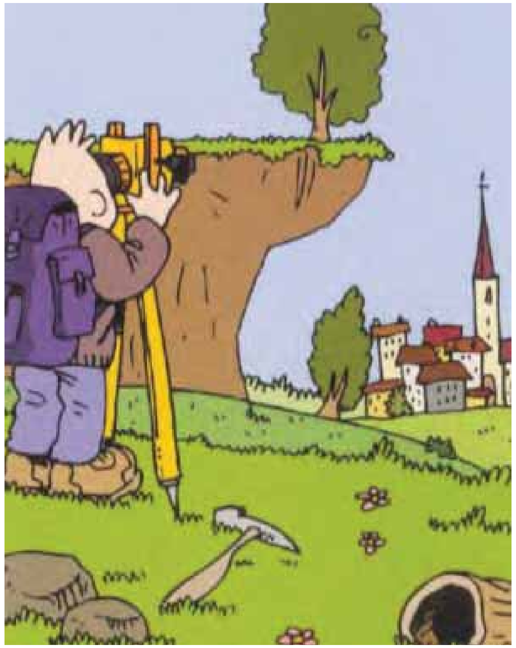
MONITORING LANDSLIDES:

WHAT WE KNOW AND WHERE RESEARCH NEEDS TO GO …

… SOME GUIDELINES FOR THE SELECTION OF THE MOST APPROPRIATE TECHNIQUES

Monitoring



Early-warning

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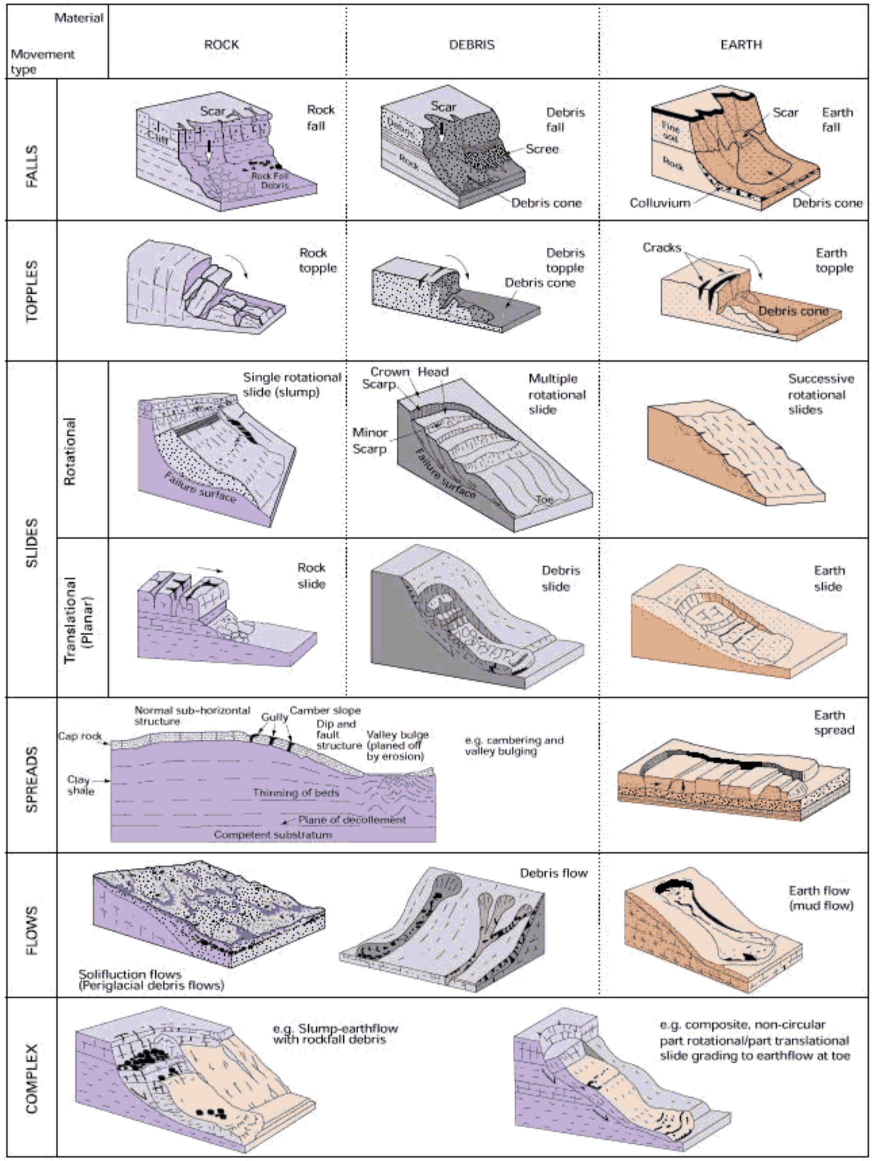
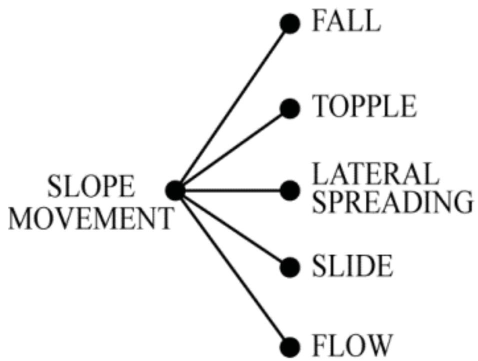
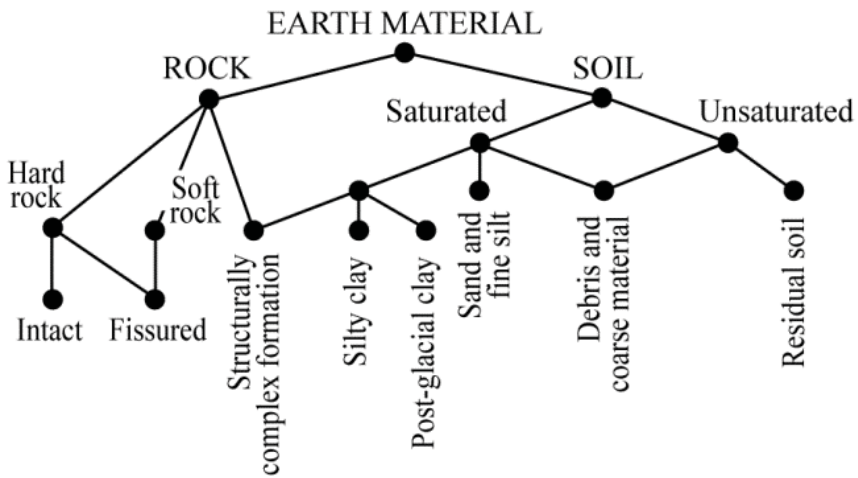
Problem: create accurate and comparable landslide observations



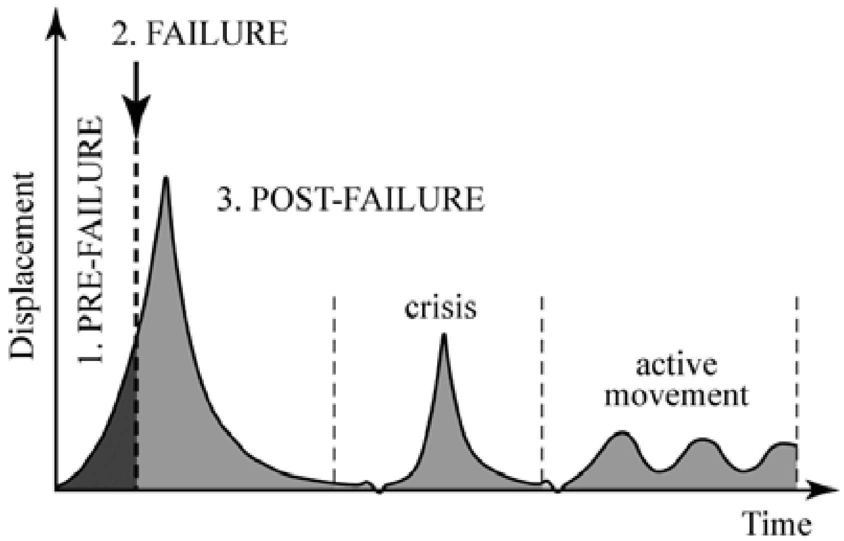
Classification of type of landslides (modified after (Varnes, 1978))

… Many landslide types …

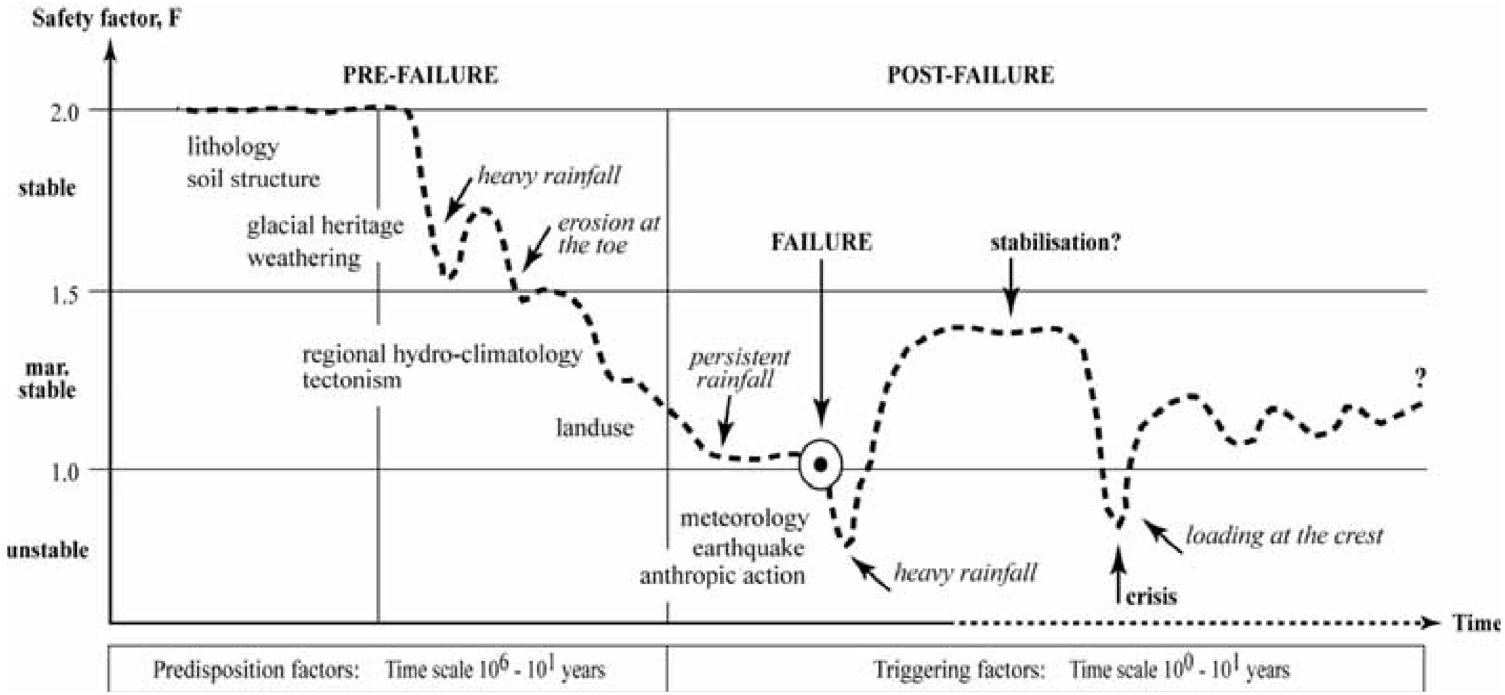




Problem: create accurate and comparable landslide observations

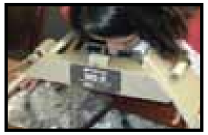


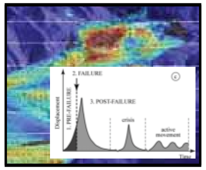
… Many stages of landslide developments …



Problem: define the focus of the monitoring …

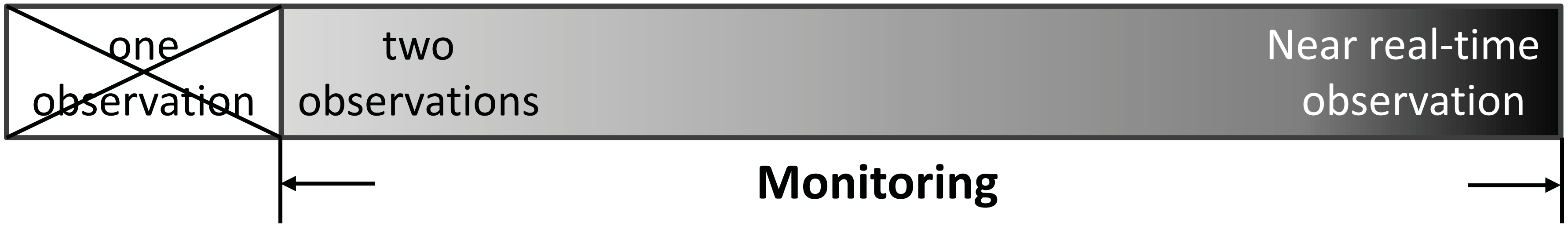
- Definition of target objectives for landslide observations?





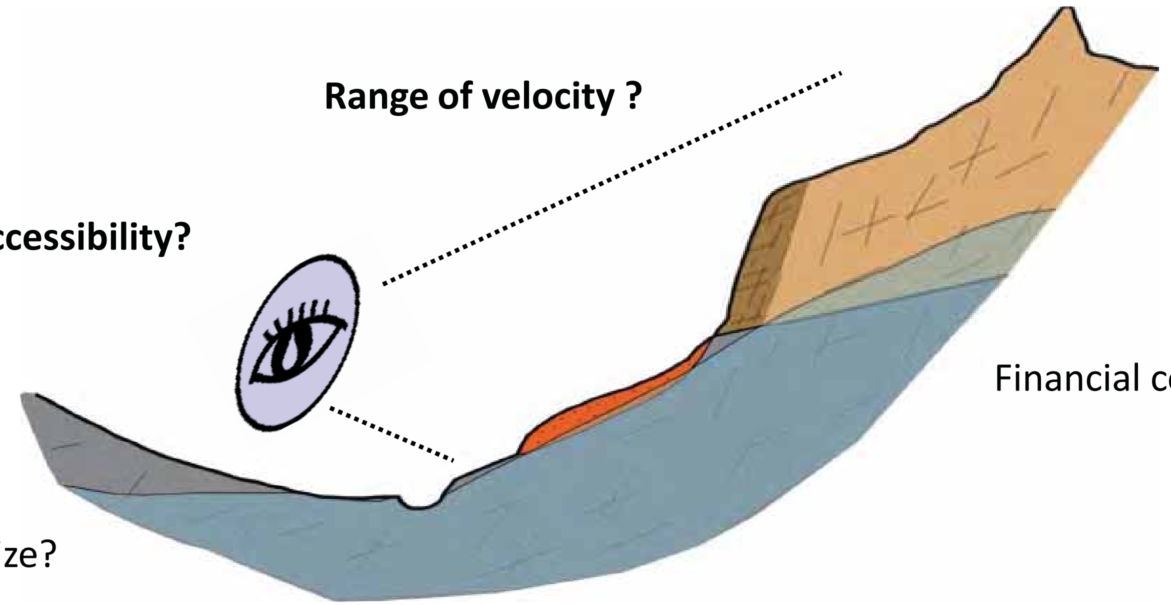
  - *Detection*: new landslides recognition from space- or airborne images
  - *Rapid mapping*: fast semi-automatic image processing for change detection and/or target detection; hotspot mapping
  - *Fast characterization*: retrieving information on failure mechanism, volume involved, and run-out length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

- Where does monitoring start? e.g. monitoring is the systematic repetition of observations



General monitoring strategy

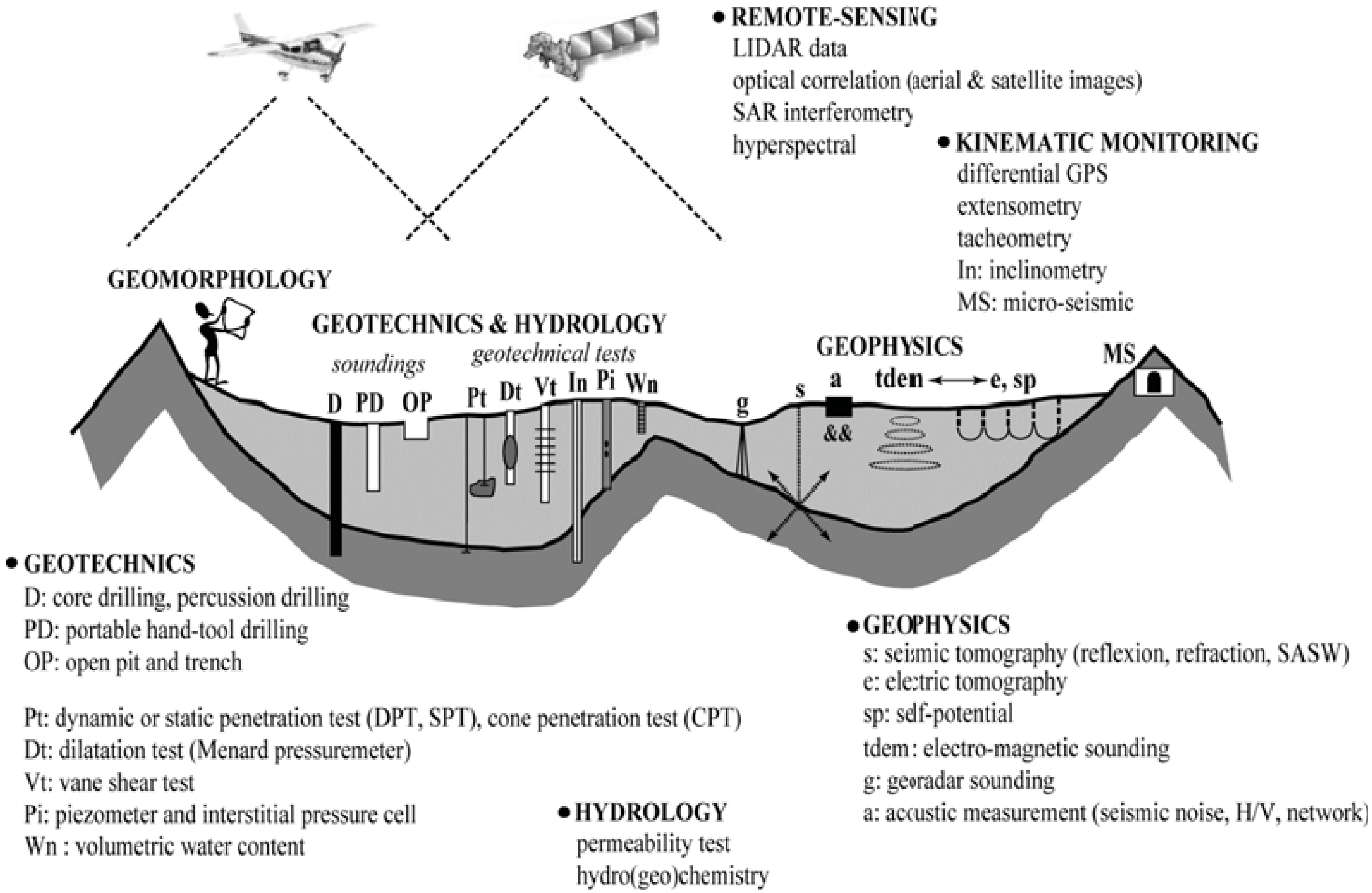
- Availability and development of many ground-based and remote sensing techniques and products in the last decade
- On-going trend: multi-technique landslide observations for multi-scale analysis



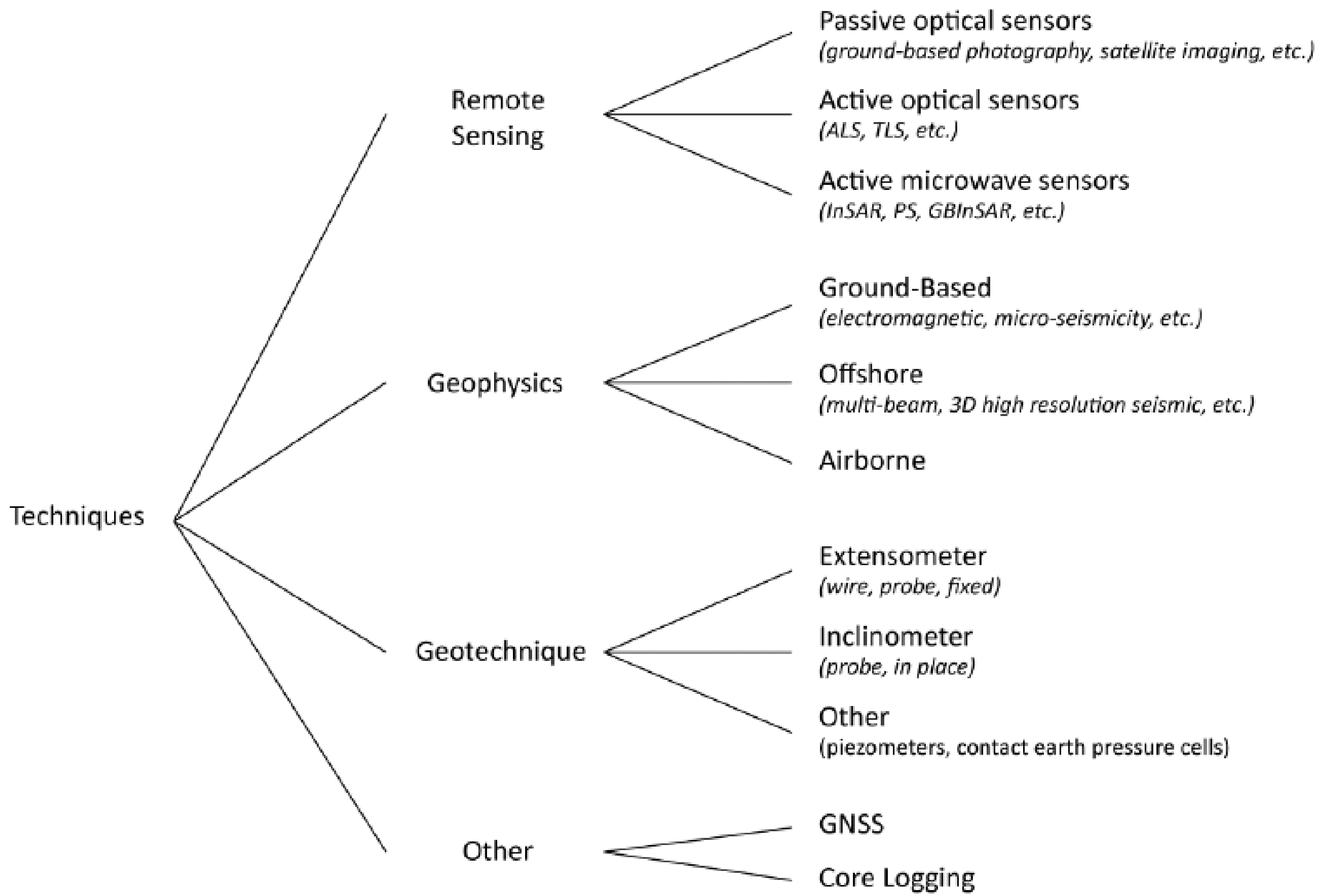
[Travelletti & Malet, 2012]

General approach ➔ monitor three types of variables

- **kinematics** (displacement, deformation, geomorphological surface changes)
- **hydro-meteorology** (pore water pressure, meteo, water balance, hydrochemistry)
- **seismology**



Many techniques available



Michoud et al. (2012) – SafeLand Report D4.1

Many techniques available

CLASS	TECHNIQUE	MEASURED PARAMETER	POSITION OF THE SENSOR	ACCURACY	THEORETICAL RESOLUTION Spatial *(points / m2)*	THEORETICAL RESOLUTION Temporal *(time lapse between acq.)*
PASSIVE OPTICAL SENSORS	□ Ground-Based Imaging	Surface radiance (Displacement/ Surface Features/ Surface Elevation)	G	cm	1-100 (and more)	second - year (1)
	□ Aerial Imagery	Surface radiance (Displacement/ Surface Features/ Surface Elevation)	A	m	1-400	month - years
	□ Satellites Imaging	Surface radiance (Displacement/ Surface Features/ Surface Elevation)	S	m	0.1-4 (VHR)	days
ACTIVE OPTICAL SENSORS	□ Distance-Meters	Distance	G	mm	0.01-1	second - year (1)
	□ Terrestrial Lidar (TLS)	3D coordinates	G	cm	10-100	hour - years (1)
	□ Airborne Lidar (ALS)	3D coordinates	A	dm	0.1-1	hour - years (1)
ACTIVE MICROWAVE SENSORS	□ Interferometric Radar Distance-Meter	Distance	G	mm	0.01-1	minute - years (1)
	□ Differential InSAR	Distance	S	mm	0.001-1	month
	□ Advanced InSAR	Distance	S	mm	0.0001-0.001-1	month
	□ Ground-Based InSAR	Distance	G	mm	0.05-2	minute - years (1)
	□ Polsar And Polinsar	Soil Moisture	S	mm	0.001	month
GROUND BASED GEOPHYSIC SENSORS	□ Seismics	Elastic parameters related to bulk modulus and shear modulus	G	dm-m	0.1-1	weeks-years
	□ Eletricity	Resistivity/conductivity, self potential, chargeability	G	dm-m	0.1-1	weeks-years
	□ Electromagnetic (low frequency)	Resistivity/conductivity	G	> m	0.01-0.1	weeks-years
	□ Ground Penetrating Radar	Electrical permittivity	G	cm-m	0.1-10	weeks-years
	□ Gravimetry	Density	G	m	0.01-1	weeks-years
	□ Borehole geophysics	All geophysical parameters depending the logging tool, + hydrology, etc.	G	cm-dm	1	days-years
OFFSHORE SENSORS	□ 2D and 3D seismic	Reflected acoustic energy	M	dm-m	0.1-1	days - years (1)
	□ Sonar	3D coordinates, backscatter,	M	cm-m	0.1-1	days - years (1)
	□ Multi-faisseau	3D coordinates, backscatter,	M	cm-m	0.1-1	days - years (1)
GEOTECHNICAL SENSORS	□ Extensometers	Distance	G	mm	max ~1	second - year (1)
	□ Inclinometers	Tilt	G	mm	max ~1	second - year (1)
	□ Piezometers	Water pressure	G	-	max ~1	second - year (1)
	□ Contact Earth Pressure Cells	Distribution, intensity and direction of total stress	G	-	max ~1	second - year (1)
	□ Multiparametric In Place Systems		G	-	max ~1	second - year (1)
OTHER SENSORS	□ Global Navigation Satellite System (GNSS)	3D coordinates	G	mm	10^{-5} to 10^{-2}	second - year (1)
	□ Core Logging	Mecanical parameters and Rock quality	G	cm	max ~1	day - year (1)

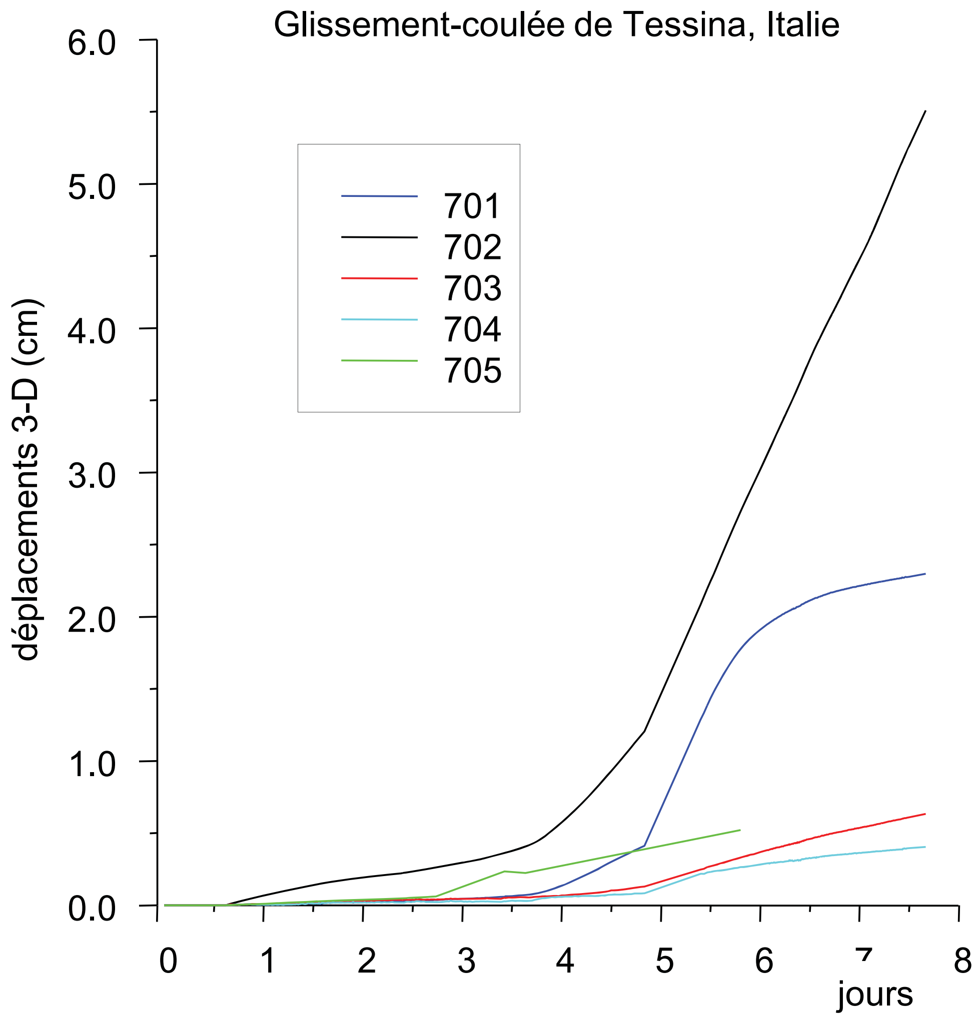
Position of the sensor: G= Ground Based; A= Aerial; S= Satellital; M= Marine
Temporal resolution: (1)= On demand

Michoud et al. (2012) – SafeLand Report D4.1

Monitoring landslide kinematics

Choice of technique and choice of spatial/temporal resolution = f(v)

Tacheometry / Total station measurements



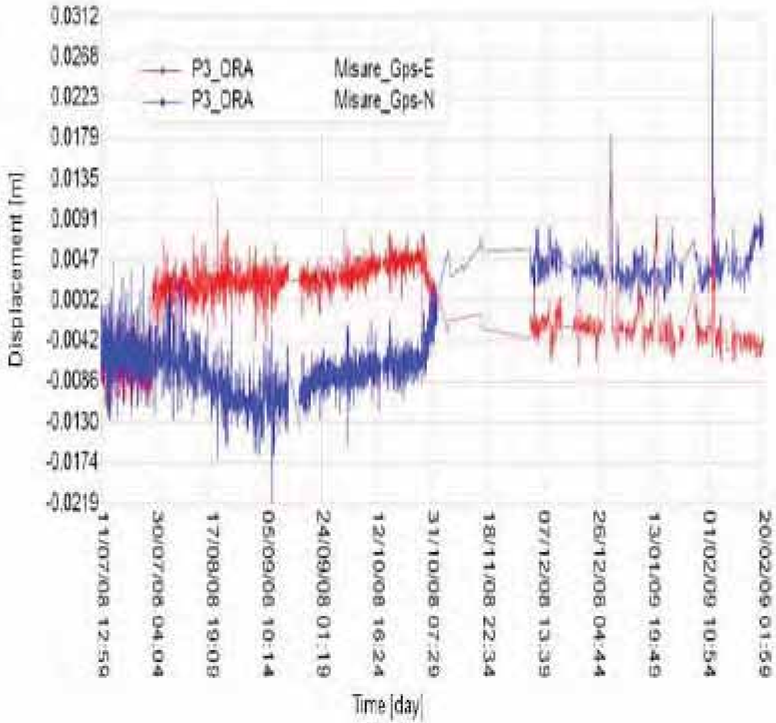
Monitoring landslide kinematics

Choice of technique and choice of spatial/temporal resolution = f(v)

dGPS measurements

Leica L1/L2 GRX1200 receiver

Examples:
Valoria landslide
Ancona landslide, Italy



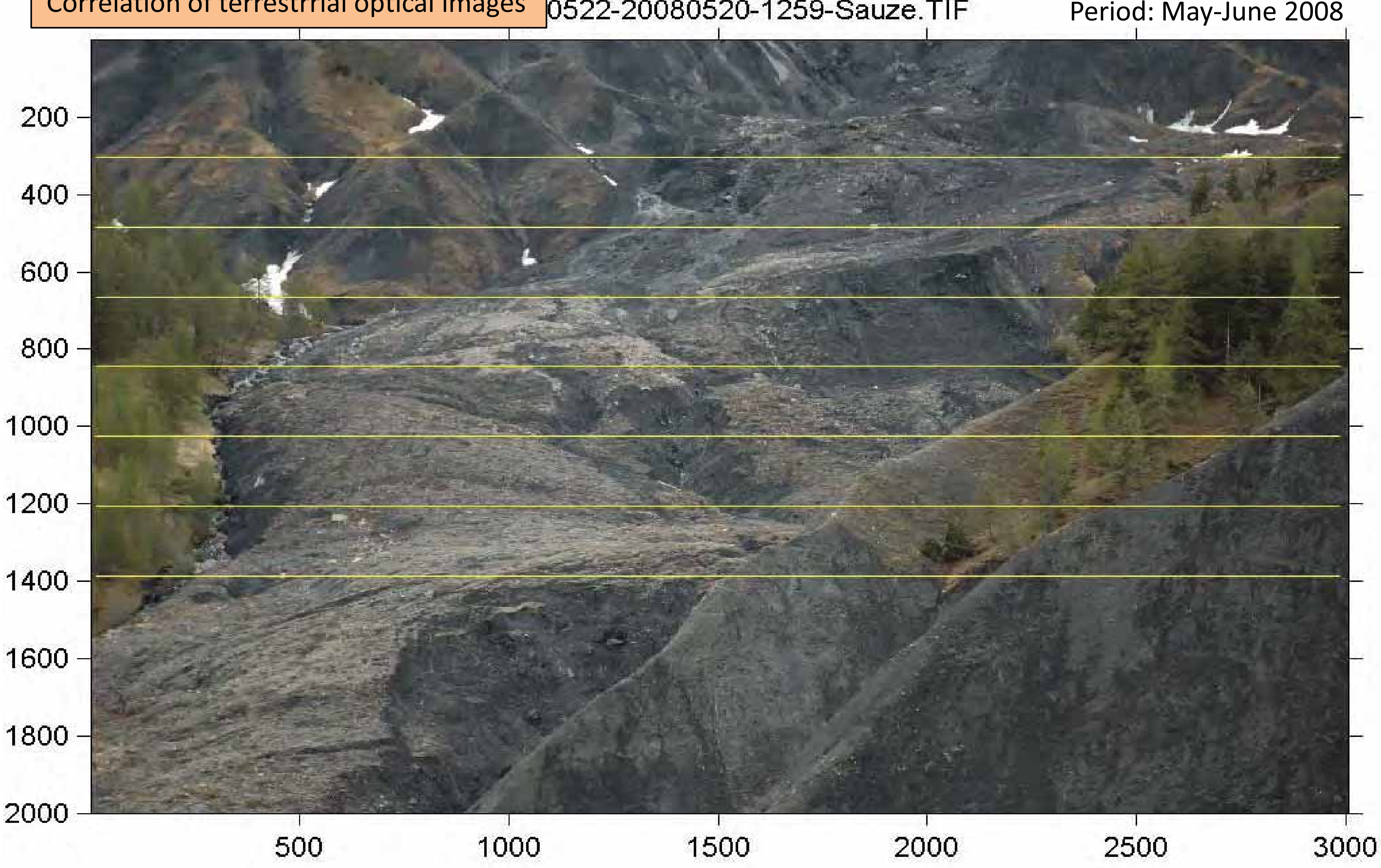
Bertacchini et al. (2010)

Monitoring landslide kinematics

Choice of technique and choice of spatial/temporal resolution = f(v)

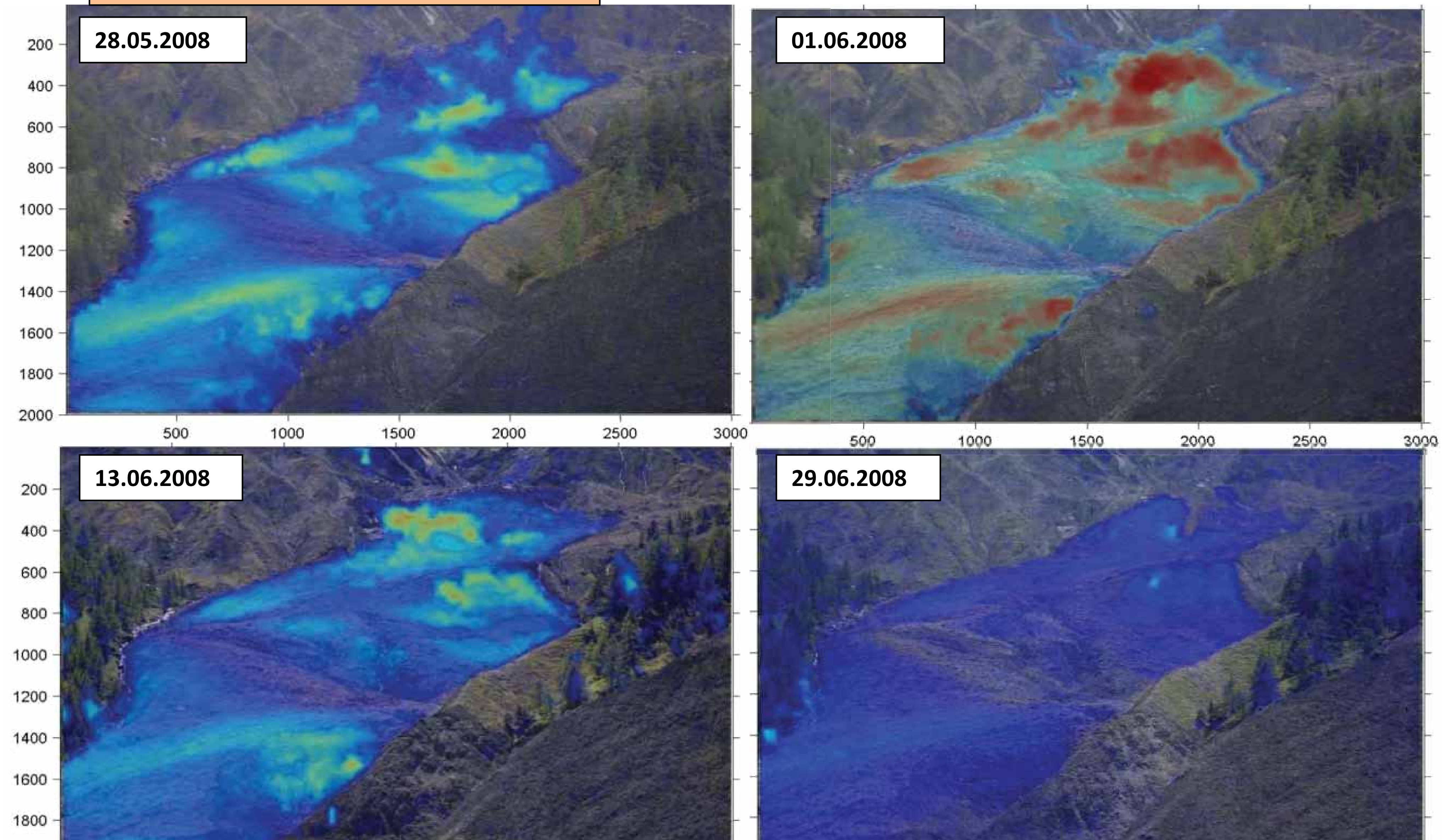
Correlation of terrestrrial optical images

Period: May-June 2008



Monitoring landslide kinematics

Correlation of terrestrrial optical images



Examples of velocity maps in the image plane during an acceleration period

Monitoring landslide kinematics

Choice of technique and choice of spatial/temporal resolution = f(v)

Terrestrial Laser Scanning - TLS

TLS LMS-Z620

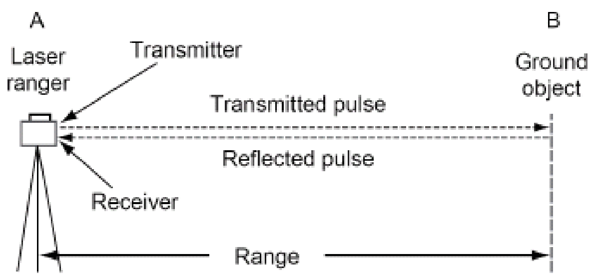
TLS ILRIS 3D (Picture extracted from: www.Optech.ca)

Trimble GX 3D

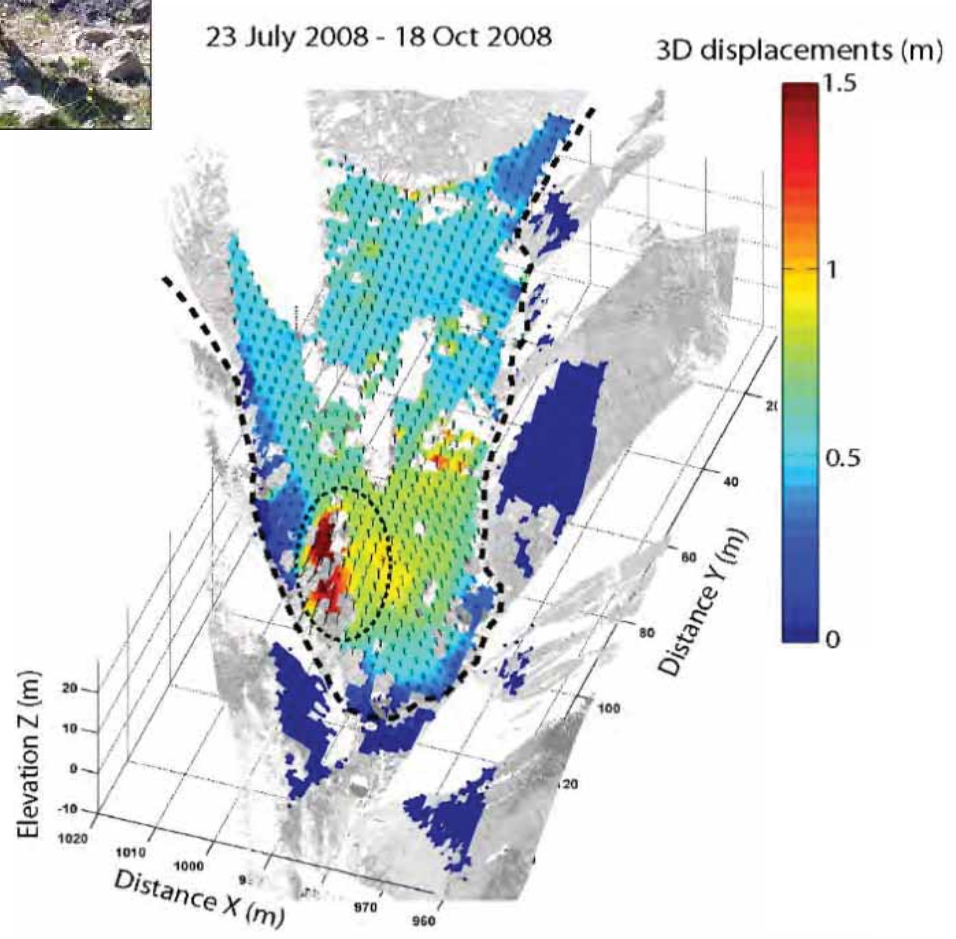
Monitoring landslide kinematics

Choice of technique and choice of spatial/temporal resolution = f(v)

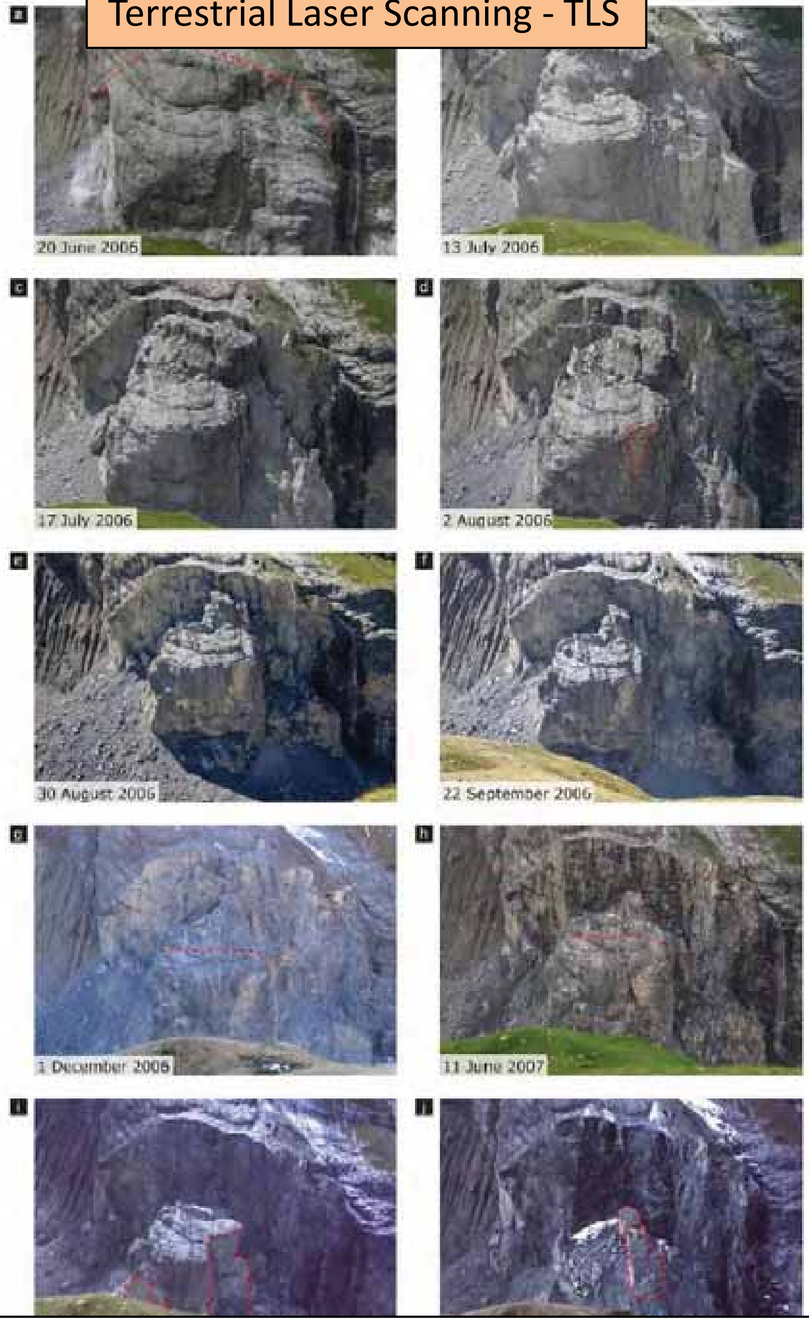
Terrestrial Laser Scanning - TLS

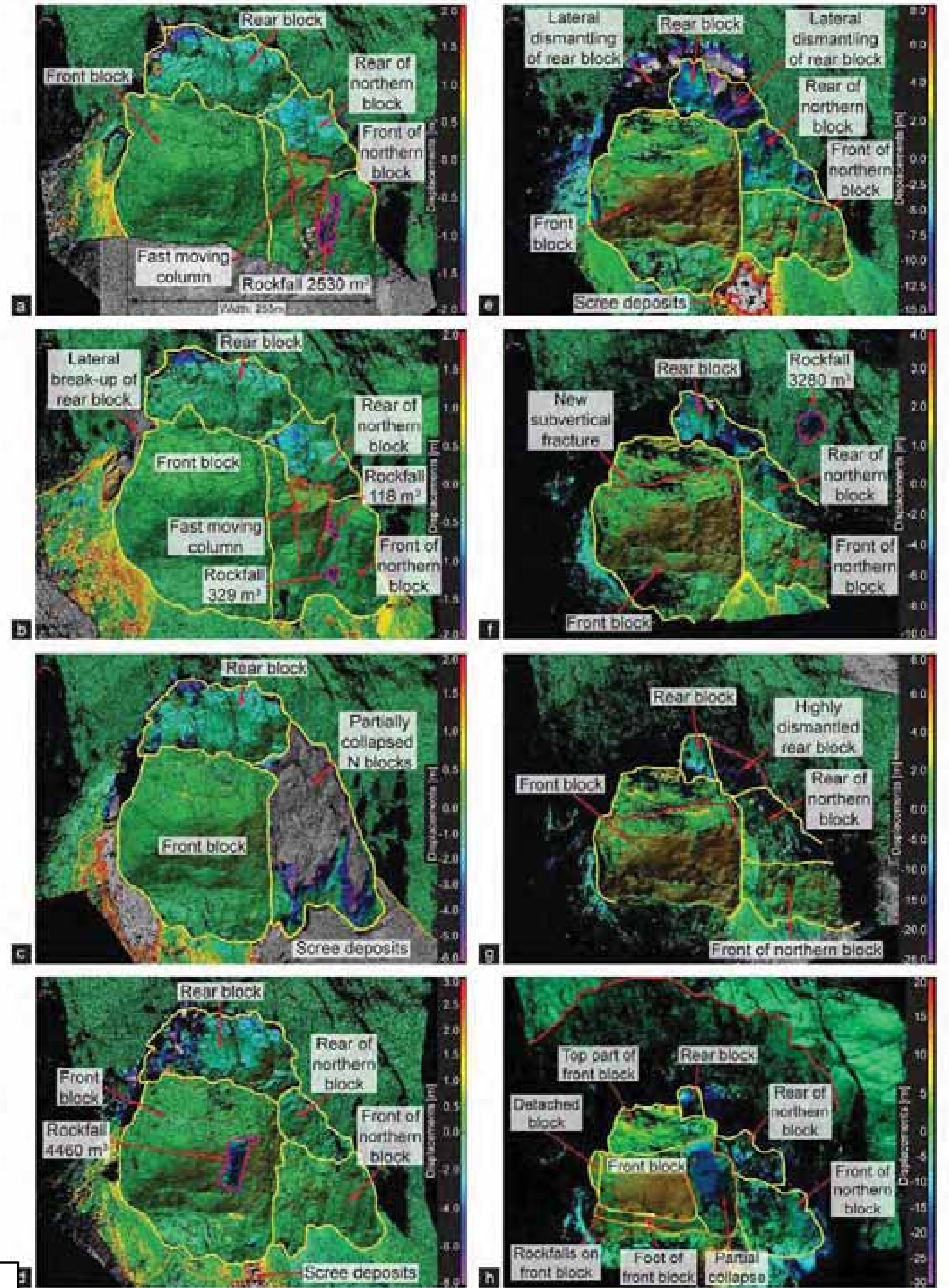


Super-Sauze landslide



Terrestrial Laser Scanning - TLS

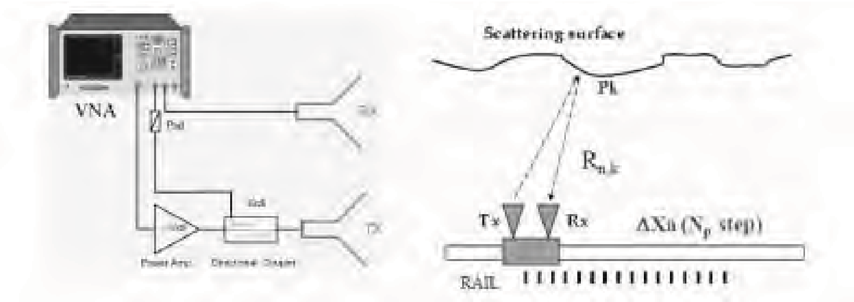


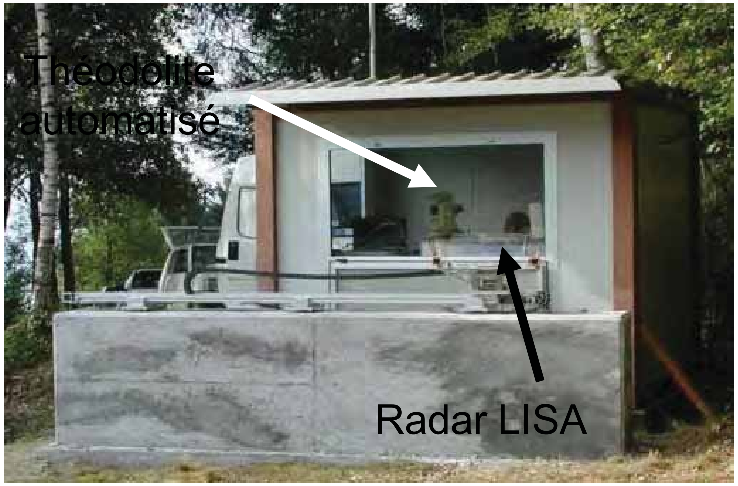


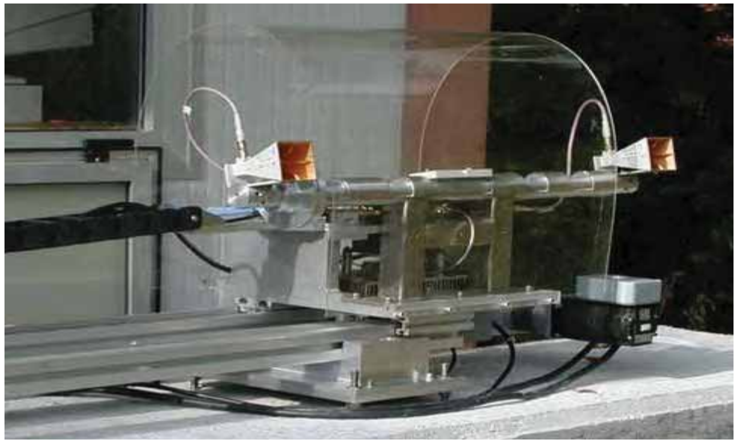
Eiger flank – rockslide at face North (2006) – Oppikoffer et al. (2008)

Monitoring landslide kinematics

Ground-based SAR (GB-InSAR, GB-PSInSAR)

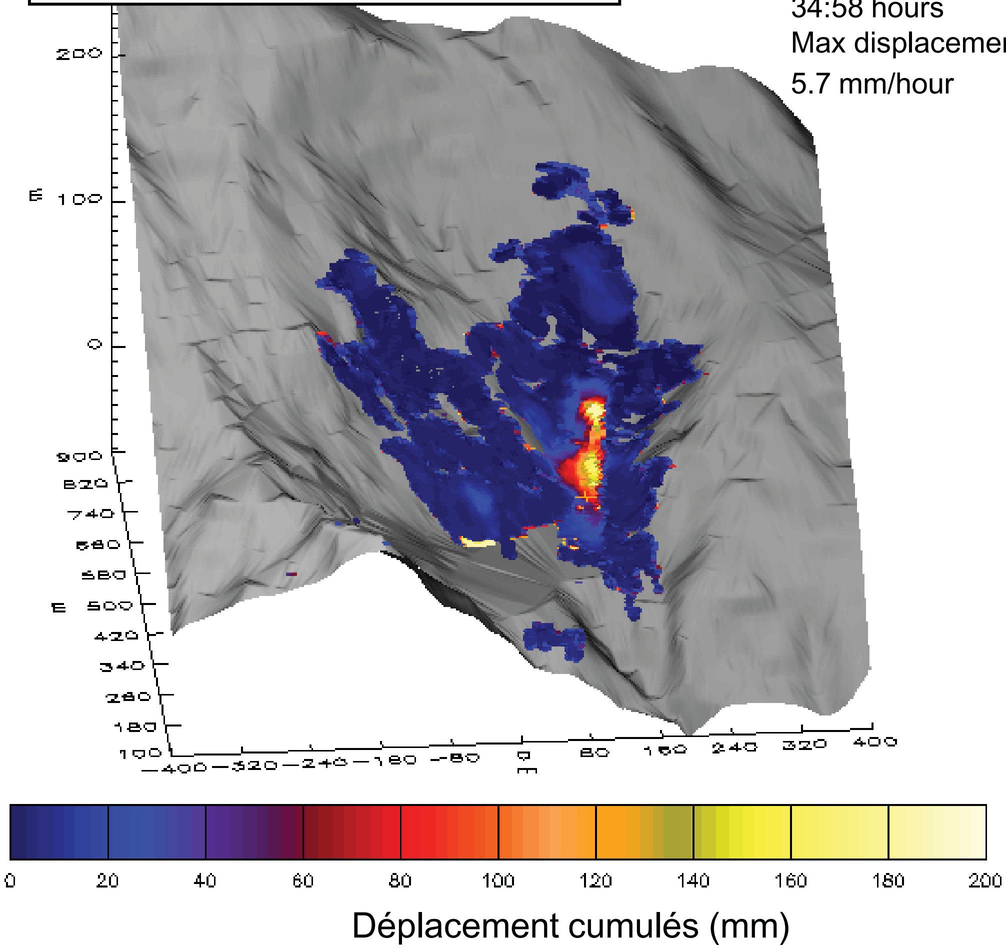






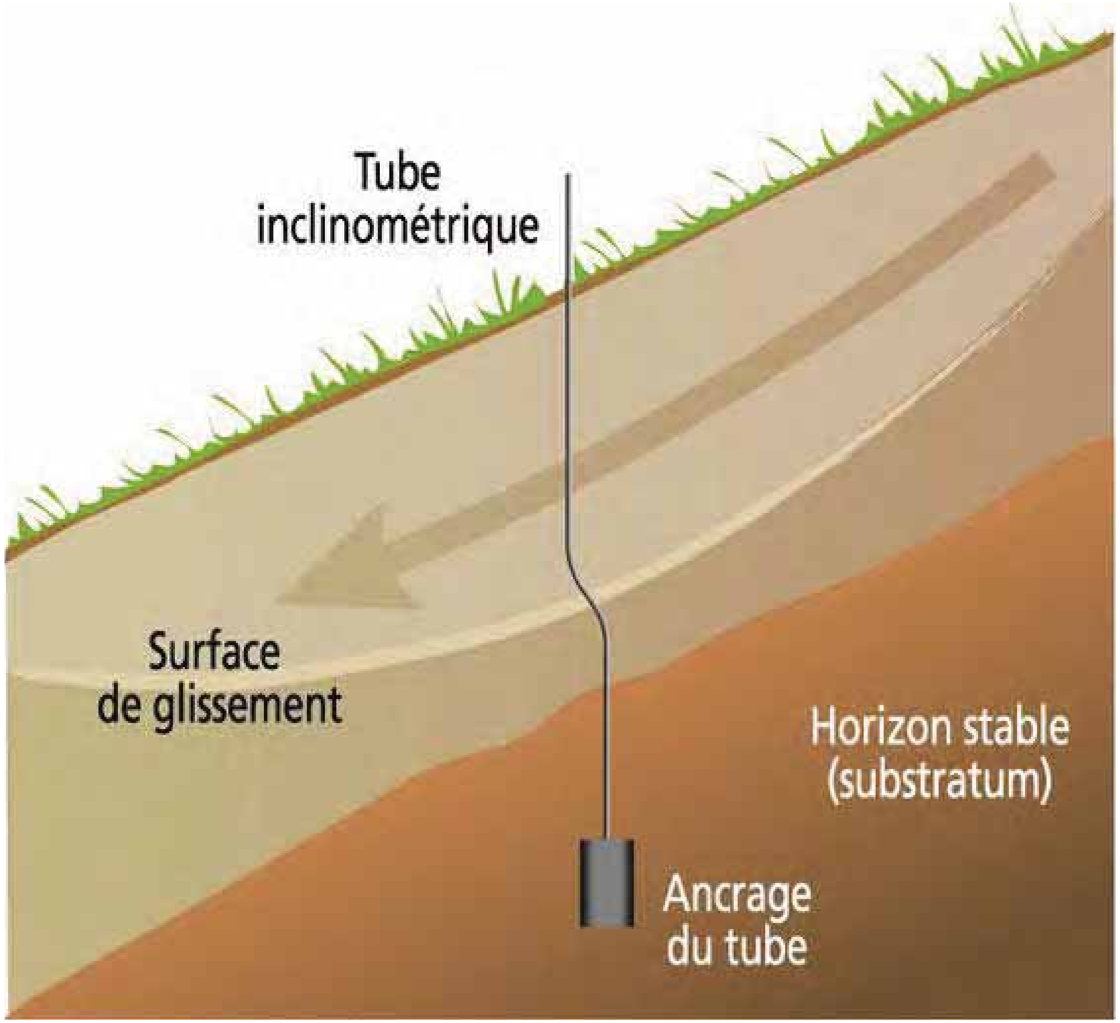
- ✓ Distance d'observation : 500 m
- ✓ Résolution spatiale: 1 × 1 m
- ✓ Précision : < 0.5 mm

Start :
27 June 2001 14:34
End:
29 June 2001 01:32
Total elapsed time:
34:58 hours
Max displacement rate:
5.7 mm/hour



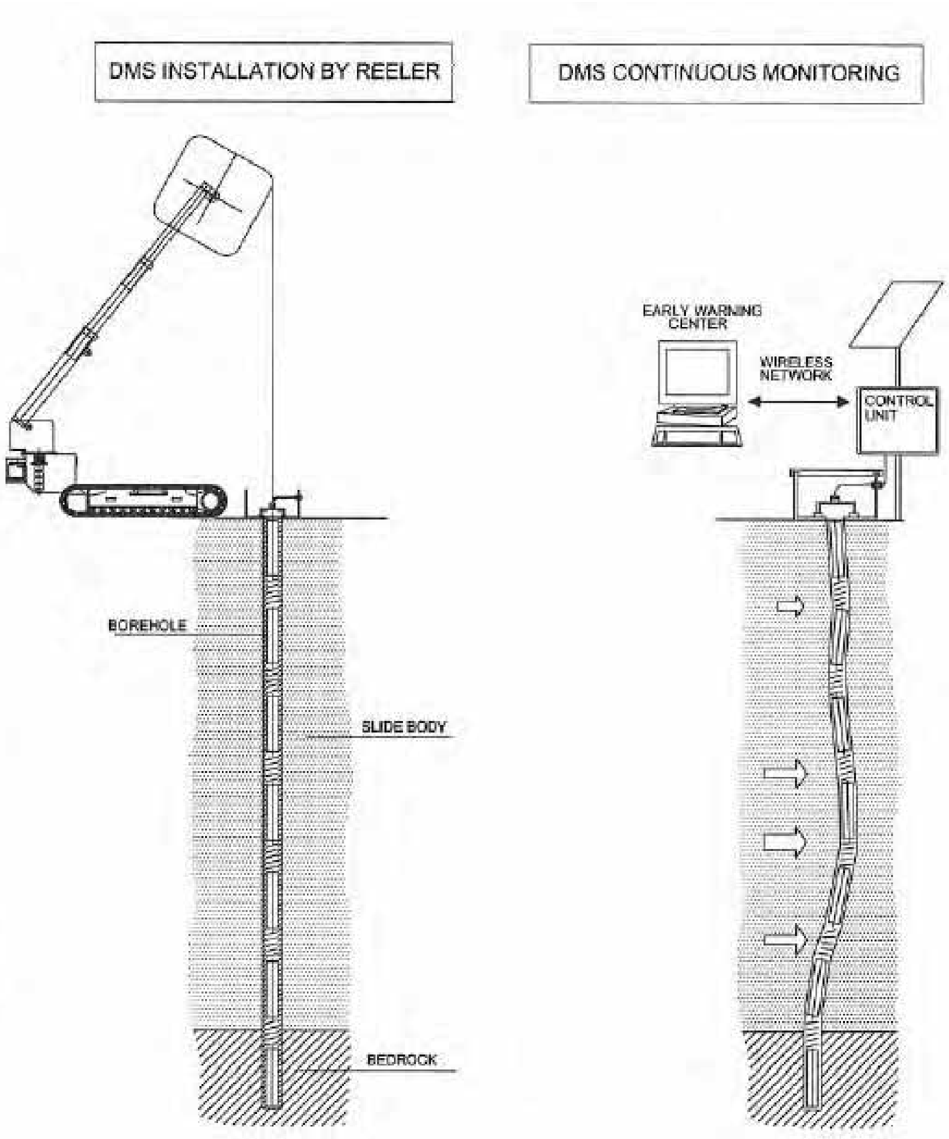
Monitoring landslide kinematics

In –depth displacement – Inclinometer measurements



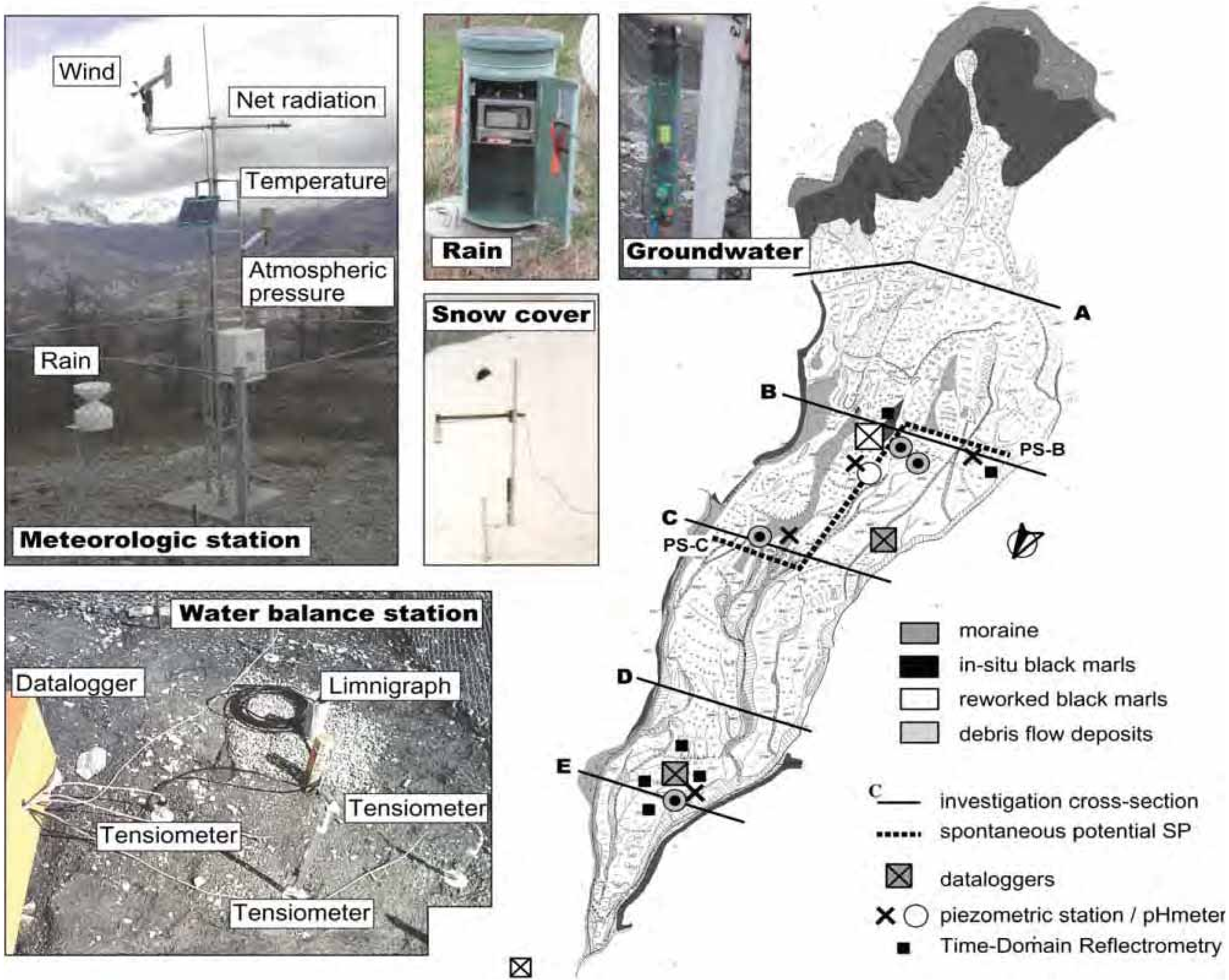
Monitoring landslide kinematics

In –depth displacement – Automated Inclinometer measurements



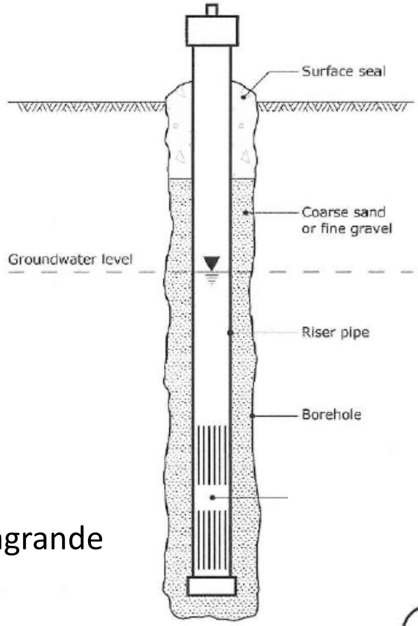
Monitoring landslide hydro-meteorology

Local meteorology

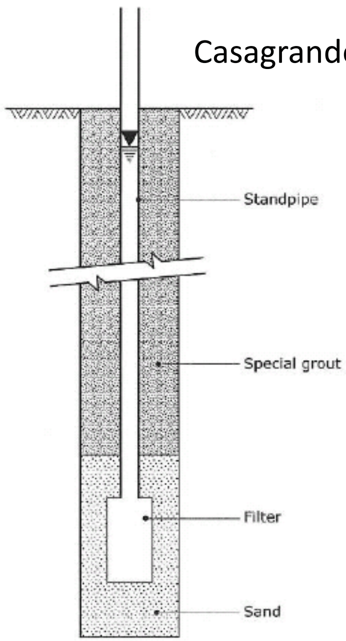


Monitoring landslide hydro-meteorology

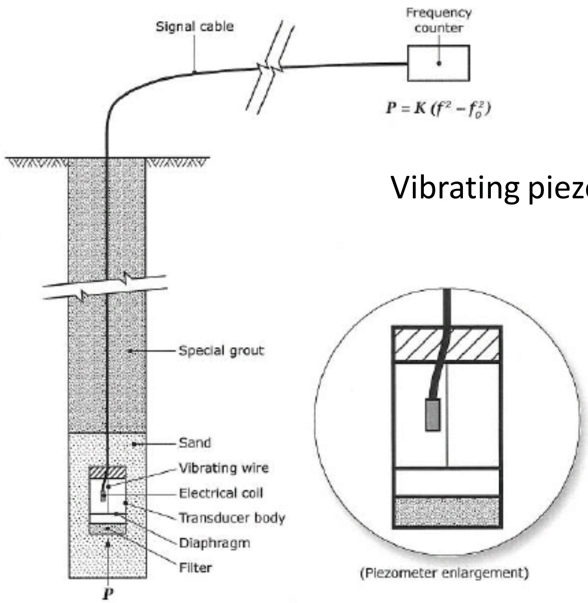
Plot scale piezometers – ground water level monitoring



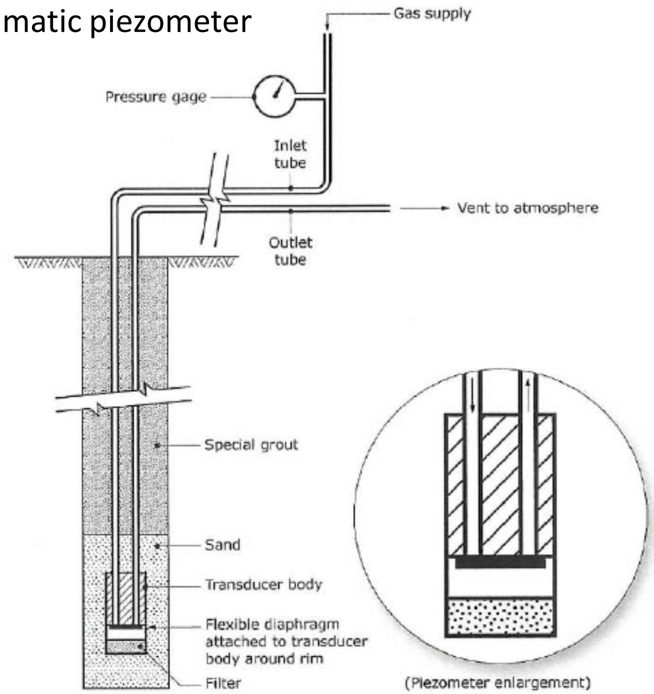
Casagrande



Vibrating piezometer

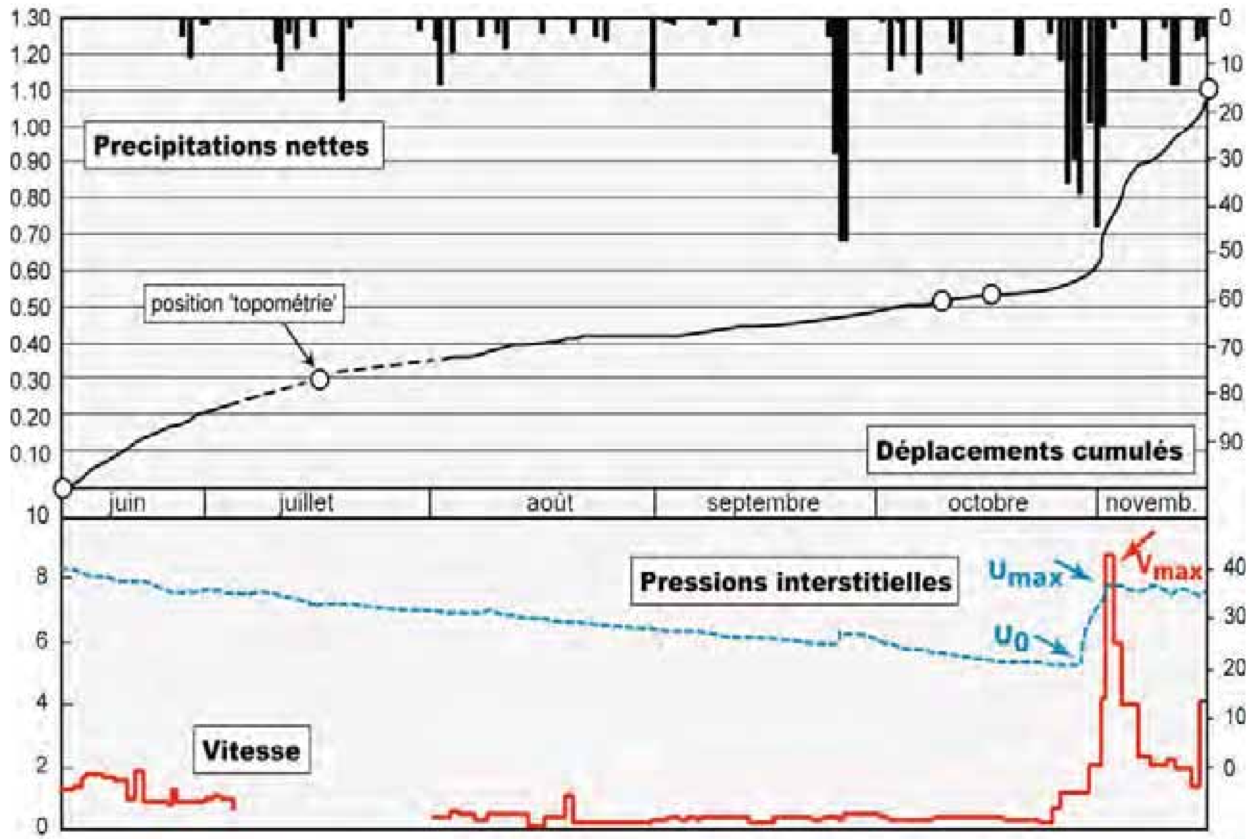


Pneumatic piezometer

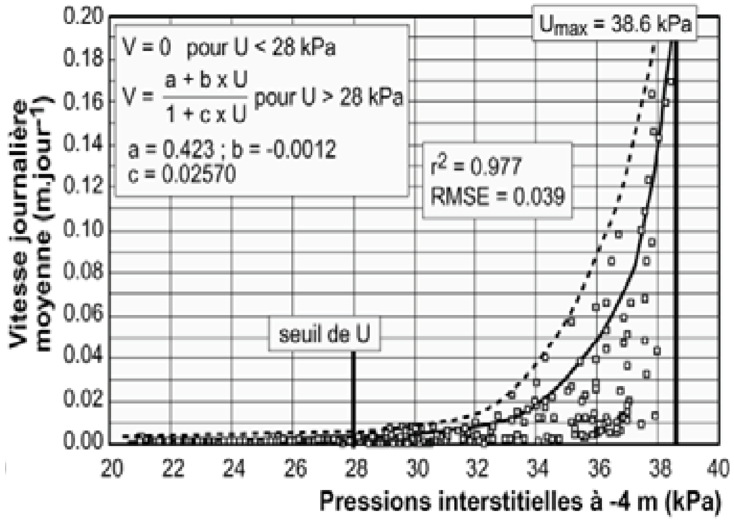


Monitoring landslide hydro-meteorology

Example of relationships: Pore Water Pressure (PWP) - Displacement



Super-Sauze, Alpes-de-Haute-Provence (Malet, 2003)



- Hyperbolic function
  - ✓ threshold curve
  - ✓ threshold U_{max}

Monitoring landslide hydro-meteorology

Hydrogeochemistry – Surface and sub-surface water quality