利用超级站$PM_{2.5}$分子与元素示踪物小时数据解析香港城市尺度空气污染源

Informing city-scale air pollution episodes using hourly time-scale measurements of $PM_{2.5}$ molecular and elemental tracers at an air quality supersite in Hong Kong

香港科技大学

化学系；环境与可持续发展学部

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Hong Kong University of Science & Technology

Introduction: Haze pollution in Hong Kong

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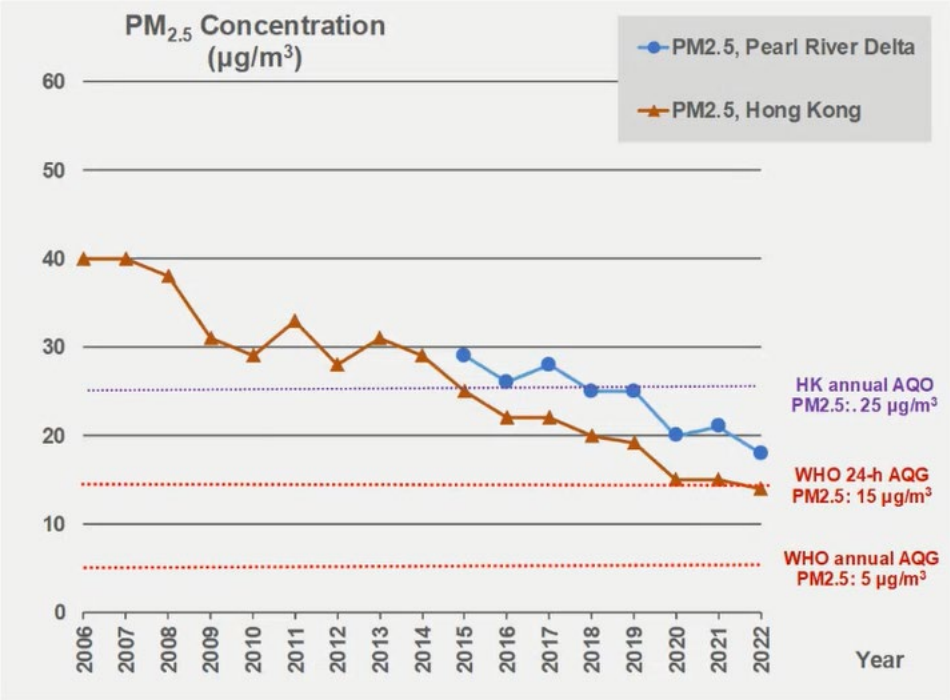

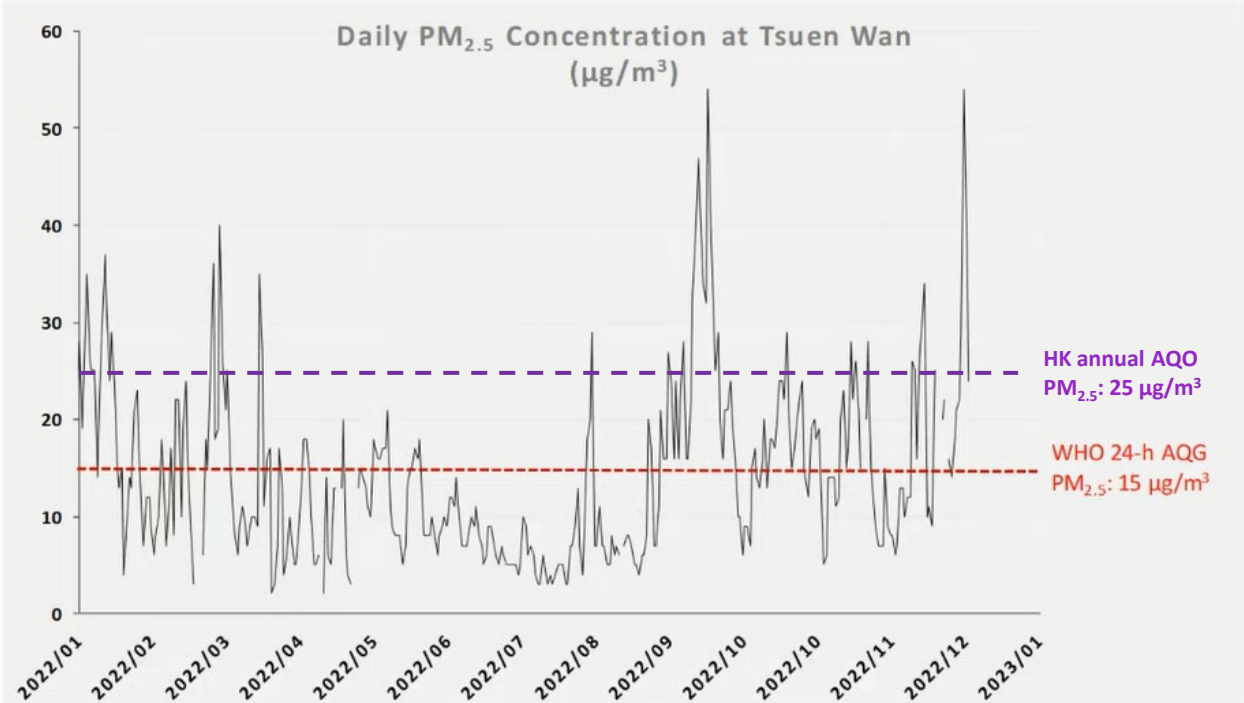

- ✓ Annual $PM_{2.5}$ levels **decreased significantly** in Hong Kong (**48%** reductions), in compliance with the national annual air quality objectives of **35 µg m^{-3}** in recent years
- ✓ **Short-term (several hours to few days) $PM_{2.5}$ pollution** sporadically occurred in winter and has become a major focus of public attention

Introduction: Haze pollution in China

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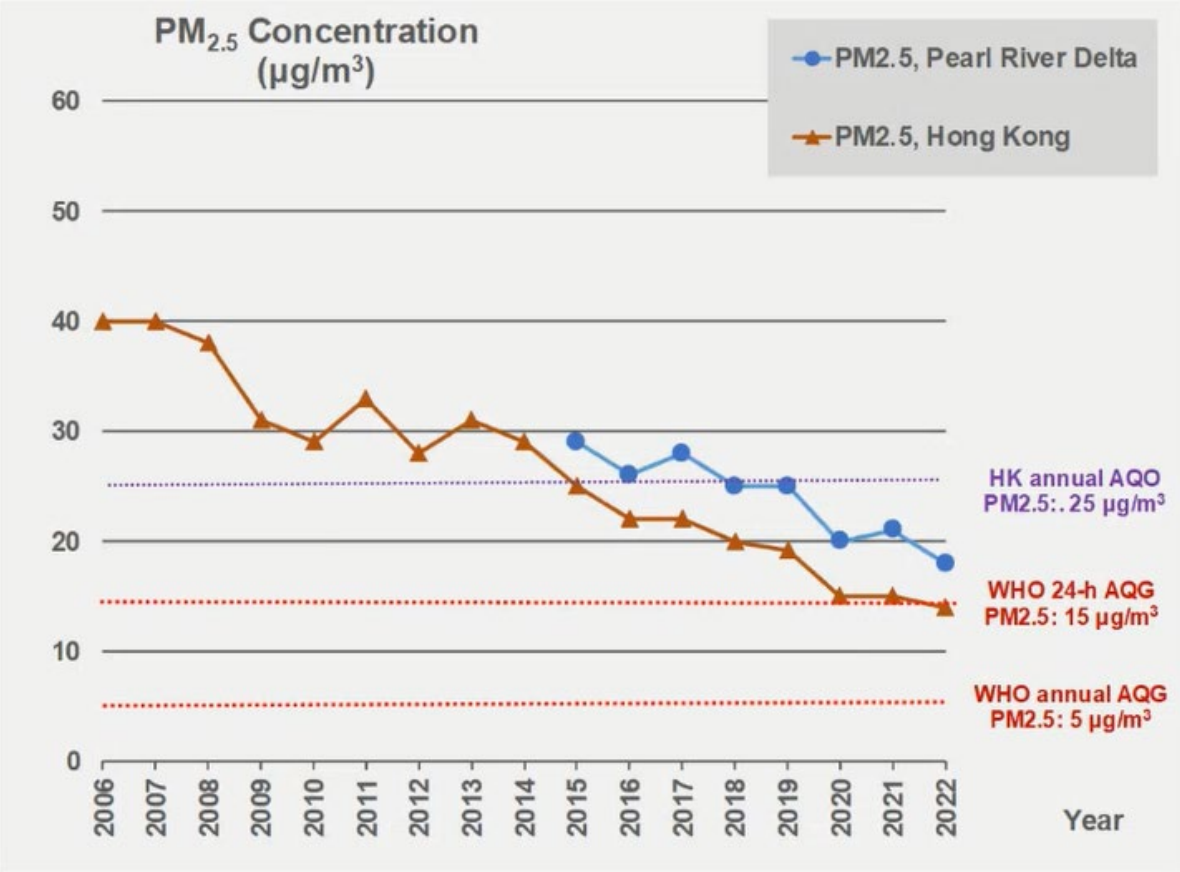

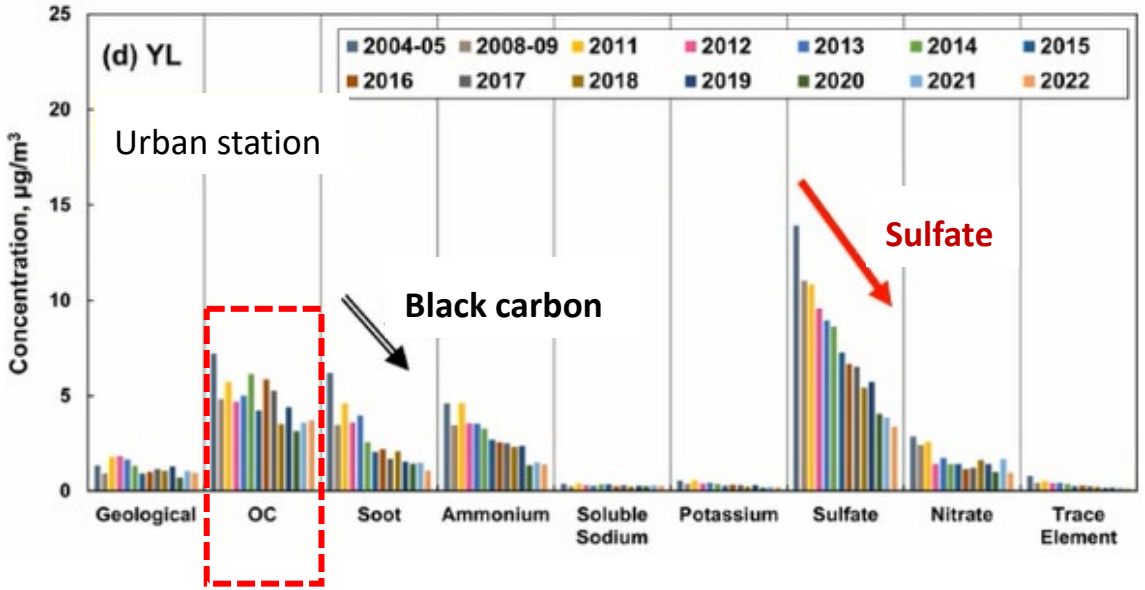

Organic aerosols (OA) becomes increasing more important, as the inorganic ion constituents have decreased notable in the past decade

Introduction: Molecular and elemental source tracers

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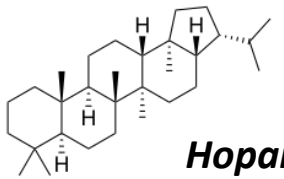
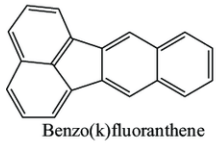
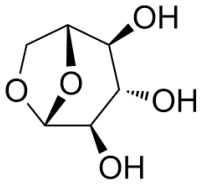
- ✓ Come from either direct emissions from specific source or atmospheric oxidation of specific VOC precursors
- ✓ Provide clues to identify various **specific sources** and/or associated **precursors**



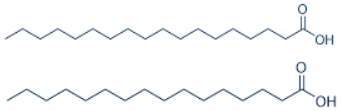
Hopanes



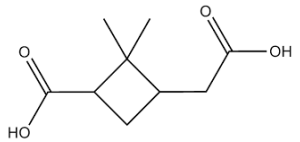
PAHs

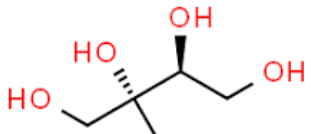


Levoglucosan

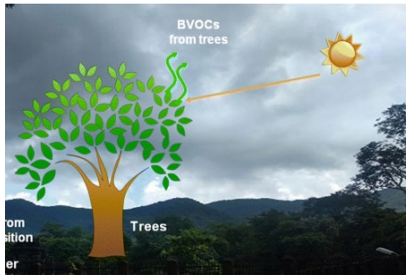


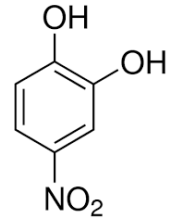
Fatty acids





SOA tracers





4-nitrocatechol

Introduction: Importance of molecular tracers

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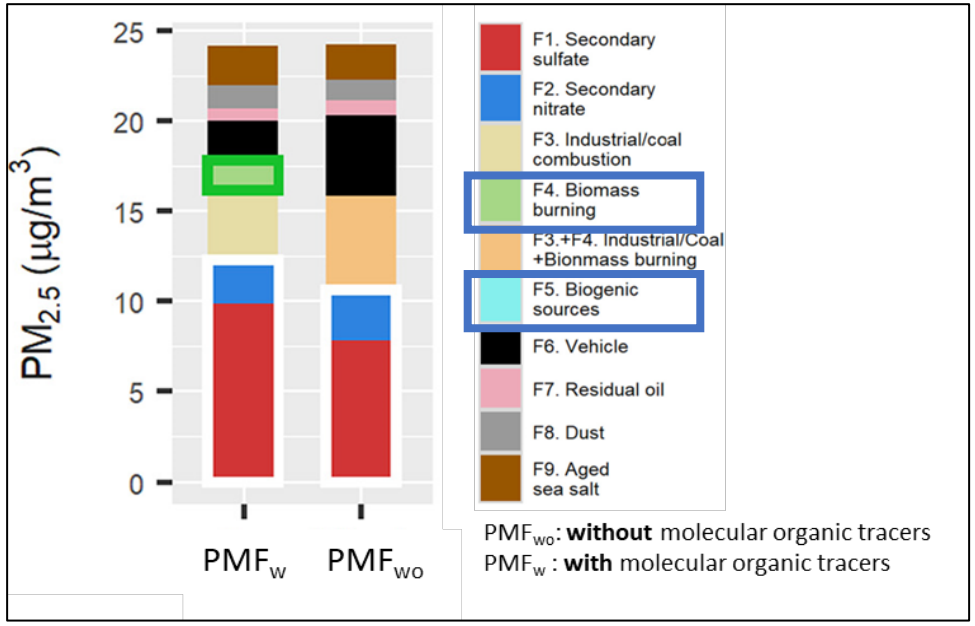
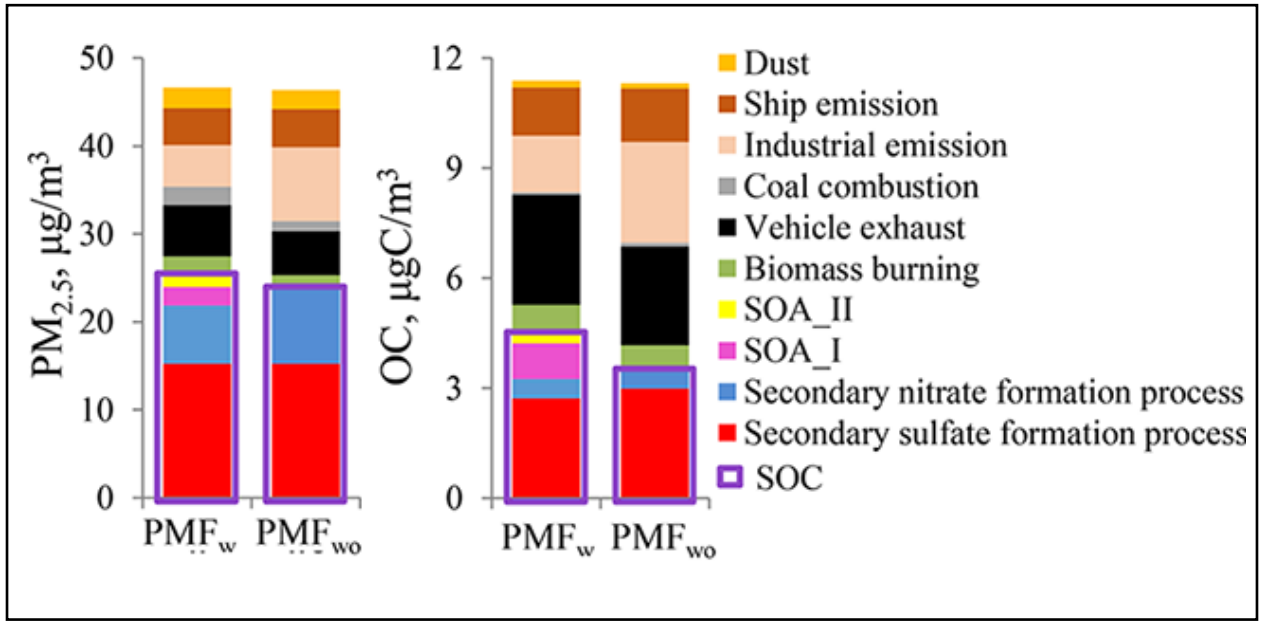
- ✓ Without organic molecular tracers, organics-dominant sources (e.g., biomass burning, biogenic sources, cooking emissions) could not be resolved
- ✓ Without secondary organic aerosol (SOA) tracers, secondary source contributions to $PM_{2.5}$, especially to OC are notably underestimated.
- ✓ Molecular tracers are crucial to apportion various primary and secondary **organics-dominant sources** through providing **unambiguous source information.**





(Chow et al., 2022; Wang et al., 2017)

Introduction: Limitations with offline measurements

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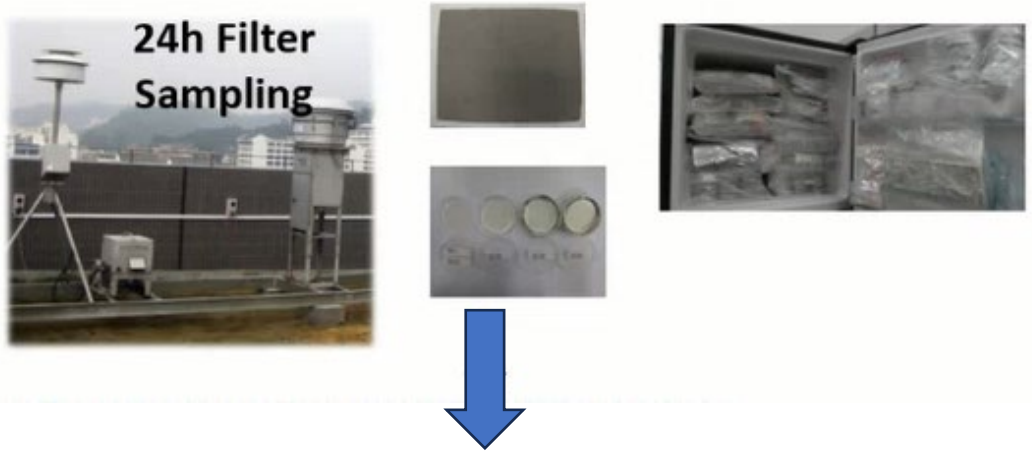
Traditionally, PM sampling and chemical species characterization is based on **24 hours filter-based** measurements (once every 6 days) and following **off-site laboratory analysis**



Limitations

- **Not timely:** a few or more months to obtain compositional data
- **Not continuous:** cannot capture or miss significant episodic events
- **Coarse time resolution:** unable to resolve the source changes and formation dynamics **at the diurnal time scale**

Introduction: Rapid changing of PM sources

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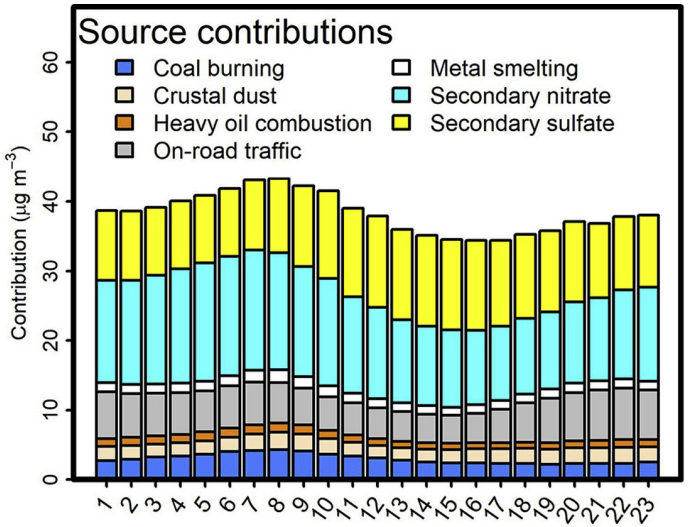
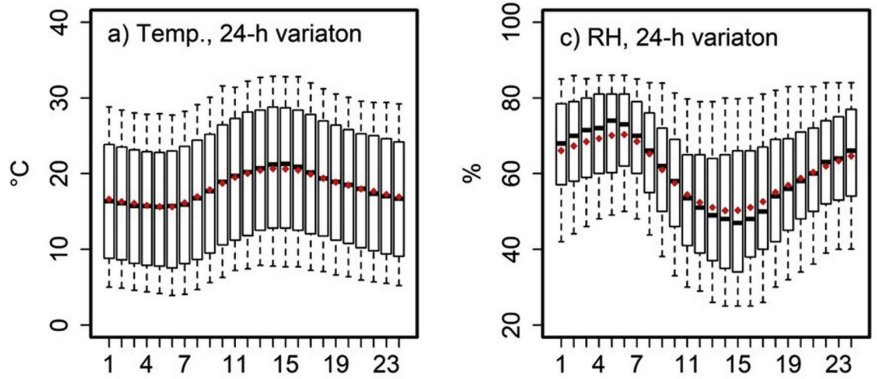
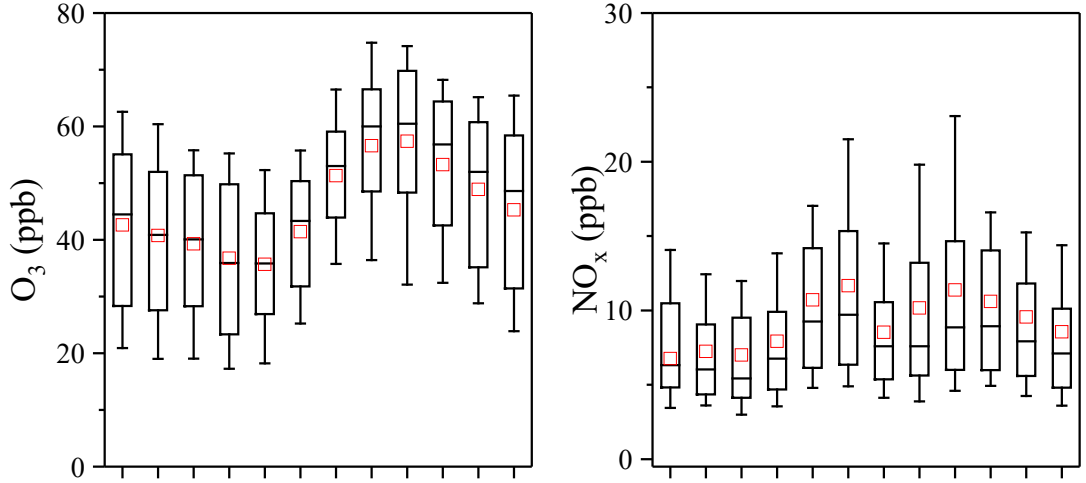
- Different diurnal pattern of emissions

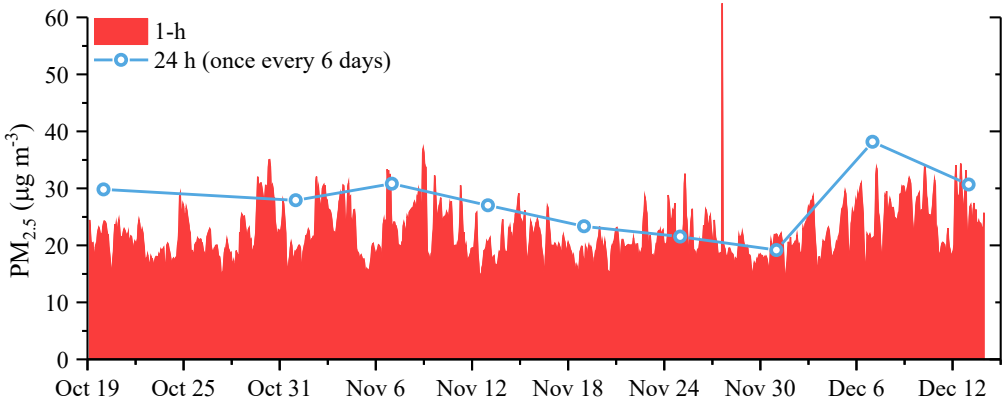


- Fast meteorology changes



- Different dominant oxidants in diel cycle





Hourly resolution measurements are needed

Introduction: Air quality monitoring network in Hong Kong

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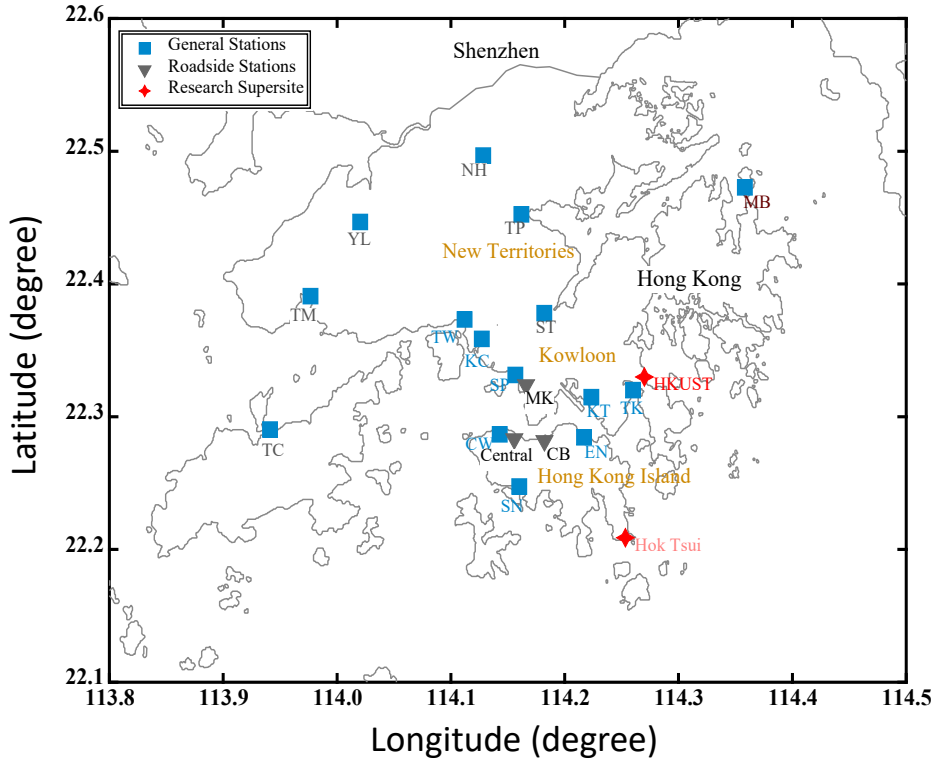
The air quality monitoring network in Hong Kong (operated by HK EPD), consists of

☐ 15 **general sites** and 3 **roadside stations:**

√ across various spatial scales

√ continuously measure criteria air pollutants (PM, O_3, etc)

X aerosol composition, potential sources, and chemical transformation processes not unavailable as the lack of more advanced instruments



☐ 2 **research supersites:**

HKUST supersite (built in 2011) and Hok Tsui supersite (new one, built in 2017)

√ more advanced, high-time-resolution instruments that enable real-time characterization of ambient PM chemical composition

X limited number, constrained by resource availability

Introduction: Instrument availability in the network

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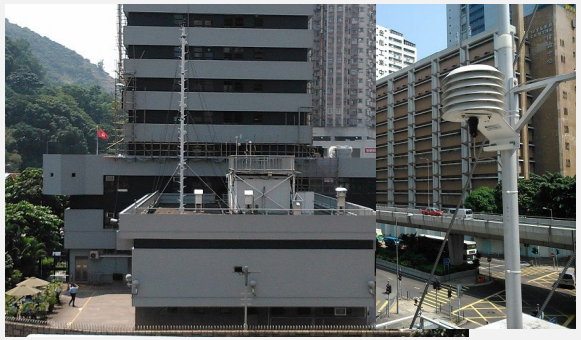
Trace Gas analyzers

PM sampler



Automatic weather station (AWS)

General stations (basis measurements) **vs.** General stations (enhanced measurements) **vs.** HKUST Supersite (more advanced online instruments)

Online X-Ray Florescence spectrometer

Monitor for AeRosols and GAses (MARGA)

Semi-continuous OC/EC analyzer

Thermal desorption Aerosol Gas Chromatography-Mass Spectrometry analyzer (TAG-GCMS)

VOCUS-PTR-ToF w/ ARI GC

Scanning Mobility Particle Sizer Spectrometer (SMPS)

etc.

Introduction: Objective & Motivations

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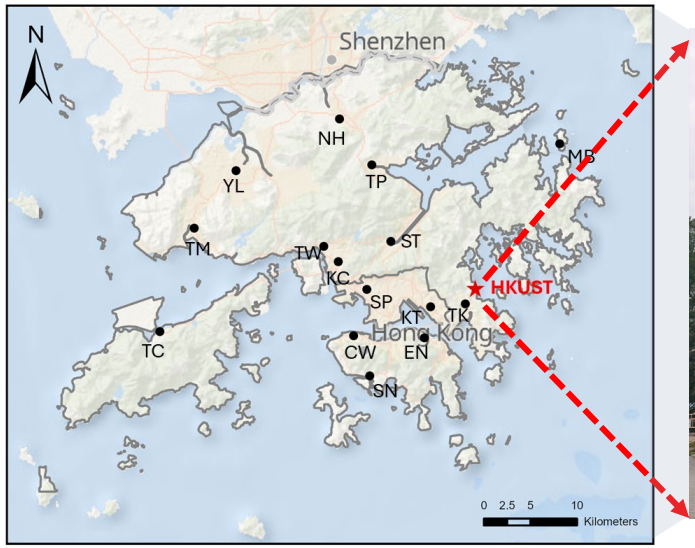
Object 1: Investigate the complementary roles of the two types of monitoring stations (**general stations vs supersite**)

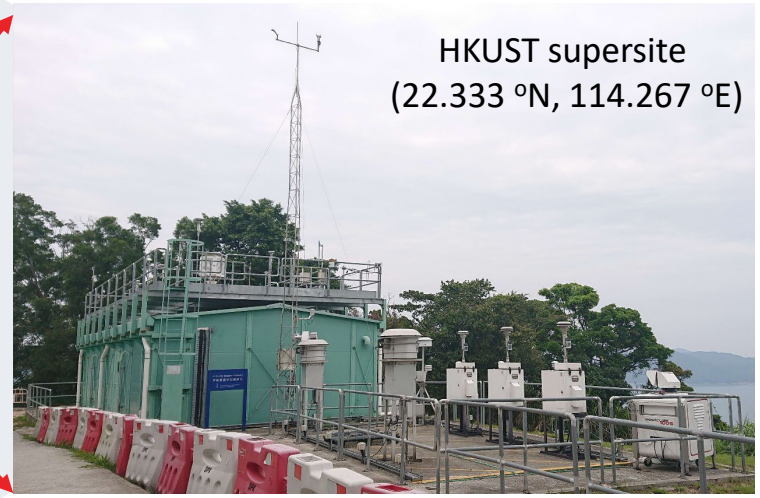
- How about the variations in $PM_{2.5}$ and major species among different sites?
- Can the comprehensive measurements at the supersite inform the city-scale pollution?

Object 2: Investigate the driven factors in accumulating the city-scale haze pollutions in Hong Kong

-- Tracer-based source contributions of $PM_{2.5}$ and OC

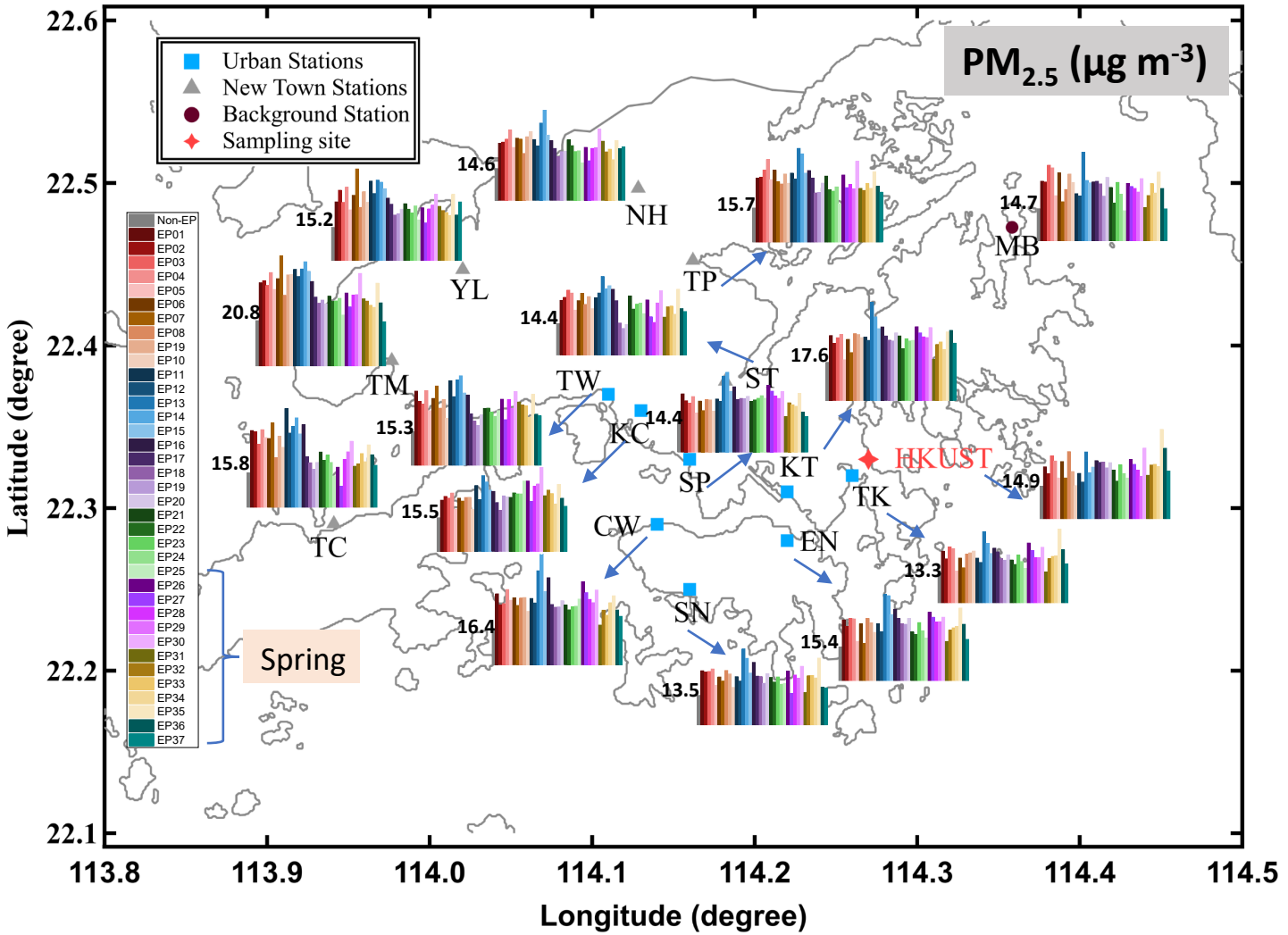
-- Evolution process





**no instruments were available to measure the individual organic molecular markers at the Hok Tsui supersite*

Results: $PM_{2.5}$ episodes and its spatial variations



**numbers on the top of the grey bar for non-episodic hours indicate the concentration values*

❑ **Entire period**

24 Nov 2020 to 2 May 2021

❑ **Criterion**

Lasted for ≥ **6 consecutive hours**

Occurred in ≥ **3 stations**

$PM_{2.5}$ mass > **25 μg m^{-3}** (WHO, AQG IT-4)

❑ **Episodes**

No. = **37** episodes

EP01-24 falls in winter

EP25-37 falls in spring

Clear spatial variations with higher levels in **northwestern stations** (e.g., YL, TM, TP)

Results: $PM_{2.5}$ and its trace element variations

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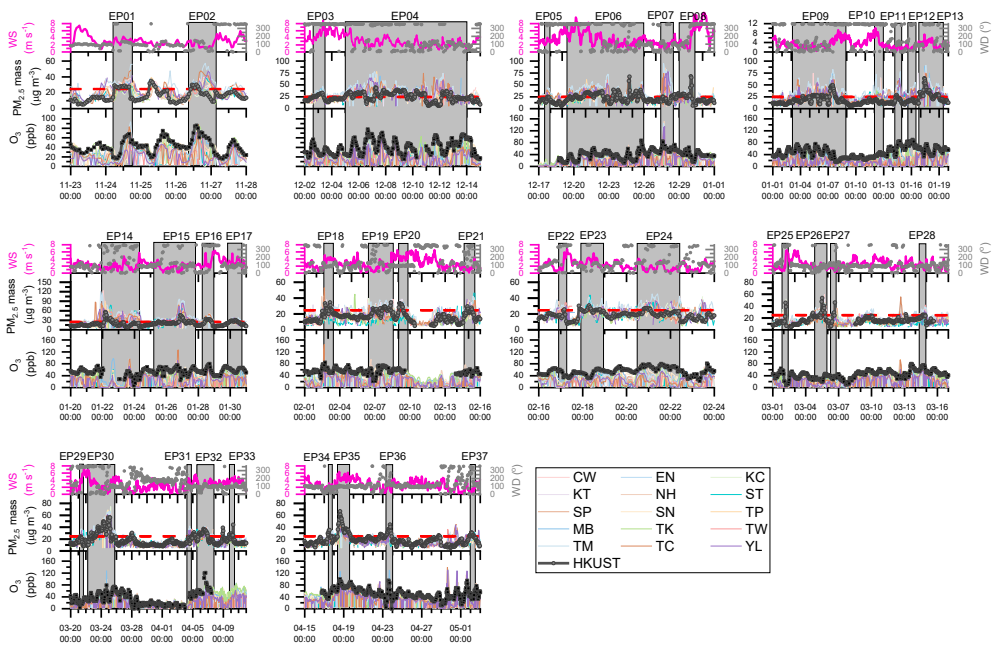
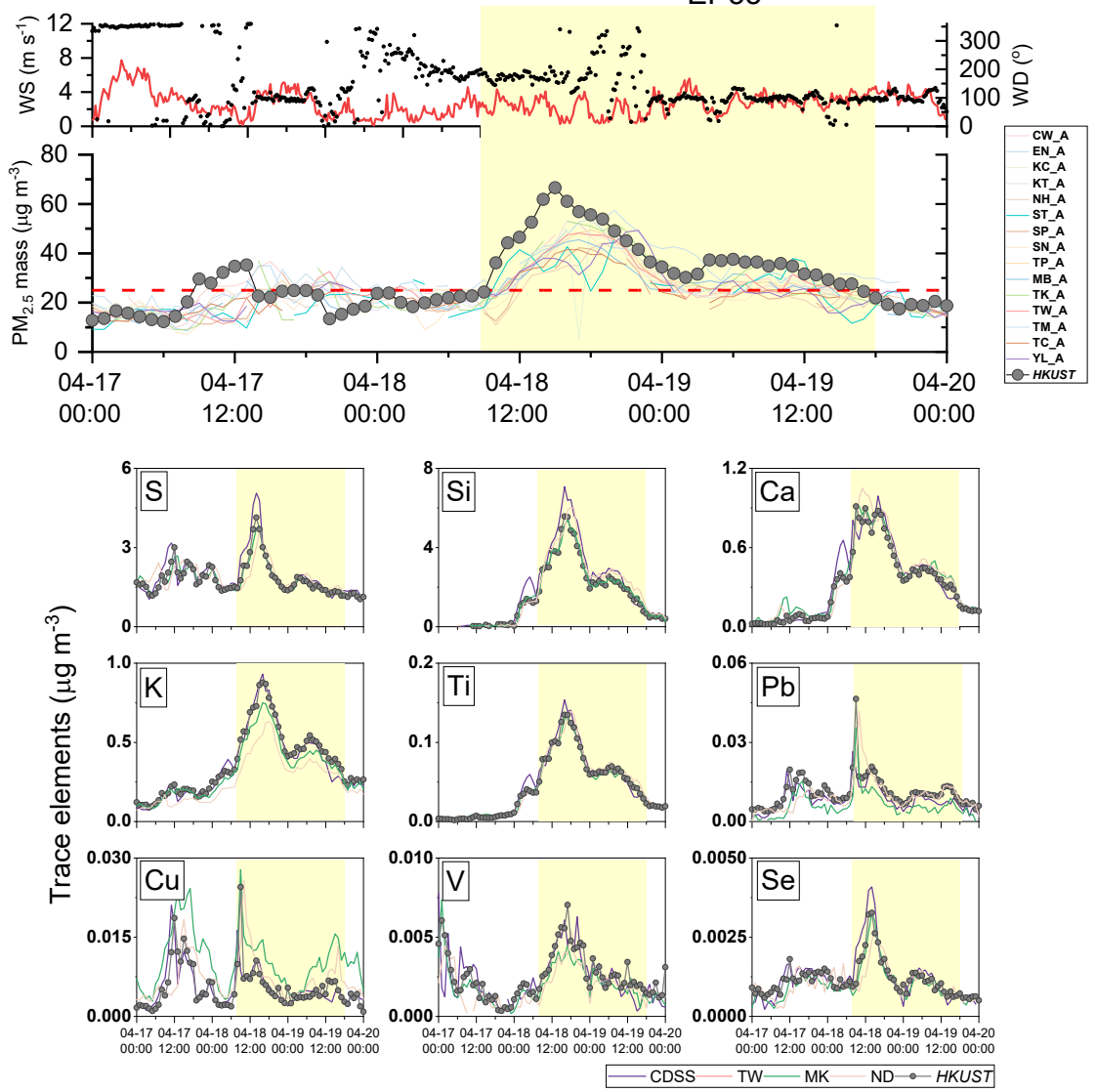


EP35 (example)



- Similar temporal variations in total $PM_{2.5}$ mass across the HKUST supersite and other 15 general stations
- Similar temporal trends in $PM_{2.5}$ trace elements between the HKUST supersite and other 4 stations

Results: $PM_{2.5}$ and its trace element correlation plots

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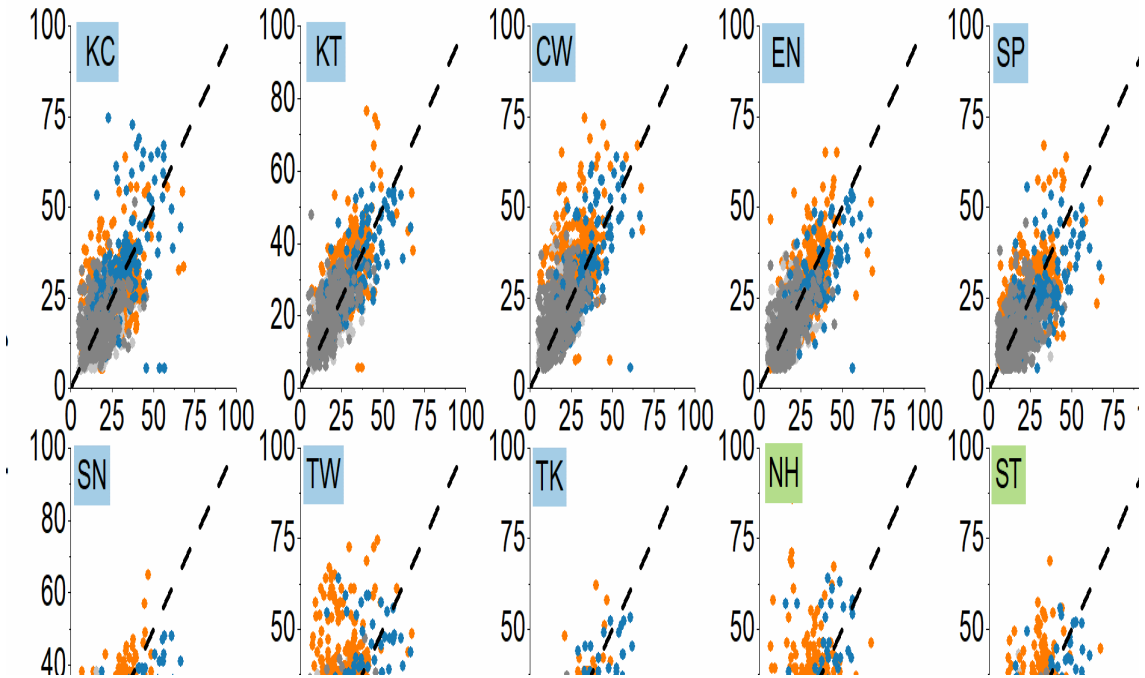

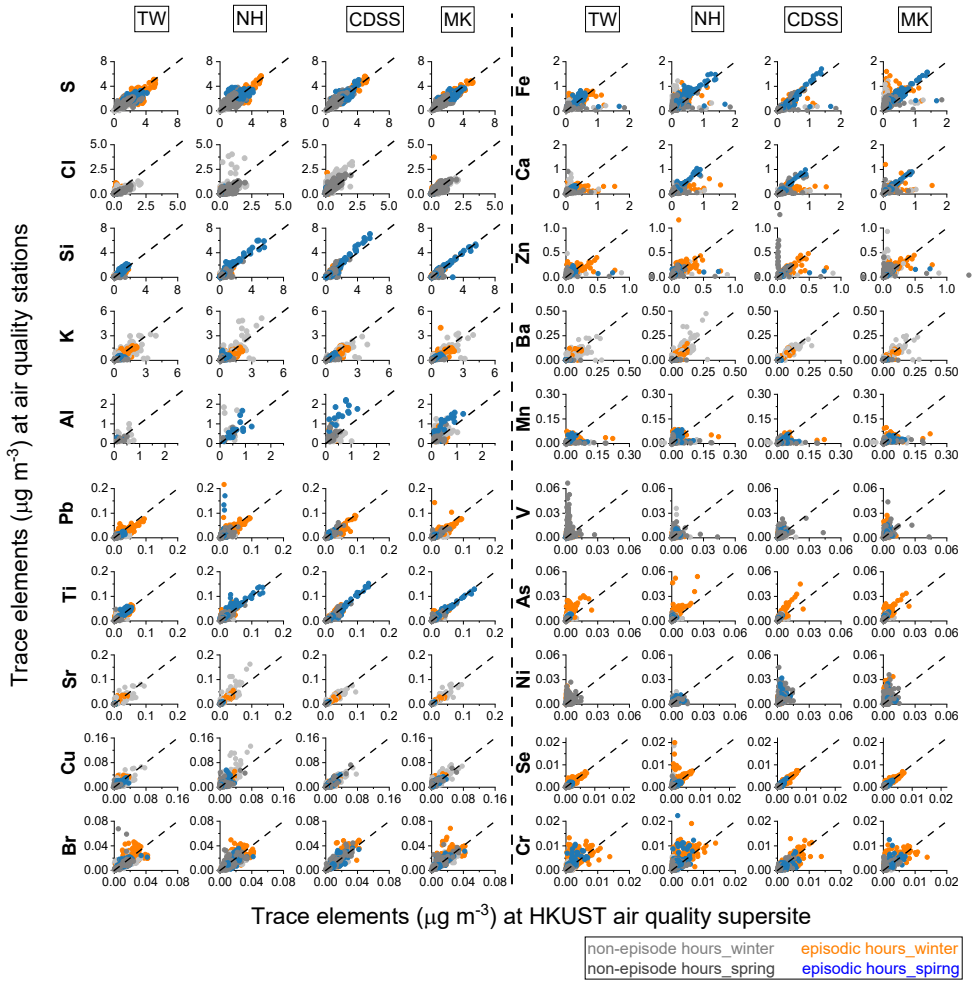

Significant correlations for $PM_{2.5}$ and its trace elements

⇒ not only the bulk $PM_{2.5}$ concentrations but also the major trace elements demonstrated regional characteristics during the 37 city-scale haze episodes

⇒ **Comprehensive chemical measurements** at the HKUST supersite could serve as a reliable reference for studying **pollution sources** during city-scale air pollution events

Results: Overview of measurements at HKUST supersite

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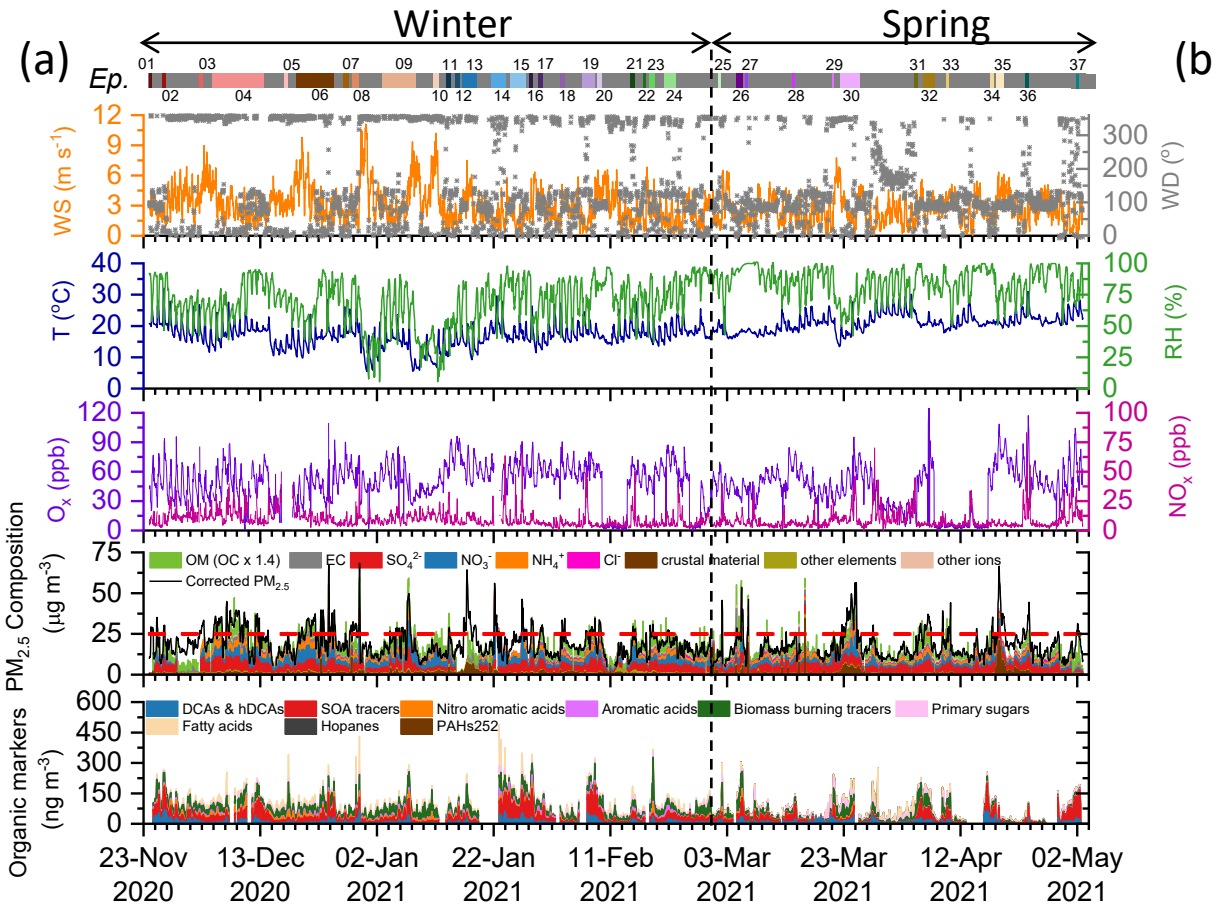

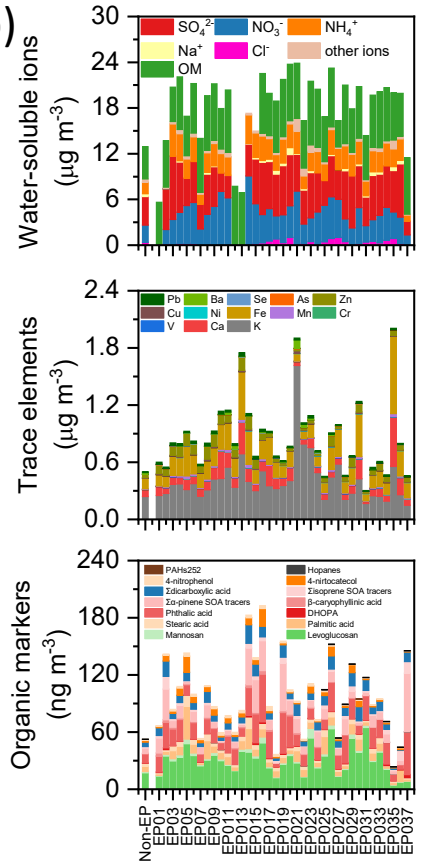

- Most episodes: substantial increases in sulfate, nitrate, OM, and trace elements
- EP37: low sulfate and nitrate concentrations but elevated OM levels and SOA tracers
- EP21: exceptionally high K and Cu, which coincided with the Chinese New Year period.

⇒ Variations in aerosol composition during haze episodes reveal distinct sources, characteristics, and evolution processes that drive air pollution accumulation

Results: Air mass backward trajectories

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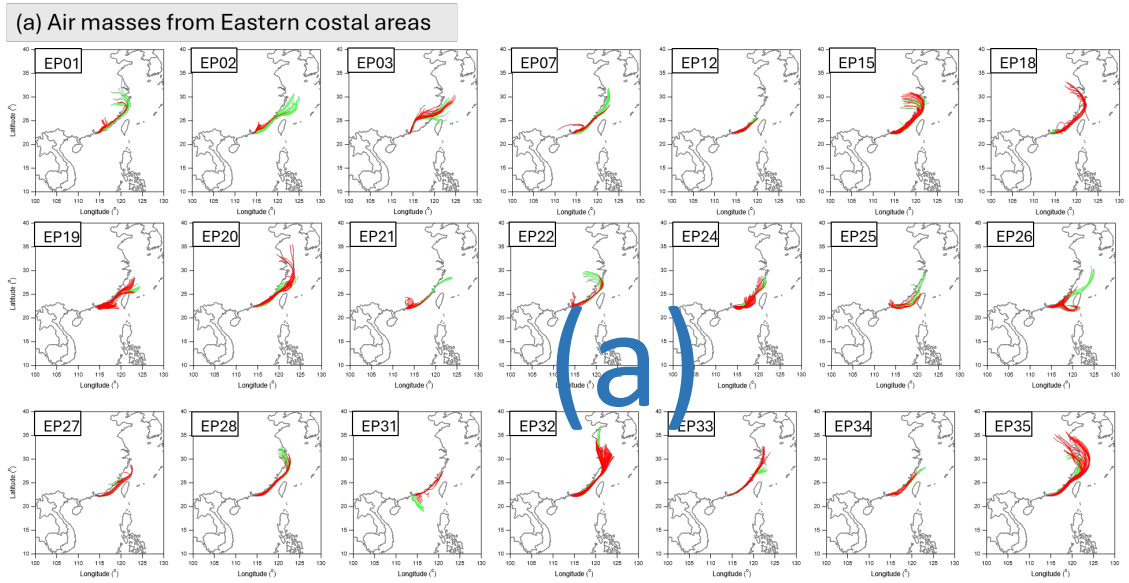

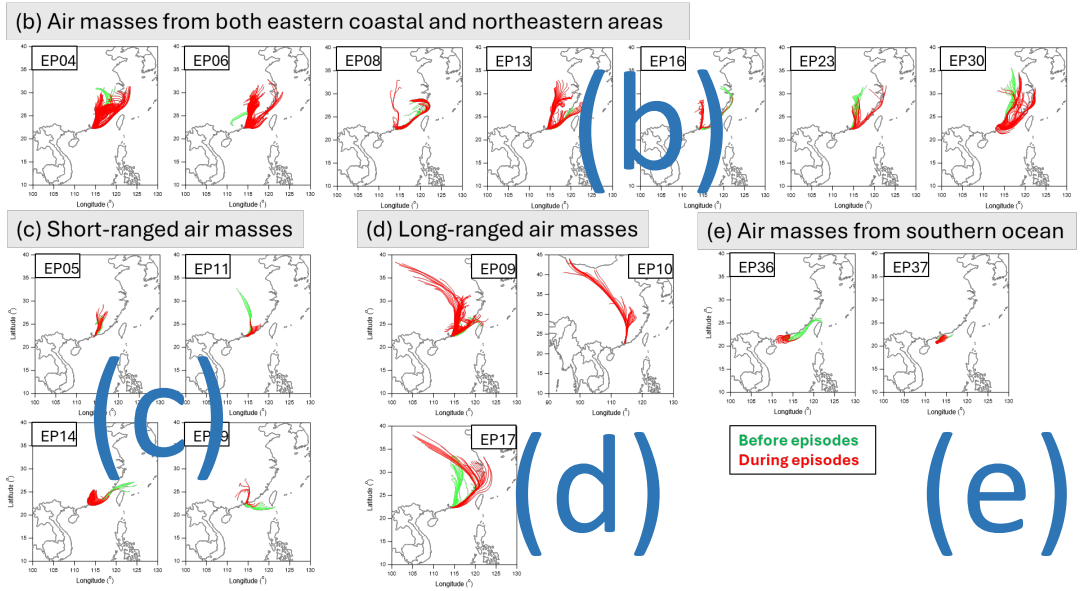

Five sub-groups

--Type **(a)**: **Eastern coastal** areas; travel slowly (WS: 2.5 m s^{-1}), 21 episodes;

--Type **(b)**: **Eastern coastal** and **northern continental** regions; moved rapidly (WS: 3.0 m s^{-1}), 7 episodes;

--Type **(c)**: **Northern inland** areas such as Guangdong provinces, moderate wind speeds (2.8 m s^{-1}), 4 episodes;

--Type **(d)**: **Long-range transport northwestern** regions, travel quickly (WS: 4.0 m s^{-1}), 3 episodes;

--Type **(e)**: **South China Sea** and circulated within the marine region, calm wind speed of 1.6 m s^{-1}, 2 episodes

Results: PMF Sources profiles in winter and spring

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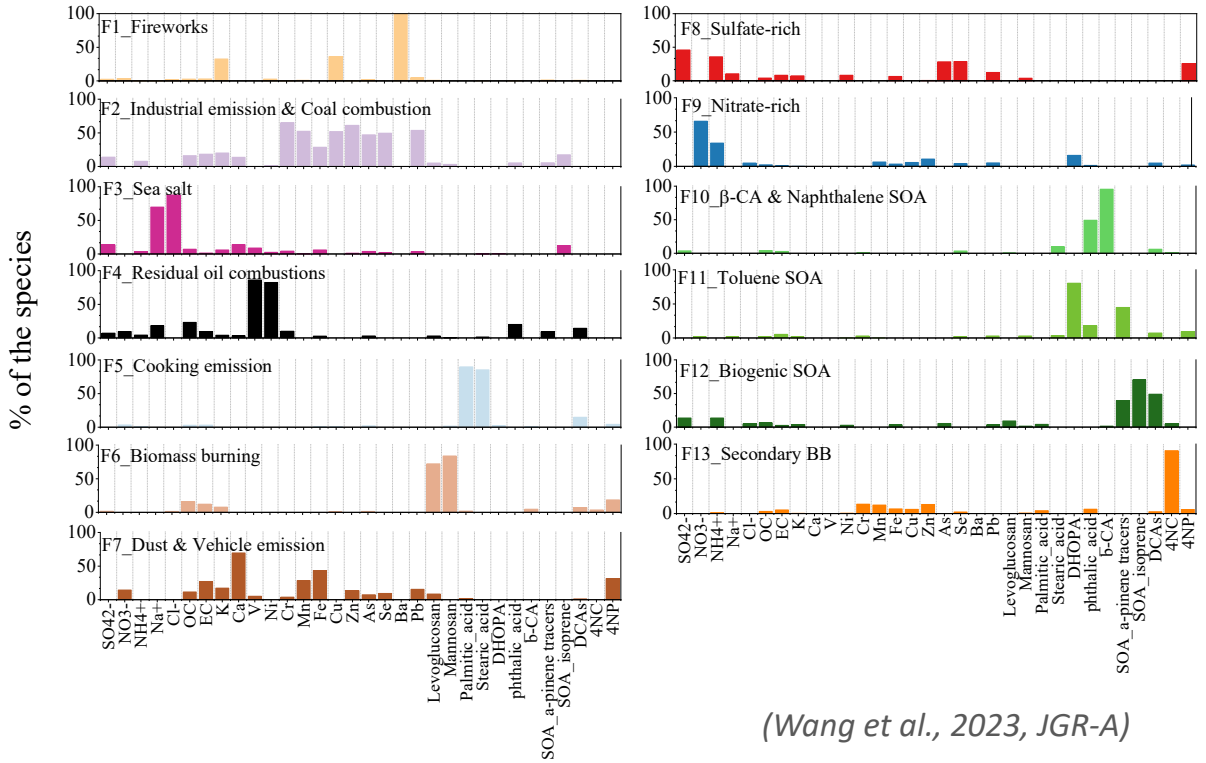
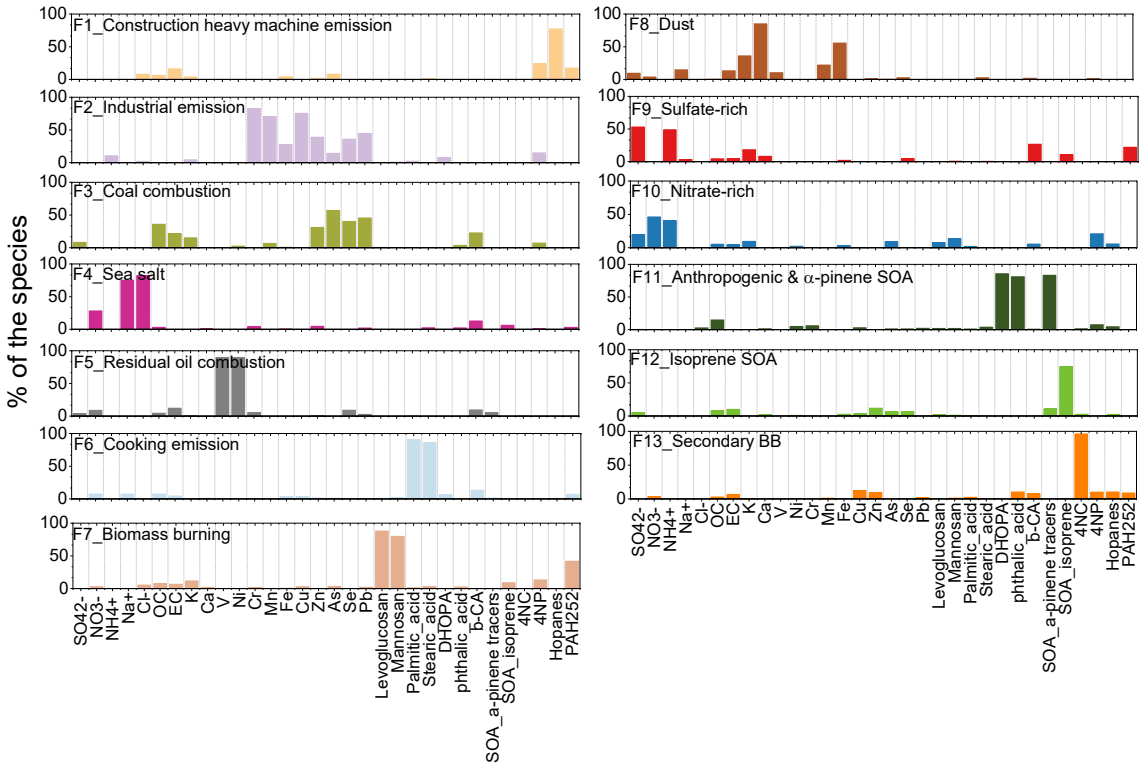
Winter season
(24 Nov 2020-28 Feb 2021)



(Wang et al., 2023, JGR-A)

Spring season
(1 March-2 May 2021)



- **Common sources (6 primary sources + 4 secondary sources)**
- **Organic sources** (biomass burning, cooking, SOA factors, secondary biomass burning): contributing to **18% and 19% (avg.) to $PM_{2.5}$**, and **27% and 32% (avg.) to OC** in winter and spring, respectively.
- **Unique sources:** firework emissions in winter, and construction heavy machine emissions in spring

Results: $PM_{2.5}$ source contributions

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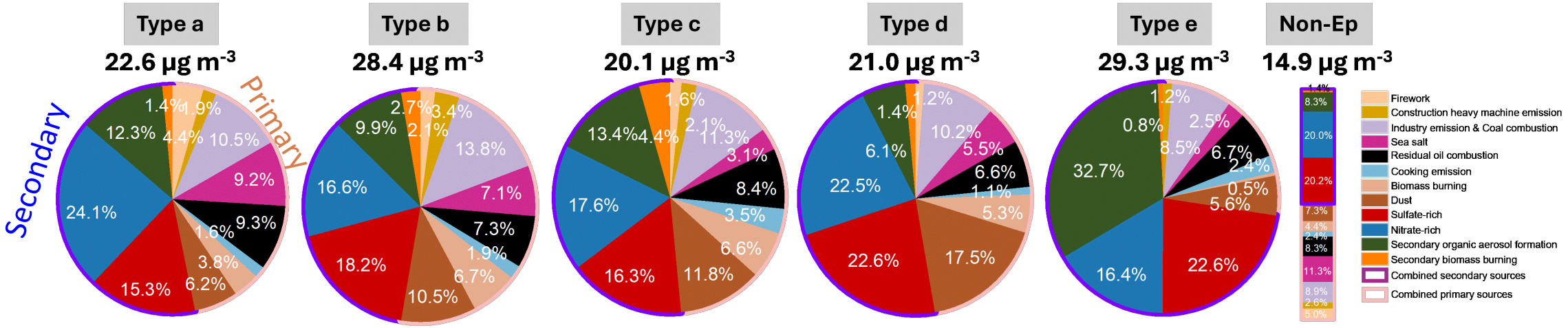

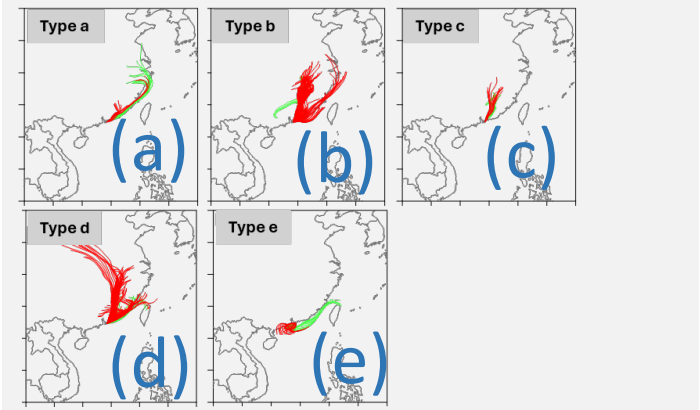

- **Type (a)**: higher absolute concentrations and percentage contributions of **secondary sources**, with **nitrate-rich** and **sulfate-rich** leading the increments, followed by SOA formation, industrial emissions & coal combustions
- **Type (b):** increased contributions from industrial emissions & coal combustions
- **Type (c):** decreased contributions from **sea salt**, while enhance levels from SOA formation
- **Type (d):** significant enhancement from **suspended dust**
- **Type (e):** remarkable reductions in **primary sources**, as well as **largely contributions from** SOA formation

Results: OC source contributions

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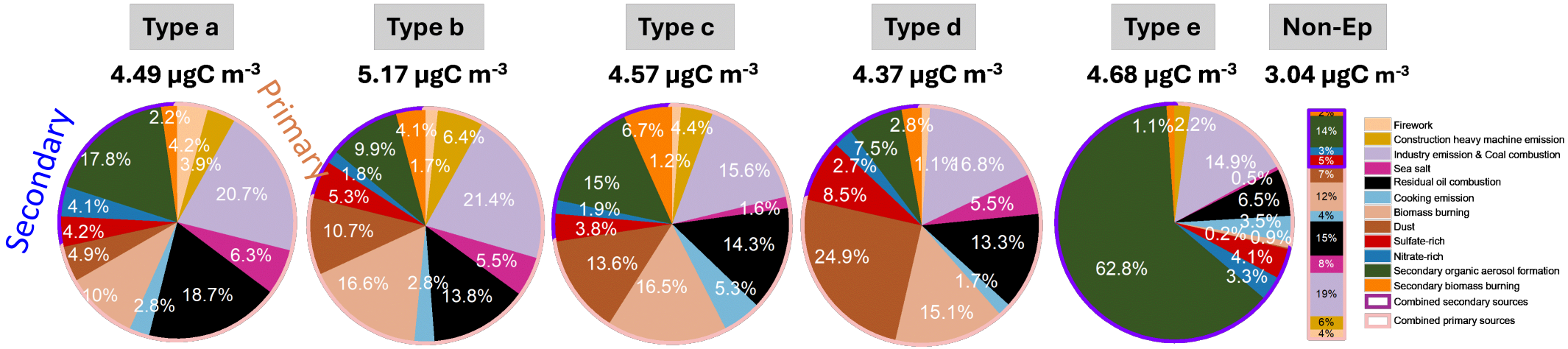

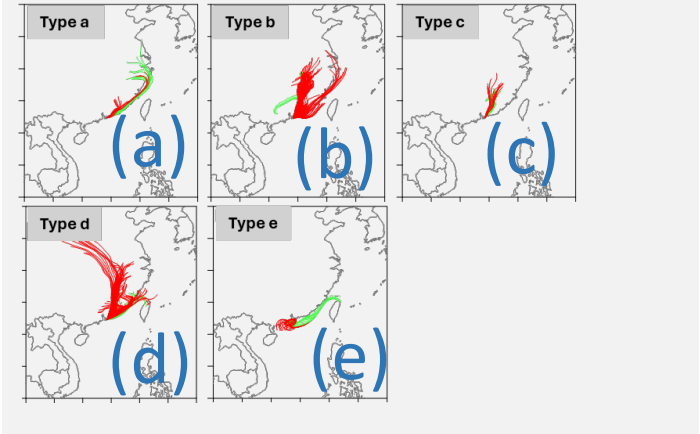

- **Type (a)**: higher absolute concentrations and percentage contributions from SOA formation, industrial emissions & coal combustions and **residual oil combustion**
- **Type (b):** increased contributions from industrial emissions & coal combustions, and biomass burning
- **Type (c):** enhance levels from SOA formation, and biomass burning
- **Type (d):** significant enhancement from **suspended dust**, and biomass burning
- **Type (e):** remarkable reductions in **primary sources**, while SOA formation was the dominant contributors

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Summary

- **General AQ stations and Research Supersites are highly COMPLEMENTARY in providing city-wide AQ status and detailed pollution sources.**
- Strong correlations in $PM_{2.5}$ and trace element concentrations between the general stations and the supersite indicate spatial homogeneity of air pollution across Hong Kong during these episodes
- Variations in air mass origin and source intensity were found to significantly influence city-scale $PM_{2.5}$ levels
- Source apportionment based on the tracer measurements revealed dynamic changes in source

Implications:

Combining routine monitoring with advanced chemical characterization at research supersites provides deeper insights into the sources, evolution, and dynamics of city-scale haze episodes.

→This integrated approach of **AQ monitoring network + Supersite** would strengthen urban air quality management by enabling more targeted and effective pollution mitigation strategies in Hong Kong and other similar megacities

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