# JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2017

## Japan Meteorological Agency

## 1. Summary of highlights

(1) The Global Ensemble Prediction System (GEPS) entered operation in January 2017, taking over the roles of the ensemble prediction systems for tropical cyclone (TC) forecasts, one-week forecasts, early warning information on extreme weather, and one-month forecasts. (4.2.5.2 (1))

(2) A new non-hydrostatic model known as ASUCA was incorporated into the Meso-scale NWP system as the related forecast model in February 2017, and vertical resolution was enhanced by increasing the number of vertical layers from 48 to 76. Selected upgrades to the ASUCA dynamical core and the physics library were also incorporated into the Local NWP system in January 2017. (4.3.2.2)

(3) Assimilation of Satellite Clear-Sky Radiance (CSR) and Soil Moisture Content (SMC) data with Variational Bias Correction (VarBC) were incorporated into the Local NWP system in January 2017. (4.3.1.2 (1))

(4) Meteosat-8 Atmospheric Motion Vector (AMV) data were incorporated into the global NWP system in March 2017. (4.2.1.2 (1))

(5) Meteosat-8 (CSR) data were incorporated into the global NWP system in March 2017. (4.2.1.2 (2))

(6) New satellite radiance data from the Advanced Technology Microwave Sounder (ATMS) and the Cross-track Infrared Sounder (CrIS), both of which are on board the Suomi National Polar-orbiting Partnership (NPP) unit, and the Special Sensor Microwave Imager/Sounder (SSMIS) items on board the DMSP F-17 and F-18 satellites were incorporated into the global NWP system in March 2017. (4.2.1.2 (3))

(7) Physical parameterization schemes, including those for cloud, convection, radiation, land surface, sea surface and methane oxidation, and the dynamical framework of the Global Spectral Model (GSM) were improved in May 2017. The background error covariance matrix of the Global Analysis system was also simultaneously updated using prediction data from the latest GSM. (4.2.2.1 (1))

(8) The method used for GNSS Radio Occultation (RO) data assimilation was upgraded in July 2017. (4.2.1.2 (4))

(9) ASUCA-based 3D-Var was incorporated into the Hourly Analysis system in July 2017. (4.3.4.2 (2))

## 2. Equipment in use

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

**Table 2-1 System computer types**

Supercomputers (Kiyose) Hitachi: SR16000 model M1

| | |
|---|---|
| Number of subsystem | 2 |
| Number of nodes | 54 physical nodes per subsystem<br>432 logical nodes per subsystem |
| Processors | 3,456 IBM POWER7 processors (32 per node) |
| Performance | 423.5 TFlops per subsystem (980 GFLOPS per node) |
| Main memory | 55.296 TiB per subsystem (128 GiB per node) |
| High-speed storage* | Hitachi AMS2500 (138 TB for primary, 210 TB for secondary) |
| Data transfer rate | 96 GiB/s (one way) (between any two nodes) |
| Operating system | IBM AIX Version 7.1 |

* Dedicated storage for supercomputers

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

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

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

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

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

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

Division Processing Servers A (Kiyose): Hitachi BS2000

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

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

| | |
|---|---|
| Number of servers | 2 |
| Processor | IBM Power6+ (4.7 GHz) |
| Main memory | 32 GiB per server |
| Operating system | IBM AIX Version 6.1 |

Decoding Servers (Kiyose): Hitachi EP8000/750

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

Mass Storage System (Kiyose)

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

** Shared by supercomputers and servers

Wide Area Network (between HQ and Kiyose)

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

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

### 3.1 Observation

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

**Table 3-1 Number of observation reports in use**

| | |
|---|---|
| SYNOP/SHIP/SYNOP MOBIL | 200,000/day |
| BUOY | 58,000/day |
| TEMP/PILOT | 7500/day |
| AIREP/AMDAR | 900,000/day |
| PROFILER | 8,000/day |
| AMSR2 | 14,000,000/day |
| GPM/GMI | 10,200,000/day |

| | |
|---|---|
| Aqua/AIRS, AMSU-A | 270,000/day |
| NOAA/AMSU-A | 960,000/day |
| Metop/AMSU-A | 640,000/day |
| NOAA/MHS | 5,800,000/day |
| Metop/MHS | 5,800,000/day |
| Metop/IASI | 600,000/day |
| Metop/ASCAT | 8,000,000/day |
| Suomi-NPP/ATMS | 3,000,000/day |
| Suomi-NPP/CrIS | 3,000,000/day |
| Megha-Tropiques/SAPHIR | 9,000,000/day |
| GOES/CSR | 600,000/day |
| Himawari/CSR | 1,200,000/day |
| METEOSAT/CSR | 1,800,000/day |
| GNSS-RO | 460,000/day |
| AMV | 10,000,000/day |
| SSMIS | 17,000,000/day |
| GNSS-PWV | 4,200,000/day |
| AMeDAS | 232,400/day |
| Radar Reflectivity | 4,200/day |
| Radial Velocity | 4,200/day |

## 3.2 Forecast products

Grid Point Value (GPV) products of the global prediction model from ECMWF, NCEP, UKMO, BOM, ECCC, DWD, KMA 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 | 0225 – 0330 | 84 |
| | 06 | 0825 – 0930 | 84 |
| | 12 | 1425 – 1600 | 264 |
| | 18 | 2025 – 2130 | 84 |
| Meso-scale Analysis/Forecast | 00 | 0055 – 0205 | 39 |
| | 03 | 0355 – 0505 | 39 |
| | 06 | 0655 – 0805 | 39 |
| | 09 | 0955 – 1105 | 39 |
| | 12 | 1255 – 1405 | 39 |
| | 15 | 1555 – 1705 | 39 |
| | 18 | 1855 – 2005 | 39 |
| | 21 | 2155 – 2305 | 39 |
| Local | 00, 01, | 0035 – 0100, 0135 – 0200, 0235 | 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 | – 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 | |
| Ocean Wave Forecast | 00<br>06<br>12<br>18 | 0330 – 0350<br>0930 – 0950<br>1530 – 1550, 1840–1850<br>2130 – 2150 | 84<br>84<br>264<br>84 |
| Wave Ensemble Forecast | 12 | 1900 – 1910 | 264 |
| Storm Surge Forecast | 00<br>03<br>06<br>09<br>12<br>15<br>18<br>21 | 0200 – 0225<br>0500 – 0525<br>0800 – 0825<br>1100 – 1125<br>1400 – 1425<br>1700 – 1725<br>2000 – 2025<br>2300 – 2325 | 39<br>39<br>39<br>39<br>39<br>39<br>39<br>39 |
| Asian-area Storm Surge Forecast | 00<br>06<br>12<br>18 | 0340 – 0355<br>0940 – 0955<br>1540 – 1555<br>2140 – 2155 | 72<br>72<br>72<br>72 |
| Global Ensemble Forecast (Typhoon/One-week) | 00<br>06<br>12<br>18 | 0305 – 0350<br>0905 – 0930<br>1505 – 1550<br>2105 – 2130 | 264<br>132<br>264<br>132 |
| Global Ensemble Forecast (Two-week) | 00<br>12 | 0530 – 0600<br>1730 – 1800<br>(every Tuesday, Wednesday, Saturday and Sunday) | 264 - 432<br>264 - 432 |
| Global Ensemble Forecast (One-month) | 00<br>12 | 0655 – 0740<br>1835 – 1940<br>(every Tuesday and Wednesday) | 432 - 816<br>432 - 816 |
| Seasonal Ensemble Forecasts | 00 | 1730 – 1910 (every 5 days) | (7 months) |

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

### 4.2.1 Data assimilation, objective analysis and initialization

#### 4.2.1.1 In operation

#### (1) Global Analysis (GA)

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

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

The specifications of the atmospheric analysis schemes are listed in Table 4.2.1-1.

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

**Table 4.2.1-1 GA specifications**

| | |
|---|---|
| Analysis scheme | Incremental 4D-Var |
| Data cut-off time | 2 hours and 20 minutes for early run analysis at 00, 06, 12 and 18 UTC<br>11 hours and 50 minutes for cycle run analysis at 00 and 12 UTC<br>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°<br>[ 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 2017) | SYNOP, METAR, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, AMDAR; atmospheric motion vectors (AMVs) from Himawari-8, GOES-13, 15, Meteosat-8, 10; MODIS polar AMVs from Terra and Aqua satellites; AVHRR polar AMVs from NOAA and Metop satellites; LEO-GEO AMVs; ocean surface wind from Metop-A, B/ASCAT; radiances from NOAA-15, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP-F17, 18/SSMIS, Suomi-NPP/ATMS, GCOM-W/AMSR2, GPM-core/GMI, Megha-Tropiques/SAPHIR, Aqua/AIRS, Metop-A,B/IASI; Suomi-NPP/CrIS, clear sky radiances from the water vapor channels (WV-CSRs) of Himawari-8, GOES-13, 15, Meteosat-8, 10; GNSS RO bending angle data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A, B/blackjack, TerraSAR-X/IGOR, zenith total delay data from ground-based GNSS |
| Assimilation window | 6 hours |

**Table 4.2.1-2 Snow depth analysis specifications**

| | |
|---|---|
| Methodology | Two-dimensional Optimal Interpolation scheme |

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

### (2) Typhoon bogussing in GA

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

## 4.2.1.2 Research performed in the field

### (1) Assimilation of Meteosat-8 Atmospheric Motion Vector (AMV) data for the Indian Ocean into the global NWP system

In association with the termination of Meteosat-7 operations, Meteosat-8 AMVs have been assimilated into the JMA global NWP model since28 March 2018. These AMV data were used in JMA’s operational global NWP system until 25 December 2007 during a period of zero-degree service. The spatial coverage and accuracy for Meteosat-8 AMVs were clearly superior to those of Meteosat-7, and Observing System Experiments (OSEs) results showed overall positive impacts on analysis wind fields over the Southern Hemisphere in particular. With this background, JMA began assimilating Meteosat-8 AMV data for the area over the Indian Ocean. (K. Shimoji and K. Yamashita)

### (2) Assimilation of Meteosat-8 Clear-Sky Radiance (CSR) data into the global NWP system

Clear-Sky Radiance (CSR) data from Meteosat-8 has been operationally assimilated into JMA’s global NWP system since 29 March 2017. The volume of incoming CSR data for Meteosat-8 is approximately twice that of the predecessor Meteosat-7. The standard deviation of the first-guess (FG) departure of Meteosat-8 CSR data is comparable to that of Meteosat-7 CSR data. OSE involving Meteosat-8 and Meteosat-7 CSR data were conducted using related parallel-disseminated data with results indicating that the assimilation of both datareduced the standard deviations of FG departures for water vapor-sensitive satellite observations over the Indian Ocean and Africa. These results suggest common improvement of upper-tropospheric water vapor fields in the FG with the assimilation of Meteosat CSR data in the global NWP system. The OSEs showed improved humidity and geopotential height forecasts. The improvements from Meteosat-8 CSR data use were greater than those from Meteosat-7 CSR data use (I. Okabe)

### (3) Assimilation of new satellite radiance data into the global NWP system

Satellite microwave radiance observation provides information on atmospheric temperature and moisture for NWP models, and exploitation of new satellite radiance data contributes to the improvement of weather forecast skill. OSEs on satellite radiance from three instruments (the Advanced Technology Microwave Sounder (ATMS) and the Cross-track Infrared Sounder (CrIS) on the Suomi National Polar-orbiting Partnership (NPP) unit and the Special Sensor Microwave Imager/Sounder (SSMIS) units on DMSP F-17 and F-18) were conducted using the global NWP system. The assimilated data were clear-sky radiance from microwave tropospheric channels (6 – 9 and 18 – 22) of ATMS, 27 selected channels of CrIS from the long-wave infrared temperature-sounding spectrum and 3 microwave humidity-sounding channels of SSMIS. The OSE results showed that the application of ATMS, CrIS and SSMIS data improves water vapor and temperature fields in the mid- and upper-troposphere, the temperature field in the upper troposphere and stratosphere, and the water vapor field in the troposphere. The detailed OSE results including quality control procedures are found in Hirahara et al. (2016), Kamekawa and Kazumori (2016), and Murakami and Kazumori (2016). Based on these findings, assimilation of radiance data from these instruments was incorporated into JMA's global NWP system in March 2017. (Y. Hirahara, N. Kamekawa and Y. Murakami)

### (4) Updates on the usage of GNSS RO data in JMA's Operational Global Data Assimilation System

The Japan Meteorological Agency (JMA) has assimilated bending-angle data into its global NWP systems via the introduction of the Radio Occultation Processing Package (ROPP) (Culverwell et al. 2015). The method of usage for Radio Occultation (RO) data in operational global analysis was updated on July 25 2017. The relevant revisions have been evaluated and tested in the pre-processing of RO data for incorporation into the operational global assimilation system. The major updates are as follows:

- New bending-angle threshold in gross error checking for the tropics
- New handling of RO quality flags (16-bit in BUFR)
- Setting of a lower-altitude limit in data selection
- ROPP update from Ver. 6 to Ver. 8

The most significant of these changes is the implementation of the new bending-angle threshold in gross error checking for the tropics. The update produced a greater volume of observation data for the upper troposphere and the stratosphere, and improved analysis of temperature and wind in these layers. (H. Owada and M. Shimada)

## 4.2.2 Model

### 4.2.2.1 In operation

### (1) Global Spectral Model (GSM)

The specifications of the operational Global Spectral Model (GSM1705; TL959L100) are summarized in Table 4.2.2-1.

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

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

| 1. System | |
|---|---|
| Model (version) | Global Spectral Model (GSM1705) |
| Date of implementation | 25 May 2017 |
| 2. Configuration | |
| Horizontal resolution (Grid spacing) | Spectral triangular 959 (TL959), reduced Gaussian grid system, roughly equivalent to 0.1875 × 0.1875° (20 km) in latitude and longitude |
| Vertical resolution (model top) | 100 stretched sigma pressure hybrid levels (0.01 hPa) |
| Forecast length (initial time) | 84 hours (00, 06, 18 UTC)<br>264 hours (12 UTC) |
| Coupling to ocean/wave/sea ice models | -- |
| Integration time step | 400 seconds |
| 3. Initial conditions | |
| Data assimilation | Four-dimensional variational (4D-Var) method |
| 4. Surface boundary conditions | |
| Treatment of sea surface | Climatological sea surface temperature with daily analysis anomaly<br>Climatological sea ice concentration with daily analysis anomaly |
| Land surface analysis | Snow depth: two-dimensional optimal interpolation scheme<br>Temperature: first guess<br>Soil moisture: climatology |
| 5. Other details | |
| Land surface and soil | Simple Biosphere (SiB) model |
| Radiation | Two-stream with delta-Eddington approximation for short wave (hourly)<br>Two-stream absorption approximation method for long wave (hourly) |
| Numerical techniques | Spectral (spherical harmonic basis functions) in horizontal, finite differences in vertical<br>Two-time-level, semi-Lagrangian, semi-implicit time integration scheme<br>Hydrostatic approximation |
| Planetary boundary layer | Mellor and Yamada level-2 turbulence closure scheme<br>Similarity theory in bulk formulae for surface layer |
| Convection | Prognostic Arakawa-Schubert cumulus parameterization |
| Cloud | PDF-based cloud parameterization |
| Gravity wave drag | Longwave orographic drag scheme (wavelengths > 100 km) mainly for stratosphere<br>Shortwave orographic drag scheme (wavelengths approx.. 10 km) for troposphere only<br>Non-orographic spectral gravity wave forcing scheme |
| 6. Further information | |
| Operational contact point | globalnwp@naps.kishou.go.jp |
| System documentation URLs | http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm |

| | |
|---|---|
| | http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2017_Japan.pdf |
| Product list URLs | http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2017_Japan.pdf |

#### 4.2.2.2 Research performed in the field

**(1) Upgrade of the GSM**

JMA plans to upgrade its Global Spectral Model (GSM) in 2019 by revising its parameterization schemes (such as gravity wave, land surface processes, deep convection). Results from several preliminary experiments showed that more physically sensitive parameterization for sub-grid orography significantly improves the representation of large-scale flow around Japan as well as general circulation. (H. Yonehara et al.)

### 4.2.3 Operationally available NWP products

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

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

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

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

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

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

| Model | Area | Forecast Time [h] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Analysis | 12 | 24 | 36 | 48 | 72 | 96<br>120 | 144<br>168<br>192 |
| GSM | Asia | $HZ_{500}^{G}$<br>$Ta_{850}O_{700}^{G}$ | | $HZ_{500}^{GJ}$<br>$T_{500}D_{700}^{GJ}$<br>$Ta_{850}O_{700}^{GJ}$<br>$PEa_{srf}^{GJ}$ | | | | | |
| | East Asia | $HWtab_{300}^{G5}$<br>$HTab_{500}^{GJ}$<br>$HTbd_{700}^{G}$<br>$HTbd_{850}^{GJ}$ | | $PE_{srf}^{G}$ | | $HZ_{500}^{G}$<br>$Ta_{850}O_{700}^{G12}$<br>$PE_{srf}^{GJ}$ | | $PE_{srf}^{GJ12}$ | |
| | Asia | | | | | | | $HZ_{500}^{G12}$<br>$P_{srf}T_{850}^{G12}$ | |
| | Asia-Pacific | $HWtaj_{200}H_{trp}^{G}$<br>$HWta_{250}^{G}$ | | $HWta_{250}^{G}$<br>$HWta_{500}^{G}$ | | | | | |
| | NW Pacific | $x_{200}^{G}$<br>$x_{850}^{G}$ | | $x_{200}^{G}$<br>$x_{850}^{G}$ | | $x_{200}^{G}$<br>$x_{850}^{G}$ | | | |
| | N Hem. | $HT_{500}^{G12}$ | | | | | | | |
| Ocean Wave | Japan | $Jbgm_{srf}^{GJ}$ | | | | | | | |
| | NW Pacific | $Jbgm_{srf}^{GJ}$ | $Jgm_{srf}^{J}$ | | | $Jgm_{srf}^{J}$ | | | |

### 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<br>0.25° × 0.25° (surface)<br>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<br>200 hPa: U, V, T, R, H, O, X, Y<br>500 hPa: U, V, T, R, H, O, Z<br>850 hPa: U, V, T, R, H, O, X, Y |

| | |
|---|---|
| | Other levels: U, V, T, R, H, O |
| Forecast hours | 0 – 84 every 3 hours,<br>90 – 264 every 6 hours (12 UTC) |
| Initial times | 00 UTC, 06 UTC, 12 UTC, 18 UTC |

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

Symbols: D: dew-point depression; E: precipitation; G: prevailing wave direction; H: geopotential height; J: wave height; M: wave period; O: vertical velocity (ω); P: sea level pressure; R: relative humidity; T: temperature; U: eastward wind; V: northward wind; X: stream function; Y: velocity potential; Z: vorticity;

The prefixes μ and σ represent the average and standard deviations of ensemble prediction results, respectively. The symbols °, *, ¶, §, ‡ and † indicate limitations on forecast hours or initial times as shown in the notes below.

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

| Model | Global Ensemble Forecast (One-week) | Ocean Wave Model |
|---|---|---|
| Destination | GISC | GTS, GISC |
| Area and resolution | Whole globe,<br>2.5° × 2.5° | 75°S – 75°N, 0°E – 359.5°E<br>0.5° × 0.5° |
| Levels and elements | 250 hPa: μU, μV, σU, σV<br>500 hPa: μH, σH<br>850 hPa: μU, μV, μT, σU, σV, σT | Surface: J, M, G |

| | | |
|---|---|---|
| | 1,000 hPa: μH, σH<br>Surface: μP, σP | |
| Forecast hours | 0 – 192 every 12 hours | 0 – 84 every 6 hours,<br>96 – 192 every 12 hours for 12 UTC |
| Initial times | 00 UTC and 12 UTC | 00 UTC, 06 UTC, 12 UTC, 18 UTC |

### 4.2.4 Operational techniques for application of NWP products

#### 4.2.4.1 In operation

#### (1) Forecast guidance

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

#### 4.2.4.2 Research performed in the field

### 4.2.5 Ensemble Prediction System (EPS)

#### 4.2.5.1 In operation

JMA put its new Global EPS (GEPS) into operation in January 2017. Covering both medium- and extended-range forecasting, the system supports the issuance of five-day tropical cyclone (TC) forecasts, one-week forecasts, early warning information on extreme weather, and one-month forecasts. GEPS took over the roles of three previous JMA systems (the Typhoon EPS (TEPS), the One-week EPS (WEPS) and the One-month EPS). The objectives of the integration were to utilize computational resources more effectively and to concentrate efforts into a single EPS system. TEPS and WEPS were replaced by GEPS in January 2017, and GEPS inherited the role of the One-month EPS in March 2017. The specifications of GEPS for the first 11 days of forecasts are shown in Table 4.2.5-1. The system involves the application of 1 control forecast and 26 perturbed forecasts. Initial perturbations are generated using a combination of the Local Ensemble Transform Kalman Filter approach (LETKF; Hunt et al. 2007) and the singular vector (SV) method (Buizza and Palmer 1995). The specifications of LETKF are shown in Table 4.2.5-2. Using this filtering technique, a six-hour cycle data assimilation system is implemented to generate initial perturbations representing flow-dependent uncertainty in the initial conditions. 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 May 2017. 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 GSM1603E (see Table 4.2.5-1). Accordingly, the dynamical framework and physical processes involved are identical to those of the high-resolution

GSM except for horizontal resolution. A stochastic physics scheme (Palmer et al. 2009) is used in GEPS in consideration of model uncertainties associated with physical parameterizations.

Unperturbed initial condition is performed by interpolating the analyzed field in global analysis (see 4.2.1.1). The sea surface temperature (SST) analysis value is used as a lower-boundary condition and prescribed using the persisting anomaly from the climatological value, which means that the anomalies shown from analysis for the initial time are fixed during time integration. The sea ice concentration analysis value is also prescribed using the persisting anomaly. A perturbation technique for SST that is designed to represent uncertainty in the prescribed SST is applied to GEPS as a surface boundary perturbation.

Table 4.2.5-1 Global EPS specifications for the first 11 days of forecasts

| | |
|---|---|
| **1. Ensemble system** | |
| Ensemble (version) | Global EPS (GEPS) |
| Date of implementation | 19 January 2017 |
| **2. EPS configuration** | |
| Model (version) | Global Spectral Model (GSM1603E) |
| Horizontal resolution/grid spacing | Spectral triangular 479 (TL479), reduced Gaussian grid system, roughly equivalent to 0.375 × 0.375° (40 km) in latitude and longitude |
| Vertical resolution (model top) | 100 stretched sigma pressure hybrid levels (0.01 hPa) |
| Forecast length (initial time) | 11 days (00, 12 UTC)<br>132 hours (06, 18 UTC) |
| Members | 1 unperturbed control forecast and 26 perturbed ensemble members |
| Coupling to ocean/wave/sea ice models | -- |
| Integration time step | 720 seconds |
| Additional comments | Forecasts from initial times at 06 and 18 UTC are issued when either of the following conditions is satisfied at the initial times:<br>· A tropical cyclone (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°).<br>· A TC is expected to reach or exceed TS intensity in the area within the next 24 hours. |
| **3. Initial conditions and perturbations** | |
| Initial perturbation strategy | Singular vectors (SVs) and LETKF |
| Optimization time in forecast | Among three targeted SV areas:<br>48 hours for Northern Hemisphere (30° – 90°N)<br>24 hours for Tropics (30°S – 30°N)<br>48 hours for Southern Hemisphere (90° – 30°S) |
| Horizontal resolution of perturbations | SVs:<br>Spectral triangular 63 (TL63), reduced Gaussian grid system, roughly equivalent to 2.8125 × 2.8125° (270 km) in latitude and longitude<br><br>Perturbations from LETKF:<br>Spectral triangular 319 (TL319), reduced Gaussian grid system, roughly equivalent to 0.5625 ×0.5625° (55 km) in latitude and longitude |
| Initial perturbation area | Global |

| | |
|---|---|
| Data assimilation method for control analysis | Four-dimensional variational (4D-Var) for Global Analysis (GA) Control analysis based on interpolation of high-resolution GA (TL959) |
| Initial conditions for perturbed members | Addition of perturbations to control analysis (SV-based components in +/- pairs) |
| Additional comments | |
| **4. Model uncertainty perturbations** | |
| Model physics perturbations | Stochastic perturbation of physics tendency |
| Model dynamics perturbations | -- |
| Additional comments | · Identical model versions for all ensemble members<br>· Above model uncertainty perturbations not applied to control forecasting |
| **5. Surface boundary perturbations** | |
| Sea surface temperature perturbations | Perturbations representing climatological distribution of analysis and forecast error of prescribed SST sampled from past realizations of analysis increment and forecast error of SST in the same season |
| Soil moisture perturbations | -- |
| Surface wind stress/roughness perturbations | -- |
| Other surface perturbations | -- |
| Additional comments | The above surface perturbations are not applied to the control forecast. |
| **6. Other model details** | |
| Surface boundary conditions | |
| Treatment of sea surface | Climatological sea surface temperature with daily analysis anomaly<br>Climatological sea ice concentration with daily analysis anomaly |
| Land surface analysis | Snow depth: two-dimensional optimal interpolation scheme<br>Temperature: first guess<br>Soil moisture: climatology |
| Model dynamics and physics | |
| Land surface and soil | Simple Biosphere (SiB) model |
| Radiation | Two-stream with delta-Eddington approximation for shortwave (hourly)<br>Two-stream absorption approximation method for longwave (hourly) |
| Numerical techniques | Spectral (spherical harmonic basis functions) in horizontal, finite differences in vertical<br>Two-time-level, semi-Lagrangian, semi-implicit time integration scheme<br>Hydrostatic approximation |
| Planetary boundary layer | Mellor and Yamada level-2 turbulence closure scheme<br>Similarity theory in bulk formulae for surface layer |
| Convection | Prognostic Arakawa-Schubert cumulus parameterization |
| Cloud | PDF-based cloud parameterization |
| Gravity wave drag | Longwave orographic drag scheme (wavelengths > 100 km) mainly for stratosphere<br>Shortwave orographic drag scheme (wavelengths approx. 10 km) for troposphere only<br>Non-orographic spectral gravity wave forcing scheme |
| **7. Products** | |
| Method of calculation (if not unique) | |
| Other specifications as necessary | Products of forecasts from initial times at 06 and 18 UTC are not externally provided on an operational basis. |

| **8. Further information** | |
|---|---|
| Operational contact | globalnwp@naps.kishou.go.jp |
| System documentation URLs | http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm<br>http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2017_Japan.pdf |
| Product list URLs | http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2017_Japan.pdf |

**Table 4.2.5-2 LETKF specifications**

| | |
|---|---|
| Model name (version) | Global Spectral Model (GSM1705) |
| Horizontal resolution | Spectral triangular 319 (TL319), reduced Gaussian grid system, roughly equivalent to 0.5625° ×0.5625° (55 km) in latitude and longitude |
| Vertical resolution (model top) | 100 unevenly spaced hybrid levels (0.01 hPa) |
| Analysis time | 00, 06, 12, 18 UTC |
| Ensemble size | 50 members |
| Data cut-off time | 2 hours and 20 minutes |
| First guess | Own 6-hour forecast |
| Analysis variables | Wind, surface pressure, specific humidity and temperature |
| Observation (as of 29 Mar 2017) | SYNOP, METAR, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, AMDAR, Typhoon Bogus; atmospheric motion vectors (AMVs) from Himawari-8, GOES-13, 15, Meteosat-8, 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, Megha-Tropiques/SAPHIR, DMSP-F17, 18/SSMIS, GPM/GMI, GCOM-W/AMSR2, Suomi-NPP/ATMS; clear sky radiances from the water vapor channels (WV-CSRs) of Himawari-8, GOES-13, 15, Meteosat-8, 10; GNSS RO bending angle data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A,B/blackjack, TerraSAR-X/IGOR, zenith total delay data from ground-based GNSS |
| Assimilation window | 6 hours |
| Perturbations to model physics | Stochastic perturbation of physics tendency |
| Initialization | Hamrud et al. (2015) |
| Covariance inflation | Adaptive multiplicative covariance inflation |
| Other characteristics | A total of 50 analyses are re-centered so that their ensemble mean is consistent with the Global Analysis (GA).<br>A total of 25 of these 50 are used to generate GEPS initial perturbations. |

### 4.2.5.2 Research performed in the field

#### (1) Upgrade of models for SV computation

JMA upgraded the non-linear, tangent-linear and adjoint models used for its SV computation in June 2017. The previous and current models are lower-resolution versions of those used in the 4D-Var data assimilation system for the GSM until October 2011 and May 2017, respectively. The upgrade includes changes in the dynamical framework of the models from a Eulerian formulation with a quadratic Gaussian grid system to a semi-Lagrangian formulation with a reduced Gaussian grid system. The model's cut-off wave number in the triangular truncation of the spherical harmonics expansion, the number of layers and the top height remained the same at 63, 40 and 0.1 hPa, respectively. These upgrades reduced the resources involved in SV computation by more than 50% and supported SV calculation with greater numerical stability and little impact on the accuracy and spread of GEPS forecasts. (K. Ochi, Y. Ota, C. Matsukawa and H. Yamaguchi)

### (2) Investigation of LETKF covariance inflation

New adaptive covariance inflation methods (Kotsuki et al. 2017) based on relaxation to prior spread (RTPS) and relaxation to prior perturbations (RTPP) have been tested in the LETKF used for generating the initial perturbations of the GEPS. The new methods were found to be more robust to observation network changes than the operational adaptive multiplicative inflation approach. However, testing with the pure LETKF cycle showed substantial detrimental impacts on the accuracy of analysis and forecasting from ensemble mean analysis. Further investigation revealed underdispersiveness in prior perturbations with the new methods, suggesting insufficient representation of model error. (Y. Ota)

### 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 was in operation until February 2017 as a mesoscale forecast model (the Meso-Scale Model, or MSM). It should be noted that the current operational MSM is based on ASUCA as described in 4.3.2.1, but the JMA-NHM is still implemented in MA for formulation of the first guess. The MA specifications are detailed in Table 4.3.1-1.

**Table 4.3.1-1 MA specifications**

| | |
|---|---|
| 4D-Var formulation | Incremental 4D-Var using a nonlinear forward model in the inner step |

| | |
|---|---|
| | with low resolution |
| Data cut-off time | 50 minutes for analysis at 00, 03, 06, 09, 12, 15, 18 and 21 UTC |
| Observation (as of 31 December 2017) | SYNOP, METAR, SHIP, BUOY, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR; AMVs from Himawari-8; ocean surface wind from Metop-A, B/ASCAT; radiances from NOAA-15, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP-F17, 18/SSMIS, GCOM-W/AMSR2, GPM-core/GMI; WV-CSR of Himawari-8; radar-raingauge analyzed precipitation; precipitation retrievals from DMSP-F17, 18/SSMIS, GCOM-W/AMSR2; GPM-core/GMI; GPM-core/DPR; GNSS RO refractivity data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A, B/blackjack, TerraSAR-X/IGOR, TanDEM-X/IGOR; Total Precipitable Water Vapor from ground-based GNSS |
| First guess | 3-hour forecast produced by the JMA-NHM |
| Domain configuration | (Outer step)<br>Lambert projection; 5 km at 60°N and 30°N, 817 × 661<br>Grid point (1, 1) is at the northwest corner of the domain.<br>Grid point (565, 445) is at 140°E, 30°N.<br>(Inner step)<br>Lambert projection; 15 km at 60°N and 30°N, 273 × 221<br>Grid point (1, 1) is at the northwest corner of the domain.<br>Grid point (189, 149) is at 140°E, 30°N. |
| Vertical levels | (Outer step) 48 levels up to 22 km (consistent with the forecast model setting)<br>(Inner step) 38 levels up to 22 km |
| Analysis variables | Wind, potential temperature, surface pressure and pseudo-relative humidity |
| Assimilation window | 3 hours |

### (2) Typhoon bogussing of the MA

The method employed is essentially as per that used for GA (see 4.2.1.1 (2)).

### (3) Local Analysis (LA)

Local Analysis (LA), which was introduced in August 2012, produces initial conditions for the Local Forecast Model (LFM) at a horizontal resolution of 2 km. For the provision of initial conditions to the high-resolution forecast model targeting small-scale severe weather events, the LA is designed to allow rapid production and frequent updating of analysis at a resolution of 5 km. An analysis cycle with hourly three-dimensional variational (3D-Var) data assimilations is executed each time for the previous three-hour period to incorporate information from newly received observations in each case. High-resolution NWP’s capacity to capture small-scale variations in topography is expected to help a reduction of representativeness errors in surface observation assimilation. In association, the LA also assimilates automated surface station (AMeDAS) data ahead of other operational data assimilation systems at lower resolutions to appropriately reflect the effects of local-scale environments near the surface. The analysis domain was expanded so that the Japan and its surrounding areas can be covered and the update frequency was enhanced to every hour in May 2013. A new system based on ASUCA and ASUCA-Var was implemented in the operational LA in January 2015 (Aranami et al. 2015), replacing the previous one based on JMA-NHM and JNoVA. The specifications of the LA are detailed in Table 4.3.1-2.

**Table 4.3.1-2 LA specifications**

| | |
|---|---|
| Analysis cycle | The three-hour analysis cycle repeats hourly assimilation with 3D-Var and one-hour forecasts. |
| Data cut-off time | 30 minutes for analysis at 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23 UTC |
| Observation (as of 31 December 2017) | SYNOP, SHIP, BUOY, AMeDAS, TEMP, PILOT, Wind Profiler, Weather Doppler radar (radial velocity, reflectivity), AIREP, AMDAR, AMVs from Himawari-8 and Total Precipitable Water Vapor from ground-based GNSS, radiances from NOAA-15, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP-F17, 18/SSMIS, GCOM-W/AMSR2, GPM-core/GMI; WV-CSR of Himawari-8, soil moisture from GCOM-W/AMSR2 and Metop-A B/ASCAT |
| First guess | Initial fields produced by the latest MSM |
| Domain configuration | Lambert projection; 5 km at 60°N and 30°N, 633 × 521<br>Grid point (1, 1) is at the northwest corner of the domain.<br>Grid point (449, 361) is at 140°E, 30°N |
| Vertical levels | 48 levels up to 22 km |
| Analysis variables | Wind, potential temperature, surface pressure, pseudo-relative humidity, skin temperature, ground temperature, soil moisture |

### 4.3.1.2 Research performed in the field

#### (1) Assimilation of Satellite Clear Sky Radiance (CSR) and Soil Moisture Content (SMC) data with Variational Bias Correction (VarBC) into the Local NWP system

In the Local NWP system, JMA started to assimilate CSR observation from Himawari-8 AHI, GPM GMI, GCOM-W AMSR2, Metop-A/B AMUS-A/MHS and DMSP SSMIS. In addition, the assimilation of SMC of L2-products from GCOM-W AMSR2 and Metop-A/B ASCAT was also initiated. These SMC data are assimilated after variable transformation using the cumulative distribution function (CDF) matching method, which involves fitting of the probability density function (PDF) of observation to the PDF of model variables. This pre-conditioning based on CDF matching helps to minimize the cost function because the innovation of SMC becomes Gaussian after CDF matching. However, it is known that satellite observation bias fluctuates over time. To adaptively remove this temporal bias, the VarBC method is used in local analysis. This enables the assimilation of CSR and SMC data as unbiased observation information and improves

atmospheric and surface forecast accuracy. Accordingly, assimilation of CSR and SMC data into the Local NWP system was commenced in January 2017. (Y. Ikuta)

## 4.3.2 Model

### 4.3.2.1 In operation

### (1) Meso-Scale Model (MSM)

JMA has operated MSM since March 2001. Its main roles are disaster prevention and aviation forecasting. JMA-NHM was adopted as 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 ASUCA forecast model was introduced in February 2017, and the number of vertical layers was increased from 48 to 76 for enhanced resolution. The specifications of MSM are listed in Table 4.3.2-1.

Table 4.3.2-1 MSM specifications

| 1. System | |
|---|---|
| System | Meso-scale model (forecast model: ASUCA) |
| Date of implementation | 1 Mar. 2001 (ASUCA: 28 Feb. 2017) |
| 2. Configuration | |
| Domain | Japan, Lambert projection, 817 × 661 grid points |
| Horizontal resolution | 5 km at 60 and 30°N (standard parallels) |
| Number of model levels | 76 |
| Model top | 21.8 km |
| Forecast length | 39 hours |
| Runs per day (times in UTC) | 8 (00, 03, 06, 09, 12, 15, 18 and 21 UTC) |
| Coupling to ocean/wave/sea ice models | None |
| Integration time step | 100/3 seconds (3-stage Runge-Kutta method) |
| 3. Initial conditions | |
| Data assimilation method | 4D-Var analysis with mixing ratios of cloud water, cloud ice, rain, snow and graupel derived from preceding forecasts in consideration of consistency with the analysis field of relative humidity<br>. |
| 4. Surface boundary conditions | |
| Sea-surface temperature | Observed SST (fixed during time integration) and sea-ice distribution |
| Land surface analysis | Climatological values of evaporability, roughness length and albedo<br>Snow cover analysis over Japan using a land surface model |
| 5. Lateral boundary conditions | |
| Model providing lateral boundary conditions | GSM |
| Lateral boundary condition update frequency | 4 times/day<br>00 – 45-hour GSM forecasts initialized at 00/06/12/18 UTC for (03, 06)/(09, 12)/(15, 18)/(21, 00) UTC forecasts |
| 6. Other model details | |
| Soil scheme | Ground temperature prediction using an eight-layer ground model<br>Evaporability prediction initialized using climatological values depending on location and season |
| Radiation | Short wave: two-stream with delta-Eddington approximation (every 15 minutes)<br>Long wave: two-stream absorption approximation method (every 15 minutes) |
| Large scale dynamics | Finite volume method with Arakawa-C-type staggered coordinates, a horizontally explicit and vertically implicit time integration scheme, and combined third- and first-order upwind horizontal finite difference schemes in flux form with a limiter as |

| | |
|---|---|
| | proposed by Koren (1993) in advection treatment for monotonicity<br>Fully compressible non-hydrostatic equations |
| Boundary layer | Improved Mellor-Yamada Level-3 scheme<br>Similarity theory adopted for the surface boundary layer |
| Convection | Kain-Fritsch convection scheme |
| Cloud/microphysics | Three-ice bulk cloud microphysics<br>Consideration of PDF-based cloud distribution in microphysics<br>Time-split treatment for rain and graupel precipitation<br>Cloud water and cloud cover diagnosed using a partial condensation scheme |
| Orography | Mean orography smoothed to eliminate shortest-wave components |
| Horizontal diffusion | None |
| Gravity wave drag | None |
| 7. Further information | |
| System documentation URLs | http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm<br>http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/report/2015_Japan.pdf |

### (2) Local Forecast Model (LFM)

Making use of the new powerful supercomputer system installed in June 2012, operation of a forecast model called LFM with an even higher resolution was launched in August 2012 along with LA. This model has 2-km horizontal grid spacing and 58 vertical layers up to a height of approximately 20.2 km above the surface, and is designed to produce more detailed forecasts with emphasis on predicting localized and short-lived severe events. 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 LA. The forecast domain was expanded so that the Japan and its surrounding areas can be covered and the update frequency was enhanced to every hour in May 2013. The ASUCA forecast model was introduced in January 2015 (Aranami et al. 2015), replacing the previous JMA-NHM model. The specifications of LFM are listed in Table 4.3.2-2.

Table 4.3.2-2 LFM specifications

| | |
|---|---|
| 1. System | |
| System | Local Forecast Model (forecast model: ASUCA) |
| Date of implementation | 30 Aug. 2012 (ASUCA: 29 Jan. 2015) |
| 2. Configuration | |
| Domain | Japan, Lambert projection, 1,531 × 1,301 grid points |
| Horizontal resolution | 2 km at 60 and 30°N (standard parallels) |
| Number of model levels | 58 |
| Model top | 20.2 km |
| Forecast length | 9 hours |
| Runs per day (times in UTC) | 24 (00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23 UTC) |
| Coupling to ocean/wave/sea ice models | None |
| Integration time step | 50/3 seconds (3-stage Runge-Kutta method) |
| 3. Initial conditions | |
| Data assimilation method | The LA produces initial conditions via a three-hour analysis cycle based on hourly assimilation with 3D-Var and one-hour forecasts |
| 4. Surface boundary conditions | |

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

#### 4.3.2.2 Research performed in the field

##### (1) ASUCA-based system upgrade

After the implementation of the ASUCA-based system into the operational LFM in January 2015 (Aranami et al. 2015), its dynamical core and the physics library (Hara et al. 2012) were upgraded toward introduction into the MSM, which was accomplished in February 2017. These improvements contribute to various forecasting enhancements, especially in summer precipitation.

- Dynamical core

An adaptive time-splitting method for vertical advection in consideration of the three-dimensional CFL condition was adopted to maintain computational stability with a longer time step and finer vertical grid spacing.

- Physics parameterization
  - ・The cumulus parameterization scheme based on Kain and Fritsch (1990) was overhauled and various upgrades were applied, including a revision of the trigger function and refinement of the entrainment rate based on comparison of cloud top height between the model and estimation from satellite observation.
  - ・The cloud microphysics scheme was also upgraded. The upgrade includes a revision of particle distribution functions for snow and rain, introduction of a PDF-based cloud condensation scheme, refinement of rain evaporation, and introduction of numerics with greater stability.
  - ・A radiation scheme for the GSM and a boundary layer scheme for the LFM were introduced.
  - ・The number of ground levels used for soil temperature prediction was increased.
  - ・In January 2017, the dynamical core improvement, radiation scheme upgrade and soil temperature prediction described above were also incorporated into the operational LFM.

### 4.3.3 Operationally available NWP products

### 4.3.4 Operational techniques for application of NWP products

#### 4.3.4.1 In operation

#### (1) Forecast guidance

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

**Table 4.3.4-1 Weather forecast guidance specifications**

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

| Element | Details | Type | NWP | Statistical tool |
|---|---|---|---|---|
| Average precipitation | 3-hour cumulative precipitation (grid average) | Grid (20 * 20 km for GSM, 5 * 5 km | GSM, MSM | KF |

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

**Table 4.3.4-2 Aviation forecast guidance specifications**

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

| Element | Details | Type | NWP | Statistical tool |
|---|---|---|---|---|
| Visibility | Minimum and mean visibility | Point<br>(91 airports) | MSM | KF |
| Probability of visibility | Probability of visibility less than 5,000 and 1,600 m | | | KF |
| Cloud | Cloud amount and height of lower 3 layers | | | ANN |
| Probability of ceiling | Probability of ceiling below 600 and 1,000 ft | | | LR |
| Wind | Time-series, maximum wind speed/direction | | | KF |
| Gust | Gust speed/direction | | | KF |
| Probability of gusts | Probability of gusting | | | LR |
| Weather | Categorized weather | | | DM |
| Temperature | Maximum, minimum and time-series temperature | | | KF |
| Turbulence | Turbulence index | Grid (40 * 40 km and 28 layers for MSM, 10 * 10 km and 45 layers for | GSM, MSM, LFM | LR |
| Icing | Icing index | | MSM, LFM | DM |

| | | | | |
|---|---|---|---|---|
| CB | CB cloud amount and CB top height | LFM) | GSM,<br>MSM,<br>LFM | DM |
| Visibility | Minimum visibility | | LFM | DM |

### (2) Hourly Analysis

JMA Hourly Analysis involves three-dimensional evaluation of temperature and wind fields with a grid spacing of 5 km to provide real-time monitoring of weather conditions. The latest MSM forecast is used as the first guess, and observational information is added through assimilation. The 3D-Var data assimilation method is adopted as the analysis technique. The hourly product is made within 30 minutes of the end of each hour, and is provided to operational forecasters and aviation users. In July 2017 a new system based on ASUCA and ASUCA-Var was implemented, replacing the original one based on JMA-NHM and JNoVA. The specifications of the Hourly Analysis schemes are almost identical except for the model configurations, as listed in Table 4.3.4-3.

**Table 4.3.4-3 Hourly Analysis specifications**

| | |
|---|---|
| Analysis scheme | 3D-Var |
| Data cut-off time | 20 minutes |
| First guess | 2, 3 or 4-hour forecast by the MSM |
| Domain configuration | Lambert projection, 5 km at 60°N and 30°N, 721 × 577 grid points<br>Grid point (1, 1) is at the northwestern corner of the domain.<br>Grid point (489, 409) is at 140°E, 30°N. |
| Vertical levels | 48 forecast model levels |
| Analysis variables | Wind, temperature, surface wind and surface temperature |
| Observation (as of 31 December, 2017) | AMeDAS, Wind Profiler, Weather Doppler radar (radial velocity), AIREP, AMDAR, and AMVs from Himawari-8 |
| Post-processing | Surface filtering (followed by adjustment of the increment within the PBL) |

## 4.3.4.2 Research performed in the field

### (1) Forecast guidance

JMA is currently developing LFM precipitation guidance (1-hour average precipitation and 1-hour maximum precipitation) for use as input in 15-hour precipitation forecasts and issuance of disaster weather information such as Warnings/Advisories in daily forecasting work.

### (2) Hourly Analysis (introduction of ASUCA-based 3D-Var)

In July 2017, JMA Hourly Analysis was updated to support 3D-Var monitoring based on ASUCA-MSM and ASUCA-Var data. As the new Hourly Analysis specifications are similar to the original ones, comparable results can be expected with identical first-guess and observation data. The vertical grid interpolation method has also been improved, with application in 3D-Var pre-processing for conversion of first-guess data from the MSM to the 3D-Var analysis field with different vertical levels (Tables 4.3.2-1 and 4.3.4-3). These upgrades have helped to improve horizontal wind fields in the middle and upper levels, especially over high-altitude regions.

## 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 using raingauge measurements from JMA's Automated Meteorological Data Acquisition System (AMeDAS) and other available data such as those from rain gauges operated by local governments)
(6) Very-Short-Range Forecasts of precipitation (VSRFs) (incorporating forecasts of one-hour cumulative precipitation based on extrapolation and prediction by the MSM and LFM (see 4.3.2.1) and covering the period from one to six hours ahead)

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

### 4.4.1 Nowcasting system (0 – 1 hrs)

#### 4.4.1.1 In operation

#### (1) High-resolution Precipitation Nowcasts

High-resolution precipitation nowcasts (HRPNs) provide five-minute-interval precipitation intensity and cumulative precipitation data up to an hour ahead. Initial precipitation intensity distribution is determined via three-dimensional analysis of storms using radar echo intensity, Doppler velocity, raingauge, surface and upper-air observation data.

Data on vertical atmospheric profiles are part of the input used for prediction generation. The initial values for such data are based on upper-air observation data, and are updated via comparison of cumulonimbus cloud profiles (echo top rising speed, ceiling height, lightning count and rainfall amount) between radar/radio-based observation and calculation using the Vertically One-dimensional Convective Model (VOCM). Thus, HRPNs are multi-observing-system-based nowcasting products beyond the scope of radar-based data with concentration on various observation data application technologies.

Two processes are adopted in HRPNs: (1) high-resolution three-dimensional prediction generated by extrapolating the three-dimensional distribution of water content and using VOCM data relating to notable regions of heavy rain, and (2) low-resolution three-dimensional prediction generated with a longer time step and reduced vertical calculation for areas outside high-resolution prediction regions. Data processing functions are designed for prediction using a dynamical estimation approach suitable for forecasting of rain phenomena that develop widely and rapidly based on a kinetic approach involving the extrapolation of phenomenon movement trends. Generation of data on convective cloud initiation triggered by three phenomena is also considered.

HRPN distribution data contain information on prediction uncertainty in the form of predictions regarding the magnitude of errors included in forecast rainfall. Knowledge of this uncertainty is considered useful in applications such as river water level prediction.

The specifications are summarized in Table 4.4.1-1.

HRPN are provided to local weather offices and the public to enable close monitoring of heavy-rain areas and support disaster prevention activities.

**Table 4.4.1-1 High-resolution Precipitation Nowcast model specifications**

| | |
|---|---|
| Forecast process | • Kinetic: non-linear motion/intensity extrapolation<br>• Dynamic: vertically one-dimensional convective model enabling calculation relating to raindrop generation, precipitation and evaporation<br>• Convective Initiation: three triggers: (1) downflow caused by heavy rainfall, (2) temporal variation of surface temperature and water vapor, (3) intersection of arch-shaped thin echo |
| Movement vector | • Precipitation system, cell and rain intensity trend motion vectors estimated using cross-correlation pattern matching and discrete |

| | |
|---|---|
| | interpolation<br>• Dual-Doppler wind |
| Time step | 5 minutes (low-resolution three-dimensional prediction)<br>1 minute (high-resolution three-dimensional prediction)<br>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<br>1 km over land and coasts 35 ― 60 minutes ahead<br>1 km from the coasts 00 ― 60 minutes ahead |
| Number of grids | 16,660,800 for distribution data, with up to 51,840,000 for internal calculation of high-resolution three-dimensional prediction |
| Initial | • Analyzed precipitation distribution determined from radar, raingauge and upper-air observation<br>• Vertical atmospheric profiles based on radiosonde and cumulonimbus cloud features |
| Update interval | Every 5 minutes |

### (2) Precipitation Nowcasts

Precipitation Nowcasts predict 10-minute accumulated precipitation and 5-minute-interval precipitation intensity by extrapolation up to one hour ahead. Initial precipitation intensity distribution is derived from radar data obtained at 5-minute intervals, and is calibrated by raingauge observation. Using estimated movement vectors, these forecasts predict precipitation distribution on the basis of extrapolation. Calculation takes approximately three minutes. These processes are scheduled to be replaced with the smoothing applied for 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 the public to help clarify precipitation transition and support disaster prevention activities.

**Table 4.4.1-2 Precipitation Nowcast model specifications**

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

### (3) Thunder Nowcasts

Thunder Nowcasts predict thunder and lightning activity up to an hour ahead. Initial activity distribution is derived from the lightning detection network system, radar data and Himawari-8/9 multiband observation conducted at 10-minute intervals. In consideration of estimated movement vectors, these forecasts predict activity distribution on the basis of extrapolation. Calculation takes approximately three minutes. The specifications are summarized in Table 4.4.1-3.

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

**Table 4.4.1-3 Thunder Nowcast model specifications**

| | |
|---|---|
| Forecast process | Extrapolation |
| Movement vector | As per the Precipitation Nowcast system |
| Grid form | Cylindrical equidistant projection |
| Resolution | Approx. 1 km |
| Number of grids | 2,560 × 3,360 |
| Initial | 4-level activity of thunder and lightning based on the lightning detection network system, radar data and Himawari-8/9 high-frequency multiband 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. Calculation takes approximately three minutes. The specifications are summarized in Table 4.4.1-4.
Hazardous Wind Potential Nowcasts are provided to local weather offices and the public to clarify the transition of areas with high potential for hazardous winds and call attention to related hazardous conditions.

**Table 4.4.1-4 Hazardous Wind Potential Nowcast model specifications**

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

## 4.4.1.2 Research performed in the field

### (1) Improvement of Thunder Nowcasts (4.4.1.1 (3))

The use of Himawari-8/9 high-frequency multiband data indicating rapidly developing cumulus cloud was started in July 2017 to improve the method for analysis of potential lightning areas (activity level 1).

### 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 data and raingauge precipitation data are analyzed every 30 minutes to create Radar/Raingauge Analyzed Precipitation (R/A) information with a resolution of 1 km. This involves the collection of radar echo intensity information from 46 weather radars operated by JMA and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and precipitation data from more than 10,000 raingauges operated by JMA, MLIT and local governments.

Radar intensity readings are collected to create one-hour cumulative radar precipitation data, and are calibrated with one-hour cumulative raingauge precipitation data. R/A is a composite of all calibrated and cumulative radar precipitation data. The initial field for extrapolation forecasting is a composite of calibrated radar intensity data.
Dissemination of “Immediate R/A” information every 10 minutes was started in July 2017. This involves the collection of information from the same number of the weather radar and the less number of raingauges in contrast to the “Regular R/A”.

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

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

Table 4.4.2-1 Extrapolation model specifications used in VSRFs

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

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

#### 4.4.2.2 Research performed in the field

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

The method used for heavy rain forecasting was improved in June 2017.

## 4.5 Specialized numerical predictions

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

#### 4.5.1.1 In operation

**(1) Global Ocean Data Assimilation System**

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

**Table 4.5.1-1 Global Ocean Data Assimilation System specifications**

| | |
|---|---|
| Basic equations | Primitive equations with free surface |
| Independent variables | Lat-lon coordinates and σ-z hybrid vertical coordinates |
| Dependent variables | Zonal and meridional velocities, temperature, salinity and sea surface height |
| Analysis variables | Sea-surface and subsurface temperature and salinity |
| Numerical technique | Finite difference both in the horizontal and in the vertical |
| Grid size | 1° (longitude) × 0.5° (latitude, smoothly decreasing to 0.3° toward the equator) grids |
| Vertical levels | 52 levels with a bottom boundary layer |
| Integration domain | Global oceans |
| Forcing data | Heat, water and momentum fluxes calculated using data from the JRA-55 Reanalysis |
| Observational data | Sea-surface and subsurface temperature and salinity and sea surface height |
| Operational runs | Two kinds of run (final and early) with cut-off times of 33 days and 2 day, respectively, for ocean observation data |

Outputs of MOVE/MRI.COM-G2 are used to monitor and diagnose tropical ocean status. Some figures based on MOVE/MRI.COM-G2 output are published in JMA’s *Monthly Highlights on Climate System* and provided through the Tokyo Climate Center (TCC) website (http://ds.data.jma.go.jp/tcc/tcc/index.html). The data are also used as oceanic initial conditions for JMA's coupled ocean-atmosphere model (JMA/MRI-CGCM2).

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

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

### (3) Ocean wave analysis

A wave data assimilation system for JMA's operational wave model was put into operation in October 2012. The system is described below.

1) Wave data are not assimilated directly; the system refers to analysis wave heights of the JMA Objective Wave Analysis System (OWAS). The specifications are shown in Table 4.5.1-2. The key factor for rectification is the ratio of wave heights between model products and OWAS products.

2) In modification, windsea and swell parts are extracted and modified. Windsea spectra are modified based on the JONSWAP spectrum profile, and the peak frequency is determined in consideration of Toba's power law. For swell spectrum modification, the system rescales swell spectrum by the ratio of wave heights between model products and OWAS products. For details of the wave analysis system, refer to Kohno et al. (2012).

**Table 4.5.1-2 JMA Objective Wave Analysis System (OWAS) specifications**

| | |
|---|---|
| Analysis scheme | Optimum interpolation |
| Data cut-off time | 6 hours and 25 minutes for early-run analysis<br>12 hours for delayed analysis |
| First guess | 6-hour forecast by the GWM |
| Analysis variables | Significant wave height |
| Grid size | 0.5° (longitude) × 0.5° (latitude) |
| Integration domain | Global oceans |
| Observational data | BUOY, SHIP, Nowphas, GPS wave meter, JASON3, SARAL |
| Assimilation window | 6 hours |

### 4.5.1.2 Research performed in the field

## 4.5.2 Specific models

### 4.5.2.1 In operation

#### (1) Environmental emergency response system

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

A Lagrangian method is adopted for the transport model, and large numbers of tracers are released at certain times and locations in line with pollutant emission information provided as part of related requests. Effects on three-dimensional advection and horizontal/vertical diffusion, dry and wet deposition and radioactive decay are computed from three-hourly outputs of the high-resolution global model (TL959L100). The standard products of the RSMC involve maps on trajectories, time-integrated low-level concentrations and total deposition up to 72 hours ahead.

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.

#### (2) Ocean-wave forecasting models

JMA operates four numerical wave models: the Global Wave Model (GWM), the Coastal Wave Model (CWM), the Wave Ensemble System (WENS), and the Shallow-water Wave Model (SWM). The GWM, CWM and WENS are based on MRI-III, which was developed at JMA's Meteorological Research Institute (MRI), and a major update was made to the current version in May 2007. The WENS has been operational since June 2016. The specifications of the models are given in Table 4.5.2.1 (2)-1.

JMA began calculating wave components (windsea and swell) for the GWM and CWM on 20 July 2016.

The SWM is based on the WAM, which was modified at the National Institute for Land and Infrastructure Management of MLIT and put into operation under a cooperative framework with MLIT’s Water and Disaster Management Bureau. The model is applied to *22 bay/limited sea*. The models’ specifications are given in Table 4.5.2.1 (2)-2.

**Table 4.5.2.1 (2)-1 Ocean-wave prediction model specifications**

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

**Table 4.5.2.1 (2)-2 Shallow-water wave model specifications**

| Model name | Shallow-water Wave Model |
|---|---|

| | | | |
|---|---|---|---|
| Model type | Spectral model (third-generation wave model) | | |
| Grid interval | 1’ × 1’ (1.7 km) | | |
| Spectral components | 1,260<br>(35 frequencies from 0.0418 to 1.1 Hz and 36 directions) | | |
| Grid form | Equal latitude-longitude grid on spherical coordinates | | |
| Areas | Domain name | Grid size | Integration domain |
| | Tokyo Bay | 37 × 43 | 35.05°N – 35.75°N<br>139.55°E – 140.15°E |
| | Ise Bay | 61 × 43 | 34.35°N – 35.05°N<br>136.45°E – 137.45°E |
| | Harima-Nada<br>Osaka Bay | 79 × 49 | 34.05°N – 34.85°N<br>134.15°E – 135.45°E |
| | Ariake Sea<br>Shiranui Sea | 43 × 73 | 32.05°N – 33.25°N<br>130.05°E – 130.75°E |
| | Off Niigata | 55 × 37 | 37.80°N – 38.40°N<br>138.35°E – 139.25°E |
| | Sendai Bay | 37 × 43 | 37.75°N – 38.45°N<br>140.90°E – 141.50°E |
| | Off Tomakomai | 121 × 43 | 42.00°N – 42.70°N<br>141.00°E – 143.00°E |
| | Suo-Nada<br>Iyo-Nada<br>Aki-Nada | 109 × 67 | 33.30°N – 34.40°N<br>131.00°E – 132.80°E |
| | Hiuchi-Nada | 103 × 73 | 33.60°N – 34.80°N<br>132.60°E – 134.30°E |
| | Off Shimane | 67 × 31 | 35.25°N – 35.75°N<br>132.55°E – 133.65°E |
| | Ishikari Bay | 49 × 43 | 43.10°N – 43.80°N<br>140.70°E – 141.50°E |
| | Off Ishikawa | 49 × 67 | 36.20°N – 37.30°N<br>136.00°E – 136.80°E |
| | Off Nemuro | 85 × 49 | 43.20°N – 44.00°N<br>145.00°E – 146.40°E |
| | Off Miyazaki | 31 × 73 | 31.50°N – 32.70°N<br>131.30°E – 131.80°E |
| | Tsugaru Strait | 61 × 67 | 40.75°N – 41.85°N<br>140.35°E – 141.35°E |
| | Off Ibaraki<br>Off Boso | 49 × 103 | 35.00°N – 36.70°N<br>140.20°E – 141.00°E |
| | Genkai-Nada | 83 × 43 | 33.40°N – 34.10°N,<br>129.55°E – 130.95°E |
| Forecast cycle | 4 times a day (every 6 hours) at initial times of 03, 09, 15 and 21 UTC | | |
| Forecast length | 39 hours | | |
| Forecast step interval | Hourly | | |
| Integration time step | Advection term: 1 minute<br>Source term: 1 minute | | |
| Assimilation | No (hindcast) | | |
| Surface forcing | Meso-Scale Model (MSM)<br>Bogus gradient winds (for typhoons in the western North Pacific) | | |
| Lateral boundary | Sea ice: analysis area regarded as land<br>CWM prediction used for boundary spectra | | |
| Shallow-water effects | Refraction and bottom friction | | |
| Product | Significant wave height, wave period and mean wave direction | | |

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

### (3) Storm-surge models

JMA operates two storm surge models. One is used 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 (3)-1.

**Table 4.5.2.1 (3)-1 Storm-surge model (Japan region) specifications**

| | |
|---|---|
| Basic equations | Two-dimensional shallow-water equations |
| Numerical technique | Explicit finite difference method |
| Integration domain | Coastal areas of Japan<br>(117.4°E – 150.0°E, 20.0°N – 50.0°N) |
| Grid | Adaptive Mesh Refinement (AMR) method<br>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) |

As part of JMA's contribution to the Storm Surge Watch Scheme (a WMO framework supporting member countries in the issuance of storm surge warnings), the Agency developed a storm surge model for the Asian region in 2010 in collaboration with Typhoon Committee Members who provided tidal observation and sea bathymetry data. The model uses the GSM for meteorological forcing. For TCs, in addition to the GSM and TC bogus, multi-scenario predictions are calculated for five selected scenarios from GEPS data. The resulting storm surge prediction information is provided to Typhoon Committee Members via JMA's Numerical Typhoon Prediction website. The model's specifications are given in Table 4.5.2.1 (3)-2.

Table 4.5.2.1 (3)-2 Storm-surge model (Asian region) specifications

| | |
|---|---|
| Basic equations | Two-dimensional linear shallow-water equations |
| Numerical technique | Explicit finite difference method |
| Integration domain | Coastal areas of Asia<br>(95.0°E – 160.0°E, 0.0°N – 46.0°N) |
| Grid | 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), Global EPS (GEPS) |
| | Bogus data for TCs (center) |
| Astronomical tides | Not included |

### (4) Ocean data assimilation system for the North Pacific Ocean

A 3D-Var ocean data assimilation system for the North Pacific is operated to represent ocean characteristics such as the movement of the Kuroshio current in the mid/high latitudes of the North Pacific with the specifications shown in Table 4.5.2.1 (4)-1. Data on ocean currents and several layers of subsurface water temperatures (products of this system) are available on the NEAR-GOOS Regional Real Time Database (https://www.data.jma.go.jp/gmd/goos/data/database.html).

Table 4.5.2.1 (4)-1 Specifications of the 3D-Var ocean data assimilation system for the North Pacific Ocean

| | |
|---|---|
| Basic equations | Primitive equations with free surface |
| Independent variables | Lat-lon coordinates and σ-z hybrid vertical coordinates |
| Dependent variables | Zonal/meridional velocities, temperature, salinity and sea surface height |
| Analysis variables | Sea-surface/subsurface temperature and salinity |
| Numerical technique | Finite difference both in the horizontal and in the vertical |
| Grid size | (1) Western North Pacific model<br>0.1° longitude × 0.1° latitude in the seas off Japan, decreasing to 0.166° toward the northern and eastern boundaries<br>(2) North Pacific model<br>0.5° longitude × 0.5° latitude |
| Vertical levels | 54 |
| Integration domain | (1) Western North Pacific model<br>From 15°N to 65°N between 115°E and 160°W<br>(2) North Pacific model<br>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 Global Ensemble Prediction System (GEPS) |
| Assimilation scheme | 3D-Var with 5-day windows |
| Observational data (as of 31 December 2017) | Sea-surface and subsurface temperature/salinity, sea surface height (Jason-3), sea ice concentration |
| Operational runs | 10-day assimilation and 30-day prediction are implemented every day |

### (5) 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 (5)-1).

**Table 4.5.2.1 (5)-1 Numerical sea-ice prediction model specifications**

| | |
|---|---|
| Dynamical processes | Viscous-plastic model (MMD/JMA 1993) – considering wind and seawater stress on sea ice, Coriolis force, force from the sea surface gradient and internal force |
| Physical processes | Heat exchange between sea ice, the atmosphere and seawater |
| Dependent variables | Concentration and thickness |
| Grid size and time step | 12.5 km and 6 hours |
| Integration domain | Seas around Hokkaido |
| Initial time and forecast time | 168 hours from 00 UTC (twice a week) |
| Initial condition | Concentration analysis derived from Himawari-8/9, NOAA and Metop satellite imagery; thickness estimated by hindcasting |

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

### (6) 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 (6)-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 (6)-1 Marine pollution transport model specifications**

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

### (7) Aeolian dust prediction model

JMA has operated an Aeolian dust prediction model since January 2004 to enable forecasting of Aeolian dust distribution. 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 in November 2014, and the horizontal resolution was enhanced from TL159 to TL479 in February 2017. The model consists of an atmospheric general circulation model (AGCM) called MRI-AGCM3 and a global aerosol model known as MASINGAR mk-2, which are linked with a coupler library called Scup (Yoshimura and Yukimoto 2008). The method of dust emission flux calculation was updated to encompass the scheme of Tanaka and Chiba (2005). The model's specifications are given in Table 4.5.2.1 (7)-1.

**Table 4.5.2.1 (7)-1 Aeolian dust prediction model specifications**

| | |
|---|---|
| Basic equations | Eulerian model coupled with the Global Spectral Model |
| Numerical technique | 3D semi-Lagrangian transport and dust emission calculation from surface meteorology |
| Integration domain | Global |
| Grid size | TL479 (0.375°) |
| 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 Global Spectral Model (GSM) forecasts |
| | Sea surface temperature (MGDSST) |

### (8) 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 (CTM) 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, and its horizontal resolution was enhanced from T42 to T106 (see Table 4.5.2.1 (8)-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 (8)-2.

**Table 4.5.2.1 (8)-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 Global Spectral Model (GSM) forecasts |
| Observational data | Column ozone from OMPS/NOAA |

**Table 4.5.2.1 (8)-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 |

### (9) Regional chemical transport model for photochemical oxidants

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

Since March 2015, numerical model prediction of photochemical oxidants has been carried out using a regional chemical transport model with finer spatial resolution (NHM-Chem; Kajino et al. 2012) driven with meteorological fields predicted using an offline non-hydrostatic atmospheric model (JMA-NHM). The related lateral boundary conditions for chemical species are given by MRI-CCM2 as described in 4.5.2.1 (8). The specifications of the regional chemical transport model are given in Table 4.5.2.1 (9)-1.

**Table 4.5.2.1 (9)-1 Specifications of the regional chemical transport model for photochemical oxidants**

| | |
|---|---|
| Model type | 3-dimensional Eulerian chemical transport model |
| Area | East Asia |
| Grid size | 20 km |
| Vertical layers | 18 (surface – 10 km) |
| Forecast time | 72 hours (initial time 12 UTC) |
| Emission inventories | REAS1.1, GFED3 and MEGAN2 |
| Meteorological fields | JMA-NHM output constrained and initialized using Global Analysis (GA) and Global Spectral Model (GSM) forecasts |
| Observational data | Surface $O_3$ concentration of Atmospheric Environmental Regional Observation System (AEROS) |

### (10) Mesoscale air pollution transport model

JMA also issues very-short-term photochemical smog bulletins on days when high oxidant concentration is expected. The bulletins provide an outlook for photochemical smog based on statistical guidance for oxidant concentration using data on weather elements and pollutant observation data as input. In addition to this statistical guidance, a mesoscale atmospheric transport model (Takano et al. 2007) is applied to very-short-range forecasting of oxidant concentrations with a grid interval of 10 km, with MSM output used to calculate the transport of highly concentrated pollutant masses in the air. Based on the oxidant forecast from the atmospheric transport model with an initial time of 03 UTC (noon in Japan), photochemical smog bulletins show hourly potential for afternoon smog in the northern part of the Kyushu region and the Kanto region, where the Tokyo metropolitan area is located.

### (11) Regional Atmospheric Transport Model (RATM) for volcanic ash

JMA introduced the Volcanic Ash Fall Forecast (VAFF) based on the Regional Atmospheric Transport Model (RATM) in March 2008 (Shimbori et al. 2009) and updated it in spring 2015 (Hasegawa et al. 2015). Three types of forecasts are sequentially provided: VAFFs (Scheduled) are issued periodically based on an assumed eruption for active volcanoes, VAFFs (Preliminary) are brief forecasts issued within 5 ― 10 minutes of an actual eruption, and VAFFs (Detailed) are more accurate forecasts issued within 20 ― 30 minutes of an actual eruption. The updated VAFFs provide information on expected ash/lapilli fall areas and/or amounts based on the RATM with LFM or MSM outputs. The specifications of RATM are given in Table 4.5.2.1 (11)-1.

**Table 4.5.2.1 (11)-1 Specifications of RATM for volcanic ash**

| | |
|---|---|
| Model type | Lagrangian description |
| Number of tracer particles | 100,000 (Scheduled, Preliminary)<br>250,000 (Detailed) |
| Time step | 1 minute (Preliminary)<br>3 minutes (Scheduled, Detailed) |
| Forecast time | 18 hours from the time of assumed eruption (Scheduled)<br>1 hour from the time of eruption (Preliminary)<br>6 hours from the time of eruption (Detailed) |
| Initial condition | Eruption column based on observational reports including eruption time and plume height, and continuance of volcanic-ash emissions |
| Meteorological field | Local Forecast Model (LFM) or Meso-Scale Model (MSM) |
| Processes | 3D advection, horizontal and vertical diffusion, volcanic-ash fallout, dry deposition and washout |

### (12) 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. The specifications of the GATM are given in

Table 4.5.2.1 (12)-1.

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

| | |
|---|---|
| Model type | Lagrangian description |
| Number of tracer particles | 40,000 |
| Time step | 10 minutes |
| Forecast coverage | 18 hours from the time of satellite observation |
| 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

A new storm surge model that solves governing equations using the finite volume method on an unstructured grid is currently being developed. The use of such a grid allows grid-size flexibility, which is expected to enable improvements in forecast accuracy and computational efficiency compared to current models. The new model will be incorporated into both storm surge prediction systems.

#### (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 (4)). 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 for aerosols using satellite sensors with a local ensemble transform Kalman filter (LETKF) (Sekiyama et al. 2010, 2016; Yumimoto et al. 2016 a, 2016 b) and a two-dimensional variational (2D-Var) (Yumimoto et al. 2017) data assimilation method 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 for stratospheric ozone using satellite data with LETKF (Sekiyama et al. 2011; Nakamura et al. 2013) and a 2D-Var data assimilation method has been developed. Verification and improvement of the system will be carried out toward operational application.

### (5) Regional chemical transport model

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

### (6) Volcanic ash concentration forecast

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

### (7) Improvement of initial conditions for volcanic ash forecasts

JMA is currently developing a method to improve data on the initial distribution of volcanic ash for numerical prediction using estimation of ash cloud thickness.

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

Based on discussions held at a 2015 meeting of the Expert Team on Emergency Response Activities (ET-ERA), a JMA expert took part in and organized a joint-RSMC Time of Arrival (ToA) product experiment conducted in June 2017. ToA products are designed to provide users with information on arrival times of toxic radioactive materials in the atmosphere along with specific contamination values to support environmental emergency response services. Specifications and procedures for the ToA system have not yet been established among related RSMCs. The results of the experiment will be discussed at the ET-ERA meeting planned for 2018.

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

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

### 4.5.3 Specific products operationally available

#### (1) 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. For the area of responsibility of the RSMC Tokyo - Typhoon Center, horizontal maps and time-series charts of storm surge predictions are provided to Typhoon Committee members via JMA's Numerical Typhoon Prediction website.

#### (2) Ocean wave forecast charts

Products from the ocean wave models shown in Table 4.2.3-1 are provided via JMA's radio facsimile broadcast (JMH) service. In addition to basic wave information such as significant wave height and wave direction, information on rough sea areas, which may be challenging for navigation, has been included in Wave Forecast Charts since March 2017. The information indicates areas of crossing waves and rough waves against currents, which make seas complex, high and chaotic.

#### (3) Aeolian dust products operationally available

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

#### (4) 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

As detailed in 4.2.5.1, JMA replaced the One-month EPS with the Global EPS (GEPS) in March 2017. The GEPS forecast range is extended from 11 to 18 days for initial times on Saturday and

Sunday and to 34 days for initial times on Tuesday and Wednesday. JMA's 18-day forecasts support the issuance of early warning information on extreme weather, and 34-day forecasts support one-month forecasting.

The specifications of the GEPS for forecasts longer than 11 days are shown in Table 4.6.1.1-1. The numerical prediction model applied for this system is a low-resolution version (TL479 up to 18 days and TL319 thereafter) of the GSM. The physical schemes and perturbation methods for forecasts longer than 11 days are shared with those for forecasts up to 11 days, while the prescription of sea ice and the combination of ensemble members are unique. Sea ice concentration for forecasts longer than 14 days is prescribed by adjusting the previous day's distribution so that initial sea ice extent anomalies in each hemisphere persist. In addition, because the ensemble size for each initial time is reduced from 27 to 13 for forecasts longer than 11 days due to limited computer resources, JMA adopts the Lagged Average Forecast (LAF) method composed of four 12-hour-interval forecasts for periods exceeding 11 days to ensure a significant ensemble member size and appropriate consideration of forecast uncertainty. Specifically, 50 members (13 from 12 UTC on Wednesday/Sunday, 13 from 00 UTC on Wednesday/Sunday, 13 from 12 UTC on Tuesday/Saturday and 11 from 00 UTC on Tuesday/Saturday) are used for the issuance of early warning information on extreme weather on Thursday/Monday and one-month forecasts on Thursday.

Table 4.6.1.1-1 Global EPS specifications for forecasts longer than 11 days

| | |
|---|---|
| Atmospheric model | GSM1603E |
| Integration domain | Global |
| Horizontal resolution | Spectral triangular 479 (TL479), reduced Gaussian grid system, roughly equivalent to 0.375 × 0.375° (40 km) in latitude and longitude for forecasts up to 18 days<br>Spectral triangular 319 (TL319), reduced Gaussian grid system, roughly equivalent to 0.5625 × 0.5625° (55 km) in latitude and longitude for forecasts longer than 18 days |
| Vertical levels (model top) | 100 stretched sigma pressure hybrid levels (0.01 hPa) |
| Forecast time | 18 days for initial times on Saturday and Sunday<br>34 days for initial times on Tuesday and Wednesday |
| Ensemble size | 50 members (13 from 12 UTC on Wednesday/Sunday, 13 from 00 UTC on Wednesday/Sunday, 13 from 12 UTC on Tuesday/Saturday and 11 from 00 UTC on Tuesday/Saturday) |

### 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<br>2.5° × 2.5° | Base time:<br>00 UTC of Wednesday<br>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 members | Sea level pressure* | - | | Base time :<br>00 UTC of Tuesday and Wednesday |
| | Rainfall amount | - | | |
| | Temperature* | Surf,<br>1000, 850, 700, 500, 300, 200, 100 | | |

| | | | | |
|---|---|---|---|---|
| | Relative humidity | 1000, 850, 700, 500, 300 | | Forecast time: 0, 1, 2,..., 31, 32 days from base time |
| | 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<br>Temperature at 850 hPa and its anomaly<br>Sea level pressure and its anomaly<br>Stream function at 200 hPa and its anomaly<br>Stream function at 850 hPa and its anomaly<br>Velocity potential at 200 hPa and its anomaly<br>Precipitation and its anomaly<br>Temperature at 2 m and its anomaly<br>Sea surface temperature (prescribed) |

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

### 4.7.1 Models

#### 4.7.1.1 In operation

JMA operates its Seasonal Ensemble Prediction System (Seasonal EPS; JMA/MRI-CPS2) using an atmosphere-ocean coupled model (JMA/MRI-CGCM2) for three-month, warm/cold season and El Niño outlooks. The current system was upgraded in June 2015. The 51-member ensemble is used for the three-month forecast issued every month and for the warm/cold season forecasts issued five times a year (in February, March, April, September and October). The El Niño outlook is also issued based on the same model results.

The JMA/MRI-CGCM2 was developed by the Meteorological Research Institute and the Climate Prediction Division of JMA. Its specifications are shown in Table 4.7.1-1. Atmospheric and land surface initial conditions are taken from JRA-55 data (Kobayashi et al. 2015; 4.6.1.2), while oceanic and sea ice initial conditions are taken from MOVE/MRI-COM-G2 (4.5.1.1 (1)). The EPS adopts a combination of the LAF method and the initial perturbation method described below. Thirteen-member ensemble predictions are made every five days, and atmospheric initial perturbations for each initial date are obtained using the BGM method. Oceanic initial perturbations are obtained with MOVE/MRI.COM-G2 forced by the surface heat and momentum fluxes of atmospheric initial perturbation fields using the BGM method.

Table 4.7.1-1 Seasonal EPS specifications

| | | |
|---|---|---|
| Model | JMA/MRI-CGCM2<br>An atmosphere-ocean coupled model rather than a Tier-2 system | |
| Atmospheric model | Model type | GSM1011C |
| | Horizontal resolution | Global TL159 reduced Gaussian grid system roughly equivalent to 1.125 × 1.125° (110 km) in latitude and longitude |
| | Vertical levels (model top) | 60 levels (0.1 hPa) |
| Oceanic model | Model type | MRI.COM v3.2 |
| | Horizontal resolution | 1 (longitude) × 0.5˚ (latitude, smoothly decreasing to 0.3˚ toward the equator) grids |
| | Vertical levels | 52 levels with a bottom boundary layer |
| Sea ice model | Model type | Dynamical sea ice model |
| Coupling | Coupling interval | 1 hour |
| | Flux adjustment | None |
| Forecast period | 7 months | |
| Model run frequency | Once every 5 days | |
| Perturbation generator | Combination of the breeding of growing mode (BGM) method and the LAF method | |
| Initial atmospheric conditions | Near-real-time operation of JRA-55 (Kobayashi et al. 2015) | |
| Initial ocean conditions | MOVE/MRI.COM-G2 (Toyoda et al. 2013) | |
| Ensemble size | 51 members per month | |
| Hindcast | Two initial dates per month for the 36 years from 1979 to 2014<br>Ensemble size: five for each initial date<br>Ensemble generated via combined application of BGM and LAF methods | |
| Timing of anomaly prediction for the next month/season | Variable (around the 20th of the month) | |
| Forecast anomaly determination method | Against climatology (30-year average for the period from 1981 to 2010) | |
| URL | http://ds.data.jma.go.jp/tcc/tcc/index.html | |
| Contact | tcc@met.kishou.go.jp | |

### 4.7.2 Operationally available EPS LRF products

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

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

The following model output products (Tables 4.7.2-1 and 4.7.2-2) for three-month and warm/cold-season forecasts are provided via the Tokyo Climate Center (TCC) website (http://ds.data.jma.go.jp/tcc/tcc/index.html).

**Table 4.7.2-1 Gridded data products (GRIB2) for three-month and warm/cold-season forecasts provided via the TCC website**

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

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

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

| | Forecast time | Parameter |
|---|---|---|
| Ensemble mean, its anomaly and spread | Three-month forecast:<br>Averages of first month, second month, third month, and three months<br><br>Warm/cold season forecast:<br>Averages of three months (JJA or DJF) | Geopotential height at 500 hPa, related anomaly and spread<br>Temperature at 850 hPa, its anomaly and spread<br>Sea level pressure, its anomaly and spread<br>Stream function at 200 hPa, its anomaly and spread<br>Stream function at 850 hPa, its anomaly and spread<br>Wind (u,v) anomaly at 850 hPa<br>Velocity potential at 200 hPa, its anomaly and spread<br>Precipitation, its anomaly and spread<br>Temperature at 2 m, its anomaly and spread<br>Sea surface temperature and its anomaly |

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

| Index | Description | Coordinates |
|---|---|---|
| Niño.1+2 | Region off coasts of Peru and Chile | 90°W – 80°W, 10°S – 0° |
| Niño.3 | Eastern/Central Tropical Pacific | 150°W – 90°W, 5°S – 5°N |

| | | |
|---|---|---|
| Niño3.4 | Central Tropical Pacific | 170°W – 120°W, 5°S – 5°N |
| Niño.4 | Western/Central Tropical Pacific | 160°E – 150°W, 5°S – 5°N |
| TNA | Tropical North Atlantic | 55°W – 15°W, 5°N – 25°N |
| TSA | Tropical South Atlantic | 30°W – 10°E, 20°S – 0° |
| TAD | Tropical Atlantic Dipole | TNA – TSA |
| WTIO | Western Tropical Indian Ocean | 50°E – 70°E, 10°S – 10°N |
| SETIO | Southeastern Tropical Indian Ocean | 90°E – 110°E, 10°S – 0° |
| IOD | Indian Ocean Dipole | WTIO – SETIO |

## 5. Verification of prognostic products

### 5.1 Annual verification summary

### 5.1.1 NWP prognostic products

Prognostic products are objectively verified against analysis and radiosonde observations according to the WMO/CBS standardized procedures for verification of deterministic NWP products as defined in the Manual on the Global Data-processing and Forecasting System.

The results of monthly verification for 2017 are presented in Tables 5.1.1-1 – 5.1.1-20. All verification scores are only for prediction from 1200 UTC initials, and are computed using procedures approved at the 16th WMO Congress in 2011.

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 8.4 | 8.1 | 7.6 | 6.6 | 6.4 | 6.4 | 5.7 | 5.9 | 6.4 | 7.0 | 6.7 | 7.9 | 7.0 |
| 72 | 27.3 | 25.9 | 24.9 | 21.9 | 21.4 | 20.5 | 18.3 | 19.3 | 20.2 | 23.4 | 21.8 | 25.8 | 22.7 |
| 120 | 56.1 | 51.1 | 50.9 | 44.7 | 45.6 | 41.0 | 36.0 | 38.6 | 41.6 | 50.6 | 47.0 | 52.4 | 46.7 |

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

Southern Hemisphere (20–90˚S)

| Hours | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 7.3 | 7.8 | 7.9 | 8.1 | 8.6 | 8.5 | 9.3 | 8.8 | 9.0 | 8.2 | 7.8 | 7.1 | 8.2 |
| 72 | 22.4 | 26.1 | 25.6 | 28.7 | 32.7 | 29.3 | 33.6 | 31.1 | 31.5 | 28.4 | 26.4 | 22.8 | 28.4 |
| 120 | 43.1 | 48.6 | 50.8 | 61.0 | 65.6 | 59.8 | 66.8 | 60.3 | 63.4 | 58.4 | 50.5 | 45.2 | 56.7 |

**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 | Annu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

|  |  |  |  |  |  |  |  |  |  |  |  |  | al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 12.8 | 13.2 | 12.7 | 10.1 | 10.3 | 9.5 | 8.6 | 9.1 | 9.7 | 11.4 | 11.4 | 13.2 | 11.1 |
| 72 | 32.3 | 34.7 | 27.6 | 23.2 | 23.4 | 19.6 | 14.9 | 15.9 | 20.2 | 27.2 | 25.4 | 30.1 | 25.2 |
| 120 | 57.5 | 61.5 | 52.1 | 42.3 | 44.3 | 35.3 | 28.2 | 28.0 | 36.5 | 51.0 | 47.5 | 66.4 | 47.4 |
| ob. num. | 89 | 90 | 90 | 84 | 86 | 87 | 87 | 86 | 87 | 87 | 88 | 88 |  |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 16.5 | 16.0 | 14.0 | 12.8 | 11.0 | 10.6 | 9.8 | 10.3 | 11.7 | 13.6 | 14.9 | 15.7 | 13.2 |
| 72 | 33.5 | 30.8 | 33.8 | 25.3 | 21.8 | 22.4 | 19.7 | 21.4 | 23.1 | 26.5 | 24.5 | 28.8 | 26.3 |
| 120 | 70.5 | 55.9 | 67.7 | 46.9 | 46.8 | 38.5 | 36.7 | 43.6 | 45.7 | 59.9 | 56.3 | 59.2 | 53.4 |
| ob. num. | 55 | 56 | 54 | 52 | 52 | 52 | 52 | 53 | 53 | 51 | 52 | 53 |  |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 14.4 | 14.1 | 14.0 | 12.9 | 12.1 | 11.8 | 11.2 | 11.3 | 10.8 | 12.2 | 12.5 | 13.7 | 12.6 |
| 72 | 24.2 | 22.7 | 22.7 | 22.5 | 22.2 | 19.1 | 17.4 | 19.2 | 17.9 | 21.0 | 19.4 | 23.0 | 21.1 |
| 120 | 46.0 | 39.0 | 37.2 | 39.9 | 42.1 | 33.7 | 26.4 | 31.8 | 34.8 | 38.4 | 35.1 | 41.6 | 37.5 |
| ob. num. | 128 | 128 | 129 | 128 | 128 | 128 | 124 | 123 | 125 | 125 | 126 | 123 |  |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 11.4 | 11.3 | 11.4 | 10.4 | 9.9 | 11.6 | 12.4 | 13.8 | 14.1 | 13.7 | 13.0 | 13.2 | 12.3 |
| 72 | 15.8 | 20.7 | 22.1 | 18.6 | 22.6 | 25.0 | 25.4 | 27.0 | 27.1 | 25.9 | 21.5 | 18.7 | 22.8 |
| 120 | 29.3 | 38.7 | 43.4 | 35.8 | 46.1 | 50.5 | 47.5 | 53.9 | 47.6 | 39.9 | 37.0 | 33.8 | 42.6 |
| ob. num. | 9 | 9 | 9 | 8 | 8 | 8 | 11 | 11 | 11 | 10 | 11 | 11 |  |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 14.3 | 14.1 | 13.6 | 12.4 | 11.9 | 11.4 | 10.9 | 11.0 | 11.4 | 12.4 | 12.8 | 14.1 | 12.6 |
| 72 | 29.7 | 28.8 | 27.2 | 24.5 | 23.7 | 22.0 | 19.1 | 20.1 | 21.5 | 24.9 | 23.7 | 27.7 | 24.6 |
| 120 | 57.6 | 52.3 | 51.3 | 44.7 | 46.0 | 39.1 | 33.8 | 37.4 | 40.3 | 50.3 | 46.3 | 55.2 | 46.7 |
| ob. num. | 392 | 395 | 394 | 378 | 380 | 379 | 376 | 374 | 376 | 378 | 379 | 377 |  |

**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 | Annu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 12.0 | 12.7 | 12.4 | 12.6 | 13.0 | 13.8 | 14.9 | 14.8 | 14.7 | 13.5 | 13.8 | 13.2 | 13.5 |
| 72 | 18.6 | 22.6 | 23.3 | 24.0 | 26.5 | 26.2 | 28.6 | 27.8 | 29.2 | 24.6 | 23.9 | 21.1 | 24.9 |
| 120 | 31.4 | 36.3 | 43.1 | 41.5 | 49.1 | 45.6 | 50.8 | 49.1 | 50.7 | 44.2 | 42.0 | 35.6 | 43.7 |
| ob. num. | 37 | 37 | 35 | 34 | 36 | 37 | 40 | 39 | 39 | 39 | 42 | 40 | |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 3.5 | 3.5 | 3.6 | 3.6 | 3.6 | 3.6 | 3.5 | 3.5 | 3.5 | 3.4 | 3.4 | 3.5 | 3.5 |
| 72 | 8.2 | 7.8 | 8.0 | 7.9 | 8.3 | 8.5 | 8.2 | 8.3 | 8.4 | 8.4 | 7.7 | 8.1 | 8.2 |
| 120 | 13.9 | 13.0 | 13.7 | 12.7 | 13.7 | 13.8 | 12.7 | 13.4 | 13.6 | 14.7 | 13.4 | 14.1 | 13.6 |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 3.3 | 3.3 | 3.4 | 3.4 | 3.6 | 3.4 | 3.5 | 3.5 | 3.4 | 3.5 | 3.5 | 3.3 | 3.4 |
| 72 | 8.0 | 8.5 | 8.3 | 8.5 | 9.2 | 8.5 | 9.1 | 8.7 | 8.6 | 8.3 | 8.5 | 8.0 | 8.5 |
| 120 | 13.0 | 13.9 | 14.1 | 15.0 | 15.6 | 14.5 | 15.2 | 14.5 | 14.7 | 13.7 | 13.5 | 12.9 | 14.2 |

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

North America

| Hours | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 6.3 | 6.2 | 5.9 | 6.4 | 6.6 | 5.8 | 5.6 | 5.5 | 5.5 | 5.5 | 5.5 | 5.6 | 5.9 |
| 72 | 11.0 | 10.9 | 10.3 | 10.8 | 10.7 | 10.1 | 9.0 | 9.1 | 10.0 | 10.7 | 10.1 | 10.6 | 10.3 |
| 120 | 16.9 | 16.9 | 16.6 | 15.9 | 16.4 | 15.1 | 12.5 | 12.8 | 15.1 | 16.6 | 16.3 | 19.2 | 16.0 |
| ob. num. | 88 | 88 | 87 | 82 | 84 | 85 | 85 | 84 | 85 | 85 | 86 | 87 | |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 4.9 | 5.0 | 5.1 | 4.5 | 4.7 | 5.1 | 5.0 | 5.1 | 5.5 | 4.8 | 5.0 | 5.2 | 5.0 |
| 72 | 9.1 | 10.2 | 9.8 | 7.9 | 8.6 | 8.8 | 9.3 | 10.0 | 10.3 | 9.5 | 8.5 | 9.3 | 9.3 |
| 120 | 17.4 | 17.8 | 17.6 | 13.0 | 15.4 | 14.6 | 14.7 | 16.9 | 17.9 | 16.9 | 16.8 | 17.5 | 16.4 |
| ob. num. | 57 | 57 | 55 | 54 | 54 | 54 | 54 | 55 | 55 | 53 | 54 | 54 | |

**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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 4.9 | 5.4 | 5.9 | 6.5 | 6.6 | 6.6 | 5.8 | 5.7 | 5.5 | 4.8 | 4.4 | 4.8 | 5.6 |
| 72 | 7.9 | 7.8 | 9.1 | 10.0 | 10.9 | 10.4 | 9.3 | 9.3 | 8.6 | 7.7 | 6.7 | 7.5 | 8.8 |
| 120 | 12.2 | 11.0 | 11.9 | 13.9 | 14.9 | 14.9 | 12.5 | 12.9 | 12.4 | 11.5 | 10.2 | 11.3 | 12.6 |
| ob. | 150 | 150 | 151 | 147 | 147 | 147 | 141 | 142 | 145 | 145 | 145 | 144 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| num. | | | | | | | | | | | | |

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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 4.8 | 5.2 | 5.4 | 5.8 | 5.0 | 5.2 | 5.1 | 5.3 | 5.4 | 5.5 | 5.7 | 5.5 | 5.3 |
| 72 | 6.8 | 7.7 | 9.2 | 8.9 | 7.9 | 8.7 | 8.0 | 8.1 | 9.1 | 8.4 | 8.5 | 8.9 | 8.4 |
| 120 | 10.2 | 11.8 | 11.9 | 12.3 | 12.6 | 14.3 | 12.3 | 14.0 | 12.2 | 12.9 | 11.1 | 11.3 | 12.3 |
| ob. num. | 10 | 9 | 10 | 9 | 10 | 10 | 13 | 12 | 12 | 11 | 14 | 14 | |

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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 5.1 | 5.3 | 5.4 | 5.7 | 5.8 | 5.7 | 5.4 | 5.3 | 5.2 | 4.8 | 4.7 | 4.9 | 5.3 |
| 72 | 8.9 | 8.9 | 9.2 | 9.2 | 9.8 | 9.8 | 9.2 | 9.3 | 9.2 | 8.9 | 8.1 | 8.7 | 9.1 |
| 120 | 14.3 | 14.1 | 14.2 | 13.7 | 14.9 | 14.7 | 13.4 | 14.1 | 14.2 | 14.6 | 13.3 | 14.8 | 14.2 |
| ob. num. | 413 | 416 | 415 | 398 | 401 | 401 | 399 | 397 | 398 | 398 | 400 | 397 | |

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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 5.1 | 5.4 | 5.3 | 5.7 | 5.8 | 5.4 | 5.7 | 5.9 | 5.7 | 6.4 | 5.8 | 5.4 | 5.6 |
| 72 | 8.4 | 8.4 | 8.8 | 9.1 | 9.4 | 8.8 | 9.6 | 9.4 | 9.8 | 9.3 | 8.6 | 8.3 | 9.0 |
| 120 | 11.6 | 12.6 | 13.4 | 14.4 | 14.5 | 13.8 | 14.5 | 14.0 | 14.2 | 13.6 | 12.5 | 11.7 | 13.4 |
| ob. num. | 40 | 40 | 38 | 38 | 39 | 41 | 44 | 43 | 42 | 43 | 45 | 45 | |

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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 1.5 | 1.4 | 1.5 | 1.4 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.4 | 1.5 | 1.5 |
| 72 | 2.7 | 2.6 | 2.7 | 2.5 | 2.5 | 2.5 | 2.7 | 2.7 | 2.8 | 2.7 | 2.5 | 2.7 | 2.6 |
| 120 | 3.4 | 3.2 | 3.4 | 3.2 | 3.1 | 3.1 | 3.4 | 3.4 | 3.6 | 3.4 | 3.1 | 3.5 | 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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 3.1 | 3.1 | 3.0 | 2.9 | 2.9 | 3.1 | 3.2 | 3.2 | 3.1 | 3.1 | 3.0 | 3.2 | 3.1 |
| 72 | 5.7 | 5.7 | 5.5 | 5.3 | 5.4 | 5.6 | 5.6 | 5.7 | 5.6 | 5.7 | 5.6 | 5.9 | 5.6 |
| 120 | 7.6 | 7.4 | 7.3 | 7.0 | 7.2 | 7.2 | 7.1 | 7.1 | 7.2 | 7.4 | 7.3 | 7.7 | 7.3 |

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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 3.5 | 3.4 | 3.5 | 3.3 | 3.2 | 3.3 | 3.4 | 3.3 | 3.4 | 3.5 | 3.2 | 3.5 | 3.4 |
| 72 | 4.2 | 4.0 | 4.1 | 3.7 | 3.7 | 3.9 | 4.1 | 3.8 | 4.2 | 4.1 | 4.0 | 4.1 | 4.0 |
| 120 | 4.7 | 4.3 | 4.5 | 4.2 | 3.9 | 4.2 | 4.7 | 4.6 | 4.9 | 4.9 | 4.5 | 4.8 | 4.5 |
| ob. num. | 70 | 71 | 72 | 71 | 70 | 68 | 63 | 64 | 65 | 67 | 66 | 65 | |

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 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 5.1 | 5.1 | 4.9 | 4.6 | 4.5 | 4.7 | 4.8 | 4.9 | 4.9 | 5.1 | 4.6 | 4.8 | 4.8 |
| 72 | 6.6 | 6.7 | 6.2 | 5.8 | 6.0 | 6.4 | 6.4 | 6.3 | 6.7 | 6.5 | 6.1 | 6.4 | 6.3 |
| 120 | 7.8 | 7.8 | 7.3 | 7.0 | 7.0 | 8.0 | 7.8 | 7.6 | 7.9 | 7.8 | 7.3 | 7.6 | 7.6 |
| ob. num. | 72 | 72 | 73 | 73 | 71 | 70 | 64 | 65 | 66 | 68 | 67 | 66 | |

The Global EPS is verified against analysis values in line with 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 2017 (December in 2016) are shown in Tables 5.1.1-21 – 5.1.1-26. Results for the period from March 2014 to December 2016 have been corrected due to a calculation error in the verification process. The adjusted results are provided on the website of the Lead Centre for Verification of Ensemble Prediction Systems.

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 | 0.923 | 0.908 | 0.876 | 0.914 | 0.905 | 0.913 | 0.888 | 0.840 | 0.896 | 0.884 | 0.896 | 0.843 | 0.771 | 0.862 | 0.843 |
| 72 | 0.792 | 0.762 | 0.715 | 0.781 | 0.762 | 0.774 | 0.710 | 0.659 | 0.750 | 0.723 | 0.737 | 0.649 | 0.557 | 0.690 | 0.658 |
| 120 | 0.617 | 0.569 | 0.524 | 0.608 | 0.580 | 0.592 | 0.504 | 0.443 | 0.575 | 0.529 | 0.533 | 0.418 | 0.316 | 0.498 | 0.441 |
| 168 | 0.424 | 0.375 | 0.339 | 0.413 | 0.388 | 0.395 | 0.314 | 0.246 | 0.364 | 0.330 | 0.328 | 0.245 | 0.106 | 0.293 | 0.243 |
| 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 | 0.905 | 0.902 | 0.872 | 0.899 | 0.895 | 0.880 | 0.883 | 0.842 | 0.884 | 0.872 | 0.834 | 0.849 | 0.809 | 0.863 | 0.839 |
| 72 | 0.725 | 0.718 | 0.653 | 0.729 | 0.706 | 0.667 | 0.673 | 0.585 | 0.690 | 0.654 | 0.587 | 0.615 | 0.515 | 0.638 | 0.589 |
| 120 | 0.509 | 0.494 | 0.419 | 0.493 | 0.479 | 0.423 | 0.436 | 0.330 | 0.447 | 0.409 | 0.312 | 0.354 | 0.231 | 0.388 | 0.321 |
| 168 | 0.318 | 0.288 | 0.215 | 0.279 | 0.275 | 0.237 | 0.239 | 0.132 | 0.238 | 0.212 | 0.122 | 0.157 | 0.054 | 0.187 | 0.130 |

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 | 0.837 | 0.816 | 0.765 | 0.803 | 0.805 | 0.796 | 0.771 | 0.730 | 0.777 | 0.768 | 0.757 | 0.720 | 0.673 | 0.756 | 0.726 |
| 72 | 0.675 | 0.629 | 0.560 | 0.619 | 0.621 | 0.615 | 0.560 | 0.507 | 0.580 | 0.565 | 0.553 | 0.481 | 0.427 | 0.549 | 0.503 |
| 120 | 0.498 | 0.452 | 0.380 | 0.465 | 0.449 | 0.441 | 0.368 | 0.316 | 0.425 | 0.388 | 0.371 | 0.273 | 0.227 | 0.376 | 0.312 |
| 168 | 0.332 | 0.266 | 0.207 | 0.293 | 0.274 | 0.286 | 0.202 | 0.142 | 0.259 | 0.222 | 0.212 | 0.123 | 0.056 | 0.212 | 0.151 |
| 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 | 0.830 | 0.833 | 0.761 | 0.821 | 0.811 | 0.775 | 0.794 | 0.715 | 0.771 | 0.764 | 0.690 | 0.758 | 0.637 | 0.715 | 0.700 |
| 72 | 0.659 | 0.648 | 0.540 | 0.647 | 0.624 | 0.580 | 0.593 | 0.477 | 0.586 | 0.559 | 0.462 | 0.553 | 0.390 | 0.513 | 0.480 |
| 120 | 0.454 | 0.453 | 0.345 | 0.464 | 0.429 | 0.365 | 0.399 | 0.280 | 0.397 | 0.360 | 0.215 | 0.347 | 0.205 | 0.308 | 0.269 |
| 168 | 0.269 | 0.265 | 0.176 | 0.272 | 0.245 | 0.190 | 0.216 | 0.130 | 0.206 | 0.186 | 0.061 | 0.167 | 0.067 | 0.125 | 0.105 |

**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 | 0.701 | 0.757 | 0.731 | 0.723 | 0.728 | 0.593 | 0.671 | 0.701 | 0.682 | 0.662 | 0.409 | 0.556 | 0.609 | 0.646 | 0.555 |
| 72 | 0.579 | 0.552 | 0.563 | 0.597 | 0.573 | 0.462 | 0.471 | 0.559 | 0.586 | 0.519 | 0.342 | 0.368 | 0.469 | 0.542 | 0.430 |
| 120 | 0.496 | 0.384 | 0.433 | 0.492 | 0.451 | 0.411 | 0.343 | 0.433 | 0.506 | 0.423 | 0.331 | 0.274 | 0.354 | 0.480 | 0.360 |
| 168 | 0.378 | 0.160 | 0.281 | 0.322 | 0.285 | 0.286 | 0.145 | 0.291 | 0.336 | 0.265 | 0.182 | 0.117 | 0.269 | 0.312 | 0.220 |
| 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 | 0.726 | 0.757 | 0.725 | 0.722 | 0.733 | 0.681 | 0.756 | 0.732 | 0.700 | 0.717 | 0.656 | 0.732 | 0.736 | 0.713 | 0.709 |
| 72 | 0.450 | 0.496 | 0.399 | 0.439 | 0.446 | 0.353 | 0.481 | 0.417 | 0.386 | 0.409 | 0.249 | 0.374 | 0.384 | 0.419 | 0.357 |
| 120 | 0.283 | 0.323 | 0.201 | 0.232 | 0.259 | 0.164 | 0.270 | 0.210 | 0.208 | 0.213 | 0.052 | 0.151 | 0.210 | 0.212 | 0.156 |
| 168 | -0.150 | 0.001 | -0.008 | -0.253 | -0.103 | -0.260 | -0.039 | 0.005 | -0.270 | -0.141 | -0.354 | -0.031 | -0.004 | -0.083 | -0.118 |

**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 | 0.474 | 0.548 | 0.487 | 0.471 | 0.495 | 0.377 | 0.482 | 0.429 | 0.424 | 0.428 | 0.294 | 0.438 | 0.365 | 0.375 | 0.368 |
| 72 | 0.181 | 0.251 | 0.225 | 0.192 | 0.212 | 0.011 | 0.207 | 0.189 | 0.176 | 0.146 | -0.144 | 0.177 | 0.156 | 0.151 | 0.085 |
| 120 | 0.103 | 0.134 | 0.110 | 0.094 | 0.110 | -0.032 | 0.120 | 0.098 | 0.093 | 0.070 | -0.120 | 0.100 | 0.081 | 0.074 | 0.034 |
| 168 | 0.087 | 0.066 | 0.031 | 0.030 | 0.053 | 0.013 | 0.074 | 0.035 | 0.037 | 0.040 | -0.014 | 0.069 | 0.034 | 0.022 | 0.028 |
| 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 | 0.622 | 0.626 | 0.536 | 0.605 | 0.597 | 0.590 | 0.604 | 0.474 | 0.549 | 0.554 | 0.546 | 0.571 | 0.392 | 0.488 | 0.499 |
| 72 | 0.386 | 0.374 | 0.277 | 0.380 | 0.354 | 0.335 | 0.347 | 0.231 | 0.325 | 0.309 | 0.275 | 0.314 | 0.172 | 0.276 | 0.259 |
| 120 | 0.274 | 0.251 | 0.128 | 0.265 | 0.229 | 0.220 | 0.245 | 0.095 | 0.211 | 0.193 | 0.158 | 0.219 | 0.050 | 0.164 | 0.148 |
| 168 | 0.200 | 0.136 | 0.023 | 0.180 | 0.135 | 0.155 | 0.142 | -0.002 | 0.136 | 0.108 | 0.107 | 0.125 | -0.035 | 0.100 | 0.074 |

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 | 0.879 | 0.921 | 0.929 | 0.921 | 0.913 | 0.856 | 0.904 | 0.910 | 0.911 | 0.895 | 0.820 | 0.874 | 0.874 | 0.878 | 0.861 |
| 72 | 0.713 | 0.764 | 0.791 | 0.774 | 0.761 | 0.682 | 0.729 | 0.751 | 0.746 | 0.727 | 0.598 | 0.664 | 0.646 | 0.661 | 0.642 |
| 120 | 0.515 | 0.573 | 0.592 | 0.583 | 0.566 | 0.468 | 0.509 | 0.520 | 0.533 | 0.508 | 0.354 | 0.395 | 0.383 | 0.422 | 0.388 |
| 168 | 0.326 | 0.367 | 0.396 | 0.379 | 0.367 | 0.261 | 0.302 | 0.328 | 0.321 | 0.303 | 0.154 | 0.197 | 0.200 | 0.221 | 0.193 |
| 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 | 0.886 | 0.900 | 0.905 | 0.911 | 0.900 | 0.872 | 0.881 | 0.887 | 0.894 | 0.883 | 0.856 | 0.866 | 0.854 | 0.882 | 0.864 |
| 72 | 0.689 | 0.703 | 0.707 | 0.741 | 0.710 | 0.656 | 0.649 | 0.659 | 0.701 | 0.666 | 0.608 | 0.613 | 0.574 | 0.671 | 0.616 |
| 120 | 0.485 | 0.468 | 0.480 | 0.529 | 0.491 | 0.425 | 0.385 | 0.414 | 0.477 | 0.425 | 0.345 | 0.310 | 0.335 | 0.429 | 0.355 |
| 168 | 0.283 | 0.262 | 0.269 | 0.340 | 0.289 | 0.218 | 0.190 | 0.197 | 0.281 | 0.222 | 0.135 | 0.127 | 0.120 | 0.224 | 0.151 |

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

| Hour | T850 anomaly +1.0 standard deviation | | | | | T850 anomaly +1.5 standard deviation | | | | | T850 anomaly +2.0 standard deviation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DJF | MAM | JJA | SON | Annual | DJF | MAM | JJA | SON | Annual | DJF | MAM | JJA | SON | Annual |
| 24 | 0.799 | 0.830 | 0.826 | 0.835 | 0.823 | 0.755 | 0.801 | 0.783 | 0.814 | 0.788 | 0.726 | 0.748 | 0.743 | 0.800 | 0.754 |
| 72 | 0.593 | 0.632 | 0.631 | 0.643 | 0.625 | 0.512 | 0.574 | 0.564 | 0.612 | 0.565 | 0.440 | 0.486 | 0.504 | 0.584 | 0.503 |
| 120 | 0.418 | 0.435 | 0.438 | 0.462 | 0.439 | 0.319 | 0.360 | 0.367 | 0.428 | 0.368 | 0.232 | 0.277 | 0.304 | 0.390 | 0.300 |
| 168 | 0.262 | 0.252 | 0.271 | 0.291 | 0.269 | 0.167 | 0.183 | 0.220 | 0.261 | 0.208 | 0.086 | 0.118 | 0.180 | 0.229 | 0.153 |
| 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 | 0.814 | 0.830 | 0.836 | 0.837 | 0.829 | 0.780 | 0.792 | 0.802 | 0.805 | 0.795 | 0.753 | 0.722 | 0.718 | 0.759 | 0.738 |
| 72 | 0.619 | 0.634 | 0.641 | 0.650 | 0.636 | 0.575 | 0.586 | 0.590 | 0.615 | 0.591 | 0.564 | 0.492 | 0.470 | 0.567 | 0.523 |
| 120 | 0.451 | 0.441 | 0.435 | 0.464 | 0.448 | 0.417 | 0.383 | 0.375 | 0.421 | 0.399 | 0.432 | 0.286 | 0.273 | 0.388 | 0.345 |
| 168 | 0.296 | 0.259 | 0.248 | 0.286 | 0.272 | 0.284 | 0.206 | 0.184 | 0.247 | 0.230 | 0.313 | 0.141 | 0.102 | 0.230 | 0.196 |

## 5.2 Research performed in the field

## 6. Plans for the future (next 4 years)

### 6.1 Development of the GDPFS

#### 6.1.1 Major changes expected in the next year

(1) The ninth-generation supercomputer system used for numerical analysis/prediction and satellite data processing will be upgraded to the tenth-generation system.

(2) The GSM forecast range will be extended from 84 to 132 hours at 00, 06 and 18 UTC initials.

(3) Meteosat-11, GOES-16 AMV and CSR data will be incorporated into the global NWP system.

(4) CSR data collected from Himawari-8 bands 9 and 10 over land surfaces will be incorporated into the global NWP system.

(5) CSR data from Meteosat-8 and -11 channel 6 will be incorporated into the global NWP system. The thinning method will also be simultaneously improved.

(6) The model run frequency of the Wave Ensemble System (WENS) will be increased from once a day at 12 UTC to twice a day at 00 and 12 UTC in June 2018.

(7) The frequency of Global EPS forecasts from 264 to 432 hours will be increased from four days a week to every day.

#### 6.1.2 Major changes expected in the next four years

(1) The physical processes of the global NWP system will be upgraded.

(2) A hybrid data assimilation method involving the use of 4D-Var and a LETKF will be incorporated into analysis of atmospheric conditions for the GSM.

(3) The vertical layers of the global NWP system and GEPS will be enhanced.

(4) GSM horizontal resolution will be improved.

(5) The forecast model adopted in the GEPS will be replaced with the latest operational GSM.

(6) The number of GEPS members will be increased.

(7) The forecast range will be extended for MSM runs initiated at 00 and 12 UTC.

(8) The range of LFM forecasts will be extended.

(9) A SiB will be incorporated into the MSM.

(10) An urban canopy will be incorporated into the SiB of the MSM.

(11) A new framework for a data assimilation system (ASUCA-Var) will be incorporated into the Meso-scale NWP system.

(12) LFM vertical resolution will be enhanced.

(13) The horizontal and vertical resolutions of Hourly Analysis will be enhanced, and the number of related daily operations will be increased.

(14) Correlation among satellite channels will be incorporated into the global NWP system.

(15) All-sky satellite microwave radiance data will be assimilated into the global NWP system.

(16) GNSS-RO bending-angle data from TanDEM-X/IGOR will be assimilated into the global NWP system

(17) The satellite data used in the global NWP system (e.g., Suomi-NPP/ATMS, Suomi-NPP/CrIS, Metop-A, B/IASI, Aqua/AIRS) will be assimilated into the Meso and Local NWP systems.

(18) More satellite data, including ScatSat-1/OSCAT, FY-3B/MWHS, FY-3C/MWHS2 and Suomi-NPP/VIIRS-AMV, will be assimilated into the Global, Meso and Local NWP systems.
(19) Meso-scale EPS will enter into operation.
(20) The 2D-Var data assimilation system will be adopted in stratospheric ozone analysis.
(21) The 2D-Var data assimilation system will be adopted in aerosol (Aeolian dust) analysis.
(22) The horizontal resolution of the regional chemical transport model will be enhanced from 20 km to 5 km.
(23) The grid resolution of the Global Wave Model (GWM) will be enhanced from 55 to 25 km.
(24) A new wave model with a 1-minute grid resolution for coastal sea areas of Japan will be put into operation.
(25) The grid resolution of the Wave Ensemble System (WENS) will be enhanced from 140 to 55 km and the shallow-water effect will be incorporated.
(26) A new coastal ocean analysis/forecasting system (MOVE/MRI.COM-JPN) with a high-resolution (2 km) forecast model covering the whole of the Japan coast and a 4D-Var assimilation system covering the North Pacific will be put into operation.
(27) A tide prediction model will be incorporated into in the storm surge model for the Asian region to predict astronomical tides and total water levels.
(28) The forecast period for both storm surge models will be extended from 39 to 51 hours for the Japan region and from 72 to 132 hours for the Asian region.
(29) A new storm surge model involving the use of an unstructured grid will be incorporated, and grid resolution will be enhanced in both storm surge models.
(30) Storm surge EPSs will be incorporated into both storm surge models based on Global EPS and Meso-scale EPS results for atmospheric forcing.

## 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) Use of dual polarized radar data for R/A, VSRF, Thunder Nowcasts and Hazardous Wind Potential Nowcasts

### 6.2.3 Planned Research Activities in Long-range Forecasting

### 6.2.4 Planned Research Activities in Specialized Numerical Predictions

(1) Time-of-arrival products for nuclear environmental emergency response

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

(2) Probability forecasts for volcanic ash

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

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