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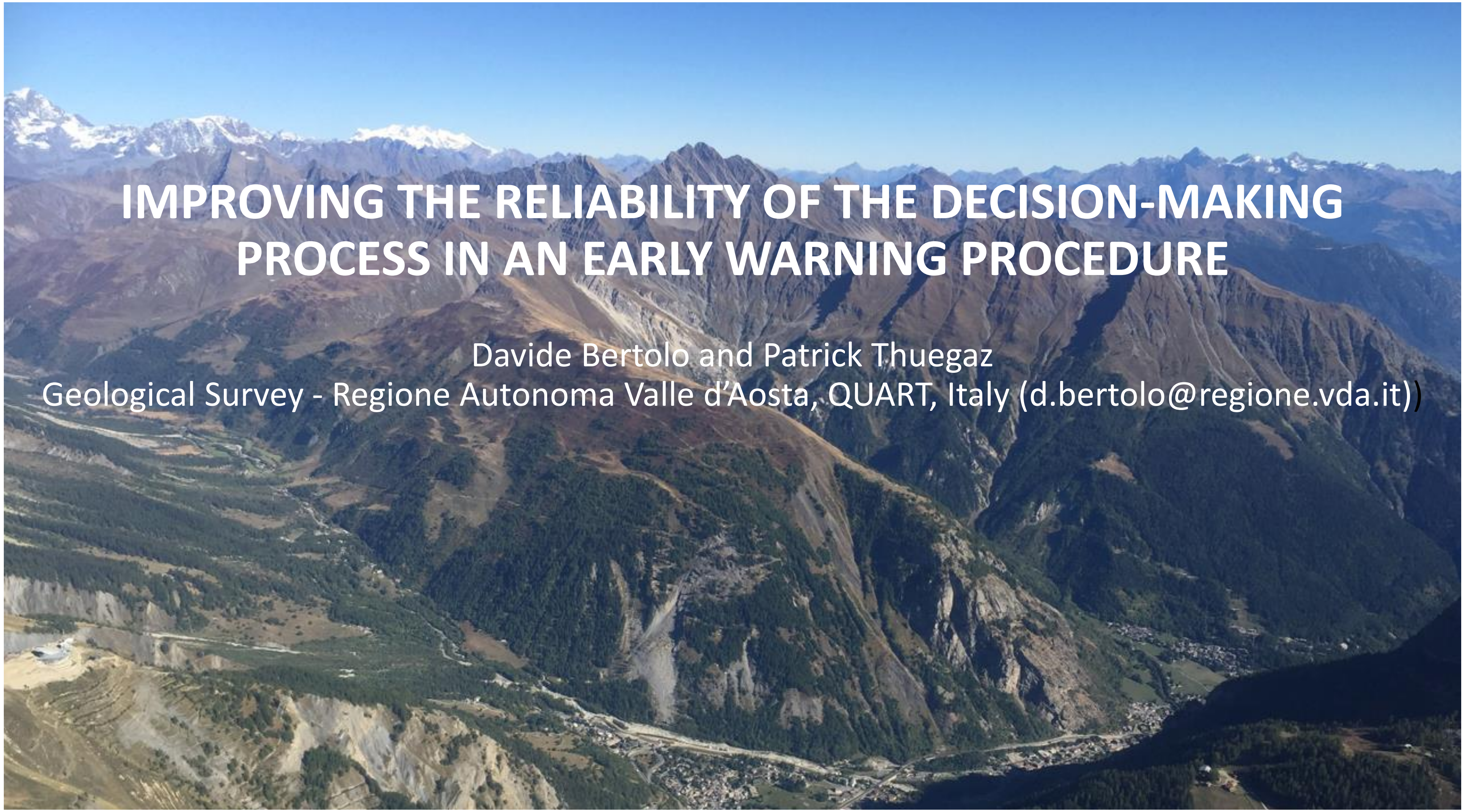

IMPROVING THE RELIABILITY OF THE DECISION-MAKING PROCESS IN AN EARLY WARNING PROCEDURE

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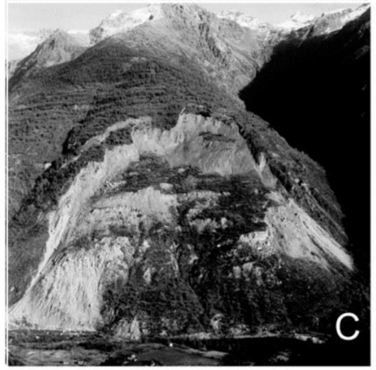
MAIN SOURCES OF BIAS INFLUENCING HUMAN DECISIONS APPLIED TO LANDSLIDE EWs MANAGEMENT

(Kahneman D. and Twersky A., 1979)

RISK AVERSION → « CRY WOLF » EFFECT →

LA CLAPIÈRE



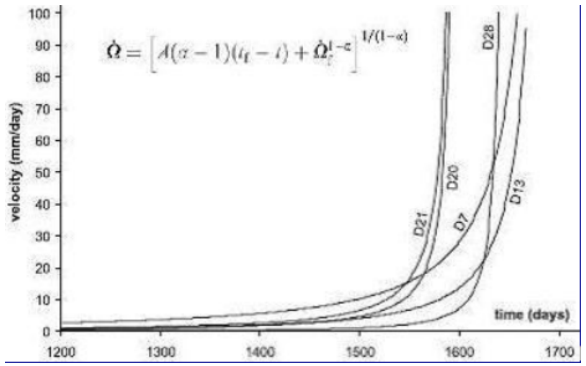
OVERCONFIDENCE → CATASTROPHE →

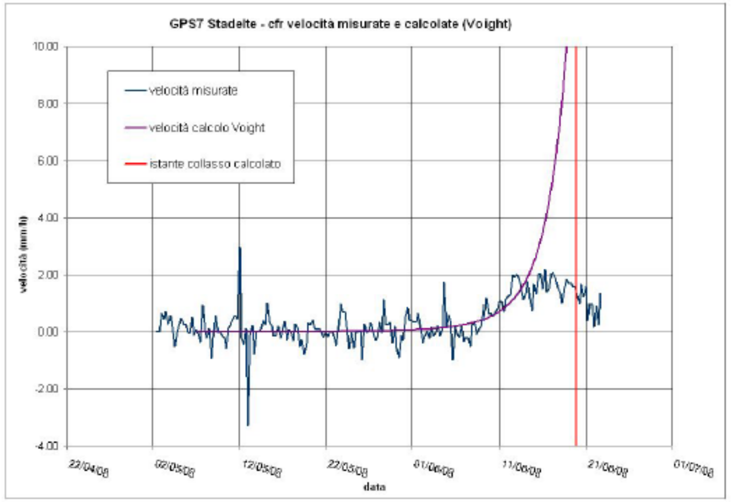
VAJONT

TAKEAWAYS

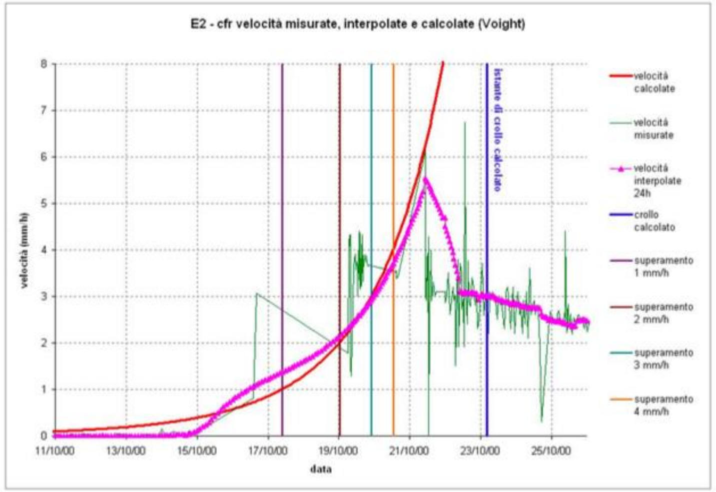
- **Need for objective and transparent decision making process in Early Warning systems;**
- **To fully exlpoit the functionalities of the modern monitoring systems, collecting all the objective evidences supporting the decisions which are taken**

Application of the Voight method
On displacement thresholds
Experience of the Aosta Valley Geological Survey
from 2000 to 2010

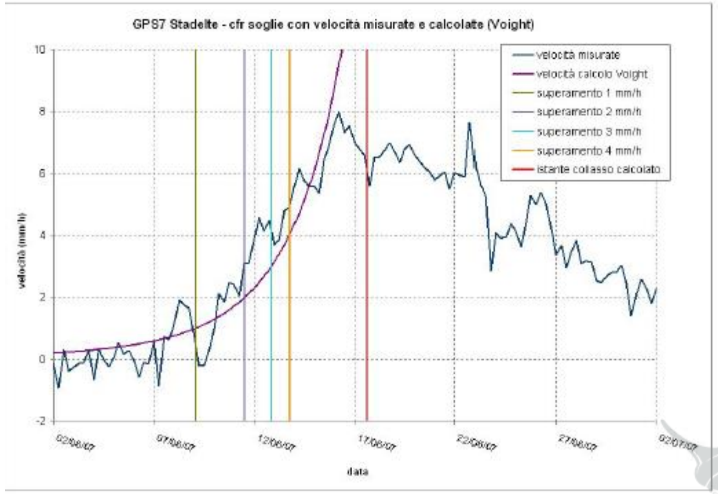




BECCA DI NONA, 2000



STADELTE LANDSLIDE, 2007



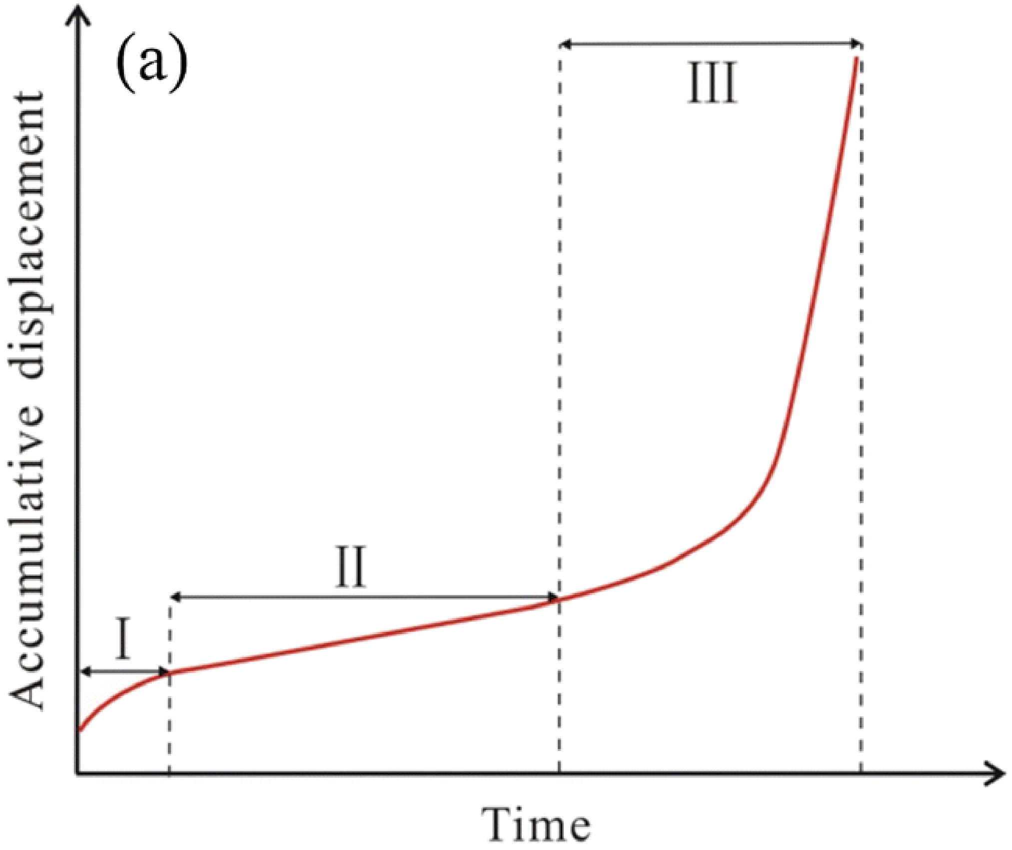
STADELTE LANDSLIDE, 2008

- **Different: Tectonic setting, Lithologies, Triggering causes (Rainfalls, Snowcover melting, Slope instability).**
- **Same thresholds calculated on world-scale statistics based on a limited sample of landslides which collapsed**

In all the above cases <u>the final collapse of the landslide didn’t occur</u>…

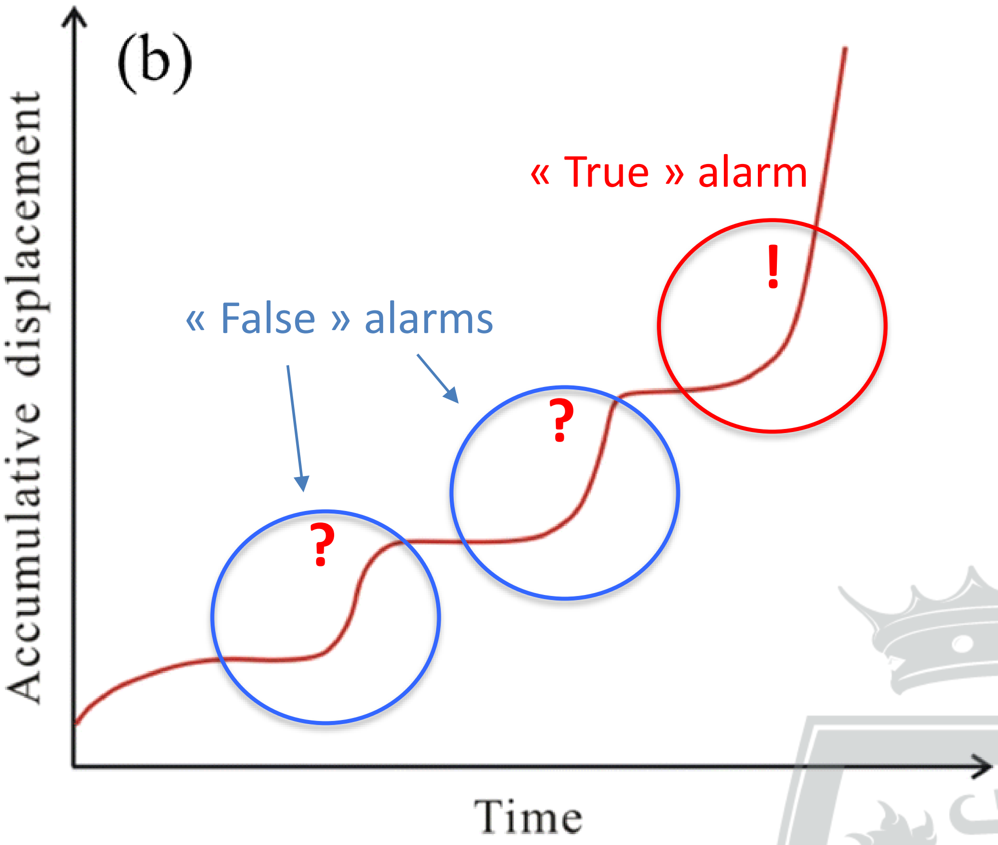
WHERE IS « OUR » LANDSLIDE ALONG ITS EVOLUTIONARY PATH ?

Creep deformation theory (Saito, 1969)



?

Step-like landslide evolution curve (Zhou et al., 2018)



- An EW system based on displacement thresholds has a conservative approach. Any alert state is triggered on the hypothesis of a final collapse. In the case of a displacement threshold, the reference behavior is the Creep deformation theory but, in case of complex landslidess seasonally reactivated, the trend displacement is multi-stage, and shows a step-like multi-year trend defined as « periodic displacement (Zhou et al., 2018).
- Displacement thresholds do not provide any insight about the real evolutionary stage of the monitored landslide. The thresholds could make sense if taking into account the real amount of deformation cumulated by the slope and the remaining amount of stress that the landslide is able to absorb without collapsing.

«QUANTITATIVE » DISPLACEMENT THRESHOLDS

STRENGHTS

- **OBJECTIVE AND REPLICABLE;**
- **DETECTION OF SMALL DISPLACEMENTS;**

WEAKNESSES

- **BASED ON QUANTITATIVE AND QUALITATIVE POOR SAMPLES**

  QUANTITATIVE:

  ✓ Poor record of collapsed landslidess available for statistic elaboration

  QUALITATIVE:

  ✓ The samples gather – IN BACK ANALYSIS – displacement velocities measured by different kinds of instruments (strain gauges, RTS, etc.) sometimes placed at the main scarp (extensometers);

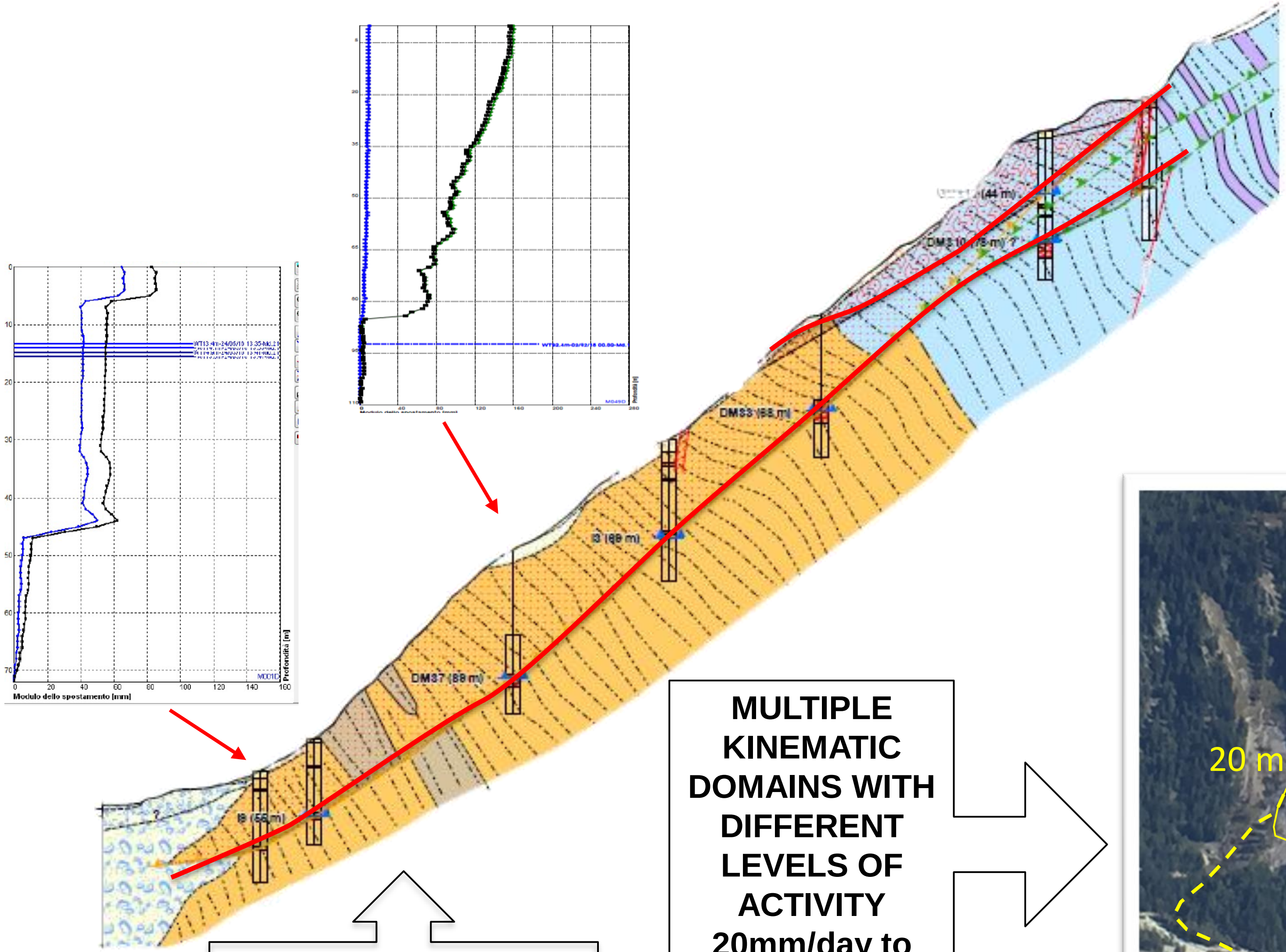
  ✓ Back analysis. The threshold setting is based on the lanslides that actually collapsed and not on the whole population of the active landslidess.

  ✓ **Thresholds do not provide any insight about the real evolutionary stage of the monitored landslide. I.E. the thresholds should be adjusted taking into account the real amount of deformation cumulated by the slope and the remaining amount of stress that the unstable mass could absorb without collapsing.**

LEARNING FROM THE EXPERIENCE OF THREE YEARS OF EMERGENCIES AT THE MONT DE LA SAXE LANDSLIDE

A COMPLEX LANDSLIDE

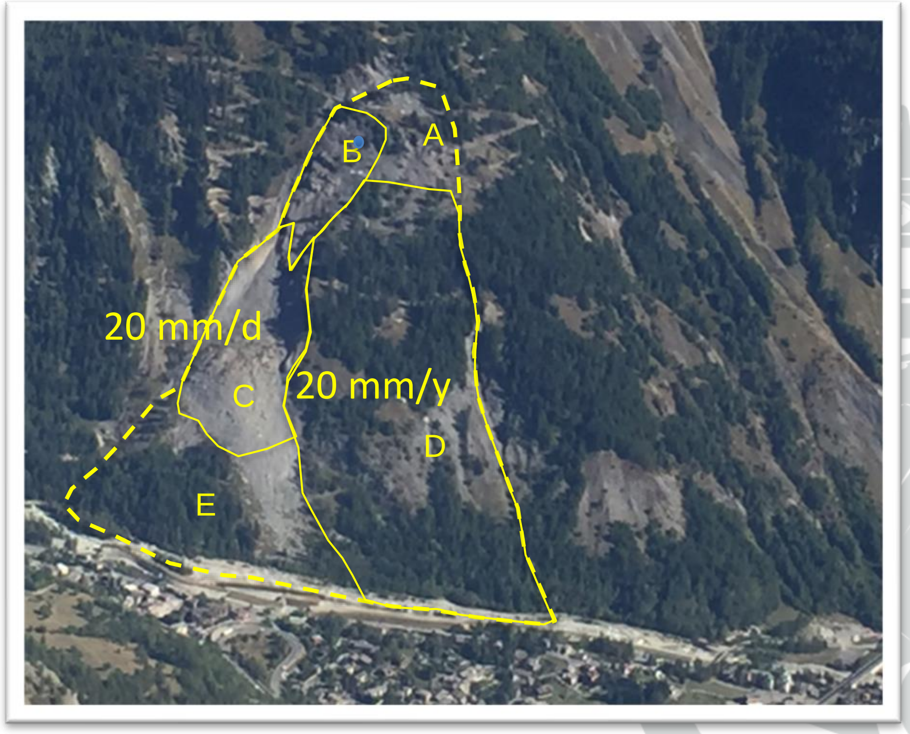
- **In Depth**
- **In surface**



MULTIPLE FAILURE SURFACES IN DEPTH

MULTIPLE KINEMATIC DOMAINS WITH DIFFERENT LEVELS OF ACTIVITY 20mm/day to 20 mm/year

MULTIPLE SEQUENTIAL FAILURES LIKELIHOOD, LEADING TO A TOTAL COLLAPSE of 8.300.000 m^3



CRITICAL TARGETS

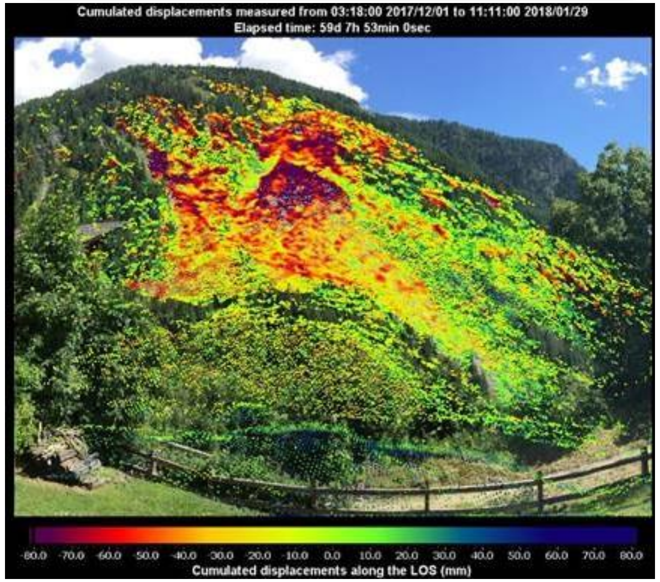
The total collapse of the Mont de La Saxe Landslide involves a volume of 8.300.000 m3. It could bury the valley floor with a layer of debris up to 40 m thick.

On the valley floor there are touristic resorts and critical infrastructures.

THE MANAGEMENT OF A COMPLEX LANDSLIDE THREATENING CRITICAL TARGETS REQUIRES A COMPLEX AND REDUNDANT MONITORING SYSTEM

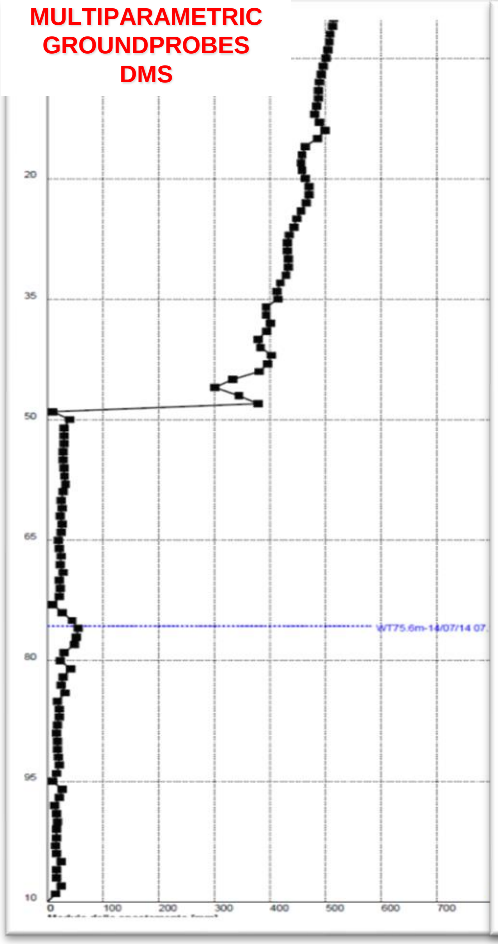
PUNCTUAL INFORMATION

SURFACE DISPLACEMENT SINGLE AND MULTIPOINT



SURFACE DIPLACEMENT

DATA SPATIALISATION AREAL INVOLVEMENT

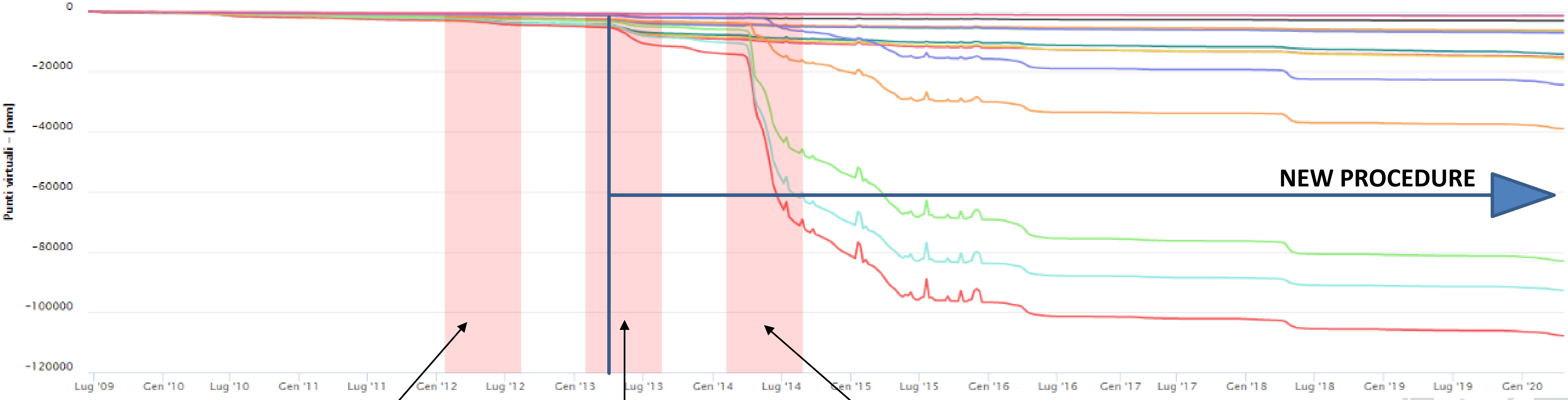


DEEP MONITORING OF THE IN-DEPTH DISPLACEMENT AND Ground Water Table (GWT) Level

UNSTABLE VOLUMES AND EVENT SCENARIOS

EVOLUTION OF THE SLOPE DEFORMATION (GB-INSAR VIRTUAL POINTS) OF THE MONT DE LA SAXE LANDSLIDE FROM 2009 TO APRIL 2020

- The deformation shows a clear step-like trend deformation, controlled by the seasonal snowcover melting.
- In 2012 the first PRE ALERT activation, in which the displacement velocity threshold was exceeded, **was based on the Voight model**.
- **During the 2013 emergency, the EW procedure was modified, integrating other sources of information coming from the integrated landslide monitoring system, to support the decision process leading to the tirggering of the civil protection plan.**
- **During the 2014 emergency**, **with the adoption of the new decision-making procedure,** despite exceptionally high displacement velocities (up to 500 mm/h) and the final collapse of an entire 450.000 m^3 domain of, people were evacuated for only 30 days.



2012 activation
- V24>1 mm/h
- Pre-Alarm condition
- Duration: 3 months

NO COLLAPSE

2013 activation
- V24>20 mm/h
- ALARM condition
- 100 people evacuated
- Duration: 50 days

NO COLLAPSE

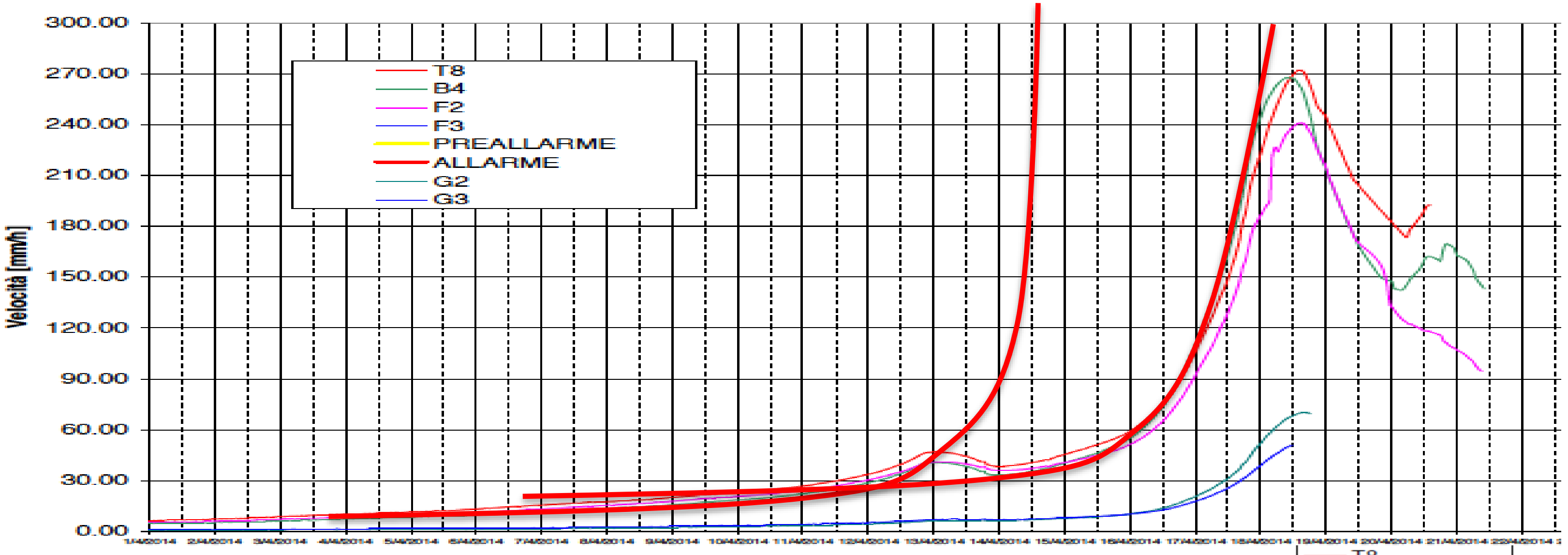
2014 activation
- V24>20 mm/h
- ALARM condition
- 100 people evacuated
- Duration: 30 days

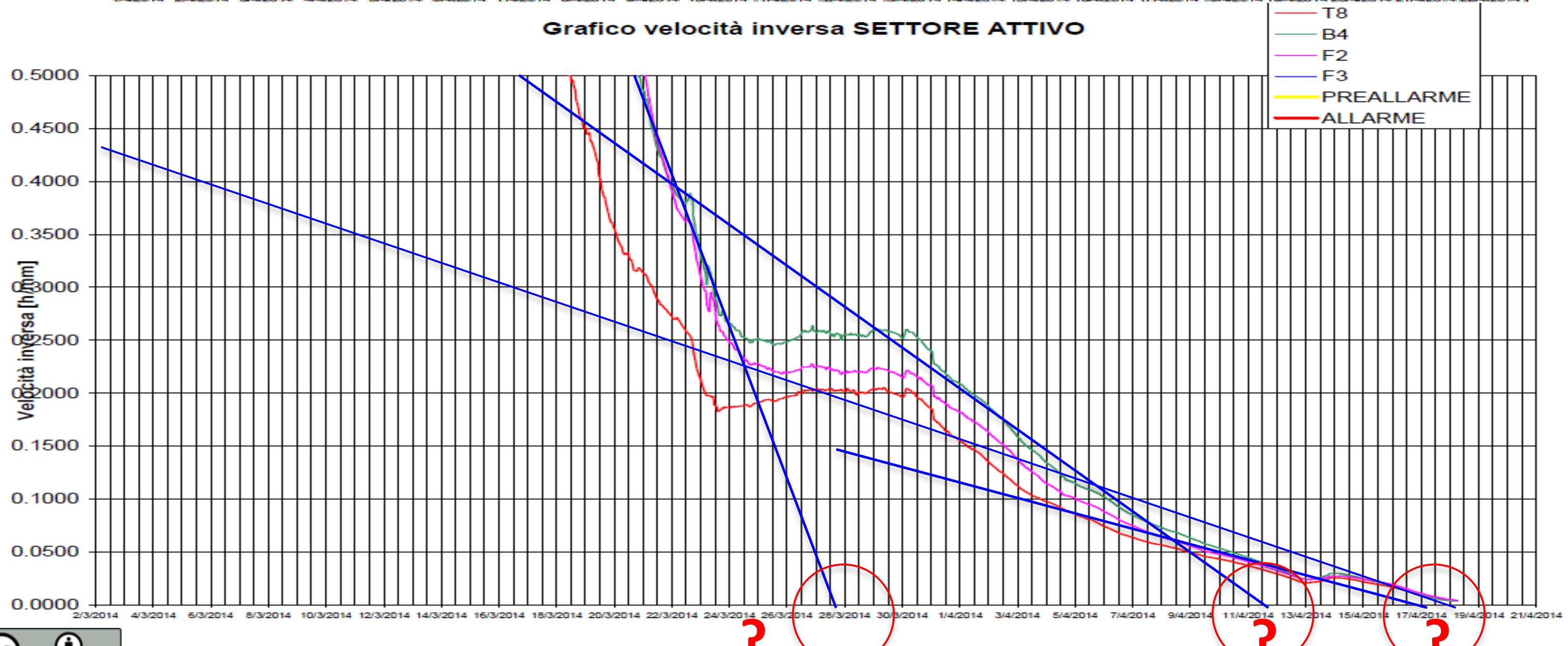
SINGLE DOMAIN COLLAPSE 450.000 m^3

LA SAXE EMERGENCY - APRIL 2014

Velocity V24 RTS 31.03.2014 - 22.04.2014

VOIGHT





During the 2014 emergency, both Voight and the « Inverse Velocity » methods had been tested

The early warning system was set on two displacement thresholds, measured by a Robotized Total Station (RTS)

In the EW the alert thresholds are calculated on the average displacement velocity on the last 24 hours:

$$V_{24}$$

Two threshold values had been set:

1) **PREALARM THRESHOLD: V24= 1 mm/h;**
2) **ALARM THRESHOLD: V24= 2 mm/h**

Both models predicted, on many dates, collapses which didn't happen in the end

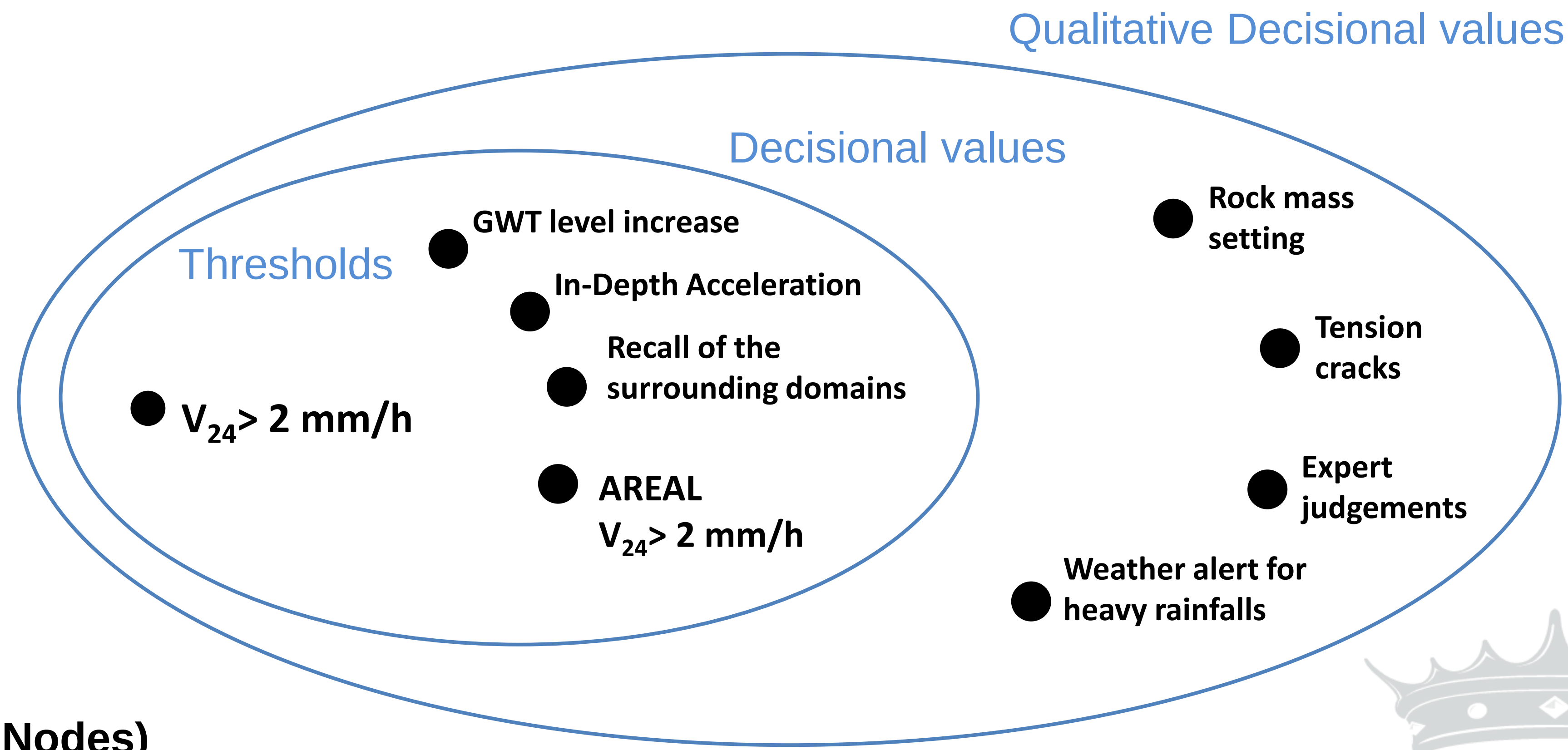
THE FEATURES OF THE NEW EARLY WARNING DECISION MAKING PROCESS

- **Providing a confidence/uncertaninty value** associated to each decisional stage, to be communicated in transparency (weather forecast-style);
- **Being clear and transparent** but **able to include** also the information coming from the **« expert judgments »**, i.e. the advices from the experts;
- **Including qualitative** (e.g.: observation of new trenches and scarps, state of fracturation of rocks mass) or semiquantitative observations (e.g.: increase in the level of the GWTable, in-depth accelerations on sliding planes) and to match them with the genuine quantitative data.

Rose and Hungr (2007), about the Inverse Velocity method:

*« The method **must not be applied in isolation**, **without being accompanied by qualitative observations of slope behaviour**, collection of data and on-going analysis of the structure of the slope, rock mass condition, stress and groundwater regime. **DISPLACEMENT MONITORING IS ONLY ONE COMPONENT OF A COMPLEX PROCESS THAT COMPRISES SLOPE STABILITY MANAGEMENT. »***

THRESHOLDS AND OTHER DECISIONAL VALUES



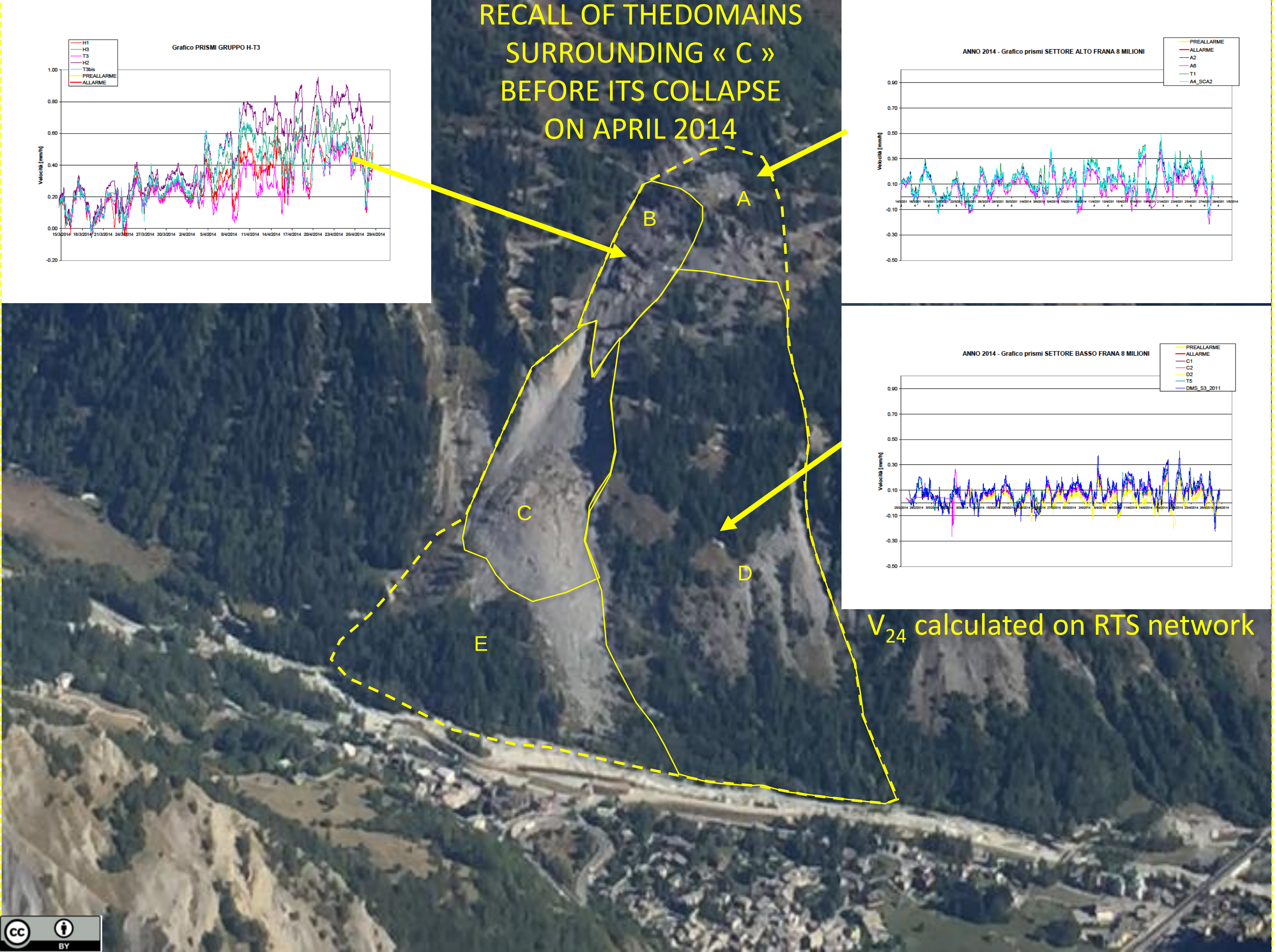
Thresholds

- Quantitative
- Coincident with numerical values
- Fixed
- Always objective

Decisional values (i.e.: Decisional Nodes)

- Quantitative and/or Qualitative
- Not necessarily objective (observation by experts or « expert judgements » e.g.: new crack observations etc.)

How to design a decision-making protocol which could combine all these types of data?



The **RECALL OF NEIGHBORING KINEMATIC DOMAINS**, which preceeded the collapse of domino C, can be interpreted as a precursor of the total collapse of the landslide by multiple sequential failures

That is an example of a **Semiquantitative Decisional value** worth to be inserted in the decision-making process

The decision making process adopts the bayesian inferential approach, successfully adopted since many years in medicine and in other fields, where decisions have to be taken in a short time and under critical conditions

Bayesian processes allow us to combine quantitative and qualitative data

The decision-making process provides to compare the exceeding of the V_{24} displacement threshold
<u>AS THE OUTCOME OF A DIAGNOSTIC TEST</u>

where the POSITIVE VALUE is assumed to be the exceeding of the threshold of V_{24} = 2 mm/h

$$\mathrm{P}\ (A|B) = \frac{\mathrm{P(B|A)P(A)}}{\mathrm{P(B)}} = H_0$$

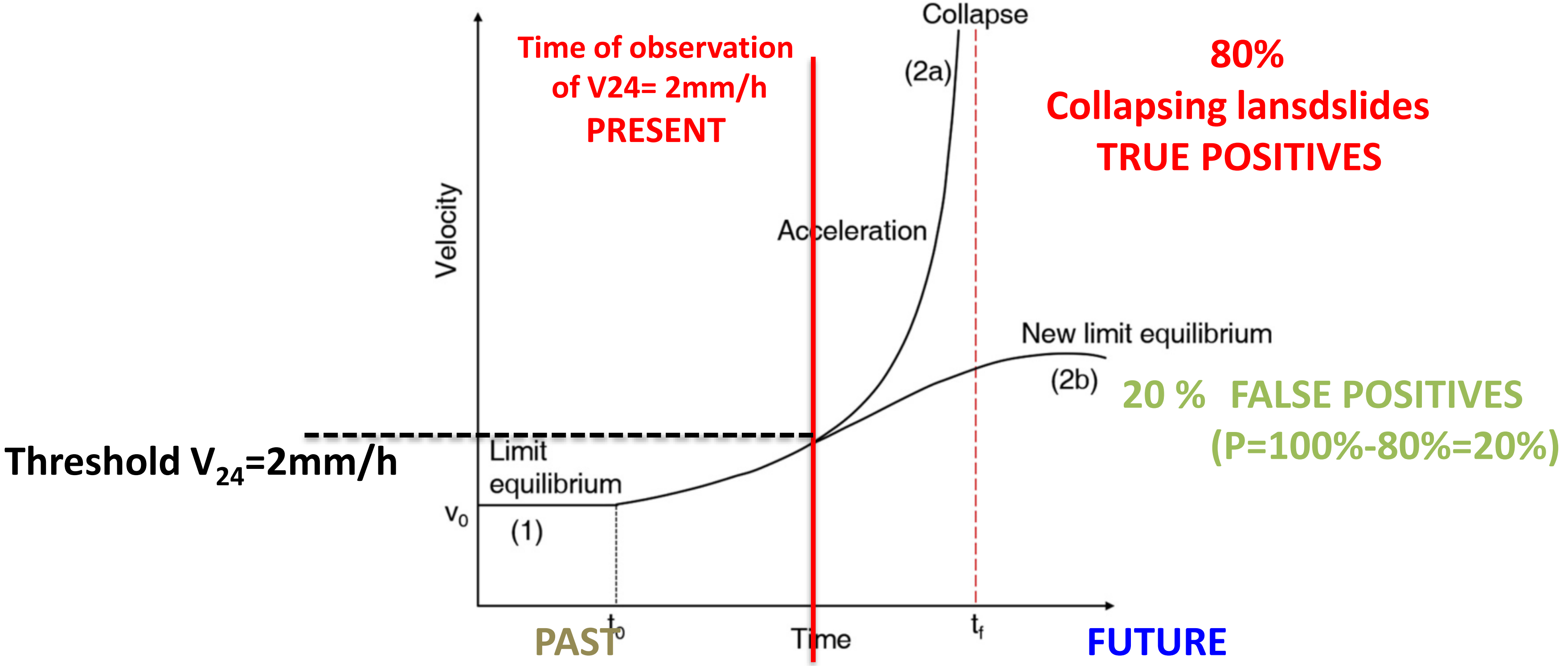
$$\text{P (Collapse|Threshold exceeding)} = \frac{\text{P (Threshold exceeding|Collapse)* P (Collapse)}}{\text{P (Threshold exceeding)}}$$

If the **V_{24} test is positive**, then **further investigations and observations** are performed, in order to diagnose the « a priori » probability of the collapse or the probability of other scenarios

TO ASSESS A CORRECT EVALUATION OF THE « V_{24} TEST » ALL THE CRITICAL PARAMETERS HAVE TO BE ESTIMATED

CALCULATING THE PARAMETERS FOR THE V_{24} TEST

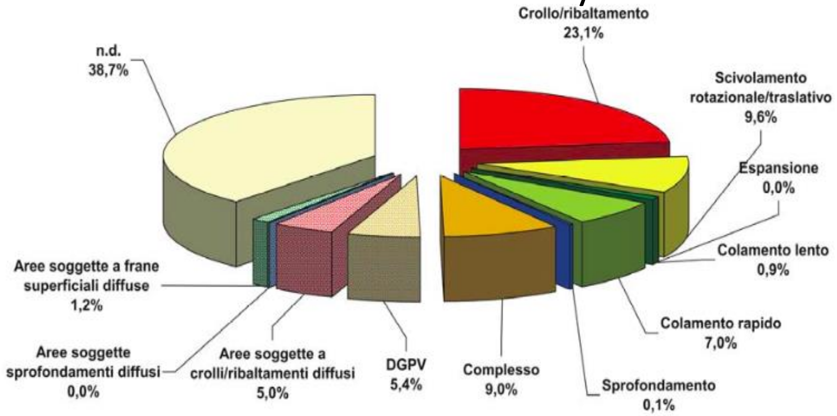
- **SENSITIVITY (Se)** = 1 =100%. That is: every recorded landslide at its collapse (terminal velocity) exceeds V_{24}=2mm/h.
- **SPECIFICITY (Sp)** = the percentage of active instabilities that, once exceeded the V_{24}=2mm/h threshold, actually collapsed: the **"true positives"**.
  The inverse of this parameter (1-Sp) is the percentage of **"false positives" that is the percentage of instabilities that, despite exceeding the V_{24}=mm/h threshold didn't collapse;**



- **PREVALENCE (Pr)**= Observed frequency of the phenomenon (landslide) in a given territory.

ESTIMATING THE PREVALENCE VALUE
Using the regional landslide susceptibility

(source: IFFI Official italian inventory for the Aosta Valley)



Superficie totale Regione (km²)	Area montano-collinare (km²)	Schede IFFI	Numero di PIFF	Area totale in frana (km²)	Densità dei fenomeni franosi (n° Frane / Superficie Regione)	Indice di Franosità % (area totale in frana / superficie Regione)	Indice di Franosità % (area totale in frana/area montano-collinare)
3262	3262	4359	2992	520,35	1,34	16	16

The susceptibility index is 16% and, excluding residual cathegories of landslides, we could set the PREVALENCE VALUE ≈ 15%

Calculating prevalence is a key step, because the prevalence value directly influences the Predicted Positive Value.

PROBABILITY OF A POSITIVE (V24<2mm/h)
IF THE LANDSLIDE IS COLLAPSING
I.E. THE SENSITIVITY

OBSERVED FREQUENCY OF THE SLOPE INSTABILITY
IN THE REGIONAL TERRITORY
I.E. THE PREVALENCE

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B|A) \cdot P(A) + P(B|nonA) \cdot P(nonA)}$$

FALSE POSITIVES

OBSERVED FREQUENCY OF NON-COLLAPSING SLOPES

PPV= Predictive Positive Value: the probability that the exceeding of the V_{24} threshold is really predicting an ongoing future collapse

PPV IN THE CASE OF V_{24}:

$$\text{PPV } (H_0) = \frac{1 * 0{,}15}{1 * 0{,}15 + (1 - 0{,}80) * (1 - 0{,}15)} = 46{,}88\% \approx 47\%$$

PROBABILITY TO DISPATCH A FALSE ALERT = 53% MORE THAN 50%!

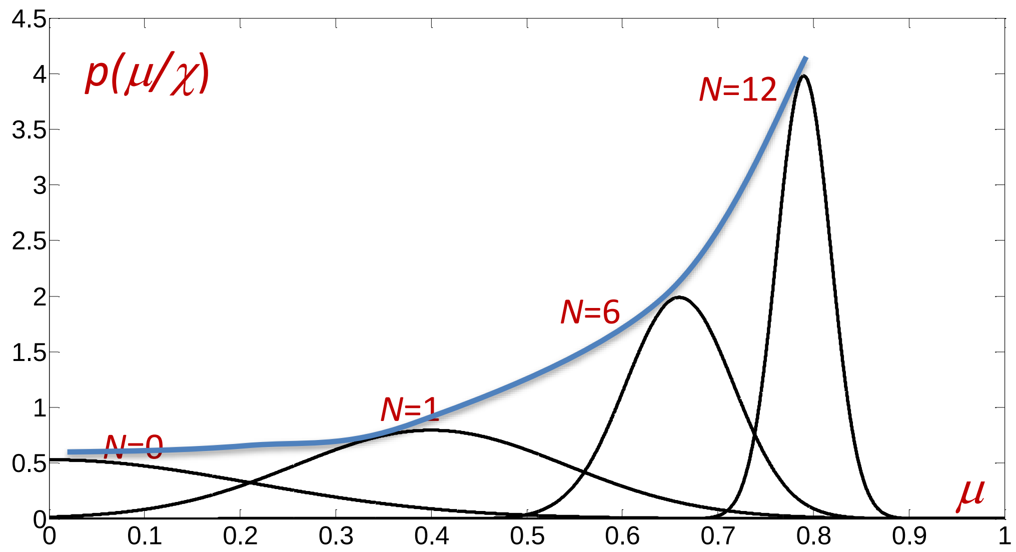
BAYESIAN INFERENTIAL ENGINE

INFORMATION

⇓

PRIOR HYPOTHESIS
(PRIOR probability of H_0 true) ⇒ BAYESIAN INFERENTIAL ENGINE ⇒ KNOWLEDGE
(« A Posteriori » probability of H_0 true)

The iteration of the process,
assuming the « a posteriori »
Probability Density Function
becomes the « a priori » Probability Density Function (PDF)
of the further test and the **true value**
Is approached step by step



PDF variation with the increasing of the decisional values checking

LA SAXE ROCKSLIDE

INCREASING THE PREDICTIVE POSITIVE VALUE THROUGH A BAYESIAN SEQUENTIAL METHOD

DECISIONAL NODE 1 PPV
V_{24}>2 mm/h

$$H_0 = \frac{1 * 0{,}15}{1 * 0{,}15 + (1 - 0{,}80) * (1 - 0{,}15)} = 46{,}88\% \approx 47\%$$

DECISIONAL NODE 2 PPV
V24mm areal extended on a single domain + in depth DMS displ.> 10 mm/d

$$H_0 = \frac{1 * 0{,}47}{1 * 0{,}47 + (1 - 0{,}80) * (1 - 0{,}47)} = 81{,}50\% \approx 82\%$$

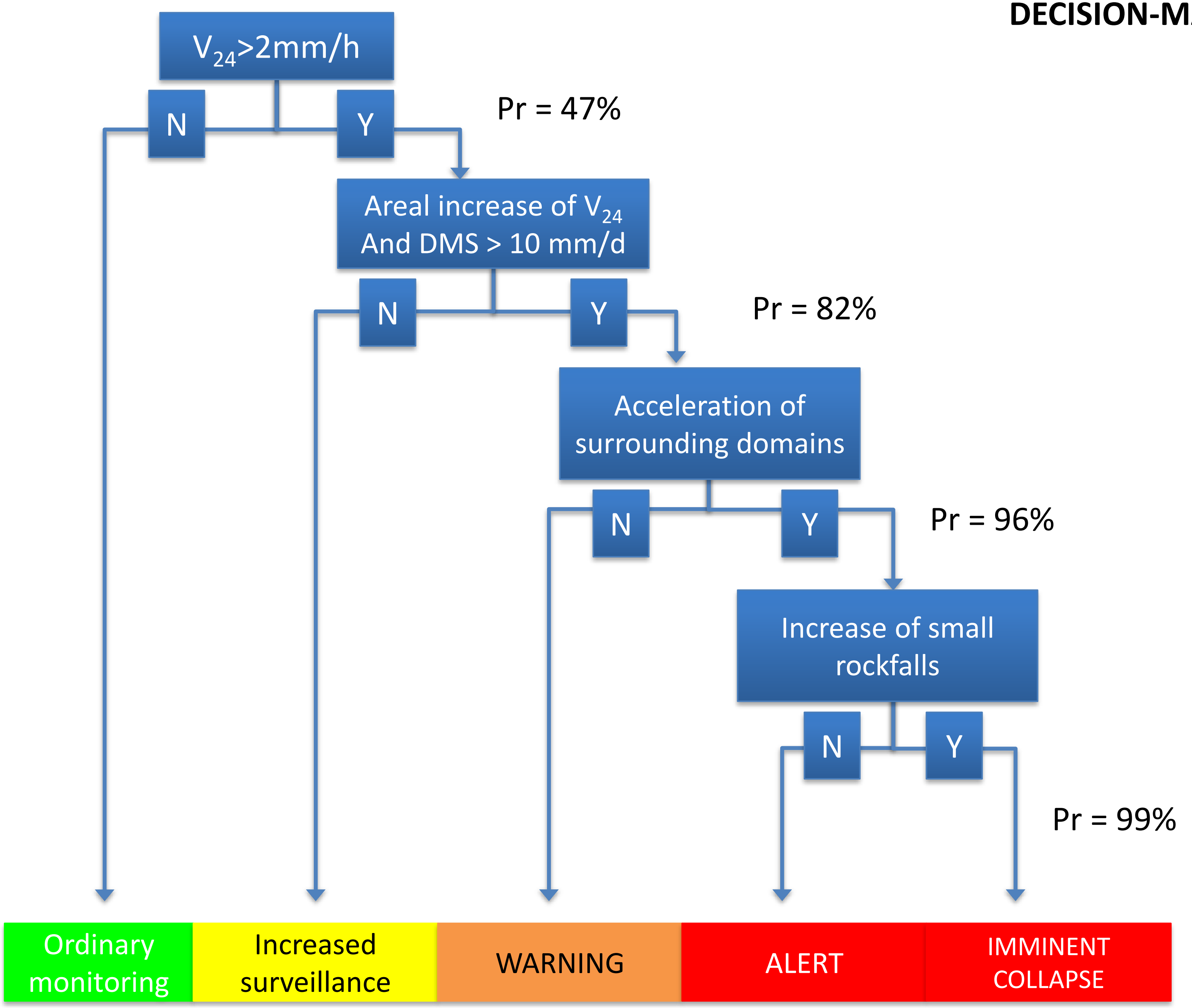
DECISIONAL NODE 3 PPV
V_{24} increasing in the surrounding domains

$$H_0 = \frac{1 * 0{,}82}{1 * 0{,}82 + (1 - 0{,}80) * (1 - 0{,}82)} = 95{,}66\% \approx 96\%$$

DECISIONAL NODE 4 PPV
increase of small rockfalls

$$H_0 = \frac{1 * 0{,}96}{1 * 0{,}96 + (1 - 0{,}80) * (1 - 0{,}96)} = 99{,}10\% \approx 99{,}0\%$$

DECISION-MAKING TREE



BY GOING THROUGH SEQUENTIAL STAGES WE LEAVE BEHIND US <u>THE ALTERNATIVE SCENARIOS</u>

V24>2mm/h ?

N → NORMAL TREND

Y → Areal increase of V_{24}

N → LOCAL LIMITED COLLAPSE (ROCKFALL)

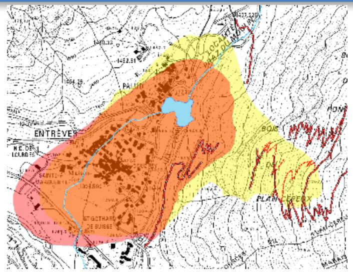
Y → In Depth Acceleration

N → SHALLOW EXTENDED COLLAPSE

Y → Acceleration of surrounding sectors

N → KINEMATIC STRUCTURAL DOMAIN COLLAPSE

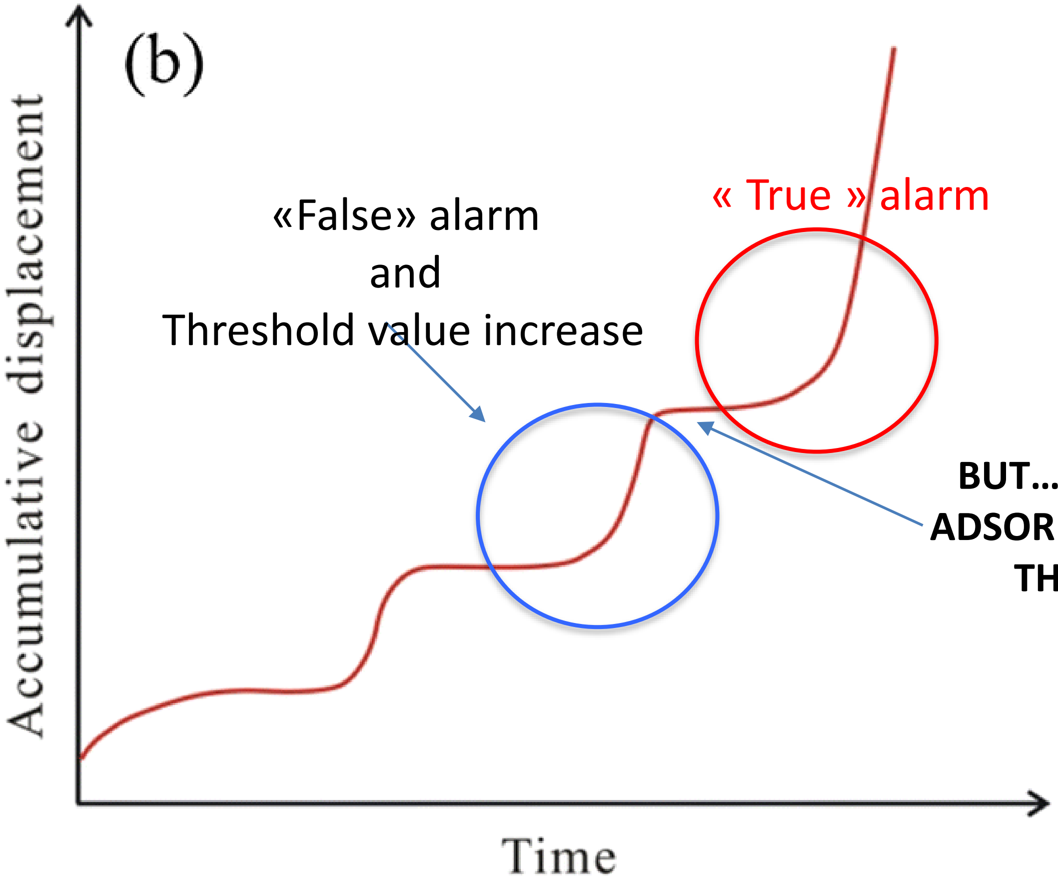
Y → TOTAL COLLAPSE H_0



TWO REASONS WHY CHANGING THRESHOLD VALUES AFTER A LANDSLIDE DIDN'T COLLAPSED IS NOT A GOOD IDEA BUT A DANGEROUS ONE

Frequently, **after a « false Alarm » event**, experts faces hard pressure by the public opinion to **raise the threshold values**. **And sometimes they do!** Here's the reason why **it might not be a good idea…**

WHERE IS OUR LANDSLIDE ALONG ITS EVOLUTION TREND ?

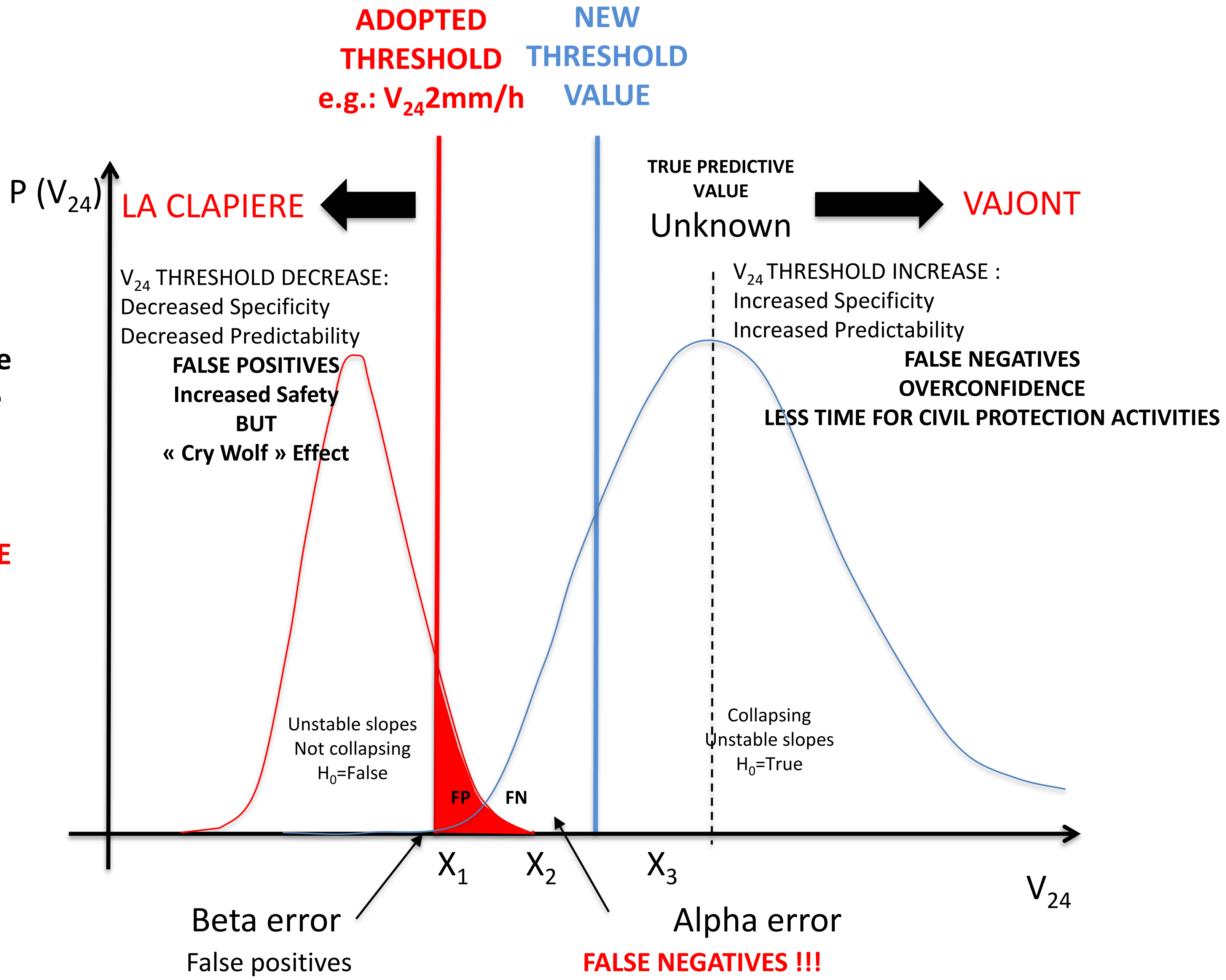


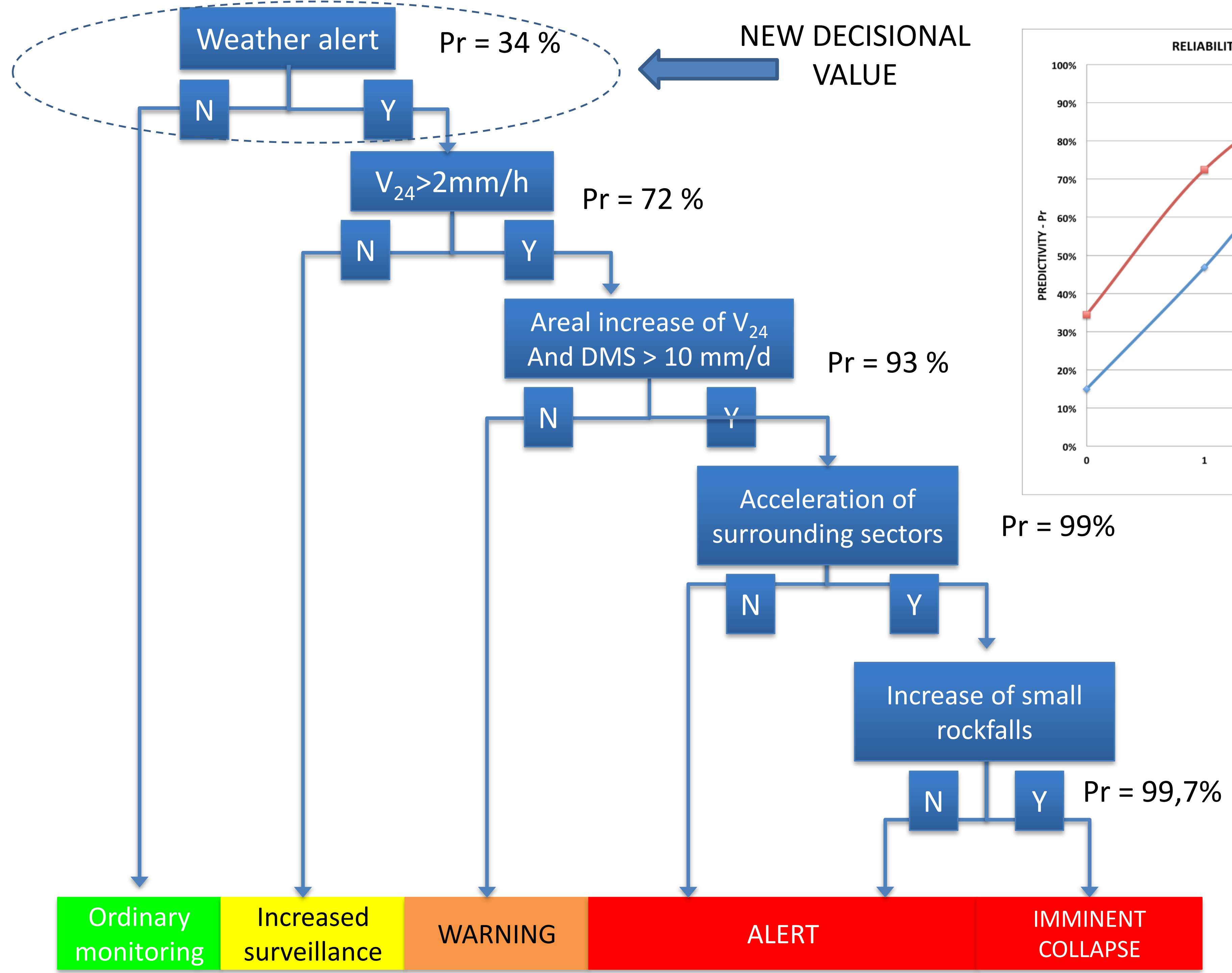
BUT…THE AMOUNT OF DEFORMATION ADSORBED BY THE SLOPE HAS INCREASED THEREFORE THE LIKELYHOOD OF COLLAPSE HAS INCREASED

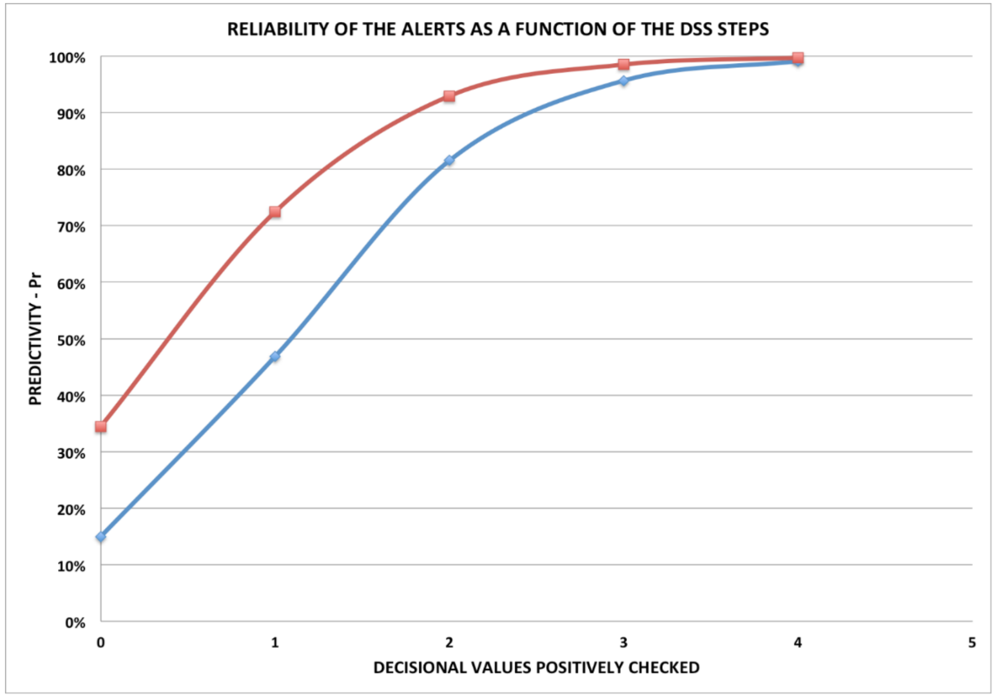
TWO REASONS WHY CHANGING THRESHOLD VALUES AFTER A LANDSLIDE DIDN'T COLLAPSED IS NOT A GOOD IDEA BUT A DANGEROUS ONE

FROM a quantitative point of view, to increase a threshold after a false alarm LEADS TO AN INCREASE FALSE NEGATIVES.

AN INCOMING COLLAPSE COULD NOT BE DETECTED!







THE SYSTEM SCALABILITY ALLOWS TO ADD NEW DECISIONAL VALUES TO IMPROVE THE PREDICTABILITY

SOME TAKEAWAYS

THE SYSTEM WE ADOPTED:

- **PROVIDES THE RELIABILITY** OF THE ALERTS BEING ISSUED (80% - 90% - 99%...)
- **ALLOWS A CLEAR, TRANSPARENT AND ASSERTIVE** COMMUNICATION TO THE CIVIL PROTECTION AUTHORITIES AND TO THE CITIZENS
- **PROVIDES THE DECISION-MAKERS** TIME THE LIKELIHOOD **DIFFERENT EVOLUTIONARY SCENARIOS** RELATED TO THE PHENOMENON;
- ALLOWS THE **INTEGRATION OF NEW DECISIONAL VALUES** EVEN IF THEY BECOME AVAILABLE DURING THE EMERGENCY PHASE;
- PROVIDES A **RATIONAL FRAMEWOR**K TO CHOOSE THE BEST INSTRUMENTS AND NETWORKS TO MONITOR THE INSTABILITIES;
- REQUIRES **A GEOLOGICAL REFERENCE MODEL** OF THE MONITORED LANDSLIDE, **OTHERWISE** IT HAS TO BE SET ON **CONSERVATIVE VALUES;**
- **REQUIRES AN INTEGRATED MONITORING NETWORK**, PREFERABLY EXTENDEND TO DEEP MONITORING, THEREFORE IS **SUITABLE FOR LANDSLIDES THREATHENING CRITICAL TARGETS.**

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