Ocean Modelling 114 (2017) 45–58

Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

Impact of data assimilation on ocean current forecasts in the Angola Basin

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A R T I C L E I N F O

Article history:
Received 31 July 2016
Revised 16 April 2017
Accepted 21 April 2017
Available online 22 April 2017

Keywords:
Altimetry
Lagrangian data
Data assimilation
4D-Var
Angola Basin
OSCAR

A B S T R A C T

The ocean current predictability in the data limited Angola Basin was investigated using the Regional Ocean Modelling System (ROMS) with four-dimensional variational data assimilation. Six experiments were undertaken comprising a baseline case of the assimilation of salinity/temperature profiles and satellite sea surface temperature, with the subsequent addition of altimetry, OSCAR (satellite-derived sea surface currents), drifters, altimetry and drifters combined, and OSCAR and drifters combined. The addition of drifters significantly improves Lagrangian predictability in comparison to the baseline case as well as the addition of either altimetry or OSCAR. OSCAR assimilation only improves Lagrangian predictability as much as altimetry assimilation. On average the assimilation of either altimetry or OSCAR with drifter velocities does not significantly improve Lagrangian predictability compared to the drifter assimilation alone, even degrading predictability in some cases. When the forecast current speed is large, it is more likely that the combination improves trajectory forecasts. Conversely, when the currents are weaker, it is more likely that the combination degrades the trajectory forecast.

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1. Introduction

Accurately forecasting regional ocean currents is of great importance for many applications including tracking ocean debris, planning search and rescue missions and responding to a major marine pollution event such as oil spills. Lagrangian trajectory forecasts are of particular importance for such applications and provide the most stringent test for an ocean model's circulation. Their challenging predictability is through the accumulation of errors including errors in the wind forcing, initial and boundary conditions, and approximations in model physics and sub-grid scale parameterizations (Griffa et al., 2004). Data assimilation (DA) is often applied to improve an ocean model's representation of the real circulation. This technique has subsequently contributed to a significant rise in forecast skill (Rabier, 2005; Bauer et al., 2015). Its objective is to derive an optimal estimate of the current and future state of the system using observations together with information from the dynamical model (Lahoz et al., 2010). Many major ocean modelling systems have implemented DA schemes (Dombrowsky et al., 2009), including the Regional Ocean Modeling System (Moore et al., 2011b), Nucleus for European Modeling of the Ocean (Mogensen et al., 2012), and Navy Coastal Ocean Model (Smith et al., 2015).

Despite advancements in the assimilation schemes themselves, ocean DA lags behind its atmospheric counterpart greatly regarding observations. The environment of the ocean means sampling is difficult, with satellite information only limited to the surface (Anderson et al., 1996). Buoys, profiling floats (Argo), satellites, moorings, coastal radars, gliders and surface drifters make up the main observational data sets for the ocean.

This study focuses on three data sets that can have the strongest influence on the upper ocean velocity: satellite altimetry, satellite-derived surface currents and drifter data. Altimetry provides ocean velocity information indirectly through the geostrophy within the model. The assimilation of altimetry has been shown to improve model circulation in numerous studies of various parts of the ocean (Fukumori et al., 1999; Dorofeev and Korotaev, 2004; Dombrowsky et al., 2009; Moore et al., 2011a; da Rocha Fragoso et al., 2016). Satellite-derived surface current products compute the geostrophic component explicitly from altimetry often combining with a wind-induced Ekman surface current component derived from surface wind data. OSCAR is a widely used satellite-derived surface current analysis product (Johnson et al., 2007) and has only been previously assimilated using a

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http://dx.doi.org/10.1016/j.ocemod.2017.04.006
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nudging technique for the Indian Ocean by Santoki et al. (2013), where surface current improvements were demonstrated. Surface drifters sample numerous scales of the ocean circulation (Lumpkin et al., 2017) and their assimilation has also been shown to improve model circulation and predictability (Molcard et al., 2003; Özgökmen et al., 2003; Molcard et al., 2005; Nodet, 2006; Salman et al., 2006; Nilsson et al., 2012; Carrier et al., 2014). The growing interest in predicting flow trajectories, due in part to the Deepwater Horizon incident, has led to a rise in the utilisation of drifters for improving forecasts (Poje et al., 2014). Recent research on the assimilation of drifter velocities remains focussed on the Gulf of Mexico (GOM) due to a large amount of drifter data available. Muscarella et al. (2015) and Carrier et al. (2016) utilised the Grand Lagrangian Deployment (GLAD) data set (300 drifters released in a short period in a localised region in the GOM) and have shown that assimilating drifter inferred velocities improves both the Lagrangian predictability and sea level forecast. Berta et al. (2015a) has combined GLAD drifters and altimetry in a Lagrangian - variational scheme to produce instantaneous estimates of ocean current velocities improving the hind-cast trajectory skill.

Our contribution focused on forecasting ocean velocities with ROMS and a 4D-Var DA scheme quantifying the relative importance of assimilating altimetry, OSCAR and limited drifter data separately and combined. Our approach was similar to that of Muscarella et al. (2015) but differed in the following ways: Firstly, we sought to separately quantify the individual and combined use of altimetry, OSCAR and drifters. This was the first time OSCAR has been assimilated using an advanced data assimilation method such as 4D-Var. Besides the additional components added to the geostrophic velocities, OSCAR closely relates to altimetry, and whether the OSCAR assimilation provides any added benefit was not understood.

Secondly, our study focused on the Angola Basin with a limited number of drifters. The Angola Basin is part of the tropical ocean and therefore has crucial characteristics that differ from the GOM, such as a much larger Rossby Radius of deformation. The Angola basin was chosen due to its diverse ocean currents (Stramma and Schott, 1999), importance as a petroleum reservoir (Clifford, 1986), and marine biodiversity (Boisribert and Virdin, 2008). This study was the first application of data assimilation in the Angola Basin. Fig. 1 shows a schematic of notable oceanographic features of the region. Major oceanic features include the Equatorial Under Current (EUC), Gabon-Congo Undercurrent (GCUC), South Equatorial Current (SEC), the South Equatorial Counter Current (SECC) which branches to become the Angola Current (AC) moving south along the coast, the Benguela Oceanic Current (BOC) and its coastal branch the Benguela Coastal Current (BCC) moving north along the coast, the Angola dome (AD), the Angola-Benguela front (ABF) and the Congo River (Stramma and Schott, 1999).

Furthermore, the Angola Basin has a limited drifter coverage. While the GOM and GLAD drifter data set remains a valuable case study, this abundance of observations constrained to a small region is not typical. In most other regions the drifter coverage would be substantially less, and in the case of a marine pollution, would likely require some form of targeted deployment (Sharma et al., 2010). Therefore this study focused on the impact of local changes near the drifters and not how information spreads to unobserved regions, with no data denial experiments performed. In a more realistic drifter limited region, the impact of assimilating the drifters together with common observations streams such as altimetry was not apparent.

The paper is organised as follows: Section 2 will present the numerical model, data assimilation scheme, observations, and methodology. Section 3 will present the results, and Section 4 will highlight the discussion, concluding in Section 5 with a summary.

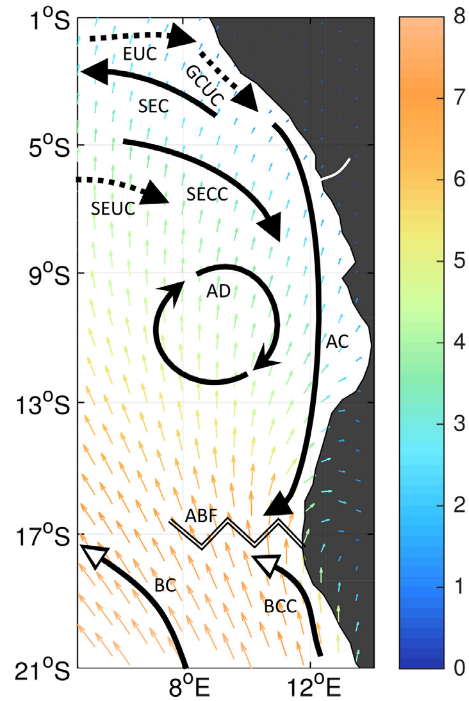

Fig. 1. Schematic of all the major oceanographic features of the Angola Basin. Warm surface currents (solid lines with black arrowheads) are the South Equatorial Current (SEC), South Equatorial Counter Current (SECC), Angola Current (AC). Warm undercurrents (dashed lines with black arrowheads) are the Equatorial Undercurrent (EUC) and Gabon-Congo Undercurrent (GCUC). Cold surface currents (solid lines with white arrowhead) are; the Benguela Oceanic Current (BOC) and Benguela Coastal Current (BCC). Also shown, The Angola Dome (AD), the Angola-Benguela Front (ABF) and the Congo River (CR). Overlaid as vector velocities (m/s) are the ERA-I (JFM) averaged winds averaged over the study period. Adapted from Pérez et al. (2001).

2. Methodology

2.1. Numerical Model

ROMS is a hydrostatic, primitive equation, Boussinesq ocean general circulation model. Shchepetkin and McWilliams (2005) describes an in-depth review of the numerics and formulation. Previous studies have utilised this model in understanding the Congo River plume dynamics (Denamiel et al., 2013) and effects on ocean temperature (White and Toumi, 2014). The model domain extends between $1^oS - 21^oS$ and $3.7^oE - 13.8^oE$ with a 10 km resolution and 40 terrain-following vertical levels. To determine the degree of vertical stretching, ROMS employs a generalised topography-following coordinate system with user-defined σ parameters. ROMS σ parameters were as follows: $h_c = 200$ m is the critical depth applied to both the surface and bottom boundary layer where there is enhanced resolution, and $\sigma_s = 10$ and $\sigma_b = 2$ control the degree of enhanced resolution at the surface and bottom boundary layer respectively. Thus, the vertical levels were compressed at the surface to increase the vertical resolution of the surface currents.

Sub-grid mixing was prescribed using the generic length-scale (GLS) scheme of Warner et al. (2005). Lateral boundary and initial conditions for temperature, salinity, ocean current velocities and sea surface height were obtained from the HYCOM reanalysis (Chassignet et al., 2007). Atmospheric forcing at the surface for downward radiative surface fluxes, sea level pressure, 2 m specific humidity, 2 m air temperature, 10m winds, and total precipitation were obtained from European Centre for Medium-Range Weather

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