Spatio-temporal aspects of vulnerability

How all comes together in Integrated Disaster Risk Management

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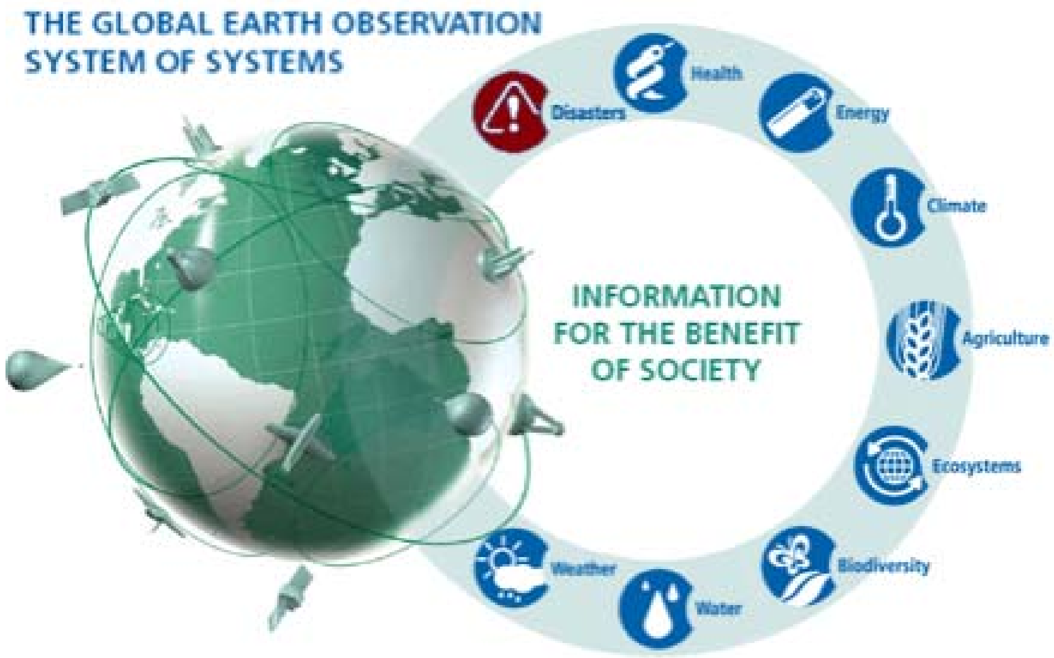
Haiti, 2010

Outline

- Disaster Management concept
  - Risk and vulnerability
  - Mitigation efforts
  - Response
  - Temporal vulnerability variability
    - Short-term
    - Long-term
- Short-term temporal vulnerability variability: Earthquake case study
  - Seismic hazard vs. seismic risk
  - Spatio-temporal human exposure to seismic intensity
- Conclusions & Outlook

Concept of Disaster Management



"The Global Earth Observation System of Systems [GEOSS] is integrate Earth observations with other information to help planners reduce vulnerability, strengthen preparedness and early-warning measures and, after disaster strikes, rebuild housing and infrastructure in ways that limit future risks."

[Group on Earth Observations GEO - GEOSS Disasters Theme]

Concept of Disaster Management

[Federal Emergency Management Agency FEMA (2005) The life cycle of disasters. www.fema.gov.]

Concept of Disaster Management

FEMA chart becomes brunt of joke.

[Jon Stewart, Comedy Central's Daily show, Oct 2005]

Commenting on **FEMA's controversial response to Katrina**, Jon Stewart said,
"What should FEMA have done?
Perhaps the answer can be found on their website…"

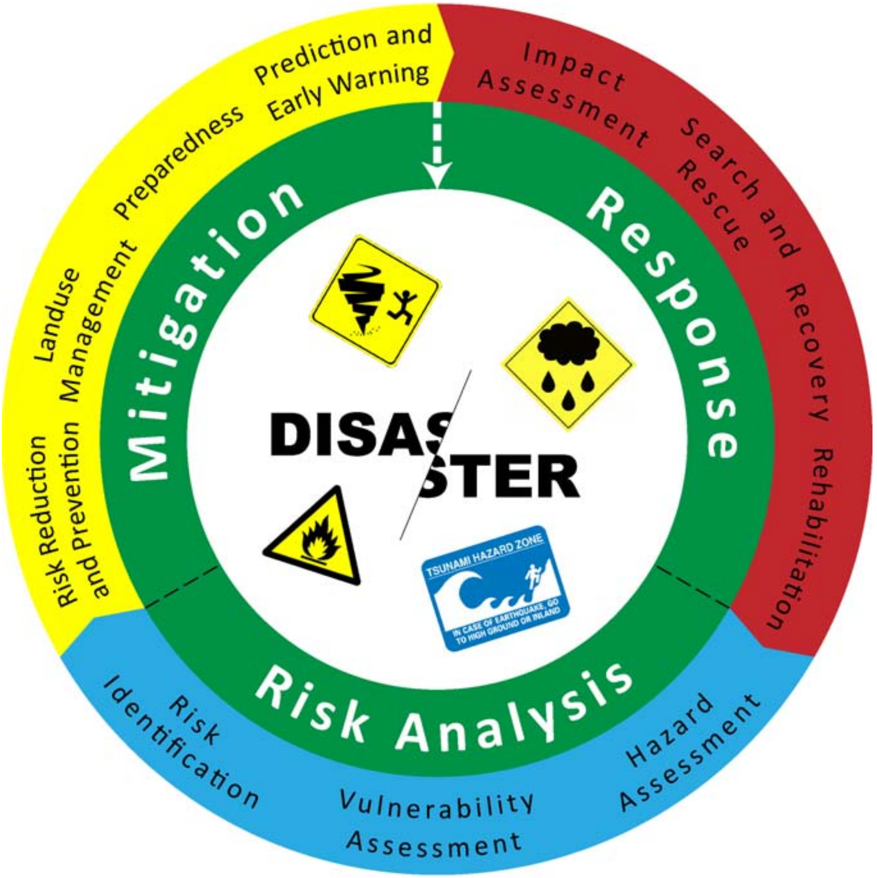
"This chart, clearly depicting the agencies responsibilities in the event of a disaster…

It begins with a **response** to a disaster, leads to **recovery**, **mitigation**, **risk reduction**, **prevention**, **preparedness**…
(dramatic pause)

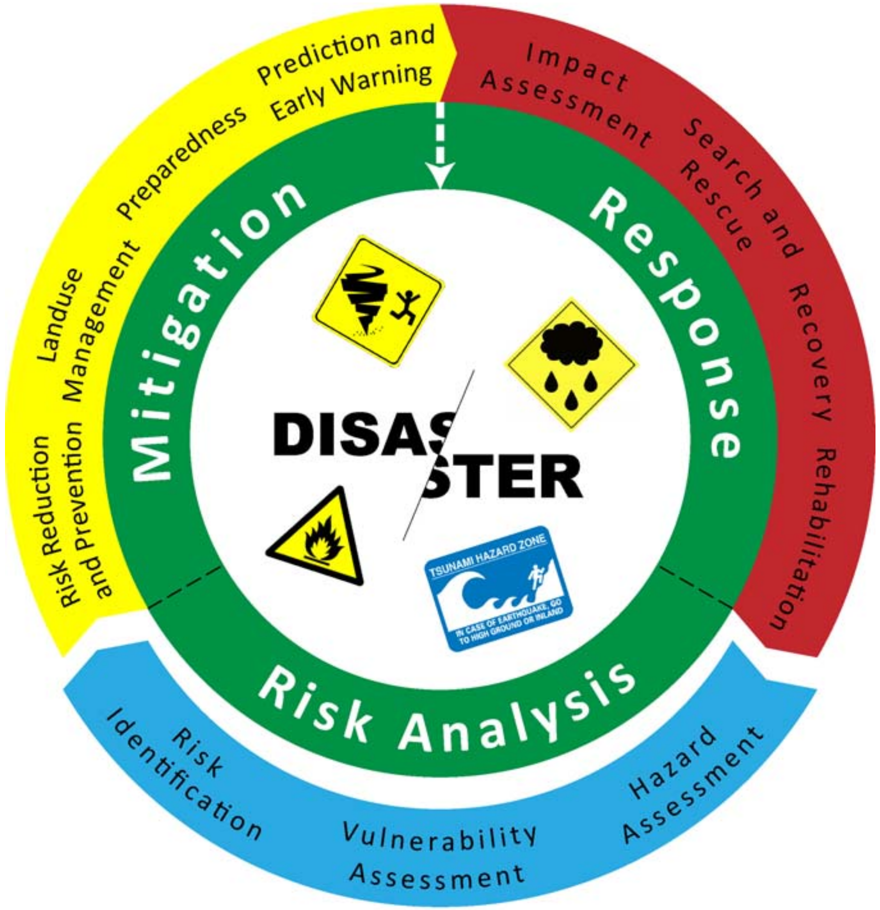
and ends up **BACK IN DISASTER**!"

"In truth, FEMA did exactly what they said they were going to do."

Integrated Disaster Risk Management



Integrated Disaster Risk Management



R = {H} x {V}

Risk (R) as a complex functional relationship of **hazard** (H) and **vulnerability** (V)

V = f (E, CC, SR, I)

where the **vulnerability** of a system (V) is a function (f) of

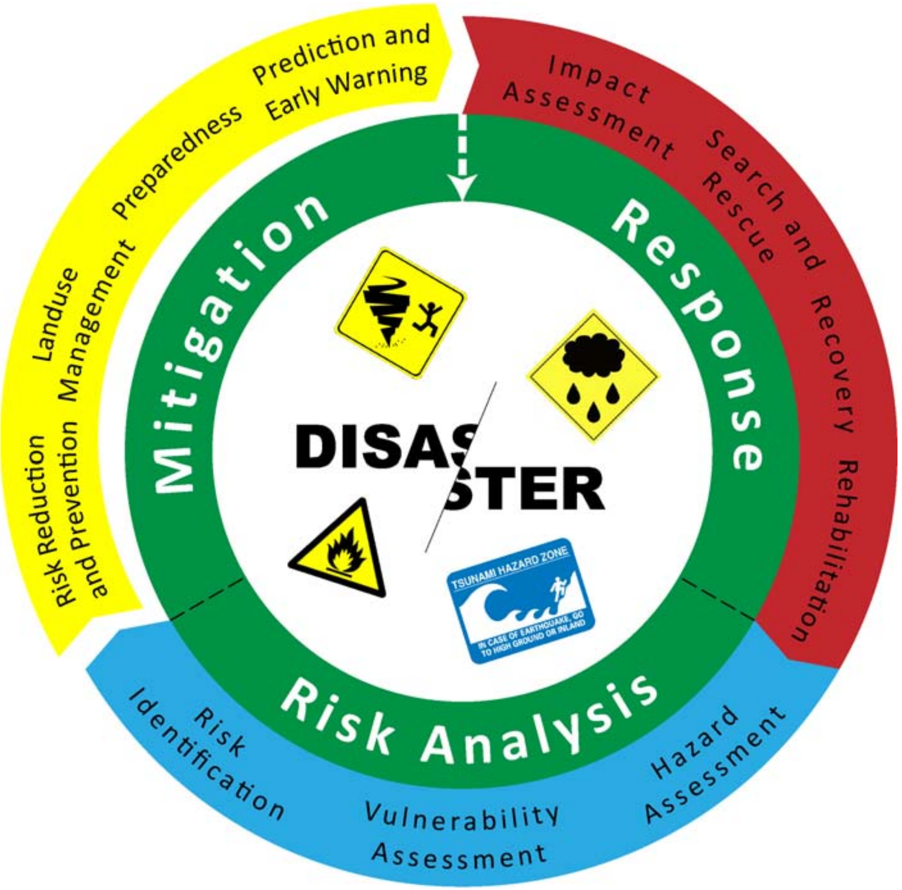
E … being the **exposure** of the system,

CC … being the initial **coping capacity** of the system,

SR … being the **social response** of the system (including early warning, public awareness etc.), and

I … being a fuzzy term considering the various **interrelations** of vulnerability factors

Integrated Disaster Risk Management



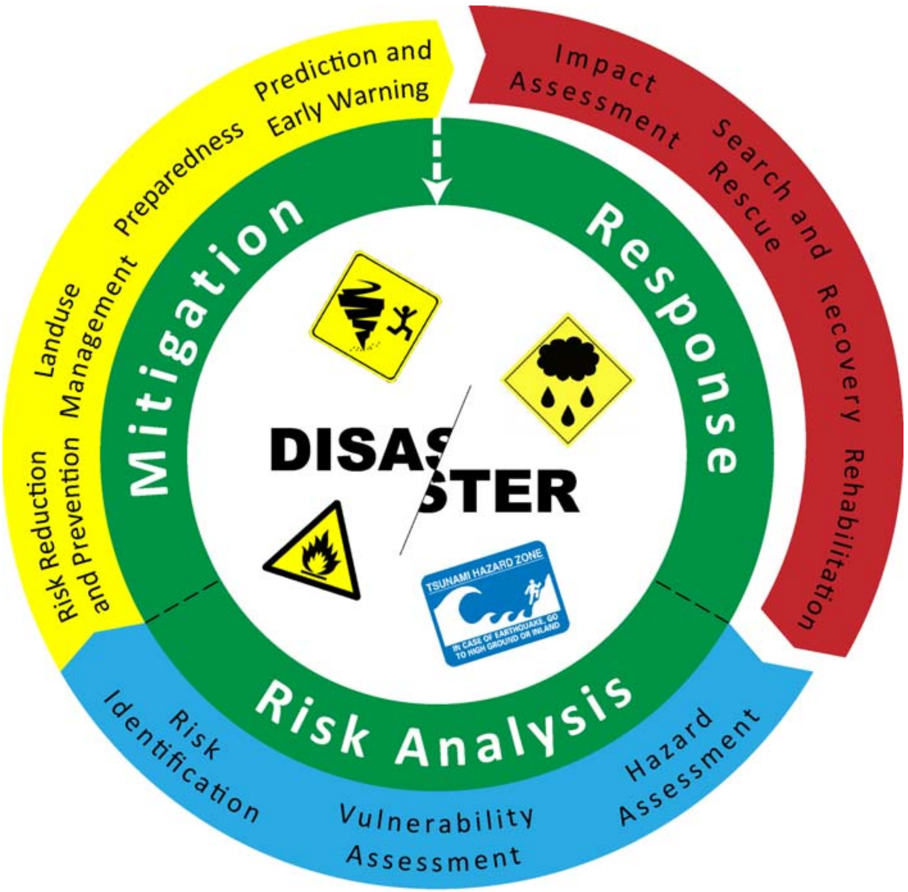
$$V_t = f\ (V_{t-1}, M_x, I_M)$$

where the **vulnerability** of a system at a **certain point in time** (V_t) is a function (f) of its previous state (V_{t-1}) and

M_x … standing for various **mitigation measures** applied to the system, and

I_M … being a fuzzy term considering **interrelations** of these mitigation measures

Integrated Disaster Risk Management



$$V_t = f\,(V_{t-1}, R_x, I_R)$$

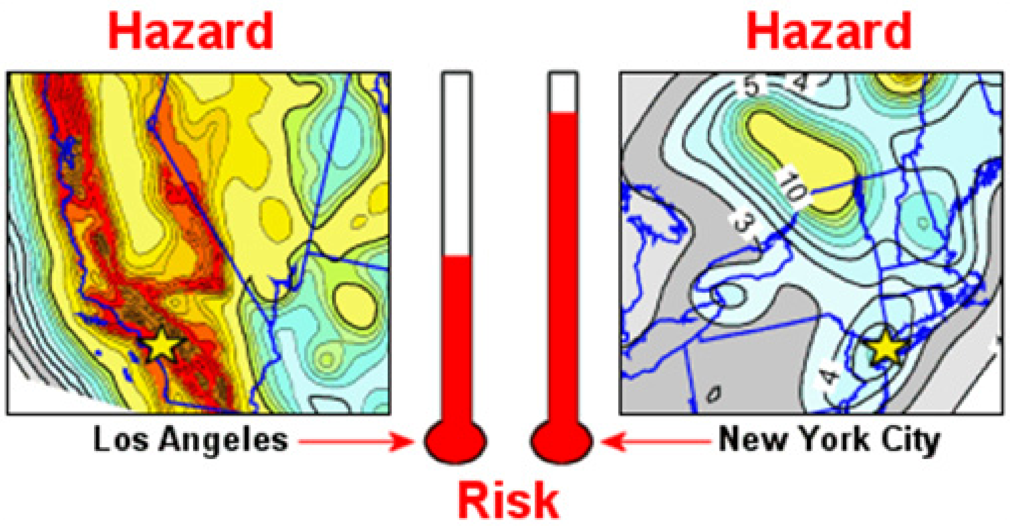
where the **vulnerability** of a system at a **certain point in time** (V_t) is a function (f) of its previous state (V_{t-1}) and

R_x … standing for various **response actions** applied to the system after a disaster occurs, and

I_R … being a fuzzy term considering **interrelations** of these response actions

- Spatial variation in the **speed of recovery** (i.e. the most socially vulnerable being the slowest to recover)
- **Limited maximal time of resistance** due to pre-existing constraints
- Further **exacerbation** of existing conditions

Seismic hazard vs. seismic risk

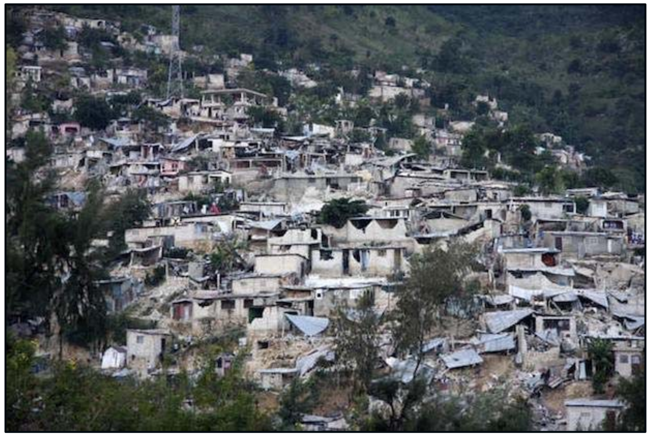


- Los Angeles has a much higher hazard than New York City ...
  ... but New York City has much higher risk, primarily because of older infrastructure and lack of seismic building codes.

Earthquake risk and population exposure

Haiti, 12 Jan 2010

Tuesday, 16:53



People were in workplaces, schools, churches

- What is the possible death toll?
  a. 30,000
  b. 50,000
  c. 100,000
  d. 200,000
  e. ?

→ There is not sufficient data for a **rough** estimate

Earthquake risk and population exposure

- Population information:
  - *"Basic necessity for exposure"*
  - *"Quality and level have direct effect on response and lives saved"*

[U.S. National Research Council, 2007; Chen et al., 2004; Sutton et al., 2003]

  - USGS uses ***LandScan*** spatial data to assess human exposure to EQ
  - ***LandScan*** models present population, not resident population
  - 1km raster data, not for local level

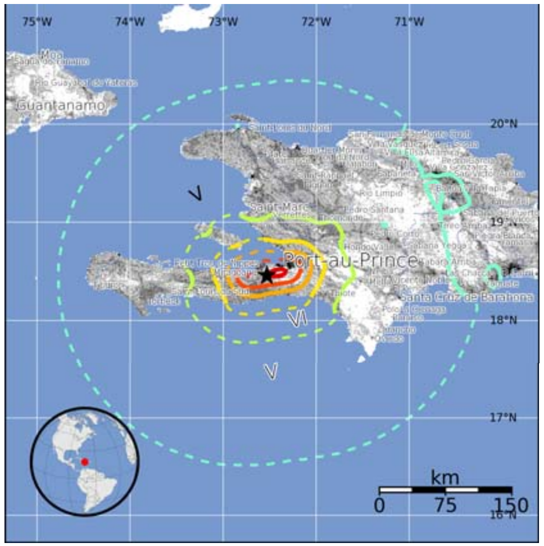
Exposure Summary | Full City Exposure List | Downloads

[USGS, 2010]

Estimated Population Exposed to Earthquake Shaking

Est. Modified Mercalli Intensity	Est. Population Exposure	Perceived Shaking	Potential Structure Damage	
			Resistant	Vulnerable
X	332k	Extreme	V. Heavy	V. Heavy
IX	2,246k	Violent	Heavy	V. Heavy
VIII	314k	Severe	Moderate/Heavy	Heavy
VII	571k	Very Strong	Moderate	Moderate/Heavy
VI	1,049k	Strong	Light	Moderate
V	7,261k	Moderate	V. Light	Light
IV	5,887k*	Light	none	none
II-III	--*	Weak	none	none
I	--*	Not Felt	none	none

*Estimated exposure only includes population within calculated shake map area



Earthquake risk and population exposure

- Population information:
  - Human life is the most valuable asset to protect
  - Population exposure analysis is usually overlooked in risk analysis
  - Assessment and mapping of vulnerability lags behind hazard analysis!

[Pelling, 2004; Balk et al., 2006; Cutter, 2003; Birkmann, 2007]

Table 6
Main uncertainties and possibility to reduce them

Module	Uncertainty type	Level of uncertainty
Seismic source	Localization	High
	Mechanism	High
	Occurrence	Medium
Wave attenuation	Spectrum	High
	Duration	
Site effect	Soil classification	Medium
	Amplitude dependence	
Typology class	Class assignment	Requires expertise
Vulnerability	Needs data and experiments	High
Inventory	Needs resources	Depend on scale
Modelling	Event-tree	Depend on scale

[Oliveira, 2008.]

As seen previously, the main problems where great uncertainties still play an important role are (Table 6):

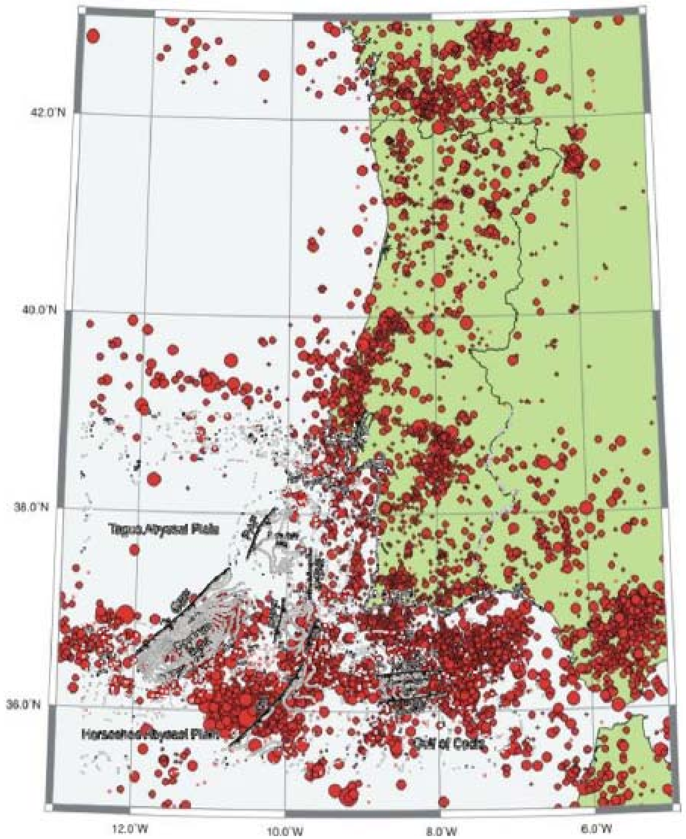
- model of occurrence—location of active faults, rate of activity and source mechanism;
- model of attenuation including site effects—specially for large interplate events (epicentral distances larger than 250 km and magnitudes greater than 8.5);
- models of vulnerability for different classes of existing structures—validated with analytical and experimental data;
- inventory of existences—using the most updated non-contaminated information such as census, remote sensing, building by building enquiry;
- inventory of population—daily, weekly commutation, etc.;
- model for casualties—validated with experimental data.

Earthquake risk in Portugal - Lisbon Metropolitan Area

- Earthquakes:
  - Prototype for major disaster
  - Low probability, rapid-onset, high-consequence events
  - Strike with faint or no warning at any day and time

Lisbon, Portugal, has significant risk of EQ

(1755, anyone?)



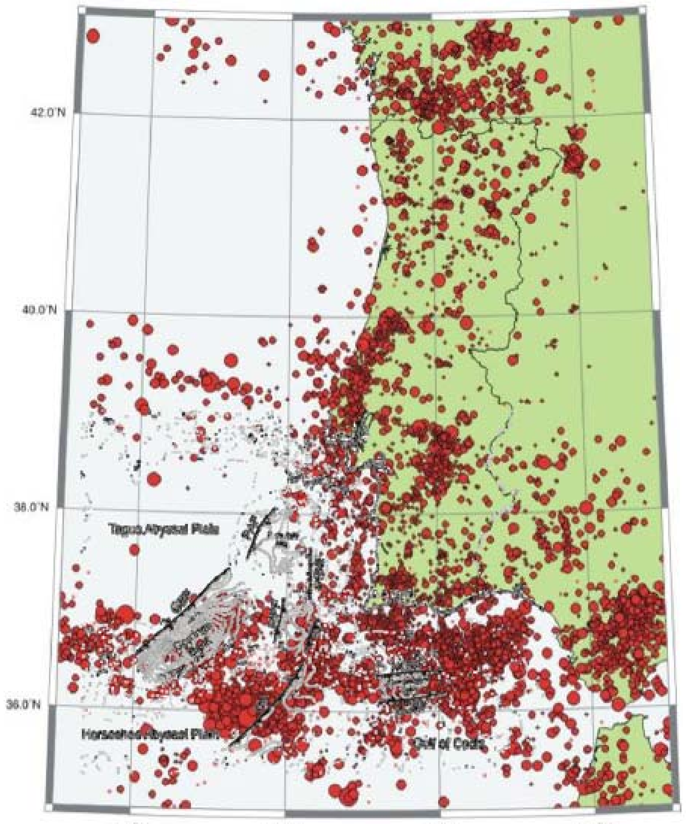
Seismic events 1960 - 2003

Earthquake risk in Portugal - Lisbon Metropolitan Area

- Earthquakes:
  - Special Emergency Plan for Seismic Risk was recently approved (Sept. 2009, launched 1981)
    - Based on a Seismic Intensity Map
    - Uses census' resident population as exposure in vector format

Lisbon, Portugal, has significant risk of EQ

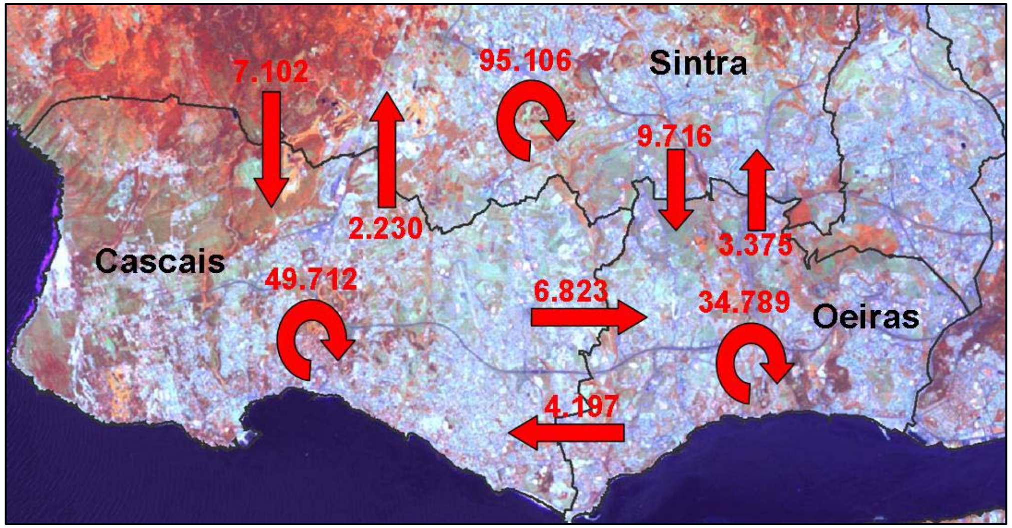
(1755, anyone?)



Seismic events 1960 - 2003

Earthquake risk in Portugal - Lisbon Metropolitan Area

- Daily commuting in the LMA (2001)



[INE, 2003]

  - Population's totals and spatial distribution vary significantly between day and night

Earthquake risk in Portugal - Lisbon Metropolitan Area

- Daily commuting in the LMA (2001)

Municipality	Nighttime Pop. (Residential)	Daytime Pop.	Difference (%)
CASCAIS	170,683	151,115	-11.5
OEIRAS	162,128	148,937	- 8.1
AMADORA	175,872	141,253	-19.7
ODIVELAS	133,847	96,653	-27.8
SINTRA	363,749	291,421	-19.9
LISBOA	564,657	898,840	59.2

[INE, 2003]

- Population's totals and spatial distribution vary significantly between day and night

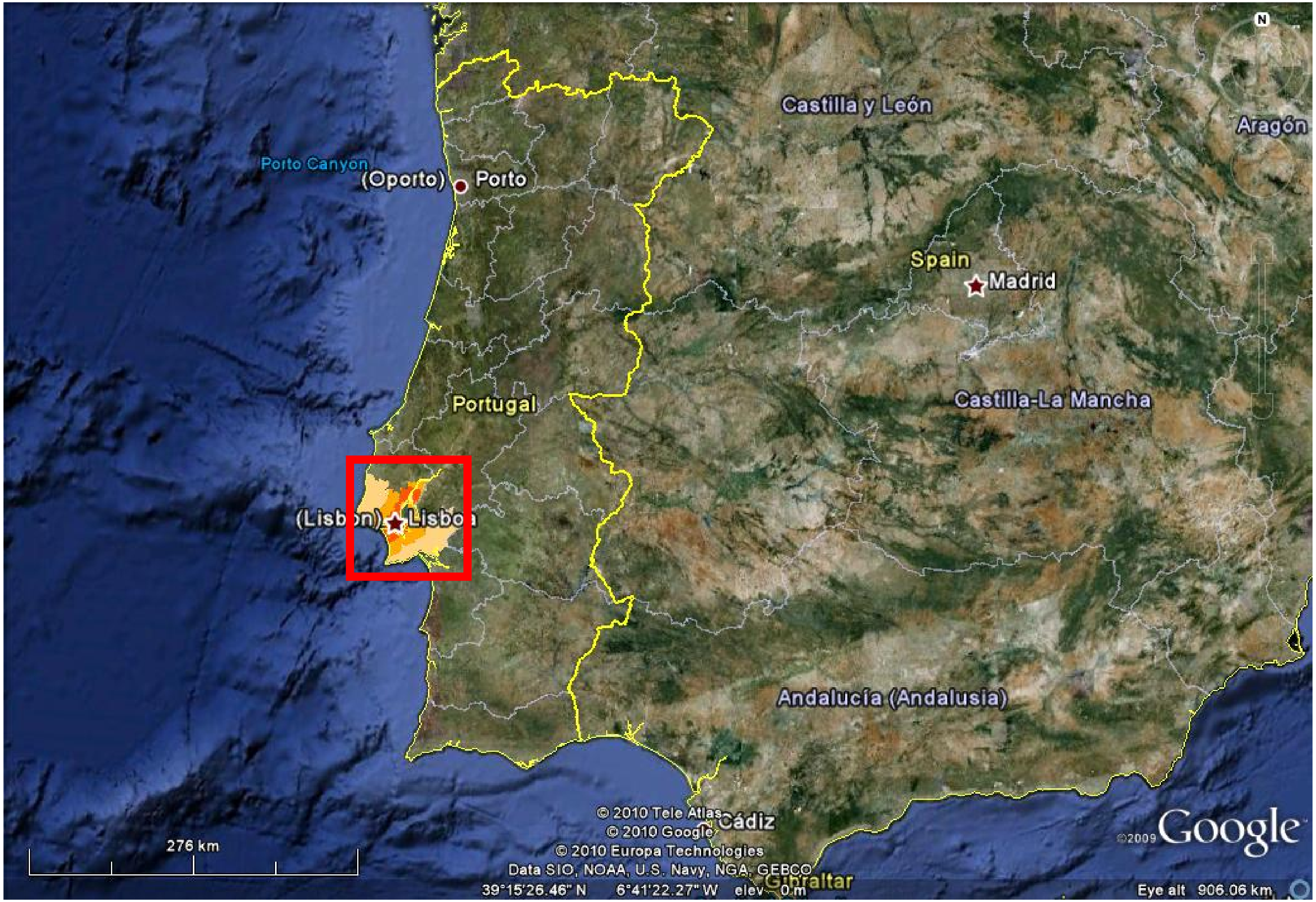
Objectives and analysis steps

- Improve EQ risk assessment in the Lisbon Metro Area:

1. Model and map nighttime vs. daytime population distribution and density at high spatial resolution

2. Assess and quantify spatio-temporal population exposure to varying seismic intensity levels

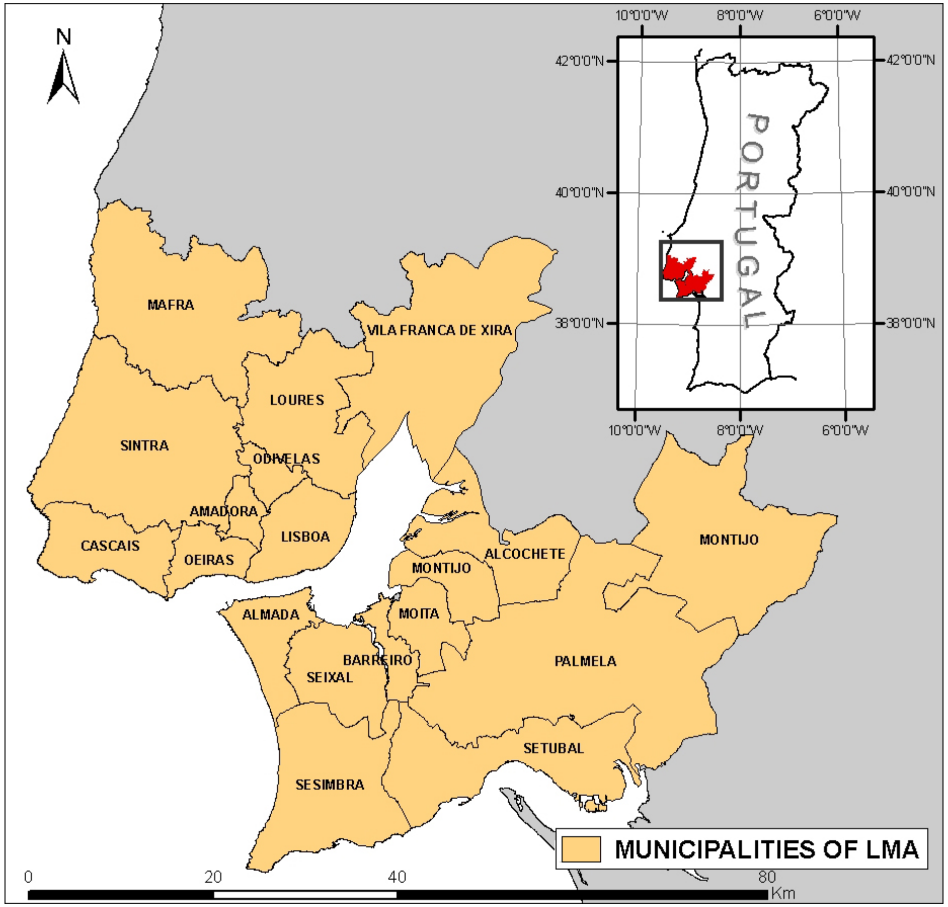
3. Integrate seismic intensity zones with spatio-temporal population density to derive and propose new detailed overall seismic risk maps


Castilla y León
Aragón
Porto Canyon
(Oporto)
Porto
Spain
Madrid
Portugal
Castilla-La Mancha
(Lisbon)
Lisboa
Andalucía (Andalusia)
© 2010 Tele Atlas
© 2010 Google
© 2010 Europa Technologies
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Cádiz
Gibraltar
276 km
39°15'26.46" N 6°41'22.27" W elev 0 m
Eye alt 906.06 km
©2009 Google

Study area - Lisbon Metropolitan Area (LMA)

- 18 municipalities
- Area: 2,963 km²
- 2,661,850 residents (26% of country)
- Mean density: 898 p./km²

- 36% of national GDP
- 30% of companies
- Heterogeneous LULC

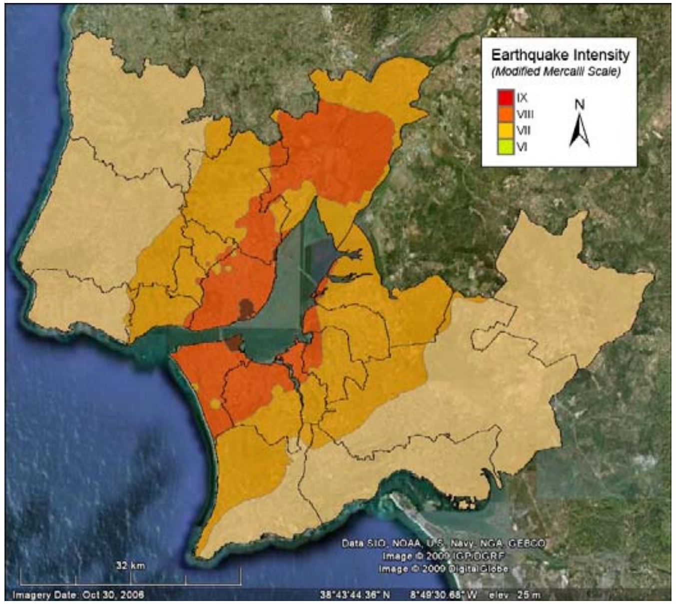


Input data sets

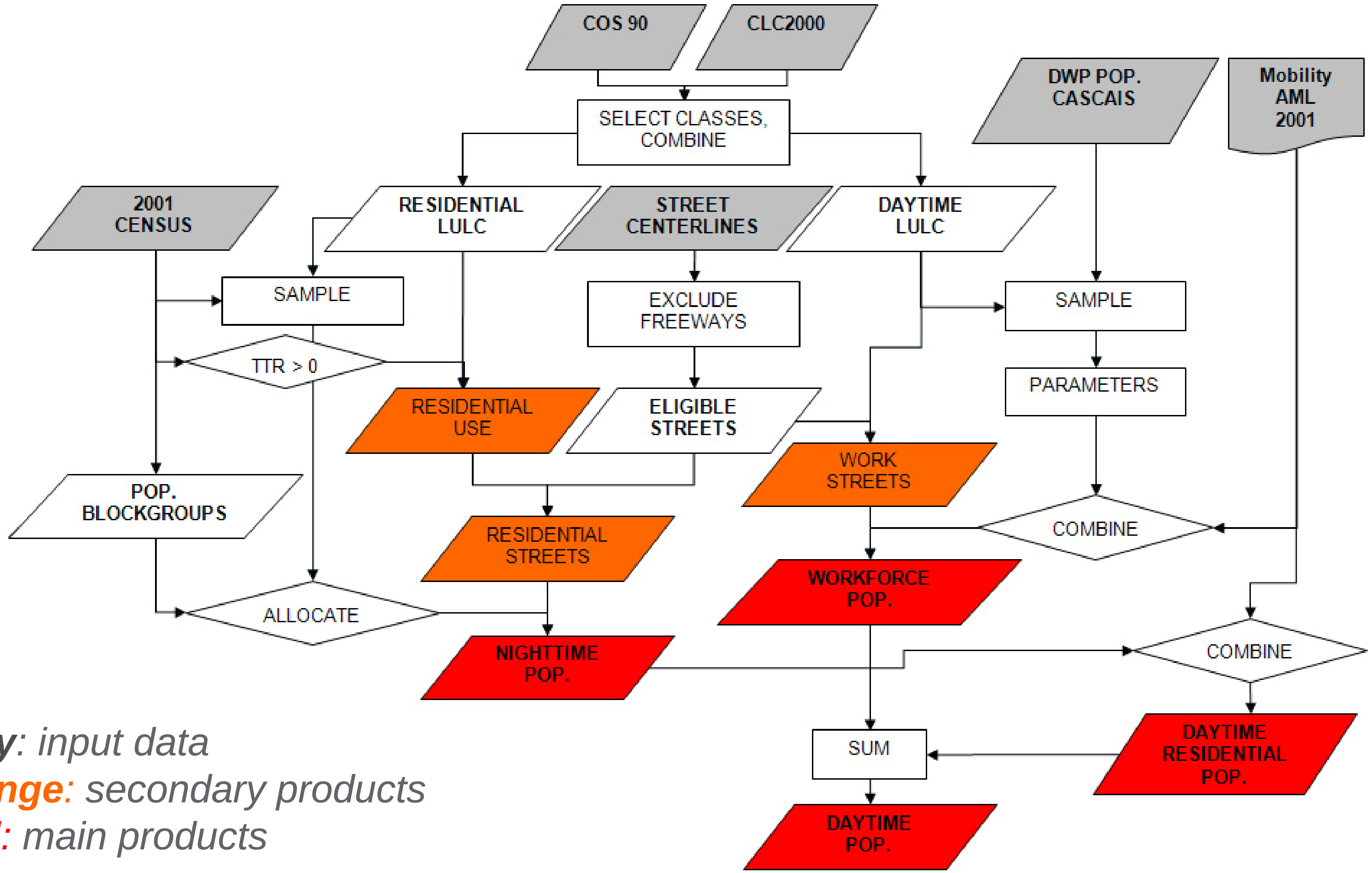
- Population distribution modeling:
  - Physiographic data
  - Census information
  - Statistical data

Data set	Date	Data type
Street centerlines	2004	Vector polyline
Land use/cover maps (COS90; CLC2000)	1990; 2000	Vector polygon
Census block groups	2001	Vector polygon
Census statistics	2001	Database (MS Access)
Commuting statistics	2001	Table (O/D matrix)
Daytime worker/student population distribution	2001	Raster (25 m)

- Seismic intensity map:
  - From PEERS-AML-CL
  - Uses M. Mercalli intensity scale
  - 6.6 / 6.7 M earthquake
  - Epicenter in lower Tagus valley



1. Modeling day / night population distribution

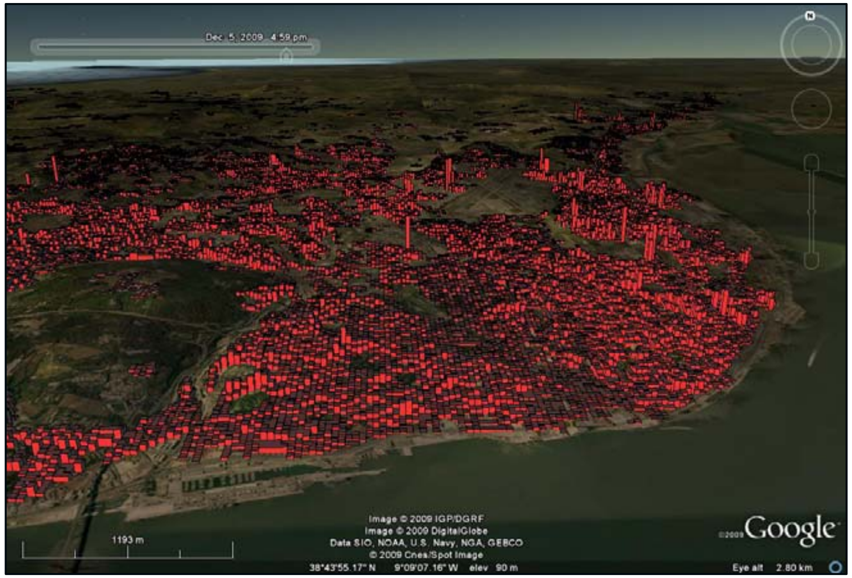


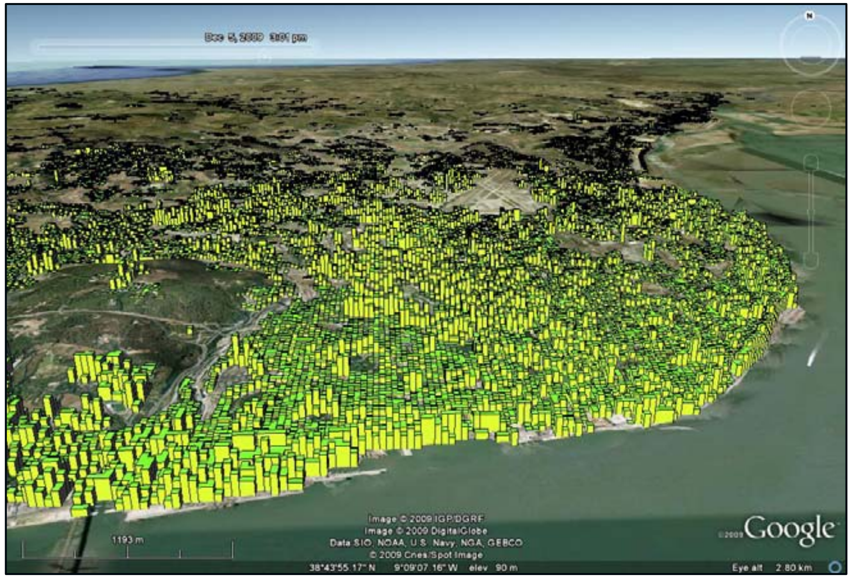
***Gray**: input data*
***Orange**: secondary products*
***Red**: main products*

1. Modeling day / night population distribution

- Zonal interpolation:
  - Intelligent Dasymetric Mapping
    (Mennis & Hultgren, 2006; McPherson & Brown, 2003)
- Two density classes
- Ancillary data:
  - LULC and streets
- Source zones:
  - Blockgroups (night)
  - Municipalities (day)
- DWP:
  - Used empirical weights from previous model (Freire, 2009)
- Raster structure:
  - 25 m resolution, aggregated to 50 m

1. Modeling day / night population distribution

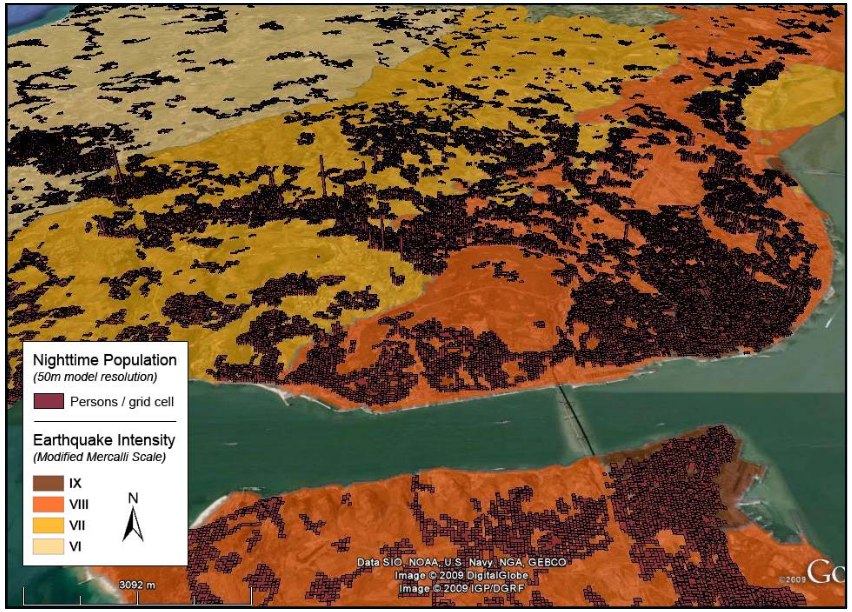




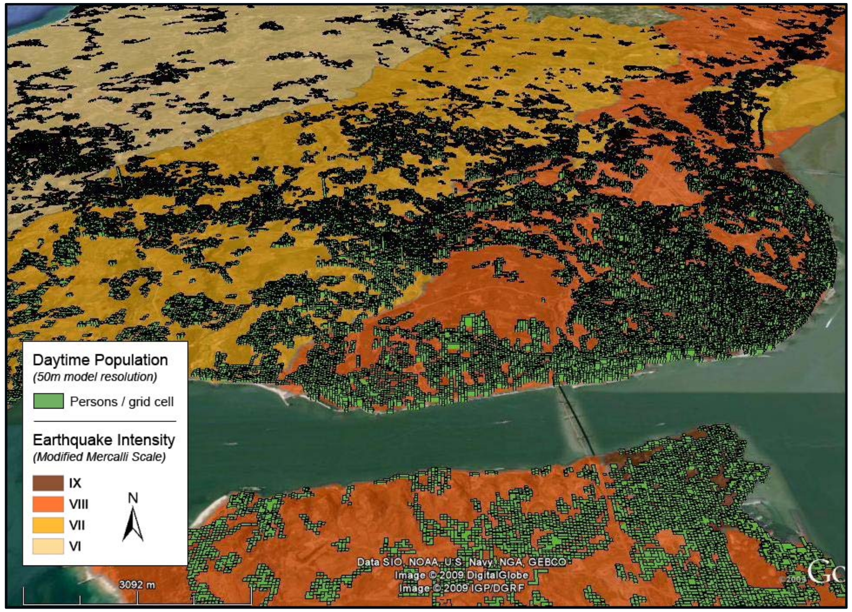
Nighttime **Daytime**

- Results represent maximum expected densities in a typical workday

2. Quantify pop. exposure to seismic int. levels in day/night



Nighttime



Daytime

- In GIS, zonal analysis was used to summarize nighttime and daytime population by each seismic intensity zone

2. Quantify pop. exposure to seismic int. levels in day/night

- Intensity VIII has largest share of population while not occupying the largest area
- From night to day exposure to level IX increases by 22% to affect 5% of the total population
- An additional 204,786 people are exposed to levels VIII and IX

EQ Intensity [M. Mercalli S.]	Population abs. [Pers.]	Population rel. [%]	
IX	112,826	4	Night
VIII	1,076,180	41	Night
VII	887,493	34	Night
VI	569,940	22	Night
Total	2,646,439	100	Night
IX	137,222	5	Day
VIII	1,256,570	47	Day
VII	746,992	28	Day
VI	535,767	20	Day
Total	2,676,551	100	Day
IX	24,396	22	Differ.
VIII	180,390	17	Differ.
VII	-140,501	-16	Differ.
VI	-34,173	-6	Differ.
Total	30,112	1	Differ.

Relative differences are relative to the night numbers

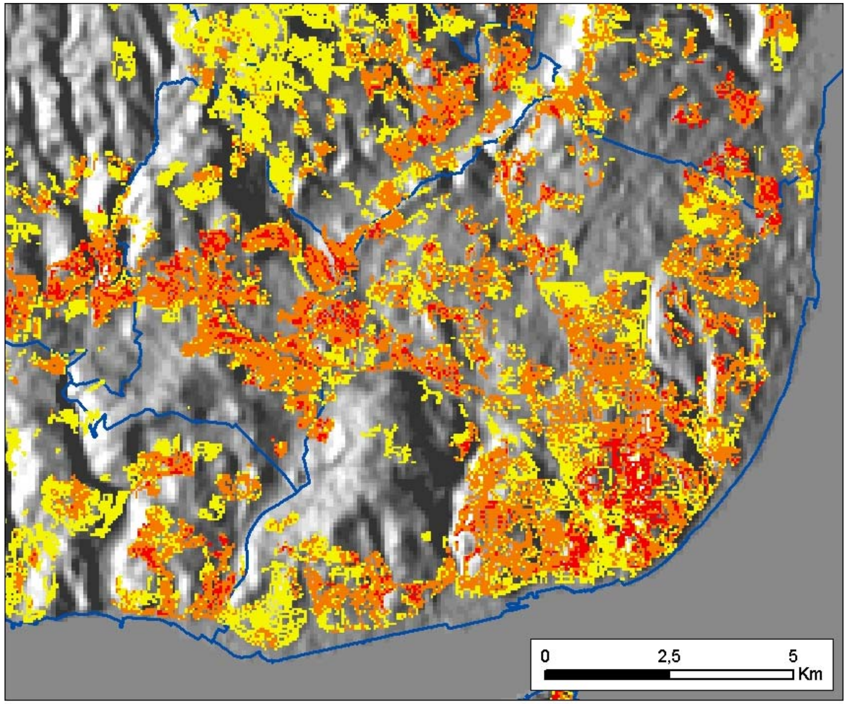
3. Derive and map overall seismic risk

- Reclassify Modified Mercalli Intensity (MMI) Scale (earthquake effect)
  - 12 levels to 4 classes based on intensity definitions
  - Lower 6: how it is felt by people
  - Higher 6: structural damage
- Reclassify day/night population density
  - 4 classes based on histogram
- Combine reclassified classes
  - Into 4 classes
  - Few classes aids in having clear perspective of risk distribution
- Map and quantify new risk categories

		Population Density [Persons/ha]			
		401-	201-400	101-200	0-100
EQ Intensity [M. Mercalli Scale]	**Risk Class**	**VH**	**H**	**M**	**L**
XII	**VH**	VH	VH	H	M
XI	**VH**	VH	VH	H	M
X	**VH**	VH	VH	H	M
IX	**VH**	VH	VH	H	M
VIII	**H**	VH	H	H	M
VII	**H**	VH	H	H	M
VI	**M**	H	H	M	M
V	**M**	H	H	M	M
IV	**M**	H	H	M	M
III	**L**	M	M	M	L
II	**L**	M	M	M	L
I	**L**	M	M	M	L

VH (very high), H (high), M (moderate), L (low)
Framed in black: Seismic intensity levels in the study area

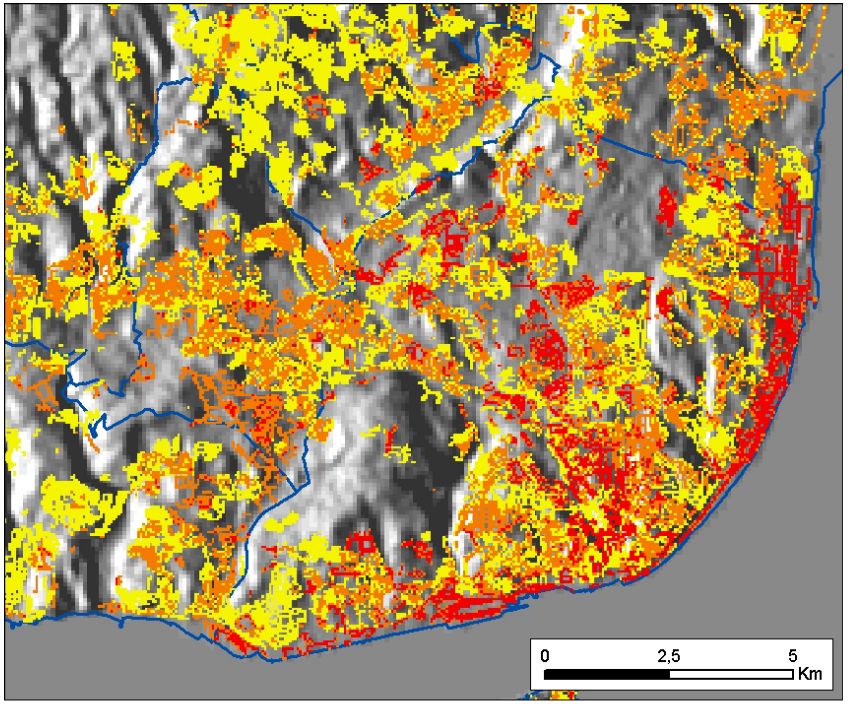
3. Derive and map overall seismic risk



Nighttime Overall Risk

very high | high | moderate

Overall risk is calculated in high detail (50m), based on seismic intensity and modeled population distribution. Unpopulated places are left blank.



Daytime Overall Risk

very high | high | moderate

Overall risk is calculated in high detail (50m), based on seismic intensity and modeled population distribution. Unpopulated places are left blank.

3. Derive and map overall seismic risk

- Most of area and population are in M or H risk classes
- While 3% of the populated area is in VH risk, this class accounts for 23% of total day population
- This is an increase of 48% in population and 31% in area from nighttime

Risk	Area		Population		
	abs. [ha]	*rel. [%]*	*abs. [Pers.]*	*rel. [%]*	
VH	884	3	423,112	16	Night
H	6,390	21	1,308,780	49	
M	22,617	76	914,550	35	
Total	29,891	100	2,646,442	100	
VH	1,154	3	626,753	23	Day
H	6,022	17	1,062,020	40	
M	27,611	79	987,772	37	
Total	34,787	100	2,676,545	100	
VH	270	31	203,641	48	Differ.
H	-368	-6	-246,760	-19	
M	4,994	22	73,222	8	
Total	4,896	16	30,103	1	

VH (very high), H (high), M (moderate), L (low)
Relative differences are relative to the night numbers

Conclusions

- Population disaggregation → Nighttime population has higher spatial resolution than census
- Comparable daytime population distribution previously unavailable

- More people potentially exposed to higher seismic intensity levels in the daytime period
- With refined exposure, an experimental overall seismic risk was proposed and analyzed

- Improved population surfaces can be used as input in hazard (EQ) simulators (e.g. modeling of human casualties), emergency evacuation planning, etc.
- Can be combined with different hazard maps to improve spatio-temporal assessment and risk mapping for any type of hazard

Future developments

- Improve spatio-temporal population distribution
  - More detailed LULC w/ functional use by building (Aubrecht et al., 2009)
  - More cycles: daily (e.g. consider commuter traffic), weekly, seasonal
- Evolve from human exposure to vulnerability
  - Include socio-economic variables
    (e.g. human health, Aubrecht et al., 2010)
- Combine with structural vulnerability to map full risk

WORK IN PROGRESS…

Thank you for your attention!

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