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RESEARCH ARTICLE

SIMULATION OF PERTURBATION IN THE PG (PERSIAN GULF)

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ABSTRACT

The upper most layers of the Persian Gulf (PG) as a pert of suface waters, along with the lower atmospheric boundary layer, play a crucial role in the air-sea fluxes of momentum, heat, and mass, thereby providing important boundary conditions for both the atmosphere and the surface waters that control the evolution of weather and climate. The principal internal feature of the thermocline is a series of thin, laminar-flow sheets of high static stability, separated by weakly turbulent layers of only moderate density gradient and a few metres thick. In this paper, the authors present evidence of a clear coupling between thermocline and turbulence in northern part of the PG. Turbulence kinetic energy increasing will be resulted from winter to summer due to thermocline development in northern part of the PG.

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INTRODUCTION

The first models of boundary layers on both sides of the air-sea interface were developed from our understanding of the turbulent flow over rigid flat surfaces and extended to the field after the landmark Kansas experiment on the terrestrial boundary layer (Businger *et al.,* 1971). The air-sea interface, however, is dynamically quite different from a solid flat surface. For one thing, the velocity field is not required to vanish at the interface. The ocean surface responds with drift currents, surface waves and turbulent eddies over a broad range of scales. There are other phenomena such as bubble injection, spray ejection, rainfall, foam and surfactants, which further affect the dynamics and complicate the problem. Consequently, one would expect the dynamics of such an interfacial layer to be significantly different from that over a solid flat surface under similar forcing conditions. Indeed, while there is evidence that, in general, and on average, the Monin-Obukov similarity theory holds over the ocean (Edson and Fairall, 1998; Edson *et al.,* 2004), there are also some notable differences. Recent measurements and models of the drag of the sea surface on the atmosphere at moderate to high wind speeds in fact suggest that much of the momentum transfer at the surface is supported by the form drag of the waves. There is also evidence that the air-sea heat flux can be modulated by the wavy surface (Veron *et al.,* 2008).

Case study zone

The PG is a shallow water enclosed sea which is located in a region of [48-56] E and [24-30] N geographical domain. Its depth varies between about 3 m in the coastal area to about 105 m close to the Strait of Hormuz, as in the topography introduced to the POM model. In winter northwesterly wind dominates and total annual precipitation is about 300 mm which is mainly in winter time. Return flow of Indian monsoon and African jet can also determine the wind regimes in the eastern and western parts of the PG. The main sustained forcing of the exchange circulation of the PG and the open sea is of course buoyancy as the warm salty water of the PG sinks near the Strait of Hormuz and flow out as a geostrophic bottom trapped frictional outflow (Swift and Bower, 2003). Figure 1 shows a map of the PG with the positions of the measurement stations of CTD of Mt. Mitchell cruise in 1992 used as the initial data for input of the model.

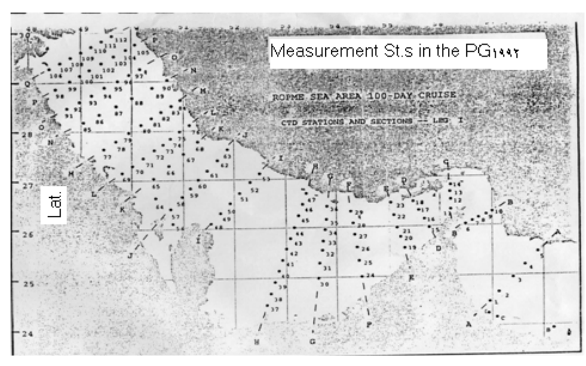

Fig. 1. A Map of the PG with the points presenting the Measurement Stations by Mt. Mitchell cruise 1992

Thermocline

In fact, thermocline development and its variation in space and time affect turbulence and internal waves propagation through water environment that affect mixing of water column. Evaporation rate and tide stress acting on the PG water have

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much bigger values in summer than in winter. As we know, river inflow of the Arvand in northwestern of the Gulf helps in stratification and then internal waves and turbulence can be formed there. Of course gradient throughout density contours in the whole of the Gulf represents existence of internal waves in the thermocline particularly in summer as a result of high solar heating. Thermocline can form in the PG in summer in spite of in winter; so this phenomenon takes place seasonally. We can express that thermocline develops in PG from summer to winter. Average vertical temperature variations through water column of the PG in summer is as shown in Figure 2.

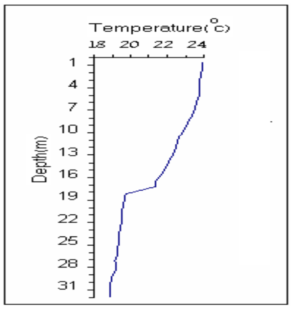

Fig. 2. Thermocline through water column of the PG in summer

The Model

The numerical feature and means used to simulate turbulence kinetic energy is turbulence closure in POM code presented by Mellor and Yamada (1982). The main formulation of the turbulence equation used in this paper is as the following.

$$\partial q^2 D + \partial U q^2 D + \partial V q^2 D + \partial \omega q^2 = \partial \left| K_q \partial q^2 \right|$$

$$+ \frac{2K_M}{D}\left[\left(\frac{\partial U}{\partial \sigma}\right)^2 + \left(\frac{\partial V}{\partial \sigma}\right)^2\right] + \frac{2g}{\rho_o} K_H \frac{\partial \tilde{\rho}}{\partial \sigma} - \frac{2Dq^3}{B_1 \ell} + F_q \quad (1)$$

Where q, D and ρ_0 are twice turbulence kinetic energy, water depth and average density of water, respectively while U, V and ω are water current under surface layer in sigma coordinates system. Also K_H and K_q diffusivity coefficients. Of course U, V and ω have been obtained running the model first by the Novier-Stokes equations in POM and F_q is forcing affecting on the kinetic energy.

Boundary and initial conditions

The initial values of T and S in the model domain are assigned from the observations (winter 1992). The main run of the model is initialized in winter when stratification is weak throughout the PG. Furthermore, interpolating among most of stations for temperature and salinity are done by the Cressman method (inverse of distance square) using temperature and salinity data for winter and summer. The surface forcing including wind stress, solar radiation and evaporation are applied as monthly mean values and integrations in time steps of 5 minutes is used and the period of integration lased for 6 months starting from winter condition. In fact for the first 6 months of integration zero surface forcing was applied in order to establish stability. Then the monthly mean surface forcing including evaporation rate, wind stress, solar radiation, Arvand river inflow and water inflow from Oman Sea were applied from winter to summer for the second 6 months of integration. In order to run the model from winter to summer, monthly average of wind velocity, solar radiation and evaporation climatological data are used. These are shown in the Table 1. The data of wind speed and solar radiation are as climatologic monthly mean values from 54 years of NOAA data and evaporation is as in (Privett, 1959) in the above table. The wind is mainly northwesterly.

Table 1. Climatological data used in the model during February-July

Month	Wind- u (m/s)	Wind-v (m/s)	Solar radiation (W/m^2)	Evaporation (mm/min)
F	1.75	-3.12	85	0.028
M	1.86	-3.86	87	0.016
A	1.89	-4.82	132	0.014
M	1.94	-5.47	179	0.013
J	2.03	-4.87	287	0.015
J	1.4	-4.5	299	0.022

RESULTS OF SIMULATIONS

It is considerable to see the turbulence energy difference in winter and summer in the north part of the Persian Gulf (the case study zone). It is so because the temperature and salinity gradients, due to the difference in the effective forcing values, in these two cold and hot seasons are serious. Turbulence is considered, often, together with the internal waves inflow that results from the water column stratification and also the existence of the mixing. It can be said that the bottom stress in the north part that is shallow, together with the water column stratification and the temperature and salinity gradients (resulting from the entering of the colder and less salinity flow of the Arvand river to the PG) are among the basic turbulence factors in this region.

(Chen *et al.,* 2000) after the turbulence modeling in a shallow area in the Main Gulf in his research concluded that the bottom stress (in shallow and coastal areas) and stratification in rivers' mouths influence the turbulence kinetic energy (Hodges *et al.,* 2000). Kitaigorodskii (1997) mentioned that wind stress and the formation of the internal waves in thermocline in water. In the present model for turbulence, the 2.5 level turbulence closure developed by Mellor and Yamada (1982) was used for turbulence modeling in the northern part of the PG. Obtaining the depth average from the turbulence kinetic energy and also in the subsurface layer, the changes of the energy during 181 days for the model running in the northwest region of the PG the result was Figure 3a & b.

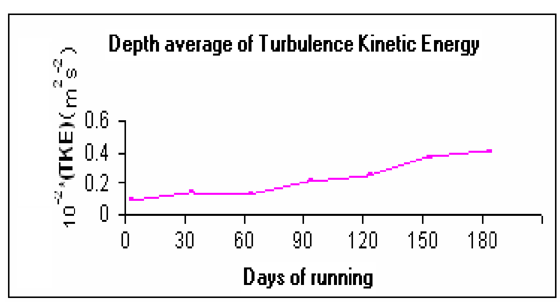

Figure 3 (a). Average depth variations of turbulence kinetic energy in the northwest region of the PG, from winter to summer

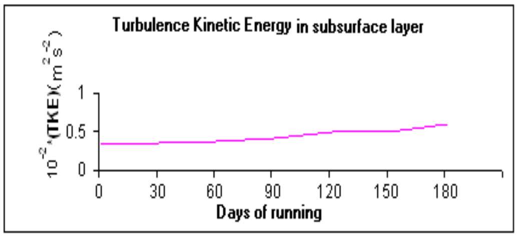

Fig. 3 (b). Variations of turbulence kinetic energy in subsurface in the northwest of the PG, from winter to summer

It can be said that some factors about causing turbulence can be mentioned such as the entering of the Arvand river with less temperature and salinity into the gulf and also the bottom stress with the thermocline increasing and the increasing of the temperature gradients in the water column causes the turbulence kinetic energy increasing from winter to summer.

Conclusion and discussion

This paper has been concerned with identifying the instability found on thin sheets in the thermocline; We know that (Woods and Fosberry 1967) investigates the effect that the instability has upon the lamination in the thermocline, and shows that if the *sheets* are continually being intensified (i.e. thinned) by entrainment into the adjacent layers, then shear instability sets a limit to how thin they can become in a given field of internal waves and drift shear. The next paper (Woods, 1968) considers the vertical flux of heat through the thermocline, comparing the heat transferred sporadically through the sheets by the short-lived, but highly conducting patches of turbulence (apertures) caused by shear instability and the far weaker leakage of heat through the remaining laminar flow area of the sheet, with the heat flux through the layers. It is concluded that the vertical heat flux is largely controlled by the frequency of formation of turbulent 'apertures'. Of the papers now in preparation, one will describe how the diurnal heating cycle penetrates the thermocline lamination by provoking extensive shear instability each morning, while another will compare the Kelvin-Helmholtz rolls found in the thermocline with similar rolls in the atmosphere, which have recently been analysed by Ludlam (1967).

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