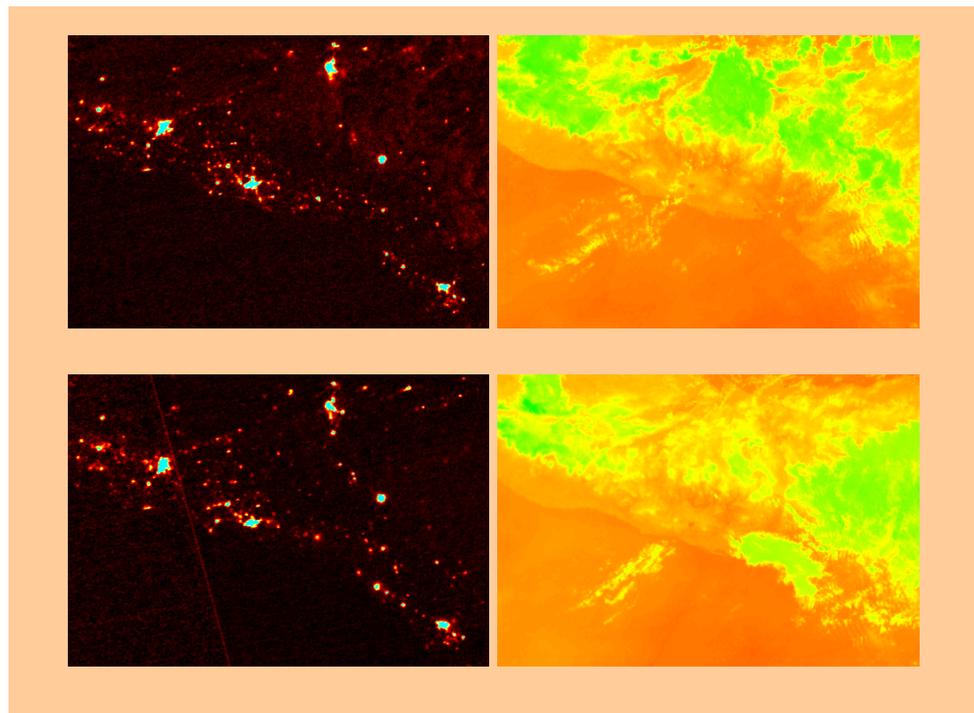




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5. DAMAGED AREA ESTIMATION BASED ON DMSP/OLS NIGHTTIME IMAGERY AND AERIAL RECONNAISSANCE

The January 13, 2001 Off the Coast of El Salvador Earthquake



VNIR and TIR images of El Salvador on January 12
before the earthquake (above) and on January 13
after the earthquake (below)

5.1 INTRODUCTION

EDM (Earthquake Disaster Mitigation Research Center) have developed EDES (Early Disaster Estimation System) using DMSP/OLS (Defense Meteorological Satellite Program's Operational Linescan System) nighttime imagery. EDES presented the estimated damaged areas in El Salvador on January 17 when was 4 days after the earthquake. JSCE reconnaissance team made an aerial survey by helicopter based on the map of the estimated damage area by EDES to understand the distribution of the earthquake-induced damage for buildings, infrastructures and landslides in El Salvador.

5.2 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 in recent major earthquake corresponded well to the reported damages considerably (Earthquake Disaster Mitigation Research Center, 2000a; Earthquake Disaster Mitigation Research Center, 2000b), so that the proposed method could be promising for rapid grasp of damaged areas.

5.3. DMSP/OLS IMAGERY

DMSP/OLS nighttime imagery has two channels, visible and near-infrared (VNIR) band (0.5-0.9 μm), and thermal infrared (TIR) band (10-13 μm). 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.

5.4 ESTIMATION METHOD

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. The satellite images observed by the DMSP/OLS are suitable for the early identification of the damaged areas for following reasons:

- 1) Due to the sensitive scanner, nighttime images are available.
- 2) The nighttime images are observed, at least, twice a day by two DMSP satellites.

These mean that we could detect significant reduction in nighttime lights at any day on a daily basis. The DMSP/OLS imagery has spatial resolution of 2.7km, and the resolution is not as high as that of the Landsat/TM or the SPOT/HRV. But the recurrent periods of the satellites with high-resolution sensors are more than two weeks and the chances to observe the image immediately after a disaster are very low. Consequently, the short recurrent period is necessary for emergency use of the observed imagery.

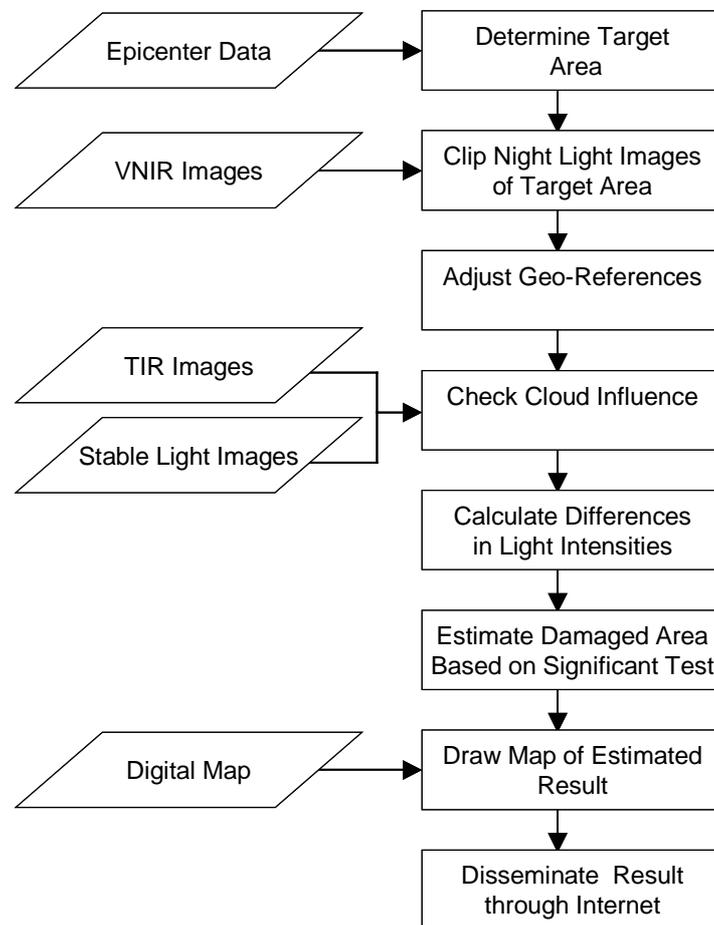


Figure 5.1 Flowchart of damaged area estimation.

The steps of damaged area estimation are shown in **Figure 5.1**. Each pixel in the visible-near infrared (VNIR) images has digital number (DN) ranging from 0 to 63. We calculated the differences of DNs on a pixel basis between before and after the earthquake in the sampled area. The cloud influences were checked using the thermal infrared (TIR) images and the stable light images. Based on the histogram of the differences, the areas that show the reduction in nighttime lights with $p > 0.995$ were determined as significant reduction due to the earthquake disaster (**Figure 5.2**).

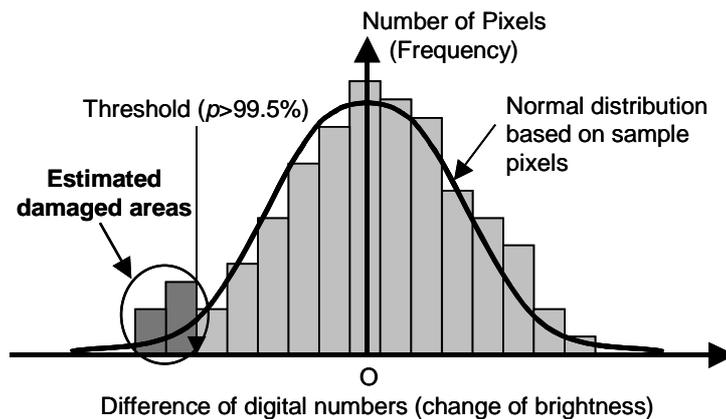


Figure 5.2 Criteria of damaged area estimation.

5.5. ESTIMATION RESULTS

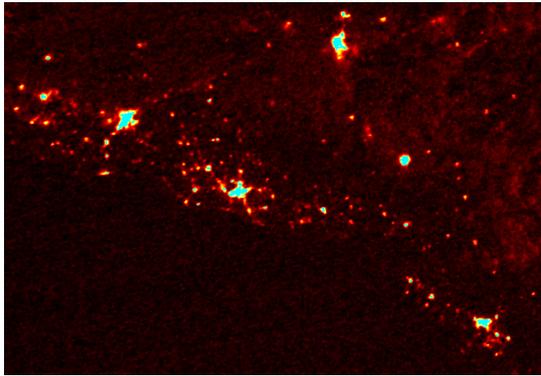
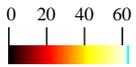
We estimated the possible impacted areas of the earthquake disaster. The DMSP/OLS images in this region were provided from National Oceanic and Atmospheric Administration's National Geophysical Data Center (NOAA/NGDC). The nighttime VNIR and TIR images on January 12 (before the earthquake), January 13 and 14 (after the earthquake) are shown in **Figures 5.3, 5.4** and **5.5**, respectively. The histogram of digital number differences between two VNIR images on January 12 and 13 is shown in **Figure 5.6**. The similar figure between January 12 and 14 is shown in **Figure 5.7**. The thresholds of $p > 95\%$ and 99% are used to estimate damaged areas. The estimated impacted areas based on Figure 6 (between January 12 and 13) and on **Figure 5.7** (between January 12 and 14) are shown in **Figure 5.8** and **5.9**, respectively.

The estimated impacted areas spread around San Salvador and eastern area including Usulután and San Miguel widely in **Figure 5.8**. In a few days after the earthquake, there was a countrywide power cut due to the damage of the transmissions and sub-stations facility (see chapter 5) so that the decrease in light intensity in the post-event images seems to reflect that influence. Because of recovery of electric power, the estimated impacted area including Usulután and San Miguel decrease after 2 days (**Figure 5.9**).

The disaster damage reported by COEN (Comité de Emergencia Nacional, 2001) is shown in Table 1. The map of prefectures in El Salvador is shown in **Figure 5.10**. The number of collapsed buildings in La Libertad, La Paz, Sonsonate, Usulután and San Salvador was over 10,000. These prefectures contained most of the estimated damaged cities in **Figure 5.9**. The estimation result showed with a high degree of correspondence with the real damage distribution.

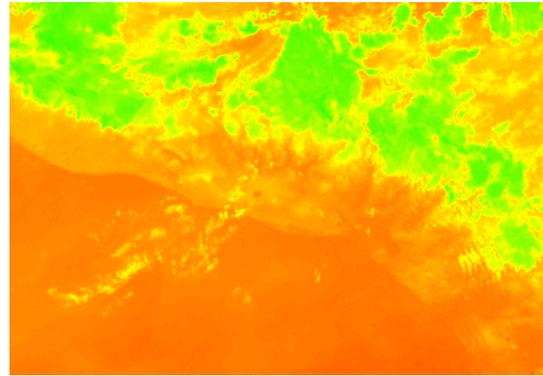
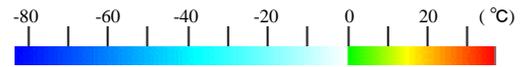
Hundreds of houses were buried due to a large landslide in Nueva San Salvador. The damage was estimated based on January 13 (**Figure 5.8**), on the other hand, the area could no be estimated because of the data saturation. It is difficult for this method to estimate the damage in highly populated area such as Nueva San Salvador.

Legend for VNIR



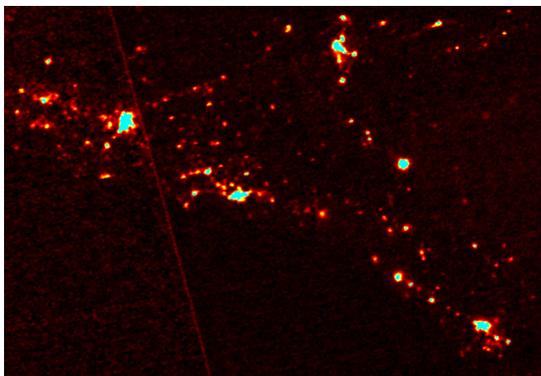
(a) VNIR image

Legend for TIR

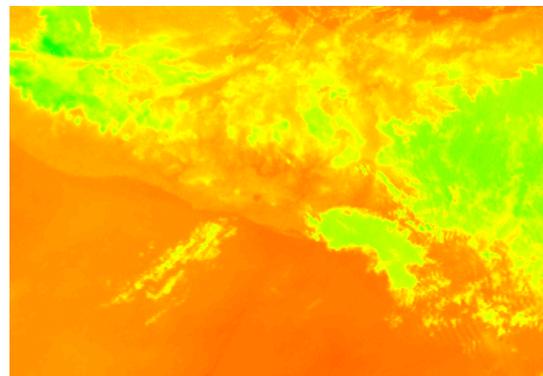


(b) TIR image

Figure 5.3 VNIR and TIR images on January 12 before the earthquake

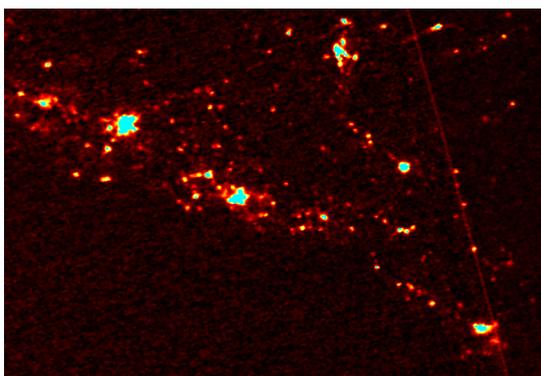


(a) VNIR image

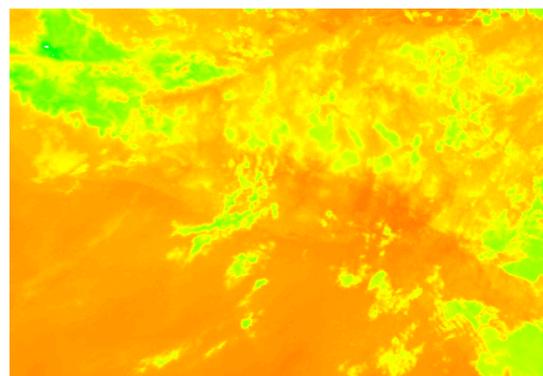


(b) TIR image

Figure 5.4 VNIR and TIR images on January 13 after the earthquake



(a) VNIR image



(b) TIR image

Figure 5.5 VNIR and TIR images on January 14 after the earthquake

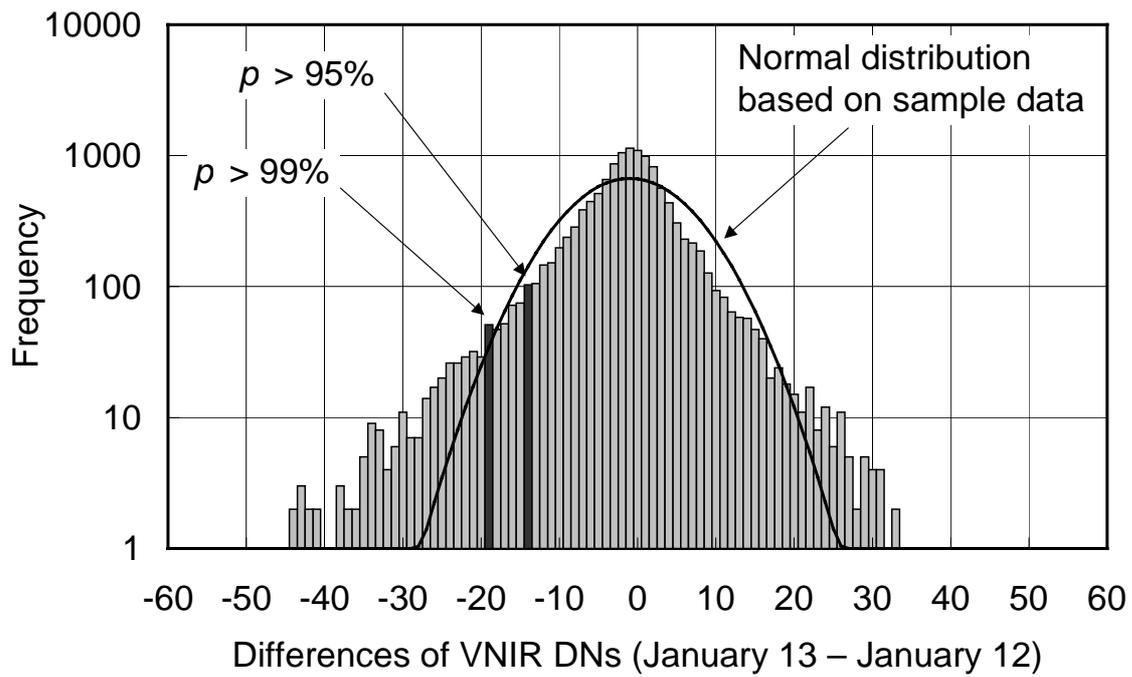


Figure 5.6 Histogram of digital number differences between two images on January 12 and 13

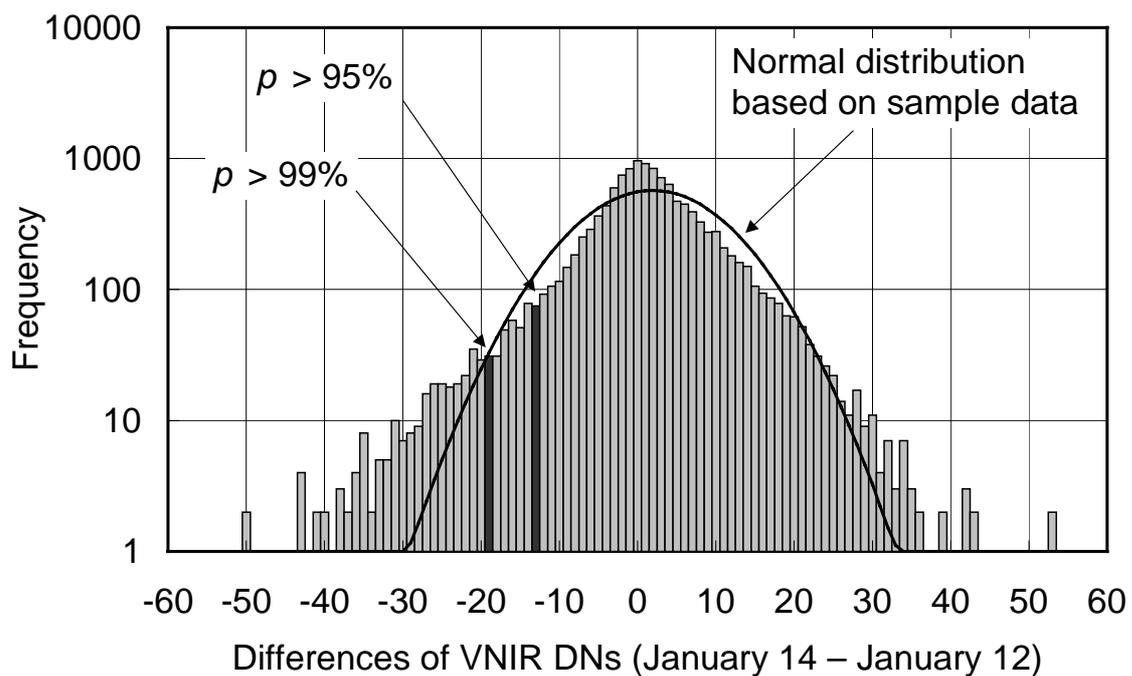


Figure 5.7 Histogram of digital number differences between two images on January 12 and 14



Figure 5.8 Estimated damaged area using two images on January 12 and 13.



Figure 5.9 Estimated damaged area using two images on January 12 and 14.

Table 5.1 Damage statistics (Comité de Emergencia Nacional, 2001)

Prefecture	Death	Injured	Damaged public buildings	Damaged houses	Collapsed houses	Buried houses	Refuge
La Libertad	685	2183	48	14558	15723	687	147708
La Paz	44	147	272	25076	17996	0	232135
Sonsonate	48	1295	38	17773	10501	0	101487
Santa Ana	47	327	5	13925	4823	0	112561
Cuscatlán	20	43	47	4762	4282	0	38119
Usulután	27	786	335	30716	29293	0	356391
San Salvador	24	391	76	12836	10372	0	107083
San Miguel	19	43	23	10624	2902	0	76665
San Vicente	29	81	40	17292	5218	0	103086
La Unión	1	8	98	2136	268	0	13094
Ahuachapán	0	247	60	18540	6553	0	71086
Cabañas	0	7	31	1153	309	0	2997
Morazán	0	3	35	94	5	0	498
Chalatenango	0	4	47	307	16	1	1250
TOTAL	944	5565	1155	169692	108261	688	1364160

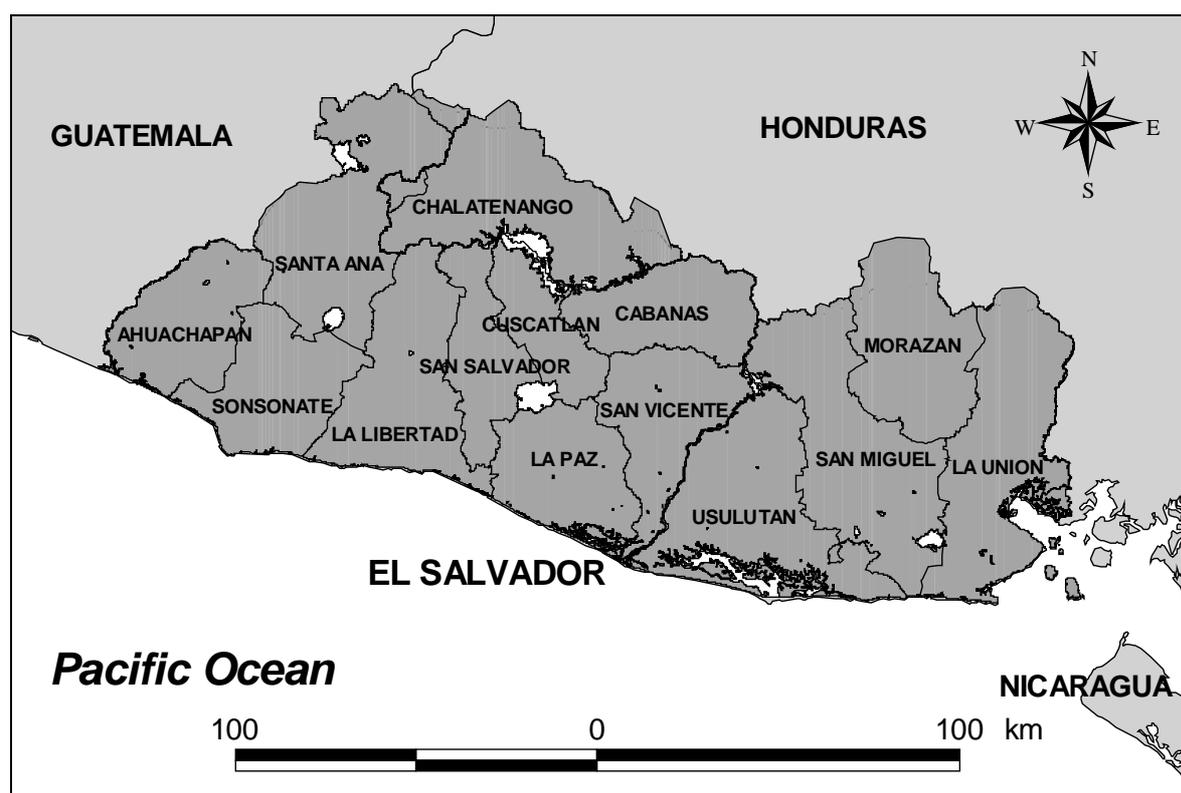


Figure 5.10 Prefecture boundary in El Salvador

5.6 AERIAL RECONNAISSANCE

JSCE reconnaissance team made an aerial survey by helicopter on February 3. The El Salvador military gave the team members a lift on a helicopter. The purpose of the flight was to obtain the overview of the geo-hazards, damage of buildings and infrastructures. The flight path is roughly illustrated in Figure 11. We departed from San Salvador military airport, and surveyed from the western area to eastern area in El Salvador. The cities of Santa tecla, San Salvador, Zacatecolca and San Miguel and the small towns of Jayaque, Comasagua, San Agustin and Santiago De Maria are located on the flight path. The overview of the damage of buildings and infrastructures will be described in this section.

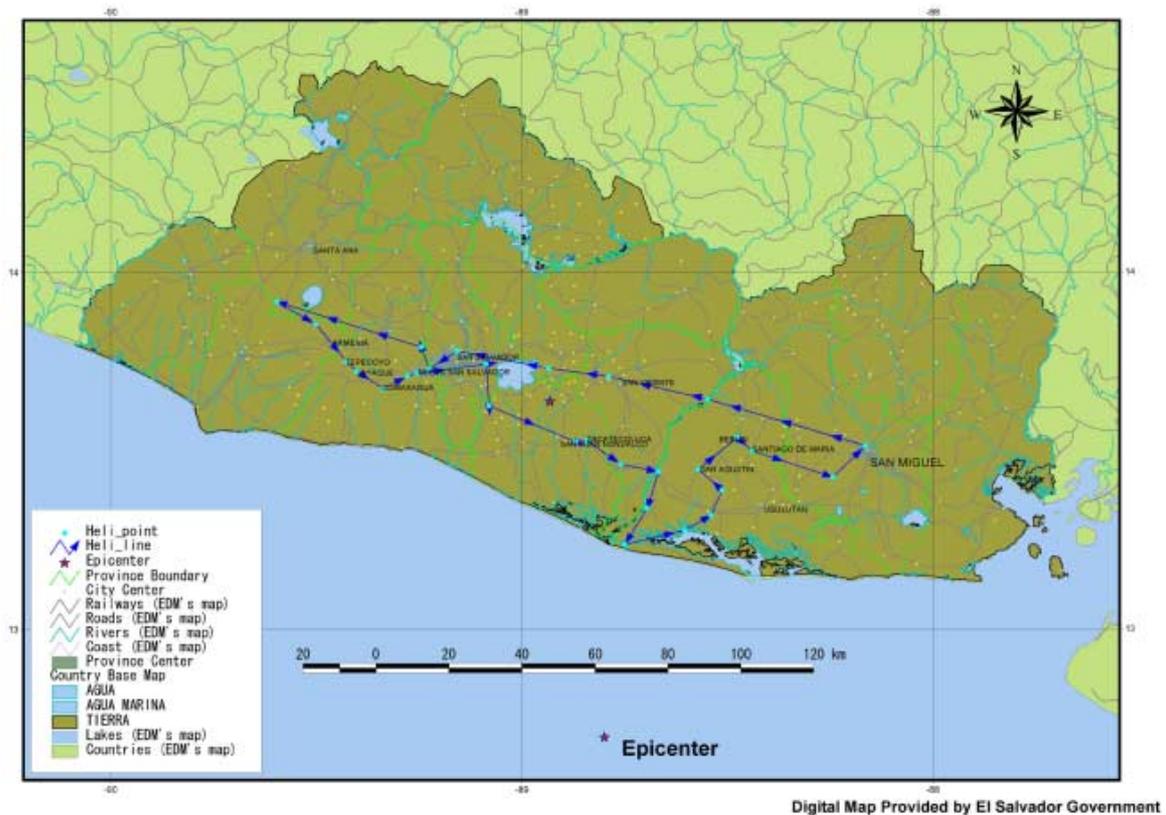


Figure 5.11 Helicopter flight route

The overview of the damage distribution of buildings and infrastructures is summarized as follows.

- 1) In western area of San Salvador, dwellings at small mountain villages such as Tepecoyo, Jayaque, Talnique and Comasagua in La Libertad suffered serious damages due to strong ground motion and landslide (**Figure 5.12**).
- 2) Las Colinas landslide destroyed hundreds of houses and killed over 500 people in Nueva San Salvador (**Figure 5.13**).
- 3) In eastern area of San Salvador, dwellings at towns such as San Juan Nonualco and Zacatecoluca in La Paz suffered slight damages of roofs and walls (**Figure 5.14**).
- 3) San Marcos Bridge on Lempa River was slightly damaged with subsidence of back fill soil behind the abutment. The girder of the old railway bridge close to San Marcos Bridge fell down due to the horizontal displacement of the riverside ground (**Figure 5.15**). The cracks and sand boils were shown in some places along Lempa River (**Figure 5.16**).

- 4) Dwellings at mountain villages such as San Augstin and Santiago de Maria in Usulután suffered damages (**Figure 5.17, Figure 5.18**). Especially, most of dwellings such as unreinforced adobe and bahareque houses were collapsed at San Augstin.
- 5) No major damages were observed in San Miguel City, which is one the largest city in eastern area (**Figure 5.19**).

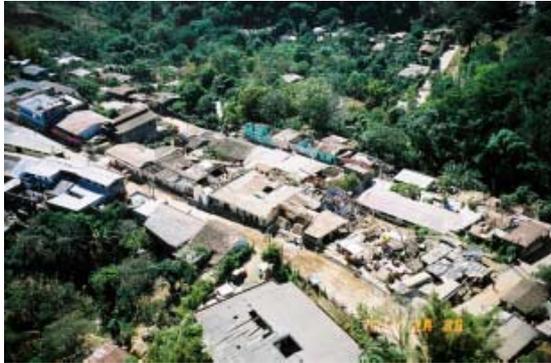


Figure 5.12 Collapsed houses at Jayaque village in La Libertad



Figure 5.13 Las Colinas landslide in La Libertad

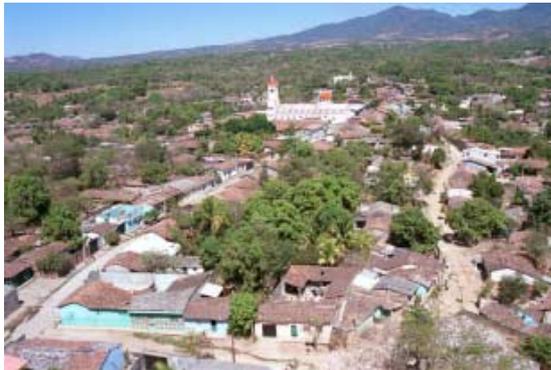


Figure 5.14 Damaged houses at San Juan Nonualco in La Paz



Figure 5.15 Damaged bridges on Lempa River



Figure 5.16 Liquefaction-induced sand boils along Lempa River



Figure 5.17 Collapsed houses at San Augstin in Usulután

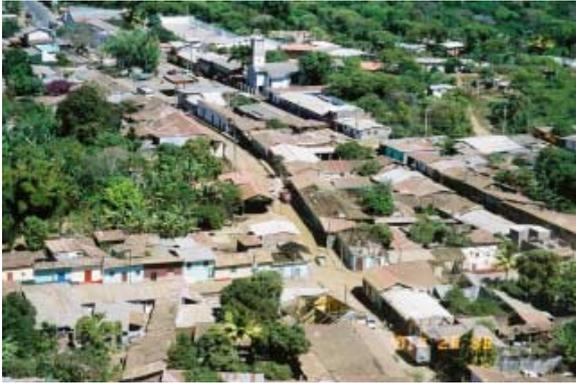


Figure 5.18 Damaged houses at Santiago de Maria in Usulután

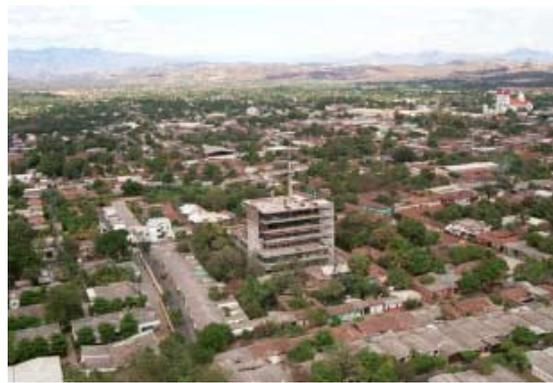


Figure 5.19 No major damage in San Miguel City

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