MODELING OF THE NEAR-COASTAL UPWELLING IN THE SHELF ZONE OF THE CRIMEA AND ITS INFLUENCE ON DYNAMIC OF THE OXYGEN-HYDROGEN SULPHIDE INTERFACE

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Abstract

An hydrodynamic model was used to study upwelling event caused by wind in the Black Sea. It was conceived to study the influence of water dynamics on oxygen and hydrogen sulphide distributions in the shelf zone of Crimea. A chemical reaction between these dissolved gases was taken into account. During upwelling event upward fluxes of cold bottom water were accompanied by displacement and penetration of the hydrogen sulphide into the near-surface layers enriched by oxygen and the extensive coexistence zone of oxygen and hydrogen sulphide formed over the shelf break. The extended area with small oxygen concentration remained after the end of chemical reactions between hydrogen sulphide and oxygen as a "trace" of upwelling event.

Key-words: Black sea, Anoxia, Waves, Models

Introduction

The Black Sea, as all inland seas, has a very specific hydrological and hydrochemical structure of waters. Due to the existence of the cold intermediate layer (CIL) with temperature lower than 8°C at 50-80 m, the Black Sea acts as an unique basin. The oxygen penetration depth do not exceed 80-100 m in central areas and 180-200 m in offshore ones. So 99% part of the Black Sea contains hydrogen sulphide and is not suitable for biological forms and communities living.The presence of oxic and anoxic zones designate the fact that investigation of space-temporal characteristics of oxygen and hydrogen sulphide distributions and their interactions is one of the central questions. If the time scale of the oceanic near-coastal upwelling is of the about weeks, a day wind forcing is sufficient for development of upwelling in the Black Sea due to the shallow thermocline and steep bottom topography. This experimental fact was often observed and confirmed. The lifting of the near-bottom cold water was accompanied by uprising of passive admixture together with dissolved gases. What is happening in upwelling areas is an important question of the up-to-date ecology.

Methodology

Coastal upwelling regions are typical areas where both advection and mixing play an important role in the water movement and transformation. So, we used a complete system of Reynolds hydrodynamic equations with non-linear terms, as well as terms responsible for turbulent exchange. The model and numerical scheme were described in Vlasenko *et al.* [1] in detail. Briefly, the full system of equations reduced to the equations for eddy and stream function. Two kinds of variables substitutes were realised. The first one concerned the transformation of an irregular calculation domain to a rectangular one, the second exaggerated the numerical grid in the layers with sharp density gradients. These manipulations resulted in a high accuracy of calculations.

Results

It is likely that the hydrogen sulphide may penetrate to the oxygen layers during deep water uprising. As it was shown [2], the minimum time of oxygen and hydrogen sulphide interaction is nearly 6 hours in the coexistence zone. Because we are concerned with processes of more than a one-day duration, diffusion - advection equations for hydrogen sulphide and oxygen with chemical reaction between them were also added for investigation of influence of upwelling events on distributions of O_2 and H_2S in the Crimean coastal zone.

The model domain was a vertical plane ranging from the sea surface to the bottom and from the coast to 200 km offshore. The depth varied from 20 m on the shelf to 2000 m in the deep part at a distance of 40 km. Typically (for the Black Sea) short wind forcing (approximately one day) and following relaxation processes of hydrophysical and hydrochemical fields were considered. At the first stage of evolution of the near-coastal upwelling, it has all features inherent to the oceanic ones [3]: the development of an alongshore Stocks drift in the upper layer due to the wind stress, excitement of cross-shore circulation by the action of the Coriolis force and formation of vertical advective cells on the shelf and a thermohaline front moving seaward.

The first interesting finding from this studies is the consideration of upwelling relaxation. After the cessation of wind forcing, an evolution of the thermochaline fields continued without any external influence. So, two types of movements were formed on the shelf and in the open part of the sea. The diagram of cross-shelf circulation during the upwelling relaxation is represented in Fig. 1. A quasi-stable dissipating vertical advective cell was formed on the shelf. Its dimension coincided with the first baroclinic Rossby radius of deformation. At the open part of the sea the following types of motions were established :

- the horizontal subinertial oscillations with current and countercurrent in upper and lower layers;
- the thermohaline front moving shoreward;
- the presence of cold water during days near the shore;
- progressive internal waves, generated at the frontal side of the moving density (thermocline) front. In the transition zone, these internal waves were divided to reflected waves and waves passed on the shelf;
- vertical subinertial oscillations over the continental slope in the transition zone.

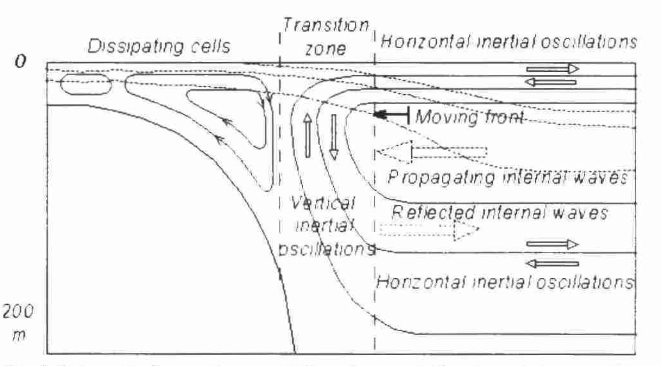

Fig. 1. Schematic diagram for upper 200 m of cross-shelf motions during upwelling relaxation. Solid lines are stream function, dashed lines are isopicnals.

Due to the different values of the local vorticity of along shore currents and different horizontal density gradients in various points of the tested area the period of subinertial oscillations changes from the inertial one (Tin = 17h) near the bottom out of the shelf up to 22 hours at the free surface in the shelf break area.

The possibility of excitement of vertical subinertial oscillations during relaxation of a near-coastal upwelling is confirmed by *in situ* data, collected in the coastal zone. Figure 2 represents the vertical displacements of the thermocline measured over the shelf-break (isobath of 100m) in the shelf zone. Measurements of thermocline dynamics were conducted by distributed sensors of temperature [4] during upwelling event in summer, 1993. It is clearly seen from Fig. 2 that during first stages of upwelling (13.06- 14.06), the thermocline was lifted by the wind forcing. After the cessation of the wind action it returned to its initial position. This return was not monotonous and took place on the background of vertical oscillations. The period of these oscillations (T = 17.9h) was not equal to the inertial one (Tin = 17.0 h) and was shift to the red part of spectrum. These results first of all confirmed the existence of the model predicted subinertial vertical oscillations in the transition zone (see Fig. 1) during process of upwelling relaxation and show also the red frequency shift.