A direct estimate of the Namibian upwelling flux

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Introduction

The coastal upwelling regions associated with the four Eastern Boundary Currents (EBC) of the world (the Canary, Benguela, California and Peru-Humboldt Currents) are important because of their high productivity. Although their area is only 0.1% of the world ocean, they account for 5% of global primary production and 17% of global fish catch (Pauly & Christensen, 1995). This high biological productivity is made possible by the presence of cold, nutrient-rich water in the illuminated surface layer as a result of equatorward wind-forced coastal upwelling. From satellite based chlorophyll images (SeaWiFS), the Benguela system is suggested to be the most productive EBC with respect to potential productivity (both for the areal mean ($gC/m^2/day$) and total primary production ($gC/year$)), while the Peru-Humboldt system is by far the most productive one with respect to landings of small pelagics such as anchovies, sardines and herrings (FAO statistics database).

The strong upwelling displays intra-, interannual and decadal variability, and since variations in fish recruitment, growth and distribution is largely dependent upon variations in the environmental conditions, one of the main tasks in marine science is to understand such relationships. A complicating and limiting factor in such studies is data availability. One approach has therefore been the use of simple proxies to explain observed variations. Owing to the lack of direct estimates of upwelling strength, various kinds of indirect upwelling indices have been used (e.g. Waldron *et al.* (1997); Skogen (2004a)).

The present work is motivated by the fact that upwelling indices already to some extent have been used to explain biological variability in the Benguela upwelling system. The key question is how to quantify upwelling, and in the present work it is proposed to use a wind and density driven coupled physical chemical and biological ocean model.

The model

The NORWegian ECOlogical Model system (NORWECOM) is a coupled physical, chemical and biological model applied to study primary production and dispersion of particles such as fish larvae or pollution. The Benguela implementation is described and has been validated in Skogen (1999). On a grid covering the African coast and the open ocean the model is used with a horizontal resolution of 20×20 km (Figure 1). In the vertical, 18 bottom-following σ-layers are used.

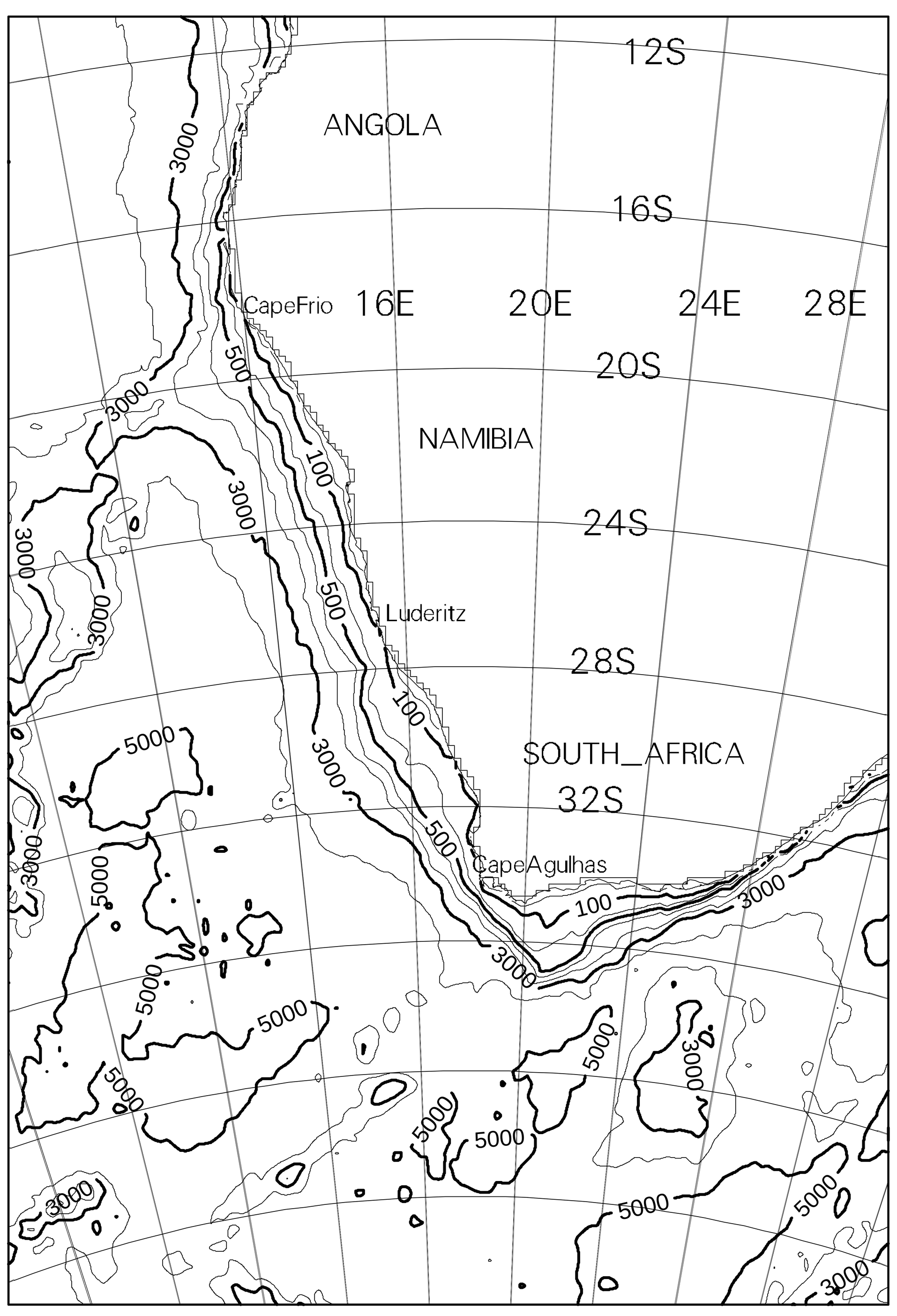

Figure 1: Model domain with bottom topography

Upwelling indices

The model has been run for 14 different years (1983/84 to 1996/97). From these results several different indices for the upwelling are computed:

1. the vertical velocity through a surface at a fixed depth
2. sea surface temperature (SST)
3. difference between coastal and open ocean SST
4. modelled primary production

Except for 3) which is very sensitive to the diatance used, there is an almost linear relationship between the other indices outside Namibia (Skogen, 2004b). The vertical velocity (m/day) and the interannual variability of the modelled upwelling outside Lüderitz (26.5^oS) is shown in Fig. 2.

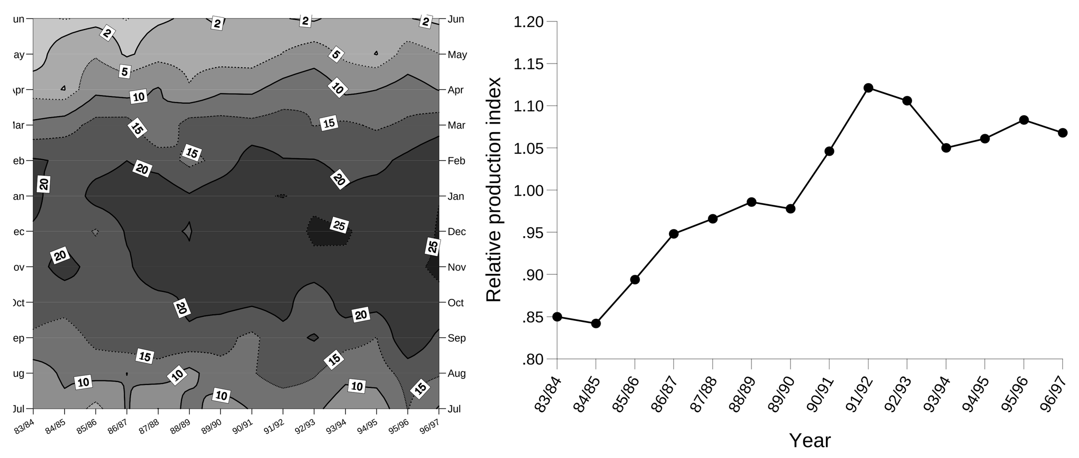

Figure 2: Monthly and annual modelled upwelling outside Lüderitz

This results suggests an increasing trend through the period, due to an increase in the NCEP/NCAR wind stress used to force the model. With this approach it is possible to give an estimate of the total vertical volume flux, and thereby the total amount of upwelled water, for the whole Namibian shelf. From the model the annual mean vertical transport through the 40 m depth surface is estimated to **2.2 Sverdrup.** The Lüderitz upwelling cell, which is the most intense one, contributes to about 40% of this. This number is of the same order of magnitude as a previous estimate of 1.5 Sv (Lutjeharms *et al.*, 1991).

Applications

One rationale for estimating the strength of upwelling is that high upwelling will increase phytoplankton production, which again act as food for copepods, and thereby have a potential positive effect on both growth and recruitment. It is therefore assumed that high upwelling gives the potential for good feeding conditions for fish larvae.

Cape anchovy spawn mainly east of Cape Point, predominantly over the Western Agulhas Bank from October to February. As anchovy are pelagic spawners, their eggs and larvae are transported by currents before the recruits migrate inshore to nursery areas along the South African north west coast. Using data of the mean individual weight of Cape anchovy recruits from 1985 to 1997 (Barange *et al.*, 1999), and calculating the upwelling in one point assumed to be a good indicator of the food conditions along the transport route, and one inside the nursery area, a simple multiple linear regression formula:

$$REC_{weight} = -14.84 + 14.45\ U_t(Oct) + 4.59\ U_n(Jan), \quad (1)$$

is able to explain 83% ($p < 0.0005$) of the observed variability (see Figure 3).

The first life stages of sardine off the South African coast are similar to that of anchovy. The main difference are spawning season. The anchovy spawn mainly between October and February, whereas sardine have a protracted spawning season peaking between August and March. Assuming upwelling as a proxy for food availability on the transport route of the larvae (from spawning to nursery areas) an OEW (Optimal Environmental Window, Cury & Roy (1989)) hypothesis can explain most of the observed variability of the individual weight of the sardine larvae. The following simple equation (Fig.3):

$$REC_{weight} = e^{-0.0349x^2+3.8634x-104.27}, \quad (2)$$

can explain 78% ($p < 0.005$) of the observed variability.

The optimal size of food particles for copepods has been estimted to be 2-5 % of their prosome length, and calanoid copepod growth rates in the southern Benguela region appear to be controlled by an interplay between body size, food size and food denisty. As a consequence, large upwelling activity will normally result in more large species than upwelling at a lower rate. This is a possible explanation for the linear relationship found between the mean individual weight of recruits of anchovy and upwelling, whereas sardine show an OEW relationship. Since the anchovy generally feed on large preys, high upwelling activity will be favourable in the sense that their food concentration will increase, while the sardine, who prefer smaller preys, will experience optimal conditions at a lower rate of upwelling.

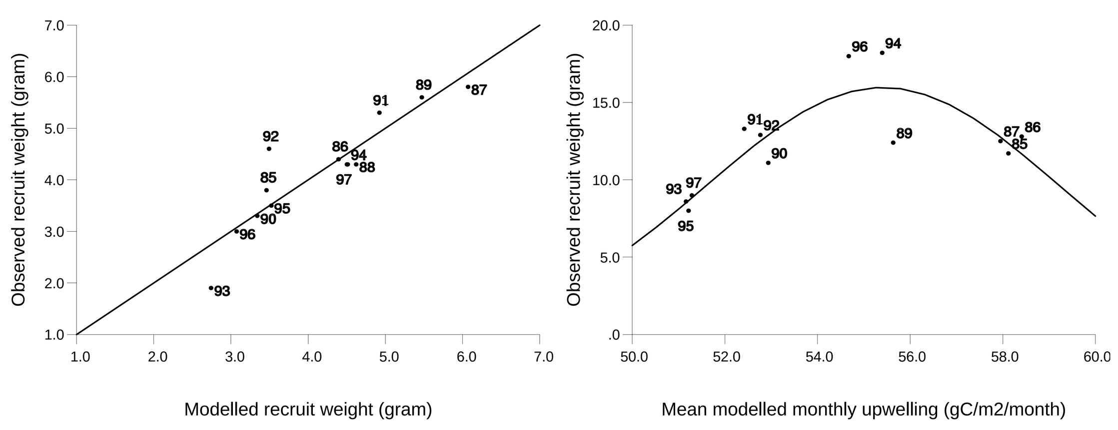

Figure 3: Modelled vs. observed mean recruit individual weight for anchovy (Eq. 1, left) and sardine (Eq. 2, right)

Acknowledgements

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