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Research article

Multiscale multifractal properties between ground-level ozone and its precursors in rural area in Hong Kong

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ABSTRACT

In rural area, due to the reduction of NOx and CO emitted from vehicle exhausts, the ozone photochemical reaction exhibits relatively weak effect and ozone formation presents different pattern with its precursors in contrast to urban situation. Hence, in this study, we apply detrended cross-correlation analysis to investigate the multifractal properties between ozone and its precursors in a rural area in Hong Kong.

The observed databases of ozone, NO_2, NOx and CO levels during 2005–2014 are obtained from a rural monitoring station in Hong Kong. Based on the collected database, the cross-correlation analysis is carried out firstly to examine the cross-correlation patterns and the results indicate that close interactive relations exist between them. Then the detrended cross-correlation analysis is performed for further analysis. The multifractal characters occur between ozone and its precursors. The long-term cross-correlations behaviors in winter are verified to be stronger than that in other seasons. Additionally, the method is extended on daily averaged data to explore the multifractal property on various time scales. The long-term cross-correlation behavior of ozone *vs* NO_2 and NOx on daily basis becomes weaker while that of ozone *vs* CO becomes stronger. The multifractal properties for all pairs in summer are found to be the strongest among the whole year. These findings successfully illustrate that the multifractal analysis is a useful tool for describing the temporal scaling behaviors of ozone trends in different time series in rural areas.

1. Introduction

Ground-level ozone is produced from a complex series of photochemical reactions in the atmosphere (Zhang et al., 2014; Seinfeld et al., 2016). Its formation process is mainly dependent on the temperature, solar radiation, NO_x emissions and ambient concentration of CO (Sillman, 1999). Consequently, the response to variations of ozone is highly non-linear (Pavon-Dominguez et al., 2013; Fernández-Guisuraga et al., 2016; Yadav et al., 2016) and any resultant reduction of it is invariably accompanied by increases in the levels of NO_2, NO_X and CO. It is therefore necessary to have a complete understanding of the relationships between ozone, NO_2, NOx and CO under atmospheric conditions.

In previous studies, ozone researches are generally based on statistical descriptions of time series, seasonal and daily patterns, threshold exceedances and prediction models (Cheng et al., 2010; Xu et al., 2015; Souri et al., 2016). However, statistics is occasionally not in a position to fully characterize processes driven by certain physical and chemical laws but with a high degree of temporal variability. In addition, statistical results of the time series are based only on a single scale analysis (i.e., the observation time) and might not necessarily reflect the features of the time series over other scales (Zeleke and Si, 2006). Fortunately, the application of the fractal theory provides alternative option to overcome such shortcomings (Fernández-Guisuraga et al., 2016; Kumar et al., 2015; Jiang et al., 2016). The fractal approach can divide the whole data into smaller self-similar fragment and discover the physical process of the data with a unique scaling behavior, which is associated with a power-law scheme. To date, there appear several fractal methods for revealing the fractal characteristics (Tang et al., 2015; Shen, 2015a; Xiong and Shang, 2017). Among them, the multifractal approach of detrended cross-correlation analysis (DCCA) is a proper tool to obtain a detailed description of the relationships between

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two-time series (Shen, 2015b).

The DCCA approach was put forward by Podobnik and Stanley (2008). This method is based on fractal theory for two non-stationary time series, can effectively avoid the phenomenon of spurious correlation sequence due to the non-stationary nature of data between the two groups, and achieve quantitative analysis of non-stationary time series correlation and fractal characteristics in the most scientific and effective way. To date, this data analyzing method has been successfully applied to the financial markets, meteorological factors, air pollution and other natural sciences (He and Chen, 2011; Vassole and Zebende, 2012; Shi, 2014). Nevertheless, less study has focused on description of multifractal property and long-term cross-correlation behavior between ozone and its precursors in rural area.

In urban area, due to abundant of nitrogen oxides (NOx) and CO emitted from vehicle emissions, photochemical reactions take effect obviously and dominate the variations of ozone formation. In contrast to the insufficient NOx and CO in rural area, the ozone formation is different and the variations of ozone present different nonlinear behaviors. Hence, in this study, we aim to investigate the multifractal property and long-term cross-correlation between ozone and its precursors of CO, NO_2, NO_X in rural area in Hong Kong via data mining on the historical observations. The goals of this work are: (1) to verify whether the hourly and daily time series of ozone and CO, NO_2, NO_X concentrations in rural area exhibit multifractal nature, (2) to reveal the difference of multifractal property between hourly and daily time series, and (3) to clarify the influence of season on multifractal property on varied scale time series.

2. Data collection and methodology

2.1. Site description

Yuen Long monitoring station is one of Hong Kong air quality monitoring stations and characterized with rural and new town (Fig. 1). It is surrounded by mountains, rolling farmland and a little industry. Additionally, Yuen Long has distinguished season. Summer is hot and humid with solar radiation while winter is mild and usually starts sunny, becoming cloudier towards February. The climate characteristics of Yuen Long linked to the relevant industry, road traffic and regional pollution make its surroundings an area of special protection against ozone pollution.

2.2. Data collection

Ten-year time series of hourly values of CO, NO_2, NOx and ozone, from 1 Jan 2005 to 31 Dec 2014, are collected at the Yuen Long monitoring station (http://epic.epd.gov.hk/EPICDI/air/station/). It is noteworthy that although ten year consists of 87,600 h, only about 84,000 readings are collected due to instrument calibration and maintenance. As it is known, the hourly data of pollutants usually presents periodic variation and the average daily variation can be easily obtained. Then the missing data can be estimated based on the average daily data and available data in that day through regression analysis (Li et al., 2015, 2016).

Fig. 2 illustrates the daily average variations of CO, NO_2, NOx and ozone for ten years. From the figure, it can be clearly found that ozone concentration begins to decrease during morning time and afterwards tends to increase. The maximal value of ozone was

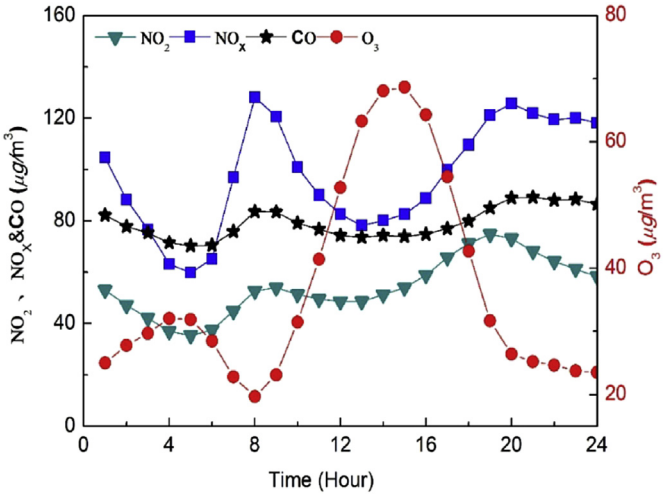

Fig. 2. Average hourly variations of CO, NO_2, NO_X and O_3 for ten years.

Fig. 1. Location of Yuan Long air quality monitoring station (google map).