An object oriented approach to detect earthquake damage in urban area from VHR optical imagery

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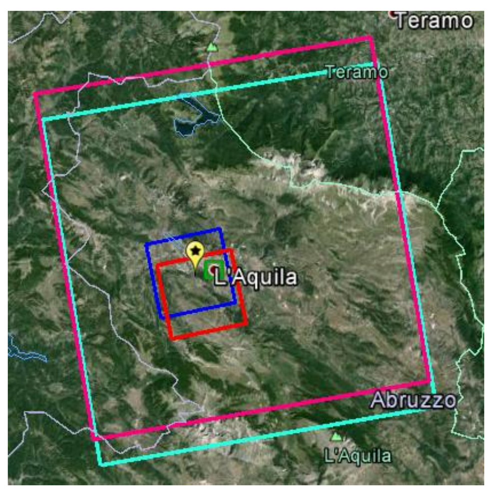
INTRODUCTION

- Satellite images are generally used to map mostly affected urban areas after an earthquake using change detection techniques applied at pixel scale
- Civil Protection Services require damage assessment of each building according to a well established scale (EMS 98) to manage rescue operations and to estimate the economical losses.
- We propose an object-oriented approach based on preexisting urban maps to detect damaged buildings from a pair of VHR optical images acquired before and after a seism.

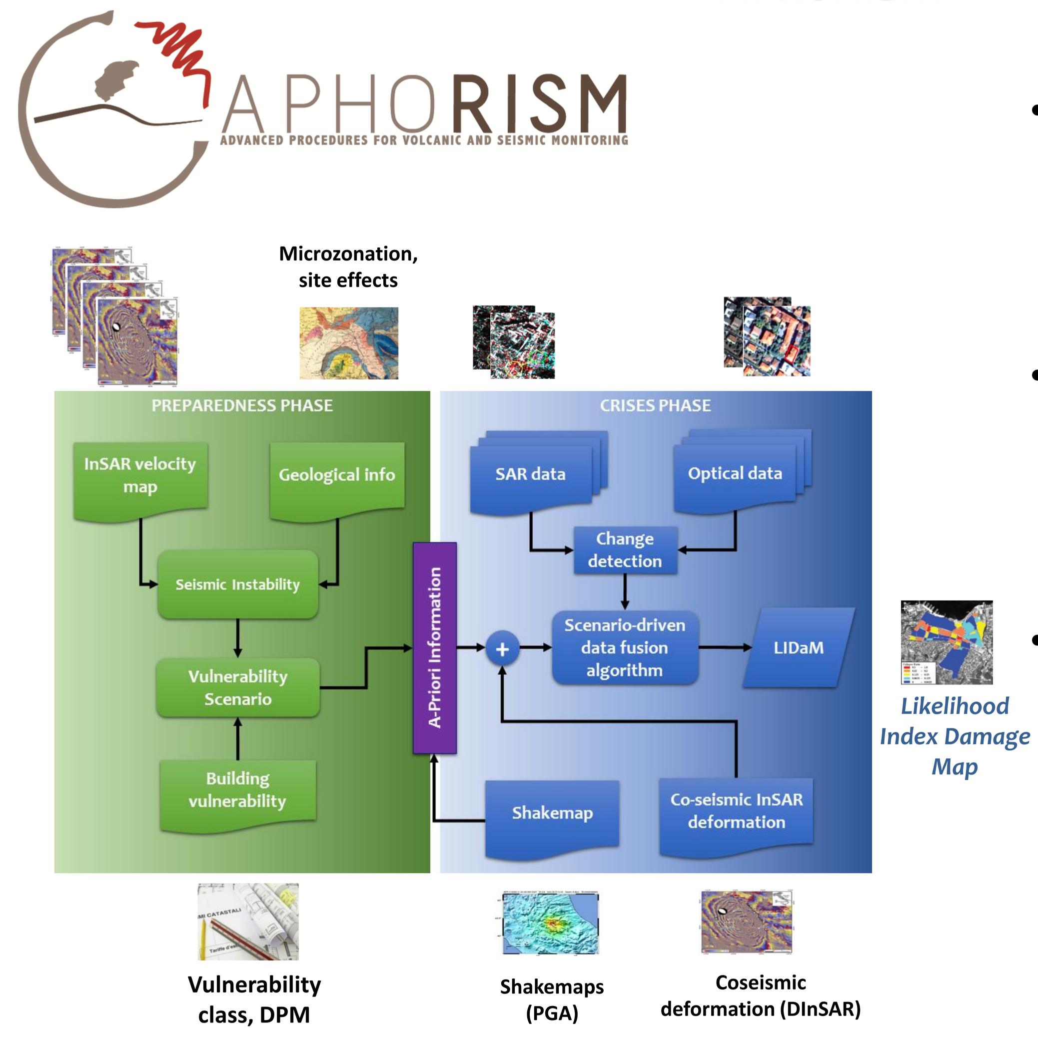


Case study: The April 6, 2009 L'Aquila Earthquake

The procedure was tested using QuickBird images taken before and after the earthquake that hit L'Aquila city (Italy) on April 6, 2009.
For validation purposes two ground based damage maps are used:
- the survey performed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV)
- the survey carried out by the Italian Civil Protection Department (DPC).

Date QB acquisition	Acquisition Mode	Looking angle
04/09/2006	PAN + MS	2.8° in- track 3.9° cross-track
08/04/2009	PAN + MS	-3.7° in- track -3.10° cross-track

APhoRISM



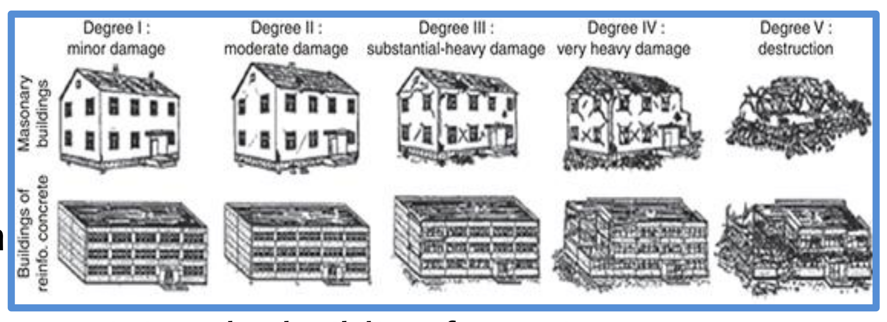
http://www.aphorism-project.eu/

- This work was performed in the frame of the FP7 project Aphorism (Advanced PRocedures for volcanIc Seismic Monitoring)
- Aphorism is developing a procedure to integrated satellite data and other pieces of information to assess damage after an earthquake.
- Pre event data about soil instability and building structural vulnerability are merged with data collected just after the earthquake, such as shakemaps, InSAR deformation, VHR images (both radar and optical)

GROUND BASED MACROSEISMIC SURVEY

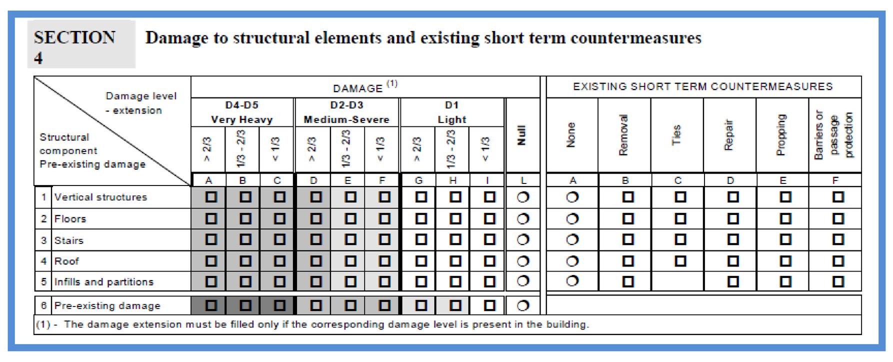
1. The INGV Ground Survey

Based on observation from exterior a unique damage grade has been assigned to each surveyed building according to the European Macroseismic Scale 98 (EMS 98).
The damage grade ranges from 0 to 5, i.e., from no damage to completely collapsed.
A georeferenced vector file has been produced containing the building footprint

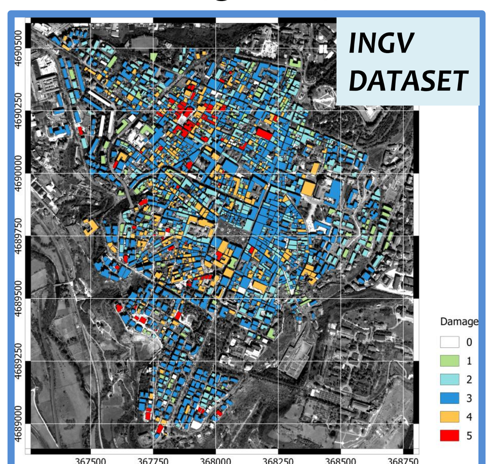


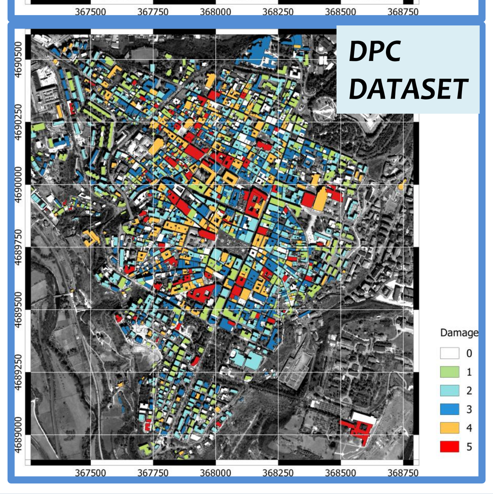
2. The DPC Ground Survey

Buildings were inspected internally (where possible) and externally. The data were collected using the AeDES forms (Agibilità e Danno nell'Emergenza Sismica)
A Damage grade (EMS98) is provided for each structural element (vertical structures, floor, stairs, roof, infills and partitions).
An overall damage indicator was calculated by CNR-ITC, L'Aquila and AeDES forms geolocated wrt existing urban maps.

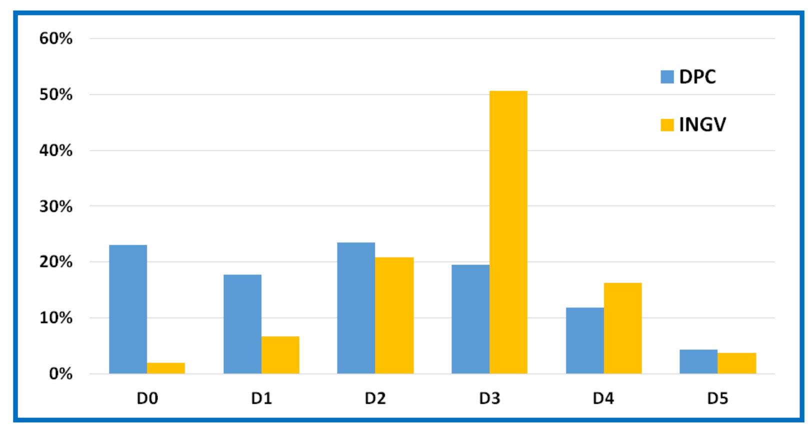


L'Aquila city centre damage maps





3. Ground Survey Comparison



Damage Grades Distribution

✓Out of 75 grade 5 INGV polygons only 59 AeDES forms were filled and only 24 of them confirms grade 5 damage.
✓For a 2-class problem (D<5, D=5) Kappa=27%, overall accuracy=93%

Confusion matrix comparing DPC and INGV damage grades

		INGV D0	D1	D2	D3	D4	D5	
DPC	D0	**13**	49	68	63	17	6	216
	D1	16	**28**	80	112	15	3	254
	D2	2	20	**92**	234	27	11	386
	D3	1	9	54	**205**	71	5	345
	D4	0	2	23	112	**76**	10	223
	D5	0	0	6	38	30	**24**	98
		32	108	323	764	236	59	1522

Overall Acuracy	28,8%
Kappa	10,1%

METHODOLOGICAL APPROACH AND RESULTS

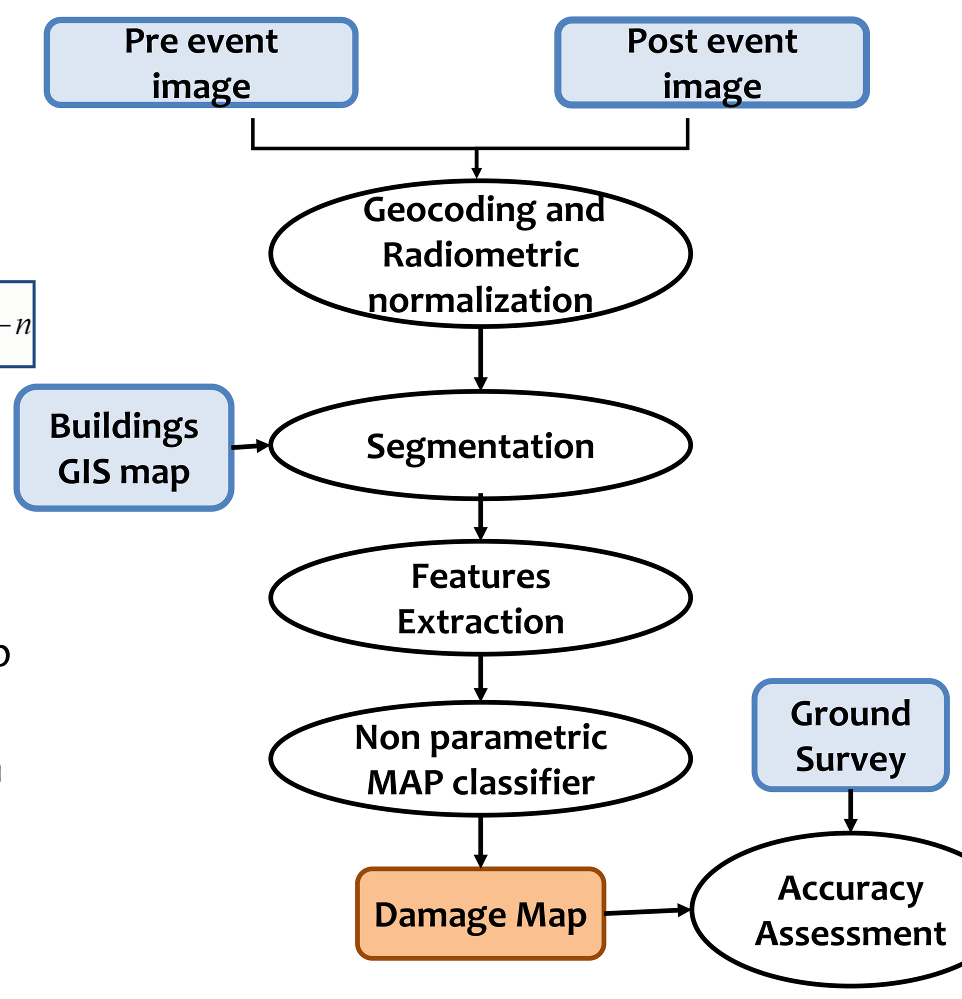
✓ Many different image **change parameters** assessed
- Image difference
- Texture parameters difference, i.e., contrast, correlation, energy, homogeneity, entropy
- Color parameter differences, i.e., hue, saturation
- Kullback-Leibler Divergence

$$D_{KL}(\mathbf{X}\mathbf{Y})=\frac{1}{2}\left[tr(\mathbf{C}_X^{-1}\mathbf{C}_Y)+tr(\mathbf{C}_Y^{-1}\mathbf{C}_X)\right]+\frac{1}{2}\left[(\boldsymbol{\mu}_X-\boldsymbol{\mu}_Y)^T\mathbf{C}_X^{-1}(\boldsymbol{\mu}_X-\boldsymbol{\mu}_Y)+(\boldsymbol{\mu}_X-\boldsymbol{\mu}_Y)^T\mathbf{C}_Y^{-1}(\boldsymbol{\mu}_X-\boldsymbol{\mu}_Y)\right]-n$$

- Mutual Information

$$MI(\mathbf{X},\mathbf{Y})=-\frac{1}{2}\log\left(\frac{\det(\mathbf{C})}{\det(\mathbf{C}_X)\det(\mathbf{C}_Y)}\right)$$

✓ Computed within **objects** extracted using a GIS buildings map (building footprints intersected with images)
✓ Discrimination between collapsed or heavy damaged (D =5 in the EMS-98) buildings and less damaged or undamaged buildings (D < 5 in the EMS-98) carried out according to the **Bayesian Maximum A Posterior (MAP)** criterion using a **non parametric** approach (Parzen window method)



✓ MAP classification performances assessed by a k-fold (k=10) cross validation procedure (note that test set is unbalanced)
✓ The effect on the classifier performance by varying the number and the combination of features used as input has been analyzed: **Mutual Information** and **Contrast** have been selected

INGV test set Confusion Matrix

		ground truth (D=5)	(D<5)		precision
classifier	(D=5)	**34**	76	110	30,9%
	(D<5)	41	**1526**	1567	97,4%
		75	1602	1677	
	sensitivity	45,3%	95,3%		

overall accuracy	kappa	normalized kappa
93,0%	33,2%	40,59%

DPC test set Confusion Matrix

		ground truth (D=5)	(D<5)		precision
classifier	(D=5)	**30**	116	146	20,5%
	(D<5)	85	**1758**	1567	95,4%
		115	1874	1989	
	sensitivity	26,1%	93,8%		

overall accuracy	kappa	normalized kappa
89,9%	17,7%	19,9%

✓ Test against INGV (accuracy=93%, Kappa=33%) is similar/better than comparison between test sets (94% ,29%), whilst test against DPC (90%, 18%) is slightly worse
✓ Matching is not optimal but EO provides results comparable to matching of ground surveys (for sure less expensive and time consuming)

CONCLUSIONS

- A **rigorous systematic test bed** has been set up to assess the VHR image damage assessment capability (**overall L'Aquila historical town, two sources of EMS-98 ground truth** in GIS format)
- An **object based** approach has been designed relying on **urban maps** and **many change detection** features have been tested
- Proper feature combination (generally **two features are enough**) and **non-parametric automatic classification** provided 2-class classification **accuracy comparable to the uncertainty** between the macroseismic surveys
- The EO classification will **be integrated with other data** (e.g., microzonation, shakemaps, building vulnerability) to generate the final Aphorism damage assessment product.