School of Earth and Environment
INSTITUTE FOR CLIMATE & ATMOSPHERIC SCIENCE

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Verification of Hydrometeor Classification with Dual-Polarisation Radar

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Supervisors

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NERC SCIENCE OF THE ENVIRONMENT

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Met Office

Why is Radar-Derived Hydrometeor Classification Important?

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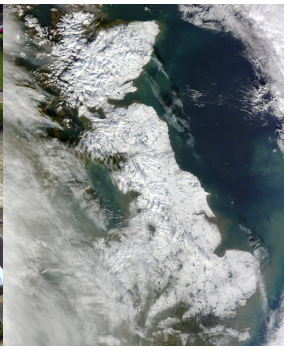
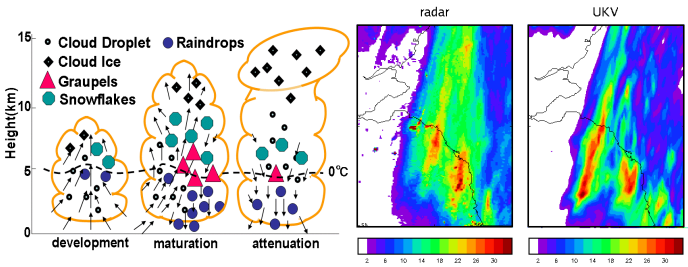
- More accurate surface precipitation quantification for snow, hail.
- The snow/rain boundary can be seen by forecasters near real-time.
- Flood forecast modelling (Environment Agency, SEPA).
- Atmospheric hydrometeor information can be assimilated into NWP models.
- Indicates interior cloud microphysical processes for additional research - improved NWP parameterisations.
- Radar has excellent temporal (5 minute) and 3D spatial resolution (<1km, 5 tilts).

Environment Agency

HIGHWAYS AGENCY

SEPA Scottish Environment Protection Agency





Single-Polarisation Radar

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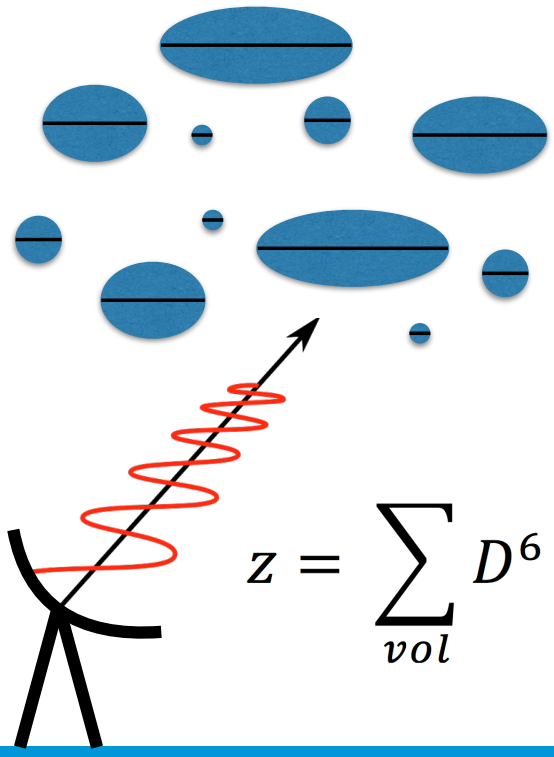
- Horizontally polarised beam.
- One output: Radar reflectivity factor [z] which is the sum of all hydrometeor diameters to the sixth power.
- Weighted to the size of the hydrometeors rather than the number concentration.
- However, lots of small liquid droplets can have the same reflectivity as a few large drops.
- For QPE, Z—R relationship assumes all liquid hydrometeors.



Dual-Polarisation Radar

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- Radar backscatter cross-sections are different for each polarisation.
- Several additional variables are derived from the Jones scattering Matrix

Tx \ Rx	h	v
h	S_{hh}	S_{vh}
v	S_{hv}	S_{vv}

Fig 1. Jones Matrix power notation

1. Differential Reflectivity: Z_{DR}
2. Correlation Coefficient: ρ_{hv}
3. Specific Differential Phase: K_{DP}
4. Linear Depolarisation Ratio: LDR_{vh}

1. Differential Reflectivity: Z_{DR}

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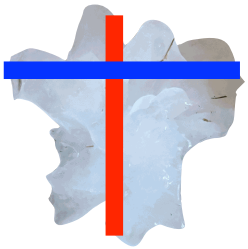
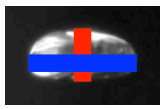
$$10log_{10}\frac{|S_{hh}|^2}{|S_{vv}|^2}$$

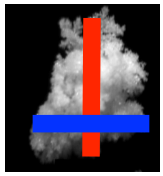
- Indicates shape of hydrometeors in the sample volume.
- Log-ratio of horizontal and vertically polarised radar reflectivity factors, Z_h to Z_v.
- Weighted to size rather than number of hydrometeors.



$Z_{DR} = 0$



$Z_{DR} > 0$



$Z_{DR} < 0$

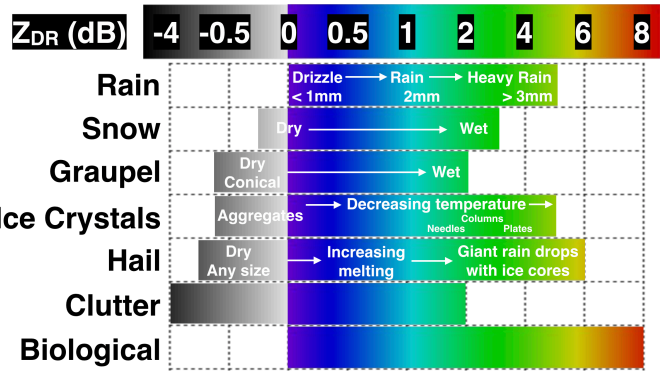


Fig 2. Typical values of Z_{DR}

2. Correlation Coefficient: ρ_{hv}

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- The amount radar pulses differ from one another within one ray.
- Indicates the uniformity of the scattering properties of the target *i.e.* the diversity of hydrometeor shapes.
- Equivalent to *r-value* in statistics.
- Mainly used to show non-hydrometeor objects like birds, insects or ground clutter which can therefore be removed from the raw data. Melting ice distinct.

$$\frac{|\langle nS_{hh}S_{vv}\rangle|}{(\langle n|S_{hh}|^2\rangle\langle n|S_{vv}|^2\rangle)^{1/2}}$$

$\rho_{hv} < 1$ $\rho_{hv} = 1$

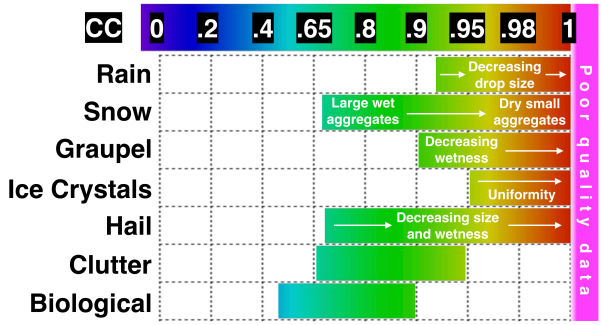

Fig 3. Typical values of ρ_{hv}

3. Specific Differential Phase: K_{DP}

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- As the beam travels through hydrometeors it slows to ~0.75·c so the phase of the beam is shifted.
- A minuscule amount of power is lost to the hydrometeor, but this becomes significant in heavy precipitation.
- A measure of pulse attenuation, caused by heavy rainfall or hail.

$$\frac{1}{2}\frac{\partial(\Phi_{hh}-\Phi_{vv})}{\partial r}$$

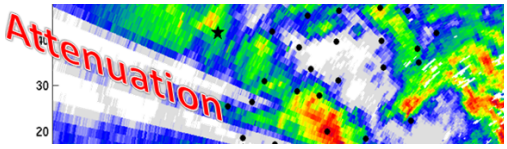


Fig 4. Attenuation shadow © Rob Thompson

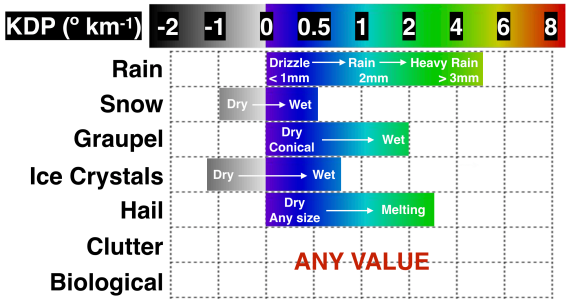
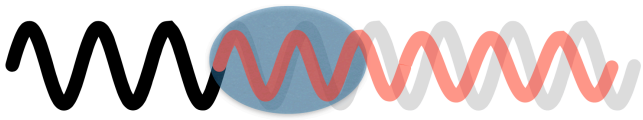


Fig 5. Typical values of K_{DP}



Original Beam

Phase shifted
Amplitude reduced

4. Linear Depolarisation Ratio: LDR_{vh}

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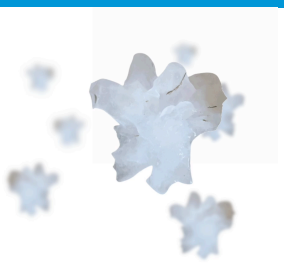
$$10log_{10}\frac{|S_{vh}|^2}{|S_{hh}|^2}$$



- Ratio of the cross-polar to co-polar backscattered signal powers. The cross-polar is transmitted in the horizontal and received in the vertical polarisation.
- Shows how much energy has switched to the other polarisation.
- Indicates slanted, tumbling (hail) or wobbling (large droplets) objects.

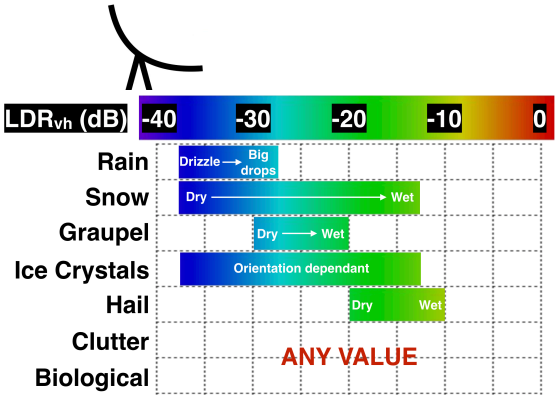


Fig 6. Typical values of LDR_{vh}

Hydrometeor Classification Algorithms

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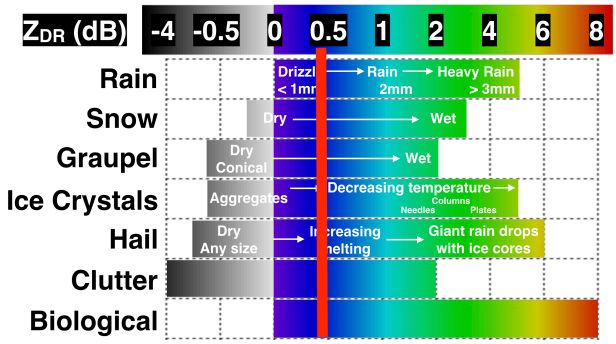

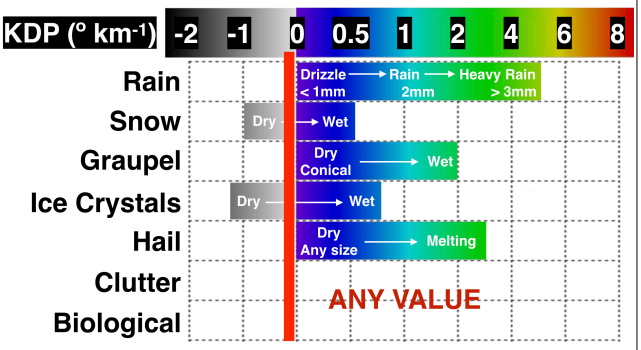

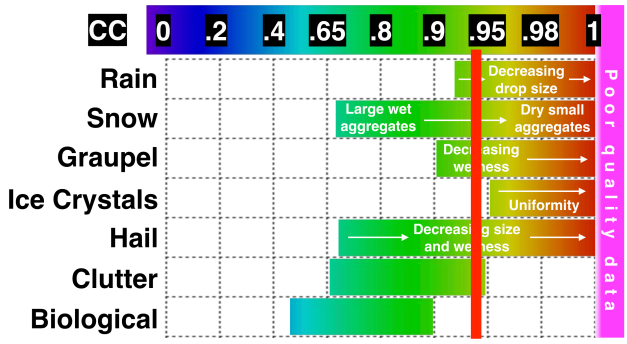

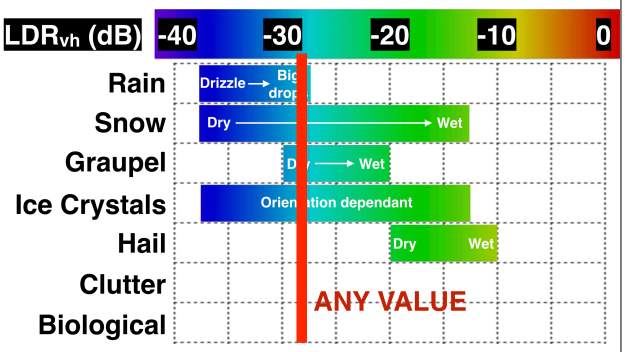

Hydrometeor Classification Algorithms

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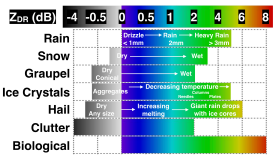
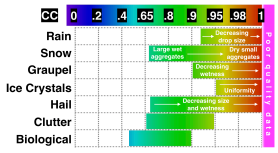
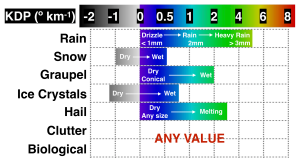
Z_{DR} →



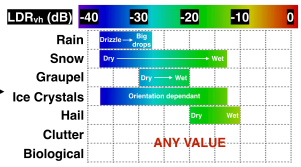
ρ_{hv} →



K_{DP} →



LDR_{vh} →



Rain	3/4
Snow	4/4
Graupel	3/4
Ice Crystals	3/4
Hail	2/4
Clutter	4/4
Biological	3/4

Output = Snow

HCAs combine observed values and knowledge of typical values to determine hydrometeor type

HCA Literature

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- Have mainly been designed for American S-band radar (Park et al. 2009) or mobile X-band (Pazmany et al. 2013). UK network is C-band.
- Commonly combine dual-pol variables with other data such as sample height, reflectivity, and *NWP temperature*.

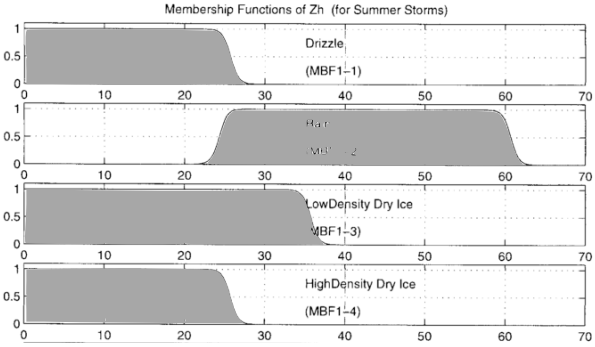

Fig 7. Liu and Chandrasekar, 2000.

Notable Papers

2000: *Liu and Chandrasekar*, fuzzy logic with neural learning i.e. self-correction.
Verified: 4 instrumented aircraft flights.

2009: *Park et al.*, USA S-band wavelength scheme (implemented 2011-2013).
Verified: human analysis of MCS & crowdsourced reports of a winter storm.

2013: *Al-Sakka et al.*, MeteoFrance fuzzy logic scheme combining multiple wavelength radars.
Verified: several human-judged cases.

Project Questions

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Q1: What is the best method to evaluate the skill of hydrometeor classification and surface precipitation type products?

Q2: What is the uncertainty of current surface type products, using single-pol radar and NWP?

Q3: How much does dual-polarisation radar reduce the uncertainty in hydrometeor classification?

Q4: What is the impact of having improved skill in hydrometeor classification?

The Importance of Uncertainty Quantification

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- Forecasters can estimate the probabilistic risk to customers from damaging precipitation such as hail.
- Uncertainty can be carried forward into QPE to give a range or probabilistic value.
- Subsequent research using radar hydrometeor data with error values will be more rigorous.
- Allows hydrometeor data to be used as initial conditions in ensemble forecasts.

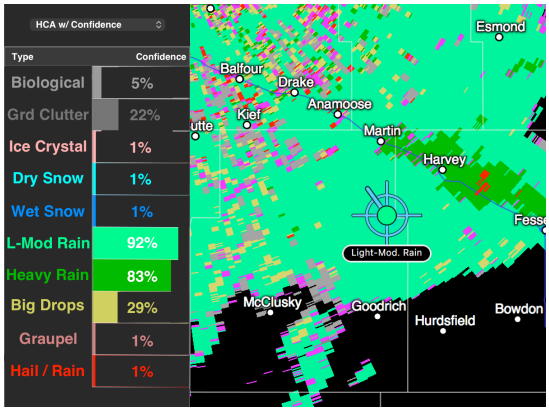

Fig 8. Render of potential MO product

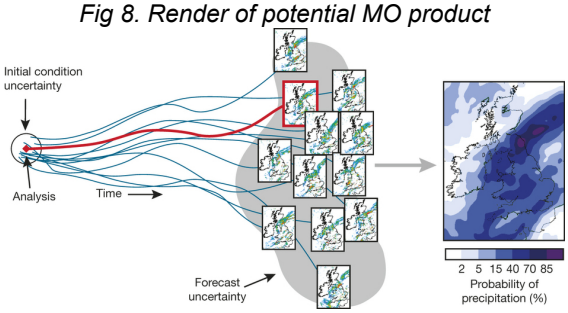

Fig 9. Bauer et al., 2015

UK Met Office C-Band Radar Network

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- 15 Met Office owned radars, 3 non-MO radars.
- 5 minute scans at 5 elevation tilts (+ 1 tilt LDR). All scans combined onto 1 km^2 cartesian grid of surface rainfall rate (QPE). C-Band (5.6 GHz)
- Incremental upgrade to DP began in 2012. Scheduled to complete November 2017. 2 radars left and in progress. 5 years total.

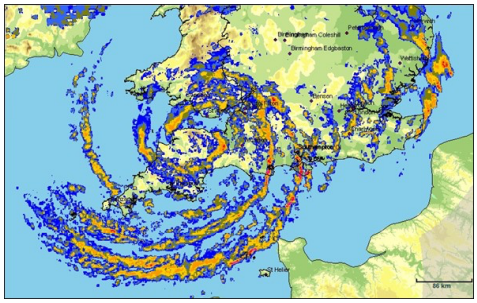

Fig 10. MO surface rainfall, 10:30 29/11/09.

Fig 11. Clee Hill (DP).

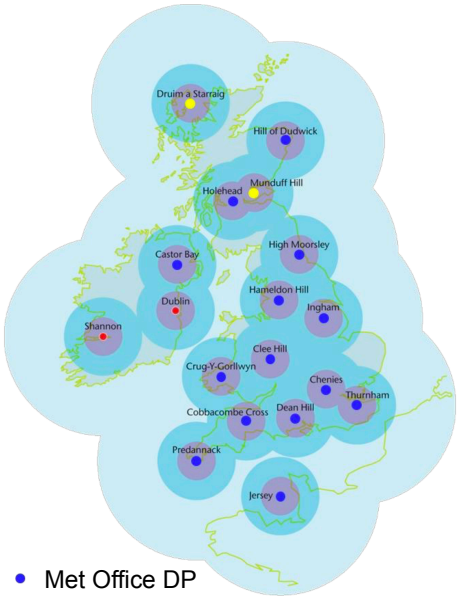

Fig 12. Met Office radar network status as of June 2017. Circles indicate resolution.

Verification Data

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In-situ

(at beam-height)

1. FAAM aircraft

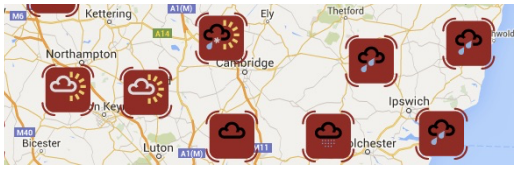
2. ~~Tethered Balloon~~
   - ~~Expensive and dangerous~~
3. ~~UAV~~
   - ~~Expensive~~
   - ~~Illegal to fly above 120m i.e. will not reach radar beam-height~~

Inferred

(at the surface)

1. Met Office surface station reports (SYNOP)

2. Crowdsourced: BBC Weather Watchers



3. DiVeN…

DiVeN: Overview

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Network of 14 laser disdrometers measuring diameter and fall speed of every hydrometeor.

Empirical relationships imply hydrometeor type: Rain, Snow, Graupel, Hail, Mix

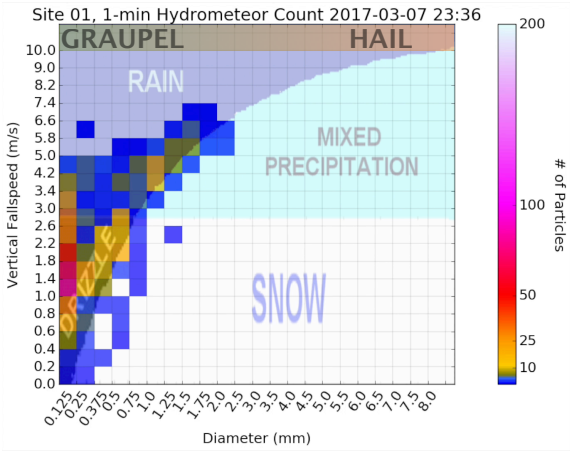

Fig 13. Sample plot from a disdrometer

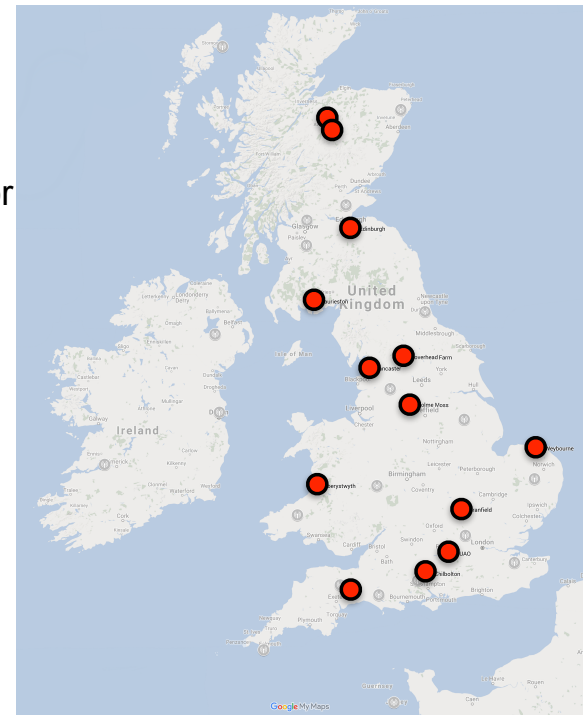

Fig 14. DiVeN locations - Chilbolton has 2 devices.

DiVeN: Install & Open Data

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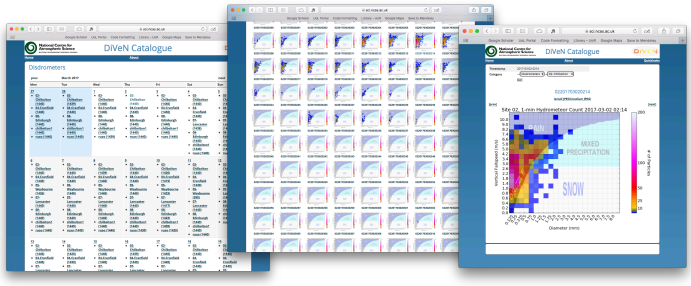
- 2,300 miles in 24 days
- Twin setup @ Chilbolton
- Opportunistic Storm Dorris measurements of snow in Scottish Uplands



- NRT (5 min) data on NCAS website.
- sci.ncas.ac.uk/diven

DiVeN: Validation

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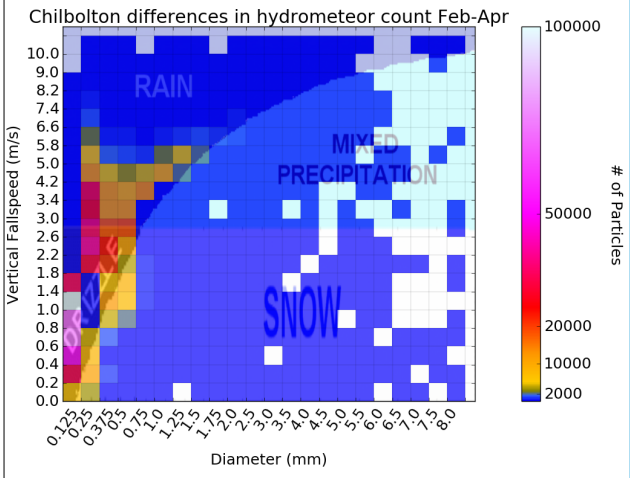
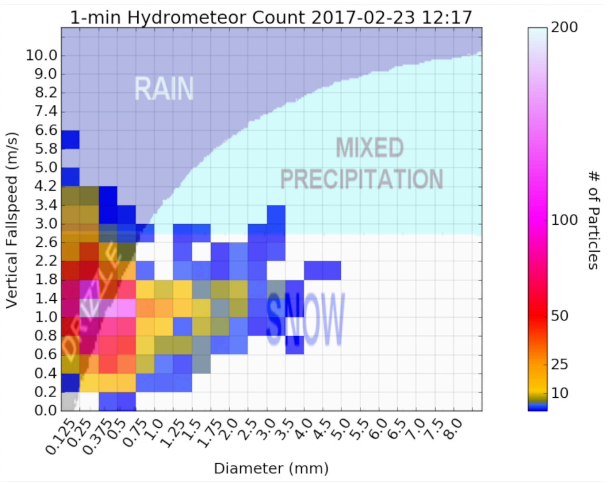
Twin Setup @ Chilbolton



- 7 million hydrometeors measured.
- 10% difference in total count.
- Oddly low difference in first two columns. Future work: time series.

Storm Dorris Case



- Captures several phase transitions.
- Rain vaguely follows Gunn-Kinzer.
- Drizzle remains at all times.

Single-Pol Study: Overview & Method

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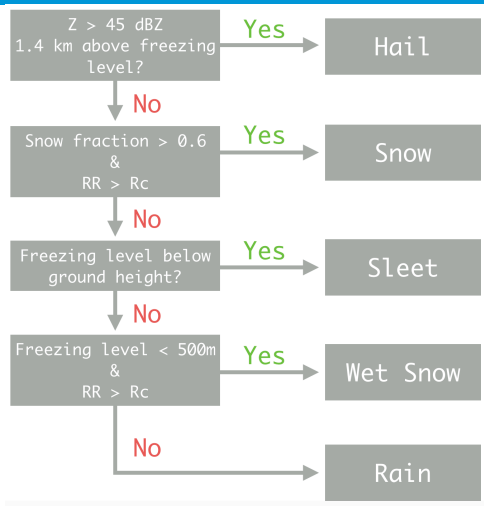
Uses the surface rain rate and model 0ºc wet-bulb isotherm from NWP model. Accounts for orography.

5 classes broadly defined. Used by MO forecasters.

Ran since 2013 so > 3 years of data is archived.



	Explicit	Implicit
Spatial	**1 pixel** **1 km x 1 km**	**9 pixels** **3 km x 3 km**
Temporal	**1 scan** **xx:00 only**	**5 scans** **xx:00 ± 10 mins**
SYNOP Code Ambiguity	**Only one precip type mentioned** *160: 'RAIN'*	**Allow Ambiguity** *93: 'Thunderstorm in past hour, slight snow (or rain & snow, or hail)'* **Would be a hit if radar said either rain, snow, or hail**

Strict and lenient approaches reveal the ***range*** of accuracy.

So the "true" accuracy must exist between those extremes

Single-Pol Study: Initial Results

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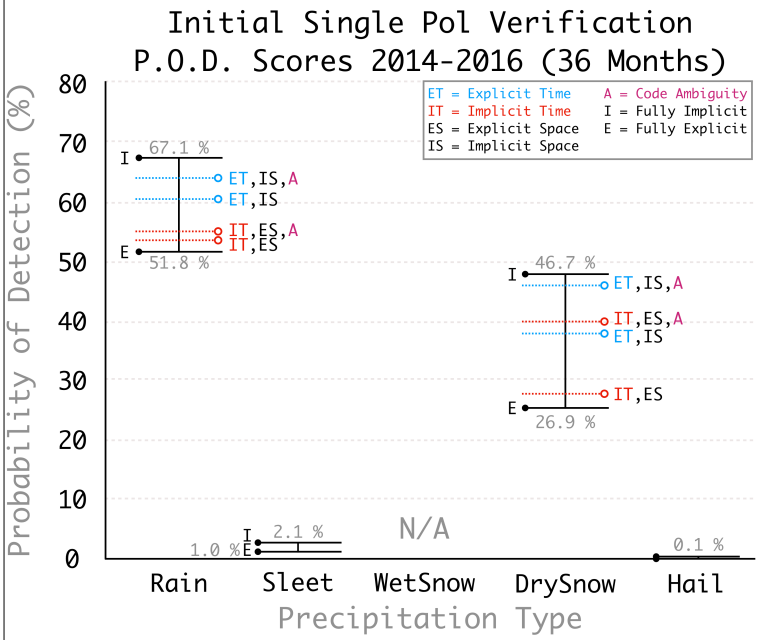
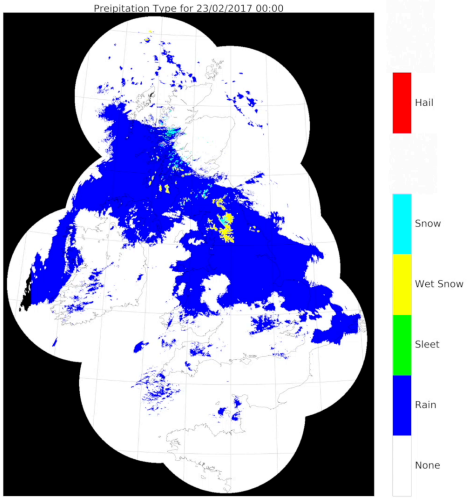


- Ranges are not too large - approach is acceptable.
- Rain: higher skill and smaller range vs. dry snow.
- Wet snow: never reported. Hail: diagnosed once.

Storm Dorris Case



- Good agreement with witness and disdrometer.
- Captures orographic detail.
- Wet vs. dry snow line jump.

Future Work *(Year 2)*

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- Methods used in single-pol verification can be applied to dual-pol verification. Cartesian grid to polar grid.
- Attempt to get crowdsourced data and perform accuracy analysis on it.
- Sift through FAAM data for compatibility with DP upgrade: is flight data in range of a DP radar? Were HC instruments working at the time?
- Assist with the collection and analysis of FAAM data on PICASSO field campaign this winter.
- Submit 2 papers this year: DiVeN & Single-pol verification.