Polarimetric C-band Radar Imagery of a Volcanic Eruption in New Zealand

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1 Introduction

At 11:52:18 UTC (11:52 pm NZST) on 6 August 2012, Mount Tongariro, located in the central North Island of New Zealand, erupted after three weeks of increased seismic and fumarolic activity. The eruption was brief, lasting only a few minutes, and occurred at Upper Te Maari Crater which had been dormant since 1897. The eruption produced a moderate sized ash cloud up to about 8 km amsl which quickly detached from the volcano and drifted eastwards downwind.

The Meteorological Service of New Zealand (MetService) operates three C-band weather radars which cover the central North Island volcanoes. These radars are located in Bay of Plenty about 122 km north of Mt Tongariro, on Mahia Peninsula about 190 km east of the volcano, and at New Plymouth Airport about 120 km west of the volcano (Fig. 1). All three radars produce real-time three-dimensional volume scans of the atmosphere every 7.5 minutes out to a range of 250 km. As well as producing standard reflectivity and velocity data, two of the radars (Bay of Plenty and Mahia) are dual-polarisation Vaisala WRM200 Weather Radar.

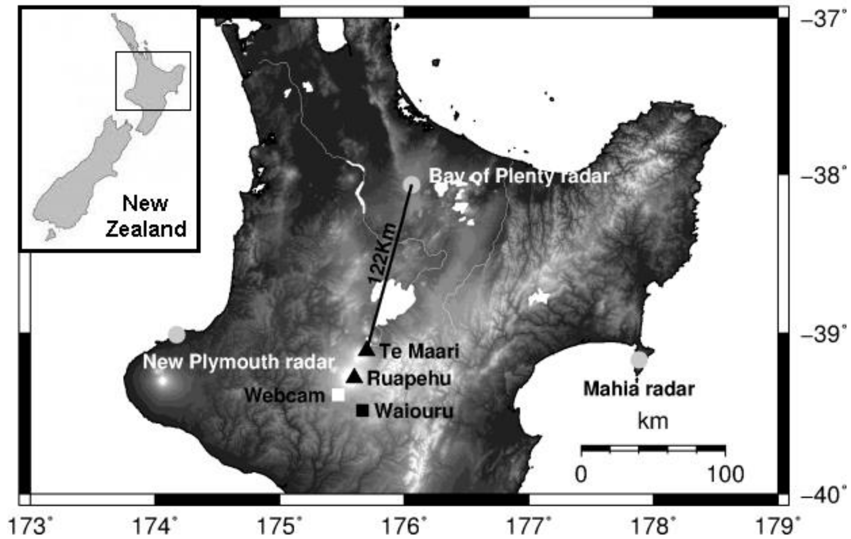

Figure 1: Location of MetService weather radars (circles), a GeoNet webcam which observed the eruption (white square), Mt. Ruapehu, and Upper Te Maari Crater on Mt. Tongariro (triangles), North Island, New Zealand.

The 6 August 2012 Tongariro eruption was observed best by the Bay of Plenty radar, which is sited at a height of 619 m amsl. The lowest elevation radar beam (0.5°) from the Bay of Plenty radar has a beam centre height of 2600 m amsl over Upper Te Maari Crater, and a vertical beamwidth of about 1950 m. The height of Upper Te Maari Crater is 1485 m amsl, meaning the centre of the lowest elevation radar beam is approximately 1100 m above the crater. Imagery of the eruption recorded by the Bay of Plenty radar for three radar fields is presented. In addition to the standard radar reflectivity field (Z_H), the dual polarisation fields of differential reflectivity (ZDR) and correlation coefficient (RhoHV) provided additional information about the structure and composition of the eruption column and subsequent ash cloud.

2 Dual Polarisation Radar Imagery of the Eruption, 11:52 UTC 6 August 2012

Figure 2 shows the Plan Position Indicator (PPI) imagery from the lowest elevation (0.5°) radar data at the time of the eruption. The data were collected between 11:52:47 and 11:53:19 UTC, within about 1 minute of the eruption commencing. Upper Te Maari Crater (marked by a black triangle) is located directly under the pink pixel in the centre of Figure 2a, corresponding to a maximum reflectivity of 61 dBZ. Of interest is the large area of reflectivity extending to about 6 km south of Upper Te Maari Crater. These reflectivity echoes extend along a radial downrange from the areas of highest reflectivity (>40 dBZ) and are considered to be a mix of volcanic targets close to Upper Te Maari Crater, and false flare echoes, or triple-body scatter spikes, further away. The correlation coefficient (RhoHV) field (Fig. 2b) generally shows low values between 0.25 and 0.80 associated with the eruption. This represents a very large diversity in radar targets, both in size and type within the eruption column. The differential reflectivity (ZDR) field (Fig. 2c) is very noisy and shows no clear target orientation in the first minute of the eruption. This is likely due to the very turbulent nature of the initial eruption column.

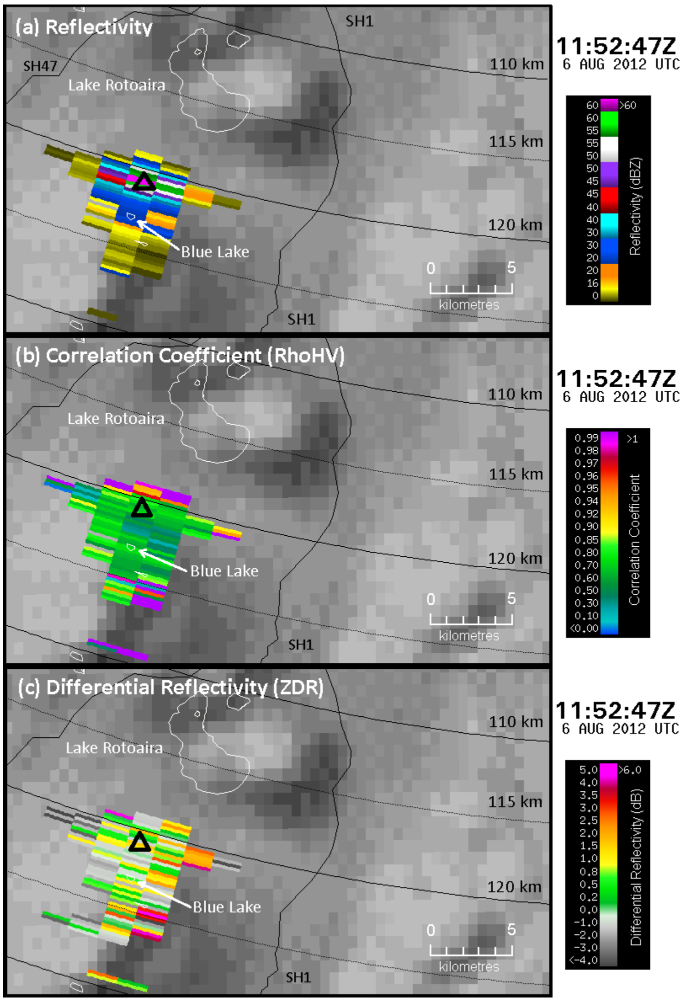

Figure 2: 0.5° PPI (Plan Position Indicator) radar imagery for 11:52 UTC 6 August 2012, showing (a) Reflectivity, (b) Correlation Coefficient and (c) Differential Reflectivity fields. The data was collected between 11:52:47 and 11:53:19 UTC. The height of the radar echoes is approximately 2600 m amsl (or about 1100 m above Te Maari). Range rings are distance from the radar. Each pixel is 200 m deep, and about 1.8 km wide. The black triangle marks the location of Upper Te Maari Crater.

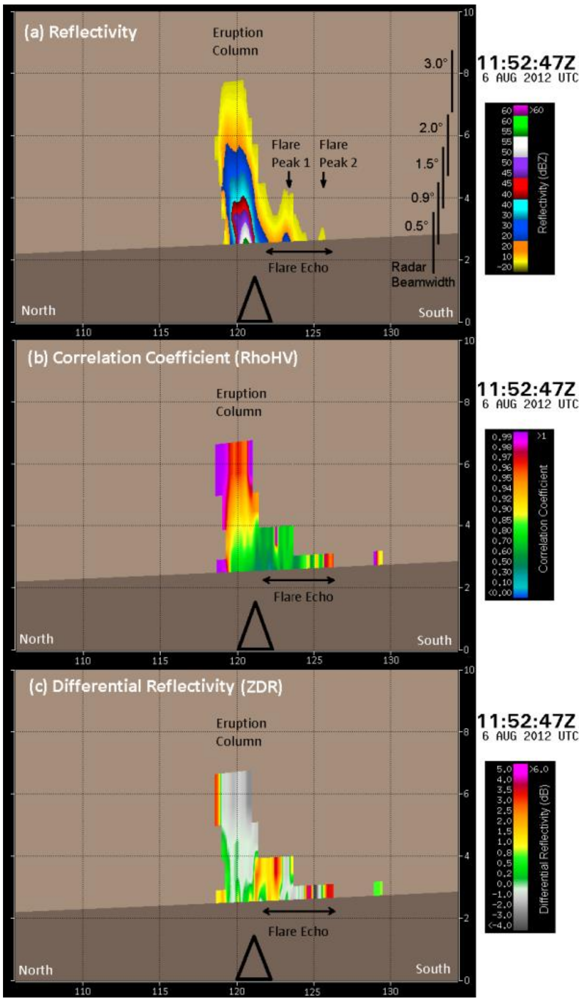

Figure 3: North-South vertical cross-sections of (a) Reflectivity, (b) Correlation Coefficient and (c) Differential Reflectivity through the axis of the eruption column shortly after the eruption. The data within the column covers the period from 11:52:47 to 11:54:54 UTC, 6 August 2012. Horizontal scale is kilometres from the radar. Vertical scale is kilometres amsl. The triangle represents the approximate height and location of Upper Te Maari Crater.

Vertical cross-sections of the eruption column are shown in Figure 3 along a north-south orientated azimuth angle just east of Upper Te Maari Crater. These data were collected between 11:52:47 and 11:54:54 UTC, giving a vertical profile of the first 2.5 minutes of the eruption. The reflectivity cross section (Fig. 5a) shows a gradient in reflectivity from over 55 dBZ at the base (about 1100 m above Upper Te Maari Crater, or 2.5 km amsl) to near 0 dBZ at the top. This represents a vertical stratification in the density and size of the particles within the eruption column. The strongest reflectivity gradients are towards the bottom of the cross-section. The correlation coefficient (RhoHV) imagery (Fig. 3b) shows low to moderate values through most of the eruption column ranging from 0.75 at low levels to 0.96 near the top. This suggests a very high diversity of targets at lower levels in the column, with increasing stratification with height, and a lower diversity of targets at the top. RhoHV values associated with the flares are very low, generally in the 0.40-0.75 range. Differential reflectivity (ZDR) values (Fig. 3c) are generally close to zero in the column, representing a random orientation of targets, but there are indications of positive values on the edges and at lower levels.

3 Dual Polarisation Radar Imagery of the Ongoing Emissions and the Ash Cloud drifting away from the vent, 12:00 UTC 6 August 2012

At 12:00 UTC the volcanic ash cloud has spread north and then eastwards downwind away from Upper Te Maari Crater, while recycling and the vertical transport of particles continues above the vent (Fig. 4).

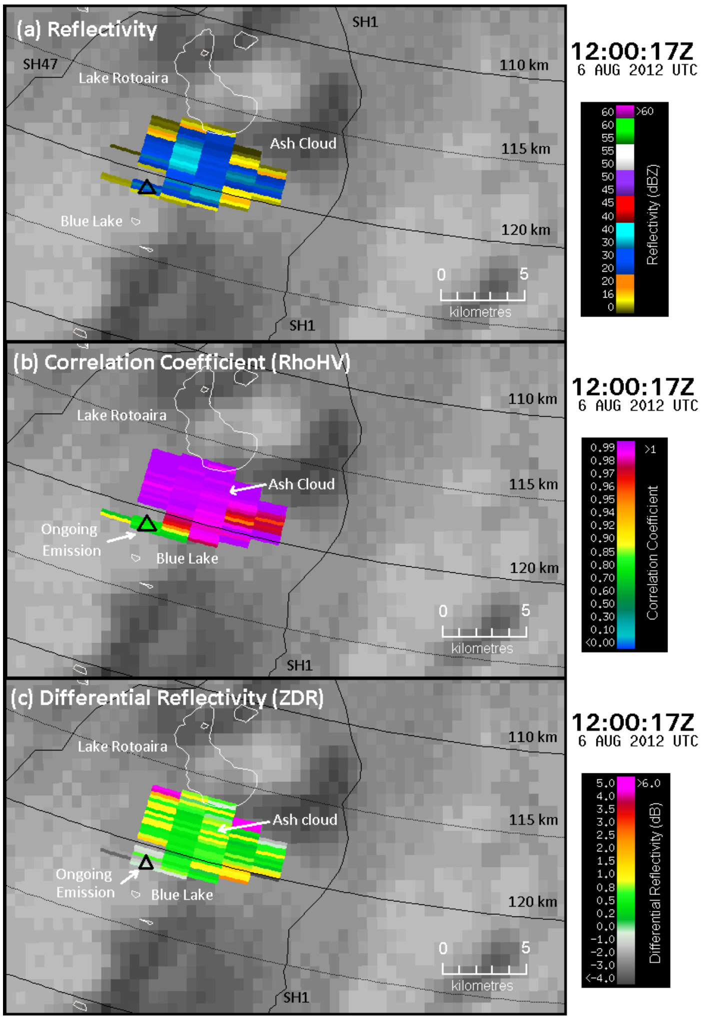

Figure 4: 0.5° PPI (Plan Position Indicator) radar imagery for 12:00 UTC 6 August 2012, showing (a) Reflectivity, (b) Correlation Coefficient and (c) Differential Reflectivity fields. The data is collected between 12:00:17 and 12:00:50 UTC. The black triangle marks the location of Upper Te Maari Crater. Each pixel is 200 m deep, and about 1.8 km wide. Range rings are distance from the radar.

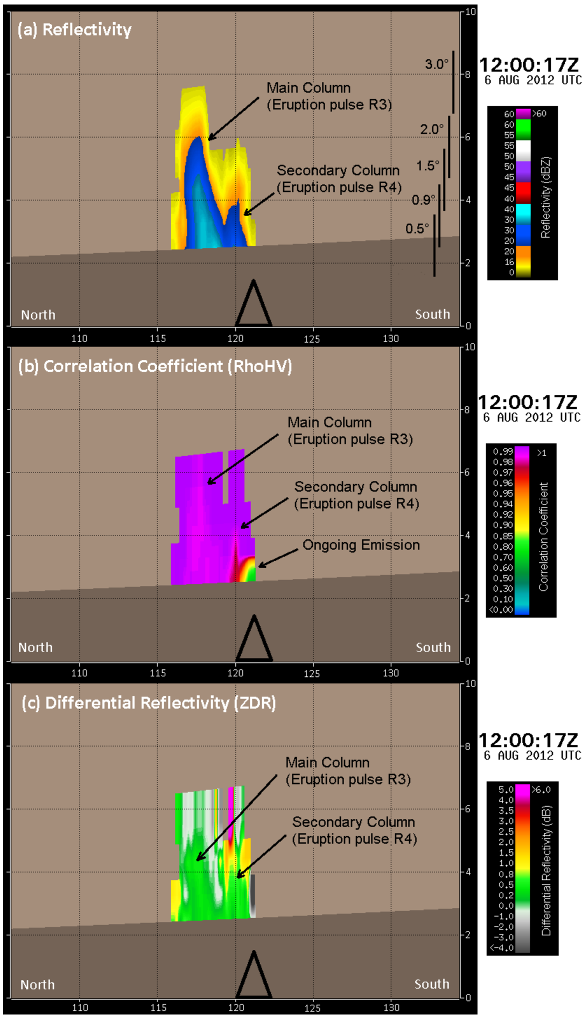

Figure 5: North-South vertical cross-sections of (a) Reflectivity, (b) Correlation Coefficient and (c) Differential Reflectivity through near Upper Te Maari Crater and the axis of the ash cloud showing the two eruption pulses. The data within the ash cloud covers the period from 12:00:17 to 12:02:57 UTC, 6 August 2012. The black triangle represents the approximate height and location of Upper Te Maari Crater.

0.5° PPI reflectivity imagery (Fig. 4a) shows values from 0 to 39 dBZ associated with both the ash cloud and the ongoing vertical emission from the vent, and it is difficult to discriminate between the two. The correlation coefficient RhoHV (Fig. 4b) and differential reflectivity ZDR (Fig. 4c) fields however show significant differences between the ash cloud and the ongoing emission above the vent. RhoHV values associated with the ash cloud are high, generally >0.98, representing a low diversity of particulates within the cloud. RhoHV values within the ongoing emission column are low to moderate (0.75 to 0.9) representing a moderate diversity of radar targets still being ejected from, or recycled above, the vent. ZDR values within the ash cloud are generally positive (0.4 to 1.5) indicating a preference for horizontally orientated ash particles falling from the cloud. In the vicinity of Upper Te Maari Crater ZDR values are around 0 dB indicating a random orientation to the radar targets associated with turbulent transport within the emission column. This difference in the RhoHV and ZDR values associated with the ash cloud and the ongoing emission column can be used to separate reflectivities associated with each of these transport regions.

The north-south reflectivity cross section (Fig. 5a) shows two reflectivity peaks, with the initial large ash cloud (R_3) moving eastwards away from Upper Te Maari Crater and a second smaller vertical column (R_4) closer to the vent. This smaller column is a secondary slightly-later emission from the volcano which eventually merges with the main ash cloud.

The correlation coefficient RhoHV cross section (Fig. 5b) show high values (0.97 to 1.0) throughout most of the ash cloud in both the main R_3 plume-generating pulse and the secondary R_4 column indicating a low diversity in targets, and clearly shows the continuing vertical emission from the crater as a column of low to moderate RhoHV values (0.75 to 0.9) extending up to about 3.4 km amsl on the southern side of the ash cloud. As in the PPI images (Fig. 4b), this significant difference in RhoHV values between the ash cloud and the emission column makes it relatively easy to separate the two transport processes. The differential reflectivity cross-sections (Fig. 5c) show generally positive values associated with reflectivity values >20 dBZ at mid and low levels, and values generally around zero at higher levels associated with low reflectivity values within the ash cloud. This suggests the larger ash particles associated with reflectivities greater than 20 dBZ are settling with a preferred horizontal orientation, while the smaller ash particles aloft are tumbling downwind in the upper level westerly flow.

4 Differential Reflectivity (ZDR) trend at high altitudes

Figure 6 shows a time series of 2° beam elevation PPI images of the differential reflectivity (ZDR) associated with the ash cloud from the time of the initial eruption through to 12:31 UTC. The height of the beam through the ash cloud during this time is between 5.4 and 6.0 km amsl, which corresponds to a free-air temperature range of about -24 to -29°C.

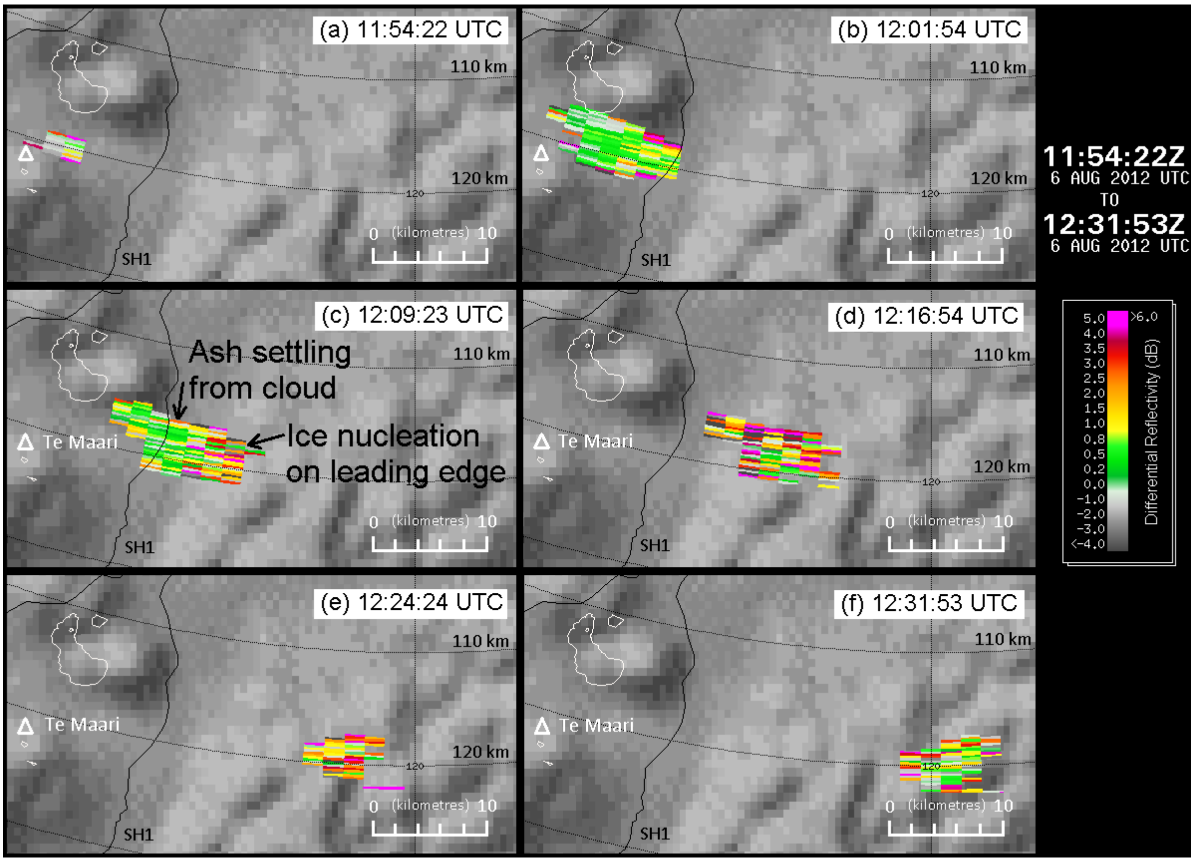

Figure 6: Time series of 2° beam elevation Differential Reflectivity (ZDR) PPI images showing a general increase in positive ZDR values during the first 20-25 minutes from 11:54:22 UTC to 12:16:54 UTC (a, b, c and d). These large positive values are maintained during the following two radar scans at 12:24:24 (e) and 12:31:53 UTC (f). The height of the beam through the ash cloud at this range is about 5.4 to 5.7 km amsl, corresponding to a free-air temperature range of about -24 to -27°C. The location of Upper Te Maari Crater is marked. Range rings are distance from the radar.

At 11:54 UTC (Fig. 6a), the scan through the initial eruption column, ZDR values are generally around 0 dB, indicating a random orientation to the particles within the column. At 12:01 UTC (Fig. 6b), 7.5 minutes later, the ash cloud has spread out and drifted downwind. Associated ZDR values have increased to be generally in the 0 to +1.0 dB range, and are most likely associated with larger settling ash particles, however there are a few ≥ 5.0 dB pixels on the northern edge. At 12:09 UTC (Fig. 6c), ZDR values continue to increase and mostly lie in the 0 to +5 dB range, with the highest values on the leading edge. ZDR values in the 0 to +1 dB range are likely associated with larger settling ash particles, while the larger positive values on the leading edge are likely associated with the ice nucleation of smaller fine ash particles. At 12:16 UTC (Fig. 6d), about 24 minutes after the initial eruption, there are now significant numbers of large positive ZDR values (up to about +7 dB), as well as a few large negative values. At this time, the large positive values of ZDR dominating the ash cloud are likely associated with the ice nucleation of fine ash particles and possibly the aggregation of these particles. This pattern of generally large positive ZDR values associated with the ice nucleated ash aggregates continues until the radar detectable ash disappears about 90 minutes after the initial eruption.

5 Summary

The dual-polarisation radar fields provided extra information about the structure of the eruption column and ash plume which could not be determined from the reflectivity fields alone. The correlation coefficient (RhoHV) field could easily discriminate between the eruption column where RhoHV values were low (generally less than 0.8), and the ash cloud where RhoHV values were high (generally greater than 0.97). This difference reflects the diversity of radar targets associated with the eruption column (a high diversity of targets or pyroclasts) and the ash cloud (a low diversity), and probably also reflects the transport mechanisms occurring in both regimes, with better sorting and size/density segregation of particles once the mixture reaches the buoyancy level and becomes transported by the wind. The significant difference in RhoHV values between the eruption column and the ash cloud provides an easy method to discriminate between the two parts of a volcanic plume, that is the turbulent vertical column and the approximately horizontal drifting ash within the umbrella region.

The differential reflectivity (ZDR) field provided information about the orientation of particles within the ash cloud. In general, ZDR values were positive at low to mid-levels of the cloud and associated with moderate values of reflectivity (20 to 40 dBZ) indicating a preferred horizontal orientation to the larger falling ash particles. At higher elevations, the ZDR values within the ash cloud at temperatures colder than -14°C were initially close to zero, but were observed to increase during the first 25 minutes, and then remain at generally large positive values until the radar detectable ash disappeared. These large positive ZDR values were associated with weak reflectivities (<10 dBZ) and high RhoHV values (generally 1.0). It is suggested that at this higher level ZDR values of 0 to +1dB are associated with the larger settling ash particles, while values of +1 to +5dB (or greater) are associated with ice nucleated, and possibly aggregated, fine ash particles within the ash cloud.

Reference

Crouch, J.F., et al., Dual polarisation C-band weather radar imagery of the 6 August 2012 Te Maari Eruption, Mount Tongariro, New Zealand, J. Volcanol. Geotherm. Res. (2014), http://dx.doi.org/10.1016/j.jvolgeores.2014.05.003