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Full Length Research Paper

A numerical study of turbulent mixing parameters at the Nile Delta, north of the Egyptian Coast

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Mixing parameters off the Egyptian Mediterranean Coast in front off the Nile Delta are studied by a semi-empirical model of vertical turbulent mixing. The results model appear that the mixing rate decreases significantly with depth and turbulent kinetic energy plays a small role in mixing production. However, shear and viscous dissipation are essential in the dynamical process of vertical turbulent mixing. Buoyancy intermittently has a substantial role in vertical mixing.

Key words: Numerical model, turbulent mixing.

INTRODUCTION

The coastal area in front off Nile Delta is considered one of the most interesting natural laboratories not only because of its coastal process and evaluation of erosion and accretion, but also of its economic important related to Egyptian natural resources. Knowledge of coastal water circulation and mixing processes are on of the basic tools useful in the management of nutrient transport and biological productivity which is essential for the fishery activity as well as oil and gas resources development.

Relatively, few efforts have been carried out to study the dynamical process of vertical turbulent mixing in front off the Egyptian Coast. Morcos and Hassan (1976) and Mohamed (1999) studied the dynamical process of mixing qualitatively by studying the existing different water masses in the south eastern Mediterranean. The mixing process and circulation pattern off Egyptian Mediterranean Coast was studied by El- Sharkawy (2007). The dynamics and mixing of the Eastern Mediterranean outflow in the Tyrrhenian Basin was studied by Sparnocchia (1999). The analysis of the turbulent mixing structure is accomplished by the dynamical computations of the mixing parameters at the Egyptian Mediterranean coast in front of Nile Delta is studied by Sharaf el Din, et al (2010). Nabil et al. (2010) studied the turbulent vertical mixing parameters at the central area of the Red Sea. Francesco et al. (2004) studied the horizontal mixing and transport structures in the surface circulation of the Mediterranean Sea, as obtained from a primitive equation circulation model. This study allows them to classify areas in the Mediterranean basin according by their mixing activity. In order to investigate the impact of numerical models spatial resolution on the convection representation and the effects of deep convection on the northwestern Mediterranean circulation, Herrmann et al. (2008), perform two numerical three-dimensional simulations (eddy-permitting versus eddy-resolving). They examine the characteristics of the deep convection (mixed layer, water masses characteristics, convection zone, and mesoscale structures) and perform temporal analysis of this event in terms of kinetic energy, buoyancy equilibrium, and deep water (DW) evolution. Sharaf El-Din (1964), Johnson (1996); Rossa and Lueckb (2005); Munka and Wunschb (1998); Robert Hallberg, (2000); Kobayashia et al. (2006); Hornea et al. (1996); McPhee-Shaw (2006) and Yoshida and Oakey (1996) have made significant contribution to a much needed understanding of the vertical turbulent mixing using the numerical models at different parts of Oceans and Seas. The aim of this study is using Le Ngoc Ly (2000), semi-empirical model of vertical turbulent mixing

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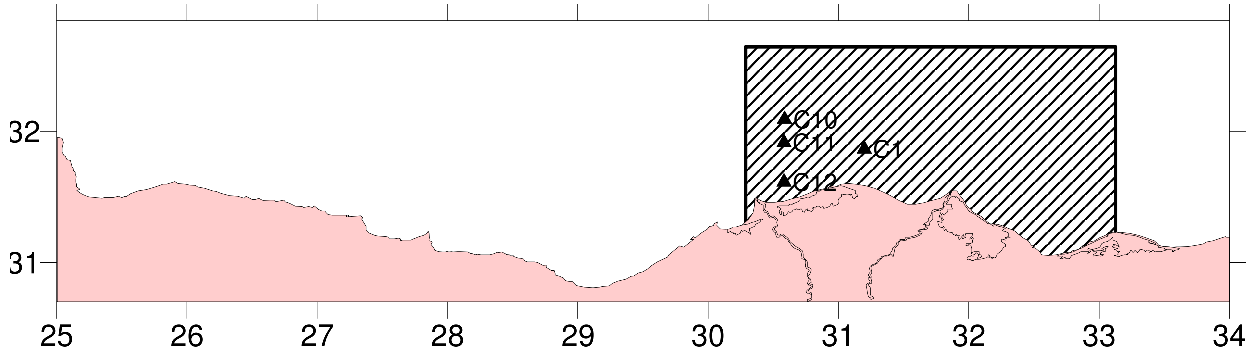

Figure 1. Area of study and location of current meter stations at south east sector of Mediterranean Sea.

to assess the relative importance of various mixing parameters off the Egyptian Mediterranean Coast in front of the Nile Delta.

MATERIALS AND METHODS

Materials

The temperature and salinity data were obtained from the Med Atlas 2002, which contains collected *in-situ* data from over 160 thousands stations in the Mediterranean Sea from the early 20th century till 2002; however, data only collected from 1970 to 2002 was used in this research. The measurements have been carried out by various instruments as CTD, MBT, XBT, and sampling bottles at the standard depths. Four stations in front off Nile Delta, named C12, C11, C10, and C1 (Figure 1) were carried out to study the current field and the mixing parameter in the studied area. This large data archive has been subject to sophisticated statistical modeling to render various types of error to the minimum. The average monthly climatologically data of 1’ X 1’ grid has used in the proceeding calculations carried out.

Numerical modeling of vertical turbulent mixing

The aim of this semi-empirical model, which was developed by Le Ngoc Ly (2000), is to explore the relative importance of the mixing parameters. The process of vertical turbulent mixing is governed by several dynamical parameters which are:

Buoyancy (Stratification)
Mean Velocity Shear
Turbulent Kinetic Energy (E)
Viscous Dissipation of Mean Kinetic Energy (ε)

In this model, the rate of viscous dissipation per unit mass $\partial \varepsilon / \partial t$ is considered to be the production rate of mixing, which is related to the dynamical mixing parameters according to the relation:

$$\frac{\partial \varepsilon}{\partial t} = \beta_1 \frac{\varepsilon}{E}\left(-\overline{U'W'}\frac{\partial U}{\partial z} - \overline{V'W'}\frac{\partial V}{\partial z} + \frac{\beta_3}{\beta_1}\frac{g}{\rho}\overline{W'\rho'}\right) - \beta_4 \frac{\partial}{\partial z}\overline{\varepsilon' W'} - \beta_2 \frac{\varepsilon^2}{E} \qquad (1)$$

Where the first two terms of the right hand side represent rate of dissipation generation by mean velocity shear (shear production rate), the next terms are the buoyancy production rate and the rate of vertical turbulent transport (turbulent production rate), and the last term is the viscous dissipation production rate.

The turbulent fluctuations are related to the mean fields through the K-closure system:

$$-\overline{U'W'} = K_m \frac{\partial U}{\partial z} \;; \qquad (2a)$$

$$-\overline{V'W'} = K_m \frac{\partial V}{\partial z} \;; \qquad (2b)$$

$$\overline{W'\rho'} = K_{eh} \frac{\partial \rho}{\partial z} \qquad (2c)$$

$$-\overline{E'W'} = K_E \frac{\partial E}{\partial z} \;; \qquad (2d)$$

$$-\overline{\varepsilon' W'} = K_\varepsilon \frac{\partial \varepsilon}{\partial z} \qquad (2e)$$

The set of Eddy coefficients for buoyancy, vertical transport of turbulent kinetic energy (E), and viscous dissipation (ε) are linked to the coefficient of Eddy viscosity by:

$$K_{eh} = K_m \qquad (3a)$$

$$K_E = 0.73\, K_m \qquad (3b)$$

$$K_\varepsilon = 0.7\, K_m \qquad (3c)$$

The β set have the values

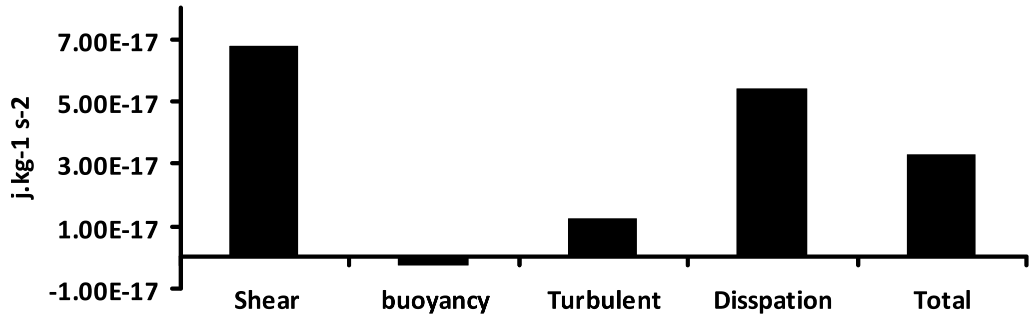

Figure 2. Modeled mixing rates results at C12 during feb-99.

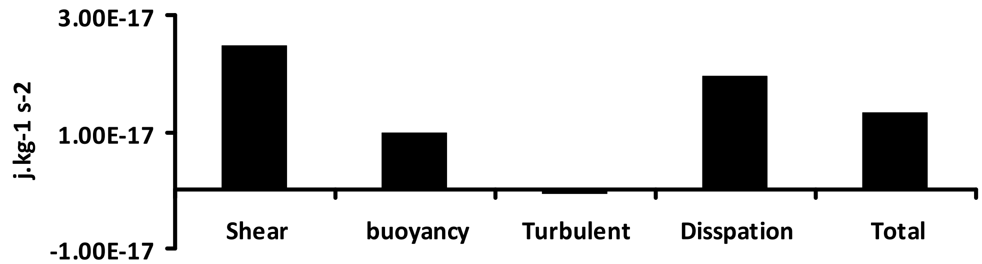

Figure 3. Modeled mixing rates results at C12 during Jun-99.

$\beta_1 = 1.43$ (4a)

$\beta_2 = 1.97$ (4b)

$\beta_3 = 1.45$ (4c)

$\beta_4 = 0.7$ (4d)

Taking advantage of Equations (2 - 4), the equation of viscous dissipation rate (equation 1) reduces to:

$$\frac{\partial \varepsilon}{\partial t} = \left(\frac{1.43\varepsilon}{E}\right) K_m \left(\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2 - \frac{g}{\rho_0}\frac{\partial \rho}{\partial z} \right) + (0.7)^2 K_m \frac{\partial^2 \varepsilon}{\partial z^2} - 1.97\frac{\varepsilon^2}{E} \quad (5)$$

This defines the mixing rate in terms of shear, buoyancy, turbulent kinetic energy, and viscous dissipation production.

RESULTS AND DISCUSSION

The turbulent mixing structure at C12

The model production rates for shear, buoyancy, turbulence, and viscous dissipation at station C12 are plotted in Figures 2, 3 and 4. During all months except June and July, shear and viscous dissipation play the major role in the dynamical process of vertical turbulent mixing. The high values of viscous dissipation that was detected by Sharaf El Din et al. (2010) through all the year except June and July coincide with our model results. At February 99, (for example) these two parameters produce vertical mixing at the rate 6.76 × 10-17 $j.kg^{-1}s^{-2}$ and 5.38 × 10-17 $j.kg^{-1}s^{-2}$ respectively, Figure (2). The rate of turbulent production is only 1.25 × 10-17 $j.kg^{-1}s^{-2}$, that is, turbulence plays a small role in vertical mixing, while buoyancy has a negligible role with a production rate -2.58 × 10-18 $j.kg^{-1}s^{-2}$ The negative magnitude of production rate indicates that the parameter tends to suppress the process of vertical turbulent mixing rather than enhancing it. The total mixing rate is 3.28 × 10-17 $j.kg^{-1}\ s^{-2}$.

The turbulent mixing structure differs slightly during Jun-99, Figure (3). The role of buoyancy in vertical turbulent mixing increases noticeably to reach a production rate of 9.76 × 10-18 $j.kg^{-1}s^{-2}$,while turbulence still plays a negligible role in vertical turbulent mixing with a rate -7.72 × 10-19 $j.kg^{-1}s^{-2}$. The shear and dissipation production rates are high as 2.49 × 10-17 $j.kg^{-1}s^{-2}$ and 1.97×10-17 $j.kg\text{-}^{1}s^{-2}$ respectively, that is, they both play together with buoyancy the major role in mixing. The total mixing rate is 1.34×10-17$j.kg^{-1}s^{-2}$. This turbulent mixing structure continues during Jul-99, where buoyancy, shear, and dissipation play the major role in vertical turbulent mixing with production rates 1.16×10-17 $j.kg^{-1}s^{-2}$, 1.14×10-17 $j.kg^{-1}s^{-2}$, 0.82 × 10-17 $j.kg^{-1}s^{-2}$ respectively,

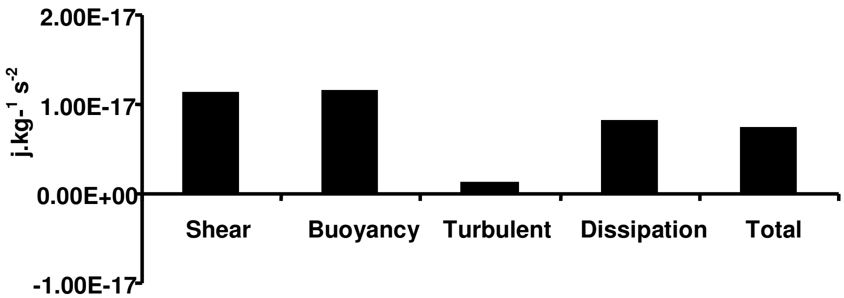

Figure 4. Modeled mixing rates results at C12 during Jul-99.

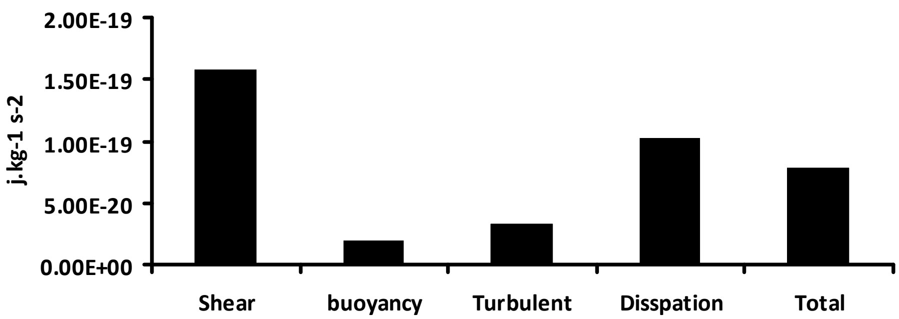

Figure 5. Modeled mixing rates results at C11 during Feb-99.

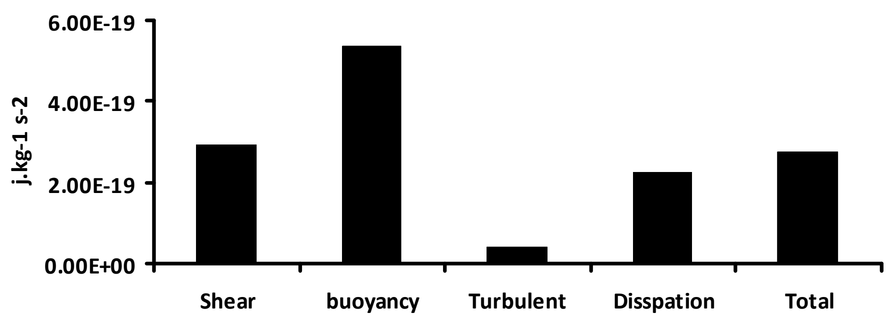

Figure 6. Modeled mixing rates results at C11 during Jun-99.

Figure (4). Turbulence continues to have a small role in vertical turbulent mixing with a rate of -1.1×10-18 j.kg^{-1}s^{-2}. The total mixing rate is 7.53 × 10-18 j.kg^{-1}s^{-2}.

The turbulent mixing structure at C11

The turbulent mixing structure at C11 during Feb-99, Mar-99 and April-99 is characterized by a primary role played by shear and viscous dissipation in the dynamical process of vertical turbulent mixing, while buoyancy and turbulence play a secondary one (Figure 5). These four dynamical parameters produce vertical mixing at the rate of 1.58×10-19 j.kg^{-1}s^{-2}, 1.02×10-19 j.kg^{-1} s^{-2}, 2.01×10-20 j.kg^{-1}s^{-2}, and 3.35×10-20 j.kg^{-1}s^{-2} respectively, while total mixing rate is 7.84×10-20 j.kg^{-1}s^{-2}. During April 99 turbulence has a negligible role in mixing production with a rate of production as small as 1.59×10-21 j.kg^{-1} s^{-2}. In general, the mixing structure is quite different during the period from May-99 to Oct-99 as buoyancy plays the major role in the dynamical process of vertical turbulent mixing. Figure 6 illustrate that buoyancy during Jun-99 is the major mixing producer with a rate 5.39×10-19 j.kg^{-1}s^{-2}, then shear and viscous dissipation follow with a production rate 2.95×10-19 j.kg^{-1}s^{-2}, and 2.27×10-19 j.kg^{-1}s^{-2} respectively. Turbulence has a small production rate of 4.07×10-20 j.kg^{-1}s^{-2}, and the total mixing rate is 2.75×10-19 j.kg^{-1}s^{-2}. Buoyancy is secondary mixing producer during Dec-99, and Jan-00. The production rates during Dec-99 for shear, buoyancy, turbulence, and

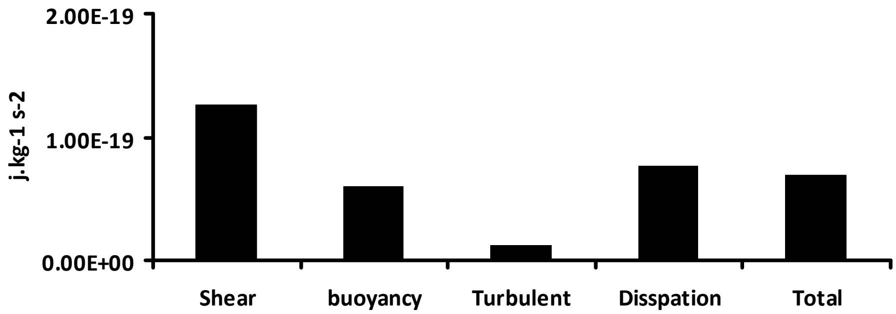

Figure 7. Modeled mixing rates results at C11 during Dec-99.

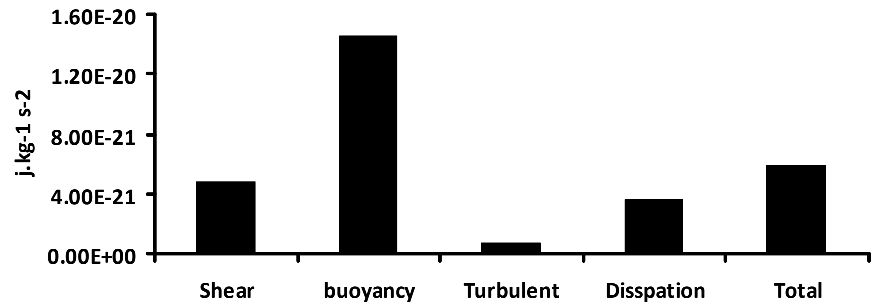

Figure 8. Modeled mixing rates results at C10 during Apr-99.

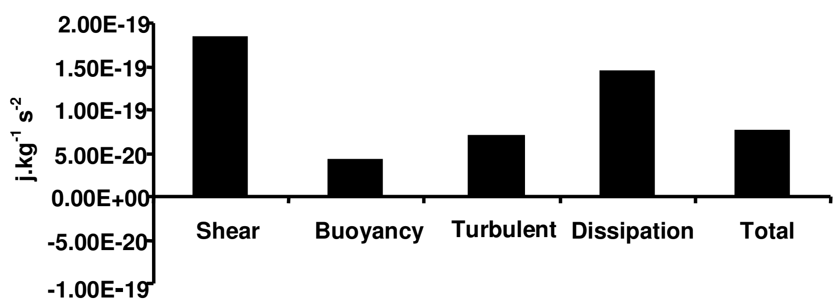

Figure 9. Modeled mixing rates results at C10 during Jan-00.

viscous dissipation are respectively 1.26×10-19 j.kg^{-1}s^{-2}, 6.07×10-20 j.kg^{-1}s^{-2}, 1.22×10-20 j.kg^{-1}s^{-2}, and 7.7×10-20 j.kg^{-1}s^{-2}, that is, turbulence relatively plays a significant role in mixing production (Figure 7). The total mixing rate is 6.9×10-20 j.kg^{-1} s^{-2}.

The turbulent mixing structure at C10

The modeled production rates for shear, buoyancy, turbulence, and viscous dissipation at station C10 show that buoyancy is the primary mixing producer during the whole year except at Jan-00 where it is a secondary producer. Figure 8 shows that during Apr-99, buoyancy has a production rate of 1.45×10-20 j.kg^{-1}s^{-2} , while shear, turbulence and viscous dissipation only have production rates of 4.78×10-21j.kg^{-1}s^{-2}, 7.41×10-22 j.kg^{-1}s^{-2}, and 3.6×10-21 j.kg^{-1}s^{-2} respectively, that is, shear and viscous dissipation play a small role in vertical mixing while turbulence plays a negligible one. The total mixing rate is 5.91×10-21 j.kg^{-1}s^{-2}. From Figure 9, Buoyancy in addition to turbulence plays a relatively small role in mixing production during Jan-00 contrary to other months. They have small production rates which are respectively 4.33×10-20 j.kg^{-1}s^{-2}, and -6.98 × 10-20 j.kg^{-1}s^{-2}. Shear and viscous dissipation play the major role in mixing

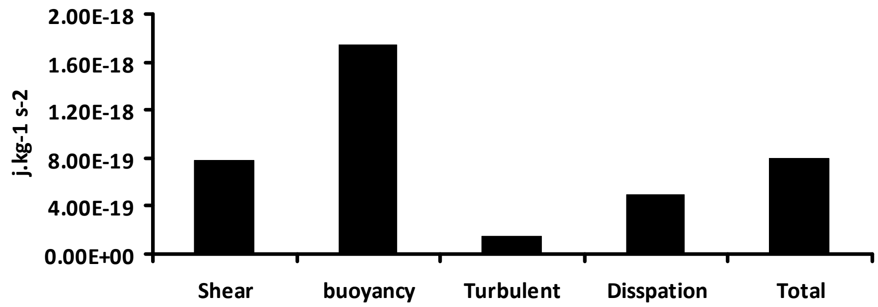

Figure 10. Modeled mixing rates results at C1 during Mar-99.

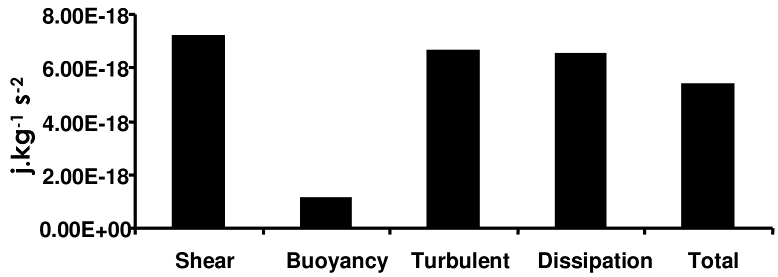

Figure 11. Modeled mixing rates results at C1 during May-99.

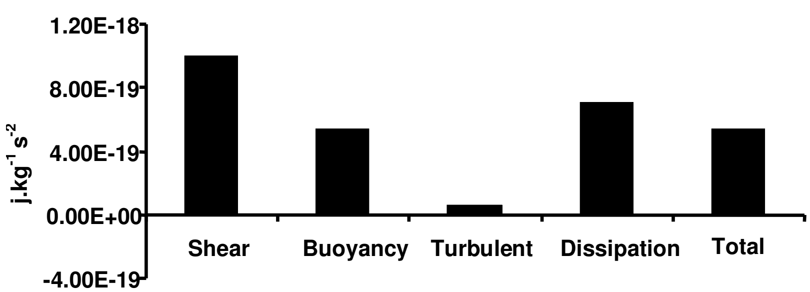

Figure 12. Modeled mixing rates results at C1 during Nov-99.

production with production rates 1.85×10-19 j.kg^{-1}s^{-2}, and 1.45×10-19 j.kg^{-1}s^{-2} respectively, while the total mixing rate is 7.59×10-20 j.kg^{-1}s^{-2}. At C10, Sharaf El Din et al. (2010) results appeared that buoyancy frequency has a high values during the whole year (especially at 42 m depth) which coincide with our model result. Also, the two results indicate that the viscous dissipation and the turbulent have a small role in mixing process

The turbulent mixing structure at C1

In general, shear, buoyancy, and viscous dissipation all together have an essential role in vertical mixing approximately around the all year. Buoyancy plays the primary role in vertical mixing during Mar-99, Figure 10, with a production rate 1.74×10-18 j.kg^{-1}s^{-2}. Shear, turbulence, and viscous dissipation play a secondary role in this dynamical turbulent process with rates of production 7.86×10-19 j.kg^{-1}s^{-2}, 1.57×10-19 j.kg^{-1}s^{-2}, 4.99×10-19 j.kg^{-1}s^{-2}. During May, Figure 11 illustrates that buoyancy production is small with a rate 1.16×10-18 j.kg-1 s-2, while shear, turbulence, and viscous dissipation have relatively large rates of production which are respectively 7.23×10-18 j.kg^{-1} s^{-2}, 6.68×10-18 j.kg^{-1} s^{-2}, and 6.55×10-18 j.kg^{-1}s^{-2}, and the total mixing rate is 8.51×10-18 j.kg^{-1}s^{-2}. During Apr 99, Aug 99 and Nov 99, buoyancy, shear and viscous dissipation all together play a primary role in vertical turbulent mixing (Figure 12). Turbulence only plays a small role in vertical turbulent mixing with a production rate ranged between -6.65×10-20 $j.kg^{-1} s^{-2}$ and 2.04×10-18 $j.kg^{-1}s^{-2}$.

Conclusions

A semi-empirical model is used to study the vertical turbulent mixing at four stations in front off Nile Delta north the Egyptian coast. The mixing rate decreases significantly with depth, and the annual average rate of mixing varies from a minimum of 1.79×10-20 $j.kg^{-1} s^{-2}$ at the deep station C10 (498 m) to a maximum of 4.87×10-17 $j.kg^{-1} s^{-2}$ at the shallow station C12 (21 m). The previous results indicate that E plays a small role in mixing production. However, shear and viscous dissipation are essential in the dynamical process of vertical turbulent mixing. Buoyancy intermittently has a substantial role in vertical mixing.

The essential role of shear and viscous dissipation, which depends directly on the squared shear, in vertical mixing show that vertical and not time variation in velocity, is important in vertical mixing. The presence of shear in the water column could result either from tides or prevailing wind stress on the sea surface. Since tidal currents are relatively weak in the Mediterranean, the wind has the major role in vertical mixing. Vertical variations of density (Buoyancy) has a role confined the sea surface where surface layers get denser as a result of the increase of salt content by evaporation enhanced by either solar radiation or wind stress. Thus, the wind is geophysical phenomena which have the greatest effect on the dynamical processes of vertical turbulent mixing.

Nomenclature

V: Northward velocity of current
W: Vertical velocity of current
ε: Viscous dissipation of turbulent kinetic energy
Km: Eddy Coefficient of viscosity
Ks: Eddy Coefficient of diffusivity of salt
Kh: Eddy Coefficient of diffusivity of heat
E: Turbulent Kinetic energy
g: Acceleration of gravity
τ: Wind stress
ρ' : Deviation of sea water density about it's mean value
U' : Deviation of eastward velocity about it's mean value
V' : Deviation of northward velocity about it's mean value
ε' : Deviation of viscous dissipation about its mean value
E' : Deviation of kinetic energy about its mean value
K_{eh} : Eddy coefficient of buoyancy
K_E : Eddy coefficient of kinetic energy
K_ε : Eddy coefficient of viscous dissipation
$\beta_1, \beta_2, \beta_3, \beta_4$: Mixing constants

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