Continental Shelf Research 143 (2017) 29–42

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Short-term variability in particle flux: Storms, blooms and river discharge in a coastal sea

Sophia C. Johannessen*, Robie W. Macdonald, Cynthia A. Wright, David J. Spear

Fisheries and Oceans Canada, Institute of Ocean Sciences, 9860 W. Saanich Rd., P.O. Box 6000, Sidney, B.C., Canada V8L 4B2

ARTICLE INFO

Keywords:
Sediment traps
Sinking particles
Rivers
Phytoplankton blooms
Storms
Strait of Georgia

ABSTRACT

The flux and composition of particles sinking in the surface ocean vary on a wide range of time scales. This variability is a component of underwater weather that is analogous to rain. The rain of particles in the coastal ocean is affected by atmospheric events, such as rainstorms and windstorms; by events on land, such as peaks in river discharge or coastal erosion; and by events within the surface ocean, such as phytoplankton blooms. Here, we use a four-year record of sinking particles collected using sediment traps moored at 50 m depth at two locations in the Strait of Georgia, a coastal sea off the west coast of Canada, to determine the relative importance of short-term events to particle flux. We identify four dominant types of particle-flux events: those associated with 1) summer freshet of the Fraser River, 2) rainstorms, 3) phytoplankton blooms, and 4) a jellyfish bloom. The relative importance of these events differs between the southern Strait, where the Fraser River freshet dominates flux and variability, and the northern Strait, where the effects of phytoplankton blooms, rainstorms and small local rivers are more evident. During 2008–2012, half of each year's total flux accumulated over 10–26% of the year in the southern Strait, mainly during the Fraser River freshet. In the northern Strait half of the annual flux accumulated over 22–36% of the year, distributed among small events during spring to fall. The composition of the sinking particulate matter also varied widely, with organic carbon and biogenic silica ranging over 0.70–5.7% (excluding one event) and 0.4–14%, respectively, in the south, compared with 0.17–22% and 0.31–33% in the north. Windstorms had no immediate effect on particle flux in either basin. A large phytoplankton bloom in April 2011, in the northern Strait contributed 25% of the year's organic carbon at that site and 53% of the biogenic silica. A jellyfish bloom in July 2008 contributed 16% of the year's nitrogen and 12% of the year's organic carbon during a single collection interval (12 days). As short-term climate variability increases in a warming climate , the importance of these sorts of events is likely to increase in the future, particularly in coastal waters that are strongly influenced by river discharge.

1. Introduction

Weather and climate occur in the ocean, just as they do on land. Mesoscale variability in upwelling, currents and eddies drives changes in biogeochemical cycles on the time scale of weeks to months, which can be considered a kind of underwater weather (McGillicuddy, 2001). McGillicuddy's "internal weather of the sea" related in particular to variability in water properties and in the timing of blooms. Another aspect of underwater weather, which is most analogous to precipitation from the atmosphere, is the sinking flux of particles from the surface of the ocean. The underwater rain of particles can be driven episodically by atmospheric events, such as rainstorms or windstorms; by events on land, such as river discharge peaks; and by events within the surface ocean, such as phytoplankton blooms.

Within the Strait of Georgia, a productive coastal sea on the west coast of Canada (Fig. 1), the rain of particles is a crucial component of biogeochemical cycles. Remineralization of sinking particles consumes dissolved oxygen and acidifies subsurface waters (Ianson et al., 2016; Johannessen et al., 2014). Particles affect nutrient and organic carbon cycles (Sutton et al., 2013) and supply food for bacteria, zooplankton and benthos. The quality of the sinking food changes on daily to interannual timescales. Sometimes there is a feast, at other times a famine. Animals that survive in this system must be able to take advantage of, or adapt to, such variability.

Short-term variability has increased over the past decades in the Georgia Basin (Whitfield et al., 2003), the catchment area for the Strait of Georgia, as indicated by an increase in the frequency of $<$ 6 h heavy precipitation events since the 1970s in Metro Vancouver (Jakob et al., 2003) and an increase in occurrence of large windstorms (Riche et al., 2014). In addition, the timing of the Fraser River freshet, the principal

* Corresponding author.
E-mail address: Sophia.johannessen@dfo-mpo.gc.ca (S.C. Johannessen).

http://dx.doi.org/10.1016/j.csr.2017.05.016
Received 8 March 2017; Received in revised form 25 May 2017; Accepted 25 May 2017
Available online 01 June 2017

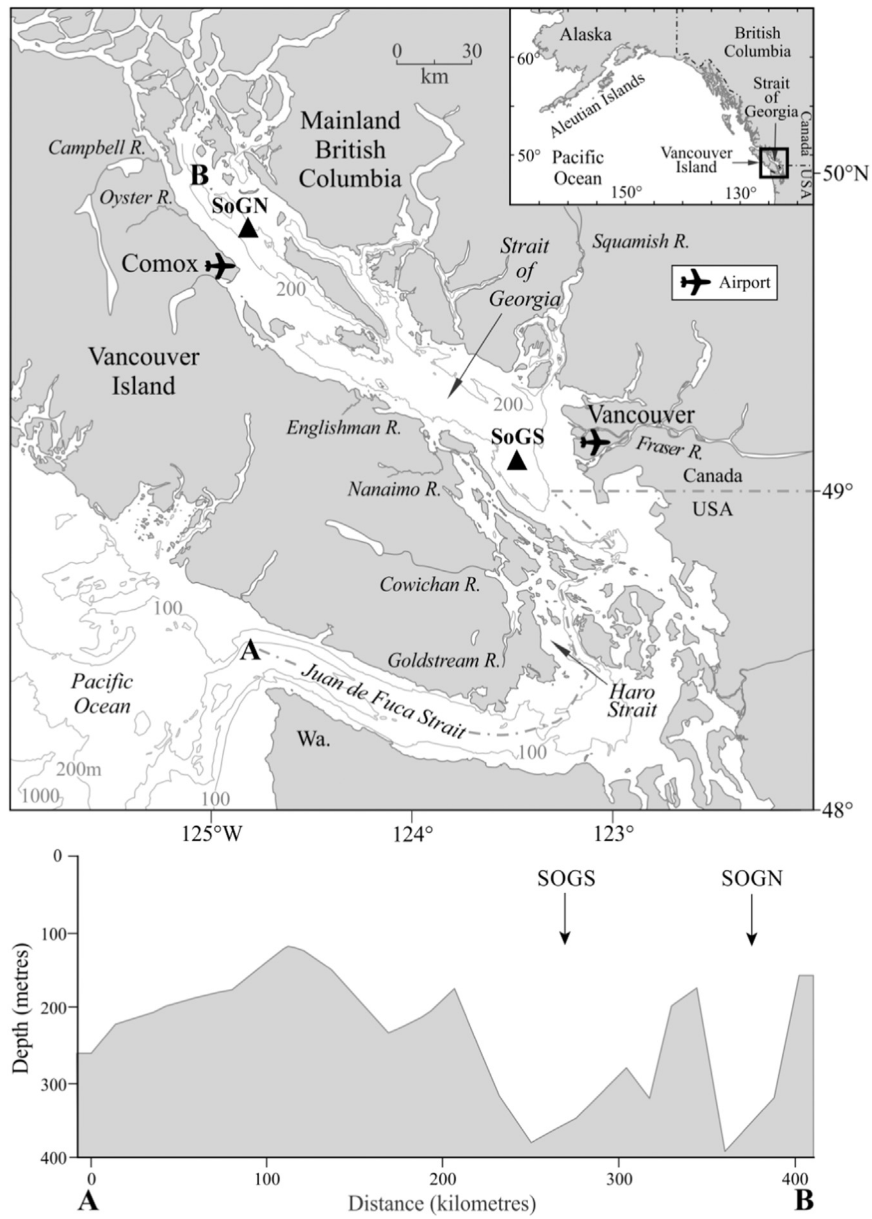

Fig. 1. Upper panel: Chart of the study area, showing mooring locations (triangles) and the major rivers that drain into the Strait of Georgia. Lower panel: Bathymetry along the centerline from the entrance of Juan de Fuca Strait (A) to the northern end of the Strait of Georgia (B) showing the locations of the moorings in the two basins.

source of fresh water to the Strait of Georgia and the main driver of its estuarine circulation, is changing, with a single, snow-fed freshet giving way to a mixture of snow- and rain-fed discharge pulses (Morrison et al., 2002). Within the Strait itself, the onset of the spring phytoplankton bloom varies by over a month, mainly in response to the timing and strength of windstorms (Collins et al., 2009), and the peak zooplankton biomass arrives significantly earlier now than it did in the 1970s [Dr. Rana El-Sabaawi, University of Victoria, pers. comm.]. These local observations are consistent with global-scale predictions of increased short-term variability in a warming climate (e.g. Kharin et al., 2013, 2007). To judge the importance and likely effects of increases in short-term variability, we need to understand the current contribution of short-term events, such as storms, blooms and fluctuations in river discharge to particle flux and associated biogeochemical cycles.

Productivity in the Strait of Georgia is sometimes strongly affected by ephemeral events. For example, a four-day increase in the Fraser River's discharge during the summer of 1991, due to a short period of intense snowmelt, increased the entrainment of nutrients into the surface water, producing blooms around the edge of the plume that were as intense as those observed during the spring bloom in the same year (Yin et al., 1997). Wind storms can also be important. Short windy periods during the summer can initiate short-lived phytoplankton blooms by breaking down stratification and replenishing nutrients in the surface layer (St John et al., 1992). Increased stream-flow results in increased turbidity and may change the quality of organic carbon washed into the Strait of Georgia, as well as the availability of light for phytoplankton. The importance and nature of ephemeral events on particle flux have been discussed in a few coastal systems (e.g. Iberian coastal upwelling system, Zúñiga et al., 2016; Saanich Inlet, Canada, Timothy et al., 2003). However, there are few such data in the Strait of Georgia.

Johannessen et al. (2005) used sediment trap records collected at three sites in the southern Strait of Georgia between March 1996 and February 1998, to determine the composition and distribution of fluxes of sediment and organic carbon in the southern Strait, e.g. the average fluxes, seasonal cycle and difference between summer and winter composition of trapped particles. Although high temporal variability