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Ozone phytotoxic potential with regard to fragments of the Atlantic Semi-deciduous Forest downwind of Sao Paulo, Brazil

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ABSTRACT

In the Metropolitan Region of Campinas (MRC), Brazil, high levels of primary pollutants contribute to ozone (O_3) formation. However, little is known regarding the O_3 effects in the tropics. Objectives in this study were to characterize the present levels of O_3 pollution and to evaluate the relevance of current concentration-based indices for assessing the phytotoxic potential of O_3. Changes in O_3 concentrations and precursors at 5 monitoring stations within towns of MRC were analyzed. The daily O_3 profile was typical for urban sites and showed little yearly variation. Given the permanently foliated forest canopy, yearly rather than seasonal O_3 indices were thus more appropriate for estimating the effective ozone dose. With yearly SUM00, SUM60 and AOT40 of 156, 16 and 14 ppm h and confirmed by evidence of O_3 injury in foliage, oxidative stress in the MRC has reached levels high enough to affect trees from the Atlantic Semi-deciduous Forest.

1. Introduction

Tropospheric Ozone (O_3) is produced by photochemical reactions including primary pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOC). These O_3 precursors have a mostly anthropogenic origin and primarily result from fossil fuel combustion (Ashmore, 2005; Cape, 2008). The first ozone measurements, performed as far back as the middle of 19th century by means of more than 300 stations in Europe and the United States of America, have documented background O_3 levels reaching 10 ppb (Vingarzan, 2004; Voltz and Kley, 1988). As a consequence of industrialization and traffic development, the O_3 levels during the 20th century have more than doubled and range between 20 and 45 ppb nowadays over the mid-latitudes of the Northern Hemisphere (Vingarzan, 2004). In the Southern Hemisphere, little information is available on past and present background O_3 concentrations but the trends appear to be basically similar to those in the rest of the world (Emberson et al., 2001; Sandroni et al., 1992). As with other industrial and densely populated regions at higher latitudes, increased air pollution in rural regions downwind from large conurbation, e.g. the metropolitan region of Sao Paulo, has also been documented (Andrade et al., 2004, 2012; Boian and Andrade, 2012; Massambani and Andrade, 1994; Molina and Molina, 2004; Orlando et al., 2010).

The adverse effects of O_3 on plants were first identified in the 1950s and O_3 is currently regarded as one of the most toxic air pollutants with respect to human and plant health (Ashmore, 2005). Because the effects of oxidative stress in plants are cumulative, concentration-based O_3 dose indices have been developed for characterizing the threat to crops, forest trees and natural ecosystems (EPA, 1996; Massman et al., 2000; Mills et al., 2011a). SUM00 and SUM60 are the reference indices for defining critical limits with regard to forest tree protection in the USA and are calculated by summing up all hourly concentrations (SUM00) and all hourly concentrations over a threshold of 60 ppb (SUM60; Bytnerowicz et al., 2008). In European countries, the AOT40 - defined as the cumulated differences between the hourly mean ozone concentration and 40 ppb threshold for all daylight hours (6:00–20:00) during the vegetation season (Mills et al., 2011a) – is the reference index. For trees, the critical limit was reduced from 10 ppm h (Kärenlampi and Skärby, 1996) to 5 ppm h accumulated over one growing season, which corresponds to a 5% yield loss on an annual basis for broadleaved trees (Mills et al., 2011b). All these indices are commonly used to assess the phytotoxic potential of O_3 in forests from the Mediterranean to the boreal vegetation belt of the Northern Hemisphere. However, critical evaluation of their

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relevance in the case of trees growing in the tropics and Southern Hemisphere is still wanting.

Given the large number of plant species sensitive to O_3, 50% of the world's forests may be affected by this pollutant (Percy et al., 2003; Shriner and Karnosky, 2003). Throughout Europe, visible O_3 injury in foliage has been reported in 30 crop species (Mills et al., 2011b; Sanz and Calvo, 2010), 95 species of grasses and forbs, 49 species of shrubs (Mills et al., 2011a) and 35 species of trees (Sanz and Calatayud, 2011). In the USA and on the basis of surveys in the national parks, 73 forb, shrub and tree species, mostly native, have been identified as being sensitive to O_3 (NPS, 2006; Porter, 2003). In the Southern Hemisphere, only a few studies, using either bioindicator species such as *Nicotiana tabacum* Bel-W3 (Sant'Anna et al., 2008) or native trees, such as *Tibouchina pulchra* (Cham.) Cogn. exposed to O_3 in controlled conditions (Furlan et al., 2008), give preliminary indications of potentially harmful ozone effects. However, the phytotoxic potential and present impact of O_3 on native plant species and tropical ecosystems of Southern Hemisphere remains mostly unknown (Sitch et al., 2007).

The present study was initiated to determine whether the actual tropospheric ozone levels may affect tropical and sub-tropical forests in an economically thriving region of the Southern Hemisphere — namely the Metropolitan Region of Campinas (MRC) downwind from Sao Paulo, Brazil. The principal objectives were to 1) characterize the daily, seasonal and interannual pattern of O_3 concentration in the MRC, 2) evaluate which current concentration-based O_3 indices are more appropriate to assess the phytotoxic potential of O_3 in forest fragments of MRC and 3) confirm the inferred phytotoxic O_3 potential with assessments of visible injury in foliage of native trees growing in fragments of the Atlantic Semi-deciduous Forest of MRC. Therefore, air pollution and meteorological data from a permanent monitoring station network established in the early 2000s at mostly urban sites were analyzed in the context of the tropical and sub-tropical climate of MRC. After selecting representative native tree species, visible leaf injury in native forest stands was assessed applying a methodology similar to that used in surveys at higher latitudes (UNECE/ICP, 2009).

2. Material and methods

2.1. Study site

The Metropolitan Region of Campinas (MRC) extends over 3.647 km^2 and includes rural, industrial and urban areas (Fig. 1). With 19 cities and nearly 3 million inhabitants, (15% of the population of Sao Paulo state), the MRC is densely populated. With the fastest rate of development in the state, it is also economically thriving and its large industrial park includes petrochemical, textile, food processing, automobile, metallurgy and pharmaceutical industries. Moreover, its infrastructures are well developed and, with 1.9 million vehicles, its car and truck fleets amount to 8% of the Sao Paulo state total (Detran, 2013 http://www.denatran.gov.br/frota2013.htm). As a consequence, the MRC has been affected by high levels of air pollution, with the road traffic (99.0, 82.5 and 81.2% of the CO, hydrocarbons and NO_x emissions, respectively) and industrial activities (66.8% of the particulate matter emissions) as the primary sources of air pollutants (Fig. 2; Ueda and Tomaz, 2011). In addition to local emissions, the MRC is also affected by sizable emissions from the Metropolitan Region of Sao Paulo (MRSP), as a result of the predominantly southerly and southwesterly winds (Fig. 1; Boian and Andrade, 2012).

The climate in the MRC is predominantly subtropical humid and, according to Thornthwaite's typology, can be classified in the B1rB'4a type (Fig. 3; Rolim et al., 2007). During the wet season (October through March), monthly rainfall and the average temperature reach 200 mm and 24 °C whereas they drop to 30 mm and 20 °C during the dry season (April through September; Franchito et al., 2008).

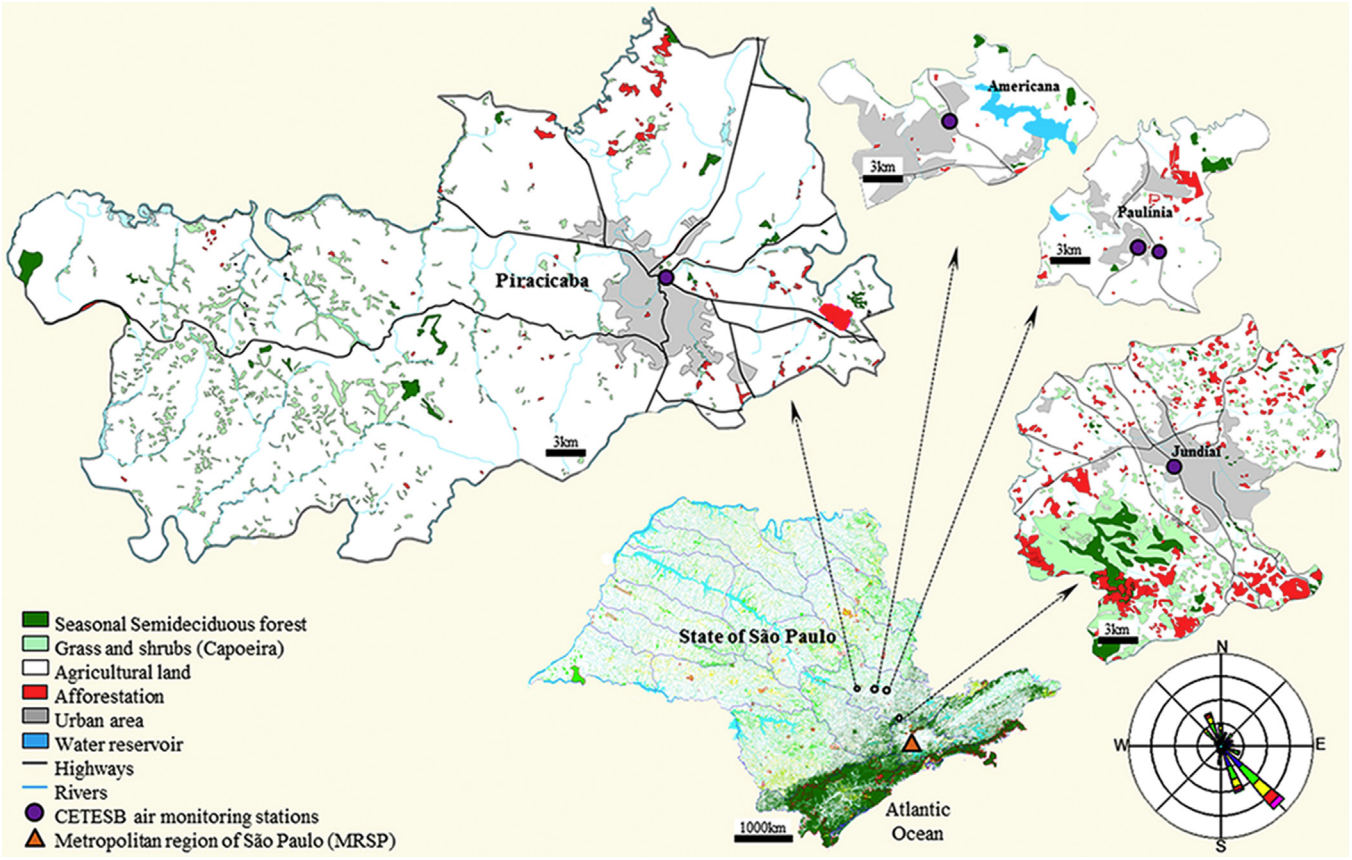

Fig. 1. Location of MRC towns within the Sao Paulo state, SE Brazil. Within each town map, the principal remnants of native vegetation, land use, and CETESB air quality monitoring stations are indicated. The wind rose graph indicates the prevailing wind directions.
Source: Instituto Florestal/Governo do Estado de São Paulo (maps), CETESB (wind rose; CETESB, 2006).