JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2014

Japan Meteorological Agency

1. Summary of highlights

(1) The Global Numerical Weather Prediction (NWP) system was upgraded in March 2014. The number of vertical levels was increased from 60 to 100, and the pressure of the top level was raised from 0.1 to 0.01 hPa (see 4.2.2.2 (1)). The parameterization schemes of the Global Spectral Model (GSM), including those for the boundary layer, radiation, non-orographic gravity waves and deep convection, were also improved (see 4.2.2.2 (2)). The upgrade incorporated improvements in data assimilation considerations such as the bending angle of the Global Navigation Satellite System (GNSS) Radio Occultation (RO) (incorporating high-altitude data up to 0.1 hPa) (see 4.2.1.2 (1)), Advanced Microwave Sounding Unit-A (AMSU-A) 14 ch radiance data (with a sensitivity peak near 2 hPa) (see 4.2.1.2 (2)), and zenith total delay data from the ground-based GNSS (see 4.2.1.2 (3)).

(2) Clear sky radiance data from hyper-spectral infrared sounding conducted via the Aqua/Atmospheric Infrared Sounder (AIRS) and the Meteorological Operational Satellite (Metop)/Infrared Atmospheric Sounding Interferometer (IASI) were introduced into the Global NWP system in September 2014 (see 4.2.1.2 (4)).

(3) Typhoon bogussing in the Global and Meso-scale NWP systems was improved in May and September 2014 (see 4.2.1.2 (5) and 4.3.1.2 (1)).

(4) The off-line simple biosphere model (SiB) was introduced for land surface analysis of the Meso-scale NWP system in November 2014.

(5) The horizontal resolution of the One-week Ensemble Prediction System (EPS) was enhanced from TL319 to TL479 in February 2014. Its update frequency was also increased from once a day to twice a day, and its ensemble size was approximately halved from 51 to 27, making the total ensemble size 54/day as opposed to 51/day (see 4.2.5.1).

(6) High-resolution Precipitation Nowcasts providing short-range prediction of precipitation with a spatial resolution of 250 m were introduced in August 2014 (see 4.4.1.1 (1)).

(7) The horizontal resolution of the Typhoon EPS was enhanced from TL319 to TL479 in March 2014. Its ensemble size was also increased from 11 to 25 (see 4.5.2.1 (1)).

(8) The horizontal resolution of the UV-index prediction model was enhanced from T42 to T106 in October 2014 (see 4.5.2.1 (9)).

(9) The horizontal resolution of the One-month EPS was enhanced from TL159 to TL319 in March 2014 (see 4.6.1.1).

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	164,000/day
BUOY	33,000/day
TEMP-A/PILOT-A	1,600/day
TEMP-B/PILOT-B	1,600/day
TEMP-C/PILOT-C	1,200/day
TEMP-D/PILOT-D	1,100/day
AIREP/AMDAR	833,000/day
PROFILER	6,500/day

AMSR2	12,000,000/day
AIRS/AMSU	280,000/day
NOAA/AMSU-A	850,000/day
Metop/AMSU-A	570,000/day
NOAA/AMSU-B	510,000/day
NOAA/MHS	5,100,000/day
Metop/MHS	5,100,000/day
Metop/ASCAT	5,100,000/day
GOES/CSR	1,120,000/day
MTSAT/CSR	120,000/day
METEOSAT/CSR	1,090,000/day
GPSRO	280,000/day
AMV	5,000,000/day
SSMIS	16,900,000/day
GNSS-PWV	710,000/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	00, 01,	0035 – 0100, 0135 – 0200,	9

Analysis/Forecast	02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23	0235 – 0300, 0335 – 0400, 0435 – 0500, 0535 – 0600, 0635 – 0700, 0735 – 0800, 0835 – 0900, 0935 – 1000, 1035 – 1100, 1135 – 1200, 1235 – 1300, 1335 – 1400, 1435 – 1500, 1535 – 1600, 1635 – 1700, 1735 – 1800, 1835 – 1900, 1935 – 2000, 2035 – 2100, 2135 – 2200, 2235 – 2300, 2335 – 2400	
Typhoon Ensemble Forecast	00 06 12 18	0305 – 0350 0905 – 0950 1505 – 1550 2105 – 2150	132 132 132 132
Ocean Wave Forecast	00 06 12 18	0330 – 0350 0930 – 0950 1530 – 1550, 1840–1850 2130 – 2150	84 84 264 84
Storm Surge Forecast	00 03 06 09 12 15 18 21	0200 – 0225 0505 – 0525 0800 – 0825 1105 – 1125 1400 – 1425 1705 – 1725 2000 – 2025 2305 – 2325	39 39 39 39 39 39 39 39
One-week Ensemble Forecast	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	2205 – 2315 (every 5 days)	(7 months)

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

4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation

(1) Global Analysis (GA)

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

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

The specifications of the atmospheric analysis schemes are listed in Table 4.2.1-1.
In March 2014, the number of vertical levels was increased from 60 to 100 and the pressure of the top level was raised from 0.1 to 0.01 hPa.

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

Table 4.2.1-1 Specifications of the GA

Analysis scheme	Incremental 4D-Var
Data cut-off time	2 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 2014)	SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, AMDAR; atmospheric motion vectors (AMVs) from MTSAT-2, 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-F16, 17, 18/SSMIS, TRMM/TMI, GCOM-W/AMSR2 Aqua/AIRS, Metop-A,B/IASI; clear sky radiances from the water vapor channels (WV-CSRs) of MTSAT-2, GOES-13, 15, Meteosat-7, 10; GNSS RO bending angle data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A/blackjack, TerraSAR-X/IGOR, zenith total delay data from ground-based GNSS
Assimilation window	6 hours

Table 4.2.1-2 Specifications of snow depth analysis

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

(2) Typhoon bogussing in the GA

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

4.2.1.2 Research performed in the field

(1) Assimilation of GNSS RO data bending angle profiles into the Global NWP system

JMA began assimilating Global Navigation Satellite System (GNSS) Radio Occultation (RO) refractivity data into the Global NWP system in March 2007. However, refractivity profiles were not assimilated at levels higher than 30 km, due to the well-documented degradation of retrieval precision above this height. To avoid such height limitations, the assimilation of bending angle data to replace refractivity data was started on 18 March 2014. In the new configuration, bending angle profiles above 30 km are not excluded, and vertical data thinning is removed. A one-dimensional observation operator provided as part of the Radio Occultation Processing Package (ROPP; developed by the Radio Occultation Meteorology Satellite Application Facility (ROM-SAF)) was introduced along with the start of bending angle data assimilation. Observing system experiments involving the use of the Global NWP system showed that the first-guess near 5 hPa was improved by the assimilation of bending angle profiles above 30 km. (H. Owada)

(2) Assimilation of AMSU-A channel 14 data into the Global NWP system

The assimilation of AMSU-A channel 14 data into the Global NWP system began on 18 March 2014 when the system’s top-level pressure was raised from 0.1 to 0.01 hPa (see 4.2.2.2 (1)). The AMSU-A channel 14 has a sensitivity peak near 2 hPa. Normal distribution for the first-guess (FG) departure of AMSU-A channel 14 radiance data after scan bias correction was verified. (T. Egawa)

(3) Assimilation of ground-based GNSS zenith total delay data into the Global NWP system

JMA began assimilation of ground-based GNSS zenith total delay data into the Global NWP system on 18 March 2014. Recently, more ground-based GNSS data have been made available on the Global Telecommunication System (GTS). The stations are distributed globally, though the majority are located in Europe and the U.S. Observing system experiments involving ground-based GNSS zenith total delay data using the Global NWP system showed that dry bias in the initial fields was improved and specific humidity fields at 850 hPa were improved for the forecast range of 24 hours. Other variables of initial fields, including temperature at 850 hPa, were neutral. (K. Yoshimoto)

(4) Assimilation of Metop/IASI and Aqua/AIRS radiance data into the Global NWP system

Observation data from the Infrared Atmospheric Sounding Interferometer (IASI) and the Atmospheric Infrared Sounder (AIRS) have been operationally assimilated into the Global NWP system since 4 September 2014. JMA utilizes the IASI dataset (consisting of 616 channels spatially thinned to one pixel from four for each scan position) and the AIRS dataset (consisting of 324 channels spatially thinned to one from nine for each scan position). Long-wave temperature sounding channels (around 15 μm) were selected as assimilation targets for accuracy improvement in the analysis temperature field. There are 69 selected channels for IASI and 76 for AIRS. For AIRS, 9 channels around 4.4 μm are added at nighttime. Cloud-contaminated observations are excluded to avoid the complexity of having to consider the effects of cloud in data assimilation. A pre-operational experiment revealed that the root mean square (RMS) of the first-guess departure for AMSU-A and MHS was reduced by the introduction of IASI and AIRS, indicating accuracy improvement for temperature fields in analysis and the first guess. Errors also exhibit a statistically significant reduction in short-range forecasting. (A. Okagaki)

(5) Modification of typhoon bogus generation method

One of the parameters used for modification of the typhoon bogus generation method was adjusted in September 2014, as it had not previously been updated in line with the improvement of the inner model’s resolution in 2011. Typhoons with too steep a pressure gradient around their center often cannot be represented using the inner model in the same way as observed because the structure around the center is too small for the model’s horizontal grid spacing. Accordingly, central pressure is modified depending on the resolution of the inner model in the typhoon bogus generation process so that the pressure gradient around the typhoon center does not become overly steep. The adjusted parameter is used in this modification process. As a result of the adjustment, typhoons with a steep pressure gradient around their center can be analyzed more appropriately. It was also found that computational stability in the minimization process of variational data assimilation was occasionally reduced by assimilating typhoon bogus data whose departure from the first guess was extremely large. For this reason, gross error checking for typhoon bogus data was introduced to enable the elimination of such extreme data. The observing system experiment was performed in the summer of 2014. Both typhoon positional error and intensity error were reduced for typhoons with steep-pressure gradients. (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 (GSM1403; 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).

In March 2014, the number of vertical levels was increased from 60 to 100 and the pressure of the top level was raised from 0.1 to 0.01 hPa. The parameterization schemes, such as those for the boundary layer, radiation, non-orographic gravity waves and deep convection, were also improved.

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

Basic equations	Primitive equations
Independent variables	Latitude, longitude, sigma-pressure hybrid coordinates, time
Dependent variables	Surface pressure, winds (zonal, meridional), temperature, specific humidity, cloud water content
Numerical techniques	Spectral (spherical harmonic basis functions) in horizontal, finite differences in vertical Two-time-level, semi-Lagrangian, semi-implicit time integration scheme Hydrostatic approximation
Integration domain	Global in horizontal, surface to 0.01 hPa in vertical
Horizontal resolution	Spectral triangular 959 (TL959), reduced Gaussian grid system, roughly equivalent to 0.1875˚ × 0.1875˚ in latitude and longitude
Vertical resolution	100 unevenly spaced hybrid levels
Time step	400 seconds
Orography	GTOPO30 dataset, spectrally truncated and smoothed
Gravity wave drag	Longwave orographic drag scheme (wavelengths > 100 km) mainly for stratosphere Shortwave orographic drag scheme (wavelengths approximately 10 km) only for troposphere Non-orographic spectral gravity wave forcing scheme
Horizontal diffusion	Linear, fourth-order
Vertical diffusion	Stability (Richardson number) dependent, local formulation
Planetary boundary layer	Mellor and Yamada level-2 turbulence closure scheme Similarity theory in bulk formulae for surface layer
Treatment of sea surface	Climatological sea surface temperature with daily analyzed anomaly Climatological sea ice concentration with daily analyzed anomaly
Land surface and soil	Simple Biosphere (SiB) model
Radiation	Two-stream with delta-Eddington approximation for shortwave

	(hourly) Two-stream absorption approximation method for longwave (hourly)
Convection	Prognostic Arakawa-Schubert cumulus parameterization
Cloud	PDF-based cloud parameterization

4.2.2.2 Research performed in the field

(1) Upgrade of the GSM

In March 2014, JMA began operation of the upgraded GSM with more vertical levels and a higher top level. The number of vertical layers was increased from 60 to 100, and the pressure of the top level was raised from 0.1 to 0.01 hPa. In particular, more layers were applied mainly in the upper troposphere and the lower stratosphere to improve forecast accuracy for the troposphere and stratosphere, respectively. The main purposes of raising the model top were to allow the assimilation of more satellite observations with sensitivity for the middle atmosphere and to reduce the effect of pseudo-reflection from the model top in the stratosphere. (H. Yonehara)

(2) Revision of physical processes

In March 2014, the parameterization schemes, including those of the boundary layer, radiation, non-orographic gravity waves and deep convection, were revised to improve the representation of atmospheric characteristics. The GSM improvements reduced mean errors (ME) and root mean square errors (RMSE) against analysis for 11-day forecasting of geopotential height for most pressure levels and all forecast times. Overall improvement was also seen in forecasts of other elements such as global mean sea level pressure and 850/250-hPa vector winds in the extratropics. The GSM upgrade reduced tropical cyclone track forecast errors in most sea areas of the world. (H. Yonehara)

4.2.3 Operationally available NWP products

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Model	One-week EPS	Ocean Wave Model
Destination	GISC	GISC
Area and resolution	Whole globe, 2.5° × 2.5°	75°S – 75°N, 0°E – 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
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 major system upgrade in February 2014 included enhancement of the horizontal resolution of the EPS model and revision of its physical processes. It also involved an increase in the frequency of operation from once a day to twice a day and an approximate halving of each ensemble size from 51 to 27. Accordingly, the total ensemble size is now 54/day as opposed to 51/day.

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 Specifications of the One-week EPS

<table>
<tr><td rowspan="4">Integration</td><td>Start of operation</td><td colspan="3">March 2001</td></tr>
<tr><td>Ensemble size</td><td colspan="3">27</td></tr>
<tr><td>Initial time</td><td colspan="3">00 and 12 UTC</td></tr>
<tr><td>Forecast range</td><td colspan="3">11 days</td></tr>
<tr><td rowspan="4">EPS model</td><td>Model type</td><td colspan="3">GSM1304</td></tr>
<tr><td>Horizontal resolution</td><td colspan="3">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="3">60 levels (0.1 hPa)</td></tr>
<tr><td>Model ensemble method</td><td colspan="3">Stochastic physics scheme</td></tr>
<tr><td rowspan="7">Initial perturbation (Initial ensemble generator | Singular vector method)</td><td>Inner-model resolution</td><td colspan="3">Spectral triangular truncation 63 (T63), 40 levels</td></tr>
<tr><td>Norm</td><td colspan="3">Moist total energy</td></tr>
<tr><td>Targeted area</td><td>Northern Hemisphere (30°N – 90°N)</td><td>Southern Hemisphere (90°S – 30°S)</td><td>Tropics (30°S – 30°N)</td></tr>
<tr><td>Physical process</td><td colspan="2">*Simplified physics</td><td>**Full physics</td></tr>
<tr><td>Optimization time</td><td colspan="2">48 hours</td><td>24 hours</td></tr>
<tr><td>Evolved SV</td><td colspan="3">Used</td></tr>
<tr><td>Number of SVs</td><td colspan="3">25</td></tr>
</table>

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

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

4.2.5.2 Research performed in the field

(1) Improvement of One-week EPS

JMA plans to improve the One-week EPS (WEPS) in 2016. The work will include an increase in the number of forecast model vertical layers from 60 to 100 (and in the pressure of the top level from 0.1 to 0.01 hPa) and revision of its physical processes, including those of the boundary layer, radiation, non-orographic gravity waves and deep convection. As a result, the dynamical framework and physical processes involved will be identical to those of the current GSM (see 4.2.2.1 (1)) except for horizontal resolution. The results of an experiment conducted for the periods of September 2013 and February 2014 showed that the WEPS improvement reduced ME and RMSE values against analysis for 11-day forecasting of geopotential height in the ensemble mean forecast for the Northern Hemisphere extra tropics with most pressure levels and all forecast times. (K. Ochi and M. Kyouda)

4.2.5.3 Operationally available EPS products

See 4.2.3.

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

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

(1) Meso-scale Analysis (MA)

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

Table 4.3.1-1 Specifications of the MA

4D-Var formulation	Incremental 4D-Var using a nonlinear forward model in the inner step with low resolution
Data cut-off time	50 minutes for analysis at 00, 03, 06, 09, 12, 15, 18 and 21 UTC
Observation (as of 31 December 2014)	SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR; AMVs from MTSAT-2; radiances from NOAA-15, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP/SSMIS-F16, 17, 18, TRMM/TMI, GCOM-W/AMSR2; WV-CSR of MTSAT-2; radar-raingauge analyzed precipitation; precipitation retrievals from TRMM/TMI, DMSP-F16, 17, 18/SSMIS, GCOM-W/AMSR2; Total Precipitable Water Vapor from ground-based GNSS
First guess	3-hour forecast produced by the MSM
Domain configuration	(Outer step) Lambert projection; 5 km at 60°N and 30°N, 817 × 661 Grid point (1, 1) is at the northwest corner of the domain. Grid point (565, 445) is at 140°E, 30°N. (Inner step) Lambert projection; 15 km at 60°N and 30°N, 273 × 221 Grid point (1, 1) is at the northwest corner of the domain. Grid point (189, 149) is at 140°E, 30°N.
Vertical levels	(Outer step) 50 levels up to 22 km (consistent with the forecast model setting) (Inner step) 40 levels up to 22 km
Analysis variables	Wind, potential temperature, surface pressure and pseudo-relative humidity
Assimilation window	3 hours

(2) Typhoon bogussing of the MA

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

(3) Local Analysis (LA)

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

Table 4.3.1-2 Specifications of the LA

Analysis cycle	The three-hour analysis cycle repeats hourly assimilation with 3D-Var and one-hour forecasts.
Data cut-off time	30 minutes for analysis at 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23 UTC
Observation (as of 31 December 2014)	SYNOP, SHIP, BUOY, AMeDAS, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR and Total Precipitable Water Vapor from ground-based GNSS
First guess	Initial fields produced by the latest MSM
Domain configuration	Lambert projection; 5 km at 60°N and 30°N, 633 × 521 Grid point (1, 1) is at the northwest corner of the domain. Grid point (449, 361) is at 140°E, 30°N
Vertical levels	50 levels up to 22 km
Analysis variables	Wind, potential temperature, surface pressure, pseudo-relative humidity and ground potential temperature

4.3.1.2 Research performed in the field

(1) Introduction of gross-error checking for typhoon bogus data in the MA

It was found that computational stability in the minimization process of variational data assimilation was occasionally reduced by assimilating typhoon bogus data whose departure from the first guess was extremely large. Accordingly, gross error checking for typhoon bogus data to eliminate such extremes was introduced on 22 May 2014. (Y. Kosaka)

4.3.2 Model

4.3.2.1 In operation

(1) Meso-Scale Model (MSM)

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

Table 4.3.2-1 Specifications of the MSM

Basic equations	Fully compressible non-hydrostatic equations
Independent variables	Latitude, longitude, terrain-following height coordinates, time
Dependent variables	Momentum components in three dimensions, potential temperature, pressure, mixing ratios of water vapor, cloud water, cloud ice, rain, snow and graupel, number concentration of cloud ice
Numerical techniques	Finite discretization on Arakawa-C-type staggered coordinates, horizontally explicit and vertically implicit time integration scheme, fourth-order horizontal finite differencing in flux form with modified advection treatment for monotonicity
Projection and grid size	Lambert projection, 5 km at 60°N and 30°N
Integration domain	Japan, 817 × 661 grid points
Vertical levels	50 (surface to 21. 8 km)
Forecast times	39 hours from 00, 03, 06, 09, 12, 15, 18 and 21 UTC
Initial fields	4D-Var analysis with mixing ratios of cloud water, cloud ice, rain, snow and graupel derived from preceding forecasts considering consistency with the analysis field of relative humidity The MSM runs three hours before the initial time for spin-up.
Lateral boundary	00–45 hour forecasts by the GSM initialized at 00/06/12/18 UTC for (03, 06)/(09, 12)/(15, 18)/(21, 00) UTC forecasts
Orography	Mean orography smoothed to eliminate shortest-wave components
Horizontal diffusion	Linear, fourth-order Laplacian + nonlinear damper Targeted moisture diffusion applied to grid points where excessive updrafts appear
Convection	Kain-Fritsch convection scheme
Cloud	Three-ice bulk cloud microphysics Lagrangian treatment for rain and graupel precipitation
Radiation (short wave)	Two-stream with delta-Eddington approximation (every 15 minutes)
Radiation (long wave)	Table look-up and k-distribution methods (every 15 minutes)
Cloudiness	Cloud water and cloud cover diagnosed using a partial condensation scheme
Gravity wave drag	No parameterization scheme included
PBL	Improved Mellor-Yamada Level 3 scheme Similarity theory adopted for surface boundary layer
Land surface	Ground temperature predicted using a four-layer ground

	model Evaporability predicted initialized by climatological values depending on location and season
Surface state	Observed SST (fixed during time integration) and sea-ice distribution Climatological values of evaporability, roughness length and albedo Snow cover over Japan analyzed daily

(2) Local Forecast Model (LFM)

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

Table 4.3.2-2 Specifications of the LFM

Basic equations	Fully compressible non-hydrostatic equations
Independent variables	Latitude, longitude, terrain-following height coordinates, time
Dependent variables	Momentum components in three dimensions, potential temperature, pressure, mixing ratios of water vapor, cloud water, cloud ice, rain, snow and graupel
Numerical techniques	Finite discretization on Arakawa-C-type staggered coordinates, horizontally explicit and vertically implicit time integration scheme, fourth-order horizontal finite differencing in flux form with modified advection treatment for monotonicity
Projection and grid size	Lambert projection, 2 km at 60°N and 30°N
Integration domain	Japan, 1531 × 1301 grid points
Vertical levels	60 (surface to 20. 2 km)
Forecast times	9 hours from 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23 UTC
Initial fields	The LA produces initial conditions through the three-hour analysis cycle based on hourly assimilation with 3D-Var and one-hour forecasts.
Lateral boundary	00–13 hour forecasts produced by the latest MSM
Orography	Mean orography smoothed to eliminate shortest-wave components
Horizontal diffusion	Linear, fourth-order Laplacian + nonlinear damper Targeted moisture diffusion applied to grid points where excessive updrafts appear
Convection	No parameterization scheme included
Cloud	Three-ice bulk cloud microphysics Lagrangian treatment for rain and graupel precipitation
Radiation (short wave)	Two-stream with delta-Eddington approximation (every 15

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

4.3.2.2 Research performed in the field

4.3.3 Operationally available NWP products

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

(1) Forecast guidance

Forecast guidance is utilized to issue warnings, advisories, information and weather forecasts. Five operational techniques are routinely used to determine guidance from NWP model output: Kalman Filter, artificial neural network, multiple linear regression, logistic regression, and diagnostic methods. These techniques are applied to grid-point values from the GSM and the MSM in order to reduce systematic errors in NWP models and extract useful information such as probabilities and categorical/diagnostic values.

The Kalman filter technique is used to determine precipitation probability, average precipitation amounts, maximum/minimum temperatures, time-series temperature, maximum wind speed/direction, gust speed/direction, time-series wind speed/direction, average and minimum visibility, and probability of minimum visibility values being less than 5,000 or 1,600 meters. Maximum wind speed/direction and time-series wind speed/direction guidance were updated in June 2013, and maximum/minimum temperature guidance and time-series temperature guidance were improved in March 2014.

The artificial neural network technique is used to determine sunshine durations, minimum humidity, cloud amounts, cloud base heights, point-type snowfall depths, and maximum 1- and 3-hour cumulative precipitation. Maximum 1- and 3-hour cumulative precipitation guidance is determined by multiplying average precipitation guidance for each grid square by an optimum ratio determined using the artificial neural network. Point-type snowfall depth guidance was improved in November 2013.

The multiple linear regression technique is used to determine maximum 24-hour cumulative precipitation, for which guidance is determined from average 24-hour cumulative precipitation guidance. The artificial neural network technique was previously used to derive maximum 24-hour cumulative precipitation guidance as well as 1- and 3-hour cumulative precipitation guidance, but this approach occasionally resulted in overestimation. To reduce unnaturally large precipitation amounts, the multiple linear regression technique was adopted in March 2013.

The logistic regression technique is used to determine thunderstorm probability, particular cloud base heights and gusting, and is also applied for turbulence indexing. Guidance for thunderstorm probability involves use of the Lagged Average Forecast (LAF) method for improved reliability. The turbulence index called TBindex (Kudo 2011) is formulated from a number of other indices used to comprehensively predict various kinds of turbulence, and was upgraded in August 2014.

The diagnostic method is used to determine grid-type maximum snowfall depths, weather categories and visibility distribution guidance, the latter of which supports the determination of visibility values based on the use of extinction coefficients for raindrops, snowfall, cloud water and humidity. The diagnostic method is also applied to the CB cloud amount, the CB top height and the aircraft icing index for area forecasts. The CB cloud amount and top height are determined via the deep convection discrimination technique used in the Kain-Fritsch convective scheme, in which the cloud top and base heights are estimated from the surrounding temperature, humidity and updraft conditions. The icing index is formulated by multiplying a distribution function of icing for temperature with one for dew-point depression based on the results of statistical research performed for the area around Japan.

(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 4.3.4-1.

Table 4.3.4-1 Specifications of the Hourly Analysis

Analysis scheme	3D-Var
Data cut-off time	20 minutes
First guess	2, 3 or 4-hour forecast by the MSM
Domain configuration	Lambert projection, 5 km at 60°N and 30°N, 721 × 577 grid points Grid point (1, 1) is at the northwestern corner of the domain. Grid point (489, 409) is at 140°E, 30°N.
Vertical levels	50 forecast model levels
Analysis variables	Wind, temperature, surface wind and surface temperature
Observation (as of 31 December, 2014)	AMeDAS, Wind Profiler, Weather Doppler radar (radial velocity), AIREP, AMDAR, and AMVs from MTSAT-2
Post-processing	Surface filtering (followed by adjustment of the increment within the PBL)

4.3.4.2 Research performed in the field

(1) Forecast guidance

Maximum wind speed/direction guidance and maximum snowfall amount guidance for one-week forecasts have been developed. The Kalman filter and diagnostic methods are used to determine maximum wind and snowfall amounts, respectively, for each One-week EPS ensemble member.

Guidance for thunderstorm probability will be improved in 2015. To enhance forecast accuracy, some predictors have been changed and all coefficients of logistic regression have been recalculated over recent periods.

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 include prediction of 5-minute cumulative precipitation/5-minute-interval precipitation intensity and error range estimation up to an hour ahead. Initial precipitation intensity distribution is determined via three-dimensional analysis of storms using radar echo intensity, Doppler velocity and upper-air observation data. Precipitation intensity is calibrated using raingauge observation data, and precipitation distribution is predicted based on calculation using methods such as kinetic and dynamic estimation. Generation of convective clouds triggered by convergence is also considered. 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 Specifications of the High-resolution Precipitation Nowcast model

Forecast process	• Kinetic: non-linear motion/intensity extrapolation • Dynamic: vertically one-dimensional convective model enabling calculationrelating to raindrop generation, precipitation and evaporation
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 － 30 minutes ahead 1km over land and coasts 35 － 60 minutes ahead 1km from the coasts 00 － 60 minutes ahead
Number of grids	16,660,800
Initial	Analyzed precipitation distribution determined from radar, raingauge and upper-air observation
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 Specifications of the Precipitation Nowcast model

Forecast process	Non-Linear motion/intensity extrapolation including the generation and lifecycle estimation of storm cells as well as orographic rainfall trend prediction
Movement vector	Precipitation system and/or cell motion estimated using the cross-correlation pattern matching and discrete interpolation
Time step	5 minutes
Grid form	Cylindrical equidistant projection
Resolution	Approx. 1 km
Number of grids	2,560 × 3,360
Initial	Calibrated radar echo intensities
Forecast time	60 minutes ahead, updated every 5 minutes

(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 Specifications of Thunder Nowcast model

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

(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

Forecast process	Extrapolation
Movement vector	As per the Precipitation Nowcast system
Grid form	Cylindrical equidistant projection
Resolution	Approx. 10 km
Number of grids	256 × 336
Initial	2-level presumed hazardous wind probabilities
Forecast time	60 minutes ahead, updated every 10 minutes

4.4.1.2 Research performed in the field

(1) Development of High-Resolution Precipitation Nowcasts

- A new nowcasting product called High-resolution Precipitation Nowcasts was introduced in August 2014 (see 4.4.1.1 (1)).

(2) Employment of finer-resolution Doppler velocity data for Hazardous Wind Potential Nowcasts

- The resolution of Doppler velocity data from radars used for Hazardous Wind Potential Nowcasts to detect meso cyclones was enhanced from 500 to 250 m in November 2014. The statistical model used to estimate hazardous wind potential was also revised utilizing the latest observation data.

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

4.4.2.1 In operation

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

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

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

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

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

Table 4.4.2-1 Specifications of extrapolation model

Forecast process	Extrapolation
Physical process	Enhancement and dissipation
Movement vector	Precipitation system movement evaluated using the cross-correlation method
Time step	2 – 5 minutes
Grid form	Oblique conformal secant conical projection
Resolution	1 km
Number of grids	1,600 × 3,600
Initial	Calibrated radar echo intensities

Forecast time	Up to six hours from each initial time (every 30 minutes = 48 times/day)

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

4.4.2.2 Research performed in the field

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

- Delayed analysis for archive data creation has been conducted since January 2014. This approach involves the use of more observation data than real-time analysis.

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

- Several improvements were introduced in May 2014, including:
  - Derivation of mid-term movement vectors based on a large-scale precipitation system
  - Estimation of storm cell life cycles from trends of precipitation intensity calculated using numerical weather prediction models

4.5 Specialized numerical 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

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

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

Basic equations	Primitive equations with free surface
Independent variables	Lat-lon coordinates and σ-z hybrid vertical coordinates
Dependent variables	u, v, T, S, SSH
Numerical technique	Finite difference both in the horizontal and in the vertical
Grid size	1˚ (longitude) × 1˚ (latitude, smoothly decreasing to 0.3˚ toward the equator) grids
Vertical levels	50 levels
Integration domain	Global oceans from 75°N to 75°S
Forcing data	Heat, water and momentum fluxes are calculated using data from

	the JMA Climate Data Assimilation System (JCDAS).
Observational data	Sea-surface and subsurface temperature and salinity and sea surface height
Operational runs	Two kinds of run (final and early) with cut-off times of 33 days and 2 day, respectively, for ocean observation data

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

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

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. A major system upgrade in March 2014 included enhancement of the horizontal resolution of the EPS model, revision of its physical processes and an increased ensemble size. The current 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 the 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 Specifications of the Typhoon EPS

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

(2) Environmental emergency response system

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

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

As part of the CTBTO-WMO Backtracking Response System, JMA is responsible for providing atmospheric backtracking products to the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) in its role as a Regional Specialized Meteorological Center. JMA developed an atmospheric backtracking transport model and built up a response system that receives e-mail notifications from CTBTO, executes backtracking calculations and provides the resulting products in line with the procedure defined in WMO no. 485. JMA began operation of the backtracking system in December 2009. Backtracking over a period up to 50 days can be provided on an operational basis. At the 2013 meeting of the Expert Team on Emergency Response Activities (ET-ERA), a representative from CTBTO asked RSMCs to adapt their operational system for a new type of request form and to adopt an SFTP file transfer protocol rather than using FTP. JMA had developed such a system by 11 June 2014.

(3) Ocean-wave forecasting models

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

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

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

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

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

Boundary conditions	-	Global Wave Model
Initial conditions	Hindcast	
Wind field	Global Spectral Model (GSM)	
	Bogus gradient winds (for typhoons in the western North Pacific)	

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

Model name	Shallow-water Wave Model		
Model type	Spectral model (third-generation wave model)		
Spectral components	1,260 (35 frequencies from 0.0418 to 1.1 Hz and 36 directions)		
Grid form	Equal latitude-longitude grid on spherical coordinates		
Grid resolution	1’ × 1’		
Areas	Domain name	Grid size	Integration domain
	Tokyo Bay	37 × 43	35.05°N – 35.75°N 139.55°E – 140.15°E
	Ise Bay	61 × 43	34.35°N – 35.05°N 136.45°E – 137.45°E
	Harima-Nada Osaka Bay	79 × 49	34.05°N – 34.85°N 134.15°E – 135.45°E
	Ariake Sea 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
Time step	Advection term: 1 minute Source term: 1 minute		
Forecast time	39 hours from 03, 09, 15 and 21 UTC		
Boundary conditions	Coastal Wave Model		
Initial conditions	Hindcast		
Wind field	Meso-Scale Model (MSM)		
	Bogus gradient winds (for typhoons in the western North Pacific)		

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

(4) Storm-surge model

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

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

Basic equations	Two-dimensional shallow-water equations
Numerical technique	Explicit finite difference method
Integration domain	Coastal areas of Japan (117.4°E – 150.0°E, 20.0°N – 50.0°N)
Grid size	Adaptive Mesh Refinement (AMR) method 45 seconds (longitude gradually doubling to 12 minutes toward offshore areas) × 30 seconds (latitude gradually doubling to 8 minutes toward offshore areas)
Boundary conditions	Modified radiation condition at open boundaries and zero normal flows at coastal boundaries
Forecast time	39 hours
Forcing data	Meso-Scale Model (MSM)
	Bogus data for TCs around Japan
Astronomical tides	Ocean tide model (Egbert and Erofeeva 2002) and data assimilation of harmonic constants at tide stations using the ensemble transform Kalman filter (ETKF)

JMA developed a storm surge model for the Asian region in 2010 in collaboration with Typhoon Committee Members providing tidal observation and sea bathymetry data. Since 1 June, 2011, horizontal maps of predicted storm surges have been published on JMA's Numerical Typhoon Prediction website. Since 5 June, 2012, time-series charts of predicted storm surges have been published. The storm surge model uses the GSM for meteorological forcing. In the case of TCs, storm surges are predicted up to 72 hours ahead using a simple parametric TC track (center) in addition to the GSM. The model's specifications are given in Table 4.5.2.1 (4)-2. JMA added 41 stations for time-series charts and total number became 51 stations in 2014.

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

Basic equations	Two-dimensional linear shallow-water equations
Numerical technique	Explicit finite difference method
Integration domain	Coastal areas of Asia (95.0°E – 160.0°E, 0.0°N – 46.0°N)
Grid size	2 minutes × 2 minutes
Boundary conditions	Modified radiation condition at open boundaries and zero normal flows at coastal boundaries

Forecast time	72 hours
Forcing data	Global Spectral Model (GSM)
	Bogus data for TCs (center)
Astronomical tides	Not included

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

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

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

Basic equations	Primitive equations with free surface
Independent variables	Lat-lon coordinates and σ-z hybrid vertical coordinates
Dependent variables	u, v, T, S, SSH
Numerical technique	Finite difference both in the horizontal and in the vertical with a three-dimensional variational (3D-Var) data assimilation system
Grid size	(1) Western North Pacific model 0.1° longitude × 0.1° latitude in the seas off Japan, decreasing to 0.166° toward the northern and eastern boundaries with the North Pacific model (2) North Pacific model 0.5° longitude × 0.5° latitude
Vertical levels	54
Integration domain	(1) Western North Pacific model From 15°N to 65°N between 115°E and 160°W (2) North Pacific model From 15°S to 65°N between 100°E and 75°W
Forcing data	Heat, water and momentum fluxes from the Japanese 55-year Reanalysis (JRA-55) and from the control run of One-month Ensemble Prediction System
Observational data	Sea-surface and subsurface temperature/salinity, sea surface height, sea ice concentration
Operational runs	10-day assimilation and 30-day prediction are implemented every day

(6) Sea-ice forecasting model

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

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

Dynamical processes	Viscous-plastic model (MMD/JMA 1993) –

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

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

(7) Marine pollution transport model

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

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

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

(8) Aeolian dust prediction model

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

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

Basic equations	Eulerian model coupled with the Global Spectral Model
Numerical technique	3D semi-Lagrangian transport and dust emission calculation from surface meteorology
Integration domain	Global
Grid size	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) Photochemical oxidant information advisory service

JMA has provided a photochemical oxidant information advisory service since August 2010. The information is produced by combining numerical prediction of photochemical oxidants in the troposphere/stratosphere and statistical guidance induced from model outputs associated with past events. The latter is produced based on verification of the model's output against observations to enable quantification of oxidant levels for operational forecasters.

Numerical prediction of photochemical oxidants is carried out using a global chemistry-climate model (MRI-CCM2). The specifications of the global chemistry model are given in Table 4.5.2.1 (10)-1. JMA plans to introduce a high-horizontal-resolution regional chemical transport model (NHM-Chem; Kajino et al. 2012) to improve the photochemical oxidant information advisory service in 2015. NHM-Chem is driven with meteorological fields predicted using JMA-NHM offline. The lateral boundary conditions of NHM-Chem are given by MRI-CCM2.

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

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

(11) Mesoscale air pollution transport model

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

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

JMA introduced the Volcanic Ash Fall Forecast (VAFF) based on the Regional Atmospheric Transport Model (RATM) in March 2008 (Shimbori et al. 2009). This is a 6-hour prediction of areas where ash is expected to fall as a result of volcanic eruptions in Japan, and is issued in principle when an ash plume reaches a height of 3,000 m above the crater rim or when the JMA Volcanic Alert Level is three or higher. The specifications of RATM, for which the outputs of the MSM are used, are given in Table 4.5.2.1 (12)-1. Quantitative forecasting of ash-fall depth has been developed and is currently under trial operation (see 4.5.2.2 (8)).

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

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

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

Since 1997, JMA has been providing information on volcanic ash clouds to airlines, civil aviation authorities and related organizations in its role as the Volcanic Ash Advisory Centre (VAAC) Tokyo. JMA introduced the Global Atmospheric Transport Model (GATM) in December 2013 as an 18-hour prediction of areas where ash clouds are expected in the 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 MTSAT-2*2 observation *1 24 hours on a trial basis (18 hours for regular operation) *2 Scheduled for replacement by Himawari-8 from MTSAT-2 on 7 July 2015
Initial condition	Location of volcanic ash particles based on the area and

	maximum altitude of volcanic ash cloud observed by satellite
Meteorological field	Global Spectral Model (GSM)
Processes	3D advection, (horizontal and vertical diffusion,) volcanic-ash fallout, dry deposition and washout

4.5.2.2 Research performed in the field

(1) Storm surge model

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

(2) Sea-ice forecasting model

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

(3) Aeolian dust prediction model

A data assimilation system with the local ensemble transform Kalman filter (LETKF) for aerosols using satellite sensors (Sekiyama et al. 2010; Yumimoto et al 2014) 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 the LETKF for stratospheric ozone has been developed (Sekiyama et al. 2011; Nakamura et al. 2013), and is scheduled to enter into operation in 2017.

(5) Regional chemical transport model

JMA plans to introduce a high-horizontal-resolution regional chemical transport model (NHM-Chem; Kajino et al. 2012) to improve the photochemical oxidant information advisory service in 2015. The Agency is currently evaluating its forecast guidance for the photochemical oxidant information advisory from the regional model.

(6) An ensemble forecast system for ocean waves

JMA has embarked on the development of an ensemble wave forecast system in response to demand for stochastic wave forecasts up to a week ahead. The Agency has run the system in quasi-operational mode since 29 May 2013 for the purposes of verification and further improvement, and plans to issue week-range wave forecasts in the second quarter of 2016.

(7) 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.

(8) Quantitative forecasting of volcanic ash-fall depth (VAFF)

As described in 4.5.2.1 (12), a VAFF update is scheduled for spring 2015 (Hasegawa et al., 2015). Thereafter, three types of VAFF will be sequentially provided: VAFFs (Scheduled) will be issued periodically based on an assumed eruption for active volcanoes, VAFFs (Preliminary) will be brief forecasts issued within 5 － 10 minutes of an actual eruption, and VAFFs (Detailed) will be more accurate forecasts issued within 20 － 30 minutes of an actual eruption. The updated VAFFs will provide information on expected ash/lapilli fall areas and/or amounts, using the RATM with the outputs of the LFM and MSM.

4.5.3 Specific products operationally available

(1) Numerical storm surge prediction products

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

(2) Aeolian dust products operationally available

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

(3) UV index products operationally available

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

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

4.6.1 Models

4.6.1.1 In operation

JMA operates One-month Ensemble Prediction System (One-month EPS) once a week and the current system was upgraded in March 2014. The numerical prediction model applied for this system is a low-resolution version (TL319) of the GSM (Table 4.6.1.1-1). 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 Specifications of the one-month EPS

Atmospheric model	GSM1304
Integration domain	Global, surface to 0.1 hPa
Horizontal resolution	TL319 (reduced Gaussian grid system, approx. 0.5625º Gaussian grid, 55 km)
Vertical levels	60 (surface to 0.1 hPa)
Forecast time	816 hours from 12 UTC
Ensemble size	50 members
Perturbation generator	Combination of breeding of growing mode (BGM) method and lagged averaged forecast (LAF) method
Perturbed area	Northern Hemisphere (20ºN – 90ºN) and tropics (20ºS – 20ºN)
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 Seasonal Ensemble Prediction System (Seasonal EPS) using an atmosphere-ocean coupled model (JMA/MRI-CGCM; Yasuda et al. 2007) for three-month, warm/cold season and El Niño outlooks. The 51-member ensemble is used for the three-month forecast issued every month and for the warm/cold season forecasts issued five times a year (in February, March, April, September and October). The El Niño outlook is also issued based on the same model results.
The JMA/MRI-CGCM was developed by the Meteorological Research Institute and the Climate Prediction Division of JMA. Its specifications are shown in Table 4.7.1-1. The model is initialized with atmospheric and oceanic analysis using the JMA Climate Data Assimilation System (JCDAS) and MOVE/MRI.COM-G, respectively. Land surface climatological conditions are used as the initial values for the CGCM, and a land surface model coupled to the AGCM is used for the prediction of land surface conditions. The climatological distribution of sea ice is used as the lower boundary condition. The EPS adopts a combination of the LAF method and the initial perturbation method described below. Nine-member ensemble predictions are made every five days, and atmospheric initial perturbations for each initial date are obtained using the BGM method. Oceanic initial perturbations are obtained with MOVE/MRI.COM-G (see 4.5.1.1 (1) for details) forced by the surface heat and momentum fluxes of atmospheric initial perturbation fields using the BGM method.

Table 4.7.1-1 Specifications of the seasonal EPS

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

4.7.2 Operationally available EPS LRF products

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

	Forecast time	Parameter
Ensemble mean, its anomaly and spread	Three-month forecast: Averages of first month, second month, third month, and three months Warm/cold season forecast: Averages of three months (JJA or DJF)	Geopotential height at 500 hPa, related anomaly and 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

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 2014 are presented in Tables 5.1.1-1 – 5.1.1-20. All verification scores are only for prediction from 1200 UTC initials.

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

Northern Hemisphere (20–90˚N)

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

24	8.0	7.7	7.1	6.7	6.2	6.3	6.0	5.7	6.1	6.4	6.9	7.3	6.7
72	24.9	25.0	23.5	21.7	20.3	19.2	18.3	16.9	19.9	21.4	23.9	25.1	21.7
120	47.6	49.8	46.4	44.2	42.9	38.1	36.4	32.3	39.8	44.9	48.9	50.2	43.5

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	7.5	7.8	8.0	7.9	8.4	8.6	8.9	9.3	8.7	7.9	7.4	7.3	8.1
72	25.4	26.3	26.8	28.3	29.5	29.1	31.7	31.7	30.1	27.1	23.6	23.4	27.8
120	47.4	51.0	54.3	56.1	62.6	59.4	61.4	61.7	58.5	54.9	47.0	46.2	55.0

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	13.1	12.1	12.6	11.0	11.3	10.8	10.2	10.9	11.8	11.7	12.0	11.7
72	32.1	26.9	24.9	23.4	19.9	19.6	16.9	15.2	18.8	23.2	26.4	27.7	22.9
120	57.3	54.8	45.9	44.8	36.0	35.2	30.6	28.7	32.4	44.2	53.1	55.2	43.2
ob. num.	92	92	93	93	93	93	92	93	93	94	93	92	92.8

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

Europe/North Africa

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	14.6	15.4	14.2	13.7	11.3	10.0	10.7	9.9	11.3	12.0	13.5	14.2	12.6
72	30.7	35.4	31.7	28.3	21.4	21.1	22.8	18.7	22.2	21.6	25.8	31.5	25.9
120	51.4	56.9	60.4	47.6	38.9	38.1	39.2	27.3	40.6	42.0	51.7	62.5	46.4
ob. num.	60	62	60	60	60	61	59	58	57	58	58	57	59.2

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	12.4	13.7	12.0	12.9	12.2	11.6	11.8	11.3	11.0	11.4	12.6	12.7	12.1
72	21.0	22.9	21.2	21.4	23.2	18.6	19.7	17.5	18.4	21.2	22.1	23.5	20.9
120	34.6	37.2	35.5	35.8	39.8	30.0	30.0	28.3	29.9	37.9	40.8	38.2	34.8
ob. num.	106	106	107	109	108	106	107	107	107	109	111	109	107.7

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

Australia/New Zealand

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	13.1	13.6	15.1	16.4	16.8	18.2	17.2	17.5	15.4	18.0	18.6	17.4	16.4
72	21.5	17.9	20.6	24.2	24.4	25.8	28.9	25.1	25.8	26.2	25.6	22.6	24.1
120	40.1	33.4	31.4	42.5	40.5	43.7	41.7	35.1	50.2	42.5	36.4	33.1	39.2
ob. num.	12	14	13	13	12	12	12	12	13	13	13	14	12.8

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	13.4	14.2	13.0	13.2	12.0	12.0	12.0	11.4	11.5	12.1	12.6	13.0	12.5
72	28.5	28.3	26.7	24.7	22.4	21.2	20.6	18.7	21.4	23.7	25.4	27.9	24.1
120	49.7	51.1	49.2	44.9	41.2	37.6	36.4	31.5	39.2	45.3	49.7	53.3	44.1
ob. num.	352	356	354	357	355	355	352	351	346	350	356	350	352.8

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

Southern Hemisphere (20–90˚S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	12.0	12.6	13.2	13.8	14.8	14.9	14.6	14.7	13.5	13.6	13.3	13.5	13.7
72	21.7	21.8	23.3	24.1	24.9	26.3	29.2	27.4	25.2	23.0	21.4	21.0	24.1
120	38.8	39.5	38.2	44.3	48.9	46.5	47.4	46.2	45.9	43.3	36.2	35.0	42.5
ob. num.	39	39	39	39	39	39	40	36	38	40	40	41	39.1

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	3.3	3.4	3.4	3.4	3.3	3.4	3.2	3.2	3.3	3.1	3.3
72	8.0	7.7	7.6	7.7	7.7	7.9	8.0	7.8	7.9	7.7	7.8	7.8	7.8
120	12.9	12.6	12.3	12.5	12.8	12.7	12.7	12.0	12.8	12.9	13.4	13.1	12.7

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	3.3	3.4	3.3	3.4	3.4	3.3	3.3	3.3	3.1	3.2	3.2	3.3
72	8.7	8.4	8.8	8.2	8.6	8.4	8.5	8.4	8.4	7.8	7.8	7.9	8.3
120	13.5	13.9	14.7	14.0	15.0	14.6	13.7	13.7	13.8	13.3	13.0	12.8	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	6.1	5.5	5.9	5.9	5.5	6.3	5.5	5.5	5.5	5.6	5.6	5.6	5.7
72	11.4	9.1	9.3	9.3	8.9	10.2	8.7	9.0	9.2	9.6	9.4	9.8	9.5
120	17.1	15.1	14.4	15.0	13.2	14.2	12.6	13.2	13.5	15.6	15.4	15.9	14.6
ob. num.	90	91	91	92	93	91	92	92	92	93	92	92	91.8

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	5.5	5.5	5.0	4.9	4.9	4.9	5.0	5.1	5.3	4.9	5.3	5.1	5.1
72	9.3	9.6	9.0	8.4	8.2	8.7	9.4	9.1	9.3	8.8	9.5	9.6	9.1
120	14.8	14.8	16.2	13.4	13.5	14.3	15.0	12.4	15.6	14.4	16.0	16.8	14.8
ob. num.	63	64	62	61	61	62	60	59	59	60	60	59	60.8

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	4.8	5.2	5.9	6.4	6.3	6.3	5.9	5.9	5.3	5.0	4.9	4.6	5.5
72	7.2	7.9	8.9	9.6	10.1	9.7	9.4	9.5	8.4	8.3	7.7	6.9	8.6

120	9.9	11.2	11.9	12.8	14.7	13.1	12.5	12.7	12.0	12.1	11.9	9.9	12.1
ob. num.	140	139	136	135	136	136	138	138	140	140	141	139	138.2

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	5.4	5.4	5.2	5.3	5.5	5.4	5.2	4.7	5.2	5.5	6.0	5.7	5.4
72	8.3	7.8	7.7	8.6	8.6	7.9	8.2	7.2	7.5	7.7	8.4	8.7	8.1
120	11.3	11.0	10.5	12.2	12.8	12.1	11.9	9.6	12.3	11.5	12.7	11.7	11.6
ob. num.	21	23	23	21	19	21	20	22	18	17	16	17	19.8

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

Northern Hemisphere (20–90˚N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	5.2	5.1	5.5	5.6	5.6	5.7	5.4	5.5	5.2	5.0	5.0	4.9	5.3
72	8.9	8.6	8.9	8.9	9.1	9.3	9.1	9.2	9.0	8.7	8.7	8.5	8.9
120	13.5	13.5	13.7	13.3	13.9	13.6	13.3	13.0	13.7	13.8	13.9	13.6	13.6
ob. num.	394	400	388	388	388	388	389	388	388	391	391	388	390.1

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	5.3	5.6	5.8	5.5	5.8	5.7	5.8	5.4	5.8	5.5	5.9	5.6	5.6
72	8.6	8.4	9.3	8.8	9.4	8.4	9.3	8.7	8.7	8.7	8.6	8.7	8.8
120	12.0	12.4	13.3	12.8	14.0	13.4	13.9	12.6	13.0	13.0	12.5	12.0	12.9
ob. num.	46	47	47	46	45	45	46	44	42	43	43	45	44.9

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

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	1.6	1.5	1.5	1.4	1.4	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4
72	2.9	2.8	2.6	2.5	2.4	2.5	2.7	2.6	2.7	2.5	2.5	2.5	2.6
120	3.7	3.5	3.4	3.1	3.0	3.2	3.4	3.4	3.6	3.2	3.2	3.2	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	3.4	3.3	3.2	3.1	2.9	3.0	3.2	3.1	3.1	2.9	3.0	3.2	3.1
72	6.4	6.1	5.8	5.7	5.2	5.4	5.6	5.7	5.6	5.5	5.6	5.8	5.7
120	8.3	7.9	7.6	7.4	6.9	7.1	7.0	7.1	7.2	7.0	7.2	7.6	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	3.7	3.5	3.4	3.3	3.1	3.4	3.5	3.4	3.4	3.4	3.3	3.6	3.4
72	4.3	4.1	4.0	3.7	3.5	3.9	4.0	3.8	4.1	3.9	3.8	4.1	3.9
120	4.8	4.5	4.4	4.2	3.8	4.2	4.6	4.3	4.7	4.4	4.2	4.4	4.4

ob. num.	62	65	70	70	70	70	70	69	67	69	70	68	68.3

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	5.4	5.2	4.9	4.8	4.7	4.7	5.1	4.8	4.9	4.6	4.5	5.0	4.9
72	7.2	6.8	6.5	6.5	6.2	6.4	6.8	7.3	6.8	6.2	6.1	6.8	6.6
120	8.4	8.0	7.7	7.6	7.4	7.7	8.1	8.6	8.1	7.6	7.4	8.2	7.9
ob. num.	63	66	71	72	72	72	73	71	68	70	71	70	69.9

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 2014 (December in 2013) 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	0.918	0.844	0.745	0.846	0.838	0.912	0.827	0.695	0.815	0.812	0.902	0.808	0.619	0.771	0.775
72	0.783	0.722	0.595	0.688	0.697	0.758	0.674	0.531	0.630	0.648	0.730	0.612	0.447	0.576	0.591
120	0.604	0.533	0.394	0.483	0.504	0.562	0.463	0.314	0.396	0.433	0.521	0.372	0.214	0.326	0.358
168	0.421	0.343	0.216	0.272	0.313	0.377	0.275	0.144	0.166	0.240	0.357	0.203	0.066	0.076	0.175
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	0.899	0.850	0.747	0.838	0.833	0.867	0.817	0.711	0.819	0.803	0.828	0.767	0.671	0.786	0.763
72	0.748	0.703	0.602	0.682	0.684	0.697	0.636	0.556	0.637	0.632	0.625	0.552	0.505	0.572	0.563
120	0.564	0.493	0.407	0.465	0.482	0.501	0.395	0.344	0.397	0.409	0.406	0.281	0.282	0.319	0.322
168	0.390	0.294	0.221	0.249	0.289	0.321	0.201	0.171	0.188	0.221	0.235	0.089	0.136	0.126	0.146

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	0.799	0.699	0.627	0.716	0.710	0.766	0.615	0.537	0.639	0.639	0.752	0.459	0.350	0.460	0.505
72	0.627	0.532	0.409	0.528	0.524	0.571	0.428	0.285	0.413	0.424	0.542	0.237	0.047	0.184	0.252
120	0.473	0.366	0.235	0.349	0.356	0.411	0.246	0.106	0.226	0.247	0.374	0.044	-0.148	-0.002	0.067
168	0.326	0.199	0.096	0.183	0.201	0.274	0.098	-0.025	0.076	0.106	0.246	-0.072	-0.263	-0.112	-0.050
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	0.818	0.650	0.459	0.645	0.643	0.780	0.475	0.169	0.482	0.477	0.728	0.138	-0.439	0.145	0.143

72	0.660	0.502	0.279	0.480	0.480	0.601	0.321	-0.005	0.308	0.306	0.521	-0.016	-0.611	-0.039	-0.036
120	0.502	0.339	0.129	0.310	0.320	0.436	0.163	-0.128	0.147	0.154	0.370	-0.163	-0.674	-0.186	-0.163
168	0.345	0.180	-0.002	0.133	0.164	0.264	0.020	-0.235	-0.013	0.009	0.194	-0.274	-0.733	-0.307	-0.280

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	0.739	0.570	0.454	0.506	0.567	0.631	0.407	0.286	0.341	0.416	0.567	0.104	-0.069	0.147	0.187
72	0.538	0.204	0.002	-0.042	0.175	0.441	-0.056	-0.464	-0.551	-0.158	0.387	-0.389	-1.436	-1.311	-0.687
120	0.385	0.036	-0.003	-0.119	0.075	0.303	-0.389	-0.347	-0.626	-0.265	0.231	-1.127	-0.970	-1.338	-0.801
168	0.207	0.023	0.001	-0.123	0.027	0.166	-0.240	-0.210	-0.603	-0.222	0.108	-0.538	-0.525	-1.281	-0.559
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	0.752	0.607	0.512	0.518	0.597	0.703	0.601	0.461	0.481	0.561	0.674	0.580	0.463	0.433	0.537
72	0.524	0.460	0.273	0.312	0.392	0.442	0.459	0.216	0.256	0.343	0.400	0.425	0.219	0.178	0.306
120	0.303	0.309	0.215	0.221	0.262	0.180	0.271	0.160	0.164	0.194	0.143	0.216	0.150	0.088	0.149
168	0.022	0.201	0.148	0.147	0.129	-0.197	0.170	0.090	0.076	0.035	-0.280	0.102	0.065	-0.004	-0.029

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	0.604	0.418	0.447	0.406	0.469	0.543	0.334	0.383	0.323	0.396	0.473	0.206	0.309	0.193	0.295
72	0.383	0.154	0.135	-0.047	0.156	0.320	-0.020	-0.007	-0.285	0.002	0.254	-0.213	-0.137	-0.526	-0.156
120	0.266	0.000	-0.012	-0.285	-0.008	0.198	-0.208	-0.200	-0.633	-0.211	0.147	-0.408	-0.363	-0.929	-0.388
168	0.190	-0.014	-0.056	-0.315	-0.049	0.128	-0.161	-0.208	-0.555	-0.199	0.095	-0.309	-0.352	-0.725	-0.323
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	0.619	0.380	0.372	0.339	0.428	0.590	0.251	0.229	0.174	0.311	0.559	0.061	-0.037	-0.119	0.116
72	0.369	0.226	0.202	0.185	0.245	0.334	0.094	0.077	0.066	0.143	0.304	-0.078	-0.135	-0.152	-0.015
120	0.264	0.139	0.130	0.101	0.158	0.229	0.000	0.025	0.006	0.065	0.203	-0.169	-0.155	-0.183	-0.076
168	0.188	0.069	0.076	0.051	0.096	0.151	-0.057	-0.017	-0.045	0.008	0.132	-0.218	-0.174	-0.229	-0.122

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	0.897	0.906	0.914	0.898	0.904	0.871	0.883	0.900	0.880	0.884	0.827	0.854	0.866	0.843	0.848
72	0.734	0.744	0.759	0.746	0.746	0.693	0.706	0.730	0.705	0.709	0.601	0.649	0.645	0.624	0.630
120	0.523	0.532	0.558	0.556	0.542	0.462	0.482	0.515	0.481	0.485	0.353	0.391	0.420	0.357	0.380
168	0.317	0.319	0.372	0.358	0.341	0.253	0.269	0.327	0.269	0.279	0.165	0.184	0.250	0.143	0.186
Hour	Z500 anomaly -1.0 standard deviation					Z500 anomaly -1.5 standard deviation					Z500 anomaly -2.0 standard deviation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
24	0.888	0.894	0.903	0.897	0.896	0.863	0.878	0.884	0.872	0.874	0.836	0.861	0.855	0.846	0.849
72	0.682	0.703	0.721	0.711	0.704	0.628	0.660	0.670	0.656	0.653	0.562	0.615	0.625	0.593	0.599
120	0.447	0.468	0.513	0.501	0.482	0.371	0.411	0.438	0.423	0.411	0.313	0.354	0.359	0.340	0.342
168	0.258	0.266	0.312	0.314	0.287	0.193	0.209	0.239	0.233	0.218	0.156	0.165	0.170	0.158	0.162

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	0.826	0.802	0.801	0.780	0.802	0.788	0.759	0.756	0.740	0.761	0.763	0.723	0.712	0.680	0.719
72	0.626	0.607	0.614	0.592	0.610	0.560	0.536	0.541	0.529	0.542	0.507	0.465	0.465	0.441	0.469
120	0.451	0.409	0.433	0.408	0.425	0.386	0.329	0.349	0.335	0.350	0.333	0.257	0.277	0.233	0.275
168	0.307	0.234	0.271	0.248	0.265	0.247	0.164	0.206	0.184	0.200	0.203	0.109	0.145	0.093	0.137
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	0.844	0.754	0.749	0.771	0.779	0.832	0.656	0.641	0.708	0.709	0.855	0.499	0.440	0.602	0.599
72	0.663	0.587	0.594	0.625	0.617	0.668	0.497	0.506	0.579	0.563	0.716	0.377	0.340	0.514	0.487
120	0.510	0.413	0.446	0.469	0.459	0.533	0.351	0.376	0.448	0.427	0.620	0.282	0.261	0.431	0.399
168	0.391	0.263	0.297	0.325	0.319	0.443	0.231	0.247	0.330	0.313	0.556	0.197	0.183	0.364	0.325

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

(2) Clear sky radiance data from the Megha-Tropiques/Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie (SAPHIR) will be assimilated into the Global NWP system.

(3) Surface pressure data from METARs will be assimilated into the Global NWP system.
(4) Clear sky radiance data from the Global Precipitation Measurement (GPM)/GPM Microwave Imager (GMI) will be assimilated into the Global and Meso-scale NWP systems.
(5) Improvements to the Seasonal EPS will include enhancement of the horizontal and vertical resolutions of the atmospheric model from TL95 to TL159 and from 40 to 60 levels, respectively, expansion of the target area to the whole globe in the oceanic model, and introduction of a sea-ice model.
(6) The horizontal resolution of the Aeolian dust model will be enhanced from TL159 to TL479.
(7) A high-horizontal-resolution regional chemical transport model will be introduced.

6.1.2 Major changes expected in the next four years

(1) Atmospheric motion vectors and clear sky radiance data from Himawari-8's Advanced Himawari Imager (AHI) will be assimilated into the Global, Meso-scale and Local NWP systems.
(2) The vertical resolution of both the One-week EPS and the Typhoon EPS will be enhanced from 60 to 100 layers.
(3) The vertical resolution of the MSM will be enhanced.
(4) A SiB will be incorporated into the MSM.
(5) An urban canopy will be incorporated into the SiB of the MSM.
(6) Surface observation data will be assimilated into the MA.
(7) A new framework consisting of a regional forecast model and a data assimilation system (ASUCA and ASUCA-Var) will be installed in the Meso-scale NWP system.
(8) A data assimilation system with the local ensemble transform Kalman filter will be introduced in aerosol and stratospheric ozone analysis.
(9) A global ensemble forecast system for ocean waves will be put into operation. The model has a grid resolution of 1.25 with 27 members.

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).

6.2.3 Planned Research Activities in Long-range Forecasting

6.2.4 Planned Research Activities in Specialized Numerical Predictions

(1) Probability forecasts for volcanic ash

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

7. Consortium

8. References

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