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Cyclones in the Arctic Ocean and their effect on sea ice

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The cyclone activity plays a very important role in the Arctic climate system. Cyclones are closely linked with precipitation, atmospheric moisture budget and sea ice distribution. In this study, cyclones entering the Arctic Ocean (cross into north of 70ºN from south) are investigated in the context of climate change and variability. A cyclone tracking scheme of the University of Reading was applied. The scheme can be divided into three parts: re-processing (filtering), detecting and tracking. We used this scheme to construct cyclone tracks from the 6 hourly ERA Interim reanalyses for the period of 1979–2012.

The results suggested that the cyclone activity has a slightly decreasing trend in spring and summer, but an increasing trend in autumn. In general, the cyclones are stronger in winter than in summer. In spring, more cyclones enter the Arctic from the North Atlantic sector, especially from the Greenland Sea and Norwegian Sea. In summer, the cyclones in the Pacific sector, in particular in the East Siberian Sea, are more numerous than in the Atlantic sector. In autumn, the cyclones occurrences in the Atlantic sector are more numerous than summer. 90% of summer cyclones have a central pressure ranging from 980 to 1010 hPa, but in winter the range is much wider, from 930 to 1015 hPa. 75–85% of cyclones last for 1–7 days, and 20–30% of cyclones have a lifetime of 1–2 days. Cyclones with a lifetime more than 14 days are more common in summer than other seasons. The singular value decomposition (SVD) method suggested that the cyclone activity is closely connected with sea ice concentration in summer.

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1. Introduction

The extra tropical cyclones, as one of the most important synoptic systems, play an important role in the poleward transport of heat and moisture, which strongly affects the amount and spatial distribution of precipitation in the Arctic. According to Zhang and Walsh (2004), Arctic cyclone activity has increased after mid-1990s, particularly in summer with more intense cyclones entering into the Arctic from the mid-latitudes. The strong winds and precipitation generated by cyclonic storms have a significant impact on short-term weather patterns affecting local high-latitude communities. In the central Arctic, the strong surface winds along with the cyclones affect sea ice through acceleration of both ice deformation and drift. Cyclones also affect local precipitation patterns and air-ice heat fluxes, resulting in thermodynamic changes of sea ice.

Early studies of extra-tropical cyclones in polar-regions were largely based on ship data and operational weather service charts. Remote sensing observations are nowadays used in tracking temporal and spatial distribution of severe cyclone activities in the high-latitude regions where *the situ* observations are rare. The comprehensive cyclone activities, however, can be investigated in more detail by analyses of the sea level pressure or 850 hPa vorticity. The development of cyclone tracking algorithms enhanced our ability to better understand cyclone climatology (e.g. Serreze, 2008; Simmonds, 2011; Tanaka et al., 2012).

In this study, we applied an automatic cyclone tracking algorithm to investigate cyclones statistics in the Arctic Ocean. The cyclones originated south of 70ºN and crossed into the Arctic were collected and examined.

2. Data and method

The 6-hour sea level pressure from ERA-interim reanalysis was the primary data source for cyclone detection. The data has a 0.75º×0.75º spatial resolution. Our investigation period was from 1979 to 2012. We applied cyclone tracking algorithm developed by Hodges (1994) in this study. The algorithm contains three core parts: pre-processing (filtering), detecting and tracking. The probability density function (PDF) is used in the algorithm to tackle the cyclone feature density, cyclonegenesis density, and cyclonelysis density. The number density is investigated here. From density as a PDF to a number density it is scaled by the total number of points used in the statistics and by the areal weighting. Here gives a unit area equivalent to a 5 degree spherical cap which is roughly 10^6 km^2. The actual number of points is the integral of the density over the area (5 degree spherical cap). The track density is not strictly a probability density due to the way it is computed. It is a function not only of the distribution of the data but also a function of the distribution of the estimation points. The more details can be found in, e.g. Hodges (1996).

3. Result and discussion

3.1 Cyclone number, intensity and duration

The annual mean number of cyclones, entering 70ºN north during the study period, is 142.2, from which the numbers for winter (Dec. – Feb.), spring (March – May), summer (June – Aug.) and autumn (Sep. – Nov.) seasons are 33.2, 36.3, 38.7 and 34.1, respectively. This result slightly differed from Sorteberg and Walsh (2008) most probably due to the differences originated from the different data sources of ERA (0.75º × 0.75º) and NCEP (2.5º × 2.5º) and the different cyclone tracking algorithms Hodges (1994) *vs* Simmonds (2011) applied. Statistics showed cyclones crossing 70°N accounted some 65 – 77% of the total cyclone occurrence north of 70ºN. So, its activity is a key factor affecting Arctic weather, climate and air-sea-ice interaction.

Table 1. Seasonal statistics for cyclones crossing 70°N from 1979 to 2012.

		Annual	DJF	MAM	JJA	SON
Average total cyclones	This study	142.2	33.2	36.3	38.7	34.1
	S & W	140.3	36.7	35.4	32.5	36
Annual percentage	This study		24.9	26.8	23.6	23.6
	S & W		26.1	25.2	23.2	26
Percentage north of 70 N (this study)		71.27	65.6	74.9	77.1	67.6

S&W: Sorteberg and Walsh (2008)

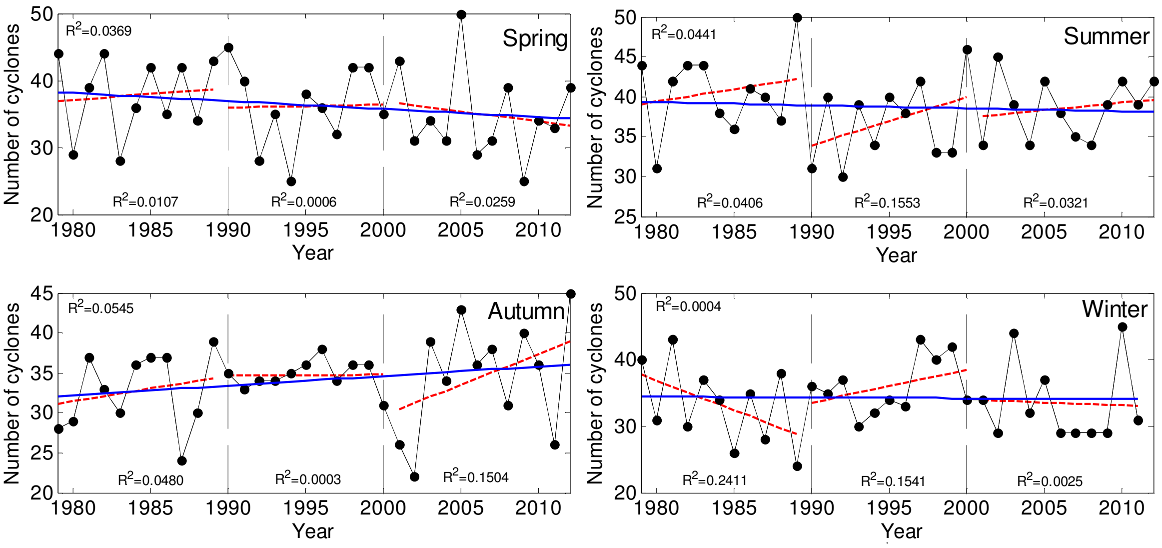

Figure 1. Time series and linear trend of seasonal average number of cyclones crossing 70°N from 1979 – 2012.

The overall cyclone number is decreasing in spring and summer, increasing in autumn, but none of these trends reach statistically significant (Fig.1). If we divide 1979–2012 roughly into three periods representing 80s, 90s and new millennium, we can see that the overall tendency of cyclone number is revised in spring with more cyclones in 80s, 90s and a more clear reducing cyclone in new millennium. In summer, cyclone number increasing can be seen in each individual decadal period. No major revision of decadal autumn cyclone trends compared to the overall 33 years period, except that cyclone number increase is more pronounced in 00s. In winter, cyclone number has a major revision in 80s and 90s, i.e. cyclone number decreases significantly in 80s, but increases in 90s. No obvious decadal changes of cyclone number trend after 2000.

The cyclone central pressure distributions are different in various seasons (Fig.2). In spring, cyclone minimum central pressure is higher than 950hpa, distributing mainly from 1010hPa – 970hPa, of which some 56% are located in 1000hPa – 980hPa. In summer, cyclone central pressure is higher than 960hPa, of which only 10% can be lower than 980hPa indicating weak cyclones in summer. In autumn, cyclone central pressure can reach 940hPa in which 1000 hPa –

970hPa accounts 74% of total central pressure distributions. The winter cyclone is the strongest with central pressure reaches 930hPa and the overall pressure distribution range is wider.

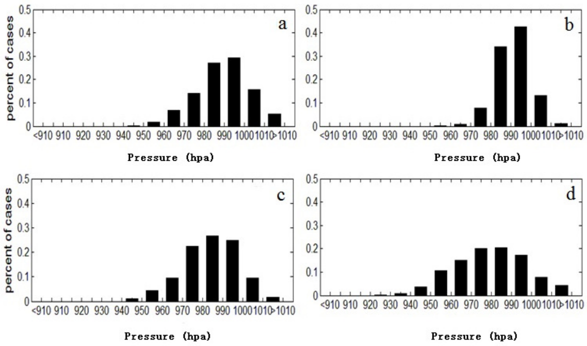

Figure 2. The distribution of cyclone central minimum pressure in spring (a), summer (b), autumn (c) and winter (d).

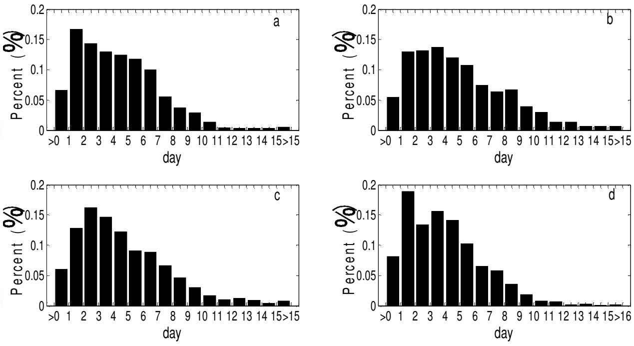

Figure 3. The distribution of cyclone life time in spring (a), summer (b), autumn (c) and winter (d).

Cyclone life statistics (Fig 3) shows that 83%, 74%, 79% and 85% of cyclone life time were confined within 7 days in spring, summer, autumn and winter, respectively. The long-live summer cyclones (up to 14 days) may reach 2%. In winter cyclone life is usually less than 12 days.

3.2 Density of cyclongenesis and tracks

The comprehensive analyses of density of cyclogenesis and tracks are given in Figure 4 and Figure 5, respectively. Both cyclone genesis and tracks have clear seasonal variations. In spring, the cyclones actively cross the Baffin Bay, Norwegian Sea–Barents Sea–Kara Sea and Taymyr Peninsula within 60 ºN – 80ºN region. Only a small amount of cyclones can enter central Arctic (north of 80ºN). In summer, the cyclogenesis in land become more active. The cyclone activity-center in Baffin Bay weakens and moves westward to the Canadian northern Archipelago. The cyclogenesis belt of Norwegian Sea–Barents sea–Kara Sea extends to eastern Siberia. Some cyclone with genesis in mid-latitudes can reach the Arctic region. There are more cyclones entering central Arctic (north of 80ºN) in summer compared with those in other seasons. In autumn, continental cyclone activity significantly decreases and frequency reduces, and the cyclone activity-center moves westward over the ocean. The continental cyclone activity area and frequency were further reduced in winter, all cyclogenesis are occurred north of 60ºN, and very few cyclones can enter into the central Arctic.

The Norwegian Sea (30ºW–30ºE) is the key area for cyclones going into the Arctic Ocean, especially in winter season (Fig.6). In summer, cyclone activities are more widely distributed, especially from 30ºE to 120ºE. The cyclone activities in 120ºE-90ºW are not high in every season.

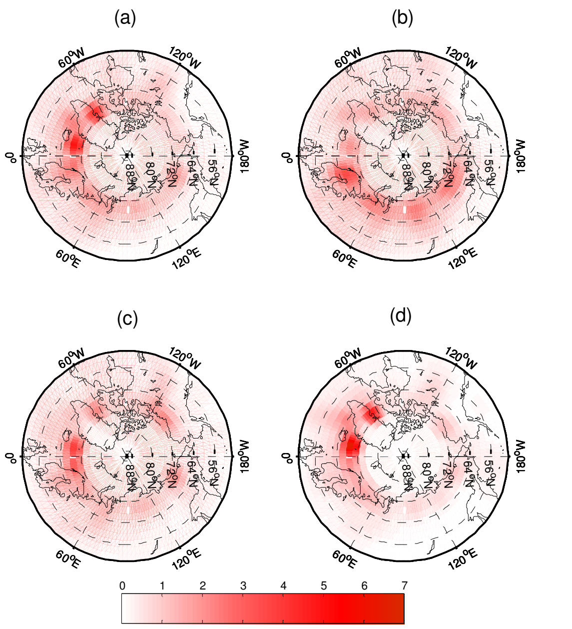

Figure 4. Cyclone genesis density in (a) spring, (b) summer, (c) autumn and (d) winter.

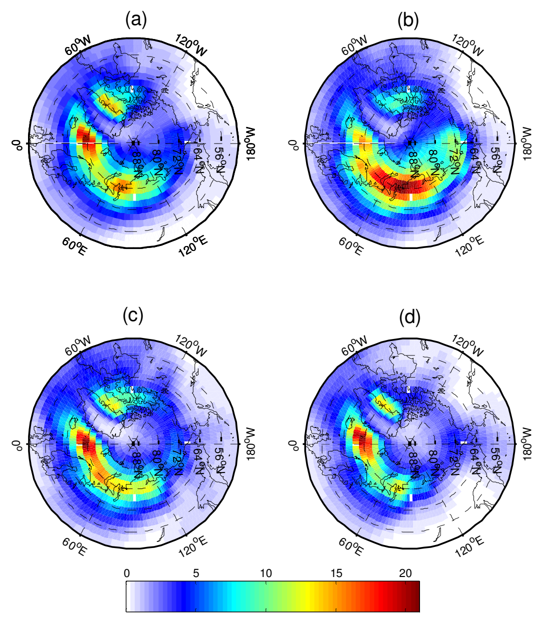

Figure 5. Cyclone track density in (a) spring, (b) summer, (c) autumn and (d) winter.

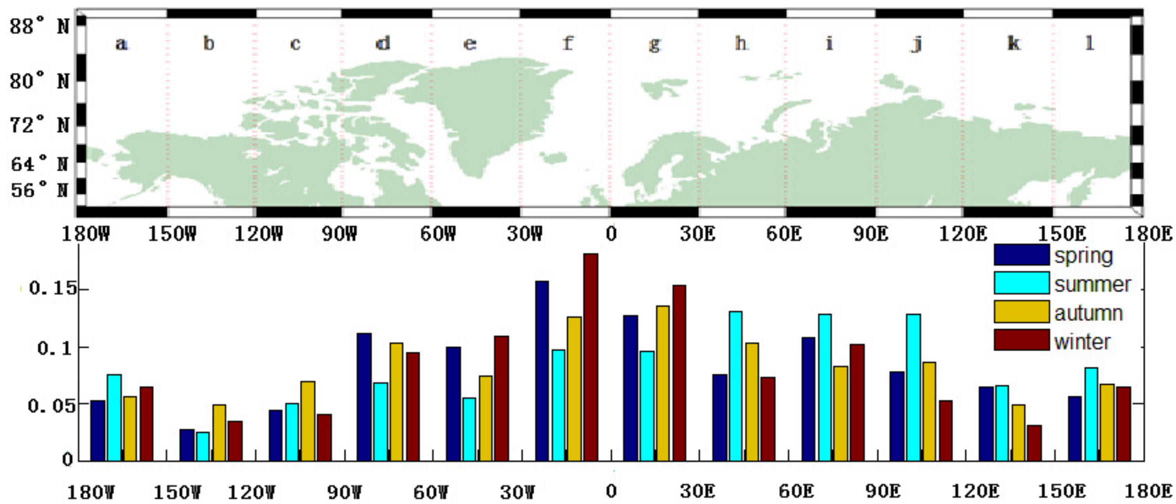

Figure 6. Average (1979 – 2012) seasonal cyclone activity along every 30 longitude degree cross section. The number of bars gives the proportion of the total cyclone crossing 70^{o}N.

3.3 Relationship between distribution of sea ice concentration and the cyclones which enter poleward of 70^{o}N in summer

The singular value decomposition (SVD) method is applied to analyses the relationship between distribution of sea ice concentration and cyclones which enter poleward of 70ºN. The result of SVD analysis shows that the covariance interpretation rate of the first pair of modality is 56.6%, which basically reveals the correlation between the sea ice concentration and the cyclones activity density. The first coupled pattern demonstrates that the sea ice concentration field has a significant positive relation to the cyclone activity density in the central Arctic. The coefficient of the first coupled pattern is 0.61. The changes of sea ice concentration and cyclone activity are strongly correlated to each other. The ice concentration changes, as a whole, is significant negative (Fig. 7a) indicating the overall abnormalities of sea ice concentration field. The cyclone field shows negative in central Arctic (Fig.7b). Most cyclones are generated in the Greenland Sea region and moved to the northwest along the region. Cyclones come into the Arctic Circle delivering heat to this region from south to north resulting in temperature rise and reduction of sea ice concentration. The most negative correlation coefficients of cyclone activities density occur in the Arctic center, which shows opposite trend of the cyclone in the edge of continental mainland. On the one hand, reduction of sea ice concentration reflects temperature increases in the Arctic, the temperature gradient between the Arctic and middle-high latitude region decreases with temperature rising, and make it more difficult for cyclones to enter the central Arctic. On the other hand, with decreasing of sea ice concentration, the heat exchange between land and open-ocean is enhanced (mainly dominated from atmosphere to ocean). Due to effect of friction and gradual demise of the energy dissipation, the cyclones are weakened faster causing a decreasing of total number of cyclones entering into central Arctic.

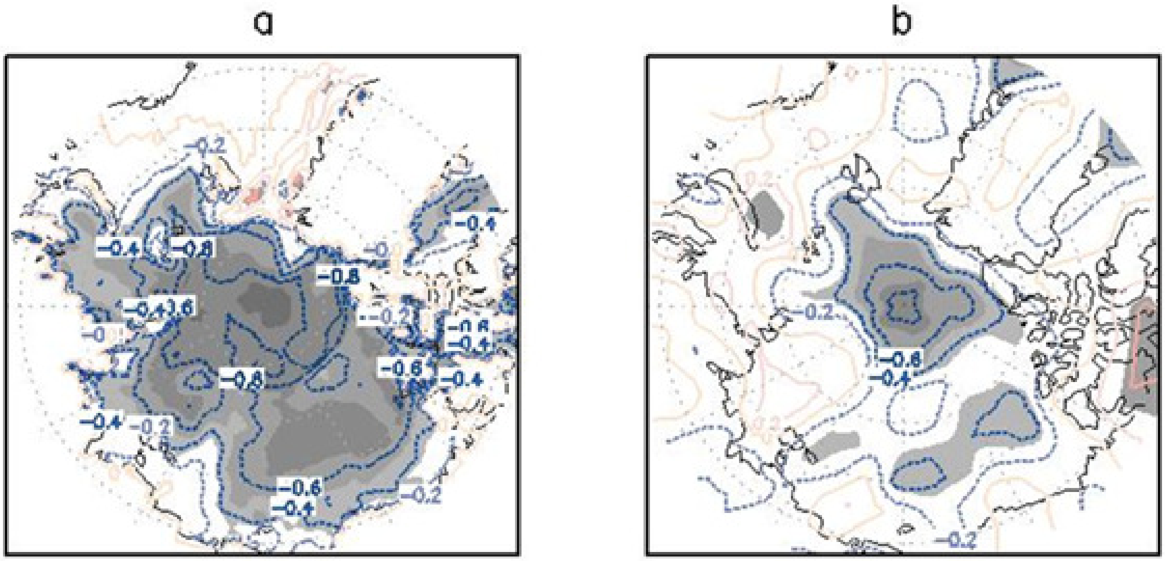

Figure 7. (a) Correlation of the time coefficient of the left singular vector of SVD1 with sea ice concentration. (b) Correlation of the time coefficient of the right vector of SVD1 with cyclone activity density. The correlation above 95% level of confidence is shaded.

4. Conclusions

The cyclone activities in the Arctic (north of 70ºN) were identified using an automatic tracking algorithm from Hodges (1994, 1996) of Reading University. The inter-relationship between cyclone activities and sea ice concentration in summer was studies using singular value decomposition (SVD) method.

In general, the cyclones are stronger in winter than in summer, but the number of cyclones generated is much lower in winter than in summer. More cyclones enter the Arctic from the North Atlantic sector in spring, especially from the Greenland Sea and Norwegian Sea. In summer, however, cyclongenesis are more numerous in the Pacific sector, particularly in the East Siberian Sea. Our results suggested that the number of cyclones has slightly decreased in spring and summer and increased in autumn, but the trends do not reach any significant level ($P < 0.05$). The variation of seasonal mean cyclone numbers shows decadal variations. Cyclones are active in summer, its genesis cover large area even down to mid-latitude region. The cyclonegenesis is active on land, in particular along the eastern Siberian coastal region. A large number of cyclones enter into Arctic from this region affecting air–sea ice–ocean interaction in summer. In winter cyclone sources distribution get narrowed, mainly at the belt of Norwegian Sea – Barents Sea – Kara Sea area, and this genesis resource is present throughout the year, especially the Norwegian Sea.

In the winter season, for example, annual mean cyclone number decreases in 80s, increases in 90s, and decreases slightly again in new millennium. A climatological Arctic lake ice modelling for 1980–2013 (Cheng et al., 2014a) reveals similar periodic variations of the portions of modelled ice compositions, i.e. columnar ice (due to freezing of lake water) and granular ice (due to freezing of snow-slush). The columnar ice formation dominates in 80s. In 90s, the granular ice formation increases significantly equally to the columnar ice. In later part of new millennium, a decreasing of columnar associated with a increasing of granular ice was modelled (Cheng, et al., 2014a). A cold winter season usually subjects to less snowfall resulting columnar ice formation, while for a warm winter, snowfall is large and consequently granular ice formation increases. So the decadal oscillation of cyclone activities could perhaps link with the snowfall pattern in high-latitude and resulting different thermodynamic ice formation mechanism. A more close investigation of cyclone activities linked with snow and sea ice thermodynamics is under way. A better sustainable snow and ice mass balance monitoring is urgently needed (Cheng, et al, 2014b).

The analysis of sea ice density and intensity of cyclones using SVD method shows that reducing the Arctic sea ice concentration in the central area is closely related to the reduction of cyclone density ($P < 0.05$). More studies are still needed to reveal the physical reasons behind the strong linkage between sea ice concentration reduction and cyclone activities in the central Arctic.

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