doi: 10.3724/SP.J.1085.2012.00072
June 2012 Vol. 23 No. 2: 72-81

Seasonal and inter-annual variations of the primary types of the Arctic sea-ice drifting patterns

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Received 22 February 2012; accepted 5 April 2012

Abstract Monthly mean sea ice motion vectors and monthly mean sea level pressure (SLP) for the period of 1979—2006 are investigated to understand the spatial and temporal changes of Arctic sea-ice drift. According to the distinct differences in monthly mean ice velocity field as well as in the distribution of SLP, there are four primary types in the Arctic Ocean: Beaufort Gyre+Transpolar Drift, Anticyclonic Drift, Cyclonic Drift and Double Gyre Drift. These four types account for 81% of the total, and reveal distinct seasonal variations. The Cyclonic Drift with a large-scale anticlockwise ice motion pattern trends to prevail in summer while the Anticyclonic Drift with an opposite pattern trends to prevail in winter and spring. The prevailing seasons for the Beaufort Gyre+Transpolar Drift are spring and autumn, while the Double Gyre Drift trends to prevail in winter, especially in February. The annual occurring times of the Anticyclonic Drift and the Cyclonic Drift are closely correlated with the yearly mean Arctic Oscillation (AO) index, with a correlation coefficient of -0.54 and 0.54 (both significant with the confident level of 99%), respectively. When the AO index stays in a high positive (negative) condition, the sea-ice motion in the Arctic Ocean demonstrates a more anticlockwise (clockwise) drifting pattern as a whole. When the AO index stays in a neutral condition, the sea-ice motion becomes much more complicated and more transitional types trend to take place.

Keywords **sea ice, ice drift, drifting pattern, seasonal and annual variation, Arctic Oscillation**

Citation: Wang X Y, Zhao J P. Seasonal and inter-annual variations of the primary types of the Arctic sea-ice drifting patterns. Adv Polar Sci, 2012, 23: 72-81, doi: 10.3724/SP.J.1085.2012.00072

0 Introduction

In the past twenty years, there have been great changes in the conditions of Arctic sea ice, such as the decline of both the whole sea-ice area and the extent of perennial sea ice[1-3], the thinning of sea-ice thickness[4-5], the acceleration of sea-ice motion[6-8], among others. All of these changes have made the sea-ice cover increasingly responsive and susceptible to the environmental forcing [9-10].

The Arctic sea-ice motion has two main characteristics: The Beaufort Gyre and a cyclonic circulation system in the Eurasian Basin, and the wind is the major driving force of the Arctic sea-ice motion[11-12]. However, sometimes reversed ice motions are found in the region of Beaufort Gyre and Transpolar Drift Stream in response to the changes in atmospheric forcing[13-14]. Later, some studies demonstrate that the wind-driven sea-ice motion in the central Arctic alternates between an anticyclonic circulation and a cyclonic circulation with uncertain durations[15-17].

The Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO) are two important physical processes related to the changes of the Northern-Hemisphere atmospheric circulation system[18-19]. In recent years, many studies have revealed the relationship between the AO/NAO and Arctic sea-ice condition, e.g., when the AO/NAO turns to a high-index polarity, the coherent changes include the following: a spin down of the Beaufort Gyre, a slight increase in the ice advection out of the Arctic Basin through the Fram Strait, a weakening of the Transpolar Drift Stream, rapid advection of ice out of the Western Arctic with increased melting and inhibited accumulation of thicker ice, etc[8,20-23]. Moreover, some studies indicated that the distribution and movement of the Arctic sea ice are also influ-

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enced by the quantity and strength of summer synoptic cyclones and storms over the Arctic Ocean[7,24-26]. But the multi-decadal changes in cyclone activity are unlikely a primary cause of the observed decline in the perennial sea ice[27-29]. Some physical processes originating in the mid and low latitudes may have effects on the Arctic Ocean in addition to the influence from the AO[30]. Furthermore, the spatial variation of the AO (i.e., the inter-decadal variation of the spatial influencing extent of the AO) has significant effects on low frequency sea-ice variation[31].

Changes in large-scale sea-ice circulation may have great effects on the delicate Arctic environment. First of all, a cyclonic ice motion contributes to divergence of sea ice, resulting in reduced ice concentration and more open water in the central Arctic Basin, which means accelerated melting as a result of more solar radiation being absorbed through the increased open water in summer[8]. However, if the cyclonic ice motion occurs in winter, then more heat will be released into the atmosphere and more salt will be injected into the ocean in the course of new ice refreezing, leading to changes in heat and salt budgets[32]. Secondly, the change in sea-ice circulation means the change in freshwater advection, which may influence the structure of the Arctic halocline[33-36]. Thirdly, abnormal sea-ice circulations and atmospheric forcing patterns in the Arctic can lead to subsequent sea-ice export anomalies through the Fram Strait[37].

Our main objective for this study is to reveal what kinds of types really exist over the Arctic Ocean and their occurrences in time, using monthly mean sea-ice motion vectors for the period of 1979—2006. Secondly, we hope to find out the seasonal and inter-annual variations of the primary types, to provide a sight on the potential Arctic circulation transformation under the background of accelerated Arctic Warming. Finally, we will explore the relationships between the evolution of the types and changes in the AO.

1 Data and method

The Arctic Ocean is a quasi-enclosed ocean with an area of approximate 9.4×10^6 km² and about one-third of the size is occupied by shallow shelf seas. All the Arctic geographical names and regions mentioned in this paper are labeled in Figure 1. According to different research objectives, the partition standard of the Atlantic sector, the Pacific sector and the Central Arctic in the Arctic remains uncertain[38-40]. Considering that the objective of our study is the ice-motion characteristics over the Arctic Ocean, we define the ocean area within the region from 145°E to 105°E and south of 80°N as the Atlantic section. Likewise, the ocean area from 30°E to 115°E and south of 85°N is defined as the Atlantic section, and the basin area between the two sections is defined as the Central Arctic, following the partition standard of Su et al.[41]

Monthly mean, gridded sea-ice vectors are obtained from the American National Snow and Ice Data Center (NSIDC), which are based on the daily Advanced Very High Resolution Radiometer (AVHRR), Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave/Imager (SSM/I), and International Arctic Buoy Programme (IABP) buoy data following Fowler[42]. The gridded data is available from November 1978 through De-

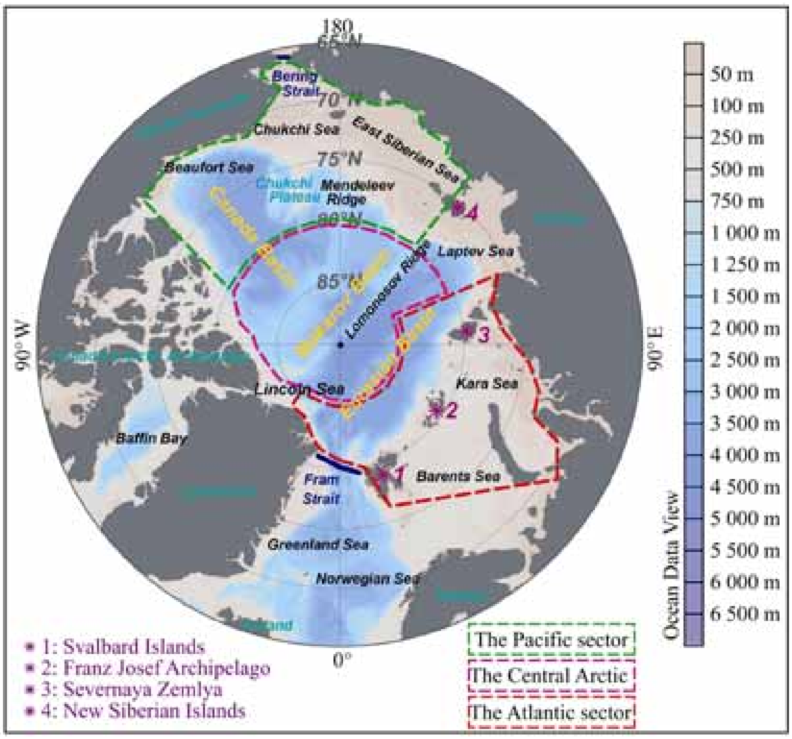

Figure 1 The Arctic geography and regions applied in this study.

cember 2006, with the spatial coverage from 48.4°N to 90°N (361×361 pixels) and from 53.2°S to 90°S (321×321 pixels). The monthly gridded ice motion vectors were averaged from the daily gridded ice motion data and used at least 20 days for the monthly mean; otherwise, the corresponding site was marked by missing data. For the gridded data, there is a value that indicates the number of vectors contributing to the mean value, which can be used to characterize data quality.

The mean gridded fields obtained from the NSIDC are projected to Northern EASE-Grids and data are in 2-byte integer binary format. We need to rotate the vectors based upon their longitudes to obtain north-south, east-west components because the original *u* (*v*) component represents the velocity value in the row (column) direction.

In spite of the fact that the patterns of sea-ice motion vary greatly, we can classify them into some types depending on their drifting features, which can make different impacts on the Arctic atmosphere-ocean-ice system. In our study, we take into accounts not only the sea-ice drifting features but also the differences in ice transport, relative vorticity and SLP. What needs to be emphasized is that even the monthly mean ice motions of the same type are not identical, but the differences will not affect the general characteristics of each type. Therefore, the conformity forms of each type and the inconformity forms of different types are both taken into accounts in the methods of classifying sea-ice patterns. In order to better illustrate the essential characteristics of each sea-ice drifting type, an average of all monthly vectors that belong to the same type is calculated to give the mean ice motion pattern of each type, i.e., the climatological sea-ice velocity field of each type. The same method is applied to obtain the corresponding climatological SLP field (Figure 2).

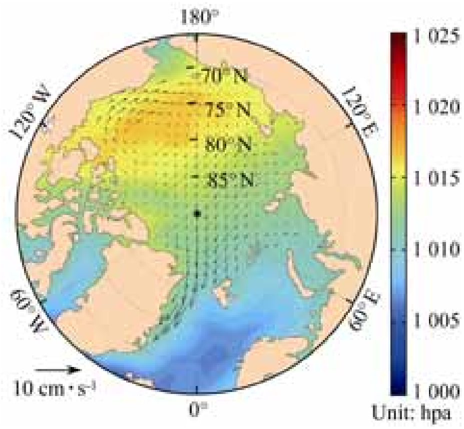

Figure 2 The sea-ice drifting velocity (arrows) and SLP pattern, averaged from January 1979 to December 2006 over the Arctic Basin.

The monthly mean SLP data is from the NCEP/NCAR reanalysis dataset (NCEP Reanalysis data is provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from the website at http://www.esrl.noaa.gov/psd/). This dataset is four-times daily, from which daily and monthly means can be obtained. It is on a global 2.5°×2.5° grid, from the year 1948 to present. For more information about the NCEP/NCAR reanalysis data, readers are referred to Kalnay et al.[43].

Although the AO index is highly correlated with the NAO index, the AO index captures more signatures of the Northern-Hemispheric variability in the atmospheric circulation while the action of the NAO is located in the Icelandic center and is relatively regional compared to that of the AO. Therefore, we choose the AO index in this study. The monthly mean AO index is taken from the NOAA's webite:http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ ao_index.html.

2 Results

2.1 Classification and description of the Arctic sea-ice drifting patterns

Using all 336 months of gridded sea-ice vectors data from January 1979 to December 2006, we find that the Arctic sea-ice drifting patterns can be classified into four primary types (the occurring probability of each type is larger than 10%) and a variety of occasional types (the occurring probability is smaller than 10%), shown in Figure 3 and Figure 4, respectively.

2.1.1 Primary Types

The four types are the primary types of the Arctic sea-ice motion, and the occurrences and evolutions of the four types may have significant effects on the physical properties and transports of the sea ice, and therefore influence the Arctic climate change. Accordingly, the seasonal and inter-annual variations of the four primary types are what we are concerned most in this study.

Type 1: Beaufort Gyre+Transpolar Drift

The mean sea-ice velocity field of this type (Figure 3a1) is similar to the Arctic mean sea-ice velocity field averaged from January 1979 to December 2006 (Figure 2) and the early known sea-ice drifting pattern consisting of the Beaufort Gyre and a slightly cyclonic motion over the Eurasian Basin. In this type, sea ice originated in the East Siberia and the Laptev Sea is transported to the North Atlantic and the axis of the transpolar drift ice stream extends from the East Siberia Sea to the Fram Strait through the Central Arctic, becoming the demarcation line of the cyclonic ice motion over the Beaufort Sea/Canada Basin and the anticyclonic ice motion over the Eurasian Basin. The mean SLP field shows that although most areas of the Arctic Ocean are occupied by high pressure, the center of this high pressure system is located over the Western Arctic in coincidence with the center of the clockwise ice motion. Meanwhile, the low pressure system extends through the Barents Sea towards north, resulting in the cyclonic ice motion over the Eurasian Basin, which was described by

Zhao and Liu [16]. The features of the corresponding relative vorticity field of Type 1 are that in the western Arctic there mainly exists positive vortcity with the core shrinking to the south of the Canada Basin, and it is to the contrary, associated with the occurrence of anticyclonic ice motion, in the Eastern Arctic (Figure 3a2).

Type 2: Anticyclonic Drift

This type (Figure 3b1) shows a well-developed anticyclonic sea-ice motion, dominating almost the whole area of the Arctic Ocean, and the anticlockwise ice motion is nearly parallel with the coastline. The center of the anticlockwise ice motion lies in the region between the Canada Basin and the Makarov Basin and the ice drifting speed becomes faster and faster from the center to the edge. In this situation, the axis of the transpolar drift ice stream shifts eastward to the Russian marginal seas, becoming a part of the large anticlockwise loop. The high pressure dominates most of the Arctic Ocean, including the Atlantic section, and the high pressure center is in coincidence with the anticyclonic ice motion center, which is the same as that of Type 1.

Figure 3b2 illustrates that in the domination of anticyclonic ice motion, the relative vortcity is negative and the maximum intensify of negative values presents in the Canada Basin and the Makarov Basin.

The sea-ice circulation of Type 2 is quasi-enclosed in the Arctic Basin. Serreze et al. [14] and Tucker et al. [23] revealed that an anticyclonic ice motion can contribute to ice convergent motion with higher ice concentration and thus lead to much reduced open water, which will restrain ice melting in summer, i.e., it has a negative feedback on the ice melting. On the other hand, an anticyclonic motion can prolong the sea ice's residence time in the Arctic Basin to promote the accumulation of perennial ice, so it plays a non-negligible role in protecting the Arctic sea-ice area.

Compared to the ice drifting pattern of Type 2, there also exists a large area under the domination of anticyclonic ice motion in Type 1, but the influencing extent decreases a lot as well as the intensity. What is more, the ice residence time of Type 1 in the Arctic Basin is shortened and the export of sea ice through the Fram Strait slightly increases as a result of more directly Transpolar Drifting Stream transporting a great mass of sea ice into the North Atlantic, which has been pointed out by Arfeuille et al. [37]. So, Type 2 contributes more than Type 1 in terms of maintaining the Arctic sea-ice area.

Type 3: Cyclonic Drift

The mean SLP pattern of Type 3 shows that a low pressure system centers over the Arctic Basin with higher pressure surrounding it over the marginal seas and lands, corresponding to a large, well-developed cyclonic ice motion (Figure 3c1). The Beaufort Ice Gyre that hardly exists at this time has shrunk much southward to the continental shelf. Meanwhile, the axis of the transpolar drift ice stream shifts towards the direction of the Canadian Arctic Archipelago, becoming a part of the large clockwise loop. Note that the drifting pattern of Type 3 is opposite to that of Type 2.

The most distinctive feature of the relative vorticity field is the positive values over most of the Arctic Basin (Figure 3c2). This situation is associated with the SLP structure and corresponding ice circulation pattern over the Arctic Basin.

The sea ice is transported eastward to the East Siberian and Chukchi Seas from the vicinity of the Kara and Laptev Seas and subsequently into the Beaufort Sea and the Canada Basin, no longer entering the North Atlantic via the Fram Strait. This cyclonic pattern contributes to more open water and lower ice concentration. If Type 3 occurs in summer, it will promote ice melting; if it occurs in winter, it probably conduces to the production of new ice. What is more, the speed of the perennial ice that drifts towards the Fram Strait and the Eurasian Basin increases apparently under the influence of Type 3, which may make adverse effects on maintaining of the Arctic perennial sea ice.

Type 4: Double Gyre Drift

The high pressure system located over the Canada Basin previously shifts southwestward to the narrow region around the Chukchi Plateau and the Mendeleyev Ridge due to the trough of low pressure extending from the Icelandic low far into the Central Arctic. This shift is accompanied by a westward movement of the Beaufort Gyre with its domination confined to the Pacific sector. In contrast to the anticyclonic ice motion in the Pacific sector, the ice in the Atlantic sector shows a pattern of cyclonic motion under the influence of the low pressure system over the region around the Lincoln Sea and the North Pole (Figure 3d1). Between the two symmetric ice motion patterns, there exists an ice drifting flow, transporting sea ice from the Russian marginal seas across the pole into the Canada Basin.

On one hand, the pattern of such ice motion contributes to enhanced ice accumulation, increased ice concentration and replenishments of the Arctic perennial ice. On the other hand, rather than exported directly via the Fram Strait as Type 1, a large amount of sea ice from the East Arctic is involved in the anticyclonic circulation, which provides a favorable condition for sea ice to become thickened around the East Siberian Sea and the adjacent basin [37]. The thickened sea ice can increase the probability of surviving through melting seasons and also has a great significance for the replenishment of the Arctic perennial ice.

Remarkably, the dominating region of negative relative vorticity still persists in the south of the Canada Basin without shifting westwards along with the anticyclonic ice circulation center (Figure 3d2). However, the area of negative vorticity is much smaller than that of Type 1. The positive vorticity covers the Atlantic sector and the Central Arctic, which is associated with the northward extension of low pressure system and the occurrence of ice anticlockwise movement.

Actually, Type 4 shows a transitional structure as a result of the interaction between Type 2 and Type 3. If the Beaufort High retreats from the Arctic Basin, Type 4 will become Type 3; and if the low pressure system is much

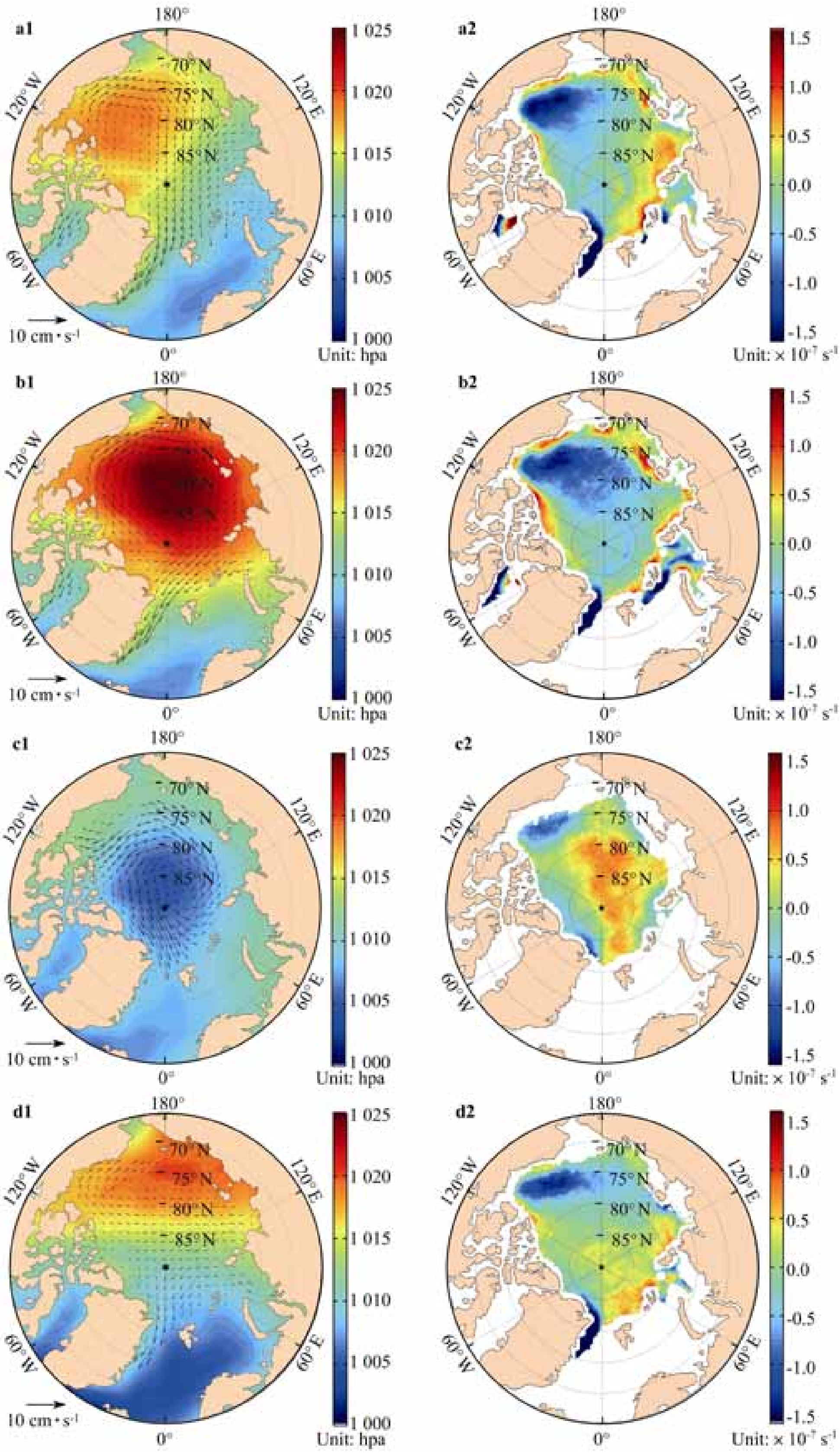

Figure 3 Distributions of the typical sea-ice drifting velocities (arrows) and SLP fields of Type 1 (**a1**), Type 2 (**b1**), Type 3 (**c1**) and Type 4 (**d1**) over the Arctic Basin. Distributions of the relative vorticity fields of Type 1 (**a2**), Type 2 (**b2**), Type 3 (**c2**) and Type 4 (**d2**), calculated from the ice drifting velocities.

reduced, then Type 2 occurs instead of Type 3. Therefore, Typee 4 is a transitional type between Type 2 and Type 3, reflecting the interrelationship of high pressure system and low pressure system over the Arctic Ocean.

2.1.2 Occasional Types

Although Type 5 (Figure 4e1) and Type 6 (Figure 4f1) belong to occasional types, they should not be neglected because of the relatively high probability of their occurrences compared to the other occasional types that are not to be discussed in this paper.

Type 5: Overall Export Drift

This type has a distinctive characteristic, that is, there exists a prevailing ice motion moving from the Pacific sector to the Atlantic sector over almost the whole Arctic Basin, accompanied by a large-scale export of ice into the North Atlantic via the channels around the Greenland and the Franz Josef Land Archipelago (Figure 4e1). What is more, the width of the transpolar drift ice stream becomes markedly broad, covering almost the whole Central Arctic. The SLP over the West Arctic is higher than that over the East Arctic, but the average SLP value of Type 5 over the Canada Basin is a bit lower compared with that of Type 1 or Type 2. The values of relative vorticity are positive in the Eastern Hemisphere, opposite to those in the Western Hemisphere (Figure 4e2). This ice motion pattern that causes overall ice export cannot exist stably over the Arctic Ocean for a long time, and the ice motion field will adjust itself to the sustainable circulation pattern soon later. Thus, Type 5 is unstable, and belongs to a transitional type.

Type 6: Overall Import Drift

Being opposite to Type 5, the ice motion pattern of Type 6 shows a reversed movement over the Arctic Basin that ice is transported into the Pacific section across the Arctic Ocean except for a small region around the Fram Strait and the North Pole (Figure 4f1). The width of the transpolar drift ice stream is similar to that of Type 5, but the ice drifting direction is just the opposite, towards the Bering Strait. Although part of sea ice is exported out of the Fram Strait, the main ice source is in the vicinity, i.e., the region around the Svalbard Islands and the Franz Josef Land Archipelago. In this situation, the SLP is higher in the Eastern Hemisphere and the high pressure center is located over the Russian marginal seas. Restricted by the southern continent, it is hard for the sea ice to develop an anticyclonic circulation, so the ice stream flows towards the Bering Strait in parallel with the coastline over the East Arctic. At the same time, most of the Arctic Basin is dominated by positive vorticity values except for the south of the Canada Basin and the Russian marginal seas (Figure 4f2). Apparently, this type also cannot exist stably for a long time on account of causing the overall ice input, and belongs to a

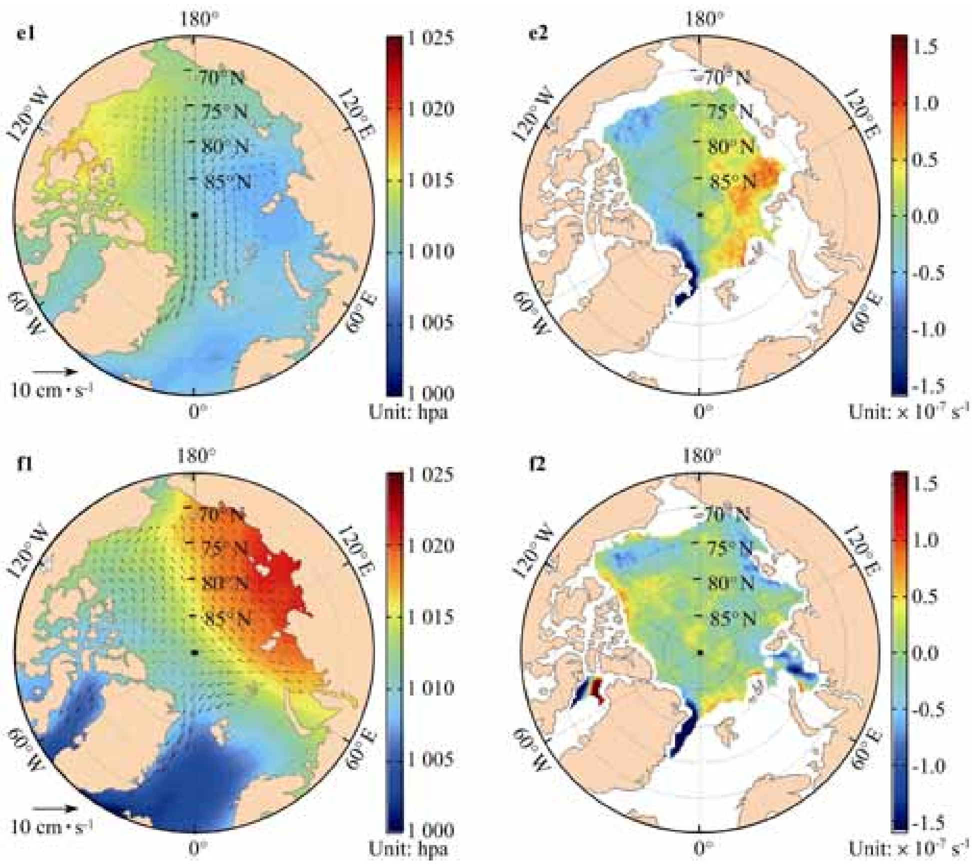

Figure 4 Distributions of the typical sea-ice drifting velocities (arrows) and SLP fields of Type 5 (**e1**) and Type 6 (**f1**) over the Arctic Basin. Distributions of the relative vorticity fields of Type 5 (**e2**) and Type 6 (**f2**), calculated from the ice drifting velocities.

transitional type, like Type 5.

2.2 Temporal variations of different types

2.2.1 Occurrences of every type in percentage of the total months

According to the classification mentioned above, we can find that the occurrence of the four primary types takes up 80% of the total 336 months (Figure 5). Type 1 is the type that happens most often, accounting for 38%, and indicates that this type of Beaufort Gyre+Transpolar Drift is the most prevailing type over the Arctic Ocean. The proportions of the other three primary types are more similar, varying from 12% to 16%. Moreover, although the total occasional types only take up 18% of the total (Figure 5), the proportions of Type 5 and Type 6 account for 8% and 6% of the total, respectively.

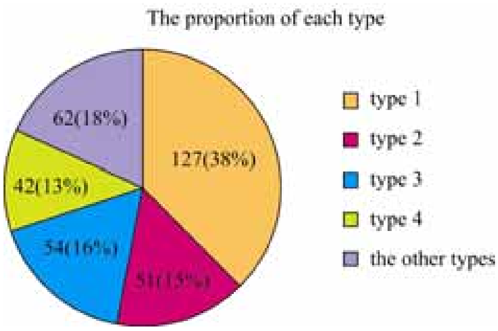

Figure 5 Occurrence of each type in percentage of the total months from January1979 to December 2006. The number in each sector represents the total occurring times of each corresponding type, and the corresponding percentage is in the bracket.

2.2.2 Seasonal variations of the primary types

Figure 6 shows the distribution of different types in each month from January 1979 to December 2006, indicating that there exist seasonal variations of the primary types. For a more clear illustration, we count the occurring times of the four primary types month by month from 1979 to 2006 (Figure 7).

We find that Type 2 with a large anticyclonic motion does not differ a lot in each season, but occurs slightly more often in winter and spring when the ice-covered area reaches its maximum. This pattern of large-scale clockwise ice circulation (Type 2) happening in ice refreezing seasons means that the sea ice over the Arctic Ocean has gone through a fully packed, accumulating and thickening process accompanied by higher ice concentration before the coming summer, and thus contributes to more ice surviving from the melting seasons. Type 1 is the most prevailing type and has two peak periods: from April to May and from October to November. Type 3 with a large cyclonic motion shows a typical characteristic of concentrated outbreak in July and August. When the Arctic Ocean is in the melting season, the solar radiation will be largely absorbed through the open water resulting from ice motion and melting, and subsequently, the extra absorbed energy will be used to melt the rest of the ice, leading to more open water. Given this positive feedback loop, the prevailing cyclonic ice movement will enhance the ice melting further since this circulation pattern will cause lower ice concentration and create more leads opening. Recently, the Arctic sea-ice area is changing fast toward a fluctuating and decreasing trend, especially reaching its minimum in the year 2007. More investigations are needed to find out what role Type 3 actually plays in the process of enhanced ice melting. Type 4 occurs more often in winter and has a peak in February. We have known that Type 4 belongs to a transitional type, but its motion pattern benefits the accumulation of the Arctic perennial ice. The peak of Type 4 happens to be within the period of ice accumulating and thickening, therefore, its evolution may have a significant effect on maintaining the Arctic sea-ice cover.

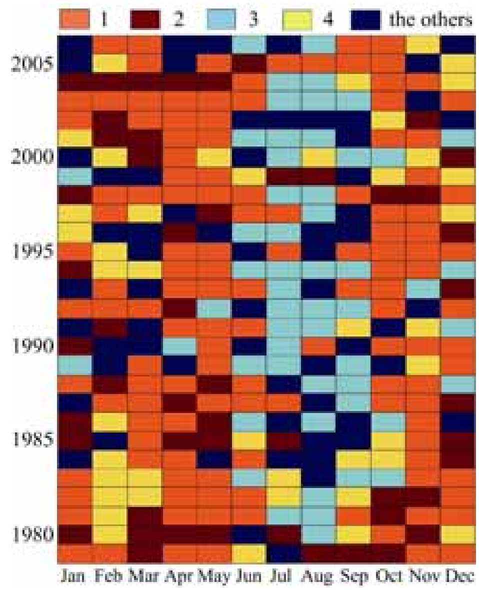

Figure 6 Distribution of different types in each month from January1979 to December 2006. The types other than Types 1—4 are marked as a whole by the dark blue color.

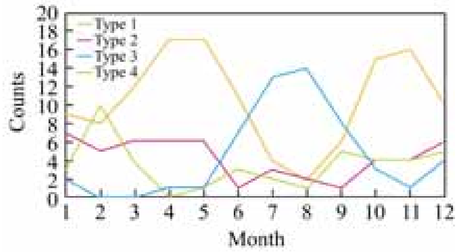

Figure 7 Occurring times of the four primary types month by month from 1979 to 2006.

2.2.3 Inter-annual variations of the primary types

In order to find out inter-annual variations of different types, we count the yearly occurring times of the primary types from 1979 to 2006. Before being compared with the AO index, we standardize the value of yearly occurring times to make it in the same order of magnitude with the AO index. The formula of standardization is: $S=(N-\bar{N})/D$, in which S is the standardized value, N is the yearly counts of each type, $\bar{N}$ is the corresponding annual average of each type and D is the corresponding standard deviation of each type.

Figure 8 illustrates that the variations of Type 2 and Type 3 correlate well with the AO index, with a correlation coefficient of −0.54 and 0.54, respectively (both significant at the confident level of 99%). While the variations of Type 1 and Type 4 have much lower correlations with the AO index, especially Type 1, which is nearly uncorrelated with the AO index. In correspondence with the period of late 1980s and early 1990s when the AO index shifts to a high positive state, the occurring times of Type 3 are obviously more than its long-term mean while the occurring times of Type 2 are fewer than the long-term mean.

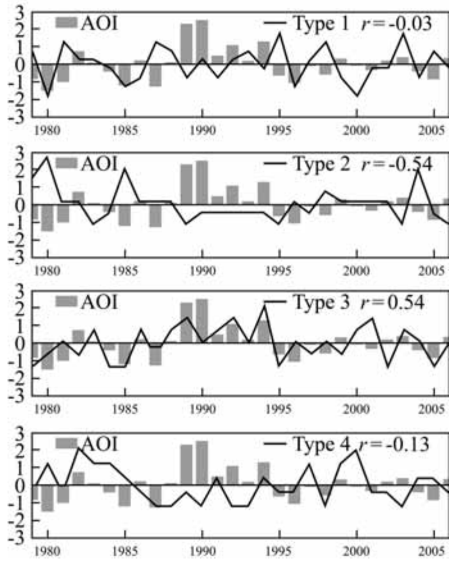

Figure 8 Time series of the four primary types and the AO index. *r* stands for correlation coefficient.

To further study the relationships between the occurrences of each type and the AO index, we identify a parameter P that equals the ratio of the yearly occurring times of each type to its total occurring times from 1979 to 2006. Obviously, the parameter P of each type has a property that $\sum P_i=1$, $i=1, 2, 3, \cdots, 28$. Different from the occurring proportion mentioned above (Figure 5), the identified P of each type is a proportion of yearly occurring times relative to itself, or a relative proportion. The purpose of this exercise is to better illustrate the regulation of each type without the confusion from large differences in each total occurring times. We can find from the scatter plot of the AO index and the parameter P that the relative proportion of Type 3 has greater values (Figure 9; shaded area B) in correspondence with a positive high-index condition of the AO (AOI >0.5), indicating that such a situation benefits the formation of a large-scale cyclonic sea ice motion over the Arctic Ocean. When the AO index is in a negative high-index condition (AOI <−0.5), Type 2 has a highe relative proportion (Figure 9; shaded area A), indicating that a large-scale anticyclonic ice motion is more likely to occur in this situation. As to the situation with a lower or neutral AO index (−0.25<AOI<0.25), the relative proportion of Type 4 is obviously larger than the others (Figure 9; shaded area C), indicating that the ice drifting field shows a dipole pattern of a clockwise circulation over the Pacific sector paired with an anticlockwise circulation over the Atlantic sector. On one hand, these associations between different types and the AO index confirm that long-term variation of the Arctic sea ice is closely related to the changes of the Northern Hemisphere's atmospheric circulation[21,23], and reveal that when the AO index stays in a high positive (negative) condition, the ice motion over the Arctic is likely to form a more consistent whole as Type 3 (Type 2); when the AO index stays in a neutral condition, the ice motion becomes much more complicated and more transitional types will take place. On the other hand, the results demonstrate that the type of cyclonic pattern and the type of anticyclonic pattern are antithetical in existence and the complicated patterns of Arctic sea-ice drift are determined by the interaction between the two opposite types, which are mainly associated with the atmospheric circulation.

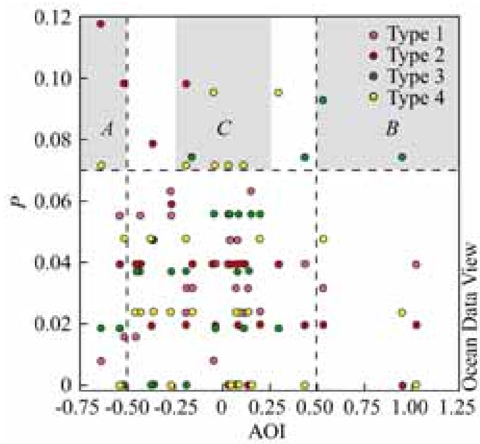

Figure 9 Scatter plot of the AO index and P_i, where P_i is the relative proportion of Type i (i=1, 2, 3, 4).

3 Conclusions

(1) Through the analyses of the monthly mean sea-ice motion vectors from January 1979 to December 2006, we have classified the Arctic sea-ice drifting patterns into four primary types (the probability of each type is larger than 10%) and a variety of occasional types (the probability of each type is smaller than 10%), taking into accounts not only sea-ice drifting features but also differences in ice transport, relative vorticity and SLP of different types. The four primary types are: Beaufort Gyre+Transpolar Drift (Type 1), Anticyclonic Drift (Type 2), Cyclonic Drift (Type 3) and Double Gyre Drift (Type 4), all of which account for 81%

of the total. The corresponding relative vorticity fields show that the vorticity field of Type 2 is dominated by negative vorticity, favoring ice accumulation and thickening, while the vorticity field of Type 3 is opposite to that of Type 2, dominated by positive vorticity, enhancing ice diverging and melting. Type 4 shows a dipole pattern of a clockwise circulation over the Pacific sector paired with an anticlockwise circulation over the Atlantic sector. Although this type belongs to a transitional type, its occurrence and evolution have an important significance on ice thickening and replenishment of the Arctic perennial ice in the basin.

(2) There exist obviously characteristics in seasonal variations of different types. In summer, the most prevailing type is Type 3, i.e., a cyclonic circulation as a whole over the Arctic Basin. Type 1 is more lightly to occur in spring and autumn, while Type 2 is more lightly to occur in winter and spring. Moreover, Type 4 tends to occur in winter and has a peak in February.

(3) Both Type 2 and Type 3 correlate well with the AO index (r_2=−0.54 and r_3=0.54, respectively, and both being significant at the confident level of 99%). When the AO index stays in a high positive (negative) condition, the ice motion in the Arctic Ocean tends to form a more consistent whole as Type 3 (Type 2); when the AO index stays in a neutral condition, the ice motion becomes much more complicated. Type 2 (i.e., a cyclonic ice motion as a whole) and Type 3 (i.e., an anticyclonic ice motion as a whole) are antithetical in existence, and the complicated patterns of Arctic sea-ice drift are determined by the interaction between the two opposite types, which are mainly associated with the atmospheric circulation.

Acknowledgement This work was supported by the National Natural Science Foundation of China (Grant no. 40631006) and the National Major Science Project of China for Global Change Research (Grant no. 2010CB951403).

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