Dynamics of Atmospheres and Oceans 65 (2014) 86–106

Contents lists available at ScienceDirect

Dynamics of Atmospheres and Oceans

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

Atmospheric and tidal forcing of the exchange between Prince William Sound and the Gulf of Alaska

Mark J. Halverson *

Prince William Sound Science Center, PO Box 705, Cordova, AK 99574, United States

ARTICLE INFO

Article history:
Received 29 April 2013
Received in revised form 25 November 2013
Accepted 2 December 2013
Available online 12 December 2013

Keywords:
Prince William Sound
Gulf of Alaska
Shelf/basin exchange
Barotropic exchange
Meteorological forcing

ABSTRACT

Current meter data from a series of oceanographic moorings spanning a total of five years was analyzed to quantify the tidal and subtidal exchange of water between Prince William Sound and the adjacent continental shelf in the northern Gulf of Alaska. Velocity profiles were used to quantify the exchange in terms of a transport through each of the two largest passages: Montague Strait and Hinchinbrook Entrance. Buoy wind and atmospheric pressure observations, as well as bottom pressure records, are then used to elucidate the role of atmospheric forcing on the exchange.

An EOF analysis shows that the barotropic component accounts for 62% or more of the variance in the velocity profiles even after tides are removed by low-pass filtering, and thus the analysis is concerned primarily with depth-integrated transport. The estimated depth-integrated transport can reach $\pm$0.6 Sv in Montague Strait, and $\pm$1.5 Sv in Hinchinbrook Entrance. The largest fluctuations occur in response to the semidiurnal tides. Transport variations on subtidal time scales, which can reach $-$0.2 Sv in Montague Strait, and +0.6 Sv in Hinchinbrook Entrance, are shown by a frequency domain analysis to be dominated by easterly wind stress events which occur at periods of 2–5 days in both summer and winter. Atmospheric pressure has much less impact on transport, but there is some evidence that it might play a small role on time scales of a few weeks.

Bottom pressure records suggest that easterly wind events set up a sea level height gradient in Hinchinbrook Entrance such that it

* Current address: Department of Earth, Ocean, and Atmospheric Sciences, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4. Tel.: +1 604 827 2377.

E-mail address: mhalverson@eos.ubc.ca

0377-0265/$ – see front matter
http://dx.doi.org/10.1016/j.dynatmoce.2013.12.001

tilts up to the east, which under geostrophy drives a barotropic flow into Prince William Sound. The same winds also raise the sea level in Hinchinbrook Entrance relative to Montague Strait, encouraging an outflow there in agreement with the ADCP observations. There is no evidence that the wind drives a vertically sheared bi-directional flow in either entrance, as has been observed in some estuaries. It is hypothesized that the lack of such a flow is possible because Prince William Sound has two major connections to the shelf, which alters the mass conservation requirement for each passage when compared to a system with just one entrance.

1. Introduction

Just 3 min after midnight on March 24, 1989, the fully laden M/T Exxon Valdez grounded on Bligh Reef in northeastern Prince William Sound (Fig. 1), releasing 11 million gallons of Alaska North Slope crude oil. It was the largest oil spill in US waters until the Deepwater Horizon disaster occurred in 2010, and it caused enormous damage to the environment and to the livelihood of local residents.

The trajectory of the spilled oil from the Exxon-Valdez disaster highlights the importance of synoptic weather-band and tidal forcing of currents in and around Prince William Sound, including the exchange of water with the Gulf of Alaska. Consider the local geography and the oil slick trajectory during the week following the grounding. Bligh reef is located 60 km north of Hinchinbrook Entrance, the largest passage connecting Prince William Sound to the Gulf of Alaska, and 120 km northeast of Montague Strait, through which the oil eventually passed (Fig. 1). In the three days after grounding, during a period of relatively light winds, the oil slick propagated 16.5 km to the southeast (Royer et al., 1990). On the evening of March 26, the weather conditions deteriorated, and northeasterly winds, gusting to 70 kt, pushed the slick 55 km southwest of Bligh Reef. After five more days of strong northeasterly winds, the leading edge of the spill was reported to have exited Prince William Sound through Montague Strait.

In addition to spill response mitigation, the exchange between the Gulf of Alaska (GoA) and PWS impacts the local oceanography. For example, the advection of freshwater originating from the Copper River and Alaska Coastal Current can form a significant part of the PWS freshwater budget (Simmons, 1996), and the additional buoyancy can then influence the circulation within PWS (Bang and Mooers, 2003; Wu, 2011; Halverson et al., 2013a). In summer, the deep inflow of dense water from below the shelf break in through HE can rapidly replace the deep waters in PWS (Halverson et al., 2013b).

The exchange, particularly inflow at HE, is expected to impact the local biology (Eslinger et al., 2001). For example, stable carbon and nitrate isotope ratios in net plankton, juvenile herring, and juvenile walleye pollock sampled in PWS show that some of these organisms originated in the GoA (Kline, 1999). Therefore, exchange between the GoA and PWS can import (or export) organisms, which has consequences for higher trophic levels.

While the oil spill spawned numerous circulation studies, there has been no detailed look at the variability on time scales shorter than a week in the two straits connecting Prince William Sound to the Gulf of Alaska. Previous studies, both observational and numerical, have focused on seasonal trends (e.g. Niebauer et al., 1994; Vaughn et al., 2001; Wang et al., 2001; Jin and Wang, 2004; Bang et al., 2005; Okkonen and Bélanger, 2008; Mooers et al., 2009; Wu, 2011). However, it is clear from the Exxon-Valdez oil spill that dynamics on weather band and tidal time scales are important.

2. Exchange between Prince William Sound and the Gulf of Alaska

Exchange of water between PWS and the GoA principally occurs through two passages, Montague Strait and Hinchinbrook Entrance. To the west, Montague Strait (MS) is about 60 km long, and approximately 8 km wide at its narrowest section, where the sub-surface moorings to be analyzed in this paper were located (Fig. 1). The maximum depth is 200 m and the cross-sectional area is 1.3 km^2.