Ekman Transport and Upwelling in the Arctic Ocean

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Ekman transport – the movement of ocean water caused by wind blowing steadily over the surface layers – is one of the most important variables in the study of oceanography. Its convergence or divergence can induce upwelling, linking subsurface oceanic processes with the surface mixed layer where air-sea and sea-ice interactions take place. Until recently, there has been no publicly assessable dataset of Ekman Transport in the Arctic Ocean. Fortunately, mathematical algorithms that are capable of retrieving sea ice motion data from satellites have been newly developed. With support from the Clark Arctic Research Initiative, I have computed a 28-year (1978-2006) daily field measurement of Ekman transport and upwelling over the entire Arctic Basin using both satellite and buoy measurements. The new data is being used in a number of investigations, including a study of the role of Ekman transport and upwelling on the retreat and partial recovery of the Arctic Cold Halocline layer (CHL) in the 1990s.

The Arctic Ocean Cold Halocline Layer is a cold water mass that lies between a cold, low-salinity surface mixed layer (ML) and a warm, salty Atlantic Water Layer (AWL) originating from the Atlantic Ocean. The CHL prevents the surface layer from mixing with the vast reservoir of heat in the AWL, therefore, helping to maintain the perennial sea-ice coverage in the Arctic Basin. Hydrographic observations have indicated that the CHL retreated in 1990s in the Eurasian Basin, which consists of Nansen and Amundsen Basins (Figure 1). The retreat enhanced upward heat flow and was estimated to result in an additional melting of sea ice in a range of 15-25 centimeters per year. According to observations recorded in the 1990s, the CHL had partially recovered.

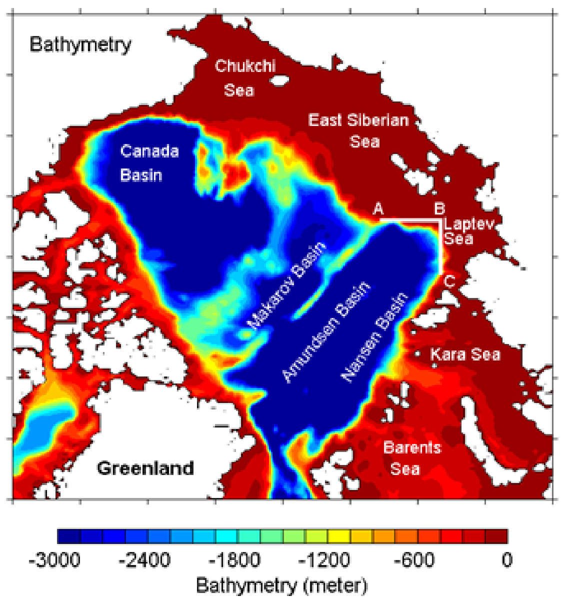

Figure 1: Area of study in the Arctic Ocean that included the Canada and Eurasian Basins.

The CHL retreat occurred within a period from 1988 to 1997 when the Arctic Oscillation (AO), a leading mode of Arctic atmospheric variability that is characterized by anomalies in sea level pressure, reached the highest level since 1950 (indicating low sea level pressure). This study focused on three periods: a high AO-index period in 1988-1997 and the periods before and after; 1979-1987 and 1998-2002, respectively, when the AO index was close to the mean level. In all three periods, there were always two sea level pressure (SLP) centers – the Beaufort High over the Canada Basin and the Eurasian Low in the Nordic Seas south and east of Greenland. Through the periods of 1979-87 and 1997-02, the Beaufort High dominated, and sea ice moved over the whole Arctic Basin. However, when the AO was high in 1988-1997, the Beaufort High weakened substantially and retreated toward the southern Beaufort Sea off the Canadian coast, and the Eurasian Low advanced northward into the Eurasian Basin. In a low pressure system such as the one that occurred in 1988-1997, the surface winds combine with the Coriolis effect (caused by Earth's rotation), to produce a counter-clockwise, or cyclonic wind. The stress from this wind forces a divergence in the surface Ekman layer away from the low SLP center, resulting in an upwelling that brings warmer, saltier water upward, thus reducing the salinity gradient and weakening the halocline layer (Figure 2).

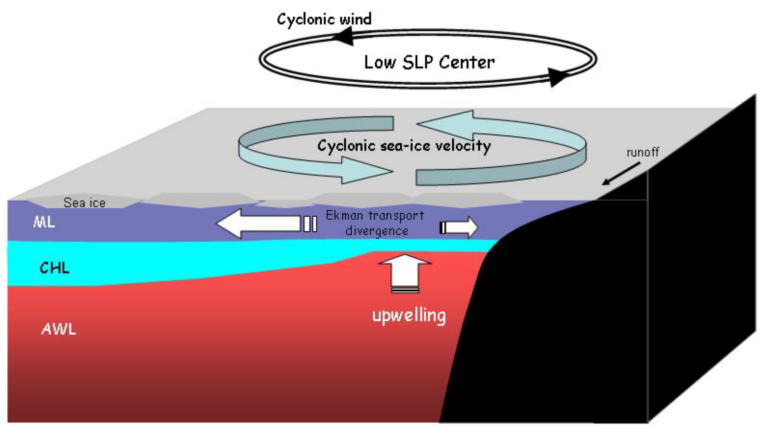

Figure 2: A schematic description of the oceanic response to a low sea level pressure (SLP) center and the resulting upwelling from the warmer, saltier, Atlantic Water Layer (AWL).

The new data showed that both before and after the CHL retreat, i.e., 1979-87 and 1988-02, the Ekman transport was roughly along the continental slope off Laptev and was directed from the Amundsen to the Makarov Basins. This changed in 1988-1997 as the Ekman transport shifted to the onshore direction from both Amundsen and Nansen Basins toward the Laptev Sea. The interior Ekman transport across the Lomonosov Ridge from the Amundsen to Makarov Basins had also increased in 1988-1997 compared to 1979-1987. These changes resulted in a larger divergence of Ekman transport and thus an enhanced upwelling in both the Amundsen and Nansen Basins. The increase in upwelling was particularly high off the Kara and Laptev Sea shelves and was largely induced by the shift of Ekman transport to the onshore direction there.

Both the upwelling and lateral Ekman transport affected the CHL state in the Arctic. Upwelling lifted the higher salinity water from below to the surface and weakened the density stratification that prevents mixing between the warm and cold layers. Hydrographic observations indicated that the salinity at 80 meters in the Amundsen Basin increased about 0.4-0.5 from 1991 to 1998 corresponded roughly to an uplift of the halocline by 30-50 meters. The averaged upwelling rate was 0.67 cm/day between 1979 and 1990 and 1.82 cm/day between 1991 and 1998. Therefore, the strengthening of the upwelling resulted in approximately an additional 30 meters of uplift of the halocline between 1991 and 1998 as compared with that prior to 1991. Moreover, the change in upwelling alone could account for a major portion of the salinity increase in the Amundsen Basin.

The data has shown that the magnitude of CHL variations is consistent with the published observations. I am grateful for the support from the Clark Arctic Research Initiative for making this research possible.