

The Potential of Weather Watch Radar to Predict the Spatial Distribution of Rainfall Patterns in the Kimberley Region and Applications for Natural Resource Management

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Abstract – This study sought to evaluate the utility of radar derived rainfall data as a unique resource for analysing the interplay between rainfall and ecosystem dynamics in the Kimberley region of Western Australia. The Bureau of Meteorology’s Weather Watch radar network was investigated as a potential source of spatially explicit radar data that could be processed to create estimates of accumulated rainfall over the rainy season. Data recorded at the Halls Creek station and covering an area of radius 256 km correlated positively with daily rainfall records from 42 ground based recording stations. However the degree of scatter in the radar accumulated rainfall was substantial, with a large proportion of the noise in the data attributed to the minimum height of the radar beam above the terrain. Radar derived rainfall data is unique in its spatial extent and temporal frequency, and it has the potential to be a valuable tool in understanding the complex interactions between rainfall, fire and ecosystem function in the Kimberley, and similar savanna ecosystems across Australian monsoonal tropics. Given the remoteness of the study area and the large distances between rainfall recording stations, radar derived rainfall estimates have the potential to assist in prioritising areas for pre-emptive fire and vegetation management.

Keywords: radar accumulated rainfall, weather watch radar, Australian wet-dry tropics.

1. INTRODUCTION

Rainfall data is a primary resource for analysing and understanding the dynamics of ecosystems in the Australian wet-dry tropics. This information is vitally important for successfully managing and conserving ecosystems and the species they sustain (For example see review by McKenzie *et al.*, 2009). But rainfall data from point sources like ground based meteorological stations are of limited use in areas that are subject to a high degree of spatially and temporally variable rainfall patterns. This is particularly the case in remote areas like the Kimberley region of north-western Australia, in which rainfall recording stations are separated by many tens or hundreds of kilometres, leaving large areas with little or no specific rainfall data. However, the Australian Bureau of Meteorology operates a network of Weather Watch radars around Australia that record rainfall intensities at approximately 10 minute intervals (Bureau of Meteorology, 2011). Rainfall data recorded by Weather Watch radar has the potential to provide current and historical high resolution spatially explicit data over large areas at a very high temporal frequency.

We evaluated the potential utility of radar derived estimates of daily accumulated rainfall by analysing historical archived data from the Bureau of Meteorology’s Halls Creek Weather Watch radar (Dillon 2010). We generated spatially explicit daily accumulated rainfall data over three wet seasons and compared the results with daily rainfall data recorded at ground-based recording stations. We also evaluated the utility of radar-derived daily accumulated rainfall data for analysing the interplay between rainfall, vegetation and fire within the study area.

2. MATERIALS AND METHODS

2.1 Study area

The Halls Creek Weather Watch radar is located at Halls Creek Airport (18°13’49’’S, 127°39’45’’E) within the central Kimberley region of Western Australia. The extent of the radar data coverage analysed in this study was limited to a radial distance of 256km from the Halls Creek radar, covering an area of 205,887 km².

2.2 The Kimberley Climate

The Kimberley region of Australia has a tropical monsoonal climate with distinct wet and dry seasons. The wet season typically occurs from October to March, followed by the dry season from April to September (Taylor and Tulloch, 1985). The wet season is characterised by very high variability and the relatively common occurrence of extreme weather events including tropical cyclones and severe thunder storms (Wheeler and McBride, 2004). The intense low pressure systems associated with these storms can bring sustained heavy rainfall to localised inland areas and significant proportions of an area's annual rainfall can be received in a small number of storm events (Bureau of Meteorology, 2008a). Annual rainfall is highest in the Northern Kimberley, averaging 1400mm on the Mitchell Plateau, and decreases southwards with increasing distance from the coast. Annual precipitation at Halls Creek in the Central Kimberley averages 554mm, but is highly variable. Annual precipitation falls to below 350mm in the Great Sandy Desert Bioregion to the south of the study area (Bureau of Meteorology, 2008a).

2.3 Radar data

Digital spatial rainfall intensity data from the Halls Creek Weather Watch radar was sourced from the Australian Bureau of Meteorology. The data was retrieved from tape archive and supplied by the Special Services Unit, Bureau of Meteorology, Melbourne. The radar data was provided in ASCII asynchronous polar format (Bureau of Meteorology 2008e). The data spanned three wet seasons: 2005/06, 2006/07 and 2007/08. Within each wet season, the data spanned the period 1 October to 31 March. Radar data from

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dry season months (April to September) was not retrieved or analysed. The final dataset comprised a total of 55,895 radar scans of rainfall intensity recorded at 10 minute intervals over three wet seasons with the exception of wind-finding periods or radar down-time.

The Halls Creek radar is a shared Weather Watch and wind-finding radar described as a Type WF 100 (C Band, 5 centimetre wavelength) radar (Bureau of Meteorology 2008c). The radar dish is supported within an enclosed tower 15.75m above the ground, the radar beam width is 1.6 degrees and the lowest elevation scan is 0.5 degrees from horizontal (Pers. Comm. Neil Bennett, Bureau of Meteorology, 2nd February 2009). The radar records rainfall intensity approximately every 10 minutes except for maintenance times and during scheduled wind-finding operations when it is used to track weather balloons (Bureau of Meteorology 2008d). The typical daily operational timing of the radar is presented in Table 1.

Table 1. Approximate operational timing of the Halls Creek Weather Watch radar (Bureau of Meteorology 2007).

Coordinated Universal Time (UTC)	Radar Operational Activity
0045 - 0515	Rainfall intensity at 10 minute intervals
0515 - 0645	Wind-finding
0645- 1115	Rainfall intensity at 10 minute intervals
1115 - 1245	Wind-finding
1245 - 1615	Rainfall intensity at 10 minute intervals
1615 - 1745	Wind-finding
1745 - 2315	Rainfall intensity at 10 minute intervals
2315 - 0045	Wind-finding

Like all Australian Weather Watch radars, the Halls Creek radar records rainfall intensity at 15 levels (Table 2). The ordinal values in this scale represent an approximate guide to the average rainfall intensity at each step, and the Bureau of Meteorology website cautions that they are not always accurate (Bureau of Meteorology 2008d).

A software program 'radar2img' provided by the Bureau of Meteorology was used to convert the data for each individual radar scan to ESRI vector shapefile format for analysis with ESRI ArcGIS 9.2. The shapefiles were projected to the Geocentric Datum of Australia 1994 and Map Grid of Australia (GDA94 MGA Zone 52). Custom Python scripts were used to batch convert the vector shapefiles to ESRI GRID format with a 100m x 100m cell size (1ha). A standardised cell alignment and spatial extent was applied to each raster grid. Every grid was exactly 512km wide x 512km high, representing a distance of 256km in each direction from the Halls Creek radar station. Each grid had a total of 5120 rows and 5120 columns. Each grid file contained data for a single 10 minute radar scan. Within each grid, each 100m raster cell was assigned an ordinal value from 0 to 15 representing the highest rainfall intensity level present over that cell in the radar scan.

Table 2. The Bureau of Meteorology Weather Watch radar rainfall intensity scale. Note that Level 0 represents the absence of a radar signal and is not actually recorded within radar data files.

Ordinal Level	Approximate rainfall intensity (mm/hour)	Estimated average mm per 10 minute radar scan
0	< 0.2	0
1	0.5	0.167
2	1.5	0.333
3	2.5	0.542
4	4	0.833
5	6	1.333
6	10	2.083
7	15	2.917
8	20	4.583
9	35	7.083
10	50	10.833
11	80	16.667
12	120	26.667
13	200	41.667
14	300	55
15	> 360	65

2.4 Derivation of radar accumulated rainfall

Daily accumulated rainfall grids were computed from the individual (10 minute) radar scan grid files in batches using python scripts and ArcGIS 9.2. Radar scan grid files were collated into discrete 24 hour periods corresponding to the standard rainfall recording period between 0901-0900 Western Standard Time. Focal counts of occurrences of each rainfall intensity level within each cell were computed from each day's set of grid files. The focal counts were converted to estimated average accumulated total mm of rain within each 24 hour period using the rainfall intensity rates per 10 minute radar scan shown in Table 2.

Seasonal accumulated rainfall grids were computed by summing the values within each cell from all the daily accumulated rainfall grids for each wet season (2005/06, 2006/07 and 2007/08).

2.5 Analysis of topographic influences on the radar beam

Topographic features close to the radar with an elevation higher than the minimum scan elevation will obscure portions of the atmosphere that lie behind them relative to the radar. A viewshed analysis was completed using ESRI ArcGIS 9.2 Spatial Analyst and a Digital Elevation Model with 3 arc-seconds of latitude and longitude (approximately 80 metres) (Geoscience Australia 2009) resampled to 100m grid cells aligned to the radar scan grids. The minimum height of the radar beam in the airspace above each 100m grid cell in the study area was computed.

2.6 Validation against ground based meteorological data

Daily rainfall data from 56 ground based recording stations present in the study region was sourced from the Australian Bureau of Meteorology. Only 42 of the 56 stations were

judged to have data of sufficient continuous coverage during one or more wet seasons within the period July 2005 to June 2008 to be used in this study. The daily rainfall data from the ground based recording stations was aligned with the daily radar accumulated rainfall estimates extracted from the point locations for each station over each corresponding 24 hour recording period. Regression analysis was used to analyse the data for each rainfall station individually and combined for each wet season.

3. RESULTS AND DISCUSSION

3.1 Daily and seasonal accumulated rainfall

The daily accumulated rainfall was spatially and temporally highly variable. On average 37.7% of the radar scan area received greater than 0mm of accumulated rainfall each day during each wet season. The average radar estimate of daily accumulated rainfall received by each 100m grid cell was less than 2mm per day in each wet season. Similar trends were recorded for each of the three wet seasons. The majority of daily and seasonal accumulated precipitation received per unit area came from low intensity rainfall – 86% from rainfall intensities less than 2.5mm/hour, and 99% less than 10mm/hour. High intensity storms with rainfall intensities greater than 50mm/hour affected an average of 6.5% of the radar scan area each wet season. Significantly, areas subjected to high intensity rainfall on average received 28% higher total seasonal accumulated rainfall than areas that were not affected by such storms. The mean proportion of total precipitation contributed by each average rainfall intensity level per radar scan in the 2005/06 wet season is presented in Figure 1.

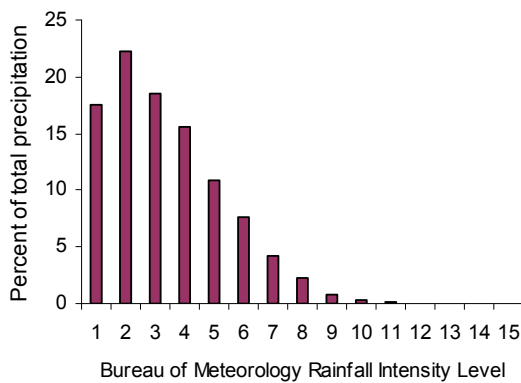


Figure 1. The average proportion of total seasonal radar accumulated precipitation recorded at each rainfall intensity level (see Table 2 for description of levels).

3.2 Estimated rainfall relative to distance from radar and height of the radar beam

The Bureau of Meteorology cautions that in general the area of accurate radar coverage extends outwards to a radius of approximately 250km from each radar. Outside of this radius rainfall echoes represent rainfall signals detected high in the atmosphere and will not necessarily correspond with precipitation experienced directly below on the ground (Bureau of Meteorology 2008b). The accurate coverage of radar may also be restricted by surrounding hills and topographic features obscuring the radar signal and creating

‘radar shadows’. The viewshed analysis showed that on average the Halls Creek radar beam had a minimum height exceeding 6000m at a distance of 250km from the radar tower.

The total radar accumulated rainfall recorded within the study area during the 2005/06 wet season is shown in Figure 2. The 2006/07 and 2007/08 wet seasons had similar results. In general accumulated rainfall is highest in a donut shaped band encircling the Halls Creek radar at a radial distance of between 50 to 200km. In general radar estimated accumulated rainfall values are substantially reduced in grid cells less than 50km away from the radar or more than 200km away from the radar.

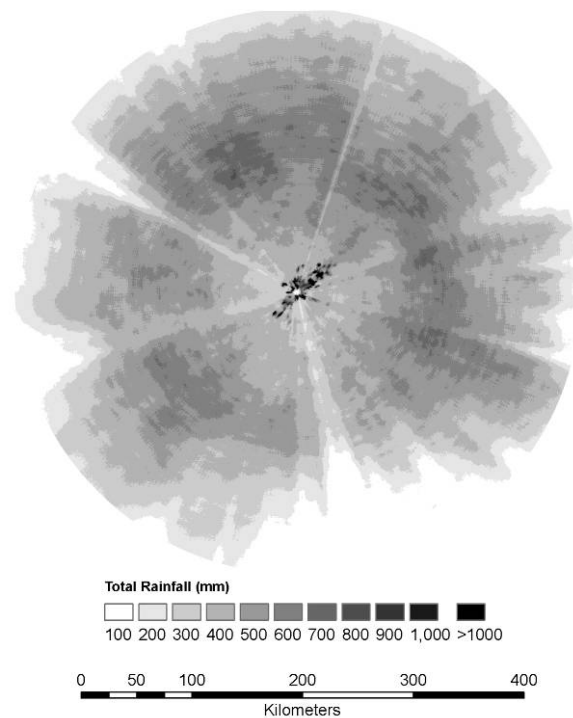


Figure 2. The total seasonal radar accumulated rainfall estimated to have fallen within a 256km radius of the Halls Creek Weather Watch radar during the 2005/06 wet season.

Radar shadows are visible in Figure 2 as radial linear features with low accumulated rainfall values extending outwards from the Halls Creek radar tower. The radar shadows occupied the same spatial position in all three wet seasons, and were strongly spatially correlated with the minimum height above each cell visible to the radar in a direct line of sight. Grid cells containing extremely high accumulated rainfall values are visible as dark areas close to the Halls Creek radar tower. These represent data from false echoes from the terrain or from atmospheric phenomena close to the ground surface.

3.3 Validation against ground based meteorological data

Regression analysis showed a significant positive correlation between daily radar accumulated rainfall and the corresponding rain gauge data ($p < 0.0001$). The proportion of deviance in rain gauge quantities predicted by the daily accumulated radar as measured by the correlation coefficient (R^2) ranged from a minimum of 0.106 to a maximum of 0.679 (average $R^2 = 0.393$). However the

average slope of the least squares regression lines was 1.95, indicating that on average the estimated radar accumulated rainfall was only about half of the actual rainfall recorded on the ground. Ground based recording stations that were located between 50 and 200km of the Halls Creek radar generally had higher correlation coefficients and slopes closer to unity, but daily variation in the relative accuracy of predicted accumulated rainfall was high. A comparison between the mean amount of rainfall (mm per day) recorded by all of the ground based recording stations combined, and the corresponding mean mm per day of radar accumulated rainfall over the point locations of all of the rainfall stations for each month of each wet season showed that in general the accumulated radar estimate tracks the rain gauge data, but on average the estimate is half or less of the actual mean daily rainfall recorded on the ground.

The Bureau of Meteorology (1997) list five reasons why radar data may not reflect ground observations accurately: (1) the radar beam will overshoot (and not detect) shallow precipitation at long ranges, (2) evaporation below the radar beam may prevent rain reaching the ground, (3) over estimation of rain intensity due to anomalously high radar signals from melting ice particles, (4) under estimation of the intensity of light rainfall (drizzle) due to the absence of large droplets, and (5) the radar beam bending in the presence of a strong hydrolapse (a rapid change in moisture with height), causing it to intercept the terrain surface. The Bureau of Meteorology (2008d) also identify obstruction caused by nearby heavy rain events as a factor reducing estimates of rainfall intensity further from the radar, and other objects can also obscure radar signals including local topography, trees, buildings, birds, aircraft and smoke. It is also likely that rain detected high in the atmosphere may not necessarily fall perpendicularly and therefore may be spatially displaced by the time it reaches the ground surface.

4. CONCLUSION

The results from this study indicate that radar accumulated rainfall is statistically positively correlated with rainfall quantities measured by on-ground rain gauges within the study area. However, the variance present in the estimates showed that overall the daily accumulated radar predictions should be treated with a moderate degree of caution. Seasonal accumulated rainfall predictions were more robust, particularly in areas in which the radar beam had a minimum height of between 1000m and 4000m above terrain.

This study demonstrates that historical radar data can be processed and analysed in a way that provides some indication of the approximate daily and seasonal accumulated rainfall received at locations for which rainfall data is otherwise not available. Radar derived rainfall data is unique in its spatial extent and temporal frequency. As a measure of actual rather than interpolated rainfall, it has the potential to be a valuable tool for improving our understanding of the interactions between rainfall, fire and ecosystem function in the Kimberley, and similar savanna systems across the Australian monsoonal tropics (e.g. Liedloff *et al.* 2009; Spessa *et al.* 2005).

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