# ATOC 1060
# Our Changing Environment

Class 11

## Aerosol, Clouds and Climate

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# Overview

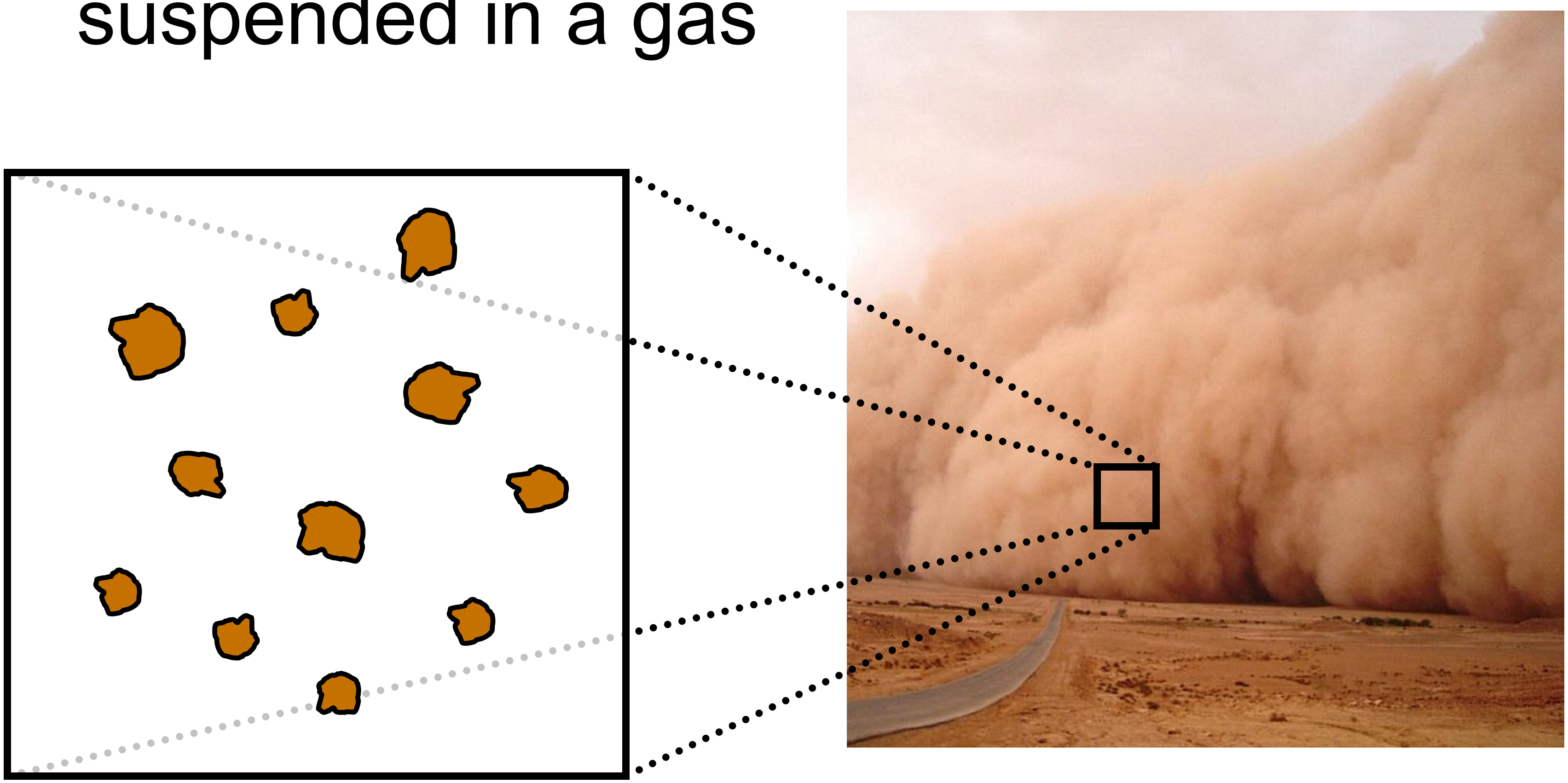
**Objective**: *to understand the impact of aerosol and clouds on climate*

- Introduce aerosol, types of aerosol and aerosol physics
- Introduce clouds and interactions among aerosol and clouds

**Key terms**: aerosol, scattering, direct aerosol effect, anthropogenic, absorption, semi-direct aerosol effect, indirect aerosol effects

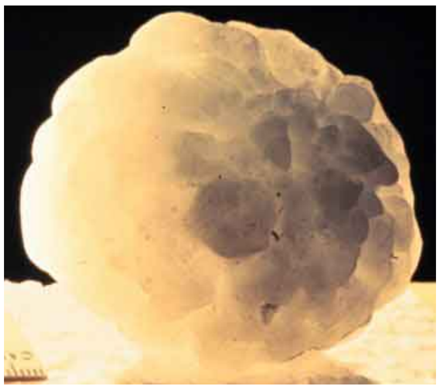
# Aerosol

- An aerosol consists of particles suspended in a gas



# Suspended Particles

**Hailstone**

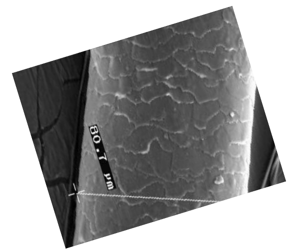


7" = 180 mm

**Raindrop**

5 mm

**Human Hair**



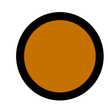
0.08 mm
= 80 μm

"micron"

**Dust**

2 μm

**Sulfate Pollution**



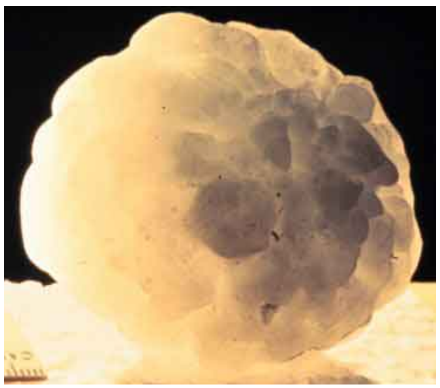
0.3 μm

- Suspended temporarily by wind
- Eventually settle to the surface

# Suspended Particles

**Lifetime is also known as "residence time."**
It's the time required to transport the particle to the surface

**Hailstone**



**minutes**

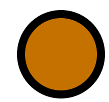
**Raindrop**

**minutes**

**Dust**

**seconds to days**

**Sulfate Pollution**



**days to years**

- Aerosol particles are difficult to simulate because of their short lifetimes; they are produced and removed rapidly

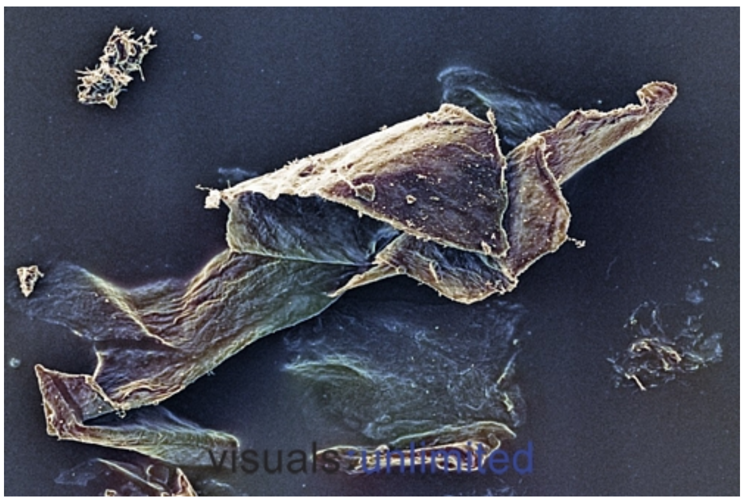
# Suspended Particles

**How do hailstones form?**

**Demonstration**

# Aerosol Particles

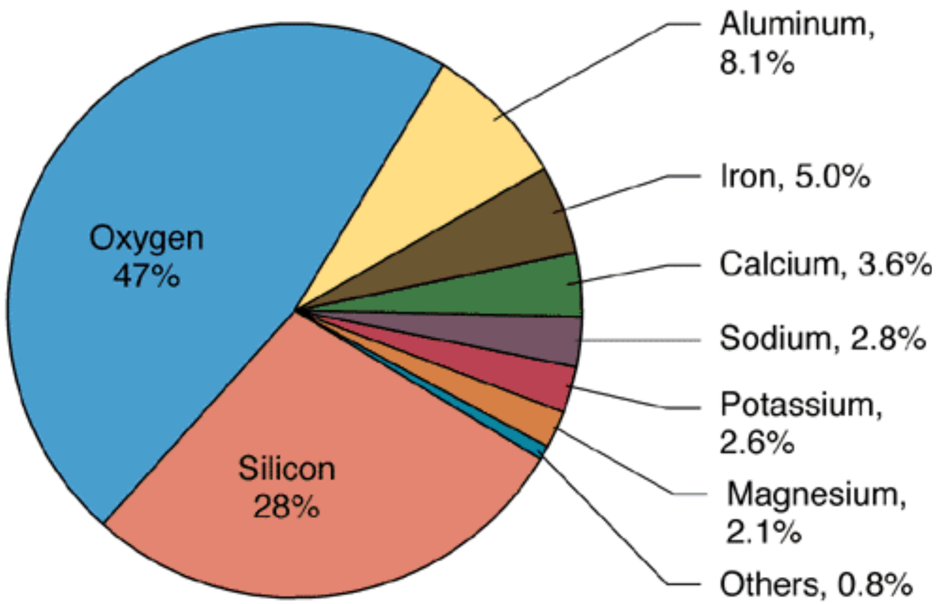
What is dust?




Household dust = shed skin

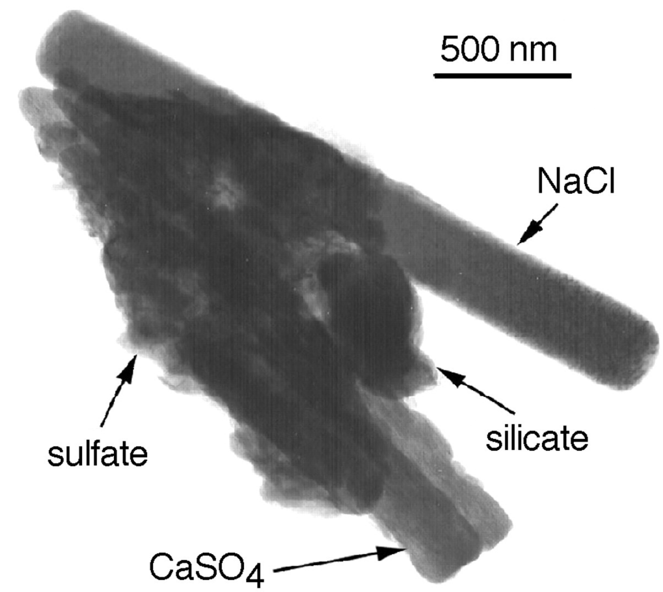
Wind-blown mineral dust

# Dust Particles



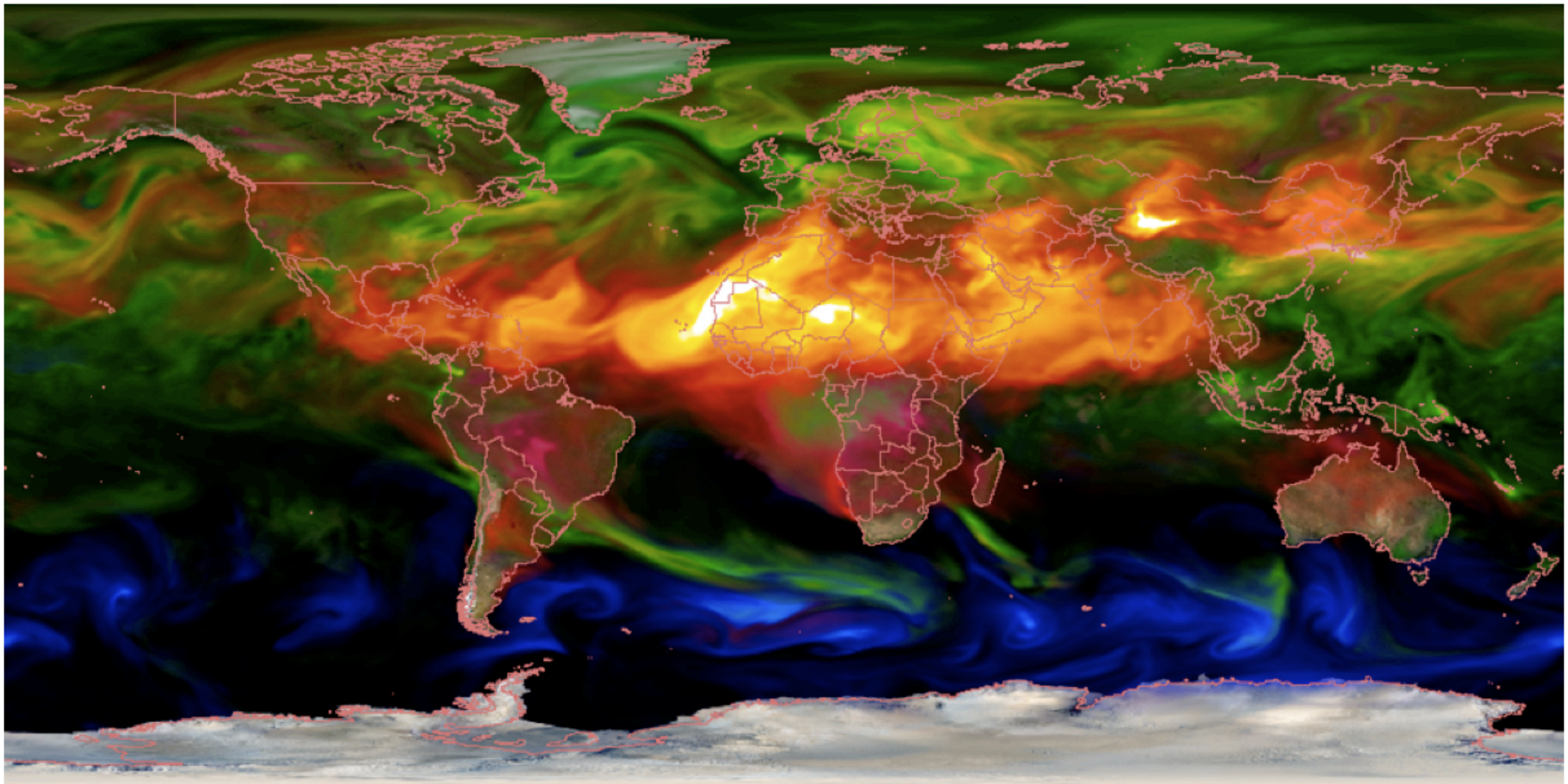

$SiO_2$

$Al_2O_3$



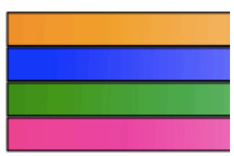

- Dust is mostly silicon dioxide, aluminum oxide and aluminosilicates, but there are a wide variety of minerals

# Aerosol Types



Dust

Sulfate




Sea Salt

Carbonaceous

NASA GSFC Atmospheric Chemistry & Dynamics Branch, Global Modeling and Assimilation Office

# “OK… I get aerosol already…”

## *Why are aerosol particles important for climate?*

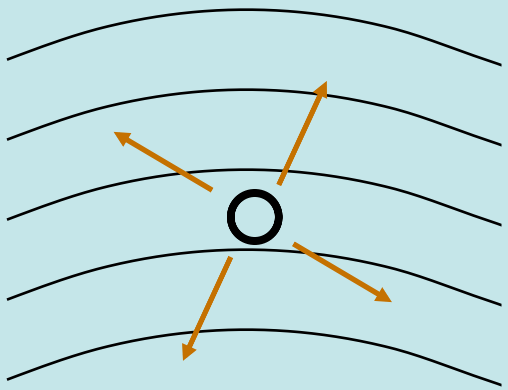
Beijing, China

Beijing, China, 2002
Dust storm and pollution

- Aerosol particles affect the amount of sunlight that reaches the Earth -- breathability might be important, too

# Are aerosol particles important for climate?

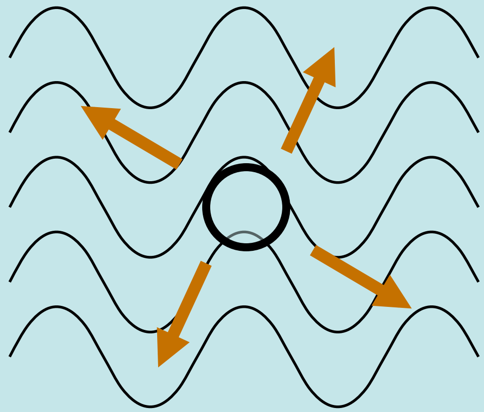
## *Aerosol Physics: Optics*



Weakly scattering

Rayleigh Scattering

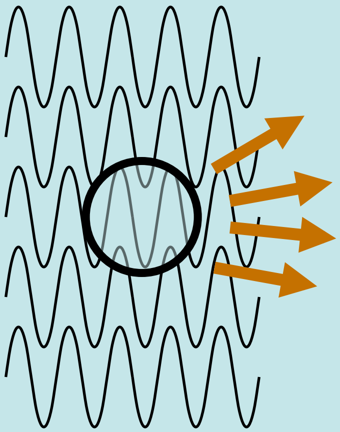
Clear Sky



Strongly scattering

Mie Scattering

Haze



Forward scattering

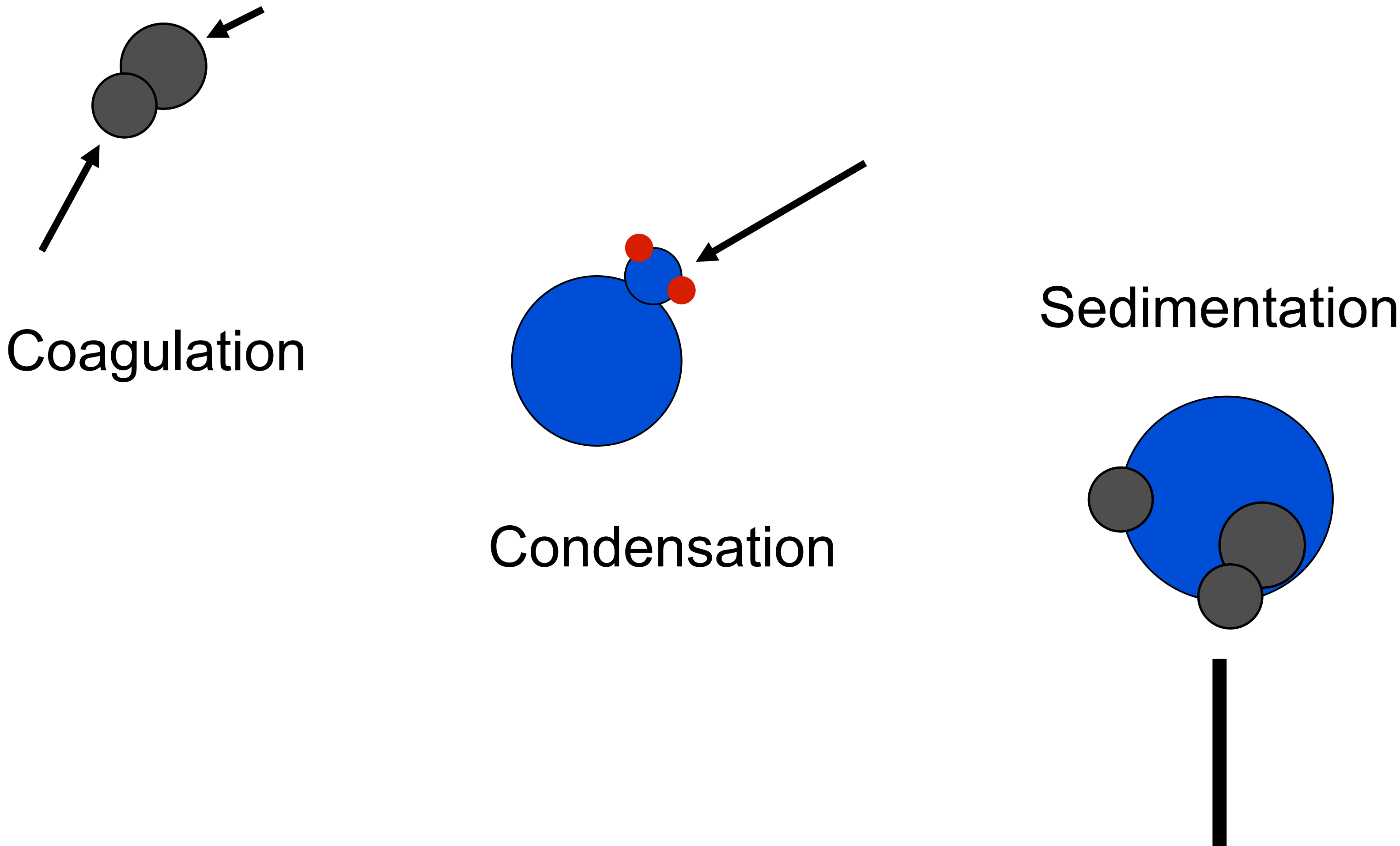
Geometric Optics

Dirty Windshield
(looking into the sun)

# Scattering

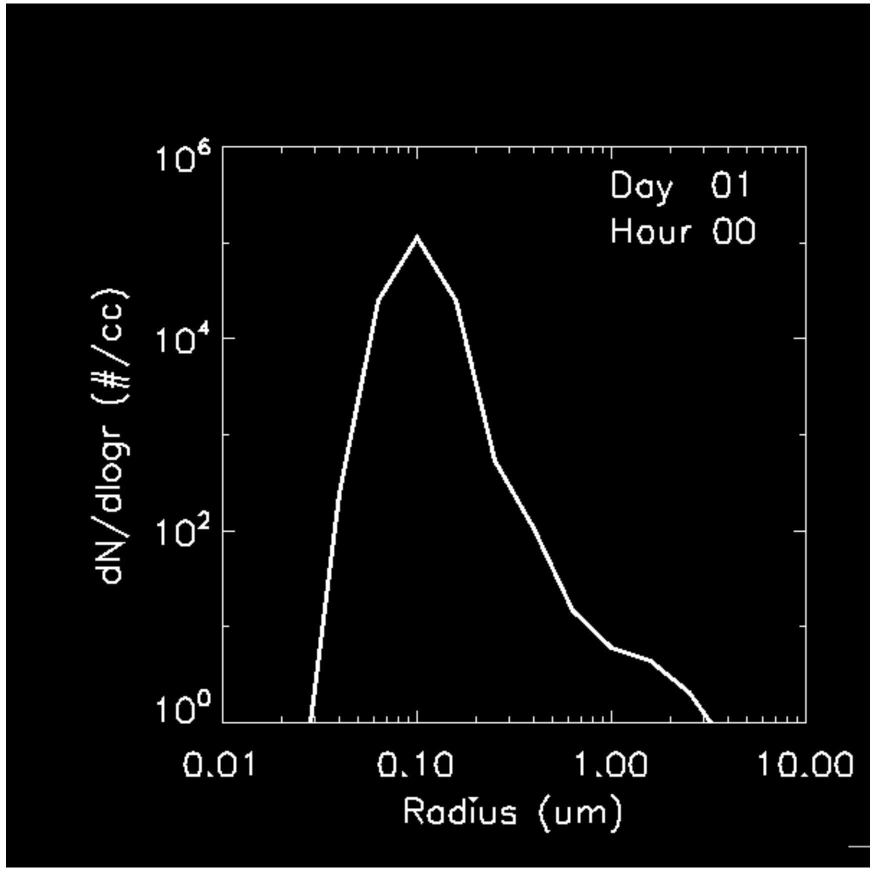
- demonstration

# Aerosol Microphysics



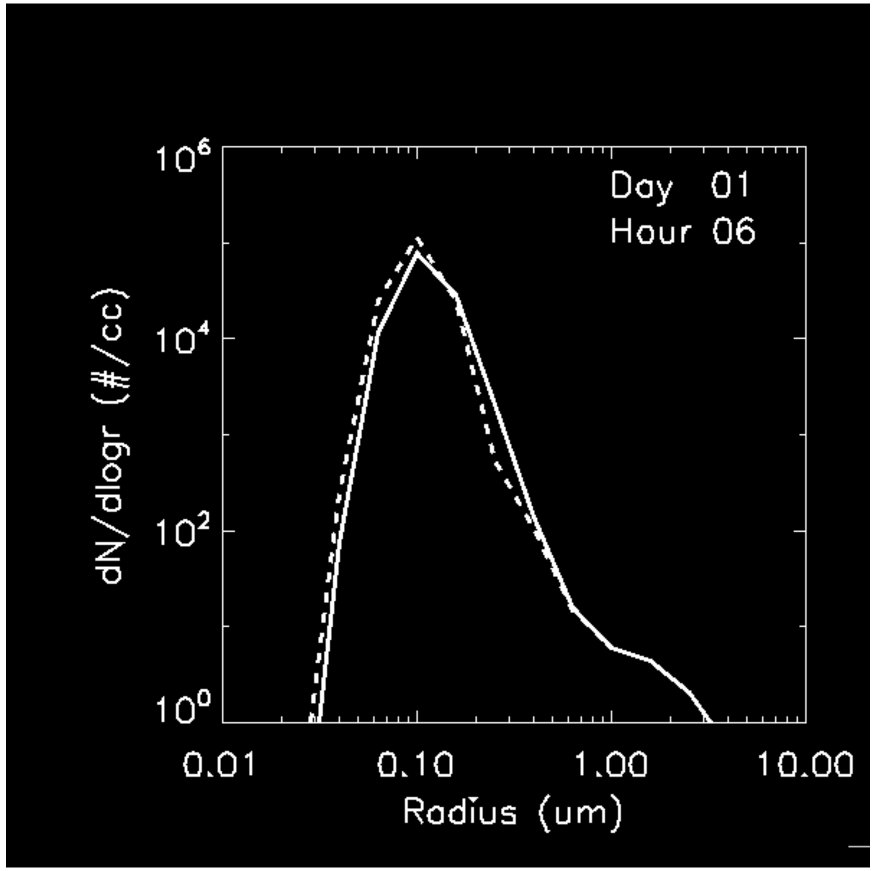

- As aerosol particles age, they grow

# “Box of Smoke” Simulation



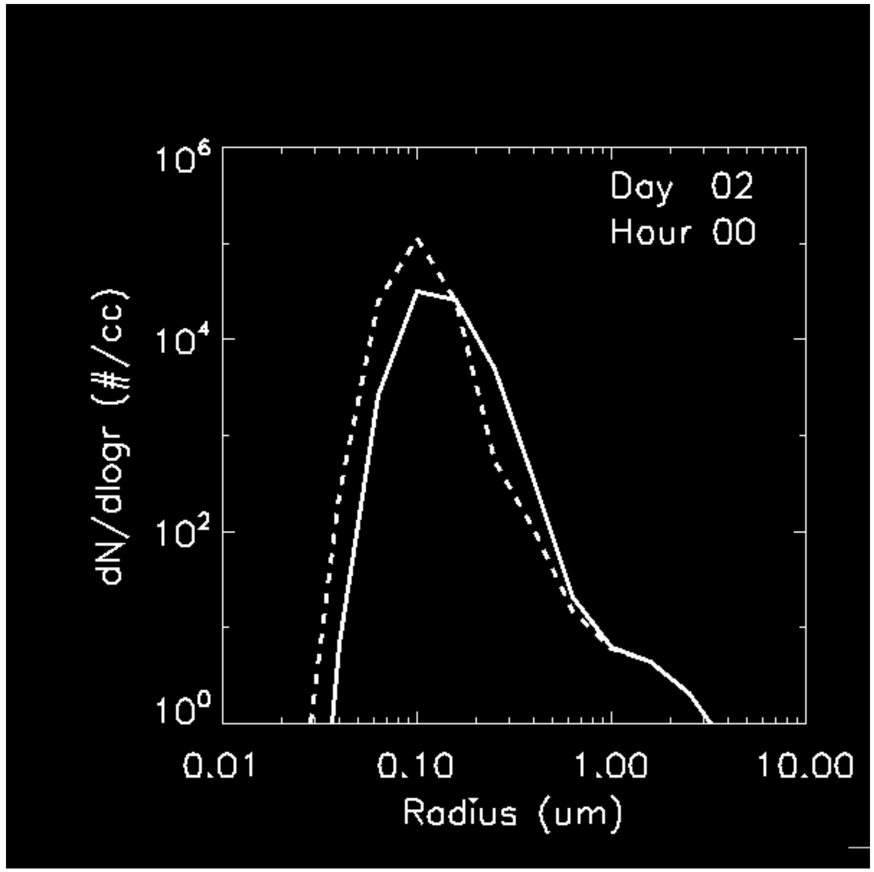

“Fresh” smoke from Haywood et al. JGR, 2003

# “Box of Smoke” Simulation



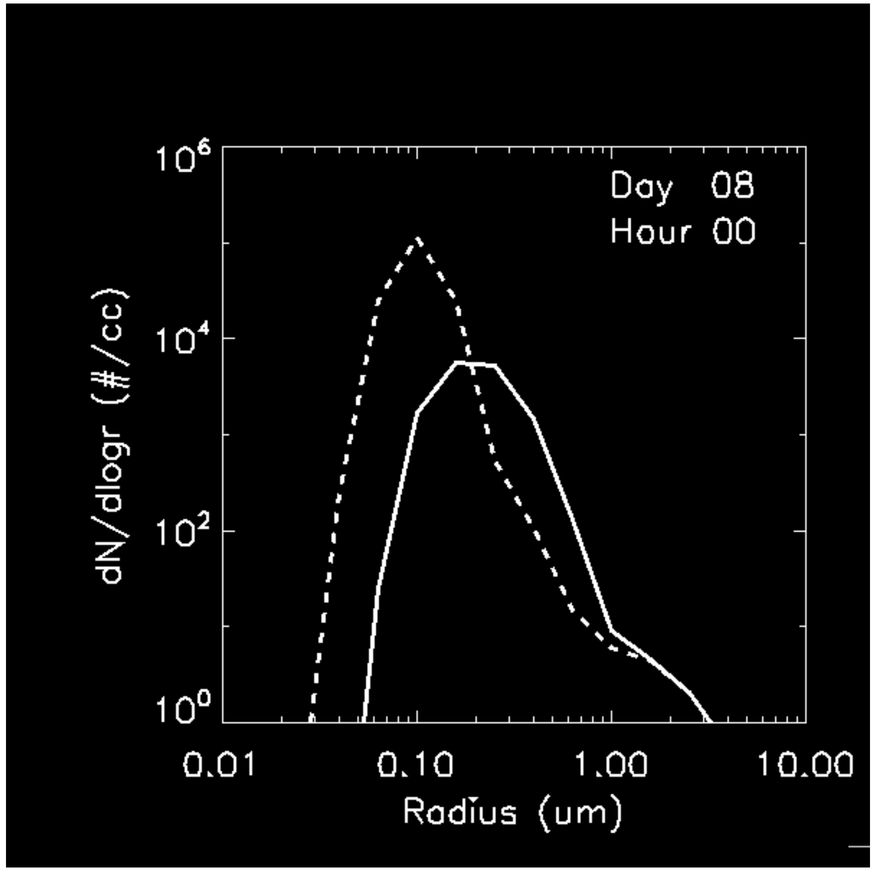

After 6 hours…

# “Box of Smoke” Simulation



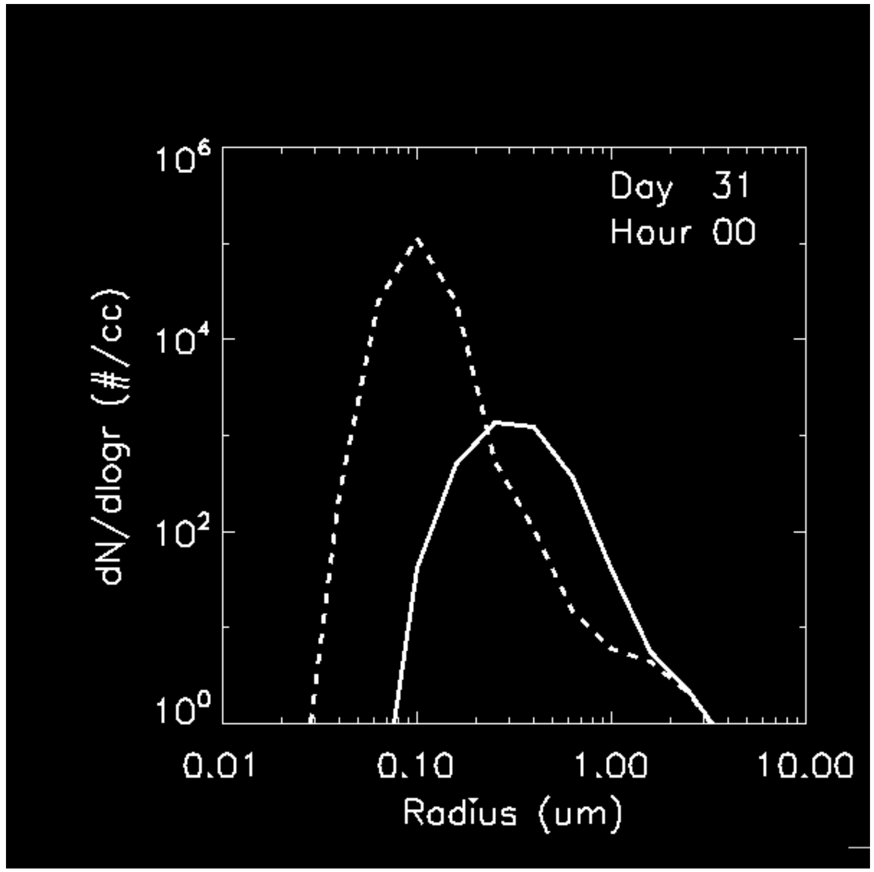

After one day…

# “Box of Smoke” Simulation




One week old

# “Box of Smoke” Simulation



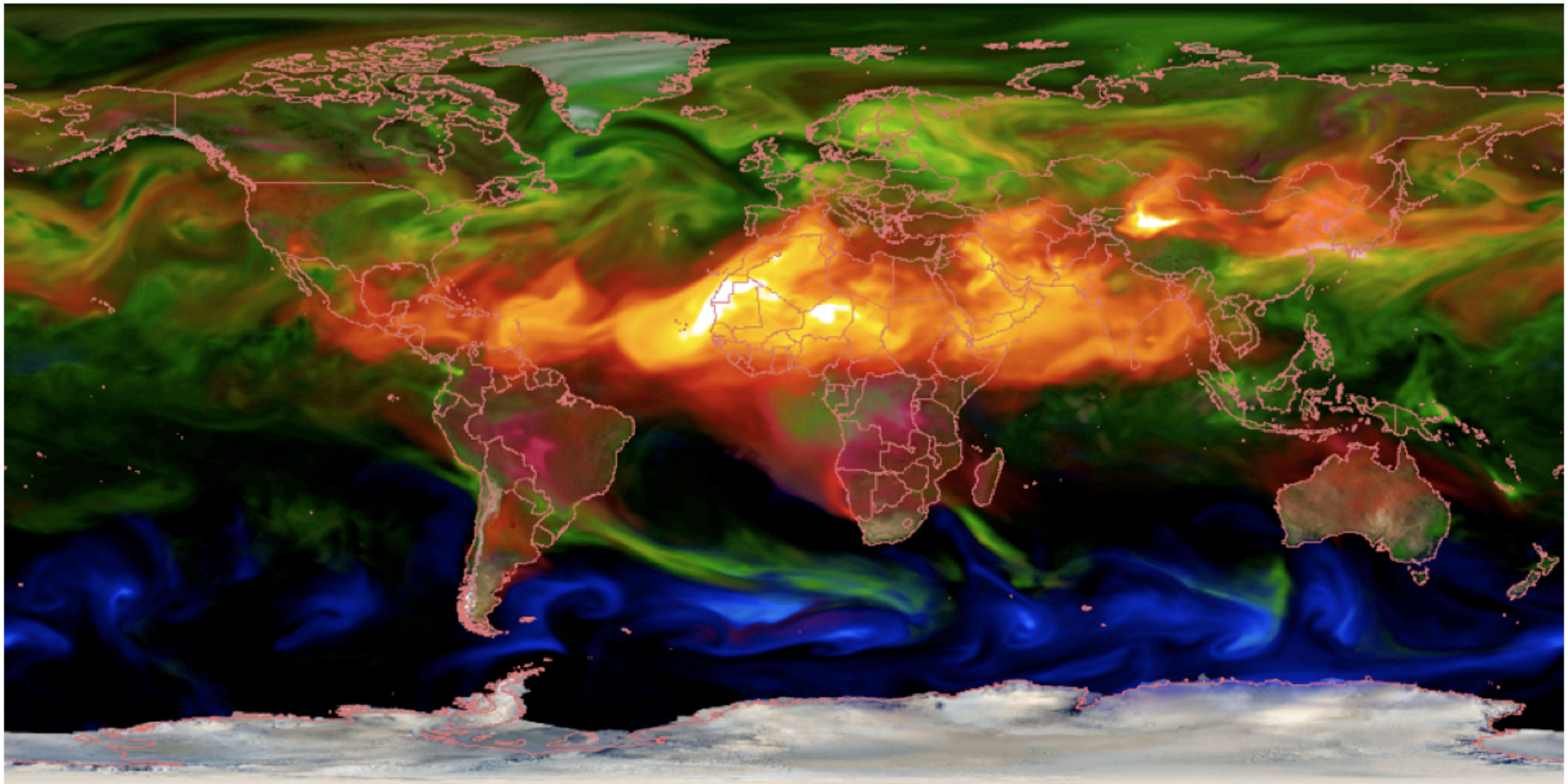

- Remember. Scattering depends on particle size.

# Coagulation and Scattering

**Left:** Fresh smoke illuminated by white light. Particles appear "blue" because they are very small and narrowly distributed in size.

**Right:** After some time, the particles "coagulate" and grow in size. Particles appear white because they scatter all wavelengths about equally.

# Aerosol and Climate



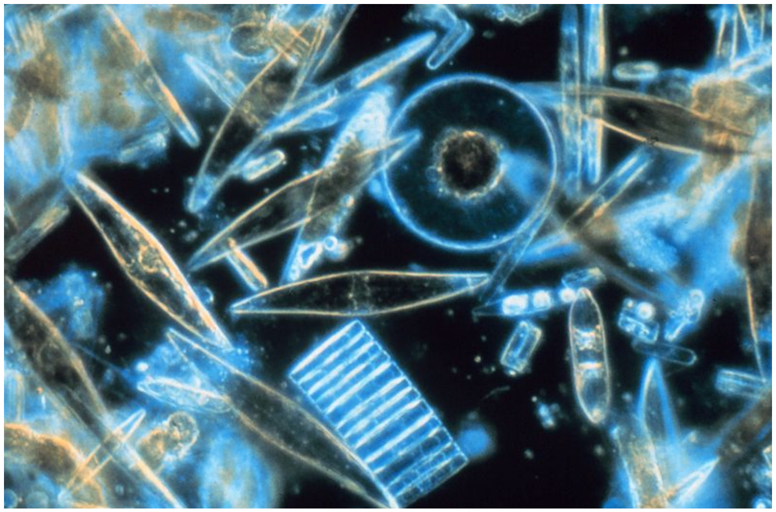
Dust
Sulfate
Aerosol

Sea Salt
Carbonaceous

NASA GSFC Atmospheric Chemistry & Dynamics Branch, Global Modeling and Assimilation Office

# Sulfate Aerosol Sources

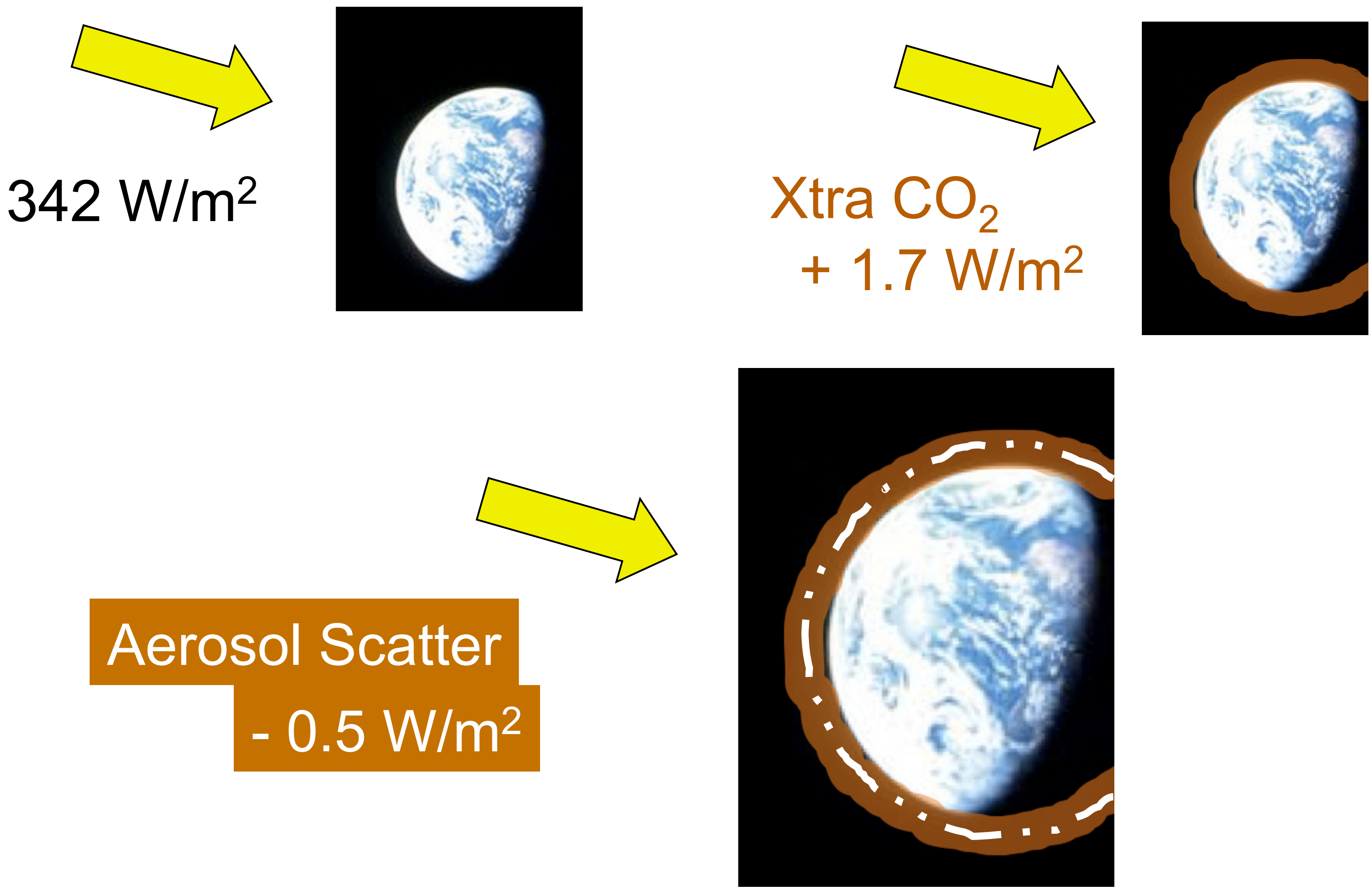
Natural (phytoplankton)



**Anthropogenic** (man-made)

- Both sources emit sulfur compounds
- These different sulfur compounds eventually oxidize to form sulfate aerosol ~ 0.3 μm
- Sulfate has many forms. Some are $H_2SO_4$, $NH_4HSO_4$ and $(NH_4)_2SO_4$

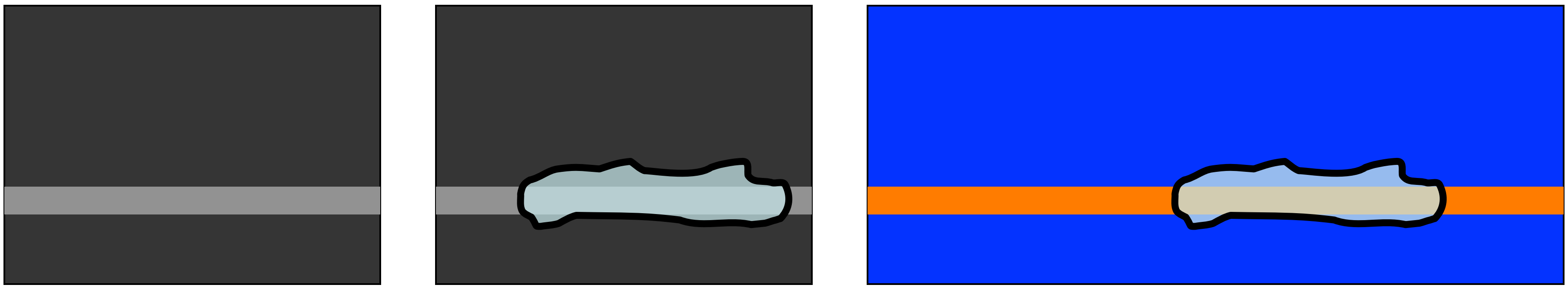
# The Direct Aerosol Effect




- Anthropogenic aerosol is counteracting greenhouse warming from anthropogenic $CO_2$

# The Semi-Direct Aerosol Effect

*Smoke makes for an odd aerosol -- it both scatters and absorbs*



Smoke layer at night does mostly nothing

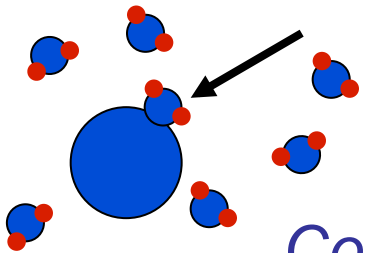
Let's say a cloud forms during the night

During the day, the smoke layer warms

*Cloud evaporates prematurely*

- Smoke evaporates existing clouds more quickly: **semi-direct aerosol effect**

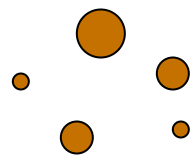
# Clouds and the Indirect Aerosol Effect

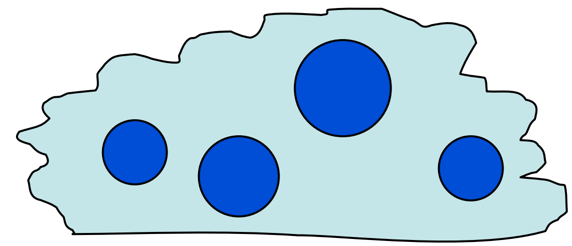


*Clouds are made of aerosol haze particles that have "grown up"*

*Condensation*

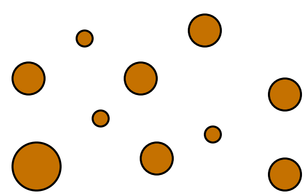
Natural Aerosol
⇒ Cloud

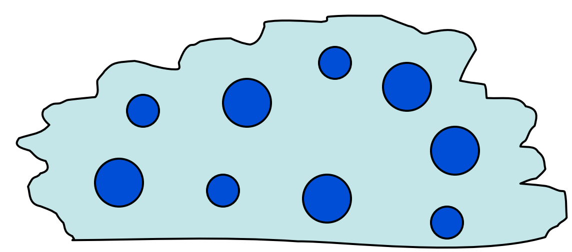




fewer, larger droplets

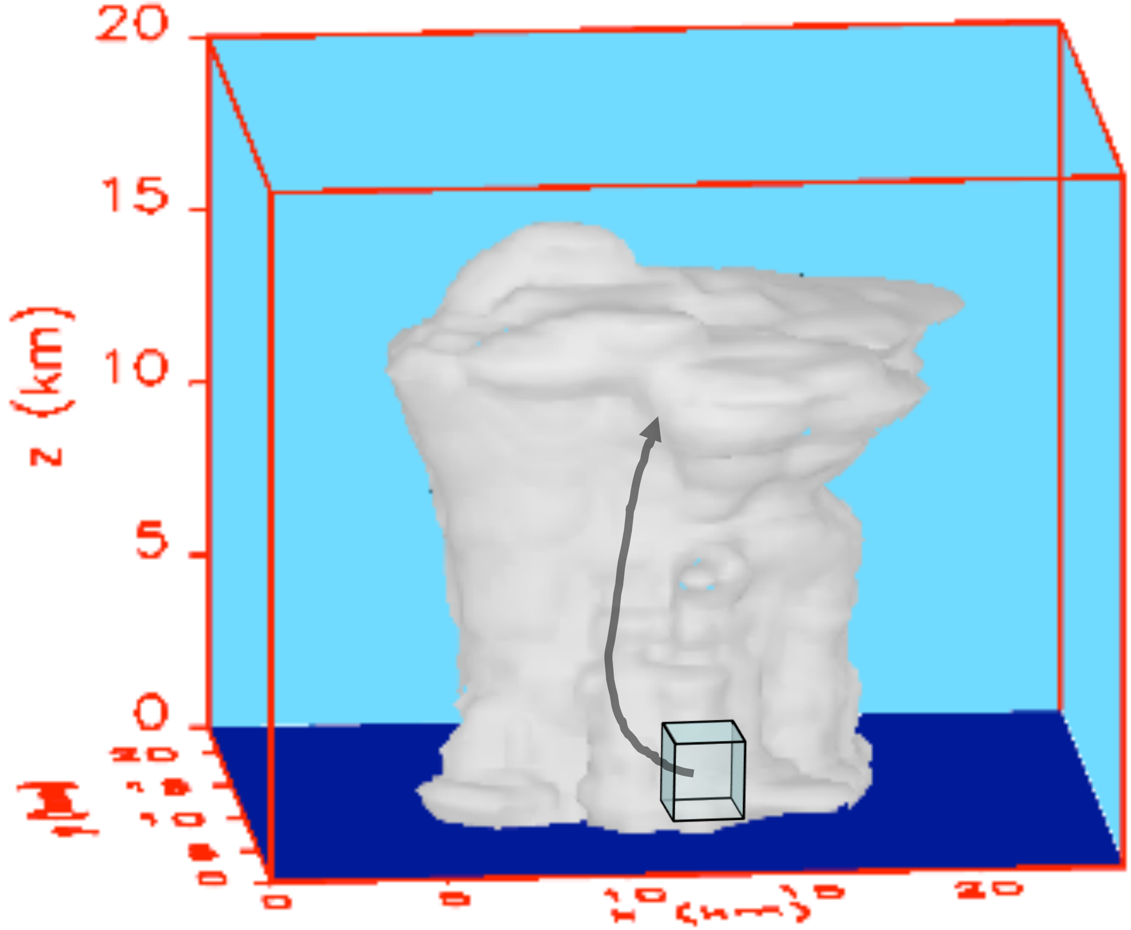
Polluted Aerosol
⇒ Cloud



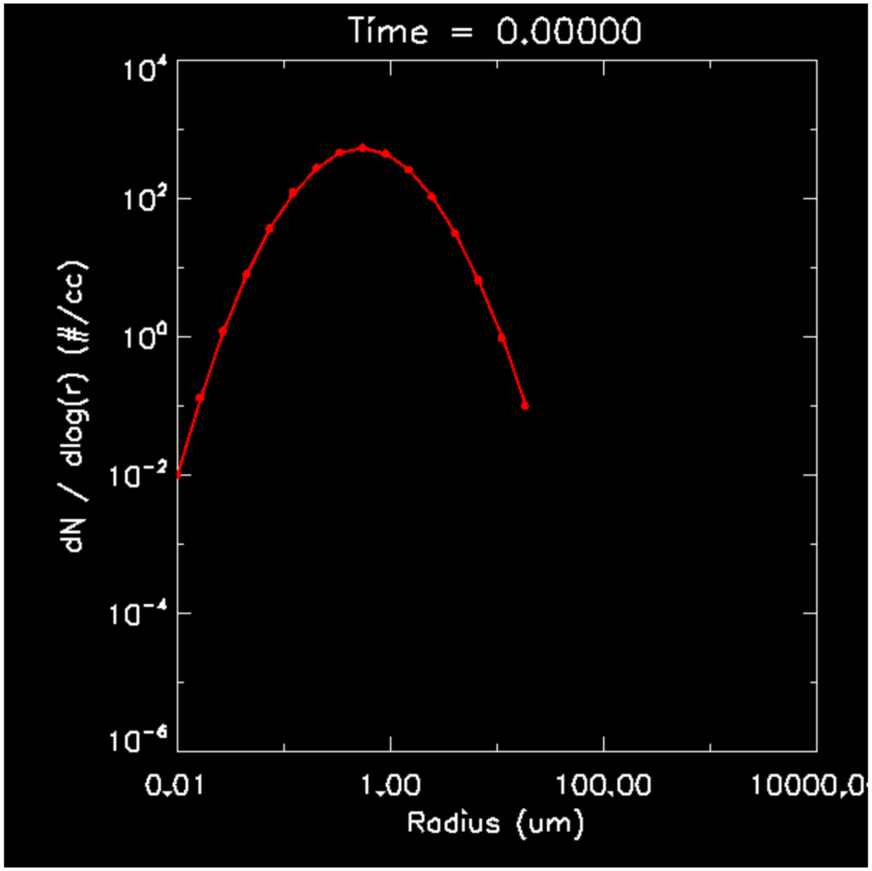


more, smaller droplets

# Deep Convection



# CARMA Parcel in an Updraft



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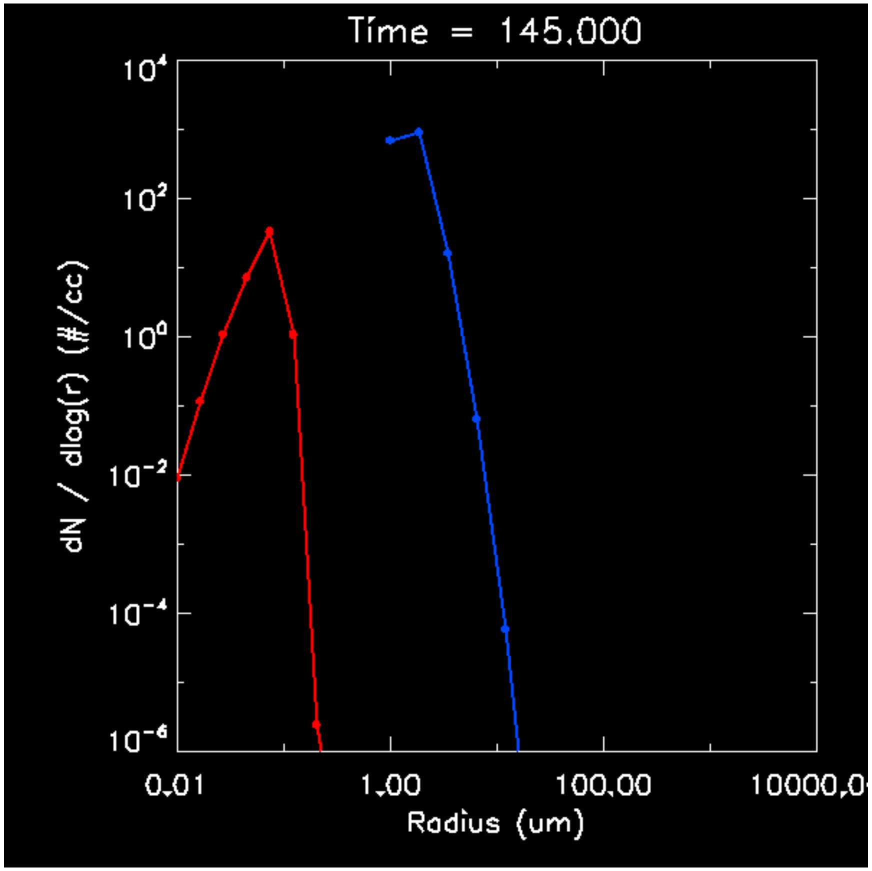

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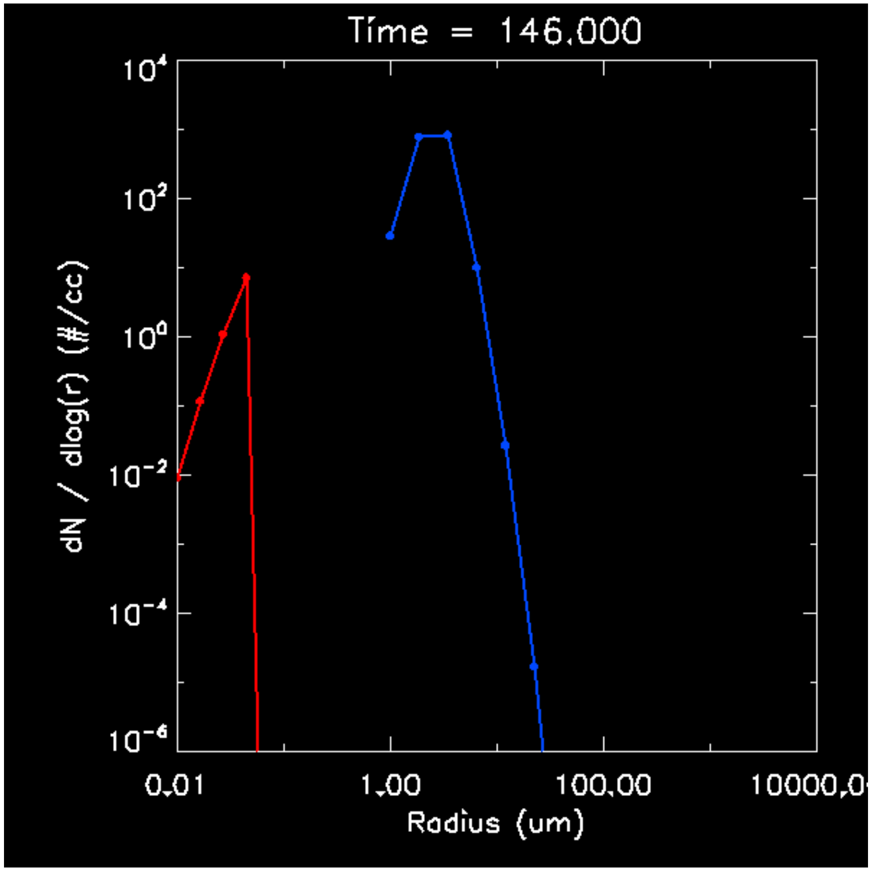

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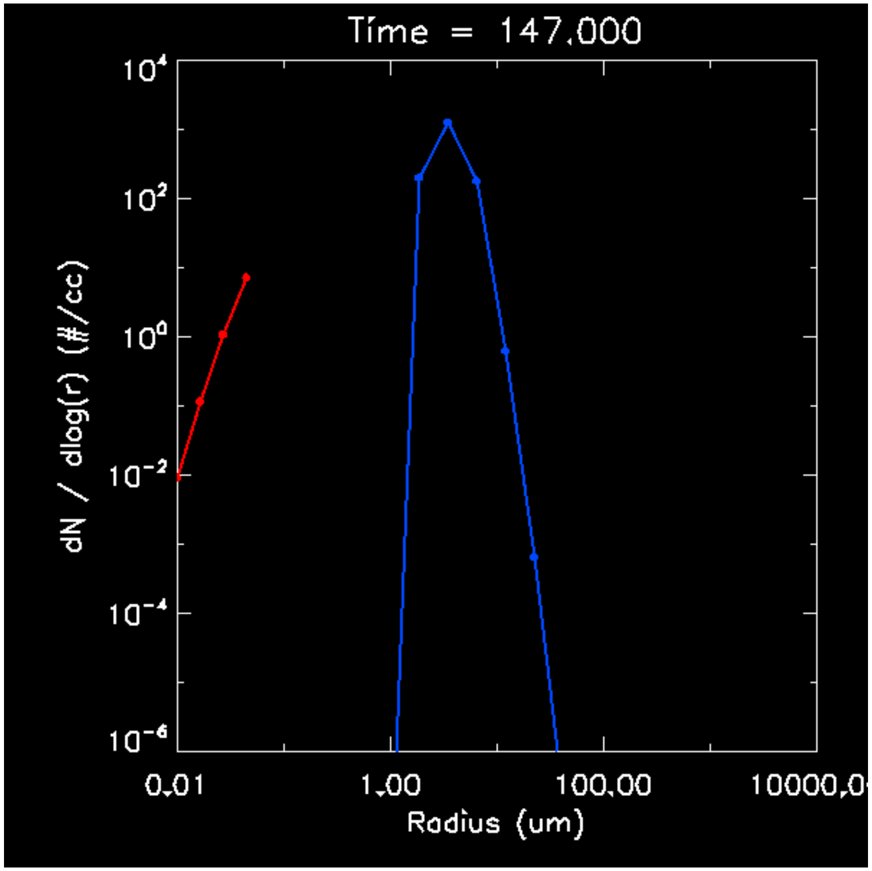

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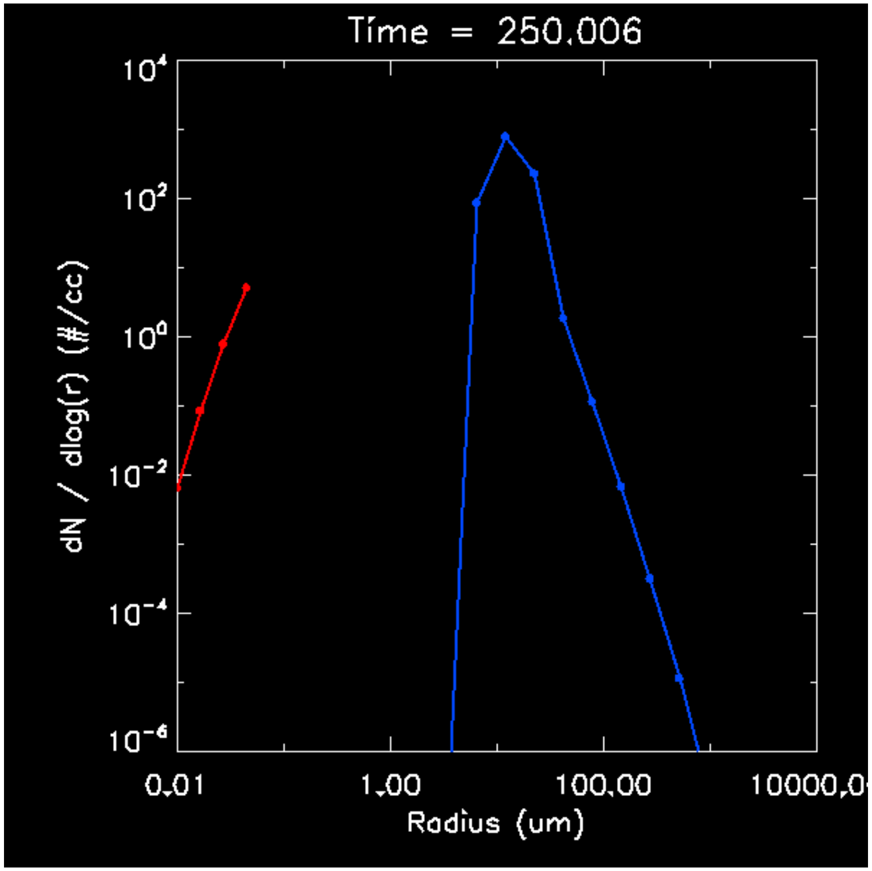

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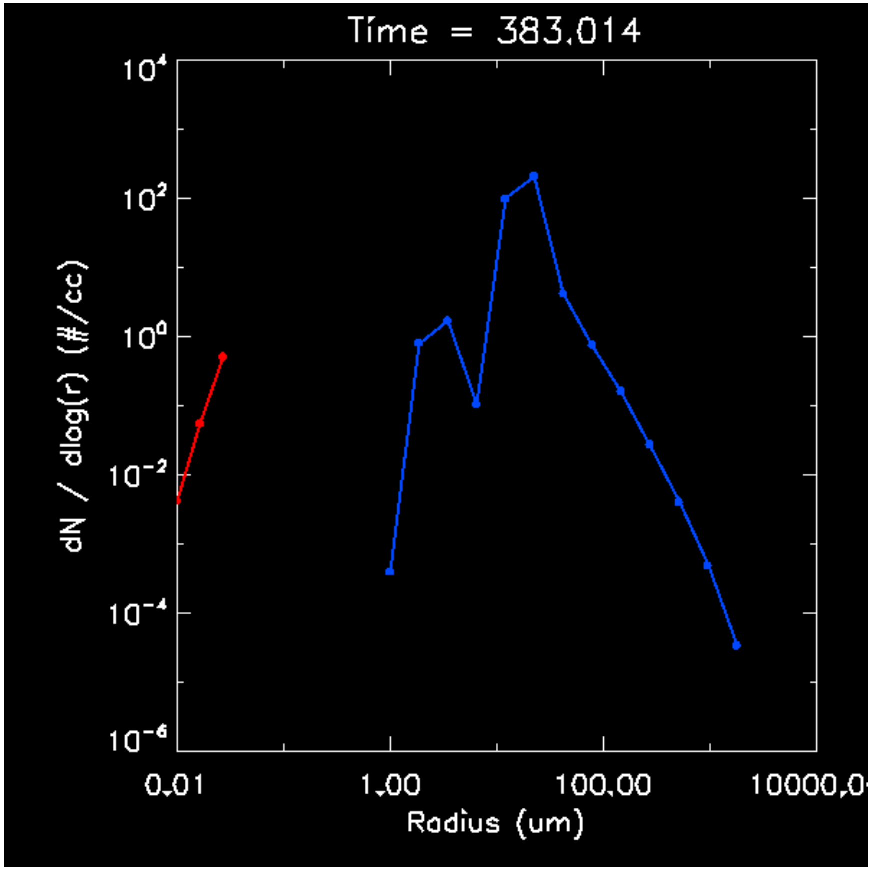

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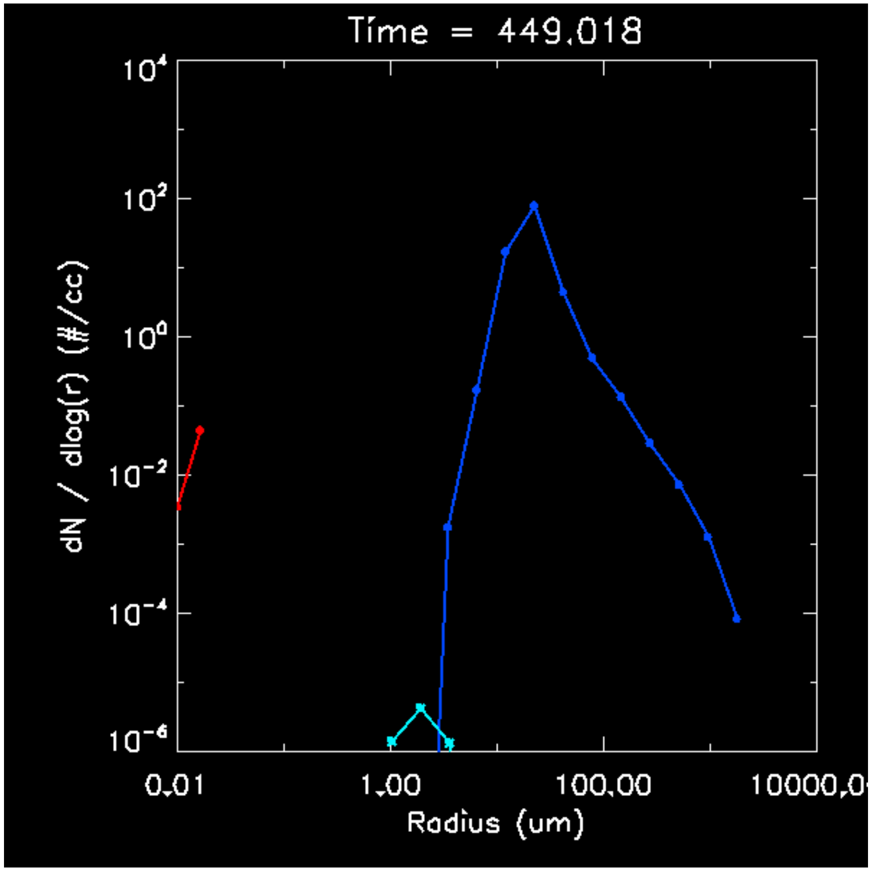

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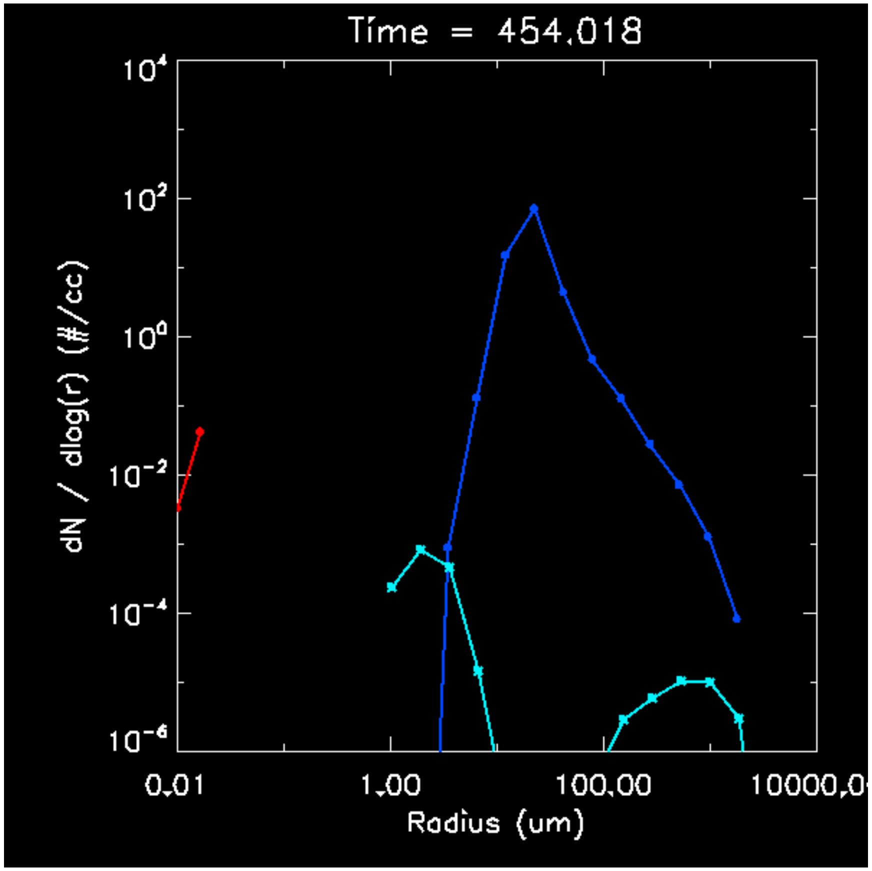

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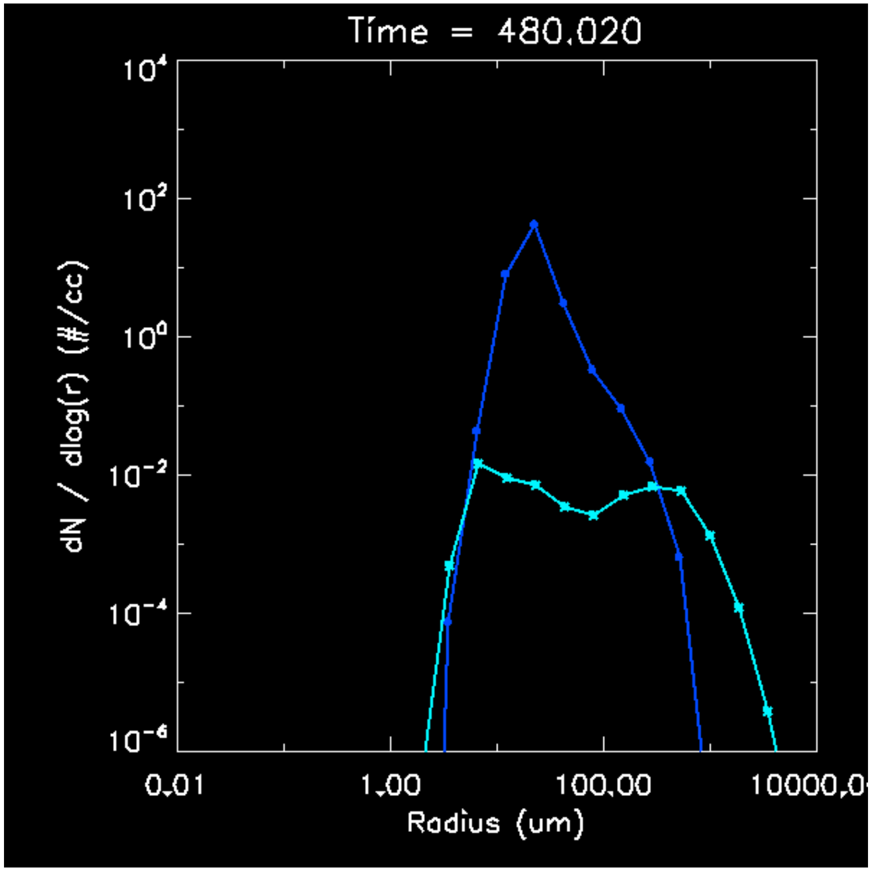

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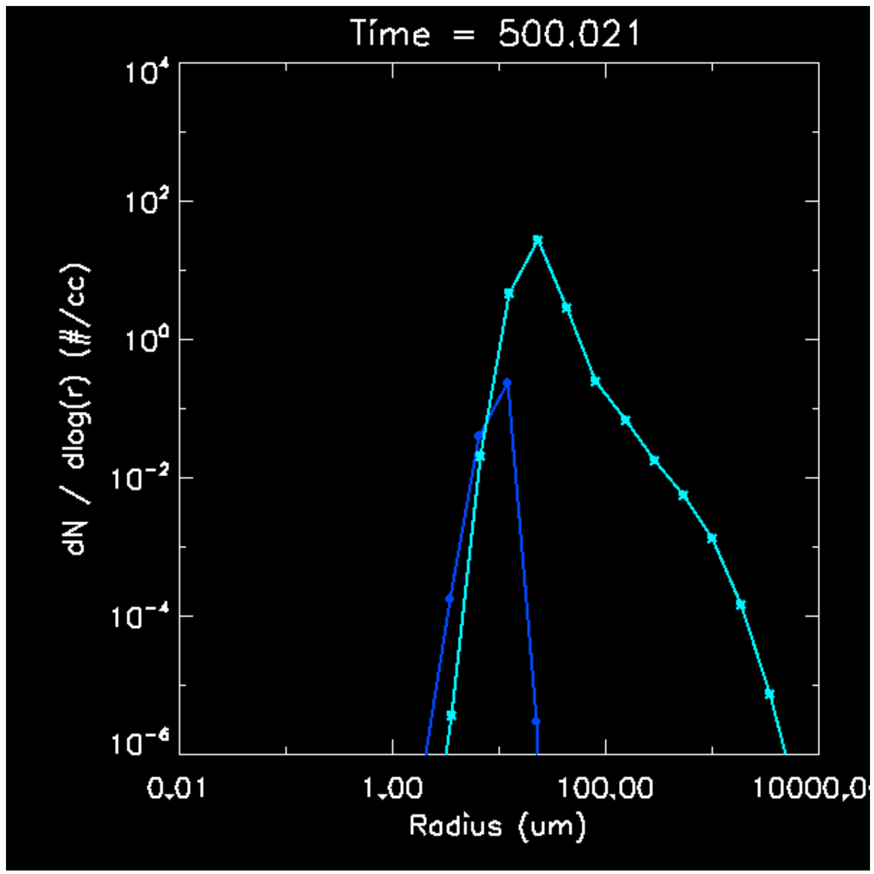

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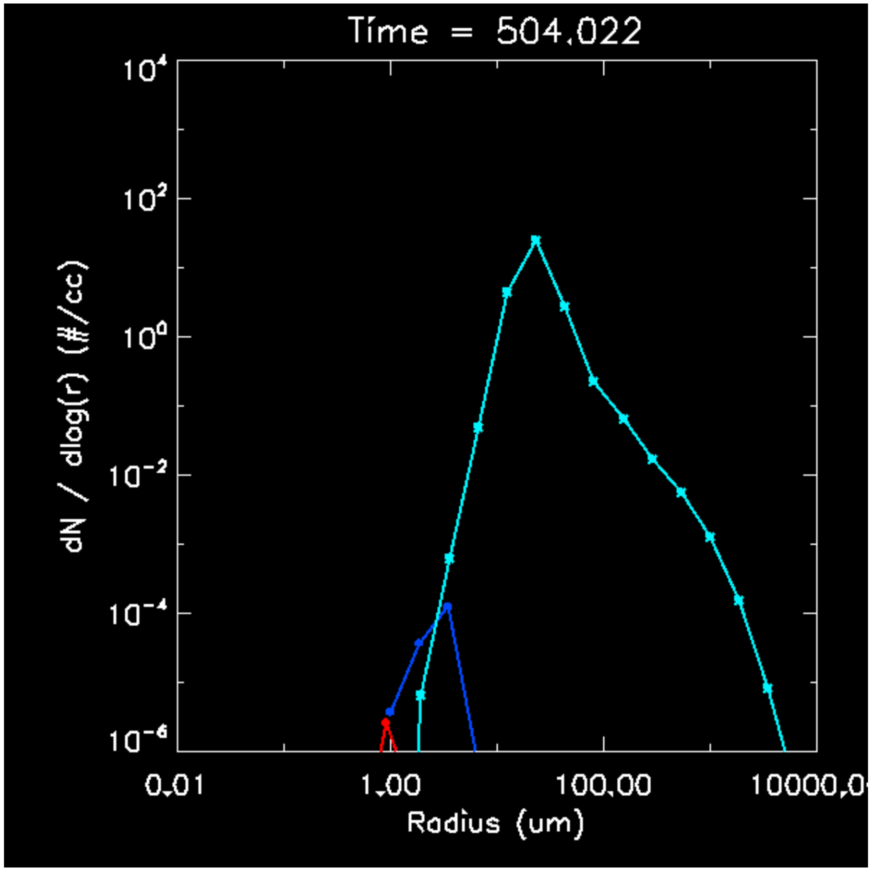

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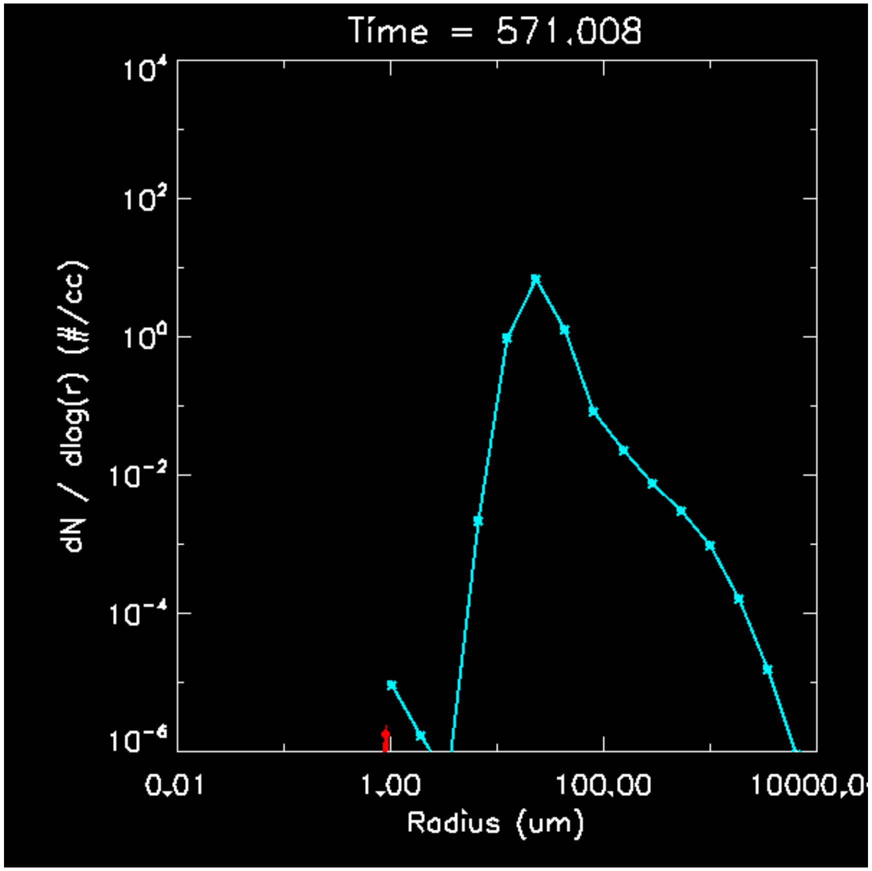

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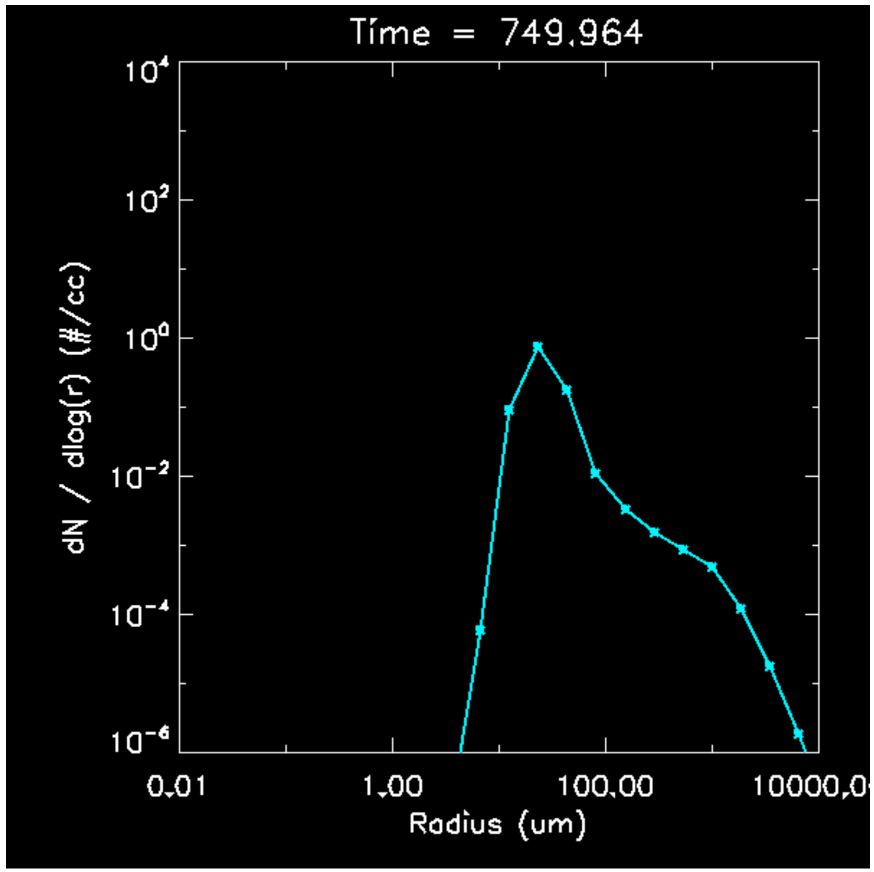
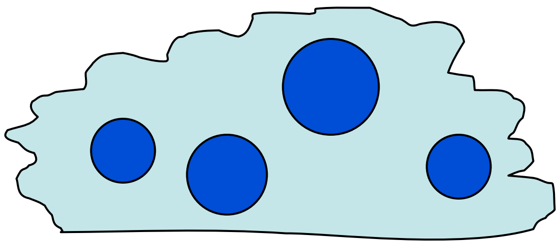
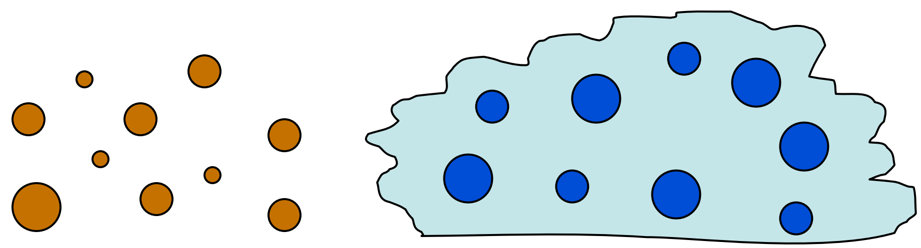


# Clouds and the Indirect Aerosol Effect



fewer, larger droplets

Polluted Aerosol
⇒ Cloud

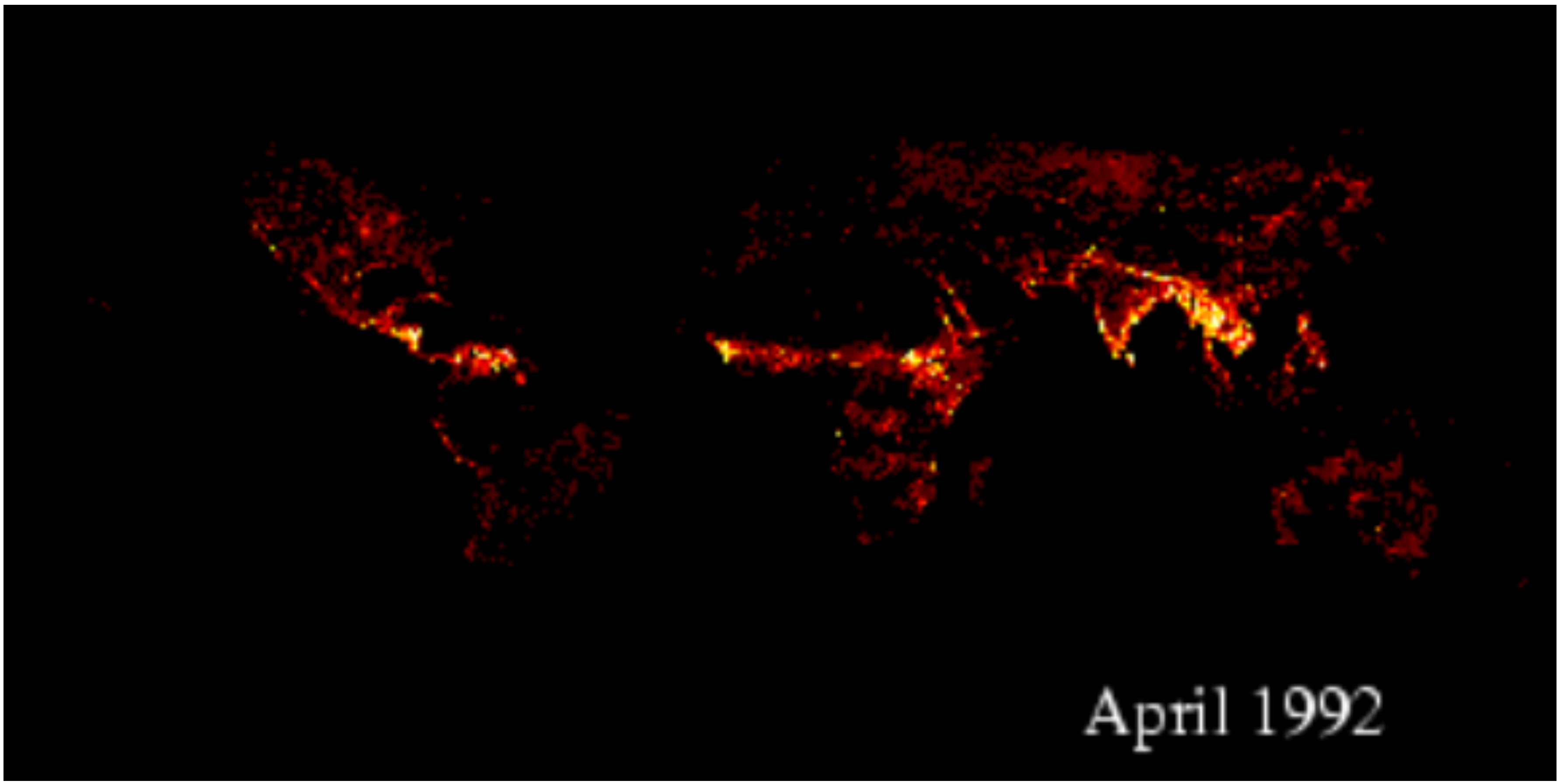


more, smaller droplets

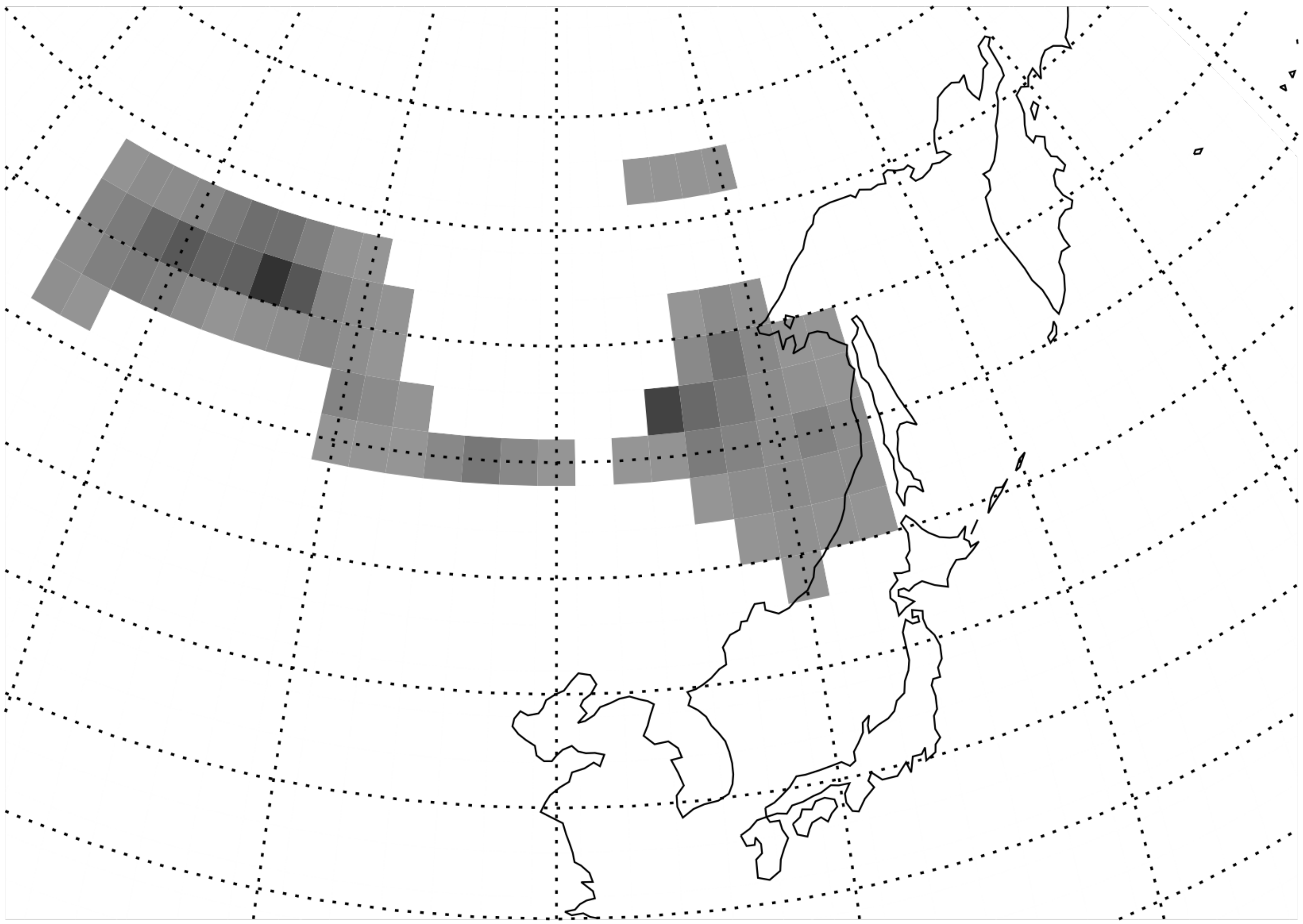
The Indirect Aerosol Effects

- Higher reflectivity
- Less drizzle
- Increased cloud height
- Increased cloud lifetime

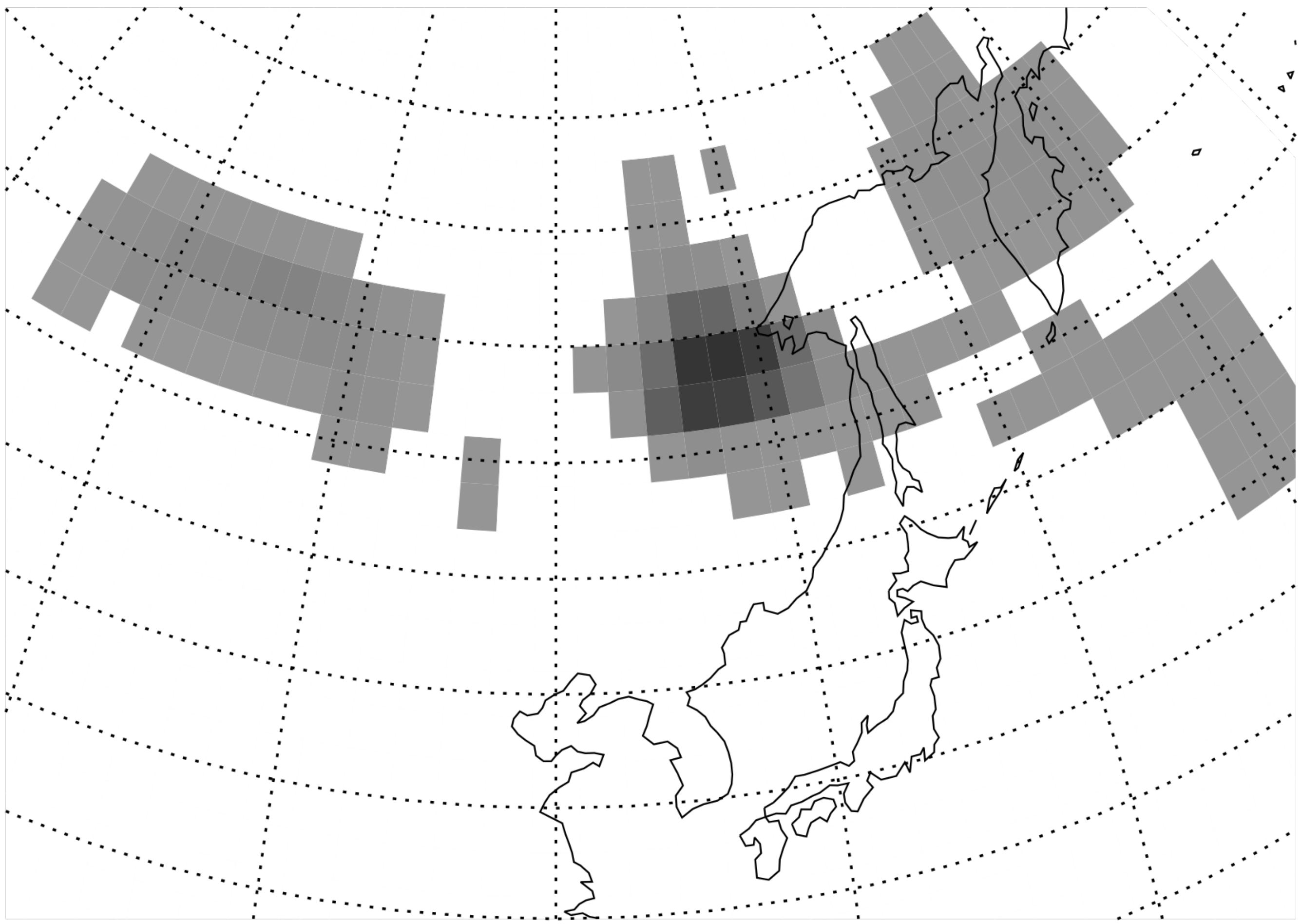
# Fire and Deforestation



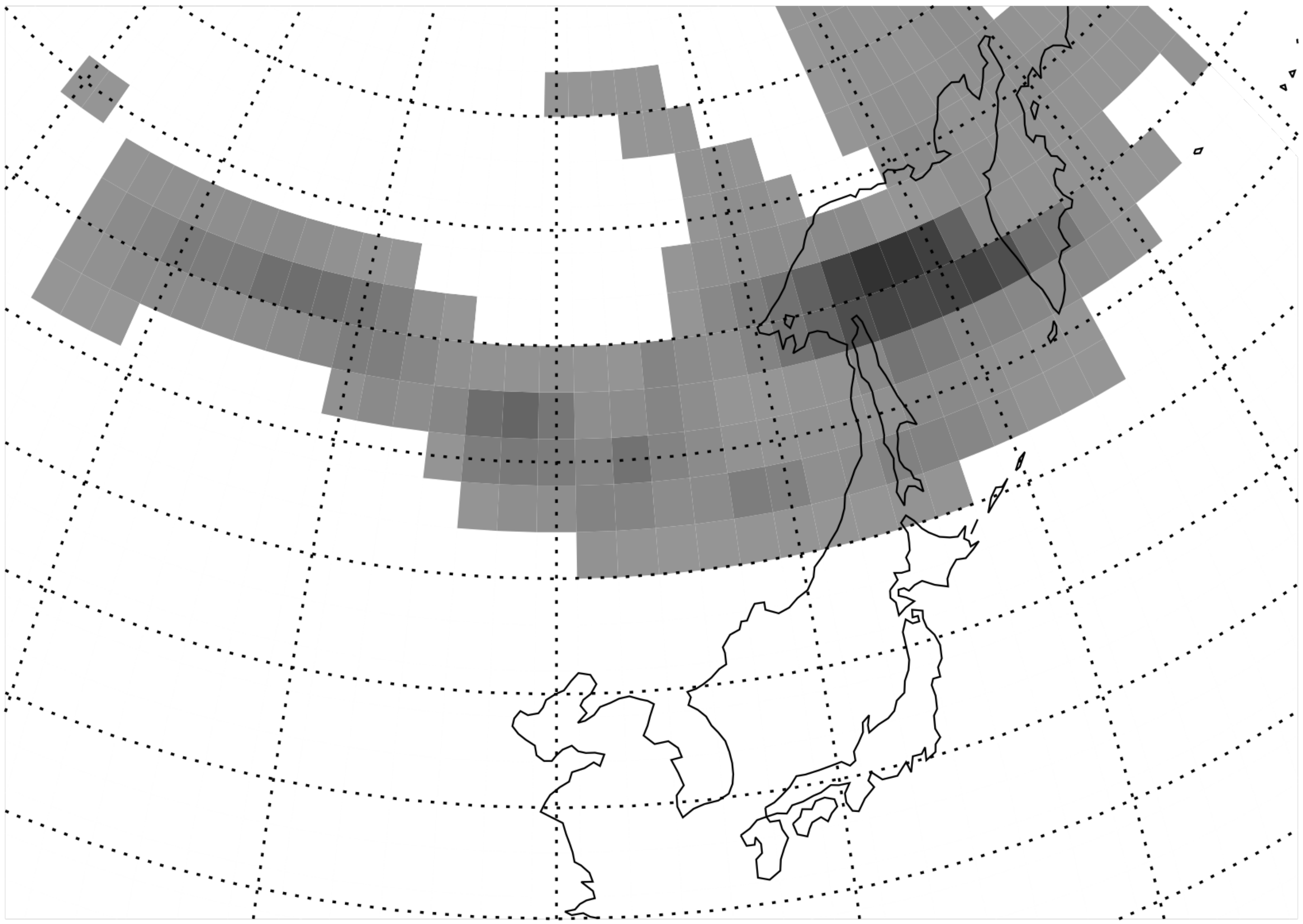
Siberian Smoke 20030501



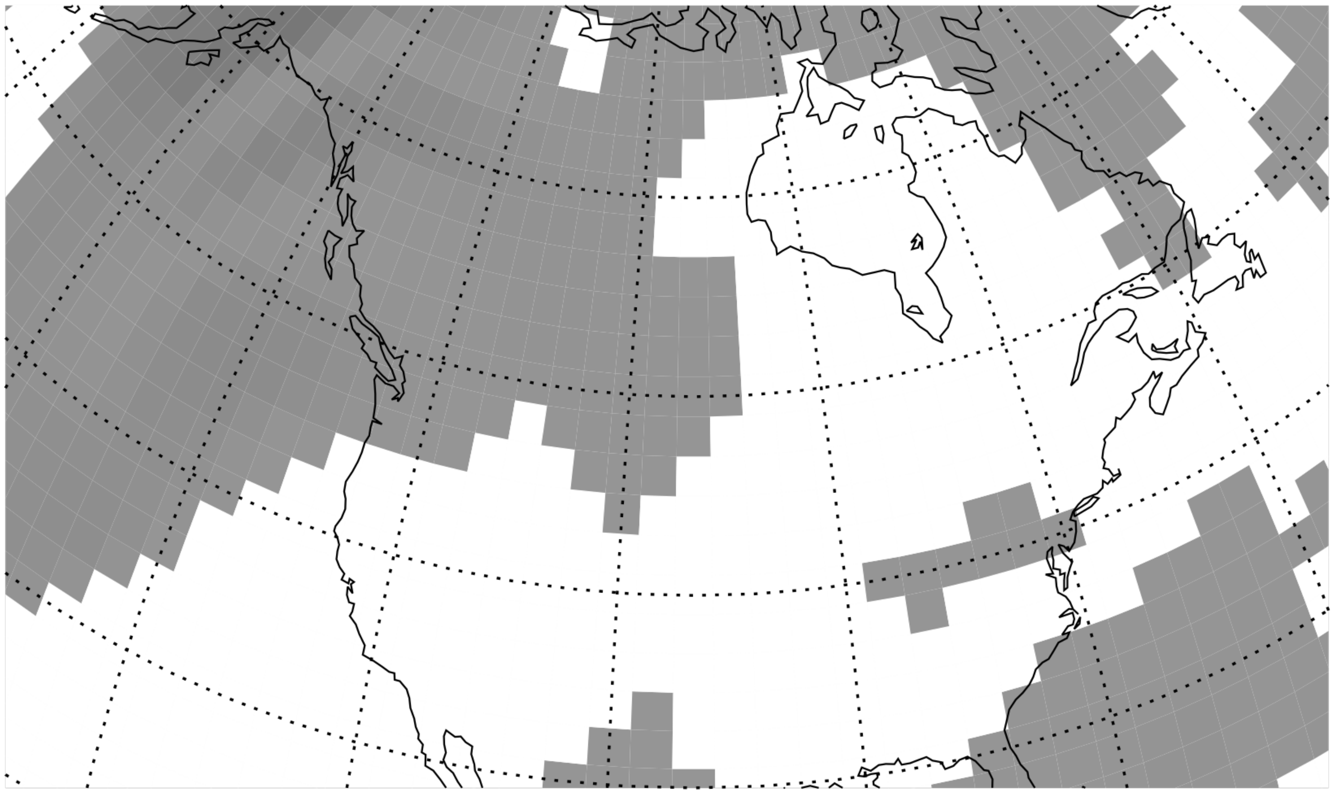
# Siberian Smoke 20030502



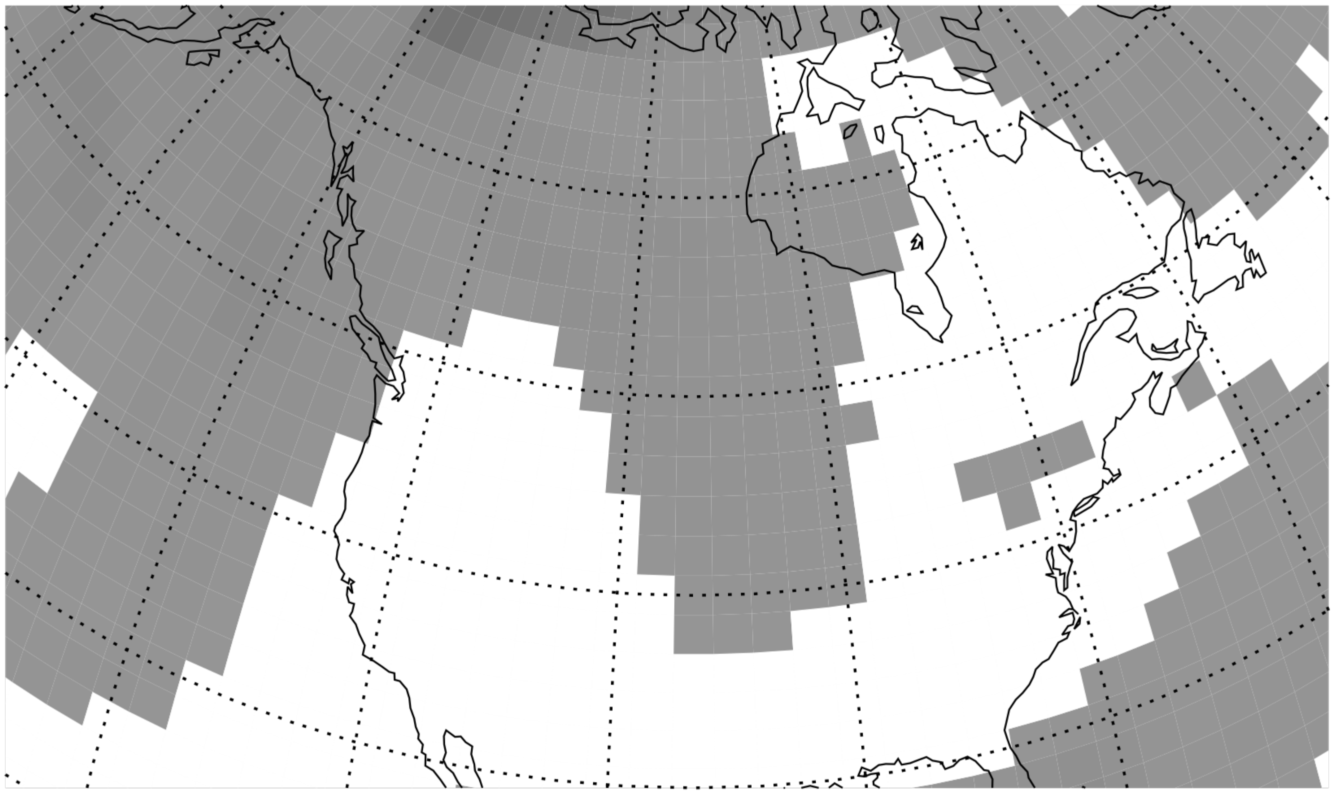
# Siberian Smoke 20030503



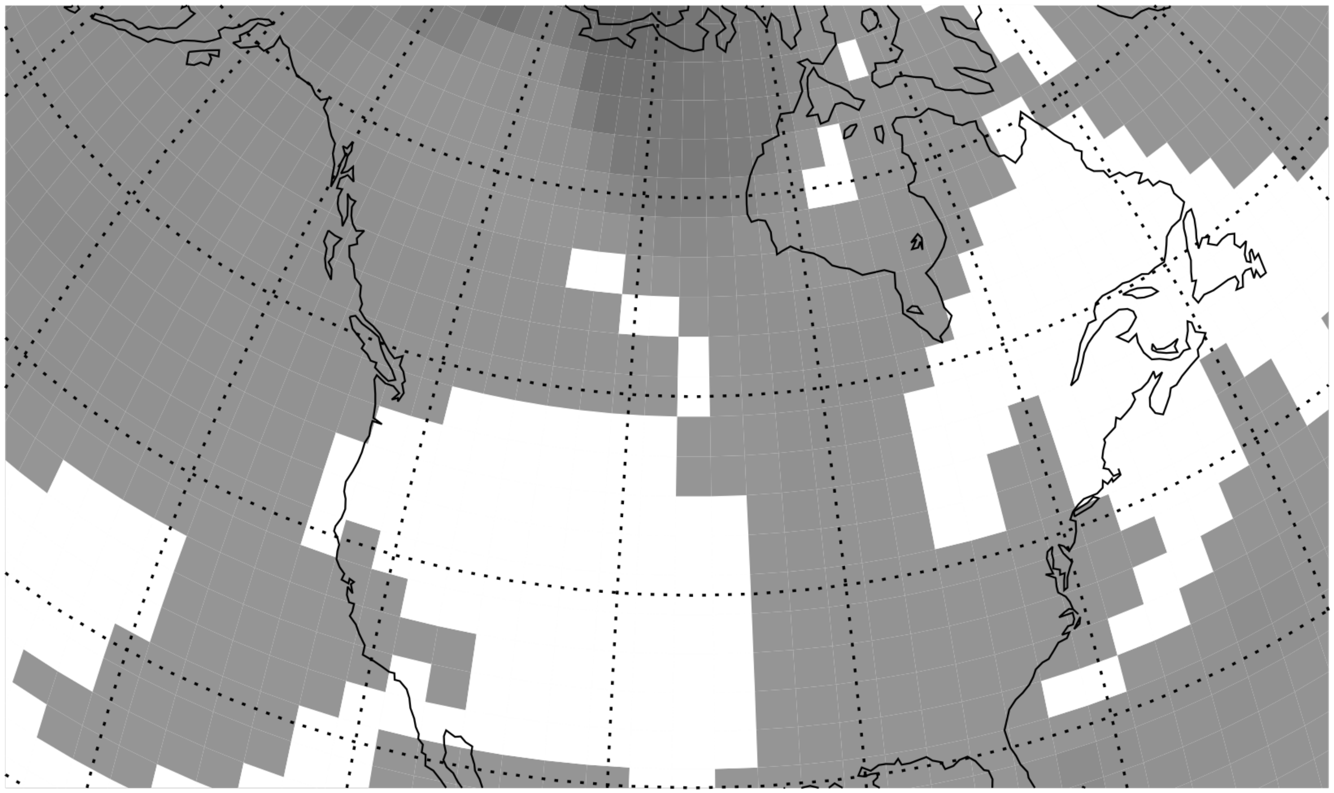
# Siberian Smoke 20030527



Siberian Smoke 20030528



# Siberian Smoke 20030529



# Summary

- Four major aerosol types: dust, sea salt, sulfate and carbonaceous
- Aerosol cool the Earth by scattering, AKA the direct aerosol effect
- Aerosol warm the Earth by absorbing and forcing cloud evaporation, AKA the semi-direct aerosol effect
- Aerosol cool the Earth by making clouds more reflective, AKA the indirect aerosol effect

# Mie Scattering



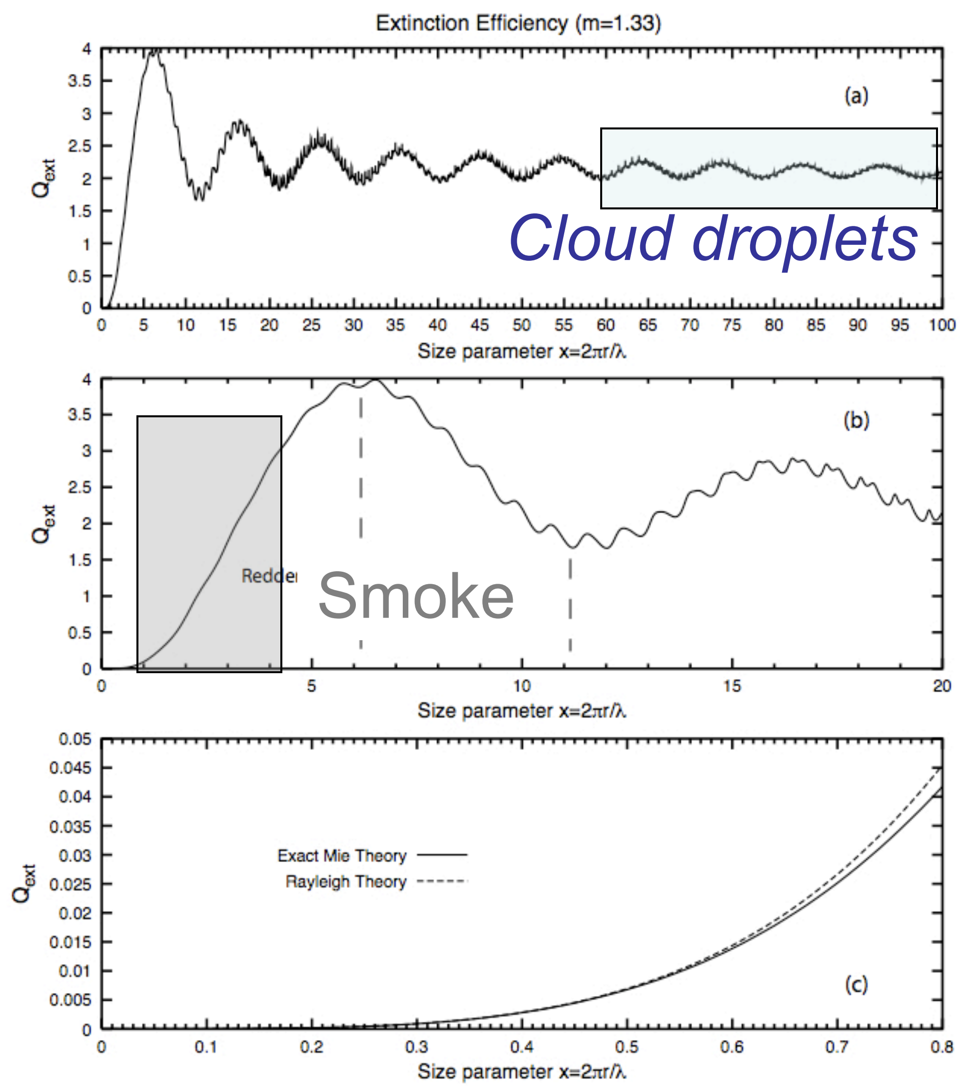



**Fig. 12.4:** The extinction efficiency $Q_e$ as a function of size parameter $x$ for a non-absorbing sphere with $m = 1.33$, for various ranges of $x$. (a) "Big picture" view, showing that $Q_e \rightarrow 2$ as $x \rightarrow \infty$. (b) Detail for $x < 20$, with examples of subranges for which extinction increases with $x$ (reddening) or decreases with $x$ (blueing). (c) Detail for $x < 0.8$, comparing the Rayleigh (small particle) approximation and exact Mie theory.

# Absorption of Sunlight and Emission of Heat