Variability in phytoplankton biomass on the Scotian Shelf as viewed from space: Imagery from the CZCS Ocean Color Sensor (1978-1986) and SeaWiFS (1997-present)

W. G. Harrison[1], T. Platt[1], B. Petrie[1], S. Sathyendranath[2]

[1] Fisheries & Oceans Canada, Ocean Sciences Division, Bedford Institute of Oceanography, Box 1006, Dartmouth, NS B2Y 4A2.
[2] Department Of Oceanography, Dalhousie University, Halifax, NS B3H 4J1.

ABSTRACT

Remote-sensing remains the only tool available to oceanographers for synoptically monitoring the marine system at the regional to global scale. The Coastal Zone Color Scanner (CZCS), 1978-1986, and the recently (1997) launched Sea-viewing Wide Field-of-view Sensor (SeaWiFS) are satellite-mounted instrument systems which provide information on the spatial and temporal variability of ocean biota (phytoplankton abundance) at the large scale. Over 700 High-resolution (2 km) CZCS colour images been processed (using improved atmospheric correction algorithms) as part of a study of the variability of phytoplankton biomass in eastern Canadian continental shelf waters. Seasonal phytoplankton cycles and regional differences in biomass levels are described and related to hydrographic and nutrient properties. Preliminary estimates of primary productivity based on CZCS data revealed regionally distinct seasonal cycles and annual production levels. New ocean colour products from the SeaWiFS mission are briefly discussed.

Introduction

The launch of the Coastal Zone Color Scanner (CZCS) aboard NASA's Nimbus-7 satellite in 1978 marked the beginning of a new era in Biological Oceanography. For the first time, high-resolution (~1 km) data on the distribution and abundance of ocean phytoplankton were obtained on a global scale; at peak operation, up to 400 images were generated per month. CZCS data were collected for more than seven years (until 1986); however, no data were collected during the intervening 10 years until the launch of a number of follow-on radiometers starting in 1996. The most recent launch, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) has been collecting high-quality data on ocean colour since September, 1997 [8]. Up until the launch of the most recent sensors, NASA expended considerable effort in processing the CZCS data and making it accessible to ocean researchers worldwide [8]. These data have been widely used in regional studies of phytoplankton and primary production [5], in the estimation of primary production on the global scale [7] and as a tool in partitioning the ocean into distinct ecological units [6].

Researchers with the Canadian Department of Fisheries and Oceans (DFO) are exploiting CZCS and SeaWiFS data in an investigation of role phytoplankton as a food source for zooplankton and gadoid ichthyoplankton on the continental shelf off Nova Scotia. This research project is one of a number Canada is contributing to the national and international

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GLOBal ocean ECosystems dynamics (GLOBEC) programs focusing on the northwestern Atlantic ocean [3]. The general goal of GLOBEC is to address the question of how global climate change will affect the abundance and production of animals in the sea, emphasizing direct environmental affects and indirect effects through foodweb interactions. The aim of the primary production component of the Canadian program is to develop a description of spatial and temporal variability in phytoplankton biomass and primary production on the continental shelf off Nova Scotia, and to use this information to help understand interrelationships of variability in hydrography, circulation, nutrients, phytoplankton biomass, zooplankton supply and gadoid ichthyoplankton distributions. This paper reviews some of the preliminary results of that project to illustrate the value of remotely-sensed ocean colour data in phytoplankton research.

Materials and Methods

From the archive of ocean colour data collected during the seven year CZCS mission (November 1978-June 1986), 746 images were generated for the continental shelf of Nova Scotia. For this data analysis, the continental shelf was subdivided into three regions: the Gulf of Maine/Georges Bank; the Scotian Shelf; and the Laurentian Channel (Fig. 1). Data reprocessing was required to provide higher resolution images than the standard NASA product, to provide more precise navigation with coastlines, and to take advantage of improved atmospheric corrections for more accurate phytoplankton biomass estimation (Table 1).

Table 1. CZCS ocean colour data processing requirements.

- *Image Registration*

  The level 1A files are required to register the data to the coastline.
- *Non-binned products*

  Products that are not spatially or temporally binned are required.
- *Higher Resolution*

  The preprocessed CZCS data are only available in 4 km resolution at best. Two (2) km resolution is required.
- *Atmospheric Correction*

  The preprocessed CZCS data are all processed using a single set of angstrom values. This produces inaccurate results for many scenes. Angstrom values specific to each scene were calculated.
- *Standard Remapping*

  A set of geographic regions has been selected for the Canadian east coast. Each CZCS scene is mapped onto one of these regions using consistent geographic coordinates and map projection.
- *Co-registering with SST*

  The above procedure allows the co-registering of CZCS data with sea-surface temperature data at the same resolution and with the same mapping.

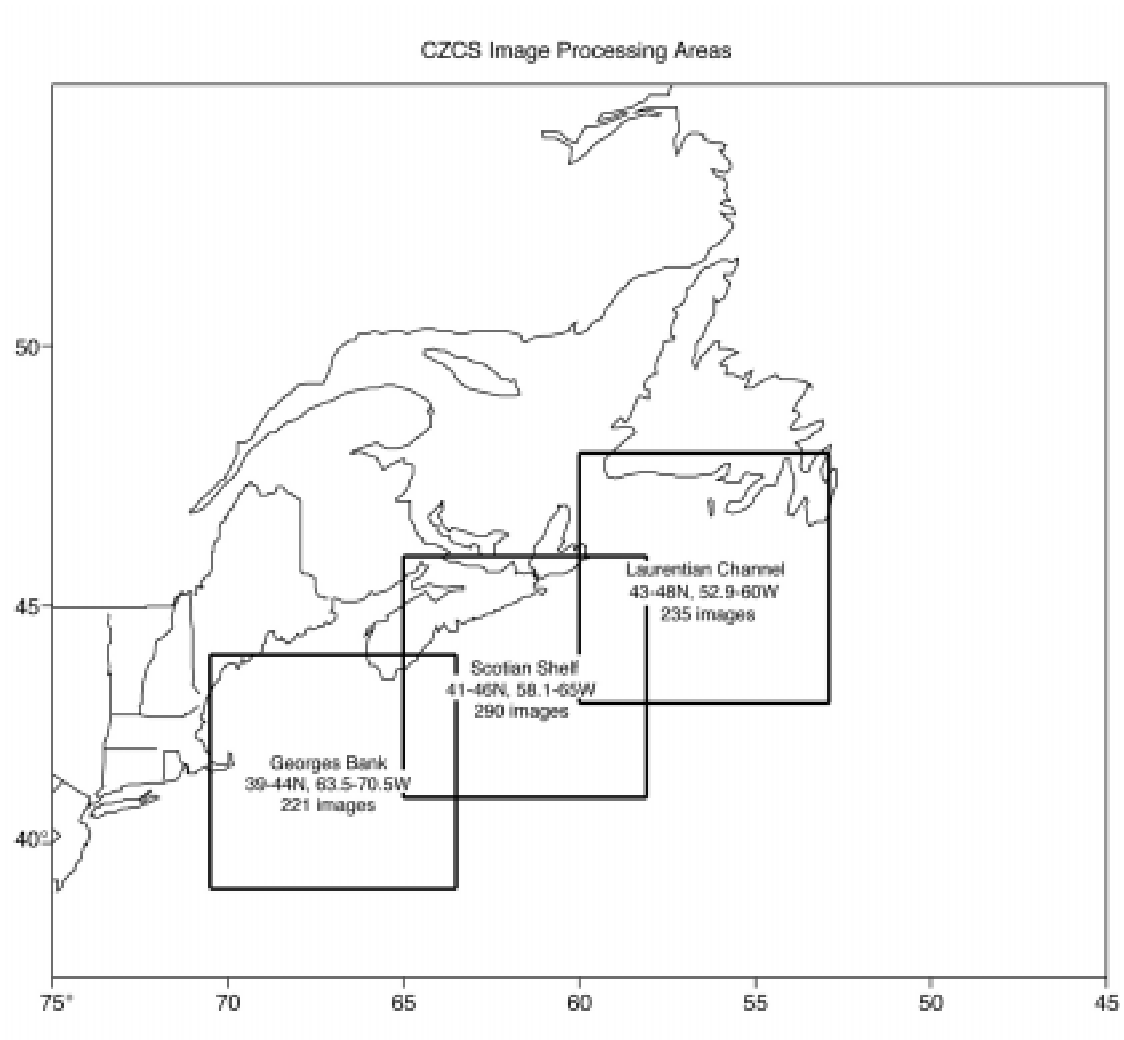

Fig. 1. CZCS image processing areas (512 x 512 pixels): Gulf of Maine/Georges Bank, Scotian Shelf and Laurentian Channel. No. of images processed for each region is indicated.

Results

Monthly and annual composite images of phytoplankton biomass were generated for the three regions. Usable data were collected for only nine months of the year (February-October) with the best coverage generally during the months of June-September. Seasonal cycles in biomass were similar among regions although levels were always highest in the Gulf of Maine/Georges Bank region. Inter-annual variations showed a general decrease in biomass over the lifetime of the CZCS mission in all regions (Fig. 2). Analysis of the interannual variations by selected months showed that this trend could be attributed largely to a decrease in biomass during late spring, summer and fall; biomass levels remained relatively stable or actually increased over time during the early spring months (Fig. 3).

Seasonal and geographical variations in phytoplankton biomass were investigated in relation to regional hydrography and nutrient distributions. Areas with seasonally persistent high biomass (observed along the inner boundaries of the Gulf of Maine, on

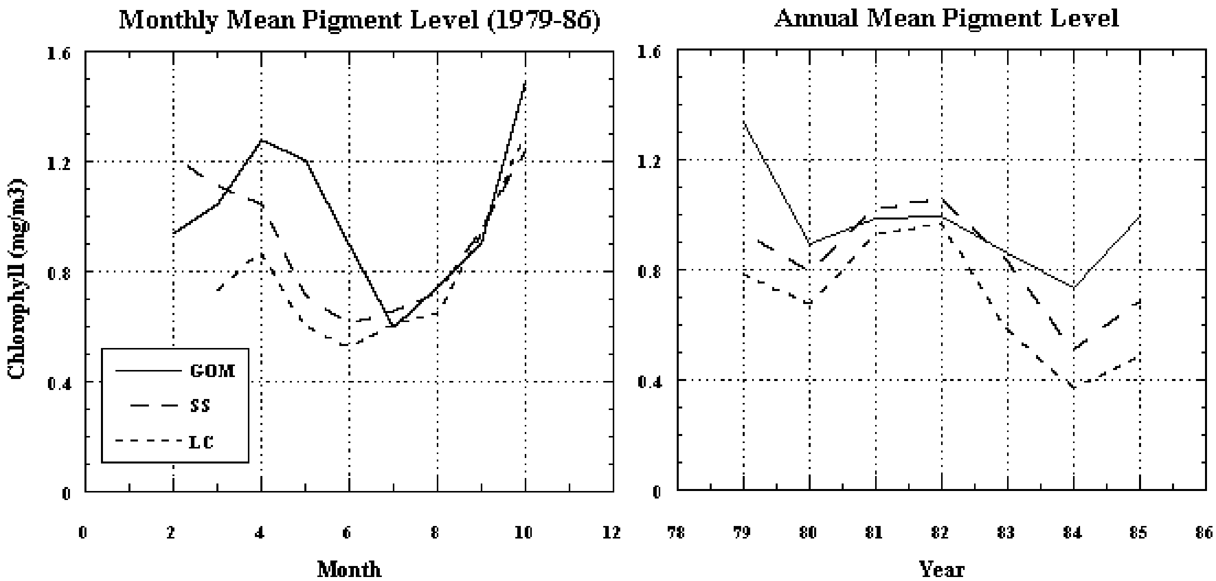

Fig. 2. Variations in phytoplankton biomass (chlorophyll a) from CZCS imagery by month (left panel) and by year (right panel) for the three regions: Gulf of Maine/Georges Bank (GOM), Scotian Shelf (SS), Laurentian Channel (LC).

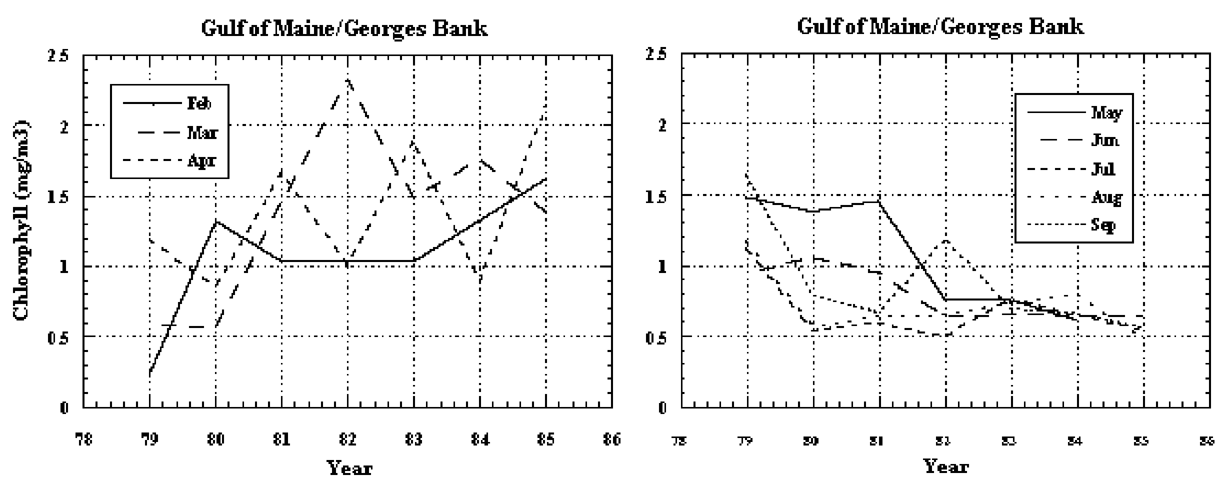

Fig. 3. Inter-annual variations in phytoplankton biomass (chlorophyll a) from CZCS imagery during the early spring months (Feb-Apr, left panel) and late spring, summer and early fall months (May-Sep, right panel).

Georges Bank and off the southwestern coast of Nova Scotia, for example) are areas of strong tidal mixing and upwelling, processes which transport nutrients that fuel high productivity and result in regional accumulation of biomass (Fig. 4). Climatological data on surface nutrient concentrations confirm this (Fig. 5). Phytoplankton biomass can also covary with nutrient distributions in an inverse sense; this can be seen on the eastern Scotian Shelf in late summer/fall where biomass levels are high and surface nutrient concentrations low (Figs. 4 & 5). In this case, it is likely that biological demand during the fall production peak exceeded the rate of nutrient supply by mixing in the region.

Discussion

An important next step in exploiting satellite ocean colour data will be the generation of primary productivity maps from the derived biomass fields. To accomplish this, however, additional information will be required, some accessible from satellites and some requiring ship-based data collection: (1) incident solar radiation; (2) optical properties of the water, i.e. light penetration; (3) the vertical distribution of phytoplankton in the water column; and

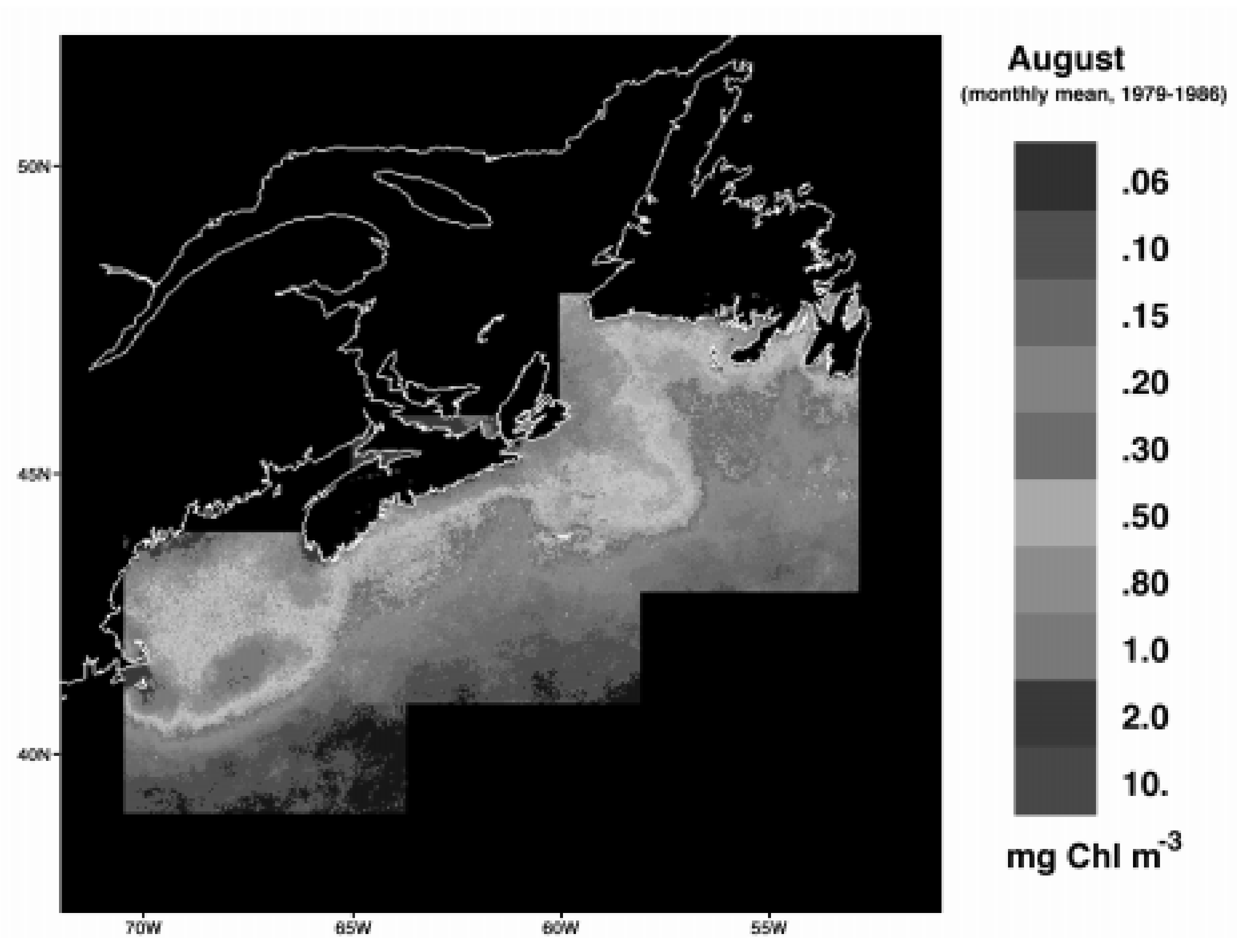

Fig. 4. Mean phytoplankton biomass (chlorophyll a) from CZCS imagery (1979-86) during August in the Gulf of Maine and along the Scotian Shelf.

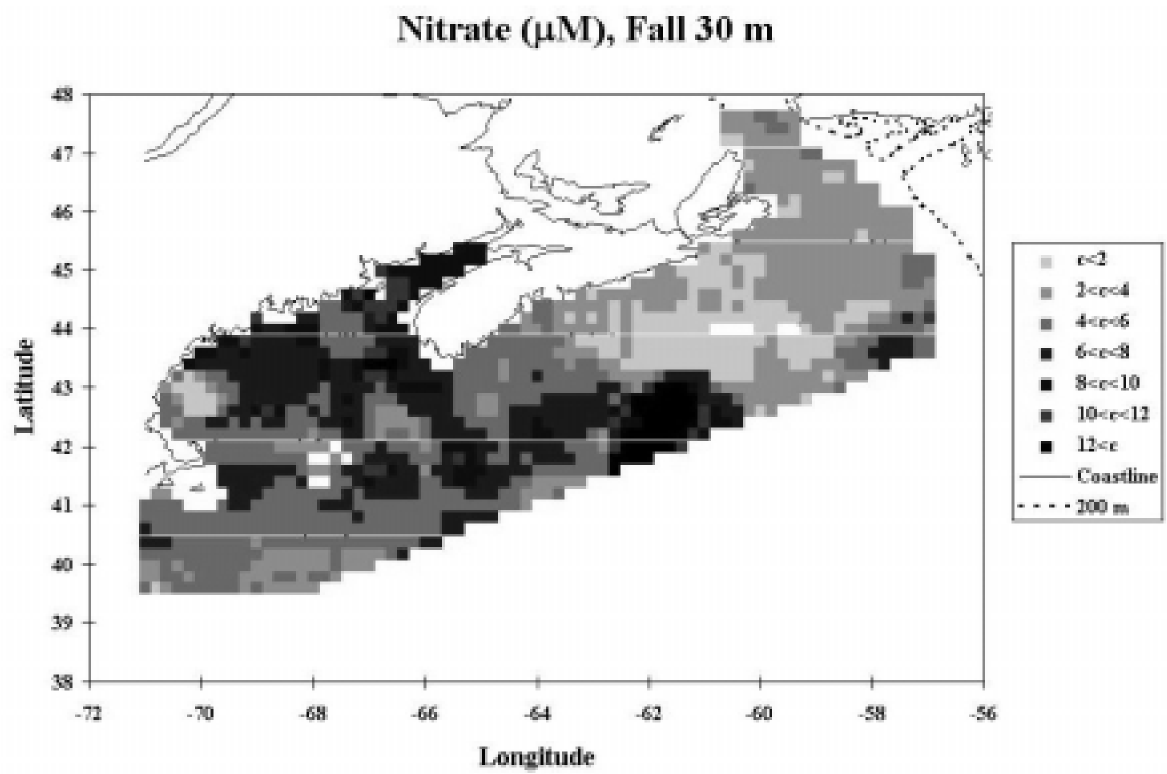

Fig. 5. Climatological mean nitrate concentrations in fall at 30 m depth in the Gulf of Maine and along the Scotian Shelf. Most of these data were collected during the period of the CZCS mission, i.e late 70s and early 80s.

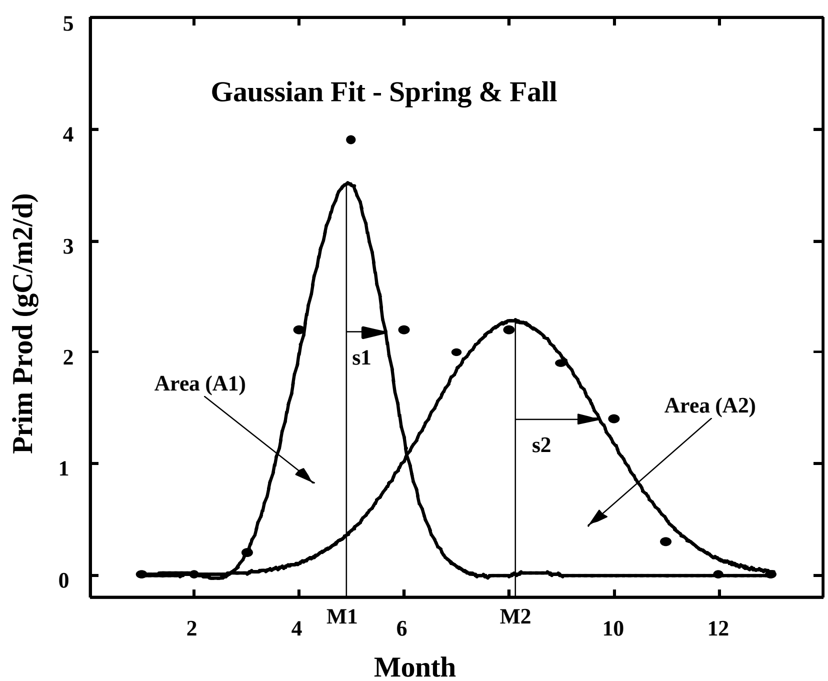

Fig. 6. Seasonal cycles of primary production in north temperate coastal marine waters are typically characterized by spring and fall "blooms" [6]. This bi-modal cycle can be mathematically described using a double-gaussian distribution where the parameters characterize the timing (M), magnitude (A) and duration (s) of the blooms.

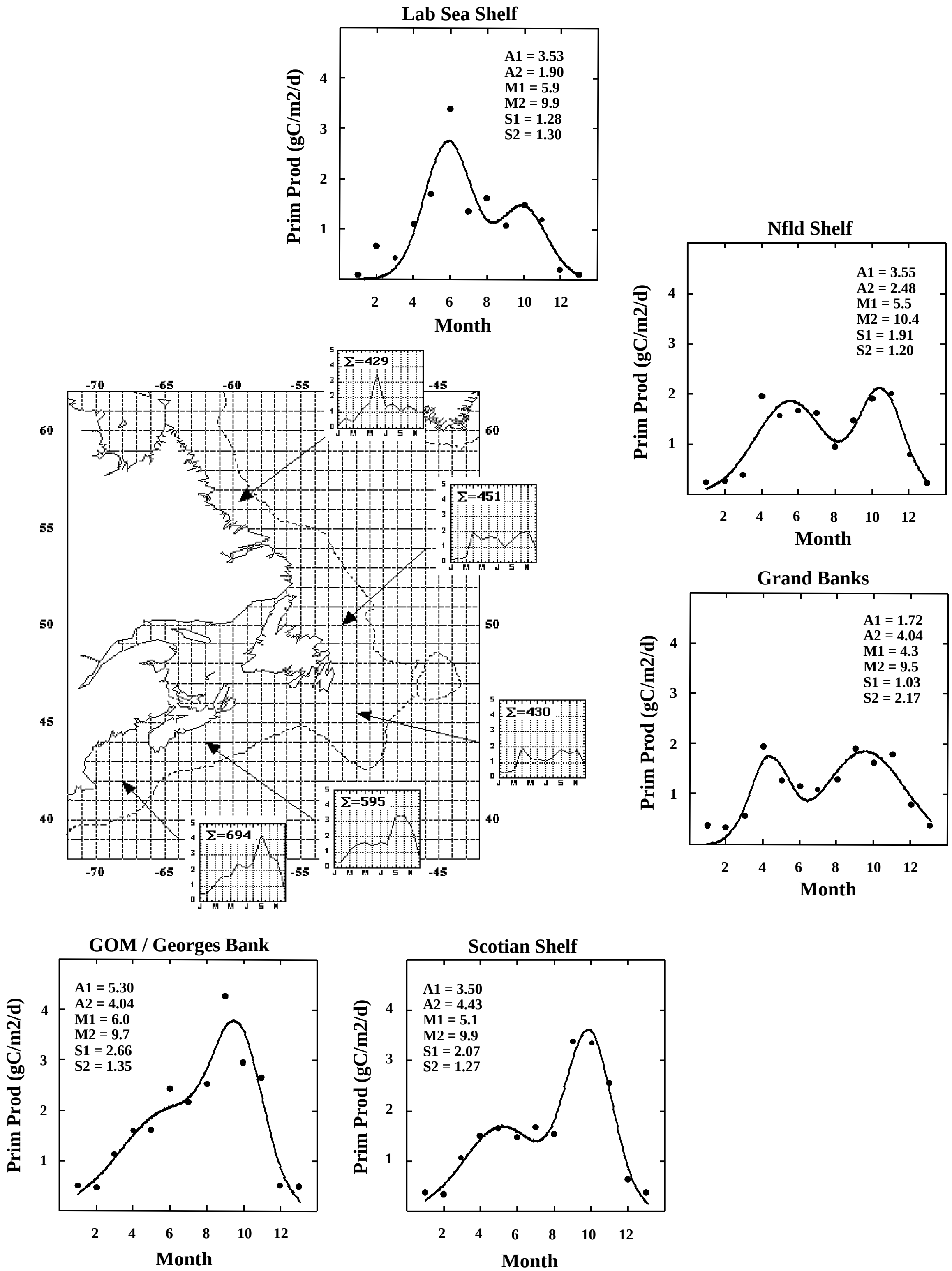

Fig. 7. Seasonal cyles of primary production in 1979 along the eastern Canadian continental shelf derived from CZCS imagery [10] (graphs of primary production are aligned with location on the map). Description of the bi-modal production peaks as Gaussian curves (see Fig. 6) reveals distinct regional differences in the timing, magnitude and duration of the spring and fall blooms.

(4) the photosynthetic properties of the phytoplankton, i.e. the photosynthesis-irradiance parameters [9, 11]. Once regional to global scale productivity maps are available on a routine basis, climate and fisheries-related problems requiring temporally resolved, large spatial scale information can be addressed. One of the important ecosystem links to fish population dynamics, for example, is thought to depend on the timing and magnitude of the spring phytoplankton bloom [1]. Seasonal cycles of primary production derived from ocean colour images can be parameterized using simple mathematical formulae (Fig. 6) and the parameters used to quantify regional differences (Fig. 7) and interannual changes in the production cycle of the base of the marine foodweb [4]. This information is also is critical for developing a better understanding of the role of ocean biota in the global carbon cycle [7].

For more than a decade following the end of the CZCS mission, no satellite-based data on ocean colour were available, a regrettable circumstance considering, for example, the fact that major declines were observed in a number of the worlds major fisheries during that period. Was this decline in some way linked to changes in regional primary production? Ocean colour data would have been an indispensable tool for addressing this issue. With the recent launch of a number of satellites carrying spectral radiometers (most notably SeaWiFS, Fig. 8), biological oceanographers once again have the tools to resume research

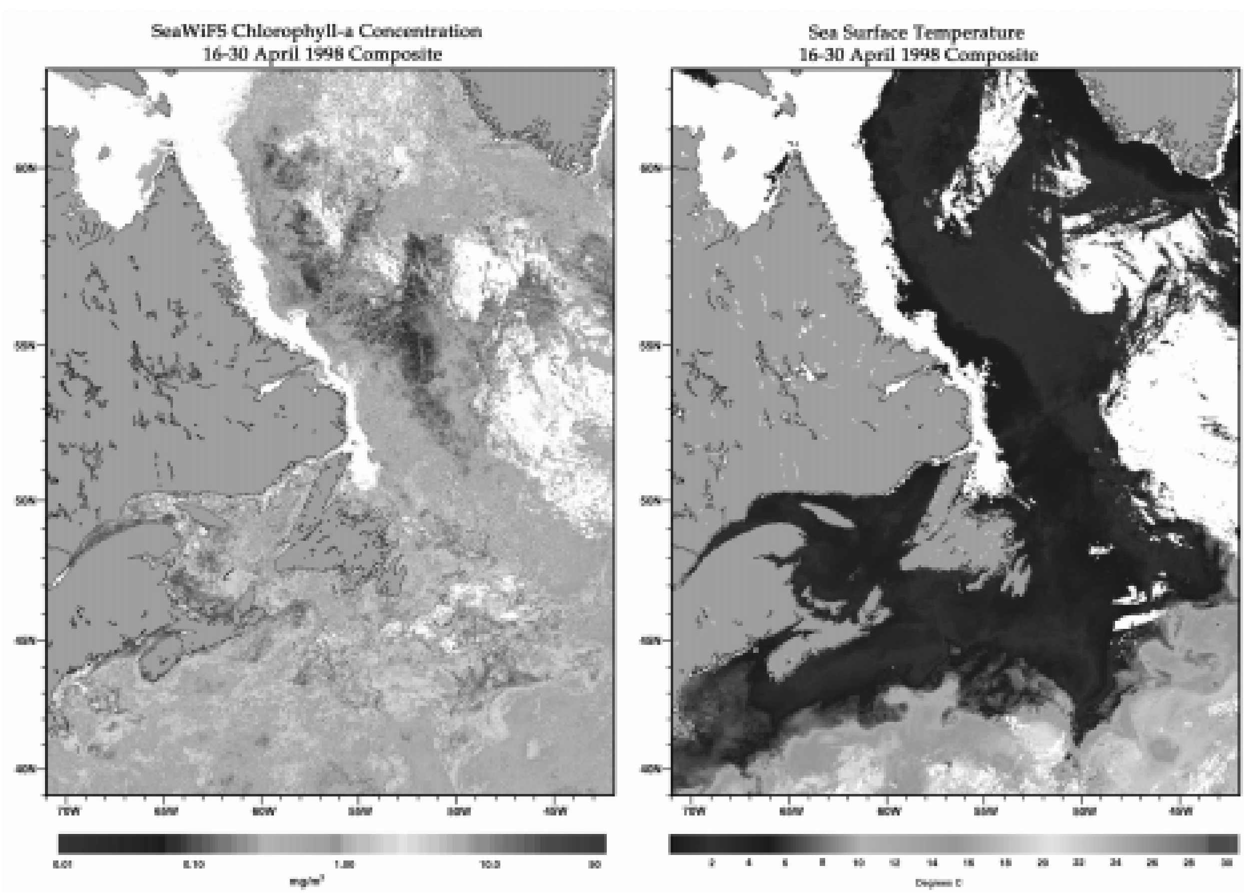

Fig. 8. High-resolution (~2 km) images of ocean colour (Sea-viewing Wide Field-of-view Sensor, SeaWiFS) and temperature (Advanced Very High Resolution Radiometer, AVHRR) during the spring of 1997. These images provide unprecedental detail of the large-scale variability and coherence in distributions of phytoplankton (ocean colour) and water mass features (sea surface temperature).

aimed at understanding the growth cycle and biogeochemical significance of marine phytoplankton on the regional to global scale.

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