CIRCLE 2

CLIMATE IMPACT RESEARCH & RESPONSE COORDINATION FOR A LARGER EUROPE

EU FP7 ERA-NET

ChangingRISKS: changing pattern of landslide risks as a response to global changes in mountain areas

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ENGAGE Geomorphological Systems & Risk Research

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ERA-NET PROJECT CIRCLE-2

CIRCLE-2 is an European Network of 34 institutions from 23 countries, committed to fund research, share knowledge on climate adaptation and to promote long-term cooperation among national and regional climate change programmes.

EU FP7 ERA-Net
Coordination & Support Action
May 2010 - April 2014
20 Partners + 14 Contributing Partners

ARNICA

Assessment of Risks on transportation Networks resulting from slope Instability and Climate change in the Alps

Lead: Centre National de Recherche Scientifique (France)

Website: http://www.lgp.cnrs-bellevue.fr/arnica/

EURAS-CLIMPACT

Impact of climate change and related glacier hazards and mitigation strategies in the European Alps, Swedish Lapland and the Tien Shan Mountains, Central Asia

Lead: Department of Environmental Geosciences, University of Vienna (Austria)

Website: http://medienportal.univie.ac.at/uniview/forschung/detailansicht/artikel/wenn-die-gletscher-schmelzen-1/

ChangingRISKS

Changing pattern of landslide risks as response to global changes in mountain areas.

Lead: Centre National de la Recherche Scientifique / Institut de Physique du Globe de Strasbourg (France)

CAMELEON

CArbon dynamics in Mountain Ecosystems: analyzing Landscape-scale Effects Of aNthropogenic changes (climate and land-use)

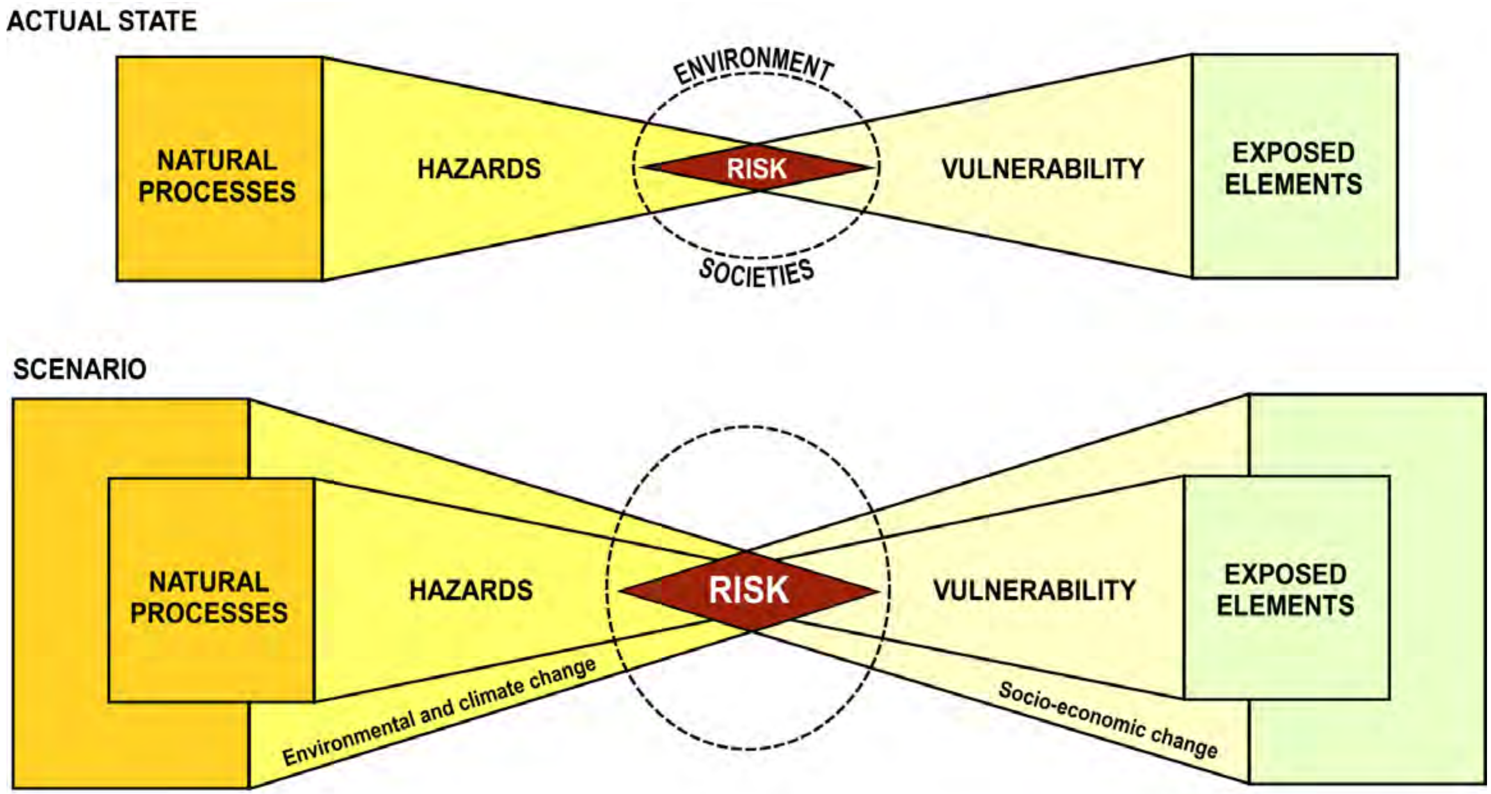
Lead: Laboratoire des Sciences du Climat et de l'Environnement - Commissariat à l'Energie Atomique (France)

ChangingRISKS

KEY RESEARCH QUESTION

- Can we identify changes in **landslide hazard** (susceptibility, frequency, magnitude) and **landslide risks** (vulnerability, costs) associated to climate and landcover change scenarios?

- What **indicators** to express these possible changes?

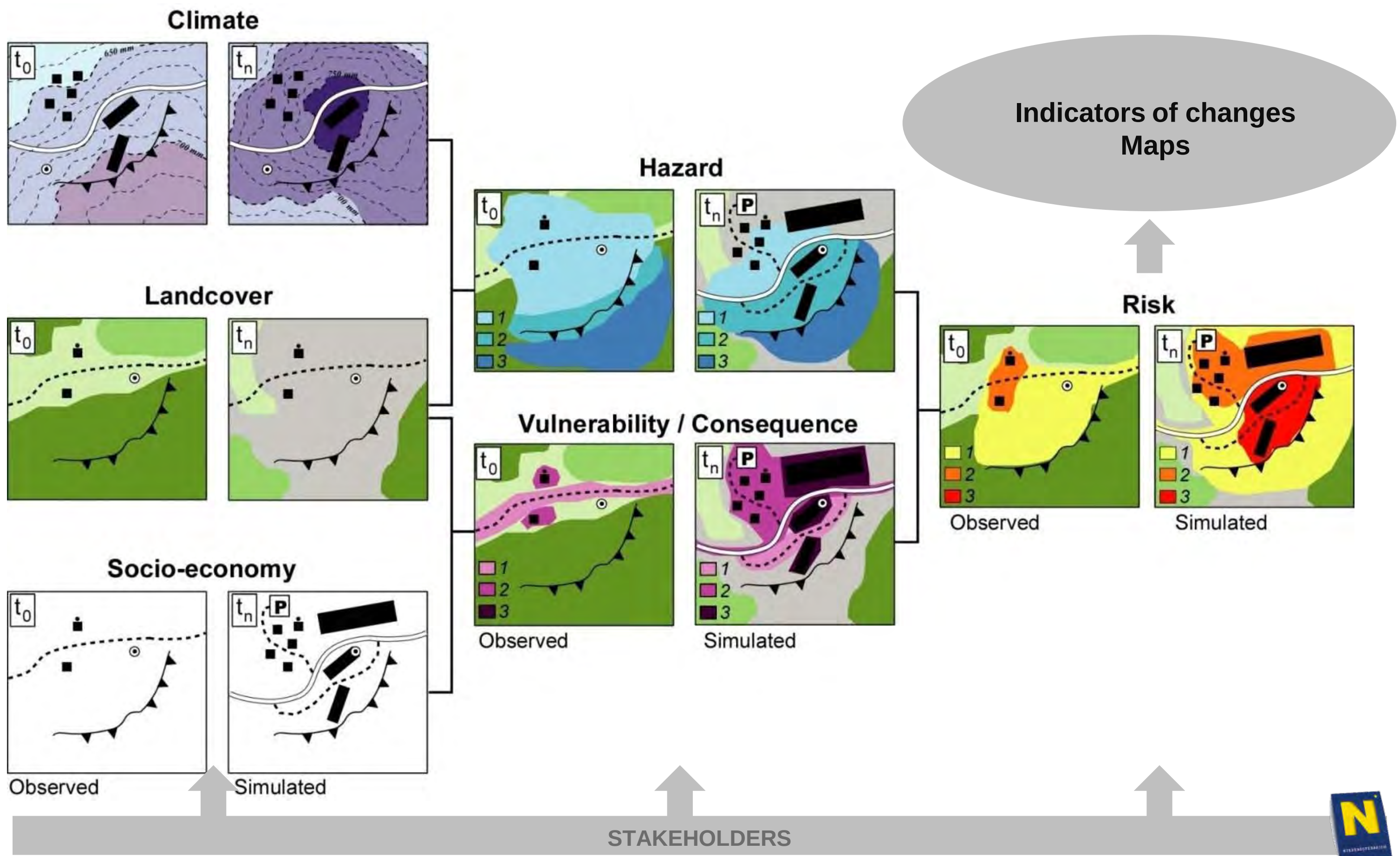


(modified from Glade & Crozier, 2005)

CONCEPT AND METHODOLOGY

- Definition of time series & maps of actual/changing predisposing/triggering factors
  ➔ Creation of actual and ‘changed’ landslide hazard maps

- Definition of ‘changed’ maps of landcover and socio-economic factors
  ➔ Creation of actual and ‘changed’ landslide risk maps



METHOD

- Comparative analysis of 2 study areas with different environmental conditions and different exposures to landslide risks

PROJECT ORGANIZATION: TASKS

Flowchart of project tasks

WP1 - Characterization of past and current landslide activity

- 1.1 Documentation and characterization of landslide activity at the regional scale
- 1.2 Conditioning and triggering factors controlling process location, timing and intensity

↓

WP2 - Characterization of past and future conditioning factors of landslide risks

- 2.1 Characterization of the past climate and simulation of the future climate and regionalization of meteorological parameters
- 2.2 Definition of the past and simulation of the future landuse characteristics
- 2.3 Definition of the past and of the future socio-economic trends

↓

WP3 - Integrated landslide hazard analysis

- 3.1 Analysis of landslide susceptibility
- 3.2 Analysis of landslide hazard through hydrology-slope stability modelling
- 3.3 Forecasting trends in landslide activity and hazards for the future

↓

WP4 - Integrated landslide risk analysis, and estimation of the consequences

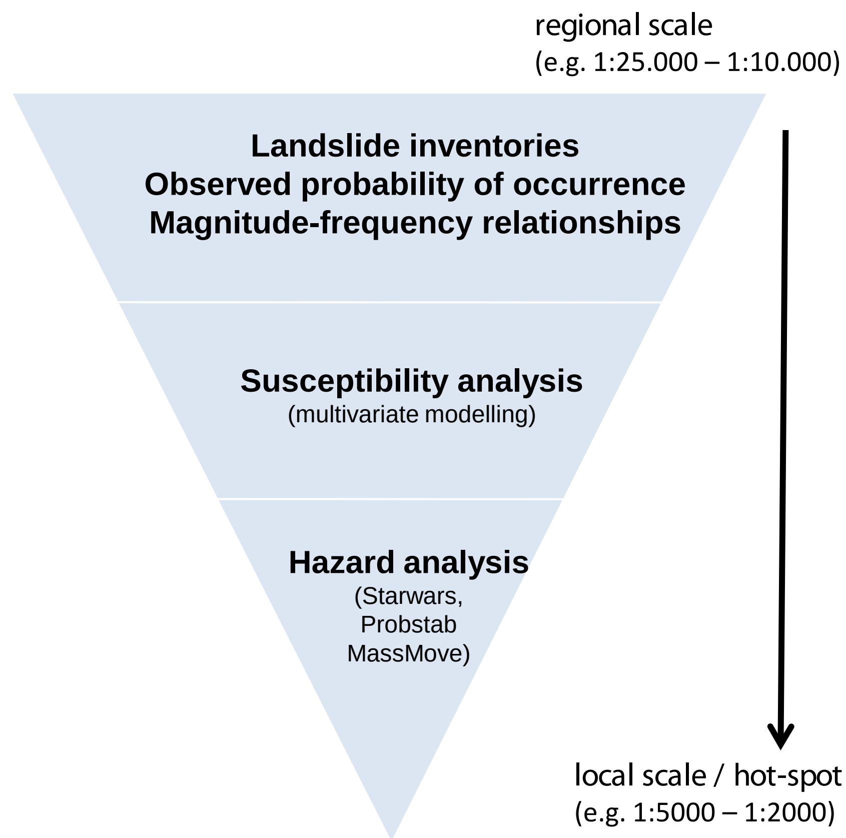
- 4.1 Analysis of analytical vulnerability and cost of landslides
- 4.2 Analysis and mapping of landslide potential consequences and risks
- 4.3 Characterization of the response of the mountain system to hazard and exposure changes

↓

WP5 - Indicators of changes on the vulnerability of mountain slopes

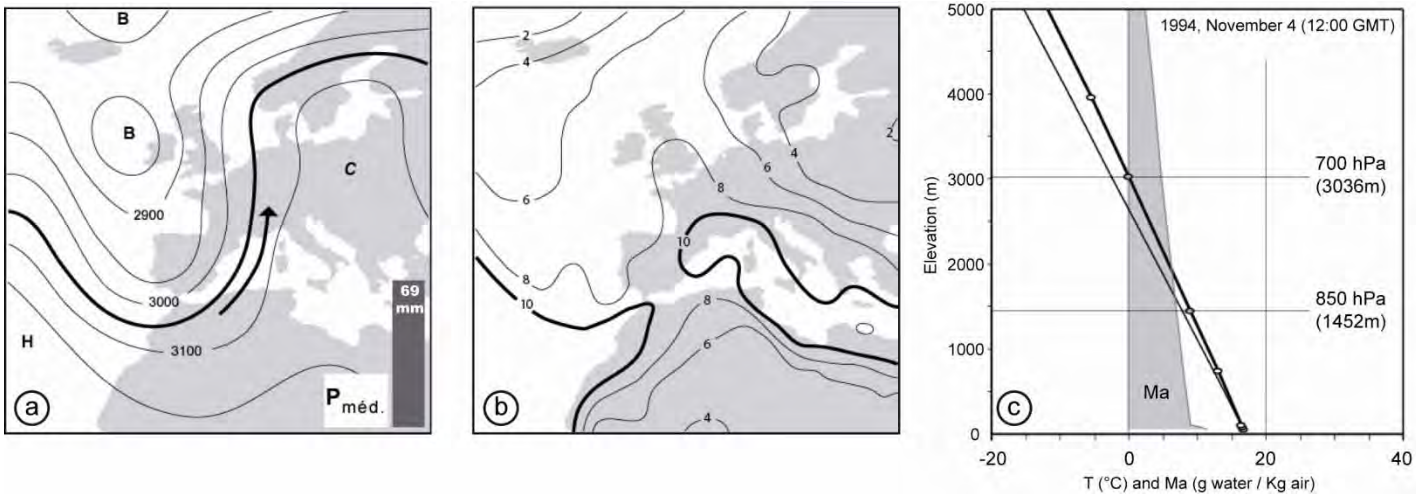
- 5.1 Definition of relevant indicators of changes.
- 5.2 Implementation of a demonstration platform for impact assessment and geovizualisation

Scale of analysis



Landslide triggering factors analysis

➔ Climate classification: analysis of synoptic weather situations for Barcelonnette



Mean characteristics of air-mass type associated to landslides triggering in the Barcelonnette basin for the 1975-2004 period.

Air-mass	Number of landslides	Number of debris flows	Number of muslides	P (mm)	Temperature at Nîmes (°C)			Altitude (m)		Atmospheric moisture (g water / Kg air)			
					ground	850 hPa	700 hPa	850 hPa	700 hPa	ground	850 ha	700 hPa	total
P med	5	3	2	35,5	18,0	8,2	-0,8	1464,6	3043,2	11,1	6,7	4,2	27,4
Pm	7	0	7	17,5	15,1	5,2	-6,9	1320,7	2862,4	7,4	4,4	2,7	16,4
Pm d	8	6	2	20,5	18,9	8,9	-0,8	1487,4	3054,8	8,1	3,9	3,1	19,3
T cont	3	3	0	18,8	31,2	16,7	4,3	1558,7	3182,7	11,5	7,0	5,2	32,6
Tm	5	3	2	26,3	23,0	12,1	4,3	1479,8	3086,5	11,9	6,2	5,2	27,8
T med	2	2	0	31,3	22,8	12,8	3,8	1473,0	3076,0	9,9	7,3	4,8	30,6

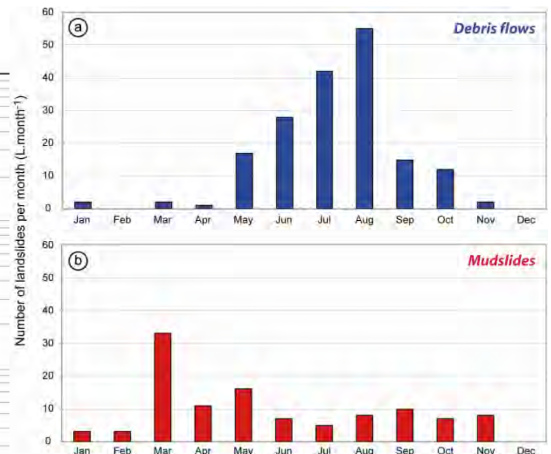
Pm: Polar maritim
Pmd: Polar mediterannean

PROGRESS

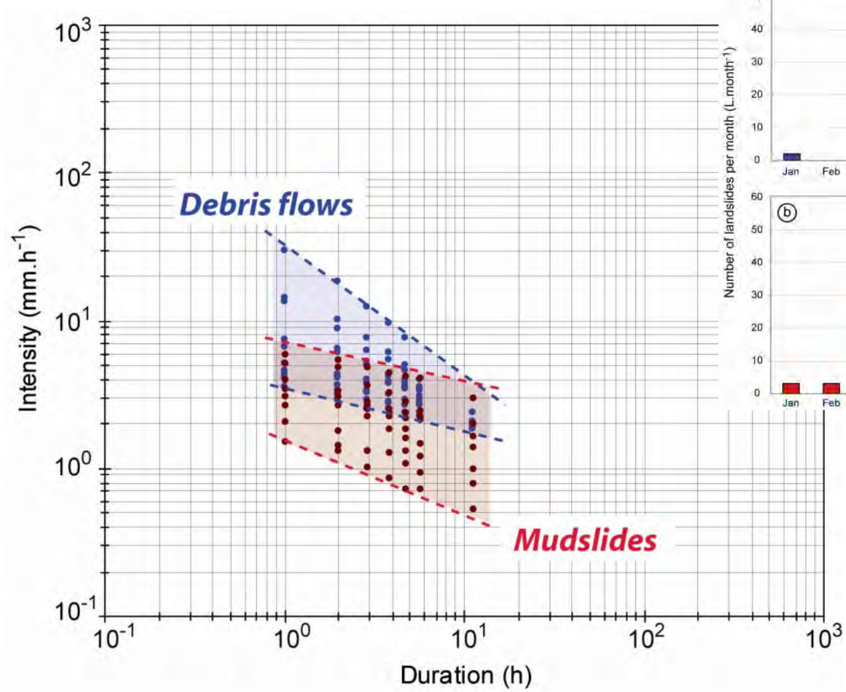
Landslide triggering factors analysis

➔ Rainfall thresholds: intensity-duration approach - Barcelonnette

Calculations based on the rainfall intensity threshold method (Caine, 1980; Montgomery et al., 2000)
The rainfall intensity is based on the total amount of rainfall for a given duration (1h; 2h; 6h; 12h; 24h), which may trigger or reactivate a landslide



Seasonal occurrence of landslides in the Barcelonnette basin



Peak intensity associated to debris flows and mudslides triggering

-> Events characterized by **high rainfall intensity** and **short episode duration** (i.e. mostly the result of localized convective storms) will trigger mostly **debris flows and shallow slides** in relatively permeable soils (e.g. moraines, scree slopes or poorly sorted slope deposits).
-> Long rainfall periods characterized by **low to moderate average and peak rainfall intensity** (i.e. the result of multiple and successive storms during a period of several weeks or months) can trigger/reactivate **shallow and deep-seated landslides** in low permeability soils and rocks (e.g., black marls, clay-rich material).

Remaître & Malet (2012) . Trrggering conditions of landslides in the Barcelonnette Basin (subm. to Geomorphology)

WP2 - Characterization of past and future conditioning factors of landslide risks

- 2.1 Characterization of the past climate and simulation of the future climate and regionalization of meteorological parameters
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PROGRESS

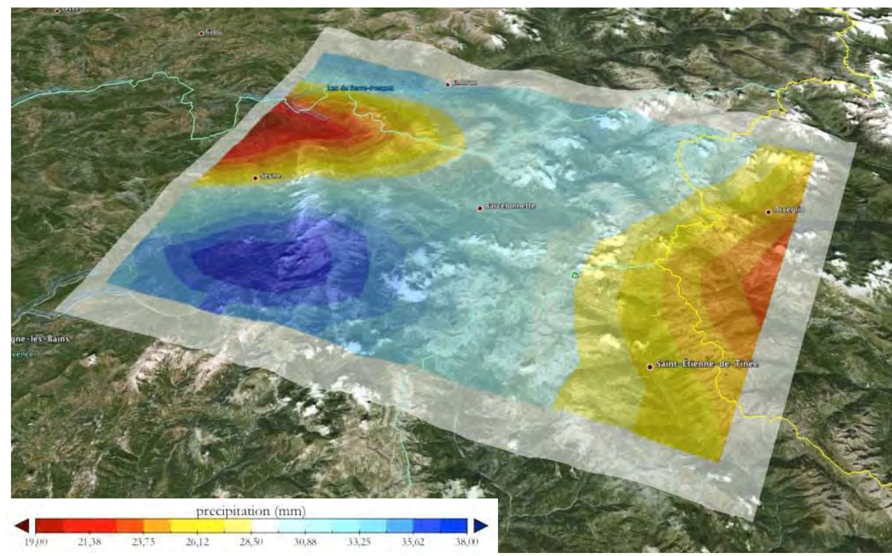
Climate modelling

Dataset: station (observed) data - Barcelonnette

- Network of six meteo stations with daily precipitation data in the Barcelonnette area
- Summer $Pnd_{q0.9}$ computed for each station

Dataset: GCM data - Barcelonnette

- Gridded data, 0.035º resolution (aprox. 4 km)
- Model CMCC-CM[1] (downscaling driven by ECHAM4-REMO GCM/RCM)
- Radiative / emmission scenarios: CMIP5 (control), RCP4.5/RCP8.5 (future)
- Periods: reference (1965–2000) and future (2001–2050)



Example: precipitation field in Barcelonnette of 1st January 1965

[1] Scoccimarro E., S. Gualdi, A. Bellucci, A. Sanna, P.G. Fogli, E. Manzini, M. Vichi, P. Oddo, and A. Navarra, 2011: Effects of Tropical Cyclones on Ocean Heat Transport in a High Resolution Coupled General Circulation Model. *Journal of Climate*, 24, 4368-4384.

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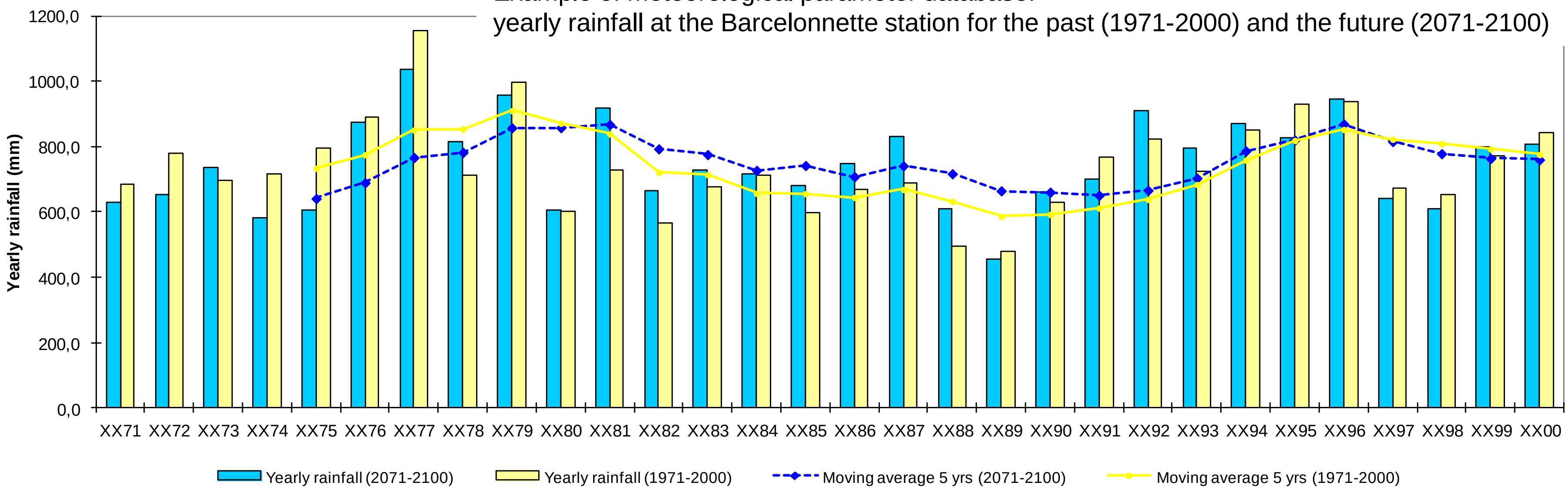
PROGRESS

Climate modelling

Example of meteorological parameter database:
yearly rainfall at the Barcelonnette station for the past (1971-2000) and the future (2071-2100)



➔ Creation of parameter maps relevant for landslide triggering

Parameter 1: 90th percentile of maximum *n*-days summer precipitation (P*n*d$_{q0.9}$, 1 ≤ *n* ≤ 10)

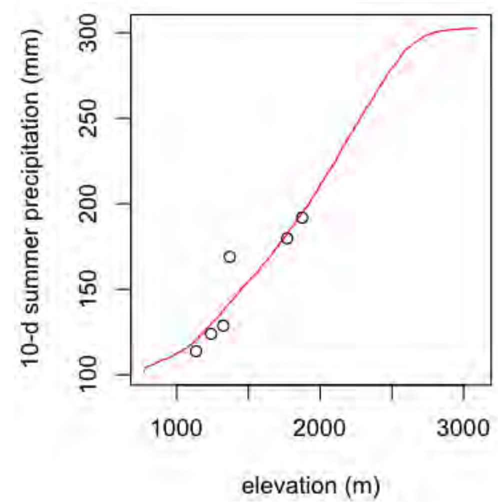
- Most landslides are related to intense summer (JJA) rainfall episodes lasting for several days.
- The 90th percentile is the extreme event associated to a recurrence period of 10 years, which seems appropriate for landslide occurrence.
- Creation of maps of summer P*n*d$_{q0.9}$ precipitation for the actual and future periods.

PROGRESS

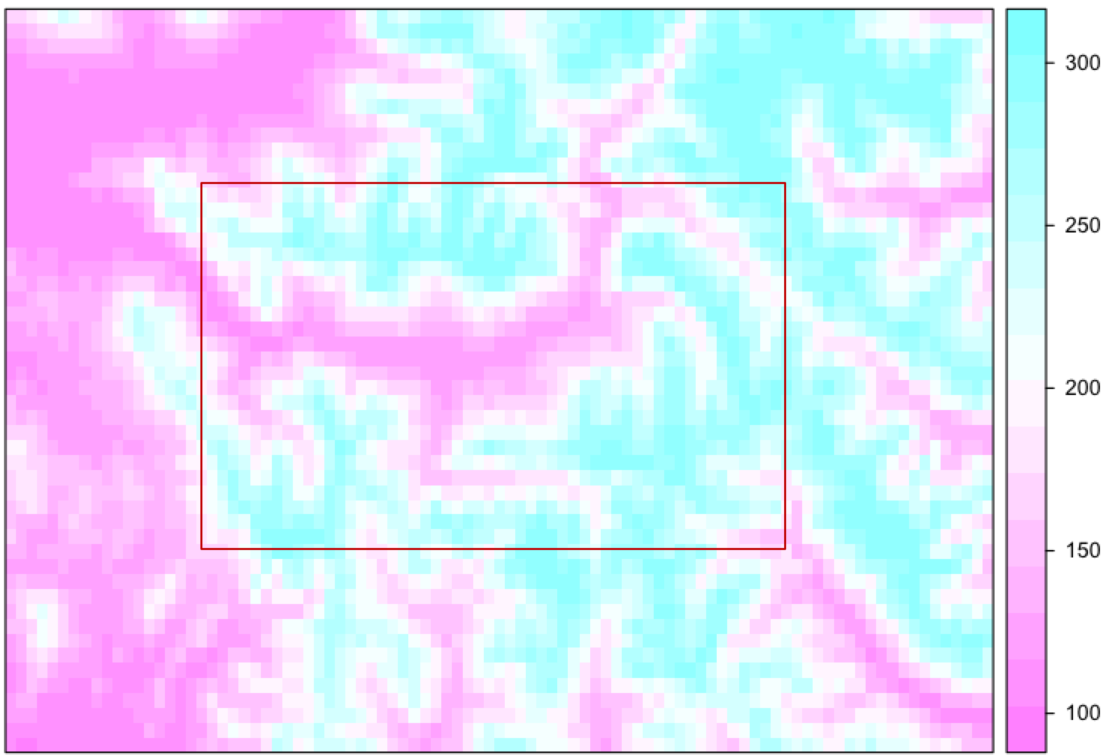
Climate modelling

Map of summer P10d$_{q0.9}$

- Good relationship with elevation (p-value = 0.00977, r^2 = 0.84)
- OLS regression with elevation as covariate.



Regression between summer P10d$_{q0.9}$ and elevation



Map of summer P10d$_{q0.9}$ for the reference period based on station-data

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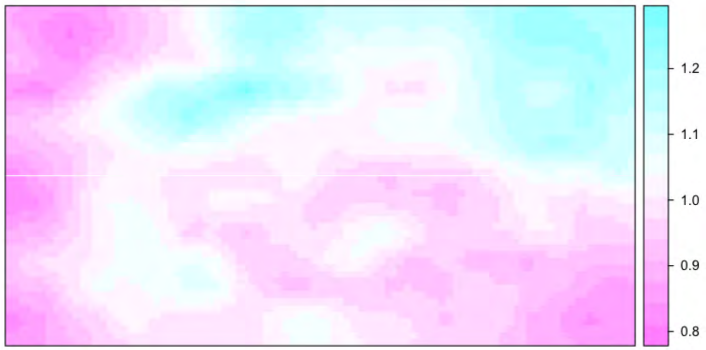
PROGRESS

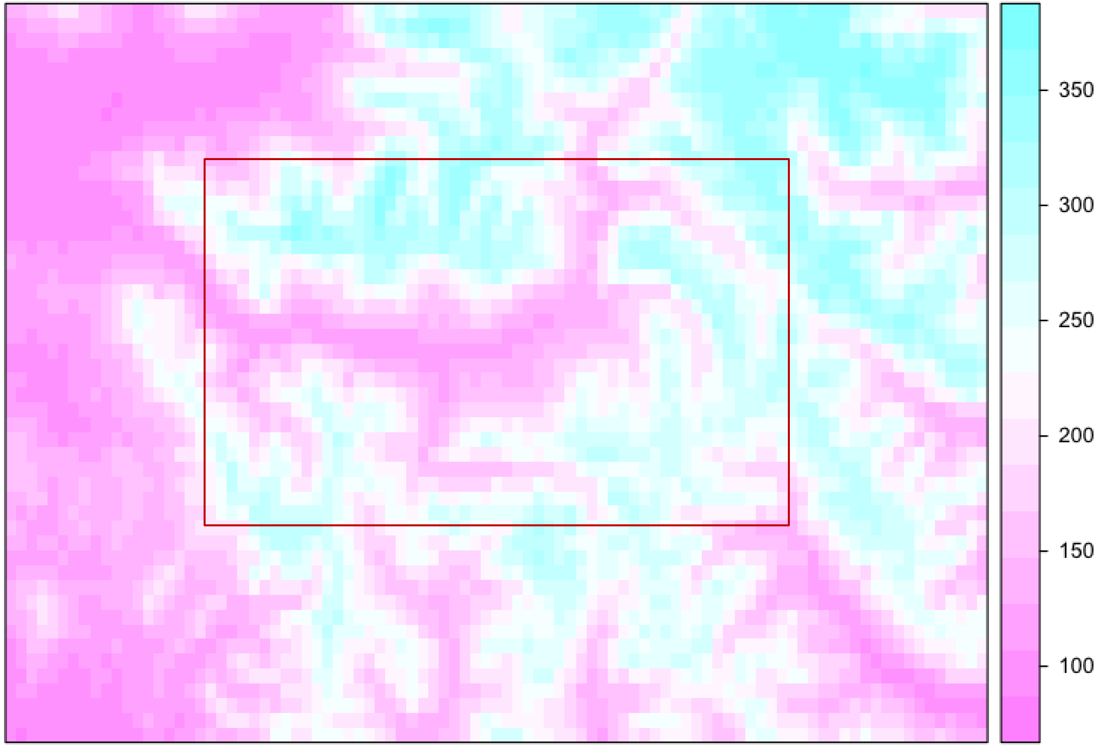
Climate modelling

<u>Extrapolating to future scenario</u>

- Maps of $P10d_{q0.9}$ were computed from GCM data for ref. and future periods.
- Ratio between future and reference periods was used for extrapolating station-based $P10d_{q0.9}$ map to future.



Ratio between future and reference summer $P10d_{q0.9}$ based on GCM data: cyan = increase, magenta = decrease



Map of summer $P10d_{q0.9}$ for the future period based on station-data and GCM projected change

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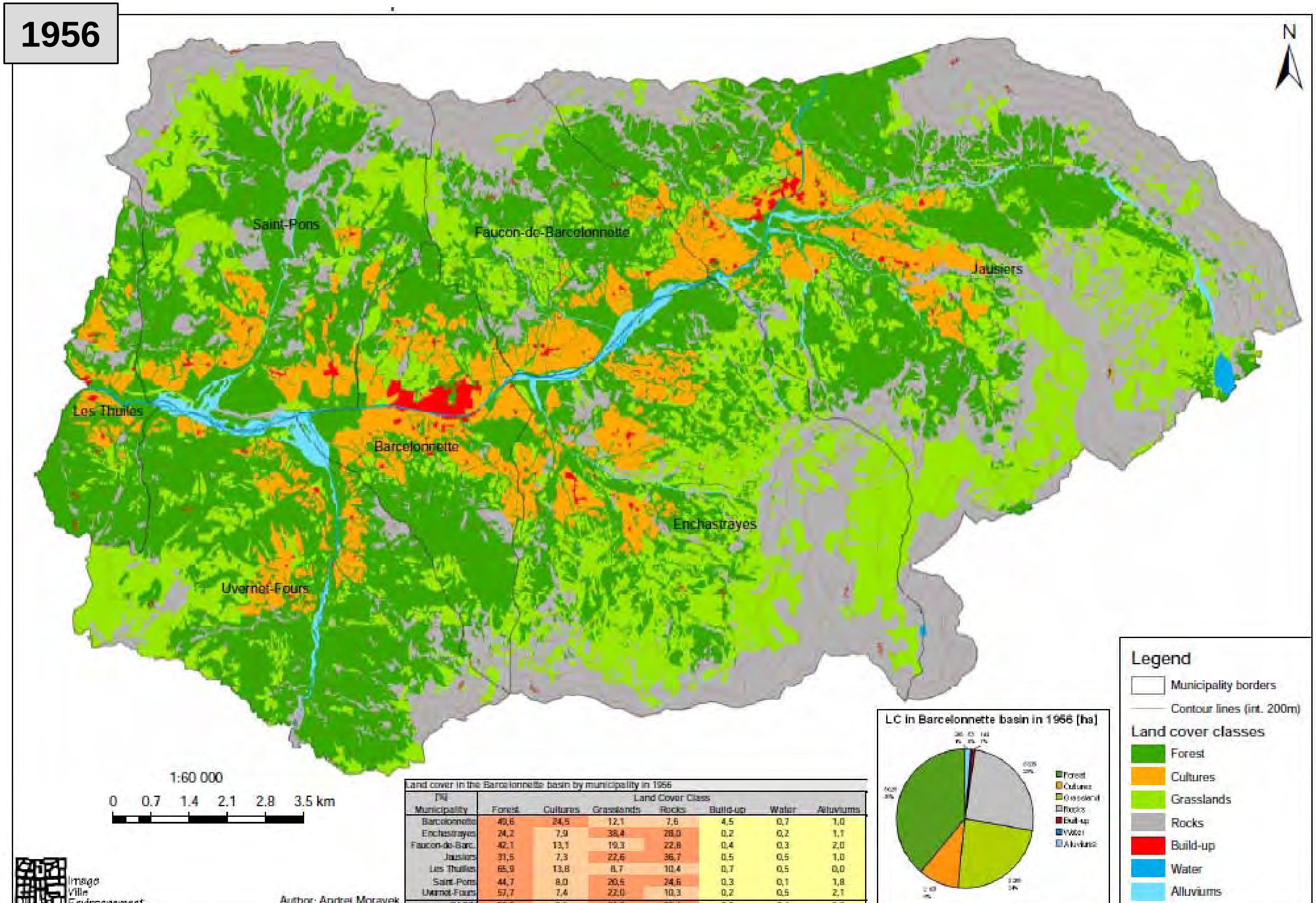
PROGRESS

Landcover modelling

1956



Land cover in the Barcelonnette basin by municipality in 1956

[%] Municipality	Land Cover Class Forest	Cultures	Grasslands	Rocks	Build-up	Water	Alluviums
Barcelonnette	40,6	24,5	12,1	7,6	4,5	0,7	1,0
Enchastrayes	24,2	7,9	38,4	28,0	0,2	0,2	1,1
Faucon-de-Barc.	42,1	13,1	19,3	22,8	0,4	0,3	2,0
Jausiers	31,5	7,3	22,6	36,7	0,5	0,5	1,0
Les Thuiles	65,9	13,8	8,7	10,4	0,7	0,5	0,0
Saint-Pons	44,7	8,0	20,5	24,6	0,3	0,1	1,8
Uvernet-Fours	57,7	7,4	22,0	10,3	0,2	0,5	2,1
BASIN	38,9	9,5	23,8	25,4	0,6	0,4	1,3

Moravek (20111)

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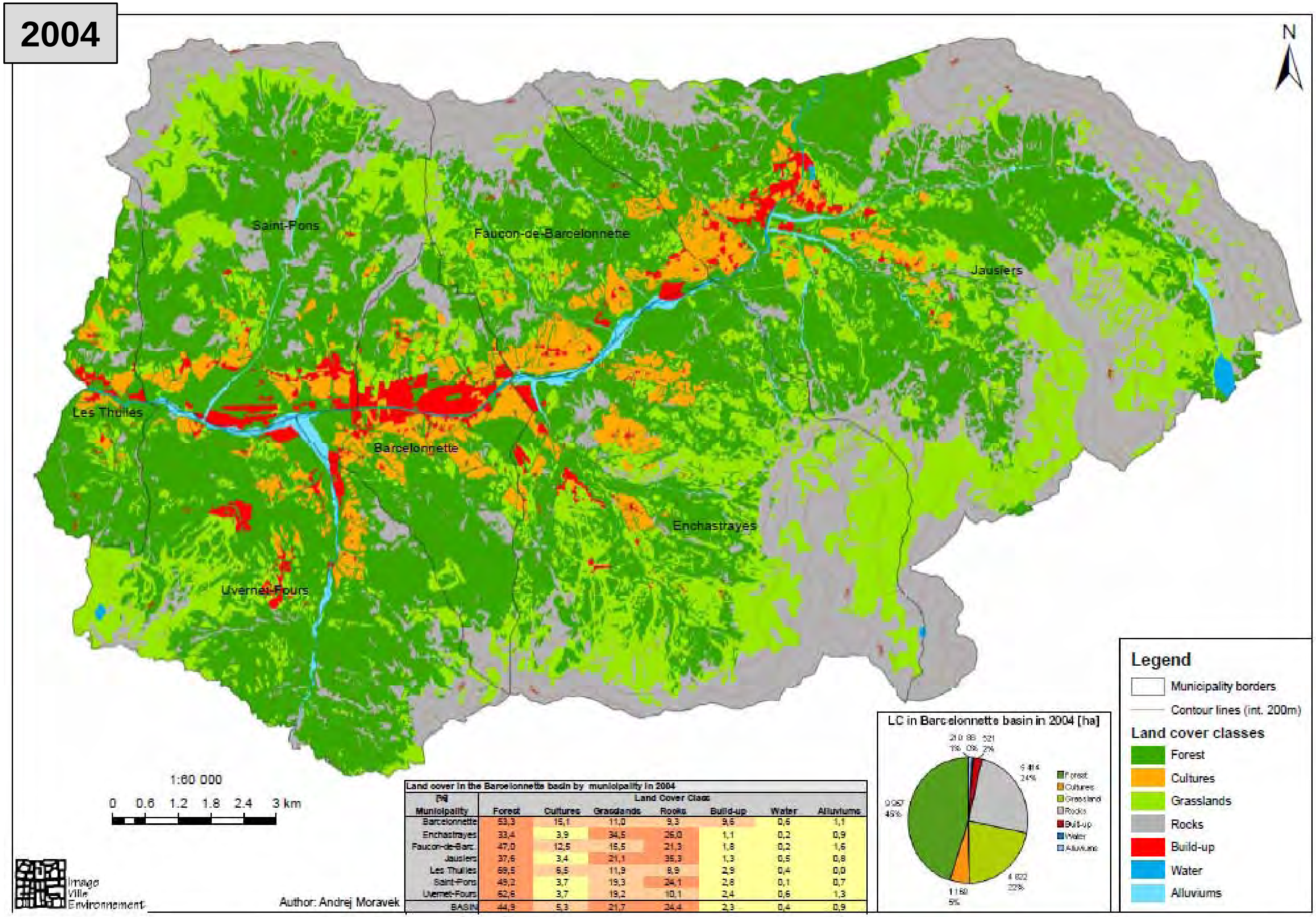
PROGRESS

- Landcover modelling



Land cover in the Barcelonnette basin by municipality in 2004

[%] Municipality	Forest	Cultures	Grasslands	Rocks	Build-up	Water	Alluviums
Barcelonnette	53,3	15,1	11,0	9,3	9,6	0,6	1,1
Enchastrayes	33,4	3,9	34,5	26,0	1,1	0,2	0,9
Faucon-de-Barc.	47,0	12,5	15,5	21,3	1,8	0,2	1,6
Jausiers	37,6	3,4	21,1	35,3	1,3	0,5	0,8
Les Thuiles	69,5	6,5	11,9	8,9	2,9	0,4	0,0
Saint-Pons	49,2	3,7	19,3	24,1	2,8	0,1	0,7
Uvernet-Fours	62,6	3,7	19,2	10,1	2,4	0,6	1,3
BASIN	44,9	5,3	21,7	24,4	2,3	0,4	0,9

Moravek (20111)

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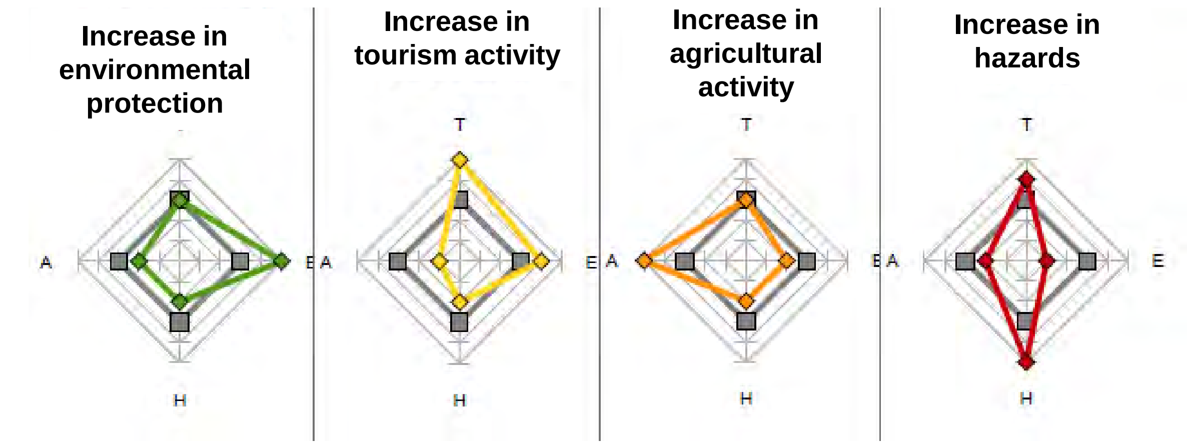
PROGRESS

Landcover modelling: observed frequency of changes

Scenario-based approach (e.g. PRUDENCE)

Driving factors:
A: Agriculture
B: Tourism
C: Environmental awareness
D. Natural hazard



Simplified spider diagram of changing scenarios, and identification of key factors

Moravek (20111)

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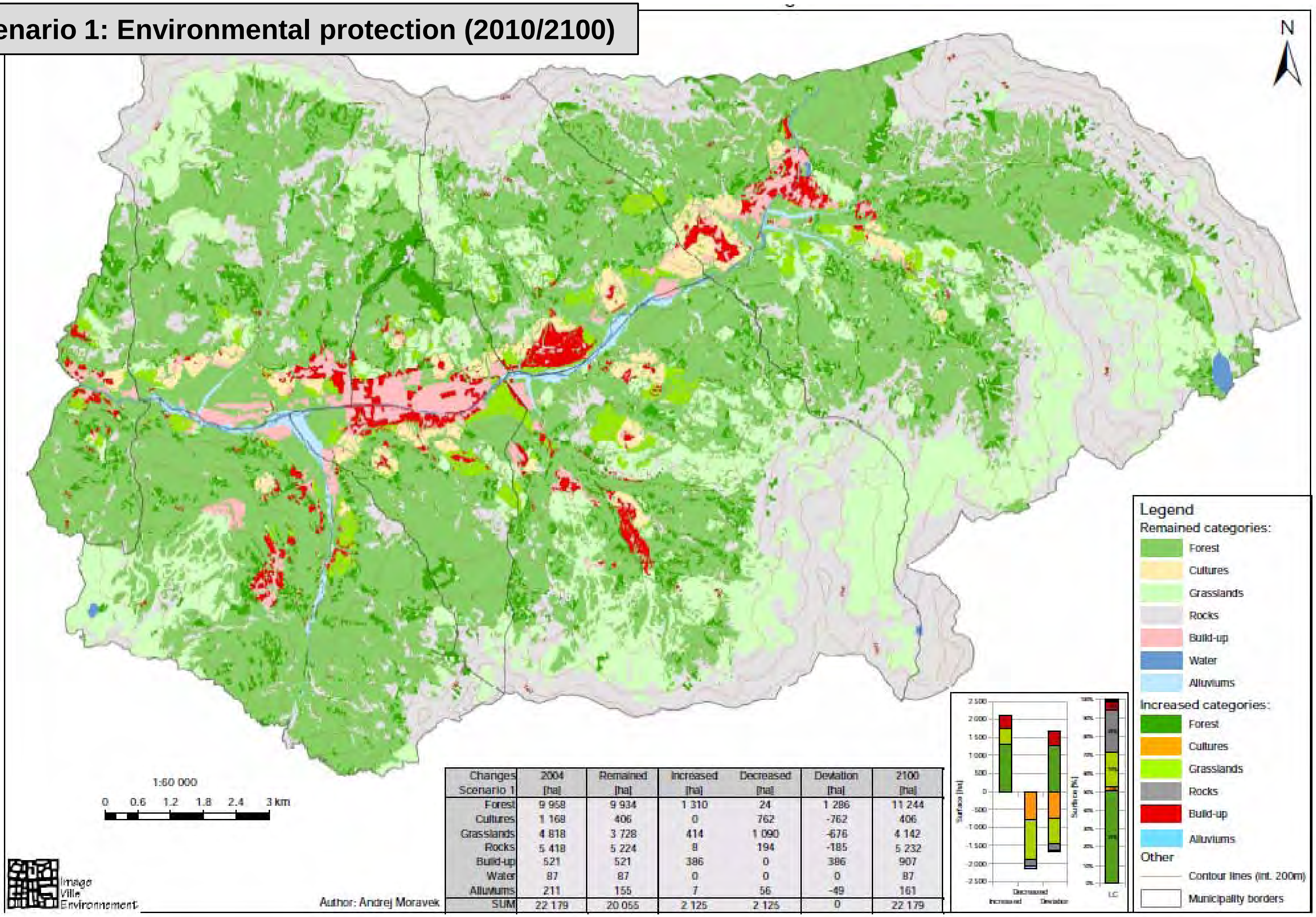
PROGRESS

Landcover modelling

Scenario 1: Environmental protection (2010/2100)



Changes Scenario 1	2004 [ha]	Remained [ha]	Increased [ha]	Decreased [ha]	Deviation [ha]	2100 [ha]
Forest	9 958	9 934	1 310	24	1 286	11 244
Cultures	1 168	406	0	762	-762	406
Grasslands	4 818	3 728	414	1 090	-676	4 142
Rocks	5 418	5 224	8	194	-185	5 232
Build-up	521	521	386	0	386	907
Water	87	87	0	0	0	87
Alluviums	211	155	7	56	-49	161
SUM	22 179	20 055	2 125	2 125	0	22 179

Moravek (20111)

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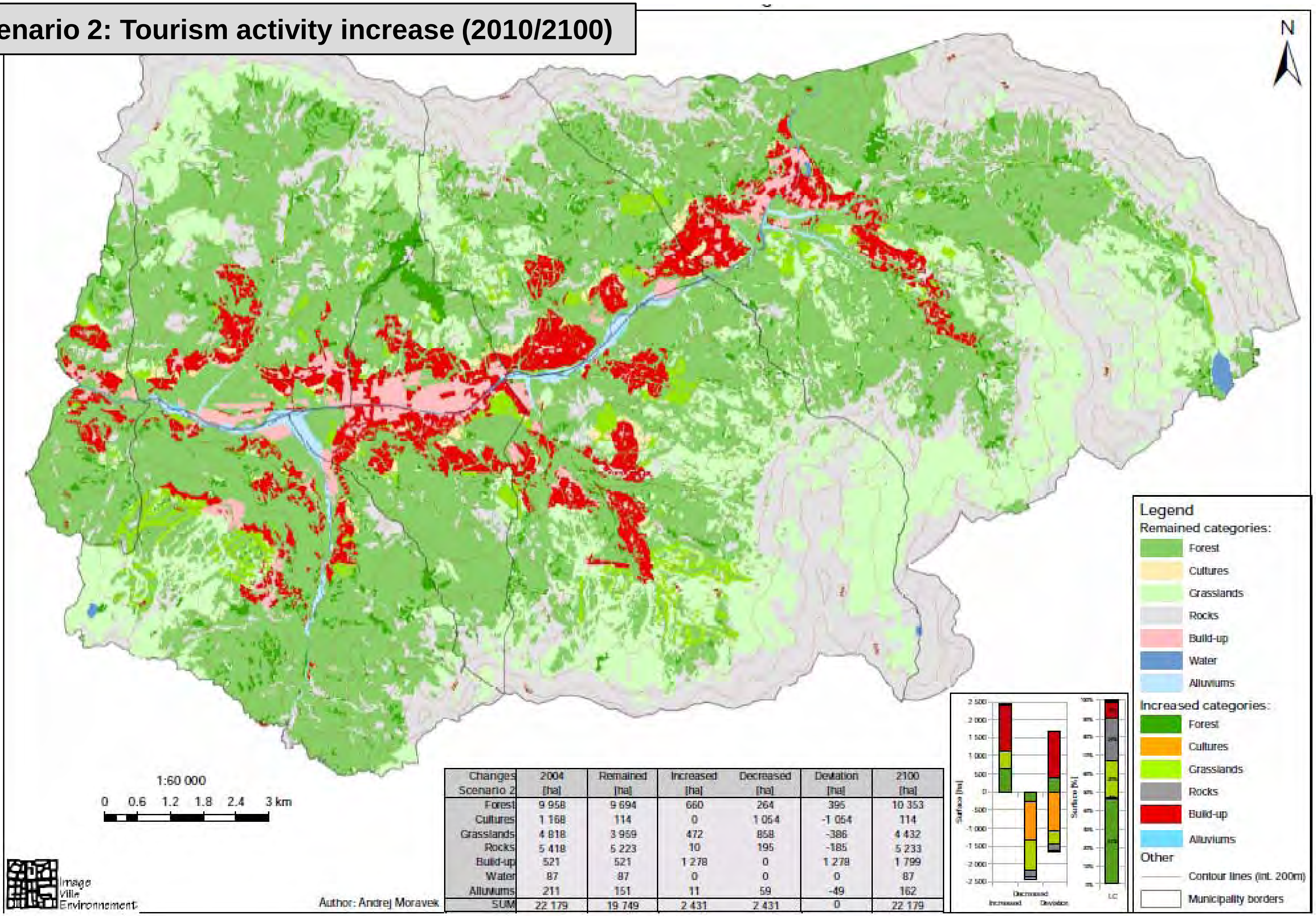
PROGRESS

- Landcover modelling

Scenario 2: Tourism activity increase (2010/2100)



Changes Scenario 2	2004 [ha]	Remained [ha]	Increased [ha]	Decreased [ha]	Deviation [ha]	2100 [ha]
Forest	9 958	9 694	660	264	395	10 353
Cultures	1 168	114	0	1 054	-1 054	114
Grasslands	4 818	3 959	472	858	-386	4 432
Rocks	5 418	5 223	10	195	-185	5 233
Build-up	521	521	1 278	0	1 278	1 799
Water	87	87	0	0	0	87
Alluviums	211	151	11	59	-49	162
SUM	22 179	19 749	2 431	2 431	0	22 179

Moravek (20111)

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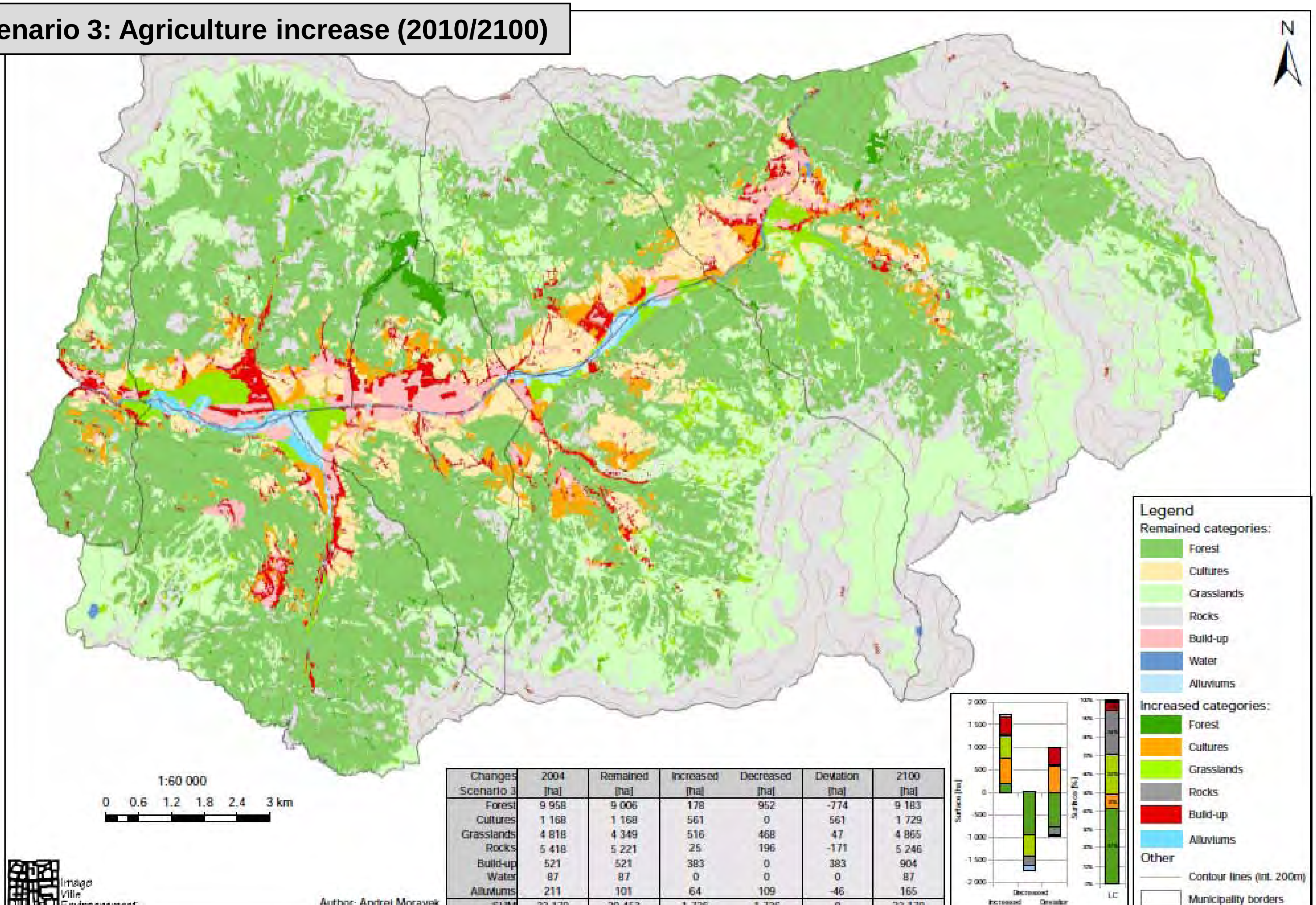
PROGRESS

- Landcover modelling

Scenario 3: Agriculture increase (2010/2100)



Changes Scenario 3	2004 [ha]	Remained [ha]	Increased [ha]	Decreased [ha]	Deviation [ha]	2100 [ha]
Forest	9 958	9 006	178	952	-774	9 183
Cultures	1 168	1 168	561	0	561	1 729
Grasslands	4 818	4 349	516	468	47	4 865
Rocks	5 418	5 221	25	196	-171	5 246
Build-up	521	521	383	0	383	904
Water	87	87	0	0	0	87
Alluviums	211	101	64	109	-46	165
SUM	22 179	20 453	1 726	1 726	0	22 179

Moravek (20111)

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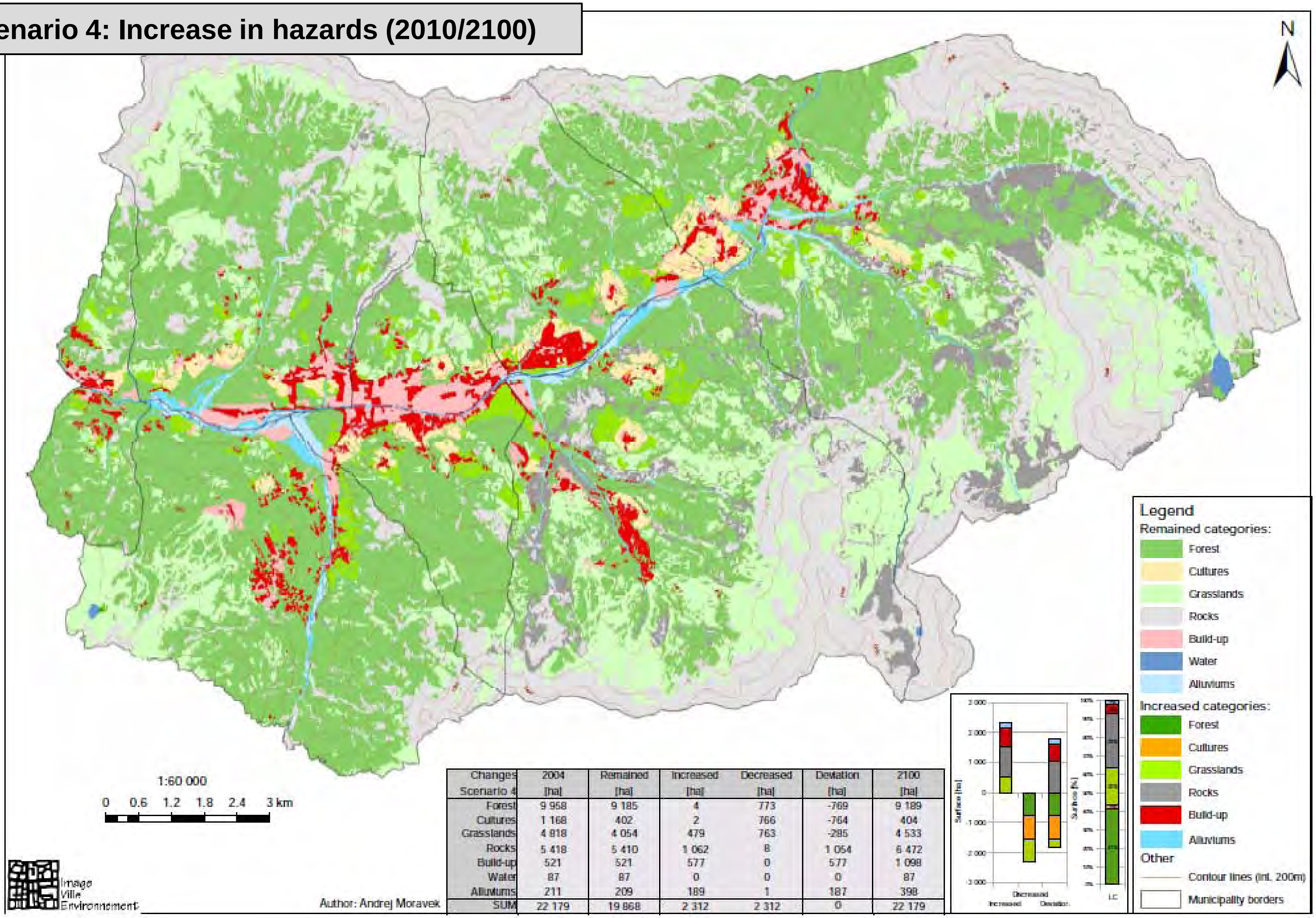
PROGRESS

- Landcover modelling

Scenario 4: Increase in hazards (2010/2100)



Changes Scenario 4	2004 [ha]	Remained [ha]	Increased [ha]	Decreased [ha]	Deviation [ha]	2100 [ha]
Forest	9 958	9 185	4	773	-769	9 189
Cultures	1 168	402	2	766	-764	404
Grasslands	4 818	4 054	479	763	-285	4 533
Rocks	5 418	5 410	1 062	8	1 054	6 472
Build-up	521	521	577	0	577	1 098
Water	87	87	0	0	0	87
Alluviums	211	209	189	1	187	398
SUM	22 179	19 868	2 312	2 312	0	22 179

Moravek (20111)

PROGRESS

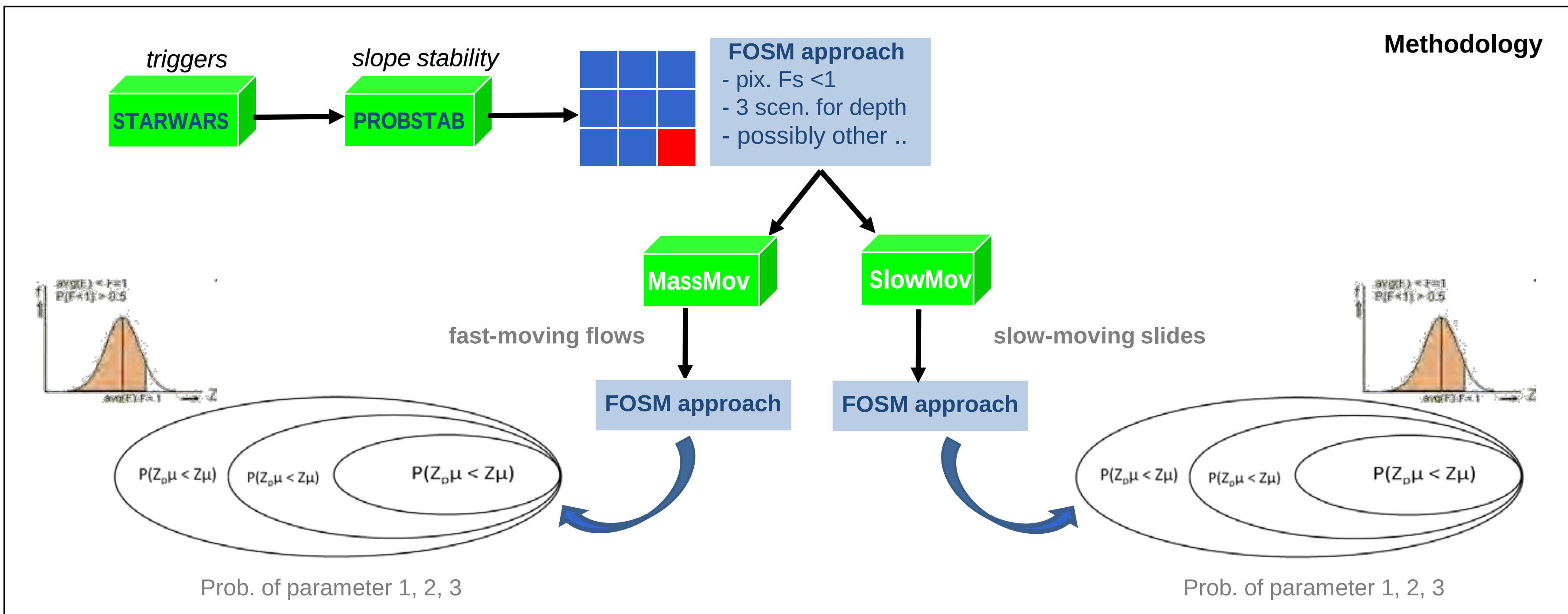
Susceptibility modelling

Integration of climate parameter maps (actual, future) and landcover maps (actual, future) in a multivariate model ➔ e.g. MSc thesis – Barcelonnette : *A. Schmidt (started in February 2012)*

Hazard modelling

Development of processing chain of process-based models:
Starwars – ProbStab – MassMove/SlowMove

(van Beek, 2002; Malet et al. 2005; Begueria et al., 2009; Spickermann et al., 2012)



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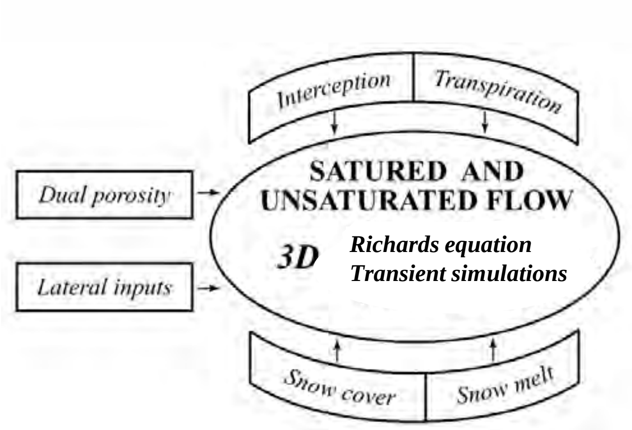
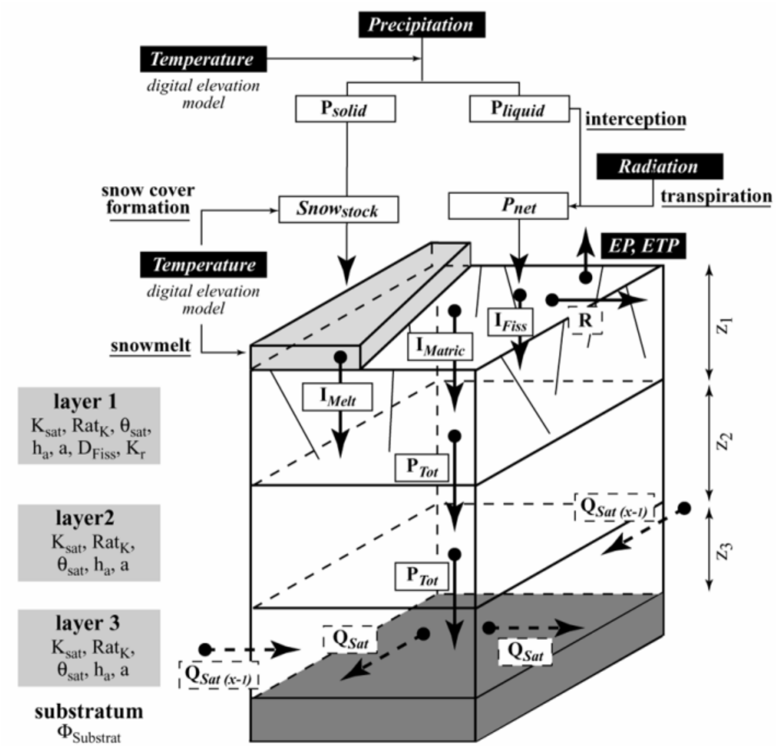
PROGRESS

- Starwars: slope hydrology (van Beek, 2002; Malet et al., 2005, … and others)





▪ Core model

- Generalized Darcy's law for saturated & unsaturated medium

$$q_i = -k_{rw} \frac{\rho_w * g}{\mu_w} k_i \nabla(\Psi + z)_p$$

- Continuity equation

$$\frac{\delta(n\rho)}{\delta t} = \rho \frac{\delta n}{\delta t} + n \frac{\delta \rho}{\delta t}$$

- Richards diffusivity equation

$$\frac{\delta}{\delta x}\left(k(\omega)\frac{\delta h}{\delta x}\right) + \frac{\delta}{\delta y}\left(k(\omega)\frac{\delta h}{\delta y}\right) + \frac{\delta}{\delta z}\left(k(\omega)\frac{\delta h}{\delta z}\right) + W = \frac{\delta \omega}{\delta t}$$

▪ Additional capabilities

- dual porosity (fissure flow, matrix flow)
- lateral inputs: $Q_{lat} = f(t)$
- snow cover formation and snow melting
- topographic control: altitude on rainfall temperature
  slope gradient on radiation
- vegetation (canopy interception, transpiration)

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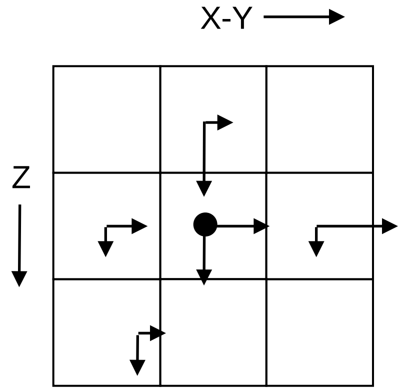


1 timestep

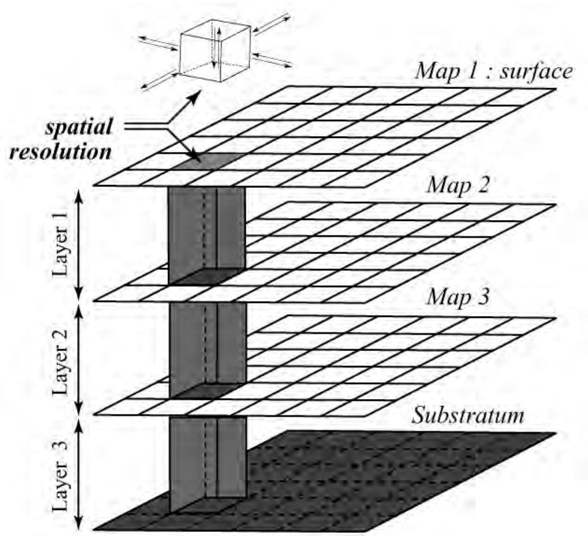
Lax partial difference scheme (explicit centered scheme, 2nd-order accuracy in space forward 1st -order accuracy in time)

▪ Numerical scheme

$$h^{t+1}_{x,y} = \frac{1}{4}\left(h^{t}_{x-1,y} + h^{t}_{x+1,y} + h^{t}_{x,y-1} + h^{t}_{x,y+1}\right) - \frac{\Delta t}{\Delta x}\left(hu^{t}_{x+1,y} - hu^{t}_{x-1,y}\right) - \frac{\Delta t}{\Delta y}\left(hv^{t}_{x,y+1} - hv^{t}_{x,y-1}\right)$$

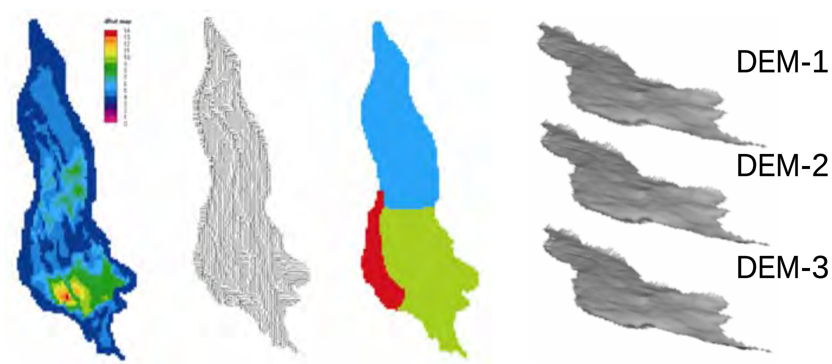
▪ Distributed 2.5-D representation (pseudo 3-D)

- cell calculation (center of the cell)
- geometry -> DEMs of layer interface



▪ Spatially explicit input parameters

- adaptive spatial resolution (0.5 m – 100m)
- adaptive temporal resolution (minutes, hours, days)
- landuse-dependant parameters (value distribution)



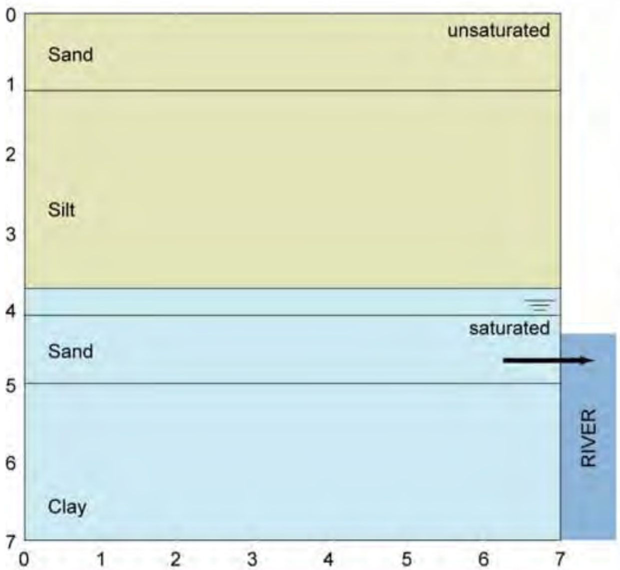
WP3 - Integrated landslide hazard analysis

- 3.1 Analysis of landslide susceptibility
- 3.2 Analysis of landslide hazard through hydrology-slope stability modelling
- 3.3 Forecasting trends in landslide activity and hazards for the future

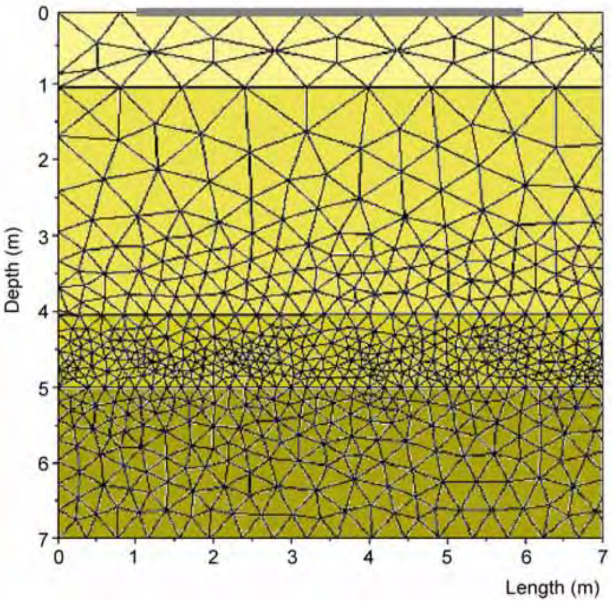
PROGRESS

- Starwars: slope hydrology (van Beek, 2002; Malet et al., 2005, … and others)

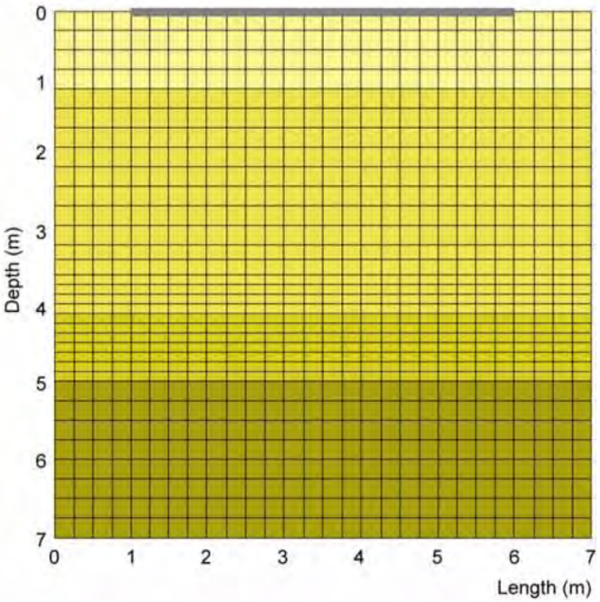
- **Benchmarking / model performance: Starwars vs. FE model HYDRUS**



HYDRUS-2D



PcRaster STARWARS-2D



Finite element mesh:
- 10074 triangular elements
- 5072 nodes
- complex Taylor-Galerkin scheme

GIS-based cells:
- 168 square cells
- 56 rectangular cells

Example: 1 model run of 600 timesteps (1 timestep = 1hour)

Computation time (Pentium IV 2.7 Ghz): **25 min** **8 min**

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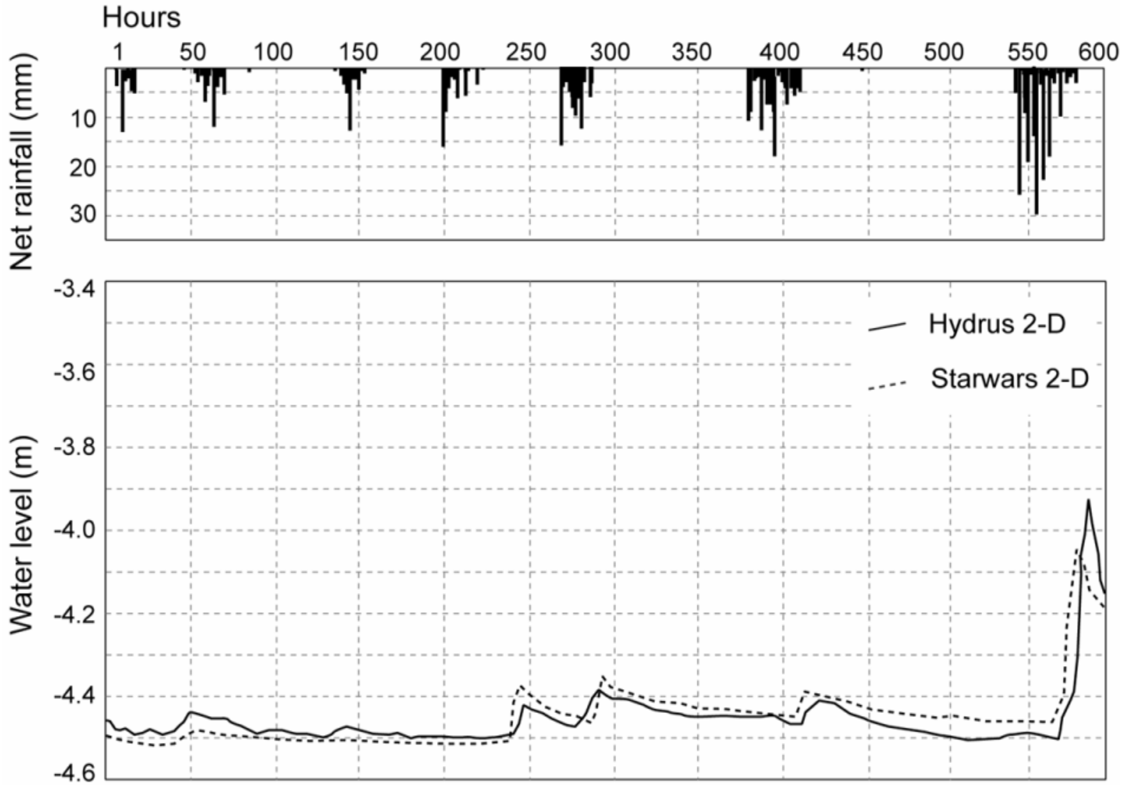

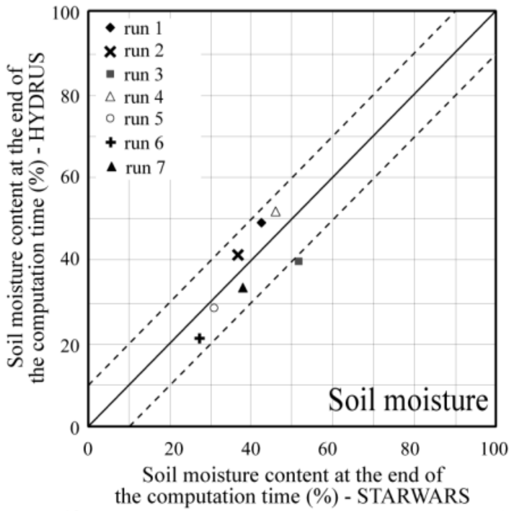

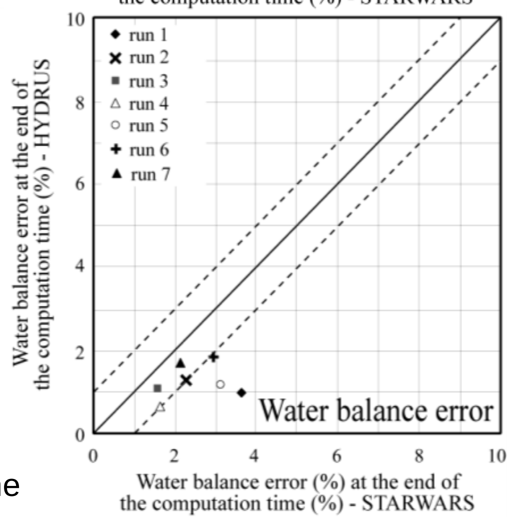

Difference in modelled storage and mass balance error at the end of the computation time

WP3 - Integrated landslide hazard analysis

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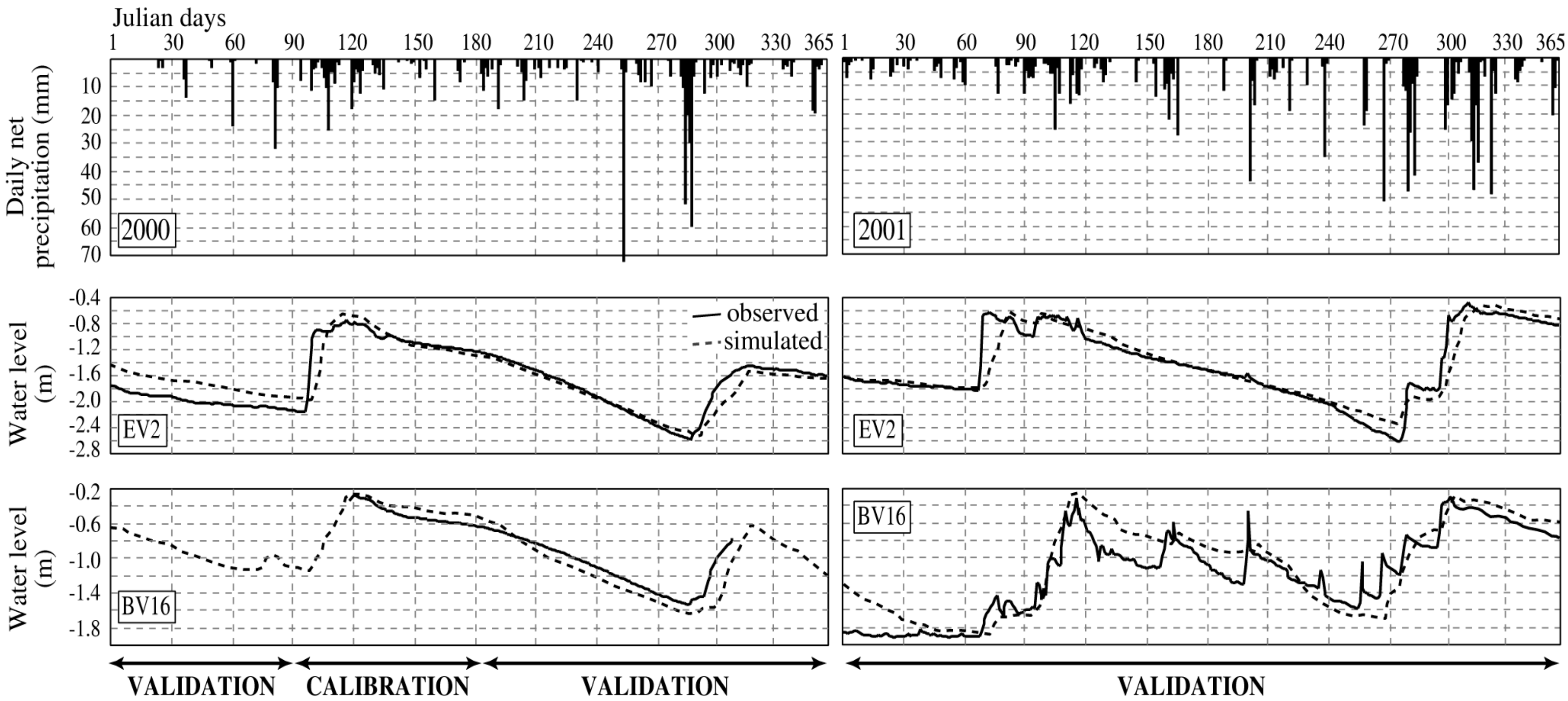
PROGRESS

- Starwars: slope hydrology (van Beek, 2002; Malet et al., 2005, … and others)

▪ Application to real data: Super-Sauze landslide

- Initial conditions: moisture content and groundwater level = 25 years of time series
- Parameter optimisation (Marquardt-Levenberg algorithm, Pest software): mean observed data +- 20%
- calibration on 2 piezometers with continuous recording + 10 piezometers with punctual measurements



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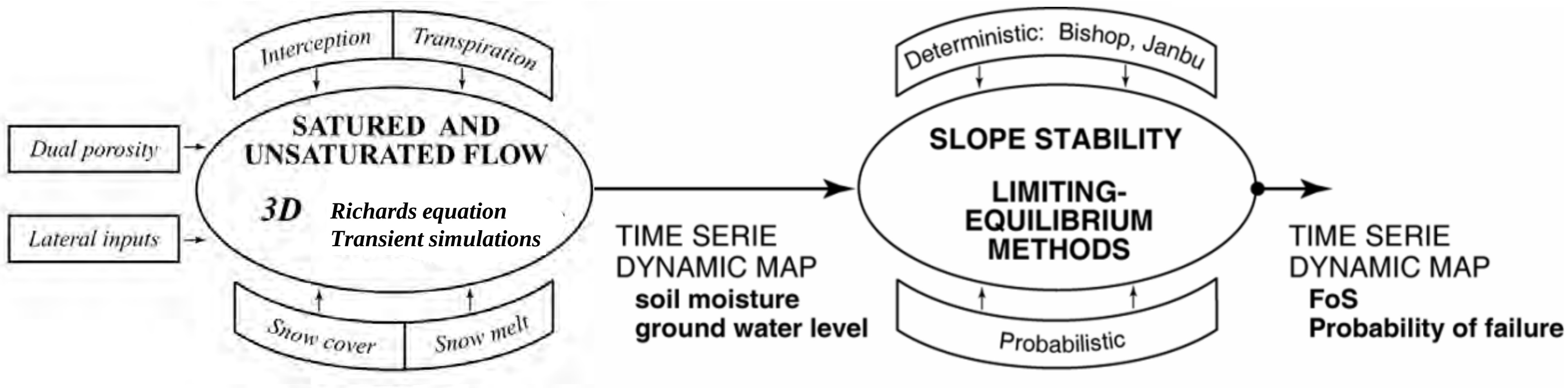
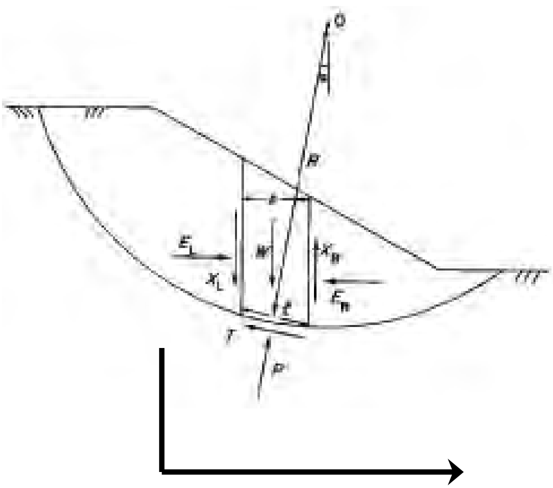
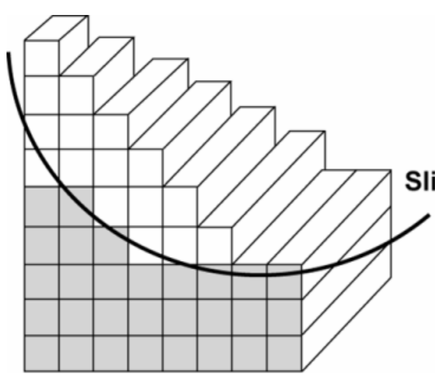
PROGRESS

- ProbStab: slope stability (van Beek, 2002; Malet, 2003, Malet et al., 2007)



- Mohr-Coulomb constitutive equation (c- and ϕ- parameters)
- Limit equilibrium approach
- Bishop or Janbu solution
- Circular or non circular slip search (minimum FOS) through a grid search specification utility function





➔ Volume of released material
➔ Probabilities of release

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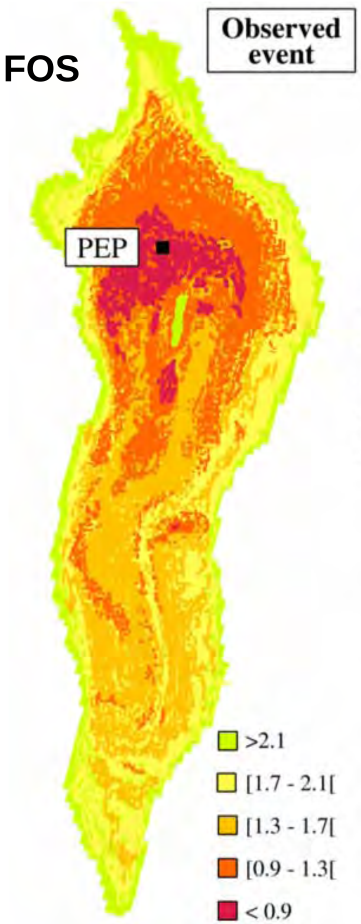
PROGRESS

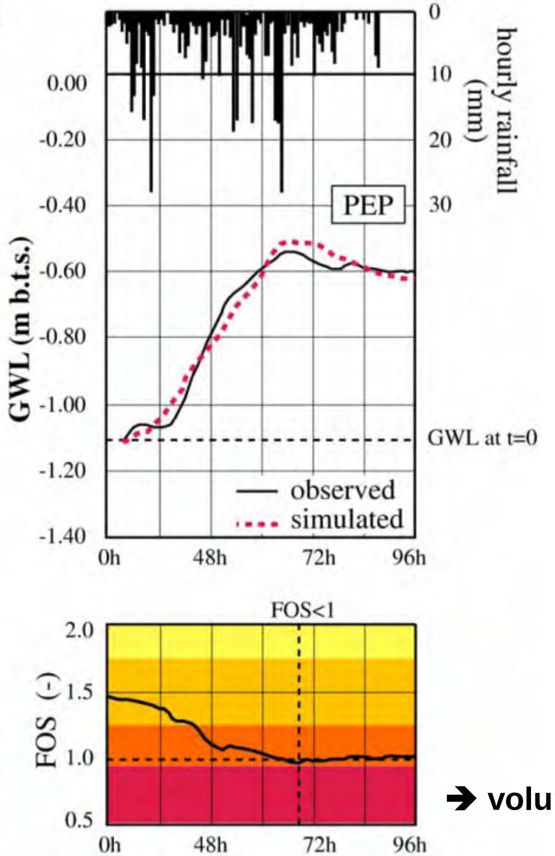
- ProbStab: slope stability (van Beek, 2002; Malet, 2003, Malet et al., 2007)

▪ Application to real data: Super-Sauze landslide; main failure in May 1999

• **FOS**

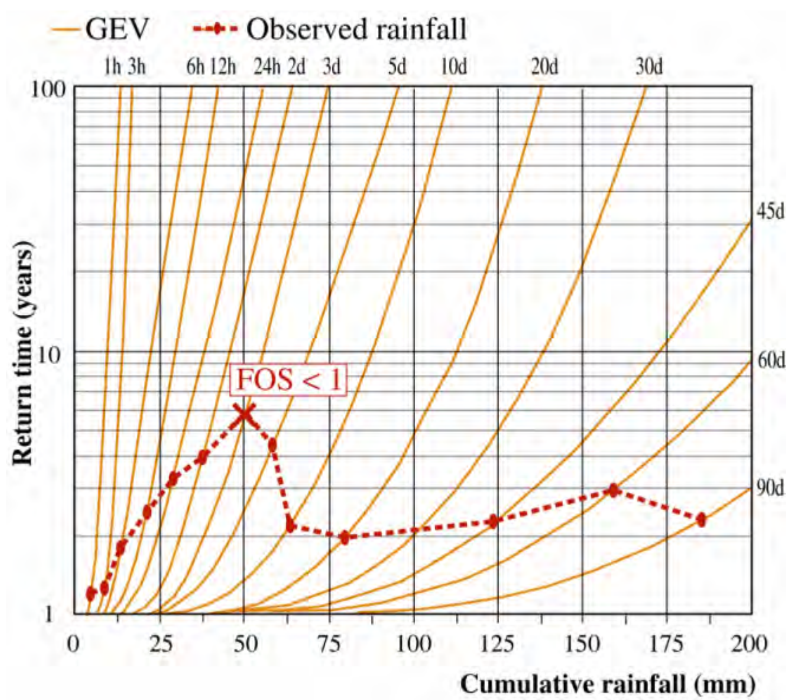


• **Observed/simulated GWLs**



➔ **volumes**

• **GEV & observed event**



• Rainfall: 50 mm in 70h
• 6-years return period

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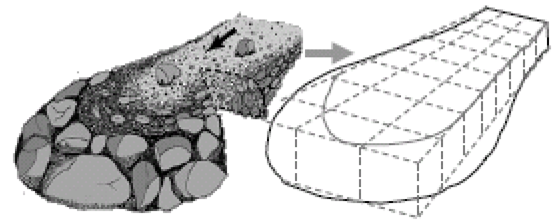
PROGRESS

MassMov: mass flow kinematics (Begueria et al., 2009)

Assumptions:

- Saint-Venant equation (shallow water approximation)
- One-phase flow
- Depth-integrated solution



Mass and momentum conservation:

flow thickness; flow velocity x-; flow velocity y-

$$\frac{\partial h}{\partial t} + c_x \frac{\partial (hu)}{\partial x} + c_y \frac{\partial (hv)}{\partial y} = 0$$

convective acceleration; pressure acceleration; local acceleration

$$\frac{\partial u}{\partial t} + c_x u \frac{\partial u}{\partial x} + c_y v \frac{\partial u}{\partial y} + c_x k \frac{\partial (c_x g h)}{\partial x} = -c_x g \left(S_x + q_x S_f\right)$$

slope; friction

$$\frac{\partial v}{\partial t} + c_y v \frac{\partial v}{\partial x} + c_x u \frac{\partial v}{\partial y} + c_y k \frac{\partial (c_y g h)}{\partial y} = -c_y g \left(S_y + q_y S_f\right)$$

Rheology:

- Viscous fluid (Bingham, Couloimb-viscous, Hershel-Bulkley)
- Frictional (pure Coulomb, Voellmy)

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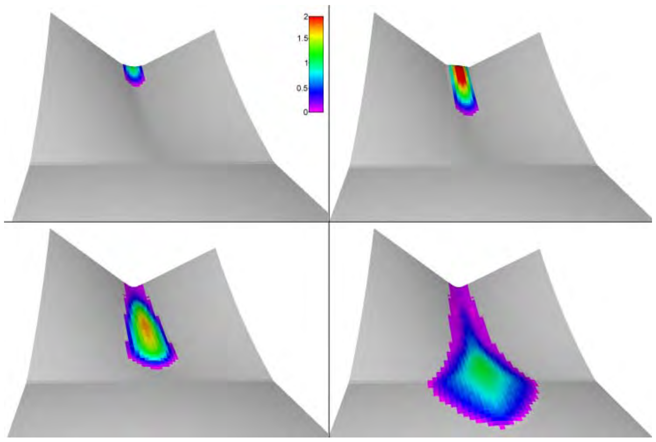
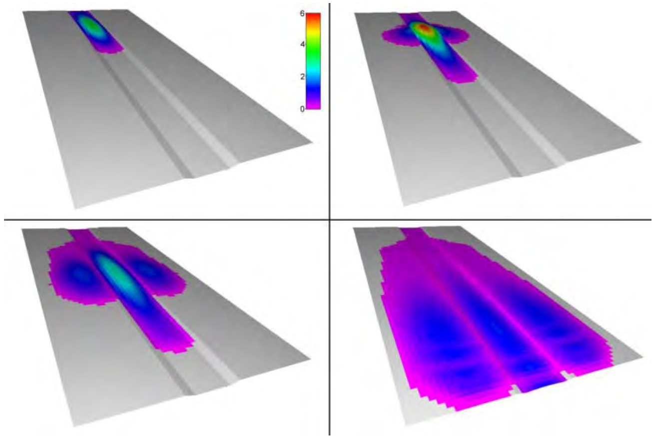
PROGRESS

MassMov: mass flow kinematics (Begueria et al., 2009)

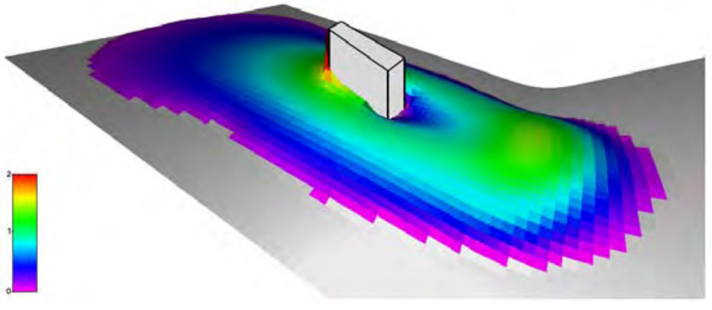
- **Application to synthetic cases**



Simulation of the propagation of a slurry wave over an idealized fan topography. An inlet area of five pixels was defined at the upper part of the fan, which represents the conextion with an upstream torrent. A constant input rate of 80 cm of mud flow was applied at the inlet during the first 20 seconds. The panels show the thickness of the flow at times t = 5, 20, 35 and 50 s, in m.



Propagation of a mud flow slurry on a channel. The input hydrograph had a triangular shape, raising from 0.65 m to 0.85 m at 25 seconds and then falling to 0 m at 30 seconds. The panels show the flow thickness at times t = 15, 30, 45 and 60 seconds.



Simulation of the interaction between a mudflow and a rigid obstacle over a slope. Color scale: flow depth (m).

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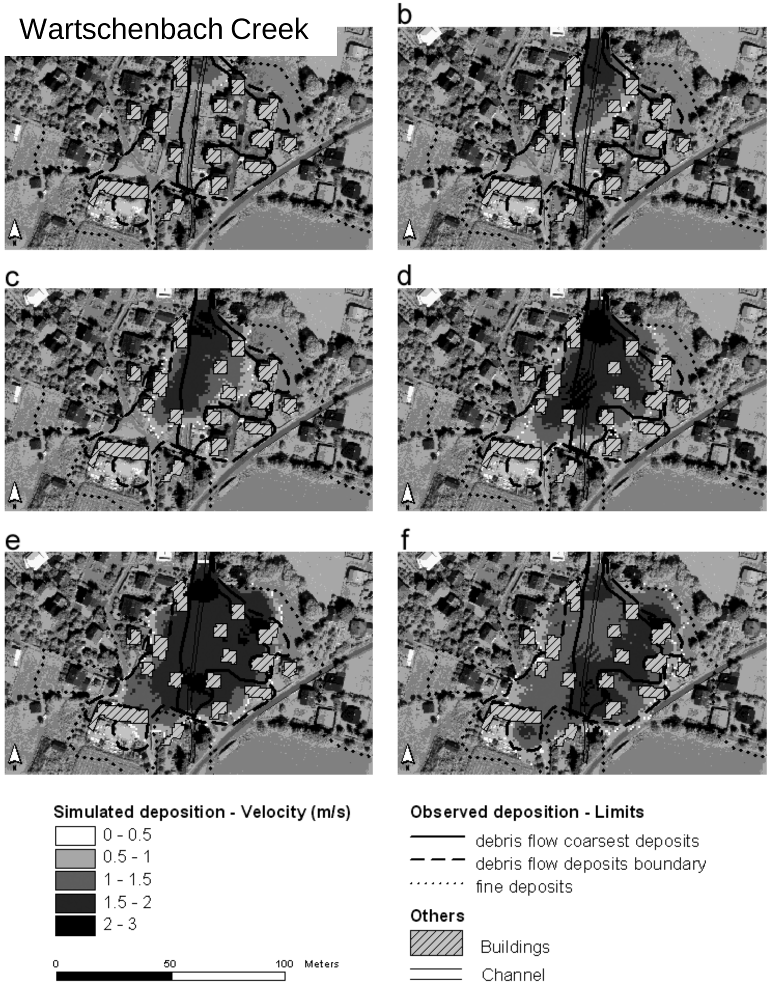
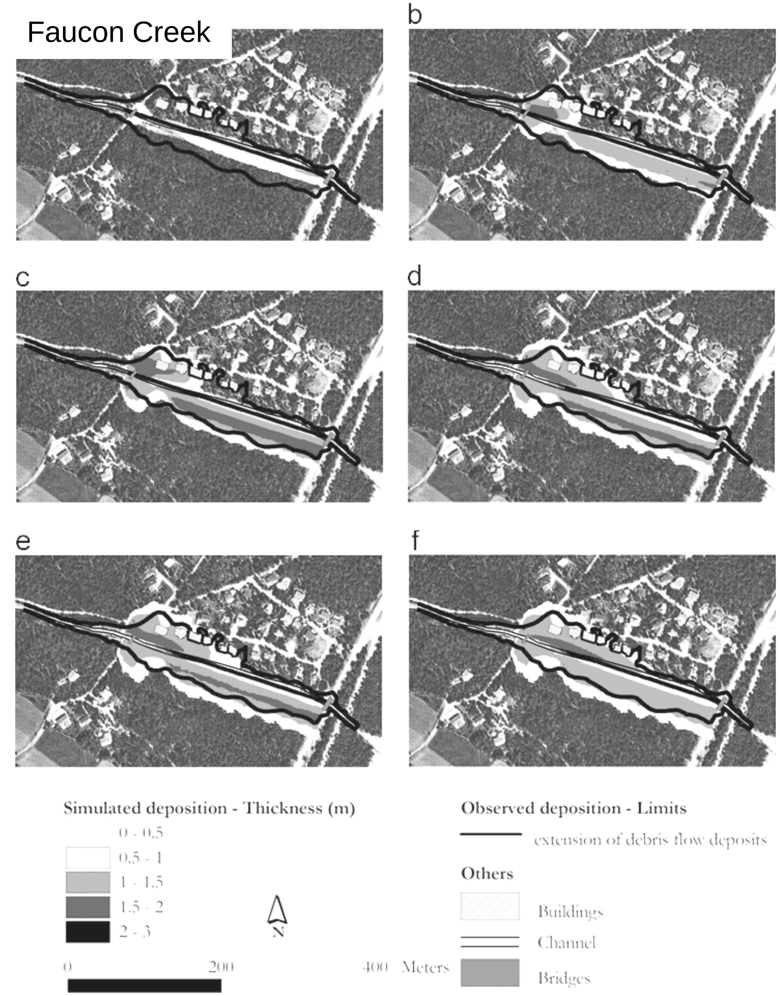
PROGRESS

MassMov: mass flow kinematics (Begueria et al., 2009)

- **Application to real data**





WP3 - Integrated landslide hazard analysis

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PROGRESS

- MassMov: mass flow kinematics

▪ **Further development of the code and new implementation (Sanchez et al., in prep).**

- closer to reality: advanced numerical solution with minimum diffusion

- faster model runs (C++ implementation)

- several interfacing options (PCRaster, GRASS, R, Python…)

- freedom to choose the license for distributing the code (was not possible with the previous implementation of MassMov2D in PCRaster)

- optimized for stochastic modelling (e.g. multi model-runs)

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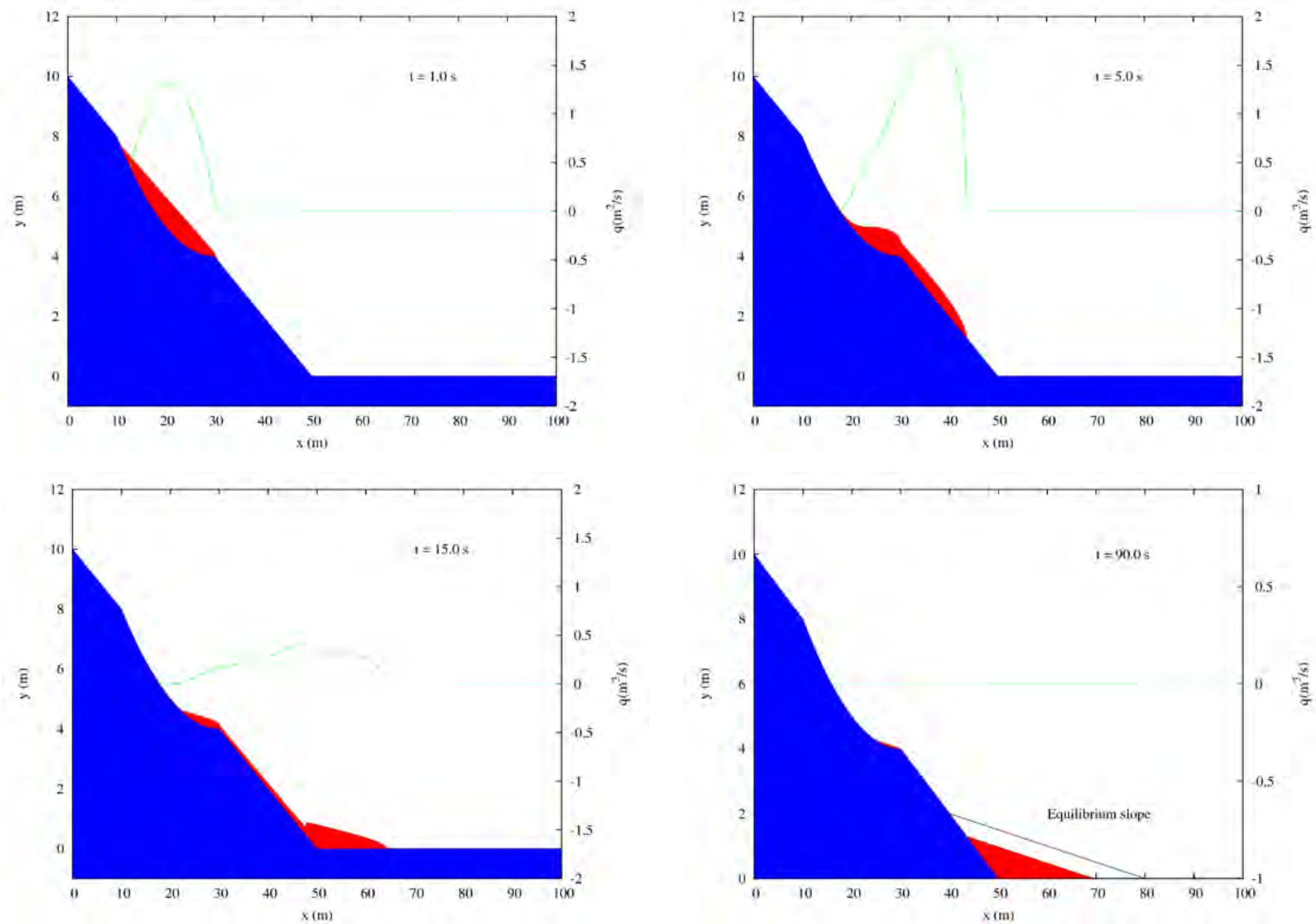
PROGRESS

MassMov: mass flow kinematics

▪ Test on a synthetic case



Example of 1D simulation: basal topography (blue), debris flow depth (red, left axis) and *q* (green, right axis). Initial state, intermediate states (t = 5, 15 s) and equilibrium (final) state.

PROGRESS

- Slow-Move: mass sliding (Spickermann et al., 2012)

Assumptions:
- Limit equilibrium theory and Mohr-Coulomb fialure criterion
- Sliding localized at shear band; possibilty of varying the vertical profile of velocity
- Up to now: fully water saturated mixture (e.g. one phase flow)

Mass and momentum conservation:

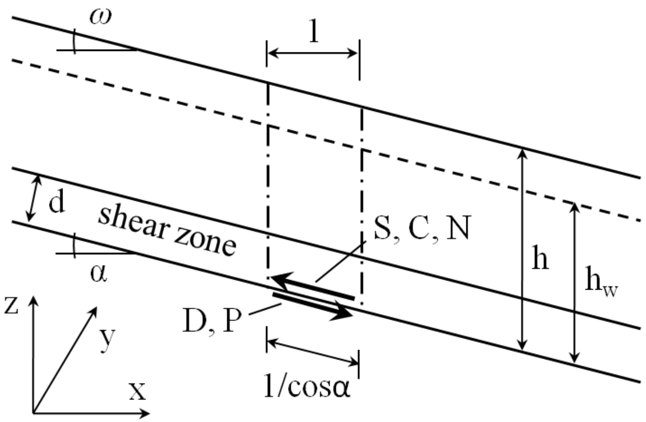
$$\rho h\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\nabla \cdot \mathbf{v}\right) = \mathbf{D} + \mathbf{P} - \mathbf{S} - \mathbf{C} - \mathbf{N}$$

$$\mathbf{D} = \frac{\mathbf{W}\sin\alpha}{1/\cos\alpha} = \mathbf{W}\sin\alpha\cos\alpha$$

$$\mathbf{P}_{\min/\max} = K_{a/p}\frac{\mathbf{W}\cos\alpha}{1/\cos\alpha}\nabla h = K_{a/p}\mathbf{W}\cos^2\alpha\nabla h$$

$$\mathbf{S} = \frac{\mathbf{W}\cos\alpha}{1/\cos\alpha}\tan\varphi_{app} = \mathbf{W}\cos^2\alpha\tan\varphi_{app}$$

$$\tan\varphi_{app} = (1 - r_p)\tan\varphi$$



$$r_p = \frac{\gamma_w h_w \cos^2\alpha}{\rho g h}$$

$$\mathbf{N} = \eta\left(\frac{\partial \mathbf{v}}{\partial z}\right) = \eta\left(\frac{\mathbf{v}}{d}\right)$$

$$\rho h\left(\frac{\partial \mathbf{v}}{\partial t}\right) = \mathbf{D} + \mathbf{P} - \mathbf{S} - \mathbf{N}$$

$$\frac{\partial h}{\partial t} + \nabla \cdot (h\mathbf{v}) = 0$$

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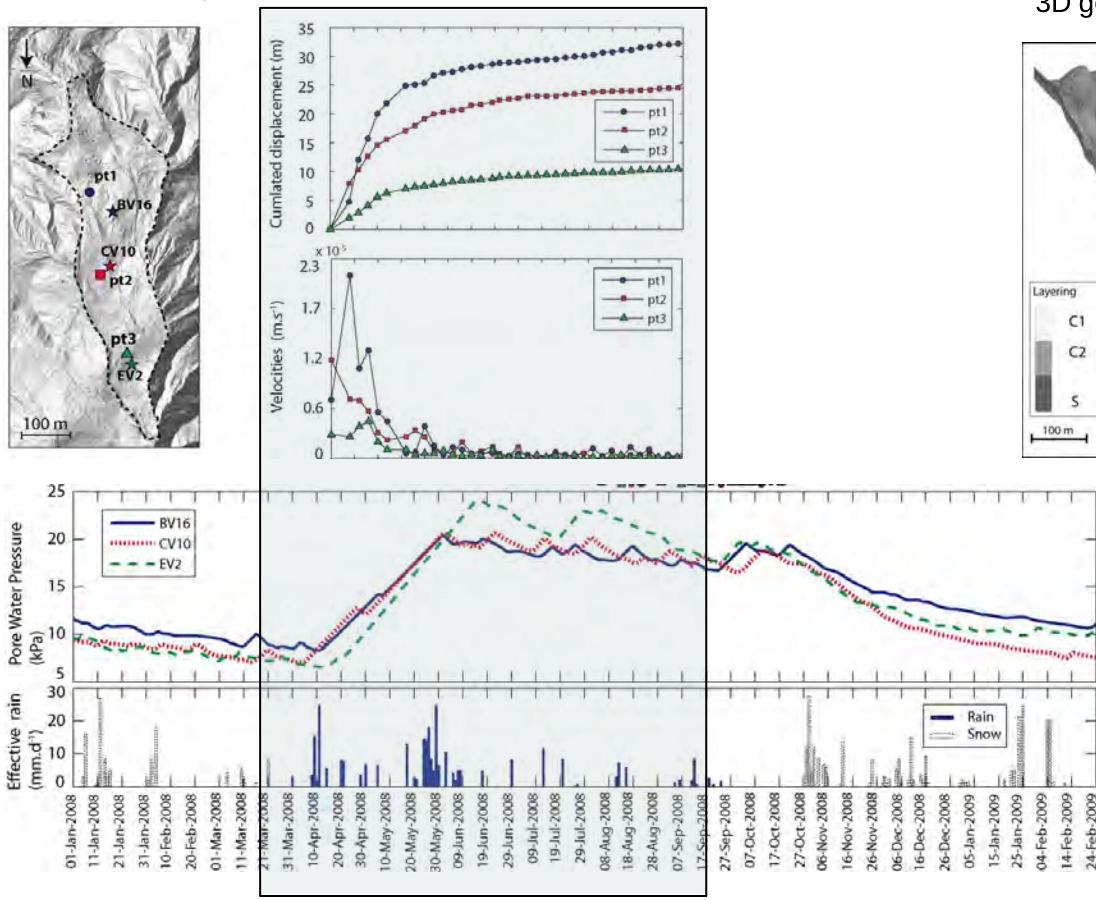
PROGRESS

- Slow-Move: mass sliding (Spickermann et al., 2012)

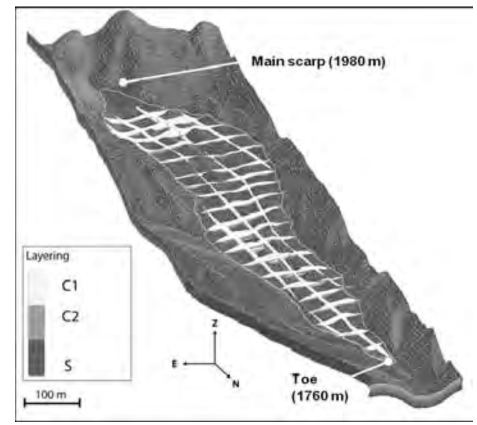
▪ Application to Super-Sauze landslide

Measurement points



Modelling period

3D geometry



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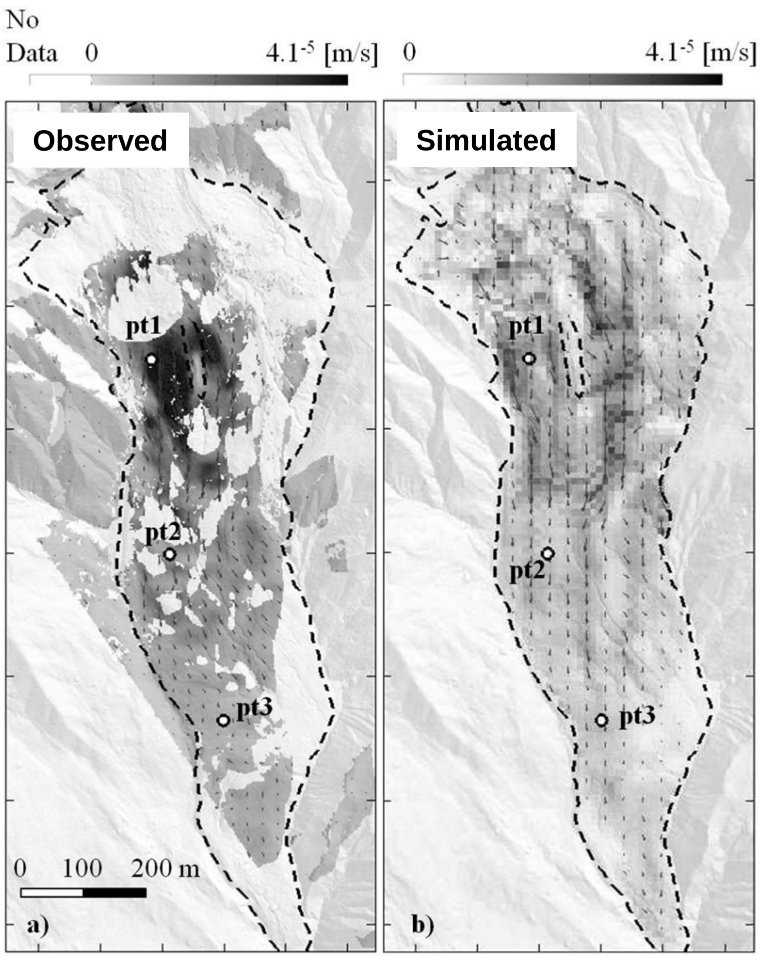
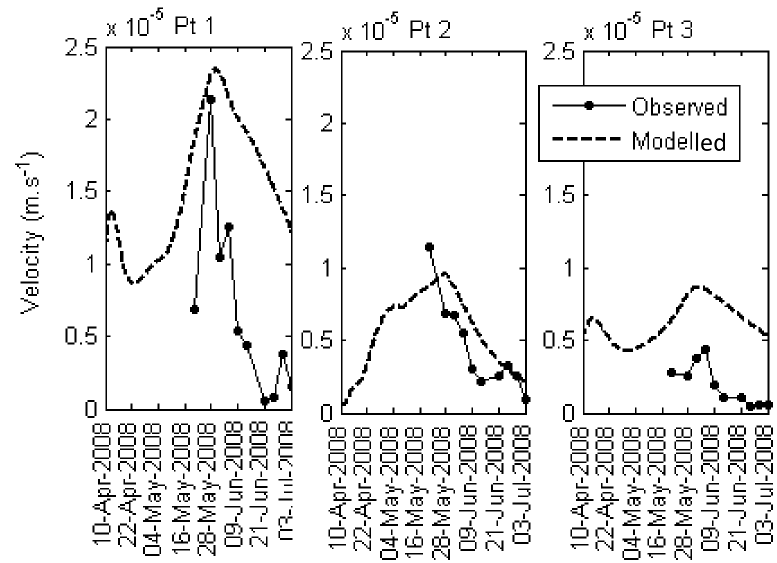
- **Application to Super-Sauze landslide**





- **Further development of the code**

  - Integration with Starwars

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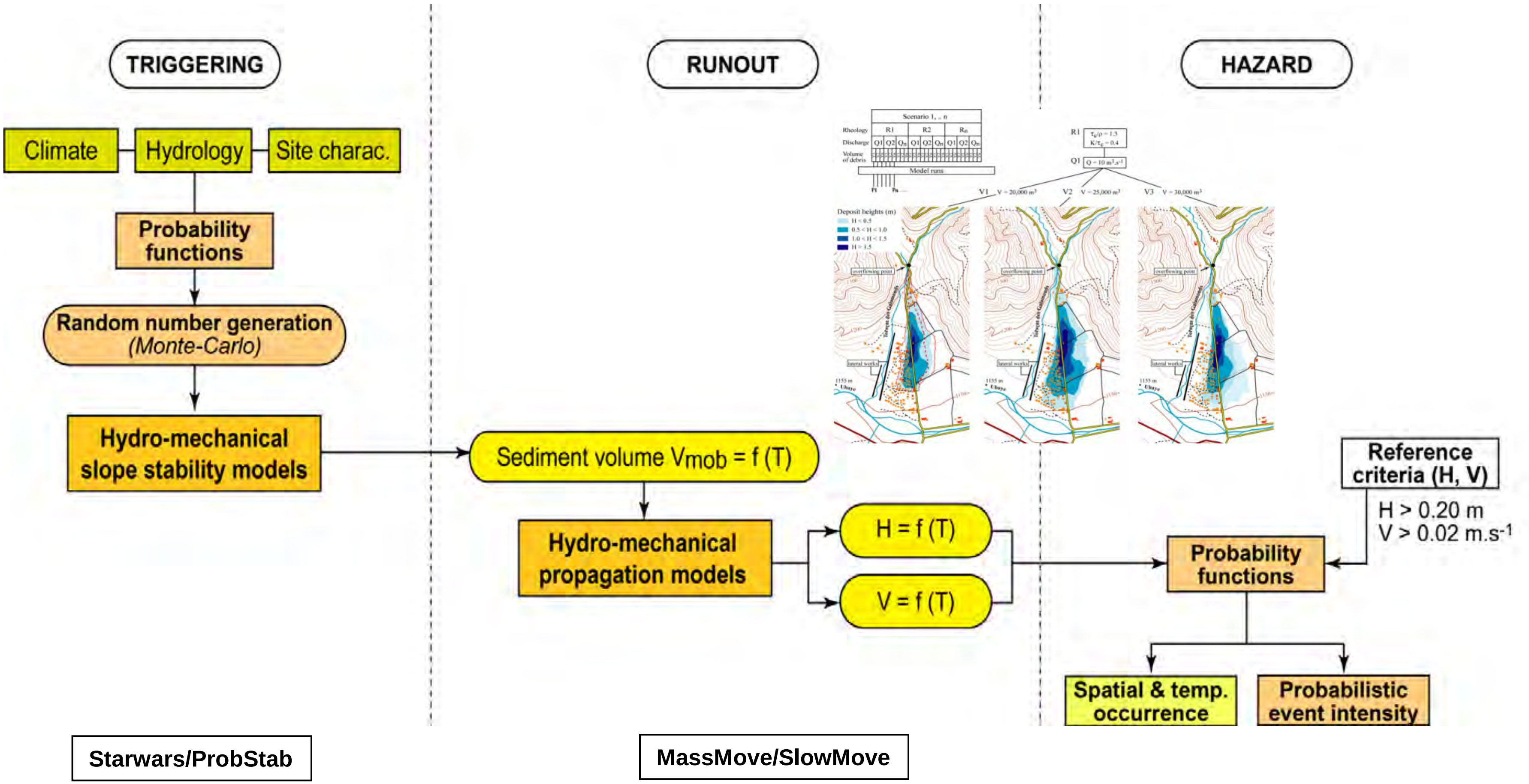
PROGRESS

Hazard assessment through modelling

Estimation of probabilities of failure, runout distances and magnitude parameters (velocity, impact forces, thickness) through Monte-Carlo simulations

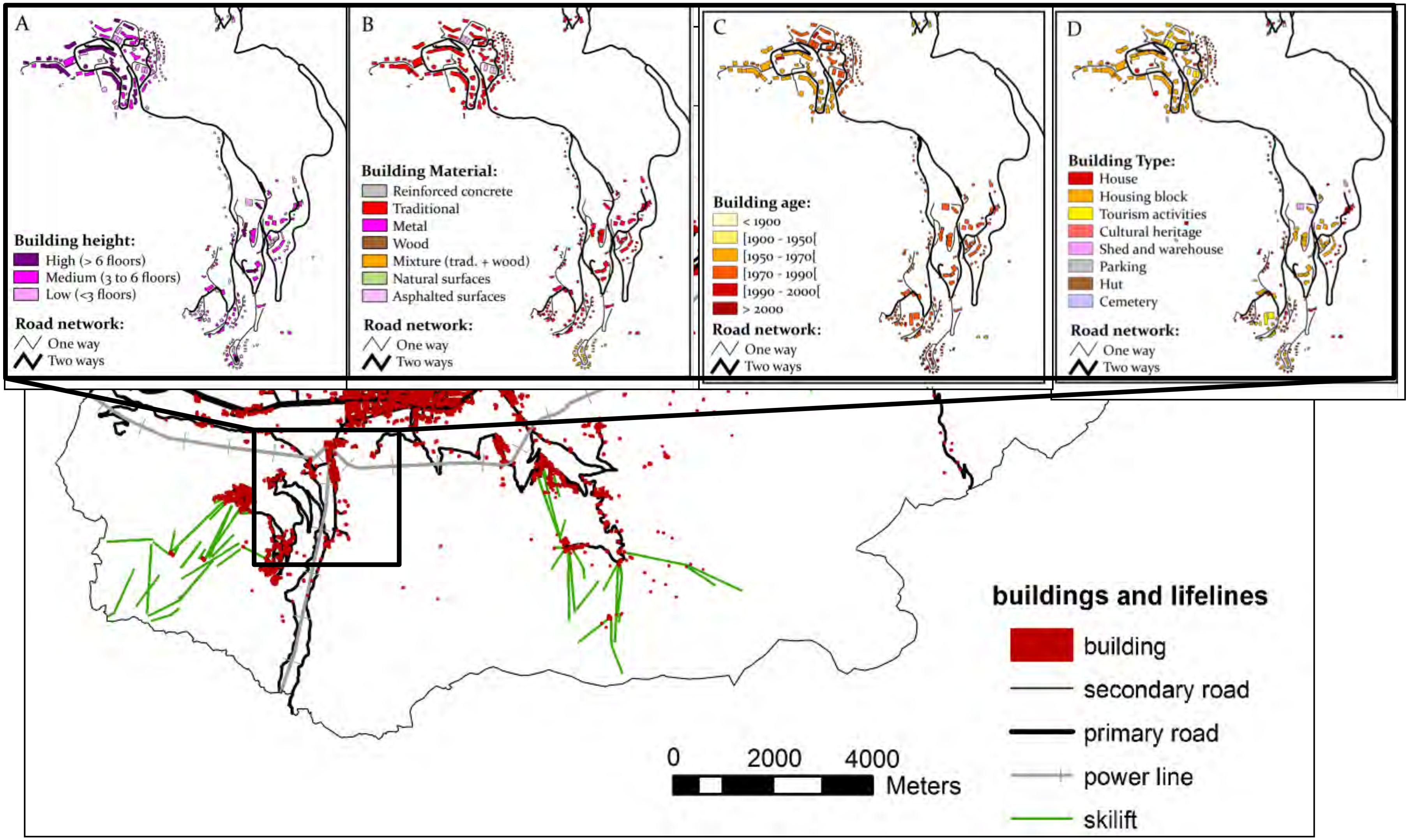


WP4 - Integrated landslide risk analysis, and estimation of the consequences

- 4.1 Analysis of analytical vulnerability and cost of landslides
- 4.2 Analysis and mapping of landslide potential consequences and risks
- 4.3 Characterization of the response of the mountain system to hazard and exposure changes

PROGRESS

- Element at risk mapping and characterization



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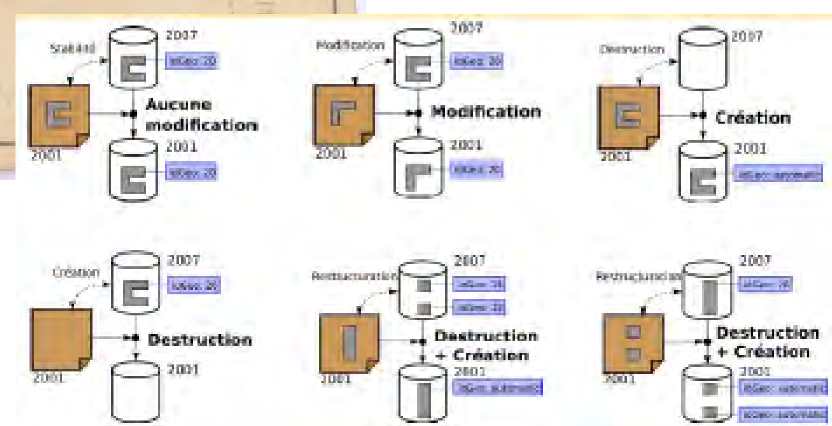
PROGRESS

- Building time serie analysis from old maps and cadasters



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PROGRESS

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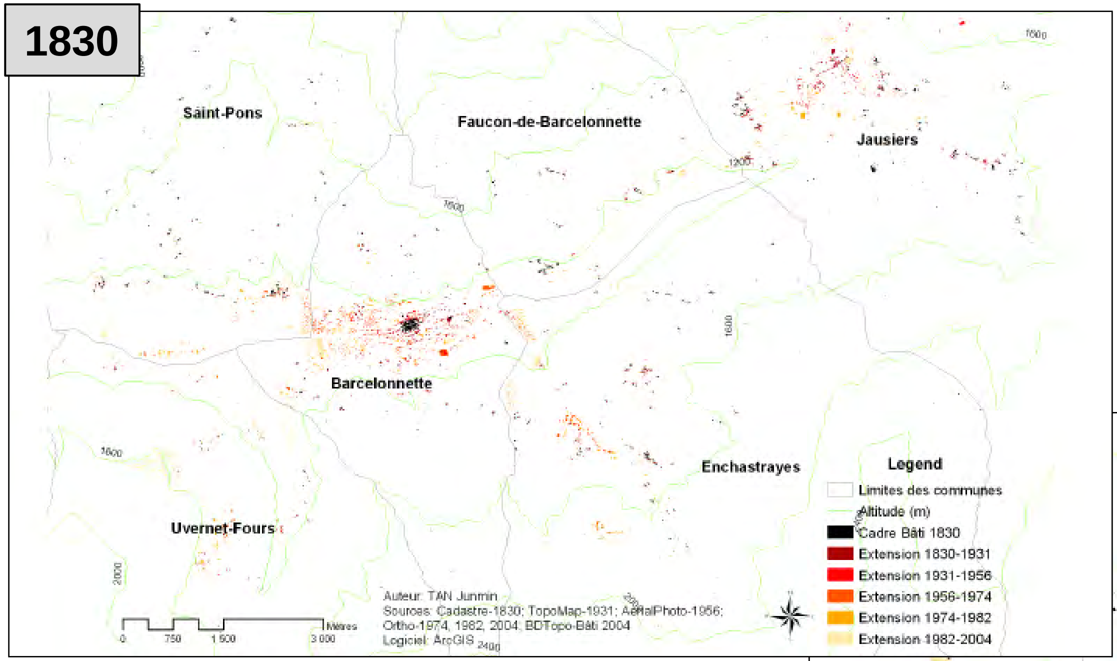
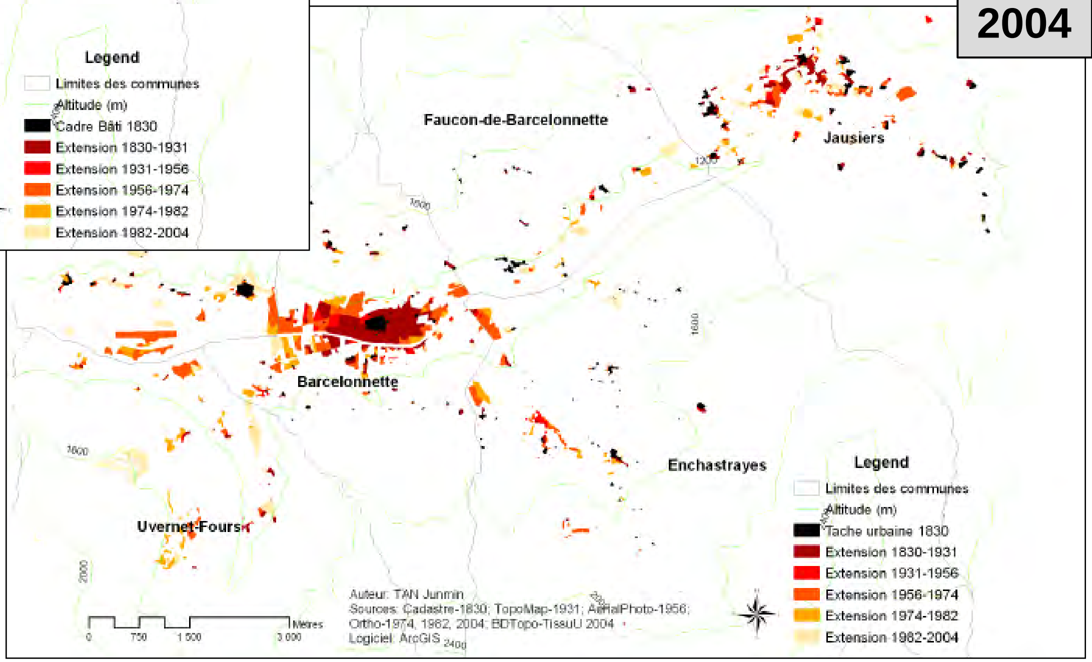
1830



2004



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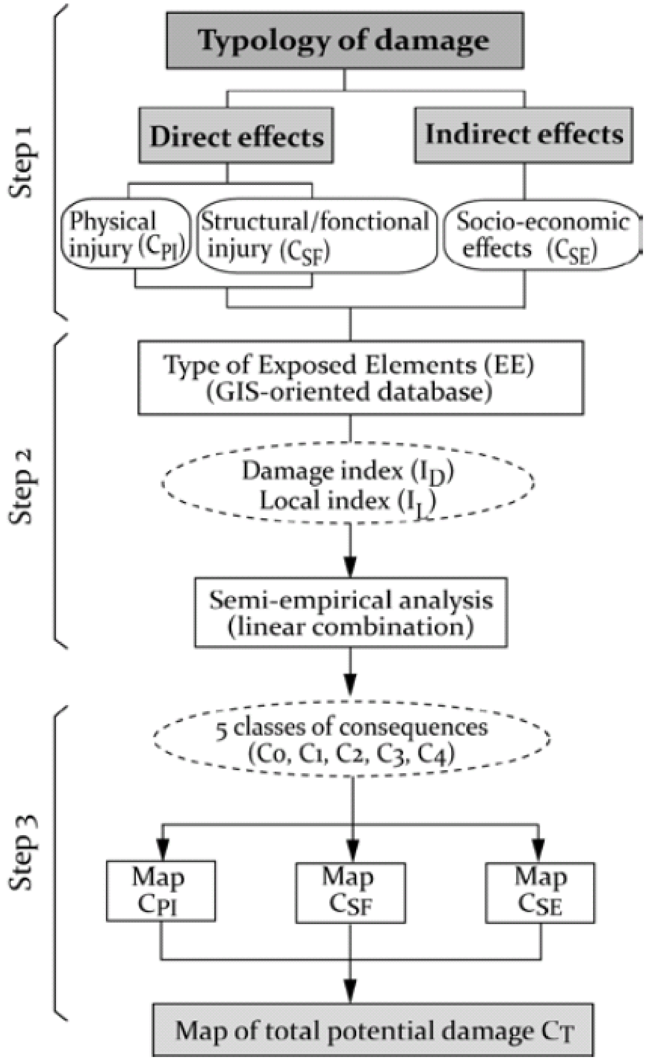
PROGRESS

Consequence analysis



➔ indicator-based methodology of Puissant et al. (2005) applied to the whole Barcelonnette Basin

WP4 - Integrated landslide risk analysis, and estimation of the consequences

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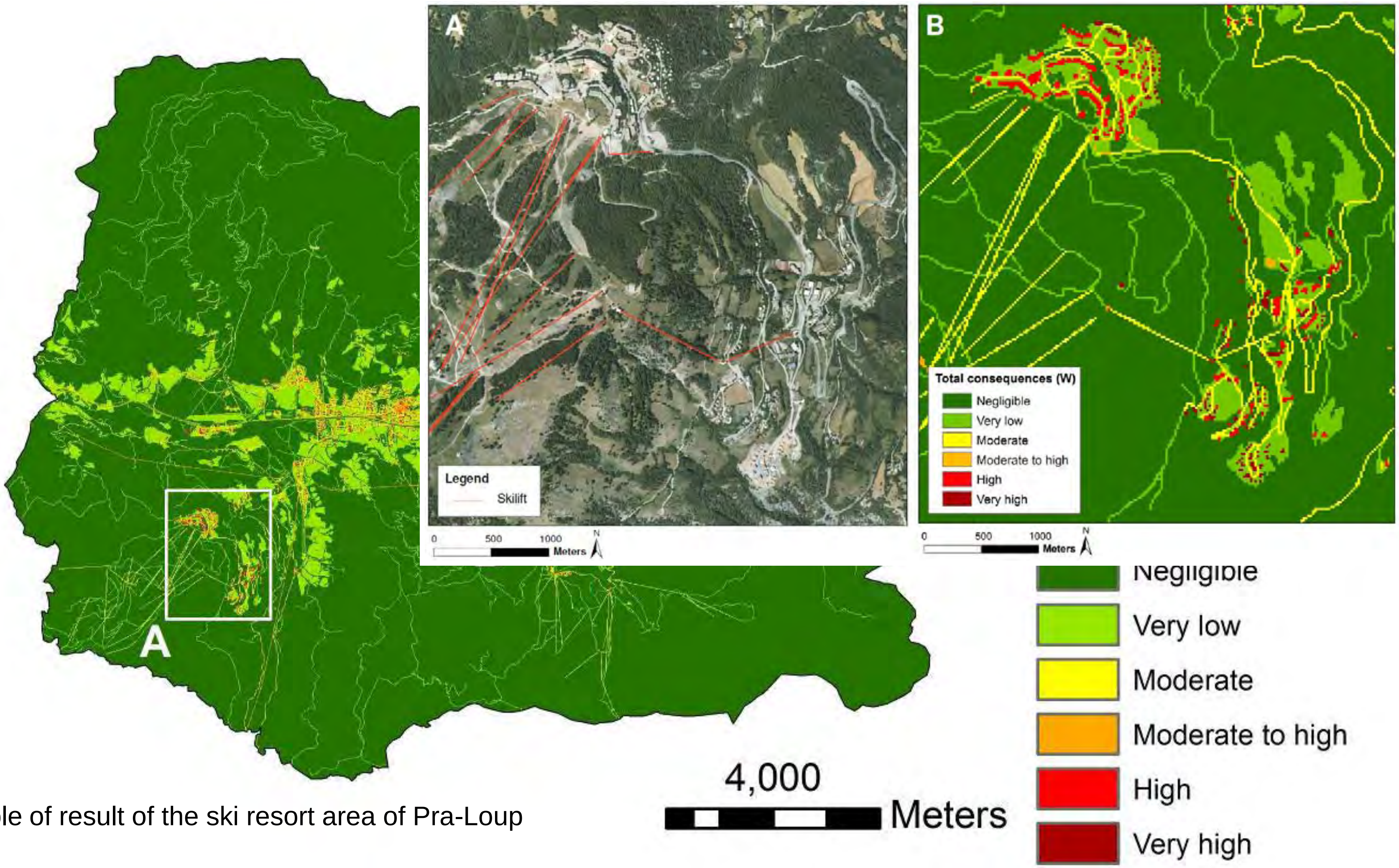
PROGRESS

Consequence analysis



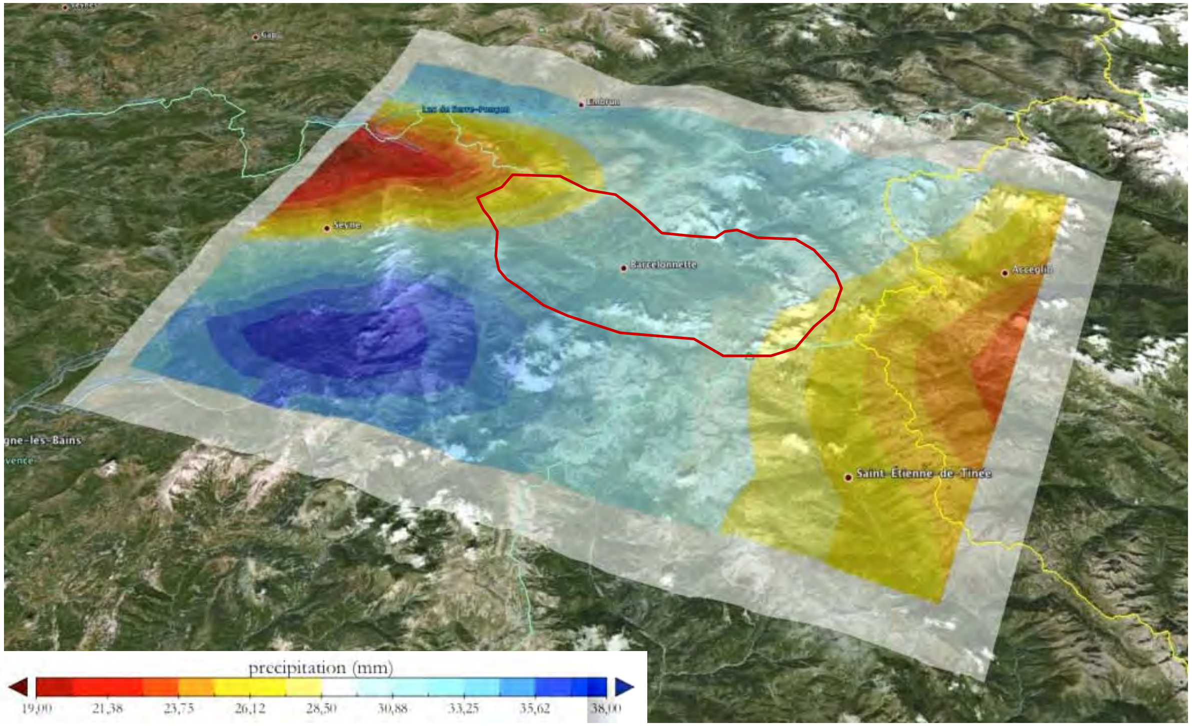
Example of result of the ski resort area of Pra-Loup

Puissant, A., Van Den Eeckhaut, M., Malet, J.-P., Hervás, J. (subm). Regional-scale semi-quantitative consequence analysis in the Barcelonnette Region, Southern France. NHESS.

PROGRESS

- Indicators of changes: to be defined

- Demonstration platform: Google Earth .kml products




Thank you for your attention!