The evaluation of a Multi-Model Ensemble Prediction System

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KMA Multi-Model Ensemble (MME)

❖A multi-model ensemble prediction system that integrates global and ensemble models used for weather forecast in KMA

❖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

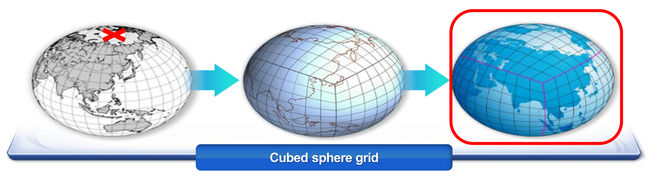
❖2022 version : UMG+ECMG+UME+ECME+KIMG+KIME

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.



❖ 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.

Weights $W_i = \dfrac{\frac{1}{E_i^2}}{\sum_{i=1}^{n}\frac{1}{E_i^2}}$ MME $F = \sum_{i=1}^{n} W_i F_i$ Weighted average

W_i : Weight of i–th model F_i: i–th model

E_i : Error of i–th model F : MME

$$F = W_{umg}F_{umg} + W_{kimg}F_{kimg} + W_{ecmg}F_{ecmg} + W_{ume}F_{ume} + W_{kime}F_{kime} + W_{ecme}F_{ecme}$$

Comparison by weight calculation methods (MME 2020)

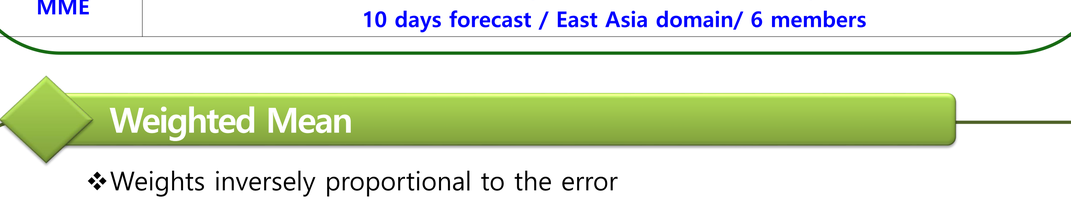
❖AVG: Same weights (simple mean)

❖E1R f(x,y,t,z,v) : different weights for each grid point and forecast time (considering both the temporal and spatial distribution of the weights)

❖E2R f(t,z,v) : different weights (horizontal domain-averaged) for each forecast time ➔ considering only the temporal distribution of weights

❖E3R f(x,y,z,v) : different weights for each horizontal grid (time-averaged) ➔ considering only the spatial distribution of weights

❖E4R f(z,v) : Averaged weight for grid points and forecast times ➔ Not considering the temporal & space distribution of weights.



❖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

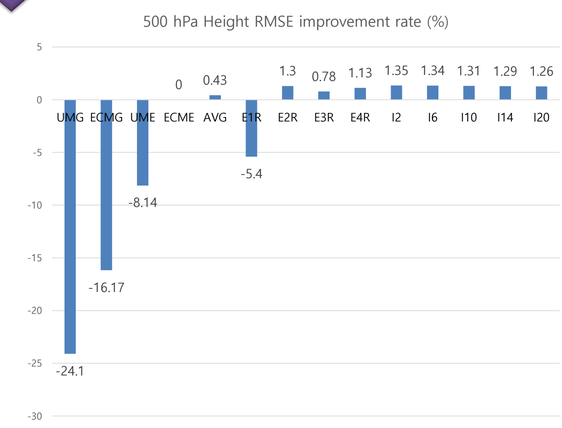
❖I20 : Average of E2R for the past 10 days from now

RMSE improvement rate

❖RMSE improvement rate(%) = $\dfrac{BMEM - EXP}{BMEM} \times 100$

- BMEM : RMSE of best member model
- EXP : RMSE of MME or member models

Verification – RMSE (MME 2020)



<500 hPa height>

❖ECME : Best member model

❖Except for E1R, MME 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

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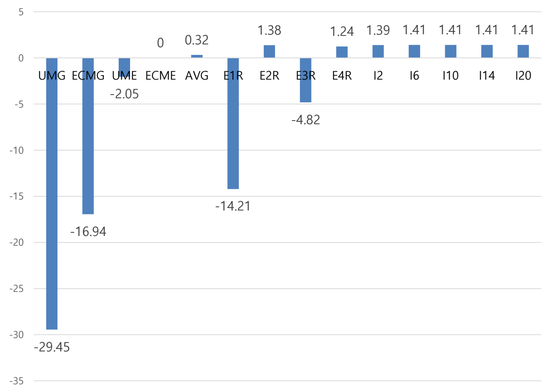
❖MME better than ECMWF ensemble model except E1R and E3R

❖E2R > E1R, E3R and E4R

❖E1R and 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.



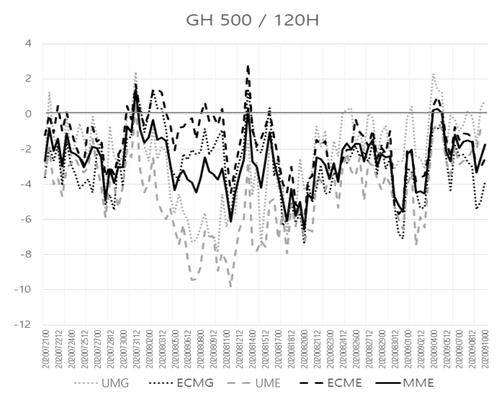
<RMSE Improvement Rate(%)Table>

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 UM analysis field as a reference field for weight calculation.

Verification – BIAS (MME 2020)

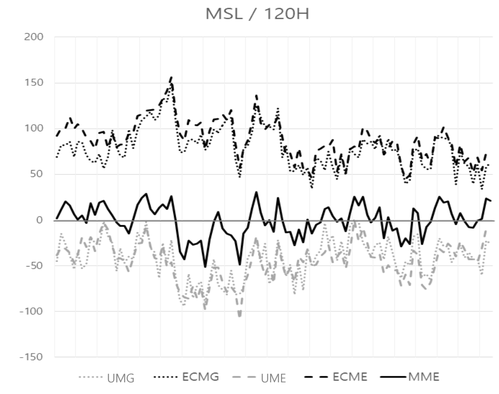


❖ECMWF models: weak negative bias

❖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.

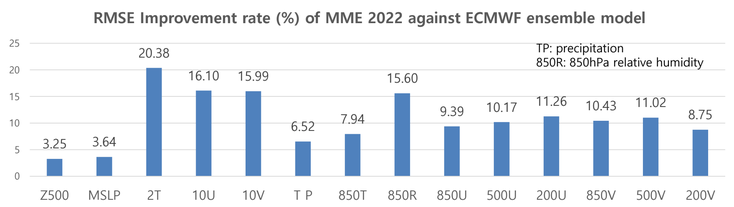
❖E2R selected as the optimal weight.

❖E1R(detailed) and E4R(simple) did not showed better performance than E2R

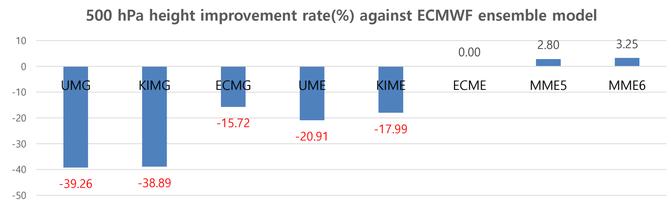
❖Averaging weights for several days not much effect

❖When the bias of the member model evenly distributed, smallest MME bias.

Verification – RMSE (MME 2021 & 2022)



MME 2022 (MME6) better than ECME



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