J1.21 WIND-FORCED CURRENTS AS A LINKAGE BETWEEN THE LAPTEV SEA (SIBERIA) AND THE ARCTIC OCEAN

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1. INTRODUCTION

The first current measurements in the Laptev Sea were carried out in 1912. However, up to now there are no general publications describing the dynamics of this sea on the basis of field observations. The descriptions given in the summarizing works by Dobrovolsky and Zalogin (1982) and Pavlov et al. (1979) are based rather on geographical conceptions than on observational material (Fig. 1). According to the diagnostic hydrodynamic calculations by Pavlov and Pavlov (1999), the cyclonic circulation in the Laptev Sea is determined mainly by the surface salinity distribution (Fig. 1). It induces baroclinic deformations of the sea level, which exceed by far barotropic wind-forced variations. However, wind-forced sea-level oscillations in the eastern part of the Laptev Sea may reach 200-220 cm (Ashik et al., 1999). Consequently, the barotropic currents due to wind-forced sea-level variations can also be of importance for the formation of the current regime. This is supported by the results of the modeling of large-scale wind-forced water and ice circulation in the Arctic Ocean of Proshutinsky and Johnson (1997) and by earlier works on the modeling of wind-forced sea-level variations by Gudkovich and Proshutinsky (1988).

So far there have been no direct simultaneous long-term measurements of currents and sea level in the Russian Arctic. For the first time in the history of the investigation of the Russian Arctic, two oceanographic bottom stations equipped with an Acoustic Doppler Current Profiler (ADCP) and a bottom CTD were deployed on the shelf of the Laptev Sea for one year in 1998-1999 within the framework of the Russian-German project “Laptev Sea System 2000”. Our article is concerned with the discussion of some results of these observations.

2. DATA SETS AND METHODS

The northern ADCP station YANA was deployed in the region of the average position of the fast ice edge on the slope of the eastern submarine valley of the Lena River at the depth of 44 m. The southern station LENA was deployed east of the Lena River delta at a depth of 22 m (Fig. 1). Current measurements were carried out every minute from August 1998 to September 1999. A Broadband Acoustic Doppler Current Profiler Workhouse 300 kHz recorded the 3-D currents, averaged every 30 minutes, and acoustic echo intensity. The ADCP observations were divided into uniform depth cells (bins) of a height of 2 m for YANA station and 1.5 m for LENA station. The bottom CTD measured temperature, water conductivity, and pressure every hour. For the interpretation of the results, the data of CTD observations during the Russian-German expeditions aboard RV “Polarstern” (July-August 1998) and RV “Yakov Smirnitsky” (August-September 1999), monthly satellite RADARSAT ScanSAR images of the Laptev Sea, and the daily meteorological information from the polar stations of Dunay and Kotelnyy islands were also used (Fig. 1). In order to exclude periodical components of currents, a high-frequency digital filter and daily and 10-day running averages were applied.

3. RESULTS

Episodical southern currents with a time interval of 2 to 7 days determine the circulation regime in the region of the eastern submarine valley of the Lena River during almost the entire year (station YANA). In the layer below the pycnocline, up to 91% of the current dispersion is caused by these. According to the data of the actual measurements (averaged over 10-day intervals), the meridional component of these currents in the layer below the pycnocline (14-16 to 44 m) strongly depends on ice conditions. It varies from 20-22 cm s^{-1} in open water to 4-8 cm s^{-1} under uncompacted drift ice. Under a compacted ice cover and fast ice, these currents do not exist. The maximum velocities are observed at the depth of 20-25 m. According to the data (10-day average), the surface water layer flows on average in a northern direction with a velocity V of up to 2 cm s^{-1} during winter and during summer in the opposite (southern) direction with a velocity of 4-8 cm s^{-1}. The zonal component of 10-day average currents does not exceed 4 cm s^{-1} for the whole year. During winter these currents with low velocities (<2 cm s^{-1}) are also traced in the near-bottom layer below the pycnocline at LENA station. At YANA station, such currents were recorded 28 times during the observation period. In six of these cases, the current velocity exceeded 45 cm s^{-1} with a direction of 174° to 189°. The maximum velocity was 59 cm s^{-1}. The development of southern near-bottom currents was always preceded by stormy

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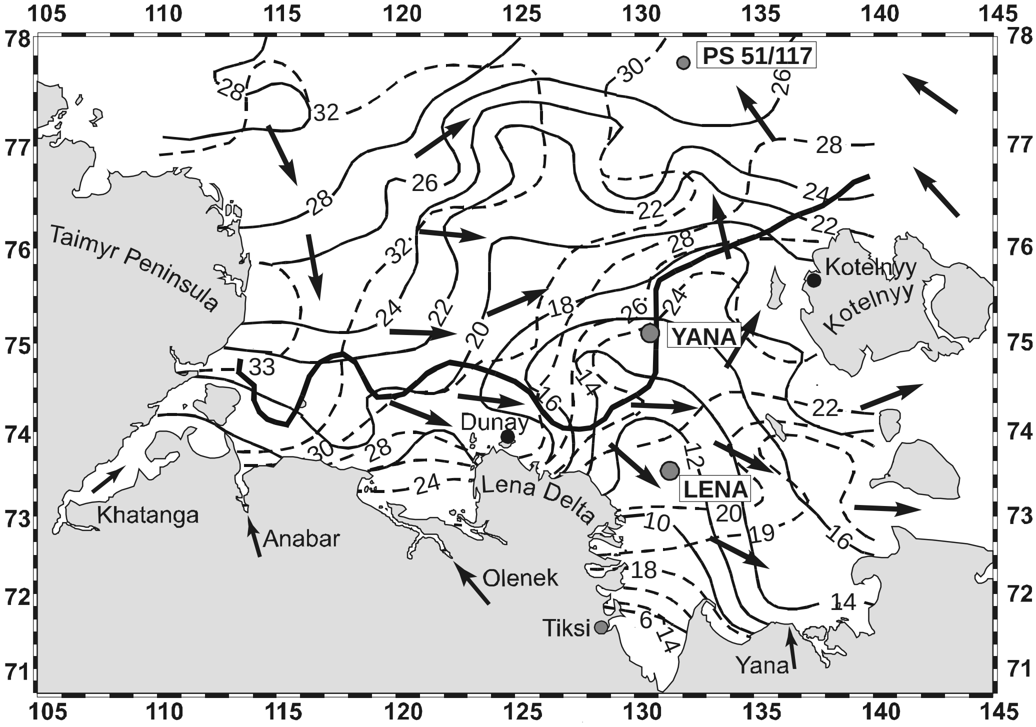

Figure 1. The position of ADCP stations and long-term average (1960-2000) surface salinity distribution for summer (solid lines) and winter (dashed lines). Surface circulation (arrows) are shown according to (Pavlov et al.,1996). The fast ice edge (bold solid line) is presented for the March-May 1999.

conditions at the sea surface. 1-2 hours before the increase in intensity of the southern current in the near-bottom layer, the surface water layer up to the depth of the pycnocline moved in a northern direction with a velocity of up to 50 cm s^{-1}. Within 1-2 days, the current direction in the surface layer changes to the opposite. A portion of records for the current vector projection on the meridian at YANA station is presented in Fig. 2.

4. DISCUSSION

The existence of reversal currents in the Russian Arctic seas was proposed by Antonov (1961). Near-bottom reversal currents in a southwesterly direction with a velocity of up to 100 cm s^{-1} were repeatedly observed in Barrow Canyon on the shelf of the Chukchi Sea (Aagaard and Roach, 1990; Weingartner et al., 1998). The frequency and intensity of reversal (upwelling) currents in Barrow Canyon as well as in the Laptev Sea decreases under the ice during winter (Aagaard and Roach, 1990). The good interrelation with local wind allows one to suppose that these currents are of an upwelling nature. For the investigation of the interrelation of wind and currents, the daily mean wind at the meteorological station on Kotelnyy Island was used. The correlation between the projections of daily wind and filtered currents in the direction of the axis of the Lena valley (168°) for the conditions of open water and under ice are presented in Table 1. They support the wind-forced origin of reversal currents.

The CTD records of sea level make it possible to understand the mechanism of the formation of reversal circulation in the eastern part of the Laptev Sea. The amplitude of the non-periodic sea-level oscillations exceeds the typical range of tidal oscillations (20 cm) by 3-5 times, reaching 80 cm. Non-periodic sea-level oscillations as well as reversal currents are subject to seasonal variation. The lowest sea level is observed while southerly winds prevail and the highest when the wind blows from northern directions. The correlation coefficients between time series of non-periodic sea-level oscillations and wind and current projections are shown in Table 1. During summer, the strong wind from the south causes stable wind-forced currents directed to the north in the southern part of the sea (station LENA). Due to this fact in the central part of the sea (station YANA), barotropic deformations (depression) of the sea level occurs, which reaches 84 cm. Compensatory southern upwelling currents with a velocity of 59 cm s^{-1} occur in order to reduce the sea-level depression. They reach a maximum within 11 hours after the beginning of the sea-level deformation. During winter the fast ice extends far from the coastline (Fig. 1). It completely restrains the influence of wind on the water column. Therefore the wind-forced currents are not observed at LENA station. Drift ice considerably weakens the influence of wind on the circulation in the

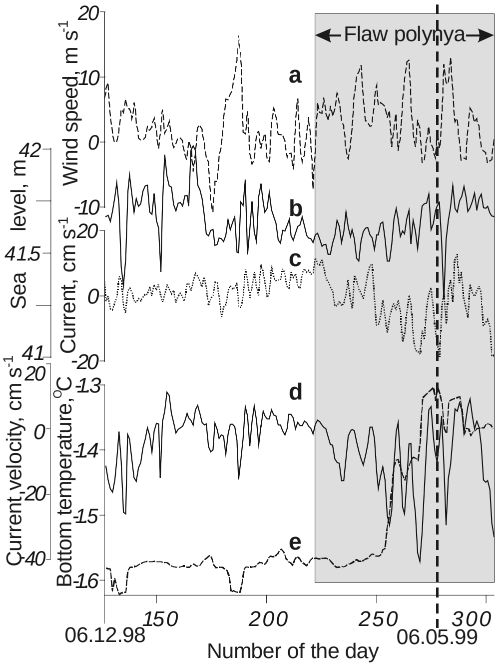

Figure 2. Time series of sea level (b), meridianal projection of wind (a), currents for 12 m (c) and 24 m (d) and bottom temperature (c) for station YANA.

surface layer. Therefore reversal currents are less strong during winter or are completely absent when the ice cover is much-compacted (Fig. 2). The fast ice reduces wind influence at LENA station. That may also explain why reversal currents from the north, reaching the shallow water area, were registered during winter at this location (Fig. 3c).

At the end of April 1999, continuous southerly winds caused the opening of a wide flaw polynya and a sharp intensification of reversal currents in the region of the YANA station. They induced advection of relatively warm waters from north to south along the submarine valley of the Lena River. In the near-bottom CTD records, a temperature increase by a value of up to 0.2°C is observed at the end of April/beginning of May 1999 (Fig. 2e). In the CTD records taken 4 km to the east of YANA station at the same time, there was also registered an increase (inversion) in temperature by 0.18°C at the depth of the pycnocline (Fig. 3d). Phenomena of increase of near-bottom water temperature due to advection of Atlantic water by upwelling currents were repeatedly observed in Barrow Canyon. It is known that the warm Atlantic waters in the Laptev Sea are found at depths below 80-100 m (Nikiforov and Shpaykher, 1980). During the RV “Polarstern” expedition in summer 1998, an increase in water temperature was registered already from 37 m onwards (Fig. 3c) at the oceanographic station PS51/117 (Fig. 1). A near-bottom temperature increase was also observed in this area during the RV “Yakov Smirnitsky” expedition in summer 1999. Probably, the temperature increase at these depths was caused by (i) heat exchange of Atlantic water with the water layers lying above in the north and (ii) advection of these warm waters to the south by reversal currents. Another consequence of reversal currents is the resuspension of bottom sediments. It was repeatedly observed while reversal currents prevailed in the form of an increase of acoustic echo intensity in the near-bottom layer.

5. CONCLUSIONS

For the first time, upwelling currents were instrumentally registered in the near-bottom layer below the pycnocline in the seas of the Russian Arctic shelf. These currents determine the water circulation in the observation area during much of the year. They show a sharply pronounced seasonality and are completely absent when sea ice is much compacted during winter. Reversal currents are caused by wind-forced deformations of the sea level occurring due to offshore winds of southeasterly directions. Upwelling currents cause the advection of relatively warm waters from the north in the layer below the pycnocline. This is an indirect proof of vertical heat exchange between the Atlantic water and the water layers lying above them in the northern Laptev Sea. Probably, reversal currents are typical of the submarine relic river valleys in the Laptev Sea. These regions of the sea can be considered as the zones of the most intensive interaction between the Arctic Ocean and the Laptev Sea.

6. ACNOWLEDGMENTS

This work was carried out with the support of the Russian Ministry of Science and the German Federal

TABLE 1. Correlation between wind, sea level and currents for the open water (right upper corner) and under the ice (left lower corner) for station YANA

	Sea level	Current, 12 m	Current, 24 m	Wind
Sea level	-	0.24* 19 h., 0.39**	0.46 11 h., 0.52	-0.56 10-11 h., –0.61
Current, 12 m	0.28 17 h., 0.38	-	0.74 5 ч., 0.75	-0.13 60-82 ч., -0.42
Current, 24 m	0.43 12 h., 0.48	0.69 3 h., 0.70	-	-0.24 31 h., -0.40
Wind	-0.23 13 h., -0.26	-0.04 < 0.10	-0.14 6-7 h., -0.15	-

*-correlation coefficient for the zero time shift, **-maximum correlation coefficient and corresponding time shift (h).

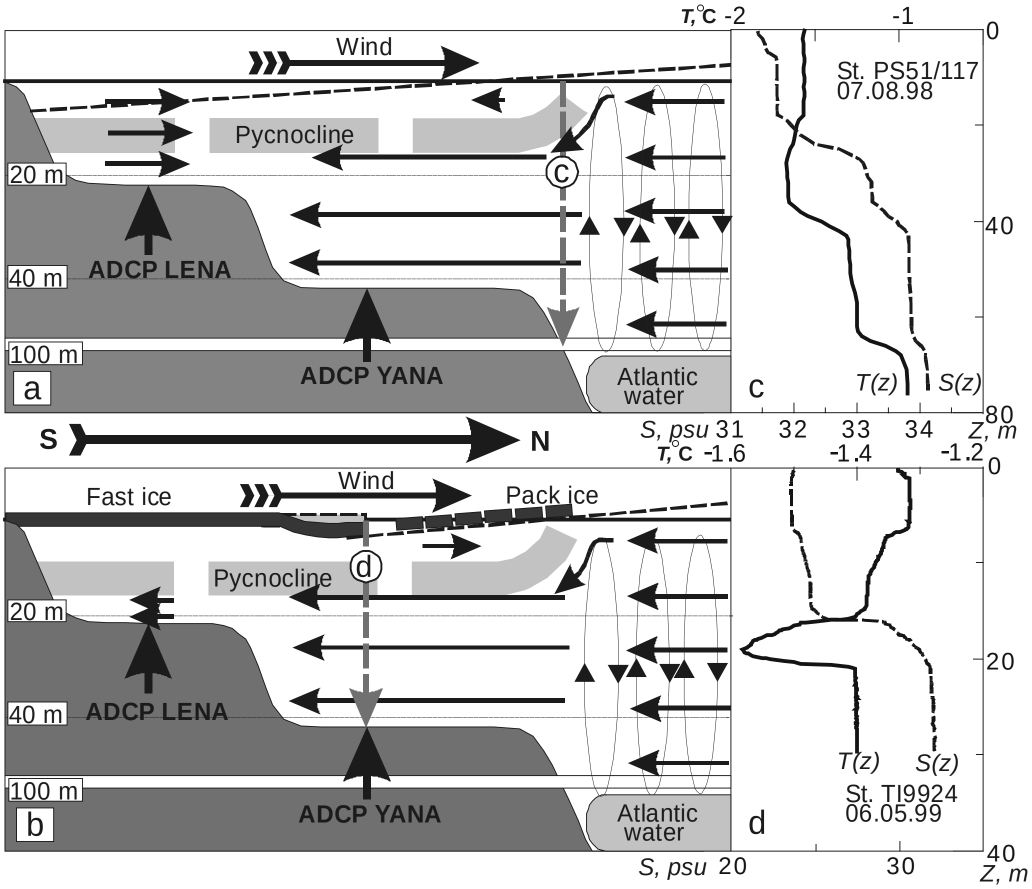

Figure 3. Schematic depiction of the reversal currents formation for summer (a), winter (b) and vertical salinity and temperature profiles for station PS51/117 (c) and TI9924 (d).

Ministry of Education and Research within the framework of the fellowship program of the Russian-German Otto Schmidt Laboratory for Polar and Marine sciences. Additional support by the National Science Foundation (OPP-9876843) is gratefully acknowledged.

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