WMO Technical Progress Report on the Global Data-Processing and Forecasting System 2005

Japan Meteorological Agency

1. Summary of highlights

The Japan Meteorological Agency (JMA) places the highest priority on prevention/mitigation of natural disasters in the upgrade of the Global Data-Processing and Forecasting System (GDPFS). Implementation of a four dimensional variational (4D-Var) assimilation system for the global model is one of the highlights in 2005 in this regard, which has significantly improved short-range and medium-range forecast as well as typhoon track forecast as compared to those from the previous three dimensional variational assimilation system. Efforts have also been concentrated on the development of the mesoscale model (MSM) with a resolution of 5 km. Major developments in GDPFS in 2005 were as follows:

(1) A 4D-Var scheme has been employed for the global and typhoon analyses since February 2005 (see 7.2.1).
(2) An incremental non-linear normal mode initialization (NNMI) and a vertical mode initialization were newly introduced, replacing the conventional NNMI for the global model in February 2005 (see 7.2.1).
(3) AMSU-A radiances on board Aqua satellite were added to NOAA/ATOVS assimilation in March 2005 (see 7.2.1).
(4) A thinning scheme for ATOVS was improved for 4D-Var in August 2005 (see 7.2.1).
(5) A semi-Lagrangian advection scheme was introduced to the Global Spectral Model (GSM) with an increase of the spectral resolution from T213 (quadratic grid) to TL319 (linear grid) in February 2005 (see 7.2.2).
(6) The cumulus convection and the prognostic cloud water schemes of GSM were modified in February 2005 (see 7.2.2).
(7) The radiation scheme of GSM was updated for the better treatment of cloud effects associated with the adoption of new ozone climatology in June 2005 (see 7.2.2).
(8) A new parameterization scheme for marine stratocumulus was introduced, and a prognostic cloud water scheme was revised for the one-week Ensemble Prediction System (EPS) model in March 2005 (see 7.2.5).
(9) The land surface model of the one-week EPS model was improved in ice sheet treatment in March 2005 (see 7.2.5).
(10) The SATOB winds derived from MTSAT imagery replaced those from GOES-9 in July 2005 (see 7.3.1.1).
(11) Thickness assimilation for meso and regional analyses was replaced with temperature assimilation from ATOVS retrievals provided by Meteorological Satellite Center in March 2005 (see 7.3.1.1 and 7.3.2.1).
(12) Assimilation of radial velocity of the Doppler Radar for Aviation Weather (DRAW) was started in March 2005 (see 7.3.2.1).
(13) A high-resolution regional transport model had been operated to predict volcanic gas spread from Miyakejima Island until September 2005 (see 7.4.2).
(14) The El Niño forecast system was modified in June 2005 to reduce its positive bias (see 7.6.5).

2. Equipment in use at the Global-Data Processing and Forecasting System (GDPFS) Center in JMA

The Numerical Analysis and Prediction System (NAPS) was upgraded on 1 March 2001. Major features of the NAPS are listed in Table 2-1. JMA installed a new UNIX server (UNIX server 3) for the very short-range forecasting system on 1 March 2003.

Table 2-1 Major features of NAPS

Supercomputer	HITACHI-SR8000E1/80
Total node	80
Total performance	768 Gflops
Total capacity of memory	640 GB
Data transfer rate	1.2 GB/s
Storage disk capacity	4.8 TB
Operating system	HI-UX/MPP
UNIX server 1	HITACHI-3500/E540PS
Total node	6
Total performance	215 SPECint95
Total capacity of memory	12 GB
Storage disk capacity	389 GB
Operating system	HI-UX/WE2
UNIX server 2	HITACHI-3500/E540PS
Total node	4
Total performance	151 SPECint95
Total capacity of memory	8 GB
Storage disk capacity	354 GB
Operating system	HI-UX/WE2
UNIX server 3	HITACHI-EP8000 630 6C4
Total node	5
Total performance	120 SPECint_rate2000
Total capacity of memory	40 GB
Storage disk capacity	640 GB
Operating system	AIX 5L
Transmitting and receiving message server	HITACHI-3500/545RM
Performance	4.8 SPECint95
Total capacity of memory	512 MB
Storage disk capacity	12 GB
Automated tape library	STORAGETEK Powderhorn 9310
Total storage capacity	80 TB
Automated DVD-RAM library 1	HITACHI DT-DVDO-02
Total storage capacity	2.5 TB
Automated DVD-RAM library 2	HITACHI DT-DVDO-02
Total storage capacity	3.1 TB

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. Data input system

Data input is fully automated with an exception of the manual input of typhoon position, size and intensity. They are used to generate typhoon bogus data for the global, regional and typhoon analyses.

5. Quality control system

Stage 1 Decoding

All the code forms of messages are checked against the WMO international code forms. When errors are detected in the forms, some procedures are applied in order to extract as much information as possible from the messages.

Stage 2 Internal consistency check

Climatological reasonability of all types of the data is checked. The data enlisted in the "exclusion list" as problematic data is rejected. The "exclusion list" is occasionally revised based on results of non real-time quality control.

Consistency of consecutive observation positions is checked for reports from mobile stations such as ships, drifting buoys and aircraft. Consistency between observation elements for consecutive reports and within each report is also checked for every surface station.

The vertical consistency is examined for TEMP and PILOT data using all parts of reports. The check items are:

(1) Icing of instruments;
(2) Temperature lapse rate;
(3) Hydrostatic relationship;
(4) Consistency among data at mandatory levels and those at significant levels; and
(5) Vertical wind shear.

Bias correction is applied to TEMP data which shows large persistent biases from the first guess fields. Another bias correction scheme which checks consistency between the surface pressure observation and the sea surface pressure has been introduced since August 1998.

Checks of lapse rate for SATEM data are also performed using the mean virtual temperature estimated from the thickness.

Stage 3 Quality control with reference to the first guess

Gross error and spatial consistency are evaluated against the first guess in order to remove erroneous observations. The difference (D) of the observation value from the first guess value is compared with tolerance limits C_P and C_R. C_P is an acceptable limit and C_R is a rejection limit. When D is smaller than or equal to C_P, the datum is accepted for use in the objective analysis. When D is greater than C_R, it is rejected. When D is smaller than or equal to C_R and greater than C_P, the datum is further checked by interpolating the neighboring data to the location of the datum. If the difference between the observational data and the interpolated value is not within a reasonable tolerance C_S, the datum is rejected.

These tolerance limits vary according to the local atmospheric conditions which can be estimated by the first guess field. They are smaller if time tendency and horizontal gradient are smaller in the first guess field. The scheme is called "Dynamic QC" and is based on the idea that forecast errors would be small if the area is meteorologically calm and large if it is stormy.

Duplicate observation reports are frequently received through different communication lines. The most appropriate single report is chosen from these duplicate reports considering results of quality control.

All information on the quality of observational data obtained during the quality control procedure is archived in the Comprehensive Database for Assimilation (CDA). The CDA is used for non real-time quality control and global data monitoring activities.

6. Monitoring of the observing system

Non real-time quality monitoring of observations is carried out by comparing real-time quality control information and the first guess archived in the CDA through the following procedures:

(1) Compilation of observational data rejected in the real-time quality monitoring;
(2) Calculation of statistics on the difference between observations and first-guess; and
(3) Statistical comparison of satellite data with collocated radiosonde data.

The above statistical information is effective in estimating systematic errors in observational data and also helpful to identify stations reporting suspect observations. If a station continuously reports suspect data for a long time, the data from the station are not used in the analysis.

The quality and availability of observational data are regularly issued as a monthly report entitled "JMA/NPD Global Data Monitoring Report". The statistics presented in the report are made according to the procedures for the exchange of monitoring results recommended by the Commission for Basic Systems (CBS). The report is sent to major GDPFS centers as well as to the WMO Secretariat.

The RSMC Tokyo has been acting as a lead center for monitoring quality of land surface observations in Region II since March 1991. The statistical characteristics of availability and quality for sea level pressure observations of land surface stations in Region II are published in the semiannual report entitled "Report on the Quality of Surface Observations in Region II".

JMA also acts as a Principal Meteorological and Oceanographic Center (PMOC) of Data Buoy Cooperation Panel (DBCP). Quality of meteorological observation data reported from ocean data buoys is monitored by time sequence maps which compares the data with the first guess field of the JMA Global Data Assimilation System. Sea surface and subsurface temperatures reported from buoys are also examined against climatic values and operational oceanographic analysis by JMA. Information on the buoys transmitting inferior quality data is sent to DBCP and other PMOCs over the Internet.

7. Forecasting system

JMA operationally performs four kinds of objective atmospheric analyses for the global, regional, mesoscale and typhoon forecast models. A four-dimensional variational (4D-VAR) scheme has been employed for the global and typhoon analyses since 17 February 2005. For the regional (mesoscale) analysis, a 4D-VAR scheme was introduced on 19 June 2003 (19 March 2002). All analyses are made on model coordinates for surface pressure, vector winds, temperature and specific humidity.

Global analyses are performed at 00UTC and 12UTC. 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 7-1. Daily global SST analysis and daily global snow depth analysis are described in Table 7-2 and Table 7-3, respectively.

Table 7-1 Specifications of operational objective analysis

Cut-off time

(global)	2.5 hours for early run analyses at 00 and 12 UTC 12.5 hours for cycle run analyses at 00 and 12 UTC 7.33 hours for cycle run analyses at 06 and 18 UTC
(regional)	3 hours for analyses at 00 and 12UTC 8.33 hours for analyses at 06 and 18 UTC
(mesoscale)	50 minutes for analyses at 00, 06, 12 and 18 UTC
(typhoon)	2.5 hours for analyses at 00 and 12UTC 1.5 hours for analyses at 06 and 18 UTC

Initial Guess

(global)	6-hour forecast by GSM
(regional)	6-hour forecast by RSM
(mesoscale)	3-hour forecast by MSM (see 7.3.2.2)
(typhoon)	6-hour forecast by GSM

Grid form, resolution and number of grids

(global)	Gaussian grid, 0.5625 degree, 640x320
(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)
(typhoon)	same as global analysis

Levels

(global)	40 forecast model levels up to 0.4 hPa + surface
(regional)	40 forecast model levels up to 10 hPa + surface
(mesoscale)	40 forecast model levels up to 10 hPa + surface
(typhoon)	same as global analysis

Analysis variables

Wind, surface pressure, specific humidity and temperature

Data Used

SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, SATEM, ATOVS, Aqua/AMSR-A, SATOB, BUFR (winds), MODIS polar winds, SeaWinds, TMI, SSM/I and Australian PAOB

Typhoon Bogussing

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 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 and regional and mesoscale analyses.

Initialization

Non-linear normal mode initialization with full physical processes is applied to the first five vertical modes.

Table 7-2 Specifications of SST analysis

Methodology	two-dimensional Optimal Interpolation scheme
Domain and Grids	global, 1x1 degree equal latitude-longitude grids
First guess	mean NCEP OI SST (Reynolds and Smith, 1994)
Data used	SHIP, BUOY and NOAA AVHRR SST data observed in the past five days
Frequency	daily

Table 7-3 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 and SSM/I snow cover data observed in the past day
Frequency	daily

JMA runs the Global Spectral Model (GSM0507; TL319L40) twice a day (90-hour forecasts from 00 UTC and 216-hour forecasts from 12 UTC) and the Regional Spectral Model (RSM0103; 20kmL40) twice a day as well (51-hour forecasts from 00 and 12 UTC). The non-hydrostatic Meso-Scale Model (MSM0409; 10kmL40) was introduced for operational use on 1 September 2004 in place of the former operational model (hydrostatic MSM; MSM0103). It is executed four times a day (18-hour forecasts starting from 00, 06, 12 and 18 UTC) for prediction of severe weather phenomena. The Typhoon Model (TYM0103; 24kmL25) is also 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. Moreover, JMA carries out 9-day Ensemble Prediction System (EPS) every day, 34-day EPS once a week for one-month outlook, 120-day EPS once a month for 3-month outlook, 150 to 210-day EPS in February, March and April for warm season outlook and in September and October for cold season outlook. The basic features of the operational forecast models of JMA are summarized in Tables 7.2.2-1, 7.3.1.2-1 and 7.3.2.2-1.

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. A high-resolution regional transport model is experimentally run every day to predict volcanic ash spread.

The very short-range forecast of precipitation (VSRF) is operationally performed every half an hour. Details of the VSRF are described in 7.3.4.

Two ocean wave models, Global Wave Model and Coastal Wave Model are run operationally. The specifications of the models are described in Table 7.4.3.1-1.

A numerical storm surge model is run four times a day to predict storm surges caused by tropical and extratropical cyclones. The specifications of the model are described in Table 7.4.4.1-1.

Ocean data assimilation systems for the whole globe (Global Ocean Data Assimilation System (ODAS)) and for the North Pacific are operated. Their specifications are given in Table 7.4.5-1 and Table 7.4.6.1-1, respectively.

A numerical sea ice model is run to predict sea ice distribution and thickness over the seas adjacent to Hokkaido Island twice a week in winter. The specifications of the model are given in Table 7.4.7.1-1.

A numerical marine pollution transport model is run in case of a marine pollution accident. The specifications of the model are described in Table 7.4.8.1-1.

7.1 System job schedule and forecast ranges

Table 7.1-1 summarizes the system job schedule of NAPS and forecast ranges. These jobs are executed in batch on the supercomputer and the UNIX server 1.

Table 7.1-1 Job schedule of the NAPS (Numerical Analysis and Prediction System)

Time (UTC)	NAPS job (Model forecast range)
0030 - 0120	12UTC decode, global cycle analysis
0030 - 0110	00UTC decode, mesoscale analysis
0110 - 0130	00UTC mesoscale forecast (0 - 18h)
0120 - 0210	18UTC decode, global cycle analysis

0140 - 0150	00UTC storm surge forecast (0 - 33h)
0230 - 0700	00UTC El Nino forecast, Ocean Data Assimilation
0230 - 0300	00UTC decode, global early analysis
0255 - 0320	18UTC decode, regional analysis
0300 - 0330	00UTC global forecast (0 - 90h)
0320 - 0345	00UTC decode, regional analysis
0330 - 0430	00UTC typhoon forecast (0 - 84h)
0345 - 0405	00UTC regional forecast (0 - 51h)
0410 - 0430	00UTC ocean wave forecast (0 - 90h)
0630 - 0710	06UTC decode, mesoscale analysis
0710 - 0730	06UTC mesoscale forecast (0 - 18h)
0730 - 0800	06UTC decode, typhoon analysis
0740 - 0750	06UTC storm surge forecast (0 - 33h)
0800 - 0900	06UTC typhoon forecast (0 - 84h)
1230 - 1320	00UTC decode, global cycle analysis
1230 - 1310	12UTC decode, mesoscale analysis
1310 - 1330	12UTC mesoscale forecast (0 - 18h)
1320 - 1410	06UTC decode, global cycle analysis
1340 - 1350	12UTC storm surge forecast (0 - 33h)
1430 - 1500	12UTC decode, global early analysis
1455 - 1830	12UTC medium-range ensemble forecast (0 - 216h)
1455 - 1520	06UTC decode, regional analysis
1500 - 1530	12UTC global forecast (0 - 90h)
1520 - 1545	12UTC decode, regional analysis
1530 - 1630	12UTC typhoon forecast (0 - 84h)
1545 - 1605	12UTC regional forecast (0 - 51h)
1610 - 1630	12UTC ocean wave forecast (0 - 90h)
1630 - 1715	12UTC global forecast (90h - 216h)
1715 - 1735	12UTC ocean wave forecast (90h - 216h)
1830 - 2135	12UTC one month forecast (34 days)
1830 - 1910	08UTC decode, mesoscale analysis
1910 - 1930	08UTC mesoscale forecast (0 - 18h)
1930 - 2000	18UTC decode, typhoon analysis
1940 - 1950	18UTC storm surge forecast (0 - 33h)
2000 - 2100	18UTC typhoon forecast (0 - 84h)

7.2 Medium-range forecasting system (3 - 9 days)

7.2.1 Data assimilation, objective analysis and initialization

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 (T63) and then it is interpolated and added to the first guess field at the original resolution (TL319).

An incremental non-linear normal mode initialization (NNMI) and a vertical mode initialization (Murakami and Matsumura 2004) were newly introduced instead of the conventional NNMI in February 2005.

The operation of the global land surface analysis system (GLSAS) was started in April 2002 to provide initial conditions of land surface parameters for the T106 version of GSM used in the medium- and long- range forecasts. The system consists of a land surface model (JMA-SiB) forced by atmospheric parameters and the JMA global snow depth analysis system. The GLSAS using daily SSM/I snow coverage was started in April 2003 to obtain an appropriate initial condition of land surface parameters.

The assimilation of QuikSCAT sea surface winds was started in May 2003. Positive impacts were found in typhoon track forecast experiments for July 2002.

AMSU-A radiances on board Aqua satellite were added to NOAA/ATOVS assimilation in March 2005. A thinning scheme for ATOVS is improved suit for 4D-Var in August 2005.

MTSAT SATOB winds were assimilated in stead of GOES-9 SATOB winds in July 2005.

7.2.2 Medium-range forecasting model (Table 7.2.2-1)

The specifications of the Global Spectral Model (GSM) are listed in Table 7.2.2-1. In February 2005, GSM was upgraded in the dynamics and physical processes. A 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). Minor modifications were also made to the cumulus convection and the prognostic cloud water schemes to accommodate them to the semi-Lagrangian advection scheme using longer time steps. Owing to these implementations, the forecast skill was improved especially in first several days of forecasts, the impact being much significant in the Southern Hemisphere (Katayama et al. 2005).

In July 2005, the radiation scheme of GSM was updated for the better treatment of cloud effects. New ozone climatology was also introduced in the radiation calculations. By this update, improvements in the forecast skill of GSM were achieved especially in between the upper troposphere and the lower stratosphere (Kitagawa and Murai 2006).

Table 7.2.2-1 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	Winds (zonal, meridional), temperature, specific humidity, surface pressure
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

7.2.3 Numerical weather prediction products for Medium-range forecast

The following model output products from GSM are disseminated through the JMA radio facsimile broadcast (JMH), GTS and RSMC Tokyo Data Serving System.

Table 7.2.3-1 Facsimile products for medium-range forecast

Content	Level (hPa)	Area (see Fig.1a)	Forecast Hours	Initial Time	Transmission Method
geopotential height, relative vorticity	500	O	96, 120, 144, 168, 192	12UTC	GTS
sea level pressure, rainfall amount	-	C	96, 120		radio facsimile

Table 7.2.3-2 Grid point value products (GRIB) for medium-range forecast

Contents	Level (hPa)	Area	Forecast Hours	Initial Time	Transmission Method
sea level pressure, rainfall amount	-	Global 2.5x2.5 Degree	96, 120	12UTC	GTS RSMC DSS
temperature, wind	surface				
geopotential height	1000				
geopotential height, temperature, wind	850, 700, 500, 300, 250, 200, 100, 70, 50, 30				
T-TD	850, 700				
sea level pressure, rainfall amount	-		144, 168, 192		
temperature, wind	surface				
geopotential height	1000				
geopotential height, temperature, wind	850, 700, 500, 300, 200				
T-TD	850, 700				
sea level pressure, rainfall amount	-	Global 1.25x1.25 Degree	96, 108, 120 132, 144, 156, 168, 180, 192	12UTC	RSMC DSS
temperature, wind, relative humidity	surface				
geopotential height, temperature, wind, relative humidity, vertical p-velocity	1000, 925, 850, 700, 600, 500, 400, 300,				
geopotential height, temperature, wind	250, 200, 150, 100, 70, 50, 30, 20, 10				
relative vorticity	500				
T-TD	850, 700				

7.2.4 Techniques for application of GSM products

Atmospheric angular momentum (AAM) functions are computed from analyzed and forecasted global wind and surface pressure data and sent to NCEP/NOAA.

7.2.5 Medium-range Ensemble Prediction System (EPS) (9-day)

A numerical weather prediction model applied for the EPS is a low-resolution version (T106) of the GSM. In March 2005, a new parameterization scheme for marine stratocumulus was introduced and the prognostic cloud water scheme was revised. The land surface model was also improved in ice sheet treatment. Thus, dynamical framework and physical processes of the model are similar to those of the high-resolution GSM (TL319) shown in Table 7.2.2-1 except for advection scheme, horizontal resolution and radiation parameterization. The atmospheric initial condition for the control run is prepared by interpolating the TL319 analysis. The initial condition for a land surface model is generated by running the land surface model with external forcing of TL319 atmospheric four-dimensional data assimilation (4DDA) as well as assimilating snow depth analysis.

Table 7.2.5-1 Specifications of 9-day Ensemble Prediction System

Numerical technique	Leapfrog, Eulerian, semi-implicit time integration scheme
Horizontal resolution	Spectral triangular 106 (T106), roughly equivalent to 1.125 x 1.125 degrees lat-lon
Time step	Variable time step length to satisfy the CFL condition for advection
Number of members	25 members
Initial state perturbation	Breeding of Growing Mode (BGM) method

	(12 independent breeding cycles in 12 hours periods)
Perturbed area	Northern hemisphere and tropics (20S-90N)

7.2.5.1 Numerical weather prediction products for Medium-range Ensemble Prediction

The following model output products from Medium-range Ensemble Prediction are disseminated through RSMC Tokyo Data Serving System.

Table 7.2.5.1-1 Grid point value products (GRIB) for Medium-range Ensemble Prediction

Contents	Level (hPa)	Area	Forecast Hours	Initial Time	Transmission Method
sea level pressure	-	Global 2.5x2.5 Degree	Every 6 hours from 0 to 192 hours	12UTC	RSMC DSS
geopotential height	1000, 500				
temperature	850				
wind	850, 250				

* Above GPVs are ensemble mean and standard deviation derived from ensemble members.

7.2.5.2 Techniques for application

The Kalman-filtering technique is applied to derive maximum and minimum daily temperature of each 3-8 forecast day from grid point values predicted by EPS. Probability of precipitation (above 1mm a day) at each grid point is derived directly from probability density of EPS.

7.3 Short-range forecasting systems

7.3.1 Short-range forecasting system (0-51 hours)

7.3.1.1 Data assimilation, objective analysis and initialization

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 7.3.2.1), except that the resolution of the inner-loop model is 40km and a six-hour assimilation window is employed. Initial and lateral boundary conditions for 4D-VAR are derived from GSM forecasts.

Assimilation of MTSAT SATOB winds started, instead of GOES-9 SATOB winds, in July 2005. For ATOVS retrievals from the Meteorological Satellite Center of JMA, thickness assimilation was replaced with temperature assimilation in March 2005, as it changed the data format from SATEM to BUFR.

7.3.1.2 Regional Spectral Model (RSM)

There were no changes to RSM in 2005. The specifications of RSM are shown in Table 7.3.1.2-1.

Table 7.3.1.2-1 Specifications of Regional Spectral Model (RSM0103)

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.

7.3.1.3 Numerical weather prediction products

The following model output products derived from GSM are disseminated through the JMA radio facsimile broadcast (JMH), GTS and RSMC Tokyo Data Serving System. No products from RSM are disseminated through these systems.

Table 7.3.1.3-1 Facsimile products for short-range forecast

Contents	Level (hPa)	Area (see Fig.1)	Forecast Hours	Initial Time	Transmission Method
geopotential height, relative vorticity	500	A'	0	00UTC 12UTC	GTS
vertical p-velocity	700				
temperature, wind	850				
geopotential height, relative vorticity	500		24, 36		
sea level pressure, rainfall amount	-				
temperature	500				
T-Td, vertical p-velocity	700				
temperature, wind	850				
sea level pressure, rainfall amount	-	C	24, 48, 72		
geopotential height, relative vorticity	500		48, 72		
geopotential height, temperature, T-Td	850		0		
geopotential height, temperature, T-Td	700				
geopotential height, temperature	500				
geopotential height, temperature, wind	300				
geopotential height, temperature, wind	200	Q	0		
geopotential height, temperature, wind	250		0, 24		
geopotential height, temperature, wind	500		24		
geopotential height, temperature	500	D	0	12UTC	
stream line	200	-	0, 24, 48		
stream line	850				
geopotential height, temperature	500	C	0	00UTC 12UTC	radio facsimile
geopotential height, temperature, T-Td	850				
sea level pressure, rainfall amount	-		48,72		

Table 7.3.1.3-2 Grid point value products (GRIB) for short-range forecast

Contents	Level (hPa)	Area	Forecast Hour	Initial Time	Transmission Method
sea level pressure	-	Global 2.5x2.5 degree	0	00UTC 12UTC	GTS Internet
temperature, wind, T-TD	Surface				
geopotential height, temperature, wind	1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10				
T-Td	1000, 850, 700, 500, 400, 300 (00UTC) 850, 700 (12UTC)				
sea level pressure, rainfall amount	-		24, 48, 72	00UTC 12UTC	
temperature, wind	Surface				
geopotential height, temperature, wind	850, 700, 500, 300, 250, 200, 100, 70, 50, 30				
T-TD	850, 700				
sea level pressure, rainfall amount	-	20S-60N 80E-160W 2.5x2.5 degree	0, 6, 12, 18, 24, 30, 36, 48, 60, 72	00UTC 12UTC	GTS Internet
temperature, wind, T-TD	Surface				
geopotential height, temperature, wind, T-TD, vertical p-velocity	850, 700				
geopotential height, temperature, wind, T-TD, relative vorticity	500				
geopotential height, temperature, wind	300, 250, 200, 150, 100				
sea level pressure, rainfall amount	-	20S-60N 80E-160W 1.25x1.25 degree	0, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84		
temperature, wind, T-TD	Surface				
geopotential height, temperature, wind, T-TD, vertical p-velocity	925, 850, 700				
geopotential height, temperature, wind, T-TD	500, 400, 300				
geopotential height, temperature, wind	250, 200, 150, 100, 70, 50 30, 20				
relative vorticity	500				
vorticity potential, stream function	850, 200				
sea level pressure, rainfall amount	-	Global 1.25x1.25 degree	0, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84	00UTC 12UTC	Internet
temperature, wind, relative humidity	Surface				
geopotential height, temperature, wind, relative humidity, vertical p-velocity	1000, 925, 850, 700, 600, 500, 400, 300,				
Geopotential height, temperature, Wind	250, 200, 150, 100, 70, 50, 30, 20, 10				
Relative vorticity	500				
Vorticity potential, stream function	850, 200				

7.3.1.4 Operational techniques for application

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 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/momentary temperatures, maximum/momentary wind speed and the associated direction at each of the JMA surface stations. This method is also used for the aviation weather forecast (TAF-Long) 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 forecasts up to 51 hours at 3-hour intervals, except for 6-hour probability of precipitation, daily maximum/minimum temperatures and daily minimum humidity.

7.3.2 Short-range forecasting system (0- 18 hours)

7.3.2.1 Data assimilation, objective analysis and initialization

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 three-hour assimilation window. Radar-AMeDAS (Automated Meteorological Data Acquisition System) precipitation data (see 7.3.4.1) in addition to conventional data is 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 for Aviation Weather (DRAW) was started in March 2005, which slightly improved the precipitation forecasts for moderate rainfall.

Assimilation of MTSAT SATOB winds started, instead of GOES-9 SATOB winds, in July 2005 For ATOVS retrievals from the Meteorological Satellite Center of JMA, thickness assimilation was replaced with temperature assimilation in March 2005, as it changed the data format from SATEM to BUFR.

7.3.2.2 Meso-Scale Model (MSM)

A non-hydrostatic Meso-Scale Model (MSM0409; 10kmL40) with 10-km resolution has been operated since September 2004 in place of the former operational hydrostatic model (MSM0103) of the same resolution. The specifications of the model are listed in Table 7.3.2.2-1.

Table 7.3.2.2-1 Specifications of Meso-Scale Model (MSM0409)

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, 10km at 60N and 30N
Integration domain	Japan, 361 x 289 grid points
Vertical levels	40 (surface to 22km)
Forecast time	18 hours from 00, 06, 12, 18 UTC
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	06-24 (12-30) hour forecast by RSM initialized at 6 (12) hours earlier for 06, 18 (00, 12) 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

7.3.2.3 Numerical weather prediction products

Products derived from MSM are disseminated through neither JMH nor GTS.

7.3.2.4 Techniques for application

Prognostic charts of significant weather, such as the location of jet axis, the area of CAT and Cb in horizontal cross-sections as well as vertical cross-sections along major flight paths for domestic aviation are derived from the grid point values of MSM.

The Kalman Filtering technique is used for the aviation weather forecast (TAF-Short) guidance, such as hourly cloud amount, minimum ceiling, minimum visibility, maximum wind speed and the associated direction up to 15 hours at each major airport.

The same techniques as in the RSM-based guidance (see 7.3.1.4) are also used to derive the following weather guidance. These are the averaged precipitation amount at each 20km square grid, maximum 1-hour and 3-hour accumulated precipitation amount in each sub-divided forecast area, and maximum wind speed and the associated direction at each observation station. The weather forecast guidance provides three hourly values up to 15 hours ahead to make disaster prevention information available in time.

7.3.3 The Hourly Wind Analysis in Lower Atmosphere

A multivariate three-dimensional optimum interpolation (3D-OI) scheme was introduced to create an objective analysis of wind fields in the troposphere and lower stratosphere, using the latest MSM forecast output as a first guess. Major wind data used in the analysis is the followings: wind profiler data from the Wind Profiler Network and Data Acquisition System (WINDAS) of JMA, and the VVP wind data from the Doppler Radar for Aviation Weather (DRAW) in the lower troposphere, and AMDAR data from domestic airlines, mostly concentrated in the upper troposphere and the lower stratosphere. This product is made every hour within 30 minutes from hourly observation time. More reliable wind fields can be analyzed in regions where a lot of observational data exist.

7.3.4 Very short-range forecasting system (0-6 hours)

7.3.4.1 Method of data processing

JMA operates 20 digitized weather radars and obtains radar echo intensity and echo top height data with a 1km resolution. JMA also collects raingauge precipitation data from more than 1300 AMeDAS stations operated by JMA, nearly 6500 raingauges of River Bureau and Road Bureau of the Ministry of Land Infrastructure and Transport (MLIT) and some local governments. Using these data, the precipitation data observed by radars is analyzed every half hour with a 1km resolution, by calibrating the accumulated radar one-hour precipitation with the raingauge observations.

The “Radar-AMeDAS” precipitation is the composite of analyzed precipitation of all the radars. An initial field for extrapolation forecast is the composite of calibrated rainfall intensities.

The extrapolation forecast and the precipitation forecast from the Meso-Scale Model (MSM; see 7.3.2.2) are merged into the very-short-range precipitation forecast. The 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.

7.3.4.2 Model

Table 7.3.4.2-1 Specifications of extrapolation model

Forecast process	Linear and nonlinear extrapolation
Physical process	Orographic enhancement and dissipation
Motion vector	Motion 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)

7.3.4.3 Products

The basic products of the very short-range forecasting system are: (a) composite radar echo (echo intensity and echo top height), (b) estimated one-hour precipitation distributions and (c) one-hour precipitation forecasts up to six hours. These products are provided at about 20 minutes after the analysis to support the local weather offices that issue weather warnings for heavy precipitation.

7.3.5 Precipitation nowcasting system (0-60 minutes)

7.3.5.1 Method of data processing

“Precipitation Nowcast” is to predict distribution of 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 rain gauge observation. Rain rates are predicted based on the echo motion of rainfall pattern analyzed in the very-short range forecasting (see 7.3.4). This method takes only into account the horizontal displacement of echo pattern, keeping rain rates at initial state unchanged.

7.3.5.2 Model

Table 7.3.5.2-1 Precipitation nowcasting model

Forecast process	Linear extrapolation
Physical process	none
Motion 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)

7.3.5.3 Products

The product of the Precipitation Nowcast is 10-minute precipitation forecasts up to 60 minutes. Precipitation forecasts are provided after 3 minutes from the observation to support the local weather offices for issuing warnings of heavy precipitation.

7.4 Specialized forecasts

7.4.1 Typhoon forecasting system

7.4.1.1 Objective analysis and initialization

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, nonlinear normal mode initialization with full physics is applied to the first five vertical modes.

7.4.1.2 Typhoon model (TYM)

There were no changes to the Typhoon Model (TYM) in 2005. The specifications of TYM are shown in Table 7.4.1.2-1.

Table 7.4.1.2-1 Specifications of Typhoon Model (TYM)

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 (1.5) hours for 00, 12 (06, 18) UTC initial
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	GTOPO3030 ”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.

7.4.1.3 Numerical weather prediction products

The following products on typhoon from the output of GSM and TYM are disseminated through GTS.

Table 7.4.1.3-1 Numerical weather prediction products for typhoon forecast

Contents	Level (hPa)	Area	Forecast Hours	Initial Time	Transmission Method
Center position and changes of intensity parameters from the initial time by GSM	-	Eq. - 60N 100E-180E	06, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90	00UTC 12UTC	GTS
Center position and changes of intensity parameters from the initial time by TYM	-	Eq. - 60N 100E-180E	06, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84	00UTC 06UTC 12UTC 18UTC	GTS

7.4.2 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.

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.

A high-resolution regional transport model had been operated until September 2005, to predict volcanic gas spread from Miyakejima Island, an active volcano in Japan.

7.4.3 Ocean wave forecasting system

7.4.3.1 Models

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 7.4.3.1-1 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 0.3Hz and 16 directions)	
Grid form	Equal latitude-longitude grid on spherical coordinate	
Grid size	1.25deg. x 1.25deg. (288x121)	0.1deg. x 0.1deg. (400x400)
Integration domain	Global 75N-75S, 0E-180-1.25W	Coastal sea of Japan 55N-15N, 115E-155E
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)	

7.4.3.2 Numerical wave prediction products

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

(NMHSs).

7.4.4 Storm surge forecasting system

7.4.4.1 Model

JMA operates a numerical storm surge model to predict storm surges that occur in coastal areas of Japan mainly due to tropical cyclones. The model also provides predictions of storm surges caused by extratropical cyclones using Meso-Scale Model (MSM) wind fields. The model specifications are given in Table 7.4.4.1-1.

Table 7.4.4.1-1 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- 143.1E, 23.5- 42.1N)
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)
	bogussing data for typhoons around Japan

7.4.4.2 Numerical storm surge prediction products

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

7.4.4.3 Operational techniques for application of storm surge prediction products

Considering the error of typhoon forecast track, storm surges for possible five typhoon tracks are predicted.

7.4.5 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 sub surface 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 Ocean Report and 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.

7.4.6 Ocean Data Assimilation System for the North Pacific Ocean

7.4.6.1 Model

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.

Table 7.4.6.1-1 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 degrees adjacent to Japan between 23N and 45N west of 180E, smoothly increasing to 0.5 degree in latitude and to 1.5 degrees in longitude
Time step	10 minutes
Vertical levels	21 levels
Integration domain	North Pacific between 13N and 55N from 120E to 110W
Forcing data	Ocean currents are driven by operational daily wind stress
Observational data	Sea surface height, sea surface and subsurface temperature

7.4.6.2 Products of the ocean data assimilation system

The output of this system is monthly averaged for the provision in a printed matter, “Monthly Ocean Report” of JMA, and on a web site, NEAR-GOOS RRTDB (http://goos.kishou.go.jp).

7.4.7 Sea ice forecasting system

7.4.7.1 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 7.4.7.1-1).

Table 7.4.7.1-1 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

7.4.7.2 Numerical sea ice prediction products

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.

7.4.8 Marine pollution forecasting system

7.4.8.1 Model

JMA operates the numerical marine pollution transport model in case of a marine pollution accident. Its specifications are shown in Table 7.4.8.1-1. 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 7.4.8.1-1 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)

7.5 Extended-range forecasting system

7.5.1 Data assimilation and Model

An extended-range ensemble prediction system is carried out as an extension of the Medium-range Ensemble Prediction System described in 7.2.5. Data assimilation, objective analysis, initialization and the model are common to those of the medium-range ensemble prediction system. For the lower boundary condition of the model, initial SST 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.

7.5.2 Methodology

An ensemble consists of 26 members per week by extending 13 member runs of the medium-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.

7.5.3 Numerical prediction 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 7.5.3-1. The map products disseminated through TCC are shown in Table 7.5.3-2.

Table 7.5.3-1 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: 12UTC 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 7.5.3-2 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.

7.5.4 Operational technique for an application of extended-range forecast

Objective guidance products of forecast elements such as the surface temperatures (monthly mean, weekly mean), precipitation amounts (monthly total), sunshine durations (monthly total), and snowfall amounts (monthly total) are derived by the Perfect Prognosis Method (PPM) technique. A clustering method is applied and cluster-averaged fields are disseminated to local meteorological observatories.

7.6 Long-range forecasting system

7.6.1 The 120-day ensemble prediction system (EPS) for 3-month outlook

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 an old and low-resolution version (T63) of GSM (Table 7.6.1-1). Thus, cumulus parameterization and associated initialization schemes are different from those of the current GSM mentioned at 7.2 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 land data assimilation system.

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 7.6.1-1 Specifications of 120-day Ensemble Prediction System

Atmospheric model	GSM0103
Integration domain	Global, surface to 0.4hPa
Horizontal resolution	T63 (about 1.875° 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 (20S-90N)

7.6.2 Numerical prediction products for 120-day ensemble prediction

A model systematic bias was estimated as an average forecast error, which was calculated from hindcast experiments for 18 years from 1984 to 2001. 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 7.6.2-1) from 120-day ensemble prediction are disseminated through the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc).

Table 7.6.2-1 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		

Global tercile probabilistic forecast is operationally produced for three-month averaged 2-m temperature and precipitation. These are obtained by applying one of the MOS (Model Output Statistics) methods, the Ordered Probit Model, to the 120-day long-range EPS outputs. The products are shown on the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc).

7.6.3 The 210-day ensemble prediction system (EPS) for warm and cold seasons outlook

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 (see 7.6.4). 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.

The following model output products (Table 7.6.3-1) from 210-day ensemble prediction are disseminated through the Tokyo Climate Center (TCC) Web site (http://cpd.kishou.go.jp/tcc).

Table 7.6.3-1 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		

7.6.4 Methodology for the prediction of global SST anomalies for 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.

7.6.5 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 7.6.5-1.

In June 2005, JMA's El Niño forecast system by the coupled atmosphere-ocean model was improved to reduce its positive predictive bias. Modifications for the improvement are as follows: (1) use of the latest analysis with a lag of 5 days as oceanic initial conditions instead of a lag of 35 days, (2) enhancement of the ensemble forecast by increasing the frequency of the forecast up to 6 times per month and the number of ensemble members up to 12 instead of twice per month with 6 members, and (3) adoption of a new bias correction by removing the model's mean error over the hindcast period from 1988 to 2003 instead of the use of Model Output Statistics (MOS).

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 7.6.5-1 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	18 months	
Model run interval	15 days	

8. Verification of prognostic products

8.1 Verification for short-range and medium-range prediction

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 2005 are presented in Tables 8.1-1 - 8.1-20. All the verification scores are only for the prediction from 1200 UTC initials.

8.2 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 8.2-1. 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 8.2-1 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

8.3 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 8.2-1 (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.

8.4 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.

9. Plans for the future

9.1 Development of the GDPFS

(1) The computer system for GDPFS Center in JMA is going to be replaced on 1 March 2006. Main components of the new system are two sets of 80 nodes HITACHI SR11000.

(2) The MSM with a resolution of 5km and 50 levels will replace that with 10km and 40 levels as operational model and will be operated 8 times a day instead of 4 times a day in March 2006.

(3) A new SST data named "Merged satellite and in situ data Global Daily Sea Surface Temperatures (MGDSST)" (Kurihara et al., 2006) will be used for MSM, RSM and TYM as the boundary condition instead of the previous SST in March 2006.

(4) The GSM operation with a forecast time of 36 hours for 06UTC and 18UTC will be added in March 2006.

(5) The global 4D-Var analysis system will enhance the resolution of its inner loop from T63 to T106 in March 2006.

(6) The one-week EPS will increase the ensemble size from 25 to 51 with some model changes such as semi-Lagrangian advection scheme in March 2006.

(7) The hourly-analysis will be improved by starting temperature analysis, using MTSAT-1R hourly atmospheric motion vector data and enhancing the resolution from 10km to 5km.

(8) The extended-range ensemble prediction system and model will be separated from those for the medium-range ensemble prediction system in March 2006. At the same time, the number of the ensemble will be increased from 26 to 50, and the prediction model will be updated to GSM0507. A new SST data set of COBESST (Ishii et al., 2005) is used as the boundary condition.

(9) The prediction model for the 120-day and 210-day ensemble prediction system will be updated to GSM0502 in March 2006. The COBESST will be also used as the boundary condition.

(10) The JMA Climate Data Assimilation System (JCDAS) will be started operationally in March 2006 after the Japanese 25-year Reanalysis Analysis (JRA-25) for 1979-2004 and JCDAS for 2005 are completed.

9.2 Research Activities in NWP

(1) Development of a new spectral dynamical core for GSM (see 9.2.1)
(2) Development of the cumulus parameterization scheme of GSM (see 9.2.2)
(3) Development of a parameterization of shallow cumulus convection (see 9.2.3)
(4) Improvements in the GSM atmospheric boundary layer scheme using a single column model (see 9.2.4)
(5) Development of a new land surface scheme (see 9.2.5)
(6) Cloud representation by GSM over the northeastern Pacific Ocean: GPCI case study (see 9.2.6)
(7) Development of high resolution MSM (see 9.2.7)
(8) Implementation of a generalized terrain-following vertical coordinate for the JMA Non-hydrostatic Model (see 9.2.8)
(9) Improvement of a radiation scheme for NHM (see 9.2.9)
(10) Improvement of the cumulus parameterization scheme for NHM (see 9.2.10)
(11) Improvement and optimization of the surface and boundary layer schemes of the Meso-Scale Model (see 9.2.11)
(12) Development of a global nonhydrostatic model based on NHM (see 9.2.12)
(13) The resolution change of the inner loop of global 4D-Var (see 9.2.13)
(14) Upgrade of 'Hourly-Analysis' (see 9.2.14)
(15) JMA-NHM based variational data assimilation system (see 9.2.15)
(16) Development of observation operator for surface data (see 9.2.16)
(17) Development of ensemble Kalman filter (see 9.2.17)
(18) Assimilation of microwave radiometer data for global DAS (see 9.2.18)

(19) Utilization of the high-density atmospheric motion vector data (see 9.2.19)

(20) Assimilation of GPS occultation data for GSM (see 9.2.20)

(21) Assimilation of clear sky radiances (CSRs) from geostationary satellites (see 9.2.21)

(22) Development of products for aviational weather application (see 9.2.22)

(23) Development of a higher resolution coupled model with a T63L40 atmosphere model and a 1deg.(lon.)x(1/3-1) deg.(lat.)L50 ocean model with particular attention to skill increase of SST forecast over the western tropical Pacific and the Indian Ocean

9.2.1 Development of a New Spectral Dynamical Core for GSM

A new spectral dynamical core with the reduced Gaussian grid system for GSM is being developed (Miyamoto 2006). In order to determine the necessary number of longitudinal grid points at each latitude, we adopt the reduced spectral transformation introduced in Juang (2004). Recently, a simplified experiment was performed to examine the accuracy of the core. The shallow water equation in advective form was integrated for 14 days on the core of the T639 reduced quadratic Gaussian grid (T_R639) with an Eulerian advection scheme. The initial condition was a zonal flow with the corresponding surface height field (one of steady state solutions to the non-linear shallow water equation; same as in the second test case by Williamson et al., 1992). The fact was confirmed that the steady state could be kept during 14-day integration. Therefore we think the new spectral dynamical core has enough accuracy for practical daily weather forecasts. (K. Miyamoto)

9.2.2 Development of the Cumulus Parameterization Scheme of the Global Spectral Model

JMA has a plan to introduce a TL959L60 global model in order to provide planetary to meso-β scale medium range forecasts with a single model. To test the resolution dependency of cumulus convection scheme, rainfall forecasts by low (TL319) and high (TL959) resolution models are compared with observation. The new convection triggering mechanism proposed by Xie and Zhang (2000) is also tested intending to improve the rainfall forecast (TL959DCP).

TL319 and TL959 forecasts tend to overestimate weak precipitation areas especially from local noon to late afternoon, which result in a strong diurnal variation of the bias score. The similarity of the forecasts by TL319 and TL959 indicates that the cumulus parameterization scheme implemented in TL319 works similarly in TL959 at least in mid-latitudes. TL959DCP substantially reduces the bias compared to TL959. The horizontal pattern of TL959DCP forecast is closer to observed rainfall distribution. These results indicate that the new triggering function for deep convection can be used to improve the rainfall forecast. (M. Nakagawa)

9.2.3 Development of a Parameterization of Shallow Cumulus Convection

A parameterization of shallow cumulus convection is being developed. The cloud model of this parameterization is a mass flux scheme based on an entrainment-detrainment plume model. Both the fractional entrainment rate and the detrainment rate are constant and they are equivalent for simplicity. The cloud top is estimated from the updraft kinetic energy so as to express the overshooting. The present model does not include such a parameterization explicitly, and this parameterization will improve cloud representation of the model at the subtropical marine boundary layer and the diurnal variation of precipitation on land. (T. Hosomi)

9.2.4 Improvements in the GSM Atmospheric Boundary Layer Scheme using a Single Column Model

In order to improve the atmospheric boundary layer (ABL) scheme of GSM, expressions of ABL were investigated with a single column version of GSM, through participating in the GEWEX Atmospheric Boundary Layer Study (GABLS) experiment. It was obvious from the 1st case that a suppression of too strong turbulent mixings in stable ABL substantially improved a nocturnal ABL simulation (Cuxart et al. 2005). Following the 1st case, a simulation of diurnal variations in ABL over land is examined using the 2nd case, which was based on the observation from the CASES-99 program at Kansas, USA. The experiment shows that an expression of diurnal variations in near surface meteorology is very sensitive to a time step length of the model time integration. In this regard, the scheme is revised so as to estimate the tendency of various physical processes sequentially. (H. Kitagawa and K. Iwamura)

9.2.5 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 (Hirai et al. 2006).

It is found in the validation study that the new land surface scheme predicts a snow cover area more properly than the current one. Moreover, the new scheme simulates a diurnal variation of near surface temperature than current one especially over snow cover area.

In order to put the new scheme into operation, detailed performance check is carrying out through assimilation and forecast trials. (M. Hirai, T. Sakashita and M. Hosaka)

9.2.6 Cloud Representation by GSM over the Northeastern Pacific Ocean: GPCI Case Study

In this study, cloud fields represented by the GSM are evaluated, especially cloud representation over the northeastern Pacific Ocean is focused on using the GCSS Pacific Cross-section Intercomparison (GPCI) case (Siebesma et al. 2004). The Hadley circulation represented by the model is somewhat too weak and horizontal extent of marine stratocumulus clouds in the model is not sufficient compared to the observation. In order to examine impacts of the turbulent transport parameterization on cloud representation, a new turbulent mixing scheme is introduced to the model. An efficient moisture transport in the revised scheme improves the representation of low-level cloudiness over ocean in the higher latitudes. In addition, influences of the frequency of radiation calculations are investigated to evaluate impacts of radiation processes on the model cloud representation. High-frequent calculation of the longwave radiation leads to modification of the Hadley circulation through improved representation of cloud-radiation interactions. (H. Kitagawa)

9.2.7 Development of a High Resolution MSM

The horizontal resolution of MSM, which is a version of the JMA Nonhydrostatic Model (hereafter NHM), will be enhanced from 10 km to 5 km, and the number of the vertical layers will be increased from 40 to 50 according to the enhancement of computational resource in March 2006. Moreover, number of the forecast will be also increased from 4 times a day to 8 times a day (3-hourly) at the same time. The model is being developed based on the current operational nonhydrostatic mesoscale model (Saito et. al 2006). Efforts are mainly devoted to improvement and optimization of the physical processes to achieve satisfactory performance for very short range forecast at the higher spatial resolution. (K. Aranami)

9.2.8 Implementation of a Generalized Terrain-following Vertical Coordinate for the JMA Nonhydrostatic Model

A generalized terrain following vertical coordinate is introduced to the JMA nonhydrostatic model, which has used a Gal-Chen and Somerville terrain-following coordinate (Gal-Chen and Somerville, 1975). Since the new coordinate transformation is given by not a linear function but a general function, the computational noise which may result from the functional dependence of the vertical layers on the terrain in the upper atmosphere can be reduced. Some ideal experiments show the effectiveness of the new coordinate, and the experiments for real case will be carried out. (J. Ishida)

9.2.9 Improvement of a Radiation Scheme for NHM

A sophisticated radiation scheme (Kitagawa 2000) that treats the cloud optical properties more properly than the current radiation scheme (Sugi et al. 1990) is introduced to the NHM. This new scheme requires cloud optical properties such as the cloud water and ice path, effective radius, as well as the cloud fraction. The cloud water content is diagnosed from the precipitable water (Hack 1998), while the cloud fraction is estimated from the relative humidity by a function of Ohno and Isa (1984). As shown in Nagasawa (2006), the new radiation scheme has large impacts on the temperature forecast; the daytime negative bias at the surface, the negative bias at around 200hPa-level and the positive bias at around 500hPa-level observed in the current MSM are all reduced. (R. Nagasawa)

9.2.10 Improvement of the Cumulus Parameterization Scheme for NHM

Even in the 5-km resolution MSM which is to be operated from March 2006, the Kain-Fritsch cumulus parameterization scheme (Kain and Fritsch 1990; Kain 2004; hereafter K-F scheme) is still used for better precipitation forecasts. With the important parameters optimized for the current 10-km resolution model, statistical scores of precipitation forecasts from the 5-km MSM were almost the same as those from the current MSM at 10 km resolution. Since the K-F scheme has large impacts on precipitation forecasts, the following three important parameters in the K-F scheme are adjusted to produce better precipitation forecasts (Ohmori and Yamada 2006).

The first parameter is the threshold of condensates to be converted into precipitation. In the K-F scheme used in the MSM, a Kessler-type precipitation formation scheme is adopted such that condensates in the updraft are converted into precipitation when their amount exceeds a prescribed value (Ohmori and Yamada 2004). The increase in this threshold has brought about an amelioration of the representation of weak rain in summer season. The second is the life time of deep convection. A decrease in this time scale results in an increase in the occurrence frequency of moderate rain. The last parameter is the life time of shallow convection. This has a relatively large impact on the precipitation forecast during cold-air outbreaks. A shorter time scale suppresses the occurrence of the excessive weak rain originated from grid-scale convection.

Owing to the fine adjustments described above, the precipitation forecasts from the 5-km MSM become much better. (S. Ohmori and Y. Yamada)

9.2.11 Improvement and optimization of the surface and boundary layer schemes of the Meso-Scale Model

The surface and boundary layer schemes of the Meso-Scale Model (MSM) are changed, and then their performance in prediction of in the surface elements such as temperature and wind speed is investigated. A prognostic scheme of the surface wetness based on the force-restore method of Deardorff (1978) is newly introduced to treat wetness as a variable consistent with predicted weather, revision of land parameters such as roughness, heat diffusion coefficients, heat capacity, etc., is made to assign respective appropriate values in accordance with detailed information on land usage. Optimization of the horizontal mixing length in the turbulence process is made to suppress excessive mixing in horizontal. Besides, revision of the diagnostic scheme for the surface elements is carried out to improve the diagnosis in the surface layer under stable condition. The changes in the surface and boundary layer schemes bring about large improvements in the representation of diurnal changes in the surface elements, in particular their impacts are very clear in nighttime. (T. Hara)

9.2.12 Development of a Global Nonhydrostatic Model Based on NHM

An attempt to develop a global nonhydrostatic model based on the nonhydrostatic mesoscale model (NHM) is under way. An experimental version of a nesting tool has been developed to run NHM over an arbitrary domain on the Earth. It has several new features which the current operational nesting tool does not have; appropriate treatments for the periodic boundary condition, singular points, and so on. For example, it can remap or interpolate data appropriately from the Gaussian grid or the lat-lon coordinate (LL) to the polar stereographic projection (PS) that includes a pole grid point. An appropriate treatment for the periodic boundary condition has been also implemented to NHM. With these developments NHM can run over an arbitrary domain on the Earth by using one of following map projections; the polar stereographic projection, the Lambert conformal projection, the Mercator projection, and the Cylindrical equidistant projection (CE) which is equivalent to LL. Preliminary test runs nested from global analysis were successfully carried out over various computational domains; zonal periodic tropical region by using CE, polar region by using PS, and so on. （Y. Yamazaki and K. Saito）

9.2.13 The Resolution Change of the Inner Loop of Global 4D-Var

Currently, the incremental method (Coutier et al. 1994) is employed in the global 4D-Var analysis system, and the resolutions of the outer and inner loops are TL319 and T63 respectively. As we are going to introduce a new computer system in 2006, which enable us to use a higher resolution inner loop for 4D-Var, we have developed 4D-Var of the higher resolution inner loop (T106), whose impact on the global model forecasts was good in our parallel run tests. The T106 inner loop will be operational in March 2006. (A. Narui)

9.2.14 Upgrade of 'Hourly-Analysis'

JMA is providing 'hourly-analysis', based on the MSM forecast and observed data, for real-time monitoring of weather condition. This product is made via optimal interpolation, using the MSM forecast as first guess. The following improvements on hourly-analysis were tested and are to be operational in March 2006: (1) Start of temperature analysis in addition to the wind formerly provided. (2) Usage of MTSAT-1R hourly atmospheric motion vector data as well as former observation types, wind profiler, aircraft data, Doppler radar wind and surface observation. (3) Employment of higher horizontal resolution (from 10km to 5km). (M. Nishijima)

9.2.15 JMA-NHM based Variational Data Assimilation System

The development of JMA-NHM-based variational data assimilation system (JNoVA) has been continued. The system is run both as the three dimensional (3DV) and as the four dimensional (4DV) data assimilation system. The JNoVA-4DV will be used as the next analysis system in the limited-area mesoscale numerical prediction system and the JNoVA-3DV will be used as the next analysis system in the 'Hourly-Analysis' system. Here are recent developments of the JNoVA-4DV.

A penalty term using a digital filter initialization is added to the system. And the adjoint model of the JMA-NHM is expanded to include the simple moist physics: the large scale condensation and the moist convective adjustment scheme. Using this adjoint model, a real data assimilation experiment for the heavy rainfall case was conducted. The JNoVA-4DV succeeded to assimilate most observation data used in operational system and improved the quantitative precipitation forecast (Honda et al. 2005; Honda et al. 2006). The adjoint code of the 2-ice bulk microphysics was also developed and implemented in the JNoVA. This moist physics can be replaced with the simple moist physics. By the JNoVA-4DV with this microphysics, we succeeded to assimilate the Radar-AMeDAS (R/A) analysis precipitation data for the same heavy rainfall case. The convective activity was reproduced in the analysis. The precipitation forecast in the first three hours became quite similar to that of the operational limited-area numerical prediction system, in which the R/A analysis precipitation was also assimilated by the four dimensional data assimilation system optimized for the hydrostatic spectral model. Besides the forecast after 3 hours was still similar to or better than that of the previous experiment using the JNoVA-4DV with the simple moist physics (Honda and Koizumi, 2006). (Y. Honda)

9.2.16 Development of Observation Operator for Surface Data

Observation operators for screen level observations (wind, temperature, relative humidity) based on the similarity theory have been developed for JNoVA. Case studies using JNoVA-3DV show that the assimilation of screen level temperature can improve temperature forecast and snow forecast. (M. Nishijima)

9.2.17 Development of Ensemble Kalman Filter

In August 2005, we began to develop the local ensemble transform Kalman filter (LETKF, Hunt 2005) with AFES (AGCM for the Earth Simulator, Ohfuchi et al. 2004) at a T159 horizontal and 48-level vertical resolution in collaboration among the Numerical Prediction Division, Japan Meteorological Agency (NPD/JMA), the Chiba Institute of Science, and the Earth Simulator Center (ESC). We developed the LETKF system based on the system constructed by Miyoshi (2005) at the University of Maryland where originally LETKF has been invented. At first we performed perfect model experiments with a simple observational operator, investigating sensitivities with the ensemble size and localization scale. We found that an ensemble size as small as 10 is large enough to stabilize the filter. The computational time is feasible in operations, less than 4 minutes on the Earth Simulator, 64GFlops per node. After the successful preliminary investigation, we developed an observational operator for conventional data that enables to assimilate real observations. Perfect model experiments with real observational locations and errors ensure stable filter performance with 40 members, although the highly irregular observations make the initial spin-up significantly longer. We are now at a stage to assimilate real observations. (T. Miyoshi)

9.2.18 Assimilation of Microwave Radiometer Data for Global DAS

The radiance assimilation approach is taken in the current study, instead of the retrieved precipitable water assimilation in the preliminary study, to extract more observation information. OSEs with the radiance assimilation have shown positive impacts on the rainfall, typhoon track and geopotential height forecasts over the tropics and southern hemisphere, with no positive impacts in the northern hemisphere. The variational bias correction method is being attempted in the following OSEs to solve this problem. (Y. Sato)

9.2.19 Utilization of the High-density Atmospheric Motion Vector Data

Temporally and/or spatially high-density atmospheric motion vector (AMV) data from GOES-10,-12, METEOSAT8 and MTSAT-1R will be used in the 4D-Var data assimilation system for GSM, RSM and MSM in 2006. Preliminary results from MSM with the assimilation of hourly AMVs from MTSAT-1R in the meso-4D-Var has shown better rain forecast because the data captured well a trough upstream of Japan. (K. Yamashita)

9.2.20 Assimilation of GPS Occultation Data for GSM

Two assimilation methods for GPS occultation data have been developed: the refractivity assimilation and the bending angle assimilation (Matsumura et al. 1999). Preliminary OSEs using the global 3D-Var showed little difference between the two methods in terms of forecast scores. Accordingly, JMA adopts the refractivity assimilation, which has more computational efficiency. From OSEs of the refractivity assimilation using the global 4D-Var, forecast scorers of geo-potential heights and temperatures in between 850hPa and 300hPa levels were improved in winter season, but they became worse in the southern hemisphere and the tropics in summer season. Adjustment of observation errors is being made. (E. Ozawa, Y. Sato, H. Tada and Y. Aoyama*)

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9.2.21 Assimilation of Clear Sky Radiances (CSRs) from Geostationary Satellites

A scheme to assimilate CSRs from geostationary satellites has been developed. OSEs with CSRs from GOES-9 showed slight improvements in the relative humidity analysis over Ocean and the 500hPa geopotential height forecast in the northern hemisphere. CSR products from MTSAT-1R are being developed in collaboration with Meteorological Satellite Center of JMA, and their impacts are being assessed using the global 4D-Var. It is planned in 2006 that MTSAT-1R CSRs will be routinely assimilated and that OSEs using CSRs from other geostationary satellites will be carried out. (T. Ishibashi and D. Uesawa)

9.2.22 Development of products for aviational weather application

The method to estimate CB amount, which had been calculated by a diagnostic method using one-hour precipitation and Showalter's stability index (SSI), will be changed to a new method based on Kain-Fritsch cumulus parameterization scheme (K-F scheme) built into MSM. The new method identifies a deep convection distinguished by K-F scheme on each grid point as cumulus nimbus, and then translates it to CB amount. Because this method estimate CB amount directly from the model output, it will be more reasonable than the previous one.

In March 2006, three revisions of the TAF-S guidance will be implemented. First, the statistical method of visibility guidance will be changed from fixed interpretation model to the adaptive method using Kalman Filter, and introduced stratification by weather. Second, the statistical method of cloud guidance will be changed from Kalman Filter to Neural Network. Third, a new hourly temperature guidance will be operated, which is based on the Kalman Filter method, and used to distinguish rain and snow on weather guidance. These revisions will be lead to substantial improvements of the TAF-S guidance.

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Table 8.1-1 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	12.9	11.8	10.6	10.6	9.6	9.3	8.9	8.3	9.1	9.5	10.4	11.5	10.2
72	33.4	30.9	30.2	29.3	27.3	25.5	23.1	22.4	25.0	26.9	29.7	32.0	28.0
120	61.0	57.4	56.4	54.3	50. 9	47.5	42.0	40.9	46.2	53.5	58.6	59.1	52.4

Table 8.1-2 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	14.3	13.5	13.1	14.3	14.1	15.0	15.0	15.1	15.0	14.3	12.6	11.6	14.0
72	34.5	34.8	37.1	44.4	41.0	44.3	46.0	43.9	43.8	38.0	35.2	32.6	39.6
120	56.9	60.8	62.6	77.7	72.3	76.7	78.8	78.1	76.1	65.9	63.0	55.7	68.7

Table 8.1-3 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	14.4	14.1	14.2	14.8	11.3	11.4	10.1	9.5	10.9	12.0	13.6	13.8	12.5
72	38.6	34.4	32.7	32.0	26.2	25.1	20.9	18.2	25.5	28.1	35.0	36.9	29.5
120	65.7	61.0	61.5	54.0	50.3	41.9	37.4	33.1	44.1	56.0	66.8	57.6	52.5
ob. num.	79	79	79	79	79	79	79	79	79	78	79	78	78.8

Table 8.1-4 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	24.7	19.2	14.6	16.3	16.0	14.1	14.9	15.2	15.4	17.8	17.1	17.9	16.9
72	42.2	38.5	30.5	31.6	27.6	27.9	26.1	26.8	28.3	27.0	32.7	31.3	30.9
120	74.4	72.1	56.9	54.1	51.6	51.6	42.5	50.3	57.2	54.2	64.6	70.3	58.3
ob. num.	55	56	56	55	56	58	57	58	58	58	58	56	56.8

Table 8.1-5 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	14.3	15.4	13.6	15.5	15.8	16.3	14.8	15.5	15.4	14.8	13.8	15.6	15.1
72	26.5	24.9	26.6	30.3	30.0	24.9	23.5	23.5	23.1	25.3	25.3	30.5	26.2
120	47.2	41.8	46.4	50.0	47.5	40.3	35.8	37.0	36.3	48.0	43.8	53.0	43.9
ob. num.	51	53	51	50	49	50	50	47	50	50	50	51	50.2

Table 8.1-6 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	14.0	15.8	12.3	12.7	15.2	15.1	14.5	14.9	15.3	15.2	13.8	14.6	14.5
72	25.4	26.3	25.6	29.9	29.5	31.3	29.0	33.5	32.4	27.1	25.7	29.5	28.8
120	46.2	45.7	47.5	52.7	54.1	49.8	67.2	62.7	56.8	43.9	47.1	51.7	52.1
ob. num.	13	12	12	11	11	13	12	11	11	12	11	11	11.7

Table 8.1-7 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	18.1	16.8	15.2	15.8	14.6	14.5	14.0	13.7	14.4	15.3	15.6	16.0	15.3
72	38.4	35.1	33.3	33.0	29.8	28.3	25.9	25.0	28.0	30.0	33.6	35.2	31.3
120	68.3	64.5	61.0	56.5	54.6	49.6	44.2	44.4	50.9	58.5	64.4	64.7	56.8
ob. num.	243	247	245	245	243	243	243	242	243	243	245	244	243.8

Table 8.1-8 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	16.4	15.5	15.9	17.5	18.7	19.9	18.5	18.7	18.5	19.1	16.5	16.8	17.7
72	28.1	25.7	31.5	37.3	36.7	36.8	39.7	37.4	35.4	34.4	30.4	28.6	33.5
120	46.4	45.8	51.3	67.4	59.3	57.7	70.5	68.6	61.3	54.3	50.2	50.4	56.9
ob. num.	27	27	27	27	27	29	29	28	28	29	29	29	28.0

Table 8.1-9 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	5.2	5.0	4.8	4.8	4.7	4.8	4.5	4.5	4.5	4.3	4.6	4.8	4.7
72	10.0	9.6	9.7	9.9	9.9	10.1	9.6	9.7	9.8	9.4	9.6	9.9	9.8
120	15.4	14.5	14.7	15.0	14.9	15.4	14.1	14.4	15.1	15.2	15.6	15.0	14.9

Table 8.1-10 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	5.3	5.0	4.9	4.9	5.0	4.9	4.8	4.9	4.9	4.8	4.7	4.7	4.9
72	11.2	10.7	10.9	12.1	11.3	11.1	11.3	11.0	11.4	10.5	10.3	10.4	11.0
120	16.1	16.3	16.1	18.9	17.5	17.0	17.3	16.9	17.3	15.5	15.7	15.4	16.7

Table 8.1-11 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	6.9	7.2	6.7	6.7	6.2	7.0	6.0	5.7	6.2	5.8	6.5	7.0	6.5
72	12.4	11.8	11.9	11.1	11.2	11.4	10.1	9.3	10.7	10.9	12.3	13.7	11.4
120	18.1	16.8	17.4	16.0	17.0	16.0	13.7	13.2	16.4	17.4	20.2	18.1	16.7
ob. num.	71	73	72	74	76	77	78	78	77	76	73	72	74.8

Table 8.1-12 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	6.5	5.9	5.8	6.1	6.3	6.5	7.0	7.2	7.2	6.5	6.8	6.3	6.5
72	10.7	10.6	10.6	10.5	9.8	11.3	11.0	12.1	12.7	10.5	11.0	10.4	10.9
120	18.7	17.8	15.7	15.3	14.5	17.7	16.2	18.2	19.4	17.7	18.4	18.8	17.4
ob. num.	53	54	55	55	56	56	54	56	56	55	55	53	54.8

Table 8.1-13 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	5.7	6.5	6.6	6.6	7.3	7.3	6.7	6.4	5.9	5.5	4.9	5.1	6.2
72	8.4	9.3	10.7	10.8	11.8	12.6	10.9	10.7	9.4	9.2	7.8	8.0	10.0
120	11.8	11.7	13.8	15.0	15.5	16.7	14.8	14.3	13.0	12.9	11.3	11.8	13.6
ob. num.	52	53	52	51	50	49	48	46	49	50	51	50	50.1

Table 8.1-14 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Australia / New Zealand

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	6.3	6.3	6.6	6.3	6.7	6.6	6.7	6.5	6.6	6.9	6.9	6.9	6.6
72	10.1	9.7	11.1	10.7	10.3	10.6	10.4	10.0	10.5	10.1	10.3	11.0	10.4
120	14.9	15.1	15.0	15.8	14.8	14.6	16.4	15.3	15.9	15.1	14.7	15.1	15.2
ob. num.	26	24	24	23	25	26	24	24	22	22	21	19	23.3

Table 8.1-15 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	6.4	6.5	6.3	6.3	6.2	6.7	6.4	6.2	6.3	5.9	6.0	6.1	6.3
72	10.8	10.8	10.9	10.8	10.8	11.5	10.7	10.8	11.1	10.3	10.6	11.0	10.8
120	16.9	16.0	15.8	15.7	15.8	16.6	15.3	15.7	16.5	16.5	17.2	16.5	16.2
ob. num.	230	238	235	237	238	237	235	237	238	237	235	232	235.8

Table 8.1-16 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	6.7	6.9	6.9	7.2	7.2	7.4	7.3	7.1	7.3	7.4	7.2	7.1
72	11.2	10.4	11.7	12.4	11.6	11.8	11.7	11.1	11.6	10.7	11.7	11.4	11.4
120	16.6	15.7	16.0	18.2	17.4	16.8	18.0	16.9	17.4	15.7	16.4	15.8	16.7
ob. num.	36	36	35	34	35	38	37	36	34	36	35	32	35.3

Table 8.1-17 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	2.3	2.3	2.1	2.1	2.0	2.0	2.1	2.2	2.2	2.1	2.1	2.1	2.1
72	3.6	3.7	3.3	3.5	3.2	3.3	3.5	3.7	3.8	3.5	3.4	3.5	3.5
120	4.4	4.4	4.0	4.2	3.9	4.0	4.3	4.4	4.5	4.1	4.2	4.3	4.2

Table 8.1-18 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	4.6	4.5	4.1	4.3	4.2	4.1	4.1	4.1	4.2	4.0	4.1	4.3	4.2
72	7.3	7.2	6.7	7.2	6.9	6.9	6.7	6.6	6.9	6.6	7.0	7.2	6.9
120	8.9	8.9	8.1	8.9	8.6	8.2	8.1	7.9	8.7	8.1	8.4	8.6	8.5

Table 8.1-19 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	4.2	4.3	4.0	3.9	3.8	4.1	4.2	4.0	4.1	3.8	3.8	4.0	4.0
72	4.7	5.0	4.6	4.3	4.2	4.7	4.9	4.5	4.7	4.2	4.3	4.5	4.6
120	5.3	5.6	5.0	4.9	4.6	5.0	5.2	5.1	5.4	4.7	4.9	4.9	5.1
ob. num.	31	32	31	30	29	31	31	31	31	31	33	33	31.2

Table 8.1-20 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	6.7	6.4	5.5	5.3	5.6	5.5	5.5	5.7	5.5	5.3	5.6	6.0	5.7
72	8.0	7.8	7.1	7.0	7.3	7.4	6.9	6.7	7.1	7.2	7.2	7.5	7.3
120	9.5	9.1	8.4	8.6	8.6	8.5	8.3	8.0	8.8	8.5	8.4	8.9	8.6
ob. num.	30	31	30	29	29	30	30	31	30	31	32	32	30.4