P1.25

BIMODALITY
OF FAST ICE EXTENT DISTRIBUTION IN THE NORTHEASTERN KARA SEA

Dmitry Divine*
Norwegian Polar Institute, Tromso, Norway
Alexander Makshtas
International Arctic Research Center, Fairbanks, Alaska, USA
Reinert Korsnes
Norwegian Defence Research Establishment, Kjellern, Norway

1.INTRODUCTION

The temporal-spatial variation of shore-fast ice extent in the northeastern part of the Kara Sea during 1953 – 1999 and its sensitivity to interannual variability of regional climate are investigated with data of regular observations by the Arctic and Antarctic Research Institute (AARI) during 1953 - 1990 and SSM/I surface brightness temperatures during 1987 – 1999 (NSIDC 2000a, 2000b). The used data are comprised of 523 air surveys supplemented with 95 identifications of shore-fast ice in spring from SSM/I surface brightness temperatures in the 85 GHz channel with the horizontal polarization (Divin, 2003). Monthly mean air temperature from Fetterer (2000), sea level pressure patterns (NCAR,), snow depth and precipitation rate from meteorological polar stations located in the study area (NSIDC 1995, 1998) were used to assess an influence of atmospheric conditions on fast ice formation. The data about wind velocity and direction from the Dikson Island were used to estimate the impact of wind stress on fast ice extent. Monthly mean data of the Ob and Yenisei rivers discharges in 1950-1987 were used for estimation of possible influence on fast ice extent also.

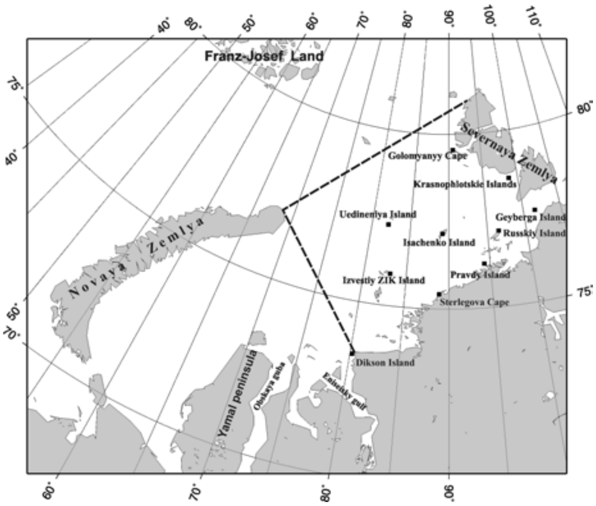

Figure 1 The locations of the meteorological stations referenced in the text.

2. SPATIAL DISTRIBUTION OF FAST ICE IN THE KARA SEA

The area under study is located in the northeastern part of the Kara Sea, behind the line connecting the Dikson Island and Zhelaniya Cape and restricted to the north by the line connecting the Zhelaniya Cape and the northern extremity of the Archipelago Severnaya Zemlya (see Figure 1). One of the basic features of spatial distribution of shore-fast ice extent in this area is a bimodality of its frequency distribution in spring, mentioned by Borodachev (2000). The results of our estimations presented in Figure 2 support this suggestion. There are evident two local maxims of fast ice area 90-110*10^3 km^2 and 120-140*10^3 km^2.

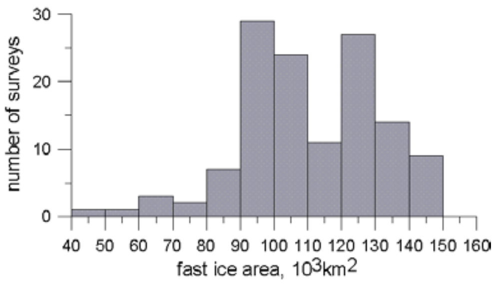

Figure 2 The frequency distribution of fast ice area in the northeastern Kara Sea in spring. Based on the AARI data (1953-1990).

Analysis of position of fast ice boundary in spring revealed the correspondence between the maxims in the frequency distribution of the area of fast ice and its spatial configuration (see Figure 3).

The first maximum, hereafter called the S-mode, is associated to the position of fast ice border following the line connecting the Archipelago Severnaya Zemlya - Isachenko Island – Sterlegova Cape. It typically extends less then 25 km from the shore along the rest part of border. With a few exceptions this mode represents the minimal possible extent of fast ice in the region under study.

The second maximum, hereafter called the L-mode, is associated to the expansion of fast ice edge to the southwest. Further consideration showed that the mode L could be split into two parts L_1 and L_2. In the case of the mode L_1 the southwestern border approaches the line between the islands of Izvestiy ZIK and the western bound of Khariton Laptev’s coast. Fast ice in the mode L_2 extends further to the southwest encompassing the area around the Sverdrup Island. This mode represents the largest extent of fast ice in the northeastern Kara Sea and

---

Corresponding author address: Dmitry Divine, Norwegian Polar Institute, Polarmiljosenteret, N-9296 Tromso, Norway, (47) 77750558; e-mail: dmitry.divine@npolar.no

forms the tale of the frequency distribution function with areas above $130*10^3$ km^2. It is seen from the Figure 3 that the seaward position of fast ice varies insignificantly, within 25 km, whereas the variations of fast ice extent in the northeastern Kara Sea are mostly due to the advances and retreats of the southwestern border of fast ice along the coast of Taymyr Peninsula.

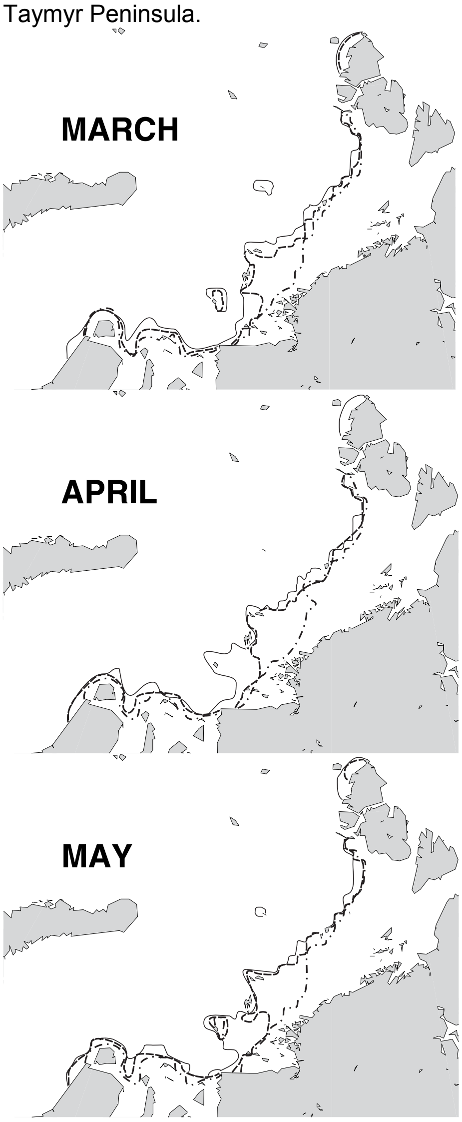

Figure 3 The average positions of fast ice borders corresponding to three modes of fast ice formation. The dash-dot, dash and the firm lines designate the S-, L_1- and the L_2-modes, respectively.

Table 1 shows mean areas and probabilities for each mode of shore-fast ice. We identified in May 20 years when fast ice in the northeastern Kara Sea had been formed in one of the L-modes and 17 years when the S-mode had been observed. The obtained results allow to suppose the existence of two different regimes of fast ice formation, partly driven by the surface air temperature anomalies and the system of prevailing winds.

Table 1 Average fast ice areas (in 10^3 km^2) and the respective relative frequencies of occurrence for three modes of fast ice in the northeastern Kara Sea.

Month	Mode S	Mode L_1	Mode L_2
March	94±5 (0.45)	125±4 (0.26)	132±10 (0.14)
April	97±5 (0.40)	120±7 (0.20)	135±8 (0.25)
May	98±6 (0.39)	124±4 (0.22)	137±8 (0.30)

3. RELATION OF TEMPORAL-SPATIAL DISTRIBUTION OF FAST ICE WITH METEOROLOGICAL CONDITIONS

The analysis showed significant correlation (about-60%) between mean winter air temperature anomalies, registered at all meteorological stations in the area under study (see Fig.1, Table 2), and average fast ice area for L-modes in May. In opposite the influence of the surface air temperature on formation of fast ice in S-mode was relatively weak. With two exceptions the correlation coefficients are insignificant, about -0.3.

There are no any significant correlations were found between fast ice extent and cumulative winter precipitation as well as with average snow depth winter.

Analysis of sensitivity of fast ice extent to the wind direction showed significant role of strong western and southwestern winds in ice extent development. During winter, winds from these directions tend to impede the expansion of fast ice. This is indicated by correlation of the same order (-55%) as for average winter temperature anomalies. Analysis of wind data also indicates that winds from northeast direction during June-July increases fast ice destruction while winds from northwest tend to restrain it. No correlations were found between the fast ice extent and the preceding summer river outflow rate.

Table 2. Correlation coefficients between average for September-April surface level air temperature and fast ice area in May for the L- and S-modes. (*Correlations significant at 95% level)

Station	L-modes	S-mode
Dikson Isl.	-0.60*	-0.05
Isachenko Isl.	-0.58*	-0.41
Sterlegova Cape	-0.57*	-0.18
Izvestiy ZIK Isl.	-0.66*	-0.28
Pravdy Isl.	-0.68*	-0.14
Russkiy Isl.	-0.58*	-0.22
Geyberga Isl.	-0.64*	-0.08
Krasnophlotskie Isl.	-0.50*	-0.19
Golomyanyy Cape	-0.60*	-0.46*
Uedineniya Isl.	-0.63*	-0.29

Analysis of the time-series of fast ice extent showed that the favourable conditions for expansion of fast ice seawards in spring are met if the atmospheric circulation over the northeast Kara Sea is controlled by the Arctic high, determining off-shore winds (from the second quarter) and significant, up to 6°C, decrease of the monthly average surface air temperature. (see Figures 4a,b). In opposite, the penetration of Icelandic low into the Kara Sea, accompanied by Arctic cyclones coming from the west is responsible for the partial break-up and decrease of fast ice extent in winter or spring (see Figure 4c).

In total time series of fast ice area in the northeastern Kara Sea shows negative trend for investigated period. The decrease is most pronounced in May and related to prevalent since 1980 the formation of shore-fast in S-mode. We speculate that the recent decrease of sea level pressure accompanied by the intensification of the western zonal flow, observed in the central Arctic, may force this process (Walsh 1996, Rogers 1995) and stipulate for more early shore-fast ice break up in the northeastern part of Kara Sea in 1990-1999 compared to 1953-1960.

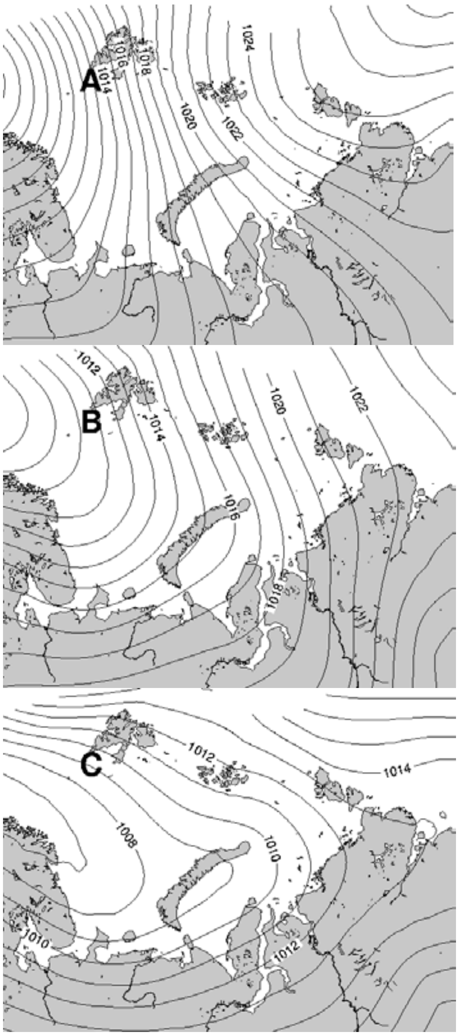

Figure 4 Mean monthly sea level pressure during events of fast ice expansion and partial break-ups: (a) 5 transitions from the mode S to the mode L_2; (b) 18 registered events of quick, within a month, fast ice expansion; (c) 6 registered events of the partial break-up of fast ice in winter or spring.

4.CONCLUSIONS

Shore-fast ice extent in the northeastern Kara Sea demonstrates significant temporal-spatial interannual variability in spring. The bimodal shape of the frequency distribution of fast ice area is determined by the spatial distribution of islands and the regime of atmospheric circulation above the Kara Sea. The analysis of sensitivity of fast ice extent to climate forcing revealed the substantial importance of the surface air temperature anomalies and western and southwestern winds on formation of fast ice in the mode L. In turn the mode S, representing the minimal possible extent of fast ice, is weakly susceptible to any interannual changes of meteorological conditions.

References

Borodachev, V.E., Gudkovich, Z.M., Klyachkin, S.V. & Smolyanitsky, V.M., 2000: Fast ice conditions in the Kara Sea and possible reasons of interannual changes of fast ice area.In *Transport and fate of contaminants in the northern seas, AARI final report*, Norwegian Polar Institute.

Divine, D.V. & Korsnes, R. 2003: Identification of shore-fast ice and flaw lead using SSM/I surface brightness temperature. *Submitted.*

Fetterer, F. & Radionov, V. (eds), 2000: Arctic Climatology Project. *Environmental Working Group Arctic Meteorology and Climate Atlas*. National Snow and Ice Data Center (NSIDC), Boulder, CO, CD-ROM.

National Snow and Ice Data Center (NSIDC), 1995: *Russian Rivers Data Set*. Boulder, CO, Digital Media.

National Snow and Ice Data Center (NSIDC), 1998: *Former Soviet Union Precipitation Archive, 1891-1993*. Boulder, CO, Digital Media.

National Snow and Ice Data Center (NSIDC), 2000a: *AARI 10-Day Arctic Ocean EASE-Grid Sea-Ice Observations*. Boulder, CO, Digital Media.

National Snow and Ice Data Center (NSIDC), 2000b: *DMSP SSM/I daily polar gridded brightness temperatures*. Boulder, CO, Digital Media.

Rogers, J. C. and E. Mosley-Thompson, 1995: Atlantic Arctic cyclones and the mild Siberian winters of the 1980s. *Geophysical Research Letters*, **22**, 799-802.

Walsh, J.E., Chapman, W.L., and Shy, T.L., 1996: Recent decrease of sea level pressure in the Central Arctic. *Journal of Climate*, **9**, 480-486.