# Annual WWW Technical Progress Report on the Global Data-Processing and Forecasting System 2004

# JAPAN

## 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. Implementation of a non-hydrostatic mesoscale model is one of the highlights in 2004 in this regard, which has significantly improved prediction of heavy precipitations as compared to the previous hydrostatic model. Efforts have also been concentrated on the improvement of the global spectral model (GSM) over the past few years. In 2004, model physics of GSM were improved and the assimilation of new satellite data was started. Major developments in GDPFS in 2004 are as follows:

(1) Direct assimilation of ATOVS level-1c radiance data for the global analysis from December 2004 (see 7.2.1).
(2) Assimilation of MODIS polar wind data in the Arctic area for the global analysis from May 2004 (see 7.2.1).
(3) Assimilation of MODIS polar wind data in the Antarctic area for the global analysis from September 2004 (see 7.2.1).
(4) Assimilation of QuikSCAT/SeaWinds data for the meso analysis from July 2004 (see 7.3.2.1).
(5) Assimilation of Aqua/AMSR-E precipitation and TPW data for the meso analysis from November 2004 (see 7.3.2.1).
(6) Assimilation of SATEM data of NOAA-17 retrieved by the Meteorological Satellite Center for the meso and regional analyses from November 2004 (see 7.3.2.1).
(7) Assimilation of temperature reports of radiosonde observations in the global analysis in place of geopotential height reports from April 2004 (see 7.2.1).
(8) Implementation of a new parameterization scheme accounting for marine stratocumulus in GSM in July 2004, and revision of both the cloud water/ice scheme and the land surface model on ice sheets (see 7.2.2).
(9) Introduction of a new long-wave radiation scheme into GSM in December 2004, and revision of a parameterization of absorption in the short-wave radiation scheme for ozone, carbon dioxide and oxygen (see 7.2.2).
(10) Incorporation of a targeted moisture diffusion scheme in RSM in April 2004 (see 7.3.1.2).
(11) Introduction of a non-hydrostatic mesoscale model with 10-km resolution for operational mesoscale forecasts on 1 September 2004 (see 7.3.2.2).
(12) Upgrade of the storm surge model in January 2004 to provide predictions of storm surges caused by extratropical cyclones (see 7.4.4)
(13) Dissemination of the monthly averaged grid point value products of all ensemble members for the 210-day ensemble forecast at grid intervals of 2.5 degrees in the global area through the Tokyo Climate Center (TCC) from February 2004. (see 7.6.3)

## 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 | 215SPECint95 |
| 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 | 151SPECint95 |
| 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 | 120SPECint_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 in use from GTS

### 3.1 Observations

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

**Table 3-1 Number of used observation reports**

| | |
|---|---|
| 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, and
GRIB AMMC.

## 4. Data input system

Data input is fully automated with an exception of the manual input of typhoon position, size and intensity data. 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 a form error is detected, some procedures are applied in order to extract as much information as possible.

**Stage 2 Internal consistency check**

Checks of climatological reasonability are performed for all types of data. The data enlisted as problematic data in the "exclusion list" are rejected. Contents of the "exclusion list" are occasionally revised based on results of non real-time quality control.

Consistency of consecutive positions is checked for reports from mobile stations such as ships, drifting buoys and aircraft. Consistency of consecutive reports and that among elements within a report are 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 have 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 three 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 of 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 recommended procedures for the exchange of monitoring results by the Commission for Basic Systems (CBS). The report is sent to major Global Data-Processing and Forecasting System (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 data for every observation element reported from ocean data buoys is monitored by time sequence maps comparing 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 three-dimensional variational (3D-VAR) scheme has been employed for the global and typhoon analyses since 26 September 2001. For the regional (mesoscale) analysis, a four-dimensional variational (4D-VAR) scheme was introduced on 19 June 2003 (19 March 2002). All analyses are made on model coordinates for surface pressure, geopotential height, vector winds, temperature and specific humidity.

Global analyses are performed at 00UTC and 12UTC. An early analysis with a short cut-off time is performed to prepare initial conditions for operational forecast, and a cycle analysis with a 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.

### 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,<br>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

(Temperature is analyzed but not used as the initial condition for the regional and meso-scale model.)

**Data Used**

SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, SATEM, ATOVS, SATOB, BUFR (winds), MODIS polar winds, SeeWinds, TMI, SSM/I and Australian PAOB.

**Typhoon Bogussing,**

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

JMA runs the Global Spectral Model (GSM0103; T213L40) 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 any typhoons exist or a typhoon is expected to form 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.

The 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.

The Global Ocean Data Assimilation System (ODAS), whose specifications are described in Table 7.4.5-1, is operated. The ocean data assimilation system in the North Pacific has been in operation since January 2001. The specifications of the model are described in Table 7.4.6.1-1.

The 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.

The 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 (00h - 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 (00h - 90h) |
| 0320 - 0345 | 00UTC decode, regional analysis |
| 0330 - 0430 | 00UTC typhoon forecast (00 - 84h) |
| 0345 - 0405 | 00UTC regional forecast (00h - 51h) |
| 0410 - 0430 | 00UTC ocean wave forecast (00h - 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 (00h - 33h) |
| 0800 - 0900 | 06UTC typhoon forecast (00h - 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 (00h - 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 (00h - 90h) |
| 1520 - 1545 | 12UTC decode, regional analysis |
| 1530 - 1630 | 12UTC typhoon forecast (00 - 84h) |
| 1545 - 1605 | 12UTC regional forecast (00h - 51h) |
| 1610 - 1630 | 12UTC ocean wave forecast (00h - 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 (00h - 33h) |
| 2000 - 2100 | 18UTC typhoon forecast (00h - 84h) |

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

### 7.2.1 Data assimilation, objective analysis and initialization (Table 7.2.2-1)

A three-dimensional variational (3D-VAR) data assimilation method is employed for the analysis of the atmospheric state for the JMA Global Spectral Model (GSM). In the 3D-VAR, a statistical linear balance that includes dynamics in tropics and surface friction effects is globally satisfied. The control variables are relative vorticity, unbalanced divergence, unbalanced temperature, unbalanced surface pressure and the natural logarithm of specific humidity. In order to save the computational efficiency, an incremental method is adopted in which the analysis increment is evaluated at a lower horizontal resolution (T106) and then it is interpolated and added to the first guess field at the original resolution (T213).

A non-linear normal mode initialization with full physical processes is applied to the first five vertical modes. The effect of the atmospheric tide is considered by adding the model tidal tendency to the specific normal modes.

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.

Temperature reports from radiosonde observations have been used instead of geopotential height reports since April 2004. The shift of data was made as a preparation for the introduction of a variational quality control (VarQC) scheme because an appropriate treatment of a strong vertical correlation in observation errors of geopotential height is difficult in the VarQC scheme. This shift slightly improved the GSM forecasts.

Direct assimilation of ATOVS level-1c radiance data (AMSU-A and AMSU-B of NOAA15, NOAA16 and AMSU-B of NOAA17) instead of NESDIS pre-processed radiance data was started in December 2004. At the same time, the radiative transfer model was updated from RTTOV-6 to RTTOV-7 that has been developed at ECMWF.

Use of MODIS polar wind data of Aqua and Terra in the Arctic area was started in May 2004 and in the Antarctic area in September 2004. These data contribute to the improvement of the forecast accuracy.

### 7.2.2 Medium-range forecasting model

The specifications of the JMA Global Spectral Model (GSM) are listed in Table 6. In July 2004, a new parameterization scheme accounting for marine stratocumulus was introduced, and a revision of both the cloud water/ice scheme and a land surface model on ice sheet was made. These brought about positive impacts: a reasonable increase in the low-level cloud amount over the ocean, especially to the west of continents, a reduction in bias in the radiation budget, and a mitigation of warm bias in the lower troposphere over the ice sheet in summer.

In December 2004, improvements were made on long-wave and short-wave radiation schemes. For the long-wave scheme, a new scheme that employs a lookup-table method and a k-distribution method is introduced instead of a traditional band model. At the same time, a number of spectral bands are increased from 4 to 9 for radiation calculation. In this new scheme, an improved parameterization of water vapor continuum absorption is also used, and the effect of trace gases such as methane, nitrous oxide and CFCs are taken into account. As for the short-radiation scheme, refinements of the parameterization of absorption by ozone, carbon dioxide and oxygen were made. The improvements in the short- and long-wave radiation schemes lead to a substantial mitigation of cooling bias in the lower stratosphere and the underestimation of the downward long-wave flux at the surface.

**Table 7.2.2-1 Specifications of Global Spectral Model for 9-day forecasts**

| | |
|---|---|
| Basic equation | Primitive equations |
| Independent variables | Latitude, longitude, sigma-p hybrid coordinate and time |
| Dependent variables | Vorticity, divergence, temperature, surface pressure, specific humidity |
| Numerical technique | Euler semi-implicit time integration, spherical harmonics for horizontal representation and finite difference in the vertical |
| Integration domain | Global |
| Horizontal resolution | T213 (about 0.5625 degree Gaussian grid) 640x320 |
| Vertical levels | 40 (surface to 0.4hPa) |
| Forecast time | 90 hours from 00UTC and 216 hours from 12UTC |
| Forecast phenomena | Synoptic disturbances and tropical cyclones |
| Orography | GTOPO30 30" x 30" dataset, spectrally truncated and smoothed. |
| Horizontal diffusion | Linear, second-order Laplacian |
| Moist processes | Prognostic Arakawa-Schubert cumulus parameterization + large-scale condensation |
| Radiation | Short-wave radiation computed every hour<br>Long-wave radiation computed every three hours |
| Cloud water | Prognostic cloud water, cloud cover diagnosed from moisture and cloud |
| Gravity wave drag | Long-wave scheme for troposphere and lower stratosphere<br>Short-wave scheme for lower troposphere |
| PBL | Mellor-Yamada level-2 closure scheme and similarity theory for surface boundary layer |
| Land surface | Simple Biosphere Model (SiB) |
| Surface state | SST anomaly added to seasonally changing climatological SST.<br>Initial soil moisture, roughness length and albedo are climatological values. The analyzed snow depth is used for the initial value. Predicted values are used for the initial soil and canopy temperatures |

### 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<br>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 | | | | |
| | 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. Thus, the dynamical framework and all physical processes are identical with those of the high-resolution GSM (T213) mentioned in 7.2.2 except for the horizontal resolution. The atmospheric initial condition for the control run is prepared by interpolating the T213 analysis. The initial condition for a land surface model is generated by running the land surface model with external forcing of T213 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**

| | |
|---|---|
| Integration domain | Global, surface to 0.4hPa |
| Horizontal resolution | T106 (about 1.125 degree Gaussian grid) 320x160 |
| Vertical levels | 40 (surface to 0.4hPa) |
| Forecast time | 216 hours from 12UTC |
| Ensemble size | 25 members |
| Perturbation generator | Breeding of Growing Mode (BGM) method<br>(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.

### 7.3.1.2 Regional Spectral Model (RSM)

In addition to ordinary 4th order horizontal diffusion scheme, targeted moisture diffusion scheme was introduced in RSM in April 2004 in order to suppress strong grid-scale updrafts and the associated intense rainfall. This scheme well inhibits a formation of pseudo small lows over the sea.

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

| | |
|---|---|
| Basic equation | Primitive equations |
| Independent variables | x-y coordinate on a 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. Orography is 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.<br>Evaporability depends on location and season. |
| Surface state | Observed SST (fixed during time integration) and sea ice distribution.<br>Evaporability, roughness length, albedo are climatological values.<br>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<br>12UTC | GTS |
| vertical p-velocity | 700 | | | | |
| temeprature, 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<br>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<br>2.5x2.5 degree | 0 | 00UTC<br>12UTC | GTS<br>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)<br>850, 700 (12UTC) | | | | |
| sea level pressure, rainfall amount | - | | 24, 48, 72 | 00UTC<br>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<br>80E-160W<br>2.5x2.5 degree | 0, 6, 12, 18, 24, 30, 36, 48, 60, 72 | 00UTC<br>12UTC | GTS<br>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<br>80E-160W<br>1.25x1.25 degree | 0, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, | | |
| 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 | | 72, 78, 84 | | |
| geopotential height, temperature, wind | 250, 200, 150, 100, 70, 50<br>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<br>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 save 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).

Non-linear normal mode initialization (NNMI) with full physical processes is applied to the first five vertical modes. Initial and lateral boundary conditions for 4D-VAR are derived from RSM forecasts.

A new tropical cyclone bogussing method was introduced in June 2003. In the new bogussing method, the following procedures are employed; 1) a bogus structure is made with the same method as the GSM bogussing. 2) pseudo observational data are made according to the 3D-structures of wind and pressure field determined from the bogus structure. 3) 4D-VAR analysis is conducted with the pseudo observational data so that the dynamical consistency in the analysis field is preserved.

Assimilation of precipitation and TPW (Total Precipitable Water) data retrieved from TMI and SSM/I for meso 4D-VAR analysis was started in October 2003. In November 2004, the usage of these data retrieved from Aqua/AMSR-E was started for meso 4D-VAR analysis. The use of precipitation and TPW data from two satellites ameliorates the quality of water vapor field to bring about positive impact on the precipitation prediction.

Assimilation of QuikSCAT/SeaWinds data was started in July 2004 for the meso 4D-VAR analysis and treat score has improved.

Assimilation of SATEM data of NOAA-17 retrieved by the Meteorological Satellite Center, JMA for meso and regional 4D-VAR analyses was started in November 2004. The quality of the data is confirmed to be almost the same as that from NOAA-16.

### 7.3.2.2 Meso-Scale Model (MSM)

A non-hydrostatic Meso-Scale Model (MSM0409; 10kmL40) with 10-km resolution was put into operation on 1 September 2004 in place of the former operational hydrostatic model (MSM0103) of the same resolution. MSM0409 has new features in dynamics and physics such as the use of non-hydrostatic equations and explicit cloud microphysics for example. The forecast domain, the map projection, the initial and boundary conditions, forecast time and update frequency of the new model are the same as those for the former one. 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 onto 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, 369 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.<br>Targeted moisture diffusion applied to the grid points where excessive updrafts appear. |
| Moist processes | Three-ice bulk cloud microphysics + Kain-Fritsch convection scheme.<br>Lagrangean 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.<br>Similarity theory adopted for the surface boundary layer. |
| Land surface | Ground temperature predicted using a four-layer ground model.<br>Evaporability depends on location and season. |
| Surface state | Observed SST (fixed during time integration) and sea ice distribution.<br>Climatological values of evaporability, roughness length, albedo.<br>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, and maximum wind speed and the associated direction up to 15 hours at each major airport.

The same techniques as the RSM-based guidance (see 7.3.1.4) are also used to derive the following weather guidance; averaged precipitation amount at each 20km square grid, maximum precipitation in each sub-divided forecast area, and maximum wind speed and the associated direction at each observation station. The weather forecast guidance produces three hourly values up to 18 forecast hours.

### 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 are the following three: 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. The reliability of the analyzed wind fields is limited in regions where many observational data exist.

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

#### 7.3.4.1 Method of data processing

Using radar reflectivity factors estimated from with the power scattered by rain particles at 20 digitized ground-based radar sites and precipitation observations by ground stations, which include more than 1300 stations operated by JMA and nearly 4,000 stations operated by other organizations, one-hour precipitation data over Japan, called Radar-AMeDAS precipitation, are analyzed every half hour with a 2.5km resolution. Radar reflectivity factors are translated into rainfall intensities with a Z-R relationship and accumulated to one-hour precipitation. The analysis of precipitation at each radar is made by calibrating the accumulated radar one-hour precipitation with the rain-gauge observations. The Radar-AMeDAS precipitation is the composite of analyzed precipitation of all the radars. An initial field for a linear extrapolation forecast is the composite of calibrated rainfall intensities.

The linear extrapolation forecast and the precipitation forecast from the Meso-Scale Model (MSM; see 7.3.2.2) are merged into the final 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 linear extrapolation model**

| | |
|---|---|
| Forecast process | Linear extrapolation |
| Physical process | Topographic enhancement and dissipation |
| Motion vector | Motion of a precipitation system is evaluated by the cross correlation method |
| Time step | 5-10 minutes |
| Grid form | Oblique conformal secant conical projection |
| Resolution | 5km |
| Number of grids | 320 x 720 |
| 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 time 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 nowcasting is to predict distribution of precipitation by extrapolation up to 1 hour. Initial rainfall intensity distribution is derived from radar data obtained at 10-minute interval, which is calibrated by AMeDAS 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 1km |
| 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 nowcasting is 10-minute precipitation forecast 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)

The specifications of the JMA Typhoon Model (TYM) are shown in Table 7.4.1.2-1. A new physical process package, including a prognostic cloud water scheme, a modified cumulus parameterization and a new radiation schemes, was introduced in July 2003. In order to suppress the excessive low pressure at and around typhoon center, the roughness length on sea surface, and the ratio of the bulk exchange coefficients of heat and moisture to that of momentum, were also revised. The resultant amelioration of heat and moisture fluxes over sea surface brings about moderate representation of typhoon intensity.

**Table 7.4.1.2-1 Specifications of Typhoon Model (TYM)**

| | |
|---|---|
| Basic equation | Primitive equations |
| Independent variables | x-y coordinate 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, virtural 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 6-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<br>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<br>100E-180E | 06, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90 | 00UTC<br>12UTC | GTS |
| Center position and changes of intensity parameters from the initial time by TYM | - | Eq. - 60N<br>100E-180E | 06, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84 | 00UTC<br>06UTC<br>12UTC<br>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 (T213L40). Main products of the RSMC are trajectories, time integrated low-level concentrations and total deposition up to 72 hours.

A high-resolution regional transport model is experimentally operated to predict volcanic gas spread from Miyakejima Island, an active volcano of Japan. The concentration of $SO_2$ is predicted up to 36 hours every day (00UTC initial). The atmospheric state is provided by the RSM forecast 3-hourly.

### 7.4.3 Ocean wave forecasting system

### 7.4.3.1 Models

JMA operates two numerical wave modes; 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<br>(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<br>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 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 was upgraded in January 2004 to provide 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<br>(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) |
| | bogusing 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 5 tracks are predicted.

## 7.4.5 Global Ocean data assimilation system

A global ocean data assimilation system (ODAS), upgraded in February 2003, 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 equation | 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 are also used as the oceanic initial conditions for the JMA coupled ocean-atmosphere model.

### 7.4.6 Ocean Data Assimilation System in the North Pacific Ocean

#### 7.4.6.1 Model

The ocean data assimilation system in the North Pacific has been in operation since January 2001, 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 in the North Pacific Ocean**

| | |
|---|---|
| Basic equation | 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 | 12.5km and 6 hours |
| Integration domain | Seas around Hokkaido |
| Initial time and forecast time | 168 hours from 00UTC 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 in 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<br>Turbulent diffusion<br>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, SST anomalies are fixed during the 34-day time integration. Soil moisture, 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, spread, and so on.

The grid point value products from extended-range ensemble prediction system disseminated through the GTS and the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc) are shown in Table 7.5.3-1. The map products disseminated through TCC are shown in Table 7.5.3-2.

**Table 7.3.5-1 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)<br>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 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, initial SST anomalies are fixed during the 120-day time integration. Soil moisture, 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 $1.875^{o}$ Gaussian grid 192by96 ~180km) |
| Vertical levels | 40 (surface to 0.4hPa) |
| Forecast time | 2880 hours from 12UTC |
| 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, spread, and so on.

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 | Rainfall amount, surface temperature at 2m, sea surface temperature, sea level pressure and their anomalies | - | Global 2.5x2.5 | Initial time : 12UTC around 15th day in each month |
| | Temperature and its anomaly | 850 | | |

| | | | | |
|---|---|---|---|---|
| time range | Geopotential height and its anomaly | 500 | degree | Forecast time :<br>Every each month and three months average |
| | Wind (u, v) and their anomalies | 850,200 | | |

### 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-day 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 7.6.2-2) from 210-day ensemble prediction are disseminated through the Tokyo Climate Center (TCC) Web site (http://cpd.kishou.go.jp/tcc).

**Table 7.6.2-2 Grid point value products (GRIB) and maps for 210-day prediction through TCC**

| Contents | | Level (hPa) | Area | Initial time & Forecast Time |
|---|---|---|---|---|
| Forecast members (only for grid-point-value), their ensemble mean and spread (standard deviation) values averaged for every each month and three months during forecast time range | Rainfall amount, surface temperature at 2m, sea surface temperature, sea level pressure and their anomalies | - | Global 2.5x2.5 degree | Initial time :<br>12UTC around 15th day in each month<br>Forecast time :<br>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 predicted with 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 corrected 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 for monthly El Niño outlook has been operated. 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. JMA makes the model results available through the Tokyo Climate Center (TCC) Web site (http://cpd2.kishou.go.jp/tcc). The

MOS-corrected NINO3 SST anomaly is used in 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 equation | Primitive equation |
| | 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 2003 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,<br>day 9–15,<br>day 16–29,<br>day 2–29 average | Geopotential height at 500hPa,<br>temperature at 850hPa,<br>sea level pressure | Northern Hemisphere (20N-90N),<br>Eurasia (20N-90N, 0E-180E),<br>North Pacific (20N-90N, 90E-90W),<br>East Asia(20N-60N, 100E -179E) |
| | | Stream function at 200hPa and 850hPa,<br>velocity potential at 200hPa and 850hPa, and<br>geopotential height at 500hPa | Global, Tropics(20N-20S),<br>Northern Hemisphere(20N- 90N),<br>Southern hemisphere(20S-90S) |

(b) Map

| | Forecast period | Parameter |
|---|---|---|
| Forecast, corresponding objective analysis, and error maps | Day 2–8,<br>day 9–15,<br>day 16–29,<br>day 2–29 average | Geopotential height and anomaly at 500hPa,t<br>temperature and anomaly at 850hPa,<br>sea level pressure and anomaly,<br>stream function and anomaly at 200hPa and 850hPa,<br>velocity potential and anomaly at 200hPa and 850hPa,<br>precipitation (forecast only) |

|  |  |  |
|---|---|---|
| Mean error map for each season |  | Geopotential height at 500hPa,<br>temperature at 850hPa,<br>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 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 TCC Web site.

### 8.4 Verification system for long range ensemble prediction for warm and cold seasons 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

Following developments are planned in 2005:

(1) Direct assimilation of Aqua /AIRS radiance data for the global analysis in late 2005.
(2) Direct assimilation of SSM/I radiance data for the global analysis in late 2005.
(3) Direct assimilation of Aqua/AMSU-A radiance data for the global analysis in early 2005.
(4) A 4D-VAR data assimilation system for the global analysis in early 2005.
(5) Introduction of a semi-Lagrangian scheme in GSM in early 2005.
(6) Implementation of new parameterization schemes for the gravity wave drag, cloud radiation, and atmospheric boundary layer processes of GSM in 2005.
(7) Revision of parameterization schemes for snow albedo, ice-cloud and stratocumulus of GSM will be revised in early 2005.
(8) 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.

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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 | 13.6 | 13.5 | 12.9 | 12.6 | 11.7 | 11.0 | 10.0 | 10.6 | 11.2 | 11.0 | 12.1 | 13.4 | 12.0 |
| 72 | 37.2 | 36.0 | 34.1 | 33.9 | 29.3 | 28.2 | 25.1 | 25.9 | 29.2 | 30.7 | 33.5 | 34.2 | 31.4 |
| 120 | 68.1 | 60.1 | 64.9 | 60.9 | 53.5 | 50.8 | 43.3 | 46.0 | 52.8 | 58.2 | 64.8 | 60.3 | 57.0 |

**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 | 15.4 | 15.5 | 16.6 | 17.0 | 18.3 | 19.8 | 20.9 | 21.7 | 18.5 | 16.7 | 15.4 | 14.3 | 17.5 |
| 72 | 40.0 | 39.1 | 43.9 | 46.6 | 45.1 | 51.0 | 53.0 | 57.0 | 50.2 | 41.8 | 39.3 | 35.3 | 45.2 |
| 120 | 64.6 | 68.1 | 72.2 | 77.4 | 77.1 | 82.8 | 89.5 | 96.9 | 82.7 | 70.4 | 64.4 | 59.6 | 75.5 |

**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 | 14.2 | 13.7 | 13.6 | 13.1 | 11.8 | 10.5 | 9.7 | 9.9 | 11.5 | 12.6 | 13.4 | 16.1 | 12.5 |
| 72 | 39.0 | 39.5 | 35.9 | 34.5 | 28.7 | 26.4 | 21.7 | 21.0 | 29.2 | 32.3 | 40.1 | 40.0 | 32.4 |
| 120 | 70.7 | 59.7 | 69.9 | 61.5 | 53.3 | 45.6 | 36.3 | 39.6 | 50.1 | 58.9 | 67.6 | 60.7 | 56.2 |
| ob. num. | 78 | 79 | 80 | 79 | 78 | 79 | 79 | 78 | 79 | 79 | 79 | 79 | 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 | 20.9 | 19.0 | 18.2 | 16.9 | 14.3 | 16.6 | 16.5 | 16.8 | 15.8 | 15.6 | 17.5 | 21.3 | 17.5 |
| 72 | 45.6 | 40.7 | 35.1 | 31.0 | 28.0 | 29.5 | 28.5 | 26.8 | 33.0 | 36.4 | 37.3 | 36.6 | 34.0 |
| 120 | 83.5 | 66.0 | 67.6 | 60.6 | 55.0 | 46.7 | 48.9 | 50.8 | 64.7 | 58.4 | 73.8 | 69.6 | 62.1 |
| ob. num. | 55 | 55 | 55 | 56 | 56 | 55 | 55 | 55 | 51 | 49 | 51 | 55 | 54.0 |

**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 | 15.6 | 14.7 | 14.3 | 14.7 | 15.4 | 16.2 | 16.5 | 15.2 | 14.3 | 15.3 | 15.4 | 15.2 |
| 72 | 31.9 | 33.9 | 29.1 | 31.7 | 26.4 | 31.3 | 24.4 | 24.9 | 27.6 | 27.8 | 28.5 | 29.9 | 29.0 |
| 120 | 59.2 | 56.9 | 48.2 | 56.8 | 44.9 | 44.1 | 37.2 | 39.1 | 46.6 | 50.0 | 49.5 | 48.2 | 48.4 |
| ob. num. | 46 | 48 | 49 | 46 | 47 | 47 | 46 | 48 | 48 | 51 | 51 | 50 | 48.1 |

**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 | 11.3 | 12.3 | 12.5 | 11.6 | 11.6 | 12.4 | 12.9 | 16.7 | 14.9 | 13.2 | 13.2 | 13.8 | 13.0 |
| 72 | 20.5 | 25.9 | 26.5 | 27.8 | 26.1 | 28.9 | 27.5 | 31.5 | 24.0 | 26.8 | 28.8 | 26.7 | 26.8 |
| 120 | 36.4 | 38.4 | 45.7 | 50.1 | 45.6 | 50.5 | 49.1 | 51.9 | 43.3 | 45.8 | 46.4 | 37.8 | 45.1 |
| ob. num. | 22 | 22 | 23 | 23 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22.2 |

**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 | 17.6 | 16.8 | 16.0 | 15.6 | 14.2 | 14.5 | 14.2 | 15.0 | 14.7 | 14.4 | 15.9 | 18.0 | 15.6 |
| 72 | 41.6 | 40.3 | 36.2 | 35.9 | 30.8 | 31.0 | 27.1 | 27.4 | 33.1 | 35.2 | 37.9 | 38.2 | 34.6 |
| 120 | 75.9 | 64.6 | 68.2 | 65.3 | 55.9 | 51.4 | 45.0 | 48.1 | 58.0 | 62.4 | 72.3 | 64.0 | 60.9 |
| ob. num. | 235 | 238 | 241 | 237 | 240 | 241 | 238 | 240 | 236 | 238 | 237 | 242 | 238.6 |

**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 | 14.2 | 15.3 | 16.4 | 16.1 | 15.5 | 18.5 | 18.5 | 20.6 | 18.3 | 17.1 | 17.0 | 16.0 | 17.0 |
| 72 | 28.0 | 32.3 | 33.6 | 36.9 | 31.8 | 38.3 | 41.2 | 39.0 | 36.9 | 34.0 | 31.3 | 29.1 | 34.4 |
| 120 | 49.5 | 53.6 | 54.6 | 60.9 | 52.8 | 61.5 | 65.4 | 64.1 | 60.2 | 57.3 | 50.7 | 46.3 | 56.4 |
| ob. num. | 37 | 39 | 39 | 40 | 38 | 37 | 37 | 36 | 38 | 39 | 40 | 39 | 38.3 |

**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 | 5.0 | 5.2 | 5.1 | 5.2 | 5.2 | 5.1 | 4.9 | 5.1 | 5.1 | 5.0 | 5.1 | 5.2 | 5.1 |
| 72 | 10.4 | 10.7 | 10.3 | 10.8 | 10.5 | 10.6 | 10.1 | 10.4 | 11.0 | 10.4 | 10.5 | 10.2 | 10.5 |
| 120 | 15.9 | 15.4 | 16.3 | 16.5 | 16.2 | 15.9 | 14.6 | 15.1 | 16.9 | 16.8 | 16.7 | 15.7 | 16.0 |

**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 | 5.4 | 5.5 | 5.4 | 5.6 | 5.8 | 6.1 | 5.8 | 6.0 | 5.8 | 5.7 | 5.4 | 5.3 | 5.7 |
| 72 | 12.2 | 11.7 | 12.2 | 12.6 | 12.3 | 13.2 | 12.8 | 13.3 | 12.4 | 11.9 | 11.3 | 10.8 | 12.2 |
| 120 | 17.5 | 17.9 | 18.4 | 19.0 | 18.4 | 19.2 | 19.6 | 20.0 | 18.4 | 17.6 | 16.6 | 15.8 | 18.2 |

**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 | 7.1 | 7.5 | 6.8 | 6.7 | 6.6 | 6.6 | 6.3 | 6.4 | 6.5 | 7.0 | 6.8 | 7.1 | 6.8 |
| 72 | 12.1 | 14.1 | 11.9 | 12.8 | 11.8 | 11.5 | 10.4 | 10.0 | 12.3 | 12.2 | 13.8 | 13.2 | 12.2 |
| 120 | 17.6 | 19.0 | 19.2 | 18.7 | 17.3 | 16.5 | 14.9 | 14.8 | 17.4 | 19.5 | 20.6 | 18.7 | 17.9 |
| ob. num. | 70 | 72 | 75 | 75 | 76 | 77 | 78 | 77 | 77 | 75 | 74 | 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 | 7.0 | 6.7 | 6.7 | 6.2 | 6.3 | 6.2 | 6.5 | 6.7 | 6.9 | 6.7 | 6.8 | 7.4 | 6.7 |
| 72 | 14.1 | 11.9 | 10.7 | 10.4 | 10.4 | 11.7 | 11.3 | 11.6 | 13.1 | 12.1 | 13.0 | 12.3 | 11.9 |
| 120 | 22.5 | 18.7 | 18.4 | 16.8 | 16.8 | 16.5 | 17.0 | 16.7 | 20.0 | 17.6 | 19.6 | 19.0 | 18.3 |
| ob. num. | 53 | 54 | 55 | 55 | 53 | 54 | 54 | 55 | 49 | 49 | 48 | 53 | 52.7 |

**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 | 6.1 | 6.5 | 7.3 | 7.0 | 7.0 | 7.2 | 6.6 | 6.6 | 6.0 | 5.9 | 5.6 | 5.7 | 6.5 |
| 72 | 9.7 | 10.2 | 10.3 | 11.2 | 11.3 | 13.3 | 11.2 | 11.7 | 10.6 | 10.0 | 8.9 | 8.9 | 10.6 |
| 120 | 13.1 | 13.6 | 14.0 | 17.6 | 16.1 | 17.4 | 14.9 | 15.0 | 15.6 | 16.0 | 14.3 | 12.1 | 15.0 |
| ob. num. | 45 | 46 | 47 | 44 | 46 | 45 | 44 | 47 | 46 | 50 | 50 | 51 | 46.8 |

**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 | 6.7 | 6.6 | 6.6 | 7.1 | 6.9 | 6.4 | 6.3 | 6.6 | 6.4 | 6.6 | 7.0 | 6.6 |
| 72 | 9.5 | 9.6 | 10.9 | 11.2 | 11.1 | 11.2 | 10.1 | 9.9 | 10.3 | 9.9 | 10.6 | 10.5 | 10.4 |
| 120 | 13.6 | 13.6 | 15.4 | 17.4 | 15.6 | 16.2 | 15.9 | 14.8 | 15.7 | 15.3 | 14.8 | 13.9 | 15.2 |
| ob. num. | 33 | 34 | 34 | 34 | 33 | 33 | 33 | 32 | 32 | 33 | 33 | 33 | 33.1 |

**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 | 6.6 | 6.8 | 6.7 | 6.5 | 6.5 | 6.5 | 6.4 | 6.5 | 6.4 | 6.4 | 6.3 | 6.6 | 6.5 |
| 72 | 12.0 | 12.1 | 10.8 | 11.5 | 11.1 | 11.8 | 11.0 | 11.2 | 12.1 | 11.6 | 11.9 | 11.5 | 11.6 |
| 120 | 18.1 | 17.2 | 17.3 | 17.7 | 16.7 | 16.7 | 15.8 | 15.8 | 18.1 | 18.0 | 18.5 | 16.8 | 17.2 |
| ob. num. | 220 | 226 | 229 | 226 | 230 | 233 | 232 | 234 | 228 | 229 | 227 | 231 | 228.8 |

**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 | 7.1 | 6.9 | 7.2 | 7.2 | 7.5 | 7.1 | 6.8 | 7.3 | 7.3 | 7.1 | 7.5 | 7.2 |
| 72 | 10.8 | 10.9 | 11.8 | 12.5 | 12.0 | 12.5 | 11.8 | 11.4 | 11.6 | 11.8 | 11.6 | 11.6 | 11.7 |
| 120 | 15.6 | 15.9 | 16.9 | 18.7 | 17.1 | 17.5 | 17.9 | 16.9 | 17.2 | 17.1 | 16.2 | 15.5 | 16.9 |
| ob. num. | 41 | 44 | 44 | 45 | 44 | 43 | 43 | 41 | 44 | 44 | 46 | 44 | 43.6 |

**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 | 2.3 | 2.3 | 2.3 | 2.4 | 2.3 | 2.4 | 2.4 | 2.4 | 2.4 | 2.2 | 2.3 |
| 72 | 3.6 | 3.7 | 3.7 | 3.6 | 3.6 | 3.8 | 3.6 | 3.9 | 3.7 | 3.7 | 3.6 | 3.5 | 3.7 |
| 120 | 4.3 | 4.4 | 4.5 | 4.2 | 4.3 | 4.5 | 4.2 | 4.7 | 4.4 | 4.3 | 4.2 | 4.1 | 4.3 |

**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 | 4.7 | 4.8 | 4.8 | 4.6 | 4.7 | 4.8 | 4.5 | 4.6 | 4.5 | 4.5 | 4.4 | 4.4 | 4.6 |
| 72 | 7.6 | 8.0 | 8.0 | 7.4 | 7.5 | 7.6 | 7.2 | 7.3 | 7.4 | 7.0 | 7.2 | 6.9 | 7.4 |
| 120 | 9.4 | 9.6 | 9.6 | 9.0 | 9.1 | 9.3 | 8.6 | 8.8 | 8.7 | 8.5 | 8.5 | 8.1 | 8.9 |

**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 | 4.1 | 4.2 | 4.2 | 3.9 | 4.0 | 4.5 | 4.0 | 4.2 | 4.1 | 3.9 | 3.9 | 4.1 | 4.1 |
| 72 | 4.6 | 4.7 | 4.8 | 4.3 | 4.4 | 5.3 | 4.7 | 5.0 | 4.7 | 4.6 | 4.2 | 4.6 | 4.7 |
| 120 | 5.0 | 5.2 | 5.4 | 4.7 | 4.8 | 5.6 | 4.8 | 5.6 | 5.1 | 5.2 | 4.7 | 5.2 | 5.1 |
| ob. num. | 34 | 35 | 35 | 34 | 33 | 33 | 34 | 33 | 32 | 34 | 34 | 33 | 33.7 |

**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 | 6.4 | 6.7 | 6.6 | 6.1 | 6.2 | 6.6 | 5.9 | 6.4 | 5.8 | 6.0 | 5.8 | 5.8 | 6.2 |
| 72 | 8.2 | 8.7 | 8.6 | 7.7 | 7.5 | 7.8 | 7.2 | 7.8 | 7.2 | 7.6 | 7.2 | 7.3 | 7.7 |
| 120 | 9.4 | 10.1 | 10.0 | 9.0 | 9.0 | 8.9 | 8.2 | 9.1 | 8.3 | 8.8 | 8.2 | 8.3 | 8.9 |
| ob. num. | 33 | 34 | 34 | 33 | 32 | 32 | 32 | 32 | 31 | 33 | 33 | 32 | 32.6 |