Climate information in hazard risk assessment

Freek van der Meer

31st January 2013, Silpakom University,
Nakompathom, Thailand
OVERVIEW OF THE PRESENTATION

- Trends and developments in earth observation
  - Global level
  - European level
- Key challenges for earth observation
- Disaster management overview
- Flooding examples
- Case study Kampala City, Uganda
- Recommendations for future research lines
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.
New challenges: global processes

GLOBAL NETWORK OF TIDE GAUGES (2001)

INCREASE OF SEA-LEVEL HEIGHT THROUGHOUT 20th CENTURY
1.5 to 2 mm/year

Global mean sea level (Topex/Poseidon)

Rate of sea level rise: 2.4 +/- 0.1 mm/yr

Topex/Poseidon orbital cycle
New challenges: global processes

Sea level height trends
from Topex-Poseidon (Jan.1993 - Oct.2001)
New cross cutting issues

High Risk of Re-emergence of Infectious Diseases
Some in connection with El Niño/La Niña events

- World Population at risk: 2 to 3 billion
- Human Mortality per yr: 3.5 to 4.5 million
  with ½ under 5 yrs (~ 5 million because of AIDS)
- Animal Mortality per yr: 10 to 15 million
The Eyjafjallajökull volcano erupts; public interest in earth observation data

But what is now exactly the volcanic Ash? The red-black Units?

Apr. 15, 2010, 1:22 PM
We can model:
Volcanic ash
distribution at 4 km altitude by HIRLAM model
14 April 17.00 17 April 20.00

So what:
We have now also
temporal dynamics
Can we trust and use this?
Use is limited for
Decision making
How remotely sensed data is ‘used’ in modern day society

Same day different maps
Are shown in the media.
No uncertainties, no legend,

Gradually airports
Are closed as can be tracked ‘life’ on the WWW

Trapped passengers:
Why is this not on Google Earth??
Key problems with earth observation

1. Lack of access to data and associated benefits in the developing world
2. Eroding technical infrastructure
3. Large spatial and temporal gaps in specific data sets
4. Inadequate data integration and interoperability
5. Uncertainty over continuity of observations
6. Inadequate user involvement
7. Lack of relevant processing systems to transform data into useful information
GEO and GEOSS

- **GEO** = Group on Earth Observation
  - 88 Nations
  - European Commission
  - 67 Participating Organizations

- **GEOSS** = One Vision
  - The global earth observation system of systems
  - A globally coordinated, comprehensive and sustained system of Earth observing systems (GMES as European contribution)

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Earth Observation Summit (EOS) I
- July 31, 2003, Washington, DC
- 34 Countries and 20 International Organizations

EOS II
- April 25, 2004, Tokyo, Japan
- 47 Countries and 26 International Organizations

EOS III
- February 2005, Brussels
- Nearly 60 Countries, EC and over 40 International Organizations

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GEO Objectives

Build:
Sustainable Comprehensive Coordinated Observation System of Systems

Provide:
Open & Easy Access to Data Anytime Anywhere

Increase:
The Use of Earth Observations
GEO’s Transverse Approach...

9 Societal Benefit Areas

1. Reduction and Prevention of Disasters
2. Human Health
3. Energy Management
4. Climate Change
5. Water Management
6. Weather Forecasting
7. Ecosystem
8. Agriculture
9. Biodiversity
Techniques and parameters are relevant to a number of Societal Benefit Areas (eg. Altimetry & Land Cover)

Societal Benefit Areas; dependent
Climate-Health
Weather-Water-Agriculture-Health
Weather-Energy-Health
CHOLÉRA AND SATELLITE DATA

- Sea-surface temperature → plancton development

- Sea-level rise → inundated land, stagnating water
GMES: Global Monitoring of Environment and Security – the European contribution to GEOSS

GMES aims at developing operational services, following the example of meteorology, but for other domains such as:

- emergency management
- air quality monitoring
- land monitoring
- ocean & sea ice monitoring etc...
- security

Science needed to create and continuously improve operational services
OBSERVING EARTH FROM SPACE
Expanding European Earth Observation capability

Meteorological Missions
driven by Weather forecasting and Climate monitoring needs. These missions developed in partnership with EUMETSAT inside the Meteosat Operational satellite programme (MOPC), forming the space segment of EUMETSAT’s Polar System (EPS), and the new generation of Geostationary Meteosat satellites (MSG & MTS-2satisfied).

GMES Sentinel Missions
driven by Users needs to contribute to the European Global Monitoring of Environment & Security (GMES) initiative. These satellite missions functional in partnership with the EUMETSAT’s, mapping radar (Sentinel-2), high-resolution optical (Sentinel-2), optical and infrared radiometer (Sentinel-3) and atmospheric composition monitoring capabilities (Sentinel-4 & Sentinel-5), on board Met missions MT and EPS-3G, respectively.

Earth Explorer Missions
driven by Scientists needs to advance our understanding of how the ocean, atmosphere, hydrosphere, cryosphere, and Earth’s interior operate and interact as part of the inter-related system. These research missions, exploiting Europe’s expertise in technological innovation, pave the way towards new development of future EO applications.
<table>
<thead>
<tr>
<th>Sentinel</th>
<th>Description</th>
<th>Launch Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentinel 1 – SAR imaging</td>
<td>All weather, day/night applications, interferometry</td>
<td>2011</td>
</tr>
<tr>
<td>Sentinel 2 – Multispectral imaging</td>
<td>Land applications: urban, forest, agriculture, Continuity of Landsat, SPOT</td>
<td>2012</td>
</tr>
<tr>
<td>Sentinel 3 – Ocean and global land monitoring</td>
<td>Wide-swath ocean color, vegetation, sea/land surface temperature, altimetry</td>
<td>2012</td>
</tr>
<tr>
<td>Sentinel 4 – Geostationary atmospheric</td>
<td>Atmospheric composition monitoring, trans-boundary pollution</td>
<td>2017+</td>
</tr>
<tr>
<td>Sentinel 5 – Low-orbit atmospheric</td>
<td>Atmospheric composition monitoring (S5 Precursor launch in 2014)</td>
<td>2019+</td>
</tr>
</tbody>
</table>
Sentinel-1A getting ready for launch in 4th Quarter 2013

S/C Structure without external panels
(Courtesy of TAS-I, I)

SAR Antenna Panel A during Antenna Pattern Tests and SAR Antenna Panel Frames D and E during integration of Deployment Mechanisms
(Courtesy of Astrium GmbH, D)
ENVISAT mission: 10 years

Serving 4000 scientific projects and many operational users

First images

Global air pollution

B-15A iceberg

Ozone hole 2005

Arctic 2007

Bam earthquake

Chlorophyll concentration

Hurricane Katrina

CO2 map

Prestige tanker oil slick

Envisat Symposium Salzburg (A)

Apr 02

Envisat Symposium Montreux (CH)

Jun 07

Living Planet Symposium Bergen (N)

Jul 12

and many workshops dedicated to specific Envisat user communities

Iceland 2010

Japan 2011

L'Aquila 2009

Arctic 2007

Ozone hole 2005

Bam earthquake

Chlorophyll concentration

Hurricane Katrina

CO2 map

Prestige tanker oil slick

Envisat Symposium Salzburg (A)

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and many workshops dedicated to specific Envisat user communities
Essential Climate Variables under the ESA CCI programme

- Cloud Properties
- Carbon Dioxide, Methane & other GHGs
- Ozone
- Aerosol properties
- Sea Surface Temperature
- Sea Level; Sea Ice
- Ocean Colour
- Glaciers and ice caps
- Land cover
- Fire disturbance
- Soil moisture
SOME KEY CHALLENGES FOR EO...

Early Warning for Disasters (eg. Tsunami) and Disease Outbreaks (eg. Malaria)
Post-Crisis Management
Capacity Building in Developing Countries
Energy and Crop Management
Provision of Observations – linking surface with satellite
Continuity of observations (eg. Landsat)
Time as a classifier?

Time as a ‘new’ variable!
Time as a ‘new’ coordinate-axis!

Dynamics of 2 days!
Dynamics of 1 year!

Change over time of spectral reflectances

Rainfall

NDVI

Our Breathing Planet
USDA Monitoring Drought Impact on Crops in Russia, 2010

Vegetation Anomaly Image, Volga District, Russia; June 26- July 11, 2010

- Low rainfall and hot temperatures were largely responsible for a reduction of 37% percent of the country’s grain crops. Global price increased 80% in 6 months

BUT WHAT WAS GROWN THERE ??
A product of “Anomaly Mapping” …

… how can this be transformed into better information??

We need info (characterization) on:
- Cropped areas
- Farming systems
- Crop calendars,
- Vulnerability,
- Coping mechanisms, etc.
How to prepare with fieldwork a crop-calendar (cropping systems) map of the rice areas of the Mekong, Vietnam?

We needed that map to study monitoring methods.

Notes:
- very cloudy area
- ongoing projects using radar images have still not delivered …

2002 Existing Rice Map
- basically 2 rice classes (2 or 3 crops/year)
- no info WHEN the crops are cultivated
We have a choice to use SPOT-VGT or MODIS (or both) ... classified NDVI images:
... and a choice which period to cover (backwards monitoring!)

... generates info on past (10-year) changes
Combining RS and Crop Models to estimate actual yields

Looking at inputs

- Weather (Ra, T, P, etc.)
- Soil
- Available-H₂O
- Yield limiting & reducing factors
- Agricultural Management

Growth

- NDVI, Biomass, Leaf-Area-Index
- Instantaneous measurements
- RS
- Accumulation measurements

Actual Yield

Real output

Less accurate

More accurate

RS to estimate potential yield or yield reduction due to water stress

RS to ‘force’ actual yield estimation

(de Bie, unpublished)
Example using Accumulation Measurements *(Rice, Mekong Delta, Vietnam)*

Rice yield estimates; 58 sites *(Nguyen Thi Thu Ha et al., in prep.)*
A definition of Disasters

“A serious disruption of the functioning of a community or a society, causing widespread human, material, economic or environmental losses which exceed the ability of the affected community to cope using its own resources.” (EEA, 2005)
A Disaster management framework

**Rapid disasters**

**Causes**
- Hazards: Landslides, floods, earthquakes

**Effects**
- Risk analysis
- Vulnerability in urban and rural areas

**Response**
- Disaster mitigation
- Damage assessment, planning, awareness

**Slow disasters**

**Causes**
- Hazards: Erosion and desertification

**Effects**
- Land degradation
- Onsite and off site effects

**Response**
- Prevention and mitigation
- Soil and water conservation
WHAT IS A DISASTER?

A natural process

Dynamics
Triggers
Frequency
Location

Society

Vulnerability
Inventory
Awareness
Coping strategies
Cost
Impact

RISK

DISASTER

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**WHAT IS A DISASTER?**

---

**A natural process**
- Dynamics
- Triggers
- Frequency
- Location

**Society**
- Vulnerability
- Inventory
- Awareness
- Coping strategies
- Cost
- Impact

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**RISK:** The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between (natural, human-induced or man-made) hazards and vulnerable conditions.
RISK ASSESSMENT CONCEPT

Risk = Probability of losses occurring
      = Hazard * Vulnerability * Amount
      = Temporal probability * Consequences or losses
      = Temporal probability * Degree of loss to Elements at risk * Quantification of Elements at risk

Climate information

Hazard
- Temporal probability
- Duration
- Time of onset
- Type of hazard
- Hazard intensity
- Spatial extent
  - Initiation
  - Spreading/runout

Vulnerability
- Vulnerability function
  - Type 1
  - Type 2
  - % damage
  - Hazard Intensity

Elements at risk
- Type of Elements at risk
- Temporal variation
- Quantification
  - Number
  - Economic value
- Location

Exposure: Spatial overlay of hazard and elements at risk
NUMBER DISASTERS DUE TO NATURAL HAZARDS

NUMBERS FOR EUROPE

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


EEA, 2010
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

Source: WWW.EM-DAT.NET, 2007
Climate change

- Climate is constantly changing
- 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

source: UNDP 2007
But our simulations are not very good...

- On-site: which fields produce runoff and sediment
- Off-site: different patterns of contributing areas cause a different discharge
- Our simulations show what \textit{might} happen, but there are many possibilities
- If we know better what happens \textit{spatially}, the predictive quality increases

\begin{center}
\textbf{Total Discharge (m3)}
\end{center}

\begin{center}
\begin{tabular}{c c c}
\hline
simulated & measured & source: De Roo and Jetten, 1999  \\
\hline
2500 & 0 & \\
2000 & 500 & \\
1500 & 1000 & \\
1000 & 1500 & \\
500 & 2000 & \\
0 & 2500 & \\
\hline
\end{tabular}
\end{center}
Combine model result with observed spatial patterns

- Add qualitative information: such as indicators, agricultural data, observed crusting
- Use landscape analysis to determine active zones
- Use high resolution images to determine active zones and confine model activity

Source: Jetten et al. 2004
Medium to small scales hazards: focus on flooding and landslides

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HAZARD TRIGGER ANALYSIS - RAINFALL DISTRIBUTION

Seasonal precipitation, Barcelonnette

France Alps

Seasonal precipitation, Pontebba

Italian Alps

Seasonal precipitation - 3 month total (mm)

France Alps

Italian Alps

Annual maximum daily precipitation (mm)

Count

Annual maximum daily precipitation (mm)
LANDSLIDE-PRECIPITATION CORRELATION

Other factors do play an role in triggering
FLOODING: DELIVERABLES FROM REMOTE SENSING

- Flood inundation mapping and monitoring
- Scientific based Damage Assessment
- Monitoring of flood controls, change in the river course
- Identification of bank erosion
- Identification of chronic flood prone areas
- Improvement in forecasting & warning models
LIMITATIONS OF REMOTE SENSING

• Availability of satellite over pass over flood affected area;
• Cloud cover problem;
• High resolution satellite data for detailed assessment;
• Assessment of structural & indirect damages; and
• Urban flood modelling.
THE FLOOD OF 1805
Flooding of the polder ‘Land van Maas en Waal’, The Netherlands

Annika W. Hesselink
Flood hazard assessment: Naga (Philippines)

Inundation depth variation

Hazard classes

Hazard classification based on multi-

criteria analysis

Duration Hrs.

Inundated duration

Maximum kinetic energy

Kinetic energy

> 15 < 400 KJ

0.00 KJ

04:00

06 09 1982

0

1.2

1.0

0.9

0.6

0.4

0.2

0

7.3

27/3

Duration of inundation (hrs)

Inundation Depth (m)

Kinetic energy (KJ)

T= Duration to reach maximum inundation depth
Floods and urban planning

- Naga City (Philippines)
- Planned shopping mall forces water in other areas (10 year flood)

Source: Muhammad Zulkarnain Bin Abd Rahman (MSc)
FLOOD CONTROL; TECHNICAL SOLUTIONS

FLOOD MANAGEMENT ISSUES

Modification of floods
• embankments
• drainage improvements
• building reservoirs
• detention basins
• afforestation, etc.

Modification of susceptibility to flood damage
• regulation of economic activity in the flood plains
• flood forecasting and disaster preparedness
• town and village protection works
• raising of villages, etc.

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Flooding in Bangkok – October 2011

- Bangkok more rain than normal (annually 1,400-1,500 mm; up to Oct 17, 2011: 2,189 mm)

Enhanced water release upstream dams from August 1 to Oct 16, 2011 compared to other years
ANOMALOUS PRECIPITATION OR MANAGEMENT?

Mean Annual Rainfall in Thailand
above-below normal in percentage
(Normal : 1971 - 2000)

Thai Met. Dept.
Anomalous precipitation or management?

Annual Rainfall (mm.) in 2011

Annual Rainfall anomalies (mm.) in 2011
Flood sub-systems

System 1: Precipitation

System 2: Upstream

System 3: Downstream

How much?

How much?

Converging flow

Diverging flow

When?

Where?
Downstream problems: flooding
Linking upstream - downstream

- Land use can change rapidly in tropical regions, much more than in Europe, for instance deforestation or biofuel plantations.
- This influences flood dynamics, direct upstream-downstream links, especially in medium sized catchments.

_LISEM-SOBEK simulations Nam Chun watershed floodplain Thailand_

Source: Saowanee Prachansri (M.Sc.), 2006
Land Development Department, Thailand
KAMPALA (UGANDA)

- UN Habitat project
- Flooding in Kampala
FLOODING OF SLUMS IN KAMPALA

- UN-HABITAT project in the Cities and Climate Change Initiative (CCCI)
- ITC (ESA, PGM); HYDROC (German Consultancy); Makarere University
- Counterpart: KCCA – Kampala Capital City Authorities

- Purpose:
  - comprehensive, city-wide assessment of the risks of flooding based on “integrated flood management”;
  - a more detailed flood risk assessment in a representative ‘hotspot’
  - offer a strategy in the form of a proposed policy, with cost-effective recommendations (including proposed bylaws) in the form of an action plan, that would pave the way for improved and integrated flood management.
KAMPALA: WETLANDS DRAINING TO LAKE VICTORIA
EXAMPLE: FLOODS IN JUNE 2012 (1:2 YEAR EVENT)
CATCHMENT ASPECTS

- Hills are densely populated, low lying wetlands unplanned settlement
- Rainstorm (=floods), 2-3 times a month during the 2 wet seasons
- High runoff percentage from surrounding hills
- Valleys are poorly drained wetlands
- Low flood levels:
  - No direct physical danger, damage to weaker houses
  - Health and pollution risk
  - interruption of social and economic activities, damage to poorly built houses and property, drainage problems
UNPLANNED SETTLEMENTS

Poor drainage
Health hazard
Local flood protection around houses
Socio-economic side:

- No waste management (partly a behavior problem)
- Already there are elevated pit latrines, but also open sewage
- No self-help in terms of drainage management (a drainage system was built but is not maintained)

Governance side:

- Land is owned (Mailo tenure system) and rented, so who takes responsibility: tenants or land owners?
- Wetlands are (will be) protected by NEMA (National Environmental Management Agency) but this is ignored. Exact wetland boundary is disputed.
PERCEPTION: CAUSE AND EFFECT?

Figure 3: Unplanned settlements in a wetland in Bwaise blocking the waterways and causing floods (2007). Construction of structures in drainage channels at Zana on Kampala-Entebbe highway resulted in flooding in 2007.

- Construction in wrong areas is seen as the cause
CLIMATE CHANGE?

- **Temperature**: significantly warmer by a few degrees in 2090
- **Rainfall annual**: no significant trend in the proportion of rainfall occurring in heavy events: 1 and 5 day rainfall maxima show small, non-statistically significant increase in months Nov-Jan.

Note:
- There are no viable rainfall data of Kampala city after 2003.
- City microclimate on the edge of lake Victoria uncertain
- The best guess of rainfall are currently satellite images (!)

Tyndall Centre for Climate Change Research, McSweeny et al. (2011)
KAMPALA RAINFALL DATA

- Official stations not functioning
- Two sources: Outspan Primary School in Bwaise Slum area
- Automatic station at Makarere University campus
- 7 floods in 2 months
- >25 mm/day of rainfall gives floods
- 10 mm rainfall gives a flood when there was rain on the day before (indicating a catchment storage mechanism)
CLIMATE CHANGE IS NOT THE IMMEDIATE PROBLEM

- Left: 1973 (left) – right: 2007

(NEMA Environmental Atlas)
DRAINAGE SYSTEM

- Tertiary drains badly maintained, blocked by garbage
- “Northern Bypass” new highway with culverts that are probably too small, blocking runoff water

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RUNOFF AND FLOOD MODELLING – OPENLISEM

- Early 90s, made for rural areas in the Netherlands to simulate the effect of proposed conservation measures to reduce downstream flooding
- Simulates individual rainstorms in detail in time and space
- Spatial modelling, GIS based
- Remote Sensing input; DTM, land use, soil parameters
- Detailed catchment scale: simulate effects of e.g. rainwater storage basins, field level soil & water conservation
- No limit in catchment size but cellsize must be between 5 m² and 1 ha because of empirical assumptions
Rooftop
some interception
no infiltration
max runoff

Vegetation, bare soil
interception
infiltration
less runoff

Drain
no interception
some infiltration
guided runoff

Murrum road
no interception
min. infiltration
runoff
(compacted)
LISEM can use these *fraction maps* with different characteristics.

Infiltration and storage processes are simulated in parallel for each type as a fraction of the water balance of the gridcell.

Runoff is the total of all partial runoff.

- House (34%)
- Grass (20%)
- Trees (20%)
- Hard surface, Roads (26%)
FROM LAND USE TO HYDROLOGY TYPE MAPS

Count per 10x10m area number of 0.5m pixels of a class and save as a fraction map of that class in 10m resolution.

- 10m Bare surface fraction
- 10m Vegetation fraction
- 10m House fraction

1m land use map

77
- Maintenance improving, but garbage
- Primary drain is being reconstructed
AUTOMATIC RECORDER MAKARERE

66 mm: Recurrence interval 2 years

Recurrence interval 1 year
SIMULATION 49 MM EVENT – INFILTRATION
(ASSUMING ALL DRAINS FUNCTION, NO FLOOD)
SIMULATION 49 MM EVENT – RUNOFF
(ASSUMING ALL DRAINS FUNCTION, NO FLOOD)
SIMULATING 25 JUNE 2012 – DISCHARGE AT BWAISE III

Rainfall = 66.2 mm
Storage and infiltration = 46.8 mm
Runoff % = 27.9%

Bwaise:
Total = 386000 m³
Peak = 75 m³/s

Note: this simulation does not take a flooded area into account
INfiltration in with more housing

Doubling the housing density to 50%

Max infiltration

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DISCHARGE ENTERING BWAISE WITH DIFFERENT SCENARIOS

Rainfall = 66.2 mm
Storage and infiltration = 46.8 mm
Runoff % = 27.9%
Bwaise:
Total = 386000 m³
Peak = 75 m³/s
Increase of ~60%

These are model results, field experience is all important!
WHICH SCENARIOS ARE POSSIBLE

- Increase in housing → unplanned or strategic?
- Climate change effects?

At house/plot level
- Storage by rainwater drums, rainwater harvesting
- Infiltration ditches below roofs (on loamy soils)

At catchment level
- Strategic planning: which locations must be kept free?
- Promote urban agriculture
- Technical solutions: e.g. delay and buffer water?
Disastrous predictions...

- Not every large event becomes a disaster everywhere, we have to be careful in what we predict.

- Large spatial uncertainty, 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?

- Which disaster scenarios to choose? Which prediction is useful?

*Asian Development Bank (2003): “100% protection is impossible and may lead to a false sense of security”*
Research in the coming years

- Improve the spatial prediction of hazards and risk:
  - Integrate better image information with spatial models, to reduce the spatial uncertainty.
  - Check models against reality.
  - Link better upstream and downstream processes, especially for extreme events.

- Improve the link between the technical and institutional phases of Disaster Management:
  - Translate technical results into useful results.
  - Play a role in the governance issues by providing disaster geo-information.
  - Improve the dialogue and assist in defining acceptable disaster reduction measures.
CHANGES stands for: Changing Hydro-meteorological risks – as Analyzed by a New Generation of European Scientists.

To develop an advanced understanding of:
- how global changes will affect the temporal and spatial patterns of landslides and flooding, and its associated risks in Europe
- how these changes can be assessed and modeled
- how these can be incorporates in sustainable risk management strategies, focusing on spatial planning, emergency preparedness and risk communication.
ACKNOWLEDGEMENT

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