Session 2
Black Carbon Definition and Measurement Approaches

Objective: Develop a common research framework to address measurement of black carbon mass concentration

Background/Overview/Facilitation – Hans Moosmüller, Desert Research Institute
1. Why Do We Care: Radiative Forcing & Climate Change
2. Carbon: Different Forms and Structures
3. What Determines Blackness
4. My Three Wishes for Definition & Measurement of Black Carbon

Existing Definitions of Black Carbon – Dan Lack, Independent Consultant (formerly NOAA)

Measurement Techniques and Considerations - Greg Smallwood, NRC Canada

Commercial Instrumentation Options – Monica Tutuianu, AVL

Practicability of Sample Preparation (Dilution Process) for On-Board Measurements – Kazuyuki Maeda, National Fisheries University
Temperature of the Earth?
0-dimensional Analysis: Štefan-Boltzmann Law

Energy Balance: \( E_{\text{in}} = E_{\text{out}} \)

\[
\pi r_E^2 S (1 - \alpha) = 4\pi r_E^2 \varepsilon \sigma T^4
\]

Resulting Temperature
\[
T = \left( \frac{(1 - \alpha) S}{4 \varepsilon \sigma} \right)^{1/4} = 289 \text{K}
\]

\( \sigma \) is the Štefan-Boltzmann constant
\( S \) is the solar irradiance (≈ 1366 W/m\(^2\))
\( \alpha \) is the planetary albedo (≈ 0.29 due to clouds, surface, aerosols)
\( \varepsilon \) is the emissivity (≈ 0.61 due to greenhouse gases, clouds, surface)

Jožef Štefan Ludwig Boltzmann
1835-1893 1844-1906

Solar Cycle Variations

Desert Research Institute
Climate Sensitivity (CS)

How much is the temperature going to change?

Energy Balance: $E_{\text{in\_solar}} = E_{\text{out\_TIR}}$

$T = 4 \sqrt{\frac{(1 - \alpha)S}{4 \varepsilon \sigma}} = 289 K$

Why do climate scientists get paid the big bucks?

Climate Feedbacks Missing from Štefan-Boltzmann

How Aerosol Albedo Affects Climate Change

Albedo (Latin) = Whiteness

Albedo is the fraction of incident optical power that is scattered or reflected by an object or a surface.

0 (totally black) ≤ Albedo ≤ 1 (totally white)

Light Absorbing Aerosols:
Black Carbon (BC), Brown Carbon (BrC), Mineral Dust

Where does BC warm the most?
Over fairly white surfaces (e.g., clouds, snow, ice, desert)
Also need to take sun angle, day time & seasons into account
Structures of Carbon

**Diamond**  
(unsafe)

**Graphite**  
(black)

**Black Carbon (BC)**  
(disordered and onion structured graphite with impurities)

**Graphene**  
(small layer of graphite)

**Ambient Black Carbon**

**Fullerenes**
Nanotubes  
Bucky-Ball ($C_{60}$)

**Fresh Black Carbon**

$N = k_g \left( \frac{2R_g}{d_p} \right)^{D_f}$  
$D_f = 1.8$  
$D_p \sim 30$ nm

TEM image of disordered structure (scale bar 5 nm)

SEM images of ambient soot particles:  
(a) embedded, (b) partly coated, (c) bare and (d) with inclusions.  
Scale bars, 500 nm.

SEM images of soot particles:  
(a) inclusions, (b) partly coated, (c) bare, (d) with inclusions.  
Scale bars, 500 nm.
What Determines Blackness
(Small albedo independent of wavelength)

1) Material Properties
   Complex Refractive Index
   \[ m = n \pm ik \quad i = \text{Sqrt}(-1) \]
   For BC: \( n = 1.95 \quad k = 0.79 \)
   Independent of wavelength in the visible
   Wave Equation
   \[ E = E_0 \exp \left( i \frac{2 \pi m z}{\lambda} - i \omega t \right) \]
   \( K = 0 \Rightarrow \) no absorption
   Bulk Absorption Coefficient \( \alpha_{abs} = 4\pi k/\lambda \)
   Penetration Depth \( 1/\alpha_{abs} \approx 55 \text{ nm} \)
   But larger \( k \) doesn’t always reduce SSA

2) Morphology
   \[ N = k g \left( \frac{2R g}{d_p} \right)^{D_f} \]
   \( D_f = 2.65 \)

3) Size

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Macroscopic

Microscopic 1

Microscopic 2
Definition & Measurement of BC (My Three Wishes)

1. Ideally “first principle” definition
   (More continuity, less dependent on technological advances; Example of operational definition: Horsepower)

2. Simple, robust, and inexpensive implementation (integrated into every smart phone)

3. Applicable to emissions, ambient, and deposited BC (needs large dynamic range)