The Benguela: Large Scale Features and Processes and System Variability

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Abstract: The Benguela is one of four major eastern boundary current regions of the World Ocean. The oceanography off the west coast of southern Africa is dominated, like the regions off California, Peru and North West Africa, by coastal upwelling; but the Benguela is unique in that it is bounded on both the equatorward and poleward ends by warm water regimes. In this paper we build on review articles which were published during the 1980s by highlighting the main advances in the conceptual understanding of the system since 1985. A large amount of research on this eastern boundary domain has been conducted in recent years by the institutes to which the authors are affiliated. This has given clear definition to four aspects of shelf dynamics, these being poleward flow at depth across the shelf and out into the slope region, the existence of baroclinic shelf-edge jets in the vicinity of the shelf break, barotropic shelf waves and the importance of variation in wind rather than constant strength of wind as a factor controlling upwelling. Short discussions of some, as yet, unpublished findings supplement published works by ourselves and other authors. Of particular importance are the events such as Benguela Niños in the north and intrusions of Agulhas water in the south. The latter, which can take the form of filaments or rings, influences the oceanography of the region of the "Greater Agulhas Current", with interactions between Agulhas rings and Benguela shelf waters.

Introduction

The Benguela is one of four major eastern boundary current regions of the World Ocean. The oceanography off the western coast of southern Africa is dominated, like the regions off California, Peru and North West Africa by a coastal upwelling system; however, the Benguela is unique in that it is bounded at both the equatorward and poleward ends by warm water regimes.

Much of the oceanographic research which has been conducted in the Benguela has been in support of biological studies associated with southern African west coast fisheries. Prior to 1970 most of the oceanographic literature was of a descriptive nature. Studies of mesoscale upwelling processes commenced during the late 1960s and were by the early 1980s a major focus of attention. This work has been reviewed by Nelson and Hutchings (1983), Shannon (1985) and Chapman and Shannon (1985). Since then the research has become more quantitative, with the emphasis being placed on shelf dynamics and ocean variability. These studies, together with larger scale investigations in the Agulhas retroflection area and in the South-east Atlantic, have provided some important new insights into this small region of the World Ocean.

In this paper we build on the reviews cited above by providing an overview of the principal characteristics of the Benguela, including its overlying wind fields, oceanic boundaries and fronts, deep and shelf circulation and system variability. The main advances in the conceptual understanding of the system since 1985 are highlighted. This article does not purport to be an encyclopaedic review of the oceanographic literature on the Benguela region of

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the South Atlantic, but rather the authors' perspective of the most important elements of the system and its dynamics emerging from a synthesis of the now several hundred papers in existence on the subject.

Geomorphology

The sediment composition and structure and bathymetry of the South-east Atlantic have been described by Birch and Rogers (1973), Birch et al. (1987) and Dingle et al. (1987) in the form of a detailed bathymetric map, and Rogers and Bremner (1991). The salient features of the bathymetry, following Shannon (1985), are as follows.

The Cape and Angola Basins, which comprise the abyssal plain in the South-east Atlantic Ocean, are separated by the Walvis Ridge, which runs from its abutment with the continental shelf at about latitude 20°S in a southwesterly direction for more than 2 500 km towards the Mid-Atlantic Ridge (Fig. 1). The Walvis Ridge forms a barrier to the northward and southward flow of water below a depth of about 3 000 m, although some leakage of Antarctic Bottom Water across the Ridge does occur (Shannon and Chapman 1991). Prominent geological features of the Cape Basin, which is bounded in the south by the Agulhas Ridge, are the numerous seamounts of volcanic origin, of which Discovery and Vema are two examples.

The bathymetry of the western continental margin off southern Africa is variable, with the shelf being narrow off southern Angola (20 km), south of Lüderitz (75 km) and off the Cape Peninsula (40 km). The widest zones occur off the Orange River (180 km) and in the extreme south (Agulhas Bank, 230 km). Double shelf breaks are common off the west coast (Siesser et al. 1974), and near Walvis Bay (23°S) there are inner and outer breaks beginning at depths of about 140 and 400 m (see insets in Fig. 1). At about 31°S, Childs Bank, another shallow feature, is situated about 150 km offshore. Farther south, in particular between 32°S and 35°S, the shelf is variable in width. Between 31°S and 33°S (Cape Columbine) there is an inner and an outer shelf break (200-380 m and 500 m) which merge south of 33°S to form a single, deep shelf break. Between 31°S and 35°S several submarine canyons cut into the shelf, the most prominent being the Cape Canyon, which runs from a head 60 km west of Cape Columbine in a southerly direction. The Agulhas Bank, a relatively wide and shallow feature, forms the southernmost margin of the continental shelf.

Of additional importance to the oceanic conditions of the region is adjacent distribution of land. The west coast of southern Africa consists of a relatively narrow coastal plain rising to the main continental escarpment, situated between 50 and 200 km inland. Much of the coastal region is arid. North of 32°S the coastline is regular and, except for Walvis Bay and Lüderitz, is devoid of significant embayments. South of this latitude, several prominent headlands occur; two granitic outcrops in the vicinity of Cape Columbine and Cape Town form the southern boundaries of bays, so leaving the bays exposed at their northern ends (St Helena Bay and Table Bay), while to the south of the outcrops there are enclosed bays (Saldanha Bay and False Bay). A large peninsula lies south of Cape Town (Cape Peninsula), along which mountains attain heights up to 1 000 m. The topography from Cape Town to Cape Point at the southern extremity of this peninsula play an important role in wind forcing over the adjacent shelf sea.

The Wind Field

Winds in the Benguela are controlled by anticyclonic motion round the South Atlantic high pressure system, the seasonal low pressure field over the subcontinent, and by east-moving cyclones which cross the southern part of the continent. The South Atlantic anticyclone is maintained throughout the year, with seasonal differences in pressure being on the order of 3-4 mb. It shifts seasonally over 6° of latitude, reaching northern and southern extremities in May and February respectively, and 13° of longitude, reaching an extreme westward position in August (Tyson 1986). The scale of the movement is shown in Fig. 2c. It forms part of the discontinuous belt of high pressure systems which encircle the subtropical southern hemisphere. Pressures over the continent change radically from well developed lows