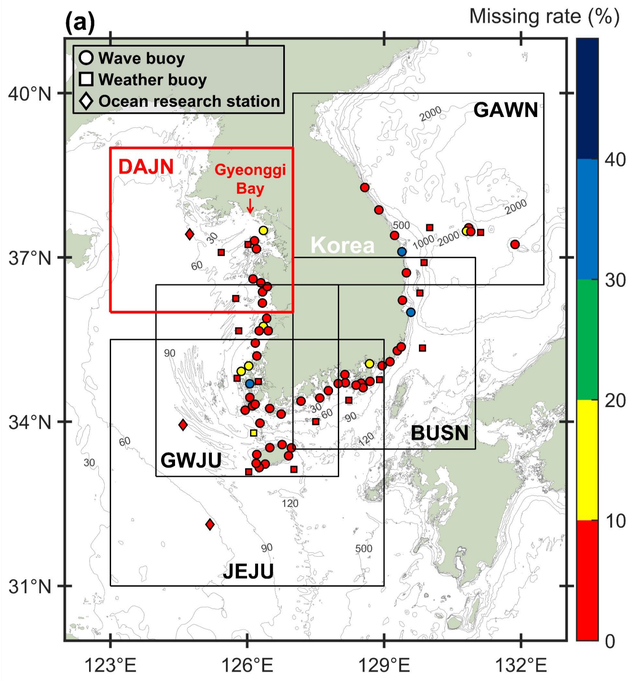
Performance evaluation of wave model accuracy in Gyeonggi Bay, west coast of Korea: investigating the cause of low accuracy

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Introduction

- Surface gravity wave has an important impact on coastal structures and sediment transport in coastal regions.
- Since in-situ observations are not sufficient to confirm the impact of waves, it is necessary to evaluate the accuracy of wave models for coastal management.
- This study evaluates the accuracy of wave models provided for Gyeonggi Bay, which is characterized by macro-tidal, shallow water, and complex bathymetry, and suggests requirements for improving the accuracy.



(b)

Wave prediction system (operated by KMA)

- Model: WaveWatch Ⅲ (WW3) ver. 4.18
- Bathymetry: ETOPO1 (global 1 arc-minute)
- Wind forcing (operated by KMA):
  - (Before March 13, 2020): Unified Model (UM)
    - Global Data Assimilation and Prediction System (GDAPS): GWW3
    - Regional Data Assimilation and Prediction System (RDAPS): RWW3 and CWW3
  - (March 13, 2020 ~ present): Korean Integrated Model (KIM)
    - Global Data Assimilation and Prediction System (GDAPS)
- Coupling: one-way (GWW3 → RWW3 → CWW3)

Global WW3 (GWW3)	→ One-way →	Regional WW3 (RWW3)	→ One-way →	Coastal WW3 (CWW3)
– Domain: 0–359.5°E, 70°S–70°N – Resolution Spatial: 1/2° (~ 55 km) Temporal: 6-hour interval – Forecast (twice a day): 288 hour (00, 12UTC)		– Domain: 115–150°E, 20–50°N – Resolution Spatial: 1/12° (~ 8 km) Temporal: 3-hour interval – Forecast (twice a day): 120 hour (00, 12UTC)		– Domain: 5 domains (BUSN) 127–131°E, 33.5–37°N (DAJN) 123–131°E, 36–39°N (GAWN) 127–132.5°E, 36.5–40°N (GWJU) 124–128°E, 33–36.5°N (JEJU) 123–129°E, 31–35.5°N – Resolution Spatial: 1/120° (~ 1 km) Temporal: 3-hour interval – Forecast (twice a day): 72 hour (00, 12UTC)

ERA5 (operated by ECMWF)

- Fifth generation ECMWF re-analysis for global climate and weather
- Availability: 1950 to present (daily update with a latency of about 5 days)
  - (2–3 months before present): final product
  - (5 days before present): preliminary product
- Bathymetry: ETOPO2 (global 2 arc-minute)
- Resolution
  - Spatial: 0.25° × 0.25° (atmosphere), 0.5° × 0.5° (ocean waves)
  - Temporal: 1-hour interval

Figure 1. (a) Bathymetry contours (m), wave model, and observation system are shown, along with the locations of 3 ocean research stations (3 diamonds) and 75 buoys (17 triangles: weather buoy, 58 circles: wave buoy), and 5 model domains of Coastal Wave Watch III (CWW3) (1 red square bounding box; DAJN: Dajeon and 4 black square bounding boxes; BUSN: Busan, GAWN: Gangwon, GWJU: Gwangju, and JEJU: Jeju). The ocean research stations were operated by Korea Hydrographic and Oceanographic Agency (KHOA). The buoys and CWW3 model were operated by Korea Meteorological Administration (KMA). The color of the marks (diamonds, squares, and triangles) denotes the missing rate of wave observations at each point during 2019-2021. (b) Modeling system of Wave prediction system operated by KMA and ERA5 operated by European Centre for Medium-Range Weather Forecasts (ECMWF).

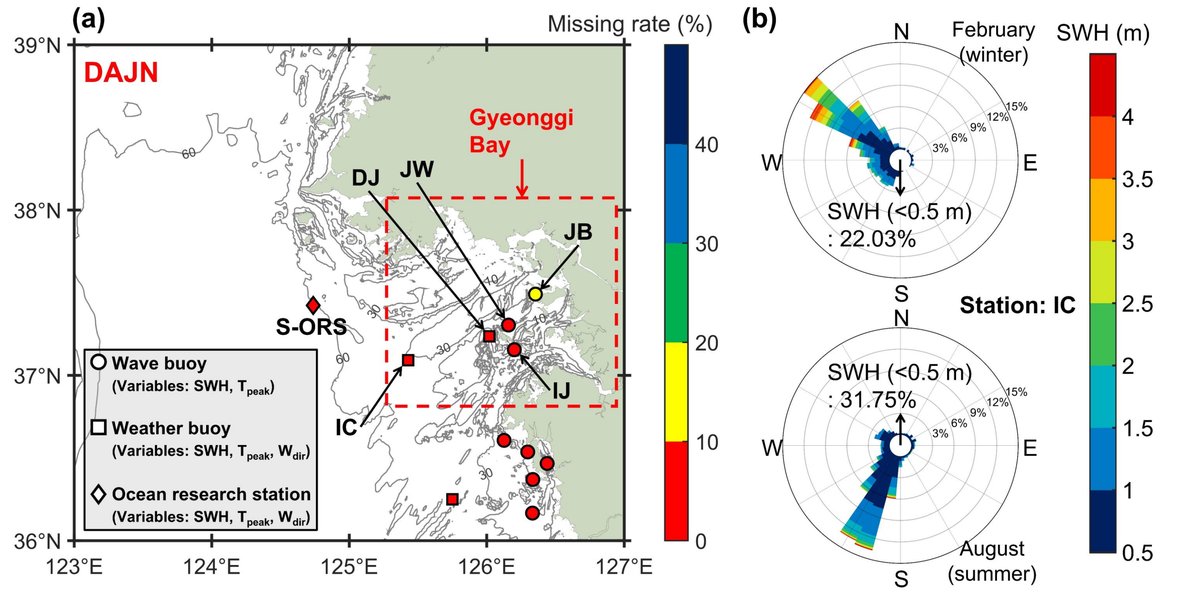


Figure 2. (a) Bathymetry contours (m) and model domain of DAJN CWW3, 5 buoys (DJ: Duckjuckdo weather buoy, IC: Incheon weather buoy, JW: Jawoldo wave buoy, IJ: Ijakdo wave buoy, and JB: Jangbongdo wave buoy) located in Gyeonggi Bay, and 1 ocean research station (S-ORS: Socheongcho ocean research station) located offshore. (b) Rose diagram for wave based on February (winter) and August (summer) during 2019–2021 at IC. The bin width is 10° and the percentage indicates the portion of waves propagating in a specific direction. Arrows indicate the percentage of observed significant wave heights less than 0.5 m.

Results (model validation)

(a) Correlation coefficient

	S-ORS	IC	DJ	JW	IJ	JB
ERA5	0.91	0.93	0.86	0.89	0.79	0.72
CWW3	0.90	0.95	0.92	0.90	0.85	0.75

(b) Index of agreement

	S-ORS	IC	DJ	JW	IJ	JB
ERA5	0.95	0.89	0.92	0.91	0.75	0.81
CWW3	0.94	0.97	0.94	0.94	0.86	0.84

(c) Normalized RMSE

	S-ORS	IC	DJ	JW	IJ	JB
ERA5	0.34	0.42	0.44	0.53	0.92	0.66
CWW3	0.37	0.25	0.44	0.41	0.63	0.65

Offshore → Coastal

S-ORS	IC	DJ	JW	IJ	JB
124.73	125.42	126.01	126.15	126.20	126.35

Longitude (°E)

• Model statistical parameters

1. **Correlation coefficient (r)**

$$r = \frac{\sum_{i=1}^{n}(O_i-\bar{O})(M_i-\bar{M})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2}\sqrt{\sum_{i=1}^{n}(M_i-\bar{M})^2}}$$

2. **Index of agreement (IOA)**

$$IOA = 1 - \left[\frac{\sum_{i=1}^{n}(M_i-O_i)^2}{\sum_{i=1}^{n}(|M_i-\bar{O}|+|O_i-\bar{O}|)^2}\right]$$

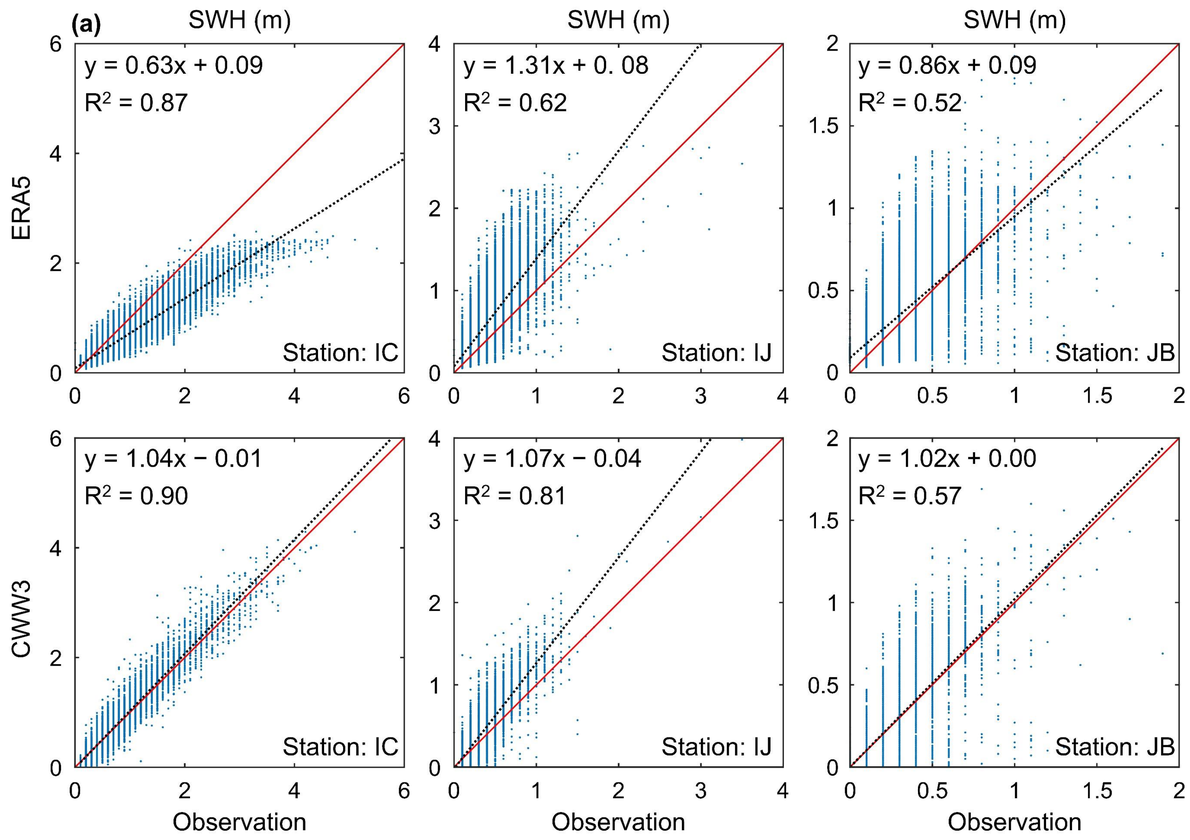
3. **Normalized root mean square error (nRMSE)**

$$nRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(M_i-O_i)^2}}{\bar{O}}$$

O: observation data, M: model data, n: number of data pairs
$\bar{O}$: mean observation data, $\bar{M}$: mean model data

Figure 3. Accuracy evaluation of modeled significant wave heights using model statistical parameters; (a) correlation coefficient, (b) index of agreement, and (c) normalized root mean square error. The models are CWW3 and ERA5 wave model, and result of statistical parameters at the nearest model grid node. The highest and lowest values are denoted by underlined text. The lower black arrow indicates the longitudes of observation points, ranging from offshore to coastal regions.

Results (comparison with observation data)



(b)

Station	ERA5	R^2	CWW3	R^2
S-ORS	y = 0.90x + 0.16	0.82	y = 0.95x + 0.11	0.81
DJ	y = 0.76x + 0.14	0.75	y = 1.09x + 0.02	0.84
JW	y = 1.09x + 0.08	0.79	y = 1.07x − 0.04	0.81

Figure 4. (a) Scatter plot of the modeled and observed significant wave heights at Incheon weather buoy (IC), Ijakdo wave buoy (IJ), and Jangbongdo wave buoy (JB). The red line and the black dotted line indicate the reference line and linear regression line, respectively. (b) The linear regression line and coefficient of determination (R^2) at Socheongcho ocean research station (S-ORS), Duckjuckdo weather buoy (DJ), Jawoldo wave buoy (JW).

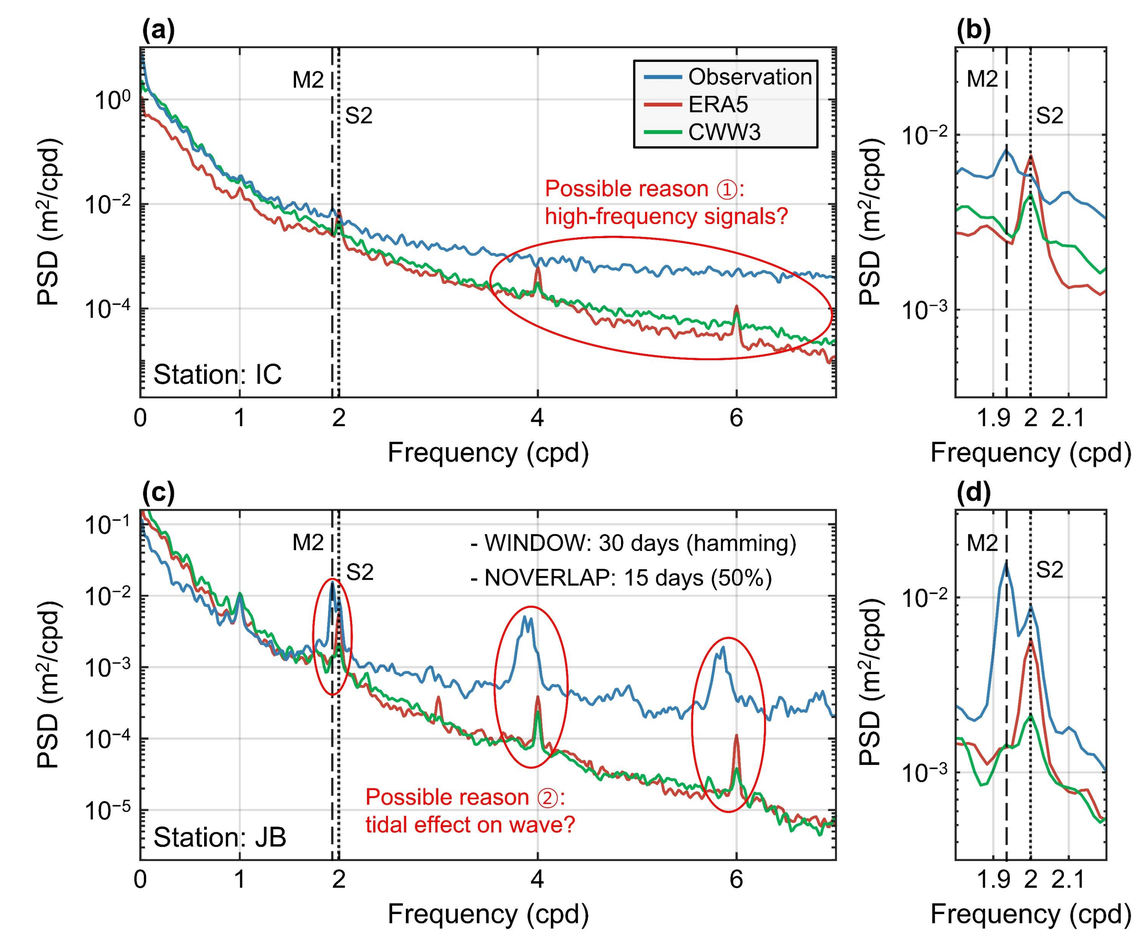


Figure 5. Power spectra of modeled and observed significant wave heights at (a–b) Incheon weather buoy (IC) and (c–d) Jangbongdo wave buoy (JB). For spectral analysis, demeaned and detrended 3-year significant wave heights are used, with a hamming window of 30 days and an overlap of 15 days applied. The vertical dashed lines indicate the semidiurnal tidal frequency of M_2 (1.93 cycle per day) and S_2 (2 cycle per day). (b and d) Power spectra of significant wave heights at IC and JB from 1.8 to 2.2 cycle per day for clarity.

Summary and Conclusions

- Both models showed good agreement with observed significant wave height at the Socheongcho ocean research station (S-ORS) and Incheon weather buoy (IC) located in offshore regions.
- However, the accuracy decreased in coastal regions, especially at the Jangbong wave buoy (JB).
- Both models over-estimated the observed significant wave heights at Ijakdo wave buoy (IJ), leading to decreased accuracy.
- The results showed a high correlation between the model errors and the tidal cycle, especially the semidiurnal tidal frequency of M_2 (1.93 cycle per day).
- These findings suggest that the tidal effects of the region should be taken into consideration to improve the accuracy of wave models in macro-tidal regions.

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