# WWW Technical Progress Report
# on the Global Data Processing System 1999
# Korea Meteorological Administration

## 1. Summary of highlights

The whole NWP system was upgraded when a new supercomputer SX5/16A was put into operation in June 1999. The new system includes the high resolution limited area model system HLAM (triple-nested mesh of 63/21/7km, 43 layers), and the global wave model GoWAM (mesh of 2 deg x 2 deg). The horizontal resolution of regional data assimilation and prediction system (RDAPS) has been enhanced by 30km with 33 layers in height.

New analysis tools and observations are incorporated in the global data assimilation and prediction system (GDAPS). PAOB data has been used for global analysis since January 1999. Direct TOVS radiance assimilation, namely 1D-VAR, is operated in GDAPS from May 1999. The overall performance of GDAPS has been significantly improved with the enhanced analysis. An ensemble prediction system with 8 members was put into operation for the projection up to one month.

## 2. Equipment in Use at the Centre

The supercomputer SX-5/16A (NEC), installed at Korea Meteorological Administration (KMA) headquarter building in June 1999, is dedicated for the numerical weather prediction and climate simulation.

- Main computer : SX-5/16A
  - Peak Performance : 128GFlops with 16 processors)
  - Memory : 128GB (shared)
  - Single CPU performance : 8GFlops
  - Mass storage system : 14Tbytes
- Other facilities : SX-4/2A
  - Peak Performance : 4 GFlops
  - Mass storage system: 14Tbytes

## 3. Data and products from GTS in use

The following types of observations are presently used in the analysis system. The numbers indicate typical amounts received during a 24 - hour period:

Table 1. Data used for daily operation

| | DATA TYPE | NUMBER OF DATA(#/DAY) |
|---|---|---|
| 1 | SYNOP/SHIP | 30000 |
| 2 | BUOY | 2500 |
| 3 | TEMP-A/PILOT-A | 1600 |
| 4 | TEMP-B | 900 |
| 5 | TEMP-C/PILOT-C | 1200 |
| 6 | TEMP-D | 800 |
| 7 | AIREP/AMDAR | 18000 |
| 8 | SATEM-A | 6800 |
| 10 | SATEM-C | 6800 |
| 11 | SATOB(SST) | 7000 |
| 12 | SATOB(WIND) | 9200 |
| 13 | TOVS | 60000 |
| 14 | PAOB | 500 |

## 4. Data Input System

Fully automated system

## 5. Quality Control System

Various real-time quality control checks are performed for each observation received from GTS. In particular:

- The vertical consistency checks are performed for TEMP and PILOT data using all parts of reports.
- Gross error and spatial consistency are checked in order to remove or correct erroneous observations.

## 6. Monitoring of Observing System

Surface observations are monitored on the national level.

## 7. Forecasting System

The GDAPS (T106L21) originally developed at Japan Meteorological Agency (JMA) has been running in operational basis. Along with the intermittent 4-dimensional data assimilation having 6 hour updating cycle, the GDAPS produces 240 hour projections for the large-scale atmospheric variables. It also produces 3-day forecasts for typhoon tracks, and time-dependent lateral boundary conditions for the regional models.

The RDAPS also runs twice a day for 48 hour forecasts, with 12 hour pre-assimilation with dynamic nudging. Four typhoon track forecasts are obtained from GFDK, BATS, RDAPS and GDAPS, when typhoon approaches Korean Peninsula.

In addition, there are two types of applied models; prognostic models for wave height on both global and regional domain, and statistical models for max/min temperature and probability of precipitation.

## 7.1. System Run Schedule

Two types of the global forecasts are produced at KMA. The GDAPS for 84-hour projection runs from the observed analysis at 0000 UTC and 1200 UTC respectively with 2.5 hour data cutoff, which is used for short-range weather forecasts and for the provision of lateral boundary condition for the regional models. The GDAPS for 10-day projection runs from observed analysis at 1200 UTC with 10 hour data cutoff, which is to utilize as much observation as available. The RDAPS runs twice a day (0000 and 1200 UTC) for 48-h forecasts. The two independent analysis system is used for the provision of initial condition for GDAPS and RDAPS respectively.

## 7.2. Medium-range Forecasting System

### 7.2.1 Data assimilation, objective analysis and initialization

The KMA global data assimilation system is a typical four-dimensional analysis/forecast system with 6-hr cycle. A 6-hr forecast from the previous run provides a first guess for the next analysis. If a typhoon exists in the Northwestern Pacific, a typhoon bogus profile is calculated and embedded in the first guess fields.

The best fits of analysis are made with the 2-D multivariate optimal interpolation analysis for heights and winds, and with the univariate analysis for relative humidity and surface observations.

- Vertical levels: 15 layers (surface, 1000, 850, 700, 500, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10hPa)

Thickness associated with moisture content is retrieved from TOVS radiance data by using the 1 D-variational technique.

- Layers: 1000-700, 700-500, 500-300, 300-100, 100-50, 50-30, 30-10 hPa

The moisture analysis is corrected with the input of cloud information at different vertical layers including cloud top temperature derived from GMS-5 images. The increments of the analysis against the first guess are computed, and the analysis increments are interpolated back to model levels.

A non-linear normal mode initialization with full physics is then performed in order to reduce the amplitude of high-frequency gravity waves. The iteration method is adopted to converge the nonlinear balanced solution, and it stops after three times of iteration. The high frequency component is filtered out for each spherical harmonic components in the five gravest vertical modes which exceeds the critical frequency.

### 7.2.2 Model configuration

*Dynamics*

| | |
|---|---|
| Basic equation | Primitive equations in sigma -p hybrid vertical coordinate |
| Numerics | The spectral representation of horizontal variables with triangular truncation of T106, corresponding to a (Gaussian) grid size of 1.125 or 110 km |
| Domain | Global, ranging from surface to 10 hPa |
| Levels | 21 vertical levels |
| Time integration | Eulerian semi-implicit scheme |

*Physics*

| | |
|---|---|
| Horizontal diffusion | Second order Laplacian, and Rayleigh friction |
| Moist processes | Kuo scheme, large-scale condensation, and shallow convection |
| Radiation | Longwave radiation calculated every three hours<br>Short wave radiation calculated every hour. |
| Gravity wave drag | Long waves (wavelength > 100km)<br>Short waves (wavelength 10 km) |
| PBL processes | Mellor-Yamada level-2 closure scheme and similarity theory for surface layer |
| Land surface | Simple biosphere model |
| Surface state | NOAAs weekly mean anomaly added to monthly changing climatological SST. Climatological values are used for the soil moisture, snow depth, roughness length and albedo. |

### 7.2.3. Numerical Weather Prediction Products

A series of standard analysis products are available in electronic or in chart form (*i.e.* surface analysis of temperature and MSLP, upper air geopotential, winds, temperature at 925, 850, 700, 500, 300, 100 hPa)

A series of standard forecast products are available in electronic or in chart form (*i. e*. MSLP and 12-hour accumulated precipitation, geopotential height, vorticity, temperature at 500 hPa, temperature and winds at 850 hPa, vertical velocity and dew-point depression at 700hPa). Other specialized products are available such as potential vorticity at isentropic surface (300, 315, 330, 350 K).

### 7.2.4. Operational Techniques for Application of NWP Products

The global forecasts of GDAPS is used for the first guess in the analyses of regional model and typhoon models.

### 7.2.5 Extended-range forecasting system

An ensemble prediction system (EPS), based on simple time lagged approach with T106 global spectral model, has been semi-operational since November 1999. An ensemble of 8 members are obtained from the sequence of 6 hourly analysis. The EPS runs for 30 day projection once a day at 12 UTC.

## 7.3. Short-range Forecasting System

After more than 12 months of pre-operational test, the new RDAPS (Regional Data Assimilation and Prediction System) became operational in June 1999. The RDAPS is adopted from the Penn State/NCAR Mesoscale Model version 5 (RDAPS). The old version (MM4) was switched off on 1 October 1999. New high resolution limited area model system (HRLM) also has been running in semi-operational mode.

### 7.3.1 Data assimilation, objective analysis and initialization

*Objective Analysis*

- First guess : GDAPS analysis
- Observations : Upper-air sounding (TEMP A, B, C, D) with 12 hour interval, and surface observations (Synop) with 3 hour interval
- Method : Banana scheme mixed with the Cressman and Ellipse scheme
- Analysis variable : Temperature, u wind, v wind, geopotential height, and relative humidity
- Vertical levels : 24 layers (sfc, 1000, 975, 950, 925, 900, 875, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 250, 200, 150, 100, 70, 50)

*Assimilation*

- Method : Four-dimensional data assimilation with nudging

*Dynamics*

- Basic Equations: Primitive equations (u, v, T, q) based on the hydrostatic frame
- Numerics : Flux form in the Arakawa-B grid

- Time integration : Hydrostatic split-explicit scheme
- Lateral boundary condition : Relaxation method

*Physics*
- Horizontal Diffusion : Fourth order diffusion in the interior domain
- Explicit moisture scheme with mixed phase of water vapor, cloud, rain, ice, snow
- Deep convection : Kain-Fritch
- Planatary Boundary condition : Nonlocal Boundary layer
- 5-layer soil model for ground temperature
- Cloud radiation

### 7.3.3 High Resolution Limited Area Model (HLAM)

*Configurations*
- Triple nested Domain (63km: 71 x 88, 21km: 88 x 121 and 7km: 106 x 106)
- dynamics : primitive equations (u, v, t, pp, q, w) based on the non-hydrostatic frame
- Vertical resolution : 43 layers with 50hPa model top
- Lateral boundary condition : Time and inflow and outflow dependent relaxation
- Boundary update frequency
  63km : 12 hours by GDAPS forecasts
  21km : 3 hours by 63km forecasts
  7km : 1 hours by 21km forecasts
- Time integration : 24 hours for 21km and 7km
- Moisture physics : Same as RDAPS, but only explicit moisture scheme is used for 7km domain

## 7.4 Application for NWP products.

A statistical model with Kalman filter (KF) produces the maximum and minimum temperature forecasts for 61 stations up to 48 hours.

## 7.5 Ocean wave Prediction system

Two numerical wave models are currently on operation: Global Wave Model (GoWAM) and Regional Wave model (ReWAM). Both models are adopted from the 3rd generation WAM model cycle 4 (developed by WAMDI group).

Table 2. Specification of ocean wave prediction models

| Model name | GoWAM | ReWAM |
|---|---|---|
| Model type | 3rd generation spectral model | 3rd generation spectral model |
| Spectral component | 25 frequencies and 12 direction | 25 frequencies and 12 direction |
| Grid form | equal latitude-longitude grid on spherical coordinate | |
| Grid size | 2 deg x 2 deg (180 x 71) | 0.25 deg x 0.25 deg (141 x 121) |
| Domain | 70°S-70°N | 20°N-50°N, 115°E-150°E |
| Time step | 720 seconds | 360 seconds |
| Forecast time | 240 hours from 12UTC | 48 hours from 00, 12UTC |
| Initial condition | 24(12) hour forecast spectra from previous run | |
| Wind fields | from GDAPS | from RDAPS |

## 7.6 Typhoon Track Prediction System

The GDAPS and RDAPS produce their own typhoon track forecasts. Typhoon track forecasts are provided from four different models, GFDK, BATS, GDAPS, and RDAPS. The GFDL hurricane model in Korea (GFDK) is the KMA version of hurricane model developed by NOAA's Geophysical Fluid Dynamics Laboratory.

It runs at 0600 UTC and 1800 UTC for the prediction of typhoon track and intensity forecasts since 1997. The GFDK has a triple-nested, movable mesh with an innermost grid spacing of 1/6 , and with the sophisticated vortex initialization procedure.

The Barotropic Adaptive grid Typhoon System (BATS) is based on the continuous dynamic grid adaptation technique with the innermost grid spacing of 0.3 . This model has an advantage to represent the typhoon vortex in more detail. It has been performed four times a day since 1997.

### 7.6.1. Geophysical Fluid Dynamic in Korea (GFDK) Typhoon Model

*Input Data*

-Provided by objective analysis procedure of GDAPS

*Vortex Bogusing and Initialization*

-Vortex specification by filtering procedure to remove the original vortex from the GDAPS analysis field

-Axisymmetric component of the specified vortex generated by time integration of the axisymmetric typhoon model.

-Asymmetric components generated by time integration of a simplified barotropic vorticity equation with beta effect

-Specified vortex (symmetry + asymmetry) + environmental field.

-Consistency of moisture field with the wind field by diagnosis of the mass field

*Dynamics*

-Basic equation : primitive equations on latitude-longitude coordinate

-Vertical resolution : 18 level sigma -coordinate

-Grid system : triply-nested movable mesh (1, 1/3, 1/6°)

-Domain : 75° in the meridional and longitudinal directions

*Physics*

-Surface flux : Monin-Obukhov framework, NOAA's weekly mean SST used

-Boundary layer : Mellor and Yamada level-two turbulence closure scheme

-Cumulus convection : moist convective adjustment

-Radiation : short wave and long wave scheme with diurnal cycle and cloud variation considered

*Products*

-Location (lat./lon.), central pressure, and maximum tangential winds every 6 hours up to 72 hours in advance.

### 7.6.2 Barotropic Adaptive Typhoon System (BATS)

*Input Data*

-Provided by objective analysis procedure of GDAPS

*Vortex Bogusing and Initialization*

-Specified vortex generated by empirical formulas

-Global objective analysis field except typhoon area + symmetric typhoon vortex

*Dynamics*

-Basic equation : shallow water equations on the latitude-longitude coordinate

-Horizontal representation : the regular grid size 0.6° and the smallest grid size 0.3° on the continuous dynamic grid adaptation

-Domain : 101 grid points both in zonal and meridional directions over the domain of 60°×60°

*Products*

-Location (lat./lon.) every 6 hours up to 60 hours in advance.

## 8. Verification

The verification statistics for GDAPS is operationally performed against analysis and radiosonde observations. Results of the monthly verification for the year of 1999 are presented in Table 3. The verification for RDAPS, wave model and KF model are shown in Table 4-6.

## 9. Plan for 2000

### 9.1. GDAPS

- Upgrade of resolution of GDAPS from T106/L21 to T213/L30
- Implementation of 3-D optimal interpolation analysis system on sigma coordinate
- Incorporation of Emanuel cumulus parameterization scheme
- Improvement of ensemble generation procedure using breeding method
- Implementation of trajectory model for dust storm (yellow sand) prediction

### 9.2 RDAPS

- Improvement of deep convection and shallow convection scheme
- Incorporation of PILOT and AIREP into regional analysis system
- Installation of 4DVAR for research
- Incorporation of typhoon bogusing scheme in the regional model.

Table 3.1 Root mean square errors of geopotential height at 500 hPa against analysis (m)

**Northern Hemisphere**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 27.4 | 26.7 | 23.7 | 24.1 | 22.0 | 20.4 | 20.4 | 18.8 | 20.1 | 20.6 | 22.4 | 22.0 | 22.4 |
| 72 | 65.0 | 64.6 | 55.9 | 55.9 | 52.3 | 44.1 | 44.0 | 38.5 | 47.1 | 49.7 | 54.9 | 53.2 | 52.1 |
| 120 | 93.1 | 101.3 | 85.2 | 88.8 | 81.3 | 67.0 | 62.1 | 56.3 | 69.8 | 77.3 | 92.1 | 88.6 | 80.3 |

Table 3.2 Root mean square errors of geopotential height at 500 hPa against analysis (m)

**Southern Hemisphere**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 38.6 | 30.1 | 26.6 | 32.7 | 31.6 | 32.9 | 32.5 | 34.7 | 35.4 | 33.8 | 31.1 | 26.3 | 32.2 |
| 72 | 68.0 | 67.8 | 64.8 | 81.2 | 77.3 | 81.5 | 80.8 | 84.9 | 87.8 | 78.6 | 76.6 | 62.7 | 76.0 |
| 120 | 81.4 | 85.8 | 85.9 | 102.6 | 101.6 | 108.5 | 107.5 | 111.4 | 113.2 | 102.2 | 101.6 | 83.0 | 98.7 |

Table 3.3 Root mean square of vector wind errors at 250 hPa against analysis (m/s)

**Northern Hemisphere**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 10.2 | 10.2 | 9.6 | 9.5 | 8.6 | 8.1 | 8.0 | 7.8 | 8.2 | 8.5 | 8.9 | 9.0 | 8.9 |
| 72 | 16.9 | 16.5 | 15.5 | 15.6 | 15.3 | 14.2 | 14.3 | 13.5 | 15.0 | 15.3 | 15.8 | 15.5 | 15.3 |
| 120 | 21.2 | 22.2 | 20.8 | 21.4 | 21.1 | 19.0 | 18.4 | 17.5 | 19.8 | 20.8 | 22.2 | 21.2 | 20.5 |

Table 3.4 Root mean square of vector wind errors at 250 hPa against analysis (m/s)

**Southern Hemisphere**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 12.1 | 11.7 | 11.7 | 13.1 | 12.5 | 12.8 | 13.3 | 13.5 | 13.4 | 13.5 | 12.8 | 11.7 | 12.7 |
| 72 | 17.1 | 17.3 | 17.6 | 19.6 | 19.0 | 19.5 | 20.1 | 20.0 | 20.0 | 19.1 | 18.9 | 17.8 | 18.8 |
| 120 | 18.9 | 19.9 | 20.8 | 22.4 | 22.6 | 22.5 | 23.2 | 23.2 | 22.7 | 21.9 | 22.0 | 20.7 | 21.7 |

Table 3.5 Root mean square of vector wind errors at 250 hPa against analysis (m/s)

**Tropic**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 8.2 | 8.1 | 7.6 | 7.8 | 7.7 | 8.1 | 8.1 | 8.1 | 7.9 | 7.6 | 7.8 | 7.9 | 7.9 |
| 72 | 10.8 | 11.2 | 10.0 | 10.7 | 10.3 | 10.8 | 10.8 | 10.8 | 10.3 | 10.2 | 10.6 | 10.9 | 10.6 |
| 120 | 12.1 | 12.6 | 11.1 | 11.9 | 11.6 | 11.7 | 11.7 | 11.6 | 11.1 | 11.4 | 12.1 | 12.3 | 11.8 |

Table 3.6 Root mean square errors of geopotential height at 850 hPa against observations (m)

**Northern Hemisphere**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 25.1 | 23.6 | 21.1 | 19.4 | 19.5 | 21.5 | 21.3 | 19.5 | 18.9 | 19.3 | 19.2 | 19.5 | 20.7 |
| 72 | 47.2 | 47.2 | 42.5 | 43.1 | 36.9 | 36.4 | 34.3 | 31.1 | 34.1 | 35.4 | 38.8 | 39.5 | 38.9 |
| 120 | 62.9 | 65.6 | 58.9 | 60.1 | 51.4 | 47.2 | 43.7 | 40.6 | 46.9 | 51.8 | 61.6 | 62.5 | 54.4 |

Table 3.7 Root mean square errors of geopotential height at 850 hPa against observations (m)

**Asia**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 21.0 | 19.1 | 18.0 | 18.4 | 21.4 | 26.7 | 27.2 | 24.6 | 21.1 | 18.9 | 18.0 | 16.8 | 20.9 |
| 72 | 31.7 | 32.2 | 34.8 | 35.0 | 32.7 | 35.7 | 35.9 | 31.7 | 30.5 | 28.6 | 30.1 | 29.3 | 32.4 |
| 120 | 40.4 | 45.0 | 49.4 | 45.3 | 43.9 | 42.4 | 43.0 | 37.5 | 37.9 | 35.8 | 40.3 | 41.2 | 41.8 |

Table 3.8 Root mean square errors of geopotential height at 850 hPa against observations (m)

**Tropic**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 12.2 | 12.3 | 12.4 | 13.5 | 14.0 | 13.6 | 13.9 | 15.3 | 13.0 | 13.6 | 12.4 | 12.8 | 13.2 |
| 72 | 16.2 | 15.6 | 16.5 | 17.9 | 19.4 | 19.3 | 18.7 | 18.9 | 16.2 | 16.3 | 16.9 | 15.5 | 17.3 |
| 120 | 18.9 | 18.9 | 17.1 | 19.8 | 19.0 | 22.2 | 22.6 | 22.7 | 19.4 | 19.0 | 17.6 | 16.6 | 19.5 |

Table 3.9 Root mean square errors of geopotential height at 500 hPa against observations (m)

**Northern Hemisphere**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 37.7 | 34.9 | 30.9 | 30.1 | 27.1 | 27.1 | 25.9 | 23.8 | 24.8 | 25.7 | 26.2 | 26.4 | 28.4 |
| 72 | 73.1 | 73.3 | 63.0 | 61.3 | 53.8 | 46.2 | 42.6 | 39.4 | 44.5 | 50.6 | 57.0 | 56.8 | 55.1 |
| 120 | 99.1 | 105.3 | 87.5 | 86.9 | 76.9 | 66.0 | 57.1 | 53.0 | 64.1 | 74.6 | 93.4 | 91.1 | 79.6 |

Table 3.10 Root mean square errors of geopotential height at 500 hPa against observations (m)

**Asia**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 32.3 | 30.1 | 25.3 | 24.0 | 26.2 | 27.8 | 28.3 | 27.3 | 24.4 | 25.2 | 24.2 | 22.2 | 26.4 |
| 72 | 50.9 | 53.8 | 50.1 | 45.9 | 41.4 | 35.6 | 34.4 | 32.2 | 32.9 | 38.9 | 43.3 | 42.5 | 41.8 |
| 120 | 67.4 | 75.9 | 67.3 | 71.8 | 57.3 | 45.5 | 42.2 | 38.0 | 41.9 | 51.0 | 58.0 | 58.3 | 56.2 |

Table 3.11 Root mean square errors of geopotential height at 500 hPa against observations (m)

**Tropic**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 19.4 | 18.7 | 17.8 | 20.8 | 22.2 | 20.9 | 19.1 | 20.1 | 20.0 | 18.7 | 17.4 | 21.5 | 19.7 |
| 72 | 25.3 | 23.2 | 22.7 | 23.2 | 26.3 | 23.5 | 22.3 | 24.0 | 22.7 | 21.3 | 20.1 | 23.4 | 23.2 |
| 120 | 30.7 | 25.9 | 22.0 | 26.7 | 22.5 | 28.5 | 25.8 | 27.5 | 24.1 | 23.9 | 23.5 | 24.4 | 25.5 |

Table 3.12 Root mean square of vector wind errors at 250 hPa against observations (m/s)

**Northern Hemisphere**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 11.5 | 11.0 | 10.5 | 10.7 | 9.6 | 9.3 | 9.1 | 8.5 | 9.2 | 9.3 | 9.3 | 9.8 | 9.8 |
| 72 | 17.5 | 18.1 | 16.6 | 16.3 | 16.3 | 14.6 | 14.7 | 13.3 | 15.1 | 15.7 | 16.1 | 16.1 | 15.9 |
| 120 | 22.2 | 23.5 | 21.5 | 21.8 | 20.9 | 19.0 | 18.4 | 16.7 | 19.8 | 20.5 | 21.8 | 21.9 | 20.7 |

Table 3.13 Root mean square of vector wind errors at 250 hPa against observations (m/s)

**Asia**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 10.2 | 10.3 | 10.9 | 10.3 | 10.0 | 9.8 | 9.5 | 8.2 | 8.4 | 8.7 | 9.0 | 9.3 | 9.5 |
| 72 | 14.0 | 14.4 | 14.9 | 14.8 | 15.8 | 13.5 | 13.9 | 12.3 | 13.0 | 13.1 | 14.0 | 13.5 | 13.9 |
| 120 | 18.2 | 17.1 | 17.5 | 20.4 | 19.6 | 16.8 | 16.8 | 14.8 | 16.5 | 16.1 | 16.5 | 16.4 | 17.2 |

Table 3.14 Root mean square of vector wind errors at 250 hPa against observations (m/s)

**Tropic**

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 8.6 | 10.2 | 8.8 | 10.8 | 8.3 | 8.4 | 8.1 | 7.9 | 7.8 | 7.6 | 9.1 | 8.9 | 8.7 |
| 72 | 10.3 | 11.9 | 10.9 | 12.2 | 9.7 | 10.2 | 9.9 | 9.4 | 9.6 | 9.2 | 11.3 | 11.3 | 10.5 |
| 120 | 11.1 | 13.1 | 11.9 | 13.2 | 11.3 | 10.9 | 10.4 | 9.9 | 10.5 | 10.7 | 12.2 | 11.5 | 11.4 |

Table 4. Root mean square errors of RDAPS and HLAM during August to December 1999

| 500GPH (RMSE, m) | | | 850 TEMP (RMSE, K) | | |
|---|---|---|---|---|---|
| 24hr RDAPS | 48hr RDAPS | 24hr HLAM (21km) | 24hr RDAPS | 48hr RDAPS | 24hr HLAM (21km) |
| 21.1 | 35.8 | 19.8 | 1.75 | 2.52 | 2.06 |

Table 5.1 Bias & RMSE of ReWAM (3 buoy, 24H FCST)

| Month(1999) | July | August | September | October | November | December | Average |
|---|---|---|---|---|---|---|---|
| Bias(m) | -0.06 | 0.06 | 0.13 | -0.29 | -0.27 | -0.19 | -0.10 |
| RMSE(m) | 0.63 | 0.72 | 0.68 | 0.67 | 0.58 | 0.69 | 0.66 |

Table 5.2 Bias & RMSE of GoWAM (18 buoy, 24H FCST)

| Month(1999) | July | August | September | October | November | December | Average |
|---|---|---|---|---|---|---|---|
| Bias(m) | n/a | -0.16 | -1.06 | -1.14 | -1.22 | -1.45 | -1.00 |
| RMSE(m) | n/a | 1.00 | 1.43 | 1.58 | 1.61 | 1.85 | 1.49 |

Table 6. The RMSE (BIAS) of KF during 1st June - 31st Dec 1999.

| Predictor / Lead time | Maximum temperature (K) | Minimum temperature (K) |
|---|---|---|
| 18 | 2.5 (0.0) | 1.9 (-0.1) |
| 30 | 2.8 (-0.1) | 2.1 (-0.2) |
| 42 | 3.2 (0.0) | 2.2 (-0.2) |