IMPROVING OPERATIONAL USE OF SCANNING RAIN RADAR ESTIMATES WITH VERTICALLY POINTING RADAR

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ABSTRACT

Accurate estimation of the spatial and time variation of rainfall across urban catchments is essential for accurate sewer and stormwater modelling and operations activities.

In previous work, the authors have described the automated processing and quality control of observations from the Auckland MetService radar, required for meaningful real-time calibration of the radar precipitation estimates using the Auckland Council rain gauge network. The high quality radar derived accumulations (1 minute time step, 500m resolution rasters) are then fed into a cloud-based GIS platform and can be interacted with by council staff, for example to extract a catchment averaged accumulation or raster stack for model input.

Some form of calibration of radar precipitation estimates is required because the absolute bias of the [MetService] scanning radar is unknown, signal losses occur due to radome and path attenuation and the relationship between the radar measurement aloft (reflectivity) and rainfall rate at the surface (mm/hr) is dependent on the raindrop size distribution, which is not able to be estimated by the scanning radar. The sampling scale differences between rain gauges (10-20 cm diameter gauges) and radar (~500x500m pixels) make it very difficult to directly compare radar and gauge measurements and can confound reliable estimation of correction factors in real time.

An alternative approach to the scanning radar calibration problem is to use small Vertically Pointing Radar (VPR) to calibrate the MetService radar measurements directly while also estimating the variability in attenuation and reflectivity-rainfall (Z-R) relationship. The skill of the VPR calibrated radar product was compared with the conventional gauge correction approach for detecting significant rainfall events. The VPR and gauge products were found to have similar skill for the detection of short duration/high intensity rainfall in the retrospective tests. A possible operational advantage of the VPR calibration approach over using the gauge network to adjust the radar measurements is reduced dependency on the gauge telemetry system, which could significantly reduce the delay between the radar measurement being made and alarms being issued.

KEYWORDS

Radar, ARI, VPR, rain-gauge.

PRESENTER PROFILE

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1 INTRODUCTION

The Auckland Council Healthy Waters Department undertakes both planning and operational activities around flood management for the 5500km^2 Auckland Region. Advanced understanding of rainfall assists greatly in undertaking modelling for planning purposes, and for operational response including support of Auckland Emergency Management and other agencies during events.

A significant issue has been the difficulty in accessing rainfall gauge information, and understanding event characteristics between rainfall gauges. Auckland Council is addressing this issue by sourcing (where possible) rainfall data from multiple organisations, and consolidating this into an online, cloud based, GIS platform. This allows rapid and consistent analysis and understanding of rainfall data across the Healthy Waters Department, with minimal system management overhead.

Previous work has demonstrated the value of making Auckland Council rain and stream level gauge data available to all Healthy Waters staff in the online platform. The natural progression from this was to mobilise Metservice rain radar in the same platform to assist in understanding rainfall characteristics, between rainfall gauges. Metservice rainfall radar data is now ingested into the same online platform, and automated analysis established for the repeatable tasks, such as removal of ground clutter, bias correction, and an advection based interpolation scheme to generate data at 1-minute time steps (Sutherland-Stacey, 2017).

Council has to date been using outputs from the Metservice radar for in-house post event reporting, and to understand rainfall patterns and accumulations during events. Considerable value is gained from this, and the potential benefits of ongoing investment in this area are clear. The long term view is to investigate the applicability of this technology for forecasting and issuing warnings for heavy rainfall, and for application in active flood event management.

Exceptional situational awareness is required to provide input in to any active event management process. To prepare the system for these potential applications, there are some issues to address. These are resilience and robustness of the systems involved, ensuring the data is as current as possible, or real time. Further work is required to understand the numerical uncertainty and consistency in processed rain radar, as to be most useful in event management, the uncertainty needs to be well understood, and preferably reduced to be comparable to rain gauge estimates.

To this end, Council has been testing the applicability of Vertical Pointing Radar (VPR), to assist in calibrating the signal from the Metservice radar. VPR is worthy of investigation as a complimentary data stream for calibration of the Metservice radar, as in technical terms, it provides direct calibration of the Metservice radar reflectivity signal and a revised and more appropriate Z-R relationship (drop size distribution) for improved rainfall calibration. Additional work is also now being carried out to investigate the use of VPR in better understanding uncertainty in accumulation estimates between gauges. A further benefit is that VPR provides an alternative data stream to the telemetered rain gauge network, adding resilience to the system, and potentially reducing the time required to provide a corrected radar data stream.

With regard to extreme events and situational management, the impacts of using VPR in correcting Metservice radar data could be considerable. For situational awareness and event management, more appropriately corrected radar data may allow more advanced analysis. A further area of investigation is around smaller events. Current work focuses on large events and flooding, smaller and more frequent events could be included in further work.

2 METHOD

The principle radar measurement is reflectivity (Z, mm6m-3), which for meteorological applications is the scattering cross section of all the targets in the radar beam at a particular range bin:

$$Z = \int_0^\infty D^6 N_v(D) dD \quad \text{(equation 1)}$$

where D is the drop diameter and N_v is the number of drops with that diameter. Reflectivity is usually expressed in decibel units, and values typically range from 20 dBZ for light rain to 55 dBZ for very heavy rain. Values over 55 dBZ are likely to indicate solid precipitation (hail).

The reflectivity measurement itself is impacted by attenuation of the radar signal due to water adhering to the radar's protective dome and due to rain falling between the radar and target, not to mention partial beam filling, interference from snow and an uncertain relationship between rain falling aloft and that arriving at the surface. Fundamentally, these measurements must be converted to rainfall rate (R mm hr^{-1}) to be useful.

The simplest method for converting radar measurements (Z) to rainfall (R) is to assume a constant form of the raindrop size distribution resulting in a fixed power law Z-R relationship (e.g. $Z=aR^b$ a=200, b=1.6) and then compare the resulting radar rainfall estimates with local rain gauges to derive a scaling factor. This approach has been used in most radar hydrology work in Auckland to date (Sutherland et al. 2016, Joseph et al. 2014). While gauge correction methods are comparatively simple to implement, they make the assumption that the rain gauge measurements are unbiased and representative of the radar pixel to which they are being compared.

A newly emerging method is to deploy a well calibrated Vertically Pointing Radar (VPR) to directly measure the variation in the raindrop size distribution and radar reflectivity simultaneously. This may be used to both quantify and compensate for any biases affecting the scanning [MetService] radar reflectivity signal (Lengfeld et.al 2014) and determine an optimal set of Z-R coefficients (Clemens et. al. 2008) to convert the resulting reflectivity estimate to rainfall.

In this work, we report on our progress using VPR observations obtained during a field study to calibrate the Auckland NZ MetService scanning radar, and a potential pathway for improving real-time alarming.

2.1 Scanning radar measurements

NZ MetService permanently operate a single-polarisation, C-band scanning rain radar to the north of Auckland. The radar performs a scan cycle every 7.5 minutes, measuring radar reflectivity at increasing altitudes up to 250 km in range. The radar is housed inside a radome.

Raw data from the NZ MetService scanning radar is treated in an automated pre-processing step to account for and remove the influence of non-meteorological signals such as return from hills (ground clutter), and apply an advection-based interpolation scheme to account for the 7.5 minute time step between measurements. An expanded discussion of the scanning radar data processing may be found in Sutherland-Stacey et al. (2016).

Figure 1: The MetService radar near Warkworth.

2.2 Vertically Pointing Radar Measurements

A vertically pointing Ku-band radar (MRR-2 Metek GMbH, see Peters et. al. 2002 for a description of the equipment) was deployed to Orewa in September 2017 (Figure 2). The VPR was configured to measure the Doppler velocity spectra and radar reflectivity at 30, 60 or 100-m height resolution and 10-second intervals.

Figure 2: The Vertically Pointing Radar at Orewa.

2.3 Calibration of the VPR measurements

The VPR is delivered with a factory estimate of the radar calibration constant. The manufacturer states that the calibration is within 10%, so field recalibration of the VPR by comparison with rain gauges is necessary to ensure both the reflectivity and rain-rate estimates are unbiased.

Calibration was performed for the entire long-term VPR data set collected in this study by comparison with the nearby (~50m separation) Auckland Council rain gauge at Orewa. The derived correction factor was then then applied retrospectively to the entire data set.

The resulting calibration results in excellent cumulative and pointwise agreement between the VPR and rain gauge (Figure 3).

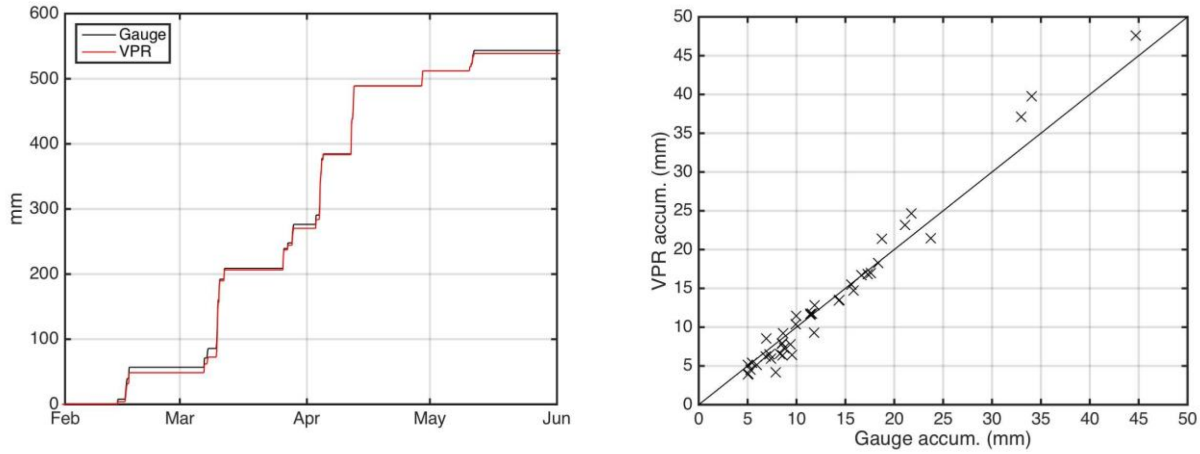

Figure 3: Comparison of rain gauge and VPR accumulations for the period during which the VPR was configured with a 30-m vertical bin resolution. Left: trace of cumulative rainfall and Right: scatter plot of 3-hour accumulations for the same period.

The recalibration is a single value, applied retrospectively to the data set. A single calibration value introduces little risk of "overfitting" the calibration when applied retrospectively. To ensure the calibration is robust and general, following the conclusion of the work reported here, the VPR was moved to the University of Auckland field station at Ardmore and the comparison of rainfall estimates with the local rain gauges was repeated. Using the previously determined calibration constants, the agreement with rain gauges was as good and no further recalibration was required.

Any unresolved calibration offset would be amplified through an incorrect correction for attenuation. Hence, even modest calibration offsets (the error in the factory calibration was found to be -0.57 dB or -12% for the period presented in Figure 3) can result in more significant errors further ranges (reaching 2 dB or ~60% at heights of 1 km). These biases can be avoided by correctly accounting for the VPR calibration. The identified calibration constant for the VPR rainfall estimates is equivalent to the correction factor for the VPR reflectivity estimates. This means the VPR reflectivity estimate at Orewa can be regarded as well calibrated and unbiased, and suitable for direct comparison with the MetService radar reflectivity measurement.

2.4 Quantification of Systematic bias in the Metservice reflectivity measurement

The MetService radar measurements above the VPR field site were processed to select times when the radar signal should be minimally impacted by attenuation (e.g. times when it was neither raining at the MetService radar site, nor was there significant rainfall intersecting the line of site between the MetService and VPR radar sites). Measurements which passed this check were compared to the VPR reflectivity estimates to derive a calibration curve for the MetService radar (Figure 4).

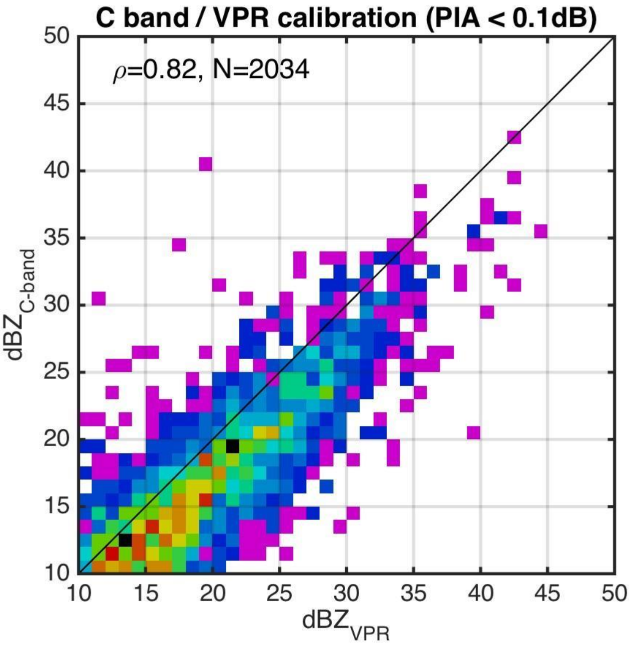

Figure 4: 2-D histogram comparing reflectivity measurements made with the VPR and coincident C-band radar pixel.

The resulting calibration curve indicated a significant low bias (-3.1 dBZ) in the MetService radar measurement. A low bias will tend to cause the MetService to underestimate the true rainfall rate, in this case by about 50%. This low bias would also significantly underestimate attenuation corrections resulting in even larger underestimates if not corrected. In order to address these biases, the MetService data was corrected with a constant +3.1 dBZ offset before further treatment.

2.5 Quantification of Radome wetting

The MetService scanning radar is protected from wind by a solid dome. While the dome itself is transparent to radiation at the radar's operating wavelength ($\lambda \simeq$5.3cm), water adhering to the outside surface results in significant attenuation of the radar signal. In order to compensate for transient losses of signal strength from "radome wetting" effects, the direct comparison between the VPR and scanning radar measurement used in the bias-correction step is reapplied for each C-band measurement frame (every 7.5 minutes) comparing the average VPR and scanning radar reflectivity estimates at the VPR location. If the scanning radar reports rain at the scanning radar location, then the difference between the VPR and scanning radar measurement is deemed to be due to radome wetting and a correction is applied to the scanning radar data.

2.6 VPR derived Z-R relationships

The long-term average ("climatological") radar reflectivity-rainfall (Z-R) relationship is useful for estimating the rainfall rate from the radar reflectivity measurement in the absence of further information. For this work, the climatological Z-R relationship was determined retrospectively by linear regression of the entire data set of VPR estimates of rainfall (R) and reflectivity (Z) at the lowest height bin (e.g. tens of meters above the ground).

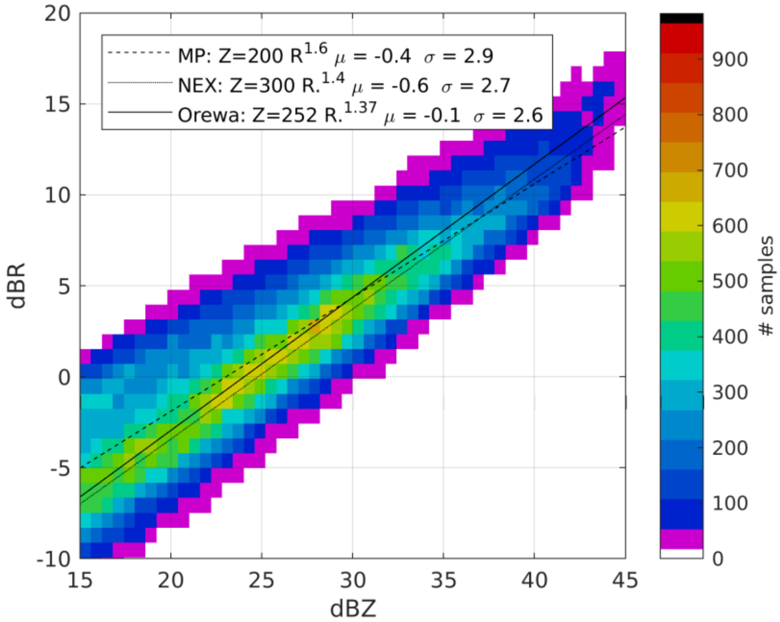

Figure 5: Z-R climatology determined from the VPR measurements at Orewa.

The climatological *Z-R* relationship ($Z=252R^{1.37}$) determined from the VPR data can be used in place of the typically employed "Marshall-Palmer" relationship ($Z=200R^{1.6}$) and is closer to the relationship used operationally in the United States for the NEXRAD S-band radars ($Z=300R^{1.4}$). This change reduces the rainfall intensity estimated from lower reflectivity (dB*Z*) values, though increases higher intensity rainfall rates.

The Z-R relationship varies from event to event and within an event. A "real-time" estimate of the *Z-R* relationship was determined retrospectively for each MetService radar frame (every 7.5 minutes) from the previous 3 hours of VPR data. In this way, the derived variable *Z-R* relationships can be considered equivalent to those which would be available operationally. At times, using the real-time *Z-R* relationship results in significantly different accumulation estimates than the long-term climatological average (Figure 6).

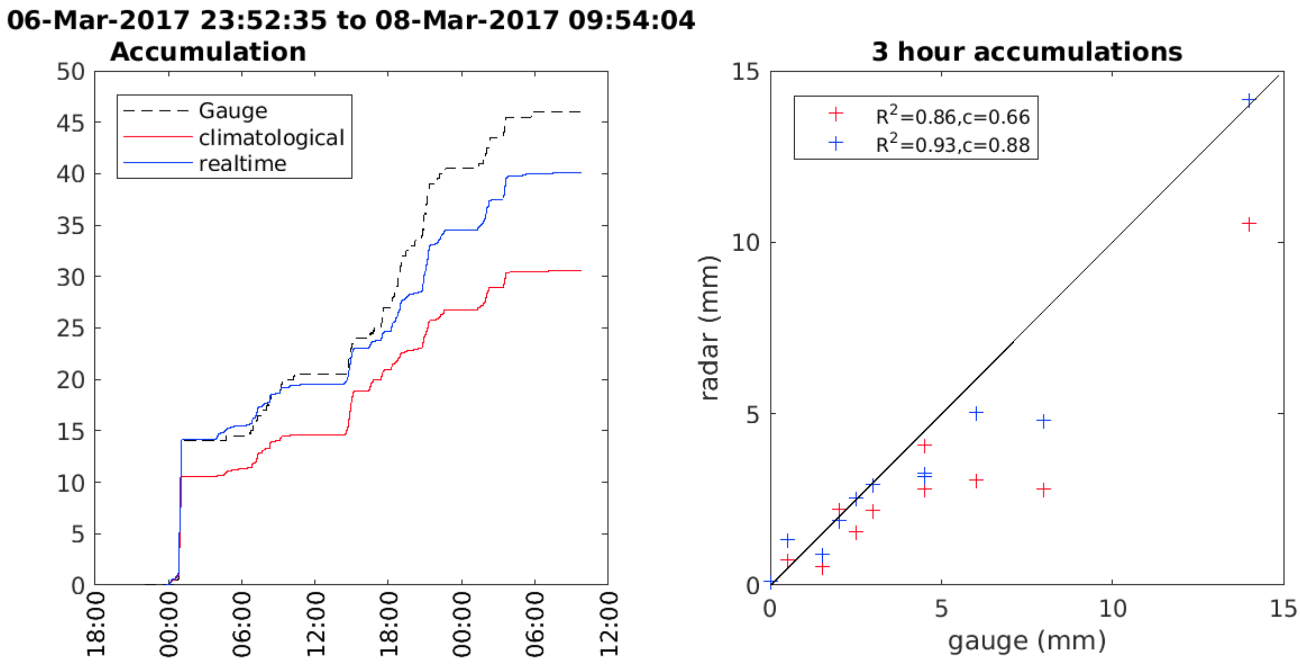

Figure 6: Comparison of total radar accumulations estimated with the climatological and real-time Z-R relationships. For this event, the real-time estimate of Z-R relationship diverges from the climatological value, and radar accumulations derived from the real-time Z-R relationship agree much better with the nearby gauge measurements.

2.7 Combining the VPR and scanning radar measurements

The radar calibration steps described so far may be categorised as climatological, in that they identify some persistent average value and real-time corrections which identify transient characteristics of the scanning radar bias. Climatological corrections can be applied to the scanning radar measurements in the absence of further VPR observations. Real-time corrections, on the other hand, require continued use of a VPR with a robust real-time telemetry system. These different data processing approaches, and the existing gauge based correction method, are summarised:

CLI (climatological): the MetService radar reflectivity measurements are first corrected for the long term bias and then accumulation estimates can be prepared with the climatological Z-R relationship. Rain gauge observations are not used.

TEL (telemetered): the MetService radar reflectivity measurements are first corrected for the long term bias, then a real-time estimate of the radome wetting is applied. Finally accumulation estimates are prepared with the best estimate of the Z-R relationship which would have been available from the VPR in real-time.

GAU (gauge-based): The VPR-based approaches can be compared with the existing gauge-based processing methodology, which is described in previous conference papers and operates in the absence of information about the MetService radar bias. This makes use of the Marshall-Palmer Z-R relationship (Marchal and Palmer, 1948) to convert to rainfall accumulations, followed by a gauge correction step.

A potential advantage of the use of the VPR calibration approaches (CLI or TEL) over the existing gauge-based processing (GAU) in an operational context is the ability to process radar data immediately, without having to wait for gauges to report in.

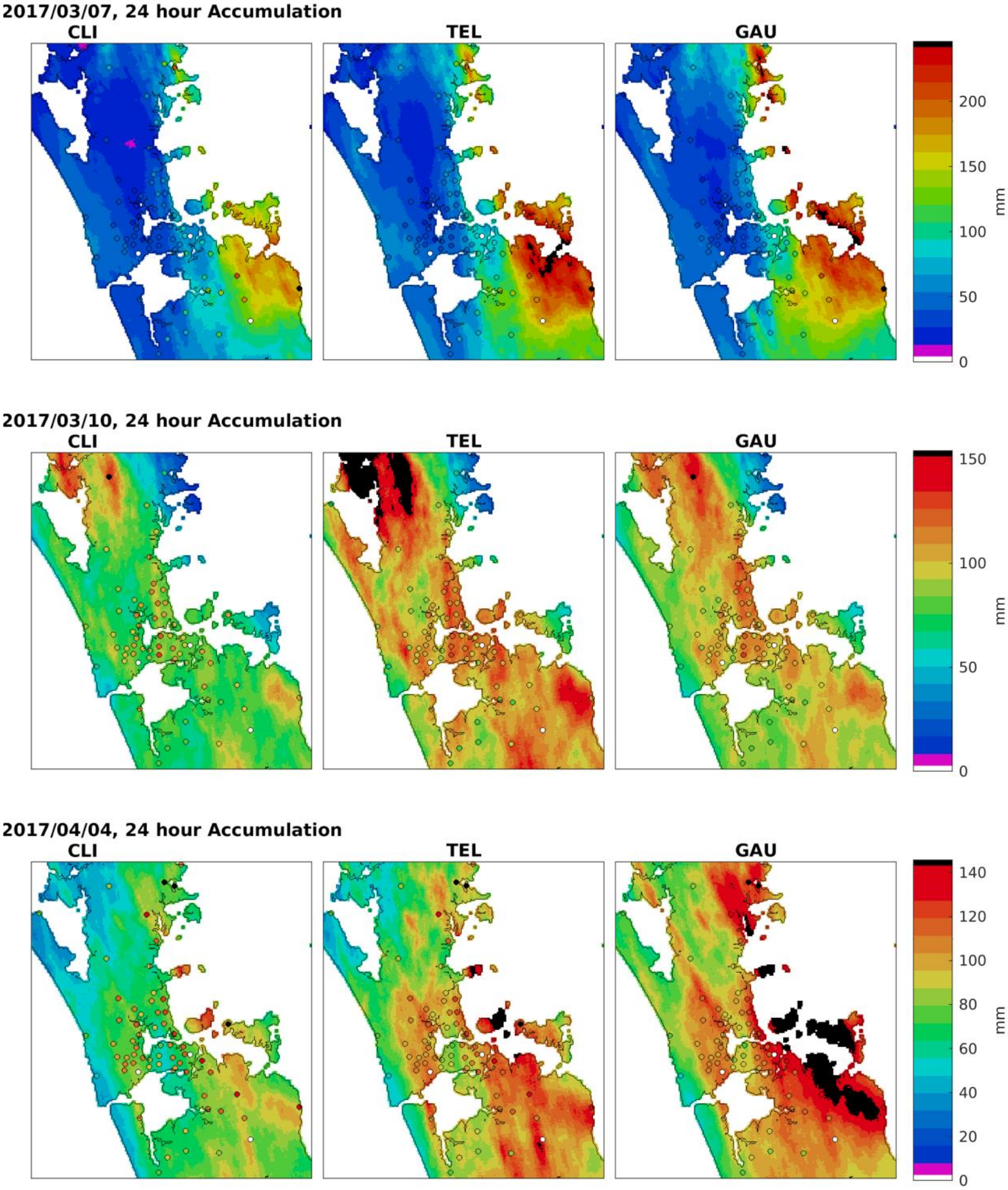

Figure 7: 24-hour radar accumulation estimates for three significant rainfall events. The radar was calibrated with the CLI, TEL and GAU methods for each case.

For comparison, total accumulations from the Auckland Council gauges are shown as black circular outlines with the gauge recorded depth shown in colour.

3. DISCUSSION AND CONCLUSIONS

Auckland Council has a considerable rain gauge network, and the Healthy Waters Department has invested in an online platform to make this data available to a wider range of people. This has been extended to include Metservice rain radar data, with automated routines to ingest, process, and perform bias correction to output estimated rainfall accumulation.

The system is invaluable, with Healthy Waters staff now having better situational awareness, and improved post event reporting capabilities. The natural progression is to consider operationalisation of the system, to provide a resilient, real time system to assist in active rain and flood event management.

There are some limitations to overcome, or to at least quantify and understand, before operationalisation for advanced event management can be considered. Correction of rain radar is currently reliant on bias correction based on rain gauge measurements, which can introduce temporal delays dependent on telemetry. The current correction of radar data is also currently limited to linear bias correction, based on rain gauge depth accumulation, rather than using a non-linear Z-R relationship based on drop size distribution.

Auckland Council has been testing Vertical Pointing Radar to assess whether this can be used to help overcome these limitations. Further work is required however the results from this initial study are pleasing.

A key consideration is reliance and temporal relevance of the system. The use of VPR is a valuable addition as it has provided a Z-R relationship relevant for Auckland. This means that if the rain gauge telemetry fails, there is a viable alternative to correct Metservice radar in real time. Use of the climatological average Z-R, whilst still a constant Z-R, provides comparable correction of radar data when compared to gauge based bias correction.

The next potential application is in providing improved correction of the Metservice radar, and better estimating uncertainty in the rainfall accumulations derived from radar. It is essential to understand uncertainties, in order to use rain radar as an input to more advanced systems for active event management – as errors propagate and magnify through any extrapolation or forecast system.

Further work from this point will investigate the use of a varying Z-R relationship for rainfall events with different typology, but still based on the sample data collected at Orewa. Further work may then investigate the use of real time VPR data, to give event specific Z-R data. An additional avenue of research may also be around radome attenuation, which the current study suggests could be significant. A permanently running VPR would assist in this.

Auckland Council are continuing work in this area, to ensure the most appropriate data sources are used and applied correctly, so as this can lead to forecasting and event management solutions when appropriate.

ACKNOWLEDGEMENTS

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