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Impacts of distinct observations during the 2009 Prince William Sound field experiment: A data assimilation study

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ABSTRACT

A set of data assimilation experiments, known as Observing System Experiments (OSEs) are performed to assess the relative impacts of different types of observations acquired during the 2009 Prince William Sound Field Experiment. The observations assimilated consist primarily of two types: High Frequency (HF) radar surface velocities and vertical profiles of temperature/salinity (T/S) measured by ships, moorings, an Autonomous Underwater Vehicle and a glider. The impact of all the observations, HF radar surface velocities, and T/S profiles is assessed. Without data assimilation, a frequently occurring cyclonic eddy in the central Sound is overly persistent and intense. The assimilation of the HF radar velocities effectively reduces these biases and improves the representation of the velocities as well as the T/S fields in the Sound. The assimilation of the T/S profiles improves the large scale representation of the temperature/salinity and also the velocity field in the central Sound. The combination of the HF radar surface velocities and sparse T/S profiles results in an observing system capable of representing the circulation in the Sound reliably and thus producing analyses and forecasts with useful skill.

1. Introduction

During the past decade, numerical models and data assimilation schemes for coastal ocean applications have rapidly advanced. Along with advances in observing technology and the establishment of coastal ocean observing networks, real-time numerical predictions of coastal oceanic conditions (e.g., waves, sea surface heights, currents, temperatures and salinity) have been actively implemented and evaluated in numerous regions around the world. One such region is the Prince William Sound (PWS), Alaska.

Located along the southern coast of Alaska in the North Pacific Ocean, the PWS is a commercially and logistically important embayment (Fig. 1). It is a nursery for many species of fishes including pink salmon and Pacific herring, which have historically supported local coastal economies. Since 1977, tanker vessels have transited the PWS departing Valdez laden with Alaska North Slope (ANS) crude oil. The 1989 grounding of the oil tanker T/V Exxon Valdez resulted in North America's largest oil spill and caused fundamental damage to the unique ecosystem in the Sound. Following this oil spill disaster, the Prince William Sound Science Center (PWSSC) and the Oil Spill Recovery Institute (OSRI) undertook to implement a prototype Nowcast/Forecast Information System for aiding in oil spill response (Schoch et al., 2011). As part of this undertaking, the development of numerical model based nowcasts and forecasts has been of central importance.

An evaluation of numerical models was conducted in the Sound in 2004. Model simulations were complemented by data collected with satellites, coastal weather stations, moorings, high frequency (HF) radars, as well as 10 m drogue and surface drifters. The ocean circulation model system, based on the Princeton Ocean Model (POM), produced real-time nowcasts/forecasts (Mooers et al., 2009). The validation and evaluation were done through comparisons of the model output against the data, and the results highlighted the complexities of the circulation in the Sound and the difficulties of making accurate nowcasts and forecasts.

The difficulties in achieving high predictive skill in 2004 were due to multiple factors. First, the PWS is a semi-enclosed sea with complex topography (Fig. 1). The central PWS is about 60 km by 90 km, which is significantly larger than the Rossby deformation radius which is about 1 km in wintertime and about 10 km in summertime (Bang et al., 2005). Because of its size, the PWS exhibits characteristics of a small inland sea with significant horizontal circulations. Due to the tremendous freshwater discharge within

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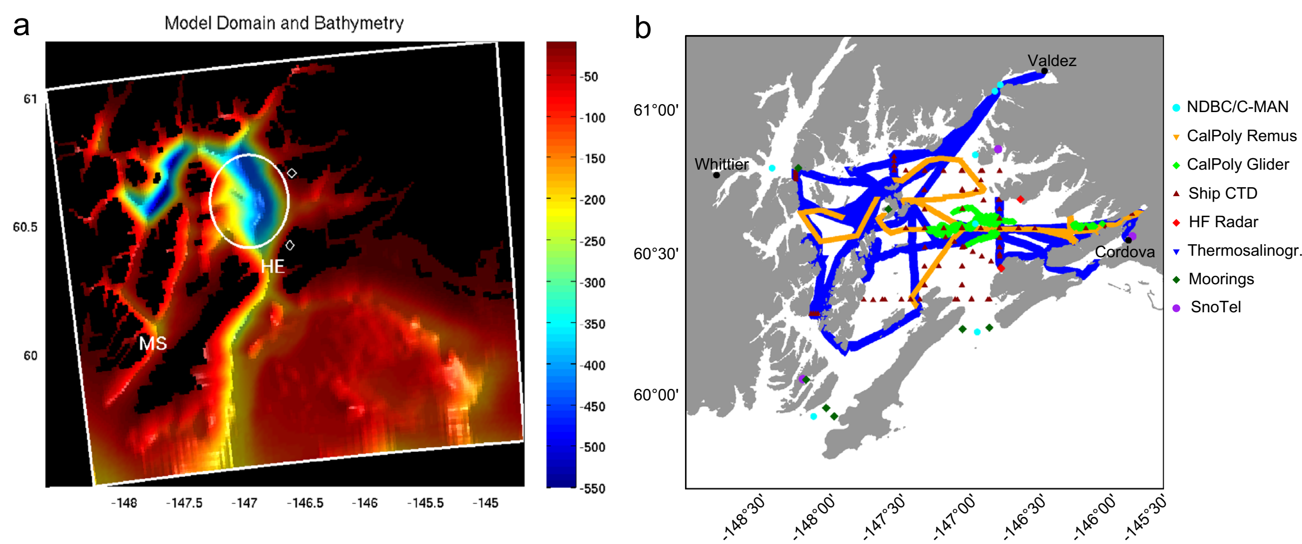

Fig. 1. ROMS model domain and bathymetry (a) and observations (b) acquired during FE2009. The colors in (a) show the depth of the bathymetry in m. Hinchinbrook Entrance is indicated by HE and Montague Strait by MS. The locations of the two HF radars are marked by diamonds. The white box indicates the model domain of the innermost nest with a resolution of 1.1 km. The white circle marks the region referred to as the Central Sound, and is coincident with the region frequently covered by HF radar velocity observations.

the Sound and the 180 m-deep shelf/sills guarding a 700 m interior depth, it can also be classified as a large, complex, fjord-type estuarine system (Schmidt, 1977; Royer et al., 1990; Niebauer et al., 2004). Further, PWS has two major passages connecting it to the Gulf of Alaska. One passage is Hinchinbrook Entrance (HE), which is about 11 km wide and about 320 m deep; and the other is Montague Strait (MS) which is about 8 km wide and about 240 m deep. The horizontal circulation in the Sound is strongly influenced by both freshwater discharge and water mass transport through the two passages. The mass transport through HE often brings saltier water into the central Sound, maintaining a high salinity center there during summertime. The high salinity center then often gives rise to a low SSH center and thus a recurring cyclonic eddy (Niebauer et al., 1994; Okkonen et al., 2005; Okkonen and Bénger, 2008). However, the temporal and spatial variability of the transport at HE is complicated and not fully known, and the circulation in the Sound delicately responds to its variability (Bang et al., 2005). To produce accurate nowcasts and forecasts, an ocean model needs to incorporate accurate high resolution topography, freshwater discharge, and vertical and horizontal mixing schemes, and most importantly, be capable of using real-time observations to initialize the model (Mooers, 2010).

As a follow-up to the 2004 field experiment, another field experiment was conducted in July and August 2009 (FE2009). One objective of FE2009 was to quantitatively evaluate the performance of a newly developed nowcast and forecasting system. This system was based on the Regional Ocean Modeling System (ROMS). ROMS has been developed for handling complex topography accurately and reliably, and is implemented with a set of desirable numeric and physical parameterization schemes (Shchepetkin and McWilliams, 2005, 2006). The details of the ROMS configuration for PWS are given in Colas et al. (this issue) and Farrara et al. (this issue). To produce more accurate model initial conditions using real-time observations, data assimilation was implemented. Data assimilation has been a common methodology for improving numerical weather predictions for more than three decades (e.g., Kalnay, 2009). We have implemented a multi-scale three-dimensional variational data assimilation (MS-3DVAR) scheme (Li et al., in preparation), which is built on top of a ROMS-3DVAR scheme (Li et al., 2006, 2008a,b). This MS-3DVAR has been developed for high resolution models, and is particularly for effectively assimilating observations from coastal observing networks that typically provide both high resolution surface and sparse subsurface observations.

During FE2009, an enhanced array of fixed and mobile observation platforms was deployed. Oceanographic moorings were enhanced by 3 ships, 44 surface drifters, an underwater glider and an autonomous underwater vehicle, as well as 2 shore-based surface current radar stations. During the experiment, a variety of observations that were available in real-time were assimilated, including the ship and glider and Autonomous Underwater Vehicle (AUV) T/S profiles, HF radar velocities, along with satellite SSTs. Fig. 1b shows the locations and types of observations acquired during FE2009. A preliminary evaluation showed that the major circulation features and their evolution were successfully reproduced in the nowcasts, and the forecasts had significant skill in the surface circulation and drifter trajectories up to 48 h (Schoch et al., 2011).

Leveraging the experience gained from the real-time operations during FE2009, we here present more detailed analyses of the performance of MS-3DVAR. We carry out a reanalysis for the FE2009 period and examine it to illustrate how MS-3DVAR improves the representation of the oceanic state in the Sound. We next perform a set of observing system experiments (OSEs) to estimate the impact of individual types of observations on the data assimilation analyses and forecasts. Using the reanalysis and OSEs we also attempt to identify aspects of MS-3DVAR that need to be improved, suggest optimal observing networks for future experiments, and explore a sustainable and affordable operational observing network for future use in the Sound.

The outline of this paper is as follows: in Section 2, we briefly describe the MS-3DVAR scheme and basic configuration of the ROMS based ocean forecast system. Section 3 discusses practical issues in the implementation of OSEs. In Section 4, a set of OSEs are presented. Finally, Section 5 summarizes and discusses the main conclusions obtained in this study.

2. Data assimilation scheme and model configuration

Data assimilation attempts to bring together all available observations to produce the best possible estimate of the oceanic state and thus the initial conditions that then produce the best forecast. In the coastal ocean community, commonly used data