

Tracing Atmospheric Metal Pollution in the Arctic

IRAVATI RAY¹, DR. RESHMI DAS², ROHIT
SRIVASTAVA¹ AND LALURAJ C. M.³

¹National Centre for Polar and Ocean Research (NCPOR)

²Jadavpur University

³National Centre for Polar and Ocean Research (NCPOR),
Ministry of Earth Sciences, Vasco-da-Gama, Goa - 403804, India

The Arctic atmosphere is experiencing significant enrichment of anthropogenic metals, including Cd, Cr, Cu, Ni, Pb, Zn. Ship traffic along the Northern Sea Route (NSR) in the Arctic circle has increased in the past decade due to climate-induced ice melt, attracting global interest. Additionally, rising wildfire frequency contributes to biomass-burning aerosols, while sea ice loss intensifies coastal erosion, increasing crustal material input into Arctic aerosols. This study investigates the primary sources of these pollutants, focusing on ship emissions, biomass burning, and crustal contributions by integrating field analysis, isotopic characterization, and statistical modeling.

Year-round PM_{2.5} samples are collected at the Indian research station Himadri, Ny-Ålesund, Svalbard, alongside natural and anthropogenic end members, including soil, seawater (for sea-spray aerosols), coal, biomass, and ship oil. These samples are analyzed for trace elements and Pb isotopes using Thermo Scientific Element XR HR ICP-MS. Analytical data suggest India and Southeast Asia contribute negligibly, highlighting the dominance of local and maritime sources.

Pb isotope systematics is a powerful tracer for emission sources as Pb isotopes do not fractionate during physicochemical processes. However, a global scarcity of Pb isotope data for ship emission limits source attribution accuracy. Notably, while Pb isotope data exist for PM₁₀ aerosols in the Arctic region, none has been reported for PM_{2.5}, where anthropogenic Pb is concentrated, making its source apportionment crucial.

The Pb isotopic composition of ship oils ranges from 1.1115 to 1.3628 in ²⁰⁶Pb/²⁰⁷Pb space and 2.3627 to 2.4118 in ²⁰⁸Pb/²⁰⁷Pb space, while Arctic PM₁₀ aerosols range from 1.1325 to 1.9474 and 2.4032 to 2.4732, in the same isotopic spaces respectively. The lower end of the aerosols aligns with ship emissions, proving it as one of the sources of atmospheric Pb in the region. Additionally, elemental markers, such as vanadium-to-nickel (V/Ni) ratios, indicate ship emissions as a major contributor. This study further uses the Bayesian Mixing Model (MixSIAR) to quantify pollution sources and assess whether local emissions are rising. Findings highlight the need for stricter regulations on marine transport emissions, while future research should expand Pb isotope databases and refine source identification methods by incorporating additional emission markers.