Annual WWW Technical Progress Report
on the Global Data Processing System 1999

Japan Meteorological Agency (JMA)

1. Summary of highlights

(1) Experimental operations of medium-range ensemble prediction began on 16 March 1999. A nine-member ensemble of eight-day forecasts is produced every day with a T63L30 version of JMA's Global Spectral Model (GSM). Perturbations in the initial conditions are generated by a breeding method.
(2) The coverage area of the storm surge model was extended over Tohhoku and Hokuriku districts (northern parts of Japan) in July 1999 .
(3) In August 1999, JMA started to issue the monthly ENSO outlook based on the model results for end users.
(4) A non-local planetary boundary layer scheme was implemented in the Regional Spectral Model (RSM) and the Mesoscale Model (MSM) on 29 November 1999. The latter model is a 10 km resolution version of RSM and has been experimentally operated twice a day to produce 12-hour forecasts since 1 March 1998.
(5) The physics package of GSM was updated on 7 December 1999. The new package includes a prognostic cloud water scheme, effects of orographic updraft and turbulence in the planetary boundary layer on cumulus convection, and direct effects of aerosol on radiation.
(6) Production of one-month forecast GPV products in GRIB format started on 1 December 1999 based on the operational ensemble forecasting system.

2. Equipment in use at the Global Data Processing System (GDPS) Center in JMA

The features of major components of the Numerical Analysis and Prediction System (NAPS) are listed in Table 1.

Table 1 Major features of NAPS computers

Supercomputer	HITAC S-3800/480
Number of vector processors	4
Number of scalar processors	4
Peak vector performance	32 Gflops
Memory capacity	2 GB
Extended memory capacity	12 GB
Data transfer rate	4 GB/s
Disk storage capacity	205 GB
Automated CMT library capacity	2.1 TB(400MB/volume)
Peripheral equipment	CMT(12 drives), LBP
Operating system	VOS3/AS
Meteorological message handling server	Hitachi unix server 3500
CPU cycle time	10 ns
Memory capacity	256 MB
Data disk storage capacity	2 GB x 2
Peripheral equipment	DAT, FPD
Workstation for NWP	
Very short-range forecast ws	Hitachi unix ws 3050RX
Memory capacity	112 MB
CPU cycle time	10 ns
Disk storage capacity	2 GB
Peripheral equipment	DAT, FPD, LBP
Graphic processing ws	Hitachi unix ws 3050RX
Memory capacity	96 MB
CPU cycle time	10 ns
Disk storage capacity	2 GB
Peripheral equipment	DAT, FPD, LBP
Backup & Maintenance ws	Hitachi unix ws 3050RX

Memory capacity	128 MB
CPU cycle time	10 ns
Disk storage capacity	3 GB
Peripheral equipment	DAT, FPD, LBP, MO(128MB)

General purpose server	Hitachi total management server
Instruction rate	18 MIPS(estimated)
Memory capacity	64 MB
Disk storage capacity	27 GB
Peripheral equipment	CMT(8 drives), MT(2 drives), LBP(4), LP
Operating system	VOS3/AS

3. Data and products in use from GTS

3.1 Observations

The following observation reports are used in the data assimilation:

Table 2 Number of used observation reports

SYNOP/SHIP	32500/day
TEMP-A/PILOT-A	1700/day
TEMP-B/PILOT-B	1700/day
TEMP-C/PILOT-C	1100/day
TEMP-D/PILOT-D	1000/day
AIREP/AMDAR	33600/day
BUOY	6600/day
SATOB (SST)	7900/day
SATEM-A	9500/day
SATEM-C	9200/day
SATOB (WIND)	53100/day
TOVS	12300/day
PROFILER	600/day
BATHY/TESAC	5500/month
ERS	200/day

3.2 GRIB products

Following model products are also used. GRIB KWBC is used for preparation of WAFS products and the other ones are for internal reference and monitoring.

GRIB KWBC
GRIB ECMF
GRIB AMMC (under test)

4. Data input system

Data input is fully automated with the exception of the manual input of typhoon position, size and intensity data. They are used to generate typhoon bogus data for 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 "black list" are rejected. Contents of the "black 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,
(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 datum 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 small if time tendency and horizontal gradient are small 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 from quality control of these reports.

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

The non real-time quality monitoring of observations is carried out using observational data, real-time quality control information and the first guess archived in the CDA. The quality monitoring is made according to:

(1) Compilation of observational data rejected in the real-time quality monitoring;
(2) Calculation of statistics on the difference between observations and first-guess;
(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 System (GDPS) centers as well as to the WMO Secretariat.

The RSMC Tokyo has been acting as a lead centre 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 reported from ocean data buoys is monitored by time sequence maps for every observation element and comparing them 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 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 three kinds of objective atmospheric analyses for the global, regional and typhoon forecast models. All of them employ three-dimensional Optimal Interpolation (3D-OI) scheme on model coordinates for the analysis of surface pressure, geopotential height, vector winds, and relative humidity.

A two-dimensional function fitting method is used for temperature and height analyses above 10hPa level to prepare initial conditions for dynamical one-month forecasts.

Global analyses at 00UTC and 12UTC are performed twice. An early run analysis with a short cut-off time is to prepare initial conditions for operational forecast, and a cycle run analysis with a long cut-off time is to keep quality of global data assimilation system. The first analysis is not performed at 06 and 18UTC.

The specifications of the atmospheric analysis schemes are listed in Table 3.

Daily global SST analysis is described in Table 4.

Table 3 Specifications of operational objective analysis

Cut-off time

(global)	2.5 and 3 hours for early run analyses at 00 and 12UTC, 13, 7.5, 12, 6.5 hours for cycle run analyses at 00, 06, 12, 18 UTC.
(regional)	3 and 3.5 hours for analyses at 00 and 12UTC
(typhoon)	1.5 hours for analyses at 06 and 18UTC
(upper stratospheric)	same as the global analysis

Initial Guess

(global)	6-hour forecast by GSM
(regional)	12-hour forecast by RSM
(typhoon)	6-hour forecast by GSM
(upper stratospheric)	analysis 6 hours before

Grid form, resolution and number of grids

(global)	Gaussian grid, 0.5625 degree, 640x320
(regional)	Lambert projection, 20km at 60N and 30N, 257x217, grid point (1,1) is at north-west corner and (165,155) is at (140E, 30N)
(typhoon)	same as global analysis
(upper stratospheric)	latitude-longitude, 2.5 degree, 144x73

Levels

(global)	30 forecast model levels up to 10 hPa + surface
(regional)	36 forecast model levels up to 10 hPa + surface
(typhoon)	same as global analysis
(upper stratospheric)	7, 5, 3, 2, 1, 0.4hPa

Analysis variables

Wind, geopotential height (surface pressure), relative humidity and temperature
(Temperature is analyzed but not used as the initial condition for the forecast.)

Methodology

Multivariate three-dimensional optimum interpolation (3D-OI) scheme on model levels is employed for the analysis of geopotential height and wind except for the tropical region (15N-15S), where univariate OI analysis is applied. Geostrophic relation between geopotential height and wind is relaxed between 15N(S)-25N(S). Univariate 3D-OI scheme is employed for the analysis of temperature and relative humidity.

A two-dimensional function fitting method is used for upper stratospheric analysis.

Data Used

SYNOP, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, SATEM, TOVS, SATOB, Australian PAOB, VISSR digital cloud data from the Geostationary Meteorological Satellite (GMS) and surface wind data by Scatterometer on ERS2.

Typhoon Bogussing

For a typhoon 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 geopotential height and wind data around a typhoon. The structure is asymmetric. At first, symmetric bogus data are generated automatically from the central pressure and 30kt/s wind speed radius of the typhoon. The asymmetric bogus data are generated by retrieving asymmetric components from the first guess field. Those bogus profiles are implanted into the first guess fields.

Initialization

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

Table 4 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

JMA runs a Global Spectral Model (GSM) twice a day (84-hour forecasts from 00 UTC and 192-hour forecasts from 12 UTC), a Regional Spectral Model (RSM) also twice a day (51-hour forecasts from 00 and 12 UTC). A Typhoon Model (TYM) is run twice a day (78-hour forecasts from 06 and 18 UTC) when a typhoon exists or it is expected to be formed in the western North Pacific. JMA carries out experimental medium-range ensemble forecast and dynamical one-month forecasts using a version of GSM with reduced horizontal resolution (T63). The basic features of the operational forecast models of JMA are summarized in Tables 6, 9 and 13.

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.

Three ocean wave models, Global Wave Model, Japan-area Wave Model and Coastal Wave Model, are run operationally. The specifications of the models are described in Table 15.

The numerical storm surge model is run four times a day when a typhoon is approaching Japan. The specifications of the model are described in Table 16.

The Ocean Data Assimilation System (ODAS), whose specifications are described in Table 17, is operated.

A numerical sea ice model runs to predict sea ice distribution and thickness over the seas adjacent to Hokkaido twice a week in winter. The specifications of the model are given in Table 18.

The very short-range forecast of precipitation is operationally performed every hour. Precipitation data measured with AMeDAS (Automated Meteorological Data Acquisition System, a high density automated observation network) and radar reflectivity data are composed to make hourly precipitation map with a resolution of 5 km. These data are extrapolated in time to produce prognostic charts of precipitation up to three hours. In addition to the kinematical methods, the growth and decay of precipitation due to orographically induced updraft and downdraft are taken into account. The specifications of the model are described in Table 12.

7.1 System run schedule and forecast ranges

The Table 5 summarizes the system job schedule of NAPS and forecast ranges. These jobs are executed in batch on the HITAC S-3800/480.

Table 5 The schedule of the NAPS operation

Time (UTC)	NAPS operation (Model forecast range)
0000 - 0035	12UTC decode, global cycle analysis
0035 - 0110	18UTC decode, global cycle analysis
0110 - 0112	SST analysis
0110 - 0120	verification
0120 - 0130	00UTC storm surge forecast (00h - 24h)
0230 - 0250	00UTC decode, global early analysis
0250 - 0305	00UTC global forecast (00h - 24 h)
0305 - 0320	00UTC decode, regional analysis
0320 - 0340	00UTC regional forecast (00h - 24h)
0340 - 0400	00UTC global forecast (24h - 51h)
0400 - 0420	00UTC regional forecast (24h - 51h)
0425 - 0450	00UTC global forecast (51h - 84h)
0450 - 0500	00UTC wave forecast (00h - 72h)
0500 – 0550	Ocean data assimilation / El Niño prediction
0700 - 0730	06UTC meso-scale forecast (00h - 12h)
0720 - 0730	06UTC storm surge forecast (00h - 24h)
0730 - 0745	06UTC decode, typhoon analysis
0745 - 0800	06UTC typhoon forecast (00h - 78h)
1320 - 1330	12UTC storm surge forecast (00h - 24h)
1320 - 1355	00UTC decode, global cycle analysis
1355 - 1430	06UTC decode, global cycle analysis
1500 - 1520	12UTC decode, global early analysis
1520 - 1535	12UTC global forecast (00h - 24h)
1535 - 1550	12UTC decode, regional analysis
1550 - 1610	12UTC regional forecast (00h - 24h)
1610 - 1630	12UTC global forecast (24h - 51h)
1630 - 1650	12UTC regional forecast (24h - 51h)

1655 - 1720	12UTC global forecast (51h - 84h)
1720 - 1730	12UTC wave forecast (00h - 72h)
1730 - 1830	12UTC global forecast (84h - 192h)
1830 - 1835	12UTC wave forecast (72h - 192h)
1835 - 1950	12UTC one month forecast (5 runs, twice a week) or medium-range ensemble forecast (0 – 192h)
1900 - 1930	18UTC meso-scale forecast (00h - 12h, 5 times a week)
1920 - 1930	18UTC storm surge forecast (00h - 24h)
1930 - 1945	18UTC decode, typhoon analysis
1945 - 2000	18UTC typhoon forecast (00h - 78h)

7.2 Medium-range forecasting system (3 - 8 days)

7.2.1 Data assimilation, objective analysis and initialization (Table 6)

A multivariate three-dimensional optimum interpolation (3D-OI) scheme on model levels is employed for the analyses of geopotential height and wind except for the tropical region (15N-15S), where univariate OI analysis is applied. Geostrophic relation between geopotential height and wind is relaxed between 15N(S)-25N(S). Univariate 3D-OI scheme is employed for the analyses of temperature and relative humidity.

VISSR digital cloud data from GMS are combined with ship or surface observations, and they are used as proxy data to generate vertical moisture profile in global analysis.

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

7.2.2 Medium-range forecasting model

Table 6 Specifications of Global Spectral Model (GSM9603) for 8-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, surface to 10hPa
Horizontal resolution	T213 (about 0.5625 deg Gaussian grid) 640x320
Vertical levels	30
Forecast time	84 hours from 00UTC and 192 hours from 12UTC
Forecast phenomena	Synoptic disturbances and tropical cyclones
Orography	Original resolution 10' x 10' data-set, spectrally truncated and smoothed.
Horizontal diffusion	Linear, second-order Laplacian
Moist processes	Prognostic Arakawa-Schubert cumulus parameterization + large-scale condensation
Radiation	Shortwave radiation computed every hour Longwave radiation computed every three hours
Cloud	Prognostic cloud water, cloud cover diagnosed from moisture and cloud water
Gravity wave drag	Longwave scheme for troposphere and lower stratosphere, shortwave 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. Initial soil moisture, initial snow depth, roughness length and albedo are climatological values.

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 or JMJ), the GTS and the RSMC Tokyo Data Serving System.

Table 7 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
temperature	850				
sea level pressure	-				
sea level pressure	-	C	96, 120		radio facsimile
rainfall amount	-				

Table 8 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, temperature,wind	850, 700, 500, 300, 250, 200, 100				
T-TD	850, 700				
sea level pressure, rainfall amount	-		144, 168, 192		
temperature, wind	surface				
geopotential height, temperature, wind	850, 700, 500, 300				
T-Td	850, 700				
wind	200				

7.2.4 Operational techniques for application of GSM products

Surface air temperature is derived by Kalman-filtering technique and cloud amount, precipitation by MOS technique. Significant weather and cross section charts for international air navigation are produced twice a day.

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

7.3 Short-range forecasting system

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

7.3.1.1 Data assimilation, objective analysis and initialization

A multivariate three-dimensional optimum interpolation (3D-OI) scheme on model levels is employed for the analysis of geopotential height and wind. Univariate 3D-OI scheme is employed for the analysis of temperature and relative humidity.

VISSR digital cloud data from GMS are combined with ship or surface observation and they are used as proxy data to generate vertical moisture profile in the analysis.

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

Physical initialization with the use of analyzed precipitation data is executed before NMI.

7.3.1.2 Short-range forecasting model (0-51 hours)

Table 9 Specifications of Regional Spectral Model (RSM9603)

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, 257 x 217 grids
Vertical levels	36
Forecast time	51 hours from 00, 12UTC
Forecast phenomena	Meso-beta scale disturbances
Initial	3 (3.5)-hour cutoff for 00 (12) UTC analysis with 12-hour

	RSM forecast as a first guess
Lateral boundary	0-51 hour forecast by GSM runs
Orography	Envelope orography. Orography is smoothed and spectrally truncated.
Horizontal diffusion	Linear, second-order Laplacian.
Moist processes	Large scale condensation + Prognostic Arakawa-Schubert convection scheme + middle level convection + shallow convection
Radiation (shortwave)	Every hour
(longwave)	Every hour
Cloudiness	Diagnosed from relative humidity, maximum overlap
Gravity wave drag	Shortwave 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 for short-range forecast

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

Table 10   Facsimile products for short-range forecast

<table>
<tr><th>Contents</th><th>Level
(hPa)</th><th>Area
(see Fig.1)</th><th>Forecast
Hours</th><th>Initial
Time</th><th>Transmission
Method</th></tr>
<tr><td>geopotential height, relative vorticity</td><td>500</td><td rowspan="10">A'</td><td rowspan="3">0</td><td rowspan="20">00UTC
12UTC</td><td rowspan="14">radio facsimile
GTS</td></tr>
<tr><td>vertical p-velocity</td><td>700</td></tr>
<tr><td>temperture, wind arrow</td><td>850</td></tr>
<tr><td>geopotential height, relative vorticity</td><td>500</td><td rowspan="7">24, 36</td></tr>
<tr><td>wind arrow</td><td>surface</td></tr>
<tr><td>sea level pressure</td><td>-</td></tr>
<tr><td>rainfall amount</td><td>-</td></tr>
<tr><td>temperature</td><td>500</td></tr>
<tr><td>dew point temperature, vertical p-velocity</td><td>700</td></tr>
<tr><td>temperature,wind arrow</td><td>850</td></tr>
<tr><td>geopotential height, temperature, isotach</td><td>250</td><td rowspan="2">Q</td><td rowspan="2">24</td></tr>
<tr><td>geopotential height, temperature, isotach</td><td>500</td></tr>
<tr><td>sea level pressure</td><td>-</td><td rowspan="5">C</td><td rowspan="3">24, 48, 72</td></tr>
<tr><td>rainfall amount</td><td>-</td></tr>
<tr><td>geopotential height, relative vorticity</td><td>500</td><td>radio facsimile
GTS(48, 72)</td></tr>
<tr><td>temperature, wind arrow</td><td>850</td><td rowspan="2">24, 48
(12UTC)
72
(12UTC)</td><td rowspan="2">radio facsimile
GTS(48)</td></tr>
<tr><td>vertical p-velocity</td><td>700</td></tr>
<tr><td>stream line</td><td>200</td><td rowspan="2">H</td><td rowspan="2">24, 48</td><td rowspan="3">radio facsimile
GTS</td></tr>
<tr><td>stream line</td><td>850</td></tr>
<tr><td>significant weather chart</td><td>-</td><td>M, N</td><td>24</td></tr>
</table>

Table 11 Grid point value products (GRIB, GRID) for short-range forecast

Contents	Level (hPa)	Area	Forecast Hour	Initial Time	Transmission Method
sea level pressure	-	Global 2.5x2.5 degree	0	00UTC	GTS RSMC DSS (GRIB)
temperature, wind, T-TD	surface				
geopotential height, temperature, wind, T-TD	1000, 850, 700, 500, 400, 300				
geopotential height, temperature, wind	250, 200, 150, 100, 70, 50, 30, 20, 10				
sea level pressure, rainfall amount	-		0 (12UTC) 24, 48, 72	00UTC 12UTC	
temperature, wind	surface				
geopotential height, temperature, wind	850, 700, 500, 300, 250, 200, 100				
T-TD	850, 700				
sea level pressure	-	20N-90N 0-360E 5.0x5.0 degree	24, 48, 72	12UTC	GTS (GRID)
geopotential height	500				
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	RSMC DSS (GRIB)
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, 72		
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				
relative vorticity	500				
vorticity potential, stream function	850, 200				

7.3.1.4 Operational techniques for application of short-range NWP products

The Kalman-filtering technique and the Neural-network technique are applied to grid point values predicted by RSM to derive forecast elements. The Kalman-filtering technique is used to derive probability of precipitation, three-hourly precipitation amount, surface air temperature and surface wind. The Neural-network technique is introduced to derive three-hourly weather, minimum humidity, probability of heavy precipitation and probability of thunderstorm.

Significant weather charts and prognostic cross section charts for domestic aviation forecast are produced twice a day (00, 12UTC).

7.3.2 Very short-range forecasting system (0 – 3 hours)

7.3.2.1 Data assimilation, objective analysis and initialization

Using digitalized radar echo intensities observed at 20 land radar sites and precipitation observations by AMeDAS (Automated Meteorological Data Acquisition System, a network of more than 1300 raingauges over Japan), one-hour precipitation data over Japan are analyzed every hour with 5km resolution. The Z-R relationship is employed in conversion from radar echo intensity to precipitation rate. Calibrated radar echo intensities (precipitation) at the initial time of a very short-range forecast are used as a initial field for the forecast.

7.3.2.2 Model

Table 12 Specifications of very short-range forecasting model

Forecast process	Linear extrapolation
Physical process	Topographic enhancement and dissipation (by seeder-feeder model)
Motion vector	Motion of precipitation system is evaluated by the cross correlation method.
Time step	10 minutes
Grid form	Oblique conformal secant conical projection
Resolution	5km
Number of grids	250 x 660
Initial	One-hour precipitation by radar echo calibrated by precipitation observations
Forecast time	Up to three hours from each initial time (hourly = 24 times/day)

7.3.2.3 Numerical weather prediction 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 with 5 km resolution and (c) one-hour precipitation forecasts up to three hours. These products are utilized to issue warnings on heavy precipitation.

7.4 Specialized forecasts
7.4.1 Typhoon track forecasting system
7.4.1.1 Objective analysis and initialization

The analysis for numerical typhoon track prediction is made using the global analysis model with data cutoff time of 1.5 hours. After symmetric typhoon bogus data is implanted into the analysis field while asymmetric components are preserved, nonlinear normal mode initialization with full physics is applied to the first five vertical modes.

7.4.1.2 Typhoon track forecast model (TYM)

The model specifications are identical to those of RSM (Table 9) except for the followings:

Table 13 Specifications of Typhoon Track Forecast Model

Basic equation	Primitive equations
Independent variables	x-y coordinate on a Lambert (Mercator) projection plane for target typhoon 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 (Merctor) projection, 40km at typhoon center when center of target typhoon is north (south) of 20N.
Integration domain	Center of domain is set at median of expected track of target typhoon in the western North Pacific, 163x163 transform grid points
Vertical levels	15
Forecast time	78 hours from 06, 18UTC, maximum two runs for each initial time
Forecast phenomena	Typhoons
Initial	Global analysis using 6-hour forecast by GSM as a guess field with data cut-off time of 1.5 hours.
Lateral boundary	6-84 hour forecast by GSM initialized 6 hours earlier
Surface state	Observed SST fixed during time integration climatological evaporability, roughness length and albedo
Typhoon bogussing	Symmetric vortex generated using manually analyzed central pressure and 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 Global Analysis with its asymmetric components preserved.

7.4.1.3 Numerical weather prediction products for typhoon forecast

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

Table 14 Numerical weather prediction products for typhoon forecast

Contents	Level (hPa)	Area	Forecast Hours	Initial Time	Transmission Method
Center position of tropical cyclones by GSM	-	Eq. - 60N 100E-180E	06, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84	00UTC 12UTC	GTS
Center position of tropical cyclones by TYM	-	Eq. - 60N 100E-180E	06, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78	06UTC 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 takes a Lagrangian method, where many tracers are released in time and space according to information on pollutant emissions, displaced due to three-dimensional advection and horizontal and vertical diffusions, dropped due to dry and wet depositions and removed due to radioactive decay. Advection, diffusion and deposition are computed from 6-hourly model-level outputs of the high resolution global numerical weather prediction (NWP) model (GSM96/T213L30). Main products of the RSMC are trajectories, time integrated low-level concentrations and total deposition up to 72 hours.

7.4.3 Ocean wave forecasting system

JMA operates three numerical wave models: Global Wave Model (GWM), Japan area Wave Model (JWM) and Coastal Wave Model (CWM). GWM and JWM are classified into the third generation model. CWM is diagnostic model.

7.4.3.1 Numerical wave prediction models

Table 15 Specifications of ocean wave prediction models

Model name	Global Wave Model	Japan-area Wave Model
Model type	spectral model (third generation)	
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	2.5deg.×2.5deg. (144×57)	0.5deg.×0.5deg. (81×81)
Integration domain	global 70N-70S, 0E-180E-2.5W	sea adjacent to Japan 55N-15N, 115E-155E
Time step	1 hour	30 minutes
Forecast time	72 hours from 00UTC 192 hours from 12UTC	72 hours from 00,12UTC
Boundary condition	- - -	Global Wave Model
Initial condition	hindcast	
Wind field	Global Spectral Model (GSM) Bogus gradient winds (for typhoons in the western North Pacific)	
Model name	Coastal Wave Model	
Model type	hybrid model of significant wave and spectral model	

Spectral component	16 direction for swell
Grid form	equal latitude-longitude grid on plain
Grid size	0.1deg.×0.1deg. (400×400)
Integration domain	coastal sea of Japan 55N-15N, 115E-155E
Time step	3 hours (Time interval, diagnostic model)
Forecast time	72 hours from 00,12UTC
Boundary condition	Japan-area Wave Model
Initial condition	(diagnostic model)
Wind field	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 wave models are disseminated to domestic users. The GPVs of GWM have been available in the RSMC Tokyo Data Serving System of JMA since August 1998.

The model products will also be reported to the Marine Pollution Emergency Response Authority (MPEROA) within the Marine Pollution Emergency Response Support System (MPERSS).

7.4.4 Typhoon tide forecasting system

7.4.4.1 Model

JMA extended the coverage area of the storm surge model over Tohhoku and Hokuriku districts (northern parts of Japan) in July 1999 . The specifications of the model are given in Table 16.

Table 16 Specifications of Numerical Storm Surge Model

Coverage area	coastal area around Japan (128.0°- 141.5°E, 30.0°- 36.5°N) (135.5°- 143.0°E, 36.0°- 42.0°N)
Grid (type and resolution)	latitudal and longitudal grid of one minute (1.9km x 1.5km) resolution
Model type	Numerical dynamical model
Boundary conditions (open and coastal boundaries)	(1)Modified radiation condition at open boundaries; and (2)Zero normal flows at coastal boundaries.
Numerical procedure, time stepping	(1)Time integration: leap frog method; (2)Space differential: central difference method; and (3)Time step: 8 seconds.
Wind input	Grid winds as a sum of the two components: (1) gradient winds calculated by the Fujita's pressure model; and (2) moving velocity of the typhoon that is estimated from movements of the typhoon center that the forecaster determines every six hours.

7.4.4.2 Numerical typhoon tide prediction products

Time series of predicted storm surge and predicted tidal level, and predicted highest tide for 142 ports are disseminated to the meteorological offices responsible for issuing storm surge advisory and warning.

7.4.5 Ocean data assimilation system

The Ocean Data Assimilation System (ODAS) with the following specifications has continued being operated.

Table 17 Specifications of 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 (salinity, nudged to climatological value)
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	Ocean currents are driven by the surface wind fields derived by operational global 4DDA, temperature in the mixed layer is nudged to the daily global SST analysis
Observational data	Sea surface and sub surface temperature
Operational runs	Two kinds of run, final run and early run, with cut-off time of 30 days and 5 days, 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 DDB homepage of JMA. The data are also used as the oceanic initial conditions for the JMA coupled ocean-atmosphere model.

7.4.6 Numerical sea ice forecasting system

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 (mainly the southern part of the Sea of Okhotsk), twice a week in winter from December 1990 (see Table 18).

7.4.6.1 Numerical sea ice prediction model

Table 18 Specification of 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
Forecast time	168 hours from 00UTC twice a week
Initial	Concentration analysis derived from GMS and NOAA satellite imagery and thickness estimated by hindcast

7.4.6.2 Products on sea ice condition

Analysis of sea ice conditions in the Sea of Okhotsk, the northern Japan Sea, the western North Pacific, the western Bering Sea and the Bohai Sea are disseminated by the JMA radio facsimile broadcast (JMH) every Tuesday and Friday from December to May. The sea ice conditions for the coming seven days predicted by the numerical sea ice model are also broadcast by JMH every Wednesday and Saturday.

7.5 Extended-range forecasting system

7.5.1 Data assimilation, objective analysis and initialization

The system is the same as that of the medium-range forecasting except for the analysis of the upper stratosphere. A two dimensional function fitting method is introduced for temperature and height analyses above 10hPa. The result of the previous analysis is used as pseudo observations over data-sparse areas in order to avoid computational instability. Wind data are used for extratropical height analysis by assuming the geostrophic relationship.

7.5.2 Model

The model specifications are the same as those of the high resolution GSM (Table 6) except for the following ones:

Table 19 Specifications of GSM for one-month forecast

Integration domain	Global, surface to 1hPa
Horizontal resolution	T63 (about 1.875 deg Gaussian grid) 192x96
Vertical levels	30 (surface to 1hPa)
Forecast time	Five 30-day runs from perturbed 12UTC initial conditions are carried out twice per week.

7.5.3 Ensemble Forecasting Procedure

For the extended-range forecast, an ensemble forecast technique is employed. Perturbations to be added to the initial analysis are determined using the singular vectors of a hemispheric balance model whose resolution is T21, 2-levels. Initial perturbations are superpositions of the greatest 10 singular vectors. A set of forecasts which are an unperturbed forecast and four perturbed forecasts is made on two consecutive days. Therefore, 10 model runs are offered for an ensemble forecast.

7.5.4 Numerical weather prediction products

JMA started to produce grid point value products for one-month forecast in GRIB format in December 1999 based on the operational ensemble forecasting system.

Table 20 Grid point value products (GRIB) for extended –range forecast

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 on Wednesday and Thursday) Forecast time : 2-8, 9-15, 16-22, 23-29 days from the latter initial time
	Temperature, T-Td, wind(u,v)	850		
	Geopotential height	500,100		
	Wind (u, v)	200		
	Sea level pressure anomaly	-	Northern Hemi-sphere 2.5x2.5 degree	
	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 the latter initial time
	Temperature	850		
	Geopotential height	500		
Occurrence probability of above (or below) normal of geopotential height. (greater or less than +-0.5*sigma of natural variability)		500		

7.5.5 Operational technique for an application of extended-range forecast

Statistics of ensemble forecasts are applied. For example, ensemble mean fields and spread (standard deviation) of individual forecasts are calculated. 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.

7.6 Long-range forecasting system

JMA started the operation of a coupled ocean-atmospheric model in 1998 for the outlook of El Niño and La Niña. The oceanic part of the coupled model is identical to the model for ODAS. The atmospheric part of the model is a reduced resolution (T42) version of the previous operational global spectral model that was used until February 1996. In August 1999, JMA started to issue the monthly ENSO outlook based on the model results for end users. JMA also plans to make the model results available through the DDB of JMA in 2000.

Table 21 Specification of the JMA coupled model

Oceanic component	Identical to the model for ODAS	
Atmospheric component	Basic equation	Primitive equation
	Domain	Global
	Resolution	T42, 21 vertical levels
	Convection scheme	Kuo type
	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

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 1999 are presented in Tables 22.1 to 22.20. All the verification scores are only for the prediction from the 1200 UTC initials.

9. Plans for the future

(1) Assimilation of ATOVS/BUFR data in the global and regional analyses will begin in January 2000.
(2) A three-dimensional variational assimilation method will be introduced to the global analysis in March 2000 with introduction of direct assimilation of TOVS radiance data.
(3) GPS data from ground receivers in the Tokai area of Japan and high resolution T_{BB} data from GMS-5 will be assimilated for preparation of initial conditions of MSM from March 2000.
(4) The land surface scheme of GSM will be upgraded in March 2000. The new scheme will include a revised snow scheme, a multi-level model for soil temperature prediction, and frozen soil.
(5) A prognostic cloud water scheme will be implemented in RSM, MSM and TYM early in 2000.

10. References

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Table 22.1 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	18.4	17.7	15.4	15.5	13.9	13.1	12.4	12.7	13.8	15.4	17.4	15.6	15.1
72	49.0	48.1	41.1	43.6	36.8	33.5	30.5	30.4	36.3	40.9	46.5	40.4	39.7
120	82.0	83.9	71.2	77.3	66.1	57.8	50.6	50.1	64.4	68.5	78.2	71.8	68.4

Table 22.2 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	20.8	23.5	21.5	24.4	25.4	28.0	28.0	24.7	25.1	22.2	21.9	21.4	23.9
72	49.2	58.3	55.6	60.1	64.0	72.3	68.3	61.5	60.4	56.7	53.4	52.7	59.4
120	76.3	82.2	85.2	90.0	98.3	106.2	101.6	89.7	90.9	84.4	81.7	76.4	88.6

Table 22.3 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	22.7	20.9	18.8	17.7	15.4	14.2	13.9	14.4	14.9	16.8	17.6	18.8	17.2
72	54.2	55.2	48.3	48.8	35.9	29.7	27.1	27.8	33.7	39.2	46.0	51.6	41.4
120	87.6	77.8	83.2	93.7	65.1	52.1	42.9	50.1	60.4	74.6	72.6	83.7	70.3

Table 22.4 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	27.2	22.7	20.3	19.2	19.4	19.2	16.4	18.0	19.3	20.8	23.7	25.6	21.0
72	58.8	51.4	43.8	40.4	48.6	37.0	29.9	29.8	36.2	41.4	56.2	46.1	43.2
120	101.9	115.4	71.8	79.3	79.0	68.4	53.0	47.4	65.3	67.5	94.8	88.7	77.4

Table 22.5 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	19.0	17.8	18.8	17.2	18.1	17.9	16.1	15.1	16.2	17.5	19.9	15.8	17.4
72	36.8	38.4	34.2	35.1	35.7	30.0	26.0	23.2	28.6	39.3	39.3	31.4	33.1
120	55.6	57.9	50.1	57.7	62.6	43.3	35.5	32.8	40.9	55.7	56.6	50.4	49.9

Table 22.6 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	15.3	20.8	18.6	21.5	21.6	29.0	23.6	19.1	20.9	20.5	17.6	15.5	20.3
72	33.9	41.2	38.4	41.5	42.4	53.6	41.0	33.5	41.1	41.1	37.7	30.0	39.6
120	56.8	54.7	50.8	52.1	60.9	65.4	65.0	57.9	60.1	57.4	49.3	44.1	56.2

Table 22.7 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	6.8	6.8	6.5	6.4	5.9	5.9	6.0	6.1	6.2	6.4	6.5	6.5	6.3
72	13.4	13.3	12.4	12.7	12.0	11.9	11.5	11.7	12.7	12.7	13.0	12.3	12.5
120	19.3	19.8	17.8	19.0	17.9	16.7	15.8	16.3	18.4	18.4	19.4	18.1	18.1

Table 22.8 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	6.6	7.1	6.8	7.0	7.5	7.7	8.1	7.5	7.6	7.2	6.8	6.9	7.2
72	13.7	15.3	14.8	15.4	16.7	17.2	16.9	15.5	15.7	15.1	14.4	14.7	15.4
120	18.6	19.8	20.5	21.0	23.0	23.5	22.9	20.8	21.6	20.5	19.6	19.3	20.9

Table 22.9 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	9.1	8.8	7.9	8.0	7.8	7.9	7.0	7.3	7.5	7.4	7.4	8.1	7.8
72	17.8	17.6	14.8	15.7	13.6	13.2	11.3	12.4	14.4	14.3	15.0	15.9	14.6
120	23.9	24.0	20.6	25.0	20.3	18.4	15.5	17.3	21.0	21.7	20.4	23.4	20.9

Table 22.10 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	8.2	7.5	7.0	7.2	7.4	7.6	7.2	7.8	8.4	8.7	8.3	8.7	7.8
72	15.1	13.6	12.6	12.6	12.2	13.4	12.2	12.5	13.5	13.9	16.3	14.0	13.5
120	23.4	25.2	18.7	20.3	18.5	21.2	18.1	17.8	20.7	20.9	24.4	21.7	20.9

Table 22.11 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	8.0	8.3	9.3	9.0	8.2	8.4	8.3	7.2	7.4	7.9	7.7	7.0	8.1
72	11.8	12.0	13.0	13.3	14.0	12.9	12.4	10.2	11.8	12.3	12.2	10.2	12.2
120	15.5	15.8	15.7	18.0	19.9	16.5	15.6	14.0	14.3	16.2	15.7	13.1	15.9

Table 22.12 Root mean square of vector wind errors at 250 hPa against observations (m/s)

Australia / New Zealand

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
24	7.5	8.5	8.6	8.9	9.5	9.0	8.9	9.0	9.1	8.7	8.3	8.5	8.7
72	11.4	13.9	13.7	14.1	14.6	14.6	14.1	13.1	14.2	13.4	12.3	13.1	13.5
120	14.1	17.9	17.9	17.6	18.5	17.9	19.3	17.2	17.9	17.5	17.0	15.4	17.3

Table 22.13 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	7.2	7.8	7.1	6.9	6.7	6.8	7.1	7.1	6.7	6.8	6.4	5.9	6.9
72	10.1	10.9	9.8	10.0	9.6	9.7	10.0	9.6	9.1	9.4	9.3	9.3	9.7
120	11.2	12.2	10.8	11.3	10.8	11.0	11.0	10.5	10.2	10.5	10.5	11.2	10.9

Table 22.14 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	4.7	5.1	4.5	4.6	4.2	4.3	4.8	4.6	4.2	4.1	4.4	4.3	4.5
72	5.6	6.0	4.8	5.2	4.6	4.9	5.2	5.1	4.7	4.6	5.1	5.0	5.1
120	6.0	6.5	5.6	5.8	4.8	5.3	5.5	5.4	5.2	5.1	5.7	5.5	5.5