On the development of an operational wave forecast system for the Korean East Coast

Sofia Caires[1], Jinah Kim[2], Jacco Groeneweg[1] and Jeseon Yoo[2]
[1]Deltares, Delft, The Netherland
[2]Korea Institute of Ocean Science and Technology (KIOST), Korea



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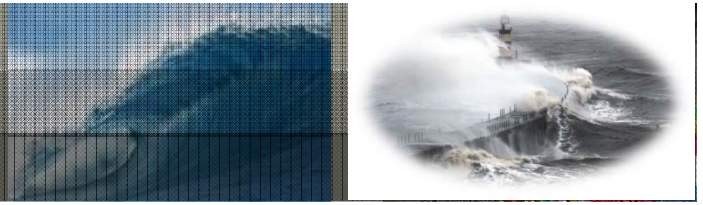
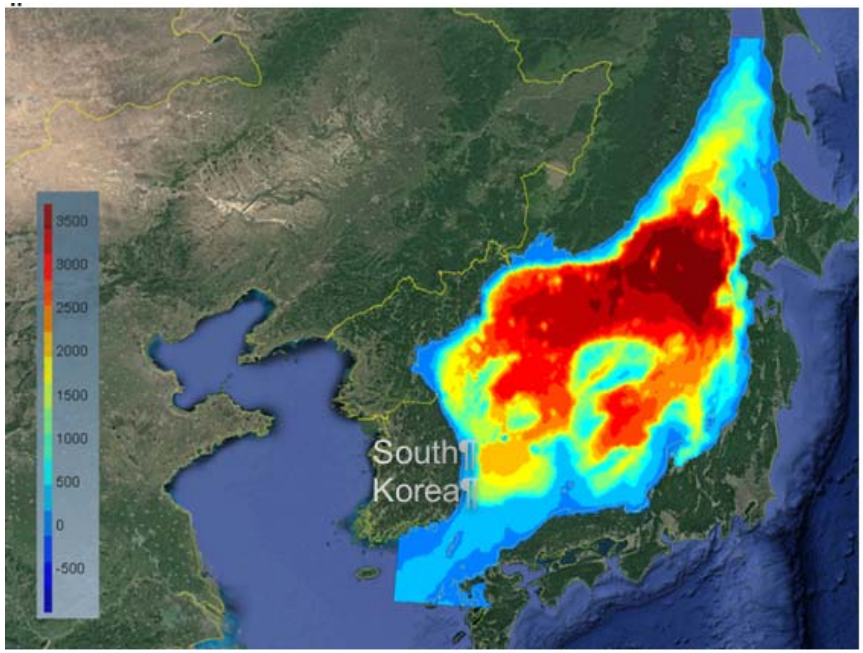
- *Data:* KHOA (Korean Hydrographic and Oceanographic Agency), KIOST-KOOS (Korea Operational Oceanographic System), KMA (Korean Meteorological Administration)

Motivation



The East Coast of Korea is prone to high wave action and an accurate wave forecast system is paramount for the prevention of offshore and coastal accidents, damage and flooding.

To respond to this need, a state-of-the-art coastal wave forecast system for the East Coast of Korea waters is being developed.



First stages:
-setup of wave model -> **SWAN**
-setup of data assimilation ->**EnKF**

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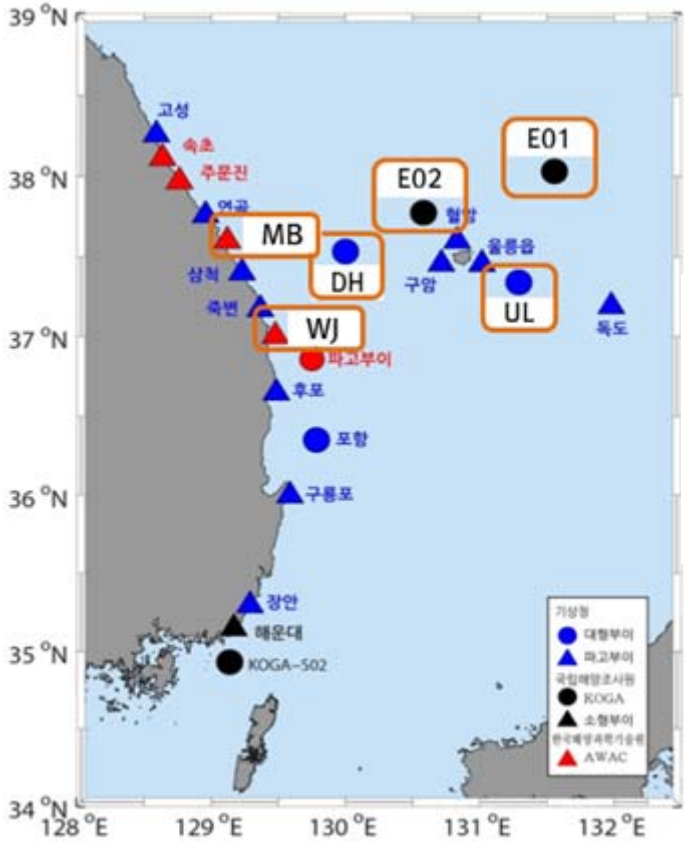
Measuring stations



Location	Longitude (°)	Latitude (°)	Depth	Variables
MB	129.219	37.410	18.7 m	Directional wave spectra
WJ	129.416	37.079	25.9 m	Directional wave spectra
DH	130.000	37.533	Deep (≈ 1,500 m)	H_s, T_p, MWD, U_{10}, U_{dir}
UL	131.100	37.450	Deep (≈ 2,100 m)	H_s, T_p, MWD, U_{10}, U_{dir}
E01	131.540	38.001	Deep (≈ 900 m)	H_s, T_p, MWD, U_{10}, U_{dir}
E02	130.564	37.722	Deep (≈ 1,200 m)	H_s, T_p, MWD, U_{10}, U_{dir}

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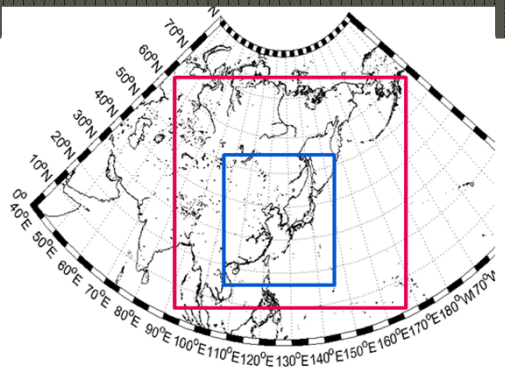
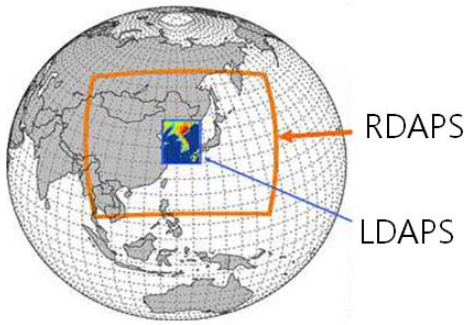
Existing models



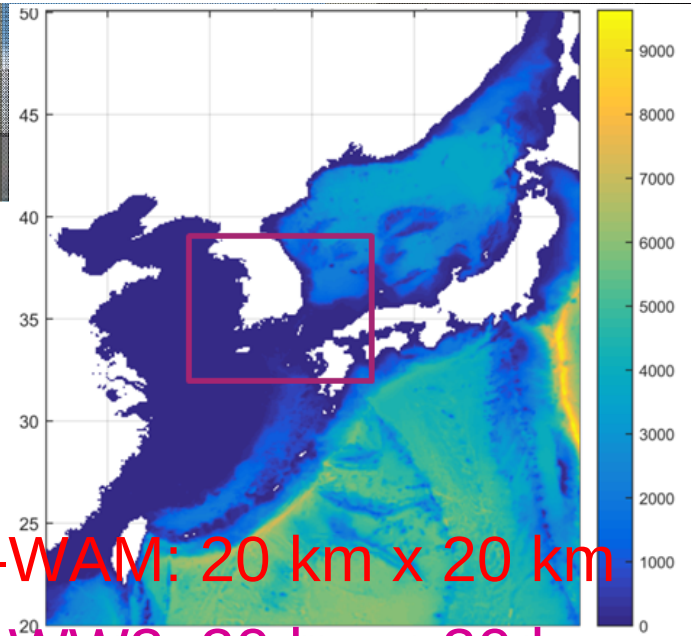
Winds

KIOST-WRF: 20 km x 20 km -> 20 km x 20 km <-GFS, hourly

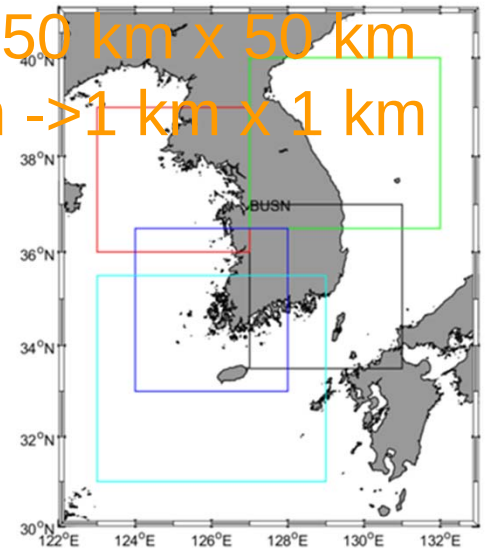
KMA-UM:. 12 km x 12 km -> ~~(1.5 km x 1.5 km)~~, 3-hourly



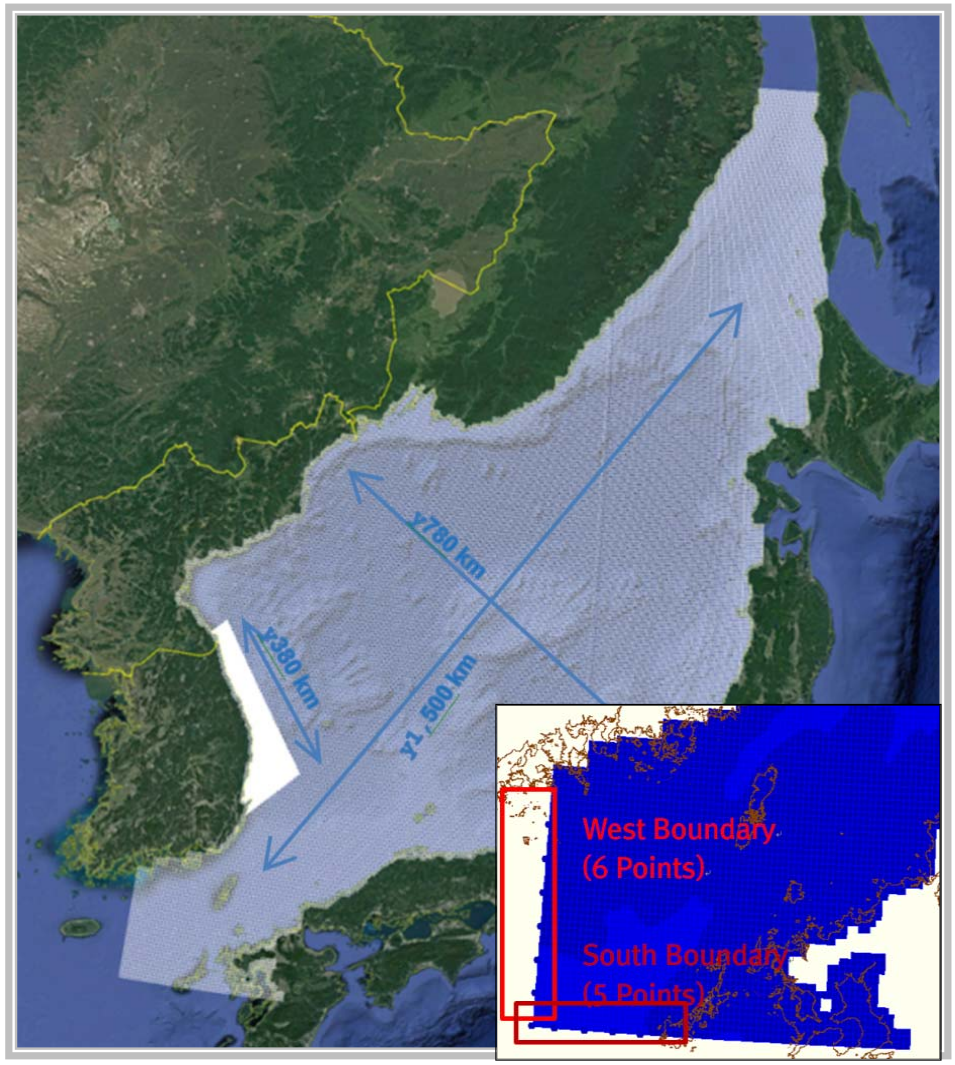
Waves



- KOOS-WAM: 20 km x 20 km
- KOOS-WW3: 20 km x 20 km ->4 km x 4 km WW3 models.
- KMA-CWW3: 50 km x 50 km ->8 km x 8 km ->1 km x 1 km WW3 model



KOREAN EAST WATERS WAVE PREDICTION MODEL



- ✓ SWAN (Delft3D-WAVE)
- ✓ Rectangular grids in spherical coordinates (WGS84)
- ✓ Two Nested Models
  - 1) Overall Model
    - 5 km x 5 km (45k active grid points)
    - etopo5
  - 2) Coastal Model
    - 300 m x 300 m (250k active grid points) (150m x 150m)
    - KorBathy30s + survey bathymetry (KHOA)
- ✓ Spectral Resolution
  - Frequency: 0.03:1.5 (41)
- ✓ - Direction : 7.5 °
- ✓ Bnd Waves: KIOST WAM 20 km (southern 11 loc.)
- ✓ Wind fields: KIOST WRF 20km, 1hr. interval

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Ensemble Kalman Filter (EnKF) data assimilation

Starting from an **initial** ensemble of model states the model is used to compute a forecast for each ensemble member:

$$\xi_i^f(t_{k+1}) = M\,\xi_i^a(t_k) + w_i(t_k)$$

system noise

sample mean $x^f(t_k) = 1/n \sum_{i=1}^{n} \xi_i^f(t_k)$

sample covariance $\mathbf{P}^f(t_k) = 1/(n-1) \sum (\xi_i^f(t_k) - x^f(t_k))(\xi_i^f(t_k) - x^f(t_k))'$

Kalman gain $\mathbf{K}(t_k) = \mathbf{P}^f(t_k)\mathbf{H}'(\mathbf{H}\mathbf{P}^f(t_k)\mathbf{H}' + \mathbf{R})^{-1}$

observation operator

error covariance of the observations

The **analysis** step of the EnKF uses a perturbation of the observations and a separate analysis for each of the ensemble members to obtain a consistent ensemble of states that incorporate the observations

$$\xi_i^a(t_k) = \xi_i^f(t_k) + \mathbf{K}(t_k)(y(t_k) - H\,\xi_i^f(t_k) - v_i(t_k))$$

perturbation of the observations

sample mean $x^a(t_k) = 1/n \sum_{i=1}^{n} \xi_i^a(t_k)$

sample covariance $\mathbf{P}^a(t_k) = 1/(n-1) \sum_{i=1}^{n} (\xi_i^a(t_k) - x^a(t_k))(\xi_i^a(t_k) - x^a(t_k))'$

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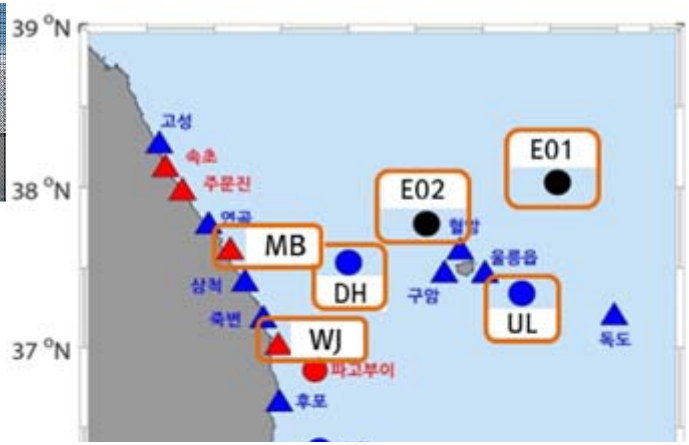
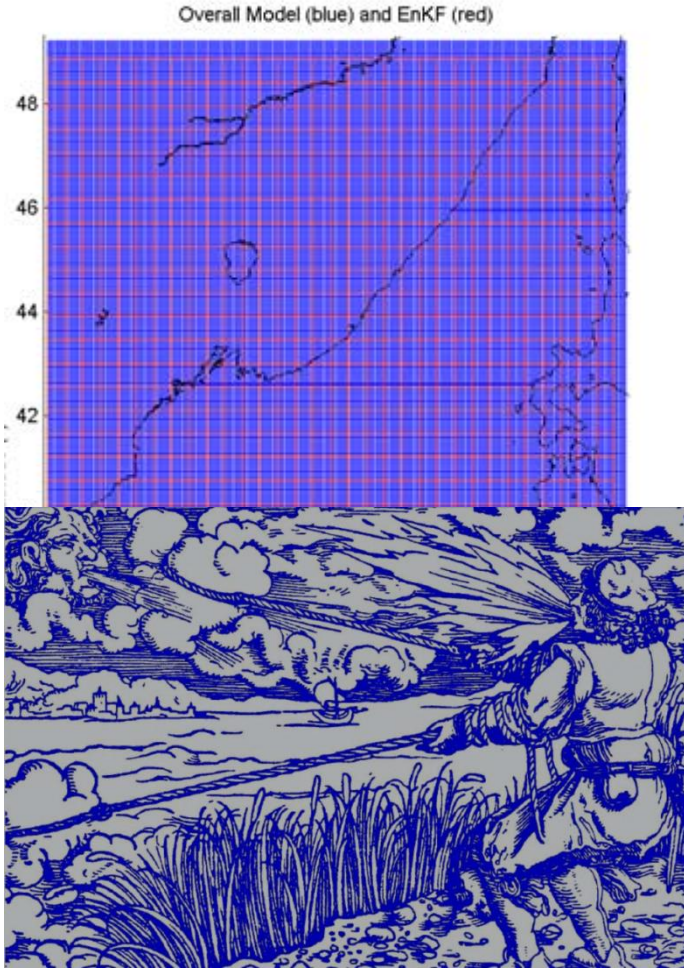
EnKF settings

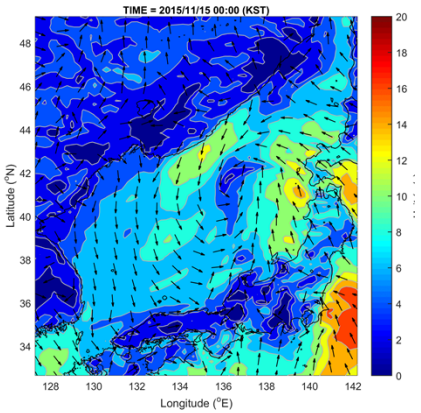
- OpenDA
- Control variable: forcing winds (x, y treated independently, standard deviation 1 m/s, exponential decay of correlation of 500km and 12h)
- Assimilated observations: H_s at DH and E01 (uncorrelated Gaussian white-noise with a standard deviation 0.2m)
- Ensemble members: 30
- To reduce the EnKF computational effort -> Overall Model computational grid coarsened 9x (0.05°x 0.05° ->0.45°x 0.45°)
- The resulting analysis wind fields are afterwards used to force the full (not coarsened) Overall Model and nested Coastal Model.



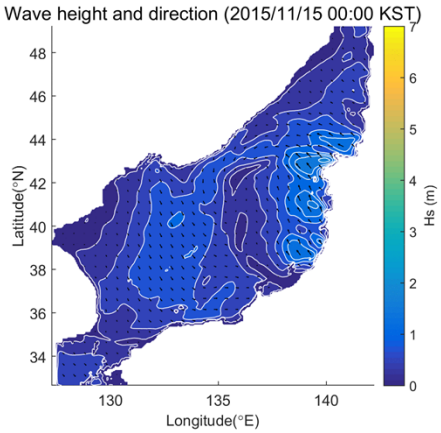


KOREAN EAST WATERS WAVE PREDICTION MODEL

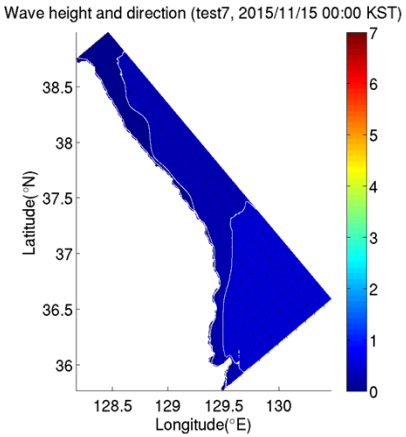
✓ Whole Period : 2016.11.15 00:00 ~ 2016.12.19 23:00



wind

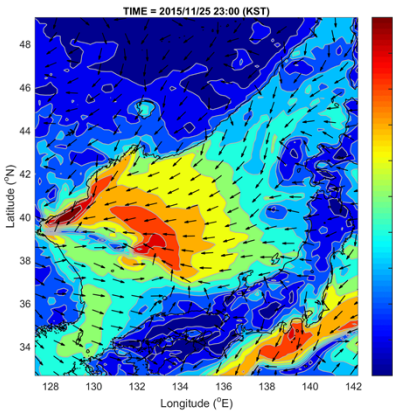


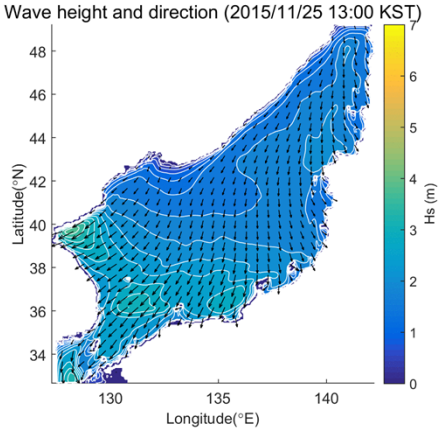
wave

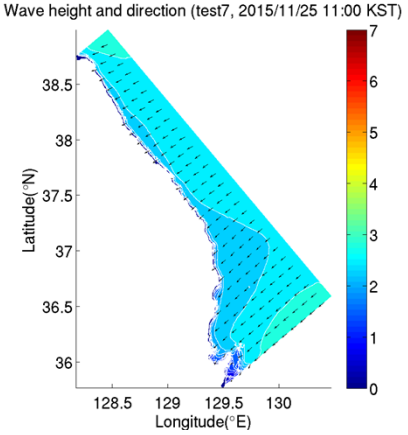


wave

✓ Winter Storm 1 : 2016.11.25 13:00 ~ 2016.11.28 23:00 – Northeast nearshore, Northwest offshore

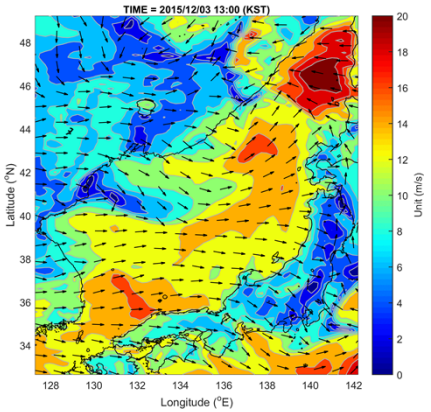




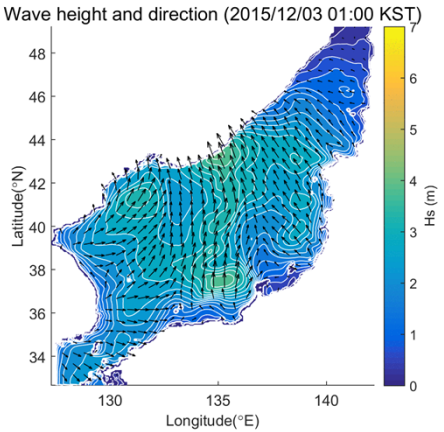


KOREAN EAST WATERS WAVE PREDICTION MODEL

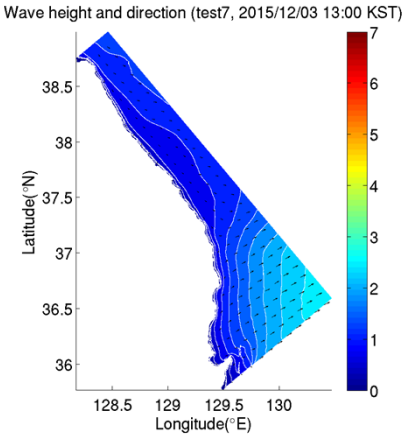
✓ Winter Storm 2. 2016.12.03 13:00 ~ 2016.12.06 23:00 – Northwest



wind

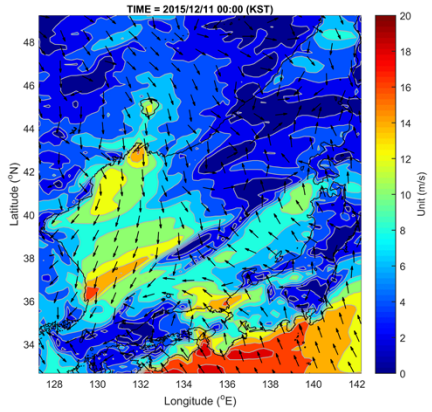


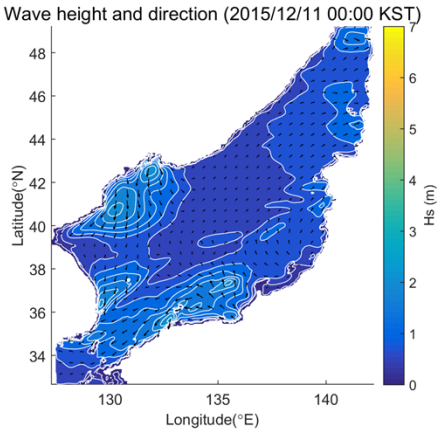
wave

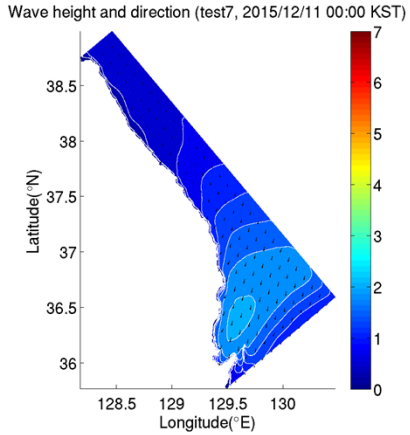


wave

✓ Winter Storm 3. 2016.12.11 00:00 ~ 2016.12.15 12:00 – Northeast







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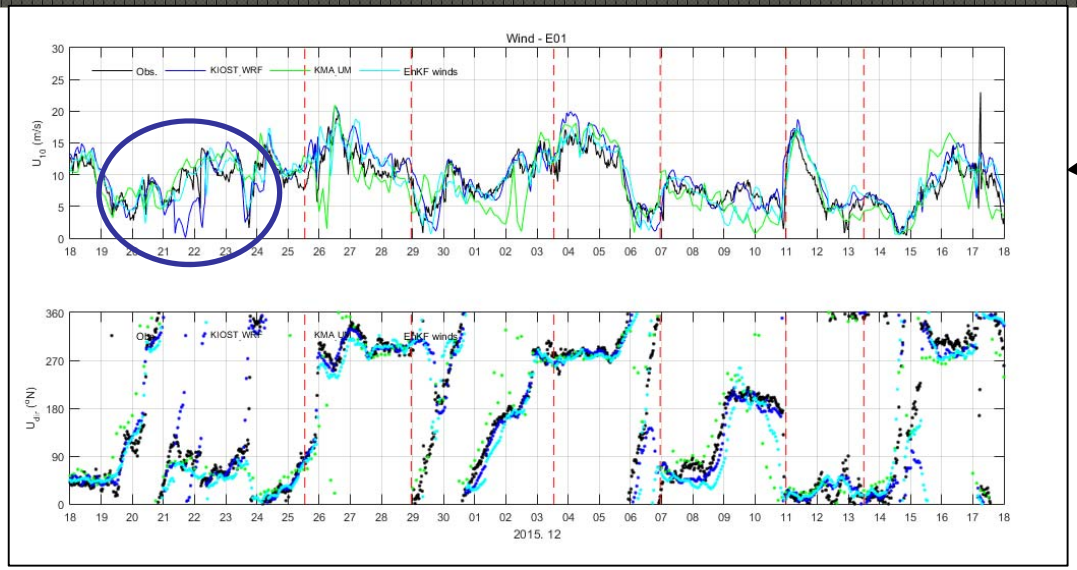
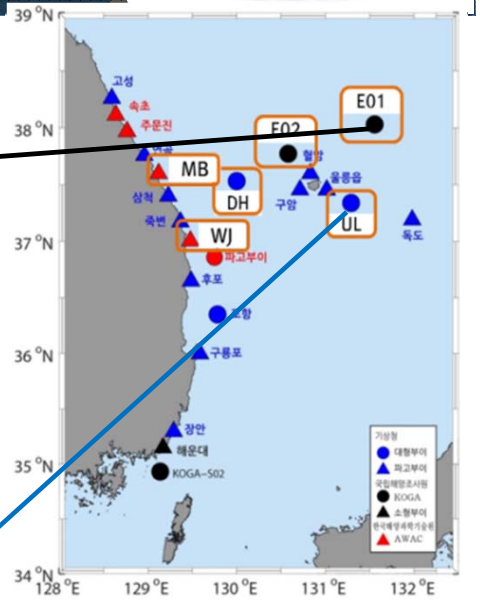
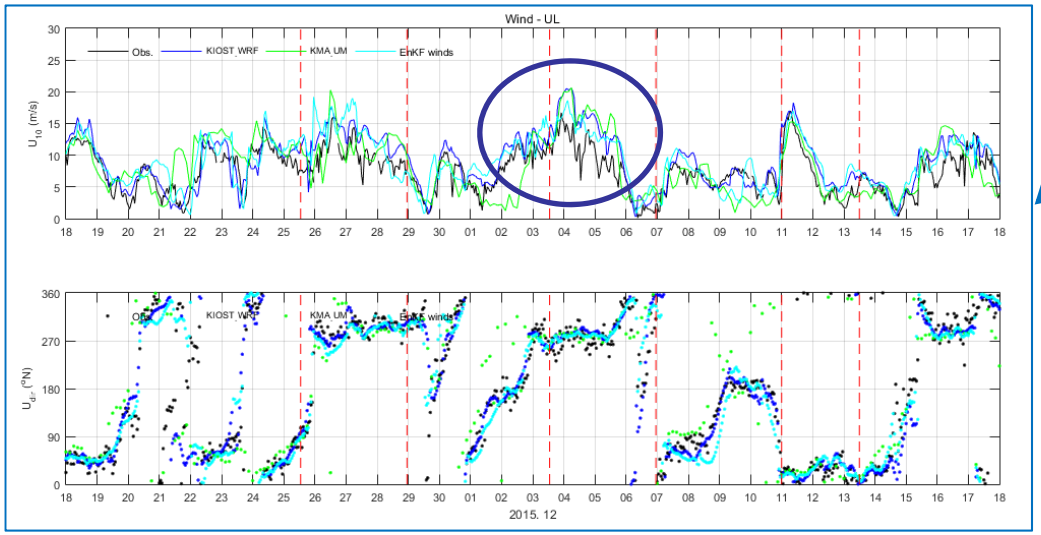
Wind speed and Direction

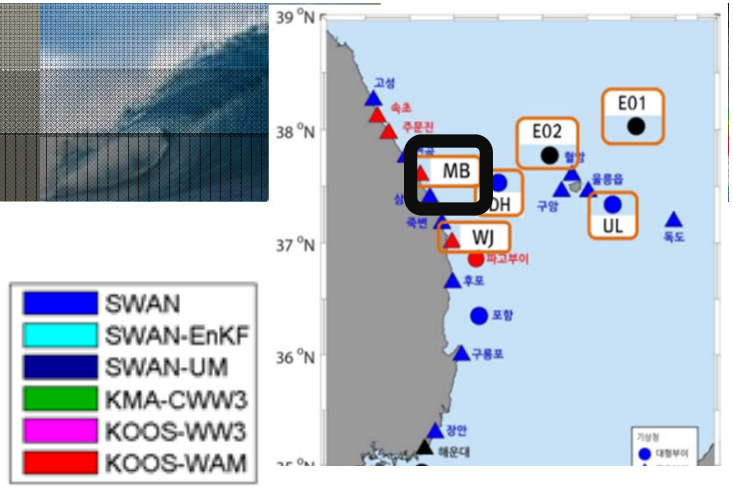


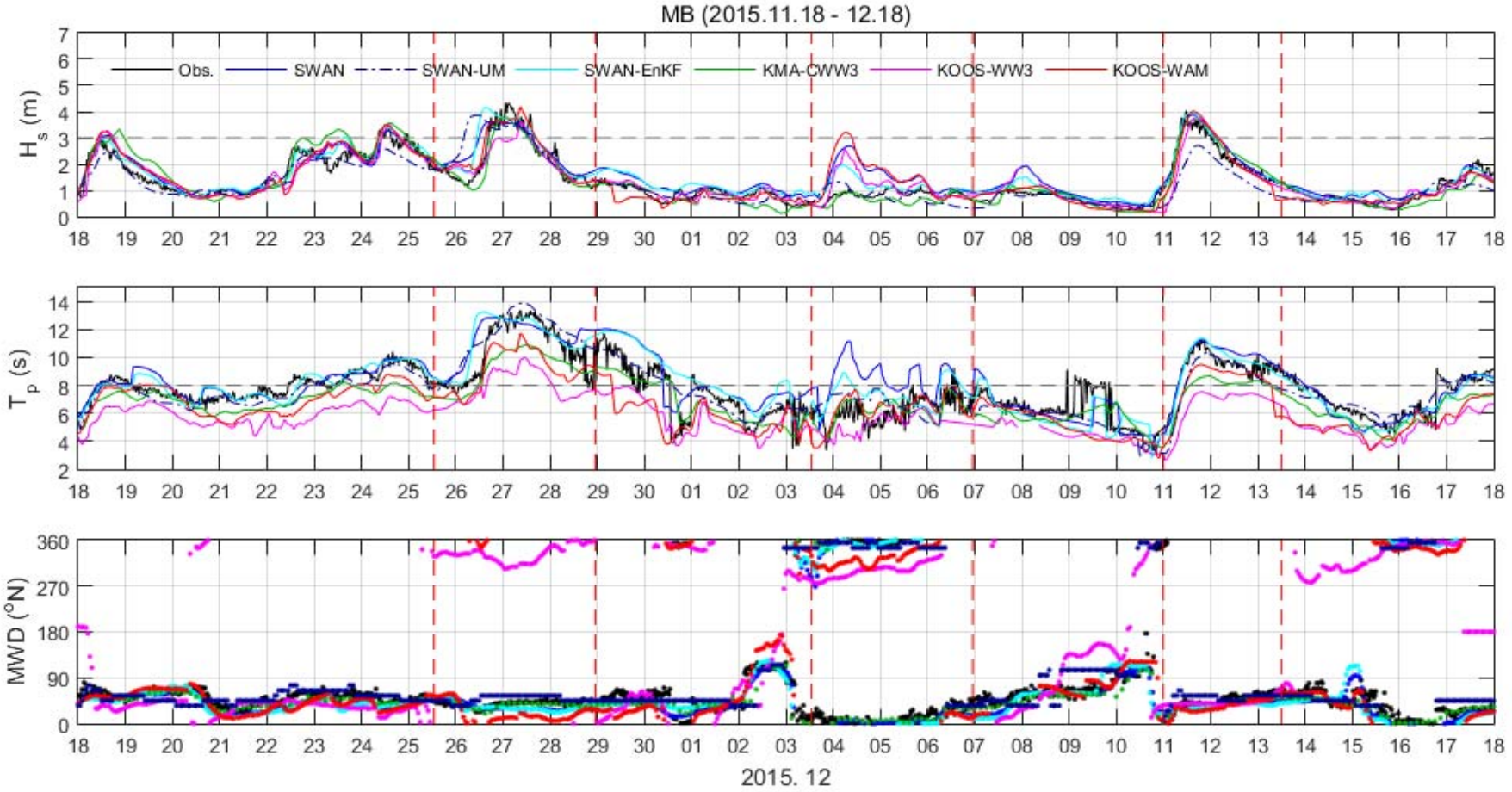




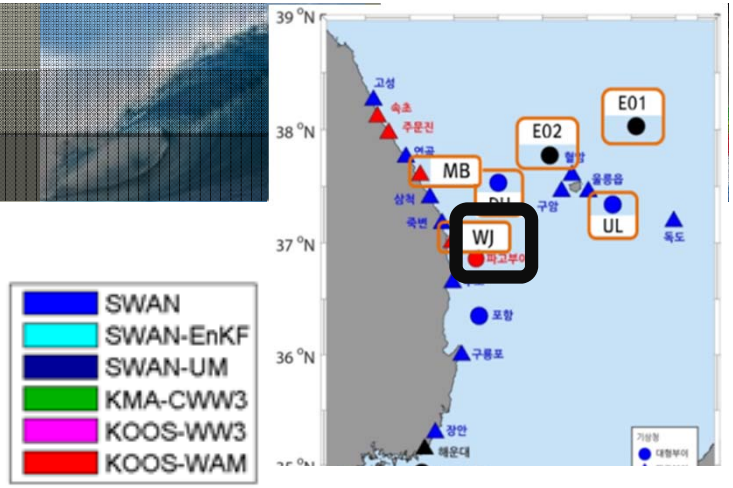
- Comparable model performances with clear WRF & UM overestimation of Storm 2
- WRF slightly better performance than UM

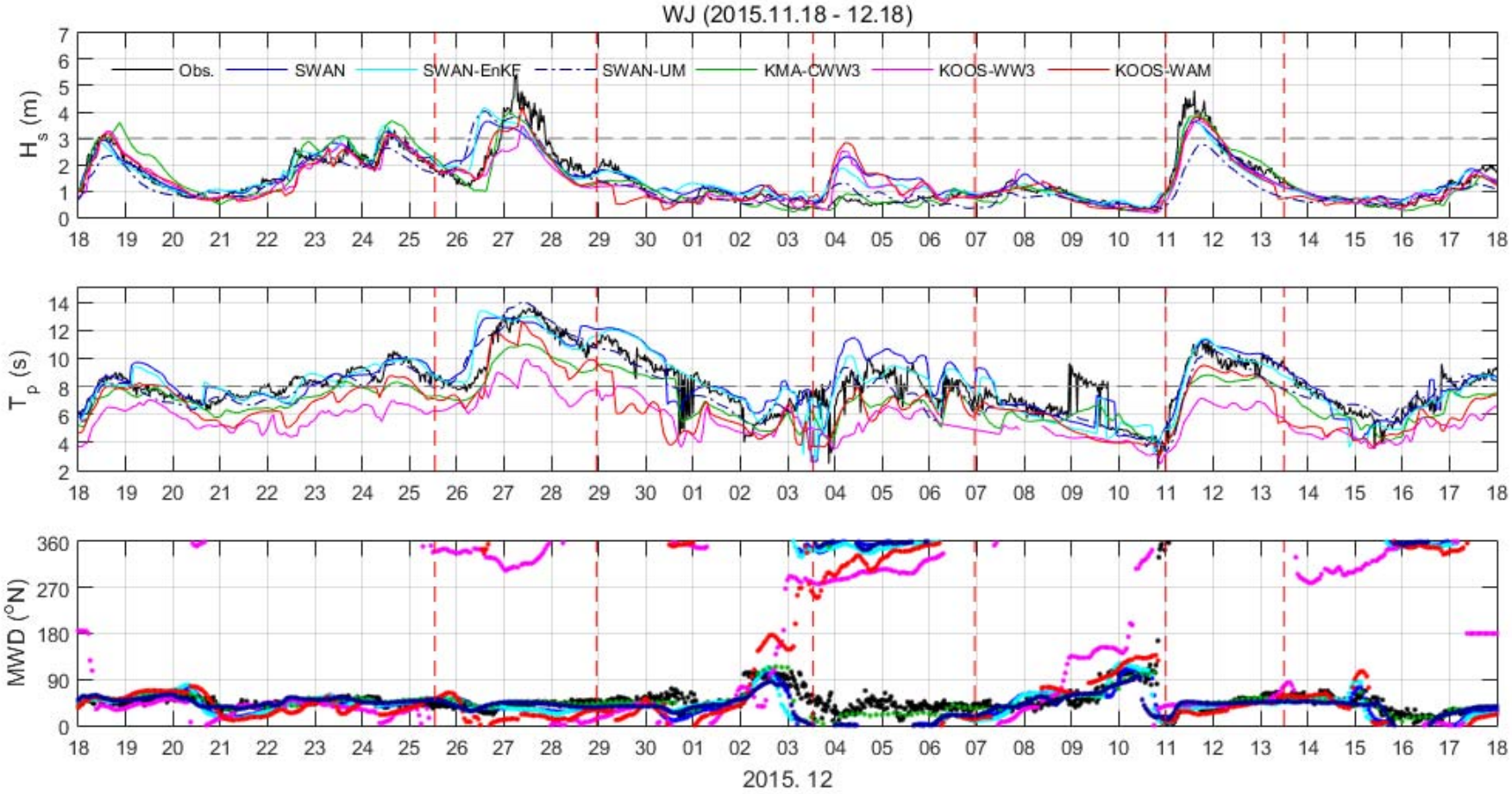
Wave conditions



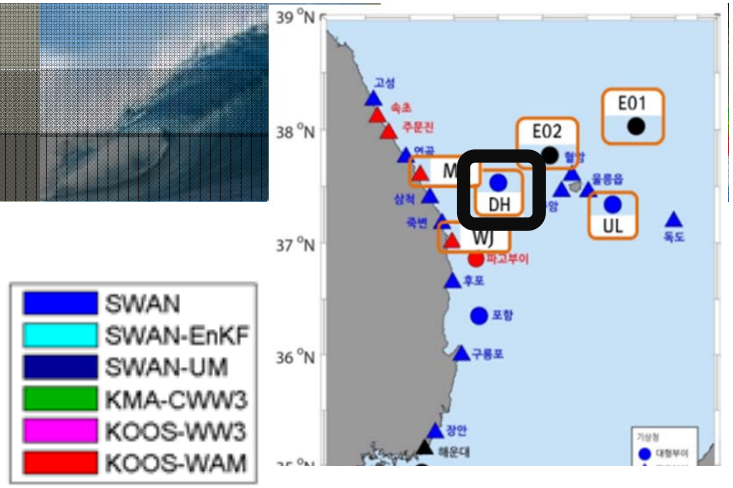


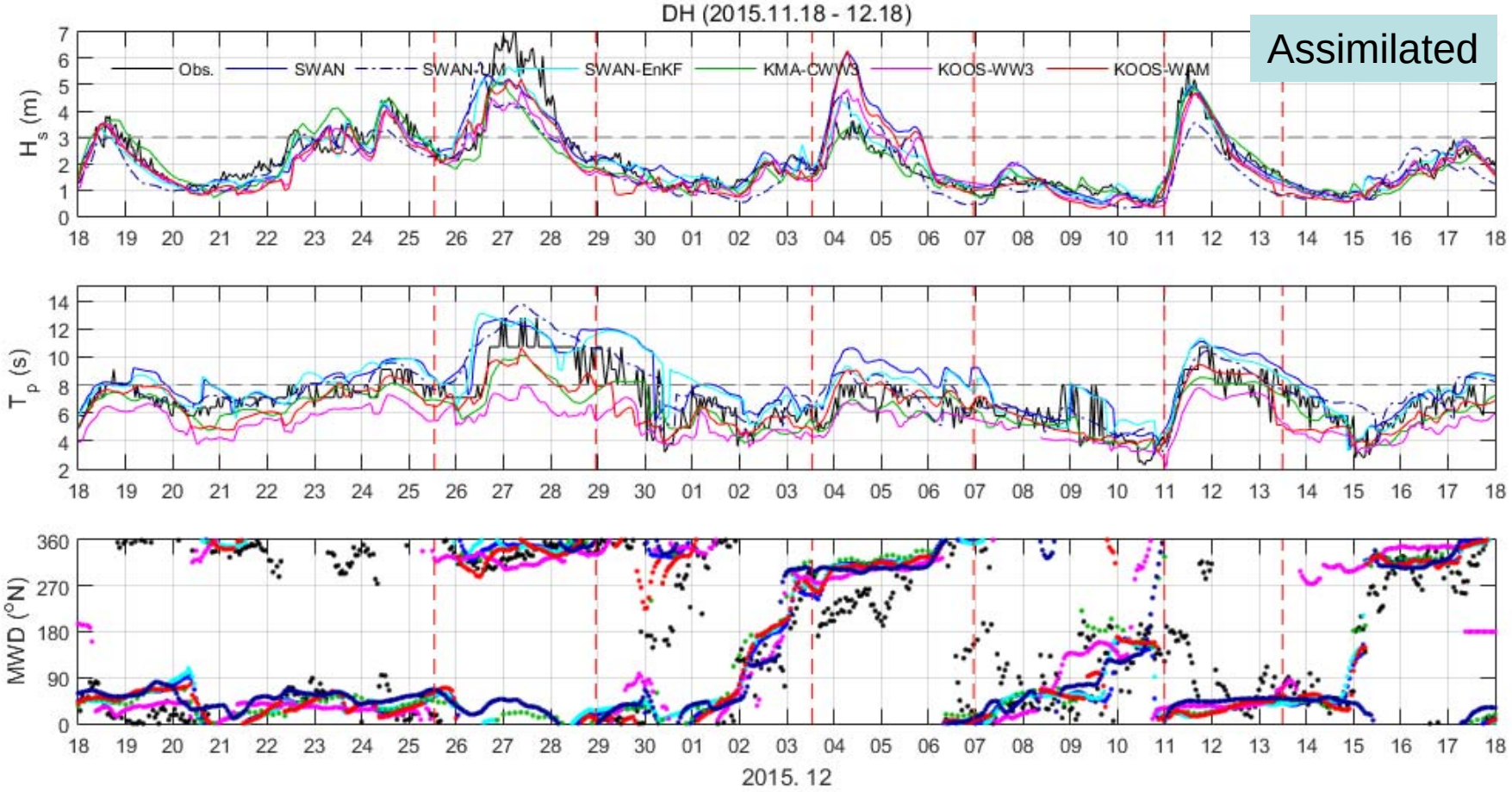
Wave conditions



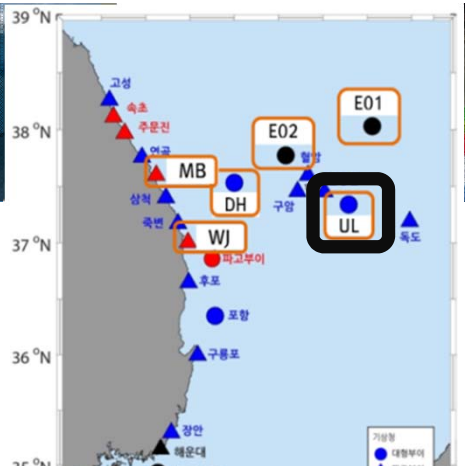


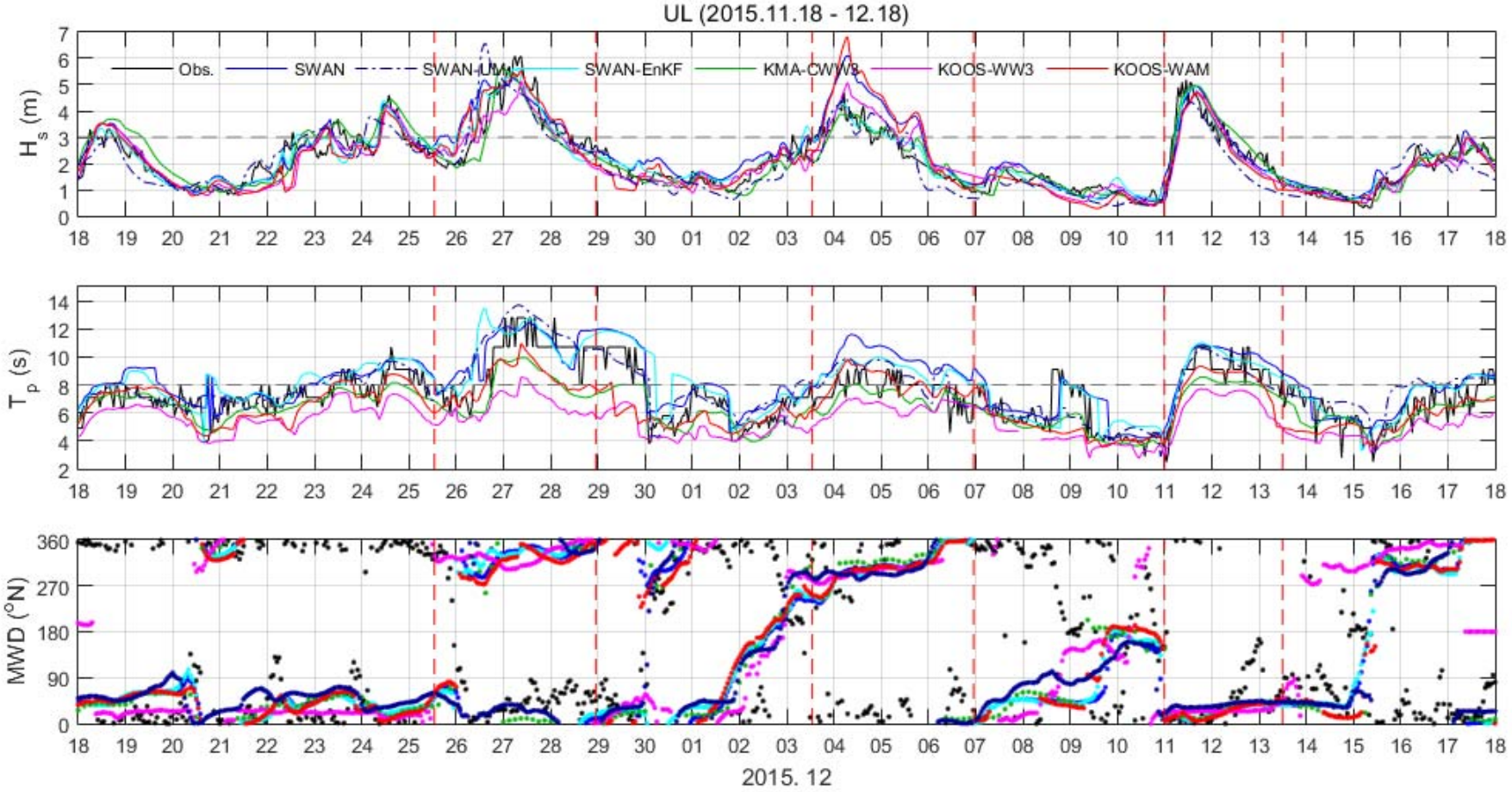
Wave conditions



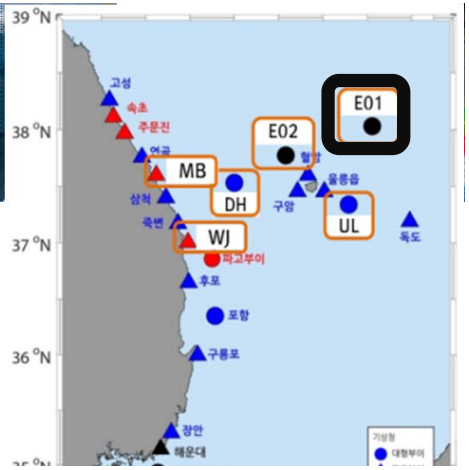


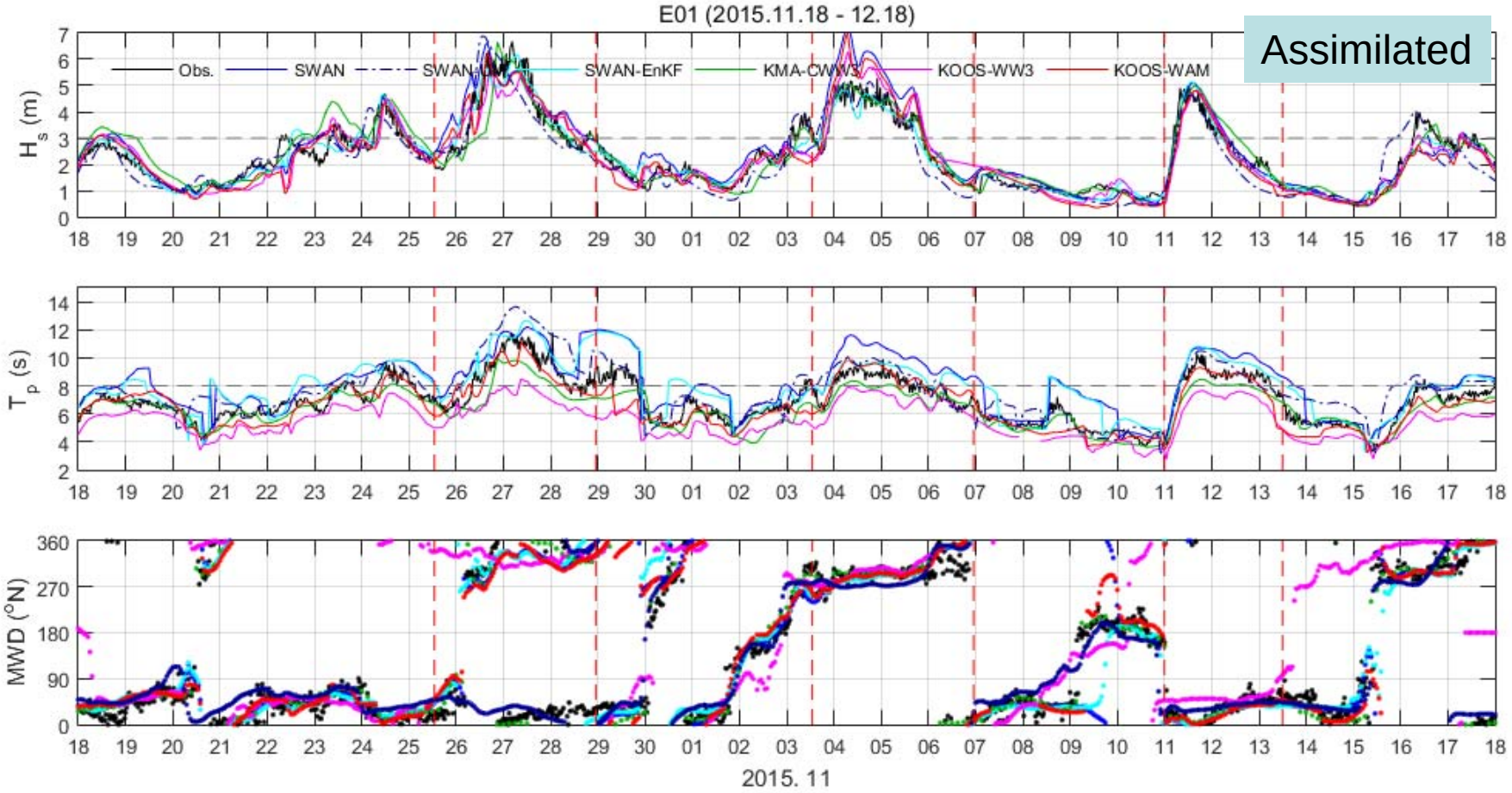
Wave conditions



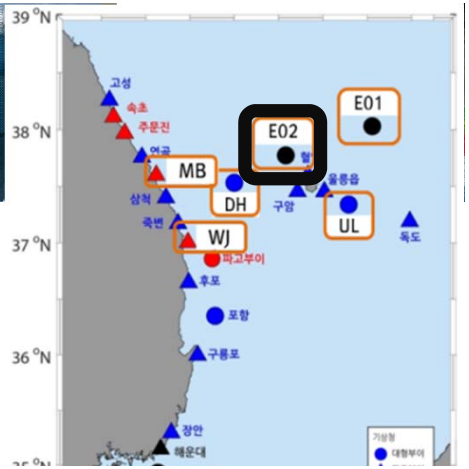


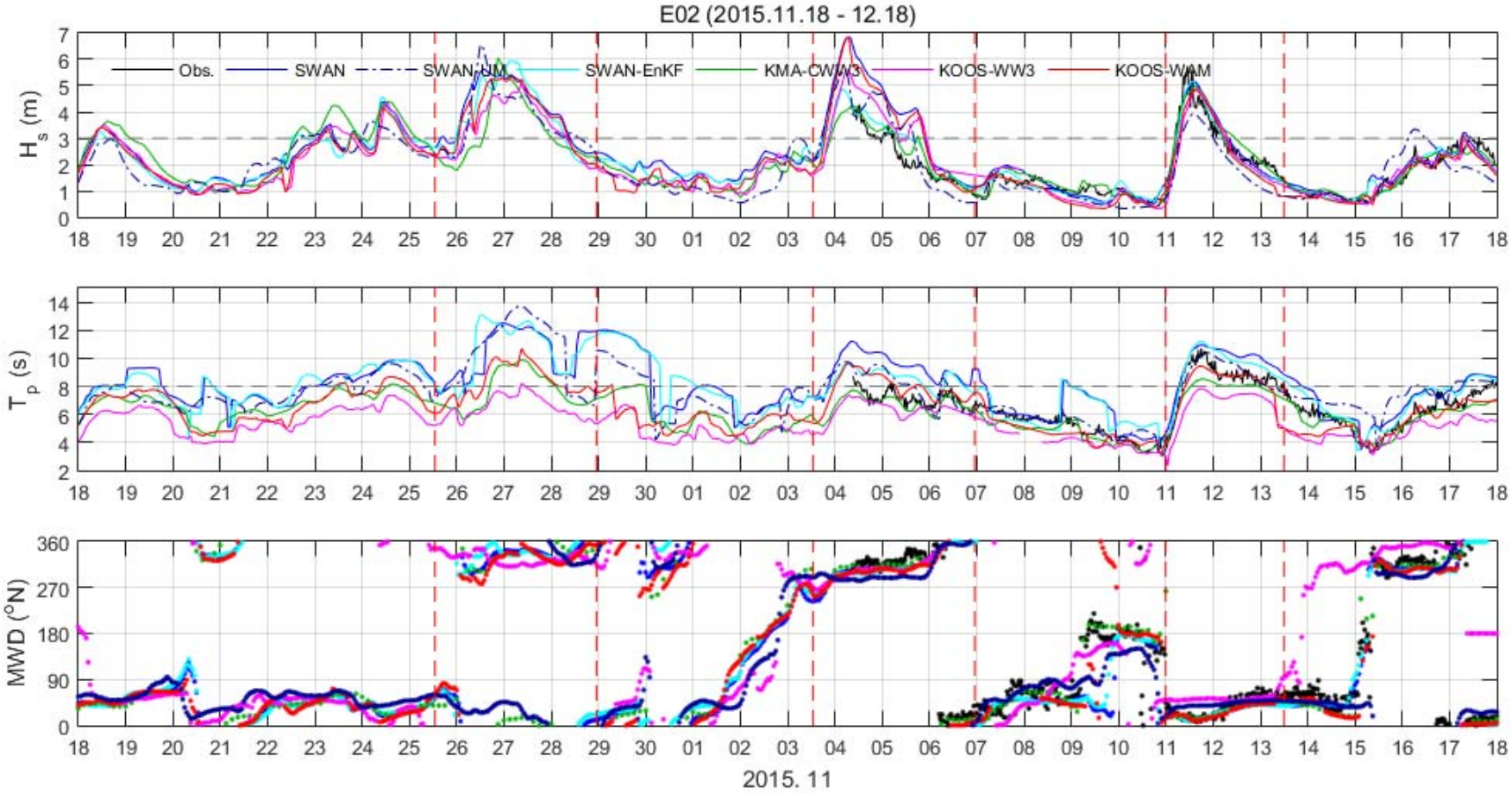
Wave conditions



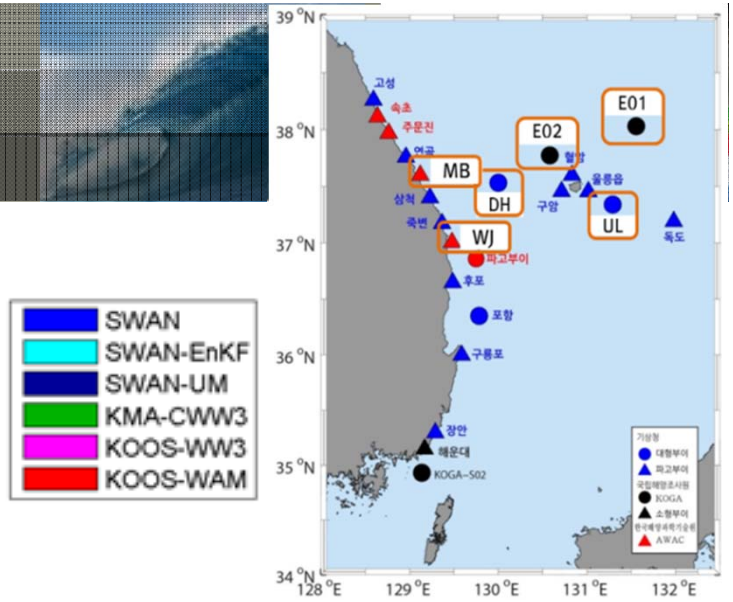


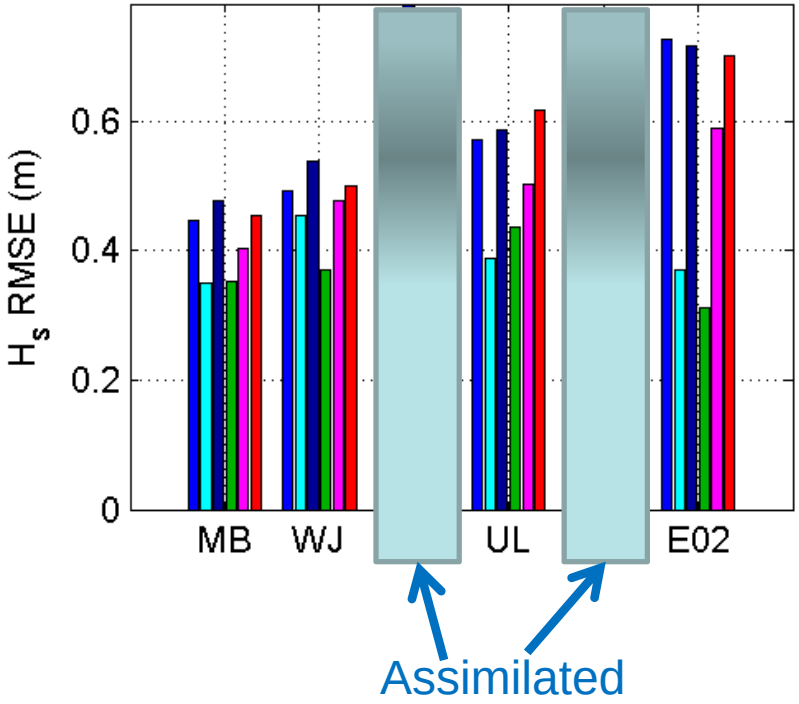
Wave conditions

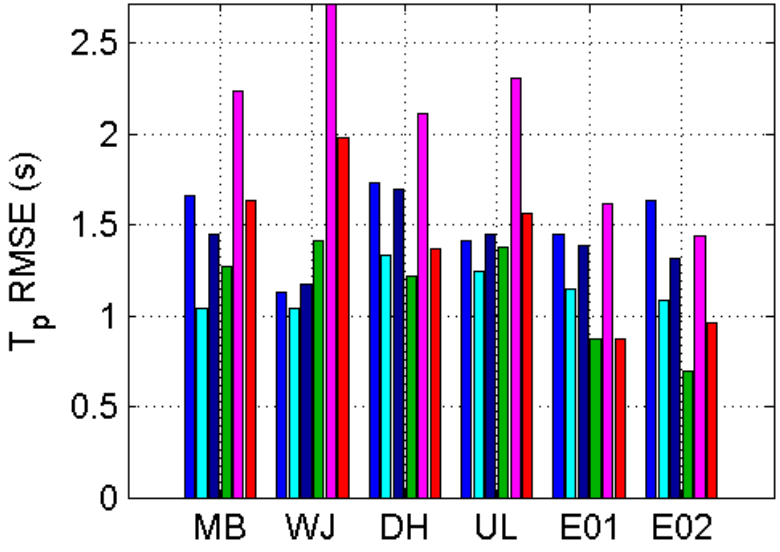




Root-mean-square-errors







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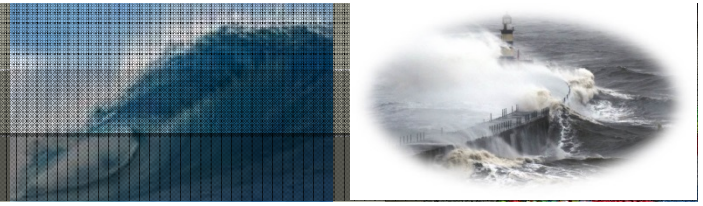
Final remarks



- A SWAN wave model with EnKF data assimilation is being developed for the East Coast of Korea.
- The validation of the model hindcasts shows that the model results are at least as accurate as those of other available local model.
- The main contributor to the model errors appears to be the errors in the forcing wind fields.
- The EnKF assimilation of significant wave height observations with the winds as control variable leads to reductions in the root-mean-square-error at locations other than those where the data were assimilated of about 50% and in the peak wave period of about 20%.

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