Workshop Summary: Exploring Science Opportunities and Concepts for a Large-Scale Aerosol-Cloud-Turbulence Research Facility

R. A. Shaw

Physics Department & Atmospheric Science Program, Michigan Technological University

Special thanks to workshop participants; and to workshop organizers and speakers:

J. Brassard (MTU), W. Cantrell (MTU), S. Chen (NCAR), P. Chuang (UC Santa Cruz), N. Donahue (Carnegie Mellon), G. Feingold (NOAA), P. Kollias (Stony Brook Univ.), A. Korolev (Env. Canada), S. Kreidenweis (Colorado State Univ.), S. Krueger (Univ. Utah), K. Marwitz (NCAR), J.-P. Mellado (Polytechnic University of Catalonia), D. Niedermeier (TROPOS), L. Xue (NCAR)

Acknowledgement: Workshop supported by U.S. National Science Foundation and the NCAR Geophysical Turbulence Program

Workshop to Explore Science Opportunities and Concepts for a
Large-Scale Aerosol-Cloud-Turbulence Research Facility
Nov. 21-22, 2019

Objectives of workshop:

Explore scientific questions and set priorities for a large-scale aerosol-cloud research facility.
Obtain a sense of priorities for the range of scientific challenges that are likely to be amenable to laboratory investigation.

Two of the overarching questions considered throughout the discussion:

- What can we learn with a large-scale aerosol-cloud chamber that would be difficult to learn otherwise?
- What would a large-scale aerosol-cloud chamber look like and what measurement capabilities should be associated with it?

Cloud-aerosol-turbulence interactions: Science priorities and concepts for a large-scale laboratory facility

Raymond A. Shaw, Will Cantrell, Sisi Chen, Patrick Chuang, Neil Donahue, Graham Feingold, Pavlos Kollias, Alexei Korolev, Sonia Kreidenweis, Steven Krueger, Juan Pedro Mellado, Dennis Niedermeier, *and* Lulin Xue
Shaw and Cantrell: Michigan Technological University, Houghton, Michigan
Chen and Xue: National Center for Atmospheric Research, Boulder, Colorado
Chuang: University of California Santa Cruz, Santa Cruz, California
Donahue: Carnegie Mellon University, Pittsburgh, Pennsylvania
Feingold: NOAA Earth System Research Laboratory, Boulder, Colorado
Kollias: Stony Brook University, Stony Brook, New York
Korolev: Environment and Climate Change Canada, Toronto, Canada
Kreidenweis: Colorado State University, Fort Collins, Colorado
Krueger: University of Utah, Salt Lake City, Utah
Mellado: Universitat Politècnica de Catalunya Barcelona, Spain
Niedermeier: Leibniz Institute for Tropospheric Research, Leipzig, Germany

https://doi.org/10.1175/BAMS-D-20-0009.1
Published Online: 5 May 2020


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Workshop Presentations

- Cloud Chamber Studies of Aerosol-Cloud Interactions: Historical Perspective (Sonia Kreidenweis)
- Laboratory Studies of Boundary-Layer Clouds (Juan Pedro Mellado)
- Aerosol-Cloud Interactions: Outstanding Questions… And how they might be addressed in a new Cloud Chamber Facility (Graham Feingold)
- Aerosol and cloud chemistry within a large-scale cloud chamber (Neil Donahue)
- Problems of mixed-phase and cold cloud microphysics and potential ways of addressing them (Alexei Korolev)
- Science opportunities and possible developments for remote sensing within a large-scale cloud chamber (Pavlos Kollias)
- Aerosol-cloud laboratory research facilities in Europe (Dennis Niedermeier)
- Aerosol-cloud laboratory research facilities in Asia (Lulin Xue)
- Aerosol-cloud laboratory research facilities in North America (Will Cantrell)
- Modeling cloud-aerosol interactions: Inter-comparison of modeled microphysics using laboratory measurements (Sisi Chen)
- Aerosol-cloud-turbulence instrumentation for a large-scale laboratory facility (Patrick Chuang)

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- All of these factors enable detailed comparison to theory and computational (simulations and models)

Examples of Processes Suitable for Laboratory Investigation

Aerosol-cloud chemistry

Ice nucleation

Aerosol processing by clouds

Secondary ice processes

Aerosol indirect effects

Radiative transfer in clouds (3D correlated clouds, ice crystals)

Collision-coalescence rates

Testing and calibration of instruments

Onset of collision-coalescence

Evaluation of Lagrangian vs Eulerian microphysics

Cloud electrification

Evaluation of LES + microphysics

US Weather Bureau Cloud Chamber
20-m diameter
3000-m^3 volume

JOURNAL OF METEOROLOGY V

AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF AIR POLLUTION ON THE INITIATION OF RAIN

By Ross Gunn and B. B. Phillips
U. S. Weather Bureau

(Original manuscript received 15 November 1956; revised Manuscript received 21 December 1956)

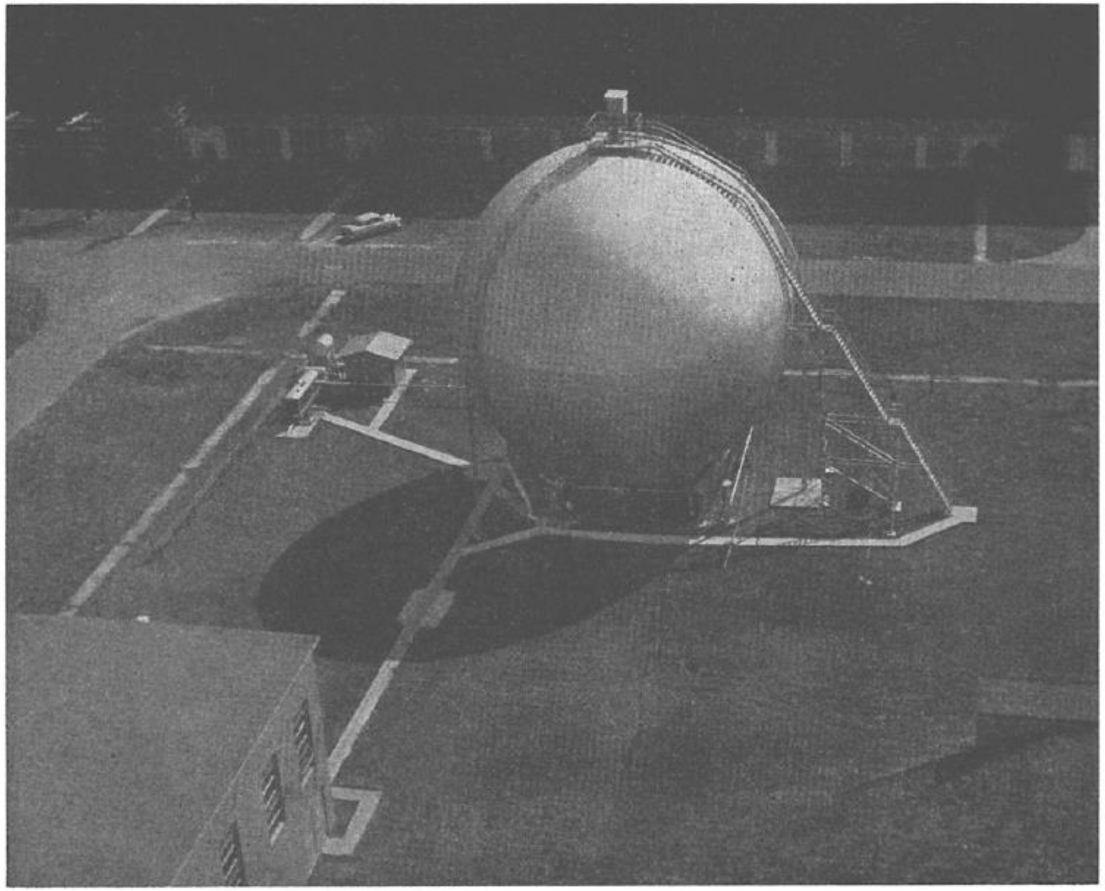
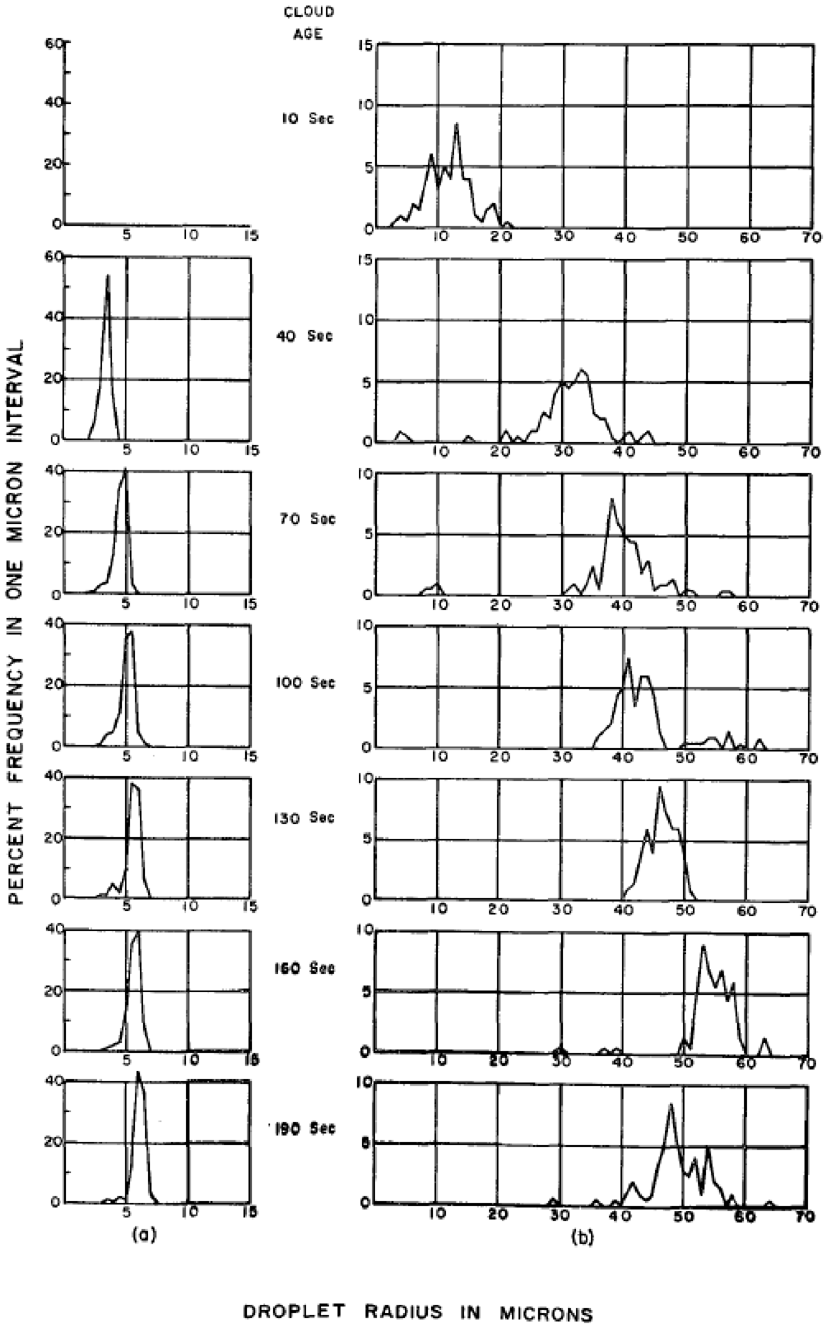


FIG. 1. Cloud chamber. Volume: 3000 m^3. Compressors at left. Main laboratory in left foreground. Access to chamber is through air lock and valve adjacent to triangular walkway. Small laboratory is located under sphere.



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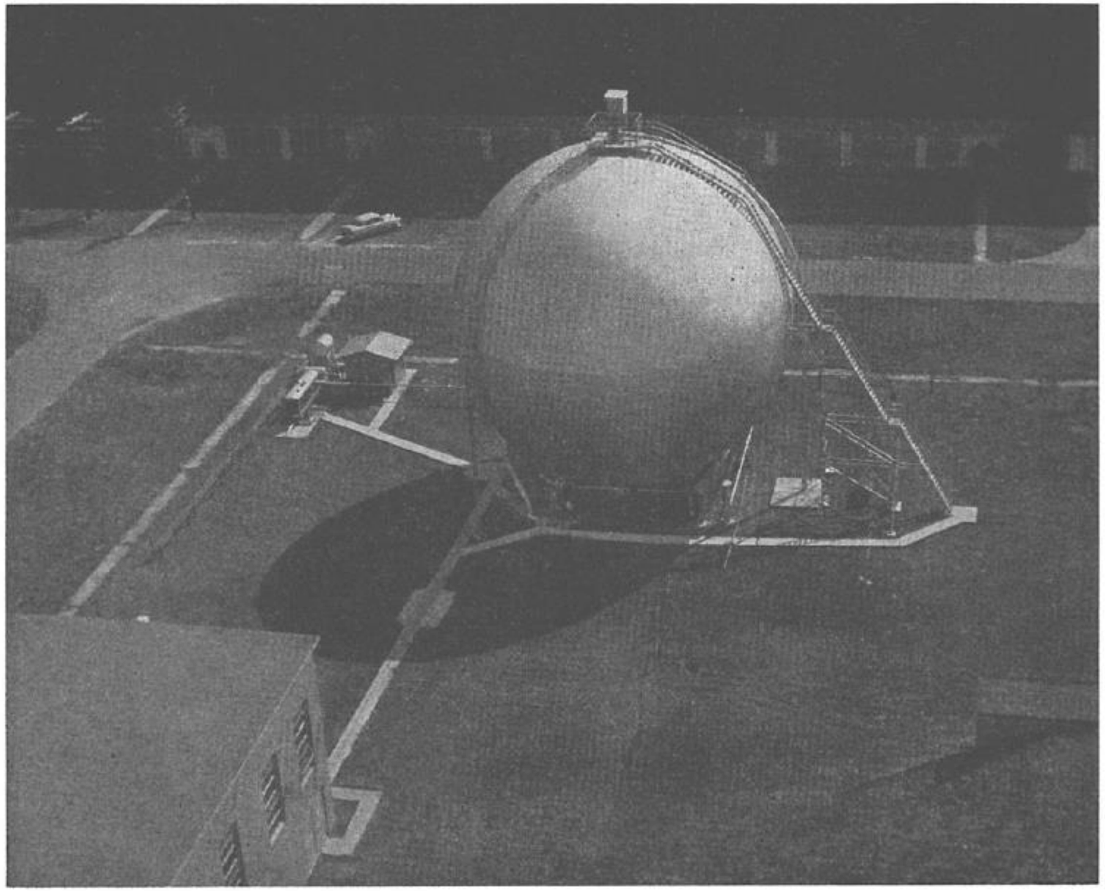

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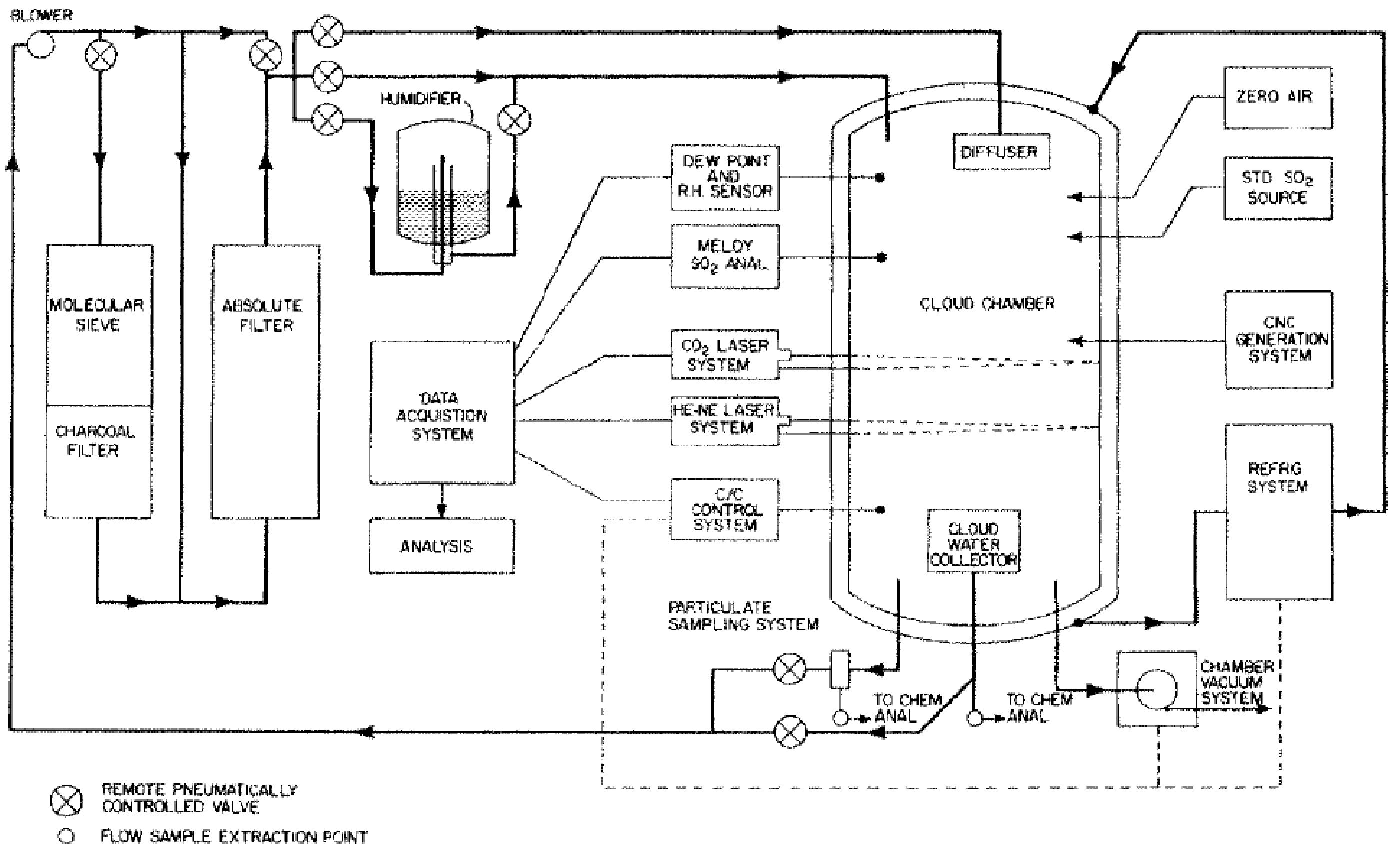


Fig. 1. Schematic representation of the DRI Dynamic Cloud Chamber System.

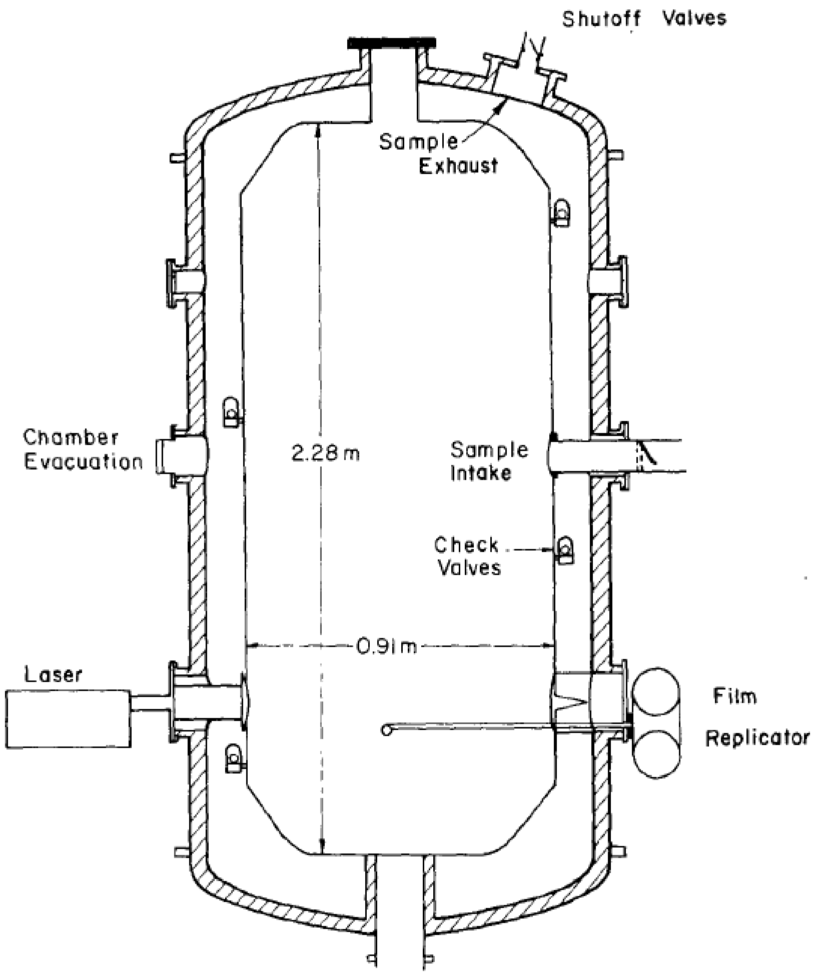


FIG. 2. Schematic of the controlled slow-expansion cloud chamber.

CLOUD CHAMBER STUDIES OF DARK TRANSFORMATIONS OF SULFUR DIOXIDE IN CLOUD DROPLETS*

R. L. STEELE, A. W. GERTLER, U. KATZ, D. LAMB and D. F. MILLER
Atmospheric Sciences Center, Desert Research Institute, Reno, NV 89507, U.S.A.

(*First received 23 September 1980 and in final form 9 February 1981*)

Testing of Cloud Seeding Materials at the Cloud Simulation and Aerosol Laboratory, 1971–1973

DENNIS M. GARVEY
Department of Atmospheric Science, Colorado State University, Fort Collins 80523

(Manuscript received 6 September 1974, in revised form 18 February 1975)

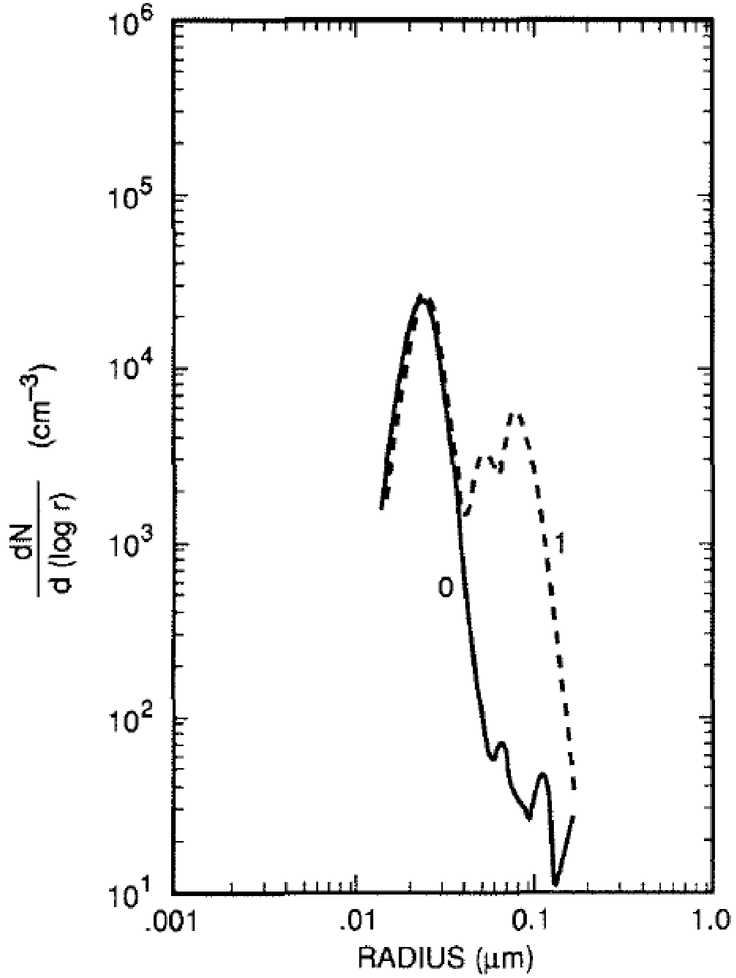
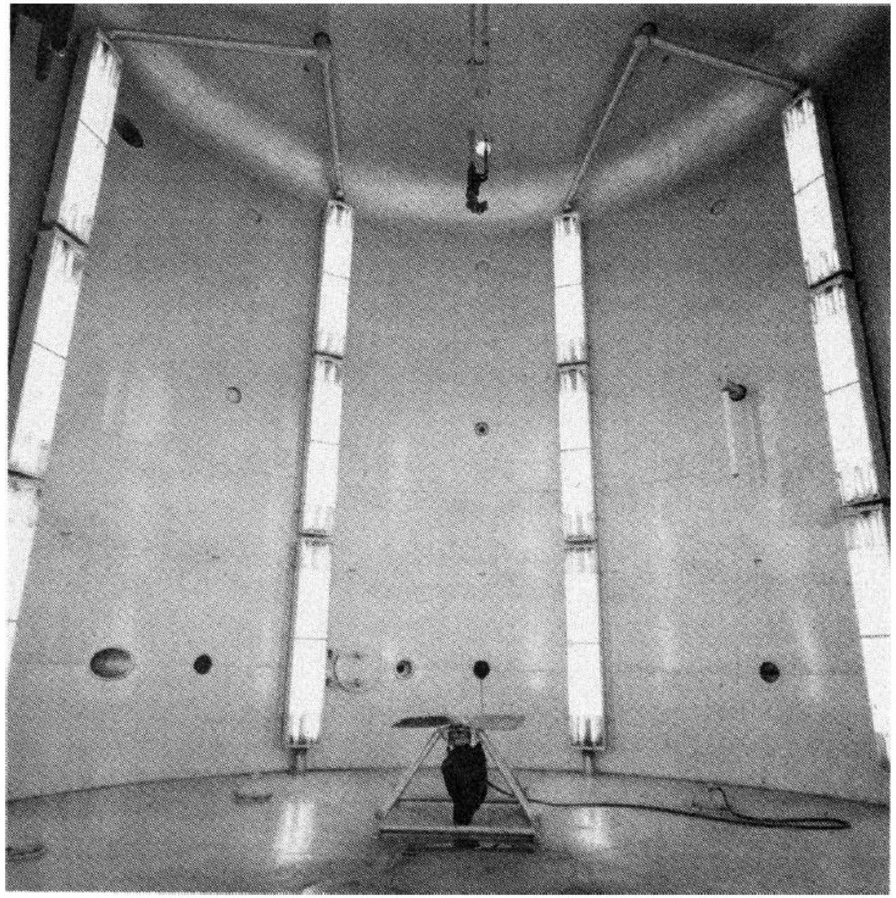


FIGURE 5. Changes in the aerosol size distribution during the first cloud cycle on November 1 (data set B). SO_2 and O_3 concentrations were 6.5 and 107 ppb, respectively

A Cloud Chamber Study of the Effect That Nonprecipitating Water Clouds Have on the Aerosol Size Distribution

W. A. Hoppel,* G. M. Frick, and J. W. Fitzgerald
Remote Sensing Division, Naval Research Laboratory, Code 7228, Washington DC 20375-5320

B. J. Wattle‡
Arvin Calspan Corporation, Buffalo, NY 14225



Calspan chamber 590 m^3

Operational Aerosol-Cloud Research Facilities
(reviewed during workshop)

Name	Volume (m^3)	Type	Location	Status
AIDA	84.5	Expansion	Germany (KIT)	1996-present
AIDA-2	3.8	Expansion with dynamic walls	Germany (KIT)	2020-present
BACIC	70	Expansion	China (BWMO)	2017-present
Big Climate Chamber	3200	Expansion	Russia (Inst. Experimental Meteorology)	1963-present
CESAM	4.2	Reaction chamber	France (LISA, CNRS)	2009-present
CLOUD	26.1	Reaction chamber / over-pressure expansion to atmos	Switzerland (CERN)	2006-present
LACIS-T	0.32 (2-m high)	Mixing wind tunnel	Germany (TROPOS)	2018-present
MICC	18 (10-m high)	Fall chamber / expansion	UK (Manchester Univ.)	2009-present
MRI	1.4	Expansion with dynamic walls	Japan (Meteorological Research Inst.)	2005-present
Pi Chamber	3.14	Convection / expansion with dynamic walls	USA (Michigan Tech. Univ.)	2015-present

“The Future of Laboratory Research and Facilities for Cloud Physics and Cloud Chemistry”:[1]

Report on a Technical Workshop Held in Boulder, Colorado, 20–22 March 1985

Roland List[2], John Hallett[3], Jack Warner[4], Roger Reinking[5]

List et al. BAMS (1986)

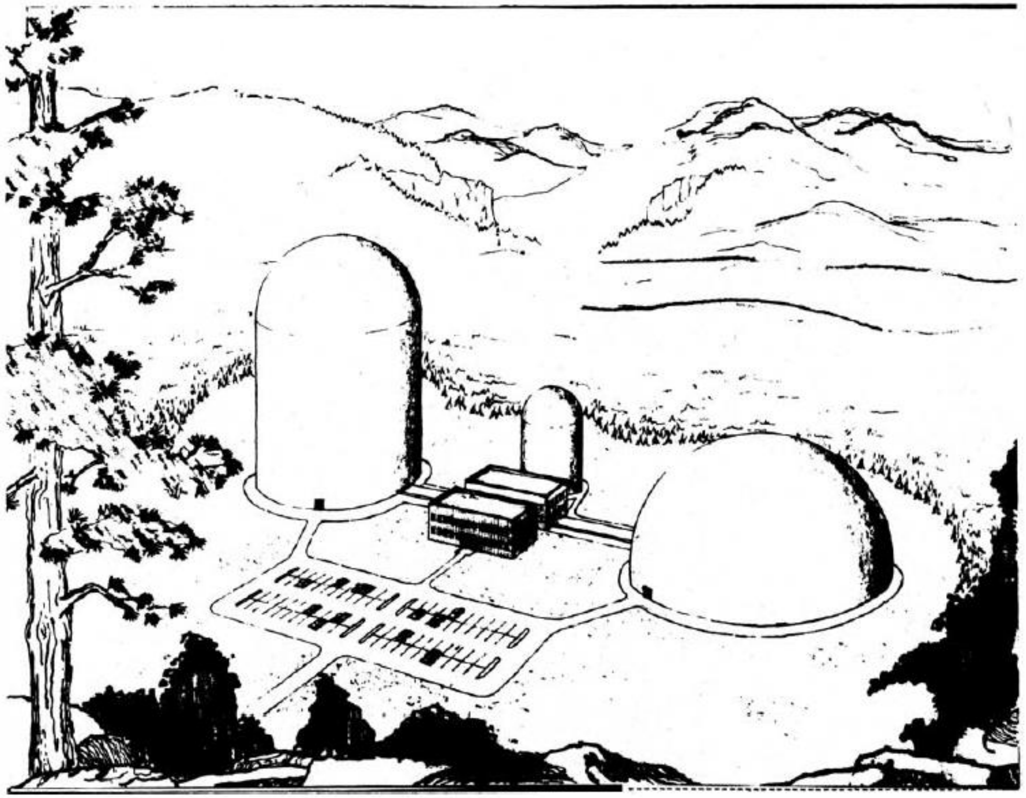


FIG. 12. Conception of a national cloud and precipitation research facility, with two soft-shelled domes (1: diameter 80 m, height 120 m, 2: diameter 120 m, height 60 m), connected by a 300 m long fog corridor with a mixed-phase icing tunnel. The smaller chamber (diameter 30 m, height 50 m) behind the office and support facility buildings is hard-shelled for adiabatic expansion and compression; it is connected to the fog corridor. A vertical wind tunnel may be placed in any of the shell structures. (Courtesy N. Fukuta)

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- Many of the same problems exist: collision-coalescence efficiency, primary and secondary ice formation in mixed-phase clouds, etc.

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- New experimental approaches (e.g., turbulent mixing cloud vs expansion chamber), and improved instrumentation for aerosol, cloud, turbulence, radiation measurements.

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- The problems are broader: more than cloud and precipitation physics. Aerosol-cloud indirect effects, radiative transfer, aerosol and cloud chemistry, turbulence interactions
- New experimental approaches (e.g., turbulent mixing cloud vs expansion chamber), and improved instrumentation for aerosol, cloud, turbulence, radiation measurements.
- Emergence of high-fidelity computational models that need to be validated and improved, but also that can be used to enhance the interpretation of measurements.

Research area	Science questions	<1m	1m	10m	100m	1000 m
	Number of science questions:	9	12	22	15	5
Aerosol / Cloud Chemistry	Aqueous photochemistry (particle scale)	x				
Aerosol / Cloud Interactions	Do we know enough about heterogeneous ice nucleation?	x				
Aerosol / Cloud Interactions	Do we know enough about droplet activation? Influence of chemical (composition) and physical properties (charge, shape)?	x				
Mixed-phase / Cold Clouds	Rate of growth/evaporation of different types of ice crystals under constant and varying environmental conditions including metamorphosis	x				
Radiative Transfer	Light scattering by single ice crystal and aggregates	x				
Turbulence-Microphysics Interaction	How does turbulence effect: collision coalescence; sedimentation, orientation and rotation of non-sphere (ice crystal) particles; ice process, diffusional growth.	x				
Aerosol / Cloud Interactions	What is the relationship between cloud/turbulence properties and aerosol scavenging?		x			
Mixed-phase / Cold Clouds	Aggregation - varying temperature and humidity conditions		x			
Mixed-phase / Cold Clouds	Terminal velocity of hydrometeors		x			
Mixed-phase / Cold Clouds	Secondary ice production	x	x	x		
Mixed-phase / Cold Clouds	Primary ice formation and its dependence on turbulence		x	x		
Radiative Transfer	Radiative cooling at Sc cloud top with droplet growth (interface chamber)		x	x		
Radiative Transfer	RT through electric field oriented ice particles		x	x		
Turbulence-Microphysics Interaction	How turbulence-induced fluctuation of concentration fields affect droplet size distribution. (Sedimentation / vertical velocity) Four main foci: (1) Supersaturation, (2) Fall speeds, (3) Clustering (4) Collision/coalescence		x	x		
Mixed-phase / Cold Clouds	Aggregation of ice - under varying RH, the effect of charge on individual particles and temp conditions, assumption of regular condensation in mixed-phase, entrainment, dynamical effects of latent heat from freezing and sublimation			x		
Mixed-phase / Cold Clouds	Rate of partitioning of phase in mixed-phase clouds, conversion of ice phase to mixed-phase clouds due to convection			x		
Turbulence-Microphysics Interaction	Coarse-grain microphysics at the 10m scale? (e.g., for coupling to LES, sampling measurements, etc.)			x		
Turbulence-Microphysics Interaction	What scales of fluctuations are most important for diffusional growth?	x	x	x	x	
Aerosol / Cloud Interactions	What are the optimal aerosol characteristics for inducing marine cloud brightening?		x	x	x	
Radiative Transfer	Exploring emerging remote sensing tech		x	x	x	
Aerosol / Cloud Chemistry	Aqueous photochemistry (cycling, parcel scale)			x	x	
Aerosol / Cloud Chemistry	Parcel scale dynamics of activation interacting with turbulence			x	x	
Aerosol / Cloud Chemistry	Interstitial scavenging			x	x	
Aerosol / Cloud Interactions	How are aerosols entrained/detrained at the cloud interface? How does turbulence			x	x	

Shaw et al. BAMS (2020)

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	influence aerosol entrainment into the cloud?					
Aerosol / Cloud Interactions	What is precipitation susceptibility as a function of aerosol properties?			x	x	
Radiative Transfer	Imaging through turbulent clouds			x	x	
Radiative Transfer	Depolarization by particle shape and multiple scattering			x	x	
Turbulence-Microphysics Interaction	Measure entrainment rates	x	x	x	x	x
Aerosol / Cloud Chemistry	Precipitation scavenging			x	x	x
Radiative Transfer	Particle correlation inducing deviations from Beer-Lambert			x	x	x
Radiative Transfer	Aerosol effect on cloud albedo (e.g., given heterogeneity in drop dist.)			x	x	x
Radiative Transfer	Signal propagation through an optically thick cloud				x	x
Radiative Transfer	RT through electric field oriented ice particles		x	x		
Turbulence-Microphysics Interaction	How turbulence-induced fluctuation of concentration fields affect droplet size distribution. (Sedimentation / vertical velocity) Four main foci: (1) Supersaturation, (2) Fall speeds, (3) Clustering (4) Collision/coalescence		x	x		
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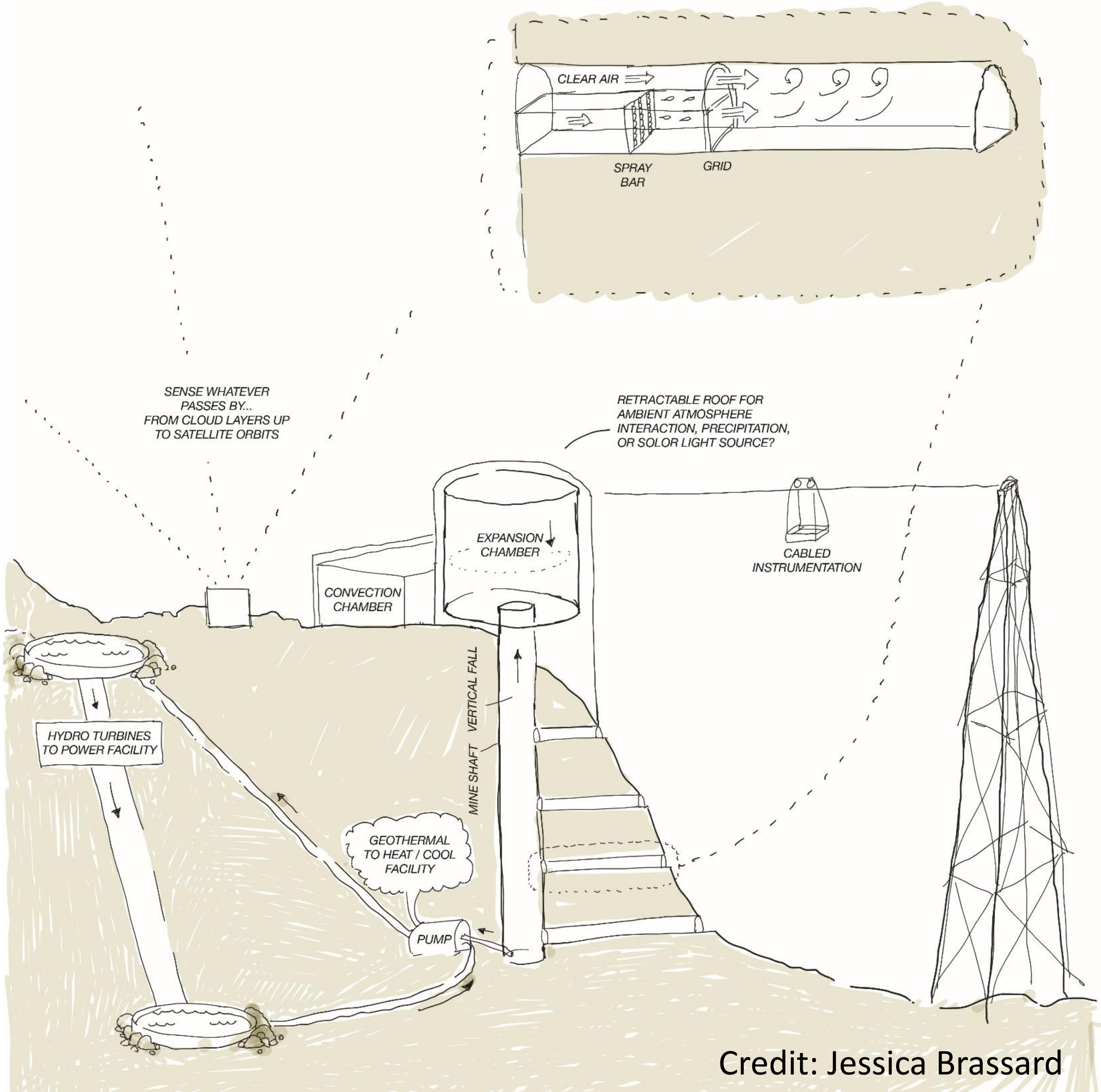
Shaw et al. BAMS (2020)



Credit: Jessica Brassard

Large-scale facility concepts:

- Entrainment, free-interface wind tunnel
- Convection chamber
- Expansion chamber with fixed air mass
- Vertical wind tunnel (e.g., mine shaft)

Possible collocation of several chambers, and in-situ/remote monitoring of environment (shared instrumentation and personnel)

Pi Convection-Cloud Chamber Model Intercomparison

- Organizers: *Sisi Chen* (NCAR) & *Steve Krueger* (Univ. Utah)
- International Cloud Modeling Workshop – Pune, India, Summer 2021
- Fall 2020 virtual meeting with 7 participating groups (NCAR, Notre Dame Univ., MTU, TROPOS, Univ. Hyogo, Univ. Utah, Warsaw Univ.)
- Simulate a “turbulent mixed-layer” with constant injection of CCN, cloud droplet growth by condensation, removal by sedimentation
- Compare microphysical properties from various modeling approaches: LES vs DNS, bin vs Lagrangian microphysics, etc.

JAMES Journal of Advances in Modeling Earth Systems

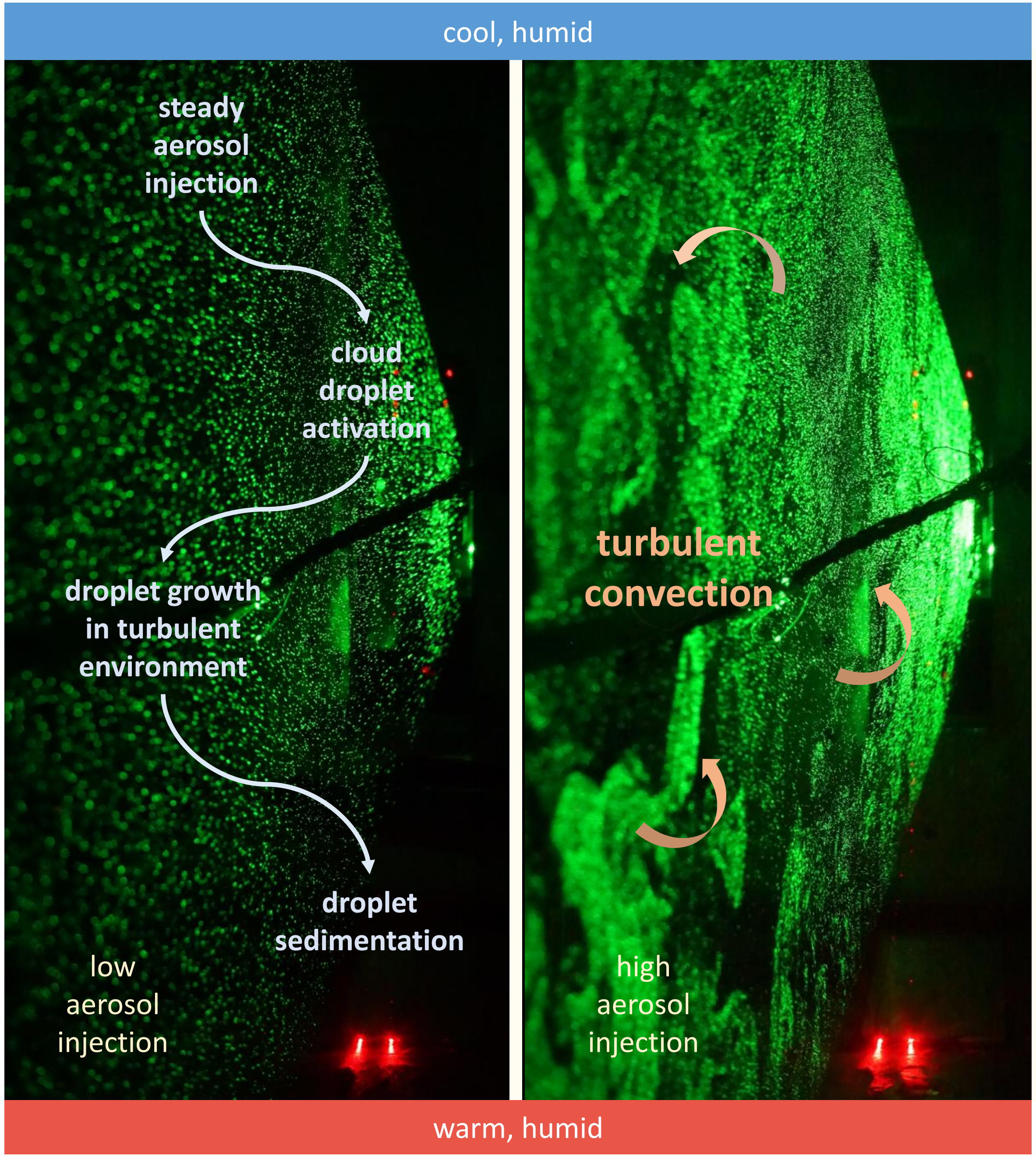
RESEARCH ARTICLE
10.1029/2019MS001670

Scaling of an Atmospheric Model to Simulate Turbulence and Cloud Microphysics in the Pi Chamber

Subin Thomas[1], Mikhail Ovchinnikov[2], Fan Yang[3], Dennis van der Voort[1], Will Cantrell[1], Steven K. Krueger[4], and Raymond A. Shaw[1]

[1]Michigan Technological University, Houghton, MI, USA, [2]Pacific Northwest National Laboratory, Richland, WA, USA, [3]Brookhaven National Laboratory, Upton, NY, USA, [4]University of Utah, Salt Lake City, UT, USA

Key Points:
- A large-eddy simulation with spectral bin cloud microphysics is scaled to simulate a laboratory convection chamber
- The simulated mixing state and turbulence properties reasonably



Chandrakar et al. PNAS (2016)

Simulations to Support Designing a Cloud Chamber for Studies of Aerosol-Cloud Interactions

BROOKHAVEN NATIONAL LABORATORY

Fan Yang (lead), Satoshi Endo, Allison McComiskey, Andy Vogelmann, Tao Zhang

Pacific Northwest NATIONAL LABORATORY

Mikhail Ovchinnikov

Michigan Tech Pi Chamber

Will Cantrell, Ian Helman, Prasanth Prabhakaran, Raymond Shaw, Abu Sayeed Md Shawon, Subin Thomas, Jaemin Yeom

ASR Atmospheric System Research

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