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Fractal Analysis of Cloud Shapes

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ABSTRACT

A study was carried out to investigate the fractal properties of cloud shapes. Water vapor images of clouds over the Indian Ocean region captured by the geostationary meteorological satellite METEOSAT-7 during the period of 2008 August to 2009 July were used in the present study. The fractal dimensions of cloud shapes have been calculated using the area-perimeter relationship and the box-counting method. To improve the extraction of cloud shapes, image preprocessing steps such as background subtraction and noise filtering were applied. Cloud shapes at different colour values were extracted from satellite images using the k-means clustering algorithm. The value of the fractal dimension varies between 0.8 and 1.6. The results of this work agree well with related studies carried out for both small and large clouds in the past. The average fractal dimension of clouds 7 km above ground level is 1.5±0.1.

1. INTRODUCTION

Fractal geometry has the ability to model natural shapes and to measure their fractional dimensions more accurately than approximating to known regular shapes [1]. Accurate representation of complex shapes is possible through fractal geometry. A variety of algorithms are available for computation of fractal dimension [2] and the fractal properties of various natural objects.

A ’fractal’ has the same degree of irregularity in all scales. In other words it can be expressed as a union of sets, each of which is a reduced sized object of the original one, which characterizes the self similarity. Similar to many other objects found in nature, clouds also have complicated and irregular shapes which cannot be described by regular shapes such as circles, triangles and squares. Thus, analyzing and characterizing the shapes of clouds using fractal methods has a number of advantages for metrological and atmospheric studies.

After the self similarity of clouds investigated by Lovejoy [3], fractal structures of clouds have been investigated by several other researchers. The relation between the fractal dimensions of rain fields and the fractal dimensions of clouds has been carried out by Lovejoy [3]. Cahalan [4] analyzed the spatial structure of the marine boundary layer and inter-tropical convergence zone (ITCZ) clouds using a high spatial resolution Landsat multispectral scanner (MSS) and a thematic mapper (TM) instrument. Schneider and Wohlke [5] studied the fractal properties of clouds using a computer simulation and reported that the dimension of clouds is 1.28. Malinowski and Leclerc [6] have used fractal techniques to investigate small scale features of clouds by analyzing individual cloud droplet distributions. Mesoscale cloud patterns have been studied by Carvalho and Dias [7] by applying fractal methods on infrared satellite images. A fractal dimension analysis on the cloud shapes over land has carried out by Gotoh and Fuji [8] using high resolution

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thematic mapper image data taken from Landsat TM bands 1, 2 and 3. They have estimated the influence of regional wind systems on the macro physical properties of cumulus clouds, such as perimeter fractal dimension, orientation angle and cloud-base height.

The present study is mainly focused on the analyzing cloud shapes observed in the region of the Indian Ocean by estimating their fractal dimension. The clouds were analyzed separately by classifying according to their height from the ground level. A computer program was developed to deploy k-means algorithm to extract cloud shapes at different heights and study their fractal properties.

2. METHODOLOGY

The study was conducted in several steps (stages) starting with cropping the regions of interest followed by noise removal, image segmentation and finally applying box counting and area perimeter technique to calculate fractal dimension of clouds. MATLAB was used as the program development environment.

2.1 Data set

The cloud images used in this research were obtained from the geostationary meteorological satellite METEOSAT-7 operated by the European Organization for the Exploration of Meteorological Satellites (EUMETSAT). Water vapour images of clouds in the Indian Ocean region within 30^o and 120^o of latitudes and $\pm30^o$ of longitudes were available in the website of EUMETSAT. For the present work, satellite images taken in every thirty minute time interval during the period from 2008 August to 2009 June was extracted. The images have the scaling of 1 pixel equivalent to 10 km at ground level. All images were of 900×700 pixels in size.

2.2 Preprocessing

Since processing of a large number of image files covering a large region of the Indian Ocean is time consuming, two regions within 60^o and 90^o of latitudes and $\pm15^o$ of longitudes, and, within 75^o and 90^o of latitudes and within 0^o and 15^o of longitudes were selected for the study. All satellite images were in '.jpg' file format. In order to read .jpg files into MATLAB, the built in function 'imread' was used. The selected two rectangular areas were cropped from the original image files relative to the longitudes and latitudes. An image which is covered large area is about 298×281 pixels and an image with small area is about 149×140 pixels.

The input image is a RGB image stored as an $m \times n \times 3$ data array that defines red, green, and blue colour components for each individual pixel. Pixels that are changed artificially must be removed, since it can interfere with the initial steps related to colour separation. Thus, pre-processing was carried out to remove the latitude and longitude lines and outline of the countries marked on the image files. The latitude and longitude lines are removed considering the black colour pixel locations. Since all these lines were being straight and having the same horizontal and vertical

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coordinates, coordinate based removal was adopted. The pixels with country outlines are replaced by the average colour values of the four nearest neighbours.

2.3 Image segmentation

Each image was split into several sub regions to classify cloud areas and non-cloud areas. The threshold to define cloud area is set as -30^{o}C for cloud top temperature. If the threshold is higher than this threshold, the parts of the ocean may be identified as clouds. The segmentation was performed based on colour values of the pixels. This was done using k-means clustering method which partitions the points in the m×n data matrix into k clusters.

2.4 Area–Perimeter calculation

Once a separate cloud area has been located, the area (A) of the cloud was determined by simply counting the number of colour pixels within the identified region. The perimeter P was calculated by calculating the distance between each adjoining pair of pixels located around the region border. The area-perimeter relationship was used to estimate the fractal dimension of clouds.

The perimeter can be approximated by the power D of the square root of the area ($P \sim \sqrt[D]{A}$) where D is the fractal dimension [1]. Therefore;

$$log(A) = \frac{2}{D}(log\ (P)) + contant$$

By estimating the gradient of the graph m, log(A) vs log(P), measument of fractal dimension D can be obtained. i.e.; $D = {}^{2}/_{m}$

Area–perimeter dimension of each cloud region is calculated as a measurement of the slope of the best fit line described above.

2.5 Box-Counting algorithm

In order to apply the Box counting algorithm to the segmented cloud regions, the following steps were followed.

- Image data was loaded into a two dimensional array
- The width (p) of the largest two dimensional box which covers the region was found
- Reduce the width of the box by half
- Count the number of two dimensional boxes (N) of size r needed to cover the image area
- Repeat the last two steps until the box size approaches the size of the pixels

The gradient of the graph of log $N(r)$ against log $(1/r)$ gives an estimation of the box counting dimension.

$$log(N) = D\left(log\left(\frac{1}{r}\right)\right) + constant$$

3. RESULTS AND DISCUSSION

3.1 Results of k-means algorithm

After the pre-processing stage, k-means algorithm was applied to extract clouds representing different colour regions (heights) from the background. K-means algorithm divides the image into small regions based on pixel colour values. When clustering levels are increased specific colour can be separated accurately (see Fig. 1).

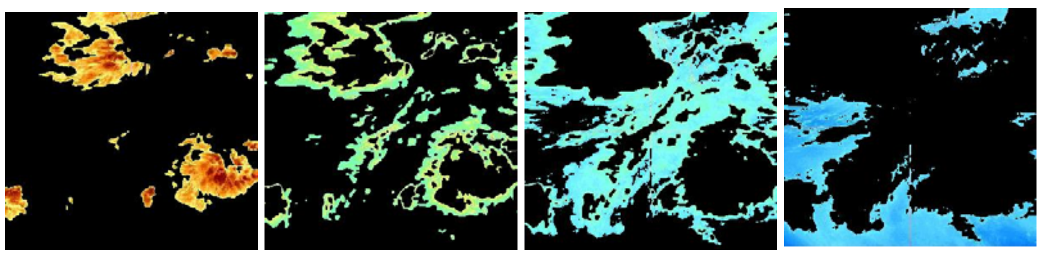

Fig. 1: Clustered image for 4 colour levels

3.2 Fractal behaviour of cloud regions

Area and perimeter is calculated for each cloud region by using the properties of area and perimeter function 'regionprops' in MATLAB. Then the calculated area and perimeter is plotted for each labeled region in log scale. The log-log graph of area against perimeter for each cloud region shows a linear behavior (see Fig. 2a).

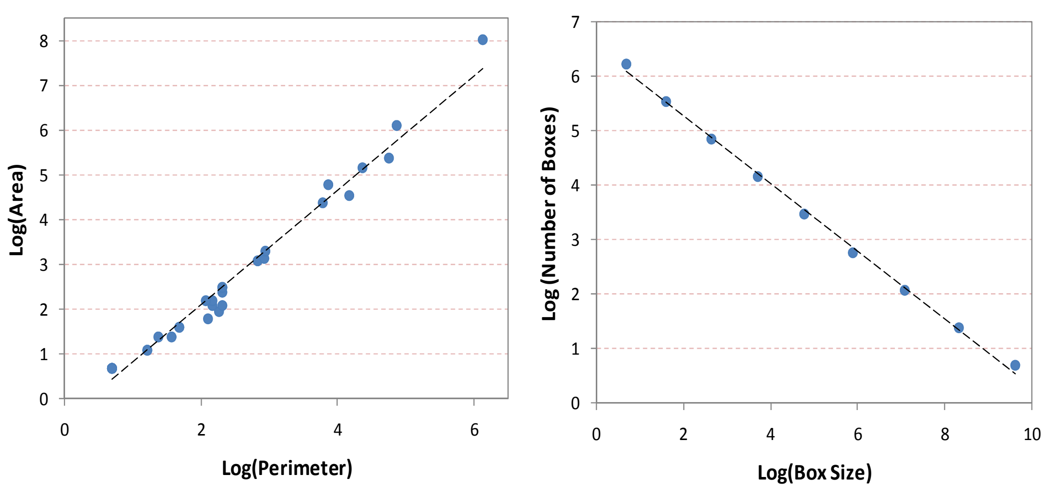

Fig. 2: (a) Area–Perimeter method (b) Box–Counting method

Box-counting dimension was calculated by using the inbuilt function 'boxcount' in MATLAB. This function calculates the number of squares with length *r* required to cover the cloud region. The square size *r* was reduced step by step and the number of boxes *N* needed to fill the cloud region was estimated. The log-log graph of box size (*r*) against the number of boxes (*N*) also shows the expected linear behavior for cloud regions (see Fig. 2b).

The above two graphs are generated by applying area-perimeter method and box-counting method to the same cloud regions. Linearity of above results indicates the fractal behaviour of cloud regions. The fractal behaviour of the cloud regions observed in the present study is in agreement with the studies carried out in the past.

3.3 Variation of fractal dimension with cloud threshold levels

Fractal dimension of clouds which are extracted for various temperature threshold levels are shown in Fig. 3.

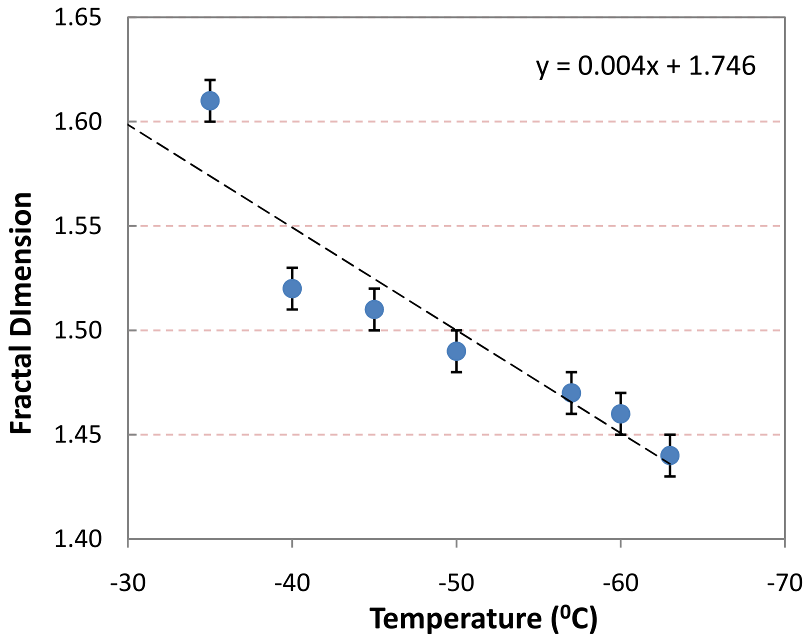

Fig. 3: Average fractal dimensions for different temperature thresholds

It can be seen that the average fractal dimension decrease with decreasing temperature (i.e. increasing cloud height) and the relationship is approximately linear expect for the maximum temperature. For every 10 ^{o}C change in temperature, the fractal dimension change by 0.04. The value of fractal dimension varies between 0.8 and 1.6.

Cloud types can be classified by means of cloud height from ground level. High level clouds as Cirrus, Cirrocumulus and Cirrostratus form between 5 km to 12 km. Heights between 5 km to 12 km have temperatures below -30^{o}C [9]. Thus, clouds analyzed in this work are the high level clouds. By extending this analysis to classify clouds and studying how water vapour aggregates to form clouds, the high

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clouds may be classified as Cirrus, Cirrocumulus and Cirrostratus based on the fractal dimension.

4. CONCLUSIONS

This paper presents the fractal properties of clouds observed in the Indian Ocean region. Both the area-perimeter method and the box-counting method performed well in describing cloud shapes. One of the important results obtained in this work is the relationship between the fractal dimension and temperature levels. The fractal dimension decreased linearly with decreasing temperature by 0.04 for every 10 Celsius change. The study shows that the average fractal dimension of clouds 7 km above ground level is 1.5±0.1.

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