Journal of Marine Systems 165 (2017) 36–46

Contents lists available at ScienceDirect

Journal of Marine Systems

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

Seasonal to interannual variability of water mass characteristics and currents on the Namibian shelf

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ARTICLE INFO

Article history:
Received 16 February 2016
Received in revised form 7 July 2016
Accepted 8 September 2016
Available online 12 September 2016

Keywords:
Benguela upwelling system
Long-term observations
Meridional advection
Warm and cold events
Benguela Niños

ABSTRACT

We present long-term current meter records from the Benguela system together with salinity and temperature observations gathered by a mooring on the Namibian shelf across 13 years (2002–2015). From this unique data set a climatological mean state is estimated enabling us to investigate seasonal to interannual variations of these variables on the Namibian shelf. The present study highlights the importance of the alongshore advection for the water mass characteristics in the Benguela system on a seasonal time scale. The annual cycle of the alongshore transport is characterized by a biannual flow reversal. Poleward directed currents dominate from October to April, and from May to September equatorward currents prevail. In addition, we present observational evidence for a biannual intrusion of tropical waters into the Benguela system with maxima in October and February.

Based on the in situ temperature data, several anomalous events are described that affect the whole water column. During the outstanding warm event in austral fall 2011 the monthly temperature anomaly exceeds one Kelvin for five consecutive months peaking in March (2.4 K) in the upper layer of the water column. Our study suggests, that the occurrence of such extreme temperature events in the Benguela upwelling system is closely related to the strength of the alongshore advection in austral summer.

1. Introduction

Hydrographic long-term observations are one of the keys to assess the interannual to decadal variability of the world oceans and hence the earth's climate. They allow a robust estimation of the system's mean state and its anomalies as well as to discover possible trends in the climate. Eastern boundary regions such as the Benguela upwelling system are hereby of particular interest due to their important role in the ocean's carbon and nutrient cycles and their impact on economic welfare (Carr and Kearns, 2003). Important reviews of the upwelling nature and the general circulation of the Benguela system are provided by Shannon (1985) and Shillington (1998).

Within the South Atlantic the Benguela upwelling system is a well observed and investigated area, see Fig. 1 for a map of the region. Hydrographic observations in the region have been performed for a long time. First measurement of the sea surface temperature (SST) in the Benguela system were already made at the very beginning of the 20th century, see Taunton-Clark and Shannon (1988). A regular monitoring of various environmental parameters including the subsurface started in the early 1950s off Namibia (Stander and De decker, 1969). Since then, standard depth resolved ship-born temperature measurements in the area off central Namibia have been continued during various campaigns and monitoring programs (Bartholomae and van der Plas, 2007). Based on these measurements and remotely sensed data, the seasonal to interannual variations of temperature and salinity in the Benguela system have been described by several studies, e.g. Shannon (1985), Cole and Villacastin (2000), Hardman-Mountford et al. (2003), and references therein.

A well known feature contributing to seasonal changes of temperature and salinity is the periodical intrusion of tropical, hypoxic waters into the Benguela upwelling system (Boyd et al., 1987). The source region of these waters is the Angola Gyre where the oxygen depletion is caused by decomposition of sinking organic matter (Mohrholz et al., 2008). Model results presented by Rouault (2012) suggest that this intrusion is of biannual nature. From the Angola Gyre, the tropical water is transported southward by the Angola current and the poleward undercurrent that deepens while penetrating southwardly, Veitch et al. (2010). The tropical water is present on the Namibian shelf in late austral summer and early fall

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http://dx.doi.org/10.1016/j.jmarsys.2016.09.003
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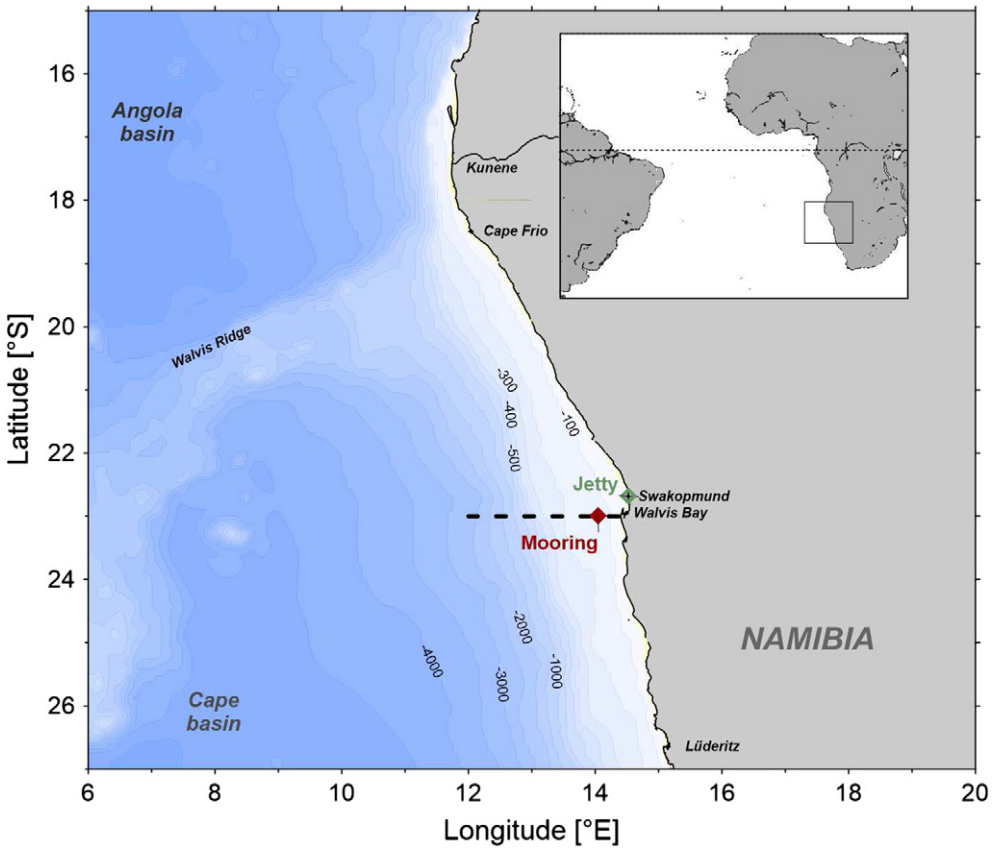

Fig. 1. Map showing the location of the mooring (red), the location of the coastal temperature sensor at the Swakopmund Jetty (green) and the monitoring transect (black dashed line).

and may reach as far south as 27°S (Duncombe Rae, 2005; Fennel et al., 2012; Gordon et al., 1995). The advection of this warm and oxygen poor water impacts the environmental conditions on the shelf heavily as it causes hypoxic–anoxic conditions and may support sulfur outbreaks (Copenhagen, 1934; Mohrholz et al., 2008; Monteiro et al., 2006; Ohde and Mohrholz, 2011).

On top of seasonal fluctuations, the hydrographic conditions in the Benguela system undergo year-to-year variations. Early investigations of the long-term SST variability in the south-east Atlantic were conducted by McLain et al. (1985) and Walker (1987). Based on 23 years of data from voluntary observing ships, Walker (1987) demonstrated region-wide warming and cooling trends in the first principal component of the SST variability. The occurrence of several warm events, often referred to as Benguela Niños, is described throughout the literature, e.g. for 1963 (Stander and De decker, 1969), 1984 (Shannon et al., 1986 and Taunton-Clark and Shannon, 1988), 1995 (Gammelsrød et al., 1998), and 2001 (Rouault et al., 2007). Mainly two mechanisms driving the interannual temperature variability in the Benguela system are discussed in the scientific community. One hypothesis under consideration is the remote forcing of the region by relaxing zonal wind stress in the eastern tropical Atlantic, e.g. Florenchie et al. (2003), Florenchie et al. (2004), Rouault et al. (2007), Lübbecke et al. (2010), and Bachelery et al. (2016). The variability in the equatorial wind forcing is transmitted to the Benguela system by Kelvin waves traveling along the equatorial and coastal wave guide. A competing hypothesis was put forward by Richter et al. (2010) who found that local wind anomalies along the south-west African coast are responsible for the variability of the SST on an interannual time scale.

Although there is quite an amount of observational and model data for the Benguela system available in the recent decades and many studies describing the seasonal to interannual variability based on those data exist, the Benguela system lacks *robust* long-term observations. Remotely sensed data near the coast is influenced by clouds and land contamination and do not allow conclusions about the conditions in the water column. Sporadic ship-born measurements may be disturbed by non-linear internal waves affecting the vertical structure of the water body on short time scales and thus biasing the results. And lastly, global general ocean circulation models suffer from severe deficits in modeling the tropical and subtropical South Atlantic adequately, e.g. Xu et al. (2014).

However, long-term high-resolution mooring data overcomes these drawbacks and therefore allows a much more solid estimation of seasonal changes, interannual variability and possible trends of the hydrographic conditions in general. In this study, we present long-term current meter records from the Benguela system together with salinity and temperature observations. This data is used to provide a climatological mean state of the hydrography as a basis for an improved understanding of seasonal to interannual variations in the region. Special emphasis is put on the alongshore advection as it appears to be a key variable controlling the hydrographic conditions on the Namibian shelf.

2. Data and methods

2.1. Mooring data

2.1.1. Mooring set up

Temperature, salinity, and currents are measured with an oceanographic mooring on the Namibian shelf at about 14°E and 23°S, see Fig. 1. The mooring site is located approximately 20 nautical miles