Separation of Stratiform and Convective Rain Types using Data from an S-band Polarimetric Radar: A Case Study Comparing Two Different Methods

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Background

- Stratiform and convective rain are associated with different microphysical and dynamical processes and generally produce drop size distributions (DSDs) with different characteristics.

- The frequency of occurrence of stratiform versus convective rain is generally around 4:1, while in terms of rain volume, it is generally around 2:3 depending on land or ocean; or tropical vs extra-tropics.

- These proportions are important for calculating the vertical profile of net latent heating for applications to storm dynamics and, as a constraint, for numerical weather prediction models.

Background

- In *Thurai et al. (ECAS-2020)*, a DSD-based separation method for stratiform and convective rain was presented and tested:

  - using disdrometer data from Delmarva peninsula, USA, a mid-latitude coastal region
  - 1 and 3 minute DSDs data from 2DVD + MPS
  - and the NASA-NPOL S-band polarimetric radar observations over the disdrometers for 'visual' validation.

- In this paper, we apply the DSD-based technique directly to NPOL radar data and compare with another, independent, well-known, texture-based method (*Steiner et al. 1995*) which utilizes the radar reflectivity and its spatial variability.

References:

i. *Steiner, M.; Houze, R.A.; Yuter, S.E. Climatological Characterization of Three-Dimensional Storm Structure from Operational Radar and Rain Gauge Data. J. Appl. Meteor.* ***1995****, 34, 1978–2007.*

ii. *Thurai, M.; Bringi, V.; Wolff, D.; Marks, D.; Pabla, C. Testing the Drop-Size Distribution-Based Separation of Stratiform and Convective Rain Using Radar and Disdrometer Data from a Mid-Latitude Coastal Region. Atmosphere* ***2021****, 12, 392.* https://doi.org/10.3390/atmos12030392

Outline

- Estimating DSD parameters from radar data (S-band)
- NPOL observations: Event on 30 April 2020
- Rain Type Classification
- CFADs
- Summary

Estimating DSD parameters from radar data

Need to estimate the two main DSD parameters, N_W and D_m

N_W : Normalized intercept parameter
D_m : Mass-weighted mean diameter

Use NPOL radar reflectivity and differential reflectivity (Z_h and Z_{dr})

The estimation of D_m is a two-step procedure, the first step involving the estimation of an intermediary parameter, D_m' which depends on two chosen reference moments, say, M_i and M_j.

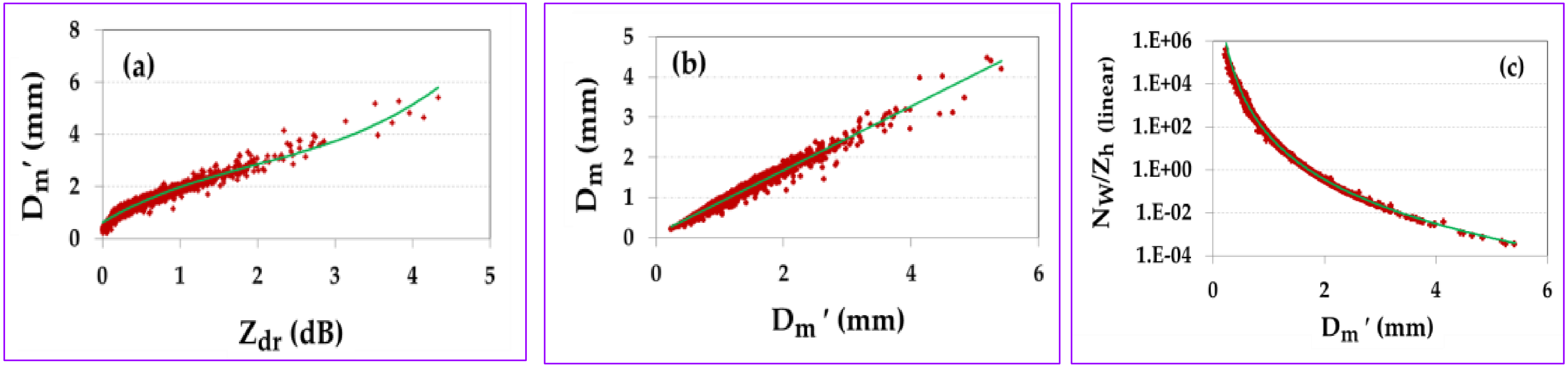
Then D_m' is given by: $$D_m' = \left(\frac{M_j}{M_i}\right)^{\frac{1}{(j-i)}}$$

For N_W, we use $$N_W = \left(\frac{4^4}{6}\right) N_0' \quad \text{where} \quad N_0' = M_i^{\frac{(j+1)}{(j-i)}} M_j^{\frac{(i+1)}{(i-j)}}$$

Estimating DSD parameters from radar data

a) Estimate D_m' from Z_{dr}
b) Estimate D_m from D_m'
c) Estimate N_W from $Z_{h(linear)}$ and D_m'

S-band scattering simulations using DSD data



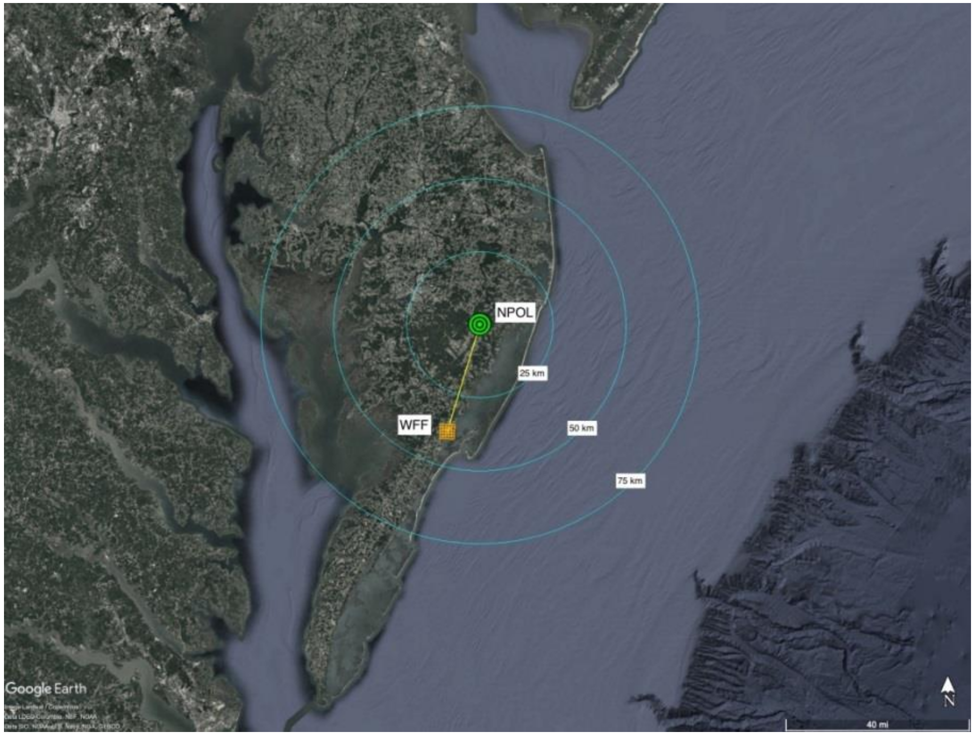
Fitted curves

(a) $$D'_m = 0.0822\, Z_{dr}^3 - 0.4841\, Z_{dr}^2 + 1.7515\, Z_{dr} + 0.628$$

(b) $$D_m = 0.7977\, D'_m + 0.0883$$

(c) $$\frac{N_W}{Z_{h\,(linear)}} = 39.446\, {D'_m}^{-6.839}$$

NPOL observations: Event on 30 April 2020



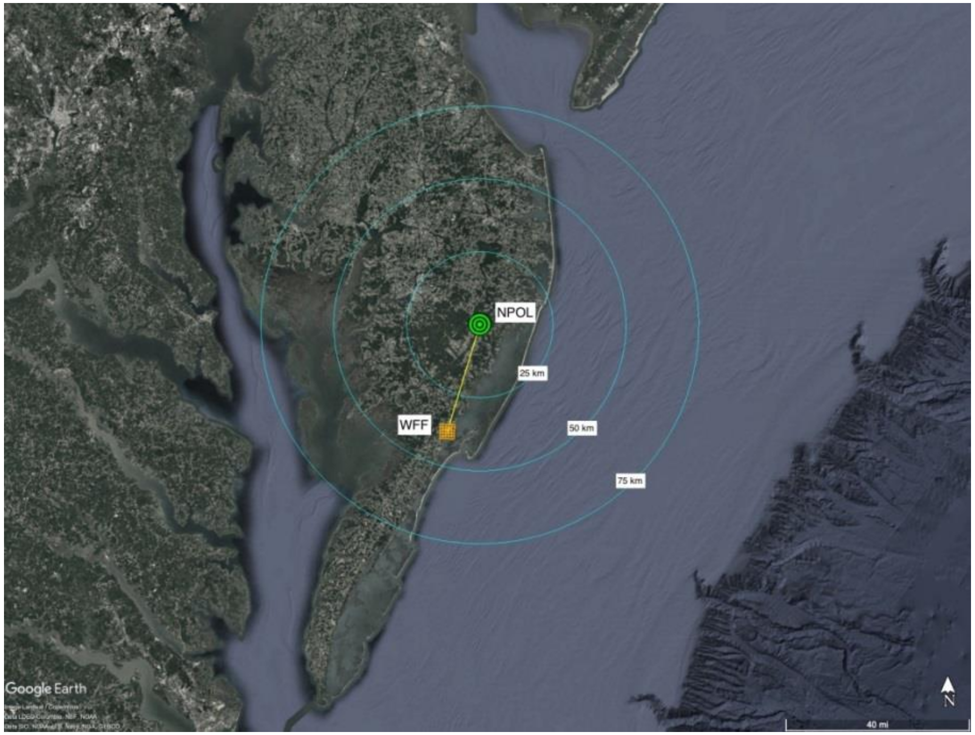
NPOL routine scan sequence includes:

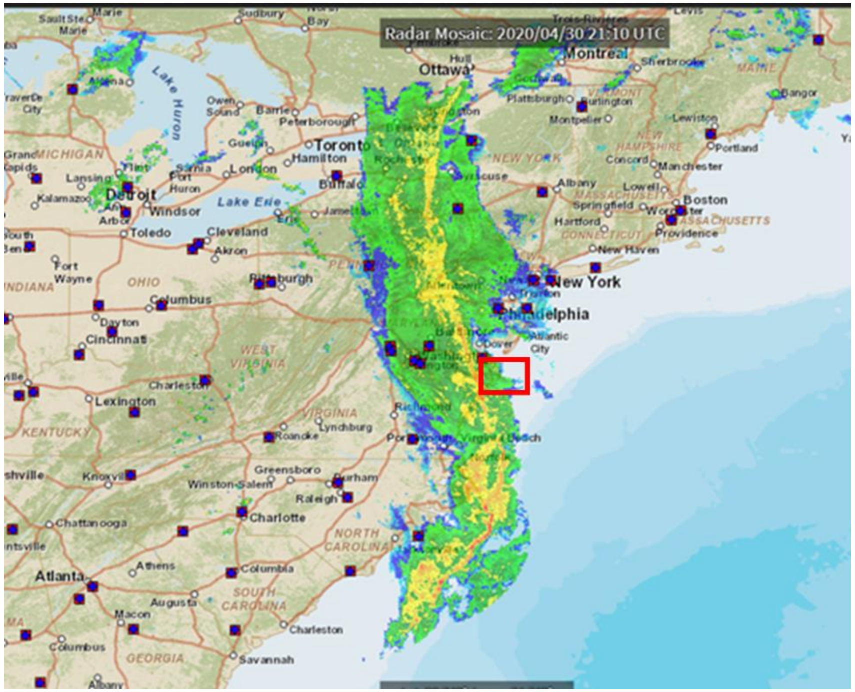
- Volume scans
- RHI scans over the disdrometer site

38 km SSW

- Network of instruments, including 2DVDs,
- MPS (Meteorological Particle Spectrometer) inside DFIR double wind-fence
- MRR, Pluvio, plus many others

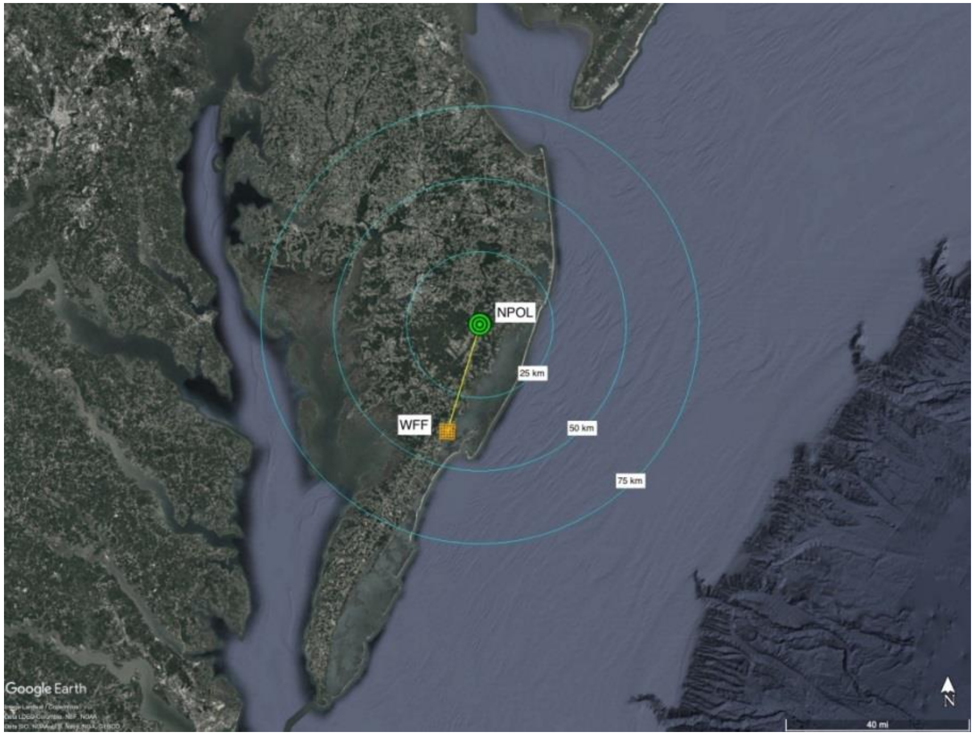
NPOL observations: Event on 30 April 2020

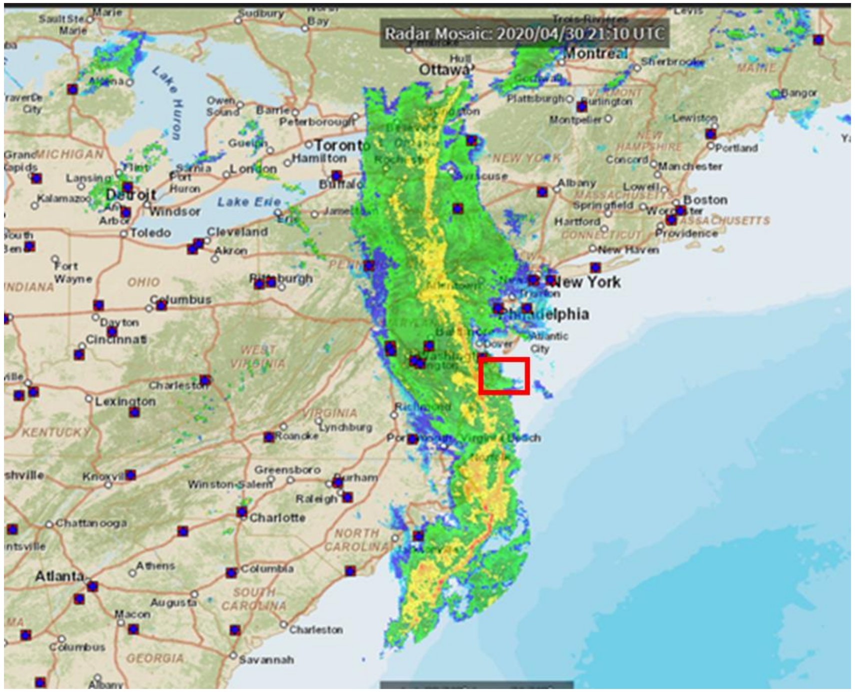




- On 30 April 2020, a slow moving cold front passed over the WFF region.
- A NW/SE oriented line of strong convection with heavy rain moved through the region.
- Reflectivity within the line was as high as 60 dBZ in areas. The convective line was embedded in stratiform with reflectivity in the range 25 to 35 dBZ.
- As recorded by NASA rain gauges at Wallops, approximately 20 mm accumulated between 19 to 22 h UTC, the majority of which fell within 30 minutes associated with the convective line.

NPOL observations: Event on 30 April 2020

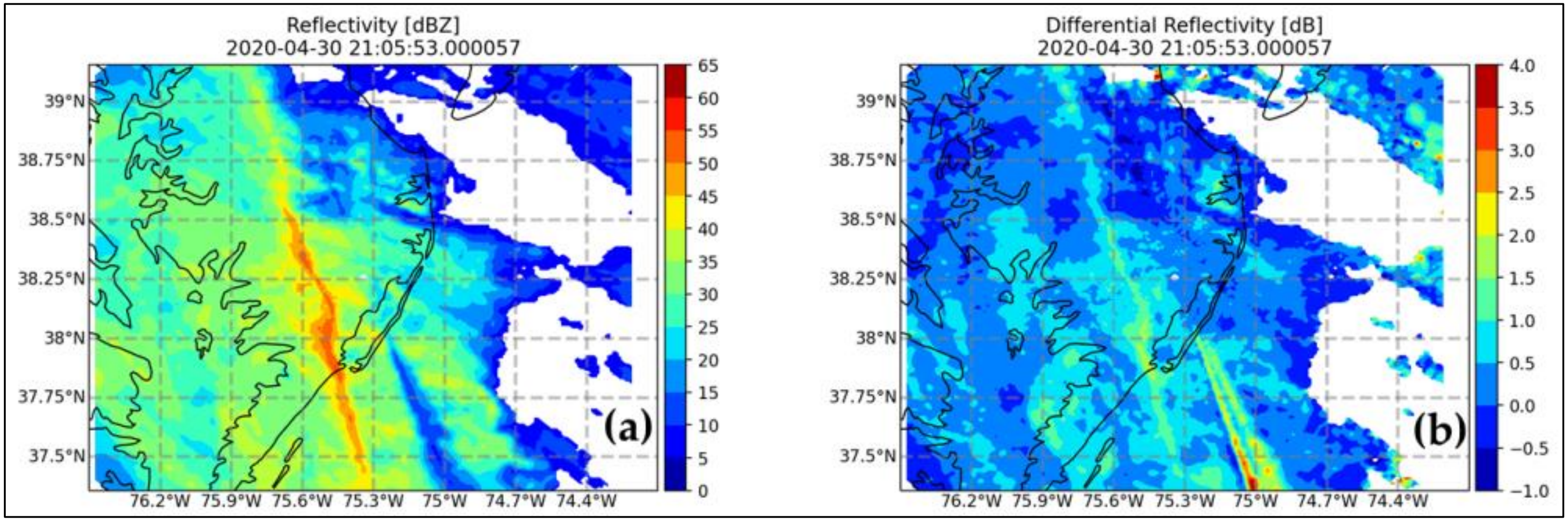




- From the NPOL volume scans ➔ Gridded data were generated for different altitudes
  ➔ Lowest at 1000 m a.g.l.
  ➔ Every 500 m, up to 8000 m a.g.l.

NPOL observations: Event on 30 April 2020

NPOL gridded data at 1000 m altitude with 500 m by 500 m pixel resolution



NPOL observations: Event on 30 April 2020

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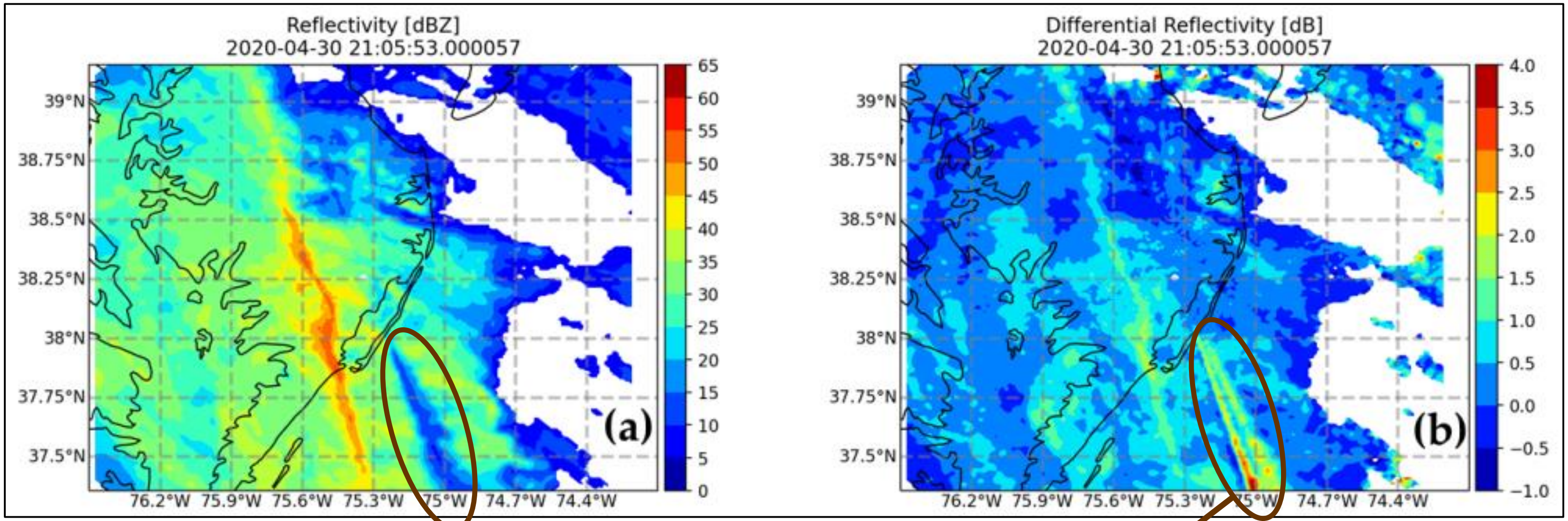
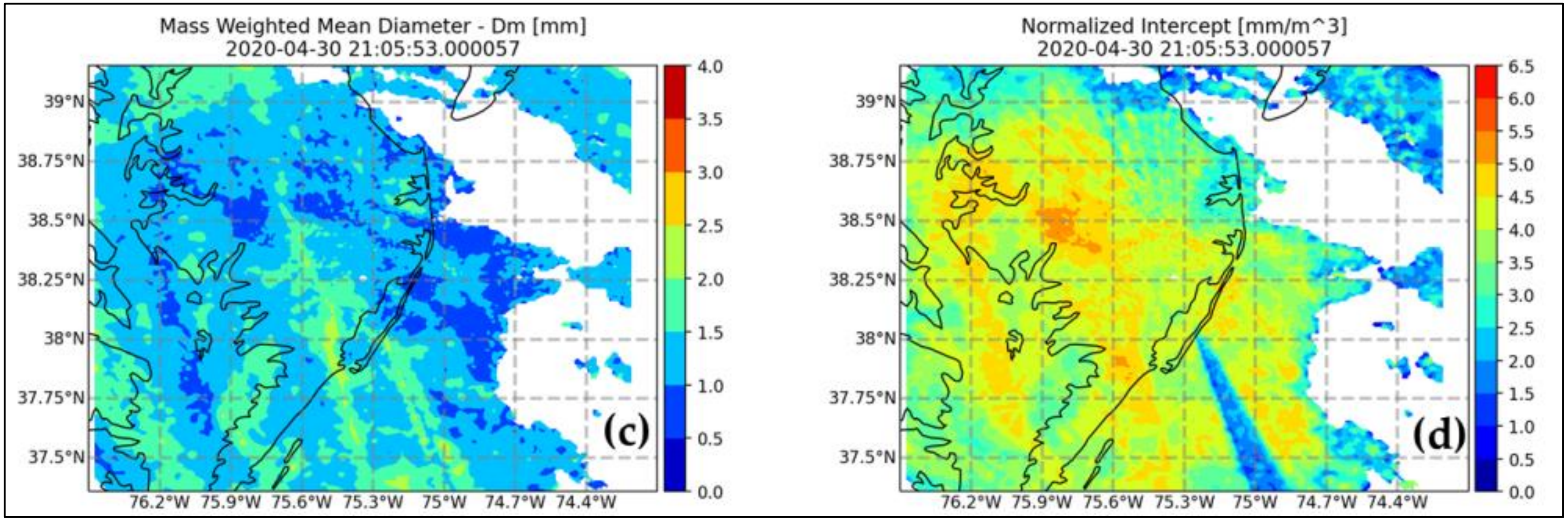


Beam Blockage
Hence need to omit
from analyses

NPOL observations: Event on 30 April 2020

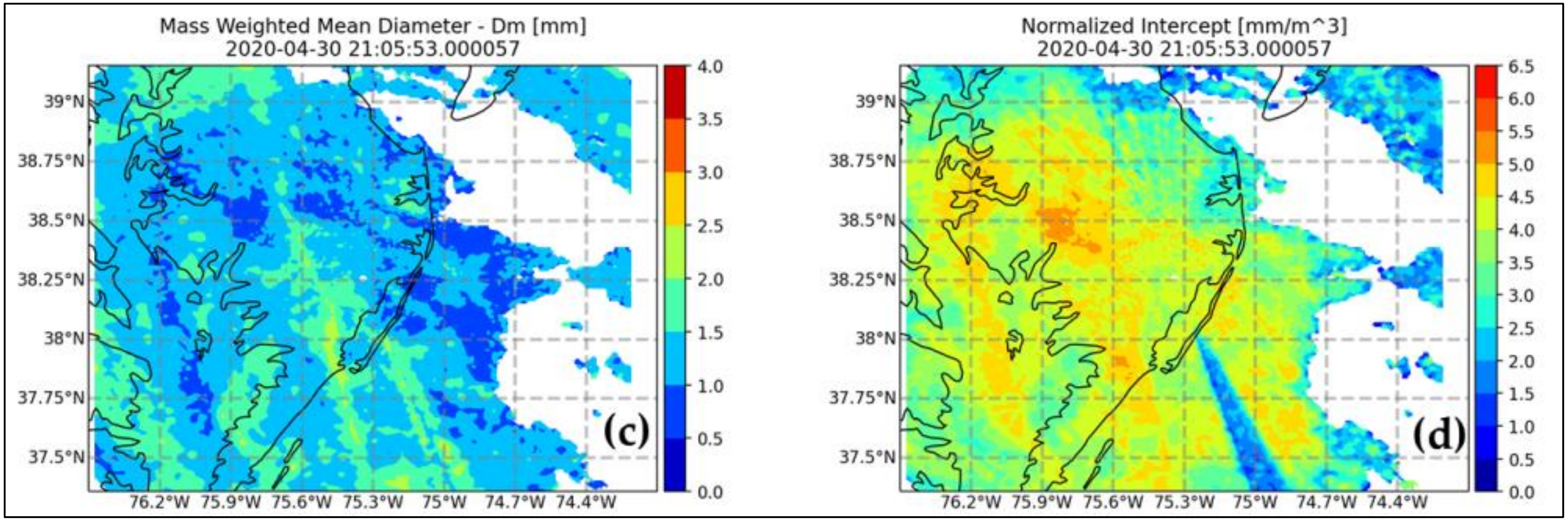
Estimated N_W and D_m from the gridded data



The gridded data ranging from -60 km to +60 km both in the North-South and the East-West directions were extracted and the classification based on the N_W -D_m values for each pixel was determined.

NPOL observations: Event on 30 April 2020

Estimated N_W and D_m from the gridded data

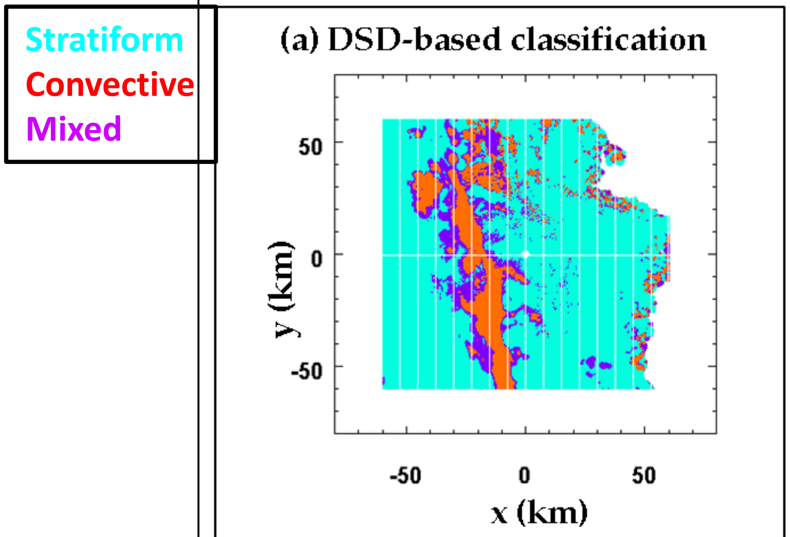


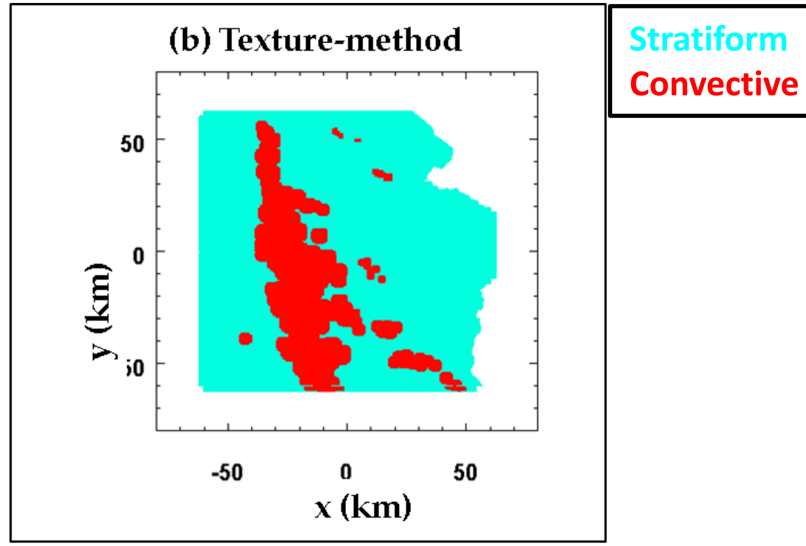
A simple 'index' parameter, *i* (empirically-derived), was used to indicate whether the N_W versus D_m lie above or below the separation line. Value of *i* for each pixel is given by:

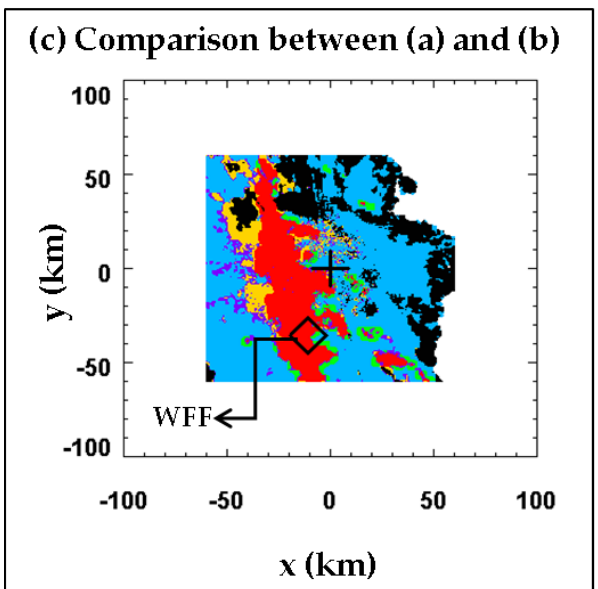
$$i = log_{10}(N_W^{est}) - log_{10}(N_W^{sep}) \qquad \text{where} \qquad log_{10}(N_W^{sep}) = c_1 D_m^{est} + c_2$$

N_W^{est} is the estimated N_W for the specific pixel and D_m^{est} the (corresponding) estimated D_m. Note: values of c_1 and c_2 may vary somewhat depending on the location, but to be consistent with our previous studies, they were set to −1.682 and 6.541, respectively.

Rain type classification: Event on 30 April 2020







(d) Color code used in (c) and results

Rain type classification by the Texture-based method	Rain type classification by the DSD-based method	Number of radar pixels	Percentage of radar pixels
Stratiform	Stratiform	26313	59%
Convective	Convective	9079	20%
Stratiform	Convective	2914	6%
Convective	Stratiforn	2218	5%
N/A	Mixed	4356	10%

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$\left.\begin{array}{l}\text{Stratiform / Convective: 6\%}\\ \text{Convective / Stratiforn: 5\%}\end{array}\right\}$ A total of 12% mismatched pixels

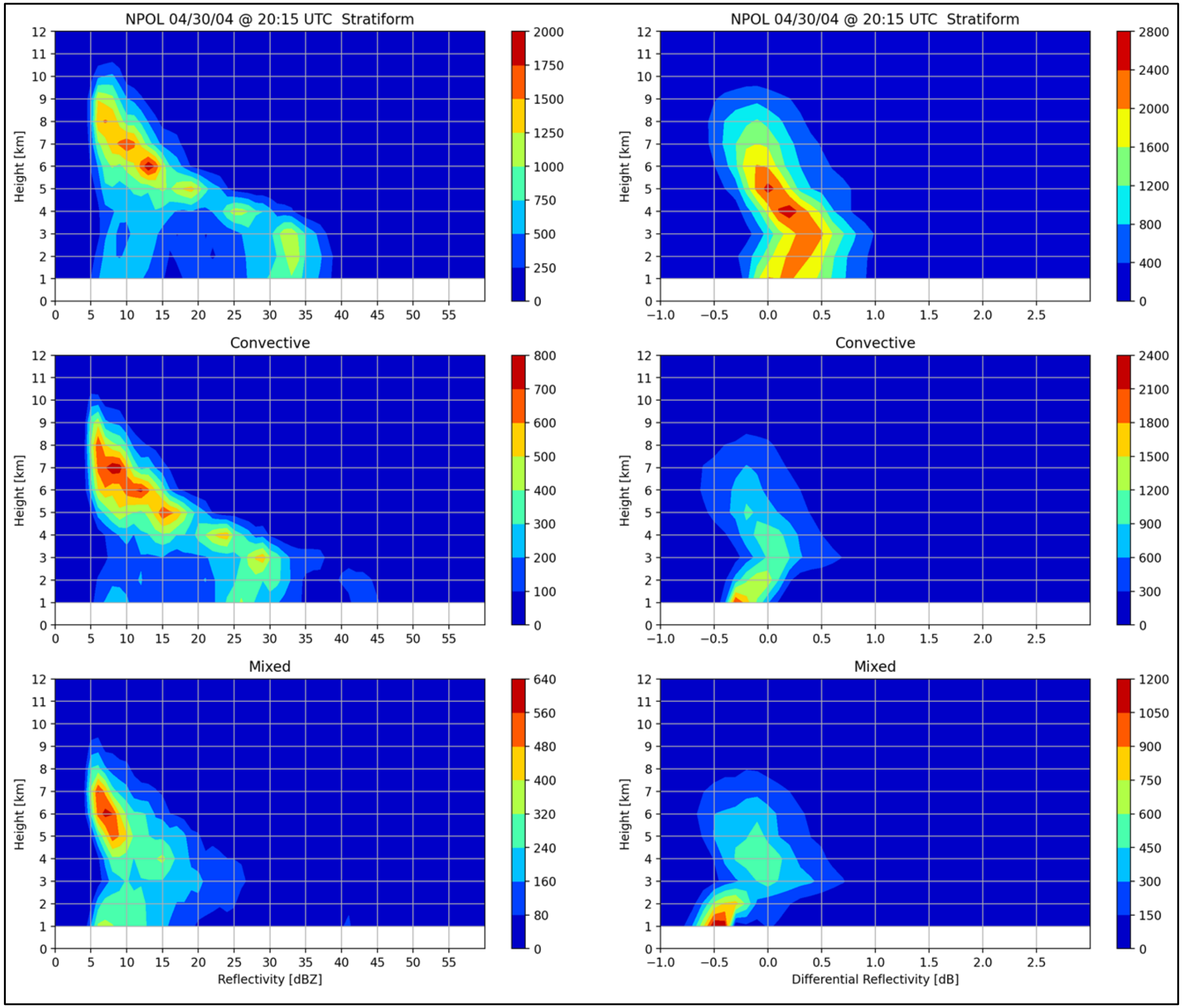
- At S-band, attenuation effects are mostly negligible, but in some regions (beyond the line convection), it did result in ~0.5 dB correction for Z_h.
- After including these effects, percentage of 'mismatched' pixels reduced from 12% to 11%.

Contoured Frequency-by-Altitude Diagrams

CFADs: useful for examining vertical structures. For the April 30, 2020 case, these were constructed separately for stratiform and convective rain regions (after applying the DSD-based separation), as well as for mixed rain type.

Left panels : Z_h ***contours***

Right panels : Z_{dr} ***contours***



For convective rain ***(middle panels)***, both Z_h and Z_{dr} decrease from 3 down to 1 km, which in turn indicates that drop break-up is the dominant process.

For stratiform rain ***(top panels)***, Z_h is almost uniform from 3 to 1 km a.g.l. but Z_{dr} decreases, indicating, once again, the possible occurrence of drop break process but also indicating an increase in number concentration (per unit volume).

Contoured Frequency-by-Altitude Diagrams

CFADs:

Left panels : N_W ***contours***
Right panels : D_m ***contours***

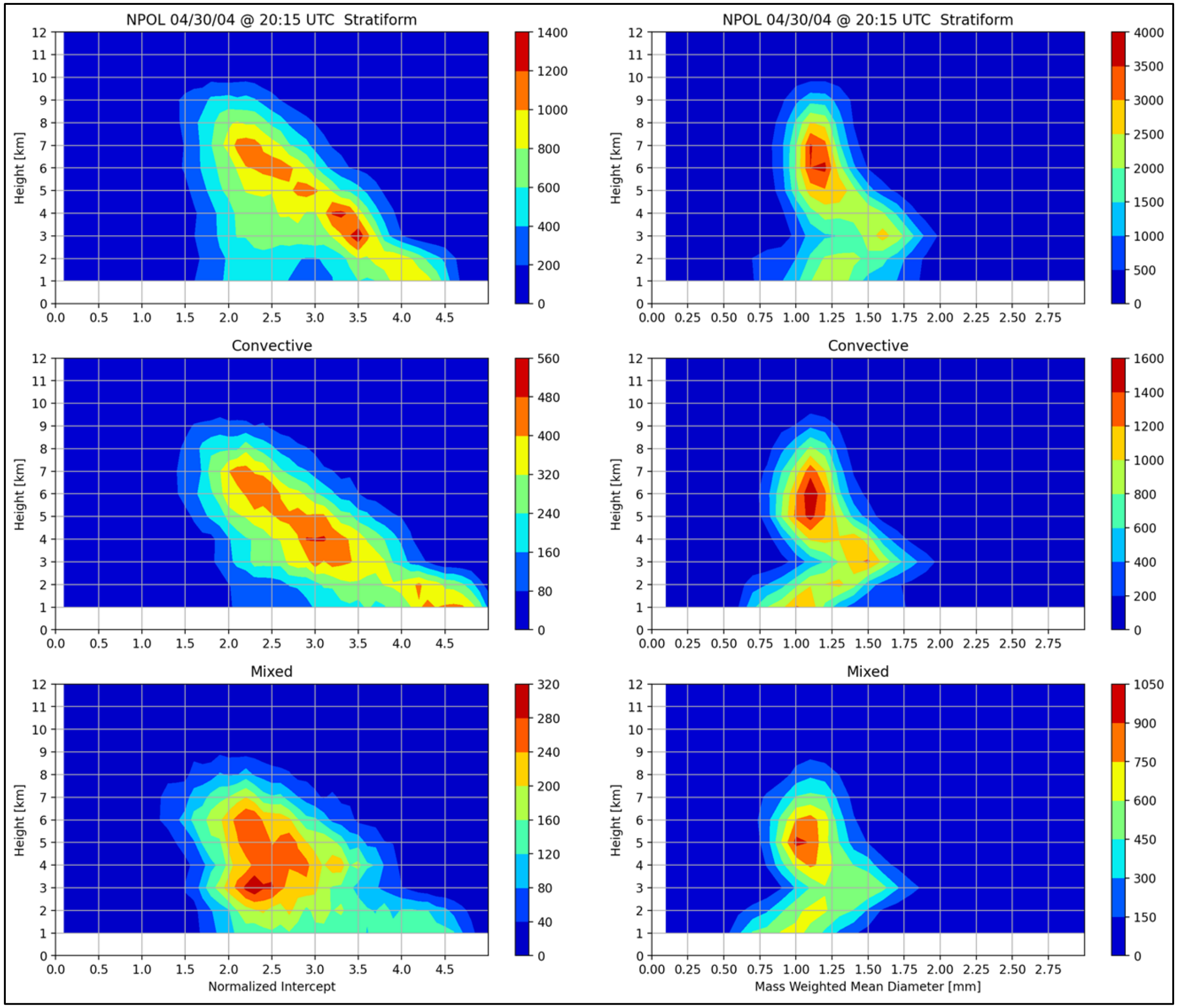
The freezing height on this day was at around 3 km hence the retrieved N_W and D_m should be neglected above this height.

In the rain region below …

i. For both stratiform and convective rain, D_m decreases from 3 km down to 1 km.

ii. But for the latter, the rate of decrease (with decreasing height) is noticeably higher, indicating that the break-up is more severe.

iii. For mixed precipitation, the rate of decrease is more similar to that for convective rain.



Summary

- The case study (of line convection embedded within a widespread system) considered here has clearly shown that there is considerable agreement between the texture-based method and the DSD-based method . Only 12% of the gridded radar data pixels showed classification mismatch. When a simple attenuation-correction method (based on differential propagation phase shift) was applied to the S-band data, the percentage of mismatch reduced to 11%.

- The DSD-based method utilized previously-derived retrievals for the two DSD parameters N_W and D_m. Stratiform and convective rain was based on where the N_W-D_m points lie in relation to the well-established separation line.

- Though the separation line was determined based on disdrometer data, we have shown that it can also be used for the gridded S-band NPOL radar data.

- A third category was also introduced to represent the mixed region. They tended to be in areas immediately surrounding the convective rain regions.

- Contoured Frequency-by-Altitude Diagrams (CFADs) were also generated for the stratiform and convective rain separately. They indicate drop breakup to be a dominant process in the rain region below the freezing height. The rate of decrease (with decreasing height) of D_m was higher in the case of convective rain, implying that the drop breakup is more severe.

Summary

- One caveat in the DSD-based technique is that there are a number of uncertainties which need to be considered when applying this technique. These include (i) variance of ‘radar measurement errors’; (ii) retrieval algorithm errors; and (iii) small uncertainties in the assumed separation line.

- Nevertheless, from this case study, it seems likely that the DSD-based technique can be used for the S-band NPOL gridded data with reasonable accuracy.

- Further, it can be applied not just to the lowest gridded data but also to higher altitudes, i.e. in the rain region, up to the nominal freezing height.