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

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Temperature of the Earth?

0-dimensional Analysis: Štefan-Boltzmann Law

Energy Balance: $E_{in}=E_{out}$ $\pi r_E^2 S(1-\alpha) = 4\pi r_E^2 \varepsilon\sigma T^4$

Resulting Temperature $T = \sqrt[4]{\frac{(1-\alpha)S}{4\varepsilon\sigma}} = 289\,K$

σ is the Štefan-Boltzmann constant $\sigma = \frac{2\pi^5 k^4}{15 c^2 h^3} = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

S is the solar irradiance (≈ 1366 W/m^2)

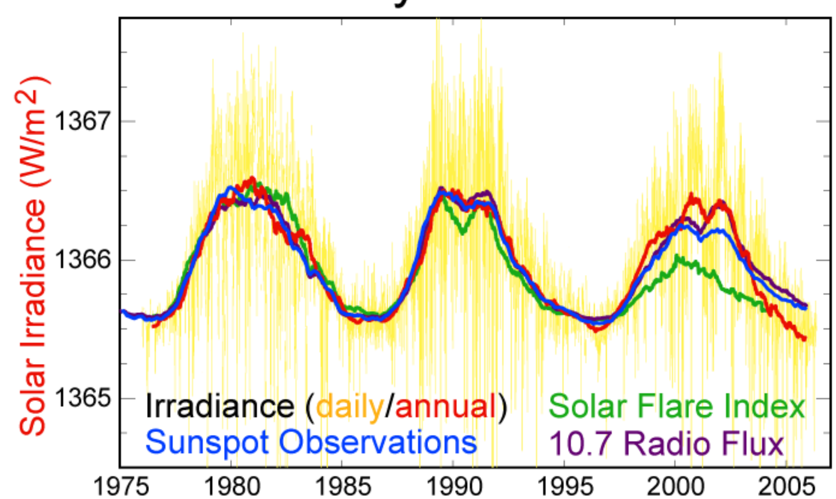
α is the planetary albedo (≈ 0.29 due to clouds, surface, aerosols)

ε is the emissivity (≈ 0.61 due to greenhouse gases, clouds, surface)

Jožef Štefan 1835-1893

Ludwig Boltzmann 1844-1906

Solar Cycle Variations

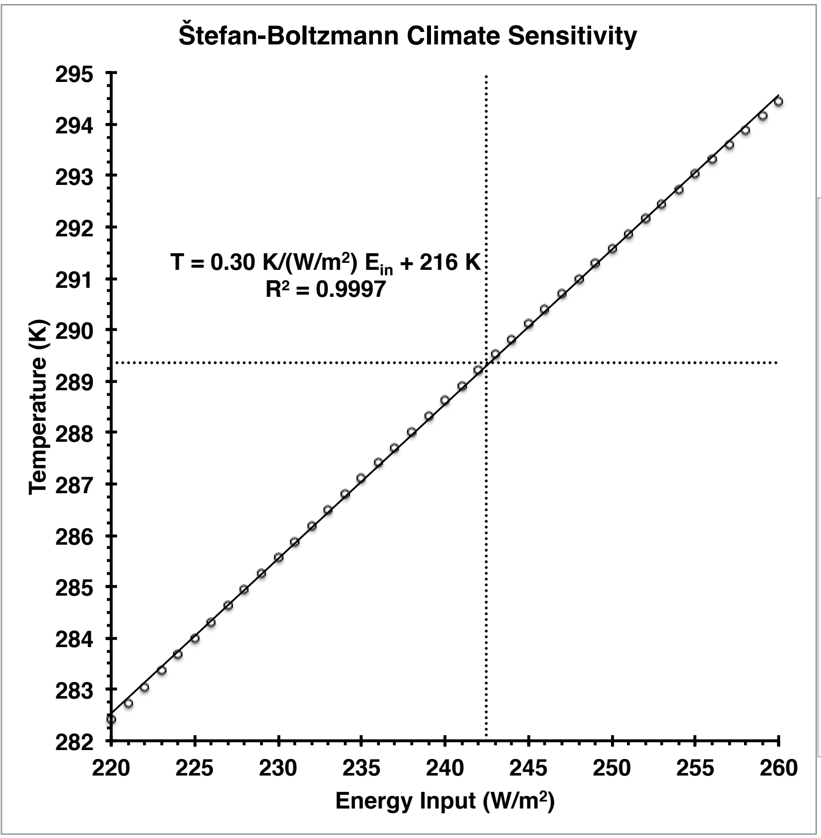


Climate Sensitivity (*CS*)

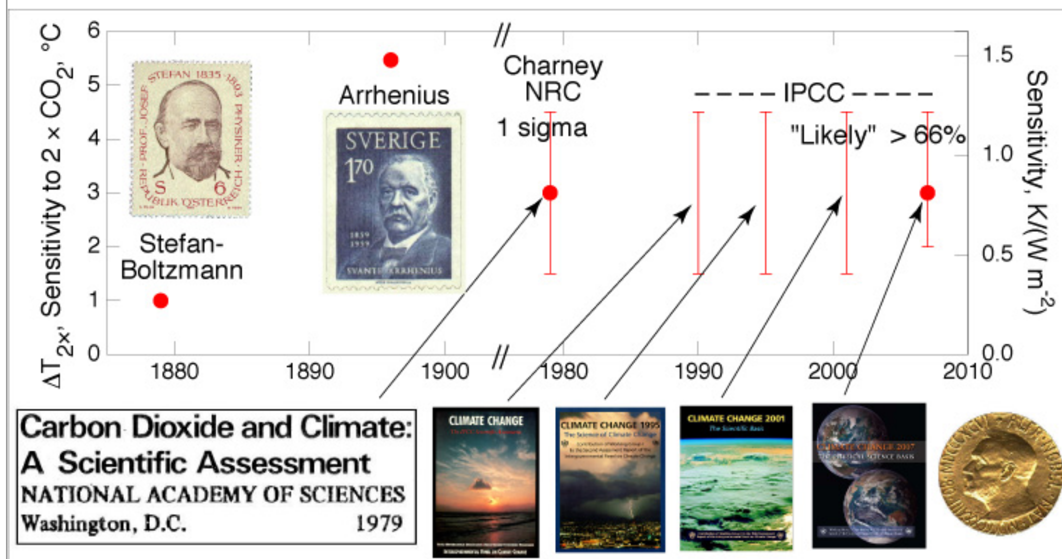
How much is the temperature going to change?

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

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



Why do climate scientists get paid the big bucks?



Climate Feedbacks Missing from Štefan-Boltzmann

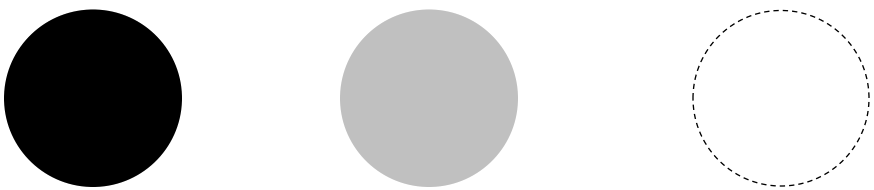
Schwartz, S. E. (2007). Heat Capacity, Time Constant, and Sensitivity of Earth's Climate System. *J. Geophys. Res.*, **112**, doi:10.1029/2007JD008746.

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)



<u>Light Absorbing Aerosols:</u>
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

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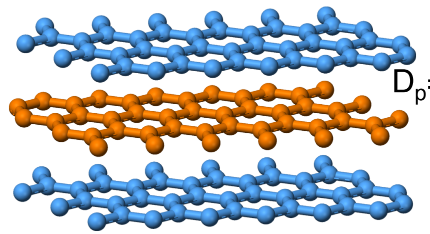
Whiter or Darker?

MODIS images of smoke from Southern California wildfires (26 Oct. 2003)

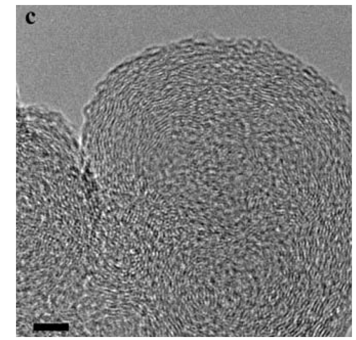
Structures of Carbon

Diamond
(unaffordable)

Graphite
(black)

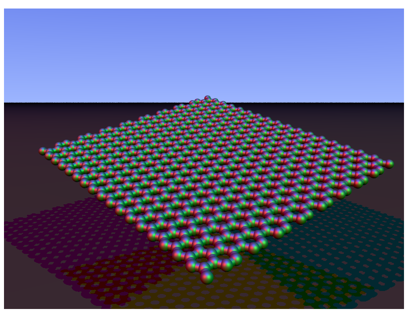


Black Carbon (BC)
(disordered and onion structured graphite with impurities)

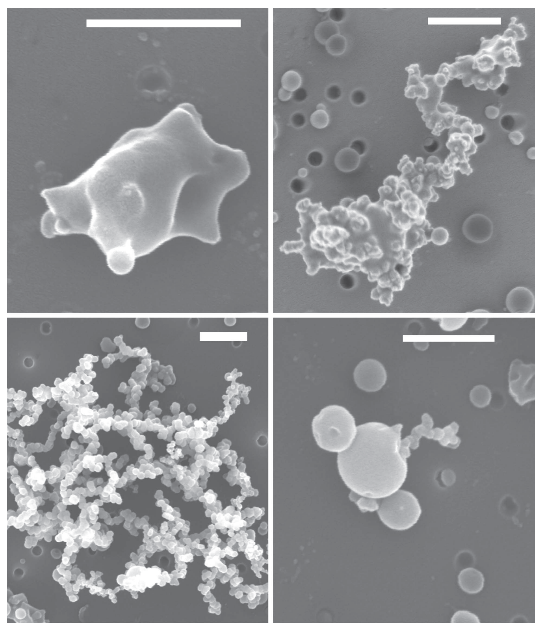


TEM image of disordered structure (scale bar 5 nm)

Graphene
(single layer of graphite)

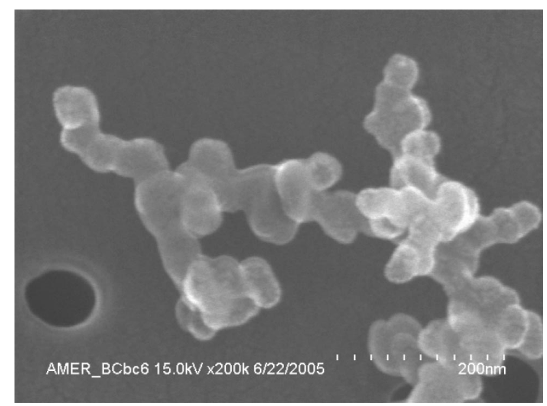


Ambient Black Carbon



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

Fresh Black Carbon



$$N = k_g \left(\frac{2R_g}{d_p} \right)^{D_f}$$

D_f = 1.8
$D_p \sim$ 30 nm

Fullerenes
Nanotubes
Bucky-Ball (C_{60})

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What Determines Blackness

(Small albedo independent of wavelength)

1)Material Properties

Complex Refractive Index

$m = n + ik \quad i = \mathrm{Sqrt}(-1)$

For BC: $n = 1.95 \quad k = 0.79$

Independent of wavelength in the visible

Wave Equation

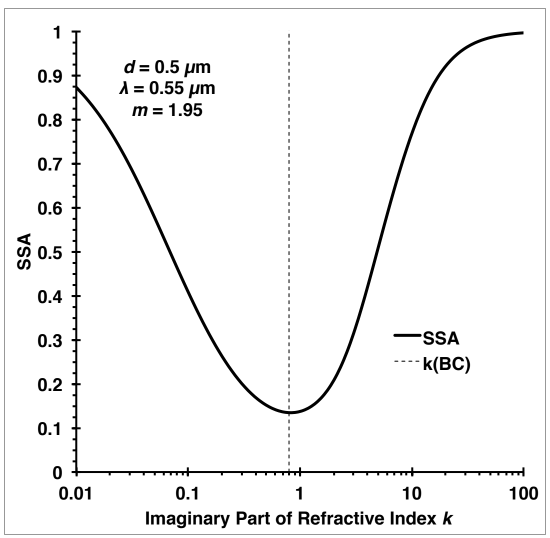
$$E = E_0 \exp\left(i\frac{2\pi m z}{\lambda} - i\omega t\right)$$

$K = 0 \Rightarrow$ no absorption

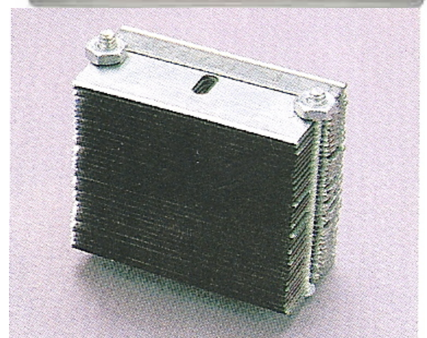
Bulk Absorption Coefficient $\alpha_{abs} = 4\pi\, k/\lambda$

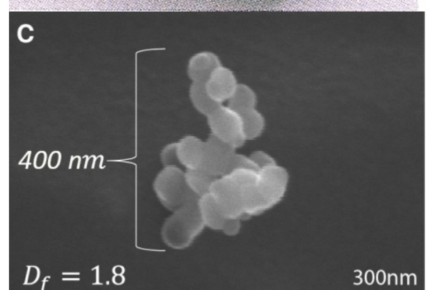
Penetration Depth $1/\alpha_{abs} \sim 55$ nm

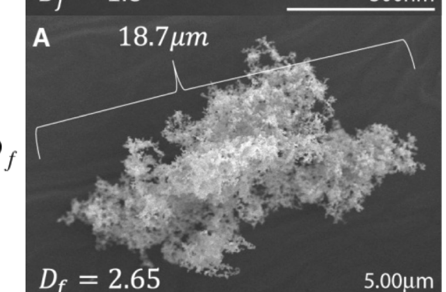
But larger k doesn't always reduce SSA



2) Morphology

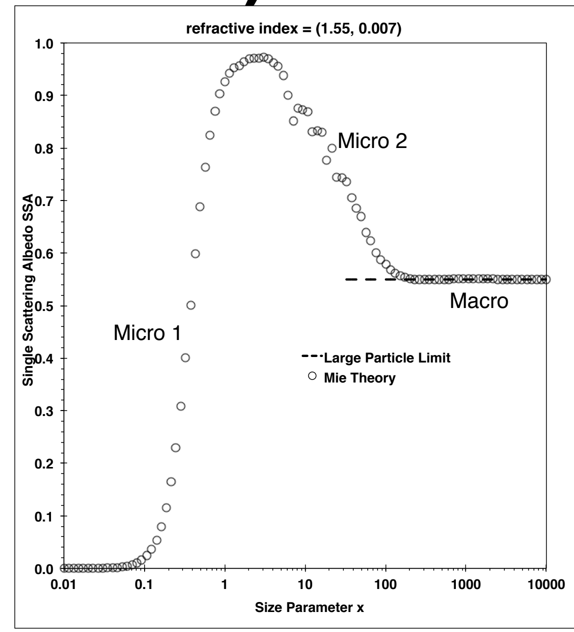




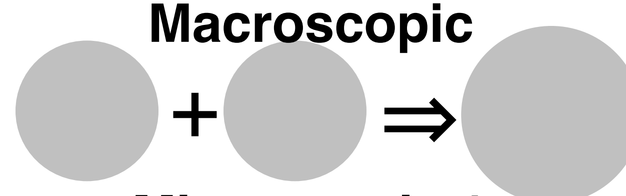


$$N = k_g\left(\frac{2R_g}{d_p}\right)^{D_f}$$

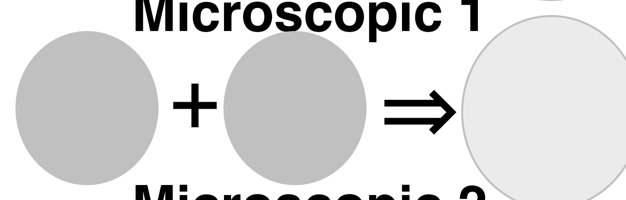
3) Size



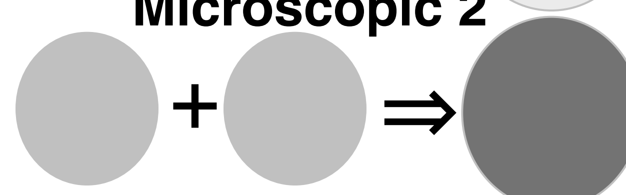
Macroscopic



Microscopic 1



Microscopic 2



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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)

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Lack, D., H. Moosmüller, G. R. McMeeking, R. K. Chakrabarty, and D. Baumgardner (2014). Characterizing Elemental, Equivalent Black, and Refractory Black Carbon Aerosol Particles: A Review of Techniques, Their Limitations and Uncertainties. *Anal. Bioanal. Chem.*, **406**, 99-122.