Water Stratification under Wave Influence in the Gulf of Thailand

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Abstract

The Gulf of Thailand is situated at the western tip of South China Sea. The average depth of the gulf is about 45 m while the deepest part in the central channel is about 80 m. The water column is stratified into 2 layers with distinctive water masses. The purpose of this study is to evaluate the influence of wave on stratification of water in the gulf using the 3-D Princeton Ocean Model (POM). Water condition during January was simulated to represent the northeast monsoon condition and that during August for the southwest monsoon condition. Constant wave mixing strength (Bv) of 0.5 and 1.0 m^2/s were added into the vertical mixing scheme. The model results indicated that while the presence of wave mixing increases water temperature in the upper layer but it doesn't increase the depth of the upper layer.

Keywords: Water stratification, Wave mixing, Gulf of Thailand

1. Introduction

The Gulf of Thailand is a small semi-enclosed sea which is connected to South China Sea via the southern end. The gulf aligns itself in the NE/SW direction. It has roughly a rectangular shape with the width of 400 km and the length of 720 km. The average depth is about 45 m with the deepest part in the central channel of about 80 m. The gulf water is diluted by fresh water discharge from rivers around the gulf and the Maekong river (Stransfield and Garrett, 1977). Saltier water from South China Sea enters the gulf through the deeper channel in the center of the gulf. Thus, the water column stratifies into 2 layers with the interface (the thermocline) lying around 40-50 m below the sea surface (Wyrtki, 1961). It is known that wind energy controls the thickness of the surface layer. But simulating the vertical mixing using the numerical model has resulted in shallower mixing depth and warmer surface water. Qiao et. al. (2006) was able to produce the right thermocline depth in the Yellow sea by adding wave mixing coefficient, ***Bv***, into the turbulence closure scheme of the Princeton Ocean Model (POM). It is interesting to see if we could generate water stratification in the Gulf of Thailand using Qiao's method.

2. Methodology

The study domain spanned from latitude 6º-14ºN and longitude 99º-105ºS. The model domain was further divided into 60 x 40 rectangular grids with the grid resolution of about 10 by 20 km respectively. The water depth was obtained from General Bathymetric Chart of the Ocean (GEBCO) database. Average wind speed for January and August was obtained from The European Center for Medium-range Weather Forecasts (ECMWF). The January wind represented the NE monsoon condition while the August wind represented the SW monsoon condition. Water temperature and salinity data for January and August were obtained from Levitus 94.

The 3-D POM model was used for this study (Blumberg and Mellor, 1987, and Mellor, G.L. 2004). This model has been used to study circulation and mixing in the Gulf of Thailand (Aschariyaphota et. al., 2008). Using sigma coordinate in the vertical axis, there were 8 layers in the vertical domain. Arakawa C-grid was used for model setup. Circulation in the gulf was induced by the surface wind. Wave induced mixing coefficient, ***Bv***, of 0.5 and 1.0 m^2/s was added to the horizontal and vertical viscosity and diffusivity coefficients respectively (Qiao et. al., 2010). Air temperature was fixed to the sea surface temperature value and solar heating was omitted. And radiation condition for surface wave was used at the open boundaries.

POM was used to simulate horizontal circulation and water stratification in January and August. Distributions of temperature and salinity from the model at latitude 8º, 10º and 12.5ºN cross-sections were compared.

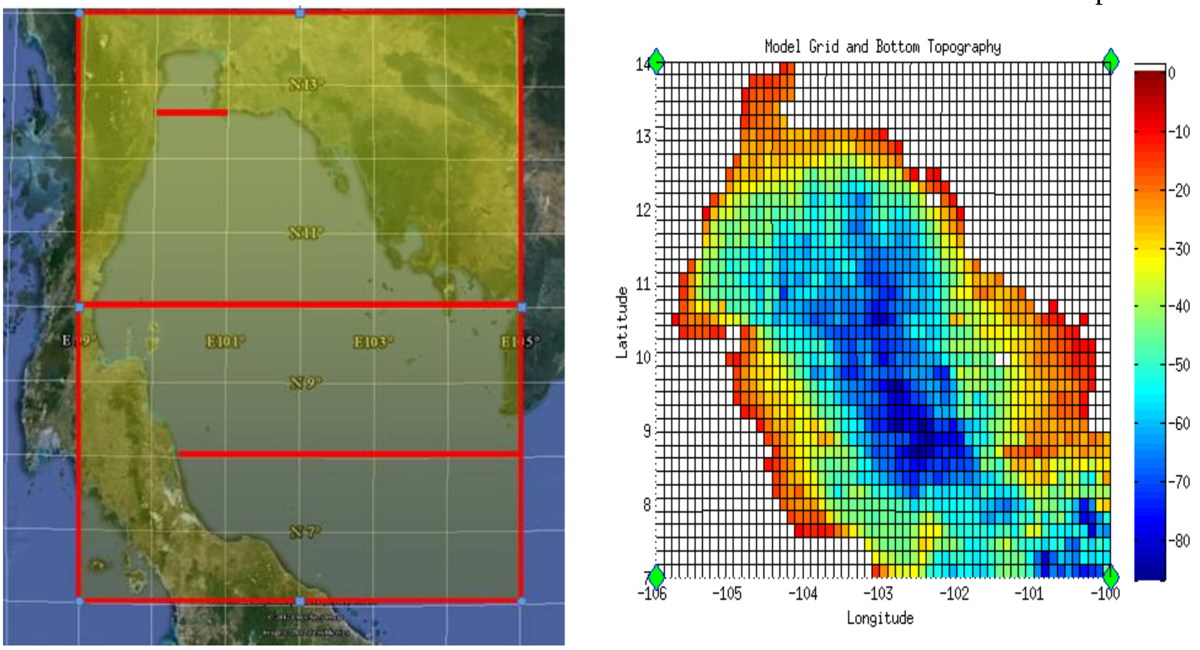
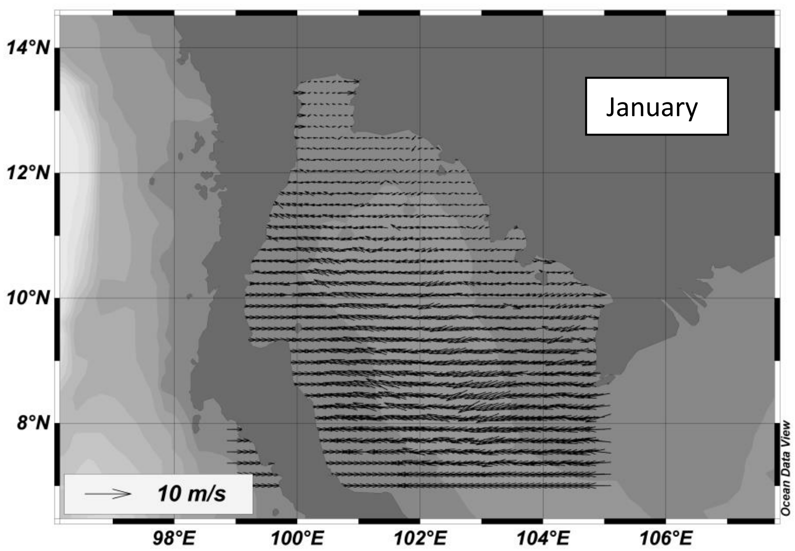


Figure 1. Study area, showing water depth (right) and 3 cross-sections where distribution of temperature and salinity were plotted.



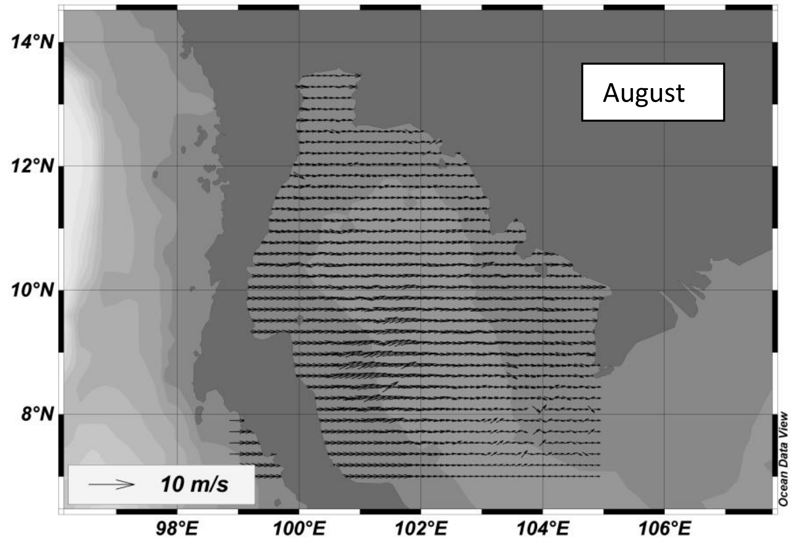


Figure 2. Wind patterns used for this study.

3. Results

Result of wind-driven circulation for January (NE monsoon condition) was shown in Figure 3. Dome of sea surface was found at the western side of the gulf. Even though the height difference between the dome center and its perimeter was merely 3 mm, the surface pressure gradient was enough to create the CW geostrophic current with the current speed around 5 cm/s at the sea surface. Near the western coast of the gulf, water flowed northward as expected for this season (Sojisuporn et. al., 2010). Circulation patterns at the middle and the lower depths were similar to that at the surface, indicating that water flowed in the same direction for the whole water column. Unfortunately, the circulation pattern found in this study was opposite to that in Chaiongkarn and Sojisuporn study (2013), probably due to different wind pattern being used. The water level did not rise up to the level as we expected

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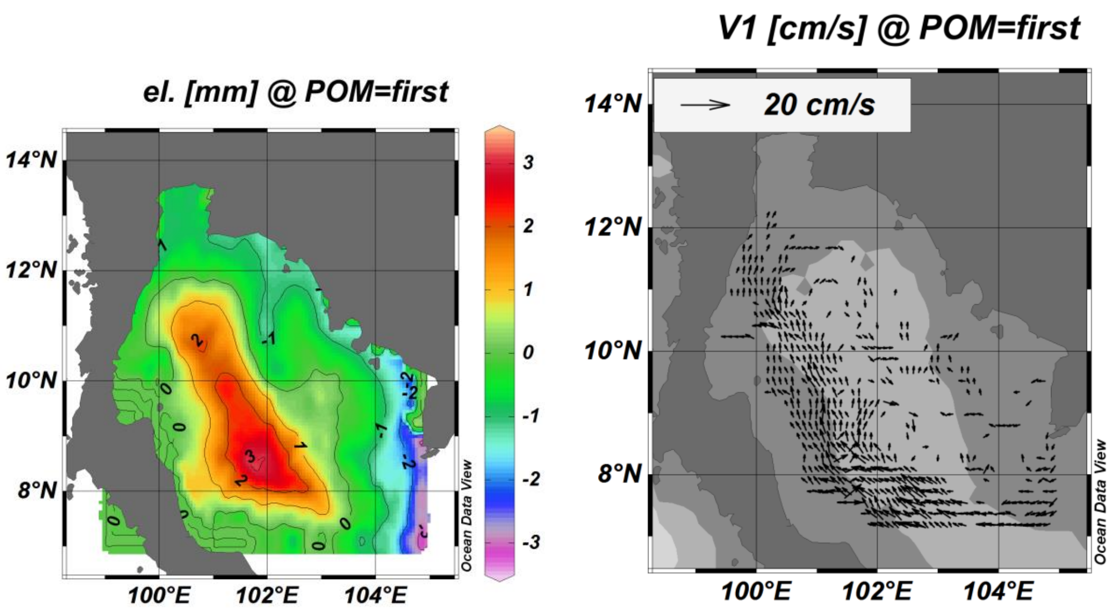


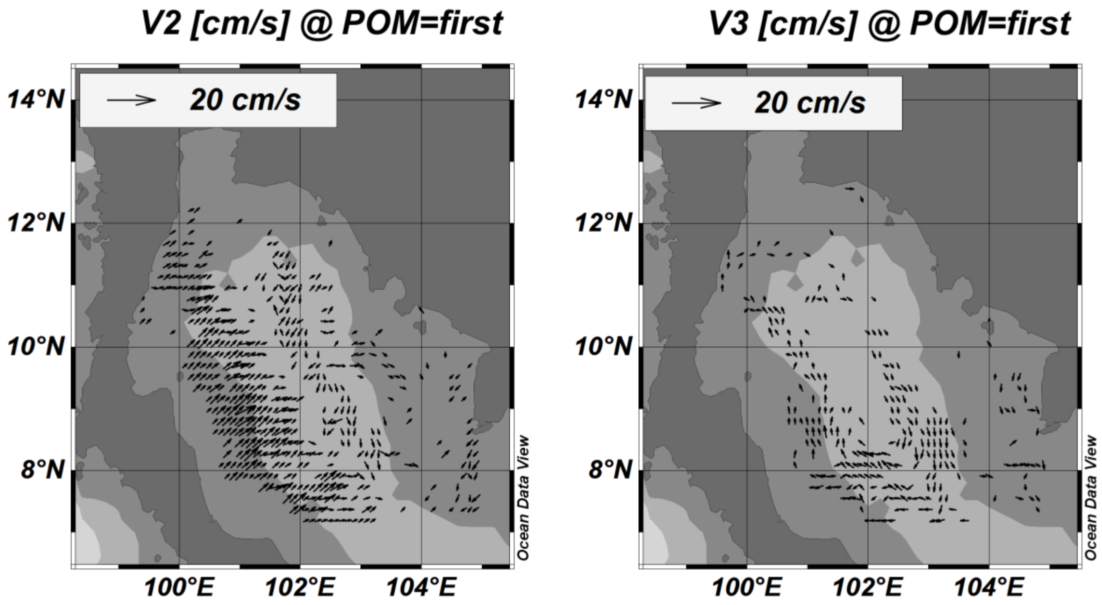


Figure 3. Model results for January simulation. Top left is surface elevation. Top right is surface residual current. Bottom left is residual current at the middle depth and the bottom right is residual current near the sea bottom.

Result of wind-driven circulation for August (SW monsoon condition) was shown in Figure 4. Dome of sea surface was moved to the eastern side of the gulf by the SW wind. The height difference between the dome center and its perimeter was even weak (0.3 mm), resulting in weaker CW geostrophic current for this month. Lower water level at the western side of the gulf created CCW geostrophic current in this area. The circulation patterns were the same in the middle and the lower depth but with weaker current speeds. Again, circulation pattern for this study differed from what was shown in Chaiongkarn and Sojisuporn study (2013). Also the water level did not decrease as we expected that SW wind regime would create the Ekman transport that draws water mass out of the gulf.

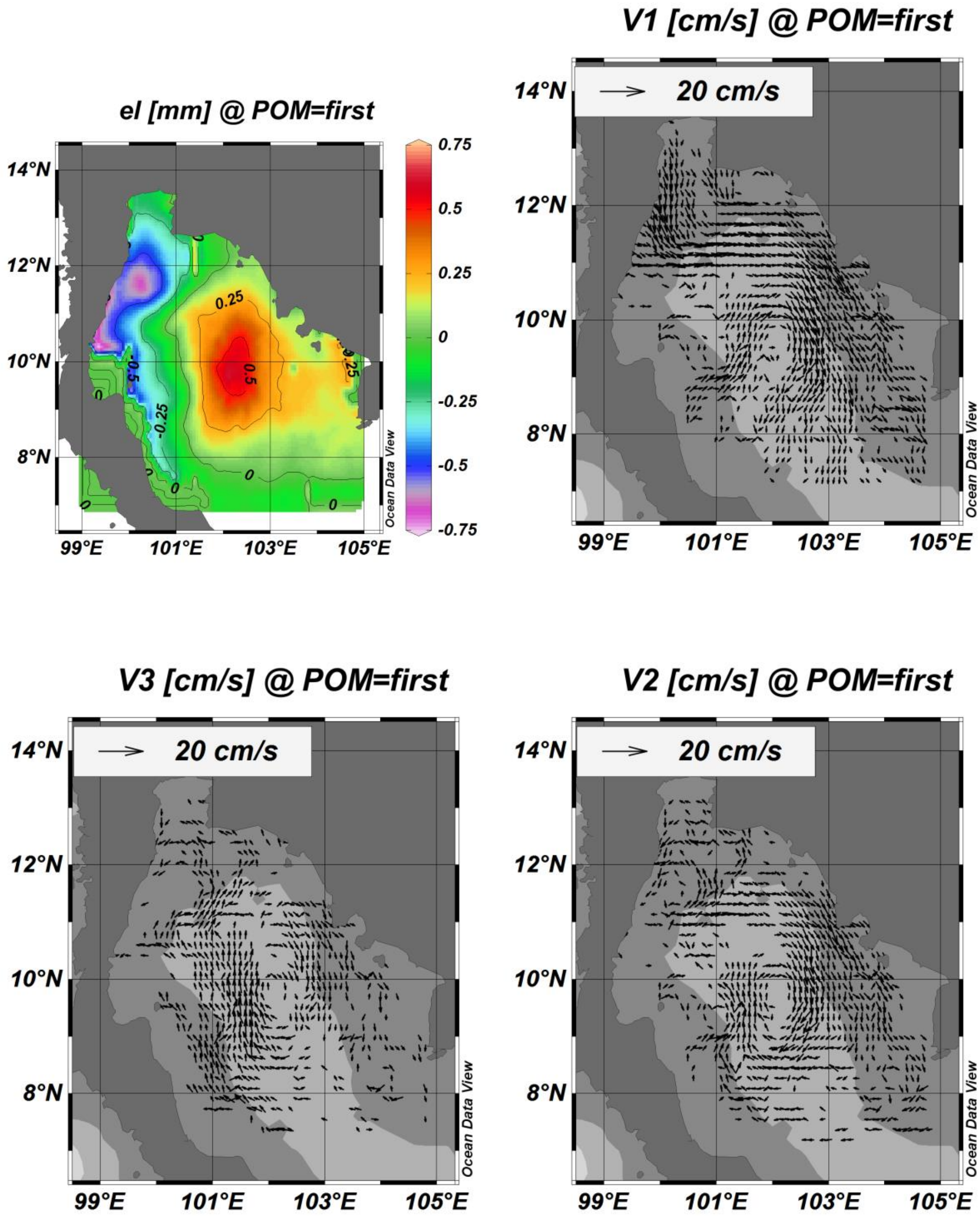


Figure 4. Model results for August simulation. Top left is surface elevation. Top right is surface residual current. Bottom left is residual current at the middle depth and the bottom right is residual current near the sea bottom.

Figure 5 displays the effect of the wave mixing coefficient, ***Bv,*** on mixing of water mass along 3 cross sections in January. The thermocline depths varied from 20 to 50 m depending on the average depth of each cross section. Clearly adding in the wave mixing scheme did not increase the thermocline depth, but rather increased the water temperature in the surface layer. The measured temperature at 8º and 10º cross-sections showed strong lateral stratification rather than the vertical stratification. It turned out that the water column was well-mixed in this month as mentioned by Yanagi et al. (2001). Thus, setting vertical stratification was not a good choice of initial condition for this month.

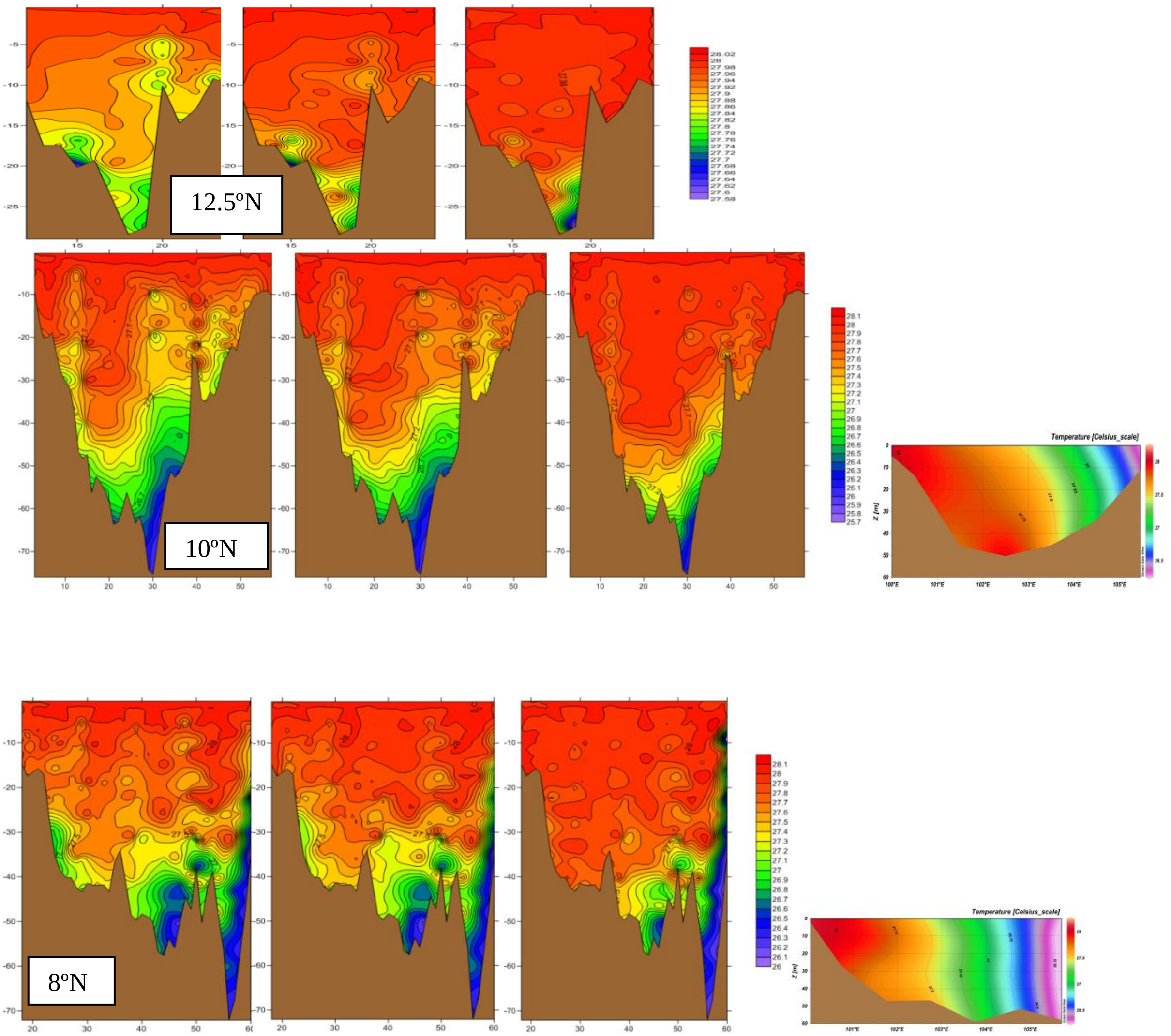


Figure 5. Temperature distributions in January from 3 simulation runs; without wave mixing (left), with wave mixing coefficient, ***Bv*** = 0.5 m^2/s (middle), and with ***Bv*** = 1.0 m^2/s (right). The top pane was for distributions at latitude 12.5ºN. The middle pane was from latitude 10ºN, and the bottom pane was from latitude 8ºN. Measured temperature from Levitus 94 database was also shown at the rightmost for 8º and 10º cross-sections.

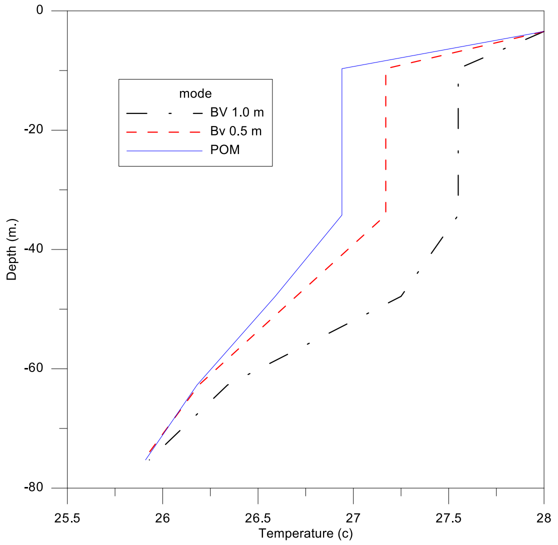
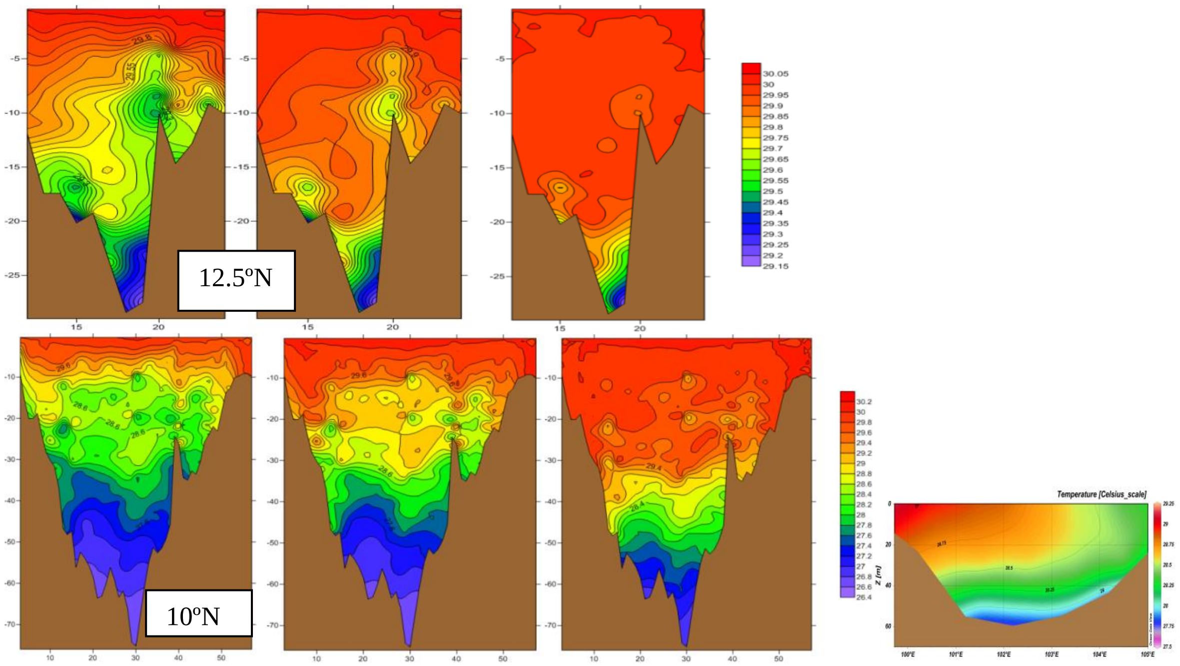


Figure 6. Three simulated temperature profiles in January at Lat. 10ºN and Lon. 102ºE.

Figure 6 displays the temperature profile in January at Lat. 10ºN and Lon. 102ºE. With the water depth of 82 m, it is the deepest part of the gulf. The surface layer was about 35 m thick. Adding the wave mixing parameter increased the surface temperature from 26.75ºC to 27.5º C, but the surface mixing depth did not increase as found by Qiao et. al. (2006).



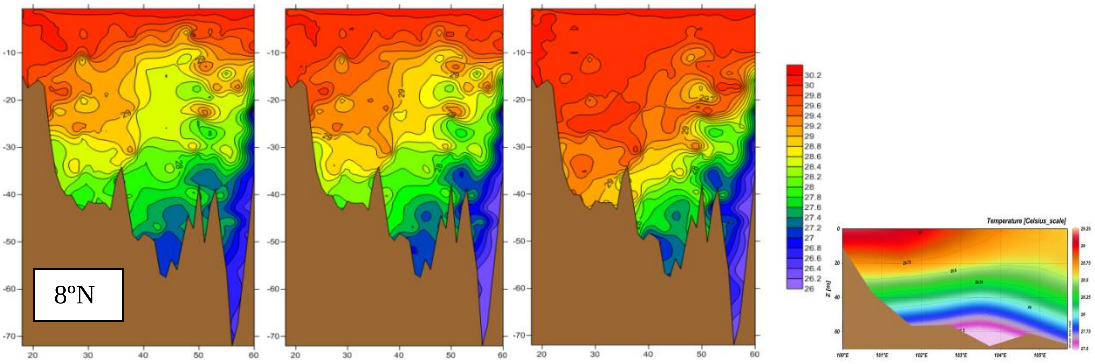


Figure 7. Temperature distributions in August from 3 simulation runs; without wave mixing (left), with wave mixing coefficient, ***Bv***=0.5 m^2/s (middle), and with ***Bv***=1.0 m^2/s (right). The top pane was for distributions at latitude 12.5ºN. The middle pane was from latitude 10ºN, and the bottom pane was from latitude 8ºN. Measured temperature from Levitus 94 database were also shown at the rightmost for 8º and 10º cross-sections.

Figure 7 displays the effect of the wave mixing (Bv) on mixing of water mass along 3 cross sections in August. The measured temperature showed strong stratification along 8ºN and 10ºN cross-sections. Warm pool was located on the left side with the thickness of 10 m. The simulated temperature distributions for this month also showed strong vertical stratification which was due to weak wind-driven current. Warm surface water was also deeper on the left side of the cross-section. Using ***Bv*** of 1.0 m^2/s created too deep surface layer than the measured data. Thus, due to weaker wind speed and weaker wind-driven current, no wave mixing or mild wave mixing were suitable for simulating vertical stratification in the gulf. Weak coastal upwelling occurred on the left side of 10ºN cross-section which was similar to the finding by Sojisuporn et. al. (2010)

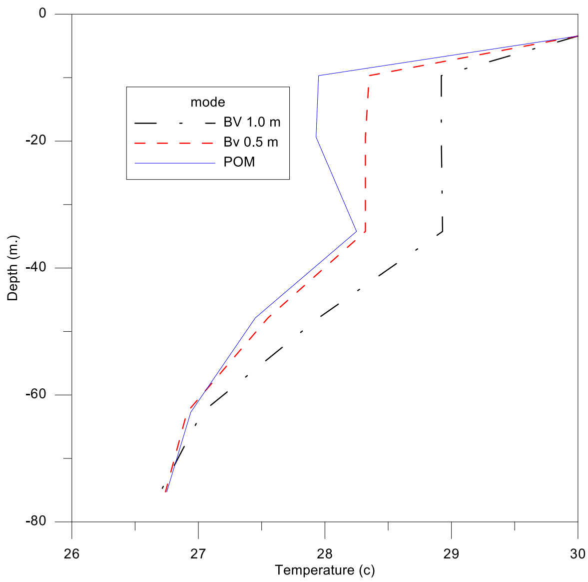


Figure 8. Three simulated temperature profiles in August at Lat. 10ºN and Lon. 102ºE.

Figure 8 displays the temperature profile in August at Lat. 10ºN and Lon. 102ºE. The surface layer thickness was about 35 m which was the same thickness as simulated for January. Adding the wave mixing parameter increased the temperature in the surface layer from 27.5 to 28.2ºC and 29ºC. The use of wave mixing coefficient (Bv) at 1.0 m^2/s created too strong vertical mixing, resulting in higher temperature for the surface layer than the measured value. Thus, low value of wave mixing coefficient was suitable for simulating water stratification for this month. Again, using ***Bv*** did not increase the surface mixing depth as mention earlier.

4. Conclusion and Recommendations

The 3-D Princeton Ocean Model was used to simulated seasonal wind-driven current and vertical stratification as influence by wave. We were able to simulate northward longshore transport during the NE monsoon season. However, the large geostrophic circulation in the gulf could not be confirmed as no measure data is available. Also we could not generate the setup/set down of water level in the gulf due to the Ekman transport

We found that strong wave mixing energy would be needed to generate well-mixed condition during the NE monsoon season. And weak wave mixing energy is needed during the SW monsoon season to increase the water temperature in the surface layer. Unfortunately, we could not generate the deepening of the mixed surface layer by the wave mixing energy.

Large effort would be needed to fine-tune the numerical model. For example good open boundary condition is essential to generate seasonal setup/set down of water level in the gulf. Tide should be input at the open boundary to give more mixing energy in the water column. Proper initial temperature and salinity profile together with appropriate boundary condition at the surface layer is needed to generate correct water stratification. And finally, simulation for circulation and mixing for the whole year will gain more inside knowledge about mixing-stratification in the Gulf of Thailand.

5. Acknowledgement

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