Available online at www.sciencedirect.com
ScienceDirect
Deep-Sea Research II 54 (2007) 2657–2671
DEEP-SEA RESEARCH
PART II
www.elsevier.com/locate/dsr2

Temporal and spatial variability of chlorophyll concentrations in the Bering Sea using empirical orthogonal function (EOF) analysis of remote sensing data

Takahiro Iida[a,*], Sei-Ichi Saitoh[b]

[a]National Institute of Polar Research, 1-9-10 Kaga, Itabashi, Tokyo, Japan
[b]Laboratory of Marine Bioresource and Environment Sensing, Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan

Received in revised form 25 January 2007; accepted 5 July 2007
Available online 19 November 2007

Abstract

Seasonal and interannual variability of surface chlorophyll concentration in the Bering Sea was examined using Empirical Orthogonal Function (EOF) analysis of data obtained by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) from 1998 to 2002. The analysis of normalized monthly fields (removing temporal and spatial monthly means) shows that different temporal and spatial patterns are evident in the eastern and western Bering Sea during the spring bloom period. The first EOF mode explains 30% of the variability and shows how the eastern shelf break region and the western Bering Sea are out of phase during the spring bloom. The second EOF mode (17.6%) indicates a pattern involving the eastern shelf break region and the Kamchatka Basin. This strong east–west signal is linked by both surface winds and light. EOF modes of wind-speed anomalies, derived from Special Sensor Microwave Imager (SSM/I), and photosynthetically active radiance (PAR) from SeaWiFS, show a similar dipole feature where the east–west pattern is related to the position and strength of the Aleutian Low pressure system. In years when the Aleutian Low shifts from west to east, weaker wind stress facilitates the development of stratification resulting in a strong spring bloom in the western Bering Sea. The variability of spring chlorophyll has a strong connection with variability in atmospheric forcing in the Bering Sea.

Keywords: Bering Sea; Ocean-color remote sensing; Chlorophyll; EOF analysis

1. Introduction

The Bering Sea is a semi-enclosed sea spanning about 2 million km^2. It is connected with the Arctic Ocean through the Bering Strait, and with the North Pacific through the Aleutian archipelago (Fig. 1). It has a broad continental shelf in the east that contrasts sharply with a deep basin in the western region. Sea ice develops in winter in the northern and eastern regions, affecting not only the physical conditions but also the biological conditions (Hunt et al., 2002). The Bering Sea is one of the most productive ecosystems in the world with annual primary productivity of up to 2.0×10^8 t C per annum, accounting for 1.5% of the total primary production in the world (Tsyban, 1999). It supports major commercial fisheries for salmon,

*Corresponding author. Fax: +81 138 40 8844.
E-mail address: tiida@salmon.fish.hokudai.ac.jp (T. Iida).

0967-0645/$ - see front matter
doi:10.1016/j.dsr2.2007.07.031

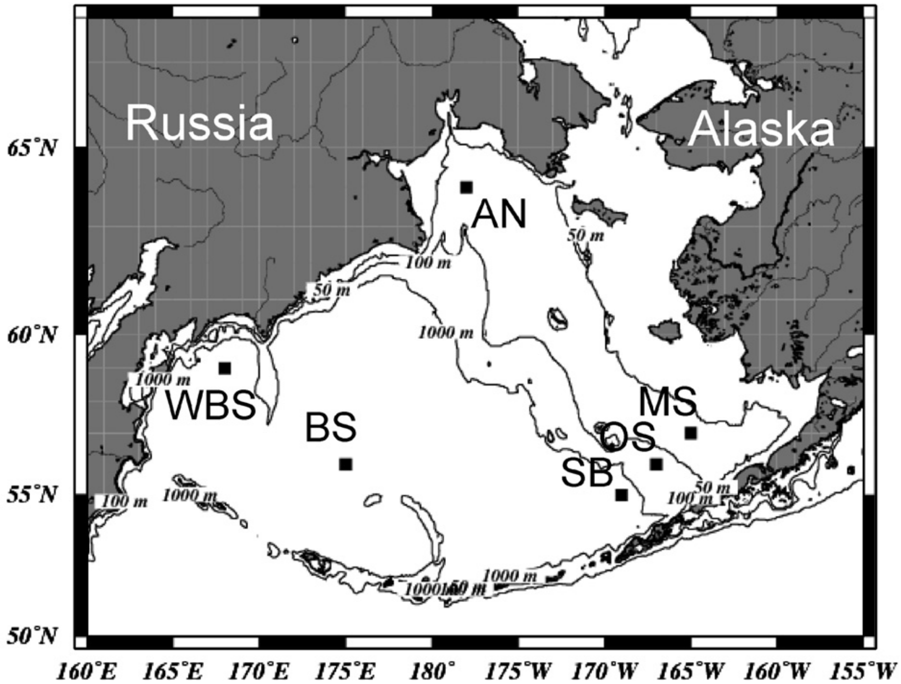

Fig. 1. Location of data sampling station in the study area. The abbreviation station names mean AN, Anadyr Bay; MS, Middle Shelf; OS, Outer Shelf, SB, Shelf; Break; BSB, Bering Sea Basin, WBS, Western Bering Sea.

crab, and walleye pollock (e.g., Loughlin et al., 1999).

The eastern Bering Sea shelf has been an area of intense scientific study in recent decades through international projects such as PROBES (Processes and Resources of the Bering Sea; McRoy et al., 1986). Recent reports suggest that the abundance of fisheries resources has been decreasing in recent decades (Schumacher et al., 2002). While the causes of these declines are uncertain, correlations between various indices of climate and the responses of marine ecosystems are thought to indicate that climate change is affecting the abundance of phytoplankton, zooplankton, and fishes in the Bering Sea (Hunt et al., 2002).

Hunt et al. (2002) proposed the Oscillating Control Hypothesis (OCH) to explain the mechanism. The hypothesis can be summarized as follows: a late retreat of sea ice in the spring leads to enhanced water-column stability and an early spring bloom in cold water associated with the sea-ice edge. In contrast, an early retreat of sea ice during warm years leads to later spring blooms because stabilization of the water column is delayed by wind mixing. The timing and magnitude of the spring bloom affect zooplankton feeding. If the bloom occurs in cold years, the abundance of zooplankton does not increase and the growth of large carnivorous fishes is limited. If blooms occur later in spring, as in warmer years, zooplankton abundance increases resulting in the growth of large carnivorous fishes. Therefore, the timing of the spring bloom is thought to be an important factor for Bering Sea marine ecosystems.

Phytoplankton synthesize carbon through photosynthesis and provide organic matter that is required by the rest of the marine food web. Zooplankton consume varying proportions of primary productivity. Springer et al. (1996) reviewed primary production in the Bering Sea and found that it is about 125–175 $\mathrm{g\,C\,m^{-2}\,y^{-1}}$ over the eastern shelf, and 150–275 $\mathrm{g\,C\,m^{-2}\,y^{-1}}$ at the eastern and western shelf break and around the Aleutian Islands region. A region of high primary production is distributed zonally along the shelf break in a region that they called the "Green Belt".

Climate affects sea-ice distribution in the Bering Sea (Niebauer, 1988; Niebauer and Day, 1989), mainly through the effect of storm events in winter. The winter Aleutian Low develops in the northern Bering Sea or along the Aleutian Islands (Schumacher and Kinder, 1983). Strong winds associated with the Aleutian Low also influence the Kamchatka Current. The magnitude of wind-induced transport