Improving hail detection and hail size estimates from polarimetric radar.

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Outline

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- Research objectives
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  - Surface hail observations overview
- Methodology
  - Current hail detection/size algorithms
  - Polarimetric hail algorithm overview
- Expected outcomes

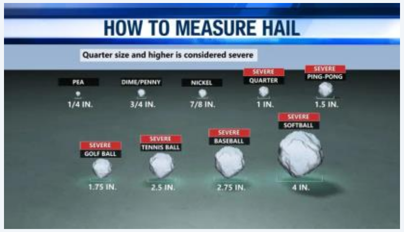
MOTIVATION

What is hail?
Precipitation in the form of balls or irregular lumps of ice, always produced by convective clouds, nearly always cumulonimbus.

Every year losses from hail damage are in the hundreds of millions of dollars. A single hail event in Calgary in June 2020 caused 1.3 billion dollars in insured losses.

Damage is not only limited to property like cars and houses, but also to farms and crops. Insured losses to Canadian crops average about $200 million/year (Air Worldwide, 2016)

1. HAIL



2. IMPACTS

MAIN RESEARCH OBJECTIVE

The overall objective of this research is to improve hail detection and hail sizes estimated from operational weather radar data by utilizing the new polarimetric variables from the Canadian S-band network.

SPECIFIC OBJECTIVES

1) To develop and apply dual polarization(DP) radar processing techniques for improving the quality of the radar data for hail identification and hail size discrimination.

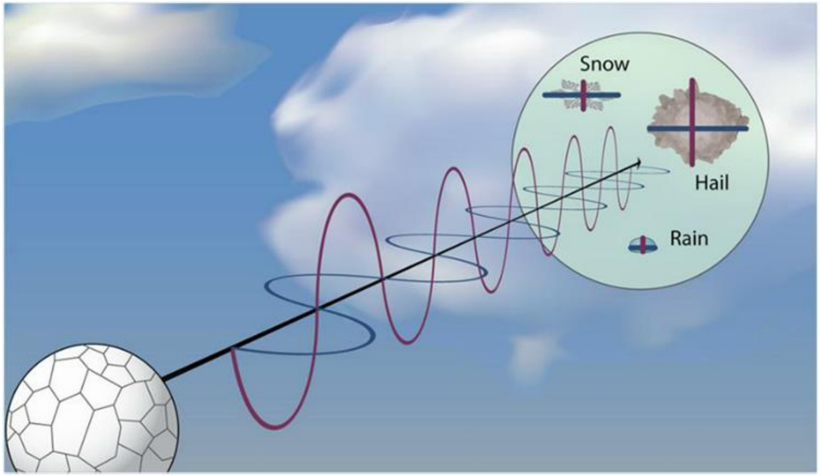
2) To revise existing hail algorithms (e.g., MESH, VIL) by using DP quality-controlled data and formulations of the hail kinetic energy flux, reflectivity thresholds and weighting parameters.

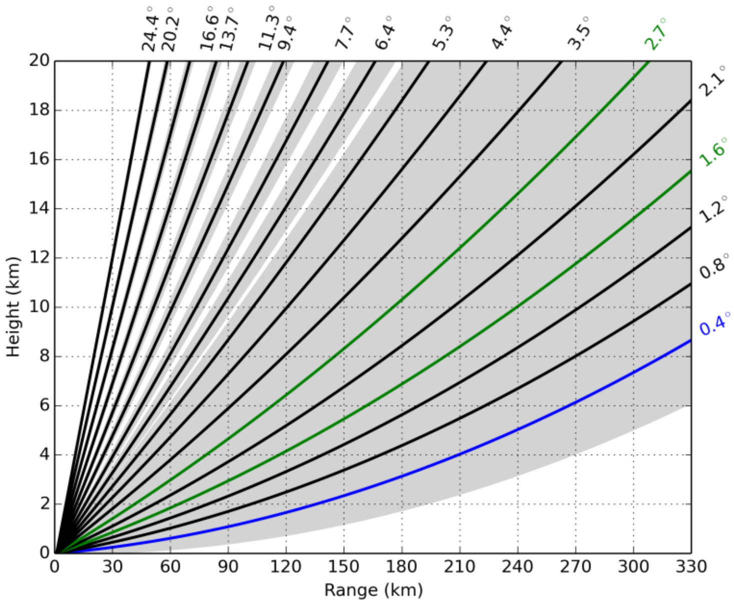
3) To develop and incorporate dual-polarization melting layer detection algorithm (MLD), that estimates freezing level heights for use in the hail algorithms.

4) To design and implement a hybrid method of hail detection and hail-size estimation that combines conventional and DP data.

5) To conduct statistical assessments of the existing and advanced hail algorithms with NHP ground observations to ensure improved performance and reliability.

RADAR OVERVIEW





1. **Radar Reflectivity** (Z_H): Related to power of H, (P_{HH}), of the backscattered electric field
2. **Differential Reflectivity** (Z_{DR}): Ratio of scattered H and V power returns (P_{HH}/P_{VV})
3. **Correlation Coefficient** (ρ_{HV}): Correlation of the time series of H and V returns
4. **Differential Propagation Phase** (ϕdp): Difference of the phase between H and V pulses
5. **Specific Differential Phase** (K_{dp}): The range derivative of ϕdp (° km^{-1})
6. **Velocity (V):** Velocity component of targets along the radar beam

RADAR DATA – Radar Reflectivity (Z_H)

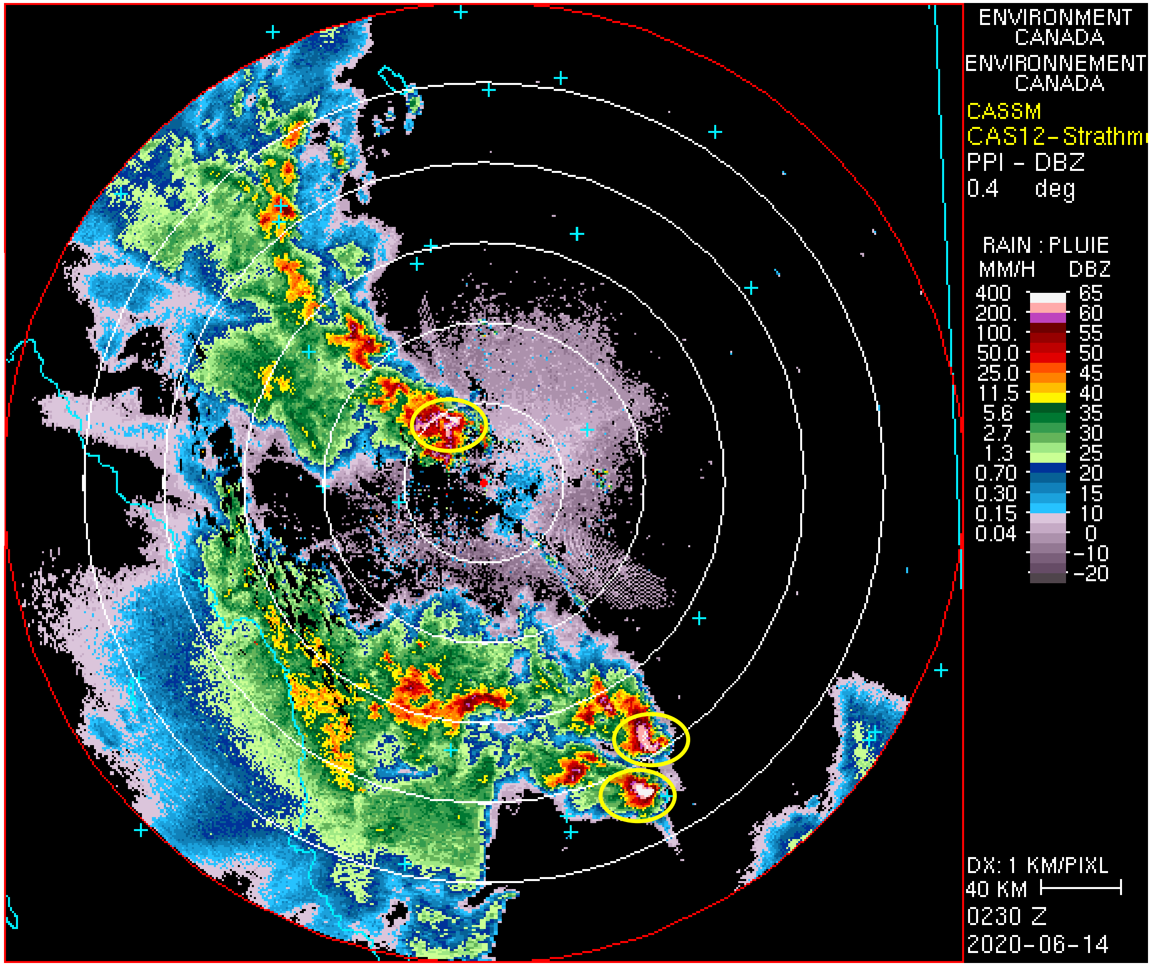
- Z_H is corrected for ground clutter and noise.

$$Z = \frac{1024(\ln 2)}{\pi^3 c}\left[\frac{\lambda^2}{P_t G^2 \tau \Phi^2}\right]\left[\frac{r^2 \overline{P}_r}{|K|^2}\right]$$

Radar Reflectivity Factor = constants * (radar properties) * (target properties)

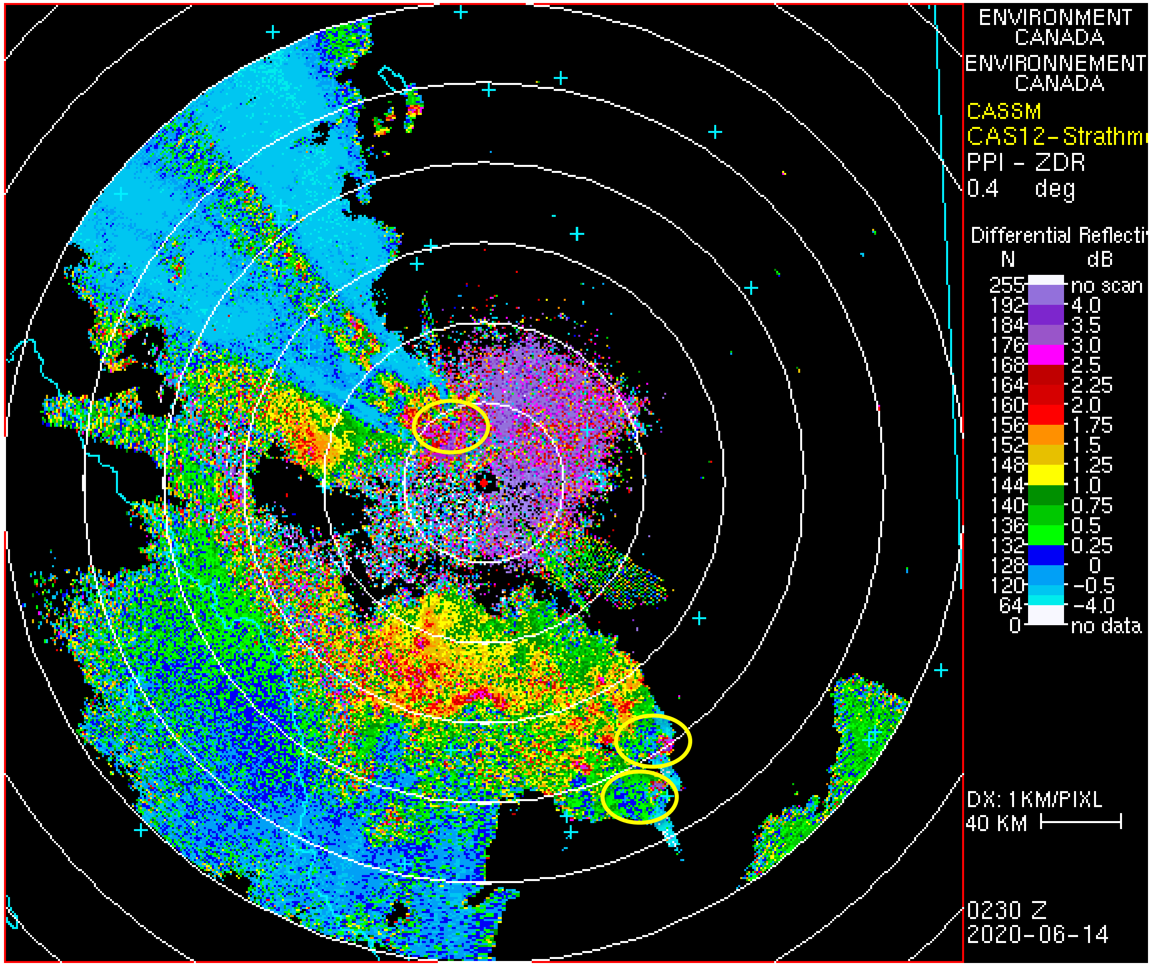
$$dBZ = 10 * log_{10} Z$$

Radar measurement are equivalent reflectivity assuming liquid water spheres.



RADAR DATA – Differential Reflectivity (Z_{DR})

- Ratio of scattered H and V power returns (P_H/P_V).



$$Z_{DR} = 10log_{10}\left(\frac{Z_{HH}}{Z_{VV}}\right)$$

Additional polarimetric variables required for algorithm development:

- Correlation Coefficient
- Differential Phase
- Specific Differential Phase

RADAR DATA – Measurement biases

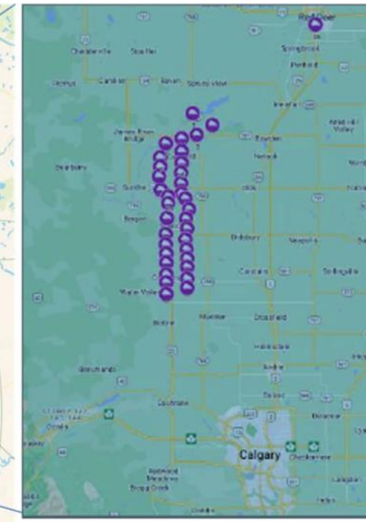
Variable biases:

- Several factors cause biases in the radar variable estimates.
- Different factors affect the variables differently.
- Some radar variables are very vulnerable to bias.
- Contamination from non-meteorological sources affect all variables.

Parameter	Calibration biases	Attenuation	Partial beam blockage	Wet radome	Low signal to noise ratio	Non-uniform beam filling
Z	Yes	Yes	Yes	Yes	Yes	Yes
Z_{DR}	Yes	Yes	Yes	Yes	Yes	Yes
ϕ_{DP}	No	No	No	No	No	Yes
K_{DP}	No	No	No	No	No	Yes
ρ_{HV}	No	No	No	No	Yes	Yes
V	No	No	No	No	No	No

DATA SOURCE - NHP Ground Observations

- Deployment of hailpads in "hail alley" ahead of thunderstorms.
- Hailpads provides estimates of hail sizes and kinetic energy of hailstones hitting the pads.
- Hail disdrometers (19) in Calgary to estimate hail sizes.
- Hail collection teams deployed to collect samples for later analysis (e.g., measure sizes, weights, densities etc.).
- Teams also conducts damage surveys and use drone to identify hail extent on the ground.



This ground observation dataset will be crucial for validating radar derived algorithms.

METHODOLOGY

Current radar-based hail algorithms broadly falls in two categories:

1) Hail identification based on reflectivity at certain height
    - Max reflectivity on a PPI or CAPPI
    - Max reflectivity in a vertical column of reflectivity
    - Difference between 45 dBZ and the melting level > 1.4 km (Waldvogel 1979).
    - Integrating reflectivity in a vertical column (VIL and VIL density, e.g., Amburn and Wolfe, 1997)
    - MESH (Witt et. al., 1998) relates reflectivity to hail kinetic energy flux to determine SHI (Severe Hail Index), which is weighted by reflectivity and temperature above the freezing level.

$$\text{SHI} \equiv 0.1 \int_{Ho}^{Hm20} W\big(Z(h)\big).\,WT(h).\,\dot{\text{E}}(Z(h))\,dh$$

$$\text{MESH} = 2.54\,(\text{SHI})^{0.5}$$

The VIL and MESH algorithms are used operationally in Canada

METHODOLOGY

2) Polarimetric methods

- Polarimetric methods are PPI based.
- Method studied so far uses reflectivity and differential reflectivity (Aydin et. al., 1986)
- Fuzzy logic hydrometeor classification methods.

$H_{DR} = Z_H - f(Z_{DR})$, where

$f(Z_{DR}) = 27$ for ($Z_{DR} \leq 0$ dB)

$= 19Z_{DR} + 27$ for ($0 \leq Z_{DR} \leq 1.74$)

$= 60$ for ($Z_{DR} \geq 1.74$ dB)

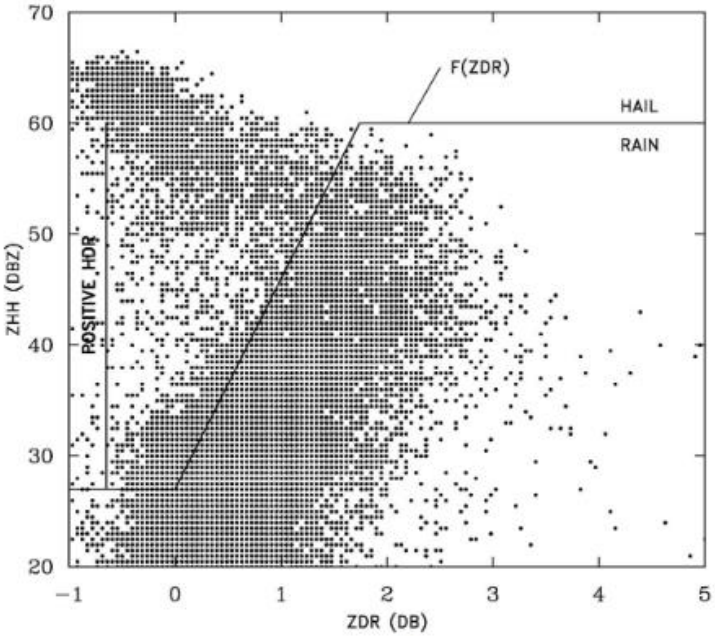
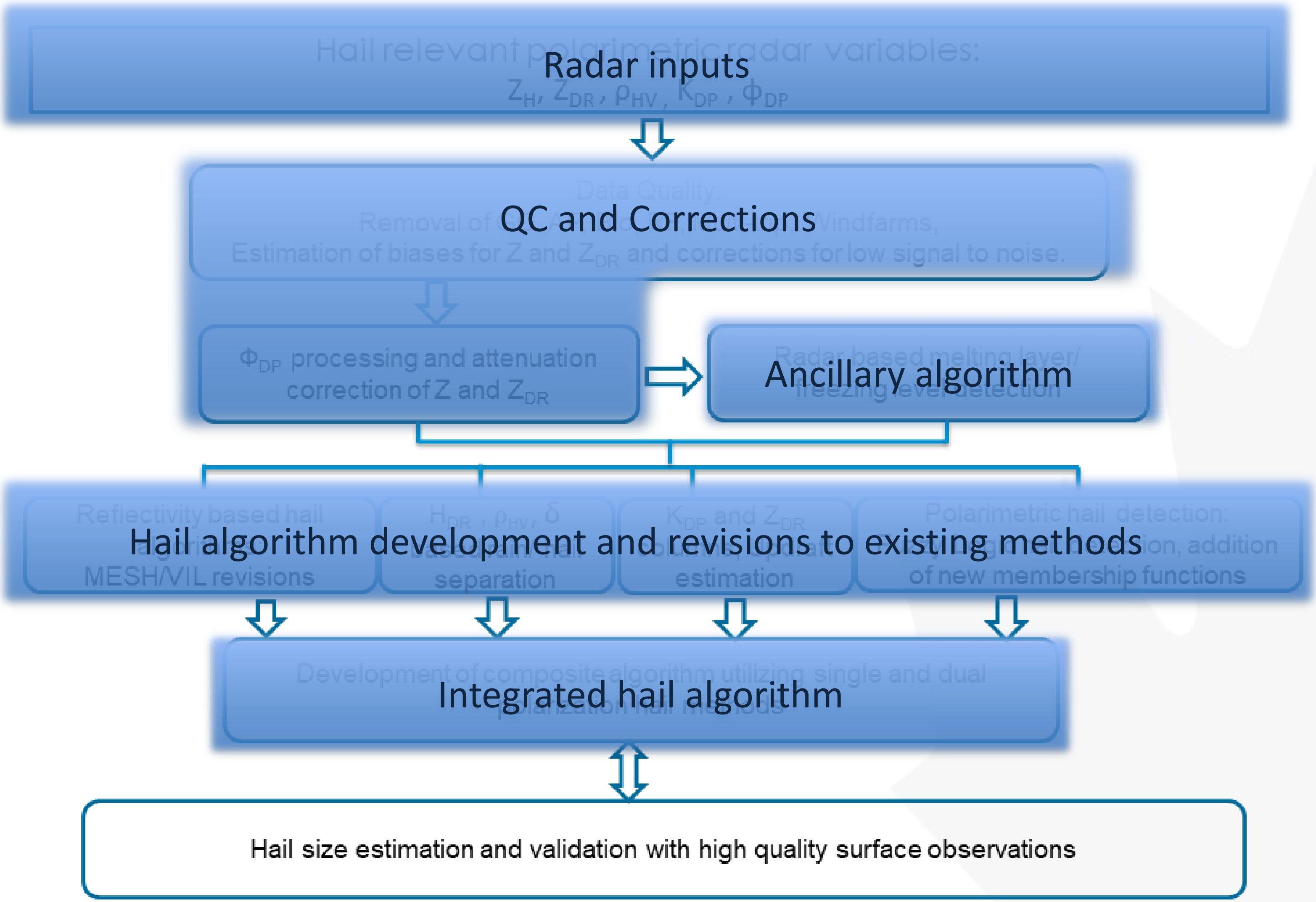


FIG. 1. Scatterplot of Z_{HH} and ZDR data collected by the CSU-CHILL radar at 0.5° elevation angle at 2343 UTC 6 Jun 2003. The H_{DR} rain–hail boundary as defined in Aydin et al. (1986) is included. (After Fig. 6 in Aydin et al. 1986.)

Hail detection and hail size estimation



EXPECTED OUTCOMES

- Improved hail algorithm from combined single polarization (with revised parameters) and dual polarimetric methods. Performance assessed with quality surface observations.
- Improved radar-based hail detection and hail size estimate algorithm are expected to be robust, performs well in most situations, and resistant, not significantly affected by biased data (use bias corrected).
- Improve the identification of damaging hail on the ground with high spatiotemporal resolution and coverage as opposed to reports which are sparse.
- Early radar detection of developing hail in thunderstorms could provide guidance to forecasters about evolving hail threats. The hail algorithms are expected to improve nowcasting.
- Radar identified hail location and hail size estimates are expected to assist with hail damage estimation methods.