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Hindcast of the timing of the spring phytoplankton bloom in the Strait of Georgia, 1968–2010

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ABSTRACT

Using a one-dimensional coupled bio-physical model, the spring phytoplankton bloom in the Strait of Georgia was hindcast for years 1968 to 2010. Relative to the long term mean (March 25), the timing of the bloom was later in the early 1970s (about April 2), earlier in the early 1990s (about March 18) and later again in recent years (about March 30). These long term shifts are related to shifts in the intensity of winter storms and cloudiness. A more dramatic shift is seen in the interannual variation in timing with the standard deviation over seven consecutive years doubling during the timeseries. Since the early 1990s there have been a few, very early blooms leading to a large interannual spread in bloom times. We show that this change is related to warming and therefore we project that this level of variation may continue under climate change.

1. Introduction

The timing of the spring phytoplankton bloom is an indicator of seasonality in temperate ocean ecosystems. Shifts in the timing have a number of implications for upper trophic levels due either to (1) mismatches between phytoplankton bloom timing and zooplankton bloom timing or (2) due to the impact on the length of the growth season. In the Strait of Georgia, early spring blooms lead to a mismatch between *Neocalanus plumchrus* migration to the surface water and the time of the rich non-nitrate limited diatoms (Sastri and Dower, 2009). In Queen Charlotte sound, the timing of the phytoplankton bloom is linked to the success of Rhinoceros Auklet breeding (Borstad et al., 2011). In Rivers Inlet, higher recruitment to the juvenile stages of some zooplankton species is observed during early spring blooms, leading to a summer species composition that does not occur during late spring blooms (Tommasi et al., 2013).

The Strait of Georgia (SoG), part of the Salish Sea, is a semi-enclosed, deep, fjord-like estuary in British Columbia, Canada. The major freshwater source is the Fraser River. It is a temperate system and the spring bloom is usually characterized by rapid growth of diatoms (*Thalassiosira* spp., followed by *Skeletonema costatum*, followed by *Chaetoceros* spp.) as light limitation is lifted, and a crash in their biomass as nitrogen becomes limiting (Harrison et al., 1983; Collins et al., 2009). In some years, it is possible that flagellates form the bloom (Timothy Parsons, personal communication) but this would only occur in years where the diatom bloom is significantly delayed. The timing of the spring phytoplankton bloom in the SoG has been observed to vary interannually by 6 weeks (Collins et al., 2009); here we investigate the longer timescale variations in bloom timing due to longer term variations in SoG conditions.

Under climate change one would expect a warming of the air and water and thus an acceleration of biological processes including growth leading to an earlier spring bloom. Winter and early spring Fraser River flow rates are expected to increase (Morrison et al., 2002). However, the spring bloom in the Strait of Georgia is primarily dependent on the winter wind stress and secondarily dependent on the cloud fraction with only weak dependence on temperature and freshwater flow (Collins et al., 2009). Thus long term changes in the timing of the spring phytoplankton bloom are not easily extrapolated.

Based on 4 years of intensive measurement as part of the STRATOGEM project (Pawlowicz et al., 2007; Halverson and Pawlowicz, 2008; Riche, 2011) a bio-physical model for the spring bloom in the Strait of Georgia was developed, tested and tuned (Collins et al., 2009; hereinafter C09). The same model is used here, with only small changes, to hindcast the timing of the spring bloom back to 1968, the year after an anemometer was installed at Sand Heads Station giving good measurements of the wind in the Strait.

The spring bloom develops over weeks to days and occurs throughout the southern Strait within 4 days (C09). Accurate detection of the timing requires high frequency sampling, at least daily, as is available from ferry sampling. As part of the STRATOGEM project ferry data on a route from Tsawwassen (near Sand Heads) to Nanaimo (Fig. 1) was collected through the spring

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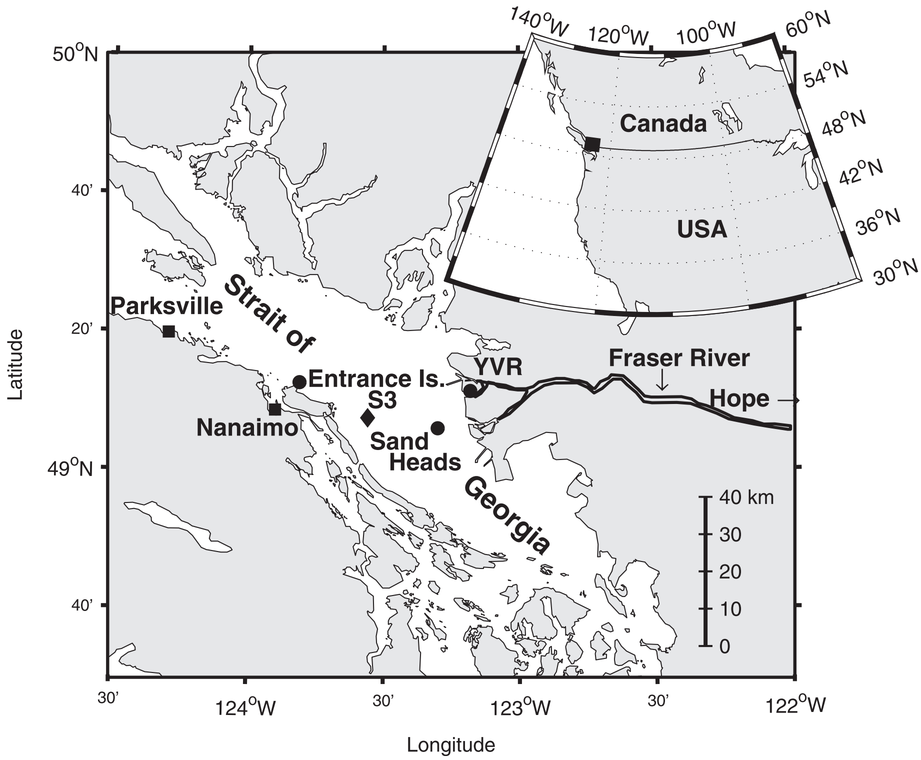

Fig. 1. Map of the Southern Strait of Georgia showing the location of the model (station S3, diamond), Fraser River, Englishman at Parksville and Nanaimo Rivers (squares), Sand Heads, Entrance Island and YVR Meteorological Stations (circles).

blooms of 2003–2006 (Halverson and Pawlowicz, 2008). Some ferry data is also available from the Tsawwassen to Victoria ferry but unfortunately, the specific ferry with the sampler is often not in service during the spring bloom (J. Gower, personal communication). A recent bloom timeseries has been developed by J. Gower based on satellite data (Gower et al., 2013); in some years the date of the bloom can be difficult to determine due to cloud cover. However, none of these series are available historically to develop a long timeseries.

Although the idea of a spring bloom is well-defined, the exact timing of a real spring bloom is not. In C09 the peak of the bloom was defined as the highest concentration of phytoplankton unless an earlier bloom (more than 5 days earlier) was associated with nitrate going to zero. J. Gower using satellite data chooses a measure of the start of the bloom as the time when 30% of the Strait of Georgia has 5 mg m^{-3} chlorophyll or higher (Gower et al., 2013). The nutritional quality of the phytoplankton appears to change when they become nutrient limited (Sastri and Dower, 2009). Thus here we use a definition that should delineate between nutrient replete spring conditions and nutrient stressed summer conditions. We use the peak phytoplankton concentration (averaged from the surface to 3 m depth) within 4 days of the average 0–3 m nitrate concentration going below 0.5 μM (the half-saturation concentration) for two consecutive days.

In Section 2, we briefly introduce the model developed by C09 and the modifications and improvements that were made to it, with details contained in Appendix A. The sources for the physical forcing data and a discussion of the initialization procedure for years without appropriate water column data are also given. In Section 3, the timeseries of the spring phytoplankton bloom date from 1968 to 2010 is shown along with its running-mean and running-standard deviation. In the discussion (Section 4) we compare the bloom timeseries to large scale climate indices, and discuss the impacts of warming on the bloom date. We finish with conclusions.

2. Method

The model is a vertical one-dimensional coupled bio-physical model. The model domain is the upper 40-m of the water column in the vicinity of Station S3 in the middle of the Strait of Georgia (Fig. 1). This station is not directly in the most recent ebb-plume of the Fraser River but is strongly affected by its freshwater. Depending on the season, S3 is affected by freshwater a day to several days after it has left the Fraser River mouth. A vertical grid-spacing of 0.5 m is used to resolve the density, nitrate and phytoplankton gradients.

The physical model is based on the KPP near-surface mixing model (Large et al., 1994) which was originally developed for the open ocean. The KPP model is forced with winds and heat fluxes at the surface and computes a mixing layer depth and the temperature, salinity, diffusivity and horizontal velocities with depth. It includes the sensible and latent heat exchange at the surface and the heating due to incoming solar radiation. Parameterizations for the estuarine circulation and the pressure gradients associated with the coasts around the Strait were added to this model (C09). The parametrization of the estuarine circulation was based on the extensive measurements made as part of the STRATOGEM project. It includes the addition of freshwater, due to the rivers, into the upper layers of Strait with the amount dependent on the incoming freshwater flux and the depth range dependent on the model computed mixing layer depth. In addition, the estuarine circulation requires a vertical upward flow due to entrainment into the surface layer which is determined by the freshwater flux. The vertical upward flow has convergence, and so fluid is lost from the water column due to this advection. Baroclinic pressure gradients are calculated by tracking the density advection and force the circulation to conform to the boundaries of the Strait.

A biological model is coupled to the physical model and all biological quantities are advected and mixed as determined by the