APPLICATION OF RADAR OBSERVATION DATA TO PREDICT A LANDSLIDE DUE TO LOCALIZED HEAVY RAIN

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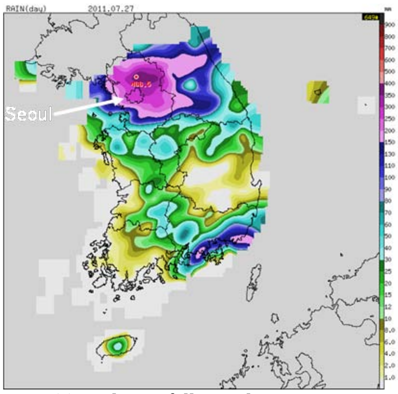
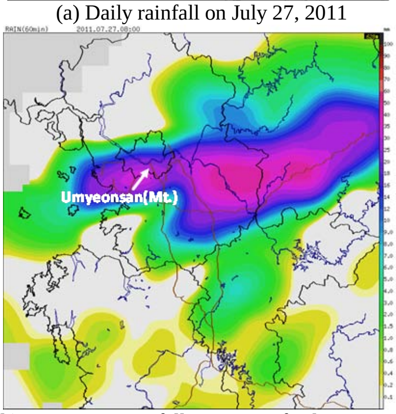
I. INTRODUCTION

During July 2011 in Seoul, Korea, a heavy rainfall with more than 40% of the annual rainfall occurred over a span of four days (July 26–29, 2011). At the event, most areas in Seoul (25 out of 28 automatic weather stations) recorded more than 50 mm of rainfall per hour and a severe rainfall zone was formed from 7 a.m. to 8 a.m. on July 27 as an east to west narrow band. This resulted in a large rainfall difference within Seoul. This localized heavy rainfall was attributed to; (1) warm and humid air continuously introduced by strong southwesters along the perimeter of North Pacific high pressure, (2) dry and cold air introduced from the northwest, (3) the said winds met at the central region of Korean peninsula and caused instable convection, and (4) high pressure near Sakhalin blocked the movement of rainfall zone.



(a) Daily rainfall on July 27, 2011



(b) 60 minutes rainfall at 8 a.m. of July 27, 2011

FIG. 1: Rainfall event on July 27, 2011 (KMA)

Due to this localized heavy rainfall, large landslides have occurred at Mountain Umyeon located in the southern Seoul (Gangnam-gu). Hydrological analysis suggested that by cumulative effect of 15 hours of heavy rainfall (230–266.5 mm), the ground had been weakened and then localized intensive rainfall for one hour triggered the landslide. Due to the short discharge time of the area (less than 5 minutes), maximum rainfall and peak discharge occurred at the same time. Given that the landslide also occurred at the same time, it can be inferred that localized heavy rainfall was the primary cause.

(a) Panoramic view of Mt. Umyeon (Naver Map)

(b) Panoramic view of a landslide at Mt. Umyeon

FIG. 2: Panoramic views of Mt. Umyeon and a landslide on July 27, 2011

Caine (1980) introduced the concept of critical rainfall regarding the rainfall standard that causes landslide and avalanche of earth and rocks. Since then, many researchers including Crosta et al. (2000) and Wilson et al. (1995) did studies on the standard for forecast and alarm of landslide. They tried to get critical rainfall by using the values of rainfall intensity, rainfall duration, preceding rainfall and total rainfall; however, they concluded that it is difficult to suggest a single standard. They said local characteristics should be reflected on such standard because the landslide or avalanche of earth and rocks can be different dependent on local topography, geology, vegetation and weather characteristics. This implies that it is difficult to identify various mechanisms until the rainfall would cause avalanche of earth and rocks though it is clear that rainfall is the cause of avalanche. It is known that the preceding rainfall, which fell before the heavy rainfall causing landslide or avalanche of earth and rocks, also has influence on the landslide occurrence; however, satisfactory result has not yet been drawn, while it is clear that amount of preceding rainfall, duration of preceding rainfall and the time difference between preceding rainfall and the heavy rainfall causing landslide are important. The Korean standard on rainfall that would set off a landslide warning or alarm generally uses hourly rainfall (rainfall intensity), daily rainfall (24 hours) and continuous rainfall. The landslide warning and alarm standard used by Korea Forest Service since 1988 is shown in Table I.

Classification	Maximum hourly rainfall (mm)	Daily rainfall (mm)	Continuous rainfall (mm)
Landslide warning	20–30	80–150	100–200
Landslide alarm	30	150	200

TABLE I: Landslide warning and alarm standard used by Korea Forest Service

Most studies on rainfall conditions that cause landslides or avalanches of earth and rocks in Korea drew substantially converging conclusions. Kim (1998) suggested that a large landslide would occur if maximum hourly rainfall would exceed 25 mm or daily rainfall on the landslide occurrence date would exceed 180 mm. Han (2001) suggested that 90% or more landslides occur within three hours after maximum rainfall intensity has been recorded. Kim et al. (2006) analyzed that rainfall is a very important external factor that causes landslide because landslides concentrically occurred in the areas where cumulative rainfall is high while almost no landslide occurred in the immediate nearby area which did not have heavy rainfall. Kim et al. (2008) suggested rainfall that causes avalanche of earth and rocks together with rainfall standard which had been suggested by existing studies as causing landslide (FIG. 3). Among the standards suggested by Hong (1990), the rainfall standard causing large-scale landslide and the rainfall standard relevant to the landslide alarm standard of Korea Forest Service were similar to the rainfalls that caused avalanche of earth and rocks.

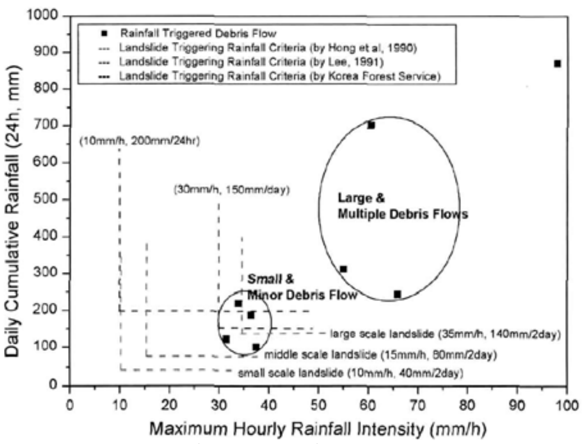
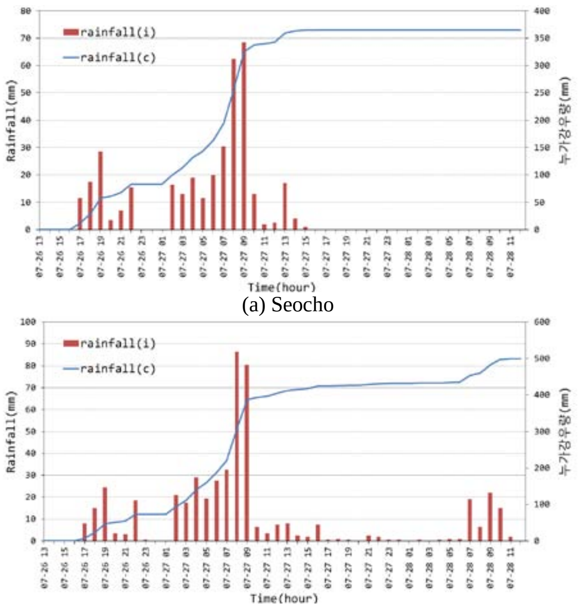


FIG. 3: Comparison of Korean rainfall standard causing avalanche of earth and rocks (Kim, 2008)

II. SCALE ANALYSIS OF LOCALIZED HEAVY RAINFALL ON SEOUL IN JULY 2011

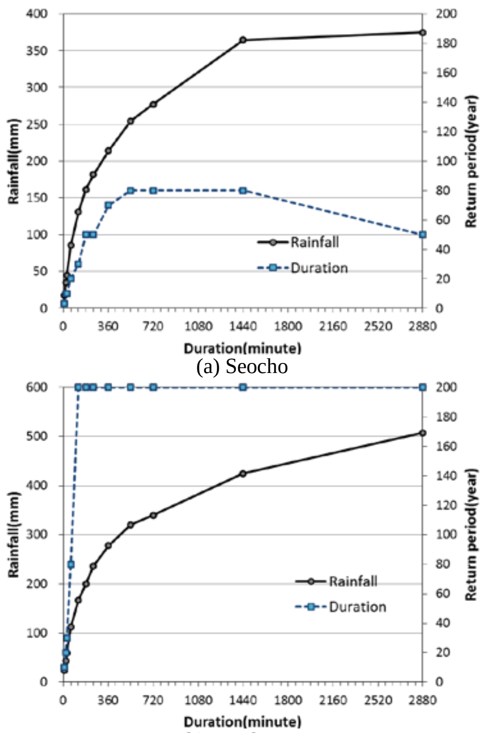
Rainfall by hour, maximum rainfall by duration of the period and probabilistic recurrence interval (frequency) from 1 p.m. of July 26 to July 28, when there was heavy rainfall in the central region of Korea including Seoul, were compared. Regarding Namhyeon and Gwanak, the rainfall recurrence intervals at 60 minutes duration were 80 years, which is close to 100 years. The recurrence intervals of Songpa, Namhyeon, Gwanak, Yangju and Gwangreung were longer than 200 years at 120 minutes duration. It should be noted that the recurrence interval decreases when duration increases in general; however, the recurrence interval of 2011 heavy rainfall continuously increased while duration increased. It implies that this heavy rainfall had record-breaking amount in addition to record-breaking intensity. Based on past cases, this is judged as very exceptional.



(a) Seocho

(b) Namhyeon

FIG. 4: Maximum rainfall for 2011



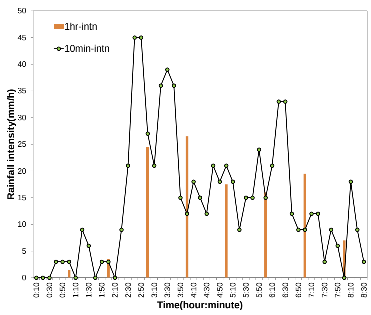
(a) Seocho

(b) Namhyeon

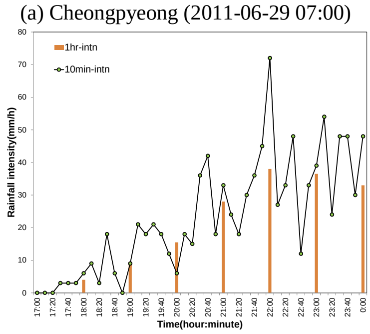
FIG. 5: Recurrence interval by duration for 2011

III. EVALUATION OF LANDSLIDE FORECAST STANDARD DEPENDENT ON RAINFALL TIME SCALE

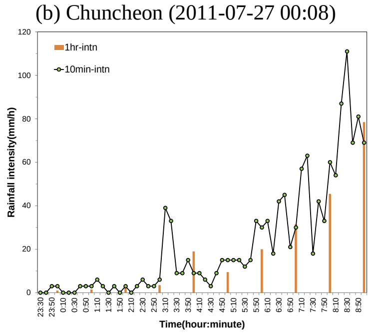
It is possible to draw substantially significant result when the sequence of occurrence of rainfall is considered together. In other words, when rainfall in a 10-minute interval is used, the time to arrive at current maximum rainfall by hour (maximum rainfall intensity) becomes shorter at a certain condition (condition that can cause landslide). Therefore, the probability of securing more preceding forecast time increases. As seen in the actual heavy rainfall cases (FIG. 6), when it is expected that heavy rainfall would continue at least ix hours since the beginning of random heavy rainfall at random location and the rainfall amount or rainfall intensity is in increasing trend or continuous trend, the hourly rainfall intensity standard cannot secure more than two hours until the landslide would occur. Therefore, in order to increase the preceding forecast time for such case, it is believed that utilizing the rainfall data with interval less than an hour (such as 10 minutes) would be more effective than using hourly rainfall intensity standard. However, even in this case, it is desirable to draw optimum level by additional analysis on whether to apply 30 mm, which is same with the hourly rainfall intensity standard, on alarm standard, or, another figure would be applied.



(a) Cheongpyeong (2011-06-29 07:00)



(b) Chuncheon (2011-07-27 00:08)



(c) Gangreung (2002-08-31 09:00)

FIG. 6: Comparison of landslide alarm set off time between 10-minute rainfall and hourly rainfall

According to existing cases and studies, the preceding rainfall before the landslide occurrence and the rainfall intensity on the landslide occurred date have close relation with landslide. According to the result of cases investigation, the maximum hourly rainfall intensity occurred mostly around the landslide location. Therefore, it is believed that the importance of preceding rainfall and rainfall intensity on the landslide occurrence have been examined to some extent. Preceding rainfall makes sufficient flow condition for landslide occurrence by weakening the friction and cohesive power among soil, rocks or vegetation roots, while increasing the load of soil. It is possible to interpret that rainfall intensity takes the role of a fuse that ignites actual landslide occurrence at certain timing at this flow condition.

In other words, a landslide occurrence from heavy rainfall can be said as something that occurs at the time when the continuing conditions of certain rainfall amount and certain rainfall intensity would be met. Because the continuous increasing condition of rainfall is made for several days, it is possible to judge it by the trend of preceding rainfall. However, the continuing condition of rainfall intensity is difficult to know because it is made within few hours at the location that is near the occurring location. From this perspective, it is expected that the forecast of landslide from heavy rainfall would be more effective when the rainfall intensity with interval less than an hour is used than when the hourly rainfall intensity is used.

Following the analysis result is an actual case. It is the comparison result of radar rainfall (RDR) at the weather station of Meteorological Administration on Mt. Gwangdeok-san in 10 minutes interval and the hourly rainfall (GAG) at nearby weather station (Namhyeon) on the date of the landslide at Mt. Umyeon on July 27, 2011. The landslide occurrence forecast standard is applied of Korea Forest Service standard. The heavy rainfall let up from 22 hour of July 26, 2011. Then it became intense again from 1:40 a.m. of July 2011. The dark black bar is GAG and the light red bar is RDR. The (1) marked in FIG. 7 is the estimated time of landslide occurrence (8:40 a.m. of July 27, 2011).

When seen by rainfall intensity standard, the RDR after let up can be seen as continuously exceeding the standard after it exceeded rainfall intensity standard 30mm/h at (2), which is 1:40 a.m. of July 27, 2011. However, GAG exceeded the rainfall intensity standard at (4), which is 7:00 a.m. of July 27, 2011. It is five hours later than RDR. The preceding rainfall exceeding timing by RDR is (3), which is 6:30 a.m. of July 27, 2011; while the same of GAG is 7:00 a.m. of July 27, 2011. Therefore, the exceeding timing of preceding rainfall also has a 30-minute difference.

When seen by standard, heavy rainfall at Mt. Umyeon continued from the 26th; the rain continued after 1 a.m. of the 27th and it already approached 200 mm of daily cumulative rainfall at 6 a.m. Therefore, it was possible to forecast for both GAG and RDR to forecast that the rainfall will exceed the preceding rainfall standard 200 mm, if it would continue until the dawn of the 27th. The rainfall actually continued. RDR analyzed with a 10-minute interval exceeded the standard at 1:40 a.m. of the27th. Since this continued, it was possible to judge that the landslide probability is very high. However, the GAG analyzed by hourly rainfall did not exceed the standard though certain rainfall intensity continued. Therefore, it would have been difficult to judge the landslide occurrence until 7 a.m. of the

27th, when the standard was exceeded.

Therefore, the RDR, which used 10 minutes interval data, could have learned that there is possibility of landslide occurrence if the heavy rainfall would continue until the dawn of the 27th, which is seven hours before the actual landslide occurrence. At 7 a.m., two hours before the actual landslide occurrence, it would have been possible to forecast that landslide possibility is very high.

However, this analysis can be very different from actual watch/alarm situation because it analyzed only technical aspect based on the post-hoc result. The key of this kind of analysis is not whether the ground rainfall was used or rainfall with interval less than an hour was used. The key is whether hourly rainfall was used or rainfall interval less than an hour was used. Therefore, it is possible to get similar result by 10 minutes interval ground rainfall, even it is not radar rainfall. However, it is difficult to make detail spatio-temporal forecast on the spatial formation, movement and disappearance of actual heavy rainfall by ground rainfall. Therefore, it is virtually impossible to forecast the continuity of rainfall intensity or rainfall. It can said that the difficulty in securing sufficient preceding time required for landslide forecast is the utilization limitation of ground rainfall gauge.

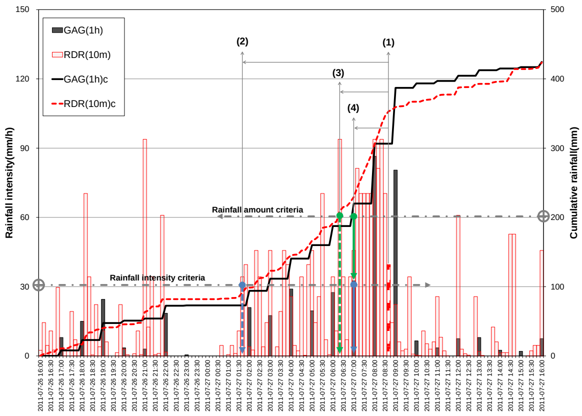


FIG. 7: Landslide occurrence standard comparison between hourly rainfall and 10 minutes interval rainfall

IV. EVALUATION OF PRECEDING TIME INCREASE POSSIBILITY OF LANDSLIDE FORECAST UTILIZING RADAR DATA

FIG. 8 shows actual RDR data marked by time in the Seoul area. Mt. Umyeon is located at the southern end of Seoul, which is marked as □ on the map. First, the distribution and movement of heavy rainfall before the landslide, which is from 1 a.m. to 8 a.m. of the 27th, were marked on the map. The heavy rainfall had let up for a while since 10 p.m. of the 26th. The heavy rainfall entered the Western Sea of Korea from 1 a.m. of the 27th. It passed through Seoul as it continued moving from southwest to northeast for eight hours. This is well illustrated in the RDR data in FIG. 8.

Though it is possible to learn the mobility of heavy rainfall with hourly data, it is difficult to learn detailed movement characteristics or continuing possibilities. Therefore, the spatial distribution characteristic of heavy rainfall was marked by 10 minutes interval from 7 a.m., from when the heavy rainfall began to stay in the area within Mt. Umyeon (south of Seoul) continuously (FIG. 8). According to the analysis result of RDR spatial distribution in 10 minutes interval, the heavy rainfall continued to move before 7 a.m., however, the center of heavy rainfall stayed at the location of Mt. Umyeon from 7 a.m. till the estimated time of landslide occurrence. When considering this, it is possible to know that the risk of landslide occurrence rapidly increased from two hours before landslide occurrence. It is believed that this space-time detailing capability is the outstanding merit of radar rainfall observation and it is an essential requirement for more accurate and precise landslide forecast.

V. SUMMARY AND CONCLUSION

The current Korea national standard of landslide watch and warning has been based on the analysis of past landslide occurrences and it is seen as appropriate when analyzing landslides after their occurrence. However, the standard may not be sufficient to use in operational forecasting due to its temporal and spatial resolution limitation. It cannot secure optimum forecast time of actual heavy rainfall due to its inability to consider rainfall interval less than an hour. The standard only considers daily rainfall, cumulative rainfall and maximum hourly rainfall (maximum hourly rainfall intensity) obtained from ground rain gauge network. Using rainfall forecast based on ground rain gauge cannot secure sufficient forecast time and it is not capable of telling local rainfall occurrence and movement pattern in a narrow area; therefore, it is difficult to utilize in the analysis and forecast of landslide with high accuracy.

This study compared the analysis results of radar observation and ground rain gauge observation in order to examine the impact of spatio-temporal observation preciseness which is required for the forecast of landslide caused by localized heavy rainfall in city-center or unobserved basin. For this, the landslide occurrence case caused by record-making localized heavy rainfall on July 2011 was analyzed. The analysis result proved the necessity of rainfall observation with interval less than an hour for landslide forecast. The usefulness of radar observation for landslide warning was also examined.

Observation with shorter interval is required for more accurate landslide forecast. Therefore, study on very short-term rainfall forecast by area utilizing small radar is required. Since dual polarization technology should be combined for accurate rainfall estimation and forecast, observation utilizing dual-polarized radar and development of interpretation technology are also required. From these perspectives, it is believed that dual-polarized X-band radar would be most efficient for the landslide caused by localized heavy rainfall forecast. Therefore, active development of a system and landslide forecast technology utilizing dual-polarized X-band radar would be also required.

VI. ACKNOWLEDGMENTS

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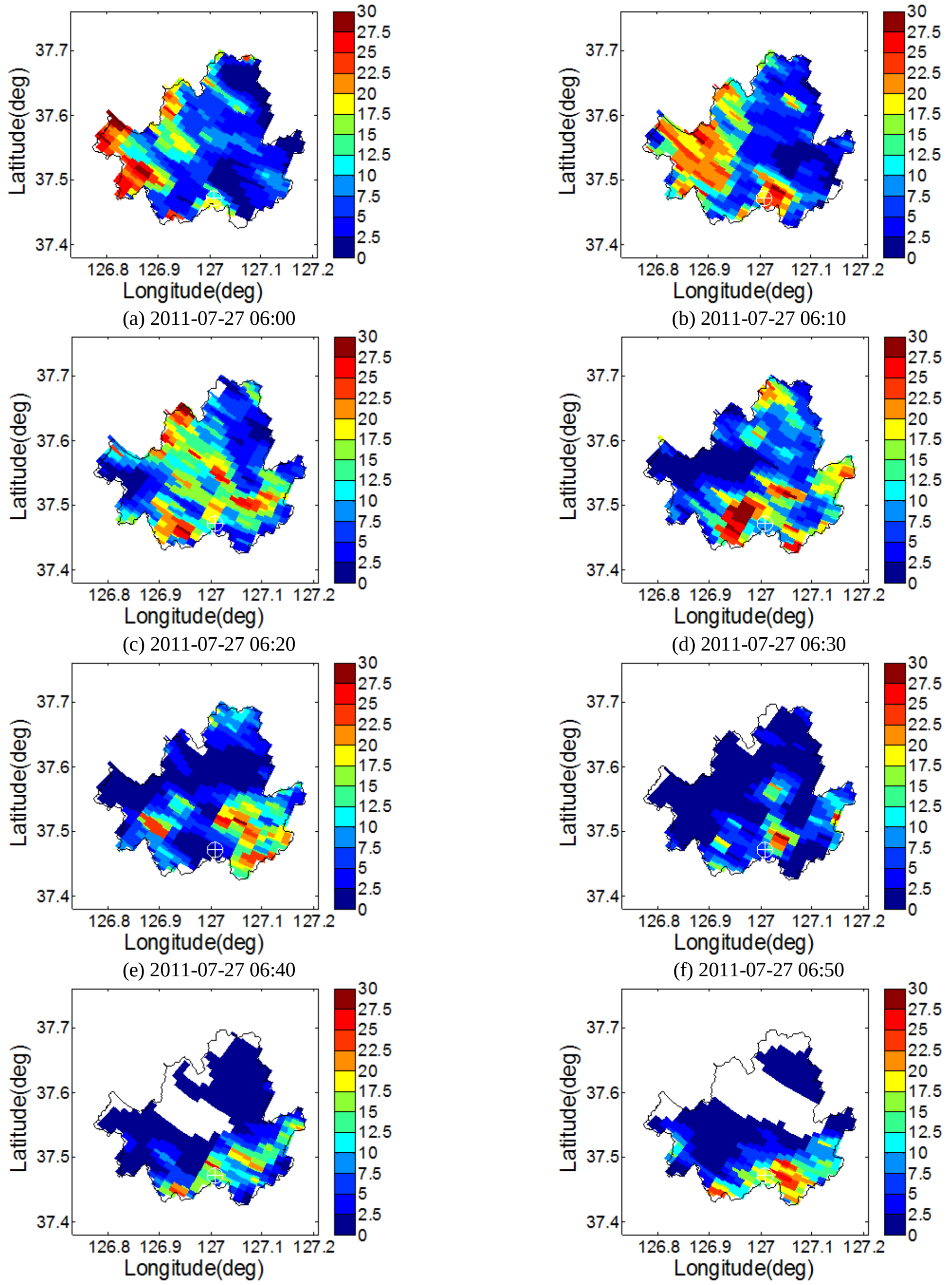
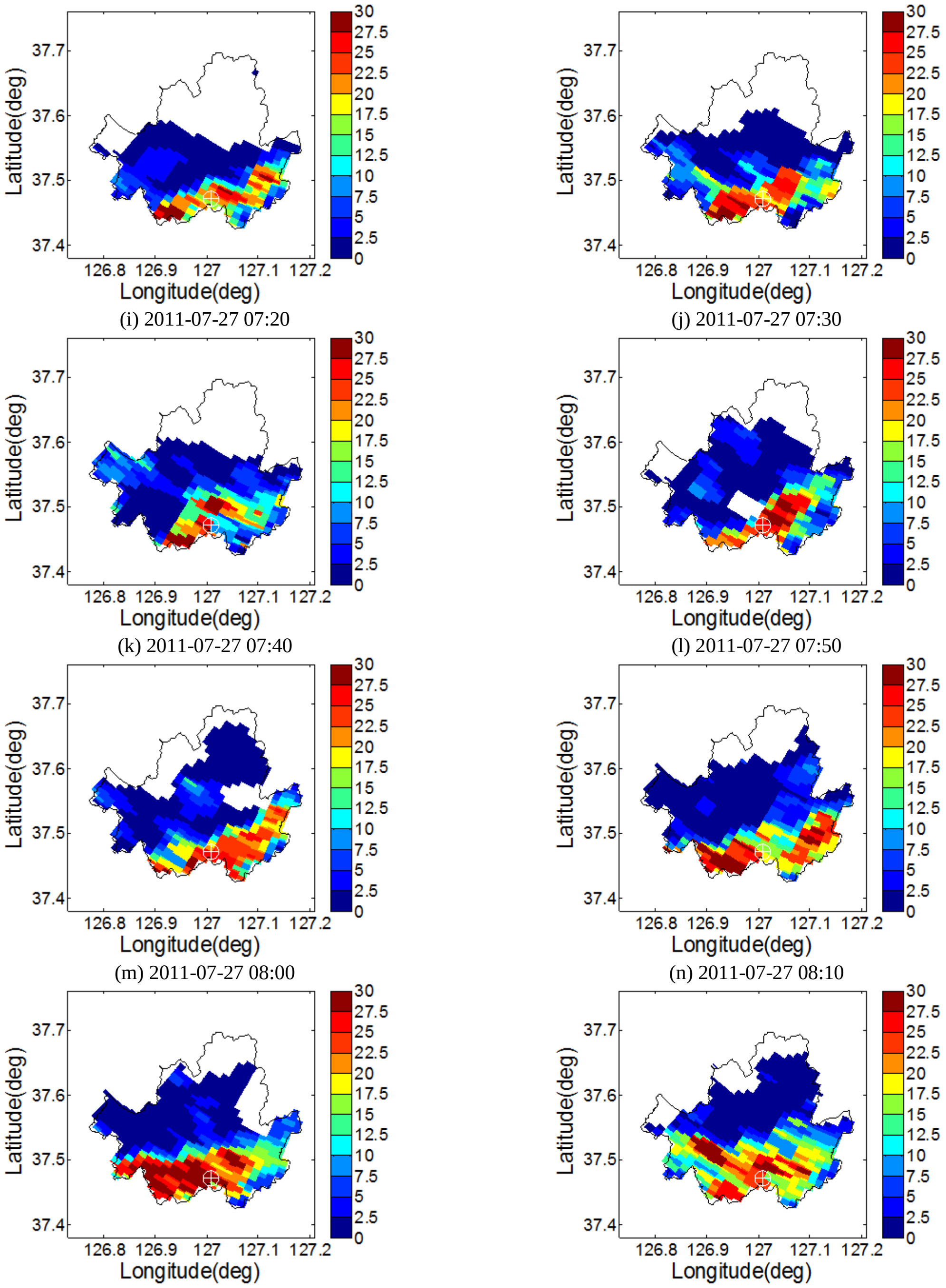


(a) 2011-07-27 06:00
(b) 2011-07-27 06:10
(c) 2011-07-27 06:20
(d) 2011-07-27 06:30
(e) 2011-07-27 06:40
(f) 2011-07-27 06:50
(g) 2011-07-27 07:00
(h) 2011-07-27 07:10

FIG. 8: Heavy rainfall nearby landslide occurrence timing



(i) 2011-07-27 07:20 (j) 2011-07-27 07:30

(k) 2011-07-27 07:40 (l) 2011-07-27 07:50

(m) 2011-07-27 08:00 (n) 2011-07-27 08:10

(o) 2011-07-27 08:20 (p) 2011-07-27 08:30

FIG. 8: Heavy rainfall nearby landslide occurrence timing (continued)