Reflectivity measurement of rain using a 94 GHz radar

Peter J. Speirs[1], David G. Macfarlane[1], Scott L. Cassidy[1], Paul D. Cole[2], Melanie J. Froude[3] and Duncan A. Robertson[1]

1. University of St Andrews, St Andrews, UK.
2. Montserrat Volcano Observatory, Montserrat.
3. University of East Anglia, Norwich, UK.

1. Project aim:

To add a rainfall measuring capability to the AVTIS-3 94 GHz FMCW (frequency-modulated continuous wave) volcano topography monitoring radar. The goal is to use this capability to monitor rainfall rates on the Montserrat Soufriere Hills Volcano, with a view to evaluating the rain's impact on volcanic activity. It is also hoped to use the capability to measure rainfall across the Belham Valley, a valley on Montserrat prone to lahars (mud flows).

2. Radar on Montserrat:

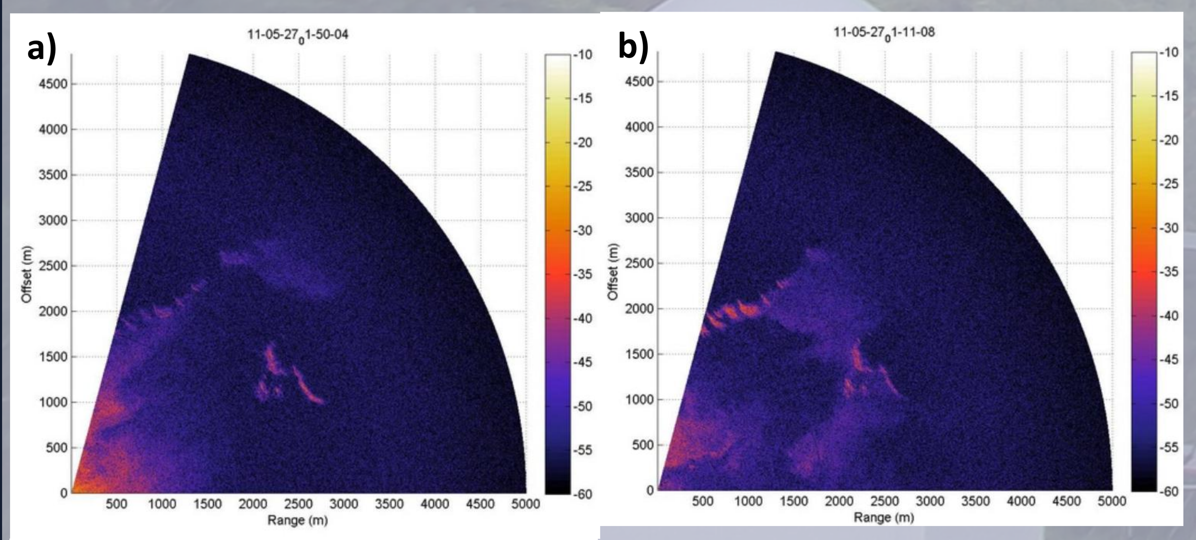
The AVTIS-3 (All-weather Volcano Topography Imaging Sensor) radar is a single frequency, single polarization 94 GHz FMCW radar permanently installed on Montserrat. It is fully autonomous, running off battery and solar power, transmitting measured data back to the Montserrat Volcano Observatory via a wireless telemetry link.

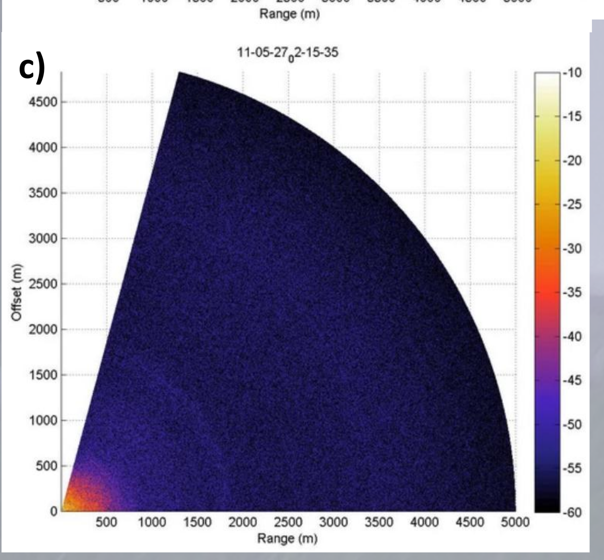
Transmit Power:	20 dBm
Antenna diameter:	0.3 m
Antenna gain:	46.2 dBi
3dB one-way beamwidth:	0.7°
Receiver noise figure	~10 dB

AVTIS-3 on Montserrat

AVTIS-3 head

3. Sample AVTIS-3 Montserrat data:





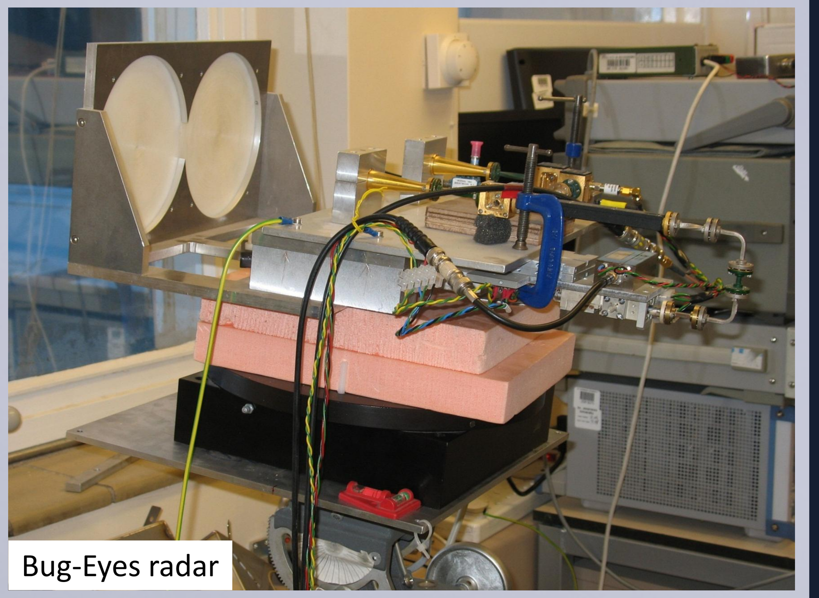
a) and **b)** show samples of the very high resolution rain images that the AVTIS-3 system is capable of capturing. The sides of the Belham Valley can also clearly be seen in these images.

c) shows a case where the rainfall rate was so intense that the radar was unable to successfully measure it beyond a very short range. It also occluded the sides of the Belham Valley.

4. St Andrews experimental setup:

A similar radar (known as "Bug-Eyes") is being used to carry out test measurements in St Andrews to help develop the technique to be used. This is also a 94 GHz FMCW radar, with the specifications given.

The radar is pointed over a field in which a Thies Laser Disdrometer is sited, approx. 70 m from the radar and below the radar beam. A weather station is located approx. 600m away and is used to provide temperature information. It also has a tipping-bucket gauge attached, which is used to corroborate disdrometer measured rainfall rates.



Bug-Eyes radar

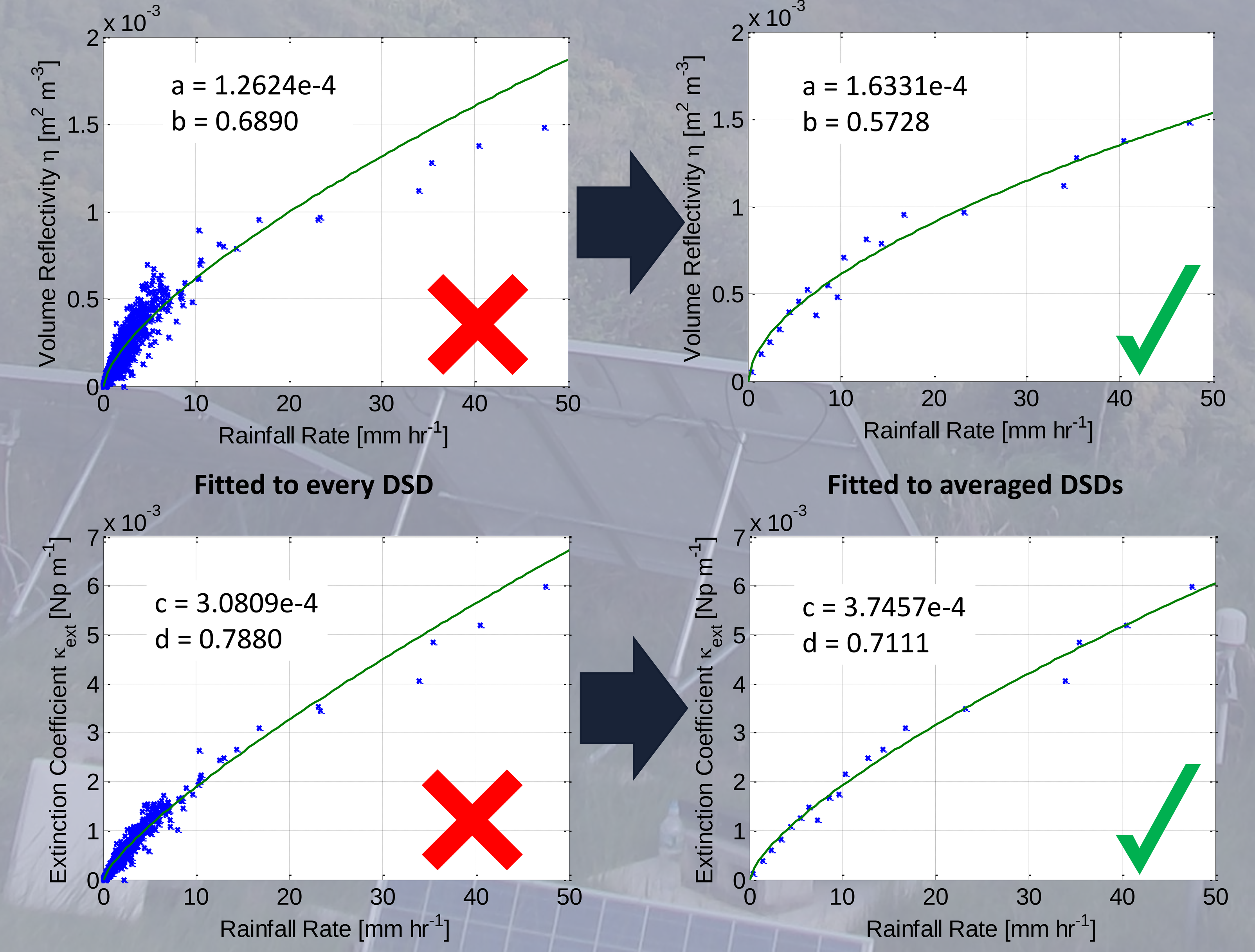
Disdrometer

Transmit Power:	7.35 dBm
Antenna gain:	40.45 dBi
3dB one-way beamwidth:	1.485°

The disdrometer measures the number of particles passing through its detector volume in 22 diameter bins every minute. It also uses this data to determine rainfall rate.

5. Creating an η-R relationship for St Andrews rainfall:

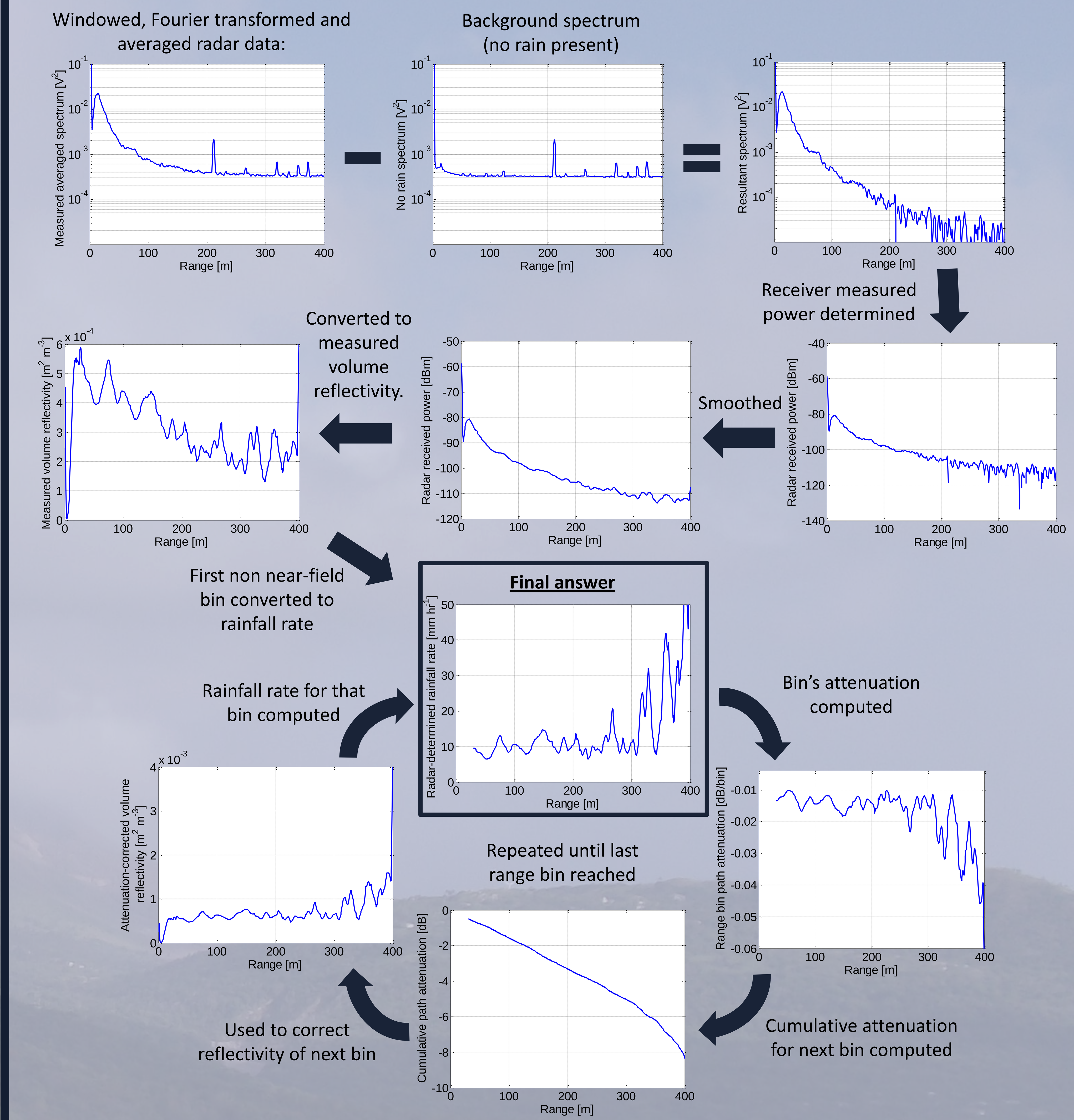
- Not possible to obtain an η-R relationship directly from radar measurements due to high attenuation at 94 GHz.
- Instead fitted normalized gamma distributions to the disdrometer measured DSDs and used these to determine a theoretical η-R relationship.
- $\eta = aR^b$ and $\kappa_{ext} = cR^d$ forms were very good fits to the resultant data .
- Due to non-uniform sampling across the rainfall rate range, the fitted curve conforms well to low rainfall rates, but not to high rainfall rates. This is corrected by fitting to the average DSD for each 1 mm hr^{-1} rainfall rate increment.



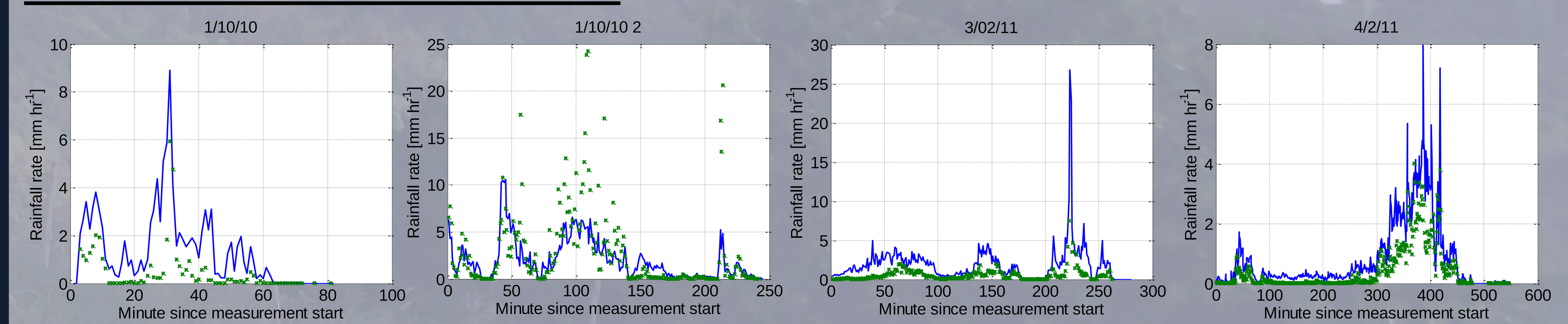
- Data collection is still ongoing – these curves are not definitive.
- An equivalent curve for Montserrat will be developed from disdrometer data gathered there.

6. Data processing technique:

To illustrate the data processing, the intermediate steps from the 43rd minute of the 1/10/10 data are shown below. Here, the disdrometer measured a rainfall rate of 10.46 mm hr^{-1} and the radar-determined rainfall rate was 10.84 mm hr^{-1} at 70 m range.



7. Some initial St Andrews results:



The blue lines show the disdrometer measured rainfall rate, and the green crosses indicate the radar-determined rainfall rate. The radar measurements are taken from the range bin closest to 70m – i.e. closest to being directly above the disdrometer.

8. Future work:

The initial results at St Andrews show that the radar-determined rainfall rates already follow the broad trend of the disdrometer-measured rainfall rates. However, the actual numerical values often show significant variation. Work is ongoing to improve the performance of the St Andrews radar measurement setup.

Once fully operational, the rainfall measurement capability on AVTIS-3 should allow for exceedingly high spatial resolution rainfall rate maps to be recorded over the volcano and also over an important catchment area on Montserrat, providing useful new information for both volcanologists and hydrologists working on the island.

The Montserrat data will soon start to become available, allowing the data processing technique refinement to begin in earnest. It is hoped to have the first results by the end of the year.

Contact:

E-mail: pjs27@st-andrews.ac.uk
Phone: +44 (0)1334 46 3079

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University of St Andrews
School of Physics & Astronomy

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