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Reflectance spectroscopy is an effective tool for monitoring soot pollution in an urban suburb

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ABSTRACT

This study examines whether converting the fossil fuel of the Tel Aviv power station from oil to gas influences air pollution in the local urban environment. To this end, the spectral properties of accumulated dust on tree leaves and paper bags were assessed before (2004) and after (2006) the conversion. The sampling site was a garden in a neighborhood located 2700 m downwind of the power station. In addition, air pollution concentrations and particulate matter parameters recorded by a local meteorological station were analyzed (PM_{10}, NO_x, NO_2, NO, and SO_2). Although differences in the average monthly concentration of pollution parameters are mostly insignificant between the two periods, the accumulated particulate matter exhibits considerably different spectral patterns. All first period samples exhibit a distinctly concave slope in the spectral region between 400 and 1400 nm, indicative of high amounts of soot, most likely due to the combustion products of fuel oil exhausted by the power plant. In contrast, the second period samples exhibit spectra that indicate reduced soot content and even appear slightly convex, evidencing the presence of dust of mineral origin, a feature likely masked by the soot in the first period. Thus, the spectral data support that the power plant conversion results in less pollution. More generally, this study corroborates that VIS-NIR-SWIR spectroscopy characterizes key properties of the particulate layer accumulating on sampled surfaces and thus, is a powerful method for monitoring the urban environment.

1. Introduction

Particles in the atmosphere arise from natural sources, such as windborne dust, sea spray and volcanoes, and from anthropogenic sources, such as combustion of fuels, agriculture, land use practices, and construction (Seinfeld and Pandis, 2006). Contaminants adsorb to atmospheric particles, and along with them either settle out or are moved by wind erosion or human activities (Al-Chalabi and Hawker, 1997). Thus, movement of particles in the atmosphere extends the geographical area affected by pollution sources and can significantly increase dust and pollution load (Tegen et al., 1996; Sokolik et al., 2001). Pollutants comprise various contaminants, such as lead, crude petroleum, petroleum byproducts, heavy metals etc. (Caravanos et al., 2006).

Many studies have focused on characterizing the physical and chemical constituents of settled dust and their distribution as a function of urban activities and characteristics, land use and climate conditions (e.g., Ganor et al., 1988; Chutke et al., 1995; Iskander et al., 1997; Erell and Tsoar, 1997; Charlesworth and Lees, 2001; Charlesworth et al., 2003; Banerjee, 2003; Farfel et al., 2005). In light of this body of research, the composition of settled dust serves as a key indicator when identifying sources and characteristics of air pollution (Vallack and Shillito, 1998; Seinfeld and Pandis, 2006). Ganor et al. (1988) studied settled dust in Tel Aviv between the years 1973 and 1984 and evidenced the presence of vanadium and nickel, tracers for air pollution originating from the Tel Aviv power station (which burned heavy fuel oil). Of note, it was found that the north of Tel Aviv is affected more by this air pollution.

Reflectance spectroscopy is a rapid, reliable and non-destructive tool that can be applied to mineralogical research of solid materials. In general, all compounds exhibit absorption/emission spectra that can be analyzed both quantitatively and qualitatively. Specifically, Visible-Near Infrared-Short Wave Infrared spectra (VIS-NIR-SWIR: 400–2500 nm) represent key aspects of both organic and inorganic matter, invaluable diagnostic information for environmental scientists. Indeed, VIS-NIR-SWIR spectroscopy can serve as a valid alternative to traditional methods for detecting plant stress due to pollution (Rosso et al., 2005). For example, Rosso et al. (2005) assessed the effect of two heavy metals (cadmium and vanadium) and two crude oil types (‘Escravos’ and ‘Alba’) on the growth and physiology of the Salicornia plant (a major component of wetlands in California). Plant stress, due to heavy metals or oil pollutants, was found to correlate with characteristic spectral changes.

The emergence of high spectral resolution imaging sensors has enabled VIS-NIR-SWIR spectroscopy to be applied to quantify dust loads

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on mangroves (Ong et al., 2003) and to assess rapidly the potential asbestos hazards of dust settling over lower Manhattan after the collapse of the World Trade Center (http:/greenwood.cr.usgs.gov). Furthermore, using this technique (Bretz and Akbari, 1997; Berdahl et al., 2002), it has been possible to study the influence of dust loads on the soiling of building surfaces and roof solar systems, in particular, how the dust affects reflectance properties of the underlying surface. Elemental carbon, due to combustion, has been found to be the principal pollutant accumulated on roofs over long periods (Berdahl et al., 2008). VIS-NIR-SWIR spectroscopy has been used also to correlate the reflectance characteristics of settled dust with its mineralogical composition (Arimota et al., 2002). Recently, VIS-NIR-SWIR spectroscopy was utilized by Chudnovsky et al. (2007) to evaluate dust settled on glass traps in indoor versus outdoor environments in Tel Aviv City during two seasons. Two main spectral shapes were observed. During the spring, a period with dust storm events, spectral shapes were convex, indicating that the dust contains minerals, whereas during the summer, a season without such storms, the spectral shapes were more concave, indicative of higher organic matter content.

Given the relationship between settled dust and air pollution, we evaluated accumulated dust using VIS-NIR-SWIR spectroscopy in order to advance understanding of the dispersion and transport of pollutants in the urban environment. Two kinds of targets, tree leaves and paper bags, were studied. Specifically, the matter accumulating at these locations was examined spectrally before and after transition of the Tel Aviv electric power station from fuel oil to natural gas.

2. Objective

The study goal was to discover whether converting the fossil fuel of the Tel Aviv power station from oil to gas influences air pollution in the local urban environment. To this end, the spectral properties of accumulated dust on tree leaves and paper bags were assessed before and after the conversion.

3. Materials and methods

3.1. Study area and time

The area selected for the study was the yard of a private house located in a residential suburban neighborhood in the northern part of the city of Tel Aviv (32°07′N, 34°48′E, Fig. 1, object 1). This neighborhood is not densely populated, comprising buildings mostly one story in height, each with a private yard of ~250 m^2. The main road of the neighborhood has two lanes and light traffic; there is a bus station located 200 m south of the house (highlighted as object 2 in Fig. 1). A feature of this neighborhood is much green vegetation, in particular, irrigated plants and grass (Fig. 1). Trees with extensive foliage growing along the main road likely serve as a barrier against pollution arising from transportation. Notably, according to a traffic survey, during 12 h on a representative day in 2004 there were 11,693 vehicles in both directions, whereas during the same period in 2006 11,171 vehicles were counted. These data suggest the traffic load is fairly constant in this neighborhood.

The power plant station of Tel Aviv, named Reading, is located ~2700 m south-west of the sampled garden. The garden is located downwind; the plume direction influenced generally by westerly winds in all seasons (Bitan and Rubin, 1994).

The experiment was performed during two periods, each four months long from July to October: 1/07/2004–30/10/2004 and 1/07/2006–30/10/2006. We focused on the dry months, as it is possible to collect matter accumulating during the entire period without the complication of rainfall.

3.2. Meteorological and air quality conditions

The city of Tel Aviv is located in a Mediterranean climate (defined as Cs_a according to the Koppen classification, i.e., temperate with dry summer) and situated north of the arid regions, which represent a source of mineral dust (Goldreich, 2003). The study period covers the

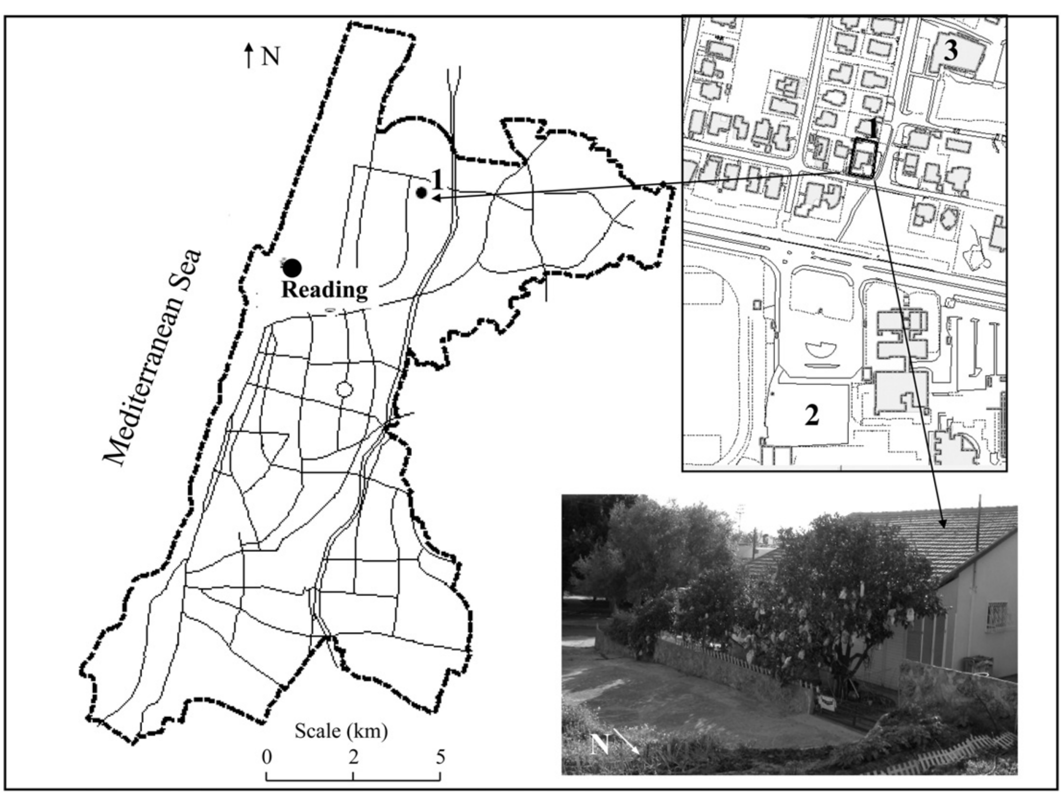

Fig. 1. A schematic map showing Tel Aviv City and the locations of the Reading power plant station and the sampled area. 1 denotes the location of the study area, 2 a bus station 200 m from the sampled site and 3 the meteorological station. The photograph shows the sampled site, orange trees and bags protecting the oranges from insects.