Diverging Chemical Evolution of Global $PM_{2.5}$ in Developing and Developed Regions from 2003 to 2023

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Understanding $PM_{2.5}$ Composition Aids Air Quality Management

- Global $PM_{2.5}$ composition profile is highly diverse due to diverse local emission patterns and natural backgrounds.
- Composition trend analysis provides insights to interpret the global $PM_{2.5}$ reversal[1].
- Understanding long-term compositional trends helps inform composition-specific air quality assessment, evaluate past regulations, and guide future policies.

Methods

- **Chemical Transport Model**: We used the GEOS-Chem chemical transport model in its high-performance implementation (GCHP) version 14.6.0 at cubed-sphere resolutions of C180 (~50 km) with Community Emissions Data System (CEDS) emission inventory release April 2025. The simulation duration is 21 years from 2003 to 2023.
- **Downscaling**: To maintain consistency with the Global Burden of Disease study and improving the accuracy of population-exposure estimates, we used 2019-2023 mean satellite-derived $PM_{2.5}$[2] to downscale the simulated $PM_{2.5}$ to 1km grid, while preserving the relative simulated composition and trend.

Regional and Compositional Drivers Behind the Global $PM_{2.5}$ Exposure Reversal

- The global $PM_{2.5}$ reversal is mainly driven by SNA-OA stagnation and reduction in HighExposure-Growth (H-G) and HighExposure-Reduction (H-R) regions, largely located in developing countries.

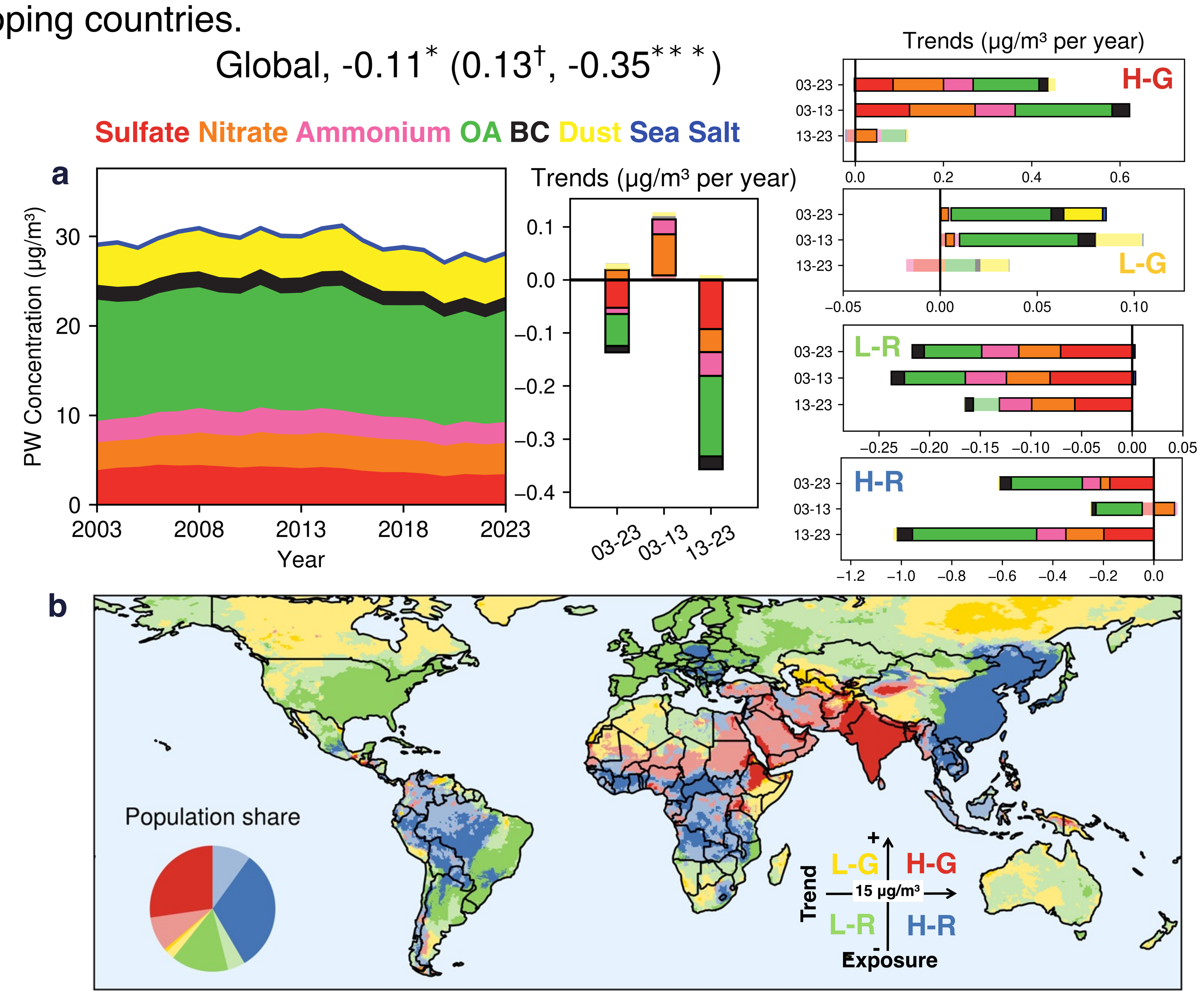

Fig. 1. **a** Population-weighted mean $PM_{2.5}$ composition and trends over 2003-2023, 2003-2013 and 2013-2023 for global and four air-quality regimes (H-G, L-G, L-R, H-R) determined by exposure level (WHO Interim Target 3, 15 μg/m³ as the threshold) and trend sign.
b Global map of the four air-quality regimes for 2003-2023. Pixels with statistically insignificant trends (p >= 0.05) are displayed with increased transparency.

Trend Drivers and Emerging Contributors in Developed and Developing Regions

- Sulfate and nitrate control the reduction in developed regions; OA drives both increasing and decreasing trends in developing regions.
- OA and nitrate have become the major emerging contributors in developing and developed regions, respectively.

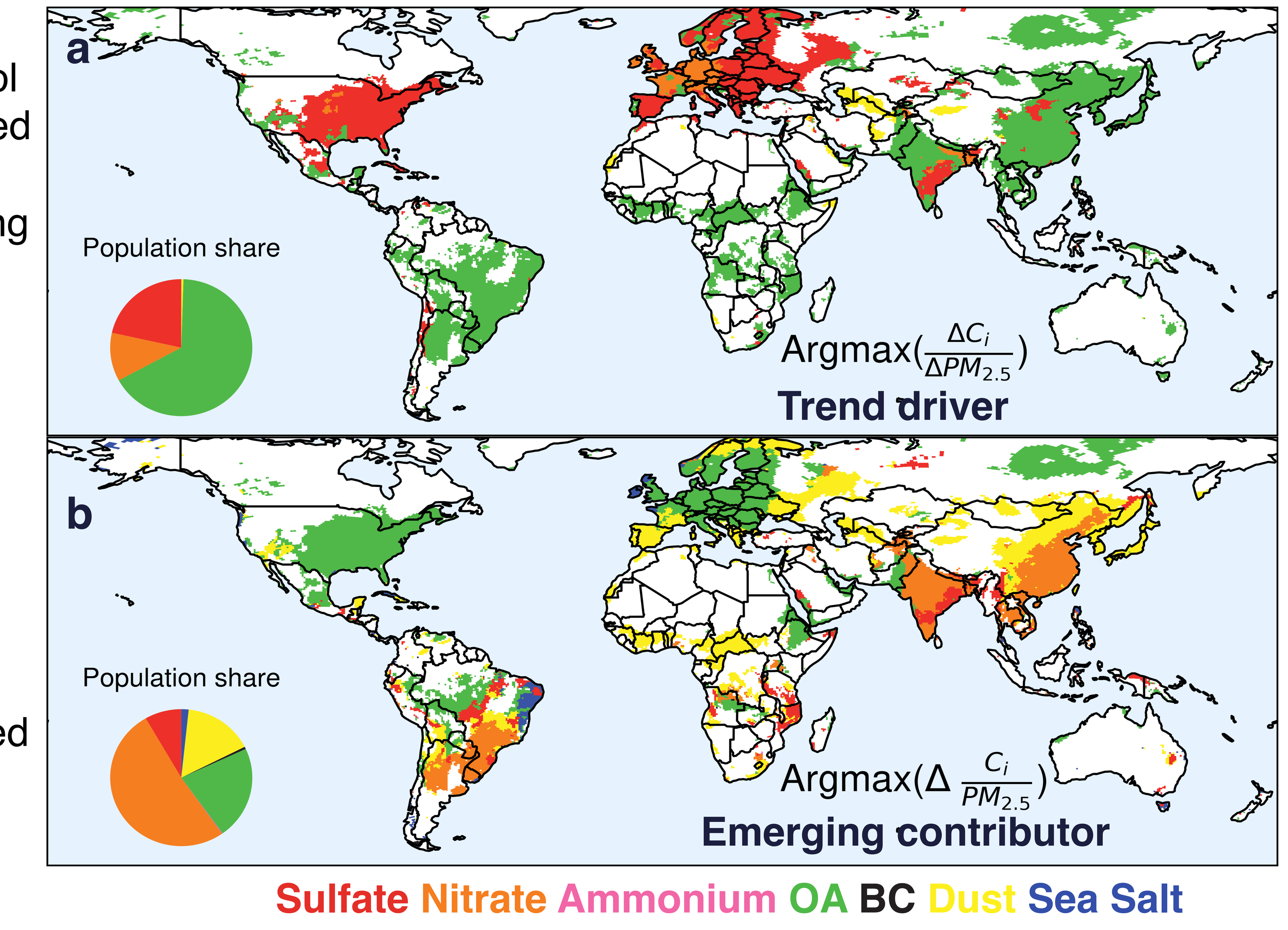

Fig. 2. Global map of compositional trend driver (**a**) and emerging contributor (**b**) to $PM_{2.5}$ over 2003-2023. Only pixels with significant trends are shown.

Diverging Characteristic Species Group in $PM_{2.5}$ control towards WHO targets

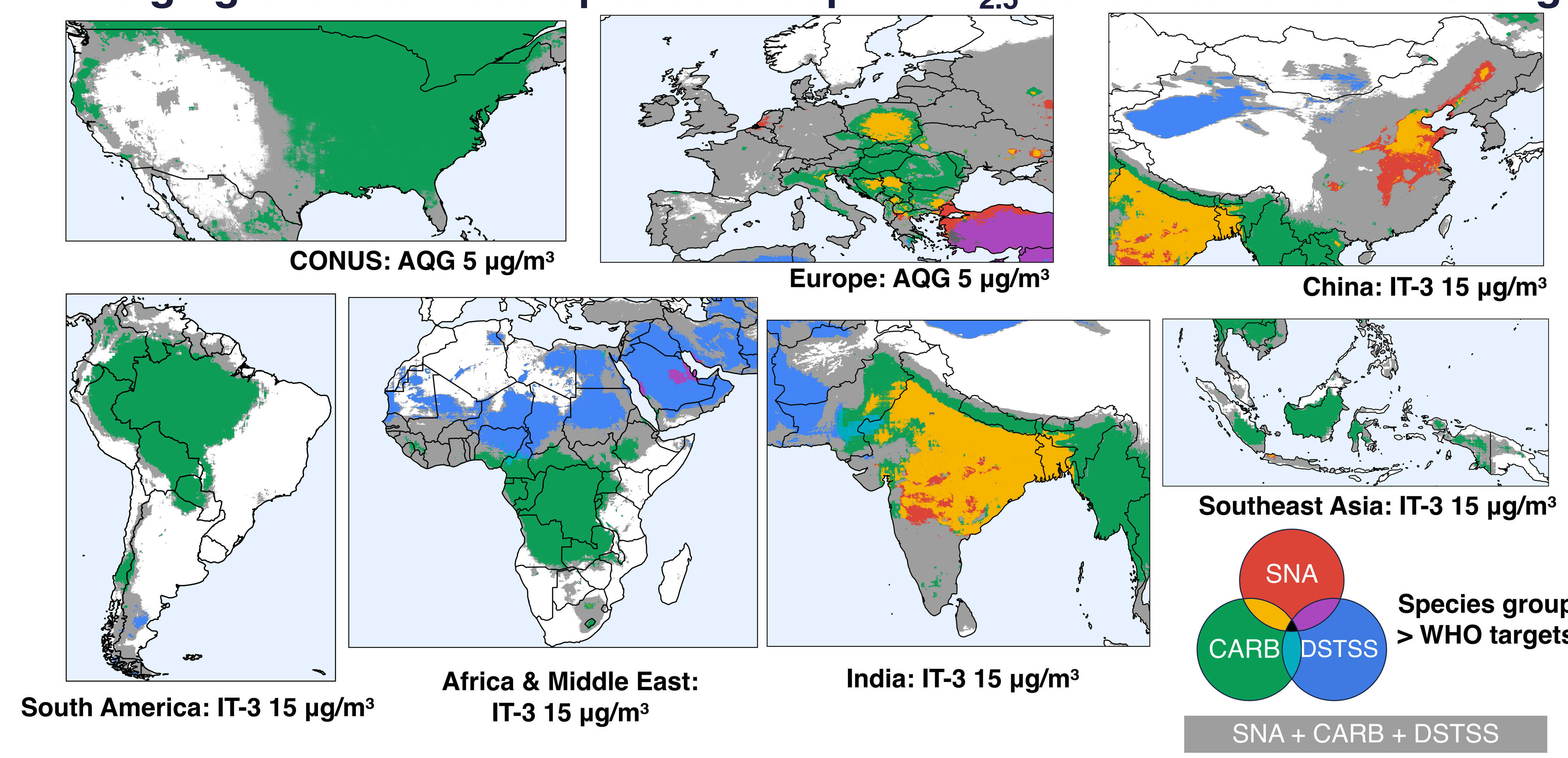

Fig. 3. Species groups violating regionally varying WHO targets in different regions for 2023

Summary

- The global $PM_{2.5}$ reversal is driven by a shift in SNA-OA trend in developing regions and assisted by continuous reduction in developed regions.
- SNA dominates $PM_{2.5}$ trends in developed regions with OA emerging as a rising contributor, whereas OA dominates in developing regions with nitrate emerging as a rising contributor.
- Diverging chemical evolution of $PM_{2.5}$ warrants diverging control strategies in developed and developing regions.

[1] Li, C. *et al.*, (2023). *Nature communications*, 14(1), 5349. [2] Shen, S. *et al.*, (2024). *ACS ES&T Air*, 1(5), 332-345.

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