MULTISCALE ANALYSIS FOR ATMOSPHERIC AIR QUALITY DATA

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Abstract The aim of this work is to analyse air quality and meteorological data collected from atmospheric field measurements in order to explore the multiscale nature of atmospheric processes. Data collected over a period of a calendar year from an Air Quality Monitoring Station located at the outskirts of Nicosia Capital City (Cyprus) is examined. Specifically 10 different atmospheric parameters were measured: 7 meteorological and 3 air-quality related variables. The power spectral density of the time series obtained from the measurement was firstly computed. The power spectra of all the parameters exhibited power law decays, a feature that indicates the presence of scaling laws in the atmospheric processes associated with the measured variables. Further analysis using the continuous wavelet transform is implemented in order to further describe the multiscale nature of the measured quantities. This paper presents results for wind speed (WS) - reflecting the flow, as well as PM_{10} - reflecting a passive scalar and NO_x - reflecting a reacting scalar.

INTRODUCTION

The physicochemical processes that take place in the atmosphere occur over a wide range of spatial and temporal scales. A well-established sub-division of scales in atmospheric modelling is made based on geographical criteria, resulting into five (5) different scales [7]- namely global/mesoscale, regional, city, neighbourhood and local [1], [7]. In order to model accurately these physicochemical processes and their interaction, it is crucial to characterise rigorously this multiscale nature of the atmosphere. Kolmogorov's theory states that fluid velocity has exhibit a spectrum which decays with a power exponent equal to -$\frac{5}{3}$. Spectral energy distributions of timeseries data may indicate the possible existence of scaling behaviour but are unabled to localize features in time, such as a discontinuity of the signal. Due to this capacity WT is applied in several fields e.g in turbulence characterisation. Studies addressing spectral energy distributions of timeseries data make use of controlled laboratory experiments such as wind tunnel studies ([2],[6]). In this paper, meteorological and air quality monitored field data were collected from an Air Quality Monitoring Station located at a sub-urban site of the Nicosia capital city (Cyprus) and were analyzed. The objective of this work is to explore the multiscale nature of the air quality timeseries, to deduce any scaling laws and thereby provides insights to atmospheric data. One of the novelties of this work is the application of WT on data collected from field measurements and not from laboratory experiments that inherently contain constraints on the spatial scale (over which the pollutant may have arise from), i.e. some externally imposed scales. Moreover the field data that were used in this paper not only wind speed but also passive and reacting scalars concentrations, thus involving interaction between physicals and chemical processes of different time scales.

METHODOLOGY

Data were collected with sampling frequency of 10Hz for an overall period of 4 years and stored as hourly-averaged values; at the same time, and over a calendar year (between May 1st 2011 and April 30th 2012) data were stored as 15min averaged values [5]. The meteorological variables monitored include wind speed, wind direction, ground temperature, barometric pressure, humidity and solar radiation, however in this paper we report wind speed; air quality measurements include concentrations of Particulate Matter of size at least 10μm (PM_{10}), Nitrogen Oxides (NO_x), Carbon Monoxide (CO) and Volatile Organic Compounds (VOCs); in this work we report results for PM_{10} (as a passive scalar) and NO_x (as a reacting scalar). It is expected that time series representating their concentration will exhibit different scaling law from those representing chemically inert substances. In order to extract more information with regards to the multiscale behavior of the measured quantities the Continuous Wavelet Transform (CWT) is used. For a given time series $f(t)$ it is defined by, [4]:

$$C(\alpha, b; f(t), \psi(t)) = \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{\alpha}}\psi^*(\frac{t-b}{\alpha})dt \tag{1}$$

where $\psi(t)$ is the mother wavelet function, which is non-zero only over a finite time interval and its integral over that interval is zero. These two conditions render $\psi(t)$ a small wave, hence its name. The mother wavelet can be dilated or compressed through the scale parameter α, for $\alpha > 1$ $\psi(t)$ is dilated whereas for $\alpha < 1$ is compressed. In order to enable analysis for all the time period $f(t)$ is defined the dilated or compressed wavelet should be tranlated accros the period $f(t)$ is defined. This is achieved by the use of b, which is known as the translation parameter. The integral (1) is interpreted as a measure of similarity at a translation b between compressed or dilated versions of $\psi(t)$ and $f(t)$. Plots of the values

$C(\alpha, b; f(t), \psi(t)$ of (1) over the plane determined by α and b can be used to extract information about the multiscale nature of the analyzed time series $f(t)$. The CWT results of the 15 minute averaged meteorological and air quality data presented in the next section were obtained using the Daubechies4 $db4$ wavelet function

RESULTS & DISCUSSION

In this section, the results obtained from the analysis of the wind speed, PM_{10} and NO_x data are presented. Specifically Figure 1(top) depicts the timeseries plot of wind speed, PM_{10} and NO_x, while the results from the spectral energy distribution from the experimental data are compared with -$\frac{5}{3}$ Kolmogorov spectral exponent. Spectral energy distribution of wind speed timeseries Figure1a(middle) shows that the fitted power law is -1,47. Figure 1b(middle) depicts PM_{10} spectrum, where the calculated power low is -1,18. Finaly the NO_x's power low is calculated -1.7 (Figure 1c(middle)).
These spectra characteristics indicate multiscale behavior. More information related to multiscale behavior can be inferred from the CWT plots given in the second row of figure 1. The first observation that can be made is that there is a significant activity at higer scales (lower frequencies) for all the specie. A feature that the CWT elucidates is the higher activity presented at lower scales at $b = 30 \times 10^4 min$ that is observed in the CWT plot of the NO_x. This is also reflected in the higher values, as compared to those of the wind speed, of the NO_x spectral density values observed at higher frequencies. A further advantage of the CWTis that it gives the time instant that this had taken place. In addition, it can be concluded that the event that caused this activity at the lower scale might also be responsible for the actual power spectrum law.

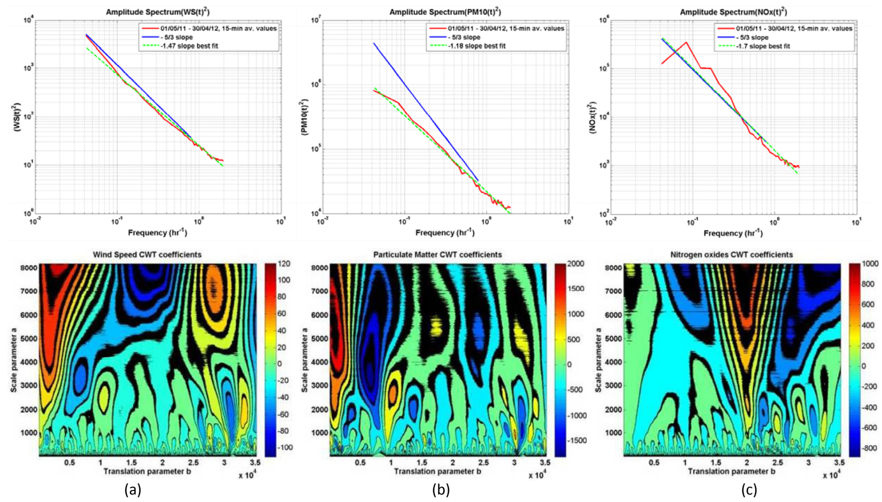

Figure 1. Air quality and meteorological timeseries data analysis. (a) Wind Speed (b) Particulate Matter of size at least 10Îijm (c) Nitrogen Oxides the timeseries plot (top); the spectral energy distribution (middle), and CWT analysis (bottom) for each variable

CONCLUDING REMARKS

The multiscale nature of air quality and meteorological field measurement data was explored. Future work will elaborate the experimental data with WT modulus maxima in order to determine the singularities of the air quality timeseries and subsequently to unveil the actual scaling laws that underlie these processes.

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