Operational use of rain radar

This is a précis of the Paper of the Year that was awarded at the 2017 Conference as the best technical paper submitted. The paper was written by Luke Sutherland-Stacey, Geoff Austin, and John Nicol, from Weather Radar; Tom Joseph from Mott MacDonald; and Ken Williams and Nick Brown from the Auckland Council Healthy Waters Department. The full paper can be read on the Water New Zealand's website here: www.waternz.org.nz

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

Currently, the Auckland region is served by an extensive rain gauge network operated by Auckland Council Healthy Waters Department.

Sampling the true area rainfall with rain gauges is inherently difficult, because rainfall varies on spatial scales much smaller than the typical separation between gauges and the land area of the Auckland region is some 5000 square kilometres, and experiences highly variable rainfall.

The paper's authors have been working collaboratively towards the use of rain-radar derived accumulations to support decision making in real time during flooding events, immediately post event for reporting to stakeholders and in long-term planning.

To date, they say, use of rain-radar derived quantitative precipitation estimates in the engineering field has been hampered by the large data volumes that need to be handled and the high level of specialised expertise required to quality control and calibrate raw radar observations.

Background

Rain radar is a well-established technology for addressing the spatial sampling problem and has been used in a variety of stormwater runoff and sewer system modelling applications internationally.

This country has been covered by the network of weather radars run by the MetService for many years. However, until recently, there have been only limited attempts to make use of radar data in stormwater and wastewater engineering applications.

This may be attributed to the technical barriers that exist in making use of complex radar data compared to simpler rain gauge measurements. In order to remove at least some of these barriers and foster more widespread use of radar data, the authors have automated data quality control from the Auckland MetService C-band radar, and operationalised real-time calibration of the radar precipitation estimates using the Auckland Council rain gauge network.

The high quality radar-derived accumulations are prepared at spatial and time resolutions suitable for urban hydrology (1 minute time step, 500x500m pixel resolution rasters) and are then fed into a cloud-based GIS platform and can be interacted with by council staff and consultants, for example to extract a catchment averaged accumulation for reporting or a raster stack for model input.

Rain measurements in Auckland

The Auckland region is served by an extensive rainfall observation network made up of telemetered tipping bucket rain gauges run by Auckland Council and now (with Watercare) monitoring local weather radar. This includes vertically pointing radar at Orewa and scanning X-band radar based at Ardmore.

The Auckland Council Research, Investigation and Monitoring Unit (RIMU) runs over 60 permanent telemetered tipping bucket rain gauge sites. The rain gauges are with a few exceptions mounted at ground level or in trenches and equipped with either 0.5 or 0.2mm buckets.

MetService operates a single-polarisation, C-band scanning rain radar located on Mount Tamahunga near Warkworth. The radar performs a scan cycle every 7.5 minutes, measuring radar reflectivity at increasing altitudes and at up to 250 kilometres in range. The radar is well positioned to provide meteorological observations for both Auckland and the Northland regions.

The most southern parts of the Auckland region are up to 100 kilometres away from the C-band radar, so beam spreading and climbing effects mean radar measurements in South Auckland are made between 1.5 and three kilometres above the ground.

To investigate the impact of range limitations on radar-derived accumulations, Weather Radar New Zealand is currently operating an X-band radar out of the University of Auckland Ardmore field site, although data from this radar is not currently part of the operational analysis.

The vertically pointing radar (VPR) at Orewa has been deployed since this year. In comparison to the MetService C-band radar near Warkworth the VPR dish does not move, but rather points directly upwards and continuously measures the vertical Doppler velocity spectra and radar reflectivity in a vertical column directly over the radar site at 100 metre height resolution and at 10-second intervals. The VPR is located about 30 kilometres to the south of the C-band radar site, allowing inter-comparison of the two radar measurements and direct calibration of the C-band radar.

How radar works

Radar is an active sensing technology that illuminates targets with electromagnetic energy and measures the properties of the reflected (or 'back-scattered') radiation in order to elucidate some physical property of the targets.

In the case of meteorological radars, repetitive pulses of electromagnetic energy are focused into the distance by a parabolic dish, by scanning the dish and recording the bearing and time taken for pulses of energy to return, a map of precipitation location and intensity can be constructed.

Radars are typically differentiated according to the operating wavelength and the authors have adopted this approach here – referring to the MetService radars that emit 5.4 centimetre wavelength radiation as "C-band". The principal radar measurement is 'reflectivity', which for meteorological application is the scattering cross section of all the targets in the radar beam at a particular range bin.

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 scattering cross section, and hence reflectivity, depends on the usually unknown raindrop size distribution, and must be converted to rainfall rate to be useful. Other factors influencing the estimation of rainfall are attenuation, ground clutter, beam blocking, uncertainty in the vertical profile of reflectivity, spatial smoothing and time intermittency of the radar measurement.

For hydrological applications, detailed quality control and processing is required to generate useable rainfall estimates.

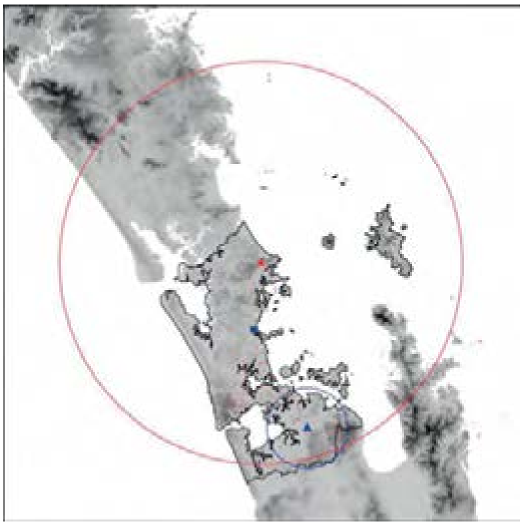
For Auckland Council's requirements, precipitation estimates were required at sub-hourly frequency, sub-kilometre resolution and with minimum systematic bias and error. This level of detail and accuracy was not available from the one-hour accumulation product generated by the C-band radar's bundled software, so raw radar data in polar format (range, bearing and reflectivity) were sourced directly from the C-band radar output files and ingested in the cloud-based GIS system through a customised post processing system.

As a first step, the C-band radar measurements were compared to coincident vertically pointing radar measurements of rain above Orewa to check for any systematic bias.

The much smaller size of the vertically pointing radar affords the luxury of direct end-to-end calibration in a laboratory setting, and it was assumed that any systematic difference in measurements between the radars is due to electrical calibration bias, or un-quantified physical losses in the C-band radar. To exclude differences arising from attenuation, the comparison was only made when there was little precipitation obstructing direct line of sight between the VPR and the C-band radar sites.

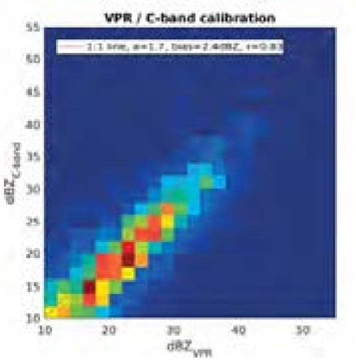
The comparison identified a low bias of approximately 2.4 dBZ in the C-band radar measurements. Because the conversion from reflectivity to rainfall is non-linear, this corresponds to a significant error in rainfall estimates, about 30 percent low bias.

Previously, a low bias had been observed in comparison

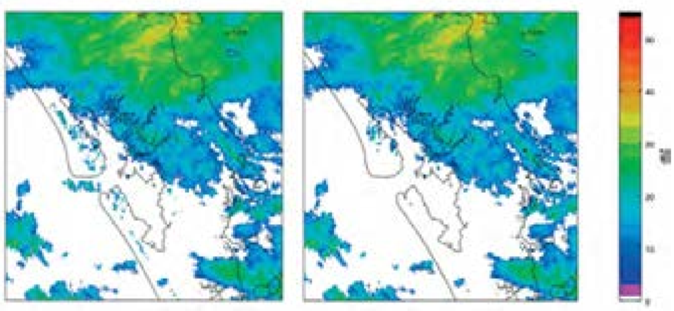


Map of the Auckland Region depicting the location of the MetService C-band weather radar (red triangle and 100 km range circle), tipping bucket rain gauges (red points), vertically pointing radar (blue square) and X-band radar (blue triangle and 20km range circle). The boundaries of the Auckland Region are also indicated with a black outline.

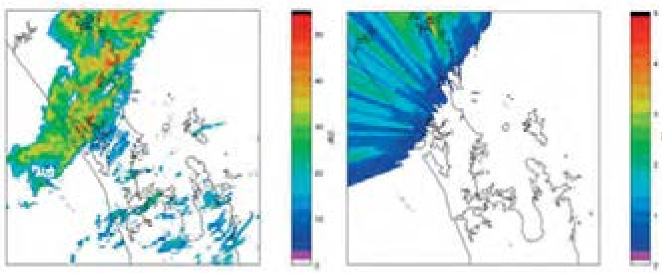
The vertically pointing radar.



Comparison of reflectivity estimates for the C-band nad VPR radars.



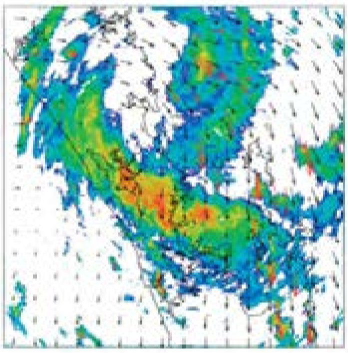
Radar reflectivity map before (left) and after (right) ground clutter suppression. Note the removal of the returns from the ridgelines of North and South head and sea surface at the Kaipara harbour mouth.



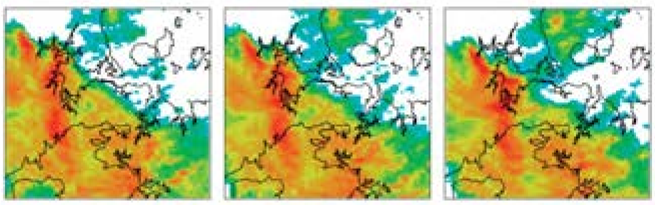
Radar reflectivity map (left) and estimated attenuation (right), 2017/07/22 11:00

C-band radar scan procedure

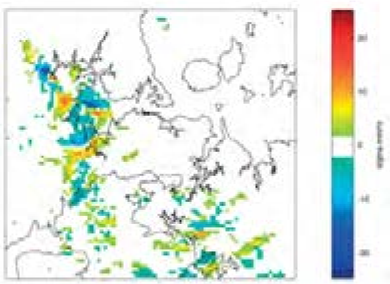
Designation	Dish Elevation (deg)	Range (km)	Doppler Velocity
SURV	0.5,1.0	320	N
VOLA	0.5,0.9,1.4,2,3,4,5,6	250	Y
VOLB	7,8.5,10,12,15,20	125	Y



Radar reflectivity image overlaid with individual precipitation feature echo motion vectors (red arrows) and the overall echo motion field (black arrows) for a cyclonic system 2017/03/12 09:23. The intense convection in the south west quadrant of the cyclone stalled over the suburb of New Lynn, delivering significant precipitation in a short space of time.



Radar images measured 2015/07/15 16:15:00 (left) and 2015/07/15 16:22:30 (right). The centre image is a synthetic image constructed by the advection interpolation scheme, valid at 16:18. Note the subtle movement of the intense precipitation features between frames. Flooding resulting from this short-duration yet intense precipitation resulted in habitable floor flooding in West Auckland.



Difference in average rainfall rate for the 7.5 minute period starting 2015/07/15 when using estimating the accumulation with just the measured frames or including the advection interpolated data.

between C-band rainfall estimates and rain- gauge measurements, so the C-band / VPR comparison helps to identify the cause of the low bias as being a characteristic of the C-band radar calibration, rather than a deficiency in assumptions made in subsequent steps when processing of the radar data itself.

Ground clutter removal

Following correction of the low bias, radar data was treated to identify and suppress ground and sea clutter.

The MetService C-band radar is equipped by the manufacturer with an automatic clutter suppression system that is intended to remove any ‘extra’ contribution to the reflectivity measurement from targets with zero relative velocity – eg, hills and buildings. In practice, the non-zero dish velocity and random motion from trees and leaves means the filter often only partially suppresses ground clutter.

Suppression of residual clutter is achieved by comparing the reflectivity measurements with a terrain elevation map. In regions where the terrain elevation is flagged as high enough to intersect with the radar beam, the radar data is treated according to a filter that checks for sharp drops in reflectivity in scans of increasing dish angle and low relative wind speed.

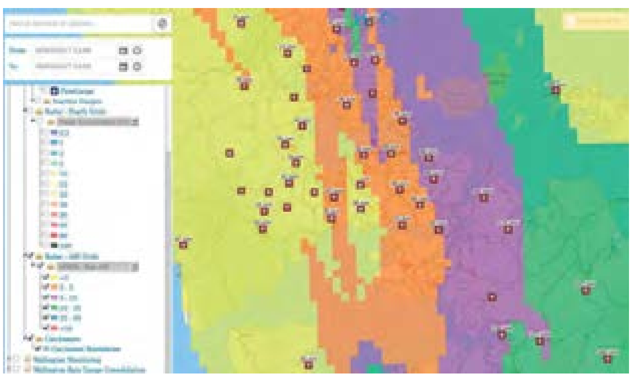
If a large negative gradient (much stronger signal near the ground) is detected it is assumed that the radar signal is due to ground clutter and the measurement is set to zero. Spurious returns from ripples on the sea surface are also suppressed in a similar manner.

Correction for attenuation of the radar signal by rain over the path of the radar beam is applied using coefficient suitable for widespread rain types. Attenuation correction is required to reduce the underestimation of rain at more distant locations from the radar site due to weakening of the radar signal by intervening hydrometeors.

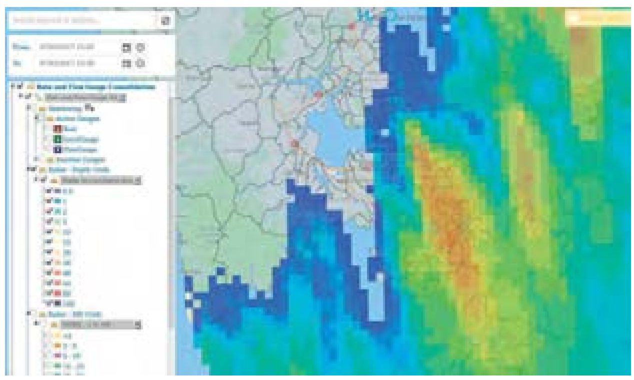
The attenuation correction method is only able to partially correct the underestimation for two reasons.

First, the raindrop size distribution is unknown and therefore so too are the correct coefficients for attenuation correction equation. Therefore, in order to avoid overcorrection a conservative estimate is used.

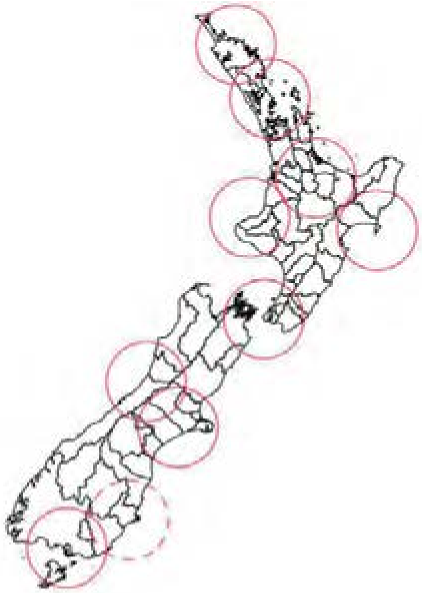
Second, for very strong attenuation, for example due to



Example of automatic generation of a maximum ARI surface from the processed radar data for the flooding event 2017/03/07.



Extraction of radar rainfall accumulation estimates for a sub hourly time period, in this case 2017/03/07 15:00 - 15:30.



Coverage map for the C-band radars which comprise the national radar network. 100km range circles indicated the maximum optimal range of the radars for quantitative precipitation estimation (QPE). The approximate coverage of the planned Dunedin rain radar is also indicated (dashed circle).

blocking by hail, the correction fails completely if the radar signal becomes too weak to correct.

Future work with vertically pointing radars will address the uncertainty in the drop size distribution and deployment of additional small scanning X-band radars has the potential to reduce the impact of attenuation by observing rain from multiple angles.

Conclusions

This project represents the first implementation of a truly GIS compatible and fully automated rain-radar analysis system in this country.

The notable technical improvements over previous efforts, aside from improved quality control, are the facility to access sub-hourly accumulation estimates and a simple web-API interface to retrieve data. Sub-hourly disaggregation of the radar data allows both estimation of short duration ARI statistics and extraction of rainfall estimates at timescales suitable for use directly in sewer and stormwater modelling applications and catchments with short hydrological response times.

This new analysis methodology is suitable not only for the Auckland region, but any area served by a local weather radar and automatic telemetered rain gauges.

Already, the Auckland Council radar processing workflow generates analyses for an area that covers 256x256 kilometres around the Auckland radar site, which includes the southern half of Northland, (including Whangarei and the Coromandel Peninsula).

Modification to the existing system required to provide radar derived rainfall estimates in these regions is limited to establishing data telemetry to the regional rain gauges. Likewise, the equivalent analysis can be extended to other radar locations.

Enabling work is underway to propagate the system to the Wellington region, but equivalently the analysis could be efficiently adapted to include major population centres such as the Bay of Plenty, Waikato and Christchurch, which are well served by the MetService radar network.

The web-based data management system established for the radar accumulations can also be used to handle other spatial data types. A natural extension to the system is ingestion of numerical weather prediction data. Current work is underway to enable ingestion and exposure of MetService forecast products to the same API to allow user interaction via the GIS portal.

Up until now, high technical barriers have prevented uptake of advanced rainfall data for water engineering applications in this country. The work described in this paper is essential for realising the value of the investment in the radar network for urban hydrology.

The authors hope that this new methodology will allow more engineering practitioners to begin to explore the use of radar data in their planning, modelling and operational applications.

They also acknowledge that the bulk of their work has been funded by Auckland Council Healthy Waters Department and C-band radar data was provided by MetService through a data access agreement with Auckland Council. Watercare Services also assisted with a field site and funding of the VPR radar monitoring. **WNZ**