# Integration of SAR-based Information and Shake Map Information to Estimate Building Damage Ratio

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# Information Flow

Data acquisition

↓

Change detection/identification
(visual, image processing, ..)

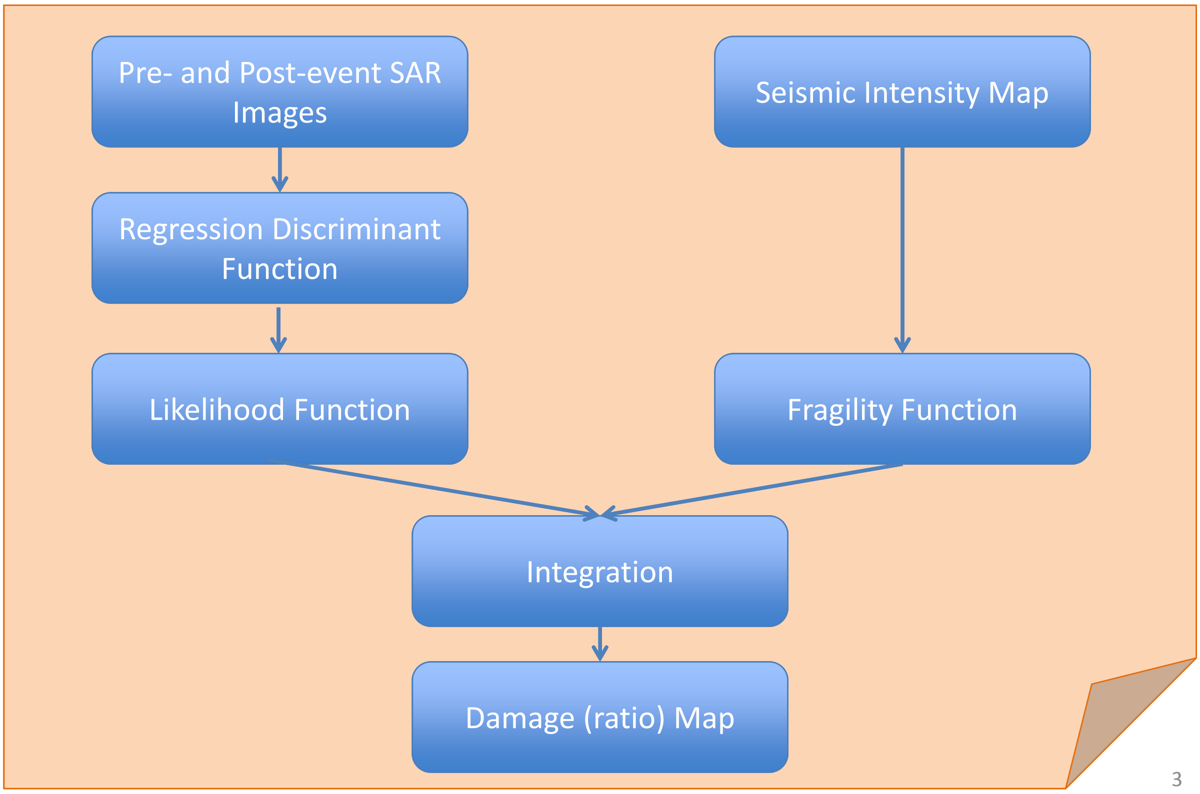
↓

Damage evaluation/quantification
(damage ratio, numbers, magnitude, volume, …)

↓

Decision making and response

# Schematic Diagram

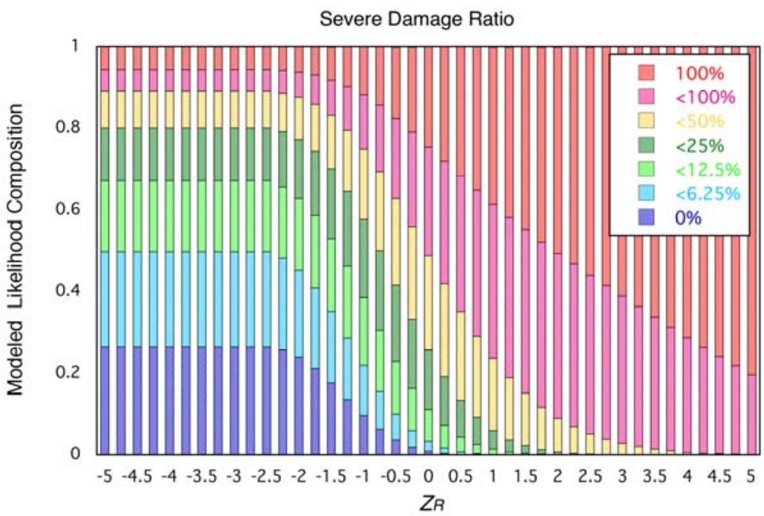




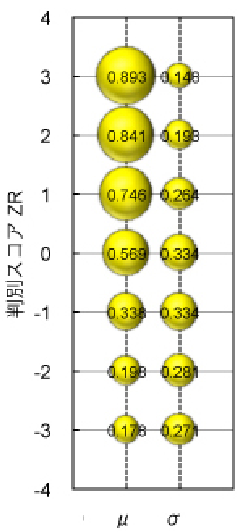

# Likelihood Function of Severe Damage Ratio from ERS-1/SAR $Z_R$

Satellite: ERS/SAR (C-band)

Earthq.: 1995 Kobe



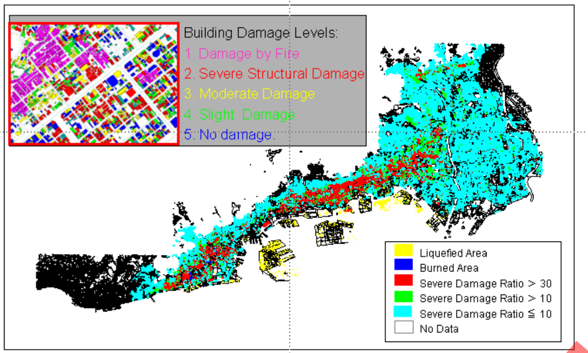

Modeled likelihood functions by $Z_R$






Nojima et al. 2006

# Fragility Function

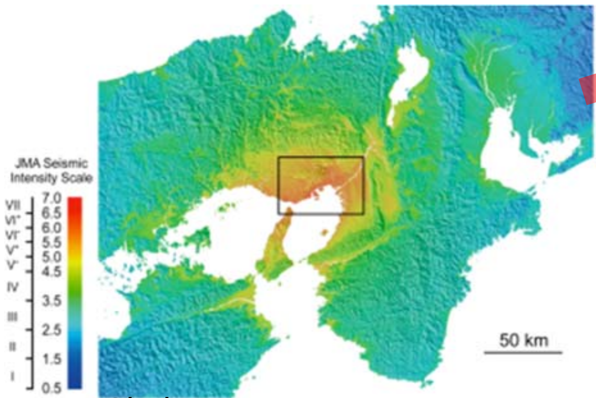



Damage map (BRI,1996)

Damage Rank

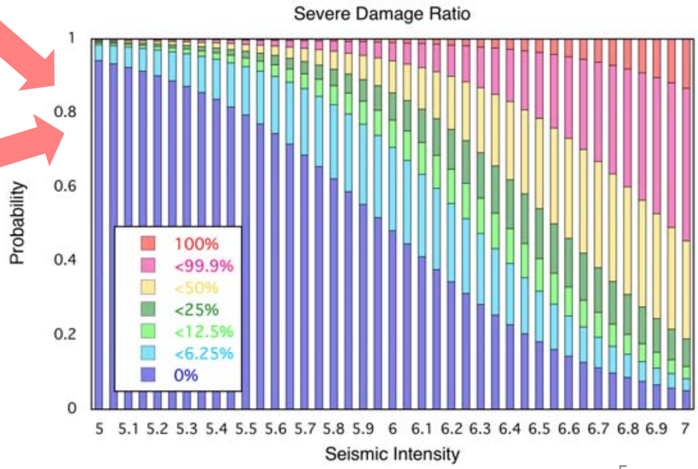
Matsuoka and Nojima,2010

| Damage Rank | Severe Damage Ratio $D$ (%) | Mid-value (%) |
|---|---|---|
| $\theta_1$ | $D = 0$ | 0.0 |
| $\theta_2$ | $0.0 < D < 6.25$ | 3.13 |
| $\theta_3$ | $6.25 \leqq D < 12.5$ | 9.38 |
| $\theta_4$ | $12.5 \leqq D < 25$ | 18.75 |
| $\theta_5$ | $25 \leqq D < 50$ | 37.5 |
| $\theta_6$ | $50 \leqq D < 100$ | 75.0 |
| $\theta_7$ | $D = 100$ | 100.0 |




Shake map

Matsuoka and Nojima,2010



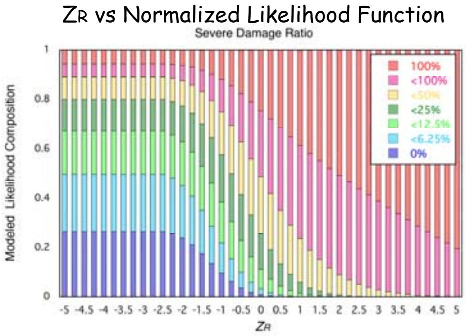

Nojima et al. 2006



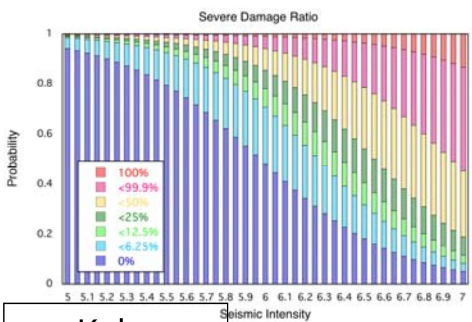
# Integration Using Bayes' Probability Update

30m res. C-band SAR

ZR vs Normalized Likelihood Function



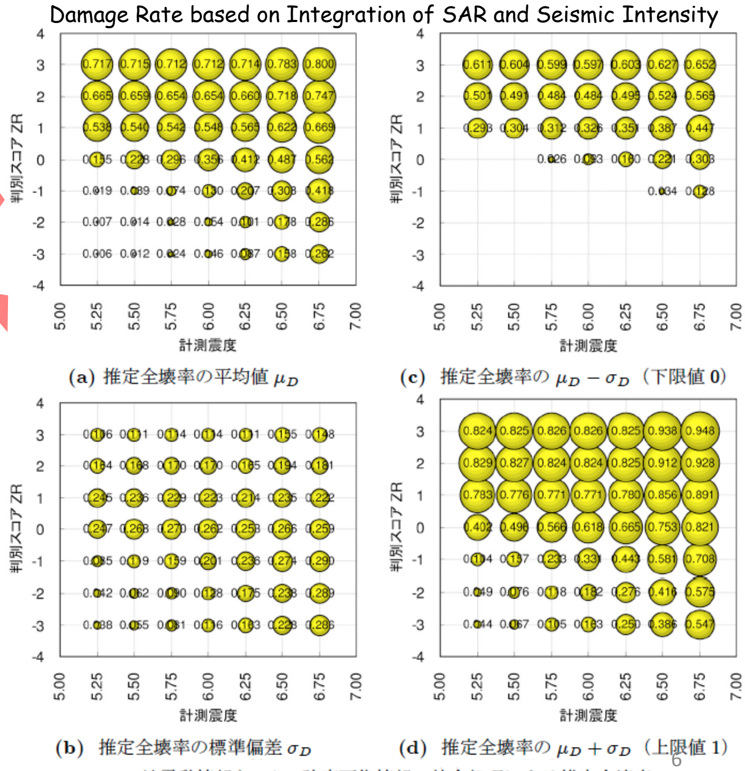

Seismic Intensity vs Fragility Function




Kobe

(Nojima et al., 2006)

Damage Rate based on Integration of SAR and Seismic Intensity



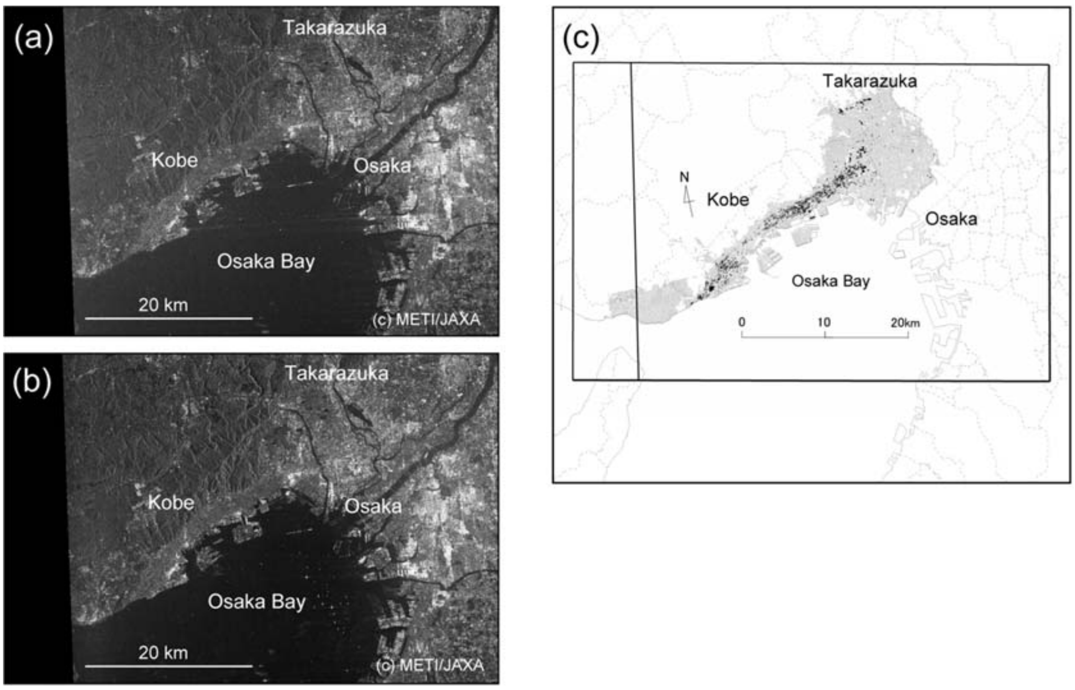

地震動情報と SAR 強度画像情報の統合処理による推定全壊率

# How to Develop Likelihood Function from SAR Imagery

- Dataset: Kobe earthq.(JERS-1/SAR (L-Band), BRI damage data)
- SAR index: difference and correlation
- Method: pixel selection for seven damage rankings to examine the relationship between indices and damage rankings
  - Combined index, $Z_{Rj}$, from Regression discriminant function
  - Likelihood function (fragility function) to estimate damage ratio from $Z_{Rj}$

M. Matsuoka and N. Nojima: Building Damage Estimation by Integration of Seismic Intensity Information and Satellite L-band SAR Imagery, Remote Sensing, MDPI, Vol.2, No.9, pp.2111-2126, 2010.9.

# Dataset (JERS-1 and Ground Truth Data for the 1995 Kobe Earthquake)




(a) 1994/5/17 (before), (b) 1995/5/4 (after), (c) Building damage survey data [BRI, 1996]

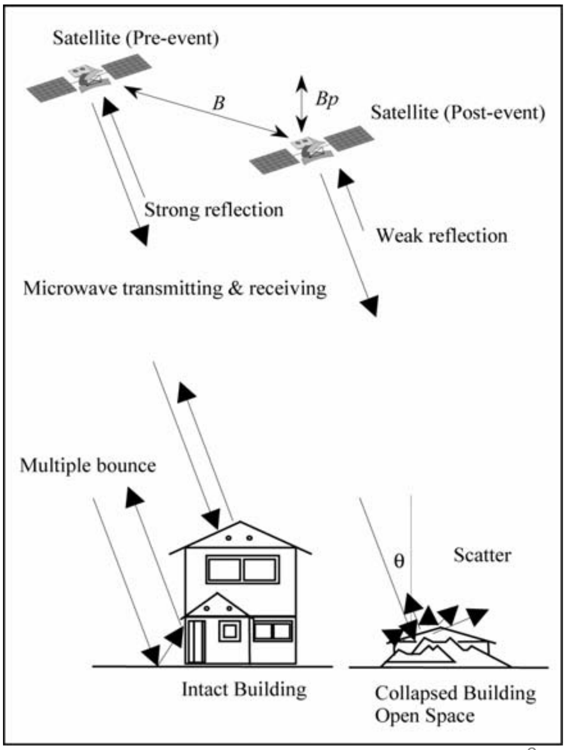
# Change Detection Index from SAR

- ✓ Image matching
- ✓ Speckle noise filtering
- ✓ Calculating following indices,
  - ✓ Difference of backscattering coefficient (after – before)

    damage < no damage

  - ✓ Correlation coefficient

    damage < no damage






# Difference in Backscattering Coefficient and Correlation

Difference:

$$d = 10 \cdot \log_{10} \bar{I}a_i - 10 \cdot \log_{10} \bar{I}b_i$$

Correlation:

$$r = \frac{N\sum_{i=1}^{N} Ia_i Ib_i - \sum_{i=1}^{N} Ia_i \sum_{i=1}^{N} Ib_i}{\sqrt{\left(N\sum_{i=1}^{N} Ia_i^2 - \left(\sum_{i=1}^{N} Ia_i\right)^2\right) \cdot \left(N\sum_{i=1}^{N} Ib_i^2 - \left(\sum_{i=1}^{N} Ib_i\right)^2\right)}}$$

where $i$ is the sample number, and $Ia_i$ and $Ib_i$ are the digital numbers of the post- and pre-images, respectively. $\bar{I}a_i$ and $\bar{I}b_i$ are the corresponding averaged digital numbers over the surroundings of pixel $i$ within a $13 \times 13$ pixel window; the total number of pixels $N$ within this window is 169, which is used to compute the two indices.

# Pixel Selection and Scatter Diagram for Damaged Areas

SAR indices images are overlaid on damage survey data, then 2000 pixels are randomly extracted from seven damage rankings.

| Damage Rank | Severe Damage Ratio $D$ (%) | Mid-value (%) |
|---|---|---|
| $\theta_1$ | $D = 0$ | 0.0 |
| $\theta_2$ | $0.0 < D < 6.25$ | 3.13 |
| $\theta_3$ | $6.25 \leqq D < 12.5$ | 9.38 |
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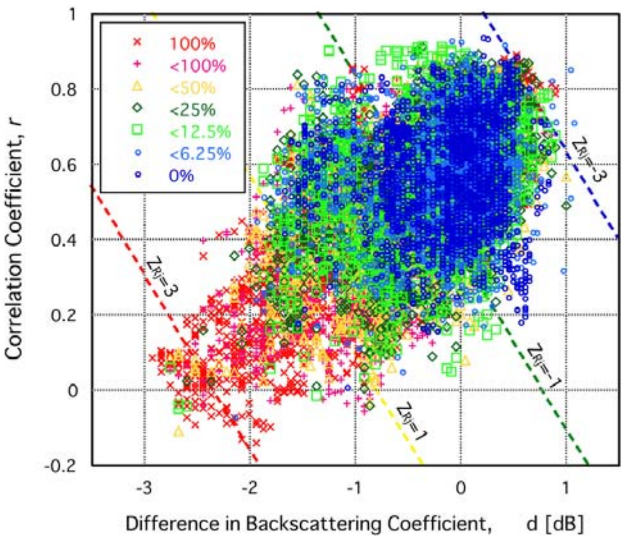



More severe damage:
difference has larger absolute value in negative, correlation has smaller

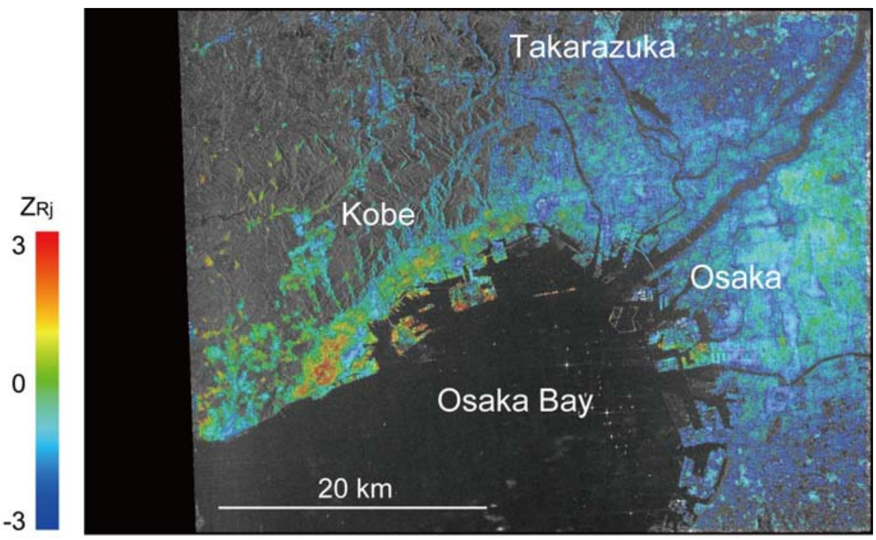


Matsuoka and Nojima,2010

# Regression Discriminant Function

$$Z_{Rj} = -1.277\, d - 2.729\, r$$

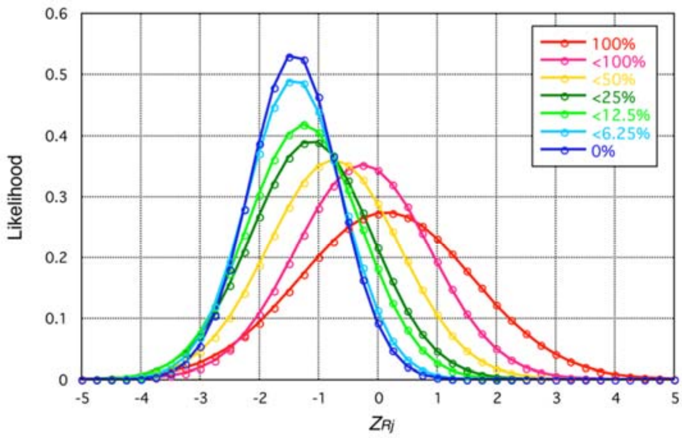
$Z_{Rj}$ : discriminant score, $d$: difference, $r$: correlation






Matsuoka and Nojima,2010

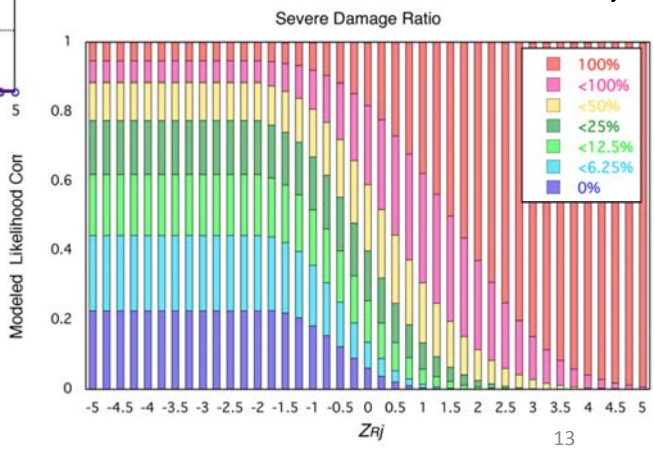
# Likelihood Function of Severe Damage Ratio from $Z_{Rj}$




Normal distribution model of $Z_{Rj}$ frequency distribution

For the region where $Z_{Rj}$ is under -2.0, a constant value obtained by extrapolating the value at $Z_{Rj}$ = -2.0 is used

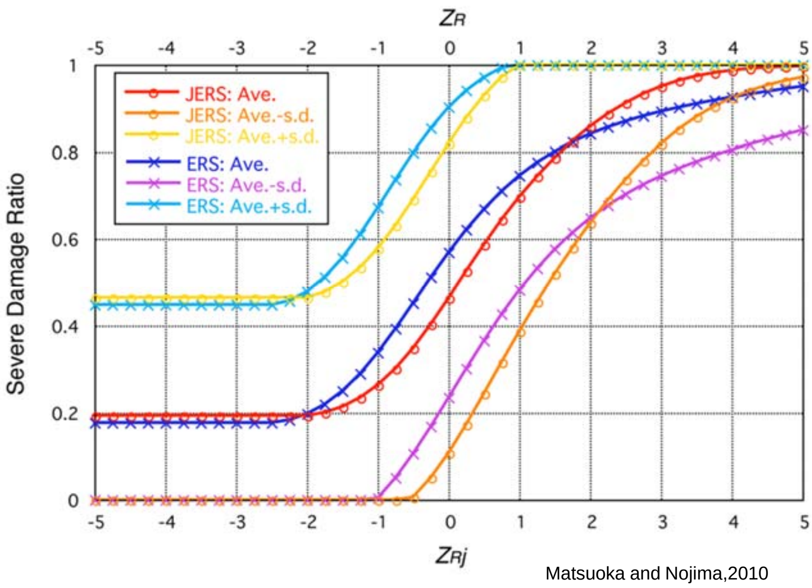
Modeled likelihood functions by $Z_{Rj}$

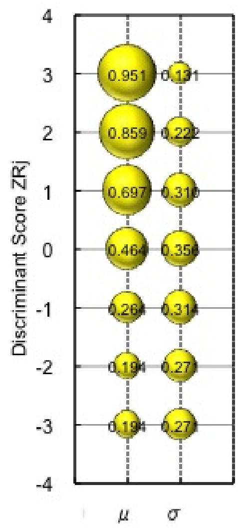





Matsuoka and Nojima,2010

# Relationship between $Z_{Rj}$ and Severe Damage Ratio

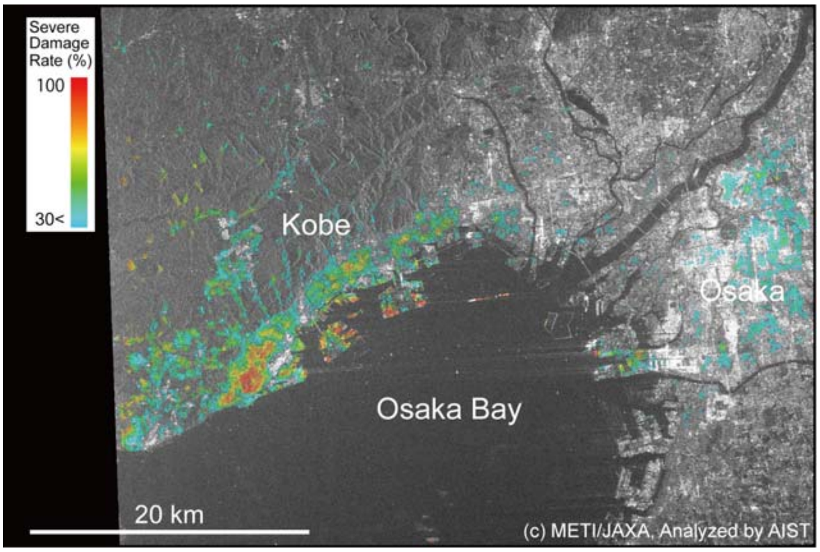



Matsuoka and Nojima,2010

This curve is equivalent to the fragility function for damage without seismic intensity information, the severe damage ratio increases with increasing $Z_{Rj}$.

# Damage Ratio derived from JERS $Z_{Rj}$ Images



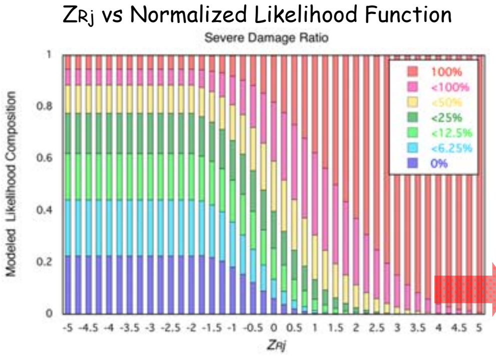

Difficult to estimate the areas where the damage ratio lower than about 30% ➡ Limitation of SAR utilization



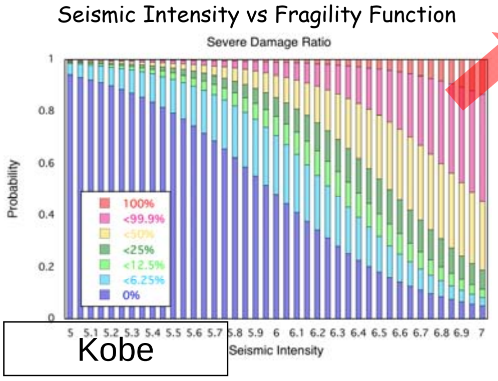
# Integration Using Bayes' Probability Update

30m res. L-band SAR

ZRj vs Normalized Likelihood Function

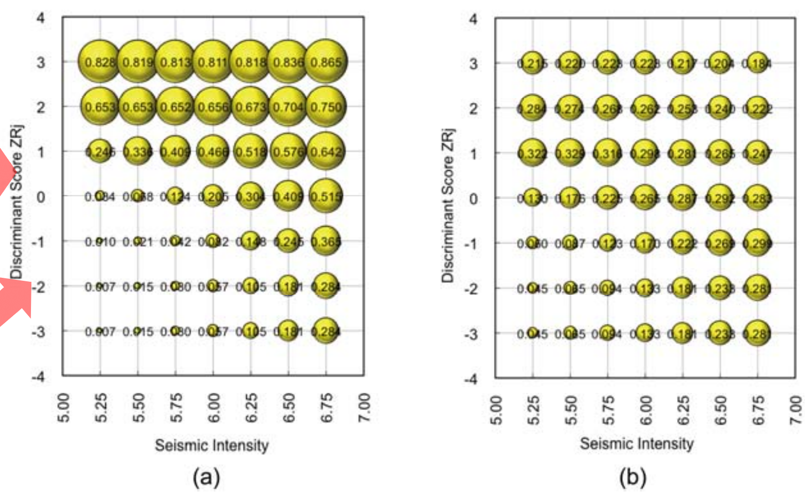



Seismic Intensity vs Fragility Function




Kobe

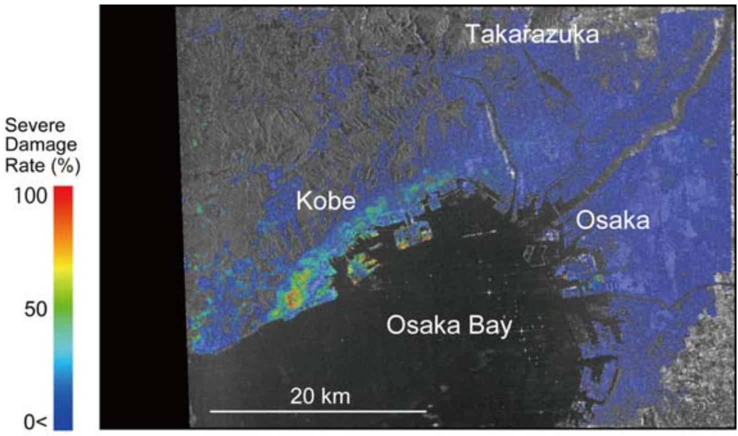
Damage Rate based on Integration of SAR and Seismic Intensity




(a) Mean (b) standard deviation

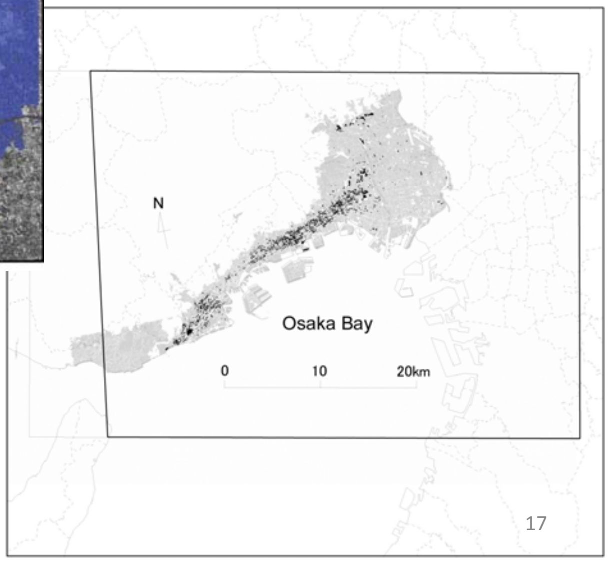
(Matsuoka and Nojima, 2010)

# Integrated Results and Comparison with Damage Survey Data




Matsuoka and Nojima,2010

A distribution which resembles the so-called "earthquake damage belt" from Kobe to Nishinomiya is obtained. [BRI, 1996]




As for Takarazuka whose seismic intensity has been underestimated, the severe damage ratio estimated by the integration is also underestimated due to small discriminant score $Z_{Rj}$ from the SAR data.



# How to Apply the Method to Other Area/Country

- For different area and SAR sensor -

- Dataset: Peru earthq.(ALOS/PALSAR (L-Band), CISMID damage data)

Development of

–Combined index, $Z_{Rp}$, from Regression discriminant function

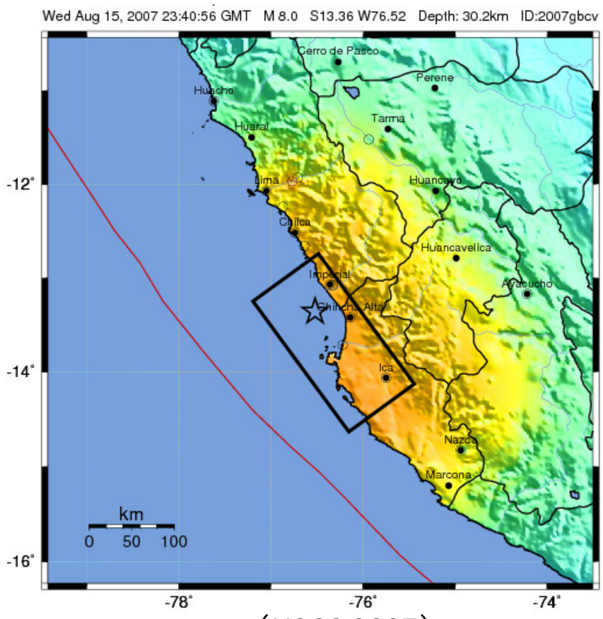
–Likelihood function (fragility function) to estimate damage ratio from $Z_{Rp}$

–Fragility function from Shake Map

# Application to ALOS/PALSAR: The 2007 Pisco Peru Earthq.

- ✓ Date: Aug. 15, 2007
- ✓ Earthquake: M8.0, 30km depth
- ✓ Death or Missing: 500 <
- ✓ Collapse or Severe damage: 35,000

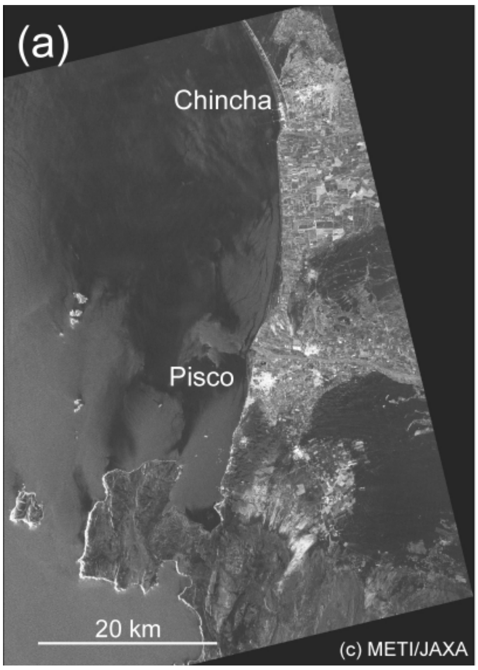
<



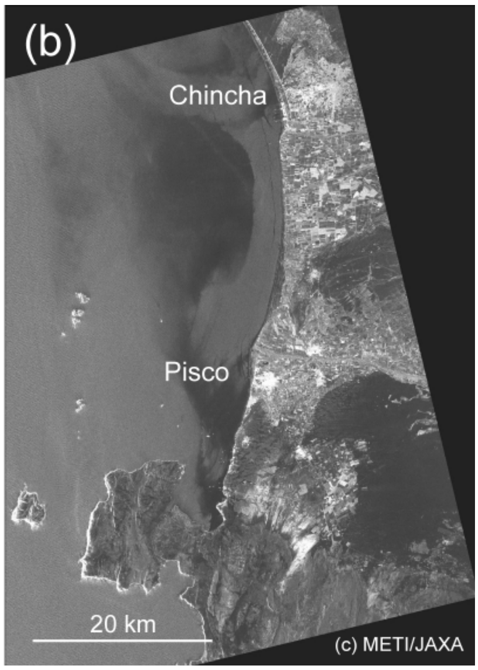
（USGS 2007）



# PALSAR Images Before and After the Earthquake

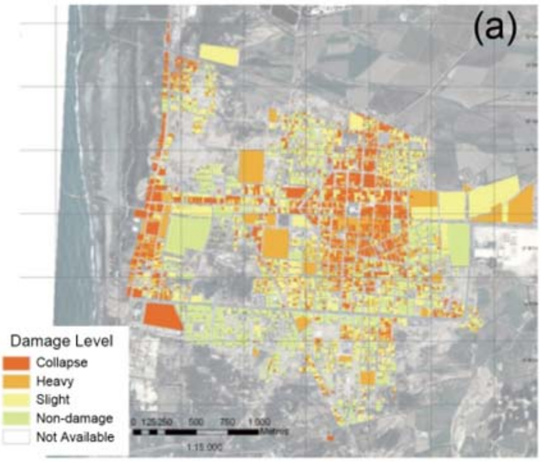


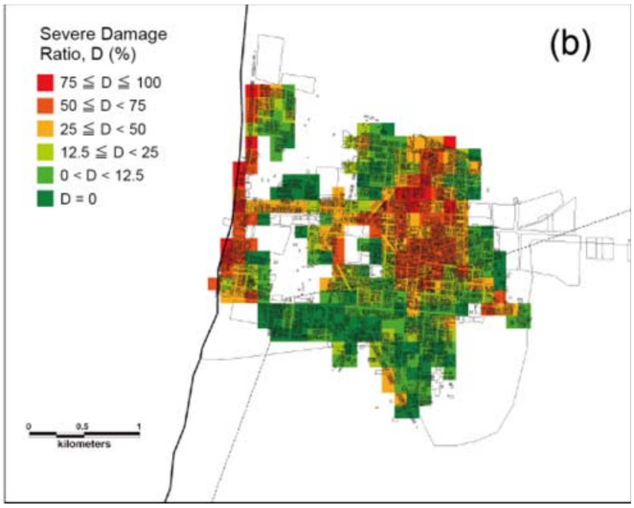
(a) 2007/7/12



(b) 2007/8/27

# Ground Truth Data
# - Pisco City -




(a) Damage map by CISMID    (b) Severe damage ratio distribution

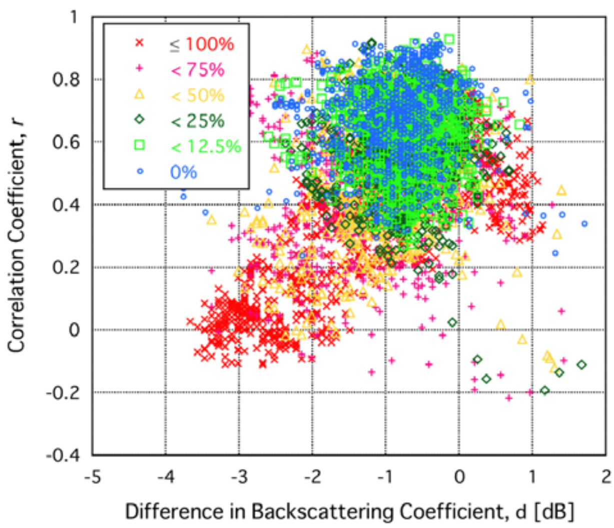
Estrada, M.; Zavala, C.; Aguilar, Z. Damage study of the Pisco, Peru earthquake using GIS and satellite images. In Proceedings of International Workshop for Safer Housing in Indonesia and Peru, Tsukuba, Japan, March 2008



# Pixel Selection and Scatter Diagram for Damaged Areas

SAR indices images are overlaid on damage survey data, then 2000 pixels are randomly extracted from seven damage rankings.

| 被災ランク | 全壊率 $D$（%） | 中央値（%） |
|---|---|---|
| C1 | $D = 0$ | 0.0 |
| C2 | 0.0 ≦ $D$ ＜ 12.5 | 6.25 |
| C3 | 12.5 ≦ $D$ ＜ 25 | 18.75 |
| C4 | 25 ≦ $D$ ＜ 50 | 37.5 |
| C5 | 50 ≦ $D$ ＜ 75 | 62.5 |
| C6 | 75 ≦ $D$ ≦ 100 | 87.5 |

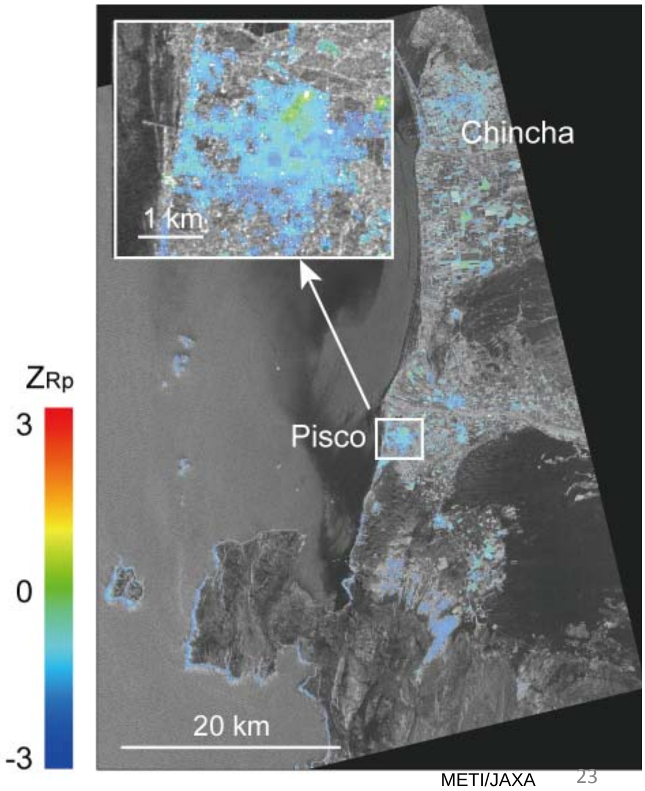



More severe damage:
difference has larger absolute value in negative, correlation has smaller

# Regression Discriminant Function

$$Z_{Rp} = -0.029\, d - 2.613\, r$$

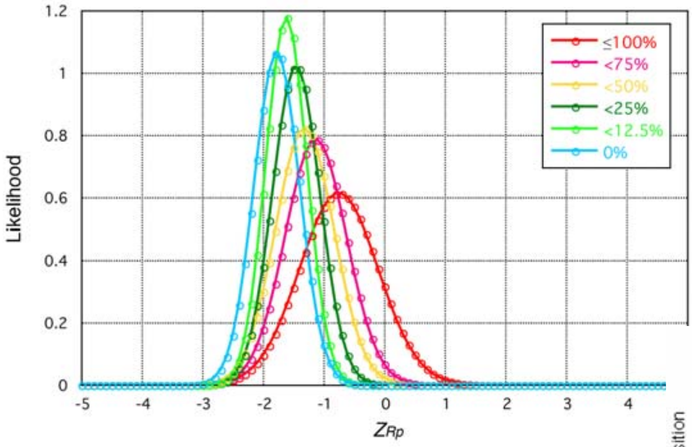
$Z_{Rp}$ : discriminant score,
$d$: difference,
$r$: correlation




METI/JAXA



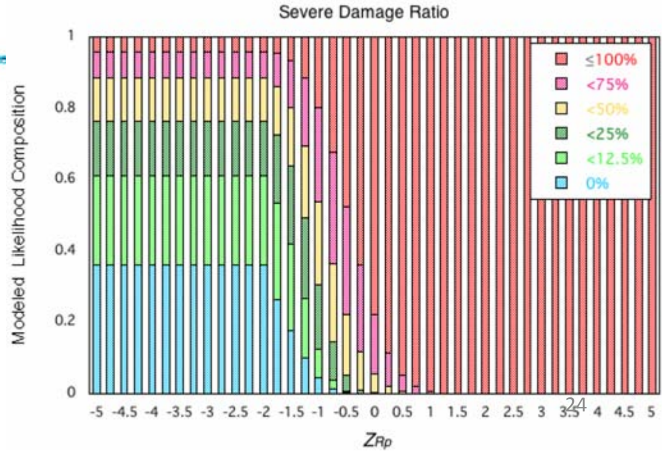
# Likelihood Function of Severe Damage Ratio from $Z_{Rp}$




Normal distribution model of $Z_{Rp}$ frequency distribution

For the region where $Z_{Rp}$ is under -2.0, a constant value obtained by extrapolating the value at $Z_{Rp}$ = -2.0 is used

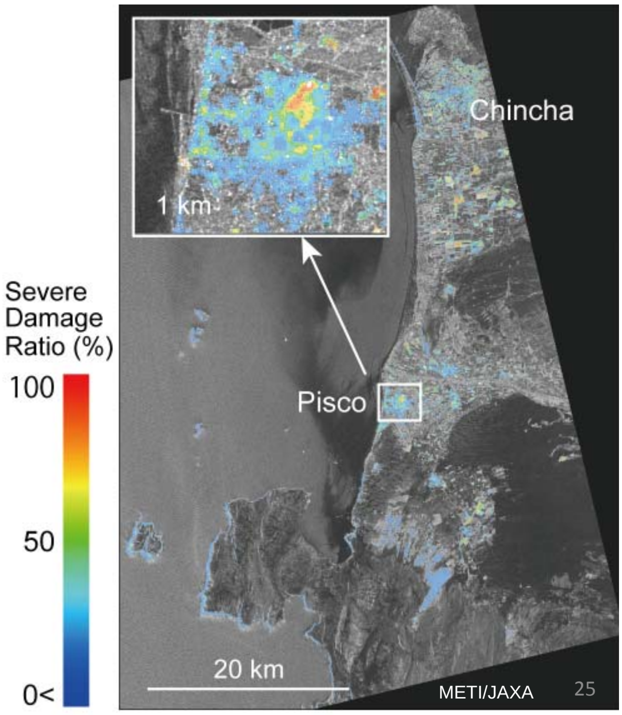
Modeled likelihood functions by $Z_{Rp}$



# Damage Ratio derived from PALSAR $Z_{Rp}$ Images

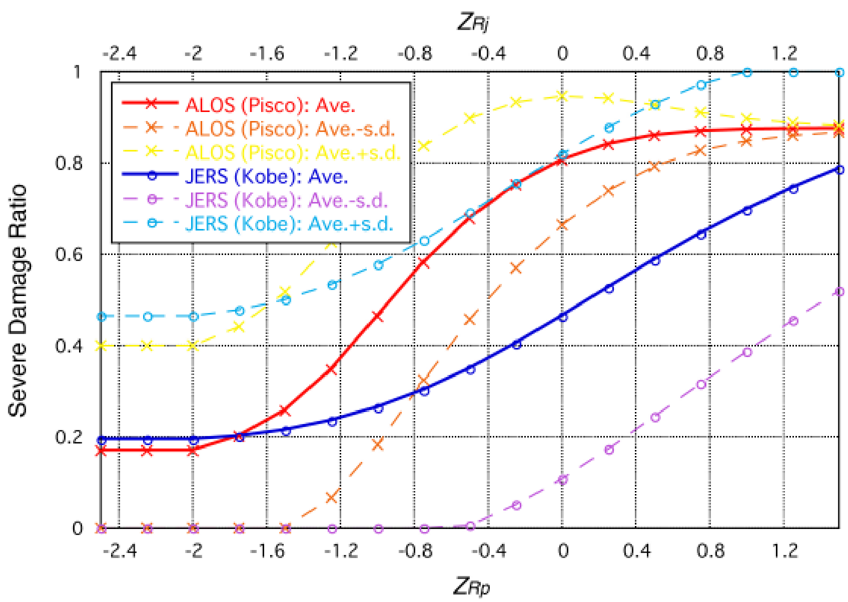
Estimated damage ratio is about 20% even in slight or no damage area.

Need to integrate shake map information






# Relationship between $Z_{Rp}$ and Severe Damage Ratio

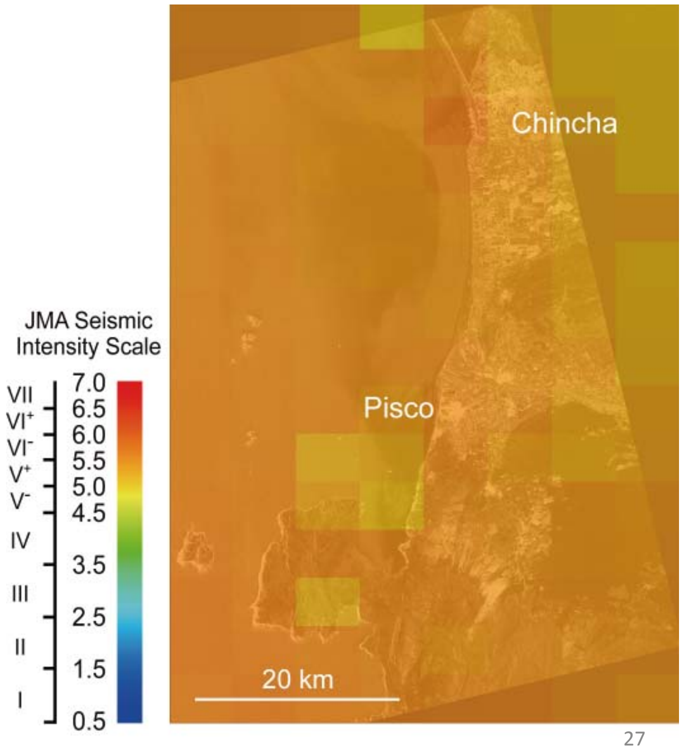



This curve is equivalent to the fragility function for damage without seismic intensity information, the severe damage ratio increases with increasing $Z_{Rp}$.

# Sample of Shake Map (USGS)

ShakeMap PGV data converted to $I_{JMA}$ using empirical equation

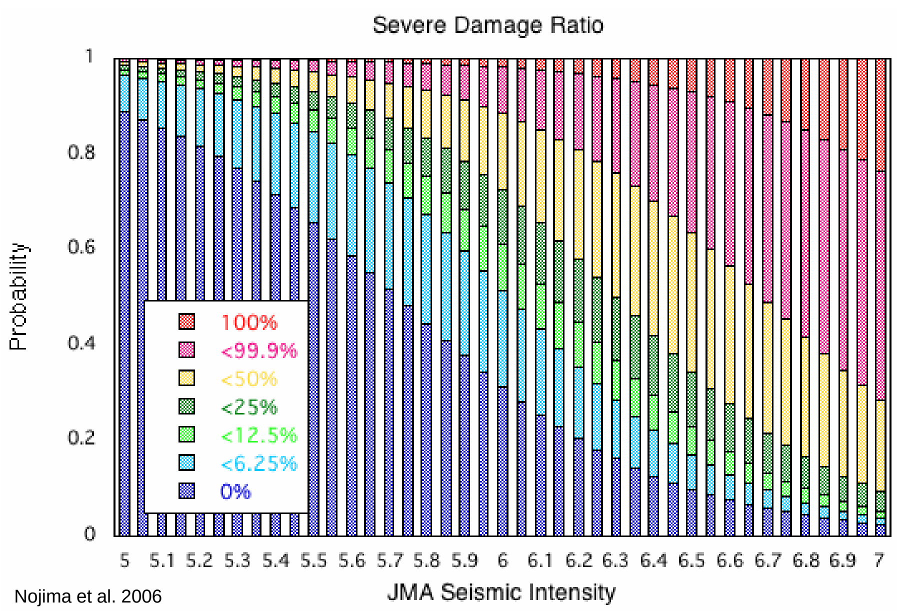
Better to use more accurate and detail information based on observation and/or estimation in Peru!






# Sample of Fragility Function in terms of Seismic Intensity

- Modified Kobe model (the curves are shifted -0.25 in terms of seismic intensity) → weaker strength than Kobe



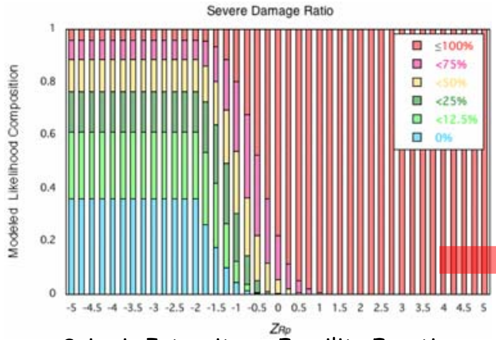

Nojima et al. 2006

Better to use suitable model taking account of building types and their vulnerabilities!

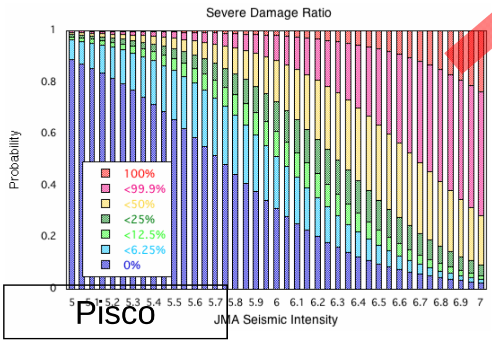
# Integration Using Bayes' Probability Update

10m res. L-band SAR

ZRj vs Normalized Likelihood Function

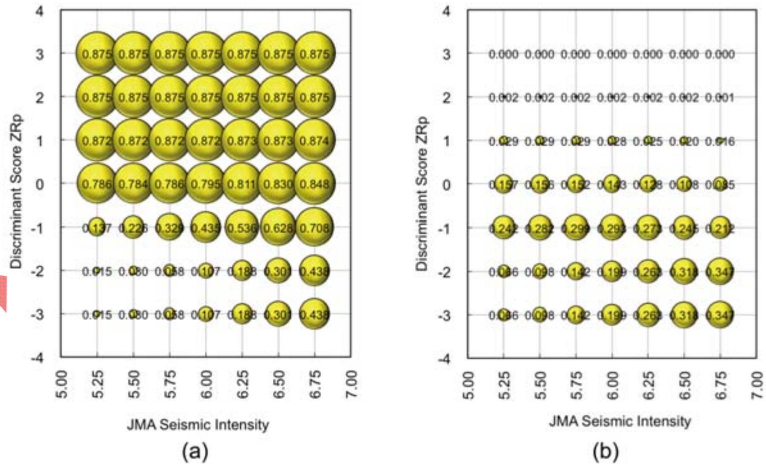



Seismic Intensity vs Fragility Function




Pisco

Damage Rate based on Integration of SAR and Seismic Intensity

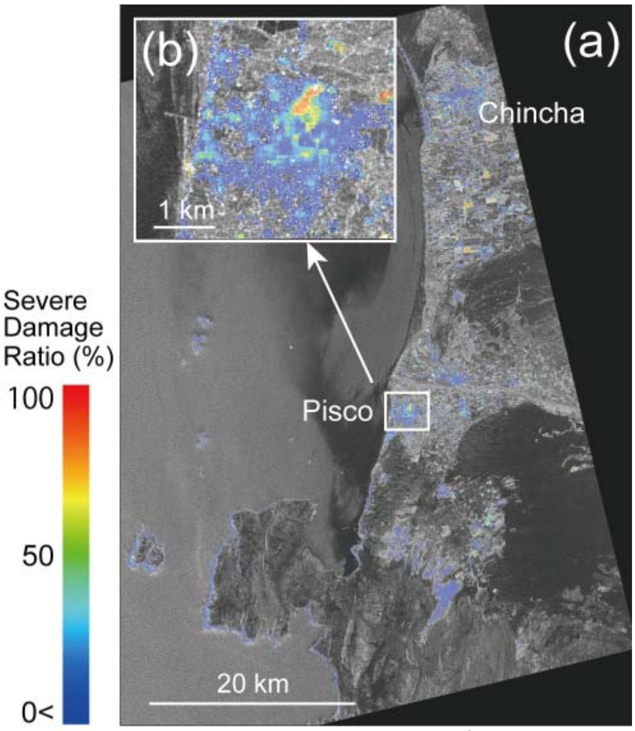



(a) Mean (b) standard deviation

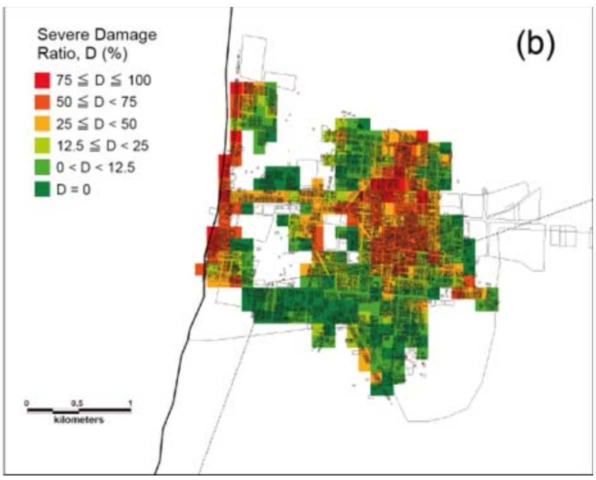
Nojima et al. 2006



# Integrated Results and Comparison with Damage Survey Data




METI/JAXA




Severe damage ratio distribution calculated from CISMID data

# Summary

- In order to develop a damage estimation model for SAR images, a discriminant scores was obtained by regression discriminant analysis, using the difference values and correlation coefficients from pre-event and post-event SAR images of the areas affected by an earthquake, as well as damage severity rankings, as explaining variables.
- Then, a modeled likelihood function for severe building damage ratio from discriminant scores was developed.
- We demonstrated that the severe building damage ratio distribution can be estimated from SAR images through integration with the fragility function for damage in terms of seismic intensity of the earthquake.
- Above mentioned procedure were applied to the 1995 Kobe and 2007 Peru earthquakes as examples, and the accuracy of the proposed models through comparisons with local field investigations was examined.