기상청
수치모델링센터

Development of heat wave impact-based forecast guidance using multi-model ensemble(MME) system

- How to use MME for impact forecast
- The performance of MME-based impact forecast

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KMA heat wave impact-based forecast

- Operation Period (May ~ September)
- Based on maximum feels-like temperature (wind chill temperature) from maximum temperature and the humidity
- 2 Types
  - DIMF: impact-based forecast based on forecaster's deterministic forecast (not model forecast)
  - MEPS: impact-based forecast based on Multi-Model Ensemble Prediction system

- feels − like Temperature : $T_{\mathrm{feel}} = -0.2442 + 0.55399\,T_w + 0.45535T_a - 0.0022{T_w}^2 + 0.00278T_wT_a + 3.0$
  - RH : Relative Humidity(%) T_a : Temperature(℃) T_w : Wet bulb temperature
  - $T_w = T_a * a\tan\left(0.151977(RH + 8.313659)^{1/2}\right) + \mathrm{atan}(T_a + \mathrm{RH}) - \mathrm{atan}(\mathrm{RH} - 1.67633) + 0.00391838(\mathrm{RH})^{3/2} * \mathrm{atan}(0.023101 * \mathrm{RH}) - 4.686035$

MME-based heat wave impact-based forecast

❖ Data

- ✓ 7 member models, total 93 members
  - Maximum feels-like temperature from maximum temperature and the humidity (dew point temperature)
- ✓ Observation from AWS (Automatic Weather Station)
  - Maximum feels-like temperature
  - Used for Bias correction

❖ Member models of KMA-MEPS

Member models	Resolutions	Forecast time
KIM global	12km L91	10 days
UM global	10km L70	
IFS global	9km L135	
UM global ensemble	32km L70 M25	
IFS global ensemble	18km L135 M51	
UM local	1.5km L70	2 days
UM local ensemble	2.2km L70 M13	3 days

- UM: Unified Model from UKMO (since 2010)
- KIM: Korean Integrated Model (since 2020)
- IFS: ECMWF model output received in real time

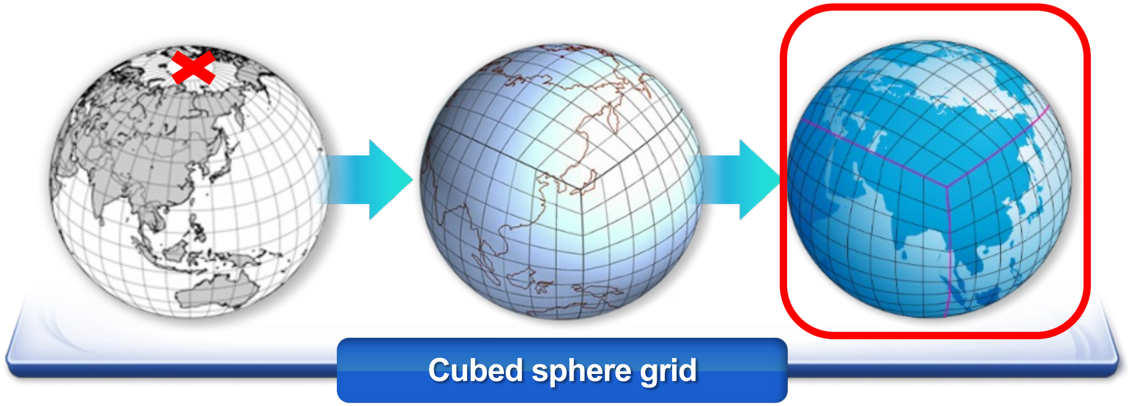
- MME to help the deterministic decision in short and medium range forecast: Weighted average
- MME for impact-based forecast: Probability information

KIM, UM, and ECMWF models

❖ UM (Unified Model) : KMA's operational model, introduced from UKMO in 2010 and used for 13 years.

❖ KIM (Korean Integrated Model) : KMA's new operational model which was developed by KIAPS* for 9 years since 2011 and has been in operational since 2020. Cubed sphere grid system.

** KIAPS: Korea Institute of Atmospheric Prediction System*



❖ IFS (ECMWF models) : Received from ECMWF every day

Bias Correction (Decaying Average)

Bias correction for all members (total 93 members)

- Mean bias correction

- Simple mean bias correction for 10 days

ex) Fday1(33.4) → 33.4 – ((1+2+3+4)/4 = 2.5)

= 30.9

- Same weights for 10 days bias.

[Bias Correction] Decaying Average [w=0.2]

$f(t_0) = F(t_0) - O(t_0)$

$f(t) = (1 - w)f(t-1) + w\big(f(t_0)\big)$

w: decaying weight, f (t) : corrected bias,

f(t0) : bias , F : forecast Value, O : Observed Value

- Bias correction by Decaying average (optimal w=0.2) for 10 days

ex) Fday1(33.4) → 33.4 – (1 → 1*0.8+2*w=1.2 → 1.2*0.8+3*w=1.56 →

1.56*0.8 + 4*w :2.048) = 33.4 – 2.048 = 31.352

- 10 days bias correction
- The different bias correction weights used for 1 day bias to 10 day bias
- Recent day bias: larger weights, old day bias: smaller weights.

GEV (Generalized Extreme Value) Probability distribution

❖ More realistic probability

- Hierarchical Bayesian Method ➔ GEV
- Normal gaussian distribution ➔ Realistic distribution
- 7 members including ensemble mean ➔ All 93 members used

: GDPS, LDPS, KIMG, ECMG, $\overline{EPSG}$, $\overline{LENS}$, $\overline{ECME}$)

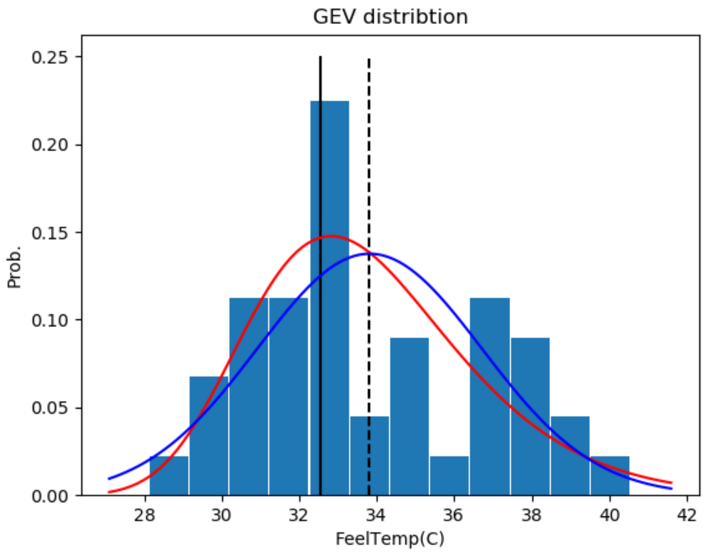
➔ GDPS, LDPS, KIMG, ECMG, $EPSG(25)$, $LENS(13)$, $ECME(51)$

GEV Fitting

$$F(x;\mu,\sigma,\xi) = exp\left\{-\left[1+\frac{\xi(x-\mu)}{\sigma}\right]^{-1/\xi}\right\}$$

Parameter - μ : location , σ : scale , ξ : shape

To define the impact level



- Difference between Gaussian and GEV distribution generated from same data
  Red: GEV / Blue: Gaussian
- Generate GEV curve from 93members.
- The probability of each temperature decided from GEV distribution curve

❖ Gaussian and GEV

- Gaussian : Distribution based on mean value. Symmetric
- GEV : More realistic distribution based on distribution shape. Non-symmetric

Decision Table based on probability

Maximum feels-like Temperature(℃)	31	33	35	38
0.01<P≤0.05	Safe	Safe	Safe	Caution
0.05<P<0.25	Safe	Safe	Caution	Caution
0.25≤P≤0.33	Safe	Concern	Caution	Caution
0.33<P≤0.5	Safe	Concern	Caution	Warning
0.5<P≤0.66	Concern	Caution	Warning	Warning
0.66<P	Concern	Caution	Warning	Alarm

Heat wave (5 impact levels) : Safe Concern Caution Warning Alarm

ex) 0.5 < The probability of maximum feels-like temp 33 ℃ <= 0.66 : Caution
0.5 < The probability of maximum feels-like temp 35 ℃ <= 0.66 : Warning

If the impact level different for each T, high impact level selected.
➔ If 'caution' from 33 ℃ and 'warning' from 35 ℃, 'warning' selected

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Verification

- Data
  - ✓True state by observation: Impact analysis chart by 175 observation stations
  - ✓Impact-based forecast by forecaster's deterministic forecast : ***DIMF***
  - ✓Impact-based forecast by Multi-model ensemble : ***MEPS***

- Period
  - ✓ : July ~ August (00UTC) of 2022

- DIMF: Deterministic Impact-based Forecast
- MEPS : Multi-model Ensemble Prediction System

Contingency table

<4 Categories>

		Observation			
		Concern	Caution	Warning	Alarm
Forecast	Concern	(1)	(2)	(3)	(4)
	Caution	(5)	(6)	(7)	(8)
	Warning	(9)	(10)	(11)	(12)
	Alarm	(13)	(14)	(15)	(16)

Ex) Concern: (1): obs-concern / fcst-concern ➔H
(2)+(3)+(4): obs-not concern / fcst-concern ➔F
(2)+(9)+(13): obs-concern / fcst-not concern ➔M

<2 Categories>

For Concern		Observation	
		Concern	Not Concern
Forecast	Concern	H=(1)	F=(2)+(3)+(4)
	Not Concern	M=(2)+(9)+(13)	C=(6)+(7)+(8)+(10)+(11)+(12)+(14)+(15)+(16)

For Warning		Observation	
		Warning	Not Warning
Forecast	Warning	H=(11)	F=(9)+(10)+(12)
	Not Warning	M=(3)+(7)+(15)	C=(1)+(2)+(5)+(6)+(4)+(8)+(13)+(15)+(16)

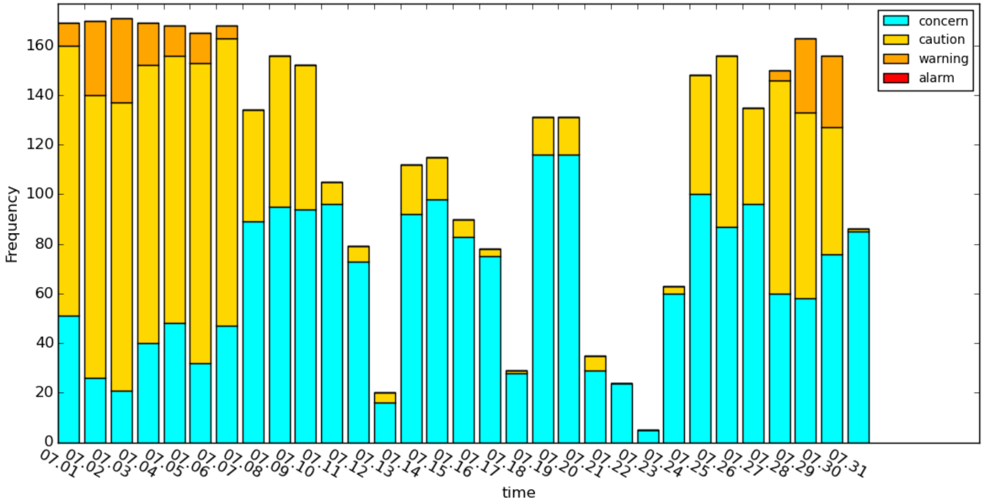
Verification Index

Index	Equation	Name or Meaning
Bias	= (H+F)/(H+M)	Greater than 1 : Overestimation Smaller than 1 : Underestimation
POD	= H/(H+C)	Probability of Detection
FAR	= F/(H+F)	False Alarm
F	= F/(F+C)	
TS(CSI)	= H/(H+F+M)	Threat Score (Critical Success Index)
ETS	= (H-ar)/(H+F+M-ar), * ar=(H+F)(H+M)/n	Equivalent Threat Score
ACC	= (H+C)/(H+F+M+C)	Accuracy
KSS	= POD-F	
HSS	=2(HC-FM)/ ((H+M)(M+C)+(H+F)(F+C))	

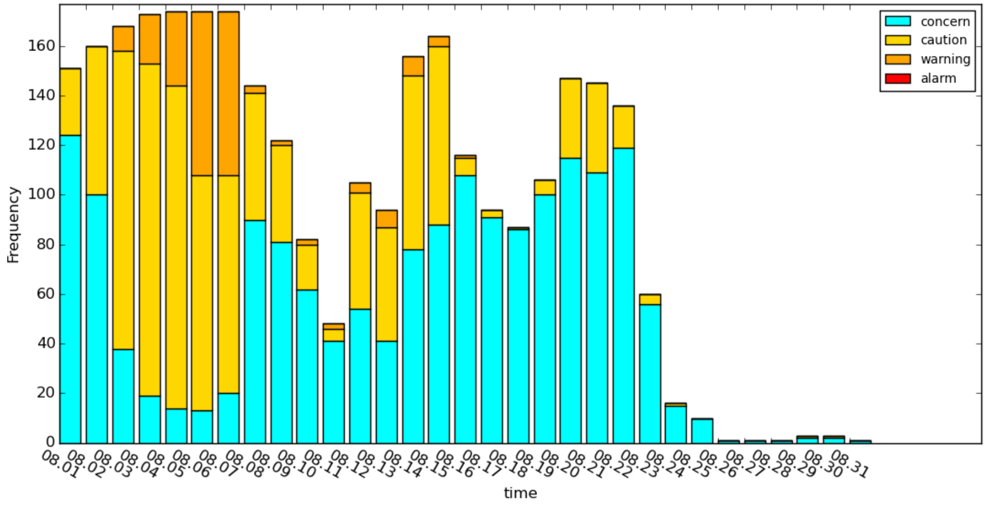
From 2 Category Contingency table

Impact Analysis by Observation

July



August



- ❖ Impact level time series by observation for July and August (Truth)
- ❖ Heat wave definition by observation ➔ 2 continuous days feels-like T

Level	July	August
Safe	1792	2409
Concern	2016	1680
Caution	1435	1111
Warning	182	225
Alarm	0	0

- ❖ Daily Maximum feels-like Temperature
  - Continuously Higher than
    - 31°C for 2 days: Concern
    - 33°C for 2 days: Caution
    - 35°C for 2 days: Warning
  - Higher than
    - 38°C just for 1 day: Alarm

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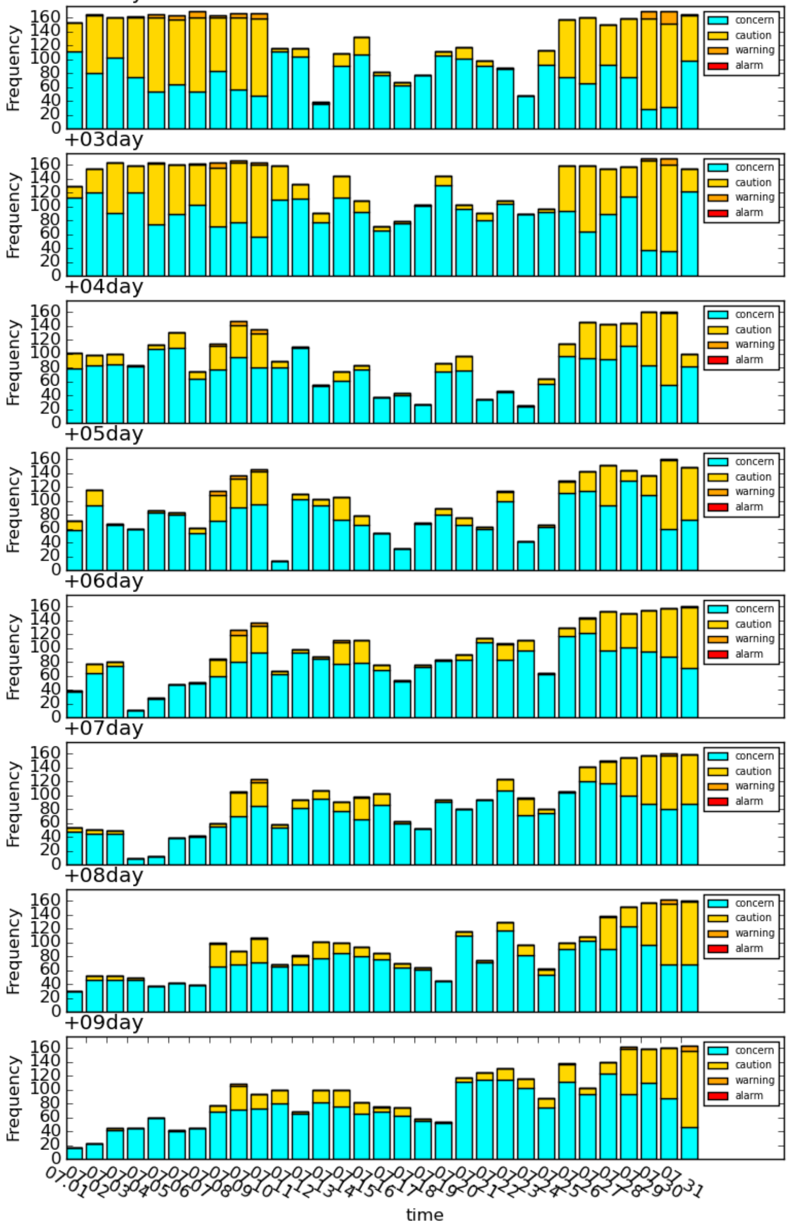
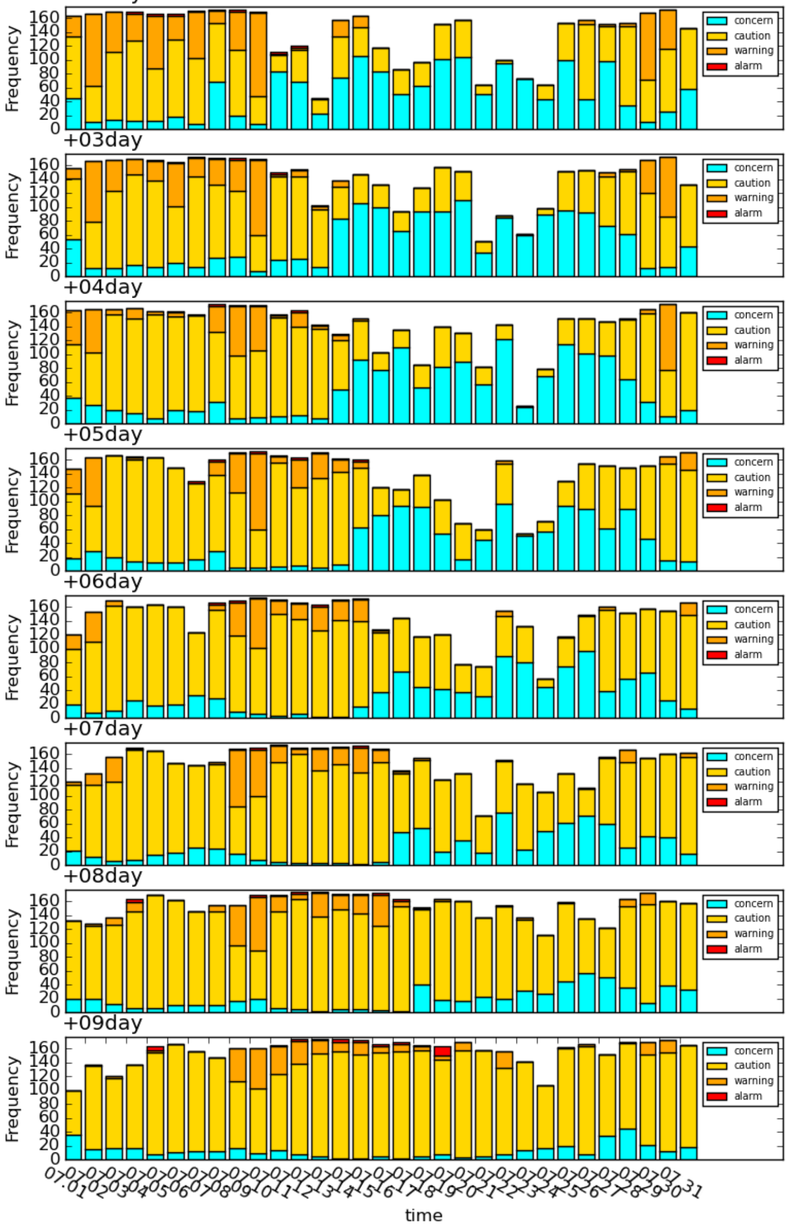
July (DIMF : MEPS : Observation)

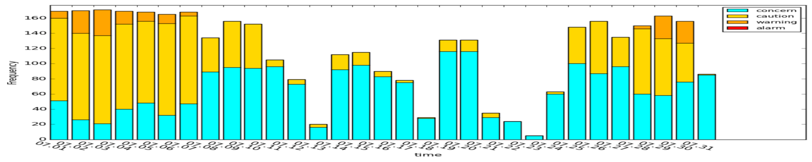
DIMF



MEPS



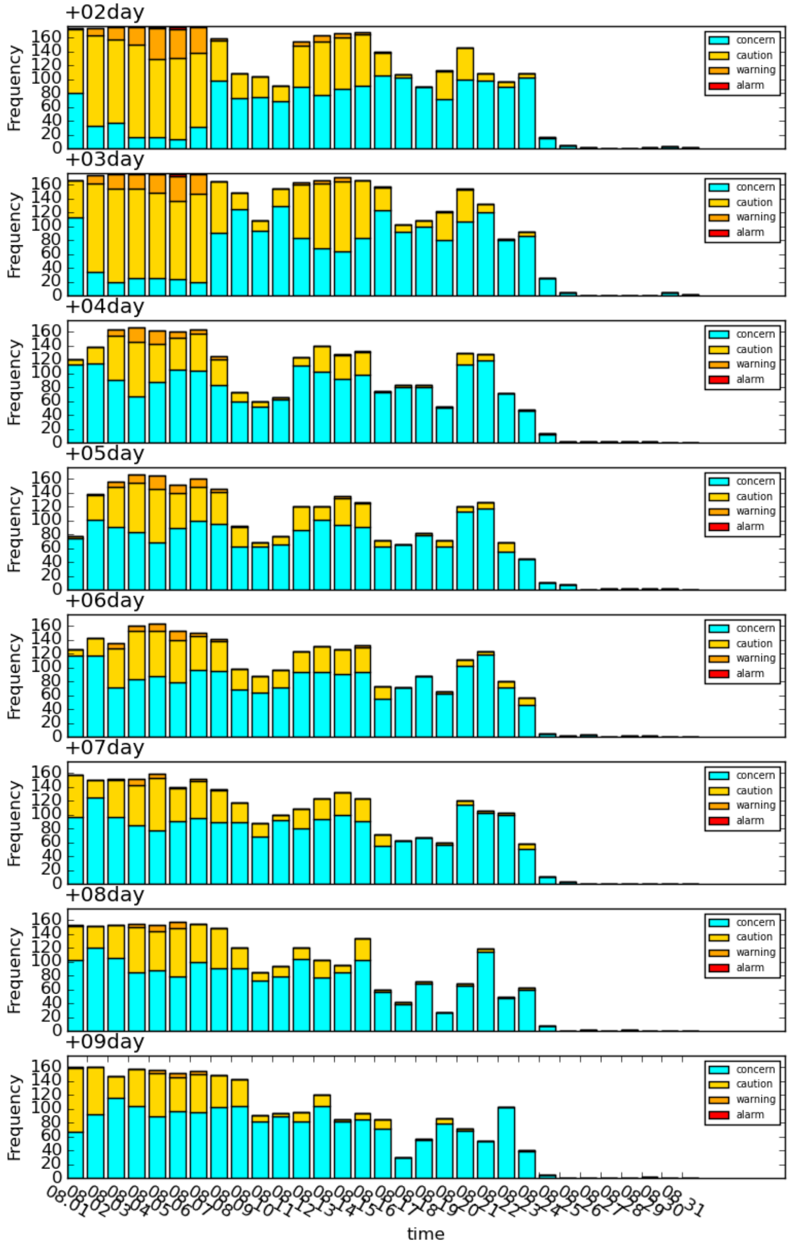
Observation



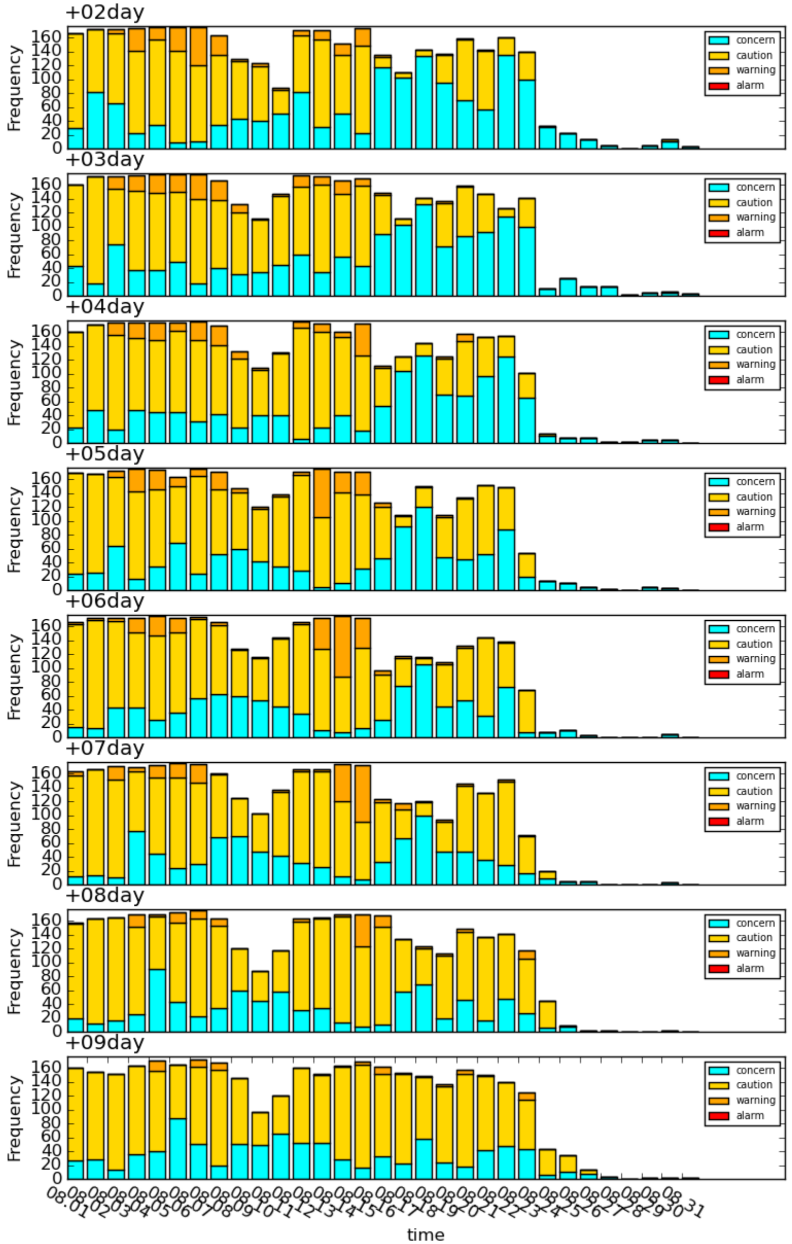
❖ Heat wave time series
- DIMF: Underestimation
- MEPS: Overestimation

Safe :
Concern
Caution
Warning
Alarm

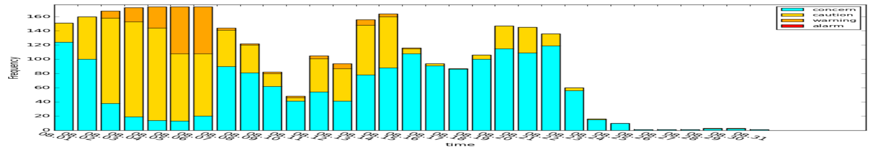
DIMF



MEPS



observation



- ❖ DIMF: Underestimation
  Less high impact level
- ❖ MEPS: Overestimation
  More high impact level

Safe :
Concern
Caution
Warning
Alarm

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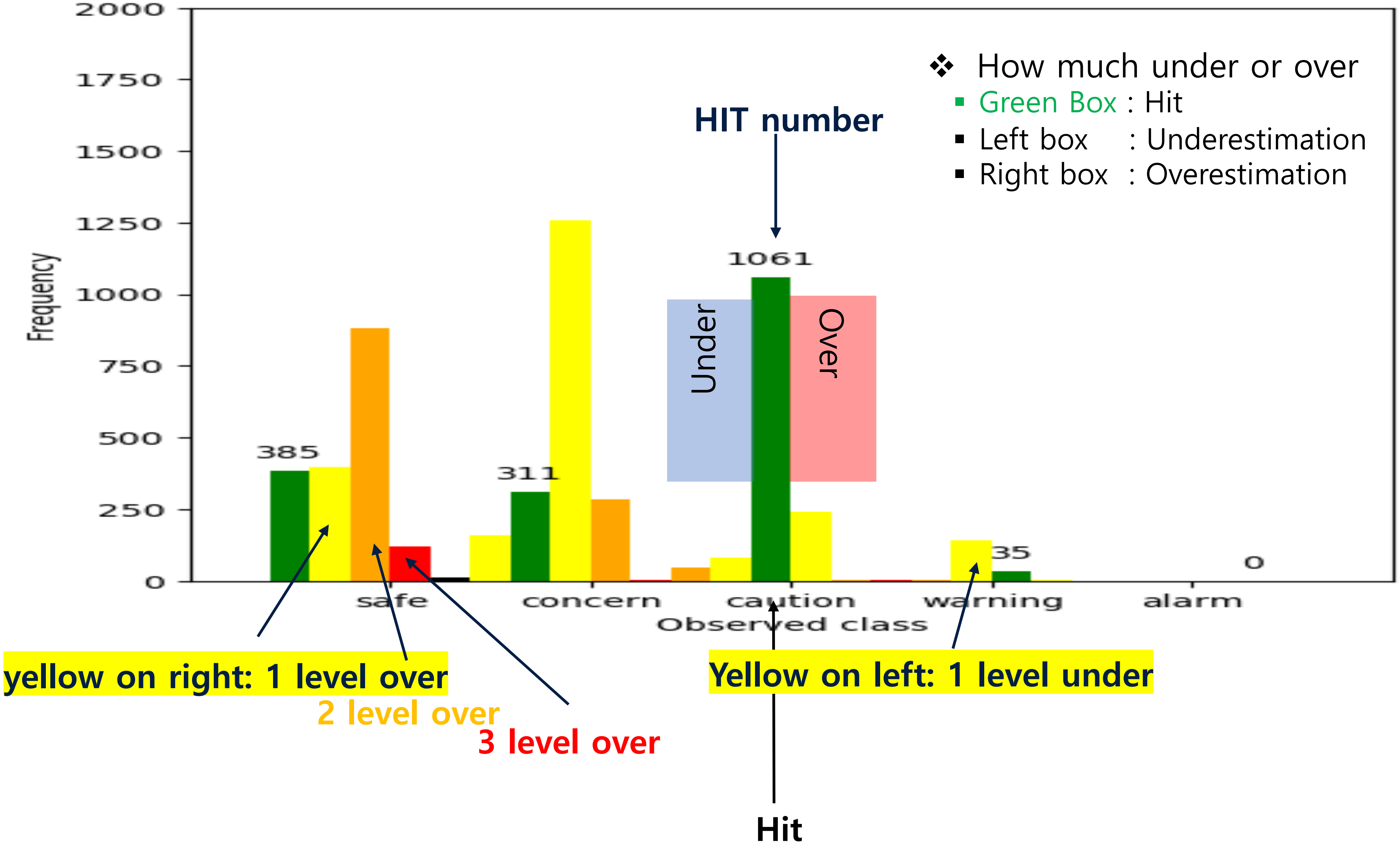
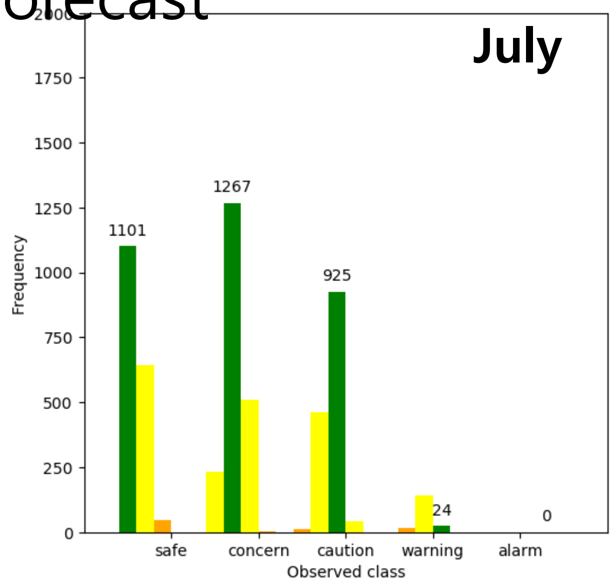
Results (Under : Over-estimation by impact level)

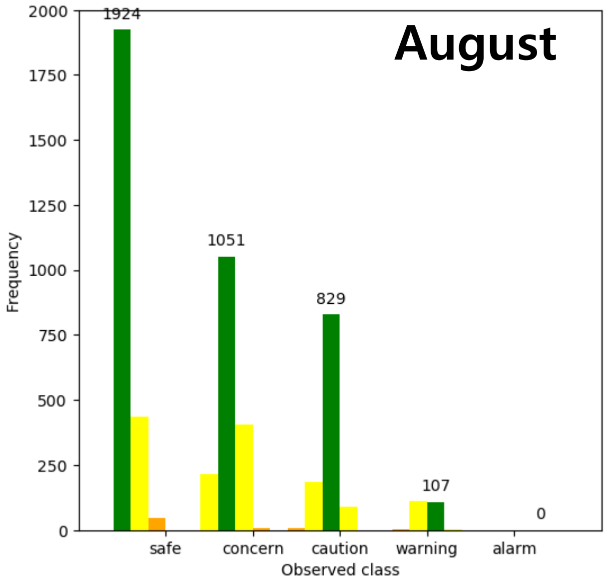


Results (Under : Over-estimation by impact level)

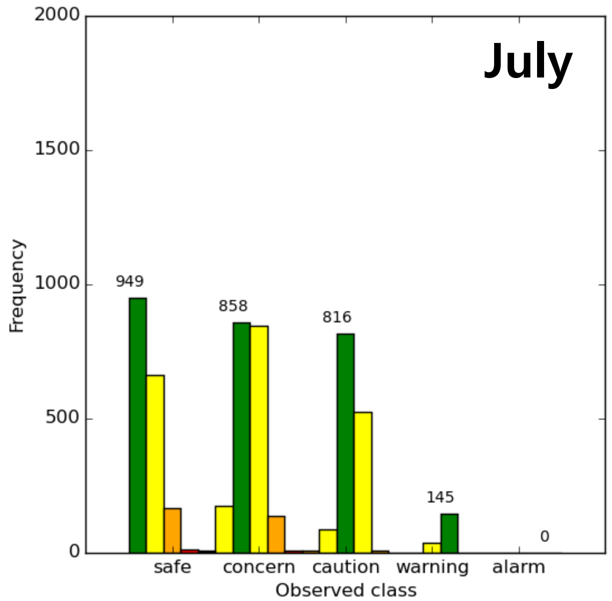
+2 day forecast

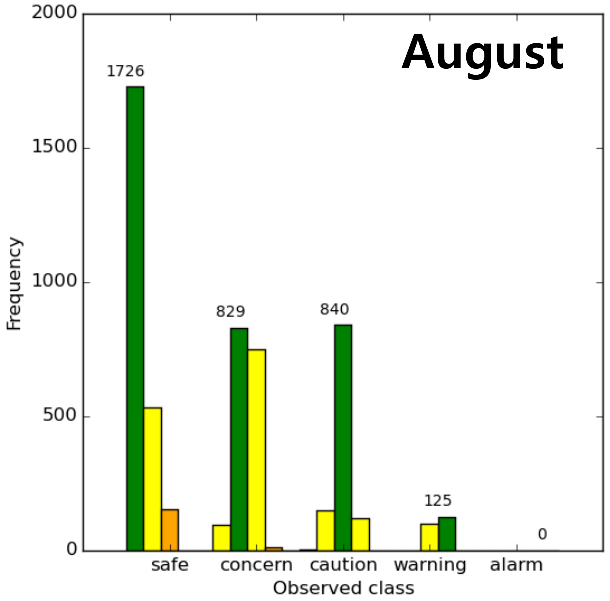
DIMF





MEPS





- ❖ For 2day forecast
  DIMF: More hits for 'Safe' ~ 'Caution'
  MEPS: More hit for 'Warning'

- ❖ Generally, DIMF better than MEPS
- ❖ Forecaster's forecast is quite good for 2 day forecast

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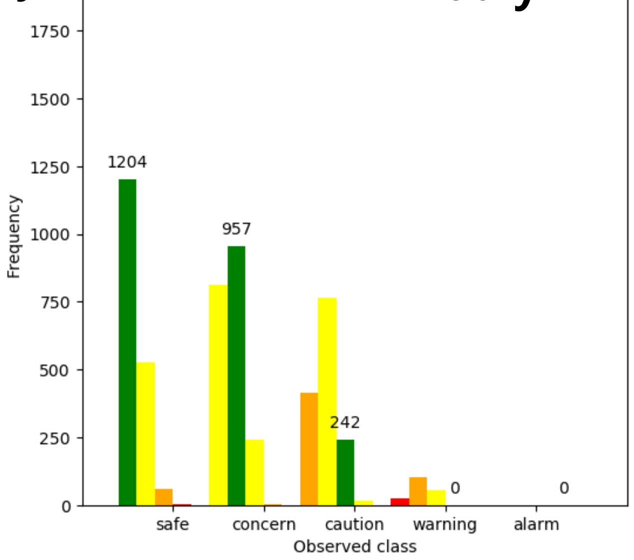
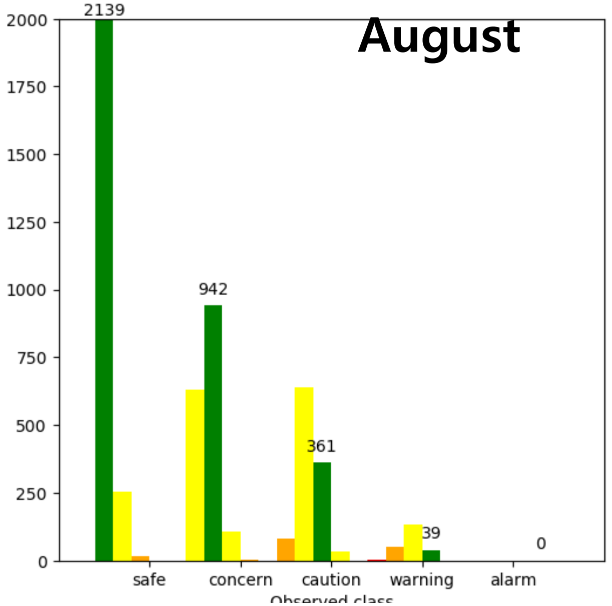
Results (Under : Over-estimation by impact level)

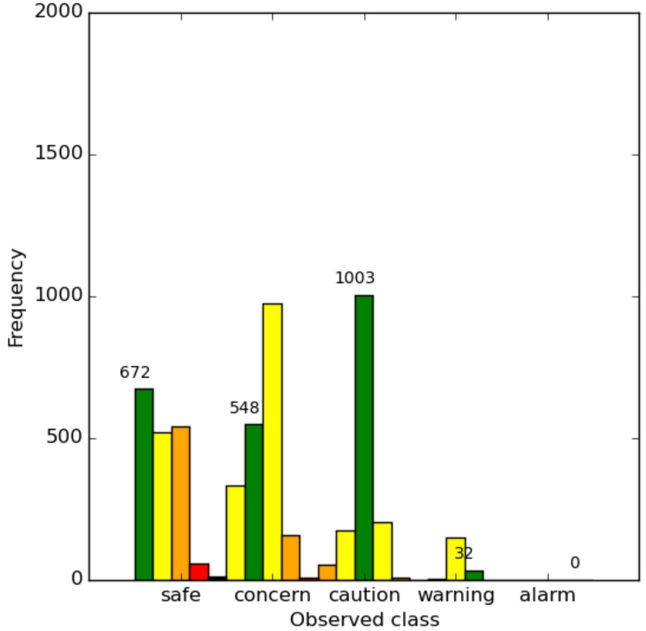
+5 day forecast

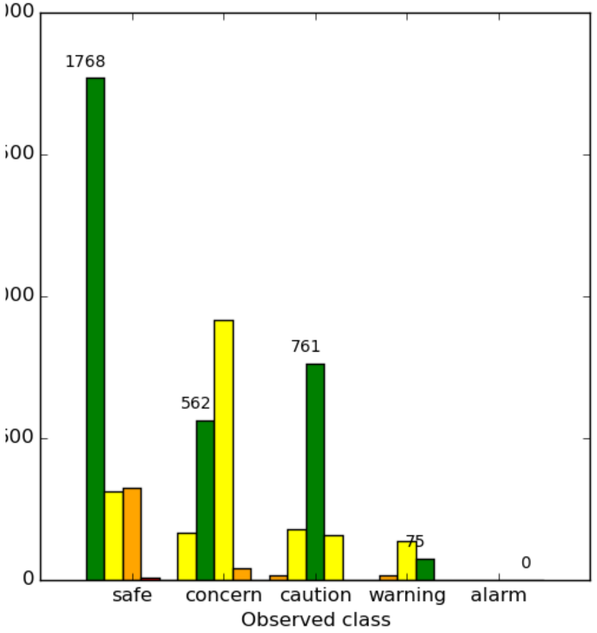
DIMF





MEPS





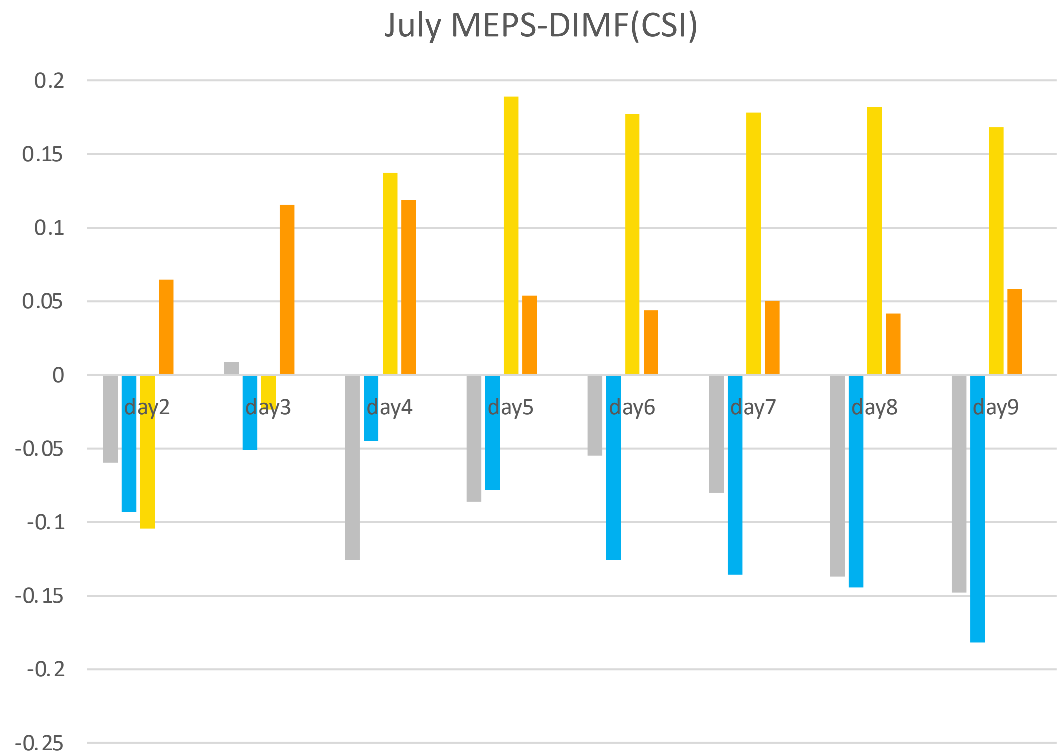
- ❖ For 5day forecast
  DIMF: More hits for 'Safe' ~ 'Concern'
  MEPS: More hit for 'Caution' ~ 'Warning'

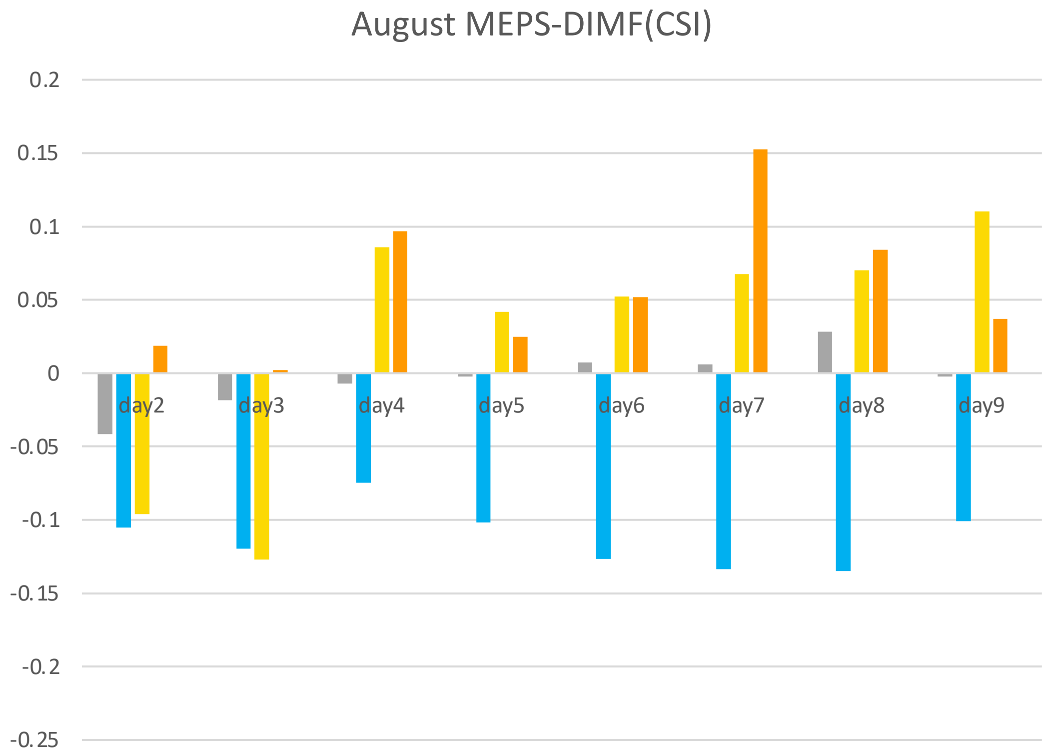
- ❖ MEPS better than DIMF at high impact levels
- ❖ MEPS better than forecaster's forecast at high impact levels of heat wave for 5 day forecast

CSI differences (MEPS-DIMF) by the impact levels

+ : MEPS better

Safe Concern Caution Warning Alarm





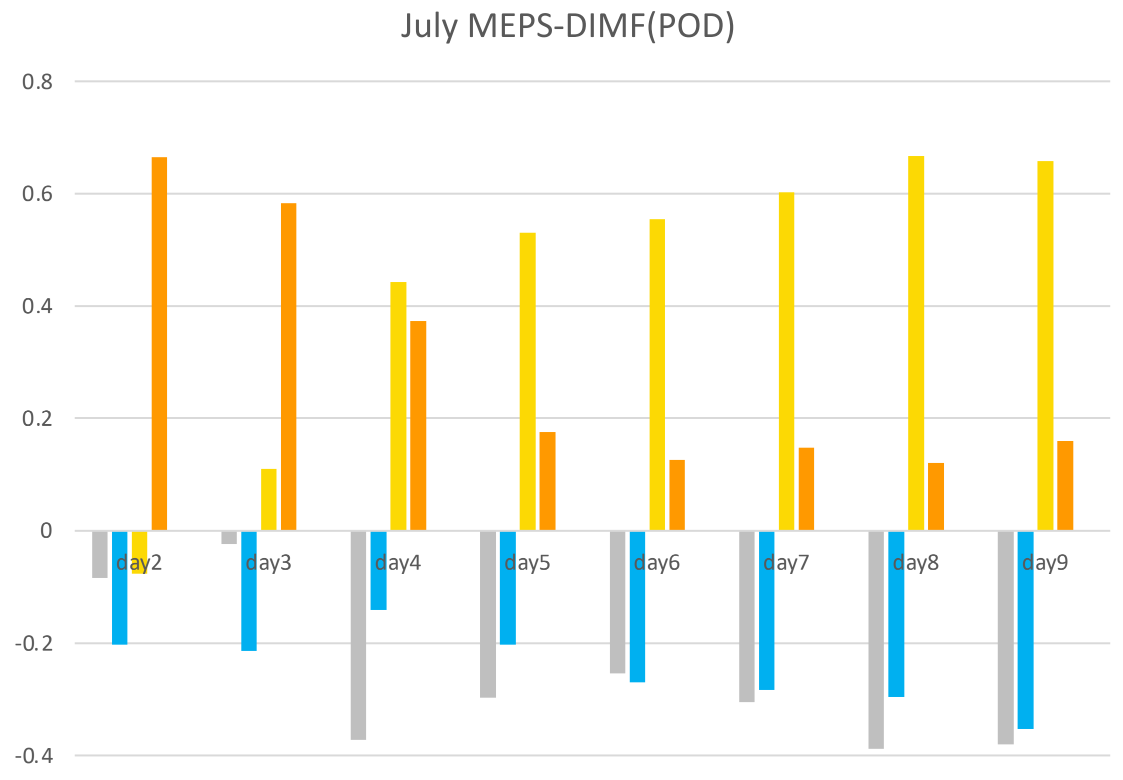
❖ MEPS
- Better at 'Caution' and 'Warning'
- Worse at 'Safe' and 'Concern'

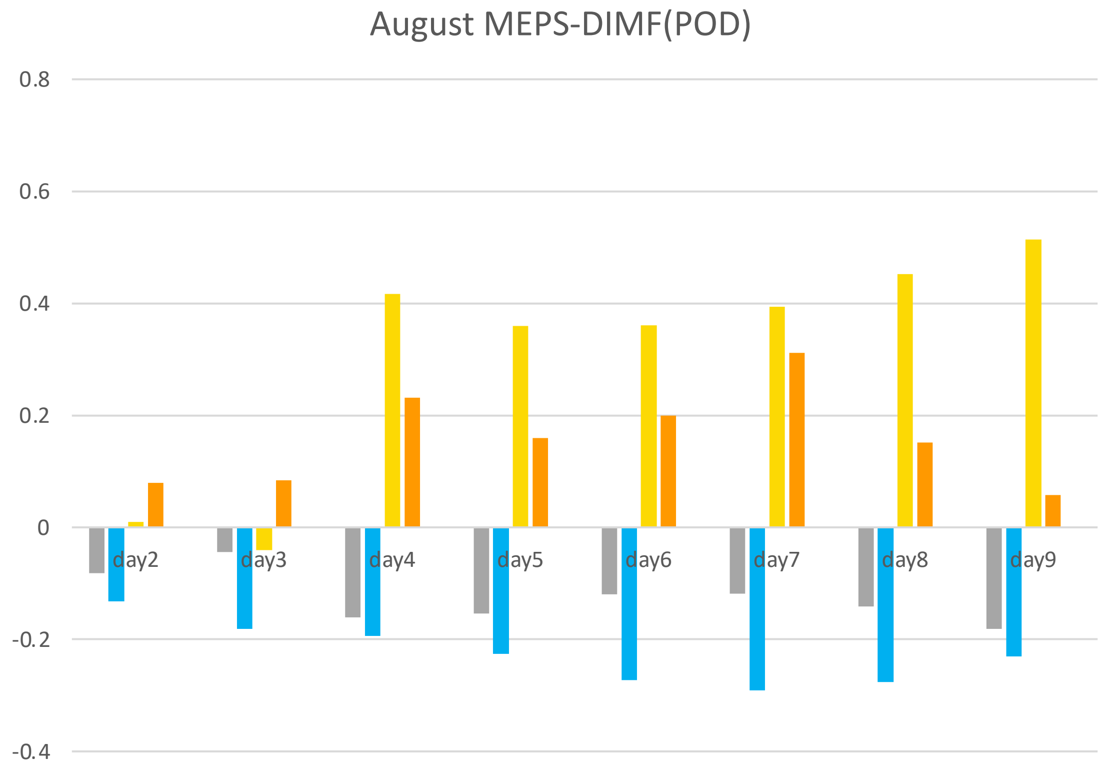
❖ MEPS
- Better at 'Caution' and 'Warning' after 4 day forecast
- Worse at 'Safe' and 'Concern'
- Worse at the most levels for 2 and 3 day forecast

POD differences (MEPS-DIMF) by the impact levels

+ : MEPS better

Safe Concern Caution Warning Alarm



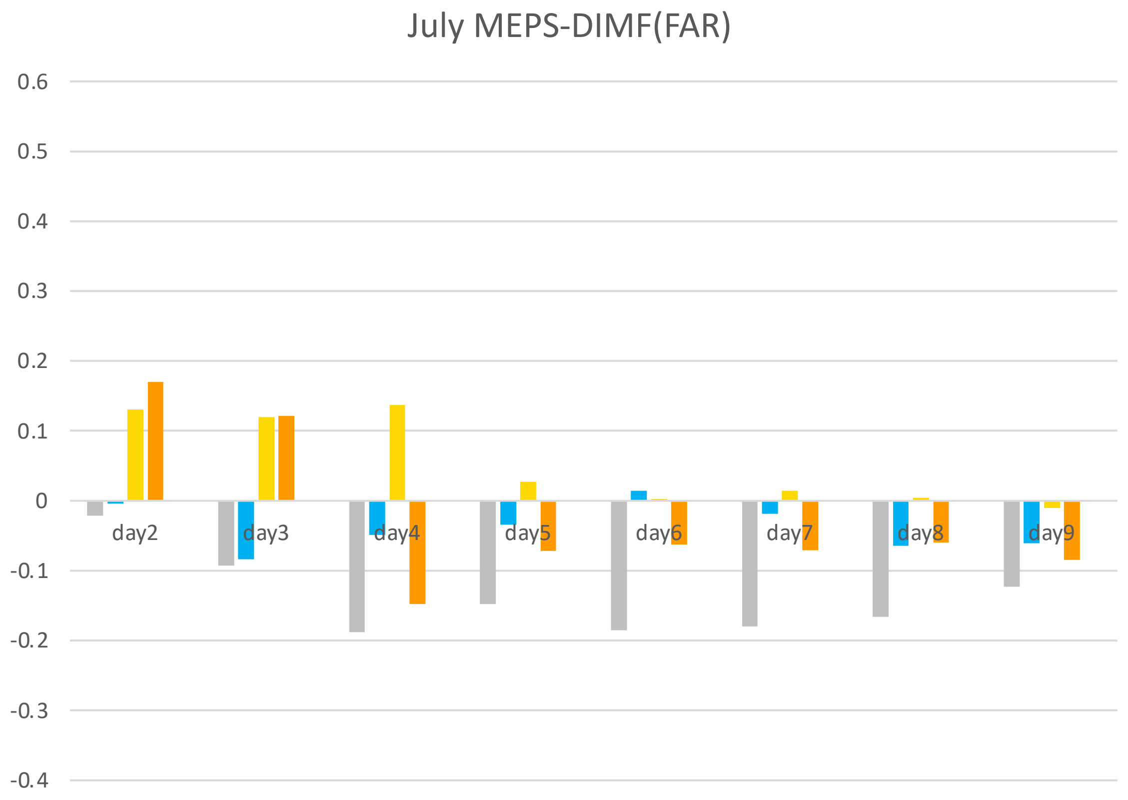


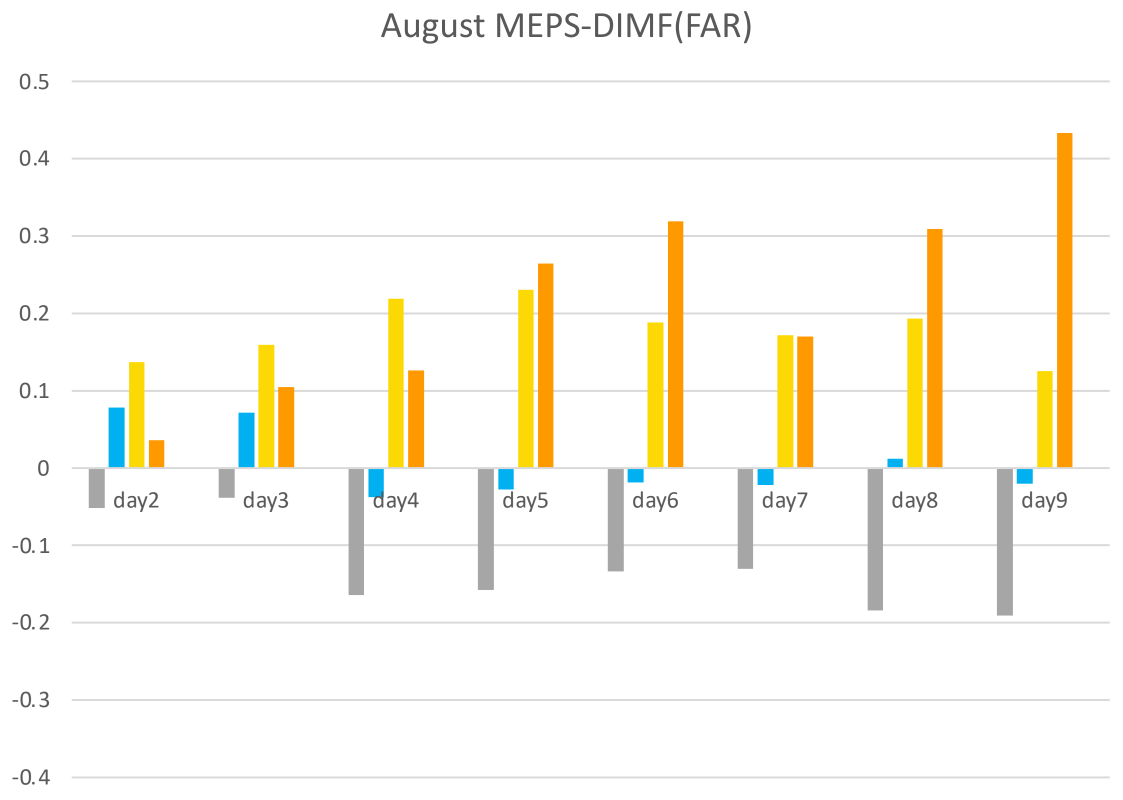
- MEPS
  - Better at 'Caution' and 'Warning'
  - Worse at 'Safe' and 'Concern'

FAR differences (MEPS-DIMF) by the impact levels

- : MEPS better (means that MEPS shows less false alarm)

Safe Concern Caution Warning Alarm





❖ MEPS
- Higher false alarm at 'Caution' and 'Warning' before 4 day forecast
- Less false alarm at 'Safe'

❖ MEPS
- Higher false alarm at 'Caution' and 'Warning'
- Less false alarm at 'Safe'

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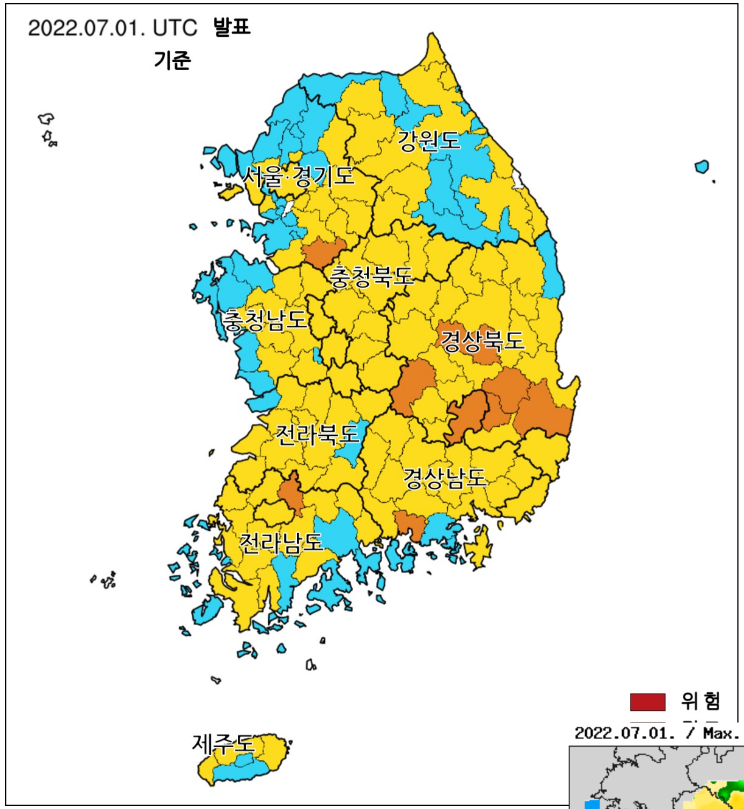
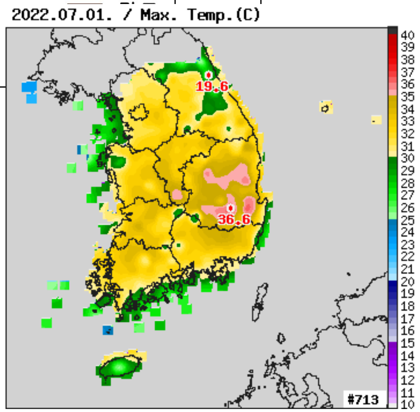
Improved Case

+3 day forecast

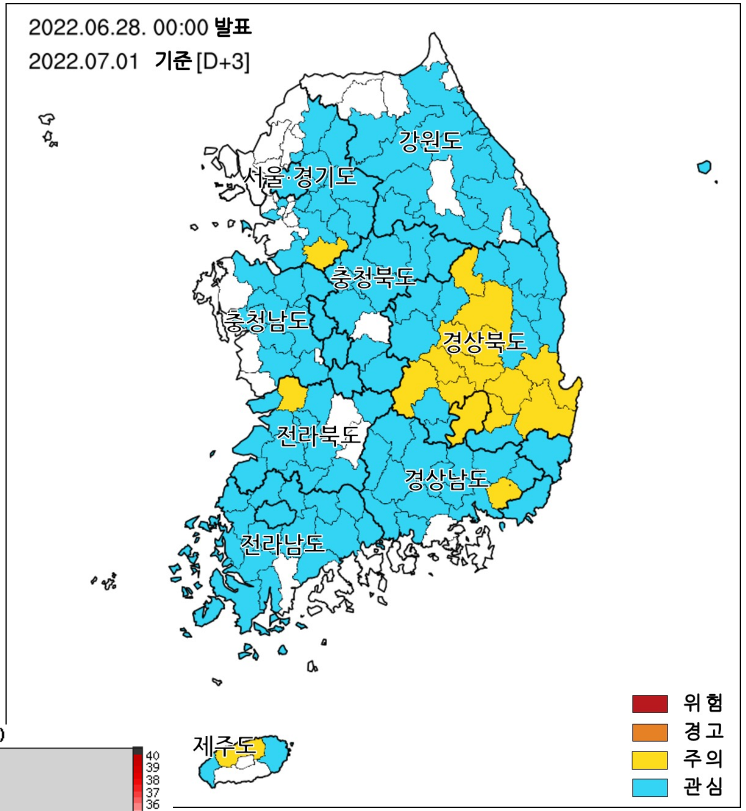
MEPS better



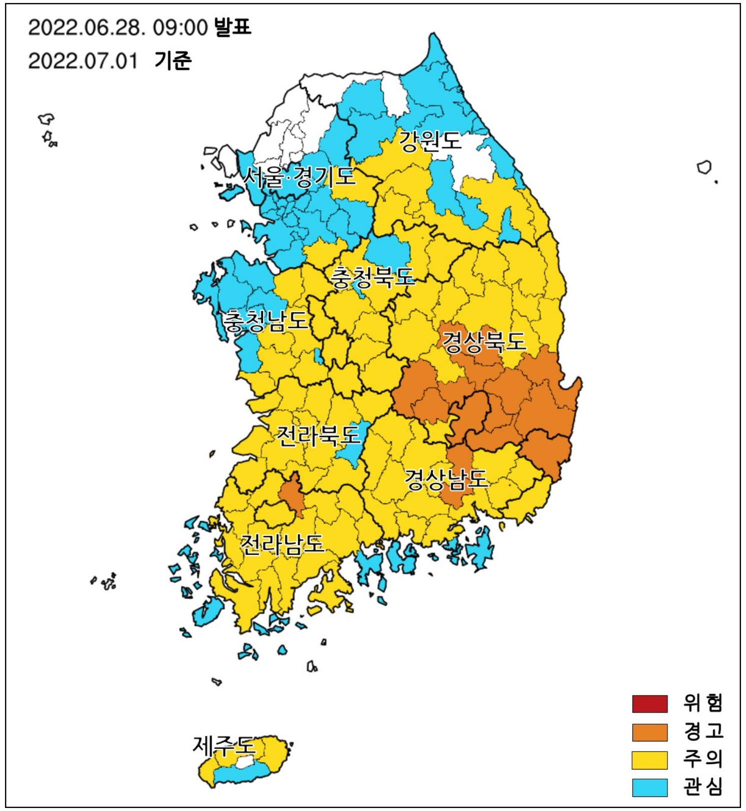
Heat wave
By Observation



Max T observation



DIMF (under-estimate)

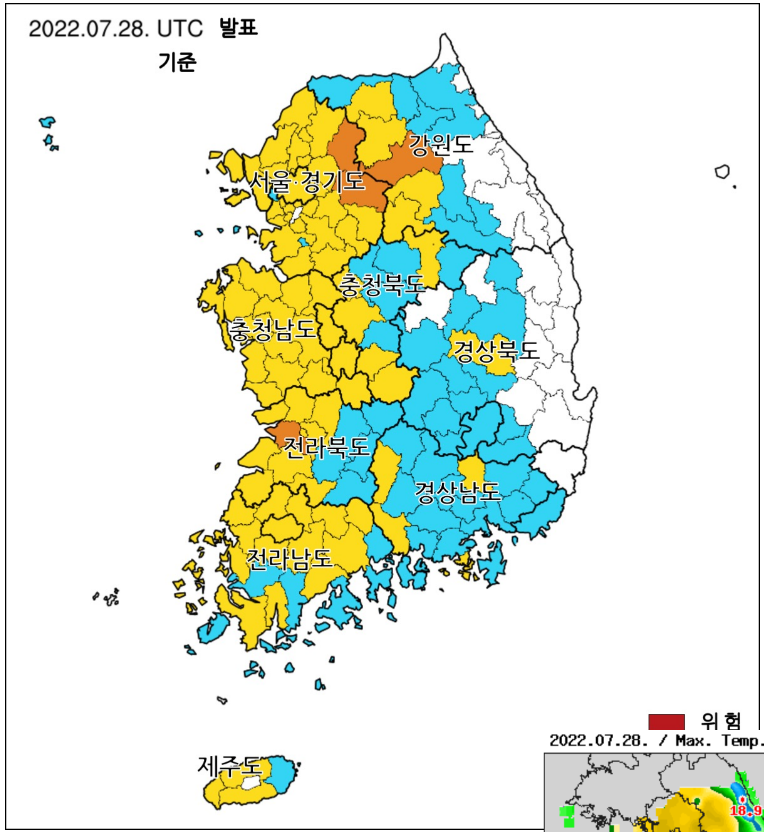


MEPS (similar to obs)

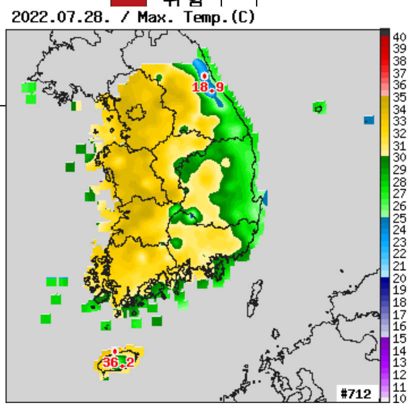
Improved Case

+5 day forecast

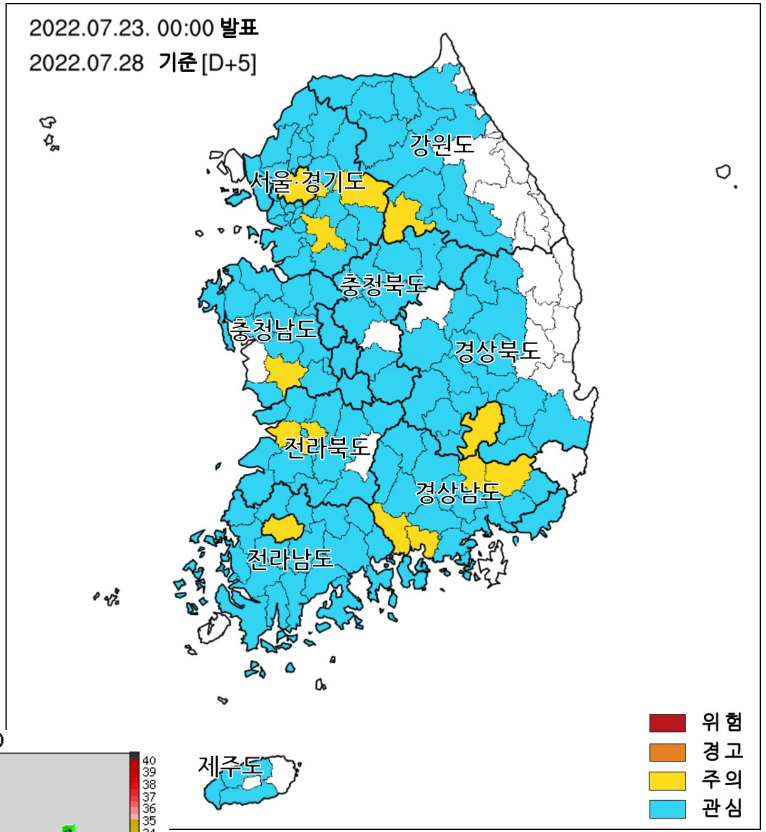
MEPS better



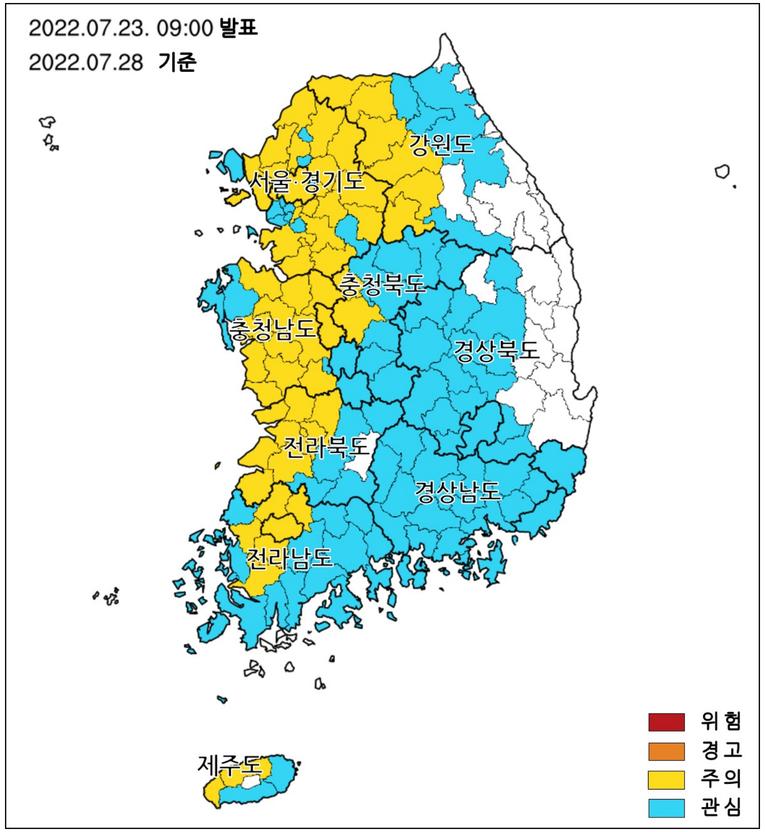
Heat wave
By Observation



Max T observation



DIMF (under-estimate)



MEPS (similar to obs)

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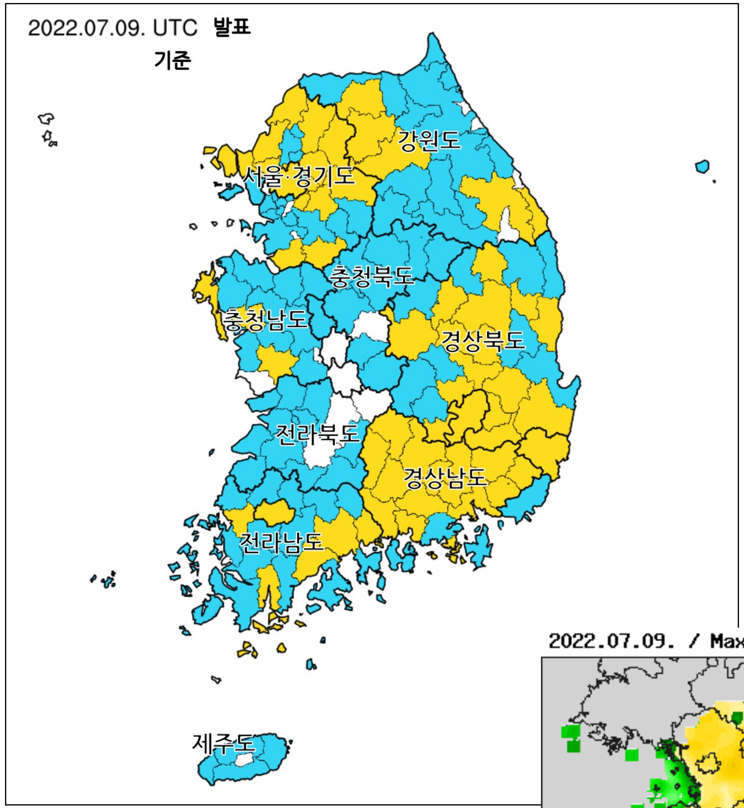
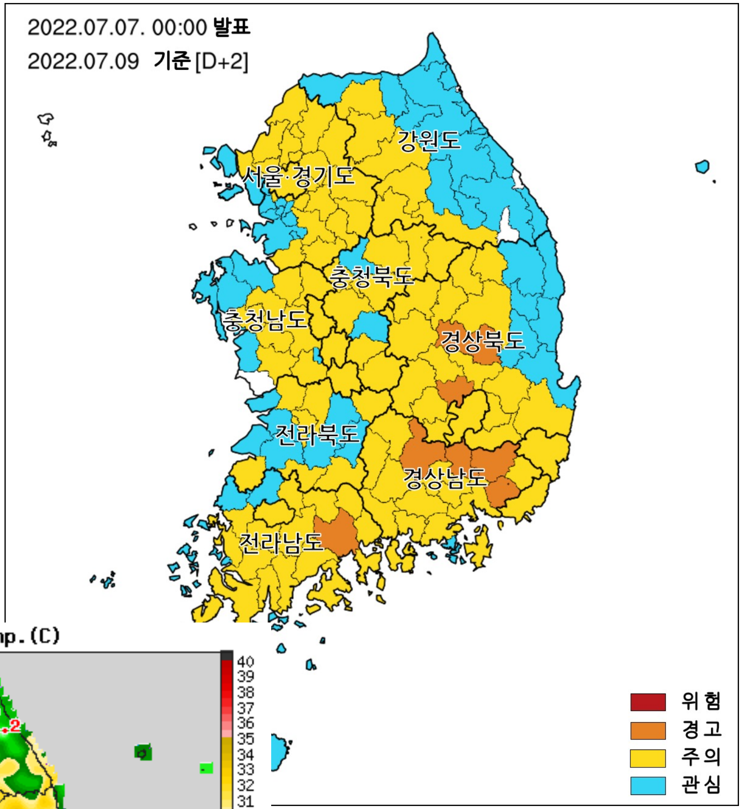
Worse Case

+2 day forecast

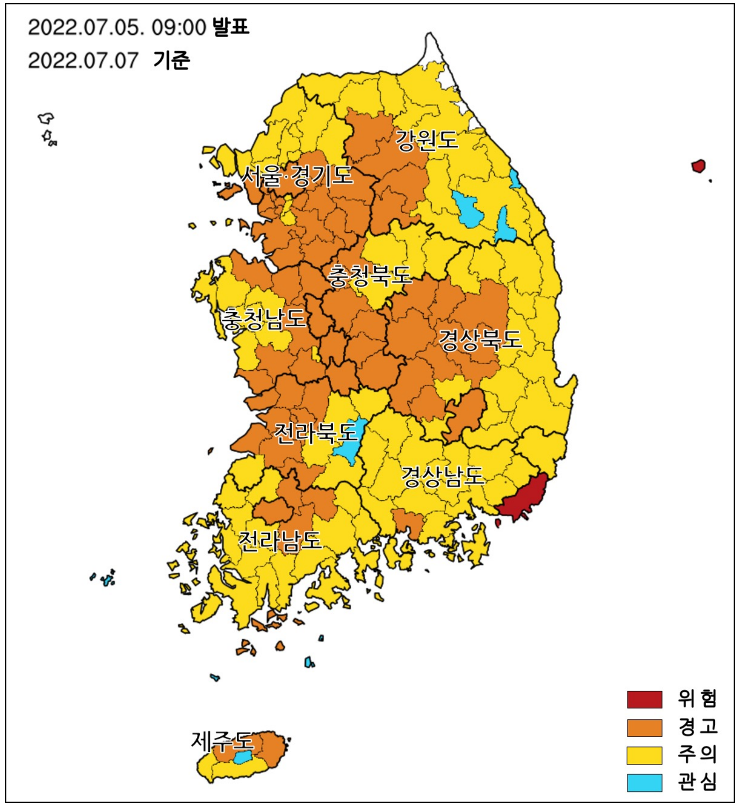
DIMF better



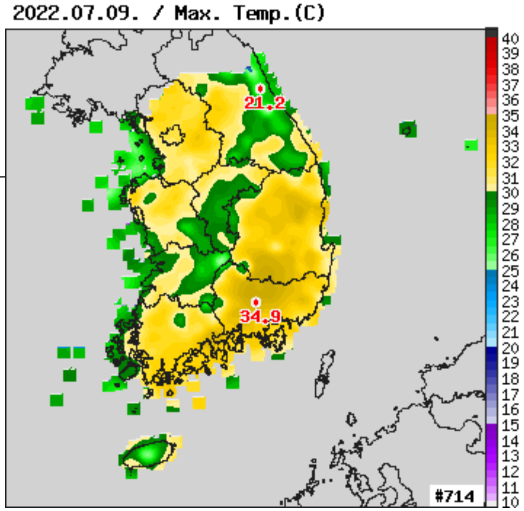
Heat wave
By Observation



DIMF



MEPS (over-estimate)



Max T observation

Summary

Summary

- The heat wave impact-based forecast by Multi Model Ensemble produced improved results than forecaster's deterministic forecast at high impact level ('Caution' and 'Warning') after 4 day forecast
- However, the results before 3 day forecast were poor and somewhat overestimated

Plans

- Introduction of KIM ensemble model, Apply continuous 2 day T concept
- Optimize probability table of heat wave level to define the impact level better

Future strategy for KMA's impact-based forecast

- 2~3 day forecast : forecaster's forecast-based
- Medium and long range forecast : ensemble-based