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Application of SeaWIFS- and AVHRR-derived data for mesoscale and regional validation of a 3-D high-resolution physical–biological model of the Gulf of St. Lawrence (Canada)

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Abstract

We present here a first attempt to validate a regional three-dimensional (3-D) physical–biological coupled model of the Gulf of St. Lawrence with coincident Advanced Very High Resolution Radiometer (AVHRR)-derived sea surface temperature (SST) and Sea-viewing Wide Field-of-view Sensor (SeaWIFS)-derived Chlorophyll-*a* (Chl-*a*) data. The analysis focused on comparisons between remotely sensed data and simulated as well as in situ temperature, salinity, Chl-*a*, and nitrate. Results show that the simulated and AVHRR-derived fields of SST were qualitatively and quantitatively in agreement with in situ measurements. By contrast, marked differences were found between the simulated and SeaWIFS-derived fields of Chl-*a*, the latter comparing better with the freshwater-associated turbidity simulated by the model. Simulated temperature, salinity, nitrate, and Chl-*a* data compared well with coincident in situ measurements, and it is then suggested that freshwater-associated turbidity related to the river discharges largely contributed to the Chl-*a* retrievals by SeaWIFS in the Gulf's waters when using the standard OC4v.4 algorithm and atmospheric correction. Nevertheless, the striking agreement between SeaWIFS-derived ocean colour data and the simulated freshwater-associated turbidity allowed to validate the regional estuarine circulation and associated mesoscale variability. This result brings support to the model's ability to simulate realistic physical and biogeochemical fields in the Gulf of St. Lawrence.

Regional index terms: Canada; Gulf of St. Lawrence
Keywords: 3-D numerical modeling; Satellite data; Coastal oceanography; Mesoscale features; Seasonal variability; Estuarine circulation

1. Introduction

The Gulf of St. Lawrence (hereafter GSL) is a highly dynamic sub-arctic marginal sea characterized by a marked synoptic wind forcing, a freshwater runoff of more than 700 km^3/yr from the St. Lawrence watersheds, and an intense tidal mixing (e.g., Koutitonsky and Budgen, 1991). This variability in the atmospheric,

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hydrologic, and oceanic forcing leads to the formation of eddies, coastal upwellings, and density fronts that superimpose on an estuarine-like circulation induced by the discharges of the St. Lawrence River and other tributaries (e.g. Koutitonsky and Budgen, 1991; Saucier et al., 2003). The chief importance of the hydrographic processes on the planktonic ecosystem dynamics has long been established for the GSL (e.g., Steven, 1974; Therriault and Levasseur, 1985; de Lafontaine et al., 1991), and recently more accurately quantified using a three-dimensional (3-D) high-resolution physical–biological coupled model (Le Fouest et al., 2003, 2005). Simulated and in situ concentrations of nitrate and Chlorophyll-*a* (Chl-*a*) were successfully compared for a yearlong simulation of 1997, supporting the model's ability to generate a consistent seasonal cycle of primary production. Furthermore, the model revealed that the intense mesoscale variability prevailing in the GSL should be as important as the seasonal variability for the annual primary production (Le Fouest et al., 2005).

Inferring this mesoscale variability and its impact on phytoplankton distribution and dynamics is difficult if not intractable with ship-based field experiments alone. Polar-orbiting satellites may help to fill the gaps by allowing a synoptic view of sea surface temperature (SST) and pigments with a high resolution in space (up to 1 km) and time (daily), and are now routinely used to quantify and characterize the mesoscale variability in open ocean waters (e.g., McGillicuddy et al., 2001; Doney et al., 2003; Mete Uz and Yoder, 2004). Previous studies of Fuentes-Yaco et al. (1997a,b) using Coastal Zone Color Scanner (CZCS)-derived Chl-*a*, as well as Tang (1980a) and Gratton et al. (1988) using Advanced Very High Resolution Radiometer (AVHRR)-derived SST, have shown the prime importance of the mesoscale to synoptic variability for the physical and biological oceanographic conditions in the GSL. An exhaustive analysis of monthly mean Sea-viewing Wide Field-of-view Sensor (SeaWIFS)-derived Chl-*a* data between 1997 and 2001 (e.g., Gower, 2004) also revealed the occurrence of peculiar phytoplankton production events in the GSL. Such events may be related to instabilities of the estuarine regional circulation but a monthly time averaging applied to produce composite images as in Gower (2004) precludes a detailed validation of the associated mesoscale variability.

In addition to strongly impact the regional circulation, freshwater runoff from the St. Lawrence River and the numerous tributaries flowing into the Lower St. Lawrence Estuary (LSLE) and northern GSL also affects the optical properties of surface waters by draining optically active constituents, such as chromophoric dissolved organic matter (CDOM absorption ca. 1 m^{-1} in average in summer; Nieke et al., 1997) and suspended solids (concentrations ca. 0.2–1.0 g/m^3, e.g., Yeats, 1988; Larouche and Boyer-Villemaire, 2005). The St. Lawrence estuarine waters hence pertain to Case 2 waters (Babin et al., 1993; Nieke et al., 1997; Jacques et al., 1998), and are characterized by a thinner euphotic zone (10–15 m, e.g., Levasseur et al., 1984) when compared to oceanic-like waters in the Gulf (30–50 m, e.g., Doyon et al., 2000). Nevertheless, the estuarine-like surface circulation and associated mesoscale instabilities may extend the influence of these turbid Case-2 waters farther in Gulf (Larouche, 1998, 2000). The presence of terrestrial CDOM (e.g., Carder et al., 1989; Gohin et al., 2002; Wang and Cota, 2003, Berthon and Zibordi, 2004; Darecki and Stramski, 2004; Harding et al., 2005) and suspended sediments (e.g., Toole and Siegel, 2001; Wozniak and Stramski, 2004) limits the ability of the standard SeaWIFS data processing (i.e., OC4v.4 algorithm and standard atmospheric correction) to adequately retrieve Chl-*a* concentrations in other coastal and freshwater-influenced areas. Regional empirical algorithms based on in situ data have been developed to improve the remotely sensed Chl-*a* retrieval in such Case-2 waters (e.g., Tassan, 1994; Kahru and Mitchell, 2001; Binding et al., 2003; Magnuson et al., 2004) but none is yet operational for the GSL. However, confidence can be addressed to the spatial gradients of SeaWIFS-derived Chl-*a* to infer qualitatively the physical–biological coupling in coastal and shelf seas (e.g., Oguz et al., 2002; Pegau et al., 2002; Stegmann and Ullman, 2004).

In this study, we present a first attempt to validate solutions of the regional 3-D physical–biological coupled model of the GSL using AVHRR-derived SST and SeaWIFS-derived Chl-*a* data. A model simulation for the year 1998, following the initial calibration by Le Fouest et al. (2005) for the year 1997, now accounts for freshwater-associated turbidity that refers here to the diffuse attenuation of underwater light due to optically active constituents other than chlorophyll (i.e. CDOM and suspended solids) drained by the freshwater runoff. The analysis is made by comparing five synoptic short-term (4–9 days) composites (one in spring, three in summer, and one in fall) of remotely sensed SST and Chl-*a* with the corresponding simulated fields of SST, Chl-*a* concentration, and freshwater-associated turbidity. Both remotely sensed and simulated fields are evaluated with respect to independent in situ measurements acquired routinely through monitoring and research programs in the GSL. The precision and accuracy of