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Salvador, Capital das Geociências

The Role of Fault Mechanisms and Tectonics on the Occurrence of Coseismic Landslides

Landslides and Hazard Risk Assessment (RS and GIS Approach)

Freek van der Meer, Cees van Westen, Tolga Gorum

47º CONGRESSO BRASILEIRO DE GEOLOGIA
21 a 26 / setembro / 2014
Salvador ★ Bahia
Trilhando as Novas Fronteiras dos Recursos Naturais

ITC an Associated Institution of the UNITED NATIONS UNIVERSITY

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Faculty ITC – formerly Institute ITC

- **Established:** 1950 - Appeal by UN in framework of official development assistance - ODA
- **Aim:** Build capacity for economic development in developing world
- **Main instrument:** Postgraduate education and training, research, project services
- **Main field of science:** earth observation, geoinformation science applied to problem-solving in earth sciences, natural and water resources and urban studies
- **Achievements**
  Education and training:
  20 000 mid-career professionals

Dean/Rector
Prof. Veldkamp

Founding father
Prof. Schermerhorn

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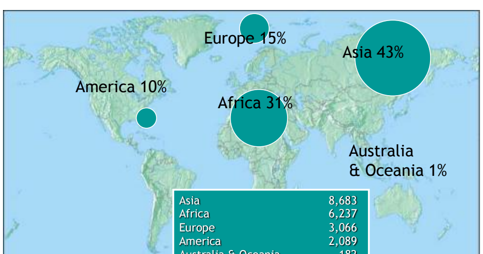
COURSE PARTICIPANTS 1950-2009

ORIGIN OF ITC STUDENTS, EXCLUDING EXTRAMURAL



Asia	8,683
Africa	6,237
Europe	3,066
America	2,089
Australia & Oceania	182
Total students 1950-2009:	20,327
Total countries 1950-2009:	175

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CONTENT OF THE TALK

- Remote sensing of landslides
- Coseismic landslides: fault controls on earthquake induced landslides
- Post earthquake events
- Disaster risk management & climate change

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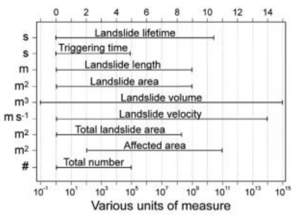
LANDSLIDE INVENTORY

- Single landslides?
  - First time failure
  - Reactivation.
  - Successive events in the same location (e.g. rockfall, debris flow)
- Many landslides?
  - Density of landslides within terrain units over time.
- Triggering events?
  - Rainfall / earthquakes
  - Soil moisture /acceleration



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WHY ARE LANDSLIDE INVENTORIES IMPORTANT?

Landslide inventories are the basis for assessing landslide susceptibility, hazard and risk

- They are essential for susceptibility models that predict landslide on the basis of past conditions: we need to know where they happened and how many
- These conditions are used to predict future ones: we need to know the causal factors
- These conditions differ for different landslide types: we need to know what happened
- Temporal information is essential to estimate the frequency of landslides: we need to know when they happened.
- Landslide inventories are used to validate landslide susceptibility, hazard and risk maps

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LANDSLIDES INVENTORY IS DIFFICULT

- Fresh landslide scarps become overgrown by vegetation within a few years after they happen!
- Signs of landslides become difficult to interpret from images
- Single events might cause many landslides at the same time

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USE OF REMOTE SENSING FOR LANDSLIDE WORK

- **Detection**: new landslides recognition from space- or airborne imagery
- **Rapid mapping**: fast semi-automatic image processing for change detection and/or target detection; hotspot mapping
- **Fast characterization**: retrieving information on failure mechanism, volume involved, and run-out length
- **Long-term monitoring**: processing data for retrieving deformation patterns and time series

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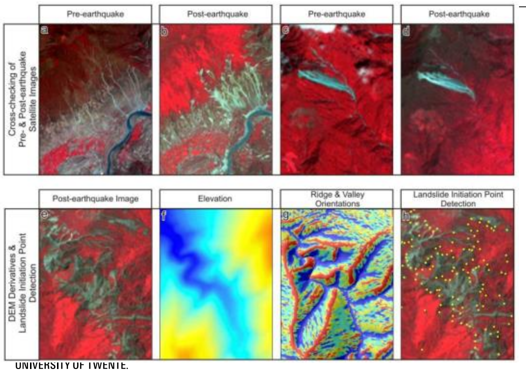
Examples aspects used in detection of landslide initiation points



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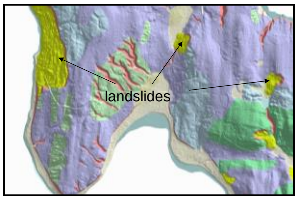
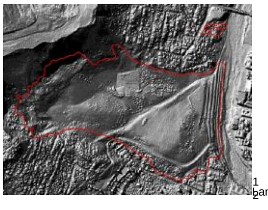
LIDAR FOR LANDSLIDE STUDIES

Source: USGS

- Best source for DEMs
- Centimeter accuracy
- Good for landslide mapping and monitoring





1
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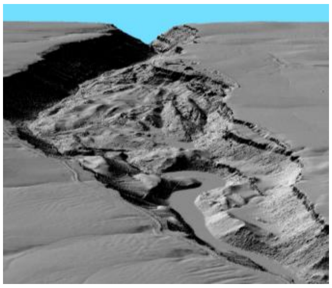
MAPPING LANDSLIDES FROM LIDAR IMAGES



- **1 m LiDAR posting image** of the **Salmon Falls Landslide** southwest of Twin Falls, ID
- Area of 0.2 km^2
- 13 million data points
- vertical resolution of 15 cm
- 100X resolution of a 10m DEM

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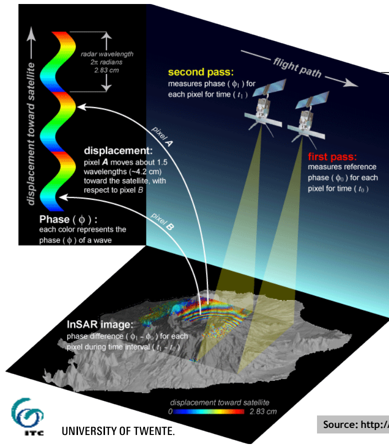

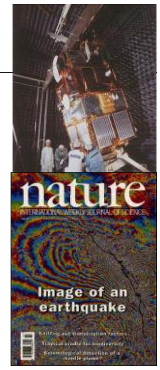

ERS1 courtesy ESA

Source: http://www.geology.wisc.edu/~feigl/482.html

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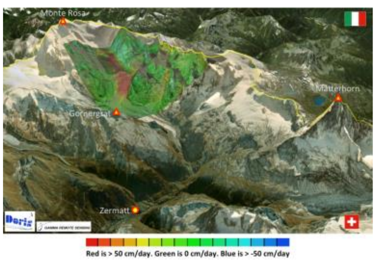
TERRESTRIAL RADAR INTERFEROMETRY



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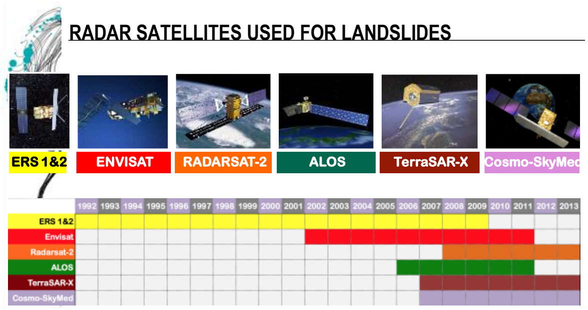
RADAR SATELLITES USED FOR LANDSLIDES



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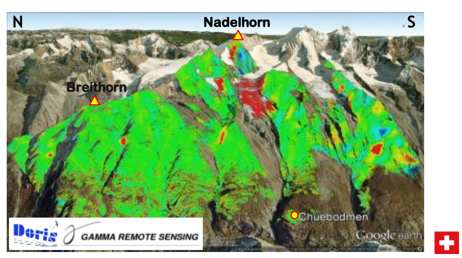
INSAR THE LONDON JUBILEE LINE EXAMPLE

Source: TERRAFIRMA

RADAR MULTI-FREQUENCY ANALYSIS



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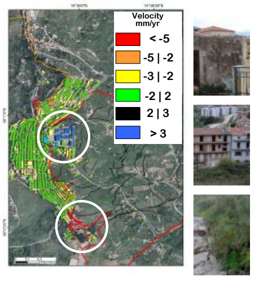
MONITORING OF BUILDINGS ON LANDSLIDES

- Exploitation of X-band SAR data allows unprecedented monitoring of individual buildings in active landslide areas



SAR Velocity Map
COSMO SkyMED | 5/2011 – 5/2012
04/02/2016

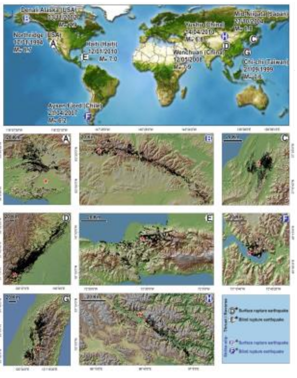
COSEISMIC LANDSLIDES AND FAULT STYLES

DATA SETS

Thrust and reverse fault earthquake events
1994 Northridge, USA (M_w 6.7) -Blind Fault
1999 Chi-chi, Taiwan (M_w 7.6)
2004 Mid-Niigata, Japan (M_w 6.8)
2008 Wenchuan, China (M_w 7.9) Surface rupture
2010 Haiti (M_w 7.0)

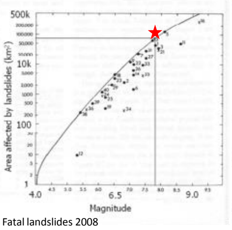
Strike slip earthquake events
2002 Denali Fault (M_w 7.9) Surface rupture
2007 Aisén Fjord (M_w 6.2) Blind fault
2010 Yushu (M_w 6.8) earthquake

66.700 coseismic landslides mapped

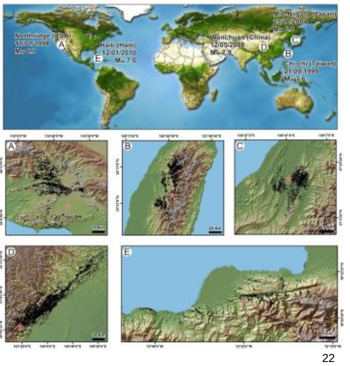


PhD thesis Tolga Gorum: http://www.itc.nl/library/papers_2013/phd/gorum.pdf

EARTHQUAKE INDUCED LANDSLIDES



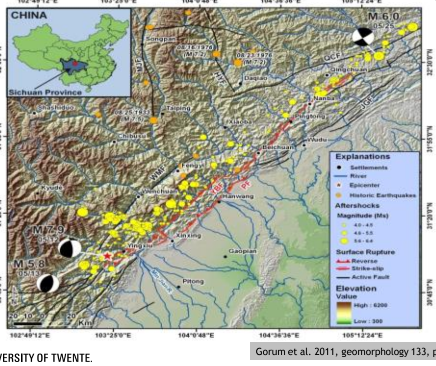
Fatal landslides 2008
International Landslide Centre: Landslide Database
D. N. Petley



BACKGROUND

- coseismic landslides depend on earthquake magnitude, ground motion parameters, distance from epicenter or from ruptured master faults, geological properties (lithology, soil, etc.), geomorphic features (rivers, ridges, etc.) and topographic variables (slope gradient, altitude, etc.).
- number and total volume of landslides triggered by an earthquake, and the area affected by landsliding scale with earthquake magnitude
- recent strong earthquakes have triggered significantly lower numbers and area affected by landslides than expected (e.g, the 2002 Denali (Mw 7.9), the 2010 Haiti (Mw 7.0) and Yushu (Mw 6.8) earthquakes)

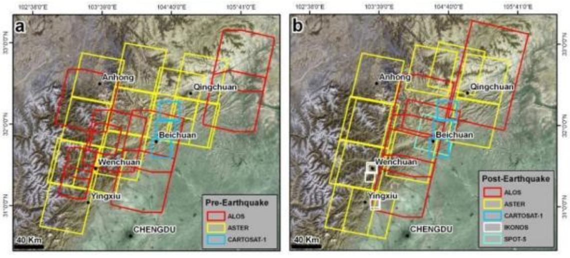
WENCHUAN EARTHQUAKE *2008 CHINA (M_W 7.9)*



Gorum et al. 2011, geomorphology 133, p. 152-167

Coseismic landslide mapping

Pre- and Post-earthquake satellite image coverage



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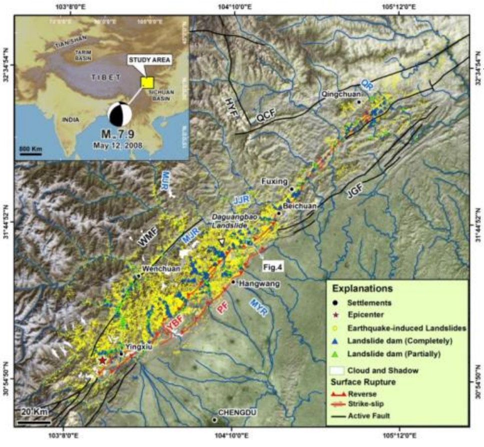
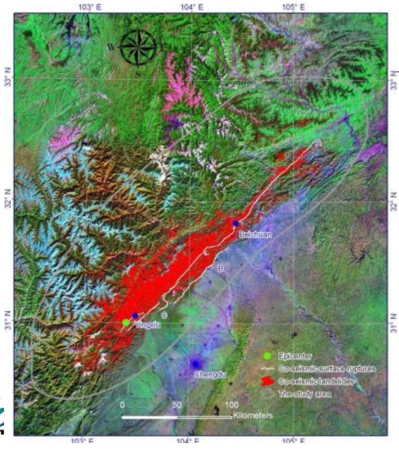


60,104 landslides

828 individual points in the initiation part of landslides,

586 caused completely damming of rivers;

242 caused partially damming;



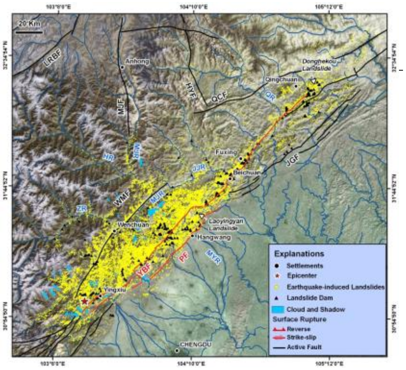
197,481 landslides
Total area:1160 km²

Xu et al. (2013)

landslides are concentrated in a zone up to 100 km northeast of the epicenter

70 percent of landslides in area with high vertical displacements

Landslide density increases in areas where lithologies are highly susceptible to landslides, relatively close to the fault rupture, and with high relief and slope gradient.



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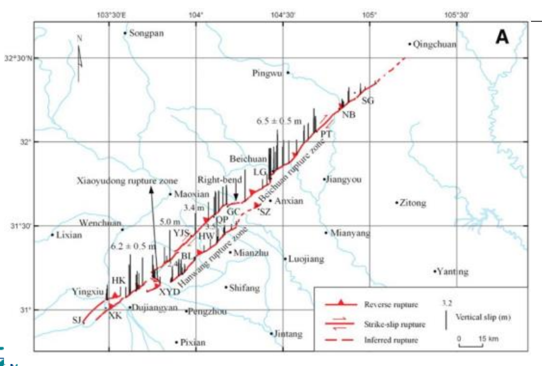
Gorum et al. 2011, geomorphology 133, p. 152-167

VERTICAL DISPLACEMENT



Xu et al., 2009

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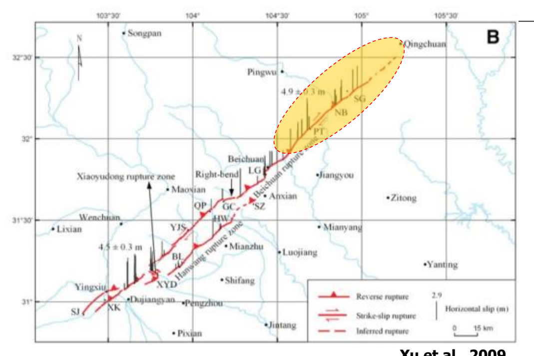
HORIZONTAL DISPLACEMENT



Xu et al., 2009

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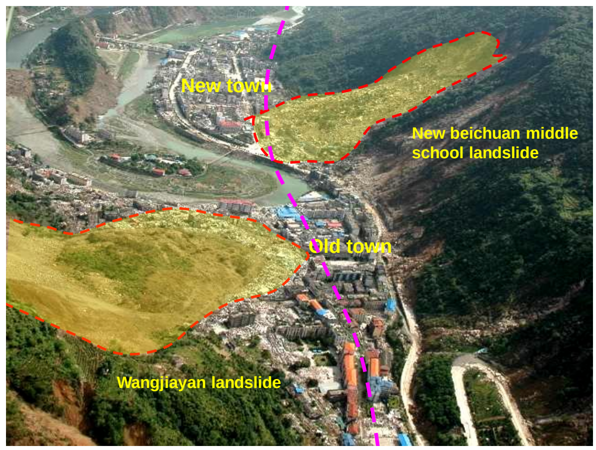

Controls of coseismic landslides

Seismic factors
- *Distance to seismic source; PGA; Intensity*
- *Slope response to seismic waves*
- *Fault type and slip rate*
- *Hanging-wall effect*
- *Locked fault-junction effect*

Terrain factors
- *Slope, terrain roughness*
- *Internal relief*
- *Topographic position etc.*

Geological factors
- *Lithology*
- *Geological structure*

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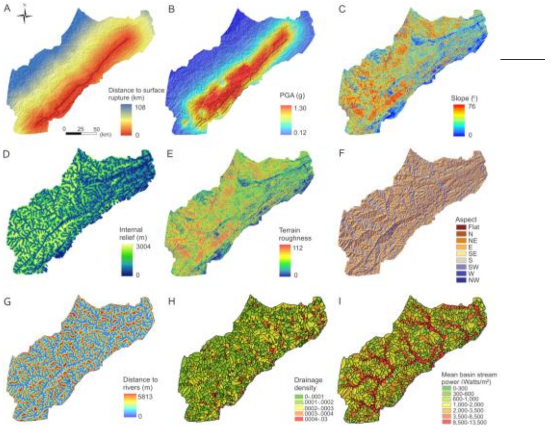
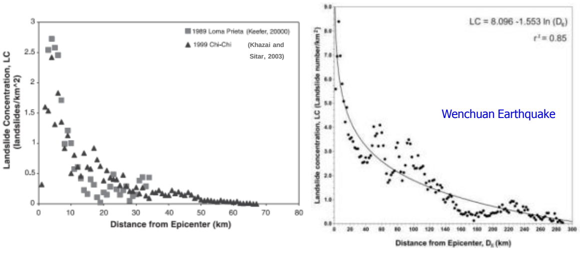


Seismic factors: *Distance to epicenter*



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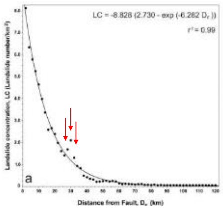
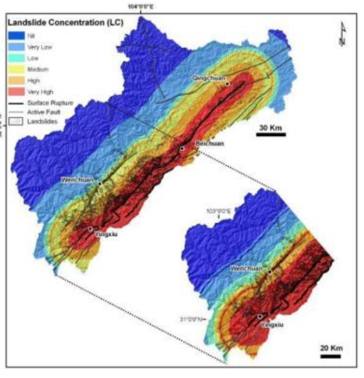
Gorum et al. 2011, geomorphology 133, p. 152-167

DISTANCE TO FAULT SURFACE RUPTURE





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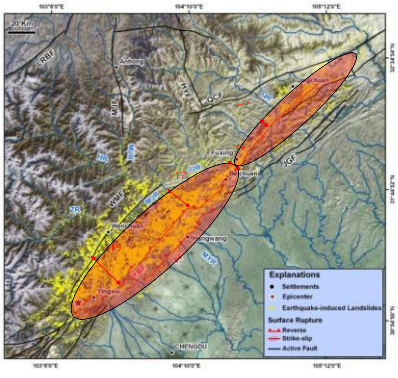
FAULT TYPE AND HANGING WALL EFFECT

Landslides distributed in a much wider zone along the thrusting part of the Yingxiu-Beichuan fault than the strike-slip part.

(Gorum et al., 2011)



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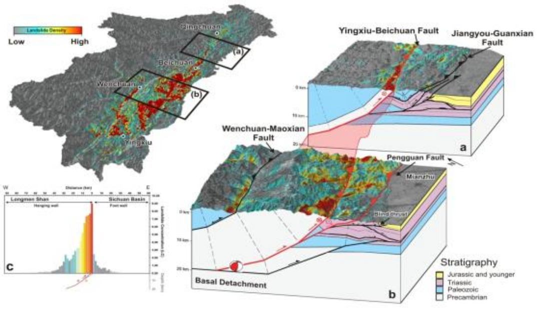
HANGING WALL EFFECT WENCHUAN



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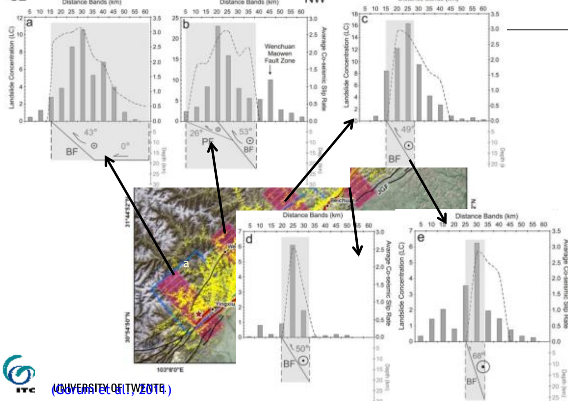
SLIP RATE



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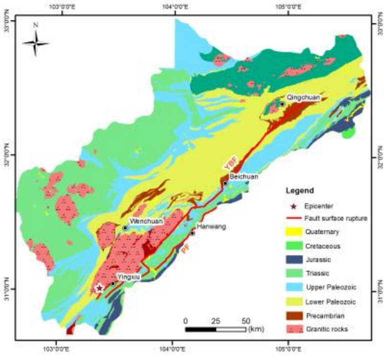
(Gorum et al., 2011)

LITHOLOGY



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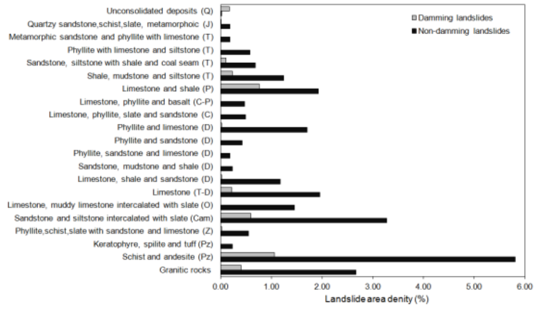
LITHOLOGY



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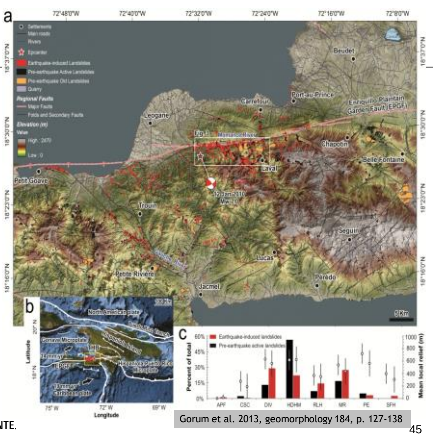
2010 HAITI (M_W 7.0)



Gorum et al. 2013, geomorphology 184, p. 127-138

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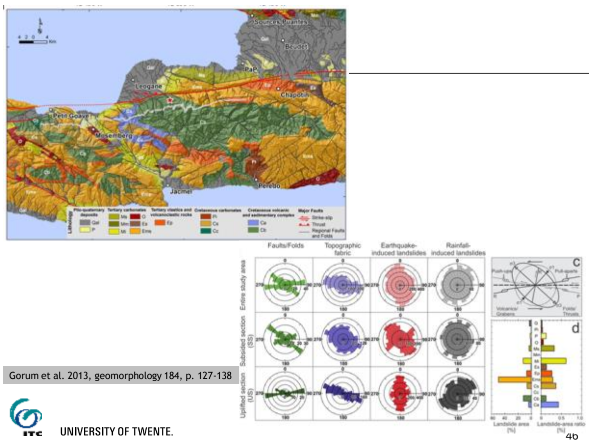

Gorum et al. 2013, geomorphology 184, p. 127-138

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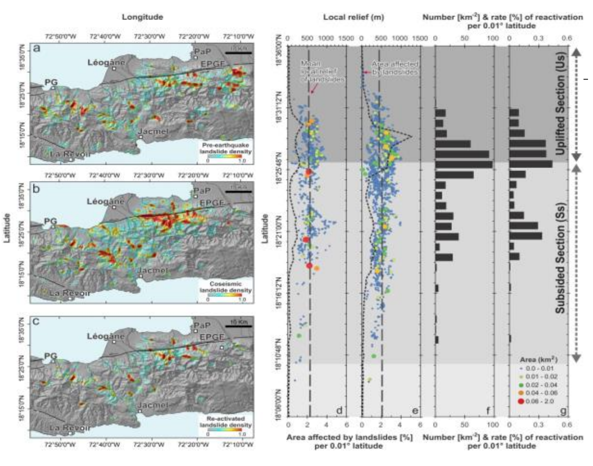

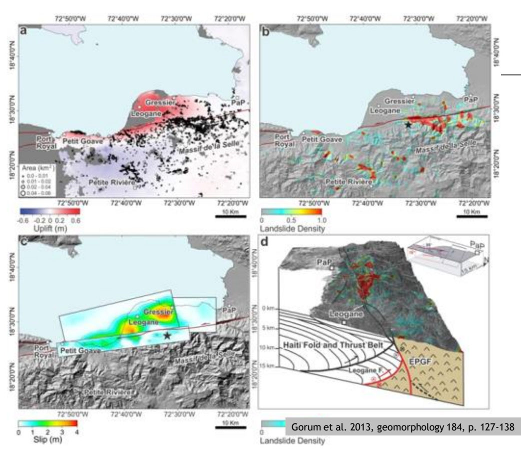

Gorum et al. 2013, geomorphology 184, p. 127-138

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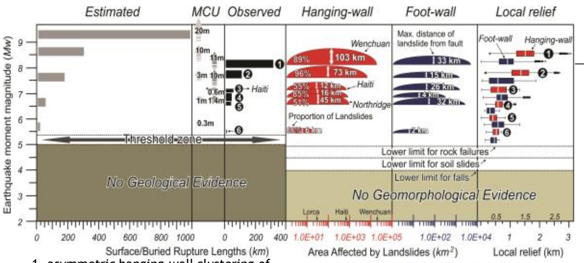
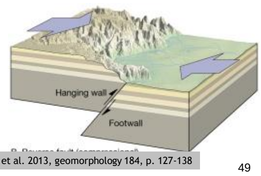


1. asymmetric hanging-wall clustering of landslides thrust earthquakes
2.ratio of coseismic hanging-wall to foot-wall landslides is lower in blind rupture earthquakes than in surface-rupture earthquakes
3.step in the ground motion from the hanging wall to the foot wall for surface-rupture earthquakes



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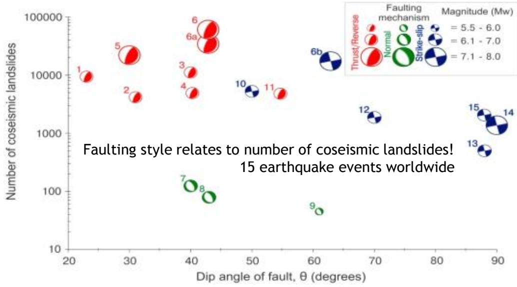
Gorum et al. 2013, geomorphology 184, p. 127-138



Faulting style relates to number of coseismic landslides!
15 earthquake events worldwide

Different faulting styles affecting rupture speed, slip distribution, and peak ground motion.
Ground motion associated with non-vertical faults is asymmetric with respect to fault-slip direction producing distinctly different rupture dynamics than during strike-slip motion

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Gorum et al. 2014, Quaternary Science Reviews 95, p.80-94

CONCLUSIONS

- lack of sufficient earthquake-induced landslide inventories; research on coseismic landslide susceptibility has less progressed in comparison to other natural (rainfall) triggers
- Haiti earthquake revealed that 572 out of 1273 aseismic landslides were re-activated -> pre/post landslides analyzed
- ground motion associated with non-vertical faults is asymmetric to fault-slip direction -> not incorporated in any known attenuation relation
- abundance and the spatial distribution of coseismic landslides strongly vary with faulting styles.
- thrust/reverse faults induce more coseismic landslides than normal and strike-slip faults

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CONCLUSIONS CONT.

- fault geometry is a key control on the spatial distribution pattern of the landslides
- coseismic landslide abundance and the spatial asymmetry decrease with increasing dip angle of strike-slip faults
- number and the overall area affected by the coseismic landslides increases with a decrease in dip angle for thrust and reverse faults for a given magnitude
- large earthquakes break the surface, however small earthquakes usually do not->rupture mechamism matters
- difference in ground motion between hanging walls and foot walls is more pronounced for surface rupture-earthquakes

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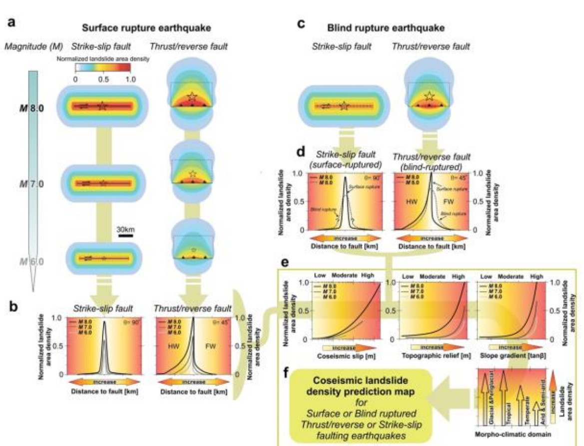
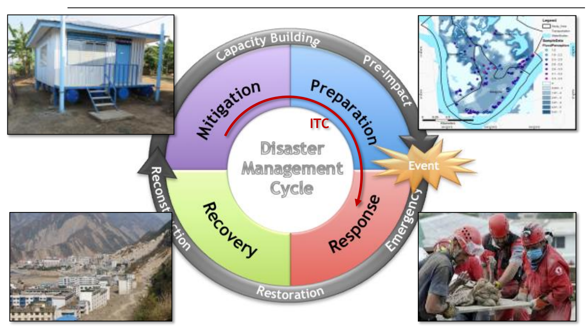


DISASTER CYCLE



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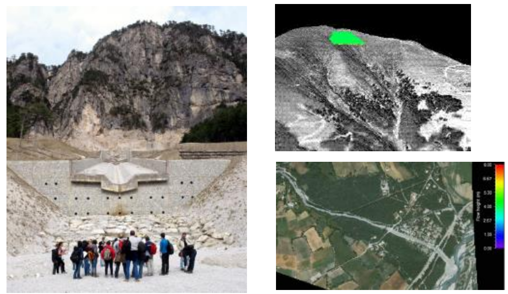
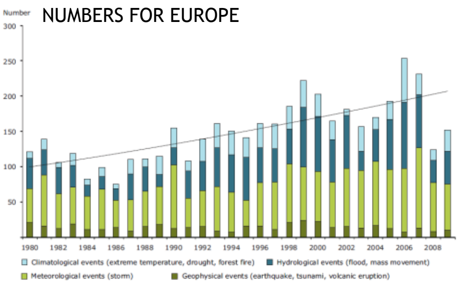
POST-EARTHQUAKE DEBRIS FLOWS

Debris flow modelling for the design of risk reduction measures



NUMBER DISASTERS DUE TO NATURAL HAZARDS

NUMBERS FOR EUROPE

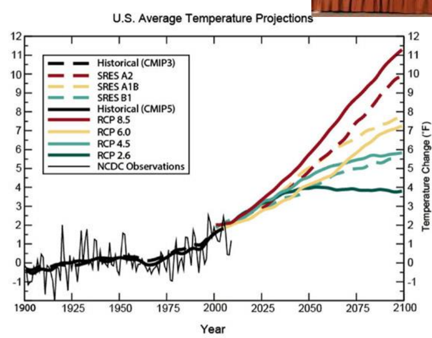


Note: Definition loss events, events can occur in several countries, events are counted countrywise.

Source: NatCatSERVICE, 2010; © 2010 Münchener Rückversicherungs-Gesellschaft, Geo Risks Research, NatCatSERVICE — as at August 2010.

EEA, 2010

IS THE CLIMATE CHANGING?



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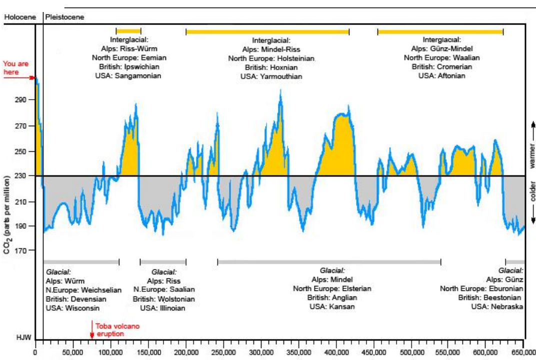

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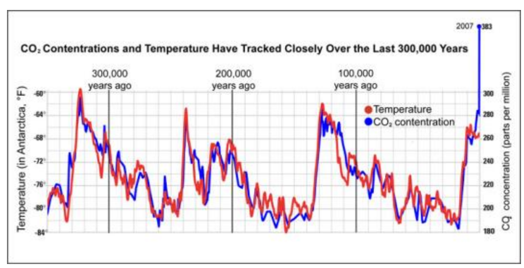

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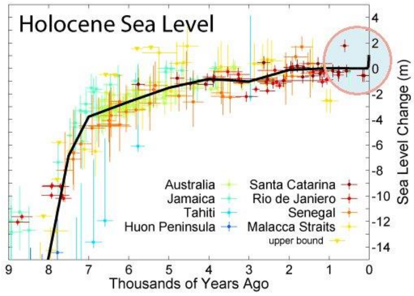
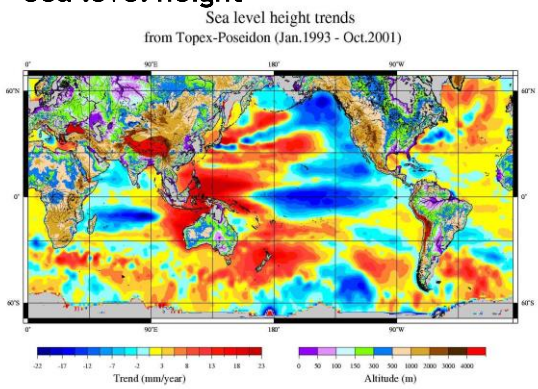
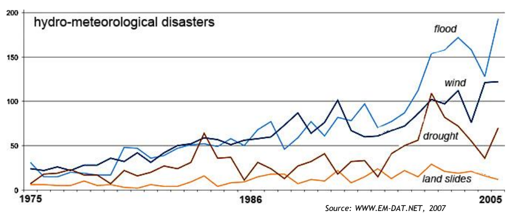


Sea level height



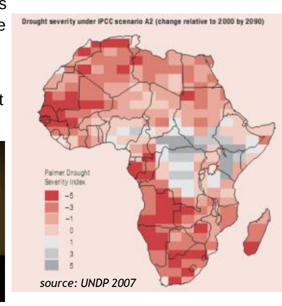
ARE DISASTERS INCREASING?

- Driving forces: climate change
- Vulnerability changes:
  - population growth
  - urbanization (coastal zones, floodplains)
  - occupation of marginal lands
  - false security by believing in 100% protection



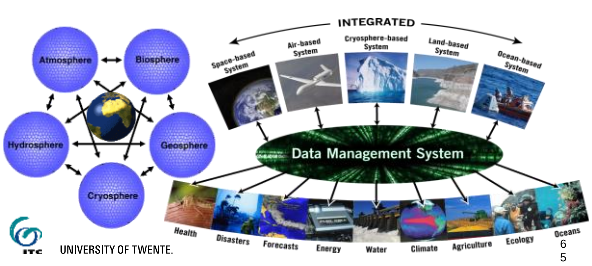
CLIMATE CHANGE; CLIMATE ALWAYS CHANGES

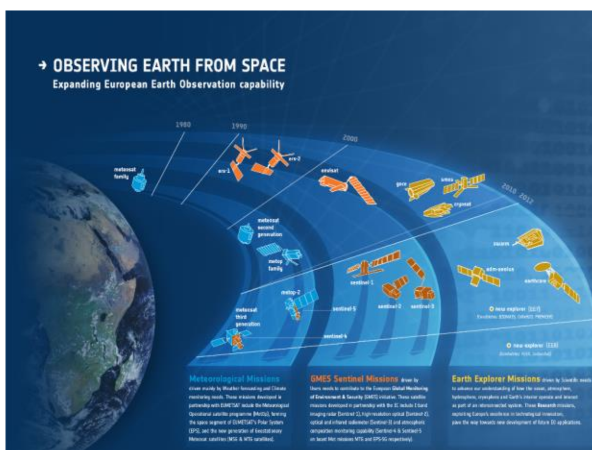
- Average global predictions are not very useful for disaster work, we need detailed weather data that trigger hazardous events
- Tropical regions more uncertain than temperate zones
- Regional spatial predictions are uncertain, large differences between models
- *Where* will extreme events happen, more important than *when* they will happen



WE NEED NEW THINKING: EARTH AS A SYSTEM

"Earth **System** Science" acknowledges that changes in the solid earth (land - lithosphere or geosphere) result from interactions among the **atmosphere (air), hydrosphere (water, including oceans, rivers, ice), biosphere (life)** and the **lithosphere**.





USING DRONES FOR RAPID DAMAGE MAPPING

Drone scanning -> 3D point cloud -> create a building object
-> recognize damage and classify

UAV SCAN OF DESTROYED CHURCH AQUILA EARHTQUAKE

Thank you

CONCLUSIONS ?...

- Models are a simplification of reality, models have uncertainties, earth is a complex system with many unknown feedbacks.
- Large spatial uncertainty in models, leads to many possibilities: with relatively little change in input, different results can be predicted.
- Tools are based on "regular" functioning of the landscape, does this system description apply to extreme events?
- *Asian Development Bank (2003): "100% protection is impossible and may lead to a false sense of security"*

LANDSLIDE RESEARCH AT ITC: COMPLETED PHD RESEARCH

- **Xuanmei Fan (China, 2013**): Earthquake induced landslide dam hazard and risk modeling
- **Tolga Gorum (Turkey, 2013):** Analyzing the relationships between seismic topographic and lithological factor on the distribution of earthquake induced landslides
- **Quan Luna, B., (Guatemala, 2012)** Dynamic numerical run - out modelling for quantitative landslide risk assessment.
- **Martha, T.R. (India, 2011)** Detection of landslides by object - oriented image analysis
- **Ghosh, S. (2011)** Knowledge guided empirical prediction of landslide hazard.
- **Jaiswal, P. (India, 2011)** Landslide risk quantification along transportation corridors based on historical information.
- **Kuriakose, S.L., (India, 2010)** Physically - based dynamic modelling of the effect of land use changes on shallow landslide initiation in the Western Ghats of Kerala, India
- **Castellanos Abella, E.A., (Cuba, 2008)** Multi - scale landslide risk assessment in Cuba.

You can download these PhD theses from: www.itc.nl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