This paper not to be cited without prior reference to the author

International Council for
the Exploration of the Sea

C.M. 1980/C: 21
Hydrography Committee

On the influence of large scale winds upon mesoscale upwelling dynamics off NW-Africa

By

E. HAGEN, W. ZAHN
Academy of Sciences of the GDR
Institute of Marine Research
Rostock - Warnemünde, GDR

The investigation area comprises the region between Cape Barbas (22° N) and Banc d'Arguin (20° N) on the NW-African shelf. Here intense cold waters, rich in nutrients, are observed in a primary coastal upwelling strip between a strong coastal parallel oceanographic surface front and the meridional coast line. The front zone strictly follows the course of shelf edge. This surface front is embeded in a strong geostrophic southerly surface jet. Weaker counter current branches to the North are existing both in the 10 km nearshore zone and off the shelf edge in 200 m/300 m depth. A nearsurface offshore mass transport is induced by the influence of the NE-trade wind. The resulting mass deficit on the shelf is balanced by compensating currents towards the coast in 100 m to 300 m depth. Therefore the oceanographic density front demarcates the upwelling waters from the warm offshore water, which is low in nutrients.

On the other hand it is a fact that characteristic mesoscale upwelling processes are superimposed on the steady state upwelling dynamics. Essential aspects of mesoscale upwellings are described by the simple linear theory of free continental shelf waves (CSW) with low vertical amplitudes (only some centimetres) in sea surface level on a time scale of several days, on an alongshore scale of some 100 to 1000 kilometers, on an offshore scale of some 10 to 100 kilometers.

Because the group velocity is a measure of energy transport of waves, the permanent energy accumulation both in the frequency and in the wave number space is given there, where the group velocity disappears in the dispersion relation (WUNSCH and GILL, 1976). It is assumed that the characteristic mesoscale upwelling patterns are essentially caused by the low dynamic stable modes of this set of CSW's.

At the other side it is demonstrated by SCHEMAINDA et al. (1975), WOOSTER et al. (1976) that the steady state upwelling conditions off NW-Africa are marked by an annual dislocation of the NW-African upwelling region in meridional direction. This shift is strictly connected with the annual course of the NE-trade wind system. Furthermore anomalies are observed in this annual shift with consequences for the large scale upwelling intensity. These "disturbed" years are marked by an unusual constellation of atmospheric pressure centers as the Azores high and as the Sahara low (TAUBER, 1975). In consequence of these anomalous constellations a change occurs in the wind direction. How is the damping effect of these large scale wind variations on mesoscale upwelling events, whose characteristic parameters are determined by free CSW's? The first step on this way is possibly a linear superposition of large scale wind-driven currents upon mesoscale pressure gradient currents. The wind drift is estimated by a numerical solution variant after WELANDER (1957) with $A_v = 100\ cm^2 s^{-1}$ as a constant coefficient of vertical momentum austausch.

Our estimations are carried out for the first three free CSW's modes with zero group velocity. The calculation procedure is in detail described by HAGEN (1979). Here the alongshore velocity component $\tilde{v}$ of CSW's is in geostrophic balance with the water level gradient dh/dx of surface topography perpendicular to coast line. This gradient is given for every mode number n in form of eigenfunctions h(x) for a fixed phase situation, respectively to Fig. 1 (with h_a = 2 cm for x = o at the coast). The used coordinate system is directed with x-axis offshore (West), y-axis to North (coincidenced with straight coast line), z-axis downwards.

For instance therefore the alongshore surface drift current v_d is linearly influenced by the alternating parts of CSW's with $\tilde{v}(2) = \pm 5.3$ cm s^{-1} and with $\tilde{v}(3) = \pm 30.6$ cm s^{-1} at x = 10 km. The results are given for v_d(cm s^{-1}):

Wind	135^o	208^o	270^o
4 m s^{-1}	- 2.9	- 0.9	+ 2.1
8 "	-11.7	- 3.4	+ 8.2
16 "	-46.6	-13.7	-32.9

The corresponding characteristic mesoscale periods and alongshore wave lengths are T(2) = 4 d, $\lambda(2) = 280$ km and T(3)=6 d, $\lambda(3) = 200$ km. The superposition of v_d upon $\tilde{v}(n)$ are demonstrated both in Fig. 2 and in Fig. 3.
A mean wind near 8 m s^{-1} to 208^o is typically for the Cap Blanc region after HAGEN (1978) where upwelling is observed during the whole year. The mean NE-trade wind direction is simulated between 135^o and 270^o. The essential result is so, that the chequered structure of the third barotropic mode is extensively independent of a variation of wind direction (Fig. 4). This is an important fact for the mesoscale upwelling dynamics in this area.
The lower modes are essentially influenced by annormal "upwelling years" in our sense, because the alongshore current parts $\hat{v}(n)$ with $n \leq 2$ are damped down by the nearsurface wind induced currents v_d as it is shown for example in Fig. 2.
A comparison between the measured mean v component and its standard deviation (measure of total kinetic energy content) in a x-z-section, given in Fig. 5, 6, and our calculations shows clearly communities for the case of mean wind conditions, e.i. $v_w = 8$ m s^{-1}, $\alpha = 208^o$, in the 200 meter top layer.
Consequently, probability is also given that the polward running counter current off the shelf edge, see Fig. 5, is rhythmically influenced by the mode n = 3 of CSW's during the upwelling season.

The southward geostrophic surface current and the oceanographic density front form meanders as it is shown in Fig. 4. The intensity of these events is even a function of the annual large scale trade wind conditions.

References

HAGEN, E.: Einige charakteristische Parameter (zeitlich und räumlich gemittelt) des mesoskalen küstennahen Kaltwa auftriebs vor Nordwestafrika im Frühjahr 1976. Geod.Geophys.Veröff. R. IV, H. 26, S. 3 - 18 (1978).

HAGEN, E.: Zur Dynamik charakteristischer Variationen mit barotro pem Charakter in mesoskalen ozeanologischen Feldverteilungen küstennaher Auftriebsgebiete. Geod.Geophys.Veröff. R. IV, H. 29, 71 S. (1979).

MITTELSTAEDT, E., PILLSBURY, D., SMITH, R.L.: Flow patterns in the Northwest African upwelling area. Dt.hydrogr.Z. 28, S. 145 - 167 (1975).

PILLSBURY, R.D., BOTTERO, J.S., STILL, R.E., MITTELSTAEDT, E.: Wind, currents and temperature off Northwest Africa along 21°40' N during JOINT-1. A complination of observations from moored current meters, Vol. 8, Data Report 62, 143 S., Oregon State University (1974).

SCHEMAINDA, R., NEHRING, D., SCHULZ, S.: Ozeanologische Untersuchungen zum Produktionspotential der nordwestafrikanischen Wasserauftriebsregion 1970 - 1973. Geod.Geophys.Veröff. R. IV, H. 16, 85 S. (1975).

TAUBER, G.M.: The variability of trade wind circulation in the North Atlantic, its dependence on large scale processes and its influence on the regime of major current systems. Trudy GOIN, 124, L., 28 - 40 (1975).

WELANDER, P.: Wind action on a shallow sea: Some generalizations of Ekman's Theory. Tellus IX,(1), 45 - 52 (1957).

WOOSTER, W.S., BAKUN, A., Mc LAIN, D.R.: The seasonal upwelling cycle along the eastern boundary of the North Atlantic. Journ.Mar.Res. 34(2), 131 - 141 (1976).

WUNSCH, C., GILL, A.E.: Observations of equatorially trapped waves in Pacific sea level variations. Deep-Sea Res. 23, 371 - 390, (1976).

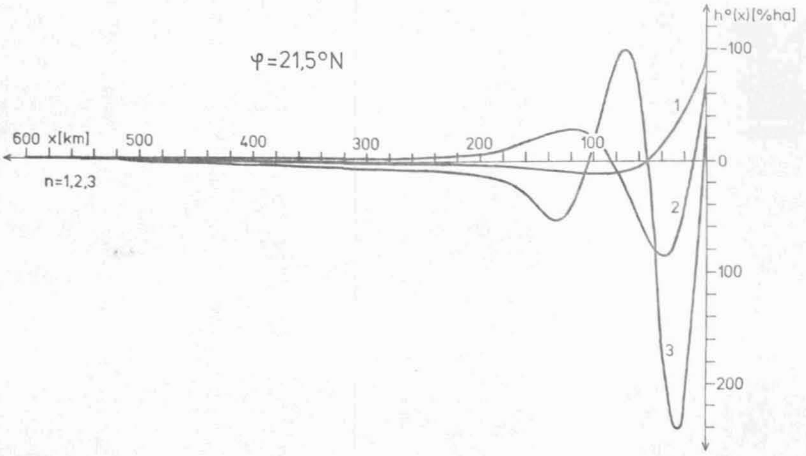


Fig. 1 Eigenfunctions of sea level h(x) of the first three modes of free CSW's with zero group velocity in per cent of sea level $h_a(x=o)$ at the coast line after HAGEN (1979)

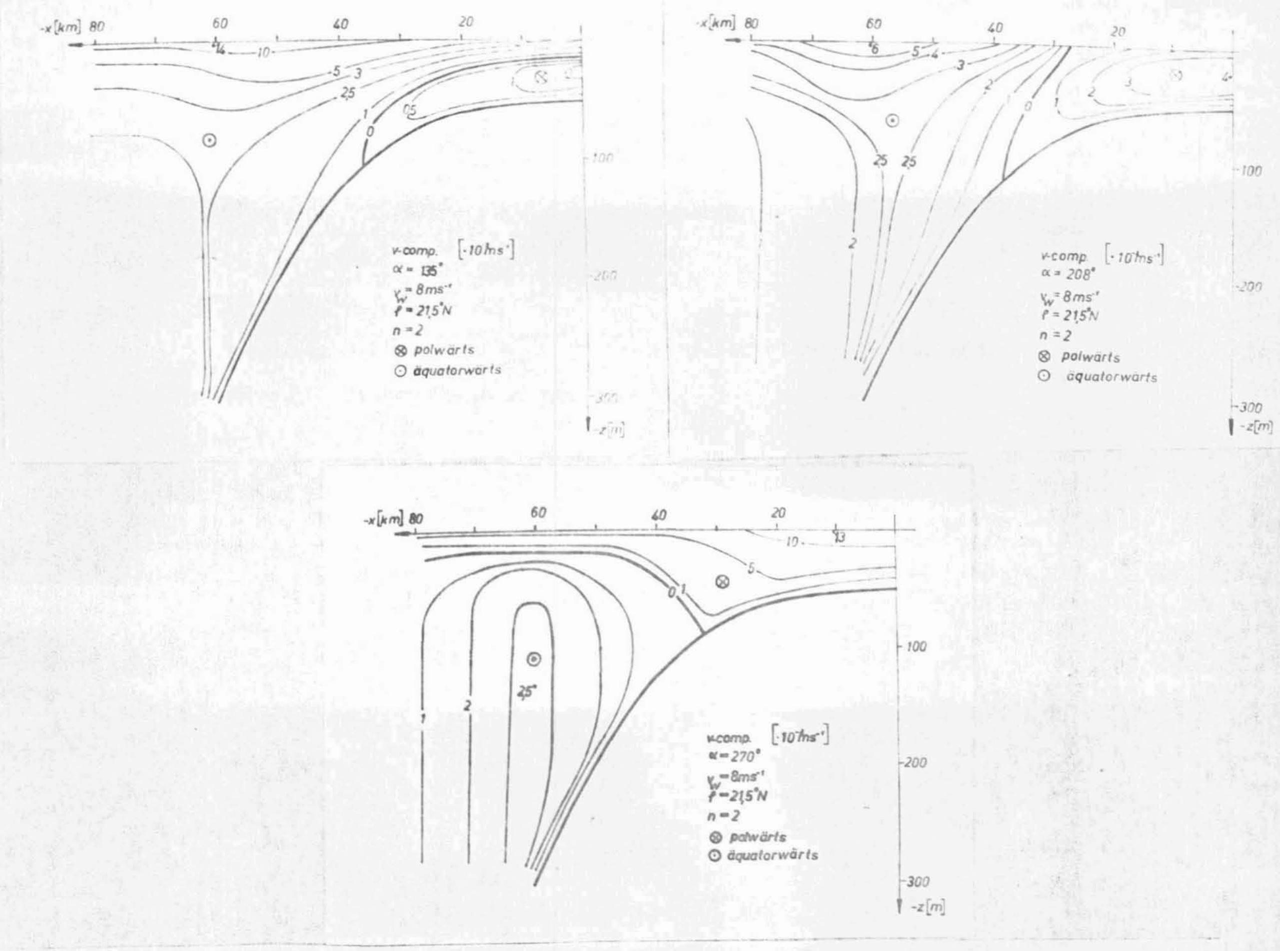


Fig. 2 Linear superposition result of a steady state wind-driven current on the pressure gradient current, which is induced by the mode n = 2 (fixed phase situation).
(v_W = wind velocity, α = wind direction
φ = latitude)

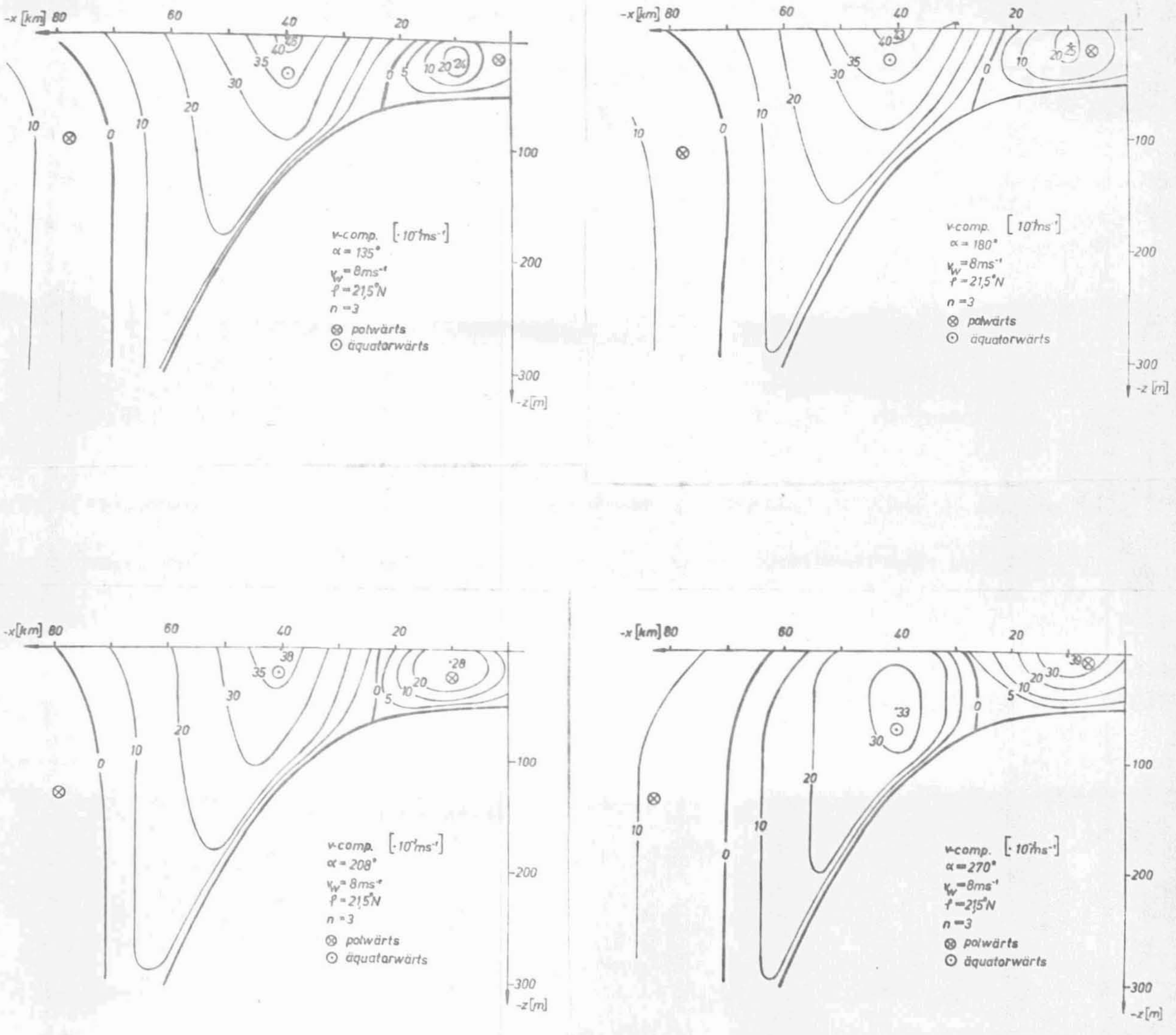


Fig. 3 Linear superposition result of a steady state wind-driven current on the pressure gradient current, which is induced by the mode n = 3 (fixed phase situation)

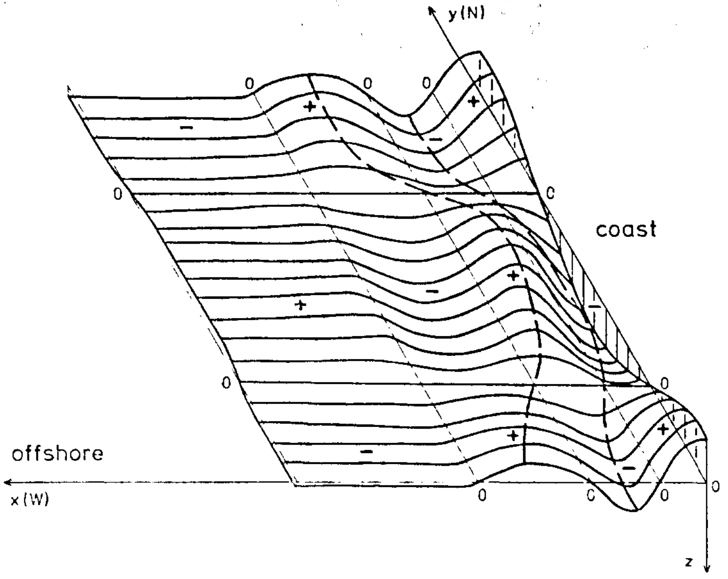
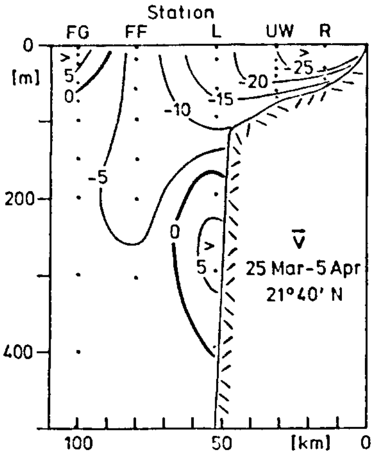


Fig. 4 Mesoscale patterns of the sea surface elevation of mode n = 3



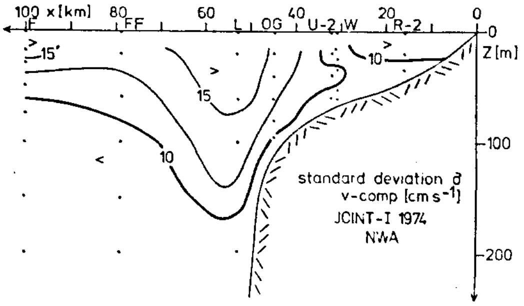


Fig. 5 Mean alongshore current component during the JOINT-1 experiment in spring 1974 after MITTELSTAEDT et al. (1974)

Fig. 6 Standard deviation of alongshore component after values by PILLSBURY et al. (1974)