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Environmental Magnetic Characterization of Iron-Bearing PM2.5 from Urban Traffic in São Paulo (2022–2023)

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Introduction

Since the Industrial Revolution, pollutant emissions have increased significantly due to rapid urbanization and industrial expansion. Suspended particles—namely PM1 (< 1 µm) and PM2.5 (< 2.5 µm)—can penetrate the respiratory tract and central nervous system, while ultrafine particles can translocate into the bloodstream. A noteworthy subclass, iron-containing particulate matter (IPM), originates from anthropogenic activities such as vehicle exhaust, industrial emissions, and road dust resuspension. Due to its potential health impacts, the characterization of IPM has attracted growing interest. Although magnetic and structural analyses have characterized IPM in Europe, Asia, and North America, South America remains largely unexplored. São Paulo—Brazil's largest metropolis, with over 11 million inhabitants—suffers from complex air pollution caused by heavy traffic, industrial processes, and secondary aerosol formation. This study addresses three main questions: (1) Which iron oxide phase dominates airborne IPM in São Paulo? (2) How do seasonal atmospheric conditions modulate IPM concentrations? (3) Can magnetic parameters serve as reliable proxies for conventional air quality indicators? To answer these questions, we conducted a detailed characterization of PM2.5 samples collected in 2022–2023 at two high-traffic sites in São Paulo, integrating magneto-structural analyses, particle morphology assessments, and seasonal trend evaluations to deliver the first such dataset for the city.

Method and/or Theory

A total of 92 PM2.5 filter samples were collected using high- and low-volume samplers at two locations: one beneath dense vegetation on the FSP-USP campus, and the other adjacent to the FMUSP parking lot. Low-frequency, low-field magnetic susceptibility (χ_{LF}) was measured to quantify magnetic mineral concentrations, followed by the acquisition of hysteresis loops to determine magnetic domain states. Isothermal remanent magnetization (IRM) curves were used to assess coercivity spectra and saturation IRM (SIRM), as well as to calculate HIRM and S-ratio parameters. Backfield demagnetization of the SIRM was performed to determine the remanent coercivity (Hcr). These magnetic parameters were analyzed in conjunction with seasonal meteorological variables—thermal inversions, wind speed, and precipitation—and conventional air pollutant concentrations (PM10, NO, NO_2, NO_x, SO_2, CO, and O_x).

Results and Conclusions

The dry season conditions, marked by atmospheric stagnation, resulted in increases of 30 to 50% in magnetic susceptibility and remanent magnetization, indicating intensified vehicle emissions and reduced dispersion. In contrast, wet season rainfall reduced iron-containing PM2.5 by 40 to 60%, demonstrating the natural cleansing effect of precipitation. Interannual climate variability further modulated these seasonal effects. Mineralogical analysis identified magnetite and maghemite as the predominant magnetic phases, while hysteresis patterns revealed a significant ultrafine superparamagnetic fraction that escapes standard monitoring but may pose high health risks. Strong positive correlations between magnetic parameters and conventional pollutants (mainly NO_2 and CO) support the application of environmental magnetism as a scalable and economical proxy for air quality assessment in megacities.