BNL Cloud Chamber:

A Programmable Atmosphere for Environmental Research

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Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

@BrookhavenLab

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Clouds Dominate the Earth’s Weather and Climate

Clouds regulate the Earth’s energy balance

- How much sunlight the planet absorbs
- How much heat it emits

Clouds control the hydrologic cycle

- How water moves through the atmosphere

Cloud drive weather systems

- Storm formation and intensification

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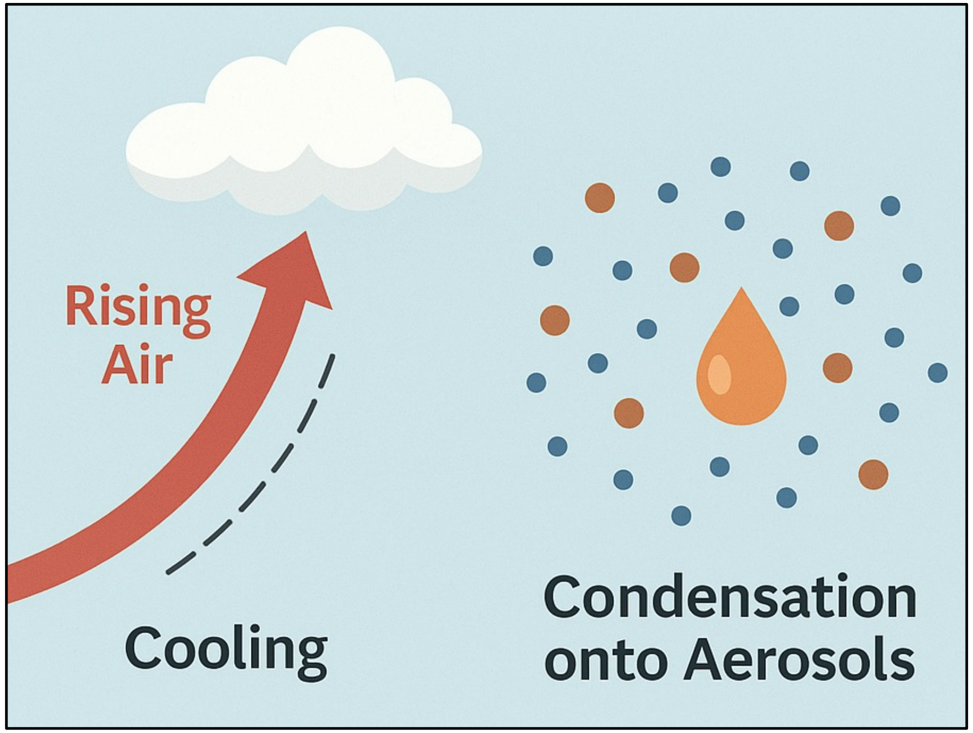
How do Clouds Form?

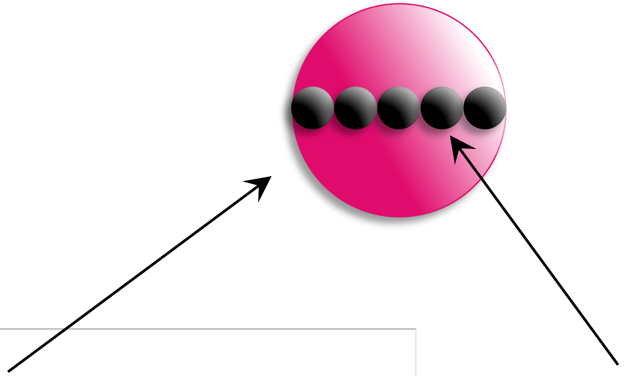


Essential ingredients

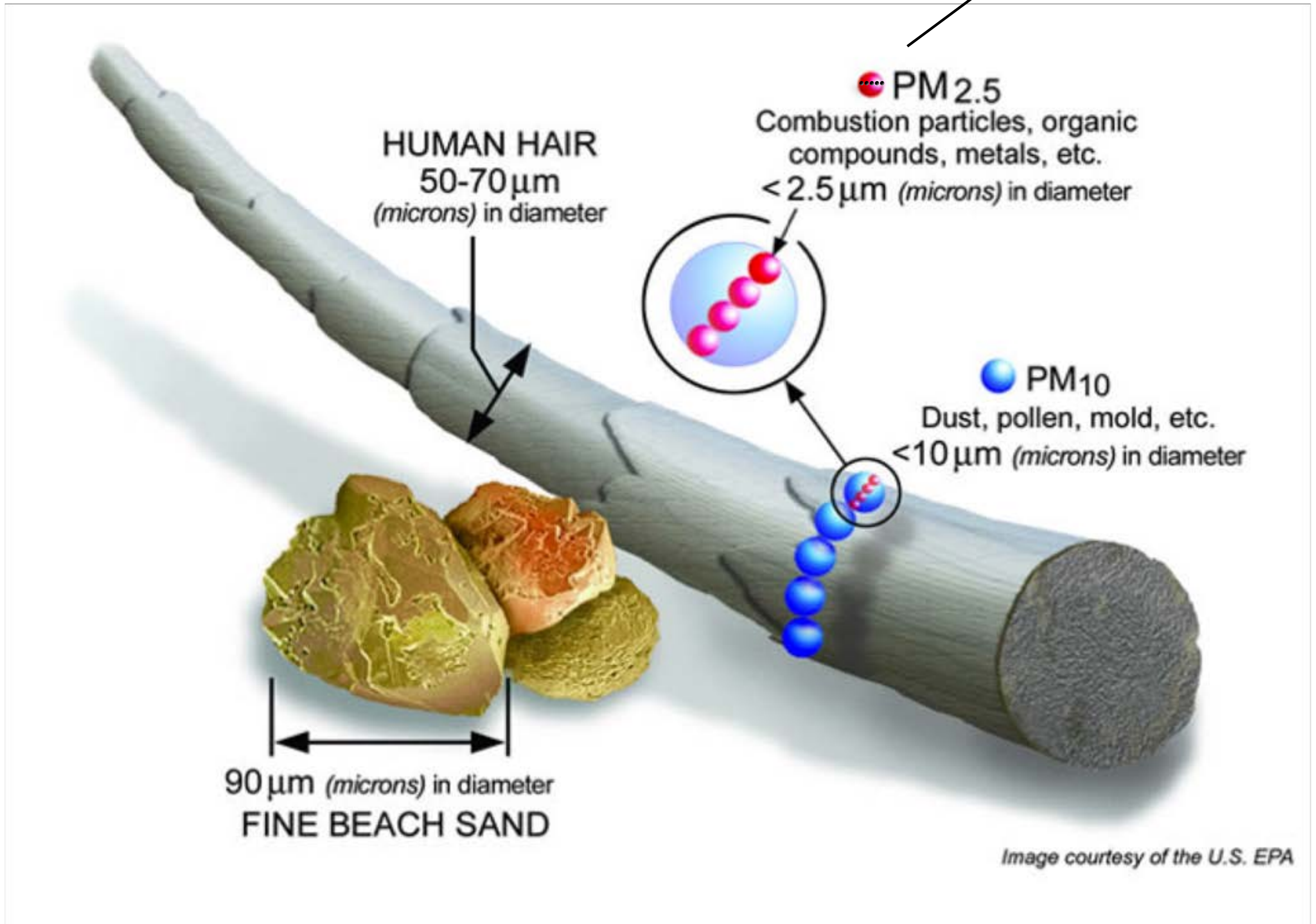
- Water vapor
- Cooling air (rising, cold front, nighttime) results in increase in relative humidity (RH)
- “Saturation” occurs when RH becomes 100%
- However, no clouds will form at this RH because of energy barrier
- Aerosol particles provides “seed” to overcome this barrier
  - These aerosol particles are called *cloud condensation nuclei (CCN)*
- At RH ≤ 100% aerosol particles that uptake water form “haze” particles
- Supersaturated conditions (RH> 100%) will cause haze particles to uptake more water and grow to cloud droplets
  - Non-precipitating clouds = cloud droplets

Side trip: What are Aerosols?

Aerosols are a suspension of solid or liquid particles in the atmosphere.



< 0.5 microns (500 nm) diameter
Examples: soot, biogenic



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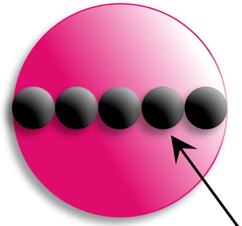

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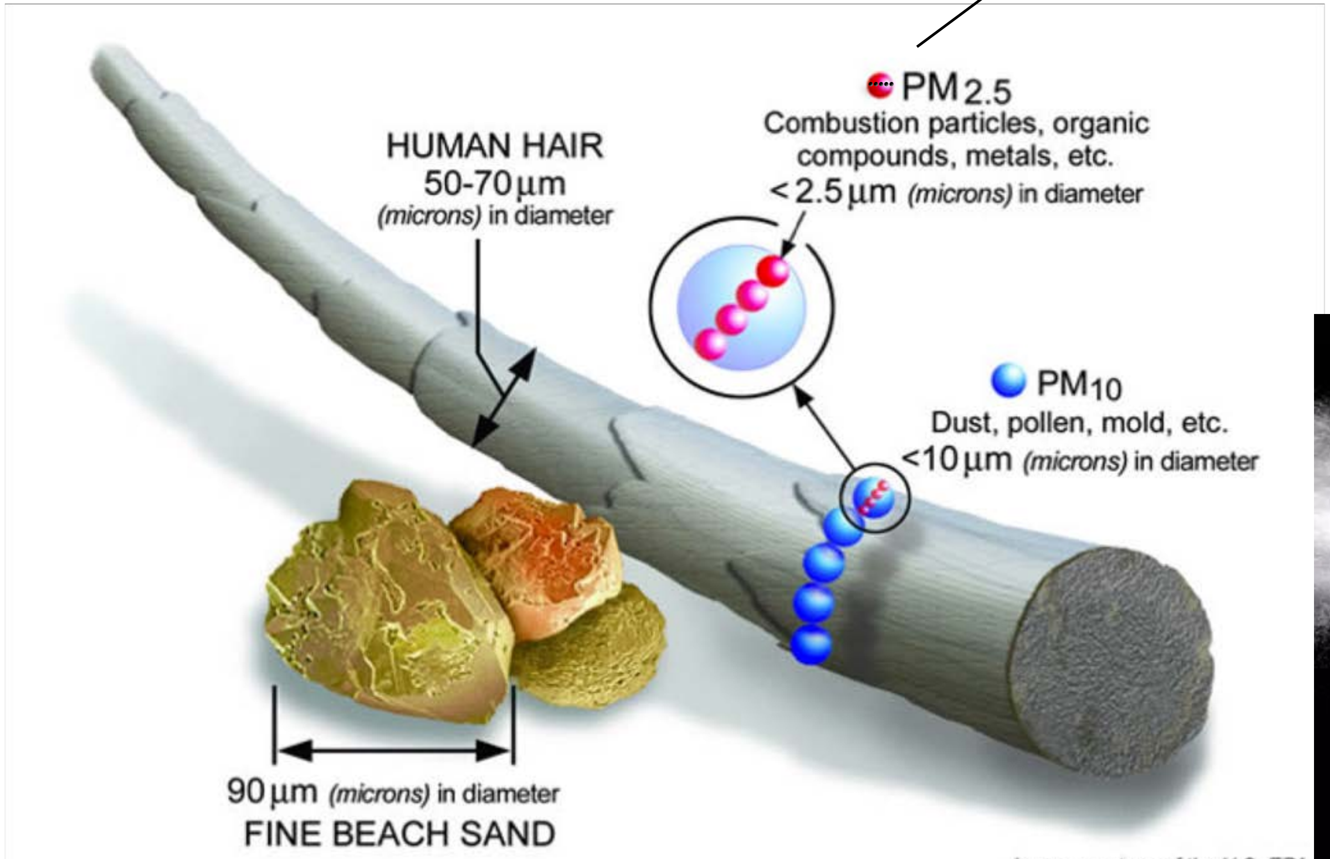

Image courtesy of the U.S. EPA

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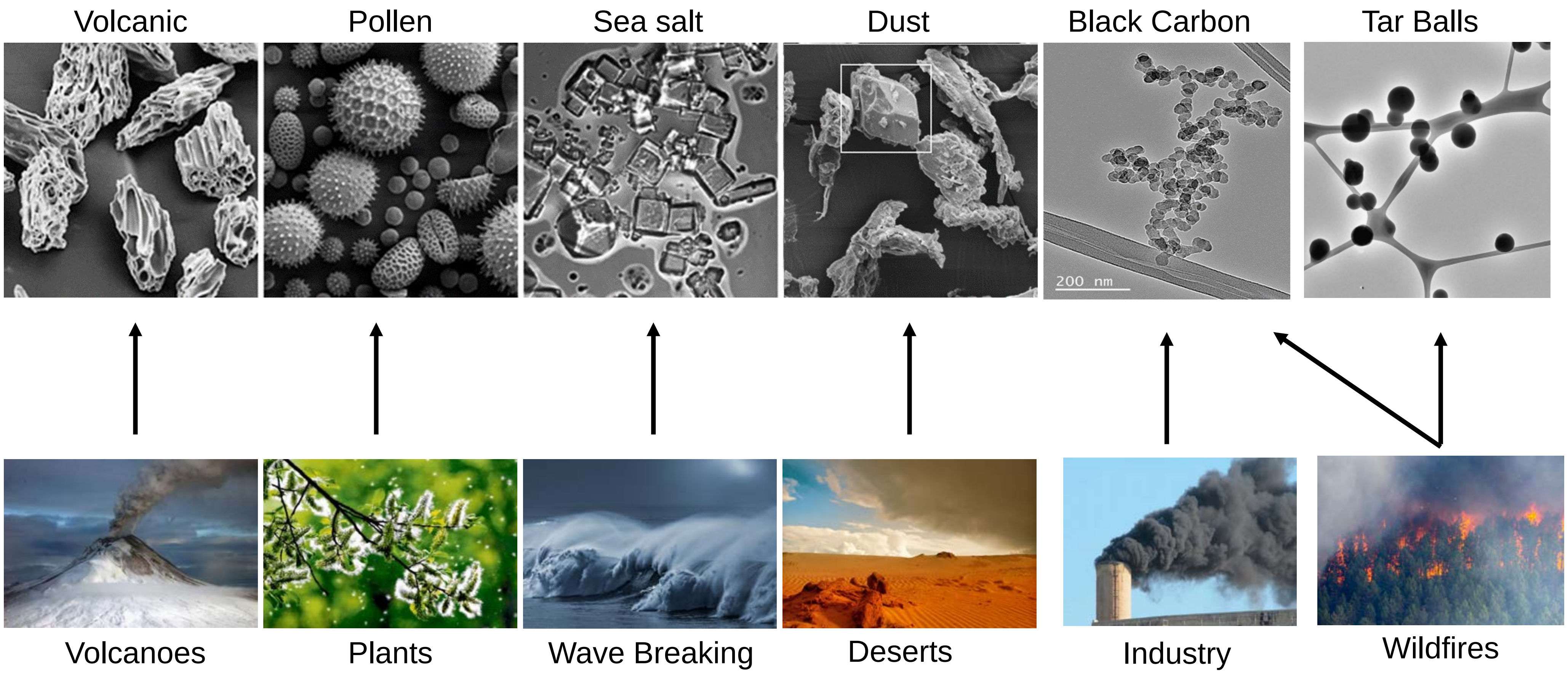
Where Do Aerosols Come From?



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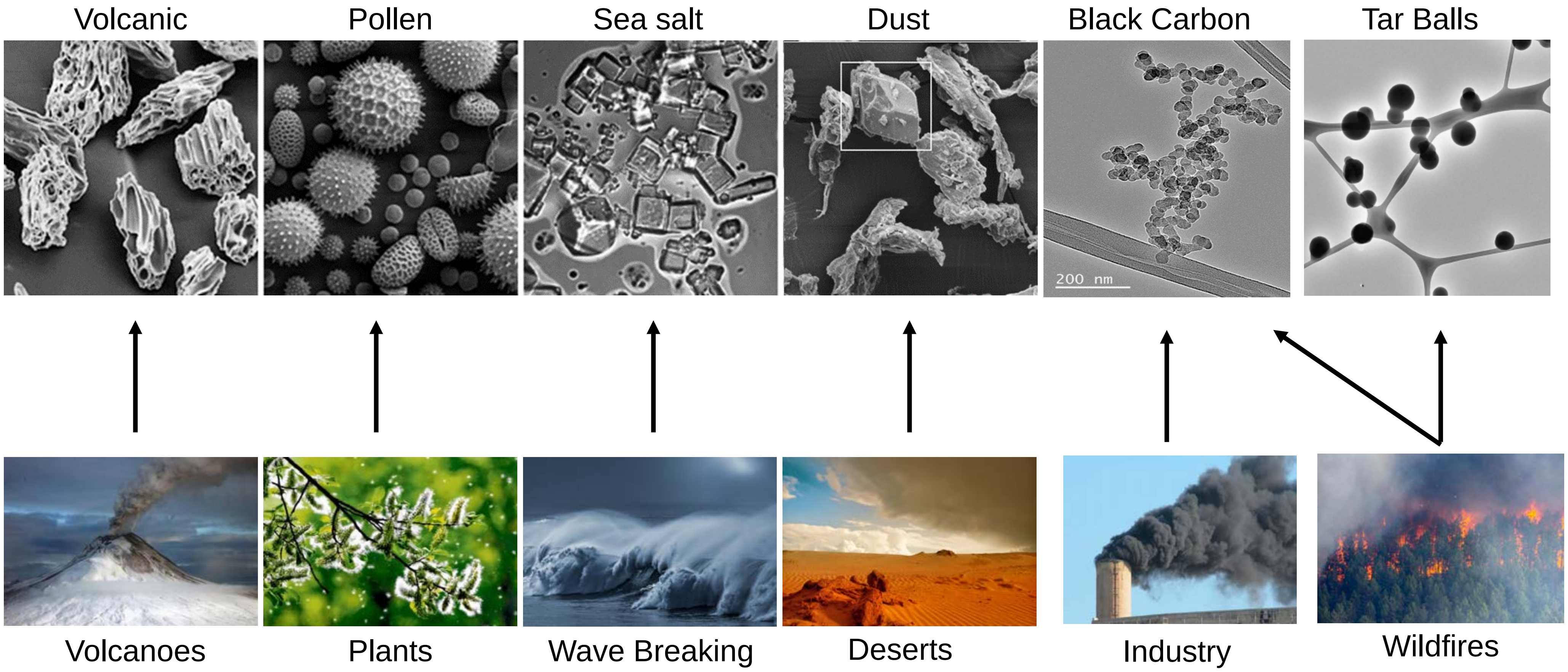
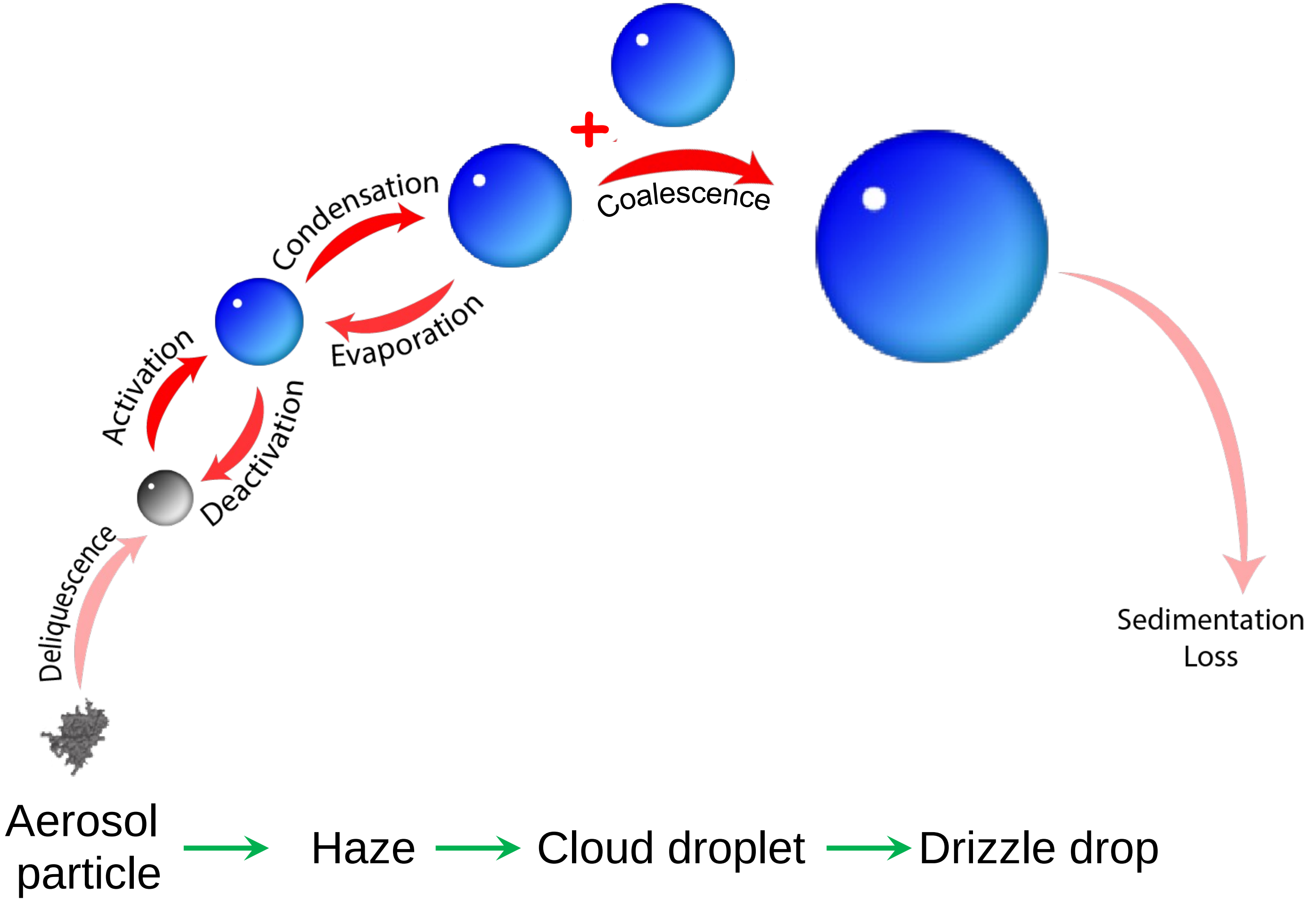


Aerosols are everywhere, so if the RH is right, clouds can be anywhere.

Aerosol-Cloud-Drizzle Continuum

The precipitation pathway remains of the largest uncertainties in weather/climate models due to poor understanding of key microphysical processes.



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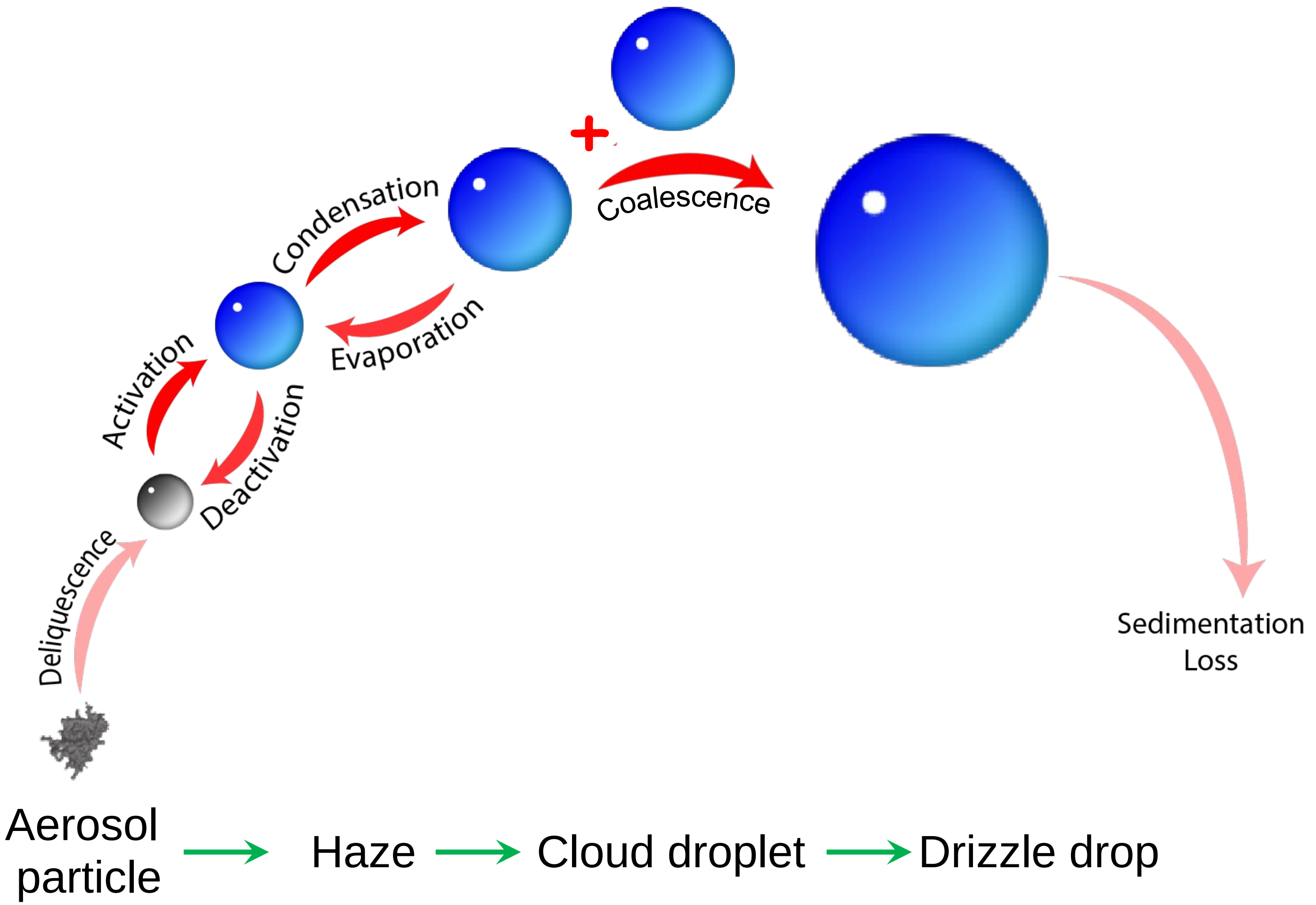

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In-cloud Measurements Are Very Difficult

Controlled Conditions → Understand Physics

Controlled laboratory experiments are the only way to develop a robust understanding the underlying physics behind these microphysical processes

Controlled Conditions → Understand Physics

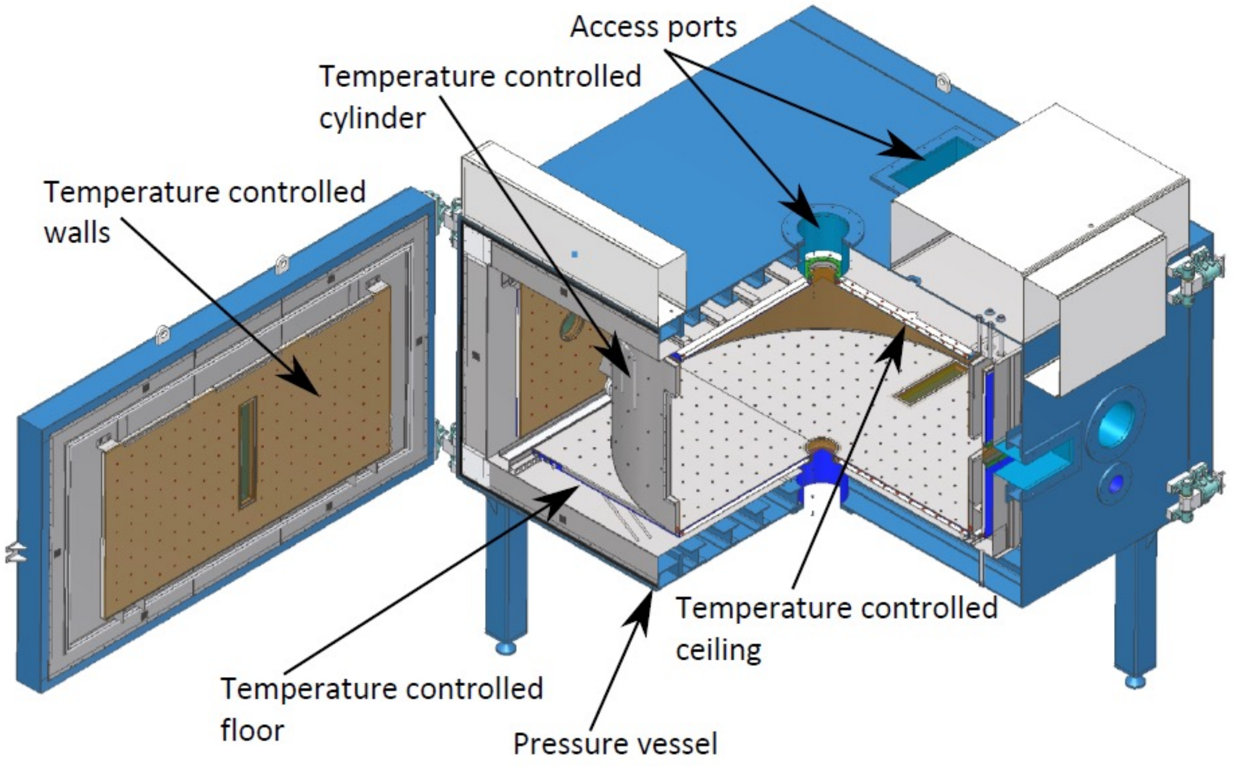
Controlled laboratory experiments are the only way to develop a robust understanding the underlying physics behind these microphysical processes

- Well-characterized boundary and initial conditions
- Known inputs, such as aerosol (controlled composition and size)
- Detailed measurement of aerosol and cloud microphysical properties (size distributions and particle phase, interstitial and residual aerosols, etc.)
- Experiment Repeatability
- Isolation of processes or mechanisms
- Enable detailed comparison to theory and computational (simulations and models)

Cloud Chambers Offer a Controlled Environment to Tackle Important Research Topics

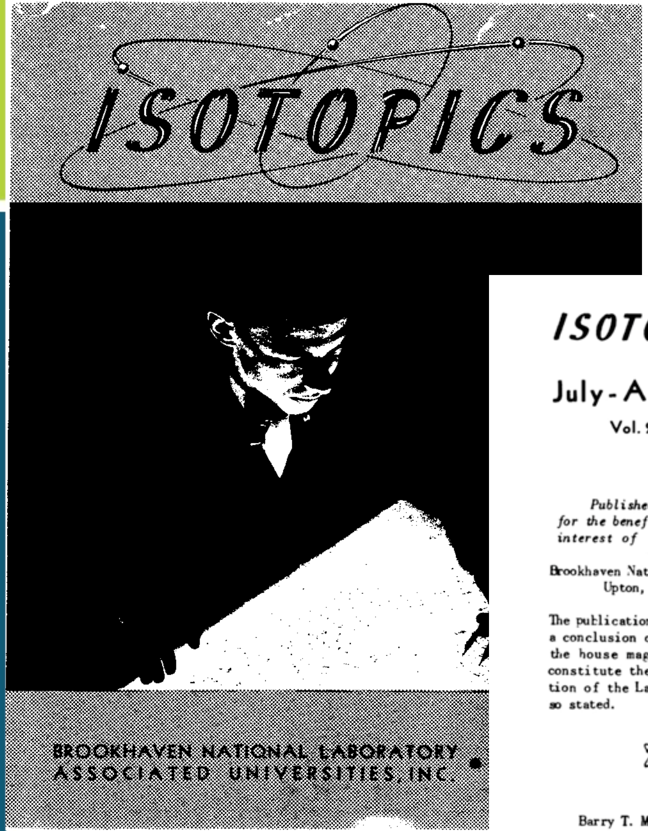
- Cloud Seeding
- Cloud Formation
- Ice Nucleation
- New Aerosol Particle Formation
- Aerosol and Cloud Chemistry
- Droplet-Turbulence Interactions
- Aerosol-Cloud-Turbulence Interactions
- Measurement in clouds is difficult

Michigan Technological Uni. Chamber
Diameter = 2 m
Height = 1 m



Only two cloud chambers exist in the US: MTU and (now) BNL

Fun Fact: BNL's Built a Cloud Chamber in 1948



ISOTOPICS

July-Aug., 1948

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Barry T. Mines, *Editor*

Illustrators
George Cox   Henry Wright

Photographers
Robert Walton   Robert Smith

COVER: Meteorologist, Philip H. Lowry, checking the weather map on a light table. (See Group Profile on pages 4 and 5.)

The Cloud Chamber

This is the third of a series of articles written for the layman, explaining some of the technical programs of the Laboratory and the meaning of the various terms used.

For weeks a large hole yawned from the Rochester Street side of the building at 51 Brookhaven Avenue. Truck-load after truck load of concrete, 24 in all, was poured into the opening to form a foundation 8 feet thick. On this pad will rest one of the most useful instruments of nuclear science, an enormous high pressure cloud chamber weighing many tons which was designed by Dr. Thomas H. Johnson, chairman of our Physics Department, and Dr. Ralph P. Shutt, of the Particle Physics Division. This will be the largest cloud chamber with the highest pressure of any in existence.

A cloud chamber, the invention of Dr. C. T. R. Wilson, an English scientist, is one of the simplest of the tools of nuclear research. In operation it takes advantage of the law of nature that when warm moisture-laden air expands it cools and the water vapor it contains condenses to form a cloud. In just this way warm air from a valley sweeping up the side of a mountain range forms clouds when it cools by expansion under the lower pressure of the higher altitude.

The interesting property of the cloud formed in a cloud chamber, on the other hand, is the fact that the water droplets form upon ions left in the path of a charged particle. (Ions are electrified particles formed when a neutral atom loses or gains one or more electrons.)

In the cloud chamber a mixture of gas and vapor, rendered as dust-free as possible, is compressed by the action of a piston or a diaphragm, just as the mixture of gasoline and air is compressed in the combustion chamber of an automobile. When the pressure in the chamber is instantaneously reduced by the opening of a valve, the cooling action that accompanies the lowering in pressure causes a mist to form. Electrically charged particles, from any source moving through the mixture produce a large number of ions along their tracks, upon which tiny droplets of water condense. At this instant a bright light is flashed and the path of each particle is recorded on a photographic plate.

When the chamber is placed between the poles of a very strong electromagnet, the tracks become curved in an arc. Scientists can learn much about the nature of the particle that caused a particular track from a study of this curvature. For example, a particle of low energy will trace a sharply curved path, while the path of a high energy particle will be nearly straight. Negatively charged particles in a magnetic field follow a course exactly opposite to the paths taken by positively charged particles.

The small cloud chamber on display as a part of the Laboratory's Nuclear Energy Exhibit depends upon particles emitted by a small amount of polonium to produce the paths that are visible to the observer. The big cloud chamber to be installed at 51 Brookhaven Avenue will contain argon or helium gas and until the cosmotron is completed, will depend upon cosmic rays to produce the paths. It was designed to obtain further information about the meson, one of the particles found among these rays of extremely high velocity and penetrating power that continuously bombard the earth. It is thought that they have their origin beyond the earth's atmosphere and may be produced by changes in the form of atoms that are taking place continuously in inter-stellar space.

Dr. Johnson, who has pioneered in the design and use of high-pressure cloud chambers, states that in an ordinary low-pressure chamber operating 12 hours a day the possibility of obtaining demonstrations of the rare cosmic ray phenomena, such as the splitting of mesons into other particles, which happens at the end of their range, would occur only about once a year because the rays are of such high velocity that they pass right through the average chamber. (The meson is one of the newest of the nuclear particles to be identified. Their existence was first suspected by the Japanese scientist, Yukava, and subsequently they were discovered in the cosmic rays by Dr. Carl Anderson, Nobelist from California. Too little is known about mesons, but it is thought that they produce the forces which hold nuclear particles together.)

Brookhaven's new cloud chamber will operate under a pressure of 4500-lbs. per square inch, making it the equivalent of approximately 300 ordinary chambers. The high pressure will slow down the rays so that splitting of more mesons will take place within the chamber. It is expected this may occur almost daily and that in a few months of operation it will furnish information to answer many of the questions regarding cosmic rays which now puzzle the physicists.

The steel yoke which will hold the chamber together under the extremely high internal pressure will weigh about 120,000 pounds and will act as the path for the magnetic field. It will be tied together at its four corners by four huge bolts and nuts, each weighing about 1,000 pounds. Four coils, each weighing three tons, will be energized by the current from four Diesel electric generators to form the magnetic field. The tracks in the chamber will not be observed visually but a pair of stereoscopic cameras will produce a three-dimensional image of the tracks, and the resulting photographs will then be studied by the physicists.

Many important discoveries in nuclear and atomic physics have been made with cloud chambers. Photographs of cloud chamber tracks have revealed the existence and characteristics of various particles that make up an atom. When the Laboratory's high-pressure cloud chamber is in operation in 1949, the physicists expect to obtain further information about mesons and the part that they play in nuclear energy.

REPRODUCTION of a photograph taken in a high-pressure cloud chamber. The heavier line starting near the top is a meson being slowed down by the gas in the chamber. The thin track running to the right from the end of the meson track is an electron of high energy created when the meson disintegrated.

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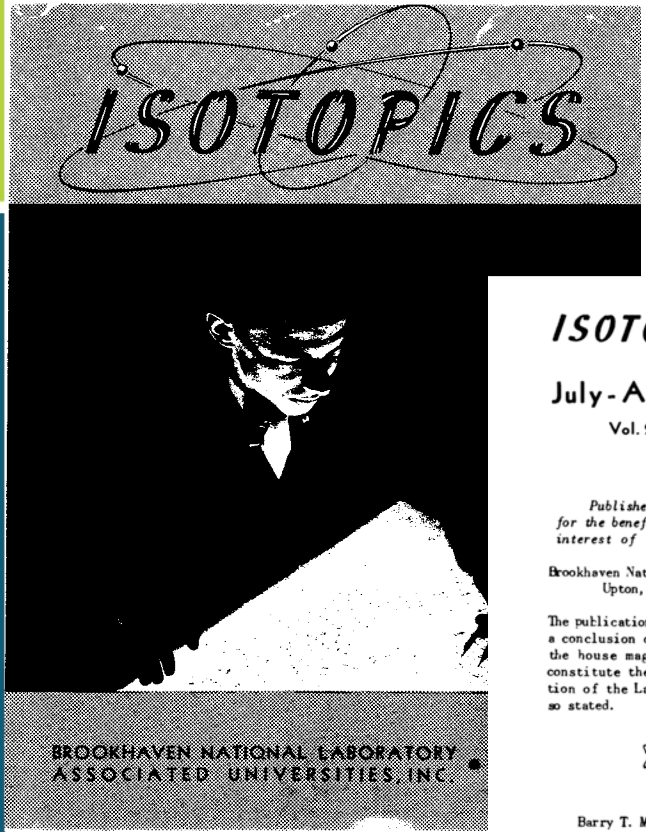

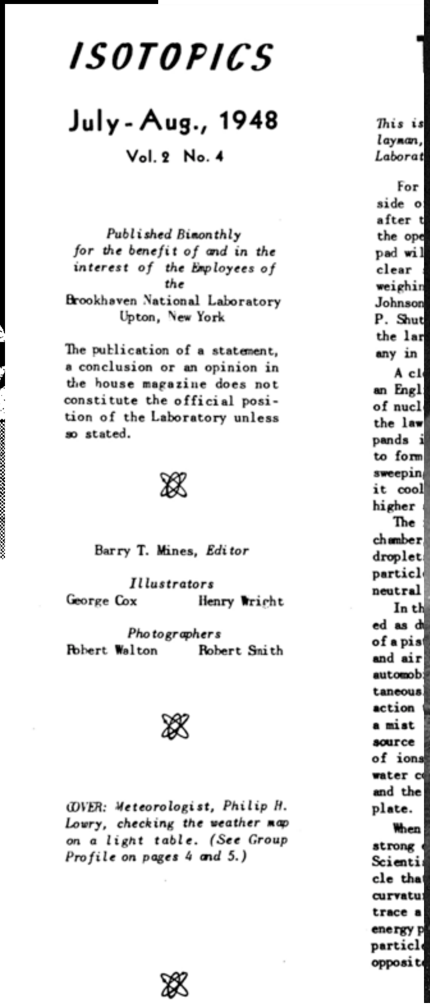

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COVER: *Meteorologist, Philip H. Lowry, checking the weather map on a light table. (See Group Profile on pages 4 and 5.)*

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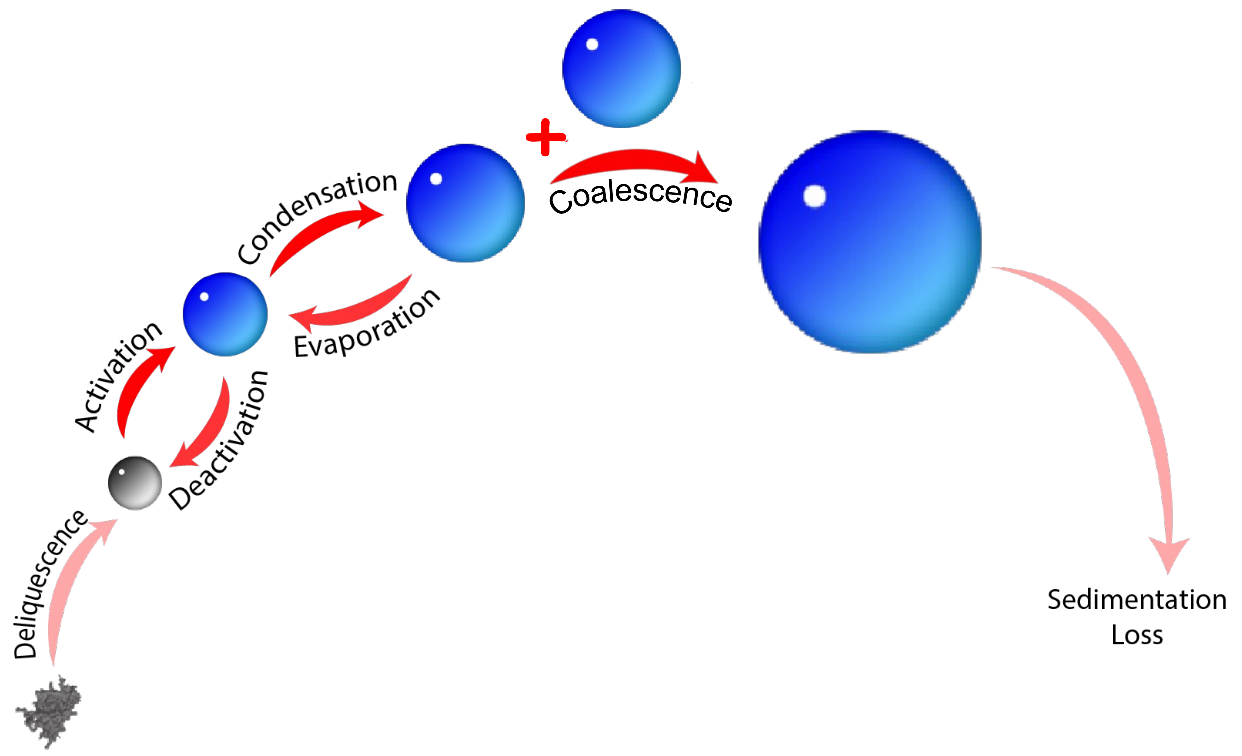
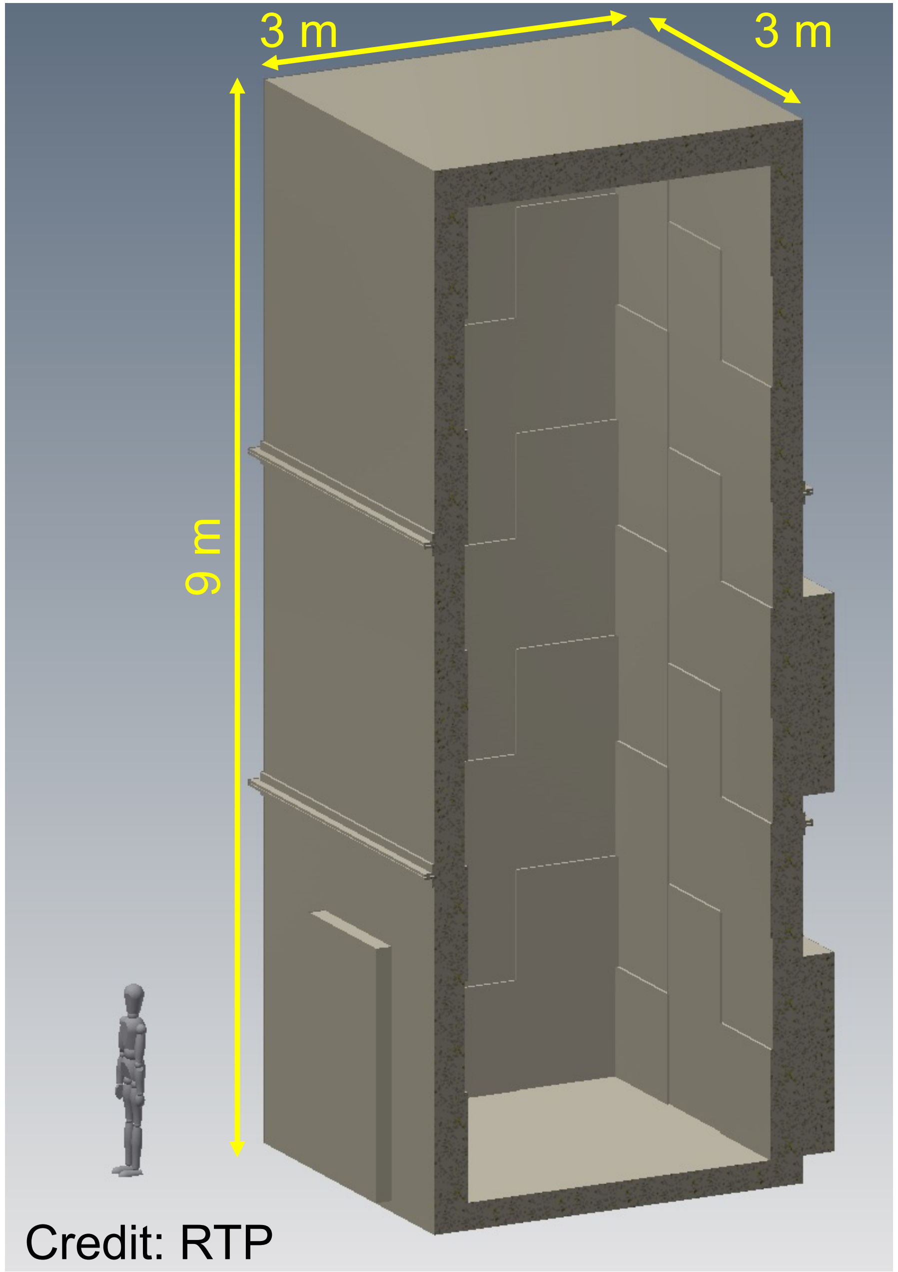
DOE BER's Interest in Cloud Chambers

Understand the Aerosol-Cloud-Drizzle Continuum



DOE Facilities Charge List (December 2023)

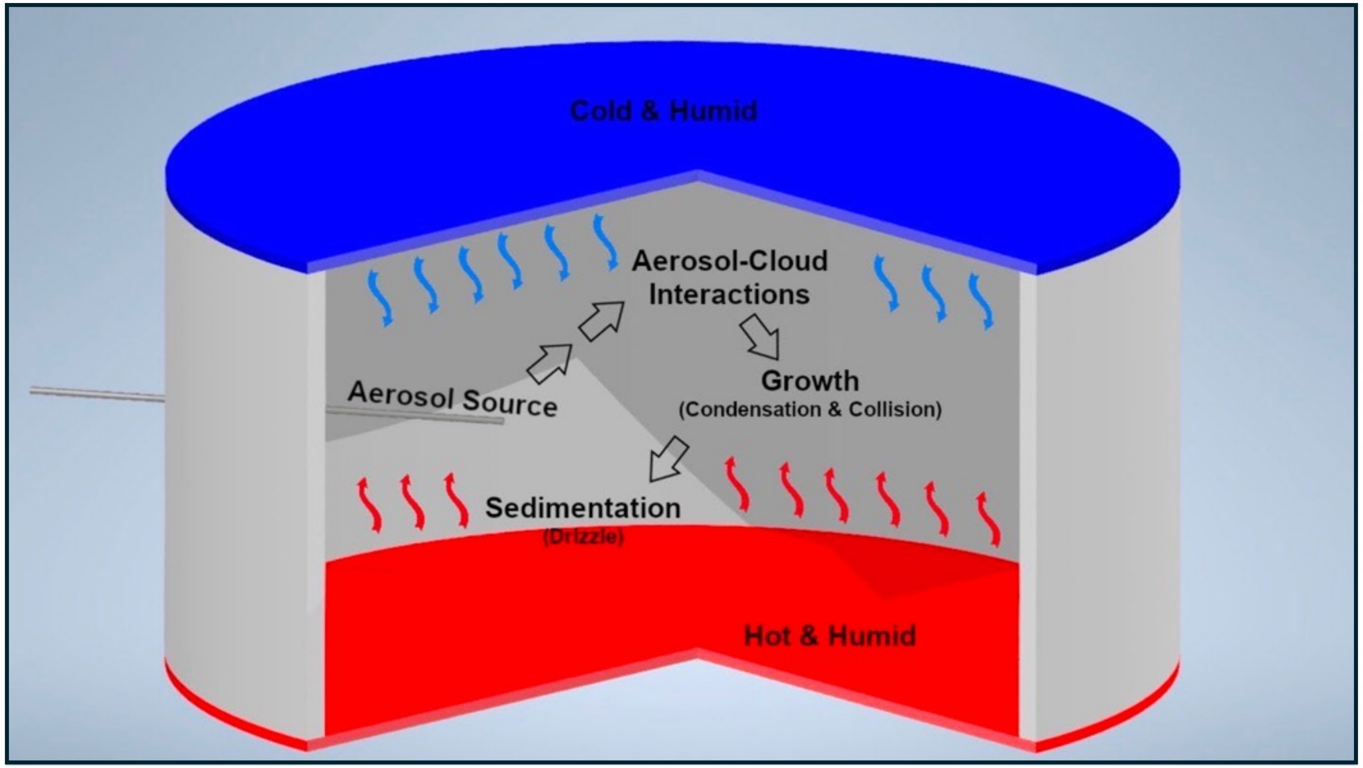


Convection Chamber Design

Turbulent Moist Convection with Aerosol Source

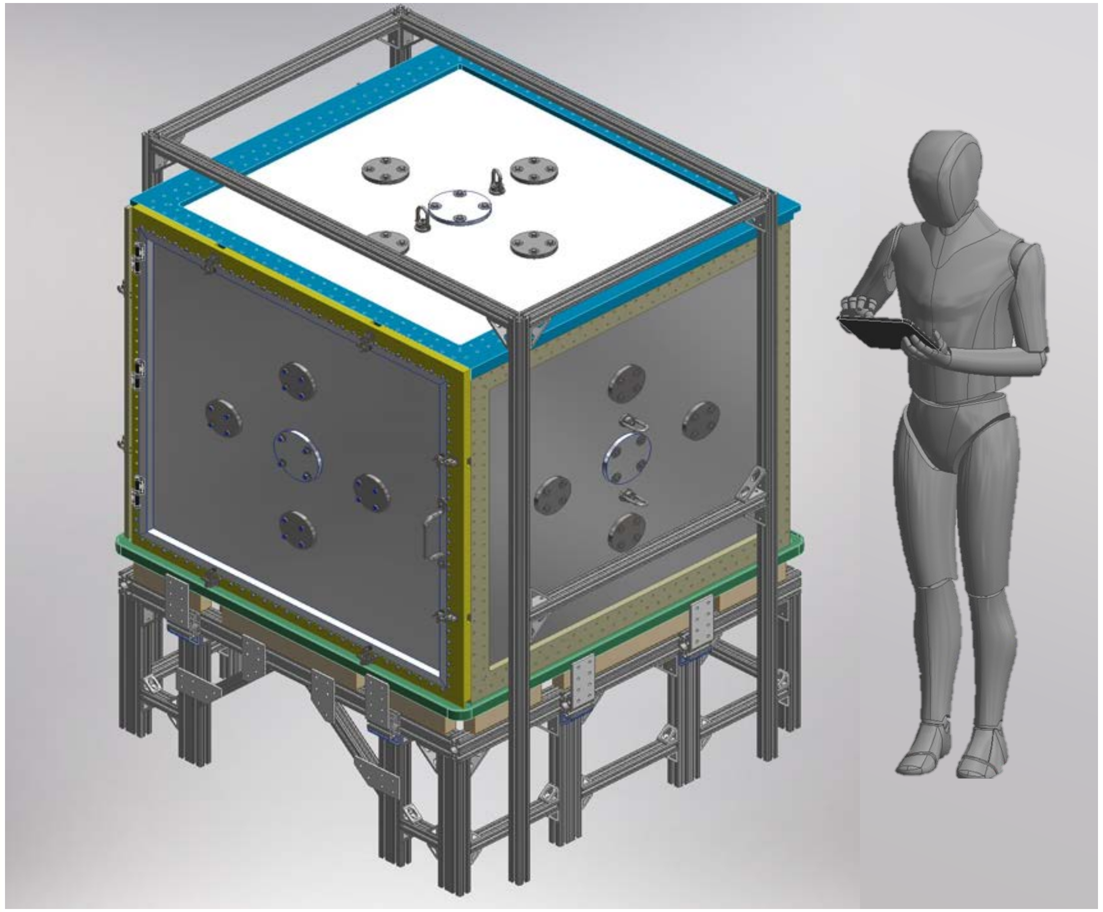
Advantages:

- Microphysical properties in *steady state*
- Achieves microphysical conditions like stratiform (layered) clouds
- Analogous to turbulent “mixed layer” rather than adiabatic parcel
- Direct comparison to models (warm and mixed-phase clouds)



R. Shaw, *Design of a convection-cloud chamber for exploring interactions between aerosols, clouds, and drizzle*; AGU 2023 presentation

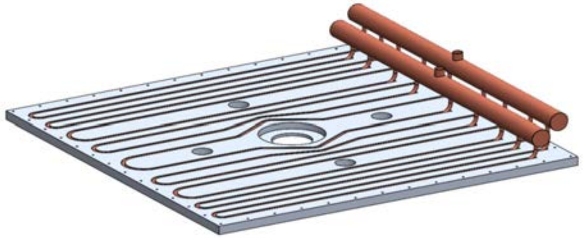
BNL's Cloud in a Box: 1-m^3 "testbed" Cloud Chamber



Connie-Rose Deane/IO

- Inner dimensions = 43 in x 43 in x 43 in
- 3 cold plates – liquid cooling
  - Top and two sides
- 3 hot plates – resistance wire
  - Bottom and two sides
- Design is completely modular
  - Switch configuration of panels

Cooling plates



Manifold and embedded tubing

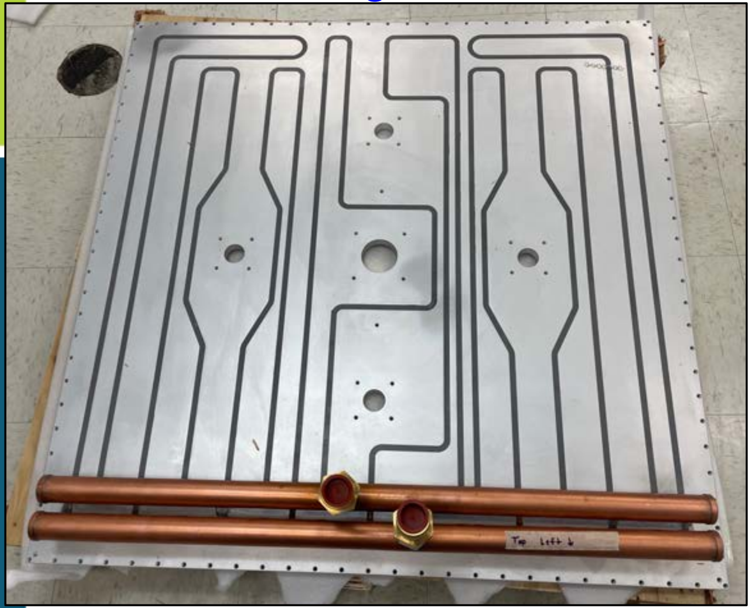
Heating plates

Resistance wiring

Modular design & temperature controllable side panels enable non-uniform environments that mimic actual clouds

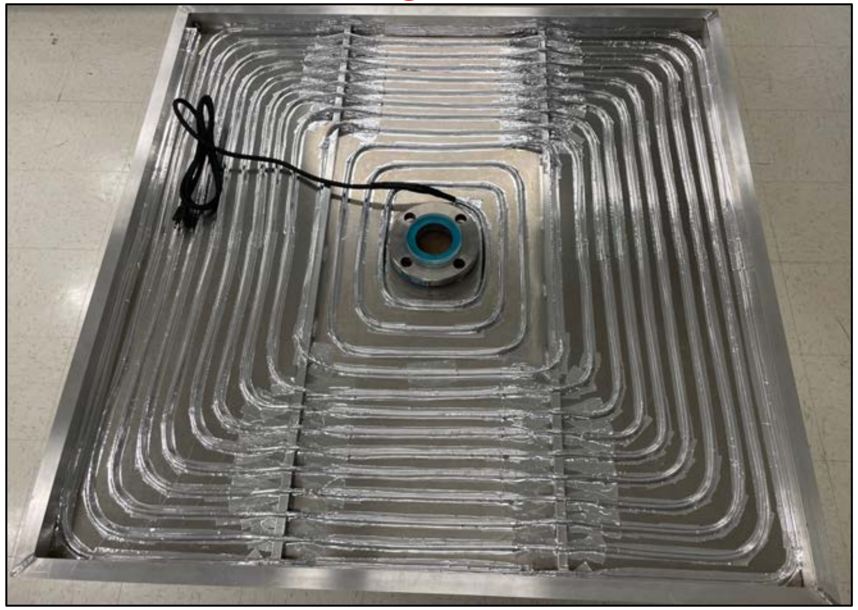
BNL's Cloud Chamber

Cooling Panel



Baseplate

Heating Panel



First cloud by end of FY25

Convection Cloud Chamber

Introducing Nephos to the World

Inter-Directorate team that built the Nephos Chamber

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By Kelly Lazzaro

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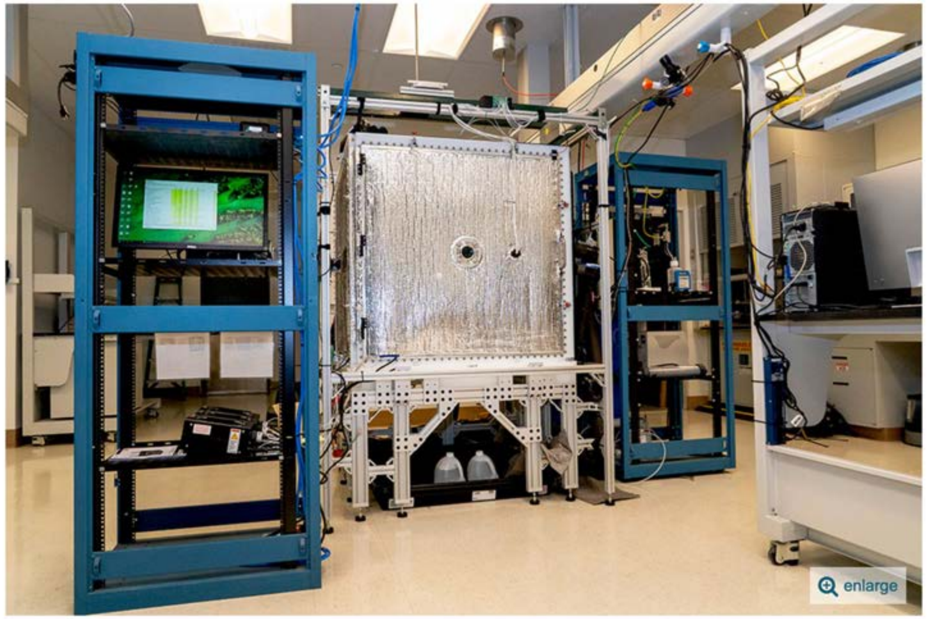
Brookhaven Lab Builds Successful 'Cloud in a Box'

New convection cloud chamber produces clouds — and research possibilities

February 17, 2026



A new cloud chamber at Brookhaven National Laboratory will allow scientists to study clouds in a controlled setting. (David Rahner/ Brookhaven National Laboratory)

Science

Scientists Create 'Cloud In A Box' To Solve Atmospheric Mysteries

Brookhaven National Laboratory's new chamber allows researchers to study cloud formation in controlled conditions

By Chris DeWeese • February 19, 2026

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https://weather.com/science/news/2026-02-18-cloud-in-a-box

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BNL's Arthur Sedlacek, Fan Yang create the nation's second cloud chamber

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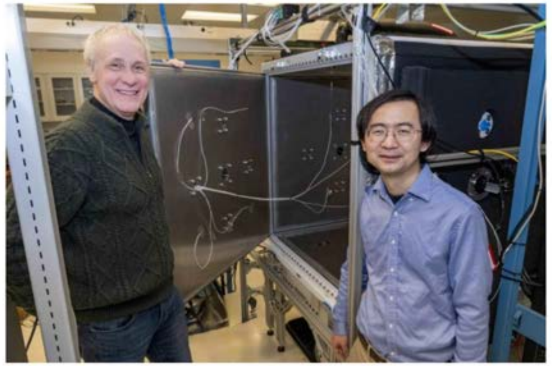
Daniel Dunaief



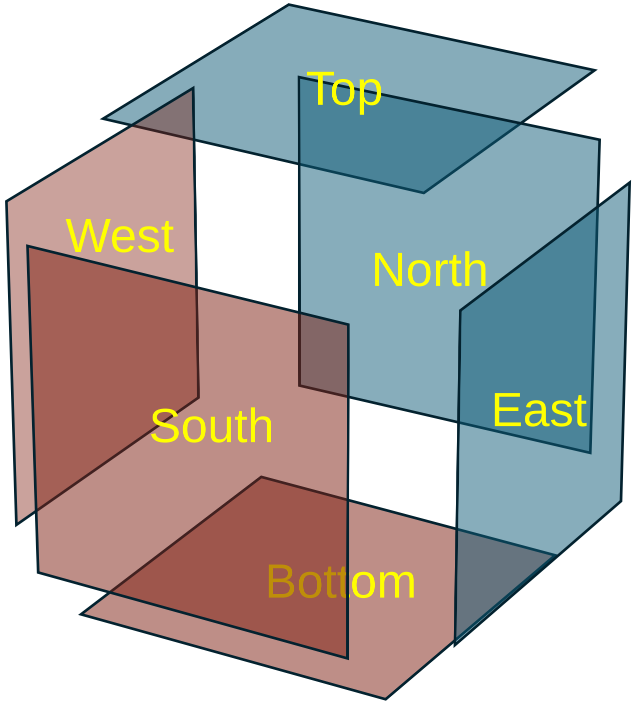
Brookhaven National Laboratory scientists Arthur Sedlacek and Fan Yang. Photo by David Rayner/ BNL

By Daniel Dunaief

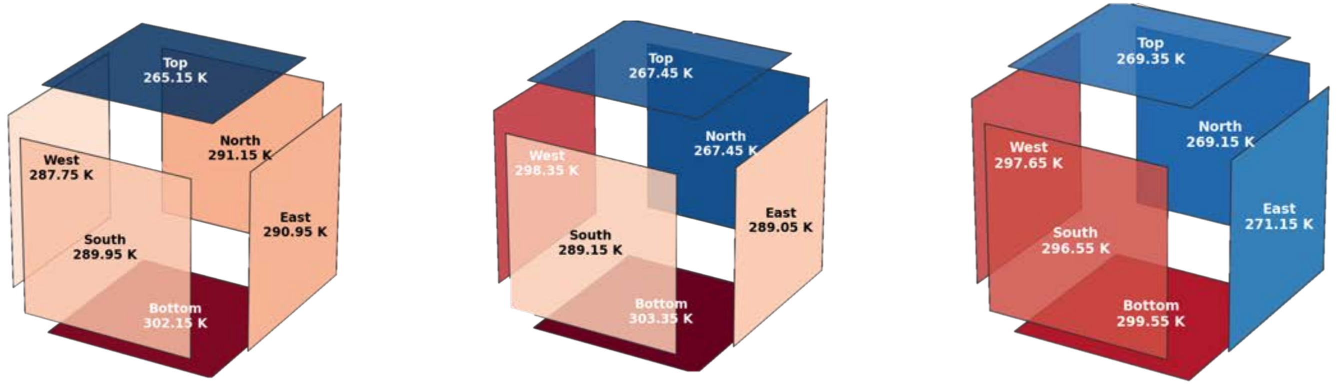
https://tbrnewsmedia.com/bnls-arthur-sedlacek-fan-yang-create-the-nations-second-cloud-chamber/

What Makes the BNL Nephos Chamber Unique

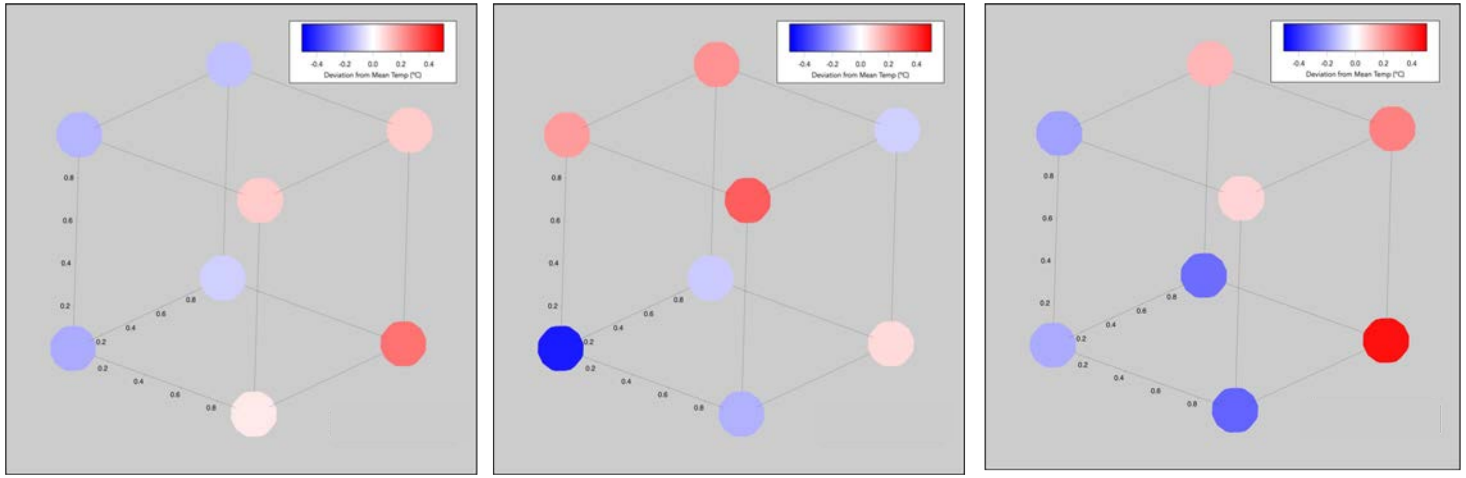
Individual Control of Panel Temperatures Enables Creation of Specific Circulation Conditions



Three cooled panels
Three heated panels



Eight temperature measurements to characterize the spatial temperature field

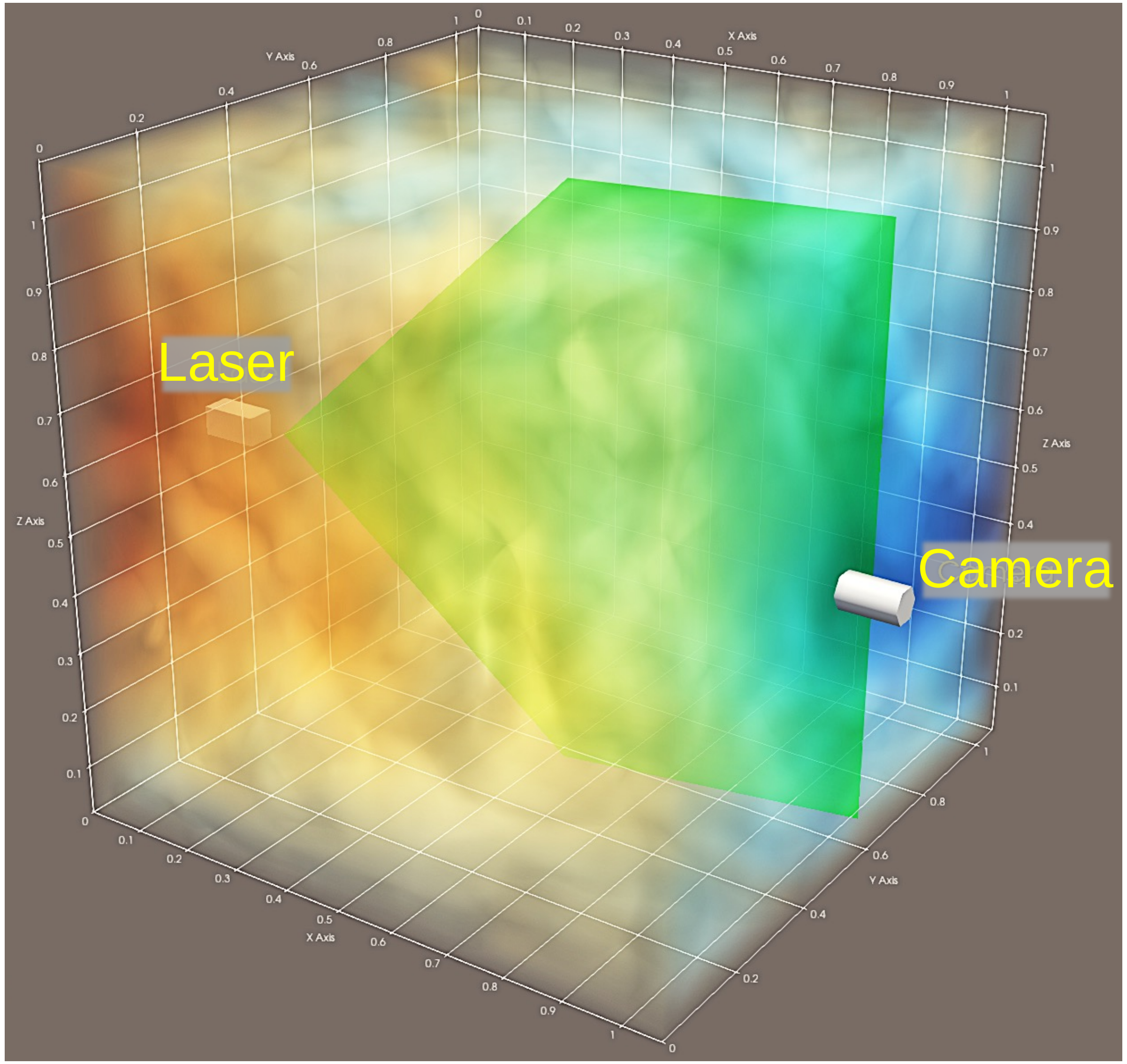


Differences in the mean temperature (T_{mean}) : Blue < T_{mean} < Red

Imaging a Cross-Section of Cloud

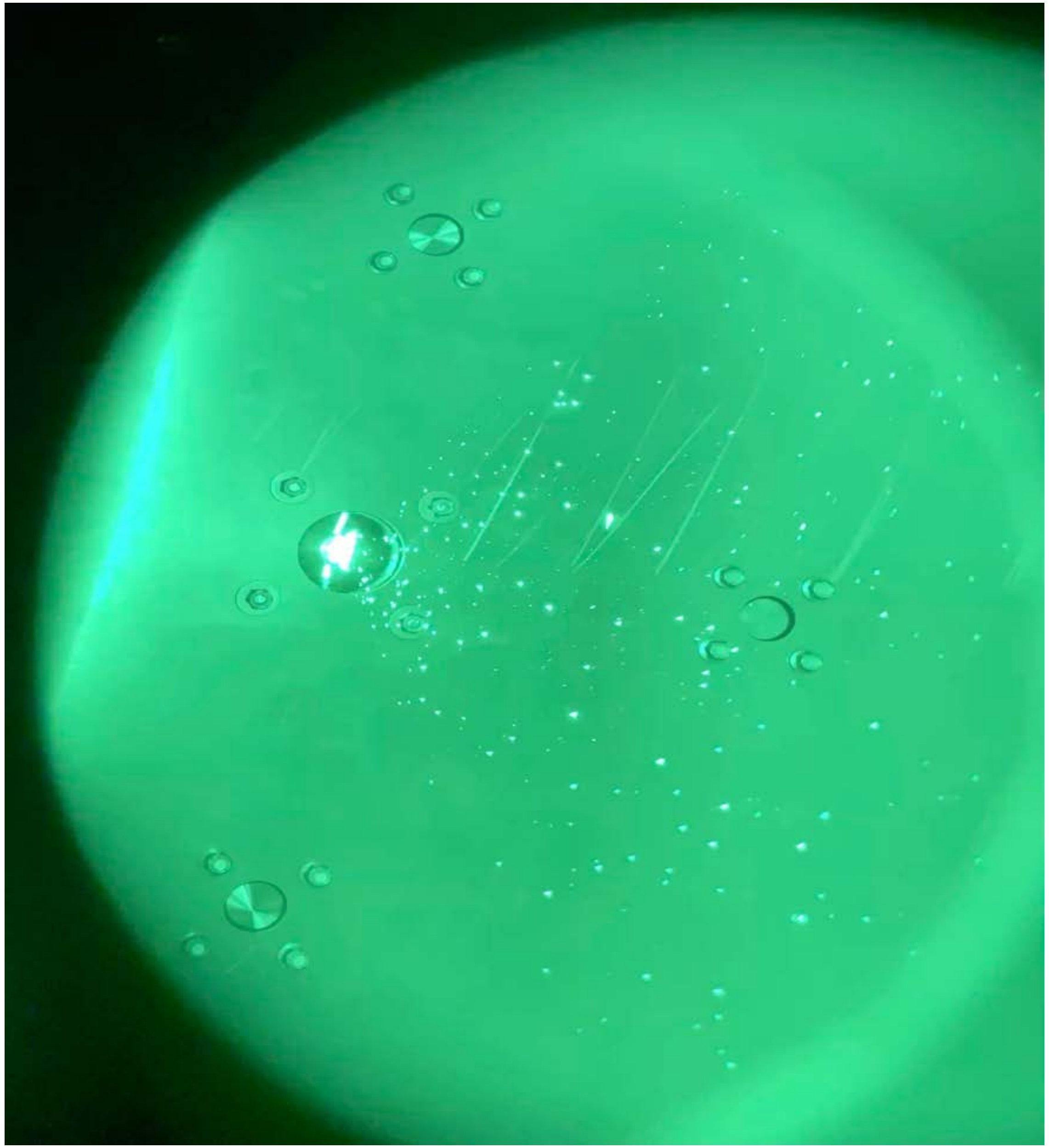
45-degree fan angle Laser

λ_{exc} = 520 nm



First Light Demonstration: Making a Cloud

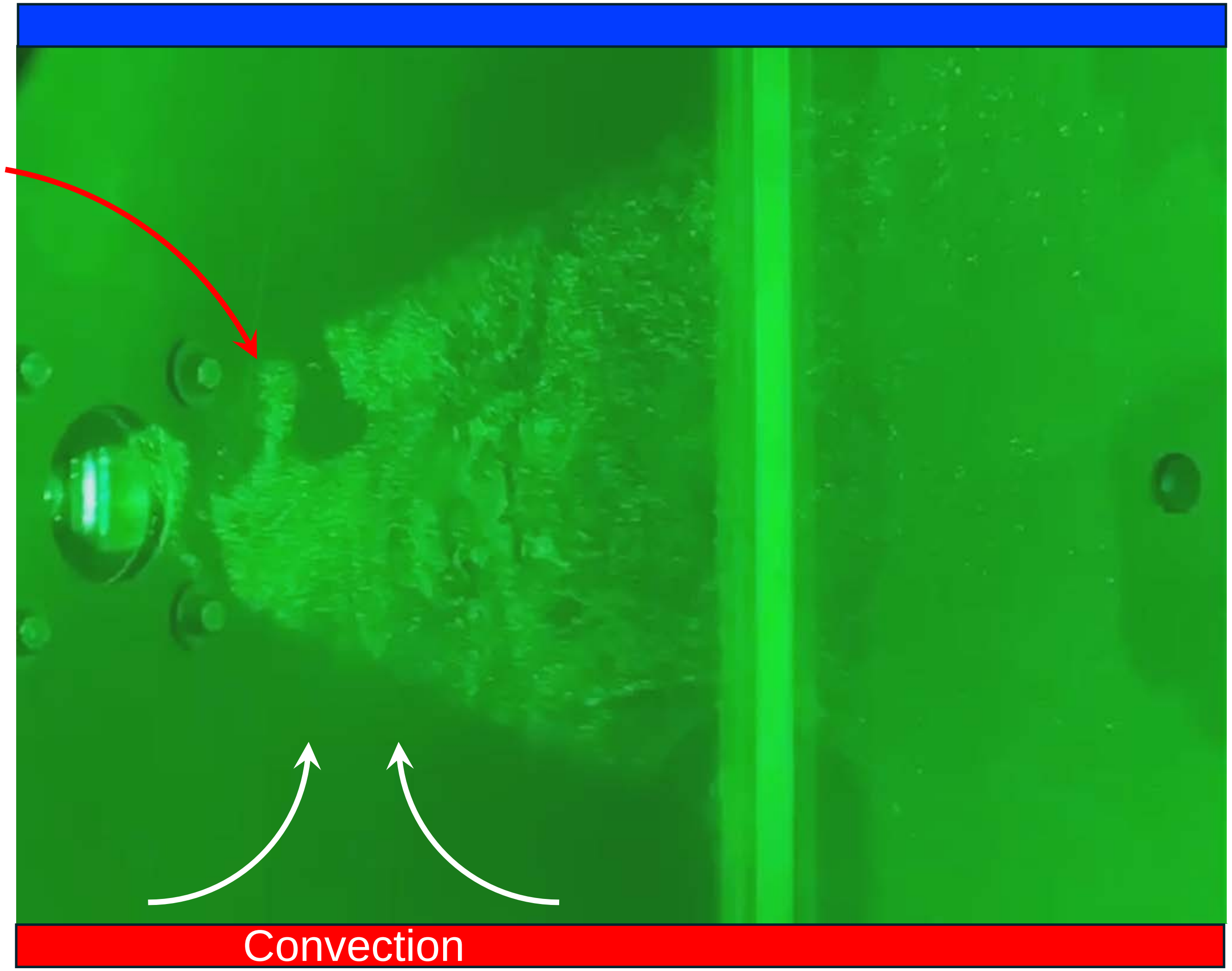
- Inject common table salt (NaCl) into a supersaturated environment
- Those first aerosol particles quickly suck up the available water vapor
- Create cloud droplet filaments that scatter laser light very efficiently
- As more aerosol is injected, the saturation conditions drop to subsaturated resulting in the creation of haze particles



First Light Demonstration: Turbulence Convection

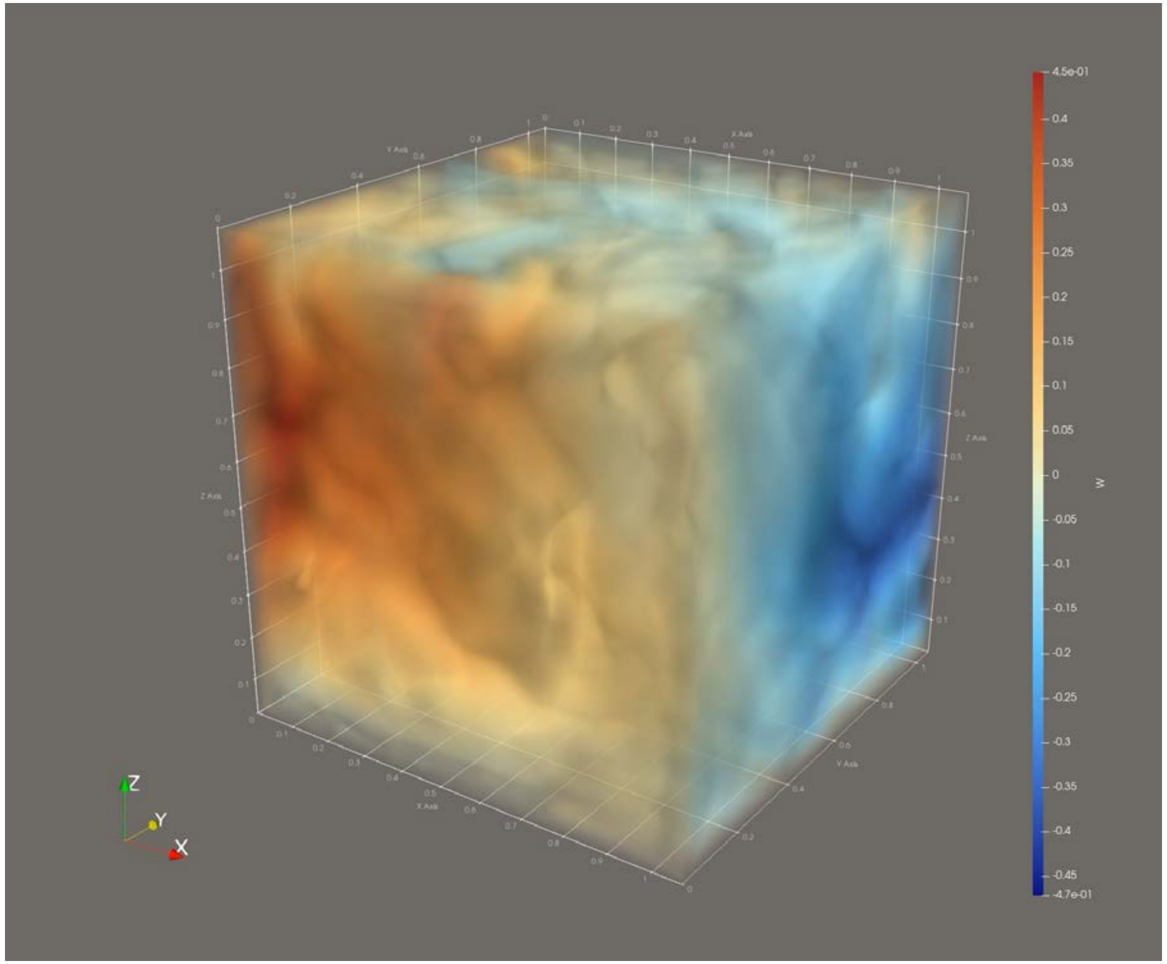
Convection and mixing visualized by illuminated cloud droplets using a 520 nm laser curtain.

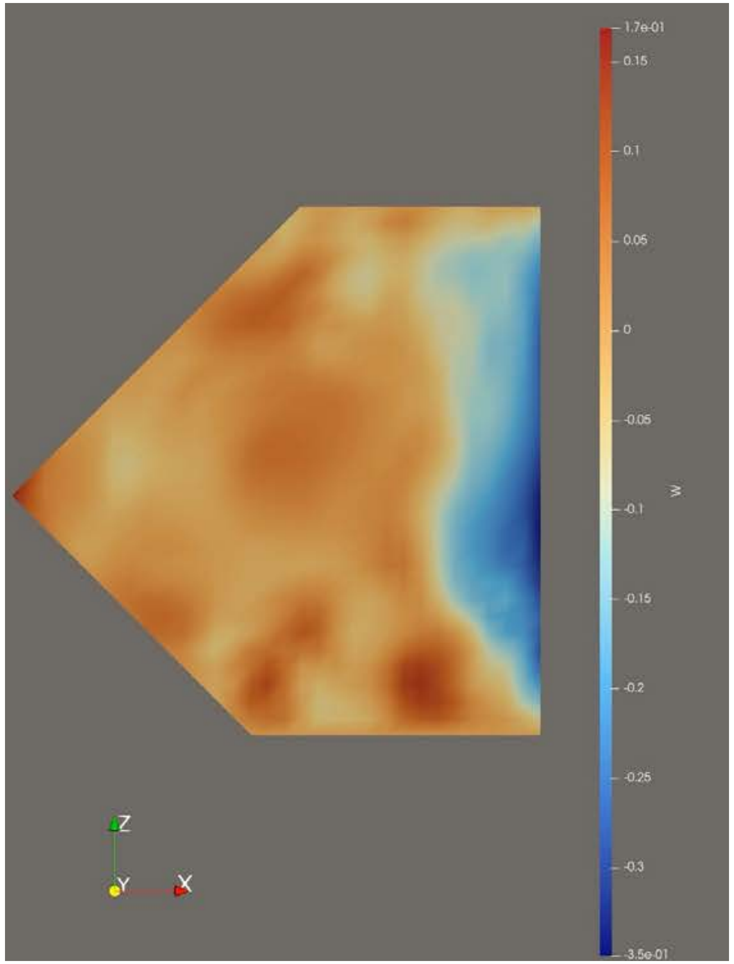
NaCl aerosols: 60 nm diameter



Visualization of 3D Vertical Velocities

Validated models allow us to see the the dynamic behavior of the created atmosphere





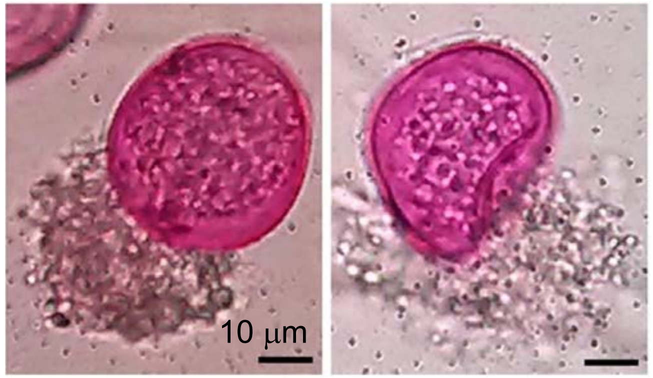
Applications Outside of Fundamental Atmospheric Science

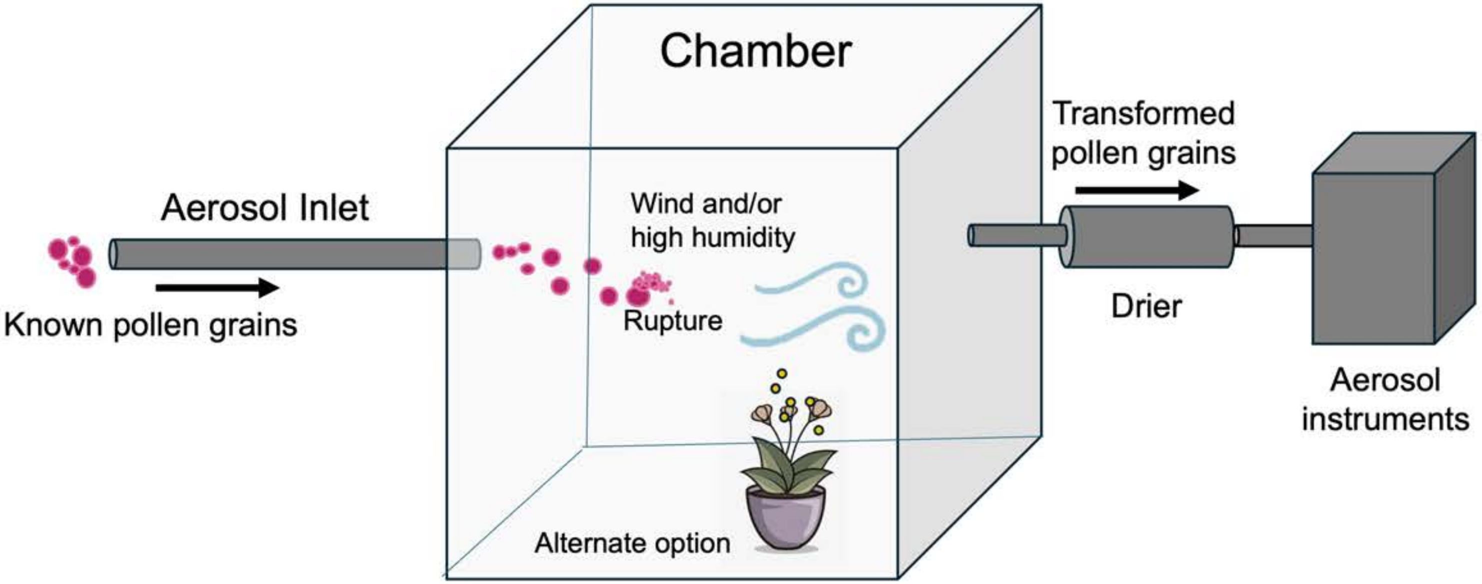
Investigating Bio-Aerosols/Pathogens Evolution

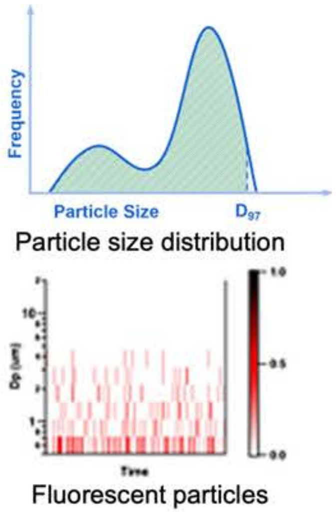
Controllable bio-energy testbed for mapping how aerosolized microbes and biomass-processing organisms behave under realistic plant conditions.

- Use pollen or fungal spores as a surrogate.
  - Particles rupture under humid atmospheric conditions
    - Rupture multiplies their health and weather impacts.

- The dynamics of these processes are difficult to observe in-situ







Investigating Energy Grid Resiliency

Repeatable atmospheric stressor emulator for grid resilience research and development.

Control turbulence, humidity, aerosol loading, and droplet spectra from smoke/haze to fog/drizzle/salt-spray from warm clouds to mix-phase clouds.

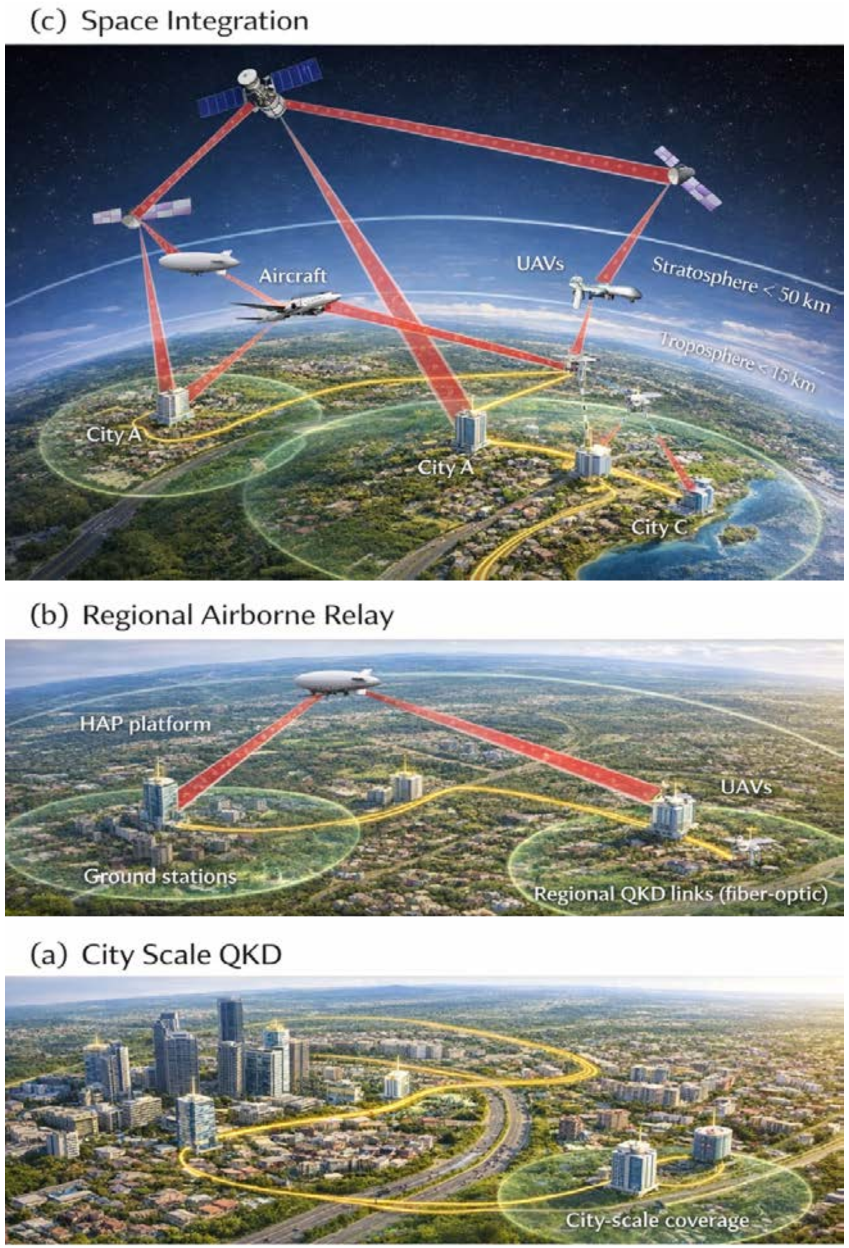
- Assess vulnerability to insulator leakage/flashover under salt or pollution fogs (aerosols deposition on insulators)
    - Validate anti-wetting/ice-phobic coatings against fogging and rime
- Map renewables impacts,
    - Spectral/angular attenuation for photovoltaic soiling/fog to improve nowcasts and dispatch

Quantum Communication

- Free-space quantum communication (QC) promises fiber-independent, city-to-city/satellite secure links directly through the atmosphere.
- However, real atmospheres impose turbulence and atmospheric extinction that degrade polarization/phase resulting in a rise quantum bit error rate.

Chamber provides a unique platform to investigate the impacts of the atmosphere by providing a

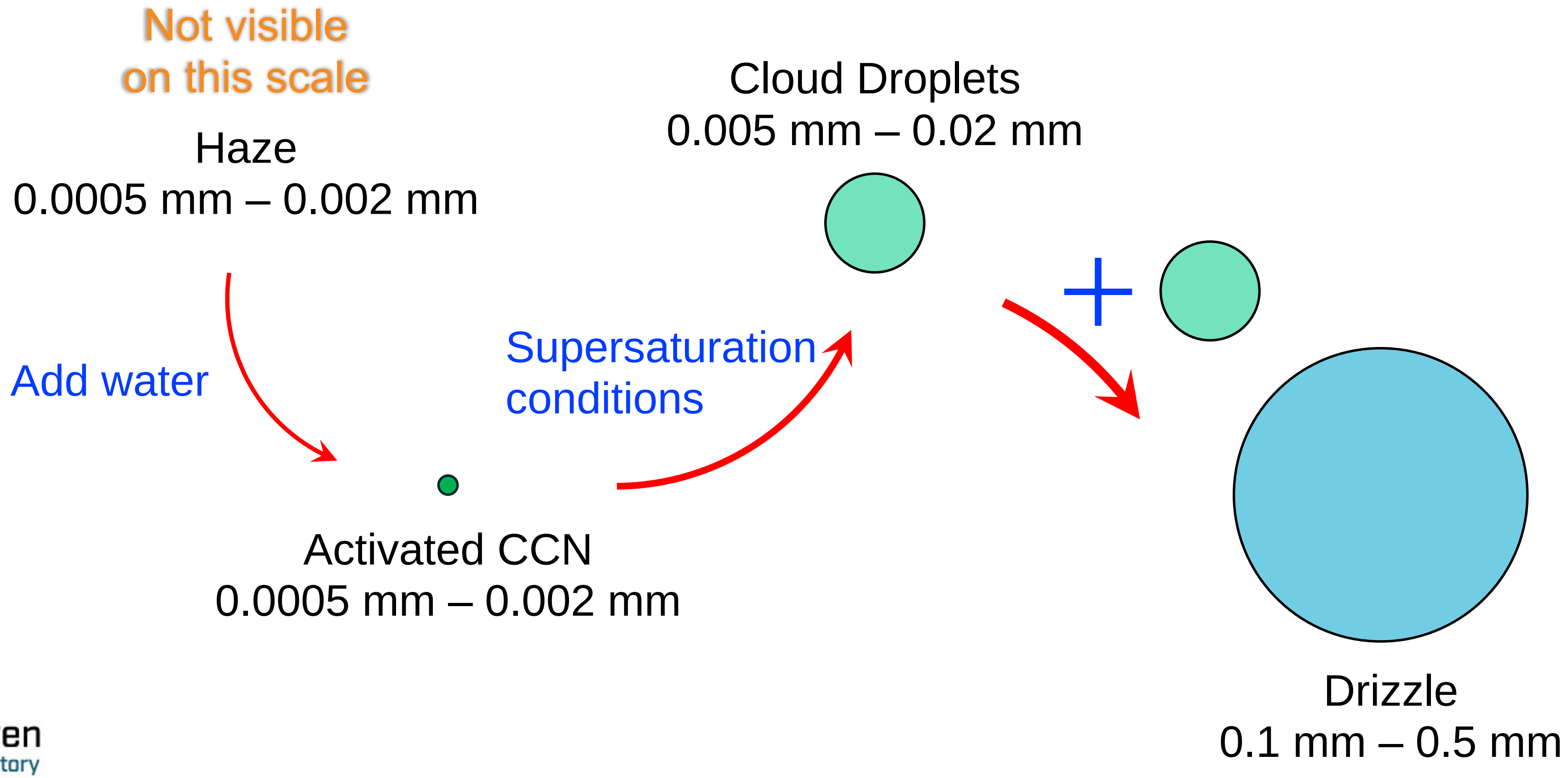
- Repeatable, physics-faithful free-space emulator with tunable turbulence, humidity, liquid water content, droplet size distributions, and aerosol chemistry
- Enable direct mapping from the atmospheric physical state to optical impairment and QC performance



ChatGPT

Next-Generation Detectors to Investigate Aerosol-to-Drizzle Continuum

Drizzle is formed when two or more cloud droplets collide and coalesce

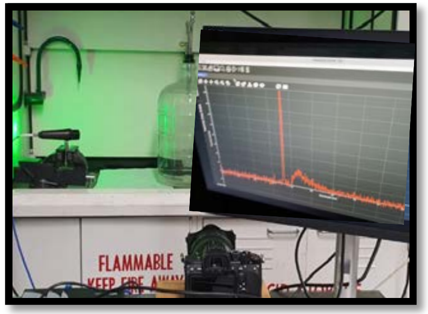


Next-Generation Non-Contact Measurements

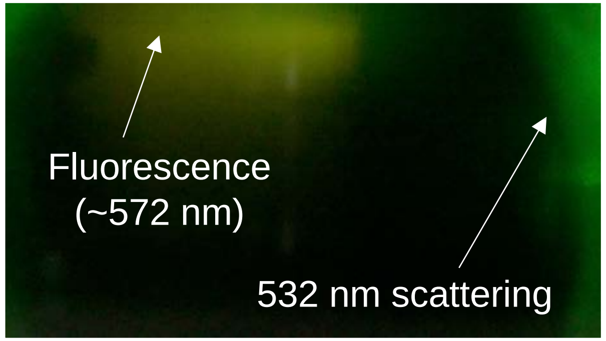
Skip

Fluorescent Tagging

Aerosol Activation

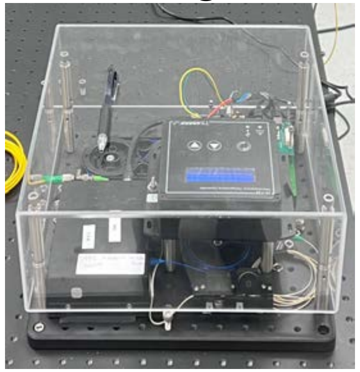


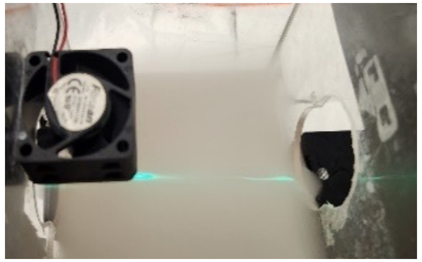
Aerosol Activation Causes Fluorescence



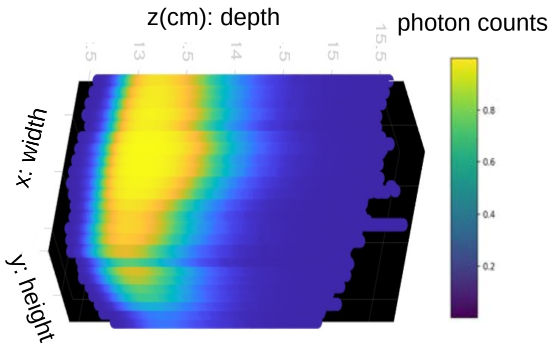
Time-Correlated Photon Counting Lidar

Cloud droplet Detection



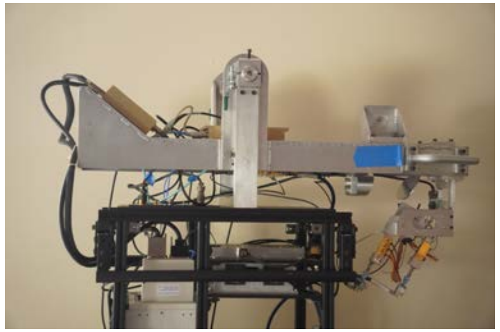


Tomographic Scan of Fog

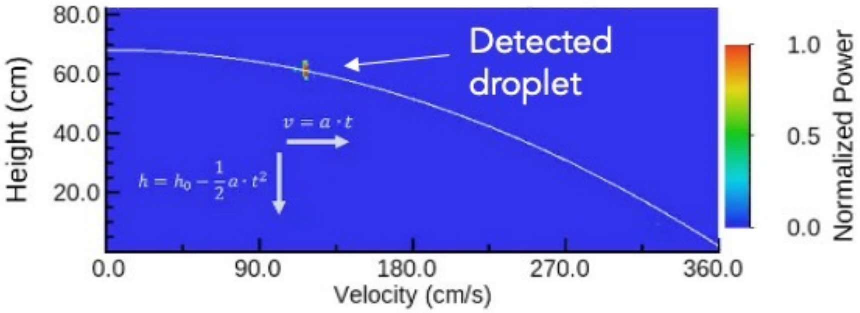


THz Radar

Drizzle Detection

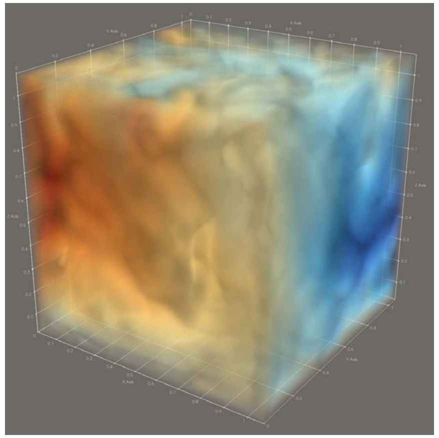


Detecting Freefalling Droplets



Summary – Five Key Takeaways

1. Modular design is unique, enabling stacking for easy expansion to larger size
2. Independent panel temperature control enables programming a wide range of simulated atmospheric conditions
3. The chamber can address critical questions on fundamental cloud microphysics
4. The chamber can address additional atmospheric science topics
   - Bio-aerosol evolution, including pathogens and humidity-induced “bursting” of pollen grains
   - Weather modification (e.g., cloud seeding)
5. The chamber offers significant opportunities for collaboration outside of atmospheric science
   - National security space (quantum communications)
   - Energy grid resilience
6. Exploit AI to ”dial-up” specific atmospheric conditions within the chamber and to accelerate discovery.



NEPHOS Testbed

Programmable Atmospheric for Environmental Research

Thank you!

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