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LEVERAGING SPATIAL CONTEXT DATA TO IMPROVE HOLODEC SEGMENTATION MODEL PERFORMANCE

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SIPARCS 2023 & NCAR MILES - Boulder, CO

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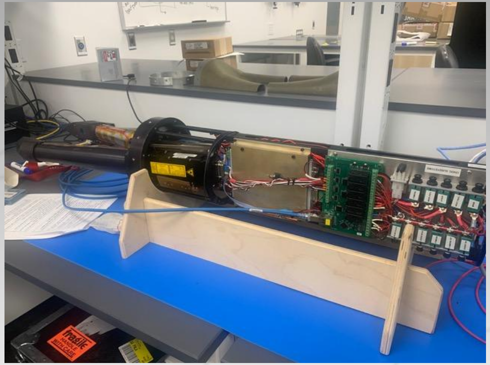
NSF

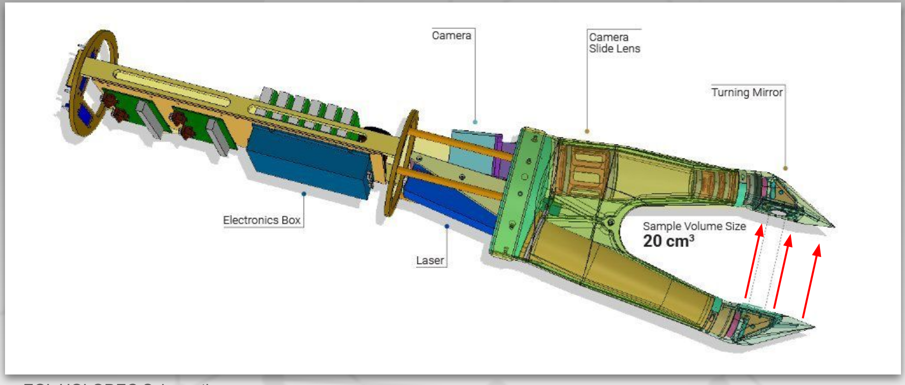
MOTIVATION

- HOLODEC-ii hydrometeor sensor from NCAR EOL[1]
- Samples 20 cubic centimeter atmosphere sample
- Returns inline complex hologram, use fourier transform to reconstruct three-dimensional image

Mounted HOLODEC Sensor



HOLODEC Hardware

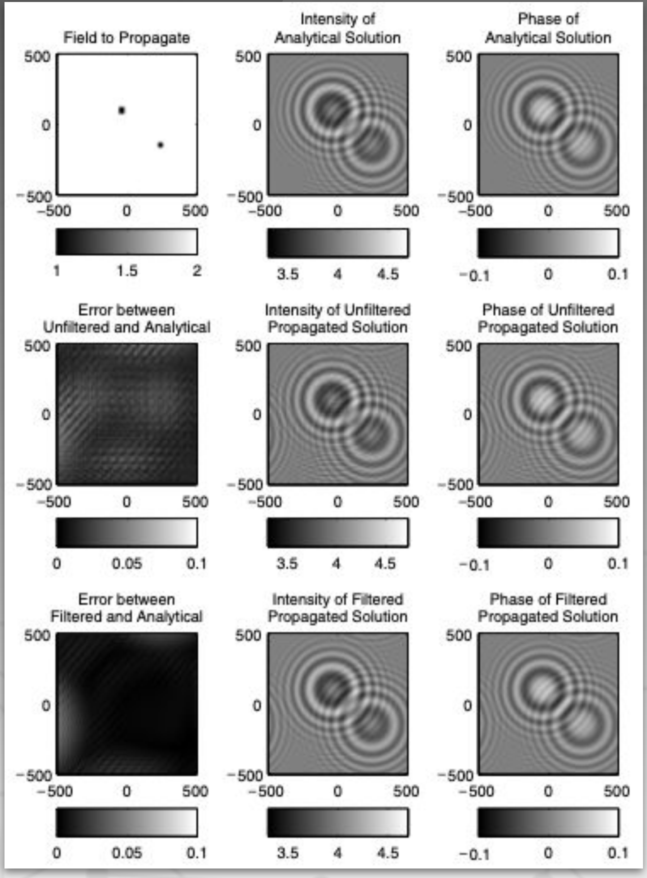


EOL HOLODEC Schematic

MOTIVATION

- Raw sensor data to hydrometeor attributes
- Requires holograms be reconstructed at target depth
- Wave propagation algorithm to unpack sensor depth dimension[2]

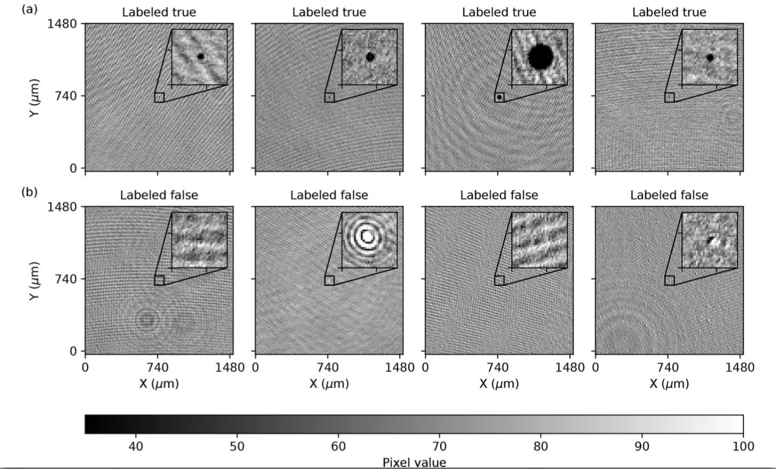
HOLOSUITE METHOD



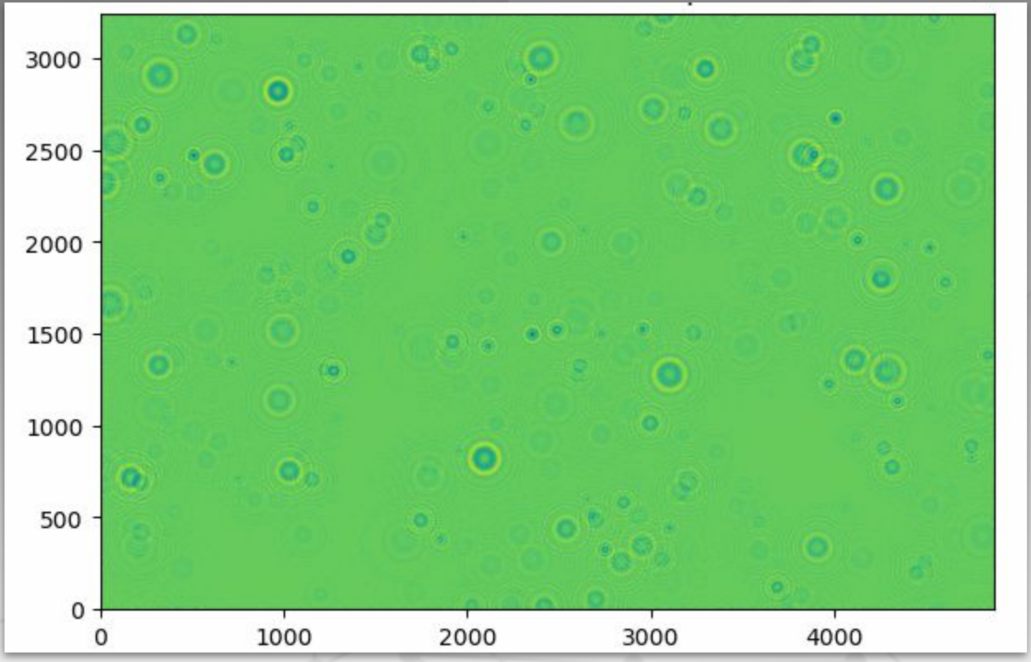
Sample HOLOSUITE Particle Interference

IMAGE REFOCUSING

- Sensor data is noisy and particles are sparse
- Water particles only for geometric simplicity
- Synthetic data here onwards



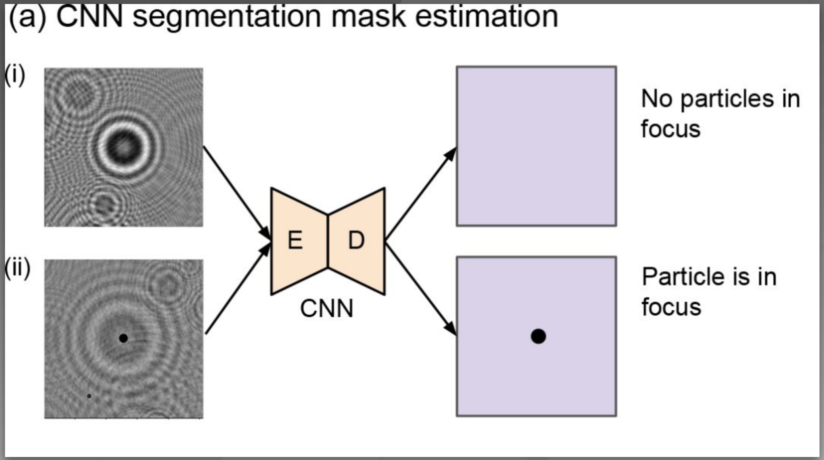
Sample Particle Prediction Labels



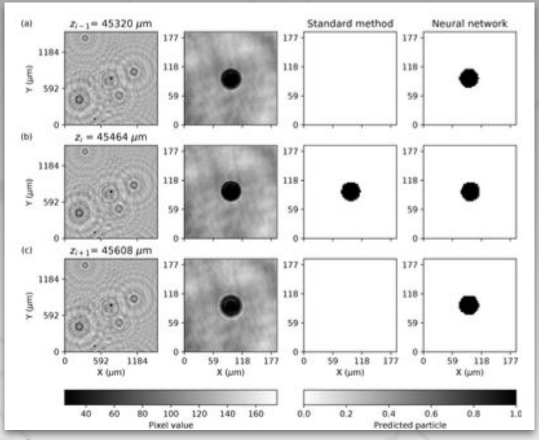
Sample Synthetic HOLODEC Hologram Data

HOLODEC-ML

- 3D complex tensor -> 2D propagation image
- NCAR MILES: ML Powered particle segmentation algorithm[3]
- PyTorch SMP network trained on synthetic particle data
- Images treated as independent, classical segmentation problem
- Higher false positive rate in sensor depth direction, particle spans reconstruction depths



Segmentation Model Outline



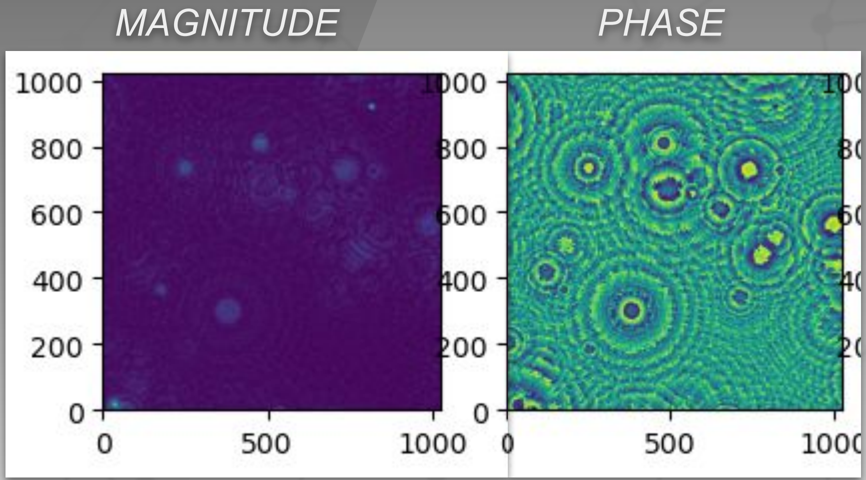
Sample Network Input Across Adjacent Depths

PyTorch

Segmentation Models

1. HOLOGRAM PHASE DATA

- Sensor data is complex wave representation (a+bi)
- Include magnitude and phase
- Old method: absolute value to convert into SMP compatible image
- New method: give magnitude and phase tensors to model, capture Z depth detail better
- Wave phase more variable with respect to propagation distance



Sample Network Input

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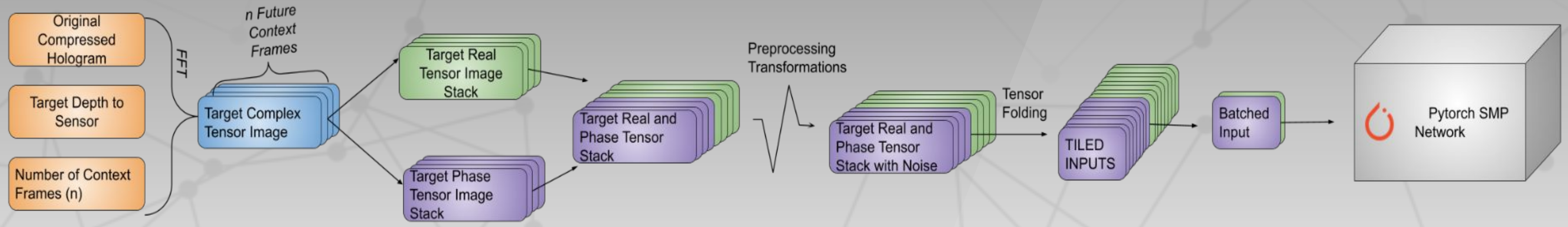
1. SENSOR DEPTH CONTEXT DATA

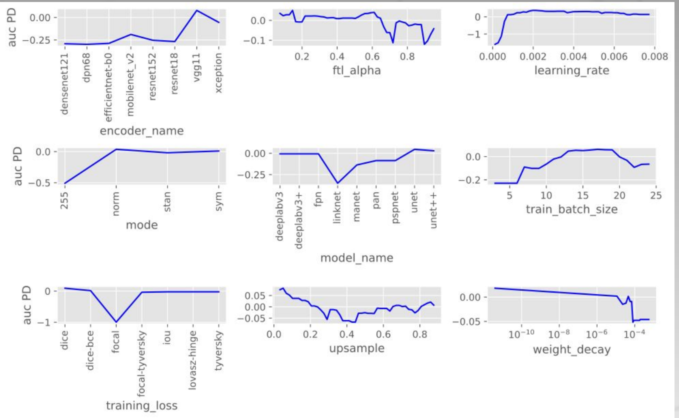
- Don't treat propagation distance frames as independent
- Give model propagation context in positive sensor direction
- Stacked in tensor color channel along with phase/magnitude components



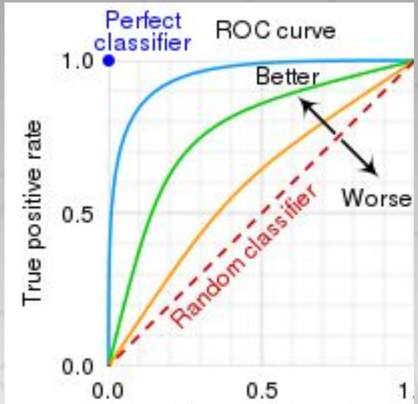
Rebuilt Preprocessing Pipeline

2. FULL-HOLOGRAM INFERENCE

- *Goal: HOLODEC hologram -> particle prediction mask data*
- New metric - area under receiver operating characteristic curve (0.5 is worst, 1.0 is best)
- Evaluated on small fixed sample, realistic inference simulation
- Greatly improved optimization time w.r.t. Minimizing FPR



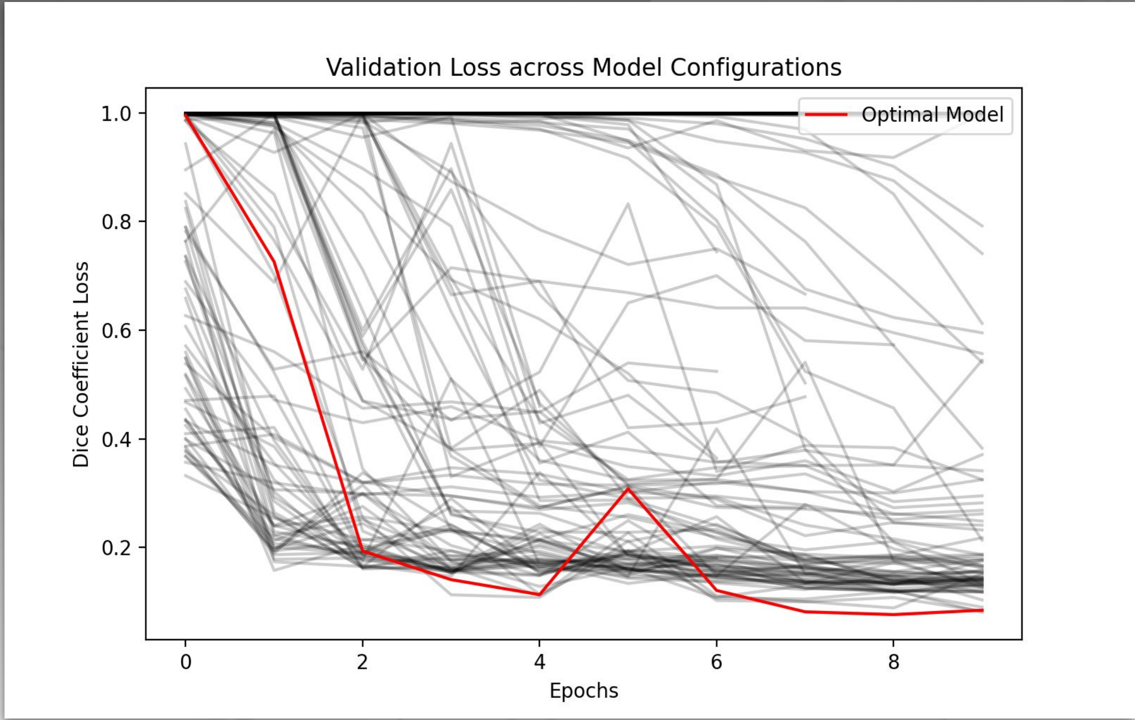
Feature Importances w.r.t AUROC Objective



Sample ROC Diagram

HYPERPARAMETER OPTIMIZATION

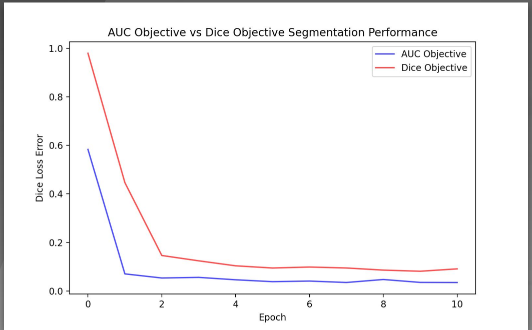
- Tuned on ECHO, NCAR MILES optimizer
  - Extension of Optuna
- Optimal configuration of hundreds of trial configurations
- Powered by CISL Casper



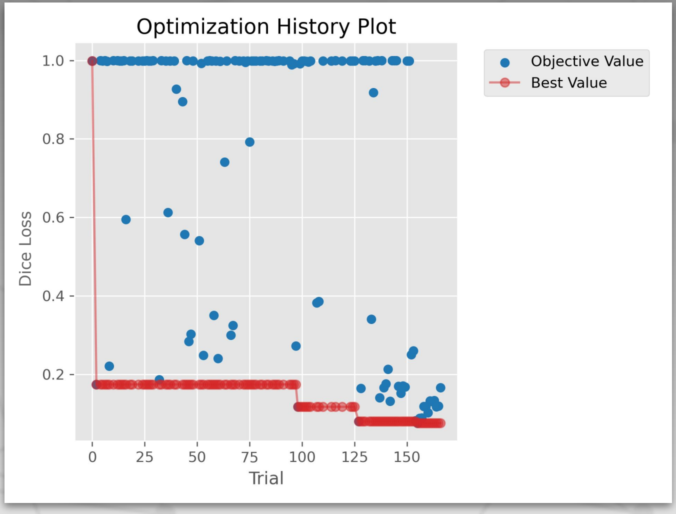
ECHO Model Configuration Performance across Time

PERFORMANCE

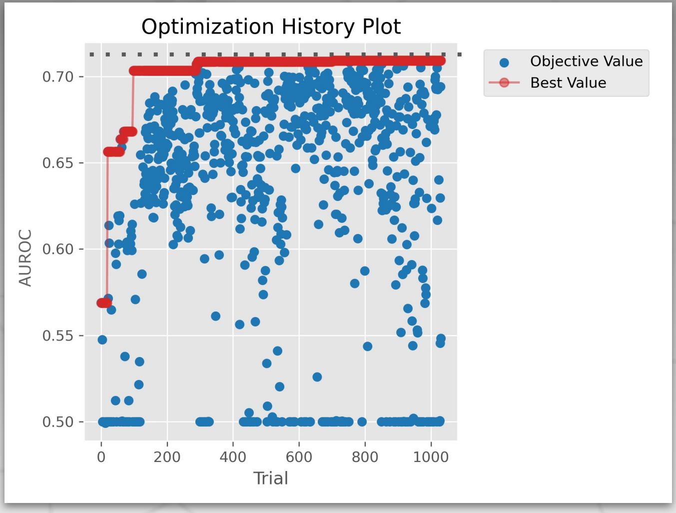
- Best validation dice loss with added context: 0.073
- Best AUC maximizing AUROC: ~0.7, dice loss of ~0.03
- Greatly improved optimization speeds



HOLODECML Performance with Dice and AUC Objective Functions



ECHO Dice Coefficient Loss and Best Value Across Time



ECHO Area Under ROC and Best Value Across Time

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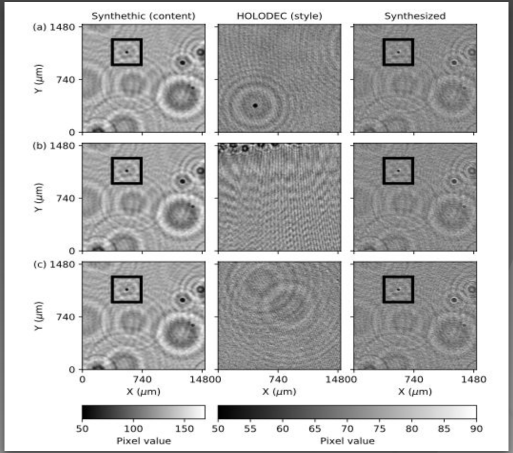
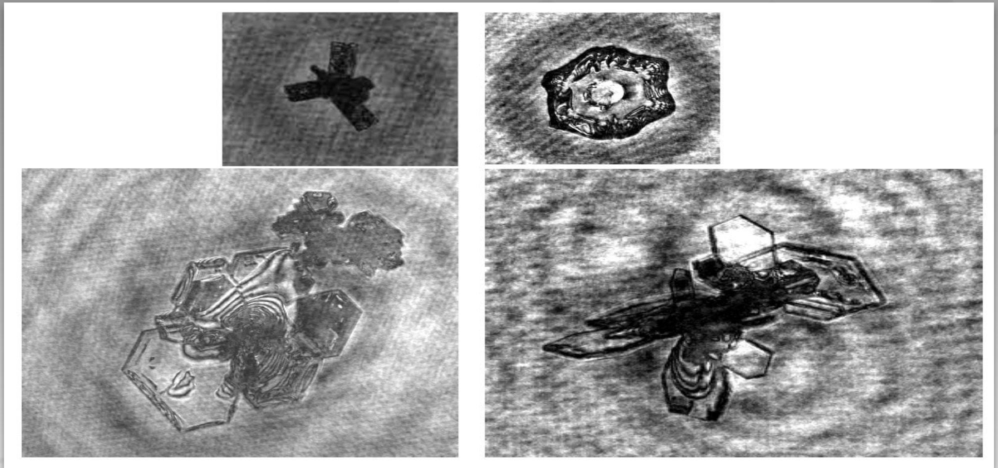
FUTURE WORK

- GAN-stylized synthetic data to mirror real data[4]
- Ice particulate segmentation
- Goal: on-the-fly image inference
- Evaluate performance on different sensors, datasets, campaigns



GAN-Stylization of Synthetic Data


Ice particle segmentation

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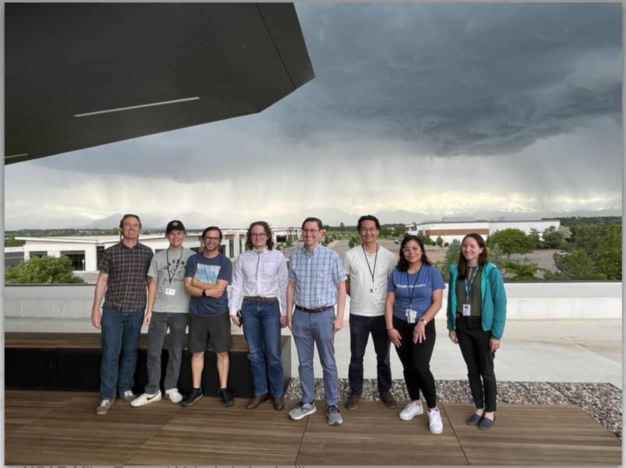

NCAR Miles Team at Vaisala in Louisville

McLovin the Australian Shepherd wearing a CISL hat

SIPARCS Interns

REFERENCES

[2]Fugal, J. P., Schulz, T. J., & Shaw, R. A. (2009). Practical methods for automated reconstruction and characterization of particles in digital in-line holograms. Measurement Science and Technology, 20(7), 075501.

[3]Schreck, J. S., Gantos, G., Hayman, M., Bansemer, A., & Gagne, D. J. (2022). Neural network processing of holographic images. *Atmospheric Measurement Techniques*, *15*(19), 5793-5819.

[4]Schreck, J. S., Hayman, M., Gantos, G., Bansemer, A., & Gagne, D. J. (2023). Mimicking non-ideal instrument behavior for hologram processing using neural style translation. *Optics Express*, *31*(12), 20049-20067.

[1]Spuler, S. M., & Fugal, J. (2011). Design of an in-line, digital holographic imaging system for airborne measurement of clouds. *Applied optics*, *50*(10), 1405-1412.