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Configuring high frequency radar observations in the Southern Chukchi Sea

Gleb Panteleev [a,*], Max Yaremchuk [b], Oceana Francis [c], Takashi Kikuchi [d]

[a] International Arctic Research Center, PO Box 757340, University of Alaska Fairbanks, Fairbanks, AK 99775, USA

[b] Naval Research Laboratory, NRL Code 7320, Building 1009, Stennis Space Center, MS 39529, USA

[c] Department of Civil and Environmental Engineering, University of Hawaii at Manoa, 2540 Dole Street, Holmes Hall 383, Honolulu, HI 96822, USA

[d] Japan Agency for Marine-Earth Science and Technology, 3173-25, Showa-machi, Kanazawa-ku, Yokohama-city, Kanagawa 236-0001, Japan

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Abstract

In recent years, monitoring offshore surface circulation in the Arctic Ocean with high frequency radars has become an issue of increasing practical importance. In this study, radar positions are optimized by minimizing the reconstruction errors of the surface currents in the Southeastern Chukchi Sea. By means of an adjoint sensitivity technique it is shown that in the case of a pair of radars, their optimal (i.e. most favorable) location is at Kivalina, a settlement near the strongest outflow of the Alaskan Coastal Current from the monitored domain. The least favorable location is at Shishmaref, a settlement near relatively weak inflow into the region as observed from the coast. However, if two pairs of radars are available, the best locations are Kivalina and Shishmaref. The results are verified using observational system simulation experiments (OSSEs) performed in the framework of a 4-dimensional variational assimilation of simulated radar observations into a numerical model. It is shown that correct specification of the first guess solution is of primary importance for obtaining realistic results from both adjoint sensitivity analysis and OSSEs. This emphasizes the necessity of obtaining accurate high resolution climatologies for future ice-free offshore regions in the Arctic.
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Keywords: Data assimilation; Optimization; Chukchi Sea; High frequency radar

1. Introduction

Rapid warming of the Arctic Ocean (Screen et al., 2012) is enabling an upward trend in commercial activity around its southern periphery where extended periods of ice-free conditions occur regularly. Increased human presence in the region inevitably results in a higher probability of accidents and environmental disasters, as well as contamination of the fragile Arctic environment by human waste. In order to prevent undesirable events and minimize their impact on the local ecology, there is a growing need to monitor the Southern Arctic by establishing observational networks along the coastal regions.

High frequency radar (HFR) is the key element of a modern observational network for coastal oceanography (e.g., Harlan et al., 2010). Located along the coast, these instruments provide surface wave and velocity data, which are among the most important

* Corresponding author. Tel.: +1 907 474 2680.
E-mail address: gleb@iarc.uaf.edu (G. Panteleev).

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sources of operational information about the ocean state. The advantage of the HFR is obvious: being deployed on the coast they do not need ship support and provide permanent data flow independent of the environmental conditions. Combined with satellite and *in situ* observations from gliders and stationary moorings, HFR data have been successfully used for hindcasting and monitoring of surface and subsurface circulation in the mid-latitude regions (e.g., Barth et al., 2010; Chavanne et al., 2007; Hisaki et al., 2001; Sentchev and Yaremchuk, 2007; Shay et al., 2008).

During the past five years, researchers have started to use HFRs in the Arctic. In particular, several HFRs have been deployed along the Northern Alaskan Coast and in the Eastern Chukchi Sea (Calder et al., 2009; Francis et al., 2010; Statscewich et al., 2009). Calder et al. (2009) pointed out that with an increase in marine transportation and offshore activities in the Arctic seas, HFRs will play a significant role in coastal velocity observations.

Since the Chukchi Sea, located in the Arctic Ocean region, is experiencing the most rapid decrease in ice cover (e.g., Kwok and Cunningham, 2010), it is becoming important to monitor its offshore regions. In particular, the Bering Strait may soon become the primary gateway for transportation between Europe and East Asia. From an academic point of view, accurate monitoring of the Bering Strait transport and circulation in the Chukchi and Beaufort Seas will benefit numerous scientific studies of climatological importance, such as Pacific–Arctic property exchange and long-term variations of freshwater storage in the Beaufort gyre. These and other criteria should be taken into account during planning of the Arctic Ocean HFR networks.

Currently there are several projects that use HFRs and gliders for the study of circulation in the Chukchi and Beaufort Seas (e.g., Francis et al., 2010; Potter et al., 2011; Winsor et al., 2011). These studies recommend the expansion of the HFR network in the South Eastern Chukchi Sea (SECS). In the present paper we attempt to optimize HFR locations with respect to the accuracy of reconstruction of the circulation in SECS, and explore the scenario in which four HFRs are deployed. Our study was initialized after deployment of one HFR in Red Dog Port during the summer of 2008, and discussion with local stakeholders. The study is focused on the reconstruction of surface currents because they are the key factor in forecasting the evolution of environmentally hazardous materials (floating debris, oil spills). Another reason is that surface flows strongly affect navigation conditions, which are important for ore transportation from Red Dog Port, and for transport between local settlements.

Taking into account that HFRs provide only surface velocity data, we explore two possibilities to specify the temperature and salinity fields. First, we mimic barotropic conditions by specifying homogeneous temperature and salinity distributions over the area. Second, the climatological temperature and salinity fields are utilized as background data. The study is based on the work of Panteleev et al. (2010) (hereinafter P10), who reconstructed climatological summer circulation in the Chukchi Sea using the 4-dimensional variational (4dVar) data assimilation approach.

Sensitivity of the data-optimized solutions to the HFR configurations was studied using the method of Köhl and Stammer (2004). Technically, this analysis is quite similar to the computation of the representative matrix elements that are extensively used in the data-space of 4dVar inversions (e.g., Bennett, 1992).

To check the validity of the results of the sensitivity analysis, a series of observational system simulation experiments (OSSEs) has been performed to analyze the quality of reconstructed SECS circulation using optimal HFR locations. Their results were compared with the results of similar experiments for non-optimal configurations. The impact of proper specification of temperature and salinity was also analyzed.

The remainder of this paper is organized as follows. We start with a description of the optimized SECS state obtained in P10 and present the theoretical background for the sensitivity analysis and the OSSE (Section 2). The results of adjoint sensitivity analysis of the surface circulation with respect to several prospective locations for HFR deployment are discussed in Section 3. In the same section, we validate these results using the OSSE technique. Finally, a discussion and conclusions are given in Section 4.

2. Methodology

2.1. Estimating the reference state

Configuration of the HFR sites is optimized by minimizing errors in reconstruction of the 1990 circulation observed in the SECS during the last navigable month of the year (October). The temporal evolution of the Chukchi Sea during September 1990–September 1991 was reconstructed by P10, who synthesized all available temperature, salinity, velocity and atmospheric observations in the framework of a regional primitive equation inverse model. The model