Dual-Doppler and Dual-Polarization Radar Analysis of the 27 November 2014 Brisbane Hailstorm

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Outline

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The overall objective is to analyze different radar observations in order to show how operational dual-polarization radars and a denser radar network allowing for dual-Doppler 3D wind retrievals could be used operationally to improve the warning lead time of a possible catastrophic storm event and assist with post-event mitigation.
Features of Brisbane Hailstorm
(27 Nov 2014)

- Golf balls size hails
- Destructive gust winds (140 km/h)
- 4 lights aircraft were flipped and extensively damaged
- 39 People injured (12 taken to the hospital)
- Over 100,000 insurance claims (2/3 for vehicles)
- Estimated damage costs was over $1.1 Billion

Source: www.abc.net.au
Radar Networks

**CP2 Radar**
- Dual frequency (S, X), dual polarization, Doppler, 1° beamwidth
- Recent upgrade of antenna
- Samples severe storms including large hail

**Mt Stapylton Radar**
- Dual Doppler with operational S-band 1° beamwidth

Tessendorf et al. (2012); BAMS
3D Wind Retrievals

Adapted from variational technique from Protat and Zawadzki (1999, JAOT), see also Collis et al. (2013, JAOT) for further refinements

Uses two radial velocities as weak constraints

Uses a weighted average of upward and downward integration of the air mass continuity equation

Uses smoothness constraint on the second order horizontal derivatives of the horizontal wind components

Typical resolution: 1.5*1.5*0.5 km grid size - Code runs semi-operationally in < 1 min for a volumetric scan in Brisbane, Sydney, and Darwin areas.

Something new: uses the dual-pol hydrometeor classification to constrain the terminal fall speed correction (important for hail!).
Impact on Fall Speed

"Ice aggregates" relationship (Protat and Williams 2011)

"Hail" relationship (Conway and Zrnic 1993)

Conway and Zrnic (1993)

\[ V_T \text{ (hail)} = -3.95 \times Z^{0.148} \quad [Z \text{ in linear units}] \]
Existing Hydrometeor Classifications

Limitations

Methods in literature: Decision tree, Fuzzy logic, Neural networks, Bayesian

- Relying on thresholds obtained by scattering simulations
- Considering polarimetric variables individually
- Assuming the shape of membership functions or PDFs
- Not naturally taking into account the radar noise characteristics
Hydrometeor Classifications
(A new approach)

Data quality control:

- $K_{dp}$ Estimation
- Data Smoothing
- Classification of Meteorological and Non-Meteorological Echoes

Hydrometeor classification

- Probability density function (PDF) based on cluster analysis
- Hydrometeor classifier:
  - Maximum Prototype Likelihood Classifier (MPLC)
  - Bayesian Classifier (BC)
  - Markov Random Field – Maximum A Posteriori method (MRF-MAP)
  - Decision Tree – Bayesian Combined method (DTB)
New Hydrometeor Classification

Advantages

Cluster-based method

- A cluster is a collection of data points in high dimensional space.
- Clustering provides objective grouping that can be related to cloud physics.
- Clusters are combined to produce PDFs for a particle hydrometeor type.

Advantages

- An incremental & case-based method
- No pre-determined shape of PDF
- Naturally handling radar-specific noise and uncertainties
- Easily tuning classifiers

Courtesy: Dr Guang Wen
**Objective Hydrometeor Classification**

**A new system for hydrometeor classification**

The cluster-based method consists of two components:

- **Prototype Generation Unit**
- **Hydrometeor Classification Unit**
Prototype Generation Unit

Flowchart of Prototype Generation Unit

Data are initially separated into two parts: ICE & LIQ. Some types, such as supercooled water and melting ice, are allowed in the “ICE”, while other types could exist in the “LIQ”.

The cluster number should be larger than the number of hydrometeor types that can possibly be discriminated with polarimetric variables & temperature (10 clusters for “ICE” & 7 clusters for “LIQ”).
Comparison: Prototype PDFs

(Wen et al. 2015a, JAOT)
PDFs for Moderate Rain

PDF for moderate rain: $Z_h-Z_{dr}$ (top left), $Z_h-K_{dp}$ (top right), $Z_h-\rho_{hv}$ (bottom left) & $Z_h$-Temperature (bottom right)
Hydrometeor Classification Unit

**Maximum Prototype Likelihood Classifier (MPLC)**

$$p_{\text{max}} = \arg \max_j \alpha_j \Pr(X | P = P_j, C)$$

The prototype with **largest prototype likelihood** is considered as the one that is the most similar with the data point.

The hydrometeor type of the **most similar prototype** could be assigned to the data point.

**Bayesian Classifier (BC)**

$$C = \arg \max_c \frac{\Pr(C)\Pr(X | C)}{\sum_{c \in C} \Pr(C)\Pr(X | C)}$$

The probability density function (PDF) for each hydrometeor type is modelled as a **Gaussian mixture** composed of the prototypes modelled as **Gaussian distribution**.

A **prior** probability is used to reflect the analyst’s subjective judgment that may not need to be a parametric form.
Hydrometeor Classification

Brisbane Hailstorm Case
Mapping to Cartesian Coordinates

Hydrometeor Classification 20141127 0651

Updraft = Yellow (+3, +6, +9 ms⁻¹)
Downdraft = Red (-3, -6, -9 ms⁻¹)

Confidence Map 20141127 0651

Hydrometeor Classification 20141127 0651

Confidence Map 20141127 0651
Mapping to Cartesian Coordinates
(Interpolation)
Mapping to Cartesian Coordinates
(Interpolation & Melting Layer Correction)
Validation (Hail Swath)

Overlaid is the Request For Assistance (RFA) Points 10 days following the storm on the 27th.
Validation (Heavy Rain Swath)

Overlaid is the Request For Assistance (RFA) Points 10 days following the storm on the 27th.
Animation of Hail Life-cycle

Hydrometeor (MPLC) Classification

Updraft = Yellow (+4, +8, +16 ms⁻¹)    Downdraft = Red (−4, −8, −16 ms⁻¹)

20 ms⁻¹

25 ms⁻¹
Hail Life-cycle

Rain/hail mixture in the beginning representing smaller hail size
Hail Life-cycle

Big updraft ahead where the hail is falling accelerating low-level gust wind
Stronger updraft leads to production of hail again
Summary

- There exist a consistency between the strong updraft and hail formation.

- A clear mechanism on how hails end up falling on the ground and creates a micro burst can be clearly seen.

- It is too early to comment on warning lead time, but we hope that the retrievals of 3D winds in real time and existence of a high reflectivity indicates that hail is going to form.

- In future, we are going to investigate the relationship between dynamics and hail core evolution quantitatively.