Chinese Journal of Polar Science, Vol. 12, No. 2, 109 - 118, December 2001

Summer sea ice characteristics of the Chukchi Sea

Kang Jiancheng (康建成)[1], Sun Bo (孙 波)[1], Sun Junying (孙俊英)[2],
Meng Guanglin (孟广琳)[3] and Kumiko Goto-Azuma[4]

1 *Polar Research Institute of China, Shanghai 200129, China*

2 *Cold and Arid Regions Environmental and Engineering Research Institute, CAS, Lanzhou 730000, China*

3 *Institute of Marine Environmental Protection, SOA, Dalian 116023, China*

4 *National Institute of Polar Research, Tokyo 173-8515, Japan*

Received September 3, 2001

Abstract During August 1999, we investigated sea ice characteristics; its distribution, surface feature, thickness, ice floe movement, and the temperature field around inter-borders of air/ice/seawater in the Chukchi Sea. Thirteen ice cores were drilled at 11 floe stations in the area of 72°24′ - 77°18′N, 153°34′ - 163°28′W and the ice core structure was observed. From field observation, three melting processes of ice were observed; surface layer melting, surface and bottom layers melting, and all of ice melting. The observation of temperature fields around sea ice floes showed that the bottom melting under the ice floes were important process. As ice floes and open water areas were alternately distributed in summer Arctic Ocean; the water under ice was colder than the open water by 0.4 - 2.8℃. The sun radiation heated seawater in open sea areas so that the warmer water went to the bottom when the ice floes move to those areas. This causes ice melting to start at the bottom of the ice floes. This process can balance effectively the temperature fluctuating in the sea in summer. From the crystalline structure of sea ice observed from the cores, it was concluded that the ice was composed of ice crystals and brine-ice films. During the sea ice melting, the brine-ice films between ice crystals melted firstly; then the ice crystals were encircled by brine films; the sea ice became the mixture of ice and liquid brine. At the end of melting, the ice crystals would be separated each other, the bond between ice crystals weakens and this leads to the collapse of the ice sheet.

Key words Arctic Ocean. sea ice. climate.

1 Introduction

The sea ice cover is the main surface feature of the Arctic Ocean. The area of the sea ice cover varies annually, with a minimum of $7.8 \times 10^6 - 7.92 \times 10^6$ km^2 in September, and a maximum of $12.31 \times 10^6 - 14.8 \times 10^6$ km^2 at the end of winter (Zakharov 1981; Parkinson *et al*. 1987; Barry *et al*. 1993). There is a great influence on the climate from the sea ice. It is because, 1) the ice albedo is much higher than sea surface albedo; 2) sea ice separates the heat exchanging between atmosphere and sea; 3) the process of freezing and melting affects the formation and intension of the ocean thermohaline circulation; 4) the process of heat absorption/release during freezing and melting of ice smoothes the extreme temperature fluctuation in the area.

Sea ice is an integral component of the polar climate system (Barry *et al*. 1993, Kang *et al*. 1999), for the area, thickness, structure and constitution of sea ice are closely related to the climate (Jeffries 1997; Rothrock *et al*. 1999; Tucker *et al*. 1999).

Though the global temperature has risen in last 100 a (Jones *et al*. 1999); ice cores and other "paleo-thermometer" records show that there should be larger Arctic temperature change than in lower latitudes (Cuffey *et al*. 1995; Moritz and Perovich 1996). Numerical GCM experiments generally show that the magnitude of global warming is much greater in northern high latitudes (Manabe *et al*. 1991). Small glaciers in the Arctic have shown a wide-spread retreat; a rapid response to the global climate than in low and middle latitudes (Xiao *et al*. 1999). There is no significant trend in the surface temperature of the Arctic Ocean over the past 40 a (Kahl *et al*. 1993). This is probably attributed to the existence of sea ice. The data for past 40 a show almost no change in ice extent in winter, small decrease trend in spring and larger decrease in summer (Chapman and Walsh 1993; Parkinson *et al*. 1999). The summer processes of sea ice may restrict the effect of global warming on Arctic Ocean. China organized a multidisciplinary expedition in the Chukchi Sea, Arctic Ocean from July to September 1999. The expedition area is shown in Fig. 1. The purposes of the expedition are to observe the distribution, thickness, and structure of the sea ice; to measure energy and mass fluxes among air, ice and sea water and to study their possible effect on climate change. From the field investigation and ice cores observation, the ice characteristics in summer and their connection with climate are discussed here.

2 Materials and methods

The Chinese polar icebreaker "*Xuelong*" and two helicopters (H9 IS360, AIS350b2) were used in the expedition. During the expedition, eleven ice floes were observed and sampled, from an area located at 72°24′－77°18′N, 153°34′－163°28′W; thirteen ice cores were drilled out from the floes, among them, 10 ice cores drilled all the way to the bottom of the ice. The weather observations (including air temperature, humidity, wind speed and direction, barometric pressure) were carried out on the ship (18 m above sea surface) as well as at ice stations. The ice thickness was measured by an ice radar at 7 floes. The ice floe movement was observed at two floes. The seawater temperature was continually measured at 7 m depth under the ship, and by CTD, XCTD around the ice floes.

Fig. 1. The area of Chinese expedition on the Arctic Ocean, July－Sept. 1999.

(1) Ice distribution becomes alternation of dense ice-zones and sparse ice-zones, the breadth of each zone is 10 – 30 km in the observed area. The ice concentration was about 85% – 90% in dense ice-zones, and 30% – 40% or less in sparse zones observed on the ship, on the helicopter and from imaging maps of Radarset Satellite.

(2) The Ice-thickness was measured from ice cores drilled at flat areas on the floes. The thickness was between 1.5 – 5.7 m, averaging 3.78 m (Table 1).

Table 1. The data of the ice cores in 1999

Drilling date	Longitude	Latitude	Ice core No.	Core length /m	Depth of permeating water /m	Ice thick /m
5 Aug.	164°59.50′W	73°26.56′N	BJ-BX01	4.00	0.30	4.00
8 Aug.	157°17.900′W	74°03.345′N	BJ-BX02	1.40	1.10	
10 Aug.	153°33.994′W	72°24.037′N	BJ-BX03	2.75	0.33	2.85
10 Aug.	153°33.994′W	72°24.037′N	BJ-BX04	2.22	0.33	2.30
18 Aug.	160°31.830′W	74°58.614′N	BJ-BX06	4.86	2.00	4.86
19 Aug.	160°49.333′W	77°18.167′N	BJ-BX07	2.90	0.50	
20 Aug.	161°32.270′W	77°04.774′N	BJ-BX08	1.50	0.49	1.50
20 Aug.	161°33.508′W	76°04.955′N	BJ-BX09	5.40	0.62	5.40
22 Aug.	161°55.175′W	76°05.632′N	BJ-BX10	2.65	0.50	2.65
22 Aug.	161°55.175′W	76°05.632′N	BJ-BX11	4.42	0.52	4.42
22 Aug.	161°55.175′W	76°05.632′N	BJ-BX12	4.45		
23 Aug.	163°28.225′W	76°30.267′N	BJ-BX13	5.67	0.56	5.67
23 Aug.	163°28.225′W	76°30.267′N	BJ-BX14	4.09	0.20	4.16

The thickness varied within short distance even at flat areas. The variation would be 0.5 – 1 m between two points separated by 10 m.

(3) The snow depths varied between 2 cm to 15 cm within 5 – 10 m spacing on the floes. The deposited snow is composed of round wet firn with a size of 2 – 5 mm, or elongated ones with a size of 2 – 7 mm.

(4) Ice cores were drilled with a 0.1 m diameter-coring auger, preserved in insulation box with clear plastic liners, and sent to the low temperature laboratory (– 15 – – 20℃) on the ship as soon as possible. Ice structure of the cores was observed under clairvoyance light in the low temperature laboratory. Generally, in the ice cores, there were 2 – 15 cm-thick coarse firns at top, then 10 – 30 cm-thick granular ice. There were many air bubbles in the granular ice. The bubbles were round at the upper part, and elongated downward. At the middle section of the cores, the major texture was columnar ice with less and small bubbles observed under higher light transparency. In some cores, there was 5 – 30 cm-thick granular ice found inside of the columnar ice. At the bottom of the ice cores, there were melting ice with significant number crevices and bubbles arranged vertically; or there was a series of botryoid ice, if the temperature under the water was higher than – 1.5℃. When the temperature was – 1.6 – – 1.8℃, the bottom of the sea ice was planar without melting trace.

(5) The ice surface temperature was measured by sonde of platinum resistance. The bulk ice temperature is measured by thermometer (thermal sensitive sonde, accuracy ±0.1℃) at a 10 cm interval from the surface to 40 cm depth in ice. The water temperature under ice was obtained using FSI-CTD from a hole with a diameter of less than 2 m. The regional water temperature was measured by a thermal sensor placed at bottom of the ship (7 m depth, measured every minute with precision 0.1℃).

3 Results and discussion

3.1 Temperature field at sea ice area

3.1.1 The temperature field before melting

The temperature field before melting was observed at a sea ice station located at 74°58.614′N, 160°31.830′W, about 1 km × 1 km in size, during the period of 18 ~ 24 August, 1999. The environmental conditions around the station was as follows: it was cloudy and snowing on 18 August, ice with 1 ~ 3 cm-thick covered the melting ponds on the ice floe and the fresh snow was 3 ~ 5 cm deep on the surface of freezing pond. The air temperature was - 2.2 ~ - 5.6℃; the seawater temperature was - 1.8℃ in 10 ~ 30 cm deep subsurface around the floe. The ice temperature was - 0.4℃ at the depth of 40 cm. There was no melting trace found in the ice core drilled on that day.

But the situation was changed in following days with sunshine on 22 ~ 23 August 1999 and the temperature on the ice surface went up higher than 0℃ in middle of daytime. The melting was found on the surface and bottom of the ice cores drilled on the days.

Around the station during 18 ~ 25 August, the sea-water temperature in the depth of 7 m was - 0.3 ~ - 1.4℃ (Fig. 2), and average was - 0.86℃. XCTD data on 19 August, showed that the temperature was about - 1.3℃ measured in the 20 m surface water layer at a distance about 100 m from the ice floe.

The air temperature fluctuated from 0.2 ~ - 5.7℃, mean number was - 3.65℃ (Fig. 3), obtained from the ship weather station during 18 ~ 25 August. The ice temperature fluctuated - 0.3 ~ - 0.4℃ at the depth of 40 cm observed on 19 ~ 24 August, measured 4 times per day. The temperature field before ice floe melting can be summarized in Figure 4.

3.1.2 The temperature field during melting

Another ice station (73°26′31″N, 164°59′30″W) was set up on 5 ~ 7 August, 1999. The air temperature had been recorded on the floe, it varied between 0.72 ~ - 0.15℃, mean value was 0.23℃ (Fig. 5). Around the ice station, the air

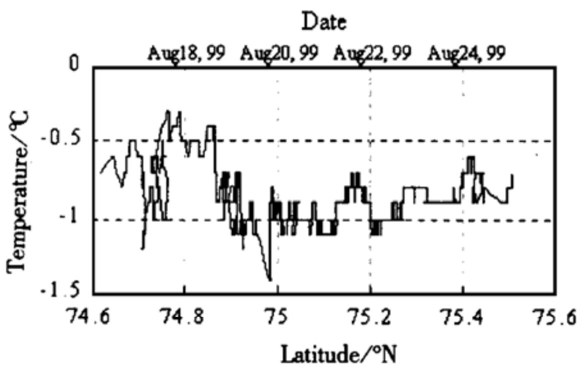

Fig. 2. The seawater temperature at depth of 7 m around the ice station of Chukchi Sea on 18 ~ 25 August, 1999.

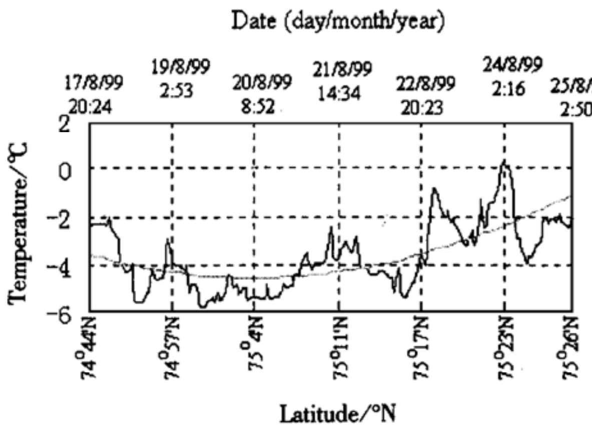

Fig. 3. The air temperature obtained from the ship weather station.

temperature was fluctuating from 3.2 ~ −1.3℃, averagely −0.26℃ (Fig. 6), measured every hour on the ship.

The ice temperature was 0℃ in approximately 30 cm deep under the surface.

The water temperature under the ice floe was approximately −1.5℃ measured by CTD along a polynya (Fig. 7). The region water temperature at the depth of 7 m, fluctuated from 1.4℃ to −0.9℃, mean value was 0.01℃ (Fig. 8), the value was changeable, because the ship sometimes broke ice, and sometimes sailed in open water area. The average water temperature was about 0.87℃ in this region higher than that observed on 18 ~ 24 August.

Several ice cores were drilled on the floe, it was found that the entire ice floe was under the melting condition. The temperature field in the sea ice during melting can be shown in Fig. 9, from the data above.

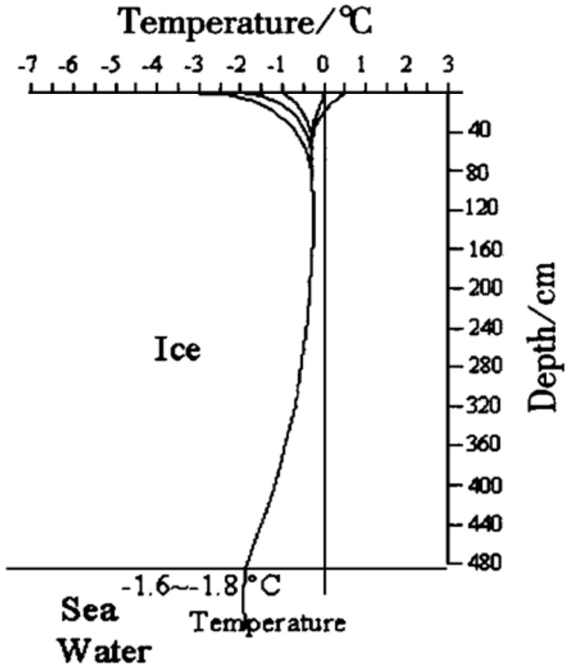

Fig. 4. The temperature field before ice floe melting.

3.1.3 Heat conduction process during ice floe melting and influence of sea ice on the climate

From the observation above, the temperature field can be got on the interfaces of air/ice/seawater during floe melting, as following: the average air temperature was higher than that in the ice, which was kept at melting point, because of decalescence during the phase-change of ice. There was a temperature jump on the interface of ice/seawater; the thickness of the jumping layer was 30 cm and the temperature difference was about 1.5℃ in the layer (Fig. 7). Under the ice floes, the seawater temperature was about −1.3 ~ −1.5℃.

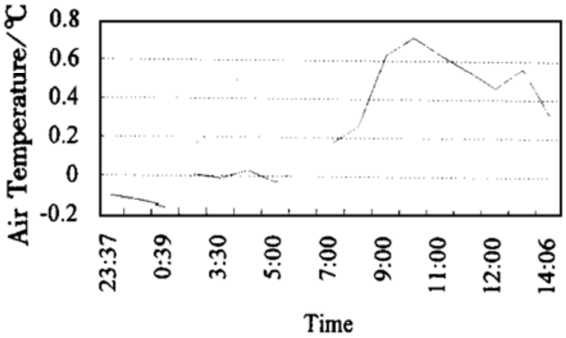

Fig. 5. The air temperature at the ice station (73°26′31″N, 164°59′30″W) on 5 August 1999, in the Chukchi Sea.

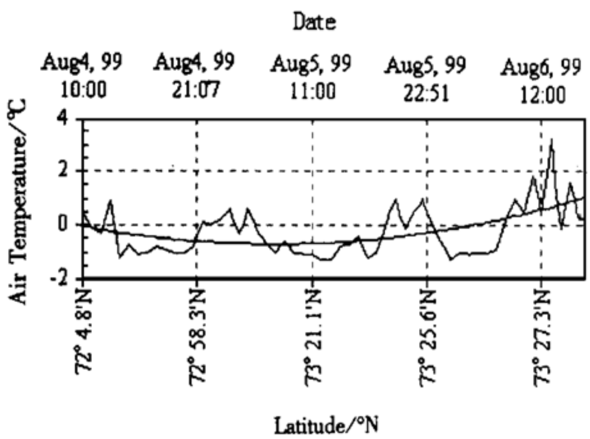

Fig. 6. The air temperature from ship weather station on 4 ~ 6 August 1999, in the Arctic Ocean.

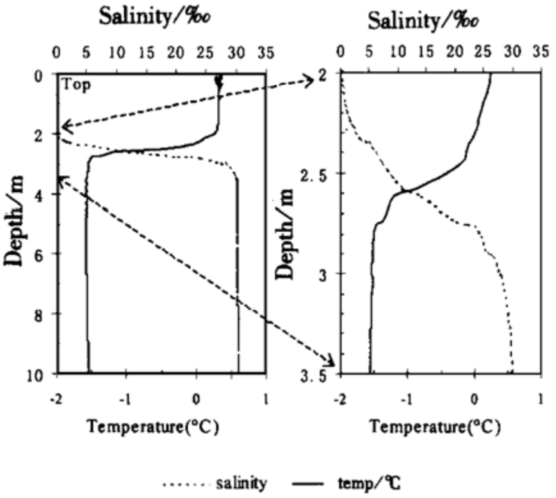

Fig. 7. The water temperature and salinity measured under the sea ice by FSI-CTD on 6 August 1999, in the ice station (73°26′31″N, 164°59′30″W) of the Arctic Ocean.

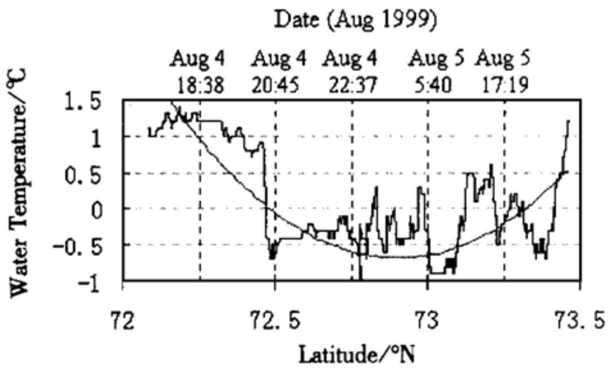

Fig. 8. The water temperature around the ice station on 4 ~ 6 August 1999, the Arctic Ocean.

The sea ice cores showed that there were two types of melting structure, one was that there was melting on top-part and bottom-part, no melting in the middle section of the ice floes; another was that the entire ice core was under the melting condition. The thermal energy for the upper part melting of ice floes comes from solar radiation and air transmission; as the albedo of ice floes is 66% ~ 90%, decalescence for surface melting is limited. The observations also showed that air temperature fluctuation of 0.2 ~ −5.7℃ or −2 ~ −8℃ on ice surface for several days could not affect to deeper than 40 cm in ice floes (this observation and Li *et al*. 1989), it means that the surface heat can not transmit to the floe bottom in days warming, where the ice is thicker than 1.5 m as most ice floes in Arctic ocean. But, the observation showed that the bottom feature changed in several days in summer Arctic ocean, with the weather changing. The question is where the heat comes from for the bottom melting and how it is transmitting.

In the first melting type, the heat on the upper part could not be transferred to the bottom through the low temperature area in the middle, so, the energy for bottom-part ice melting should come from sea water. In the second type, maybe some melting water would bring heat to the bottom, when the melting water permeates the ice downward. But the density of fresh water is lighter than that of saline seawater, and it is difficult to penetrate down through the ice, as the floe bottom receives the pressure upon the seawater, some seawater would infiltrate upward into the ice body. So, that the heat transferred down to bottom across ice body is ignored. The energy for the ice bottom melting should come from seawater. As there is alternate distribution of ice floes and open water areas in summer Arctic Ocean, and a large difference on albedo between ice floes and open water area (the former is about 66% ~ 90%, the latter only 5% ~ 10%), it makes the temperature difference between the water under floes and the open water area to be 0.4 ~ 2.8℃. The ice floes were moving in the sea with drift speeds of 1 ~ 10 cm • s^{-1} (Barry *et al*. 1993). When the floes move to the warm-open-water-area, the heat carried by warm water is sent to the floe bottom directly to melt the bottom ice (Fig. 10). The processes of heat transferring make the ice bottom melt continuously. It can balance the temperature wave in all of the sea in summer.

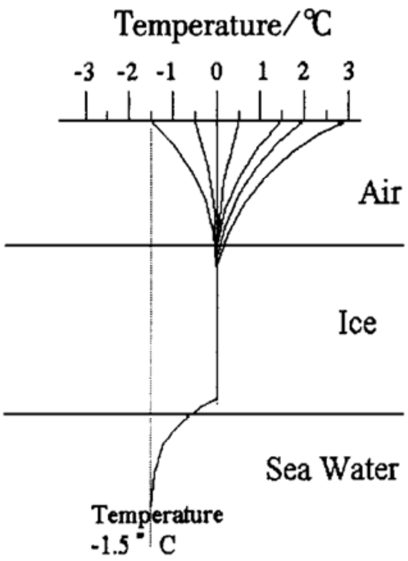

Fig. 9. The sea ice temperature field during melting.

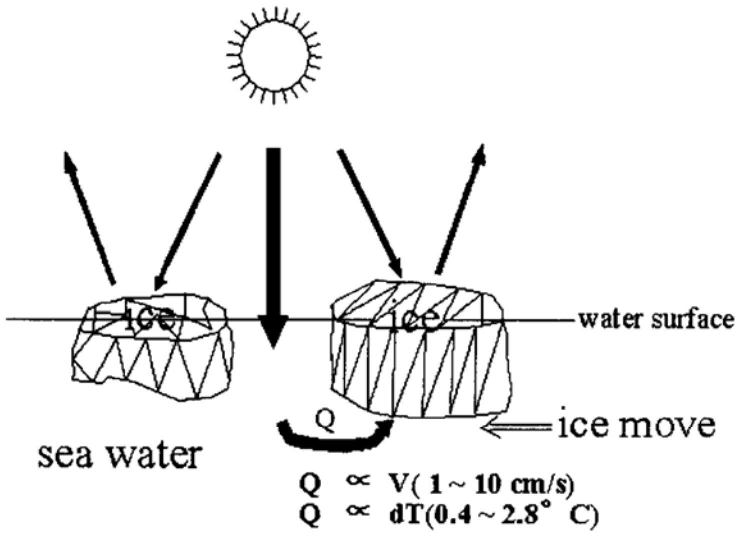

Fig. 10. The sun radiation heats seawater in open sea area, then the ice moves onto the warm water, the heat energy is directly sent to the ice bottom.

3.2 Ice structure, process of sea ice melting and their relationship with climate

3.2.1 Observation

(1) Ice structure before melting. An ice core, 4.86 m thick, was drilled from a floe (74°58.614′N, 160°31.830′W) on 18 August, 1999. The ice structure profile is as follows (from top to bottom) (Fig. 11): a mixture layer of grain firn and ice slices (8 cm thickness); a layer with 80% granular ice and 20% grain firn (7 cm thick); granular ice (14 cm thick); columnar ice (194 cm thick); columnar ice (28 cm thick) with more air bubbles; and columnar ice (235 cm thick) onto the bottom. The bottom face is a mirror face, without melting trace.

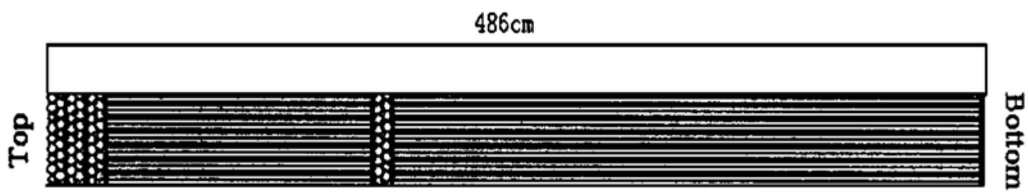

Fig. 11. The ice structure of the core drilled from the floe (74°58.614′N, 160°31.830′W) on 18 August, 1999.

The floe was clean, the average surface albedo of the floe was 75%. The temperature field around the ice floe shows as in section 3.1.1. It can be got that the sea ice was still in freezing situation.

(2) Ice structure during melting. Four full thickness ice cores were drilled in the region (76°05.632′ – 76°30.267′ N, 161°55.175′ – 163°28.225′W) from different

floes on 22 – 23 August. The length of the cores was 2.65, 4.42, 5.67 m and 4.09 m respectively. The common feature of the ice structure was that there was melting trace at bottom, which was a 20 cm-thick layer with significant number crevices and bubbles arranged vertically.

(3) Ice structure at end of melting. Ice cores, about 4 m thick, were drilled from a floe (73°26′31″N, 164°59′30″W), on 5 August, 1999. The ice structure profile was observed as (Fig. 12): at the top, there were three wet firn layers with 8 – 9 cm thickness, separated by ice layers with 1 – 2 cm thickness; the wet firn layers were made of grain crystals in 2 – 5 mm size; then the core was composed of irregular lens ice and grain crystals, the size was increasing downward. The entire ice core was not conglutinated by freezing, the lens ice and grain crystals were scattered loosely along their interfaces. The melting of this floe was intensively; the melting water appeared in the depth of 20 cm under the surface.

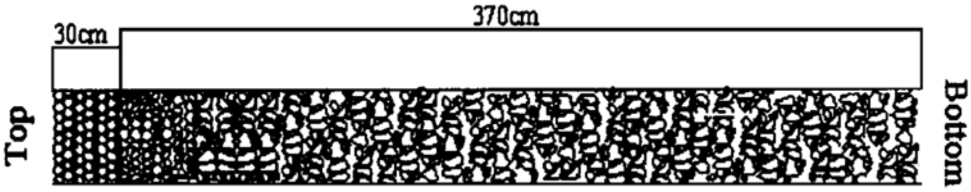

Fig. 12. The ice structure of the core drilled from the floe(73°26′31″N, 164°59′30″W), on 5 August 1999.

The floe surface albedo was 66% – 67%, it was more discolored than other ice floes when observed from the helicopter. The temperature field around the floe was as Fig. 9.

The question is (a) why the ice becomes loosely-scattering structure; (b) what it implies from the ice structure and temperature profile in the air/ice/seawater.

3.2.2 Process of sea ice melting and its effect to climate

The freezing process and relative sea ice structure have been discussed by many researchers (as Weeks and Ackley 1982; Wang and Dieckmann 1993; Li Zhijun *et al*. 1992; Barry *et al*. 1993). It needs to point out, that there are still brine ice films between sea-ice crystals frozen lastly. It can be observed from ice cores, that there are some "clouds" around columnar ice crystal, they locate at the interface of crystals, made of salt cells and air bubbles.

The process of the ice melting is reverse with the freezing. When the sea ice melting, the brine-ice films between ice crystals, which have higher salinity and lower melting point, frozen late and melt first. The ice crystals are encircled by brine films after the brine-ice films melted; then, the brine-channel-system(BCS) formed and seawater will infiltrate the ice along the channels pushed by pressure (the permeating water can be found in the hole of ice core). When the ice cores during melting are placed levelly in cool room, there is re-freezing ice with higher salinity and low intension covering the cores. It is refreezing brine permeated out from the BCS. This process is developed firstly on the top and bottom of the cores.

When the BCS is interpenetrating, the sea ice becomes the mixture of ice and water, with a structure of ice skeleton full of melting water. At the end of melting, the freezing conglutination between ice crystals is greatly decreased by this process, for example, the ice structure of the cores drilled on 5 August. The ice floe with this kind of ice structure will collapse easily at the end of melting. It will affect the climate calamitously, if happened in large area.

4 Preliminary conclusion

4.1 The moving ice floes are the conditioner for the temperature fluctuation in summer Arctic Ocean

As ice floes and open water areas were alternately distributed in summer Arctic Ocean; the water under ice was colder than the open water by 0.4 – 2.8℃. The sun radiation heated seawater in open sea areas so that the warmer water went to the bottom when the ice floes move to those areas. This causes ice melting at the bottom of the ice floes continually. This process can balance effectively the temperature fluctuating in the Arctic sea in summer.

4.2 The process of the sea ice melting companied with a destroy of ice structure, the ice floe would easily collapse at last

The sea ice was composed of ice crystals and brine-ice films. During the sea ice melting, the brine-ice films between ice crystals melted firstly; then the ice crystals were encircled by brine films; the sea ice became the mixture of ice and liquid brine. At the end of melting, the ice crystals would be separated each other, the bond between ice crystals weakens and this leads to the collapse of the ice sheet.

Acknowledgments We are grateful to the officers, and crew of "*Xuelong*" icebreaker and helicopters, who provided outstanding logistical support for the ice program. We are also grateful for the helpful discussion with professors Chen Liqi, Yan Qide, Dong Zhaoqian, Qin Weijia, E Dongchen, Qu Shaohou, Bian Lingen, Zou Han, Xie Simei, Zhao Jinping. We also thank a lot to Dr. Toshiyuki Kawamura for his excellent reviews and suggestions. This work is supported by Chinese Polar Administration and Shanghai Municipal Foundation for Returnee Scholars.

References

Barry RG, Serreze MC, Maslanik JA, Preller RH (1993): The Arctic sea ice-climate system: Observations and modeling. Reviews of Geophysics, 31(4): 397 – 422.

Chapman WL, Walsh JE (1993): Recent variation of sea ice and air temperature in high latitudes. Bull. Am. Meteorol. Soc., 74: 33 – 47.

Cuffey KM, Clow GD, Alley RB, Stuiver M, Waddington E, Saltus RW (1995): Large Arctic temperature change at the Wisconsin-Holocene glacial transition. Science, 270: 455 – 457.

Jeffries MO (1997): Describing the composition of sea-ice cores and the development of the Antarctic sea-ice cover. Antarctic Journal-Review, 55 – 56.

Jones PD, New M, Parker DE, Martin S, Rigor IG (1999): Surface air temperature and its changes over the past 150 years. Reviews of Geophysics, 37(2): 173 – 200.

Kahl JD, Charlevoix DJ, Zaitseva NA, Schnell RC, Serreze MC (1993): Absence of warming over the Arctic Ocean in the past 40 years. Nature, 361: 335 – 337.

Kang JC, Yan QD, Sun B, Wen JH, Wang DL, Sun JY, Meng GL, Kumiko Goto-Azuma (1999): The Arctic sea ice, climate and its relation with globe climate system. Chinese Journal of Polar Research, 11(4): 301 - 310.

Li ZJ, Sui JX, Yan DC, Meng GL(1989): Temperature, salinity and density profiles in a fast ice sheet in Liao Dong Bay. POAC'89, 1: 218 - 224.

Li ZJ, Zhang T, Meng GL (1992): Ice features in Liaodong Gulf in the winter of 1988 - 1989. Abstracts of 7th International Symposium on Okhotsk Sea and Sea Ice, 317 - 320.

Manabe S, Stoffer RJ, Spelman MJ, Bryan K (1991): Transient response of a coupled ocean-atmosphere model to gradual changes of atmospheric CO_2, I: Annual mean response. J. Climate, 4: 785 - 818.

Moritz RE, Perovich DK (1996): Surface heat budget of the Arctic Ocean (SHEBA). Science Plan.

Parkinson CL, Comiso J, Zwally HJ, Cavalieri DJ, Gloersen P, Campbell WJ (1987): Arctic sea ice, 1973 - 1976: Satellite passive microwave observations. NASA Spec. Publ., Sp-489.

Parkinson CL, Cavalieri DJ, Gloersen Per, Zwally HJ, Comiso JC (1999): Arctic sea ice extents, areas, and trends, 1978 - 1996. J. Geophys. Res., 104(C9): 20837 - 20856.

Rothrock DA, Yu Y, Maykut GA (1999): Thinning of the Arctic sea-ice cover. Geophys. Res. Lett., 26(23): 3469.

Tucker III WB, Gow AJ, Meese DA, Bosworth HW (1999): Physical characteristics of summer sea ice across the Arctic Ocean. J. Geophys. Res., 104(C1): 1489 - 1504.

Wang ZP, Dieckmann G (1993): Ecological environmental features of Antarctic sea ice and its role in the marine ecosystems. Chinese Journal of Polar Research(Name used before: Antarctic Research), 5 (1): 1 - 15.

Weeks WF, Ackley SF (1982): The growth, structure, and properties of sea ice. CRREL Monograph, 82 - 1, 1 - 130.

Xiao CD, Qin DH, Ren JW, Li ZQ (1999): Progress of mass balance study on glaciers in the Arctic. Journal of Glaciology and Geocryology, 21(3): 200 - 206.

Zakharov VF (1981): Ldy Arktikii Sovremennyye Prirodnyye Protsessy (Arctic Ice and Present Natural Processes), Leningrad, Gidrometeoizdat, 136.