Introduction of KMA Multi-Model Ensemble Prediction System

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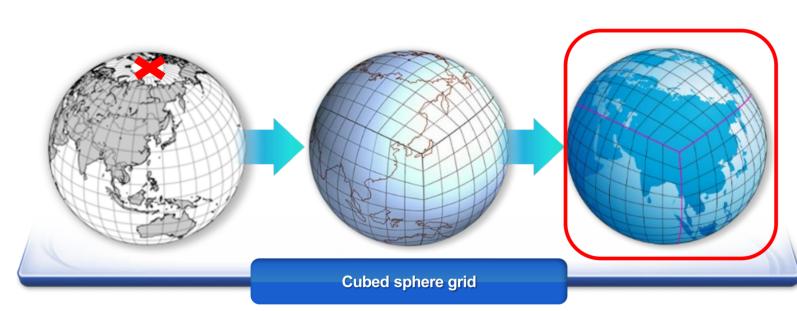**Korea Meteorological Administration**

> **KMA multi-model ensemble(MME) prediction system that integrates KIM, UM, ECMWF global and ensemble models was developed and its performance was evaluated. KMA MME showed the better performance than ECMWF ensemble model, which is the best member model.**

KMA Multi-Model Ensemble (MME)

❖ Members : ECMWF, UM(Unified Model), KIM(Korean Integrated Model)
- UMG (UM global model ; 10kmL70)
- KIMG (KIM global model ; 12kmL91)
- ECMG (ECMWF global model ; 9km L135)
- UME (UM global ensemble model ; 32kmL70, 25 members)
- KIME (KIM global ensemble model ; 32kmL91, 26 members)
- ECME (ECMWF global ensemble model ; 18kmL135, 51 members)

❖ 2020 version : UMG+ECMG+UME+ECME
❖ 2021 version : UMG+ECMG+UME+ECME+KIMG
❖ 2022 version : UMG+ECMG+UME+ECME+KIMG+KIME

Member Models

❖ UM (Unified Model) : KMA's operational model, introduced from UKMO and used for 12 years.
❖ KIM (Korea Integrated Model) : KMA's new operational model which was developed by KIAPS* for 9 years since 2011 and has been in operational since 2020. Based on cubed sphere grid system.

  * KIAPS: Korea Institute of Atmospheric Prediction System.

Cubed sphere grid

❖ ECMWF models : Received from ECMWF twice every day

	KIMG	UMG	ECMG	KIME	UME	ECME
Resolution	12km L91	10kmL70	9km L135 (25kmL25)	32km L91	32km L70	18km L135 (Surface 25kmL3) (Upper 50kmL3)
Forecast time	12 days	12 days	10 days	12 days	12 days	12 days
Grid system	Cubed sphere	Lat-lon	Lat-lon	Cubed sphere	Lat-lon	Lat-lon
No. of members	1	1	1	26	25	51
MME	Resolution: 10km L3 (Surface, 850, 500, 200 hPa) / Lat-Lon 10 days forecast / East Asia domain/ 6 members					

Weighted Mean

❖ Weights inversely proportional to the error
❖ MME: Weighted average of member models based on weights.

$$W_i = \frac{\frac{1}{E_i^2}}{\sum_{i=1}^{n}\frac{1}{E_i^2}} \qquad F = \sum_{i=1}^{n} W_i F_i$$

W_i : Weight of i–th model
E_i : Error of i–th model
F_i : i–th model
F : MME

Comparison by weight calculation methods (MME 2020)

❖ AVG: Same weights (simple mean)
❖ E1R $f(x,y,t,z,v)$: different weights for each grid point and forecast time
❖ E2R $f(t,z,v)$: different weights (horizontal domain-averaged) for each forecast time
❖ E3R $f(x,y,z,v)$: different weights for each horizontal grid (time-averaged)
❖ E4R $f(z,v)$: Averaged weight for grid points and forecast times

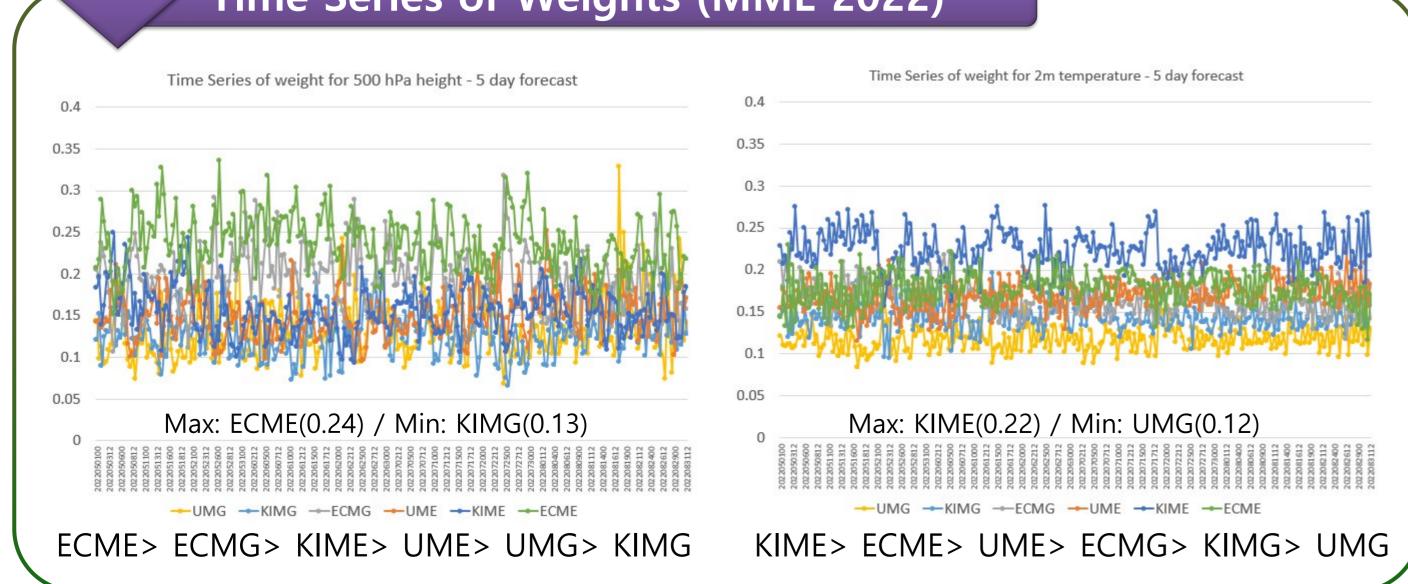Forecast time: 12h 24h 36h 48h 60h 72h 84h 96h 108h 120h

E1R=f(x,y,t,z,v)
E2R=f(t,z,v)
E3R=f(x,y,z,v)
E4R=f(z,v)

x : x-grid
y : y-grid
z : z-grid
t : forecast time
v : variable

❖ I2 : Average of E2R for the past 1 day from now
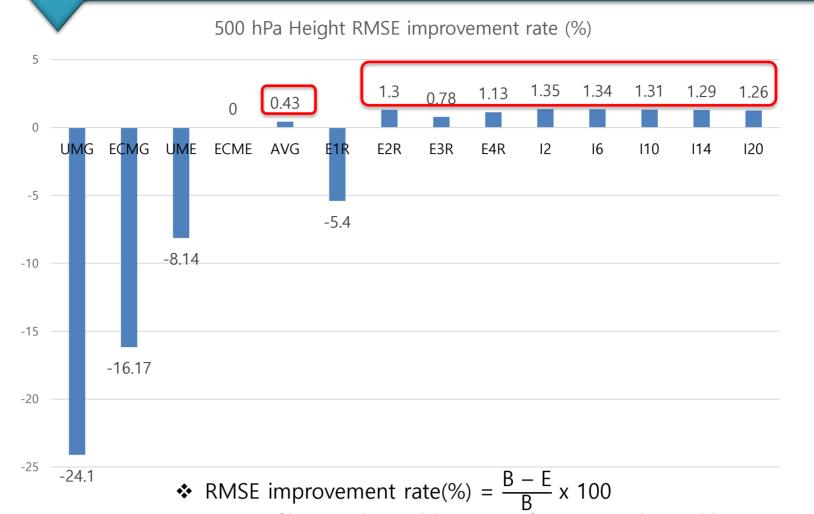❖ I6 : Average of E2R for the past 3 days from now
❖ I10 : Average of E2R for the past 5 days from now
❖ I14 : Average of E2R for the past 7 days from now
❖ I20 : Average of E2R for the past 10 days from now

Time Series of Weights (MME 2022)

Time Series of weight for 500 hPa height - 5 day forecast

Max: ECME(0.24) / Min: KIMG(0.13)

ECME> ECMG> KIME> UME> UMG> KIMG

Time Series of weight for 2m temperature - 5 day forecast

Max: KIME(0.22) / Min: UMG(0.12)

KIME> ECME> UME> ECMG> KIMG> UMG

Verification – RMSE (MME 2020)

500 hPa Height RMSE improvement rate (%)

$$\text{RMSE improvement rate(\%)} = \frac{B - E}{B} \times 100$$
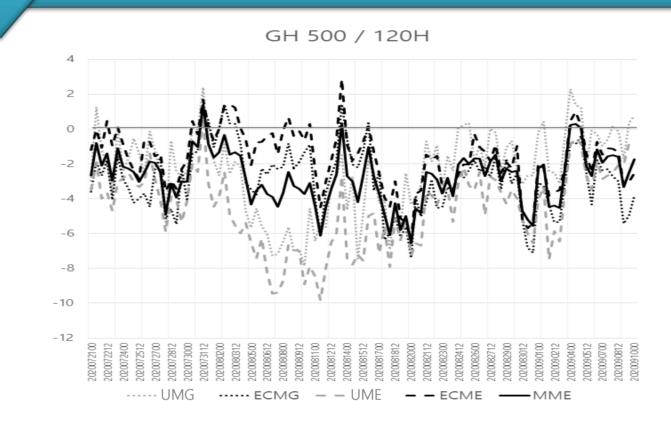B: RMSE of best member model / E: RMSE of MME or member models

<500 hPa height>
❖ ECME : Best member model
❖ Except for E1R, All MMEs better than ECME
❖ Ensemble modes better than global models
❖ E2R > E1R, E3R and E4R
❖ Too much detailed weight or too much simple weight did not show better performance than domain averaged weight(E2R)
❖ I2, I6, I10, I14, I20 did not significantly improve performance

<RMSE Improvement Rate(%) of MME against best member>

Best member model	Elements	AVG	E1R	E2R	E3R	E4R
ECMWF Ensemble Model	500hPa height	0.32	-5.4	1.3	0.78	1.13
	850hPa U wind	0.34	-5.05	1.45	1.08	1.22
	500hPa U wind	0.24	-5.04	1.34	0.82	1.16
	200hPa U wind	1.55	-4.15	2.55	2.01	2.5
	850hPa V wind	0.35	-5.21	1.42	1.01	1.21
	500hPa V wind	-0.32	-5.53	0.8	0.35	0.65
	200hPa V wind	-0.91	-6.21	0.32	-0.01	0.27
	850hPa humidity	1.01	-5.25	2.41	1.8	2.09
	10m U wind	1.81	-3.94	2.75	2.15	2.5
	10m V wind	1.3	-4.24	2.29	1.79	2.04
	Accumulated precipitation	0.32	-14.21	1.38	-4.82	1.24
UM Ensemble Model	Mean sea level pressure	-5.87	4.7	4.72	10.25	0.54
	850hPa temperature	-2.58	1.33	2.68	6.93	0.71

❖ E2R (domain-averaged) selected as optimal weights
❖ The excellent performance of E3R for MSLP and low-level temperature: biased results caused by using a UM analysis field as a reference field for weight calculation.
❖ Also, E3R cannot be used for precipitation, because if the model predicts no rain for no rain areas, the model error becomes zero and weights cannot be obtained properly at that area.

Verification – BIAS (MME 2020)

GH 500 / 120H

MSL / 120H

❖ ECMWF models: weak negative bias
❖ UM models: strong negative bias
❖ MME: negative bias
❖ 0 > ECME > ECMG > MME(E2R) > UMG > UME

❖ ECMWF models: positive bias
❖ UM models: negative bias
❖ MME: smallest bias
❖ ECME > ECMG > MME(E2R)~0 > UMG > UME

Summary for MME 2020 version

❖ KMA MME established by merging UM and ECMWF global and ensemble models
❖ MME better than any other member model
❖ The ensemble models better than the global models
❖ E2R (horizontally domain-averaged weights) better than E1R, E3R and E4R
❖ The excellent performance of E3R for MSLP and low level temperature: a kind of biased results.
❖ E2R selected as the optimal weight.
❖ E1R(detailed) and E4R(simple) did not showed better performance than E2R
❖ Averaging weights for several days not much effect
❖ When the bias of the member model evenly distributed, smallest MME bias.

Verification – RMSE (MME 2021 & 2022)

RMSE Improvement rate (%) of MME 2022 against ECMWF ensemble model
TP: precipitation
850R: 850hPa relative humidity

Z500	MSLP	2T	10U	10V	T P	850T	850R	850U	500U	200U	850V	500V	200V
3.25	3.64	20.38	16.10	15.99	6.52	7.94	15.60	9.39	10.17	11.26	10.43	11.02	8.75

MME 2022 (MME6) better than ECME

500 hPa height improvement rate(%) against ECMWF ensemble model

UMG	KIMG	ECMG	UME	KIME	ECME	MME5	MME6
-39.26	-38.89	-15.72	-20.91	-17.99	0.00	2.80	3.25

MME 2022 (MME6) / MME 2021 (MME5)
Performance: MME6 > MME5 > ECME > KIME > KMA-UME > ECMG > KIMG > KMA-UMG

Issues

❖ How to select member models (Evenly distributed bias)
❖ More sophisticated method in merging members (AI,…)
❖ Underestimation of precipitation and tropical cyclone intensity

Typhoon forecast (MME 2022)

rank	24h	24h	48h	48h	72h	72h	96h	96h	120h	120h	144h	144h
1	ECMG	56.44	MME6	124.86	ECMG	267.74	ECME	236.9	MME6	315.44	UMG	464.07
2	MME6	61.03	ECMG	129.15	MME6	269.26	UME	249.91	ECME	328.58	KIME	527.57
3	ECME	62.86	UME	143.49	KIMS	293.41	KIMS	250.59	KIMS	335.53	UME	539.4
4	UMG	71.34	ECME	148.97	ECME	308	ECMG	255.98	ECMG	349.18	ECME	598.67
5	KIMS	87.22	KIMS	182.52	KIME	323.67	KIME	258.8	KIME	366.25	ECMG	622.12
6	KIME	89.02	KIME	187.7	UMG	330.26	MME6	261.37	UME	389.89	KIMS	653.21
7	UME	101.87	UME	192.62	UME	365.02	UMG	268.87	UMG	403.32	MME6	738.98

❖ Average track error of MME for 2022 Typhoons, compared with member models
- Generally better than members(1st or 2nd) up to 72-hour forecast.
- Worse than members as the spread between members increased after the 72-hour forecast