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Bred-ensemble ocean forecast of loop current and rings

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Abstract

Ocean forecasting with a General Circulation Model (GCM) commonly begins from an initial analysis obtained by data assimilation. Instead of a single initial state, bred-ensemble forecast [BEnF; which is used for weather forecasting at the National Centers for Environmental Prediction] begins from an ensemble of initial states obtained by using the GCM to breed fast-growing modes into the analysis. Here we apply the technique to forecast the locations and strengths of the Loop Current and rings from July through September 2005. Model results are compared against satellite observations, surface drifter trajectories, and moored currents. It is found that BEnF gives closer agreements with observations than the conventional single forecast. The bred-vectors (perturbed minus unperturbed state-vectors) have growth rates ≈0.04–0.08 day^{-1} and spatial (cyclone–anticyclone) scales ≈200–300 km suggestive of baroclinic instability mode in the Loop Current and rings. As in atmospheric applications, initializations with these growing vectors contribute to the more accurate ensemble mean forecast.

Keywords: Bred-ensemble forecast; Ocean circulation; Loop current; Rings

Regional Index Terms: Gulf of Mexico; Caribbean Sea

1. Introduction

The Loop Current is the dominant feature of the circulation in the eastern Gulf of Mexico and the formation region of the Florida Current-Gulf Stream system (Figs. 1 and 2). It originates at the Yucatan Channel through which approximately 23–27 Sv (1 Sv = 10^6 m^3 s^{-1}) transport passes with a large minimum–maximum range of 14–36 Sv (Johns et al., 2002; Sheinbaum et al., 2002). Peak speeds of 1.5–1.8 m s^{-1} have been observed near the surface in the Loop Current (e.g., Nowlin, 1972; Forristal et al., 1992; see Oey et al., 2005a for other references). The Loop Current feeds the Florida Current which transports significant amounts of heat poleward. The Loop episodically sheds warm-core rings (e.g., Cochrane, 1972; Vukovich, 1995) at intervals of approximately 3–18 months (Sturges and Leben, 2000; Leben, 2005). These rings have diameters

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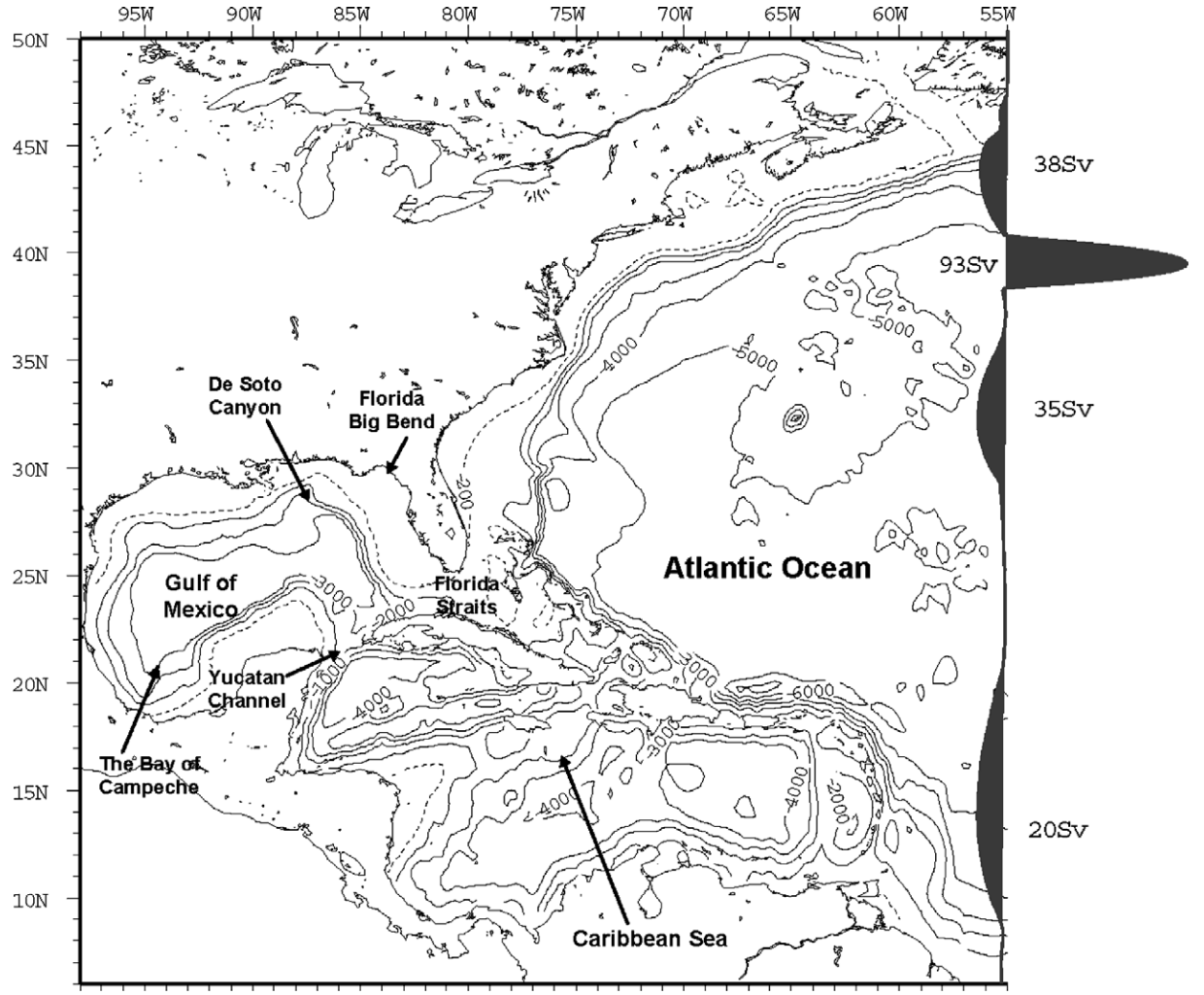

Fig. 1. A locator map of the study region: the Gulf of Mexico and surrounding ocean regions. The domain shown is also the model domain. Time-independent inflow and outflow that account for the large-scale transports (Svedrup + thermohaline) are specified across the open boundary at 55 °W as a function of latitude (as indicated with silhouette profiles). Contours show isobaths in meters.

≈200–300 km, vertical extent ≈1000 m, and swirl speeds ≈1.8–2 m s^{-1}; they generally translate westward at 2–5 km day^{-1} and have lifetimes of months to approximately a year (Nowlin, 1972; Elliott, 1982; Vukovich and Crissman, 1986; Cooper et al., 1990; Forristal et al., 1992). The Loop Current and its rings are powerful oceanic features that affect, either directly or indirectly through their smaller-scale subsidiaries, just about every aspect of oceanography of the Gulf (Oey et al., 2005a).

In addition to producing strong ocean currents, the Loop and rings possess, by virtue of their deep thermoclines, large values of the Ocean Heat Content (OHC; Leipper and Volgenau, 1972):

$$\mathrm{OHC} = \rho_0 C_p \int_{Z_{26}}^{\eta} (T - 26)\mathrm{d}z, \quad T \geqslant 26\,^{\circ}\mathrm{C},$$

where Z_{26} (>0) is depth of the 26 °C isotherm, η = sea-surface height (SSH), ρ_0 density of sea water and C_p the specific heat of water. Sea surface temperatures (SST's) in excess of 26 °C are necessary for tropical cyclogenesis (Palmen, 1948; DeMaria and Kaplan, 1994). Regions where OHC > 60–90 kJ/cm^2 have been empirically found to be conducive to storm intensification, and OHC has been used as one of several parameters in hurricane prediction schemes (DeMaria et al., 2005). Typical values of OHC in summer through autumn easily