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Advances in Space Research 51 (2013) 2155–2170

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Semi-automatic determination of the Azores Current axis using satellite altimetry: Application to the study of the current variability during 1995–2006

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Received 30 April 2012; received in revised form 9 November 2012; accepted 28 December 2012
Available online 7 January 2013

Abstract

Satellite altimetry has been widely used to study the variability of the ocean currents such as the Azores Current (AzC) in the North Atlantic. Most analyses are performed over the region that encloses the current, thus being somehow affected by other oceanographic signals, e.g., eddies. In this study, a new approach for extracting the axis of a zonal current solely based on satellite altimetry is presented. This is a semi-automatic procedure that searches for the maximum values of the gradient of absolute dynamic topography (ADT), using the geostrophic velocity as auxiliary information. The advantage of this approach is to allow the analyses to be performed over a buffer centered on the current axis instead of using a wider region. It is here applied to the AzC for the period June 1995–October 2006.

Regular 0.25° × 0.25° latitude–longitude grids of multi-mission sea level anomaly (SLA) were generated at a 10-day interval for the Northeast Atlantic using an optimal interpolation methodology with a realistic space-time correlation function. From these, regular grids of ADT and horizontal components of surface geostrophic velocity (U, V) were generated. By applying the methodology to these oceanographic fields, the AzC axis position for each 10-day frame has been derived.

The time-mean position of the AzC axis shows a good agreement with the highest root-mean-square values of sea level anomaly in the Azores Current region. Zonal means of axis position, SLA and U and V have been calculated over the longitude range of the current (35°W–15°W) to assess the AzC variability. The decomposition of the time series of the zonal mean of AzC position into trend and seasonal components shows the existence of significant inter-annual variability in the axis position, while seasonal variability is small. The AzC is found at its southernmost position from the beginning of the period to mid-1998, the minimum value occurring in late summer of 1996, and a northward displacement of the jet position is clearly visible up to the end of 2006.

Keywords: Northeast Atlantic Ocean; Azores Current; Satellite altimetry; Inter-annual variability

1. Introduction

The Azores Current (AzC) is a (quasi-) permanent baroclinic current of the North Atlantic, reaching a depth of about 1000 m, that flows almost zonally between latitudes 33°N and 35°N (Klein and Siedler, 1989; Pingree et al., 1999). The AzC originates as a branch of the Gulf Stream (GS), which turns southeastward from the Grand Banks of Newfoundland and crosses the Mid-Atlantic Ridge (MAR) towards the Gulf of Cadiz. In the Eastern Atlantic basin, the AZC supplies the Canary Current that joins the westwards North Equatorial Current (Gould 1985; Käse and Siedler, 1982). The westward counterflow, northwards of the AzC, reported by several studies (e.g., Cromwell et al., 1996; Alves and Colin de Verdière, 1999) is referred to as the Azores Countercurrent (AzCC).

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http://dx.doi.org/10.1016/j.asr.2012.12.021

The mesoscale circulation in the region is dominated not only by the meandering of the current itself but also by the associated recirculations and eddies (Käse and Siedler, 1982; Alves and Colin de Verdière, 1999; Pingree et al., 1999).

To first order, the Azores Front (AzF)/Azores Current system (sometimes called Subtropical Front/Azores Current system) is in geostrophic balance (Pingree, 1997; Alves et al., 2002). The AzF has a clear manifestation in the meridional distribution of eddy kinetic energy (EKE), both in drifter data and altimetry (Käse and Krauss, 1996; Stammer and Böning, 1996; Cromwell, 2006; Barbosa Aguiar et al., 2011; Volkov and Fu, 2011), and instability processes have been pointed out as the causes of the increase in energy-level in the region (e.g., Käse et al., 1985; Kielmann and Käse, 1987; Beckmann et al., 1994; Cipollini et al., 1997). Recent studies from Volkov and Fu (2010, 2011) have demonstrated that the inter-annual variability of the AzC eastward velocity and eddy energy may be driven by the adjustment of the ocean to the strength of westerly and trade winds, modulated by the North Atlantic Oscillation.

The questions concerning the mechanisms for the formation and persistence of the AzC system are still open (Juliano and Alves, 2007; Barbosa Aguiar et al., 2011). Käse and Krauss (1996) review the wind and buoyancy forcing mechanisms that have been hypothesized by earlier studies. The authors suggested that the wind stress curl undergoes large seasonal and inter-annual fluctuations, despite being significantly negative in the 35°N–50°N latitudinal range, and that under these conditions nonlinear inertial effects could control the dynamics in the GS extension, leading to its separation into the North Atlantic Current and the AzC. The authors also suggested that a relative minimum of the wind stress curl exists in the inner region of the North Atlantic subtropical gyre and therefore that conditions for the formation of a quasi-zonal flow like the AzC are present. More recently, studies using general circulation models proposed a different mechanism responsible for the AzC formation. According to Jia (2000), the AzF is situated southward of the mean zero wind stress curl, where Ekman pumping leads to a southward transport, implying that its zonal orientation cannot be totally explained by Sverdrup dynamics. The author has suggested that the entrainment of the upper North Atlantic Central Water (NACW) by the underlying denser Mediterranean Outflow Water (MOW) in the Gulf of Cadiz is able to induce the AzC. These results are also supported by e.g., Özgökmen et al. (2001), Kida et al. (2008) and Volkov and Fu (2010). The mechanism suggested by these studies to explain the existence of the AzC thus relies on the so-called β plume and can also be responsible for the existence of the AzCC (Jia, 2000; Özgökmen et al., 2001).

The analysis of the spatial and temporal variability in the position of the axis of oceanic currents is a valuable basis for assessing the variability associated with the currents themselves. Satellite altimetry, by providing the sea level anomaly (SLA) accurately enough for open-ocean studies can be considered a valuable technique to analyze the dynamics of the oceanic systems (Le Traon et al., 1998; Efthymiadis et al., 2002; Fu and Le Traon, 2006). Several oceanographic fields can be derived from SLA, including the absolute dynamic topography (ADT) and the horizontal components of surface geostrophic velocity field (U and V), providing that the mean dynamic topography (MDT) is known.

Assuming that the speed of an oceanic current is largest along its axis, the steepness of ADT slopes can be used as a proxy to axis position. Despite this advantage, only few studies concerning the axis extraction from altimetry-derived oceanographic fields have emerged in last years: e.g., Kelly et al. (1999), Lebedev (2006) and Lebedev and Sirota (2007), with focus on the analysis of the Gulf Stream, Antarctic Circumpolar Current and South Pacific Current, respectively. In these studies, gradients of sea surface temperature provide information on the position of the front/current systems and therefore infrared radiometry data have been used simultaneously with altimetry. On the contrary, the AzF does not have a clear surface thermal signature throughout the year (Juliano and Alves, 2007), and for this reason, only altimetry is used in this study to analyze the dynamics of the AzC.

For studying the variability of ocean currents, most analyses make use of satellite altimetry data over a region that encloses the current. Often, the mesoscale circulation in the region is dominated by the meandering of the current itself and also by the associated recirculations and eddies, which could affect the analyses.

In this study, a new approach for extracting the axis of a zonal current solely based on satellite altimetry is proposed. It is a semi-automatic procedure that searches for the maximum values of the gradient of absolute dynamic topography (ADT), using the geostrophic velocity as auxiliary information. In this way, for each time step, the current axis is extracted over a predefined longitudinal range. The advantage of this approach is to allow the analyses to be performed over a buffer centered on the current axis instead of using a wider region.

The aim of this study is twofold: (1) to present a semi-automatic methodology for extracting the position of the Azores Current axis from satellite altimetry, and (2) to analyse the seasonal and inter-annual variability of the AzC axis for the period 1995–2006.

Section 2 describes the oceanographic fields derived from satellite altimetry used in this study, as well as the semi-automatic algorithm specifically implemented to extract the AzC axis position over the study period. The time series describing the variability of the altimetry-derived oceanographic fields and their decomposition into seasonal and trend components are presented in Section 3. In Section 4, the results are discussed and conclusions are drawn.