Theme
geoSMART Planet & You!
resources + infrastructure

GEOSPATIAL WORLD FORUM

THE USE OF GEOMATIC TECHNIQUES FOR THE PREVENTION AND MANAGEMENT OF LANDSLIDES

T. Fernández [ab], J.L. Pérez [ab], F.J. Cardenal [ab], J. Delgado [a], E. Mata [a], A.T. Mozas [a]
J. Jiménez [c], J.A. Palenzuela, R. El Hamdouni [c], C. Irigaray [c], J. Chacón [c]

a Department of Cartographic, Geodetic and Photogrammetric Engineering-Photogrammetric and Topometric Systems. University of Jaén (Spain)

b Advanced Studies Center on Earth Sciences (CEACT). University of Jaén (Spain)

c Department of Civil Engineering. University of Granada (Spain)

Tomás Fernández

Genève, 5-9 May 2014

Summary

- Introduction
- Susceptibility
- Hazard
- Risk
- Crisis management
- Conclusions

Natural hazards

- Natural hazards are those processes that occur naturally and in its development cause damages or affect people, properties or the environment

- They are processes of increasing importance in the globalized world of today

- In the 20th century more than 4,5 millions people died and 200 million were damaged by natural risks

- Additionally, economic losses are uncountable

Landslides

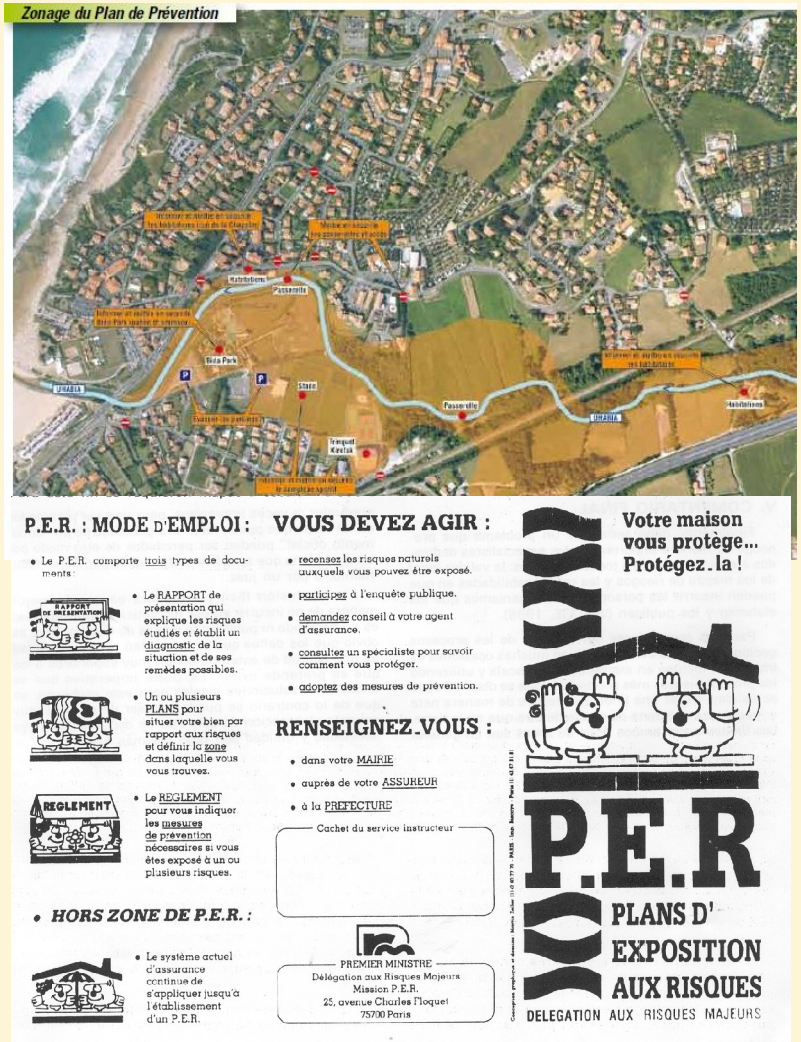
- Landslides are one of the most costly risks processes:
  - although large catastrophic events are rare,
  - small movements are very frequent and
  - produce a large amount of economic losses at the long term
- Estimated losses by landslides reach about 4,600 million € and 70 human lives for the period 1986-2016 in a study of Geological Institute of Spain

Tomás Fernández (University of Jaén, Spain)

Cartographic techniques

GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

- It is necessary an impulse to develop measures to mitigate risks because of the large impact that they represent in the current and future society
- Among the preventive measures, which however extend to the event and the post event, we have the cartographic techniques involving maps of different level that underlie other actions as:
  - regional planning
  - evacuation plans,
  - insurance policies,
  - social awareness, and so on



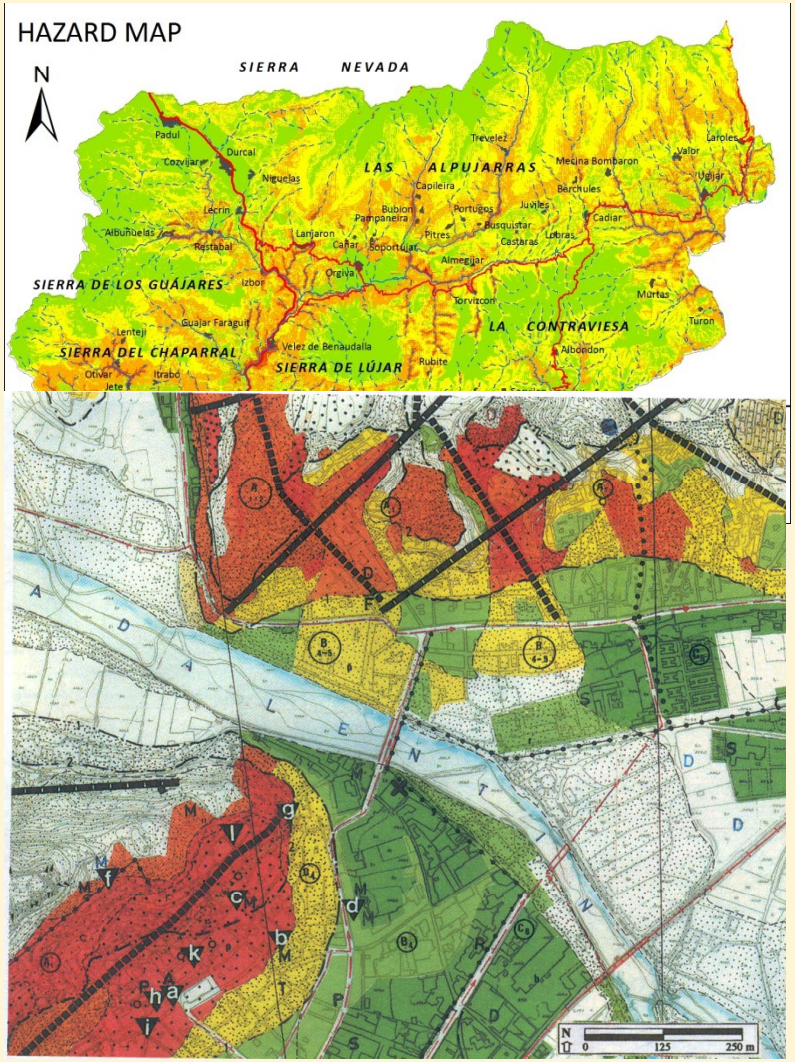
Risk mapping

- Risk assessment must take into account social, economic and environmental risk and it is computed from its components, through the general equation of risk (adopted by UNDRO):

$$R = \Sigma (Pi * Ei * Vi)$$

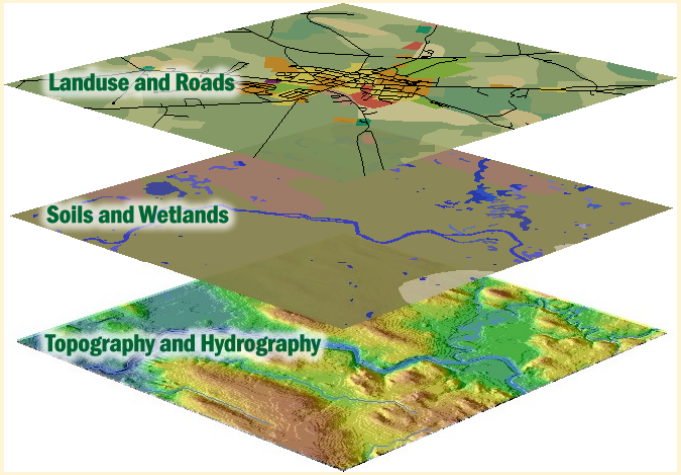
  - H: Hazard
  - E: Exposition
  - V: Vulnerability
  - R: Risk

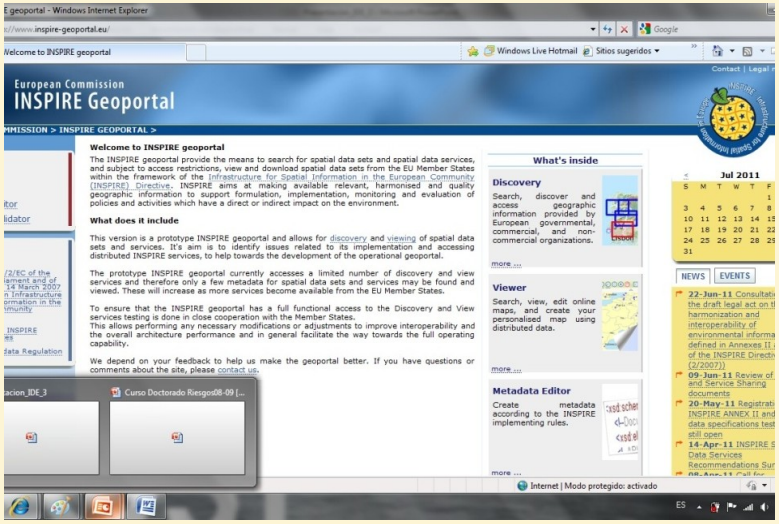
- Since natural hazards are spatial phenomena, the analysis must also be spatial or cartographic, through different level maps



GIS and SDI

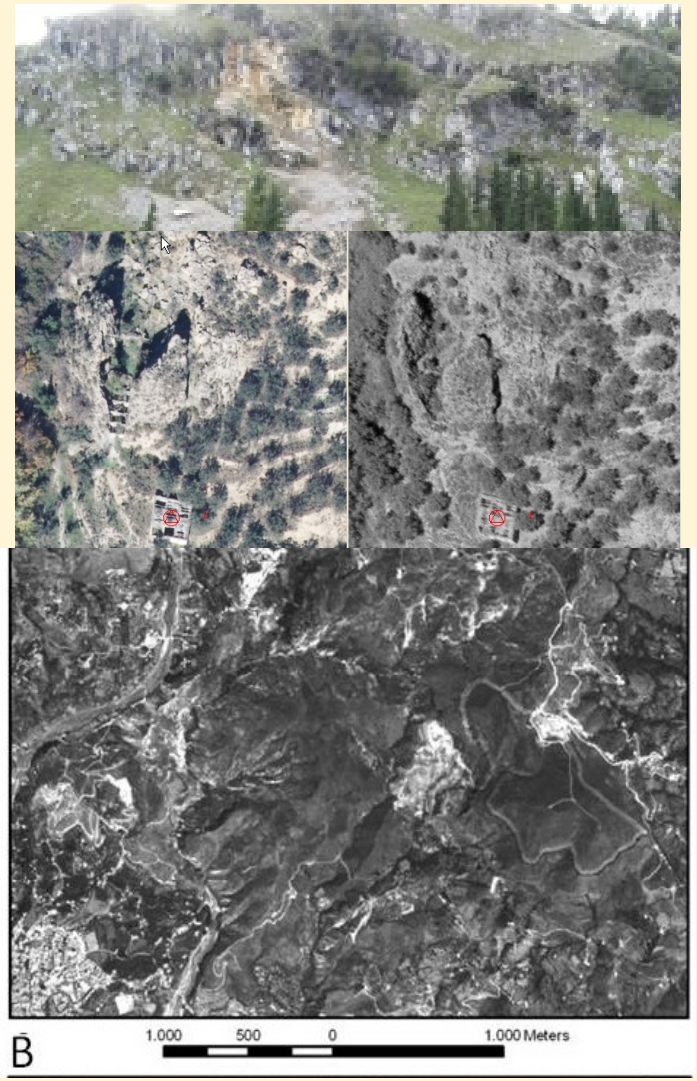
- The widespread use of GIS from the 80s and 90s, was a major impulse to the environmental and thematic mapping, as it provided tools for data analysis and modeling, previously very limited
- However, the emergence of Spatial Data Infrastructures is which emphasizes conclusively the importance of environmental data and maps and relates them to basic cartographies
- SDI allow the availability of the updated data, promote the production of new sets of information and ensure the presence of metadata to report on the quality of the input data





Geospatial techniques

- In a wider perspective, different geospatial or geomatic techniques of data acquisition are used depending on the scale:
- Land techniques for detailed studies:
  - Terrestrial laser scanner (TLS),
  - Photogrammetry (VNIR and TIR)
  - GNSS and Surveying
  - Wireless Sensor Networks (WSN)
- Aerial techniques: Photogrammetry and LiDAR for large (UAV) and middle scales
- Space techniques: Remote sensing from satellites for small scales



Summary

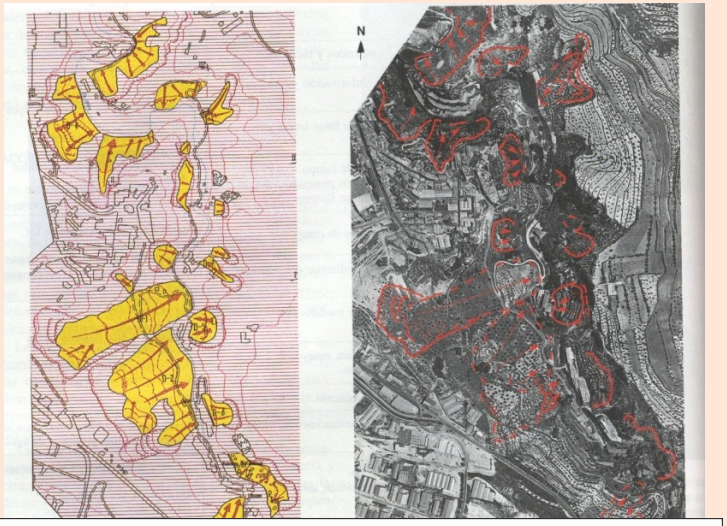
- Introduction
- Susceptibility
- Hazard
- Risk
- Crisis management
- Conclusions

Tomás Fernández (University of Jaén, Spain)

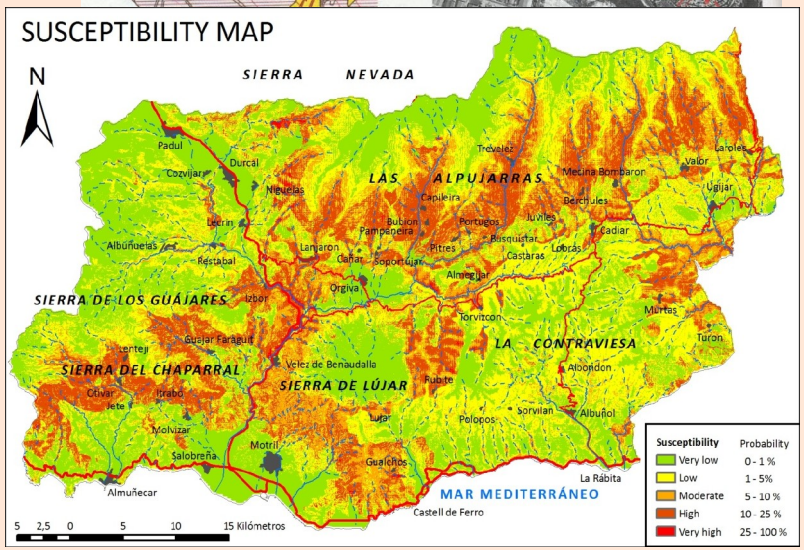
Risk maps levels

GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

- Most basic level: Mapping inventory or databases of phenomena, showing:
  - the spatial location of the phenomenon,
  - its location in time, if possible, and
  - another set of attributes to be described and valuated



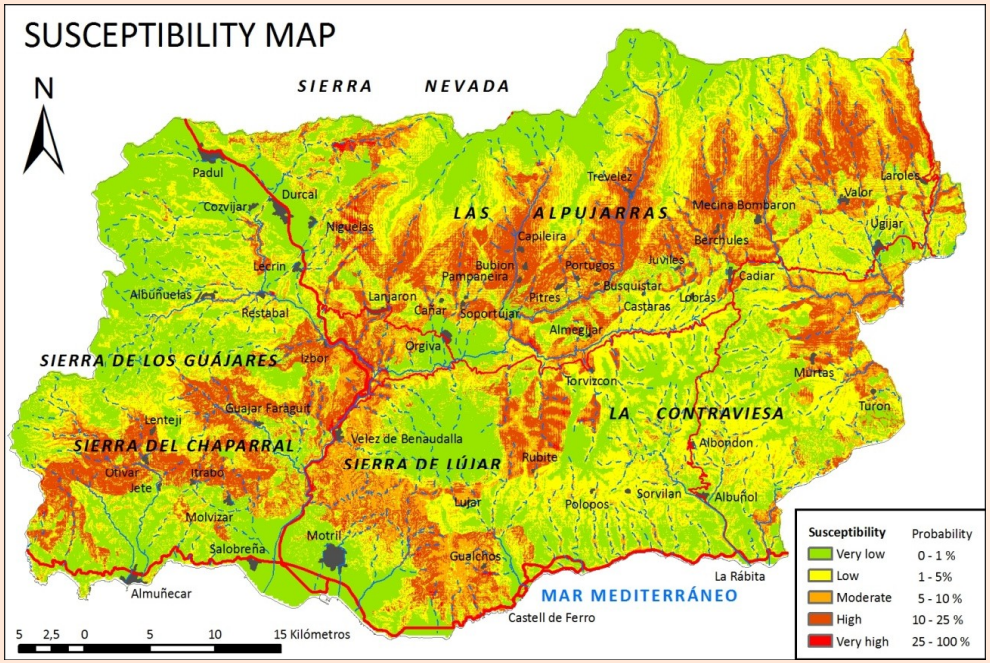
- From them, we can derive a set of higher-level maps:
  - Susceptibility (spatial likelihood)
  - Hazard (space-time likelihood),
  - Vulnerability (degree of damage of property and structures),
  - Risk (damage estimation)



Susceptibility

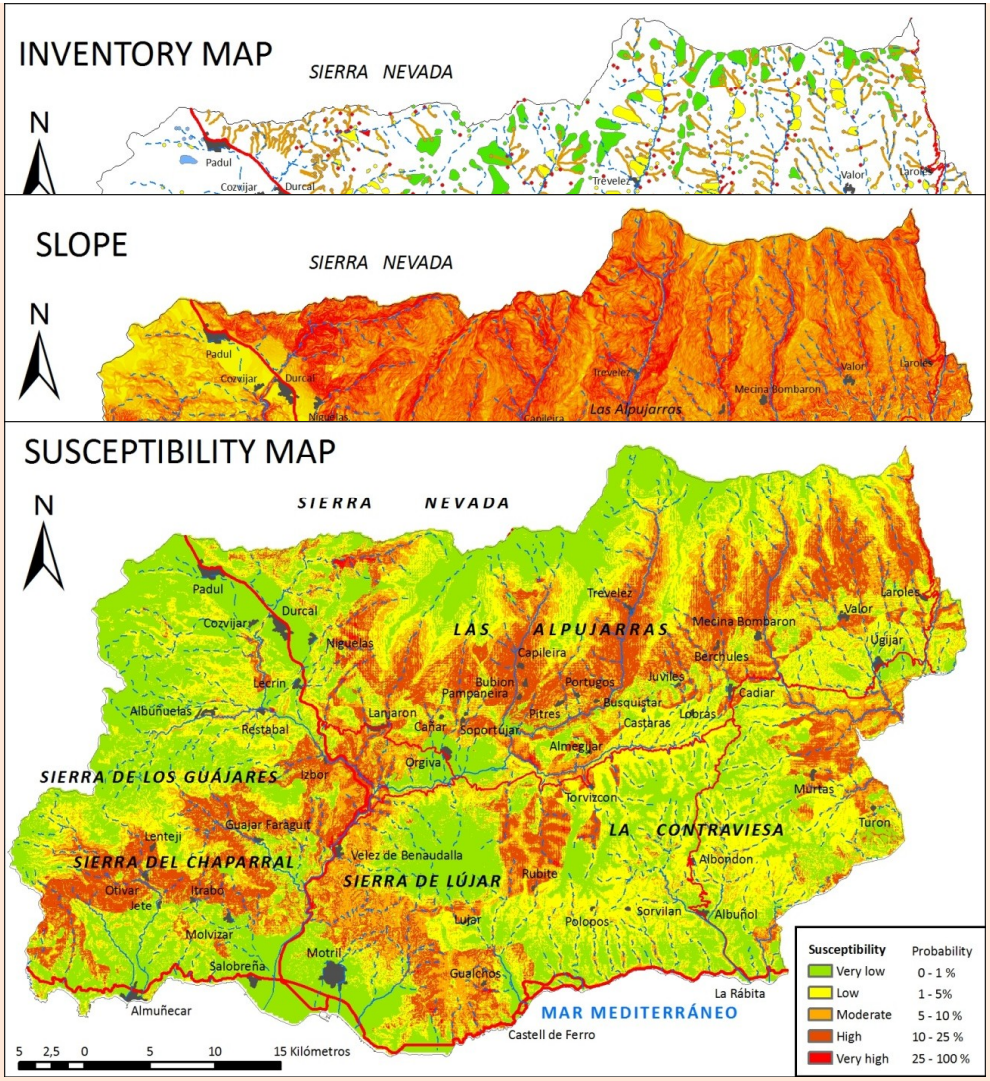
- Susceptibility is the probability or likelihood that a risk phenomenon happens in a specific area and in a not determined date, based on the correlation of the conditioning factors with the distribution of past events (Brabb, 1984)

- The susceptibility or spatial likelihood is often all that can be determined in the case of landslides, given the difficulty for dating the events



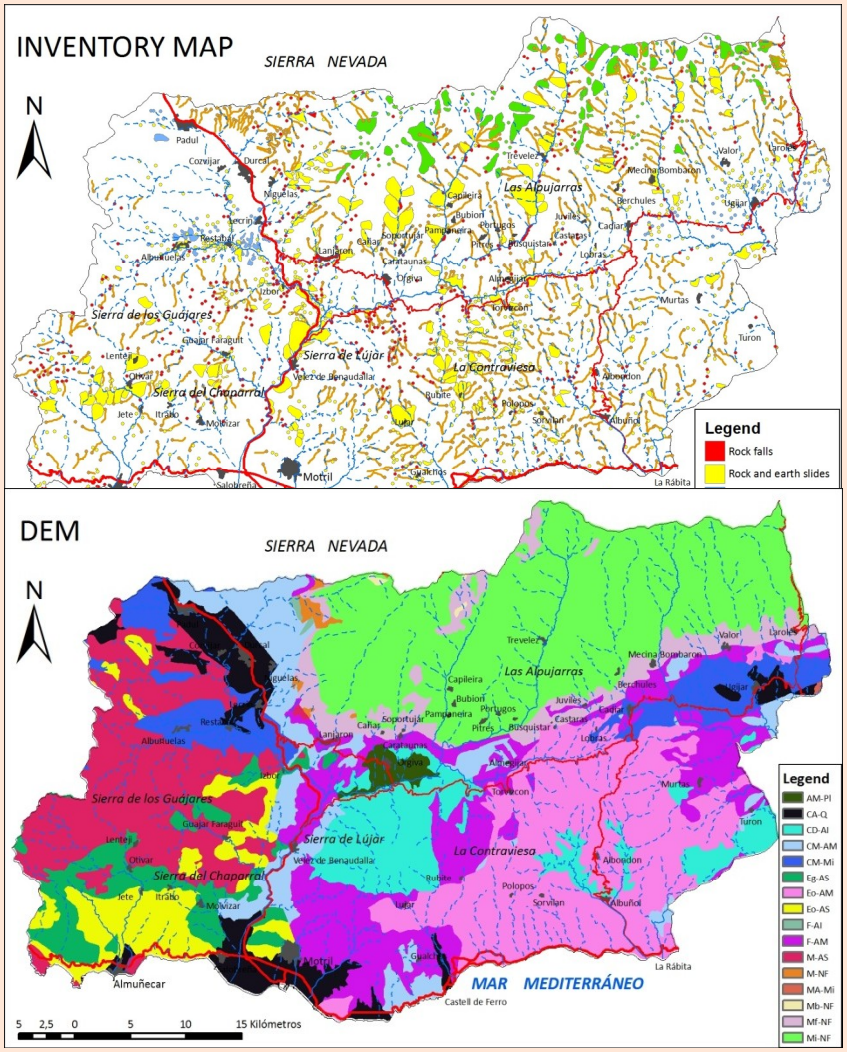
Methodology

- The first phase is the inventory of movements from photo-interpretation, supplemented by fieldwork
- The second phase is the factor analysis to identify those factors that determine the instability and the conditions under which different types of landslides appear.
- Once the factor have been identified, in the third phase they are combined to obtain the susceptibility maps



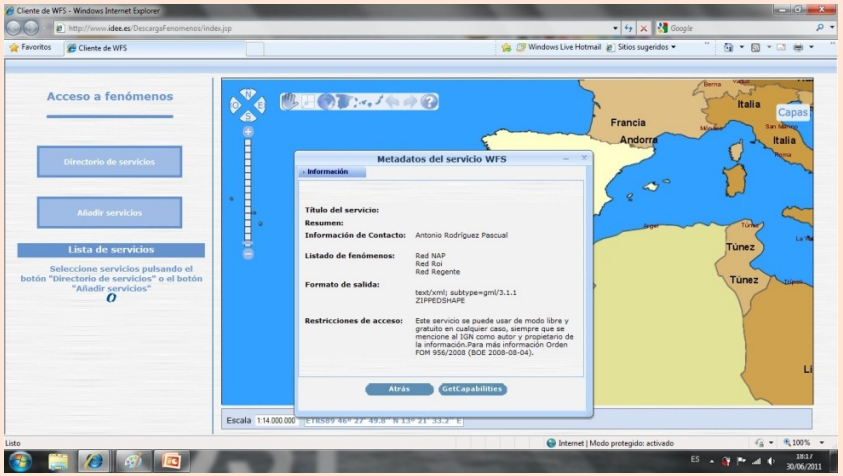
Using GIS

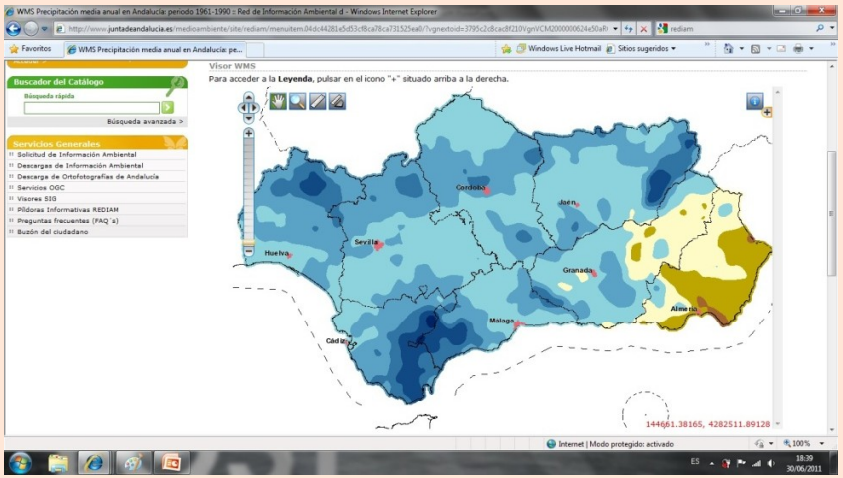
- GIS provide important support in these studies, as they allow territorial analysis in which several layers of information are employed, both phenomena inventory as factors
- The whole process from landslides inventories to the modeling and mapping of susceptibility, through factor analysis, is implemented today in GIS environments
- In recent years, several specific tools for the estimation of stability have been developed, with models based both on deterministic as on statistical methods such as the matrix method



Using SDI

- The information was obtained from the Spanish SDI of the National Geographic Institute, as well as some other services such as the Geological Survey, the Meteorological Agency …
- Regional services such as the Andalusian SDI and the Environmental Information Network (REDIAM) were also considered
- Data related to landslides, both the basic cartography, the DTM, the images and orthophotos, the geological and meteorological data a all available in WFS or WCS services or are freely downloadable



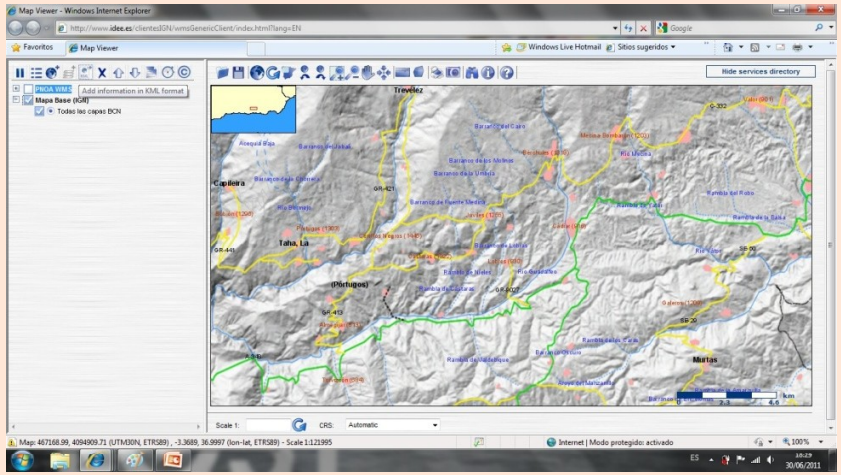


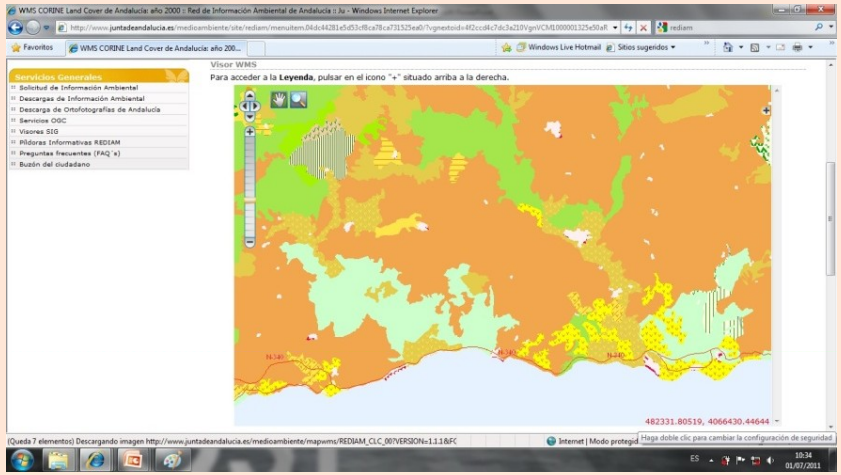
Tomás Fernández (University of Jaén, Spain)

Available data in SDI

GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

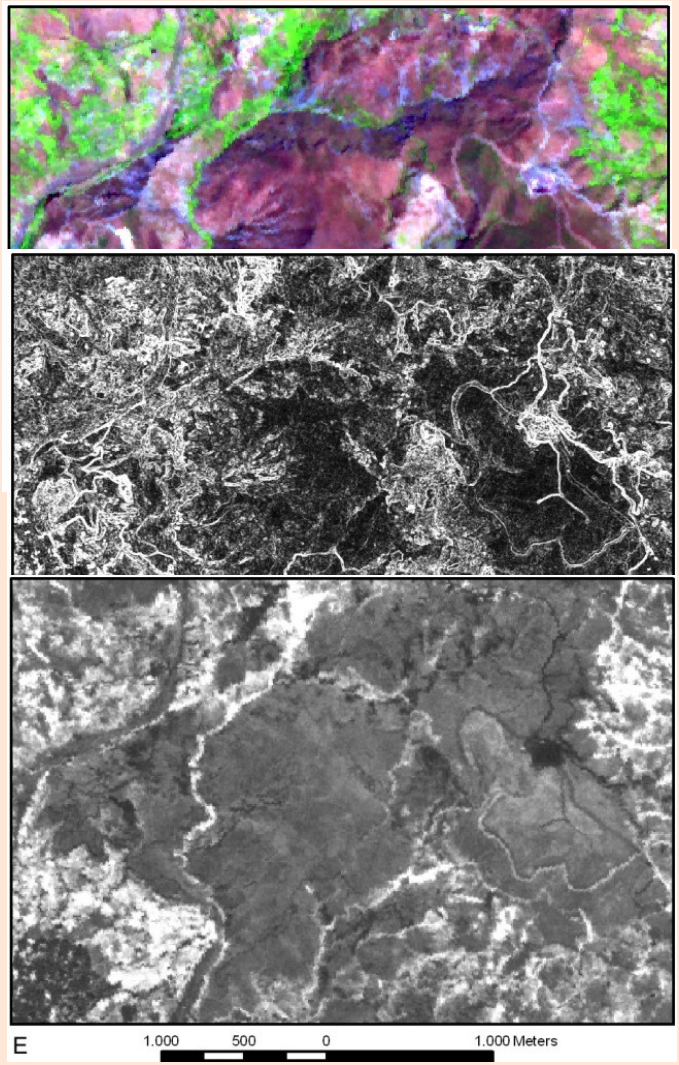
- Here the inventory has been own elaborated because the information about landslides in Spanish SDI is still at a very low scale and resolution
- DTM of 25 m resolution was downloaded from the National SDI in ASCII format and converted to raster format, from which models of slope, aspect and curvature were obtained
- Geological and meteorological data were also downloaded from Geological and Mining Institute (IGME) or the Environmental Information Network of Andalusia (REDIAM)





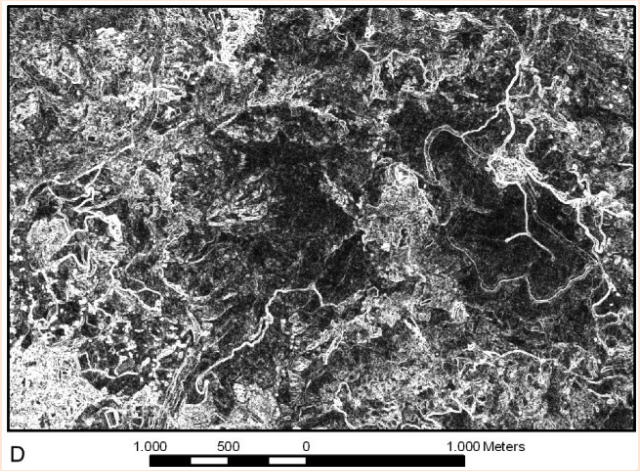
Remote sensing

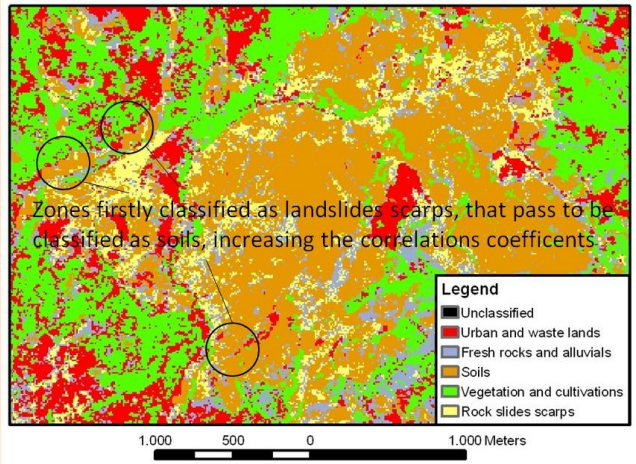
- Remote sensing is applied to detect landslide scarps and masses and to make factor maps
- Color composites including near-infrared bands (vegetation), middle-infrared (lithology and moisture) and thermal infrared (moisture)
- High-pass filters and edge detectors as well as other filters for calculating textural variability between pixels and identify irregular shapes
- Vegetation indexes to detect scarps in vegetated areas in which this coverage is lost when the scarps are formed



Digital classification

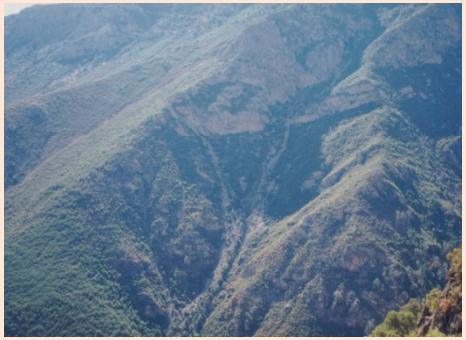
- Supervised classifications allow discriminate between:
  - different land uses or materials
  - different types of landslides
- Separability analysis is necessary to test if it is possible to distinguish between landslides and stable areas
- However, in many cases classifications allow identify movements scarps, but mixed with other land-uses (soils, fresh rock and alluvial materials)
- The use of textural filters, which have high values in mobilized areas, resolves this uncertainty





Factor analysis

- Factor analysis was made by cross correlation between factors and landslide inventory and correlation coefficients was calculated
- The determinant factors are:
  - Rock falls: slope, curvature, lithology and rainfalls
  - Rock and earth slides: height, slope, curvature, lithology
  - Earth flows: height, curvature and lithology
  - Debris flows: slopes, curvature and lithology

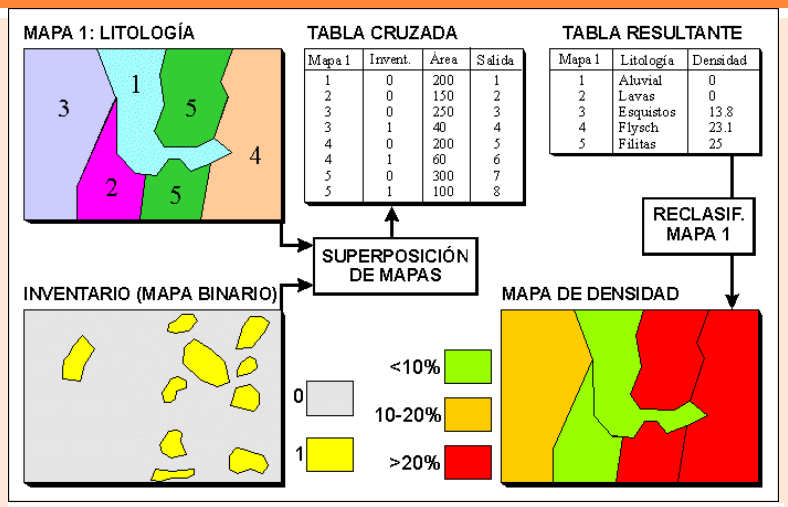


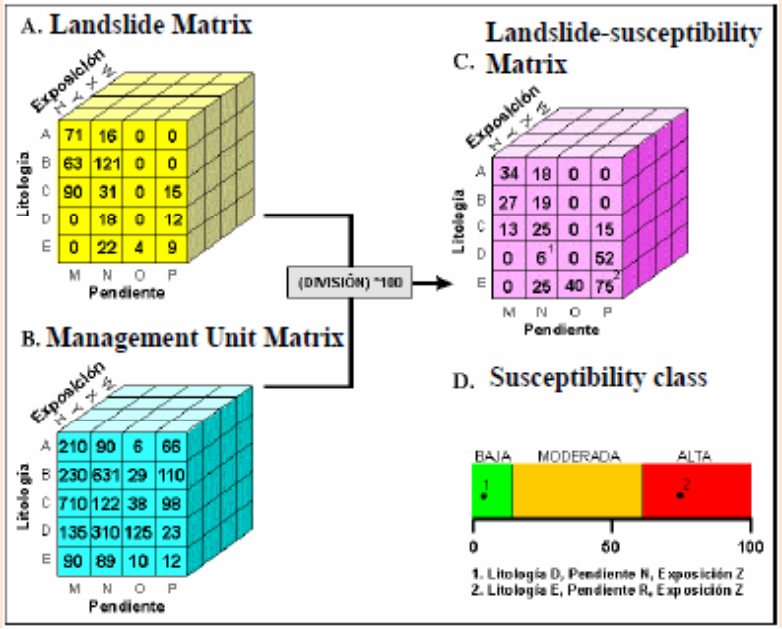
	Height	Slope	Aspect	Curvat.	Lithol.	Rainfall
Rock falls	0.451	0.795	0.253	0.534	0.615	0.482
Slides	0.515	0.481	0.110	0.554	0.597	0.392
Debris flows	0.190	0.465	0.066	0.568	0.545	0.183
Earth flows	0.813	0.382	0.274	0.493	0.992	0.606

Tomás Fernández (University of Jaén, Spain)

Susceptibility modeling

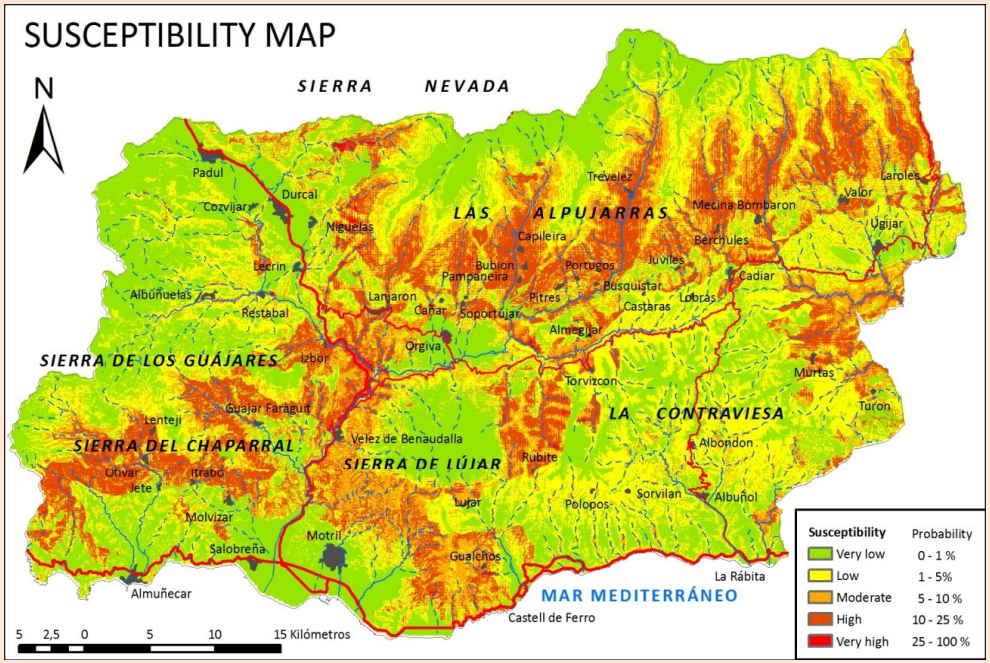
- There are different types of methodologies for modeling susceptibility
  - Based on the experience
  - Deterministic methods
  - Probabilistic methods, both of bivariate and multivariate character
- In probabilistic methods, susceptibility at each point is expressed in terms of probability as the percentage area of each factor combination which is occupied by landslides





Advantages and limitations

- Susceptibility maps extend the affected areas beyond the zones that have already been mobilized or have already been identified as mobilized
- The main limitation is that maps can be conservative since some movements originated in conditions very different to the current have been used in the correlation analysis

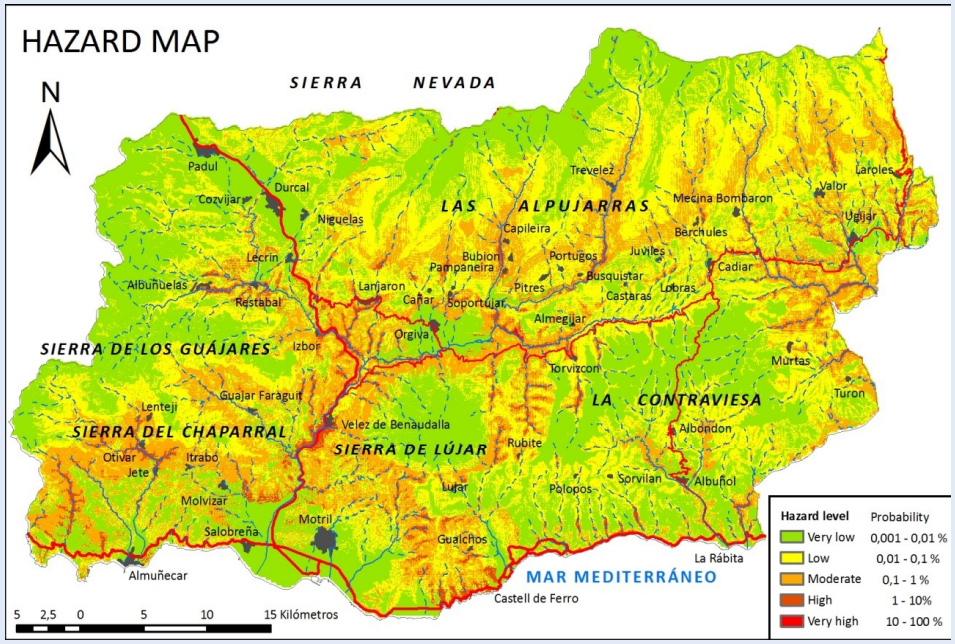


Summary

- Introduction
- Susceptibility
- Hazard
- Risk
- Crisis management
- Conclusions and future works

Hazard

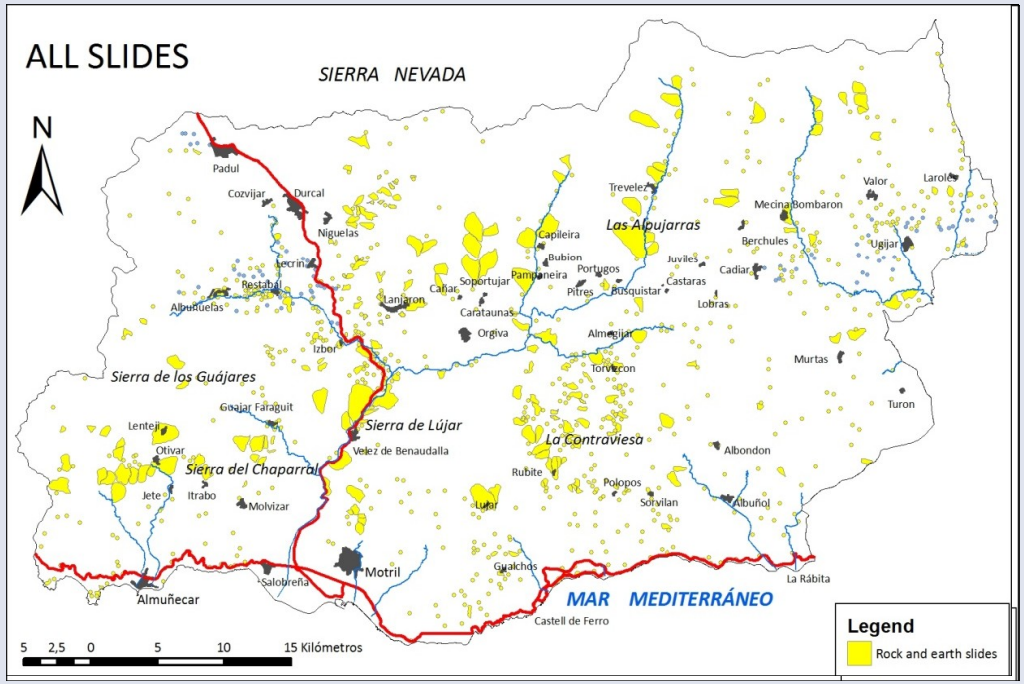
- Hazard: Likelihood of occurrence of a risk phenomenon, with a given severity and in a certain period of time
- It applies the same methodology of susceptibility mapping, but using inventories for different return periods
- It is necessary to date the events but the historical record is difficult in these processes, unlike earthquakes or floods
- We use two type of techniques depending on the temporal resolution of data



Coarse dating

- First we use a semi-quantitative dating based on the observed activity, historical aerial photography and a coarse analysis of rainfall time series

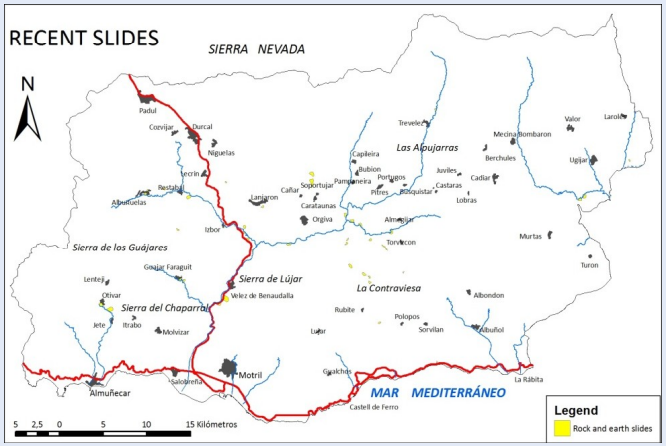
- Four activity styles and return periods are considered :
  - Active or suspended: Until 10 years
  - Dormant: Until 100 years
  - Abandoned: Until 1000 years
  - Relict: Until 10000 years



Tomás Fernández (University of Jaén, Spain)

Active landslides

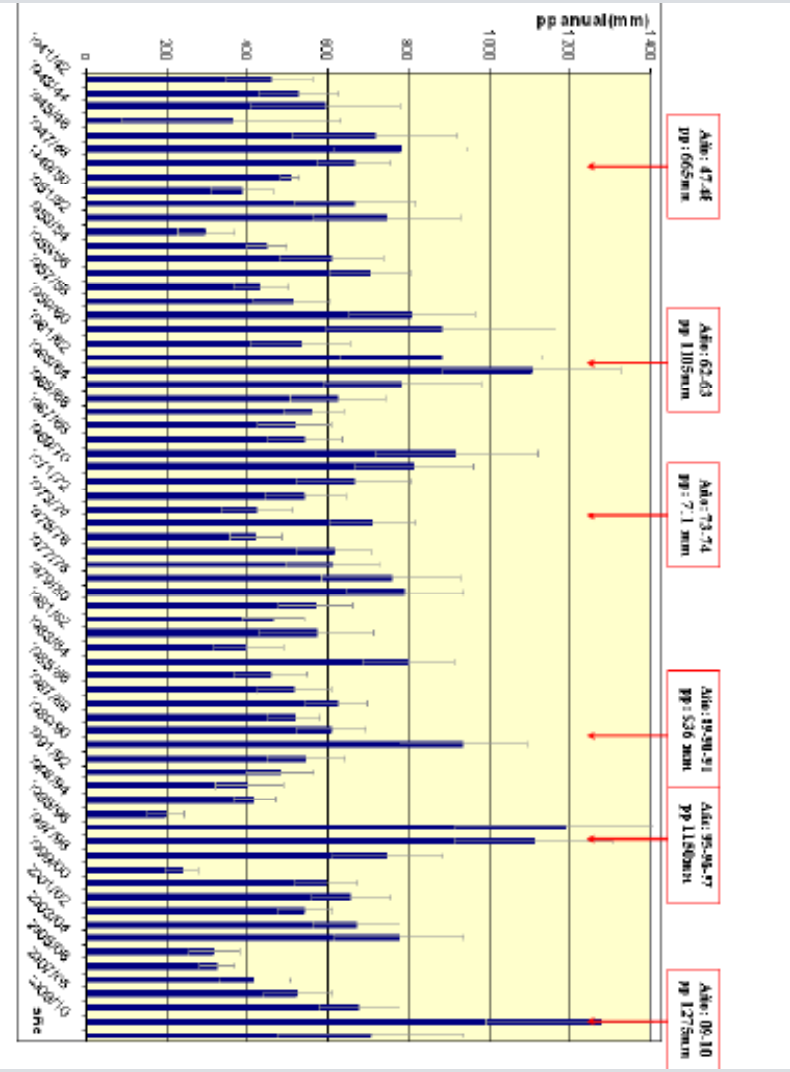
- Active movements are those which are mobilizing now
- Suspended movements are those with a continuous or intermittent activity in recent years
- In areas such as southern Spain with activity related to intense rainfall events, movements are suspended not only seasonally but for several years
- Since these episodes are repeated every 8 to 15 years, we can consider in this group those movements active during the last 10 years
- Techniques: Multitemporal analysis of aerial photographs and satellite images, sensor monitoring and dendrochronology



Tomás Fernández (University of Jaén, Spain)

Rainfall data

- The relationship between rainfalls and the slope movements is well known and established in this area
- From the analysis of rainfall data available on a wide time range (1940-2010), we can find that the frequency of rainfalls, similar to 1996-97 or 2008-10 , that potentially trigger movements is around 8-15 years
- It agrees with other global data of rainfalls in southern Europe, related to negative values of North Atlantic Oscillation index in winter (NAOi)



Recent landslides detection

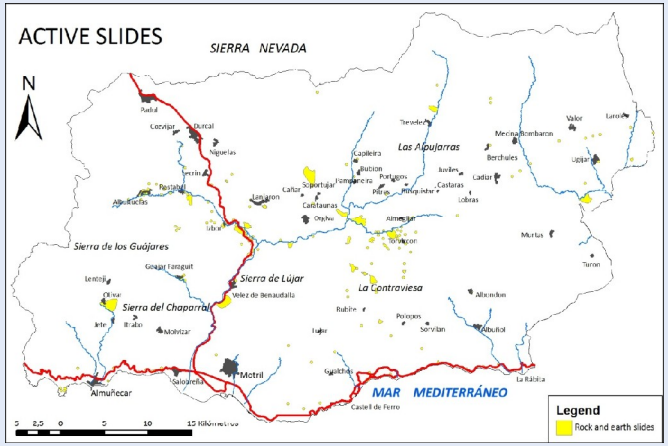
- Aerial photographs corresponding to a flight from 1992 (previous to heavy rainfalls of 1996-97) were stereoscopically interpreted and orthophotos from 2001 (after the rainfalls) were monoscopically examinated
- Landslide evidences observed in 2001 but not in 1992 allow classified those movements as active
- More detailed information has been obtained using other images and flights (including those captured with UAV) by photogrammetric techniques, and other methodologies such as TLS

Tomás Fernández (University of Jaén, Spain)

Dormant landslides

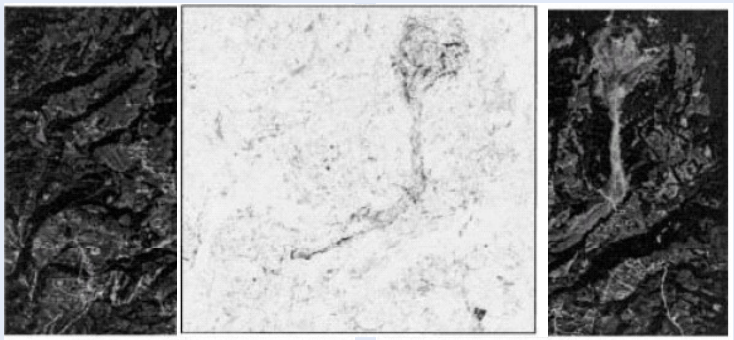
GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

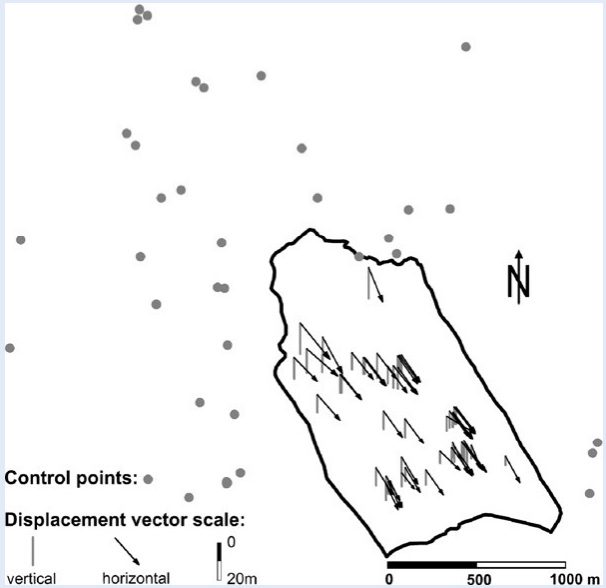
- Dormant landslides are those without evidence of activity in recent rainfalls cycles in the area (1996/97 and 2009/10), but in the last 100 years
- The causes of these processes, which remain dormant, can produce movements returns again to activity, at least partially, by the action of a triggering factor
- They are identified by photogrammetry and digital image analysis, including historical photographs, and other methodologies such as dendrochronology



Multitemporal analysis

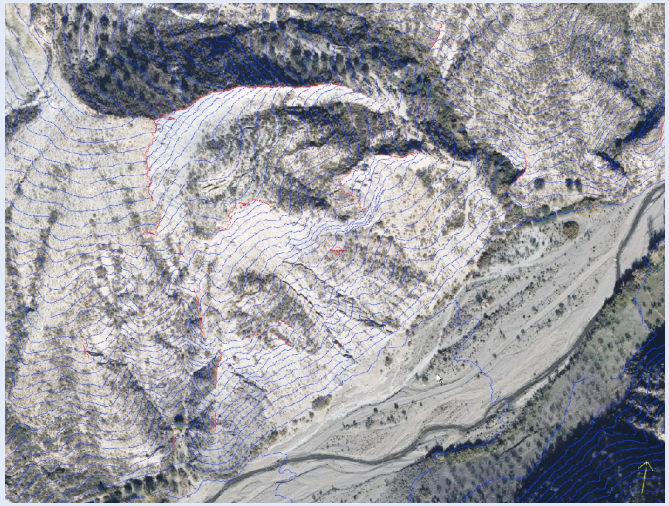
- Multitemporal approaches can be addressed through the comparison of original or classified images by means of change detection techniques in pixels
- On his hand, photogrammetric techniques allow:
  - The 3D digital stereo-plotting to inventory movements that can be analyzed along time
  - Compare DTMs obtained from different flights, calculating distances and volumes
  - Compare points and other features to determine displacement vectors





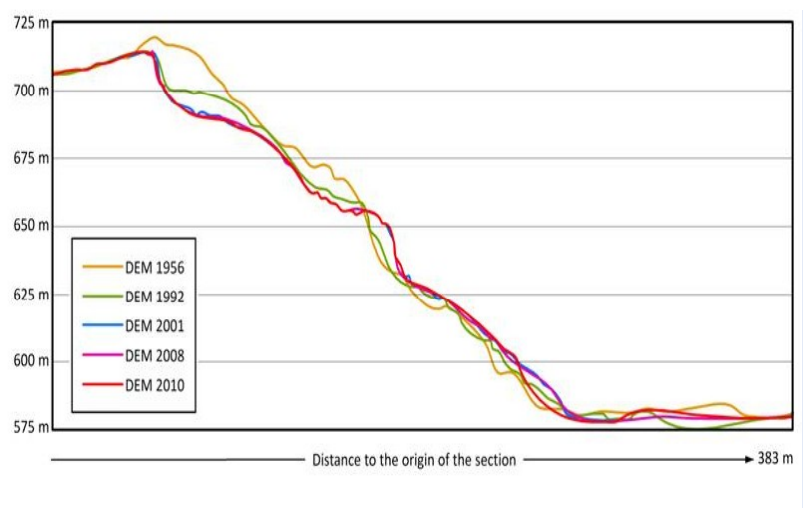
Photogrammetry

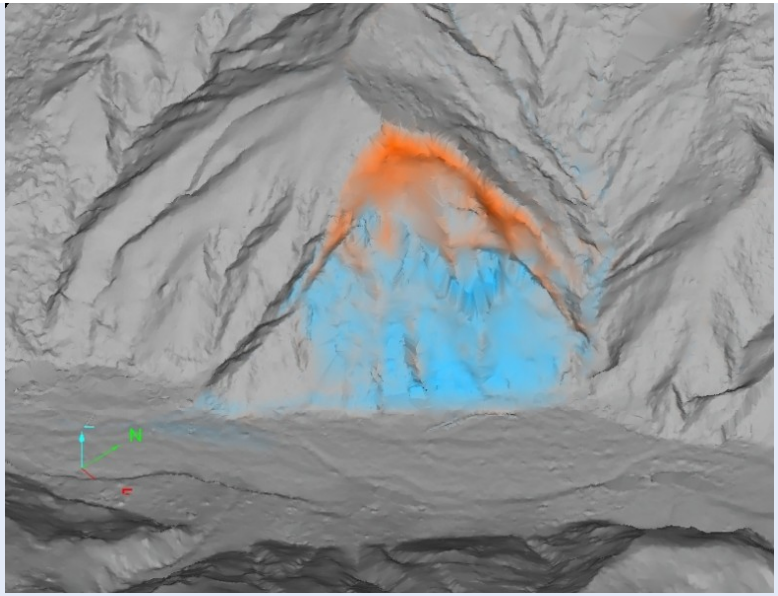
- The photogrammetric methodology starts with the orientation of most recent and accurate flight through triangulation and adjustment of the different LiDAR strips
- Once this is done, the reference system should be transmitted from the latest flight of refe-rence to the other historical flights, by identifying common points in both flights
- DTMs are built:
  - The latest one is obtained from LiDAR data once edited on the flight stereoscopic model
  - The historical ones, editing the recent model on the oriented flights and modifying only when significant changes are observed



DTM comparison

- Operations and calculations:
  - Vertical distances by subtracting DTMs (differential DTMs)
  - Volumes of material of the model which is compared that is below or above the reference model
  - Longitudinal sections
- Two types of zones are detected:
  - Depleted zones, matching with the upper parts or landslide scarps
  - Accumulation areas in the lower parts where the displaced material accumulates

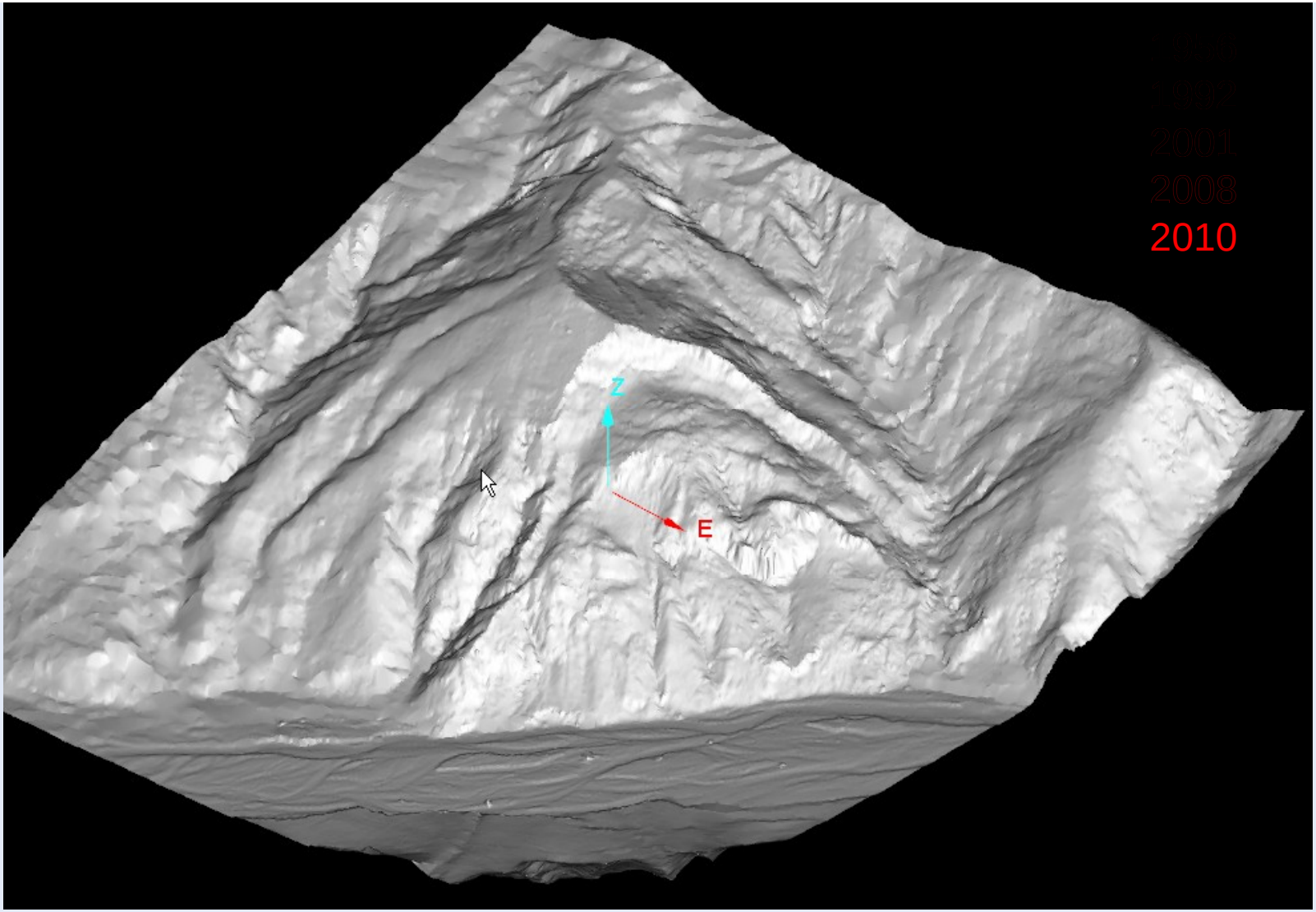




Tomás Fernández (University of Jaén, Spain)

Landslide evolution

GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

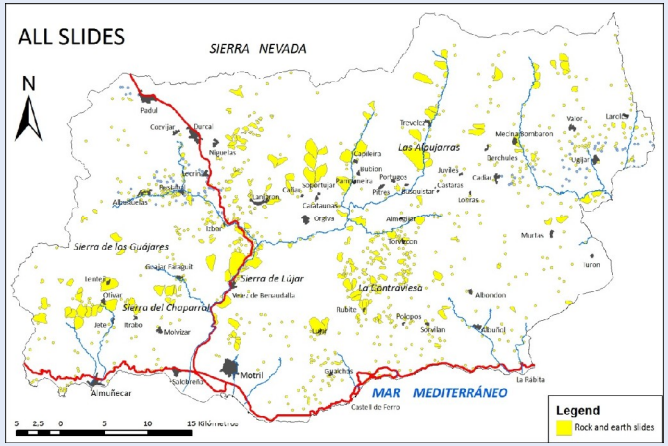


Tomás Fernández (University of Jaén, Spain)

Abandoned and relict

GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

- Abandoned movements are those without recent activity; the causes may have even disappeared. The land morphology remains fresh indicating a non-remote activity
- Relict movements are those in which their features can be observed, but dismantled or eroded
- The causes of these processes have disappeared, although it is possible that a new change in conditions can re-activate them.
- The used techniques are the interpretation of aerial photographs under morphological criteria, supported by isotopic dating



Older landslide detection

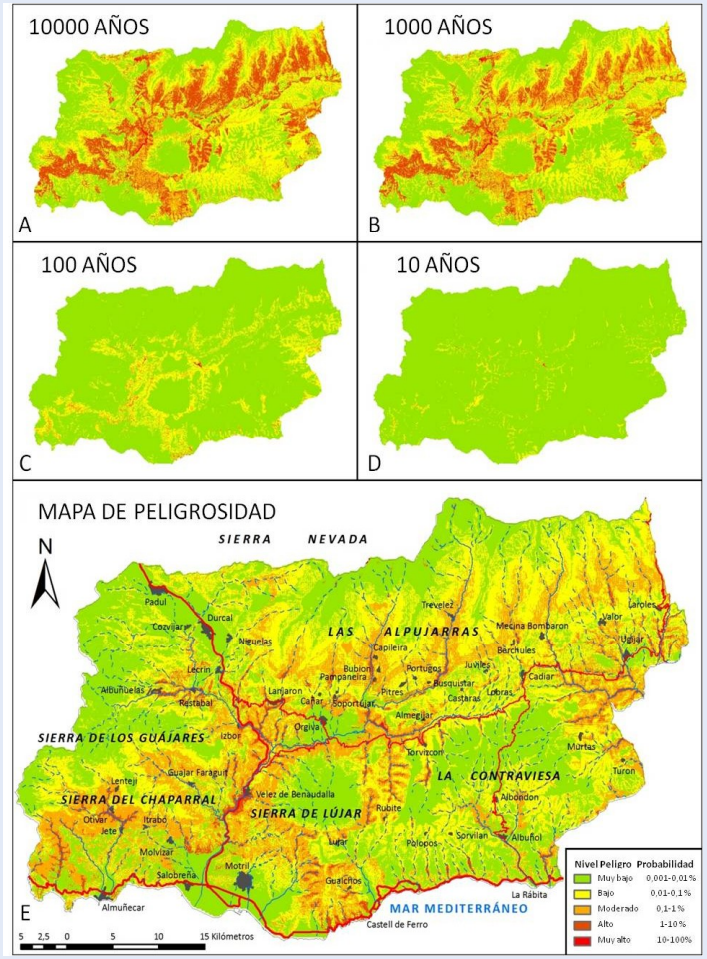
- In this study, the older landslides (abandoned and relict) are those identified in the orthophotos corresponding to 1956 flight
- To distinguish between abandoned and relict we attend to a qualitative approach based in geomorphic features of some landslides and its elements: crown, scarps, lateral boundaries, tension cracks, toe, etc.
- These observations were made by stereoscopic photo-interpretation on the 1992 flight

Tomás Fernández (University of Jaén, Spain)

Hazard mapping

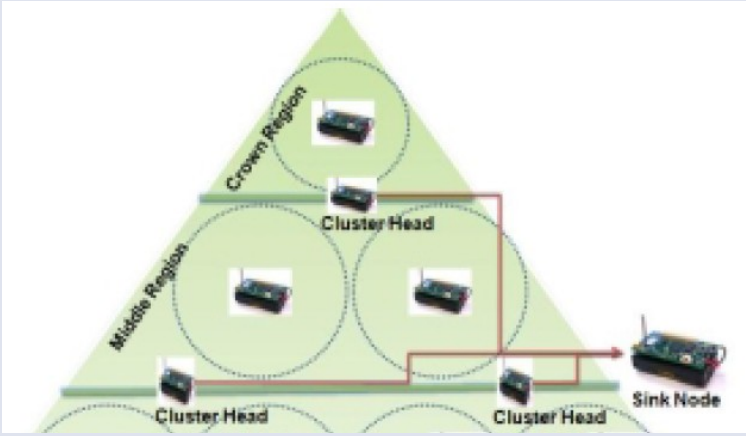
GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

- Once the activity was estimated for every movements, an inventory for each of the periods can be elaborated
- From these inventories we obtain the susceptibility maps based on the methodology developed for it
- To convert susceptibility in hazard, it is divided by the number of years of return period, thus calculating the annual probability in each period
- The total hazard is obtained overlying the different hazard maps and taking the maximum value of all of them, presenting the map classified in 5 hazard intervals



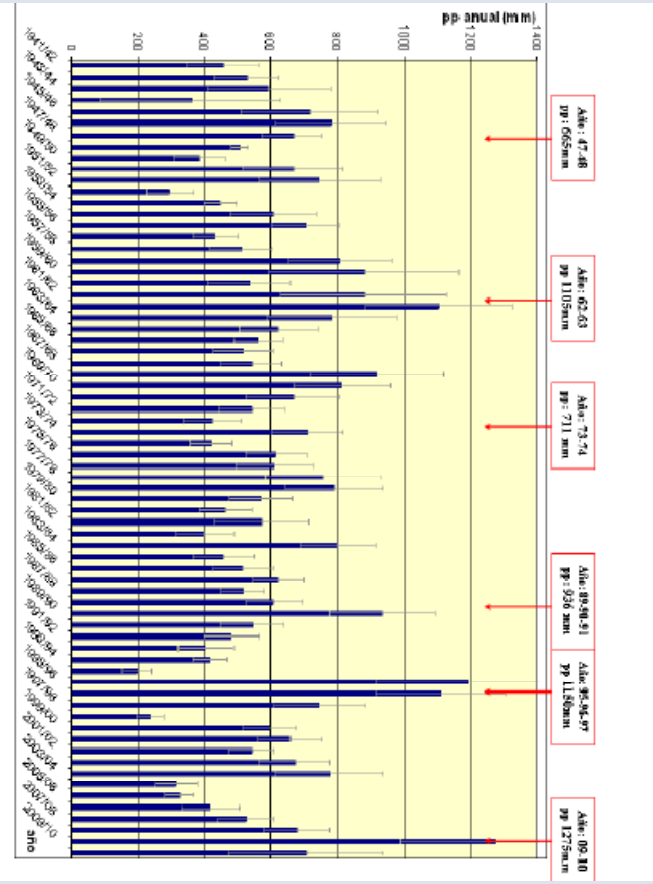
Fine dating

- Fine dating is based in a shorter sampling interval of landslides and a more detailed analysis of rainfall data series
- To shortening the sampling interval we have to apply different techniques:
  - Terrestrial or UAV photogrammetry
  - Terrestrial or UAV laser scanning
  - Wireless sensors networks



Frequency

- From these data and daily rainfalls, the relation between landslides and rainy events can be established and studying the frequency of these episodes, landslides frequency and hazard can be estimated
- There are interesting advances in this field, by means of the application of probabilistic models:
  - Poisson distribution to continuous time-scale
  - Binomial distribution if time intervales (months, years) are considered
- In any cases, rainfall umbrales of instability can be calculated

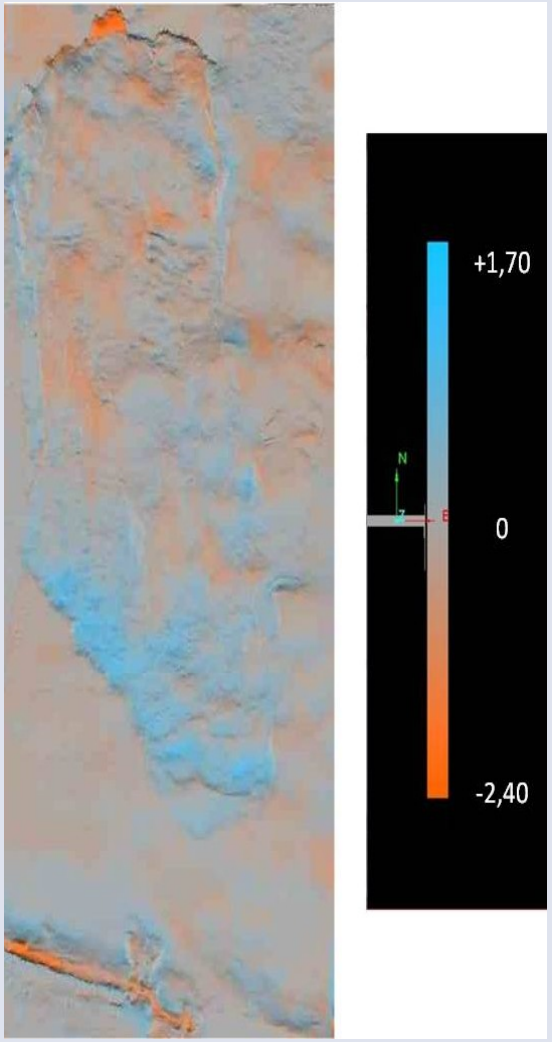


UAV capture

- UAV fights can be made easily and quickly, so it is a efficient and flexible technique to capture recent landslides
- There are several types of UAV with different times and height of flight, than can be used for different scales (local, regional) and resolutions
- We use until now helicopters such as Falcon 8 (Astec Technologies):
  - GPS, IMU and 8 rotors
  - Weight: 2,2 Kg and payload: 750 g
  - Camera: Sony Nex-5N (14,2 mp)
  - Time of flight: 15-20 minutes

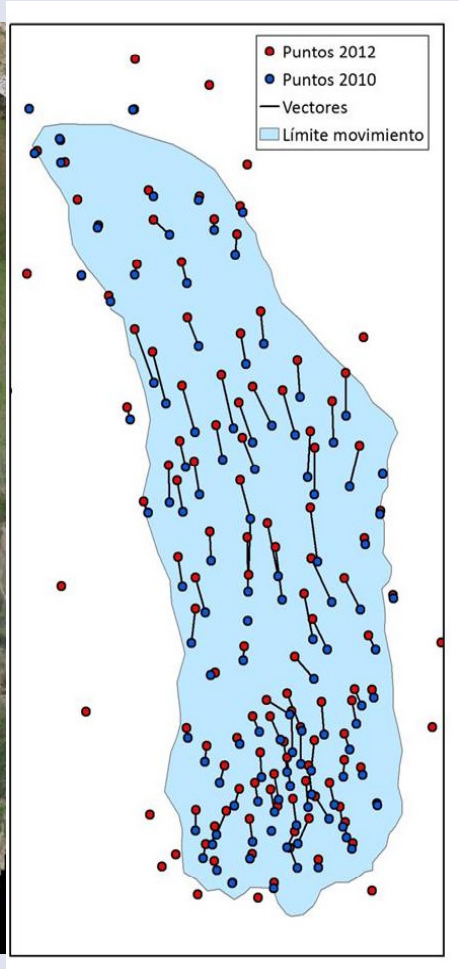
UAV processing

- UAV flights are orientated using control points captured with GPS and tie points
- From the oriented flights, DSM are built by automated matching and the DSM are filtered and edited to obtain DTM
- Comparing DTM, vertical displacements of terrain surface are calculated



UAV processing

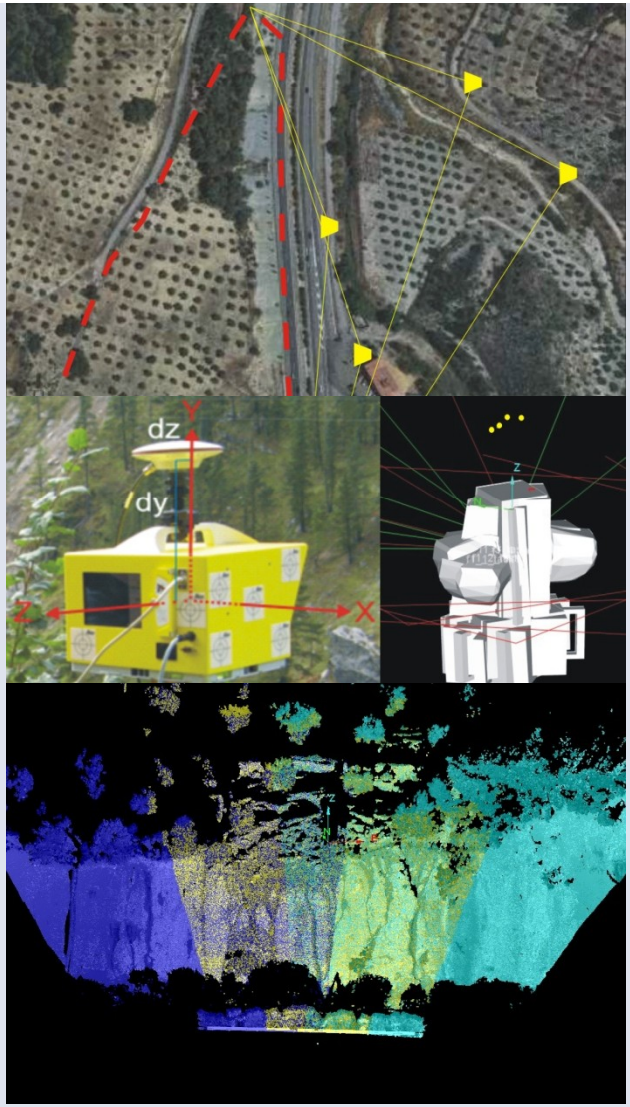
- From oriented flights we can obtain also ortophotographies
- Identifying singular elements (ways intersections, plants, etc.), horizontal displacements can be calculated



Tomás Fernández (University of Jaén, Spain)

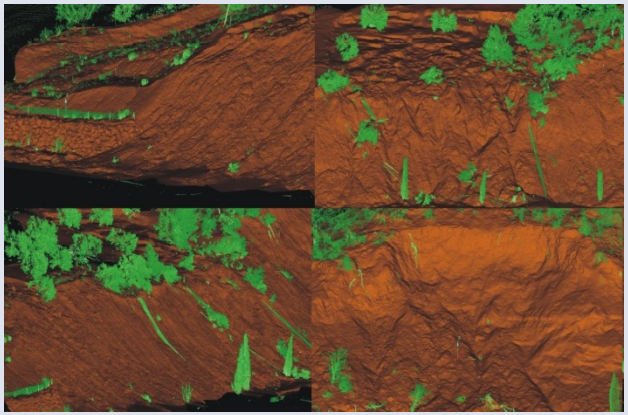
Terrestrial Laser Scanner

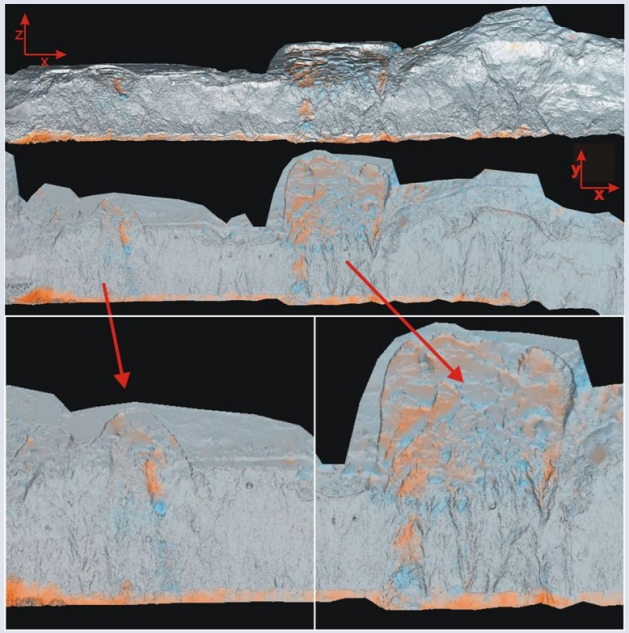
- Using LiDAR data, aerial (ALS) and terrestrial (TLS), for measuring deformations is gaining interest, as it allows obtain point clouds of high density and positional quality
- Observations by TLS techniques must be made from different not-aligned points, with several scanning from each point
- The scanning position is determined by GPS, placing a GPS antenna on the scanner instrument
- The point clouds are merged and georeferenced in a global system that also allows comparing different observational campaigns



DSM and DTM

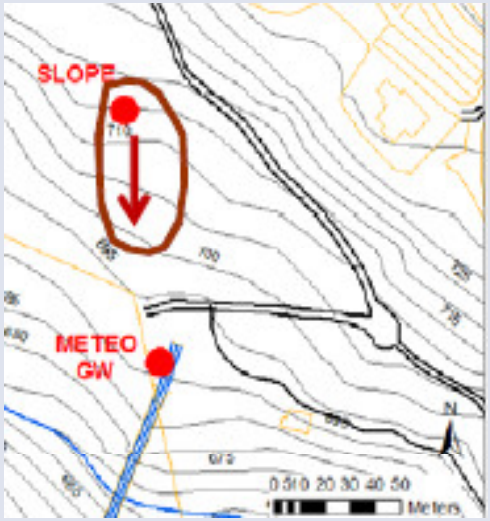
- The points should be classified as ground or not- ground points (trees, works, cables ...) by means filtering operations
- From the surface models we can see the development of landslides and the displacement of the ground surface and the objects on it
- It also allows identify areas of erosion and accumulation in the top and bottom of the slope, and to quantify volumes or masses
  - eroded
  - accumulated
  - lost or evacuated

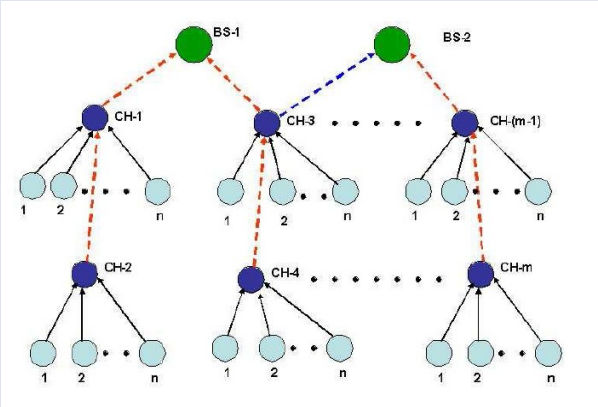




WSN monitoring

- Wireless Sensor Networks (WSN) is an excellent technique to continuous landslide monitoring
- Multiple sensors can be placed in a single movement to study the evolution of different variables:
  - Motion sensors: tiltmeters and extensometers
  - Webcams and geophones
  - Meteorological sensors: temperature, rainfall and humidity
  - Soil moisture and piezometers ...
- All the sensors are connected to a datalogger and send a signal to a gateway





Summary

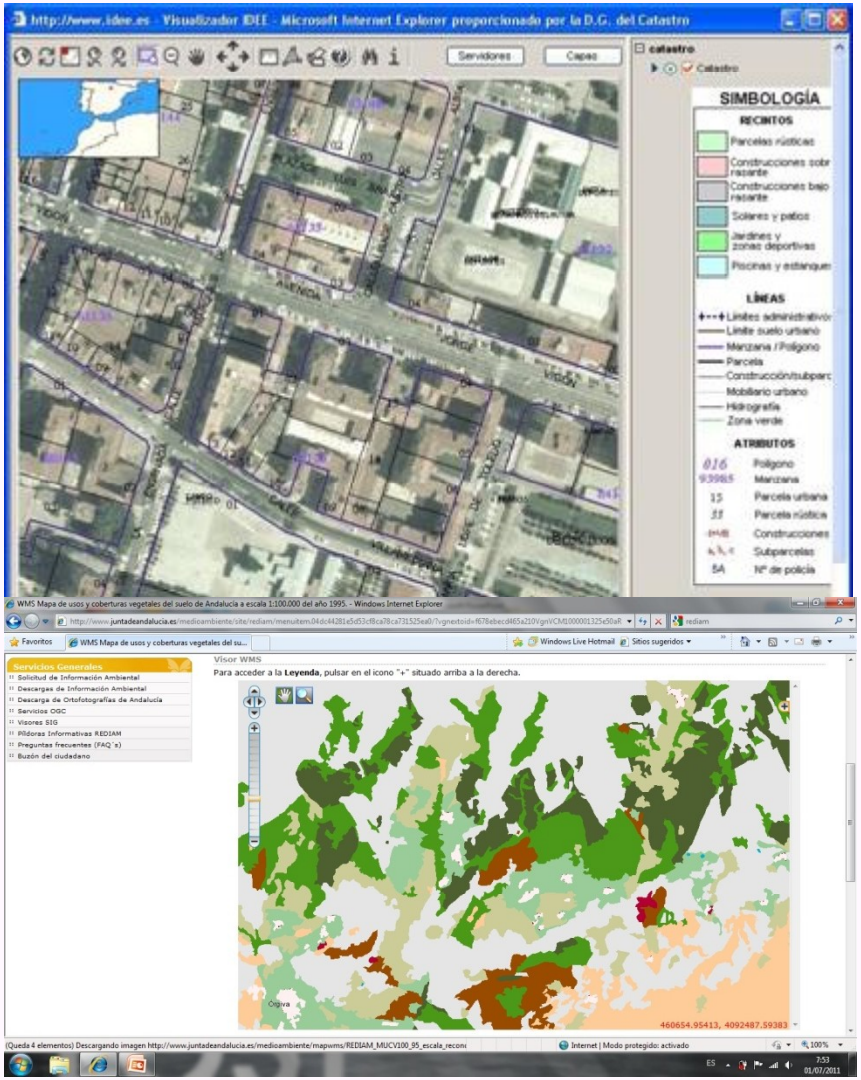
- Introduction
- Susceptibility
- Hazard
- Risk
- Crisis management
- Conclusions and future works

Tomás Fernández (University of Jaén, Spain)

Elements at risk

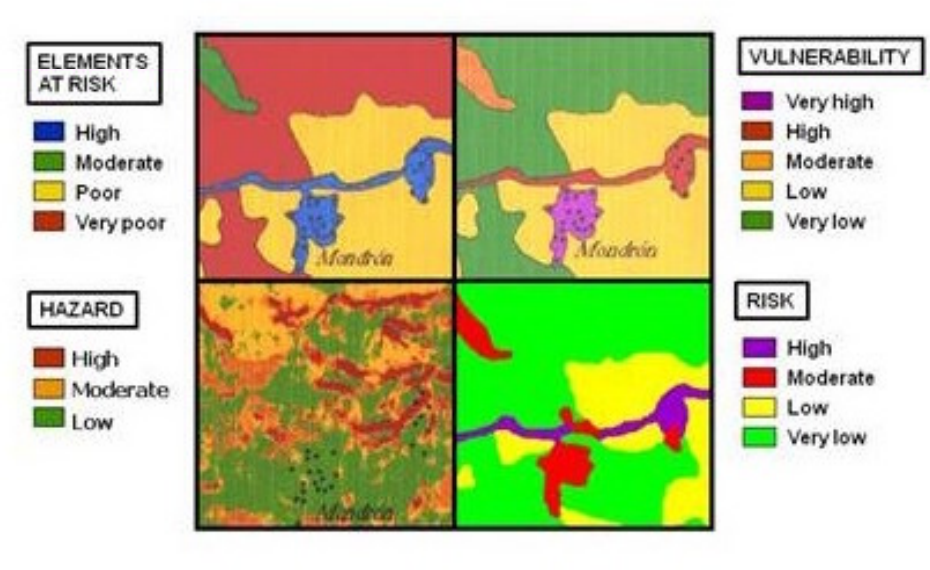
GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

- The first element at risk for landslides is population, available as:
  - information layers in SDI
  - statistical data (institutes)
  - cadastral data
- The second data set are road and railway networks, constructions and buildings, obtained also as SDI layer
- The third data set are land uses available as information layers in SDI
- All this information can be refined and updated with data captures



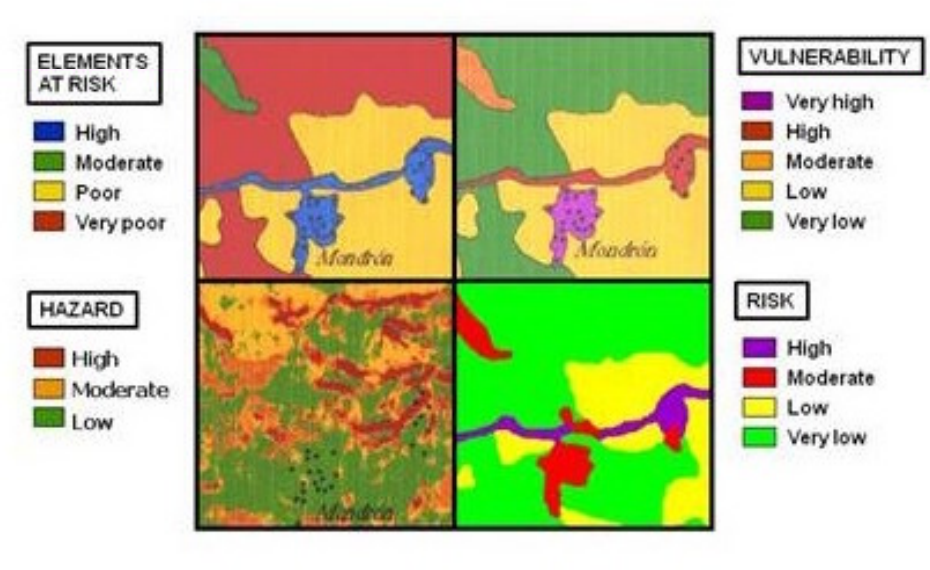
Vulnerability

- Vulnerability is the component more difficult to obtain from SDI
- There is few information of these topics in landslides, and only can be addressed from professional studies of engineering, architecture and even of health
- Some simple approaches are based on the comparison of length/area of a damaged infrastructure, building, crop, etc., with the total
- A detailed data capture can be help to a more accurate vulnerability estimation



Valuation and risk

- Elements at risk valuation can be estimated by cadastral data, insurances policies and technical studies
- Finally, risk is calculated from its three components: hazard, exposition and vulnerability
- Hazard maps are powerful tools to landslide prediction as risk mapping to decision makers awareness
- Both map levels can help to prevention or mitigation of risk processes



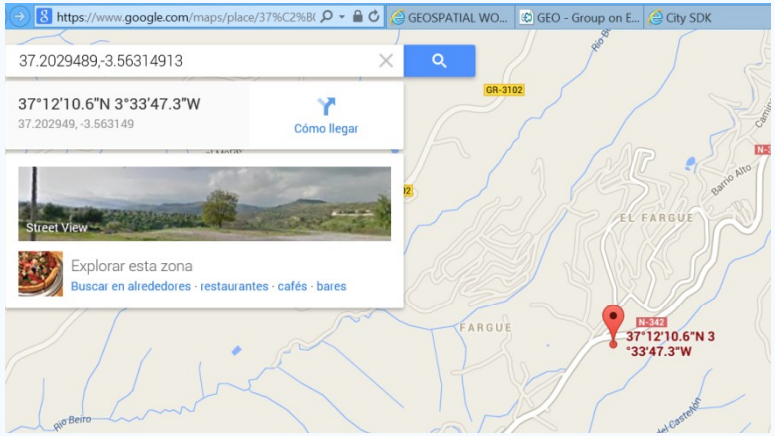
Summary

- Introduction
- Susceptibility
- Hazard
- Risk
- Crisis management
- Conclusions and future works

Tomás Fernández (University of Jaén, Spain)

Crisis management

- Prevention is important in the pre-event but also in the event or crisis management
- In these moments other factors must be taken into account such as action plans (including evacuation), civil protection, people formation, etc.
- Geospatial technologies contributed to these actions by means of several ways:
  - Sensor networks to early warning systems and process monitoring
  - Crowd- sourcing data in the same sense
  - UAV to monitoring and victims rescue
  - GNSS positioning also to victims rescue

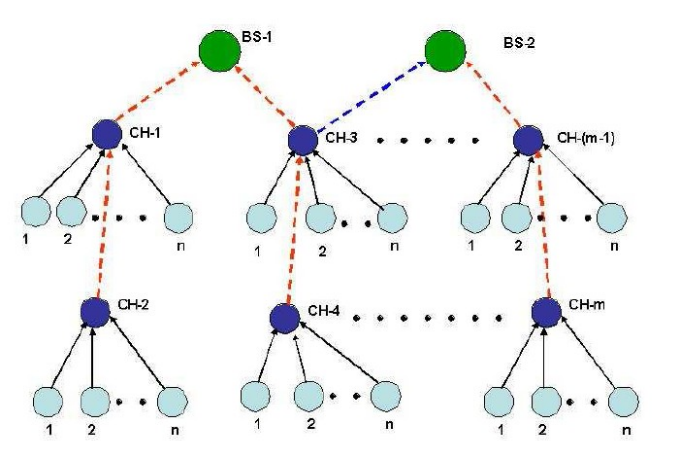


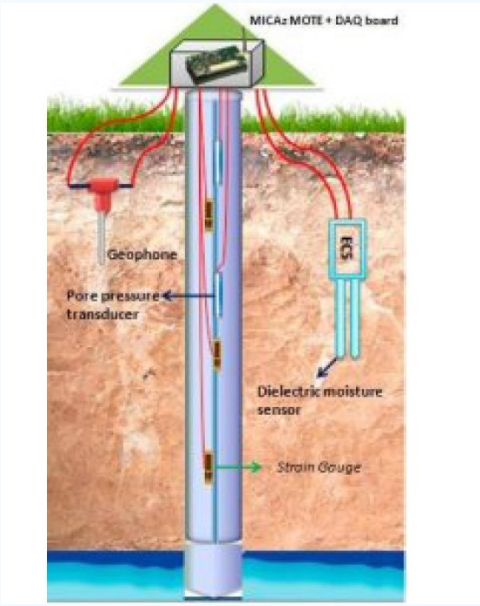
Tomás Fernández (University of Jaén, Spain)

Early warning systems

GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

- Wireless sensor networks are very useful to detect the start of a risk process
- In landslides triggering factors such as strong rainfalls or earthquake can be logged and activate early warning systems
- Also it is possible to detect high soil moisture, piezometric level or even an incipient movement by sensors in a particular movement o several ones
- In the same way, crowd sourcing data can inform of the start of a process and activate warning systems



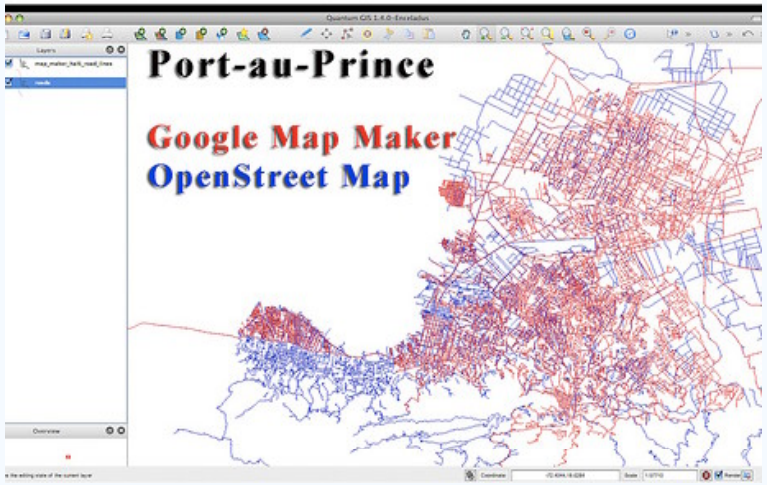


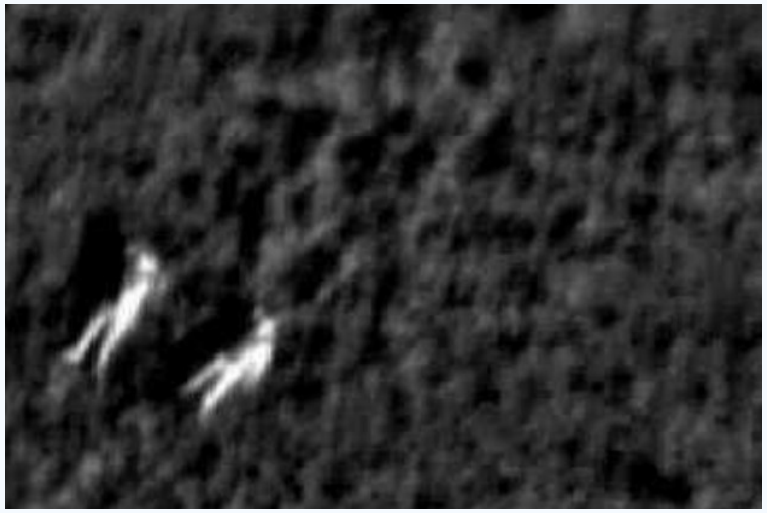
Tomás Fernández (University of Jaén, Spain)

Crowd sourcing and UAV

GEOSPATIAL WORLD FORUM
Geneve, 5-9 May 2014

- Crowd sourcing platforms must be known for people or at least for technicians
- These platforms can be created to a specific process or can use existent infrastructures (Google Maps, OpenStreetMap, social networks …)
- Crowd sourcing systems can follow being used in the post event to help in evacuation and victims location and rescue
- In the same way, UAV can be used to locate people (especially if takes a thermal infrared sensor) and to serve to evacuation systems





Summary

- Introduction
- Susceptibility
- Hazard
- Risk
- Crisis management
- Conclusions

Conclusions

- Landslides susceptibility and hazard mapping is very necessary today due to the strong impact of these processes on people and their goods.
- Susceptibility maps are very useful, but hazard maps are a significant improvement because they can address the problem in a less conservative and more reliable way
- However, the major obstacle to this mapping in landslides is dating or at least determining their activity in a given period (return period). We propose a methodology of determining the susceptibility in different return periods from landslide inventories with a certain activity in these periods
- The activity was estimated in a coarse or fine way applying different techniques (aerial and UAV photogrammetry, TLS, WSN ...)

Conclusions

- The overall hazard maps are obtained as the probability of ocurrence of landslides in a given zone and period of time and then risk maps by integration of hazard, element at risk exposition and vulnerability
- Both map levels (hazard and risk) can help to prevention or mitigation of risk processes
- Prevention is important in the pre-event (mitigation measures) but also in the event or crisis management. In these moments other factors must be taken into account such as actuation plans (including evacuation), civil protection, people formation, etc.
- Geospatial technologies contributed to these actions by means several ways: sensor networks to early warning systems and process monitoring, crowd- sourcing data in the same sense and UAV to process monitoring and victims rescue

Thank very much for your attention

This research was funded by

ISTEGEO project RNM-06862 funded by the Andalusian Research Plan, and

Research Groups TEP-213 and RNM-221 of Andalusian Research Plan.

Advances Studies Center on Earth Sciences of the University of Jaén