Continental Shelf Research 105 (2015) 101–111

Contents lists available at ScienceDirect

Continental Shelf Research

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

Barotropic tidal dynamics in a frictional subsidiary channel

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ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form
21 May 2015
Accepted 22 May 2015
Available online 29 May 2015

Keywords:
Subsidiary channel dynamics
Numerical modeling
Viscous parameterization
Horizontal eddy viscosity coefficient
Energy flux
Energy dissipation

ABSTRACT

Barotropic M_2 tidal dynamics are studied in a subsidiary tidal channel in Kyuquot Sound, Canada, a site proposed for multi-trophic aquaculture. A regional model with no stratification or forcing other than the tide found that the sea level in the subsidiary channel responded in phase with the rest of Kyuquot Sound, but that the velocity response was almost 180° out of phase. Further, this velocity difference was strongly dependent on the choice of viscous parameterization in the model. A simple linear analytical model was developed to explain the simulated changes in terms of the phase lag induced by viscosity, and allowed a larger parameter regime to be explored. These results suggest that verifying models of smaller channels using sea level measurements alone is inadequate, and velocity measurements are necessary.

1. Introduction

Kyuquot Sound (see Fig. 1) is located on the northwestern coast of Vancouver Island. It supports a number of aquaculture facilities and is home to natural populations of salmon and sablefish as part of their coastal-offshore life cycles. This study was motivated by the development and pre-commercial scale testing of a Sustainable Ecological Aquaculture (SEA), or Integrated Multi-Trophic Aquaculture (IMTA), site located in the northwest region of Kyuquot Sound (SEA Vision Group; see Fig. 1). Combining species from different trophic levels, a SEA/IMTA system is designed to intercept and extract both inorganic and organic wastes. In our case, scallops, oysters, sea cucumbers, and kelp are used to extract wastes generated from the fed culture species, sablefish (Barrington et al., 2009). Operational efficiencies of a SEA/IMTA system can significantly improve from a better understanding of local ocean circulation. In particular, fine resolution circulation models provide hydrodynamic information for the SEA/IMTA site to assist in the assessment and optimization of the system.

Despite the biological importance of the Kyuquot Sound region, the physical oceanography is poorly studied. Union Island is in the middle of Kyuquot Sound, delineating the main Kyuquot Channel from the shallower and narrower Crowther Channel (Fig. 1). The length of the main channel is about 30km, its width is about 2 km, and the average depth is 85 m (ranging from ~10 m to more than ~250 m, Fig. 2). The channels are narrow, so the Coriolis force is neglected in this paper. The tidal flow in this system has not been studied, but the presence of two openings under different tidal forcing, and the potential for high friction in the constrictions of Crowther Channel make predicting the flow at the aquaculture site challenging. Below we show that the friction in the smaller Crowther Channel drives the velocity to be almost 90° out of phase with the elevation forcing.

Flows with friction have been extensively studied theoretically and through field/laboratory experiments and numerical models. The tides can be described as a standing wave in a frictionless rectangular channel (Freeland and Farmer, 1980), where the phase of the currents lags the phase of the elevation by 90°. Hunt (1964), using the Thames River as a case study, pointed out that friction is the cause of phase differences between currents and sea surface elevation in fjord-like channels. When friction is present in a channel, the waves can no longer be considered as a combination of the incoming and the reflective waves with equal amplitude in opposite directions. Energy is lost through friction, so the amplitudes of an incoming and a reflective waves decrease along their propagation directions (Sverdrup, 1942). The difference between the current velocity phase and the elevation phase varies

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http://dx.doi.org/10.1016/j.csr.2015.05.011

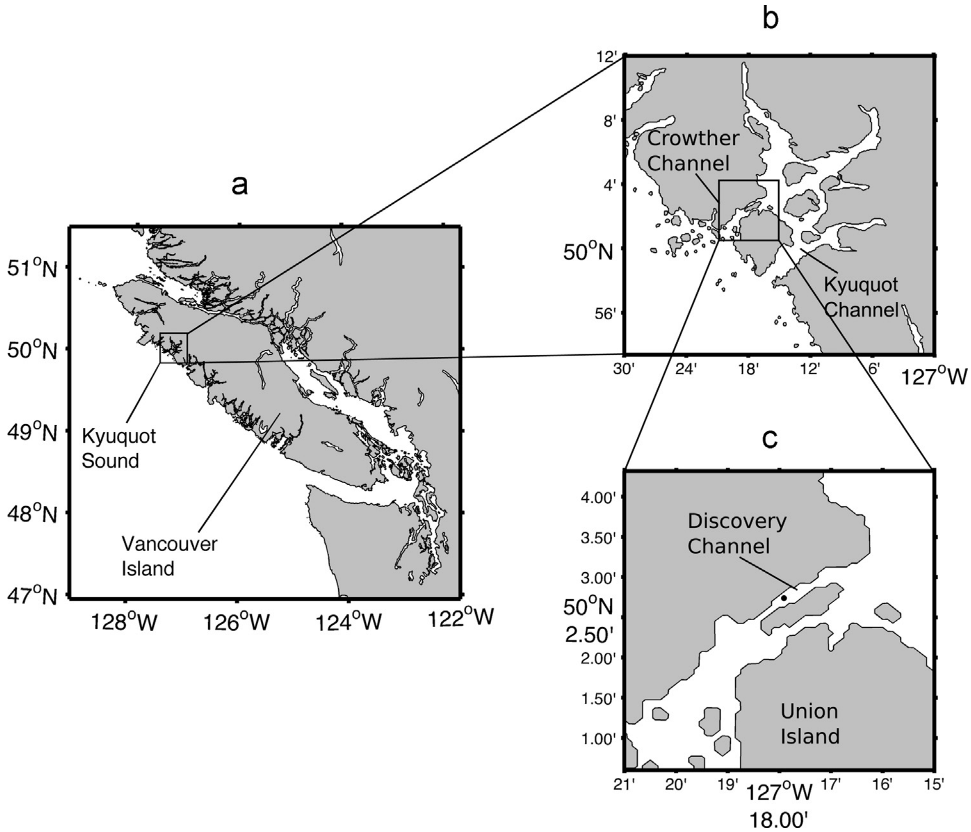

Fig. 1. (a) Vancouver Island. (b) Kyuquot Sound. (c) close-up near the SEA Vision Group farm site (the black dot at 50º 03' N, 127º18' W). The island between Kyuquot Channel and Crowther channel is Union Island, and henceforth, Crowther Channel will be used to refer to both Crowther and Discovery channels.

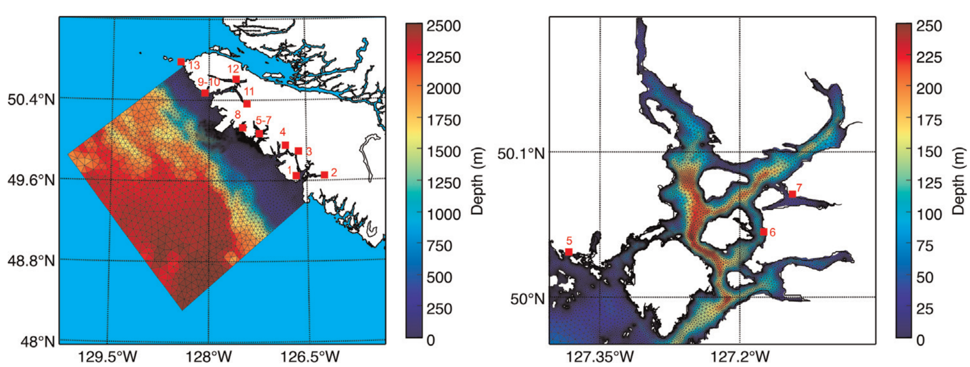

Fig. 2. Bathymetry of the computational domain and the computational grid of Kyuquot Sound. Numbered red dots indicate the locations of 13 tide gauges whose names are listed in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

continuously along the channel (Freeland and Farmer, 1980). There had been many studies on barotropic energy partitions in fjords (De Young and Pond, 1989; Stacey, 2005), but most only considered the energetics of the fjord's main channel. This paper is focused on the circulation and the energy removal in a subsidiary channel of a fjord system.

This paper examines the barotropic M_2 tidal circulation in Kyuquot Sound and the energy removal in a subsidiary channel (Crowther Channel). Based on numerical results from a Finite-Volume Coastal Ocean Model (FVCOM) application for the region (Section 2), a linear analytical model that describes a two-channel system is developed. This model re-parameterizes the friction as Reynolds drag, and explains the relatively constant elevation phases throughout the main sound. Moreover, it also offers explanations for the difference in velocity phases between a main (Kyuquot) channel and a subsidiary (Crowther) channel, and variations in velocity phase as we move along the subsidiary channel (Section 3). Finally, we utilize the linear model to explain the nonlinear energetic response in the subsidiary channel, test how the velocity in the subsidiary channel changes with the different horizontal viscous parameterizations, and conclude that the velocities are relatively sensitive to these parameterizations (Section 4). The conclusions are summarized in Section 5.

2. Numerical observations

Given the lack of information about Crowther Channel, we have begun a hierarchy of modeling studies, starting with a simple barotropic tidal model that is the focus of this work. The model is the Finite-Volume Coastal Ocean Model (FVCOM) that was developed by Chen et al. (2003, 2006), and uses an unstructured grid to resolve irregular estuarine coastlines. The model is forced with the M_2 tidal elevation and phase specified at open boundaries and is