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Observations and predictions of summertime winds on the Skagit tidal flats, Washington

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ABSTRACT

Wind speeds and directions measured in June, July, and August, 2009 at 5 locations separated by up to about 5 km on the Skagit tidal flats (near La Conner, WA) are compared with predictions of a triple-nested Weather Research and Forecast (WRF) model with 1.3-km resolution. The model predicts the observed diurnal fluctuations of the wind speeds (bias < 0.4 m s^{-1}, root-mean-square error (rmse) < 1 m s^{-1}, correlation coefficient $r^2 \approx 0.9$) and directions (bias $< 9^\circ$, rmse $< 30^\circ$, $r^2 > 0.5$). The observed and predicted minimum and maximum wind speeds occur in early morning and late afternoon, respectively. Wind speeds and directions are decorrelated over distances shorter than the length scale of the tidal flats (about 10 km). Observed and predicted wind directions are predominantly W and NW on the north flats, and S and SW on the south flats. The spatial and seasonal variability of the winds are investigated using model simulations.

1. Introduction

Owing to the shallow water depths on tidal flats, the effects of winds (and the resulting waves) on the hydrodynamics and sediment transport can be strong, even in areas with short fetches (Le Hir et al., 2000; Yang et al., 2003; Carniello et al., 2005; Manning and Bass, 2006; Manning et al., 2006; Fagherazzi et al., 2007; Ralston and Stacey, 2007; Talke and Stacey, 2008). Winds can cause changes in water levels (and thus duration of submergence over a tidal cycle), can strengthen or weaken tidal-flow asymmetries, and can cause mixing and straining (Geyer et al., 2000; Valle-Levinson et al., 2003; Scully et al., 2005; Burchard 2009; Ralston et al., 2013). For example, during low river discharge, water typically stratified during ebb tide can become completely mixed during moderate winds (less than 6 m s^{-1}). Surface plumes, and the shear just below the water surface, are strongly influenced by local winds (Henderson and Mullarney, submitted for publication). Simulations suggest that strong winds can reverse the direction of the alongshore currents (Yang et al., 2010; Nowacki and Ogston, submitted for publication). Additionally, winds generate waves, which can enhance bottom stresses, cause additional mixing, and drive mean flows (Christie et al., 1999; Christiansen et al., 2006; Mariotti and Fagherazzi, 2013). Thus, measurements or simulations of local winds are needed to model circulation, waves, and sediment transport on tidal flats (Friedrichs and Aubrey, 1996; Dyer et al., 2000; Boldt et al., submitted for publication; Ralston et al., 2013).

Winds on tidal flats surrounded by low-relief topography, such as those along the southeastern US coast, may be spatially uniform and well represented by measurements at a single nearby station. However, winds in the Puget Sound Basin (including the Skagit Bay tidal flats), which is surrounded by mountainous terrain, vary significantly over distances of only a few km. Studies of diurnal summertime winds (Mass, 1981; Ferber and Mass, 1990) have shown that northerly or westerly winds during the day arise from low pressure over the Cascade Mountains and high pressure over coastal regions, and reach a maximum in late afternoon. At night, winds weaken and come from the south or east owing to a reversal of the pressure gradient. These winds interact with the nearby mountain ranges and bodies of water to create complicated diurnal and seasonal atmospheric flow patterns (Mass, 1981; Chien and Mass, 1997). Thus, the appropriate density of observation stations or resolution of atmospheric simulations must be high to capture the spatial variability of the winds over the Skagit tidal flats.

Owing to the spatial heterogeneity of the winds in this region, it is difficult to obtain sufficient measurements to evaluate the importance of wind-driven processes. High-resolution mesoscale meteorological models have been used to provide wind forcing to drive coastal ocean circulation models (Skogseth et al., 2007; Cowles et al., 2008; Foreman et al., 2008; Liu et al., 2009).

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Mesoscale models, such as the Advanced Research Weather Research and Forecasting model (WRF, Skamarock et al., 2008), have been shown to predict polar weather, large eddy turbulence, tropical cyclones, regional climate fluctuations, coastal winds, and atmospheric pollution (Snow et al., 2003; Tinis et al., 2006; Moeng et al., 2007; Davis et al., 2008). These models also predict winds well in regions with complicated, mountainous topography (Zhong and Fast, 2003; Bianco et al., 2006). In regions of complex coastal topography, highly resolved atmospheric models may be useful tools to drive surface fluxes in hydrodynamic simulations. Here, high-resolution WRF simulations are evaluated using winds observed on the Skagit tidal flats, a region that has complex topography and shallow coastal flows where local winds are important for mean currents, waves, and sediment transport.

2. Field observations

Wind speeds and directions were measured in June, July, and August 2009 at 5 locations (red symbols in Fig. 1) separated by up to about 5 km on the Skagit tidal flats in Puget Sound (near La Conner, WA).

2.1. Geographic setting

Skagit Bay is bordered by Whidbey Island to the west and by Fir Island (a deltaic area of low-lying farmland between the north and south forks of the Skagit River) to the east. Skagit Bay connects to the rest of Puget Sound through Saratoga Passage to the south and to the Strait of Juan de Fuca through Deception Pass to the north. Both of these passages are bracketed by hills up to 150 m high (Fig. 1b). West of Whidbey Island, the Strait of Juan de Fuca passes between the Olympic Mountains (with some peaks higher than 2000 m) and Vancouver Island, and connects to the Pacific Ocean (Fig. 1a). East of Skagit Bay, the Cascade Mountains also have peaks higher than 2000 m. Interactions between the low-level westerly flows from the Pacific Ocean and these mountain ranges and bodies of water create complicated atmospheric flow patterns (Mass, 1981; Chien and Mass, 1997).

2.2. Measurements

Two 3-cup anemometers mounted on towers on the north and mid flats were deployed from July 7 until August 31, 2009 at 6.1 m above the flats. These instruments were designated as N0 and N1734, respectively, where the number refers to the distance in m along the flat (parallel to Skagit Bay) from N0 (Fig. 1b). Another 3-cup anemometer was located on a tripod at the top of a small island at the east edge of the flats (July 7—August 31, 2009; 28.4 m above the flats; N1588). Two 4-bladed helicoid propeller anemometers were mounted on buoys on the south tidal flats (one deployed from June 1 to June 26 and another deployed from June 1 to July 25, 2009; both 1.2 m above the sea surface when floating; N4941 and N4193, respectively).

The spring tidal range in Skagit Bay is roughly 4 m, and at low tide, sandy tidal flats extending about 5 km west from Fir Island are exposed. Although Skagit Bay is protected from ocean swell by Whidbey Island, the local winds may drive currents and can create 1-m-high waves (Ralston et al., 2013; Webster et al., submitted for publication).

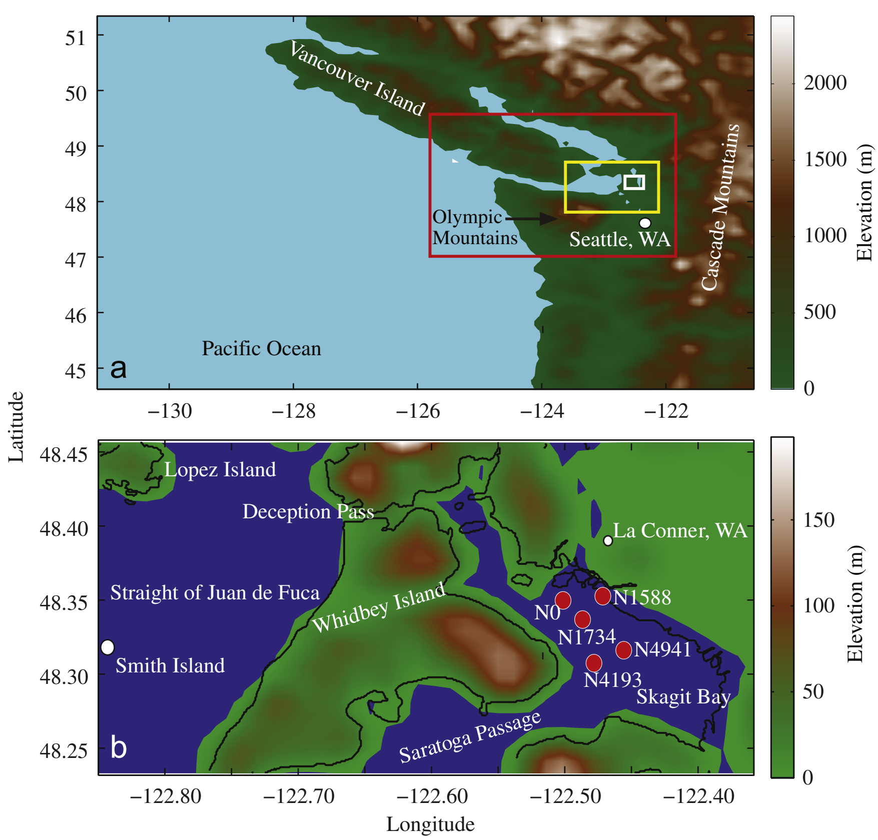

Fig. 1. (a) Region encompassed by the largest model grid (nest 1) with rectangles showing the regions for nest 2 (red), nest 3 (yellow), and the Skagit tidal flats (white), and (b) magnified image of the Skagit tidal flats region (white box in (a)) showing locations of anemometers (red circles). Colors represent topographical elevations used in (a) nest 1 (12-km resolution) and (b) nest 3 (1.3-km resolution) (scales on right). The black curve in (b) is the NOAA shoreline (http://www.ngdc.noaa.gov/mgg/coast/). Note that Puget Sound and Johnstone Pass (on the northeast side of Vancouver Island) are not well resolved by the 12-km grid, and the narrow Deception Pass is not well resolved by the 1.3-km grid.