Advanced Observations for Microphysics Scheme Evaluation, Using GCPEx Data and Beyond

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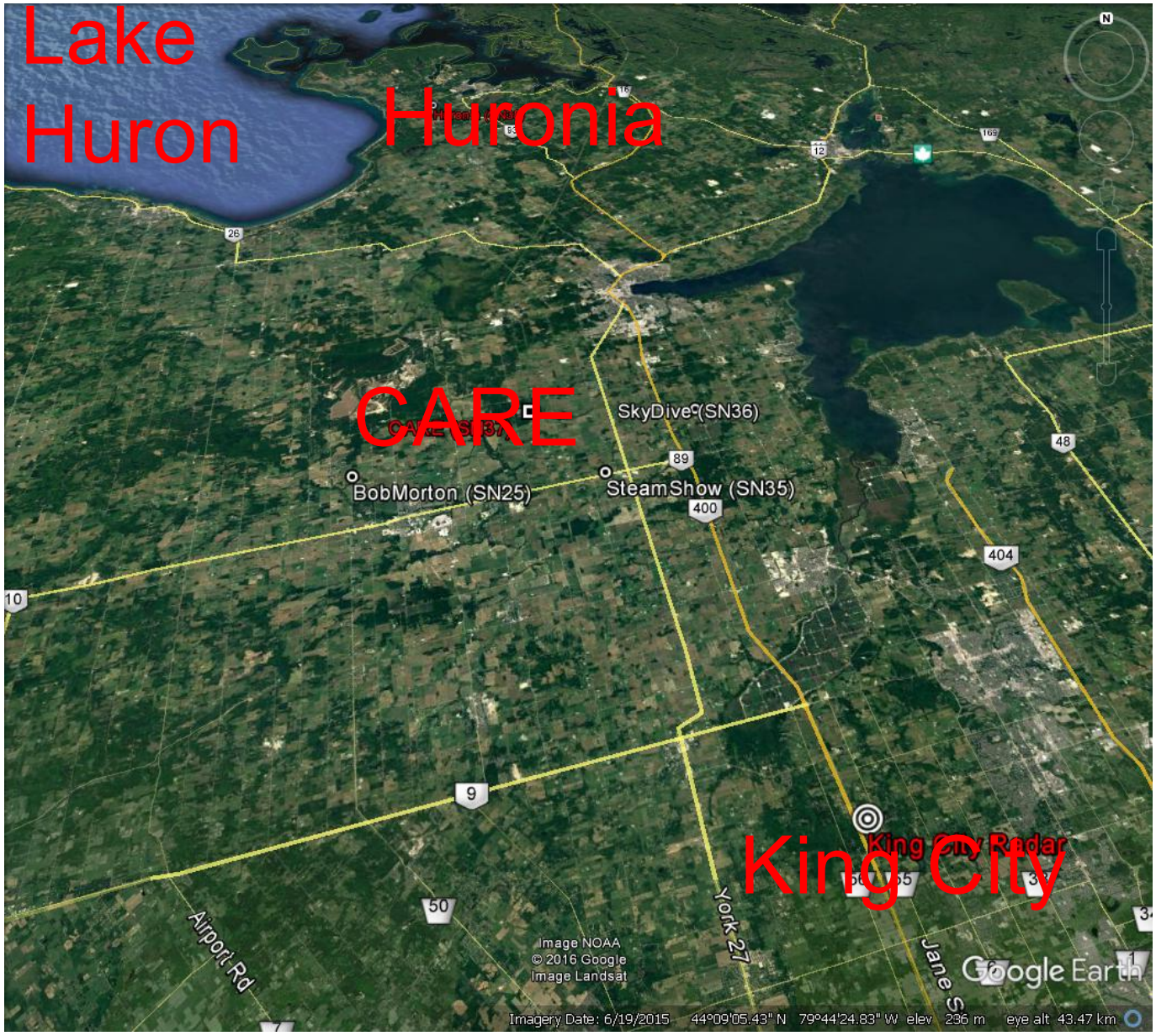
NASA PMM Grant NNX16AE43G

Introduction

- GCPEx had many advanced in situ and remote sensing observations for ground validation and microphysical studies
- Proposal goal: Use 2DVD, PIP, scanning radar (King City Radar), POSS, MRR, etc. for comparisons to WRF bin microphysics simulations
  - Our focus is on the 30-31 January 2012 lake effect and large-scale synoptic snowfall events
    - Lake effect was convective in nature, high reflectivity values, spatially heterogeneous
    - Synoptic frontal event was due to large-scale uplift, spatially more homogeneous

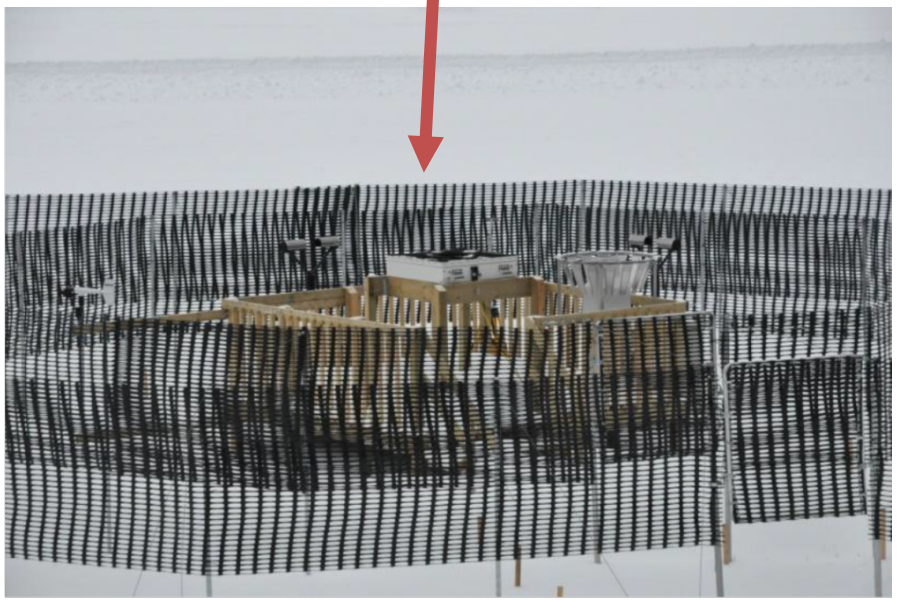
Site Overview



Instrumentation

Obs Sites

DFIR wind fence



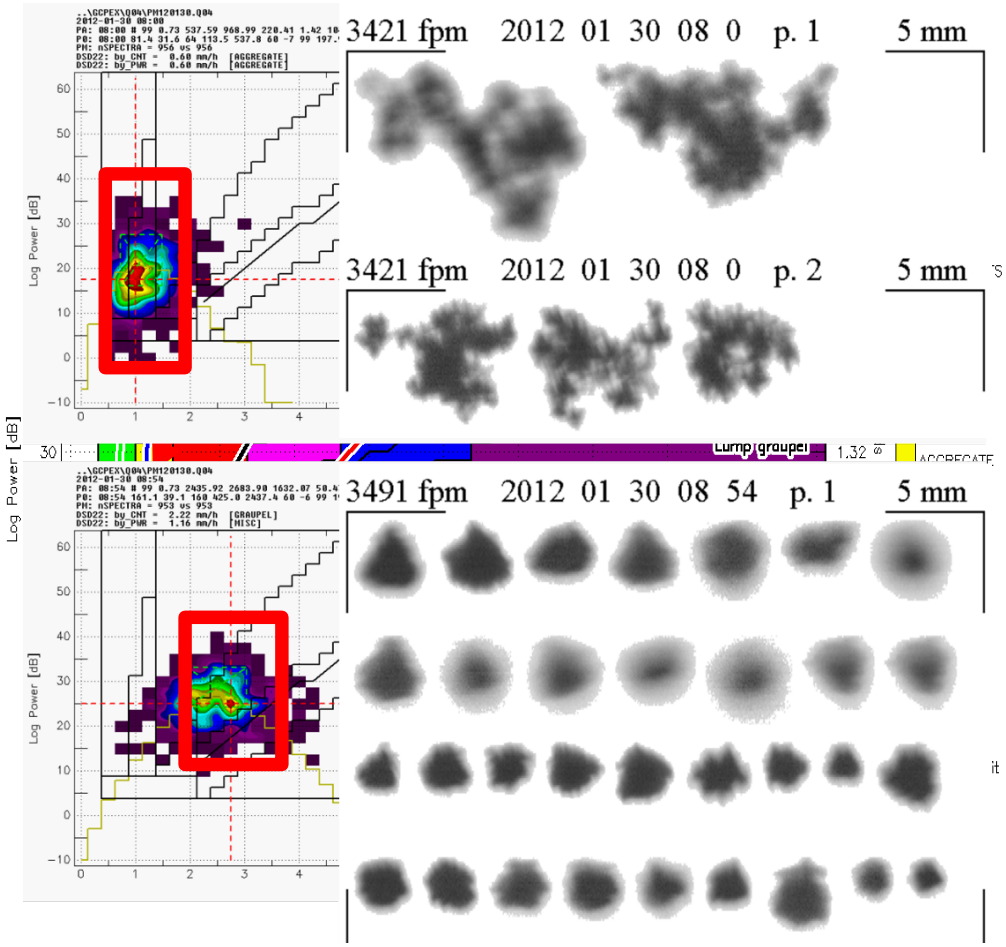
2DVD

POSS

SVI

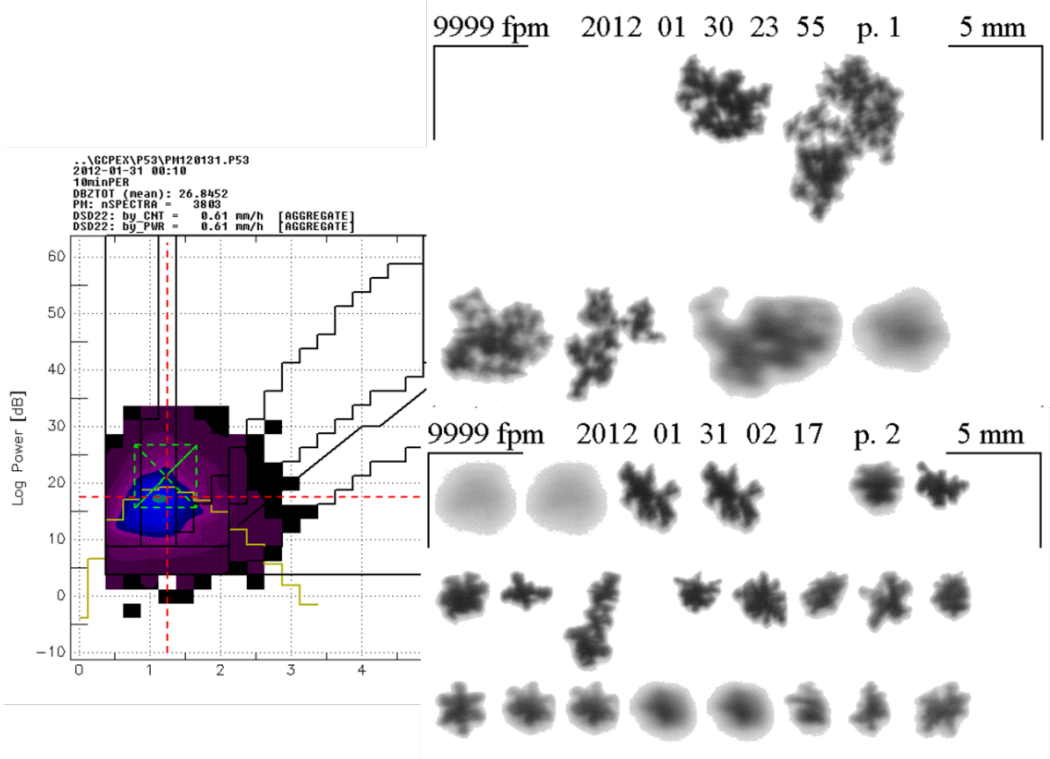
Lake Effect Event

- POSS & PIP particle characterization:
- Extreme aggregation and graupel present in lake effect cells
- POSS identifies both
- Aggregates and graupel alternate throughout event in PIP data as well



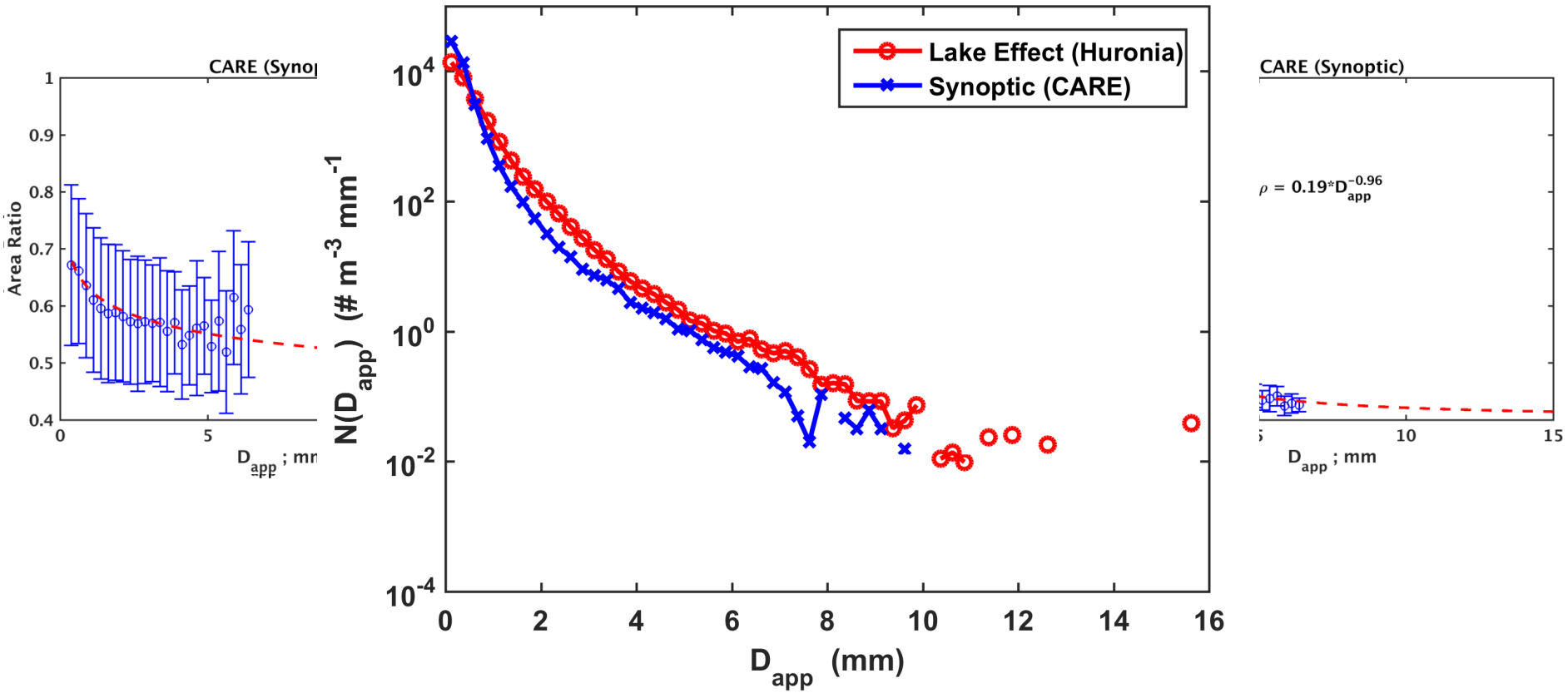
Synoptic Event

- POSS & PIP particle characterization
- General aggregation
- POSS primary classification is aggregates
- Identifiable dendrites/stellars in PIP data
  - Indicates little to no riming



2DVD Results

- Lake effect event had complex area, fall-speed and density-size relationships
  - Higher density than aggregates
- Synoptic event has classical aggregate relationships
- PSDs similar N_o and shape (slightly negative μ)
  - Lake effect had more mid-size (2-6mm) particles and > 1cm



Z-SR Generation Methodology

(Huang et al. 2014: Light Precip Validation Expt or LVPEX)

Measure

- Particle Image
- Fall Speed

"Size" D_{app}

Böhm Equation
Environmental Data

- Liquid Equivalent Snowrate (SR)
- Z_e

PSD $N(D_{app})$

Density-Size Relations $\rho = \alpha D_{app}^{\beta}$

$Z = a*SR^b$

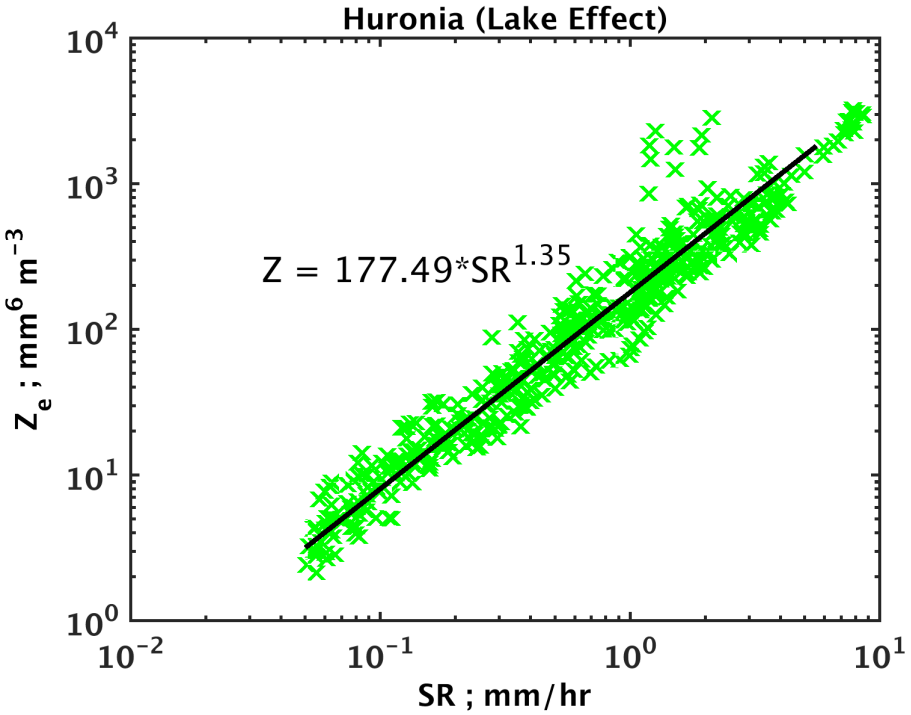
Snow Map Using Radar

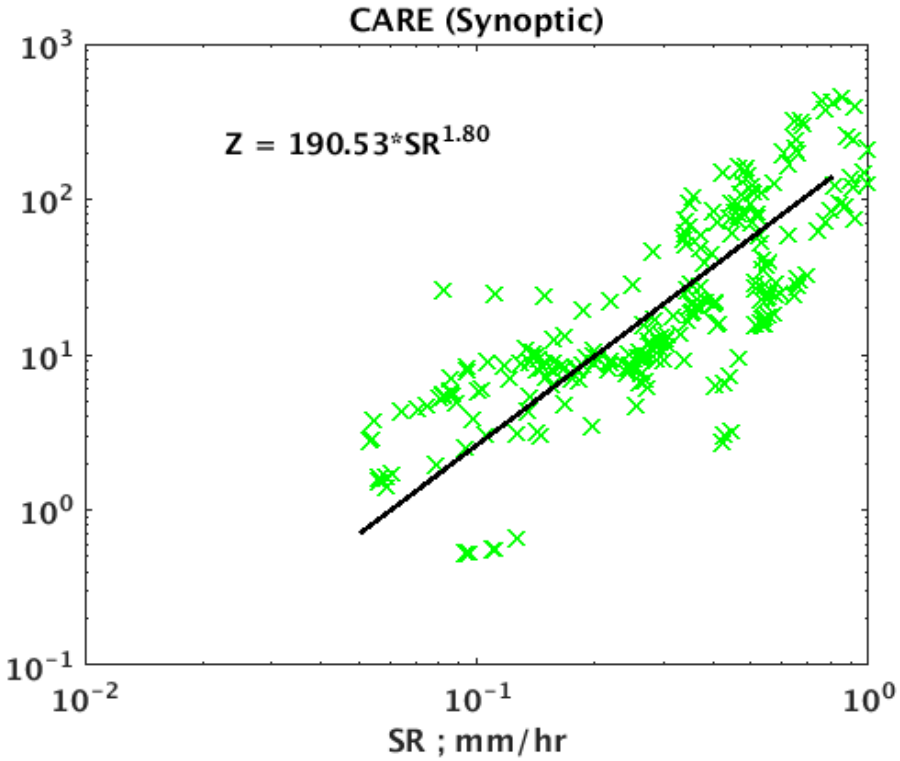
Similar approach has been done by W. Szyrmer and I. Zawadzki (2010) by using HVSD.

Reflectivity (C-band) calculation assumes soft spheroid model with dielectric constant based on Maxwell-Garnet mixing formula (consistent with density). This scattering model needs to be improved for higher frequencies such as Ku or Ka-band.

Z-SR Results

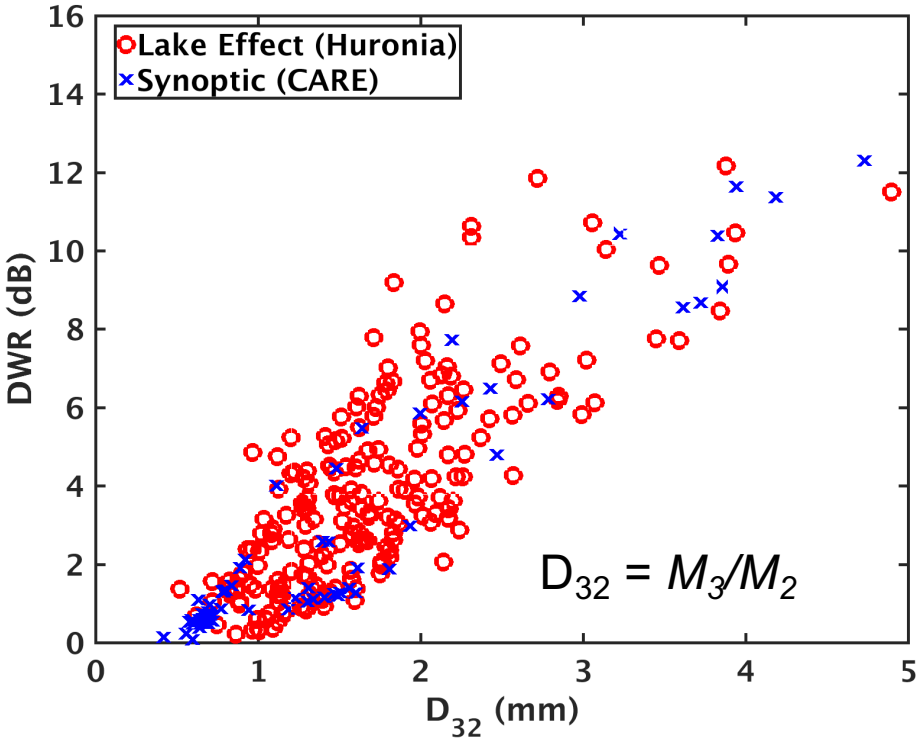
- Lake effect (left) and synoptic event (right) Z-SR relationships primarily differ in exponent
  - 1.35 vs 1.80 respectively

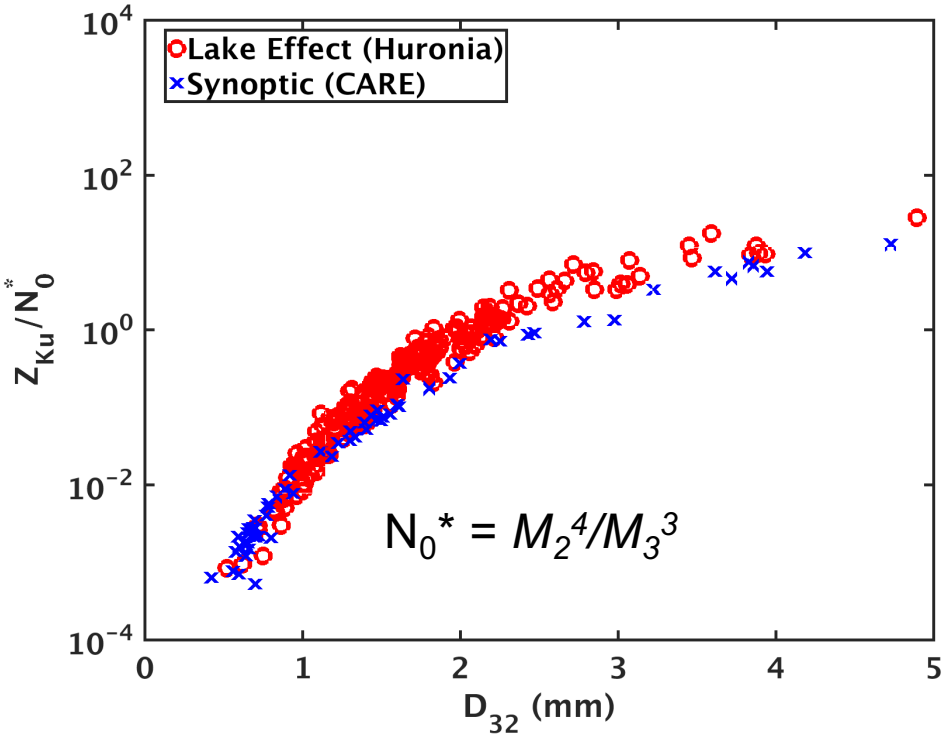




Scattering Results using 2DVD

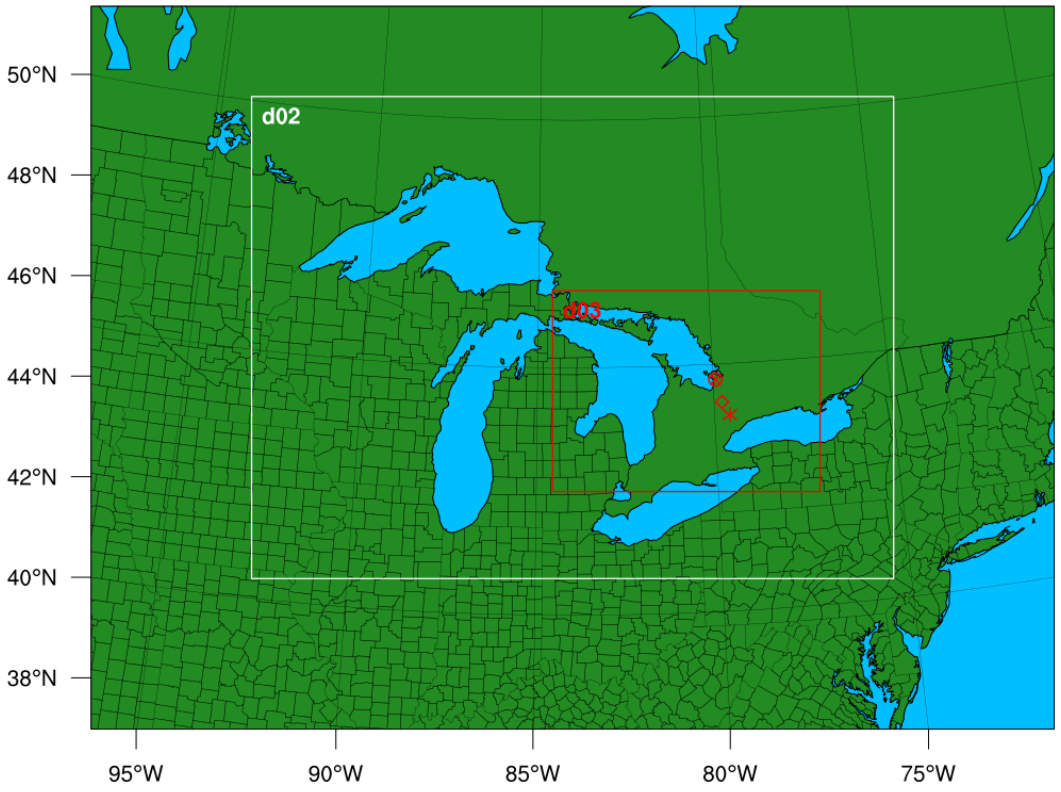
- Scattering based on soft sphere model (consisting of a homogeneous mixture of ice and air)
- Dual-wavelength ratio (DWR), Z_{Ku}/Z_{ka}, vs 3rd to 2nd PSD moment has large scatter
  - Density and PSD variability; also 2DVD measurement uncertainty
- Z_{ku}/N_o^* (normalized intercept parameter) has some variation between events
  - Synoptic event smaller Z_{ku}/N_o^* for same D_{32}





Initial Model Configuration & Results

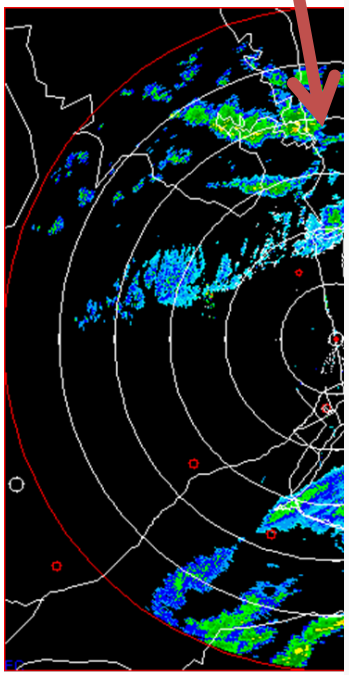
- Configure WRF with nested domains
  - 4, 1.5, 0.5 km grid spacing
  - 0.5 km grid (red outline) will run HUCM bin microphysics
- Initial [illegible] F to capture featur
  - Imp [illegible] physics con
    - [illegible] d boundary
    - [illegible] ons impact lake-
    - [illegible] configuration
  - Res
    - [illegible] IUR high-

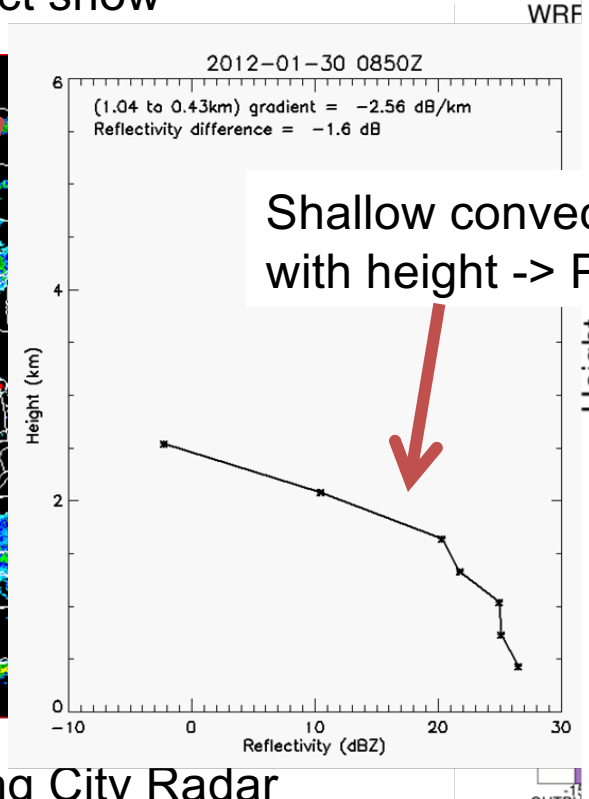


Initial Model Results: Lake Effect

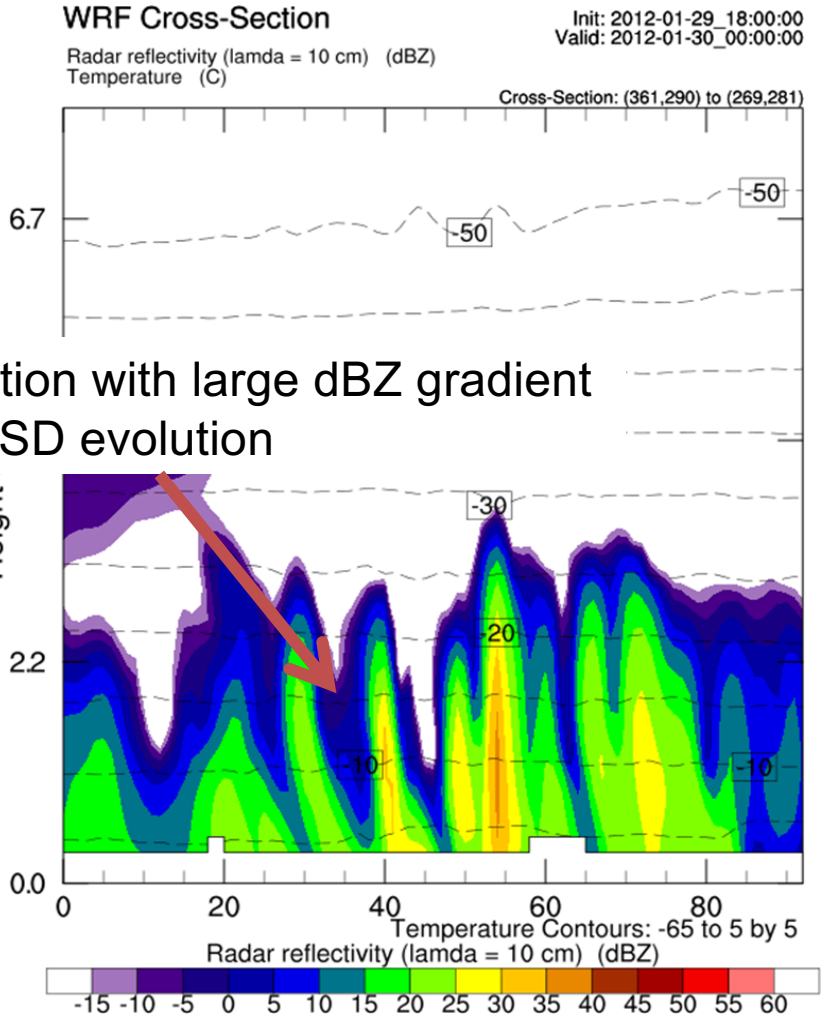
- Lake effect snow at the Huronia site on 30 January
- Banded features passed through the area
- Initial WRF simulation captures horizontal banding, cellular structures
- Vertical depth also well simulated

Lake effect snow





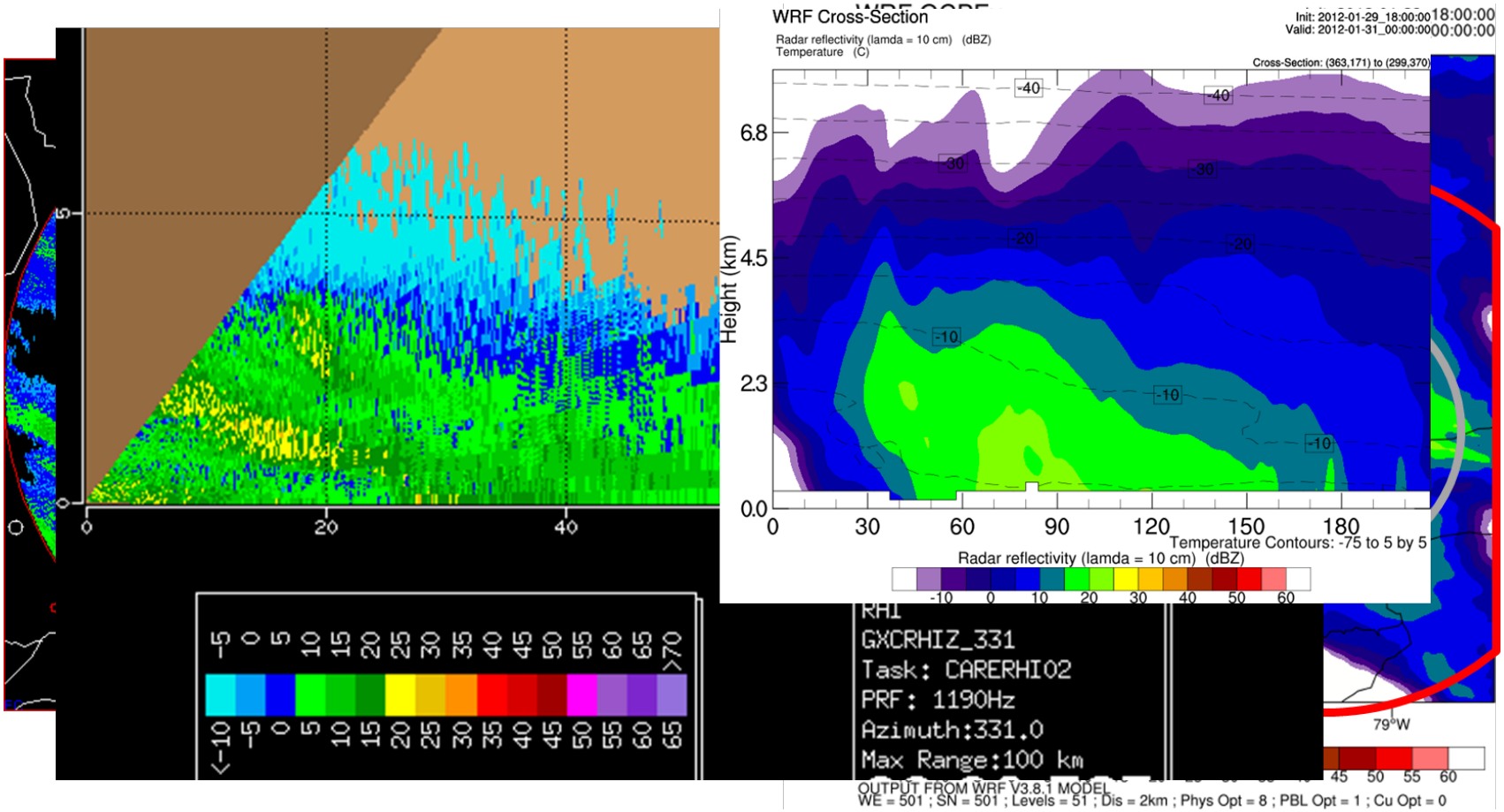
King City Radar



Shallow convection with large dBZ gradient with height -> PSD evolution

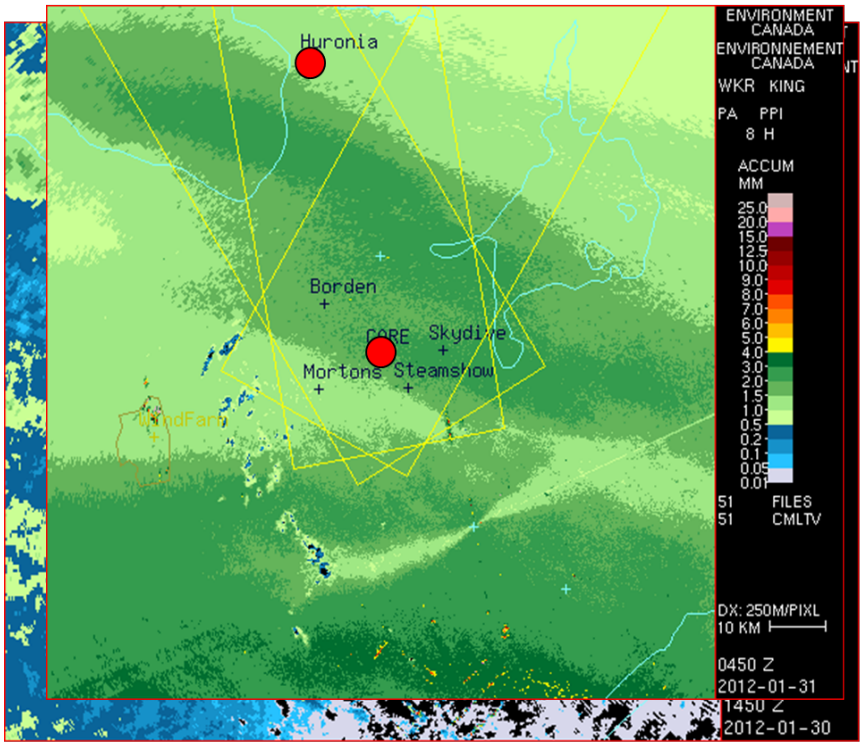
Initial Model Results: Synoptic Event

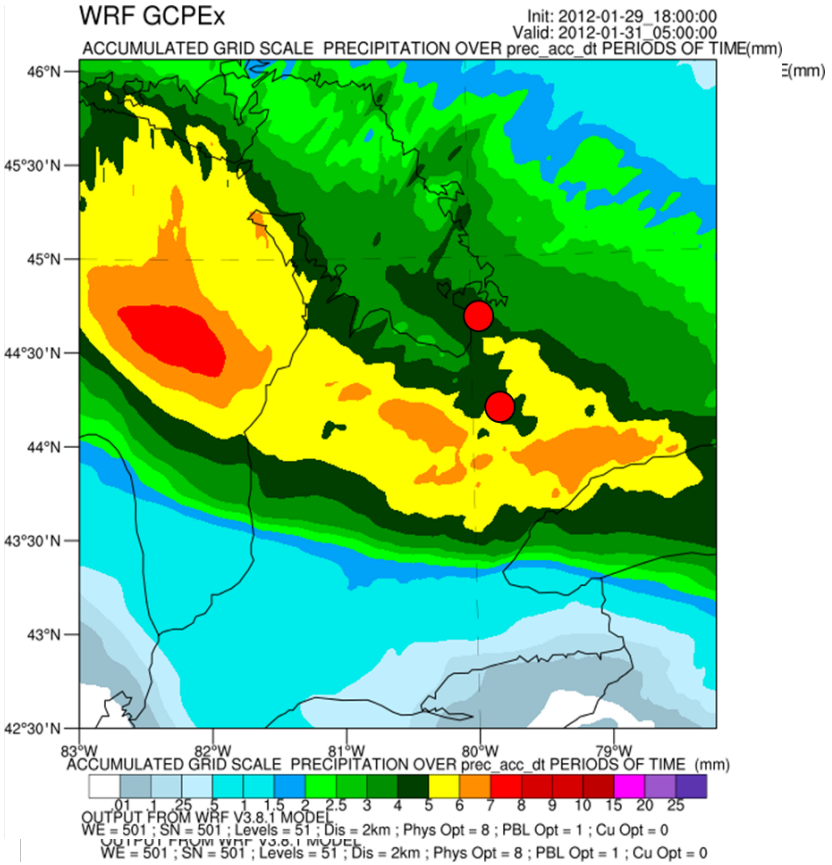
- Timing, placement of synoptic event very good
  - Some over-prediction of spatial coverage
- Vertical extent well simulated also



Initial Model Results: Accumulation

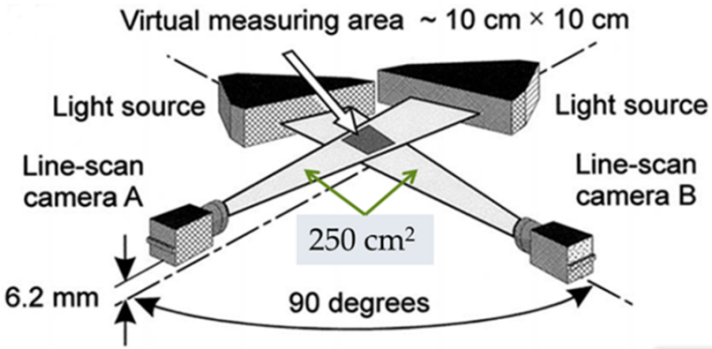
- Z-SRs applied to King City radar
  - WRF slightly misplaces lake effect, but spatial structure similar
  - Spatial placement of synoptic band very good, slight over-estimate of amounts

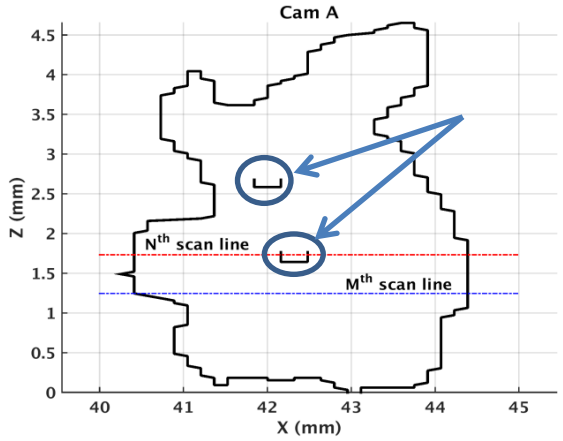


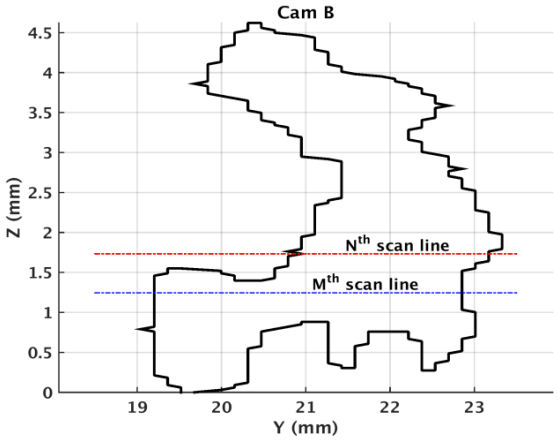


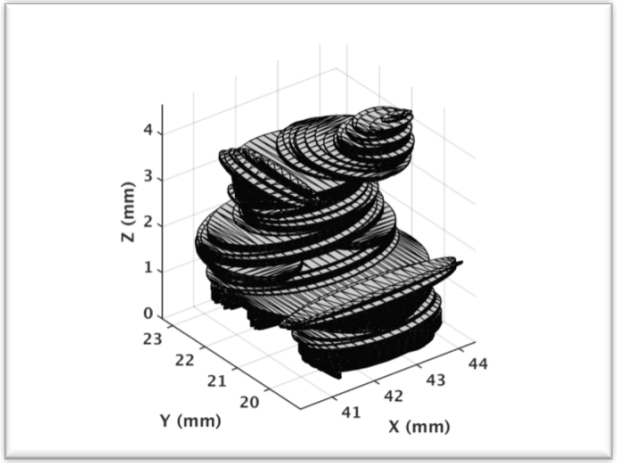
Some Remarks Based on GCPEx Analysis

- Need to improve scattering model beyond soft spheroids especially at higher frequencies
  - Need to account for 3D shape via reconstruction from multiple views
    - 2DVD has poor resolution and 2 orthogonal views are insufficient
      - Plus cannot deskew distortion due to horizontal wind
    - SVI/PIP images are in one plane so cannot do 3D reconstruction







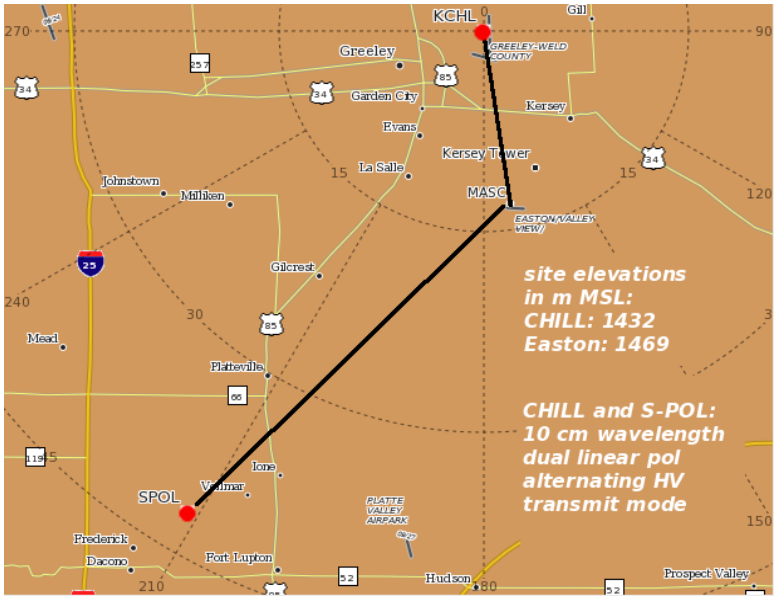


MASCRAD (MASC + Radar) Instrumentation Site



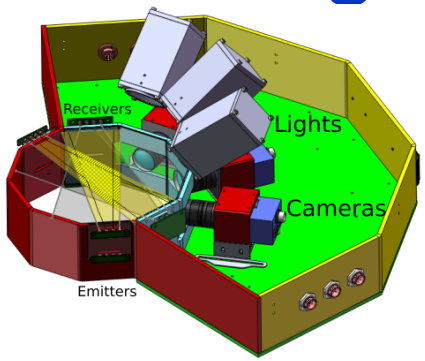


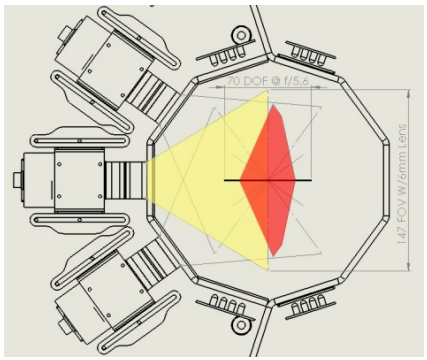
- **Multi Angle Snowflake Camera (MACS)**
  - Acquisitions of 3 (5) high-res images and fall-speed
- **2 Dimensional Video Disdrometer (2DVD)**
  - Orthogonal scanline contours and fall-speed data
- **Meteorological Particle Spectrometer (MPS)**
  - PSD and fall speed of small particles (50μm)
- **Precipitation Occurrence Sensor System (POSS)**
- **NCAR GPS Advanced Upper-Air System (GAUS) Sounding System**
  - Temperature, humidity, pressure, and winds
- **Pluvio Precipitation Gauge**
  - Liquid equivalent snow measurements
- **VAISALA weather station**
- **CSU-CHILL Radar and NCAR SPOL Radar**
  - State-of-the-art polarimetric weather radars

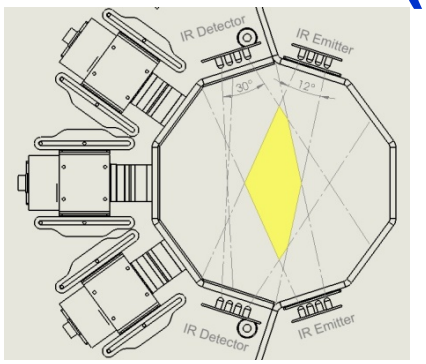


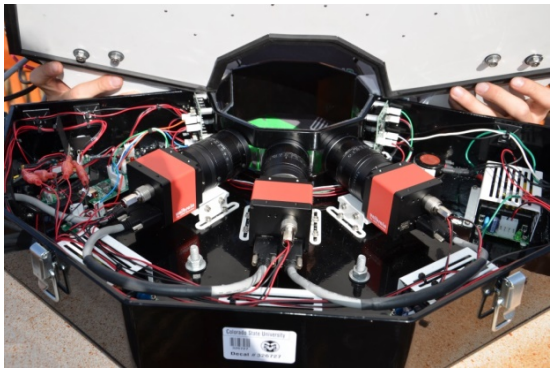


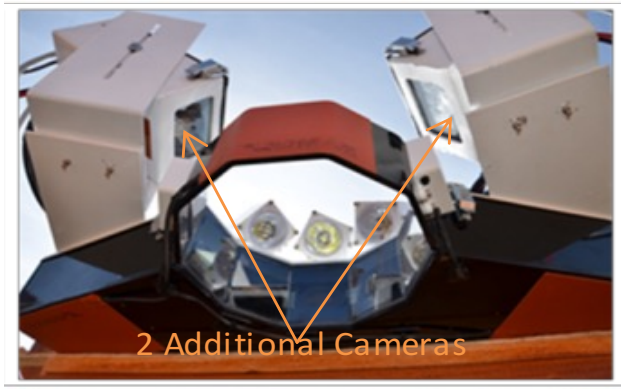
Multi Angle Snowflake Camera (MASC)

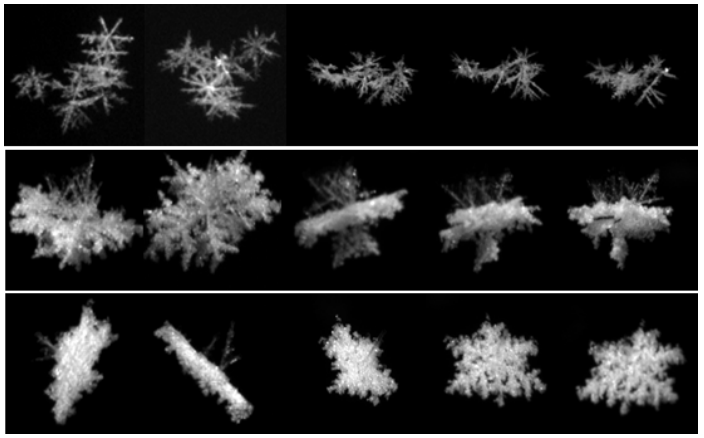


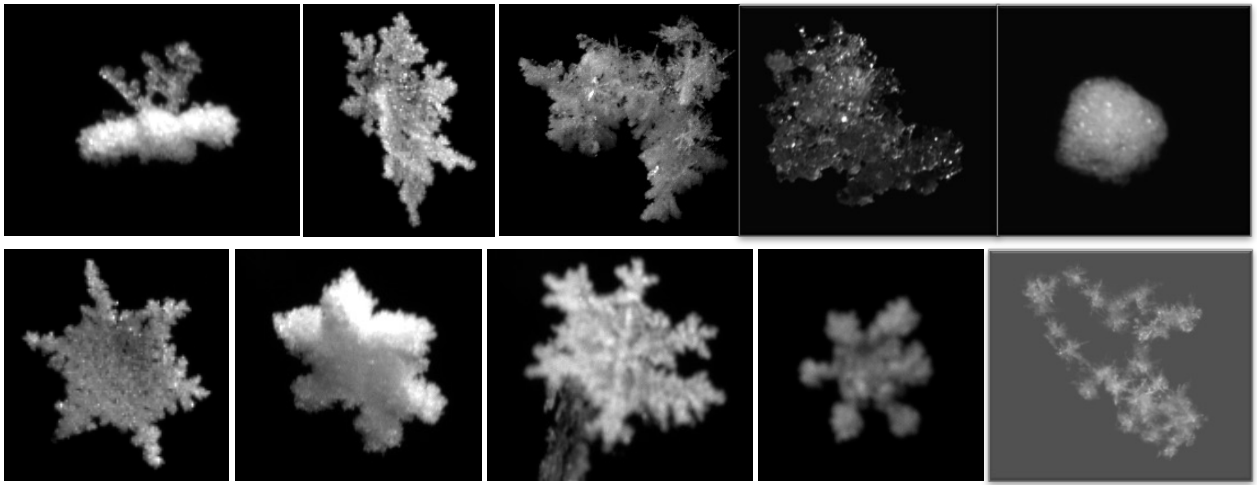






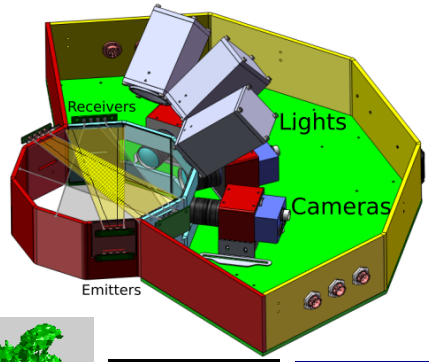


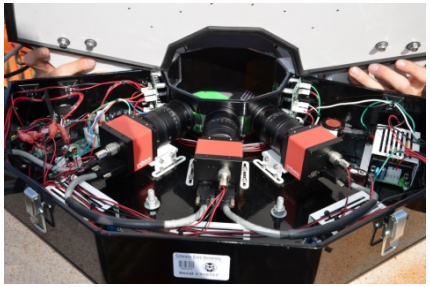


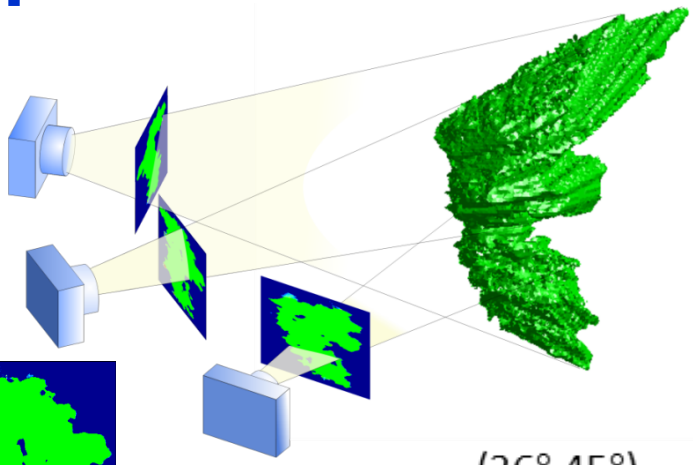


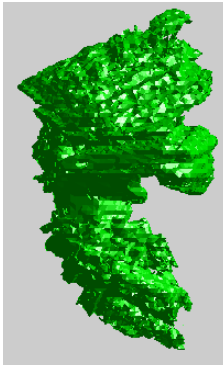
- Improved Mechanical Calibration
- Developed Software Calibration
- Added Two External Cameras
- Handling Multiple Particles in Image

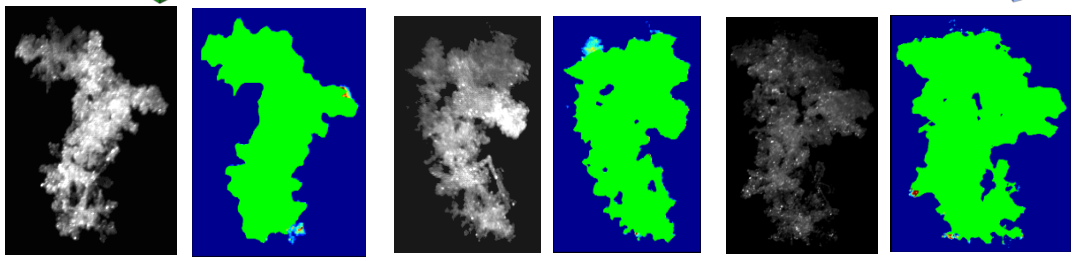
Visual Hull Method for 3D Shape Reconstruction

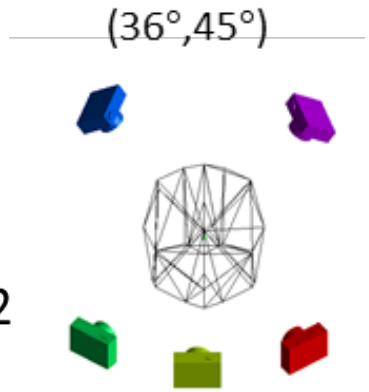


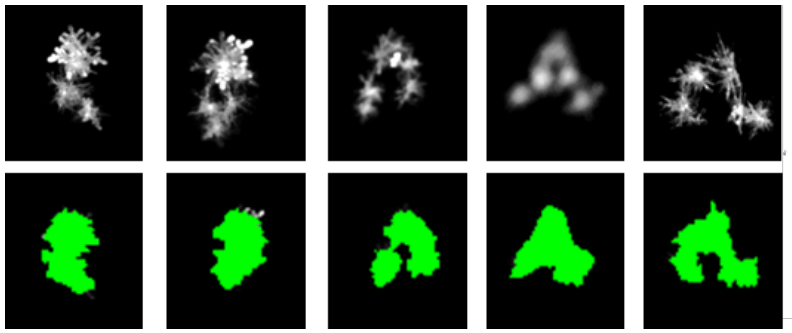


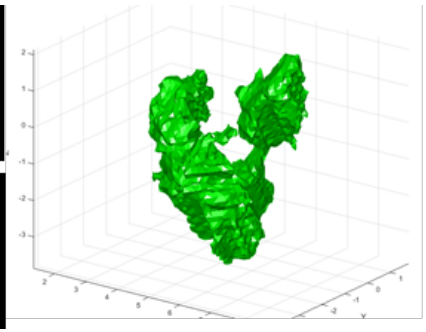




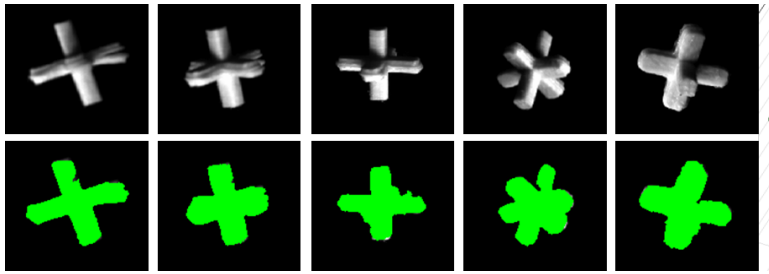


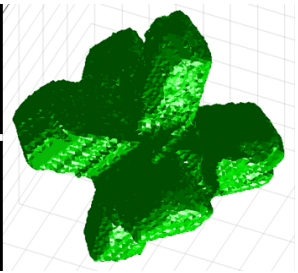






Flake ID: 46922
V = 13.64 mm^3
SA = 69.87 mm^2
AR = 0.58

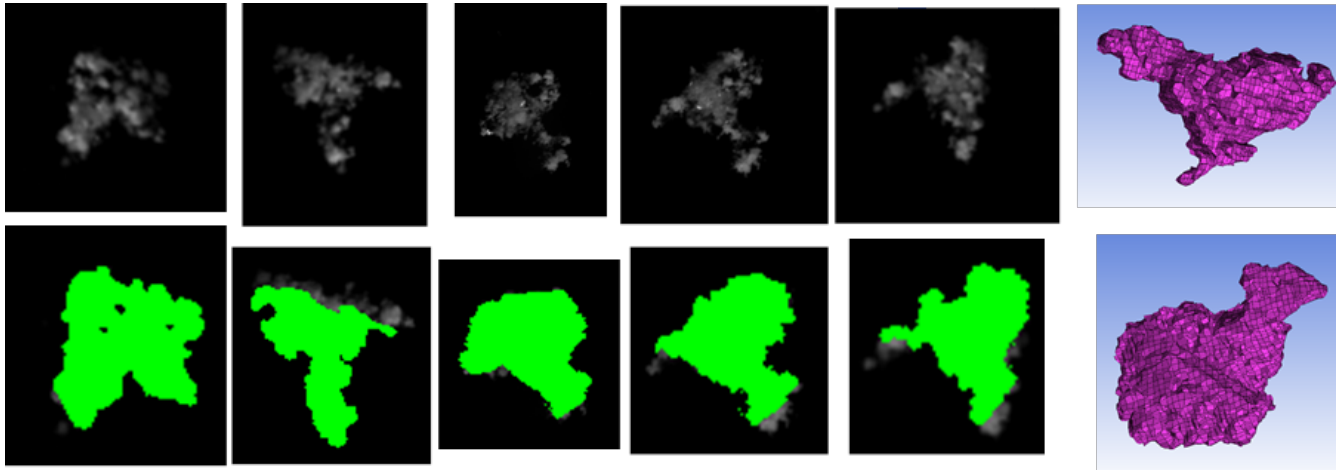




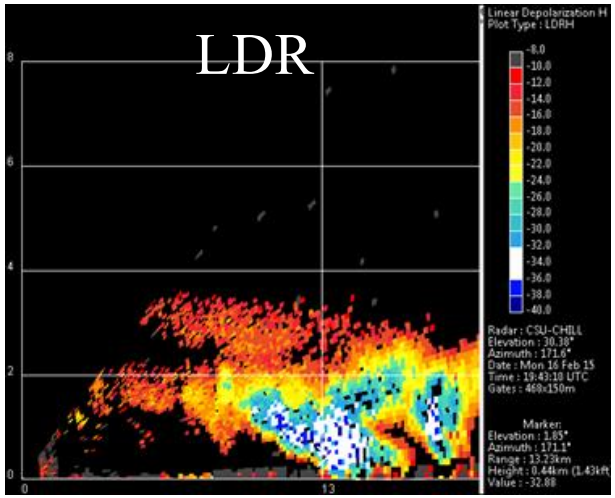
V Error: 1.65%
SA Error: 1.40%
AR Error: 8.30%
Spheroid Error: 231.53%

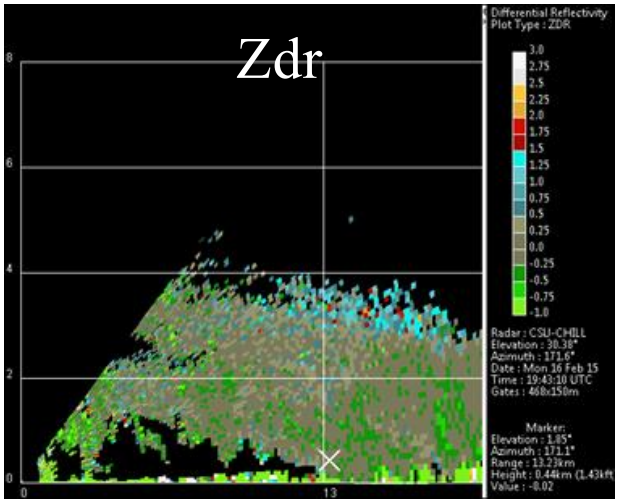
Böhm's method

Example of MASCRAD Observations and Computations (MASC Images, Visual Hull Shape Reconstruction, MoM-SIE Scattering, CSU-CHILL Radar): February 16, 2015, Hour 19, Unusual Winter Graupel Shower



V. N. Bringi, P. C. Kennedy, G.-J. Huang, C. Kleinkort, M. Thurai, and B. M. Notaroš, "Dual-polarized radar and surface observations of a winter graupel shower with negative Z_{dr} column," *Journal of Applied Meteorology and Climatology*, 2016, in press.





- LDR Radar: -33 dB
- Zdr Radar: -0.02 dB
- LDR MoM-SIE = -24.5 dB
- Zdr MoM-SIE = -0.05 dB
- Dielectric Constant: 1.275 - j0.0003

- Method of moments (MoM) - Surface Integral Equation (SIE)
- Comparsion with T-matrix and DDA

E. Chobanyan, N. J. Sekeljic, A. B. Manic, M. M. Ilic, V. N. Bringi, and B. M. Notaros, "**Efficient and Accurate Computational Electromagnetics Approach to Precipitation Particle Scattering Analysis Based on Higher-Order Method of Moments Integral Equation Modeling**," *Journal of Atmospheric and Oceanic Technology (JTECH)*, Vol. 32, October 2015, pp. 1745–1758

Particle Size Distribution from MASC

Estimation of PSD using MASC has not been done so far

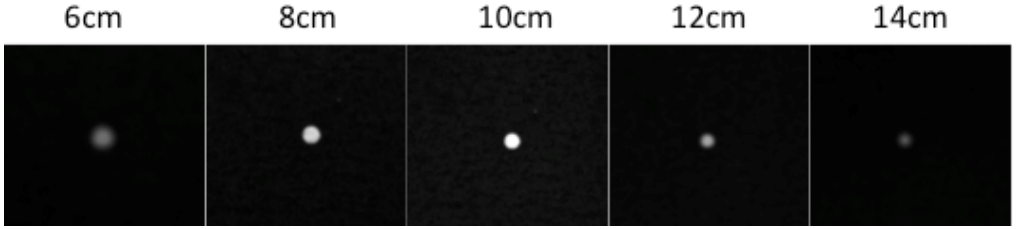
Instead, the users of MASC usually present a histogram of particle size (Garrett et al. 2012)

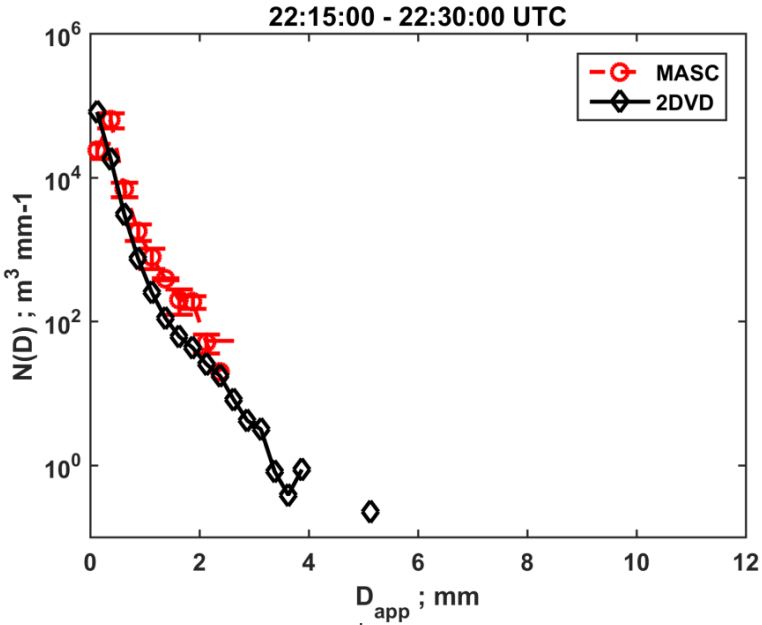
$$N(D_i) = \frac{1}{\Delta t} \sum_{k=1}^{M} \frac{1}{V_k \Delta D_i}$$

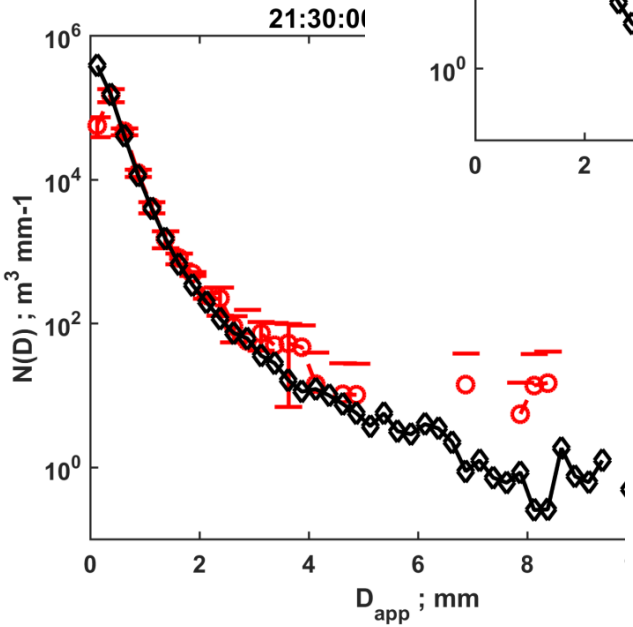
Measurement Volume =
Field of View Horizontal
x Field of View Vertical
x Depth of Field

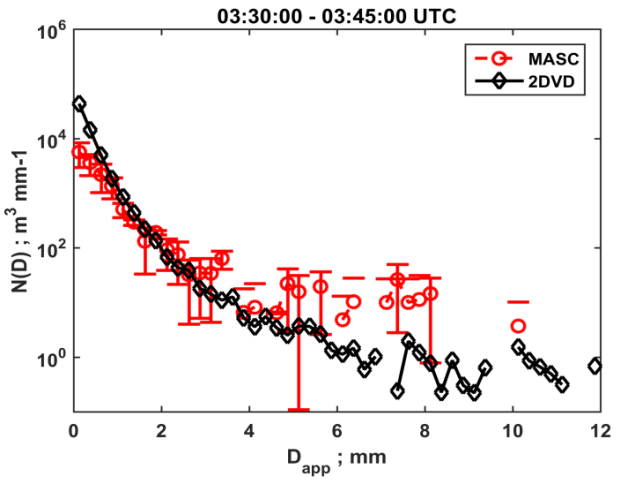
FOV can be easily computed from FOA (field of angle), which can be obtained from lens data sheet, and focal distance

DOF is determined experimentally



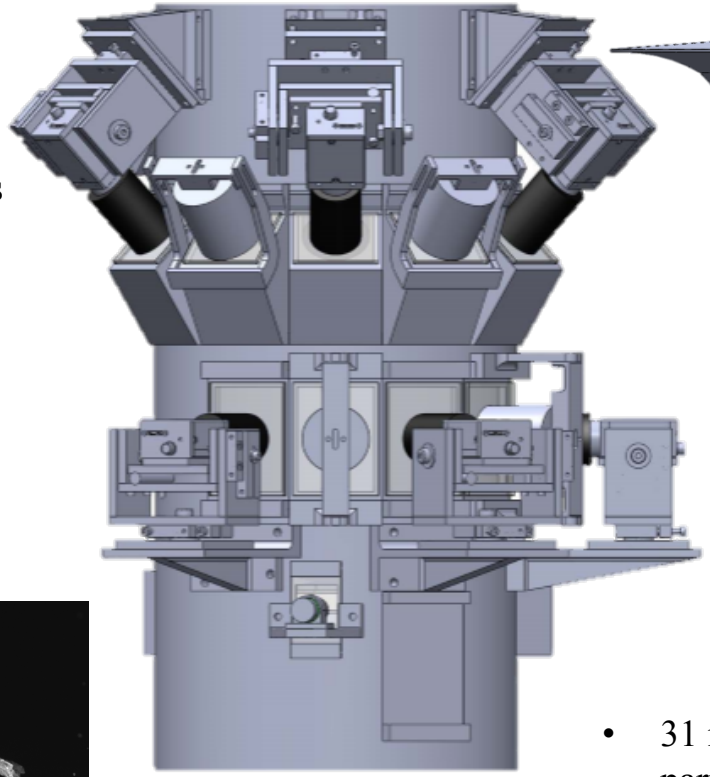




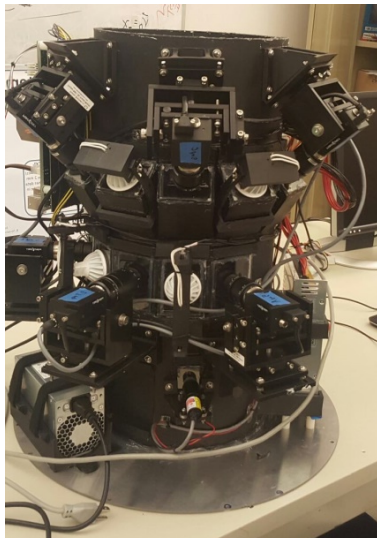


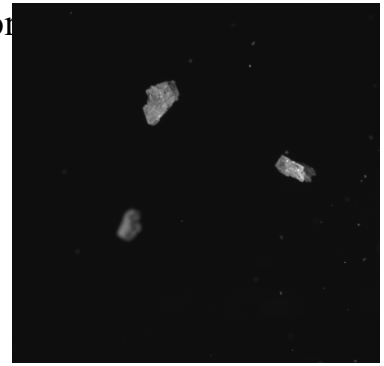
Snowflake Measurement and Analysis System (SMAS)

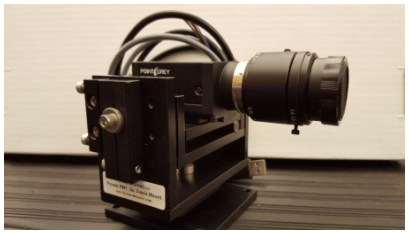
- Six 5 MP cameras for 3D reconstruction
- One 2 MP camera for fall speed calculations
- 5 flashes at 615 lumens each
- Custom camera and flash brackets
- Custom break beam snowfall sensor
- Custom PCB's: sensing and power
- Weather station for external weather data
- USB 3.0 for data transfer
- Dedicated workstation for
- Nipher shield shape



Outer chassis (Nipher shield)







- 31 micron resolution (dust particles)
- Detect snowflakes as small as .5 mm
- Simultaneously collect weather data
- Calculate fall speed of every flake in the frame
- 7 unique camera angles with a single focal point
- Melt snow from outer chassis

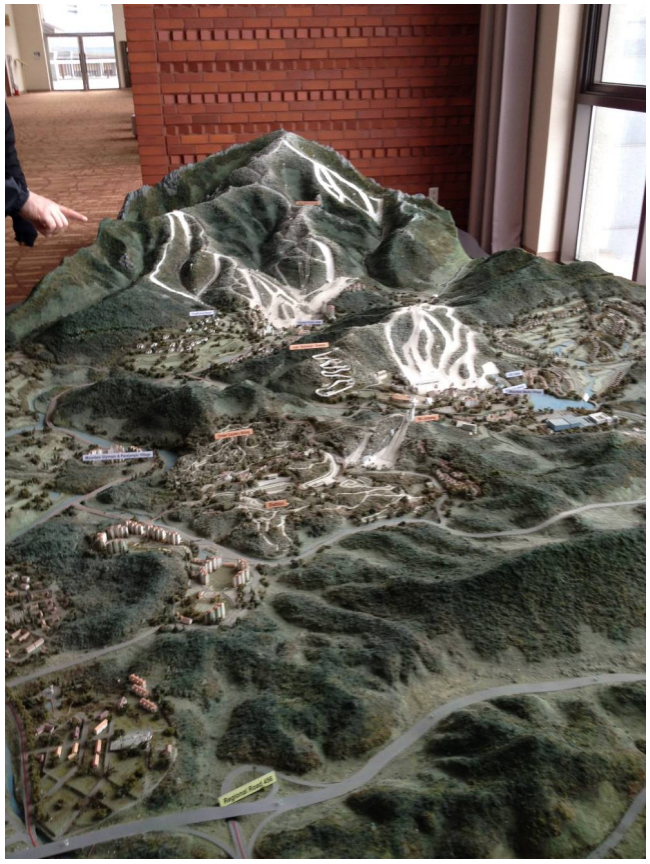
Conclusions

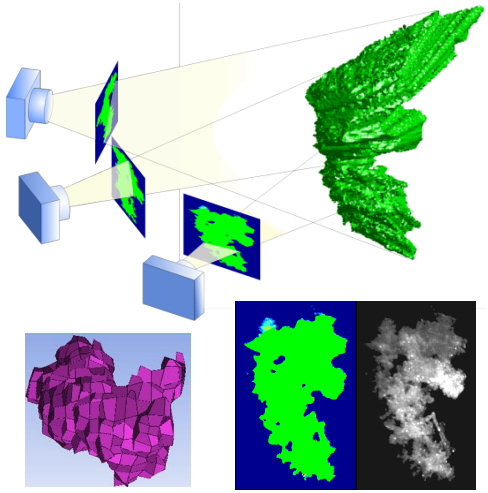
- Multiple *in situ* and remotely sensed instruments from GCPEx will enable holistic model evaluation and process understanding
- 30-31 January lake effect and frontal precipitation offer diverse frozen phase microphysics
  - Initial lake effect has intense aggregation and riming
  - Frontal precipitation has little riming, more pristine crystals and smaller aggregates
- WRF is able to capture dynamics of event, should lead to successful bin simulations

Next Steps

- Finalize WRF configuration
- Bin simulations for both events
  - Sensitivity analysis focused on key uncertain parameters, diffusional growth, collection efficiency
  - Quantitative comparisons to observations

Future Work





- ICE-POP 2018 – there will be 3 MASCs collocated with 2DVD, POSS, etc.; DWR, D3R, …
- More detailed study possible in different climatology; practical impact on improving or validating snow microphysics modeling.
- A number of numerical forecast models will be used during Olympics and it is very important to get the microphysics "correct".