature*	Surf, 1000, 850, 700, 500, 300, 200, 100		Tuesday and Wednesday Forecast time: 0,1, 2,...,31,32 days from base time
	Relative humidity	1000, 850, 700, 500, 300		
	Geopotential height*	1000, 850, 700, 500, 300, 200, 100		
	Wind (u,v)	1000, 850, 700, 500, 300, 200, 100		
	Stream function	850, 200		
	Velocity potential	200		

* Geopotential height, sea level pressure and temperature are calibrated by subtracting the systematic error from the direct model output.

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

	Forecast time	Parameter
Ensemble mean	Averages of days 3 – 9, 10 – 16, 17 – 30, 3 – 30	Geopotential height at 500 hPa and its anomaly Temperature at 850 hPa and its anomaly Sea level pressure and its anomaly Stream function at 200 hPa and its anomaly Stream function at 850 hPa and its anomaly Velocity potential at 200 hPa and its anomaly Precipitation and its anomaly Temperature at 2 m and its anomaly 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 its Seasonal Ensemble Prediction System (Seasonal EPS; JMA/MRI-CPS2) using an atmosphere-ocean coupled model (JMA/MRI-CGCM2) for three-month, warm/cold season and El Niño outlooks. The current system was upgraded in June 2015. 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-CGCM2 was developed by the Meteorological Research Institute and the Climate Prediction Division of JMA. Its specifications are shown in Table 4.7.1-1. Atmospheric and land surface initial conditions are taken from JRA-55 data (Kobayashi et al. 2015; 4.6.1.2), while oceanic and sea ice initial conditions are taken from MOVE/MRI-COM-G2 (4.5.1.1 (1)). The EPS adopts a combination of the LAF method and the initial perturbation method described below. Thirteen-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-G2 forced by the surface heat and momentum fluxes of atmospheric initial perturbation fields using the BGM method.

Table 4.7.1-1 Seasonal EPS specifications

Model	JMA/MRI-CGCM2 An atmosphere-ocean coupled model rather than a Tier-2 system	
Atmospheric model	Model type	GSM1011C
	Horizontal resolution	Global TL159 reduced Gaussian grid system roughly equivalent to 1.125 × 1.125° (110 km) in latitude and longitude
	Vertical levels (model top)	60 levels (0.1 hPa)
Oceanic model	Model type	MRI.COM v3.2
	Horizontal resolution	1 (longitude) × 0.5˚ (latitude, smoothly decreasing to 0.3˚ toward the equator) grids
	Vertical levels	52 levels with a bottom boundary layer
Sea ice model	Model type	Dynamical sea ice model
Coupling	Coupling interval	1 hour
	Flux adjustment	None
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	
Initial atmospheric conditions	Near-real-time operation of JRA-55 (Kobayashi et al. 2015)	
Initial ocean conditions	MOVE/MRI.COM-G2 (Toyoda et al. 2013)	
Ensemble size	51 members per month	
Hindcast	Two initial dates per month for the 36 years from 1979 to 2014 Ensemble size: five for each initial date Ensemble generated via combined application of BGM and LAF methods	
Timing of anomaly prediction for the next month/season	Variable (around the 20th of the month)	
Forecast anomaly determination method	Against climatology (30-year average for the period from 1981 to 2010)	
URL	http://ds.data.jma.go.jp/tcc/tcc/index.html	
Contact	tcc@met.kishou.go.jp	

4.7.2 Operationally available EPS LRF products

JMA provides gridded data and map products for three-month forecasts every month. Warm-season (June-July-August; JJA) forecasts are issued in February, March and April, and cold-season (December-January-February; DJF) forecasts are issued in September and October.

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 (Tables 4.7.2-1 and 4.7.2-2) for three-month and warm/cold-season forecasts are provided via 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) for three-month and warm/cold-season forecasts provided via the TCC website

Details		Level (hPa)	Area	Base time & forecast time
Ensemble mean, its anomaly, and spread (standard deviation) values of forecast members	Sea level pressure*, its anomaly and spread	-	Global 2.5° × 2.5°	Base time: 00 UTC around the 15th of each month Forecast times: One- and three-month averages for targeted terms
	Rainfall amount, its anomaly and spread	-		
	Sea surface temperature* and its anomaly	-		
	Temperature*, its anomaly and spread	Surf, 850		
	Geopotential height*, its anomaly and spread	500		
	Wind (u, v), its anomaly and spread	850, 200		
Individual ensemble members	Sea level pressure* and its anomaly	-		Base time: 00 UTC on each initial date of prediction (every 5 days) Forecast times: One-month averages for targeted terms
	Rainfall amount and its anomaly	-		
	Sea surface temperature* and its anomaly	-		
	Temperature* and its anomaly	Surf, 850, 500, 200		
	Relative humidity and its anomaly	850		
	Specific humidity and its anomaly	850		
	Geopotential height* and its anomaly	850, 500, 300, 200, 100		
	Wind (u,v) and its anomaly	850, 500, 200		

* Geopotential height, sea level pressure, temperature and sea surface temperature are calibrated by subtracting the systematic error from the direct model output.

Table 4.7.2-2 Map products for three-month and warm/cold-season forecasts provided via the TCC website
<http://ds.data.jma.go.jp/tcc/tcc/products/model/map/4mE/index.html>

	Forecast time	Parameter
Ensemble	Three-month forecast:	Geopotential height at 500 hPa, related anomaly and

mean, its anomaly and spread	Averages of first month, second month, third month, and three months Warm/cold season forecast: Averages of three months (JJA or DJF)	spread Temperature at 850 hPa, its anomaly and spread Sea level pressure, its anomaly and spread Stream function at 200 hPa, its anomaly and spread Stream function at 850 hPa, its anomaly and spread Wind (u,v) anomaly at 850 hPa Velocity potential at 200 hPa, its anomaly and spread Precipitation, its anomaly and spread Temperature at 2 m, its anomaly and spread Sea surface temperature and its anomaly

Table 4.7.2-3 SST Index Time Series
<http://ds.data.jma.go.jp/tcc/tcc/products/model/indices/3-mon/indices1/shisu_forecast.php>

Index	Description	Coordinates
Niño.1+2	Region off coasts of Peru and Chile	90°W – 80°W, 10°S – 0°
Niño.3	Eastern/Central Tropical Pacific	150°W – 90°W, 5°S – 5°N
Niño3.4	Central Tropical Pacific	170°W – 120°W, 5°S – 5°N
Niño.4	Western/Central Tropical Pacific	160°E – 150°W, 5°S – 5°N
TNA	Tropical North Atlantic	55°W – 15°W, 5°N – 25°N
TSA	Tropical South Atlantic	30°W – 10°E, 20°S – 0°
TAD	Tropical Atlantic Dipole	TNA – TSA
WTIO	Western Tropical Indian Ocean	50°E – 70°E, 10°S – 10°N
SETIO	Southeastern Tropical Indian Ocean	90°E – 110°E, 10°S – 0°
IOD	Indian Ocean Dipole	WTIO – SETIO

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 2016 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	7.8	7.7	7.0	6.7	6.3	6.0	5.8	5.8	5.8	6.5	6.9	7.8	6.7
72	26.0	25.2	23.2	22.1	20.8	20.0	18.0	18.0	19.0	21.7	22.5	25.9	21.9
120	49.9	49.7	46.5	43.7	43.5	39.5	34.4	36.2	39.3	44.3	46.6	51.1	43.7

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	7.4	7.5	7.8	8.1	8.1	8.4	8.6	8.8	8.6	7.8	7.4	7.0	8.0
72	24.3	24.5	27.3	28.5	28.3	29.5	29.3	32.2	29.4	26.7	24.0	22.7	27.2
120	47.9	47.0	53.9	56.8	55.1	59.7	58.3	63.5	61.1	53.6	47.0	45.3	54.1

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	12.7	12.4	12.9	10.7	9.7	8.6	8.8	8.7	9.8	10.1	11.6	11.7	10.6
72	28.6	27.7	25.7	23.9	21.6	18.9	16.6	15.2	18.9	21.7	26.2	29.6	22.9
120	53.1	50.4	48.0	46.6	41.9	35.6	29.4	26.9	39.1	40.0	49.0	58.4	43.2
ob. num.	90	89	90	92	90	90	90	89	89	89	89	89	89.7

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	13.0	15.1	13.0	11.8	10.5	9.3	9.6	10.1	12.0	11.5	13.3	15.5	12.1
72	28.7	32.3	29.7	25.1	19.5	18.1	17.1	18.3	24.1	21.6	26.5	30.9	24.3
120	47.9	61.0	51.2	40.2	42.1	33.3	32.9	36.4	48.2	45.0	51.0	57.0	45.5
ob. num.	61	59	62	63	61	61	61	60	59	59	58	55	59.9

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	13.8	13.9	12.2	13.3	12.5	11.8	11.6	11.3	11.0	11.8	12.7	13.6	12.5
72	23.6	24.5	21.9	22.5	23.2	20.2	19.5	19.0	18.1	21.1	23.6	24.7	21.8
120	40.4	42.5	38.1	38.2	38.3	32.4	31.2	30.5	31.5	34.4	39.1	41.0	36.5
ob. num.	123	126	128	129	129	131	129	130	131	131	132	131	129.2

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	11.3	12.7	11.7	11.3	12.3	12.9	13.7	11.6	12.0	10.9	11.5	11.7	12.0
72	22.8	19.2	17.9	22.3	24.3	25.2	22.8	22.1	26.8	23.2	17.0	19.2	21.9
120	41.9	29.6	31.0	39.0	40.3	49.6	42.1	39.9	48.3	38.6	29.8	32.7	38.6
ob. num.	8	8	8	8	8	8	8	8	8	8	8	9	8.1

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	13.7	14.1	13.2	12.8	12.1	11.3	11.1	11.2	11.5	11.7	12.8	13.6	12.4
72	28.5	28.8	25.9	24.5	23.4	21.5	19.5	19.7	21.7	22.9	25.7	28.7	24.2
120	50.7	53.9	47.8	44.4	44.5	38.6	34.2	35.1	41.8	42.7	46.8	52.8	44.4
ob. num.	390	392	405	408	403	410	407	405	407	406	405	402	403.3

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	12.5	13.4	13.4	13.4	13.9	14.0	14.4	14.4	13.4	13.4	12.9	13.2	13.5
72	20.3	20.0	23.2	26.5	25.2	26.8	26.5	29.6	26.8	24.4	21.4	21.7	24.4
120	37.0	33.2	42.2	44.1	40.4	50.7	46.0	51.5	50.8	42.4	37.1	36.4	42.7
ob. num.	37	35	34	34	34	35	35	35	34	36	38	37	35.3

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	3.3	3.4	3.3	3.4	3.3	3.4	3.3	3.2	3.1	3.2	3.3	3.3
72	8.0	7.6	7.5	7.6	8.0	8.0	8.2	7.9	7.9	7.9	7.7	7.9	7.9
120	12.8	12.7	12.2	12.1	13.5	12.8	12.6	12.8	13.4	13.4	13.3	13.6	12.9

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	3.1	3.3	3.3	3.3	3.3	3.2	3.3	3.2	3.2	3.2	3.1	3.2
72	8.3	8.0	8.6	8.5	8.5	8.7	8.2	8.6	8.2	8.0	7.7	7.6	8.2
120	13.7	13.3	14.8	14.3	14.0	14.6	13.7	14.6	14.4	13.2	12.6	12.7	13.8

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	6.3	6.0	6.0	5.8	6.1	5.6	5.9	5.1	5.5	5.3	5.7	5.6	5.7
72	10.8	10.2	9.5	9.6	10.1	9.3	9.4	8.1	9.3	9.4	9.9	10.2	9.7
120	16.3	14.9	14.3	14.9	16.0	14.2	13.2	11.7	15.6	15.1	15.7	17.7	15.0
ob. num.	88	88	88	90	90	89	89	87	88	88	88	88	88.4

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	5.4	5.7	5.0	4.7	5.0	5.2	4.8	4.9	5.4	5.2	4.9	4.9	5.1
72	9.0	9.5	9.2	8.2	8.3	8.6	8.3	8.4	9.9	9.3	9.1	8.8	8.9
120	14.9	16.5	14.1	12.4	14.5	14.2	13.1	14.1	17.3	16.4	15.1	14.5	14.8
ob. num.	63	61	65	66	63	64	63	63	61	61	59	57	62.2

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	5.1	6.0	6.5	6.2	6.4	5.9	5.3	5.3	4.8	4.7	4.9	5.5
72	7.4	7.7	8.8	10.0	10.2	10.4	10.3	8.6	8.5	7.4	7.2	7.6	8.7
120	11.2	11.5	12.0	13.2	13.5	14.2	14.0	12.4	12.3	10.6	11.0	11.2	12.3
ob. num.	150	148	147	147	148	153	152	154	154	154	154	153	151.2

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	6.2	5.3	5.4	5.1	5.9	5.6	5.2	5.3	5.3	5.2	4.9	5.5	5.4
72	9.5	7.7	8.4	7.8	9.0	9.4	8.1	8.0	8.2	7.6	7.6	7.5	8.2
120	13.5	11.7	12.1	11.4	13.5	13.1	11.6	11.3	12.5	11.2	10.3	11.2	11.9
ob. num.	11	13	12	11	9	10	10	10	10	10	10	10	10.5

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	5.3	5.2	5.5	5.6	5.7	5.6	5.5	5.2	5.2	4.9	4.9	4.9	5.3
72	8.9	8.7	8.7	9.1	9.4	9.4	9.4	8.6	9.0	8.4	8.3	8.5	8.9
120	13.7	13.9	13.0	13.1	14.3	14.0	13.6	13.0	14.4	13.5	13.4	13.8	13.6
ob. num.	419	415	424	429	427	436	433	432	432	432	429	424	427.7

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	5.4	5.7	5.5	6.0	5.7	5.5	5.7	5.6	5.7	5.8	5.3	5.6
72	8.6	8.0	9.3	8.8	9.5	10.0	8.8	8.9	8.9	8.7	8.8	7.8	8.8
120	12.3	12.0	14.5	13.2	13.9	14.8	13.3	14.4	13.8	12.7	12.5	11.6	13.3
ob. num.	40	40	36	37	37	38	38	38	37	39	41	41	38.5

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	1.5	1.5	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
72	2.7	2.8	2.5	2.4	2.3	2.5	2.5	2.7	2.7	2.5	2.5	2.5	2.6
120	3.6	3.5	3.1	3.1	2.9	3.2	3.3	3.5	3.4	3.2	3.2	3.3	3.3

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	3.3	3.4	3.1	2.8	2.8	2.9	3.0	3.0	2.9	2.9	3.0	2.9	3.0
72	6.0	6.3	5.9	5.3	5.4	5.3	5.6	5.8	5.4	5.5	5.6	5.8	5.7
120	7.6	8.1	7.5	7.1	7.2	7.0	7.0	7.7	7.1	7.5	7.5	7.8	7.4

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	3.4	3.4	3.3	3.2	3.0	3.3	3.2	3.5	3.3	3.5	3.3	3.6	3.3
72	3.9	3.9	3.7	3.6	3.3	3.8	3.7	4.2	3.9	4.0	3.9	4.1	3.8
120	4.4	4.3	4.0	3.9	3.6	4.3	4.1	4.9	4.4	4.6	4.3	4.6	4.3
ob. num.	77	78	78	79	78	79	75	74	76	75	73	69	75.9

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	5.1	5.0	4.9	4.6	4.7	4.6	4.7	5.0	4.6	4.6	4.4	4.8	4.8

72	7.0	7.1	6.8	6.1	6.5	6.3	6.4	6.7	6.1	6.0	5.9	6.2	6.4
120	8.4	8.4	8.0	7.2	7.9	7.6	7.7	8.4	7.4	7.5	7.1	7.5	7.8
ob. num.	79	81	80	80	80	80	76	73	76	76	74	70	77.1

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 2015 (December in 2014) 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	0.909	0.854	0.747	0.848	0.839	0.888	0.813	0.694	0.819	0.804	0.881	0.780	0.584	0.769	0.753
72	0.788	0.744	0.646	0.730	0.727	0.758	0.698	0.601	0.693	0.688	0.743	0.659	0.481	0.625	0.627
120	0.629	0.567	0.483	0.549	0.557	0.583	0.522	0.426	0.502	0.508	0.551	0.481	0.311	0.432	0.444
168	0.456	0.380	0.302	0.356	0.373	0.407	0.354	0.261	0.316	0.334	0.364	0.293	0.156	0.231	0.261
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	0.876	0.852	0.763	0.864	0.839	0.838	0.832	0.747	0.842	0.815	0.790	0.802	0.722	0.809	0.781
72	0.707	0.701	0.608	0.715	0.683	0.629	0.661	0.566	0.653	0.627	0.565	0.609	0.517	0.588	0.570
120	0.508	0.491	0.393	0.503	0.474	0.420	0.447	0.345	0.414	0.407	0.334	0.389	0.302	0.320	0.336
168	0.325	0.313	0.214	0.319	0.293	0.222	0.271	0.173	0.242	0.227	0.128	0.231	0.143	0.170	0.168

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	0.795	0.668	0.558	0.655	0.669	0.743	0.596	0.440	0.575	0.588	0.662	0.483	0.219	0.490	0.464
72	0.639	0.517	0.365	0.488	0.502	0.575	0.430	0.209	0.386	0.400	0.474	0.305	-0.068	0.284	0.249
120	0.487	0.365	0.224	0.346	0.356	0.422	0.273	0.084	0.255	0.259	0.312	0.141	-0.175	0.154	0.108
168	0.327	0.210	0.094	0.206	0.209	0.252	0.130	-0.024	0.129	0.122	0.147	0.030	-0.238	0.049	-0.003
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	0.725	0.550	0.328	0.598	0.550	0.597	0.331	-0.027	0.386	0.322	0.336	-0.110	-0.650	-0.143	-0.142
72	0.576	0.396	0.141	0.429	0.385	0.427	0.179	-0.213	0.192	0.146	0.168	-0.259	-0.844	-0.336	-0.318
120	0.425	0.243	-0.015	0.258	0.228	0.278	0.039	-0.347	0.011	-0.005	0.043	-0.368	-0.922	-0.502	-0.437
168	0.281	0.092	-0.151	0.109	0.083	0.151	-0.085	-0.474	-0.106	-0.129	-0.048	-0.451	-1.022	-0.594	-0.529

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	0.738	0.716	0.569	0.548	0.643	0.718	0.697	0.485	0.418	0.579	0.678	0.619	0.329	0.150	0.444
72	0.531	0.592	0.451	0.331	0.476	0.482	0.557	0.386	0.149	0.394	0.381	0.423	0.218	-0.258	0.191
120	0.448	0.522	0.399	0.321	0.423	0.416	0.508	0.380	0.202	0.376	0.335	0.412	0.291	-0.072	0.241
168	0.326	0.433	0.258	0.234	0.313	0.303	0.443	0.257	0.153	0.289	0.230	0.364	0.171	-0.055	0.177
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	0.716	0.635	0.550	0.638	0.635	0.693	0.618	0.600	0.586	0.624	0.683	0.617	0.611	0.597	0.627
72	0.473	0.462	0.329	0.450	0.429	0.436	0.443	0.385	0.390	0.413	0.417	0.427	0.368	0.390	0.401
120	0.331	0.281	0.235	0.322	0.292	0.308	0.250	0.259	0.250	0.267	0.264	0.208	0.233	0.213	0.229
168	0.175	0.116	0.034	0.155	0.120	0.145	0.052	0.069	0.103	0.092	0.115	0.034	0.085	0.052	0.071

Table 5.1.1-24 BSS for temperature at 850 hPa over the Tropics (20˚S–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	0.598	0.392	0.121	0.062	0.293	0.568	0.202	-0.201	-0.264	0.076	0.495	-0.150	-0.612	-0.596	-0.216
72	0.441	0.181	-0.255	-0.393	-0.006	0.381	-0.130	-0.845	-1.033	-0.407	0.228	-0.770	-1.695	-1.803	-1.010
120	0.340	0.111	-0.319	-0.475	-0.086	0.263	-0.194	-0.832	-1.074	-0.459	0.077	-0.804	-1.449	-1.678	-0.964
168	0.280	0.085	-0.291	-0.437	-0.091	0.217	-0.157	-0.667	-0.860	-0.367	0.068	-0.600	-1.017	-1.193	-0.685
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	0.455	0.304	0.215	0.282	0.314	0.308	0.138	-0.021	0.088	0.128	0.092	-0.090	-0.455	-0.272	-0.181
72	0.261	0.116	0.062	0.130	0.142	0.112	-0.040	-0.131	-0.030	-0.022	-0.070	-0.257	-0.513	-0.356	-0.299
120	0.181	0.051	0.001	0.069	0.075	0.043	-0.104	-0.171	-0.066	-0.074	-0.149	-0.299	-0.505	-0.325	-0.319
168	0.094	-0.001	-0.057	0.023	0.015	-0.043	-0.159	-0.215	-0.098	-0.129	-0.237	-0.359	-0.506	-0.319	-0.355

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	0.881	0.905	0.916	0.894	0.899	0.853	0.873	0.903	0.865	0.874	0.813	0.831	0.877	0.851	0.843
72	0.729	0.766	0.779	0.748	0.756	0.681	0.714	0.758	0.700	0.713	0.605	0.652	0.716	0.646	0.655
120	0.561	0.582	0.607	0.553	0.576	0.507	0.515	0.570	0.493	0.521	0.438	0.435	0.507	0.428	0.452
168	0.375	0.389	0.416	0.363	0.386	0.322	0.334	0.372	0.291	0.330	0.250	0.270	0.301	0.222	0.261
Hou	Z500 anomaly -1.0 standard deviation					Z500 anomaly -1.5 standard deviation					Z500 anomaly -2.0 standard deviation				

r	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.895	0.905	0.911	0.904	0.904	0.877	0.887	0.884	0.885	0.883	0.855	0.869	0.855	0.866	0.861
72	0.730	0.724	0.734	0.738	0.731	0.682	0.676	0.666	0.699	0.681	0.638	0.633	0.596	0.654	0.630
120	0.530	0.506	0.518	0.533	0.522	0.466	0.438	0.421	0.482	0.452	0.402	0.364	0.320	0.427	0.378
168	0.343	0.317	0.318	0.348	0.332	0.271	0.236	0.214	0.296	0.254	0.207	0.155	0.117	0.238	0.179

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	0.769	0.781	0.793	0.772	0.778	0.730	0.720	0.753	0.719	0.730	0.682	0.663	0.690	0.642	0.669
72	0.577	0.599	0.625	0.595	0.599	0.510	0.504	0.568	0.516	0.524	0.436	0.419	0.490	0.414	0.440
120	0.408	0.427	0.455	0.419	0.427	0.326	0.326	0.396	0.330	0.345	0.229	0.241	0.326	0.229	0.256
168	0.257	0.265	0.288	0.258	0.267	0.182	0.187	0.235	0.177	0.195	0.094	0.119	0.175	0.093	0.120
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	0.808	0.741	0.751	0.757	0.764	0.790	0.624	0.654	0.670	0.685	0.807	0.443	0.455	0.521	0.556
72	0.660	0.575	0.606	0.615	0.614	0.657	0.472	0.520	0.537	0.547	0.727	0.336	0.344	0.412	0.455
120	0.516	0.404	0.437	0.458	0.454	0.539	0.338	0.376	0.404	0.414	0.664	0.254	0.260	0.338	0.379
168	0.385	0.271	0.280	0.322	0.314	0.446	0.235	0.255	0.295	0.308	0.614	0.192	0.202	0.285	0.323

5.2 Research performed in the field

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 physical processes of the Global NWP system will be upgraded.
(2) A new framework of a regional forecast model (ASUCA) will be incorporated into the Meso-scale NWP system, and the vertical resolution of the MSM will be enhanced.
(3) ASUCA and the physics library in the LFM will be upgraded to the latest versions.
(4) Assimilation of the satellite radiance data used in the Meso NWP system into the Local NWP system will be commenced. At the same time, a variational bias correction method will be incorporated into the Local NWP system.
(5) Satellite soil moisture data retrieved from GCOM-W/AMSR2 and Metop-A B/ASCAT will be assimilated into the Local NWP system.

(6) Advanced microwave radiometer data from Suomi-NPP/ATMS will be assimilated into the Global NWP system.
(7) Hyper-spectral IR sounder data from Suomi-NPP/CrIS will be assimilated into the Global NWP system.
(8) Clear-sky data from the humidity sounding channels (183 GHz) of DMSP-F17 18/SSMIS will be assimilated into the Global NWP system.
(9) The method of satellite GNSS RO data assimilation will be improved for the Global NWP system.
(10) One-week EPS and Typhoon EPS will be unified into Global EPS, and the number of vertical levels will be increased from 60 to 100. The local ensemble transform Kalman filter (LETKF) will be incorporated into Global EPS to produce initial perturbation values.
(11) The horizontal resolution of the Aeolian dust model will be enhanced from TL159 to TL479.
(12) In major updates to the Global Wave Model (GWM) and the Coastal Wave Model (CWM), shallow-water effects and modification of wind input will be implemented in the second quarter of 2017.
(13) A nudging technique will be incorporated to support assimilation of surface ozone observation data into the regional chemical transport model analysis field.
(14) One-month EPS will be replaced with an upgraded version of One-week EPS (Global EPS; see 6.1.1 (10)).
(15) A new framework for a data assimilation system (ASUCA-Var) will be incorporated into Hourly Analysis.

6.1.2 Major changes expected in the next four years

(1) The computer system for the GDPFS will be replaced in 2018.
(2) The physical processes of the Global NWP system will be upgraded.
(3) A SiB will be incorporated into the MSM.
(4) An urban canopy will be incorporated into the SiB of the MSM.
(5) A new framework for a data assimilation system (ASUCA-Var) will be incorporated into the Meso-scale NWP system.
(6) Correlation among satellite channels will be introduced in the Global NWP system.
(7) All-sky satellite microwave radiance data will be assimilated into the Global NWP system.
(8) The satellite data used in the Global NWP system (e.g., Suomi-NPP/ATMS, Suomi-NPP/CrIS, Metop-A, B/IASI, Aqua/AIRS) will be assimilated into the Meso-scale NWP system.
(9) More satellite data, including FY-3B/MWHS, FY-3C/MWHS2 and Suomi-NPP/VIIRS-AMV, will be assimilated into the Global, Meso and Local NWP systems.
(10) Meso-scale EPS will be put into operation.
(11) A data assimilation system with the local ensemble transform Kalman filter (LETKF) will be adopted in stratospheric ozone analysis.

(12) A two-dimensional variational (2D-Var) data assimilation system will be adopted in aerosol analysis.
(13) The horizontal resolution of the regional chemical transport model will be enhanced from 20 km to 5 km.
(14) The grid resolution of the Global Wave Model (GWM) will be enhanced from 55 to 25 km.
(15) A new wave model with a 1-minute grid resolution for coastal sea areas of Japan will be put into operation.
(16) The grid resolution of the Wave Ensemble System (WENS) will be enhanced from 140 to 55 km, and the model will run twice a day.
(17) A new coastal ocean analysis/forecasting system (MOVE/MRI.COM-JPN) with a high-resolution (2 km) forecast model covering the whole of the Japan coast and a 4D-Var assimilation system covering the North Pacific will be put into operation.

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 Himawari-8 highly-frequent multiband data to improve Thunder Nowcasts (see 4.4.1.1) in 2017.

6.2.3 Planned Research Activities in Long-range Forecasting

6.2.4 Planned Research Activities in Specialized Numerical Predictions

(1) Time-of-arrival products for nuclear environmental emergency response
In line with a development plan set by the CBS expert team on Emergency Response Activities (ET-ERA), JMA is currently researching time-of-arrival products. These exhibited the highest demand in a 2016 Regional Association II (Asia) user request survey.
(2) 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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