South China Sea Wind Wave Characteristics

Part 1: Validation of WAVEWATCH-III Using TOPEX/POSEIDON Wave Height Data

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Abstract

A full-spectral third-generation ocean wind-wave model, WAVEWATCH-III, has been implemented in the South China Sea (SCS) for hindcast of wind wave characteristics. This model was developed at the Ocean Modeling Branch (OMB) of the National Centers for Environmental Prediction (NCEP). The NCEP re-analysis data four times daily were used to simulate the wind waves for the whole year in 1996. The significant wave heights from WAVEWATCH-III are compared to the TOPEX/POSEIDON (T/P) wave height data, and the NCEP re-analyzed wind data are compared to the T/P wind data, both over the satellite crossover points. The model errors of significant wave height have Gaussian-type distribution with negative mean value (model under-prediction). The discrepancy occurs mostly in the low sea state regions. Hence, WAVEWATCH-III has the capability to predict the significant wave height. The model accuracy is higher in high than low winds, and higher in deep water than in shallow water.
1. Introduction

The South China Sea (SCS) is a semi-enclosed tropical sea located between the Asian land mass to the north and west, the Philippine Islands to the east, Borneo to the southeast, and Indonesia to the south (Fig. 1), a total area of $3.5 \times 10^6$ km$^2$. It includes the shallow Gulf of Thailand and connections to the East China Sea (through Taiwan Strait), the Pacific Ocean (through Luzon Strait), the Sulu Sea, the Java Sea (through Gasper and Karimata Straits) and to the Indian Ocean (through the Strait of Malacca). All of these straits are shallow except Luzon Strait whose maximum depth is 1800 m. Consequently, the SCS is considered a semi-enclosed sea. The complex topography includes a broad shallow shelf in the south/southwest; the continental shelf of the Asian landmass in the north, extending from the Gulf of Tonkin to Taiwan Strait; a deep, elliptical shaped basin in the center, and numerous reef islands and underwater plateaus scattered throughout. The shelf that extends from the Gulf of Tonkin to the Taiwan Strait is consistently nearly 70 m deep, and averages 150 km in width; the central deep basin is 1900 km along its major axis (northeast-southwest) and approximately 1100 km along its minor axis, and extends to over 4000 m deep. The south/southwest SCS shelf is the submerged connection between Southeast Asia, Malaysia, Sumatra, Java, and Borneo and reaches 100 m depth in the middle; the center of the Gulf of Thailand is about 70 m deep.

The SCS wind waves are largely affected by the monsoon winds. From April to August, the weaker southwesterly summer monsoon winds result in a monthly mean wind stress of just over 0.1 N m$^{-2}$ (Fig. 2a). From November to March, the stronger northeasterly winter monsoon winds corresponds to a maximum monthly mean wind stress of nearly 0.3 N m$^{-2}$ (Fig. 2b). The transitional periods are marked by highly
variable winds and surface currents. The SCS wind wave characteristics can be
investigated numerically using a fully spectral third-generation ocean wind-wave model,
WAVEWATCH-III (henceforth denoted as WWATCH).

WWATCH should be evaluated before being applied to the regional sea wave
prediction. The seasonal varying monsoon wind systems and complicated topography
make the SCS a perfect location for WWATCH evaluation. The in-situ wind wave data
are mainly collected by voluntary ships and wave buoys. However, these data are very
sparse, especially there is no wave buoy in the SCS. Remote sensing is an alternative
approach to obtain wind wave data over a vast area. Altimetry and Synthetic Aperture
Radar (SAR) have been used to determine the significant wave height and directional
spectrum, respectively. Many satellites have been launched with altimetry and/or SAR
until now, such as TOPEX/POSEIDON (T/P), ERS-1/2. Remote sensing data is
becoming main source of wind wave data. This paper describes the WWATCH
evaluation using the T/P wave height data.

2. Preparation of the Data Set

The T/P satellite, jointly launched by NASA and the French Space Agency, the
Center National d'Etudes Spatiales (CNES) in August 1992, carried a state-of-the-art
radar altimetry system (Fu et al. 1994). In addition to precise measurements of the
distance between the satellite and the surface, the significant wave height (SWH) was
derived from the shape of the leading edge of the returning radar pulse (Rufenach and
Alpers 1978). The accuracy of SWH measurement by T/P was within the accuracy of the
Geosat measurements (Callahan et al. 1994), i.e., 10% or 0.5 m, whichever is greater
(Dobson et al. 1987). T/P was maneuvered into a 9.9156-day repeat period during which
two T/P SWH data (i.e., temporal resolution around 5-day) are available at each
crossover point. There are 21 crossover points in the SCS (Fig. 3). The crossover points
are divided into three groups: central SCS with nine points (8, 9, 10, 12, 14, 15, 16, 19, 21),
northern SCS with five points (3, 6, 13, 17, 22), and southern SCS with seven points
(1, 2, 4, 5, 7, 11, 18). The twenty one time series of SWH at the crossover points for the
year of 1996 are used for evaluating WWATCH.

3. The WWATCH Model

3.1. Description

WWATCH, a fully spectral third-generation ocean wind-wave model, has been
developed at the Ocean Modeling Branch of the Environmental Modeling Center of the
National Centers for Environmental Prediction (NCEP). It is based on WAVEWATCH-I
and WAVEWATCH-II as developed at the Deft University of Technology, and NASA
Goddard Space Flight Center, respectively (Tolman 1999).

The wave spectrum F is generally a function of all phase parameters (i.e., wave
number k, direction S, intrinsic frequency σ, and absolute frequency ω), and of space (x)
and time (t), that is \( F = F(k, S, \sigma; \omega; x, t) \). However, it is usually assumed that the
individual spectral components satisfy the linear wave theory (locally), so the following
dispersion relation and Doppler type equation to interrelate the phase parameters.

\[
\sigma^2 = gk \tanh kd
\]

\[
\omega = \sigma + ktU
\]

where d is the mean water depth and U is the (depth- and time- averaged) current
velocity. When the current velocity vanishes, only two independent phase parameters
among (a, k, S) exist, and the local and instantaneous spectrum becomes two-
dimensional. The traditional wave models (such as WAM) use the frequency-direction ($\mathbf{a}$, $\mathbf{S}$) as the independent phase variables.

WWATCH uses the wavenumber-direction ($k$, $\mathbf{S}$) as the independent phase variables. Without currents, the energy of a wave package is conserved. With currents the energy of a spectral component is no longer conserved (Longuet-Higgins et al. 1961), but the wave action ($A \equiv \text{Energy}/\sigma$) is conserved (Whitham 1965; Bretherthon and Garrett 1968). Thus, in WWATCH the balance equation is for the wave action spectrum $N(k,\theta; x, t)$,

$$\frac{\partial N}{\partial t} + \frac{1}{\cos \phi} \frac{\partial}{\partial \phi} (N \cos \theta + \frac{\partial}{\partial \lambda} \lambda N + \frac{\partial}{\partial k} k N + \frac{\partial}{\partial \theta} \theta N) = \frac{S}{\sigma} = \frac{S_{in} + S_{nl} + S_{ds} + S_{bot}}{\sigma} \tag{3}$$

where $N(k,\theta; x, t)$ is the traditional frequency-direction spectrum $F(\mathbf{a},\theta)$, which is calculated from $F(k, \theta)$ using Jacobean transformations. The two model parameters are set up as follows: seed = 2, swell factor = 0.125. Other parameters are the same as in Tolman (1999).

3.2. Discretization
The model is implemented for SCS (0° to 25° N, 105°-122°E) using realistic bathymetry data from the Naval Oceanographic Office DBDB5 database. The horizontal grid spacing is 0.5° (i.e., $AV = Ad = 0.5°$). The wavenumber grid spacing is determined by the frequency intervals (total 25)

$$\sigma_{m+1} = X_{\sigma} \sigma_m, \ m = 0, 1, \ldots, 24,$$

with

$$X_{\sigma} = 1.1, \ \sigma_0 = 0.0418.$$  

The wave direction ($S$) grid spacing is 15° (i.e., $AS = 15°$).

Four time steps are used in WWATCH to reach computational efficiency: (a) global time step (300 s) representing the propagation of the entire solution, (b) spatial time step (300 s) representing the spatial propagation, (c) spectral time step (300 s) for intra-spectral propagation, and (d) source time step (100 s) for the source term integration.

### 3.3. Wind Input

The surface wind vectors ($\mathbf{U}$) are obtained from the National Centers for Environmental Prediction (NCEP) four times daily reanalysis wind data 10 m above the sea surface. The horizontal resolution of the wind data is about 1.875° by 1.905° in SCS. The quadratic interpolation is used to generate wind fields from the NCEP data to match the spatial and temporal resolution of the WWATCH model. The wave heights are approximately scaled with the square of the wind speed. This implies that an error of 10% in the wind speed leads to an error of 20% in the wave height. Wave forecast errors are dominated by errors in the wind fields.

### 3.4. Friction Velocities
The friction velocities are needed for the input source function $S_{in}$. In WWATCH, the friction velocity ($u^*$) is computed from the wind speed ($U$) at a given reference height $z_r$, in terms of a drag coefficient $C_z$ (Tolman and Chalikov 1996)

$$u^2_r = C_z U^2 (z_r),$$

$$C_z = 10^{-3} (0.021 + \frac{10.4}{R^{2.33} + 1.85}),$$

$$R = \ln \left( \frac{z_g g}{\chi \sqrt{\alpha U^2}} \right),$$

where $\epsilon = 0.2$ is a constant, and $J$ the conventional nondimensional energy level at high frequencies, which is parameterized by (Janssen 1989)

$$\alpha = 0.57 \left( \frac{u^*}{c_p} \right)^{3/2},$$

where $c_p$ is the phase velocity at the spectral peak frequency.

An iteration process is adopted to obtain $u^*$. Wu’s (1982) empirical relation

$$C_D (U) = \begin{cases} 1.2875 \times 10^{-3} & U < 7.5 \text{ m s}^{-1}, \\ (0.8 + 0.065U) \times 10^{-3} & U \geq 7.5 \text{ m s}^{-1}, \end{cases}$$

is used to obtain

$$u^{(0)} = \sqrt{C_D U (z_{10})},$$

as the first guess friction velocity. Here, $z_{10} = 10$ m. The iteration starts from $u^{(0)}$. Let $u^{(n)}$ be the friction velocity at $n$-th iteration. Use of (14), (13), (12), and (11) consecutively leads to the friction velocity at $(n+1)$-th iteration, $u^{(n+1)}$. The iteration stops when the change of the friction velocity is smaller than a prescribed criterion. Such iterations are performed during the model initialization, but are not necessary during the
actual model run, as $u_*$ changes slowly (Tolman 1999). The effect of the atmospheric instability on the friction velocity is parameterized using an effective wind speed $U_e$ (Tolman 1998), which depends on the surface air and sea temperature difference.

3.5. Model Integration

WWATCH is integrated with four times daily NCEP surface wind data (at 10 m height) from the Jowswap wave spectra (XXX) on January 1, 1996 until 31 December 1996. The model SWH data are interpolated into the T/P crossover points, where the hindcast and altimeter wave heights are compared. At each crossover point, there are $M$ pairs (approximately 72) of modeled ($H_m$) and observed ($H_o$) SWH data in 1996 (around 2 pairs per 10 days).

4. Methodology of Verification

The difference of the modeled and observed SWH,

$$AH = H_m(x, y, t) - H_o(x, y, t)$$

represents the model error. We may take the probability histogram of $AH$ as the error distribution.

4.1. Verification at Crossover Points

Three parameters, bias, root-mean-square error (rmse), and correlation coefficient (cc) for each crossover point

$$\text{bias}(x, y) = \frac{1}{M} \sum_{i=1}^{M} \Delta H(x, y, t_i),$$

$$\text{rmse}(x, y) = \sqrt{\frac{1}{M} \sum_{i=1}^{M} [\Delta H(x, y, t_i)]^2},$$

(17)
are used to verify WWATCH. Here $\tilde{H}_m(x,y)$ and $\tilde{H}_o(x,y)$ are temporal mean modeled and observed SWH,

$$\tilde{H}_m(x,y) = \frac{1}{M} \sum_{i=1}^{M} H_m(x,y,t_i), \quad \tilde{H}_o(x,y) = \frac{1}{M} \sum_{i=1}^{M} H_o(x,y,t_i),$$

(21)

at the crossover points.

4.2. Verification at Time Instance

Three parameters: bias, root-mean-square error (rmse), and correlation coefficient (cc),

$$\text{bias}(t) = \frac{1}{N} \sum_{j,k} \Delta H(x_j, y_k, t),$$

(21)

$$\text{rmse}(t) = \sqrt{\frac{1}{N} \sum_{j,k} [\Delta H(x_j, y_k, t)]^2},$$

(22)

$$\text{cc}(t) = \frac{\sum_{j,k} [H_m(x_j, y_k, t) - <H_m>(t)][H_o(x_j, y_k, t) - <H_o>(t)]}{\sqrt{\sum_{j,k} [H_m(x_j, y_k, t) - <H_m>(t)]^2} \sqrt{\sum_{j,k} [H_o(x_j, y_k, t) - <H_o>(t)]^2}},$$

(23)

where $<H_m>(t)$ and $<H_o>(t)$ are spatial mean (over all crossover points) modeled and observed SWH at time instance $t$.

5. Model Evaluation

5.1. Statistical Evaluation

The easiest way to verify WWATCH-SCS performance is to plot $H_m$ against $H_o$ at each crossover points. The scatter diagrams for the central SCS show clustering of
points approximately around the line of $H_m = H_o$ with more data below the line (Fig. 4). The errors are usually large in the low sea state ($H_o < 1.5$ m), and the rmse varies from 0.41 m at Point #14 (114.81°E, 9.80°N) to 0.78 m at Point #19 (117.65°E, 17.20°N). The bias is negative over all the nine crossover points and varies from -0.24 m at Point #10 (111.98°E, 17.20°N) to -0.59 m at Point #19. The correlation coefficients vary from 0.87 at Point #21 (119.07°E, 13.60°N) to 0.95 at Point #10 (111.98°E, 17.20°N). At Point #19, the rmse and negative bias reach the maximum values, however, the correlation coefficient is quite high (0.92). This indicates that the model errors in the central SCS are largely due to the underprediction.

The scatter diagrams for the northern SCS show a similar model under-prediction pattern at all the five crossover points (Fig. 5). The rmse varies from 0.59 m at Point #6 (109.14°E, 17.18°N) to 1.00 m at Point #22 (119.07°E, 20.58°N), which is averagely larger than in the central SCS. The bias is negative over all the five crossover points and varies from -0.36 m at Point #6 (109.14°E, 17.18°N) to -0.87 m at Point #22 (119.07°E, 20.58°N). The correlation coefficients vary from 0.68 at Point #3 (107.73°E, 20.59°N) to 0.88 at Point #22 (119.07°E, 20.58°N). The co-location of the maximum rmse and negative bias with the maximum correlation coefficient (Point #22) indicates that the model errors in the northern SCS are also largely due to the underprediction.

The scatter diagrams for the southern SCS show a similar model underprediction pattern at all the seven crossover points (Fig. 6). The rmse varies from 0.38 m at Point #11 (113.4°E, 5.97°N) to 0.60 m at Point #5 (109.14°E, 9.81°N), which is averagely smaller than in the central SCS. The bias is negative over all the seven crossover points and varies from -0.22 m at Point #2 (107.73°E, 5.96°N) to -0.48 m at Point #4 (109.14°E,
The correlation coefficients vary from 0.81 at Point #1 (106.31°E, 2.01°N) to 0.93 at #2 (107.73°E, 5.96°N). The maximum negative bias is co-located with the maximum correlation coefficient (Point #2).

The model errors for SWH hindcast have Gaussian-type distribution (Fig. 7a) with mean values of -0.36 m in the central SCS, and of -0.61 m in the northern SCS. The model underprediction is the least in the central SCS (Fig. 7b) with 526 negative errors versus total 624 data (ratio of 0.84). It enhances to the northern SCS (Fig7c) with 315 negative errors versus total 339 data (ratio of 0.92), and to the southern SCS (Fig7d) with 384 negative errors versus total 436 data (ratio of 0.88). Thus, WWATCH-SCS has a better hindcast performance in the central SCS than in the southern and northern SCS.

5.2. Spatial Error Estimation

Figure 8 shows the spatial distributions of bias, rmse, and cc of SWH over SCS. The bias is around -0.3 m in parts of central and southern SCS (Fig. 8a). The value of bias becomes large (-0.7 m) in the northern SCS. This indicates that WWATCH-SCS model underpredicts the SWH over the whole SCS with weaker prediction capability in the northern SCS than the central and southern SCS. The rmse of SWH is around 0.5 m in the central SCS with a minimum around 0.4 m northwest of Borneo (Fig. 8b). The value of rmse increases from the central SCS to the other regions, and is larger than 0.7 m in most of northern SCS.

The cc of SWH (Fig. 8c) the modeled and T/P data in 1996 is larger than 0.85 in almost everywhere in SCS except in the Gulf of Tonkin. The $T$-value can be constructed from cc by

$$T = \frac{cc\sqrt{M-2}}{\sqrt{1-cc^2}}, \quad M = 72.$$
For $cc = 0.85$, $T = 13.50$, which is much larger than $t_{0.005}$ for degree of freedom of 70 (2.576). The modeled and T/P SWH data are highly correlated, which indicates that the model errors are mainly caused by the model bias (under prediction).

5.3. Model-Data Comparison at Crossover Points

Point # 12 represents the central SCS (Fig. 3). The modeled SWH data coincide better with the T/P SWH data in the winter than in the other seasons. The maximum differences generally occur in low sea state, $H_o < 1.5$ m (Fig. 9a) in the summer monsoon season, i.e., on Julian Day 120-200 (May – July). Point # 13 represents the northern SCS. The modeled and T/P SWH data are not as coincidence as at Point 12 in the central SCS (Fig. 9b). The negative model bias is evident in all seasons. Point 2 represents the southern SCS. The modeled and T/P SWH data are as coincidence as at Point 12 in the central SCS (Fig. 9c), and better than at Point 13 in the northern SCS.

5.4. Boundary Effect

Comparison of the SWH hindcast is conducted between crossover points 1 and 2 to test the boundary effect. The model errors are comparable at both points during the (northeast) winter monsoon season (Julian Day 1-90, and 290-365), but much larger at the crossover point 1 during the (southwest) summer monsoon season (Julain Day 120-270). In fact, the modeled SWH at the crossover point 1 is near 0 on Julian Day 120-270 (Fig. 9d). The unrealistic southern and western rigid boundaries shorten the fetches of the southerly and westerly winds. The southerly winds prevailing during the summer monsoon season at the crossover point 1 (Fig. 10). The shortening of the southerly wind
fetches makes WWATCH unable to simulate waves forced by the winds with long fetches.

5.5. Temporal Error Estimation

The bias of SWH over the whole SCS (i.e., 21 crossover points) is negative all the time and fluctuates between -0.32 m and -0.39 m from January 1 to July 31. The negative bias monotonically increases from -0.36 m to -0.42 m after July 31 (Fig. 11a). The model underprediction (bias: -0.32 to -0.42 m) needs to be improved. Bauer et al. (1992) shows the great improvement of WAM simulated mean wave heights using data assimilation in the regions which are dominated by swell, but not in the regions with high sea state, which consist of mainly the wind sea. The rmse of SWH over the whole SCS fluctuates between 0.52 m and 0.58 m from January 1 to August 31, and increases from 0.54 m to 0.6 m after August 31 (Fig. 11b).

6. Comparison of Monthly Mean SWHs between WWATCH and T/P Data

June (1996) mean SWH field shows the existence of a high SWH center in the north central SCS (north of 15°N) with a maximum value around 0.6 m in the WWATCH simulation (Fig. 12a) and 1.0 m from the T/P data (Fig. 12b), and the southward decrease from 15°N with 0.2-0.4 m in the WWATCH simulation (Fig. 12a) and around 0.5 m in the T/P data.

December (1996) mean SWH field shows much high values (Fig. 13) than that in June. A southwest to northeast oriented high SWH region, which is enclosed by 2 m isoline in the WWATCH simulation (Fig. 13a) and 2.5 m isoline in the T/P data (Fig. 13b), extends from the south coast of Vietnam to west coast of Luzon Island. Its size is comparable in both modeled and observed data, and the maximum SWH occurs in the
northern SCS with 2.5 m southeast of Hainan Island (110°–115°E, 15°–18°N) in the WWATCH simulation (Fig. 13a) and 3.0 m west of Luzon Island (115°–118°E, 15°–18°N).

Thus, WWATCH simulates the seasonal variability of SWH reasonably well. The high SWH center always occurs north of 15°N with larger values in the winter monsoon season. The orientation of the high SWH region coincides with the orientation of the monsoon winds (Fig. 2). The major wave characteristics and the physical processes will be discussed in Part 2 of this paper.

7. Conclusions

Comparing the South China Sea significant wave height fields hindcast by the third generation wave model Wavewatch-III with significant wave heights measured by the TOPEX/POSEIDON altimeter for the entire year of 1996, several characteristics of the model results are obtained for the three subregions: central, northern, and southern SCS.

(1) The model errors for SWH hindcast have Gaussian-type distribution with mean values of -0.36 m in the central and southern SCS, and of -0.61 m in the northern SCS. The model underprediction exists in the whole SCS with the least bias in the central SCS and the largest bias in the northern SCS.

(2) At crossover points, the root mean rms error varies from 0.41 m to 0.78 m in the central SCS, from 0.38 m to 0.60 m in the southern SCS, and from 0.59 m to 1.00 m in the northern SCS. The bias is negative and varies from -0.24 m to -0.59 m in the central SCS, from -0.22 m to -0.48 m in the southern SCS, and from -0.36 m to -0.87 m in the northern SCS. The correlation coefficient coefficients vary from 0.87 at Point #21
(119.07°E, 13.60°N) to 0.95 at Point #10 (111.98°E, 17.20°N). At Point #19, the rmse and negative bias reach the maximum values, however, the correlation coefficient is quite high (0.92). This indicates that the model errors in the central SCS are largely due to the underprediction.

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The scatter diagrams for the southern SCS show a similar model underprediction pattern at all the seven crossover points (Fig. 6). The rmse varies from 0.38 m at Point #11 (113.4°E, 5.97°N) to 0.60 m at Point #5 (109.14°E, 9.81°N), which is averagely smaller than in the central SCS. The bias is negative over all the seven crossover points and varies from -0.22 m at Point #2 (107.73°E, 5.96°N) to -0.48 m at Point #4 (109.14°E, 1.99°N). The correlation coefficients vary from 0.81 at Point #1 (106.31°E, 2.01°N) to 0.93 at #2 (107.73°E, 5.96°N). The maximum negative bias is co-located with the maximum correlation coefficient (Point #2).
(1) The correlation between the modeled and observed (from T/P) significant wave heights is quite good in general. The correlation coefficient $cc$, as defined by equation (20), for the entire year of 1996 is above 0.9 in most crossover points. The high correlation is statistically significant even with the tolerance limit of 0.005.

(2) The underestimation of modeled wave heights for the central SCS is varying with the season. In large parts of this region the wave heights are underestimated by up to about 30% during May through September, while relatively good agreement with T/P data is found for the rest of the year. The mean symmetrical regression coefficients for the southern hemisphere are 0.90 during May through September and 0.96 during the rest time.

The effect of underestimated wave heights in the southern hemisphere and the tropical region was found already by Bauer et al. [1992] in a validation study with data from the Seasat altimeter. It was attributed to inadequate wind stress fields driving the WAM model. However, the analyzed ECMWF wind fields, which were used as input for the WWATCH model for the 1988 hindcast, should be more reliable than the wind fields used by Bauer et al. The persisting differences between the WAM and T/P wave heights are very likely related mainly to the remaining simplifications in the algorithm for converting wind speed into wind stress fields. The wind stress driving the WWATCH model was calculated simply by multiplying the wind speed at a height of 10 m with a drag coefficient depending only on the wind speed. The actual atmospheric stratification was not taken into account.
Finally, the good overall agreement of W AM and T/PI wave heights allowed an extended quality analysis of the T/P data, using the W AM wave heights as reference. It was found that a clear relationship between the quality of the T/P wave height data and some additional T/P parameters exists. The correlation between WWATCH and T/P wave heights can be slightly improved if data points at given attitudes outside the interval between 0.250 and 1.20, automatic gain control values below 18 dB and standard deviations USWH of more than 12 cm are discarded.

(1) The correlation between the model results

The hindcast experiments using the NCEP wind fields as forcing altimetry data have been widely used in wave model validation for the last 10 years\textsuperscript{[11]}. Since there isn’t long period wave data from wave buoy in the SCS, the T/P wind speeds and significant wave heights data are used to compare to the NCEP wind speeds and the SWHs output of WWATCH. Accordingly, the following conclusion can be obtained:

The variations of SWHs from WWATCH and T/P are similar, but the SWHs from WWATCH are generally lower than that from T/P, and the maximum differences between SWHs from WWATCH and T/P occur in low wind speeds during summer monsoon especially. In space, the consistency of SWHs from WWATCH and T/P in center areas is better than that close to the model boundary. Future work should include the data assimilation and further improve the wind input in WWATCH.

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References


Fig.3. T/P tracks and crossover points in SCS.
Fig. 4 Scatter diagrams of SWHs for the central SCS.
Fig. 5 Scatter diagrams of SWHs for the northern SCS.
Fig. 6 Scatter diagrams of SWHs for the southern SCS.
Fig. 7. Histogram of model errors of SWH (m) over: (a) total crossover points, (b) nine central SCS crossover points (8, 9, 10, 12, 14, 15, 16, 19, 21), (c) five northern SCS crossover points (3, 6, 13, 17, 22), and (d) seven southern SCS crossover points (1, 2, 4, 5, 7, 11, 18).
Fig. 9. Comparison between WWATCH modeled (solid curve) and T/P observed (denoted by ‘o’) significant wave heights at (a) Point #12 (Central SCS), (b) Point #13 (northern SCS), (c) Point #2 (southern SCS), and (d) Point #1 (southern SCS).
Fig. 10. Temporal varying wind vectors at the crossover point 1. Here, the vector indicates the direction in which the wind is blowing.