Progress Report on the Global Data Processing and Forecasting System in 2007

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1. Summary of highlights

In 2007, the main changes to the global and regional versions of the numerical prediction suites were the followings:

15 th May The 10km resolution regional model based on WRF is in parallel run for the operational usage. The model system is equipped with its own data assimilation cycle using the 3dVAR of WRF-Var system.

31st May The polar wind data from MODIS sensor of TERRA/AQUA satellite was assimilated for the global model and showed the positive impact not only in the polar region, but also in the whole global domain.

30 th Jul. A post-processing using a decaying average bias estimation method (Bo Cui, 2000) was introduced to the operational global ensemble prediction system.

30th Aug. Rayleigh friction parameterization on the model layers above 100 hPa is implemented in the Global Data Assimilation and Prediction System (GDAPS).

2. Equipment in use at the KMA

The supercomputer Cray X1E-3/192-L is dedicated for the operation of the short, medium, and long-range numerical weather prediction including climate simulation.

💻 Supercomputer: Cray X1E-3/192-L

-Peak Performance：18.5 T Flops

-Memory ：4.096T bytes

- Single CPU performance: 18.08G flops

-Direct Attached Storage ：62T bytes

-SAN Disk : 20Tbytes

3. Data and products from GTS in use

Synoptic observations and various a-synoptic observations, including satellite and wind profiler data, are used daily in the GDAPS. Table 1 presents the types and numbers of the observation that are available from the GTS and FTP. The pre-processing procedures such as data acquisition, quality control, and decoding, are fully automated. The percentage of data used in data assimilation means the rate of final data used in assimilation to total input data.

Table 1. The types and numbers of observations received through GTS, and the percentage of data used in global data assimilation for 24 hours in 2007.

	Data type	Number of data/day	% used in assimilation
1	SYNOP/ SHIP	47,423	45
2	BUOY+QSCAT	71,966	7
3	TEMP/ PILOT	5,454	33
4	AIREP/ AMDAR/ACARS	227,303	16
5	SATEM	35,142	39
6	SATOB	116,757	15
7	ATOVS	37,162	4
8	AWS	14,760	59
9	PAOB	400	100
10	Wind profiler	265	87

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 and FTP. Special quality control is applied to the satellite data assimilation.

6. Monitoring of the observing system

Most observations are monitored in terms of availability and quality. The innovation and analysis increment of the horizontal distribution are monitored at every analysis time and the histogram and time series of them are also monitored monthly. The satellite data monitoring system shows domain averaged time series of innovation with and without bias correction, too.

7. Forecasting System

7.1 System run schedule and forecast ranges

The GDAPS for 10-day projection runs at 00 UTC and 12 UTC with 2.5-hour data cutoff. The 84-hour projection is used for short-range weather forecasts, weekly forecast and for the provision of lateral boundary condition for the two high-resolution (10km and 5km with 33 layers) regional models. The RDAPS runs twice a day (00 and 12 UTC) for 66-hour forecasts. Four typhoon track forecasts are obtained from DBAR, RDAPS, GDAPS (T426/L40), and EPS when typhoon appears in Western Pacific. In addition, there are two types of applied models; Wave models for wave height and direction on both global and regional domain, and two statistical models of Perfect Prog Method (PPM) and Kalman Filter (KF) method for probability of precipitation and max/min temperature, respectively.

KMA produces three types of long-range weather forecasts: 1-month, 3-month (seasonal), and 6-month forecast. The 1-month forecasts are issued three times a month and include temperature, precipitation, and air pressure pattern for the next 30 days. The 3-month forecast which is produced on a monthly basis include the trends of temperature, precipitation including special seasonal events such as Asian dust, Typhoon and Changma for the next 3 months. The 6-month forecast is issued two times a year (May and November). The system run schedule and products are listed in Table 2.

Table 2. Long range forecasting system run schedule and products.

	1-month forecast	3-month forecast	6-month forecast
Issue Date	· 3rd , 13th, and 23rd day of each month	· 23rd day of each month	· 23rd day of May and Nov.

Forecast type	Three type categories : above, below and near normal The anomalies are based on model's climatologies obtained from a 28 year Database (1979 to 2006).		
Contents	· 10-day mean temperature and precipitation · 30-day mean temperature and precipitation	· 1-month mean temperature and precipitation · 3-month mean temperature and precipitation *[1]*Asian dust outlook* *[2]*Typhoon outlook* *[3]*Changma outlook*	· 1-month mean temperature and precipitation (Jun. to Nov./Dec. to May)
Forecast area	Temperature : whole Korea Precipitation : whole Korea	Temperature : whole Korea Precipitation : whole Korea	Temperature : whole Korea Precipitation : whole Korea

*[1]*Asian dust outlook* is issued in late February including frequency and density of Asian dust expected to affect Korea for the upcoming spring.

*[2] *Typhoon outlook* is issued in late May and Aug. regarding the number of Typhoon expected to affect Korea for the upcoming summer and fall.

*[3] *Changma outlook* is issued in late May regarding the duration and intensity of Changma .

7.2 Medium-range forecasting system

7.2.1 Data assimilation, objective analysis and initialization

The major characteristics of the operation global 3dVar are almost same as those of 2006.

- The analysis resolution : T426L40
- The inner loop resolution : T106L40
- The analysis domain top : 0.4 hPa
- The climatologic constraint of zonal averaged vorticity is applied in the cost function formulation.
- The 1 hour interval FGAT is applied to reduce the error caused by the time difference between observation and background.
- The moisture profile which is selected based on the cloud information derived from MTSAT-1R imaginary data and the profile is assimilated in 3dVar.
- The direct assimilation of ATOVS radiance data (level 1D type) is embedded in the 3dVar system.

- Sea surface wind data retrieved from the QuikSCAT satellite is assimilated using the PBL operator that is based on the MRF PBL method.
- A Non-linear Normal Mode Initialization (NNMI) with full physics is performed to suppress the amplitude of high-frequency gravity waves.

There were several main improvements and changes about the data assimilation and initialization in 2007.

The unified 3dVar which could be used for both global and region model had been developed by expanding NCAR WRF-3dVar and was introduced to KWRF 10km operational cycle. Introduction of data assimilation by the unified 3dVar improved the performance of KWRF. In case of the global unified 3dVar, several modifications such as version upgrade and tunning were applied and its performance is being evaluated. The unified 3dVar shares the observation operators and other possible transform operators for global and regional application to save the developing effort when new observation data is assimilated into both global and regional model at the same time. The vertical decouple of background error is executed by applying the empirical orthogonal function and the physical decouple is accomplished by introducing the unbalanced velocity potential, unbalance temperature, unbalanced surface pressure to the stream function. For horizontal decoupling of the background error, regional application uses recursive filter while the global application uses wave decoupling.

The MODIS polar wind data were assimilated in the global 3dVar. The forecast performance was verified and showed the positive scores in the Northern Hemisphere.

Typhoon bogusing process was applied to KWRF and the impact was tested. The typhoon bogus module was brought from KMA Global Data Assimilation and Prediction System (GDAPS). GDAPS typhoon bogus uses the Fujita (1952)'s formula to correct the sea level pressure with the typhoon observation data in the typhoon area. The distance error of typhoon center location was decreased and the typhoon intensity forecast was improved a little bit with typhoon bogus.

The QuikSCAT Data Products (Level 2.0), which have been processed and distributed by the NASA Jet Propulsion Laboratory (JPL), were assimilated in KWRF and its impact was evaluated. The data assimilation cycle with thinned QuikSCAT data provided more improved typhoon track forecast than the one without QuikSCAT.

7.2.2 Model

Table 3. Specifications of global forecast model for 10-day forecasts

Dynamics

Initialization	Nonlinear normal mode initialization
Basic equation	Primitive equations in sigma-pressure hybrid vertical coordinate
Numerics	Spectral representation of horizontal variables with triangular truncation of T426, corresponding to a Gaussian grid size of 0.28125 degrees or 30km
Domain	Global
Levels	40 sigma-pressure levels ranging from surface to 0.4 hPa
Time integration	Eulerian semi-implicit scheme

Physics	
Horizontal diffusion	Second order Laplacian
Vertical damping	Rayleigh friction
Moist processes	Kuo scheme, large-scale condensation, and shallow convection scheme
Radiation	Long wave radiation calculated every three hours Short wave radiation calculated every hour
Gravity wave drag	GWD due to orography for long waves (wavelength>100km) and short waves (wavelength ≈10km) (Iwasaki et al., 1989)
PBL processes	Non-local diffusion scheme and similarity theory for surface layer (Holtslag and Boville, 1993)
Land surface	Simple biosphere (SiB) model (Sellers et al., 1986)
Surface state	NCEP daily SST 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

NWP products are automatically generated from NWP systems of KMA. Various model outputs, including the potential vorticity fields on isentropic surfaces, are available in both graphic and imagery form. Those products are also disseminated to the end users through intranet of KMA or Internet (http://www.kma.go.kr/eng/wis/wis04_nwp01.jsp).

A statistical model with KF produces 3-hourly temperature forecasts including the maximum and minimum temperature for 61 domestic stations up to 48 ~ 84 hours in advance. 10 days maximum and minimum temperatures are also provided by the KF method. The Probability of Precipitation (PoP) for 12 hour forecast of four sets up to 2 days is derived with PPM

7.2.4 Operational techniques for application of NWP products

The 6-hour forecast of GDAPS is used for the first guess in the analyses of regional model and the steering flow of typhoon model. The surface winds predicted by GDAPS and RDAPS are used as an input for the global and regional wave model. The wind field predicted by GDAPS is also used as an input for the trajectory model of yellow sand.

7.2.5 Ensemble prediction system

The global ensemble prediction system (EPS), based on breeding method with global model (T106L21) was made operational in 2001. As the horizontal and vertical resolution of the operational global forecast model was enhanced from T213L30 to T426L40 in December 2005, high-resolution global ensemble prediction system (T213L40) was constructed and was made operational in June 2006.

An ensemble of 16 members is obtained using a rotated bred vector method, i.e. apply factor rotation after 12-hours of initial growing of perturbation and then foster perturbation for another 12-hours. Global EPS runs twice a day up to 10 days at 00 and 12 UTC to support weekly forecast. A post-processing using a decaying average bias estimation method (Bo Cui, 2000) has been introduced to the operation since 30th July 2007.

KMA participates in the WMO THORPEX TIGGE program and provides global ensemble products to the TIGGE archive centers since December 2006 (in operational mode since December 2007), and the standard verification scores of EPS will be regularly exchanged through the EPS verification web-site hosted by JMA. The main structure of the global EPS is summarized in the table below.

Table 4. Specifications of global ensemble prediction system for medium-range forecasts

Model	
Basic equation	Primitive equations in sigma-pressure hybrid vertical coordinate
Numerics	Spectral representation of horizontal variables with triangular truncation of T213, corresponding to a Gaussian grid size of 0.5625 degrees or 55km
Domain	Global
Levels	40 vertical levels ranging from surface to 0.4 hPa
Time integration	Eulerian semi-implicit scheme

Operation	
Data Assimilation (for control analysis)	3dVar with 6hr window (wave truncation of analysis field for global forecast system T426L40)
Forecast length	10 days
Runs per day	2 (00UTC, 12UTC)
Initial perturbation strategy	Rotated Bred Vector method (Factor rotation)
Initial perturbation area	Northern Hemisphere (20N~90N)
Number of perturbed ensemble members	16 members or 32 members (using time lag) excluding control

7.3 Short-range forecasting system

KMA runs the Regional Data Assimilation and Prediction System (RDAPS) twice a day. The RDAPS was constructed based on the NCAR/PSU meso-scale model (so called MM5) and has been operated since 1997. At the beginning of its operation the RDAPS had single domain of 30km grids and 33 vertical layers. After going through updates for about 7 years, the RDAPS has been frozen since 2004 with current features of the RDAPS. Currently, the RDAPS features 2 nested domains (10km, 5km), non-hydrostatic dynamics, etc. Following table illustrates key features of the RDAPS.

The 30km domain covers East Asia region and forecasts for 66 hours. Because it also covers much of North Pacific Ocean, the RDAPS 30km is utilized in Typhoon Track and intensity forecasts in the Typhoon season when a typhoon nears Korean peninsula. The 10km domain covers Korean peninsula and its encompassing areas. It has its own analysis cycle using 3dVAR technique. The 5km domain covers South Korea. The 10km and 5km domains are for prediction of high-impact weather and forecast for 24 hours. As of May 15, 2007, KMA began to operate WRF-based regional modeling system in parallel with the RDAPS.

Key model parameters of RDAPS

Assimilation	Four-dimensional Data Assimilation with nudging
First guess	GDAPS previous 6-hour prognosis
Observations	SYNOP, TEMP, PILOT, ACARS, SATEM, and SATOB with 12 hour interval Radar data for 10km grid spacing with 3-hour interval AWS for 10km and 5km grid spacing with 3-hour interval
Method	FDDA(Grid Nudging)/3dVar (for nested 10 km domain)

Variables	Wind, geopotential height, and relative humidity
Vertical levels	33 model sigma levels

Dynamics	
Grids	Triply nested domain (30km for 171 x 191, 10km for 160 x 178 and 5km for 141 x 141 gird points)
Numerics	Primitive equations based on the non- hydrostatic frame
Vertical resolution	33 layers with the model top of 50 hPa
Boundary condition	Time and inflow/ outflow dependent relaxation
Boundary update Frequency	30km : 12-hour interval by GDAPS forecasts 10km : 3- hour interval by 30km forecasts 5km : 3- hour interval by 10km forecasts
Time integration	66 hours for 30km mesh, and 24 hours for both 10km and 5km meshes

Physics	
Horizontal Diffusion	Fourth order diffusion
Precipitation physics	Explicit moisture scheme
Deep convection	New Kain-Fritch only for 30 km and 10km grid domains
Planetary layer	Non-local boundary layer
Surface physics	5-layer soil model for ground temperature
Radiation	Simple cloud scheme

7.4 Specialized numerical predictions

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 3 shows the description of wave models.

Table 3. The operational wave models at KMA

	GoWAM	ReWAM
Source Code	WAM model cycle 4	WAM model cycle 4
Coordinate	Spherical coordinate	Spherical coordinate

Spatial Domain	70°S-70°N	20°N-50°N, 115°E-150°E
Spatial Resolution (Dim.)	1.25° (288 by 113)	0.25° (141 by 121)
Spectral Resolution	25 frequency 24 direction	25 frequency 24 direction
Integration Time Step	720 second	360 second
Lead Time	240 hour (00/12UTC)	66 hour (00/12UTC)
Elapsed Time	12 minute	2.5 minute
Initial Condition	Previous 12 hour forecast	Previous 12 hour forecast
Sea Surface Wind Input	GDAPS 12-hour interval	RDAPS 3-hour interval

3-dimensional analysis system

The 3-dimensional analysis system, which provides the quick analysis field for the forecasters within 10 minutes at every hour, has been maintained since 2006 without any considerable change. It assimilates all available in-suit data and remote sensing data such as satellite, radar, and wind profiler. All available data used in the 3-dimensional analysis system are shown on Table 3. The analysis scheme is based on the LAPS and the background field is produced by the 10km MM5 cycling system.

Table 1 Data used in the 3-dimensional analysis system

Type	Variable	Data Format	Numbers
Wind profiler	Wind	Burf	5 sites in Korea
MTSAT	IR image VIS image	Binary	MTSAT
Radar	Reflectivity	UF	8 sites in Korea
AWS	Temp. Wind Humidity	ASCI	614 sites in Korea
Lighting	Frequency	ASCI	-
AMEDAS	Temp. Wind Humidity	GTS	222 sites
METAR	Temp. Cloudiness	ASCI	30 ~ 41sites

Typhoon track prediction system

Typhoon track forecasts are provided from four different models, the Double Fourier Series BARotropic typhoon prediction model (DBAR), GDAPS (T426/L40), RDAPS (30km grid spacing), and EPS. KMA replaced the Barotropic Adaptive grid Typhoon System (BATS) with DBAR in 2004. DBAR is specially designed to run with high resolution grids within little computational load. It runs four times a day by 6-hour interval.

Double Fourier Series Barotropic Typhoon Prediction Model (DBAR)

Input Data	GDAPS analysis
Vortex Bogusing And Initialization	Geophysical Fluid Dynamics Laboratory (GFDL) bogussing
Dynamics	Spectral method using Double Fourier Series
Basic equation	Shallow water equations on the latitude-longitude coordinate
Horizontal representation	Grid distance of 0.356˚
Domain	1024 x 512
Products	Central position (lat./lon.) every 6 hours up to 72 hours in advance.

7.5 Extended range forecasts (10 days to 30 days)

For the extended range forecast system, KMA has been operating global climate model with a predicted sea surface temperature (2-Tier system). To predict the global sea surface temperature as a boundary condition for the 2-tier system, the global ocean forecasting system has been developed as a combined system of dynamical and statistical models. The global long-range forecasting system, using global climate models, is also being developed, and the SMIP2/HFP-type climatology for each model is produced to remove model bias and improve predictability. Detailed information about the model climatology is given on Table 4. The official products of extended range forecasts are 3-categorical forecasts of temperature and precipitation over the Korea peninsula (see Table 2).

Table 4. Description of SMIP2/HFP Experiment

SMIP2/HFP Experiment		
Experiment design		28-year integration(1979-2006) 4-month integration for each case
Ensemble member		20 ensemble members
Initial member		00, 06, 12 & 18Z of 5 days for each case
Initial condition	Atmosphere	NCEP/NCAR reanalysis(U,V,T,q,Ps)
	Land surface	Climatology
Boundary condition	SST and sea ice	Predicted SST using dynamical and statistical prediction model
	Etc.	Same as SMIP2

7.5.1 Global Climate Model

The operational extended forecasts system is based on the global spectral model, GDAPS (Global Data Assimilation and Prediction System) with horizontal resolution of T106 and 21 vertical levels of hybrid sigma-pressure coordinate. For the Ensemble forecasts, we utilize 20 ensemble members by lagged average method with about 15-day forecast lead-time (see Table 4). Detailed model description is summarized on Table 5.

Table 5. Detailed description for global climate model

		GDAPS(Operational model)
Major Physics	Cloud Convection	Kuo (1974)
	Land Surface & PBL	SiB; Yamada-Meller (1982)
	Radiation	Lacis & Hansen (1974) for SW, Roger & Walshaw (1966); Glodman & Kyle (1968); Houghton (1977) for LW
	Large scale condensation	Kanamitsu et al.(1883)
Dynamics		Three-dimensional global spectral model with hydrostatic primitive equations Hybrid sigma-pressure coordinate Semi-implicit method
Resolution		T106L21
Ensemble size		20 members
Sea Surface Temperature		Predicted SST anomaly
Land Surface Initial Condition		Observed Climatology
Model Climatology		SMIP2/HFP simulation (1979 to 2006)
Forecast range		1-month forecast 3-month forecast 6-month forecast

7.5.2 Global sea surface temperature forecasting system

The El Nino prediction system (Kang and Kug, 2000) is based on the intermediate ocean and statistical atmosphere model. The ocean model differs from the Cane and Zebiak (1987) model in the parameterization of subsurface temperature and the basic state. The statistical atmosphere model is developed based on the singular value decomposition (SVD) of wind stress and SST.

To reduce the uncertainty of initial field on the ENSO model, the breeding technique is applied. In the case of an ideal experiment, it works for better predictability, yet for our El Nino prediction model, its effect is not so clear because it has weak non-lineality. Using coupled GCM shows some possibilities of contributing for the predictability improvement for the complicated future ENSO prediction.

In order to improve the western Pacific SST prediction, KMA introduced the heat flux formula and vertical mixing parameterization to the ocean model. The initialization of the model is done by combining observed SST and wind stress. Wind stress is calculated by using the 925hPa wind of NCEP/NCAR reanalysis data. The method with calculated wind stress for initialization has a better forecast skill than that with FSU wind stress in recent predictions. (Kug et al., 2001). In addition, the present prediction is attended with random noise which is considered weather noise, and generates many sets of prediction. Our approach for random noise is similar to that of Kirtman and Schopf (1998).

Then, to correct the systemic error in the prediction model, the statistical model is also applied. The used Coupled Pattern Projection Model (CPPM, Lee and Kang 2003) is a kind of point-wise regression model, and the main idea of the model is to generate realization of predictions from projections of covariance patterns between the large-scale predictor field and the regional predictions from the large-scale predictor field at the target year. By applying this model to the dynamic model results and compositing the results from both the dynamical and statistical models, the predictability over the tropical Pacific is improved.

To predict the whole global SST, a statistical global SST prediction system is being developed by combining Coupled Pattern Projection Model(CPPM), Lagged Linear Regression Method(LLRM), El Nino prediction model, and the persistence method. In the tropical Pacific, predictions produced by El Nino prediction model are used, and in other regions the best results between CPPM, LLRM, and persistence are used. The LLRM is one of the point-wise statistical model based on the lag relationship between the global SST and ENSO index and the optimal lag is selected by the hindcast process in the model. This is developed to determine predict the Indian SST prediction. Using this global ocean forecasting system, the boundary conditions for the global climate model are also produced.

7.6 Long range forecasts (30 days up to two years)

The long range forecast system is the same as the extended range forecast system described in section 7.5 except the forecast range. The official products of extended range forecasts are 3-categorical forecasts of temperature and precipitation over the Korean peninsula for the upcoming 3 months (see Table 2).

For the long range forecasts, KMA also utilizes the multi model ensemble (MME) technique which has been developed and operated by APEC Climate Center (APCC). The APCC collects the historical and real-time forecast data of 15 different models from 8 countries and constructs the automatic MME input data producing system. The APCC has developed various MME techniques for deterministic and probabilistic seasonal predictions. For deterministic forecast, three kinds of linear MME techniques are used, namely biased and unbiased simple composite, weighted combination of multi-models based on SVD, and MME with statistical corrections. For probabilistic forecast, three ranges are determined by ranking method based on the percentage of ensemble members from all the participating models in those three categories. Moreover, regional MME system version MME I-IV has been developed for Asian Monsoon region.

8. Verification of prognostic products

The summary of annual verification statistics for GDAPS is calculated by comparing the model forecast to the analysis and radiosonde observation (see Table 6.1 and 6.2). Table 7.1 to 7.5 present detailed monthly verification statistics for GDAPS, by comparing the model forecast to the analysis.

Table 6.1. RMSE verification of KMA's global model (GDAPS) against the analysis in 2007.

Statistic	Area.	T+24 hr	T+72 hr	T+120 hr
Z500	Northern Hemisphere	15.78	38.72	64.60
Z500	Southern Hemisphere	24.43	59.04	90.42
V250	Northern Hemisphere	6.13	11.65	16.75
V250	Southern Hemisphere	6.93	14.15	19.82
V250	Tropics	6.13	11.65	16.75
V850	Tropics	3.07	4.81	5.51

Table 6.2. RMSE verification of KMA's global model (GDAPS) against observation in 2007.

Statistic	Area.	T+24 hr	T+72 hr	T+120 hr
Z500(geopotential height)	North America	18.24	43.45	68.79
Z500	Europe	16.63	35.34	67.68
Z500	Asia	17.46	31.66	49.63
Z500	Australia/ New Zealand	19.21	40.21	59.63
V250(wind)	North America	8.31	15.16	20.77
V250	Europe	7.31	12.43	19.43
V250	Asia	7.38	11.81	16.63
V250	Australia/ New Zealand	8.78	14.08	18.64
V250	Tropics	7.70	9.86	11.63
V850	Tropics	4.90	5.76	6.13

Table 7.1. Monthly mean RMSE of 500 hPa geopotential height forecast (m) in Northern Hemisphere (GDAPS verification against analysis).

FCST	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
24H	19.79	18.65	18.57	16.05	15.36	14.56	12.97	12.46	13.19	14.79	15.64	17.38	15.78
72H	49.06	47.19	46.02	38.36	38.01	35.47	29.78	29.45	30.93	37.38	39.45	43.49	38.72
120H	75.83	80.10	77.81	67.04	60.98	57.81	46.66	50.36	53.28	65.24	69.93	70.18	64.60

Table 7.2. Monthly mean RMSE of 500 hPa geopotential height forecast (m) in Southern Hemisphere (GDAPS verification against analysis).

FCST	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
24H	22.98	21.99	23.74	24.41	24.59	25.96	25.86	27.33	25.96	27.25	22.68	20.45	24.43
72H	55.33	53.11	56.75	63.07	58.85	62.76	64.63	66.35	59.48	64.06	56.41	47.68	59.04
120H	79.95	81.04	89.84	96.74	92.15	101.44	99.31	98.66	93.27	93.43	86.91	72.28	90.42

Table 7.3. Monthly mean RMSE of 250 hPa wind forecast (m/s) in Northern Hemisphere (GDAPS verification against analysis).

FCST	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
24H	6.37	6.50	6.41	6.22	6.08	6.19	5.83	5.95	5.95	5.94	5.74	6.34	6.13

FCST	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
72H	12.18	12.29	12.04	11.59	11.62	11.90	10.82	11.03	11.09	11.66	11.19	12.35	11.65
120H	17.13	18.13	17.35	16.78	16.73	16.95	14.68	15.49	15.84	17.27	16.86	17.80	16.75

Table 7.4. Monthly mean RMSE of 250 hPa wind forecast (m/s) in Southern Hemisphere (GDAPS verification against analysis).

FCST	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
24H	7.09	6.76	6.77	6.86	6.92	7.27	7.33	7.24	6.90	7.01	6.49	6.52	6.93
72H	14.36	13.69	13.83	14.95	14.34	14.88	14.66	14.62	13.82	13.91	13.65	13.04	14.15
120H	19.44	18.97	19.61	20.98	20.80	21.32	20.31	20.54	19.38	19.19	19.35	17.92	19.82

Table 7.5. Monthly mean RMSE of 250 hPa wind forecast (m/s) in Tropic (GDAPS verification against analysis).

FCST	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
24H	6.37	6.50	6.41	6.22	6.08	6.19	5.83	5.95	5.95	5.94	5.74	6.34	6.13
72H	12.18	12.29	12.04	11.59	11.62	11.90	10.82	11.03	11.09	11.66	11.19	12.35	11.65
120H	17.13	18.13	17.35	16.78	16.73	16.95	14.68	15.49	15.84	17.27	16.86	17.80	16.75

9. Plans for the future

9.1 Development of the GDPFS

KMA sets up the plan to install the observation pre-processing and 4dVar system from UK met-office for global and regional application. The research version is now installed in the CRAY X1E supercomputer and will be in operation from 2010 in the KMA's next supercomputer. In order to make the 4dVar operation in KMA, the background and observation error will be tuned for the regional application. Surface conditions such as land use, snow cover, and sea surface temperature will be also adjusted for the East Asian environment.

Before the operation in 2010, KMA will focus on the simple but effective improvement or tunning of the current data assimilation system and the utilization of local data such as the dense Automatic Weather System (AWS) and Wind Profiler network over the Korean peninsula. The existing unified 3dVar and KWRF will be upgraded by applying new version of NCAR WRF and WRFVAR and the number of vertical level will be increased from 31 up to 40. FGAT (First Guess At Appropriate Time) will be also applied to the KWRF unified 3dVar. The interactive monitoring system will be developed to diagnose the latency time, quality, and sensitivity of the observation. The meteorological products from COMS (Communication, Oceanography and Meteorology Satellite), which is to be launched in 2009, will be assimilated. Observation Data Base (ODB) developed by ECWMF will be installed to facilitate the application of the observation data to the UM. From 2010 when the next supercomputer is available, R&D project will be launched to develop a hybrid ensemble-4dVar type data assimilation system to incorporate more a-synoptic observations from remote sensing measurements, i.e, ensemble based background error covariance used in 4dVar. In addition, development of the operator and tuning of hyper-spectral satellite data assimilation will be performed.

KMA also plans to adopt the Unified Modeling system of UK Met. Office within a few years. Therefore, by 2010 or so we are expecting a regional modeling system other than the RDAPS at KMA.

To enhance predictability in the long-range forecast, Climate Prediction Division (CPD) is planning to implement new global climate model (United Model System (UMS)-based AOGCM), which is developed by Met Office. Climate Research Laboratory (CRL) in the National Institute for Meteorological Research will be working on installing the model in Cray-X1E in the year 2008. After installing and evaluating the model, UMS based AOGCM will be used as an extended and long-range forecast system. The operational climate prediction system for 1-month to annual forecast will be constructed by 2011 with the new model. This system is based on the UMS-based AOGCM; however, additional evaluation of the newly developing AOGCM version (developed by CRL, AGCM coupled with different OGCM) will be also performed to investigate the possibility of the use for an operational climate prediction system.

In order to make operational regional long-range forecasts available in 2009, statistical and dynamical downscaling methods have been developed in cooperation with APEC Climate Center (APCC) and CRL in the National Institute for Meteorological Research. Based on basic analysis of the regional climate and topography over the Korean peninsula, the regional climate sectors are divided into 3-5 areas. In 2008, 3-5 areas will be tested by using the statistical downscaling outputs and the regional long-range forecasts will be ready for the operation in 2009.

From 2009, extended to long-range forecast (including regional) will be issued by probabilistic method. The probabilistic technique will be developed in cooperation with Climate Research Lab. in 2008.

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