Operational Regional and Coastal Storm Surges/Tide Forecasting System in Republic of Korea

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ABSTRACT

This study was performed to compare storm surges simulated by the operational storm surges/tide forecast system of the Korea Meteorological Administration(KMA) during nine typhoons that occurred between 2005 and 2007. The maximum and minimum root mean square errors (RMSEs) were 14.61 and 6.78 cm, which occurred for Typhoons Khanun(2005) and Usagi (2007), respectively. For all nine typhoons, total averaged RMSE was approximately 10.2 cm. Also, this study was performed to compare storm surges/tide simulated by the regional and coastal storm surges/tide forecast system(RTSM, CTSM) models during Chanhom typhoons in 2015. The CTSM using input from UM simulate a little well the storm surges/tide pattern in the complex coastal areas. The result showed that the storm surges by the coastal storm surges/tide model with high resolution input was in somewhat good agreement with the observed sea level occurred by high tide and storm surges in the coastal areas.

Keywords : Storm surges/tide, RTSM, CTSM, KMA

INTRODUCTION

The coastal areas around Korean peninsula are one of the challenging places in ocean modeling for reasonable prediction of nearshore storm surges/tide conditions. Various oceanographic systems interact along the coast of Korea, which has a complex coastline and a high tidal range along western and southern region and deep depth and no tide along eastern region. With increasing property development along coastal regions, storm surge damage is becoming an important concern and accurate forecasting is crucial. For Korea's coastal regions, floods caused by typhoon-induced storm surges are among the most serious threats. To protect lives and property, accurate forecasting of storm surges is essential.

Establishing of newly devised storm surge/tide prediction system of KMA is underway in conjunction with high computing environment. The development of high resolution model is very essential to predict the storm surges patterns in the complex coastal area of Korea. The main objective of this study is to apply and verify the high resolution regional and coastal storm surges/tide operational prediction system using atmospheric condition by different weather forecasting model.

Since 2006, the KMA(Korea Meteorological Administration) has operated regional storm surges/tide prediction system, called RTSM (Regional Tide/Storm surges Model), with 8km horizontal resolutions including the Yellow Sea, East China Sea and the East Sea, marginal seas around Korea. Also we developed the high resolution coastal storm surges/tide prediction system (CTSM : Coastal Tide/Storm surges Model) in order to produce detailed ocean forecasting field. Developed CTSM covers 5 coastal areas around Korea peninsula. The horizontal grid intervals are 1km for each area. The model output from RTSM is used for boundary condition of CTSM.

In this study, we applied RTSM to predict storm surges induced by nine typhoons that affected Korea between 2005 and 2007. We compared the modeled surges with *in situ* observations from tidal stations around the coastal region of Korea (You, 2010).

Also, this study was performed to compare storm surges/tide simulated by the regional and coastal storm surges/tide forecast system(RTSM, CTSM) models during Chanhom typhoons in 2015.

MODEL AND INPUT DIESCRIPTIONS

The RTSM covers the northwestern Pacific Ocean from 115–150°E, 20–52°N (Fig. 1). The horizontal grid intervals are 1/12° in both latitudinal and longitudinal directions. The model bottom topography is based on the National Geophysical Data Center ETOPO5 data with 5-min resolution. As mentioned, the CTSM covers 5 coastal domains around Korean Peninsula with the horizontal grid intervals are 1km for each area. The model output from regional storm surges/tide prediction system is used for boundary condition of coastal storm surges/tide prediction system.

The storm surge/tide model used in this study was based on the Princeton Ocean Model (POM), a primitive general ocean circulation model described by Mellor (1998). From POM, we made a two-dimensional depth-integrated tide and storm surges model with an Arakawa C-grid system. The amplitudes and phases of the tidal constituents of the open boundary condition are taken from eight constituents (M_2, S_2, K_1, O_1, K_2, P_1, N_2, and Q_1) described by Matsumoto *et al.* (2000). Detailed model descriptions is found in You and Seo (2009) and You (2010)

In order to acquire atmospheric conditions, sea winds and mean sea level pressure, we used results by two operational models. The first operational weather models of

KMA are the RDAPS(Regional Data Assimilation Prediction System) with 30 km grid resolution. And the UM(Unified Model) is second operational weather prediction system of Korea with collaboration of the Met Office. The domain of two operational weather models fully covers our tide/storm surge model domain. The UM currently provides meteorological information for the KMA's operational storm surge/tide prediction system. We conducted experiments with 2 different storm surge model (RTSM, CTSM) and 2 weather model(RDAPS, UM) to investigate the differences in simulated storm surge heights and to verify the results using observations.

First experiment is the comparison of regional storm surge predictions for the case of 9 Typhoons driven by the RDAPS from 2005 to 2007. Second experiment is the comparison of regional and coastal storm surge predictions driven by the UM for the case of Typhoon Chanhom in 2005.

We compared the sea level observed at tidal stations during the Typhoons with those predicted by regional and coastal storm surge/tide model, conducting statistical analysis to determine the bias (mean error, Eq. 1) and root mean square error (RMSE, Eq. 2) between modeled and observed values as follows :

$$bias = \frac{1}{N}\sum (Y_m - Y_o) \quad (1)$$

$$RMSE = \sqrt{\frac{1}{N}\sum \left(Y_m - Y_o\right)^2} \quad (2)$$

In the above equations, N is the total number of data, Y_m is the predicted sea level, Y_o is the observed sea level, $\overline{Y_m}$ is the average predicted sea level, and $\overline{Y_o}$ is the average observed sea level.

.RESULTS

1) **Preliminary verification of Regional Storm surge prediction during Typhoon Periods (2005-2007)**

We analyzed storm surges for nine typhoons that occurred between 2005 and 2007 (Table 1). Figure 2 shows the best tracks of these typhoons. In 2005, 23 tropical cyclones occurred in the northwestern Pacific Ocean. Among these typhoons, Matsa (0509), Nabi (0514), and Khanun (0515) approached the Korean Peninsula, with Nabi coming closest. While not making direct landfall on Korea, Typhoons Matsa and Khanun had very similar tracks. Twenty-three tropical cyclones also occurred in the northwestern Pacific Ocean in 2006. Among these, Typhoons Ewiniar (0603), Wukong (0610), and Shanshan (0613) approached the Korean Peninsula. A total of 24 tropical cyclones occurred in 2007, Typhoons Manyi (0704), Usagi (0705), and Nari (0711) affected the Korean Peninsula.

For example, in 2006, Typhoon Ewiniar brought maximum storm surges of 45 cm to the southern Ryukyu Islands. As Typhoon Ewiniar moved into the Yellow Sea of Korea, it created storm surges of approximately 35 cm that directly affected the southwestern coast of Korea (Fig. 3).

Table 2 and Figure 4 show statistical comparisons between predicted and observed surges for the nine typhoons at the following 30 tidal stations: Incheon (INCH), Pyeongtaek (PYOY), Daesan (DAES), Anheung (ANHG), Boryeong (BORG), Janghang (JANH), Gunsan-out (KSOT), Wido (WIDO), Yeonggwang (YONG), Mokpo (MOKP), Daeheuksan-do (DAEH), Jindo (JIND), Chuja-do (CHUJ), Wando (WAND), Geomun-do (KOMU), Goheung (GOHG), Yeosu (YOSU), Tongyeong (TONY), Masan (MASN), Busan (BUSN), Jeju (JEJU), Mosulpo (MOSL), Seogwipo (SOGW), Seongsanpo (SEOS), Ulsan (ULSN), Pohang (POHA), Hupo (HUPO), Mukho (MUKH), Sokcho (SOKC), and Ulleung-do (ULEU). We computed the bias (mean error) and RMSE between the modeled and observed results for the nine typhoon periods. Insufficient observational data or abnormal data caused by observational error were excluded manually.

The model overestimated or underestimated storm surges according to the input boundary condition and the typhoon characteristics. The results (bias) showed that in cases in which the model overestimated (underestimated) storm surge heights, overestimation (underestimation) tended to occur at all coastal stations. The maximum positive bias of 6.92 cm was found for Typhoon Ewiniar (2006), while the maximum negative bias of –12.06 cm was shown for Typhoon Khanun (2005). The RMSE results showed maximum and minimum errors of 14.61 and 6.78 cm for Typhoons Khanun (2005) and Usagi (2007), respectively. The total averaged RMSE for the nine typhoons studied here was approximately 10.2 cm.

Large differences in modeled and observed storm surge heights were observed in two types of cases: a very weak typhoon causing very low storm surges, such as Typhoon Khanun in 2005, or errors in typhoon strength predicted by the RDAPS led to errors in storm surge predictions such as Typhoon Nari in 2007.

2) Comparison of Regional and Coastal Storm surge prediction results

We analyzed storm surges for typhoons Chanhom that occurred in 2015. Figure 5 shows the best tracks of typhoon Chanhom. Typhoon Chanhom originated at 9.9°N, 159.6°E around 12UTC 30 June 2015 with a maximum central pressure and wind speed of 975 hPa and 32 m/s, respectively, at 18KST, 2 July 2015.

The RTSM and CTSM are simulated by the sea winds and mean sea level pressure of UM. Figure 6 show the horizontal sea wind and mean sea level pressure by UM during Typhoon Chanhom (12UTC 11 Jul. 2015). Cyclonic circulation of strong sea winds by the typhoons was well represented by the UM.

Figure 7 shows the spatial distribution of simulated storm surge elevations by RTSM and CTSM. In 2015, typhoon Chanhom approached the southwestern part of Korea Peninsula while not making direct landfall on Korea. The RTSM and CTSM runs were carried out for same typhoon period.

Figure 8 present time-series comparisons between modeled and observed total sea level and storm surges excluding astronomical components at selected coastal stations(Goheung and Geomundo). Observed storm surge heights were defined by observed sea level minus calculated tidal level, where tidal elevations were calculated using 64 harmonic constituents.

Table 3 and Figure 9 show statistical comparisons between predicted and observed sea level for the two typhoons at the following 7 tidal stations: Wido (WIDO), Yeonggwang (YEOG), Daeheuksan-do (DAEH), Wando (WAND), Geomun-do (GEOM), Goheung (GOHN), Yeosu (YOSU). We computed the bias (mean error) and RMSE between the modeled and observed results for the two typhoon periods. Insufficient observational data or abnormal data caused by observational error were excluded manually.

For Typhoon Chanhom, there was little difference in bias and RMSE value among stations. The minimum bias(RMSE) were 5.74(10.64) and 5.33(10.09) cm in RTSM and CTSM results, respectively. In conclusion, the coastal storm surges/tide models, CTSM, simulate a little well the storm surges/tide pattern in the complex coastal areas. The result showed that the storm surges by the coastal storm surges/tide model with high resolution input was in well agreement with the observed sea level occurred by high tide and storm surges in the coastal areas.

CONCLUSIONS

The coastal areas around Korean peninsula are one of the challenging places in ocean modeling for reasonable prediction of nearshore storm surges/tide conditions. Establishing of newly devised ocean prediction system of KMA is underway in conjunction with high computing environment.

This study was performed to examine the characteristics of storm surges associated with nine typhoons between 2005 and 2007 by comparing operational storm surge model results and observations from 30 tidal stations. The model overestimated or underestimated storm surges according to the input boundary condition and the typhoon characteristics. The results (bias) showed that in cases in which the model overestimated (underestimated) storm surge heights, overestimation (underestimation) tended to occur at all coastal stations.

The development of high resolution model is very essential to predict the storm surges patterns in the complex coastal area of Korea. The storm surges/tide were hindcasted using sea wind and pressure fields of Typhoon which is approaching Korean Peninsula. The result showed that the storm surges by the coastal storm surges/tide model with high resolution input was in well agreement with the observed sea level occurred by high tide and storm surges in the coastal areas. The higher resolution input data should enhance the accuracy of storm surge predictions. In addition, a more advanced model is needed to produce high-resolution predictions of storm surges along the complex coastline of Korea.

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Table 1 Typhoons affecting Korea between 2005 and 2007.

Year	Typhoon	Duration (YYYYMMDD)	Minimum Pressure(hPa)	Maximum Wind(m/s)
2005	MATSA (0509)	20050731 – 20050809	955	41
	NABI (0514)	20050829 – 20050909	925	49
	KHANUN (0515)	20050907 – 20050915	945	43
2006	EWINIAR (0603)	20060701 – 20060712	920	51
	WUKONG (0610)	20060813 – 20060821	980	23
	SHANSHAN (0613)	20060910 – 20060921	925	52
2007	MANYI (0704)	20070709 – 20070719	930	49
	USAGI (0705)	20070729 – 20070806	945	45
	NARI (0711)	20070913– 20070919	940	48

Table 2 Mean bias and RMSE storm surge statistics (in cm) for typhoons between 2005 and 2007. A positive (negative) bias indicates overestimation (underestimation) by the model.

Typhoons	bias	RMSE
Matsa (0509)	3.54	7.72
Nabi (0514)	-6.14	11.41
Khanun (0515)	-12.06	14.61
Ewiniar (0603)	6.92	12.00
Wukong (0610)	-0.43	8.32
Shanshan (0613)	-1.76	8.63
Manyi (0704)	4.69	8.95
Usagi (0705)	3.34	6.78
Nari (0711)	-7.99	12.19

Table 3 Mean bias and RMSE storm surge statistics (in cm) for typhoon Chanhom. A positive (negative) bias indicates overestimation (underestimation) by the model.

Model	Bias	RMSE
RTSM	5.74	10.64
CTSM	5.33	10.09

LIST OF FIGURES

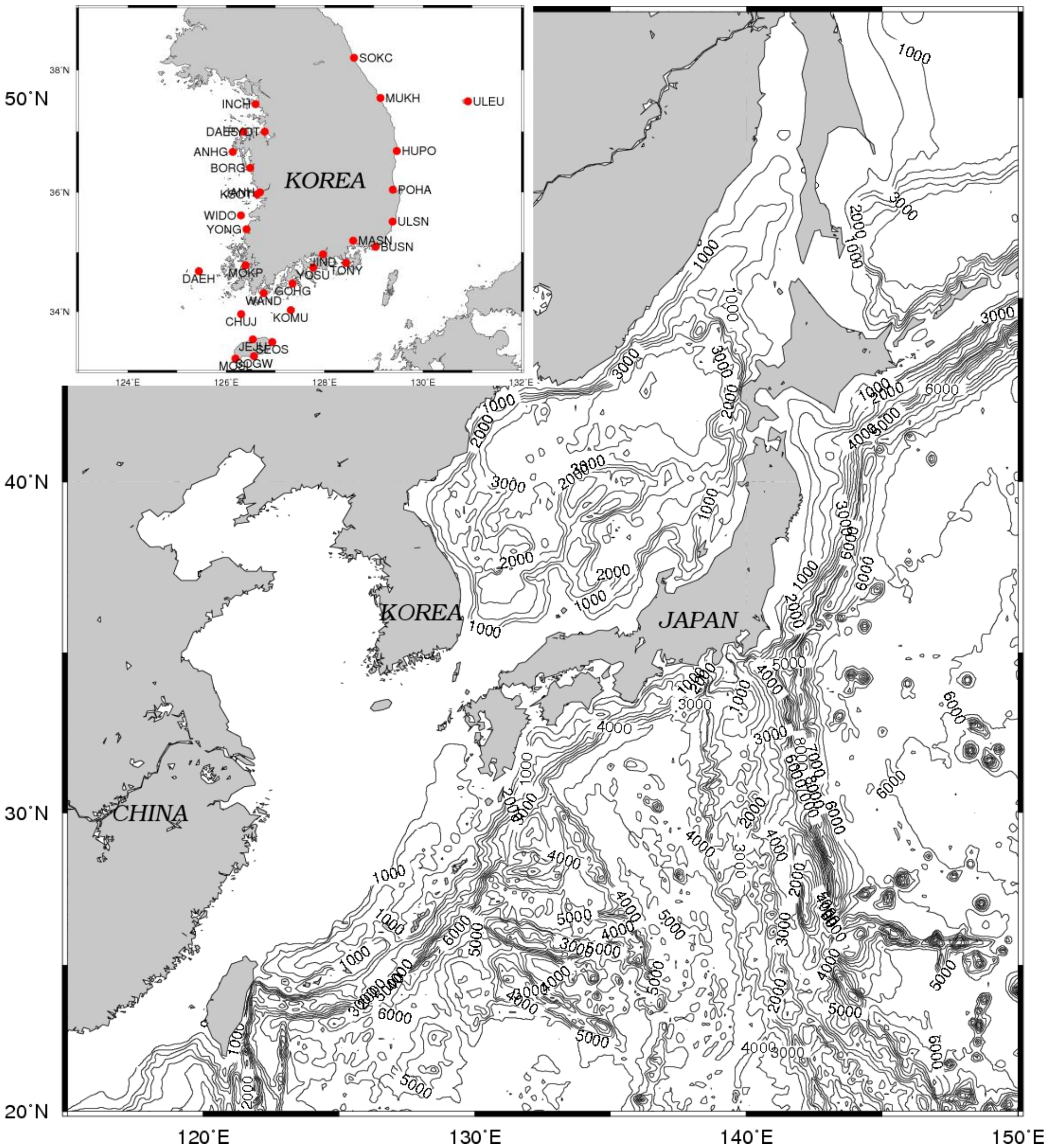


Fig. 1 Modeled area with topography and locations of the selected coastal stations (small figure).

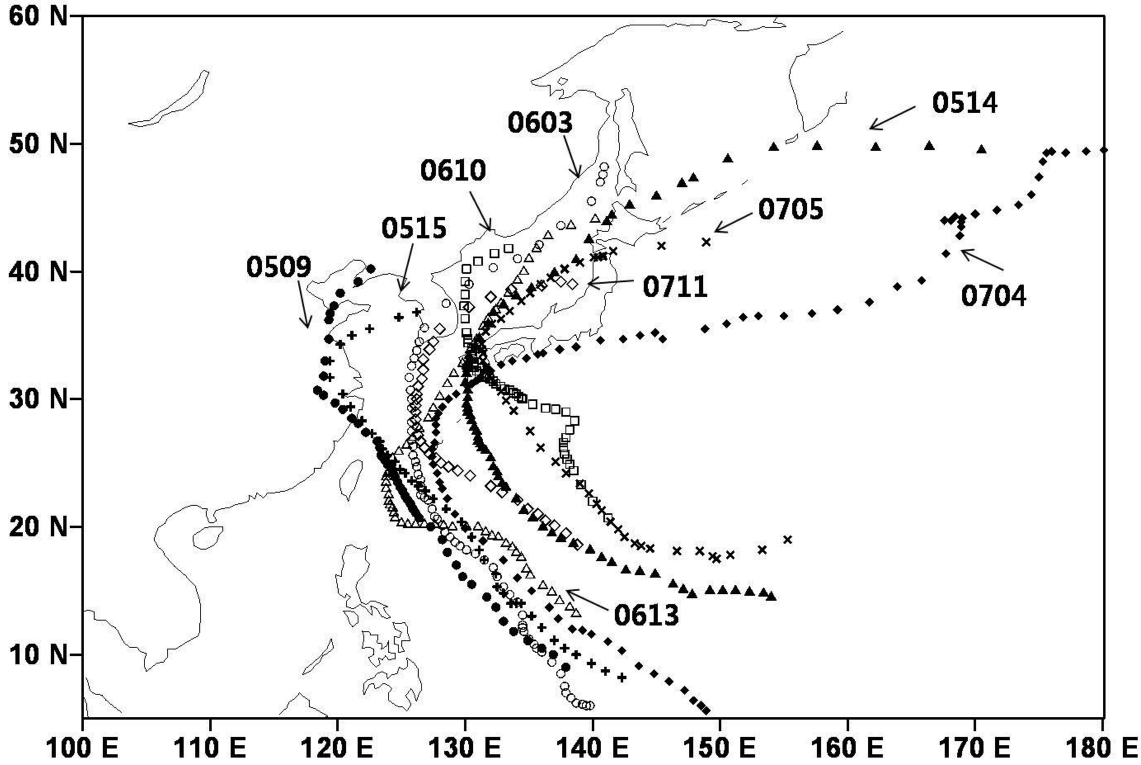


Fig. 2 Tracks of typhoons affecting the Korean Peninsula between 2005 and 2007. (0509(●),0514(▲),0515(✚),0603(○),0610(□),0613(△),0704(◆),0705(✖),0711(◇))

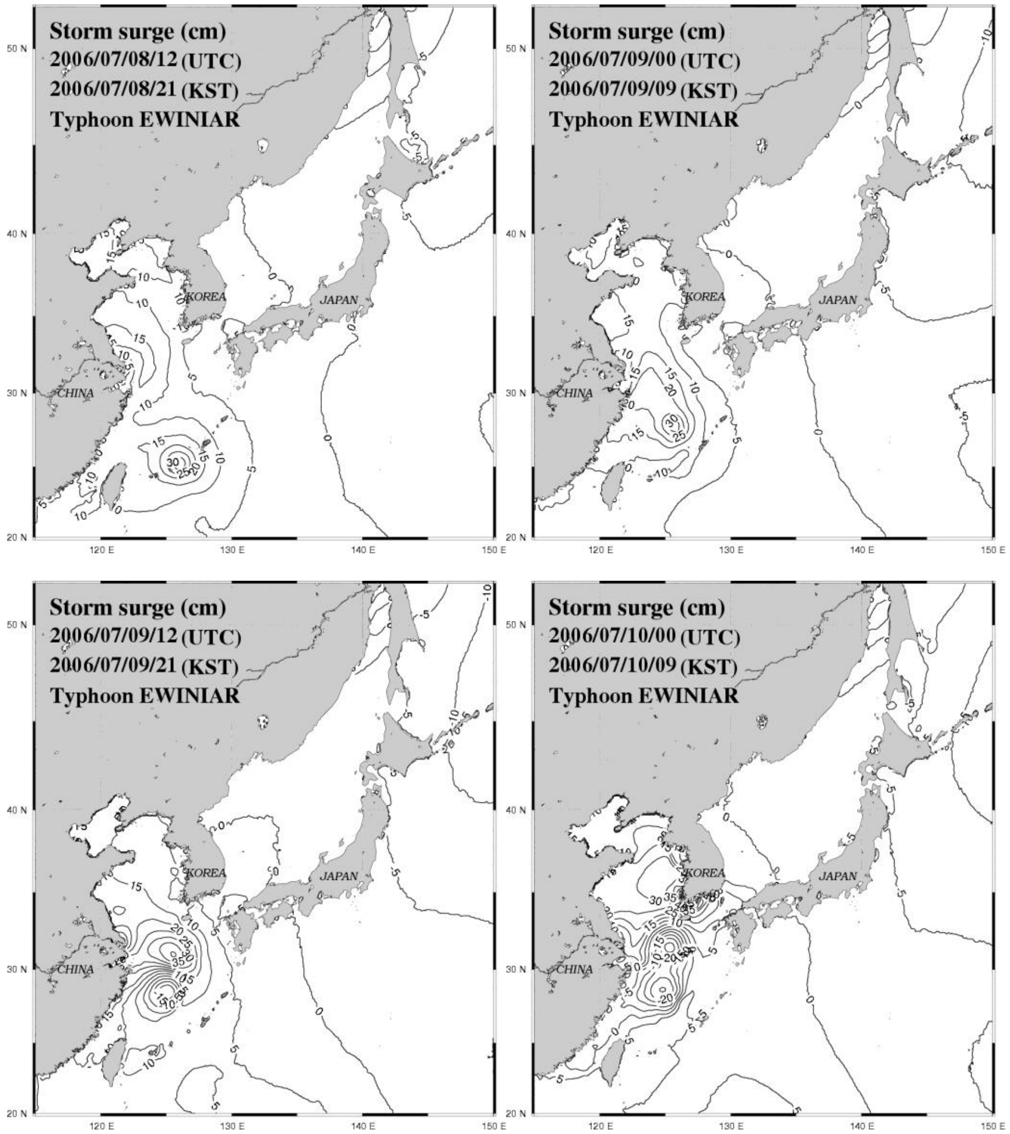


Fig. 3 Predicted storm surge height during Typhoon Ewiniar.

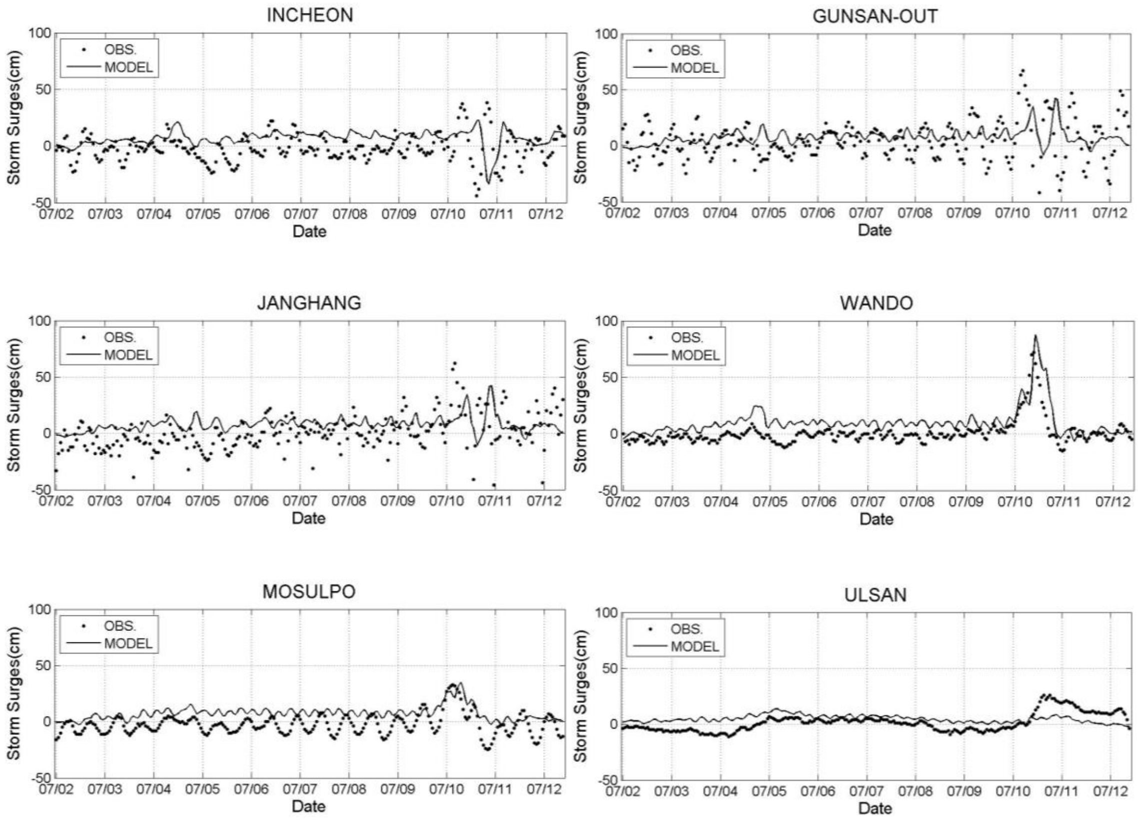
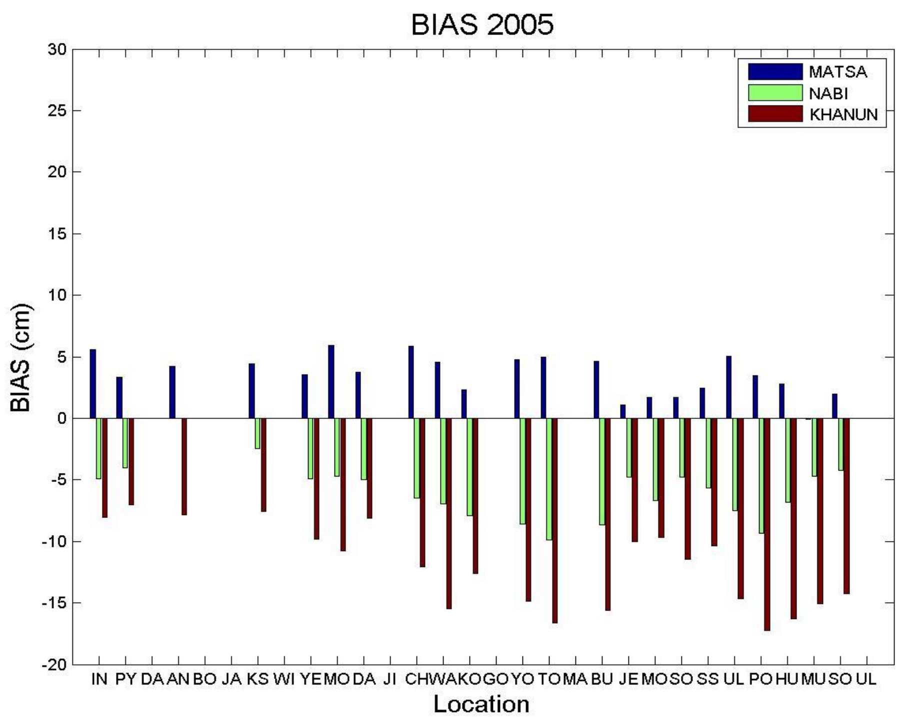
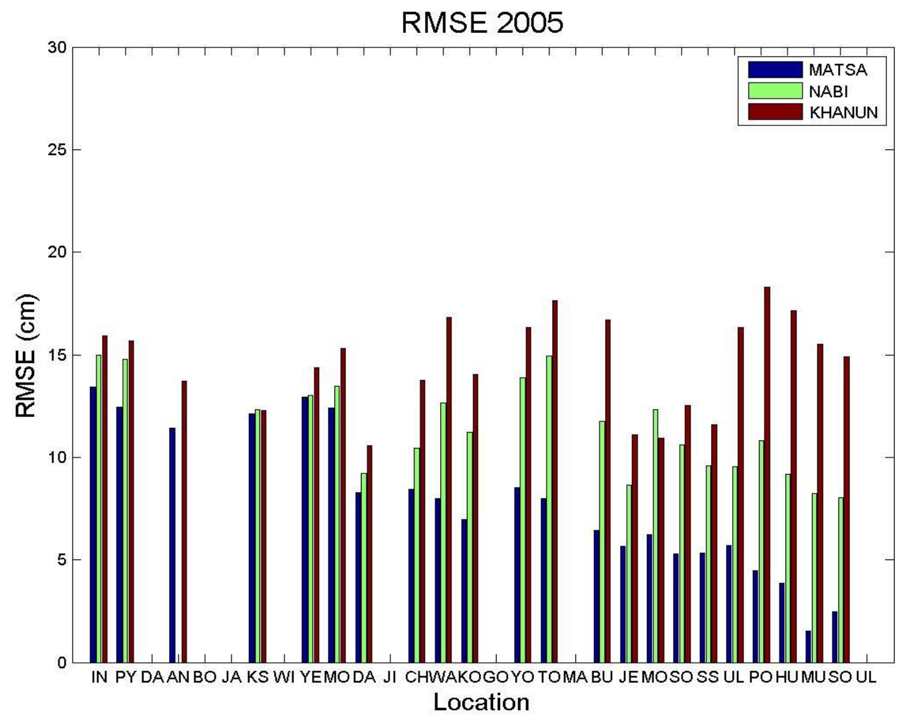


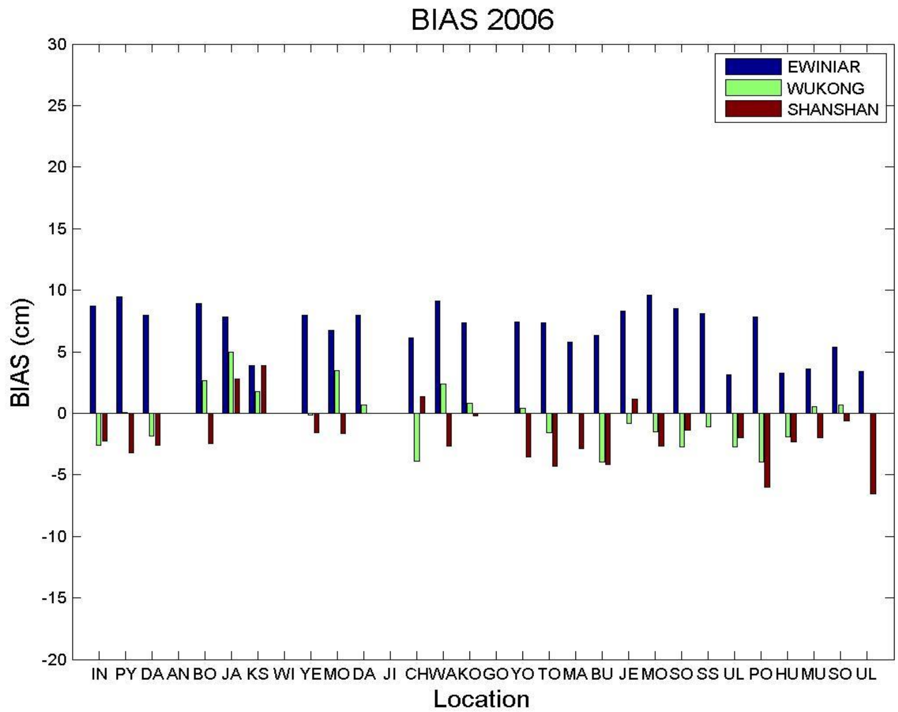
Fig. 3(Cont.) Predicted storm surge height during Typhoon Ewiniar

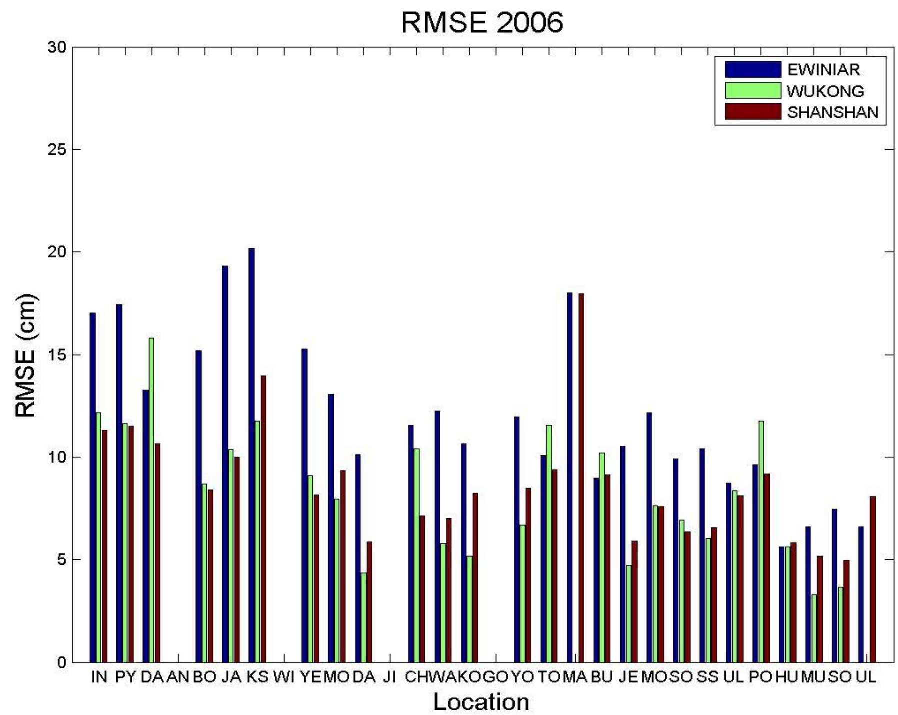
(a) 2005 year


BIAS 2005
MATSA
NABI
KHANUN
BIAS (cm)
30
25
20
15
10
5
0
-5
-10
-15
-20
IN PY DA AN BO JA KS WI YE MO DA JI CH WA KO GO YO TO MA BU JE MO SO SS UL PO HU MU SO UL
Location

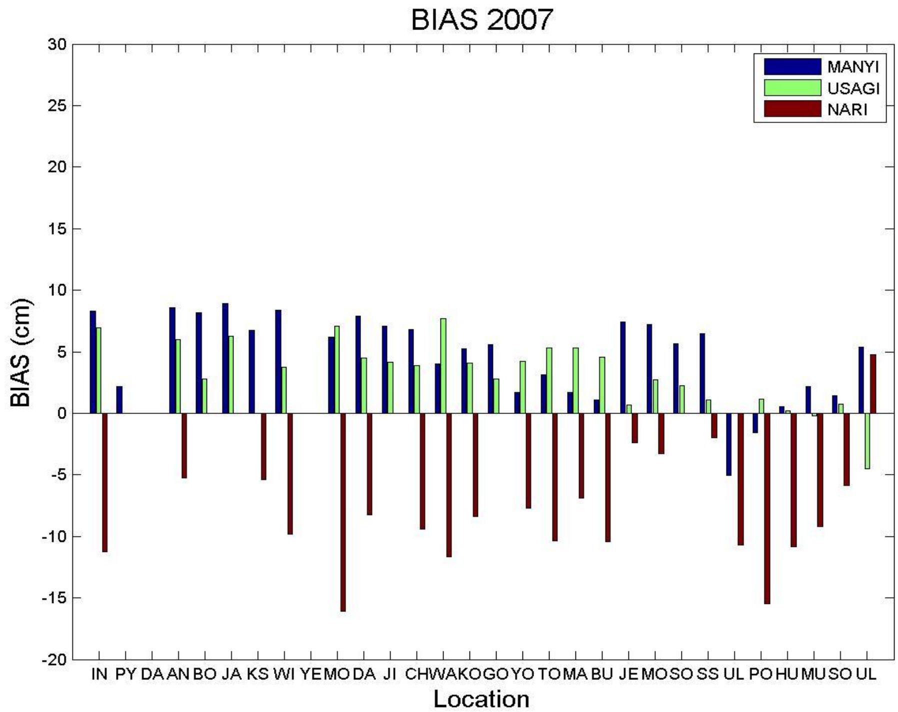

RMSE 2005
MATSA
NABI
KHANUN
RMSE (cm)
30
25
20
15
10
5
0
IN PY DA AN BO JA KS WI YE MO DA JI CH WA KO GO YO TO MA BU JE MO SO SS UL PO HU MU SO UL
Location

(b) 2006 year


BIAS 2006
EWINIAR
WUKONG
SHANSHAN
BIAS (cm)
30
25
20
15
10
5
0
-5
-10
-15
-20
IN PY DA AN BO JA KS WI YE MO DA JI CH WA KO GO YO TO MA BU JE MO SO SS UL PO HU MU SO UL
Location


RMSE 2006
EWINIAR
WUKONG
SHANSHAN
RMSE (cm)
30
25
20
15
10
5
0
IN PY DA AN BO JA KS WI YE MO DA JI CH WA KO GO YO TO MA BU JE MO SO SS UL PO HU MU SO UL
Location

(c) 2007 year



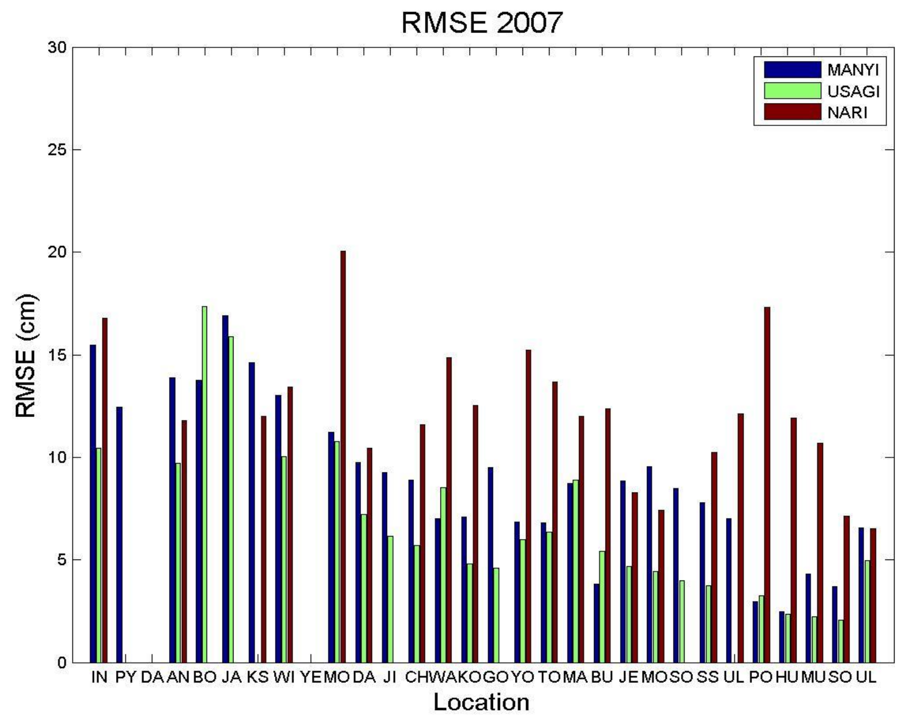


Fig. 4 Variations of bias and RMSE between modeled and observed storm surges caused by typhoons in (a) 2005, (b) 2006 and (c) 2007.

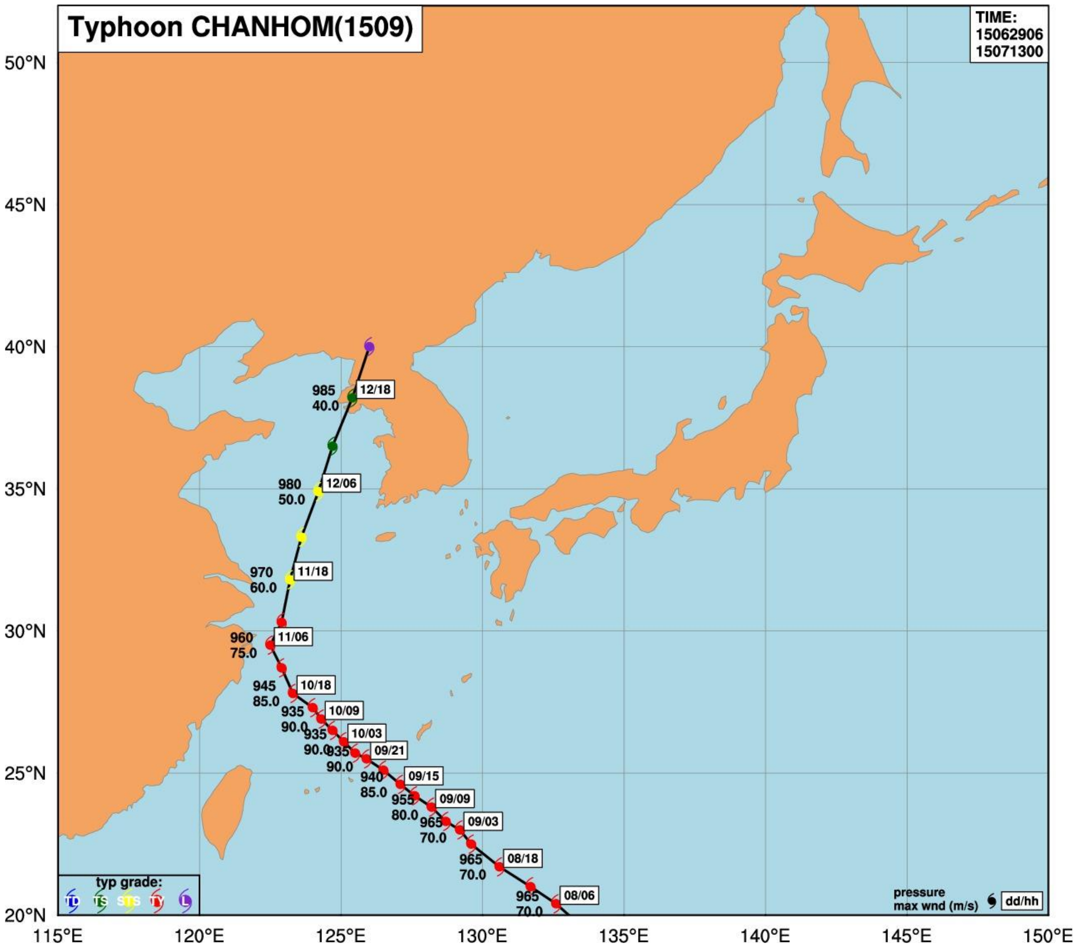


Fig. 5 Tracks of typhoon Chanhom(1509)

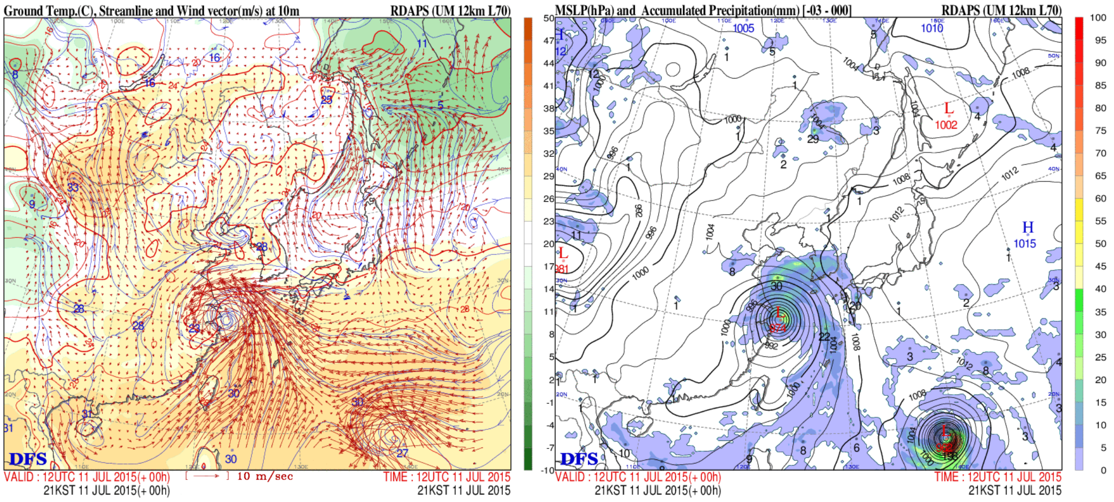


Fig. 6 Horizontal distribution of mean sea level pressure and surface wind during Typhoon Chanhom at 12UTC 11 Jul. 2015.

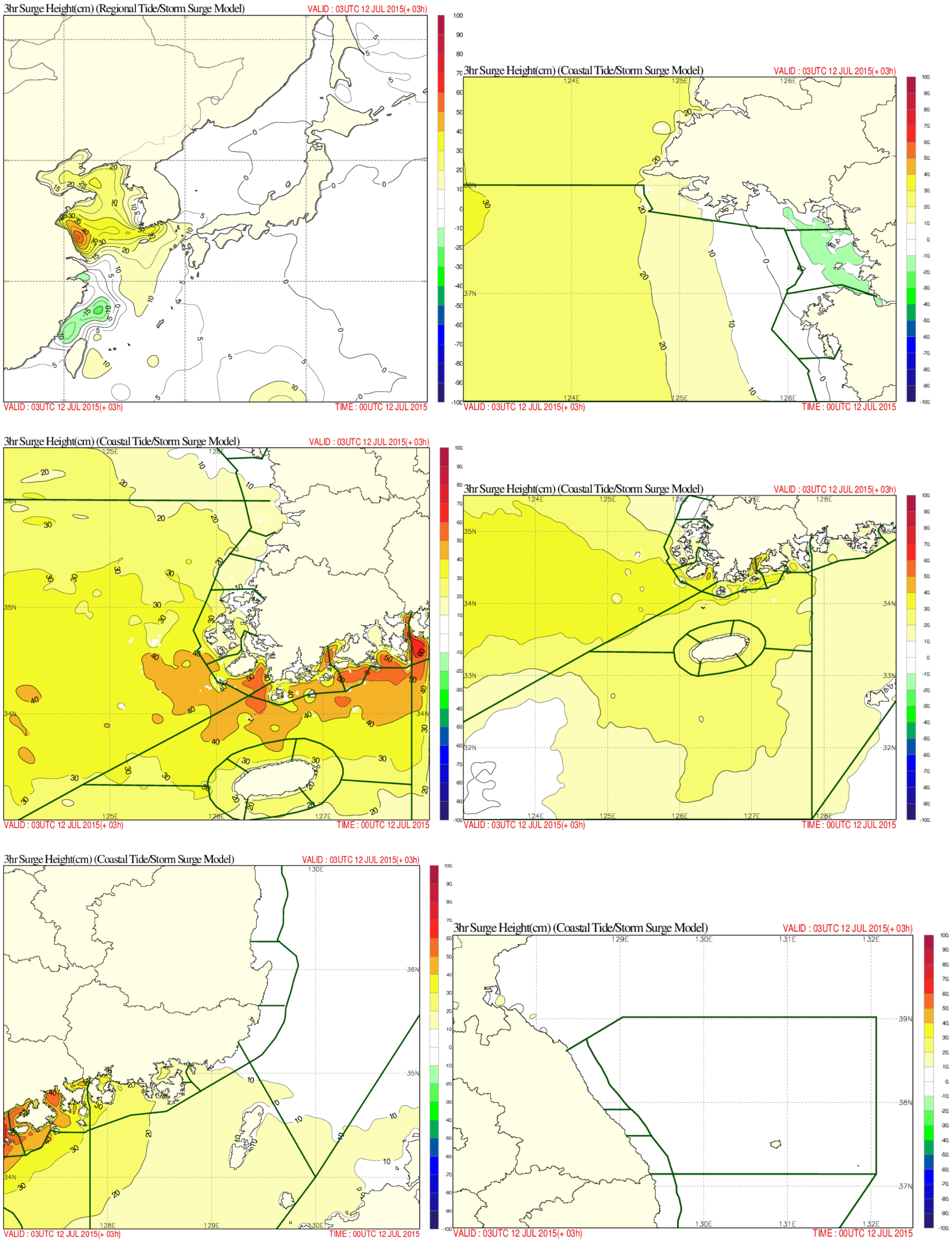


Fig. 7 Simulated storm surge height by RTSM and CTSM during Typhoon Chanhom at 03 UTC 12 Jul. 2015.

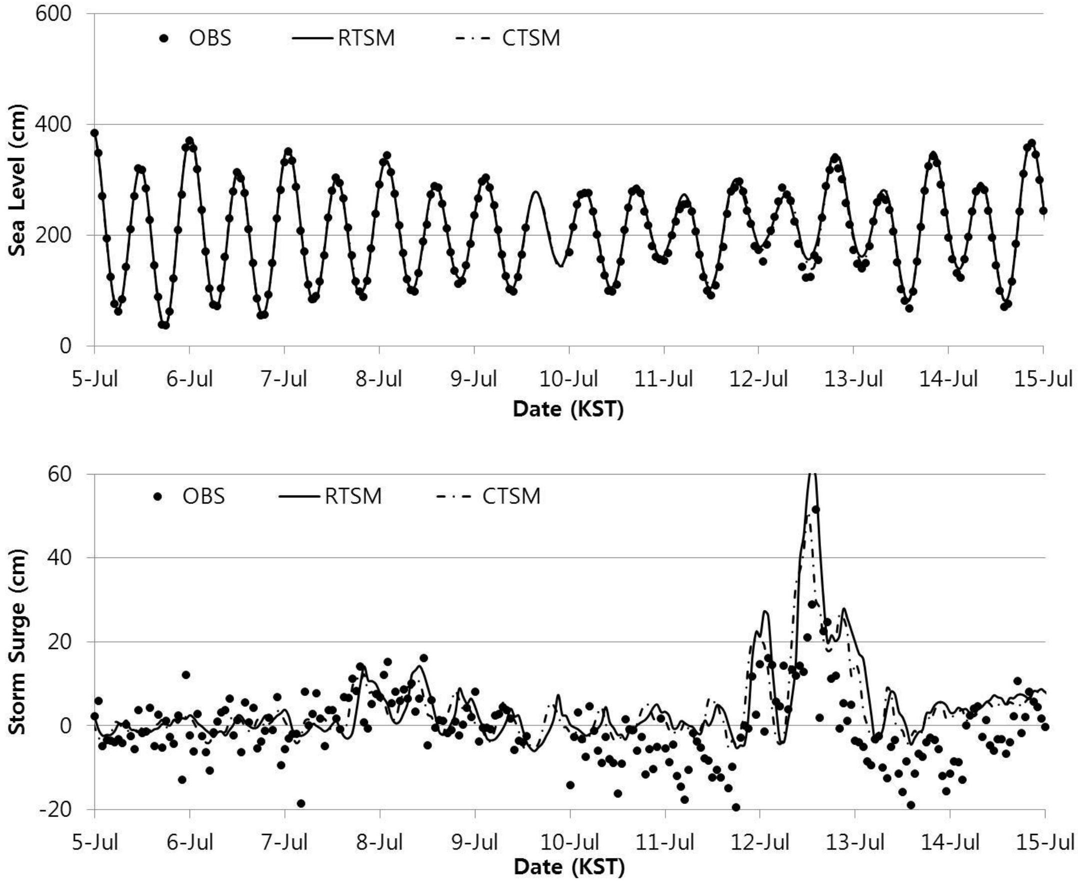


Fig. 8 Time series of the observed and computed storm surges at Goheung(upper) and Geomundo(lower) tidal stations during Typhoon Chanhom periods.

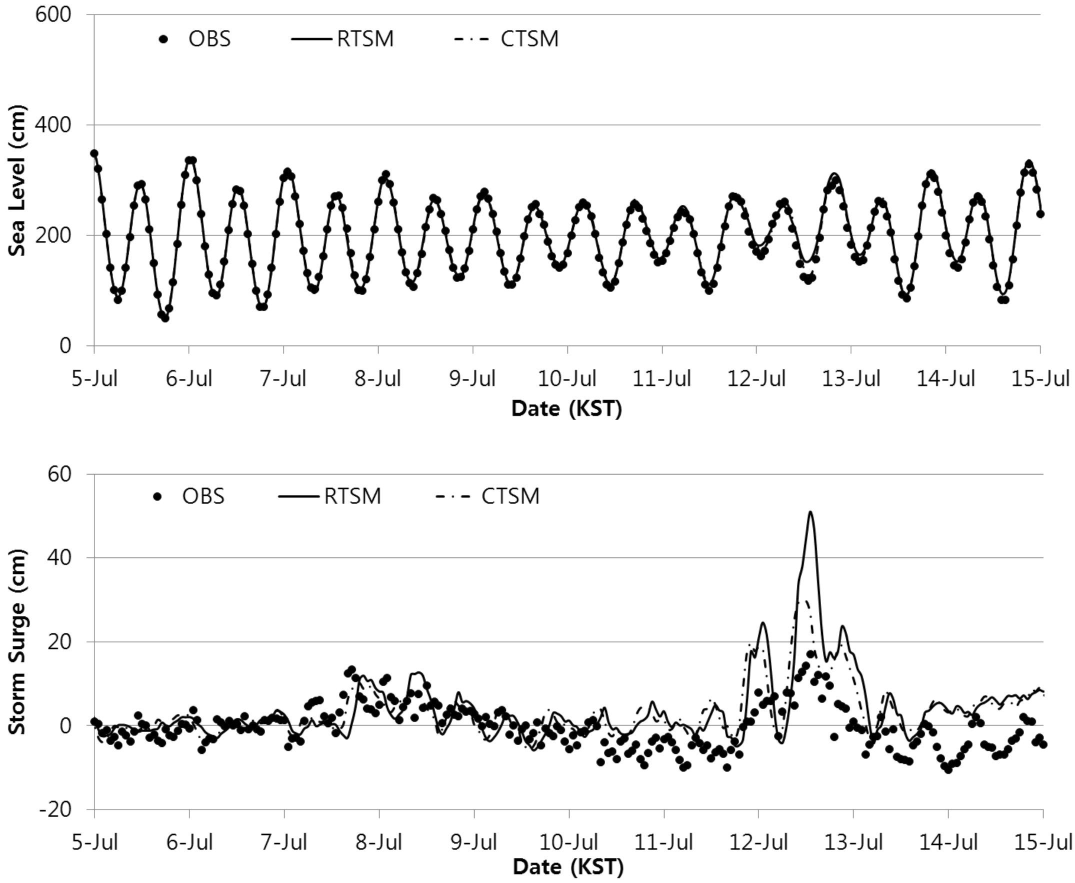


Fig. 8(Cont.) Time series of the observed and computed storm surges at Goheung(upper) and Geomundo(lower) tidal stations during Typhoon Chanhom periods.

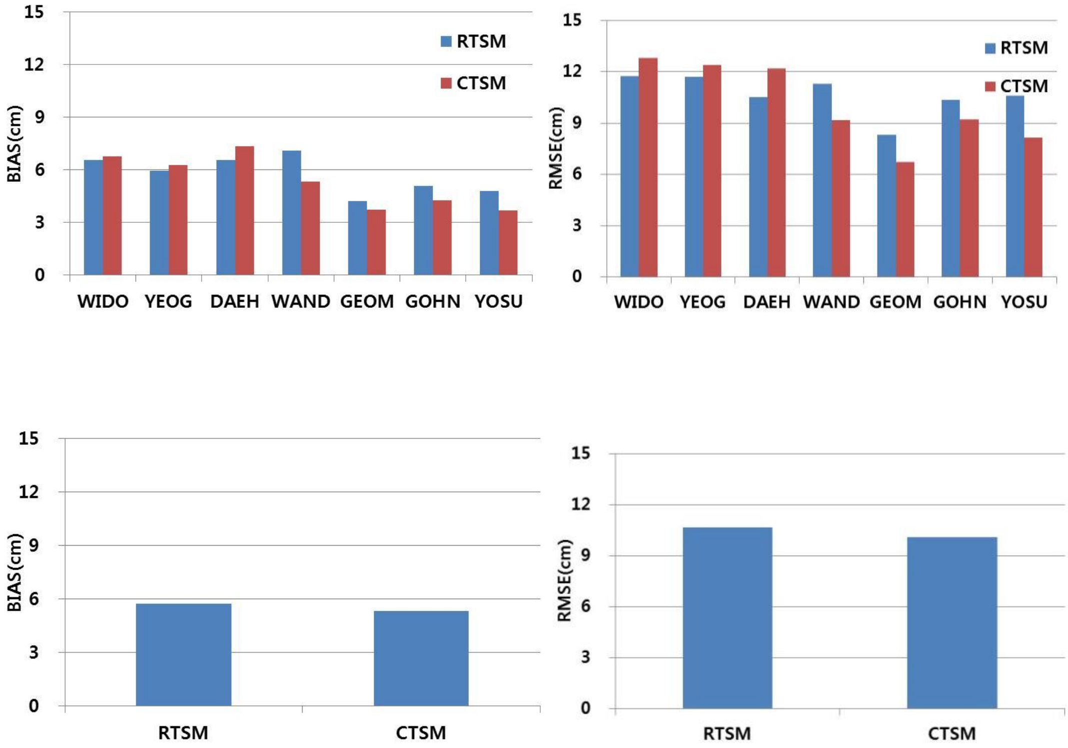


Fig. 9 Variations of bias and RMSE between modeled and observed storm surges caused by Chanhom typhoon.