CHAPTER 3 METHODOLOGY

3.1 Experiment Cases

The asymmetric wind model (AWM) is used to enhance the weak observed wind speeds. Typhoon GAY (8929) and VAMEI (0126) are used as the study cases because they are the only tropical cyclones with typhoon intensity that developed in the Gulf of Thailand. The experiment cases are shown in Table 3.1.

Table 3.1 Experiment cases.

Year	Name of Tropical cyclone	International Number ID	Initial Time of Simulation	Ending Time of Simulation
1989	GAY	8929	01/11/1989 00 UTC	03/11/1989 00 UTC
2001	VAMEI	0126	26/12/2001 12 UTC	27/12/2001 00 UTC

Information of these tropical cyclones is obtained from the Joint Typhoon Warning Center (JTWC, 2012).

The data used as the initial conditions for simulation with the shallow water model are obtained from the National Oceanic and Atmospheric Administration (NOAA) (NOAA, 2012) for typhoon GAY, and from the National Center for Environmental Prediction (NCEP) (NCEP, 2012) for typhoon VAMEI. The zonal wind component (u), meridional wind component (v) and geopotential height (Φ), at 850 hPa are used as the initial conditions for the shallow water model. The information on the position, maximum wind speed and intensity of the storms for the experiment cases from JTWC are shown in Tables 3.2 and 3.3.

Table 3.2 Information of typhoon GAY (8929) (JTWC, 2012).

Date	Hour (UTC)	Latitude (degree N)	Longitude (degree E)	Maximum Wind Speed (ms^{-1})	Intensity
01/11/1989	00	7.1	103.7	12.86	Depression
01/11/1989	06	7.7	103.1	12.86	Depression
01/11/1989	12	8.0	102.6	12.86	Depression
01/11/1989	18	8.1	102.4	15.43	Depression
02/11/1989	00	8.2	102.2	18.01	Tropical Storm
02/11/1989	06	8.3	102.0	18.01	Tropical Storm
02/11/1989	12	8.7	101.9	18.01	Tropical Storm
02/11/1989	18	9.1	101.8	23.15	Tropical Storm
03/11/1989	00	9.3	101.5	33.44	Typhoon

Table 3.3 Information of typhoon VAMEI (0126) (JTWC, 2012).

Date	Hour (UTC)	Latitude (degree N)	Longitude (degree E)	Maximum Wind Speed (ms^{-1})	Intensity
26/12/2001	12	1.4	106.5	12.86	Depression
26/12/2001	18	1.5	105.8	18.01	Tropical Storm
27/12/2001	00	1.5	105.1	33.44	Typhoon

3.2 Single Level Primitive Equation Model

The single level primitive equation (SILEPE) model is used in this thesis. The model is based on the shallow water model as discussed Section 2.3. This model consists of the specification of grid structure, time integration scheme, advection scheme, boundary condition and initial field. The model uses the set of Eqs. (2.25)-(2.27) as its framework. It is a semi-Lagrangian, explicit time scheme, shallow water model. The simulation equations has the zonal and meridional components of the wind (*u* and *v*) and the geopotential height (Φ) as the predicted variables (Krishnamurti, 1986).

From the equations of motion in Eqs. (2.22)-(2.25), assume non-divergent flow, given a velocity field $\vec{V}$, let $\vec{V}_\psi$ be the non-divergent part and $\vec{V}_\lambda$ the divergent part, then

$$\vec{V} = \vec{V}_\psi + \vec{V}_\chi \tag{3.1}$$

This implies

$$\vec{\nabla} \cdot \vec{V}_\psi = 0 \text{ and } \vec{\nabla} \times \vec{V}_\psi = 0 \tag{3.2}$$

For two dimensional velocity field, $\vec{V}_H$, the non-divergent part of the flow is represented in terms of a scalar stream function ψ. In Cartesian coordinates,

$$u = -\frac{\partial \psi}{\partial y} \text{ and } v = \frac{\partial \psi}{\partial x} \tag{3.3}$$

Thus the vorticity ζ can be written as

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \tag{3.4}$$

or

$$\zeta = \nabla^2 \psi$$

Differentiate Eq. (2.22) by $\frac{\partial}{\partial x}$ and Eq. (2.23) by $\frac{\partial}{\partial y}$ and take the sum of these two equations, the equation after scaling is

$$\nabla^2 g\Phi = \vec{\nabla} \bullet f\vec{\nabla}\psi + 2J\left(\frac{\partial \psi}{\partial x}, \frac{\partial \psi}{\partial y}\right) \tag{3.5}$$

where $J\left(\frac{\partial \psi}{\partial x}, \frac{\partial \psi}{\partial y}\right)$ is the Jacobian.

Eq. (3.5) is used in the initialization for adjust the relations between wind field and geopotential to satisfy the assumption in SILEPE model (Krishnamurti, 1986).

3.3 SILEPE Model Setting

The model is run with the initial data from the National Oceanic and Atmospheric Administration (NOAA, 2012) for typhoon GAY and the National Center for Environmental Prediction (NCEP, 2012) for typhoon VAMEI. The experiment setting is shown in Table 3.4.

Table 3.4 The experiment setting.

Model Domain	Latitude: 20°*S* to 60°*N* and Longitude:180°*W* to 180°*E*
Study Domain	Latitude: 5°*S* to 25°*N* and Longitude: 90°*E* to 130°*E*
Model Resolution	$\Delta x = \Delta y = 0.2°$ in longitude, latitude and Δt=10*S*
Initial Data	GAY: National Oceanic and Atmospheric Administration (NOAA) data on 01/11/1989 00UTC, 850 hPa VAMEI: National Centers for Environmental Prediction (NCEP) data on 26/12/2001 12UTC, 850 hPa
Boundary Condition	Cyclic in the west-east boundary Open in the north-south boundary

The model domain covers the area between longitudes 180°*W* to 180°*E* to satisfy the cyclic boundary condition, and between latitudes 20°*S* to 60°*N* to reduce errors at the north and south boundaries as shown in Figure 3.1.

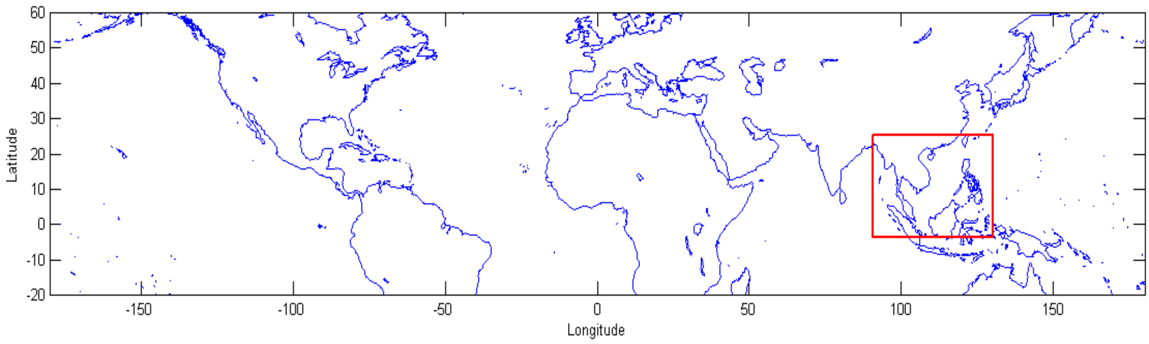

Figure 3.1 Model domain and the study domain (small red rectangular).

However, the study domain covers only the area between longitudes 90°*E* to 130°*E* and latitudes 5°*S* to 25°*N* as shown in Figure 3.2.

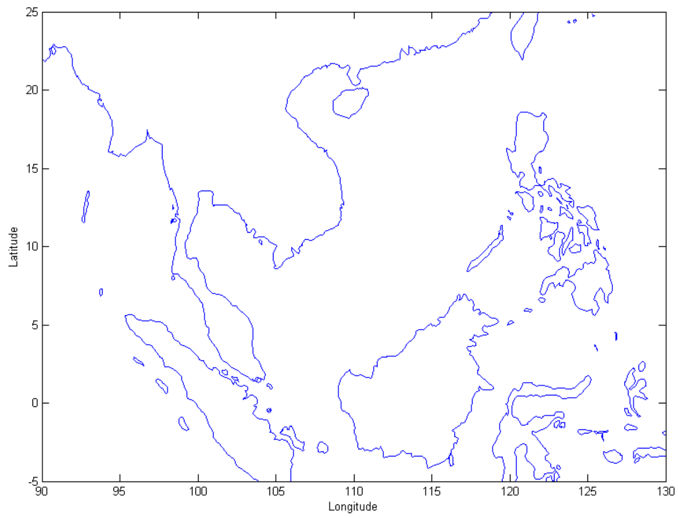

Figure 3.2 The study domain.

3.4 Step of the Vorticity Simulation

The steps for the simulation of tropical cyclones development are as follows.

Step 1: Preparing the initial condition

- Download the data files from NOAA/NCEP.
- Unzip the data files (.txt) and (.tar) to get data of u, v and Φ at 850 hPa with 2.5×2.5 degree resolution (NOAA) and 1×1 degree resolution (NCEP).
- Interpolated initial data of NOAA from 2.5×2.5 degree resolution and NCEP from 1×1 degree resolution to 0.2×0.2 degree resolution.

Therefore, the data from NOAA for the model domain which contains 32×144 grid points with 2.5×2.5 degree resolution and the data from NCEP for the model domain which contains 80×360 grid points with 1×1 degree resolution, are interpolated to 400×1800 grid points with 0.2×0.2 degree resolution.

Step 2: Generate bogus wind by the asymmetric wind model (AWM) in Eq. (2.12) using input data from JTWC.

- Input the following values

  air density $\rho = 1.15\,\text{kgm}^{-3}$

  mean earth radius $a = 6378\times10^3\,\text{m}$

  maximum wind speed $V_{\max}$ (ms^{-1})

  latitude, longitude of the storm center 6 hours before the initial time (lat1, lon1)

  latitude, longitude of the storm center at the initial time (lat2, lon2)

  central pressure p_{center} (hPa)

  environmental pressure p_{env} (hPa)

  radius of maximum wind speed $R_{\max}$ (m)
- Calculate the asymmetric wind speed (V_{asym}) by Eq. (2.12) and the direction of the asymmetric wind vector.
- Calculate the x-component and y-component of the asymmetric wind.
- Insert the bogus wind obtained from AWM into the interpolated initial data.

Step 3: Enhance northeast monsoon wind in the area 15 degrees along the latitude and longitude from the center of the storm. The northeast monsoon wind is defined as wind with direction between 22.5 degree to 67.5 degree as shown in Table 2.1.

Step 4: Initialize the data obtained from Step 2 by SILEPE model to adjust the relations between wind field (u and v) and geopotential height (Φ) to satisfy the assumption in the SILEPE model.

Step 5: Use the data obtained from Step 3 as the initial condition for SILEPE model.

Step 6: Determine the wind fileds of GAY and VAMEI by using the simulation outputs of SILEPE model for 48 hours and 12 hours, respectively.

Step 7: Compute vorticity of GAY and VAMEI from the results of Step 6 (ζ_{Model}) using Eq. (2.31).

A cyclic boundary condition is assumed in the west-east direction of the model domain. Let nx be the last grid point along the x-axis and my the last grid point along the y-axis. Vorticity along the western (i=1) and eastern (i=nx) boundaries of the model domain are computed from

$$\zeta_{1,j} = \left[\frac{v_{2,j} - v_{nx-1,j}}{2\Delta x}\right] - \left[\frac{u_{1,j+1} - u_{1,j-1}}{2\Delta y}\right] \tag{3.6}$$

and

$$\zeta_{nx,j} = \zeta_{1,j} \tag{3.7}$$

The values of vorticity at the northern and the southern boundaries are obtained through linear extrapolation. At the corners of the domain it is assumed that

$$\zeta_{nx,1} = \zeta_{1,1} \tag{3.8}$$

$$\zeta_{nx,my} = \zeta_{1,my} \tag{3.9}$$

The steps of simulation can be summarized as follows.

First, the grid data from NOAA/NCEP are interpolated to the model resolution (0.2×0.2 degree) before being used in the shallow water model. The bogus wind from the asymmetric wind model, Eq. (2.12), is then inserted at the storm position to replace the unrealistically weak observed wind of the storm. In addition, the northeast monsoon wind is also enhanced to better represent the strong wind of the monsoon. This enhancement is based on the analyzed vorticity from the observed wind of JTWC. The rest of the procedure for the experiments are the standard steps of the shallow water model, which includes initialization using Eq. (3.5) to ensure the balance between wind and geopotential fields. The final output of the simulation is the vorticity of the storm.

The maximum vorticity from JTWC data is computed from Eq. (2.31) using the values of u and v at the radial of maximum wind. It is assumed that at the radial of maximum wind, the wind around the center of the storm is anti-symmetric and $|u| = |v|$ as shown in Figure 3.3 where $u = U$ and $v = V$.

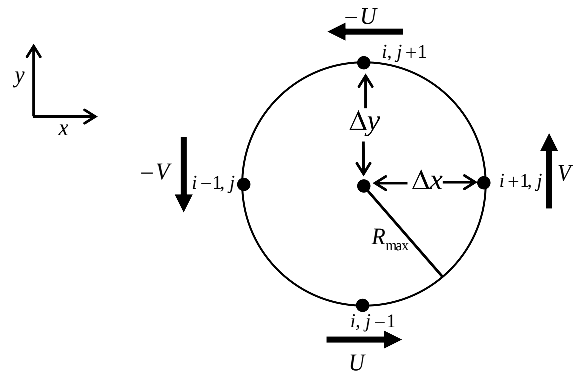

Figure 3.3 Wind directions and speeds from JTWC data at the radius of maximum wind, R_{max}.

However, the maximum vorticity computed from JTWC maximum wind is at the surface while the maximum vorticity from SILEPE is at 850 hPa. Thus, the maximum vorticity at 850 hPa from SILEPE has to be adjusted to the maximum vorticity at the surface to account for the increase in wind speed with height. Wind data from NOAA / NCEP show that the vorticity at 850 hPa is about 1.5 times of the vorticity at the surface. Thus, the maximum vorticity at the surface from JTWC (ζ_{JTWC}) is compared with $\zeta_{SILEPE}/1.5$.

3.5 Enhancement of Northeast Monsoon Wind

Typhoons GAY and VAMEI intensified rapidly due to strong northeast monsoon. To include the effect in the simulations by SILEPE model, northeast monsoon winds at the initial times of simulations are enhanced. This is done to improve the weak observed monsoon wind in NOAA / NCEP data. The northeast monsoon wind speeds are enhanced based on the relationships between the values of vorticity computed from JTWC wind data and from simulated winds by SILEPE model.

The area of enhanced northeast monsoon wind covers 15 degrees along the latitude and longitude as shown in Figure 3.4. Only the winds with directions between 22.5 degree to 67.5 degree in this area are enhanced.

For tropical cyclone, if the relation between ζ_{JTWC} and ζ_{Model} (a) is

$$\zeta_{JTWC} = a\zeta_{Model} \tag{3.10}$$

where a is the constant obtained from linear regression.

Then, from Eq. (2.31)

$$\left(\left[\frac{v_{i+1,j} - v_{i-1,j}}{2\Delta x}\right] - \left[\frac{u_{i,j+1} - u_{i,j-1}}{2\Delta y}\right]\right)_{JTWC} = a\left(\left[\frac{v_{i+1,j} - v_{i-1,j}}{2\Delta x}\right] - \left[\frac{u_{i,j+1} - u_{i,j-1}}{2\Delta y}\right]\right)_{Model} \tag{3.11a}$$

From Eq. (3.11a) and Figure 3.3

$$\left(\left[\frac{V-(-V)}{2\Delta x}\right]-\left[\frac{(-U)-U}{2\Delta y}\right]\right)_{JTWC} = a\left(\left[\frac{V-(-V)}{2\Delta x}\right]-\left[\frac{(-U)-U}{2\Delta y}\right]\right)_{Model} \quad (3.11b)$$

Assume that $\Delta x = \Delta y$, Eq. (3.11b) becomes

$$(2U-[-2U])_{JTWC} = a(2U-[-2U])_{Model} \quad (3.11c)$$

$$U_{JTWC} = aU_{Model} \quad (3.12)$$

The enhanced wind speeds (U_{Enh}) is then defined as

$$U_{Enh} = aU_{Model} \quad (3.13)$$

within the square area of the storm as shown in Figure 3.4.

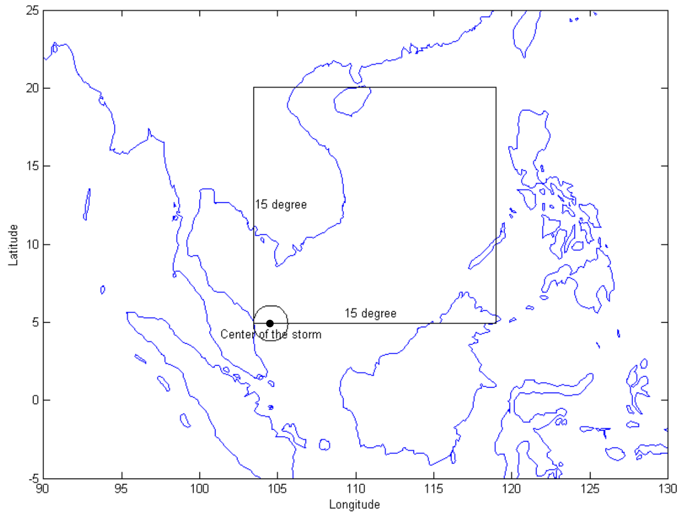

Figure 3.4 The area with enhanced northeast monsoon wind.

The steps for the simulation are shown in Figure 3.5.

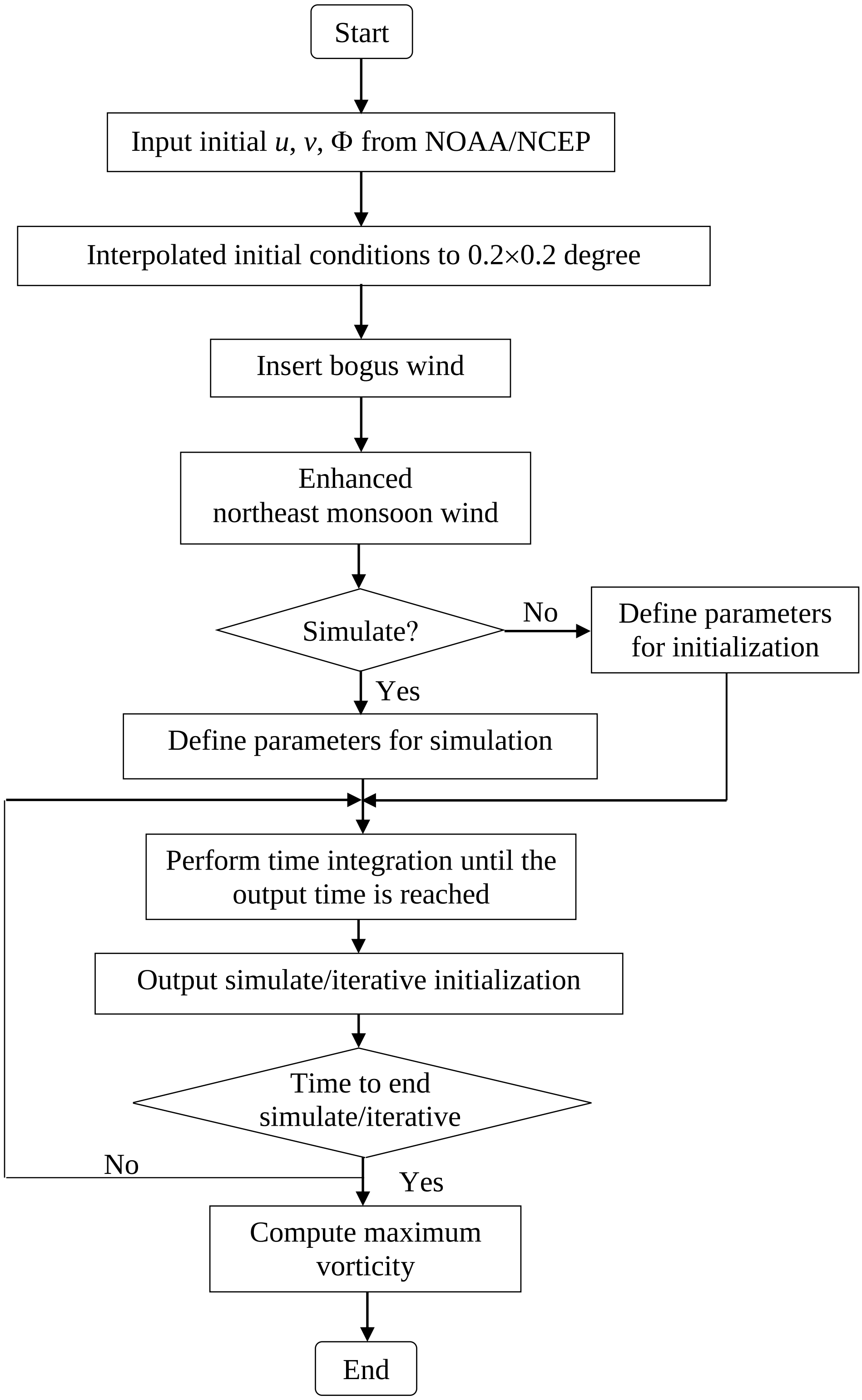

Figure 3.5 Flow chart showing the steps of simulation.