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Simulation of Turbulence in Northern Part of the Persian Gulf in Vicinity of Thermocline

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Abstract: In the present study, authors present evidence of a clear coupling between thermocline and turbulence in northern part of the Persian Gulf (PG). A mechanism for generating the turbulence observed on the thermocline sheets is established by running a turbulence closure through the POM (Princeton Ocean Model). Turbulence kinetic energy increasing will be resulted from winter to summer due to thermocline development in northern part of the PG. That is, the static stability of the sheet is sufficient to restrain any instability due to the shear across it at that instant. As we know, thermocline is the place of strong stratification and so internal waves exist there. These waves propagate through thermocline layer formed underwater due to density gradients. This paper studies these phenomena in the PG with the data collected in 1992 on the basis of Mt. Mitchell cruise during 100 days during 100 continuous days from Feb. till Jul. 1992 and running the turbulence closure through POM (Princeton Ocean Model). In fact, turbulence can be produced by factors like climatological, water exchange and bottom stress and so could propagate through thermocline. This paper, present results from model running (POM) that show evidence of coupling between the turbulent velocity fields and the thermocline. It also show evidence of relation between bottom stress and the turbulent fields.

Key words: POM · PG · CTD · NOAA · TKE

INTRODUCTION

The exchange flow between the PG and open ocean is mainly due to buoyancy, resulting from excess evaporation of this water body (the net water loss is about 1.5 m,2). While tidal and wind forcing are two important factors responsible for mixing and circulation in the PG, solar heating during the summer (when the wind is usually calmer than other time of the year,2) create a strong summer thermocline which effectively shots off the surface water from the deeper parts. 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 layer3. The air-sea interface, however, is dynamically quite different from a solid flat surface. There is evidence that, in general and on average, the Monin-Obukov similarity theory holds over the ocean4-5, 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 suggest that much of the momentum transfer at the surface is supported by the form drag of the waves. There is evidence that the air-sea heat flux can be modulated by the wavy surface. When the dyed thermocline sheet appears (upon even the closest Indian Journal of Geo-Marine Sciences 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.

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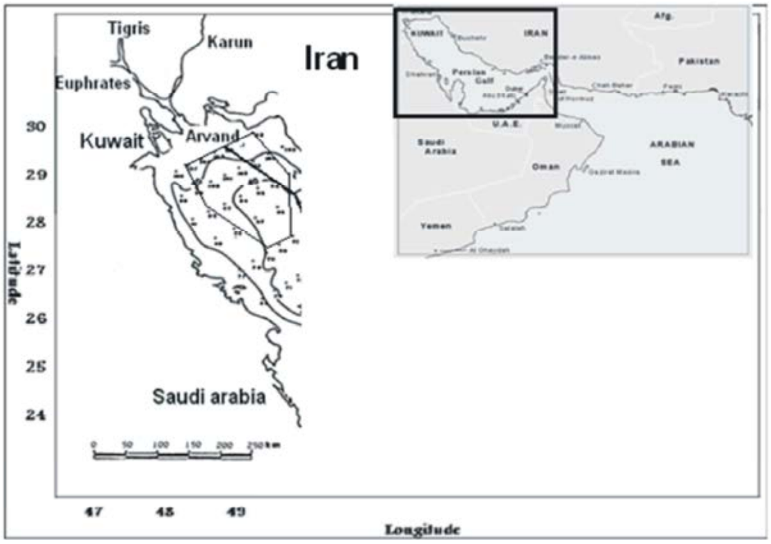

Fig. 1: A Map of the PG with the points presenting the Measurement Stations by Mt. Mitchell cruise 1992

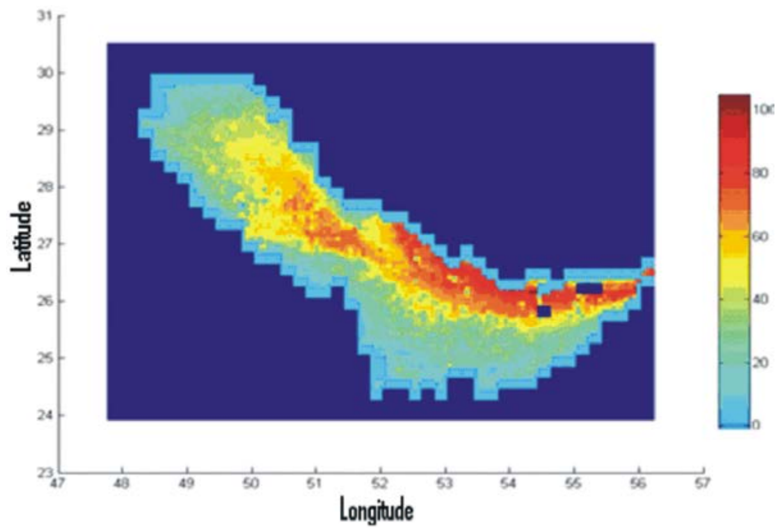

Fig. 2: Depth contour of the Persian Gulf

Fig. 1 shows a map of the PG with the positions of the measurement stations of CTD of Mt. Mitchell cruise in 1992 with the bottom topography shown in Fig. 2 used as the initial data for input of the model [1-5].

Accurately8. In fact, thermocline devel-opment 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 much bigger values in summer than in winter. 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 and velocity variations through water column of the PG in summer are as shown in Fig. 3. When the dyed thermocline sheet appears (upon even the closest inspection) to be everywhere smooth, then we may confidently state that the flow is laminar and the sheet is *stable.* That is, the static stability of the sheet is sufficient to restrain any instability due to the shear across it at that instant. The PG is a shallow water enclosed sea which is located in a region of [48-56] E and [24-30] N.

Structure of Thermocline: A full description of the fine structure of the thermocline is determined by the Fig. 4.

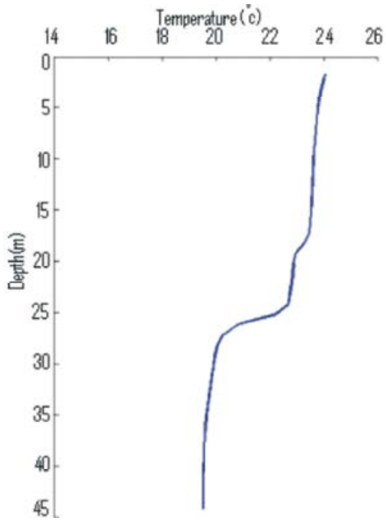

Fig. 3: The Gulf model of the summer thermocline

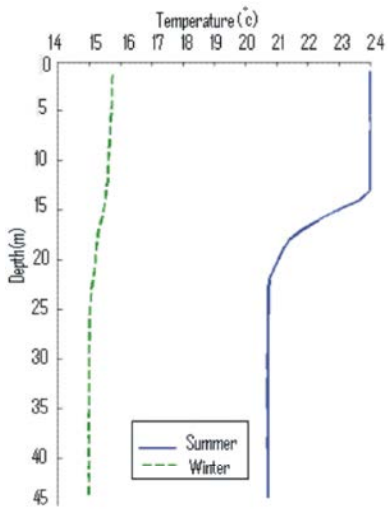

Fig. 4: Mean temperature vertical variations through thermocline through water column of the PG in summer and winter

The resolution of detail within the thermocline is limited by the thermal response time of the bathythermograph. Horizontal extent of these sheets has yet to be established, but the evidence of (i) repeated soundings at a single, fixed site and (ii) simultaneous soundings at two separate sites, suggests that individual sheets are at least some tens of miles across. Thermocline, turbulence and internal wave's formation are three important parameters studied and paid much attention in this research.

Pom Model: The numerical feature and means used to simulate turbulence kinetic energy is turbulence closure in POM code presenteds. Main formulation of the turbulence equation used in this paper is as the following. Where q, D and 0 are twice turbulence kinetic energy, water depth and average density of water, respectively while U, V and are water current under surface layer in sigma coordinates system. Also *H K* and *q K* diffusivity coefficients. Of course U, V and have been obtained running the model first by the Novier-Stokes equations in POM and is forcing affecting on the kinetic energy [5-10].

Boundary and Initial Conditions: Initial values of T and S in the model domain are assigned from the observations (winter 1992). 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. The forcing such as wind stress, Arvand river to the PG in northwest, solar radiation, water inflow from the Oman Sea through the Strait of Hormuz in a layer of about 60 m thickness from surface and evaporation affect the temperature variations in the water column and cause thermocline formation in the PG in summer. Here, we employ the monthly average of wind velocities at 10 m height above sea surface,U10, using the Meteorological data. The surface wind stress is calculated using the bulk transfer formula: Where is the density of air (equals to 1.225 here), is the 10 m wind speed. The drag coefficient, C_D, used in the wind stress is given by:

$$C_D = (1.29 + 0.024U_{10}) \times 10^{-3} \qquad U_{10} \langle 8(ms^{-1})$$

The other forcing affecting on the PG, the Arvand river outflow originates with an angle 35° rather than horizontal arriving in the northwest of the PG. The annual mean inflow from the river is 624 and 308 in winter and summer, respectively.

The sidewalls are assumed to be rigid with 3 m in depth voiding numerical errors running the POM code.

Table 1: Climatological data used in the model during February-July Month Wind- u Wind-v Solar radiation Evaporation

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	0.0
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

The model is run from winter with ROPME data and a time-step of 300 s under wind stress, solar radiation, evaporation and water exchange with Arvand River and the Oman Sea. The open boundary conditions in east in the Strait of Hormuz is assigned with temperature and salinity observations from surface to depth of 60 m of the inflow plume from the Oman Sea and, an inflow of water equal to 0.17 Sv in winter and 0.03 Sv in summer9. For the appropriate determination of the basic variables, there is a need for the model simulation including exact forcing values. 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 in10 in the above table. The wind is mainly northwesterly [10-15].

RESULTS AND DISCUSSION

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 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, 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 was used for turbulence modeling in the northern part of the PG. Obtaining the

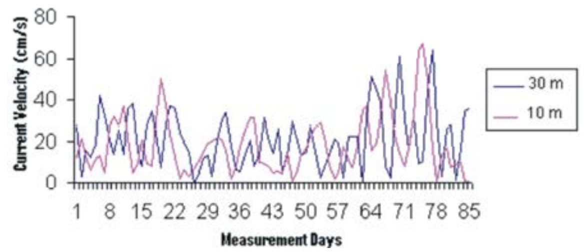

Fig. 5: Average depth variations of turbulent current velocity in the northwest region of the PG, from winter to summer

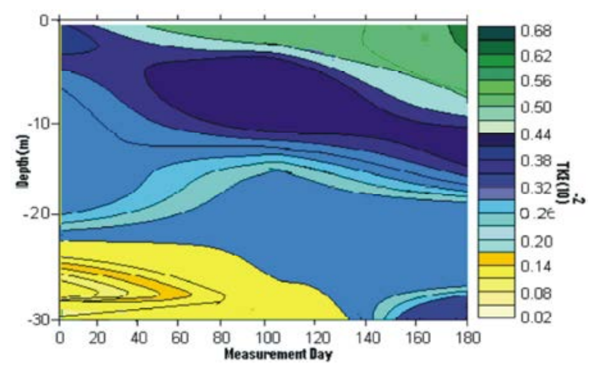

Fig. 6: Variation contours of turbulence kinetic energy in subsurface in the northwest of the PG, from winter to summer

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 Figs. 5 & 6. 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. It can really be said that the amount of the falling and rising of the internal waves and turbulence in the water column in the north part of the PG in summer is more than this in winter. Since the developed thermocline is along with the temperature gradients, the internal waves in the thermocline layer are also formed. So it can be expected that in spring and summer with the increasing in the vertical temperature and salinity gradients causing internal waves and with the spreading of the internal waves in the seasonal thermocline in the PG and the braking of them the turbulence kinetic energy caused by internal waves (irregular internal waves and turbulence) as compared with the winter, has relatively increased. The northern part of the PG as compared with the other parts is shallower and as a result of this, the bottom stress is more; so turbulence at the bottom layer through the water column is more [21, 22].

CONCLUSION

This paper has been concerned with identifying the instability found on thin sheets in the thermocline; 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 analyzed 6. Also it is resulted from the used model that turbulence kinetic energy increases in the northwestern part of the PG from winter to early summer that could be due to increase in internal waves activities and stability intensified through water column during this time. According to the contours about turbulence kinetic energy through water column and in subsurface layer, the main result is that TKE (turbulence kinetic energy) increases from winter to summer; as it was mentioned before, thermocline is the place for internal waves propagation and while thermocline depth varies, internal waves break and so turbulence happens. It is the phenomena takes place in the northern part of the PG because of thermocline formation seasonally in summer in spite of in winter. In fact as a result of thermocline formation gradually from winter to summer, internal waves activity increases during the months and so turbulence kinetic energy (TKE) increases through water column in the northern part of the PG during winter to summer.

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