Calibration of ground-based radars in the Brisbane region using TRMM

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Radar calibration issues

• Reflectivity is related to the returned power $P$ from a target at range $r$ by the radar equation:

$$Z = CPR^2$$

where, $C$ is the *radar constant*.

• Calibration error occurs when the assumed value of $C$ differs from the true value.

• This gives rise to a spatially uniform error in the measured reflectivity.

• Calibration error can result from thermal effects and degradation, repair, or replacement of the radar hardware.

• Given knowledge of the true reflectivity at a particular location and time, the calibration error can be computed and corrected for.
Tropical Rainfall Measurement Mission (TRMM)

- Sun-asynchronous measurements at low latitudes (35°S–35°N) from 1997–2014
- Orbited the Earth 16 times per day (overpasses roughly twice daily)
- Onboard Ku-band (13.8 GHz) precipitation radar (PR) measured profiles of reflectivity with a range resolution of 250 m

N.B. Following an altitude boost in August 2001, the IFOV and swath width increased to 5 km and 246 km respectively.
## Ground radars

<table>
<thead>
<tr>
<th>Site</th>
<th>Radar</th>
<th>Max. range (km)</th>
<th>Gate width (m)</th>
<th>Beam width (°)</th>
<th>Scan freq. (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt Stapylton</td>
<td>Meteor1500S</td>
<td>150</td>
<td>250</td>
<td>1.0</td>
<td>6</td>
</tr>
<tr>
<td>Marburg</td>
<td>WSR74S-14</td>
<td>256</td>
<td>1000</td>
<td>1.9</td>
<td>10</td>
</tr>
<tr>
<td>Gympie</td>
<td>DWSR8502S-14</td>
<td>300</td>
<td>500</td>
<td>2.0</td>
<td>10</td>
</tr>
<tr>
<td>Grafton</td>
<td>WSR74S-14</td>
<td>256</td>
<td>1000</td>
<td>1.9</td>
<td>10</td>
</tr>
</tbody>
</table>
Comparison methodology

- Numerous proposed methods for comparing space-borne and ground-based radar measurements; most involving remapping both to a common 3D grid.
- For ground validation of the Global Precipitation Mission (GPM), Schwall and Morris (2011)* developed a method based on overlapping sample volumes.

1. Find all days with significant rain within 140 km of the ground radar (GR) site using the gridded gauge-based AWAP product
2. For these, find any TRMM overpass events coinciding with significant rainfall
3. For any such suitable overpass, identify the nearest GR scan within ± 5 mins
4. Loop over all TRMM profiles containing at least one bin with $Z \geq 18$ dBZ
5. Loop over the radar elevation sweeps
6. At the location where the two measurements coincide, average the PR data in range over the depth of GR beam and average the GR data in azimuth and range over the PR beam diameter
7. Compare the averaged GR and PR reflectivity values at all beam intersections, excluding samples containing significant missing data or values below the minimum reflectivity threshold (0 dBZ for the GR; 18 dBZ for the PR)
8. Store matching GR and PR samples together with TRMM-derived precipitation type, bright-band height, and path-integrated attenuation
Regridding example

PR Reflectivity - $\theta = 1.8^\circ$

GR Reflectivity - $\theta = 1.8^\circ$
Reflectivity comparison example

![Graphs showing reflectivity comparison example.](image-url)
GR reflectivity offset example

mean = 1.9
median = 2.1

$r = -0.10$
Partial beam filling
Frequency correction

• Using theoretical simulations, Cao et al. (2013)* developed an empirical method for converting Ku-band reflectivity measurements to S-band

• Given $Z_{(\text{Ku})}$, the reflectivity at Ku-band (in dBZ), the dual frequency ratio (DFR, in dB) is given by:

$$\text{DFR} = a_0 + a_1 Z_{(\text{Ku})} + a_2 Z_{(\text{Ku})}^2 + a_3 Z_{(\text{Ku})}^3 + a_4 Z_{(\text{Ku})}^4$$

where the coefficients $a$ are derived from the simulations, with unique values for rain, dry snow, dry hail, and snow and hail at various stages of melting (from 10% to 90% melted in 10% increments)

• The reflectivity at S-band is then given by:

$$Z_{(S)} = Z_{(\text{Ku})} + \text{DFR}$$

• This correction is applied to the PR data prior to averaging, with the melting layer defined as the TRMM-derived bright band height $z_{\text{bb}} \pm 300$ m

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For stratiform precipitation, offset between the PR and GR reflectivities is fairly constant with height, except close to the bright band—suggests that frequency correction in the melting layer is too small.

For convective precipitation, the GR offset becomes increasingly positive below the bright band—suggests that TRMM is under-correcting for attenuation.
Reflectivity and offset histograms
GR offset sensitivities
GR offset time series

2008

2009

2010
Identifying possible calibration changes

30/05/2005 - STATION - (andrewa) Proposed
30/05/2005 - OBJECT - (andrewa) Diagram/MAP
30/05/2005 - STATION - (andrewa) latitude Changed to -27.7181
               [Corrected(date); item(oldvalue), ...] > Corrected (28-04-2006); lation_deriv(MAP 1:250 000)
30/05/2005 - STATION - (andrewa) lation_error Changed to
30/05/2005 - STATION - (andrewa) longitude Changed to 153.24
               [Corrected(date); item(oldvalue), ...] > Corrected (28-04-2006); lation_deriv(MAP 1:250 000)
30/05/2005 - STATION - (andrewa) name Changed to BRISBANE (MT STAPYLTON)
30/05/2005 - STATION - (andrewa) stn_h Change to 150
30/05/2005 - STATION - (andrewa) stn_h deriv Changed to MAP 1:250 000
30/05/2005 - STATION - (garrys) lation_deriv Changed to GPS
30/05/2005 - COMMENT - Data supplied to start new station by Agnes Apostolou Program Ops and Standards Gp OEB. -aaqros
30/05/2005 - COMMENT - Station located UBD Map 285 Ref 1C - Extension to Yellowood Rd off the Stapylton-Jacobs Well Rd. -aaqros
30/05/2005 - ACTION - (andrewa) Station New Station - Please allocate a station number for the proposed Mt Stapylton Radar site.
               This station will be managed by the BOM. Further details re site contact . Station due to open during August 2005
               CLEARED - (hca) 01 JUN-05 Please note station number issued in district 40
18/11/2005 - SYSTEM - (johnh) Tools and Test Equipment Holdings Commenced
18/11/2005 - SYSTEM - (johnh) Communications Commenced
18/11/2005 - SYSTEM - (johnh) WeatherWatch Commenced
18/11/2005 - SYSTEM - (johnh) Computing Commenced
18/11/2005 - SYSTEM - (johnh) Infrastructure Commenced
Time-averaged GR offsets

2008

2009

2010
The GR offset $O$ can be expressed by a linear regression model:

$$O = \bar{O} + b(Z_{PR} - \bar{Z}_{PR})$$

Here $\bar{O}$ is the previously determined (time-varying) mean offset, $Z_{PR}$ is the PR reflectivity, $\bar{Z}_{PR}$ its mean, and $b$ is the regression coefficient.

For Mt Stapylton, $b$ turns out to be small (0.03).

This may not be the case for the other radars, in particular Marburg and Grafton which have analogue/logarithmic receivers.
Future work

• Repeat calibration analysis for other three Brisbane radars and CP2
• Verifying that the calibration improves radar agreement by comparing reflectivities in regions of overlapping coverage
• Produce 3D high-resolution (1 km), high frequency (5 min) multi-radar mosaics for all storm days in the Brisbane region (defined by GPATS lightning data)
• Perform storm identification and tracking using TITAN software
• Associate storms with insurance claims associated with hail damage
• Develop logistic relationship between TITAN-derived storm properties and the occurrence of damaging hail
• Use these to create a map of the hail hazard in the Brisbane region
• Repeat this analysis for the Sydney region
Creating a 3D radar mosaic