論文題目(Dissertation Title):

THEORETICAL CONSIDERATION ON THE CRITERIA OF COASTAL UPWELLING ASSOCIATED WITH "AOSHIO" IN TOKYO BAY
(東京湾の青潮に関する沿岸湧昇の発生基準の理論的考察)

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Abstract:

At the head of Tokyo Bay, coastal upwelling of oxygen depleted bottom water, induced by northeasterly wind-driven circulation, sometimes leads to the deaths of many shellfish and other aquatic animals across large areas, resulting in substantial economic loss to coastal fisheries. One of chemical actions associated with this dynamics process is the oxidation of hydrogen sulfide in the bottom water into a colloidal sulfur substance. With sunshine reflects off surface water containing these sulfur particles, the seawater appears milky blue. This phenomenon has been termed "Aoshio". One of the most important issues to address concerning upwelling in relation to Aoshio is to accurately predict when it will occur as well as its area and scale.

In the preliminary study described here, we propose criteria for the occurrence of northeasterly wind-driven coastal upwelling associated with Aoshio in Tokyo Bay using several analytical solutions. These analytical solutions were derived based on some specific simplifications and assumptions in the context of a two-layered fluid which simply represents the water body under typical stratified condition in Tokyo Bay. Depending on different shores of the bay on which Aoshio occurs, the criteria have different mathematical expressions. In general, these criteria express the minimum wind conditions needed for the occurrence of upwelling in relation to Aoshio, and include many parameters, such as the densities of the upper and lower layers, the initial thicknesses of the upper and lower layers, the length or the width of the bay, and friction coefficient.

Criteria for the occurrence of upwelling associated with Aoshio on the northeast shore consist of three expressions. The first one indicates that the northeasterly wind must last for a time shorter than a value at which the direction of motion of the two-layered fluid is deflected toward the southeast shore due to the Coriolis force. The second one means that, for a given wind duration, the wind stress should be stronger than some value. The third expression, obtained by considering a simple steady state of the two-layered fluid, implies that the wind stress should be not weaker than some value, no matter how long the wind duration is.

Comparison of these derived criteria with field observational data for Aoshio on the northeast shore of Tokyo Bay showed that fifty-six percent of real cases satisfied the criteria.

The results of analyses of the sensitivity of criteria for upwelling associated with Aoshio on the northeast shore to all of the parameters incorporated into them were found to be in accord with our qualitative understanding of Aoshio phenomenon. In the two-layered fluid system, increasing the density of the upper layer or decreasing the density of the lower layer means decreasing the

relative gravity of the lower layer against wind-shear effect, implying that upwelling will become easier. Increasing the thickness of the upper layer is equivalent to lengthening the spatial distance of upwelling. Thus, with the approximately same upwelling velocity, the time required for upwelling will increase, making upwelling more unlikely. In fact, the spatial distance of the upwelling is approximately equal to the thickness of the upper layer. Therefore, the sensitivity of the criteria to the thickness of the lower layer should be relatively low. In the case of a long bay, upwelling will become easier. This can be interpreted from a geometrical perspective: the displacement of the interface near the northeast shore is roughly equal to the product of the tangent of inclination angle of the interface and the half length. For a given surface-wind stress, the angle of inclination can be simply regarded to be a constant. A long bay coupled with almost the same angle of inclination should mean a larger interface displacement, so upwelling can happen more easily. Additionally, the larger friction coefficient (that is, the parameter expressing the influences of interface friction and bottom friction or interface-friction coefficient), the more unlikely upwelling becomes. This is due to the fact that a large friction coefficient means high energy dissipation, implying that a stronger wind is needed for the two-layered fluid system to induce the interface tilt on the shore.

Criteria for the occurrence of upwelling associated with Aoshio on the southeast shore are also composed of three expressions. The first expression shows that the wind duration must be longer than the value discussed above, and the second one indicates that the product of the surface-wind stress and the wind duration (or we can name it the wind-stress impulse) should exceed some value. The last one, which is similar to that for upwelling associated with Aoshio on the northeast shore, expresses the minimum wind stress when wind lasts for an infinitely long time.

It was found that, by comparing the derived criteria with field observational data for Aoshio on the southeast shore, ninety-one percent of real cases were consistent with the criteria.

The results of analyses of sensitivity of criteria for upwelling associated with Aoshio on the southeast shore to all of the parameters incorporated into them were similar to those for upwelling on the northeast shore which have been presented above and were also found to be in accord with our qualitative understanding of Aoshio phenomenon.

In addition, the optimal wind direction for coastal upwelling, in the case of a narrow, infinitely long channel, is discussed. It was found that the optimal wind direction for coastal upwelling varied with the wind duration. If the wind duration is very short, the optimal wind direction is almost across channel while, with the increasing wind duration, the optimal wind direction approaches gradually along-channel. This transition is attributed to the increasingly important role that played by the Coriolis force, in the motion of the two-layered fluid with the increasing wind duration.