3. Disaster Management

3.1 Damaged Area Estimation Based on DMSP/OLS Nighttime Imagery

After an earthquake, spatial distribution of damaged areas is indispensable information for disaster management. Response and relief actions should be supported by efficient resource allocation based on spatial information. Hayashi et al. (2000) and Kohiyama et al. (2000) proposed estimation method of earthquake-damaged areas using the Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) nighttime images. Significant reduction in nighttime lights can be an indication of possible impacted areas due to earthquake disasters, because of power failure, building damage, or slowdown of human activity. DMSP/OLS images are observed on a daily basis, and the short repeat period of DMSP is more suitable for the emergency use than other high-resolution satellites. The estimated damaged areas due to the 1999 Kocaeli Earthquake, Turkey corresponded well to the reported damages considerably, so that the proposed method could be promising for rapid grasp of damaged areas. We apply the estimation method for the 1999 Chi-Chi Earthquake, Taiwan.

3.1.1 Damage Detection by Satellite Remote Sensing

In a large earthquake disaster, it is important to allocate limited human and physical resources efficiently, and it is also necessary to grasp spatial distribution of damaged areas in an early stage of post-disaster operations for more efficient response actions. Remote sensing using satellite is a powerful measure for this sake, and recent researches have conduced the advanced information services in disaster management, e.g., detection of building damages in wide areas (Aoki et al., 1998, Matsuoka and Yamazaki, 1999) and monitoring of recovery process (Hashitera et al., 1999a).

It can be expected that city lights will observably decrease after a large earthquake due to various reasons such as electricity failure, building collapses, evacuation to shelters or the suspension of commercial activities. Therefore, the significant reduction in nighttime lights can be an indication of possible impacted areas due to earthquake disasters. Satellite images observed by DMSP/OLS are suitable for early identification of the damaged areas for following reasons: 1) low light imaging capabilities permit the detection of faint light sources present at the earth's surface, and 2) The nighttime images may be observed twice or more times in a single night due to orbital overlaps and multiple day-night DMSP satellites. These suggest that we could detect significant reduction in nighttime lights at any day on a daily basis. The DMSP/OLS imagery has spatial resolution of 2.7 km, and the resolution is not as high as that of the Landsat/TM or the SPOT/HRV. But repeat periods of satellites with high-resolution sensors are longer than 24 hours, and the probability to acquire imagery of impacted areas immediately after a disaster is very low. In addition, it takes yet longer to deliver the imagery data in available form. Consequently, short repeat period is necessary for emergency use of observed imagery.

3.1.2 DMSP/OLS Imagery

DMSP/OLS nighttime imagery has two channels, visible and near-infrared (VNIR) band (0.5-0.9 um), and thermal infrared (TIR) band (10-13 um). The pixel of VNIR image has digital number (DN) ranging from 0 to 63 to represent relative light intensity. The TIR image pixel has DN ranging 0 to 255 corresponding from 190 to 310 K. Both images are re-sampled into grids system of 30 arc sec. by 30 arc sec. from the ground sample distance of 2.7 km.

Each pixel is geolocated based on the geodetic subtrack of the satellite orbit, satellite altitude, OLS scan angle equations, an Earth sea level model, and digital terrain data (Elvidge et al., 1999). The estimated pixel location is quite exact, but there are a-few-pixel gaps in comparing several images. This problem is overcome by offsetting the images to the position that minimizes the variance of VNIR DN differences, which can be assumed as an index of discrepancy of two images. For this use, the pixels in the same location are assumed to have the same DN. Thus pixels with little cloud and earthquake influence should be selected.

The gain settings of optical instruments are controlled and changed to observe clouds illuminated by moonlight for air navigation. The gain settings of each orbit cannot be known, but images of the consecutive nights or of the same lunar phase nights are assumed under the same gain settings, and the light intensity changes are calculated comparing DNs of two VNIR images.

3.1.3 Estimation Method

In nighttime imagery, brightness at each pixel can fluctuate due to many reasons. Figure 3.1.1 shows the criteria of estimated damaged area based on the histogram of DN differences between images before and after the earthquake. For the 1999 Kocaeli Earthquake, Turkey, we determine the threshold value that show the reduction in VNIR DNs with $p > 0.995$ as significantly reduced due to the earthquake disaster (Hashitera et al., 1999b), and the estimation results shows with a high degree of correspondence with the real damages (General Directorate of Disaster Affairs, 1999).

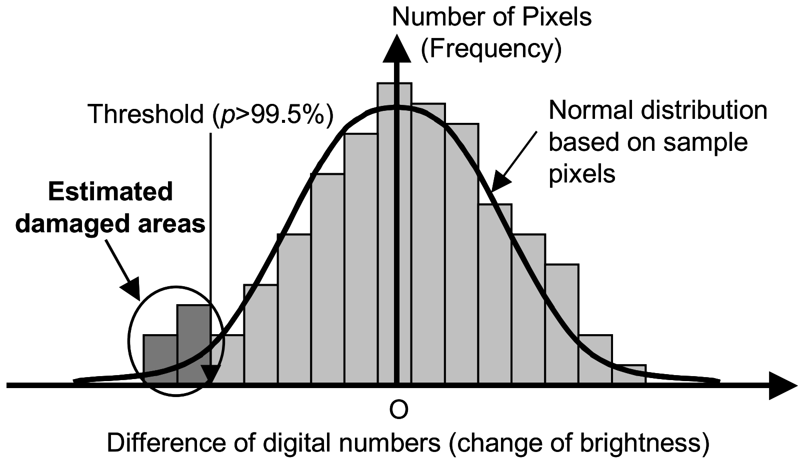


Figure 3.1.1. Criteria of damaged area estimation.

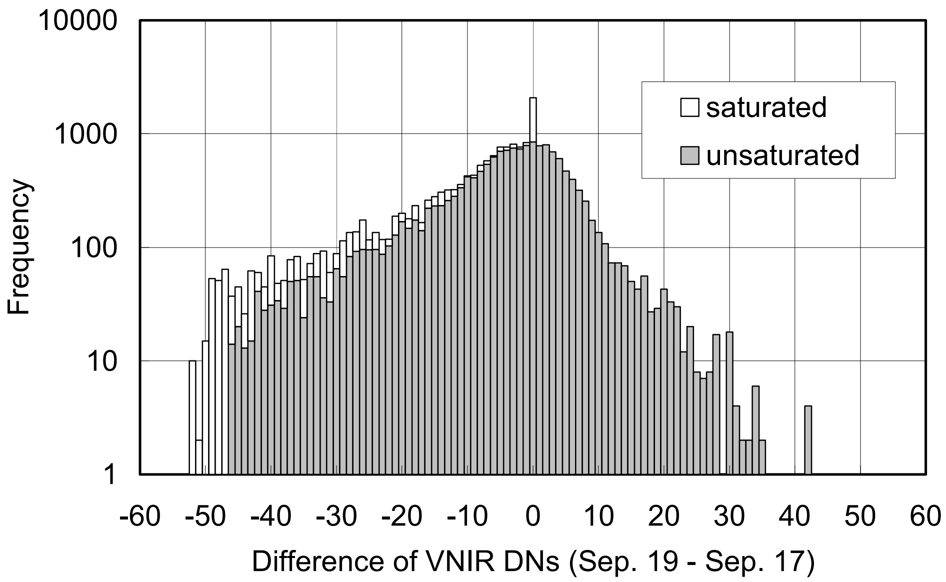


Figure 3.1.2. Histogram of digital number differences between images on September 17 and 19, 1999 in Taiwan.

The DN differences between two VNIR images, observed under the similar phase of lunar cycle, are induced by clouds, atmosphere and city lights themselves. Some other causes, fishing fleets (Cho et al., 1999) and biomass fires (natural or agricultural fires) (Cahoon et al, 1992) are noticeable, but by extracting urbanized area as a target area, those influences can be negligible. Elvidge et al. (1997) produced the world map of stable nighttime lights (SL), in which each pixel has DN ranging from 0 to 100 that shows the probability to detect the lights exceeding certain thresholds. Non-urban areas can be easily eliminated by choosing DN = 0 in SL map.

When observed light is brighter than threshold of DN saturation intensity, the VNIR DN yields 63. If an analyzing image has considerable number of saturated pixels, these pixels should be treated separately. This could happen when highly industrialized areas are in the scope. Figure 3.1.2 is the histogram of DN differences between images of Taiwan on September 17 and 19, 1999. In the figure, the frequencies of pixels which have unsaturated DN on September 17 are painted in gray, and those of saturated DN are in white. Great number of saturated pixels form an unrelated set like a spike where difference of DNs equals to zero. In this case, if treating saturated and unsaturated pixels in the same data set of difference of DNs, the variance of the data set will be smaller than that of data set with only unsaturated pixels, and determination of threshold value for damaged area estimation should be difficult.

When a pre-earthquake image is observed under the influence of heavy clouds, the cloud-free image can be estimated by using SL data. Figure 3.1.3 shows the scatter plot of VNIR DN observed under full moon and SL DN. The regression quadratic curve (the correlation coefficient: 0.63) is also shown in the figure. Regression curves in other moon phases can be evaluated in the similar way.

3.1.4 Estimation Results

At first, we replicated the estimation method of the possible impacted areas that was used for the 1999 Kocaeli Earthquake again. Because heavy clouds covered the area on the day before the event, we selected the images on September 17 as the pre-event baseline image, which has little cloud influence. VNIR and TIR images before and after the earthquake are shown in Figure 3.1.4 and Figure 3.1.5, respectively. There are consecutive three-day images after the earthquake in these figures. Figure 3.1.6 shows the estimated results neglecting influence of clouds, moonshine and gain setting difference. There was a countrywide power cut due to the damage of the trunk transmission facility in Chung-liao (National Center for Research on Earthquake Engineering, 1999) so that the decrease in light intensity in the post-event images seems to reflect that influence. But the interval between observation dates of pre-event image and post-event images may cause serious moonshine influence because of different gain setting of OLS.

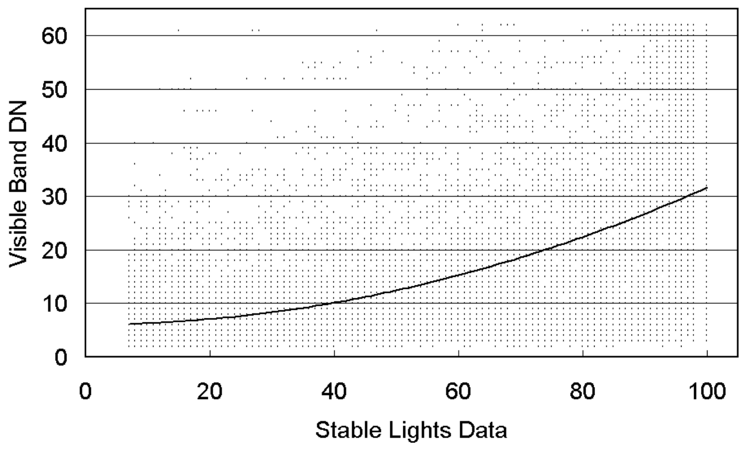


Figure 3.1.3. Scatter plot of visible-near infrared digital number (observed under full moon) versus stable lights digital number and regression curve.

Then, we estimated the possible impacted areas by improving following ways,

a) Eliminate non-urban areas using SL to defecate city lights.

b) Estimate the pre-earthquake image with SL and the regression curve.

We selected an image observed on September 23 as a post-event image, which has little cloud influence, and

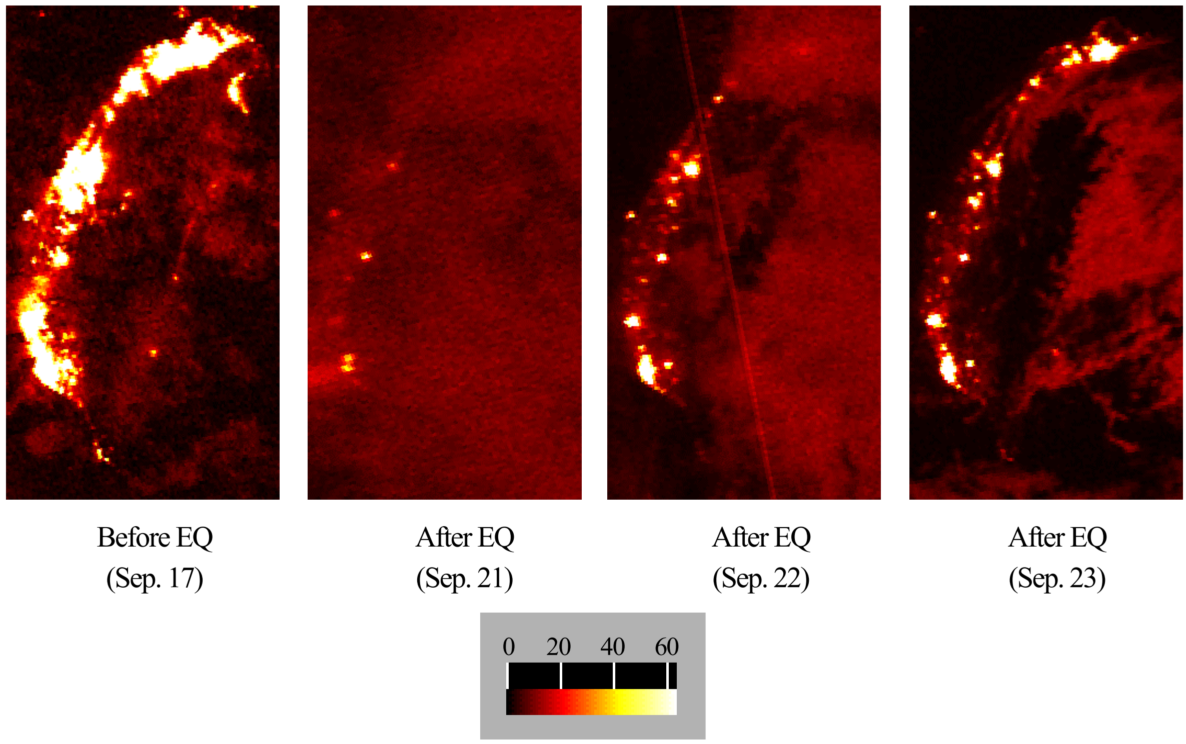


Figure 3.1.4. VNIR images before and after the earthquake (Refer to color figure 2).

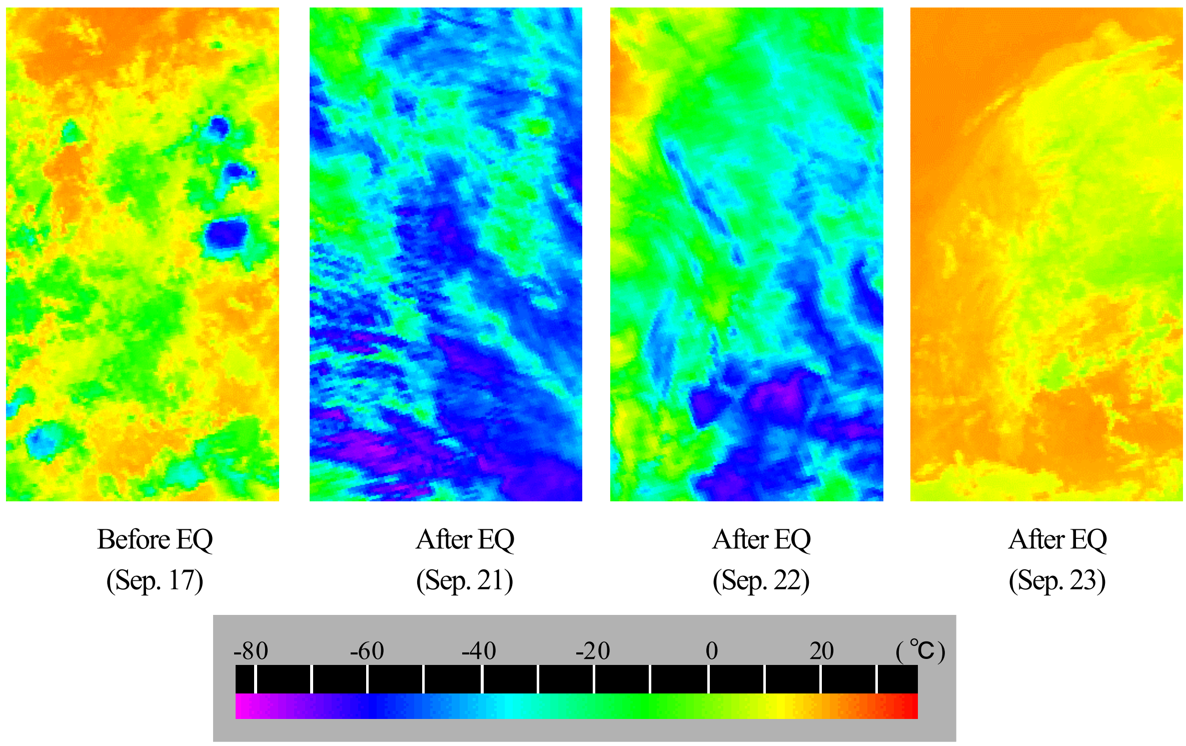
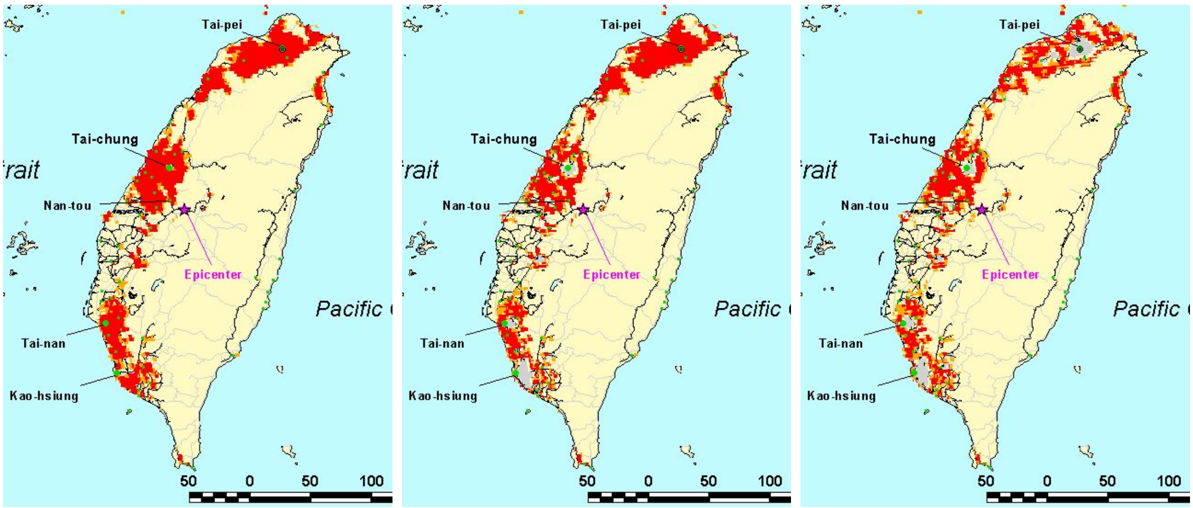


Figure 3.1.5. TIR images before and after the earthquake.

estimated an artificial pre-event image using SL and the regression curve.

Figure 3.1.7 shows the histogram of DN differences between two images, and the thresholds of $p > 95\%$ and 97.5% are used to estimate damaged areas. The estimation result of this improved method is shown in Figure 3.1.8. The improved result has less influence of moonshine reflection and gain shift of OLS than the estimated result shown in Figure 3.1.6. But the further investigation with the actual damage is needed to prove the validity of this method.



1st Night (Sep. 21) | 2nd Night (Sep. 22) | 3rd Night (Sep. 23)

Red: possible impacted areas ($p > 99.5\%$), Gray: incapable of estimation due to saturated data

Fig.3.1.6. Estimated results neglecting influence of clouds, moonshine and gain setting difference.

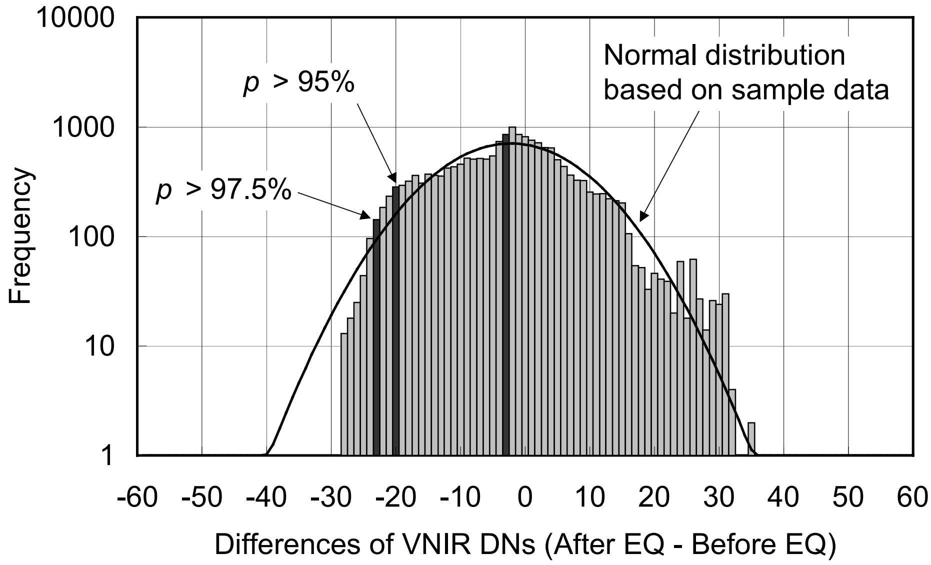
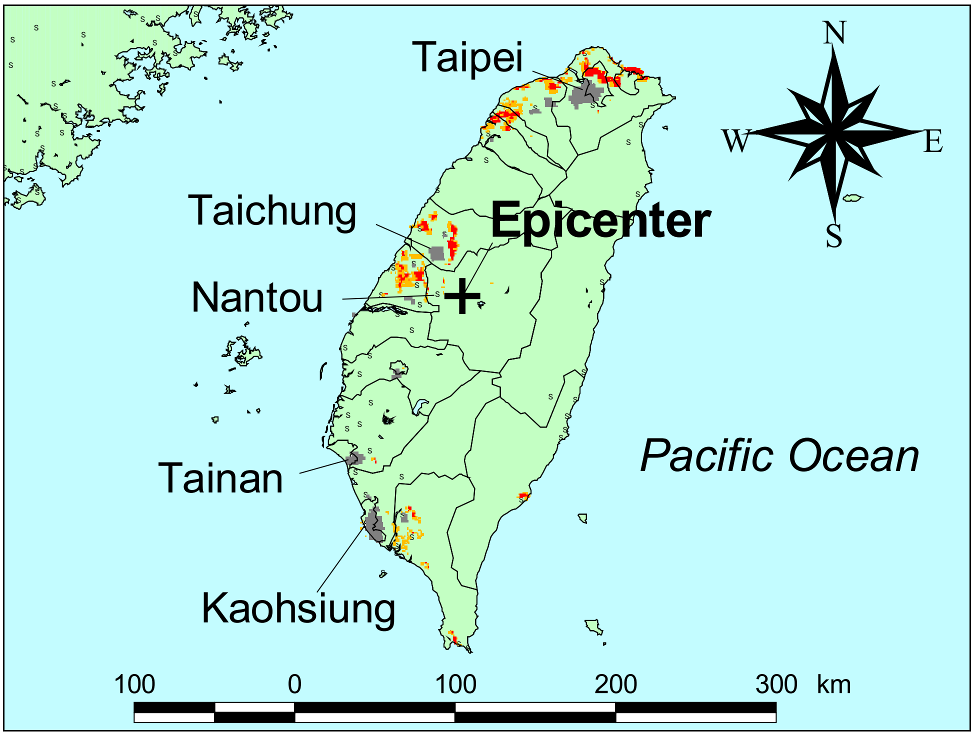


Figure 3.1.7. Histogram of digital number differences between artificial pre-earthquake image and image observed after the 1999 Chi-Chi Earthquake, Taiwan.



Red: possible impacted areas ($p > 97.5\%$), Yellow: possible impacted areas ($p > 95\%$)
Gray: incapable of estimation due to saturated data

Figure 3.1.8. Estimated damaged areas of the 1999 Chi-Chi Earthquake, Taiwan (Refer to color figure 3).

3.1.5 Summary

We proposed an estimation method of damaged areas, and applied it to the Chi-Chi Earthquake Disaster. Because of heavy clouds around the onset day of the earthquake, a pre-event image is estimated based on the Stable Lights Data and the regression curve representing relationship between digital numbers of observed image and Stable Lights Image. But it is needed to compare the estimated results with the real damage like power outage distribution to prove its validity. In addition, it is also needed to examine the availability of cloud-influenced images for a post-event image. We continue further investigations and examinations to devise a robust and reliable estimation method under various conditions.

In the 1999 Kocaeli Earthquake Disaster, we publicize the estimated result three weeks after the earthquake. As for the 1999 Chi-Chi Earthquake Disaster, it took ten days since the onset of the earthquake disaster to disseminate the final results, and it is still too long to support emergency actions. The entire process should be reduced to less than 24 hours since an onset of a disaster by establishing a proper procedure of analysis and dissemination process.

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