Bozen-Bolzano 2019 EWS Debris Flows

Regional Scale Debris-Flow Warning Using Weather Radar Applications. Experiences from Catalonia

Marcel Hürlimann[1],

Rosa Palau[1,2], *Marc Berenguer*[2]

[1] Div. of Geotechnical Engineering and Geosciences, UPC BarcelonaTECH

[2] Center of Applied Research in Hydrometeorology, UPC BarcelonaTECH

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Department of Civil and Environmental Engineering

Division of Geotechnical Engineering and Geosciences

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA

INDEX

- Introduction - fundamentals
- Susceptibility analysis
- Rainfall analysis
- Application, conclusions and outlook

Introduction

Terminology: ***Forecasting – (early) warning – alarm systems***

Stähli et al. (2015 - NHESS):

"Early warning systems can be divided into three classes"

- Alarm systems (AS)
  - detect process parameters of ongoing hazard
  - reaction time is short

after triggering

- Warning systems (WS)
  - detect significant changes, before the triggering
  - reaction time is longer than in AS
- Forecasting systems (FS)
  - predict the level of danger by expert criteria, thus no thresholds are needed as in AS and WS
  - reaction time is longer (e.g. daily report of landslide forecast)

before triggering

Introduction

- Necessary components of regional EWS

What type of process (debris flows) may occur?

When debris flows may occur?

Rainfall (soil moisture…)

DYNAMIC INPUTS

Where debris flows may occur?

Susceptibility Map

STATIC INPUTS

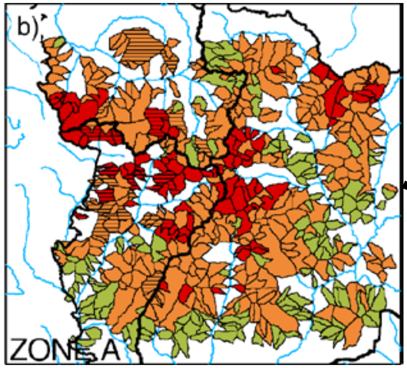
Warning level

Very Low | **Low** | **Moderate** | **High**

Introduction

- Example regional debris-flow forecasting from the Pyrenees

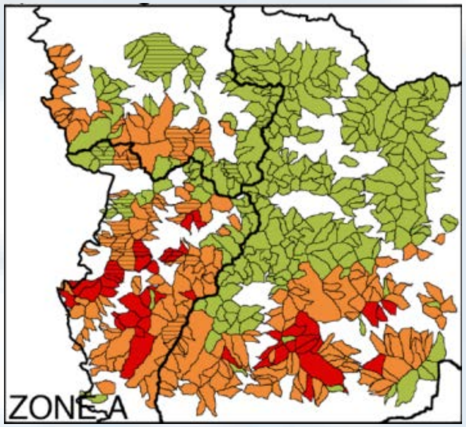
susceptibility map



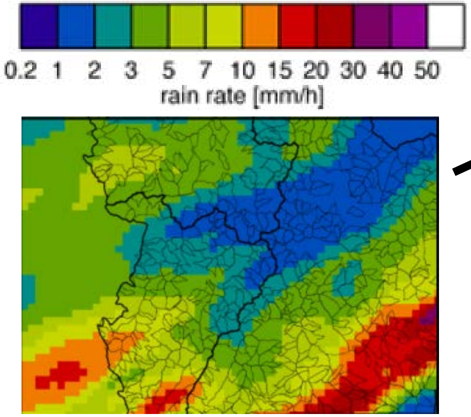
warning matrix

		DF susceptibility (S_1)		
		Low (S_1)	Moderate (S_2)	High (S_3)
Rainfall situation	Weak (R_1)	Low (W_1)	Low (W_1)	Low (W_1)
	Moderate (R_2)	Low (W_1)	Moderate (W_2)	Moderate (W_2)
	Severe (R_3)	Moderate (W_2)	High (W_3)	High (W_3)

warning map



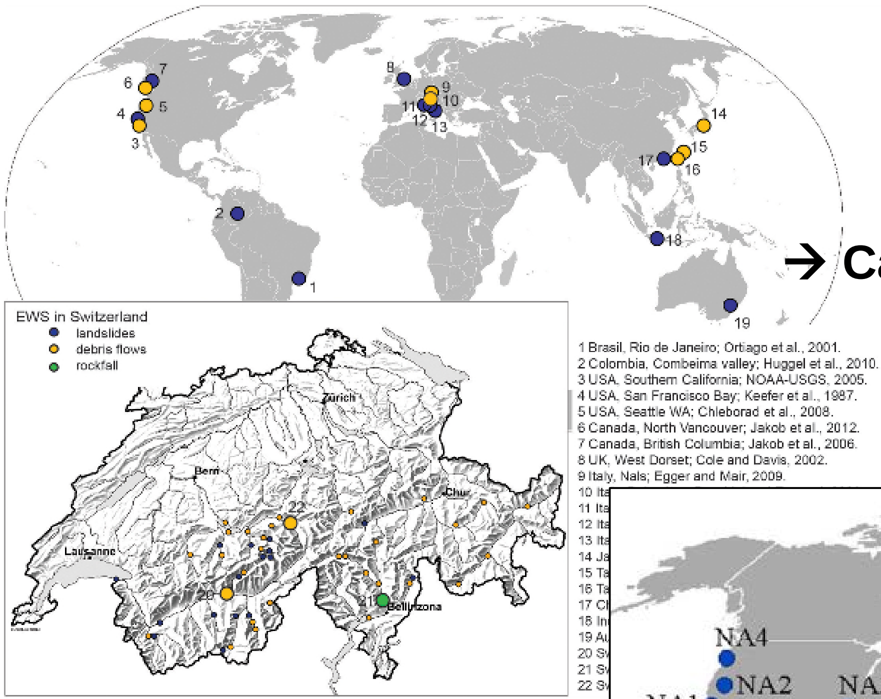
Rainfall records (weather radar)



Berenguer et al. (2015) – NHESS

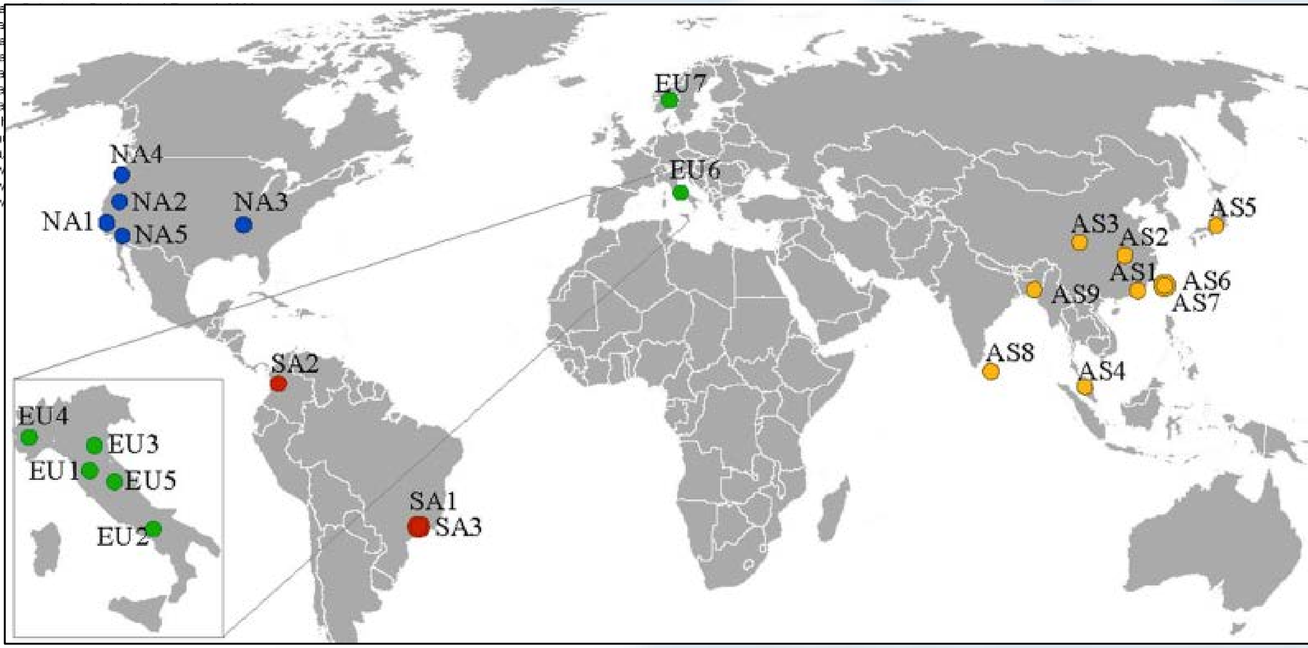
Introduction

- Existing regional early warning systems (EWS)



Selected EWS-sites for rapid mass movements
Stähli et al. (2015)

→ **Catalan landslide EWS is not operational!**



EWS for rainfall-induced landslides
(debris flows and shallow slides)
Piciullo et al. (2018)

Introduction

- Why only very few landslide EWS are operational?
- Some explanations:

Existence of false alarms (economic, social and legal aspects)

↕

Difficulty of creating correct susceptibility maps (technical aspect)
Difficulty of defining correct rainfall thresholds (technical aspect)

→ **Susceptibility analysis**
→ **Rainfall analysis**

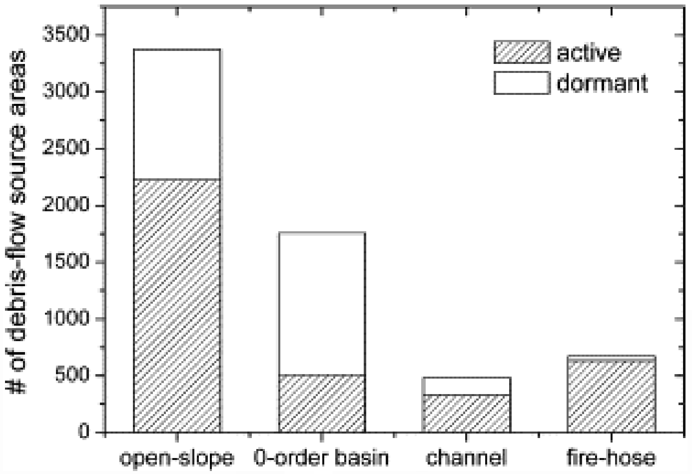
INDEX

- Introduction - fundamentals
- Susceptibility analysis
- Rainfall analysis
- Application, conclusions and outlook

Debris flow susceptibility analysis

Important facts and difficulties:

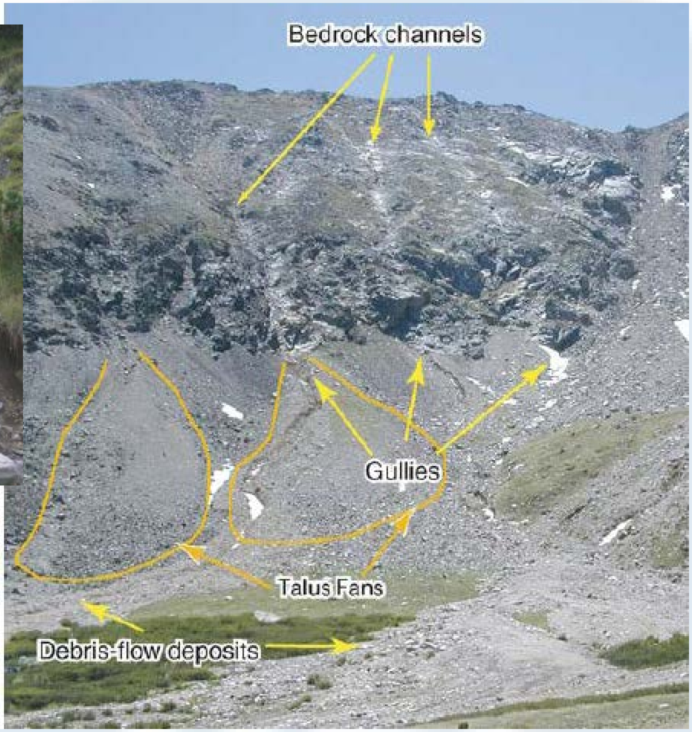
- Different types of initiation mechanisms for debris flows
- …



Carrara et al. (2008)

Val d´Aran – Pyrenees

Ensija – Pyrenees

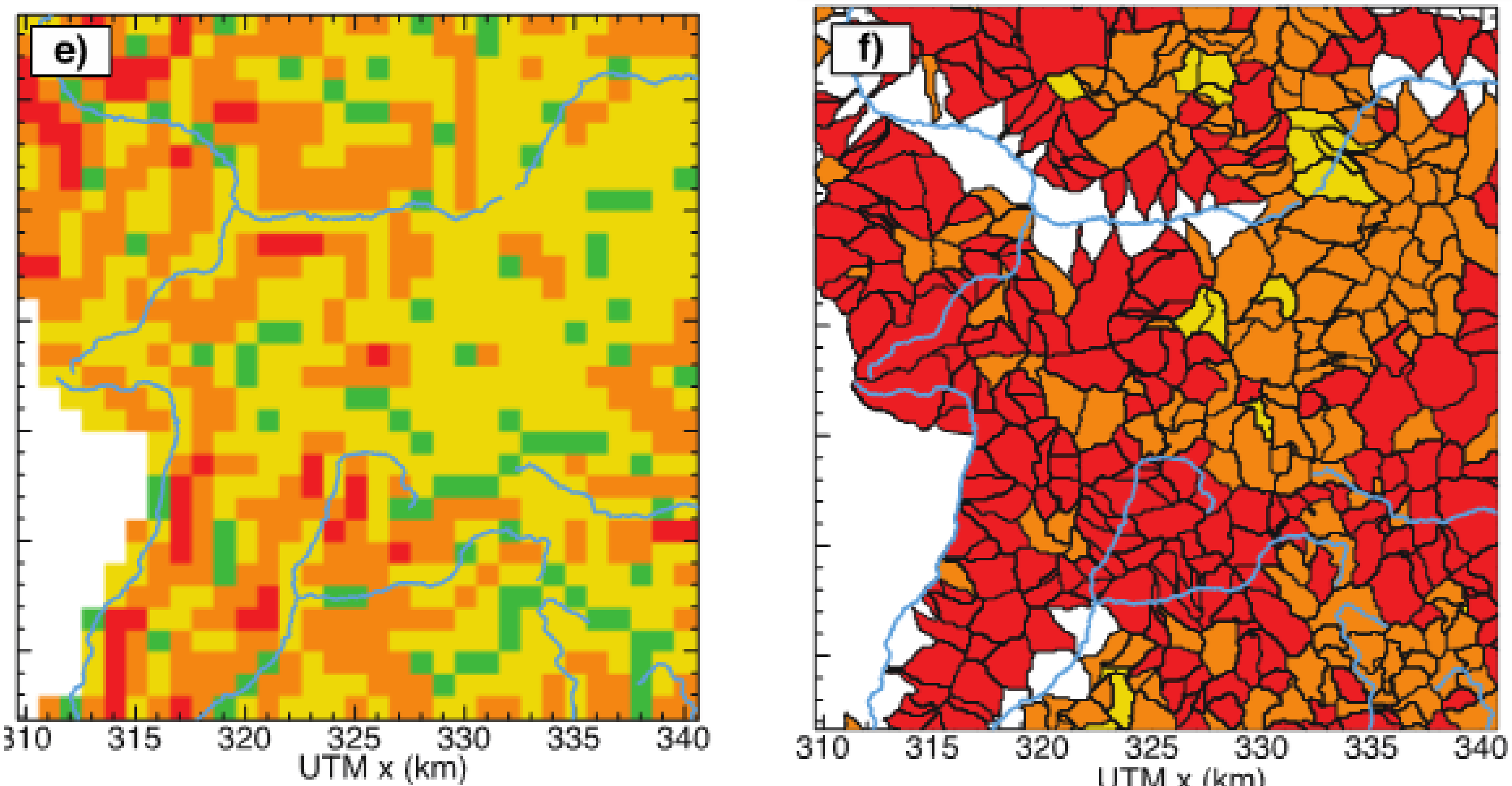


Godt & Coe (2007) – Colorado USA

Debris flow susceptibility analysis

Important facts and difficulties:

- Different types of mapping units (slope units):
  - Pixel (grid cell)
  - Catchment, municipality etc. (polygon)



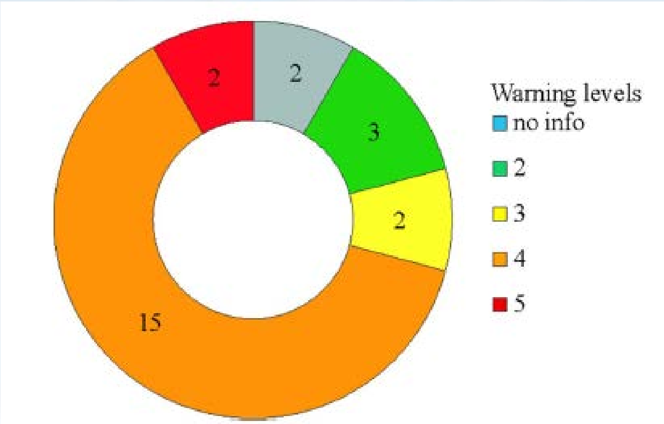
Palau et al. (under review)

Debris flow susceptibility analysis

Important facts and difficulties:

- Different types of methods:
  - Heuristic
  - Fuzzy-logic
  - Physically-based
  - Statistical
  - Data mining
  - …
- Output:
  - Quantitative susceptibility (e.g. FS or value 0 – 1)
  - Qualitative susceptibility (classes)

→ **EWS warning by (4) classes**



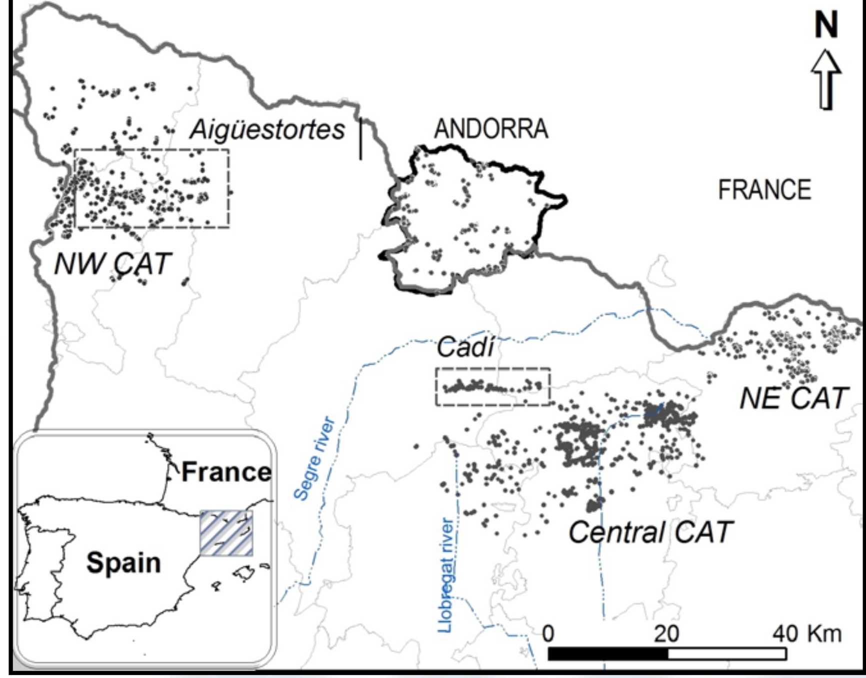
Piciullo et al. (2018)

Susceptibility analysis

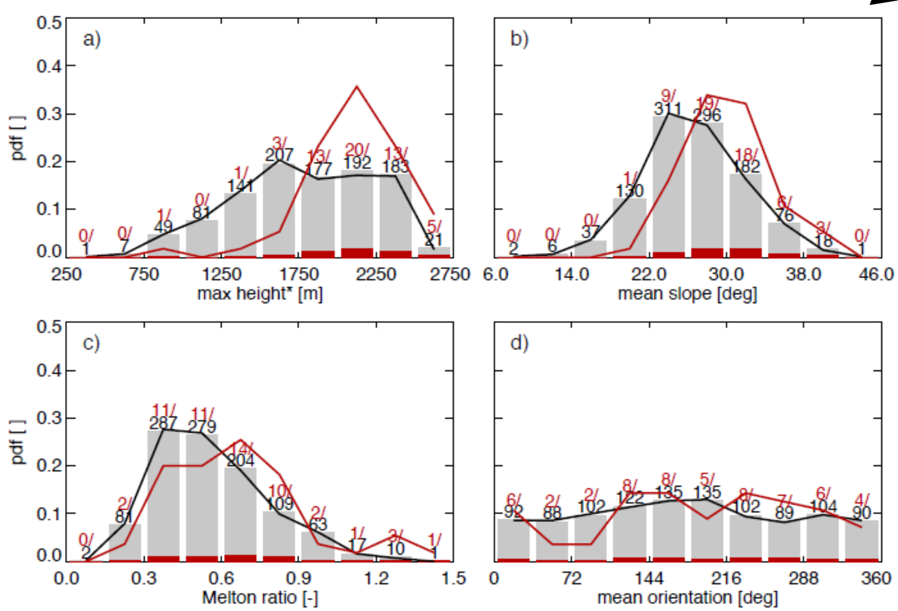
- Catalan experience:

Definition of governing factors:

debris flow inventory (2474 entries)

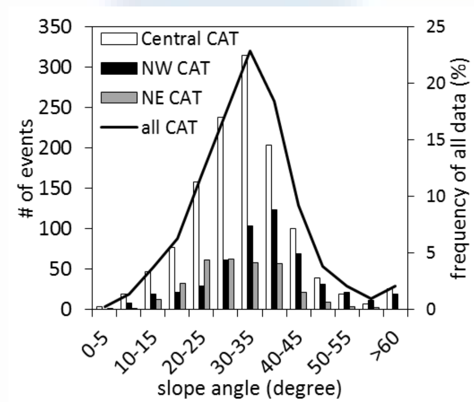


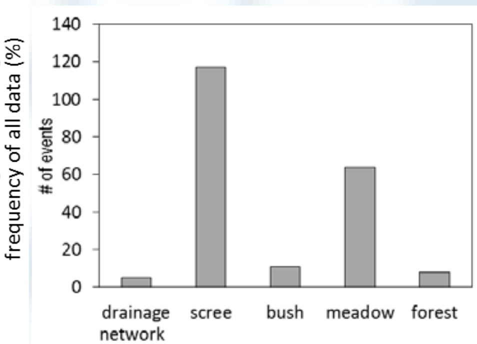
Morphometric variables:



Chevalier et al. (2013) - NatHaz
Berenguer et al. (2015) – NHESS

Slope angle & land use/cover





Hürlimann et al. (2016) - ISL
Palau et al. (2018) – EGU

Susceptibility analysis

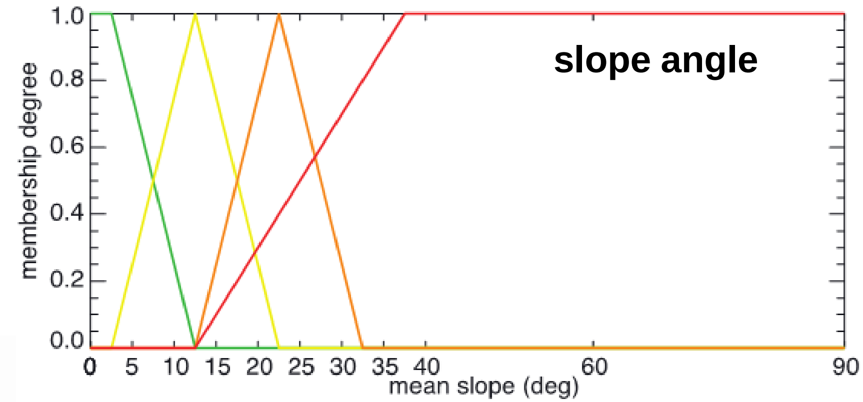
- Catalan experience:

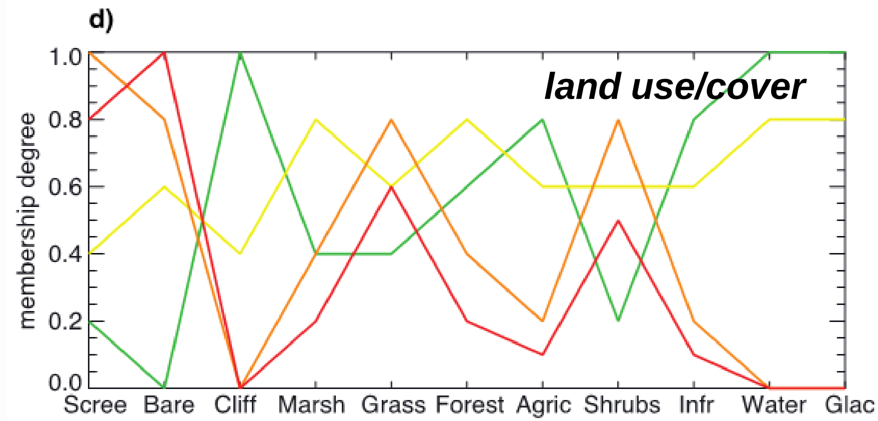
  Governing factors
  - ***Slope angle & land use/cover***

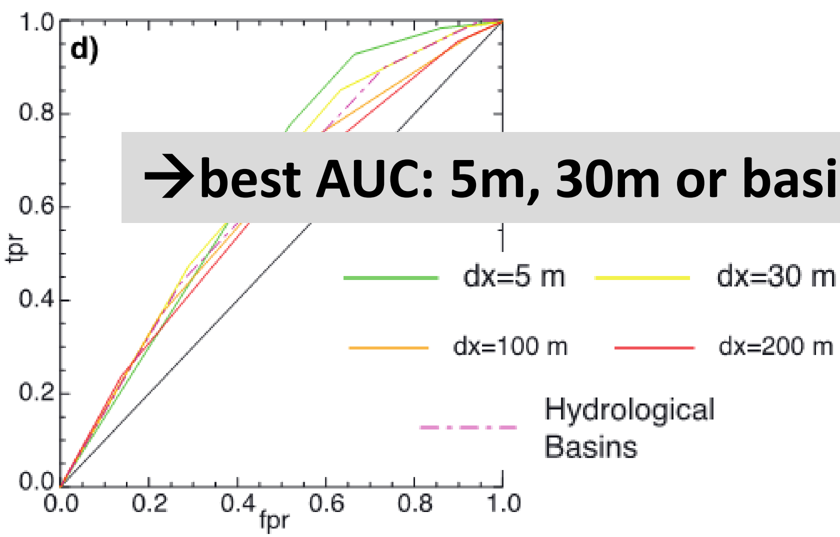
  Different method tested, but
  - ***fuzzy-logic selected***

  Four susceptibility classes
  - ***Very low** to **high***

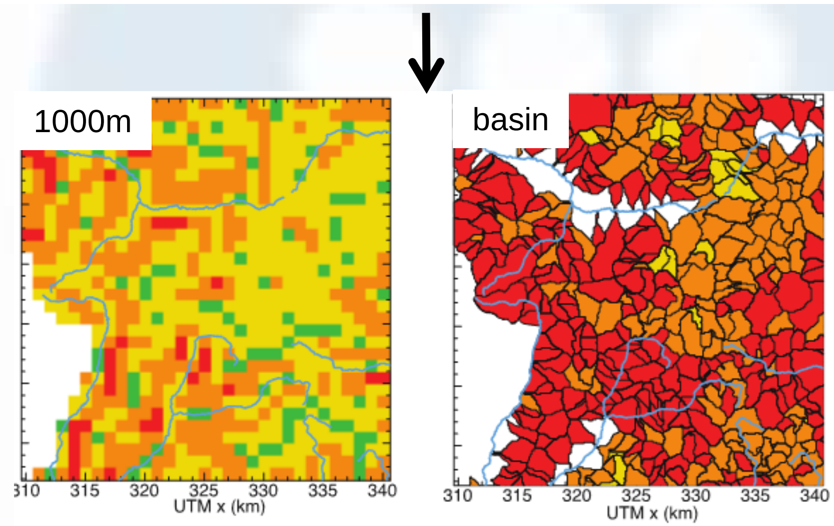
  Mapping units:
  - ***Pixel versus polygon (basin)***







→best AUC: 5m, 30m or basins



Palau et al. (under review)

Susceptibility analysis

Concluding remarks and recommendations:

- Susceptibility method and governing factors:
  - Apply simple method (e.g. fuzzy logic) and use classes (e.g. four; very low to high)
  - Combine slope angle and sediment availability/soil strength (e.g. land-use/cover, soil or geotechnical map)

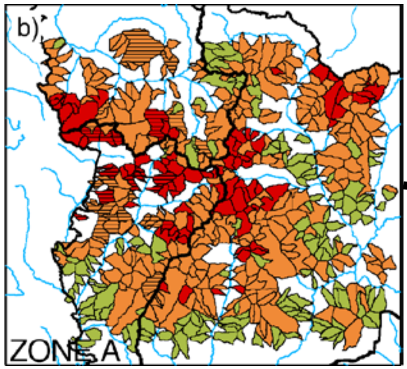
- The comparison of the different mapping unit approaches:
  - 5m or 30m pixel may give better AUC, but basins have an easier interpretation (see later)

INDEX

- Introduction - fundamentals
- Susceptibility analysis
- Rainfall analysis
- Application, conclusions and outlook

Rainfall analysis: general flowchart

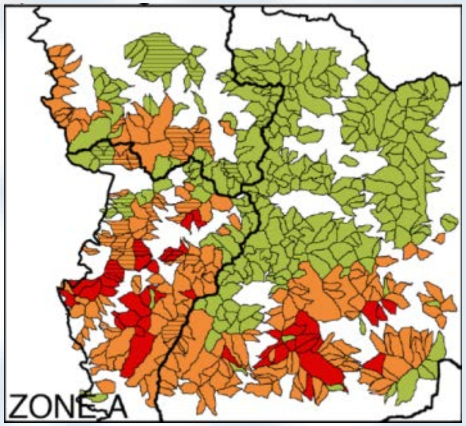
susceptibility map



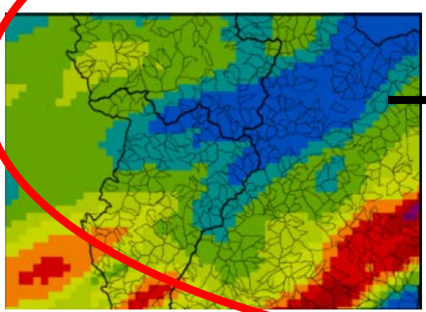
warning matrix

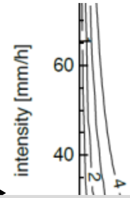
		DF susceptibility (S_i)		
		Low (S_1)	Moderate (S_2)	High (S_3)
Rainfall situation	Weak (R_1)	Low (W_1)	Low (W_1)	Low (W_1)
	Moderate (R_2)	Low (W_1)	Moderate (W_2)	Moderate (W_2)
	Severe (R_3)	Moderate (W_2)	High (W_3)	High (W_3)

warning map



Rainfall records





threshold criteria

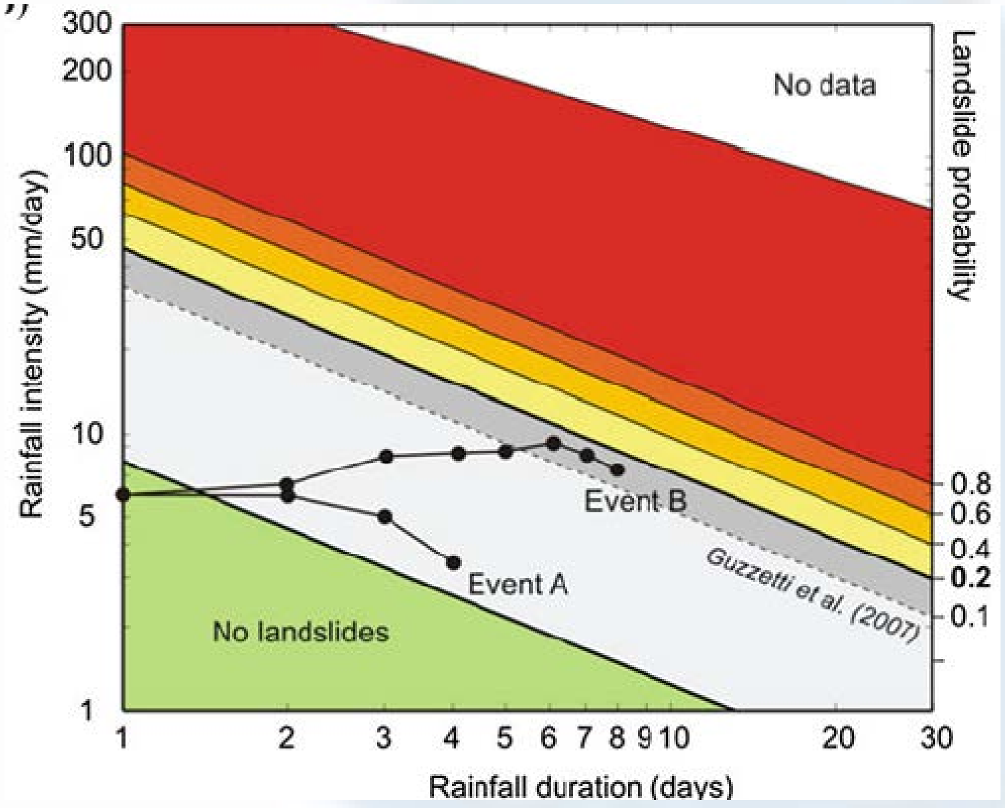
Main uncertainties:

- Correct thresholds
- <u>Correct rainfall measurements</u>

Rainfall analysis: thresholds

- Different approaches to establish thresholds:
  - *Empirical approach (most common)*
  - *Physically-based approach*

- Most popular threshold definition: $I = \alpha D^{\beta}$



Berti et al. (2014)

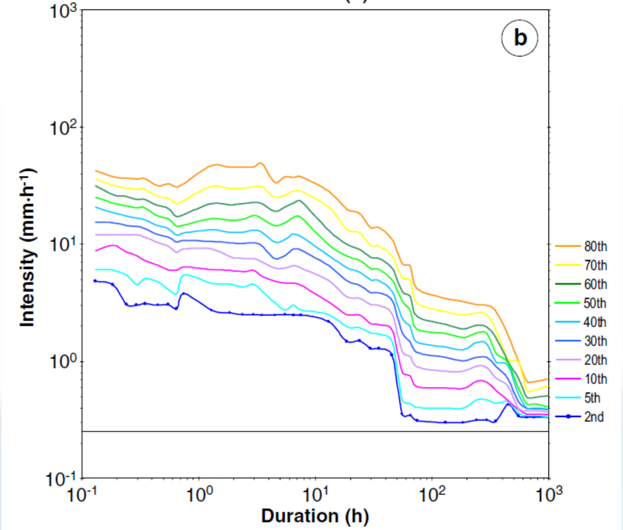
Alert system: Emilia-Romagna Region (Italy)

Rainfall analysis: thresholds

- Catalan experience:
  - *Physically-based approach*
  - *Empirical approach*

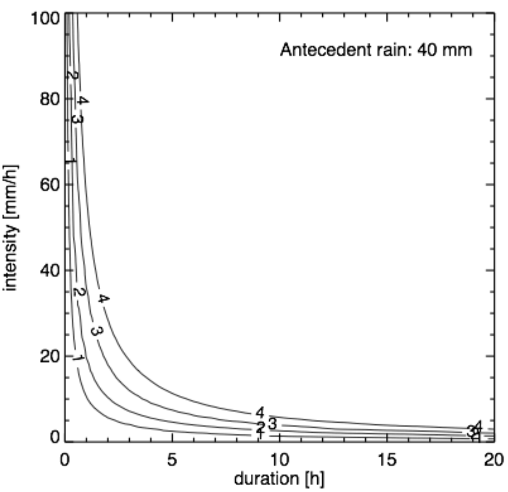
Worldwide dataset from Guzzetti et al. (2008):

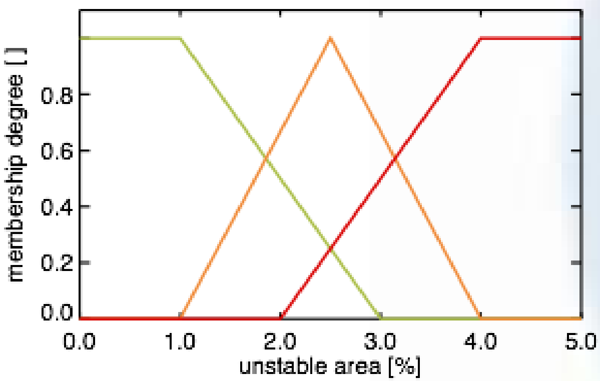
→ *Rainfall hazard level*

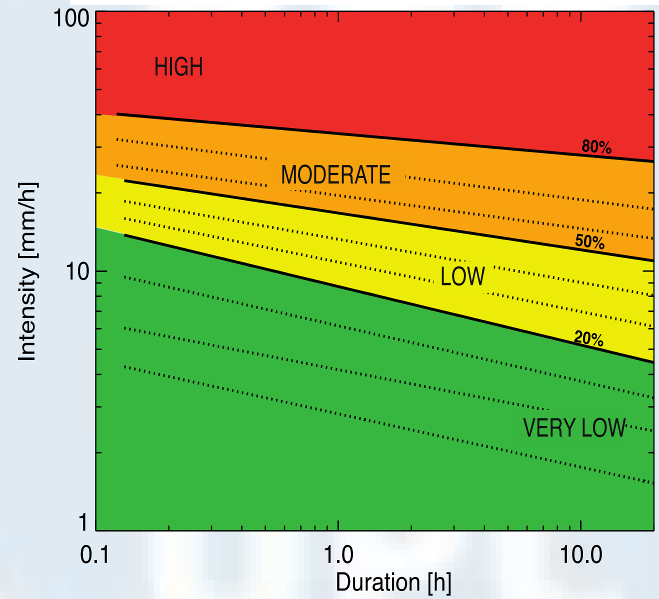


Infinite slope analysis and fuzzy logic:

→ *Rainfall hazard level*





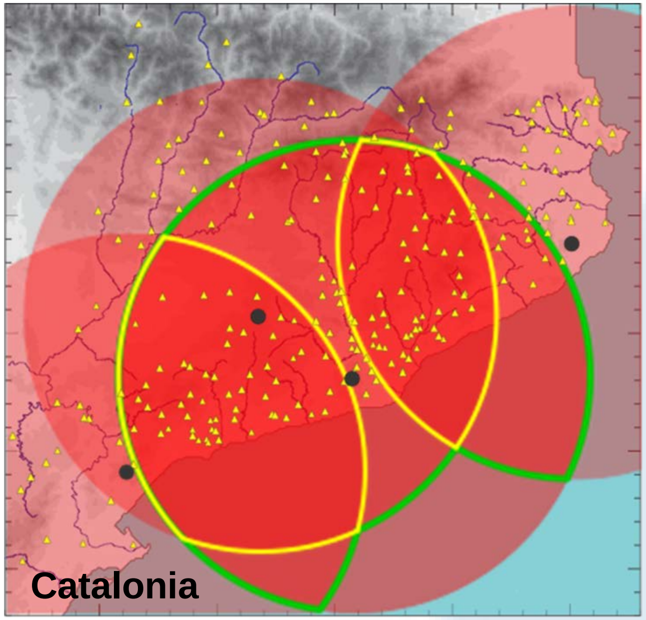


Papa et al. (2012) - HESS
Berenguer et al. (2015) – NHESS

Palau et al. (under review)

Rainfall analysis: measurements

- Uncertainty caused by spatial variability of rainfall
  → Raingauges vs. Radar



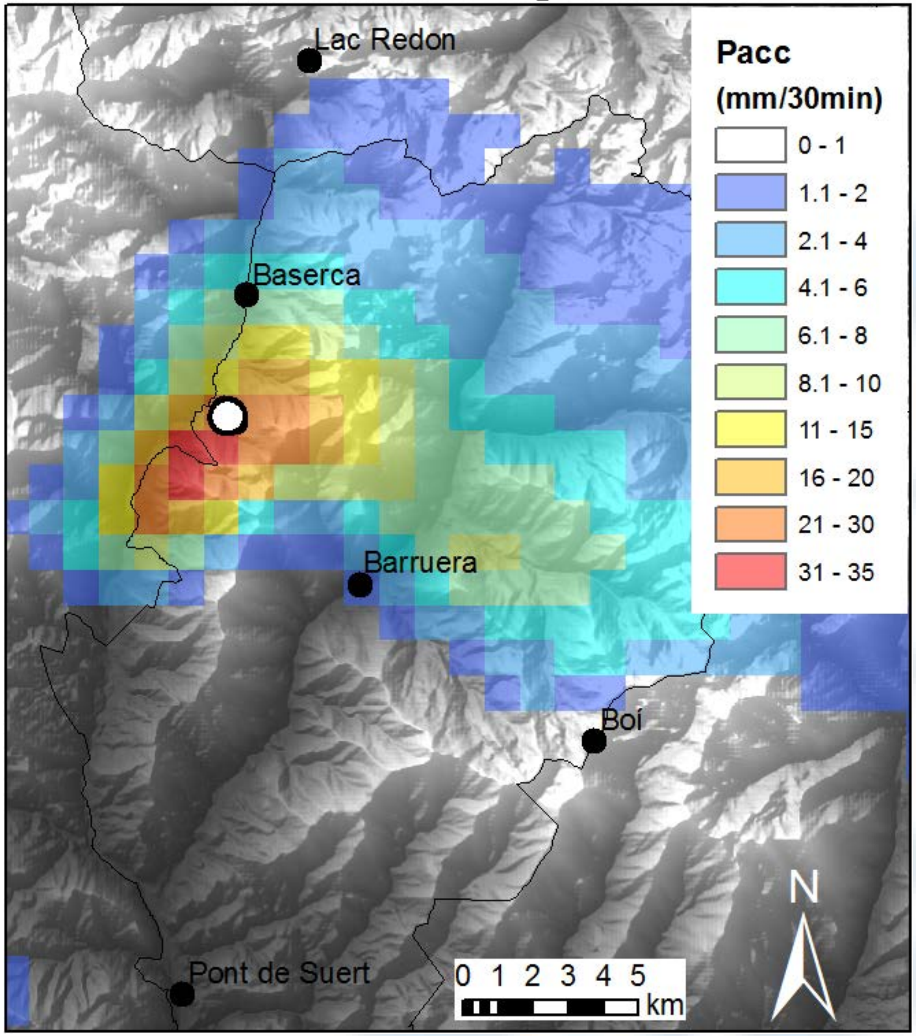
- Point measurements (~200 cm²).
- Irregularly distributed in the territory.
- Low spatial distribution (~1/150km²).

- Indirect measurement.
- Remote observations up to 120 km (sampling volume of ~1km^3)
- High spatio-temporal observations (1km and 5-10 minutes).

Rainfall analysis: measurements

- Spatial variability of rainfall

Example: Rebaixader debris-flow monitoring site



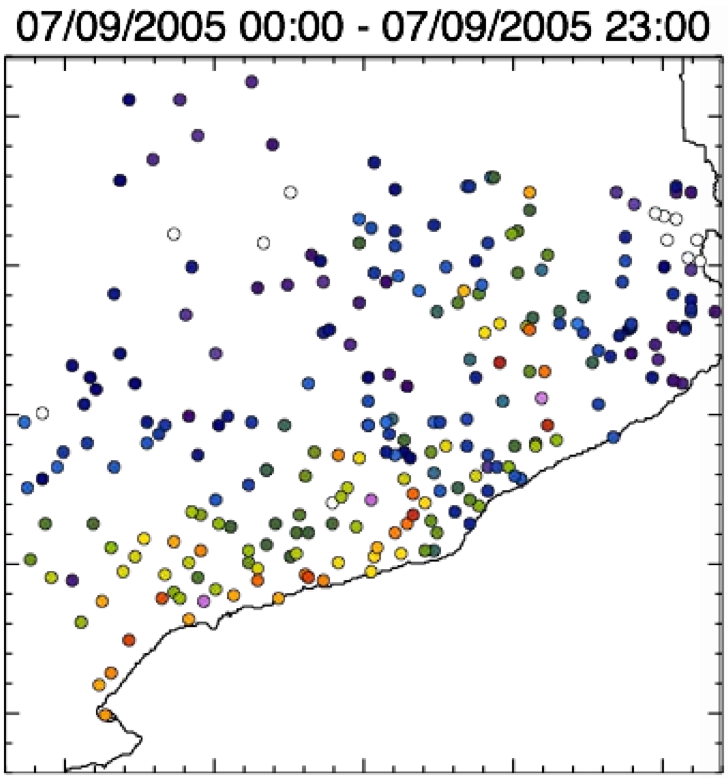
Debris flow, July 11, 2010:

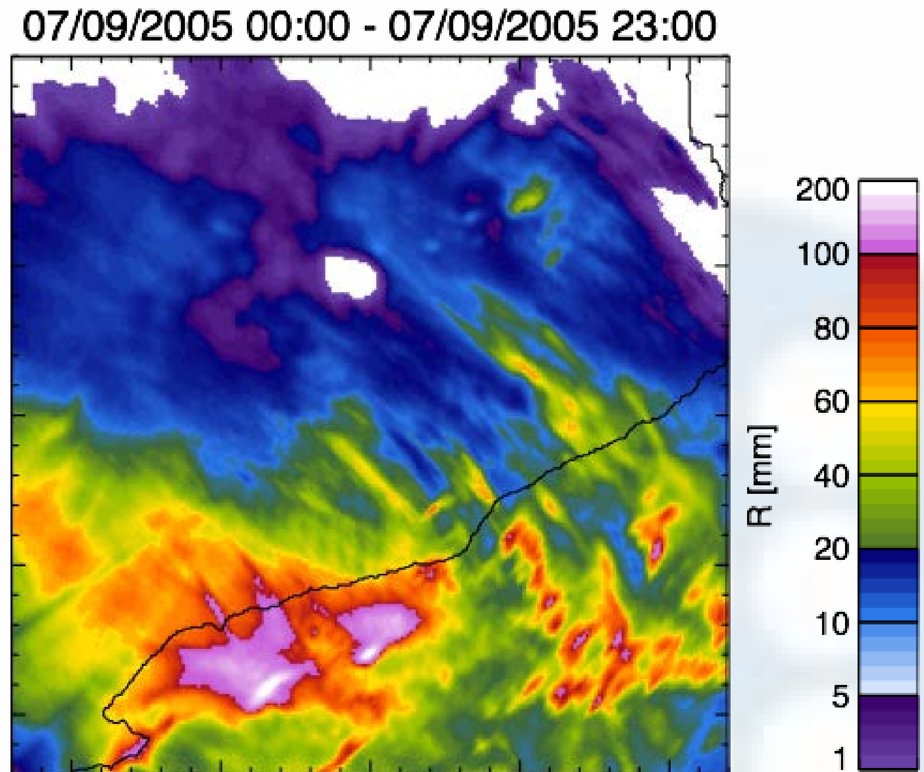
Accumulated rainfall between 13:30 and 14:00

Abancó et al. (2016)

Rainfall analysis: Raingauge vs. Radar

- Catalan experience:



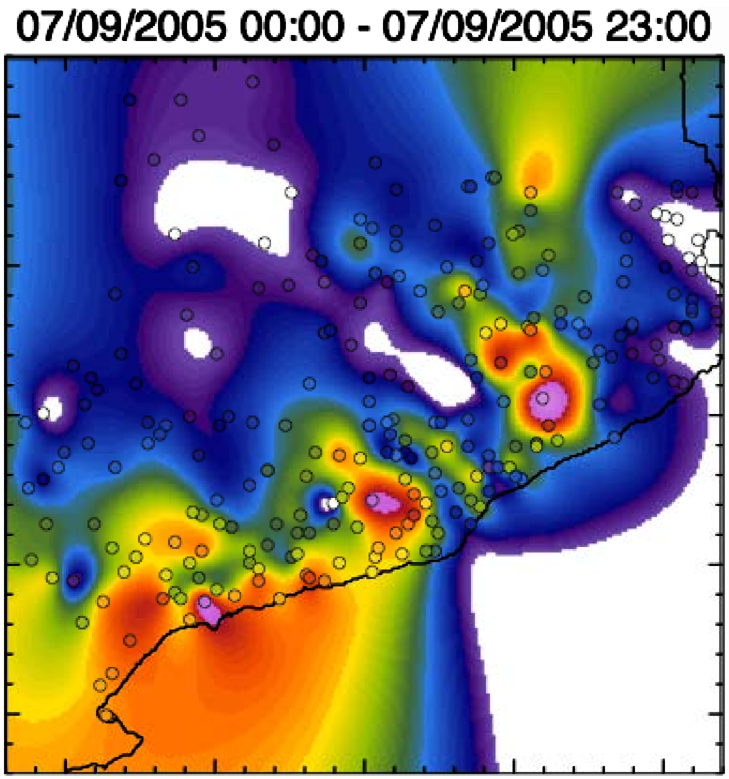


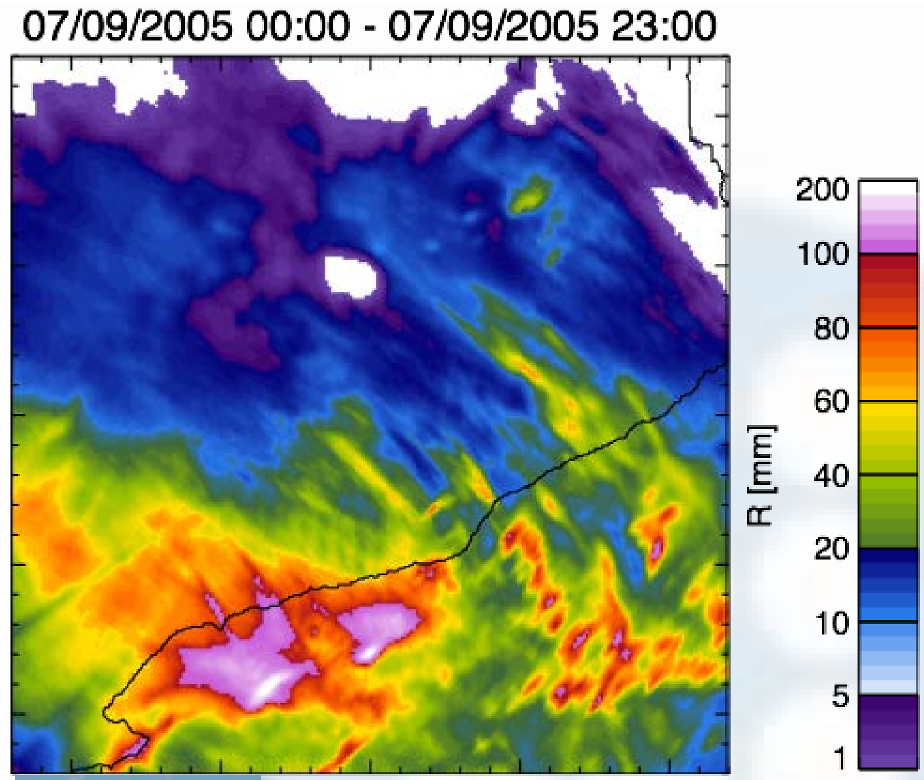
Direct rainfall measurements

Space-time variability of the field

Rainfall analysis: Raingauge vs. Radar

- Catalan experience:





Direct rainfall measurements

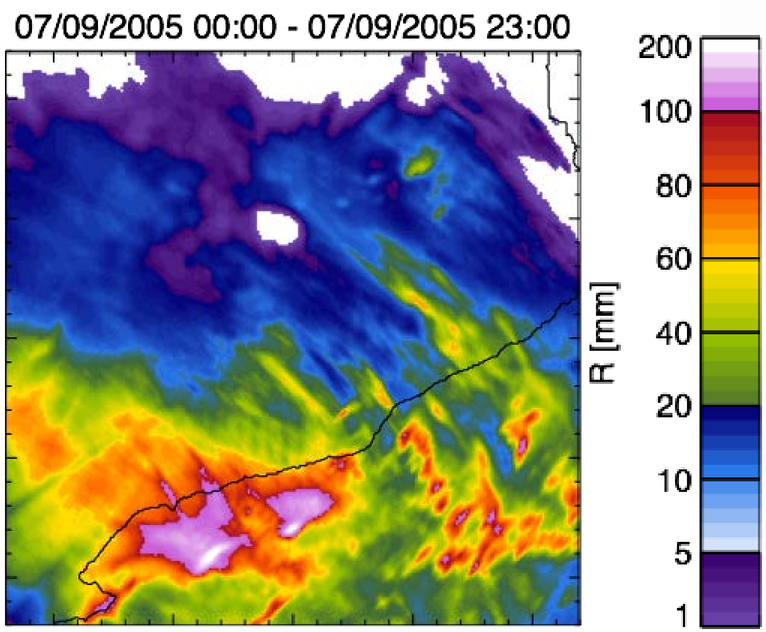
Space-time variability of the field

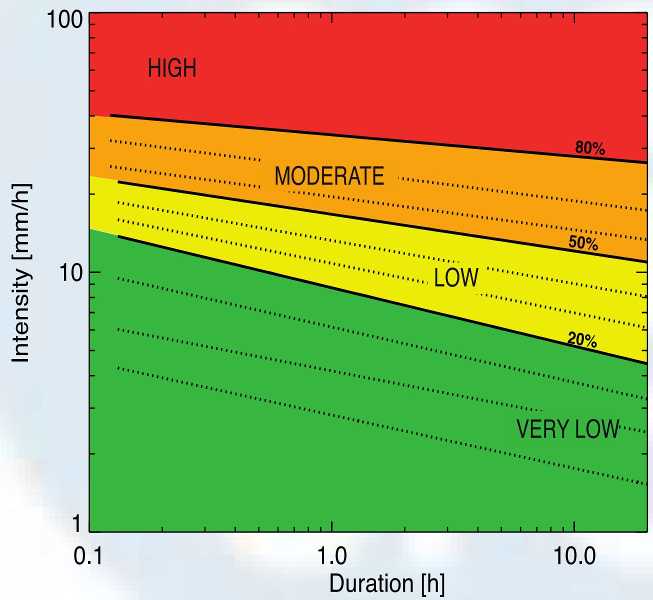
Rainfall analysis

Concluding remarks and recommendations:

- Definition of thresholds is a complex task containing large uncertainties
  - rainfall measurements (spatial variability, convective storms)
  - method to derive thresholds

- Catalan experience:
  - *Radar measurement*
  - *Empirical thresholds*



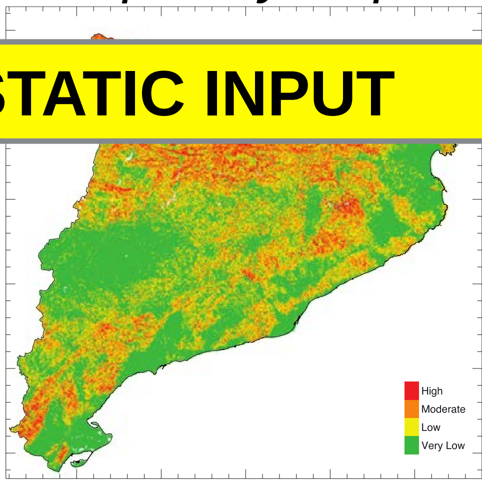


INDEX

Application: new EWS prototype for Catalonia

susceptibility map

STATIC INPUT

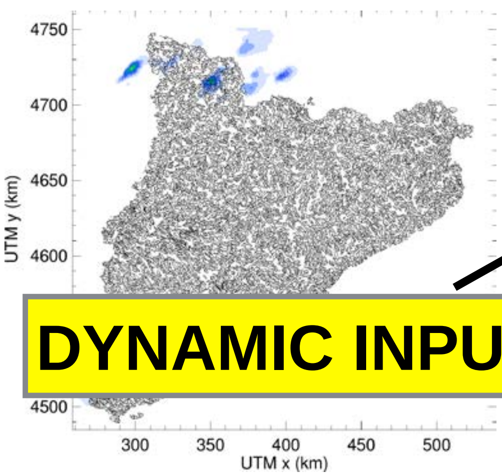


Warning level matrix

Susceptibility

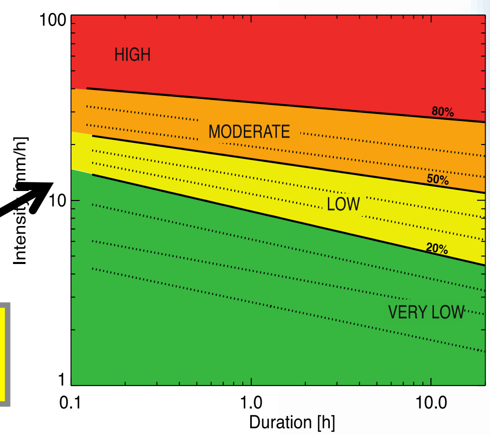
Rainfall hazard level		Susc Very Low	Susc Low	Susc Moderate	Susc High
	Rain Very Low	VL	VL	VL	L
	Rain Low	VL	L	L	M
	Rain Moderate	VL	L	M	H
	Rain High	L	M	H	H

Rainfall records (radar) every 30 min

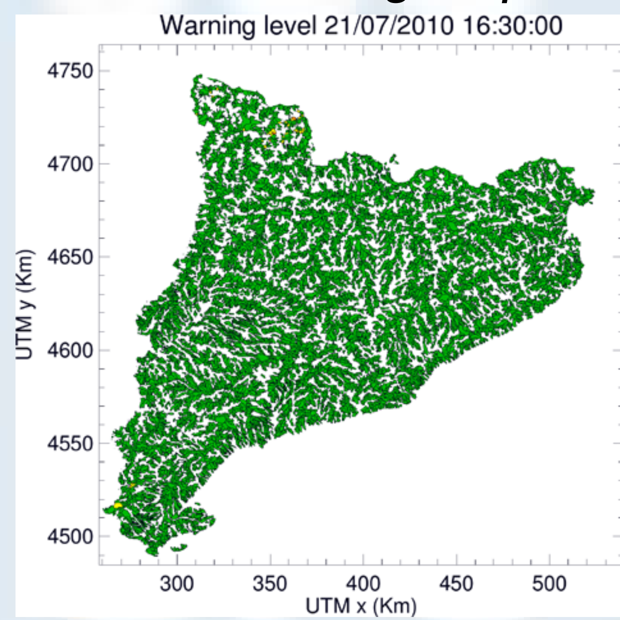


DYNAMIC INPUT

threshold criteria



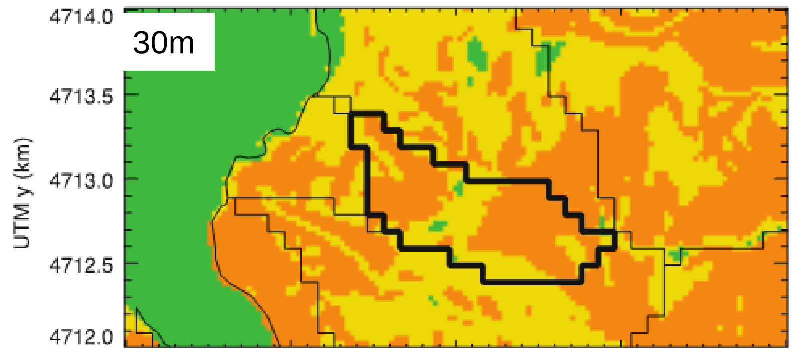
warning map



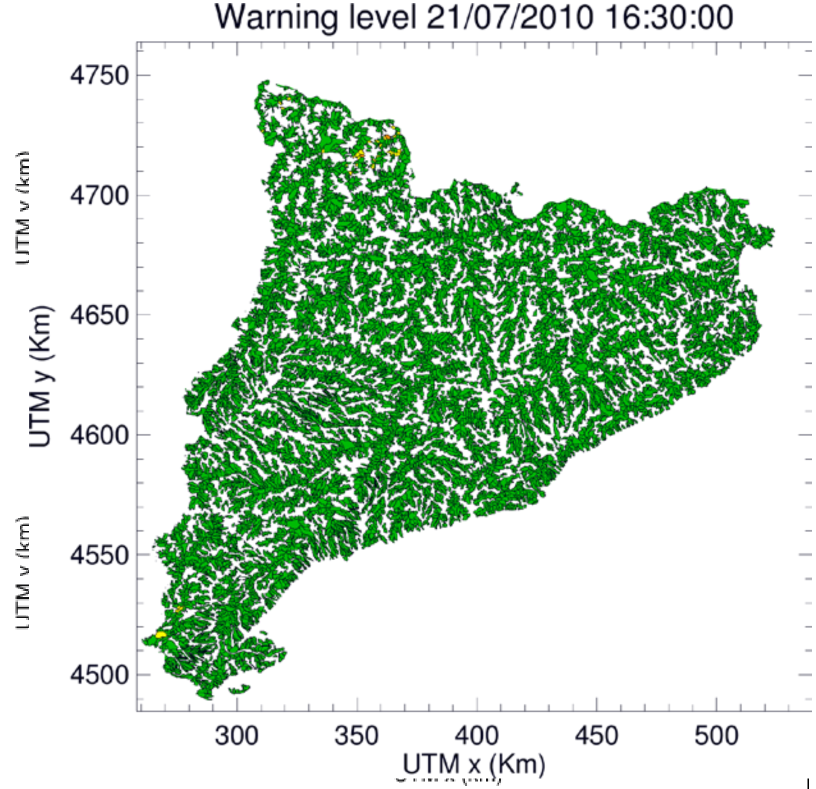
Palau et al. (under review)

Application: new EWS prototype for Catalonia

- General requirements of EWS:
  - *Good performance (→validation)*
  - *Fast calculation*
  - *Easy interpretation*

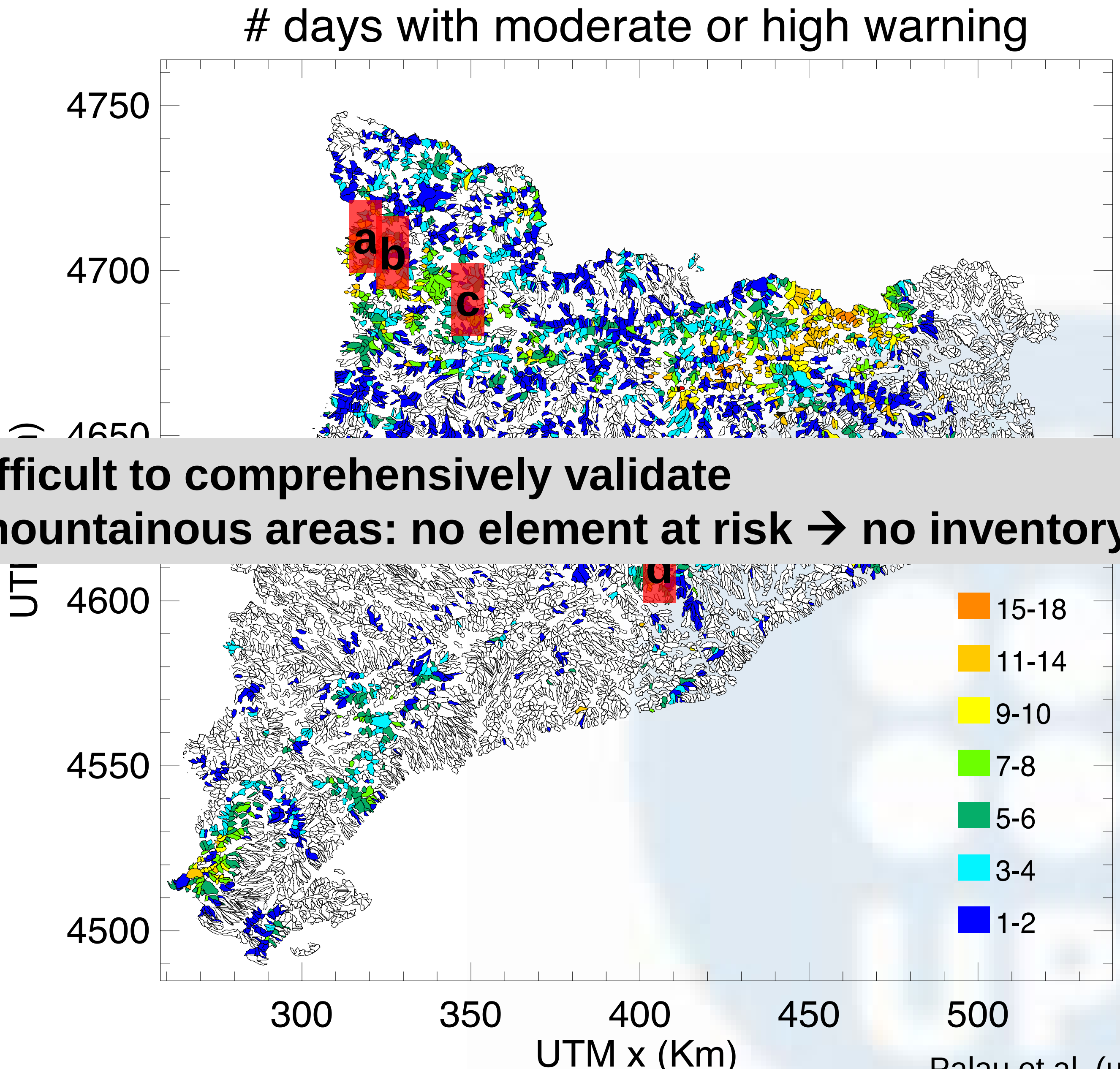


Computational time (entire CAT):
~~5m: 50min~~
30m: 1.5 min (35.5 million pixels)
200m: 2.9 s
Basins: 0.7 s (18000 basins)



Easy interpretation:
→ using basins

Application: Validation phase of 7 months in 2010

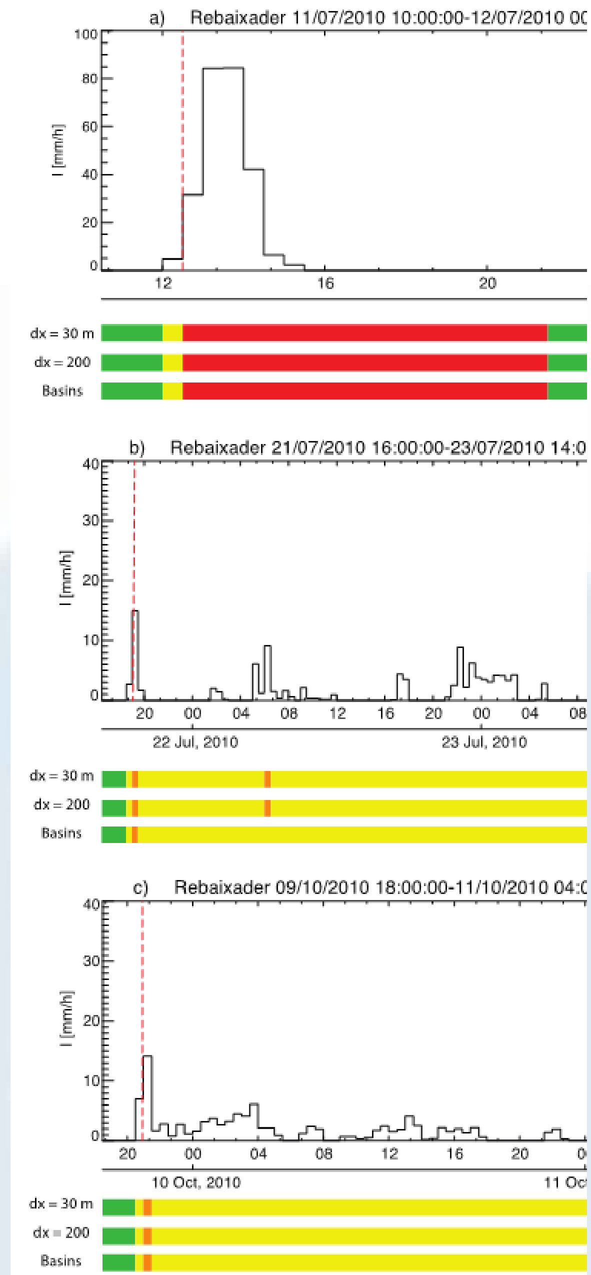


→ **Difficult to comprehensively validate**
(mountainous areas: no element at risk → no inventory)

Palau et al. (under review)

Application: Validation phase in 2010

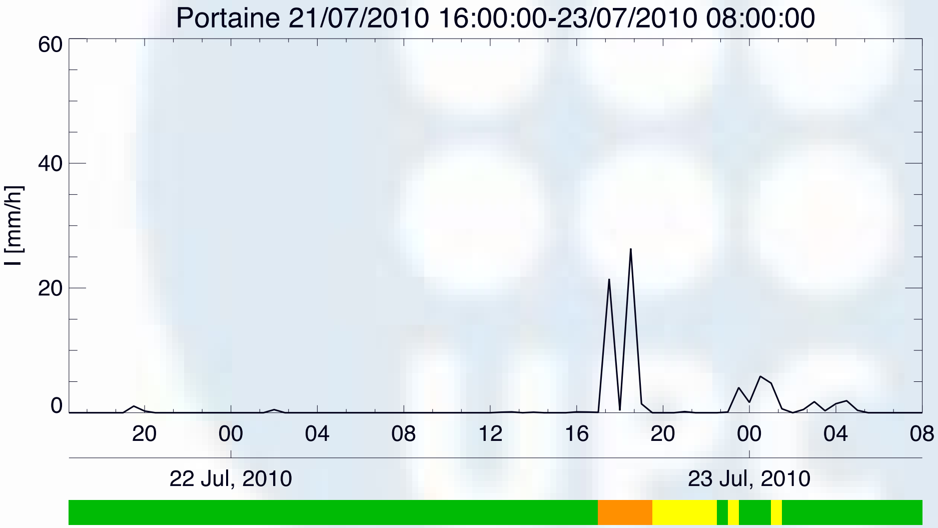
- Validation: Rebaixader monitoring site



Palau et al. (under review)

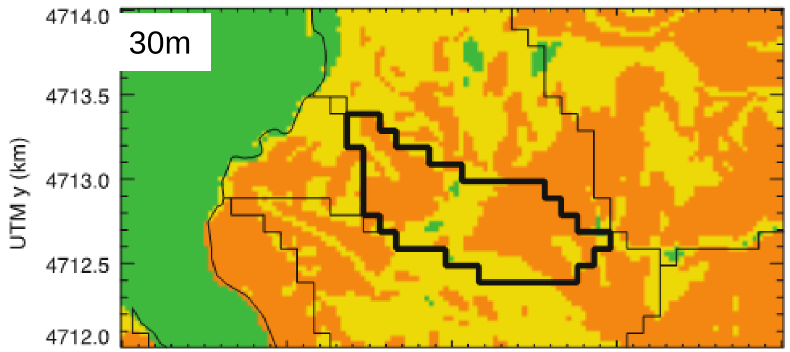
Application: Validation phase in 2010

- *Validation: Portainé*

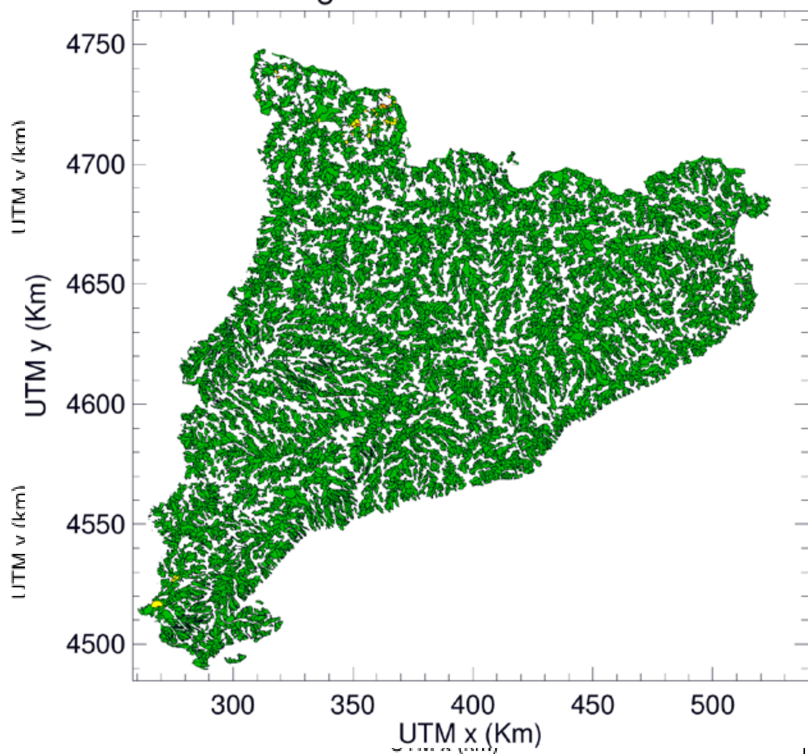


Application: new EWS prototype for Catalonia

- Characteristics
  - *Performance (satisfying results)*
  - *Fast calculation (every 30min)*
  - *Easy interpretation (basins)*



Warning level 21/07/2010 16:30:00



Final prototype:
→ Calculations using 30m pixels, but visualization by basins
→ Possibility to zoom-in

Outlook: rainfall nowcast/forecast to improve EWS

- Over a network of 170+ radars. 5-h forecasts.

Concluding remarks

- *EWS are very helpful - necessary tools*
- *Still many uncertainties (false alarms!)*

- ***Where** debris flows occur → correct susceptibility maps*
  - *Future changes (e.g. vegetation cover)*
- ***When** debris flows occur → correct rainfall thresholds*

  → correct rainfall measurements

  → incorporation of nowcasting/forecasting
  - *Future changes*

- *We are on the right way, but there is still a lot of work to do!!*

Questions?

marcel.Hurlimann@upc.edu