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Measuring of Tropical Cyclone Intensity Using Fractal Dimension

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Abstract

The 3-dimension fractal dimension of an object represents roughness of the object. The object with higher fractal dimension is rougher than the object with lower fractal dimension. For an ensemble of clouds in satellite images, a high value of fractal dimension indicates that the difference between the heights of cloud tops is large. In this article, the fractal dimension of tropical cyclone in the satellite image was investigated in order to find a relationship between tropical cyclone intensity and its fractal dimension in satellite image. Nine tropical cyclones in the year 2006 were selected as study cases. An improved variation method for fractal dimension calculation was proposed.

Keywords: Fractal dimension, Variation method, Tropical cyclone

1. Introduction

A geometric pattern which has an irregular shape and surface is a fractal. Simple shape such as circle, triangle, and square cannot be used to represent a fractal. Fractals have infinite details because smaller copies of themselves usually contain within the original [1]. Many objects in nature, for examples, cauliflowers, clouds and ferns are fractal. The roughness of the object can be represented by fractal dimension. The object with higher fractal dimension is rougher than the object with lower fractal dimension. Thus, fractal dimension measures the degree of complexity of a fractal [2]. Box-counting method was used as a classification algorithm for approximating the fractal dimension of the coarse iris image according to the texture and structure. An algorithm based on the variation method was used to classify the roughness of sea surface from sea synthetic aperture radar (SAR) image by the fractal dimension for sea surface anomaly [3]. In the tropics, the relationship between cloud and fractal dimension showed that different clouds have different fractal dimensions [4]. Although, the fractal dimension of cloud may not change during cloud evolution, fractal dimension varied according to cloud types [5].

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Tropical cyclones are an ensemble of clouds; identification of tropical cyclones intensity based on images of clouds from meteorological satellites is possible. One such technique is a widely used system developed by Dvorak in the year 1975 to subjectively estimate tropical cyclone intensity based solely on cloud patterns in satellite images. Thus, identification of tropical cyclone intensity based on cloud pattern and texture in the meteorological satellite image has been used by weather forecasters for many years.

Tropical storm is classified into 3 classes based on intensity; depression which has the maximum wind speed less than 61 km/hr, tropical storm which has the maximum wind speed between 62-117 km/hr, and typhoon which has the maximum wind speed more than 118 km/hr [6].

The first Multi-functional Transport Satellite (MTSAT-1R) is the meteorological satellite that covers East Asia. There are four infrared channels and one visible channel of meteorological observations with different wavelength intervals.

The wavelength intervals of Infrared1 (IR1) and Infrared2 (IR2) channels are effective in detecting height-level cloud. The wavelength interval of Infrared3 (IR3) channel is effective in detecting water vapor and the wave length interval of Infrared4 (IR4) channel is effective in detecting low-level cloud. The visible channel is available during the daytime only [4-5]. For the satellite images used in this study, each pixel has the value of gray scale intensity in the interval between 0 and 255. For the same channel, the higher the cloud top, the larger the value of grey level intensity.

2. Methodology

2.1 Study Area and Experimental Cases

Tropical cyclone report of the Northwest Pacific area for the year 2006 from National Institute Informatics is selected for this paper. The satellite images are download from website http://weather.is.kochi-u.ac.jp/sat/GAME/2006 which mapped data between latitude N70 - S20 and longitude E70 - E160 with the image size of 1800 x 1800 pixels and each pixel has $1/20 \times 1/20$ degree resolution. The positions of the storm centers are downloaded from the website http://agora.ex.nii.ac.jp/digital-typhoon/index.html.en. Each satellite image is cropped to the size of 99×99 pixels with the eye of the storm located in the center of the image [7].

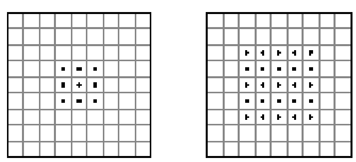
In Table 1, the report of maximum wind speed of tropical cyclone over a Northwest Pacific area in 2006 show that the maximum wind speeds of tropical cyclone numbers 1, 3, 5, 6, 8 and 9 are classified into typhoon. Nine tropical cyclones were selected as study cases. Among these, 6 were typhoons and 3 were tropical storms. The fractal dimension of IR1 and IR4 images determined by the improved variation method are used to make the scatter plot of fractal dimension and the linear regression.

Table 1 Report of tropical cyclone on Northeast Pacific area in 2006

Number	Name of Cyclone	Birth (UTC)	Death (UTC)	Maximum wind speed
1	CHANCHU	2006-05-09 12:00	2006-05-19 0:00	90 knot
2	JELAWAT	2006-06-27 6:00	2006-06-29 0:00	40 knot
3	EWINIAR	2006-06-30 18:00	2006-07-11 6:00	100 knot
4	BILIS	2006-07-09 6:00	2006-07-15 6:00	60 knot
5	KAEMI	2006-07-19 6:00	2006-07-26 6:00	80 knot
6	PRAPIROON	2006-08-01 6:00	2006-08-05 0:00	70 knot
7	MARIA	2006-08-05 12:00	2006-08-11 0:00	60 knot
8	SAOMAT	2006-08-05 12:00	2006-08-11 0:00	95 knot
9	IOKE	2006-08-27 6:00	2006-09-07 0:00	105 knot

2.2 Variation Method

In the variation method, the fractal dimension of an image is determined from the intensity variation of pixels in the image using different sizes of neighborhood specified by the length ε.The size of ε is varied from the smallest to the biggest possible neighborhood.



$\varepsilon = 1$ $\varepsilon = 2$

Figure 1 Expansion of neighborhood from specific distance [3]

In Figure 1, for each ε specified, the neighborhood is expanded into the length of $2\varepsilon + 1$. The ε-oscillation for each neighborhood is defined as the difference in intensity between the maximum and minimum values in all pixels within the specified neighborhood. The ε-variation for each ε, denoted by $V_I(\varepsilon)$, is the summation of all ε-oscillations for the image divided by the number of neighborhoods in the image as defined by ε. The fractal dimension is estimated by 3 minus the value of $\log V_I(\varepsilon)$ divided by log ε [3],[8].

2.3 Improved Variation Method

Using the same idea of variation method, when the value of ε is large, each neighborhood will cover a large portion of the image. The largest size of the neighborhood is equal to the size of the image. When the size of ε is decreased, the size of neighborhood is also reduced and the number of the neighborhood required to cover the image is increased. There are some values of ε that may result in the neighborhoods that could not cover the image completely. In this new method the problem associated with the incomplete coverage by neighborhood of certain sizes in the original variation method was reduced by rotation of the image 90 degree at a time and calculated the fractal dimension for 4 times [7].

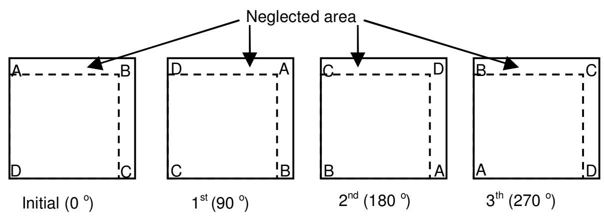


Figure 2 Rotation of the image

3. Results and Discussion

3.1 Fractal Dimension and Regression Equation

The hourly values of fractal dimension for IR1 and IR2 images are very close. This is because the fractal dimensions of IR1 and IR2 satellite images are both represent the roughness of cloud top in tropical cyclone. Fractal dimension of IR3 is not used because IR3 channel is designed for measurement of upper level moisture content not cloud top temperature. IR4 satellite image is related to low cloud while IR1 is related to high cloud. The intensity of typhoon (as measure by maximum wind speed) is more than that of tropical storm, and the intensity is be related to the development of low cloud and high cloud in the storm which is represent by the fractal dimensions of the clouds. Thus, the values of IR1 and IR4 fractal dimensions are used in trying to find relationship between tropical cyclone intensity and its fractal dimension.

From the difference between the fractal dimensions of IR1 and IR4, and the trend in fractal dimension time series, it is very difficult to differentiate intensity of tropical cyclone. There is an exception to this during the decaying stage of tropical cyclone in which the fractal dimensions of both IR1 and IR4 are increasing and IR4 image has higher fractal dimension than that of IR1 image.

The regression equation for the fractal dimension of IR1 and IR4 during the decaying stage of tropical cyclones is determined. Verification of the regression equation for the decaying stage is done by comparing the IR4 fractal dimensions obtained from the equation with the corresponding dimensions calculated**.** The results show good agreement between the dimensions from the regression equation and the dimensions from the variation method as shown in Figure 3.

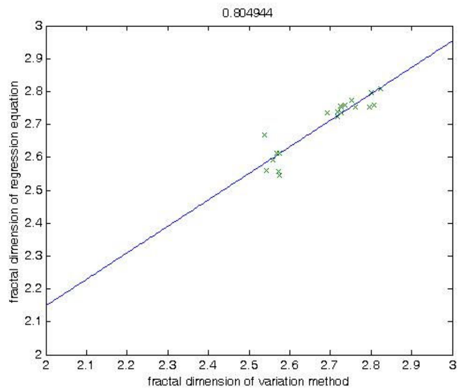


Figure 3 Fractal dimensions of IR4 during the decaying stage of tropical cyclones

Thus, the regression equation for the 3D fractal dimension of IR1 and IR4 during the decaying stage could be used to determine tropical cyclone intensity over the Northwest Pacific Ocean and could also be used to determine the decaying stage of tropical cyclones in this region.

3.2 Neighborhood Specification

The size of ε which is used to define the neighborhood in the variation method plays a significant role in the calculation of fractal dimension. If the size of ε is too small, the value of oscillation obtained could be too low, and if ε is too large the oscillation could be too high. That is the roughness of fractal image is directly depended on the size of selected ε. The size of ε is increased by 3 pixels at a time, starting from the first size of ε at 3 pixels. This increment rate is obtained experimentally. The values of ε used for the image of the size 99 × 99 pixel in this study, from the smallest to the largest, are 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45 and 48. The corresponding sizes of the neighborhood for these 16 values of ε are 7, 13, 19, 25, 31, 37, 43, 49, 55, 61, 67, 73, 79, 85, 91 and 97, respectively. The smallest value of ε, 3, will result in the largest number of neighborhood, 196, as shown in Figure 4 with the starting point at the lower left corner of the image [7].

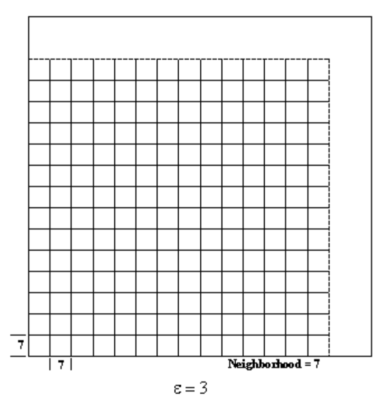


Figure 4 Neighborhoods for $\varepsilon = 3$

3.3 2-Dimension Fractal Dimension

The 2-dimension fractal dimension which represents the shape of tropical cyclones can be calculated by the box-counting method. This method approximates the fractal dimension by counting the number of boxes that covering the fractal and the number of boxes and size of boxes are related to calculate the fractal dimension. Linear regression analysis shows that the relationship between maximum wind speed and the 2D fractal dimension has large variation of the 2D fractal dimension for the same maximum wind speed. Thus, the 2D fractal dimension could not be used to classify the intensity of tropical cyclone.

4. Conclusion

Fractal dimension of tropical cyclone in the MTSAT-1R satellite image was investigated in order to find a relationship between tropical cyclone intensity and its fractal dimension in the image. An improved variation method for fractal dimension calculation was proposed. In this new method the problem associated with the incomplete coverage by neighborhood of certain sizes in the original variation method was reduced by rotation of the image 90 degree at a time and calculated the fractal dimension for 4 times. In addition, appropriate values for neighborhood specification were also found.

Linear regression equations between the 3-dimension fractal dimension for IR1 and IR4 satellite images could be used to classify tropical cyclone intensity over the Northwest Pacific Ocean and could be used to determine the decaying stage of tropical cyclones. For the 2-dimension fractal dimension which represents the shape of tropical cyclones, as calculated by the box-counting method, it could not be used to classify the intensity of tropical cyclones due to the poor relationship between the 2-dimension fractal dimension and the tropical cyclone maximum wind speed.

With further improvement in calculation method, the fractal dimension has a potential to be a good indicator for tropical cyclone intensity identification.

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