The oceans around southern Africa and regional effects of global change

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In the last few decades, a great deal of work has been carried out on the nature of the oceanic circulation around southern Africa. Attempts have been made to determine regional ocean–atmosphere interactions and the effect of changing sea-surface temperature fields on weather and climate. At the same time, the marine biology and ecosystems of coastal waters have been extensively studied. Few studies have been concerned with the possible effects of global change on the physical and biological components of the systems and their linkages in the regional earth system of the subcontinent. In this paper, a first attempt is made to integrate past work and synthesize it using a systems approach framework. Attention is focused on the nature of the regional ocean circulations affecting southern Africa. The features of the Agulhas and Benguela systems most likely to be affected by global change are discussed and contrasted. At the same time the links to the marine biological and coastal ecosystems of the east and west coasts are explored and the inter-dependencies between physical, biogeochemical and ecological components of regional ocean systems and their anthropogenic modulation are considered.

Introduction

The oceanic circulation systems adjacent to southern Africa are some of the most diverse and complex to be found anywhere (Fig. 1). To the south of the subcontinent is the wide expanse of the Southern Ocean that links all the world's oceans and has a recognized role in global climate. Some of the weather systems that affect southern Africa directly are generated over this ocean and are substantially influenced by it.[1] Bordering the east coast of the subcontinent is the warm Agulhas Current, an intense western boundary current. Its geographic dimensions are limited, but it plays a critical role in the transport of warm water in the South Indian Ocean, in regional weather modification and in the inter-ocean exchange of tropical and subtropical water.[2] The latter process has important climatological implications on a global scale.[3,4] The South Atlantic Ocean to the east of southern Africa is the conduit through which warm products of the Agulhas Current move equatorward.[5–8] Furthermore, the South Atlantic Ocean contains one of the largest coastal, wind-driven, upwelling systems in the world[9,10] (Fig. 1). The upwelling process and the large expanse of cold surface water that is created in this way interacts with the atmosphere as a link in local climate variability.[11,12] It also exerts a dominant control on productivity of the coastal ocean. Few other continental regions of this size are influenced by such diverse ocean systems that may all affect the regional reaction to climate change or be affected by it.[13] Southern Africa also has been shown, however, to be influenced by changes in sea-surface temperature (SST) over much larger regions than purely local.[14,12]

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Ocean–atmosphere linkages

Sea-surface temperature changes

The oceans surrounding southern Africa have sea-surface temperature anomalies that are regionally extensive.[11,15,16,12] These anomaly fields are persistent and clearly linked to rainfall variations over the subcontinent at a variety of spatial and temporal scales.[17–21] However, in most cases the mechanisms supporting the different teleconnections remain poorly understood.[12,22,23] Some promising possibilities to explain the associations between sea-surface temperature and rainfall have been identified.[24] Statistical models using sea-surface temperatures to forecast seasonal rainfall tendencies over southern Africa have been developed[21,25]and some are in operational use.[26] Some models depend on forecasting SST fields.[26] To enhance this capability, further knowledge of the currents, and in particular the surface currents, is required.[27]

Modelling reveals that over periods of a decade or less it is likely that the anomalies of sea-surface temperatures in the southern African region are largely driven by the atmosphere.[28] Ocean currents may play a relatively minor role in affecting high-frequency climate variability. However, over a longer time it seems that it is the SST anomalies that drive atmospheric changes. These suggestions need empirical validation and theoretical verification by further modelling.[29] The former will not be easy, since good oceanographic data for the region, particularly for components of the Agulhas Current system, are sparse or lacking.

The Agulhas Current system

The greater Agulhas Current system (Figs 1, 2) consists of the sources of the current, the current itself, its outflow, its shedding products and its effect on the circulation on the adjacent continental shelf. The shelf circulation will be dealt with separately.

The Agulhas Current, once fully constituted off KwaZulu-Natal, South Africa, extends to a depth of at least 2000 m[30] (Fig. 2). In the upper layers it carries predominantly tropical and subtropical surface water poleward at rates of ~2 m s^{-1}. This water is largely derived from a strong recirculation in the South West Indian Ocean subgyre.[31] The contribution through the Mozambique Channel is small by comparison. It seems that the southern limb of the East Madagascar Current — another potential contributory — makes no significant contribution to the Agulhas Current proper.[32] This does not imply that no water from the eastern side of the island of Madagascar reaches the Agulhas Current, but that this water does not come from the East Madagascar Current itself. It is possible that rings and filaments of this water reach the current to the south without having a major impact on its volume flux.[33] Although the water volume passing through the Mozambique Channel forms only a small component of the total Agulhas Current flux, it may make a considerable contribution to the seasonality of the current.

Agulhas system variability

It has long been considered logical that the Agulhas Current should exhibit a seasonal signal. At first, it was deemed likely that the seasonal reversal of the Somali Current off north-east Africa would contribute water to the flux through the Mozambique Current during the North-East Monsoon season, but divert water from this flow during the South-West Monsoon flow when the Somali Current sets northward.[34] Investigations of the surface movement of the Agulhas Current have, however, established no statistically significant seasonal signal of this kind.[35] Coarse-grid general circulation models confirm this finding: a large seasonality in the Somali Current, only a small, but still noticeable, seasonal signal in the flow though the Mozambique Channel and no discernible seasonality to the flow of the Agulhas Current.[36] A higher-resolution nested model, however, developed specifically for the Agulhas Current system,[37] suggests that the flow in the Mozambique Channel is largely influenced by the seasonal meridional movement of the atmospheric anticyclone over the South Indian Ocean.[38] During the austral summer the more northern location of this high pressure system drives more surface water into the channel and thus into the Agulhas Current. Traces of this Tropical Surface Water are indeed found on the inshore side of the Agulhas Current at times,[39] but the data are as yet insufficient to show if its presence has a seasonal component.

Other observational data suggest a degree of seasonality of the Agulhas Current. Altimetric measurements of the oceanic subgyre in the South West Indian Ocean, supported by occasional lines of hydrographic data, indicate a seasonal intensification of the subgyre.[40] This accords with the seasonality of the wind field driving the subgyre. Furthermore, changes in the variability at the Agulhas Current retroflection[41] have been shown to have a seasonal component.

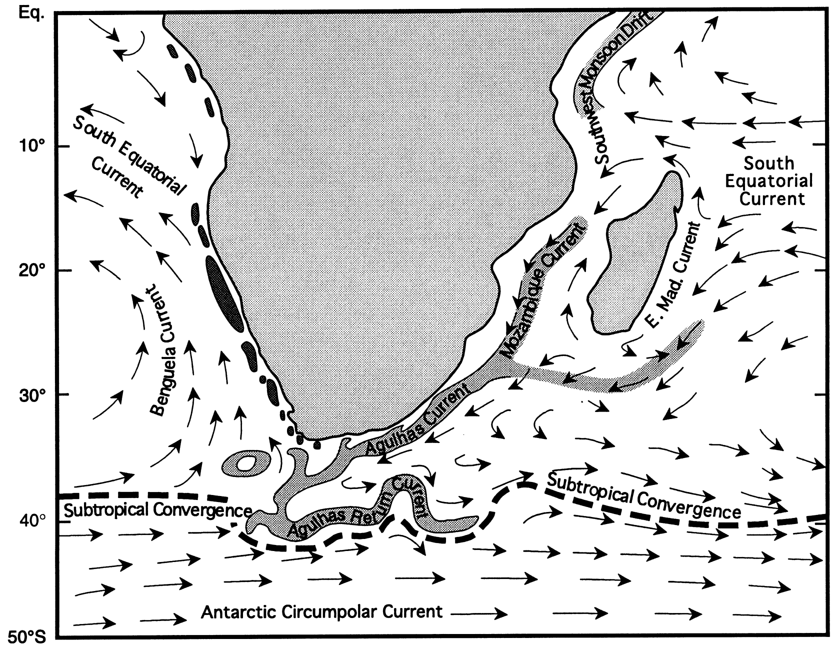

Fig. 1. Ocean currents around South Africa.[68] The shaded areas off the west coast represent cells of upwelling of cold water in the Benguela upwelling system.

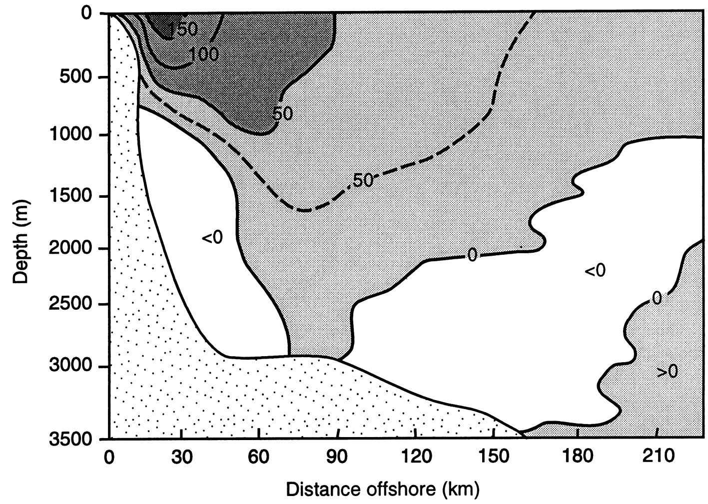

Fig. 2. A vertical section through the Agulhas Current off the east coast of South Africa near Durban to show the speed of the current in cm s^{-1} (ref. 69).

Climate change response

With global warming, a widely accepted scenario is one of strengthened atmospheric circulation and wind stress on the southwestern Indian Ocean, together with an increase in surface water temperatures in the subtropics. Under these conditions, more and warmer water would flow south in the Agulhas Current. The current's influence on the overlying atmosphere would increase[42] and have a possible positive impact on the rainfall of adjacent coastal areas.[43] The amount of heat carried by the current and shed into the South Atlantic Ocean would increase, with possible global consequences. Likewise, an increase in the amount of warm surface water accumulating in the Agulhas retroflection region could be expected, with a concomitant influence on synoptic weather patterns over southern Africa.[44] The situation is complicated by important meso-scale features of the Agulhas system, such as the Natal Pulse,[45] which may also respond to global change.

The Natal Pulse

The northern Agulhas Current is unique among western boundary currents in having an extremely stable trajectory. The current follows the continental shelf edge closely, with meanders to either side of less than 15 km.[46] On irregular occasions, but occurring about 4–6 times a year, a solitary meander, the Natal Pulse, interrupts this stable flow pattern.[45] The feature moves down the current at a rate of about 20 km d^{-1}, affecting not only the inshore coastal water circulation, but also the downstream behaviour of the Agulhas Current itself. One dramatic consequence of a large pulse is to cause the Agulhas Current to retroflect far upstream at the Agulhas Plateau.[47] In this way the waters in the current do not reach the normal retroflection locality and are not available for inter-ocean exchange. Incomplete early retroflections may also siphon off water at upstream locations.[48]

The northern Agulhas Current is largely stabilized by the morphology of the shelf edge along the southeast African seaboard.[49] The narrow shelf and the steep continental slope