A Comparative Study of Rain Intensities Retrieved from Radar and Satellite Observations: Two Cases of Heavy Rainfall Events by Changma and Bolaven (TY15)

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Abstracts: The heavy rainfalls caused large property damages and human casualties. For example, Changma caused 0.25 billion dollars in damages and 57 deaths and 112 missing by accompanying the torrentially convective heavy rainfall in Seoul, 2011. In addition, TY15 (Bolaven) caused a small damage by bringing a relatively small amount of rainfall and strong wind in Gwanju, 2012. The investigation and analyses of these mesoscale processes of rainfall events for different physical properties using KLAPS for weather environments of the above cases were performed. These typical and ideal mesoscale systems by better and more favorable cloud systems were chosen to retrieve rain intensity from Radar and Chullian data. The quantitative rain intensities of Radar and Chullian differ greatly from the ground-based gauge values with underestimating over 50 mm/hr at the peak time of hourly maximum rain intensity about over than 85 mm/hr. However, the Radar rain intensity demonstrated approximately lower than 35 mm/hr, and the Chullian rain intensity less than 60 mm/hr for Changma in Seoul, 2011. For typhoon (TY15, Bolaven) in Gwangju, similarly, the quantitative rain intensities of Radar and Chullian differ from the ground-based gauge values. At the peak time, the hourly maximum rain intensity of ground-based gauge was more than 15 mm/hr. However, the Radar rain intensity showed lower than 5 mm/hr, and the Chullian rain intensity lower than 10 mm/hr. Regarding the above two cases of typhoon and Changma, even though Radar and Chullian rain intensities have been underestimated when compared to the ground-based rain intensity, the distributions of time scale features of both Radar and Chullian rain intensities still delineated a similar tendency of rain intensity distribution of the ground-based gauge data.

Keywords: rain intensity, Chullian, mesoscale, quantitative rain intensity
예측시스템을 사용하여 집중호우 시 다른 물리적 요소들에 의한 중규모 과정들의 조사 및 분석을 수행하였다. 이것은 레이더관측과 천리안 위성관측 자료로부터 강우강도를 도출하는데 호조건의 전형적인 중규모 시스템이기 때문에 선택되었으며, 두 사례는 모두 집중호우 발생에 좋은 환경임을 보였다. 2011년 장마에 동반되어 서울에 나타난 사례에서 레이더와 천리안의 정량적인 강우강도를 지상강우계 관측과 비교했을 때, 최대 관측값이 85 mm/hr 이상이 나타난 시점에 비해 약 50 mm/hr 이상이 과소 추정되는 차이가 나타났으나, 레이더 강우강도는 35 mm/hr의 차이와 천리안 강우강도는 60 mm/hr의 차이를 보였다. 그러나 2012년 8월 27일 15호 태풍 볼라벤 동반되어 광주광역시에서 나타난 강우강도와 지상강우강도의 경향은 위의 사례와 유사하게 나타났으며, 정량적인 강우강도 차이는 최대 관측값이 17 mm/hr 이상이 나타난 시점에 비해 약 10 mm/hr 이상이 과소 추정되는 차이가 나타났으나, 레이더 강우강도는 5 mm/hr의 차이와 천리안 강우강도는 10 mm/hr의 차이를 보였다. 이것은 태풍 볼라벤에 의한 집중호우가 상대적으로 약했기 때문이었다. 두 사례에 대해 레이더 강우강도와 천리안 강우강도는 지상강우강도와 시계열적으로 비교했을 때, 모두 유사한 경향을 보였다.

주요어: 강우강도, 천리안 위성, 중규모, 정량적 강우강도

Introduction

KMA has operated 10 Doppler weather radar systems (8 S-band and 2 C-band) in which the signals undergo far less attenuation than C-band signals covering Korean peninsula and islands and observing rainfall intensity and distribution. These radars have sensitive Doppler capabilities that can detect the internal wind structure of storms, enabling better nowcasting of severe storms. This radar is very useful for precipitation estimates with higher and instant monitoring for mitigating the huge natural disasters (Lee et al., 1994). Precipitation intensity is measured by a ground-based radar that bounces radar waves off of precipitation. “Reflectivity (echo intensity)” to be measured by dBZ (decibels) is the amount of transmitted power returned to the radar receiver after hitting precipitation (Park and Chung, 2004). The rain intensity retrieved by Radar is available in that area at very high repeat cycle (every 25 km and 1 minute), giving the liable weight of most definitive rain-gauge-adjusted radar rainfall estimates at corresponding spatial and temporal resolutions (accumulated by every 25 km and 10 minutes).

Satellite imagery is a powerful tool to support very-short range forecasting, including nowcasting, through the provision of near-real time products to monitor and track convective development. Chullian meteorological imager, hence images and diagnostic products (convective potential, instability index) are available in that area at very high repeat cycle (every 4 km and 15 minutes). Satellites can also contribute to estimating rainfall rates, wind speed and direction over the compact area and relatively wider region, too (Cha et al., 2007; Thu and Sohn, 2010; Jang et al., 2012). The Chullian difference analyses, although significantly lower than the corresponding radar products, demonstrated the need to benchmark reference data sources prior to their quantitative use in validating remote sensing retrievals.

Even though this advantage of Chullian products is prone to larger systematic errors and more uncertainty sources in comparison with ground based radar and gauge precipitation products, Chullian’s rain intensity estimates for 4 times per hour may be the alternatively available source of information for operational hydrological and flash flood prediction combined with radar and ground gauge products. However, this network was used extensively to support weather predictions, storm identification, and aviation applications.

There exists a great need for improvement of accurate estimation and short range prediction of precipitation used by Radar and Chullian satellite with reasonable liable spatial and temporal resolution in this days. A number of study radar and satellite rainfall estimation have been reviewed to Bellon et al. (1980), Austin (1981), and Ryu et al. (2011), who showed the improving the short range forecast of precipitation combined by radar and satellite
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This study set out to compare rainfall intensity between the reflectivity of a weather radar and the ground rainfall of ASOS (Automatic Surface Observation System) by analyzing many different cases of heavy rain, Lee et al. (1994) had developed the algorithm of predicting of precipitation using Radar and Satellite data, especially in the area accompanied by Typhoon. Gourley et al. (2010) compared rainfall estimates from algorithms based on measurements from satellite, radar, rain gauges, and combinations to highlight their relative performance for seasonal, daily, and hourly time scales. Chung (2012), Shin and Lee (2005), and Kim and Lee (2006) studied and analysed the major convective type of clouds for heavy rainfall events occurred frequently over Korean peninsula.

Data and Method

This study is two cases of extreme impact natural disasters, one is which was record-broken the amount of rainfall over 86 mm/hr and over 301 mm/day in Seochogu, Seoul at Jul. 26-27, 2011 and the other the amount of rainfall over 26 mm/hr accompanied by typhoon (TY15) Bolaven in Gwangju at Aug. 27-28, 2012, which composed of Radar rain intensities and Chullian rain intensities with every 30 minute intervals. Radar and Chullian rain intensities can produce 6 times per hour and 4 times per hour, respectively. Thus this study have selected and used the comparing 2 times of rain intensities in collocation and coincidence of Radar and Chullian observations.

Radar rain intensity represents 1 hour interval of Rain-1 formulated by the following (Lee and Ryu, 2009).

\[ Z = 200 R^{1.6} \]

where \( R \) represents the rain intensity, \( Z \) can derive from the equation \( dBz = 10 \log_{10} Z \) which used at least more than 10 the CAPPI products with the reflectivity (dBz; decibels for 6 minutes resolution) on the level of 1.5 km for eliminating ground clutters and considering the effect of freezing level. The final liable value of Radar rain intensities should be adjusted by ground gauge observations with weight function (Lee et al., 2010).

Chullian rain intensities represent processed by CMDPS with geostationary brightness temperature adjusted against DMSP SSM/ I precipitation data, that Atlas et al. (1990) and Crosson et al. (1996) developed and explained empirically for PMM (Probability Matching Method). The products generally rely on innovative methods that combine geostationary IR observations/estimates with estimates from passive microwave observations which time scales of about 3-hourly, spatial resolutions of 0.25°, coverage from 60°N-60°S, and records beginning within the last several years. The Relationship between Brightness Temperature (BT) of MTSAT-IR and Rainfall intensity (R) of M/W using the Probability Matching Method (PMM) Apply temporal limit (12 hr) and making the Lookup table for Rainfall Intensity (RI). Therefore the estimation and rainfall intensity (RI) for estimation of Chullian (COMS) represent like the following equation.

\[
\int_{R_{1}}^{R} P(R)dR = \int_{BT_{1}}^{BT} P(BT)dBT
\]

Fig. 1. The structure of KMA 3 dimensional Local Analysis and Prediction system (KLAPS).
For the KLAPS (Korea Local Analysis and Prediction System: NIMR, KMA, 2006), as the analysis of data uses, the mesoscale cross-section fields were supported by during the period of the heavy storm events and typhoon in collocation and coincidence. Through the data analyses, especially the structures of stormy clouds were likely to favorable condition for retrieving the rain intensity by Radar and satellite observations. In the uses and analysis of vertical structure of favorable heavy rainfall events, several parameters such as wind, convective and baroclinic instability, atmospheric and moisture convergence and divergence were derived and illustrated.

In Fig. 1 shows KLAPS has used MM5 model with the horizontal resolution of 5 km, vertical resolution of 35 levels using). In this study 2 cases of heavy rainfall events were selected and implemented with mesoscale analyses. using nowcasting system served with every hour product within 20 minutes after all of available observation processes, immediately.

Discussions and Results

The selected cases for the actively convective clouds can be used by rather easily and accurately monitoring and estimating the rain intensity from Radar and Chullian observations. One is the favorable estimation of rain intensity with active cumulus type cloud with Changma, the other is the typhoon rain band.

Case 1 for Seoul, Korea in 2011

In aspect of synoptic concept for Jul. 26-27, 2011 ad shown in Fig. 2 the central part of Korean peninsula is surrounded three different air masses, one is actively influencing the south peninsula by the Northwest Pacific High to strongly support the warm and humid low level jet stream northward, the other is making lots effectiveness over the north peninsula by the Continental High to blow down with cold and dry high level jet stream and another is strong maintaining over the East Sea to move hesitantly the Low system to flow eastward by the tall and stationary High. This is the main reason why the torrential heavy rainfall event had occurred oner the south part of Seoul.

According to the Radar images for Jul. 26 1500Z (27 0000KST) and 2300Z (27 0800KST), Fig. 3 (left) represents the weak rain or no rain event because the main rain intensity band located over the northern Kyunggi Prov. yet. But the Fig. 3 (right) occurred the maximum record-broken amount of rainfall with stronger than 30 mm/hr over Seoul being the zonal strait rain band.

On the Chullian images for Jul. 26 1500Z (27 0000KST) and 2300Z (27 0800KST), Fig. 4 (left) represents the beginning development of opposite V-shape convective cloud system with weak rain over the northern part of Seoul but Fig. 4 (right) shows the wider coverage over Seoul by explosively opposite V-shape convective system which make occurred abundantly heavy rain intensity.

For analyzing the characteristics of meso-scale system over Seochogu, Seoul, Korea which had occurred the record-broken downpour and heavy rainfall event, the W-E cross-section of dynamical parameters such as equivalent potential temperature, convergence/divergence (con./div.), and moisture flux divergence (color images and green line and relative vorticity of heavy rainfall system (37.6°N, 125.9°E-37.6°N, 128.1°E) was investigated whether the weak rain or no rain and the heavy rain have occurred.

Fig. 5 showed the cross sections of equivalent
potential temperature (EPT; color images and purple line), temperature (green line) and wind (vector arrow) with weak rain or no rain on 1500Z (left) and maximum rainfall recorded (right). The central part of cross section chart illustrates over the Seoul. In Fig for 2300Z, at the lower altitude, the equivalent potential temperature depth decrease in the western part, but in contrast the eastern part the depth of EPT increases rapidly rather lower level which meant more unstable, and also the low level jet stream was blown strongly eastward to the southern part of Seoul, compared with the former chart at 1500Z. This means one of the strong instability in the this system to move toward to Seoul.
Fig. 6 (left) showed the vertical and zonal distribution of vertical motion and conv./div. fields at Jul. 1500Z and 2300Z over Seoul. On the dynamic field of moisture flux divergence at the beginning of rain, the shallow and wavy moisture convergence (~20 g/kg/12 hr) at the lowest level under the 850 hPa, penetrates into Seoul continuously and but the balloon-type wider and taller moisture divergence (+20 g/kg/12 hr) stacks up above the middle to the upper level to 200 hPa. Near the surface there exists the strong sinking motions, but on the peak time of heavy rainfall the negative omega field dominates highly to tropopause level, which the strong upward motions stretches up to upper level with actively
strong divergence. Therefore at the time of maximum amount of rainfall, the strong convergence zone like heat tower exists on the middle level to upper level. In Fig. 6 (right) the time of maximum rainfall event, the tall heat-tower train of continuous moisture convergence (+20 g/kg/12 hr) above 900 hPa to the level of 100 hPa keep moving from west to east over the south of Seoul. This is the evidence to expect the torrential heavy rainfall event on the Seoul at Jul. 26, 2300Z, 2011.

Fig. 7 represents the moisture flux divergence and relative vorticity at 1500Z (left) and 2300Z (right) 26 July 2011. In Fig. 7 (left) for the dynamic field of moisture flux divergence at the beginning of rain, the shallow and wavy moisture convergence (~20 g/kg/12 hr) at the lowest level under the 850 hPa, penetrates into Seoul continuously and but the balloon-type wider and taller moisture Divergence locates on lifted over 850 hPa to 500 hPa. on the west of Seoul, the tall tower type of moisture convergence consecutively moving eastward. In Fig. 7 (right) the time of maximum rainfall event, the tall heat-tower train of continuous moisture convergence (~100 g/kg/12 hr) from surface to 100 hPa keep staying over the east of Seoul. This is the proper evidence to expect the torrential heavy rainfall event and to relatively estimate easy the rain intensity on the Seoul at Jul. 26, 2300Z, 2011, too.

Fig. 8 show the AWS time-series of amount of rainfall, temperature, wind and pressure in Seochogu, Seoul, Korea on Jul. 26-27, 2011 (AWS No. 401). In the comparison of Rain intensity with Radar and Satellite retrievals shown in Fig. 9 there exists the big difference from ground-based rain intensity for the
peak time. The aspect of quantitative rain intensity differs lots from ground-based gauge values. At the peak time of hourly maximum rain intensity is about over than 85 mm/hr, but Radar rain intensity is recorded approximately lower than 50 mm/hr, and also Chullian rain intensity lower than 60 mm/hr. Even though Radar rain intensity can underestimate poorly rather than the feature of ground-based rain intensity, they still delineate similarly the tendency of rain intensity distribution of ground-based gauge dat better than Chullian rain intensity.

Case 2 of Gwangju, Korea in 2012

In aspect of synoptic concept for Aug. 27-28, 2012, Fig. 10 showed that the track and characteristics of TY15 Bolaven had passed northward over the Yellow Sea beside the Honam Prov., which gust wind over 50 m/sec (Wando) and maximum amount of rainfall over 242 mm/day (Sungsamjai, Jiri Mt.) affects seriously. Beside the edge of Northwest Pacific High to strongly support the warm and humid over the East Sea, Honam Prov. except for southern part of Korean peninsula and Gwangju have been recorded comparatively less amount of heavy rainfall and strong wind accompanied by TY15 Bolaven with the maximum amount of rain intensity of 15 mm/hr and total amount of rainfall with 88 mm/day and strong wind over 13.5 m/sec on Gwangju, Korea.

Fig. 11 (left) for Aug. 27 1400Z (27 2300KST) represents the weak rain or no rain event because the secondary rain band moved northward from the southern Honam Prov. where do not influences yet. But the Fig. 11 (right) for 2300Z (28 0800KST), 2012 occurred the maximum amount of rainfall over 15 mm/hr and strong gust greater than 13.5 m/sec on Gwangju, Korea.

In Fig. 12 shows the Chullian images for Aug. 27 1400Z (27 2300KST) and 2300Z (28 0800 KST), 2012. Fig. 12 (left) represents the beginning development of weak main rain band passed northward, but in contrast the secondary convective rain band passed over Gwangju. Fig. 12 (right shows the wide coverage of Gwangju with secondary rain band of TY15 Bolaven, which makes occurred abundantly heavy rain intensity.

For analyzing the characteristics of meso-scale system over Gwangju, Korea which had occurred the heavy rain and strong gust event by TY15 Bolaven, the W-E cross-section of dynamical parameters such as equivalent potential temperature, conv./div., and moisture flux divergence(color images and green line and relative vorticity of heavy rainfall system (37.6°N,
125.9°E-35.26°N, 128.0°E) was investigated whether the weak rain or no rain and the heavy rain have occurred.

Fig. 13 showed the cross sections of equivalent potential temperature (EPT; color images and purple line), temperature (green line) and wind (vector arrow) with weak rain or no rain at 1400Z (left) and maximum rainfall recorded at 2300Z (right). The central part of cross section chart illustrates over Gwangju, Korea. In Fig. 13 (left), at the lower altitude, the equivalent potential temperature depth maintains balancing with the southeasterly from the south. Fig. 13A (right) displays the strong rain at 2300Z.
Honam Prov. in the chart with no change. But in contrast in the eastern part the depth of EPT, increases rapidly rather lower level from east part of Gwangju adjacent area which meant becoming more unstable, and also the southerly low level jet stream was blown more stronger from the southern part of the Hoam Prov., compared with the former chart at 1400Z. This means one of the strong instability in this area due to the on approaching of TY15 Blaven to move toward to Gwangju, Korea.

Fig. 14 (left) and Fig. 14 (right) showed the vertical and zonal distributions of vertical motion and conv./

Fig. 13. Cross-section of equivalent potential temperature (color images and purple line), temperature (green line) and wind (vector arrow) over Gwangju at 1400Z (left) and 2300Z (right) 27 August 2012.

Fig. 14. Same as Fig. 11 but for omega fields (ascending air flow, color images), vertical circulation (purple line) and divergence (green line).
div. fields at Aug. 27. 1400Z and 2300Z on Gwangju. On the dynamic field of moisture flux divergence at the beginning of rain in Fig. 14 (left), the shallow Divergence near the surface and tall eye-wall type vertical Divergence (+12 g/kg/12 hr) unto the level 150 hPa, penetrates into Gwangju continuously. In contrast the east part of Gwanju, the moisture flux convergence move westward the tall eye-wall type vertical convergence (−12 g/kg/12 hr) unto the level 150 hPa, penetrates into Gwangju continuously. At the 250 hPa, two anticlockwise circulations with dipole shape which mean the two eye-wall circulations located. Near the surface to middle level there exists the very small, vertical shear.

In Fig. 14 (right) the time of maximum rainfall event, the tall heat-tower train of continuous moisture convergence (+20 g/kg/12 hr) above 900 hPa to the level of 100 hPa keep moving from east to west over Gwangju, which means the evidence to expect the heavy rainfall and strong gust event with several rain bands accompanied by TY15 Bolaven. Aug. 27 2300Z, 2012. On contrast dynamic field of moisture flux divergence at the peak rainfall, on 450 hPa, four anticlockwise circulations with twin dipole shapes which mean the two rain-bands circulations located. Near the surface to middle level there exists the larger vertical shear. Therefore at the time of maximum amount of rainfall, the strong convergence zone like weaker heat rain bands exists on the middle level to upper level.

In Fig. 15 represents the moisture flux divergence and relative vorticity at 1400Z (left) and 2300Z (right) 27 Aug. 2012. In Fig. 15 (left) for the dynamic field of moisture flux divergence (+20 g/kg/12 hr) at the beginning of rain, the shallow and wavy moisture divergence at the lowest level under the 850 hPa, penetrates into Gwangju continuously and but the balloon-type wider and taller moisture Divergence locates on lifted over 850 hPa to 200 hPa, but on the east of Gwangju the tall tower type of moisture convergence (−20 g/kg/12 hr) consecutively moving eastward. In Fig. 15 (right) on contrast at the peak time of rainfall event, the lower train of continuous moisture convergence (+20 g/kg/12 hr) above 900 hPa to 700 hPa keep moving wavy forms from east to west over Gwangju, which means the evidence to expect the heavy rainfall and strong gust event with several rain bands accompanied by TY15 Bolaven. Aug. 27 2300Z, 2012.

Fig. 16 represents the AWS time-series of amount
of rainfall, temperature, wind and pressure in Gwangju, in Aug. 27-28, 2012 with maximum amount of rainfall over 15 mm/h. The minimum of temperature and pressure represents coinstantaneously the passage of TY15 Bolaven over Gwangju at the peak time of rain intensity. In the comparison of rain intensities with Radar and Satellite retrievals shown in Fig. 17, there exist rather bigger differences from ground-based rain intensity for general tendency, especially at the peak time. Even though Radar rain intensity rather than Chullian rain intensity illustrated the tendency of rain intensity distribution of ground-based gauge data. The quantitative rain intensity differs lots from ground-based gauge values.

At the peak time the hourly maximum rain intensity of ground-based gauge is about over than 15 mm/hr, but Radar rain intensity showed approximately lower than 5 mm/hr, and also Chullian rain intensity lowest than 10 mm/hr. Even though Radar rain intensity better than Chullian rain intensity underestimated poorly rather than the feature of ground-based rain intensity, they still delineate similarly the tendency of rain intensity distribution of ground-based gauge data.

**Conclusions**

Two cases of heavy rainfall events for Changma and rain-bands of typhoon (TY15, Bolaven) are chosen by retrieving relatively easy and accurate the rain intensity Radar and Satellite observations for the favorable condition of rain measurement. One is the heavy rainfall event over Seochgu, Seoul. in Jul.27, 2011 for the maximum hourly amount of rainfall with 87 mm/hr and 86 mm/hr and 301.5 mm/day in Seochogu, Seoul Korea at Jul. 26-27, 2011 and the other the amount of rainfall 15 mm/hr and total amount of rainfall with 88 mm/day and strong wind over 13.5 m/sec on Gwangju Korea accompanied by typhoon (TY15) Bolaven at Aug. 27-28, 2012.

For investigating and analyzing the characteristics of meso-scale systems over Seoul (2011) and Gwangju (2012), Korea which had been occurred the heavy rainfall events by Changma and the moderate heavy rainfall and strong gust by TY15 Bolaven, these W-E cross-sections of dynamical parameters such as equivalent potential temperature, convergence/divergence, etc. (37.6°N, 35.26°N, and 125.9°E-°N, 128.0°E) were used and illustrated, respectively.

In the comparison of rain intensity retrievals of radar and Chullian against the ground-based rain
gauge data, there exist the bigger differences from ground-based rain intensity for the peak time, even though the typical and ideal mesoscale systems have been chosen by better and more favorable cloud systems to retrieve rain intensity with Radar and Chullian data. The quantitative rain intensities of Radar and Chullian differ lots from ground-based gauge values with underestimating over 50 mm/hr at the peak time of hourly maximum rain intensity was about over than 85 mm/hr, but Radar rain intensity demonstrated approximately lower than 35 mm/hr, and also Chullian rain intensity lest than 60 mm/hr for Changma (2011) in Seoul. Radar and Chullian rain intensity illustrated the tendency of rain intensity distribution of ground-based gauge data. Also for typhoon (TY15, Bolaven in Gwangju). Similarly, the quantitative rain intensity of Radar and Chullian rain intensities differ from ground-based gauge values. At the peak time the hourly maximum rain intensity of ground-based gauge is about over than 15 mm/hr, but Radar rain intensity showed approximately lower than 5 mm/hr. Even though for both cases Radar and Chullian rain intensities have been underestimated poorly compared from ground-based rain intensity, the distribution of time scale feature of both rain intensities still delineated similarly the tendency of rain intensity distribution of ground-based gauge data better than Chullian rain intensity heavy rainfall events.

In the near future the more studies of using Radar and Chullian observations need to improve up the retrieval algorithm of rain intensity for coinstantaneous Radar and Chullian data for fitting up against the ground-based gauge rain intensity.

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