Remote Sensing and Earthquake Damage Detection Using Optical Images

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What is Remote Sensing?

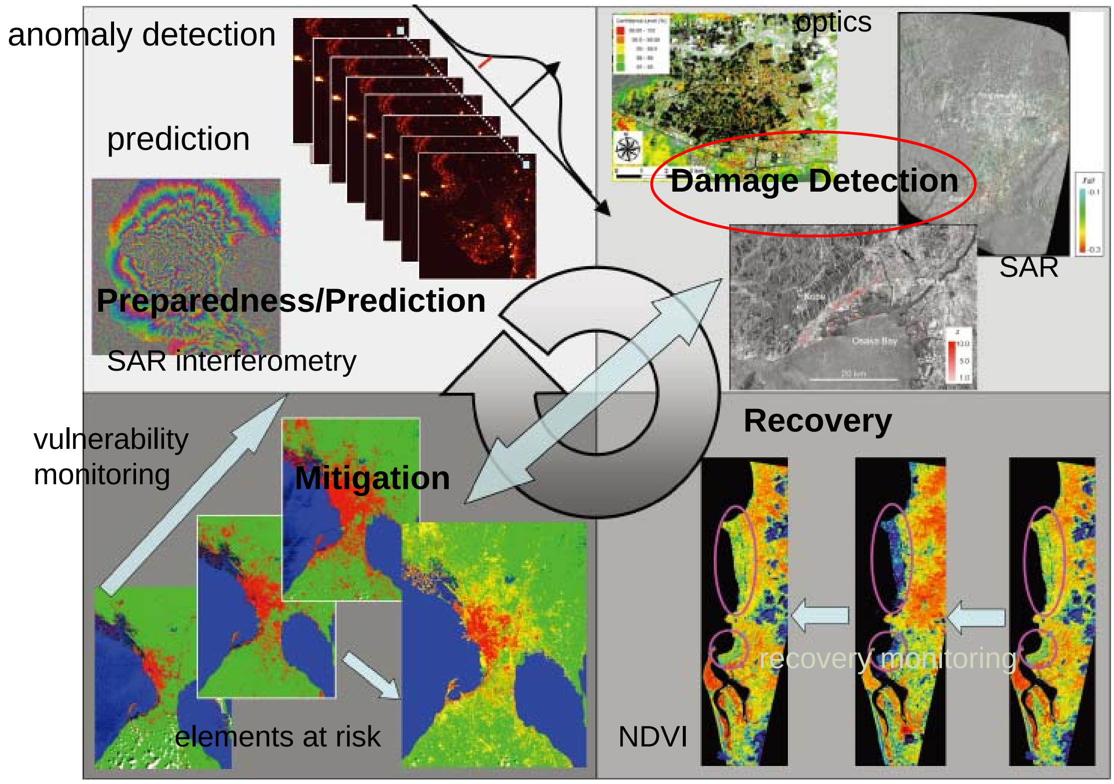
"Remote" means far away. Remote sensing means sensing things from a distance. Of **our** five senses **we** use three as remote sensors when we:

a. watch a football game from the stands (sense of sight)
b. smell freshly baked bread in the oven (sense of smell)
c. hear a telephone ring (sense of hearing)

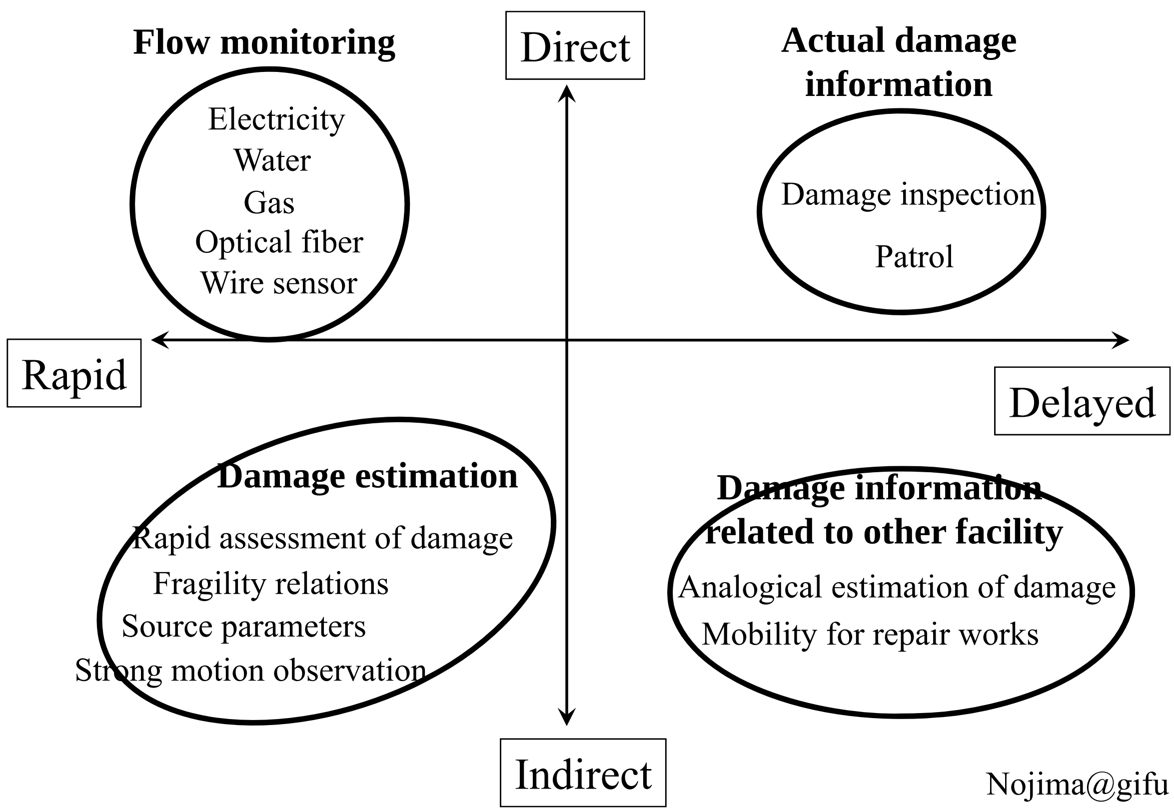
What are our other two senses and why aren't they used "remotely"?

five senses 〔touch, taste, hearing, eyesight, and smell〕

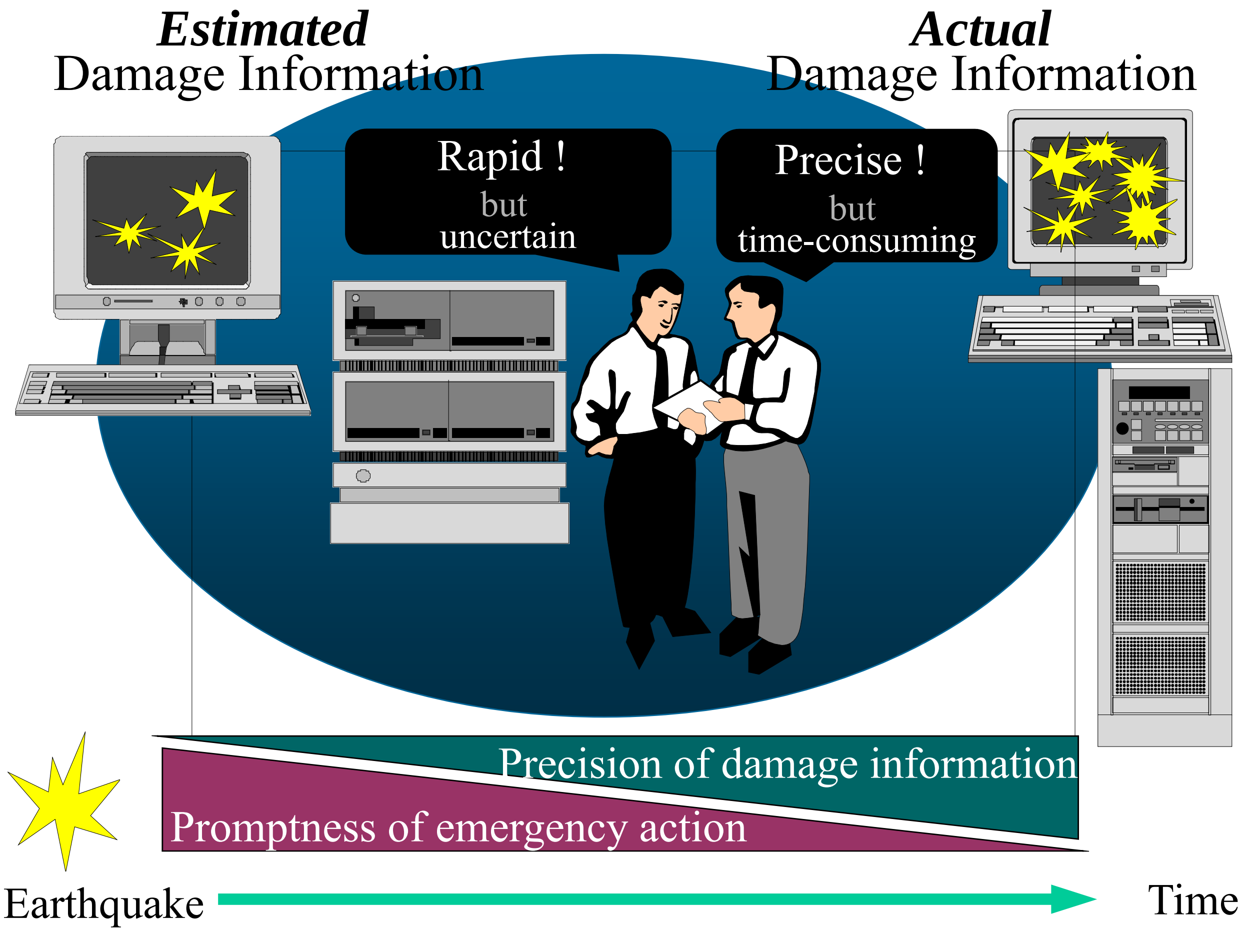
Information from Remote Sensing data in terms of Disaster Management Cycle



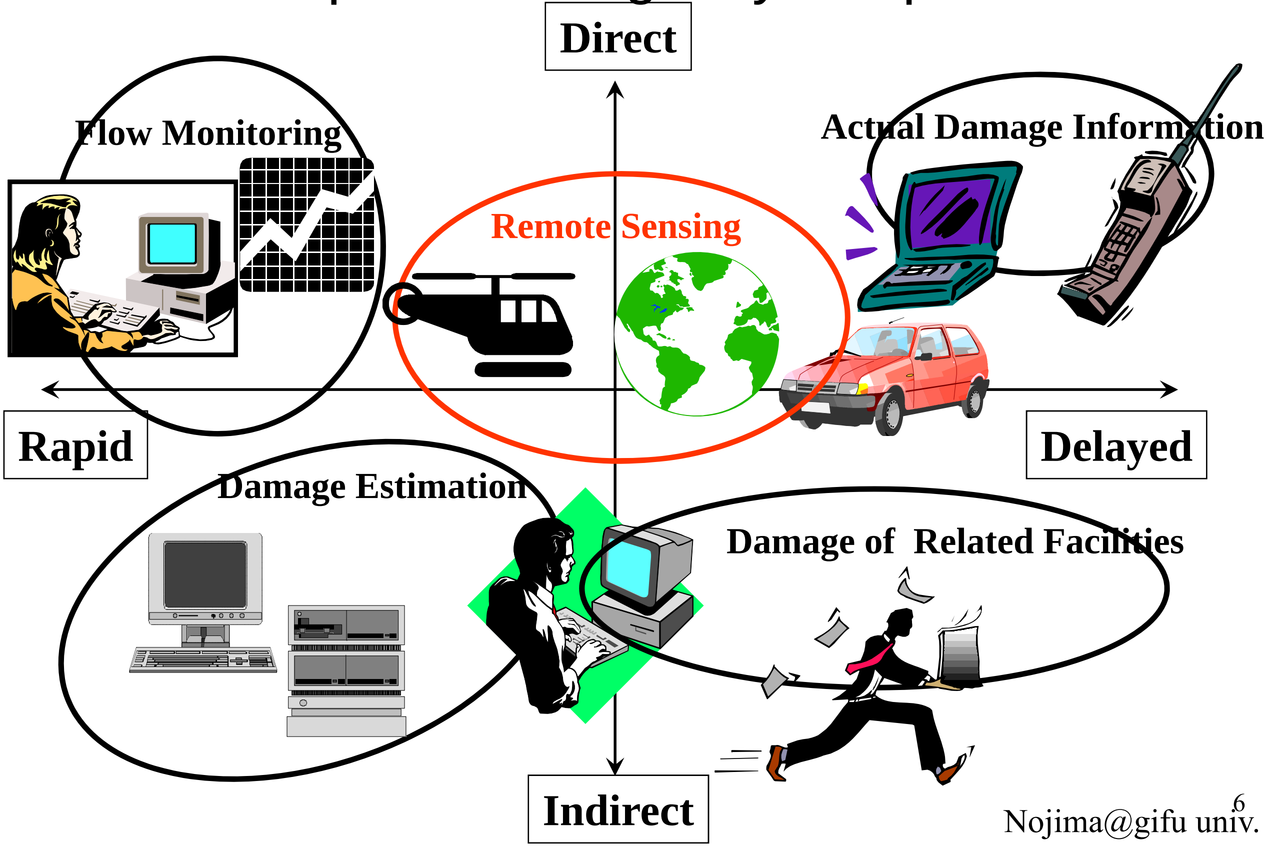
Various Information Sources for Earthquake Emergency Response



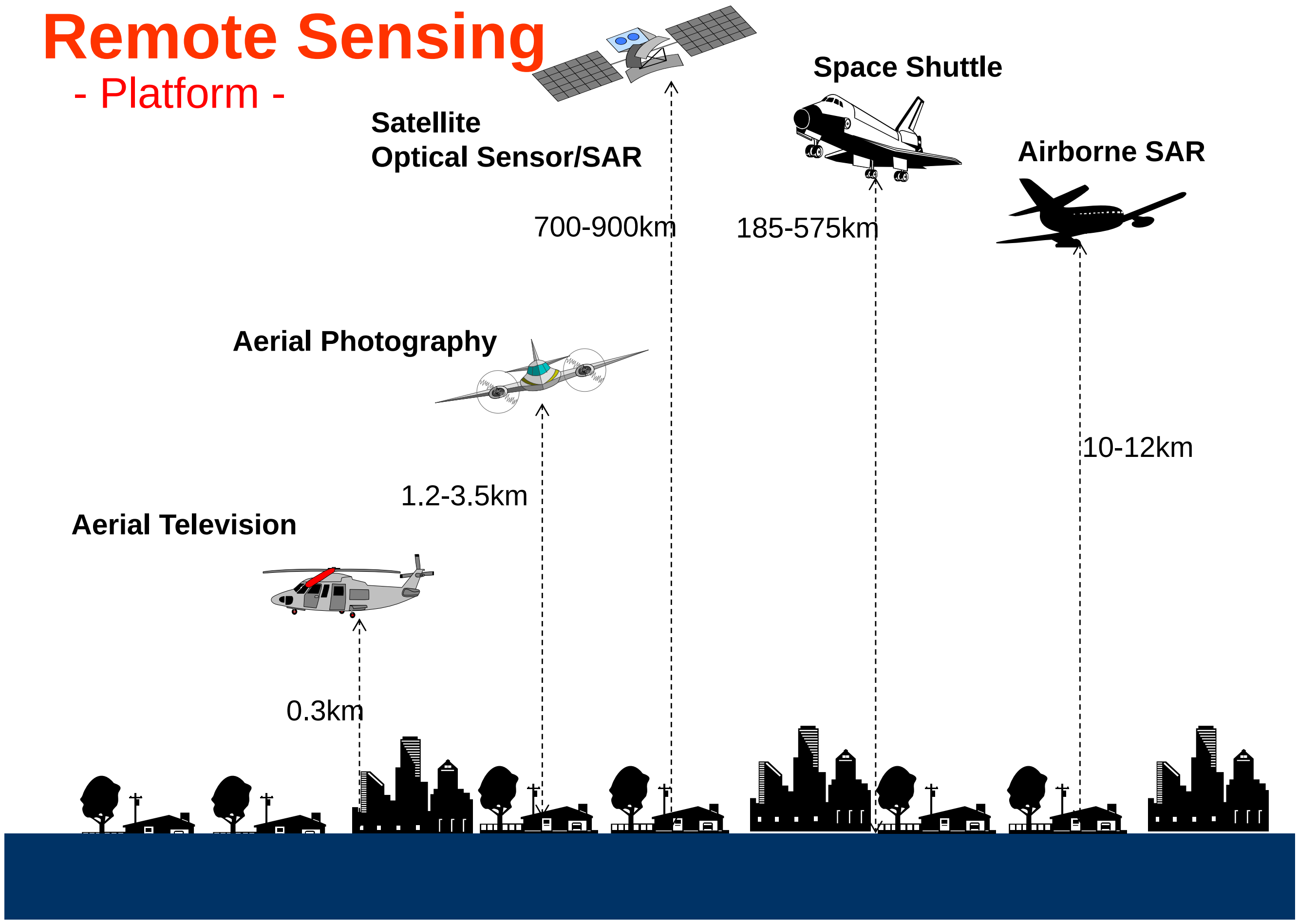
Nojima@gifu univ.



Various Information Sources for Earthquake Emergency Response



Remote Sensing
- Platform -



Damage Assessment
(Resolution-based Comparison)

- Macro Scale Estimation
  Meteorological Satellites
  (MTSAT, NOAA, DMSP, etc.)
- Intermediate Scale Detection
  Earth Observatory Satellites
  (ALOS, Landsat, SPOT, Envisat, etc.)
- Micro Scale Identification
  High-resolution Satellites,
  Airplane, Helicopter

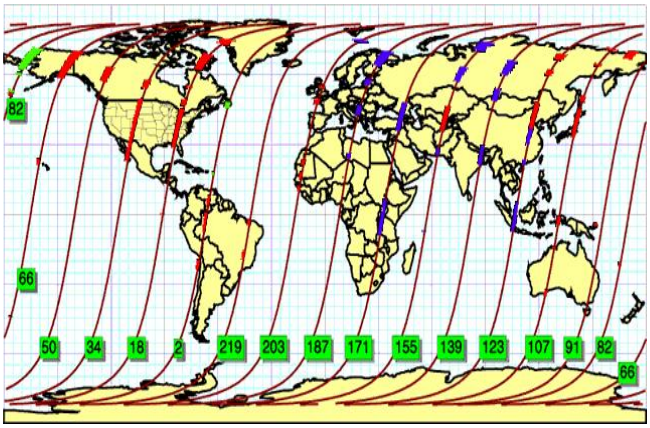
Spatial Resolution of Satellites

- Images where only large features are visible are said to have **coarse or low resolution**.
- In **fine or high resolution** images, small objects can be detected. **Military** sensors for example, are designed to view as much detail as possible, and therefore have very fine resolution.
- **Commercial** satellites provide imagery with resolutions **varying** from a few meters to several kilometers.
- Generally speaking, **the finer the resolution**, **the less total ground area** can be seen.

Multispectral Sensors of Moderate-Resolution Satellites

Multispectral								
Sensor - Satellite		**Sponsor**	**Lifespan**	**Spatial Resolution**	**Swath**	**Spectral Bands**	**Other Sensor Specs**	**Repeat Cycle**
Landsat 4 & 5	TM	NASA/NOAA/USGS	1984-	30m MS 120m TIR	185x172 km	MS 7 Bands VNIR-TIR		16 days
Landsat 7	ETM+	NASA/NOAA/USGS	April 15th 1999 - ongoing** 6 yrs	15m Pan 30m MS 60m TIR	185x172 km	Pan 520-900nm 5 Bands VNIR 2 Bands SWIR 1 Band TIR	** Data quality dropped significantly since the SLC failure in June 2003.	16 days
SPOT 4	2xHRV-IR & Vegetation	CNES	March 1998 - ongoing ?	10m Pan 20m MS	60x60 km	MS 4 bands (500-590, 610-680, 790-890, 1580-1750nm) Pan (610-680nm)	Also Vegetation Instrument at 1.1km pixel	3 to 26 days ±27° inclination
IRS-P6	LISS-4, LISS-3 & AWiFS	INDIA (ISRO)	Oct. 2003 - ongoing	5.8, 23.5 & 56m	23.9, 141 & 740 km	LISS-4 3 bands 520-860nm		24 days
ASTER	Terra	MITI/NASA	December 1999 6 yrs mission	15m VNIR 30m SWIR 90m TIR	60 km x 60 km	3 bands VNIR 520-860nm, 6 bands SWIR 1600-2430nm, 5 bands TIR 8125-11650nm, Bands for stereoscopy 780-	ASTER DEM product available, about 30m accuracy.	16 days
CBERS-2	CCD Camera	CHINA-BRAZIL	Oct. 2003	2 yrs	20m	CCD(high-res.,5bands)	113 km	26 days
ALOS	AVNIR-2	JAXA	Jan. 2006	10m MS		4 bands		46 days
	PRISM	JAXA	Jan. 2006	2.5m Pan		1 band		

http://homepage.mac.com/alexandreleroux/arsist/arsist.html



Paths of Landsat 7

http://landsat.usgs.gov/

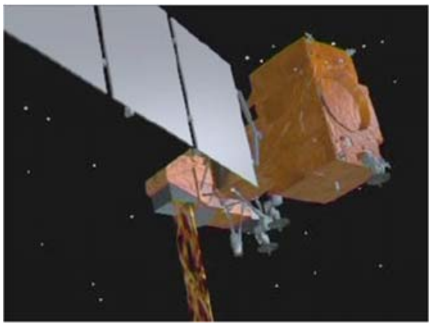
= Path (orbit)

61 = Path Number

= USGS/EROS Data Center - Sioux Falls, SD

= Svalbaard, Norway

= Poker Flat, Alaska



Path and Row of Landsat 7
and the areas affected by
the 2004 Indian Ocean Tsunami

Sensors of High-Resolution Satellites

High Resolution								
Sensor - Satellite		Sponsor	Lifespan	Spatial Resolutio	Swath	Spectral Bands	Other Sensor Specs	Repeat Cycle
ORBView-3		Orbimage	June 2003 5 yrs mission	1m Pan 4m MS	8 km	MS 4 bands (450-520, 520-600, 620-690, 760-900nm) Pan (450-900nm)	±45° off nadir	< 3 days
Quickbird-2		DigitalGlobe	Oct. 2001 - ongoing	0.61m Pan 2.44m MS	16.5 km 165 km track	MS 4 bands (450-520, 520-600, 630-690, 760-890nm) Pan (450-900nm)	QB 2 polar orbit ±30° in all directions Stereo	1-3.5 days
IKONOS-2		Space Imaging	Sept. 1999 - ongoing	1m Pan 4m MS	11.3 km wide at nadir	MS 4 bands (450-520, 520-600, 630-690, 760-900nm) Pan (525.8-928.5nm)	±26° inclination 11 bits data	1-3 days
EROS 1A		West Indian	Dec. 2000 - ongoing	1.8m Pan	12.6x12.6 km	Pan (500-900nm)		1.8-4 days
SPOT 5a	HGR & Vegetation	Spot Image	May 2002 > 5 yrs mission ?	2.5 & 5m Pan 10m MS 20m SWIR	60 km	MS 4 bands (500-590, 610-680, 790-890, 1580-1750nm) Pan 510-730nm	Also Vegetation Instrument	3 to 26 days ±31° inclination
IRS-1C & 1D	LISS3 & WiFS sensors	INDIA (ISRO)	1C: Dec. 95 - ongoing 1D: Sept. 97 -	5m Pan 20m MS 180m WiFS	70x70 km Pan 142x142 km MSS 774x774 km WiFS	Pan 500-750nm MS 4 bands (520-590, 620-680, 770-860, 1550- WiFS 2 bands (620-680, 770-860nm)	Pan ±26° inclination	24 days 5-24 off-nadir Pan
WorldView-1		DigitalGlobe	Sept. 2007	0.5m Pan	17.6km	Pan		1.7 days
WorldView-2		DigitalGlobe	Oct.. 2009	0.5m Pan	16.4km	**MS 8 bands** (1.8m) + Pan (0.5m)		1.1 days
GeoEye-2		GeoEye	Sept.. 2008	0.4m Pan	15.2km	**MS bands** (1.6m) + Pan (0.4m)		2.1 days

http://homepage.mac.com/alexandreleroux/arsist/arsist.html

QuickBird-2

Launch

on October 18, 2001

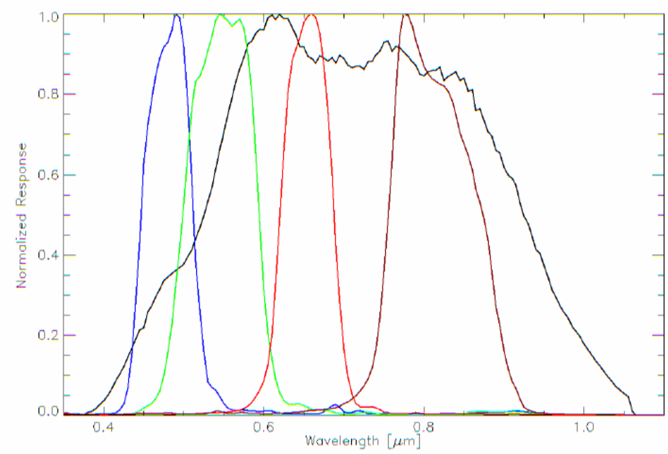
Features

Highest resolution sensors commercially available

Sensor Resolution

61-cm panchromatic at nadir
2.44-m multi-spectral at nadir

Blue -Band 1	**450-520 nm**
Green -Band 2	**520-600 nm**
Red -Band 3	**630-690 nm**
Near IR-Band 4	**760-900 nm**
Panchromatic	**450-900 nm**

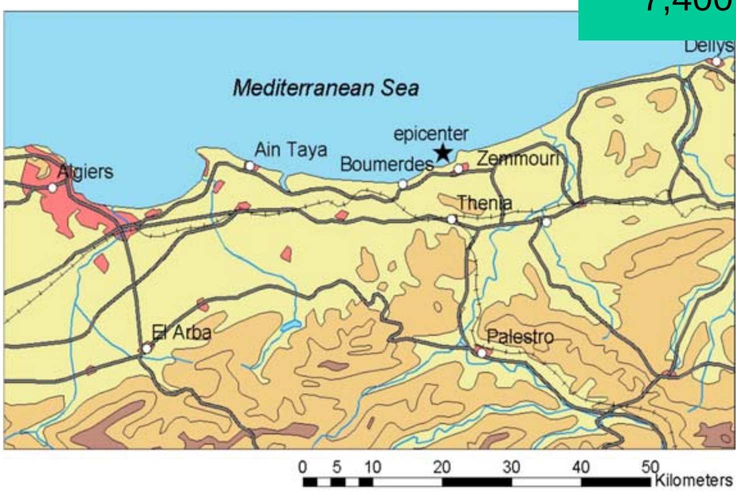


Normalized QB spectral band responses

http://www.digitalglobe.com

QuickBird Captured Affected Areas of the 2003 Boumerdes, Algeria Earthquake

- Mw = 6.8
- The epicenter is located offshore of the province of Boumerdes.
- Approximate numbers of collapsed and heavily damaged buildings were 7,400 and 7,000, respectively.



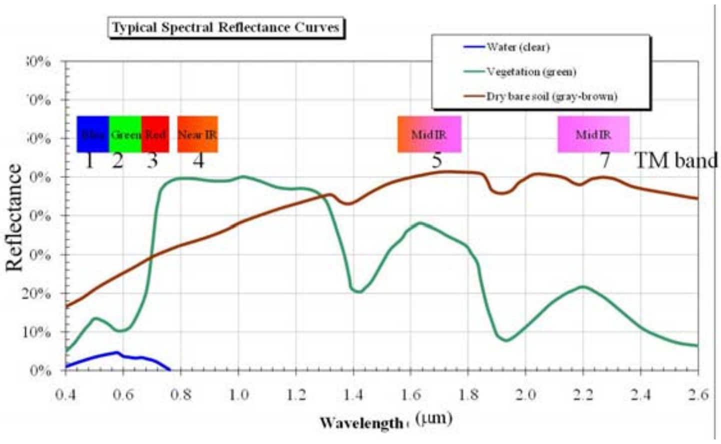
South Campus, Boumerdes University

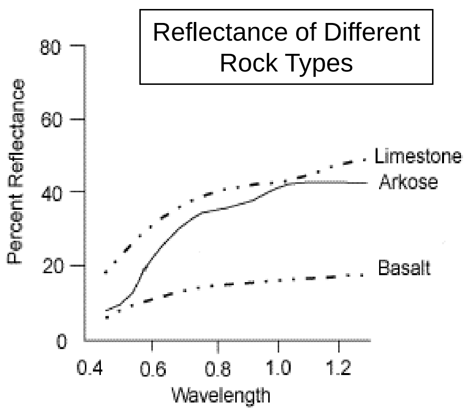
Photo by Dr. K. Meguro on 22 July, 2003

Spectral Resolution

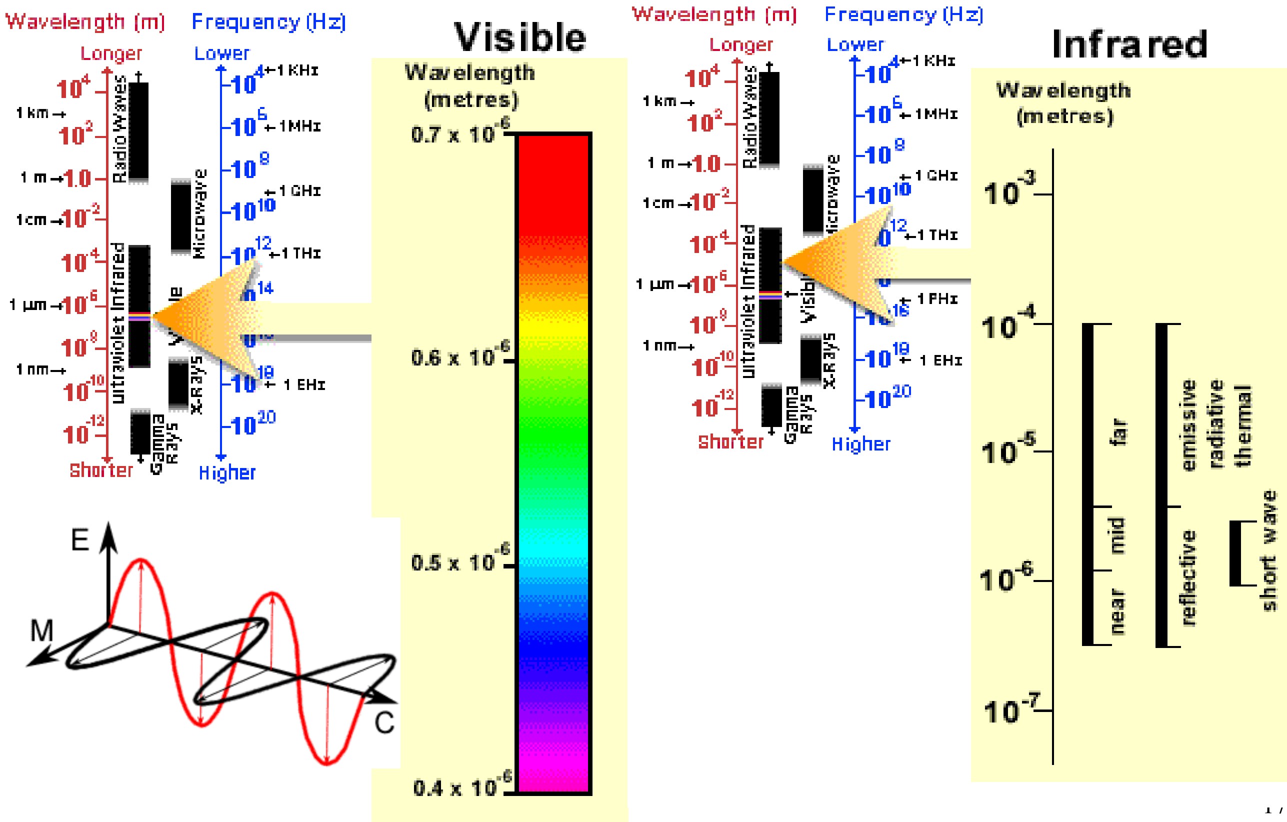
Different classes of features and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges. **Broad classes**, such as water and vegetation, can usually be separated **using very broad wavelength ranges** - the visible and near infrared .

Other **more specific classes**, such as different rock types, may not be easily distinguishable using these broad wavelength ranges and would require comparison **at much finer wavelength ranges** to separate them.



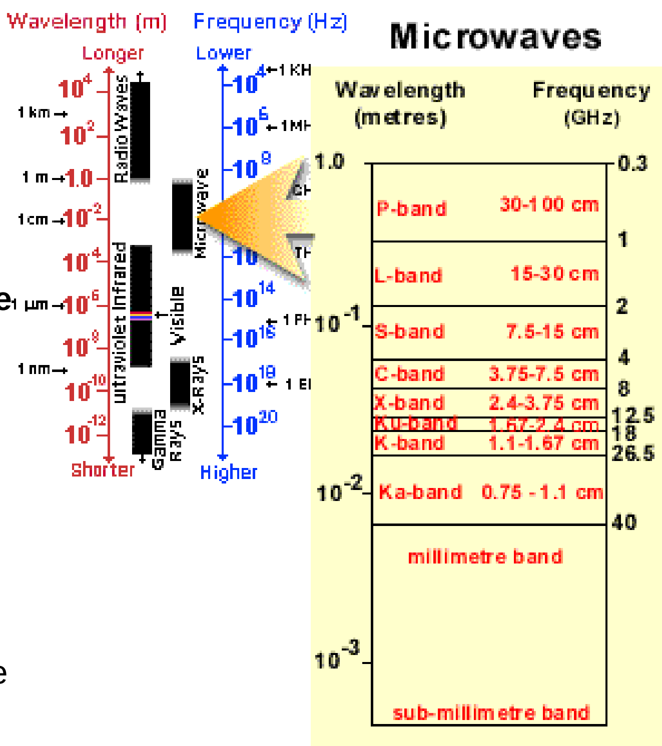


Electromagnetic Spectrum



Microwave fundamentals

- **Ka, K,** and **Ku bands**: very short wavelengths used in early airborne radar systems but uncommon today.
- **X-band**: **used extensively** on **airborne** systems (e.g. PI-SAR) for military reconnaissance and terrain mapping.
- **C-band**: **common** on many **airborne** research systems (e.g. NASA AirSAR) and **spaceborne** systems (ERS-1, 2 and RADARSAT).
- **S-band**: used on board the Russian ALMAZ satellite.
- **L-band**: used onboard SEASAT and JERS-1 satellites and airborne systems.
- **P-band:** longest radar wavelengths, used on NASA experimental airborne research system.

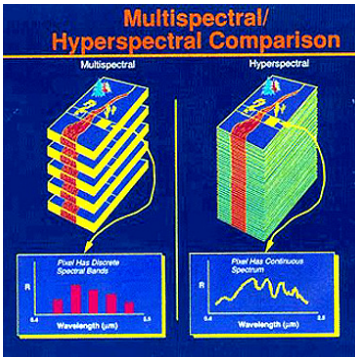


Multi-spectral and Hyper-spectral Sensors

Many remote sensing systems record energy over **several separate wavelength** ranges at various spectral resolutions. These are referred to as **multi-spectral sensors**.

Advanced multi-spectral sensors called **hyperspectral** sensors, detect **hundreds of very narrow spectral bands** throughout the **visible**, **near-IR**, and **mid-IR** portions of the EM spectrum.

Their very high spectral resolution facilitates **fine discrimination** between different targets based on their spectral response in each of the narrow bands.

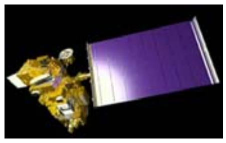


Hyperspectral Sensors

Hyperspectral Sensor - Satellite		Sponsor	Lifespan	Spatial Resolution	Swath	Spectral Bands	Other Sensor Specs	Repeat Cycle
EO-1	Hyperion	NASA	Dec. 1999 - ongoing ! (sept. 2003) 1 yr mission	30m	7.5 km x 100 km	220 bands 400nm to 2500nm @10nm Grating Imaging Spec Grating Imaging Spec		
EO-1	LEISA AC	NASA	12/1/1999 1 yr mission	250m	7.5 km x 100 km	309 Bands 850-1600nm @2.4nm Wedge Imaging Spec		
Envisat-1	MERIS	ESA Aerospatiale France, Cannes, ACRI	May 2002 5 yrs mission	300m @nadir and 1200m global	1150 km	15 bands programmable 390-1040nm @2.5nm	5 identical sensors	35 days
ADEOS-2	GLI	NASDA	Dec. 2002 - Oct. 2003 3 yrs design	250/1000m		19 bands 375-865nm @8-20nm 4 bands 460-825nm @50-110nm 6 bands 1050-2210nm @20-220nm 7 bands 3715-12000nm @330-1000nm	Failed prematurely on october 25 2003	

http://homepage.mac.com/alexandreleroux/arsist/arsist.html

Terra-MODIS (Moderate Resolution Imaging Spectroradiometer)



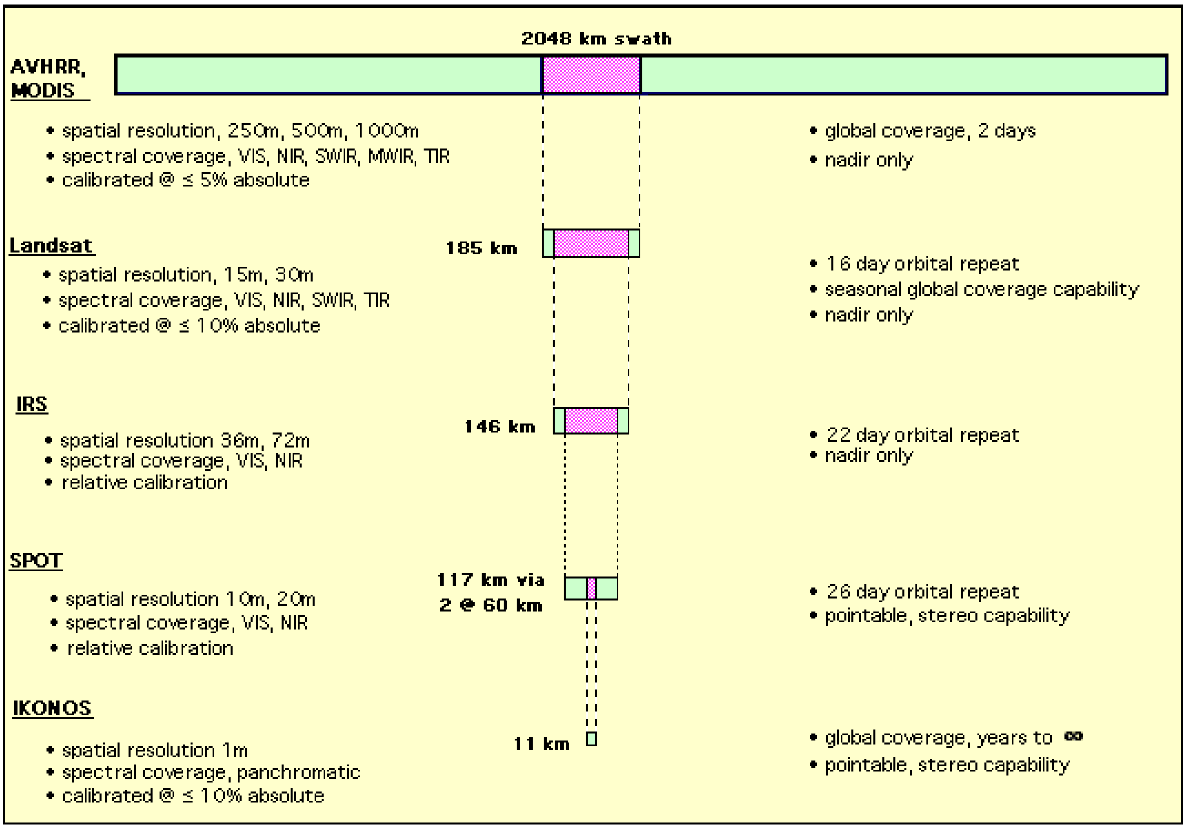
Sees every point on our world every 1-2 days
in 36 discrete spectral bands.

Primary Use	Band	Bandwidth
Land/Cloud	1	620- 670
Boundaries	2	841- 876
Land/Cloud	3	459- 479
Properties	4	545- 565
	5	1230- 1250
	6	1628- 1652
	7	2105- 2155
Ocean Color/	8	405- 420
Phytoplankton/	9	438- 448
Biogeochemistry	10	483- 493
	11	526- 536
	12	546- 556
	13	662- 672
	14	673- 683
	15	743- 753
	16	862- 877
Atmospheric	17	890- 920
Water Vapor	18	931- 941
	19	915- 965
Surface/Cloud	20	3.660- 3.840
Temperature	21	3.929- 3.989
	22	3.929- 3.989
	23	4.020- 4.080
Atmospheric	24	4.433- 4.498
Temperature	25	4.482- 4.549
Cirrus Clouds	26	1.360- 1.390
Water Vapor	27	6.535- 6.895
	28	7.175- 7.475
	29	8.400- 8.700
Ozone	30	9.580- 9.880
Surface/Cloud	31	10.780- 11.280
Temperature	32	11.770- 12.270
Cloud Top	33	13.185- 13.485
Altitude	34	13.485- 13.785
	35	13.785- 14.085
	36	14.085- 14.385

Bands 1 to 19, nm; Bands 20-36, µm
Spatial Resolution: 250 m (bands 1-2)
(at nadir): 500 m (bands 3-7)
1000 m (bands 8-36)

250m | 1km | 500m

Swath of various satellites

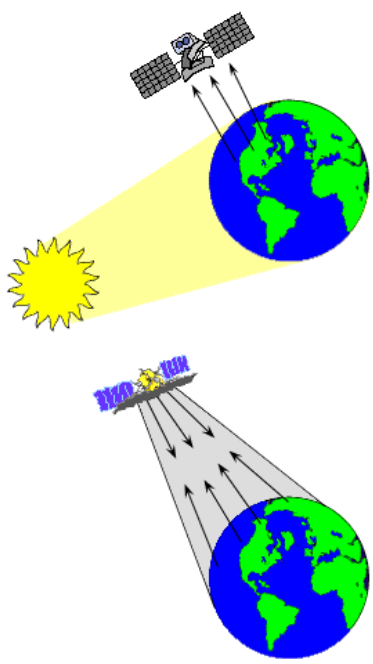


Type of Sensors

- ✓ Optical
  - ✓ Visible and near-infrared
  - ✓ Thermal
- ✓ LiDAR (Light Detection And Ranging)
- ✓ Radar (Radio Detection And Ranging)

The Remote Sensing Framework

- Source of Energy
  - – Passive Sources (Natural)
    - Reflected solar radiation
    - Emitted terrestrial radiation
  - – Active Sources (Man-made)
    - Flash photography
    - Radar/LIDAR/Sonar



International Charter on Space and Major Disasters

- Background
  - Following the UNISPACE III conference held in Vienna, Austria in July 1999, the European and French space agencies (ESA and CNES) initiated the International Charter "Space and Major Disasters", with the Canadian Space Agency (CSA) signing the Charter on October 20, 2000. In September of 2001, the National Oceanic and Atmospheric Administration (NOAA) and the Indian Space Research Organization (ISRO) also became members of the Charter. The Argentine Space Agency (CONAE) joined in July 2003. The Japan Aerospace Exploration Agency (JAXA) became a member in February 2005. The United States Geological Survey (USGS) has also joined the Charter as part of the U.S. team. BNSC/DMC and China National Space Administration (CNSA) became a member in November 2005 and May 2007, respectively.

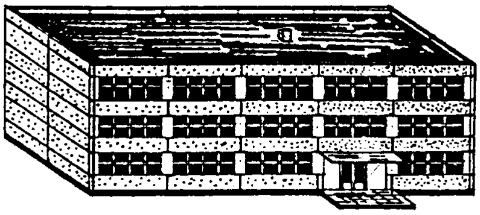
- Aim and activity
  - The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through authorized users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property.
  - Earth Observation (EO) satellite image-based maps and other regional maps are also opened to public through the web site. (http://www.disasterscharter.org/)

Index in Building Damage

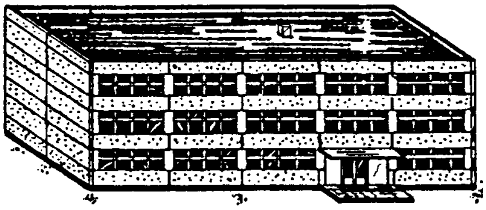
Based on the classification of damage to buildings of reinforced concrete used in the European Macroseismic Scale (EMS)

Index	Description	Interpretation
Grade 1	Slight Damage	Cosmetic cracking, no observable distress to load bearing structural elements
Grade 2	Moderate Damage	Cracking in load bearing elements, but no significant displacements across the cracks
Grade 3	Heavy Damage	Cracking in load bearing elements with significant deformations across the cracks
Grade 4	Partial Collapse	Collapse of portion of the building in plan view (i.e. a corner, or a wing of building)
Grade 5	Collapse	Collapse of the complete structure or loss of a floor of the structure

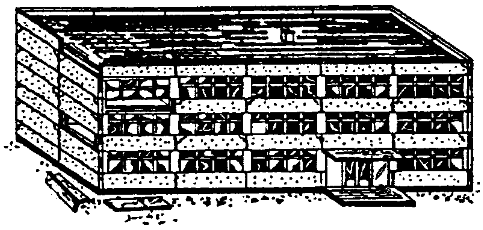
Classification of damage to buildings of reinforced concrete used in the European Macroseismic Scale (EMS)



Grade 1: Negligible to slight damage
(no structural damage, slight non-structural damage)
Fine cracks in plaster over frame members or in walls at the base.
Fine cracks in partitions and infills.



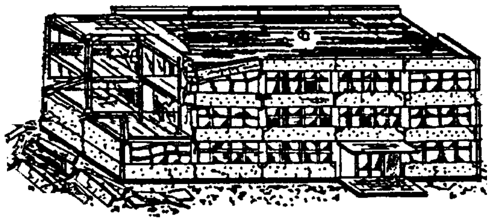
Grade 2: Moderate damage
(slight structural damage, moderate non-structural damage)
Cracks in columns and beams of frames and in structural walls.
Cracks in partition and infill walls; fall of brittle cladding and plaster.
Falling mortar from the joints of wall panels.



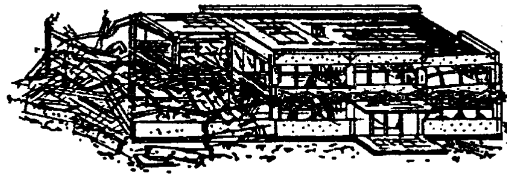
Grade 3: Substantial to heavy damage
(moderate structural damage, heavy non-structural damage)
Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods.
Large cracks in partition and infill walls, failure of individual infill panels.

http://www.gfz-potsdam.de/portal/gfz/Struktur/Departments/Department+2/sec26/projects/04_seismic_vulnerability_scales_risk/EMS-

Classification of damage to buildings of reinforced concrete used in the European Macroseismic Scale (EMS)



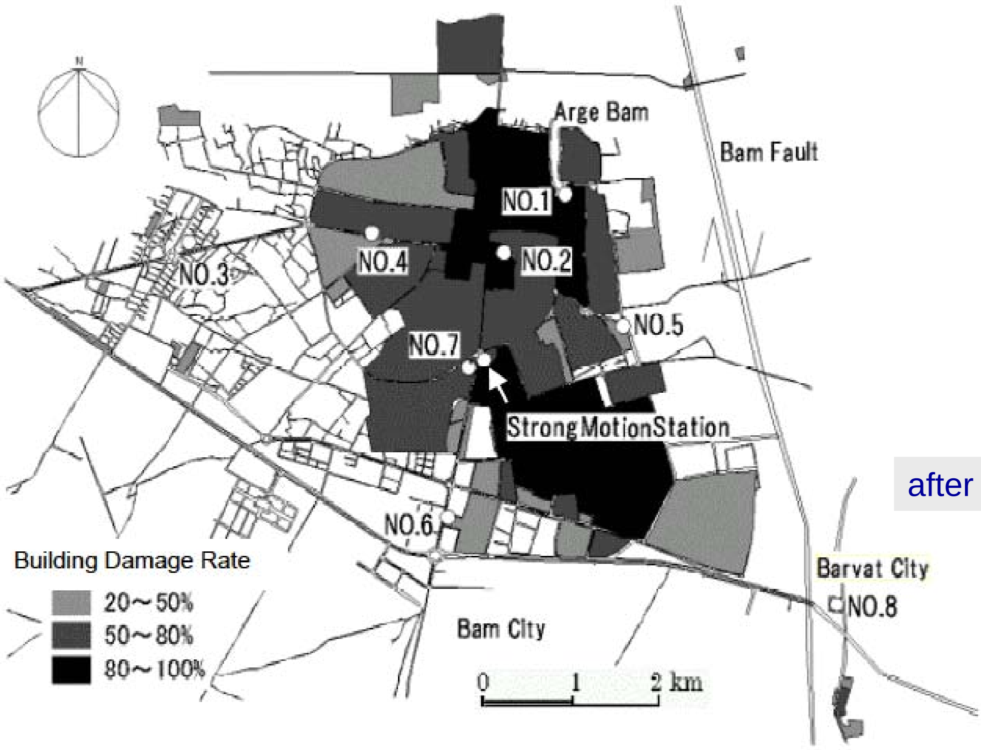
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)
Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.



Grade 5: Destruction
(very heavy structural damage)
Collapse of ground floor or parts (e. g. wings) of buildings.

http://www.gfz-potsdam.de/portal/gfz/Struktur/Departments/Department+2/sec26/projects/04_seismic_vulnerability_scales_risk/EMS-

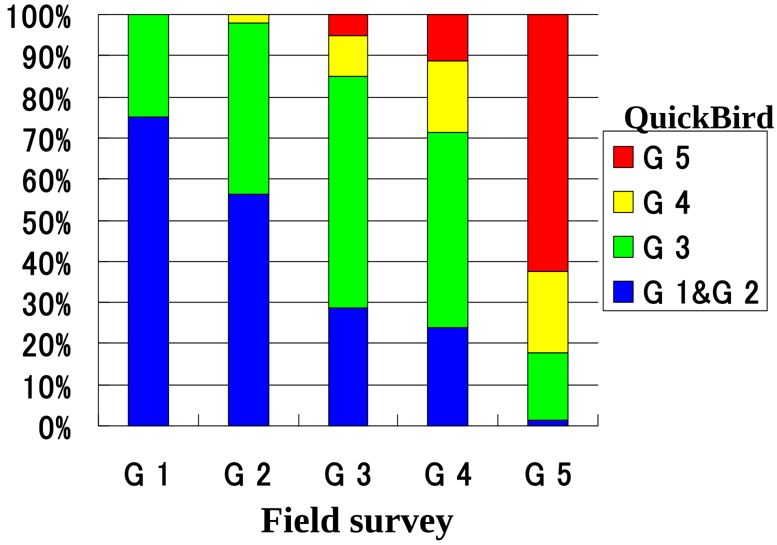
Damage map of Bam and Baravat and the strong motion and aftershock stations



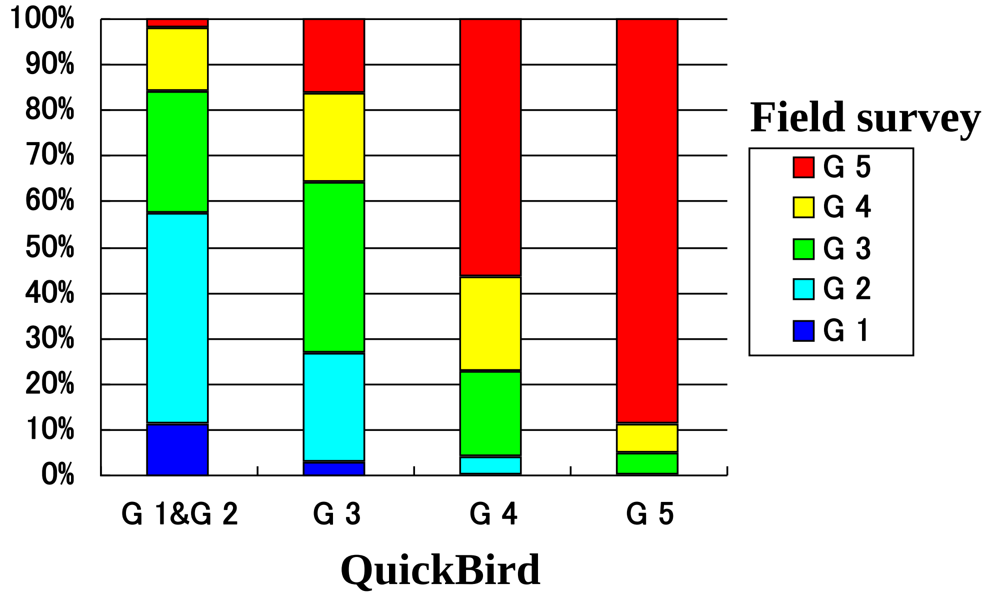
after Prof. Hisada

Summary of comparison for 7 stations

QuickBird \ Field survey	G 1	G 2	G 3	G 4	G 5	sum
G 1 & G 2	12	50	29	15	2	108
G 3	4	37	57	30	25	153
G 4	0	2	10	11	30	53
G 5	0	0	10	7	95	107
sum	16	89	101	63	152	421



Summary of comparison for 7 stations



Damage Detection

- Visual Interpretation
- Image Processing
  - Color composite (pre- and post-event)
  - Index (band ratio, texture…)
  - Supervised Classification
  - Non-supervised Classification

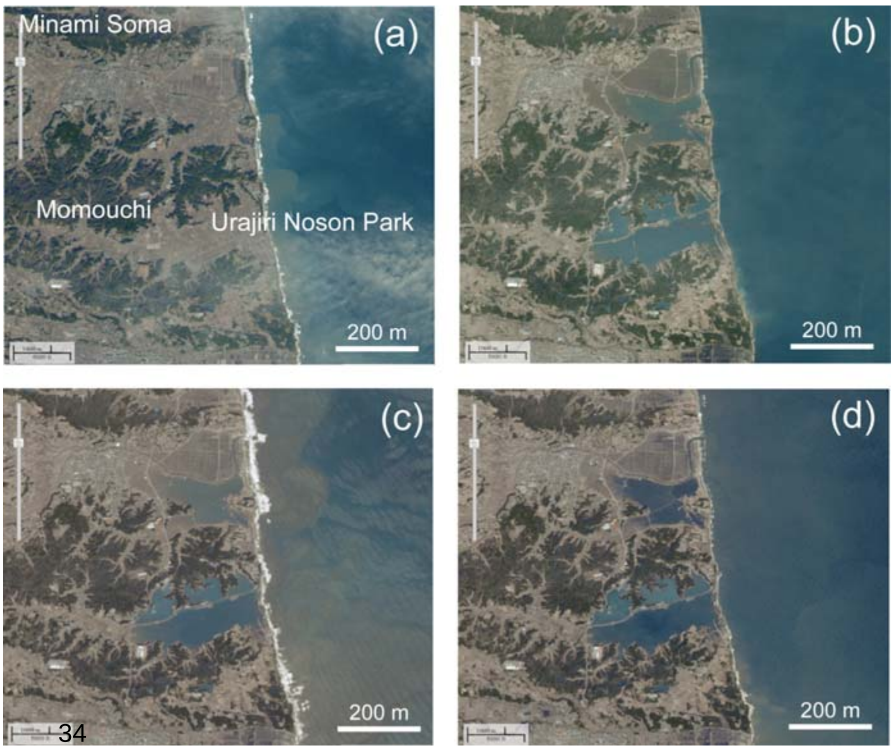
High-resolution Satellite Images Before and After Tsunami

- Banda Aceh: QuickBird, res.: ps.0.6m, swath: 40km -

Pre-tsunami image (June 23, 2004) | Post-tsunami image (Dec. 29, 2004)

source: UNOSAT

ASTER Images Before and After Tsunami



(a) 2008/12/25

(b) 2011/3/14

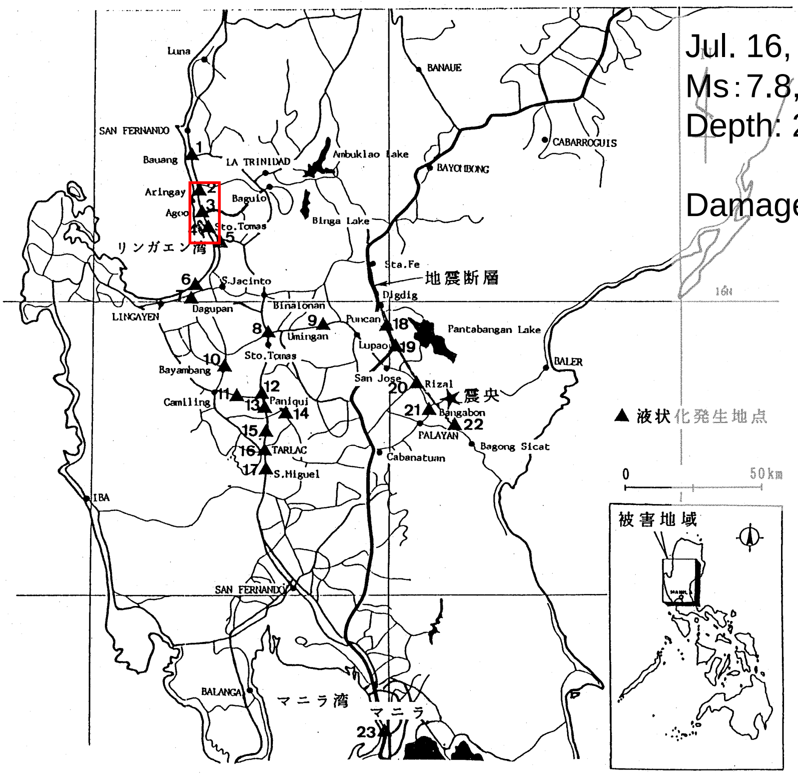
(c) 2011/3/19

(d) 2011/3/28

Minami-Soma

Considerable erosion and remaining water, even two weeks after the earthquake

The 1990 Luzon Earthquake, The Philippines



Jul. 16, 1990
Ms：7.8, Mw:7.6
Depth: 25km

Damage (Aug.12,1990)
death toll：1,666
missing：460
injured：3,516
severe and moderate damage：104,614 buildings
damage cost：99 billion Peso (400 billion yen, US$ 3 billion)

Damage at East Coast of Lingayen Gulf

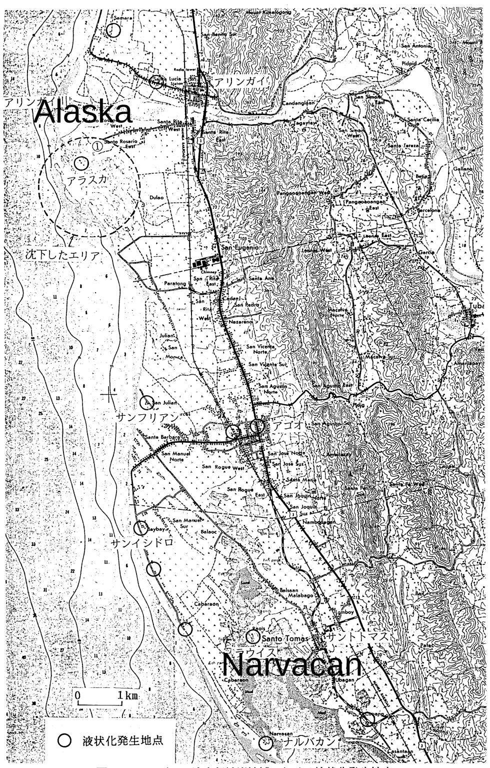
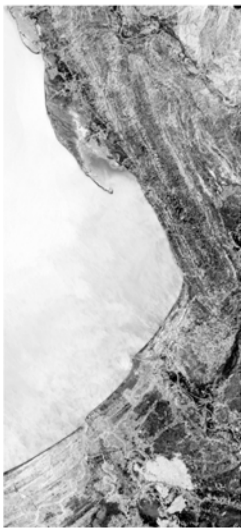


図4.1 リンガエン湾東部沿岸地域における液状化発生地点

Barrio Narvacan
(villages sunk into the sea due to liquefaction)

Color Composite Image to Estimate Damaged Areas



Inverse image of post-event (for red color)

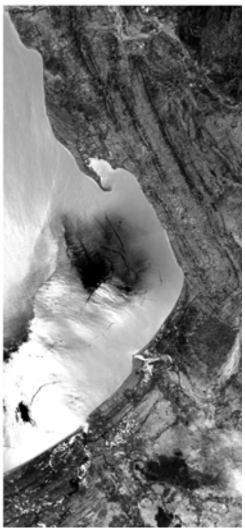
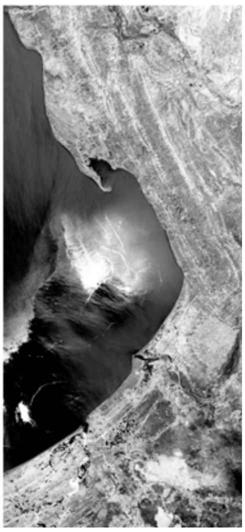
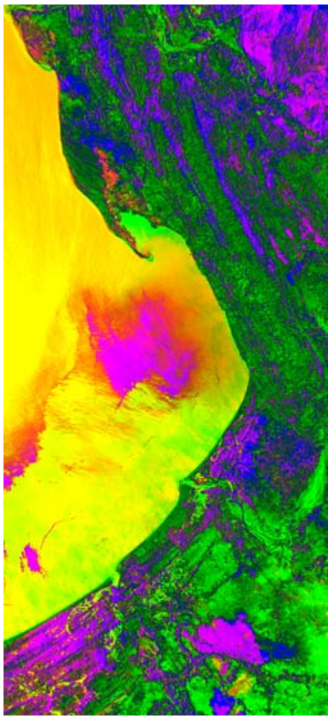


Image of pre-event (for green color)

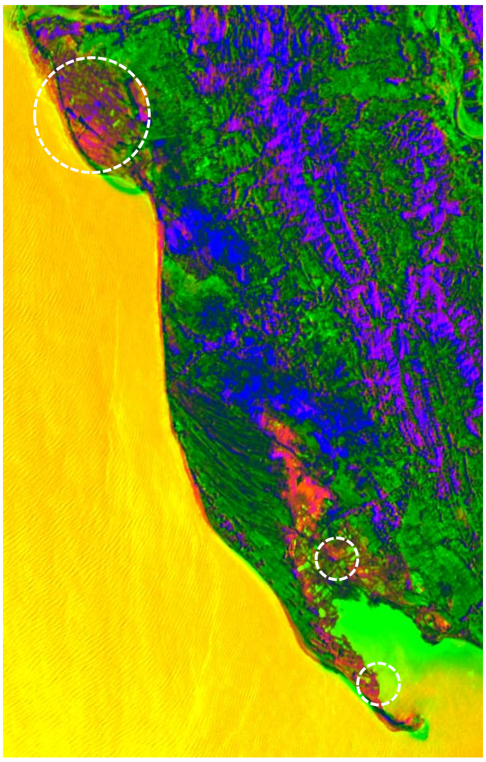


Inverse image of pre-event (for blue color)



Pink color area
…reflectance became low
(area of sunk into the sea due to EQ.)

Comparison with Survey Report



Color composite image

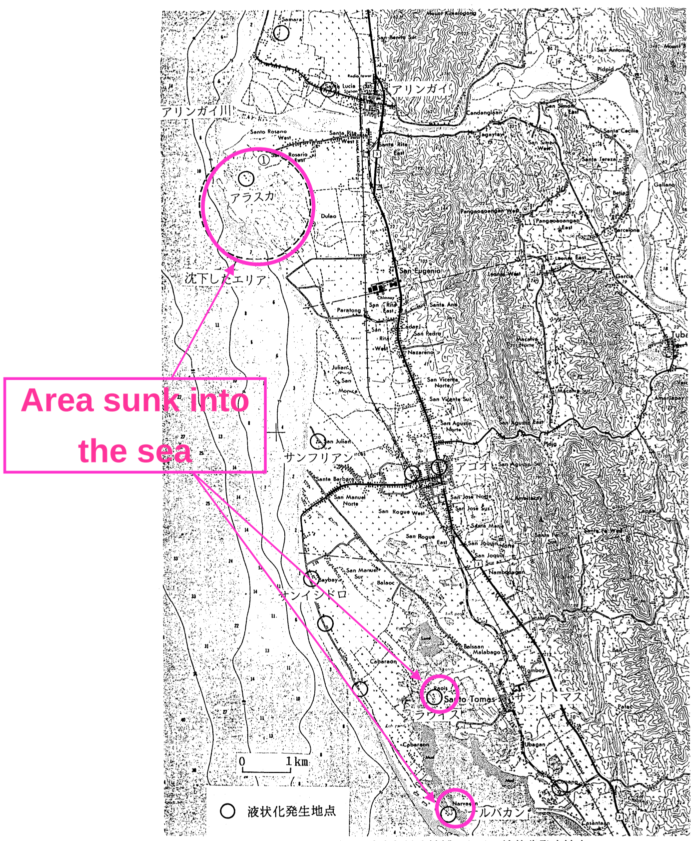


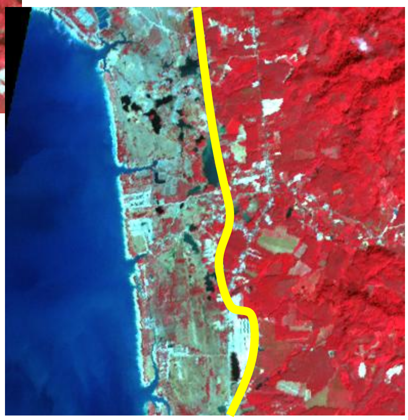
図4. 1　リンガエン湾東部沿岸地域における液状化発生地点

Tsunami-Affected Area Detection

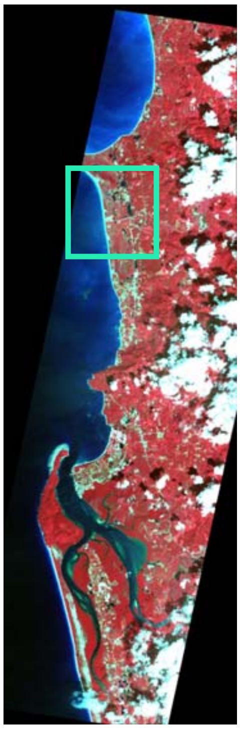
Sumatra Earthquake Tsunami on Dec. 23, 2004

ASTER (15 m resolution)

**KHAO LAK,
Phang nga,
THAILAND**



Easily to detect the boundary of the affected areas because vegetation was stripped away.



2002/11/15 **2004/12/31**

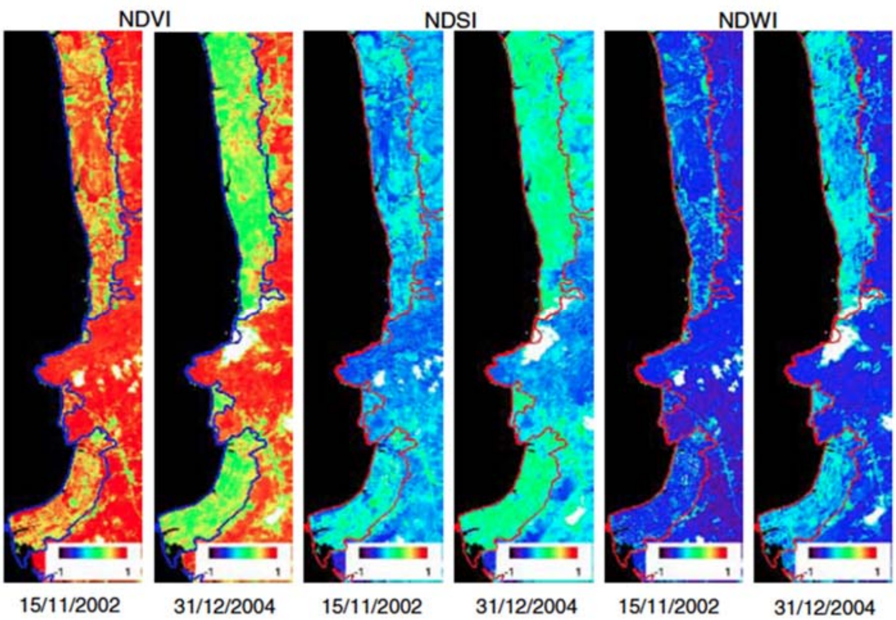
Several Indices of Tsunami Damaged Area

ASTER (15 m resolution)

Normalized Difference Vegetation Index, NDVI = (NIR – Red) / (NIR + Red)

Normalized Difference Soil Index, NDSI = (SWIR – NIR) / (SWIR + NIR)

Normalized Difference Water Index, NDWI = (Red - SWIR) / (Red + SWIR)



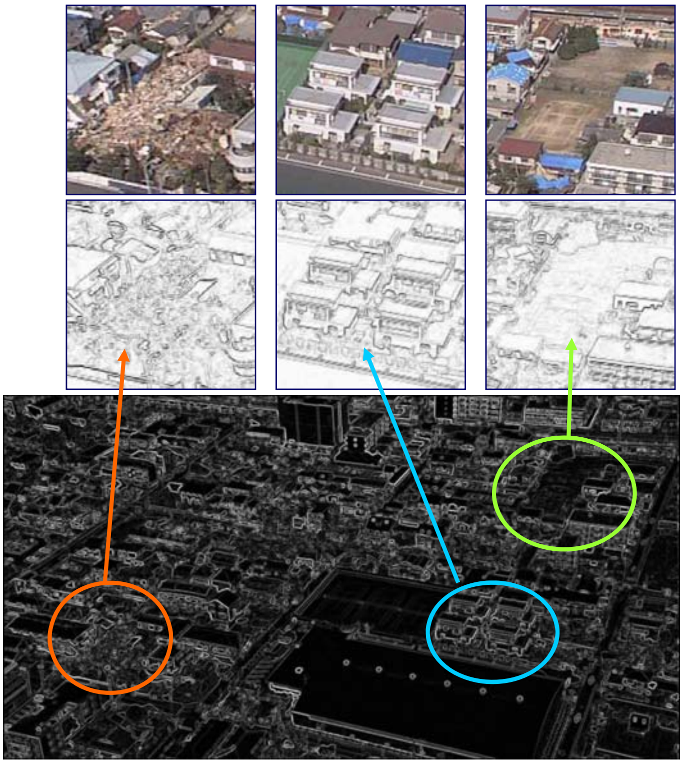
Yamazaki et al., Forecast of Tsunamis from the Japan–Kuril–Kamchatka Source Region ,Natural Hazards, Volume 38, Number 3, July 2006 , pp. 411-435(25) Springer, DOI: http://dx.doi.org/10.1007/s11069-005-2075-7

Automated Damage Detection Technique Using Image Texture

Jan. 27, 1995
(10 days after the Kobe EQ)
HDTV (High definition TV)

9 cm/pixel (lower)
17 cm/pixel (upper)

Nishinomiya City
HDTV image taken on 1995/1/27



Edge intensity image

Procedure of Edge-based Damage Detection

- Edge textures are computed from the intensity image
- Edge intensity (*Ei*) is maximum value in eight directions derived from 7x7 Prewitt filter.
- Using *Ei*, edge intensity variance (*Ev*) is computed in 7x7 local window.
- The ratio of predominant direction of *Ei* (*Ed*) is also computed in 7x7 local window.
- Then, co-occurrence textures: angular second moment (*Ta*) and entropy (*Te*) are computed in 7x7 local window.
- Collapsed buildings show a strong trend of non-uniformity. Our investigation showed the following threshold values are suitable,

Fig.10.9.1 Examples of spatial filters of 3 × 3 window

SPATIAL FILTERS	3 × 3 OPERATOR	EFFECTS
Sobel	$\lvert A \rvert + \lvert B \rvert$ or $\sqrt{A^2+B^2}$ where, $A=\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$ $B=\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$	gradient (finite differences)
Gradient -Prewitt	$\lvert A \rvert + \lvert B \rvert$ or $\sqrt{A^2+B^2}$ where, $A=\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$ $B=\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$	gradient (finite differences)
Laplacian	$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}$ or $\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$	differential
smoothing	$\begin{bmatrix} 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \end{bmatrix}$ or $\begin{bmatrix} 0 & 1/5 & 0 \\ 1/5 & 1/5 & 1/5 \\ 0 & 1/5 & 0 \end{bmatrix}$	smoothing
median	Replaced with median of 3 × 3 window	noise removal
High-pass	$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$ or $\begin{bmatrix} -1/9 & -1/9 & -1/9 \\ -1/9 & 8/9 & -1/9 \\ -1/9 & -1/9 & -1/9 \end{bmatrix}$	edge-enhancement
sharpening	$\begin{bmatrix} 1/9 & -8/9 & 1/9 \\ -8/9 & 37/9 & -8/9 \\ 1/9 & -8/9 & 1/9 \end{bmatrix}$	clear image

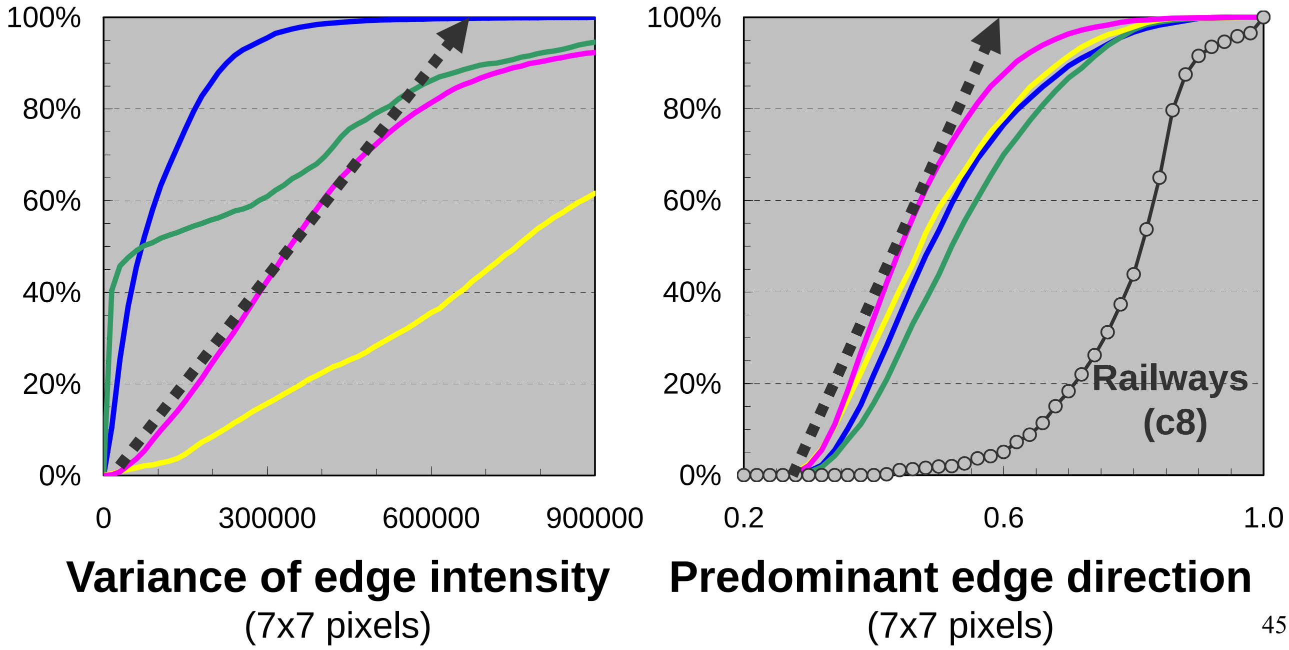
Edge Information (1)

- <u>Variance of edge intensity (7x7 pixel window)</u>
  “Collapsed” : a lot of edge elements
  “Non-damaged” : a small of edge elements

- <u>Ratio of predominant edge direction (7x7 pixel window)</u>
  To distinguish between “Collapsed” and “Non-damaged”
  (Prewitt-type template can indicate an edge direction with the strongest edge intensity)

Cumulative Relative Frequencies for Training Data

- : Collapsed buildings (c1)
- : Brown walls (c5)
- : Asphalt roads & parking lots (c9)
- : Bare ground (c10)



Edge Information (2)

■ Angular second moment (7x7 pixel window)

$$Ta = \sum_{k=0}^{15} \sum_{l=0}^{15} \left[\delta(k,l)\right]^2$$

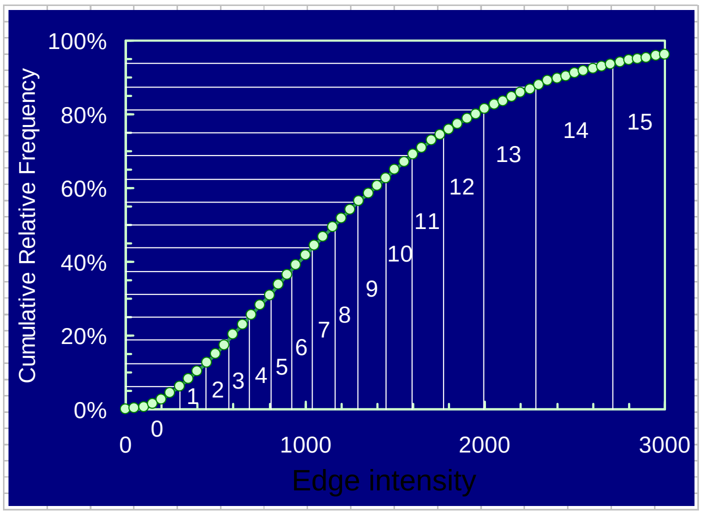
large Ta ⟶ uniform texture

■ Entropy (7x7 pixel window)

$$Te = -\sum_{k=0}^{15} \sum_{l=0}^{15} \left[\delta(k,l) \log_e \delta(k,l)\right]$$

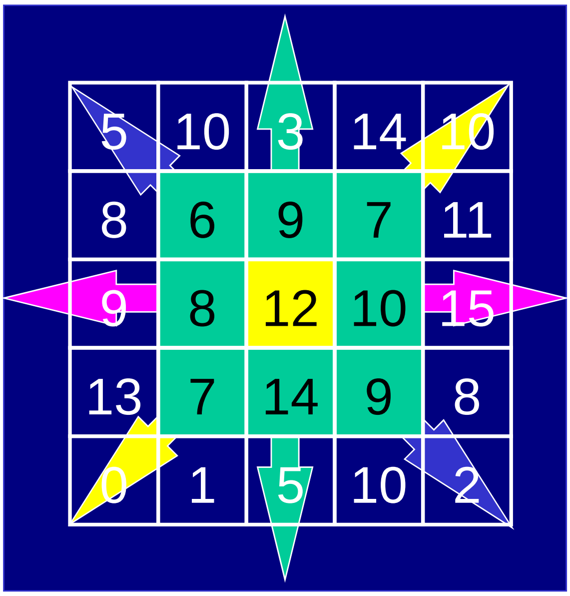
small Te ⟶ uniform texture

How to derive “Edge Texture”



- Cumulative relative frequency of collapsed buildings (c1) is converted from 8 to 4-bit data

How to derive “Edge Texture”



Value of a reference pixel, “*K*(=12)”

Value of neighboring 8 pixels, “*L*”

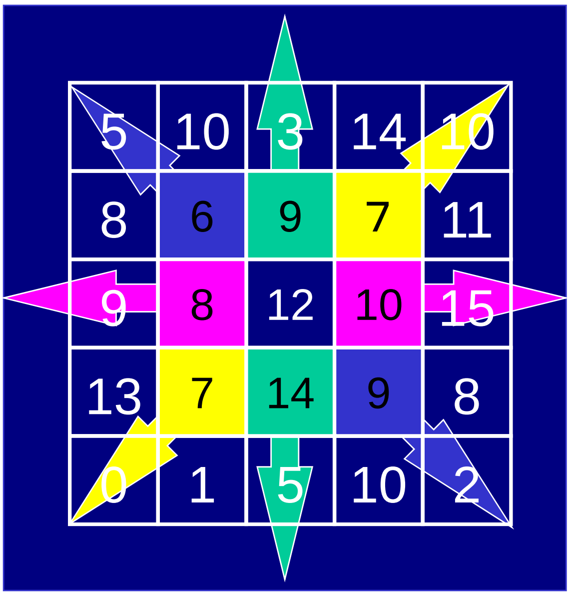
↓

co-occurrence probability, *δ*(*K*, *L*)

↓

Edge intensity
with 4-bit data

How to derive “Edge Texture”

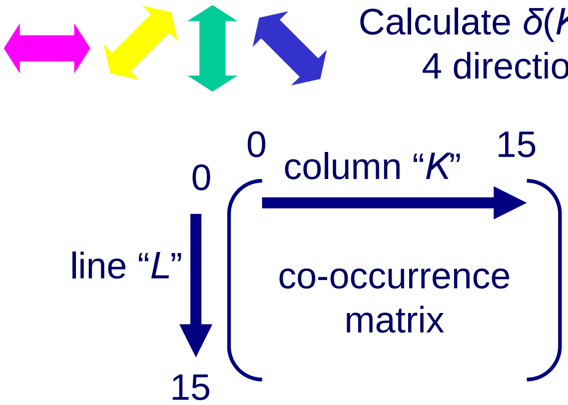


Edge intensity
with 4-bit data

Value of a reference pixel, “*K*(=12)”

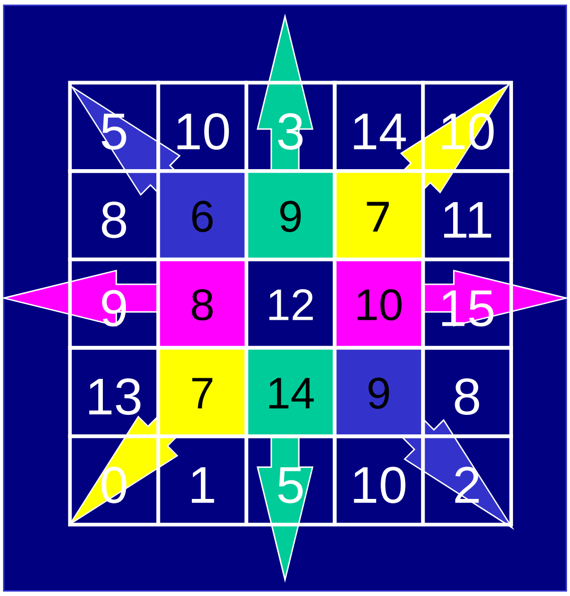
Value of neighboring 8 pixels, “*L*”

co-occurrence probability, *δ*(*K*, *L*)



(each direction)

How to derive “Edge Texture”



(each direction)

Calculate “Edge Texture”
from co-occurrence matrix

(1) Angular second moment, *Ta*

$$Ta = \sum_{k=0}^{15}\sum_{l=0}^{15}\left[\delta(k,l)\right]^2$$

large *Ta* → uniform texture

(2) Entropy, *Te*

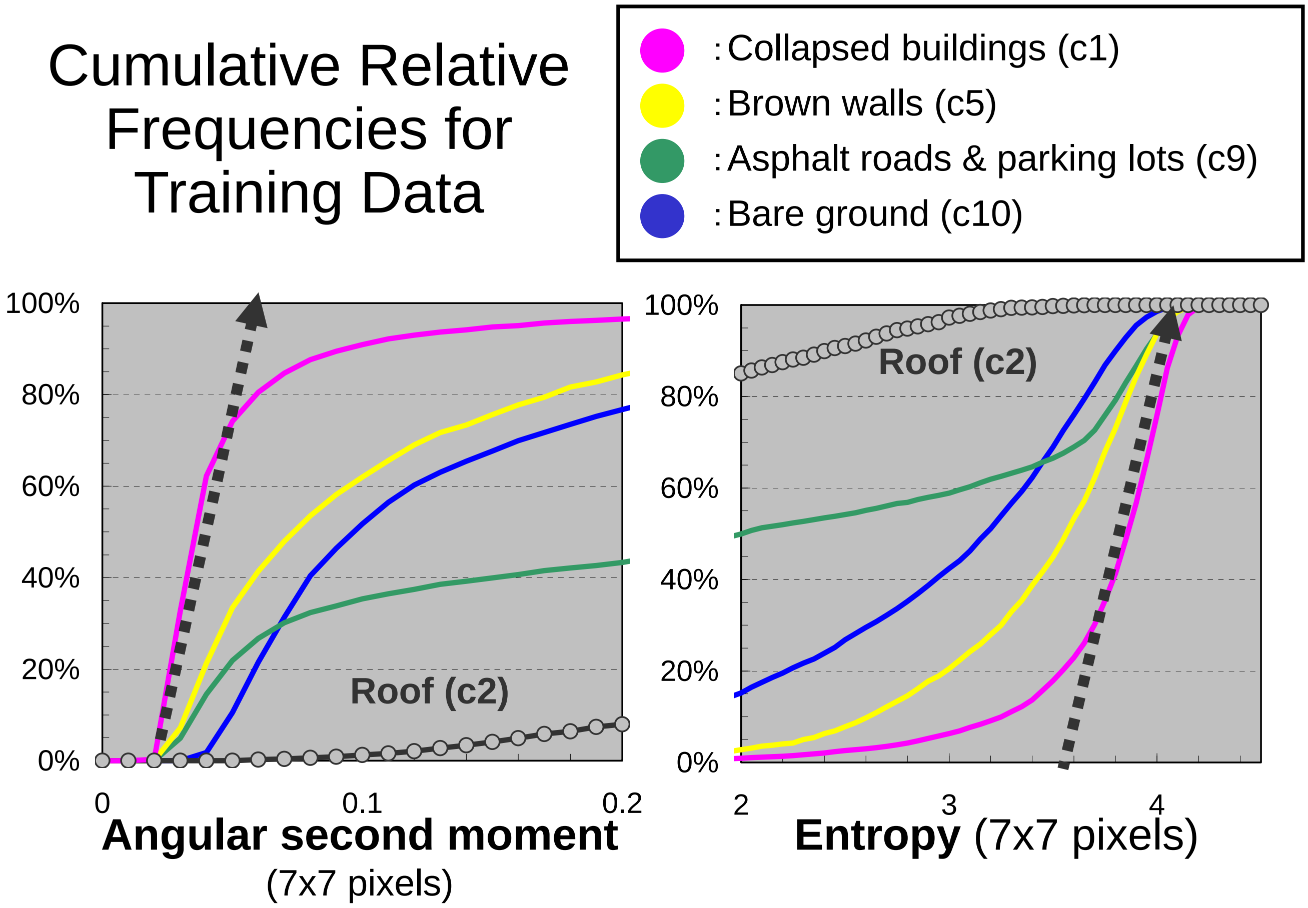
$$Te = -\sum_{k=0}^{15}\sum_{l=0}^{15}\left[\delta(k,l)\log_e \delta(k,l)\right]$$

small *Te* → uniform texture

Representative texture value is · · ·

Maximum value of textures derived from co-occurrence matrices in 4 directions

Cumulative Relative Frequencies for Training Data



Collapsed buildings show the strongest trends of non-uniformity

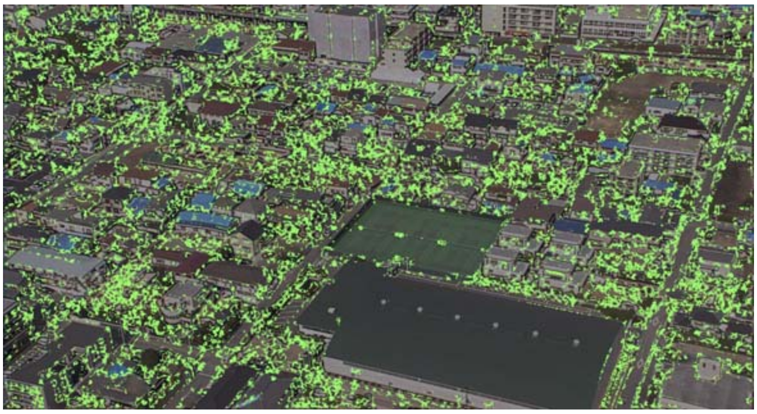
Procedure of Edge-based Damage Detection

Index	Threshold values
Ev (edge variance)	2.0 - 6.8 (x 10^5)
Ed (edge direction)	0.3 - 0.6
Ta (angular second moment)	0.75 - 6.6 (x 10^{-2})
Te (entropy)	3.5 - 4.2

- Finally, local density of the detected pixels is assessed to remove the meaningless spots.

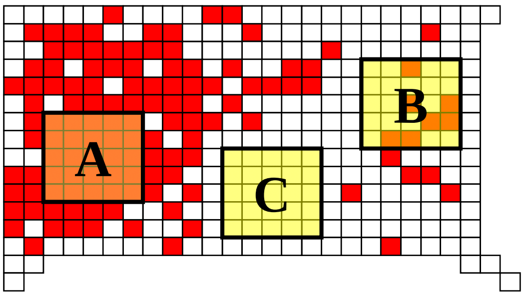
Threshold Values to Extract Pixels in Damaged Areas

■ Variance of edge intensity, *Ev*:	2.0 - 6.8 (x10^5)
■ Predominant edge direction, *Ed*:	0.3 -0.6
■ Angular second moment, *Ta*:	0.75 - 6.6 (x10^-2)
■ Entropy, *Te*:	3.5 - 4.2



Spatial Filtering

Calculate the percentage of the extracted pixels in the window of the size of approximately one building.

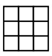


Example

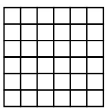
A : 1.00
B : 0.24
C : 0.00

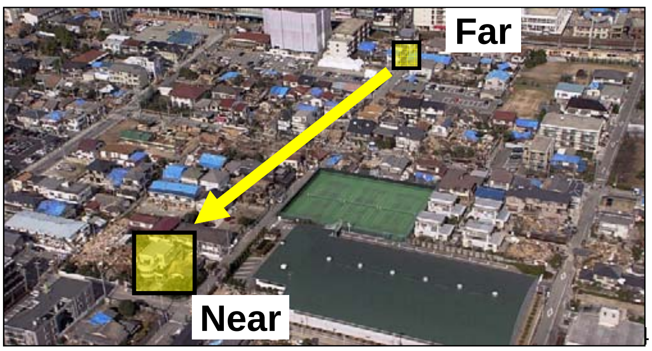
Red : the extracted pixels

Consider the influence of the distance from the camera

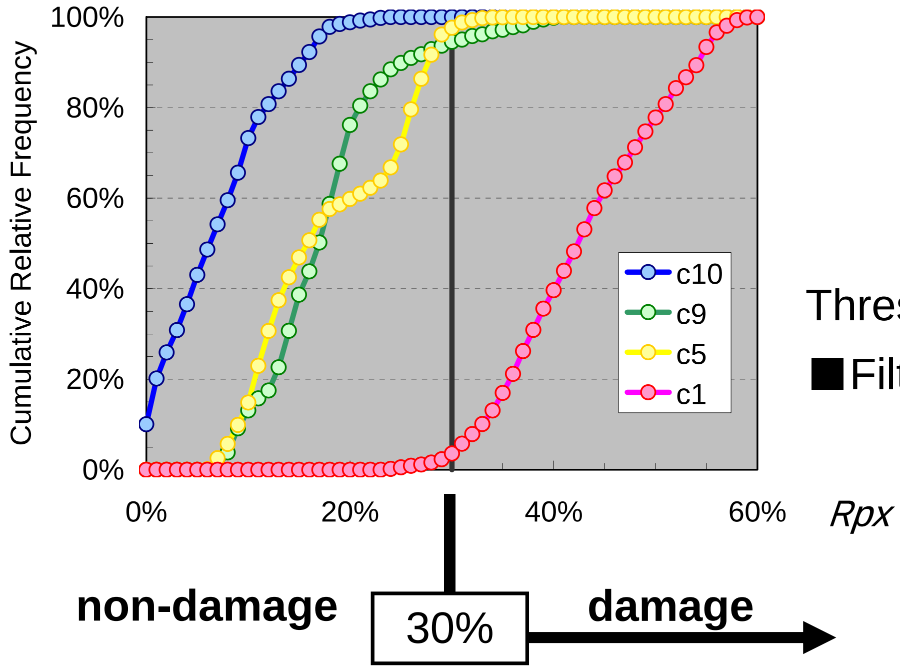
Far  31 x 31 pixels window

Change a window width

Near  63 x 63 pixels window



Cumulative Relative Frequency of Local Density of Extracted Pixels



Threshold

■Filtering, *Rpx*: 30%

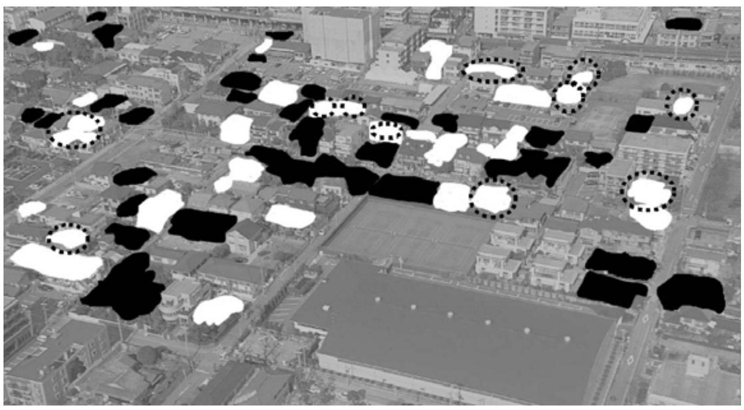
Result from Aerial Television Image taken after Kobe Earthquake

Estimated damage ←

Black: damaged building (level slice by edge information)

Actual damage by field survey

Black: collapsed
White: severe damage
(dotted area: plastic sheet covered on roof) →

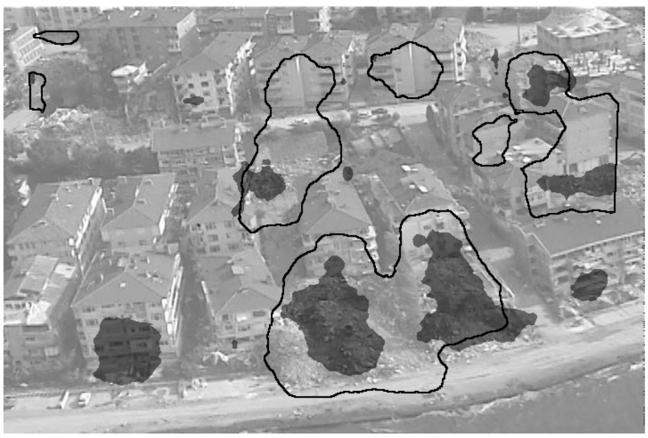


Near Real-time Damage Detection Using Only Post-event Aerial Images

Application to Other Earthquakes

Aerial image of Golcuk, Turkey taken after the 1999 earthquake

Estimated damage



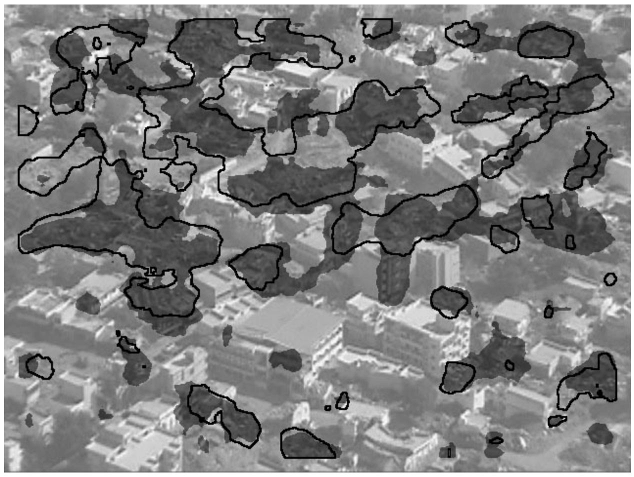
Black: damaged building

Threshold values are same as the Kobe earthquake

Application to Other Earthquakes

Aerial image of Bachau, India taken after the 2001 earthquake ←

Estimated damage →

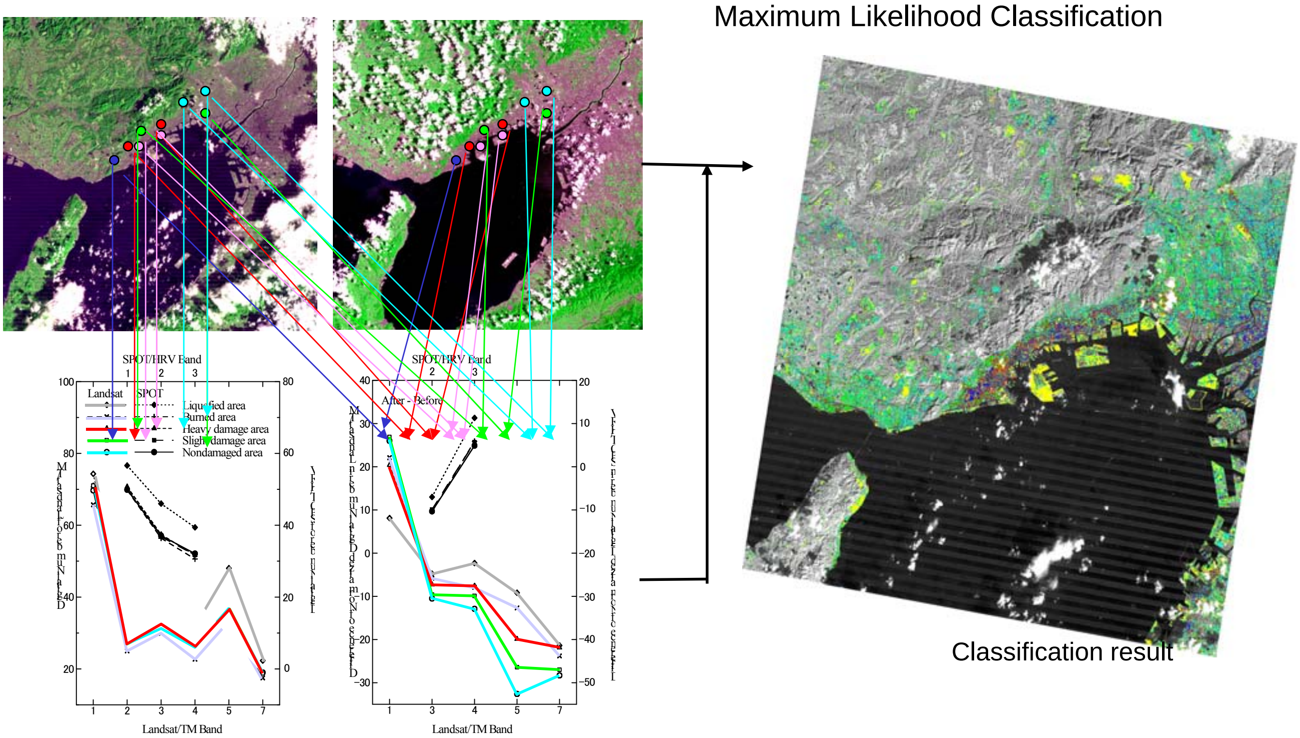


Black: damaged building

Threshold values are same as the Kobe earthquake

Damage Detection Using Supervised Classification

Maximum Likelihood Classification

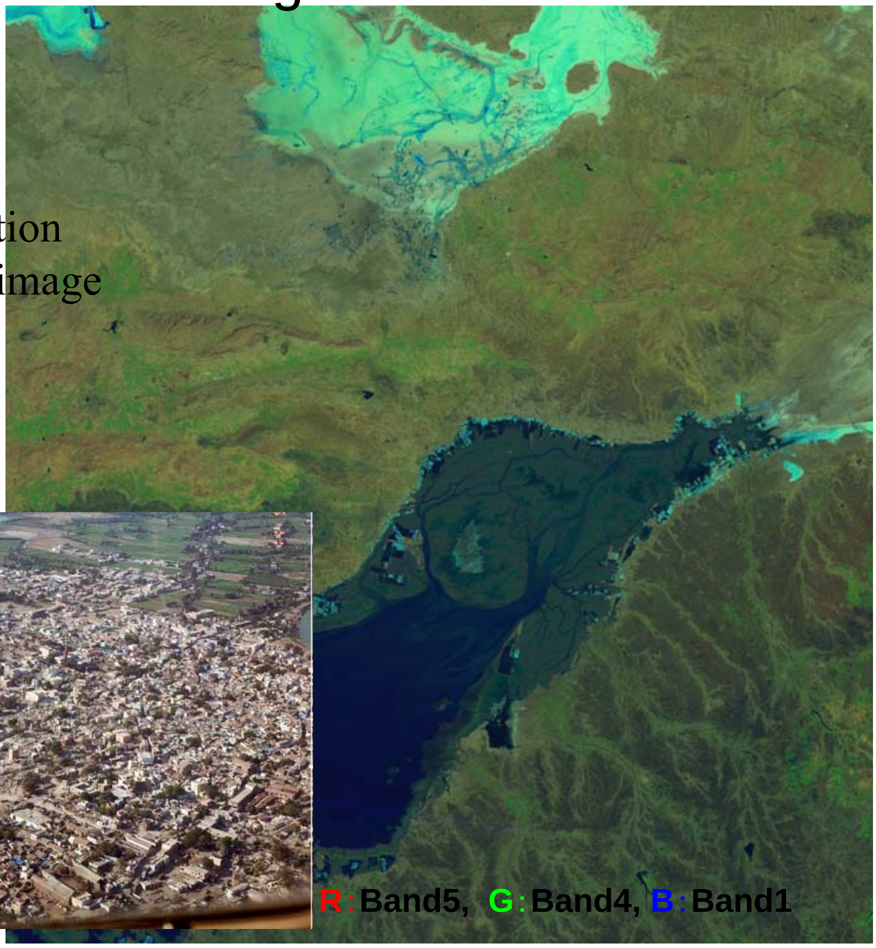


Classification result

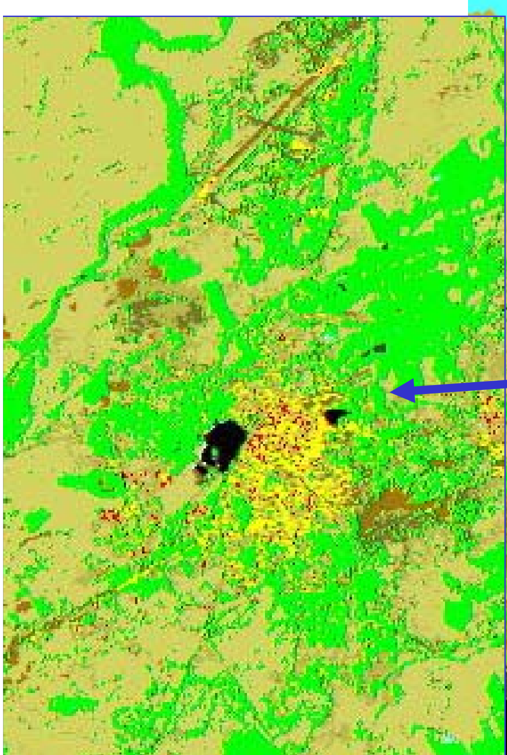
Spectral changes of damaged areas

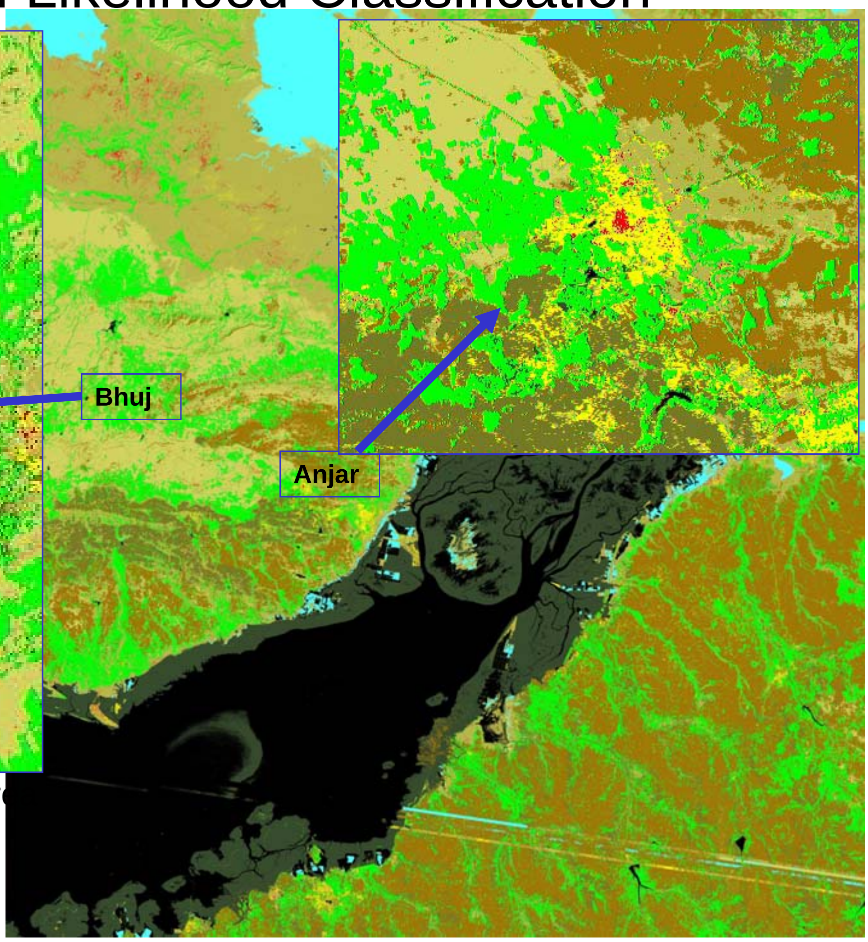
Supervised Damage Estimation

Trial for damage detection
using post-earthquake image
and limited truth data



Maximum Likelihood Classification





RED : Extracted damaged ar
GREEN : Vegetation
YELLOW: Urban
BLACK : Water