



*Part II: Examples in the Alps*

# INTEGRATION OF MONITORING SYSTEMS

## CORVARA LANDSLIDE (SOUTH TYROL)

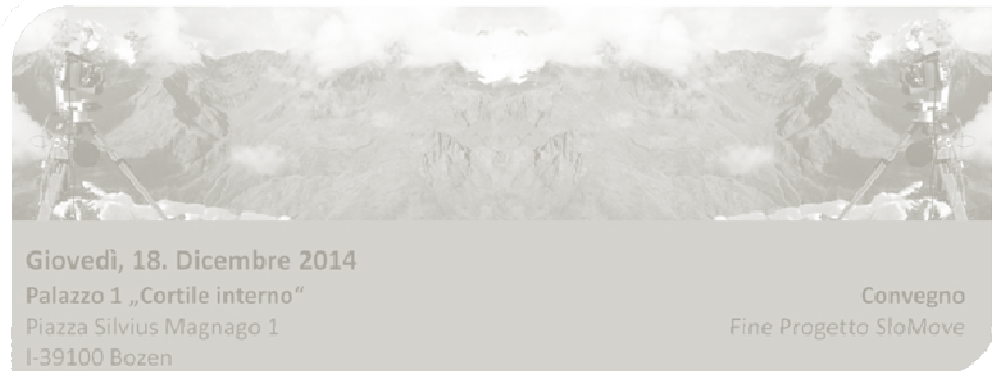
**By: Alessandro Corsini \***  
(DSCG – UniMoRe)

### Partnership

Province of BZ (RIP.11, RIP.30, RIP32)  
Municipality of Corvara in Badia  
DSCG - UniMoRe  
IRPI-CNR Padua  
EURAC-Bz

### Data & figures acknowledgements

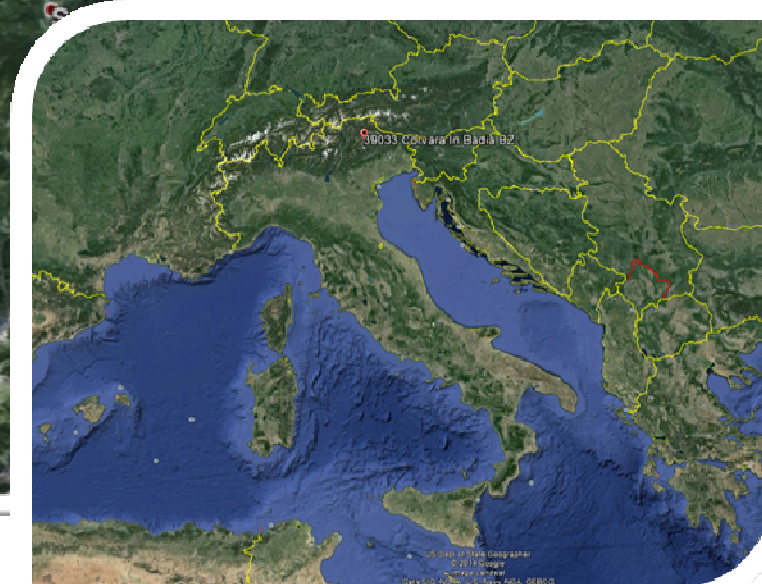
Dr. M. Mulas (DSCG - UniMoRe)  
Dr. G. Marcato (IRPI-CNR Padua)  
Dr. G. Chinellato (EURAC-Bz)



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## Site location





## Site location







## Hazard & Risk



today



mid XX century



## Hazard & Risk



# Holocene slope evolution

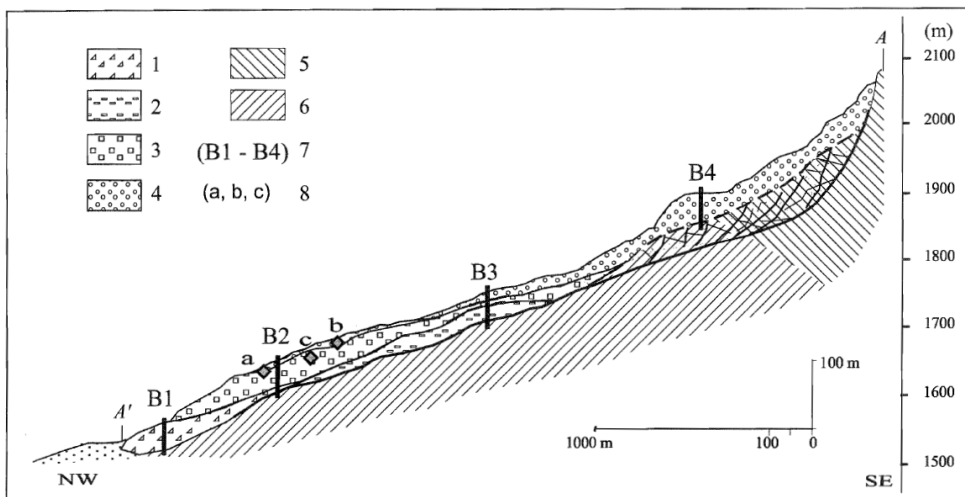


FIG. 5 - Interpreted chronological cross section of the Corvara landslide. Legend: 1 - events ca. 10.000 cal. yr BP (provenance Cianacai; Arlara landslide; see fig. 3); 2 - events ca. 9000 cal. yr BP (provenance Freines; see fig. 3); 3 - events ca. 5000-4000 cal. yr BP (provenance Freines and Bicocca; see fig. 3); 4 - events ca. 3000-2000 cal. yr BP (provenance Bicocca; see fig. 3); 5 - La Valle Formation; 6 - S. Cassiano Formation; 7 - boreholes (see fig. 3); 8 - tree trunks collected in the Rutorio river scarp (see fig. 3).

ALESSANDRO CORSINI (\*), MAURO MARCHETTI (\*) & MAURO SOLDATI (\*)

### HOLOCENE SLOPE DYNAMICS IN THE AREA OF CORVARA IN BADIA (DOLOMITES, ITALY): CHRONOLOGY AND PALEOCLIMATIC SIGNIFICANCE OF SOME LANDSLIDES



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### Landslides and climate change in the Italian Dolomites since the Late glacial

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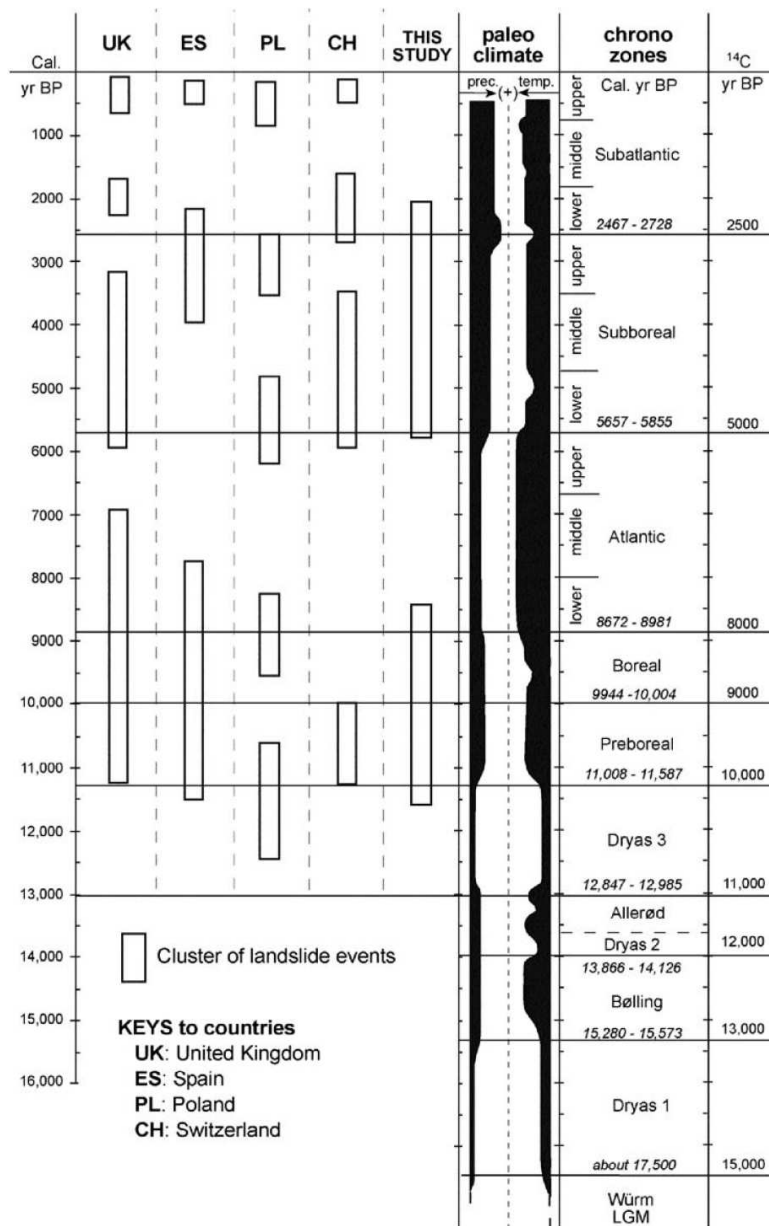


Fig. 6. Temporal distribution of landslide activity since the Late glacial in different parts of Europe and comparison with paleoclimate trends.



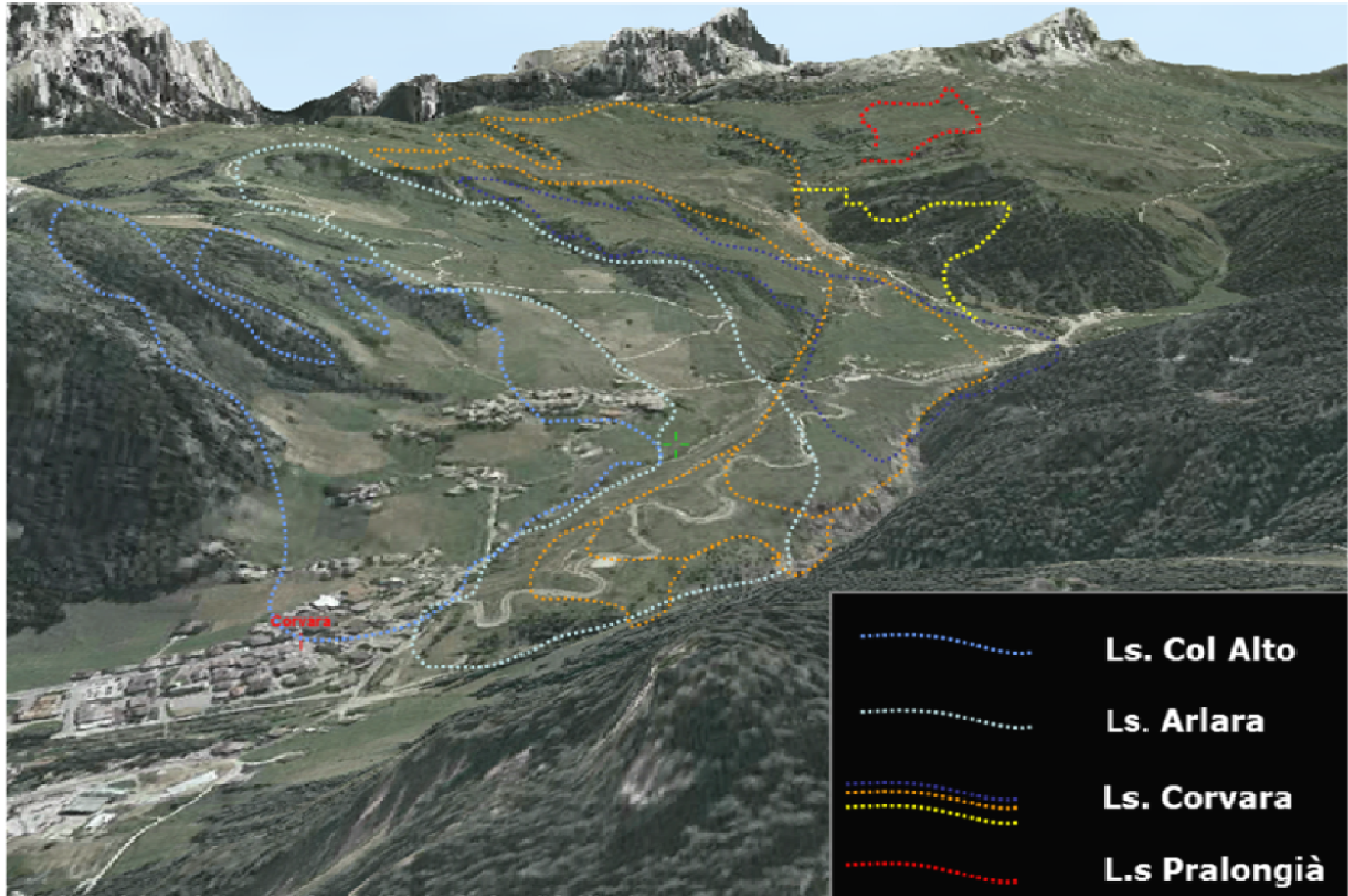
## Holocene slope evolution

Radiocarbon dating in Alta Badia; data calibrated with Radiocarbon Calib. Program 4.1 by Stuiver and Reimer (1993), data set by Stuiver et al. (1998)

ID	Landslide name	Landslide type	Sample code	Sample type	Site of collection	Depth (m)	Conventional age ( $^{14}\text{C}$ year BP)	Calendar age $2\sigma$ (cal year BP)	Paleoclimatic significance
(A)									
12	Corvara	rotational rock slide-earth flow	B-112032	wood	borehole (C1)	25.70	$8820 \pm 50$	10,152-9632	high
12	Corvara	rotational rock slide-earth flow	B-112033	wood	borehole (C1)	26.40	$8560 \pm 90$	9709-9334	high
12	Corvara	rotational rock slide-earth flow	B-112031	organic sediment	borehole (C3)	22.70	$7920 \pm 70$	9009-8543	low
12	Corvara	rotational rock slide-earth flow	B-154704	wood	borehole (C6)	69.70	$8020 \pm 60$	9030-8650	high
12	Corvara	earth flow	Ki-9233	wood	borehole (C6)	47.50	$5543 \pm 72$	6471-6199	high
12	Corvara	earth flow	Ki-9230	wood	borehole (C6)	19.10	$4616 \pm 64$	5575-5052	high
12	Corvara	earth flow	B-112029	wood	borehole (C2)	7.50	$4260 \pm 70$	5025-4575	high
12	Corvara	earth flow	B-112030	wood	borehole (C2)	20.00	$4260 \pm 70$	5025-4575	high
12	Corvara	earth flow	Ki-9234	tree trunk	erosion scarp	8.00	$3888 \pm 64$	4513-4094	high
12	Corvara	earth flow	B-105976	tree trunk	erosion scarp	6.00	$3830 \pm 60$	4417-3999	high
12	Corvara	earth flow	B-105977	tree trunk	erosion scarp	4.50	$2860 \pm 60$	3207-2792	high
12	Corvara	earth flow	B-93975	tree trunk	erosion scarp	5.00	$2490 \pm 60$	2750-2352	high
12	Corvara	earth flow	B-112034	wood	borehole (C4)	37.40	$2260 \pm 50$	2351-2129	high
13	Arlara	rotational rock slide-earth flow	B-105975	tree trunk	erosion scarp	3.5	$6870 \pm 50$	7789-7592	high



## Holocene slope evolution





# State of activity

- Università di Modena e Reggio Emilia  
Dipartimento di Scienze della Terra
- CNR - Consiglio Nazionale delle Ricerche di Padova  
IPF - Istituto di Ricerca per la Protezione Idrogeologica
- Provincia Autonoma di Bolzano - Alto Adige  
Reg. 10 - Ufficio Geologico e prove materiali  
Reg. 32.3 - Ufficio Pianificazione Forestale
- Comune di Corvara in Badia

Indagini finalizzate alla definizione della pericolosità ed all'identificazione di possibili misure di mitigazione della frana di Corvara in Badia (BZ)

### Lineamenti Geologici e Geomorfologici

Elaborazione carte:  
A. Corradi, A. Ghini

#### Gruppo di Lavoro

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Prof. M. Maresca

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Ing. A. Pasetto

Dott. V. Profanter

Dott. V. Rill

Dott. M. Spangher

Com. G. Vignolatti

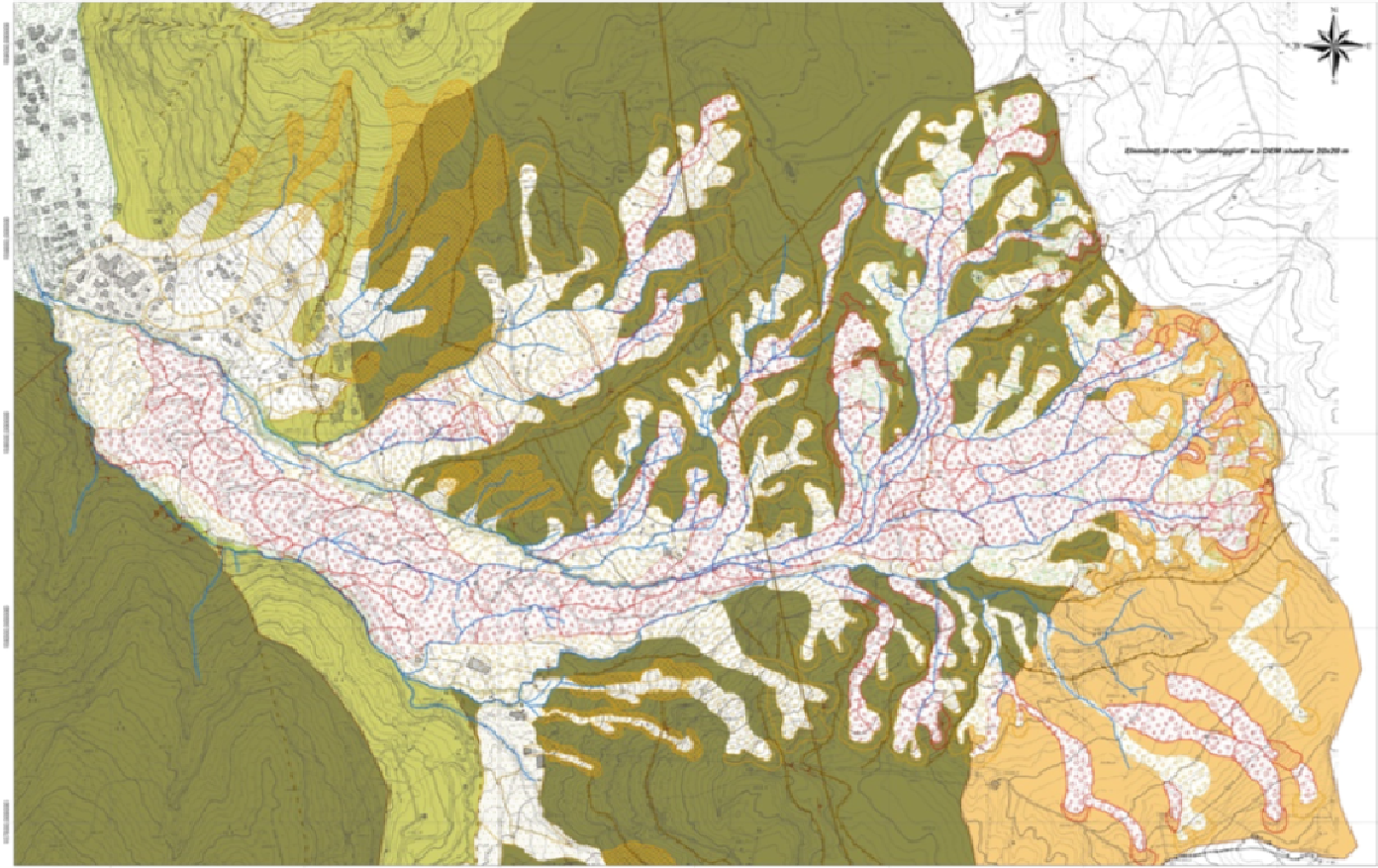
Comune di Corvara in Badia

Ing. M. Pasetto (responsabile)

Ing. M. Maresca

Ing. S. Tassi

Scala carta: 1:5000



### Elementi geologico-strutturali

- Aspetto degli strati
- Orlo di scarpata strutturale
- Faglia
- Faglia neo-tettonica
- Arenarie e conglomerati vulcanoclastici, liivi (f.m. di Femazza e Conglomerato Marmoiada; Gruppo di Wengen)
- Sequenze flyschoidi di arenie vulcanoclastiche, silti e argille (Formazione di La Valle - Gruppo di Wengen)
- Sequenze flyschoidi di marne, calcareniti e argille (Formazione di S. Cassiano)

### Fenomeni franosi

#### Scivolamenti di Roccia traslativi e rotativi (traslational or rotational rockslides)

Scarpata di distacco (quiescente)

Corpo / Accumulo (quiescente)

#### Colate di Fango (mudflows)

Zona sorgente (quiescente)

Zona di transito (quiescente)

Zona d'accumulo (quiescente)

#### Scivolamenti-colate di Terra (earthslides - earthflows)

Scarpata di distacco (attivo)

Scarpata di distacco (quiescente)

Corpo / Accumulo (attivo)

Corpo / Accumulo (quiescente)

Orlo di scarpata sepolta

Orlo di zona ad acciuffi accentratata

### Idrografia

Corso d'acqua

Zona umida

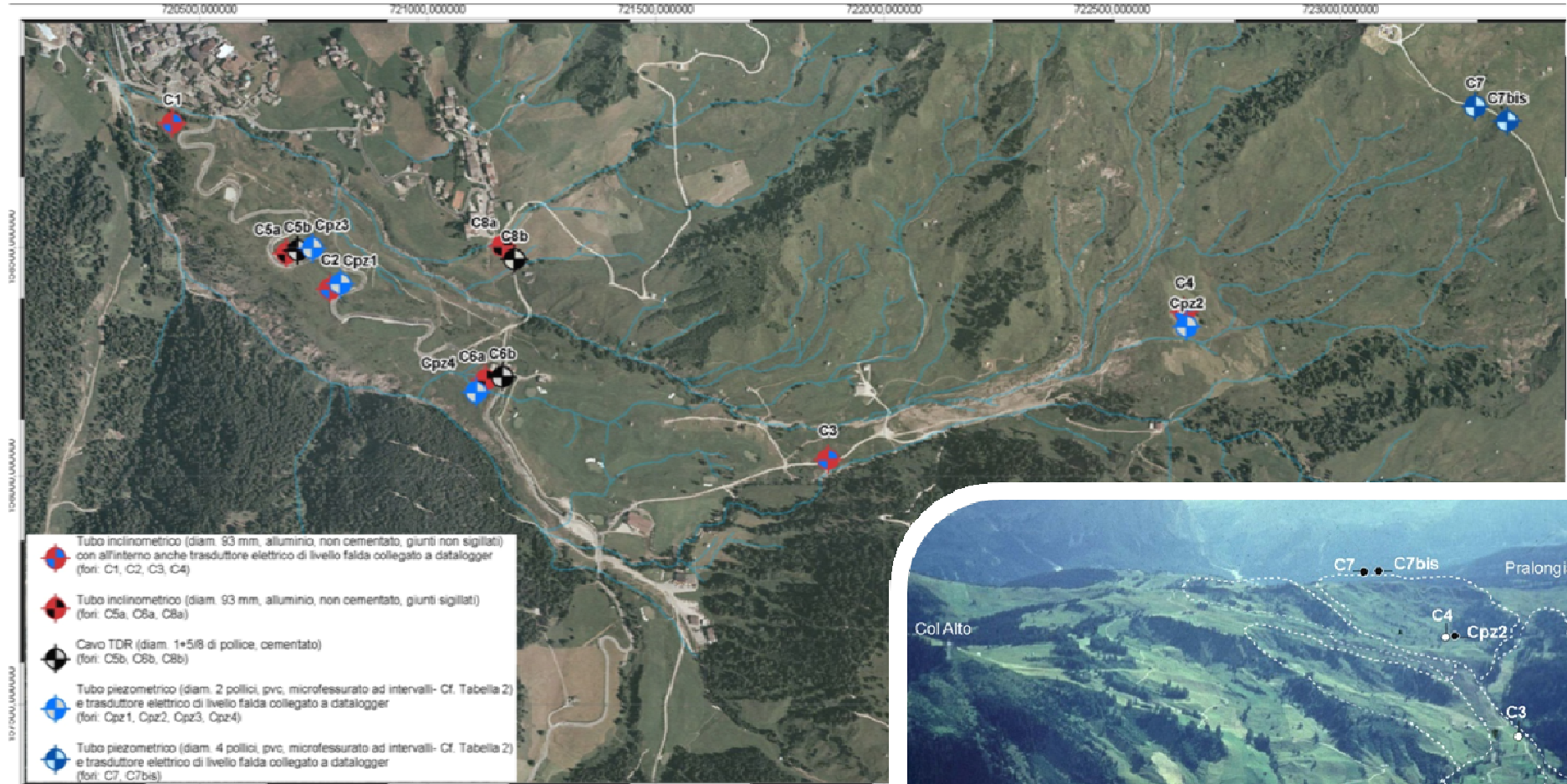
### Erosione-accumulo torrentizio-alluvionale

Scarpata d'erosione (attivo)

Scarpata d'erosione (quiescente)

Deposito torrentizio-alluvionale (quiescente)

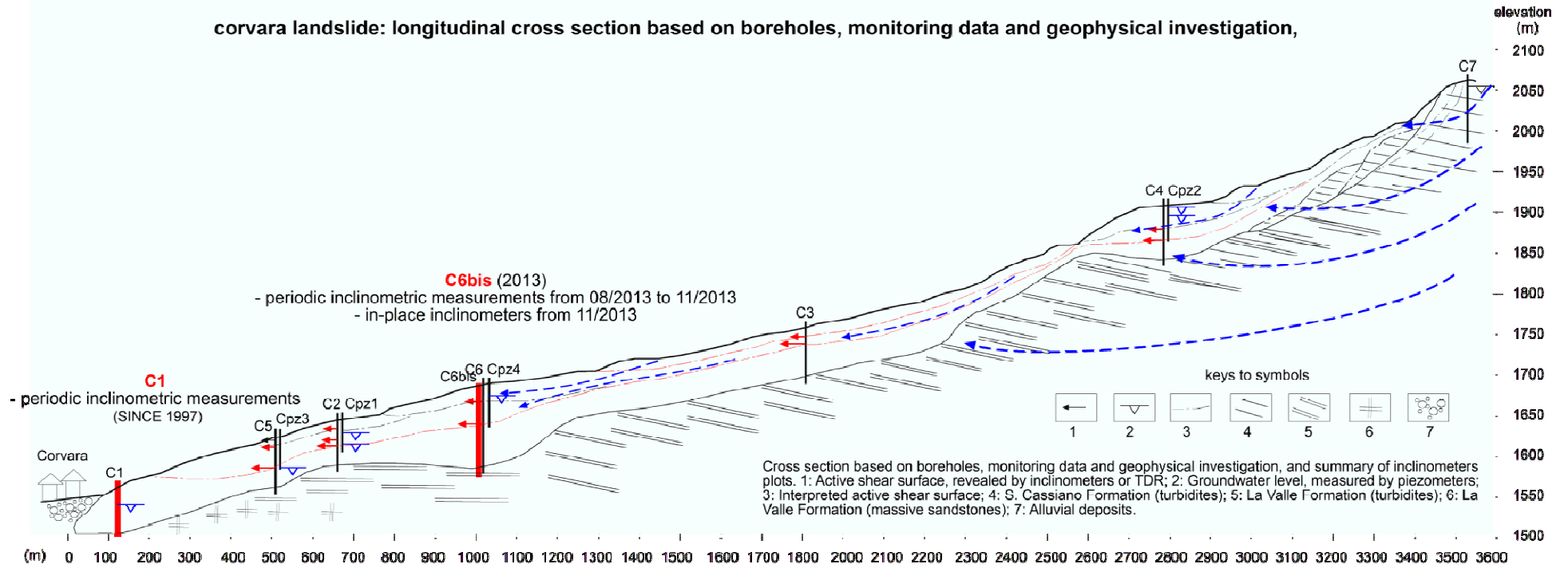
## Boreholes monitoring 1997-2006



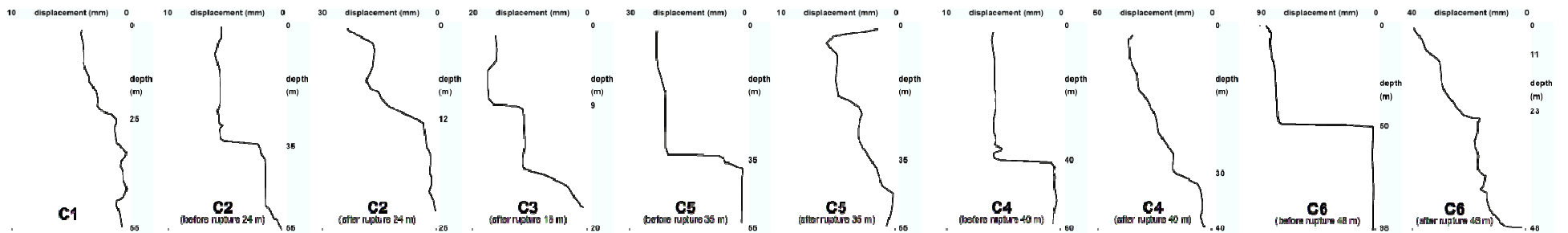


## Boreholes monitoring 1997-2006

corvara landslide: longitudinal cross section based on boreholes, monitoring data and geophysical investigation,



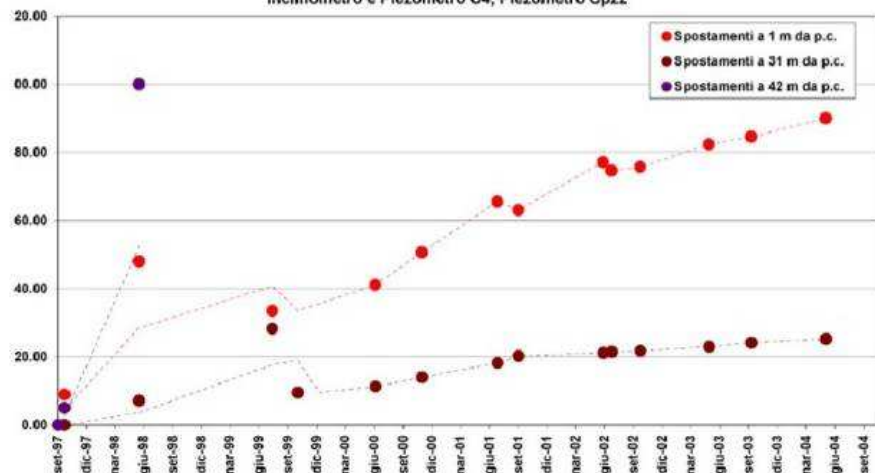
### SINTHESIS OF PERIODIC INCLINOMETRIC MEASUREMENTS 1997 - 2004



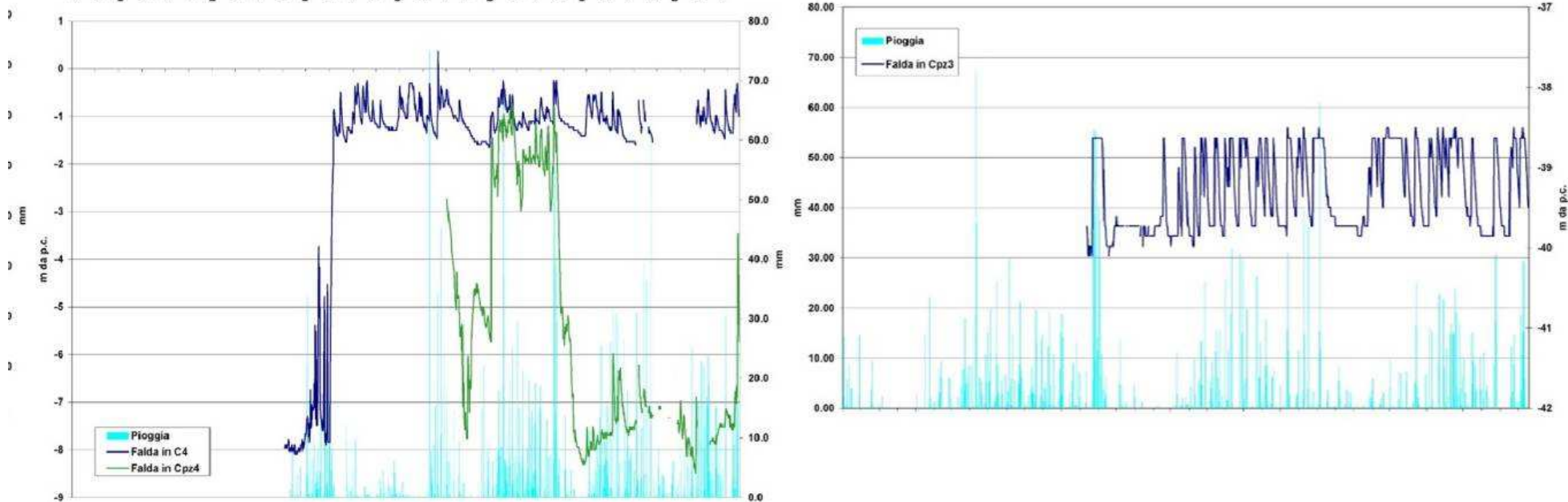
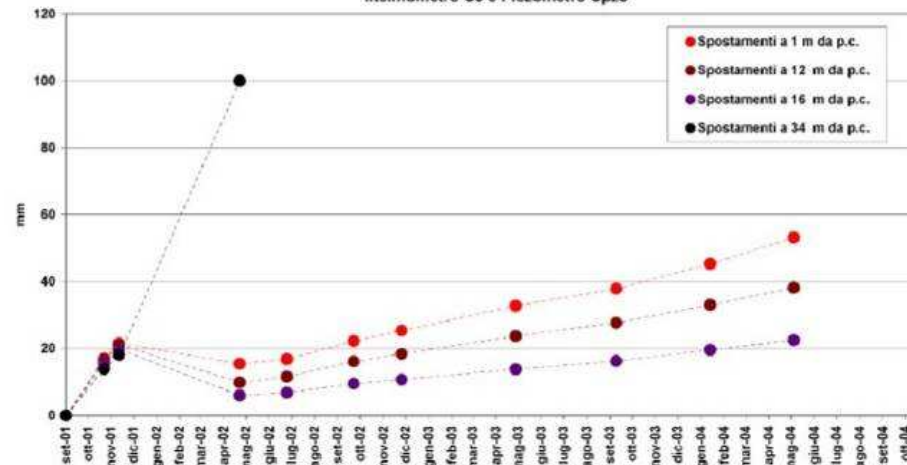


## Boreholes monitoring 1997-2006

Inclinometro e Piezometro C4, Piezometro Cpz2



Inclinometro C5 e Piezometro Cpz3





## Boreholes + seismic + geoelectric surveys 1997-2006

- Università di Modena e Reggio Emilia**  
Dipartimento di Scienza della Terra
- CNR - Consiglio Nazionale delle Ricerche di Padova**  
IRPI - Istituto di Ricerca per la Protezione Idrogeologica
- Provincia Autonoma di Bolzano - Alto Adige**  
Rip. 11.6 - Ufficio Geologia e prove materiali  
Rip. 30 - Opere Idrauliche  
Rip. 32.3 - Ufficio Pianificazione Forestale
- Comune di Corvara in Badia**

*Indagini finalizzate alla definizione della pericolosità  
ed all'identificazione di possibili misure di mitigazione  
della frana di Corvara in Badia (BZ)*

### Bilancio di Massa del Corpo di Frana

Elaborazione carta e grafici:  
A. Corsini, D. Piacentini, L. Borgatti, S. Moretto

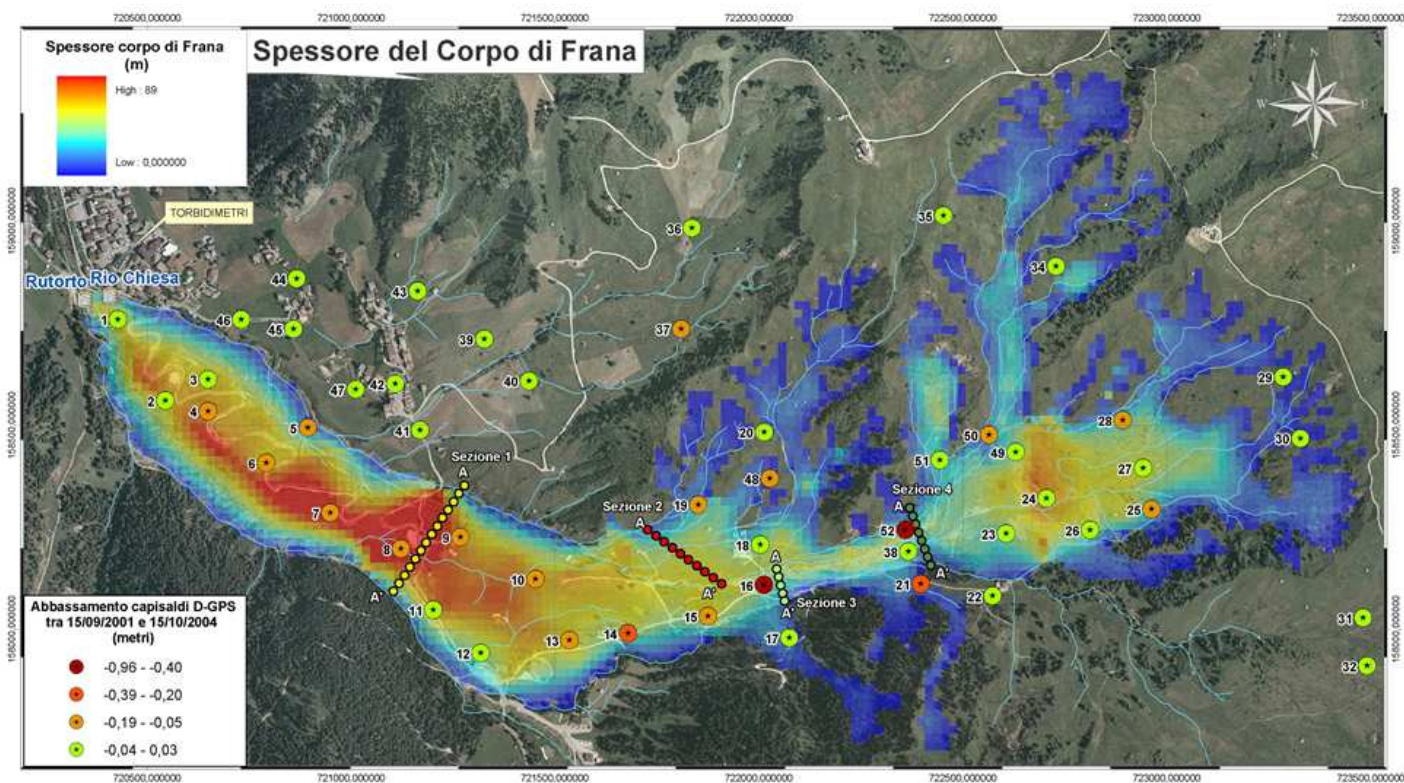
#### GRUPPO DI LAVORO

Università di Modena e Reggio Emilia  
Prof. M. Panizza (responsabile)  
Prof. M. Soldati  
Prof. M. Marchetti  
Dott.ssa L. Borgatti  
Dott. A. Corsini  
Dott. A. Ghinai  
Dott.ssa D. Piacentini

CNR - Consiglio Nazionale delle Ricerche, Padova  
Dott. S. Silvano (responsabile)  
Dott. A. Pasuto  
Ing. M. Mantovani  
Dott. G. Marcato  
Dott.ssa S. Moretto  
Ing. A. Zannoni

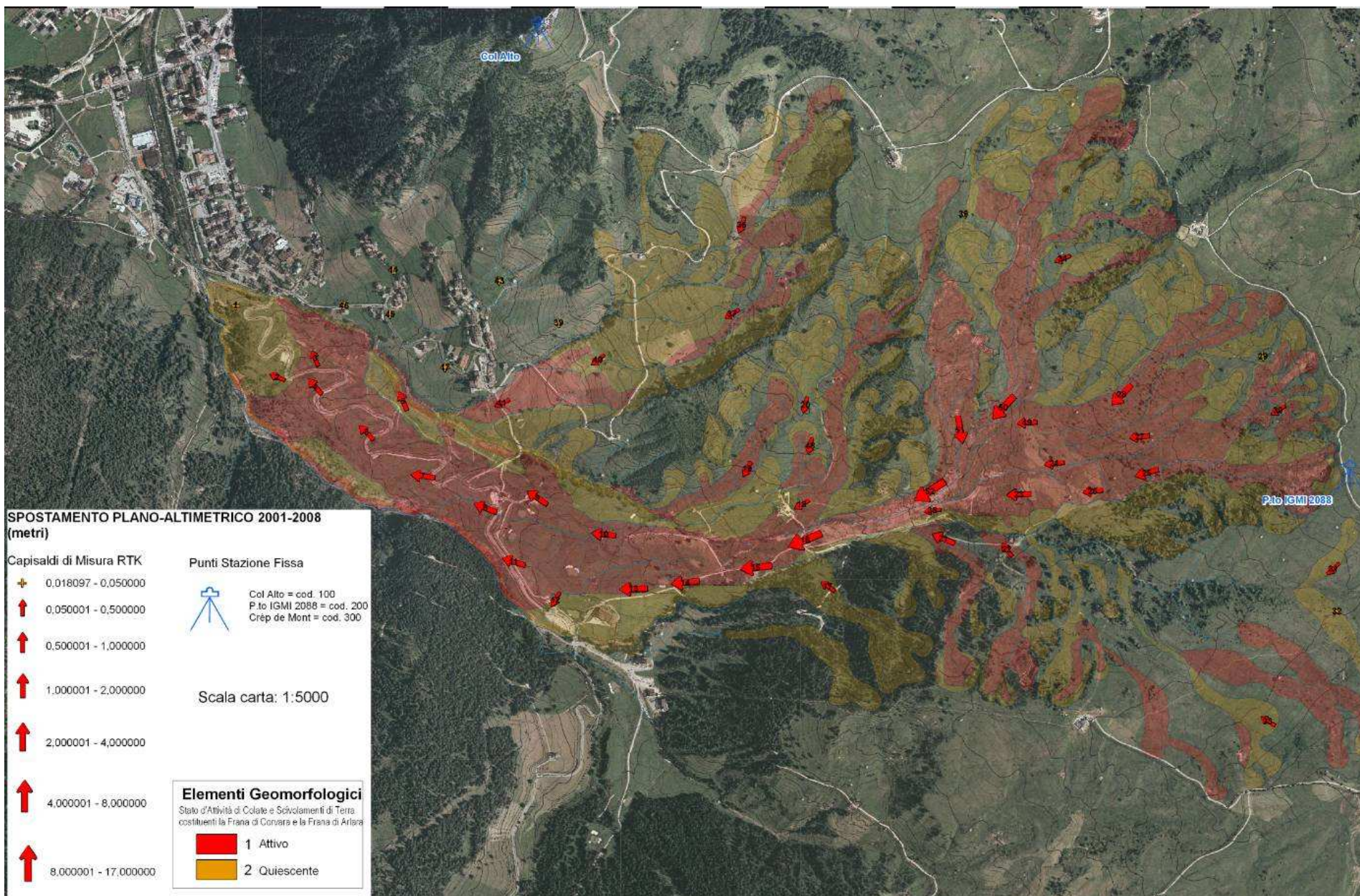
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Dott. P. Profanter  
Dott. V. Mair  
Dott. M. Sperling  
Geom. G. Valentinioti

Comune di Corvara in Badia  
Sig. H. Kostner (responsabile)  
Sig. R. Rottonara  
Ing. S. Tiezza



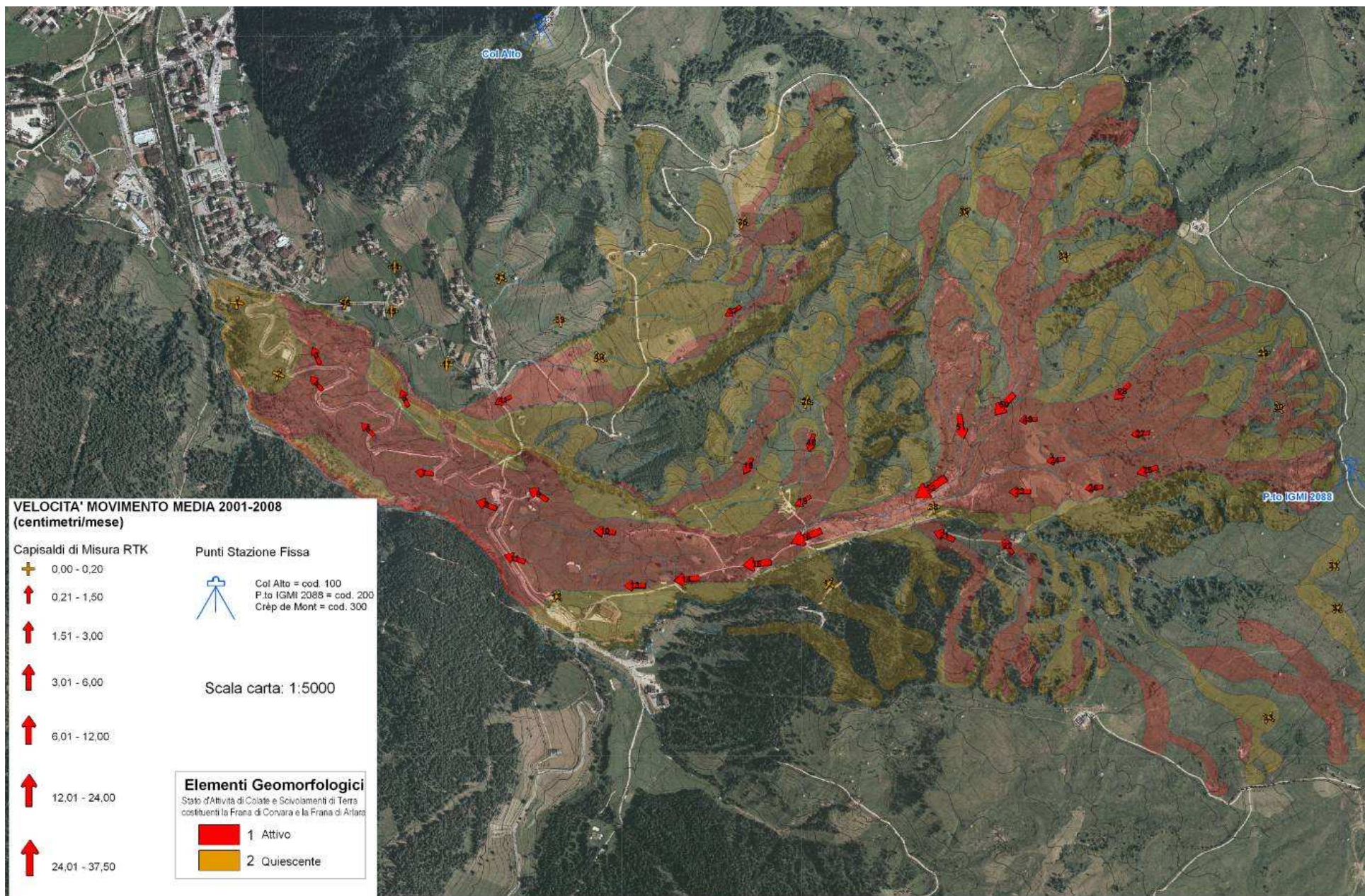


## GPS monitoring 1997-2008 [total displacement (m)]





## GPS monitoring 1997-2008 [mean velocity cm/month]

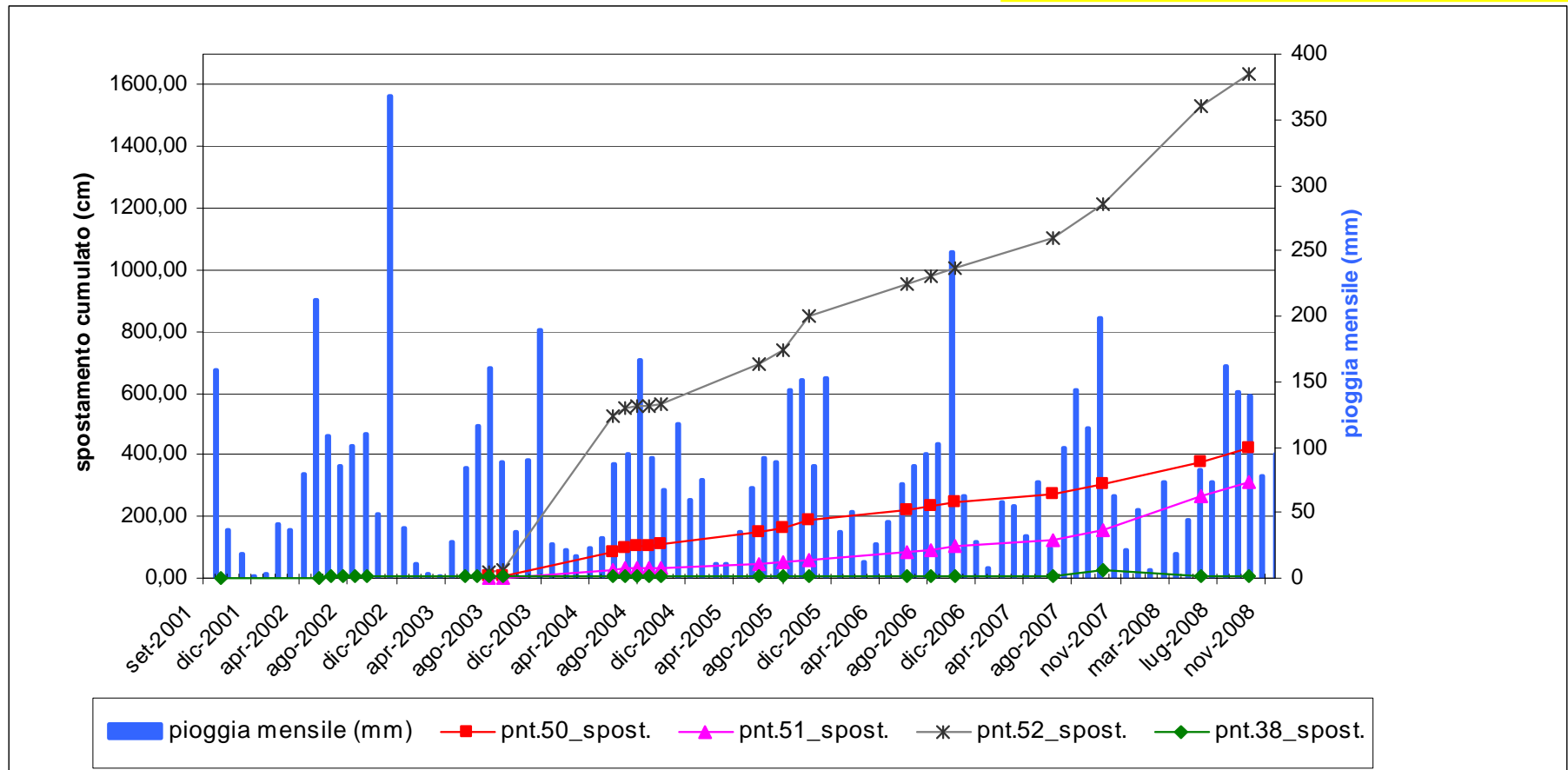
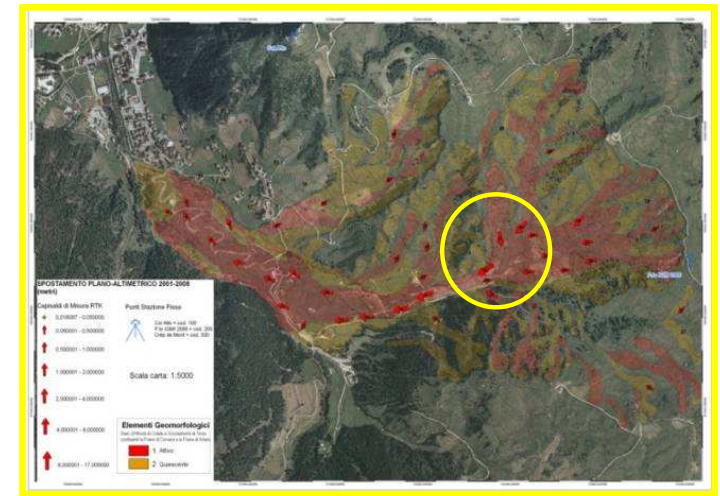






## GPS monitoring 1997-2008 [displacement (cm)]

### ZONA SORGENTE S2: SETTORE BASSO E ZONA DI TRASPORTO: SETTORE ALTO Capisaldi n° 38 – 50 – 51 – 52

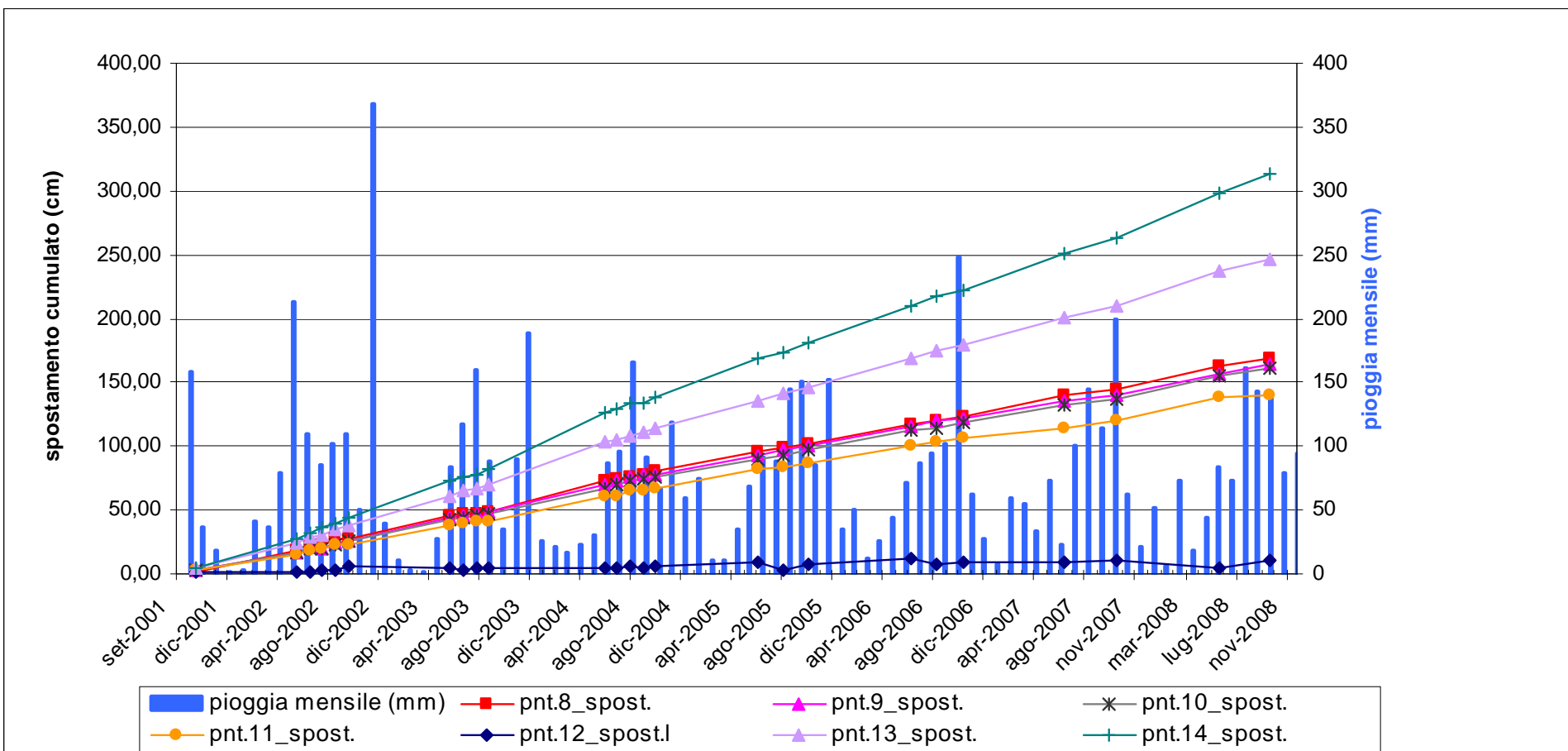
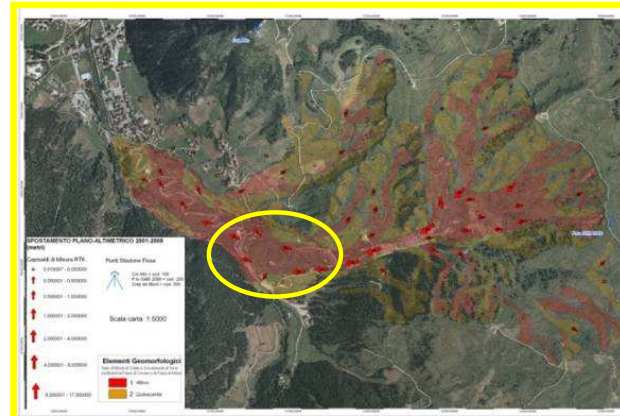




## GPS monitoring 1997-2008 [displacement (cm)]

### ACCUMULO FRANA: SETTORE ALTO

Capisaldi n° 8 – 9 – 10 – 11 – 12 – 13 – 14



### SUPPORT OF SATELLITE RADAR TO HAZARD ZONE MAPPING IN THE ITALIAN ALPS

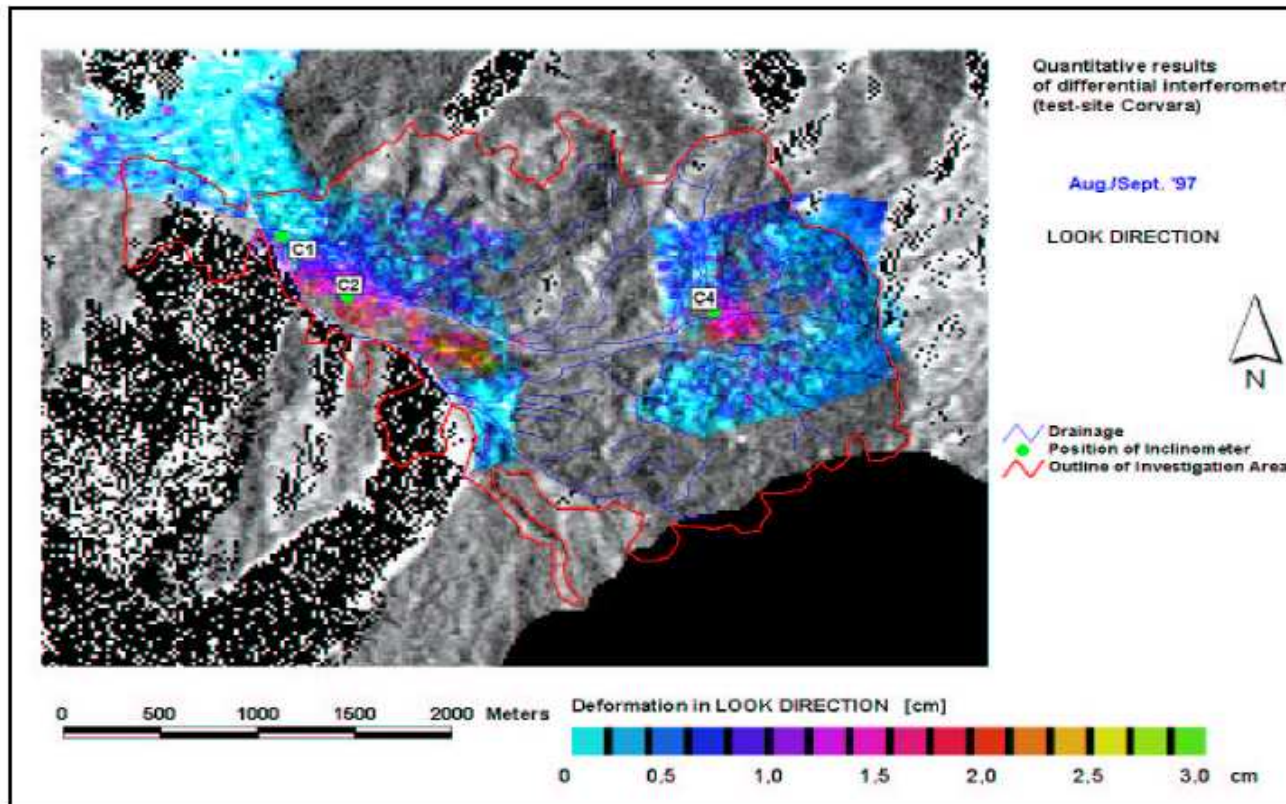
Belitz, K.<sup>(1)</sup>, Corsini, A.<sup>(4)</sup>, Mair, V.<sup>(2)</sup>, Strozzi, T.<sup>(3)</sup>, Wegmüller, U.<sup>(3)</sup>, Zilger, J.<sup>(4)</sup>

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<sup>(2)</sup> Amt für Geologie und Baustoffprüfung, Autonome Provinz Bozen-Südtirol  
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<sup>(3)</sup> Gamma Remote Sensing AG  
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Largo S. Eufemia 19, 41100 Modena, Italy, Email: allecors@unimo.it



ERS dataset  
(C-band)

Fig. 4. Quantitative results of DInSAR in look direction, Aug-Sept 1997.

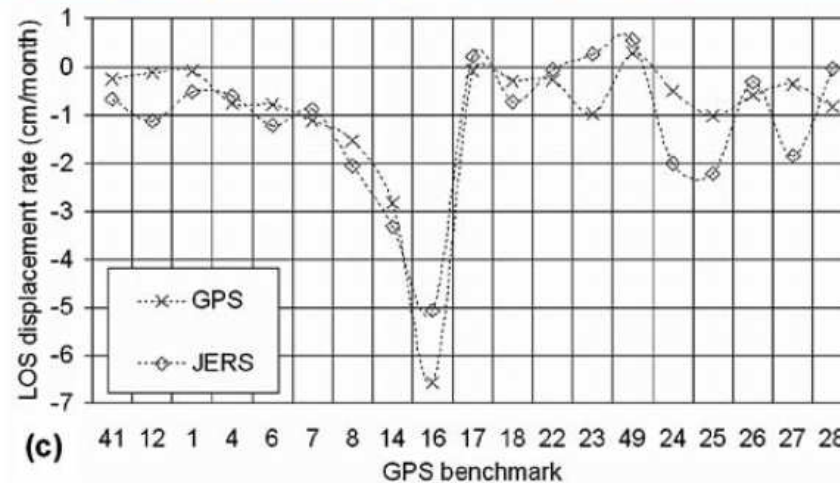
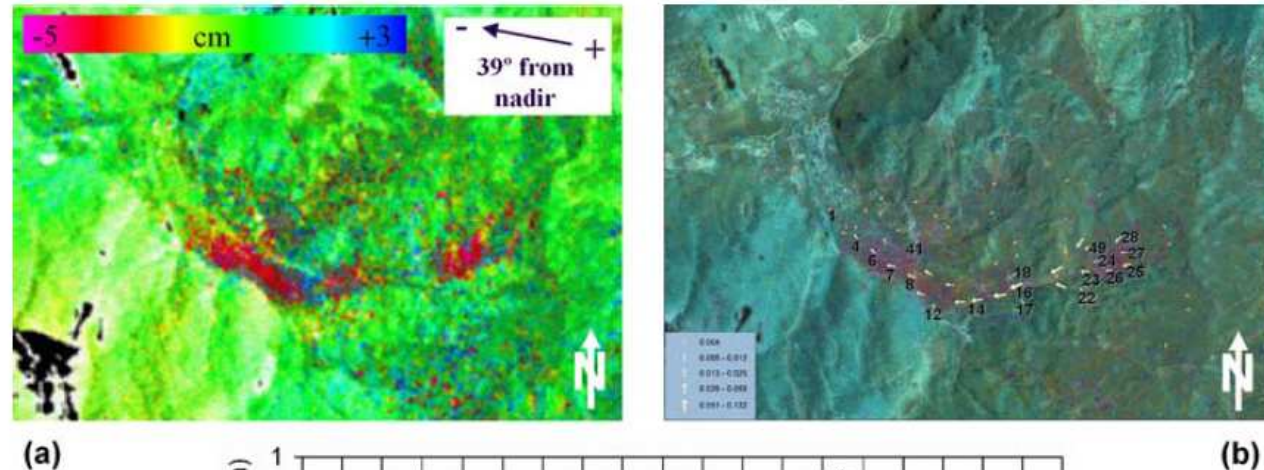
Original Paper

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Received: 4 April 2005  
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Tazio Strozzi · Paolo Farina · Alessandro Corsini · Christian Ambrosi · Manfred Thüring · Johannes Zilger · Andreas Wiesmann · Urs Wegmüller · Charles Werner

## Survey and monitoring of landslide displacements by means of L-band satellite SAR interferometry

**Fig. 2** Corvara in Alta Val Badia. **a** Geocoded JERS displacement map in the line-of-sight direction for the time period 2 July to 28 September 1998 (88 days, 217 m), **b** GPS measurement rates (in meter/month from September 2001 to September 2003) superimposed on the interferogram of Fig. 1a, orthophotograph in the background, **c** Comparison between measurement rates in the JERS line-of-sight (LOS) direction of selected GPS benchmarks and the corresponding pixels in the JERS displacement map of Fig. 2a. See Fig. 2b for the location of the GPS benchmarks



JERS dataset  
(L-band)



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UNIVERSITÀ DEGLI STUDI DI  
MODENA E REGGIO EMILIA



Ateneo fondato nel 1175

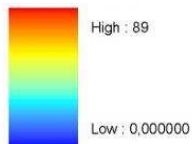
DIPARTIMENTO DI SCIENZE CHIMICHE E GEOLOGICHE

*...was there more to be found out?*

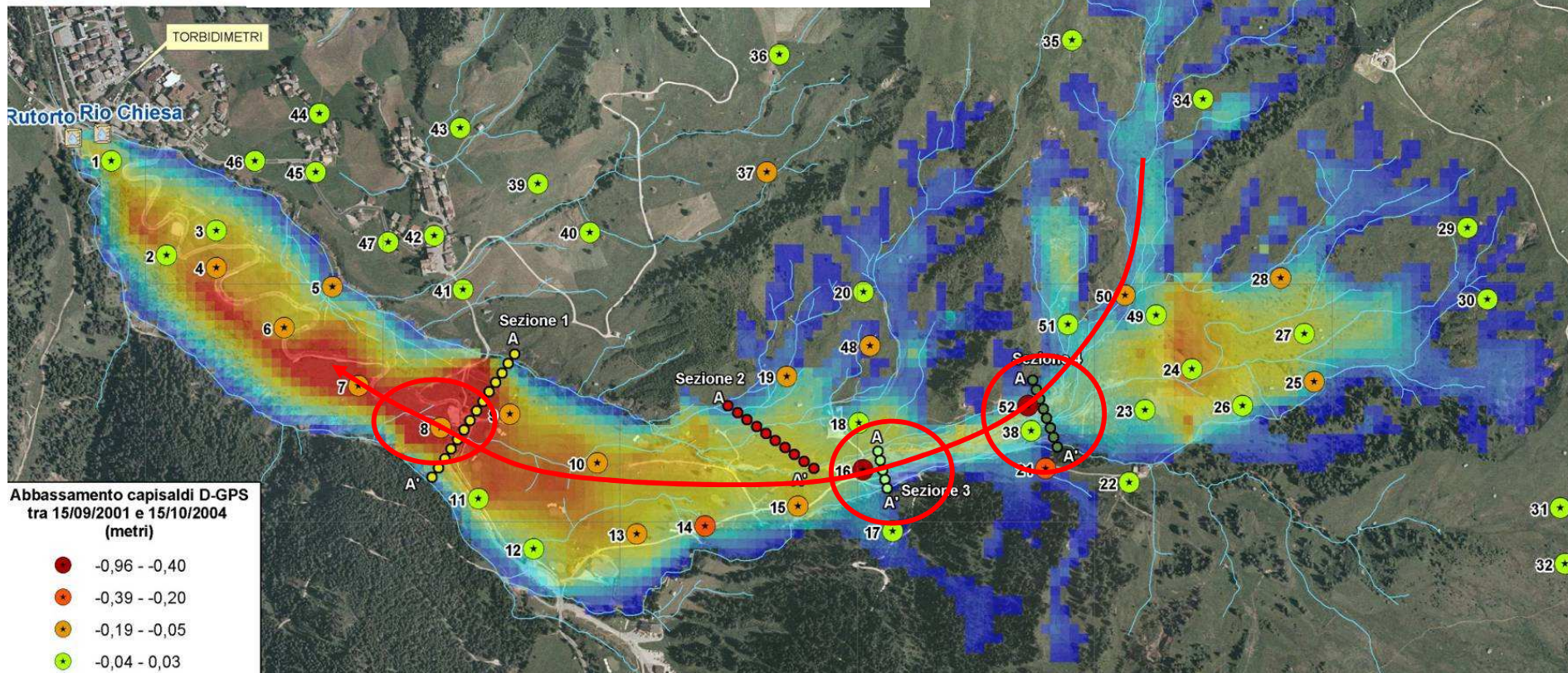


## Mass balance 1997-2006

ID_SEZIONE	AREA TOTALE (m2)	AREA STIMATA ATTIVA (da inclinometri o altre stime) (m2)	VELOCITA' MEDIA AREA ATTIVA (da dati GPS) (m/anno)	VOLUME TRANSITATO ANNUALMENTE (m3/anno)
4	2349	1174 (stima al 50%)	2,40 (media tra GPS # 52, 51, 50)	2818
3	1900	1555 (da inclinometro C3)	1,68 (GPS # 16)	2612
1	17122	11551 (da inclinometro C6)	0,24 (GPS # 8, 9, 11)	2784

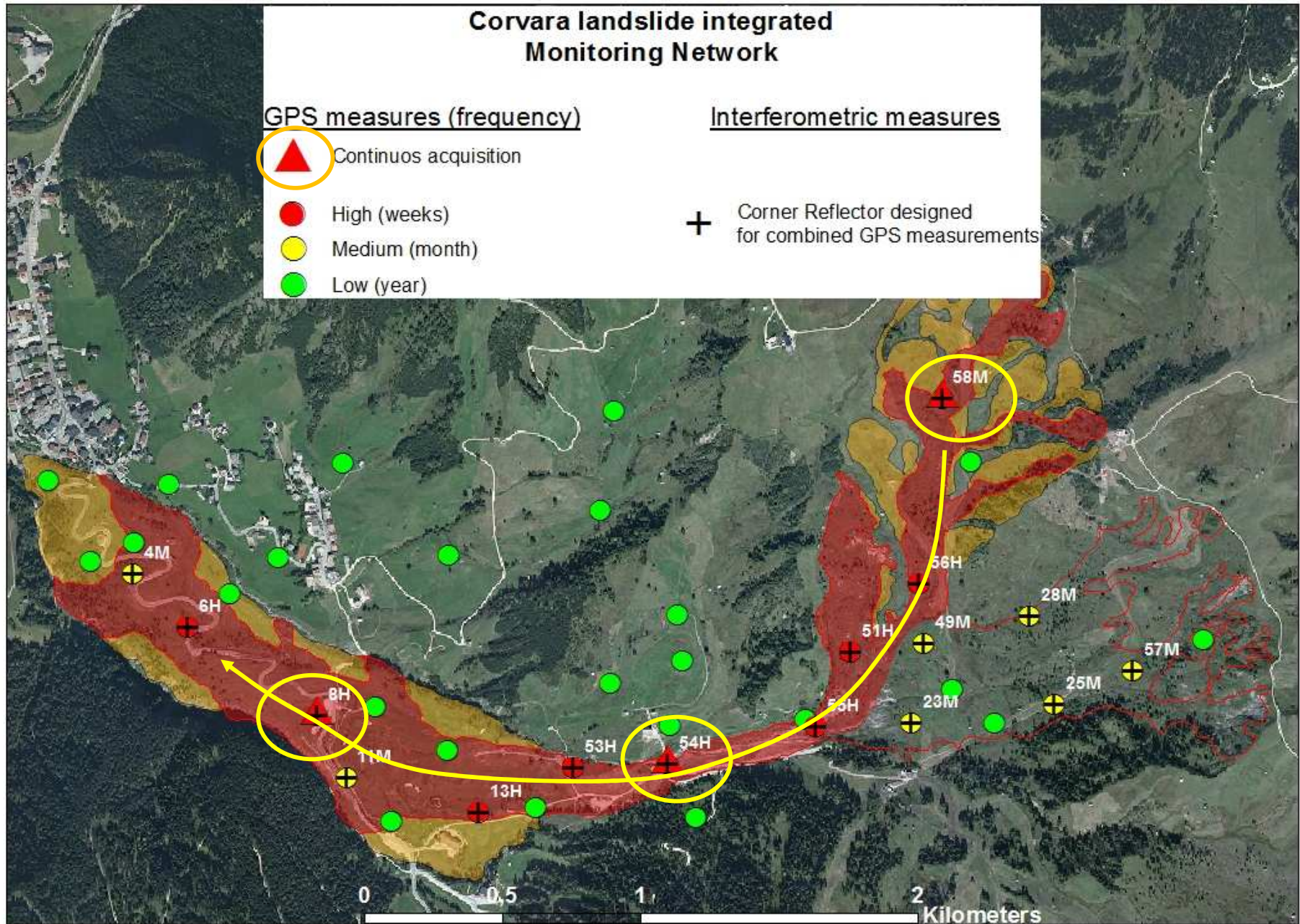


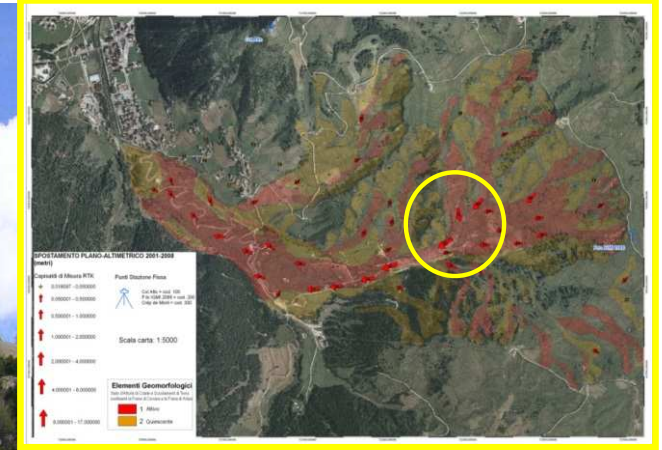
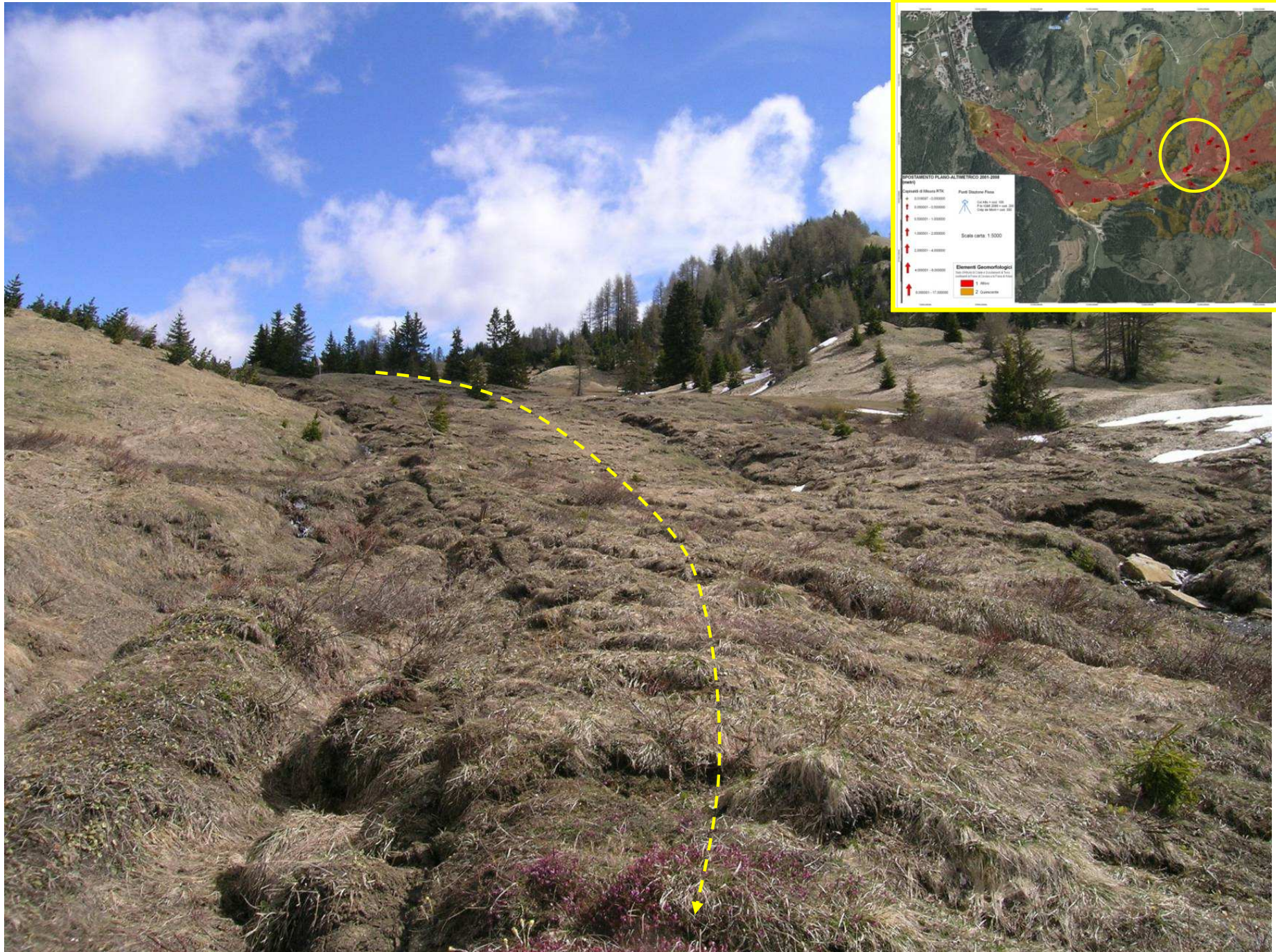
**TIMING? PROCESSES? CAUSES?**  
**....higher temporal resolution**

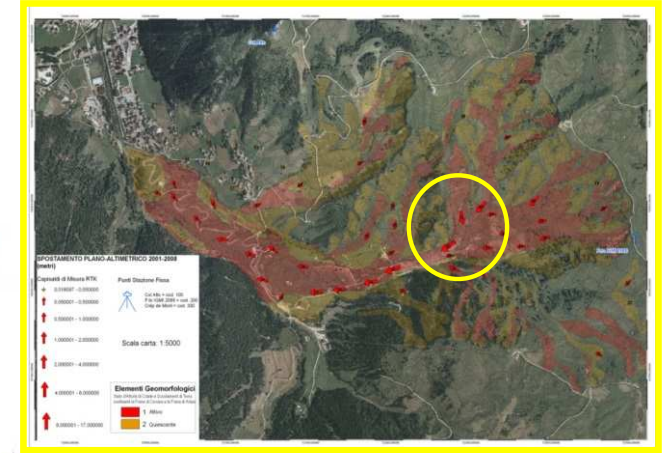




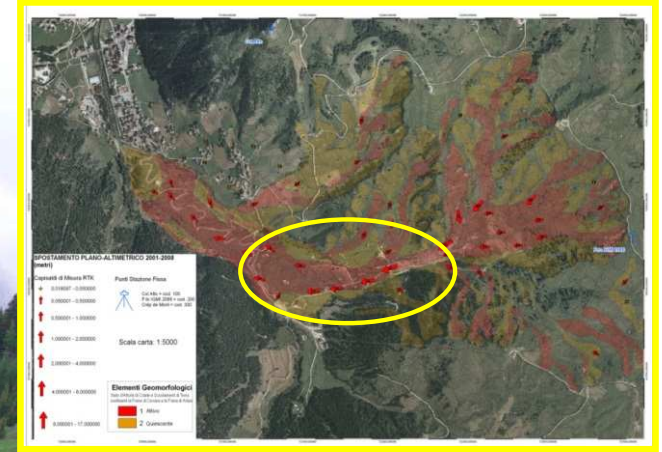
## GPS + AR-PS monitoring 2013 to date: operative set-up





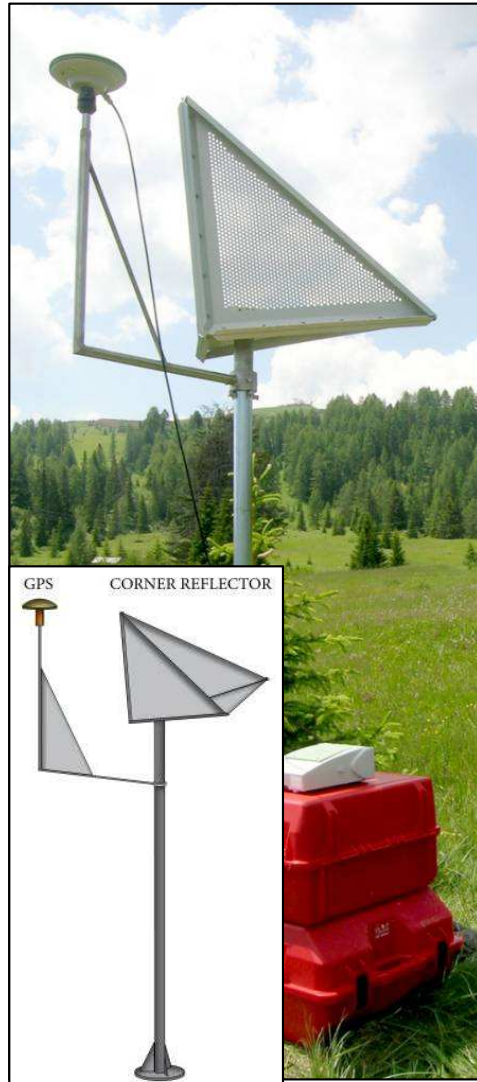








## GPS + AR-PS monitoring 2013 to date: operative set-up





## Borehole monitoring 2013 to date

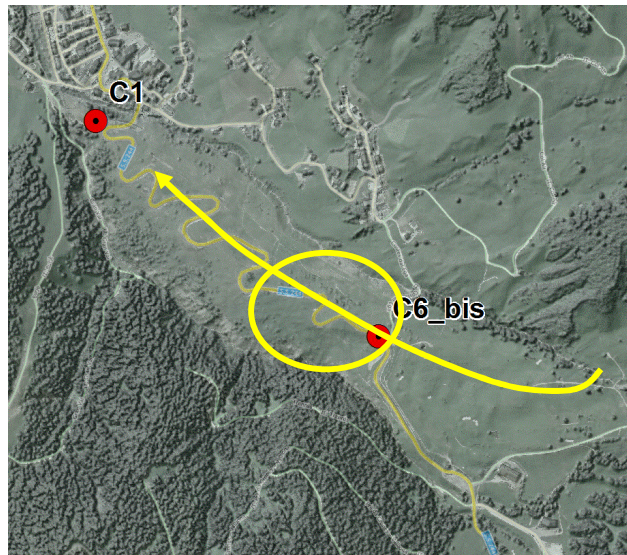


Fig.23 – Costes da l'Ega, cantiere C6 bis. Sullo sfondo l'ubicazione del tubo inclinometrico C6.

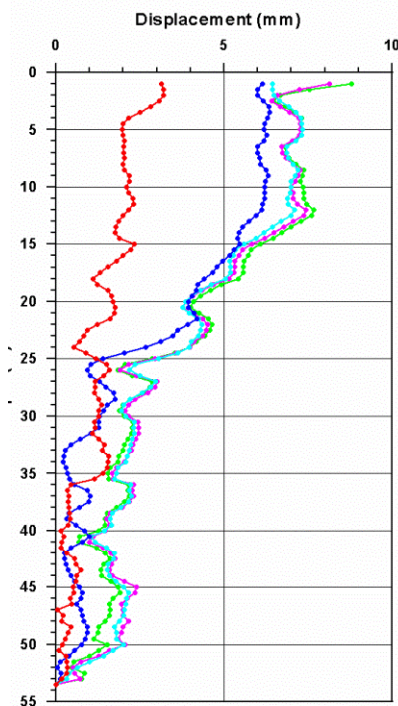


# Borehole monitoring 2013 to date: operative set-up

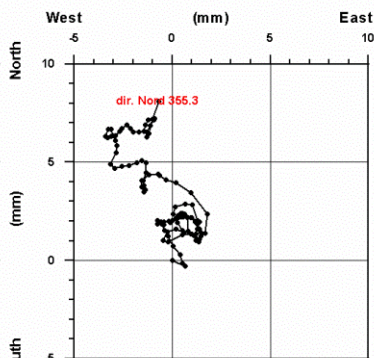
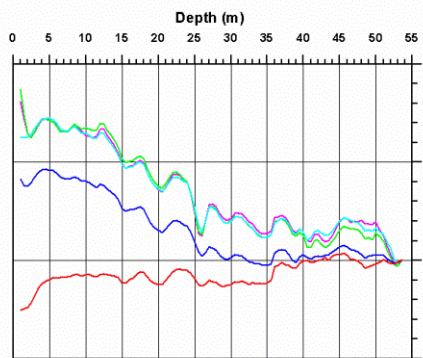
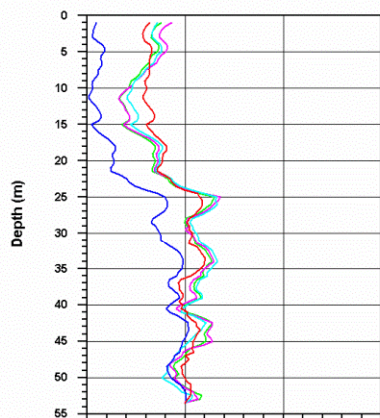
## C6bis (since fall 2013)

### C1 (since 1997)

#### INCLINOMETRIC SURVEY



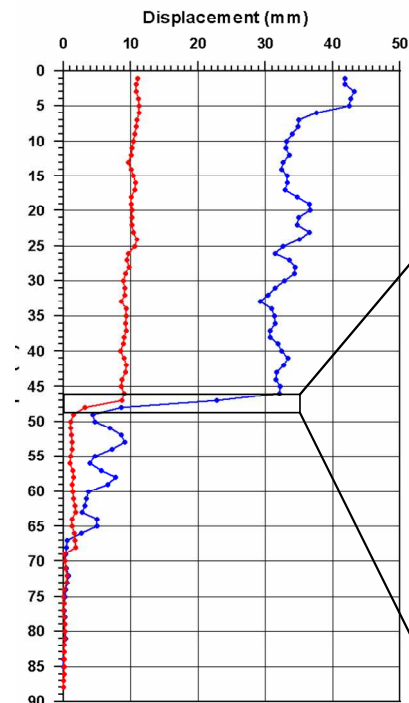
Site : Corvara C1  
 First Reading: CORVC1.001 Date: 23-set-1997  
 Reading 1 (red): CORVC1.010 Date: 22-mag-2001  
 Max step displ. 0.74 mm depth 35.5 m North dir. 160.4  
 Reading 2 (blue): CORVC1.020 Date: 05-feb-2004  
 Max step displ. 0.67 mm depth 24.0 m North dir. 294.6  
 Reading 3 (cyan): CORVC1.024 Date: 26-ott-2012  
 Max step displ. 1.09 mm depth 24.5 m North dir. 324.9  
 Reading 4 (green): CORVC1.025 Date: 24-set-2013  
 Max step displ. 1.33 mm depth 1.0 m North dir. 11.7  
 Reading 5 (magenta): CORVC1.025 Date: 17-lug-2014  
 Max step displ. 1.40 mm depth 24.5 m North dir. 321.9



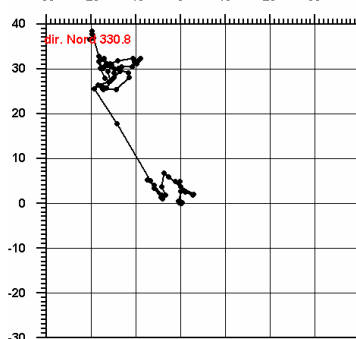
Last reading - Plan

Reading 2 (blue): CORC6BIS.003 Date: 17-nov-2013  
 Max step displ. 14.69 mm depth 47.0 m North dir. 329.2

#### INCLINOMETRIC SURVEY



West (mm) East  
 -30 -20 -10 0 10 20 30 40



Last reading - Plan

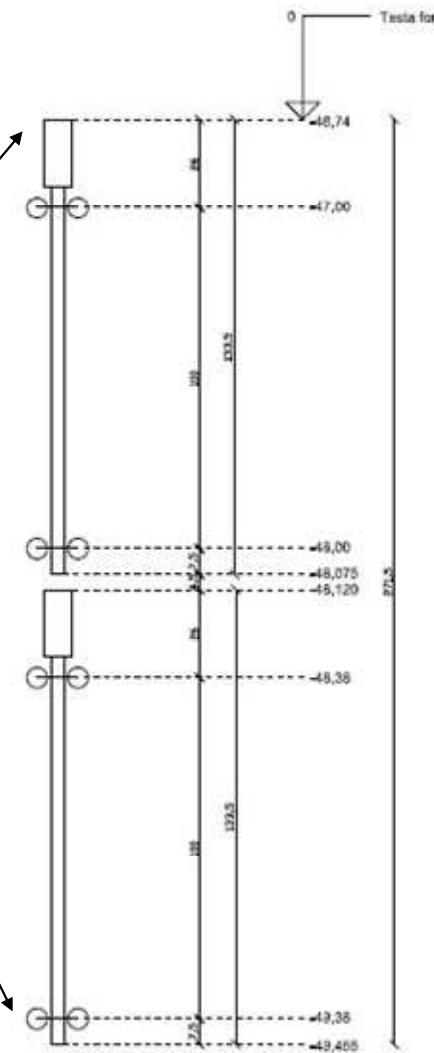


Fig. 26 - Schema di installazione sonde inclinometriche fisse nel tubo C6 bis.

## Borehole monitoring 2013 to date



Fig. 27 - Pozzetto C6 bis. Terminale in acciaio a cui sono ancorate le sonde inclinometriche fisse.

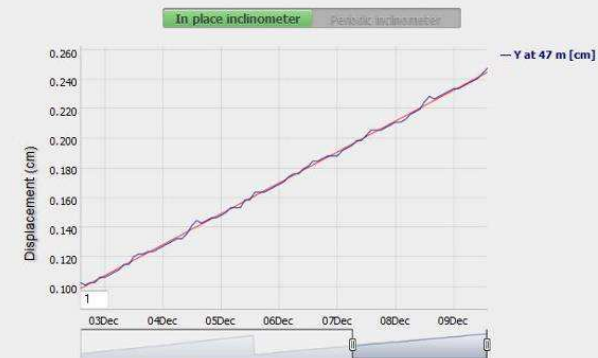


Fig. 28 - C6 bis, unità di acquisizione e trasmissione dati

Comune di Corvara in Badia  
Provincia di Bolzano - Alto Adige  
CNR-IRPI - UOS of Padova

[ Corvara Landslide ] Select the element you are interested  
[ Intensity map ] (C1, C6\_bis and the green line are available, up to now)  
[ Arrow map ]  
[ Passo Gardena Landslide ]  
[ Documents ]

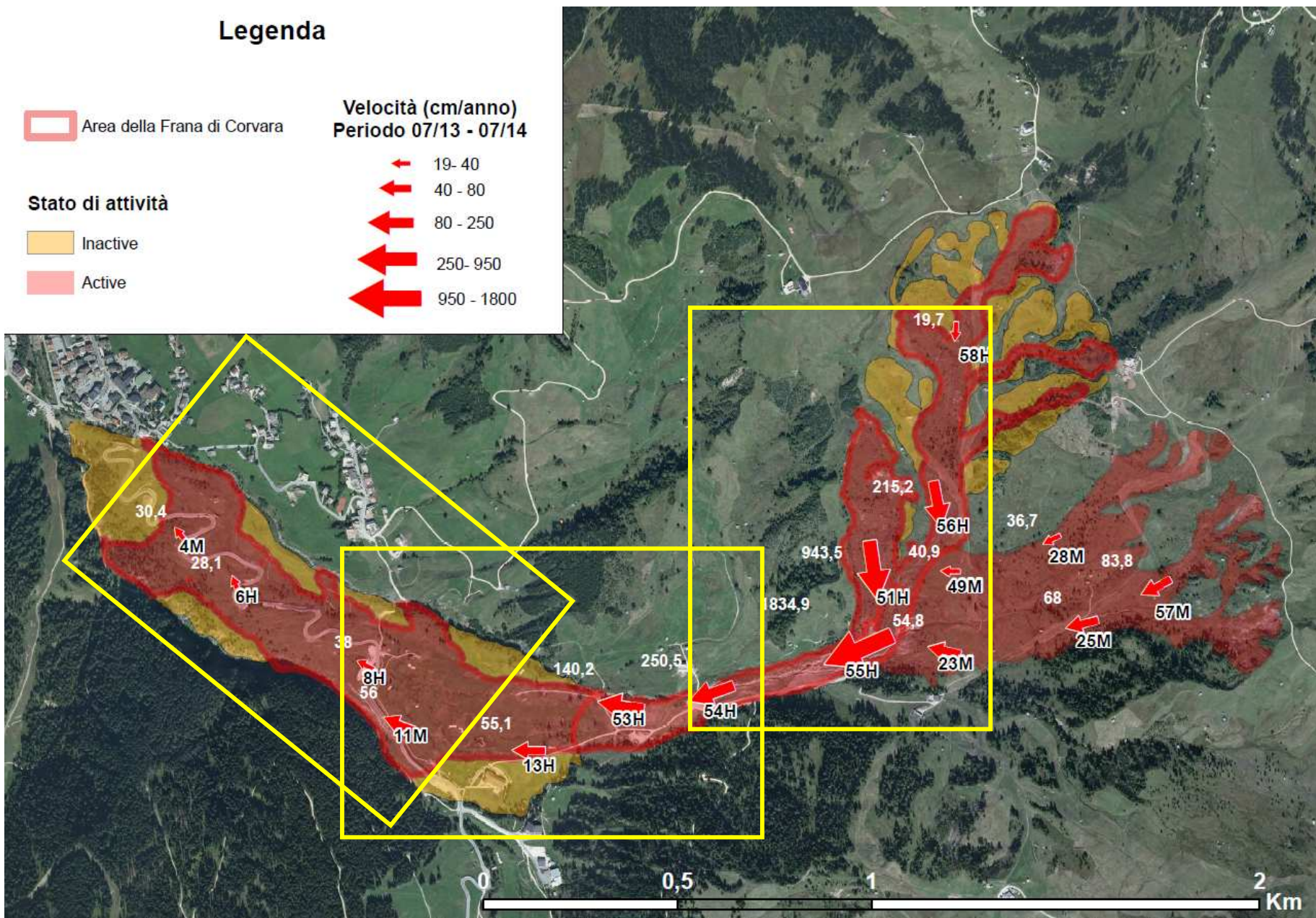
2012-2013 © Copyright Luca Schenato - CNR-IRPI UOS di Padova - Last modified 08/22/14 09:51





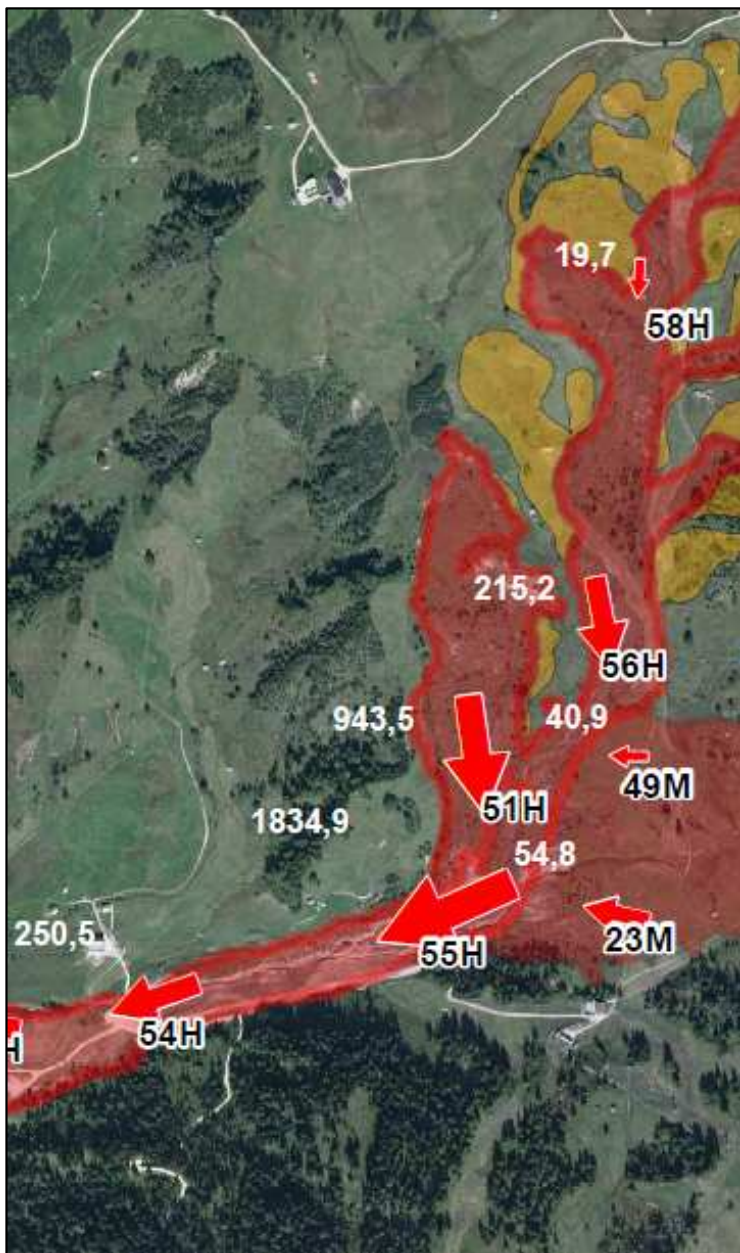
# Periodic GPS

## Legenda

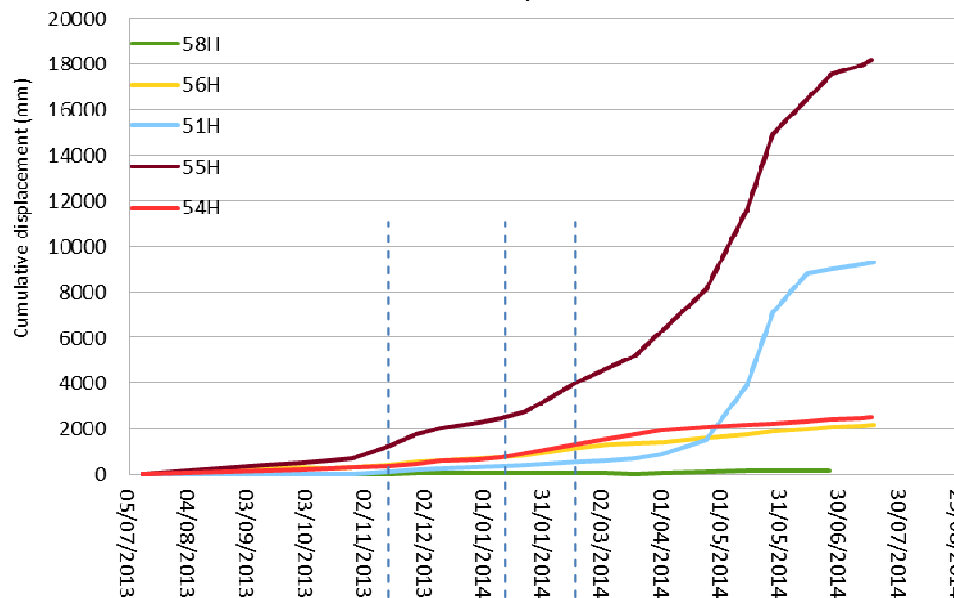




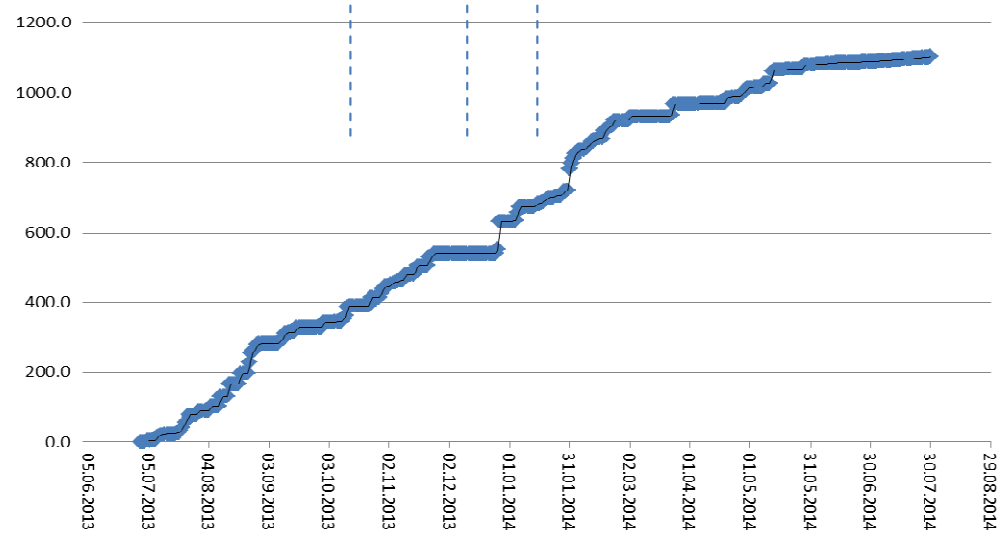
# Periodic GPS



Source A : Displacement

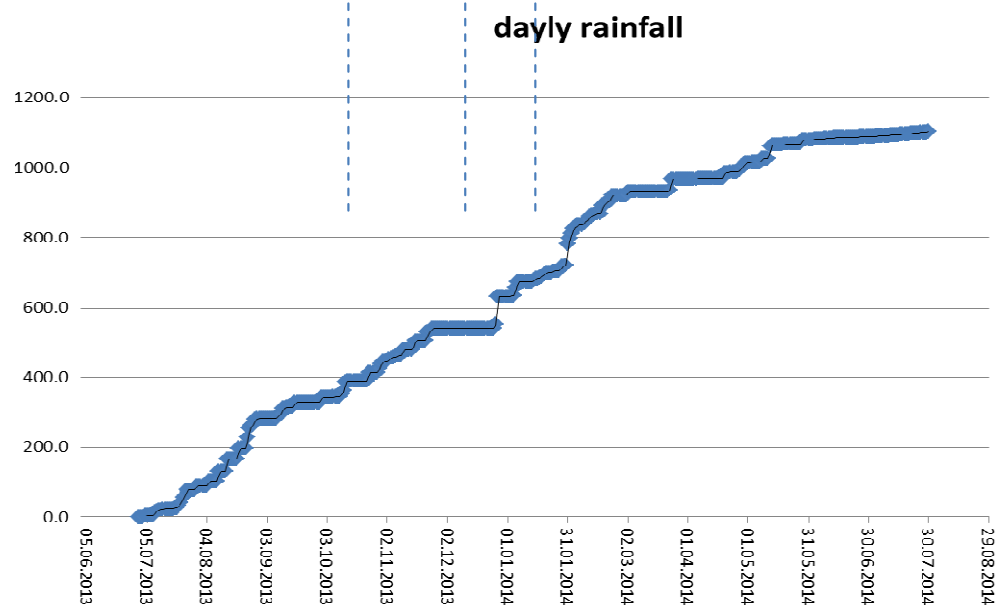
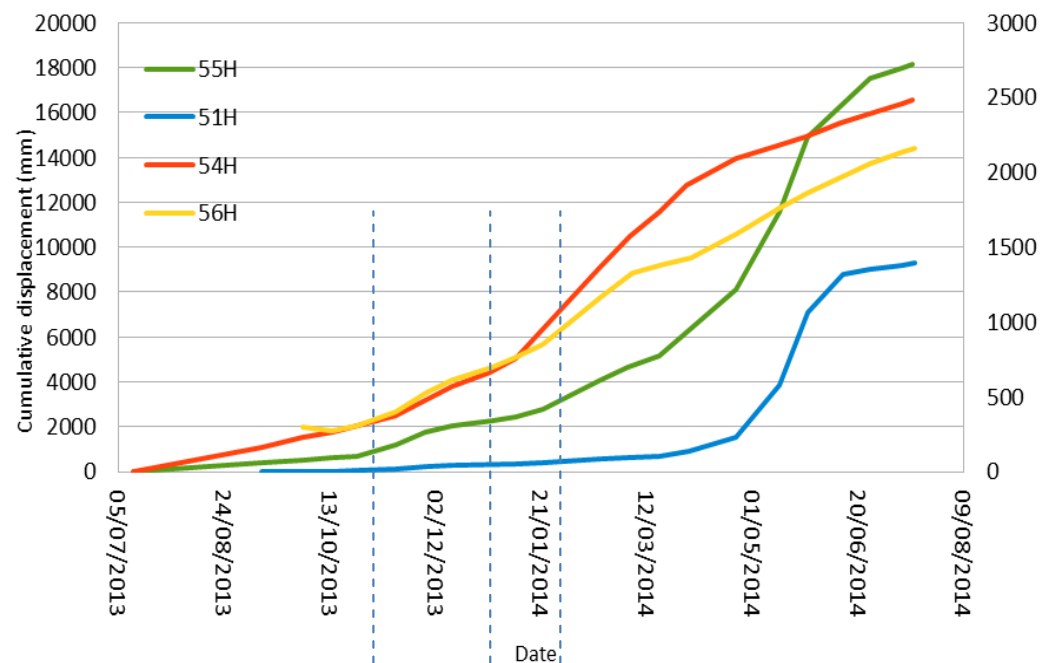
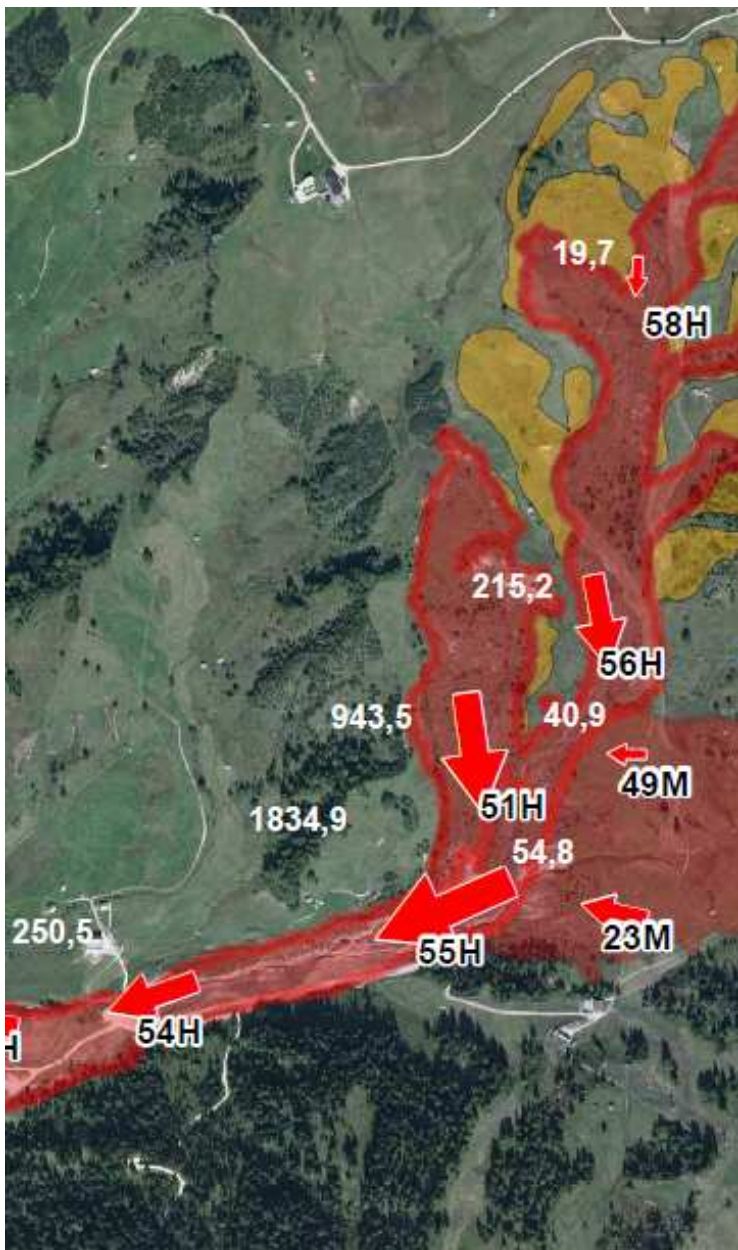


daily rainfall



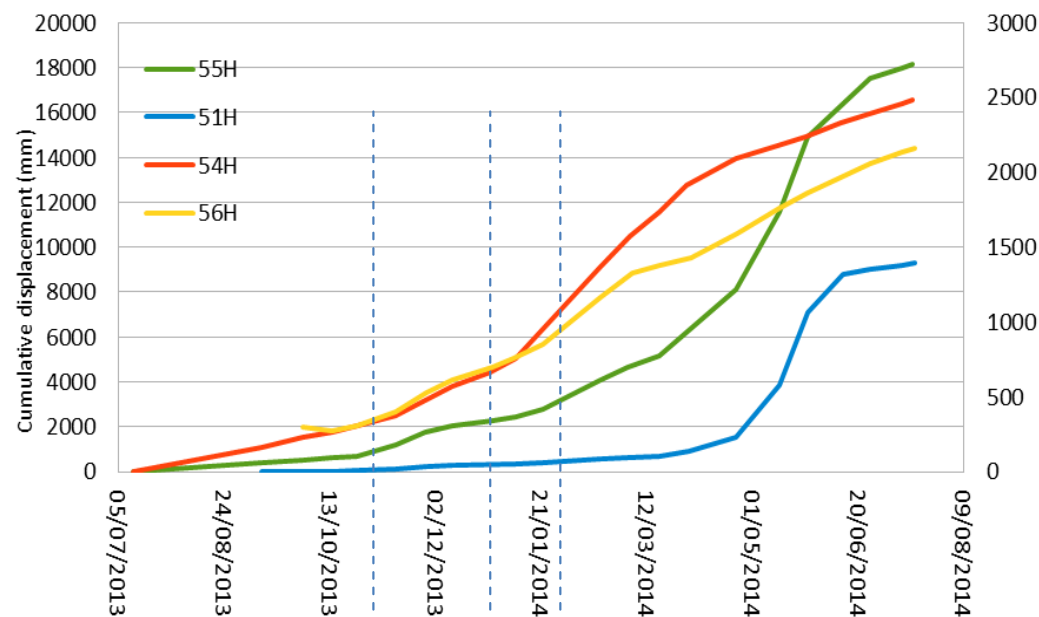
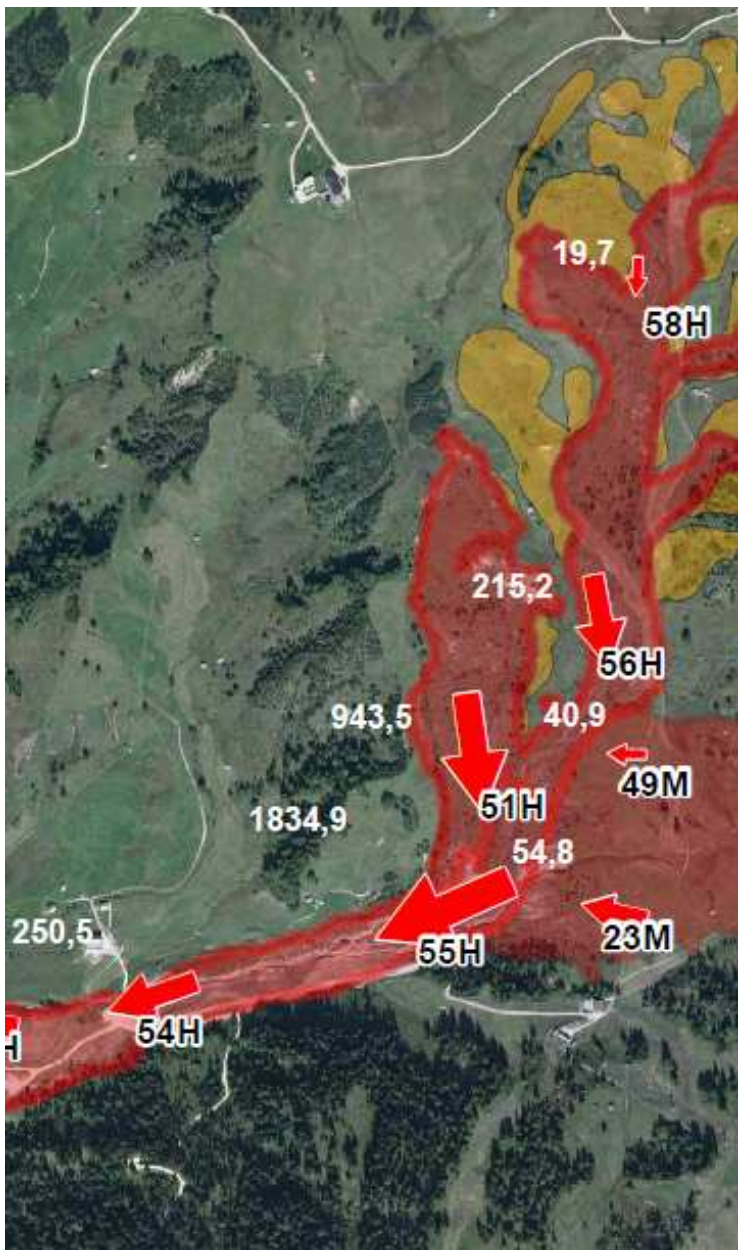


# Periodic GPS



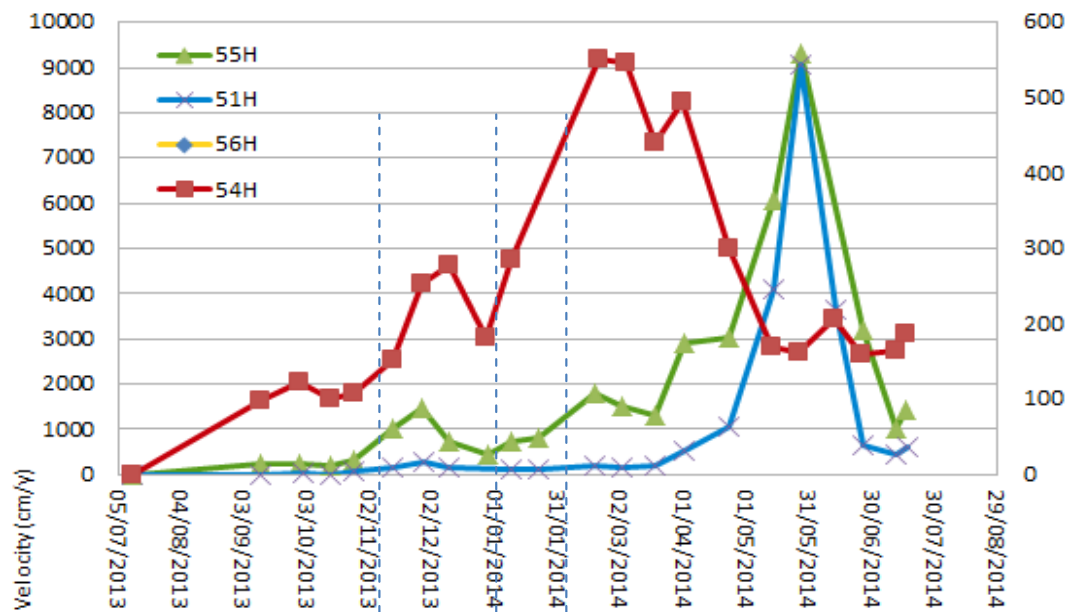
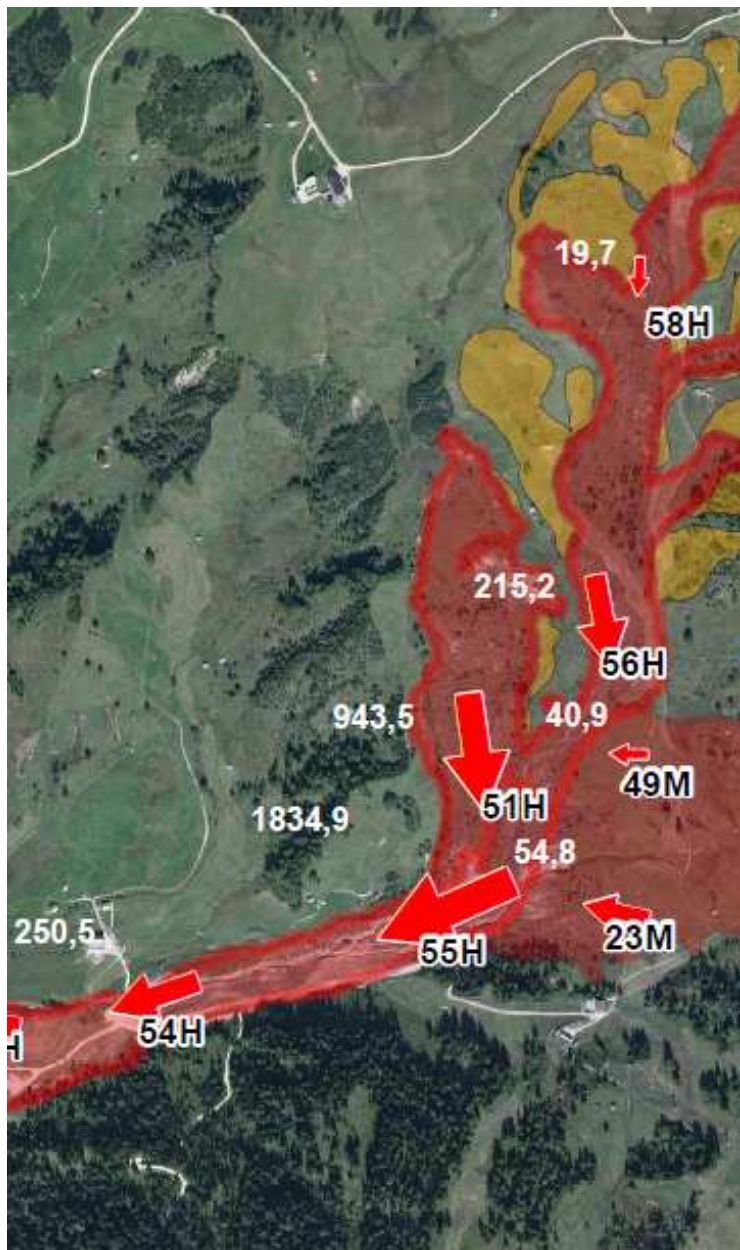


# Periodic GPS



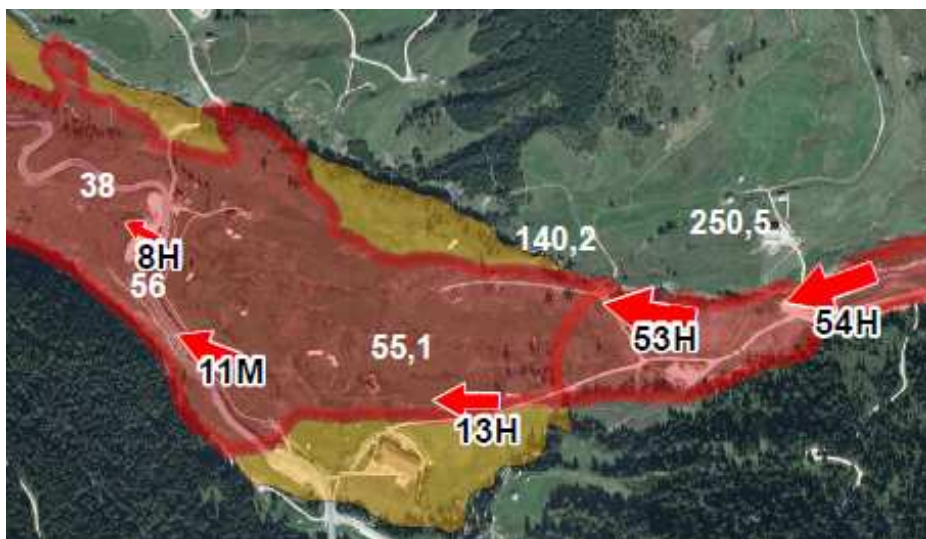


# Periodic GPS

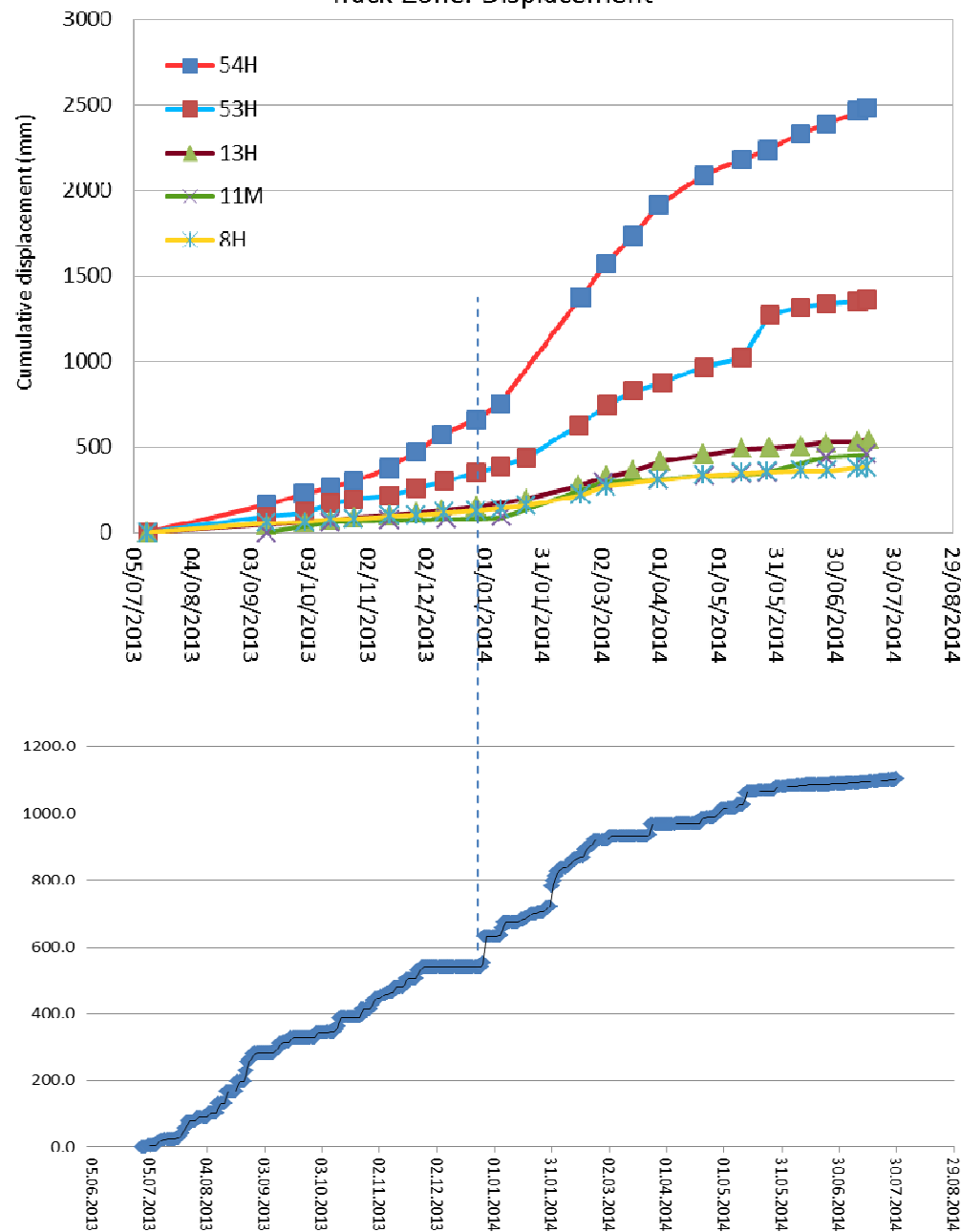




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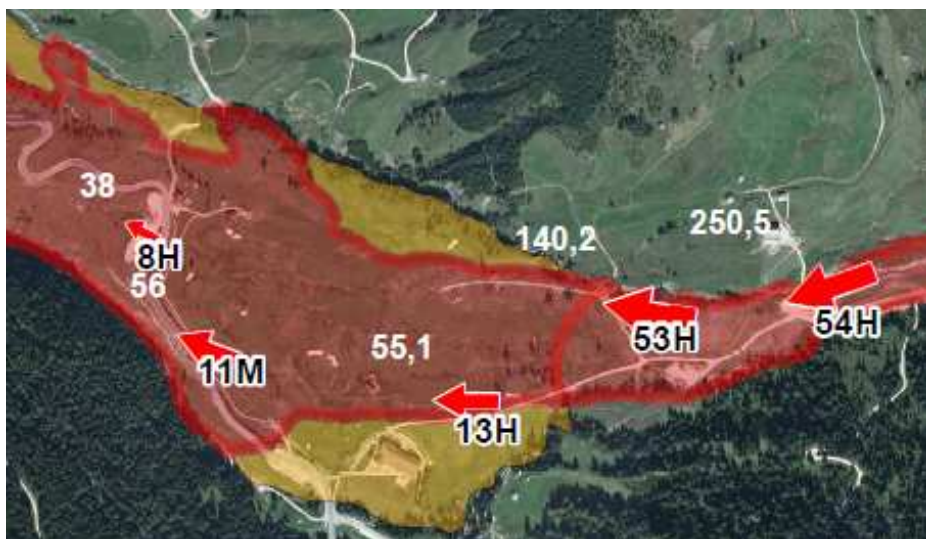


Track Zone: Displacement

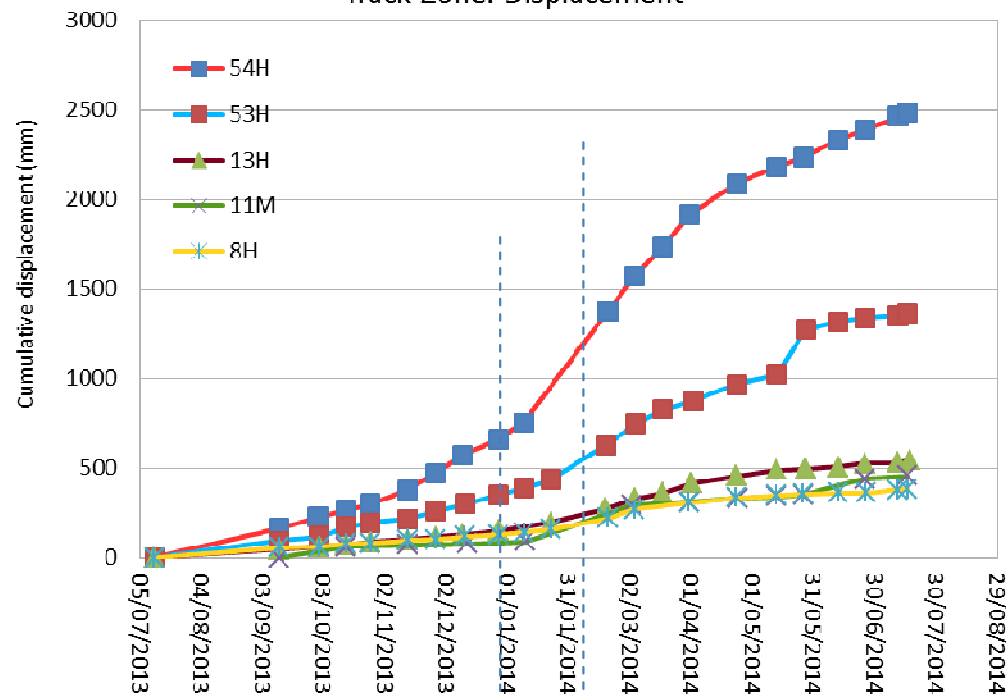




# Periodic GPS

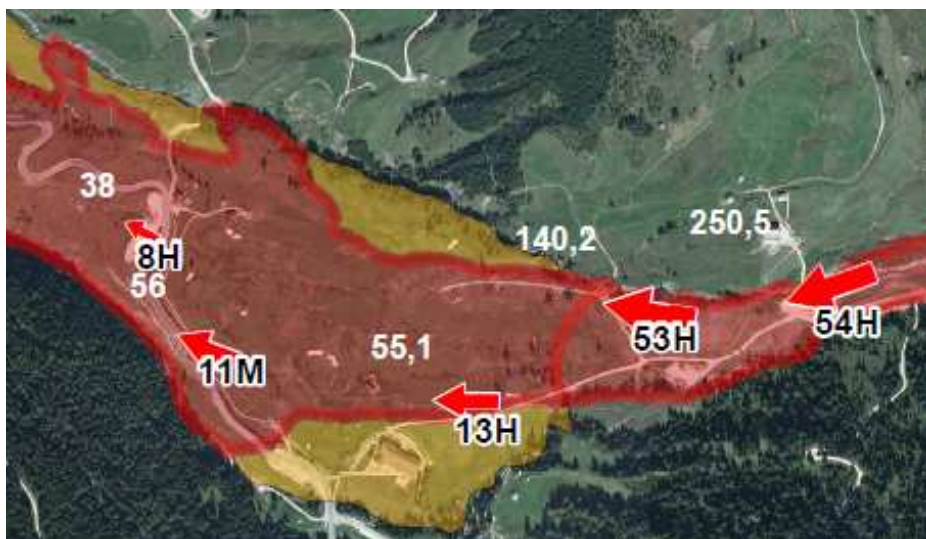


Track Zone: Displacement

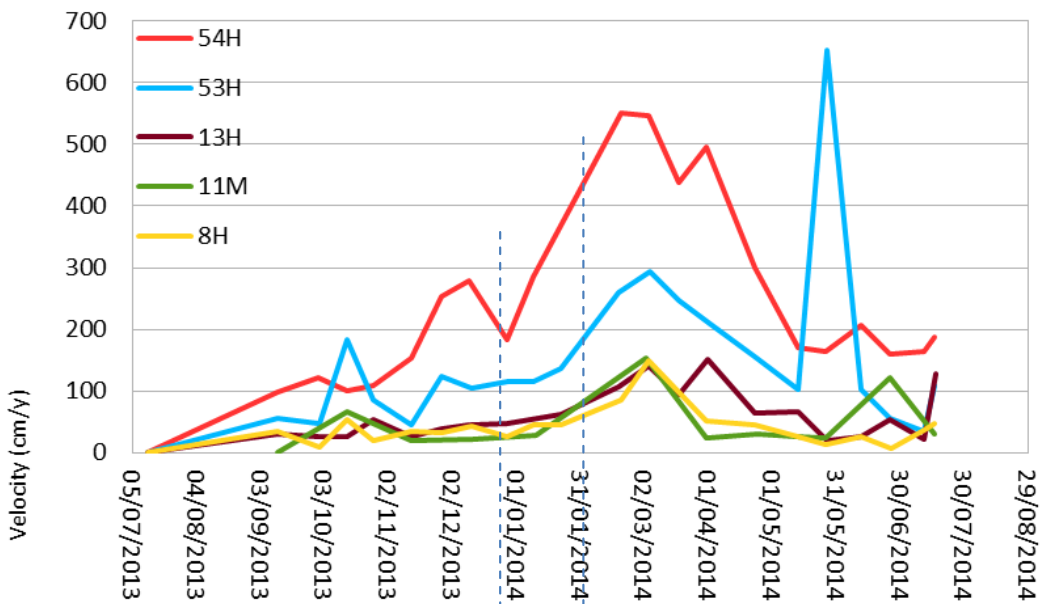




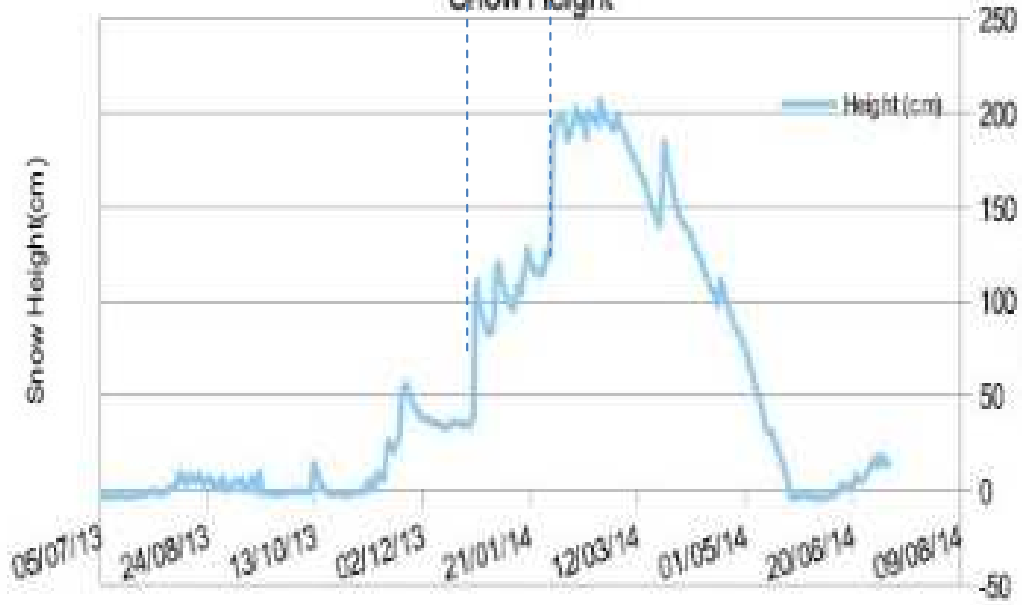
# Periodic GPS



Track Zone: Velocity

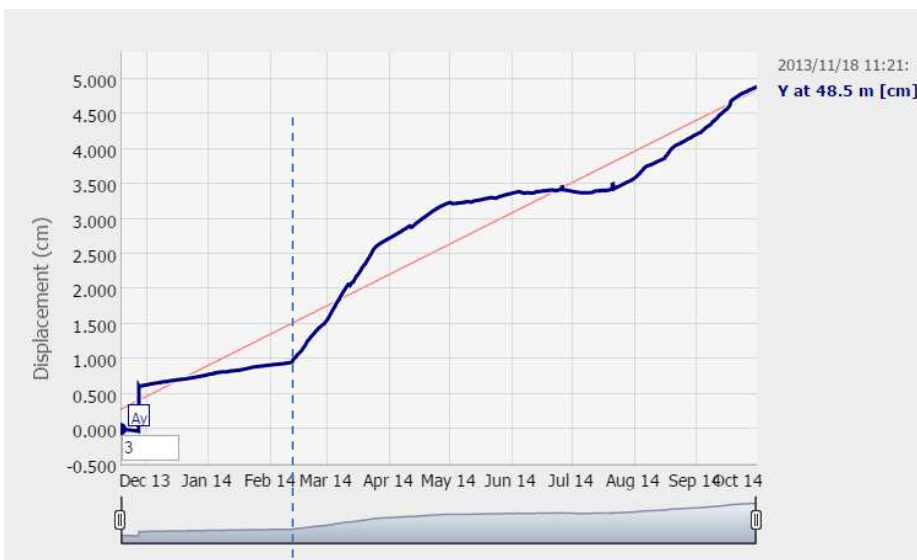


Snow Height



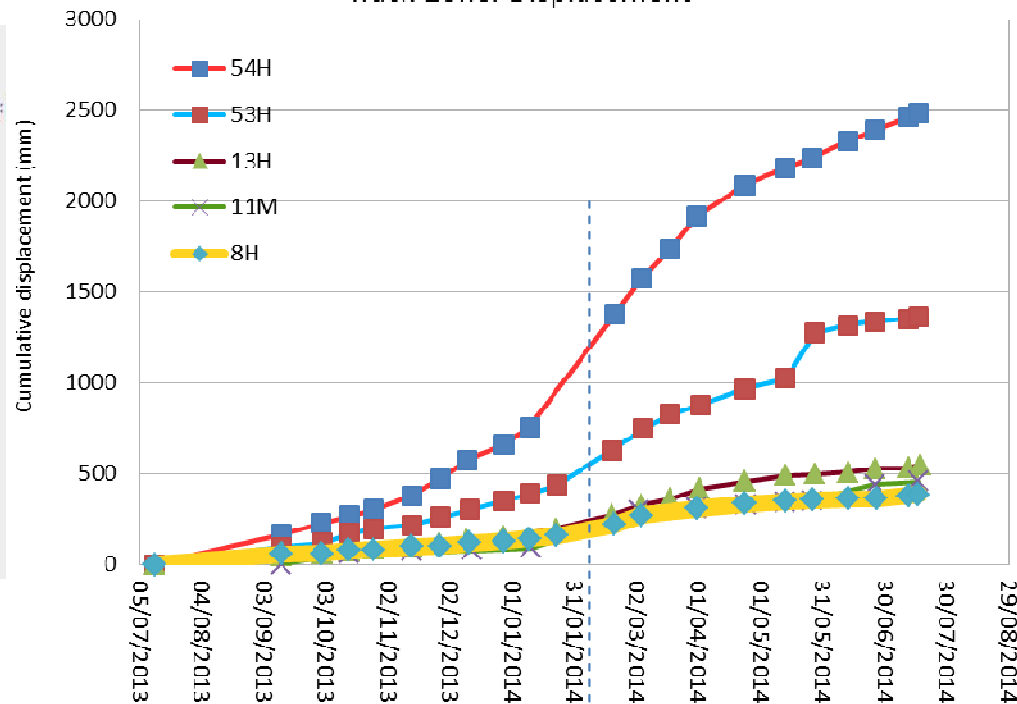


## In-place inclinometers

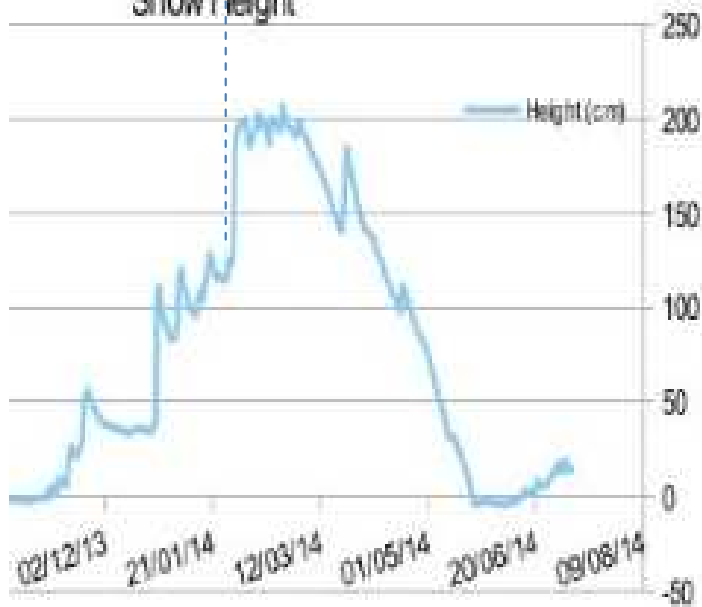


## Periodic GPS

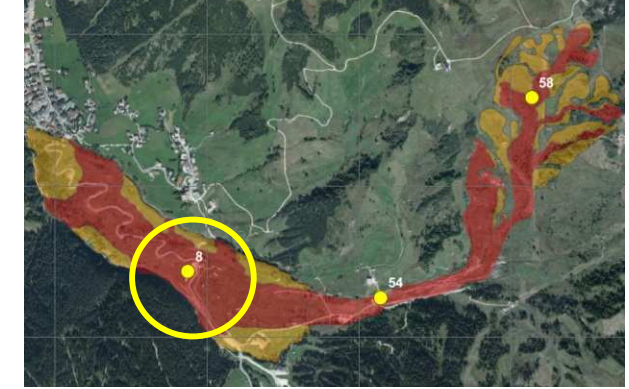
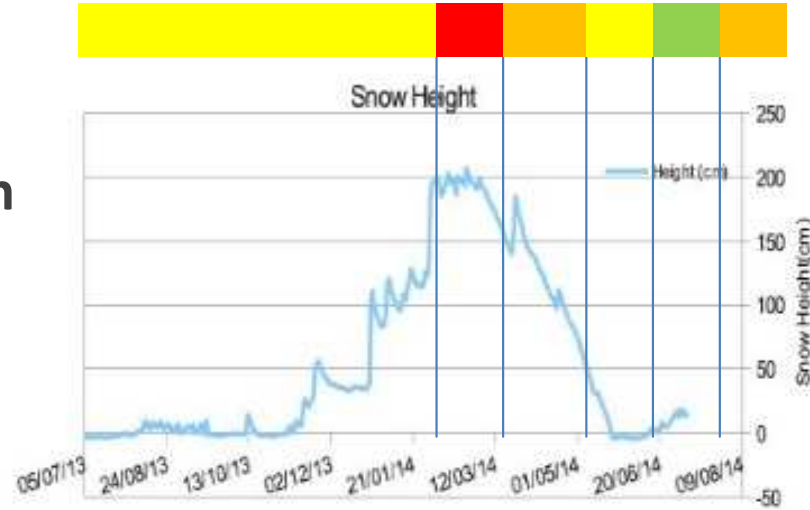
Track Zone: Displacement



Snow Height



## Snow accumulation



## Continuous In-place inclinometers (Dec. 2013 to Nov. 2014)

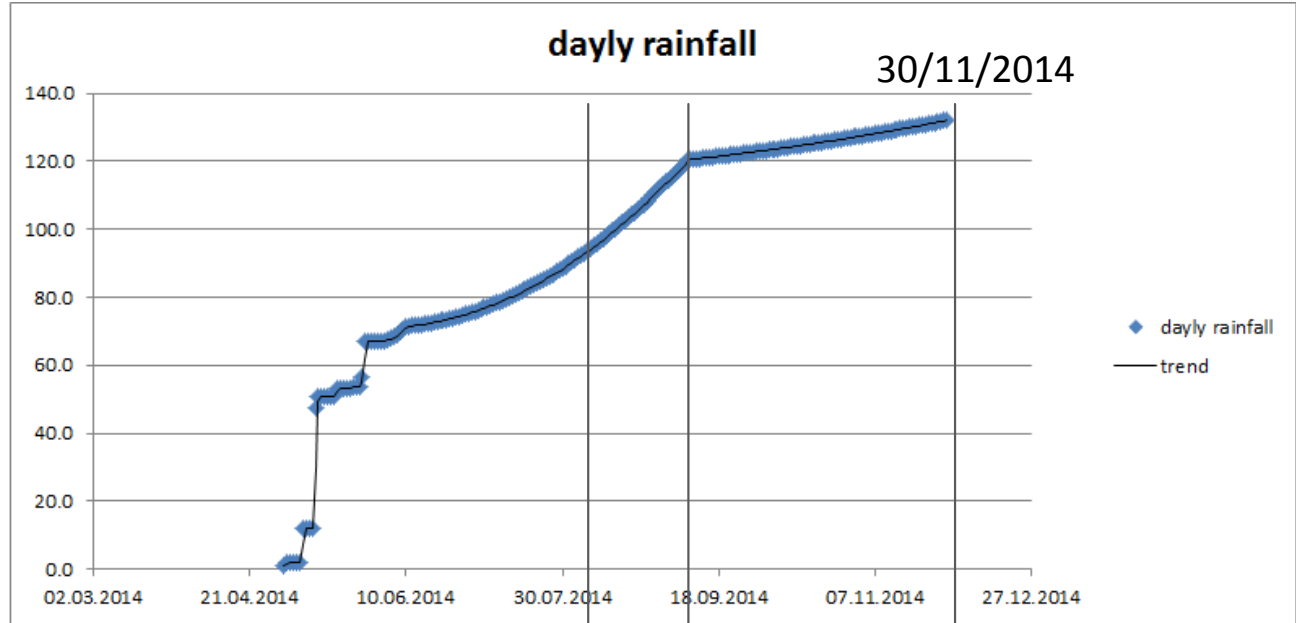


- ✓ Fase 1: da novembre 2013 all'8÷10 febbraio 2014.  
(Vel\_media asse Y: prof. 47 m = 0.2 mm/d; prof. 48.5 m = 0.05 mm/d)
- ✓ Fase 2: dall' 8÷10 febbraio 2014 al 25÷27 marzo 2014  
(Vel\_media asse Y: prof. 47 m = 1.5 mm/d; prof. 48.5 m = 0.4 mm/d)
- ✓ Fase 3: dal 25÷27 marzo 2014 al 02÷03 maggio 2014  
(Vel\_media asse Y: prof. 47 m = N.D; prof. 48.5 m = 0.17 mm/d)
- ✓ Fase 4: dal 02÷03 maggio 2014 al 27÷28 giugno 2014  
(Vel\_media asse Y: prof. 47 m = N.D; prof. 48.5 m = 0.04 mm/d)
- ✓ Fase 5: dal 27÷28 giugno 2014 al 20÷21 luglio 2014  
(Vel\_media asse Y: prof. 47 m = N.D; prof. 48.5 m = 0.001 mm/d)
- ✓ Fase 6: dal 20÷21 luglio 2014 al 20 novembre 2014  
(Vel\_media asse Y: prof. 47 m = N.D; prof. 48.5 m = 0.2 mm/d)



# Continuous In-place inclinometers (Dec. 2013 to Nov. 2014)

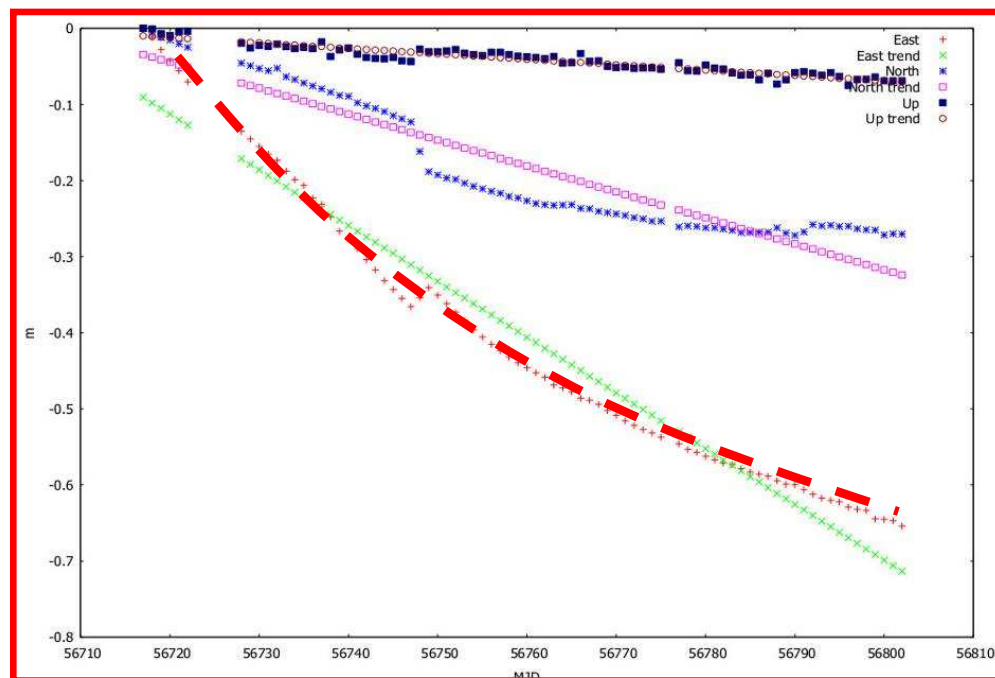
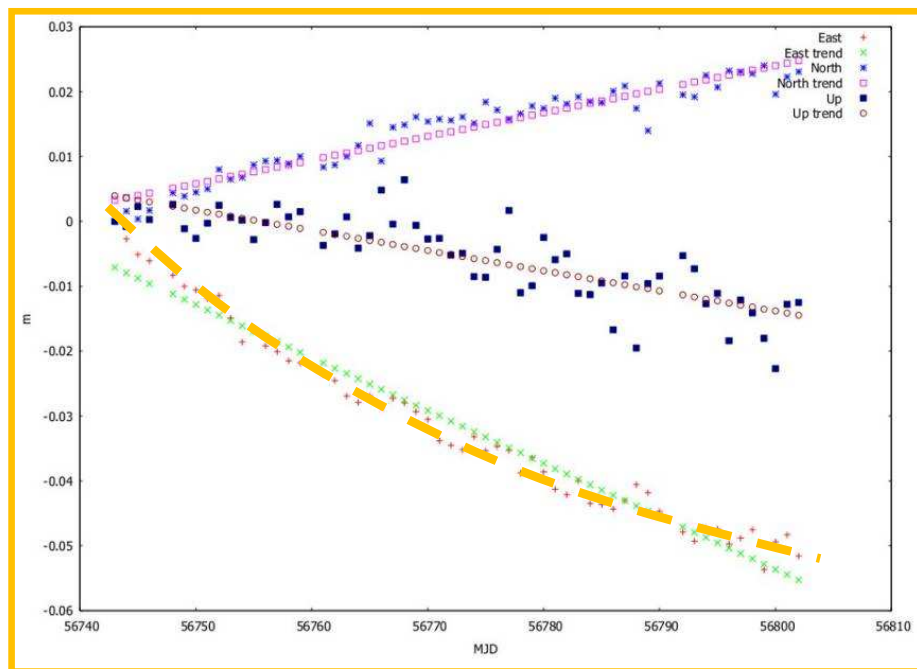
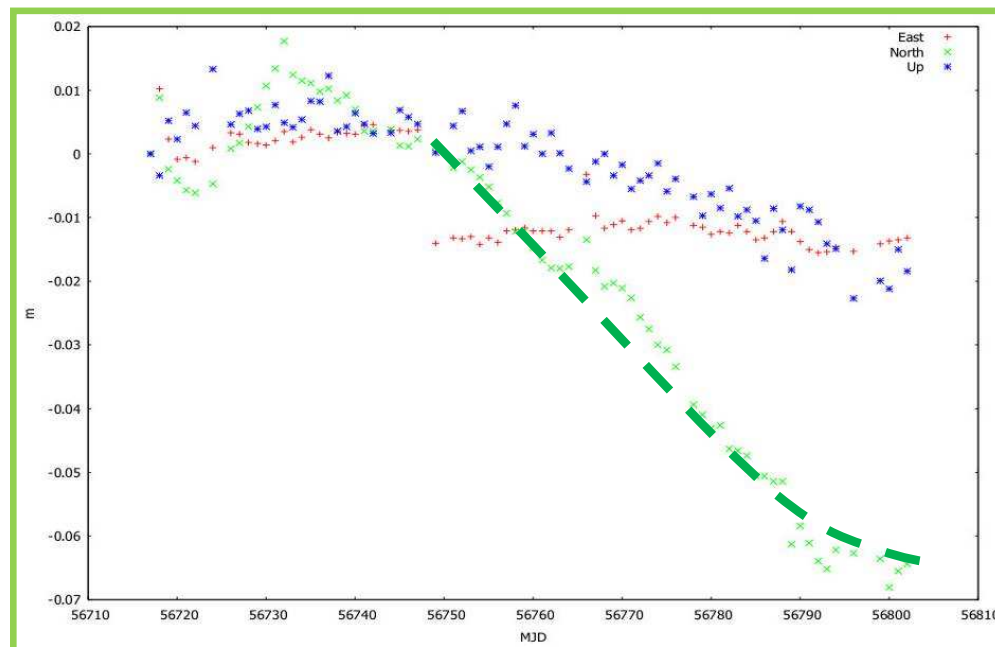
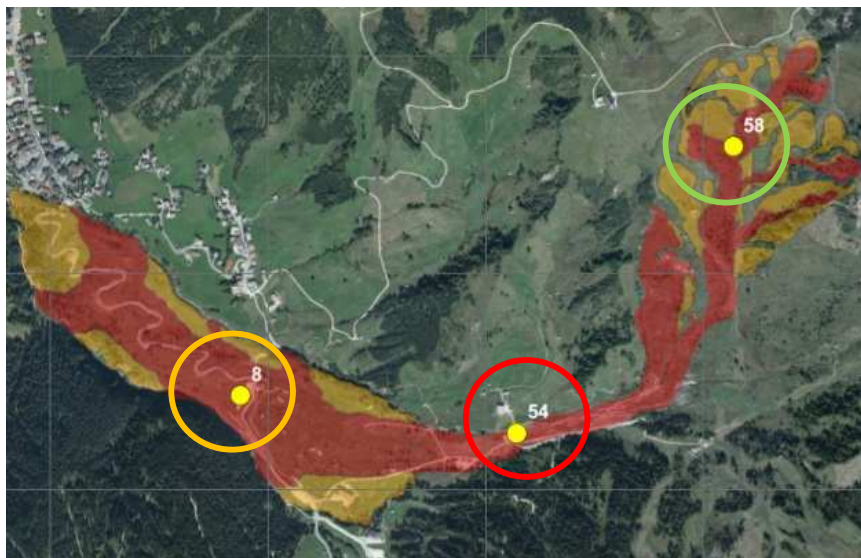
*more than just rainfall*





# Continuous GPS (from Feb 2014..)

(data from Feb 2014. to May 2014)





**UNIMORE**  
UNIVERSITÀ DEGLI STUDI DI  
MODENA E REGGIO EMILIA



*Ateneo fondato nel 1175*

DIPARTIMENTO DI SCIENZE CHIMICHE E GEOLOGICHE

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**Thanks for your attention**

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