Geophysical Research Abstracts
Vol. 12, EGU2010-474, 2010
EGU General Assembly 2010

Application of the joint multifractal analysis for describing the influence of nitrogen dioxide on ground-level ozone concentrations

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High concentrations of ground-level ozone have a negative impact on human health and the environment. Detailed knowledge on the effects of nitrogen dioxide on the ozone seasonal pattern is convenient to prevent these undesirable effects. Thus, the joint multifractal approach has been used to complete the information provided by descriptive statistics. The joint multifractal spectra were obtained for 10-minute [O_3] and [NO_2] time series, recorded at Córdoba (southern Spain) in 2007, revealing the presence of two main seasonal patterns: autumn-winter and spring-summer.

It could be verified that the joint multifractal spectra were convex surfaces confirming the presence of the multifractal nature in the time series. There was similitude in the shapes of the joint multifractal spectra corresponding to spring-summer months. A comparable looking was also found for the spectra of the autumn-winter months. This fact evidenced the influence of [NO_2] on the [O_3] seasonal pattern. According to the recorded data, the concentrations of ozone and nitrogen dioxide were negatively correlated. This circumstance was caused by the presence of high and low [O_3] at low and high [NO_2] values, respectively. In all the cases, the spectra exhibited a clear orientation from top left region, where high [NO_2] and low [O_3] values were found, to bottom right part, corresponding to low [NO_2] and high [O_3].

The single multifractal spectra exhibited a longer tail to the right of the maximum value for all the months indicating that there was a greater heterogeneity in the lower values in the ozone concentration time series. This heterogeneity was lower for autumn-winter months, especially for January due to the shorter lengths shown by their spectra right tails, compared to those obtained for the spring-summer season. The left tails of the spectra corresponding to the spring-summer and autumn-winter months tended to be overlapped, confirming that there was a seasonal similarity in scaling behaviour for the high values in the ozone concentration. However, the presence of a shorter left tail in the spectrum denoted less heterogeneity in the higher values in the ozone concentration data recorded for July.

When the single multifractal spectra of [O_3] were analyzed for high values in [NO_2] it was demonstrated that the spring-summer months exhibited a clear asymmetry with longer right tails. This feature indicated that high nitrogen dioxide concentrations were related to the heterogeneity detected in the lower values of [O_3]. The findings described before were in agreement with the coefficients of correlation for [O_3] and [NO_2] that showed a more negative value in the case of the spring-summer months. Regarding the low concentrations of NO_2, the presence of high rare [O_3] values should be noted, as could be inferred from the significant number of points located at the left extremes of the single spectra. This detail was more evident for January and October and had a direct relation with the positive values found for the coefficients of skewness in the [O_3] time series. In contrast, the effect of having less accumulation of points at the end of the left tails of the spectra of spring-summer months was translated into coefficients of skewness near zero or negative.

The analysis illustrated the linkage of both pollutants by taking advantage of the independence of the time series parameters over a range of scales and the assumption of a non specific distribution. The joint multifractal analysis provided complementary information to descriptive statistics. Thus, it determined the heterogeneity in the high and low [O_3] values corresponding to different concentrations of NO_2, allowing to check the presence of extreme data, as well as offering a detailed explanation of the correlation between these pollutants by detecting the [NO_2] and [O_3] values that had major influence to this relationship in autumn-winter and spring-summer season.