# Characteristics of Light Absorbing Carbonaceous Aerosols in Southeast Asia

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# Outline

1. Introduction
2. Objectives
3. Materials & Methods
4. Results
5. Conclusions and implications

# Climate impacts of Black Carbon and Brown Carbon

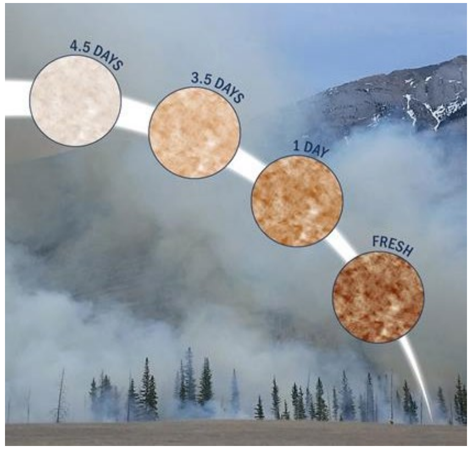
**LACA = BC and BrC**

## Black Carbon (BC)

- BC is the most strongly light-absorbing component of particulate matter (PM)
- Affects climate by:
  - Directly absorbing sunlight (⇒ warming)
  - Darkening clouds, snow and ice (⇒ warming)
  - Altering precipitation and cloud patterns (**uncertain** ⇒ cooling and/or warming)
- Remains in atmosphere days to weeks
- Atmospheric processes ('aging') affects light-absorbing properties

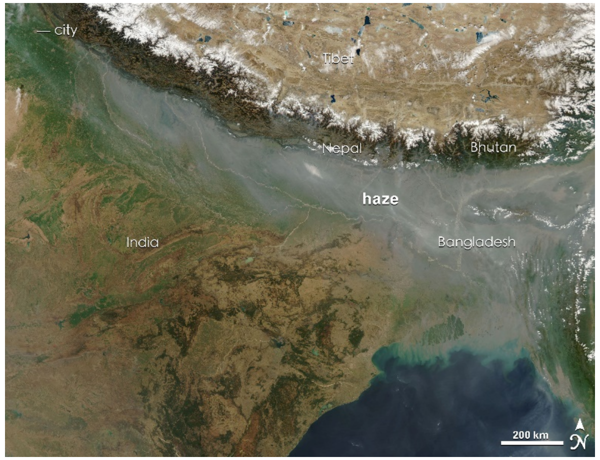
## Brown Carbon (BrC)

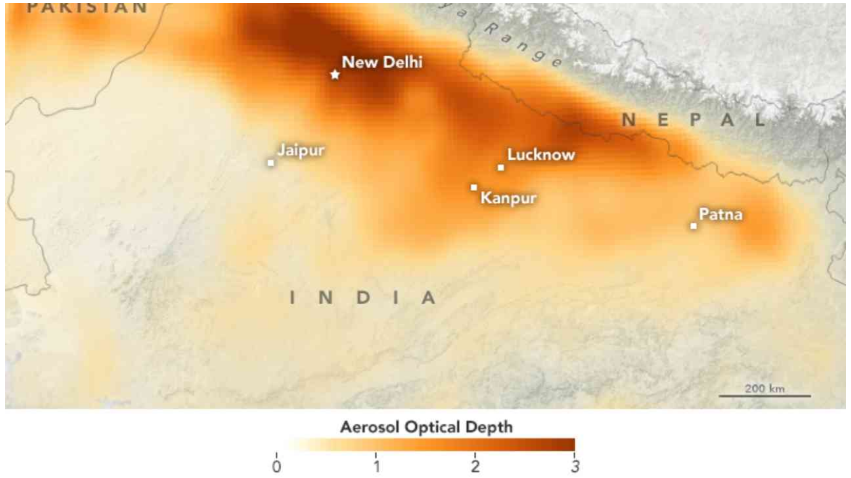
- Light-absorbing component of organic carbon (OC)
- Aging affects light-absorbing properties
- Radiative impacts on atmosphere uncertain

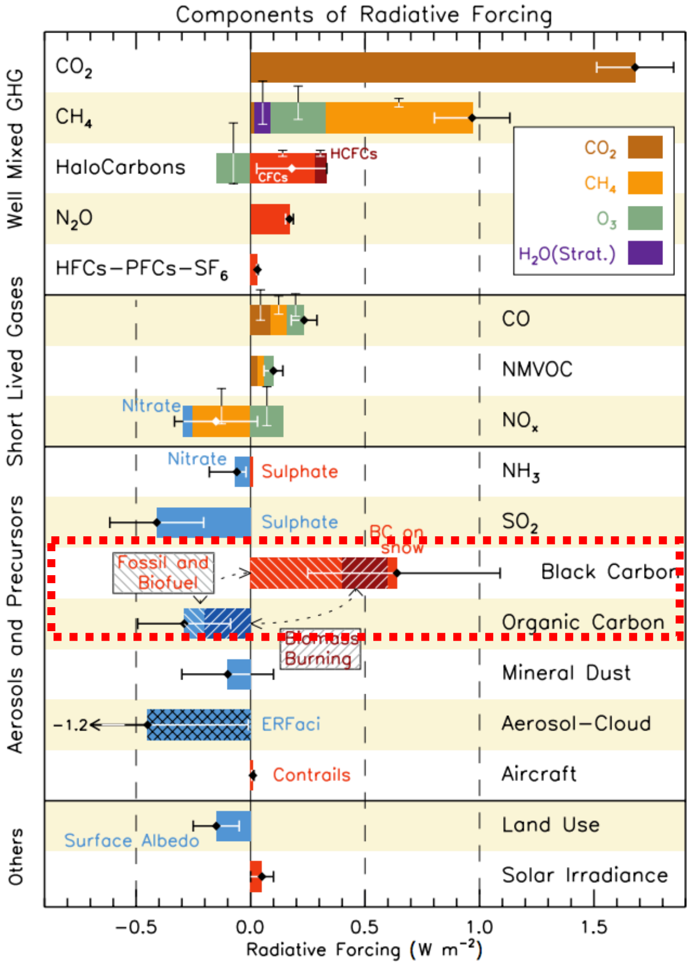


# Climate impacts of Black Carbon and Brown Carbon

- Atmospheric Brown Cloud (ABC): build-up of aerosols emitted from **coal burning, combustion, biomass burning, industrial processes** in **South Asia (China, India among others)** during **winter monsoon season.**




*IPCC-AR5*

**Large uncertainties associated with direct radiative forcing of BC and OC.**

# Sources of BC and BrC

LACA = BC and BrC

**Black Carbon (BC)**

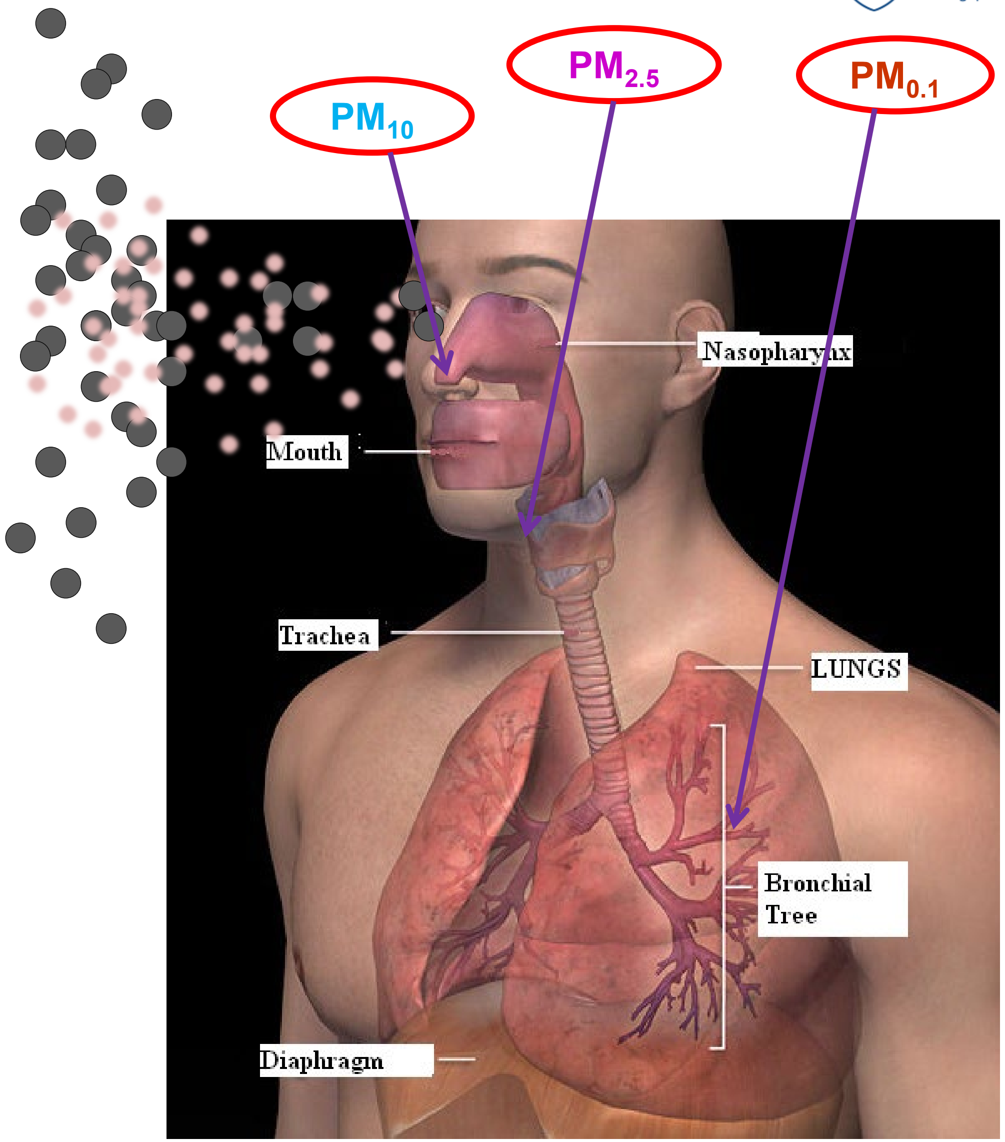
- Incomplete combustion of fossil fuels
- Biomass burning

**Brown Carbon (BrC)**

- Biomass burning
- Photochemical reactions of volatile organic compounds (VOCs)

# Health effects of BC

- BC usually less than 100 nm in diameter.
- A range of human health effects are associated with inhalation of fine particulate matter (PM less than 2.5 µm) and its component BC.
- Once inhaled, BC particles (<100 nm) can pass from the lungs into the bloodstream and affect the cardiovascular system.
- BC can act as carrier of co-emitted carcinogens (e.g., PAHs).



# Objectives

- To study the temporal and spatial variations of BC in an urban environment → fixed site and personal exposure monitoring of BC.
- To characterize the optical properties of water-soluble organic carbon, the water-soluble fraction of BrC.
- Form a scientific basis for development of environmental policies to mitigate climate change and to improve urban air quality.

# Materials and Methods

# Black carbon measurements

## Aethalometer AE33


Fixed site measurements

## microAeth AE51

Personal exposure measurements

- Optical method to measure absorption due to aerosols at 7 wavelengths (370, 470, 520, 590, 660, 880, 950 nm) in real-time
- BC collected on filter tape
- Absorption at wavelength 880 nm is exclusively due to BC and proportional to BC mass concentration

- Handheld, portable version of AE33 based on same working principle
- Only absorption at one wavelength (880 nm)

# Analysis of BrC measurements

**TAS MiniVol**

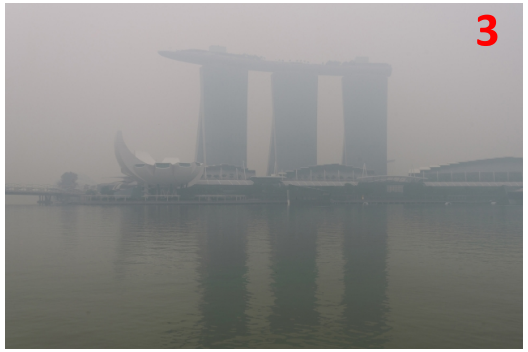
$PM_{2.5}$ Samples from:

1) NUS Rooftop
2) Roadside
3) Samples from 2015 haze episode (Sep/Oct)

**UV-VIS Spectrophotometer**
(200 – 800 nm)

**WSOC Analysis**



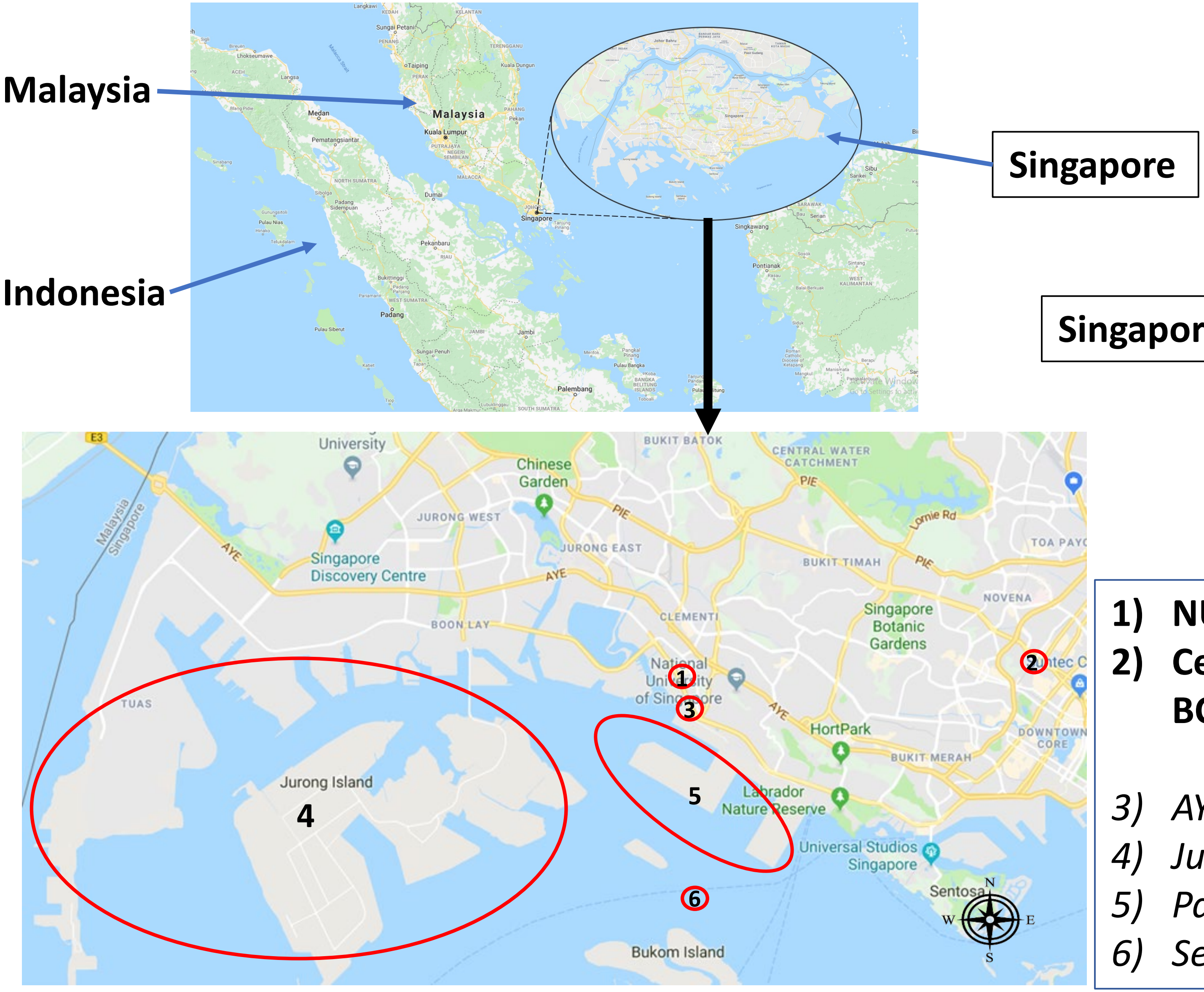


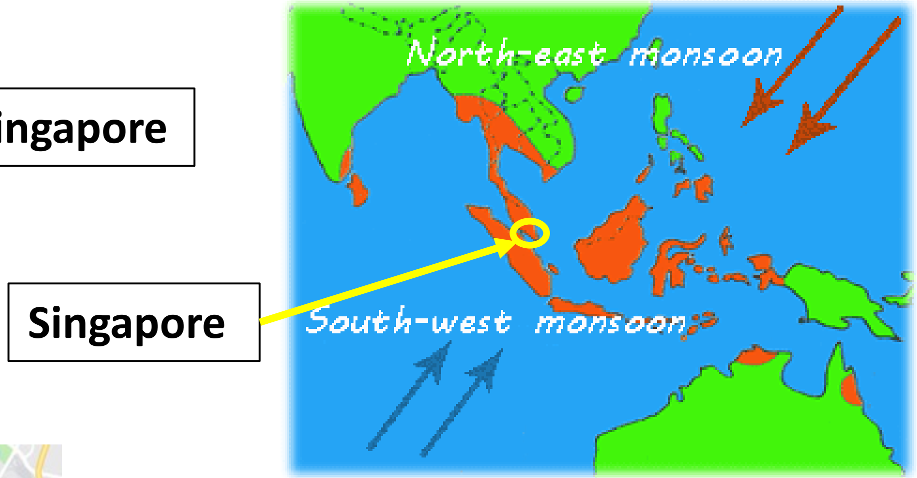

**Light absorption properties determined**

**Absorption Ångström Exponent, AAE**

**Mass Absorption Efficiency, $MAE_{BrC}$**

# Geographical Location of Monitoring Locations




Southwest monsoon – dry
Northeast monsoon – wet

1) **NUS - fixed BC monitoring site**
2) **Central Business District - personal exposure BC**

3) *AYE Expressway*
4) *Jurong Island & Tuas Industrial Areas*
5) *Pasir Panjang Terminal*
6) *Sea*

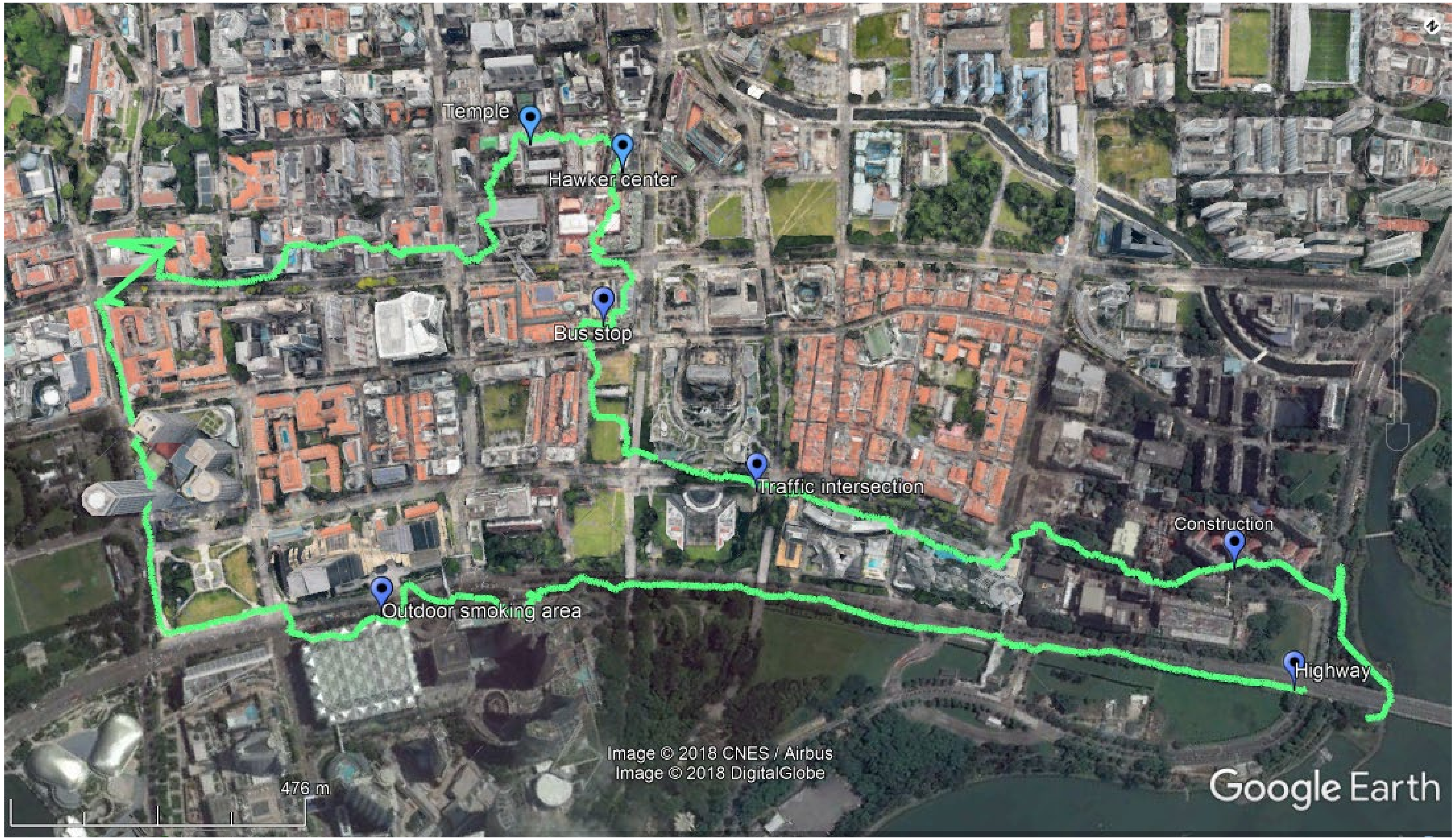
# Route and locations of mobile study

**Microenvironments monitored (7 km route):**

- Highway
- Bus Stop
- Traffic Intersection
- Construction Site
- Smoking Area
- Temple
- Hawker Centre

**Three different timings of the day:**

- morning
- afternoon
- evening



# Results

# Seasonal variation of BC and AAE

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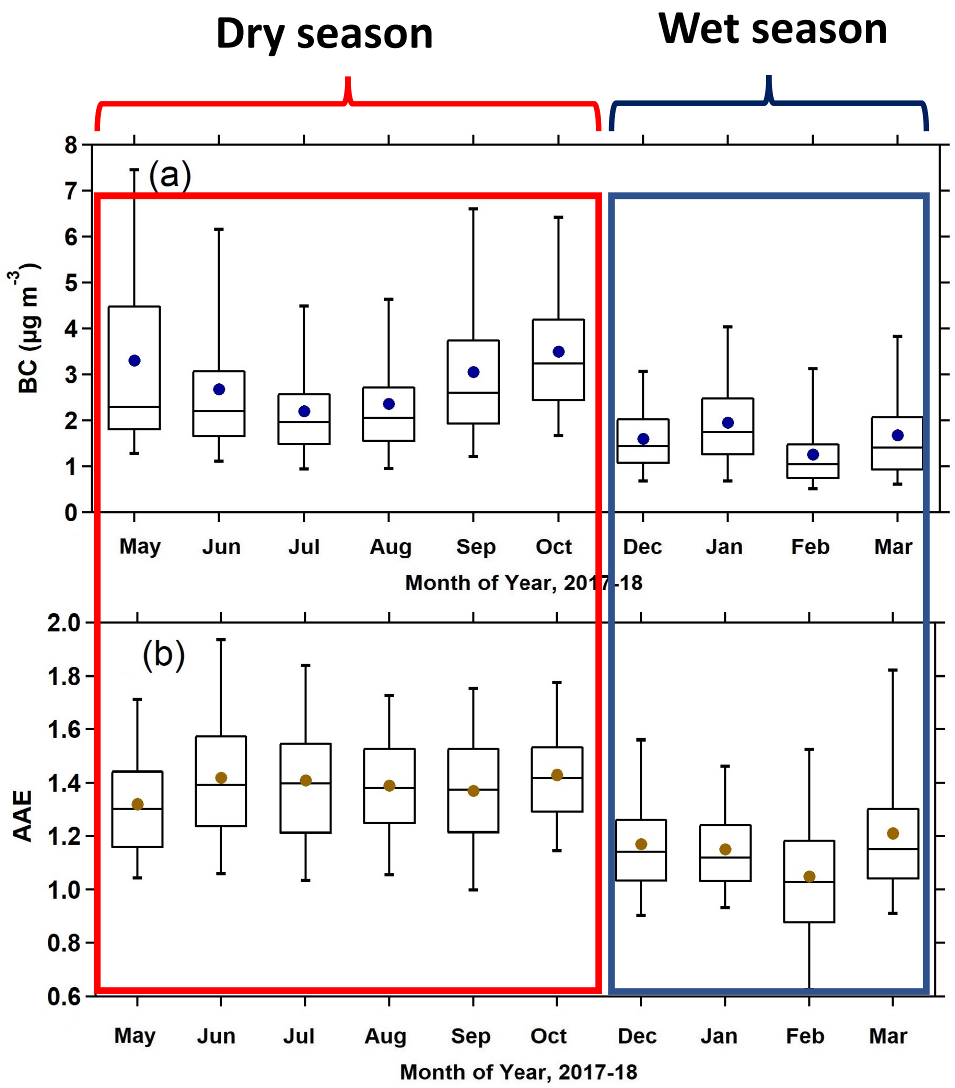


**(a) BC**

- Higher BC concentrations during Southwest monsoon season (dry; June to October) compared to Northeast monsoon (wet; December to March).

**(b) AAE**

**AAE = 1 for 'pure' BC from fossil fuel**
**AAE > 1.8 for biomass burning aerosol**

*AAE computed over wavelength range 370 - 950 nm*

- Correspondingly higher AAE values during dry compared to wet season.
- Higher AAE values indicative of absorption at lower wavelengths → BrC. Influence of biomass burning emissions from transboundary transport.

# Fire hotspot activity in SEA

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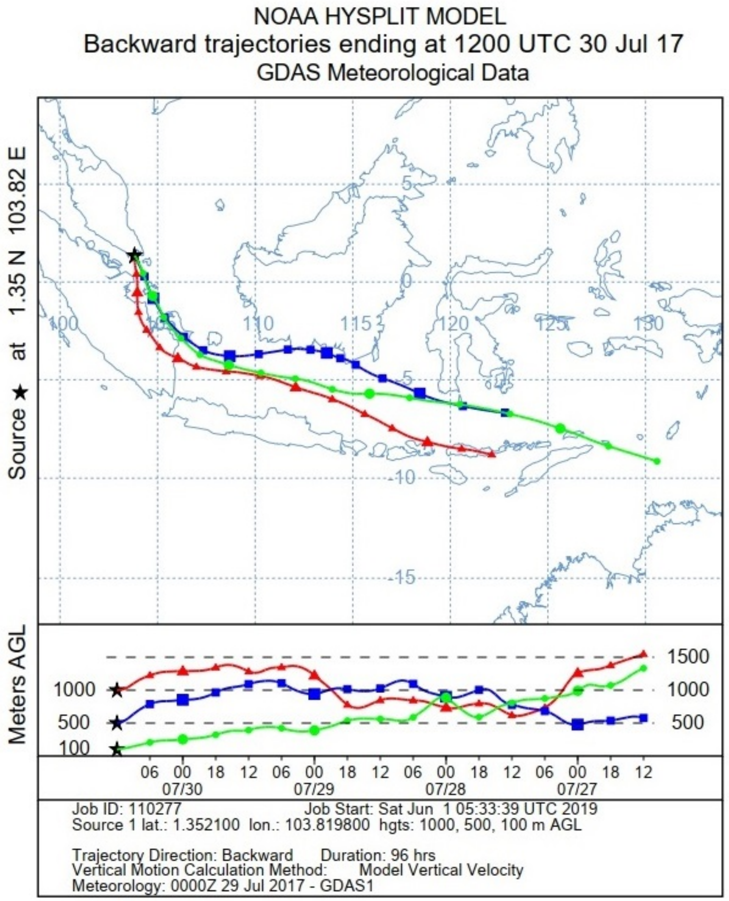
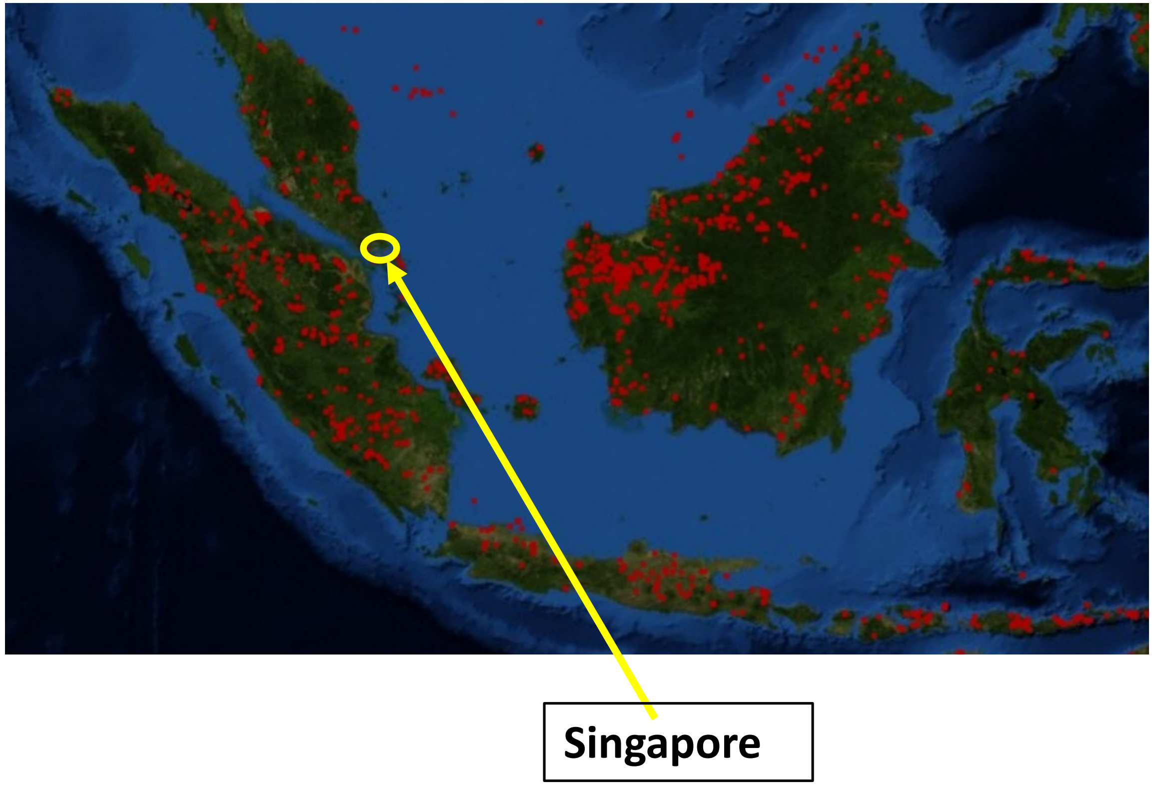
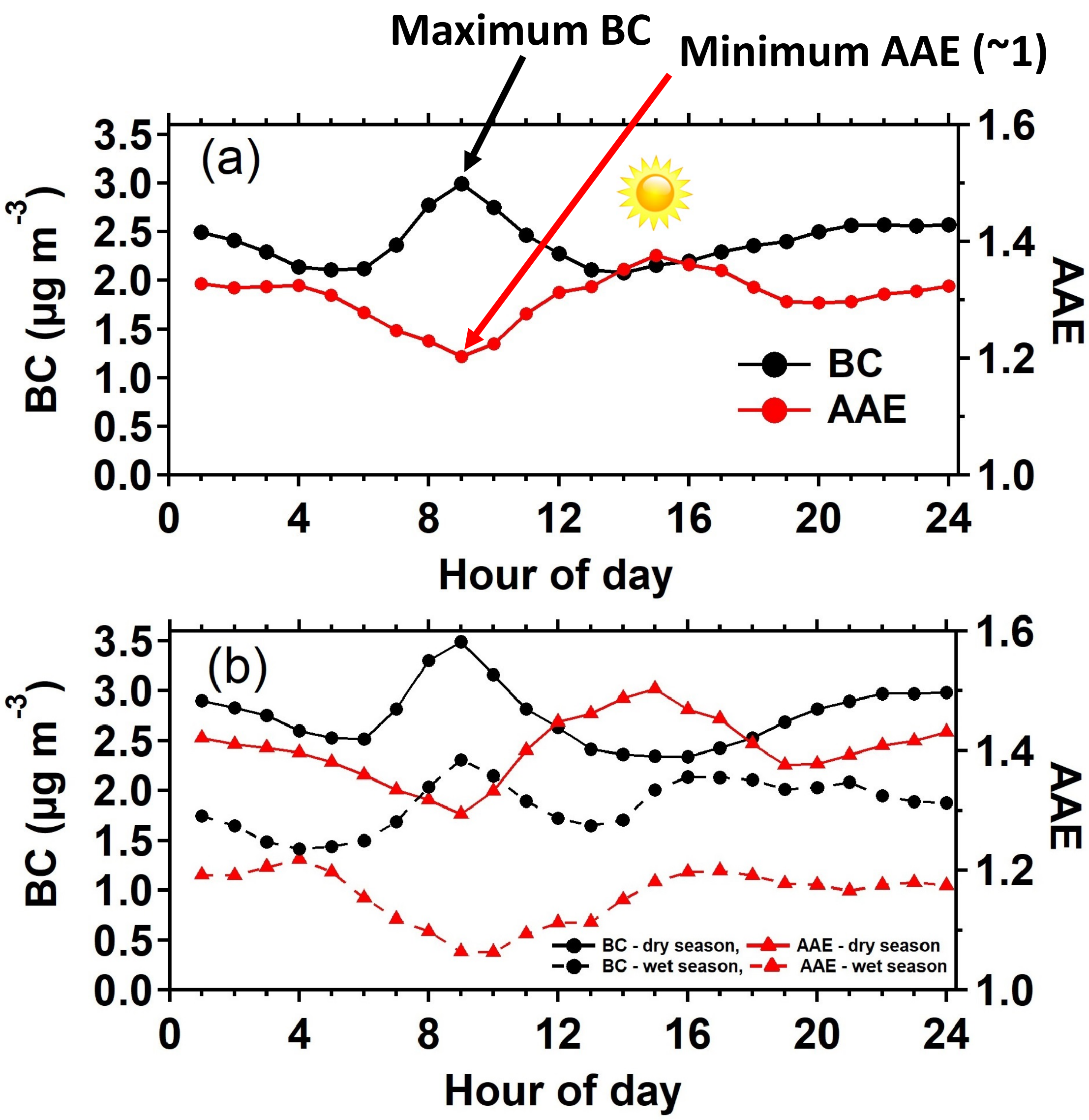



- Illustrative example, 30 July 2017:
  - NOAA HYSPLIT 96-hour airmass back-trajectory
  - fire hotspot activity (NOAA, Visible Infrared Imaging Radiometer Suite (VIIRS))

# Diurnal variation of BC and AAE




**(a) Entire dataset**

- BC peak between 8 – 10 am, coinciding with peak morning rush hour traffic.
- Daytime minimum BC due to dilution effects (boundary layer expansion, sea breeze)
- Daytime maximum AAE in conjunction with $PM_{2.5}$ maximum indicative of photochemical formation of BrC

**(b) Grouped by season**

- Diurnal variation of BC and AAE lower during wet season compared to dry season.
- During wet season, BC secondary peak observed, and AAE peaks at a later time compared to dry season.

# Radiative properties of WSOC

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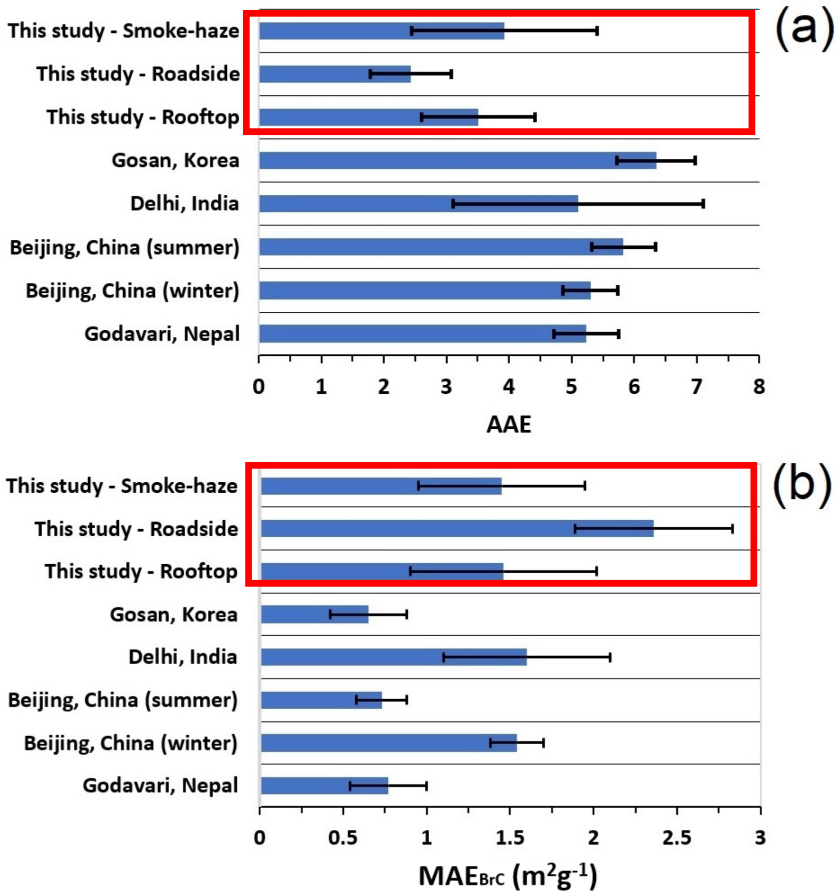
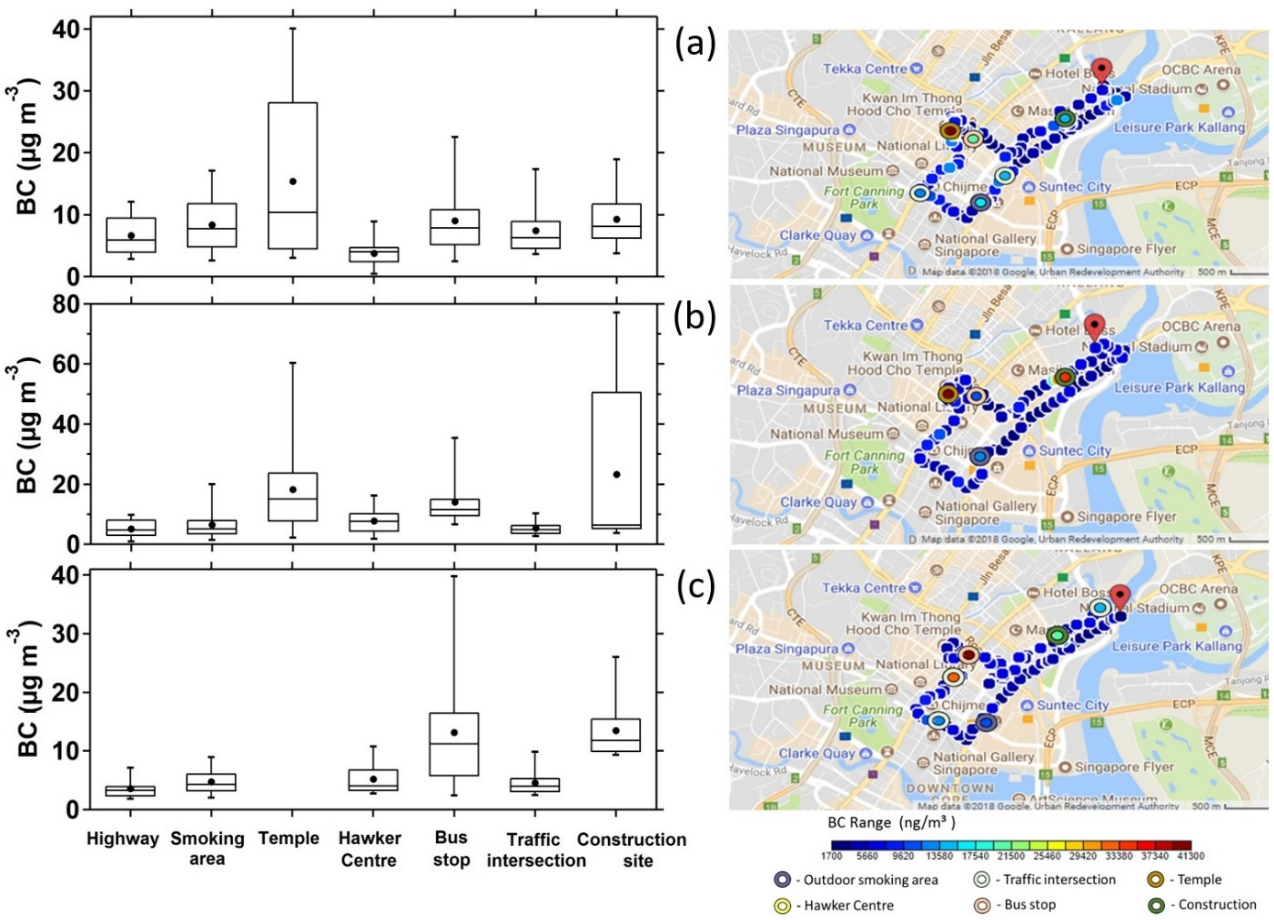



| Parameter | Rooftop | Roadside | Smoke-haze |
|---|---|---|---|
| AAE | 3.51 ± 0.91 | 2.43 ± 0.65 | 3.93 ± 1.48 |
| MAE, $m^2/g$ | 1.46 ± 0.56 | 2.36 ± 0.47 | 1.45 ± 0.50 |

AAE and MAE were determined for samples taken during the wet season:

- Roadside measurements indicate presence of BrC from traffic emissions.
- Secondary formation of WSOC (through photochemical reactions of VOCs) likely responsible for higher AAE values at rooftop location.
- Highest AAE from smoke-haze sample while bleaching of chromophores may be responsible for relatively low MAE values.
- The differences of the AAE and MAE of WSOC in Singapore compared to the other studies can be attributed to differences in formation and/or pollution sources.

# Personal exposure measurements of BC




- Highest exposure at construction site and temple.
- Lowest exposure at highway and food court (hawker centre).
- Consistent enhancement of personal exposure measurements compared to background BC levels measured at NUS rooftop.

**Enhancement of BC in microenvironments compared to fixed monitoring site**

| Microenvironment | Morning | Afternoon | Night |
|---|---|---|---|
| | BC enhancement | BC enhancement | BC enhancement |
| Highway | 4.90 ± 2.17 | 2.50 ± 1.23 | 2.61 ± 1.24 |
| Bus stop | 3.88 ± 2.38 | 7.28 ± 3.95 | 8.73 ± 6.32 |
| Traffic intersection | 3.13 ± 1.65 | 2.79 ± 1.06 | 3.15 ± 1.61 |
| Construction site | 3.95 ± 1.72 | 13.12 ± 16.45 | 6.00 ± 2.10 |
| Hawker centre | 1.71 ± 0.93 | 4.34 ± 2.46 | 3.40 ± 1.04 |
| Smoking area | 4.93 ± 2.65 | 3.65 ± 2.91 | 3.37 ± 1.37 |
| Temple | 7.22 ± 5.99 | 10.97 ± 13.29 | - |

**motorized** (Highway, Bus stop, Traffic intersection, Construction site)

**Non-motorized** (Hawker centre, Smoking area, Temple)

(a) Morning (0730-1000 local time); (b) Afternoon (1200-1430 LT); (c) Evening (1930-2200 LT)

# Conclusions

- BC shows seasonal variations in Singapore with **higher BC values** during **dry season compared to wet season**.
- The **diurnal cycle of BC and AAE** indicates strong influence from **traffic emissions**.
- **Higher biomass burning** contribution during **dry season** inferred from **AAE and air mass trajectories + fire hotspots**.
- WSOC measurements indicate **presence of BrC from traffic emissions** as well as **photochemical production** of BrC **from VOC precursors**.
- **Personal exposure measurements of BC** in **different microenvironments** indicate **consistently higher** values than **fixed monitoring values**. **Highest exposure** values were observed at a **construction site** and **temple**.

# Implications of this study

- Reductions of fossil fuel burning related emissions will lead to near-term climate change benefits on several scales (local to global) not only in terms of BC reductions but also BrC which has in several recent studies shown to potentially significantly contribute to atmospheric warming.

- Personal exposure monitoring of BC on an intra-urban scale is advised to identify hotspots of anthropogenic air pollution consequently enabling urban authorities to provide advisories to the public to safeguard human health.

# Thank you!

# Additional slides

# Sources of Black Carbon

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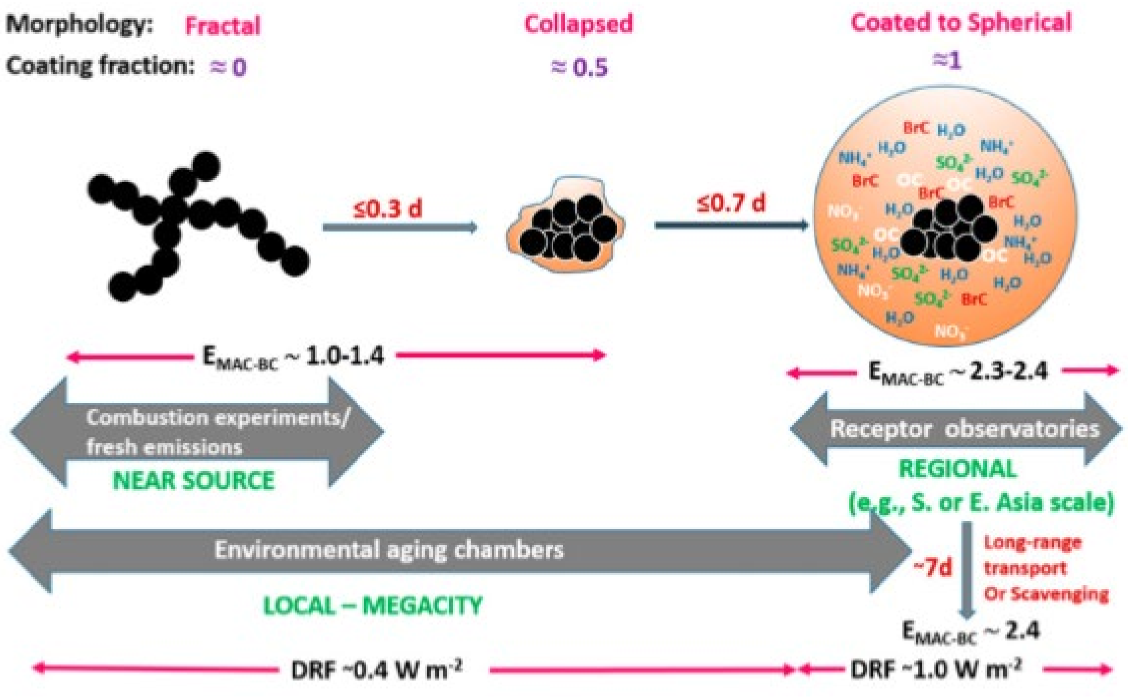
Open burning: BC+ organic carbon

Residential cooking: BC + organic carbon

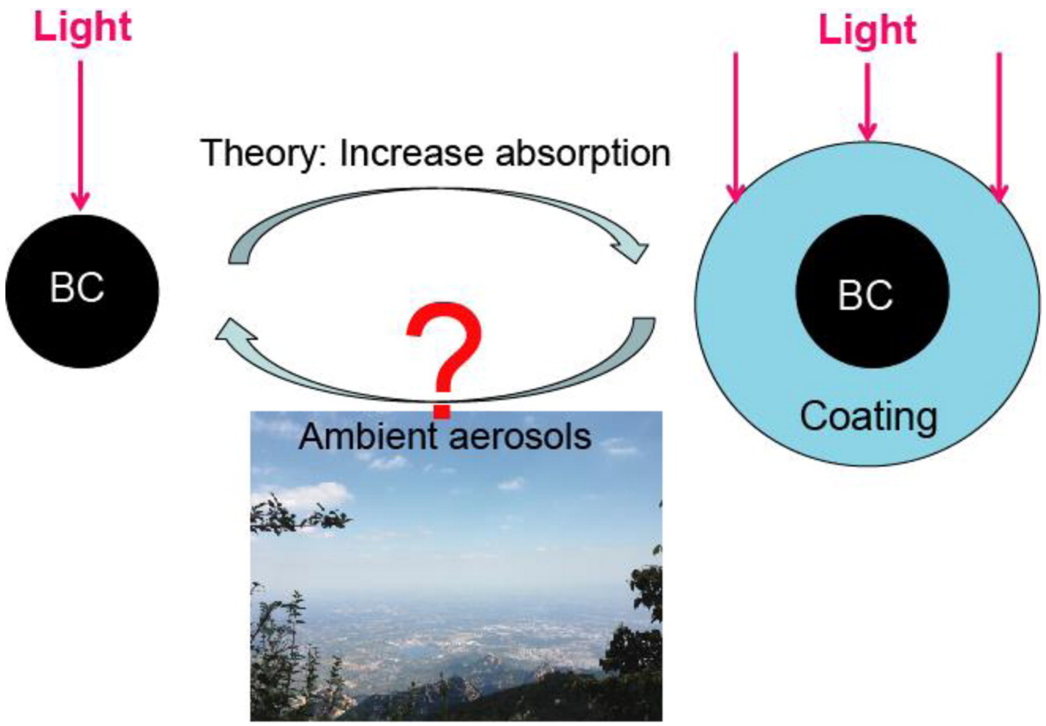

Transportation: Diesel is BC rich

Industry (coke) BC and sulfate

# BC coating and lensing effect




Evolution of BC in the atmosphere ('aging')




Lensing effect

$$\mathrm{babs}_{365}(\mathrm{M\ m^{-1}}) = \left[\frac{(A_{365} - A_{700}) \times V_{ext} \times \ln(10)}{V_{air} \times l}\right] \quad (2.8)$$

Where A365 and A700 are the measured absorbance values at 365 and 700 nm; $V_{ext}$ is the volume of Milli-Q water used for the extraction of the aerosol filter, $V_{air}$ is the volume of air filtered through the aerosol filter and ℓ is the path length of the beam of light through the extract.

$$\mathrm{MAE_{BrC}}\ (\mathrm{m^2\ g^{-1}}) = \frac{b_{abs-365}}{[WSOC]} \quad (2.9)$$

where [WSOC] is the mass concentration of WSOC in air (μg $m^{-3}$)

The mass absorption coefficient varies as a function of wavelength and can be fitted into a power law in the form:

$$b_{abs-\lambda}(M\ m^{-1}) = a \times \lambda^{-AAE} \quad (2.10)$$

Where $b_{abs-\lambda}$ is the mass absorption coefficient at wavelength λ, *a* is a wavelength-independent constant, λ is the wavelength of light and AAE is the Absorption Ångström Exponent. The absorbance spectra in the wavelength range 300 to 700 nm were used to estimate the AAE.

# Black carbon measurements

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## Aethalometer AE33


Fixed site measurements

| Parameters | |
|---|---|
| BC Detection Range | <0.01 to >100 µg/$m^3$ |
| Time Base | 1 min |
| Flow Rate | 3 l/min |
| Wavelengths Used | 370, 470, 520, 590, 660, 880 & 950 nm |
| **BC concentration measurement is defined by the absorption measurement at 880 nm** | |

## microAeth AE51

Personal exposure measurements

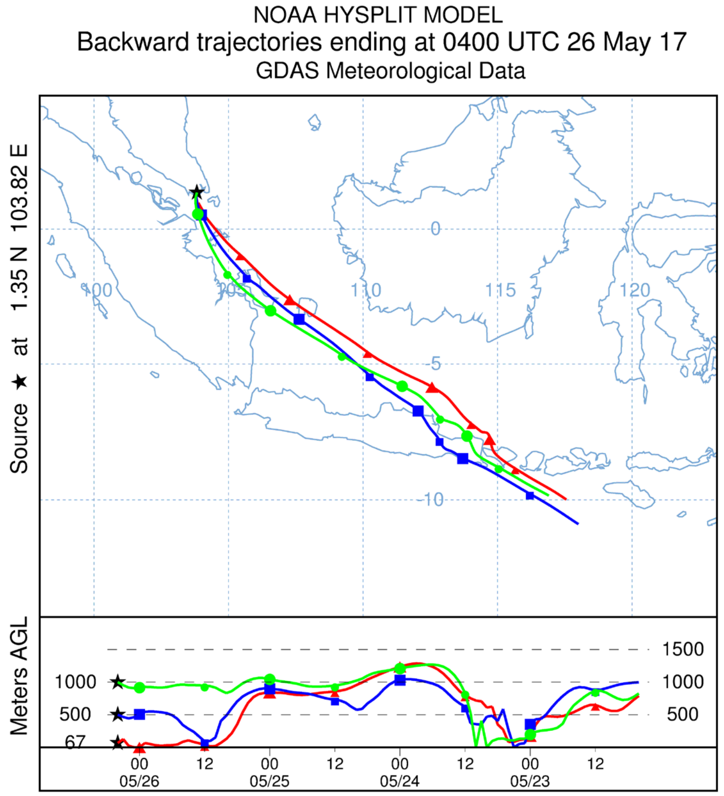
| Parameters | |
|---|---|
| BC Detection Range | 0 – 1 mg/$m^3$ |
| Time Base | 10 - 60 sec |
| Flow Rate | 150 ml/min |
| Wavelength Used | 880 nm |

# Setup for personal exposure data collection

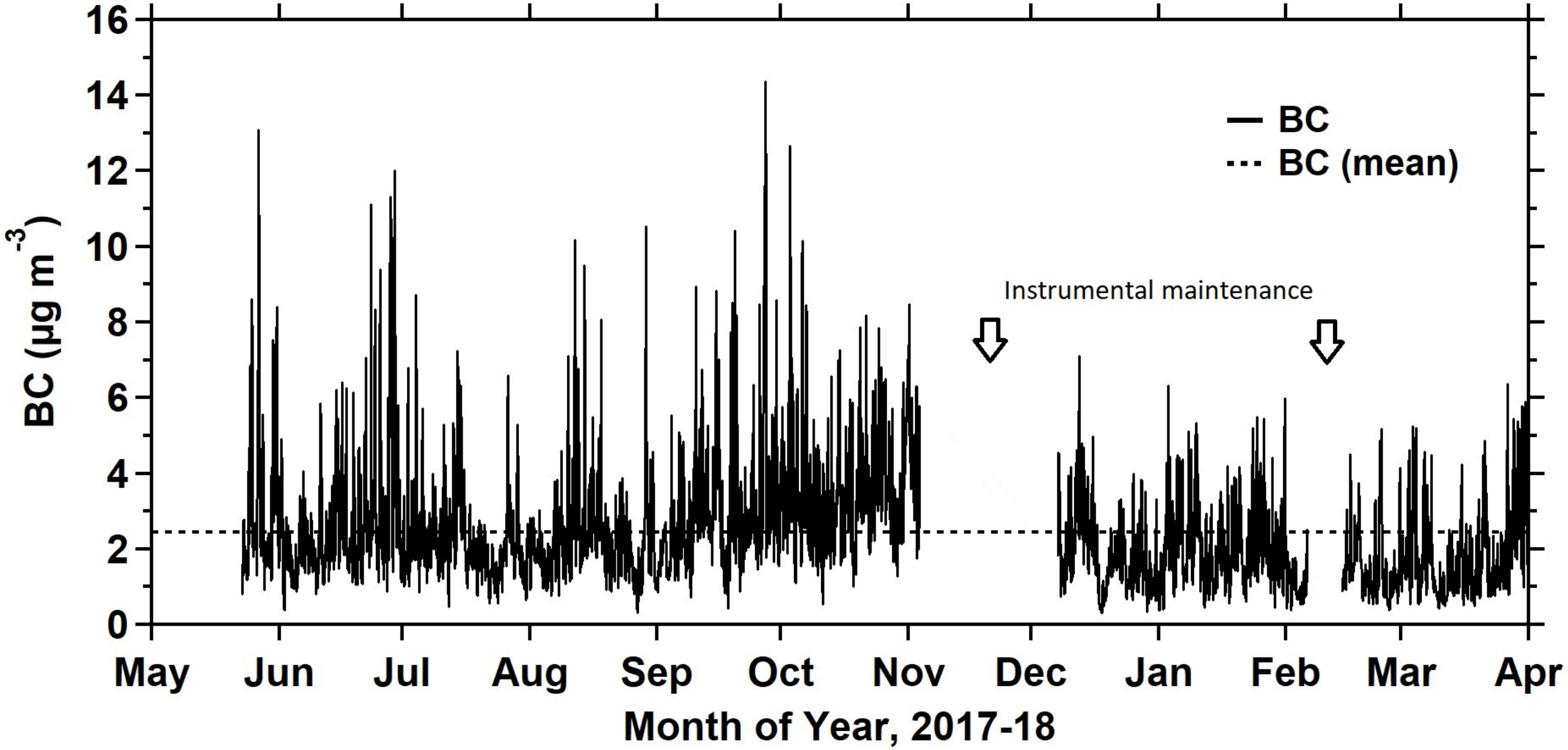
# Air mass back-trajectory analysis

- HYbrid SingleParticle Lagrangian Integrated Trajectory (HYSPLIT) is used to determine the back-trajectories
- Application: e.g. to address whether the trajectory originated over land or ocean; rising or sinking air parcel
- Useful for interpretation of the OA factors

**Example of air mass back-trajectory**

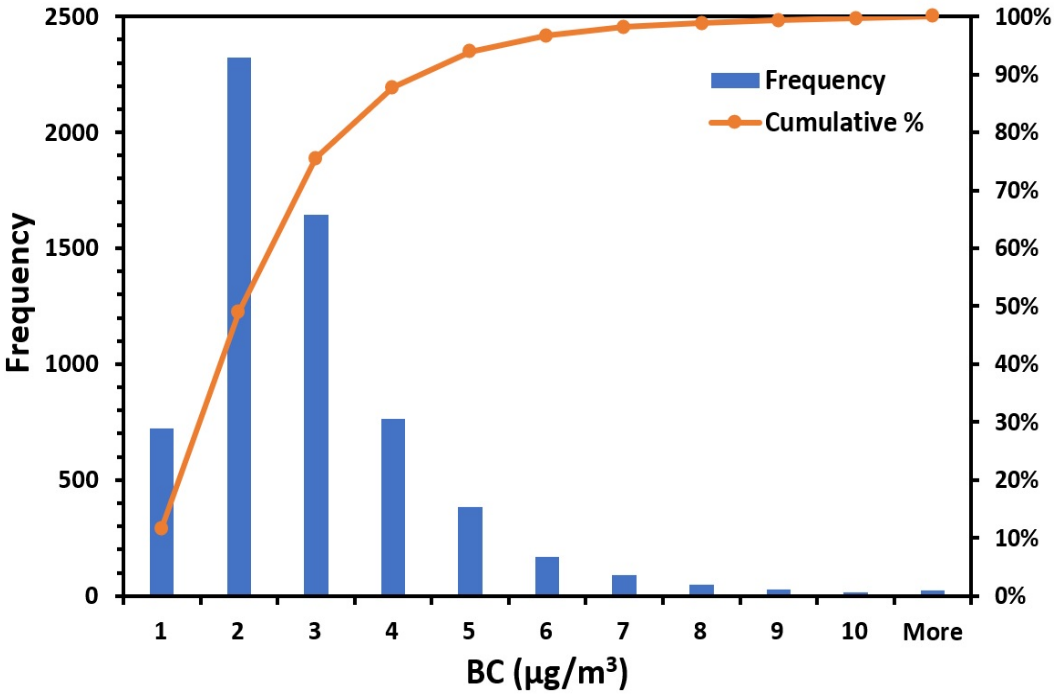


# Timeseries of BC fixed site measurements

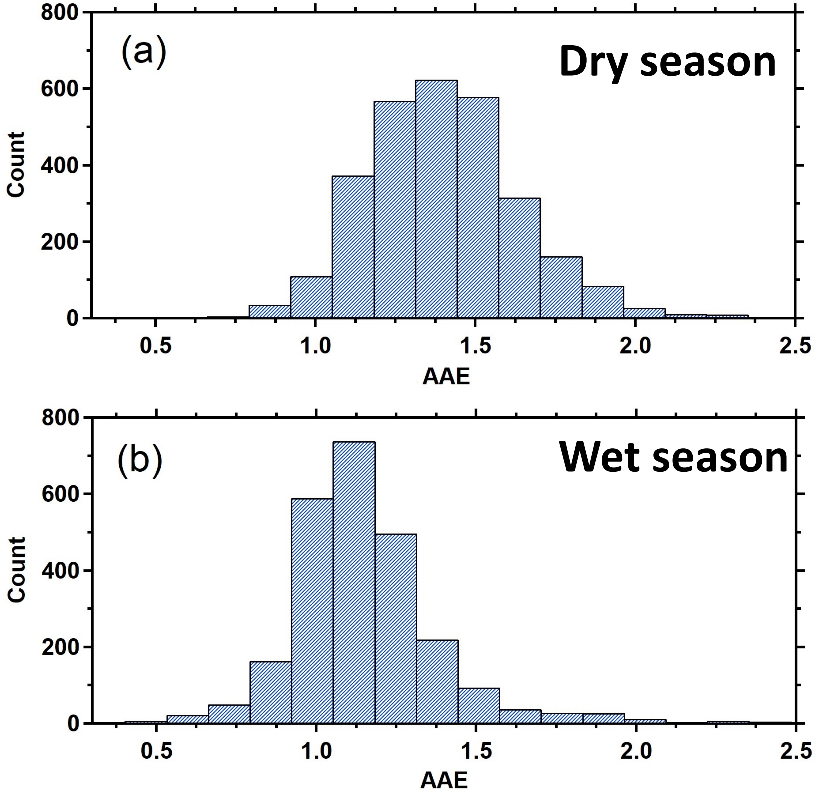



- **Measurements from mid-May 2017 to end of March 2018**
- **Hourly average shown**
- **Mean BC = 2.44 ± 1.51 μg/m$^3$**

# Frequency distribution of BC and AAE

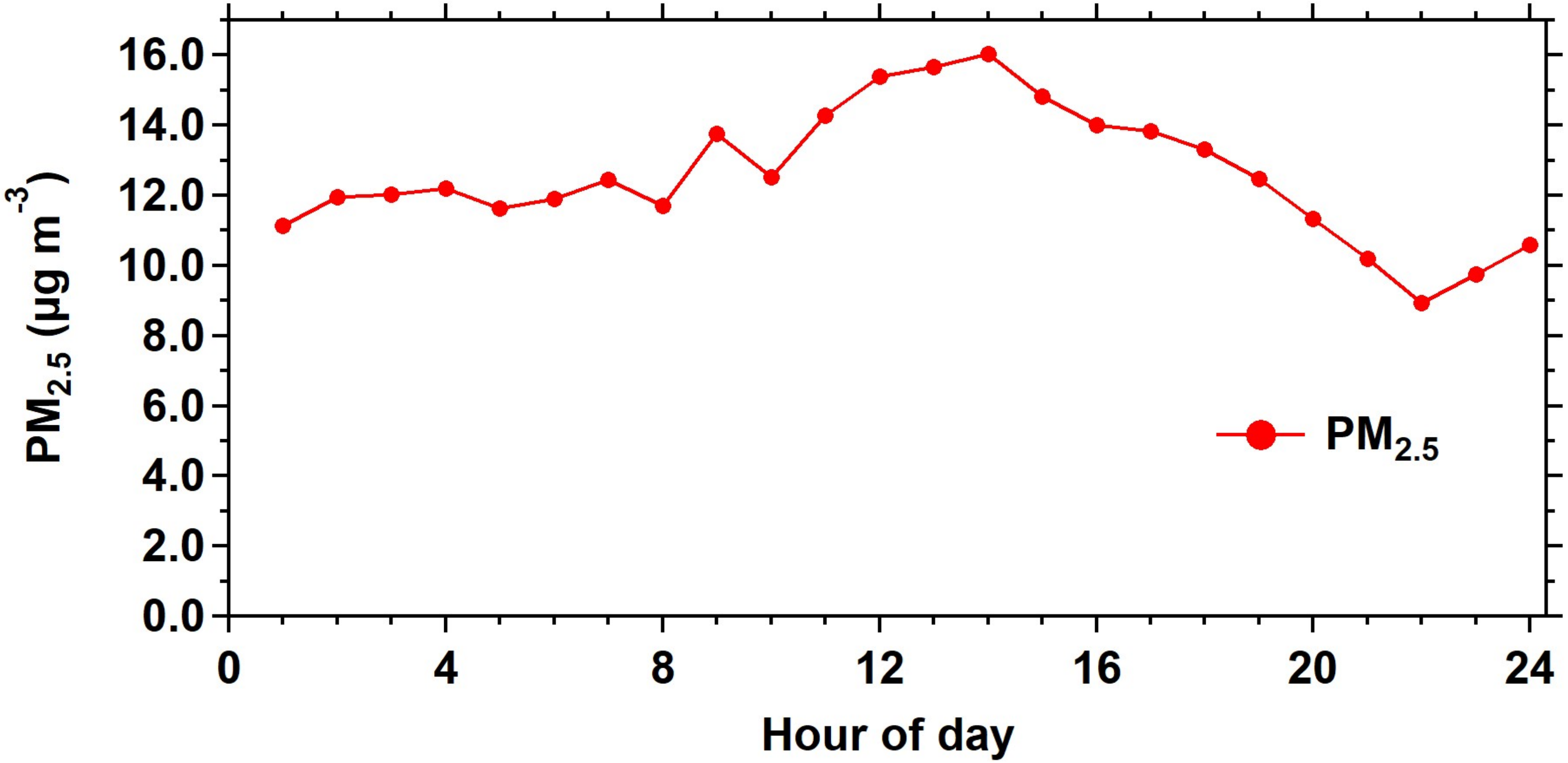



Frequency distribution of hourly BC values. Entire dataset (n = 6403).




Frequency distribution of hourly AAE values, grouped by dry and wet season.

# Diurnal $PM_{2.5}$ from fixed site monitoring (NEA)



# BC effects and benefits