Acta Oceanol. Sin., 2023, Vol. 42, No. 2, P. 74–82
https://doi.org/10.1007/s13131-022-2030-4
http://www.aosocean.com
E-mail: ocean2@hyxb.org.cn

Validation and accuracy analysis of wind products from scatterometer onboard the HY-2B satellite

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Received 15 June 2021; accepted 27 April 2022

Abstract

The Chinese marine dynamic environment satellite HY-2B was launched in October 2018 and carries a Ku-band scatterometer. This paper focuses on the accuracies of HY-2B scatterometer wind data during the period from November 2018 to May 2021. The HY-2B wind data are validated against global moored buoys operated by the U.S. National Data Buoy Center and Tropical Atmosphere Ocean, numerical model data by the National Centers for Environmental Prediction, and the Advanced Scatterometer data issued by the Remote Sensing System. The results showed that the wind speeds and directions observed by the HY-2B scatterometer agree well with these buoy wind measurements. The root-mean-squared errors (RMSEs) of the HY-2B wind speed and direction are 0.74 m/s and 11.74°, respectively. For low wind speeds (less than 5 m/s), the standard deviation of the HY-2B-derived wind direction is higher than 20°, which implies that the HY-2B wind direction for low wind speeds is less accurate than that for moderate to high wind speed ranges. The RMSE of the HY-2B wind speed is slightly larger in high latitude oceans (60°–90°S and 60°–90°N) than in low latitude regions. Furthermore, the dependence of the residuals on the cross-track location of wind vector cells and the stability of the HY-2B scatterometer wind products are discussed. The wind stability assessment results indicate that a clear yearly oscillation is observed for the HY-2B wind speed bias which is due to seasonal weather variations. In general, the accuracy of HY-2B winds meets the operational precision requirement and is consistent with other wind data.

Key words: sea surface wind, validation, microwave remote sensing, scatterometer

Citation: Yang Sheng, Mu Bo, Shi Haoqiang, Ma Chaofei, Zhou Wu, Zou Juhong, Lin Mingsen. 2023. Validation and accuracy analysis of wind products from scatterometer onboard the HY-2B satellite. Acta Oceanologica Sinica, 42(2): 74–82, doi: 10.1007/s13131-022-2030-4

1 Introduction

As a fundamental geophysical environmental variable, sea surface wind is of great importance to marine science research and its engineering applications. Among the diverse methods used to observe sea surface wind, satellite scatterometers play a crucial role. Satellite scatterometers provide excellent global coverage and scatterometer data have been available for decades. Wind observed by space-borne scatterometers is widely adopted as an input, such as wind-driven current systems, ocean surface waves, air-sea fluxes of momentum (Ebuchi et al., 2002), numerical weather prediction assimilation, storm warning (Isaksen and Stoffelen, 2000; Stoffelen and van Beukering, 1997), climate scale research (Chelton and Freilich, 2005), extratropical cyclones (Yang and Zhang, 2019) and tropical cyclones prediction (Wentz, 1990) and other nowcasting applications.

The Chinese HY-2B satellite was launched in October 2018 as a continuation of the HY-2A end mission. The HY-2B satellite is equipped with a scatterometer, enabling it to monitor ocean surface wind data. However, the satellite scatterometer does not measure sea-surface wind directly, and the scatterometer wind data must maintain consistency and high accuracy for the various wind applications. Thus, it is necessary to assess the quality of the HY-2B wind data. In recent years, validation issues of remotely sensed satellite winds have been addressed by many researchers (Bentamy et al., 2008; Ebuchi et al., 2002; Freilich and Dunbar, 1999). After the launch of the HY-2A satellites, validation studies of scatterometer wind products have been conducted using wind data from *in situ* buoys, numerical weather prediction models, and another spaceborne scatterometer (Mu et al., 2014; Wang et al., 2013; Zhu et al., 2014). Previous studies confirmed good consistency between the HY-2A scatterometer measurements and other wind products. For the HY-2B scatterometer, a similar evaluation was performed with the MetOp-C scatterometer but the data period was very limited (only half a year from December 2018 to May 2019) (Wang et al.,2020).

The objective of the present work is to analyze the accuracy of the HY-2B scatterometer wind measurements from November 2018 to May 2021. Overall, HY-2B winds are compared with wind data from buoys provided by National Data Buoy Center (NDBC) and Tropical Atmosphere Ocean (TAO). On a global scale, the HY-2B winds are compared to wind retrieved from Advanced Scatterometer (ASCAT) onboard the MetOp-A satellite and the National Centers for Environmental Prediction (NCEP) model data in different latitude regions. Moreover, the systematic error of the pencil-beam rotating scanning scatterometer and the stability of the HY-2B wind bias are also discussed. The abovemen-

Foundation item: The National Key Research and Development Program of China under contract No. 2021YFB3900400.
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tioned data and collocating method, the data quality control, and the wind speed conversion method are outlined in Section 2. Section 3 presents the results and discussion, illustrating the quality of HY-2B winds. The conclusions follow in Section 4 with a summary.

2 Data and methods

2.1 *Collocated data*

The HY-2B scatterometer operational L2B products require significant processing before distribution by the ground-based application systems of the National Satellite Ocean Application Service (NSOAS), China. These improved wind-derived data are processed by the multiple solution scheme in conjunction with a two-dimensional variational ambiguity removal method. Note that before wind retrieval, HY-2B sea ice masking is performed by using sea ice edge products from the EUMETSAT Ocean and Sea Ice Satellite Application Facility. All HY-2B wind products used in this study are on the 25-km swath grid. In addition, since the low and high wind speed flags of the HY-2B scatterometer L2B products are 3 m/s and 30 m/s, respectively, only the wind data ranging between 3 m/s and 30 m/s are accounted for in the validation analysis.

To compare with the HY-2B wind data, we collocated the wind data from 56 NDBC buoys operated by the NDBC located in the Northern Hemisphere, and 50 TAO buoys operated by the TAO located in the Pacific Equator. The buoy winds are measured by averaging the wind speed and direction over 10 min. To avoid the impact of land pollution on the accuracy of winds measured by the HY-2B scatterometer, only buoys with an offshore distance greater than 50 km were selected. The geographical locations of the buoys in this work are shown in Fig. 1.

Spatial and temporal variability in the wind vector cell (WVC) can lead to differences between wind velocity measurements acquired at different locations and times. These differences can, in principle, be minimized by restricting the spatiotemporal matching rules, although the basic incompatibility between scatterometer and buoy measurements precludes eliminating the differences (Freilich, 1986). Nevertheless, overly stringent collocation criteria can greatly reduce the number of collocated matchup pairs, leading to increased sampling errors and statistical uncertainties in the calculated comparison metrics. Therefore, the temporal difference and spatial separation between the HY-2B and buoy observations in this study were limited to less than 30 min and $25/\sqrt{2}$ km, respectively.

The NCEP FNL (Final) Operational Global Analysis data are provided by the Nation Center for Atmospheric Research (NCAR) (http://rda.ucar.edu/datasets/ds083.2/), which are on a global 1°×1° grid, and the temporal resolution is 6 h (i.e., measurement times are 00:00, 06:00, 12:00 and 18:00 UTC). These products are

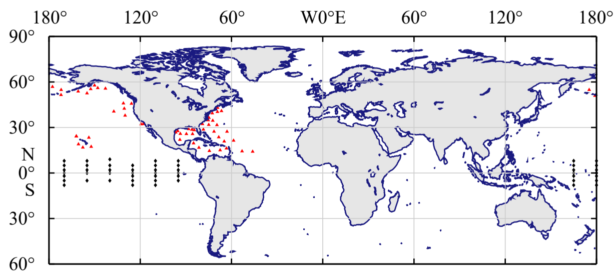

Fig. 1. Locations map of the screened NDBC buoys (red triangle) and TAO buoys (black diamond) in this study.

from the Global Data Assimilation System, which continuously collects observational data from the Global Telecommunications System, and other sources, for many analyses. The U-components and V-components of the wind vectors of the NCEP data during the period of HY-2B wind data are utilized in this study and were converted to the wind speed and direction for collocation. The NCEP model data are interpolated in space and time over the HY-2B swath by employing the trilinear method (Chelton and Freilich, 2005).

The Advanced Scatterometer (ASCAT) is onboard the EUMETSAT Metop-A satellites that was launched in October 2006. The ASCAT scatterometer data used in this paper are in the same period as the HY-2B data, which were publicly released by the Remote Sensing System (RSS) (ftp://ftp.remss.com/ascat). Although several grid sizes of wind products are available, and the wind products at a 25-km spatial resolution are used. These data are spatially comparable with HY-2B winds, thus minimizing spatial match errors. These new V2.1 ASCAT wind data were retrieved with the empirical C-2015 geophysical model function. For the collocation between HY-2B and ASCAT data, the matching criteria are set as within $25/\sqrt{2}$ km for geographical distance and 10 min for the temporal difference. The validation processing flow for the retrieved winds of HY-2B is shown in Fig. 2.

2.2 *Quality control and elimination method*

The HY-2B scatterometer is sensitive to heavy precipitation. Rainfall will increase the backscattering coefficient at low and medium wind speeds, while it dominates the attenuation effect and decreases the backscattering coefficient at high wind speeds. Therefore, HY-2B wind measurements contaminated by heavy rainfall should be removed. If the Royal Netherlands Meteorological Institute Quality Control (QC) flag is set in a WVC, then the backscatter information is not useful for various geophysical reasons, such as rain and complicated sea states, and should be abandoned in the calculation of the ambiguity removal step to avoid causing a large inversion residual (Verhoef and Stoffelen, 2012).

Screened by the QC flag discrimination, the rejected ratio of HY-2B wind data is 5.5%. The scatterometer QC rejected winds are excluded from the statistics. The comparison statistics were further refined by eliminating collocation data with wind direction differences of more than 90° (Freilich and Dunbar, 1999). This screening criterion of wind direction resulted in discarding 0.47%, 0.52%, 0.38%, and 3.81% of the data for NDBC buoy, TAO buoy, NCEP, and ASCAT, respectively. Some previous studies have eliminated wind directions that differed by more than 3 times the standard deviation (STD) (Chen et al., 2020). Stricter elimination standards may cause different assessment results. Furthermore, when the wind direction difference exceeds 180° caused by the cross-360° wind direction problem (for example, the difference in the direct subtraction value is 340° for the observed wind directions of 350° and 10°, but the actual difference is only 20°). The direction conversion method is given by other researchers (Mu et al., 2014). However, the wind direction in the wind direction scatter plots (Figs 5 and 8) are not converted by the abovementioned method to show the distribution characteristics of the wind direction.

2.3 *Wind speed conversion*

The scatterometer-derived winds are represented by the stress-equivalent (SE) winds at a 10-m height over a WVC, while the NCEP model data intend to estimate the actual winds at 10 m and the buoy data represent the actual wind at the height of the

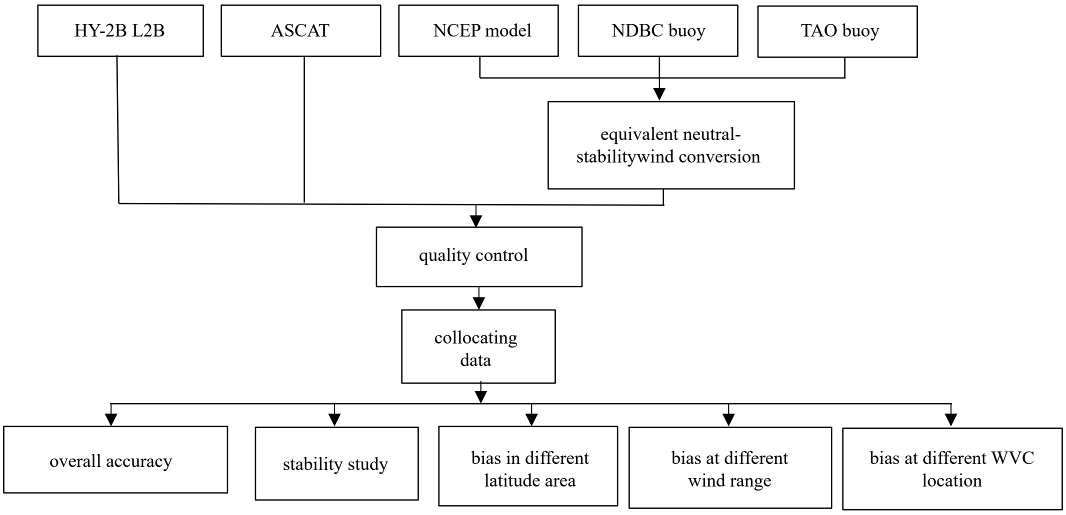

Fig. 2. The validation data processing flow for the retrieved winds of the HY-2B scatterometer.

anemometer, which is between 3.8 m and 5 m. Thus, the NCEP and buoy winds need to be converted to atmospheric stability winds at a height of 10 m using the Liu and Tang method (Liu and Tang, 1996). There is no need to convert wind speed when comparing the winds between the HY-2B and ASCAT scatterometers.

3 Results and discussion

3.1 *Comparison of the HY-2B scatterometer and buoy data*

Based on the QC, the comparisons of the HY-2B scatterometer wind products and NDBC and TAO global moored buoys for the period ranging from November 2018 to May 2021 are presented as follows. The number of collocated data pairs for NDBC buoys is 25 980 and 22 805 for TAO buoys, respectively. According to the collocation data, statistical parameters—the RMSE, bias, and correlation coefficient—are computed to evaluate the quality of HY-2B wind data through the direct comparison of HY-2B data with moored buoy wind data.

The statistical results within 3–30 m/s summarized in Table 1 demonstrate that wind speeds and directions between HY-2B and buoys agree well. The NDBC buoys are mainly located offshore of the Northern Hemisphere and the TAO buoys are located in the tropical Pacific Ocean; thus, the results of the comparison with the NDBC and TAO buoys reflect the accuracy of the HY-2B winds in the Northern Hemisphere ocean and tropical ocean. For wind speed, the biases are −0.15 m/s and −0.14 m/s for the NDBC and TAO buoys, respectively. The negative biases reveal that the HY-2B wind speeds are slightly underestimated. However, the positive bias for the wind direction shows that the HY-2B wind direction is on the right side of the buoy wind direction. The correlation coefficients of the scatterometer-TAO are relatively lower than those with the NDBC buoys, which may be attributed to the wind speed distribution: more than 95% of scatterometer-TAO matchups are in low wind speed ranges of 3–10 m/s, which is approximately 7.5% higher than scatterometer-NDBC matchups (Fig. 3). Indeed, in the equatorial region where TAO buoys are located, more than 40% of wind speeds are less than 5 m/s, whereas the percentage is approximately 17% over the global ocean (Bentamy et al., 2008). The maximum wind direction RMSE between the HY-2B observations and buoys occurs in the low wind speed range (or calm sea surface). This is because the sea surface is relatively smooth under low wind speeds, which is similar to a mirror sea state. The signal-to-noise of the backscattering coefficient of the sea surface measured by the HY-2B scatterometer is low under such low wind speed conditions, resulting in a larger measurement error of the backscatter coefficient. The low upwind/crosswind modulation of the microwave backscattering from the sea surface and less accurate ambiguity removal procedure at low wind speeds may also cause inaccurate retrieval wind of the scatterometer.

Former studies show that the root-mean-squared errors (RMSEs) of wind speed and wind direction between HY-2A winds and NDBC buoy winds are 1.44 m/s and 23.5°, respectively (Yang and Zhang, 2019). The HY-2B wind shows better agreements with the buoy data than HY-2A. This may be caused by the update of the HY-2B wind retrieval algorithm, different quality control methods and different selected wind speed ranges between the two studies.

The histograms of the wind speed distribution and deviation for HY-2B compared with buoys are shown in Fig. 3, demonstrating that the deviation of the HY-2B scatterometer wind speed from the NDBC buoy and TAO buoy is an approximately Gaussian normal distribution. Most of the wind speed deviations are

Table 1. Summary of statistics between buoys and HY-2B wind data during November 2018–May 2021

	Wind speed/ $(m·s^{-1})$	Number of data	Wind speed			Wind direction		
			Bias/$(m·s^{-1})$	RMSE/$(m·s^{-1})$	Correlation coefficient	Bias/(°)	RMSE/(°)	Correlation coefficient
NDBC	3–10	22 787	−0.13	0.70	0.97	1.24	11.85	0.99
	⩾10	3 193	−0.24	0.75	0.90	1.47	7.46	1.00
	⩾3	25 980	−0.15	0.74	0.97	1.26	11.74	0.99
TAO	3–10	21 718	−0.13	0.83	0.88	2.17	13.62	0.97
	⩾10	1 087	−0.16	0.76	0.59	4.43	11.63	0.93
	⩾3	22 805	−0.14	0.88	0.88	2.31	13.64	0.97

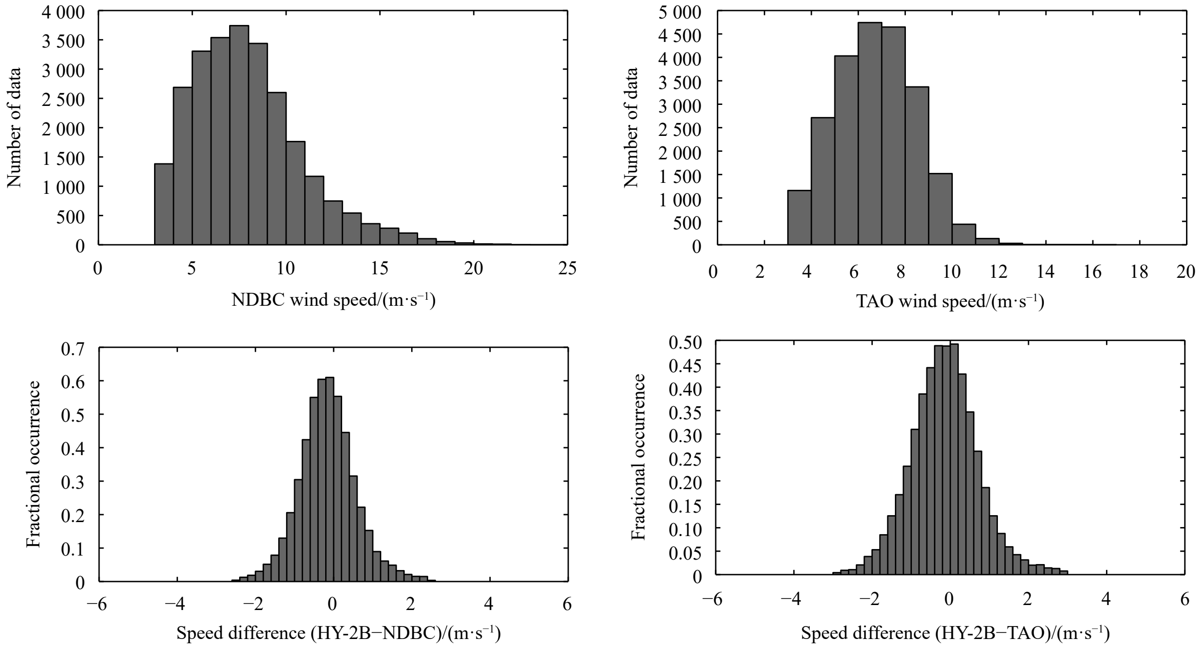

Fig. 3. The histogram of the wind speed distribution and deviation for HY-2B compared with NDBC (left) and TAO (right).

less than 2 m/s and concentrated near 0 m/s, implying that there is no obvious systematic deviation.

The dependencies of the wind speed residual (HY-2B-buoy) on the buoy wind speed for the HY-2B winds and the STD of the wind direction difference between the HY-2B and NDBC buoys and the TAO buoy as a function of buoy wind speed are shown in Fig. 4. It is shown that the HY-2B wind direction standard deviation appears mainly at low wind speeds. When the wind speed is greater than 5 m/s, the wind direction STD remains below 20°, and the minimum wind direction STD emerges at approximately 10 m/s. When the wind speed exceeds 10 m/s, the STD of the HY-2B wind direction fluctuates, which may be attributed to the insufficient number of samples under the conditions of high wind speeds. The number of matchups collected for such high wind conditions (⩾10 m/s) is 20 times and 7 times lower than that for medium wind speeds (3–10 m/s) for the TAO buoy and NDBC buoy, respectively.

The scatter plots of the wind direction distribution characteristics are shown in Fig. 5. There are sporadic (scattered) sample distributions in the upper left and lower right corners, which can be attributed to the cross-360° wind direction problem as mentioned above.

3.2 *Global wind quality evaluation and cross-track variations in the HY-2B scatterometer wind*

The NCEP wind data were collected to evaluate the wind

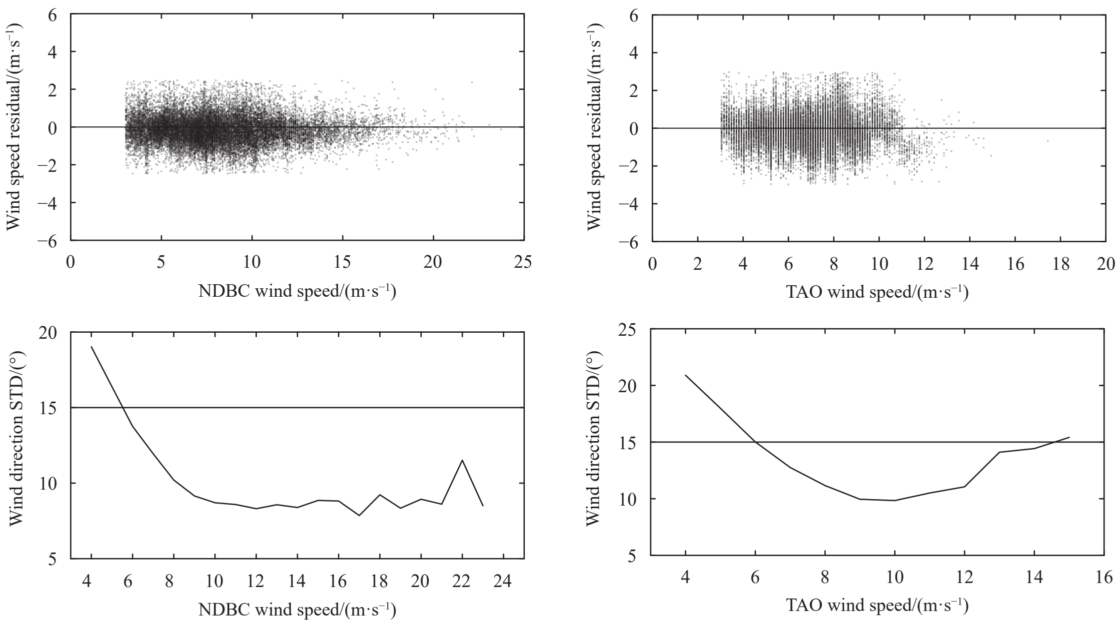

Fig. 4. Dependence of wind speed residual (HY-2B-buoy) on the buoy wind speed for the HY-2B winds (upper panel). The STD of the wind direction difference between the HY-2B and NDBC buoys and the TAO buoy as a function of buoy wind speed (lower panel).

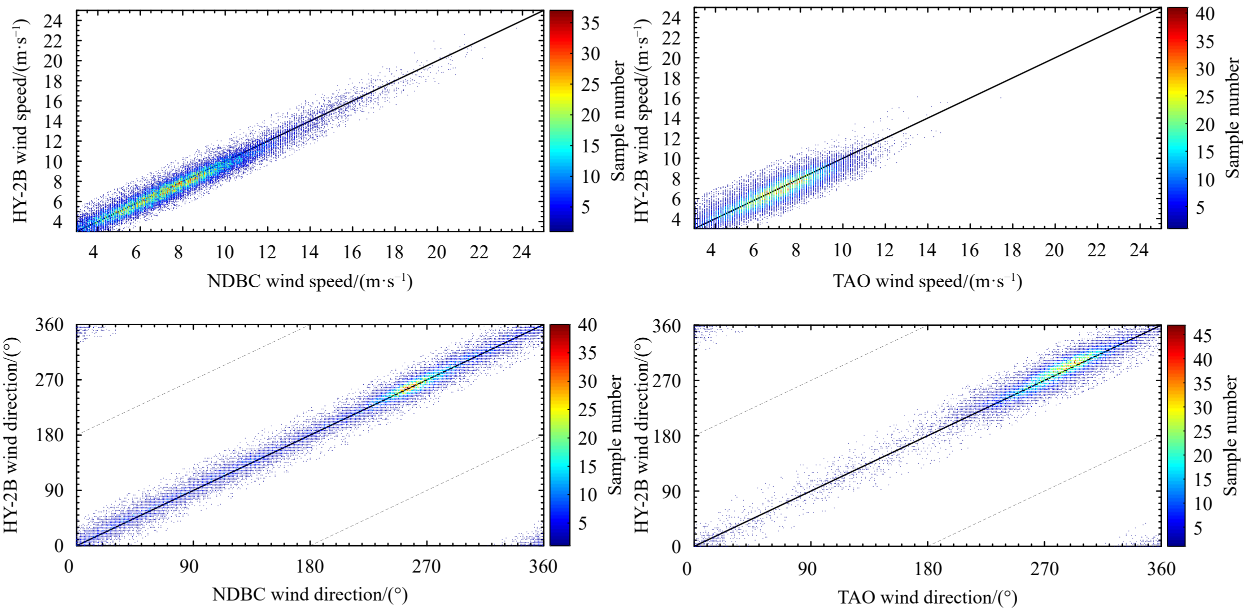

Fig. 5. Scatterplots of wind speeds and directions derived from NDBC and HY-2B (left) and from TAO and HY-2B (right).

products of the HY-2B scatterometer. Under the assumption that the quality of the HY-2B wind products is consistent, the HY-2B-NCEP data pairs totaling 112 674 559 are distributed uniformly from November 2018 to May 2021. The same datasets are used for stability analysis. The collocated data are distributed over the global ocean. We divided the global ocean into five latitude regions, the Antarctic Ocean (60°–90°S), Southern Ocean (10°–60°S), Tropical Ocean (10°S–10°N), Northern Ocean (10°–60°N), and Arctic Ocean (60°–90°N), to investigate the accuracy of the HY-2B scatterometer wind products. Table 2 shows the statistics of the comparisons of the HY-2B scatterometer and NCEP wind speeds and directions.

Over the global ocean, the RMSE of the wind speed between the HY-2B scatterometer and NCEP is approximately 1.10 m/s and the wind direction is 12.45°. However, the HY-2B wind speed is less accurate in high latitude areas (60°–90°S and 60°–90°N) which may be due to the decreases or even saturation of the sensitivity of the backscattering coefficient with the increasing wind speed. Such phenomena may increase the difficulty of wind retrieval under high wind conditions. Furthermore, for high wind speeds (⩾20 m/s), it is difficult to acquire sufficient high-quality synchronous observations for the establishment of geophysical models. The shortage and inaccuracy of *in situ* measurement data which include research vessel observations and buoy data under high wind speed conditions mean that the present geophysical model function NSCAT-4 needs further refinement.

As shown in Fig. 6, the wind speeds of collocated data between scatterometer-NCEP are concentrated in the range of 3–20 m/s. When the wind speed is greater than 20 m/s, the number of samples is rare. The wind speed residual is almost zero, indicating that the HY-2B wind speed has no systematic dependence on the NCEP wind speed at 3–20 m/s.

Figure 7 shows the variation in the wind direction STD with wind speed, which illustrates that the STD increases at low wind speeds, corresponding to the results shown in Fig. 4. In the wind speed range below 5 m/s, the STD of the wind direction is higher than 20°, which is quite consistent with the HY-2B-buoy comparison. For wind speeds greater than 6 m/s, the STD remains lower than 10°. Figure 8 is a scatter plot of the collocated wind speed and direction for HY-2B and NCEP, HY-2B, and ASCAT.

The HY-2B scatterometer carries a rotating dish antenna with two pencil beams that sweep in a circular pattern, resulting in systematic cross-track variability in the accuracy of the wind estimates. The maximum number of observations occurs at the position of the outermost WVC that can be measured by the inner beam. Figure 9 shows the distributions for the total numbers of independent measurements for each WVC according to the cross-track WVC index.

Figure 10 shows the cross-track variations in comparisons between HY-2B measurements and spatially and temporally interpolated NCEP wind. Since the wind speed errors in the NCEP do not vary with locations within the HY-2B swath, any cross-track variations in low-order comparison statistics can be interpreted as swath-dependent errors in the scatterometer winds.

Table 2. Statistics of the comparisons of the HY-2B scatterometer and NCEP wind speeds and directions during November 2018–May 2021

		Global	Arctic Ocean 60°–90°N	Northern Ocean 10°–60°N	Tropical Ocean 10°S–10°N	Southern Ocean 10°–60°S	Antarctic Ocean 60°–90°S
Wind speed	Number of data	112 674 559	5 584 522	30 374 914	18 026 431	54 033 676	4 655 016
	Bias/(m·s^{-1})	0.09	0.24	0.07	0.07	0.05	0.41
	RMSE/(m·s^{-1})	1.10	1.39	0.94	1.03	1.02	1.97
	Correlation coefficient	0.93	0.88	0.92	0.85	0.94	0.86
Wind direction	Bias/(°)	−0.07	−2.04	−2.59	0.41	1.28	0.89
	RMSE/(°)	12.45	13.87	12.80	14.17	10.84	15.35
	Correlation coefficient	0.99	0.99	0.99	0.99	1.00	0.99

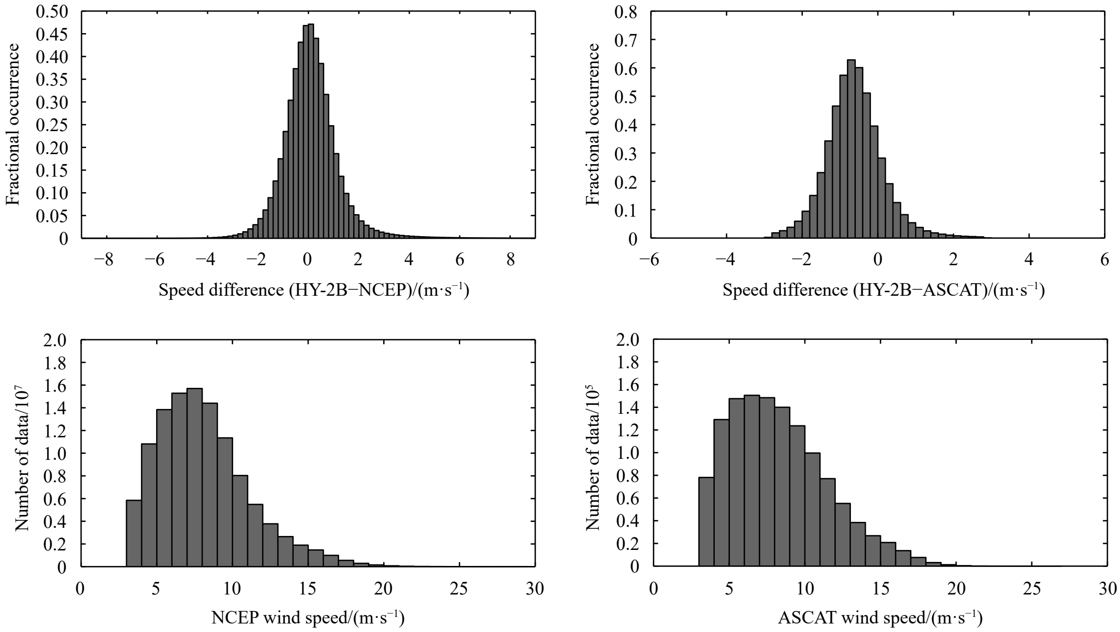

Fig. 6. The histogram of the wind speed distribution and deviation for HY-2B compared with NCEP (left) and ASCAT (right).

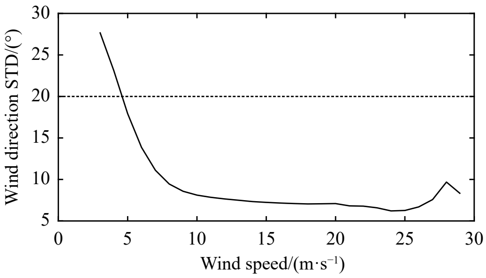

Fig. 7. The STD of the wind direction difference between HY-2B and NCEP as a function of NCEP wind speed.

The accuracy of the HY-2B scatterometer winds improves roughly with the increase in the number of beam observations. When the wind vector is located in the swath center (approximate cell between 29–48), the wind speed STD of HY-2B is approximately 1.1 m/s. For the outer edges of the swath (approximate falling into cells 1–8 and cells 69–76), where only vertically polarized beams can illuminate at a very narrow cross-track relative azimuth angle, the STD of wind speed increases rapidly. For the wind direction, larger differences were found near the center and the outer edges of the swaths. The total cross-track STD in the wind direction difference is less than 2°.

Figure 11 shows the monthly averages of wind speed bias and wind direction bias over the period from November 2018 to May 2021. The HY-2B wind speed and direction biases against buoy measurements appear to be somewhat larger than the biases against model winds. The wind speed bias between HY-2B and NCEP is approximately −0.2 m/s to 0.2 m/s, while the bias is −0.5 m/s to 0.2 m/s compared with buoys. Notably, a clear annual oscillation is visible for the wind speed bias, and such bias is

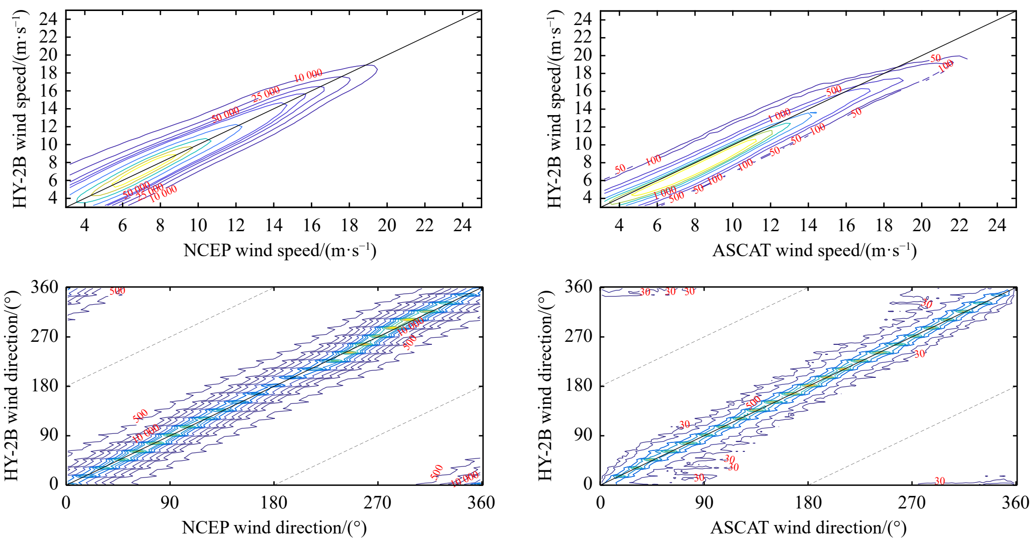

Fig. 8. Contours of histograms of wind speeds and directions derived from HY-2B and NCEP (left), HY-2B and ASCAT (right). The red number in the figure indicates the number of samples.

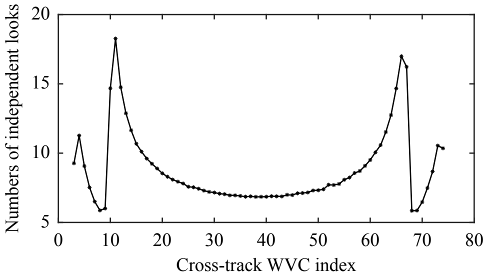

Fig. 9. Distributions for total numbers of independent measurements for each wind vector cell (WVC) according to the cross-track WVC index.

caused by seasonal weather variations. Seasonal weather variations cause differences in the distribution of wind speeds. These wind speed differences lead to variations in the region representativeness errors related to the scatterometer wind validation, resulting in different statistics. In comparison with NCEP wind data, the seasonal oscillation is less obvious. On the other hand, the oscillations appear stronger when we observe the wind speed bias for the NDBC buoys in the Northern Hemisphere. When we focus on the wind speed biases for the TAO buoys only, it is interesting to note that there is only a very weak yearly oscillation, which means that the oscillations may be connected with seasonal variations in specific regions. The wind direction bias falls within 1° compared with NCEP winds. In contrast, there are no similar oscillations regarding the biases of the HY-2B wind direction because the accuracy of the wind direction depends mainly on the magnitude of the wind speed. The long-term trend of the HY-2B wind bias still needs further investigation.

3.3 *Comparison with the ASCAT scatterometer*

For consistency with other scatterometer validations, the same standard statistical methods are utilized (Yang and Zhang, 2019; Wang et al., 2013; Li and Shen, 2015). The number of collocated data samples between the HY-2B scatterometer and ASCAT from November 2018 to May 2021 is 1 261 753. In the current wind products, approximately 0.5% of C-band ASCAT wind data are flagged and discarded due to rain effects. Owing to the different local equator crossing times (the local equatorial crossing time of HY-2B is 6:00 am, whereas MetOp-A is 9:30 am), the spatially and temporally collocated global data are not evenly distributed: more than 97% of the collocated data are found in high latitude areas above 60° North/South, especially in the Arctic/Antarctic polar region. The matched points between HY-2B and ASCAT are illustrated in Fig. 12.

The comparison statistics for the HY-2B scatterometer and ASCAT wind data are listed in Table 3. The RMSE of the HY-2B scatterometer wind speed is 0.96 m/s, and 15.47° for wind direction. It is worth noting that the bias of the HY-2B wind speed is −0.61 m/s, which reveals that the HY-2B wind speed is slightly underestimated in comparison with the ASCAT wind speed. In addition, the HY-2B scatterometer has a wind direction RMSE of more than 20° in the low and middle latitudes (where less than 2.7% of collocated data are found in the same area).

However, caution should be taken when interpreting the above results. Previous studies suggest that such types of statistical methods are suitable for intercomparison between the same datasets (e.g., model-model and satellite-satellite) and inadequate for “absolute” validation (Stoffelen, 1998). It has been proven that different types of data may have their own detection errors, including measurement accuracy and digitizing effects, and interpretation errors that are made when transforming the measurement to the required variables. For example, the scatterometer winds are compared with other *in situ* data assuming that the latter represent “true” wind using standard statistical methods, neglecting the presence of systematic errors in both direct buoy wind speed measurements and, more importantly, in the buoy 10 m equivalent neutral wind speeds calculated even after the removal of apparent deterministic errors in the direct

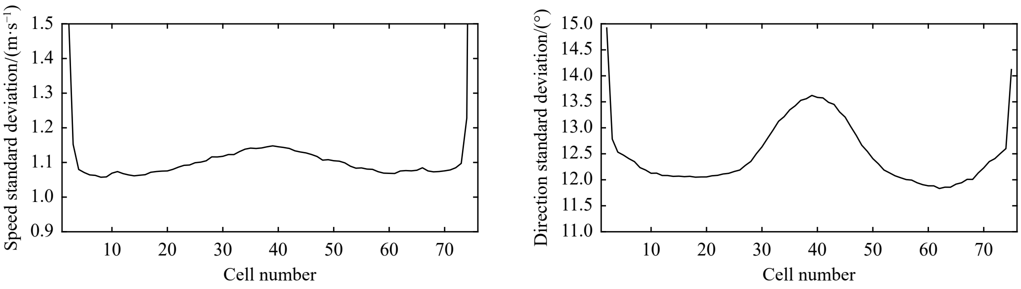

Fig. 10. Cross-track variations between HY-2B measurements and spatially and temporally interpolated NCEP wind: STDs of wind speed differences (left), and STDs of wind direction differences (right). Only collocated measurements for which HY-2B and NCEP wind directions differed by less than 90° were considered (see text).

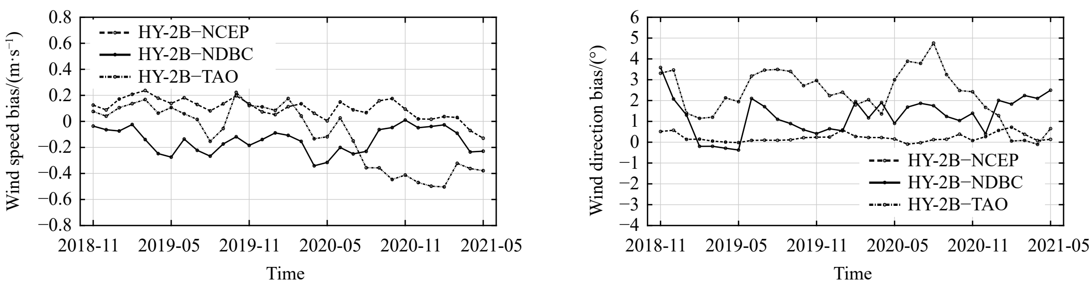

Fig. 11. The bias of HY-2B winds versus NCEP winds and buoys from November 2018 to May 2021.

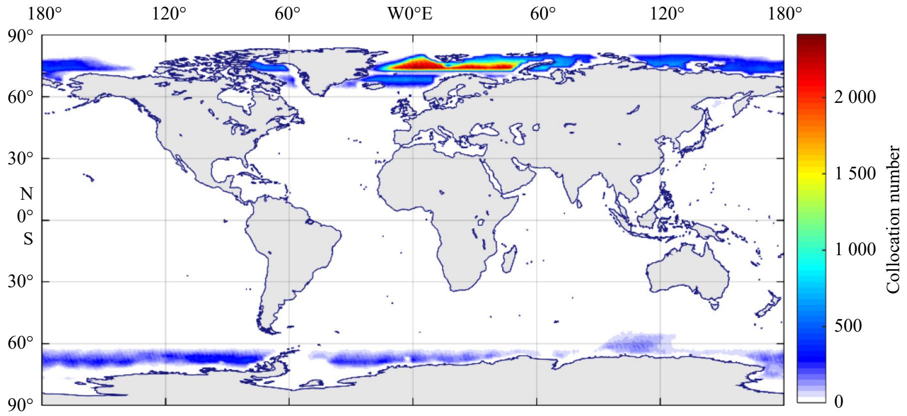

Fig. 12. The matched points between HY-2B and ASCAT.

Table 3. Statistics of the comparisons of the HY-2B scatterometer and ASCAT wind speeds and directions during November 2018–May 2021

		Global	Arctic Ocean 60°–90°N	Northern Ocean 10°–60°N	Tropical Ocean 10°S–10°N	Southern Ocean 10°–60°S	Antarctic Ocean 60°–90°S
	Number of data	1 261 753	1 085 240	11 956	2 232	20 712	141 613
Wind speed	Bias/(m·s^{-1})	–0.61	–0.51	0.05	0.13	–0.49	–0.86
	RMSE/(m·s^{-1})	0.96	0.90	1.37	1.29	1.98	1.44
	Correlation coefficient	0.97	0.96	0.88	0.79	0.85	0.96
Wind direction	Bias/(m·s^{-1})	0.57	0.72	–1.09	3.43	–1.98	0.47
	RMSE/(m·s^{-1})	15.47	15.19	24.38	22.24	23.78	14.46
	Correlation coefficient	0.99	0.99	0.97	0.96	0.95	0.99

anemometer measurements. The triple collocation approach for combined random and bias error estimation of surface winds is suggested in a future study to avoid pseudo biases in scatterometer-derived wind validation (Chakraborty et al., 2013).

4 Conclusions

Satellite scatterometer observations are one of the major methods used to acquire quasi-synchronous global ocean surface wind. There is an urgent need for the validation of HY-2B scatterometer wind products. In this article, the HY-2B level 2 wind products from November 2018 to May 2021 are validated by comparison with collocated measurements from moored buoys and with global matchup data from NCEP and ASCAT. The following conclusions can be drawn:

For the comparison of HY-2B scatterometer wind products, a total of 106 global moored buoy wind data, including NDBC and TAO buoys, are used for the comparison of the HY-2B wind vectors, and more than 40 000 buoy data pairs are collocated. The results show that when compared with NDBC buoys, the overall average biases and RMSEs of wind speed are –0.15 m/s and 0.74 m/s, and those of wind direction are 1.26° and 11.74°, respectively. The statistics indicate the consistency between the HY-2B wind data and buoy wind data. The main discrepancy between the HY-2B wind and other data is found in the low wind speed range. In particular, when the wind speed is less than 5 m/s, the HY-2B wind direction STD is greater than 20°.

More than one hundred million data pairs of HY-2B and NCEP wind data are collocated for the evaluation of the HY-2B wind quality in the global ocean. The results show that in high latitude areas (60°–90°S and 60°–90°N), the wind speed errors of the HY-2B scatterometer are slightly larger but still better than the design requirements of the HY-2B scatterometer. The wind accuracy analysis of the cross-track WVC shows that the system error characteristics are similar to those of other pencil-beam rotating scatterometers. Using the data over the period from November 2018 to May 2021 as a statistical sample, the quality of the HY-2B scatterometer wind products is demonstrated to be good and stable. However, a clear annual oscillation is observed for the wind speed bias, which is caused by seasonal weather variations. A total of 1.2 million data pairs of HY-2B and ASCAT wind data are collocated during the same period and are mainly located in high latitude areas. The result shows that the HY-2B wind speed retrievals tend to be underestimated compared with ASCAT.

In general, the HY-2B scatterometer wind products show quite good quality and would greatly contribute to application and scientific research.

Acknowledgements

The authors are grateful to National Data Buoy Center, Pacific Marine Environmental Laboratory, National Centers for Environmental Prediction, National Satellite Ocean Application Service and Remote Sensing System, for providing the buoy, numerical, and satellite data used in this study.

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