Met Éireann

Technical Note No. 62

Verification of Met Éireann Weather Radar

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Glasnevin Hill, Dublin 9
2013

Disclaimer

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Abstract

Met Éireann operates two weather radars, located at Dublin and Shannon airports. Data from these radars assist in monitoring the development and movement of rain-producing systems affecting Ireland, and in providing real-time rainfall estimates to internal, public, and Local Authority customers. This study aimed to provide a high-resolution verification of the performance of the weather radar in the detection of rainfall. Radar performance was analysed over the period of January – December 2012. Daily rainfall accumulations, as estimated by the radar, were compared with rain gauge observations from the Irish climate network, with both datasets being merged onto a 1km resolution grid.

Overall, it was shown that the Irish radar network is under-detecting rainfall amounts countrywide, most significantly along the north, northwest, southwest, and southeast coasts. The mean rainfall detection performance over Ireland by the primary radar product (Pseudo CAPPI) was approximately 40% when compared with the rain gauge derived data. In general, the radar at Dublin airport was shown to be performing significantly better than the Shannon radar. Distance from the radar was found to be the primary factor influencing performance, with a rapid decline in performance detected beyond ~100km range. Orographic blocking by high ground is creating a number of large radar shadow areas in Ireland particularly in the southeast and southwest, where radar rainfall detection is 10 – 30%.

Examining the impact of meteorological and seasonal variables, radar performance was observed to improve in months with warmer temperatures and lower rainfall amounts, with improved rainfall detection during frontal conditions when compared with convective situations. However, this study would need to be expanded to include a review of several years of data to further clarify and quantify these relationships.

Table of Contents

1 Introduction

Weather radar plays an important role in the detection and forecasting of rainfall in Ireland. Within Met Éireann, data from weather radar are used to assist in confirming the location, strength, and movement of frontal and convective systems, in estimating rainfall amounts received on the ground, and to provide a visual information source to the public on current weather conditions. In the future, it is hoped that radar data could be assimilated into Numerical Weather Prediction models used by Met Éireann to improve model initial conditions and forecast verification. The potential to generate short-range, high-resolution rain forecasts or 'nowcasts' through the use of radar data is also being investigated.

Considering its current importance and the need for accuracy in potential future applications, it is vital that the performance of the weather radar in Ireland is properly verified and understood. The aim of this study is to provide a comprehensive description of radar performance in Ireland, and to detect and quantify errors in rainfall detection.

2 Current Weather Radar

2.1 Basic Radar Operation

The term radar is an acronym for "**ra**dio **d**etection **a**nd **r**anging." Weather radar works by transmitting a pulse of microwave energy, and listening for the return of the reflections or 'echoes' from this pulse. The wavelength of the radar beam is tuned to be reflected by precipitation in the atmosphere; the travel time and the power of the echo providing information on the location and intensity of the precipitation.

The radar antenna rotates on the horizontal plane through 360°, while transmitting rapid, narrow pulses to each segment, and listening for the return. This rotation is repeated over several elevation angles of the antenna, building up a volume of precipitation data for the region surrounding the radar unit.

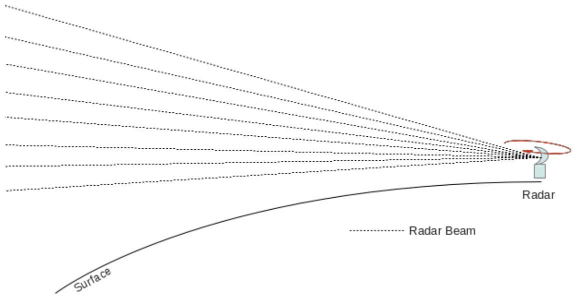

Figure 2.1: Basic scan pattern of a weather radar.

2.2 Met Éireann Radar

Met Éireann has two weather radars, located at the airports in Dublin and Shannon. Both are manufactured by Selex, the Dublin model being a Meteor 600C, and the Shannon model a Meteor 360C. Both of these units underwent hardware upgrades during 2010/2011. They are C-band radars which use a radar pulse with a wavelength of 5.6cm. This wavelength is suited to operation in Ireland, as it is sensitive enough to detect light rain and drizzle (common forms of precipitation) but is not as severely affected by attenuation as radars with shorter wavelengths (Commins, 1998). Attenuation refers to the weakening of the power of a radar pulse due to the absorption and scattering of its energy by particles in the atmosphere (e.g. water droplets, aerosols).

Each radar transmits data to Met Éireann every 5 minutes. These data are composed of 360° scans from 10 different elevation angles, and are stored in a HDF5 format. From this sample volume, a number of products are generated.

2.3 Pseudo CAPPI Radar Product

The Pseudo CAPPI radar product (PCR) is the primary product used to interpret and visualise radar data in Met Éireann, and it is the product of choice for the display of radar data in internal and public information systems. For this reason, the performance verification carried out in this study will focus predominately on the PCR.

The PCR product is a combination of the CAPPI (Constant Altitude Plan Position Indicator) and PPI (Plan Position Indicator) products. Essentially, sections from the various scans that correspond to an altitude of 1500m are merged together, providing a layer of radar data at constant altitude (see Figure 2.2). This layer extends out to the point where the lowest radar scan rises above 1500m, at approximately 80km range. From this point, the data from the lowest beam make up the remainder of the product, out to a range of 240km.

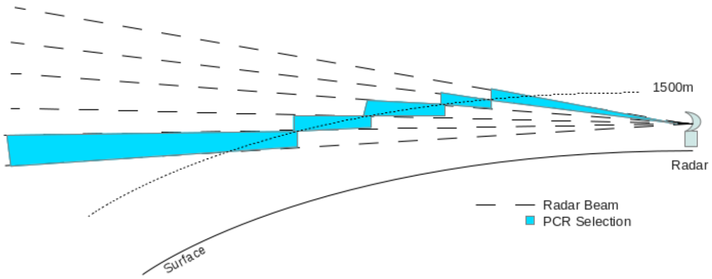

Figure 2.2: Simplified diagram of the composition of the PCR radar product.

2.4 Surface Rainfall Intensity Product

The overall performance of the Surface Rainfall Intensity product (SRI) was also assessed as part of this study. The SRI product has a relatively short range of 75km. It is composed of scan sections that correspond to a height of 1000m above the ground. When composing this layer, the SRI takes account of topography, meaning that the layer generated follows the terrain, maintaining a height of 1000m above ground rather than 1000m above sea level (Selex, 2008). The SRI product also applies corrections for errors caused by high ground, a topic which will be examined in section 5.

3 Verification Method

3.1 Introduction

The aim of this study is to accurately verify the performance of the weather radar currently in use by Met Éireann. In order to obtain a precise metric of performance, rainfall detection by the radar needs to be compared with a reference value which equates to the actual received rainfall on the ground. This section describes the data and techniques used to achieve these aims.

3.2 Data Sources

3.2.1 Radar Data

The radars at Dublin and Shannon had recently undergone upgrades, which were completed in 2011. In order to avoid extended periods of missing data, and to provide an up-to-date verification of the radar system as it currently exists, it was decided that post- 2011 data would be used for this project. An analysis of an entire year of radar data was desirable in order to observe the performance of the radar in a full range of atmospheric conditions and to detect any associated trends. Therefore, the period from January to December 2012 was selected as the optimal study period.

Precipitation accumulation files are generated for the PCR and SRI products every hour. These files contain estimates of the total rainfall accumulation over an hour period, as calculated from the rainfall rates observed by the specified radar product (Selex, 2008). These data are archived on the sol database in Met Éireann at the address: /d0/data/sat_radar. The hourly files for both products of each radar were obtained for the year 2012, amounting to approximately 35,000 files (24 hours x 366 days x 2 products x 2 radars).

3.2.2 Rain Gauge Data

There are approximately 500 rainfall measuring stations across Ireland in Met Éireann's climate network. In general, 24 hour rainfall accumulations, collected by a 5" rain gauge, are measured daily at 0900 UTC by an observer, with the values returned to Met Éireann at the end of each month (Walsh, 2011). The data are quality controlled initially at source by the observer using a numerical indicator system, which provides information on the readings, such as whether the value has been measured or estimated, or whether it is a daily value or a cumulative value from a number of days etc. Additional quality control is carried out within Met Éireann, where the daily values are compared with those recorded at neighbouring rainfall stations within a 35km radius.

Using these rain gauge measurements, gridded datasets of 1km resolution are generated for daily rainfall across Ireland by the Climatology and Observations (C&O) Division in Met Éireann. Inverse distance weighted interpolation is used to determine rainfall values for each grid point. Essentially, the grid point value is calculated as being the weighted average of the rainfall values from the neighbouring gauge stations, with the weights determined by the distance of each of the stations from the grid point:

$$u(x) = \sum_{i=0}^{N} \frac{w_i(x) u_i}{\sum_{j=0}^{N} w_j(x)'} \quad \text{where} \quad w_i(x) = \frac{1}{d(x, x_i)^p} \qquad \textbf{(3.1)}$$

x is the unknown interpolated grid point, x_i is a known station point, d is the distance between x and x_i, N is the number of station points used in the interpolation, and p is the power parameter which determines how the weighting decreases with distance from x. The calculated daily grid point values are analysed against the monthly normal rainfall and monthly total rainfall values, and adjusted so that the sum of the daily values corresponds to the gridded monthly values.

For this project, 12 rainfall grid files for 2012 (one for each month) were obtained from the sol database at the address: /home/swalsh/newR/GRIDRAIN/MONTHLY/OUT/. Each file is in .csv format, and contains the Irish national grid coordinates and the daily rainfall values for each grid point (106,698 points) for every day of the month.

3.3 Data Pre-processing

For each radar product (2 for each station; 4 in total), the hourly radar rainfall accumulation files were first binned into directories for each day. The rain gauge data provide values of daily accumulated rainfall in the 24 hour period from 0900 to 0900 UTC, with the date assigned to the daily value corresponding to the date of the end of this period. Therefore, the hourly radar data was binned into directories using the same time step, beginning with the 0900 – 1000 UTC file from the previous day and ending with the 0800 – 0900 UTC file for the current day.

As the rain gauge data, to which the radar data have to be compared, consisted of daily rather than hourly totals, only the days with a complete set of 24 radar files (one for each hour) could be used for the comparison (see Table 3.1).

Each of the hourly radar files were then converted from cartesian coordinates to Irish national grid coordinates to match the projection of the gridded rain data, with the data saved to .csv files. The 24 files for each day were then merged into a single file, with the values summed to provide a daily radar rainfall accumulation total for each grid point.

Month	Dub PCR	Dub SRI	Snn PCR	Snn SRI
January	29	26	29	25
February	28	28	25	23
March	30	30	26	29
April	30	29	30	29
May	30	30	27	26
June	29	28	28	28
July	28	28	26	26
August	25	23	29	27
September	28	22	28	26
October	24	22	27	13
November	30	28	24	7
December	27	20	17	11
Year	338	314	316	270

Table 3.1: Number of days in each month that had a complete set of hourly radar rainfall accumulation files for each radar product.

3.4 Comparison of Rain Gauge and Radar Data

The daily radar rainfall accumulation values for each product were paired with the corresponding values from the gridded rain gauge data. This was carried out by scanning the gridded rain and radar files to locate the values that had matching dates and national grid references. The resulting dataset for each product consisted of 12 months of 1km resolution gridded data, with daily values of rain gauge and radar derived rainfall for each grid point.

For the purpose of the comparison, the gridded rain gauge data were deemed to be the actual received rainfall for each grid point. This allowed the radar performance to be verified by examining how its values differed from those derived from the rain gauge observations. Daily, monthly, seasonal and annual performance comparisons were carried out. Changes in radar performance relative to changes in external factors such as location, range and atmospheric conditions were also examined.

4 Results

4.1 Irish Radar Performance for 2012

The performance of the Dublin and Shannon radars was analysed over the entire study period of January – December 2012. Radar rainfall accumulation values, calculated from the PCR product, have been expressed as percentages of the corresponding rain gauge derived values to provide a performance indicator for each grid point. Figure 4.1 displays a composite map of the Dublin and Shannon radar performance for the total rainfall in 2012. Radar performance maps for the total monthly rainfall for each of the 12 months are available in Appendix A. Figure 4.2 shows the standard deviation at each grid point of the monthly performance values over 2012.

The merging of the Dublin and Shannon data to generate the composites was carried out by examining each of the 106,697 grid points and determining which radar had the highest performance over the course of the year in detecting rainfall at that grid point. The data from that radar would then be used for that grid point when generating the various composite images (see Figure 4.3).

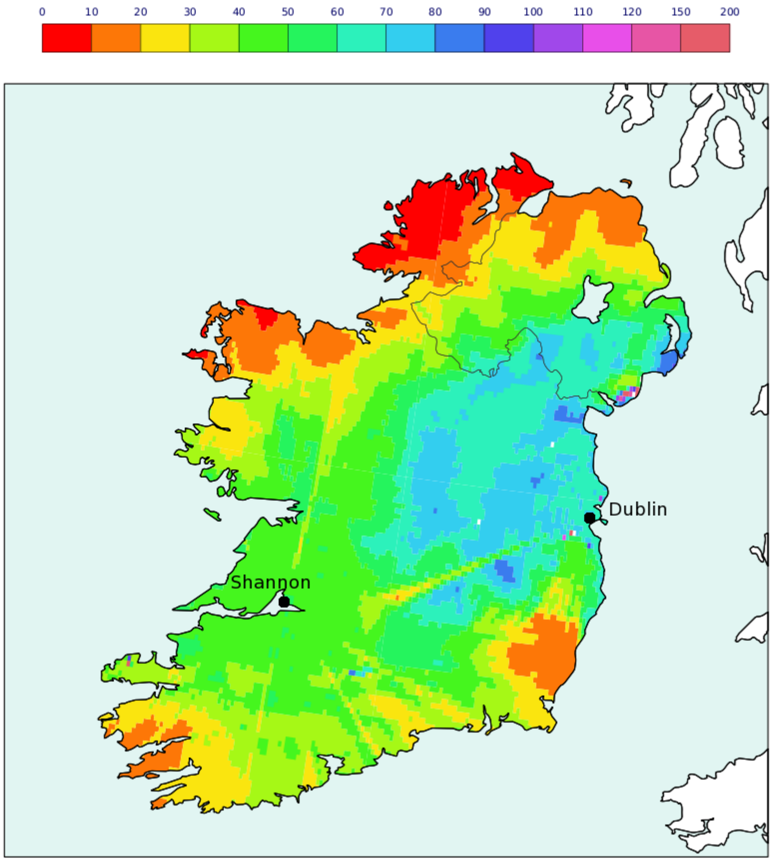

Figure 4.1: Irish radar performance for 2012. The total annual radar-detected rainfall is shown expressed as a percentage of the total annual gauge-observed rainfall.

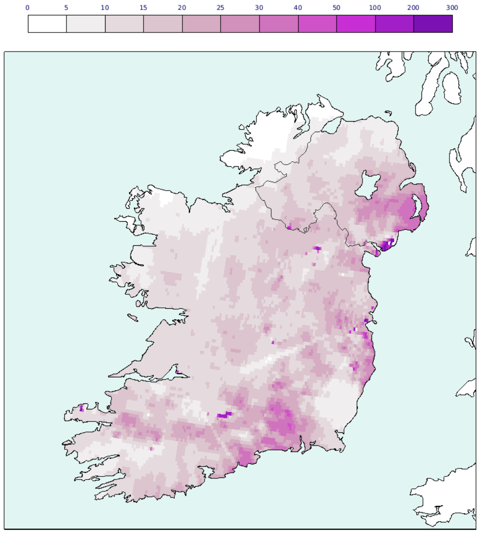

Figure 4.2: Standard deviation of monthly PCR performance values for 2012.

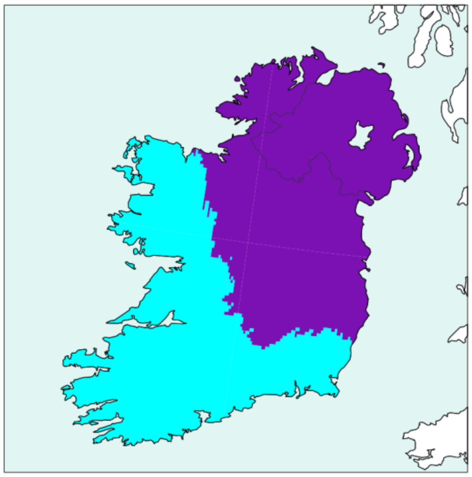

Figure 4.3: Regions of dominant rainfall detection performance for the Dublin (purple) and Shannon (cyan) radars for 2012.

The root mean square error (RMSE) for the radar data was calculated for each grid point to identify the areas where the radar values differed the most, in terms of millimetres (mm) of rainfall from the gauge-derived values. Equation 4.1 was used to calculate both the daily and monthly RMSE values:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(g_t - r_t)^2}{n}} \qquad \textbf{(4.1)}$$

n is the number of readings for the grid point in question (n = 12 for the monthly values, ~ 330 for the daily values), g_t is the gauge rainfall value for the period t, and r_t is the corresponding radar rainfall value. Figure 4.4 displays the mapped monthly and daily RMSE values.

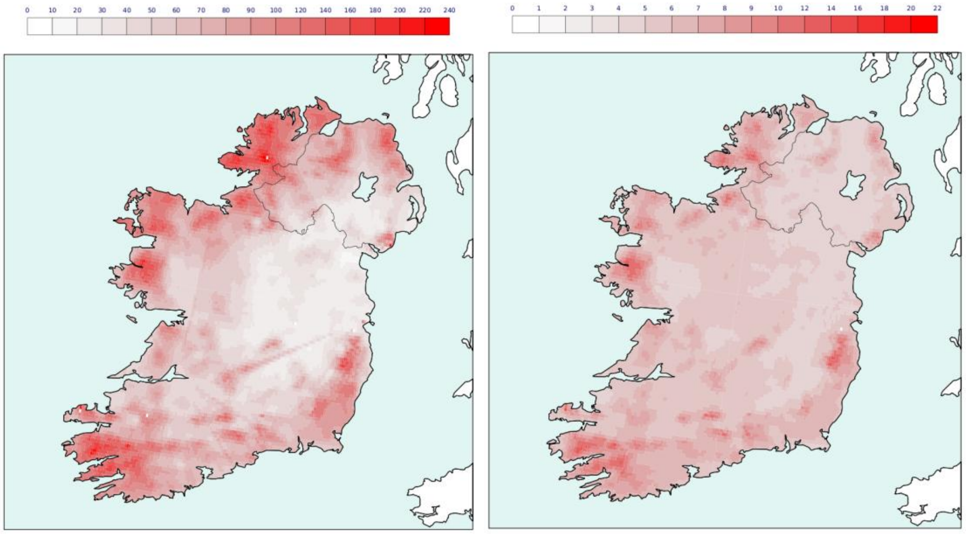

Figure 4.4: Monthly (left) and daily (right) RMSE values in mm of rain for the Irish PCR products in 2012.

4.2 Dublin and Shannon Radar Performance

Figure 4.5 displays the individual annual performance maps for the Dublin and Shannon PCR radar product for the year 2012. The radar data has again been expressed in terms of percentages of the corresponding rain gauge derived values. Figure 4.6 displays the correlation values between the PCR and rain gauge derived rainfall data for 2012, for both radars. The mean correlation of the PCR data with the rain gauge data for both radars was 0.73.

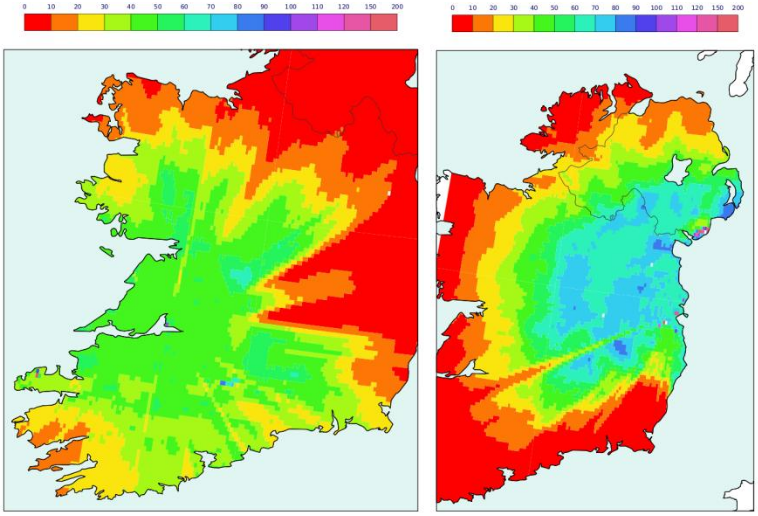

Figure 4.5: Total annual performance for the PCR product for 2012 for the Shannon (left) and Dublin (right) radars.

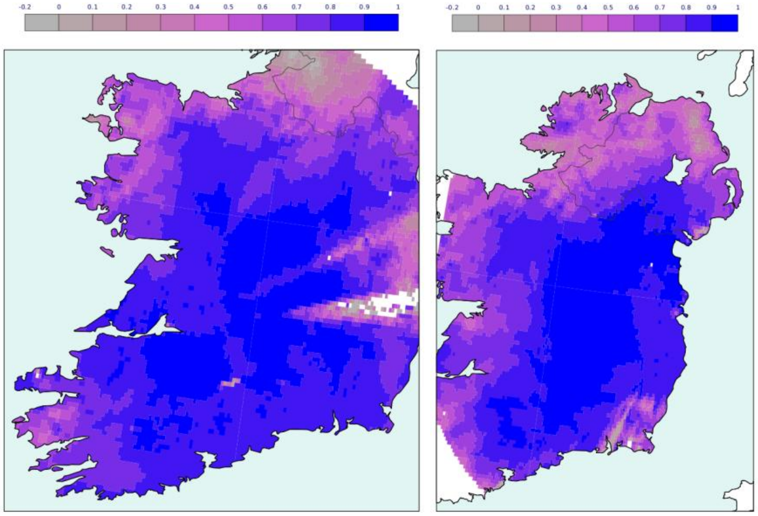

Figure 4.6: Correlation values for the PCR product for 2012 for the Shannon (left) and Dublin (right) radars.

	Ire PCR	Dub PCR	Snn PCR
Mean Annual Performance %	40.38	30.89	23.22
Mean Standard Deviation	15.03	11.25	9.23

Table 4.1: Mean performance values of the PCR product for the Irish composite, Dublin, and Shannon radars for 2012.

4.3 SRI Performance

The performance of the SRI product over 2012 was assessed for the Dublin and Shannon regions. Figure 4.7 shows the performance maps for the Dublin and Shannon SRI products for the total annual rainfall.

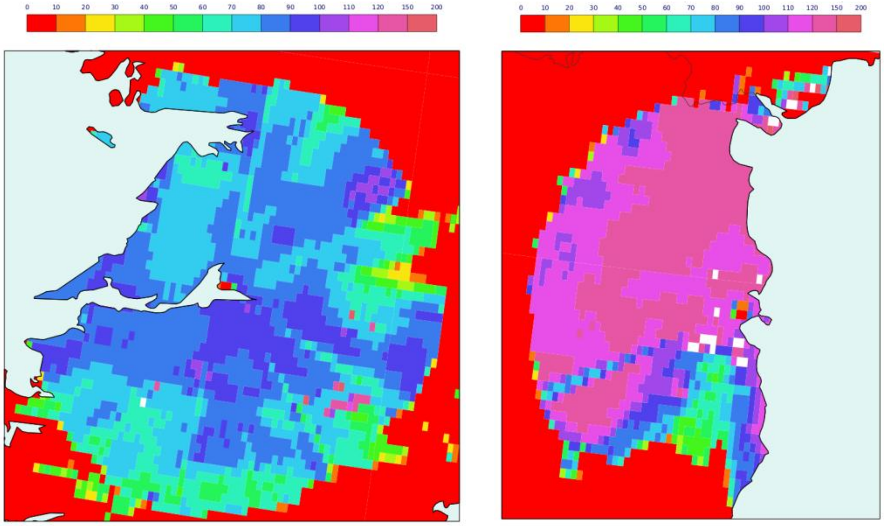

Figure 4.7: Annual performance of the SRI product for 2012 for the Shannon (left) and Dublin (right) radars.

	Snn SRI	Dub SRI
Mean Annual Performance %	78.57	114.85
Mean Standard Deviation	14.64	23.14

Table 4.2: Mean performance values of the SRI product for Dublin and Shannon radars for 2012.

5 Discussion

5.1 Introduction

The results obtained from this verification show that both radars display significant underperformance in the detection and estimation of rainfall. Sizeable portions of the country have radar rainfall estimation rates of less than 30% of the rain gauge observed values. The Dublin radar was shown to be performing better than Shannon but with some regional variation.

In this section, an attempt has been made to identify some of the potential causes of the observed radar underperformance and to quantify the impact of these factors.

5.2 Range Impact

Examining the performance data for the Irish radar network (see Figures 4.1, 4.5), the most prominent pattern observed in this study is the reduction in rainfall detection with increasing distance from the radar stations. This finding agrees with the general consensus in other studies regarding radar performance (Kitchen and Jackson, 1993; Lambkin, 2007). Attenuation of the energy of the radar pulse due to absorption and scattering in the atmosphere, and a broadening of the beam as it moves away from the radar are the main recognised reasons for the reduction in performance with range. Beam overshooting of precipitation targets due to the rising of the beam with distance, relative to the Earth's surface, is another source of range error.

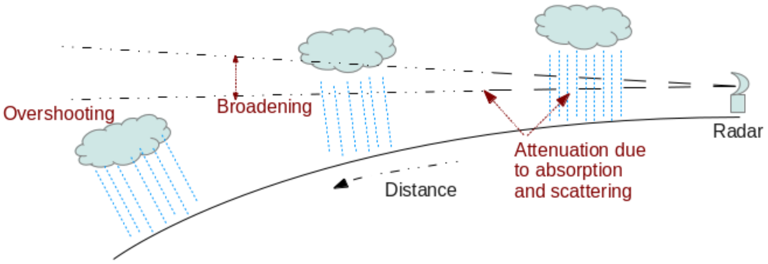

Figure 5.1: Primary causes of reduction in radar performance with distance.

The distance of each grid point from the radar stations was calculated, and then plotted against the performance percentage values for both the Dublin and Shannon PCR products. Figure 5.2 shows the annual relationship between radar performance and distance from the radar for the Dublin and Shannon PCR data. For both radars, performance is shown to decrease with increasing distance, with correlation values of -0.81 and -0.86, for Dublin and Shannon, respectively. The relationship was also examined for all 12 individual months, returning similar values (see Appendix B).

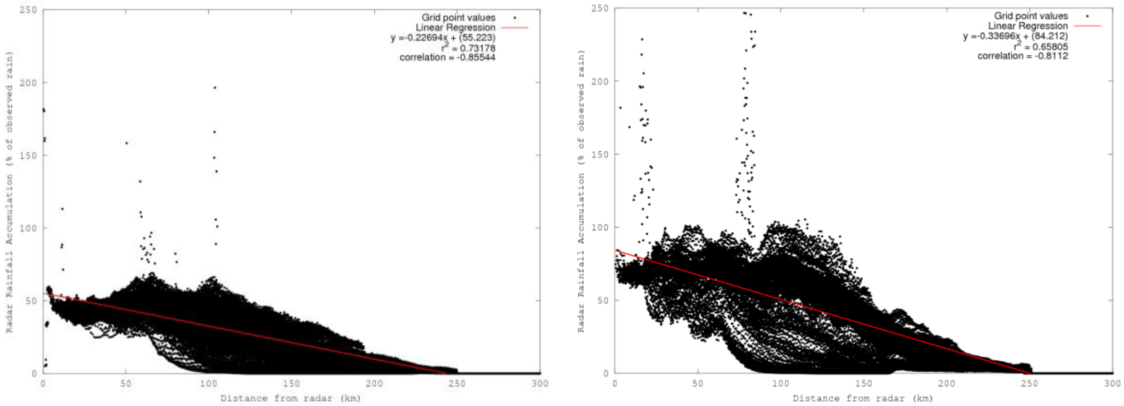

Figure 5.2: Relationship between range from the radar and performance for the Shannon (left) and Dublin (right) PCR products for the year 2012.

A linear trend line was fitted to both datasets, and the first degree polynomial equations were used to test if a linear distance relationship could be used to model the performance of the radars, and perhaps be implemented as a correction. However, it appears that the relationship is not linear. The performance remains relatively constant for a range of ~100km, before steadily declining. This relationship was observed in virtually all distance-performance plots generated, and is particularly evident when individual radials of grid points are examined (see Figure 5.3). This agrees with findings observed in previous studies (Kitchen and Jackson, 1993). It may also indicate a reduction in performance associated with the way the PCR product is constructed; the performance decline commences shortly after the point (~80km) where the lowest radar scan replaces the 1500m CAPPI layer (as discussed in Chapter 2).

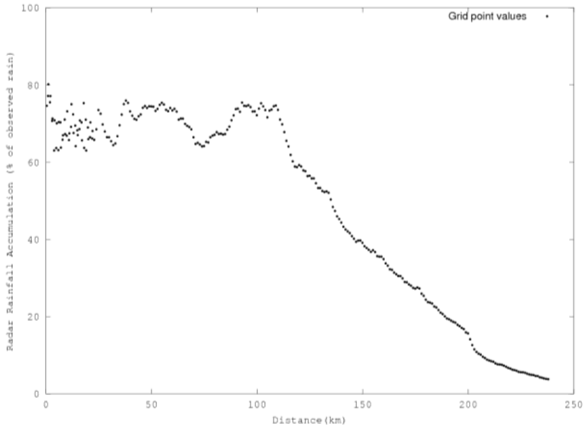

Figure 5.3: Variation of mean PCR performance with distance for 2012 along a due west (270°) radial from the Dublin radar.

Cubic trend lines were fitted to the distance-performance data, as shown in Figure 5.4. The third degree polynomial equations for both radars were used to generate performance percentages based on range from the radar. The values obtained were compared with the observed performance values, in order to determine if a cubic relationship could be used to correct for radar error. Figure 5.5 shows the observed and modeled performance maps for the Dublin and Shannon radars.

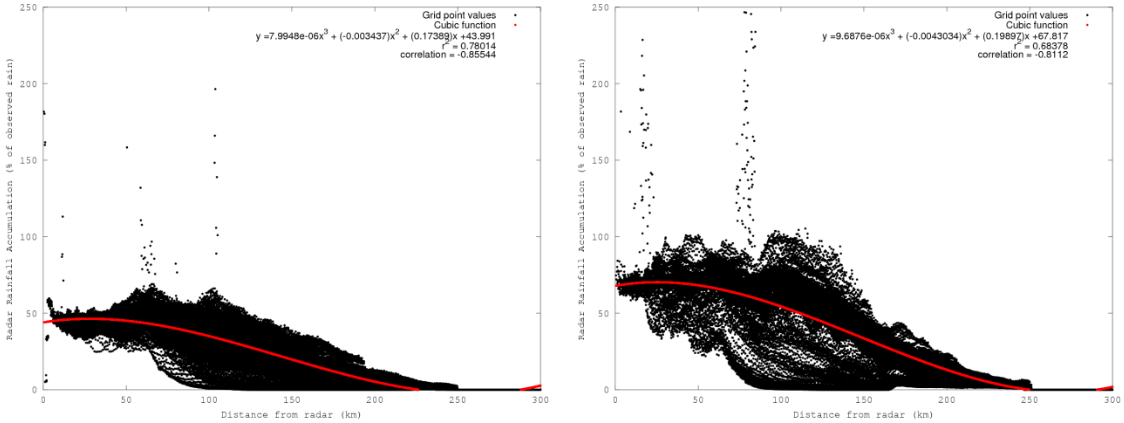

Figure 5.4: Relationship between range from the radar and performance for the Shannon (left) and Dublin (right) PCR products for the year 2012. A cubic trend line has been fitted to the data

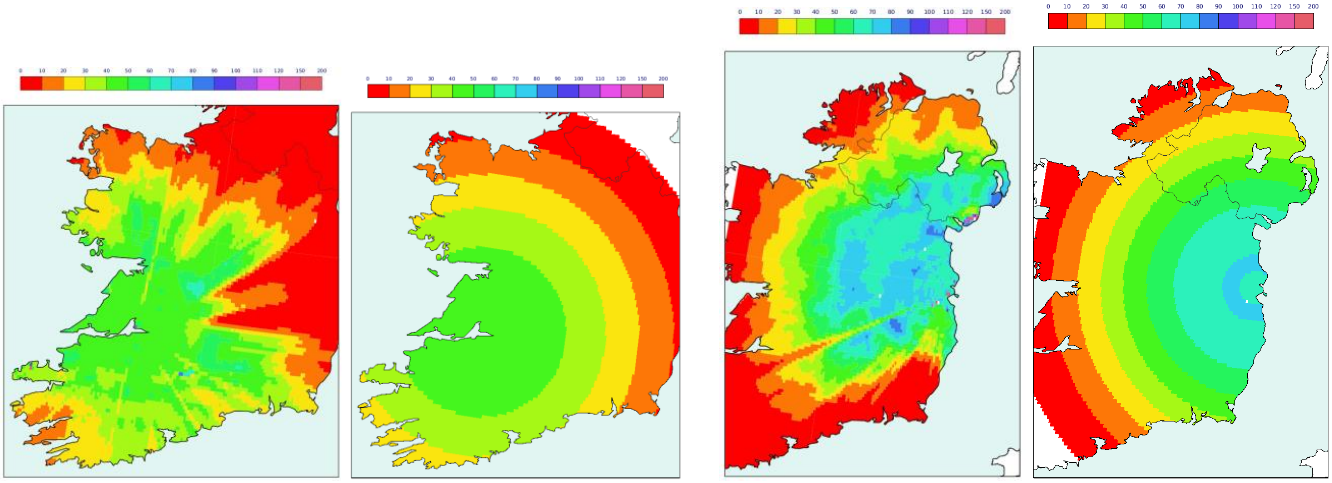

Figure 5.5: Observed and range-modeled performance maps of the Shannon (left) and Dublin (right) PCR for 2012.

The cubic range relationship for both radars models the general position of the performance bands quite well, but highlights areas where radar performance is significantly lower than can be accounted for due to range error.

5.3 Orographic Impact

In order to investigate other potential influences on radar performance, the impact of range on performance was removed from the data from both radars, using the cubic relationships obtained previously. These data were plotted (as shown in Figure 5.6), and it was observed that several areas of poor performance were associated with regions of high ground. Orography can affect radar performance through a number of mechanisms and these have been investigated in this section.

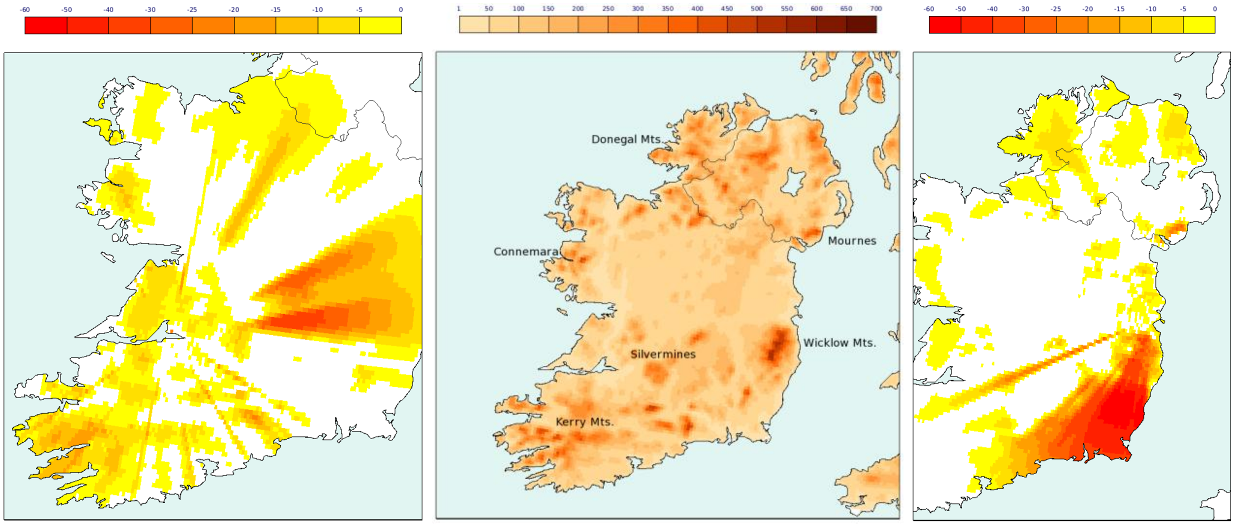

Figure 5.6: Performance of the Shannon (left) and Dublin (right) PCR products where the effects of range on the radar have been removed, and a map of Irish topography (centre). The two radar maps show regions where the performance of the radar was lower than can be accounted for by range error.

5.3.1 Beam Blocking

High ground located within the range of a weather radar may partially or totally block the radar beam from scanning the atmosphere on the far side of the hill or mountain. This can create a radar shadow area, where rainfall detection by the radar is greatly reduced (see Figure 5.7). The impact and scale of the beam blockage is obviously dependent on the size and height of the blocking object, but also on its distance from the radar itself.

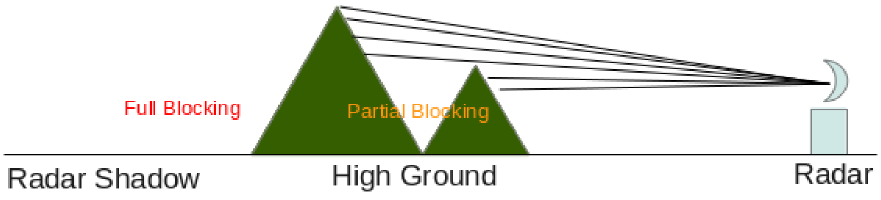

Figure 5.7: Blockage of radar beam by high ground, creating a radar shadow.

Examining the Dublin radar data, the wedge-shaped area of poor radar performance in the south east of Ireland appears to be the result of beam blockage by the Wicklow Mountains. This is an extensive area of high ground, stretching over 500km^2, with 39 peaks over 600m with the highest being 925m (Whittow, 1975). In addition to the dimensions of this area, the Wicklow Mountains rise within 30km of the radar at Dublin airport, and therefore intercept the beam for a wide range of azimuth and altitude angles. Figure 5.8 shows a clear example of this blocking from 2 January 2012, which gives the appearance of rainfall weakening and ceasing while passing through the southeast, before re-intensifying on emergence from the shadow zone.

Beam blockage is also impacting the Shannon radar performance, with extensive shadow areas to the east of the station extending into the Irish midlands, due to the presence of the Silvermine hills (Figure 5.6). Structures in close proximity to a radar station, such as buildings and masts, can also block portions of the radar beam and may account for the number of narrow regions of poor performance which extend out from both stations.

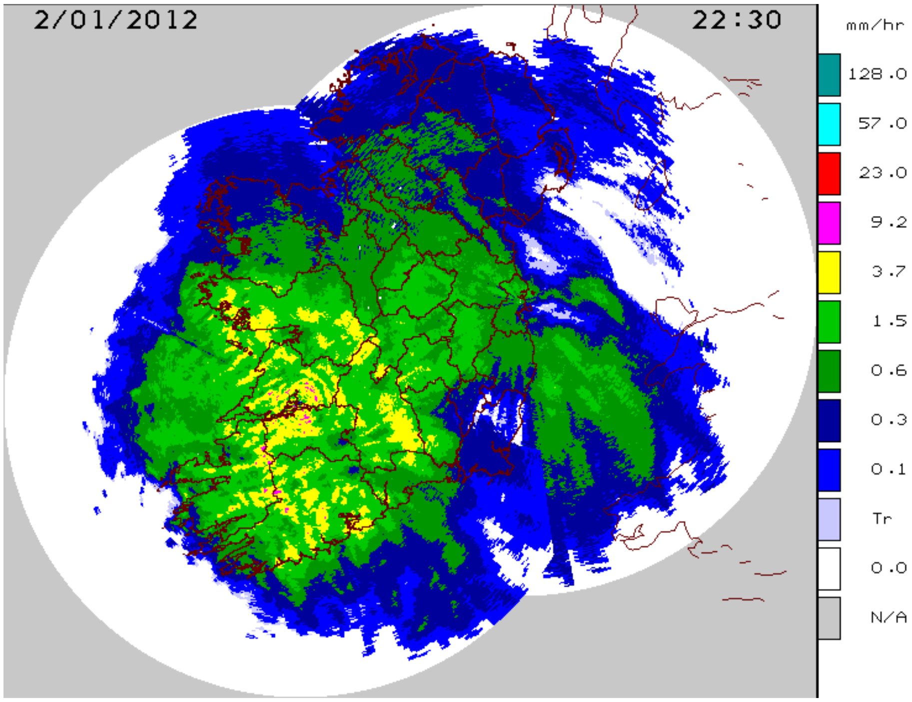

Figure 5.8: Example of beam blockage due to the Wicklow Mountains, resulting in a region of rainfall under-detection in South-East Ireland on 2 January 2012.

5.3.2 Orographic Rain Enhancement

The orographic enhancement of rainfall can be another cause of under-detection by weather radar (Harrison *et al*., 2000). Low cloud or fog can form on hills and mountains as moist air cools as it is forced to rise. Rain falling from cloud at a higher level may pass through this lower layer of cloud, colliding with and sweeping out water droplets, and greatly increasing the rainfall received at the surface (see Figure 5.9). As this enhancement occurs very close to the surface, the radar beam may not be able to detect it, overshooting the region of enhancement and instead, sampling the unenhanced layer of rainfall above. This may be a contributing factor to the poor radar performance observed in the various mountainous regions including Kerry, Connemara, Sligo/Donegal and Antrim.

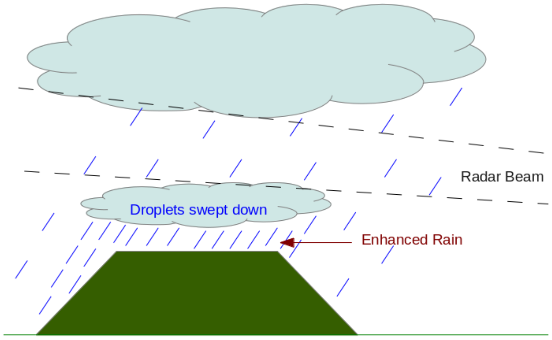

Figure 5.9: Orographic rainfall enhancement can lead to the under-detection of rainfall by radar.

5.3.3 Permanent Echoes

In Figure 4.1, it can be seen that there is a region to the south of the Mourne Mountains (in Co. Down) where the radar overestimates rainfall amounts. This over-reading is caused by a permanent echo or ‘ground clutter’ associated with the region of high ground. Radar pulses are reflected by the mountains and are received and interpreted as precipitation echoes by the radar. Similar spurious echoes can be received from structures close to the radar (e.g. Dublin city). As these echoes are generally caused by stationary objects, they can be partially corrected for by compiling a clutter map of the locations and intensities of the permanent echoes during periods with no rainfall.

5.4 Meteorological Effects

5.4.1 Introduction

It has been shown that range and orography have a significant impact on radar performance, and many of the features observed in the performance data for both radars can be attributed to these two factors. They also help explain the pattern of regional dominance of the two radars in Ireland, as observed in Figure 4.3.

The effects of range and orography on radar performance should be essentially constant with time, as the radar locations are stationary, and changes to orography are negligible. However, there is significant variance present in the performance values (see Figure 4.2). When radar performance is examined over the course of the year, as shown in Figure 5.10, significant variability is observed from month to month. In particular, when the variability of performance with time is examined for the individual radars, it can be seen that both Dublin and Shannon have very similar trends, despite being approximately 200km apart. This would suggest that large scale, variable factors are acting on both radars, resulting in similar trends in performance. In an effort to identify and quantify these factors, the effects of a number of seasonal and meteorological variables on radar performance were explored. It should be stated at this point that in order to confirm the absence or presence of such relationships, an expansion of this study over several years would be required to see if similar patterns are observed.

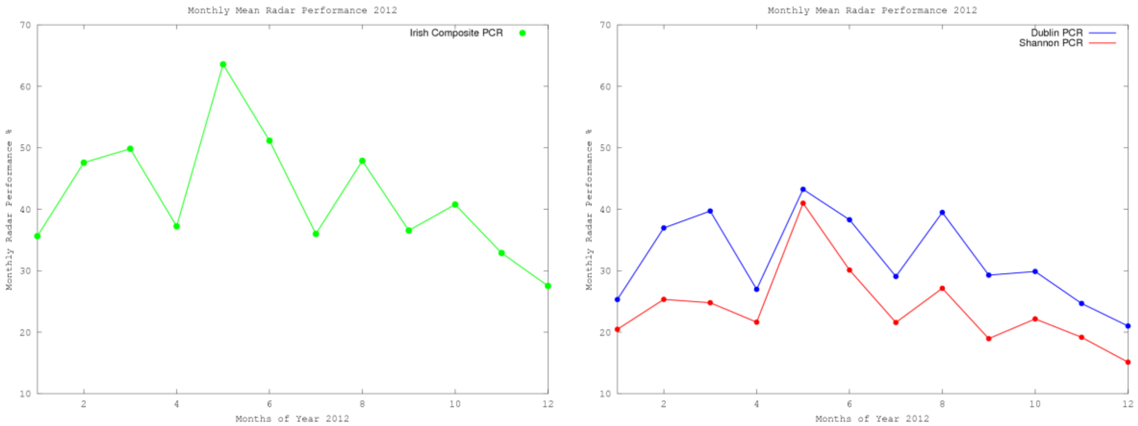

Figure 5.10: Monthly mean radar performance during 2012 for the Irish composite of the PCR products (left), and the Dublin and Shannon PCR products separately (right).

5.4.2 Rainfall Intensity

The attenuation of the radar beam by rain drops and aerosols in the atmosphere is a primary cause of rainfall under-detection by weather radar. Radar performance was examined against daily and monthly rainfall totals to test whether increased levels of rain in the atmosphere could be shown to be a cause of reduced performance. Both Dublin and Shannon radars showed a decrease in radar performance with increasing daily rainfall (see Figure 5.11). Similar trends were observed in the monthly totals data. There was significant variability observed in this relationship however, with low correlation values of -1.2 on average.

When the mean values of total rainfall and radar performance for each month are examined, as shown in Figure 5.12, evidence of an inverse relationship between the two is visible from January to June, after which the pattern appears to break down. To confidently attribute dips in radar performance due to rainfall, higher temporal resolution rain gauge data would be required. This would allow the intensity and location of individual rainfall events to be resolved, and the impact of these factors on radar performance and range to be more accurately quantified.

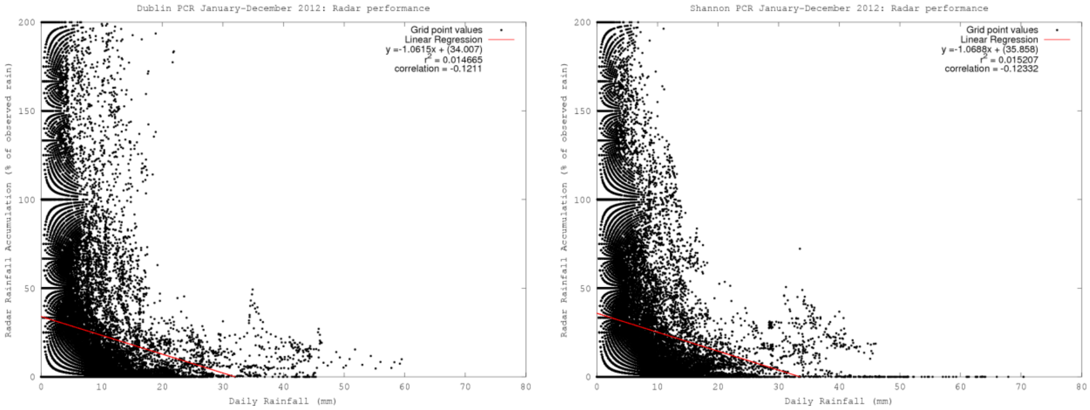

Figure 5.11: Relationship between daily total rainfall and radar performance over 2012 for the Dublin (left) and Shannon (right) radars.

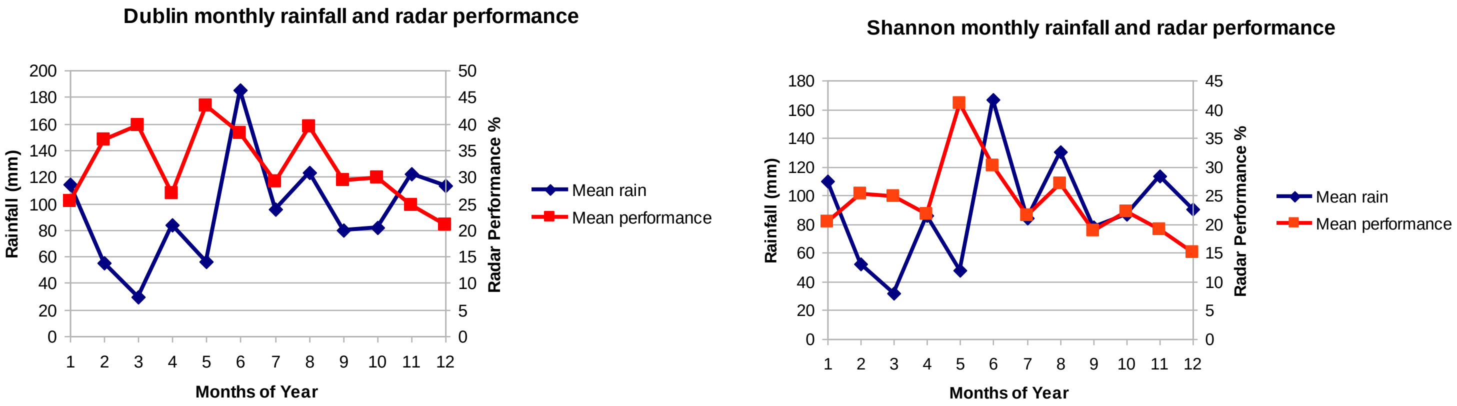

Figure 5.12: Mean monthly rainfall and radar performance trends over the year 2012 for the Dublin and Shannon radars.

5.4.3 Seasonal Effects

To test for the presence of a seasonal trend in radar performance, the data from 2012 were binned into seasons: December, January, and February for winter; March, April, and May for spring; June, July, and August for summer; September, October, and November for autumn. Radar performance was found to be stronger in spring and summer than in autumn and winter (see Figure 5.13). In particular, it was observed that the performance at the range of the radar was significantly reduced in winter when compared with summer, as shown in Figure 5.14.

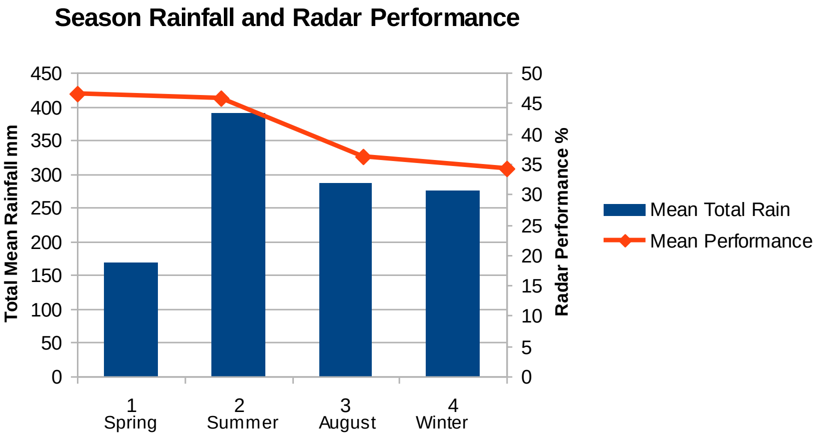

Figure 5.13: Seasonal rainfall and radar performance values for 2012.

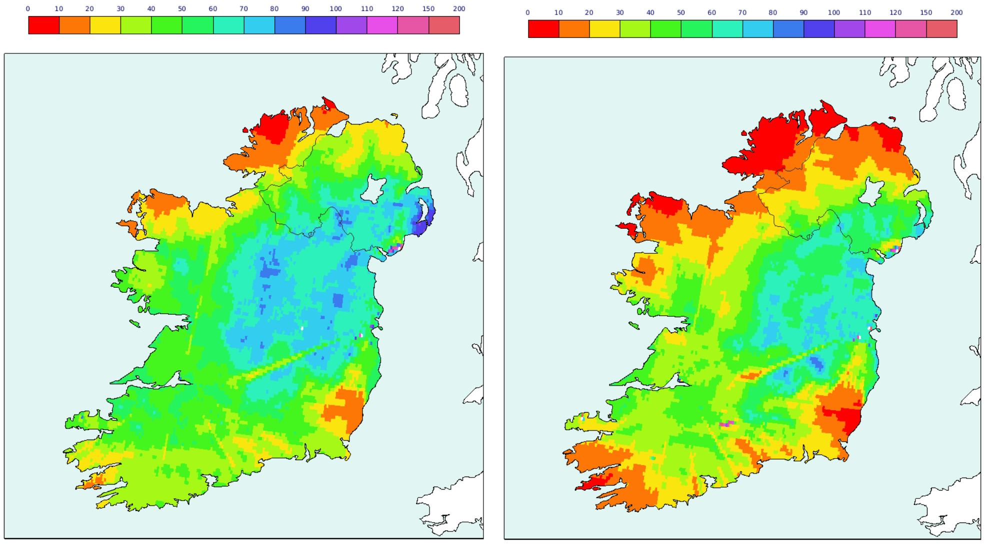

Figure 5.14: 2012 seasonal radar performance (%) for summer (left) and winter (right).

5.4.4 Impact of Temperature

In an effort to isolate a cause for a potential seasonal difference in performance, monthly mean temperature and radar performance data were compared. Performance was observed to increase with warmer temperatures, with a correlation of 0.38. The trends over 2012 for the temperature and performance data (Figure 5.15) were shown to follow similar patterns outside of the summer months when the relationship appears to break down. The unusually wet summer of 2012 may explain why the performance trends do not follow the increasing temperature trend during these months.

The boost in radar performance during the warmer months and the decreased performance at range during winter may be partially due to the influence of the bright band. This is the layer in the atmosphere where snowflakes melt into raindrops. As they begin to melt, the large diameter snowflakes will have a liquid water surface; the combination of large diameter and liquid water giving them a high reflectivity (Rinehart, 1991). The echoes from this layer can be interpreted by the radar as high-intensity rain, leading to spurious overestimations of rainfall. As the melting layer will be higher in the atmosphere during warmer temperatures, the radar beam will intersect the bright band at more distant and wider ranges (i.e. beyond 80km where the lowest scan is used to make up the pseudo CAPPI). This may add a spurious boost to detection performance in regions where rainfall detection is normally low due to distance from the radar. Similar bright band contamination was observed in studies by Harrison *et al*. (2000).

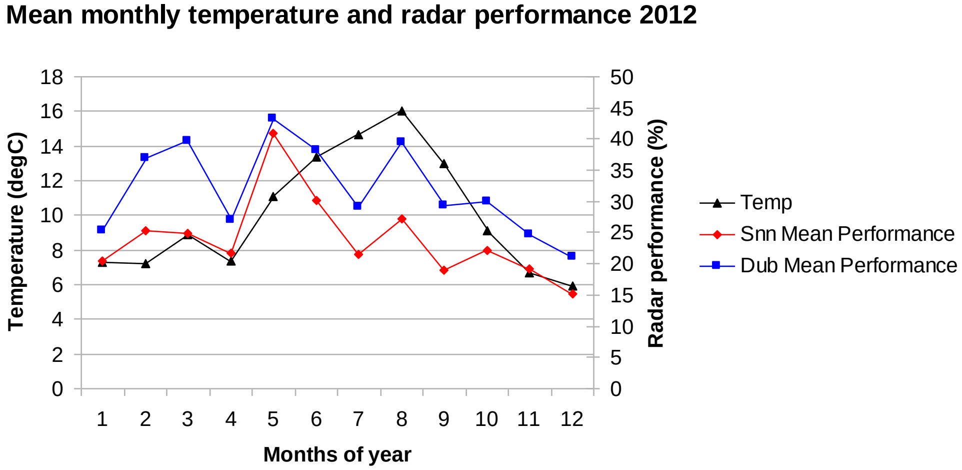

Figure 5.15: 2012 mean monthly temperature and radar performance.

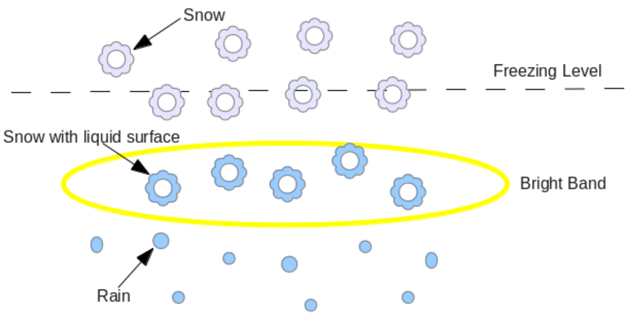

Figure 5.16: The bright band layer contains partially melted snowflakes with liquid water surfaces.

5.4.5 Frontal and Convective Conditions

Ireland receives its rainfall throughout the year from a combination of frontal systems and convective showers, often with both on the same day. The data from this study were examined to see whether or not rainfall type had a measureable impact on radar performance. Using weather reports and archived satellite and radar images, 50 days from 2012 were selected, where rainfall was either frontal or convective (25 days each). Days which had significant mixtures of both were avoided.

Radar performance was observed to be slightly stronger during days with frontal rainfall rather than convective conditions, despite more rainfall being received during the frontal days. A Mann-Whitney test was carried out on these two datasets with the null hypothesis that the frontal and convective performance values were the same. At the 95% confidence level, a p value of $< 2.2e^{-16}$ was returned, and the null hypothesis was rejected.

Conditions	Mean Total Rain	Mean Performance %
convective	66.03	40.51
frontal	93.05	46.12

Table 5.1: Mean total rain and radar performance over Ireland during the 25 days each of convective and frontal rain conditions.

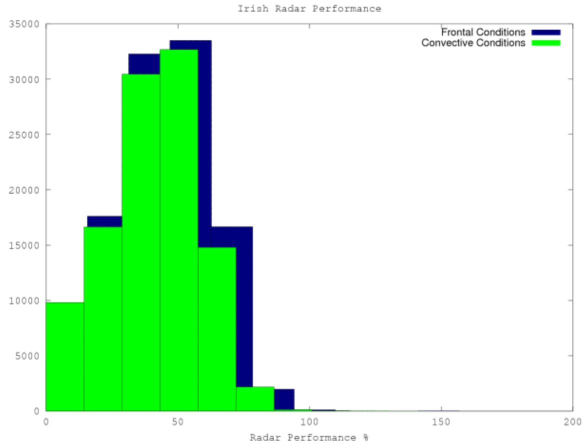

Figure 5.17: Distribution of the radar performance during frontal and convective conditions.

5.5 SRI Verification

The overall performance of the SRI product was examined during this study. As can be seen from Figure 4.7 and Table 4.2, the Shannon product shows good performance within its operational range, with a mean annual performance of 78.57%. The Dublin SRI shows a significant tendency to overestimate rainfall with a mean annual performance of 114.85%.

When compared with the performance of the PCR product in this region (see Figures 5.18 and 5.19), the Shannon SRI radar product appears to be a more reliable product for the detection of rainfall for the cities of Limerick and Galway and the surrounding counties of Limerick, Clare, south Galway, and west Tipperary. At present, the Dublin SRI product's positive bias would preclude it from replacing the PCR as the product of choice for rainfall detection over Dublin city.

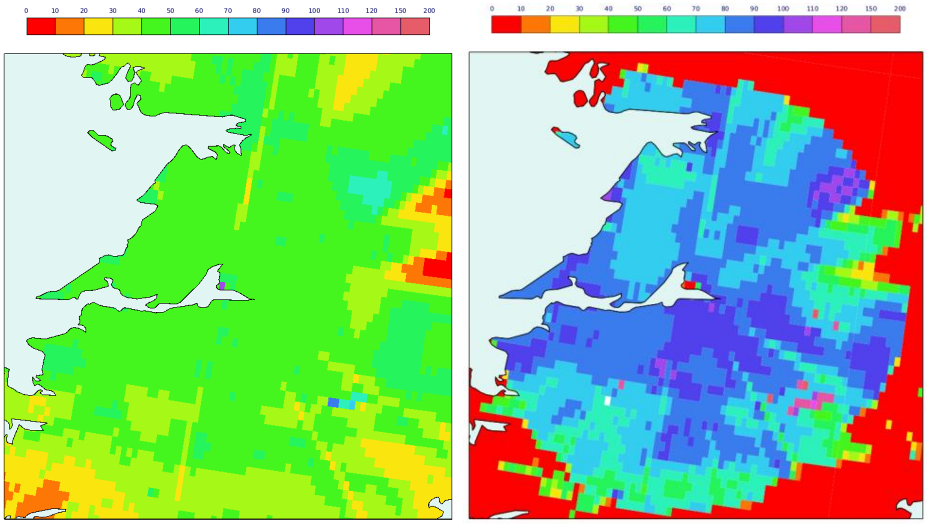

Figure 5.18: Comparison of the performance of the PCR (left) and SRI (right) products for the Shannon radar. The data are for the total annual rainfall for 2012 in the operational range of the SRI product.

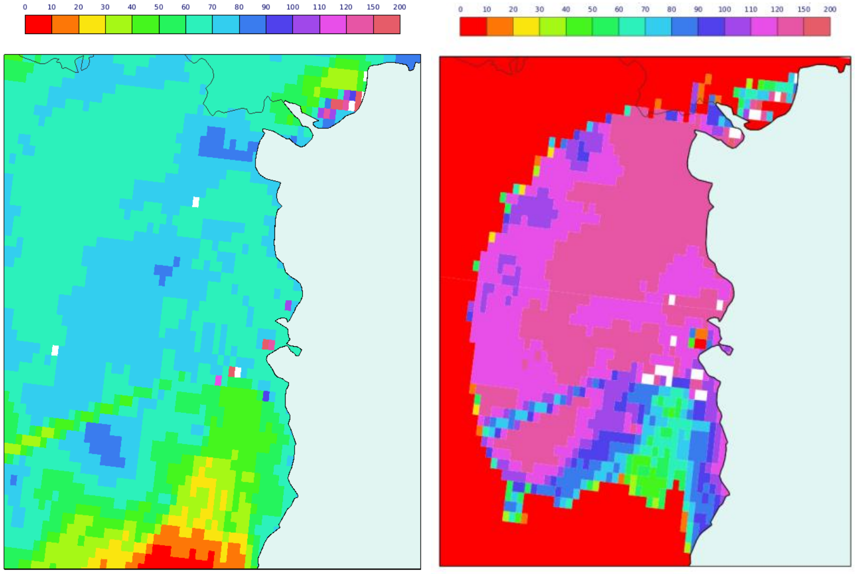

Figure 5.19: Comparison of the performance of the PCR (left) and SRI (right) products for the Dublin radar. The data are for the total annual rainfall for 2012 in the operational range of the SRI product.

6 Conclusion

The aim of this study was to verify the performance and reliability of Met Éireann's weather radar in the detection and estimation of rainfall. Rainfall values derived from the rain gauge and radar data were compared and analysed for the year 2012. Overall, it has been found that the Irish radar network is under-observing rainfall amounts countrywide, most significantly along the north, northwest, southwest, and southeast coasts. The radar at Dublin airport was shown to be performing better than the Shannon radar when the main PCR products were compared.

Distance from the radar was found to be the primary factor influencing performance in Ireland, with the counties of Donegal, Sligo, and Mayo most affected by this. A significant decline in performance beyond ~100km range was noted for both the Dublin and Shannon radars, highlighting the potential benefit of additional radars in the Irish network.

Orographic blocking by high ground is a major issue for both radars, creating a number of large radar shadow areas. The Wicklow-Wexford region in the southeast has particularly bad radar performance due to a combination of extensive blocking of the Dublin radar by the Wicklow Mountains, and the region's distance from the second radar in Shannon. This results in only 10-30% of rainfall being detected in this area, on average. A similar situation exists to the south of the mountainous regions in Kerry.

An investigation into the impact of meteorological and seasonal variables on radar performance found evidence of possible influencing relationships. In general, performance was observed to improve in months with warmer temperatures and lower rainfall amounts, with improved rainfall detection during frontal conditions when compared with convective situations. This study would need to be expanded over several years to further clarify and quantify these relationships.

The findings of this report, and in particular, the generated performance map shown in Figure 4.1, could be used as a guide for those involved in interpreting Irish radar data. However, due to the observed variability in performance, the real-time correction of radar values using historical data alone may not be feasible. Real-time validation could potentially be realised through the combined use of historical data, and the input of real-time rain gauge data, following further automation of the climate rainfall network.

7 Acknowledgements

I would like to thank Séamus Walsh and the Climatology and Observations Division in Met Éireann, who provided the gridded rain gauge data and informed me on the processes involved.

I would also like to thank Kieran Commins, Keith Lambkin, and Morgan Geraghty for providing me with information on the radar system, and Ray McGrath and Eoin Whelan for advice regarding the software and data used.

Sincere thanks to Mairéad Treanor for her assistance in publishing this report.

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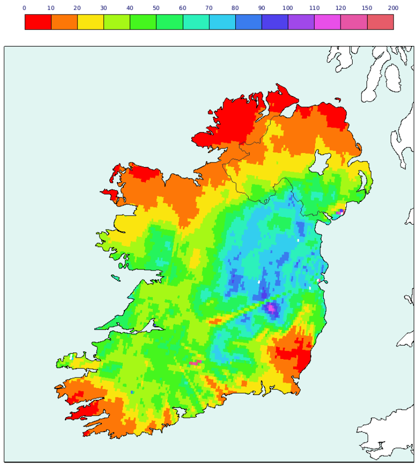
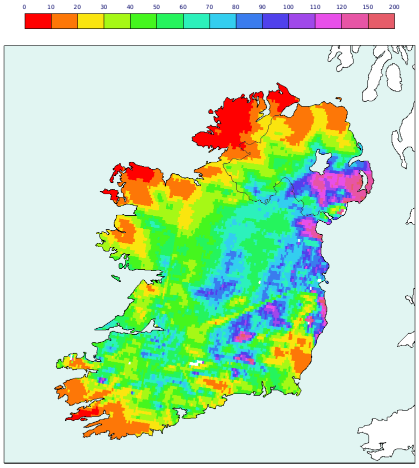
Appendices

Appendix A

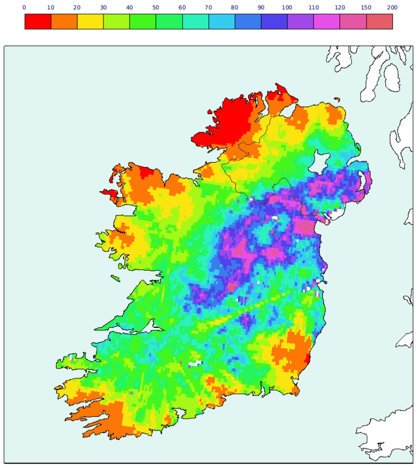
The images below are radar performance maps for total monthly rainfall for each of the 12 months of 2012. Radar rainfall accumulation values, calculated from the PCR product, have been expressed as percentages of the corresponding rain gauge derived values, to provide a performance indicator for each grid point. The maps are composites of the Dublin and Shannon radar data, compiled using the regional dominance template, as shown in Figure 4.3.



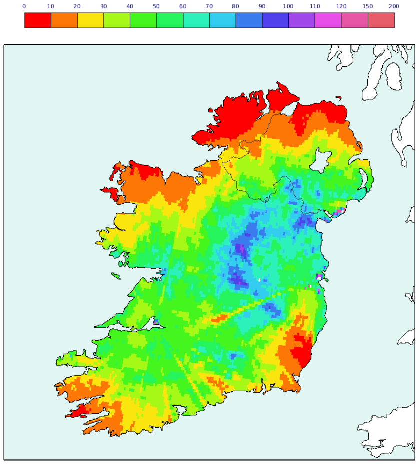
January



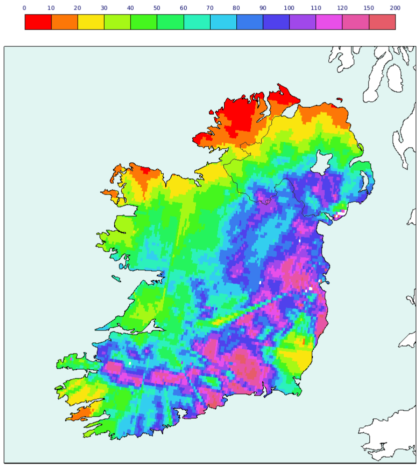
February



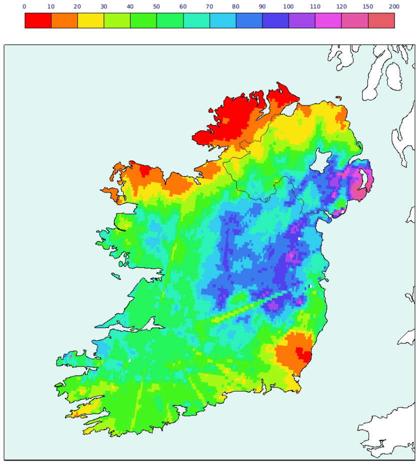
March



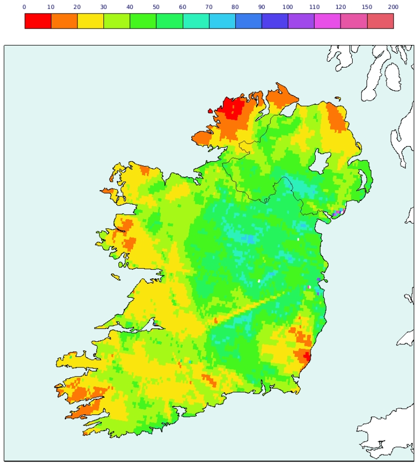
April



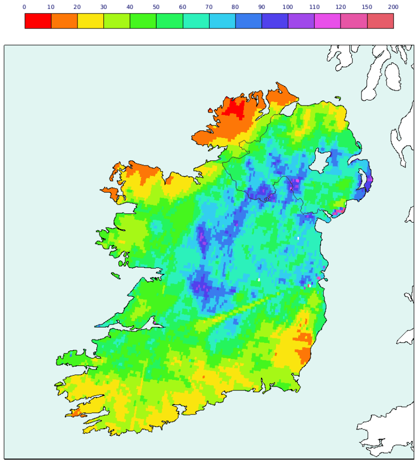
May



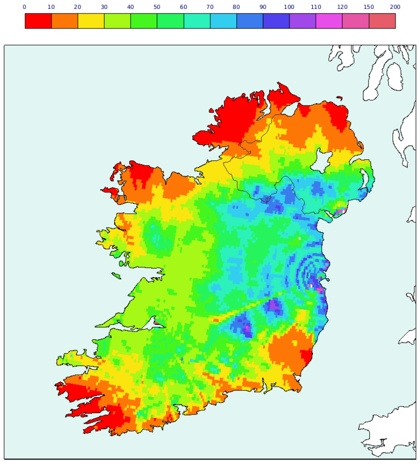
June



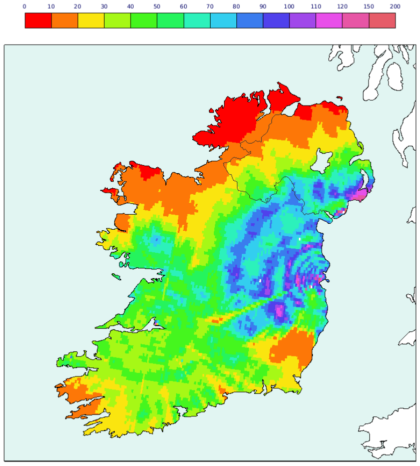
July



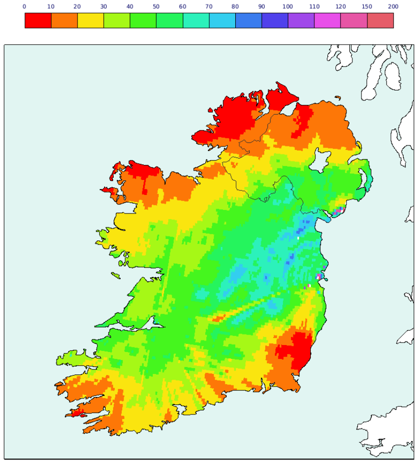
August



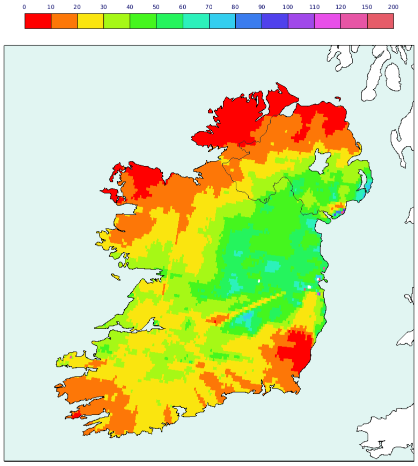
September



October



November

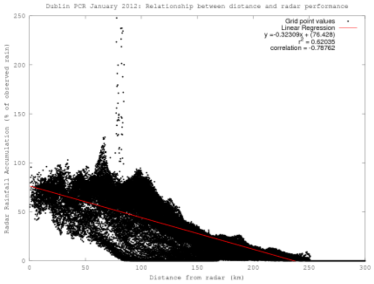


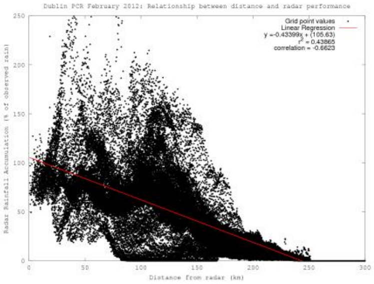
December

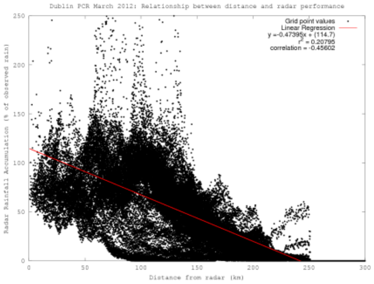
Appendix B

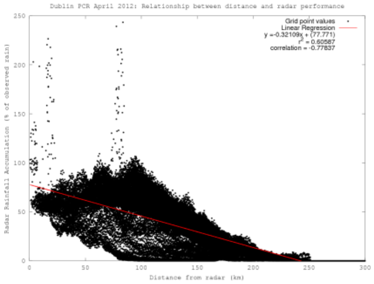
The images below show the monthly relationship between radar performance and distance from the radar for the Dublin and Shannon PCR data for the year 2012.

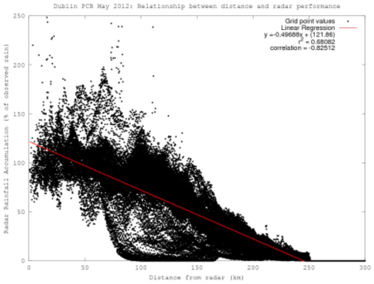
Dublin PCR

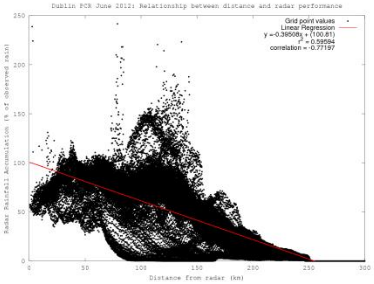


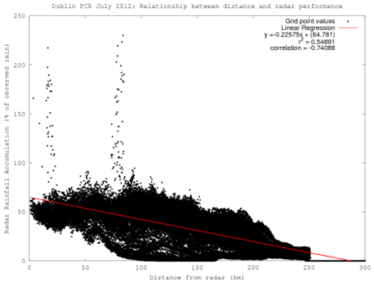


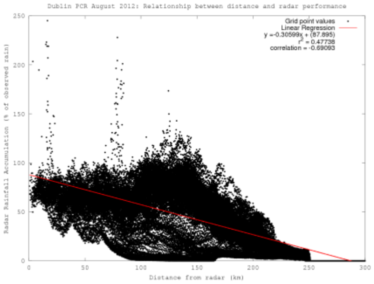


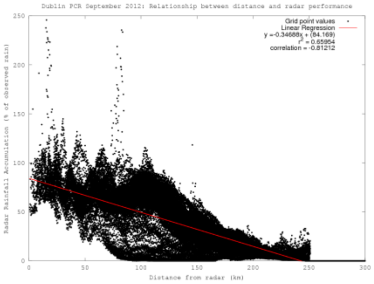


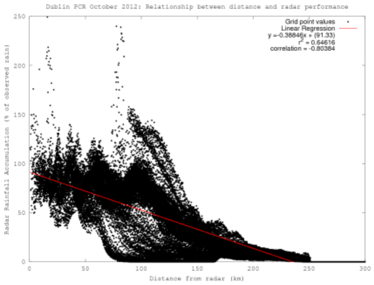


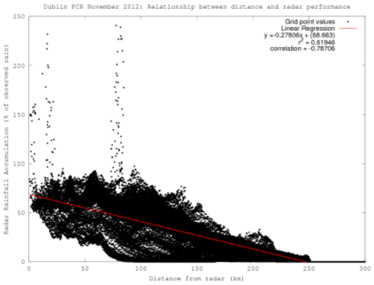


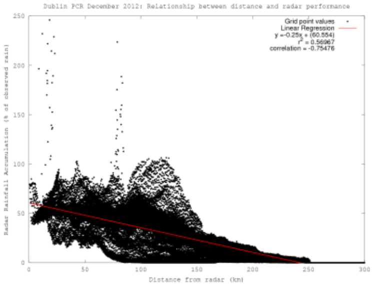




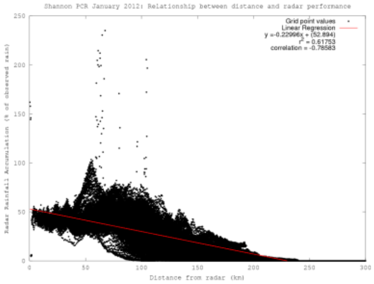


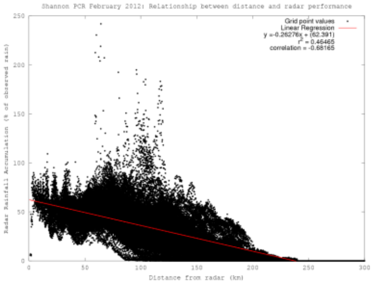


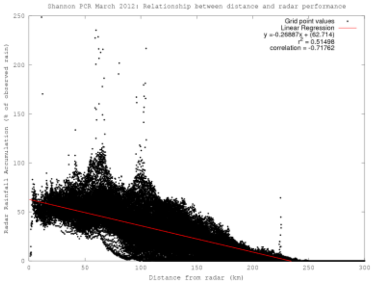


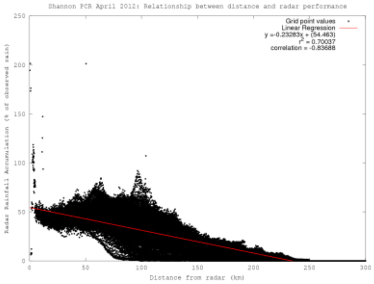


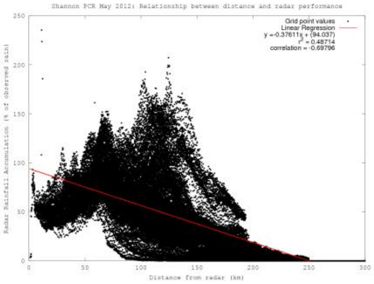
Shannon PCR

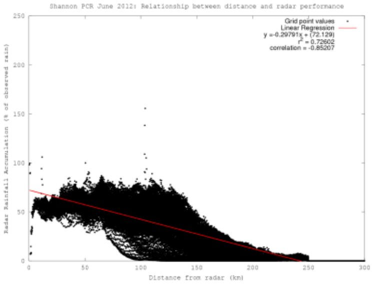

Shannon PCR January 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.22996x + (52.894)
r² = 0.61753
correlation = -0.78583
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300

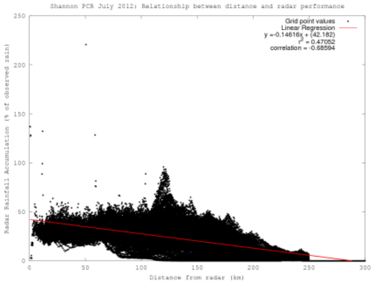

Shannon PCR February 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.26276x + (62.391)
r² = 0.46465
correlation = -0.68165
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300

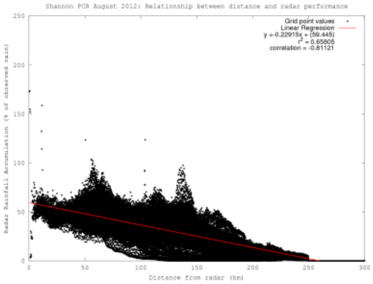

Shannon PCR March 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.26887x + (62.714)
r² = 0.51498
correlation = -0.71762
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300

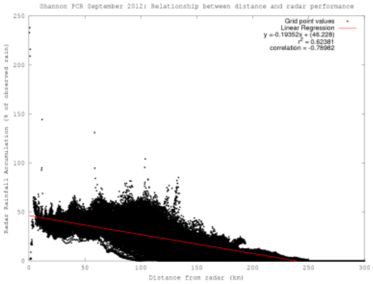

Shannon PCR April 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.23283x + (54.463)
r² = 0.70037
correlation = -0.83688
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR May 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.37611x + (94.037)
r² = 0.48714
correlation = -0.69796
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR June 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.29791x + (72.129)
r² = 0.72602
correlation = -0.85207
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR July 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.14616x + (42.182)
r² = 0.47052
correlation = -0.68594
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR August 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.22915x + (59.445)
r² = 0.65805
correlation = -0.81121
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR September 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.19352x + (46.228)
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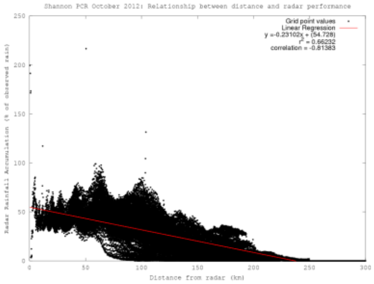
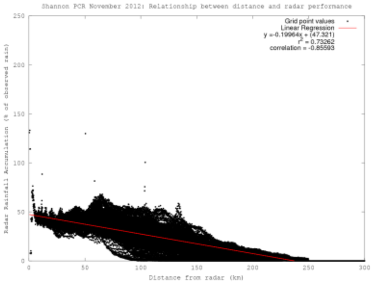
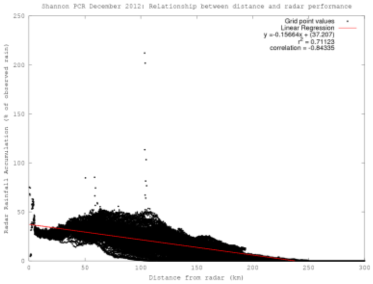
correlation = -0.78982
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR October 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.23102x + (54.728)
r² = 0.66232
correlation = -0.81383
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR November 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.19964x + (47.321)
r² = 0.73262
correlation = -0.85593
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300


Shannon PCR December 2012: Relationship between distance and radar performance
Grid point values
Linear Regression
y =-0.15664x + (37.207)
r² = 0.71123
correlation = -0.84335
Radar Rainfall Accumulation (% of observed rain)
0
50
100
150
200
250
Distance from radar (km)
0
50
100
150
200
250
300