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MINISTRY OF ENVIRONMENT AND WATER

Technical Note No. 1/2020

Quality Control of Radar and QPE Calibration with Rain Gauge in Malaysia Using JMA Techniques

Fauziana Ahmad, Mahluddin Sahrin, A. Kamiluddin Hj. Ibrahim, Asmadi Abdul Wahab, Ismail Alias, Maqrun Fadzli Mohd Fahmi, Mohd Hafizi Mat Yasin

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Abstract

The sources of radar errors in term of meteorological and non-meteorological can be eliminated using quality control algorithms and techniques. The techniques and software that provided by JMA are successfully improved the MMD raw radar data. The techniques that have been implemented are beam blockage analysis, statistical approach, removing interference and clutter, clutter map and adjustment of radar rainfall intensity and coverage. The radar data of MMD are improved by applying those techniques. After improving the raw radar quality, the QPE calibration with raingauge is needed to obtain the accurate radar rainfall estimation. JMA introduced two type of calibration which are first and second calibration respectively focused on the calibration over the whole radar observation range and calibration over land. The main aspect to obtain the accurate radar rainfall estimation is using the dense of rain gauge data. It is recommended to study more about the adjustment of radar rainfall for improving the precipitation estimation.

Acknowledgement

I would like to express the deepest appreciation to Japan Meteorological Agency (JMA) experts for continuous co-operation and providing the software for the radar quality control techniques and QPE.

Weather Radar Workshop at MMD
2-6 November 2015

Bilateral Training Workshop on Radar QC and QPE at JMA
19-23 December 2016

Technical Meeting on Radar QC and QPE at JMA
12-15 December 2017

1. Introduction

Weather radar quality control is emphasized to obtain the accurate radar rainfall estimations. These stated problems will be affected the quality of raw data. Discussion by (Jan Szturc, 2012), the performance of radars are burdened by the number of errors from different source in term of meteorological and technical problems. Hardware errors are related to electronic problems, antenna accuracy and digital signal processing. Interference could be happened due to the sun and other microwave emitters. The attenuation problems caused by the wet covered radome and rain attenuation by different wavelengths particularly C and X-band result in the strong underestimation in precipitation, especially in case of hail. Ground clutter, anomalous propagation of radar beam due to atmospheric condition and biological echoes from birds, insects provide the inaccurate information on the radar images. In addition, the beam blockage is the main problems at the radar site due to topography and by nearby objects such as trees and buildings. In view of the above stated technical, meteorological and non-meteorological sources of errors can be eliminated by the quality control algorithms that applied on weather radar reflectivity data. For instance, ground clutter removal is determined by using statistical or Doppler filtering. Non-meteorological echoes can be removed by the dual polarization radars and relevant algorithms for echo classification. Meanwhile, removal of external interference signals should be checked in any azimuth, lower elevations and detection of high reflectivity.

In the line with the importance of improving the radar quality control, with the assistance from Japan Meteorology Agency (JMA) experts, MMD radar data are implementing the quality control process. The co-operation between JMA and MMD began from 2014 until now. The techniques of radar quality control and Quantitative Precipitation Estimation (QPE) are established thru mutual discussion between MMD and JMA. The eleven radar stations have their own problems related to blockage, ground clutter, interference, scanning strategies and so on, the techniques and software that provided by JMA are beneficial to lessen the problems occurred. Henceforth, the evaluation of each radar stations should be checked and the quality of raw radar data can be improved.

On the other hand, another source of error that affecting the radar rainfall estimation is Z-R relationship variability. Nowadays, a single polarization radar apply a single or seasonal-dependent Z-R relationship such as Marshal Palmer ($Z=200R^{1.6}$) or Rosenfeld ($Z=250R^{1.2}$). However, fixed Z-R relationship can lead to significant errors in rainfall estimation as it depends on precipitation type (stratiform or convective). The QPE methods can solved this problem by using the rain gauge information, as it is assumed that rain gauge measures exactly whereas radar provides information about space distribution. QPE techniques consider the calibration with rain gauges until accurate radar rainfall is obtained. There are some methods that studied by the researchers such as mean field correction, multiple regression, geostatistical approach and Kalman filtering approach. Study by (J-L Champeaux), the adjustment factor is computed using radar and rain gauges in good visibility areas (~ up to 80 km range distance from the radar in flat terrain) and specially in case of heavy rainfall. The accurate radar rainfall can be applied into the hydrological model for the runoff and flood forecasting model.

2. Data and Methodology

In this study, eleven (11) radar stations are selected to examine the radar quality for the selected period. The techniques that applied for this purpose is implemented by Japan Meteorology Agency (JMA) by sharing the software to MMD. The step of radar quality control is below:

IRIS Raw Data			
Using radar-library.jar of JMAPCappiMain	EIL Table	Sitelowmake_mmd.ini	Clutter Map

⇩

PCAPPI Data	
Using radar-library.jar of CompositeMain	Composite.ini

⇩

10 Minutes Composite GRIB2
Using radar-library.jar of GISGrib2PNG to convert to image file

⇩

1 Hour Composite GRIB2	
Using java RadarQPE Main –qpe=60	Accumulate .ini

⇩

QPE 1 Hour	
Location.txt	Using java PointView

- IRIS Raw Data can be viewed by the radar_library.jar of IRISRawView. This library can examine the elevation angle for each radar stations.
- Echo Intensity Lowest (EIL) Elevation Angles should be studied by using R-programming with the GTOPO30 Digital Elevation Model (DEM) data to observe the performance of radar related to topography data. This is vital to check for each azimuth of radar observation (360 degree) for the blockage area and coverage area for each elevation angle for each radar station. The height of CAPPI can be modified to study the radar beam which intersect with the topography.
- Sitelowmake_mmd.ini is the parameter which focused on the rain_cut and noise_cut that can be altered depend on the performance of radar station.
- Clutter map used for removing the ground clutter that will affect the performance of radar as the forecasters may confuse between rain and permanent echoes.
- Composite.ini is used to setting the Malaysian composite with the additional of rain_cut parameters which will remove the rainfall less than 0.3mm/hour.
- After applying radar quality control for each station, QPE-1Hour is produced by averaging 10 minutes interval data.

- The quantitative precipitation estimation (QPE) at certain locations can be known by using library Point View as file of location.txt consisted of station id, latitude and longitude.
- The conversion from radar reflectivity to radar rain rate is using Marshal Palmer relationship.

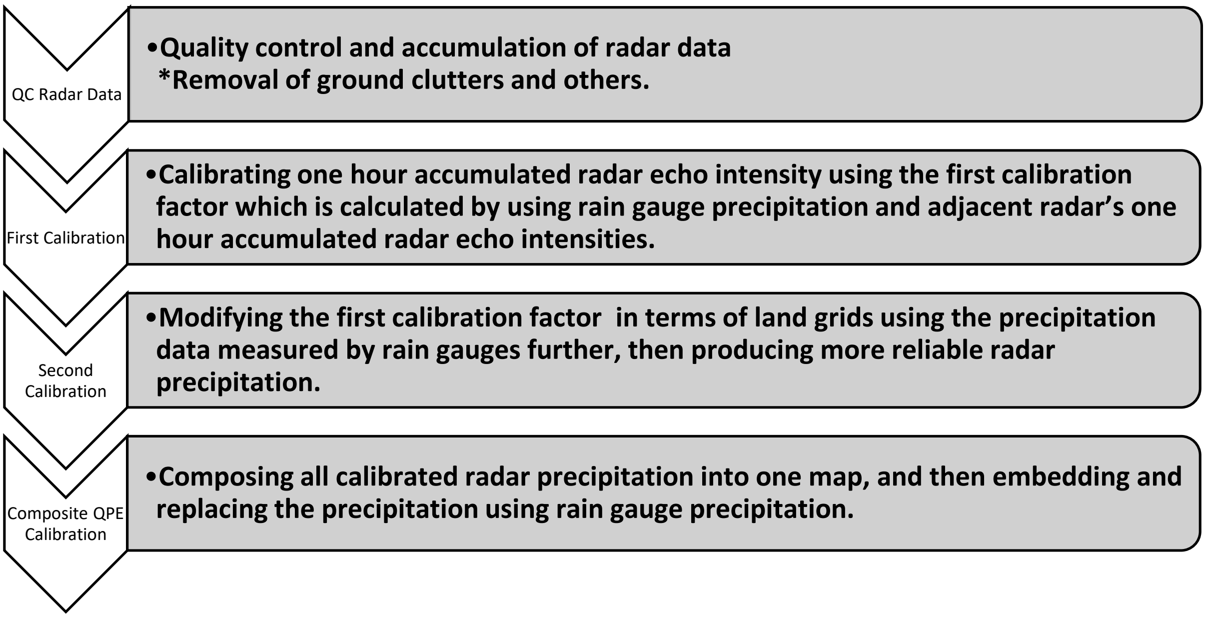
JMA also sharing their expertise to improve the quality of radar data by examining the statistical of radar data for each month at each radar stations. Using these statistical data, the suspicious data can be identified by comparing appearance and average data. The indicator of statistical data as Table 1:-

Table 1: The statistical indicator for appearance and average approach

Performance Indicator	Data	% Values	Results
Suspicious	Appearance	1	Clutter caught merely but strong
	Average	35	
Not suspicious	Appearance	6	Normal precipitation
	Average	5	
Suspicious	Appearance	6	Clutter caught week but continuous
	Average	1	

The statistical data can be analysed for raw data, PCAPPI and composite data that beneficial to identify shadowed area, observable area, low quality area, clutter and interference by modifying the EIL Table to obtain better quality of radar data. Meanwhile, existence of ground clutter can be removed by using clutter map software.

After making quality control for radar data at each stations, QPE calibration with raingauges is needed to obtain better rainfall estimation. The step of Radar QPE calibration with raingauge as below:-


QC Radar Data
•Quality control and accumulation of radar data
*Removal of ground clutters and others.
First Calibration
•Calibrating one hour accumulated radar echo intensity using the first calibration factor which is calculated by using rain gauge precipitation and adjacent radar’s one hour accumulated radar echo intensities.
Second Calibration
•Modifying the first calibration factor in terms of land grids using the precipitation data measured by rain gauges further, then producing more reliable radar precipitation.
Composite QPE Calibration
•Composing all calibrated radar precipitation into one map, and then embedding and replacing the precipitation using rain gauge precipitation.

3. Results and Discussion

3.1 The analysis for each stations are described as below for each elevation angle:-

a) Kota Bharu (KB1) Radar Station

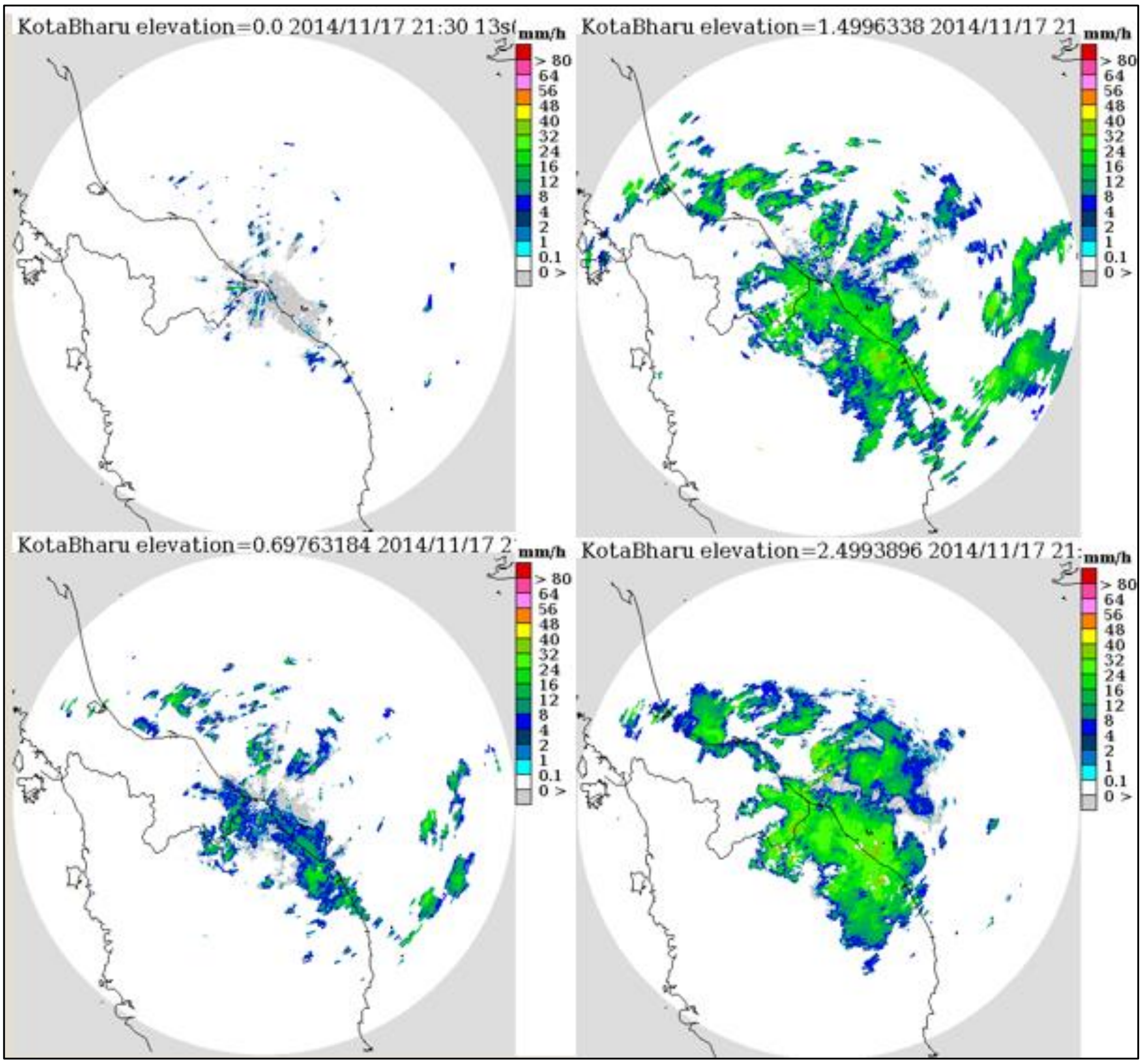


Figure 1: The performance of radar observation for each elevation angles

From the observation in Figure 1, we can see that the lower elevation angles (0.0 and 0.7 degree) had weak echo with elevation angle 0.0 degree almost no echoes. This situation is abnormal condition because the lowest elevation angle should capture more echoes to optimize the detection of low level weather. Hence, the recommendation to change the scanning elevation angles from (0.0, 0.7, 1.5, 2.5 degrees) to (0.9, 1.8, 3.5, and 10.0). The new scanning elevation angles capture better coverage than previous angles that reduction of blockage areas can be shown in Figure 2.

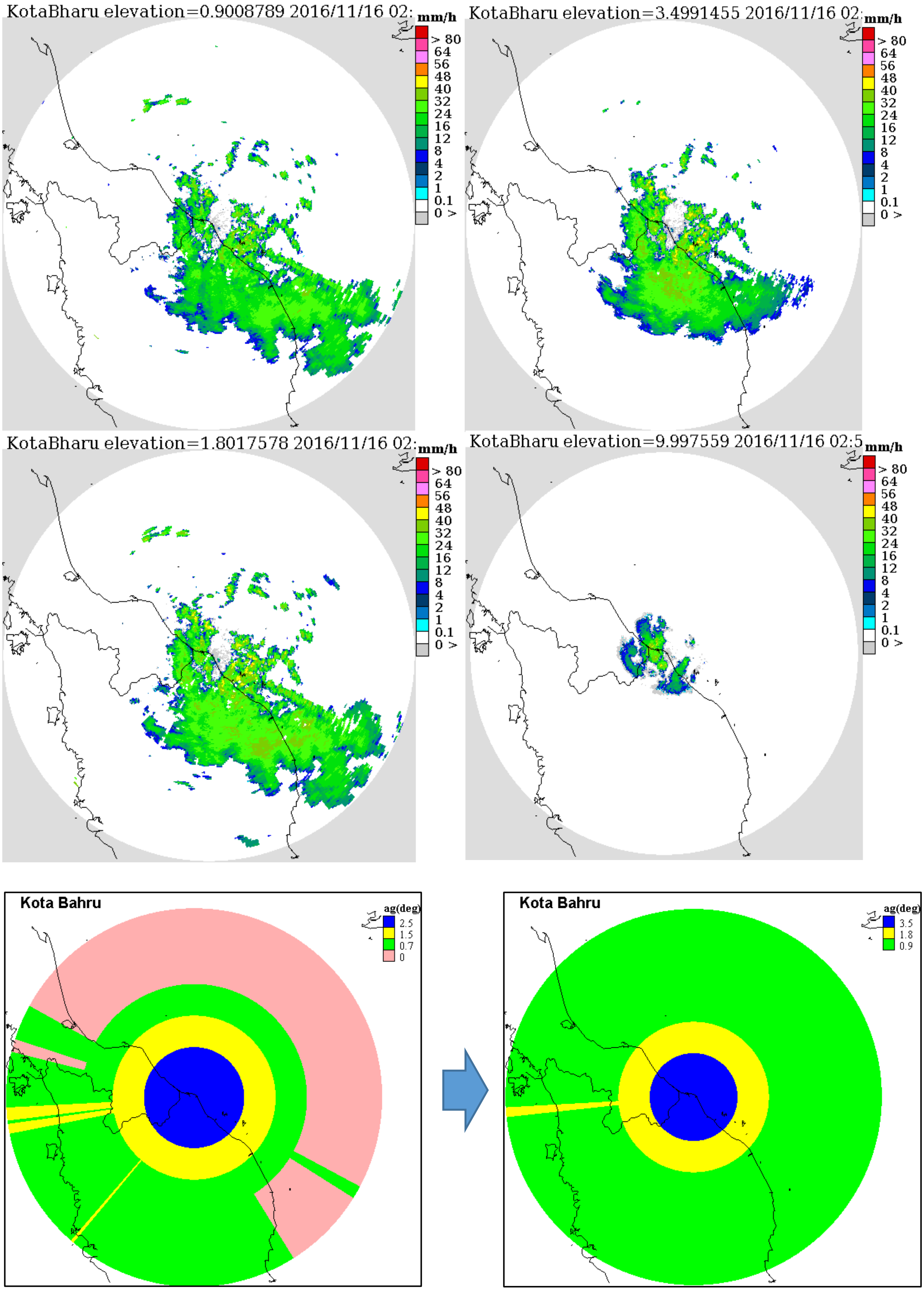


Figure 2: The performance of radar observation for each elevation angles and its improvement of new elevation angles

b) Kuantan Radar Station (KN1)

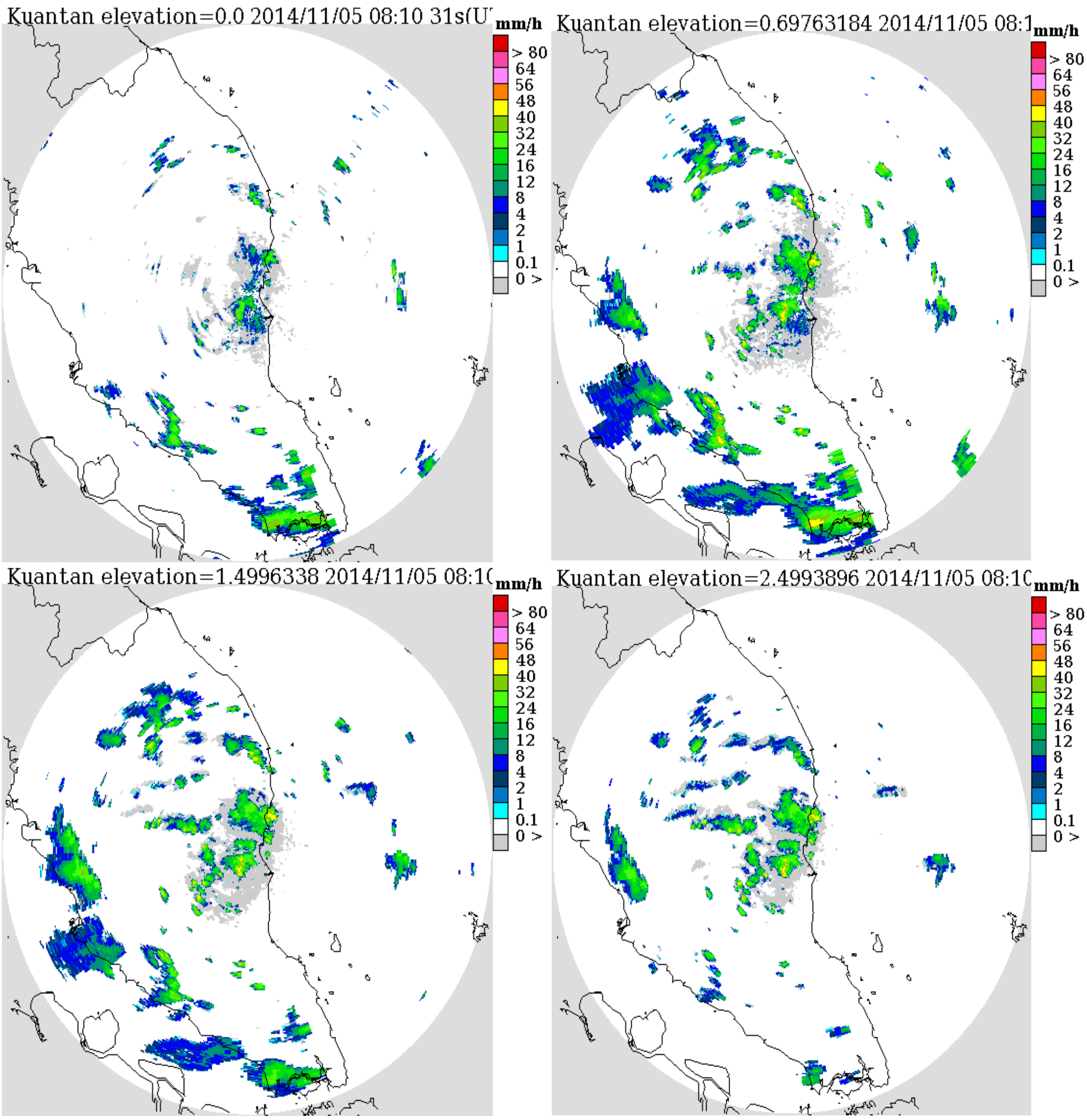


Figure 3: The performance of radar observation for each elevation angles

From this observation as described in Figure 3, we can see that the lower elevation angles (0.0 and 0.7 degree) had weak echo with elevation angle 0.0 degree almost no echoes. This situation is abnormal condition because the lowest elevation angle should capture more echoes. The lowest angle is operated to optimize the detection of low level weather. Hence, the recommendation to change the scanning elevation angles from (0.0, 0.7, 1.5, 2.5 degrees) to (1.0, 1.8, 3.5, and 10.0). The new scanning elevation angles capture better coverage than previous angles as shown in Figure 4.

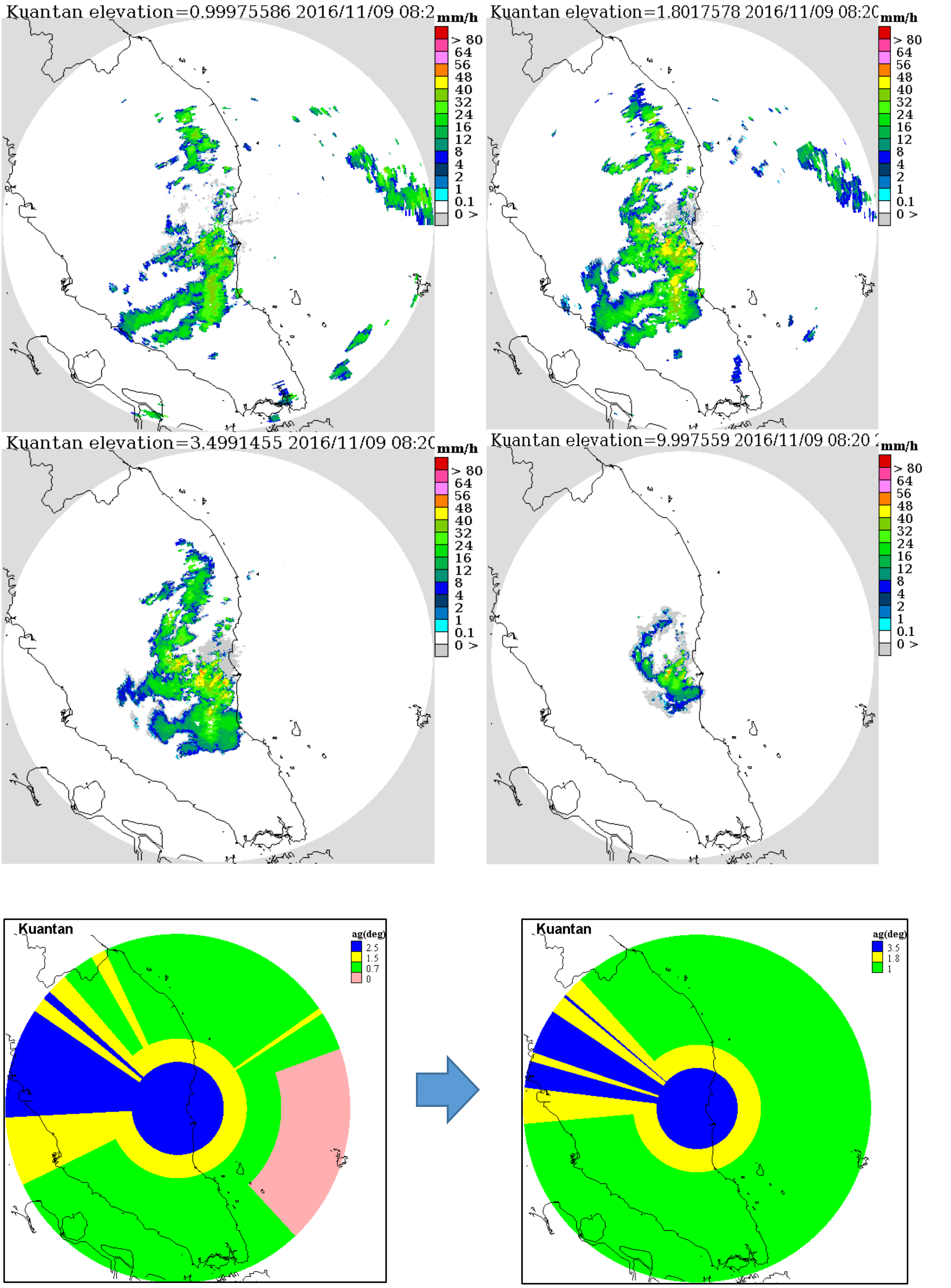


Figure 4: The performance of radar observation for each elevation angles and its improvement of new elevation angles

c) Kluang Radar Station (KG1)

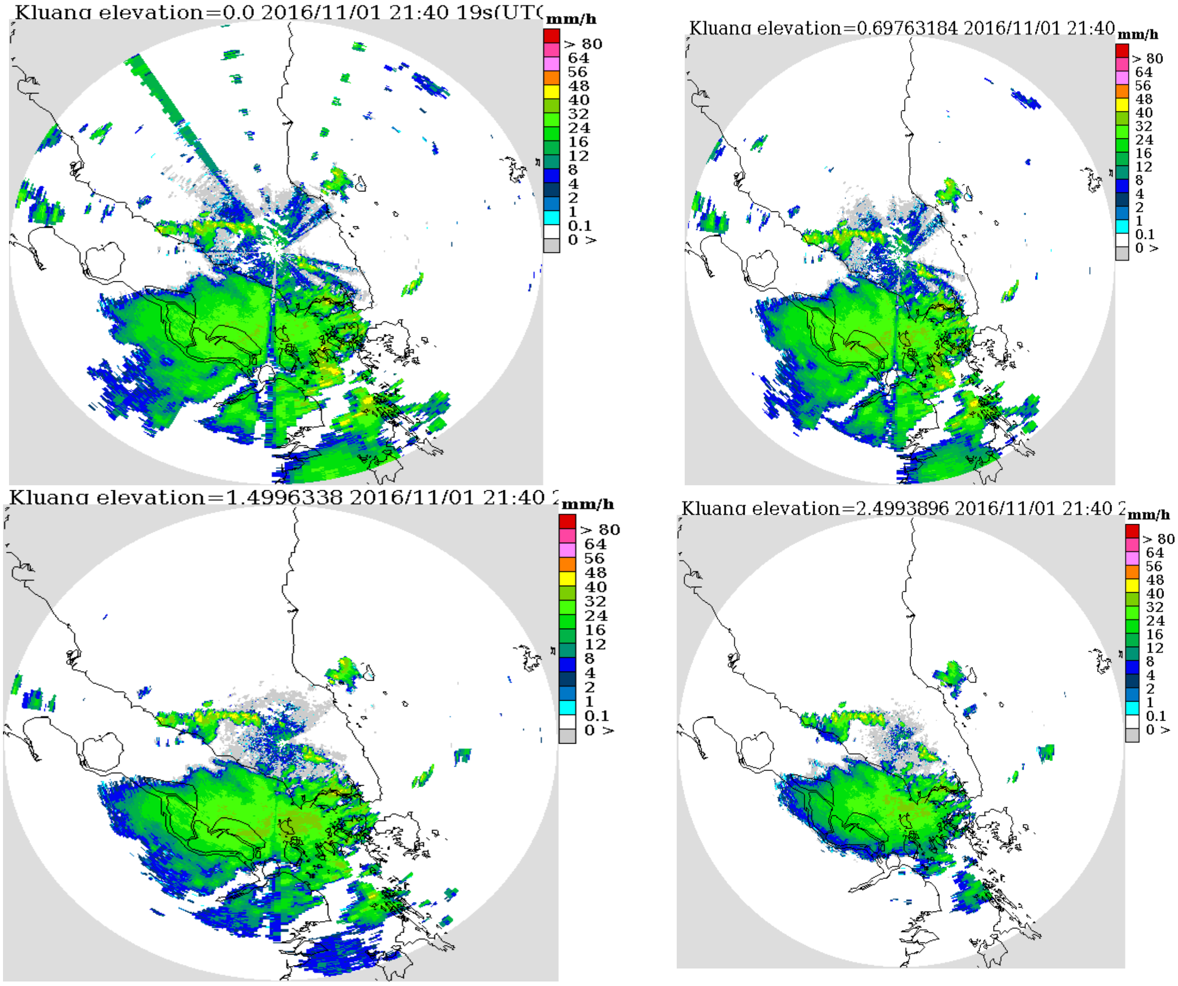


Figure 5: The performance of radar observation for each elevation angles

From this observation in Figure 5, we can see that the performance of KG1 is better in term of coverage of intensity for every elevation angle. However, KG1 faces the blockage problem at the east side of radar stations that cannot be eliminated since until 2.5 degree, the blockage area still existed as shown in Figure 6.

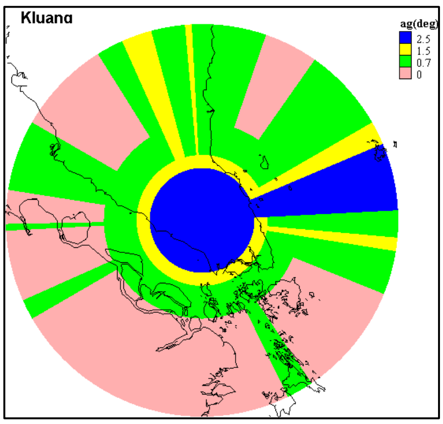


Figure 6: The blockage areas related to topography data at KG1 station

d) Subang Radar Station (SG1)

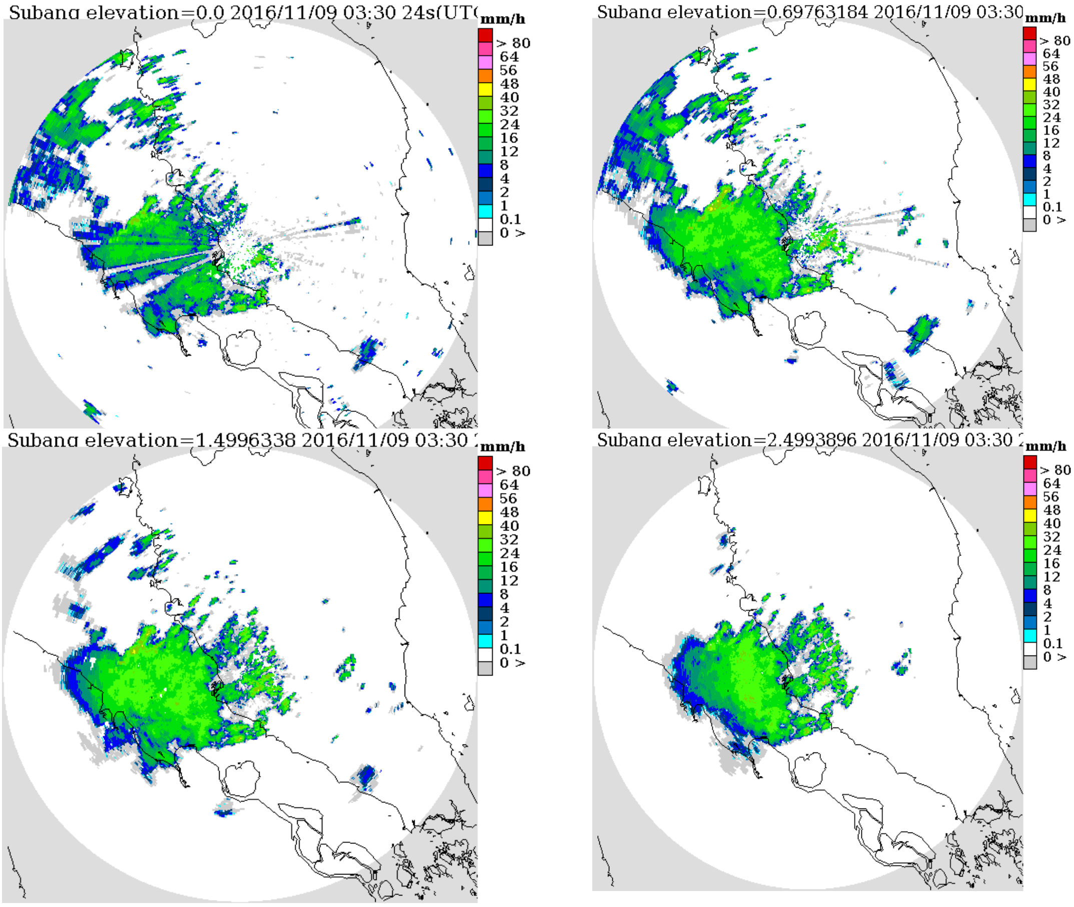


Figure 7: The performance of radar observation for each elevation angles

The performance of SG1 is better in term of coverage of intensity for every elevation angle as shown in Figure 7. However, SG1 faces the blockage problem at the east side of radar stations that can be captured until 2.5 degree as shown in Figure 8.

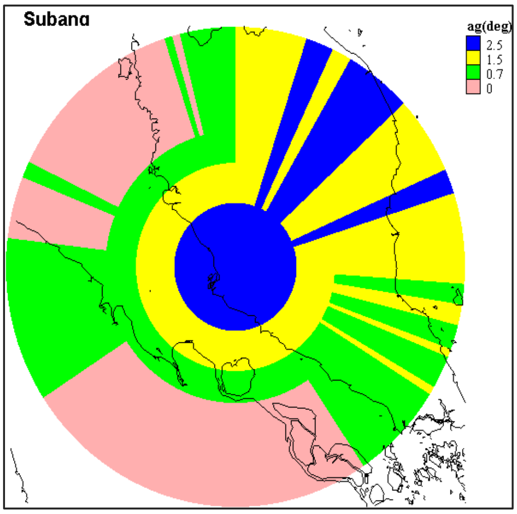


Figure 8: The blockage areas related to topography data at SG1 station

e) Butterworth Radar Station (BW1)

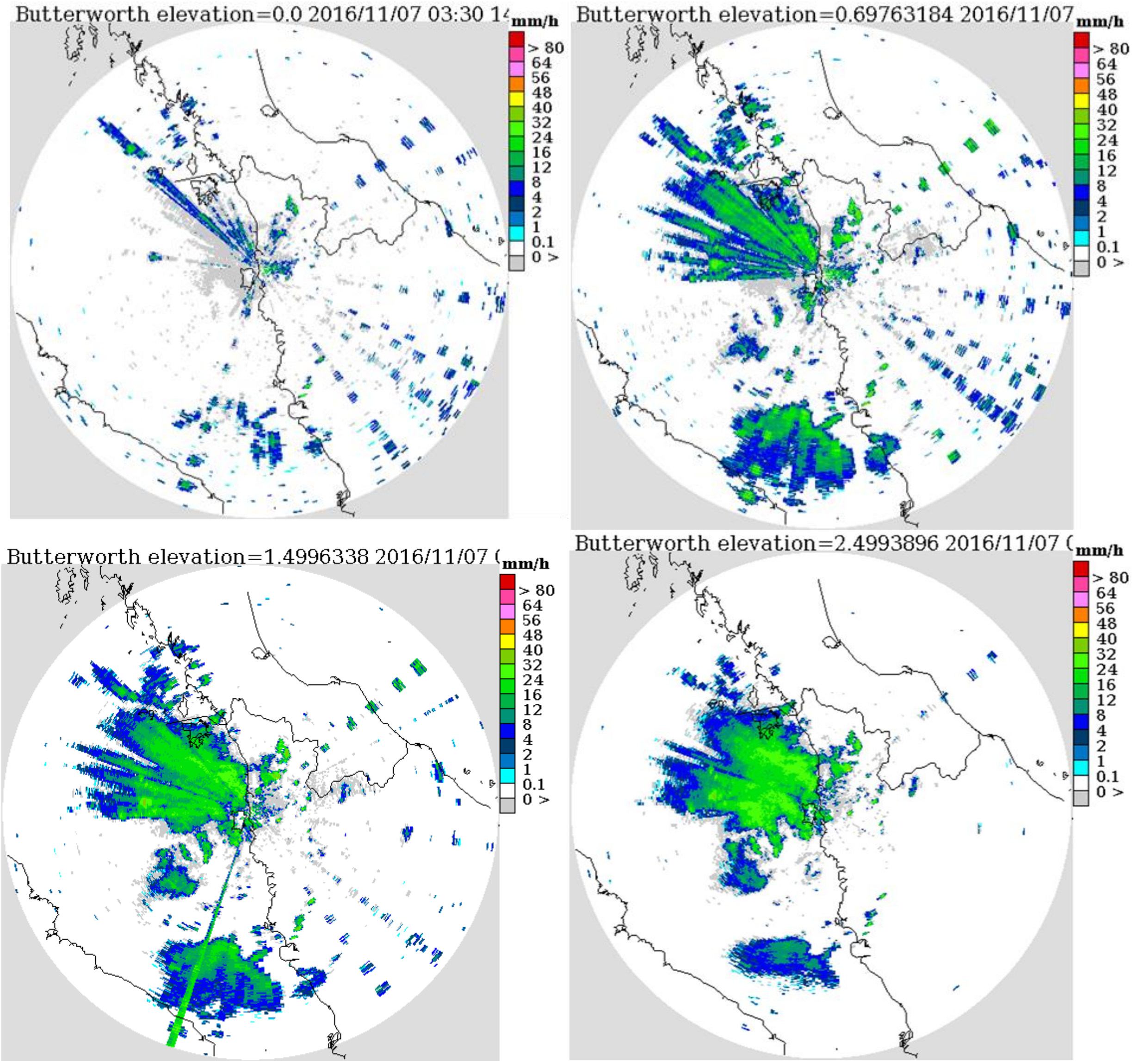


Figure 9: The performance of radar observation for each elevation angles

From this observation in Figure 9, we can see that the lower elevation angles (0.0 and 0.7 degree) had weak echo with elevation angle 0.0 degree almost no echoes. This situation is abnormal condition because the lowest elevation angle should capture more echoes. The lowest angle is operated to optimize the detection of low level weather. In addition, BW1 is contaminated with the noise and interference. Hence, the recommendation to change the scanning elevation angles from (0.0, 0.7, 1.5, 2.5 degrees) to (1.2, 2.2, 4.0, and 10.0). The new scanning elevation angles capture better coverage and less noise as revealed in Figure 10.

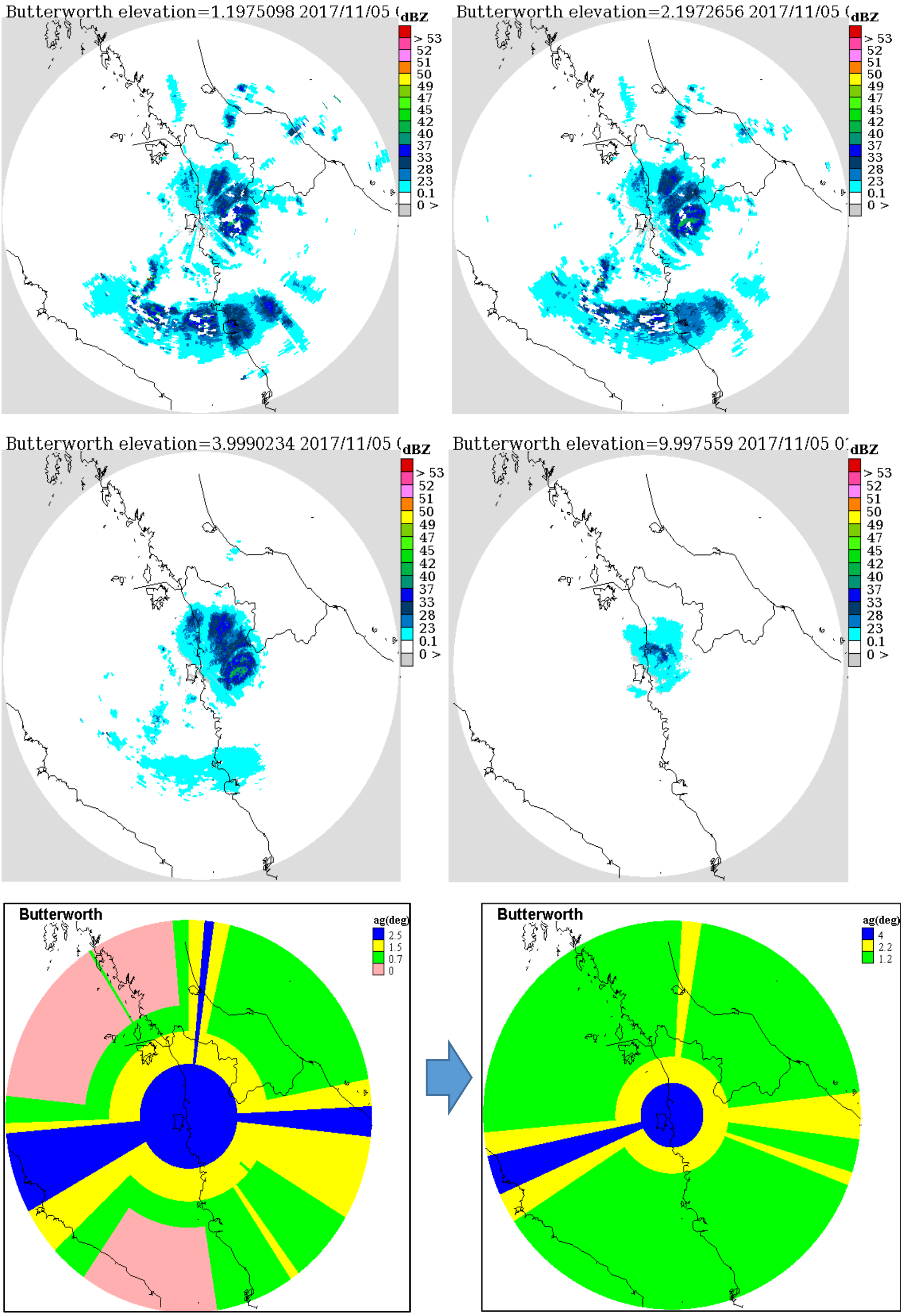


Figure 10: The performance of radar observation for each elevation angles and its improvement of new elevation angles

f) Alor Star Radar Station (AS1)

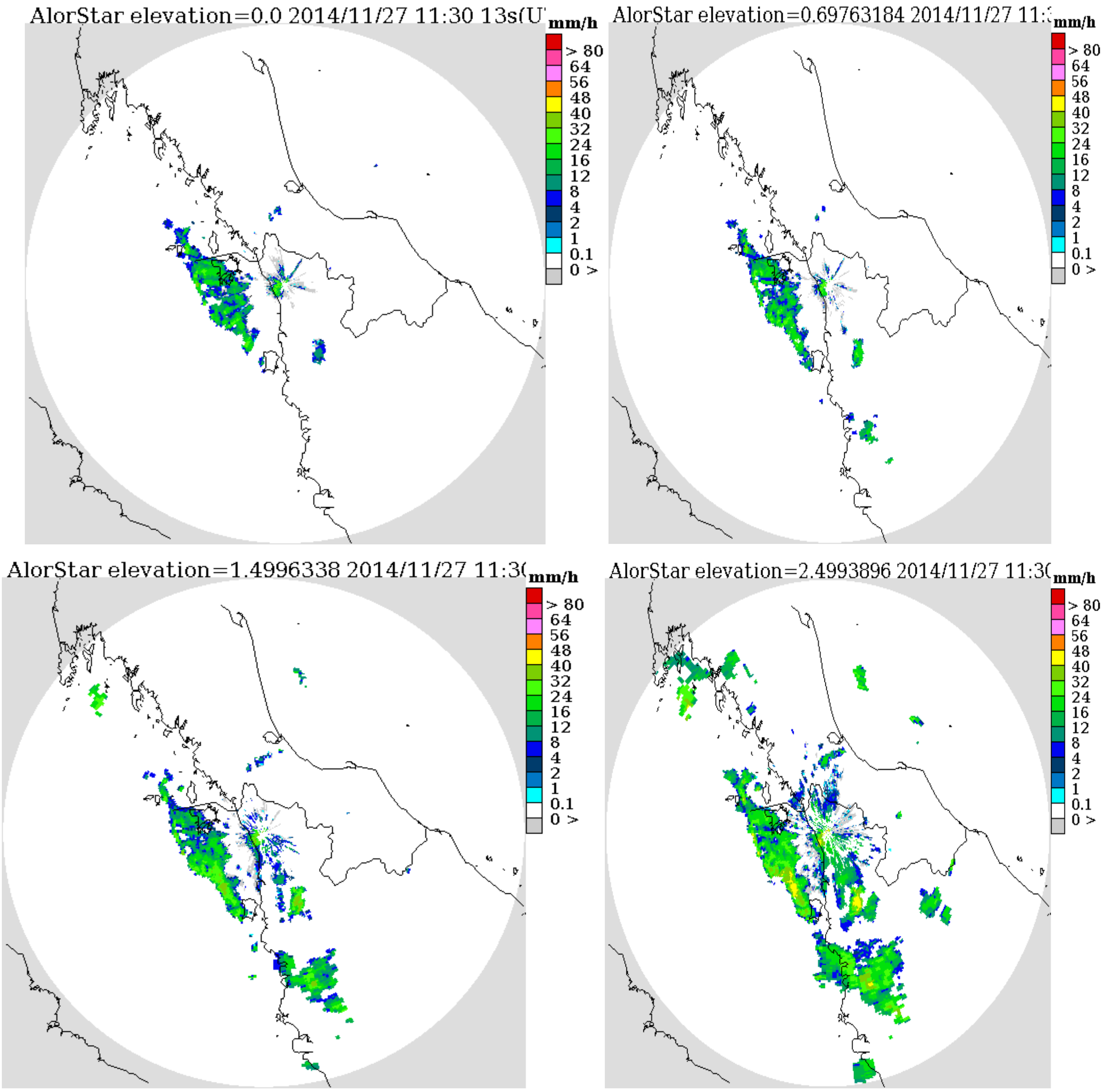


Figure 11: The performance of radar observation for each elevation angles

From this observation in Figure 11, we can see that the lower elevation angles (0.0 and 0.7 degree) had weak echo with elevation angle 0.0 degree almost no echoes. This situation is abnormal condition because the lowest elevation angle should capture more echoes. The lowest angle is operated to optimize the detection of low level weather. In addition, BW1 is contaminated with the noise and interference. Hence, the recommendation to change the scanning elevation angles from (0.0, 0.7, 1.5, 2.5 degrees) to (1.2, 2.2, 4.0, and 10.0). The new scanning elevation angles capture better coverage and less noise at the images shown in Figure 12.

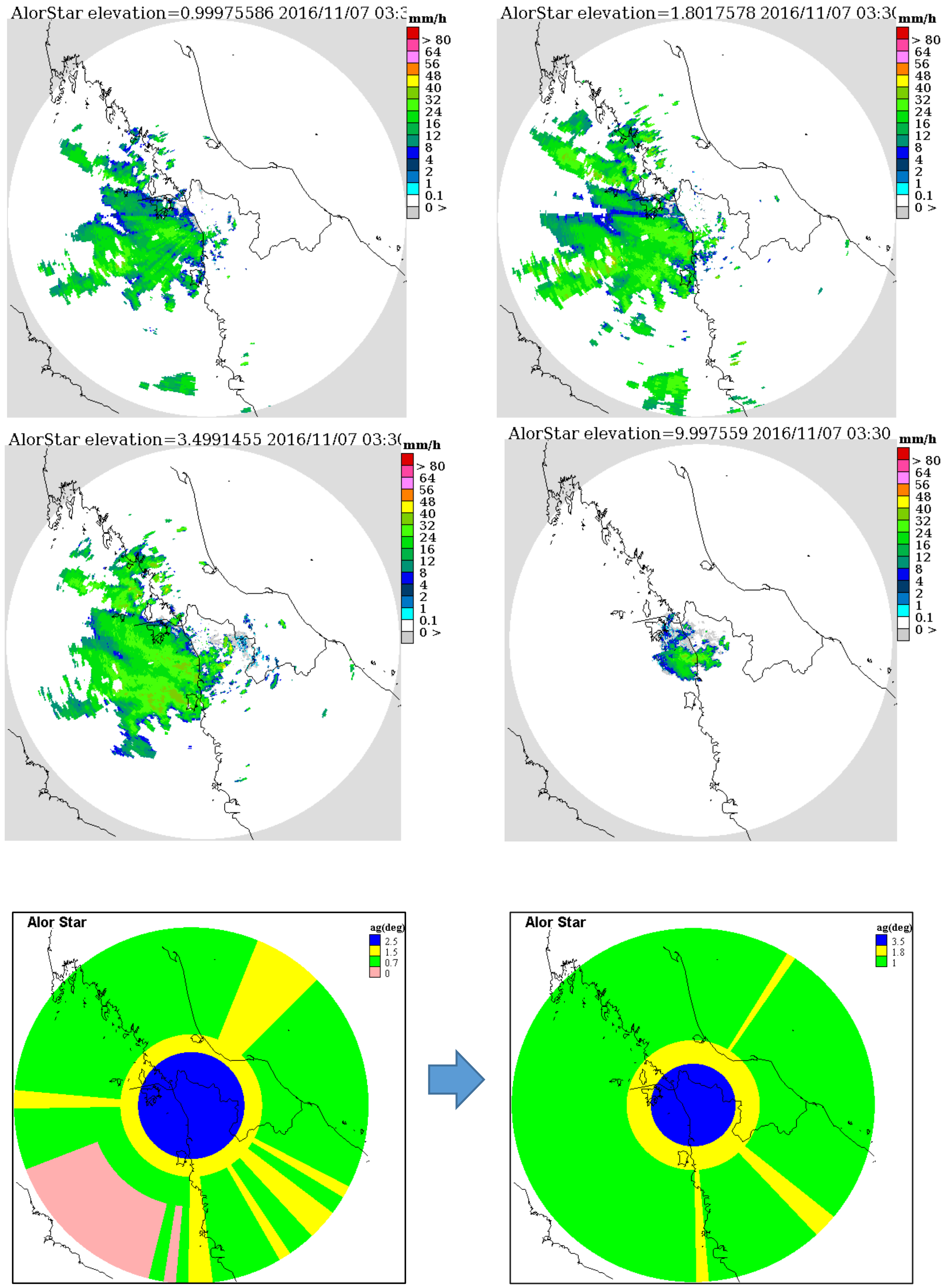


Figure 12: The performance of radar observation for each elevation angles and its improvement of new elevation angles

g) Kuching Radar Station (KC1)

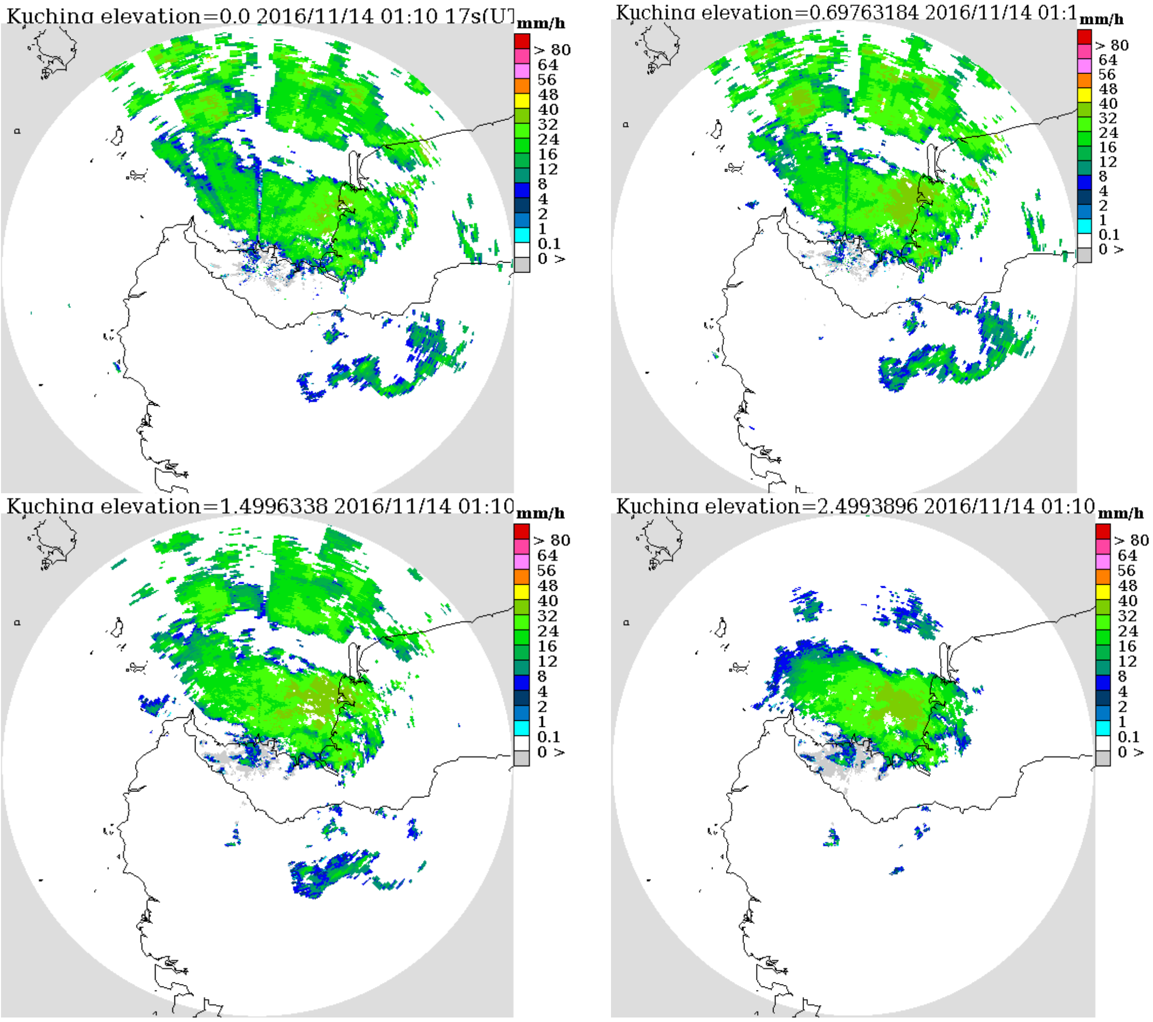


Figure 13: The performance of radar observation for each elevation angles

The performance of KC1 is better in term of coverage of intensity for every elevation angle as described in Figure 13. However, KC1 faces the blockage problem at the northern and southwestern of radar stations that can be captured until 2.5 degree as shown in Figure 14.

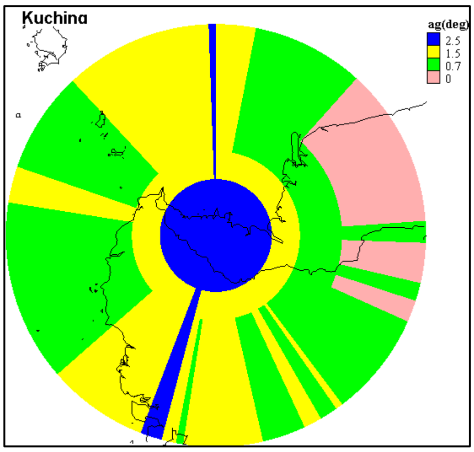


Figure 14: The blockage areas related to topography data at KC1 station

h) Bintulu Radar Stations (BN1)

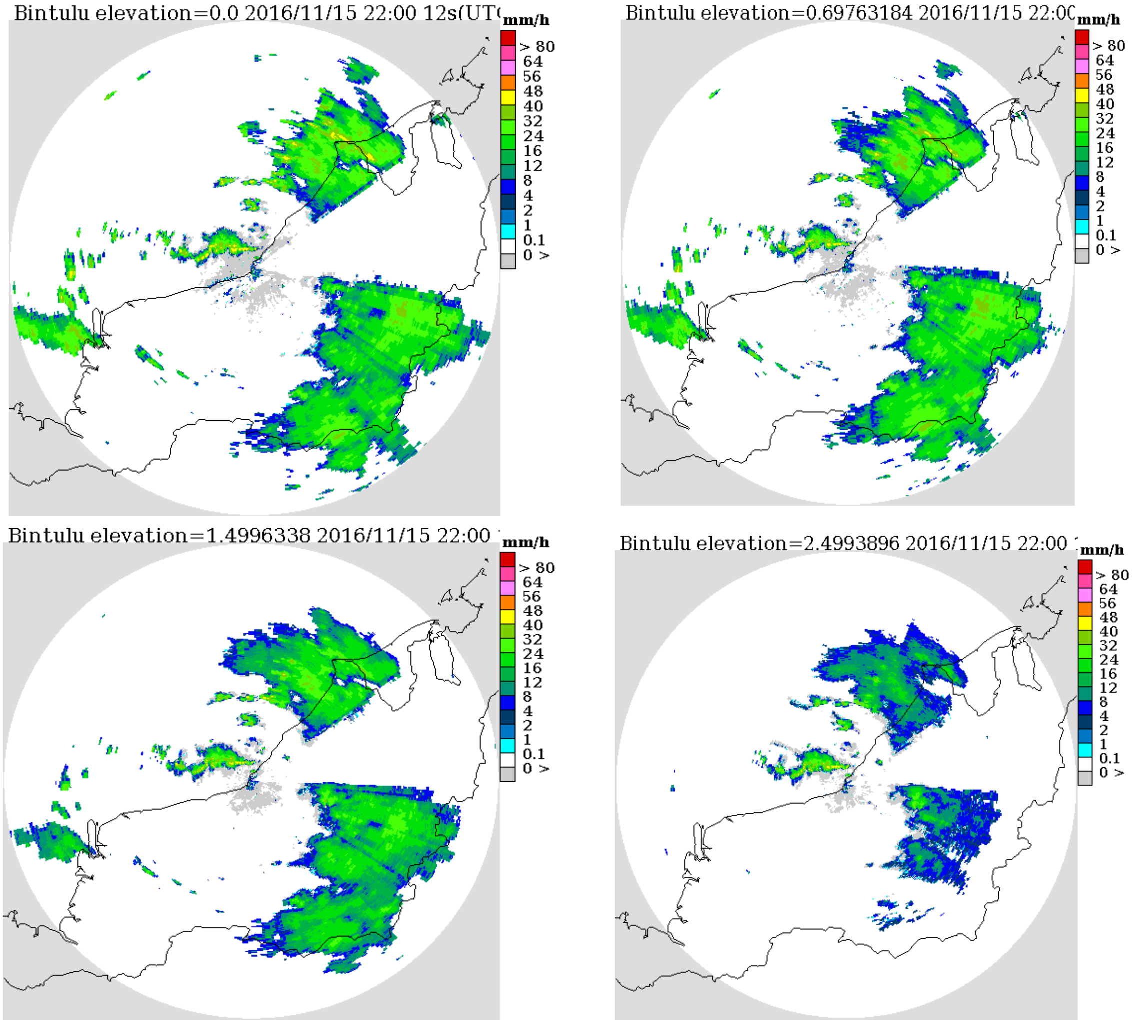


Figure 15: The performance of radar observation for each elevation angles

The performance of BN1 in Figure 15 is better in term of coverage of intensity for every elevation angle. However, BN1 faces the blockage problem at the east side of radar stations as shown in Figure 16.

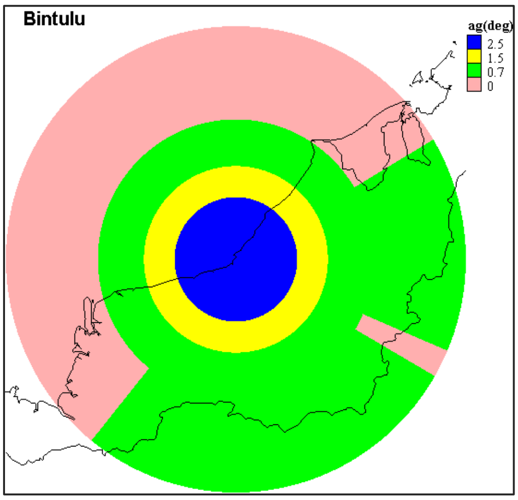


Figure 16: The blockage areas related to topography data at BN1 station

i) Miri Radar Station (MR1)

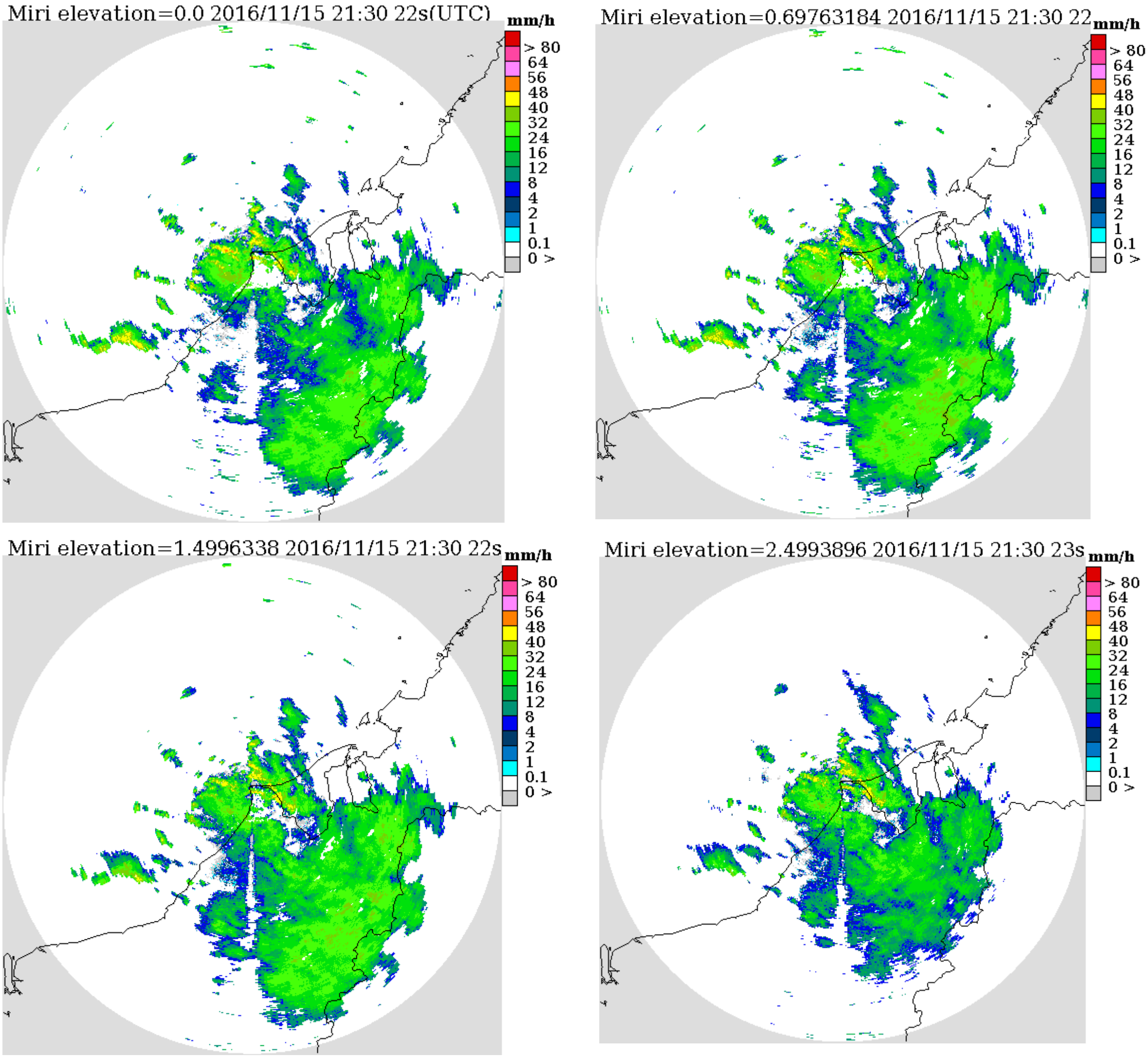


Figure 17: The performance of radar observation for each elevation angles

The performance of MR1 is better in term of coverage of intensity for every elevation angle.

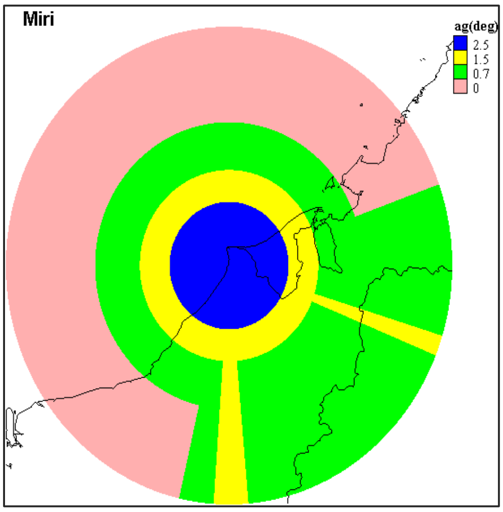


Figure 18: The blockage areas related to topography data at MR1 station

j) Kota Kinabalu Radar Station (KK1)

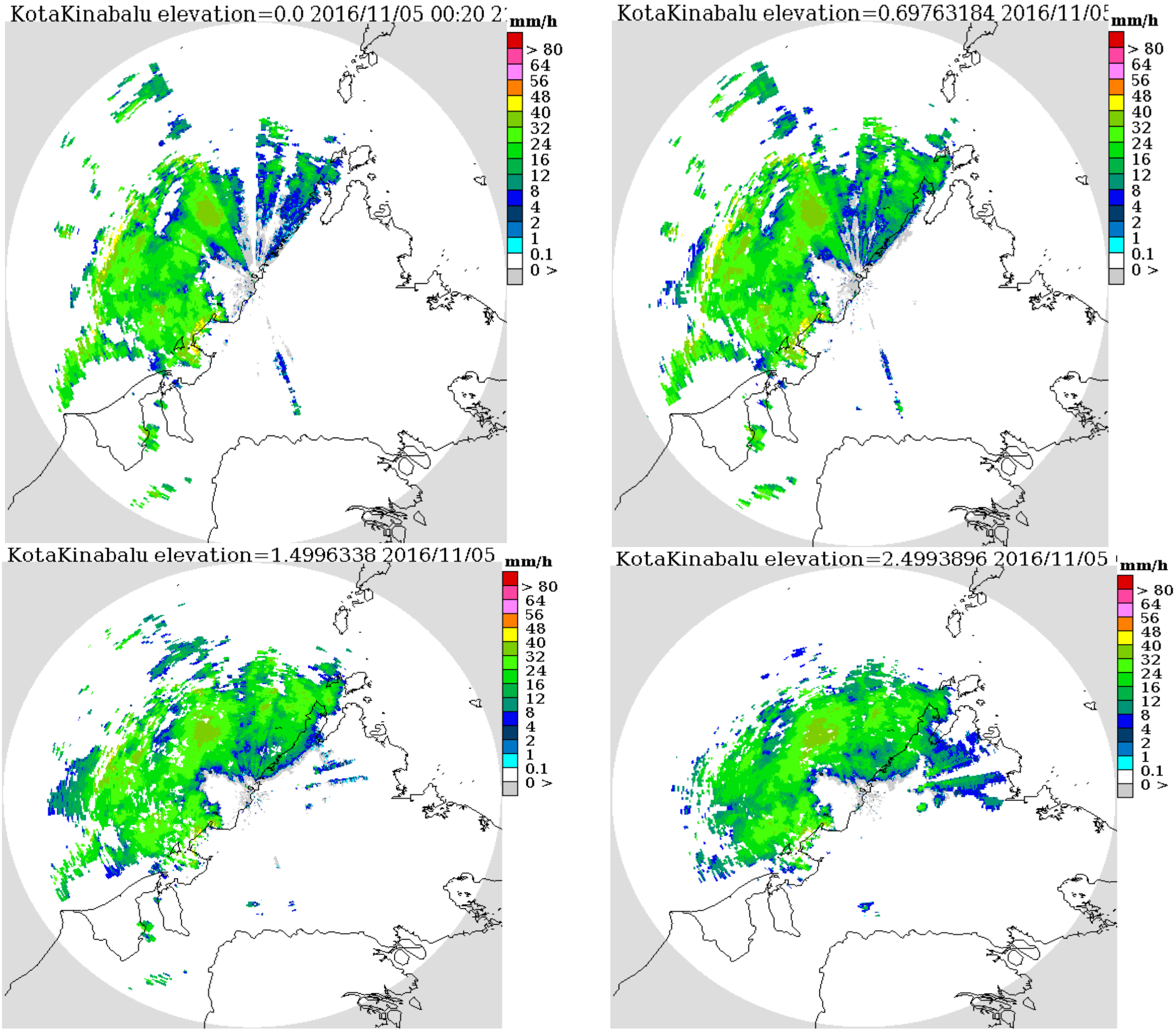


Figure 19: The performance of radar observation for each elevation angles

The performance of KK1 is better in term of coverage of intensity for every elevation angle as described in Figure 19. However, KK1 faces the blockage problem at the east side of radar stations as illustrated in Figure 20.

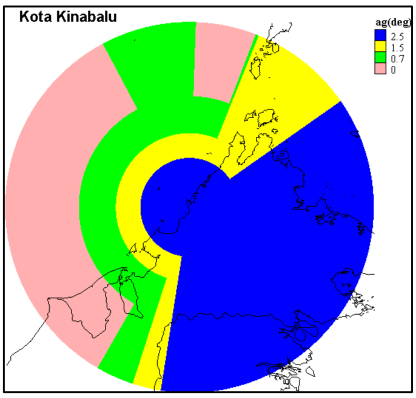


Figure 20: The blockage areas related to topography data at KK1 station

k) Sandakan Radar Station (SN1)

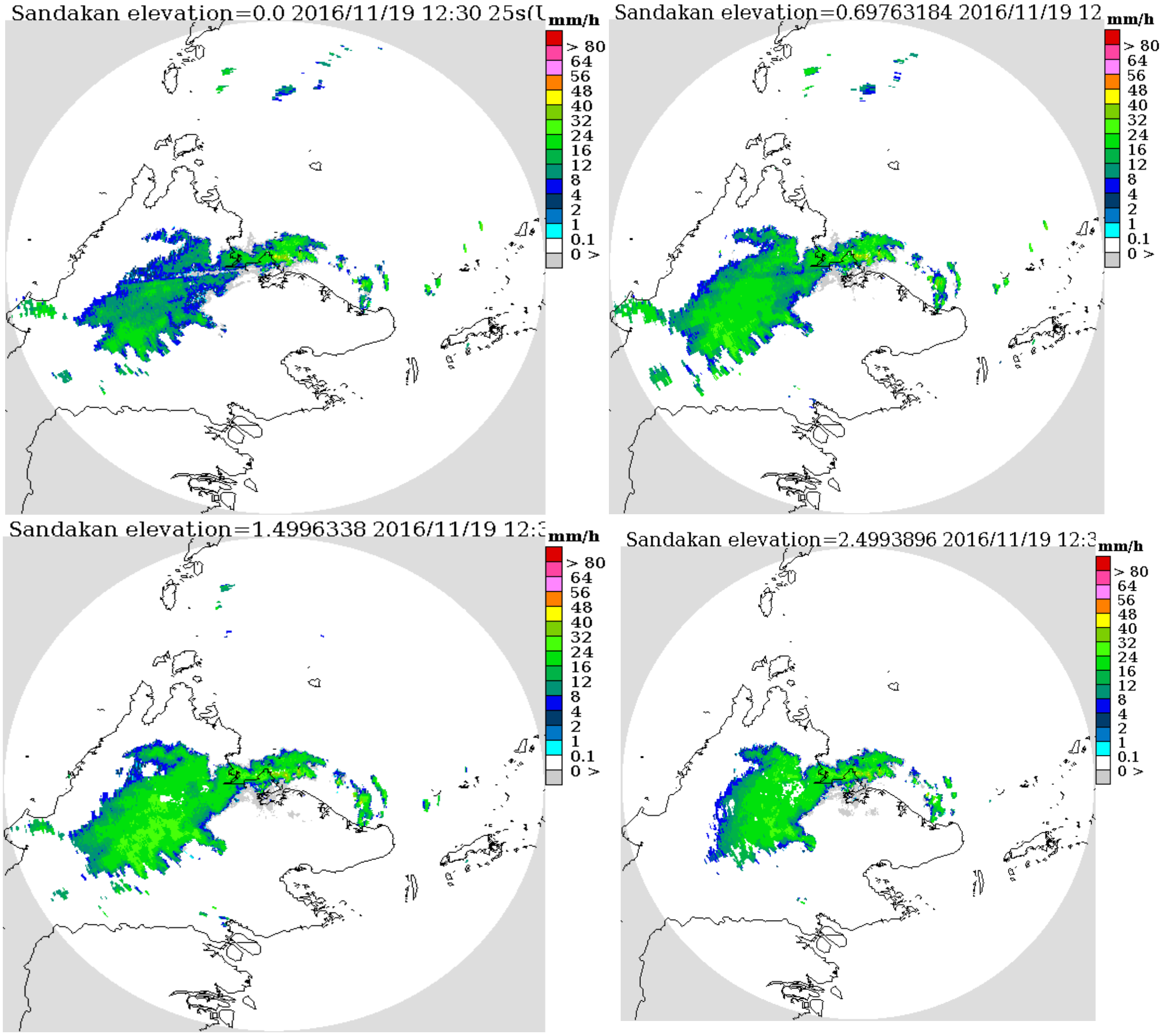


Figure 21: The performance of radar observation for each elevation angles

The performance of SN1 is better in term of coverage of intensity for every elevation angle in Figure 21.

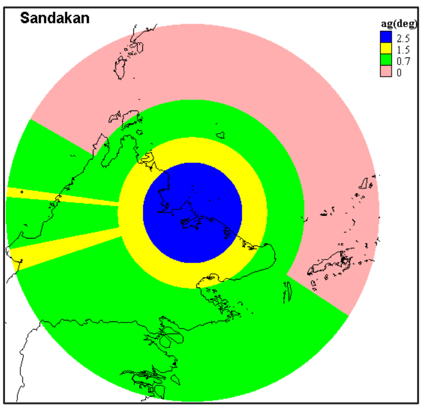
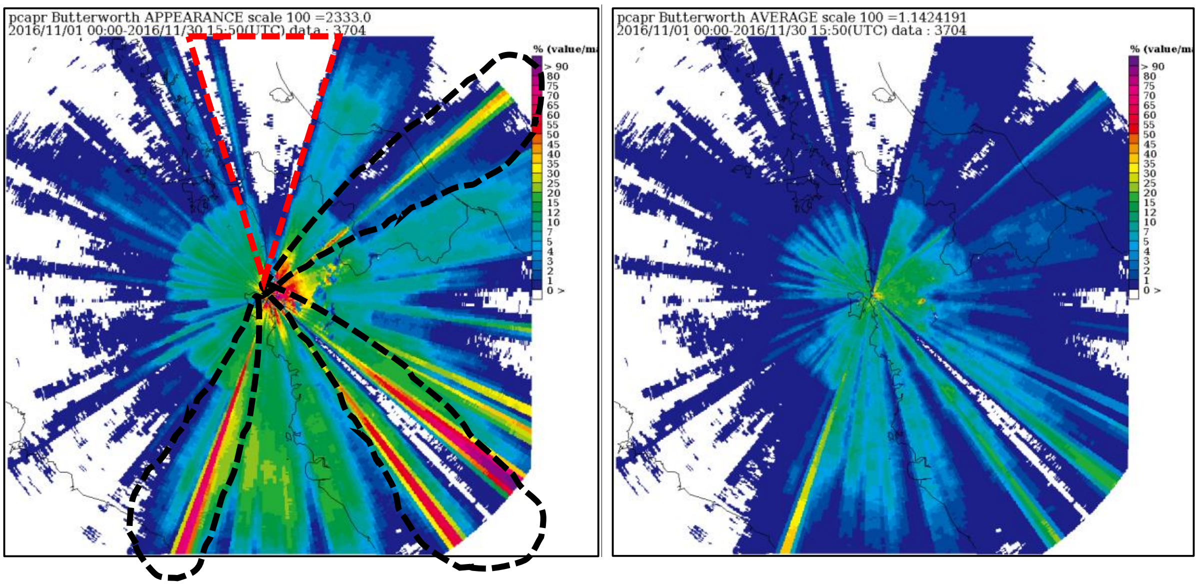


Figure 22: The blockage areas related to topography data at SN1 station

3.2 The techniques of radar data quality control

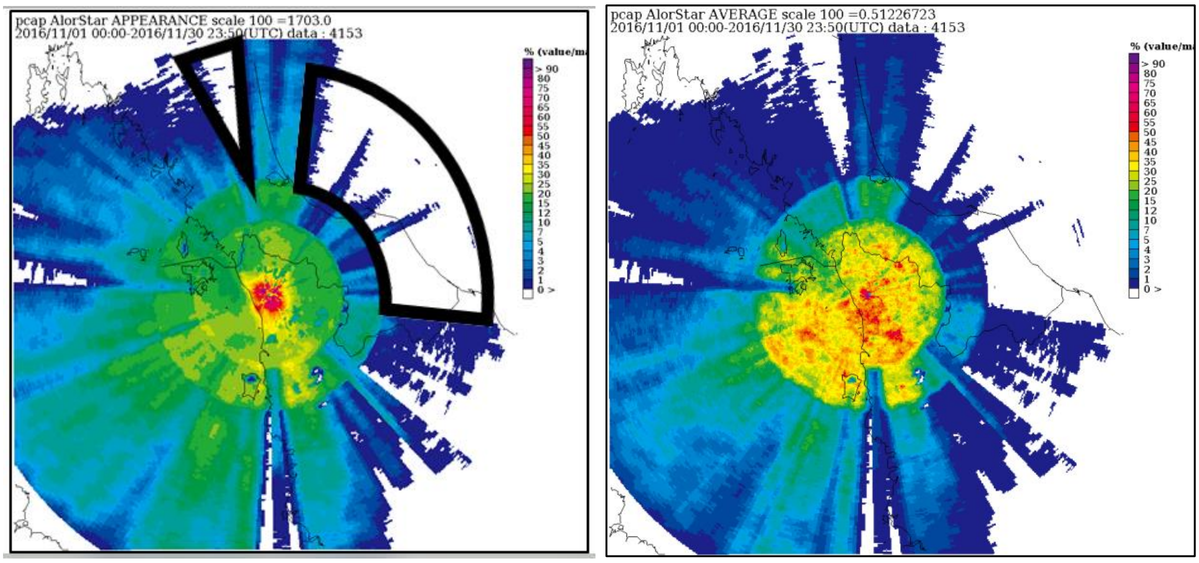
3.2.1 Statistical Approach

a) Butterworth



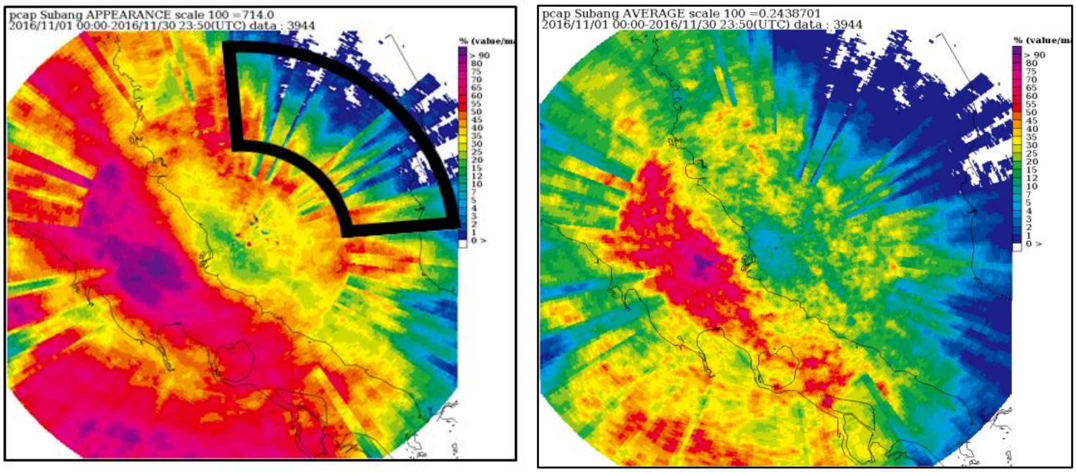
Refering to Table 1, the appearance data value is high meanwhile the average data showed lower value. This images indicate BW1 has suspicious data with clutter caught is weak but continuous indicator for interference problems (black dashed line). From these statistical images from 01 Nov-30 Nov 2016, described the blockage areas as shown in red color dashed line.

b) Alor Star



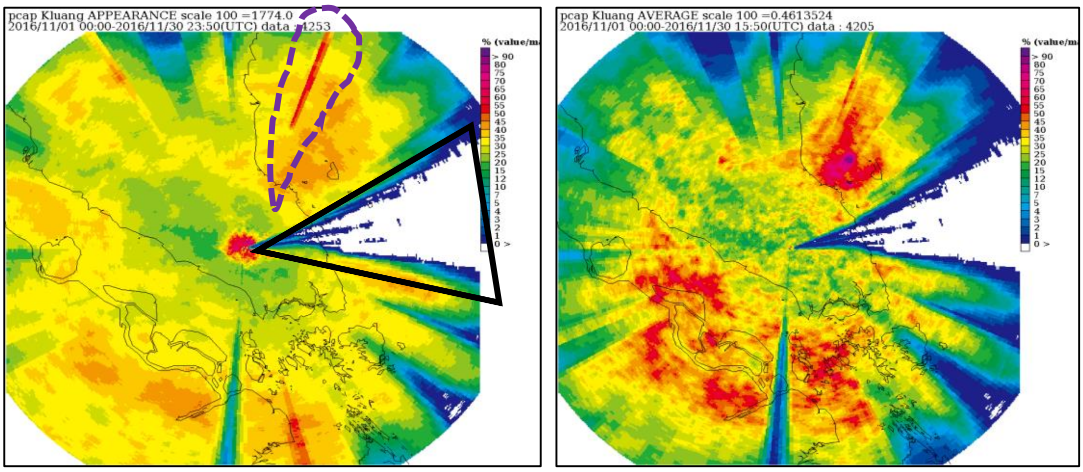
Refering to Table 1, the appearance data value is lower meanwhile the average data showed higher value. This images indicate AS1 has suspicious data with clutter caught merely but strong. From these statistical images revealed the blockage areas as shown in black color.

c) Subang



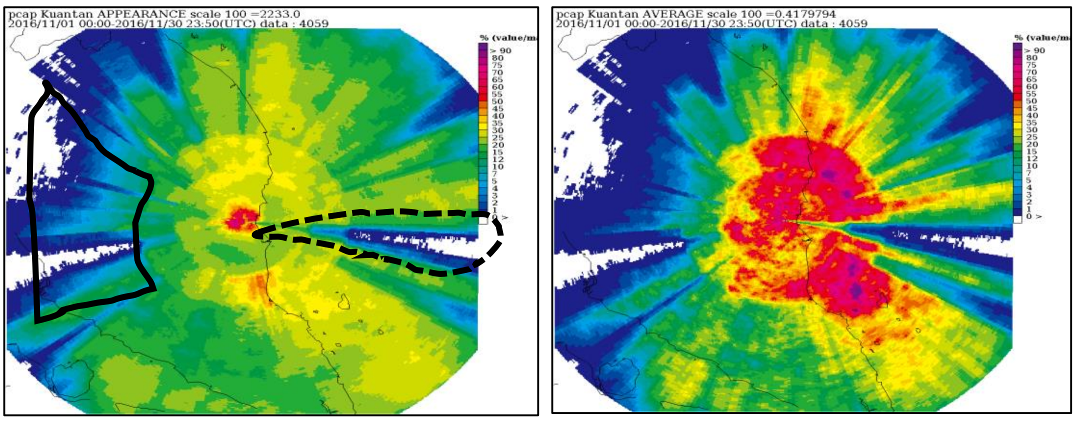
These images showed the shadowed areas at the east of radar site.

d) Kluang



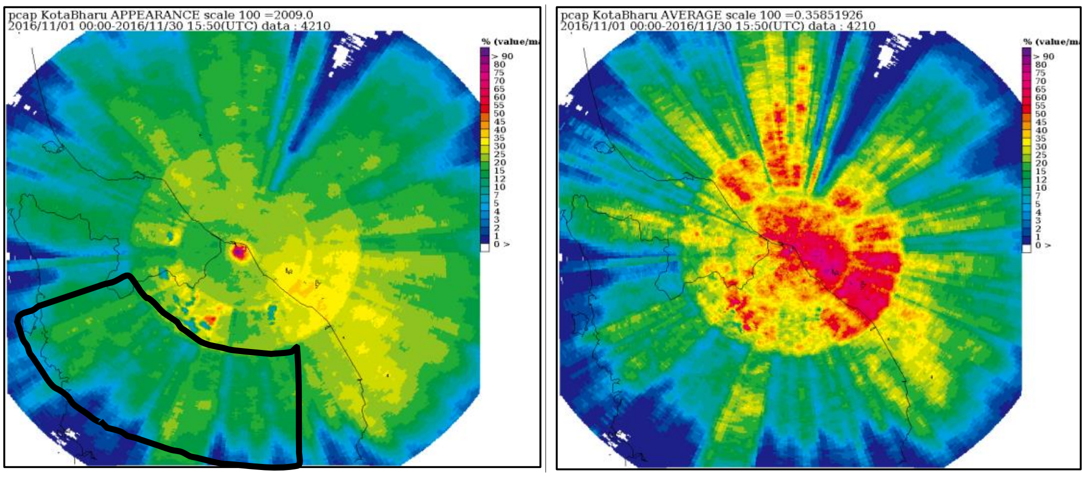
These images showed the shadowed areas at the east of radar site and interference occurred at stated in the purple colour.

e) Kuantan



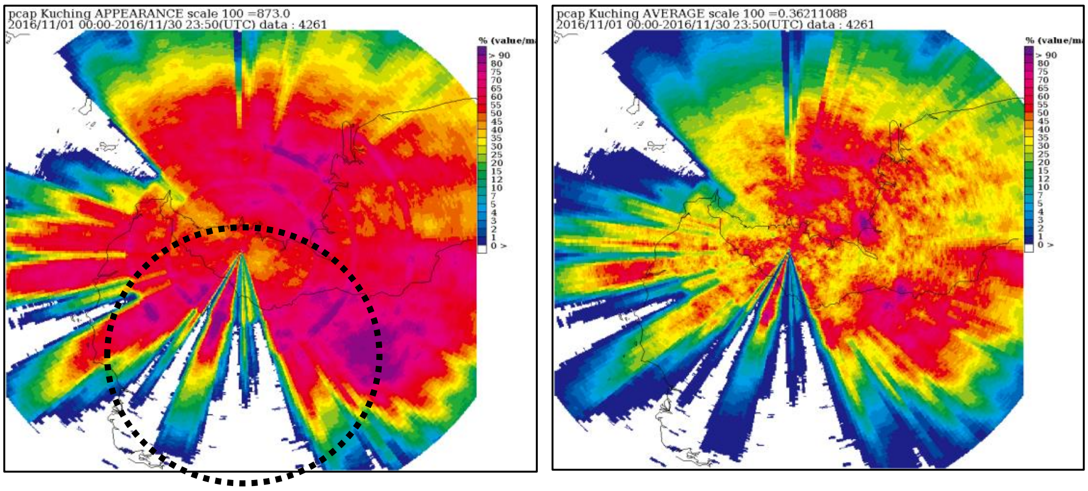
These images showed the blockage areas at the east and west of radar site.

f) Kota Bharu



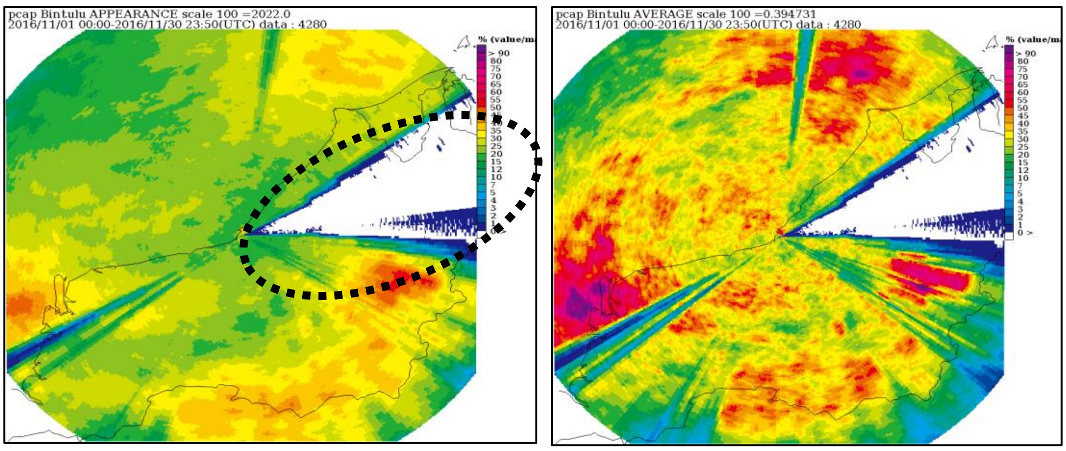
These images showed lower observation at the drawn areas.

g) Kuching



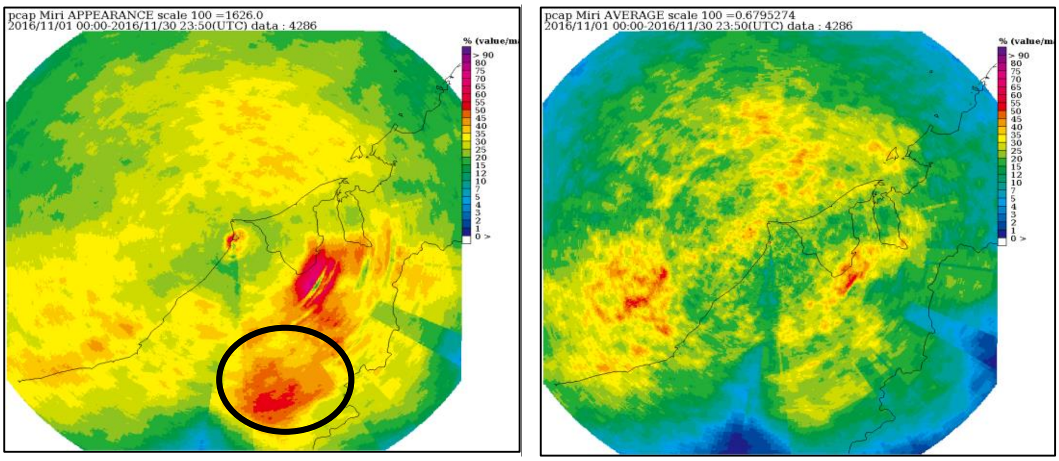
These images showed the blockage areas at the southern of radar site.

h) Bintulu



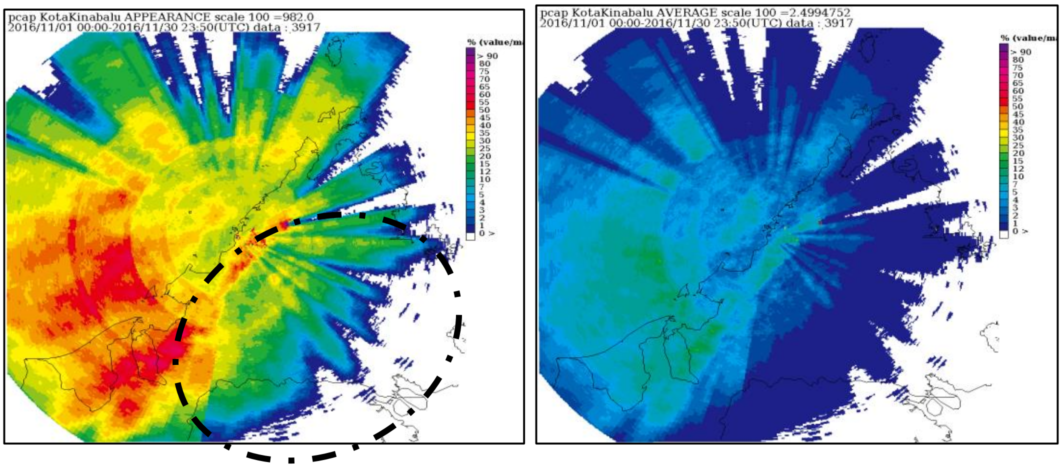
These images showed the blockage areas at the eastern of radar site.

i) Miri



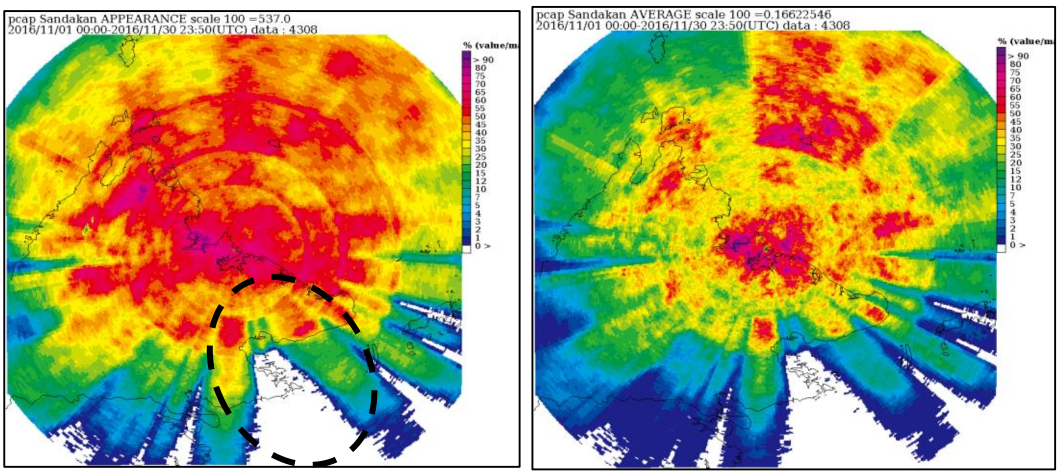
Refering to Table 1, the appearance data value is higher meanwhile the average data showed lower value. This images indicate MR1 has suspicious data with clutter caught merely but strong.

j) Kota Kinabalu



These images showed lower observation at the circle areas due to the topography.

k) Sandakan



These images showed the blockage areas at the southern of radar site.

3.2.2 Removing interference

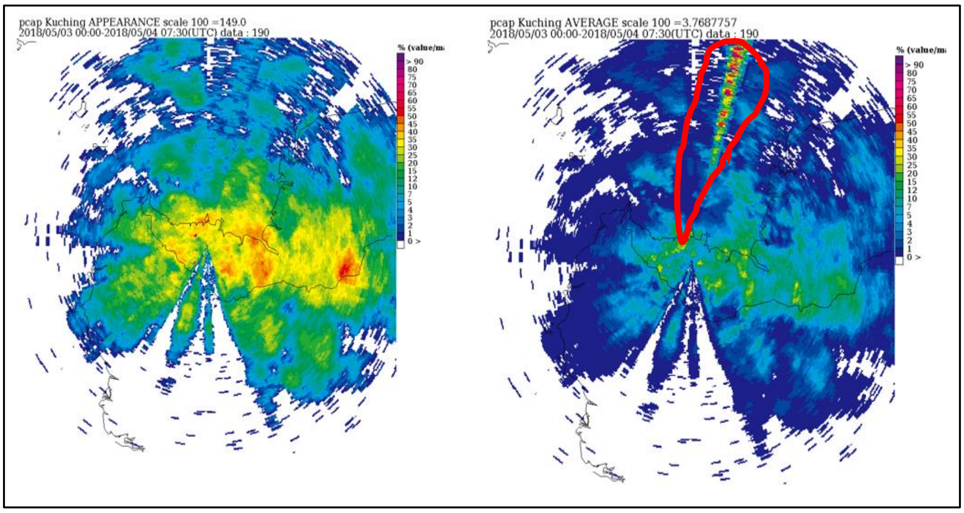
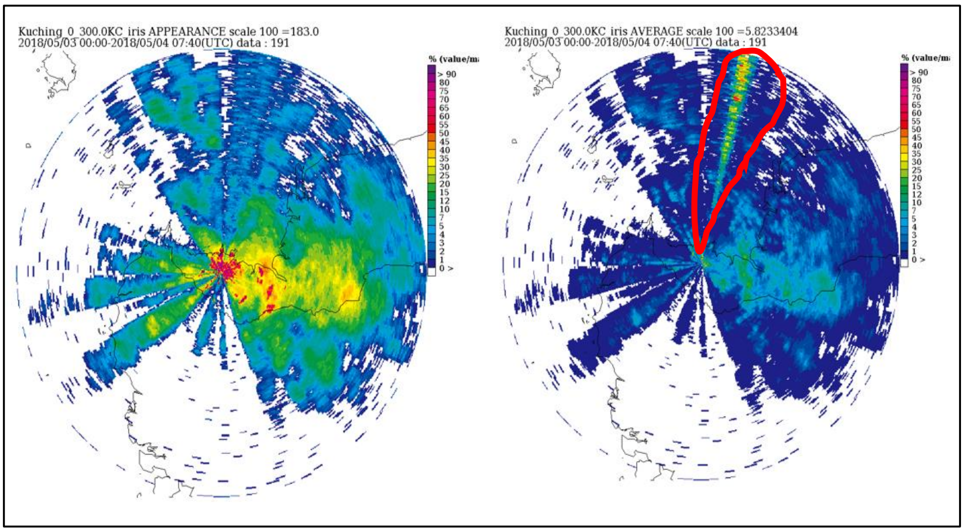
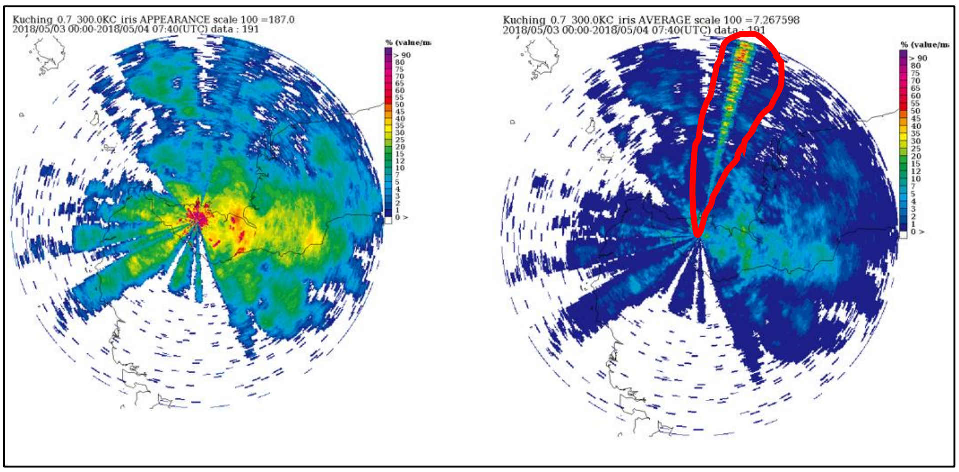


Figure 23: PCAPPI statistical data to show the interference signal

KC1 radar of PCAPPI data showed the interference images from 3rd-4th May 2018 as described in Figure 23 when comparing with the appearance and average data, which can concluded that the clutter caught is very strong. Hence, we should check each elevation angles to modify the EIL table for removing the interference signal.





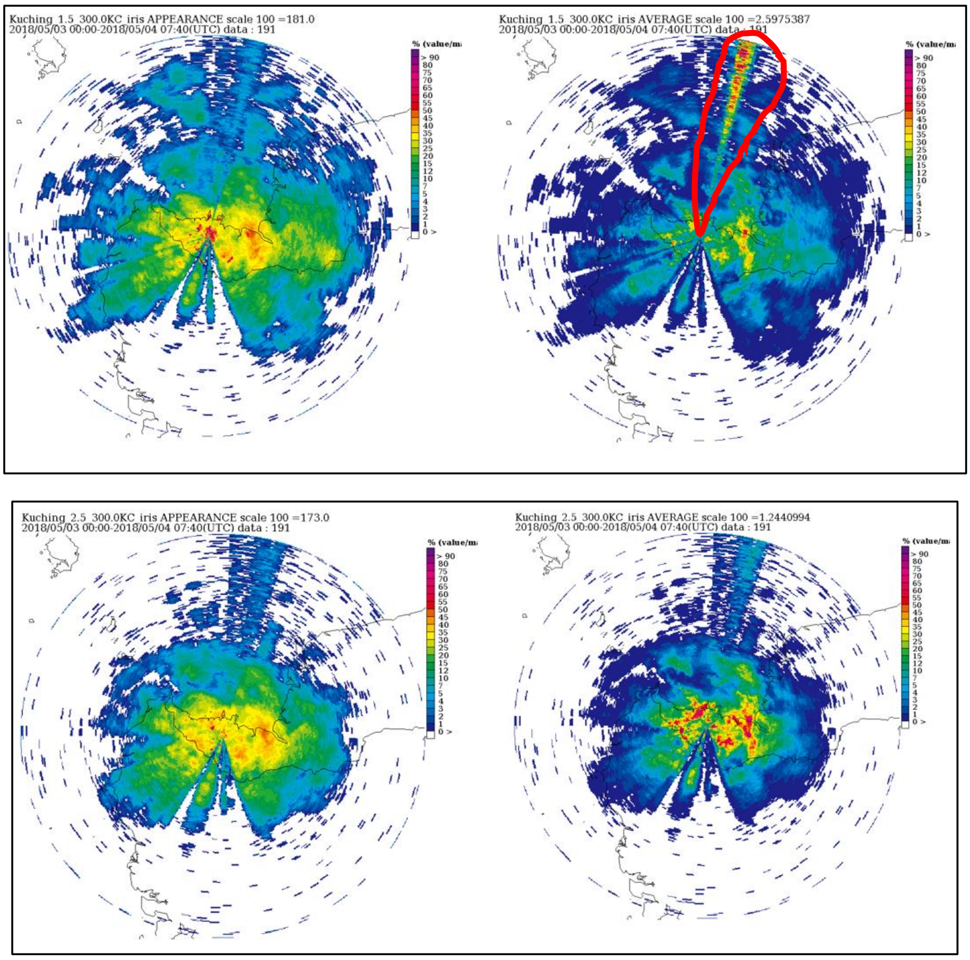


Figure 24: Statistical data for each elevation angles to analyse the effected angles.

By analysing the images in Figure 24, we can see that elevation angles 0.0, 0.7 and 1.5 degrees are contaminated with the interference meanwhile 2.5 degree is not exposed with the interference signal. Therefore, the EIL Table as shown in Figure 25 has to modify by removing lowest angle and concentrate on 2.5 degree only at the specific azimuth.

```
11,0,2.5,80,1.5,300,,,,
42,0,2.5,80,1.5,120,0.7,300,,
86,0,2.5,80,1.5,120,0.7,180,0,300
92,0,2.5,80,1.5,120,0.7,300,,
103,0,2.5,80,1.5,120,0.7,180,0,300
108,0,2.5,80,1.5,120,0.7,300,,
114,0,2.5,80,1.5,120,0.7,180,0,300
143,0,2.5,80,1.5,120,0.7,300,,
145,0,2.5,80,1.5,300,,,,
150,0,2.5,80,1.5,120,0.7,300,,
155,0,2.5,80,1.5,300,,,,
167,0,2.5,80,1.5,120,0.7,300,,
189,0,2.5,80,1.5,300,,,,
191,0,2.5,80,1.5,120,0.7,300,,
195,0,2.5,80,1.5,300,,,,
201,0,2.5,300,,,,,,
229,0,2.5,80,1.5,300,,,,
317,0,2.5,300,,,,,,
358,0,2.5,80,1.5,300,,,,
360,0,2.5,300,,,,,,
```

```
11,0,2.5,80,1.5,300,,,,
50,0,2.5,300,,,,
86,0,2.5,80,1.5,120,0.7,180,0,300
92,0,2.5,80,1.5,120,0.7,300,,
103,0,2.5,80,1.5,120,0.7,180,0,300
108,0,2.5,80,1.5,120,0.7,300,,
114,0,2.5,80,1.5,120,0.7,180,0,300
143,0,2.5,80,1.5,120,0.7,300,,
145,0,2.5,80,1.5,300,,,,
150,0,2.5,80,1.5,120,0.7,300,,
155,0,2.5,80,1.5,300,,,,
167,0,2.5,80,1.5,120,0.7,300,,
189,0,2.5,80,1.5,300,,,,
191,0,2.5,80,1.5,120,0.7,300,,
195,0,2.5,80,1.5,300,,,,
201,0,2.5,300,,,,,,
229,0,2.5,80,1.5,300,,,,
317,0,2.5,300,,,,,,
358,0,2.5,80,1.5,300,,,,
360,0,2.5,300,,,,,,
```

Figure 25: The modification of EIL Table to remove the interference error on the image

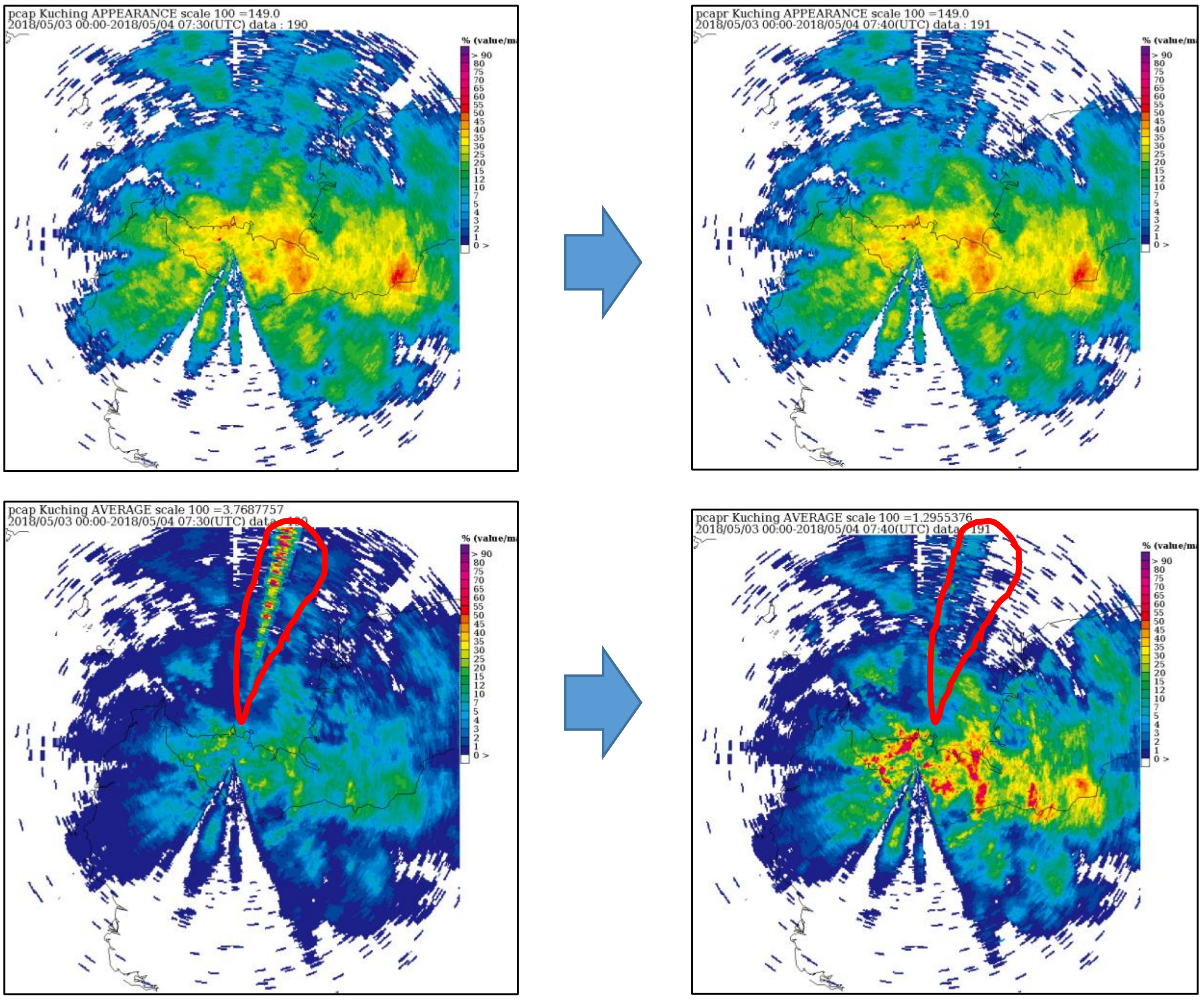


Figure 26: The comparison before and after the EIL modification resulting in the elimination of interference on the radar images

In line with the adjustment of EIL table, the interference can be removed from the image of PCAPPI data as illustrated in Figure 26. This technique is better to eliminate noise and interference from unknown sources.

3.2.3 Removing clutter using clutter map

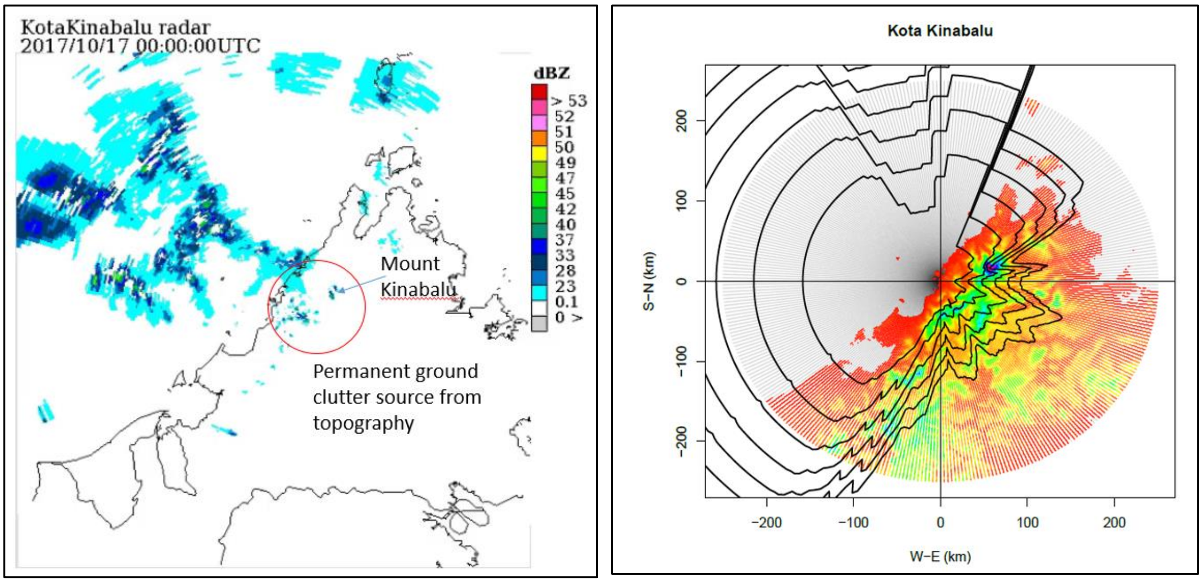


Figure 27: The ground clutter source from Mount Kinabalu data existed on the KK1 radar image

KK1 radar image was contaminated with the ground clutter mainly source from Mount Kinabalu topography from 21st August 2017 as presented in Figure 27. This permanent clutter remained about few days that confusing the forecasters between rain echoes or not. Thus, the clutter map is applied at KK1 radar stations to remove the permanent clutter as Figure 28.

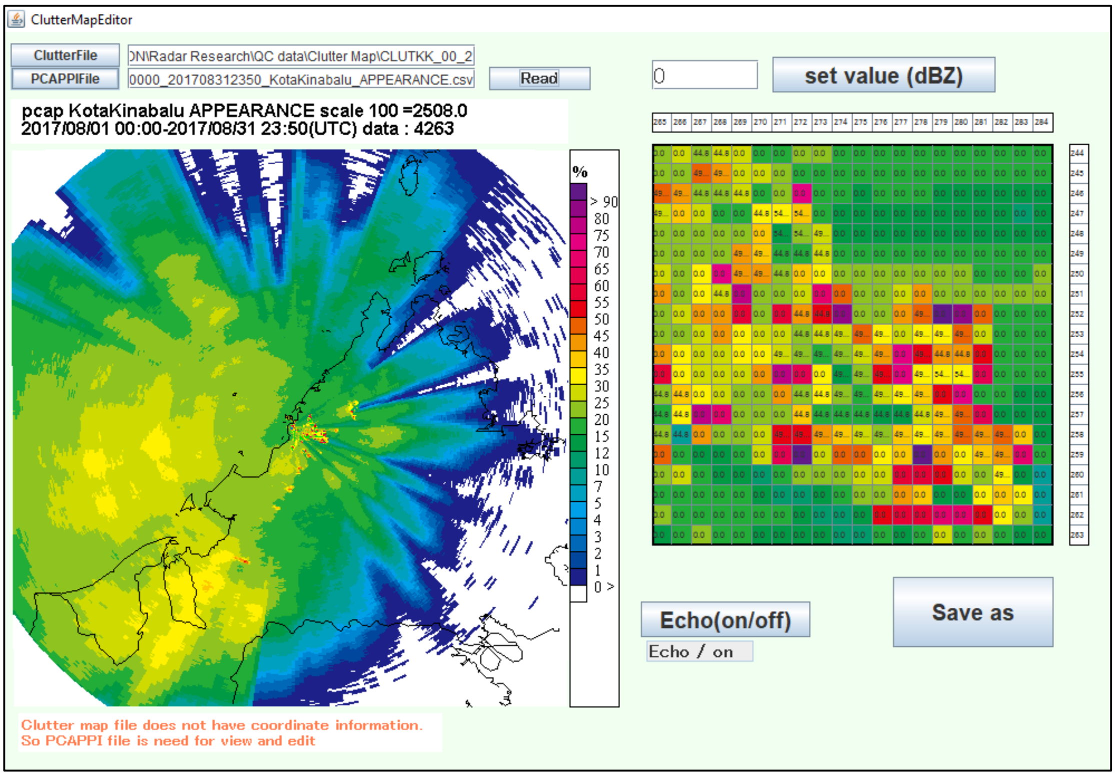


Figure 28: Clutter map software to remove the clutter for KK1 radar station

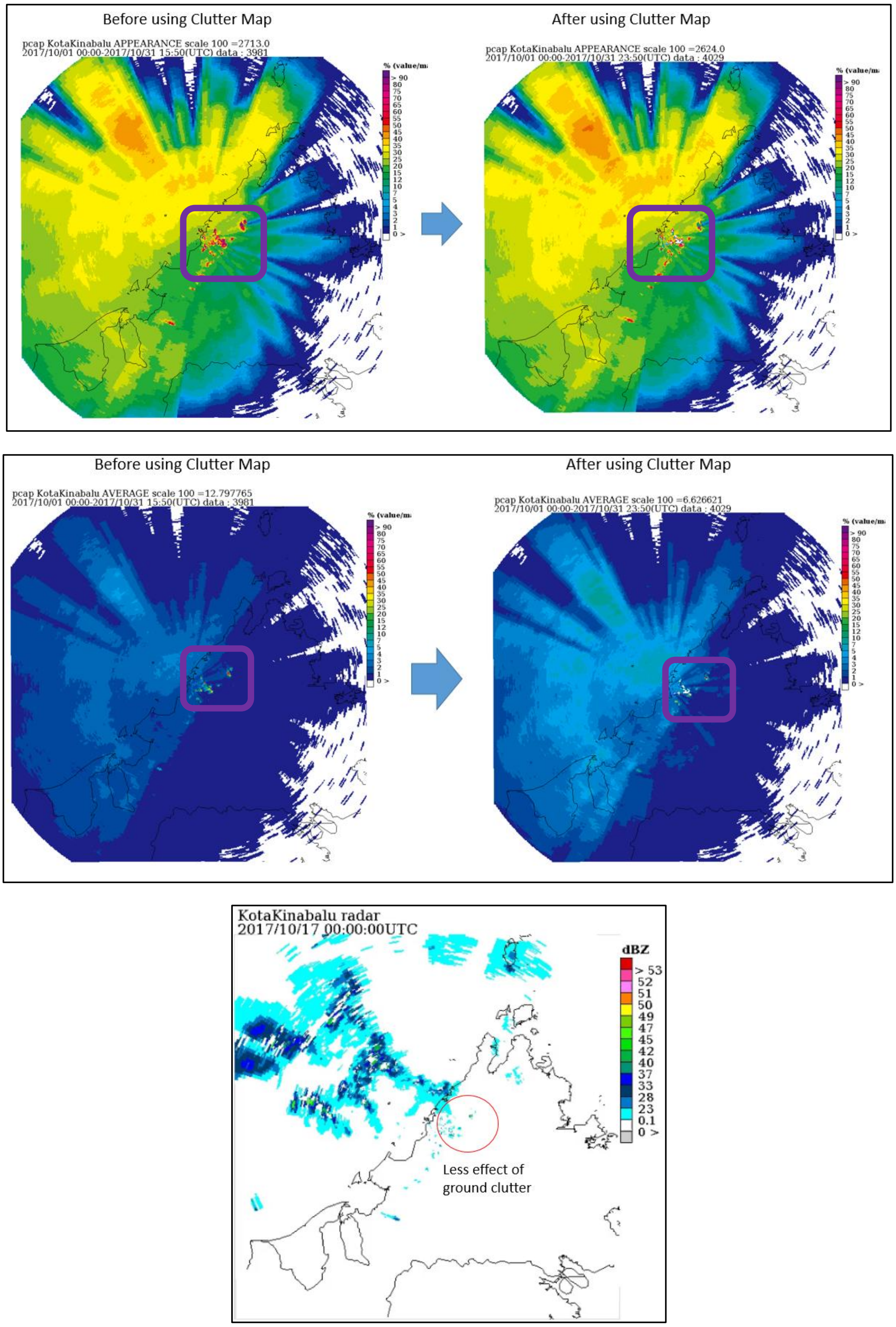
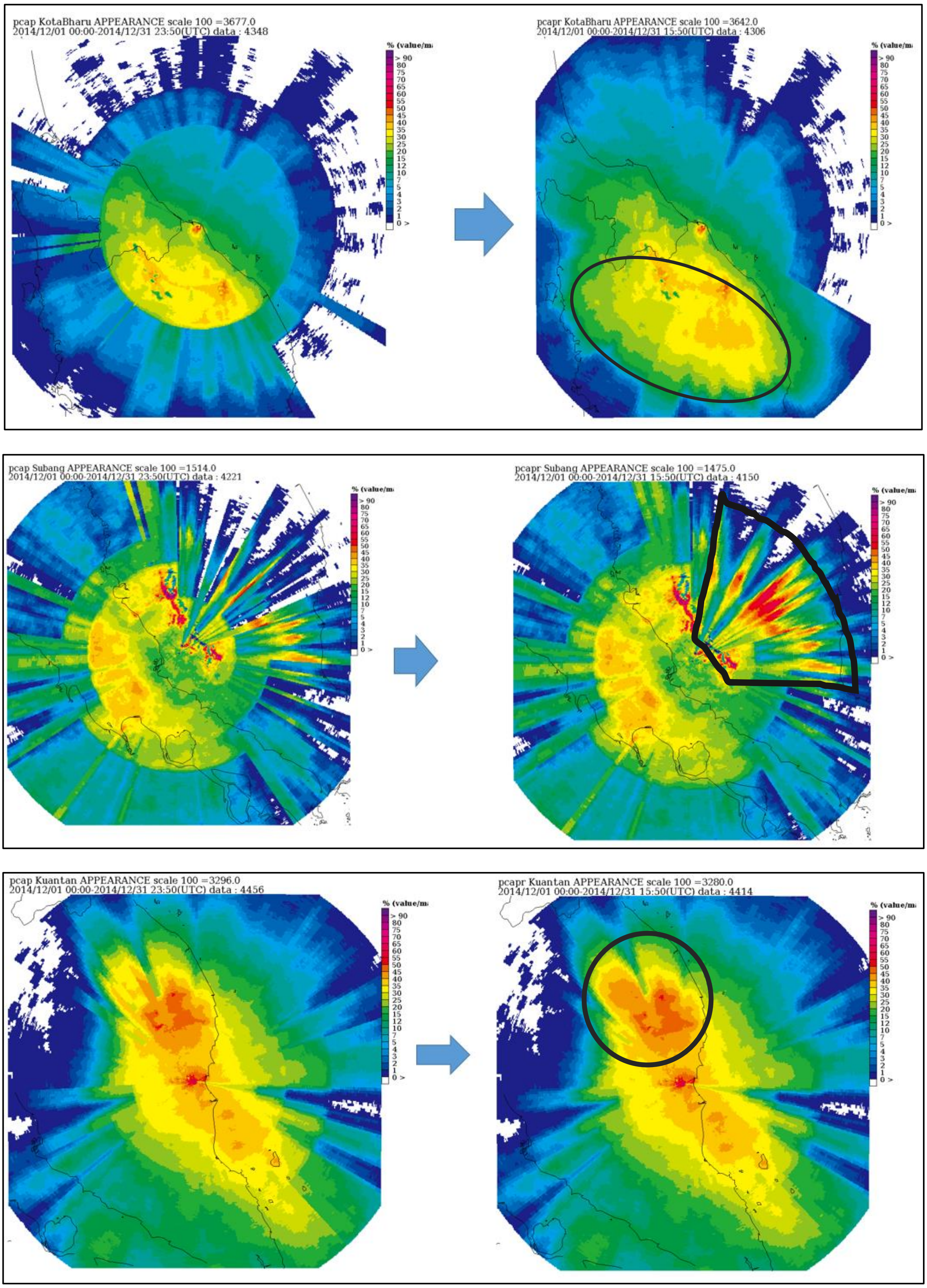


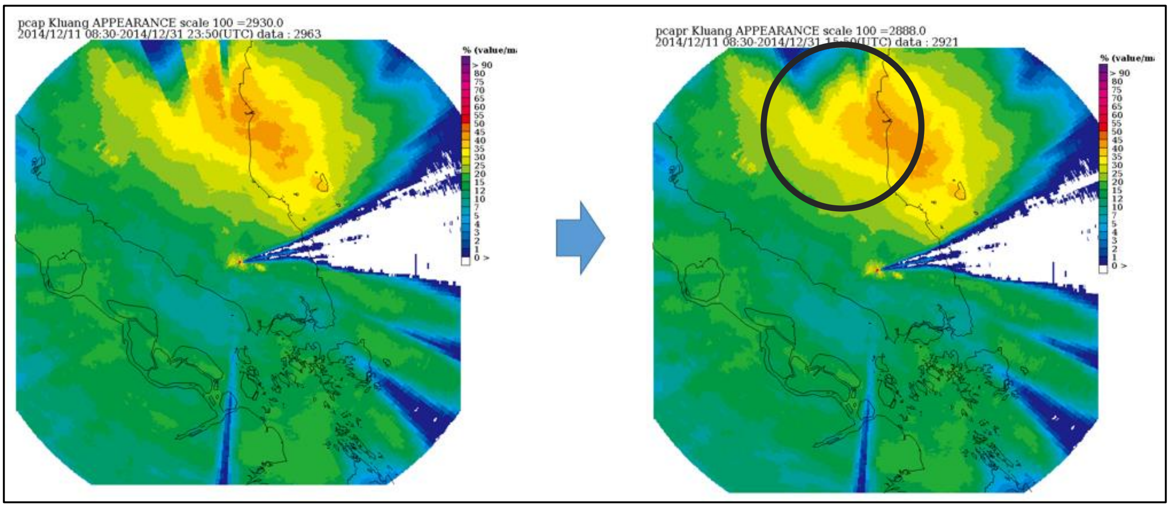
Figure 29: The comparison before and after using clutter map

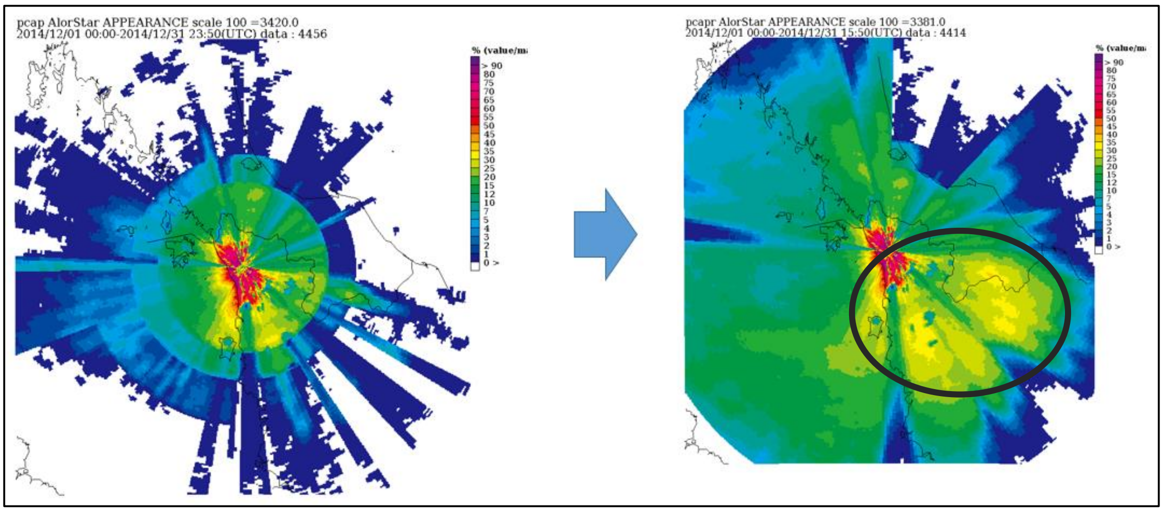
Clutter map is well-functioned for removing the effect of clutters source from topography or ground clutter or permanent echoes as shown in Figure 29. The statistical monthly data is essential to examine the existence of clutter or suspicious data.

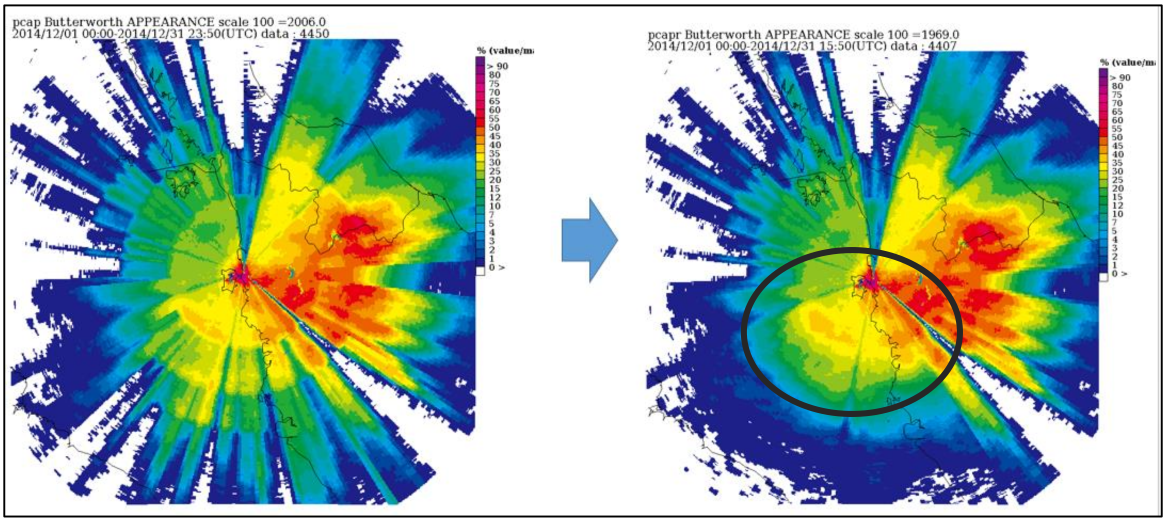
3.2.4 Modification/Adjustment of EIL Table for better intensity

Modification of EIL table is needed to obtain better intensity and coverage at certain radar surroundings as presented in Figure 30. This technique can assist to reduce the blockage areas and obtain better intensity at shadowed areas. The performance of December 2014 show better intensity and coverage after applying modification of EIL table as described in Figure 31.




pcap Kluang APPEARANCE scale 100 =2930.0
2014/12/11 08:30-2014/12/31 23:50(UTC) data : 2963
pcapr Kluang APPEARANCE scale 100 =2888.0
2014/12/11 08:30-2014/12/31 15:50(UTC) data : 2921


pcap AlorStar APPEARANCE scale 100 =3420.0
2014/12/01 00:00-2014/12/31 23:50(UTC) data : 4456
pcapr AlorStar APPEARANCE scale 100 =3381.0
2014/12/01 00:00-2014/12/31 15:50(UTC) data : 4414


pcap Butterworth APPEARANCE scale 100 =2006.0
2014/12/01 00:00-2014/12/31 23:50(UTC) data : 4450
pcapr Butterworth APPEARANCE scale 100 =1969.0
2014/12/01 00:00-2014/12/31 15:50(UTC) data : 4407

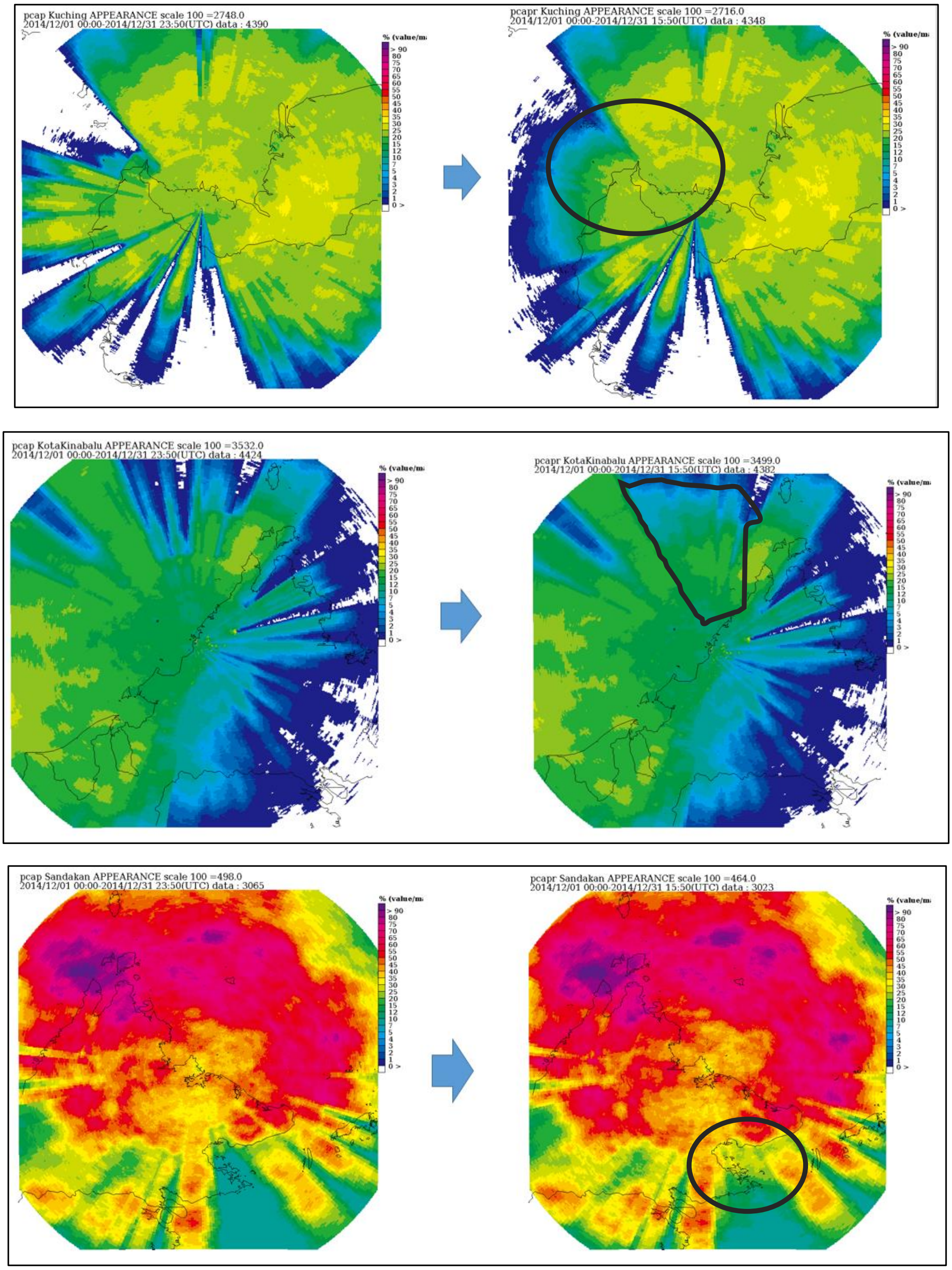


Figure 30: The modification and adjustment of EIL table for each radar stations are performed to gain better coverage and intensity

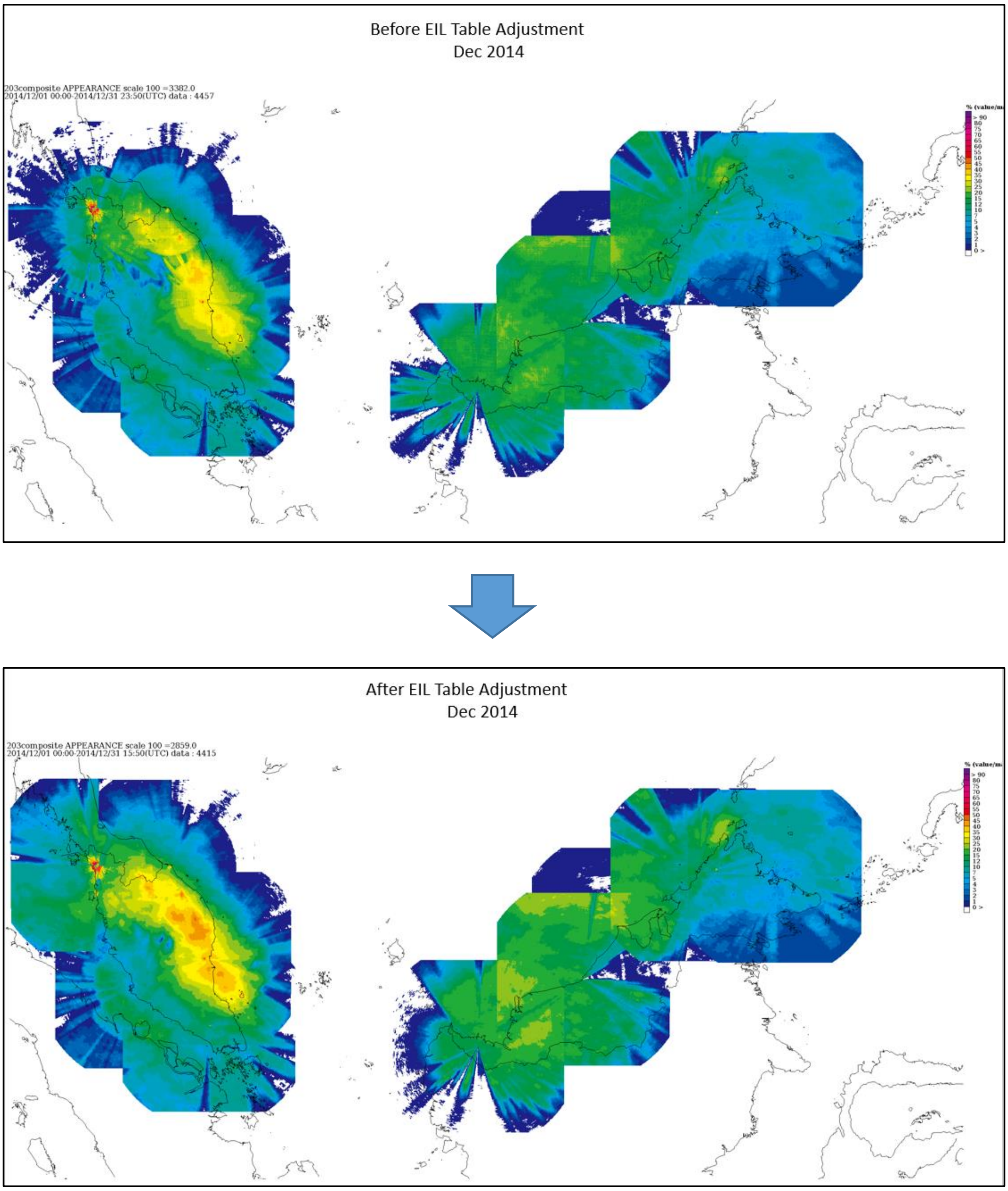


Figure 31: The statistical performance data in December 2014 after applying the technique of EIL Table adjustment

3.3 QPE Calibration with the raingauge data

As mentioned in Section 3.2, the radar quality control should be emphasized to reduce the radar errors such as blockage areas, ground or permanent clutter, interference and so on. Thereafter, the radar may provide the underestimate rainfall estimation due to the error such as conversion of radar reflectivity to rainrate using Z-R relationship, the difference in characteristics of each radar and the attenuation of transmitting wave through the wet radome. In addition, the difference in the distribution of precipitation observed between grounds and aloft. Although radar can observe larger areas with high spatial resolution, it may produce different reading as it measures the amount of rain overhead. Raingauges data can measure the accurate total amount of rainfall at the certain location will reduce the underestimation of radar rainfall. Hence, first calibration of radar precipitation will be implemented for all the radar observational range to correct the radar precipitation.

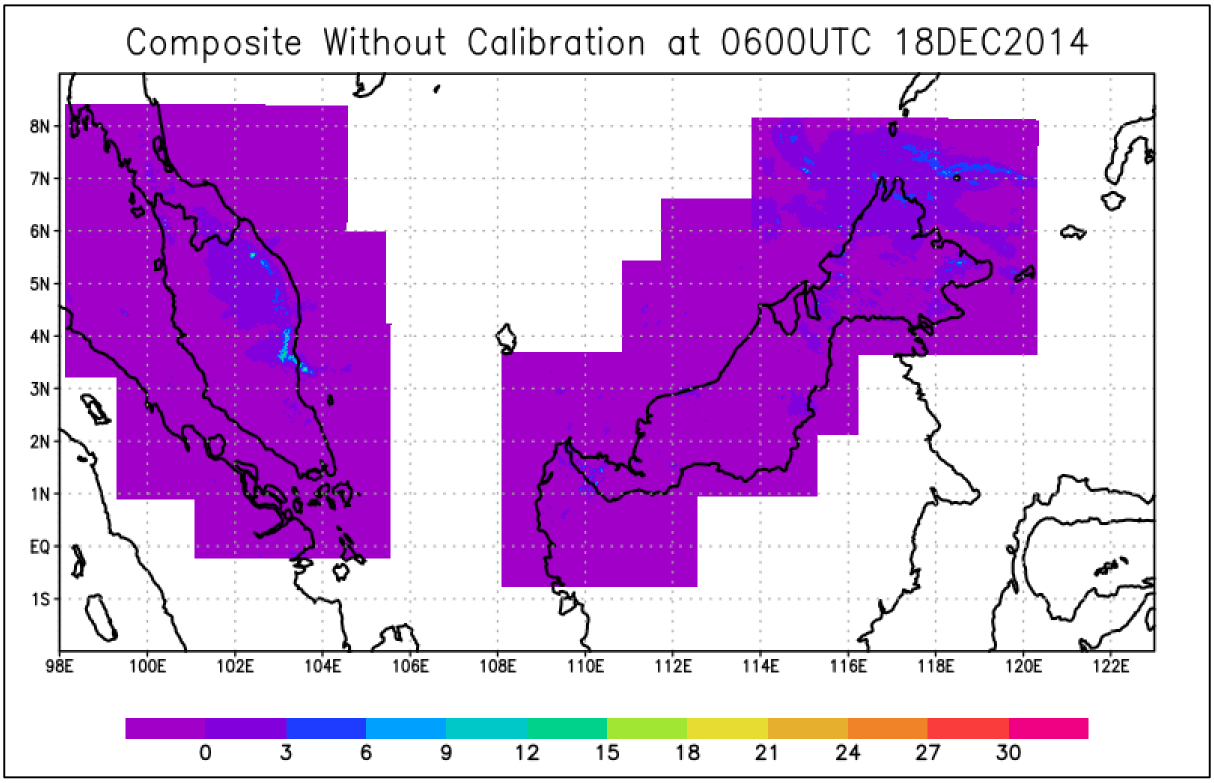
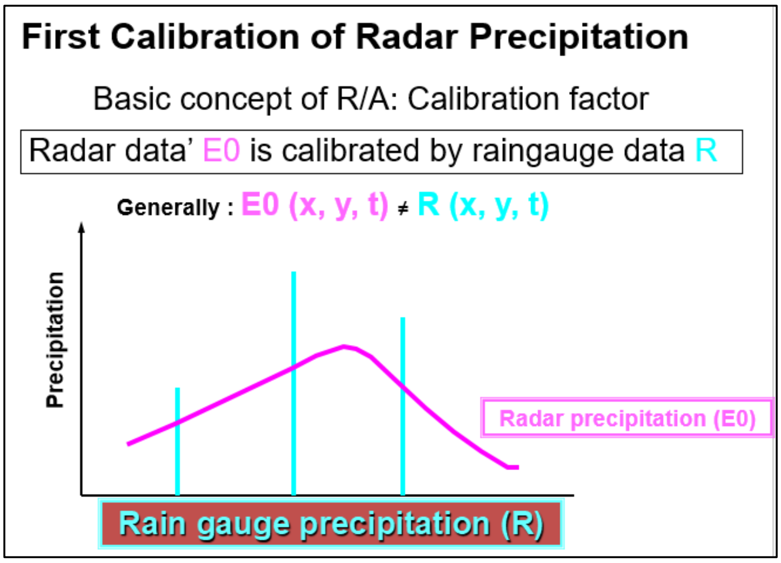
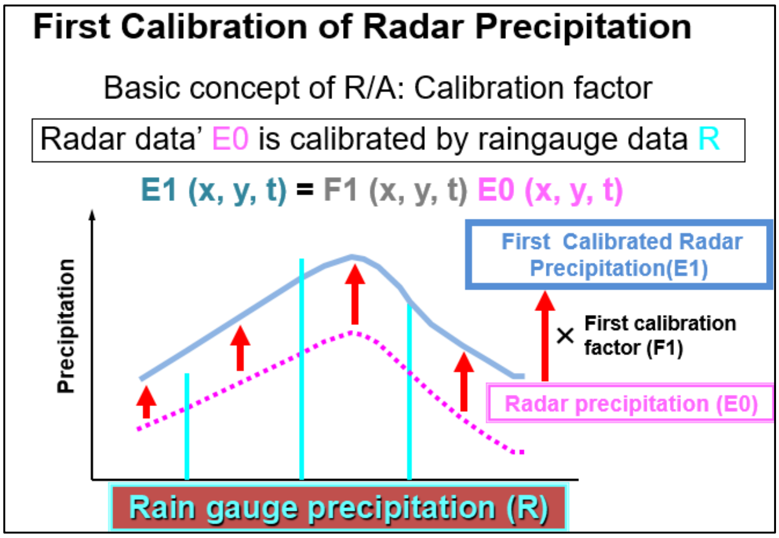


Figure 32: The non-calibration QPE composite radar indicated the underestimation of radar rainfall

Figure 32 showed that the composite radar image without calibration with the raingauges. The underestimation of radar rainfall can be identified when comparing with the raingauge data. The techniques that implemented by JMA are consisted of First and Second Calibration to obtain the accurate radar rainfall. The First Calibration are illustrated as Figure 33. Meanwhile, Second Calibration is considering first calibration estimation with the raingauges data for each grids by using weighing factors as shown in the Figure 34. The composite with second calibration is illustrated as Figure 35 that yield the overestimation of radar rainfall estimation. This problem existed probably because of the lack of raingauge data consuming in this analysis.





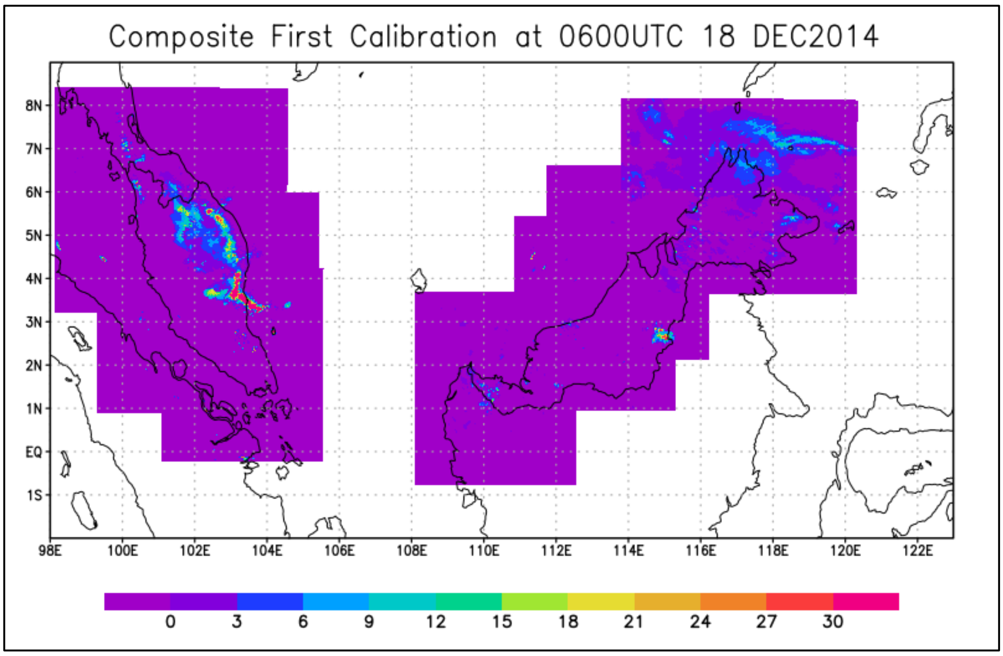
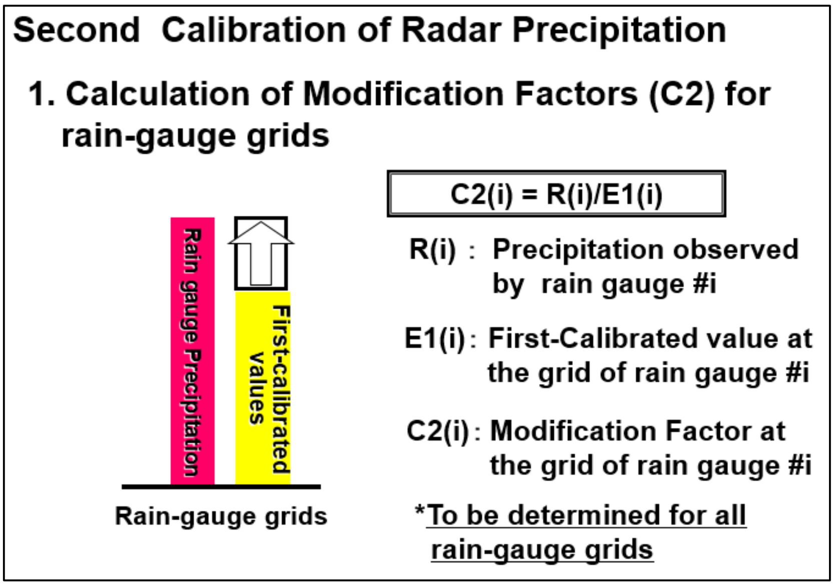
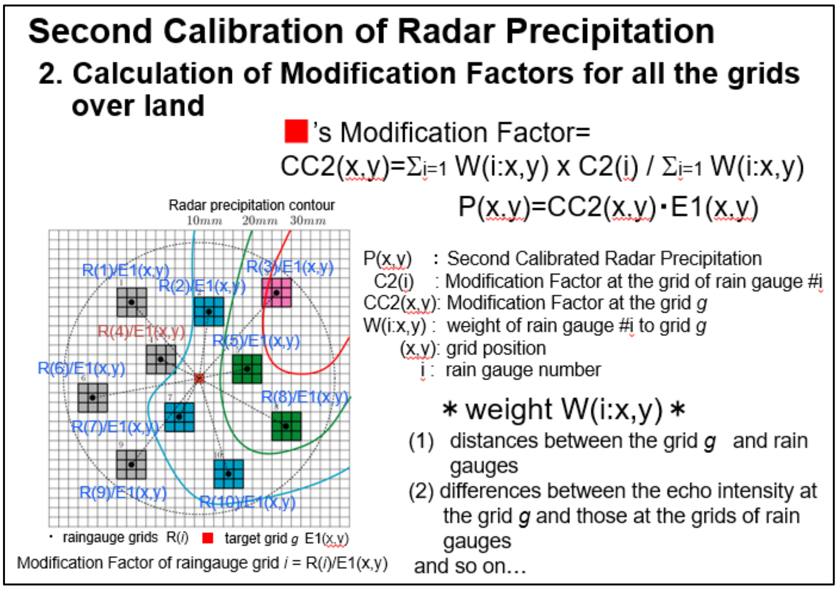
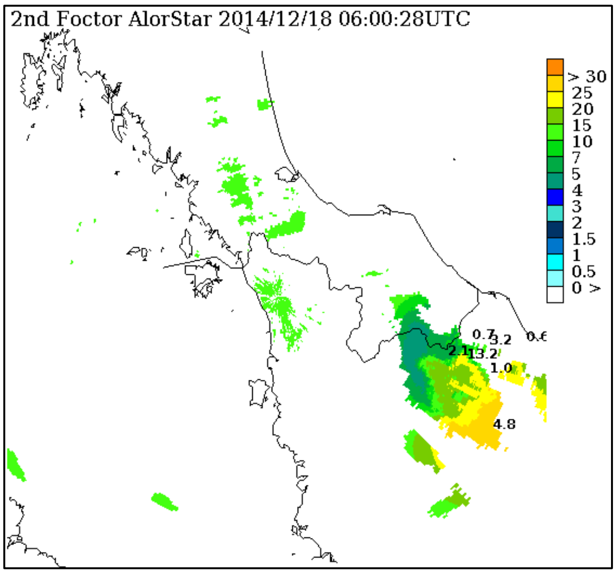


Figure 33: The first calibration techniques and its image


Second Calibration of Radar Precipitation
1. Calculation of Modification Factors (C2) for rain-gauge grids
C2(i) = R(i)/E1(i)
Rain gauge Precipitation
First-calibrated values
Rain-gauge grids
R(i) : Precipitation observed by rain gauge #i
E1(i) : First-Calibrated value at the grid of rain gauge #i
C2(i) : Modification Factor at the grid of rain gauge #i
*To be determined for all rain-gauge grids


Second Calibration of Radar Precipitation
2. Calculation of Modification Factors for all the grids over land
's Modification Factor=
CC2(x,y)=Σi=1 W(i:x,y) x C2(i) / Σi=1 W(i:x,y)
P(x,y)=CC2(x,y)･E1(x,y)
Radar precipitation contour
10mm 20mm 30mm
R(1)/E1(x,y)
R(2)/E1(x,y)
R(3)/E1(x,y)
R(4)/E1(x,y)
R(5)/E1(x,y)
R(6)/E1(x,y)
R(7)/E1(x,y)
R(8)/E1(x,y)
R(9)/E1(x,y)
R(10)/E1(x,y)
・ raingauge grids R(i) target grid g E1(x,y)
Modification Factor of raingauge grid i = R(i)/E1(x,y)
P(x,y) : Second Calibrated Radar Precipitation
C2(i) : Modification Factor at the grid of rain gauge #i
CC2(x,y): Modification Factor at the grid g
W(i:x,y) : weight of rain gauge #i to grid g
(x,y): grid position
i : rain gauge number
＊weight W(i:x,y)＊
(1) distances between the grid g and rain gauges
(2) differences between the echo intensity at the grid g and those at the grids of rain gauges
and so on…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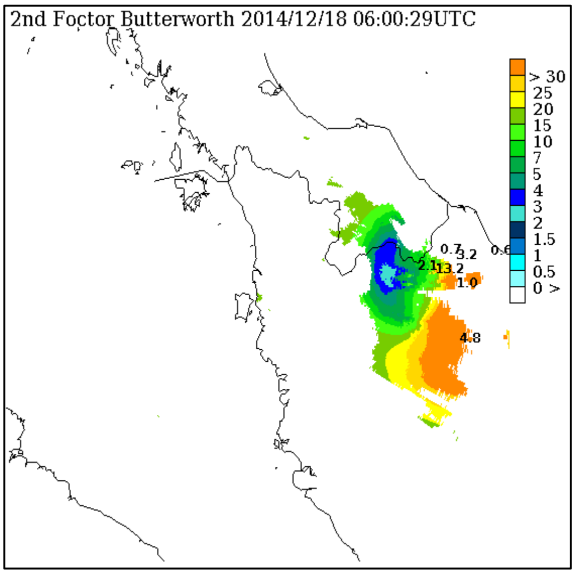
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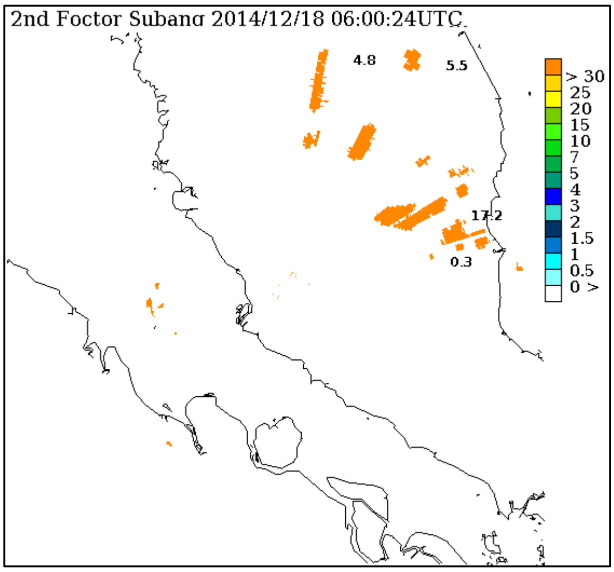
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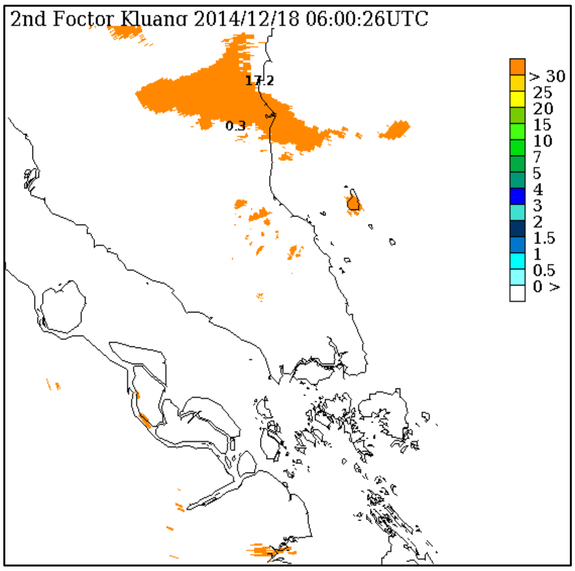
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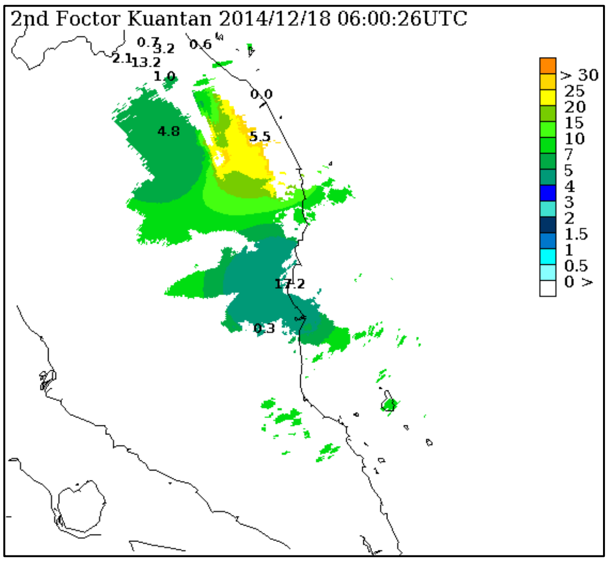
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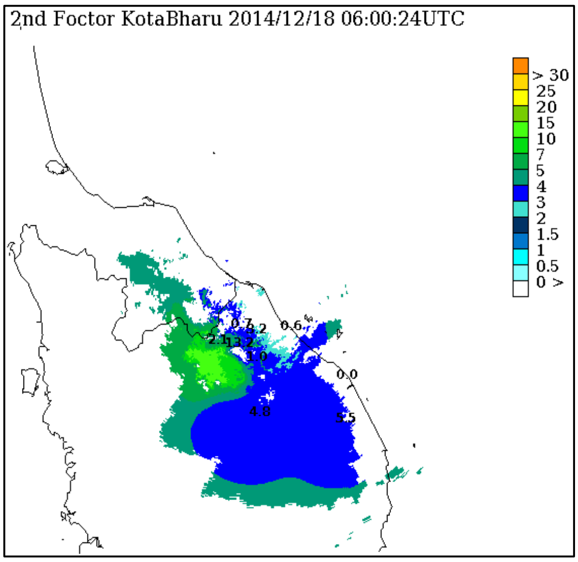
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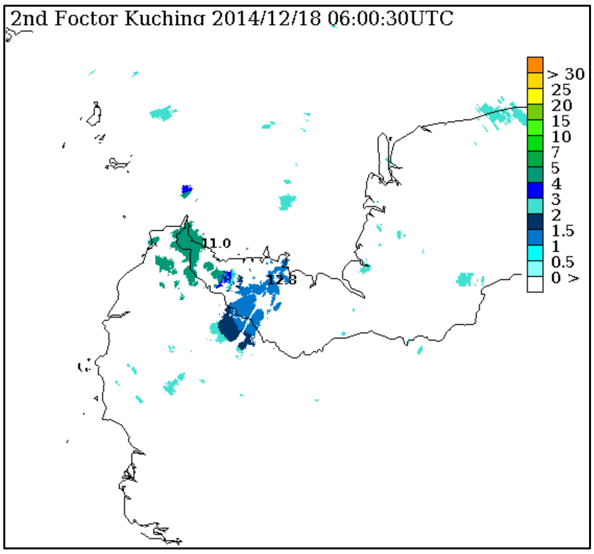
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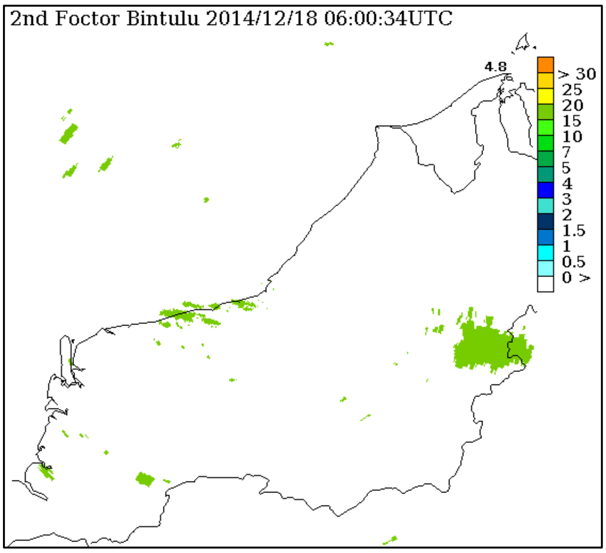
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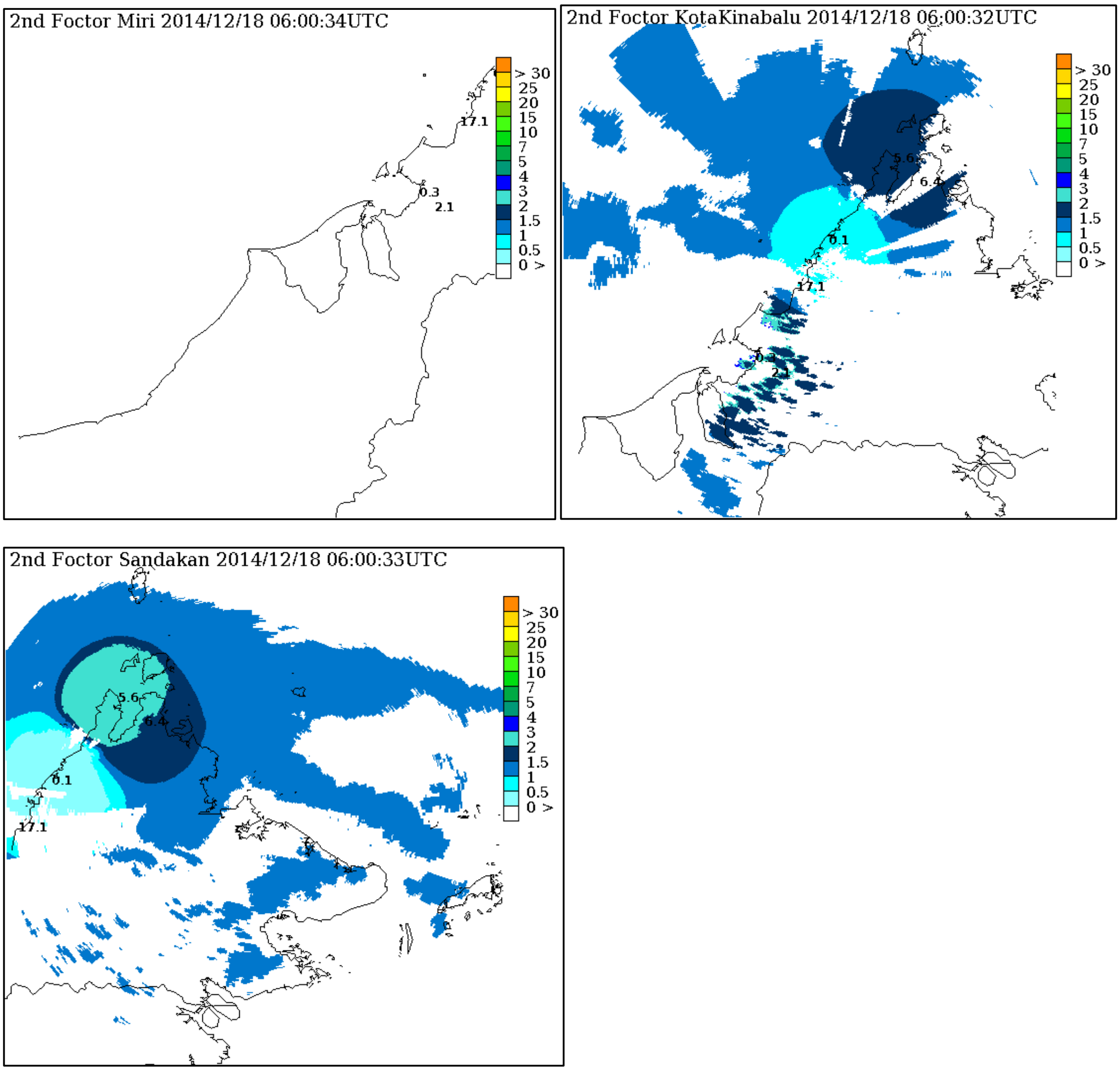

Figure 34: The second calibration images for each radar station with the rainfall data used in the calibration

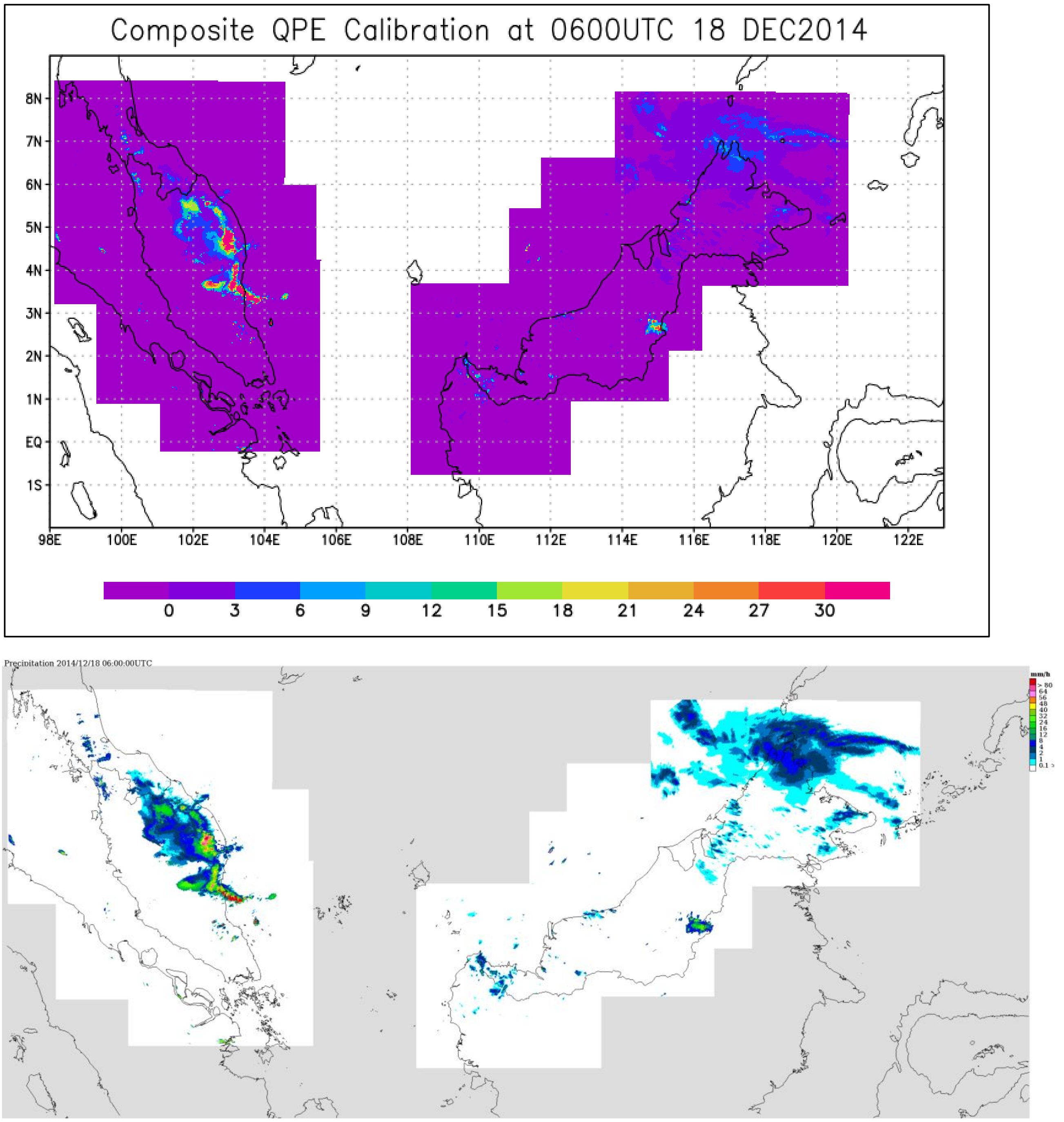

Figure 35: The composite of radar images after QPE calibration with raingauges

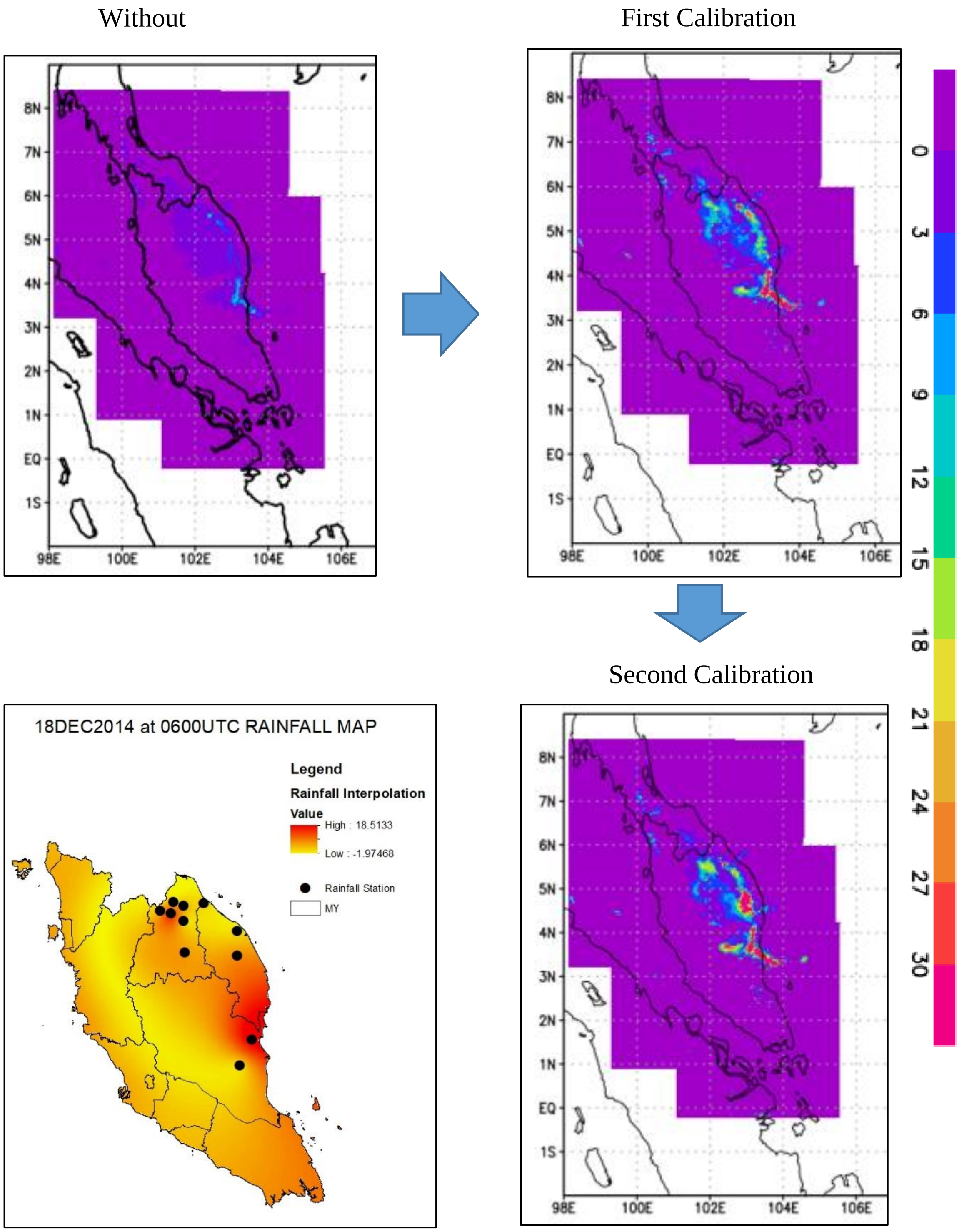

Figure 36: The comparison before and after the calibration with raingauges by using only 11 good stations

Figure 36 showed that comparison with radar rainfall estimation and rainfall map. These analysis revealed that overestimation of radar rainfall estimation occurred by using only 11 rainfall stations. The extraction of best perforamnce between radar and rainfall stations is done by using R-programming provided by JMA software.

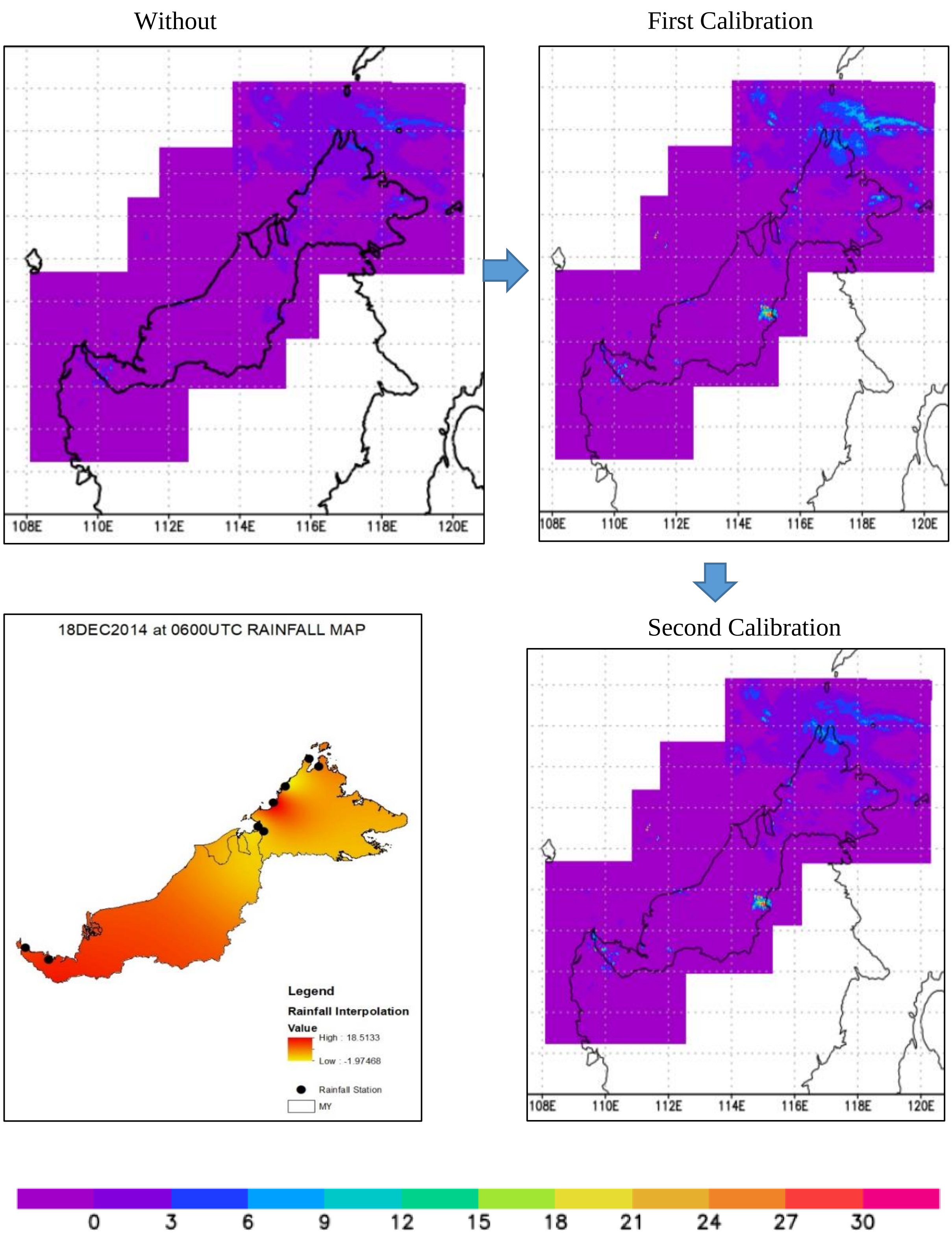

Figure 37: The comparison before and after the calibration with raingauges by using only 8 good stations

Figure 37 showed the radar rainfall estimation not described same with the rainfall map since the density of raingauges data used for calibration is not sufficient to obtain better radar rainfall estimation. The problems of raingauges data is crucial for getting the accurate radar rainfall estimation. Hence, it is recommended to acquire the dense of raingauge network for providing better QPE.

4. Conclusions

The main objective of this technical paper is to provide the information about the techniques of quality control for the radar data and QPE method to obtain the accurate radar rainfall estimation. Hence, eleven radar stations in Malaysia are selected to achieve this purpose. The lower elevation angles are investigated to analyze the performance of radar stations in term of coverage and intensity. The evaluation of scanning strategies can improve the performance of radar station by modifying the elevation angles. Moreover, topography data is used in the analysis of beam blockage by utilizing R-programming for every azimuth. This software can interpret the blockage areas that used for the echo intensity of lowest elevation angles (EIL) that utilized in the radar quality control and QPE algorithm. The provided software can eliminate the interference and remove the ground clutter using the clutter map. The statistical approach consisting of appearance and average in monthly basis can assist to monitor the performance of radar quality. This will help radar operators to improve the intensity of precipitation and coverage areas. The statistical approach can identify the clutter, noise, interference and suspicious data that can be eliminated using the adjustment of EIL Table.

After applying the quality control techniques to the radar data, the QPE calibration with raingauges is applied to obtain better radar rainfall estimation. The first and second calibration resulting in the accurate precipitation estimation on condition needed the dense raingauge network. The less number of raingauges yield the inaccurate radar rainfall estimation. Hence, the further research is recommended to obtain better QPE results.

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J-L Champeaux, O. B. (n.d.). *Quantitative precipitation Estimation using Rain gauges and radar networks: inventory and prospects at Meteo-France.* Retrieved from https://pdfs.semanticscholar.org

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