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Development of a UAV-mounted Holographic Cloud Particle Imager

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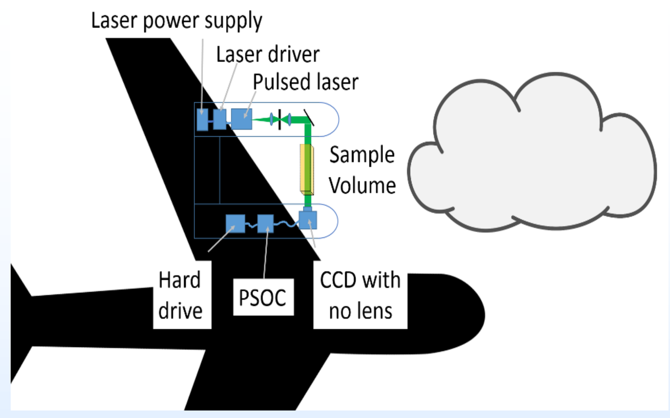
Abstract

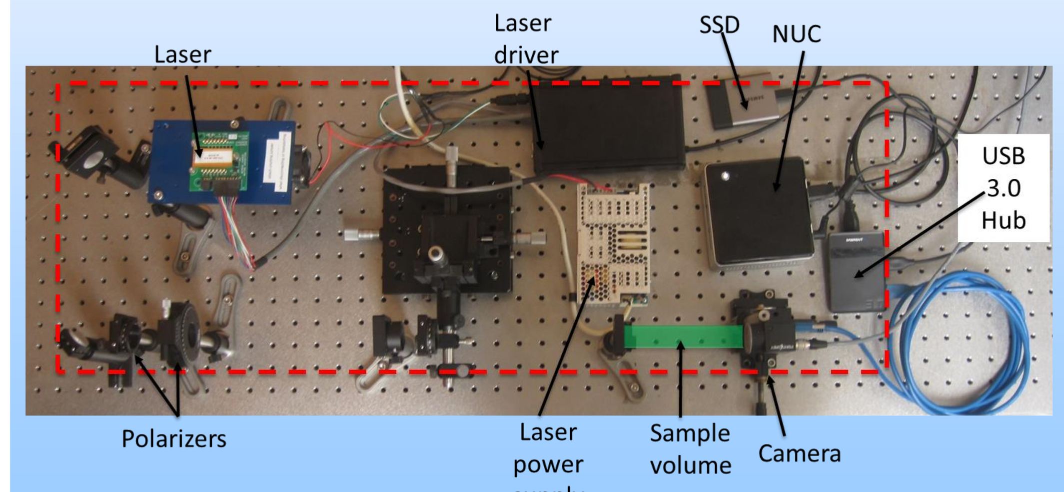
- Many current climate models assume a homogeneous and uncorrelated spatial distribution of the particles within clouds.
- *In situ* measurements point toward small-scale (mm to m) correlations between particles due to droplet inertia and turbulence and adjusting climate models to account for the inhomogeneity of clouds would increase the accuracy of climate predictions.
- This work presents the development of a UAV-mountable holographic cloud particle imager (HCPI) that measures both the 3D spatial distribution and size distribution of cloud particles in the 10 μm to several millimeter size range in a sample volume of about 20 cm^3.
- There is no blurring at airspeeds of 100 m/s due to nanosecond pulsed laser exposure.

Benchtop HCPI

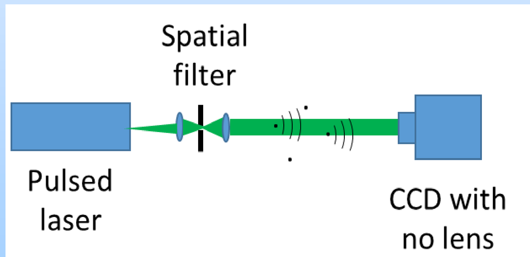
- Benchtop system takes up about 3 sq. ft. without any stacking of components.
  - Power used: 135 W
  - Weight (no housing): 3.2 kg
  - Requirements: <150 W, <6 kg



General system concept

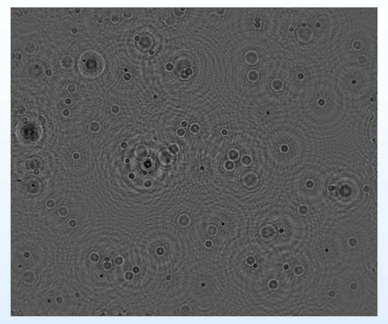


Benchtop setup



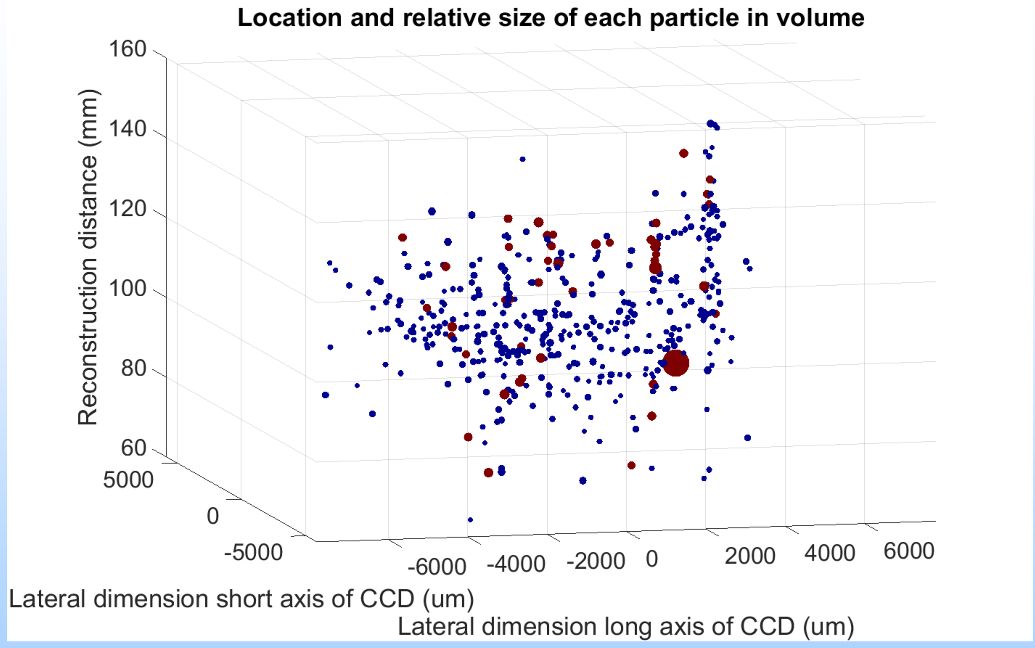
General in-line holography setup

Nasal Spray Demonstration



Reconstruction of a plane within a group of nasal spray particles

Nasal spray

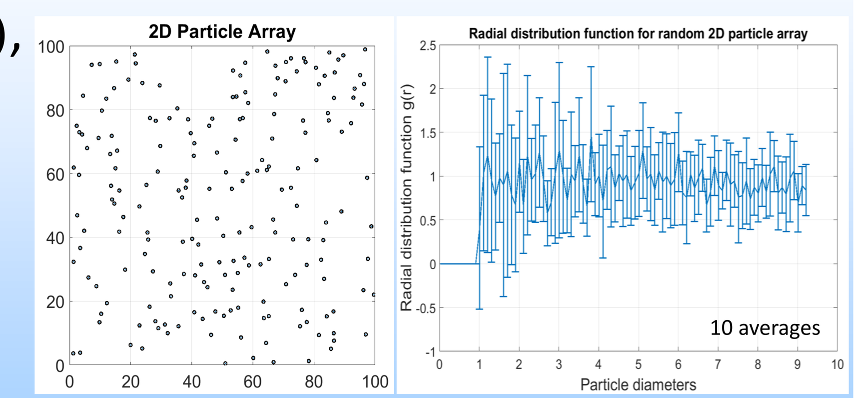


Example output from device with particle locations and sizes

- Laser pulse exposure: 1 ns
- Allows for capturing clear images of fast-moving particles.

Pair Correlation Function

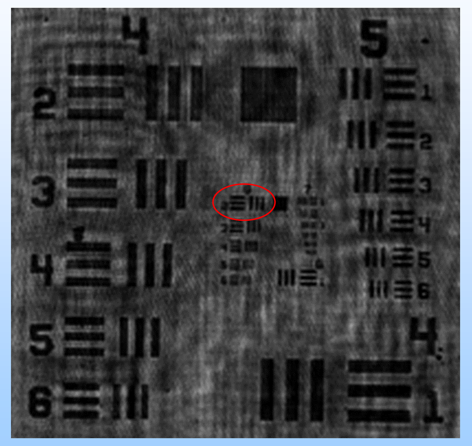
- A common way of quantifying spatial distributions is with the pair correlation function, $\eta(r)$, which is closely related to the more commonly used radial distribution function, $g(r)$.
- $P_{1,2}(r) = \bar{n}dV[1+\eta(r)]$
- $g(r) = \eta(r) + 1$
- Random distribution corresponds to $\eta(r) = 0$ or $g(r) = 1$.



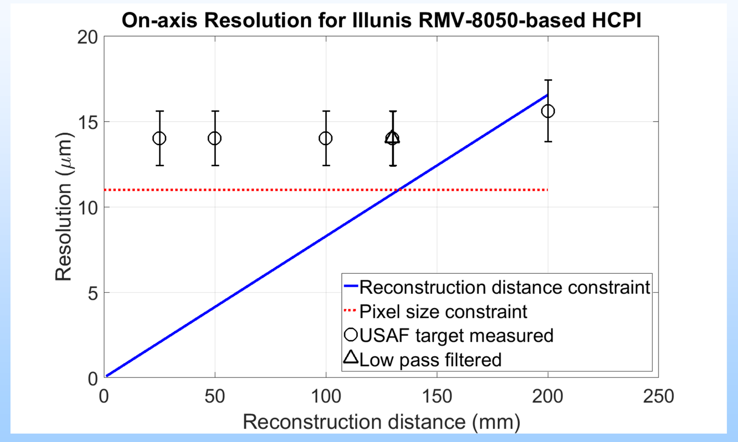
2D random system, left) geometry, right) radial distribution function

Characterization Measurements

- Resolution quantified with 1951 USAF resolution target.
- Performance may be improved by better beam uniformity.

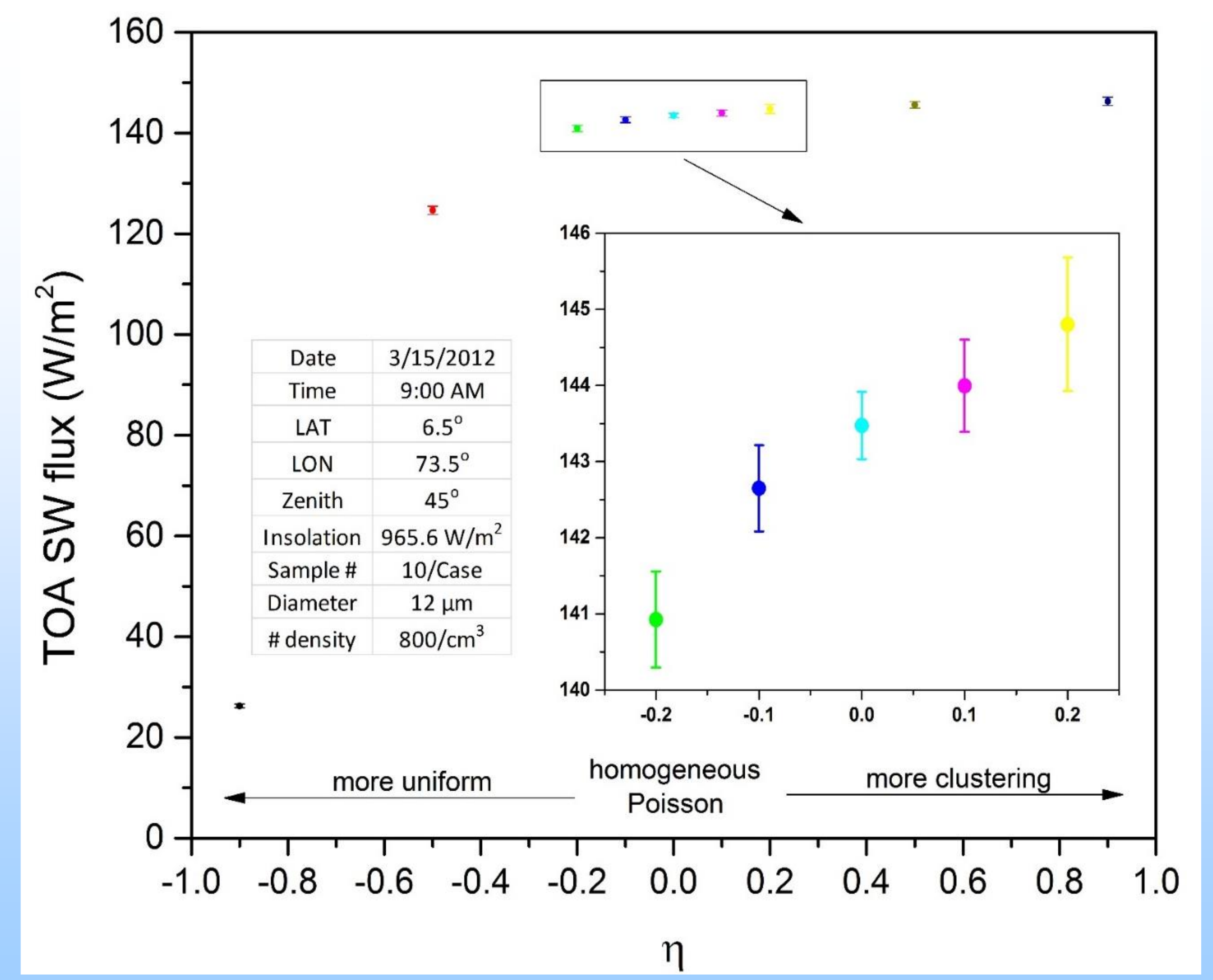


1951 USAF Resolution Target – Group 6, Element 2 corresponds to 14 µm per line pair



Resolution vs. Reconstruction distance compared to theoretical constraints

Monte Carlo Simulation



Date	3/15/2012
Time	9:00 AM
LAT	6.5°
LON	73.5°
Zenith	45°
Insolation	965.6 W/m^2
Sample #	10/Case
Diameter	12 µm
# density	800/cm^3

- Monte Carlo simulation of the top of atmosphere shortwave flux for clouds with various spatial distributions.

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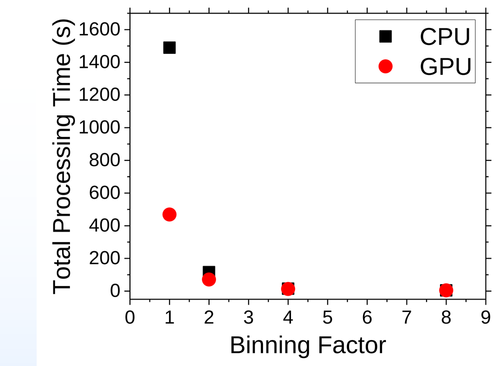
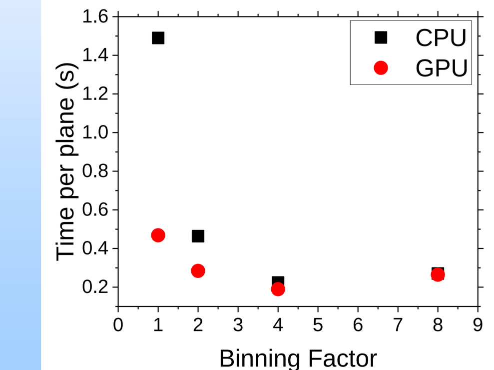
Holographic Reconstruction

- Reconstructing the sample volume from the hologram is computationally intensive.
- The process can be sped up by optimizing the code for a graphics processing unit (GPU).
- Consultant (EM Photonics, Inc., Newark, DE) was hired to estimate potential reduction in processing time.
  - One hologram with 1000 reconstructed planes was estimated to take 5 seconds per hologram.



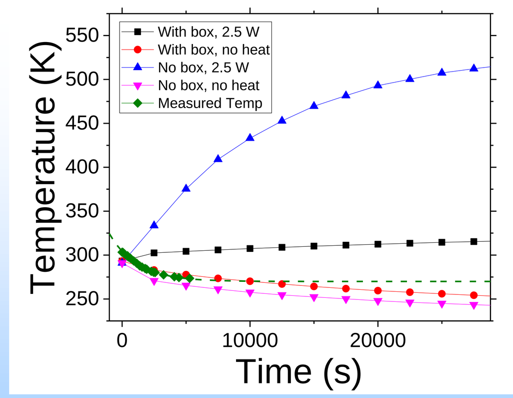
Measured total processing time vs. binning factor for CPU and GPU



Measured time per reconstructed plane vs. binning factor for CPU and GPU

Operating Temperature Range

- At altitude, the instrument will be exposed to temperatures reaching -40 ºC.
- Thermal modeling and a test in an environmental chamber suggest the combination of self-heating and housing insulation will keep components within their operating ranges.

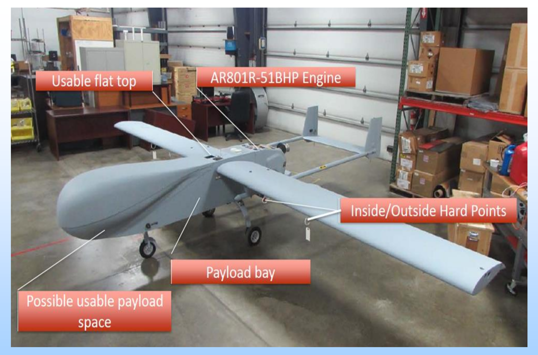


Temperature vs. time for model of camera (4 cases) and measurement in environmental chamber

Phase II Plans

- Testing on piloted aircraft.
- Designing housing for mounting on TigerShark UAV.

Twin Otter aircraft with nose mount



TigerShark UAV (image provided by PNNL)

"Observations Lead the Way"

- UAV-mounted cloud instruments enable greater sampling statistics (every cloud is different).
- The long-term promise of UAVs is reduced cost of operations.
- The HCPI not only provides data for radiative transfer models, but also models of raindrop production by collision/coalescence and turbulent mixing at cloud edges.
- This instrument improves ice cloud observations by accounting for shattering.

References

1. J. P. Fugal, R. A. Shaw, E. W. Saw and A. V. Sergeyev, "Airborne digital holographic system for cloud particle measurements," *Applied Optics,* vol. 43, no. 32, pp. 5987-5995, 2004.
2. M. J. Beals, J. P. Fugal, R. A. Shaw, J. Lu, S. M. Spuler and J. L. Stith, "Holographic measurements of inhomogeneous cloud mixing at the centimeter scale," *Science,* vol. 350, no. 6256, pp. 87-90, 2015.