CHAPTER 4 RESULTS AND DISCUSSION

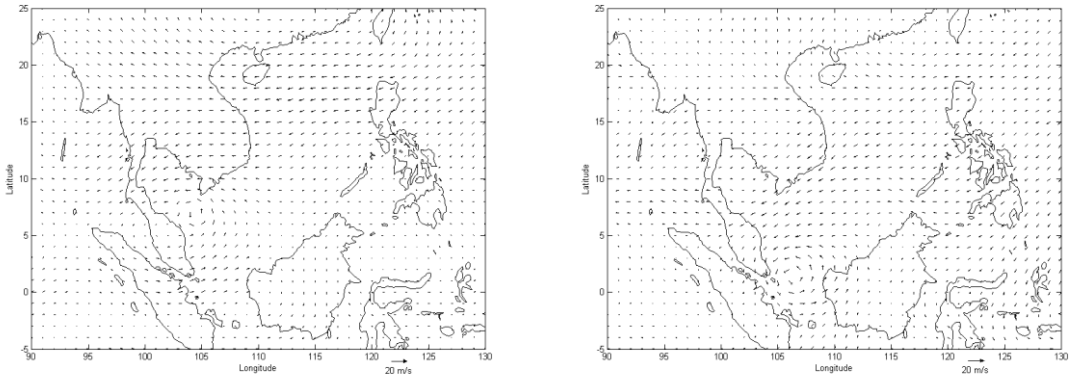
4.1 Simulation without Bogus Wind

Table 4.1 shows the input data $V_h(R_{max})$ or maximum winds from NOAA/NCEP on 01/11/1989 00UTC for GAY and 26/12/2001 12UTC for VAMEI.

Table 4.1 Maximum winds from NOAA/NCEP at the initial time of simulations.

Typhoon	$V_h(R_{max})$
GAY	7.86 ms^{-1}
VAMEI	8.17 ms^{-1}

The initialized winds are shown in Figure 4.1.

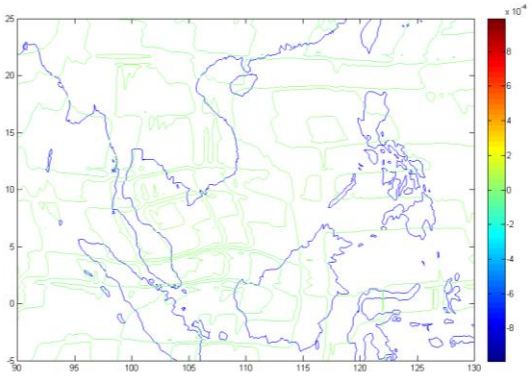


(a) (b)

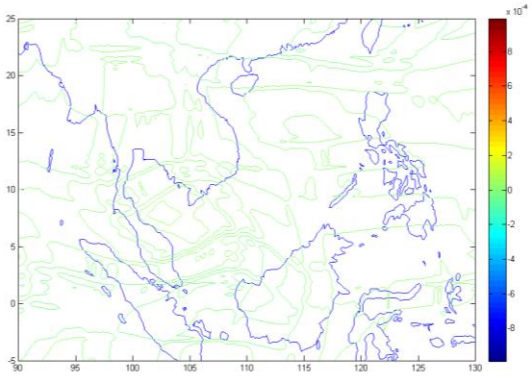
Figure 4.1 The initialized winds (ms^{-1}) of (a) GAY and (b) VAMEI.

4.1.1 Typhoon GAY

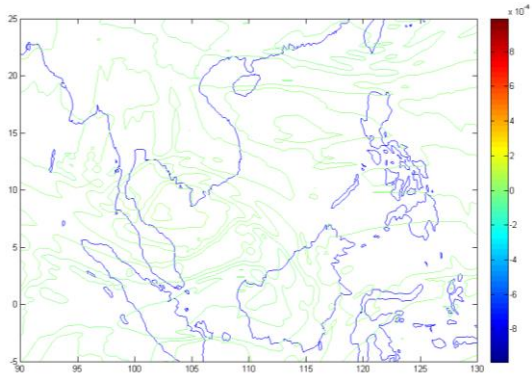
The simulated vorticity (s^{-1}) of GAY for every 6-hour interval from 01/11/1989 06UTC to 03/11/1989 00UTC is shown in Figure 4.2. In the figure, the *x*-axis is longitude and the *y*-axis is latitude.



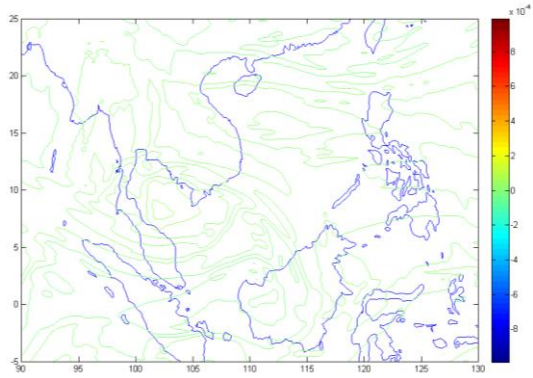
01/11/1989 06UTC



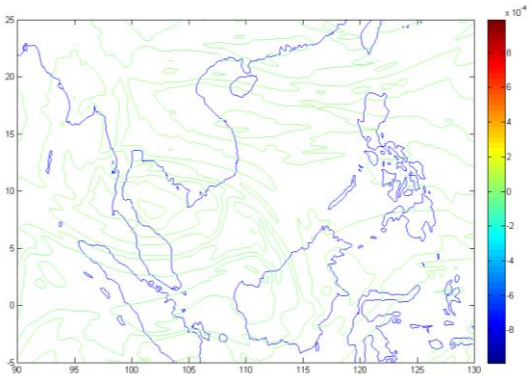
01/11/1989 12UTC



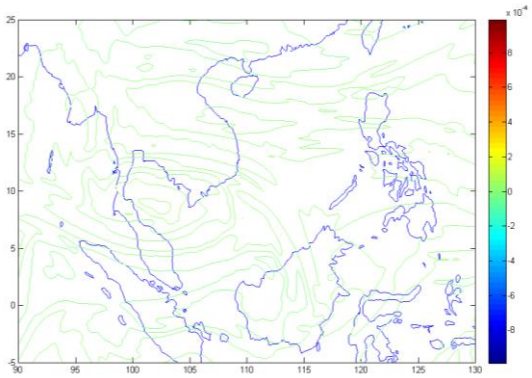
01/11/1989 18UTC



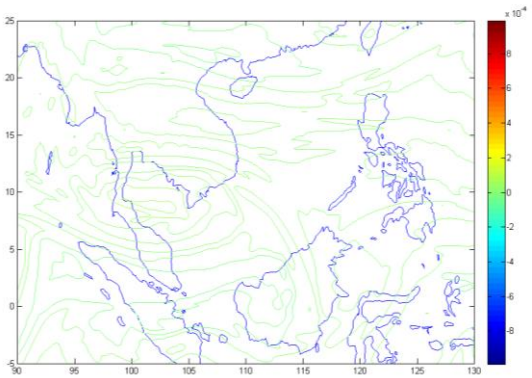
02/11/1989 00UTC



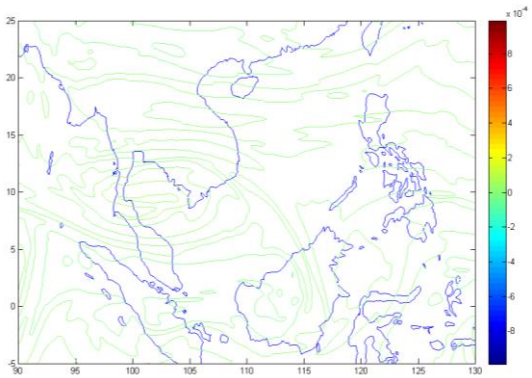
02/11/1989 06UTC



02/11/1989 12UTC



02/11/1989 18UTC



03/11/1989 00UTC

Figure 4.2 The simulated vorticity of typhoon GAY without bogus wind.

The values of simulated vorticity without bogus wind from SILEPE model (ζ_{Model}) and vorticity computed from JTWC data (ζ_{JTWC}) are shown in Table 4.2.

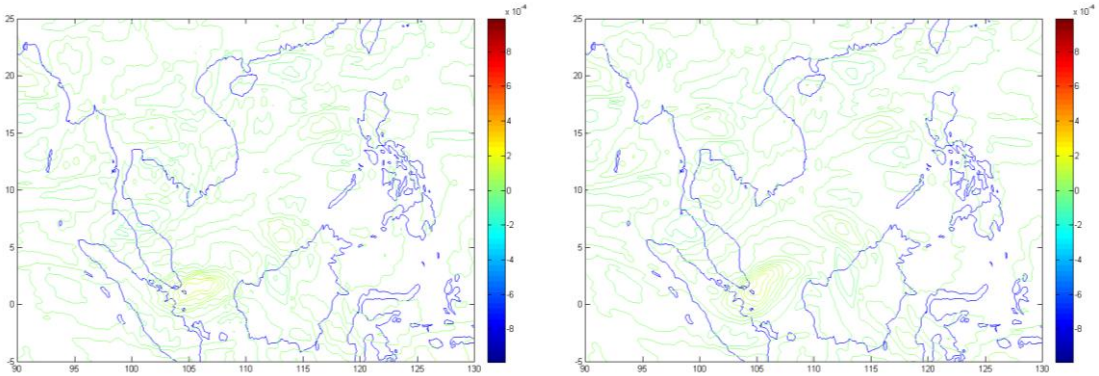
Table 4.2 The simulated vorticity of typhoon GAY without bogus wind.

Date	Hour (UTC)	ζ_{JTWC} ($\times 10^{-4}$ s^{-1})	Type	ζ_{Model} ($\times 10^{-4}$ s^{-1})	Intensity
01/11/1989	00	2.01	Depression	1.21	Depression
01/11/1989	06	2.01	Depression	1.12	Depression
01/11/1989	12	2.01	Depression	1.02	Depression
01/11/1989	18	2.25	Depression	0.95	Depression
02/11/1989	00	2.46	Tropical Storm	0.87	Depression
02/11/1989	06	2.46	Tropical Storm	0.79	Depression
02/11/1989	12	2.46	Tropical Storm	0.71	Depression
02/11/1989	18	2.79	Tropical Storm	0.67	Depression
03/11/1989	00	4.26	Typhoon	0.63	Depression

From Table 4.2, the simulations from SILEPE model without bogus wind show that the vorticity is less than JTWC data. Thus, the simulated vorticity without bogus wind from SILEPE model cannot be used to analyze the formation of typhoon GAY.

4.1.2 Typhoon VAMEI

The simulated vorticity of VAMEI for every 6-hour interval from 26/12/2001 18UTC to 27/12/2001 00UTC are shown in Figure 4.3.



26/12/2001 18UTC 27/12/2001 00UTC

Figure 4.3 The simulated vorticity of typhoon VAMEI without bogus wind.

The values of simulated vorticity without bogus wind from SILEPE model (ζ_{Model}) and vorticity computed from JTWC data (ζ_{JTWC}) values are shown in Table 4.3.

Table 4.3 The simulated vorticity of typhoon VAMEI without bogus wind.

Date	Hour (UTC)	ζ_{JTWC} ($\times 10^{-4}$ s^{-1})	Type	ζ_{Model} ($\times 10^{-4}$ s^{-1})	Intensity
26/12/2001	12	2.05	Depression	1.53	Depression
26/12/2001	18	2.43	Tropical Storm	1.42	Depression
27/12/2001	00	4.05	Typhoon	1.34	Depression

From Table 4.3, the simulations from SILEPE model without bogus wind show that the vorticity is smaller than JTWC data. Thus, the simulated vorticity without bogus wind from SILEPE model cannot be used to analyze the formation of typhoon VAMEI.

4.2 Simulation with Bogus Wind

To generate tropical cyclone bogus wind filed to be used in the initial data of the shallow water model, the analyzed wind speeds of the storms from NOAA/NCEP are enhanced by the wind speeds obtained from AWM.

The parameters in AWM are set as follows;

1. Determine the distance of the storm between the previous position of the storm and the present position,
   Distance = sin(lat1)sin(lat2) + cos(lat1)cos(lat2)cos((lon1-lon2)×*RAD*)
   where lat1 = latitude1×*RAD*
   lat2 = latitude2×*RAD*
   lon1 = longitude1×*RAD*
   lon2 = longitude2×*RAD*
   latitude 1 = latitude of the previous 6-hour position
   latitude 2 = latitude at the initial position of the storm
   longitude 1 = longitude of the previous 6-hour position
   longitude 2 = longitude at the initial position of the storm
   RAD = π/180 =0.0175

2. Determine translation speed (V_{center}) of the storm from
   $V_{center} = D/(6\times 3600)$
   $D = 6371000\times\cos^{-1}$(Distance)
   The results of these 2 step are shown in Table 4.4.

Table 4.4 Input initial data and results from Steps 1 and 2.

Typhoon	Latitude1 degree N	lat1	Latitude2 degree N	lat2	lon1 degree E	lon2 degree E	*D* (m)	V_{center} (ms^{-1})
GAY	7.0	0.14	7.1	0.14	104.4	103.7	49728	2.30
VAMEI	1.3	0.03	1.4	0.03	107.0	106.5	44478	2.06

3. Calculate parameter *b* (Harper et.al, 1999) from

$$b = \frac{\rho . e\left(V_{\max} - V_{center}\right)^2}{p_{env} - p_{center}}$$

The condition that $1 < b < 2.5$ has to be satisfied.
Let air density ρ = 1.15 kgm^{-3}, environmental pressure p_{env} = 1008 hPa for typhoon GAY, p_{env} = 1005 hPa for typhoon VAMEI and the radius of maximum wind speed $R_{\max}$ = 100 km, then the values of b are obtained as in Table 4.5.

Table 4.5 The initial values of b and the corresponding inputs.

Typhoon	p_{center} (hPa)	$V_h(R_{\max})$ (ms^{-1})	V_{center} (ms^{-1})	b
GAY	996	7.86	2.30	1.15
VAMEI	997	8.17	2.06	1.81

4. Compute rotational speed of GAY and VAMEI from the symmetric wind model Eq. (2.1),

$$V_h(R) = -\frac{fR}{2} + \frac{1}{2}\sqrt{f^2R^2 - 4\frac{b}{\rho}\left(\frac{R_{\max}}{R}\right)^b (p_{env} - p_{center})\exp\left[-\left(\frac{R_{\max}}{R}\right)^b\right]}$$

Let R denotes the distance (radius) from the storm center, the input data for this step and the corresponding results are shown in Table 4.6,

where $V_h(R_{\max})$ is the maximum wind speed from the symmetric wind model.

Table 4.6 Input initial data for Step 3 and the corresponding results from the symmetric wind model.

Typhoon	p_{center} (hPa)	$V_h(R_{\max})$ (ms^{-1})	V_{center} (ms^{-1})	b	$V_h(R_{\max})_{JTWC}$ (ms^{-1})
GAY	996	7.86	2.30	1.15	13.18
VAMEI	997	8.17	2.06	1.81	13.92

To account for the increase of wind speed with height, a scaling factor 1.5 is multiplied to the bogus wind speed before insert into the shallow water model. This is because the bogus wind is computed from 10 m wind while the SILEPE is applied at 850 hPa level. The value 1.5 is obtained from the linear relationship between wind speeds at the surface and 850 hPa level.

Table 4.7 shows the input data $V_h(R_{\max})$ from NOAA/NCEP and corresponding results of bogus winds from AWM or V_{asym} ($R_{\max}$,θ). Only winds within the storm radius are enhanced. Initialized process is then performed to adjust the relation between the bogus wind field and the geopotential height to satisfy the assumption in the shallow water model. The initialized winds and geopotential heights are shown in Table 4.8.

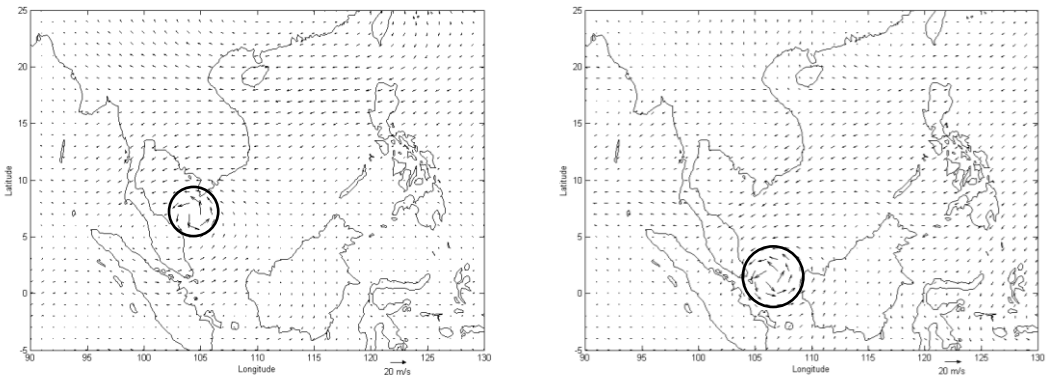
Table 4.7 Maximum winds from NOAA/NCEP and the corresponding maximum bogus winds at the initial time of simulation.

Typhoon	$V_h(R_{\max})$ (ms^{-1})	$V_{asym}(R_{\max},\theta)$ (ms^{-1})
GAY	7.86	17.52
VAMEI	8.17	18.96

Table 4.8 Maximum bogus wind speed after initialization.

Typhoon	$V_h(R_{\max})$ (ms^{-1})	$V_{asym}(R_{\max},\theta)$ (ms^{-1})
GAY	7.86	17.34
VAMEI	8.17	18.75

The initialized winds are shown in Figure 4.4. The circle represents the storm radius (200 km for GAY and 250 km for VAMEI)



(a) (b)

Figure 4.4 The initialized winds (ms^{-1}) of (a) GAY and (b) VAMEI with bogus winds (in the circles).

4.2.1 Typhoon GAY

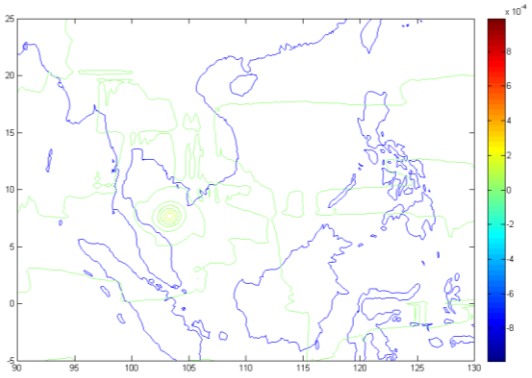
The simulated vorticity for every 6-hour interval from 01/11/1989 06UTC to 03/11/1989 00UTC with bogus wind are shown in Figure 4.5.

The values of simulated maximum vorticity with bogus wind from SILEPE model and maximum vorticity at 850 hPa computed from JTWC data are shown in Table 4.9.

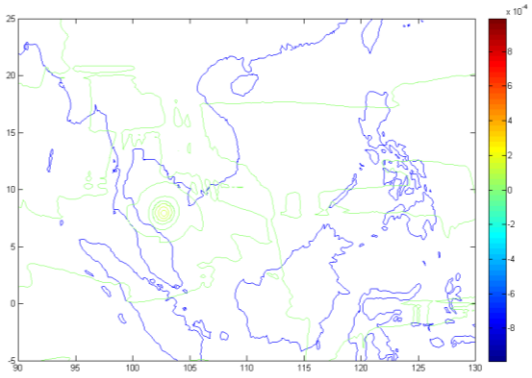
Table 4.9 The simulated maximum vorticity of typhoon GAY with bogus wind.

Date	Hour (UTC)	ζ_{JTWC} ($\times 10^{-4}$ s^{-1})	Type	ζ_{Model} ($\times 10^{-4}$ s^{-1})	Intensity
01/11/1989	00	2.01	Depression	2.32	Depression
01/11/1989	06	2.01	Depression	2.17	Depression
01/11/1989	12	2.01	Depression	1.98	Depression
01/11/1989	18	2.25	Depression	1.83	Depression
02/11/1989	00	2.46	Tropical Storm	1.72	Depression
02/11/1989	06	2.46	Tropical Storm	1.66	Depression
02/11/1989	12	2.46	Tropical Storm	1.68	Depression
02/11/1989	18	2.79	Tropical Storm	1.42	Depression
03/11/1989	00	4.26	Typhoon	1.21	Depression

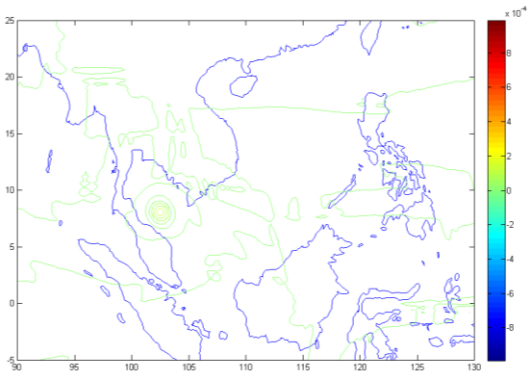
From Table 4.9, the values of simulated maximum vorticity with bogus wind from SILEPE model are still less than the values from JTWC data starting from the initial time (01/11/1989 06 UTC) and decreasing until the end of simulation. Thus, the vorticity with bogus wind from SILEPE model still cannot be used to analyze the formation of typhoon GAY.



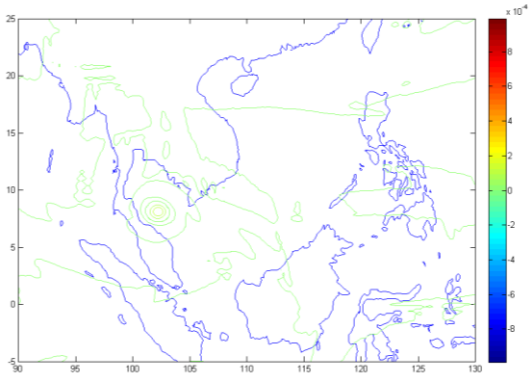
01/11/1989 06UTC



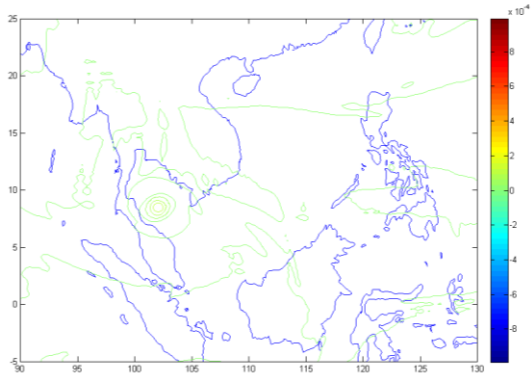
01/11/1989 12UTC



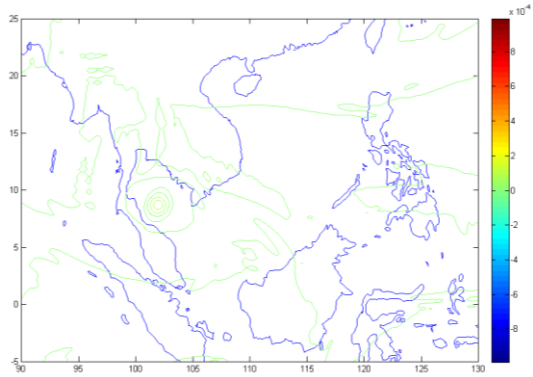
01/11/1989 18UTC



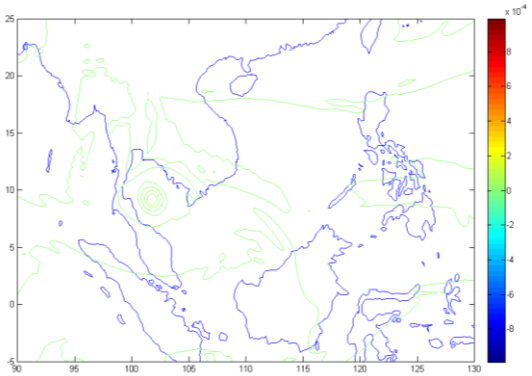
02/11/1989 00UTC



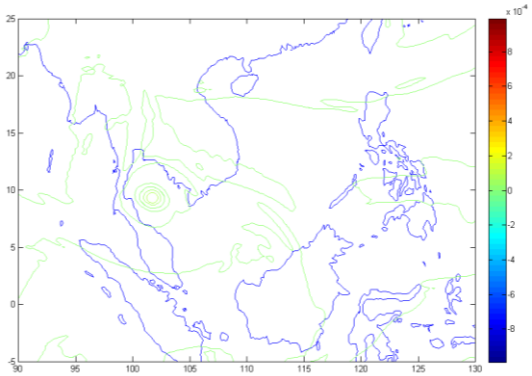
02/11/1989 06UTC



02/11/1989 12UTC



02/11/1989 18UTC

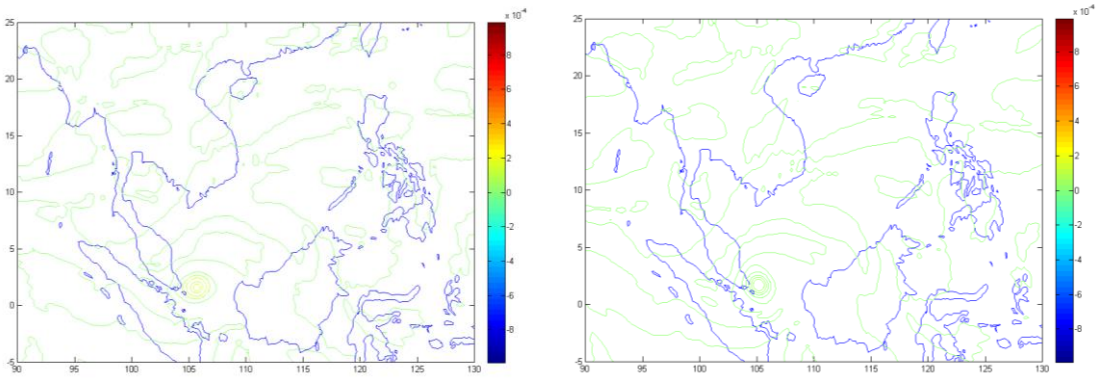


03/11/1989 00UTC

Figure 4.5 The simulated vorticity of typhoon GAY with bogus wind.

4.2.2 Typhoon VAMEI

The simulated vorticity for every 6-hour interval from 26/12/2001 18UTC to 27/12/2001 00UTC is shown in Figure 4.6.



26/12/2001 18UTC 27/12/2001 00UTC

Figure 4.6 The simulated vorticity of typhoon VAMEI with bogus wind.

The values of simulated maximum vorticity with bogus wind from SILEPE model and the maximum vorticity at 850 hPa computed from JTWC data are shown in Table 4.10.

Table 4.10 The simulated maximum vorticity of typhoon VAMEI with bogus wind.

Date	Hour (UTC)	ζ_{JTWC} ($\times 10^{-4}$ s^{-1})	Type	ζ_{Model} ($\times 10^{-4}$ s^{-1})	Intensity
26/12/2001	12	2.05	Depression	2.48	Tropical Storm
26/12/2001	18	2.43	Tropical Storm	2.13	Depression
27/12/2001	00	4.05	Typhoon	1.18	Depression

From Table 4.10, the values of simulated maximum vorticity with bogus wind from SILEPE model are still less than the values from JTWC data. Thus, the vorticity with bogus wind from SILEPE model still cannot be used to analyze formation of typhoon VAMEI.

4.3 Simulation with Bogus Wind and Enhancement of Northeast Monsoon Wind

The maximum vorticity obtained from the shallow water model with bogus wind is still weaker than maximum vorticity from JTWC, as shown in Tables 4.11 and 4.12 for GAY and VAMEI, respectively. This is due to the fact that the observed northeast monsoon winds used as initial conditions in the model are weaker than it should be because of inadequate observation. Thus, the northeast monsoon winds are enhanced before the simulations. The northeast monsoon wind speeds are enhanced based on the relationships between the values of maximum vorticity computed from JTWC wind data and from simulated winds by the shallow water model.

Table 4.11 The maximum vorticity of GAY from JTWC data (ζ_{JTWC}) and the maximum vorticity from shallow water model (ζ_{Model}).

Date	Hour (UTC)	ζ_{JTWC} ($\times 10^{-4}$ s^{-1})	ζ_{Model} ($\times 10^{-4}$ s^{-1})
01/11/1989	00	2.01	2.32
01/11/1989	06	2.01	2.17
01/11/1989	12	2.01	1.98
01/11/1989	18	2.25	1.83
02/11/1989	00	2.46	1.72
02/11/1989	06	2.46	1.66
02/11/1989	12	2.46	1.68
02/11/1989	18	2.79	1.42
03/11/1989	00	4.26	1.21

Table 4.12 The maximum vorticity of VAMEI from JTWC data (ζ_{JTWC}) and the maximum vorticity from shallow water model (ζ_{Model}).

Date	Hour (UTC)	ζ_{JTWC} ($\times 10^{-4}$ s^{-1})	ζ_{Model} ($\times 10^{-4}$ s^{-1})
26/12/2001	12	2.05	2.48
26/12/2001	18	2.43	2.13
27/12/2001	00	4.05	1.18

For GAY, from Table 4.11 the linear relation between ζ_{JTWC} and ζ_{Model} is

$$\zeta_{JTWC} = 2.33\zeta_{Model} \tag{4.1}$$

That is a = 2.33 in Eq. (3.10).

From Eq. (3.13), the enhanced northeast monsoon wind components (u_{Enh}, v_{Enh}) for GAY can be computed from

$$u_{Enh} = 2.33\, u_{Model} \tag{4.2a}$$

$$v_{Enh} = 2.33\, v_{Model} \tag{4.2b}$$

For VAMEI, from Table 4.12 the relation between ζ_{JTWC} and ζ_{Model} is

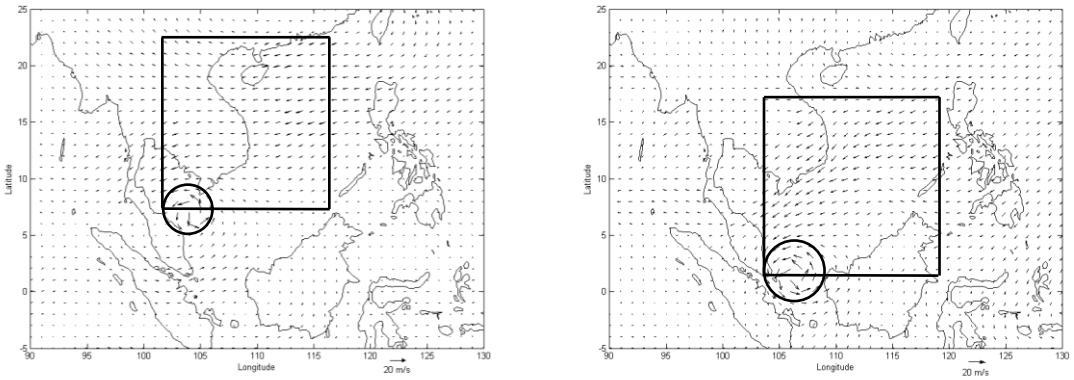
$$\zeta_{JTWC} = 2.44\zeta_{Model} \tag{4.3}$$

Similar to the case of GAY, the enhanced wind components for VAMEI are

$$u_{Enh} = 2.44\, u_{Model} \tag{4.4a}$$

$$v_{Enh} = 2.44\, v_{Model} \tag{4.4b}$$

Figures 4.7(a) and 4.7(b) are the initialized winds of GAY and VAMEI with bogus winds and enhanced northeast monsoon winds.



(a) (b)

Figure 4.7 Initialized winds (ms^{-1}) of (a) GAY and (b) VAMEI with bogus winds and enhanced northeast monsoon winds. The square area represents the area with enhanced northeast monsoon wind.

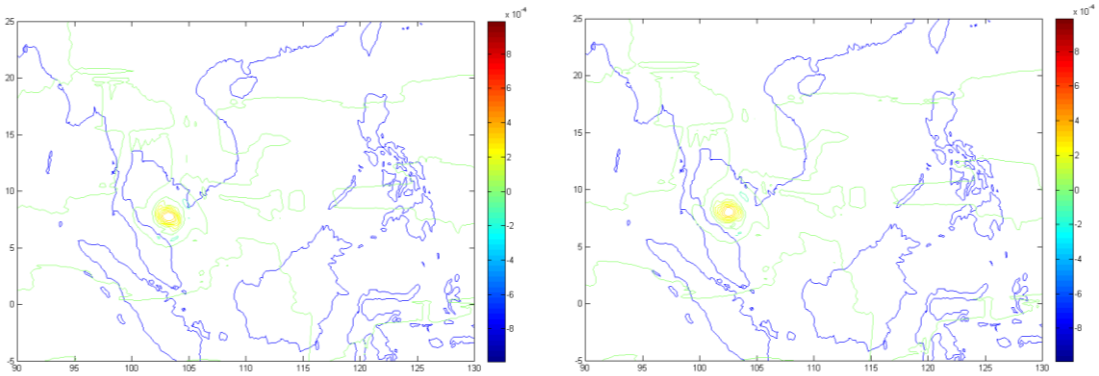
4.3.1 Simulation of GAY

The simulated vorticity of GAY for every 6-hour interval with enhanced northeast monsoon wind from 01/11/1989 06UTC to 03/11/1989 00UTC are shown in Figure 4.8 and Table 4.13.

Table 4.13 The simulated maximum vorticity of GAY with bogus wind and enhanced northeast monsoon wind.

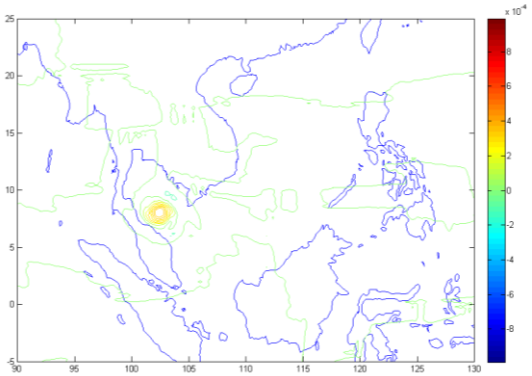
Date	Hour (UTC)	ζ_{JTWC} ($\times 10^{-4}$ s^{-1})	Type	$\zeta_{Simulated}$ ($\times 10^{-4}$ s^{-1})	Intensity
01/11/1989	00	2.01	Depression	2.73	Tropical Storm
01/11/1989	06	2.01	Depression	2.81	Tropical Storm
01/11/1989	12	2.01	Depression	2.95	Tropical Storm
01/11/1989	18	2.25	Depression	3.19	Tropical Storm
02/11/1989	00	2.46	Tropical Storm	3.38	Tropical Storm
02/11/1989	06	2.46	Tropical Storm	3.57	Tropical Storm
02/11/1989	12	2.46	Tropical Storm	3.74	Tropical Storm
02/11/1989	18	2.79	Tropical Storm	3.91	Tropical Storm
03/11/1989	00	4.26	Typhoon	4.71	Typhoon

In Table 4.13, the intensity of the simulated maximum vorticity is classified according to that of JTWC. From Table 4.13, between 02/11/1989 18UTC and 03/11/1989 00UTC the intensity of GAY is transformed from tropical storm to typhoon. In order to see when GAY is intensified into typhoon, the simulated vorticity for every 1-hour interval are shown in Figure 4.9 and Table 4.14.

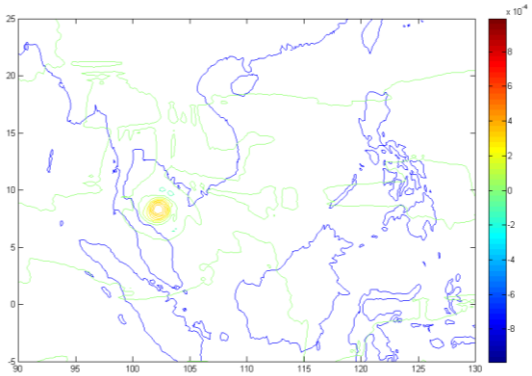


01/11/1989 06UTC

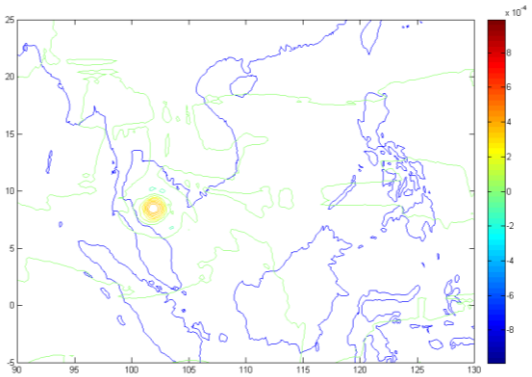
01/11/1989 12UTC



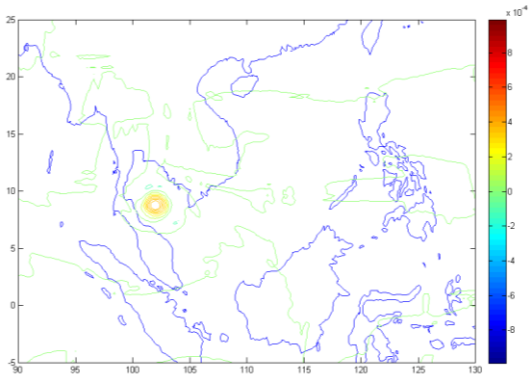
01/11/1989 18UTC



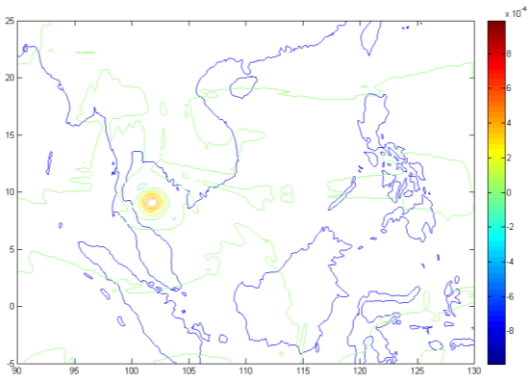
02/11/1989 00UTC



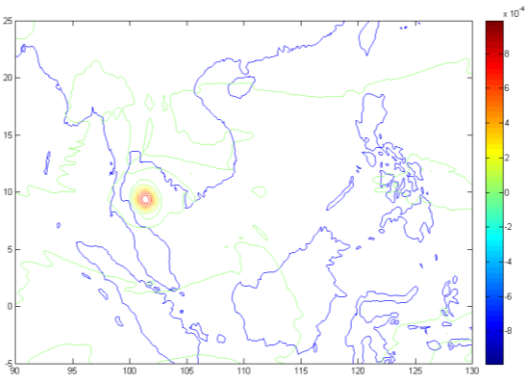
02/11/1989 06UTC



02/11/1989 12UTC

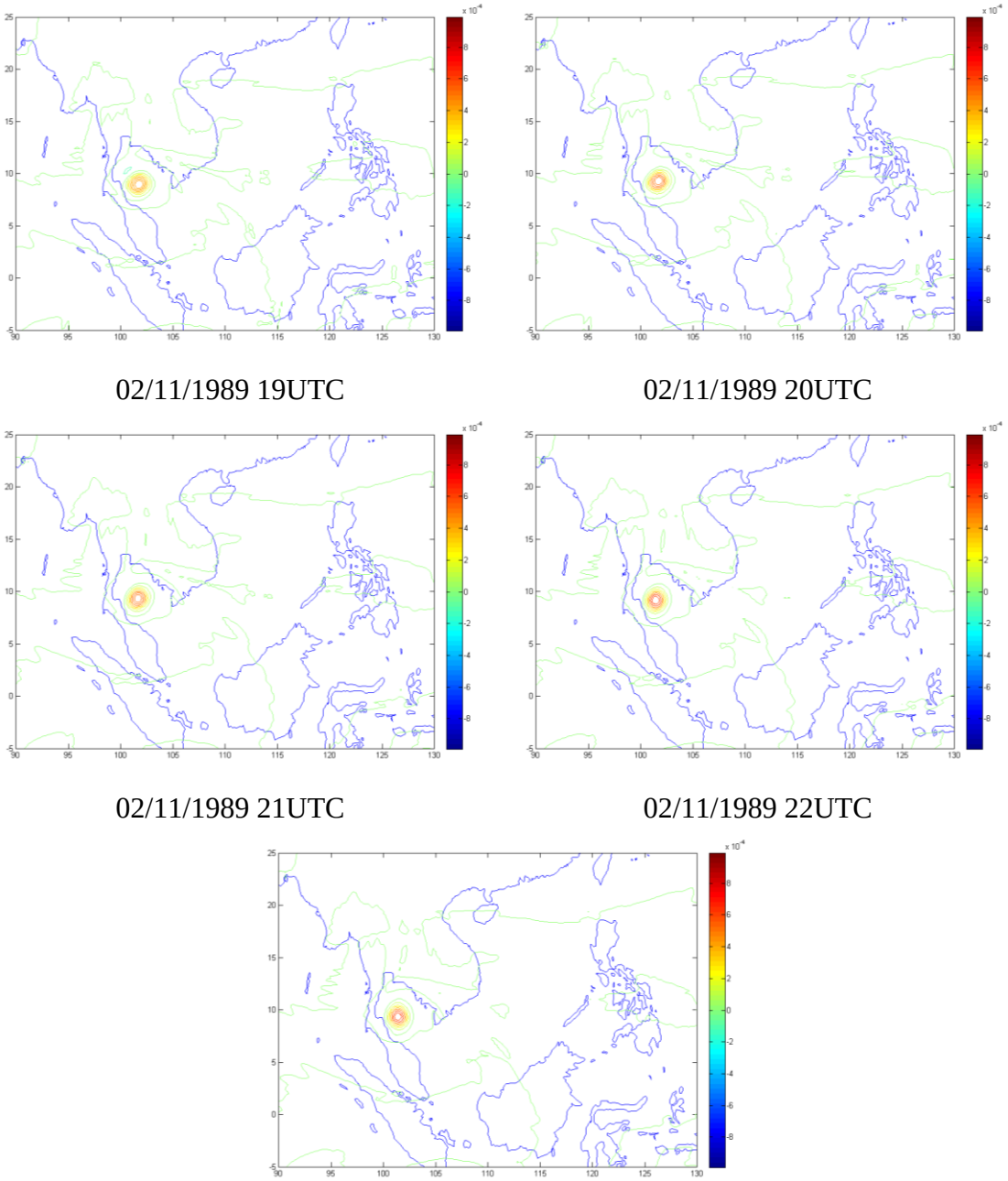


02/11/1989 18UTC



03/11/1989 00UTC

Figure 4.8 The simulated vorticity of GAY with bogus wind and enhanced northeast monsoon wind.



02/11/1989 19UTC

02/11/1989 20UTC

02/11/1989 21UTC

02/11/1989 22UTC

02/11/1989 23UTC

Figure 4.9 The simulated vorticity of GAY for every 1-hour interval.

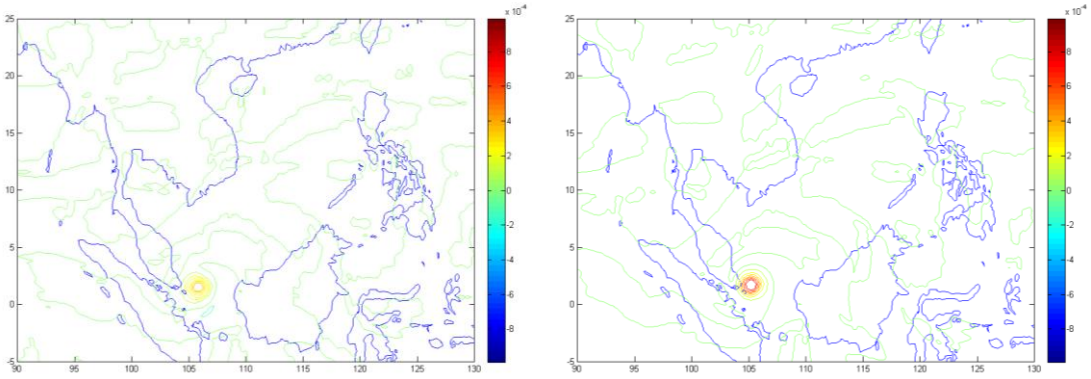
Table 4.14 The simulated maximum vorticity of GAY with bogus wind and enhanced northeast monsoon wind for every 1-hour interval.

Date	Hour (UTC)	$\zeta_{Simulated}$ ($\times 10^{-4}$ s^{-1})	Intensity
02/11/1989	19	4.05	Tropical Storm
02/11/1989	20	4.29	Typhoon
02/11/1989	21	4.38	Typhoon
02/11/1989	22	4.47	Typhoon
02/11/1989	23	4.58	Typhoon

From Table 4.14, the simulated maximum vorticity from 02/11/1989 20UTC onward is more than that of JTWC data in Table 4.11 (4.26×10^{-4} s^{-1}).

4.3.2 Simulation of VAMEI

The simulated vorticity of VAMEI for every 6-hour interval with enhanced northeast monsoon wind from 26/12/2001 18UTC to 27/12/2001 00UTC are shown in Figure 4.11 and Table 4.15. The simulation for every 1-hour interval is shown in Figure 4.11 and Table 4.16.



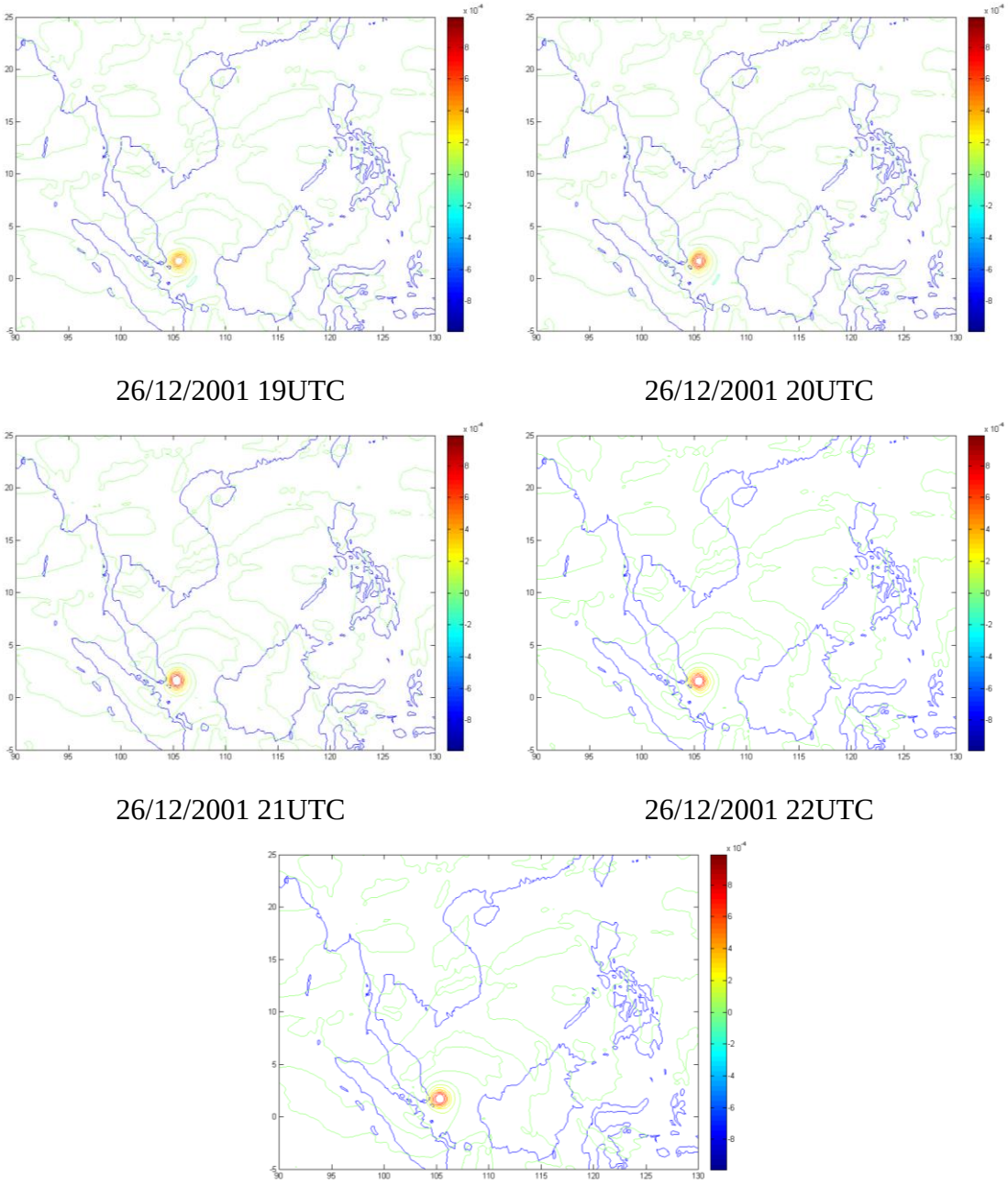
26/12/2001 18UTC 27/12/2001 00UTC

Figure 4.10 The simulated vorticity of VAMEI with bogus wind and enhanced northeast monsoon wind.

Table 4.15 The maximum vorticity of VAMEI with bogus wind and enhanced northeast monsoon wind.

Date	Hour (UTC)	ζ_{JTWC} ($\times10^{-4}$ s^{-1})	Type	$\zeta_{Simulated}$ ($\times10^{-4}$ s^{-1})	Intensity
2001/12/26	12	2.05	Depression	2.83	Tropical Storm
2001/12/26	18	2.43	Tropical Storm	3.45	Tropical Storm
2001/12/27	00	4.05	Typhoon	4.67	Typhoon

In Table 4.15, the intensity of the simulated maximum vorticity is classified according to that of JTWC. From Table 4.15, between 26/12/2001 18UTC and 27/12/2001 00UTC the intensity of VAMEI is transformed from tropical storm to typhoon. In order to see when VAMEI is intensified into typhoon, the simulated vorticity for every 1-hour interval are shown in Figure 4.11 and Table 4.16.



26/12/2001 19UTC

26/12/2001 20UTC

26/12/2001 21UTC

26/12/2001 22UTC

26/12/2001 23UTC

Figure 4.11 The simulated vorticity of VAMEI for every 1-hour interval.

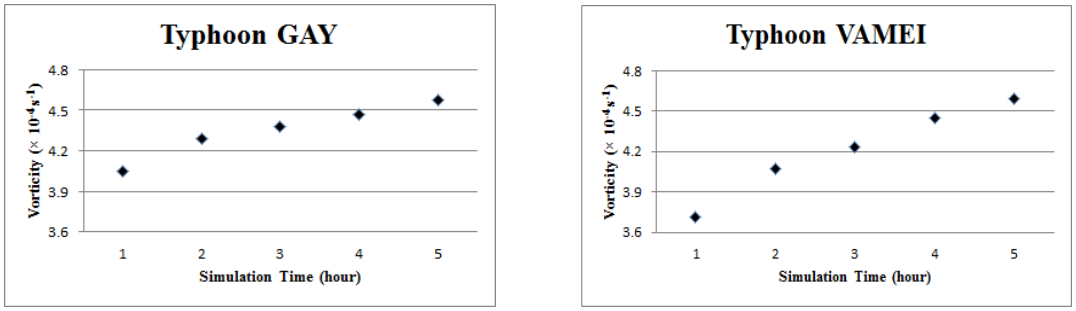
Table 4.16 The simulated maximum vorticity of VAMEI with bogus wind and enhanced northeast monsoon wind for every 1-hour interval.

Date	Hour (UTC)	$\zeta_{Simulated}$ ($\times 10^{-4}$ s^{-1})	Intensity
2001/12/26	19	3.71	Tropical Storm
2001/12/26	20	4.07	Typhoon
2001/12/26	21	4.23	Typhoon
2001/12/26	22	4.45	Typhoon
2001/12/26	23	4.59	Typhoon

From Table 4.16, the simulated maximum vorticity from 26/12/2001 20UTC onward is more than that of JTWC data in Table 4.12 (4.05×10^{-4} s^{-1}).

4.4 Storm Intensification

The simulated maximum vorticity during the development from tropical storm to typhoon for GAY in Table 4.14 from 02/11/1989 19UTC to 23UTC and Table 4.16 for VAMEI from 26/12/2001 19UTC to 23UTC are plotted with respect to time in Figure 4.12 The plots suggest straight-line relationship between vorticity intensification and time (t).



(a) (b)

Figure 4.12 Simulated maximum vorticity of (a) GAY and (b) VAMEI as plotted with respect to time.

The following linear regression equations are obtained from Tables 4.14 and 4.16

$$\zeta_{GAY} = 3.982+0.124t \quad (4.5)$$

$$\zeta_{VAMEI} = 3.568+0.214t \quad (4.6)$$

From these two equations, vorticity intensification of VAMEI, as represented by the coefficient of t, is more than that of GAY. That is VAMEI is intensified faster than GAY.

Another investigation to see the effect of northeast monsoon wind in the intensification of GAY and VAMEI from tropical storm to typhoon is done by compare with the development of typhoons CHANTHU (0405) and MUIFA (0425). The study period for CHANTHU is between 11/06/2004 12UTC to 12/06/2004 06UTC and for MUIFA is between 20/11/2004 18UTC to 21/11/2004 12UTC. CHANTHU and MUIFA are intensified from tropical storm to typhoon over the Pacific Ocean which is not influenced by northeast monsoon wind.

The linear regression between time and vorticity computed from JTWC data for the 4 typhoons are shown in Eqs. 4.7-4.10

$$\zeta_{GAY\,(JTWC)} = 2.133+0.096t \quad (4.7)$$

$$\zeta_{VAMEI\,(JTWC)} = 2.143+0.117t \quad (4.8)$$

$$\zeta_{CHANTHU\,(JTWC)} = 2.301+0.093t \quad (4.9)$$

$$\zeta_{MUIFA\,(JTWC)} = 3.151+0.068t \quad (4.10)$$

It can be seen from Eqs. 4.7-4.10 that intensification of GAY and VAMEI are faster that those of CHANTHU and MUIFA. This is due to the northeast monsoon wind in the Gulf of Thailand that accelerates the vorticity intensification of GAY and VAMEI.