Interannual variability of spring bloom in the Gulf of Maine observed by SeaWiFS

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ABSTRACT: Eight years of SeaWiFS data quantify variability in the time/space patterns of spring bloom development in the Gulf of Maine (GOM). Maximum and earliest spring bloom are usually observed over Georges Bank, later on the deep basins from the west to the east GOM, and latest development along the eastern Maine coast in cold, tidally mixed water. Pronounced interannual variability of spring bloom timing, spatial position, and magnitude are shown in the GOM. Strongest negative anomalies are present in April 1998 and 2001 over Georges Bank and the eastern GOM, and in January to April of 2005 over the most of GOM. Positive anomalies are strong in April 2001, 2003 and 2004 in varying locations as well as in February and March 1999. It is suggested that interannaul variability in spring phytoplankton bloom concentrations is strongly associated with changes in water mass and stratification which might be influenced by basin-scale forcing due to large climate change.

KEY WORDS: Gulf of Maine, spring bloom, ocean color, chlorophyll, Sverdrup hypothesis

1. INTRODUCTION

The Gulf of Maine (GOM) is a semi-enclosed continental shelf sea surrounded by the Northeastern coast of America and Nova Scotia (Fig. 1). Intrusion of deep slope waters through the Northeast Channel is an important source of nutrients supporting biological productivity in the GOM (Townsend, 1991). The flux of deep water into the surface layer is linked to vertical mixing by tides and winter convection. River discharge and surface cold, low salinity Scotian Shelf Waters entering the GOM are important to biological production in terms of nutrient source and vertical stratification (Townsend, 1998).

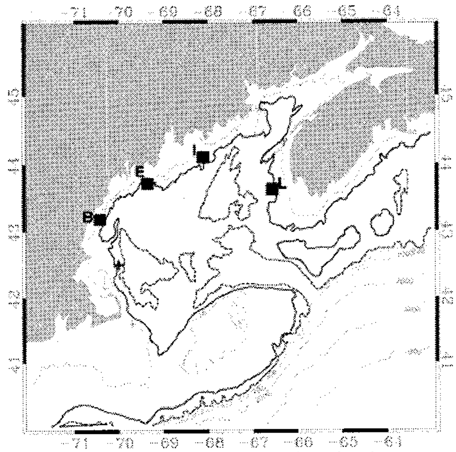

Figure 1. The Gulf of Maine showing bathymetry (thick closed line–100m, dashed line–200m) and major geographic features. GOMOOS buoy stations (squares) are also shown.

The spring bloom is an important biological event in the GOM. Studies have described the spatial and temporal pattern of spring bloom over the GOM based on ship measurements showing that the spring bloom begins earliest in shallow coastal areas, later over offshore banks and latest over deeper basins and the shelf edge (Bigelow, 1927; Riley, 1947).

Ocean color satellite data such as the Coastal Zone Color Scanner (CZCS) and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) have been used to address the spatial and temporal patterns of phytoplankton pigment concentration in the Northwest Atlantic including the GOM (Eslinger et al., 1989; Yoder et al., 2002). They observed that pigment increase over the deeper basins of the southern GOM occurred in March and April and that spring peak of chlorophyll concentrations appeared in March–April in the Northwest shelf. Thomas et al. (2003) showed that the timing and magnitude of spring phytoplankton bloom in the GOM varies with regions using four-year time series of SeaWiFS images.

Few studies have been achieved on interannual variability of the oceanic environment in and around the GOM. Interannual variability of the spring bloom seems to be controlled by differences in vertical stability on the Scotian helf (Perry et al., 1989). Changes in deep water flux through the Northeast Channel may strongly control the budget of nutrients in the GOM, which influence the phytoplankton production (Townsend et al., 1987). It has been suggested that large scale climate variability such as the North Atlantic Oscillation (NAO) could influence nutrient ratios and zooplankton population in the GOM as well as hydrological structure (Pershing et al., 2001).

In this paper, we quantify the time and spatial patterns of mean seasonal and interannual variability of spring bloom development in the GOM over the 8 year (1998–2005) time series of SeaWiFS chlorophyll measurements. We explore relationships between bloom variability, forcing, and stability using various data set.

2. DATA and METHODS

Eight years (1998-2005) SeaWiFS daily Level-2 chlorophyll-a (OC4 ver. 5) images at a resolution of 1×1 km were obtained from the NASA Goddard Distributed Active Archive Center. The level-2 data were remapped to a standard mercator projection at 1.1 km resolution. Since January of 2005, SeaWiFS data are available only at a resolution of 4×4 km from the NASA due to the expiration of the contract between NASA and the ORBIMAGE. The SeaWiFS Level-2 chlorophyll-a from January to June of 2005 were used and then resampled to the standard mercator projection at 1.1 km resolution to match the data before 2005.

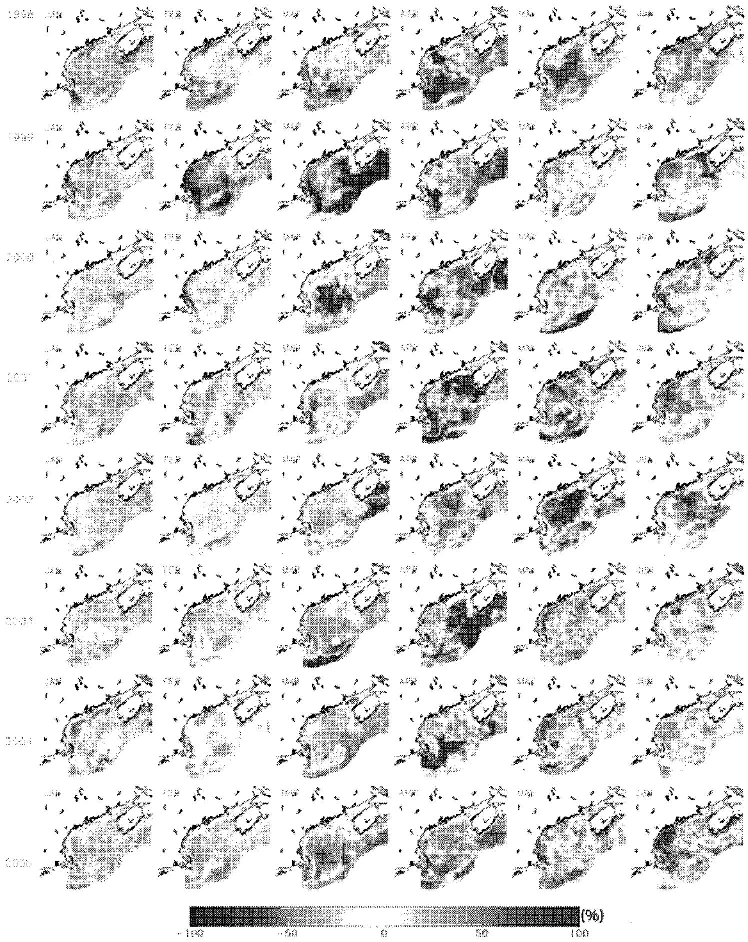

Figure 2. Anomaly percent of monthly SeaWiFS chlorophyll for the first 6 months in 1998-2005.

3. RESULTS

To investigate interannual differences in patterns of timing, spatial position, and magnitude of spring bloom development, the time series of anomaly percentage images of the SeaWiFS monthly chlorophyll composites from January to June over the 8 years is shown in Fig. 2. We used the anomaly percent since the magnitude of chlorophyll variability over Georges Bank and the coastal regions are very significant, which could hamper to see relatively the variability over the basin and the offshore regions. In 1998, strong negative anomalies are present over Georges Bank and positive anomalies are over the mid-western GOM. This year is characterized by relatively lower anomalies over all regions in both May and June. However, strong positive anomaly appears over the Western Maine Coastal Currents (WMCC) area. Early and strong positive anomalies are shown over Georges Bank, shelfbreak region, and the Scotian Shelf in 1999 (February and March). In April, anomalies over the eastern GOM and the Scotian Shelf are negative. Positive anomalies appeared over the western area of Nova Scotia in June. Relatively early and strong positive concentrations are over the western GOM including Georges Bank in March, 2000. In April, negative anomalies are present over the eastern GOM, but positive over Georges Bank and the Scotian Shelf. Opposite anomaly patterns are shown in April 2001 (positive over the eastern GOM and negative over Georges Bank and the Scotian Shelf). In 2002, the anomalies over the GOM are negative in April and switch to positive in May (strongest) and June. Strong positive anomalies are present over the eastern portion of the GOM and the Scotian Shelf in April 2003 while negative anomalies are over the western portion. Strong positive anomalies are shown over the western area of Georges Bank in April, 2004. Relatively strong negative anomalies are shown over most of the area in January–April, 2005. Especially, negative anomalies are pronounced over the most of regions with the strongest anomalies of April.

Climatological bloom development quantifies the climatological spatial and temporal pattern over the study area (Fig. 3). Initiation of the climatological spring bloom begins earliest over Nantucket Shores and then over Georges Bank and the Scotian Shelf (about 60 days). Later, the spring bloom develops in the west of the GOM (about 90 days) and moves to the east (about 100 days). Latest bloom development is in the northeastern coastal region and the Bay of Fundy (about 120 days). However, there is significant interannual variability in timing of spring bloom. Unlike general pattern of timing of the spring bloom, the timing is earlier in the east of the GOM (about 50 days) than in the west (about 100 days) in 1999. Slightly earlier spring bloom in the eastern GOM than that in the west is shown in 2003. Relatively later spring bloom over Georges Bank is present in 2001, 2003, and 2004. In 2000, there is a significant gradient in the timing of spring bloom between the northeastern and the southwestern GOM. In addition, the latest bloom is present over the northeastern region and the southern fronts of Georges Bank. The timing of spring bloom is earliest over the Wilkinson Basin and the western Maine coastal current area in 2001.

4. DISCUSSION

Over the GOM, the satellite-measured spring phytoplankton bloom generally occurred from March to May, but magnitude and timing of the pattern varies with location (Fig. 2). Early spring bloom is observed on Georges Bank and the Scotian Shelf. Then the spring bloom appears in the west GOM, later in the east GOM, and latest in the Bay of Fundy and the northeastern coastal region. These general patterns of spring bloom are consistent with those presented in the literature. Ship measurements from Georges Bank have shown the spring bloom over the region develops relatively early, even in January and February (Townsend and Thomas, 2001), induced by limitation in the depth of vertical mixing due to the shallow bathymetry (Townsend et al., 1994). The late spring bloom along the eastern Maine coast seems to be associated with strong advection and a cold, well mixed water column throughout the year. However, spring bloom development does not always move from the west to the east of the GOM: spring bloom appeared earlier in the east GOM than in the west in 1999 and 2003 (Fig. 3).

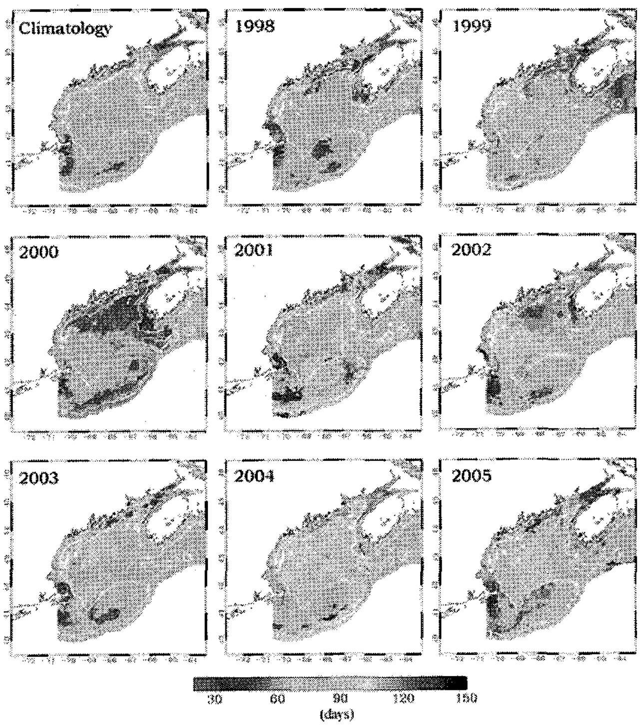

Figure 3. Timing of initial day of spring bloom for climatology and each year from 1998 to 2005.

Pronounced interannual variability of spring bloom development is observed over the GOM (Fig. 2 and Fig. 3). Strongest negative anomalies are present in April 1998 over Georges Bank and the eastern Gulf of Maine, and in Jan-Apr of 2005 over the most of the GOM. Positive anomalies are strong in April 2003 over the eastern region and April 2004 over the west, and also in February and March 1999 over the most of the GOM. Two possible mechanisms which would link interannaul variability of deepwater properties to the surface chlorophyll interannual variability have been well summarized by Thomas et al. (2003). It is inferred that nutrient concentrations within the GOM is strongly controlled by deepwater input through the Northeast Channel that would support growth of phytoplankton in the surface waters through strong vertical mixing (Townsend et al., 1987). The other possibility is related to subsurface stratification at the depth shallower than the critical depth (Townsend and Spinrad, 1986). In the Northeast Channel, a pycnocline and vertical stability due to warm, saline subsurface water assisted initiation of spring bloom in March 1997 and 1999, while spring bloom was delayed or reduced by lack of vertical stratification in upper waters in March 1998 (Thomas et al., 2003). They suggested that the reduced concentrations in 1998 are coincident with cold, low salinity and that interannaul variability in phytoplankton biomass is induced by basin-scale forcing associated with the NAO.

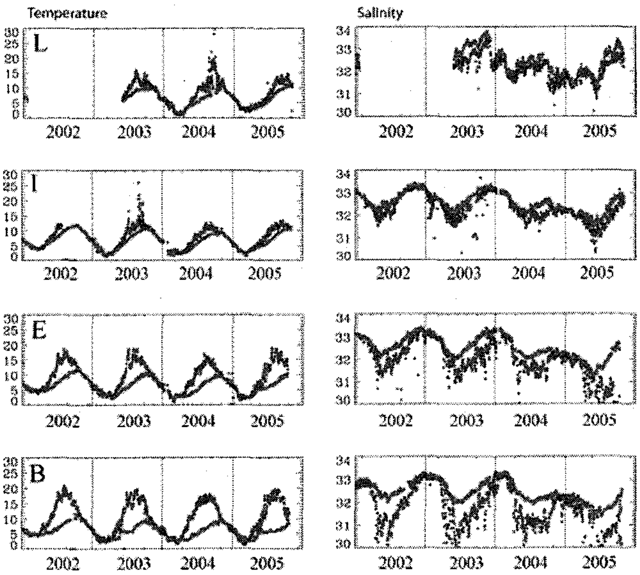

Figure 4. 4-year time-series of temperature and salinity at 1m (blue) and 50m (red) measured at four GOMOOS buoy locations shown in Fig. 1.

Time series of temperature and salinity at 1 m and 50 m measured by the GOM Ocean Observation System (GOMOOS) buoys are shown in Fig. 4. While no pronounced interannual change in temperature is observed, significant low salinity appeared from late-2004 to early-summer in 2005. Although salinity at surface water in the costal stations could be strongly influenced by river discharge from spring to fall season, the waters at 50 m are not likely affected by fresh waters from river. In most of stations, salinity in winter 2004-2005 is lower by about 1 psu than that in winter of other years. Dense Slope Waters are known as important water masses to oceanography in the GOM with vertical mixing and river discharges (Hopkins and Garfield, 1979). The cold, low salinity Scotian Shelf Waters account for about half of freshwater budget for the GOM (Smith, 1983) and are an important source of nutrients entering the eastern GOM as much as Dense Slope Waters through the Northeast Channel (Townsend, 1998). Townsend and Thomas (2001) showed that high phytoplankton chlorophyll observed on March 1997 are associated with a stable water column induced by the Scotian Shelf Waters. However, it is also possible that strong vertical stratification during winter due to the apparently lower salinity impedes input of enough nutrients to the surface layer. Thus it is inferred that the reduced chlorophyll concentrations in spring 2005 are associated with the pronounced low salinity through changes in water stability.

Large scale climate variability such as NAO influences the circulation and water mass properties of the Labrador Current and the Gulf Stream, which affects the GOM (Taylor and Stephens, 1998). Annual average abundance of zooplankton (*Calanus finmarchicus*) was highly correlated with NAO with 3-4 years lag (Pershing et al., 2001). It has been known that advective transport in the GOM is associated to *Calanus finmarchicu* populations (Miller et al., 1998). It is inferred that interannual variability in biological constituents in the GOM are related with basin-scale forcing induced by climate change through the influence on the water column properties with time lag.

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