A Global View on the Swell and Wind Sea Climate by the Jason-1 Mission: A Revisit

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ABSTRACT

In this study, a global climatology of swells and wind seas was investigated using near-10-yr collocated wind speed and significant wave height (SWH) measurements from the basic Geophysical Data Record (GDR) of the Jason-1 mission. A statistical method to estimate the wind sea and swell SWHs, respectively, on the basis of wave energy and wind sea/swell probability was proposed. The global distributions of swell/wind sea probability displayed the swell’s dominance in the World Ocean. Their seasonal variation showed not only the regions called “swell pools” with high swell probability throughout the year at low latitudes, which have been found in previous studies, but also the regions with high swell probability only in hemispheric summer, termed “seasonal swell pools,” located at the midlatitudes of open oceans. The seasonal geographical patterns of the swell SWH were similar to those of the SWH due to the swell’s dominance, and the patterns of the wind SWH were similar to those of the wind speed because of their well-coupled nature. The results could be used as a reference for related applications such as ocean engineering, seafaring, validation of wave models, and studies on climate change.

1. Introduction

Wind sea and swell are two main classes of waves at the ocean surface (Munk et al. 1963). Wind seas are waves under growth or in equilibrium with local wind, which usually have short wavelengths and slow propagation speeds. They require momentum from the surface wind persistently and are strongly coupled to the local wind (Janssen 1989). When the local wind diminishes, or the waves are generated from elsewhere, the residual waves are referred to as swells. Swells usually have longer wavelengths (and periods) and faster propagation speeds than wind seas. They travel long distances, radiating momentum and energy across the ocean (Munk et al. 1963; Kinsman 1965).

Different methods and concerns are employed in the studies on swells and wind seas as a result of different dynamics and purposes. Literature about wind seas mainly focuses on the generation and growth of the waves, the momentum and energy flux from the atmosphere to the ocean, and the development of wave models for the purpose of forecasting (Pierson and Moskowitz 1964; Alves et al. 2003). There is an increasing interest in the study of swells not only because of their impacts on coastal structures and sea-going activities but also because they are related to a reverse momentum and energy flux from the ocean to the atmosphere (Mettlach et al. 1994; Grachev and Fairall 2001; Semedo et al. 2009).

Using data from voluntary observing ships (VOS), satellite and model hindcasts, global maps of wave parameters such as significant wave height (SWH) and wave period (WP) became available (Young 1999). In addition, studies of global-scale climatology and the variability of waves were published (Sterl and Caires 2005; Young et al. 2011; Fan et al. 2012) and studies of extreme global-scale wind and wave climate conditions were also accomplished (Chen et al. 2004; Izaguirre et al. 2011; Vinoth and Young 2011; Young et al. 2012). Methods from studies were introduced to distinguish and identify wind seas and swells and methods were presented from the perspective of wave spectra (Wang and Hwang 2001; Portilla et al. 2009; Hwang et al. 2012) and using wind-wave relations or experiences (Chen et al. 2002; Gulev et al. 2003; Semedo et al. 2011). Based on these methods, studies on global-scale wind sea and swell climatology were carried out using synthetic aperture radar (SAR; Heimbach et al. 1998), satellite data.
VOS (Gulev et al. 2003; Gulev and Grigorieva 2006), and reanalysis (Semedo et al. 2011).

Although spectral partitioning is considered the best method to isolate wind sea and swell characteristics (Hanson and Phillips 2001), the global spectral description of the wave field cannot be easily obtained from observational data. SAR can retrieve wave spectral values with its wave mode (Heimbach et al. 1998), but access to SAR data is limited and the sampling of SAR wave mode is intermittent. VOS data have long time series, but the wind sea–swell separation of VOS data lacks reliability and the spatial coverage of VOS data is short in consistency and homogeneity. Satellite coverage is suitable for global-scale studies and the consistence will be excellent when the data are from the same platform (Vinoth and Young 2011). Coincident measurements of sea surface wind speed and SWH can be used in studies of wind sea–swell separation and related wave climate (Chen et al. 2002). Because the altimeter-derived wind speed is not independent of SWH (Hwang et al. 1998), a collocated dataset of SWH and wind speed, compiled by Gourrion et al. (2000) from the 2-yr Ocean Topography Experiment (TOPEX) using the National Aeronautics and Space Administration (NASA) Scatterometer (NSCAT) and Quick Scatterometer (QuikSCAT) missions, was employed. However, the use of different scatterometers will lead to errors. A spatial and temporal resolution is set to ensure wind speed and SWH are quasi-synchronous and the two sensors do not observe the same location precisely. Both wind speed and SWH, especially the wind speed (which has higher frequency than the SWH), may change during the time difference between the two satellites’ observations. These problems would increase the potential errors. Moreover, the number of data pairs after collocating two satellites was less than that from one satellite. In this case, most of the 1° × 1° grids only had a data density of less than 80 and no grid had a density of more than 200, which was not enough to approximate swell/wind sea probability by their frequencies. When these data pairs were separated into four seasons, this error was further enlarged.

The study of Chen et al. (2002) presented a feasible statistical method to partition wind sea and swell events with synchronous data of wind speed and SWH. After TOPEX, which was used in their study, the Geophysical Data Record (GDR) of the altimeter satellite began to provide operational nadir wind speed data measured by a microwave radiometer, which is independent and synchronous of SWH data. In this study, near-10-yr microwave radiometer–measured sea surface wind speed and altimeter-measured SWH data pairs from the GDR of the Jason-1 mission were used to present a more detailed global view of wind sea and swell characteristics, validating previous studies. A method based on energy and swell/wind sea probability using large amounts of synchronous wind speed and SWH data to estimate the global distributions of average wind sea and swell SWHs was also presented here.

2. Data and method

2a. Jason-1 wind–wave dataset

Coincident nadir SWH and wind speed data can be obtained with an altimeter satellite. Long time duration and large amounts of data can be achieved by using multiple altimeter platforms, but multiple platforms involve errors caused by different sensors and retrieving methods. A joint calibration of multiplatform altimeter measurements of wind speed and wave height over 20 years has been made by Zieger et al. (2009). An alternative choice is to use only one platform with a relatively large amount of data, such as Jason-1. In this study, the basic GDR data of Jason-1 from January 2002 to June 2011 were chosen to generate a synchronous dataset of collocated wind speed and SWH. No calibration was applied to the data, and all the records with the flags of rain or ice were eliminated from the dataset. The SWH measurements from the Ku-band altimeter and wind speed measurements from the Jason Microwave Radiometer (JMR) on the Jason-1 satellite were selected to generate the data pairs. The JMR-measured wind speed is selected because it is independent of SWH data from the altimeter. The C-band SWH and altimeter wind speed were used to make a simple quality control of the dataset: data pairs would be discarded if the difference between the two SWHs is more than 0.5 m or if the difference between the two winds is speeds more than 5 m s⁻¹. By using quality control, 1% of the data was discarded. It has been tested that although changing the criterion used to reject SWH data from 0.2 to 2 m or changing the criterion of wind speed data from 2 to 8 m s⁻¹ had impacts on the total quantity of the data pairs, the results of this study remained the same. The spatial density of the processed dataset within each 1° × 1° grid was shown in Fig. 1 without the base map of land. Almost all cells from the sea area had a data density of more than 1000, which could serve studies on swell/wind sea probability.

2b. Wind–wave relation

Experiments have shown that sea surface wind speed and SWH follow a fully developed relationship. In the study of Chen et al. (2002), the Wave Model (WAM) was chosen because it has an intermediate overall growth rate for wind speed ranging from 0 to 50 m s⁻¹ (Pierson...
1991). WAM was also selected in this study to have a comparison with previous studies.

Based on the WAM, approximating the value of gravitational acceleration as 9.8 m s\(^{-2}\), the wind–wave relation for fully developed seas is (Pierson 1991)

\[ H = 1.6 \times 10^{-2} U^2 \quad (0 \leq U \leq 7.5 \text{ m s}^{-1}) \quad \text{and} \]

\[ H = 10^{-2} U^2 + 8.1 \times 10^{-4} U^3 \quad (7.5 < U \leq 50 \text{ m s}^{-1}), \]

where \( U \) (m s\(^{-1}\)) is the wind speed at 10-m height and \( H \) (m) is the SWH. The curve of this relation is shown in Fig. 2, overlaying a scatter diagram of \textit{Jason-1} 10-m wind speed and SWH. The color depicted the number of data within a 0.2 m \( \times \) 0.2 m s\(^{-1}\) grid box. The curve might serve as a standard to divide the sea state; the records below the curve are seen as measurements from wind sea states and the records above are mostly from the swell-dominated sea. Although this standard is not valid for all records, it can be expected to be meaningful from a statistical point of view (Chen et al. 2002).

c. Wind sea and swell significant wave heights

To quantify the frequency of occurrences of wind sea and swell, two probability indices were introduced by Chen et al. (2002):

\[ P_s = N_s/N \quad \text{and} \]

\[ P_w = N_w/N, \]

where \( N_s \) and \( N_w \) are the numbers of swell-dominated and wind sea–dominated events at a given grid. Note that \( N = N_s + N_w; \) thus, in a relative view, a true sea state is considered as either swell dominated or wind sea dominated. Whether a case is wind sea or swell dominated can be determined using the fully developed wind–wave curve in Fig. 2.

The total wave energy \( E \) at a given grid could be divided into two parts: swell-associated energy \( E_s \) and wind sea–associated energy \( E_w \). In the study of Chen et al. (2002), the product of the predicted energy (calculated from wind speed) and the wind sea probability was used to approximate the wind wave energy. When the sea state is mostly wind sea dominated, this product might be larger than the total observed wave energy, indicating the inaccuracy of this approximation. But both their results and the results of Semedo et al. (2011) showed that the global distribution of the swell energy’s proportion is similar to that of swell probability \( P_s \). As the swell is not coupled with local wind, the swell and wind sea heights can be respectively seen as independent events. When the swell has a higher proportion in total wave energy overall, it will have more chances to dominate the sea state and vice versa for the condition of the wind sea. Therefore, \( P_s \) and \( P_w \), which were seen as statistically meaningful descriptions of the proportions of the swell and wind sea’s dominances, could be statistically approximated to the swell and wind sea’s energy proportions to the total wave energy at the sea surface. The validity of this approximation can also be intuitively understood from extreme cases: if there is no swell energy, then \( P_s \) is equal to zero and there will be no swell event; if there is no wind sea, then \( P_w \) is equal to zero and there will be no wind sea event.

The National Data Buoy Center (NDBC) real-time spectral wave data of buoys from 14 December 2012 to 28 January 2013 were also employed to test the validity of this approximation. The temporal resolution of the data was 1 h, and to ensure the statistical significance, only the data from 63 buoys with more than 1000 records were used. The scatter diagram of swell probability and swell energy proportion based on these measurements are shown in Fig. 3, where each dot represents a result.
from a buoy. Although most of these NDBC buoys are not set in the open ocean, most of the results (38 out of 63) are still swell dominated. And in swell-dominated regions, the swell energy proportion is systematically lower than the swell probability. However, from the figure, it could still be found that the assumption of the swell energy proportion being approximately equal to the swell probability is basically valid.

Based on that assumption, the $E_s$ and $E_w$ can be expressed as

$$E_s = E \times P_s$$  \hspace{1cm} (3a)  
$$E_w = E \times P_w.$$  \hspace{1cm} (3b)

It is understood that the relation between wave energy and SWH is

$$H = 4\sqrt{E}.$$  \hspace{1cm} (4)

Then the swell and wind sea SWHs ($H_s$ and $H_w$) can be calculated by

$$H_s = 4\sqrt{E_s} = 4\sqrt{EP_s} = H\sqrt{P_s}$$  \hspace{1cm} (5a)  
$$H_w = 4\sqrt{E_w} = 4\sqrt{EP_w} = H\sqrt{P_w}.$$  \hspace{1cm} (5b)

The assumption is not strict and the statistical method does not work well for studies of short time scale such as 1 day. However, this method is helpful to give a global climatological view of wind sea and swell SWHs with near-10-yr available Jason-1 GDR.

3. The global wind sea and swell climatology

The JMR data of wind speed and the altimeter data of SWH from Jason-1 GDR were processed to examine the geographical behaviors of probabilities and SWHs of wind sea and swell. Data were also organized as four seasons (in the Northern Hemisphere), spring (March–May (MAM)), summer [June–August (JJA)], autumn [September–November (SON)], and winter [December–February (DJF)], to explore the seasonal variations of these parameters.

a. Swell probability

As shown in Fig. 2, the occurrences of swell events become less and less with the increase of wind speed. But most of the data pairs are above the WAM curve, in line with Fig. 1 in Chen et al. (2002), which means the dominance of swell in World Ocean. The global distribution of $P_s$ was displayed in Fig. 4. As $P_w$ can be obtained by the relation between $P_s$ and $P_w$ ($P_s + P_w = 1$), its spatial pattern was not presented here in order to save space. The value of $P_s$ is found to be higher than 80% in most areas of open oceans, which confirms the dominance of swell in World Ocean. Three well-defined “swell pools” (Chen et al. 2002) can be clearly observed in the tropical areas near the east coast of each ocean. The Pacific swell pool is the largest in area and the highest in $P_s$, and the Indian Ocean swell pool has relatively small area and low $P_s$. These results are similar to the findings of Chen et al. (2002). Some different information is also revealed using a data source with a higher spatial and temporal resolution and longer time duration. For instance, in their study $P_s$ monotonically decreases with increasing latitude, but here it rebounds around 20° latitude in all three oceans, which means the waves receive less momentum from the air in these regions than from both sides of these regions. The swell pools at low latitudes in this study are smaller than in Chen et al. (2002). Moreover, besides the waters

![Fig. 3. The scatter diagram of swell probability and swell energy proportion based on 45-day NDBC buoy measurements.](image_url)

![Fig. 4. Global distribution of $P_s$ derived from Jason-1 GDR.](image_url)
surrounding Indonesia and north Australia, some small tropical archipelagoes have significant influences on the swell probability: regions near Hawaii, Marshall, Fiji, and French Polynesia all have low values of $P_s$, which shows their weakening of swell influence. However, the data measured from these regions should be applied with care. Patterns revealed by this study are less valid in shallow water than in open oceans because terrain is also an important factor of sea state in shallow water, such as island coast and small, marginal, or enclosed seas, and the relationship of the fully developed sea in WAM is not applicable for these shallow waters.

The average swell probability of different seasons is listed in Table 1 (hemispherical and global). As is consistent with what Chen et al. (2002) has reported, the swell probability undergoes an opposite annual cycle for the two hemispheres. In both hemispheres, $P_s$ reaches the maximum in hemispheric summer and the minimum in hemispheric winter. But in this study, the values of $P_s$ are a little smaller and the amplitudes are larger, showing greater seasonality.

The geographical distributions of $P_s$ for the four seasons are shown in Fig. 5 to give a better understanding of their seasonal variations. The global distributions of JMR-measured wind speed in DJF and JJA are shown in Fig. 6 for reference. The swell pools still can be clearly recognized in all seasons with a $P_s$ of more than 95% and with a weak northward offset in JJA. The seasonality of $P_s$ is obvious, but most areas of the World Ocean are still swell dominated throughout the year with a $P_s$ of more than 80%, even along the extratropical storm areas in hemispheric winter. Another feature in Fig. 5 is that at latitudes greater than 25° in the three oceans, dramatic seasonal variations of $P_s$ were observed. These regions have high values of $P_s$ in hemispheric summer but relatively low in hemispheric winter. These zones can be called “seasonal swell pools” to show their difference from the “permanent swell pools” in tropical oceans. The gaps between the two kinds of swell pools are also observed in DJF and JJA, especially the gap in the North Atlantic. Together with the geographical distributions of swell probabilities for MAM and SON (Figs. 5a,c), the forming and disappearing process of the seasonal swell pools are reflected clearly. The asymmetry of the global swell/wind sea probability is also distinctly observed. The seasonal swell pools in the North Pacific or North Atlantic are better defined than that in the Southern Ocean (SO). The northern seasonal swell pools shrink fast from JJA to SON, but the southern ones never shrink in such a quick speed. In the Indian Ocean (IO), although the permanent swell pool exists throughout the year, the $P_s$ there has a clear seasonality with the largest area and the highest value in JJA and the smallest area and the lowest value in DJF.

It is known that swells can be further distinguished as the waves generated from elsewhere and remained after local wind diminished. In hemispheric winter, strong gales at the midlatitudes generate seasonal wind waves. When the wind diminishes, these residual waves become swell, as the second condition. Because strong gales do not last long, the new generated swells will dominate the sea state, even in hemispheric winter. Wind sea-dominated regions can only be found near the coast of each continent and in marginal or enclosed seas where the fetch limits the waves’ development. In the tropical Pacific and Atlantic, where their permanent swell pools are located, the wind speed is low throughout the year (Fig. 6), but waves from both hemispheres can propagate

<table>
<thead>
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<th></th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
<th>DJF</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Northern Hemisphere</td>
<td>84.3</td>
<td>89.6</td>
<td>84.4</td>
<td>78.0</td>
<td>82.8</td>
</tr>
<tr>
<td>Southern Hemisphere</td>
<td>89.5</td>
<td>85.1</td>
<td>89.5</td>
<td>93.0</td>
<td>88.9</td>
</tr>
<tr>
<td>Global</td>
<td>87.6</td>
<td>86.8</td>
<td>87.5</td>
<td>87.4</td>
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</tr>
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to these regions, especially in their respective hemispheric winter. These remaining waves are still higher than the waves local winds can generate, which cause these regions to be intensely swell dominated.

Waves generated from the extratropical storm areas can even propagate across the equator into the summer hemispheres. In the hemispheric summer, wind speed is low, so the waves generated are also low (Fig. 6). When the swells from the winter hemispheres propagate into these regions, they dominate the sea state and seasonal swell pools appear. The wind speed and SWH in the Southern Hemisphere (SH) being higher than those in the Northern Hemisphere (NH) in both their respective hemispheric summer and hemispheric winter (Fig. 6) causes the asymmetry of $P_s$ in different seasons. In the equatorial IO, wind speed is low throughout the year, but the Indian Ocean sector of the SO has strong winds in JJA but weak winds in DJF. The IO permanent swell pool cannot get swells from the NH in DJF but can get strong swells from the SH in JJA, leading to its seasonal variation. The existence of the seasonal swell pools in hemispheric summer can explain the rebound of the value of $P_s$ at subtropical regions. The "gaps" between the permanent swell pools and the seasonal swell pools correspond to the zonal bands where mean wind speed is 1 m s$^{-1}$ higher than both sides of the gaps (Fig. 6). This means that the wind can transfer more momentum to the sea in these gaps than from both sides of the gaps in hemispheric summers.

Global distributions of $P_s$ have been made by Chen et al. (2002) and Semedo et al. (2011). The largest common feature among this study and theirs is the permanent swell pools east of tropical oceans, validating their results. Seasonal variation of swell probability in the IO permanent swell pools of this study is different from the results of Chen et al. (2002) but consistent with the results of Semedo et al. (2011). The average data density in the studies of Chen et al. (2002) is less than 60, which cannot express the $P_s$ well when the data were divided into four seasons. The island attenuation effect can also be clearly observed in the results of Semedo et al. (2011), showing that increasing the data volume reveals better details. But in their result from reanalysis data, the distributions of $P_s$ in the Arabian Sea and Bay of Bengal are different. Another main difference between the $P_s$ of this study and that of Semedo et al. (2011) is the existence of the seasonal swell pools. The results of Chen et al. (2002) in these regions were also different from either Semedo et al. (2011) or this study, as the wind speed data in other studies were different [Figs. 6 and 1 in Semedo et al. (2011)], and different wind sea–swell classification schemes were applied. More data and methods need to be taken advantage of to have a better knowledge of these issues.

Besides swell pools, there are some other features in Fig. 5. The geographical patterns of swell probability are similar to those of wind speed but in an opposite trend. As swell probability decreases with the increase of wind speed in a statistical view (Fig. 2), this phenomenon as well as the seasonal swell pools can be explained in the sense that districts with commonly little wind are known for big swells (Groen 1967). In DJF, the northwest Pacific and Atlantic have low swell probabilities because of the fetches' limitation. This is also applicable to the areas near the Antarctic and enclosed seas such as the Mediterranean and Gulf of Mexico since swells cannot propagate into the enclosed seas. Moreover, some regional features of the wind field can be found having a clear impact on the patterns of swell probability. Examples are the coast of Namibia, southern Brazil, and Western Australia.

b. Wind sea and swell significant wave heights

Following the method proposed in section 2, seasonal maps of $H$, $H_w$, and $H_n$ were made. To save space, only the maps for DJF and JJA are shown in Figs. 7 and 8. The seasonal variation of $H$ is similar to that of the wind speed as expected. The maxima of $H$ are found in extratropical areas in hemispheric winters, and the highest value appears in the Indian Ocean sector of the SO in JJA. The seasonality of the $H$ is clearer in the NH than in the SH, corresponding to that of the wind speed. Regional features of the wind speed can be reflected in the maps of $H$; for example, the patterns near the Drake Passage nicely show the northeastward propagation of waves in the SH, and near the coast of California in JJA, the enhancement of wind speed results in the maximum of $H$ in the northern Pacific.
The geographical patterns of $H_s$ show high similarity to those of $H$ both in their spatial distributions and seasonal variations, again displaying the swells’ dominance in the World Ocean. In the SO, the SWH of swells are high throughout the year with the maxima in JJA. The IO is dominated by the swells from the SO in all seasons but also involves the contribution from the summer monsoon in JJA. The North Pacific and North Atlantic show more obvious seasonality, and the propagation of swells is clearly influenced by this seasonal variation. During DJF, the swells are strong in the extratropical areas of both hemispheres but stronger in the north, so the “swell front” marking the boundary between the domains of the swells’ dominance from different hemispheres appears to the south of the equator. During MAM (not shown), the swells are weakened in the NH but enhanced in the SH, which causes the northward movement of the front. In JJA, the swell SWH reaches its maximum in the SH but its minimum in the NH, resulting in the strongest dominance of northward swells from the SO. The front goes on moving northward and becomes obscure, especially in the Pacific Ocean extending from New Zealand to Central America in DJF.

Chen et al. (2002) mentioned in their study that the western coast of each continent is likely to suffer from swell damages at low and midlatitudes because of high swell probability. However, at low latitudes, although the swell probability is high, the wave height there limited the damage. From Figs. 7b and 8b, it can be deduced that the regions with more swell damage are still located on the western coast but only at the midlatitudes. This point of view can be well validated from the data of VOS, which show that on the western coast of continents, the mean swell SWH is more than 2.5 m at the midlatitudes but lower than 2 m in tropical regions (Gulev et al. 2003). In the study of Mettlach et al. (1994), the buoys recorded waves with SWH of more than 7 m in the northeast Pacific and swells with heights of near 4 m in the coastal areas. It has also been reported that in the SO large swells (8–10 m) are frequently generated (Hamilton 1992), once again validating this conclusion.

Compared with the $H_s$, the patterns of $H_w$ are more similar to those of the wind speed than those of the SWH. The highest $H_w$ values are also found in the extratropical areas during hemispheric winter but at higher latitudes than the areas with highest $H_s$ values. The regions with high $H_w$ values are mainly distributed near the northwestern coast of the oceans in the NH and near the coast of the Antarctic in the SH, which is consistent with the direction of the wind. The lowest $H_w$ values in
all seasons are found at low latitudes and are even close to zero at the center of the permanent swell pools. Different from $H$ or $H_s$, the seasonality of $H_w$ in the SH is more apparent with the maximum in JJA and the minimum in DJF. The $H_w$ of the SO–Indian Ocean sector still keeps the highest values in the SH in every season and the $H_w$ of the SH in DJF is still higher than the $H_w$ of the NH in JJA. The geographical patterns of the $H_w$ are the most similar to those of wind speed among the patterns of $H$, $H_s$, and $H_w$, which show the well-coupled relationship between wind and wind sea.

The global distributions of wind sea and swell SWHs have also been achieved by reanalysis (Semedo et al. 2011). VOS (Gulev et al. 2003), and SAR retrieval (Heimbach et al. 1998). Although different data and criteria were selected, the results here are mainly in line with their results. Nevertheless, some differences still exist, especially with the $H_s$ and $H_w$ of the Arabian Sea in JJA and the $H_w$ of the SO in DJF. And for DJF, the wind sea SWHs are less than the results of other studies for latitudes less than 25°N. As discussed in section 3a, these differences of results are due to the differences of wind field data sources or the wind sea–swell isolating method. Because the patterns of $H_w$ are found to be similar to those of the wind speed in both the results here and the results of Semedo et al. (2011), differences are more likely to be led to by wind speed measurement. It should also be noted that neither altimeters nor radiometers have been considered the best measurement of wind until now (Keihm et al. 1995; Wentz and Ricciardulli 2011). The accuracy of this method can still be improved when better measurements of the wind speed can be obtained by an altimeter or radiometer.

4. Summary and conclusions

Using near-10-yr GDR data from the Jason-1 mission, the global distribution and seasonal variations of swell and wind sea probabilities were investigated validating the method of Chen et al. (2002). The global distributions of $H_s$ and $H_w$ during different seasons was presented assuming that swell/wind sea probability can be approximated to the swell/wind sea energy proportions, showing a new application of the data of SWH and wind speed from altimeter satellites. The results agree well with previous studies of wind sea and swell climate or variability. In the low latitudes, where the swell pools were found, the dominance of swell is close to 100%. Regional conditions of the wind sea and swell were revealed and the seasonal swell pools were found at the midlatitudes during hemispheric summer for the first time, reflecting the impact of the partitioning method and data. The global wave field is still found to be dominated by swells in the open oceans, even along the extratropical storm areas in hemispheric winters, where the wind sea part is the highest in the wave spectra (Semedo et al. 2011).

Further exploration could use other methods to validate the data-dependent results such as seasonal swell pools, with more kinds of collocated wind waves, longer duration of higher-quality data, or better retrieval results of altimeter/radiometer wind speed. These methods and results can be regarded as a useful reference for ocean engineering, seafaring, and studies of more complete description of the swell and wind sea climate, such as interannual variability and its relations to climate change.

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