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Assimilation of HF radar-derived radials and total currents in the Monterey Bay area

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ABSTRACT

Impact of HF radar surface-current assimilation on ocean circulation model predictions in the Monterey Bay area is studied and evaluated during the time frame of the Autonomous Ocean Sampling Network (AOSN-II) experiment (August–September 2003). In the first instance, a previously described method for assimilation of surface current data is applied to 33-h low-pass-filtered data and a non-tidal version of the circulation model. It is demonstrated that assimilation of surface velocity data significantly improves the surface and subsurface correlation of model currents with moored current observations. These results from the AOSN-II period illustrate that surface-current assimilation is beneficial even in cases for which very high-resolution (3 km) atmospheric forcing is utilized. The assimilation approach is also tested with hourly, unfiltered, CODAR-type HF radar-derived surface currents within a model configuration that includes tidal forcing. It is shown, that assimilation of unfiltered (with tides) surface-current observations into the model with tides improves the sub-tidal model predictions to the level comparable with the assimilation of filtered data into the non-tidal model, which is significant with respect to options for designing real-time nowcast and forecast systems. Finally, the approach is extended and evaluated for the direct assimilation of HF radar-derived radial velocity components. The model runs that included assimilation of radials from at least two HF radar sites show better correlations with observations than the non-assimilative run, especially those runs that included radials from the Santa Cruz site. Directions of radials for that site coincide with the directions of dominant southward flow during upwelling events and the northward flow during relaxation events. Direct assimilation of radial currents extends the range of influence of the data into regions covered by only one HF radar site.

1. Introduction

During the last decade high-frequency (HF) radar systems have been installed operationally throughout the world. Assimilation of HF radar surface currents into oceanic models has been a subject of a number of studies (Lewis et al., 1998; Breivick and Sætra, 2001; Oke et al., 2002; Kurapov et al., 2003; Paduan and Shulman, 2004; Wilkin et al., 2005). Surface-current data assimilation experiments based on high-frequency radar observations in summer 1999 and 2000 were described in Paduan and Shulman (2004). In that study, low-pass-filtered surface currents were assimilated into a non-tidal circulation model of Monterey Bay based on a nested implementation of the Princeton Ocean Model (POM). That model was forced with either the 91-km-resolution winds from the Navy's Global Atmospheric Prediction System (NOGAPS; Rosmond et al., 2002) or 9-km resolution-winds from the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™; Hodur et al., 2002). The evaluated assimilation scheme consists of two steps: the physical-space statistical analysis system (PSAS) is used to derive corrections to the model surface velocity based on comparisons with observed surface currents. Then corrections are projected downward through the frictional boundary layer assuming that the model-data velocity differences at the surface represent the top of a constant eddy viscosity Ekman boundary layer (see Paduan and Shulman, 2004, and Section 3 below). The underlying hypothesis in this procedure is that inadequate wind-stress forcing can be partially compensated by adjusting model currents toward the observed surface currents. It was shown that assimilation of CODAR-type HF radar data improved model simulations at mooring locations down to 120 m (which was well below the depths directly influenced by the Ekman-layer-assimilation procedure; Paduan and Shulman, 2004).

The present study represents a follow-on to the work of Paduan and Shulman (2004) that takes advantage of the data collected around Monterey Bay as part of the Autonomous Ocean

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Sampling Network Experiment (AOSN-II) in August–September 2003. Also important is the initiation of a high-resolution (3 km) COAMPS™ atmospheric model nest covering the central California region that was first put in place during AOSN-II (Doyle et al., 2008). In this study, we address the following issues:

1. Impact of assimilation of low-pass-filtered HF radar surface currents on model predictions during AOSN-II time frame.
2. Impact of assimilation of unfiltered HF radar surface currents on model predictions during AOSN-II time frame. The data assimilation approach of Paduan and Shulman (2004) was designed for correcting wind-driven, sub-tidal currents. For this reason, the 33-h low-pass-filtered CODAR data were assimilated into the circulation model. Oke et al. (2002), for example, used a rather more computationally expensive pre-filtering in their data assimilation scheme to minimize shocks in the model responses. We investigate whether the assimilation of unfiltered data improves or degrades sub-tidal model predictions in comparison to the assimilation of pre-filtered observations.
3. Impact of assimilation of HF radar radials on model predictions during AOSN-II time frame. Benefits of direct radial velocity assimilation include the ability to avoid the total vector combination step and errors associated with geometric dilution of precision effects. The area of data influence can be extended by including some information in regions covered by just one HF radar site. Direct assimilation of radial velocity components also expands the possibility to assimilate HF radar data from ships and petroleum platforms. Formulation of the assimilation problem in terms of radial velocity components does, however, greatly expand the apparent number of observations that must be dealt with during each assimilation time step.

2. Observation and model descriptions

2.1. HF radar network

Surface-current observations used in this study were derived from a network of five SeaSonde-type HF radar instruments deployed in the region of Monterey Bay (Fig. 1). Those instruments, commonly referred to as CODAR-type HF radar systems, exploit information in the radiowave backscatter from the ocean surface to infer movement of the near surface water. Electromagnetic waves in the HF band (approximately 3–30 MHz) exhibit Bragg-resonant reflections from wind-driven gravity waves on the ocean surface whose physical wavelength is precisely 1/2 the wavelength of the transmitted radiowave. During the AOSN-II period in August–September 2003, four SeaSonde systems were operating at frequencies near 12.5 MHz and one system (in Moss Landing) was operating at 25.4 MHz, which meant that the Bragg-resonant scatter from the sea surface was due to gravity waves whose wavelengths were, approximately, 12 and 6 m, respectively.

Several studies have investigated the performance of the Monterey Bay HF radar network by comparing the radar-derived currents with in situ velocity observations and by comparing radar-to-radar velocity estimates on the over-water baselines between radar sites (e.g., Paduan and Rosenfeld, 1996; Paduan et al., 2006). Consistent uncertainty values emerge in the range of 10–15 cm/s for the remotely estimated velocities. In addition to those performance measures, Paduan and Shulman (2004) described monthly tabulations of cross shore and along shore velocity decorrelation scales based on earlier computations from the Monterey domain. These same uncertainty and decorrelation values are used in this study.

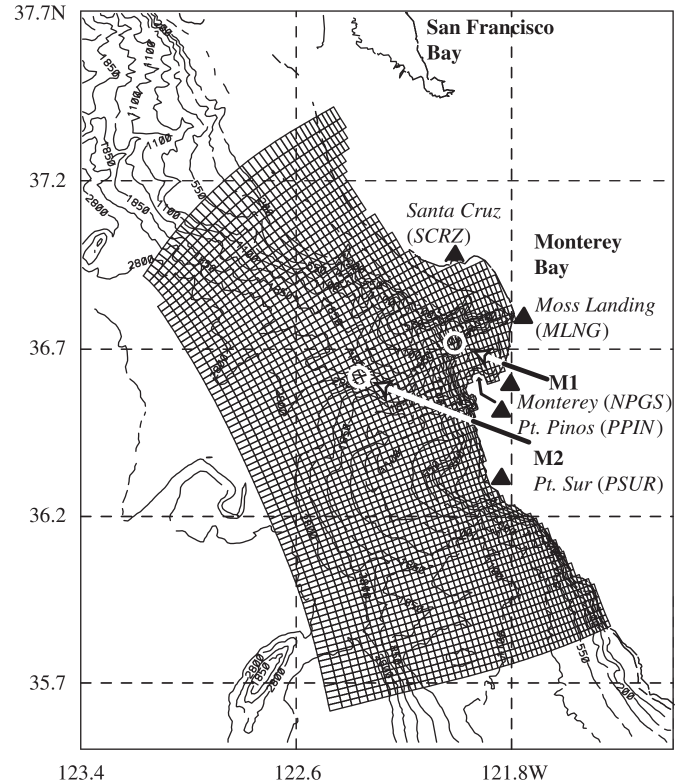

Fig. 1. The ICON model domain with local bathymetry and the locations of coastal HF radar sites (triangles) and offshore moorings (M1 and M2).

Also relevant to this study are the basic descriptions of data availability from the HF radar network. Each individual SeaSonde instrument provides a distribution of so-called "radial" velocity observations each hour on a polar coordinate grid centered on the radar site. Independent estimates of the speed of the water approaching or receding from the radar site are provided at scales of 3 km in range (1.5 km for the 25.4-MHz system) and 5° in azimuth. Each hour's spatial set of radial velocity estimates is not necessarily filled in. This is due to limitations of the direction finding algorithm used with a compact HF radar system such as the SeaSonde (see, for example, Barrick and Lipa, 1997; Laws et al., 2000; de Paolo and Terrill, 2007; Toh, 2005). The cumulative radial velocity coverages are shown in Fig. 2 for each radar site. In the figure, the value at each grid location depicts the percentage of the total possible hourly observations obtained at that location during the analysis period. From the figure, it can be seen that the offshore range for the 12.5-MHz systems was between about 50 and 60 km, while the range for the 25.4-MHz system was about 40 km. Vector current estimates require overlapping radial observations from two or more HF radar sites, which results in more limited coverage. Vector currents were estimated on a Cartesian grid with a horizontal resolution of 3 km by computing the best-fit vector velocity components using all radial velocity observations within a radius of 3 km for each grid point each hour (hence, neighboring vector current results are not completely independent). The percent coverages by grid location for (total) vector currents are also shown in Fig. 2.

Finally, it is important to point out what are the approximate depths of the HF radar-derived current estimates. Because the HF radar measurement depends on the ocean currents impeding or assisting the Bragg-resonant gravity waves, the depth or thickness of the relevant ocean currents depends on the penetration depths of the resonant wave's particle motions. The weighted averaged