Analyzing the Effect of Bias Correction on Marine Weather Predictions from the WaveWatch3 Model (also known as WW3) Using Artificial Intelligence Techniques

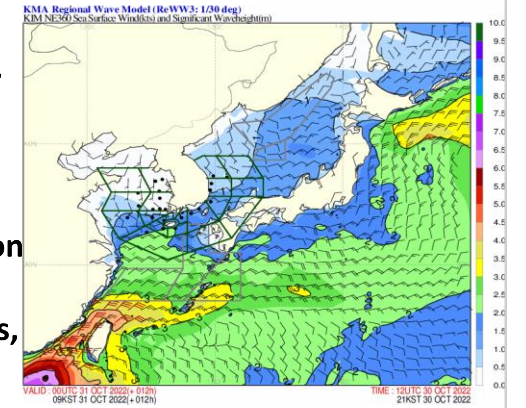
Korea Meteorological Administration

October 4, 2023

Yong June Park [1], Seung Kyun Park [1], Soyoug Lee [1], Taeyun Lee [1],
Sang Hun Park[2], Do Yeon kim[2]

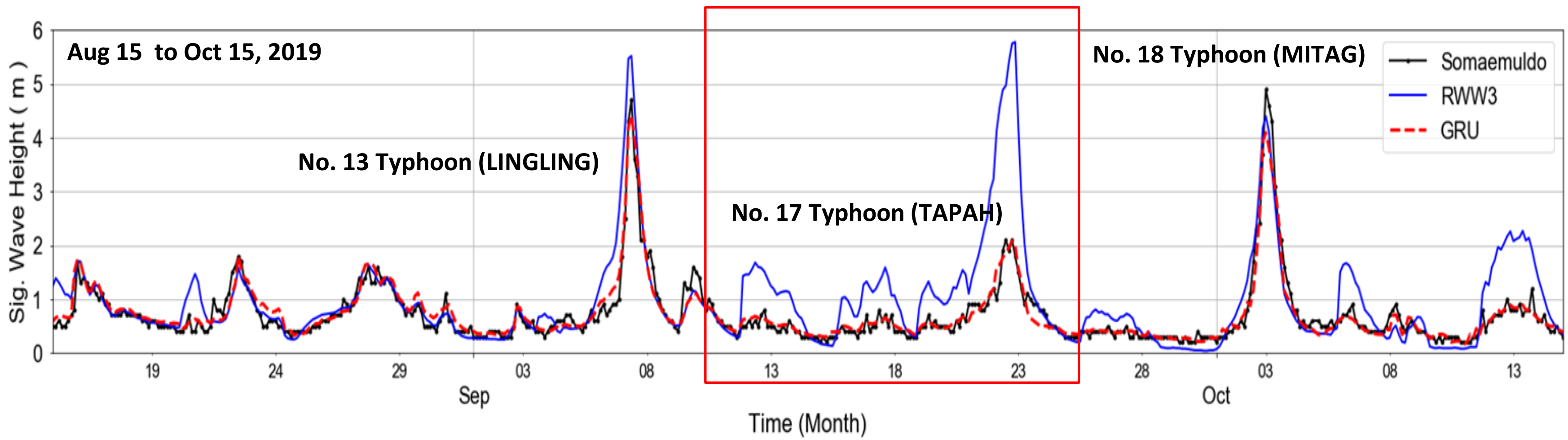
Contents

1. Introduction



- The KMA is currently operating various numerical prediction models for marine weather forecasts and warnings.
  - Wave prediction models: GWW3, RWW3, CWW3, EWW3, KWW3

- Various methods are being applied to provide more accurate marine weather information to the public and related organizations.
  - These methods provide information on waves, swells, storms, tidal waves, rip currents, and total water levels.



- Recently, we constructed a point-by-point artificial intelligence model using the Gated Recurrent Unit (GRU) technique and calculated the significant wave height prediction correction of the regional blue prediction system (RWW3).

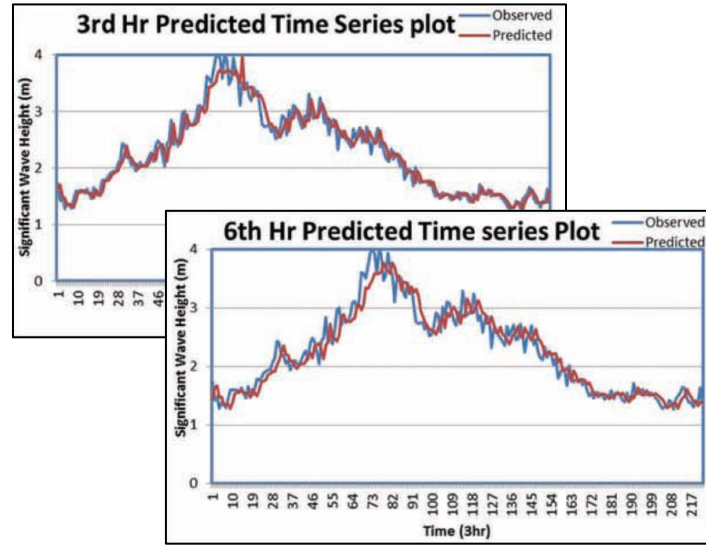
- However, the GRU method has the drawback of inefficiency when dealing with a large number of locations and elements, as the model needs to be configured and trained for each point and element, separately.

- In this study, a Multi-Layer Perceptron (MLP) technique capable of multiple point/element correction was employed using a single model.

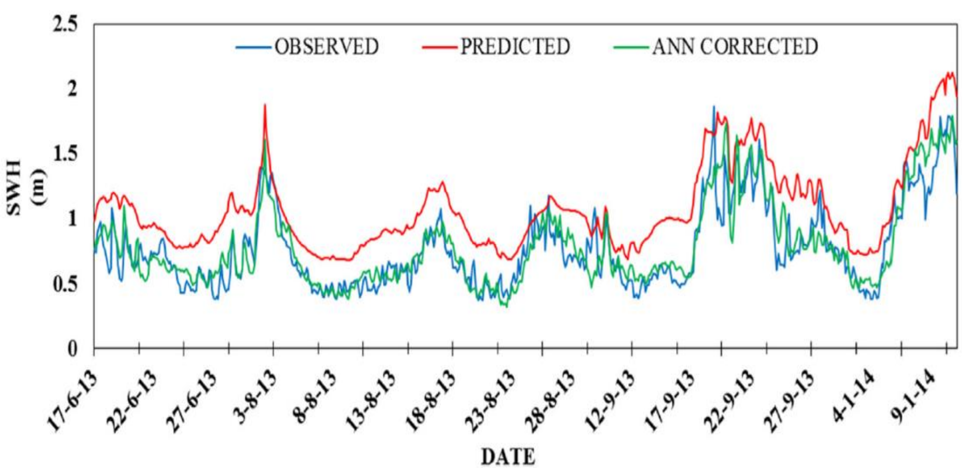
1. Introduction

Examples of Application of Artificial Intelligence Techniques

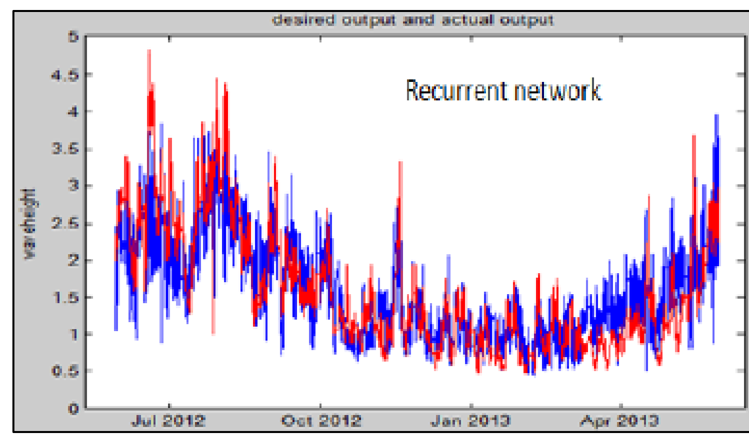
Vimala et al. (2014)	**Significance wave height prediction using ANN method**
Vimala et al. (2014)	**Comparison of significant wave high prediction results using WAM and ANN method**
Londhe et al. (2016)	**Significance wave height prediction using ANN method**
Srinivasan et al. (2017)	**Significance wave height prediction using FFNN and RNN method**



Comparison of predictions and observations using ANN method (Vimala et al., 2014)



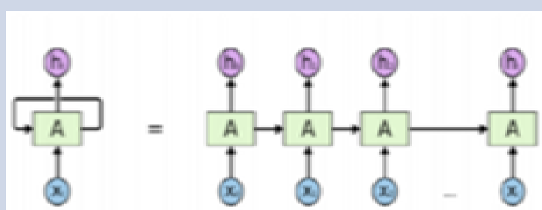
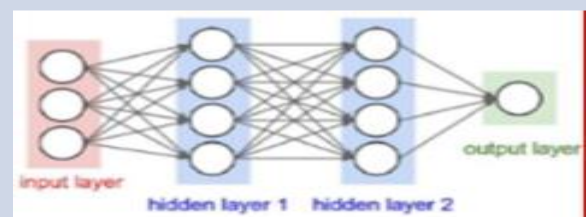
INCOIS (MIKE), ANN forecast comparison results (Londhe et al., 2016)



RNN+Bayesian predictions and observations (Srinivasan et al., 2017))

1. Introduction

Types of Artificial Intelligence Technique Algorithms

	CNN (Convolution Neural Networks)	RNN (Recurrent Neural Network)	MLP (Multi-Layer Perceptron)	SVM (Support Vector Machine)
Definition		It is a deep learning analysis model with a recursive structure that reflects data sequence. It is a technique that focuses on specific data to improve the performance of the model information. 	An analytical model that combines perceptron (mimicking the human nervous system) into several layers - The beginning of deep learning algorithms 	

"Using the KMA"

2. Data and Metho

1. AI correction for point-by-point

Correction Points (Elements)

- **(RWW3)** Significant wave height, maximum wave height, wave period, and wind speed
- **(GWW3)** Significant wave height, wind speed

Artificial Intelligence Techniques

- Multi-Layer Perceptron (MLP)

How to Configure

- AI learning using observation and prediction data from 16 marine meteorological buoys
- Study period: 2017 to 2019 (3 years)

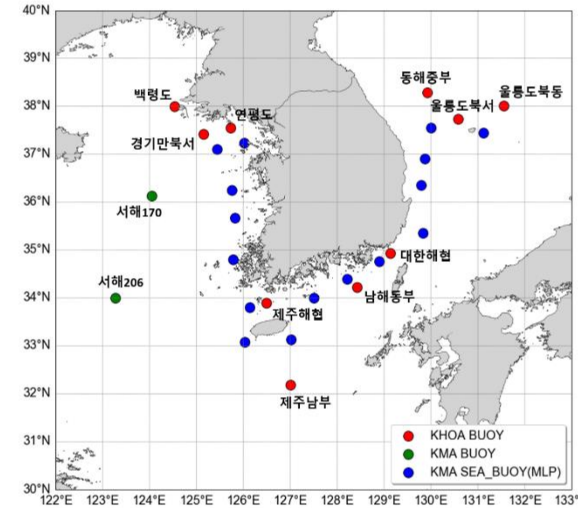


Fig 1. AI Learning (Blue) and Test (Red, Green)

		Point-by-Point (Observation name)
Learning Points	**Buoy (10m)**	Deokjeokdo, Incheon, Oeyeondo, Buan, Chilbaldo, Chujado, Marado, Seogwipo, Geomundo, Tongyeong, Geojedo, Ulsan, Pohang, Uljin, Ulleungdo-Dokdo, East Sea
Test	**Buoy (10m)**	West Sea 170 and West Sea 206
		Baeknyeong-do, Gyeonggi-man Northwest, Yeonpyeong-do, Jeju Strait, Jeju South, Namhae East, Korean Strait, Ulleungdo Northwest, Ulleungdo Northeast, Central East Sea

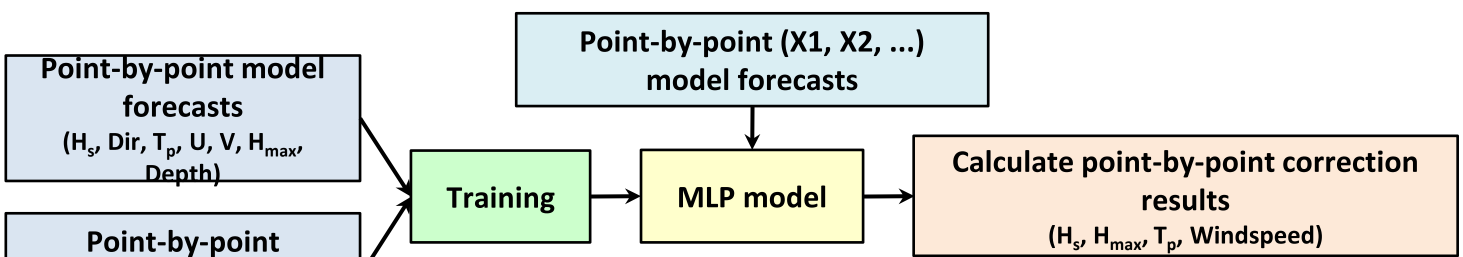


Fig 2. MLP algorithm training and calibration flow chart

2. Data and Method

2. AI Spatial Correction Test

- **Correction point (Element)**
  - (RWW3) Significant wave height

- **Test**
  - Unlearned points: 12 stations
    (KMA 2 stations; KHOA 10 stations)

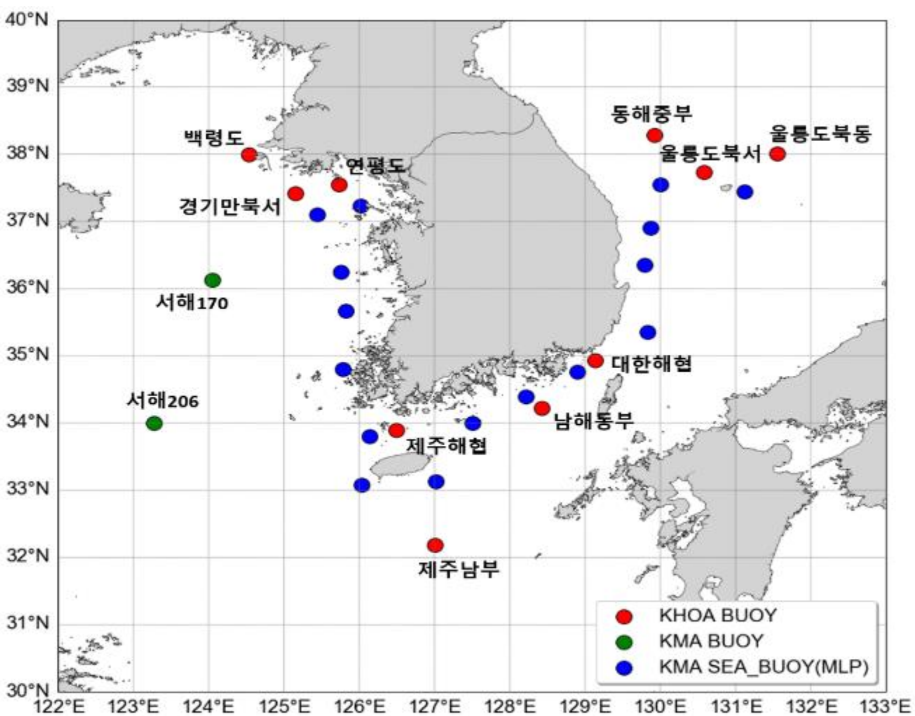


Fig 1.AI Learing (Blue), Test (Red, Green)

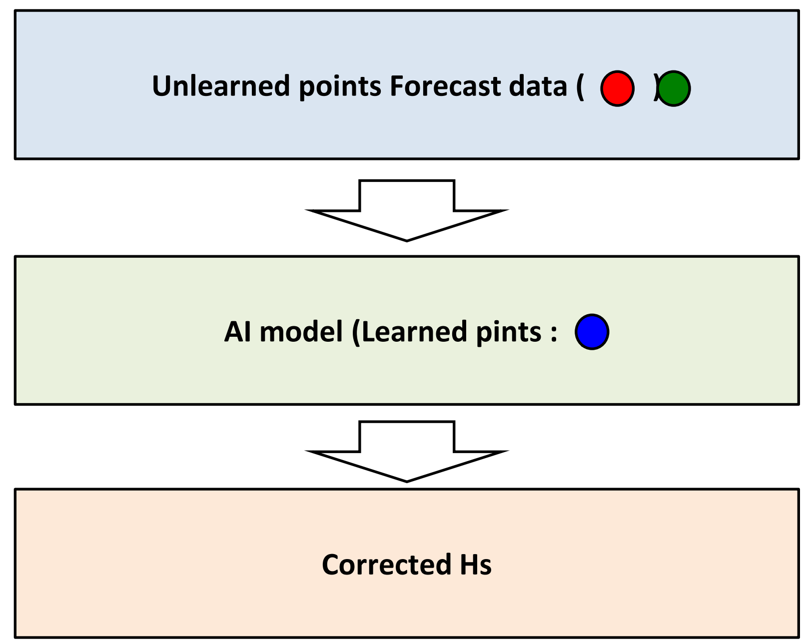


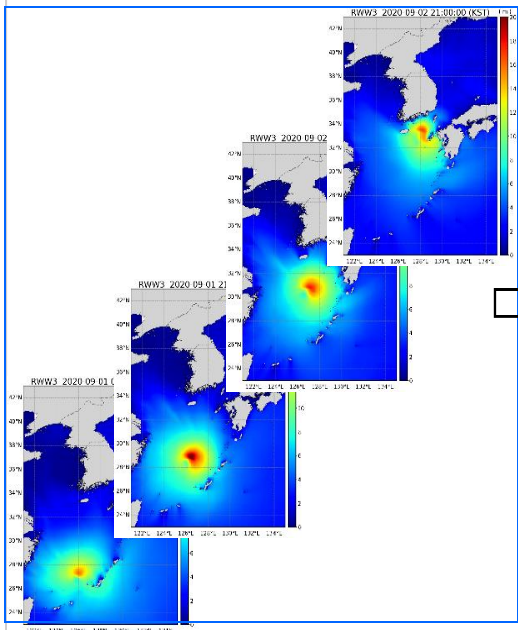
Fig 2. Flow chart for spatial correction test application

2. Data and Method

3. AI Correction Test During Typhoon Period

- **Correction point (Element):**
  - RWW3 significant wave heights
  - Analysis of spatial distribution of significant wave heights

- **Test Period**
  - No. 9 Typhoon Maisak
  - September 1st to 4th, 2020.



RWW3 Spatial Predictions and Depth (wave height, period, wave direction, wind speed, water depth)

↓

MLP Model

↓

Spatial correction result calculation (wave height)

Fig 3. Flow Chart of correction test

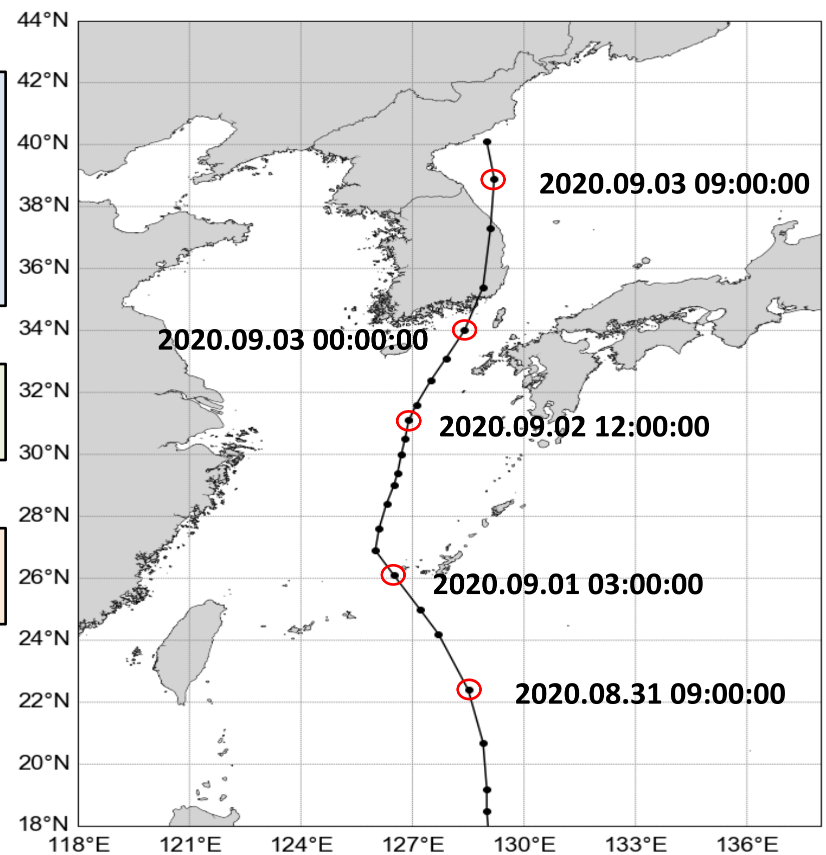


Fig 4. Track of Typhoon MAISAK NO. 9

3. Verification and Results

1. Verification of Correction Performance at Point-by-Point (1)

- **Correction Point (Station)**

  - Period: January to December, 2020
  - Elements: RWW3 (Significant wave height, maximum wave height, wave period, wind speed)
    GWW3 (Significant wave height, wind speed)

❖ **Verification of Correction Performance in RWW3 Significant Wave Height**

- **(Bias)** For wave heights exceeding 5 m, we examined the possibility of correction regarding overestimation in RWW3 up to a forecast period of 60 hours
- **(Bias)** Underestimation of AI models after 60h
- **(RMSE)** For significant wave heights ranging from 3 to 5m and exceeding 5m, MLP correction reduced errors for all prediction times

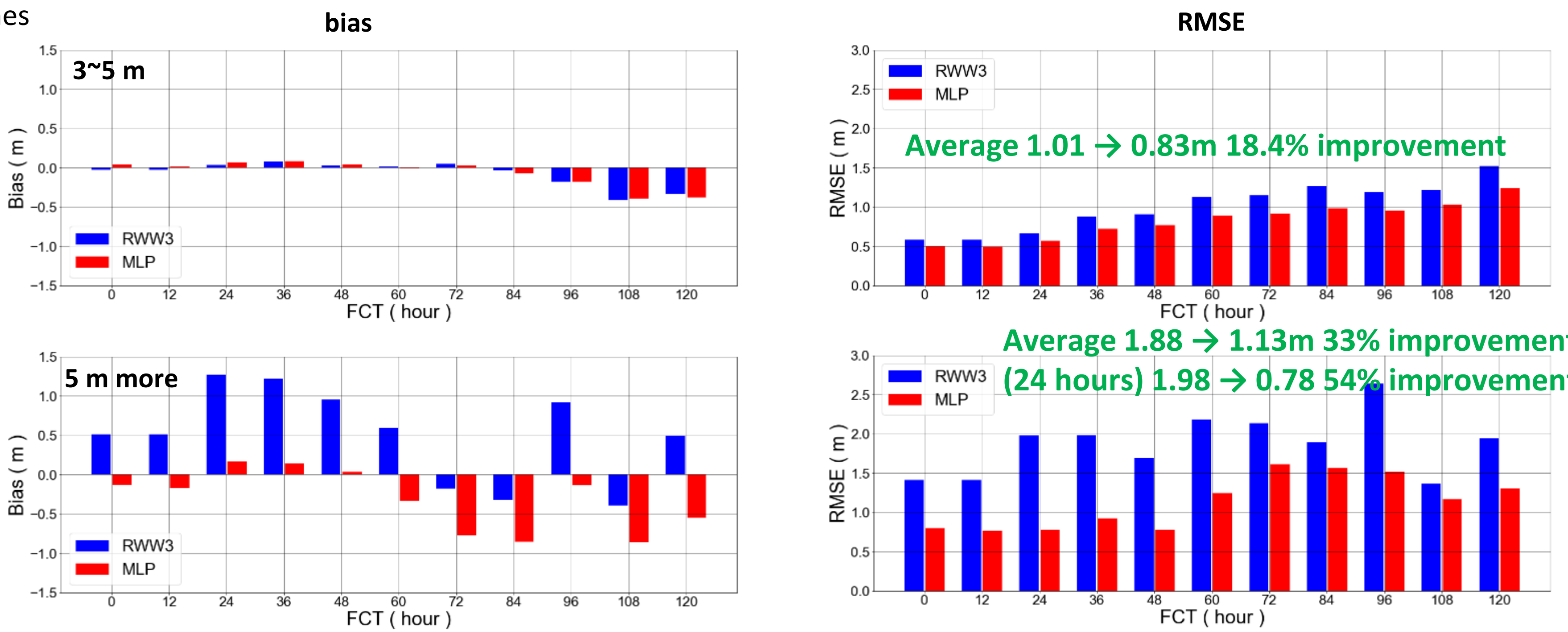


Fig 5. Analysis of bias and RMSE by prediction time for significant wave heights of 3 to 5m or 5m and more in numerical model and artificial intelligence correction

3. Verification and Results

1. Verification of Correction Performance at Point-by-Point (2)

❖ **Verification of correction performance in RWW3 maximum wave height, period, and wind speed**

- **(bias)** Artificial intelligence corrected the overestimation of maximum wave height, wave period, and wind speed
  - (However, the wind speed is underestimated in the 0-h prediction)
- **(RMSE)** Confirmed that the error is reduced in all prediction times

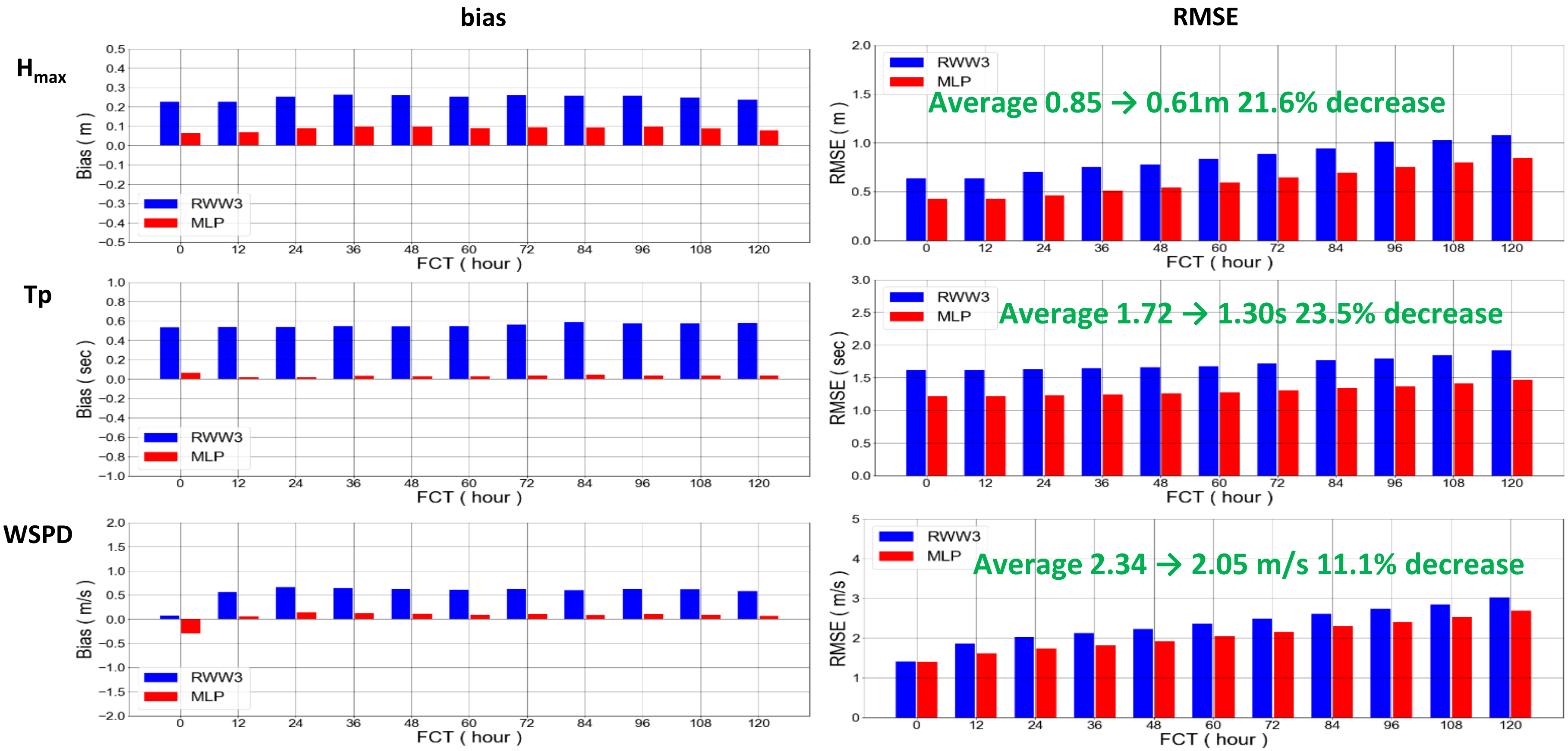


Fig 6. Analysis of the Bias and RMSE by predication time for maximum wave height, period, and wind speed in numerical model and artificial intelligence correction

3. Verification and Results

1. Verification of Correction Performance at Point-by-Point (3)

❖ **Verification of correction performance in GWW3 significant wave height and wind speed**

- **(bias)** Confirmation of error reduction by forecast time at significant wave height (3~5m)
- **(bias)** From significant wave height (~5m) to 180-hour prediction, bias increases slightly due to underestimation of the artificial intelligence model
- **(bias)** Particularly noticeable underestimation of wind speeds occurred at 0 hours
- **(RMSE)** Error reduction in most forecast times for all factors
  - · Error increase observed in the 108-hour prediction for significant wave heights (~5m)

bias **RMSE**

Hs (3~5m)

Hs (5m~)

WSPD

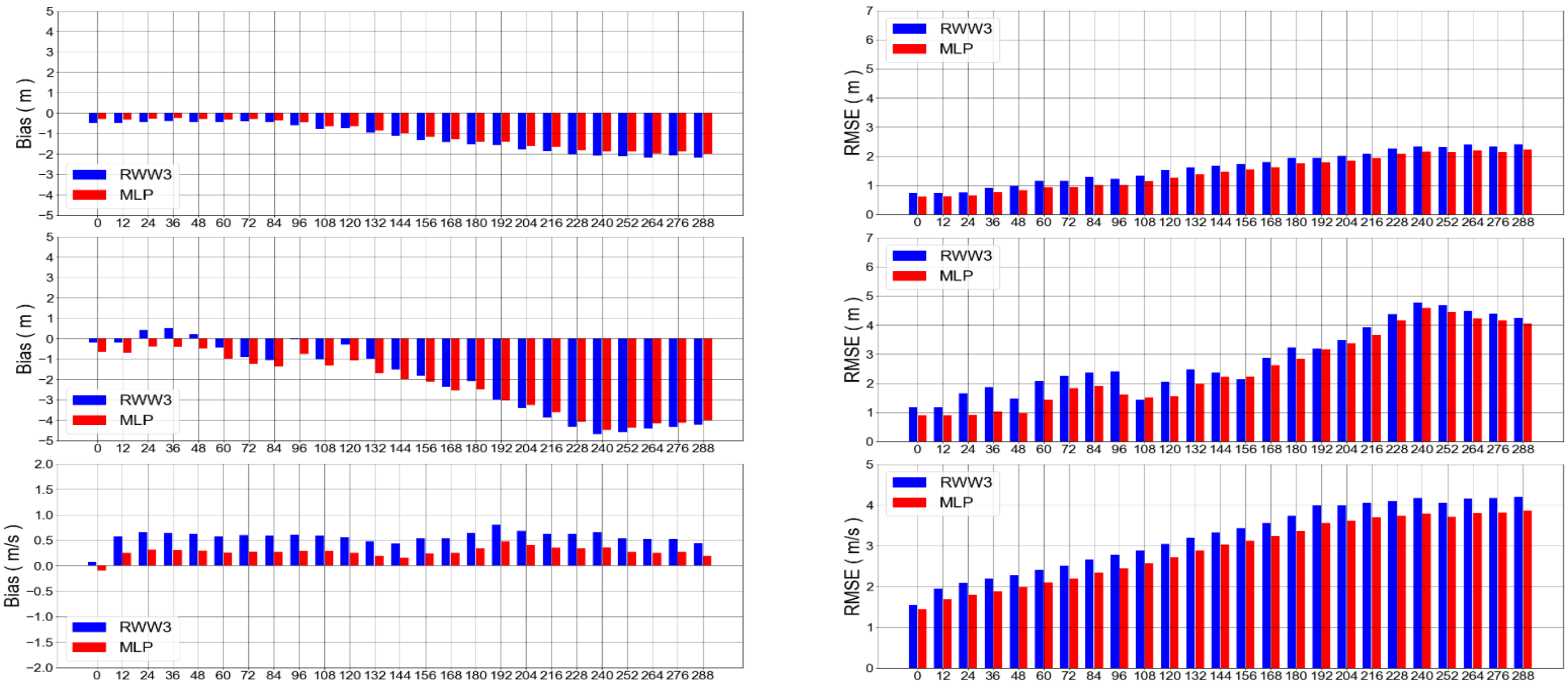


Fig 7. Analysis of the Bias and RMSE by predication time for significant wave height and wind speed in numerical model and artificial intelligence correction

3. Verification and Results

2. Verification of Correction Performance in Spatial Context (1)

▪ **Verification method**

- Verification of bias and RMSE by forecast time
- Period: January to March, 2020
- Element: RWW3 significant wave height
- Analysis of errors in wave height and observation points

❖ Verification of correction performance at observation points

- Slight increase in bias in low-wave sections
  · The deviation between the West Sea 170 and the West Sea 206 points increased by 0.15 and 0.12 m, respectively, in the total significant wave height.
  · The higher the wave height, the greater the artificial intelligence correction effect
- At the observation points of the West Sea and East Sea, it was confirmed that the error was reduced for wave heights of more than 5 m.
- The correction performance in spatial areas was confirmed at the unlearned points.

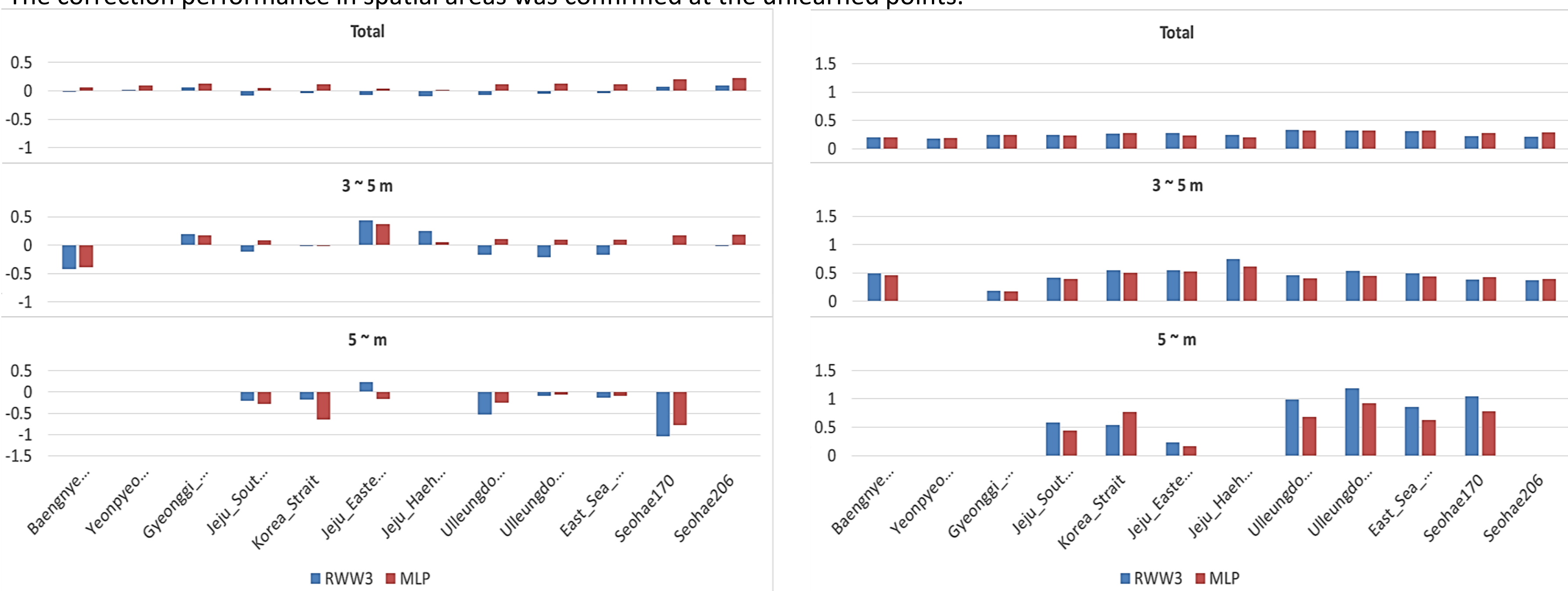


Fig 8. Analysis of the Bias and RMSE by prediction time for significant wave height of 3~5m and more than 5m in numerical model and artificial intelligence correction

3. Verification and Results

2. Verification of Correction Performance in Spatial Context (2)

bias **RMSE**

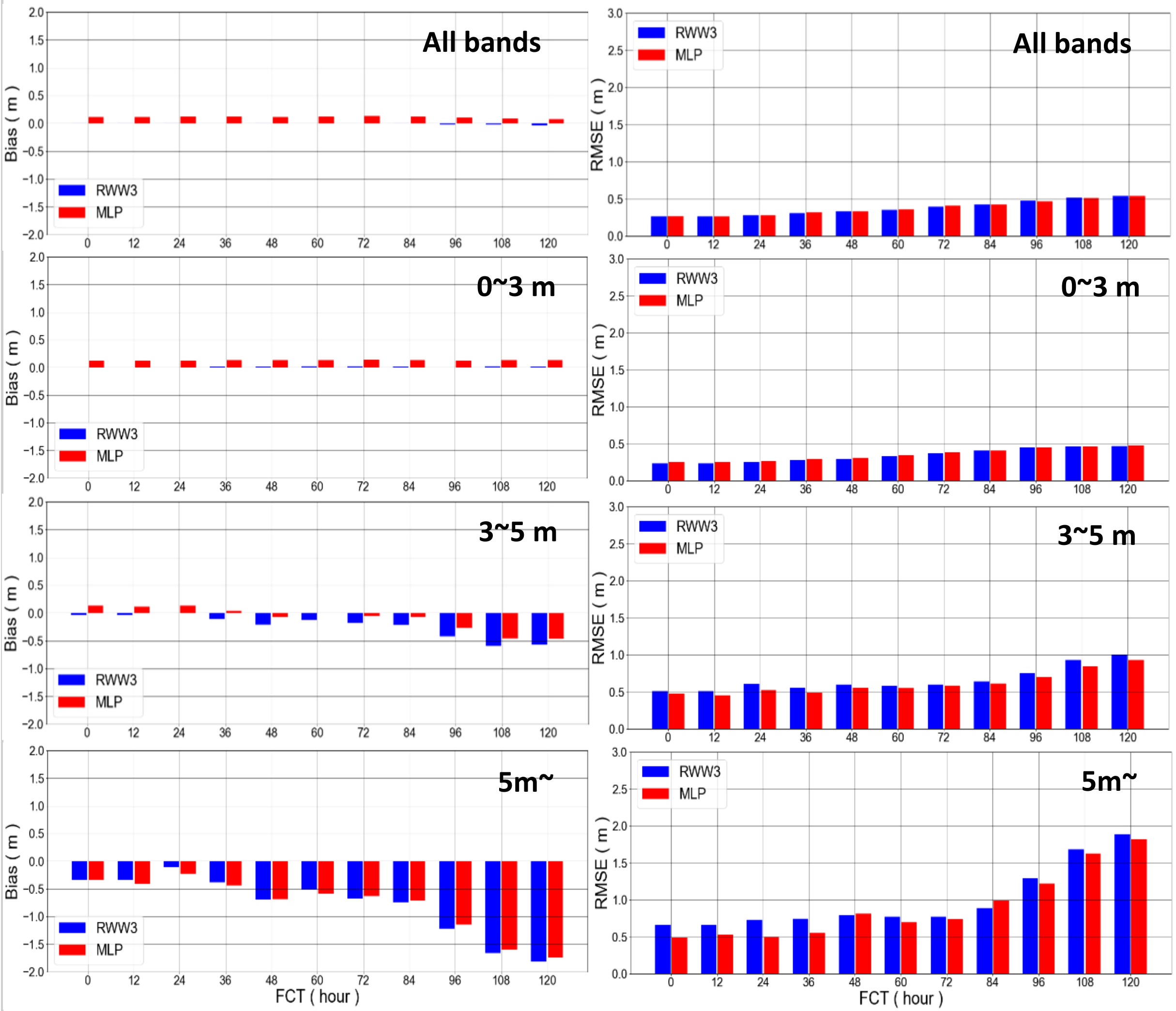


Fig 9. Comparison of Bias and RMSE of the RWW3-MLP model by prediction time and significant wave interval

❖ **Analysis of spatial correction error by forecast time**

- Comparison of calculating average error values for each prediction time at untrained points

- Confirmation of significant wave height errors (all bands)
  - **(bias)** Confirmation of over-simulation tendency
  - **(RMSE)** Reduced errors across most forecast times

- Verification of errors in 0~3m wave height bands Slight increase in bias and RMSE after AI correction

- **Verification of errors in sections of 3 to 5 m and above 5 m**
  - **(bias)** Tendency to increase errors within 0.1 m
  - **(RMSE)** Confirmation of error reduction across most forecast times

- **Analysis of the potentials for significant wave height correction by artificial intelligence models**
  - Confirmation of RMSE reduction in high wave height sections

3. Verification and Results

3. Verification of Correction Performance During Typhoon Period (1)

❖ **Comparison of significant wave height distribution during typhoon**

- MLP AI Model Correction Significance: On September 2nd, in the waters south Jeju Island, RWW3 underestimates the wave height

- MLP correction and RWW E3 results are similar to actual significant wave height distribution when landing on the Korean Peninsula on September 3

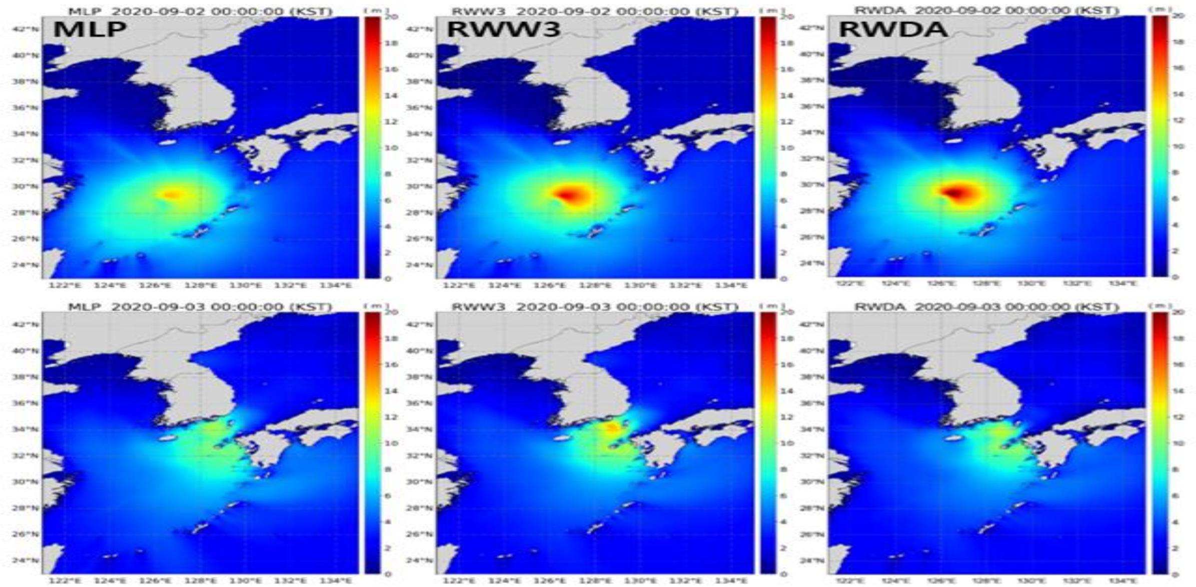


Figure 10. Significant wave height distribution diagram on September 2, 2020 (upper) and September 3, 2020 (lower)when a typhoon approaches the Korean Peninsula

❖ **Comparative analysis of significant wave heights using the learning(non-learning) points during the passage of typhoons through the Korean Peninsula**

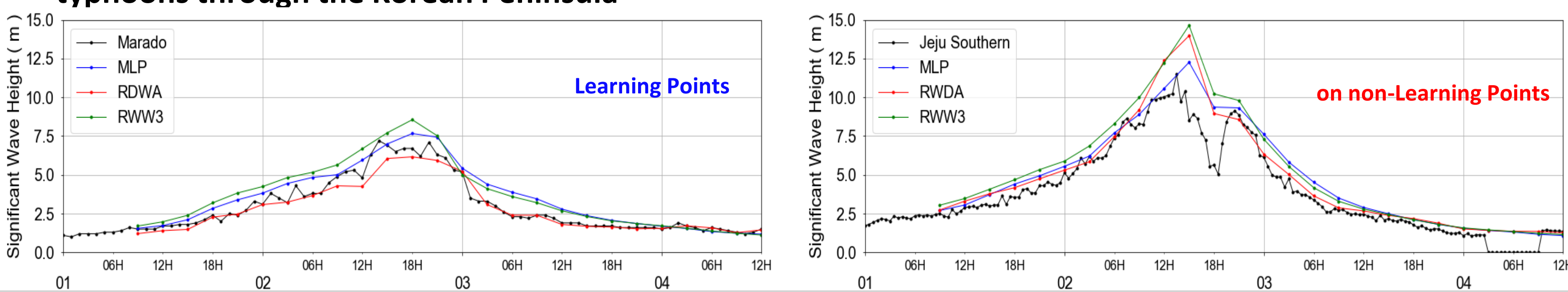


Fig 11. Time series and typhoon track map of the Marado (on learning point) and the southern part of Jeju (non-learning point)

- **Over-simulation of RWW3 model data compared to artificial intelligence model data**
  - Confirmation of error reduction in the high wave section by MLP artificial intelligence correction
  - Confirmation of the possibility of correction of the significant differences at unlearned points

3. Verification and Results

3. Verification of Correction Performance During Typhoon Period and Season (2)

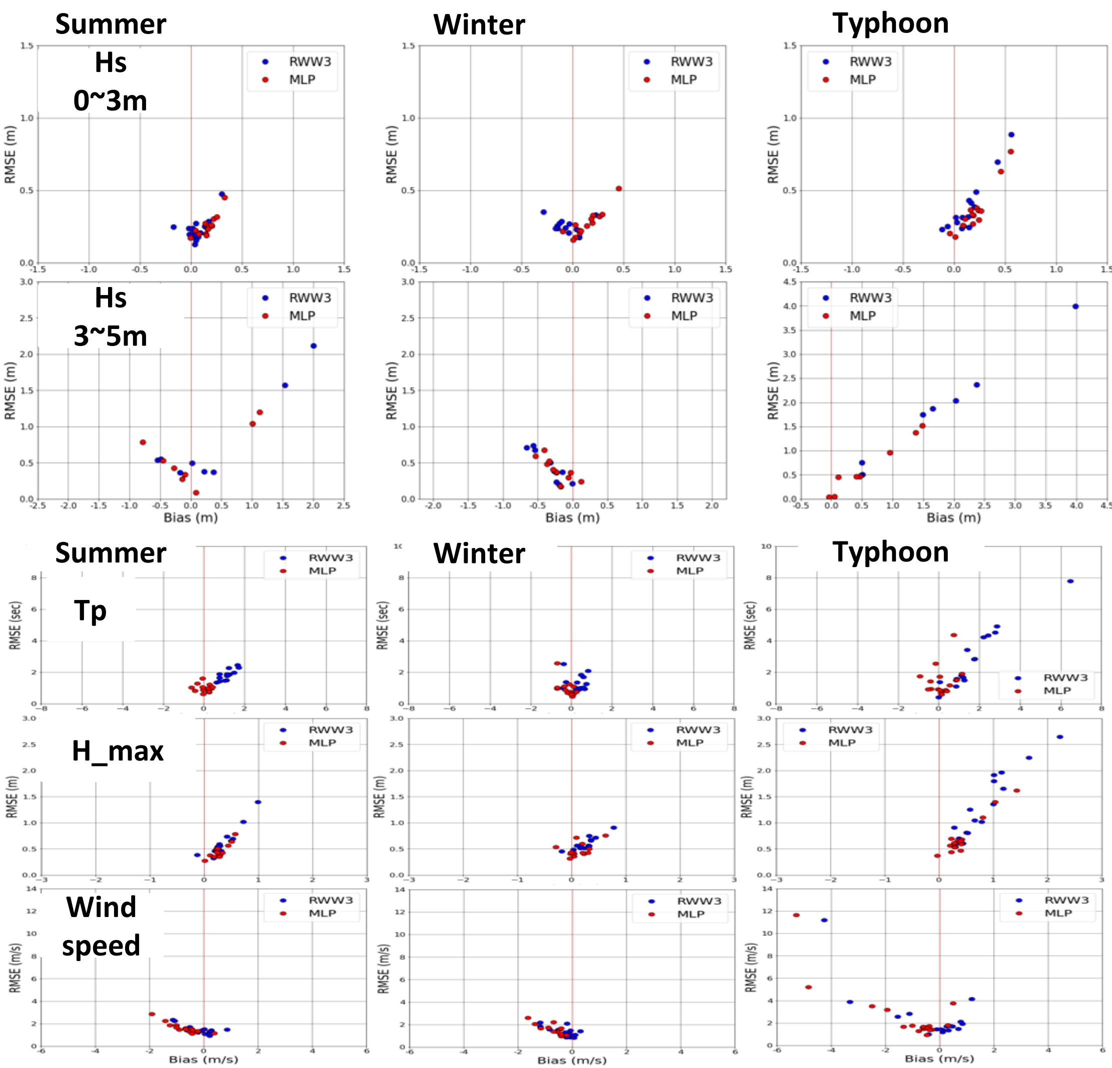


Fig 12. Analysis of RMSE on significant waves, wave periods, and wind speeds in MLP and numerical models (0fct)

(Significant wave height) Comparison of Bias RMSE for significant wave heights of 0~3 m or exceeding 3 m (0 fct)

- **Corrected significant wave height bias slightly increased in lower wave height section compared to RWW3, significant decrease in bias and RMSE in higher wave height section**

- **(Wave Period, maximum wave height, wind speed)**

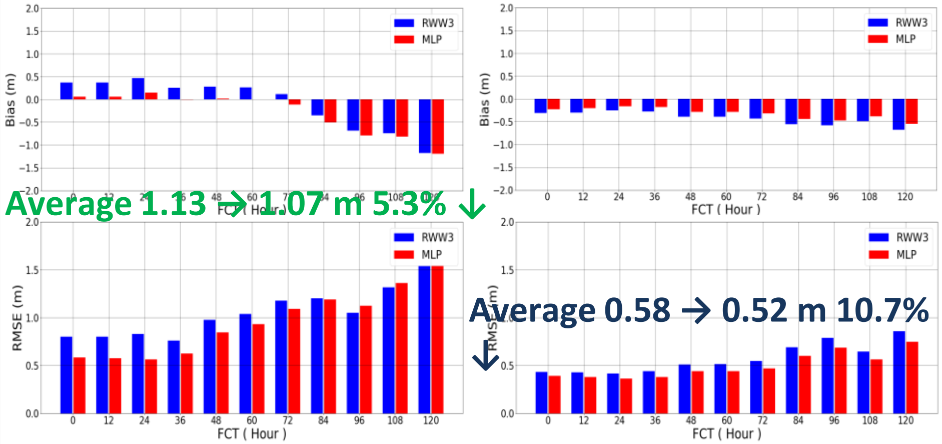
  All decrease in bias and RMSE by period (0 fct)

  A relatively large decrease in bias and RMSE was observed during hazardous weather conditions (typhoon periods).

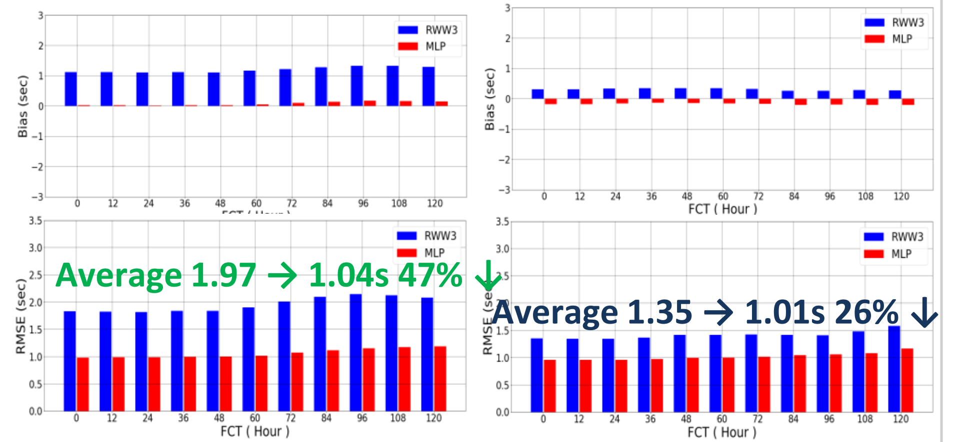
3. Verification and Results

3. Verification of Correction Performance During Typhoon period and Season (3)

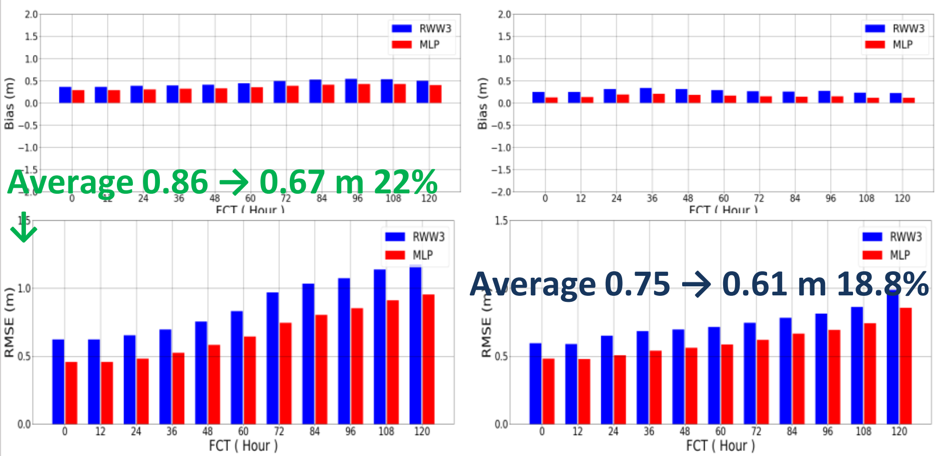
- Comparison of bias and RMSE by predicted time for each calibration factor (Full)
- Significant reductions in bias and RMSE were observed for significant wave heights (~3 m), period, and maximum wave height for each prediction time.
- Wind speed exhibited an increase in negative bias in the early stage of prediction, but its overall trend was similar.



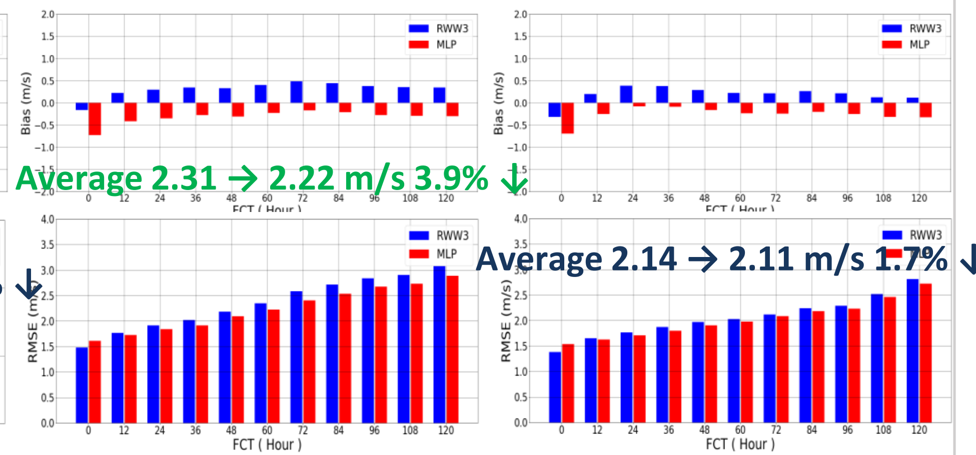
Summer (left)/Winter (right) Significant wave by predicted time (3–m) Bias, RMSE



Summer (left)/Winter (right) Wave Period by predicted time Bias, RMSE



Summer (left)/Winter (right) Maximum wave by forecast time Bias, RMSE



Summer (left)/Winter (right) Wind speed by forecast time Bias, RMSE

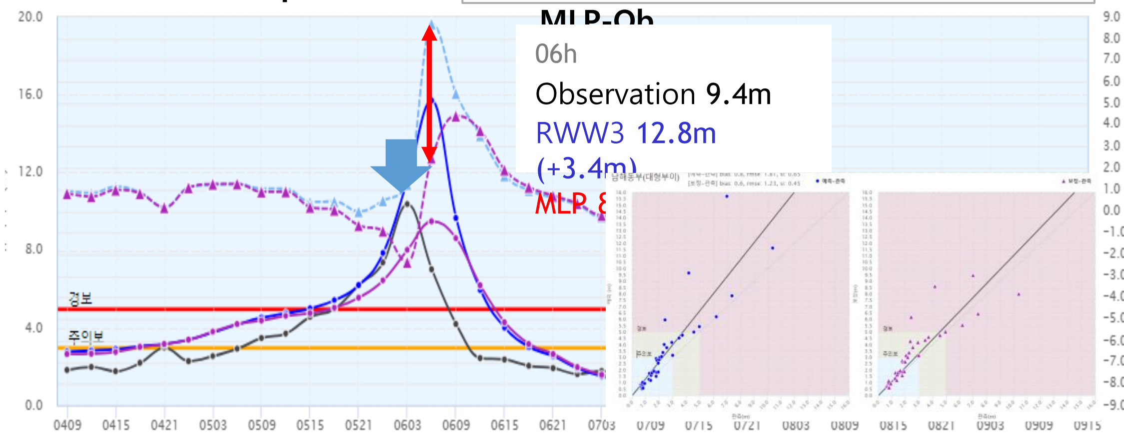
3. Verification and Results

3. Verification of Correction Performance During Typhoon Period (4)

Improvement of over-simulation

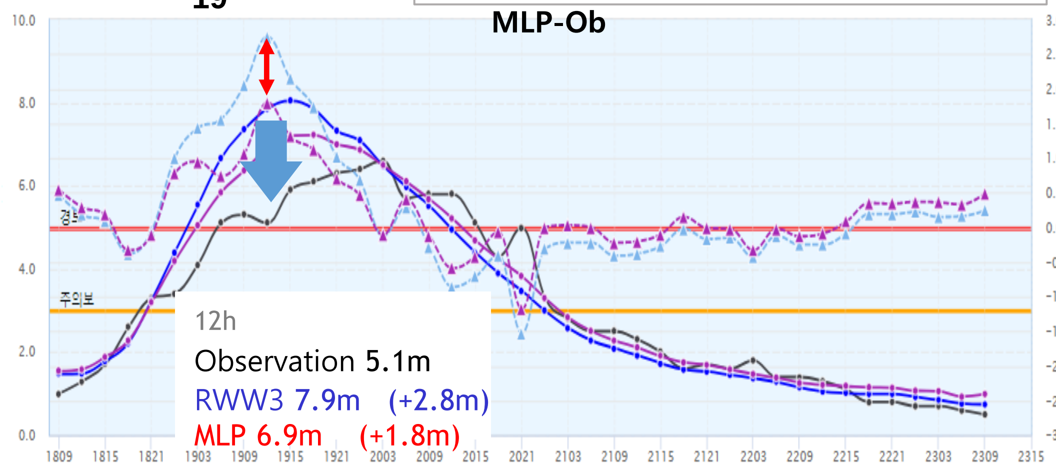
East South Sea | September 4

Observation — RWW3 — MLP - - - RWW3-Ob — MLP-Ob

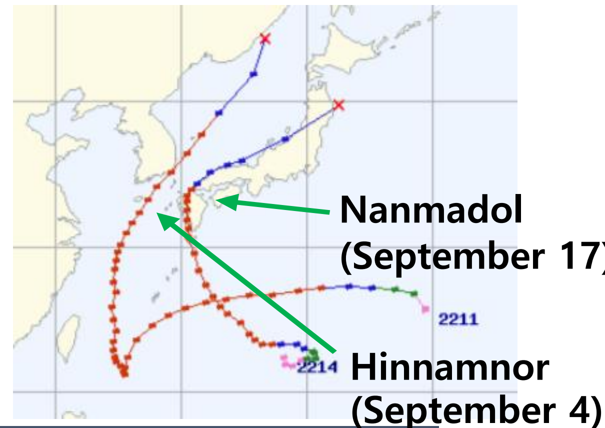


Ulsan | September 19

Observation — RWW3 — MLP - - - RWW3-Ob — MLP-Ob

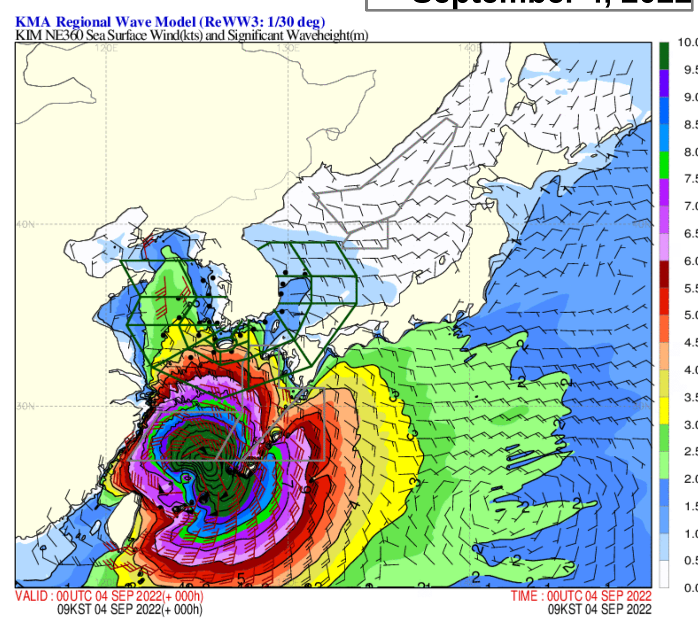


Typhoons in 2022



RWW3 Significance Wave Prediction

September 4, 2022



4. Conclusion

Confirmation of significant wave height correction for points and spaces using artificial intelligence techniques
In particular, for high wave height ranges from 3 m or more, bias and RMSE analyses by prediction time intervals showed a reduction in RMSE over time.

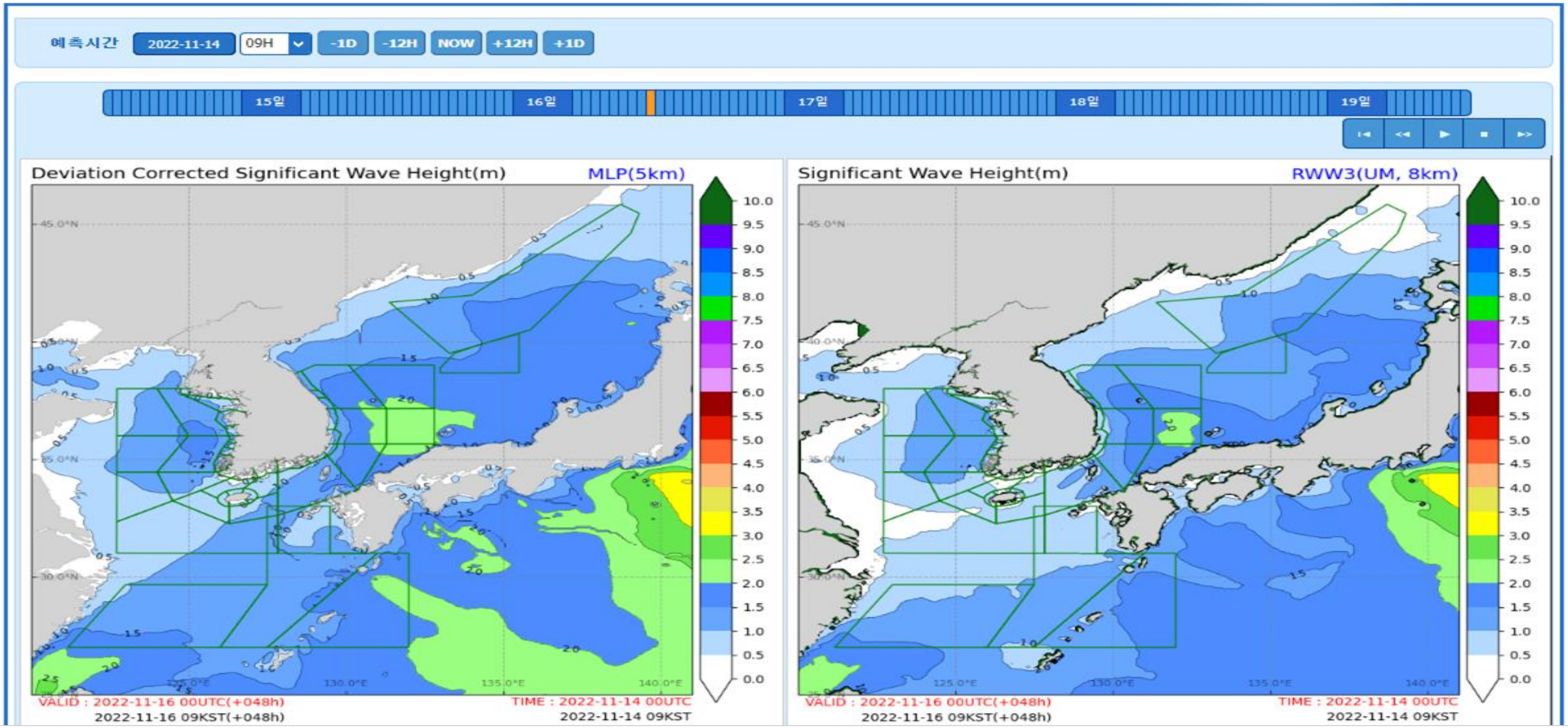
1. Significant Wave (3m~) Seasonal characteristics: 1.13 → 1.07 m or more 5.3% improvement in summer
0.58 → 0.52 m 10.7% improvement in winter

2. The higher the wave height, the greater the predicted performance improvement rate.

Even during the typhoon period, significant wave height, which is over-simulated in the numerical model at all points, is corrected using MLP technique with artificial intelligence.

The expansion of spatial deviation technology based on the Korean numerical model (KIM) is currently being promoted ('23~).

< Applying RWW3 space prediction data to MLP artificial intelligence models >



Thank you

juni8207@korea.kr

Korea Meteorological
Administration