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Mass and nutrient fluxes around Sedlo Seamount

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ABSTRACT

We use data from a hydrographic cruise in November 2003 over Sedlo Seamount, in conjunction with historical hydrographic and altimeter data, to describe the circulation patterns near the seamount and within the region. A mixing model that incorporates two water types and two water masses assesses the water composition within the region, and an inverse model provides estimates of mass transports within different water strata. Eastern North Atlantic Central Water dominates for the upper neutral-density (γ_n) levels, $\gamma_n<27.2$, and Western North Atlantic Central Water does so in the $27.2\leqslant\gamma_n\leqslant27.7$ band. In the $27.5\leqslant\gamma_n\leqslant27.8$ band Mediterranean Water constitutes slightly more than 10%, except in the northwestern portion where this water type is less abundant. For $27.7\leqslant\gamma_n\leqslant27.9$ Labrador Sea Water becomes the predominant water mass. The results from the inverse model and direct velocity measurements draw a gross picture of central waters flowing northwest along the northeastern margin of the seamount, while the net fluxes of Labrador Sea Water are relatively small. The central water flow appears to be topographically guided, with a region of high eddy kinetic energy over a spur that stretches southeast from the Mid-Atlantic Ridge. A gross calculation suggests the existence of significant net nutrient transport into the seamount that would support an enhanced level of primary production.

1. Introduction

The eastern North Atlantic (30–5°W, 20–45°N) is a deep basin, down to 5000–6000 m, bounded by the Mid-Atlantic Ridge (MAR) to the west and the European and African continents to the east (Fig. 1). This basin is characterized by the presence of many seamounts, in several instances emerging as archipelagos (Azores, Madeira, Canary, and Cape Verd). Sedlo is one of this many seamounts, located at 40.4°N–26.9°W, north of the Azores Archipelago (Fig. 1). Sedlo's odd bathymetry can be described as a three-summit seamount rising up to 800 m below the sea surface, oriented northwest–southeast (Fig. 2).

What makes Sedlo special is its key location near the MAR, so that it is influenced by both eastern and western Atlantic central waters, and west of the Iberian Peninsula, in the path of the Mediterranean outflow. At mid-latitudes, most of the upper ocean consists of subducted water that recirculates along the upper thermocline (Harvey, 1982; Talley and McCartney, 1982; Pollard and Pu, 1985; Emery and Meincke, 1986; Harvey and Arhan, 1988; Rios et al., 1992; Pollard et al., 1996). In the western North Atlantic the upper-thermocline layers are influenced by relatively fresh waters of southern origin reaching the western boundary through the equatorial region. These waters are transported north by the Gulf Stream, and later northeast via the North Atlantic Current and east via the Azores Current, as they raise towards the sea surface with the outcropping isopycnals. They constitute the Western North Atlantic Central Water (WNAW) and, west of the MAR, occupy the whole permanent thermocline. In the eastern North Atlantic the winter mixed layer gets quite deep, up to some 500 m, so that high-salinity surface waters reach the upper thermocline and give rise to the Eastern North Atlantic Central Water (ENAW). ENAW have been further divided between those of subpolar and subtropical origin by Rios et al. (1992), according to their latitude of formation and their posterior propagation.

Mediterranean Water (MW) spreads west initially through advection, as far as 22°W, and further beyond by diffusion, possibly enhanced by the propagation of Mediterranean lenses (Iorga and Lozier, 1999a, b) and their collision with seamounts (Bashmachnikov et al., 2009). As the result, the intrusion of MW properties has the shape of an intermediate-depth wedge over most of the North Atlantic (Joyce, 1981; Sy, 1988; Spall et al., 1993; Lozier et al., 1995; Iorga and Lozier, 1999a; Mauritzen et al., 2001).

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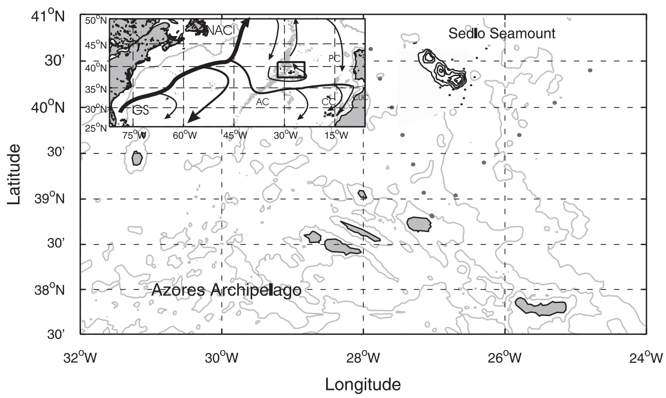

Fig. 1. Sedlo's location near Azores Archipelago. Bigger gray dots indicate the location of stations near Sedlo during the *A24 WOCE* cruise. Smaller black dots correspond to *OASIS M60* cruise. The inner figure shows a cartoon with the main currents in the North Atlantic: GS, Gulf Stream; NAC, North Atlantic Current; AC, Azores Current; PC, Portugal Current; CC, Canary Current; CUC, Canary Upwelling Current (adapted after Richardson, 1981; Paillet and Mercier, 1997; Machin et al., 2006a).

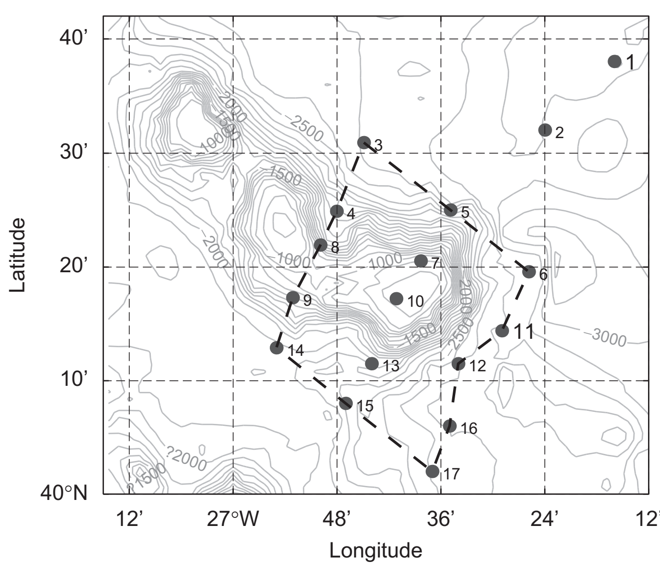

Fig. 2. Stations' location over Sedlo Seamount during the *M60* cruise. Isobaths labeled every 100 m. Dashed lines indicate the boundaries of the box for the inverse model. Bathymetry generated by the OASIS team.

Finally, Labrador Sea Water (LSW) reaches the eastern basin of the North Atlantic through the Charlie–Gibbs Fracture Zone and travels southward as a deep western boundary current (Paillet and Mercier, 1997; Speer et al., 1999; Machín et al., 2006a, b). Sedlo's summit (800 m) is located in the lower thermocline, at the depths of influence of both WNAW and MW.

In this paper, we examine the water masses present around Sedlo and relate their presence with estimates of mass and nutrient transports in the region. Section 2 describes the data set from one specific cruise over the region as well as from available historical hydrographic, nutrient and altimetry data. In Section 3 we present a mixing model, with the peculiarity of having a continuous description for the central waters, and use it to determine the water mass composition. Section 4 describes an inverse circulation method and applies it to calculate the mass and nutrient transports. In Section 5 we discuss the observed mass transports, and present a hypothesis on how these transports may be connected with the large-scale flow patterns. We end in Section 6 with some conclusions.

2. Data

From 18 to 28 November 2003, a total of 17 CTD casts were performed over the southeasternmost summit of Sedlo as part of cruise *Meteor 60/Leg 1*, carried out within the OASIS (OceAnic Seamounts: An Integrated Study) Project (Figs. 2 and 1). Temperature and salinity observations were interpolated to 1 dbar vertical intervals, from the sea surface down to about 1500 m or the sea floor if shallower.

A 38 kHz Ocean Surveyor ADCP system (RD Instruments) operated almost continuously during the cruise, leading to a high spatial-coverage of the Sedlo Seamount area, down to nearly 2000 m depth. The ADCP data processing was carried out with the CODAS (Common Oceanographic Data Access System) software (Firing et al., 1995). The main data processing steps are: (1) raw data were reduced to 5-min ensembles and rotated from transducer to earth coordinates, (2) the quality of the ensemble-averaged ADCP profiles (on-station and underway) was controlled, (3) the ship's gyro heading was corrected using Ashtech heading information, (4) the amplitude and transducer orientation (relative to the gyro compass) of each data set were estimated through a water track calibration procedure, (5) a navigation calculation was carried out to obtain absolute ADCP currents in geographical coordinates, (6) the method described by Candela et al. (1992) was used to spatially decompose the absolute velocity profiles into tidal and residual contributions, and (7) the residual currents were interpolated to a rectangular horizontal grid. The processing of this data set is carefully described in an accompanying paper (Mohn et al., 2009).

Fig. 1 shows the location of several hydrographic stations in the vicinity of Sedlo, taken as part of the *A24 WOCE* cruise. We have interpolated the observations from this cruise to Sedlo's location, down to 1500 m, to obtain a nutrient concentration profile over the seamount. In Fig. 3 we show the calculated phosphate, silicate, nitrate, and oxygen concentrations as a function of γ_n. On it we also present the nutrient and oxygen concentrations curves, obtained after interpolation of the available data to the position of Sedlo Seamount.

We also have used delayed-time maps of sea-level anomaly (SLA) (DT-MSLA-Ref) produced by Collecte Localisation Satellites (CLS) in Toulouse (France) and distributed by AVISO (SSALTO/DUACS, 2006), which combine the signal of two available altimeters. These maps are processed including usual corrections (sea-state bias, tides, and inverse barometer) and with improved ERS orbits using TOPEX/Poseidon to reduce the noise of ocean signal variability before computing the mean profile (Le Traon et al., 1998; Ducet et al., 2000; SSALTO/DUACS, 2006). For our calculations we have used a total of 618 maps corresponding to the period 14 October 1992–11 August 2004. Sea-level anomaly is regularly produced by subtracting a 7-year mean value (1993–1999) and low-pass filtering with a Lanczos filter, the cutoff wavelength depending on latitude (Ducet et al., 2000). SLA maps are then built every 7 days on 1/3 degrees Mercator grid. Finally, geostrophic velocities are estimated using finite differences. From these fields the sea-level variance (SLV, $\sigma_h{}^2$) and eddy kinetic energy (EKE) may finally be computed.

In an attempt to assess whether the flow patterns near Sedlo Seamount are topographically guided we have used the ETOP05 bathymetry data set, produced by NOAA from different sources of data (National Geophysical Data Center, 1988). The large-scale gradients of bottom topography are computed through finite differences of the original ETOP05 bottom depths, smoothed with a 10-point window.

3. Water masses analysis

In order to estimate the water-mass composition in Sedlo we assume that at every density level there is mixing of three water