HYDROLOGICAL MODELING APPLICATIONS OF HIGH RESOLUTION RAIN RADAR

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ABSTRACT

In many hydrological modelling applications it is considered advantageous to measure, in real time, the state of catchments and make predictions about future outflows. Precipitation data is typically fed into hydrological models from sparse gauge networks, or from just a single gauge.

An alternative to a rain gauge network is high resolution rain radar. In this paper we present results from a field campaign using our mobile X-band high resolution rain radar to image the spatial and temporal distribution of rain down to 300 m resolution over a small catchment. The project was sponsored by Mighty River Power and focused on sub-catchments of the Waikato River.

The radar data agrees well with rain gauge measurement on a point wise basis, but provides much wider coverage. The demonstrable spatial and temporal heterogeneities in real rain fields preclude the use of sparse rain-gauge networks for measurement of areal rainfall. An unmanageable number of gauges would be required to approach measurements made with radar remote sensing.

The response of a simple hydrological model to high resolution rain radar data is compared to that of rain gauge measurements.

The utility of such data in real time operations is being investigated.

KEYWORDS

Rain Radar, Hydrologic, Model, Rain Gauge

1 INTRODUCTION

The University of Auckland Atmospheric Physics Group runs a number of novel high resolution X-band mobile weather radars. These systems infer rainfall intensity by measuring the scattering of microwave energy from raindrops. The radars are unusual in that they operate at very high spatial and temporal resolution (100 m and 20 seconds) as compared with normal meteorological service radars (2 or 4 km and 7.5 minutes). They also operate close to the selected catchments and can thus be placed to give optimum results for small catchments in mountainous terrain.

The university was engaged to deploy a 'trailer' type radar (Figure 1) to the Maraetai area for a preliminary 'proof of principle' study. The group would deploy for 28 days from 15th October, 2008 and attempt to measure the rain field in the area and specifically over the Waipapa catchment. This radar data would be compared to existing rain gauge and flow measurements. A further deployment is currently underway. Data from both field campaigns is presented here.

Figure 1. A 'Trailer Type' radar deployed in the field near the Waipapa Catchment and Maraetai Dam.

Specific examples of the utility of rain radar derived precipitation input into hydrological models are also presented.

2 RADAR THEORY

2.1 RADAR HARDWARE

The Atmospheric Physics Group's radar works by generating a 25 kW short duration pulse of microwave energy. This pulse of energy passes through a waveguide to the antenna (a parabolic dish) from where it is transmitted as a focused beam. The same antenna is used for both receiving and transmitting. If objects are in the path of this beam, part of the microwave energy is scattered back to the radar. The range of targets from the radar is found from the time that the pulse takes to return. Once the returned signal is received by the antenna, it makes its way to the receiver. The microwave frequency RF signal is converted down to a lower intermediate frequency (IF) where it is amplified and filtered. The signal is next demodulated, removing the IF carrier frequency. After passing through a video amplifier, the signal is digitized by a high speed PC digitizer card. Averaging is performed before the signal is saved to a hard disk.

2.2 OBTAINING RAINFALL INFORMATION

The digitised reflectivity data needs to be converted to rainfall rate to be useful. The power returned (P_r) from a volume of raindrops is given by the following formula.

$$P_r = \frac{CZ}{r^2}$$

where Z is the radar reflectivity, r is the range from the radar to the target volume and the radar constant C includes all of the hardware parameters, such as transmitter power, wavelength and radar beam width as well as the type of target (rain or snow). From this equation it is evident that there is a large drop-off of power with range.

The radar reflectivity Z depends on the target (in this case rain drops) and is defined as follows,

$$Z = \sum_{i}^{N} D_i^6$$

Where D_i are the diameters of the raindrops in the radar illuminated volume. From the above equation we see that to obtain rainfall rate information from radar reflectivity, the drop size distribution must be known. Due to its ease of use, the Marshall and Palmer (MP) distribution is conventionally used.

If the MP distribution is assumed, one finds the following formula to relate radar reflectivity, Z, to rainfall rate R (in mm/hr).

$$Z = 200R^{1.6}$$

Other forms of the equation exist for convective precipitation. Some additional processing is also undertaken, for example to account for attenuation of distant signals (after Nicols and Austin, 2003).

3 EXPERIMENTAL RESULTS

To check that the rain radar is making sensible estimates of the overall rain field, precipitation determined by the radar in a particular pixel is correlated with that measured by a rain gauge situated somewhere inside that pixel.

3.1 RADAR DATA

Radar data was collected in 2008 continuously for 31 days in October and November and since June 25th in 2009. In 2008, radar logging was limited to 25 km range and in 2009 the range is 50 km. The actual maximum range at which radar rain data is considered to be accurate varied from 20 to 35 km. The principle limitation on radar range in this project came from 'beam overshooting' and 'attenuation'.

The radar dish needs to be pointed at a high enough angle so as not to receive ground returns from the surrounding terrain. Naturally then, the height of the radar beam above the ground, and hence the height at which raindrops are measured increases with range. At long range the radar beam is at a greater altitude than the rain. This limitation was mitigated somewhat with a composite scanning strategy.

If it is raining very heavily or over a large area then the radar returns from long range can be attenuated and rain not detected.

Maps of the areal distribution of precipitation are generated on a timescale of about a minute. An example is given in figure 2.

3.2 RADAR DATA DESIMINATOIN

Radar data is streamed back to campus in real time. It is then processed into human and machine readable formats for dissemination to end users. The public can access visualisations of the current data at *www.rainradar.co.nz*. An example page is given in figure 2.

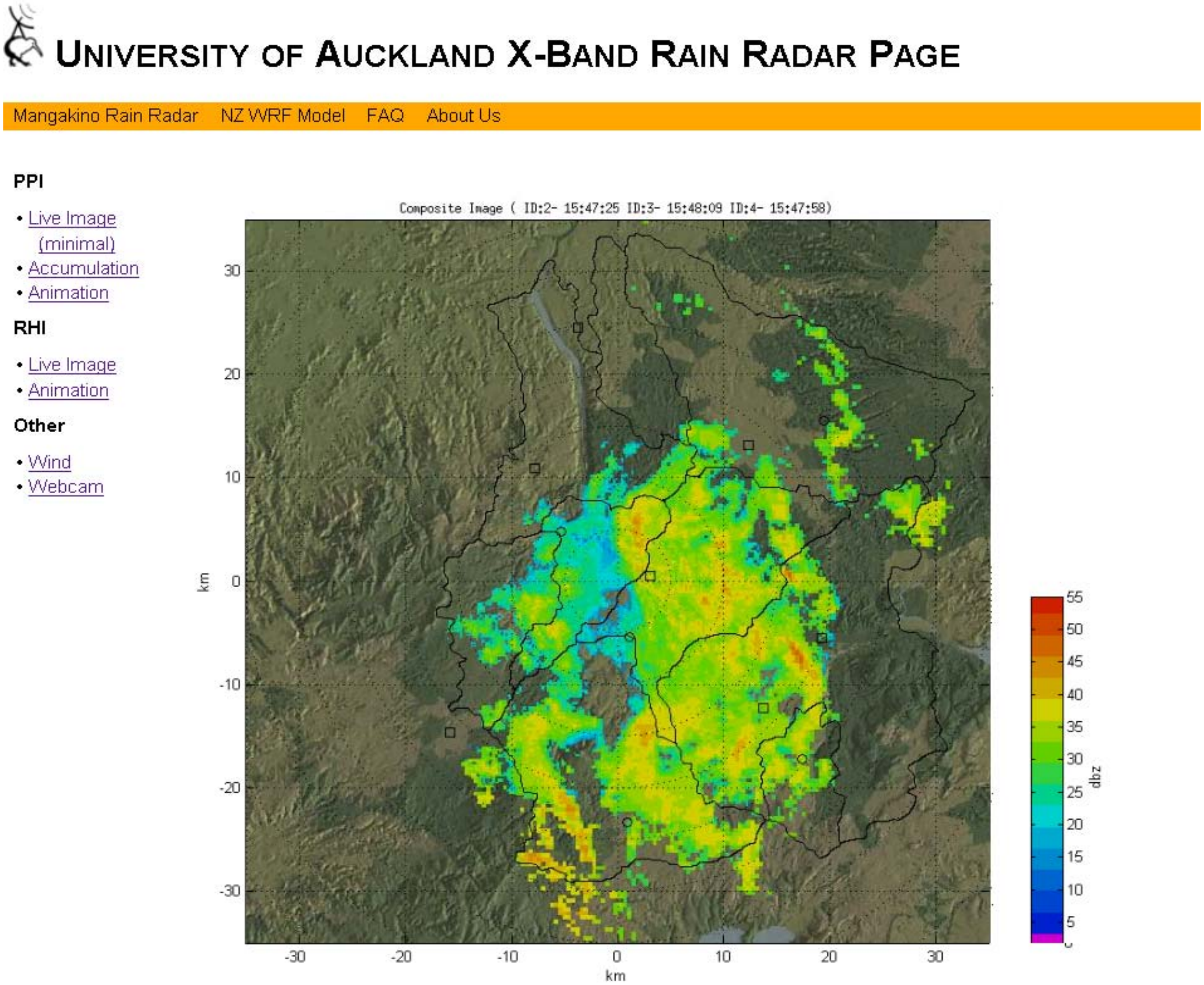

Figure 2. A screen capture from www.rainradar.co.nz. This page displays a rain radar PPI image indicating the (then) real-time instantaneous distribution of precipitation around the Southern Waikato region. Catchment outlines are given (solid black) along with locations of rain gauges belonging to the UoA and NIWA (squares and circles respectively)

3.3 GAUGE NETWORK

A number of rain gauges run by NIWA were already located within the area covered by the radar. Additional high resolution rain gauges were deployed specifically for comparison. The rain gauge locations are summarised in figure 2.

3.4 GAUGE TO RADAR COMPARISON

Data for each radar pixel over the rain gauge location was compared on a 5-minute time basis to the appropriate gauge.

Before considering bulk statistics between rain gauge and rain radar measurements it is informative to compare the performance per event and in doing so gain insight into the physical processes which may be resolved with a radar or rain gauge.

It is apparent that the temporal patterns in rainfall evolution detected by the rain gauge are qualitatively well resolved by the rain radar. The time and location that rainfall is recorded by the radar can differ from when it is recorded by the rain gauge due to wind drift as the rain falls from the height of the radar beam to the ground.

At times the quantitative accumulation from both the radar and rain gauge agree very well however at other times there is some divergence in the total accumulation (e.g Figure 3).

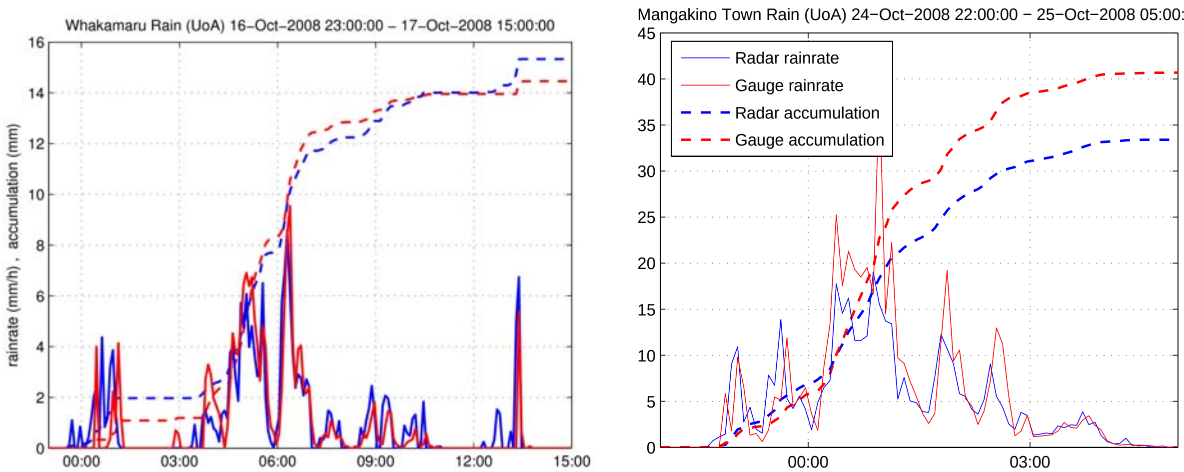

Figure 3. Comparisons of radar and rain gauge accumulation.

3.5 RADAR DERIVED CATCHMENT ACCUMULATION

A measurement made with a rain gauge is a function of the precipitation over a very small area, of order 100 cm². However, for hydrological considerations, it is not unusual to be interested in catchments of order 100-1000 km² (the Waipapa catchment is approximately 130 km²). When measuring with rain gauges, assumptions must be made about the homogeneity of the rain field in space in order to scale point values up to catchment accumulations. It is easy to demonstrate that simple scaling techniques fail to capture the spatial variability of the rain field (e.g. Figure 4 and 5).

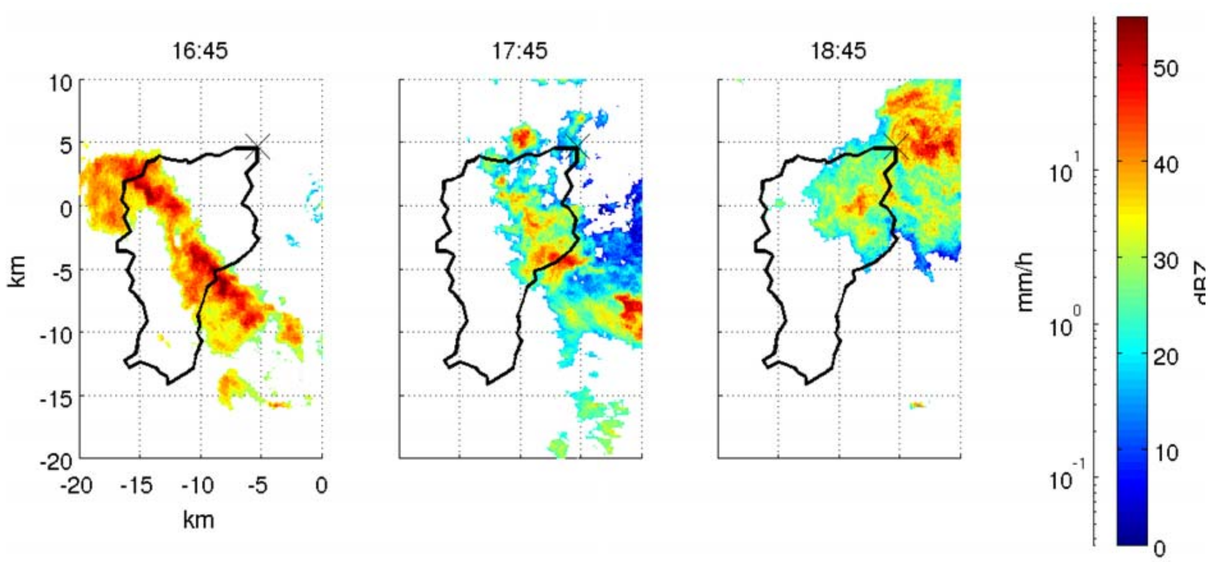

Figure 4. Radar Images of convective precipitation over the Waipapa catchment (black solid line) on the 23rd of October. The location of the rain gauge is indicated with an x.

Precipitation measurements made with high resolution X-band radar naturally avoid this spatial sampling problem. They do still suffer from the usual radar problem of relating the observed returned power to rainfall rate however, as demonstrated in the previous section. Within certain constraints the radar resolved rain field can be used as a surrogate for terrestrial measurements. It is therefore instructive to compare the radar derived precipitation over a catchment with the estimate that could be made with a rain gauge and decide which is likely to be better under particular circumstances.

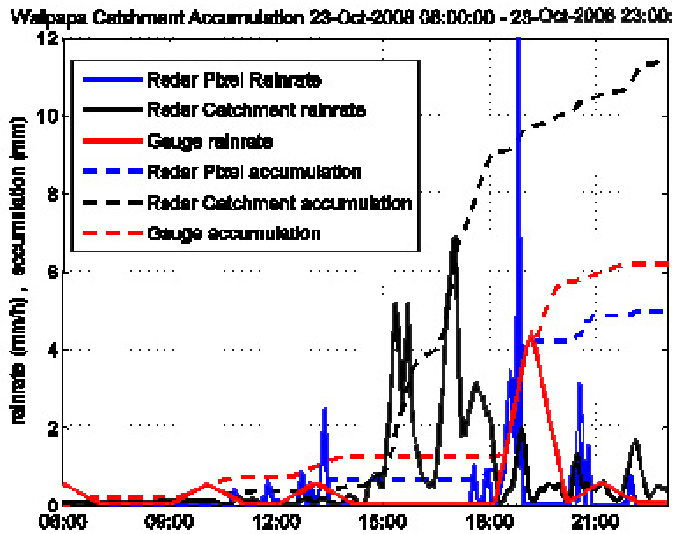

Figure 5. Expanded accumulation plot for the Waipapa catchment. The catchment wide radar accumulation (dashed black) differs from the point accumulations at the gauge site (dashed red and blue).

The Waipapa catchment has one rain permanent gauge. For some rain events the rain gauge accumulation is similar to the radar catchment accumulation. At other times, however, the gauge under or over estimates the total rain falling in the catchment. By examining rain events at higher resolutions, it is possible to identify heterogeneities in the rain field as the reason for these discrepancies. Accumulations from such periods are presented in figure 5.

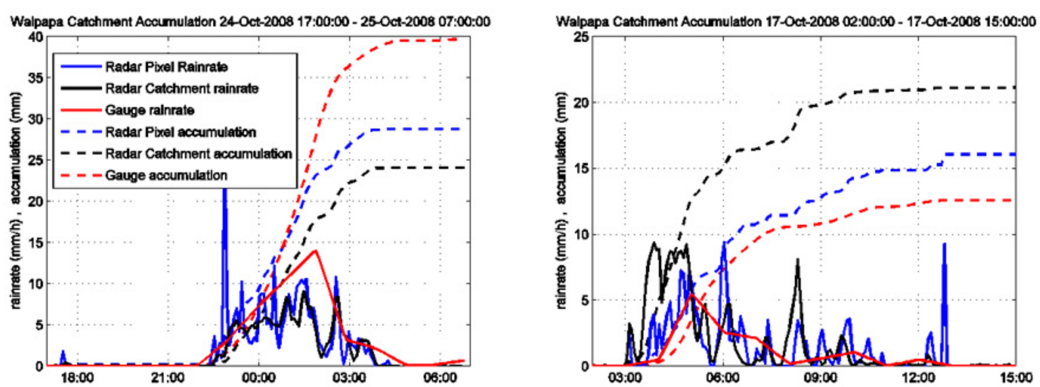

Figure 5. Additional examples of the discrepancy between catchments and point derived accumulations.

As the variation between catchment and point determined accumulations is attributed to spatial heterogeneity in the rainfall field it is perhaps not so surprising that during stratiform (widespread) rain there is less difference between radar measurements made in the pixel over the rain gauge and the catchment wide average.

Radar measurements can be used to address the uncertainties in rain gauge measurements and provided greater certainty as to the distribution of precipitation and improved certainty about the quantity of accumulation.

4 MODELING RESULTS

Radar derived precipitation can be integrated into hydrological models in much the same way as rain gauge data. In this paper preliminary results from integration of radar data with a block model are presented.

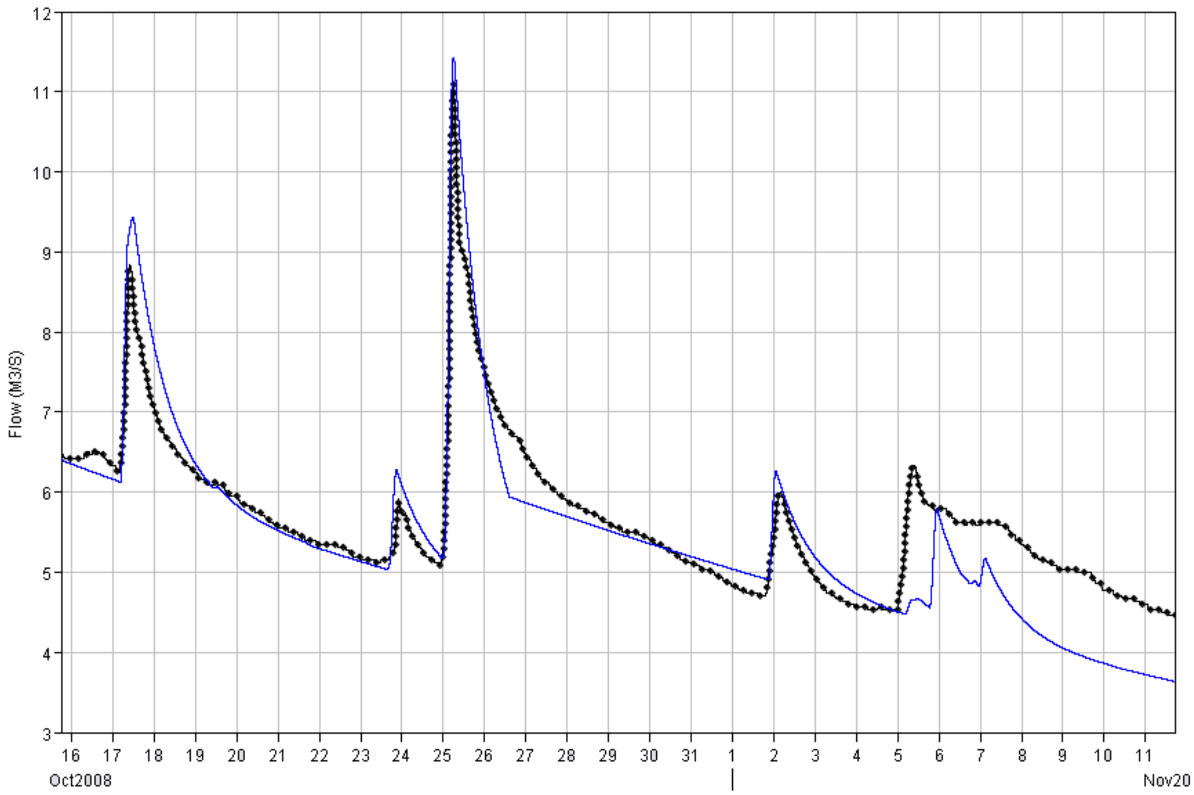

Figure 6. Preliminary modeling results. Output from a lumped hydrological model (HEC-HMS) driven with radar data (solid blue line) to observed flow (black dotted line).

Of particular interest is the failure of the lumped model to correctly determine the start time of the last rain event (6^{th} Nov). This is related to the extremely convective and localised nature of rainfall during this time leading to local saturation and rapid runoff.

We will soon integrate radar data with a distributed hydrological model. In principle the spatial treatment of the rain field in the model and resulting improvement in physical realism should improve predictive results.

5 CONCLUSIONS

Work investigating the utility of areal rain radar measurements is ongoing.

ACKNOWLEDGEMENTS

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REFERENCES

Nicol J.C. and Austin G.L. (2003) 'Attenuation correction constraint for a single-polarisation weather radar' *Meterol Appl* 10, 345-354