Key factors explaining severe air pollution episodes in Hanoi during 2019 winter season

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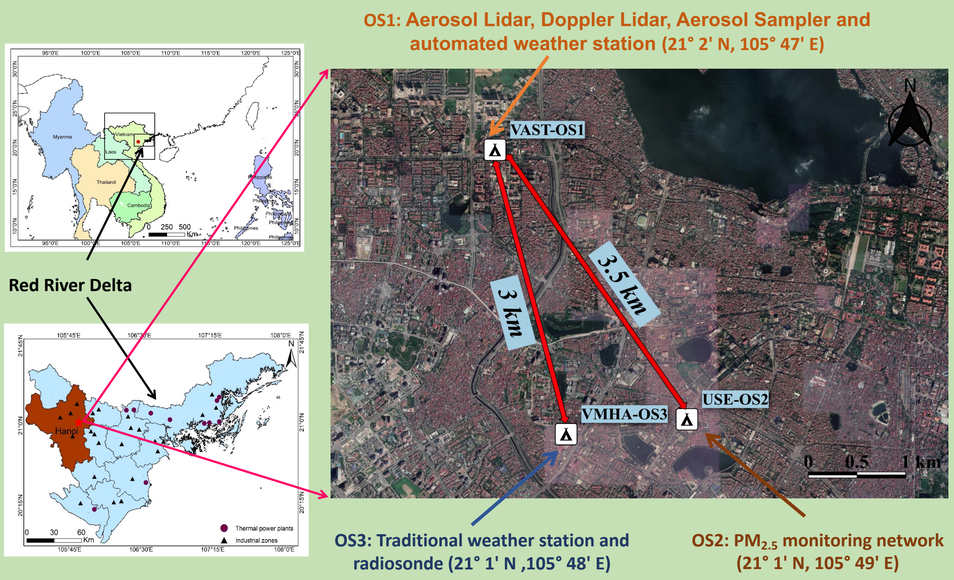
- High levels of PM are recorded in Hanoi during the winter, when northern Vietnam is affected by the northeast monsoon.
- The VASP (Vietnamese Aerosol Sampling and Profiling) campaign was carried out from 11 January to 22 March 2019 in Hanoi. The main objective was focused on the identification of the key factors explaining severe pollution events (a series of consecutive days with $PM_{2.5}$ concentrations > 50 µg m^{-3}) in Hanoi during winter.
- The structure of the boundary layer and vertical wind profile were thoroughly studied for the first time in Hanoi using Lidar measurements.

1/ Hanoi: capital of Vietnam with 8,000,000 inhabitants



2/ VASP Campaign (11/01 – 22/03/2019)

Aerosol micro-pulse Lidar (SLIM)	
Altitude of lidar	30 m a.g.l.
Emission power :	12 mW (eye-safe)
Laser wavelength:	808 nm
Blind distance:	220 m
Meas. Frequency:	10min (1hr averaging)
Spatial resolution :	15 m

Doppler Lidar (WINDCUBE 2)	
Altitude of lidar	30 m a.g.l.
Pulse duration:	175ns
Emission power :	7 mW (eye-safe)
Minimum range:	60 m
Laser wavelength:	1.543 µm
Spatial resolution :	20 m
Meas. Frequency:	5s (10min averaging)

External devices:

1. Aerosol sampling :

+ TSP were collected by total filtration with 1-week period (10 samples) on cellulose filter (Whatman® grade 41) with a flow rate of 1.2 m^3 h^{-1} .

+ A fraction of each filter was used for the analysis of the water soluble fraction by ionic chromatography and elemental analysis by SEM/EDX.

2. Davis Vantage Pro 2 Automatic Weather Station

3/ External data and model

$PM_{2.5}$ data:

- **Hourly $PM_{2.5}$ data** in Hanoi are retrieved from an international monitoring network of the World Air Quality Index at the US Embassy at OS2 site (https://www.airnow.gov/).

Radiosonde data:

- **Radiosonde profile** was retrieved at 07:00 and 19:00 local time in OS3 site (http://weather.uwyo.edu/upperair/sounding.html).

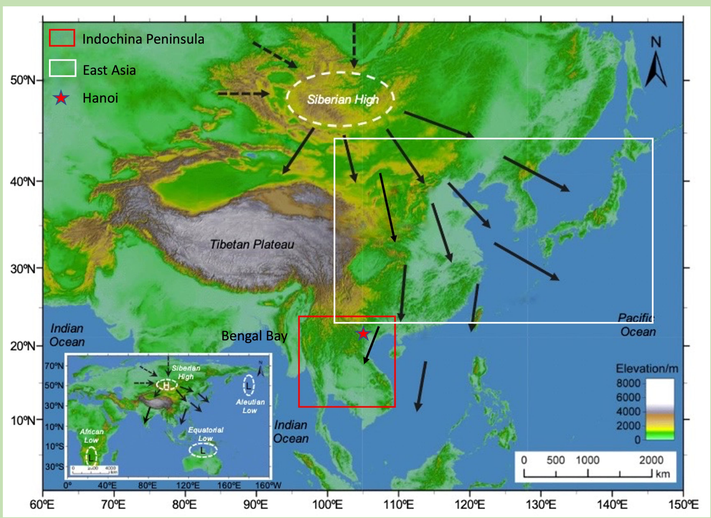
HYSPLIT model:

- The **PC Windows-based HYSPLIT model** was used for generating backward trajectories ending every hour at 100, 300, 600 and 1000m at Hanoi, to evaluate the pollution origin over Hanoi during **2 months**.
- **4-days backward trajectories** was generated.
- All backward trajectories were included in a **cluster analysis.**

Time averaging & matching:

Lidar, meteorological data were averaged to match the **PM2.5 data** resolution (1-hour)

4/ Northeast monsoon



Source: modified from Kang et al., (2020)

Mechanism:

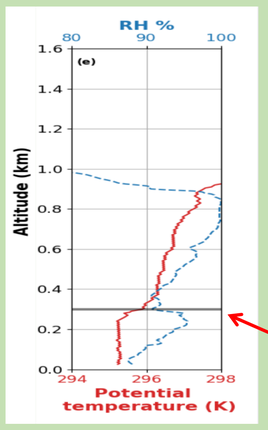
A high-pressure ridge from polar air **in Siberia** results in the **northeast monsoon** bringing **continental cold air** from this area either:

+ through inland China **(dry period)** from **November to January**

+ via the Gulf of Tonkin **(humid period)** from **January to March**

5/ Boundary layer determination

Boundary layer height (BLH) can be derived from **Radiosonde** or **Lidar**



BLH determined by radiosonde

BLH is defined at the altitude where the strongest **gradients of potential temperature** coincides with the lowest **gradient of relative humidity**

BLH from radiosonde (07:00 and 19:00 local time) is used to **compare with** BLH from Lidar measurements (hourly retrieval).

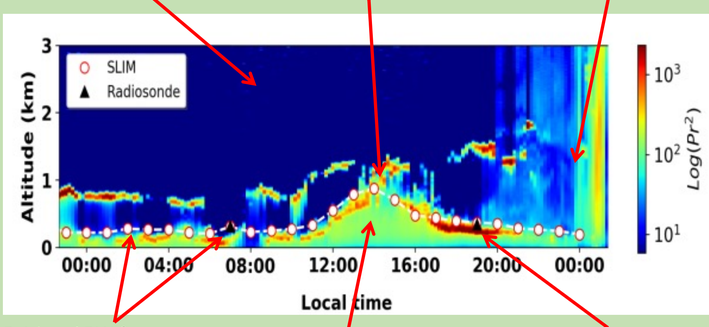
The top of boundary layer

Lidar wind profiles quick-looks

No signal over clouds as the laser beam is extinguished by scattering in the clouds

Top of BL rises during daytime; daily max at the beginning of the afternoon

Increase of signal at all altitudes below the cloud due to rain



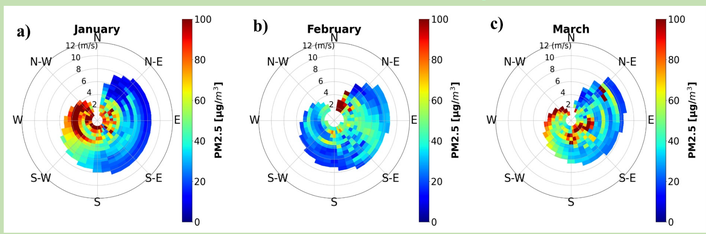
Retrieved BLH from radiosondes (black triangle) and lidar (white circle).

Aerosols are trapped in boundary layer: stronger signal than in the free troposphere

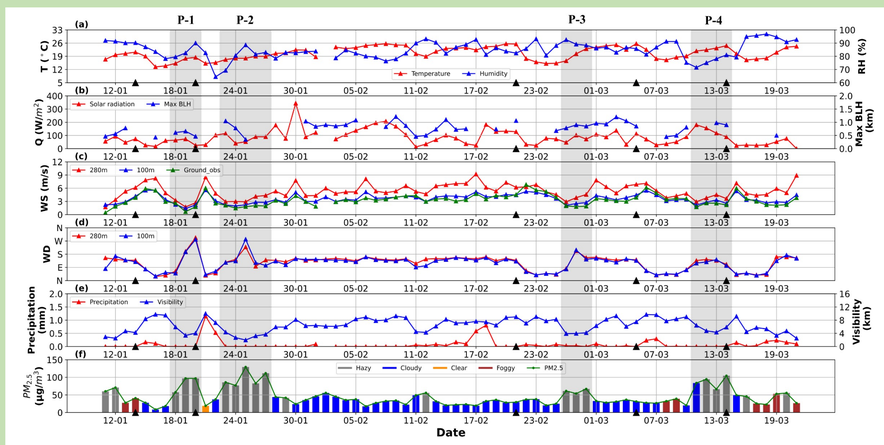
Low-level cloud: very strong signal due to scattering by water droplets, then drop of signal as the beam is extinguished

6/ Influence of the weather conditions

Pollution roses in combination with wind speed and direction

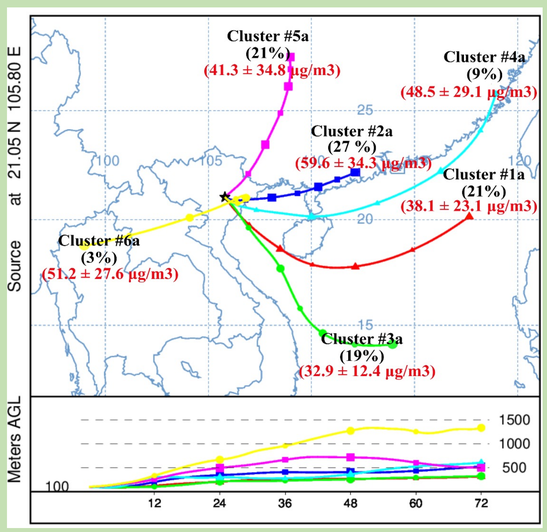


- **The highest levels of $PM_{2.5}$** were mainly related to weaker wind speed, so probably due to local emissions that are not well dispersed.



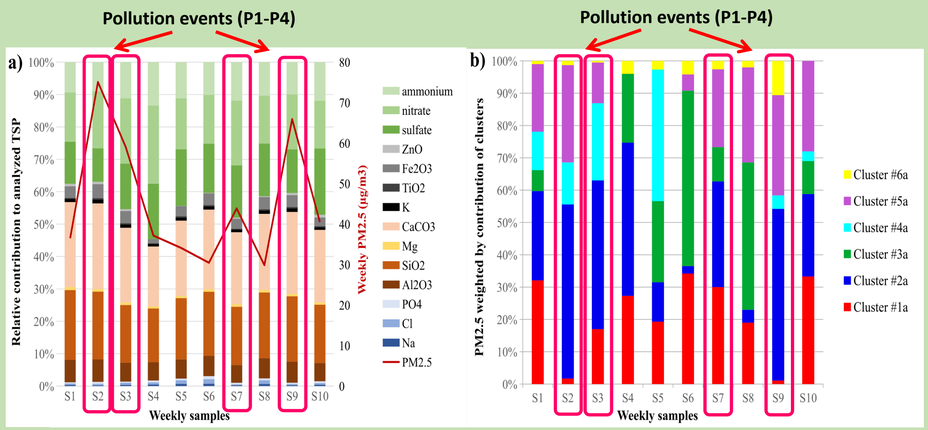
- **Max daily BLH** varied from a few hundred meter up to 1200 meter during the campaign
- Four distinct weathers types were observed in Hanoi:
  - ✓ Hazy days (daily visibility ≤ 5km and daily RH ≤ 95%) → 29% of total days
  - ✓ Foggy days (daily RH ≥ 90%) → 11% of total days
  - ✓ Clear day (daily visibility ≥ 10km) → 1% of total days
  - ✓ Cloudy days (the remaining cases) → 59% of total days
- **4 pollution events (P1 – P4, in grey areas)** were all associated with hazy days charecterized by low BLH in combination with stagnant conditions.
- Pollution events occurred after the onset of a NE monsoon cycle (black triangles on the axis), resulting from the impact of long-range transport (LRT).

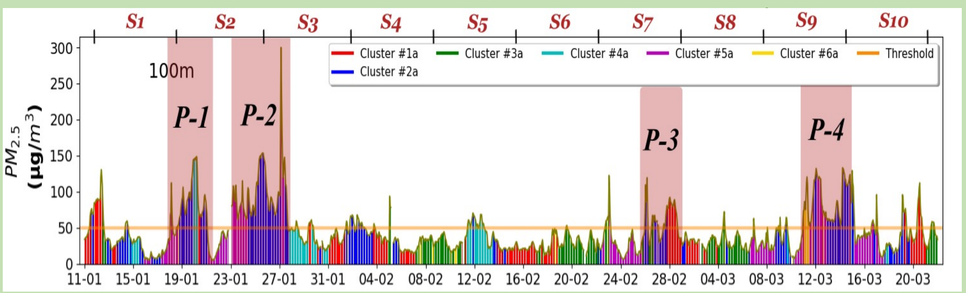
7/ Local against Long-Range Transport



Cluster analysis:

- For the back-trajectories ending at 100m, the northeast air masses from continental China were predominant (**cluster #2a**, **cluster #4a** and **cluster #5a**), and accounted for 57% of time during the campaign
- **The highest $PM_{2.5}$ concentrations** were observed with **cluster #2a** (59.6 ± 34.3µg m^{-3} in average) and **cluster #4a** (48.5 ± 29.1µg m^{-3} in average).

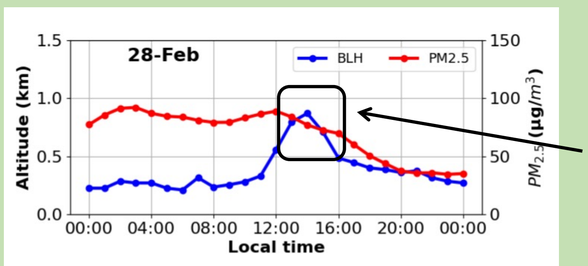




Long-range transport (LRT):

- **TSP chemical composition remained similar throughout the campaign**, although there was a huge different in TSP concentrations and air mass origins between the weeks. It proves **a similarity in the major chemical composition between local emissions and those coming from LRT**.
- **The highest $PM_{2.5}$ concentrations** were observed for weekly samples **S2, S3, S7** and **S9** associated with **the pollution event (P1-P4).**
- During the **pollution events (P1 - P4),** the air mass originating from continental China is overwhelmed (**cluster #2a**, **cluster #4a** and **cluster #5a**).

8/ A typical pollution day (28/02/2019)

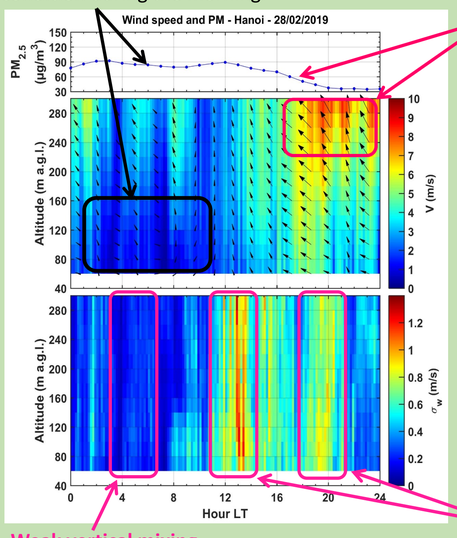


Growth of BLH → **decrease of $PM_{2.5}$**

- From 12:00 LT, the $PM_{2.5}$ level started to fall gradually with the simultaneous increase of BLH. But the BL growth is limited during hazy days.
- BLH only is not sufficient to explain PM2.5 variability, since the $PM_{2.5}$ still drop in the afternoon while the BL is decaying…

High $PM_{2.5}$ level due to **calm wind condition** during the morning.

PM2.5 drop due to the **wind rising**



Vertical wind profile:

- BLH growth in the afternoon is associated with the enhancement of **vertical mixing,** resulting in the slow decrease of $PM_{2.5}$ level.
- The **rising wind in the afternoon** is associated with increased **wind shear**, also enhancing the vertical mixing and increasing the dispersion of $PM_{2.5}$ near the surface.

Weak vertical mixing

High vertical mixing

9/ Conclusions & perspectives

Conclusions:

- **The pollution events (P1 – P4) were mainly related to the long-range transport** derived from northeast monsoon.
- **The chemical composition of TSP was pretty constant** over the 10 weeks of sampling, indicating that locally emitted particles had a major chemical composition which was relatively similar to those coming from long-range transport.
- **The aerosol Lidar observations showed a large variability in the daytime boundary height among different weather conditions:** the daily maximum of the hourly BLH varied from **700m up to 1200m** during cloudy days, while it was typically below **1000m** during hazy days.
- **The vertical mixing can vary significantly during daytime**, while it can be reinforced during nighttime when a Low-Level Jet appears, relating to the PM variations in Hanoi.

Perspectives:

- **Longer in situ measurement need to be carried out i**n order to bring a more accurate view for understanding the PM variations during the whole year in Hanoi
- With the aim of analyzing more precisely the chemical composition of local and long-range transport, **a shorter-resolution (daily) aerosol sampling needs to be perfomed.**

References

Kang, S., Du, J., Wang, N., Dong, J., Wang, D., Wang, X., Qiang, X., Song, Y., 2020. Early Holocene weakening and mid- to late Holocene strengthening of the East Asian winter monsoon. Geology 48, 1043–1047. https://doi.org/10.1130/G47621.1

Supporting information (the publication paper from all results) to this poster are available at the website. Please scan the following QR code in the right.

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Acknowledgements

The authors sincerely acknowledge the financial support from the Institute Environmental Technology funded by Vietnam National Independent Program for Space Technology under the grant number VT-UD.11/17-20. This work is a contribution to the CPER (Contrat de Plan Etat-Région) research project IRenE (Innovation et Recherche en Environnement) and Climibio. It is supported by the French Ministère de l'Enseignement Supérieur, de la Recherche et de l'Innovation, the region Hauts-de-France and the European Regional Development Fund. The work is also supported by the CaPPA (Chemical and Physical Properties of the Atmosphere) project, which is funded by the French National Research Agency (ANR) through the PIA (Programme d'Investissement d'Avenir; no. ANR-11-LABX-0005-01) and by the regional council of Nord-Pas-de-Calais and the European Regional Development Fund.