



Particle Size Measurements from the first Fundamentals of Ice Crystal Icing Physics Test in the NASA Propulsion Systems Laboratory

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Outline

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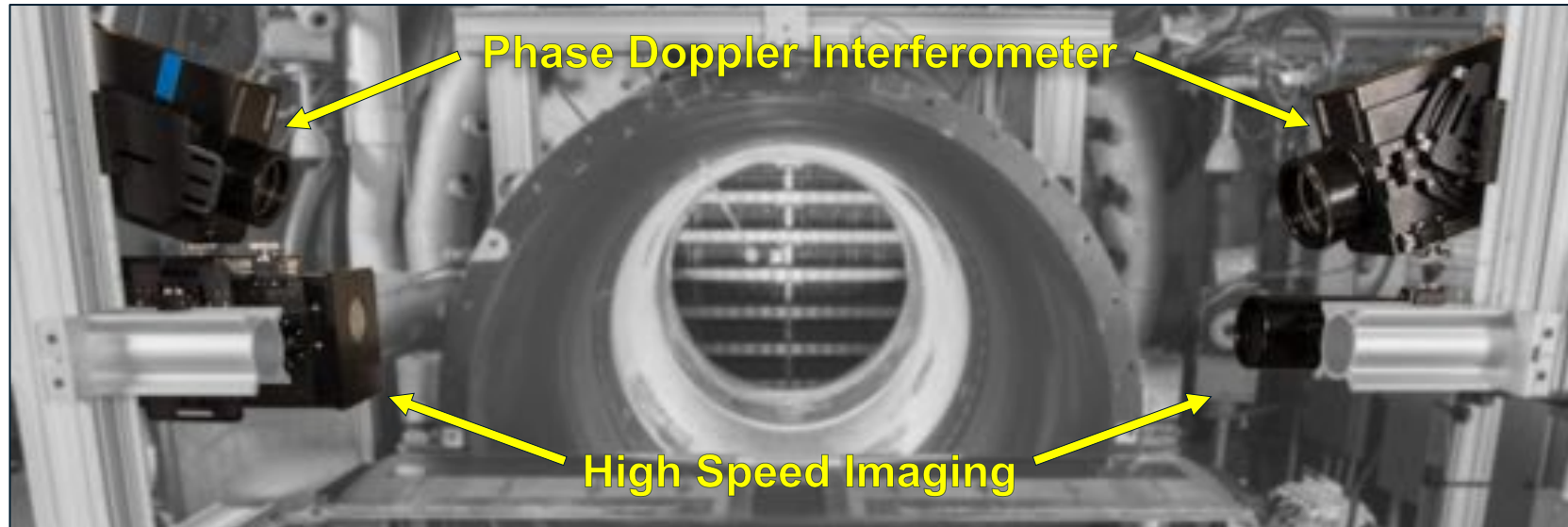
Introduction



- NASA is studying ice crystal icing (ICI) conditions to advance the understanding behind this aviation safety hazard
- The unique nature of ICI conditions has slowed cloud characterization in PSL, but it has also stimulated the development of instrumentation
- This work presents select cases of particle measurements acquired using the PDI and HSI in PSL during a March 2016 test



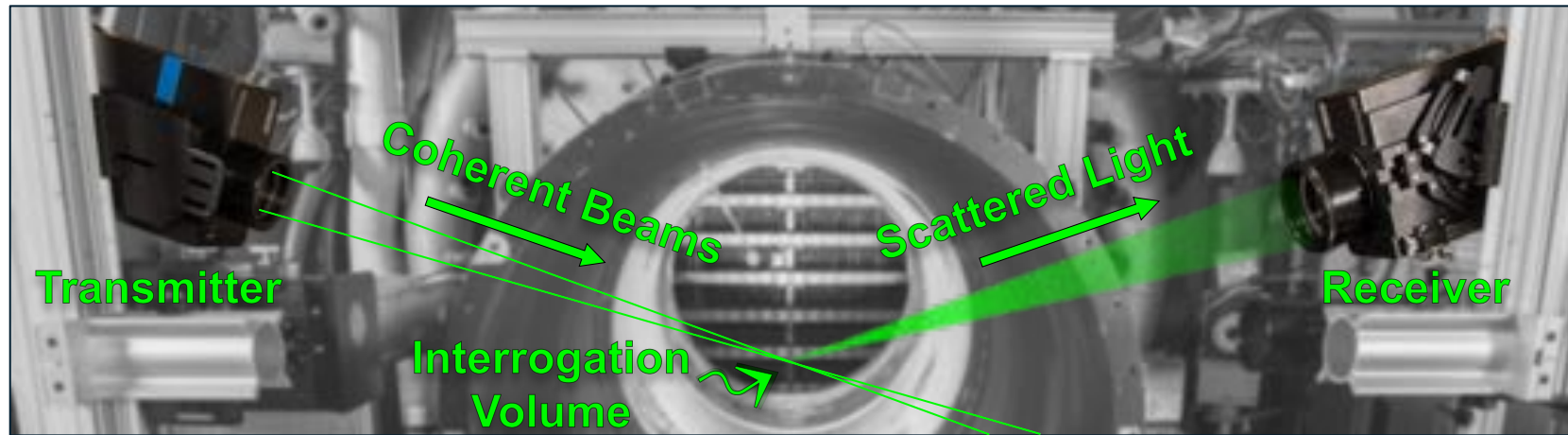
Objective and Approach



- Objective: Evaluate capabilities of Phase Doppler Interferometer (PDI) and High Speed Imaging (HSI) instruments to measure and discriminate glaciated conditions
- Approach: Measure the icing cloud through a series of controlled conditions, varying only the Wet-Bulb Temperature, T_{WB} , thereby increasing the presence of glaciated particles in the cloud to examine instrument response



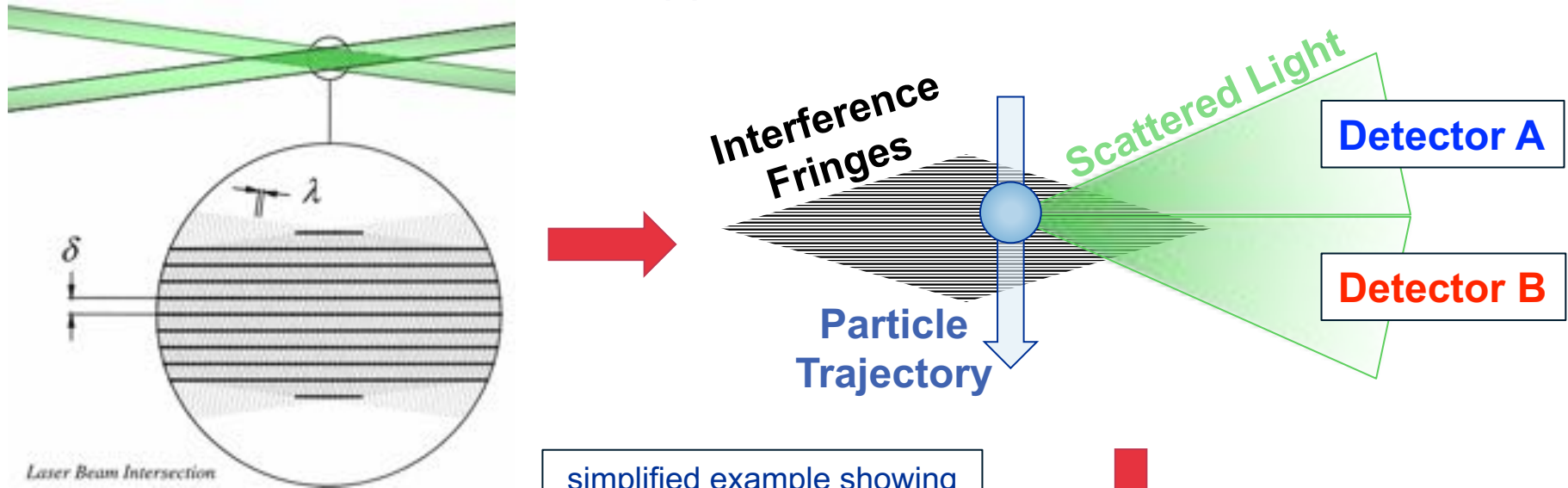
Instrumentation: *Phase Doppler Interferometer*



- PDI is a single particle counter using a flux sampling technique that can size spherical and quasi-spherical particles
- Two coherent beams create an interrogation volume and a local interference fringe pattern
- Particles scatter light, create a Doppler burst signal, which is measured by 3 detectors at separate locations, resulting in a phase shift used to size
- Phase shift from 3 detectors provides a means of shape discrimination (spherical, quasi-spherical or irregular-shaped)

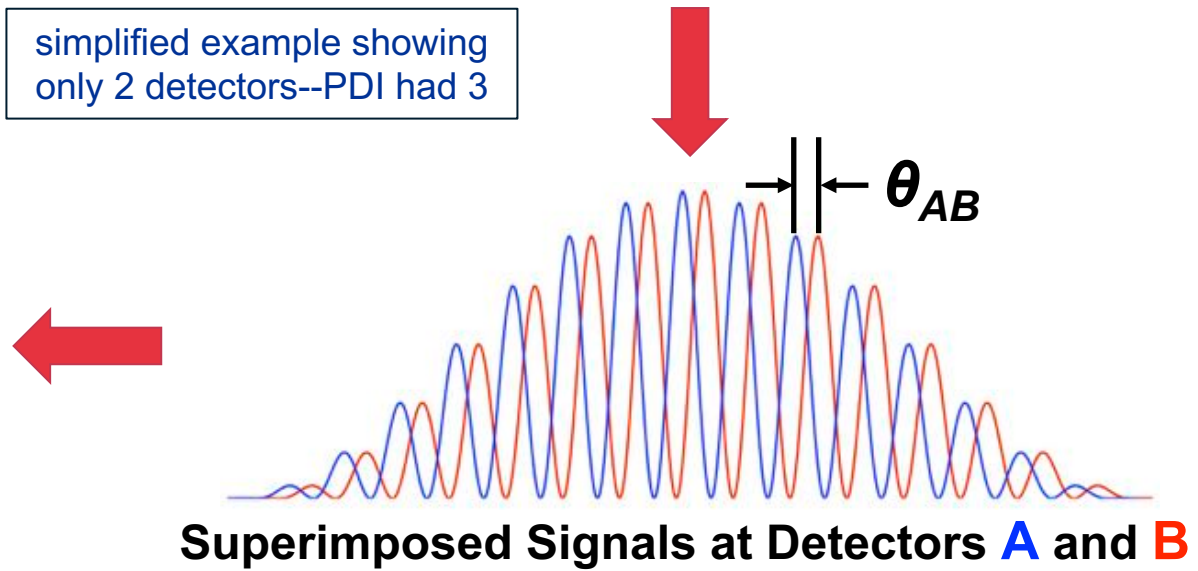
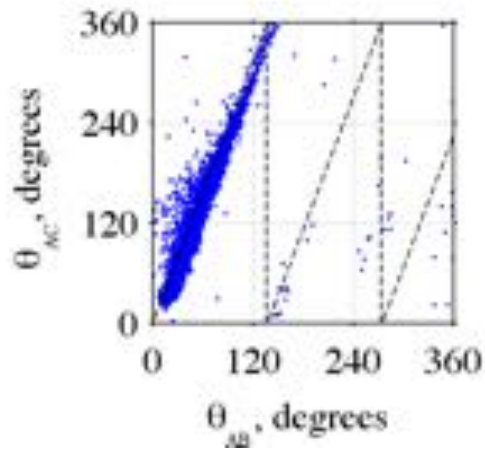


Instrumentation: *Phase Doppler Interferometer*



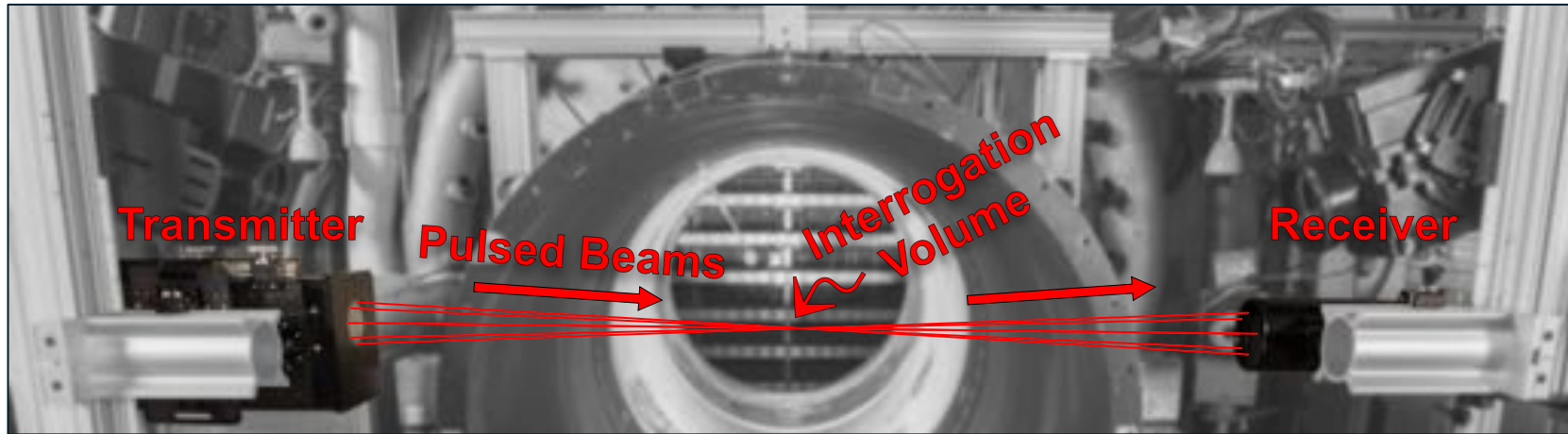
Laser Beam Intersection

simplified example showing only 2 detectors--PDI had 3





Instrumentation: *High Speed Imaging*



- HSI uses a spatial sampling technique that can size spherical to irregular-shaped particles
- Acquires high-resolution images of particles passing through the interrogation volume created by several pulsed laser beams with a CMOS camera
- 1.8 $\mu\text{m}/\text{pixel}$ resolution during March 2016 test
- Parameters measured in images provide means of quantitative shape discrimination of particles



Instrumentation: High Speed Imaging



Sample Image Capture

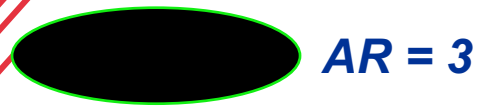
representation only to help interpret data



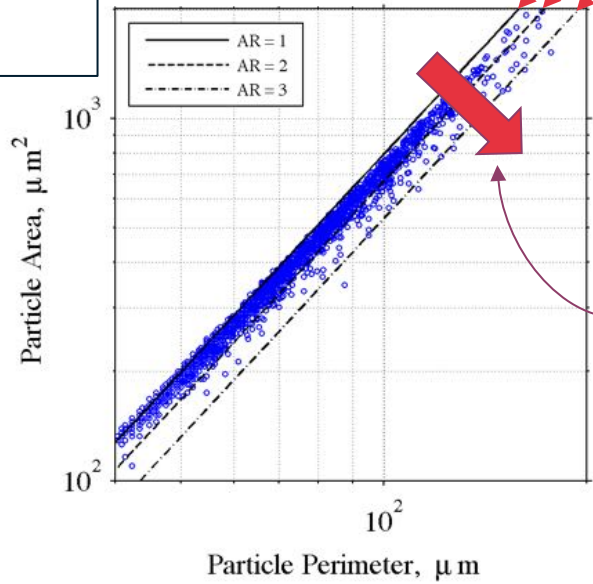
AR = 1



AR = 2



AR = 3



Direction of Increasing Aspect Ratio



Experimental Methodology

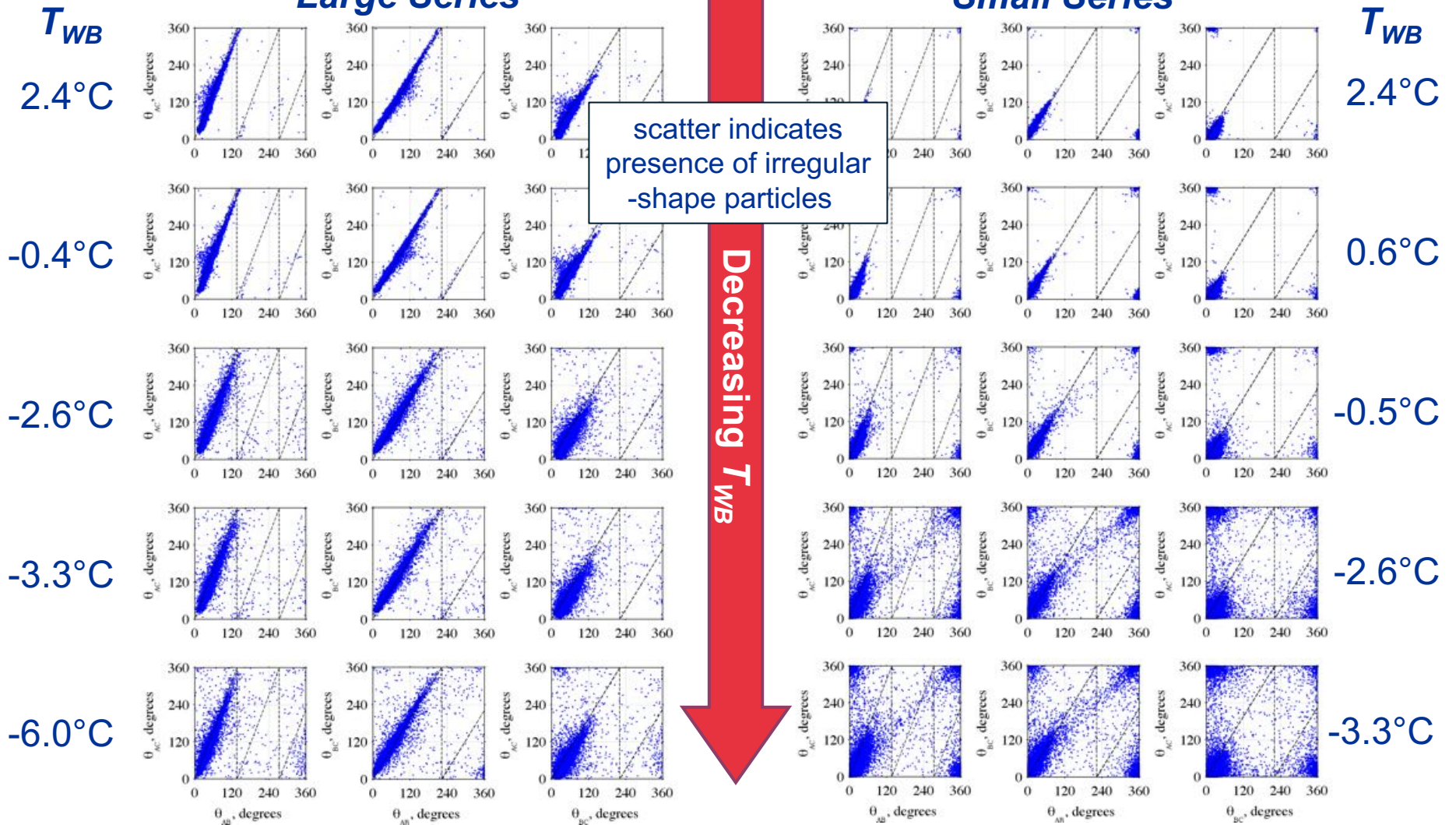
- Tests were conducted in March 2016 in PSL
- Modular versions of the PDI and the HSI were focused approximately 152 mm above the centerline of the approximately 1 m diameter exit duct
- Simulated icing conditions were generated with either a Large MVD_i or a Small MVD_i
 - Large $MVD_i = 50 \mu\text{m}$, Small $MVD_i = 15 \mu\text{m}$
 - Spray bar conditions based on the Icing Research Tunnel PSD Calibration and MVD_i does not necessarily represent PSD at duct exit
- The plenum T_{WB} was driven down incrementally for each test condition in the Large MVD_i Series and the Small MVD_i Series by varying plenum humidity
 - Large MVD_i Series: $T_{WB} = 2.4^\circ\text{C}$ to -6.0°C , $u = 85 \text{ m/s}$
 - Small MVD_i Series: $T_{WB} = 2.4^\circ\text{C}$ to -3.3°C , $u = 85 \text{ m/s}$
- Data was acquired with the PDI and the HSI simultaneously during each test condition



Results: PDI Raw Signal Phase Difference Trend

Large Series

Small Series

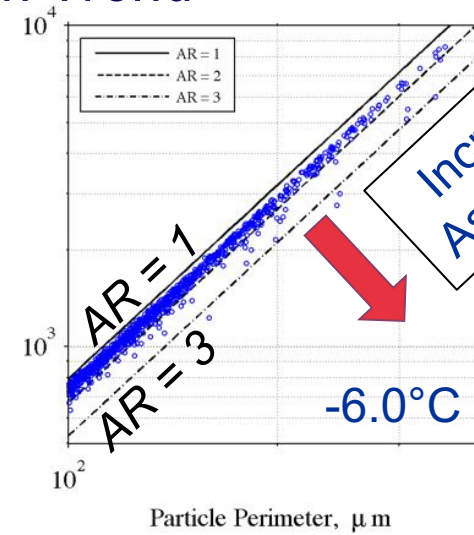
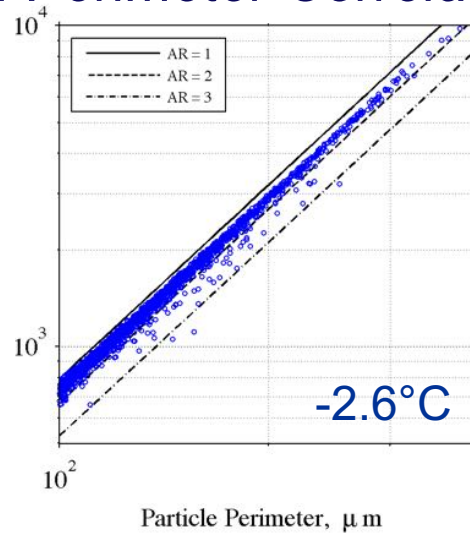
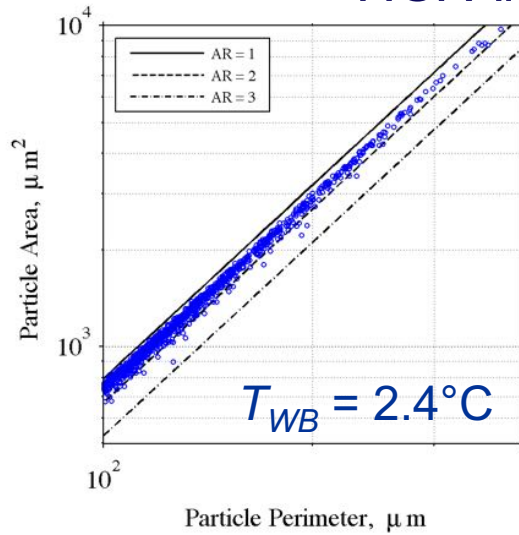




Results:

HSI Area-Perimeter Correlation Trend

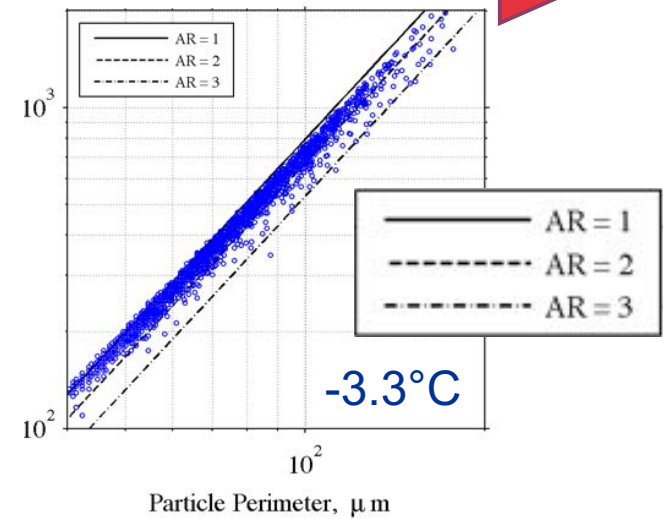
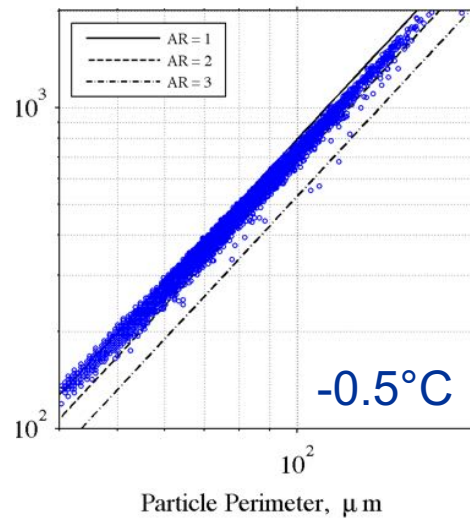
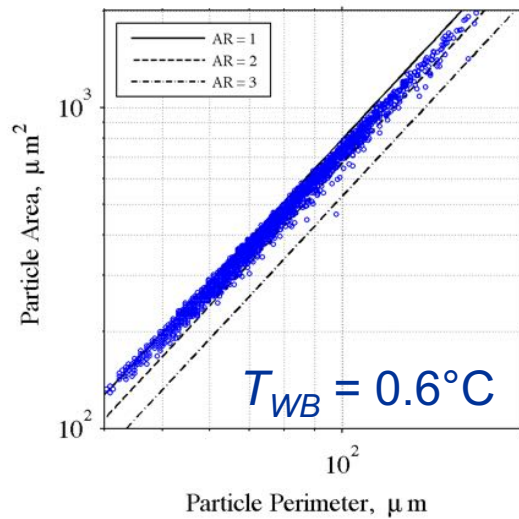
Large Series



Increasing Aspect Ratio

Decreasing T_{WB}

Small Series

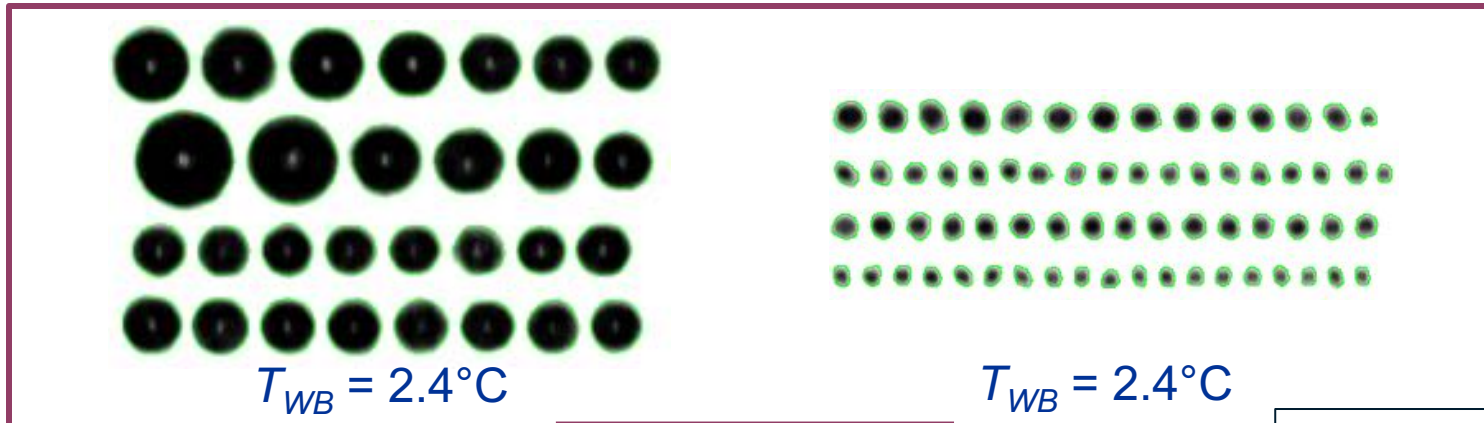




Results: *HSI Sample Images Trend*

Large Series

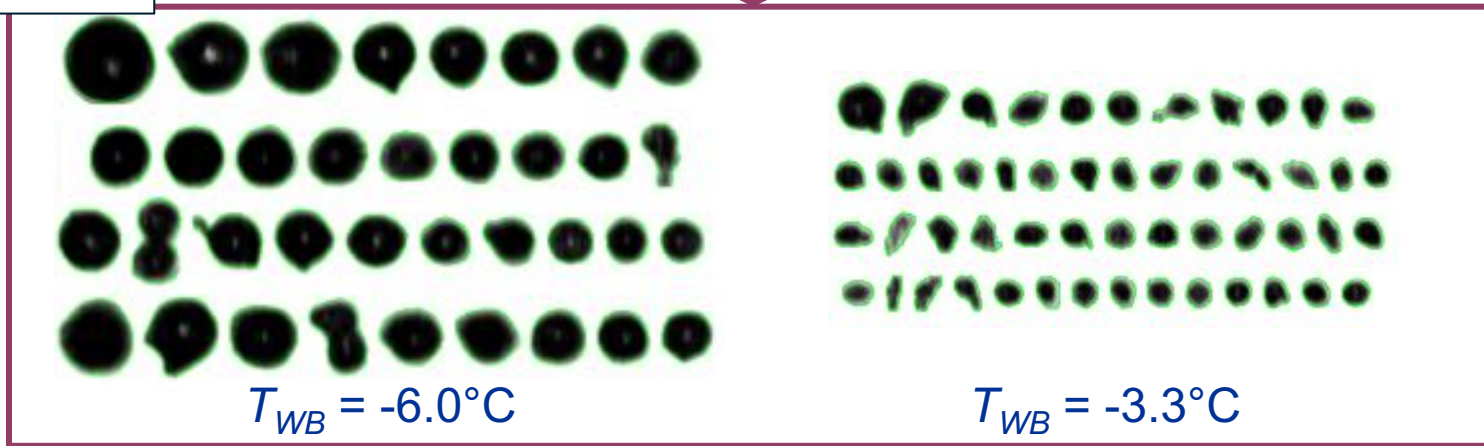
Small Series



all images are same scale

Decreasing T_{WB}

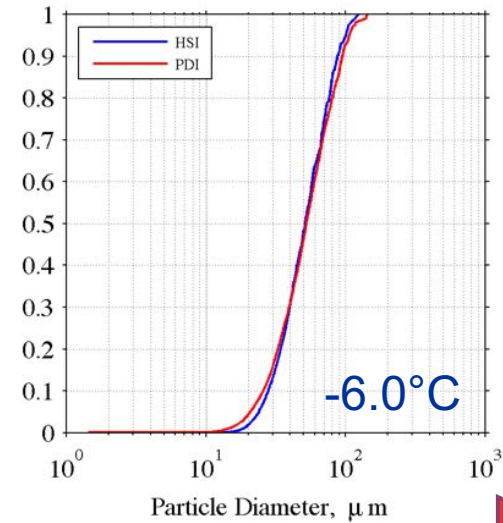
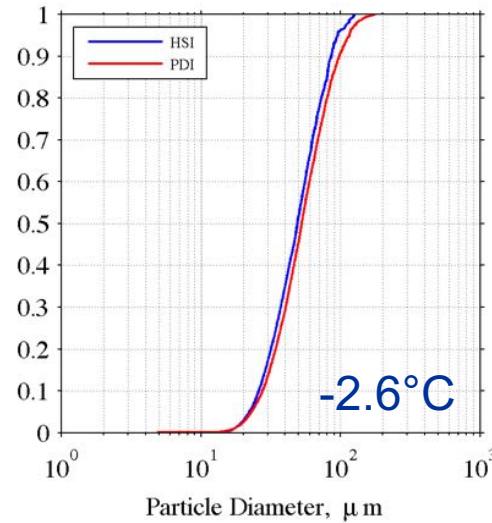
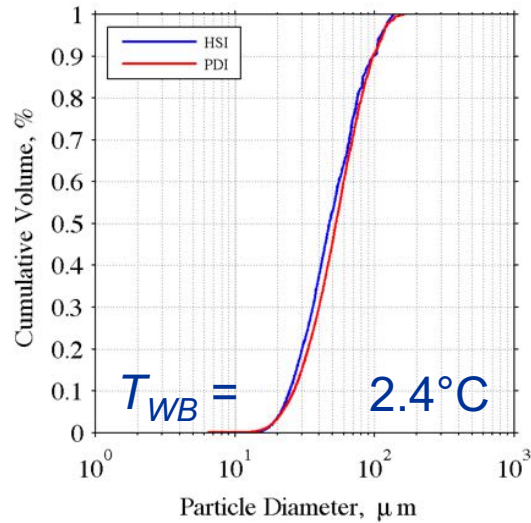
random selection of particles





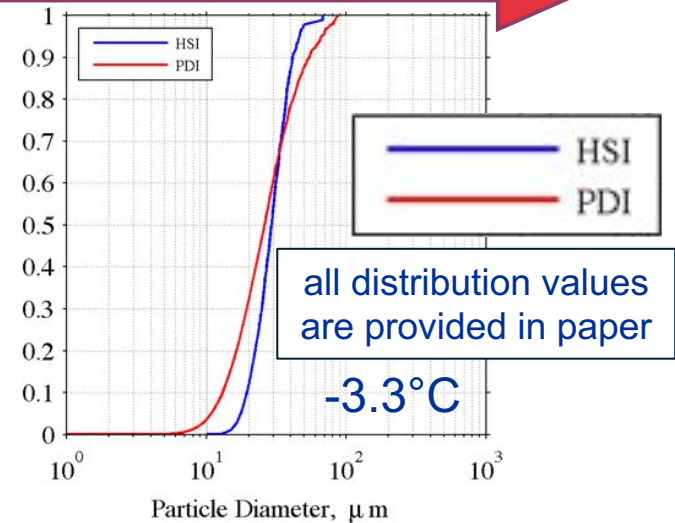
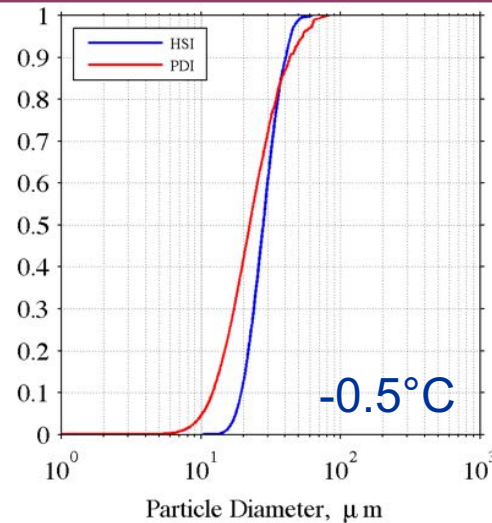
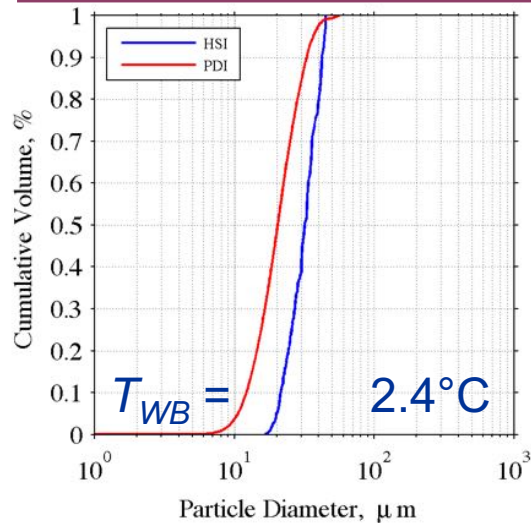
Results: Size Distribution Trend

Large Series



Decreasing T_{WB}

Small Series

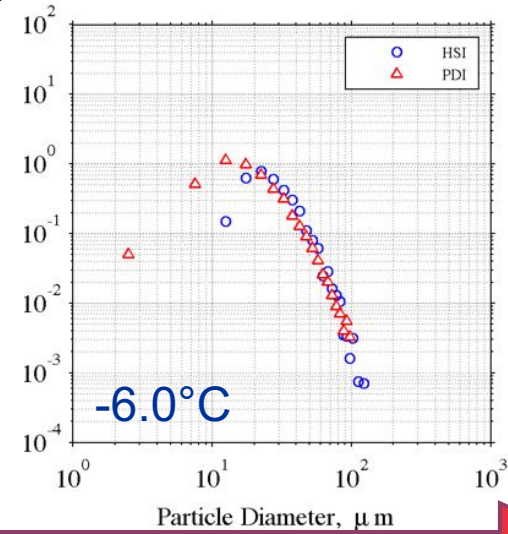
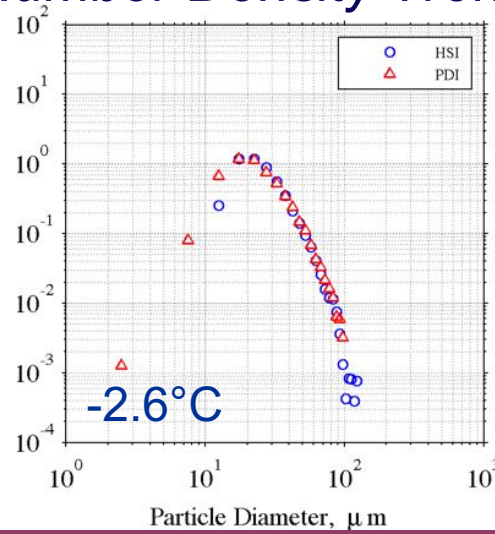
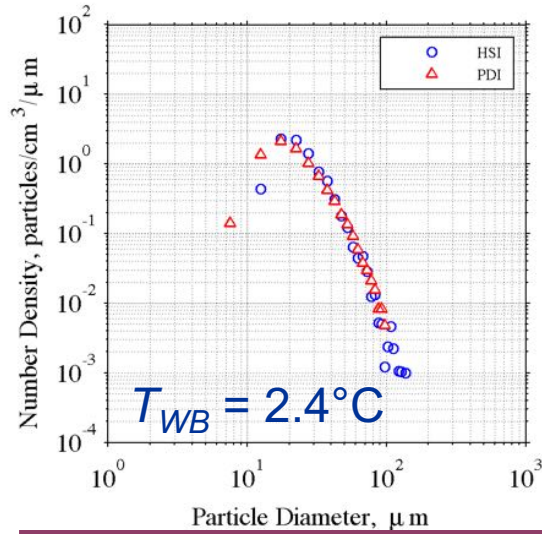




Results:

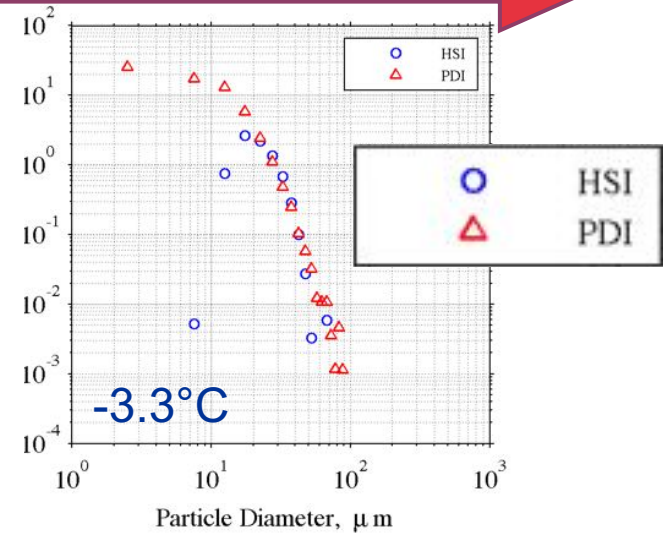
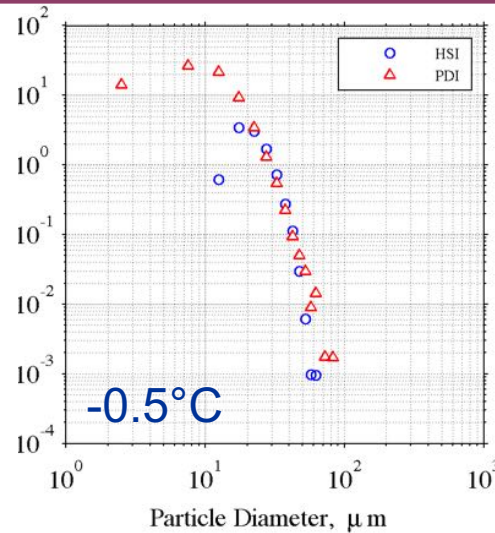
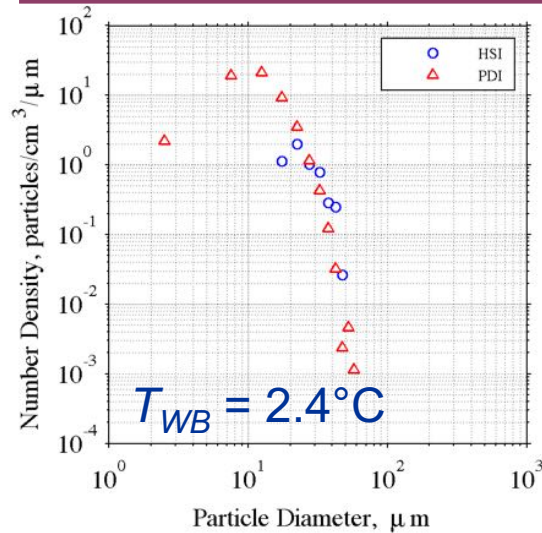
Number Density Trend

Large Series



Decreasing T_{WB} ➔

Small Series





Summary

- NASA has completed the first Fundamentals of Ice Crystal Icing Physics test in PSL
- The Artium Technologies, Inc. PDI and HSI instruments were successfully used to measure the icing cloud during the test
- The PDI and HSI demonstrated good agreement during the Large MVD_i Series through a range of T_{WB}
- Due to minimum measurable range of the HSI, there was not good agreement between the PDI and HSI during the Small MVD_i Series
- Further development of the PDI and HSI towards measuring the lower end of the irregular-shape particle spectrum is necessary
- The PDI raw signal phase difference and HSI area-perimeter correlation demonstrated the current capability to examine particle morphology, and consequently discriminate glaciated conditions
 - Further evaluation is required



Acknowledgements

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