JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2016

Korea Meteorological Administration
Republic of Korea

1. Summary of highlights

- **Major changes in the global model in 2016**
  - The resolution of global model was improved from 25km to 17 km
  - Six additional satellite data as like ATMS, GroundGNSS, CrIS, MVIRI, SEVIRI and GOES became available for global model
  - Global model became more stabilized with improving model dynamics ('New Dynamics' to 'ENDGAME')

- **Major changes in the global ensemble model in 2016**
  - Ensemble model resolution was changed from 40km to 32 km
  - Number of ensemble members were increased from 24 to 49
  - Model dynamics was changed to ENDGAME which was used in the global deterministic model.

- **Major changes in the local model in 2016**
  - The domain of local model which has 1.5km resolution was extended to cover the eastern part of China and Japan.
  - Model dynamics was also changed to ENDGAME

- **Major changes in the local ensemble model in 2016**
  - Only model dynamics was changed to ENDGAME, maintaining the resolution and number of members.

- **Operation of a new Seasonal Prediction System (GloSea5) (see 4.8)**
  - New seasonal forecasting system of KMA was implemented operationally in Jan. 2014. This system, named the global seasonal forecasting system version5 (GloSea5), is a joint seasonal forecast system between KMA and UK Met-Office. Both centers share their model results each other.

Table 1.1 Main operational atmospheric and application models in KMA as of Dec. 2016

Purpose	Model (domain)		Resolution	Forecast range
Long-range forecast	GloSea5 (Global)		N216L85	Seasonal (7 months)
Medium-range forecast	UM(Global)	Deterministic	N768 L70 (17km)	288 hours
		Ensemble	N400 L70 M49 (32km)	288 hours
Short-range regional forecast	UM (East Asia)		12km L70	87 hours
Short-range local forecast	UM (Korea)	Deterministic	1.5km L70	36 hours
		Ensemble	3.0kmL70 M13	72 hours
Very short-range forecast	KLAPS (Korea)		5km L40	12 hours
Ocean wave	WaveWatch3 (Global)		55km (1/2°)	288 hours
	WaveWatch3 (Regional)		8km (1/12°)	87 hours
	WaveWatch3 (Coastal)		1km (1/120°)	72 hours
Tide/Storm surge	POM (Regional)		8km (1/12°)	87 hours
Asian dust and Haze	ADAM2-Haze (Regional)		25km L49	72 hours
Tropical cyclone	DBAR (Regional)		35km	72 hours

2. Equipment in use

The supercomputer Cray XC40 is dedicated to the operation of short-, medium-range numerical weather prediction as well as long-range forecast and climate simulations.

- **Name of the model:** Cray XC40
- **CPUs and performance**
  - Number of nodes: 5,808
  - Number of cores: 139,392
  - Core performance: Intel 2.6GHz 12-cores processor
  - Peak performance: 5.8 P Flops (2.9 [operational purpose] + 2.9 [back-up & research purpose])
- **Operating system:** SUSE Linux 11
- **Memory**
  - Memory per node : 128 GB
  - Memory total : 743 TB
- **Disk storage**
  - Lustre file system: 15 PB
  - Backup file system (VTL, TAPE LTO-4 media): 6.5PB

3. Data and Products from GTS in use

The number of observation data used for the operational NWP models has been gradually increased. The ATMS, CrIS, and several Clear Sky Radiances from Geostationary Satellite were newly introduced for the operational global NWP suite. The impact of various satellite radiance data was successfully verified and so it was also added at the end of June, 2016. The ratios of assimilated observation against received observation are presented in Table 3.1.

Table 3.1 Types and extent of observations received through GTS/FTP and assimilated in KMA's operational global data assimilation system (2016.11.30. early run)

	In-situ observation			Indirect assimilation		Direct assimilation							TOTAL
	Surface	SONDE	Aircraft	Scatwind	AMV	CSR	ATOVS	AIRS	IASI	GPS-RO	NPP	GrGPS	
Received	337970	8233	534676	1854510	4122270	2095591	3895916	172800	373710	171265	275632	280914	14123487
Assimilated	150328	2486	82742	62594	180509	52957	173776	24333	70984	143633	56501	1289	1002132
Ratio(%)	44.5	30.2	15.5	3.4	4.4	2.5	4.5	14.1	19.0	83.9	20.5	0.5	7.1

- Surface : SYNOP, Ship, Buoy, METAR
- SONDE : TEMP, PILOT, Wind Profiler, Drop-sonde
- Aircraft : AMDAR, AIREP
- Scatwind : Metop-A/B ASCAT
- AMV : Himawari-8, GOES-E/W, METEOSAT-7, METEOSAT-10, COMS, MODIS, AVHRR
- CSR : COMS, SEVIRI(METEOSAT-10), MVIRI(METEOSAT-7), GOES-E/W
- GPSRO : COSMIC-1~6, Metop-B GRAS
- NPP : ATMS, CrIS
- Ground based GNSS : E-GVAP(Europe)

4. Forecasting System

4.1 System run schedule and forecast ranges

Short- and medium-range forecast

- Global Data Assimilation and Prediction System (GDAPS; UM N768L70) is used for 12-day forecast (00/12UTC) and 87-hour forecast (06/18UTC) with 2 hours 25 minutes observation data

cut-off. GDAPS is used for short-range weather forecasts and weekly forecast as well as for the provision of lateral boundary conditions of the two short-range regional NWP systems and a local very short-range forecasting system

- Regional Data Assimilation and Prediction System (RDAPS; UM 12kmL70) is operated 4 times daily (00/06/12/18UTC) for 87-hour forecast.
- Local Data Assimilation and Prediction System (LDAPS; UM 1.5kmL70) runs 4 times daily (00/06/12/18UTC) to produce 36-hour forecast with 3-hourly 3DVAR cycle, and KLAPS (5km L40) and VDAPS(1.5kmL70), a local very short-range forecasting systems run every hour analysing weather conditions around the Korean peninsula.
- For typhoons originating in the western North Pacific, three track forecasts are obtained from RDAPS (UM 12kmL70), GDAPS (UM N768L70), and global EPS (UM N400L70M49).

Long-range forecast

- Seasonal forecast is run every day including forecast and hindcast (re-forecast). 9 members of hindcast and 4 members of forecast are implemented for a day. And once a week (every Tuesday), ensemble products for the long range forecast are generated. (see section 4.8 for details.)

4.2 Medium range forecasting system (4-10 days)

4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation

The table 4.1 shows the major characteristics of KMA's operational global data assimilation in 2016.

Table 4.1 Configuration of operational data assimilation for the global NWP suite in 2016

Analysis resolution	N320L70 (horizontal resolution : ~40km)
Inner loop resolution	None
Analysis domain top	80km
Analysis method	Hybrid Ensemble 4DVAR (from 49 members of Ensemble Prediction System)
Observations used	SYNOP, Ship, Buoy, METAR, ASCAT, Sonde, Pilot, Windprofiler Airep, ACARS(Amdar), AMV-Meteosat7, AMV-Meteosat10, AMV-GOES, AMV-MTSAT, AMV-MODIS, AMV-AVHRR, AMV-COMS, ATOVS(global, EARS, AP-RARS, SA-RARS), IASI, AIRS, GPSRO, CSR-COMS, CSR-Meteosat7, CSR-Seviri, CSR-GOES-W/E, ATMS, CrIS
Data Base	ODB(Observation Data Base) from ECMWF
Pre-process	OPS(Observation Processing System): Quality control and reformation of observation data for data assimilation

KMA's global data assimilation system has been upgraded every year since KMA started operation of the Unified Model system (2010) introduced from the UK Met Office. The followings show major improvements in global data assimilation system in 2016.

- Hybrid data assimilation system based on 4D-VAR have been upgraded to use 49 members from the ensemble forecast system in June 2016.
- SSMIS, MT-SAPHIR, FY3, AMSR2 data will be used in next operational system.

Table 4.2 Configuration of surface analysis in operation for the global NWP suite

Land Surface Model(LSM)	JULES
Analysis method	Extended Kalman Filter (EKF) for soil moisture contents

KMA's global data assimilation system has adopted JULES as LSM and Extended Kalman Filter (EKF) for surface analysis of soil moisture contents.

- EKF uses both of background error of model and observed error of soil moisture contents and gives optimized soil moisture and soil temperature in analysis.

- JULES model was applied to surface analysis process. JULES is being used to get H-matrix by ensemble which consists of 4 layered soil moisture and soil temperature and skin temperature.

4.2.1.2 Research performed in this field

- **Variational bias correction of satellite data**

The variational bias correction (VarBC) method is an effective method to separate the observational bias from the systematic errors in the model background. We have a plan to introduce the VarBC in the operational data assimilation and prediction system at Korea Meteorological Administration (KMA) in October 2017.

The verified results obtained with the VarBC applied to satellite radiance data (AIRS, ATMS, ATOVS, IASI, MVIRI, SEVIRI) in the operational hybrid 4dVar-ensemble data assimilation system of the KMA showed overall positive impact on forecast performance over the northern hemisphere.

4.2.2 Model

4.2.2.1 In operation

Global model resolution was improved from 25km (N520L70) to 17km (N768L70) and model stability was also improved by changing model dynamics from 'New Dynamics' to 'ENDGAME'. Forecast verification score was generally enhanced with use of 17km model(Fig 4.1). Table 4.3 shows main characteristics of 17km global model.

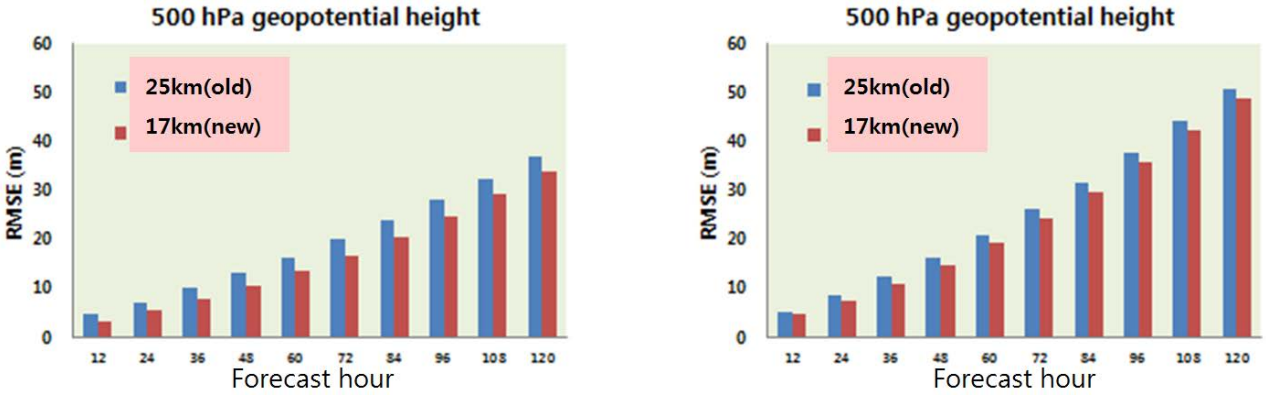

Fig. 4.1 RMSE of 500 hPa geopotential height for the 17 km 'ENDGAME' global model compared to the 25 km operational model with 'New Dynamics', for (left) July 2015, and (right) Jan 2016.

Table 4.3 Key model parameters of global model (GDAPS [UM N768L70]) for medium-range forecast

Dynamics	
Basic equation	Non-hydrostatic finite difference model with full equation.
Prognostic variables	Horizontal and vertical wind components, virtual dry potential temperature, Exner pressure, dry density, mass mixing ratio of water vapour and prognostic cloud fields
Integration domain	Global
Horizontal grid	Spherical latitude-longitude gird with Arakawa C-grid staggering of variables. Resolution : 0.156 ° latitude and 0.234° longitude (~17km)
Dynamic core	ENDGame(Even Newer Dynamics for General Atmospheric Modelling of the Environment)
Vertical grid	70 levels (surface~80km). Hybrid-η vertical coordinate with Charney-Phillips grid staggering of variables.
Time integration	Two time-level semi-Lagrangian advection with a pressure correction semi-implicit time stepping method using a Helmholtz solver to include non-hydrostatic terms. Model time step = 450 sec.
Forecast range	288 hours.

Physics	
Cloud	Prognostic cloud fraction and condensate cloud scheme (PC2, Wilson et al, 2008).
Precipitation	Wilson and Ballard (1999) single-moment bulk microphysics scheme, coupled with the PC2 prognostic cloud scheme(3D scheme). Abel and Shipway (2007) rain fall speeds
Convection	Modified mass-flux convection scheme with convective available potential energy (CAPE) closure, momentum transports and convective anvils based on Gregory and Rowntree (1990).
Radiation	Edwards-Slingo (1996) radiation scheme with non-spherical ice spectral files. 6 absorption bands in the SW, and 9 bands in the LW.
Boundary Layer	First order non-local boundary layer scheme of based on Lock et al. (2000)
Horizontal/Vertical diffusion	None
Gravity wave drag	Orographic scheme including a flow blocking scheme which represents the effects of sub-grid orography. Non-orographic spectral scheme which represents the effect of gravity waves in the stratosphere and mesosphere.
Land surface	Joint UK Land Environment Simulator (JULES) 4 layer soil model using van Genuchten (1980) soil hydrology

4.2.2.2 Research performed in this field

- **Dynamics test**
  - Numerical noise and stability tests associated with orography in high altitude area

- **Physics test**
  - Refinement of surface / soil ancillaries related to land mask
  - Sensitivity test of convection scheme: mass flux convection → revised updraught mass flux convection

4.2.3 Operationally available Numerical Weather Prediction Products

Operational global products routinely available on model's original horizontal resolution in GRIB-II format are as follow

- Pressure level data : 3-hourly up to +84 hours, 6 hourly for +90~+288 hours
  - 3-dimensional wind components : 26 levels (1000~0.4 hPa)
  - Geopotential height : 26 levels (1000~0.4 hPa)
  - Temperature : 26 levels (1000~0.4 hPa)
  - Relative humidity w.r.t. ice/water : 19 levels (1000~10 hPa)
  - Wet bulb temperature : 850/700/500 hPa
- Single level or soil layer data
  - 107 single level or soil layer variables are also operationally available as 3-hourly data, which are instant values or accumulated/time-averaged/maximum/minimum values.
- Graphical products
  - Weather charts of basic products in the domain of Korea, East Asia and Northern hemisphere
  - Guidance charts for significant weather phenomena such as stability parameters, visibility etc.
  - Guidance at stations within Korea such as the Meteogram and the Skew T-Log P diagram
  - Thumbnail views for the accumulated precipitation
- International NWP cooperation activities
  - Under SWFDA-SeA project, NWP output such as weather charts, Skew T-Log P and EPSgram has been supported for 75 cities in 4 South East Asian countries.
  - Under cooperation of KMA and East African countries, above product has been also supported for 71 cities in 10 countries of Africa.
  - Under RAII project, weather charts, meteogram and EPSgram have been supported for 317 cities in 22 Asian countries.

4.2.4 Operational techniques for application of NWP products *(MOS, PPM, KF, Expert Systems, etc.)*

4.2.4.1 In operation

The application techniques for both the medium- and short-range forecasting systems are described in section 4.3.4.1.

4.2.4.2 Research performed in this field

The research is described in section 4.3.4.2.

4.2.5 Ensemble Prediction System (EPS)

4.2.5.1 In operation

KMA medium range global ensemble forecast system which is based on the UK Met Office Global and Regional Ensemble Prediction System (MOGREPS) has been running operationally since March 2011. It uses ETKF(Ensemble Transform Kalman Filter) and has model physics perturbation. It also provides the ensemble error mode for global hybrid-4dVAR which has been operated since 2013. Every year model version and physics process were updated. In 2016, ensemble model resolution was improved from 40km to 32km and model dynamics was ungraded from 'New Dynamics' to 'ENDGAME' giving more stabilized model forecast results.
It runs 4 times a day and produces 12 days forecast at 00 and 12 UTC to support weekly forecasts and runs up to 9 hours at 06 and 18UTC.
KMA participates in the WMO THORPEX TIGGE program and provides operational global ensemble products to the TIGGE archive centres. The standard verification scores of EPS are regularly exchanged through the EPS verification website hosted by JMA.

Table 4.4 Configuration of the global ensemble prediction system for medium-range as of 2016.

	Ensemble Prediction System for Global (EPSG)
Period	Operational launch : March. 2011 / Recent upgrade : June 2016
Horizontal resolution	N400 (~32km)
Vertical resolution (model top)	70 levels (80km)
Forecast model	Deterministic Global Data Assimilation and Prediction System(GDAPS)
Model version and physics	UM vn7.9 / PS28(GA3.1)
Data assimilation for control analysis	The hybrid Ensemble-4DVAR using Global deterministic forecast for background field
Forecast length	12 days at 00, 12 UTC / 9 hours at 06, 18 UTC
Number of runs per day (time)	4 (00, 06, 12, 18UTC)
Initial perturbation method (area)	ETKF(Ensemble Transform Kalman Filter)
Initial SST perturbation	ETKF
Ensemble size	49 members (1 control + 48 perturbed members) per run
Perturbation of physics	Random Parameter(RP), Stochastic Kinetic Energy Backscattering(SKEB2)
Ancillary	CAP7.7(aerosol, ozone, soil, vegtation, etc)

4.2.5.2 Research performed in this field

Soil moisture perturbation will be added and its impact will be evaluated in 2017

4.2.5.3 Operationally available EPS Products

The following products from global EPS are available:

- Mean and Spread for MSLP, geopotential height at 500hPa, temperature and equivalent potential temperature at 850hPa and precipitable water
- Spread and Spaghetti for geopotential height at 500hPa
- Stamp map for geopotential height at 500hPa, MSLP and precipitation
- Probability of precipitation for several thresholds and probability of snow and visibility
- Ensemble meteogram of temperature, total cloud amount, precipitation, wind speed at 10m, and surface air temperature for around 104 major cities
- Ensemble meteogram of surface air temperature (bias corrected) for 104 cities
- Extreme Forecast Index (EFI) for daily rainfall, wind gust, maximum and minimum temperature
- Probability of Tropical Cyclone genesis and existence in monitoring area
- 3hour, 6 hour, 12 hour and daily accumulated rainfall forecast chart (control, median, 75%, 90%, max)

4.3 Short-range forecasting system (0-72 hrs)

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

4DVAR has been used as a main data assimilation system for 12km limited area model based on the Unified Model which covers the East Asia domain since it was introduced to the operational suite in 2011. Most of the observation types assimilated in the global NWP system are also available for the regional system. This system has been maintained without any change since the last improvement in 2015.

Table 4.5 Configuration of operational data assimilation for 12km regional model as of 2016

	RDAPS (UM 12kmL70)
Data assimilation	4DVAR
Initial condition	From regional 4DVAR
Boundary condition	From the Global UM
Number of vertical layers	70
Domain top	80km
Horizontal grids	540 X 432
Horizontal resolution of analysis	12km
Inner loop resolution	36km 70 layers
Initialization	-
Domain	East Asia

4.3.1.2 Research performed in this field

Nothing to report

4.3.2 Model

4.3.2.1 In operation

KMA introduced the regional model based on the Unified Model in 2010 and coupled it with 4DVAR in 2011. This regional model coupled with 4DVAR was called RDAPS (Regional Data Assimilation and Prediction System). It has 12km horizontal resolution and 70 vertical layers (top~80km) and provides 87-hour prediction 4 times a day. KWRF (based on WRF), which was another regional model, was dropped from operation in 2015 and so RDAPS became only regional forecast system which produced longer forecast than 3 days. Table 4.6 shows configuration of RDAPS.

Table 4.6 Key model parameters of regional models (UM 12kmL70) for short-range forecast

	RDAPS (UM 12km L70)
Base Model	UM(Unified Model)
Governing Equation	Complete equation (Non-hydrostatic)
Horizontal Resolution	12km(0.11x0.11)/540x432
Number of vertical layers	70
Model time step	200sec
Forecast Length	87 hours
Initial condition	From regional 4DVAR
Time integration	Semi-implicit Semi-Lagrangian scheme
Radiation Process	Edwards-Slingo general 2-stream scheme
Surface Process	Joint UK Land Environment Simulator (JULES) 4 layer soil model using van Genuchten (1980) soil hydrology
PBL Process	First order non-local boundary layer scheme of based on Lock et al. (2000)
Convection Process	Mass flux convection with CAPE closure
Microphysics	Mixed-phase precipitation
Gravity Wave Drag	G.W. drag due to orography (GWDO)
Surface B. C.	Surface Analysis + Climatology
Operation Frequency	Four times daily / 6hour D.A. cycle

4.3.2.2 Research performed in this field

Nothing to report

4.3.3 Operationally available NWP products

Operational RDAPS (Regional Data Assimilation and Prediction System) products routinely available on model's original horizontal resolution in GRIB-II format are as follow:

- Pressure level data : 3-hourly up to +87 hours
  - 3-dimensional wind components : 24 levels (1000~50hPa)
  - Geopotential height : 24 levels (1000~50hPa)
  - Temperature : 24 levels (1000~50hPa)
  - Relative humidity w.r.t. ice/water : 24 levels (1000~50hPa)
  - Wet bulb temperature : 850/700/500hPa
  - Ertel Potential Vorticity at theta surface : 330/315/300K
- Single level or soil layer data
  - 115 single level or soil layer variables are also operationally available as 3-hourly data, which are instant values or accumulated/time-averaged/maximum/minimum values.
- Graphical products
  - Same as in the section 4.2.3

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

For medium-range forecast, MOS and PPM scheme based on GDAPS have been used to provide temperature guidance for 19 major cities. Ensemble MOS (EMOS) based global EPS (UM N320L70M24) was newly implemented in 2014 and modified to use higher resolution EPS (N400L70M25) in 2016 . EMOS provides daily Max/Min temperature and cloud cover up to 12 days for synoptic stations and airports. EMOS products were displayed in form of EPS meteograms. For short-range forecast, MOS and PPM scheme based on RDAPS, GDAPS, and ECMWF model have also been used to provide sensible weather variables(see Table 4.6) for about 700 surface observational points which are synoptic observation stations, automatic weather stations and airports in Korean peninsula.

To provide single 'best' guidance to KMA digital forecast, MOS, PPM and direct model outputs are blended with performance weight and bias correction. This 'best' guidance for 2m temperature, daily max/min temperature, relative humidity outperforms by 10 % more to existing any guidance in KMA.

For non-observational location, SSPS (site-specific processing system) has been operated. SSPS is one of packages of UKPP in MetOffice and extract guidance of specific location with NWP grid data. SSPS in KMA provides mountain guidance with RDAPS prediction.

Table 4.7 Operational statistical techniques for application of NWP

NWP Model	Element	Techniques	Basis	Projection	Interval
RDAPS (UM 12km)	2m temperature	MOS	00, 12 UTC	+6 ~ +87h	3h
	Daily max/min temperature	MOS	00, 12 UTC	+3day	1d
	Total cloud cover	MOS, PPM	00, 12 UTC	+6 ~ +87h	3h
	Probability of precipitation over 0.1mm	MOS	00, 12 UTC	+6 ~ +87h	3h
	Type of precipitation	MOS, PPM	00, 12 UTC	+6 ~ +87h	3h
	2m relative humidity	MOS	00, 12 UTC	+6 ~ +87h	3h
	10m wind direction/speed	MOS	00, 12 UTC	+6 ~ +87h	3h
GDAPS (UM N768)	Daily max/min temperature	MOS	00, 12 UTC	+12day	1d
	Type of precipitation	PPM	00, 12 UTC	+12day	12h
	Total cloud cover	PPM	00, 12 UTC	+12day	12h
EPSG (N400)	Daily max/min temperature	EMOS	00, 12 UTC	+12day	1d
	Total cloud cover	EMOS	00, 12 UTC	+12day	12h
ECMWF (0.25°)	2m temperature	MOS	00, 12 UTC	+6 ~ +87h	3h

4.3.4.2 Research performed in this field

To improve precipitation forecast, the statistical post-processing were explored for precipitation type and probability of precipitation (hereafter called "POP") to cover short term prediction. The precipitation type guidance was trained by the random forest method, which is an ensemble method for randomly learning the relation between prediction factors and prediction elements. As a result of verifying case of the temperature range between -4℃ and 5℃ for which it is difficult to predict the precipitation type, the accuracy was increased about 10%p than the existing Matsuo and the improved Matsuo method. The

sensitivity experiments for POP was explored for multiple linear regression, support vector regression and logistic regression, and the logistic regression outperformed to the others methods. It also outperformed by 11%p for existing MOS based on RDAPS.

In 2018 the Olympic Winter Games are to be held in PyeongChang, Republic of Korea. A suite of statistical guidance has been explored with NWP model prediction and the observation installed at the important locations of venues. For the short and medium range prediction, the traditional MOS was applied. For up to 24 hour prediction, hourly updated bias correction and best grid selection were experimented. The probabilistic approach with ensemble prediction was also explored to provide impact based forecast to the decision makers of Olympic Games. The statistical guidance showed significantly positive improvement for the prediction of dry variables.

4.3.5 Ensemble Prediction System

4.3.5.1 In operation

KMA has been running the short-range ensemble prediction system (LENS; Limited area ENsemble System) operationally since October 2015 to provide guidance for early warning by producing a probabilistic prediction of high impact weather. LENS, which has 3km horizontal resolution, was designed to forecast 72 hours at every 12 hours based on enhanced KMA global ensemble prediction system (EPSG) via downscaling of initial perturbation. The LENS, which mainly covers Korean peninsula, consists of one control member and 12 perturbation members. In 2016, the improved model dynamics, named 'ENDGAME' , was applied operationally, replacing the existing one (named 'New Dynamics')

4.3.5.2 Research performed in this field

The impact of domain extension of local ensemble model will be evaluated and optimal domain will be suggested. Also, higher resolution ensemble model with 2.2km grid interval will be tested and reviewed its possibility for operational use.
Currently local ensemble perturbations are simply given by downscaling the global ensemble perturbations. So more advanced method to get perturbation will be studied.

4.3.5.3 Operationally available EPS Products

The following products from the LENS are available:

- Mean and Spread for MSLP and 1.5m temperature
- Probability of precipitation, snow, wind gust, and visibility for several thresholds
- Ensemble meteogram of temperature, total cloud amount, precipitation, wind speed at 10m, and surface air temperature for 25 major cities
- Probability matching precipitation amounts
- 3hour accumulated rainfall forecast chart (control, median, 75%, 90%, max)

4.4 Short-range Local Forecasting system (0-24 hrs)

4.4.1 Data assimilation, objective analysis and initialization

4.4.1.1 In operation

All observations within 1 hour 30 minutes time range from analysis time are assimilated by incremental 3DVAR. The analysis increments are computed on the 3km horizontal resolution inner grid by minimizing the cost function, which measures the differences from the model forecasts and observations. The rain rate data derived from radar reflectivity and rain gauge observations with 10 minute interval is added to be assimilated via latent heat nudging. The incremental analysis update(IAU) is applied to remove noises in analysis increments.
In June 2016 the model domain was extended from Korean Peninsula area to a part of Japan and China to simulate the synoptic weather phenomenon well. So, the number of used observation data was increased.

4.4.1.2 Research performed in this field

The assimilation of ground-based GNSS and AMSU-B for LDAPS (Local Data Assimilation and Prediction System) has been investigated in 2016. The results of ground-GNSS data assimilation using 40 stations which were increased from 15 stations in 2015 by the improvement of pre-processing system show the positive impacts on quantitative rainfall forecasts, especially heavy rainfall forecast. Microwave radiance data is less sensitive to cloud than other radiance data, so it can provide the vertical temperature and humidity profiles at the cloudy area. The impact study of high resolution microwave satellite data (AMSU-B) with enhancement of cloud detection was conducted in LDAPS and the results show better performance of LDAPS prediction.
And the update module for observation data quality control had been developed by collaboration of KMA and UK Met Office since 2015. By using this module the statistical observation data quality information can be handled easily. This will be implemented operationally in 2017.

4.4.2 Model

4.4.2.1 In operation

KMA started running LDAPS (UM 1.5kmL70) operationally on 15 May 2012 to produce detailed short-range weather prediction for the Korean peninsula. The model with 1.5km horizontal resolution, 70 vertical layers (top~40km) provides 36-hour prediction 4 times a day. Table 4.7 shows configuration of the LDAPS model. In June 2016, Majority parts of LDAPS such as version of model and domains were upgraded to improve the precipitation forecast and simulation of synoptic scales over Korean Peninsula.

- Major changes in the operational local model(LDAPS) :
  - Update the version of model and a dynamic core for more stability and faster calculations
  - Change the frequency of the Latent Heat Nudging from 10min to 1 hour to overcome the spin-up problem
  - Expand the domain of LDAPS from the Korean Peninsula to Far East Asia to keep the consistency of the synoptic scale. The variable grid area(1.5~4km) was only changed, while the fixed grid area(1.5 X1.5) was not changed.

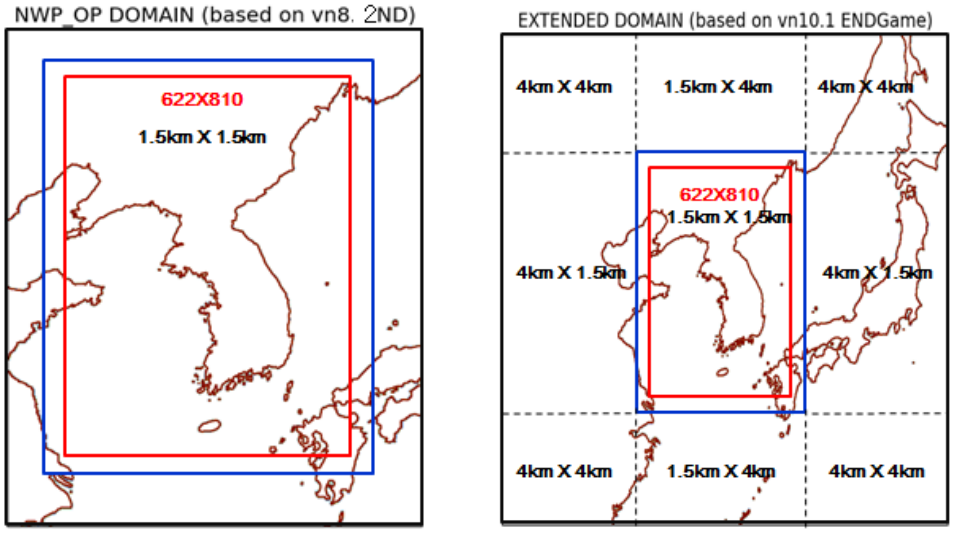

Fig 4.2 Domain comparison between operational LDAPS(left ; 744 x 928) and extended LDAPS (right ; 1188x1148)

4.4.2.2 Research performed in this field

By applying the extended-domain with the variable grid of LDAPS, the sensitivity test was performed for the improvement of synoptic-scale simulation and the precipitation prediction during July 2016. The new version of LDAPS shows improved verification scores (ACC, ETS) and less bias during the whole forecast period. Due to the improvements of latent heat nudging process and dynamic core, performance of precipitation simulation was improved at the beginning of the forecast time and the problem of underestimation of the precipitation was reduced than the previous version.

Table 4.8 Key model parameters of LDAPS (UM 1.5kmL70) for short-range local forecast

Horizontal grid/grid points	Variable grid (Inner: 1.5km, 0.0135X0.0135)/1,188x1,148
Vertical grid	70 levels (surface~39km).
Time step	60 sec
Forecast range	36 hours.
Dynamic core	ENDGame(Even Newer Dynamics for General Atmospheric Modelling of the Environment)
I.C / Data assimilation	3DVAR (FGAT, IAU)
Boundary condition	From the global model
Surface B. C.	Surface analysis + Climatology
Operation Frequency	8 times daily / 3-hourly D.A. cycle
Time integration	Semi-implicit Semi-Lagrangian scheme
Radiation Process	Edwards-Slingo general 2-stream scheme
Surface Process	Joint UK Land Environment Simulator (JULES) 4 layer soil model using van Genuchten (1980) soil hydrology
PBL Process	First order non-local boundary layer scheme of based on Lock et al. (2000)
Microphysics	Mixed-phase precipitation
Gravity Wave Drag	G.W. drag due to orography (GWDO)

4.4.3 Operationally available NWP products

Operational LDAPS products routinely available on model's original horizontal resolution in GRIB-II format are as follow

- Pressure level data : 1-hourly up to +36 hours
  - 3-dimensional wind components : 24 levels (1000~50hPa)
  - Geopotential height : 24 levels (1000~50hPa)
  - Temperature : 24 levels (1000~50hPa)
  - Relative humidity w.r.t. ice/water : : 24 levels (1000~50hPa)
- Single level or soil layer data
  - 136 single level or soil layer variables are also operationally available as 1-hourly data, which are instant values or accumulated/time-averaged/maximum/minimum values.
- Graphical products
  - Same as in the section 4.2.3

4.4.4 Operational techniques for application of NWP products

4.4.4.1 In operation

Nothing to report

4.4.4.2 Research performed in this field

Nothing to report

4.4.5 Ensemble Prediction System

4.4.5.1 In operation

Nothing to report

4.4.5.2 Research performed in this field

Nothing to report

4.4.5.3 Operationally available EPS Products

None

4.5 Nowcasting and Very Short-range Forecasting Systems (0-6 hrs)

4.5.1 Nowcasting System

4.5.1.1 In operation

The Lagrangian extrapolation-based nowcasting system at KMA provides sky condition, precipitation, and lightning forecasts up to 6 hour with 15 minute interval for sky conditions and 10 minute interval for precipitation and lighting data.

Table 4.9 Nowcasting forecast products

Type	Forecast products	interval
Satellite	Moisture image	15 min
	Ultraviolet image	
	Cloud amount	
Radar	Precipitation amount	10 min
	Precipitation types	
Lightning	Distribution of lightning	
	Probability of lightning	

4.5.1.2 Research performed in this field

Nothing to report

4.5.2 Models for Very Short-range Forecasting Systems

4.5.2.1 In operation

The operational very short range forecast system is called Korea Local Analysis and Prediction System (KLAPS), and runs every hour with 5-km horizontal resolution. The lateral boundary conditions are provided from the 15-km resolution forecasts 4 times a day.

The KLAPS has a cloud analysis and a diabatic initialization scheme for the very quick precipitation spin-up within a 1-h integration of numerical weather prediction model. The KLAPS also produces 8 current weather information (temperature, sky condition, precipitation amount, relative humidity, wind direction, speed, and precipitation types, and lightning) and 4 prediction elements (precipitation amount, sky condition, precipitation type, probability of lightning) at selected grid points. In June 2016, the lateral boundary data from GDAPS was also changed to catch up with the new version of KMA global model

4.5.2.2 Research performed in this field

Nothing to report

Table 4.10 Operational configuration of KLAPS as of 2016

	Domain 1	Domain 2
Horizontal resolution	15km	5km
Number of grid-points	251 x 251	235 x 283
Domain distance(km)	10,800 x 10,800	3,150 x 3,150
Vertical layers/Model Top	40 sigma layers / 50 hPa	
Time step for integration	60s	20s
Cumulus Parameterization	New Kain-Fritsch	None
Boundary layer	YSU PBL	
Microphysics	WDM6	
Radiation	Dudhia & RRTM	
Land-surface	5 layer thermal diffusion scheme	
Lateral Boundary data	GDAPS(UM N768L70) forecast data	

4.6 Specialized Numerical Predictions

4.6.1 Tropical Cyclone Prediction System

4.6.1.1 Research performed in this field

- **TRUM (Typhoon Regional Unified Model) :**
  The UM-based typhoon prediction model TRUM was operationally tested in real time at the National Typhoon Centre. The dynamical initialization and GFDL-type bogussing were applied.

Table 4.11 Configuration of TRUM as of 2016

Base Model	UM (Unified Model) version10.1
Horizontal Resolution	6km x 6km (1200 x 1000)
Number of Vertical Layers	70 levels (surface~80km)
Time Step	75s
TC vortex initialization	Dynamical initialization and GFDL-type bogussing
Surface Process	MOSES-II Land-surface Scheme
PBL Process	MOSES-II Non-local PBL
Cumulus parameterization	None
Gravity Wave Drag	G.W. drag due to orography (GWDO)
Initial and Lateral Boundary data	GDAPS(UM N768L70) forecast data
Forecast length	120 hours, 2 times/day (00/12 UTC)

4.6.2 Ocean Wind Wave Prediction System

4.6.2.1 In operation

The current operational ocean wave prediction systems consist of the global (GoWW3, 1/2°), the regional (ReWW3, 1/12°), the coastal (CoWW3, 1/120°) systems which employ the 3rd generation community wave model WAVEWATCH-III version 4.18. The operational cycles of 3 systems are two times per day (00, 12UTC) and the lead forecast times are 12 days for global, 87hours for regional and 72hours for coastal system. The directional wave spectra at boundary of regional domain is provided from the GoWW3. The five CoWW3 systems, which have 1km spatial resolution, cover the responsible

marine area of Regional Forecast Offices and are nested inside the regional domain. The directional wave spectra at boundaries of coastal domain are provided from the ReWW3.

Table 4.12 Configuration of operational ocean wind wave prediction systems as of 2016

	GoWW3	ReWW3	CoWW3 (5 Domains)
Code	WAVEWATCH-III v. 4.18		
Coordinate	Spherical Coordinate		
Domain	70°S-70°N 0°E-358.75°E	20°N-50°N 115°E-150°E	Daejeon: 36.0°-39.0°N, 123.0°-127.0°E (481x361) Gwangju: 33.0°-36.5°N, 124.0°-128.0°E (481x421) Busan: 33.5°-37.0°N, 127.0°-131.0°E (481x421) Kangwon: 36.5°-40.0°N, 127.0°-132.5°E (661x421) Jeju: 31.0°-35.5°N, 123.0°-129.0°E (721x541)
Spatial Resolution /Dimensions	1/2° (720 x 281)	1/12° (421 x 361)	1/120°
Spectral Resolution	Frequency no. 25, Direction no.: 36 (10° interval)		
Time Step	720 sec	300 sec	30 sec
Forecast Length	288 hours	87 hours	72 hours
Number of Runs	2 times / day (00, 12 UTC)		
Initial & Boundary Data	12-hour forecast from the previous run	12-hour forecast from the previous run, GoWW3 boundary	12-hour forecast from the previous run, ReWW3 boundary
Forcing Data	GDAPS (UM N768L70) Sea SFC Winds (6-hour interval)	RDAPS(UM 12kmL70) Sea SFC Winds (3-hour interval)	

Table 4.13 WAVEWATCH-III Grid pre-processor input information chosen for GoWW3

Frequency increment factor and first frequency (Hz)	1.1 0.04118 25 36
Time steps (global / CFL for x-y / for k-theta / source)	1440 / 720 / 1440 / 720 sec
Input Source Terms	Ardhuin et al.,2010 / SIN4 BETAMAX = 1.33, ZWND = 10.
Nonlinear interactions	Discrete Interaction Approximation (DIA)
Dissipation Source Terms & Bottom Friction	Ardhuin et al.,2010 / JONSWAP SBT1 GAMMA = -0.038
Propagation schemes	Ultimate-Quickest with averaging
Grid Definition	- Latitude-longitude grid (LLG): 720 (0.0) 281 (-70.0) - Bottom depth: 10m - Sub-grid information: YES

4.6.2.2 Research performed in this field

An ensemble prediction system for the regional wave forecast has been developed for the KMA's next wave forecast system. The number of member is 24 with same resolution in space and time of the current regional wave model. Following the implementation plan, this could be setup as operational model after late 2018.

4.6.3 Tide and Storm Surge Prediction System

4.6.3.1 In operation

The current operational Tide and Storm Surge Model are the regional (RTSM, 1/12°) and the coastal (CTSM, 1/120°) systems based on POM (Princeton Ocean Model) (Blumberg and Mellor, 1987). In this model, the level of storm surge was calculated by the difference between tide level and sea level

change caused by meteorological effects. Those systems have same operational cycle and resolutions as ocean wind wave prediction system

Table 4.14 Configuration of operational Tide and Storm Surge models as of 2016

	RTSM	CTSM(5 Domains)
Model	2-D Ocean Circulation Model (POM 2D)	
Coordinate system	Spherical coordinate	
Model domain	115 °E-150 °E, 20 °N-52 °N	Daejeon: 36.0°-39.0°N, 123.0°-127.0°E (481x361) Gwangju: 33.0°-36.5°N, 124.0°-128.0°E (481x421) Busan: 33.5°-37.0°N, 127.0°-131.0°E (481x421) Kangwon: 36.5°-40.0°N, 127.0°-132.5°E (661x421) Jeju: 31.0°-35.5°N, 123.0°-129.0°E (721x541)
Horizontal resolution	1/12 ° by 1/12 °, (421 ×385)	1/120°
ΔT	200 sec	200 sec
Prediction time	87 hour (00,12UTC)	72 hours (00,12UTC)
Initial field	Hot start	
Input data	RDAPS sea surface wind and MSLP, 8 tidal constituents	

4.6.3.2 Research performed in this field

Nothing to report

4.6.4 Asian Dust and Haze Prediction System

4.6.4.1 In operation

The ADAM2-Haze[1] model is developed to forecast both Asian Dust and Haze case. Anthropogenic and biogenic emissions are implemented for haze initial condition. The ADAM2-Haze uses 2006 INTEX-B[2]and 2008 CAPSS[3] emissions as emission inventories for East Asia and Korea region. The ADAM2-Haze applies the data assimilation technique to improve the initial state of surface PM concentration and aerosol species. OI (Optimal Interpolation) is used to assimilate ground-based surface PM_{10} and $PM_{2.5}$ data from more than 1500 observation sites operated in China and Korea

Table 4.15 Configuration of Asian dust and Haze prediction system as of 2016

Model	ADAM2-Haze
Meteorological model	Operational global model (UM N768L70)
Model domain	East Asia
Horizontal/Vertical resolution	Horizontally 25km (with 340 x 220 grids) Vertically 49 layers (up to 100 hPa)
Prediction range	72 hours (00/06/12/18UTC)
Dust size range	0.2 ~ 74 (μm in diameter)
Dust size bins	11 bins
Dust density	2600 kg m^{-3}
Dust particle size distribution	Log normal distribution
Vegetation data	SPOT NDVI (1km resolution)
Domestic emission inventory	2008 CAPSS
Foreign emission inventory	2006 INTEX-B
Data Assimilation Method	Optimal Interpolation
Assimilated data	Surface PM_{10} and $PM_{2.5}$ data

1 Asian Dust and Haze Forecast Model

2 Intercontinental Chemical Transport Experiment

3 Clean Air Policy Support System

- Major changes in the operational Asian dust and Haze model :
  - Data assimilation of surface PM_{10} and $PM_{2.5}$ concentrations

4.6.4.2 Research performed in this field

A high-resolution forecasting system based on the ADAM2-Haze model was evaluated. The domain is centered at the metropolitan area of Seoul and spatial resolution of the model is 1.5 km. The nest grid system has been used and the prediction model accuracy has been improved by applying the high-resolution emission inventory in the metropolitan area.

4.7 Extended Range Forecasts (ERF) *(10 days to 30 days)*

4.7.1 Models

4.7.1.1 In operation

See 4.8.1

4.7.1.2 Research performed in the field

Nothing to report

4.7.2 Operationally available NWP model and EPS LRF products

See 4.8.2

4.8 Long Range Forecasts (LRF) *(30 days up to two years)*

4.8.1 In operation

A new seasonal forecasting system of KMA was implemented operationally in Jan. 2014. This system, named the global seasonal forecasting system version5 (GloSea5), is a joint seasonal forecast system between KMA and UK Met-Office. Both centers share their model results each other.

GloSea5 is the ensemble prediction system for seasonal forecasting and it is a fully coupled model with atmosphere, ocean, land surface and sea-ice components. The component models are coupled through the OASIS coupler. The atmospheric model is based on Met Office Unified Model(UM) and land surface model is JULES and their resolution is 0.83 × 0.56 degrees. The ocean model is based on NEMO, Sea ice model is CICE and the grid spacing is 1/4 degrees. The stochastic physics scheme - SKEB2 is used to generate ensemble spread.

• Initialisation
For the forecasting, the initial atmospheric conditions are generated by the KMA NWP 4DVAR(00Z) and the initial conditions of ocean and sea-ice are taken from Met-Office daily.

Two members run out to 240 days (for seasonal forecast) and two members run out to 75 days(for intra-seasonal forecast). The first 75 days of all forecast members (four members) are used for intra-seasonal products.

ECMWF ERA-Interim data are used to initialize the atmosphere and land surface in the hindcast members. Also, NEMOVAR for ocean and sea-ice is used for hindcast. The hindcast period is 20 years from 1991 to 2010 and the hindcasts are initialized 4 times a month (1, 9, 17 and 25 in each calendar month). Hindcast set consists of three members per start date per year.

Table 4.16 Configuration of seasonal prediction system (GloSea5) as of 2016

GloSea5 Model Configuration (GC 2.0)	
Atmosphere	Met Office Unified Model (GA 6.0) N216L85 : 0.83x0.56 deg. 85layers
Ocean	Nucleus for European Modelling of the Ocean (GO 5.0), Orca Tri-polar grid at 0.25, 75layers
Land-Surface	Joint UK Land Environment Simulator(GL 6.0)
Sea-Ice	The Los Alamos Sea Ice Model(GSI 6.0)
Coupler	OASIS3

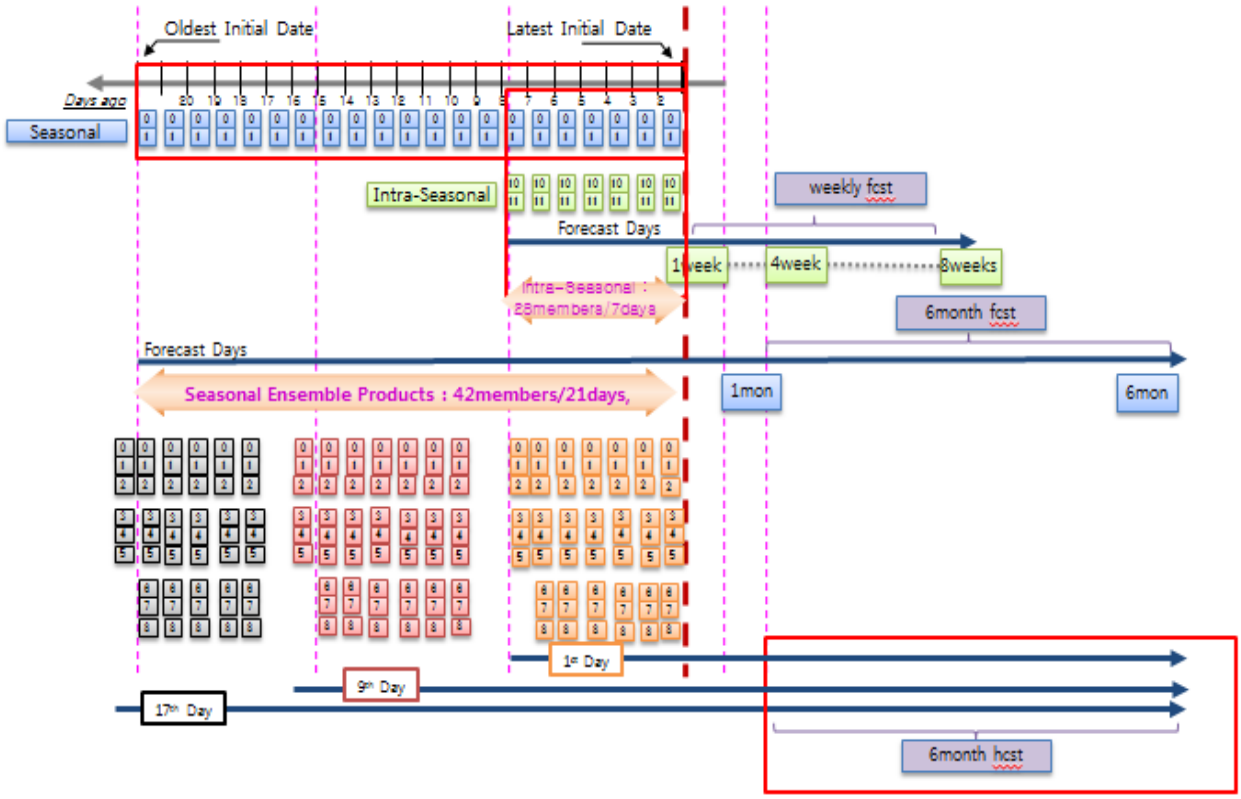

Fig. 4.3 GloSea5 operational schedule (forecast and hindcast) and composition of ensembles

4.8.2 Operationally available EPS LRF products

KMA LRF products are interpreted by forecasters and gridded data are supplied for the WMO lead center and APCC Multi-Model Ensemble. Every week, LRF products are generated as anomalies relative to a model climatology and are calculated as weekly mean fields, monthly mean fields and 3-monthly mean fields respectively. Probabilities are produced for MSLP, 2m Temperature and precipitation and applied to the 1month, 3month and seasonal outlook.

5. Verification of prognostic products

5.1 Annual verification summary

The summary of annual verification statistics for GDAPS is calculated by comparing the model forecast to the analysis and radiosonde observation (see Table 5.1 and 5.2). Table 5.3 presents annual verification statistics of global ensemble prediction system (EPSG) against analysis. All verification scores are only for prediction from 1200 UTC initials.

Table 5.1 GDAPS annual scores against analysis in 2016

VERIFICATION AGAINST ANALYSIS in **2016**							
		24 hour		72 hour		120 hour	
		2016	2015	**2016**	2015	**2016**	2015
Northern Hemisphere	500-hPa height RMSE (m)	**7.26**	7.35	**21.52**	21.88	**43.59**	43.27
	Wind RMSE 250 hPa (m/s)	**3.86**	3.87	**8.16**	8.15	**13.22**	13.09
Southern Hemisphere	500-hPa height RMSE (m)	**9.02**	9.20	**27.13**	27.11	**53.29**	53.08
	Wind RMSE 250 hPa (m/s)	**4.09**	4.14	**8.83**	8.82	**14.26**	14.14
Tropics	Wind RMSE 850 hPa (m/s)	**1.92**	1.96	**2.99**	3.03	**3.69**	3.77
	Wind RMSE 250 hPa (m/s)	**3.67**	3.60	**6.25**	5.89	**8.04**	7.56

Table 5.2 GDAPS annual scores against radiosondes measurements in 2016

VERIFICATION AGAINST RADIOSONDES in 2016(2015)							
		24 hour		72 hour		120 hour	
		2016	2015	**2016**	2015	**2016**	2015
Asia	500-hPa height RMSE (m)	**12.35**	12.15	**20.29**	20.62	**34.51**	33.53
	Wind 850 hPa (m/s)	**3.74**	3.75	**4.98**	5.02	**6.51**	6.42
	Wind 250 hPa (m/s)	**5.52**	5.57	**8.57**	8.69	**12.15**	12.20
Australia New Zealand	500-hPa height RMSE (m)	**12.07**	12.78	**20.72**	22.73	**38.61**	39.37
	Wind 850 hPa (m/s)	**3.95**	3.94	**5.34**	5.41	**7.09**	7.00
	Wind 250 hPa (m/s)	**5.35**	5.33	**8.57**	8.61	**12.74**	12.52
Europe	500-hPa height RMSE (m)	**11.08**	10.63	**23.32**	23.44	**44.85**	46.06
	Wind 850 hPa (m/s)	**3.53**	3.59	**5.02**	5.03	**6.92**	6.85
	Wind 250 hPa (m/s)	**4.88**	5.07	**9.21**	9.57	**14.98**	15.35
North America	500-hPa height RMSE (m)	**10.07**	9.52	**22.42**	21.37	**40.70**	39.85
	Wind 850 hPa (m/s)	**4.06**	3.97	**5.69**	5.55	**7.65**	7.49
	Wind 250 hPa (m/s)	**5.80**	5.69	**9.99**	9.93	**15.13**	14.78
Northern Hemisphere	500-hPa height RMSE (m)	**12.01**	11.64	**22.90**	23.13	**42.40**	42.47
	Wind 850 hPa (m/s)	**3.82**	3.81	**5.25**	5.24	**7.09**	7.01
	Wind 250 hPa (m/s)	**5.29**	5.34	**8.97**	9.14	**13.68**	13.82
Southern Hemisphere	500-hPa height RMSE (m)	**11.60**	12.92	**21.74**	24.22	**39.39**	42.49
	Wind 850 hPa (m/s)	**4.40**	4.36	**5.77**	5.65	**7.45**	7.30
	Wind 250 hPa (m/s)	**5.91**	6.00	**9.26**	9.32	**13.65**	13.61
Tropics	Wind 850 hPa (m/s)	**3.49**	3.59	**4.07**	4.16	**4.58**	4.65
	Wind 250 hPa (m/s)	**5.14**	5.10	**6.91**	6.80	**8.19**	8.62

Table 5.3 Global Ensemble Prediction System (EPSG) annual scores against analysis in 2016

EPSG VERIFICATION AGAINST ANALYSIS in 2016(2015)								
			72 hour		120 hour		192 hour	
			2016	2015	**2016**	2015	**2016**	2015
Northern Hemisphere	500-hPa height	Ensemble mean RMSE (m)	**23.02**	24.67	**42.04**	44.65	**67.30**	70.4
		Spread/EM error (%)	**107.78**	116.3	**101.07**	104.7	**97.10**	96.63
		Brier Skill Score +1.0 standard deviation	**0.81**	0.80	**0.62**	0.61	**0.35**	0.33
	850-hPa temperature	Ensemble mean RMSE (m)	**1.63**	1.7	**2.36**	2.46	**3.06**	3.45
		Spread/EM error (%)	**88.96**	95.29	**91.95**	95.93	**93.01**	93.04
		Brier Skill Score +1.0 standard deviation	**0.66**	0.64	**0.49**	0.48	**0.27**	0.25

6. Plans for the future *(next 4 years)*

6.1 Development of the GDPFS

6.1.1 Major changes in the operational DPFS which are expected in the next year

- Medium-range Forecasting System
  - VARBC (VARiational Bias Correction) of satellite data will be introduced operationally for the global model.
  - The soil moisture perturbation will be applied in global ensemble model.
  - SSMIS, FY-3C, AMSR2, and MTSAPHIR will be operationally used for the global model, when they show the positive impact.
  - Forecast regarding heat wave in August 2016 over East Asia will be focused in research.

- Short-range Local Forecasting System
  - Development of extended domain local prediction system
  - 4dVar will be developed and more non-conventional observation data will be incorporated

- Long-range Forecasting System
  - Nothing to report

6.1.2 Major changes in the operational DPFS which are envisaged within the next 4 years

- Operational Launch of Next Generation Global Model (KIM)
  - KMA's next generation global model, named KIM (Korea Integrated Model), has been being developed by KIAPS(Korea Institute of Atmospheric Prediction System) since 2011
  - KIM, which is based on the cubed sphere grid system, will be introduced operationally in 2020.
  - After operational launch, it will be maintained in parallel with current UM and its performance will be compared with UM.
  - Its horizontal resolution will be 10~12km and model top will be 80km.
  - Retirement of current regional model (12km resolution) and development of KIM high resolution regional model (~4km)

- Improvement of local ensemble system
  - Current local ensemble system which has 3km horizontal resolution will be improved to 2.2km resolution system

- Also, its domain will be extended to cover East Asia region partly.
- KIM based ~1km local ensemble system will be developed.

- Data Assimilation
  - 4DEnVAR which uses ensemble forecast system to keep the flow-dependency even without PF model, will be developed with the aim of its operational application.
  - COMS follow-on geostationary satellite will be applied to NWP system.
  - Improved variational bias correction for geostationary satellites and polar orbit satellites will be applied

6.2 Planned research Activities in NWP, Nowcasting and Long-range Forecasting

6.2.1 Planned Research Activities in NWP

- **Development of a new global NWP system (KIM)**
  - An R&D project for development of a new global NWP system (KIM) in Korea started in 2011. KIAPS (Korea Institute of Atmospheric Prediction Systems) developed core modules for the new NWP system – dynamical core, physics parameterization package, observation pre-processing, data assimilation and their framework, etc.
  - 4km resolution model(KIM) coupled with 4DEnVAR will be operated in semi-real time and its performance will be compared with current UM in 2017.
  - More computational resources will be invested to support the development of KIM
  - Performance of KIM will be continuously improved to get the comparable performance with UM.
- **Support for Impact-Based Forecast**
  - KMA has a plan to introduce impact-based forecast system by 2020.
  - Multi-Ensemble system which combines the global, ECMWF and local ensemble models will be developed to support impact-based forecast.
  - Also, the technique to transform relatively-low resolution model fields to higher resolution will be developed and this high resolution data will be used for impact-based forecast.

6.2.2 Planned Research Activities in Nowcasting

Nothing to report

6.2.3 Planned Research Activities in Long-range Forecasting

- **Reanalysis data based on KIM**
  - KMA will start to make reanalysis data for global & regional for recent 10 years. (2020)

- **Ocean coupled medium range forecast model**
  - Data assimilation and forecast with coupled model (2020)

7. References

- http://www.wmolc.org/~GPC_Seoul : WMO LRF MME web site – contains information on KMA's LRF system and products
- http://web.kma.go.kr/eng/biz/forecast_02.jsp : Brief introduction of KMA's NWP system
- http://super.kma.go.kr/eng/index.jsp : National Center for Meteorological Supercomputer web site – contains information on KMA's supercomputer
- https://www.kiaps.org/eng/main.do : KIAPS(Korea Institute of Atmospheric Prediction Systems) web site