QPE/QPF for hydrology applications and flood forecasting

Siriluk Chumchean

Department of Civil Engineering
Mahanakorn University of Technology
Contents

1. Investigation of Z-R relationship for different types of rain clouds
2. Application of radar data for runoff estimation
3. Bangkok flood forecasting project
4. 2010 Nakorn Ratchasima Floods, Thailand
5. 2011 Brisbane Floods, Australia
6. Other radar applications
   - Use of radar for evaluating effectiveness of cloud seeding activities
Investigation of Z-R relationships for different types of rain-clouds

Chumchean, S. ¹, P. Aungsuratana ², A. Khommuang ¹ and R. Hanchoowong ³

¹Department of Civil Engineering, Mahanakorn University of Technology, Thailand
²Bureau of Royal Rainmaking and Agricultural Aviation, Thailand
³Department of Civil Engineering, Thammasat University, Thailand

Typhoon Committee Roving Seminar 2011, Malaysia (20-23 September 2011)
Using radar CAPPI to explain characteristics of a rain-cloud

- Raining area
- Velocity
- Life cycle
- Spatial variation of rainfall
- Average reflectivity
Horizontal characteristic of rain-cloud

Cumulus (Cu)  Cumulonimbus (Cb)  Nimbostratus (Ns)

Radar CAPPI images
Z-R relationship for each rain-cloud

Parameters ‘a’ and ‘b’ varies on rain drop size distribution.

- **Cumulus**
- **Cumulonimbus**
- **Nimbostratus**
Objectives

- To study physical characteristics and dynamics of rainfall events that arise from different rain-cloud types.
- To propose a classification criteria for classifying type of rainfall event.
- To estimate a suitable Z-R relationship for each rain-cloud type.
- To evaluate rainfall intensity, rainfall amount and raining area of rainfall events that arise from different cloud types during summer and rainy seasons.
Data - Pimai radar, Nakorn Ratchasima

54 rainfall events recorded from Pimai radar during 2003-2005

50 automatic rain gauges
Average raining area of a rain-cloud
Velocity of a rain-cloud

- Rainy season
- Summer

- Cumulonimbus
- Cumulus
- Nimbostratus
- Cumulonimbus
- Cumulus

Direction of Movement

Rainfall events vs. Velocity (m/s)

(events)
Life cycle of a rain-cloud
Coefficient of spatial variation of a rain-cloud
Average reflectivity of a rain-cloud

![Graph showing average reflectivity of rain clouds during rainy season and summer, with different cloud types represented by symbols.](image-url)
## Proposed criteria for classifying type of a rainfall event

<table>
<thead>
<tr>
<th>No.</th>
<th>Classification criteria</th>
<th>Rain-cloud type</th>
<th>Cumulus</th>
<th>Cumulonimbus</th>
<th>Nimbostratus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raining area : (km²)</td>
<td></td>
<td>&lt; 5,200</td>
<td>≥ 5,200</td>
<td>≥ 3,000</td>
</tr>
<tr>
<td>2.</td>
<td>Velocity : (m/s)</td>
<td>≥ 3</td>
<td>≥ 3</td>
<td>&lt; 3</td>
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<td>3.</td>
<td>Life cycle : (minutes)</td>
<td>&lt; 100</td>
<td>≥ 100</td>
<td>≥ 120</td>
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<tr>
<td>4.</td>
<td>Coefficient of spatial variation of rainfall intensity</td>
<td>&gt; 0.23</td>
<td>&gt; 0.20</td>
<td>≤ 0.20</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Average reflectivity values : (dBZ)</td>
<td>&gt; 23</td>
<td>≥ 21</td>
<td>&lt; 21</td>
<td></td>
</tr>
</tbody>
</table>

The proposed classification criteria were used to classify type of the validated 8 events correctly about **83%**.
Z-R relationship of each type of rain-cloud (Calibration)
Z-R relationship of each type of rain-cloud

- **Cumulus**
  - Rainy season: $Z = 29R^{1.5}$
  - Summer: $Z = 38R^{1.5}$
  - Rainfall rates: 10.58 mm/h, 8.93 mm/h

- **Cumulonimbus**
  - Rainy season: $Z = 55R^{1.5}$
  - Summer: $Z = 90R^{1.5}$
  - Rainfall rates: 6.90 mm/h, 4.99 mm/h

- **Nimbostratus**
  - Rainfall rate: 2.85 mm/h

**Rainy season**

**Summer**
RMSE obtained by using different Z-R relationships

- **Calibration**
  - Rainy season
  - Summer

- **Verification**
  - Rainy season
  - Summer
Evaluating of radar rainfall using the proposed Z-R relationships

**Average rainfall intensity**

<table>
<thead>
<tr>
<th>Rainy season</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
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</tbody>
</table>

**Rainfall amount**

<table>
<thead>
<tr>
<th>Rainy season</th>
<th>Summer</th>
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</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

**Average raining area**

<table>
<thead>
<tr>
<th>Rainy season</th>
<th>Summer</th>
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</thead>
<tbody>
<tr>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
</tr>
</tbody>
</table>
The classification parameters to classify a rainfall event consists of raining area, average velocity, life cycle, coefficient of spatial variation of rainfall intensity and average reflectivity value of a rainfall event.

The proposed classification criteria can identify rain-cloud type of the validated rainfall events correctly by 83%.

The ‘a’ parameters of the proposed Z-R relationships of Cu, Cb and Ns rain-clouds were increased respectively, if b parameter was fixed.

Using the proposed Z-R relationship of each rain-cloud type to estimate radar rainfall gave more accurate rainfall data than Z=300R^{1.4} and Z=200R^{1.6}.

Rainfall amount, rainfall intensity and raining area of rainfall events calculated from the proposed Z-R relationship of each rain-cloud type were corresponding to their physical characteristics.
Acknowledgements

- The Bureau of Royal Rainmaking and Agricultural Aviation (Thailand) for funding support by grant No. 11/2551 and providing the radar and rain gauge data used in this study.

- Mahanakorn University of Technology, Bangkok, Thailand.
Application of Weather Radar Data for Runoff Estimation
Case Study: Lam Thakong Basin

C. Wuttisak and S. Chumchean

1 Department of Civil Engineering, Mahanakorn University of Technology, THAILAND
Study area

- Located inside the Pimai radius
- Rainfall and stream flow stations
- Basin area around 2,180 km²
Methodology

Using different rainfall data

Rain gauge

$Z = 200R^{1.6}$

Runoff Estimation

$Z = 300R^{1.4}$

Evaluate effectiveness of using radar rainfall for runoff estimation

Z-R relationship for different types of rain clouds
Sub-Basin Classification

- Sub-Basin 1
  - Lam Takhong Dam
  - M38C
  - M177
  - Sub-Basin boundary
  - Lam Takhong river
  - Rain gauge station
  - Runoff station

- Sub-Basin 2
  - M164
  - M189
  - Sub-Basin boundary
  - Lam Takhong river
  - Rain gauge station
  - Runoff station

- Sub-Basin 3
  - Sub-Basin boundary
  - Lam Takhong river
  - Rain gauge station
  - Runoff station

- Sub-Basin 4
  - Sub-Basin boundary
  - Lam Takhong river
  - Rain gauge station
  - Runoff station

- Sub-Basin 5
  - Sub-Basin boundary
  - Lam Takhong river
  - Rain gauge station
  - Runoff station
Schematic flow direction for HEC-HMS

- Sub-Basin 1
- Sub-Basin 2
- Sub-Basin 3
- Sub-Basin 4
- Sub-Basin 5
- Lam Takhong Dam
- Node 1
- Node 2
- Node 3
- M164
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<tr>
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<th>Parameter</th>
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<td>Initial abstraction</td>
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<td>Curve number</td>
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<td>Impervious</td>
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<tr>
<td>Surface flow</td>
<td>The SCS Unit hydrograph</td>
<td>SCS Lag</td>
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<td></td>
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<td>Recession constant</td>
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<td>Exponential recession</td>
<td>Base flow Initial flow</td>
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<td>Base flow threshold flow</td>
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<td>Runoff</td>
<td>Muskingum</td>
<td>Muskingum K</td>
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<td></td>
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<td>Muskingum X</td>
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<tr>
<td></td>
<td></td>
<td>Number of steps</td>
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</table>
Calibration Results

Calibration period: 18 Jun – 1 Jul 2009

Discharge (m³/sec)

Calibration period: 11 – 23 May 2009

Discharge (m³/sec)
### Calibration results (Cont.)

**Rain RMSE (m³/sec) Percent Error (%)**

<table>
<thead>
<tr>
<th>Rain</th>
<th>RMSE (m³/sec)</th>
<th>Percent Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain gauge</td>
<td>2.48</td>
<td>0.08</td>
</tr>
<tr>
<td>Z = 200R⁺¹.₆</td>
<td>2.54</td>
<td>0.24</td>
</tr>
<tr>
<td>Z = 300R⁺¹.₄</td>
<td>2.42</td>
<td>0.10</td>
</tr>
<tr>
<td>Z-R relationship for different types of rain clouds</td>
<td>2.41</td>
<td>0.07</td>
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</tbody>
</table>

**Calibration period:** 4 – 17 Jun 2009

**Discharge (m³/sec) vs. Time**

- **Observed**
- **Rain gauge**
- **Z = 200R⁺¹.₆**
- **Z = 300R⁺¹.₄**
- **Z-R relationship for different types of rain clouds**
### Application to rainfall–runoff model

#### Validation period: 29 Jul – 11 Aug 2009

<table>
<thead>
<tr>
<th>Z-R relationship</th>
<th>RMSE (m³/sec)</th>
<th>Percent Error (%)</th>
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</thead>
<tbody>
<tr>
<td>Rain gauge</td>
<td>3.60</td>
<td>57.20</td>
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<tr>
<td>$Z = 200R^{1.6}$</td>
<td>3.50</td>
<td>42.33</td>
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<td>$Z = 300R^{1.4}$</td>
<td>3.54</td>
<td>44.15</td>
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<tr>
<td>Z-R relationship for different types of rain clouds</td>
<td>3.45</td>
<td>40.46</td>
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Bangkok Flood Forecasting System

Siriluk Chumchean
Mahanakorn University of Technology, Bangkok, Thailand

Thomas Einfalt
Hydro & meteo GmbH & Co. KG, GBR

Kannika Pahonepipat
Asdecon Corporation Co., Ltd., Thailand
- City rapid’s urbanisation
- Inflow of the Chao Praya river
- Inadequate drainage capacity
- Back water from the tidal effect
- Increases in ground water assumption
- Heavy rainfall
Flooding in Bangkok 1983
Flooding in Bangkok 1983
Flooding in Bangkok 1995
Objectives of the project

- To integrate information from rain gauges, hydrometric stations, radar measurements, and NWP results for forecasting of rainfall over 12-hour ahead.
- To forecast rainfall over Bangkok area with 60% accuracy within 3-hour forecast.
- To predict water levels within 5 cm accuracy by updating the forecast water levels every hour.
Department of Drainage and Sewerage (DDS)
Bangkok Metropolitan Administration (BMA)

FLOOD FORECASTING AND MANAGEMENT SYSTEM

REAL TIME TELEMETRY

FLOOD WATCH

SCOUT RAINFALL FORECAST

MIKE 11 GIS FLOOD MAPPING

MIKE 11

simulated

forecasts

Actual peak

phase error,
assumed decreasing

Exact match

observed

Time of forecast

DISSEMINATION
BKK Rainfall Forecasting System
Objectives of rainfall forecasting system

- Prepare rainfall information for the FLOODWATCH water level forecast
- Prepare rainfall information for the web
- Provide warning information in real time
Forecast combination

- Radar
  - Observe
  - Radar 1-3 hr
  - NWP 4-12 hr

- main system
  - Radar

- backup system
  - NWP
  - ANN 1-12 hr

- Time of Forecast
  - Radar images and forecast
  - Numerical Weather Prediction

Volume

Time
Results (30 events)

- 1-hour ahead: 73% accuracy
- 2-hour ahead: 67% accuracy
- 3-hour ahead: 65% accuracy
**Forecast combination (4-12 hours)**

**Thailand NWP model:** prediction every 12 hours, 1 hour time step

<table>
<thead>
<tr>
<th>UTC time</th>
<th>NWP rainfall forecasts</th>
<th>Don Muang radar measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 hours</td>
<td>60 min 60 min 60 min 60 min 60 min 60 min 60 min 60 min 60 min 60 min 60 min 80 min</td>
<td>30 min 30 min 30 min 30 min 30 min 30 min 30 min 30 min 30 min 30 min 30 min 60 min 60 min 60 min</td>
</tr>
</tbody>
</table>
Rainfall forecast for 4-12 hr using NWP result

Thailand NWP model prediction every 12 hours
1 hour time step
Application of rainfall forecast for flood forecasting
Flood forecasting system

1. ANN, NWP → SCOUT
2. Rainfall Runoff HD – DA Models → FLOODWATCH
3. MIKE GIS → FLOODWATCH
4. FLOODWATCH → SCOUT
5. SCOUT → NAM, HD, DA
6. MIKE GIS → NAM, HD, DA

- Request output
- SCOUT
- MIKE GIS
- NAM, HD, DA
Rainfall forecast time series of each sub-catchment

Send forecast time series to Hydrological Model
Rainfall-Runoff Module

Sub 12

Rainfall (mm)

TOF

TOF

31-10-2002
13:50

31-10-2002
14:20

Q (cms)

Q (cms)
Rainfall information on Web-site
ระบบงานชายแดน จุฬาภรณ์มณฑล เพื่อให้ความสะดวกรวดเร็วในการจัดระเบียบ สำหรับการจัดการกับการไหลที่ผ่านผ่านข้ามแนวชายแดน คุณภาพน้ำ หรือการขนส่งทางน้ำ ทั้งนี้เพื่อให้การขนส่งด่วนได้ปลอดภัย การเร่งด่วนการจัดรูปแบบและการบริการที่มีประสิทธิภาพ ได้แก่ การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light) การจัดระบบสัญญาณการจราจร (Traffic Light)
รายละเอียดการเดินทางภูมิศาสตร์พื้นที่ในประเทศ วันที่ 2 ตุลาคม 2548 เวลา 16:15 น.

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Image by SCOUTView at 2005-10-02 16:15
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</tbody>
</table>

Forecast by SCOUTview for 26 8 2005 17 10
Sending warning email
Conclusion

Main system

1-12 hour forecast

SCOUT

- DMC radar (main)
- BMA radar (backup)

NWP

- rainfall & Met.

E-mail

Flood forecasting system

Backup system

1-12 hour forecast

ANN

- rain & Met.

WEBSITE

WEBSITE
Acknowledgement

- Department of Drainage and Sewerage (DDS)
- Bangkok Metropolitan Administration (BMA)
- The Thai Meteorological Department (TMD)
Nakorn Ratchasima Floods, October 2010 (Thailand)
Causes of Flooding

✓ Occurred during October 10 – 31, 2010

✓ Causes of flooding
  ➢ Influence of trough lies on south, central and east of Thailand
  ➢ Influence of southwest monsoon
Flood extent on 22 October 2010
Flood extent on 23 October 2010
Flood extent on 30 October 2010
Radar rainfall on 12 October 2010

Calculated by Scout software (developed by Dr Thomas Einfalt)
Accumulated radar rainfall on 12 October 2010

Step: 06.42 – 10.54

Calculated by Scout software (developed by Dr Thomas Einfalt)
Accumulated radar rainfall in Nakorn Ratchasima province between 12 – 15 October 2010

Maximum rainfall = 1,421 mm
Accumulated Average Rainfall in Nakorn Ratchasima Province

12 Oct : 06.36 – 20.30
13 Oct : 08.00 – 20.00
14 Oct : 07.36 – 19.48
15 Oct : 09.06 – 20.42
Flood extent during 22 - 23 October 2010

Maximum rainfall = 1,421 mm
Losses from flooding
Losses from flooding

- 32 districts, 277 tambons, 3,022 villages have been affected by flooding
- People have suffered more than 310,000 households
- Deaths of 18 people
- More than 1.7 million rais farmland damaged
- Losses total more than one billion Baht
Brisbane Floods, January 2011
(Queensland, Australia)
Causes of Flooding

✓ Occurred during 9 - 17 January 2011

✓ Causes of flooding

- heavy rainfall caused by Tropical Cyclone Tasha that combined with a trough during the peak of a La Niña event

(From: http://blog.travelpod.com/)
Accumulated radar rainfall between 9 -11 January 2011

Calculated from Mapview radar software (developed by Dr Alan Seed)
Flood Map of Brisbane in January 2011

(FROM: http://www.bbc.co.uk/news/world-asia-pacific-12173960)
Losses from flooding
Losses from flooding

✓ At least seventy towns and over 200,000 people were affected

✓ killed 12 people and 51 people missing

✓ 30,000 houses collapsed

✓ Damage was estimated at around AUD$ 1 billion
Comparison between rainmaking and natural rainfall in the Northeastern part of THAILAND

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“Royal Rainmaking is one of His Majesty the King Bhumibol’s initiative projects derived from his concern over the poverty of his people, particularly those who repeatedly face drought disasters due to variation and deviation of the season.”

http://www.youtube.com/user/modweather
Rainmaking activities in Thailand

- Use knowledges of meteorological and chemical physics for stimulating rain by enlargement of clouds.
- To increase the amount and extent of rainfall in the target area.
Rainmaking Operation

- Assign the target area
- Collect and analyze weather data
- Meeting for rainmaking planning
- Cloud seeding
- Conclude the result of rainmaking activity
1) To investigate an appropriate method that can be used to evaluate effectiveness of cloud-seeding.

2) To evaluate efficacy of rainmaking activities in the Northeastern part of Thailand.
Study area: Northeastern part of Thailand
Rainfall events recorded from Pimai radar during 2003-2009

Pimai radar

50-rain gauge network (2003-2005)
33-rain gauge network (2006-2009)
Data collection
Radar Rainfall Estimation Method

- Radar and Rain gauge quality control
- Convert radar reflectivity into rainfall rate using climatological Z-R ($Z=56.5R^{1.5}$)
- Bias adjustment using rain gauge data
Z-R pairs used in this study

Calibration

39 events during 2003-2004

Verification

5 events during 2005
Range dependent errors

\[ \sigma_{GR}^2 = 0.1320 \]

\[ N \sum_{i=1}^{N} \left( \log R_G(i) - \log R_R(i) \right)^2 \mid R_G(i) > r \]

\[ \sigma_{GR}^2 = 0.0003 \left( R_0 - 70 \right) + 0.1320 \]

Anagnostou et al. (1999)
Investigation of bias adjustment method

- Bias adjustment using rain gauge data
  - case 1: Climatological uniform adjustment method
  - case 2: Climatological range dependent method
  - case 3: Uniform bias adjustment factor for each event
  - case 4: Range dependent bias adjustment factor of each event
  - case 5: Hourly uniform bias adjustment (hourly)
  - Case 6: Range dependent-hourly bias adjustment method
RMSE between radar and gauge rainfall

Range dependent hourly bias adjustment method

- Calibration

RMSE (mm/hr)

- Z=56.5R^{1.5}
- Z=300R^{1.4}
- Z=200R^{1.6}
RMSE between radar and gauge rainfall

Verification

RMSE (mm/hr)

Z=56.5R^{1.5}
Z=300R^{1.4}
Z=200R^{1.6}

case1  case2  case3  case4  case5  case6

Range dependent hourly bias adjustment method
Developing radar rainfall estimation model for evaluating natural and rainmaking rainfall
Assumption

Input data

- 2.5 km CAPPI data
- Hourly raingauge data
- Coordinating of the rainmaking target area

Output data

- Average rainfall intensity and accumulated rainfall (inside and outside the benefit area)
Example # 1. 7-April-2008
Rainmaking or natural rainfall?

Step 1: 11:00 – 11:12
Step 2: 11:15 – 11:30
Step 3: 14:21 – 14:34
Accumulated rainfall

K Index = 31.1

Stability indexes
   SI = 0.1
   LI = 0.7

Average RH at CCL = 81%
Rainfall occurs inside and outside target area

Graph showing average rainfall intensity (mm/hr) over time.

- **Inside** rainfall line
- **Outside** rainfall line

**Steps:**
- **Step 1:** 11:00 – 11:12
- **Step 2:** 11:15 – 11:30
- **Step 3:** 14:21 – 14:31

Rainfall values and time intervals are shown in the graph and legend.
Effect of upper air data on rainfall

K Index = 31.1
SI = 0.1
LI = 0.7
Average RH at CCL = 81%

K Index = 28.7
SI = 3.1
LI = 1.5
Average RH at CCL = 53%
Evaluation of rainmaking activities

Accumulated rainfall inside and outside the benefit area

![Graph showing accumulated rainfall inside and outside the benefit area during rainy season and summer.](image)
Evaluation of rainmaking activities

Rainy season
- 4 events
- 71% of 10 events

Summer
- 3 events
- 63% of 5 events

Inside > outside
Inside < outside
Conclusions

1. Range dependent hourly bias adjustment method gives the smallest RMSE between radar and rain gauge measurements for the Pimai radar.

2. Mostly, the amount of rainfall that occurred inside the benefit area correspond to SI, LI, KI and average RH at CCL level. High rainfall has been observed if SI and LI indexes are low while KI index and average RH are high.

3. According to 22 events, it showed that 71% and 63% of the operational rainmaking days during rainy season and summer gave higher average rainfall intensity and rainfall amount inside the rainmaking’s benefit area than outside the benefit area.
Acknowledgement

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