Simulation of sea surface temperature (SST) and sea surface salinity (SSS) in the Bay of Bengal

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Abstract. The simulation of Bay of Bengal (included Andaman Sea) has been done. This investigation used equation of motion (Navier-Stokes equation). The equation of motion was solved by means of Hamburg Shelf Ocean Model (*HAMSOM*). The analysis is done for the year of 2007. The National Centers for Environmental Prediction (*NCEP*) data for year of 2007 is used to force the Bay of Bengal. The sea surface temperature (SST) and sea surface salinity (SSS) have been obtained and analyzed. The highest SST occurs in April 2007, while the lowest SST occurs in October 2007. The pattern of SST depends on the wind vector. From January untill June 2007, the SSS pattern is a west-east pattern. The SSS value is lower in the east and higher in the west. From July untill December, the higher value of SSS is generally in the middle of the Bay of Bengal. Generally, the value of SSS is higher in July and August, while in December and January the value of SSS is lower. Some results have been compared and consistent with the study of Vinayachandran dan Kurian (2008) and Vinayachandran and Yamagata (1998).

Key words: sea surface temperature, sea surface salinity, bay of bengal

Introduction

The Bay of Bengal is a region of large freshwater input, high sea-surface temperature, and variable monsoonal forcing. The Bay of Bengal has been studied numerically by McCreary et al*.* (1993) and Vinayachandran and Yamagata (1998). McCreary et al.. (1993) studied the Bay of Bengal as part of Indian Ocean. McCreary et al*.* (1993) investigate the dynamics and thermodynamics of these and other phenomena using a numerical ocean model. The model is a 2½-layer system with a mixed layer imbedded within the upper layer. They focused on their study to determine the relative importance of *remote vs local forcing* in the northern Indian Ocean, particularly with regard to the coastal currents along India and Somalia, but they also comment on the remotely-forced circulation in the southern Indian Ocean generated by the Pacific-Ocean throughflow.

Vinayachandran and Yamagata (1998) found two links that allow exchange between the Bay of Bengal and the rest of the Indian Ocean: The first is the Southwest Monsoon Current (SMC), which is an open ocean current, and the second is the equatorward East India Coastal Current during November–January, which is closely attached to the coast. Bimonthly maps of temperature from the model at a depth of 35 m were presented by Vinayachandran and Yamagata (1998).

Vinayachandran and Kurian (2008) compared their model simulation, observed SST (WOA05) and climatology data. They found that their model results are consistent with observed SST and climatology data. In this investigation, the distribution of SST and SSS in the Bay of Bengal is presented.

Materials and Methods

The HAMSOM model

HAMSOM is a three-dimensional baroclinic primitive equation model. The underlying differential equations are as follows (Pond dan Pickard 1983; Backhaus 1983, 1985; Pohlmann 1996, Rizal dan Sündermann 1994; Huang et al.., 1999; Rizal 2000, Rizal, et al*.*, 2009, 2010):

x-component momentum equation :

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho}\frac{\partial p}{\partial x}+A_H\nabla^2 u+\frac{\partial}{\partial z}\left(A_V\frac{\partial u}{\partial z}\right)+F_x\,,$$

y-component momentum equation :

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho}\frac{\partial p}{\partial y}+A_H\nabla^2 u+\frac{\partial}{\partial z}\left(A_V\frac{\partial v}{\partial z}\right)+F_y.$$

The variables are three components of the velocity u, v, and w, pressure p, density ρ, three space variables, i.e., x (positive in the east direction), y (positive in the north direction), z (positive upwards), time t, and Coriolis acceleration f. The variables A_H and A_v are the horizontal and vertical coefficients of turbulent viscosity, respectively, while F_x and Fy are the components of the horizontal exterior forces.

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0.$$

Hydrostatic equation:

$$\frac{\partial p}{\partial z}=-\rho g,$$

where g is the gravity acceleration.

Heat transport equation:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=K_H^T\nabla^2 T+\frac{\partial}{\partial z}\left(K_V^T\frac{\partial T}{\partial z}\right)+S_T,$$

and salt transport equation :

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}=K_H^S\nabla^2 S+\frac{\partial}{\partial z}\left(K_V^S\frac{\partial S}{\partial z}\right)+S_S,$$

where K_H and K_V are the horizontal and vertical coefficients of turbulent diffusion, respectively, and S_T and S_S are sources of heat and salinity, respectively.

At the surface, the kinematic boundary condition is used:

$$\frac{\partial \zeta}{\partial t}=w$$

where ζ is the water level height.

The differential equations are integrated over the vertical extent of the model layer to arrive at differential equations for the layer-averaged fields of transports (U, V), temperature T and salinity S. The deduction of the layer averaged equations of motion can be found in Pohlmann (1991). These latter equations are transformed into finite-difference representations on the staggered Arakawa c-grid (Arakawa and Lamb 1977).

For the discretization of the time domain a two-time level scheme is introduced. The prognostic variables ς, U, V, T, S which enter the implicit algorithm, are defined at staggered time-levels. In order to eliminate the stability limitation imposed by the CFL criterion in the hydrodynamic equations, semi-implicit algorithms for sea surface height in the horizontal direction and vertical shear stress in the vertical direction are applied.

In the equations of motion, a stable second-order approximation is introduced to the Coriolis terms, in order to avoid linear numerical instability arising from the forward-in-time approximation (Backhaus 1985).

Model arrangements for Bay of Bengal and Andaman Sea

The model covers the region 6.6° N – 24.6° N, and 78,2° E – 98,2° E, 90.5 E to 103.5E and 1.5 N to 17.5 N (Fig. 1). In this investigation, the model area is discretized with a horizontal mesh size of Δx = Δy = 10 angular minutes. In the vertical direction, the model has 10 layers, i.e., 0-10 m, 10-10 m, 10-30 m, 30-50 m, 50-100 m, 100-300 m, 300-500 m, 500-800 m, 800-1500 m, and 1500-2500 m. Data used in the model consists of bathymetry data 10'×10' (Fig. 1), Tidal assimilated data, temperature and salinity data (Levitus and Boyer 1994a, b) and 4-times daily secondary data of meteorology for the year of 2007 from the National Centers for Environmental Prediction (NCEP), namely: U-wind speed at 10 m (m/s), V-wind speed at 10 m (m/s), Air temperature at 2 m (K), Precipitation rate (kg/m2/s), Specific humidity at 2 m (kg/kg), Sea level pressure (Pa) and Total cloud cover (%).

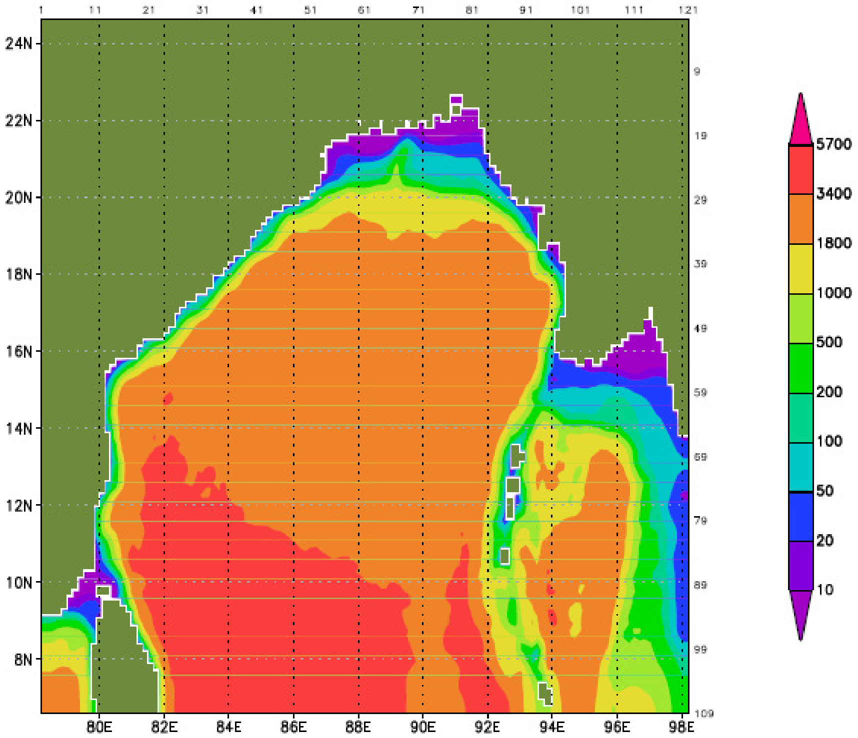

Figure 1. Topography of the Bay of Bengal

Results and Discussion

Sea Surface Temperature

Figure 2 shows the SST from January 2007 to December 2007. We chose 2007 because 2007 is a normal year based on Southern Oscillation Index (SOI). In general, SST maps showed similar results with the study of Vinayachandrand and Yamagata (1998) and Vinayachandran dan Kurian (2008). As can be seen in Vinayachandran dan Kurian (2008), the maximal SST occurs in the month of April and May. In this investigation, the maximal SST also occurs in April and May. In January 2007, the SST values ranged between 25-31 °C. The pattern of SST in February is almost the same as the pattern of SST in January.

With The pattern of SST in March, the lowest temperature is around 25 °C and located in the middle of the Bay of Bengal. The highest temperature is about 31 ° C and it is located in the right side of the Andaman Sea. In April, the SST has a value of temperatures much higher than the temperature in March. In the middle of the Bay of Bengal temperatures are around 27 °C. Maximum temperature in April is more than 31 °C. In May 2007, in the middle of the Bay of Bengal, SST has a value of about 25 °C, while the maximum temperature reached is more than 31 °C. In June 2007, in the middle of the Bay of Bengal, the temperature is around 22 °C and maximum temperatures are in the same area in as of May 2007. Maximum value of temperature is more than 31 °C. In July 2007, in the middle of the Bay of Bengal, the SST is about 20 °C.

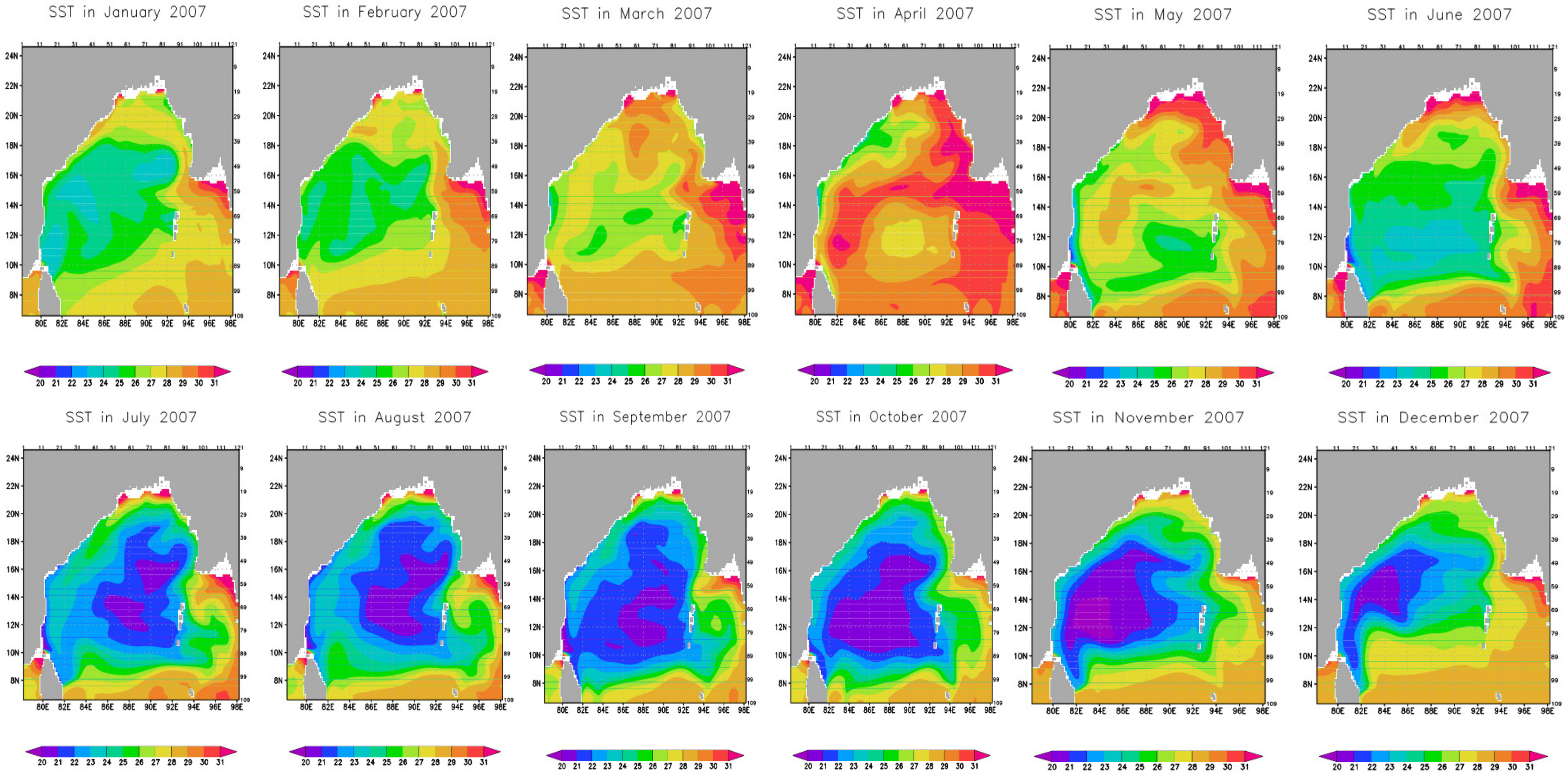

Figure 2. The distribution of sea surface temperature for each month in the year of 2007 in the Bay of Bengal

The highest SST values is about 31 °C. SST in August 2007, showed a similar pattern with the pattern of SST in July 2007. In September 2007, the SST pattern is almost the same as in July and August, with the tendency of decreasing the value of SST. Similarly, in October 2007, the SST minimum is located in the middle of the Bay of Bengal. It has widened significantly. The pattern of SST in October 2007 is almost the same as the pattern of SST in September 2007. In November 2007, the lowest value of SST is located in the middle of the Bay of Bengal. This pattern of low SST has shifted to the west. The lowest SST is smaller than 20 °C. In December 2007, the pattern of low SST is constantly shifted to the west of the Bay of Bengal. It could be that the pattern of low SST shifted to the west because at that time, the wind comes from north and northeast to the southwest. As a result, this pattern will shift to the west due to wind. The wind vector in December 2007 can be seen in Figure 3.

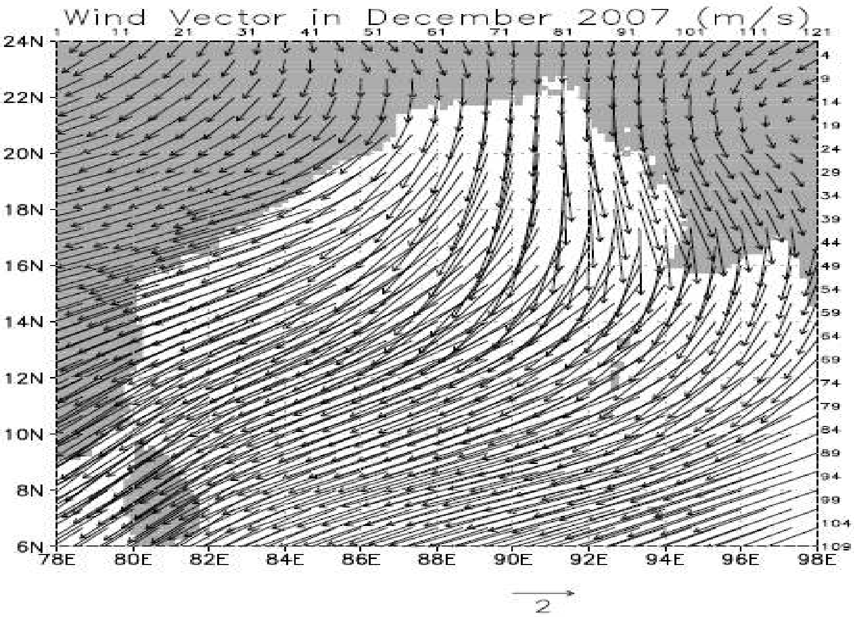

Figure 3. Wind vector in December 2007. The unit is in m/s.

Sea Surface Salinity

Figure 4 shows the pattern of sea surface Salinity (SSS) in the Bay of Bengal and the Andaman Sea in 2007 for each month. In January 2007, the lowest SSS is located in the Andaman Sea. SSS increases to the west of the Bay of Bengal. SSS pattern in February 2007 is almost the same pattern as SSS in January. The highest SSS both in January and February is about 34.4 psu. Like in January and February, the lowest SSS in March is located in the Andaman Sea and the SSS value increases to the west. The same pattern occurred in April, the SSS value increases to the west. Compared to the SSS in March, SSS in April is higher.

In May, SSS value remains the lowest in the east (i.e. in the Andaman Sea). The more to the west, the higher the value of SSS. In June, the SSS pattern is similar to SSS pattern in May, but with the higher SSS. In July, the SSS pattern starts to change. Towards the middle of the Bay of Bengal, the value of SSS is higher. The pattern of SSS in August has almost the same pattern of SSS in July.

In September, the highest SSS is located in the west of the Bay of Bengal. Highest SSS is more than 34.6 psu. In general, the pattern of SSS in October is almost equal to the pattern of SSS which occurs in September. In November, generally the high SSS is located in the middle of the Bay of Bengal. The lowest SSS occurs in the Andaman Sea, with a value of less than 32.2 psu. In general, the pattern of SSS in December is almost the same as the pattern of the SSS in November.

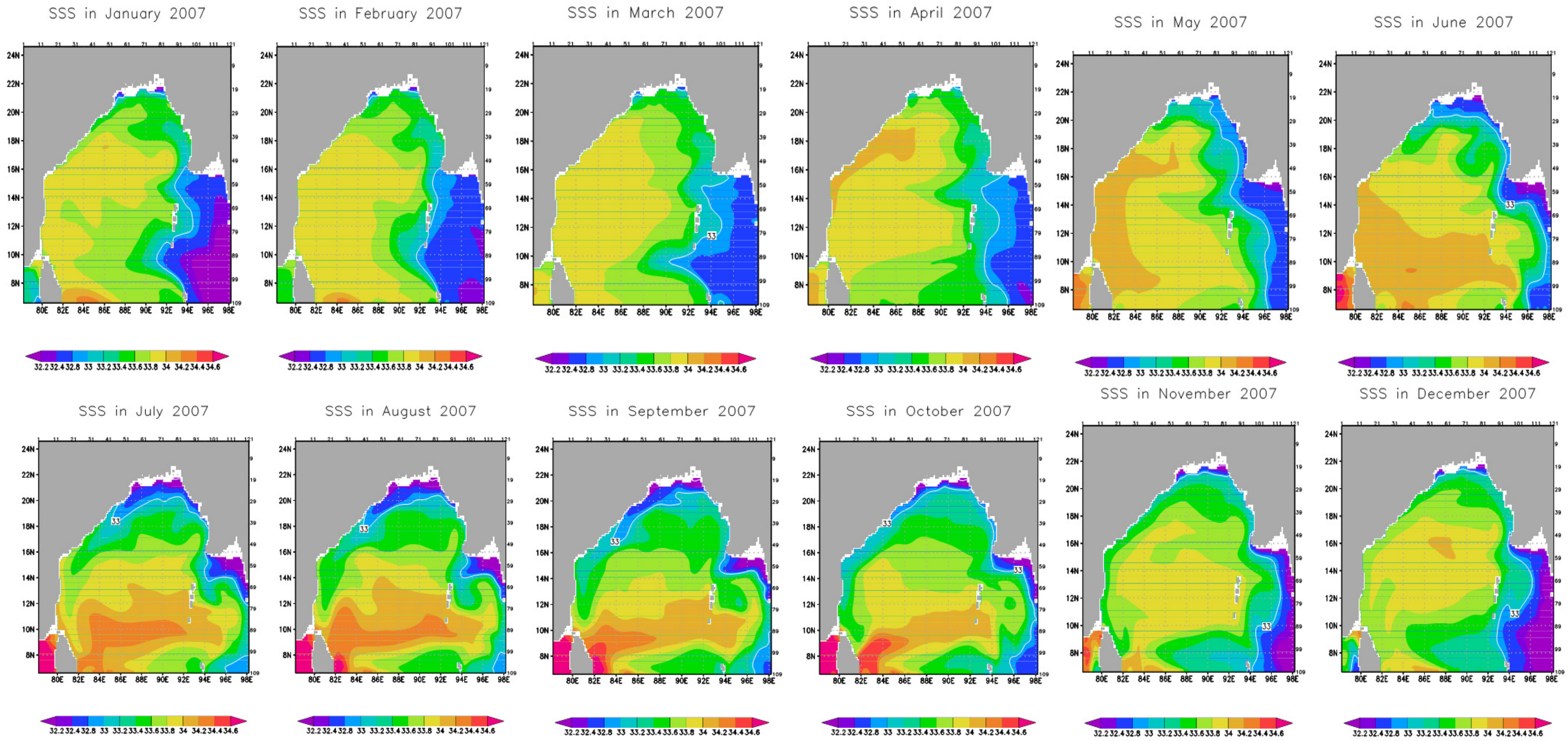

Figure 4. The distribution of sea surface salinity (SSS) for each month in the year of 2007 in the Bay of Bengal

Conclusions

The sea surface temperature (SST) and sea surface salinity (SSS) have been simulated successfully by using HAMSOM model. The highest SST occurs in April 2007, while the lowest SST occurs in October 2007. The pattern of SST depends on the wind vector. From January until June 2007, the SSS pattern is west-east pattern. The SSS value is lower in the east and higher in the west. From July until December, the higher value of SSS, is generally in the middle of the Bay of Bengal. Generally, the value of SSS is higher in July and August, while in December and January the value of SSS is lower.

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