Distributions and Emission Signatures of VOCs Based on Airborne Observations over the Seoul Metropolitan Area and the Yellow Sea during the 2024 ASIA-AQ

Jimin Lee[1)], Jinsoo Park[2)], Jungho Kim[3)], Limseok Chang[2)], Gangwoong Lee[4)], Eric C. Apel [5)], Donald R. Blake[6)], Isobel J. Simpson[6)], Meehye Lee[1)] [1)] Korea University, Seoul, South Korea [2)] NIER, Incheon, South Korea [3)] Open Space Co., Seoul, South Korea [4)] HUFS, Yongin, South Korea [5)] NSF NCAR, Boulder, Colorado 80307, United States [6)] UC Irvine, Irvine, CA, US

Contact : Jimin Lee, jm8411@korea.ac.kr

Introduction

- VOCs are key precursors involved in ozone, O_3, and OH radical formation, and their impacts on regional and long range air quality depend on their reactivity and atmospheric lifetime.
- The Yellow Sea is an important region where foreign emission sources, including China, and atmospheric transport processes interact.
- Aircraft observations are effective for resolving horizontal and vertical concentration structures and for examining the combined influence of transboundary inflow and natural emissions over the Yellow Sea.
- This study investigates winter and spring VOC distributions over the SMA and Yellow Sea using ASIA AQ 1900D aircraft observations, focusing on long range transport and domestic emission influences.

Method

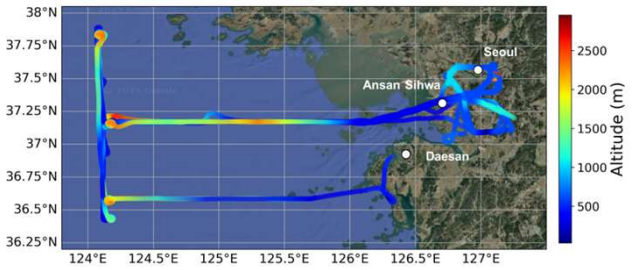

Fig 1) flight tracks of the 1900D aircraft represent by altitude (m)

Measurements & Analysis

- **Instrument**: PTR-ToF-MS 1000, Ionicon, Austria, aboard the Beechcraft 1900D aircraft for real-time VOC measurements.
- **Campaign**: ASIA-AQ, February 7–March 10, 2024; ascent and descent observations up to 3000 m over the SMA and Yellow Sea.
- **Target VOCs**: Acetonitrile, acetone, MEK, benzene, toluene, C8 aromatics, and trimethylbenzene.
- **Data processing**: 1 s measurements averaged over 10 s; mean uncertainty of 8.5–12%.
- **Calibration**: 100 ppbv TO-14 mixture standard gas, $R^2 > 0.98$ for all curves.

Results

1 Complementarity with DC-8 Observations

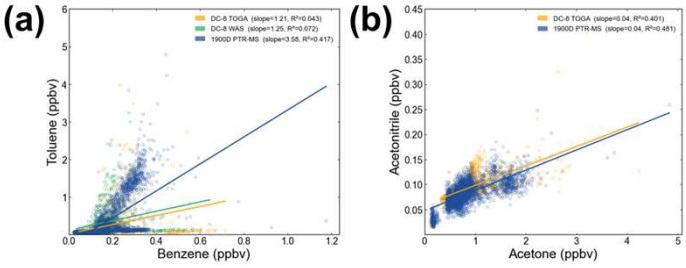

Fig 2) Toluene–benzene and acetonitrile–acetone relationships from 1900D and DC-8 observations during concurrent flight days.

- Same-date observations: The 1900D and DC-8 sampled Korea and the Yellow Sea on the same dates, but were used as complementary datasets due to platform differences

(DC-8: regional and broad altitude coverage / 1900D: repeated low-altitude PBL sampling)

- Acetonitrile–acetone: Similar relationships across platforms (Fig 2-b)

➢ Regionally mixed VOC signals

- Toluene–benzene: Higher slope in 1900D data (Fig 2-a)

➢ Low-altitude urban/industrial plume influence

✓ The 1900D effectively captures source-influenced VOC enhancements at low altitude.

2 Vertical distributions of VOCs

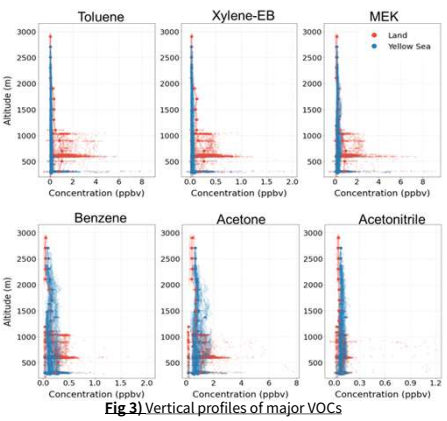

Fig 3) Vertical profiles of major VOCs

- High concentrations and variability at low altitudes, decreasing aloft
- Toluene, xylenes, MEK: Higher over land, with peaks near 300 m over the sea

➢ Local/coastal emission influence

- Benzene, acetone: Relatively stable vertical distributions

➢ Long-range transport influence

- Acetonitrile: Low and vertically uniform concentrations

Results

3 Emission Signatures: Regional VOC Relationships

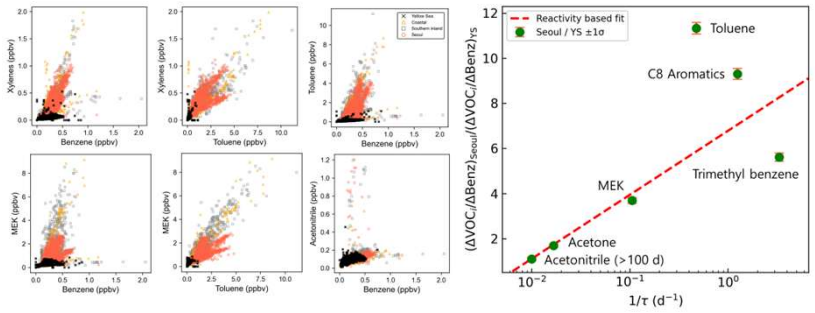

Fig 4) Major VOC relationships below the PBL (<1100 m) using benzene, toluene, and MEK as reference species by region, Seoul to Yellow Sea regression slope ratios plotted against VOC reactivity, 1/τ.

- VOC relationships: Seoul, coastal, and Yellow Sea clusters varied with the reference species, benzene, toluene, or MEK

➢ VOC relationships showed distinct source signatures among regions

- Seoul vs Yellow Sea: VOC to benzene slope ratios increased with reactivity

➢ More reactive VOCs showed stronger regional contrasts

- Toluene & C8 aromatics: Higher ratios than the reactivity-based trend

➢ Additional influence of Seoul aromatic source signatures

✓ VOC composition reflects both chemical aging during transport and distinct urban source signatures.

4 Comparison with CAPSS Emission Inventory

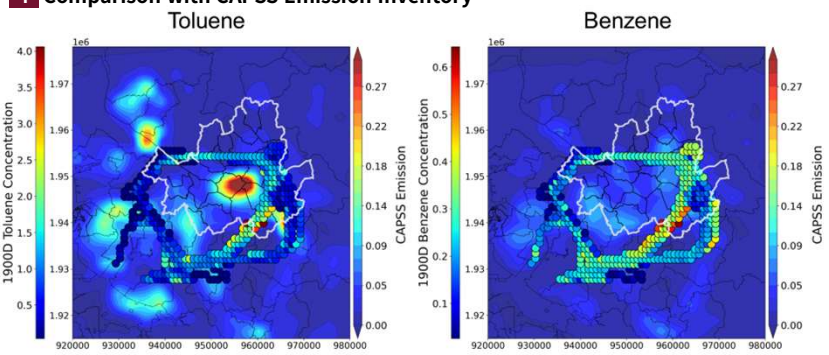

Fig 5) 2021 CAPSS emissions (mole/s/km²) with overlaid 1900D VOC observations over the SMA.

- Qualitative comparison between the 2021 CAPSS surface emission inventory and wintertime 1900D observations
- **Toluene:** Airborne enhancements broadly matched CAPSS hotspots in central and southeastern Seoul
- **Benzene:** More spatially uniform than toluene : Reflects stronger regional background influence

✓ 1900D data complement CAPSS by capturing localized and temporally variable VOC enhancements.

5 Estimation of VOCs flux across the Yellow sea

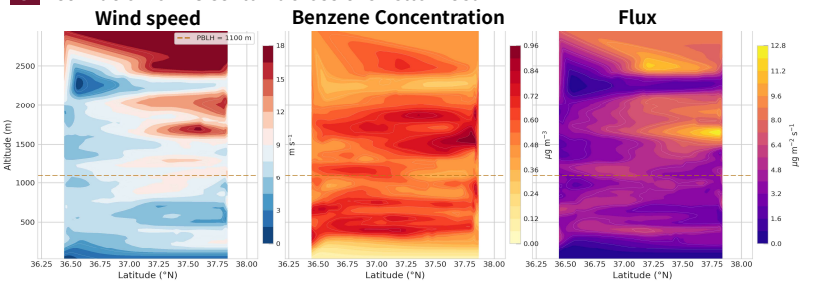

Fig 6) Spatial distribution of zonal wind speed (m/s), benzene concentration (μg/m³), benzene flux (μg/m²/s) measured at longitude 124°

➢ **Advection flux** = $\int_0^z \int_{x_1}^{x_2} v \cdot C_i \, dx dz$ (v = zonal winds z = 0 - 2000m ,x = ~ 150 km C_i= observed con

Benzene: Elevated near 2000 m; transport toward Korea was 87.6 ton month^{-1}, about 30% of CAPSS

• Toluene: Transport toward Korea was 108.2 ton month^{-1}, about 6% of CAPSS, with stronger local source influence

Implication: Transboundary transport effects vary by VOC species and are stronger for benzene.

Unit : ton/ month

VOCs	Benzene	Toluene
Long-range transported flux within the PBL	283.1	249.5
Estimated VOCs Influx into Seoul within PBL (0–1,100 m)	87.6	108.2
CAPSS	307.7	1678

Conclusion & Discussion

- The 1900D and DC-8 provided complementary observations: the DC-8 captured regional and vertical, while the 1900D resolved low-altitude PBL source gradients.
- 1900D PTR-ToF-MS observations showed ΣVOCs about 2.3 times higher over the SMA than over the Yellow Sea, with clear VOC enhancements in the low-altitude PBL and coastal plumes.
- VOC variability depended on chemical lifetime and emission characteristics, with more reactive VOCs showing stronger Seoul–Yellow Sea contrasts.
- Aircraft observations are useful for resolving horizontal and vertical VOC distributions and transport effects, with transboundary transport estimated at about 30% of CAPSS for benzene and 6% for toluene.