

CHAPTER 3 METHODOLOGY

3.1 Severe Thunderstorm Cases

Severe thunderstorm cases for this research are selected based on severe weather reports over Thailand from the Thai Meteorological Department. Severe thunderstorms are accompanied by heavy rain, gusty wind and sometimes hail.

The severe thunderstorm reports for the years 2002 and 2003 from the Thai Meteorological Department are summarized in Tables 3.1 and 3.2.

Table 3.1 Severe thunderstorm events for the year 2002 as reported by the Thai Meteorological Department (Saerour, 2004).

Event Description	Location	Date
Thunderstorm & Gusty winds & Hail	Khon Khen, Sakonnakorn	17 Mar 02
Thunderstorm & Gusty winds	Loei, Mahasarakham	22 Mar 02
Thunderstorm & Gusty winds	Mahasarakham	24 Mar 02
Thunderstorm & Gusty winds	Kalasin	26 Mar 02
Hail	Nakhon Phanom	3 Apr 02
Flash Flood	Nakhon Phanom	10 Jul 02
Gusty winds	Loei	11 Jul 02
Flash Flood	Nong Khai	30 Jul 02

Table 3.2 Severe thunderstorm events for the year 2003 as reported by the Thai Meteorological Department (Saerour, 2004).

Event Description	Location	Date
Thunderstorm & Gusty winds & Hail	Buri Ram	20 Mar 03
Gusty winds	Loei	24 Mar 03
Thunderstorm with gust	Kalasin	10 Apr 03
Hail	Nakhon Ratchasima	
Thunderstorm & Gust	Nong Khai, Udon Thani, Kalasin, Nakhon Phanom	18 Apr 03
Hail	Maha Sarakham	21 Apr 03
Thunderstorm & Gusty winds	Roi Et	24 Apr 03
Thunderstorm & Gusty winds	Kalasin	26 Apr 03
Thunderstorm & Gusty winds	Nakhon Ratchasima	29 Apr 03

Additional reports on damages from severe thunderstorms for the years 1996-2003 from the Ministry of Interior are shown in Table 3.3.

Table 3.3 Damages from severe thunderstorms for the years 1996-2003 as reported by the Ministry of Interior (Saerour, 2004).

Event Description	Damage	Location	Date
Thunderstorm, Gusty wind & Hail	118 houses, 2 injured	Loei	24 Mar 96
	80 houses	Kalasin	
Thunderstorm, Gusty wind & Hail	113 houses destroyed 2 injured	Loei	25 Mar 96
	114 houses	Sakon Nakhon	
Thunderstorm & Hail	355 houses, 2000 injure	Nong Bua Lam Phu	28 Mar 96
Thunderstorm & Hail	≈ 200,000 baths	Chaiyaphum	11 Apr 96
Severe Thunderstorm, Gusty wind & Hail	47 houses	Kalasin	13 Mar 97
	24 houses	Nakhon Phanom	
	50 houses	Nakhon Ratchasima	
	150 houses, 3 temples, 3 schools	Udon Thani	
Thunderstorm, Gusty wind & Hail	200 houses, I dead	Nakhon Phanom	14 Mar 97
Thunderstorm, Gusty wind & Hail	Trees overthrown	Mukdahan	01 Apr 97
Severe Thunderstorm & Hail	20 houses	Nakhon Ratchasima	06 Apr 97
Severe Thunderstorm, Gusty wind & Hail	≈ 10,000,000 baths. Electricity poles overthrown.	Nakhon Phanom	07 Apr 97
	230 houses, I schools 2 electricity poles	Loei	
Severe Thunderstorm & Hail	30 houses, I dead 5 injured	Nakhon Ratchasima	23 Apr 97
Thunderstorm & Hail	Trees overthrow Housetop damaged	Khon Kaen	03 Mar 98
Thunderstorm & Hail	170 houses	Maha Sarakham	03 Mar 99

Table 3.3 (Cont.).

Event Description	Damage	Location	Date
Thunderstorm, Gusty wind & Hail	155 houses Fire 7 housed	Udon Thani	15 Mar 99
Thunderstorm, Gusty wind & Hail	400 houses	Si Sa Ket	12 Apr 01
Thunderstorm & Hail	25 houses 21 farming areas	Loei	13 Jan 02
Thunderstorm, Gusty wind & Hail	50 houses Trees overthrown	Si Sa Ket	17 Mar 02
	City Hall >100 trees overthrown	Sakon Nakhon	
	50 houses > 200 trees overthrown	Nong Khai	
Thunderstorm, Gusty wind & Hail	85 houses, 1 temple, 3 schools, 1 dead	Surin	30 Mar 02
Thunderstorm, Gusty wind & Hail	118 house	Amnat Charoen	31 Mar 02
Thunderstorm, Gusty wind & Hail	44 house	vakhon Ratchasima	02 Apr 02
Severe Thunderstorm & Hail	100 houses, 1 cattle farm	Amnat Charoen	17 Apr 02
Thunderstorm & Hail	205 houses, 4 mills Electricity poles overthrown	Amnat Charoen	23 Apr 02
Thunderstorm & Hail	305 houses	Kalasin	29 Apr 02
Thunderstorm, Gusty wind & Hail	-	Loei	20 Apr 03

3.2 Steps of Fractal Dimension Approximation

Steps for fractal dimension approximation of thunderstorm clouds from satellite images by the area-perimeter method can be summarized as follows.

- Step 1. Download the selected satellites images from the web site of Kochi University at weather.is.kochi-u.ac.jp/archive-e.html.
- Step 2. Crop the image of selected cloud in satellite image. The cloud image shows the value of cloud top temperature. The cloud top temperature of $\leq -40^{\circ}\text{C}$ is defined as thunderstorm cloud (Pilotfriend, 2013).
- Step 3. Change the gray level image into black (no cloud) and white (thunderstorm cloud) image so that thunderstorm cloud can be isolated.
- Step 4. Compute the area of the cloud.
- Step 5. Compute the perimeter of the cloud.
- Step 6. Change the reduction factor r (resolution) and repeat Steps 4 to 6 for several times.
- Step 7. The results of perimeter (P) and associated area (A) with various values of reduction factor are used to find the linear regression between $\log A$ versus $\log P$. The coefficient in the regression is the fractal dimension.

Steps 1 to 5 are explained in details in the following sections.

3.2.1 Step 1

Download the selected satellites images from the web site of Kochi University at weather.is.kochi-u.ac.jp/archive-e.html, These images are in the Geo-coordinate mapped data between latitudes $70^{\circ}\text{N} - 20^{\circ}\text{S}$, longitudes $70^{\circ}\text{E} - 160^{\circ}\text{E}$, with $1/20$ degree resolution, 1800×1800 pixels in PGM (Portable Gray Map) format with Gzip compression (Kochi University, 2002). The satellite image for 10 April, 2003 at 11 UTC is show in Figure 3.1 as an example.

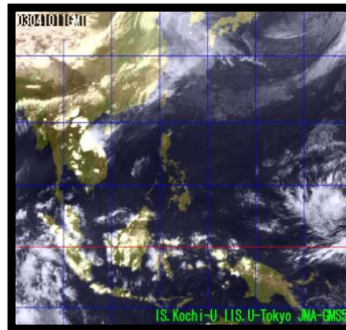


Figure 3.1 Satellite image GMS503041011IR1.pgm.

3.3.2 Step 2

From the original area of the downloaded image (Figure 3.2), the thunderstorm cloud is identified from cloud top temperature $\leq -40^{\circ}\text{C}$. Then the smallest area that covers the selected cloud is used for cropping of the original image into the required image size. An example of a cropped area is shown in Figure 3.3 using Thailand as the desired cropped area.

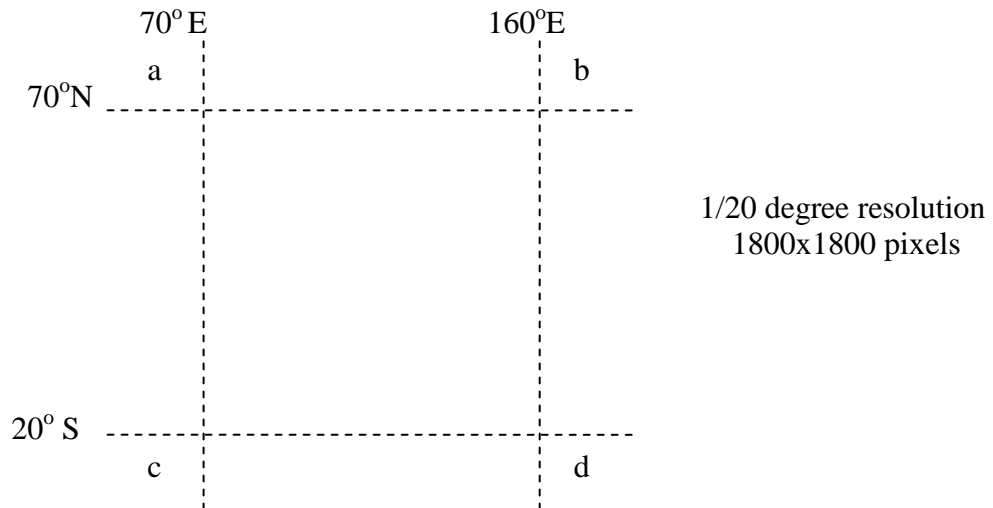


Figure 3.2 Original area of downloaded GMS-5 image (Saerour, 2004).

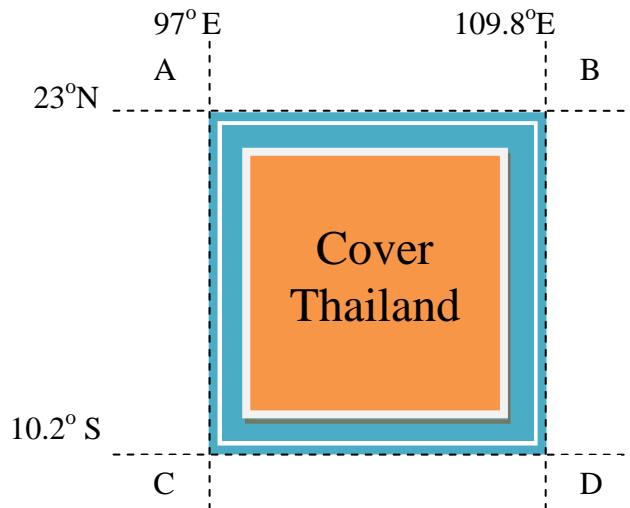


Figure 3.3 Cropped area over Thailand.

To crop over Thailand portion from the whole image, four specific coordinates close to Thai border are chosen and listed as positions A, B, C and D. Their respective coordinates are: A (97°E , 23°N); B (109.8°E , 23°N); C (97°E , 10.2°S) and D (109.8°E , 10.2°S) as displayed in Figure 3.3. The cropped image now has 256×256 pixels. The cropped area is defined by ABCD.

In order to make the cropped image, the following calculations are performed.

The locations for the points A, B, C and D of the cropped area in Figure 3.3 with reference to the points *a*, *b*, *c* and *d* of the original area of the satellite image in Figure 3.2 can be calculated as follows:

$$\begin{aligned}
 A : (97^{\circ}\text{E} - 70^{\circ}\text{E}, 70^{\circ}\text{N} - 23^{\circ}\text{N}) &= (27, 47) \\
 B : (109.8^{\circ}\text{E} - 70^{\circ}\text{E}, 70^{\circ}\text{N} - 23^{\circ}\text{N}) &= (39.8, 47) \\
 C : (97^{\circ}\text{E} - 70^{\circ}\text{E}, 70^{\circ}\text{N} - 10.2^{\circ}\text{N}) &= (27, 59.8) \\
 D : (109.8^{\circ}\text{E} - 70^{\circ}\text{E}, 70^{\circ}\text{N} - 10.2^{\circ}\text{N}) &= (39.8, 59.8)
 \end{aligned}$$

In terms of pixels, these locations are defined as follows:

$$\begin{aligned}
 A : (27 \times 20, 47 \times 20) &= (540, 940) \\
 B : (39.8 \times 20, 47 \times 20) &= (796, 940) \\
 C : (27 \times 20, 59.8 \times 20) &= (540, 1196) \\
 D : (39.8 \times 20, 59.8 \times 20) &= (796, 1196)
 \end{aligned}$$

3.2.3 Step 3

After the target area has been cropped (Figure 3.4), the next step is to isolate the thunderstorm cloud.

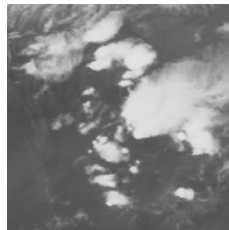


Figure 3.4 Cropped image.

This is done by changing the gray level image into black (no cloud) and white (thunderstorm cloud) image (Figure 3.5).



Figure 3.5 Black and white image.

3.2.4 Step 4

This step computes the area of the cloud with a defined reduction factor, r . The first reduction factor is r_0 which is equals to $1/20$ degree or 0.05 degree. Then, $r_1=0.1$ degree, $r_2=0.2$ degree and so on.

The areas with different values of reduction factor are shown in Figures 3.6.

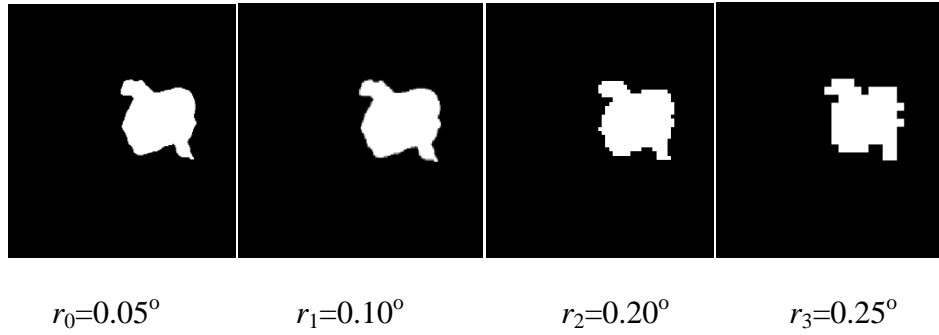


Figure 3.6 The area with the corresponding reduction factor r .

In this research the area is calculated from the number of pixel in the thunderstorm cloud, as shown as an example in Figure 3.7. Each pixel has 1 unit area.

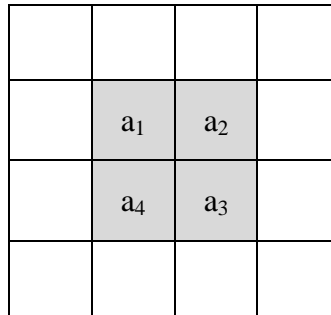


Figure 3.7 The number of pixels in a cloud.

Calculating the area from the formula

$$A = \sum_{n=1}^{\infty} a_n \quad (3.1)$$

The area of the cloud in Figure 3.7 is

$$A = a_1 + a_2 + a_3 + a_4$$

$$A = 1 + 1 + 1 + 1 = 4$$

So the area of cloud in Figure 3.7 is 4 units.

3.2.5 Step 5

In this step, the perimeters associated with the areas in step 4 are calculated. Perimeter is defined as the distance around the boundary of the region. The perimeter is calculated from the distance between the center of each adjoining pair of pixels around the border of the region.

That is, the distance, d_n , between each pair of pixels is

$$d_n = \sqrt{(x_{i+1} - x_i)_n^2 + (y_{i+1} - y_i)_n^2} \quad (3.2)$$

Thus, the perimeters , P , is

$$P = \sum_{n=1}^{\infty} d_n \tag{3.3}$$

where n is the n^{th} pair of pixels around the boundary of cloud, (x_i, y_i) is the center of the i^{th} pixel.

Examples of determination of perimeters for several border shapes are presented as follows. For the example in Figure 3.8, the area has only one pair of pixel along the horizontal axes. Thus, the perimeter (P) is the sum of the distance along the upper boundary (d_1) and lower boundary (d_2).

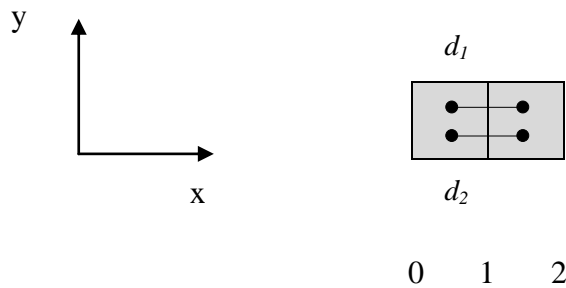


Figure 3.8 Area with 2 pixels along the horizontal axis x .

From Equations 3.2 and 3.3,

$$d_1 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

$$d_2 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

Thus,

$$P = d_1 + d_2 = 1 + 1 = 2$$

So the length of the perimeter in Figure 3.8 is equal to 2.

For the area with 3 pixels in the horizontal (Figure 3.9), the perimeter is calculated from Equations 3.2 and 3.3.

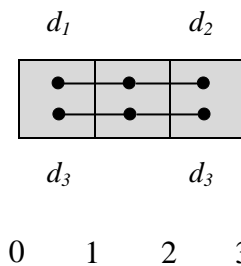


Figure 3.9 Area with 3 pixels along the horizontal axis x .

$$d_1 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

$$d_2 = \sqrt{(2.5 - 1.5)^2_x} = 1$$

$$d_3 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

$$d_4 = \sqrt{(2.5 - 1.5)^2_x} = 1$$

Thus,

$$P = 4$$

If the area also has a pair of pixel along the left and right boundaries as in Figure 3.10, the perimeter is the sum of distance along the 4 boundaries.

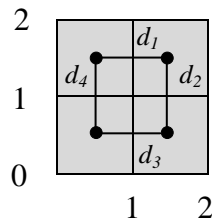


Figure 3.10 Area with 4 pixels along x and y axes.

From Equations 3.2 and 3.3,

$$d_1 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

$$d_2 = \sqrt{(1.5 - 0.5)^2_y} = 1$$

$$d_3 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

$$d_4 = \sqrt{(1.5 - 0.5)^2_y} = 1$$

Thus,

$$P = 4$$

Perimeters of more complicated area shapes are shown in Figures 3.11 - 3.13.

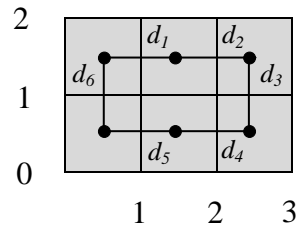


Figure 3.11 Area with 6 pixels along x and y axes.

From Figure 3.11,

$$d_1 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

$$d_2 = \sqrt{(2.5 - 1.5)^2_x} = 1$$

$$d_3 = \sqrt{(1.5 - 0.5)^2_y} = 1$$

$$d_4 = \sqrt{(2.5 - 1.5)^2_x} = 1$$

$$d_5 = \sqrt{(1.5 - 0.5)^2_x} = 1$$

$$d_6 = \sqrt{(1.5 - 0.5)^2_y} = 1$$

Thus,

$$P = 6$$

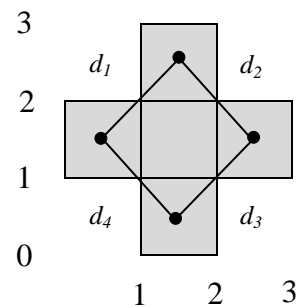


Figure 3.12 Area with cross shape.

From Figure 3.12, using Equations 3.2 and 3.3,

$$d_1 = \sqrt{(1.5 - 0.5)^2_x + (2.5 - 1.5)^2_y} = \sqrt{2}$$

$$d_2 = \sqrt{(2.5-1.5)^2_x + (2.5-1.5)^2_y} = \sqrt{2}$$

$$d_3 = \sqrt{(2.5-1.5)^2_x + (1.5-0.5)^2_y} = \sqrt{2}$$

$$d_4 = \sqrt{(1.5-0.5)^2_x + (1.5-0.5)^2_y} = \sqrt{2}$$

Thus,
$$P = \sqrt{2} + \sqrt{2} + \sqrt{2} + \sqrt{2}$$

$$P = 5.6569$$

In Figure 3.13, the shape of area is more complex.

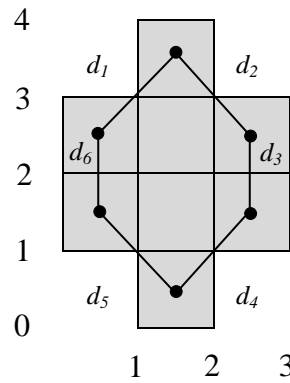


Figure 3.13 Area with complex shape.

From Equations 3.2 and 3.3,

$$d_1 = \sqrt{(1.5-0.5)^2_x + (3.5-2.5)^2_y} = \sqrt{2}$$

$$d_2 = \sqrt{(2.5-1.5)^2_x + (3.5-2.5)^2_y} = \sqrt{2}$$

$$d_3 = \sqrt{(2.5-1.5)^2_y} = 1$$

$$d_4 = \sqrt{(2.5-1.5)^2_x + (1.5-0.5)^2_y} = \sqrt{2}$$

$$d_5 = \sqrt{(1.5-0.5)^2_x + (1.5-0.5)^2_y} = \sqrt{2}$$

$$d_6 = \sqrt{(2.5-1.5)^2_y} = 1$$

Thus,
$$P = 7.6569$$

3.3 Overlapping Area-Perimeter Method

In the determination of perimeter for the area-perimeter method, there is a problem with discontinuity in the perimeter. This happens when the reduction factor is large.

To reduce the broken of perimeter, a new method called “overlapping area-perimeter (OAP)” is proposed in this research.

The concept of this method is to combine the perimeter of cloud with cloud top temperature of $\leq -40^{\circ}\text{C}$ with perimeter of the same cloud but with cloud top temperature of $\leq -38^{\circ}\text{C}$. The combination of the two perimeters yields a new perimeter with no broken part.

An example of the OAP method is shown in Figures 3.14 - 3.16.

Let X be the perimeter of cloud with cloud top temperature $\leq -40^{\circ}\text{C}$. Let Y be the perimeter of the same cloud with cloud top temperature of $\leq -38^{\circ}\text{C}$. Figure 3.14 shown perimeter X and Figure 3.15 shows perimeter Y . The union of X and Y is shown in Figure 3.16.

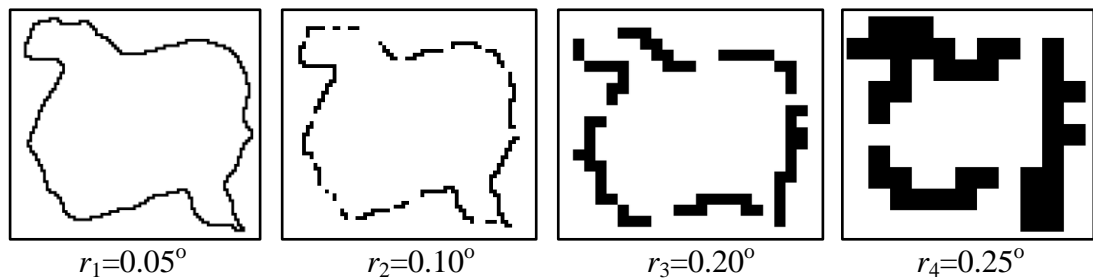


Figure 3.14 Perimeter X .

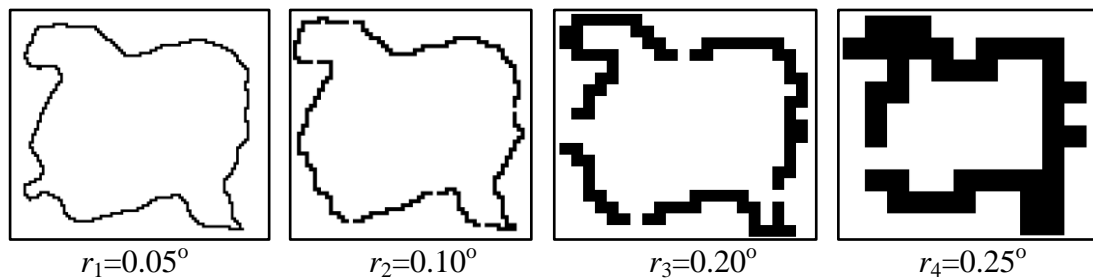


Figure 3.15 Perimeter Y .

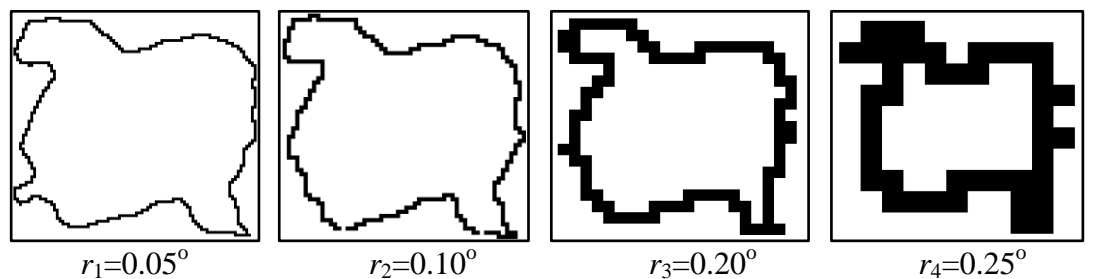


Figure 3.16 Perimeter $X \cup Y$.

3.4 Experiments Cases

The overlapping area-perimeter method is used to identify the fractal dimension of severe thunderstorm clouds from the experiment cases shown in Table 3.4. These cases are selected from Tables 3.1, 3.2 and 3.3. Tables 3.5 shows the cases of non-thunderstorm clouds that are used for comparison of fractal dimension between severe thunderstorm clouds and non-thunderstorm clouds.

Table 3.4 The experimental cases for severe thunderstorm clouds.

Event Description	Damage	Location	Date
Thunderstorm, Gusty wind & Hail	118 houses, 2 injured	Loei	24 Mar 96
	80 houses	Kalasin	
Thunderstorm, Gusty wind & Hail	113 houses destroyed 2 injured	Loei	27 Mar 96
Thunderstorm & Hail	355 houses, 2000 injure	Nong Bua Lam Phu	31 Mar 96
Severe Thunderstorm, Gusty wind & Hail	≈ 10,000,000 baths. Electricity poles overthrown.	Nakhon Phanom	07 Apr 97
	230 houses, I schools 2 electricity poles	Loei	
Thunderstorm, Gusty wind & Hail	155 houses Fire 7 housed	Udon Thani	15 Mar 99
Thunderstorm & Gusty winds	-	Kalasin	25 Mar 02
Thunderstorm, Gusty wind & Hail	400 houses	Si Sa Ket	16 Apr 02
Severe Thunderstorm & Hail	100 houses, 1 cattle farm	Amnat Charoen	17 Apr 02
Thunderstorm & Hail	205 houses, 4 mills	Amnat Charoen	23 Apr 02
Thunderstorm & Hail	305 houses	Kalasin	29 Apr 02
Thunderstorm	-	Loei	24 July 02
Thunderstorm with gust	-	Kalasin	10 Apr 03
Hail	-	Nakhon Ratchasima	
Thunderstorm & Gust	-	Nong Khai, Udon Thani, Kalasin, Nakhon Phanom	18 Apr 03
Thunderstorm & Gusty winds	-	Nakhon Ratchasima	29 Apr 03

Table 3.5 The experimental cases for non-severe thunderstorm clouds.

Location	Date
Si Sa Ket	17 April 01
Nakhon Phanom	16 July 01
Buri Ram	12 December 01
Amnat Charoen	19 April 02
Loei	16 July 02
Kalasin Loei	16 November 02