Operational wave forecasting system in KMA and its application

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Outline

- **Background**

  - NWP switched to KIM model → KIM based WW3 system (parallel run)

- **Overview about operational wave modeling system in KMA**

  - Global/ Regional/ Coastal models, Regional ensemble model, Rapid refresh model

- **Recent upgrades, and on-going developments**

  - Data assimilation for Global, Regional, and Rapid refresh model
  - Wave-tide interaction

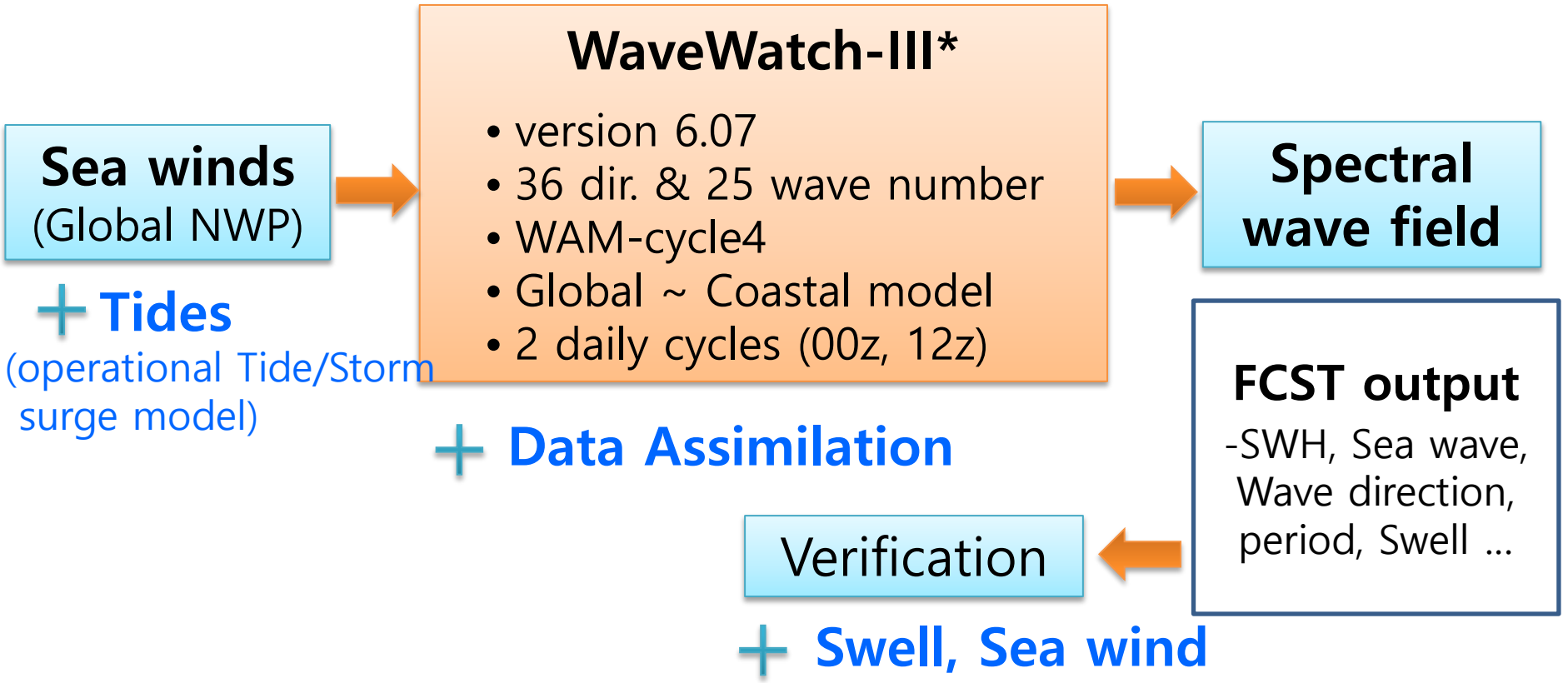
- **Applications and services from KMA**

  - National Services: KMA
  - Applications: Swell warning, Rip current forecasting system, Total water level forecasting system

- **Future work**

KMA wave model (WaveWatch-III)

- Since 2008, KMA has used the WaveWatch-III as operational wave model
- In 2018 and 2019, ensemble regional model and rapid refresh model started operating
- In 2021, data assimilation was implemented in the global wave model

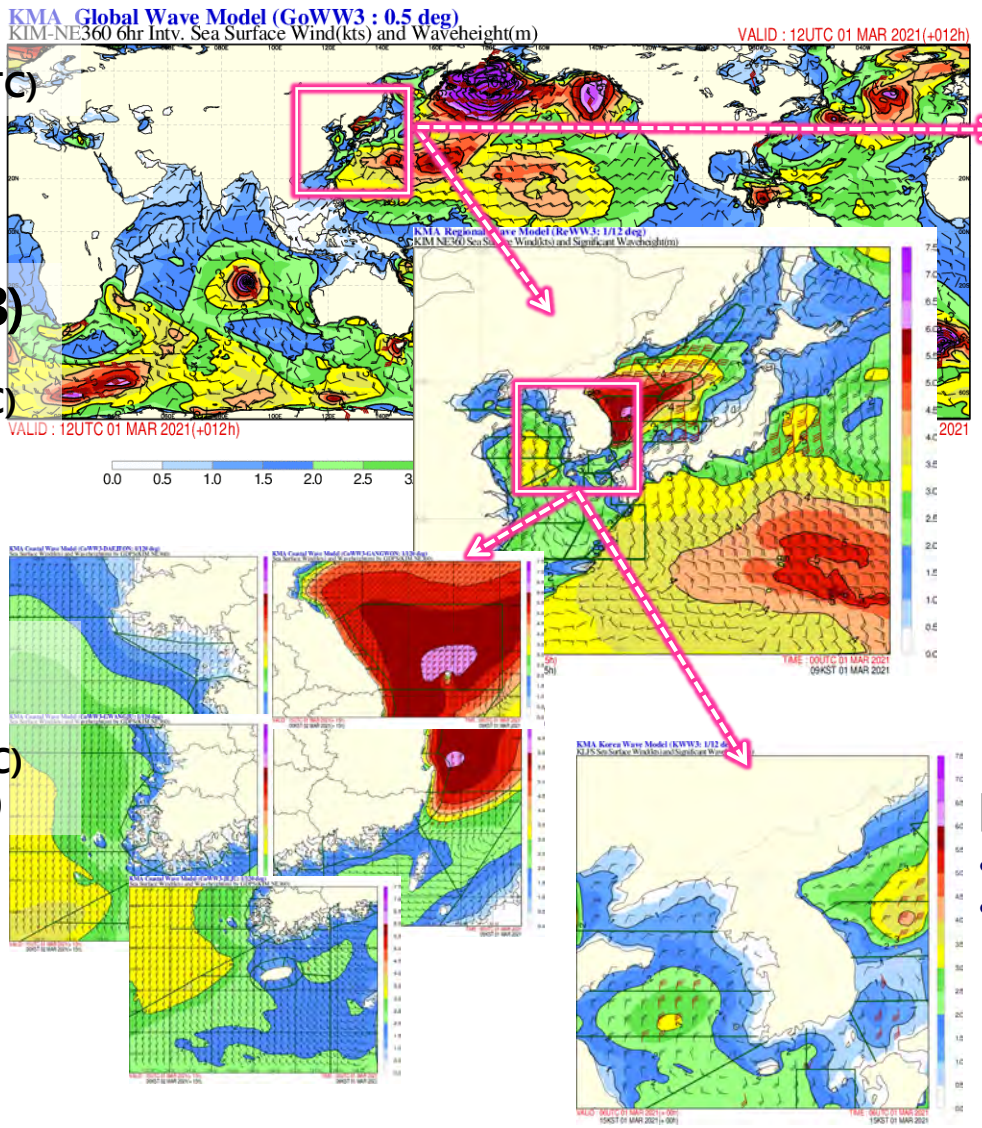


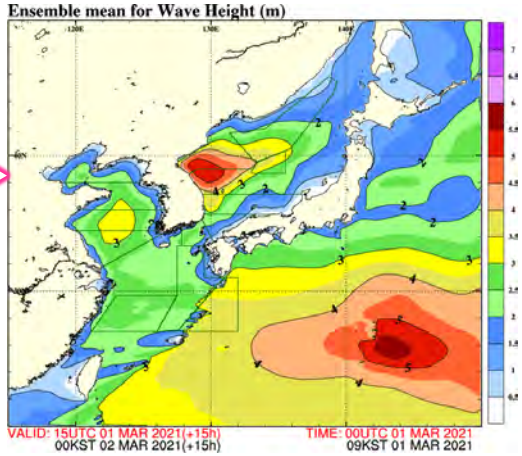
Wave Forecasting System in KMA

Global (GWW3)
- 25 km/ 55 km
- 12 day fcst (00,12UTC)

Regional (RWW3)
- 4 km/ 8 km
- 5 day fcst (00,12UTC)

Coastal (CWW3)
- 1 km/ 1 km
- 5 day fcst (00,12UTC)
- 1 / 5 (num. domain)



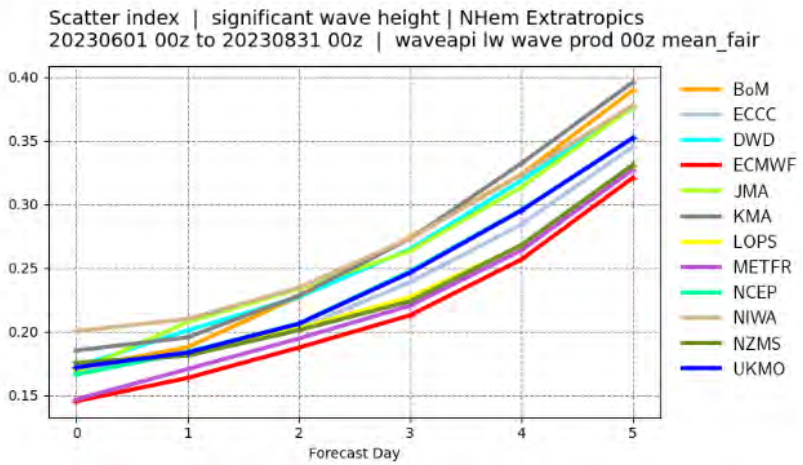


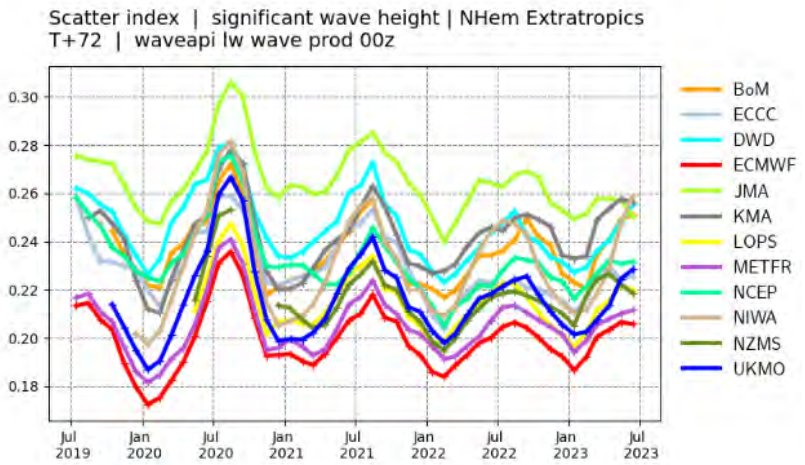
Ensemble (EWW3)
- - / 8 km
- 5 day fcst (00,12UTC)
- 24 members

Rapid refresh (KWW3)
- - / 8km
- 12hr fcst (24 hourly cycles)

Verification

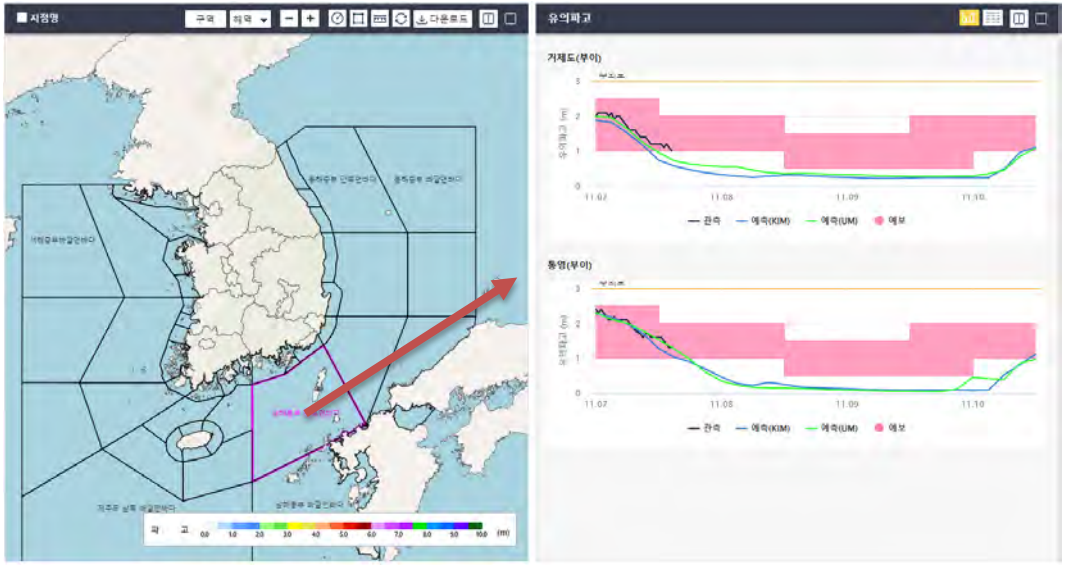
confluence.ecmwf.int





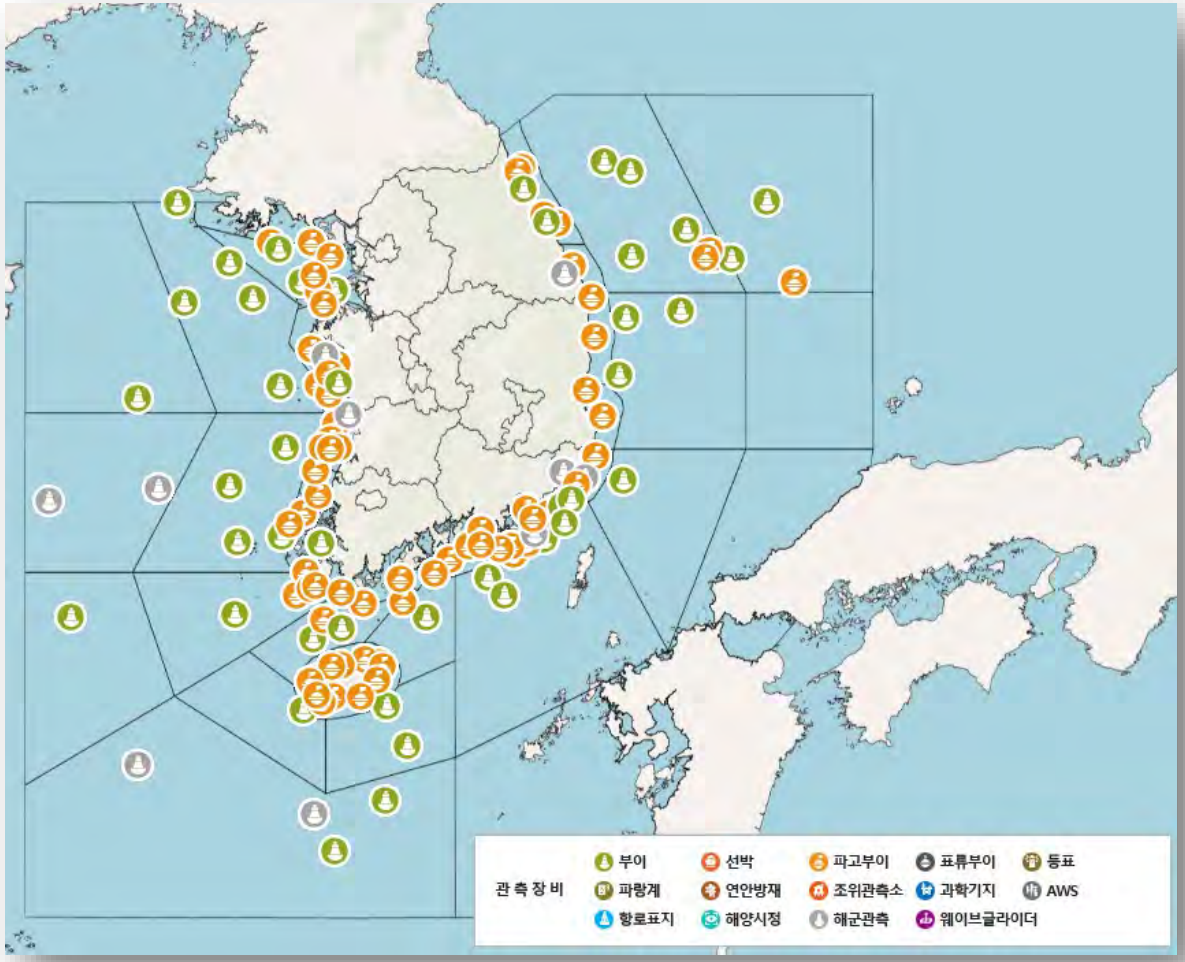
Real-time validation system

Monitoring qualification of regional and coastal wave models at moored buoy locations



(Wave) Buoy observations

- Buoy observations near Korea peninsula by KMA and KHOA
- Use for verification and data assimilation

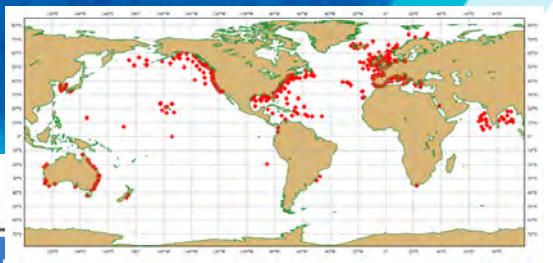


KMA runs 103 buoys
 * Sea-Met buoy (28)
 * Pago buoy (75)

Recent upgrades (Oct. 2021)

- Upgrade to WaveWatch-III version 6.07
- Implement higher resolution grid to global and regional model
  - (GWW3) 50 to 25 km, (RWW3) 8 to 4 km
- Five coastal model (CWW3) domains are unified, and forecast period is extended to 5-day
- Implement satellite-observed SWH data assimilation for GWW3
- GEBCO 2020 bathymetry

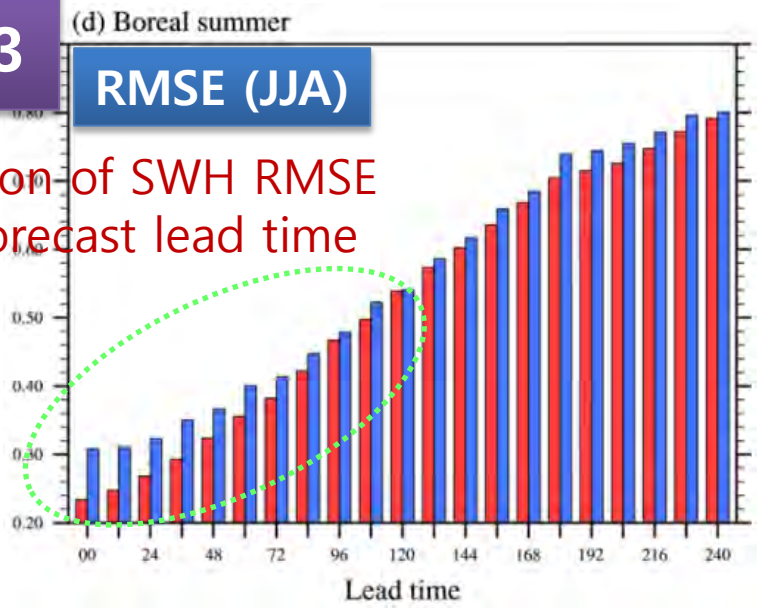
Recent upgrades: model accuracy



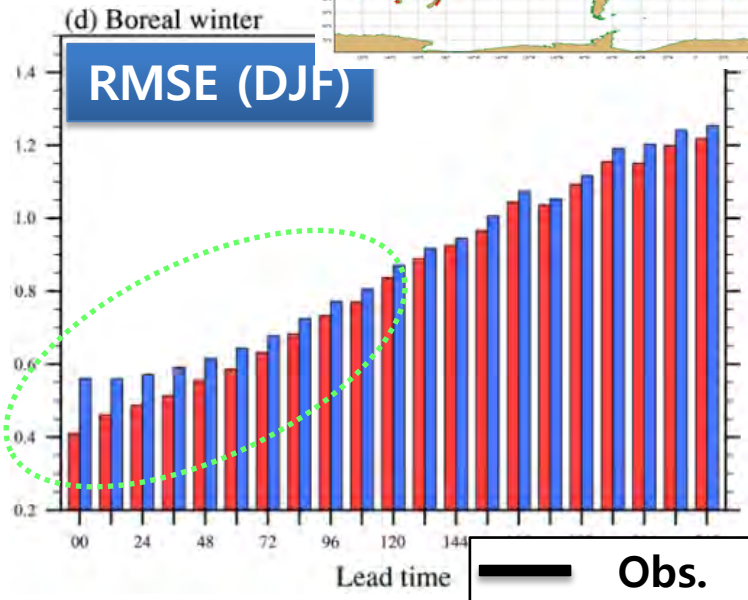
GWW3

RMSE (JJA)

Comparison of SWH RMSE against forecast lead time

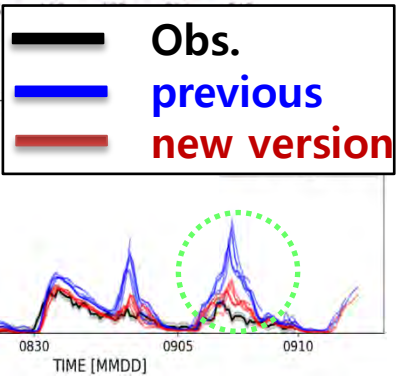


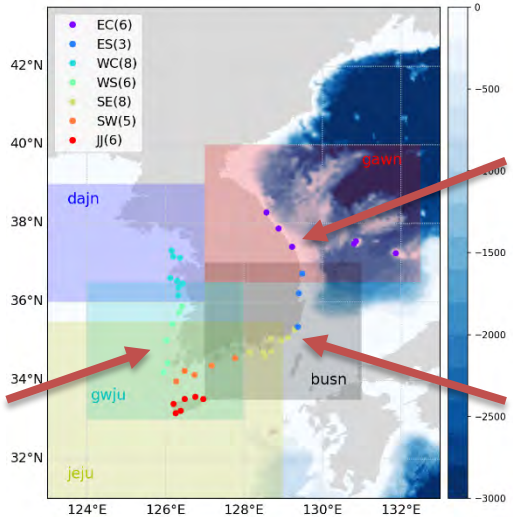
RMSE (DJF)

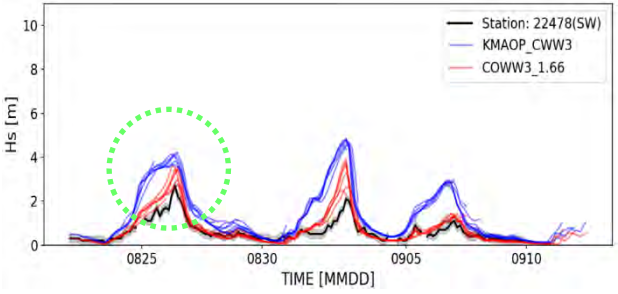


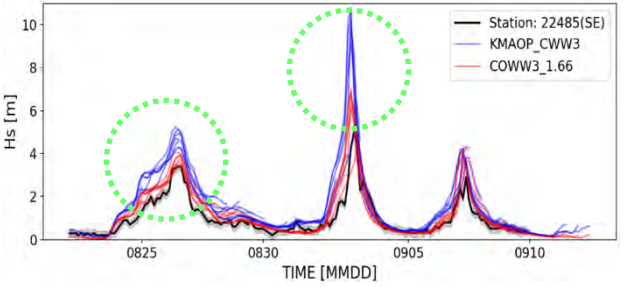
CWW3

Comparison of SWH forecasts
22. Aug. ~ 10. Sep. (3 typhoons)



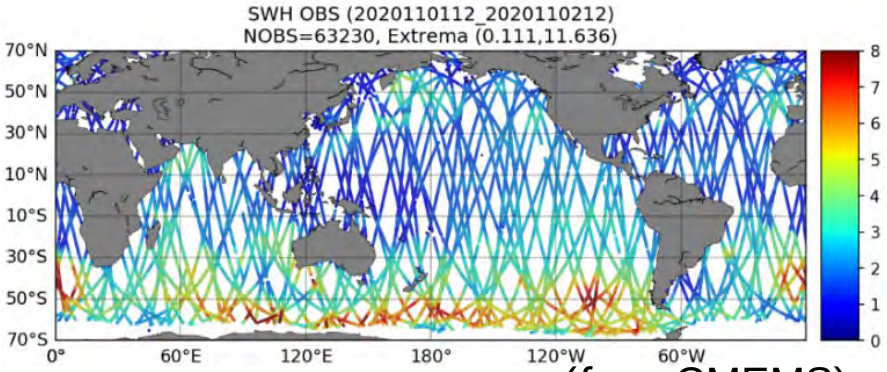






(GWW3) Data assimilation

- Optimal interpolation method
- Assimilate satellite-observed significant wave height (SWH)
- Update wave spectrum by using SWH analysis fields



(*from* CMEMS)

Obs. (SWH)

Pre-processing

Background (spectrum)

SWH (background)

Assim.

SWH (analysis)

correct wave spectrum

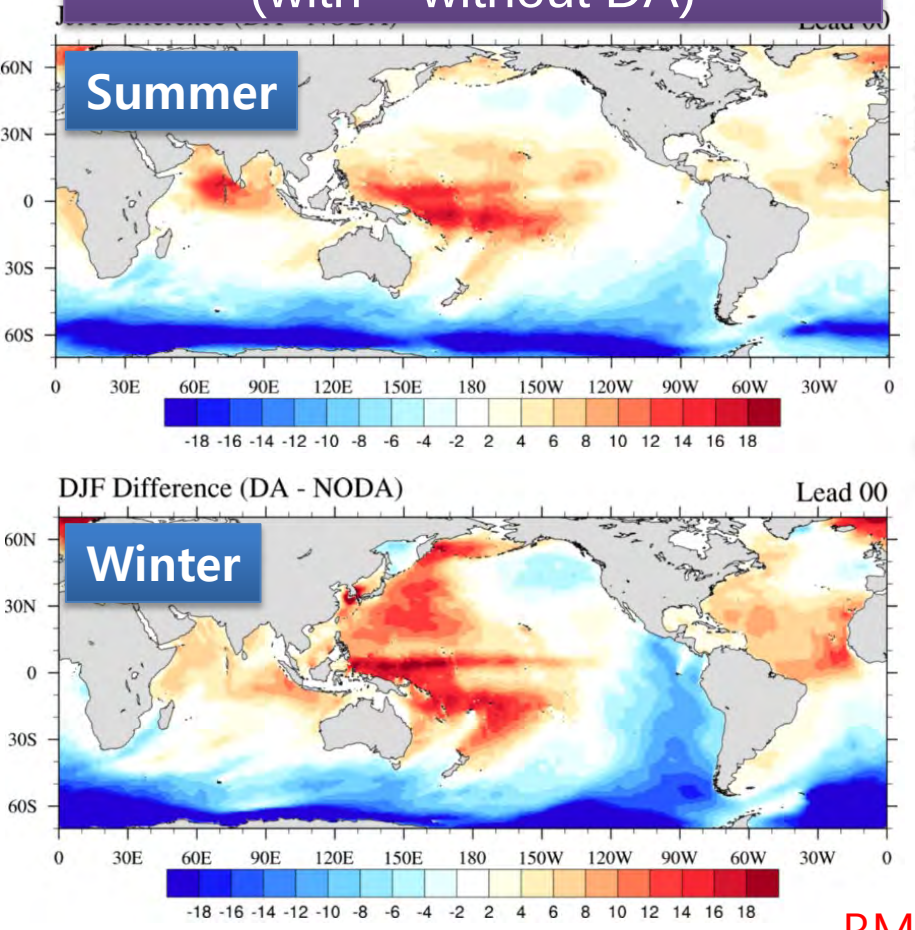
Predict (0~288H run)

- Assimilation with 30 min. interval
  - (-24 to 0h)

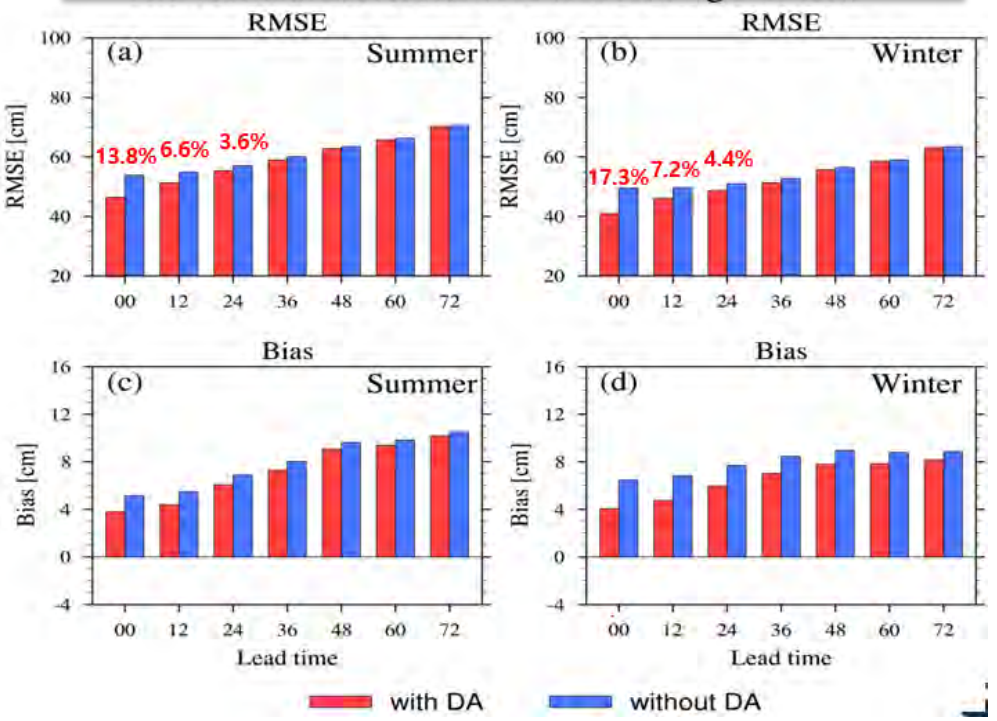
$$RI = \left(\frac{SWH_A}{SWH_F} \right)^2$$

(GWW3) Impact of data assimilation

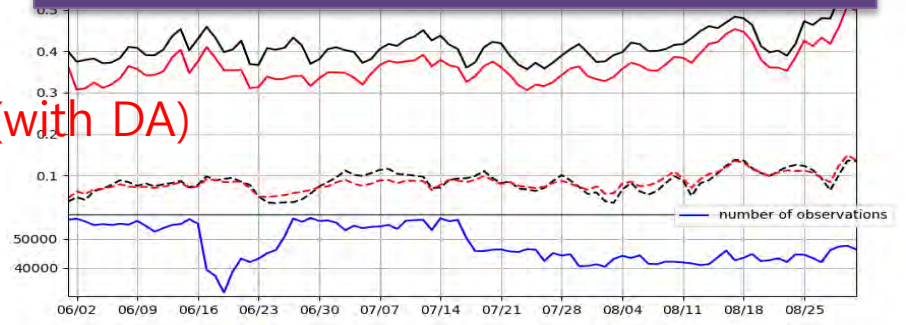
Difference of initial wave height (with – without DA)



SWH errors (0~72h fcst. lead time)

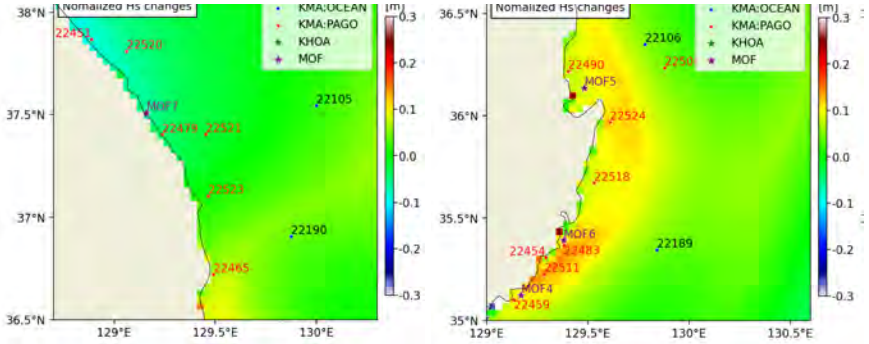


Innovation stats. (JJA 2020): time series of SWH errors

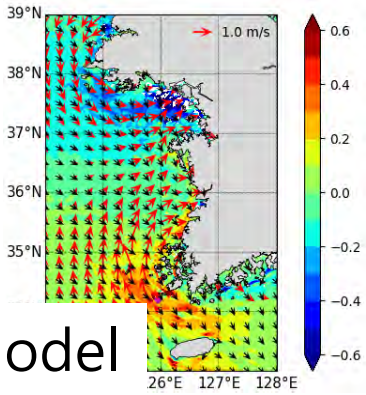


Ongoing developments

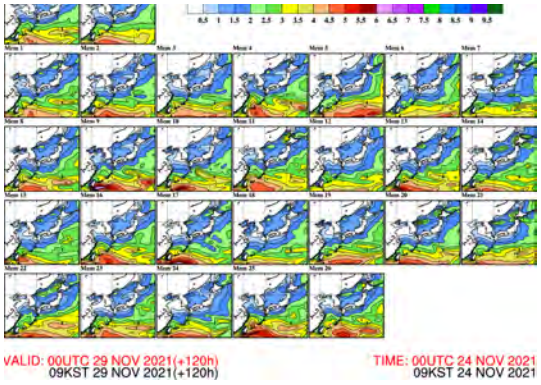
Data assimilation for regional model



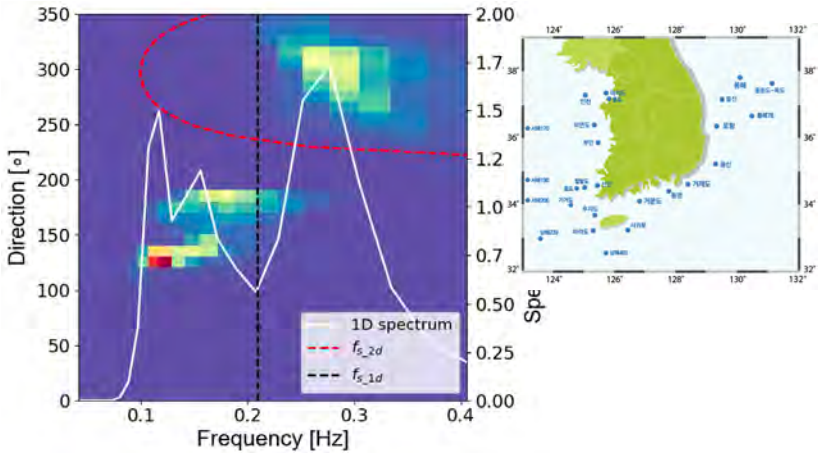
Wave-Tide interaction



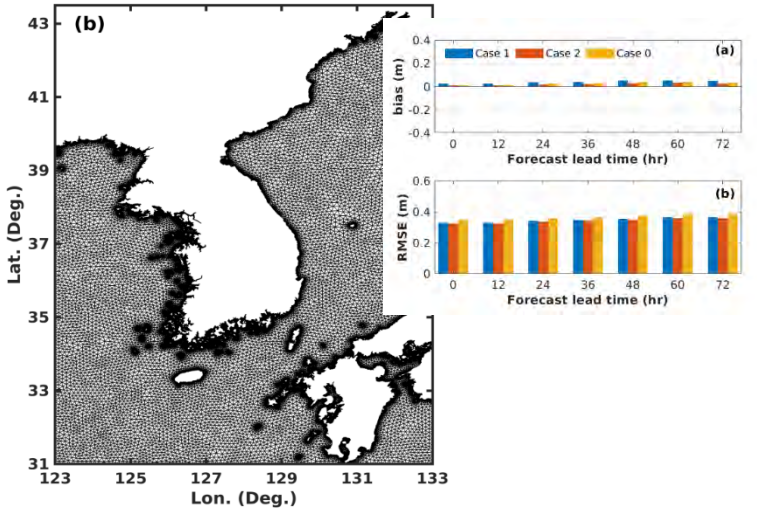
KIM-Ensemble wave model



Swell & Wind sea verification



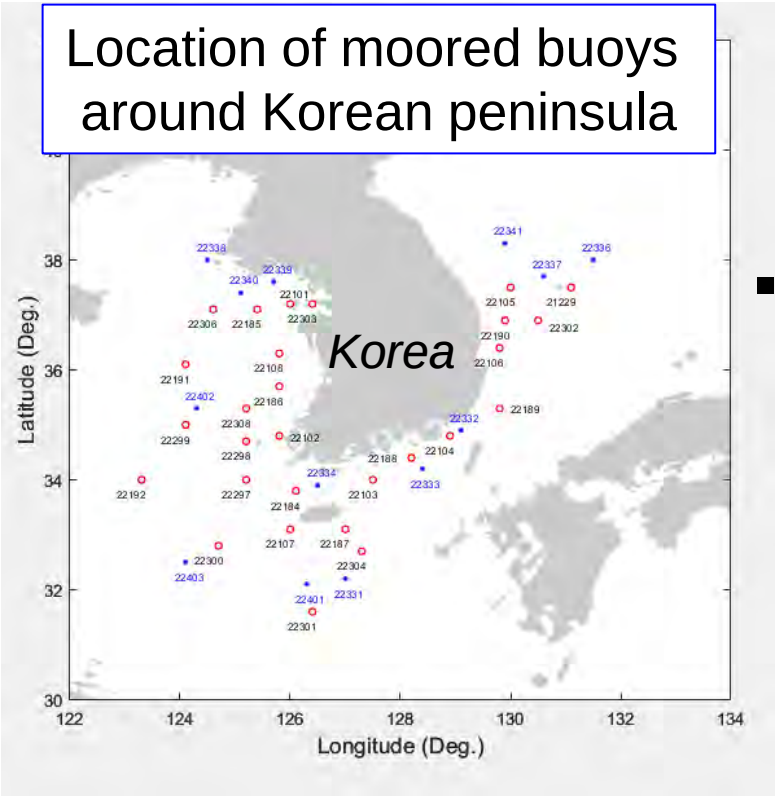
Unstructured grided model



Ongoing developments

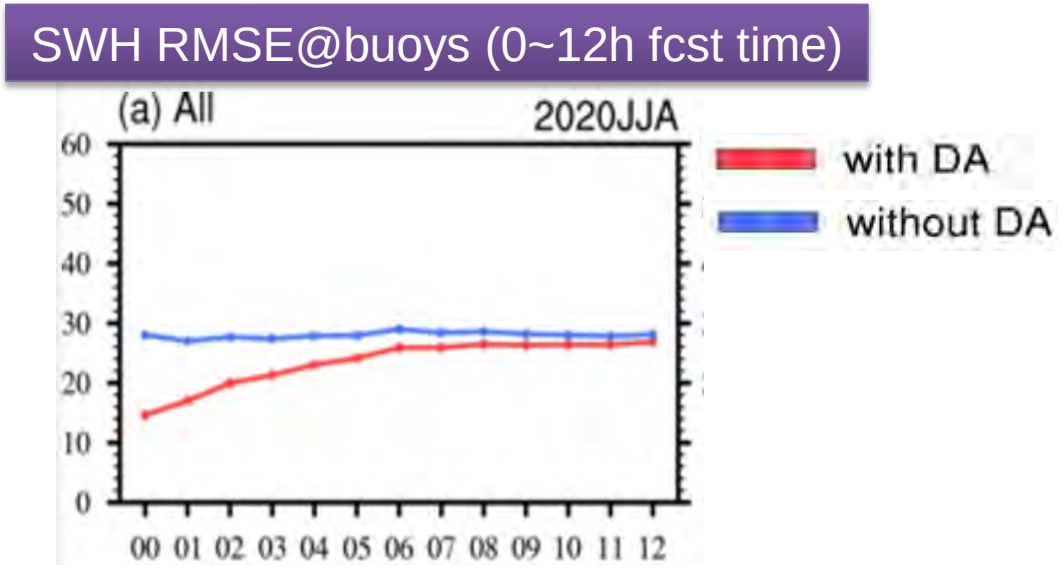
1. Data assimilation for improving regional fcst
2. Wave-tide interaction (application to CWW3)

(RWW3) Data assimilation for regional wave fcst.



- KMA Sea-Met buoys
- KHOA KOGA buoys

- Using similar data assimilation method to GWW3, buoy observations are assimilated to RWW3 SWH background
  * with correlation length scale of 100 km
- SWH forecasts improved, but improvement decreases rapidly (~+6hr)

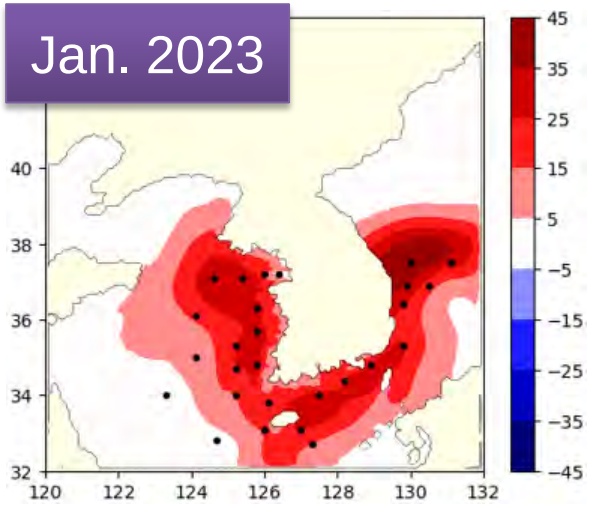


Apply DA to rapid refresh wave model (24 cycles per day)?

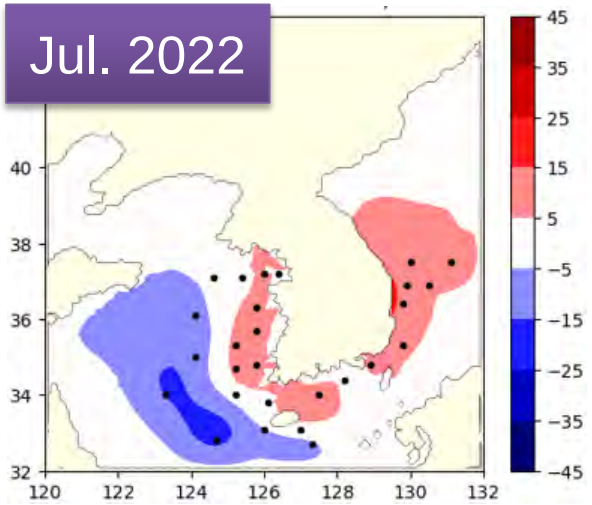
(Rapid refresh model) DA for regional wave fcst.

Difference of SWH initial fields
(with_DA *minus* without_DA)

Jan. 2023



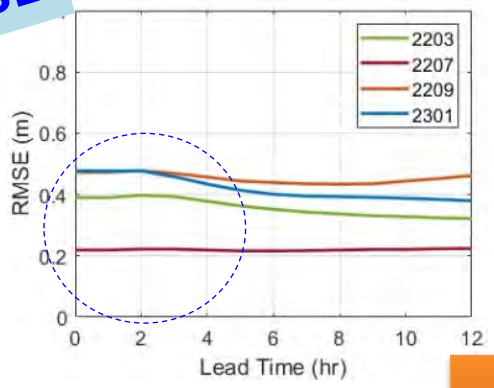
Jul. 2022



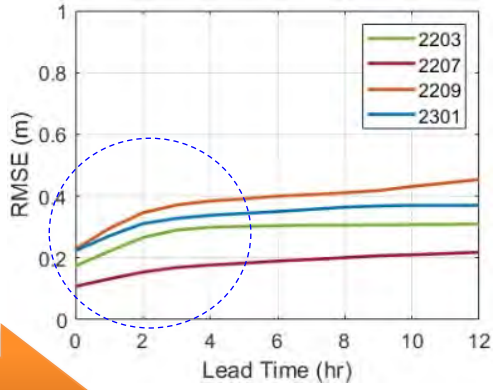
Comparison of forecast errors
(Jan., Mar., Jul., Sep. 2022)

RMSE

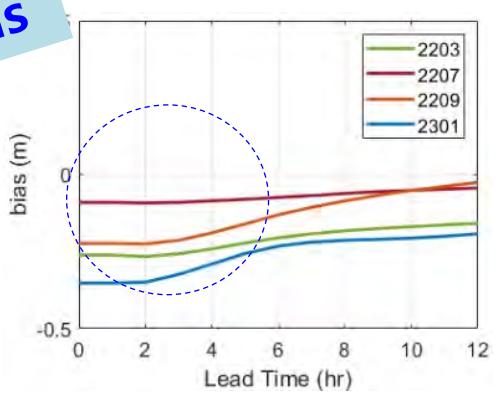
without DA

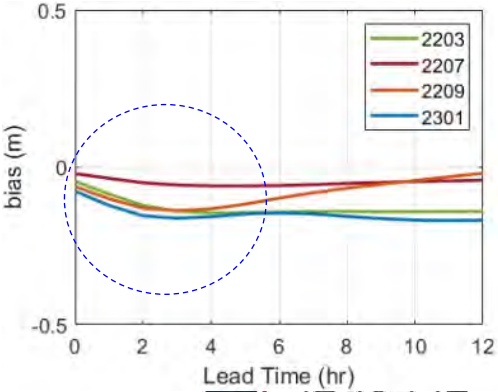


with DA



bias





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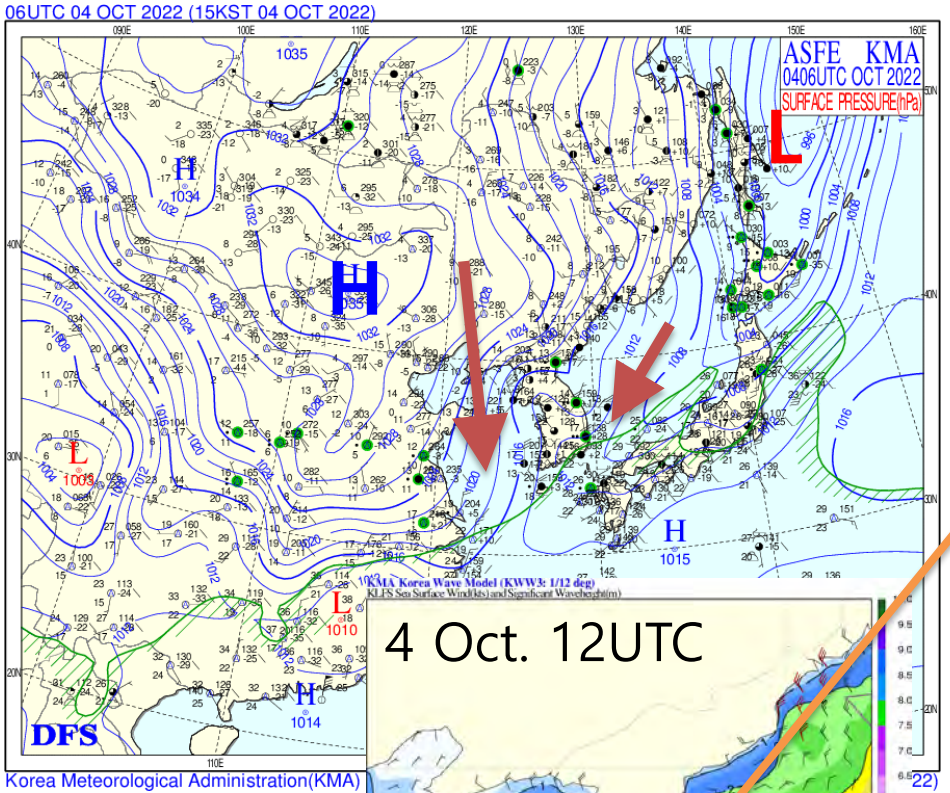
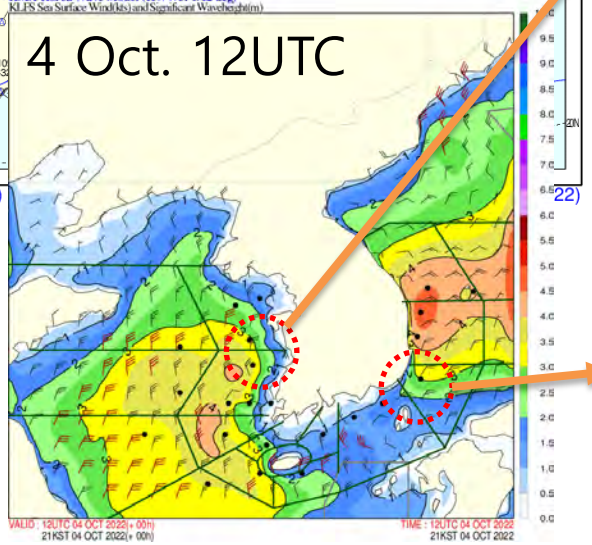
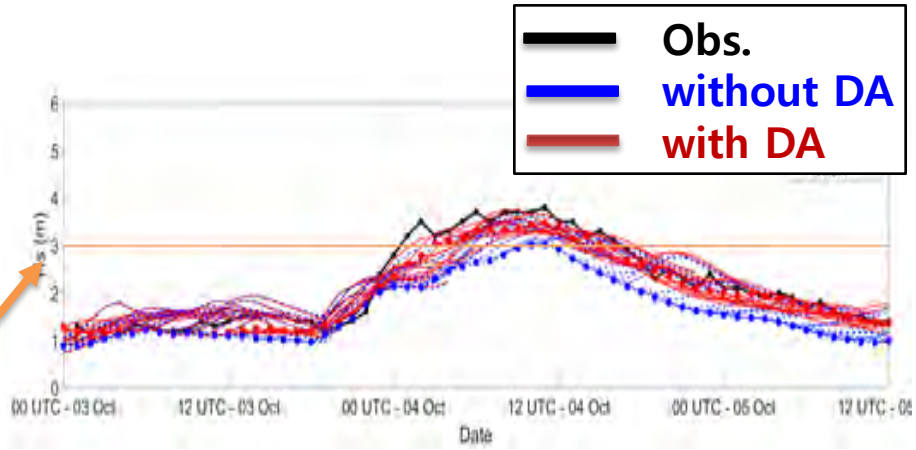
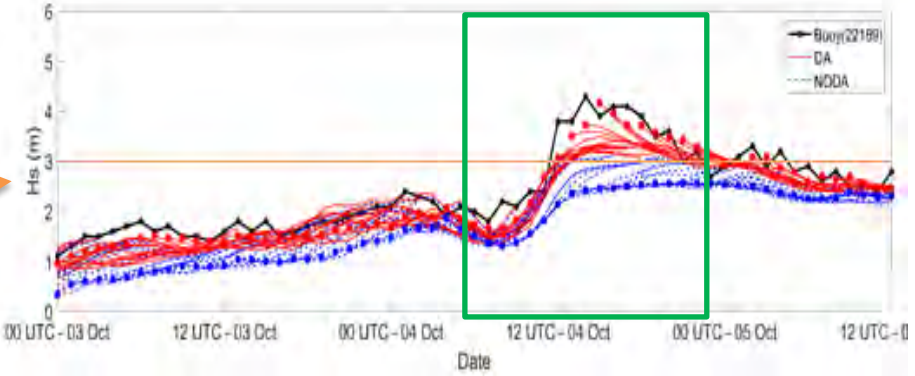
(Case Study) 4 October 2022





Rapid increase of wave height is found in the DA results





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Ongoing developments

1. Data assimilation for regional wave fcst
2. **Wave-tide interaction (application to CWW3)**

Tidal impact on wave forecasting in the Yellow Sea

Coastal Tide/Storm surge model (CTSM)

- NEMO, 1km Resol., NWP
- 2 daily cycles, 72h fcst

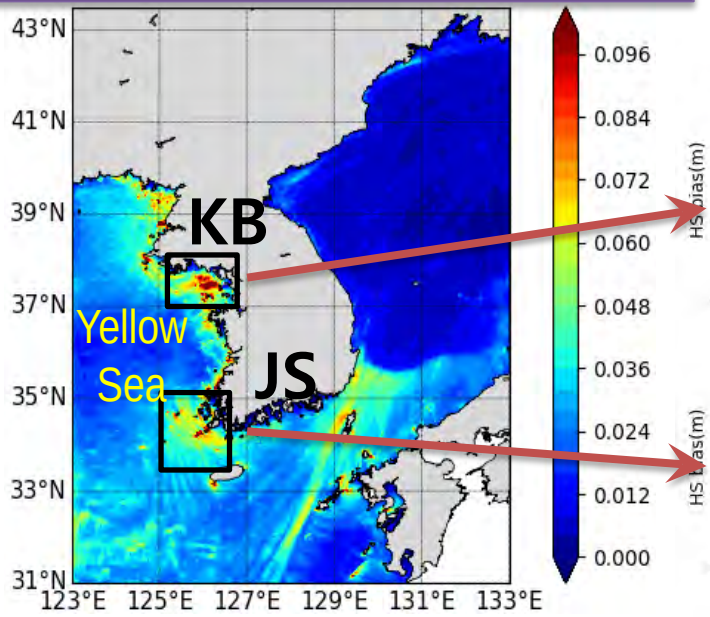
Tide

1 ~ 31 Jan. 2023

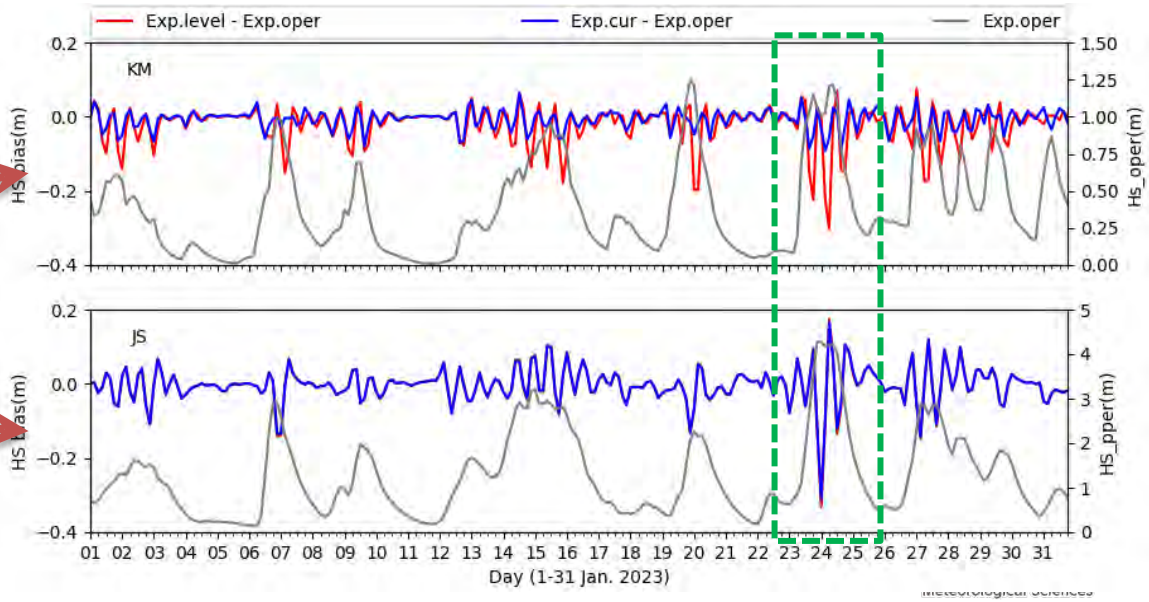
Coastal WaveWatch-III model (CWW3)

- Wavewatch-III, 1km Resol., NWP
- 2 daily cycles, 120h fcst

SWH mean difference Jan. 2023 (Exp. Tide – Exp. Oper)

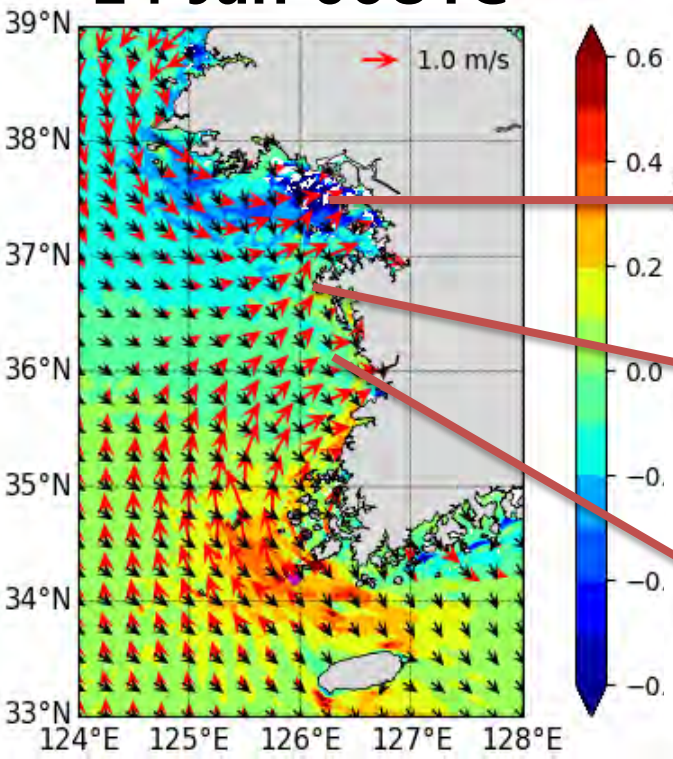


Time variation of SWH difference (1~31 Jan) (Exp. Tide – Exp. Oper)

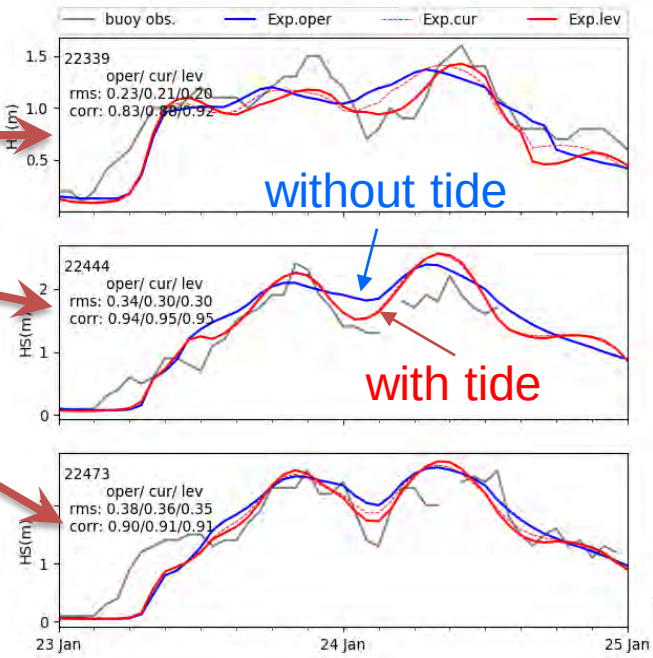


Tidal impacts under severe weather condition

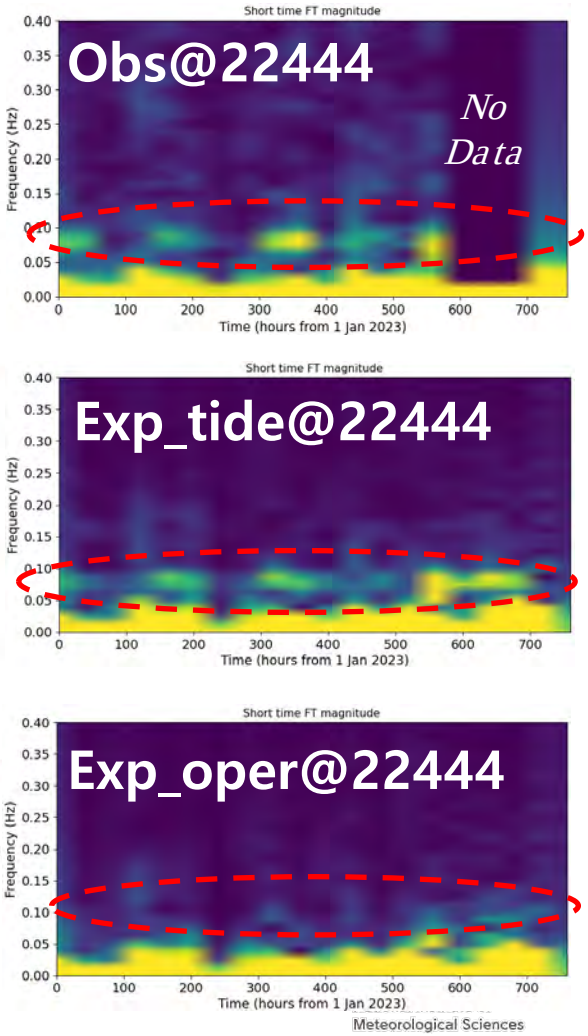
SWH difference (Exp. Tide – Exp. Oper)



SWH comparison (23~24 Jan)



Short time FT of SWH (1~31 Jan)



Applications and Services from KMA

National Services: KMA

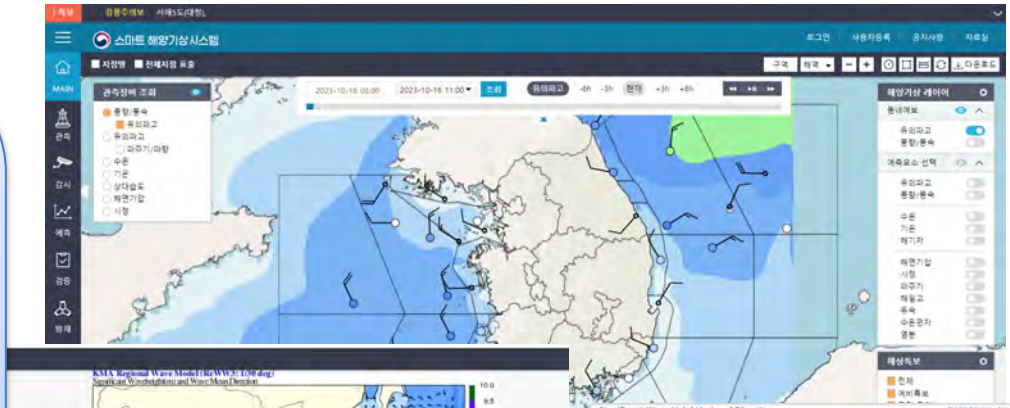
Products and Services

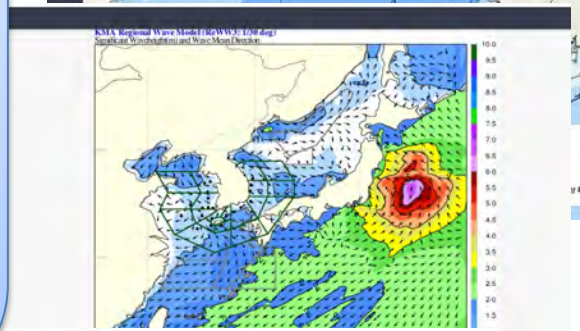
Graphical products

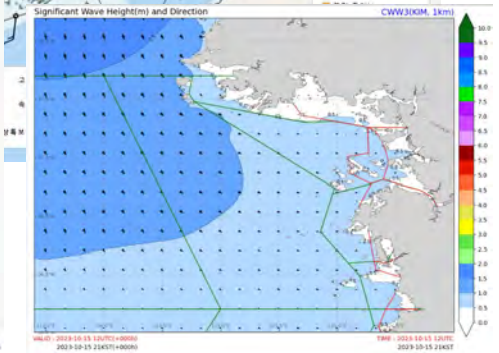
KMA marine information Portal
(marine.kma.go.kr/mmis/)

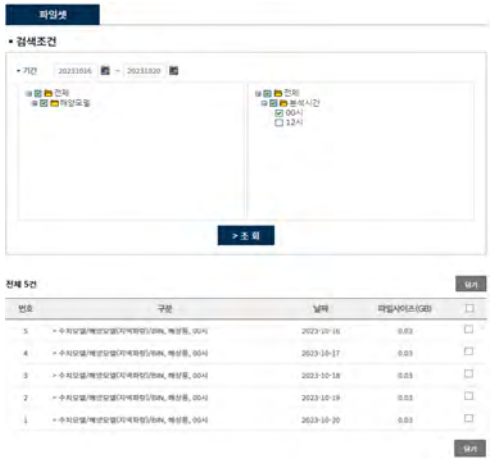
Data services

Open MET Data Portal
(data.kma.go.kr/data/)



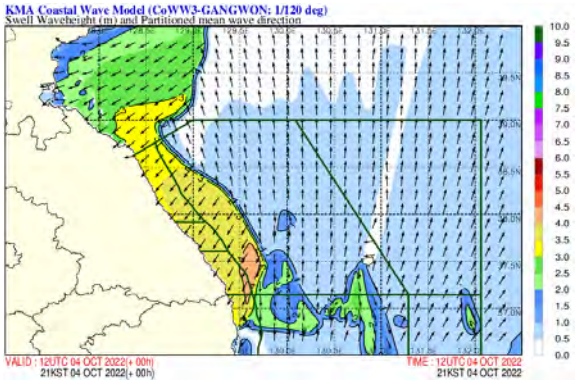


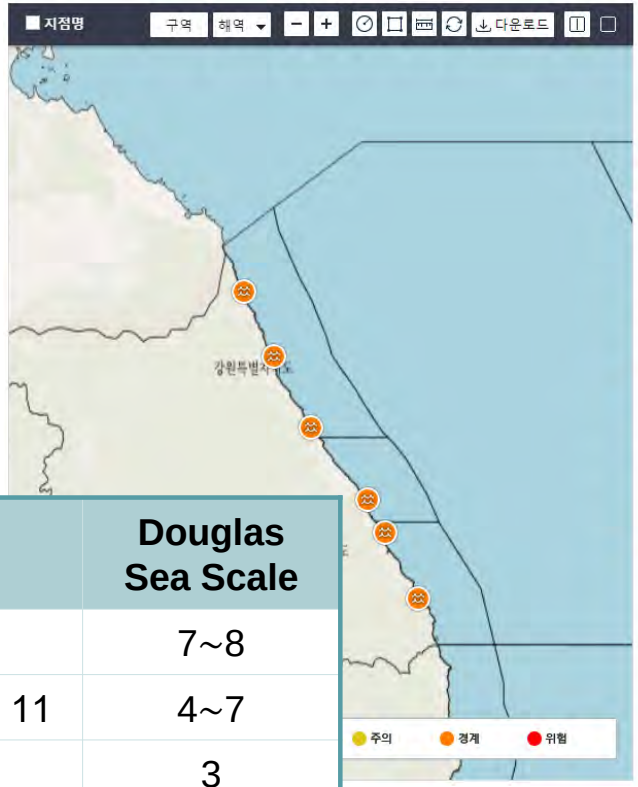




Application: Swell warning system for east coast of Korea

- running swell warning system for 19 stations along the east coast
- Warning level is determined by using the coastal wave model output

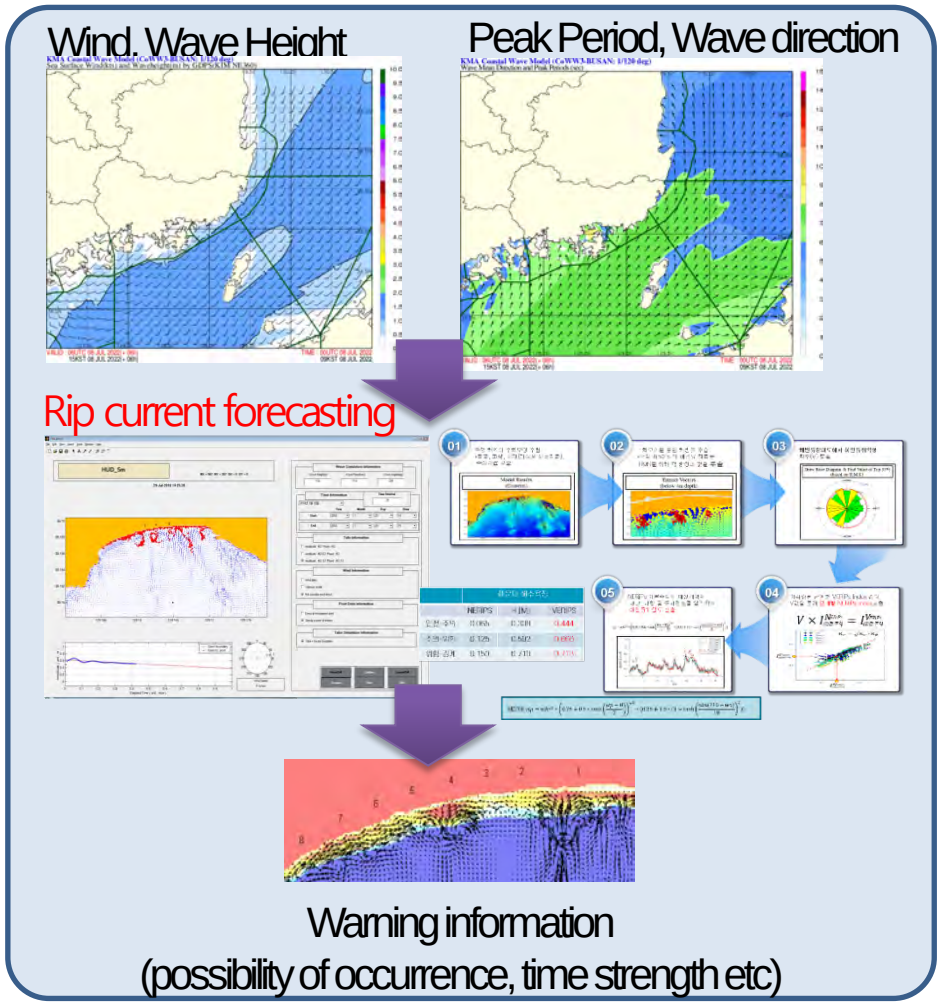


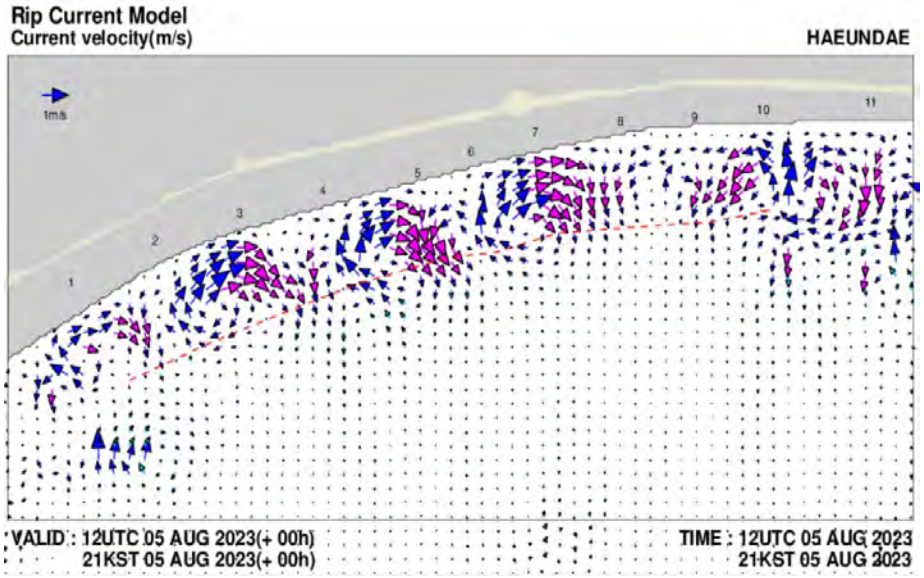


Level	Hs(m)	Tp(s)	Douglas Sea Scale
Hazard	≥ 4	> 11	7~8
Caution	> 2	8.0 ≤ ~ ≤ 11	4~7
Notice	> 2	≤ 8.0	3
Attention	≤ 2	> 8.0	1~2
Normal	< 2	< 8.0	0~1

Applications: Rip current forecasting system

- Rip current forecasting system runs for 8 major beaches
- forced by wind and wave forecasts (height, peak period, direction etc)





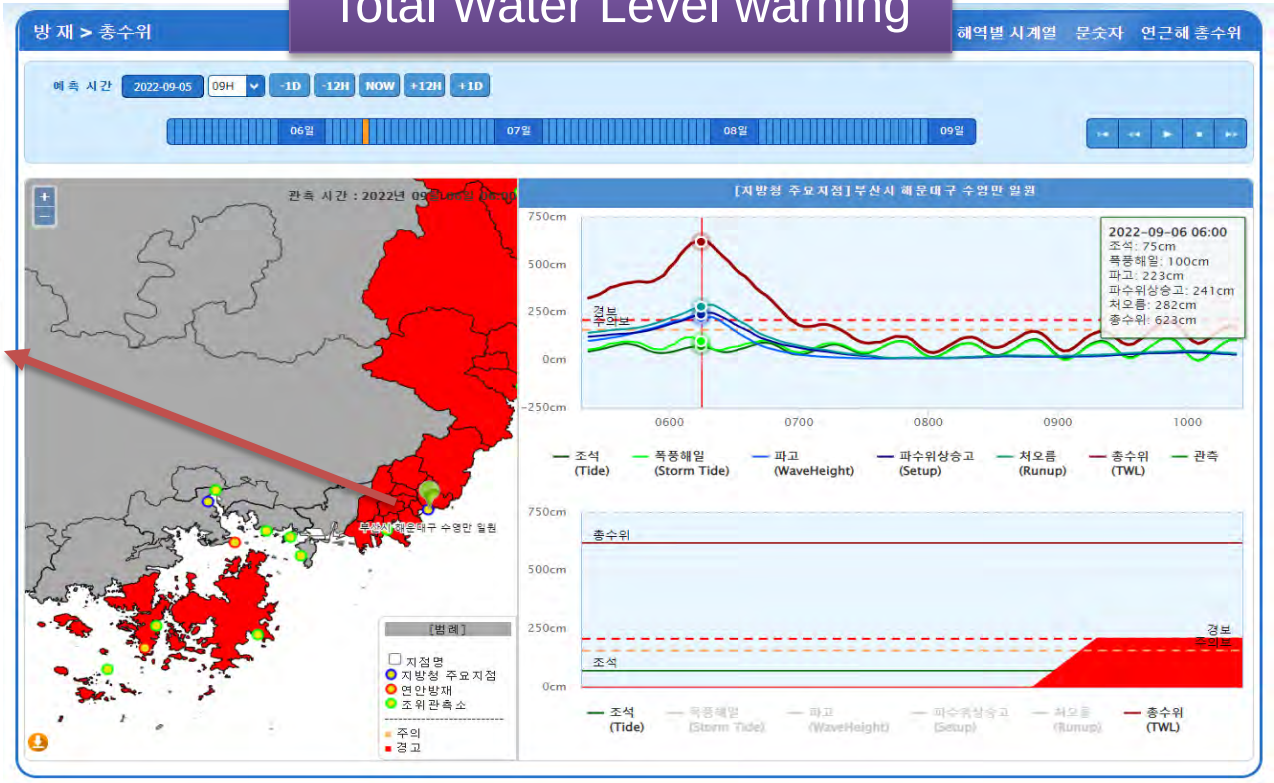
Applications: Total water level (TWL) forecasts

- Total Water Level = Tide + Surge + wave run-up + wave setup

  - Wave induced water level is estimated by empirical equation, based on the wave forecasts (height, period) and coastal slope

▲ 6일 오전 부산 해운대구 마린시티에서 파도가 도로를 덮치고 있다. 연합뉴스

Total Water Level warning



Summary

- Overview operational wave forecasting system in KMA
- Recent upgrades in wave models

  - WaveWatch-III version, enhancing grid resolution, data assimilation…
- Data assimilation improves regional wave forecasts

  - but the improvement rapidly decreases

  - apply to Rapid refresh model, which will be implemented operationally in 2024
- Tidal impact on the coastal wave forecasting in the Yellow Sea

  - induces large wave height differences about 10 % during severe weather

  - detect a distinct tidal modulation along the coast

  - work is ongoing to implement in the operational model
- Applications of wave forecasting