JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2006

Japan Meteorological Agency

1. Summary of highlights

(1) Computers for numerical analysis and prediction of JMA were upgraded from 0.768 TFlops to 21.5 TFlops on 1 March.
(2) Following upgrades of NWP system were made on 1 March.
  - Horizontal resolution of the tangent-linear and adjoint model for the global analysis was increased from T63 to T106.
  - 36-hour forecast of Global Spectral Model at 06 and 18 UTC started.
  - Assimilation window of the mesoscale analysis was extended from 3 hours to 6 hours.
  - Horizontal resolution of the Meso-Scale Model (MSM) was upgraded from 10km to 5km grid distance and vertical levels were increased from 40 to 50.
  - The frequency of operation of MSM was increased from 4 times a day to 8 times a day (3 hourly) with the shortening of forecast time from 18 hours to 15 hours.
  - Number of ensemble members for 9-day EPS was increased from 25 to 51.
  - Horizontal resolution of the hourly analysis was enhanced from 10km to 5km grid distance and temperature analysis started.
(3) Spaceborne microwave imager radiance data started to be used in the global analysis on 15 May. (see 4.2.1.2 (3))
(4) Variational bias correction was introduced to the global analysis for satellite radiance data on 15 May. (see 4.2.1.2 (4))
(5) Assimilation method for ATOVS data in the global analysis was improved on 21 August. (see 4.2.1.2 (5))
(6) Usage of Atmospheric Motion Vectors from geostationary satellites in the global analysis was revised on 18 October. (see 4.2.1.2 (6))
(7) Radial velocity data of Tokyo radar started to be used in the mesoscale analysis on 11 December. (see 4.3.1.2 (2))
(8) JMA Climate Data Assimilation System (JCDAS) has been operational since March 2006, which was transitioned from Japanese 25-year Reanalysis (JRA-25) (see 4.6).

2. Equipment in use at the GDPFS in JMA

Computers for numerical analysis and prediction of JMA were upgraded on 1 March, 2006. The computers are located across the Headquarters in central Tokyo and Office of Computer Systems Operations in Kiyose City, which is 30km west from the Headquarters and connected via wide area network. Major features of the computers are listed in Table 2-1.

Table 2-1 Major features of computers

Supercomputers (Kiyose) HITACHI SR11000/K1

Number of nodes	160 (80 nodes x 2 subsystems)
Processors	2560 POWER5+ processors (16 per node)
Performance	10.75TFlops per subsystem (134.4GFlops per node)
Main memory	5.0TB per subsystem (64GB per node)
Attached storage*	HITACHI SANRISE 9585V (6.8TB per subsystem)
Data transfer rate	8.0GB/s (one way), 16.0GB/s (bi-directional) (between any two nodes)
Operating System	IBM AIX 5L Version 5.2

UNIX servers (Kiyose) HITACHI EP8000/570

Number of nodes	3
Performance	85 SPECint rate 2000 per node
Main memory	16 GB per node
Attached storage*	HITACHI SANRISE 9533V (1.4TB)
Operating System	IBM AIX 5L Version 5.2

*…the dedicated storage for the supercomputers / servers.

Workstations (Kiyose) HITACHI HA8000/130W

Number of nodes	18
Performance	18.2 SPECint rate 2000 per node
Main memory	4.0GB per node
Operating System	Red Hat Enterprise Linux ES release 3

Storage Area Network (Kiyose) HITACHI SANRISE 9585V

Total storage capacity	22.9 TB

Automated Tape Library (Kiyose) StorageTek PowderHorn 9310

Total storage capacity	0.9PB
Tape drives	StorageTek 9940B (6 drives)

Workstations (HQ) HITACHI HA8000/130W

Number of nodes	11
Performance	10.7 SPECint rate 2000 per node
Main memory	1.0GB per node
Operating System	Red Hat Enterprise Linux ES release 3

Network Attached Storage

Total storage capacity	3.0TB (HQ) + 21.0TB (Kiyose)

Wide Area Network (between HQ and Kiyose)

Network bandwidth	200Mbps (two independent 100Mbps WAN)

3. Data and Products from GTS in use

3.1 Observations

The observation reports listed in Table 3-1 are used in the data assimilation.

Table 3-1 Number of observation reports in use

SYNOP/SHIP	51700/day
TEMP-A/PILOT-A	1700/day
TEMP-B/PILOT-B	1700/day
TEMP-C/PILOT-C	1100/day
TEMP-D/PILOT-D	1100/day
AIREP/AMDAR	141900/day
BUOY	12800/day
SATOB (SST)	4700/day
SATOB (WIND)	414100/day
SATOB (EUMETSAT)	319200/day
SATEM-A	11000/day
SATEM-C	10700/day
TOVS	82000/day

PROFILER	900/day
DMSP/SSMI	4431400/day

3.2 GRIB products

Following model products are used for internal reference and monitoring.

GRIB KWBC
GRIB ECMF
GRIB AMMC

4. Forecasting system

4.1 System run schedule and forecast ranges

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

Table 4.1-1 Schedule of the analysis and forecast system

Model	Initial Time (UTC)	Run schedule (UTC)	Forecast Range (hours)
Global Analysis/Forecast	00 06 12 18	0225-0300 0825-0855 1425-1500, 1745-1755 2025-2055	90 36 216 36
Regional Analysis/Forecast	00 06 12 18	0310-0325 1500-1510 1510-1525 0300-0310	51 (only analysis) 51 (only analysis)
Mesoscale Analysis/Forecast	00 03 06 09 12 15 18 21	0050-0150 0350-0450 0650-0750 0950-1050 1250-1350 1550-1650 1850-1950 2150-2250	15 15 15 15 15 15 15 15
Typhoon Forecast	00 06 12 18	0340-0355 0900-0915 1540-1555 2100-2115	84 84 84 84
Ocean Wave Forecast	00 12	0340-0350 1540-1550, 1840-1845	90 216
Storm Surge Forecast	00 06 12 18	0200-0205 0800-0805 1400-1405 2000-2005	33 33 33 33
Medium-range Ensemble Forecast	12	1530-1700	216

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 and initialization for the GSM

A four-dimensional variational (4D-VAR) data assimilation method is employed for the analysis of the atmospheric state for the JMA 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 the computational efficiency, an incremental method is adopted, in which the analysis increment is evaluated first at a lower horizontal resolution (T106) and then it is interpolated and added to the first guess field at the original resolution (TL319).

Global analyses are performed at 00, 06, 12 and 18UTC. An early analysis with short cut-off time is performed to prepare initial conditions for operational forecast, and a cycle analysis with long cut-off time is performed to keep the quality of 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 operated since March 2000 to provide initial conditions of land surface parameters for the GSM used in the medium range forecasts. The system includes the daily global snow depth analysis to obtain an appropriate initial condition of snow coverage and depth. Daily global snow depth analysis system is explained in Table 4.2.1-2.

For initialization of atmospheric states of the GSM, the incremental non-linear normal mode initialization (NNMI) and the vertical mode initialization (Murakami and Matsumura 2004) were introduced in February 2005, while the GSM used in the ensemble prediction system employs the conventional NNMI. The non-linear normal mode initialization with full physical processes is applied to the first five vertical modes.

Table 4.2.1-1 Specifications of global analysis

Cut-off time
- 2.33 hours for early run analyses at 00, 06, 12 and 18 UTC
- 11.5 hours for cycle run analyses at 00 and 12 UTC
- 5.5 hours for cycle run analyses at 06 and 18 UTC

Initial Guess
- 6-hour forecast by GSM

Grid form, resolution and number of grids
- Gaussian grid, 0.5625 degree, 640x320

Levels
- 40 forecast model levels up to 0.4 hPa + surface

Analysis variables
- Wind, surface pressure, specific humidity and temperature

Data Used
- SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, NOAA/ATOVS radiances, Aqua/AMSU-A radiances, SATOB, BUFR (winds), MODIS polar winds, SeaWinds, Mirowave imager radiometer radiances (AMSR-E, TMI, SSM/I) and Australian PAOB

Table 4.2.1-2 Specifications of Snow Depth analysis

Methodology	two-dimensional Optimal Interpolation scheme
Domain and Grids	global, 1x1 degree equal latitude-longitude grids
First guess	USAF/ETAC Global Snow Depth climatology (Foster and Davy, 1988)
Data used	SYNOP snow depth data

Frequency	daily

(2) Typhoon Bogussing of the global analysis

For typhoon forecasts over the western North Pacific, typhoon bogus data are generated to represent its accurate structure in the initial field of forecast models. They are made up of artificial sea-surface pressure, temperature and wind data around a typhoon. The structure is axi-asymmetric. At first, symmetric bogus data are generated automatically based on the central pressure and 30kt wind speed radius of the typhoon. The axi-asymmetric bogus data are then generated by retrieving asymmetric components from the first guess field. Finally, those bogus profiles are implanted into the first guess fields of global cycle-run analysis, and they serve as pseudo-observation data for the global early-run analysis.

4.2.1.2 Research performed in this field

(1) Modification of typhoon bogussing

Modification of typhoon bogussing are tested for high-resolution global data assimilation to improve short-range and medium-range typhoon track and intensity forecast. The use of pseudo-observation type typhoon bogus data is planned for the global cycle-run analysis, in place of the current implant type bogussing. Adjustment of bogus data distribution for global cycle-run analysis and global early-run analysis is tested to improve initial typhoon center position and short-range typhoon forecast. (Y.Kosaka, T. Iriguchi and H. Mino)

(2) Development of LETKF

The Local Ensemble Ttransform Kalman Filter (LETKF) has been developed with the JMA global spectral model (GSM). Miyoshi and Sato (2007) succeeded in assimilating satellite radiances with the GSM-LETKF system, so that it assimilates all observations used in JMA's operational global 4D-Var. Sensitivity experiments with varying tuning parameters indicated that LETKF performed essentially identical to the 4D-Var in the Northern Hemisphere. Ensemble prediction of the 13th typhoon in 2004 initialized on 12 UTC 8 August, which is famous for its difficulty of prediction, indicated advantages of the LETKF; it not only improves the control forecast, but also it shows that the spread is small, indicating high confidence in its accuracy. The initial spread is reasonably small, which grows in time adequately. (T.Miyoshi and Y.Sato)

(3) Introduction of spaceborne microwave imager radiance data into the global analysis

Radiance data from spaceborne microwave imagers, such as DMSP/SSM/I, TRMM/TMI and Aqua/AMSR-E have been introduced into the global analysis since 15 May 2006 with a variational bias correction technique (see following section). These data are used over the clear sky or thin cloudy ocean with sea surface temperature higher than 5 degree Celsius.

Cycle experiments for the microwave data showed a good impact on the typhoon track forecast. The forecast error was reduced especially in the forecast time from 36-hour to 60-hour. The rainfall forecast was also improved by assimilating the microwave data. Monthly averaged 24-hour rainfall forecast was evaluated by using Global Precipitation Climatology Project (GPCP) rainfall data. The rainfall data in the experiments showed higher correlation coefficient values against GPCP data than those values in the control experiment. (Y. Sato)

(4) Introduction of variational bias correction technique into the global analysis

A variational bias correction technique, which was originally developed at NCEP, has been introduced into the global analysis since 15 May 2006. The technique is an adaptive bias correction technique and the optimized bias correction coefficients are obtained in each analysis.

The technique is adopted for the satellite radiance data, from NOAA/ATOVS, Aqua/AMSU-A and microwave imagers. One-year cycle experiment with this technique showed that the biases are well corrected automatically. (Y. Sato)

(5) Improvement of ATOVS radiance assimilation

In August 21 2006, several changes were made in ATOVS pre-processings such as improving QC, recalculating scan bias correction, and modifying AMSU-A observation errors assigned. The QC improvement includes update of an algorithm to derive total column cloud liquid water (TCCLW) used for detecting cloud/rain-affected radiances and correcting air-mass dependent observation biases, stricter gross-error QC, adding rain detection based on TCCLW.

It was found, from several cycle experiments that the pre-processings made the fit of temperature analysis against radiosonde observation better in the Tropics and Southern Hemisphere although worse in the stratosphere of the Northern Hemisphere. The forecast impacts for the 850 hPa temperature and 500 hPa geopotential height were positive in the Tropics and Southern Hemisphere while neutral in the Northern Hemisphere. Especially there were obvious positive impacts in short-range forecast in the Southern Hemisphere. Typhoon track forecast errors were clearly reduced at the forecasts of 30-hour and hereafter. (K. Okamoto and H. Owada)

(6) Revision of geostationary AMV usage

A pre-processing system for Atmospheric Motion Vector (AMV) in the BUFR encoded dataset (BUFR AMV) generated from all geostationary satellites was revised in the JMA operational global 4D-Var assimilation system on 18 October 2006. Several revisions of the pre-processing system for AMVs are as follows. First, the usage of the data is more strictly limited reflecting the error characteristics according to their heights. Secondly, fewer but more reliable data are assimilated by setting more rigorous QI threshold. Lastly, a new, intelligent thinning scheme is introduced to select the data, taking into account the QI and observation location and time, so that they are homogeneously distributed.

To assess the impacts of the new AMV scheme, one-month cycle experiments were performed for January 2006 and September 2005. The experiment for January 2006 demonstrated positive impacts on forecast skills in terms of the 500hPa geopotential height while impacts for the experiment for September 2005 are neutral. Typhoon track forecast errors are slightly reduced at the forecasts from 24-hour to 66-hour. (K. Yamashita)

(7) Introduction of GPS radio occultation data into the global analysis

An assimilation of refractivity data from space-based GPS radio occultation has been developed. The data were used with height from 5km to 35km where small biases were found. A procedure to correct the observation biases is based on a linear regression approach and their regression coefficients are estimated by Kalman filter in every analysis. The predictors for the bias correction are latitude, height, and refractivity.

Cycle experiments using the refractivity data from CHAMP satellite (Wickert et al. 2000) conducted for August 2004 and January 2005. The forecast scores of these experiments showed positive impacts especially for the geopotential height from 500hPa to 200hPa. (E. Ozawa)

4.2.2 Model

4.2.2.1 In operation

The specifications of the operational Global Spectral Model (GSM0603; TL319L40) are summarized in Table 4.2.2-1. In February 2005, the semi-Lagrangian advection scheme

(Yoshimura and Matsumura, 2003) was introduced with an increase of the spectral resolution from T213 (quadratic grid) to TL319 (linear grid).

JMA runs the GSM four times a day (operations at 06, 18UTC were started on March 2006 with forecast time of 36 hours, in addition to 00UTC with that of 90 hours and 12UTC with that of 216 hours).

Table 4.2.2-1 Specifications of Global Spectral Model for 9-day forecasts

Basic equation	Primitive equations
Independent variables	Latitude, longitude, sigma-pressure hybrid coordinates and time
Dependent variables	Surface pressure, winds (zonal, meridional), temperature, specific humidity, cloud water content
Numerical technique	Spectral (spherical harmonics basis functions) in horizontal, finite differences in vertical Leapfrog, semi-Lagrangian, semi-implicit time integration scheme Hydrostatic approximation
Integration domain	Global in horizontal, surface to 0.4 hPa in vertical
Horizontal resolution	Spectral triangular 319 (TL319), roughly equivalent to 0.5625 x 0.5625 degrees lat-lon
Vertical resolution	40 unevenly spaced hybrid levels
Time step	15 minutes
Orography	GTOPO30 dataset, spectrally truncated and smoothed
Gravity wave drag	Longwave scheme (wavelengths > 100 km) mainly for stratosphere Shortwave scheme (wavelengths approximately 10 km) only for troposphere
Horizontal diffusion	Linear, fourth-order
Vertical diffusion	Stability (Richardson number) dependent, local formulation
Planetary boundary layer	Mellor and Yamada level-2 turbulence closure scheme Similarity theory in bulk formulae for surface layer
Treatment of sea surface	Climatological sea surface temperature with daily analyzed anomaly Climatological sea ice concentration
Land surface and soil	Simple Biosphere (SiB) model
Radiation	Two-stream with delta-Eddington approximation for shortwave (hourly) Table look-up and k-distribution methods for longwave (every three hours)
Convection	Prognostic Arakawa-Schubert cumulus parameterization
Cloud	Prognostic cloud water, cloud cover diagnosed from moisture and cloud water

4.2.2.2 Research performed in this field

(1) Development of the Cumulus Parameterization Scheme of the Global Spectral Model

GSM has a tendency to overestimate weak precipitation areas especially from local noon to late afternoon, which results in a strong diurnal variation of the bias score. The excessive precipitation is calculated primarily by the cumulus convection scheme. A new convection triggering mechanism proposed by Xie and Zhang (2000) is introduced to improve the rainfall forecast. Using this model, a data assimilation and forecast experiment was performed with high resolution (TL959L60). The precipitation forecast was verified against raingauge observation over Japan. The new model substantially reduces the bias seen in weak precipitation compared to the operational model. The diurnal variation of the bias score is also reduced. (M. Nakagawa)

(2) Improvement of the Precipitation Processes in the High-Resolution Global Spectral Model

JMA has a plan to enhance the horizontal resolution (from TL319 to TL959) and the vertical resolution (from 40 layers to 60 layers) of the operational Global Spectral Model (GSM). Since a different model resolution changes a precipitation balance in grid and subgrid scale condensation processes, it is necessary to modify the precipitation processes to suit the TL959L60.

A parameterization of shallow cumulus convection is being improved with a single column version of GSM, through participating an intercomparison project and simulating a single day in the RAIN In Cumulus over the Ocean (RICO) measurement campaign. Cloud and precipitation characteristics were investigated and modified with TL959L60 through some validation studies of frequency of cloud occurrence. It is found that these modifications of the precipitation processes provide a distinct and improved typhoon eyewall structure according to the results of the comparison between GSM simulated images and MTSAT satellite images. (T. Komori)

(3) Development of a New Land Surface Scheme

The current land surface scheme has a systematic error of an overestimation of thaw. In addition, it treats the soil processes too crude to simulate a formation of frozen soil properly. Therefore, JMA and MRI have been collaborating to develop a new land surface scheme, which is more sophisticated than the operational one in terms of snow scheme as well as soil water and temperature representation.

The long-term integration experiment with each scheme shows that the new scheme simulates seasonal change of temperature and snow-covered areas reasonably well during the melting season, whereas the operational one predicts excessive snowmelt. However, the assimilation and forecast trials indicate that the new scheme tends to have cooling bias of surface temperature in the early night over snow-covered area. It implies that the new scheme requires further modification in terms of thermal transport within the deep snow and surface skin. (M. Hirai)

4.2.3 Operationally available NWP Products

The following model output products from GSM are disseminated through the JMA radio facsimile broadcast (JMH), GTS, RSMC Tokyo Data Serving System (RSMS DSS) and the WMO Distributed Data Bases project server (DDB).

Table 4.2.3.1 List of facsimile charts transmitted through GTS and JMH.
Symbols for contents: Z: geopotential height, ζ: vorticity, T: temperature, D: dewpoint depression, ω: vertical velocity, W: wind speed by isotach, A: wind arrows, P: sea level pressure, R: rainfall.

Model	Area	Contents and Level	Forecast Hours	Initial Time	Availa-bility
GSM	Far East	500hPa (Z, ζ)	Analysis	00/12UTC	GTS
			24, 36	00/12UTC	GTS/JMH
		500hPa (T), 700hPa (D)	24, 36	00/12UTC	GTS/JMH
		700hPa (ω), 850hPa (T, A)	Analysis	00/12UTC	GTS
			24, 36	00/12UTC	GTS/JMH
		Surface (P, R, A)	24, 36	00/12UTC	GTS/JMH
	East Asia	300hPa (Z, T, W, A)	Analysis	00UTC	GTS
		500hPa (Z, T, A)	Analysis	00/12UTC	GTS/JMH
		500hPa (Z, ζ)	48, 72	00/12UTC	GTS
		700hPa (Z, T, D, A)	Analysis	00/12UTC	GTS
		700hPa (ω), 850hPa (T, A)	48, 72	12UTC	GTS
		850hPa (Z, T, D, A)	Analysis	00/12UTC	GTS/JMH
		Surface (P, R)	24, 48, 72	00/12UTC	GTS/JMH

			96, 120	12UTC	JMH
	Asia	500hPa (Z, ζ)	96, 120, 144, 168, 192	12UTC	GTS
		850hPa (T), Surface (P)			
	Asia Pacific	200hPa (Z, T, W), Tropopause (Z)	Analysis	00/12UTC	GTS
		250hPa (Z, T, W)	Analysis, 24	00/12UTC	
		500hPa (Z, T, W)		00/12UTC	
	Northern Hemisphere	500hPa (Z, T)	Analysis	12UTC	GTS
	North West Pacific	200hPa (streamline)	Analysis, 24, 48	00/12UTC	GTS
		850hPa (streamline)		00/12UTC	
		500hPa (Z, Z anomaly to climatology)			

Table 4.2.3.2 List of GPV products (GRIB) transmitted through GTS, RSMC DSS and DDB. Symbols for contents: Z: geopotential height, U: eastward wind, V: northward wind, T: temperature, D: dewpoint depression, H: relative humidity, ω: vertical velocity, ζ: vorticity, ψ: stream function, χ: velocity potential, P: sea level pressure, R: rainfall. Prefixes μ and σ stand for average and standard deviation of ensemble prediction results, respectively. Symbols °*¶§‡† indicate limitations on forecast hours or initial time as shown in notes below.

Model	GSM	GSM	GSM
Destination	RSMC	GTS, RSMC, DDB	GTS, RSMC, DDB
Area and resolution	Whole globe, 1.25°×1.25°	20°S–60°N, 60°E–160°W 1.25°×1.25°	Whole globe, 2.5°×2.5°
Levels and elements	10hPa: Z, U, V, T 20hPa: Z, U, V, T 30hPa: Z, U, V, T 50hPa: Z, U, V, T 70hPa: Z, U, V, T 100hPa: Z, U, V, T 150hPa: Z, U, V, T 200hPa: Z, U, V, T, ψ, χ 250hPa: Z, U, V, T 300hPa: Z, U, V, T, H, ω 400hPa: Z, U, V, T, H, ω 500hPa: Z, U, V, T, H, ω, ζ 600hPa: Z, U, V, T, H, ω 700hPa: Z, U, V, T, H, ω 850hPa: Z, U, V, T, H, ω, ψ, χ 925hPa: Z, U, V, T, H, ω 1000hPa: Z, U, V, T, H, ω Surface: P, U, V, T, H, R†	10hPa: Z, U, V, T 20hPa: Z, U, V, T 30hPa: Z, U, V, T 50hPa: Z, U, V, T 70hPa: Z, U, V, T 100hPa: Z, U, V, T 150hPa: Z, U, V, T 200hPa: Z§, U§, V§, T§, ψ, χ 250hPa: Z, U, V, T 300hPa: Z, U, V, T, D 400hPa: Z, U, V, T, D 500hPa: Z§, U§, V§, T§, D§, ζ 700hPa: Z§, U§, V§, T§, D§, ω 850hPa: Z§, U§, V§, T§, D§, ω, ψ, χ 925hPa: Z, U, V, T, D, ω 1000hPa: Z, U, V, T, D Surface: P¶, U¶, V¶, T¶, D¶, R¶	10hPa: Z*, U*, V*, T* 20hPa: Z*, U*, V*, T* 30hPa: Z°, U°, V°, T° 50hPa: Z°, U°, V°, T° 70hPa: Z°, U°, V°, T° 100hPa: Z°, U°, V°, T° 150hPa: Z*, U*, V*, T* 200hPa: Z, U, V, T 250hPa: Z°, U°, V°, T° 300hPa: Z, U, V, T, D*‡ 400hPa: Z*, U*, V*, T*, D*‡ 500hPa: Z, U, V, T, D*‡ 700hPa: Z, U, V, T, D 850hPa: Z, U, V, T, D 1000hPa: Z, U*, V*, T*, D*‡ Surface: P, U, V, T, D‡, R†
Forecast hours	0–84 every 6 hours and 96–192 every 12 hours † Except analysis	0–84 every 6 hours § additional 96–192 every 24 hours for 12UTC ¶ 0–192 every 6 hours	0–72 every 24 hours and 96–192 every 24 hours for 12UTC ° 0–120 for 12UTC † Except analysis * Analysis only
Initial times	00UTC and 12UTC	00UTC and 12UTC	00UTC and 12UTC ‡ 00UTC only

Model	GSM
Destination	RSMC
Area and resolution	20°S–60°N, 80°S–160°W 2.5°×2.5°
Levels and elements	100hPa: Z, U, V, T 150hPa: Z, U, V, T 200hPa: Z, U, V, T 250hPa: Z, U, V, T 300hPa: Z, U, V, T 500hPa: Z, U, V, T, D, ζ 700hPa: Z, U, V, T, D, ω 850hPa: Z, U, V, T, D, ω Surface: P, U, V, T, D, R
Forecast hours	0–36 every 6 hours, 48, 60, and 72
Initial times	00UTC and 12UTC

4.2.4 Operational techniques for application of NWP products

See 4.3.4.1(1). Both techniques for application of short-range forecast and medium range one are described in 4.3.4.1(1).

4.2.5 Ensemble Prediction System (EPS)

4.2.5.1 In operation

JMA carries out 9-day Ensemble Prediction System (EPS) every day. A numerical weather prediction model applied for the EPS is a low-resolution version (TL159) of the GSM. In March 2006, the semi-Lagrangian advection scheme was introduced with an increase of the spectral resolution from T106 (quadratic grid) to TL159 (linear grid). Thus, dynamical framework and physical processes of the model are same as the high-resolution version (TL319) of the GSM shown in Table 4.2.2-1 except for horizontal resolution.

In March 2006, number of ensemble members was increased from 25 to 51. The atmospheric initial condition for the control run is prepared by interpolating the TL319 analysis. For the perturbed run, the perturbations to be added to initial fields of the control run are generated in 25 independent breeding cycles executed every 12 hours by the Breeding of Growing Mode (BGM) method. The basic features of the operational 9-day EPS are shown in Tables 4.2.5-1.

Table 4.2.5-1 Specifications of 9-day Ensemble Prediction System

Horizontal resolution	Spectral triangular 159 (TL159), roughly equivalent to 1.125 x 1.125 degrees lat-lon
Vertical resolution	40 unevenly spaced hybrid levels
Time step	20 minutes
Number of members	51 members
Initial state perturbation	Breeding of Growing Mode (BGM) method (25 independent breeding cycles in 12 hours periods)
Perturbed area	Northern hemisphere and tropics (20S-90N)

4.2.5.2 Research performed in this field

(1) Upgrade of medium range ensemble prediction system

JMA has a plan to increase the resolution of the medium-range EPS model to TL319L60 in the second half of 2007. At the same time, the generator of initial condition perturbations will be changed to a SV-based method to enable directly to identify tropical perturbations that have an active influence on weather forecasting in low latitudes of the Northern hemisphere.

The numerical experiment on EPS is conducted to investigate the forecast skill of the high-resolution ensemble in the medium-range for upgrade of the operational EPS. The verification results show that the high-resolution ensemble is more skillful than the operational ensemble, especially to orographical weather events such as orographic precipitation. It is also found that the high-resolution ensemble skill of tropical cyclones is improved, which suggests that the SV-based perturbations accurately represent initial condition uncertainties over both the tropical and extra-tropical zones. (M. Kyouda)

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

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

The specifications of the regional and mesoscale analysis schemes are listed in Table 4.3.1-1.

(1) Regional analysis

A regional 4D-VAR system was introduced on 19 June 2003 for the analysis of the atmospheric state for the JMA Regional Spectral Model (RSM). The architecture of the system is almost the same as those of the mesoscale 4D-VAR (see below), except that the resolution of the inner-loop model is 40km. Initial and lateral boundary conditions for 4D-VAR are derived from GSM forecasts. Non-linear normal mode initialization with full physical processes is applied to the first five vertical modes.

(2) Mesosclae analysis

A four-dimensional variational (4D-VAR) data assimilation method has been employed since 19 March 2002 for the analysis of the atmospheric state for the JMA Meso-Scale Model (MSM) with a six-hour assimilation window. Radar-Raingauge Analyzed Precipitation data in addition to conventional data are used for assimilation. The control variables are surface pressure, temperature, unbalanced wind and specific humidity. In order to improve the computational efficiency, an incremental method is adopted in which the analysis increment is evaluated at a lower horizontal resolution (20km) and then it is interpolated and added to the first guess field at the original resolution (10km).

Assimilation of radial velocity of the Doppler radar at Tokyo Japan was started in December 2006, which slightly improved the precipitation forecasts for moderate rainfall.

Table 4.3.1-1 Specifications of regional and mesoscale analyses

Cut-off time		
	(regional)	2.75 hours for analyses at 00 and 12UTC 8.75 hours for analyses at 06 and 18 UTC
	(mesoscale)	50 minutes for analyses at 00, 03, 06, 09, 12, 15, 18 and 21 UTC
Initial Guess		
	(regional)	6-hour forecast by RSM
	(mesoscale)	6-hour forecast by MSM
Grid form, resolution and number of grids		
	(regional)	Lambert projection, 20km at 60N and 30N, 325x257, grid point (1, 1) is at north-west corner and (200, 185) is at (140E, 30N)
	(mesoscale)	Lambert projection, 10km at 60N and 30N, 361x289, grid point (1, 1) is at north-west corner and (245, 205) is at (140E, 30N)
Levels		
	(regional)	40 forecast model levels up to 10 hPa + surface
	(mesoscale)	40 forecast model levels up to 10 hPa + surface
Analysis variables		
	Wind, surface pressure, specific humidity and temperature	
Data Used		
	SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, SATEM, ATOVS SATOB, BUFR (winds), MODIS polar winds, SeaWinds, Mircrowave imager radiometer retrievals (AMSR-E, TMI and SSM/I)	

(3) Typhoon Bogussing of the regional and mesoscale analyses

For typhoon forecasts over the western North Pacific, typhoon bogus data is generated to represent its accurate structure in the initial field of forecast models. They are made up of artificial sea-surface pressure, temperature and wind data around a typhoon. The structure is axi-asymmetric. At first, symmetric bogus data is generated automatically based on the central pressure and 30kt wind speed radius of the typhoon. The axi-asymmetric bogus data is then generated by retrieving asymmetric components from the first guess field. Finally, those bogus profiles serve as pseudo-observation data both for the regional and mesoscale analyses.

4.3.1.2 Research performed in this field

(1) Development of JMA-NHM-based variational data assimilation system

The development of JMA-NHM-based variational data assimilation system (JNoVA) （Honda et al. 2005） has been continued. A forecast/analysis system with quality control of observation data has been constructed. Parallel experiments have been done to compare the performance of JNoVA with that of operational mesoscale 4D-Var (Meso 4D-Var). According to the statistical verification of quantitative precipitation forecasts, the equitable threat score of the JNoVA is better than that of Meso 4D-Var when the threshold of the rain is equal to or larger than 15mm/3hour. On the other hand, the JNoVA still shows worse performance to predict the weak rain than the Meso 4D-Var. (Y. Honda and K. Sawada)

(2) Usage of radial velocity data of Tokyo radar

The JMA started the use of radial velocity data (Vr) of Tokyo radar with the JMA operational mesoscale 4D-VAR analysis on December 11, 2006. To estimate the impact of assimilating the Vr of Tokyo radar in NWP routine, three-hourly forecast-analysis cycle was performed without and with the Vr of Tokyo radar in the period during 8-17 June 2006. In this period, 15-hour forecasts were made eight times a day at 00, 03, 06, 09, 12, 15, 18, and 21 UTC. The results of this experiment indicated that assimilating the Vr of Tokyo radar has significantly positive impacts on the precipitation forecasts. In case of a heavy rain during the experiment period, more precipitation is predicted and the precipitation pattern is closer to the observation. (Y.Ishikawa)

(3) Development of LETKF

The local ensemble transform Kalman filter (LETKF) has been developed with the JMA nonhydrostatic mesoscale model (MSM). Following the successful perfect-model investigations by Miyoshi and Aranami (2006) with the MSM-LETKF system, real observations used in the operational MSM in July 2004 have been assimilated. (T.Miyoshi and K.Aranami)

4.3.2 Model

4.3.2.1 In operation

(1) Regional Spectral Model (RSM)

JMA runs the Regional Spectral Model (RSM0404; 20kmL40) twice a day (51-hour forecasts from 00 and 12 UTC). The specifications of RSM are given in Table 4.3.2-1.

Table 4.3.2-1 Specifications of Regional Spectral Model

Basic equations	Primitive equations
Independent variables	x-y coordinates on Lambert projection plane and sigma-p hybrid coordinate

Dependent variables	Wind components of x-y direction, virtual temperature, natural log of surface pressure and specific humidity
Numerical technique	Euler semi-implicit time integration, double Fourier for horizontal representation and finite difference in the vertical
Projection and grid size	Lambert projection, 20km at 60N and 30N
Integration domain	East Asia centering on Japan, 325 x 257 transform grid points
Vertical levels	40 (surface to 10hPa)
Forecast time	51 hours from 00, 12UTC
Forecast phenomena	Meso-beta scale disturbances
Initial	First guess is 3-9 hours forecast of RSM initialized 6 hour earlier
Data cutoff	3 (9)-hour cutoff for 00, 12 (06, 18) UTC
Lateral boundary	0-51 hours forecast by GSM runs
Orography	Envelope orography, smoothed and spectrally truncated
Horizontal diffusion	Linear, second-order Laplacian with targeted moisture diffusion
Moist processes	Large scale condensation + Prognostic Arakawa-Schubert convection scheme + middle level convection + shallow convection
Radiation	(short-wave) Every hour (long-wave) Every hour
Cloudiness	Diagnosed from relative humidity, maximum overlap
Gravity wave drag	Short-wave scheme for lower troposphere is included
PBL	Mellor-Yamada level-2 closure scheme for stable PBL, non-local scheme for unstable PBL, and similarity theory for surface boundary layer
Land surface	Ground temperature is predicted with the use of four levels in the ground. Evaporability depends on location and season.
Surface state	Observed SST (fixed during time integration) and sea ice distribution Evaporability, roughness length, albedo are climatological values. Snow cover over Japan is analyzed every day.

(2) Meso-Scale Model (MSM)

A non- hydrostatic Meso-Scale Model (MSM0603; 5kmL50) with grid spacing of 5km has been operated since March 2006 in place of the former operational non-hydrostatic model (MSM0409; 10kmL40) with grid spacing of 10km. At the same time, the forecast frequency has increased from 4 times a day to 8 times a day although the forecast time was shortened from 18 hours to 15 hours. The specifications of MSM0603 are listed in Table 4.3.2-2.

Table 4.3.2-2 Specifications of Meso-Scale Model (MSM0603)

Basic equations	Fully compressible non-hydrostatic equations
Independent variables	Latitude, longitude, terrain-following height coordinates and time
Dependent variables	Momentum components in three dimensions, potential temperature, pressure, mixing ratios of water vapor, cloud water, cloud ice, rain, snow and graupel
Numerical technique	Finite discretization on the Arakawa-C type staggered coordinates, horizontally explicit and vertically implicit time integration scheme, fourth order horizontal finite differencing in flux form with modified advection treatment for monotonicity
Projection and grid size	Lambert projection, 5km at 60N and 30N
Integration domain	Japan, 721 x 577 grid points
Vertical levels	50 (surface to 21.8km)
Forecast time	15 hours from 00, 03, 06, 09, 12, 15, 18, 21UTC

Forecast phenomena	Severe weather
Initial fields	4D-VAR analysis with mixing ratios of cloud water, cloud ice, rain, snow and graupel derived from preceding forecasts considering consistency with the analysis field of relative humidity
Lateral boundary	03-27 hour forecast by RSM initialized at 00 (12) UTC for 03, 06, 09, 12 (15, 18, 21, 00) UTC forecast
Orography	Mean orography smoothed to eliminate the shortest-wave components
Horizontal diffusion	Linear, fourth order Laplacian + nonlinear damper Targeted moisture diffusion applied to the grid points where excessive updrafts appear
Moist processes	Three-ice bulk cloud microphysics + Kain-Fritsch convection scheme Lagrangian treatment for the fall of rain and graupel
Radiation (short-wave)	Every 15 minutes
Radiation (long-wave)	Every 15 minutes
Cloudiness	Diagnosed from relative humidity with maximum overlap assumed
Gravity wave drag	No parameterization scheme included
PBL	Diffusion processes based on diagnosed turbulent kinetic energy, considering non-local effect by adjusting mixing length Similarity theory adopted for the surface boundary layer
Land surface	Ground temperature predicted using a four-layer ground model Evaporability depends on location and season.
Surface state	Observed SST (fixed during time integration) and sea ice distribution Climatological values of evaporability, roughness length and albedo Snow cover over Japan analyzed every day

4.3.2.2 Research performed in this field

(1) Development of next operational Meso-Scale Model (MSM0705)

The operational MSM of JMA with horizontal resolution of 5km has been providing 15-hour forecasts every 3 hours (8 times a day). In May 2007, MSM is scheduled to extend forecast time to 33 hours 4 times a day out of 8 times (Hara et al., 2007). It enables to provide consistent information to prevent disaster for about one day.

Simultaneously with the extension, the new model, in which physical processes such as turbulence, radiation, cloud physics and cumulus convection are remarkably improved, is introduced instead of the current operational model. It has been confirmed that the new model is superior to the current MSM and the current operational regional spectral model of JMA (RSM) on accurate prediction of precipitation, vertical profiles of temperature and wind velocity, and the diurnal change of surface temperature and wind. (T.Hara)

(2) Implementation of improved Mellor-Yamada Level 3 scheme and partial condensation scheme

Improved Mellor-Yamada Level 3 scheme (Nakanishi, 2002; Nananishi and Niino, 2004, 2006) is newly introduced to the JMA non-hydrostatic model (JMANHM) (Hara, 2007). In the scheme, new diagnosis method for mixing length is suggested and closure constants are revised from original Mellor-Yamada model (Mellor and Yamada, 1982) based on the result of Large Eddy Simulation (LES). Comparing the current turbulent scheme based on Klemp and Wilhelmson (1978) with non-local effect by Sun and Chang (1986), more suitable boundary layer is realized. In particular, the diffusion coefficient for momentum in the unstable layer derived from the current scheme seems to be too small to represent the structure of mixing layer appropriately.

The partial condensation scheme based on Deardorff (1977) is also introduced, in which deviation width of probability density function is derived with the variables predicted in the turbulent scheme. Cloud fraction and quantity of condensed water with subgrid effect derived from the scheme are used in the radiation scheme and to evaluate buoyancy flux. Bias error of shortwave radiation flux toward surface is well reduced compared to that of the current radiation cloud which is diagnosed from relative humidity. (T.Hara)

(3) Implementation of the sophisticated clear sky radiation scheme to the JMA Nonhydrostatic model

Clear sky radiation scheme of the current JMA Nonhydrostatic model (JMA, 2002) based on broad band model (Goody, 1952) has the positive bias in the middle of the troposphere and the negative bias in the bottom of the troposphere on the longwave radiation heating rate. To remove these biases, sophisticated clear sky radiation scheme (Murai and Yabu, 2005) based on Chou et al. (2001) is implemented in the model. Consequently, the vertical profile of the temperature is improved. (R. Nagasawa)

(4) Development of a high-resolution local forecast model at JMA

A high-resolution local forecast model (LFM), whose horizontal grid spacing is 2 km, has been developed to provide more detailed information for disaster prevention and aviation safety. The LFM is based on the JMA nonhydrostatic operational model (Saito et al., 2006). For its initial condition, the JNoVA 3D-Var (JMA Non-hydrostatic Model based Variational Data Assimilation System) is employed. The assimilated data are wind and temperature data observed on the ground and by aircraft and Doppler radar, all of which are suitable instruments to capture mesoscale phenomena. An experimental run of the LFM has been executed 3-hourly (8 times a day) since 1 June 2006 for Tokyo area with 151 x 151 grid points. (K. Takenouchi)

4.3.3 Operationally available NWP products

See 4.2.3. Both products of short-range forecast and medium range one are described in 4.2.3.

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

(1) Kalman-filter and Neural-network

Two types of operational techniques for application are routinely used; one employs the Kalman-filter, and the other an artificial Neural-network. These techniques are applied to grid point values from RSM (0-51 hour of forecast), GSM (51-75 hour forecast), and MSM (0-15 hour forecast) output in order to reduce systematic forecast errors or to extract some useful information on such as probabilistic or categorical values in an adaptive manner.

The Kalman-filtering technique is used to derive probability of precipitation, precipitation amount in each 20km square grid, maximum/minimum/indicated-time temperatures, maximum/indicated-time wind speed and the associated direction at each of the JMA surface stations. This method is also used for the aviation weather forecast (TAF) guidance for cloud amount, minimum ceiling, minimum visibility, wind speed and the associated direction, and minimum/maximum temperatures at each major airport for example.

As for the artificial Neural-network technique, it is employed for forecasting weather category, probability of heavy precipitation and probability of thunderstorm in each 20km square grid, and minimum humidity at each meteorological observatory of JMA. This technique also constitutes an essential basis for forecasting a maximum precipitation and the snowfall depth. The maximum precipitation forecast is obtained by multiplying average precipitation in each forecast area by an optimum ratio, derived from Neural-network, of the observed maximum precipitation to an average precipitation from model output. The snowfall depth forecast, operationally used since March 2004, estimates the depth of snowfall by multiplying model-derived precipitation amount and a Neural-network-derived optimal ratio that determines the empirical relation between observed snowfall depth and precipitation.

The above two types of techniques produce forecast guidance up to 51 hours at 3-hour intervals and up to 72 at 6-hours intervals, except for 6-hour probability of precipitation, daily maximum/minimum temperatures, and daily minimum humidity.

TAF guidance gives visibility, 3-layer cloud base and amount, wind speed and direction, weather and temperature up to 27 hours produced by MSM (0-15 hour forecast) for TAF-S and RSM (15-27 hour forecast) for TAF-L.

(2) Hourly Analysis

JMA is providing 'hourly-analysis' with grid spacing of 5km for real-time monitoring of weather condition. It based on the MSM forecast and observed data, and the latest MSM forecast output is used as a first guess. The product is made every hour within 30 minutes from hourly observation time and is provided to operational forecasters and aviation users. The specifications of the hourly-analysis schemes are listed in Table 4.3.4-1.

Table 4.3.4-1 Specifications of hourly-analyses

Cut-off time
    0.25 hours for analyses
Initial Guess
    2 or 3 or 4-hour forecast by MSM
Grid form, resolution and number of grids
    Lambert projection, 5km at 60N and 30N, 721x577,
    grid point (1, 1) is at north-west corner and (489, 409) is at (140E, 30N)
Levels
    40 forecast model levels + surface
Analysis variables
    Wind, temperature, surface wind, and surface temperature
Data Used
    AMeDAS, Wind Profiler(WINDAS), Doppler Radar (radial data) of JMA,
    AMDAR(aircraft) and Satellite wind

4.3.4.2 Research performed in this field

We will change TAF guidance with extending forecast time of MSM since MAY 2007. TAF-S and TAF-L guidance will be merged and produced from only MSM. Logistic regression technique interpreting non-adaptive will be applied to new aviation guidance of probability of thunderstorm.
We also plan to develop ensemble guidance for tropical storms. Research will be started from the next year.

4.4 Nowcasting and Very Short-range Forecasting Systems (0-6 hrs)

JMA has been routinely operating a fully automated system of precipitation analysis and very short-range forecasting to monitor and forecast local severe weather since 1988. In addition to these, JMA has been operating 'Precipitation Nowcast' since June 2004.

The system has three products as below:

(1) 'Radar-raingauge Analyzed precipitation' (hereafter R/A)*, which is 1-hour accumulated precipitation based on observation of the radars calibrated half-hourly by the raingauge measurements of the Automated Meteorological Data Acquisition System (hereafter AMeDAS) operated by JMA and other available data, such as raingauges by local governments.

(2) 'Very-Short-Range-Forecast of precipitation' (hereafter VSRF), which is a forecast of 1-hour accumulated precipitation based on extrapolation and prediction of the Meso-scale Model (MSM, See 4.3). The forecast time of VSRF is from 1 to 6 hours.

(3) 'Precipitation Nowcast', which is a forecast of 10-minute accumulated precipitation based on extrapolation. The forecast time of Precipitation Nowcast is from 10 to 60 minutes.

* Before 15 November 2006, it was called as 'Radar-AMeDAS precipitation'. Since then, the radar data of Ministry of Land Infrastructure and Transport (MLIT) are also used for R/A and it is renamed as "Radar-Raingauge Analyzed Precipitation". JMA is one of the external organs of MLIT, so the "Radar-Raingauge Analyzed Precipitation" belongs to MLIT.

4.4.1 Nowcasting system (0-1 hr)

4.4.1.1 In operation

Precipitation Nowcast predicts 10-minute accumulated precipitation by linear extrapolation up to 1 hour. Initial rainfall intensity distribution is derived from radar data obtained at 10-minute interval, which is calibrated by raingauge observation. Using the movement vector of VSRF, it predicts precipitation distribution by extrapolation within 3 minutes after the radar observation to support the local weather offices for issuing warnings of heavy precipitation.

Table 4.4.1 Precipitation nowcasting model

Forecast process	Linear extrapolation
Physical process	Simplified orographic dissipation
Movement vector	Taken from very-short range forecasting system
Time step	1 minute
Grid form	Cylindrical equidistant projection
Resolution	about 1 km
Number of grids	2560 x 3360
Initial	Calibrated radar echo intensities
Forecast time	Up to 60 minutes from each initial time (every 10 minutes = 144 times/day)

4.4.1.2 Research performed in this field

To improve the accuracy of forecasts, we revised the prediction algorism and added an orographic effect on precipitation of VSRF in a simplified form, in which some of its complicated parts are omitted for their long calculation time. The revised version of 'Precipitation Nowcast' becomes in operation since October 2006.

'Precipitation Nowcast' uses movement vectors of VSRF which are obtained half-hourly and focused on a forecast in a time scale more than 1 or 2 hours. For the improvement of forecasts, it is desirable to derive movement vectors every 10 minutes using a method suitable for a forecast in a time scale less than 1 hour. We are now developing some simplified and fast calculation methods for movement vector, such as an optical-flow method.

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)

R/A is a precipitation distribution analysis with 1km resolution and is derived half-hourly (i.e. every the hour and past half an hour). Radar data and raingauge precipitation data are used to make R/A. The radar data is intensity data of 20 weather radars of JMA and 1(one) radar of the Ministry of Land Infrastructure and Transport (MLIT). The raingauge precipitation data is collected from more than 1300 AMeDAS stations operated by JMA and about 7000 raingauges of MLIT and some local governments.

After collecting these data, each radar intensity data is accumulated to make the 1-hour accumulated radar precipitation data. Each accumulated radar precipitation data is calibrated with the 1-hour accumulated raingauge precipitation data. The R/A is the composite of all calibrated and accumulated radar precipitation data. An initial field for extrapolation forecast is the composite of calibrated radar intensity data.

(2) Very Short-Range Forecast of precipitation (VSRF)

The extrapolation forecast and the precipitation forecast from the Meso-Scale Model (MSM; see 4.3.2.1 (2)) are merged into the very-short-range precipitation forecast. Merging weight of MSM forecast is nearly zero at one hour forecast and gradually increased with forecast time to a value determined from the relative skill of the MSM forecasts.

Table 4.4.2 Specifications of extrapolation model

Forecast process	Extrapolation
Physical process	Orographic enhancement and dissipation
Movement vector	Movement of a precipitation system is evaluated by the cross correlation method
Time step	2-5 minutes
Grid form	Oblique conformal secant conical projection
Resolution	1 km
Number of grids	1600 x 3600
Initial	Calibrated radar echo intensities
Forecast time	Up to six hours from each initial time (every 30 minutes = 48 times/day)

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

4.4.2.2 Research performed in this field

In March 2006, JMA has changed the specification of these products, R/A and VSRF. The resolution of R/A was enhanced from 2.5km x 2.5km mesh to 1km x 1km mesh and the resolution of VSRF was enhanced from 5km x 5km mesh to 1km x 1km mesh.

To incorporate MLIT radar data with JMA radar, R/A development has been focused on the harmonization of their different characteristics. In November 2006, the first MLIT radar, Hakodake, is incorporated with R/A. The others will be incorporated with R/A by March 2008.

As for the VSRF, we introduced two type movement vectors; the first is movement vector for heavy rain with fine mesh data, the other is for background precipitation corresponding to large spatial scale with coarse grained mesh data. Watching the precipitation movement, we replace the heavy rain vector with background large scale vector to improve the accuracy of some abnormally remained forecast of heavy rains. To improve the accuracy of forecasts, we are now developing refined orographic effects and some simplified and fast calculation methods for movement vector.

4.5 Specialized numerical predictions

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

4.5.1.1 In operation

(1) Typhoon

The analysis for numerical typhoon track prediction is made using the global analysis model. After symmetric typhoon bogus data is implanted into the analysis field with asymmetric components preserved, non-linear normal mode initialization with full physical processes is applied to the first five vertical modes.

(2) Global Ocean data assimilation system

A global ocean data assimilation system (ODAS) has been in operation. Its specifications are shown in Table 7.4.5-1.

Table 7.4.5-1 Specifications of the Global Ocean Data Assimilation System

Basic equations	Primitive equations, rigid lid
Independent variables	Lat-lon coordinate and z vertical coordinate
Dependent variables	u, v, T, S
Numerical technique	Finite difference both in the horizontal and in the vertical
Grid size	2.5 degree (longitude) x 2.0 degree (latitude, smoothly decreasing to 0.5 degree toward the equator) grids
Vertical levels	20 levels
Integration domain	Global (from 66N to 80S, toward poles from 60N and 60S, prognostic fields are nudged to climatology)
Forcing data	Heat, water, and momentum fluxed are driven from the operational global 4DDA
Observational data	Sea surface and subsurface temperature and salinity, sea surface height
Operational runs	Two kinds of run, final run and early run, with cut-off time of 30 days and 1 day, respectively, for ocean observation data

The output of ODAS is fed to an interactive graphic tool for the analysis of tropical ocean status. Some figures based on ODAS outputs are included in the Monthly Report on Climate System of JMA, and provided through the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc). The data is also used as the oceanic initial conditions for the JMA's coupled ocean-atmosphere model.

(3) High-resolution Sea Surface Temperature Analysis for Global Ocean

High-resolution daily sea surface temperatures (SSTs) in the global ocean on a grid of 1/4˚ x 1/4˚ are objectively analyzed for ocean information services and for providing boundary conditions of the atmospheric short-range prediction models and the North Pacific Ocean models. SSTs obtained from AVHRRs on the NOAA polar orbital meteorological satellites and the AMSR-E on the earth observation satellite AQUA are used together with in-situ SST observations. The analysis data are available on the NEAR-GOOS Regional Real Time Data Base (http://goos.kishou.go.jp).

4.5.2 Specific Models

4.5.2.1 In operation

(1) Typhoon Model (TYM)

The Typhoon Model (TYM0306; 24kmL25) is run four times a day (84-hour forecasts starting from 00, 06, 12 and 18 UTC) when typhoons exist or are expected to be formed over the western North Pacific. The specifications of TYM are given in Table 4.5.2-1.

Table 4.5.2-1 Specifications of Typhoon Model

Basic equations	Primitive equations
Independent variables	x-y coordinates on a Lambert (Mercator) projection plane for the target tropical cyclone north (south) of 20N and sigma-p hybrid coordinate
Dependent variables	Wind components of x-y direction, virtual temperature, natural log of surface pressure and specific humidity
Numerical technique	Euler semi-implicit time integration, double Fourier for horizontal representation and finite difference in the vertical
Projection and grid size	Lambert (Mercator) projection, 24 km at the tropical cyclone center when center of the target tropical cyclone is north (south) of 20N
Integration domain	Center of domain is set at median of expected track of the target tropical cyclone in the western North Pacific, 271x271 transform grid points
Vertical levels	25 (Surface to 17.5hPa)
Forecast time	84 hours from 00, 06, 12, 18UTC, maximum two runs for each initial time
Forecast phenomena	Tropical cyclones in the western North Pacific
Initial	Global analysis using six-hour forecast by GSM as a guess field with data cut-off time of 2.5 hours
Lateral boundary	0-84 hour forecast by GSM for 00, 12 UTC initial 6-90 hour forecast by GSM initialized 6 hours earlier for 06, 18 UTC initial
Orography	GTOPO30 30 ”x30” dataset, spectrally truncated and smoothed
Horizontal diffusion	Linear, second-order Laplacian
Moist processes	Large scale condensation + Prognostic Arakawa-Schubert convection scheme + shallow convection
Radiation (short-wave)	Every hour
Radiation (long-wave)	Every hour
Cloud	Prognostic cloud water, cloud cover diagnosed from moisture and cloud water
Gravity wave drag	Short-wave scheme for lower troposphere is included
PBL	Mellor-Yamada level-2 closure scheme for stable PBL, and similarity theory for surface boundary layer

Land surface	Ground temperature is predicted with the use of four levels in the ground. Evaporability depends on location and season.
Surface state	Observed SST fixed during time integration, climatological evaporability, roughness length and albedo
Typhoon bogussing	Symmetric vortex generated using a manually analyzed central pressure and the radius of 30kt winds with gradient-wind balance assumed in the free atmosphere, Ekman-frictional inflow and compensating outflow added in PBL and in upper levels, respectively. The vortex is blended with the global analysis in combination with asymmetric components taken from TYM's own forecasts, when available.

(2) Environmental Emergency Response System

JMA is a Regional Specialized Meteorological Center (RSMC) for Environmental Emergency Response in RA II for preparation and dissemination of transport model products on exposure and surface contamination of accidentally released radioactive materials. An operational tracer transport model is run on request of national Meteorological Services in RA II or the International Atomic Energy Agency (IAEA) for RSMC support for environmental emergency response.

The transport model adopts a Lagrangian method. In the model, many tracers are released in time and location according to information on pollutant emissions. Effects for three-dimensional advection and horizontal and vertical diffusions, dry and wet depositions and radioactive decay are computed from 3-hourly model-level outputs of the high resolution global model (TL319L40). Main products of the RSMC are trajectories, time integrated low-level concentrations and total deposition up to 72 hours ahead.

(3) Ocean wave forecasting model

JMA operates two numerical wave models; Global Wave Model (GWM) and Coastal Wave Model (CWM). Both models are classified into the third generation wave model.

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

Model name	Global Wave Model	Coastal Wave Model
Model type	Spectral model (third generation wave model)	
Spectral component	400 components (25 frequencies from 0.0375 to 0.3 Hz and 16 directions)	
Grid form	Equal latitude-longitude grid on spherical coordinate	
Grid size	1.25˚ x 1.25˚ (288x121)	0.1˚ x 0.1˚ (400x400)
Integration domain	Global 75˚N-75˚S, 0˚E-180-1.25˚W	Coastal sea of Japan 55˚N-15˚N, 115˚E-155˚E
Time step	30 minutes	5 minutes
Forecast time	90 hours from 00UTC 216 hours from 12UTC	84 hours from 00, 12UTC
Boundary condition	-	Global Wave Model
Initial condition	Hindcast	
Wind field	Global Spectral Model (GSM)	Regional Spectral Model (RSM) with the supplement of GSM
	Bogus gradient winds (for typhoons in the western North Pacific)	

The grid point values (GPVs) of CWM are disseminated to domestic users. The GPVs of GWM are available in the RSMC Tokyo Data Serving System of JMA for National Meteorological and Hydrological Services (NMHSs).

(4) Storm surge model

JMA operates a numerical storm surge model to predict storm surges that will occur in coastal areas of Japan using sea surface wind and pressure fields predicted by Meso-Scale Model (MSM). In the case of a tropical cyclone (TC), taking account of the error of the TC track forecast, storm surges for possible five TC tracks are predicted using TC bogus data on each track. The model specifications are given in Table 4.5.2.1(4)-1.

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

Basic equations	Two dimensional shallow water equations
Numerical technique	Explicit finite difference method
Integration domain	Coastal area of Japan (122.5- 146.5˚E, 23.5- 46.5˚N)
Grid size	1 minute (longitude) x 1 minute (latitude)
Boundary conditions	Modified radiation condition at open boundaries and zero normal flows at coastal boundaries
Forcing data	Meso Scale Model (MSM)
	bogus data for TCs around Japan

(5) Ocean Data Assimilation System for the North Pacific Ocean

An ocean data assimilation system for the North Pacific has been in operation, to represent the ocean structure such as the Kuroshio in the mid/high latitudes of the North Pacific with the following specifications. Ocean current and water temperature at 100-m depth, the products of this system, are available on the NEAR-GOOS Regional Real Time Data Base (http://goos.kishou.go.jp).

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

Basic equations	Primitive equations, rigid lid
Independent variables	Latitudinal and longitudinal in horizontal coordinate, z in vertical coordinate
Dependent variables	Ocean current components of latitudinal and longitudinal direction, temperature and salinity (nudged to climatology deeper than 2,000 m)
Numerical technique	Finite difference both in the horizontal and in the vertical, nudging with observational temperature, estimated temperature and salinity from sea surface height
Grid size	Variable horizontal resolution, 1/4˚ x 1/4˚ adjacent to Japan between 23˚N and 45˚N west of 180˚E, smoothly increasing to 0.5˚ in latitude and to 1.5˚ in longitude
Time step	10 minutes
Vertical levels	21 levels
Integration domain	North Pacific between 13˚N and 55˚N from 120˚E to 110˚W
Forcing data	Ocean currents are driven by operational daily wind stress
Observational data	Sea surface height, sea surface and subsurface temperature

(6) Sea ice forecasting model

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

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

Dynamical processes	Viscous-plastic model (MMD/JMA, 1993. wind and sea water stress to sea ice, Coriolis' force, force from gradient of sea surface and internal force are considered)
Physical processes	Heat exchange between sea ice, atmosphere and sea water
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	Concentration analysis derived from GMS and NOAA satellite imagery and thickness estimated by hindcast

The grid point values (GPVs) of the numerical sea ice model are disseminated to domestic users. The sea ice conditions for the coming seven days predicted by the model are broadcast by JMH twice a week.

(7) Marine pollution transport model

JMA operates the numerical marine pollution transport model in the case of a marine pollution accident. Its specifications are shown in Table 4.5.2.1(7)-1. The ocean currents as the input data of the model are derived from the result of the ocean data assimilation system for the North Pacific Ocean.

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

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

(8) Kosa prediction model

JMA operates a Kosa (sand dust storm) prediction model to predict Kosa distribution since January 2004. The model is directly coupled with a low resolution version global spectral model (GSM) and can make use of several GSM parameters without temporal or spatial interpolation. The model specifications are given in Table 4.5.2.1(8)-1.

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

Basic equations	Eulerian model coupled with Global Spectral Model
Numerical technique	3D semi-Lagrangian transport, dust emission calculation from surface meteorology.
Integration domain	Global
Grid size	T106 (1.125deg.)
Vertical levels	20 levels(surface – 45hPa)
Initial time and forecast time	48 hours from 12 UTC once a day

Boundary conditions	Almost same as global spectral model
Forcing data (Nudging)	Global analysis and forecast of Global Spectral Model (GSM)
	Snow depth analysis

(9) UV index prediction system

JMA operates a UV index prediction system since May 2005. The system consists of chemical transport model (CTM) which is directly coupled with a low resolution version of GSM and radiative transfer model. The model specifications are given in Table 4.5.2.1(9)-1 and 2.

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

Basic equations	Eulerian model coupled with Global Spectral Model
Numerical technique	3D semi-Lagrangian transport, chemical reaction
Integration domain	Global
Grid size	T42 (2.8125deg.)
Vertical levels	68 levels(surface – 0.01hPa)
Initial time and forecast time	48 hours from 12 UTC once a day
Boundary conditions	Almost same as global spectral model
Forcing data (Nudging)	Global analysis and forecast of Global Spectral Model (GSM)
Observational data	Column ozone from OMI/NASA

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

Basic equations	doubling and adding method
Numerical technique	Look up table technique
Integration domain	Regional (110 – 150E, 20 -50 N)
Grid size	0.25 x 0.20 degree
Boundary conditions	Albedo, aerosol (climate), altitude, distance between the sun and the earth
Forcing data	Column ozone (from CTM), weather forecast

4.5.2.2 Research performed in this field

(1) Ocean wave forecasting model

A third generation global wave model MRI-III has been modified at MRI for several years, and the new version model is now semi-operationally run and examined for operational use at JMA. In the model, swell dissipation term has been newly introduced to improve the representation of swell. The new model has higher accuracy than the present model, especially in the ocean of the Southern Hemisphere. The model is planned to be put into operation in May 2007.

(2) Storm surge model

The following researches are underway to improve the storm surge model.

(a) Higher grid resolution

For better estimate of geographical effects, the grid size will be changed from 1 minute (about 1.5~1.8 km) to 1 km.

(b) Estimate of wave setup

Wave setup sometimes plays a predominant role in generating a storm surge at several Japanese ports facing an open ocean but this effect is not included in the current version of the model. JMA is developing a method to estimate sea level change caused by wave setup using numerical wave model products.

(c) Estimate of regional distribution of astronomical tides

Astronomical tides are required for predicting storm tides (sum of storm surge and astronomical tide). Currently, they are available only at tide stations, since they are produced through harmonic analysis with tide data observed at each station. To predict spatial distribution of storm tide, a data assimilation method for astronomical tide is being developed.

(3) Ocean Data Assimilation System for the North Pacific Ocean

A new ocean data assimilation system for the North Pacific Ocean has been developed. The model in the system solves free surface variation. The turbulent closure scheme is adopted to calculate the vertical mixing coefficient. The horizontal grid size of the model is 1/10° and the number of vertical levels is 54. The system adopts a multivariate 3DVAR analysis scheme and the Incremental Analysis Update technique to correct the model temperature and salinity fields. The new system is planned to be in operation from March, 2008.

(4) 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 4.5.2.2(d)). Ocean current data produced by the ocean model and data assimilation system will be newly introduced into the sea ice forecast model. The model is planned to be put into operation in March 2011.

(5) Kosa prediction model

Meteorological Research Institute develops earth system model which contains several chemical species and aerosol to predict global warming.

(6) UV index prediction system

Meteorological Research Institute develops earth system model which contains several chemical species and aerosol to predict global warming.

(7) Improvement of photochemical oxidant information by applying transport model to oxidant forecast

The JMA has produced a statistical guidance of oxidant using weather and pollutant observation and issued photochemical oxidant information for prefectures in high oxidant concentration days. We have applied an atmospheric transport model (Takano et al., 2007) in which the output of the MSM is used to transport the oxidant. The model has good precision in each forecast district throughout the forecast time in the southern part of the Kanto region. We come to be able to announce the photochemical oxidant information supplemented with the model oxidant forecast 04-09UTC in this area after 04UTC. The MSM is planned to adopt a hybrid terrain following vertical coordinate (JMA, 2007), then the transport model will be modified to adopt the same coordinate. (Y. Aikawa)

4.5.3 Specific products operationally available

(1) Numerical storm surge prediction products

Time series of predicted storm surge and tidal level, and predicted highest tide for about 300 ports are disseminated to local meteorological observatories. This information is used as a major basis for issuing storm surge advisories and warnings.

(2) Kosa products operationally available

Time series of predicted Kosa concentrations are provided via Japan Meteorological Business Support Center and internet (http://www.jma.go.jp/jp/kosa/index.html) once a day.

(3) UV index products operationally available

Time series of predicted UV index information are provided via Japan Meteorological Business Support Center and internet (http://www.jma.go.jp/en/uv/index.html) twice a day.

4.6 Extended range forecasts (ERF) *(10 days to 30 days)*

4.6.1 Models

4.6.1.1 In operation

An extended-range ensemble prediction system is operated once a week. The numerical prediction model applied for the extended-range ensemble prediction system is a low resolution version of (TL159) of GSM (Table 4.6.1.1-1). For the lower boundary condition of the model, initial COBESST (Ishii et al., 2005) anomalies are fixed during the 34-day time integration. Soil moisture, soil temperature and snow depth are predicted by the model, and their initial states are provided by the land data assimilation system.

An ensemble consists of 50 members per week by extending 25 member runs of the extended-range ensemble prediction system on consecutive two days up to 34 days. Thus, initial perturbation is prepared with a combination of a breeding of growing mode (BGM) method and a lagged average forecast (LAF) method.

Table 4.6.1.1-1 Specifications of extended-range Ensemble Prediction System

Atmospheric model	GSM0603C
Integration domain	Global, surface to 0.4hPa
Horizontal resolution	TL159 (about 1.125° Gaussian grid 320by160 ~120km)
Vertical levels	40 (surface to 0.4hPa)
Forecast time	816 hours from 12 UTC
Ensemble size	50 members
Perturbation generator	Combination of breeding of a growing mode (BGM) method and a lagged averaged forecast (LAF) method
Perturbed area	Northern hemisphere and tropics (20S-90N)

4.6.1.2.1 Climate data assimilation system

JMA Climate Data Assimilation System (JCDAS) is an atmospheric global analysis for operational climate use and has been operational since March 2006. It was transitioned from Japanese 25-year Reanalysis (JRA-25) which covered 26 years from 1979 to 2004 and was produced by JMA and the Central Research Institute of Electric Power Industry (CRIEPI) (Onogi et al. 2007). JCDAS is using the same data assimilation system as that of JRA-25. It has a spectral resolution of T106, equivalent to a horizontal grid size around 120km, and 40 vertical layers with the top level at 0.4hPa. The data assimilation method of JCDAS is the three dimensional variational (3D-VAR) which had been used in JMA operations until February 2005. The background error statistics were taken from 2003 operational analyses which were the latest statistics available at the time JRA-25 production started. For surface variables, surface pressure is assimilated simultaneously with upper air variables in the 3D-VAR; other surface variables of temperature, wind and relative humidity are assimilated separately with a uni-variate 2-dimensional optimal interpolation (2D-OI).

Many advantages have been found in the JRA-25 and JCDAS. Firstly, predicted 6-hour global total precipitation distribution and amount are well reproduced both in space and time. The performance is the best among vis-a-vis reanalyses, such as NCEP/NCAR Reanalysis 1 and NCEP/DOE Reanalysis 2 (both continuously operated as CDAS), 15-year and 40-year reanalyses of European Centre for Medium-Range Weather Forecasts (ERA-15 and ERA-40). Especially after July 1987, assimilating retrieved precipitable water from SSM/I radiance data contributed to the good performance. Furthermore, tropical cyclones (TC) are properly analyzed owing to the assimilation of reconstructed wind profile around tropical cyclones.

JRA-25 and JCDAS jointly provide long term consistent and high quality global analysis fields since 1979. For the operational use of the JRA-25 at JMA, a new climate normal value was created and is being used as a basic reference data for climate monitoring services. Reanalysis data, produced by the model whose characteristics are the same as the seasonal forecast model, can provide consistent initial field and verification data for the seasonal forecast and hindcast. Consequently the JRA-25 and JCDAS data greatly contributes to the development of the seasonal forecast model.

4.6.2 Operationally available NWP model and EPS ERF products

A model systematic bias was estimated as an average forecast error which was calculated from hindcast experiments for years from 1984 to 1993. The bias is removed from forecast fields, and grid point values are processed to produce several forecast materials such as ensemble mean and spread.

The grid point value products from extended-range ensemble prediction system are disseminated through the GTS and the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc). Details of those are shown in Table 4.6.2-1. The map products disseminated through TCC are shown in Table 4.6.2-2.

Table 4.6.2-1 Grid point value products (GRIB) for extended–range forecast through GTS and TCC

Contents		Level (hPa)	Area	Initial time & Forecast Time
Ensemble mean value of forecast members averaged for 7 days forecast time range	Sea level pressure, rainfall amount	-	Global 2.5x2.5 degree	Initial time: 12 UTC of 2 days of the week (Wednesday & Thursday) Forecast time: 2-8, 9-15, 16-22, 23-29 days from later initial time
	Temperature, RH, wind (u, v)	850		
	Geopotential height	500,100		
	Wind (u, v)	200		
	Sea level pressure anomaly	-		
	Temperature anomaly	850		
	Geopotential height anomaly	500,100		
Spread (Standard deviation) among time averaged ensemble member forecasts	Sea level pressure	-		Forecast time: 2-8, 9-15, 16-22, 23-29, 2-15, 16-29, 2-29 days from later initial time
	Temperature	850		
	Geopotential height	500		
large anomaly index* of geopotential height		500		

* large anomaly index is defined as {(number of members whose anomaly is higher than 0.5xSD) – (number of members whose anomaly is lower than – 0.5xSD)}/{number of members} at each grid point, where SD is defined as observed climatological standard deviation.

Table 4.6.2-2 Map products for extended–range forecast through TCC

	Forecast time	Parameter
Ensemble mean	Day 2–8, day 9–15, day 16–29, day 2–29 averages	Geopotential height and anomaly at 500hPa, temperature and anomaly at 850hPa, sea level pressure and anomaly
Spread (Standard deviation) among time averaged ensemble member forecasts		Geopotential height at 500hPa
Large anomaly index*		
Time-longitude cross section	7-day running mean	Velocity potential at 200hPa averaged in the equatorial region (from 5N to 5S)
Time sequence		Several circulation indices

* large anomaly index is defined as {(number of members whose anomaly is higher than 0.5xSD) – (number of members whose anomaly is lower than –0.5xSD)}/{number of members} at each grid point, where SD is defined as observed climatological standard deviation.

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

4.7.1 Models

4.7.1.1 In operation

(1) 120-day prediction system

The 120-day long-range EPS for 3-month outlook is operated once a month and is completed by the 25th day. The numerical prediction model applied for the long-range EPS is a low-resolution version (TL9563) of GSM (Table 4.7.1-1). Thus, cumulus parameterization and associated initialization schemes are different from those of the current GSM mentioned at 4.2.2 in addition to the horizontal resolution. For the lower boundary condition of the model, SST anomalies for the previous month are prescribed during the 120-day time integration. Soil moisture, soil temperature and snow depth are predicted by the model, and their initial states are provided by the climatology.

An ensemble consists of 31 members including a control run. The initial condition for the control run is prepared in the same way as those for the medium-range EPS. Their initial perturbations in the atmosphere are prepared with a Singular Vector (SV) Method.

Table 4.7.1-1 Specifications of 120-day Ensemble Prediction System

Atmospheric model	GSM0502
Integration domain	Global, surface to 0.4hPa
Horizontal resolution	TL9563 (about 1.875º Gaussian grid 192by96 ~180km)
Vertical levels	40 (surface to 0.4hPa)
Forecast time	2880 hours from 12 UTC
Ensemble size	31 members
Perturbation generator	Singular Vector (SV) Method
Perturbed area	Northern hemisphere and tropics (20S20N-90N)

(2) 210-day prediction system

The 210-day long-range EPS for warm and cold seasons outlook is operated twice a year by the 25th day in February and September, respectively. The 210-day ensemble prediction system is carried out as an extension of the 120-day ensemble prediction system except that separately predicted SST anomalies are prescribed as a boundary condition. Note that 180- and 150-day EPSs are also conducted in March, April and October for warm and cold season outlook in the same way as the 210-day EPS.

A two-tiered way is adapted for the 210-day EPS; first, global SST anomalies are predicted, then the integration of the atmospheric model (GSM) is performed during 210 days under the prescribed global SST anomalies.

It is assumed that initial SST anomalies persist for first two months of the 210 days. To predict global SST anomalies for the last two months of the 210 days, the Niño3 (a region in eastern-equatorial Pacific) SST anomaly is given by forecasters based on the El Niño prediction model (atmosphere-ocean coupled model) and corrected by the MOS (Model Output Statistics) method. Then, global SST anomalies are regressed against the given Niño3 SST anomaly. The regressed SST anomalies are prescribed globally as the GSM boundary condition for the last two months. The interpolated global SST anomalies are applied to the months between the first and the last two months.

(3) El Niño prediction system

A coupled atmosphere-ocean model has been operated for monthly El Niño outlook. The atmospheric part was replaced by a low-resolution version (T42L40) of the one used in the current 120-day forecast system. The specifications of the coupled model are shown in Table 4.7.1.1-1.

JMA makes the model results available through the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc). The NINO3 SST anomaly is used for the 210-day dynamical forecast.

Table 4.7.1.1-1 Specifications of the JMA coupled model

Oceanic component	Identical to the model for ODAS	
Atmospheric component	Basic equations	Primitive equations
	Domain	Global
	Resolution	T42, 40 vertical levels
	Convection scheme	Arakawa-Schubert
	Land surface processes	SiB of Sellers et al. (1986)
Coupling	Coupling interval	24 hours
	Flux adjustment	Monthly heat and momentum flux adjustment
Forecast period	14 months	
Model run interval	5 days	

4.7.2 Operationally available EPS LRF products

A model systematic bias was estimated as an average forecast error, which was calculated from hindcast experiments for 18 years from 1983 to 2003. The bias is removed from forecast fields, and grid point values are processed to produce several forecast materials such as ensemble mean and spread.

The following model output products (Table 4.7.2-1) from 120-day ensemble prediction are disseminated through the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc).

Table 4.7.2-1 Grid point value products and maps for 120-day prediction through TCC

Contents		Level (hPa)	Area	Initial time & Forecast Time
Ensemble mean and spread (standard deviation) values of forecast members averaged for every each month and three months during forecast time range	Rainfall amount, surface temperature at 2m, sea surface temperature, sea level pressure and their anomalies	-	Global 2.5x2.5 degree	Initial time: 12UTC around 15th day in each month Forecast time : Every each month and three months average
	Temperature and its anomaly	850		
	Geopotential height and its anomaly	500		
	Wind (u, v) and their anomalies	850, 200		

The following model output products (Table 4.7.2-2) from 210-day ensemble prediction are disseminated through the Tokyo Climate Center (TCC) Web site (http://cpd.kishou.go.jp/tcc).

Table 4.7.2-2 Grid point value products (GRIB) and maps for 210-day prediction through TCC

Contents		Level (hPa)	Area	Initial time & Forecast Time
Forecast members (only for grid-point-value), their ensemble mean and spread (standard deviation) values averaged for every each month and three months during forecast time range	Rainfall amount, surface temperature at 2m, sea surface temperature, sea level pressure and their anomalies	-	Global 2.5x2.5 degree	Initial time : 12 UTC around 15th day in each month Forecast time : Every each month and three months average
	Temperature and its anomaly	850		
	Geopotential height and its anomaly	500		
	Wind (u, v) and their anomalies	850,200		
	Relative humidity and its anomaly	850		

5. Verification of prognostic products

5.1 Annual verification summary

5.1.1 NWP prognostic products

Objective verification of prognostic products is operationally performed against analysis and radiosonde observations according to the WMO/CBS recommendations. Results of the monthly verification for the year of 2006 are presented in Tables 5.1.1-1 - 5.1.1-20. All the verification scores are only for the prediction from 1200 UTC initials.

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

Northern Hemisphere (20-90N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	11.7	11.2	10.2	9.6	9.3	9.0	8.8	8.2	8.9	9.0	9.9	10.1	9.7
72	32.9	31.2	31.0	27.7	26.1	25.0	25.3	21.5	26.1	26.3	30.1	30.5	27.8
120	59.1	56.5	60.7	51.6	49.3	45.8	46.7	37.8	48.0	51.1	58.1	56.9	51.8

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

Southern Hemisphere (20-90S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	11.1	11.6	11.6	12.5	13.2	13.9	14.2	14.2	13.7	12.5	11.6	10.5	12.6
72	32.8	32.6	35.1	37.0	40.0	41.8	45.5	44.9	39.0	33.7	33.6	29.9	37.2
120	56.8	56.7	64.8	66.5	70.8	72.7	80.6	79.4	71.9	63.5	59.4	57.2	66.7

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	Ave
24	14.0	13.0	14.9	13.4	11.9	10.6	10.0	10.1	11.5	12.8	13.4	13.6	12.4
72	36.9	33.4	33.2	31.7	27.0	23.1	21.0	20.7	25.1	28.6	32.0	37.6	29.2
120	60.5	63.1	55.2	57.2	48.0	40.7	36.1	35.2	45.0	59.0	55.7	66.3	51.8
ob. num.	78	75	78	74	79	78	78	76	76	79	79	79	77.4

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

Europe

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	17.1	17.2	19.1	19.4	19.3	14.1	12.2	14.8	13.0	16.9	18.1	18.9	16.7
72	39.8	30.7	33.7	32.4	28.0	26.8	21.6	27.1	25.1	31.5	31.7	30.8	29.9
120	65.6	50.4	61.5	58.5	45.8	47.6	43.6	44.6	43.8	54.5	55.8	55.2	52.2
ob. num.	54	54	56	55	57	58	58	57	58	57	57	56	56.4

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

Asia

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	15.5	15.6	15.2	15.5	15.5	14.4	16.6	15.4	14.8	14.4	13.8	14.8	15.1
72	27.6	29.1	28.1	29.0	27.7	27.3	26.8	23.2	25.9	27.7	28.5	27.7	27.4
120	49.5	43.3	51.9	44.1	45.2	40.1	36.7	31.7	41.9	45.5	48.8	45.3	43.6
ob. num.	50	50	55	56	55	54	54	55	55	54	54	56	54.0

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

Australia / New Zealand

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	13.8	13.9	14.1	14.1	14.4	15.4	15.4	15.8	15.5	16.6	16.1	16.1	15.1
72	23.7	25.8	26.6	28.3	29.2	30.2	31.4	30.6	28.8	28.3	26.2	30.1	28.3
120	44.1	47.7	48.7	52.9	53.2	45.1	58.3	59.7	54.7	53.0	39.4	44.5	50.1
ob. num.	12	11	12	12	11	11	11	11	11	11	11	11	11.3

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

Northern Hemisphere (20-90N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	16.1	15.9	16.7	16.4	15.8	14.0	13.8	14.1	13.6	14.8	15.4	15.9	15.2
72	38.2	33.9	34.8	32.9	29.1	28.1	26.4	25.1	27.9	30.7	33.4	34.3	31.2
120	64.6	59.8	64.3	57.2	51.3	47.7	45.8	40.7	48.9	58.1	59.2	60.5	54.9
ob. num.	241	237	252	247	253	251	252	250	249	252	252	251	248.9

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

Southern Hemisphere (20-90S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	15.7	16.8	17.4	19.0	18.1	19.4	20.0	18.7	19.5	19.6	18.1	16.3	18.2
72	28.6	30.6	30.2	34.6	33.8	35.8	40.1	39.5	36.4	32.5	32.7	30.1	33.7
120	50.0	51.3	54.9	61.0	56.5	60.8	67.8	69.9	64.5	57.3	52.3	47.6	57.8
ob. num.	29	27	29	28	26	26	28	27	28	28	29	29	27.8

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

Northern Hemisphere (20-90N)

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

24	4.8	4.8	4.5	4.5	4.5	4.5	4.4	4.4	4.4	4.2	4.3	4.3	4.5
72	9.8	9.4	9.2	9.2	9.6	9.5	10.0	9.0	9.8	9.2	9.5	9.4	9.5
120	14.7	14.4	14.5	14.1	14.9	14.6	15.0	13.1	14.9	14.9	15.4	15.1	14.6

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

Southern Hemisphere (20-90S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	4.5	4.6	4.5	4.6	4.7	4.8	4.7	4.6	4.7	4.5	4.4	4.3	4.6
72	10.5	10.6	10.8	10.7	10.7	11.1	11.3	11.0	10.5	10.0	10.0	9.5	10.6
120	16.2	15.6	16.8	16.5	16.4	16.7	17.6	17.3	16.4	15.7	15.1	15.3	16.3

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

North America

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	6.7	6.7	6.3	6.6	6.4	6.1	5.9	5.7	6.2	6.1	6.3	6.8	6.3
72	12.5	11.9	10.7	10.7	11.1	10.7	10.5	9.9	11.2	11.2	11.1	12.1	11.1
120	17.9	17.3	16.5	15.7	16.2	15.7	15.1	13.4	16.7	18.6	17.7	19.5	16.7
ob. num.	71	66	73	71	76	77	77	75	74	75	75	73	73.6

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

Europe

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	6.6	6.0	6.0	6.1	6.2	6.3	5.9	6.7	6.3	6.7	6.3	7.0	6.3
72	12.4	9.9	9.8	10.6	9.4	10.8	9.8	11.8	11.0	11.2	10.6	11.0	10.7
120	18.7	15.5	15.2	16.7	15.2	16.4	15.1	17.0	16.2	17.3	16.8	17.7	16.5
ob. num.	52	52	53	53	54	55	56	54	55	54	56	54	54.0

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

Asia

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	5.9	6.3	6.2	6.5	6.8	7.2	6.6	6.1	5.6	5.6	5.9	5.9	6.2
72	8.3	9.7	9.0	10.6	11.2	11.7	10.7	9.9	9.8	9.2	9.6	8.8	9.9
120	11.7	12.3	12.9	13.5	16.0	16.0	13.7	13.0	13.7	13.4	13.5	12.3	13.5
ob. num.	49	50	55	56	55	54	54	56	56	56	55	56	54.3

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

Australia / New Zealand

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	7.1	6.3	6.6	6.2	6.1	5.9	6.1	5.9	5.7	6.4	6.1	6.2	6.2
72	10.6	10.2	10.7	9.6	10.3	9.9	10.0	9.3	8.7	10.1	9.0	9.1	9.8
120	15.5	14.0	14.9	15.3	14.9	14.8	14.9	15.3	13.0	14.6	12.3	12.9	14.4
ob. num.	20	21	22	21	20	20	20	19	18	15	19	16	19.3

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

Northern Hemisphere (20-90N)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	6.2	6.2	6.0	6.1	6.2	6.3	6.1	6.2	6.0	6.0	6.0	6.3	6.1
72	11.1	10.5	10.0	10.3	10.4	10.8	10.6	10.5	10.9	10.5	10.4	10.8	10.6
120	16.3	15.3	15.2	15.1	15.7	15.8	15.3	14.7	15.9	16.8	16.1	16.8	15.7
ob. num.	229	223	241	238	245	244	246	245	243	244	244	241	240.3

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

Southern Hemisphere (20-90S)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	6.9	7.0	6.9	6.9	6.6	6.8	6.7	6.7	6.7	7.0	6.9	6.8	6.8
72	11.0	11.4	11.5	11.2	11.1	11.0	11.3	11.0	10.5	10.8	11.0	10.4	11.0
120	16.1	15.4	16.5	17.1	16.6	15.9	17.1	17.6	15.9	16.2	15.4	15.4	16.3

ob. num.	34	32	34	32	30	30	32	31	31	30	31	29	31.3

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

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	2.1	2.1	2.0	1.9	2.0	2.0	2.2	2.2	2.2	2.2	2.0	2.1	2.1
72	3.4	3.4	3.3	3.2	3.3	3.3	3.6	3.6	3.7	3.8	3.4	3.4	3.4
120	4.1	4.1	3.9	3.8	3.9	3.9	4.4	4.5	4.5	4.5	3.9	4.0	4.1

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

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	4.4	4.5	4.0	4.0	4.0	3.9	4.2	4.0	3.9	4.0	3.7	4.1	4.1
72	7.4	7.3	6.6	6.5	6.7	6.5	6.9	6.5	6.2	6.6	6.1	6.7	6.7
120	9.1	8.7	8.2	8.1	8.5	7.9	8.6	8.0	7.5	8.1	7.6	8.0	8.2

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

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	4.1	3.9	3.9	3.8	3.9	4.1	4.2	4.4	4.1	4.1	3.6	4.1	4.0
72	4.9	4.4	4.4	4.4	4.3	4.7	4.6	4.8	4.6	4.6	4.0	4.4	4.5
120	5.4	4.9	4.9	5.0	4.7	5.1	5.2	5.2	5.0	5.1	4.4	4.8	5.0
ob. num.	31	31	34	31	32	34	33	33	34	32	34	35	32.8

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

Tropic

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	6.0	5.8	5.9	5.3	5.3	5.1	5.8	5.5	5.1	5.6	5.2	5.7	5.5
72	8.0	7.7	7.6	6.9	6.8	7.0	7.6	7.0	6.6	7.1	6.9	7.4	7.2
120	9.1	8.9	8.9	8.5	8.2	7.9	8.6	8.1	7.8	8.3	8.3	8.6	8.4
ob. num.	30	31	33	30	31	32	32	33	34	32	31	33	31.8

5.1.2 Verification system for extended-range ensemble prediction

Scores of the extended-range ensemble prediction for each season and year are shown using anomaly correlation and root mean square error for broad geographic areas. Error maps are produced for every single forecast and each season. These are available on the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc) as listed in Table 5.1.2-1. Other various verification methods of reliability diagrams, relative operating characteristics, reduction rates of total loss and ranked probability score for each season are also applied.

Table 5.1.2-1 Verification products of extended-range ensemble prediction at TCC Web site

(a) Score

	Forecast period	Parameter	Verification areas
Anomaly correlation and root mean square error	Day 2–8, day 9–15, day 16–29, day 2–29 average	Geopotential height at 500hPa, temperature at 850hPa, sea level pressure	Northern Hemisphere (20N-90N), Eurasia (20N-90N, 0E-180E), North Pacific (20N-90N, 90E-90W), East Asia(20N-60N, 100E -179E)
		Stream function at 200hPa and 850hPa, velocity potential at 200hPa and 850hPa, and geopotential height at 500hPa	Global, Tropics(20N-20S), Northern Hemisphere(20N-90N), Southern hemisphere(20S-90S)

(b) Map

	Forecast period	Parameter
Forecast, corresponding objective analysis, and error maps	Day 2–8, day 9–15, day 16–29, day 2–29 average	Geopotential height and anomaly at 500hPa, temperature and anomaly at 850hPa, sea level pressure and anomaly, stream function and anomaly at 200hPa and 850hPa, velocity potential and anomaly at 200hPa and 850hPa, precipitation (forecast only)
Mean error map for each season		Geopotential height at 500hPa, temperature at 850hPa, sea level pressure

5.1.3 Verification system for long range ensemble prediction for 3-month outlook

Error maps for operational 120-day ensemble prediction are available on the TCC Web site in the same way as Table 5.1.2-1 (b). Additionally, hindcast experiments are verified by showing the scores for surface air temperature at 2m, precipitation, sea level pressure, 850hPa temperature and 500hPa geopotential height according to the Standard Verification System (SVS) for Long-Range Forecasts (LRF) as well as the scores of anomaly correlation and root mean square error. These are also available on the TCC Web site.

5.1.4 Verification system for long range ensemble prediction for warm and cold season outlook

Hindcast experiments are verified by showing the scores for surface air temperature at 2m, precipitation, sea level pressure, 850hPa temperature and 500hPa geopotential height according to the Standard Verification System (SVS) for Long-Range Forecasts (LRF). These are provided from TCC Web site.

5.2 Research performed in this field

5.2.1 Development of a verification method of high-resolution QPFs

The critical success index is known to be inappropriate for the verification of high-resolution quantitative precipitation forecasts when precipitation data are averaged over verification grids. This is because the process of averaging smoothes out the peak of the grid value of precipitation which might be represented better in the high-resolution model. To mitigate this problem, we propose the precipitation area score (PAS) which can assess both the intensity and the coverage of precipitation forecasts the same time.

The PAS is defined as the mean square error of ratio of precipitation area over the threshold in verification grids. This formulation is similar to that of Brier score except using the ratio of precipitation area instead of probability of precipitation. According to the statistical verification with PAS, the MSM0705 (under development) with grid spacing of 5km apparently shows the better performance than the RSM with grid spacing of 20km, even for the threshold where the threat score of MSM0705 is poorer than that of RSM. The PAS makes the disagreement small between the subjective verification and the objective verification. (Segawa and Honda, 2007)

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

6.1 Development of the GDPFS

6.1.1 Major changes which are expected in the next year

(1) Modification of the typhoon bogussing will be completed in 2007. (see 4.2.1.2 (1))
(2) GPS radio occultation data is introduced to global analysis in March 2007. (see 4.2.1.2 (7))
(3) Increase of a spatial resolution of the GSM from TL319L40 to TL959L60 is planned for the medium range deterministic forecasting.
(4) It is planned to introduce a coupled oceanic mixed layer-atmosphere model into the medium range deterministic forecasting.
(5) Increase of a spatial resolution of the GSM from TL159L40 to TL319L60 is planned for the medium range ensemble forecasting, where initial perturbations will be generated based on the singular vector calculation.
(6) Operation of the typhoon ensemble prediction system will start in 2007 using the GSM TL319L60 with 11 members, where initial perturbations will be generated based on the singular vector calculation.
(7) The improved Meso-Scale Model (MSM0705, 5kmL50) will be in operational in May 2007 in place of MSM0603. (see 4.3.2.2 (1))
(8) The forecast time of the Meso-Scale Model initialized at 03, 09, 15, 21UTC will be extended from 15 hours to 33 hours when the Meso-Scale Model is upgraded in May 2007. (see 4.3.2.2 (1))
(9) Analysis scheme of the hourly analysis will be upgraded from 3D-OI to 3D-Var and radial velocity data from Doppler radars will be used instead of VVP wind data in March 2007.
(10) The atmosphere transport model using the output of the Meso-Scale Model will be in operational to upgrade the photochemical oxidant forecast in May 2007. (4.5.2.2 (7))
(11) Physical processes in the extended-range ensemble prediction model will be updated to reduce model bias in March 2007. At the same time, the methodology for initial perturbation will be updated to describe relevant state of Madden Julian Oscillation (MJO).
(12) The number of ensemble in the prediction model for the 120-day and 210-day ensemble prediction system will be increased from 31 to 51 in the second half of 2007.

6.1.2 Major changes which are expected in the next 4 years

(1) Semi-Lagrangian advection scheme will be introduced to the tangent-linear and adjoint models of global 4D-Var data assimilation system and their horizontal resolution will be upgraded.
(2) Non-hydrostatic model-based 4D-Var will be implemented for mesoscale analysis in early 2008. (see 4.3.1.2 (1))
(3) A simple biosphere model will be implemented into the Meso-Scale Model.
(4) The atmosphere transport model using the output of the Meso-Scale Model will be in operational for high resolution prediction of volcanic ash-fall.
(5) The ocean data assimilation system will be replaced by a new one, which consists newly developed ocean general circulation model and data assimilation scheme developed by MRI in March 2008. The OGCM is of higher resolution, 1deg.(lon.)x(1/3-1deg.(lat.)L50, than the current system.
(6) The coupled atmosphere-ocean model for El Nino Prediction will be replaced by a higher resolution coupled model with a TL95L40 atmosphere model and a 1deg.(lon.)x(1/3-1deg.(lat.)L50 ocean model in March 2008.

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