Continental Shelf Research 124 (2016) 134–141

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Spatial and temporal variability of sea-surface temperature fronts in the coastal Beaufort Sea

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ARTICLE INFO

Article history:
Received 4 September 2015
Received in revised form
20 April 2016
Accepted 2 June 2016
Available online 3 June 2016

Keywords:
Oceanic front
Sea surface temperature (SST)
Satellite imagery
Beaufort Sea
Canadian Arctic

ABSTRACT

An analysis of 11 years of sea surface temperatures images allowed the determination of the frontal occurrence probability in the southeastern Beaufort Sea using the single-image edge detection method. Results showed that, as the season progresses, fronts become more detectable due to solar heating of the surface layer. Some recurrent features can be identified in the summer time frontal climatology such as the Mackenzie River plume front, the Cape Bathurst front, the Mackenzie Trough front and the Amundsen Gulf front. These areas may be playing an important role in the biological processes acting as drivers to local enhanced biological productivity.

1. Introduction

The Arctic Ocean is currently at the forefront of climate change with a decrease in ice thickness over the central Arctic Ocean (Rothrock et al., 1999), a loss of multi-year ice.

(Perovich and Richter-Menge, 2009; Kwok and Cunningham, 2010) and an increase in the length of the ice free season (Smith, 1998; Rigor et al., 2002; Serreze et al., 2007; Comiso et al., 2008). This reduced ice cover means a more open ocean where phytoplankton production can occur (Arrigo and van Dijken, 2011, 2015; Ardyna et al., 2014; Tremblay et al., 2011). Phytoplankton production is a key ecosystem element that is at the base of the marine food chain. It is intimately linked to physical processes that regulate the availability of nutrients in the euphotic layer through modifications of the stratification. Such process includes wind mixing, tidal mixing, freshwater release during the ice melt period and terrestrial freshwater inputs closer to shore. Another process is the development of density fronts where different water mass encounters. Fronts are often characterized by convergent flow at the surface (Bowman and Iverson, 1978) resulting from processes such as baroclinic instability of coastal currents, coastal wind stress, and coastal upwelling events. Fronts are particularly ubiquitous physical features in the oceans. They play a major role in marine ecosystems (Longhurst, 2006) being directly linked to biologically productive regions (Castaleo et al., 2006; Miller, 2004, 2009; Takahashi and Kawamura, 2005; Belkin and O'Reilly, 2009) and thus acting as hotspots even in the subpolar oceans (Taylor and Ferrari, 2011). Therefore, to study the possible impacts of changing physical processes on phytoplankton productivity there is a need to assess the spatial and temporal variability of frontal features.

Satellite remote sensing is a powerful tool for monitoring key environmental parameters at global, regional and local scales. The identification and delineation of thermal fronts greatly benefited from the availability of long time series of sea surface temperature (SST) data and the advent of new edge detection algorithms. Recent studies described frontal features around Alaska (Belkin et al., 2003, 2009; Belkin and Cornillon, 2003, 2005), the Iberian Peninsula (Miller, 2004, 2009), the continental shelf off the northeast U.S. coast (Mavor and Bisagni, 2001; Ullman and Cornillon, 1999, 2001), the Baltic Sea (Kahru et al., 1995), the Japanese coast (Shimada and Kawamura, 2005), the East China sea (Hickox et al., 2000) and the northern South China Sea (Chang et al., 2010). Some studies were able to correlate frontal locations with atmospheric or oceanic forcing sources (Ullman and Cornillon, 1999; Wang et al., 2001). In the Arctic regions, Belkin et al. (2003; 2009) documented the presence of mesoscale fronts using low resolution (9 km) Advanced Very High Resolution Radiometer (AVHRR) data. Due to the low resolution of the data used, that approach was not able to detect the presence of fronts in the coastal areas. The objective of this paper is thus to investigate the spatial and temporal variations of SST fronts in the coastal Beaufort Sea and relate these to known biological features.

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http://dx.doi.org/10.1016/j.csr.2016.06.001
0278-4343/

2. Data and methods

2.1. Study area

The southeastern Beaufort Sea is located at the southern margin of the Canada Basin. It is known for its biological richness and is also the site of major hydrocarbon deposits. This area was well studied recently particularly during major oceanographic cruises (Ice Drift, CASES, CFL, ArcticNet, Malina, Icescape). It can be further divided in two regions having distinct bio-physical characteristics: the Canadian Beaufort Shelf and the Amundsen Gulf (Fig. 1). The Mackenzie Shelf is a broad, shallow continental shelf (~120 km wide; ~530 km long) that stretches from the Mackenzie Trough, a large canyon crossing the continental shelf and where large wind-driven upwelling events occur (Carmack and Kulikov, 1998; Williams et al., 2006), to the Amundsen Gulf. It is a unique Arctic ecosystem that receives large amounts of freshwater runoff from the Mackenzie River, the largest North American source of freshwater for the Arctic Ocean (Stewart et al., 1998), carrying large amounts of inorganic and organic matter, including living biota (Telang et al., 1991; Garneau et al., 2006).

The second important bio-physical region is the Amundsen Gulf located at the western end of the Northwest Passage, connecting the Dolphin and Union Straits, and the Prince of Wales Strait with the Beaufort Sea, and the Arctic Ocean. It is approximately 400 km in length and 150 km in width and is characterized by a southeasterly oriented deep central channel cutting through the shallow Mackenzie Shelf allowing water exchange with the Beaufort Sea up to a depth of ~300 m (Lanos, 2009). The area is characterized by the presence of the third largest polynya in the northern hemisphere, the Cape Bathurst polynya, offering habitats to birds and mammals (Harwood and Stirling., 1992; Dickson and Gilchrist, 2002; Harwood and Smith, 2002).

The entire area is usually covered by sea ice from November to June (Galley et al., 2008).

Water masses in the Beaufort Sea comprise the relatively fresh Polar Mixed Layer (0–50 m depth), the Pacific halocline and its winter-summer components derived from Bering Sea waters (50–200 m) and the deep waters of Atlantic origin (> 200 m) (Carmack and Macdonald, 2002; Jackson et al., 2010). The summer surface circulation is driven mainly by wind forcing, the Mackenzie River discharge (Ingram et al., 2009) and the anti-cyclonic Beaufort Gyre. Summer surface circulation in the Amundsen Gulf is weak, complex and variable being highly influenced by the winds (Ingram et al., 2009; Lanos, 2009; Sévigny et al., 2015). The eastward flowing Beaufort Undercurrent dominates the sub-surface circulation, bringing waters of Pacific and Atlantic origin into the Amundsen Gulf (Barber et al., 2010).

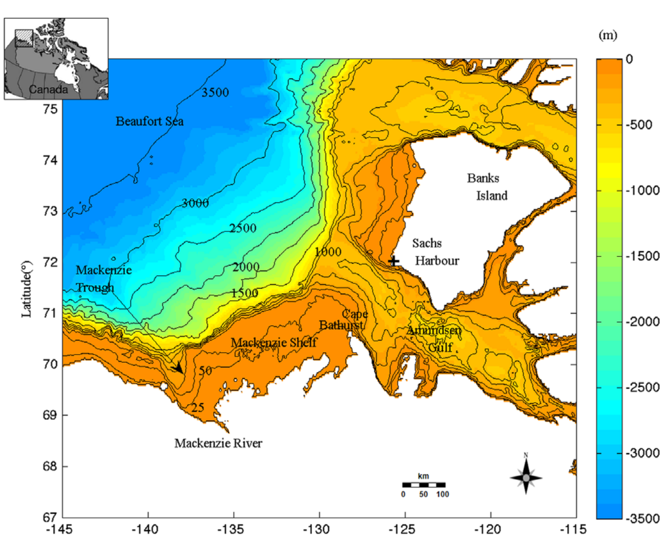

Fig. 1. Study area.

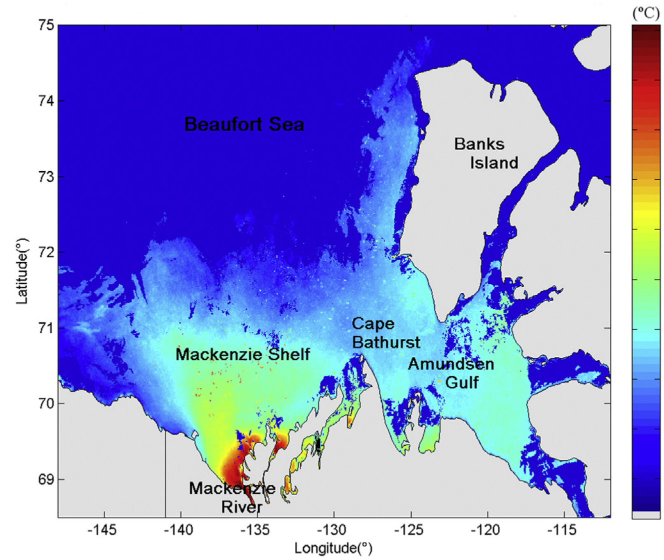

Fig. 2. Average (May–October) sea surface temperature (1998–2008) for the southeastern Beaufort Sea.

Fig. 2 shows the average summer months SST of the Southeastern Beaufort Sea. The Mackenzie Shelf is characterized by strong temperature gradients associated with the large Mackenzie River plume expansion leading to a general decrease of SST towards the offshore. In the Amundsen Gulf, the higher SST are found in the Eastern part of the gulf, in Darnley and Franklin Bays, and along Banks Island leaving the colder water to the central deeper portion. There are also areas of cold waters observed near Cape Bathurst and along the southern shore of the Amundsen Gulf. There is a large variability of that mean pattern that is highly influenced by the winds (Mulligan et al., 2010).

2.2. Data

Eleven years (1998–2008) of full resolution (1.1 km) AVHRR data were used to study thermal fronts in the Beaufort Sea. A total of 6602 individual images (day and night passes) were acquired and processed by the Maurice-Lamontagne Institute remote sensing laboratory (www.slgo.ca) covering the Beaufort Sea from 145°W to 115°W (Table 1). The raw AVHRR images were navigated and cloud and ice screened using the TeraScan software package (Seaspace Inc.) using tests that are based on pixel albedo in the two visible channels and temperature in the three thermal channels.

Tests are also made on the spatial uniformity of albedo and temperature over a 3×3 pixel box. These flagged data are then compared to ice coverage maps generated by the National Snow and Ice Data Center (NSIDC) to detect abnormal pixels that could have gone undetected through the cloud screening. Any NOAA pixel comprised within a NSIDC pixel having non zero ice coverage is flagged as ice covered. The sea surface temperatures (SST) were computed from each pass using the 'split window' Multi-Channel Sea Surface Temperature algorithm (McClain et al., 1985). A final test is done to further eliminate abnormal values that may have gone through cloud/ice screening by first applying a temporal homogeneity filter that compares SST with all other measurements made during a 15-day window centered on the image time, and then using a climatological filter that eliminates outliers above