BOSMATTO

Municipality: Gressoney Saint Jean, locality Bosmatto

Type of landslide: Complex landslide, evolved into a debris flow.

Height min/max.: 1460 – 2150 m a.s.l.

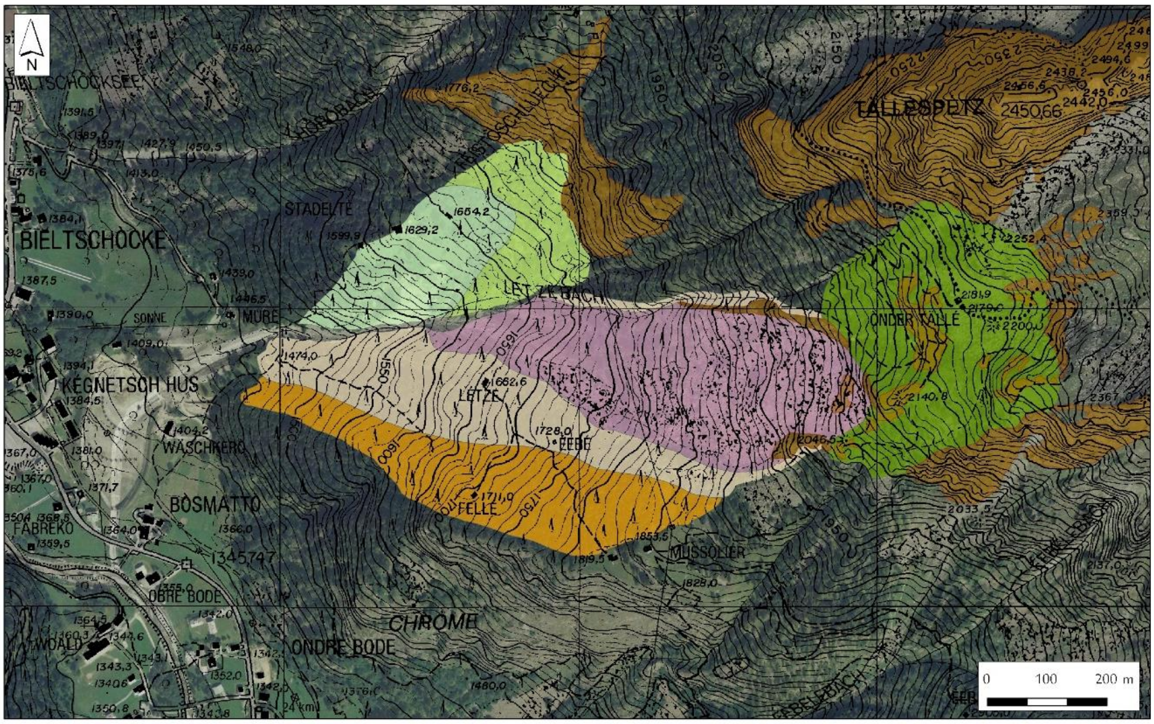
Land use: Open spaces with little or no vegetation, bare rock or deposits; localized urban areas associated to pastures.

Geology: Austroalpine Domain, divided in two principal units: i) Sesia-Lanzo Zone, composed by the Eclogitic Micaschists Complex, the Gneiss Minuti Complex, and the Second Dioritic kinzigitic Zone; ii) Dent Blanche *s.l.* nappe.

Geomorphology: Letzé catchment divided in: i) an upper sector characterized by extended scree material, with local rock fall deposits sometime associated to glacial deposits; ii) a lower sector characterized by a glacial step with a lateral-end moraine. Processes of river capture in correspondence of the basin watershed.

The October 2000 flood event: the Bosmatto landslide evolved into a debris flow, affecting the alluvial fan of the Letzé River, by modifying the morphometric aspects. Subsequently activation of the landslide located on the right side of the Letzé River.

The 2002 flood event: Stadelte landslide activation, involving the moraine deposits.



Landslides subdivision (modified from the technical report edit by Geodes S.r.l. (may 2010)).

- Stadelte Landslide - no vegetated
- Stadelte Landslide - vegetated
- Bosmatto (or Letzé) Landslide - no vegetated
- Bosmatto (or Letzé) Landslide - vegetated
- Mussolier Landslide - vegetated
- Area characterized by unstable bedrock
- Bare rock

1 PREVIOUS WORKS ANALYSIS

The previous data analysis revealed a large number of technical and scientific studies, associated to thematic maps and technical annexes, drafted by diverse private agencies over time (from March 2002 to September 2012). All the collected data are summarized in the table below, separated in eight categories. In general, the existence of two separate phenomena, the Bosmatto landslide and the Stadelte landslide, was observed. In the first row is specified when the report speaking of Bosmatto, or Stadelte landslide, or both.

BOSMATTO LANDSLIDE

	Bosmatto		Stadelte	Bosmatto + Stadelte	
Category	Agency 1 Mar. 2002	Agency 1 Apr. 2002	Agency 2 Nov. 2006	Agency 3 May 2010	Agency 4 Jun 2011
Geological-Geomorphological survey	X	-	X	X	-
Geological Map	X	-	-	X	-
Geomorphological Map	X	-	-	X	-
Structural survey map	X	-	-	X	-
Geological Profile	X	-	-	X	-
Hydrologial/Hydrogeological survey	X	-	X	X	-
Risk scenarios/Spatial prediction model	-	X	-	X	X
Monitoring network analysis	-	-	X	X	-

The collected data also included ancillary data, including technical test results and specific surveys, reported in the table below.

Technical test/survey	Society	Month/Year
Snow water equivalent assessment	Agency 4	Aug. 2010 Nov. 2011 Sept. 2012
Geophysical survey	Agency 5	Jun. 2006
Borehole thecnical specification	Agency 3	Oct. 2007

1.1 Geological, Geomorphological, Structural and Hydrogeological aspects

The previous data analysis show an exhaustive framework from a geological, geomorphological, structural and hydrogeological point of view. From March 2002 to September 2012 various technical and scientific studies have been carried out for the Letzé catchment, drafted by three distinct private agencies: 1) Agency 1 (2002); Agency 2 (2006); Agency 3 (2010).

Agency 1 (March 2002)

Definition of two old landslides, named "**Paleofrana 1**" and "**Paleofrana 2**", located on the left side of the Letzé River. The technical report sets out a **complete geological study**, comprehensive of geological setting definition, geomorphological survey, lithological survey, structural survey, aimed at the establishment of the landslide activation during **the October 2000** flood event, **focusing on the effect of the landslide activation on the Letzé torrent alluvial fan**. A technical annex is reported in figure below.

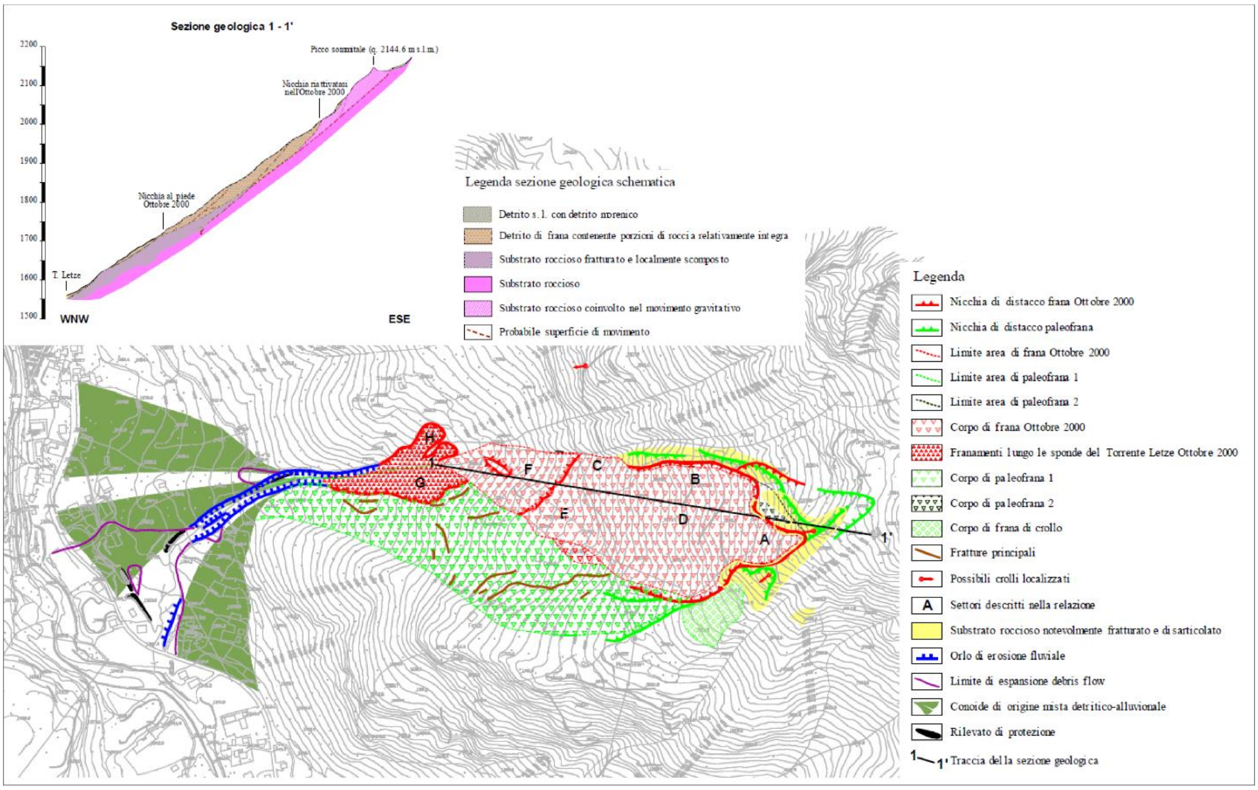


Figure 1 – Technical annex of the geomorphological map of the Paleofrana 1 and Paleofrana 2, relative to the October 2000 flood event (from Agency 1 2002).

Agency 2 (November 2006)

Definition of the **hydrogeological aspect of the Letzé catchment**, comprehensive of a geological setting definition, a detailed geomorphological field survey, and ground deformation measurement acquisition from the **GPS monitoring network**, active from the August 2004.

Specifically, this technical report analyzes the **Stadelte landslide**, located in the right side of the Letzé River, activated during the summer of 2002. Ancillary data are available, with several **seismic sections** along and across the landslide body, revealing a landslide body with a variable thickness from 5 to 20 m. From the GSP measurements analysis, a cross-correlation from snowmelt and seasonal reactivation (in May-June) has been assumed.

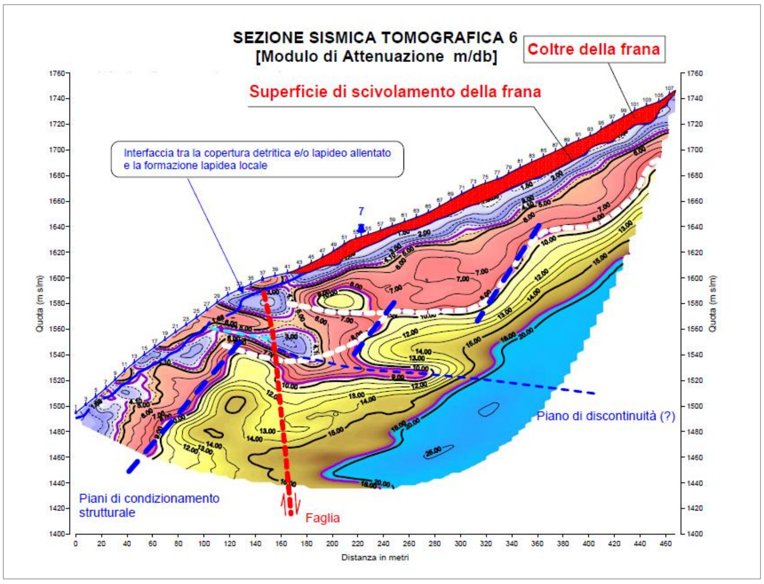


Figure 2 – Tomographic profile (from Agency 5 in Agency 2' report, 2006). The blue line corresponds to the Stadelte landslide surface.

Agency 3 (May 2010)

Revision of the state of knowledge of the **Bosmatto landslide**, in the left side of the Letzé River, and the **Stadelte landslide**, on the right side. By exploiting the previous knowledge (Agency 1, 2002, Agency 2, 2006), integrated with a photo-interpretation of the basin, field survey, hydrogeological survey, monitoring network data analysis, and new seismic survey, the definition of the landslides occurred within the Letzè basin is provided. This technical report is a good example of an **in-depth characterization of the landslides evolution** over time, **integrating previous data** in a complete geological study.

For the **Stadelte landslide**, a superficial movement involving residual soil (thickness from 12-18 m to 18-20 m), with a landslide surface corresponding to the soil-rock interface is proposed. The landslide behavior is highly related to the rain and snow precipitation, with late-spring reactivation.

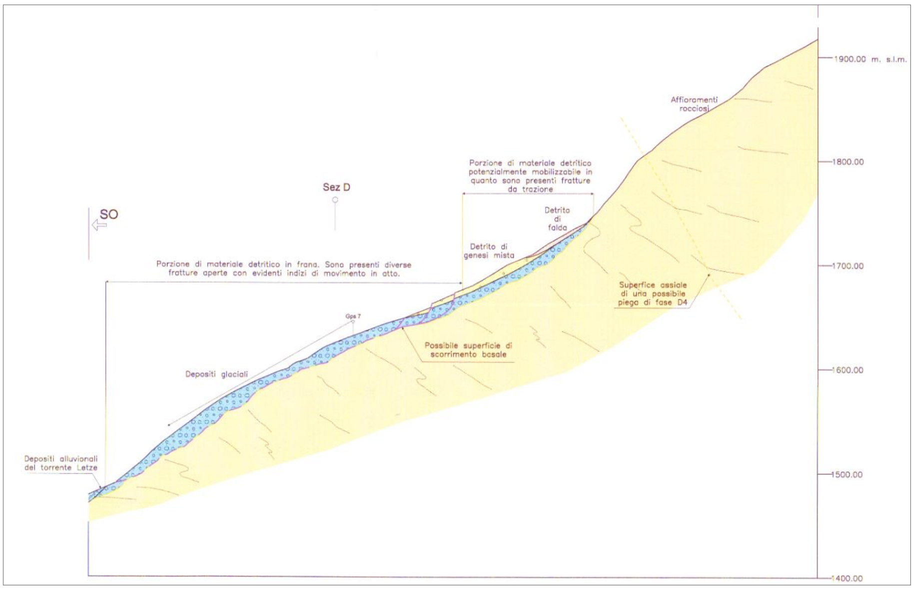


Figure 3 – Geological profile of the Stadelte landslide (from Agency 3, May 2010).

For the **Bosmatto landslide**, a deeper landslide involving the bedrock, with surface variable from 25 to 60 m in depth, and surmounted by two smaller superficial landslides, is proposed. The landslide behavior results independent from the rain and snow regime.

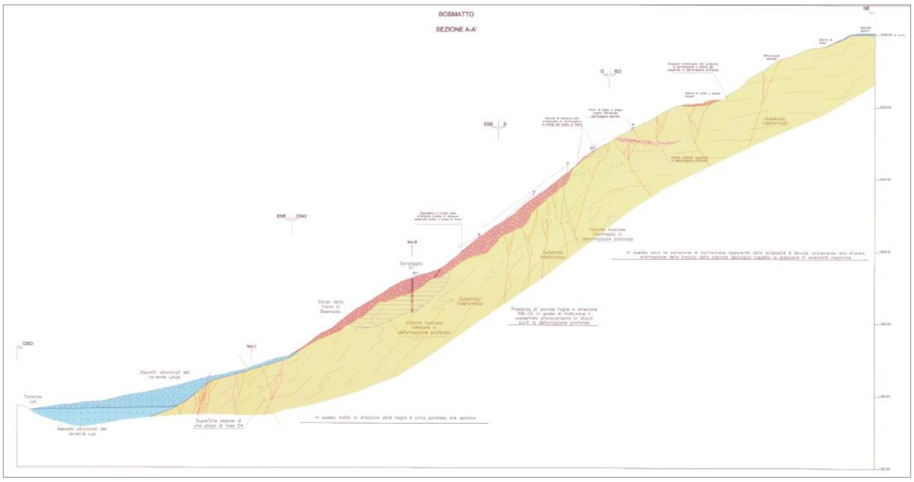


Figure 4 – Geological profile of the Bosmatto landslide (Agency 3, May 2010).

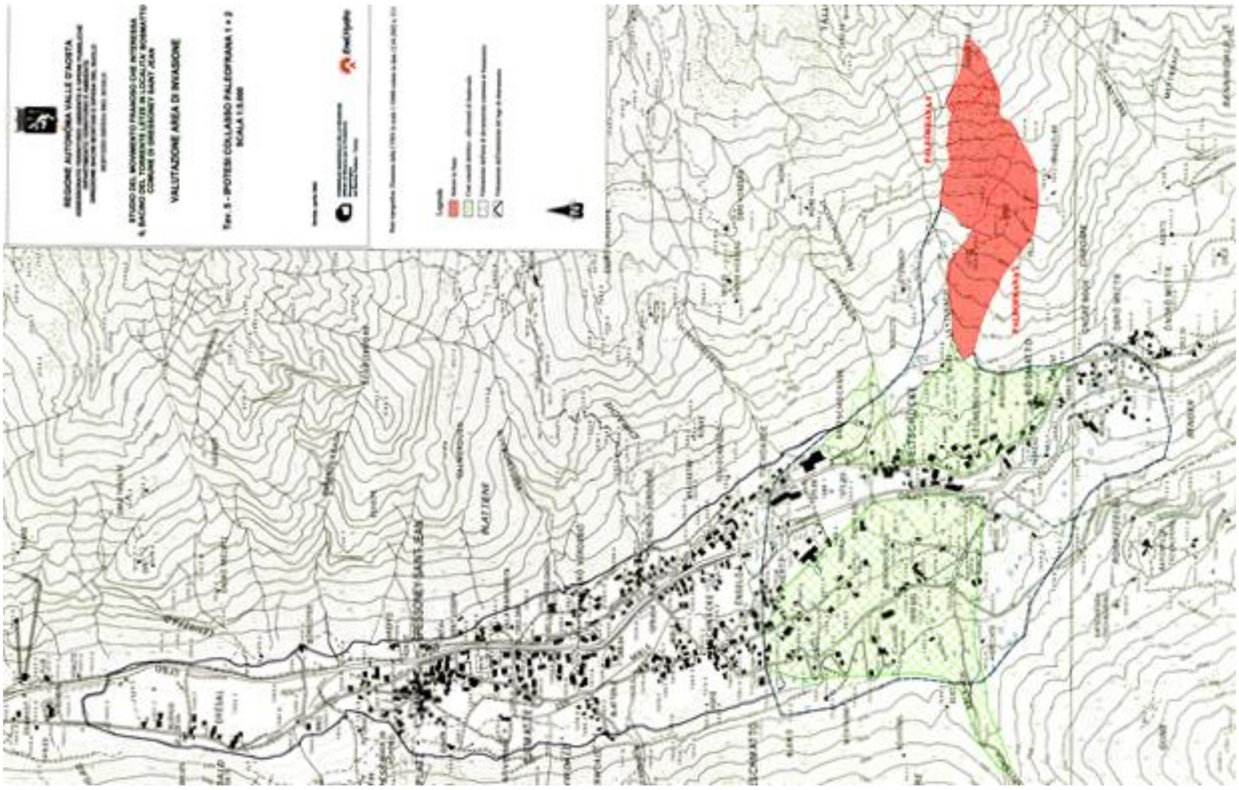
1.2 Risk scenarios and spatial prediction model

Relative to the risk scenarios and the spatial prediction model, three private agencies (Agency 1, Agency 2, Agency 4) drafted technical report from April 2002 and June 2011.

Agency 1 (April 2002)

Definition of the prediction model by computing:

- Evaluation of maximum rate of the flow and its lateral expansion
- Accumulation and/or invasion area of the Bosmatto landslide
- Accumulation and/or invasion area of debris flow associated

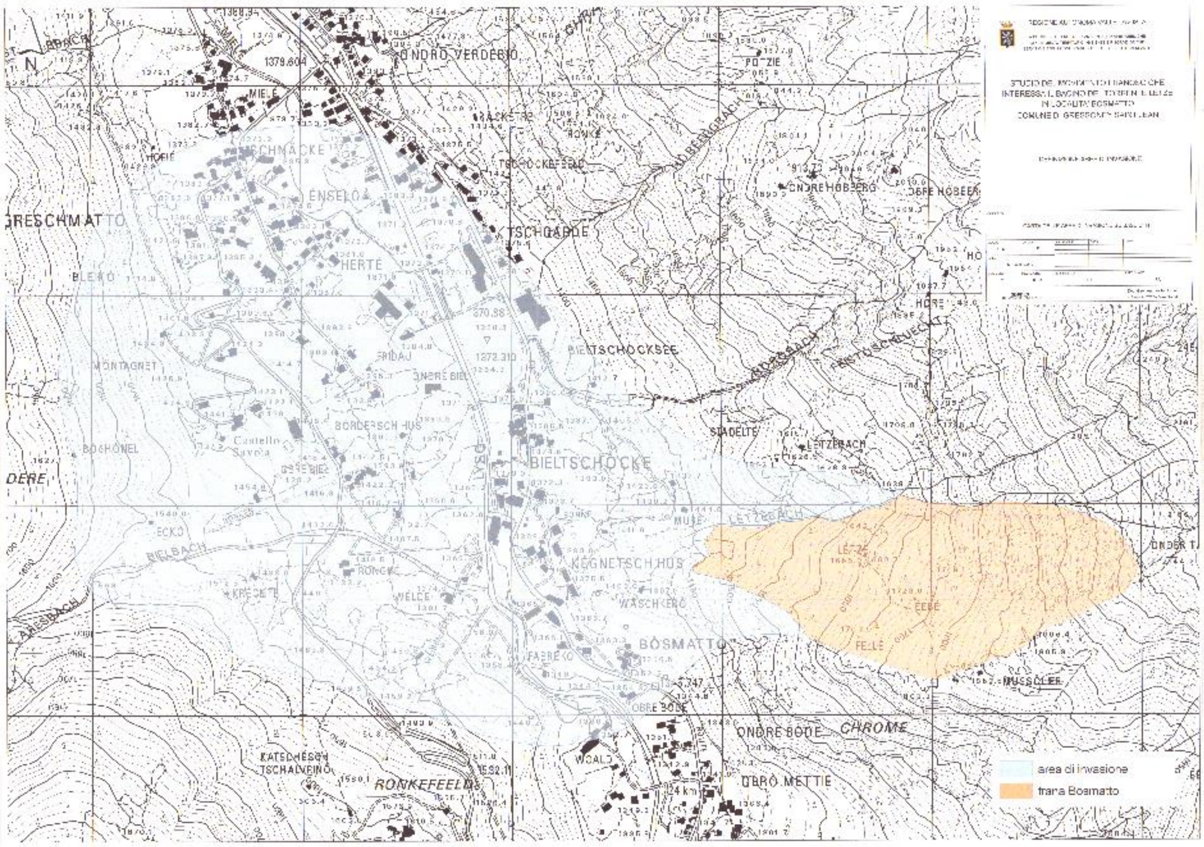


Bosmatto landslide accumulation and/or invasion area (from Agency 1, Apr 2002).

Agency 2 (May 2010)

Definition of:

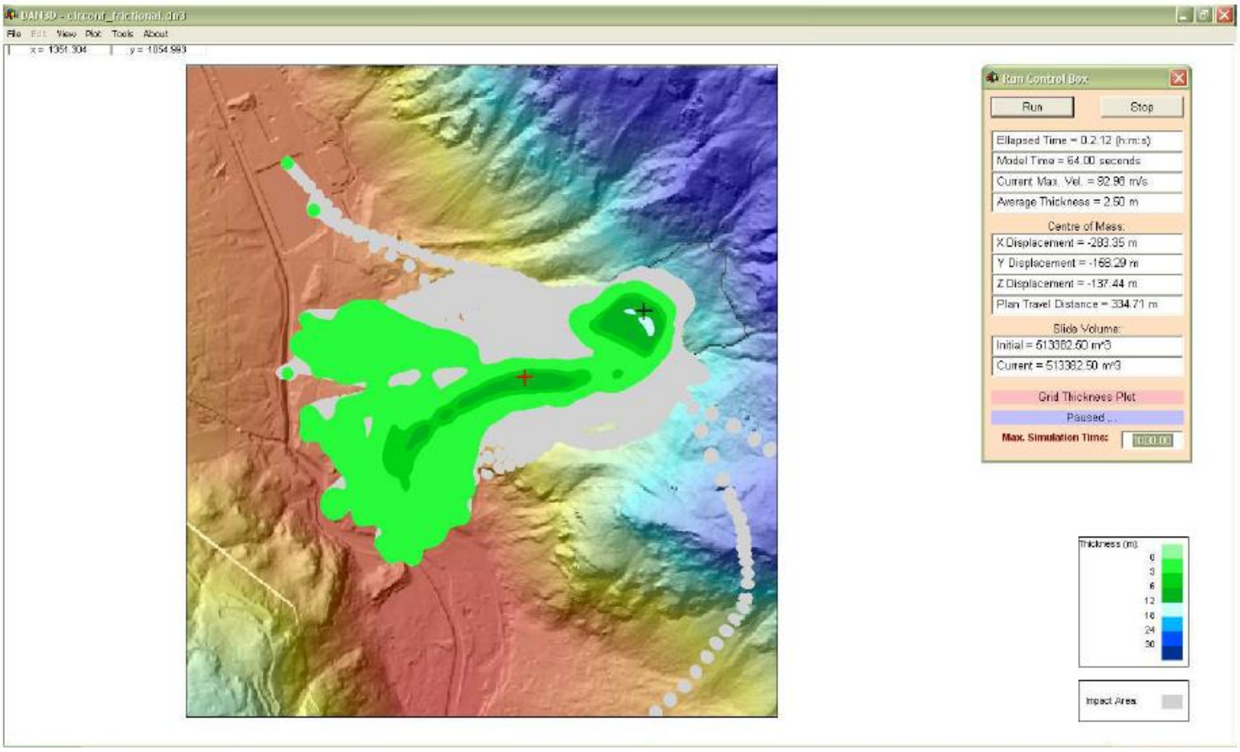
- Computation of the trigger model and of the Bosmatto and Stadelte landslides evolution
- Prediction model with definition of axial speed and lateral expansion
- Accumulation and/or invasion areas delimitation
- Prediction model with definition of pre-alert and alert thresholds



Bosmatto landslide accumulation and/or invasion area (from Agency 2, May 2010).

Agency 4 (June 2011)

Definition of accumulation and/or invasion areas with the computation of the run out of the Stadelte landslide by DAN3D.



Example of runout computation with DAN3D for the Stadelte landslide (Agency 4, June 2011).

The table below summarize the principal data and results collected by the three private agencies.

Author	Landslide	Type of movement	Volume (m³)	Risk scenario
Agency 1 (April 2002)	PALEOFRANA 1	Rock and debris avalanche	3.270.000	Straight propagation along the Letzè river, up to the valley floor.
	PALEOFRANA 2	Rock/debris slide	1.700.000	Propagazione rettilinea NO-SE, con impatto sul versante destro del T. Letzé, scavalcandolo nel tratto terminale, sino ad invadere il fondovalle principale
Agency 2 (May 2010)	Bosmatto landslide		4.946.928	
	Mussolier landslide		1.141.928	
	Stadelte landslide, active portion		328.525	

	Stadelte landslide dormant portion		373.485	
Agency 4 (June 2011)	Hypothesis 1 (Paleofrana 1)	Planar surface	380.000	Landslide with basal surface corresponding to the rock/deposit interface, based on seismic data
	Hypothesis 2	Rotational surface	510.000	Most probable scenario based on geotecnical data

1.3 Monitoring network data

The monitoring network data acquisition and analysis is carried out by three diverse private agencies, in different period over time (table below). Generally a discrepancy in data representation has been observed.

	First acquisition	Last acquisition
Agency 2 **November 2006**	August 2004	July 2006
Agency 3 **May 2010**	2000	2008
RAVdA **Internal annual reports**	2010	2014

From the previous data analysis the distinction between the Bosmatto and Stadelte monitoring network has been delineated.

The Stadelte monitoring network consists of:

- Four extensometers
- One automated GPS

The Bosmatto monitoring network consists of:

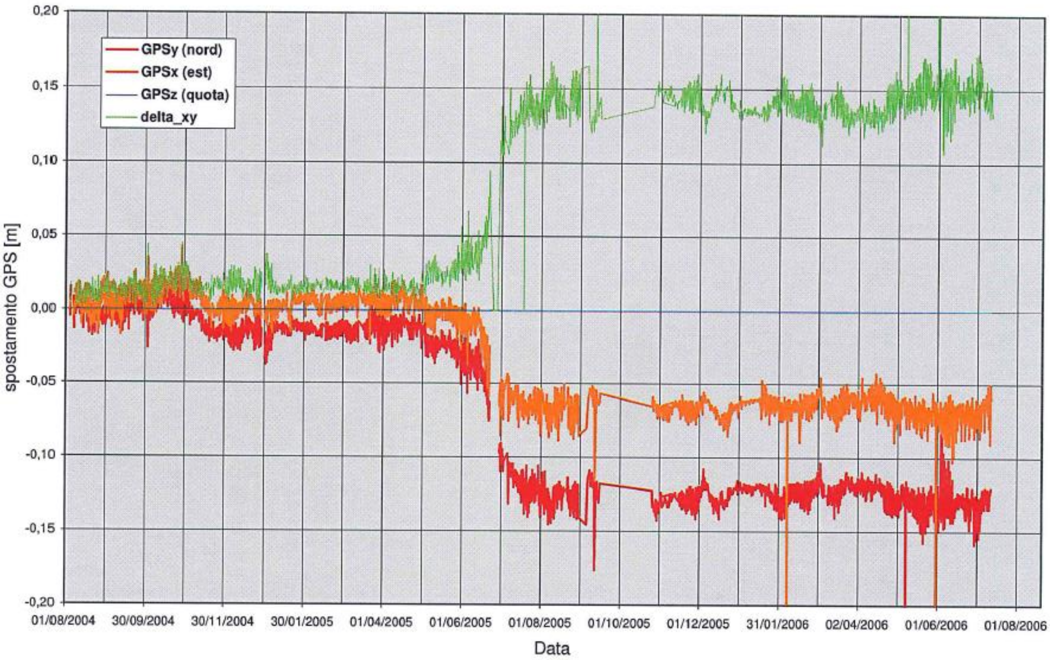
- Four extensometers (removed in 2010);
- Two automated GPS and one reference point;
- Seven GPS benchmarks (manual);
- One piezometer;
- Three Webcam;
- A meteorological station.

	Monitoring network	Acquisition range	First acquisition	N° of elements	Note
Stadelte landslide	Extensometers (Stadelte)	Hourly	1 Jun. 2007 (E1) 2 May. 2010 (E2, E3) Dec 2011 (E4)	3 + 1	Late spring and autumn acquisitions. The instruments do not guarantee a proper functioning.
	Automated GPS	4 sessions/day	Aug. 2004	1	
Frana di Bosmatto	Extensometers (Bosmatto)		Aug. 2006	4	Active only during the late spring and autumn. Instruments removed in 2010.
	Automated GPSi	4 sessions/day	2002	2+1 REF	Short break in data acquisition in 2005. GPS7 recorded the landslide reactivation in 2005 and from 2010 to 2014.
	Manual GPS	yearly	Jul. 1997	7+1 REF	
	Piezometer	Hourly	Summer 2009	1	

Table 5 – List of the instruments constituting the Stadelte and Bosmatto monitoring networks.

Agency 2 (November 2006)

Monitoring network data acquisition and elaboration of the Stadelte landslide from 2004 to 2006. In specific, the ground surface deformation time series of the automated GPS7 are generated and compared with the available meteorological parameters. In the late spring of 2005 a reactivation (15-20 cm) was recorded, as a result of the snowmelt. The time series show separately the East, North and altimetric components, for each year in the period of acquisition.

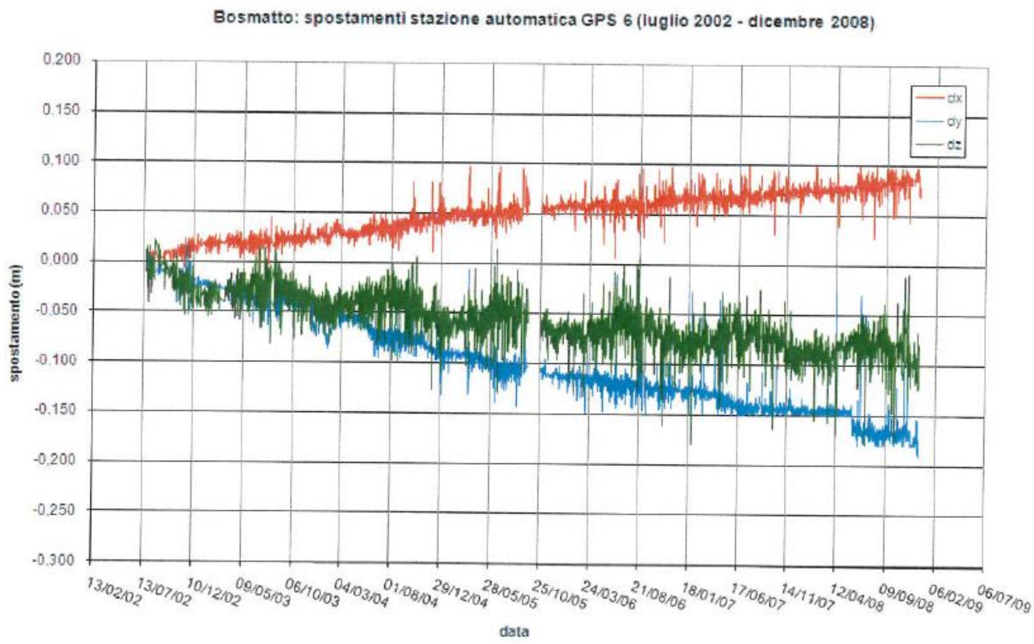


Example of ground deformation time series presentation, relative to an automated GPS (Agency 2, November 2006). The graph report the East, North, planimetric and altimetric time series of the Stadelte GPS from August 2004 to July 2006

Agency 3 (May 2010)

Monitoring network data acquisition and elaboration of the Stadelte and Bosmatto landslides from 1992 to 2008. The period is very extensive due to the PS data availability, processed by the PSInSAR technique, relative to the period from 1992 to 2000 (table below).

	First acquisition	Last acquisition
Extensometers	2006	2008
Manual GPS	2002	2008
Automated GPS	2002	2008
Permanent Scatterers	1992	2000



Example of ground deformation time series presentation, relative to an automated GPS (Agency 3, May 2010). The graph report the three displacement components East, North and altitude from July 2002 to August 2008.

For the **Bosmatto landslide**, the monitoring network consists of four extensometers, two automated GPS, and eight manual GPS are measured. The extensometer are measured only from the late spring to autumn, due to the snow cover. Agency 3 establishes these instruments unusable and disagree with the other instruments.

The **manual GPSs** are measured once a year, and the ground deformation time series report the planimetric and altimetric displacement, with planimetric displacements variable from 3 cm/year to 14 cm/year, with ESE-WNW direction, and altimetric displacements variable from 1 and 7 cm/year.

The **automated GPS** network are measured four times a day, and the ground deformation time series report the three component East, North and altimetric with variable displacement from 1.5 to 3.5 cm/year.

The **PS data** analysis point out the October 2000 event activation, with LOS displacement of about 28 mm/year. From 2005 a general reduction in rate has been recorded.

For the **Stadelte landslide**, the monitoring network consists of one automated GPS and one extensometer, while in 2010 and 2011 three other extensometers are installed.

The automated GPS recorded a displacement of about 4 m, until 2008, with an acceleration during the 2007 spring. A good agreement with the extensometer measurements has been recognized.

RAVdA INTERNAL REPORTS (from 2009)

From 2009, internal reports drafted by the Aosta Valley authority are available. The ground deformation time series report variably the singular component of the displacement (e.g. East, North, altitude) and /or the planimetric and 3D displacement, without a standardized format. In the table below are reported the annual displacement recorded from each monitoring network and the associated time series reported.

	Monitoring network	Type of acquisition	2009	2010	2011	2012	2013	2014
Stadelte Landslide	GPS 7	Planimetric and Altimetric displacement	5.08 m	1 m	35 cm	15 cm	80 cm	32-35 cm
	E1	Displacement	4 m	80 cm	25-30 cm	10-12 cm	Operational problems	21 cm
	E2	Displacement		80 cm		No data	Instrument removal	-
	E3	Displacement		65 cm	25-30 cm	10-12 cm	80 cm	30 cm
	E4	Displacement				7 cm	60 cm	33 cm
Frana di Bosmatto	E1 E2 E3 E4	Displacement form 2006 to 2009			Instruments removal			
	GPS 5	3D displacement	0,012 m	0.0048 m	0.001 m	0.013 m	0.007 m	0.013 m
	GPS 6	3D displacement	0,08 m (Jun-Dec)	0.0262 m	0.026 m	0.021 m	0.02 m	0.031 m
	B2	3D displacement	0.009 m	0.009 m	0.002 m	0.008 m	0.09 m	0.098 m
	B3	3D displacement	0.314 m	0.218 m	0.121 m	0.215 m	0.147 m	0.104 m
	B4	3D displacement	0.166 m	0.009 m	0.007 m	0.015 m	0.013 m	0.006 m
	B5	3D displacement	0.092 m	0.052 m	0.034 m	0.04 m	0.065 m	0.039 m
	B6	3D displacement	0.113	0.035	0.025	0.04	0.038	0,019
	B7	3D displacement	0.044 m	0.025 m	0.018 m	0.029 m	0.023 m	0.017 m
	B8	3D displacement	0.102 m	0.064 m	0.045 m	0.062 m	0.06 m	0.039 m

Table 7 – Extensometers and GPS displacement measurements relative to the RAVdA.

2 GROUND DEFORMATION TIME SERIES ANALYSIS

The analyses of the monitoring systems of Bosmatto and Stadelte landslides resulted in a large amount of data covering approximately two decades (see Table 8).

MONITORING SYSTEM	BEGINNING OF ACQUISTION	LAST AVAILABLE DATA
GPS manual	July 1997	October 2014
GPS automatic	July 2002	December 2015
Extensometer	June 2007	December 2015

Table 8 – Periods of data availability for Bosmatto landslide.

The collection and revision of the bibliographic material showed a certain variability in the presentation of ground deformation series from various monitoring networks. Furthermore, there is no a clear distinction between the presented data of the two landslide bodies (Stadelte and Bosmatto). Moreover, different choices were made by different companies to perform data elaboration, both for the type of data representation (e.g. graphs, vectors) and for the parameters to be represented (e.g. planimetric, three-dimensional displacement).

In order to standardize the monitoring data sets received from the Department of public works, soils conservation and public housing, the data were first analyzed and reprocessed in Matlab environment, creating the most complete and continuous historical time series. Specifically, time series without interruptions were obtained for the GPS 5 and 7. In the case of GPS 6, the continuity of data was interrupted in 2009 by an avalanche, and in consequence, two separate time series are reported (pre and post avalanche).

For automatic GPS 5 and 6 of Bosmatto landslide, the following plots were generated:

- time series of planimetric displacement for entire period
- time series of altimetric displacement for entire period

A smoothing function based on a moving average was applied to the raw data of GPS 5 and 6. Figures 8 and 9 show the evolution of planimetric and altimetric displacement of GPS 5 and 6.

It should be noted that during 2009 an avalanche affected the GPS6, and for this reason only data from June to December were considered. The measures acquired in that year showed a significant variation in altimetric direction, with movements not comparable with previous years. After all, in 2010, it was found that this problem was related to the repositioning of the pylon on which GPS benchmark was located.

It should be noted that the extensometers installed within the Bosmatto landslide were acquiring the data from 2006 to 2010. These instruments were removed in summer 2010, as the measures were non-representative of the evolution of the landslide body. It should be noted that, in accordance to the present convention, the raw data from four extensometers installed within Bosmatto landslide were not included in the material delivered by the RAVdA. For data related to the manual GPS, please refer to the annual internal reports of RAVdA. These data are not available in this document.

The following plots were generated, for automatic GPS 7 of Stadelte landslide:

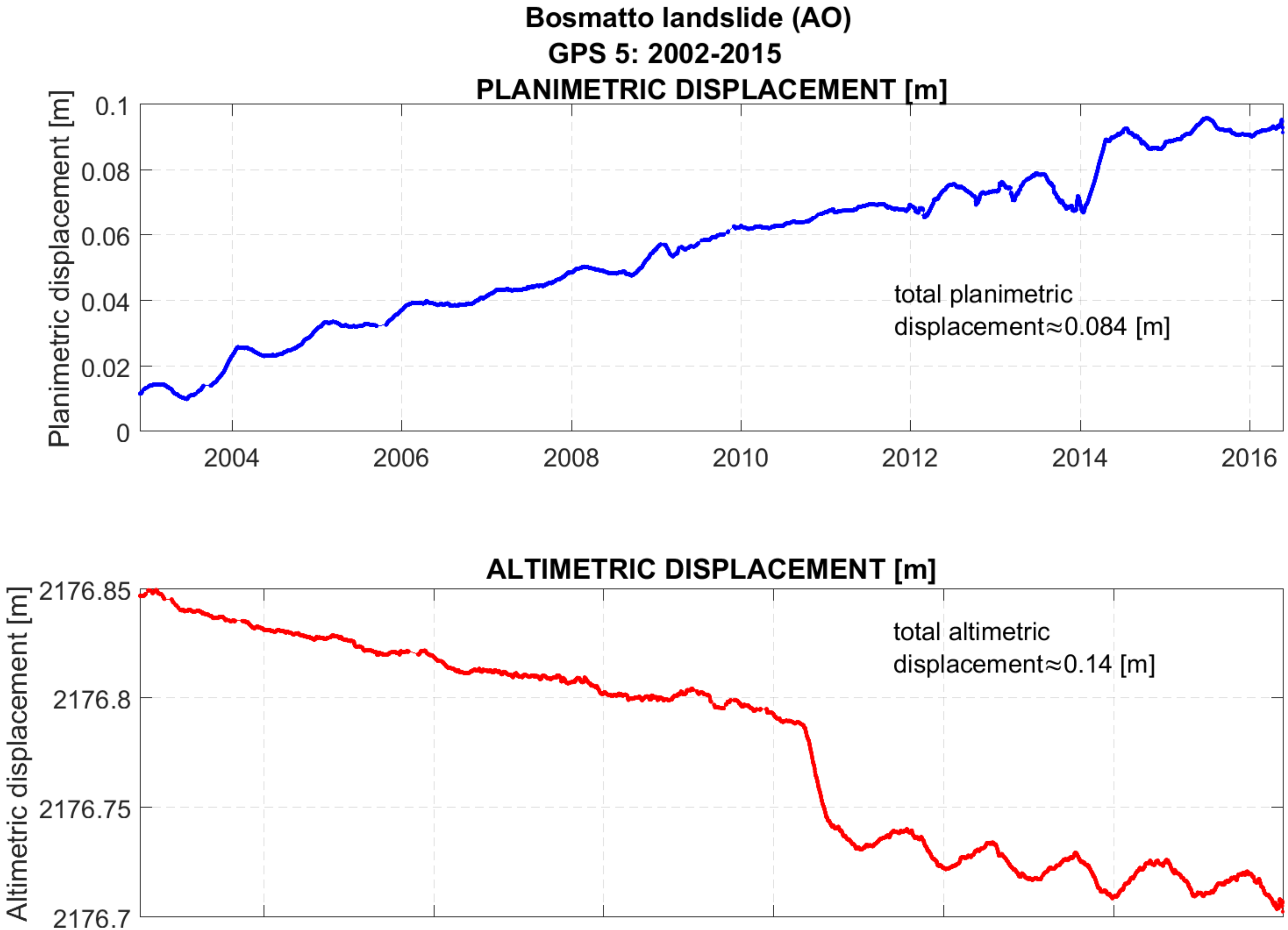
- time series of planimetric displacement for entire period
- time series of altimetric displacement for entire period
- comparative representation of planimetric displacement on one year time window
- comparative representation of altimetric displacement on one year time window

As for the other GPS, a smoothing function based on a moving average was applied. Figures 10, 11 and 12 show the elaborated plots for the GPS 7, where the reactivations are noticeable.

Figures 10 and 11 highlight the highly seasonal trend of this landslide, which is certainly affected by the melting effect of the snowpack.

For the extensometric network, the available data were revised in order to create the most continuous possible time series (Figures 13, 14, 15 and 16). No time intervals have been defined with limits set a priori, but data are presented when available and reliable. The presented data are shown separately for each year. However, the analysis showed a strong heterogeneity of the data, as shown in Table 9, in which the level of reliability of the extensometric series, based on the comparative analysis of the data, is presented.

FIGURE 8: AUTOMATIC GPS 5 FOR THE PERIOD 2002 – 2015



Bosmatto landslide (AO)
GPS 5: 2002-2015
PLANIMETRIC DISPLACEMENT [m]
Planimetric displacement [m]
0.1
0.08
0.06
0.04
0.02
0
2004
2006
2008
2010
2012
2014
2016
total planimetric
displacement≈0.084 [m]
ALTIMETRIC DISPLACEMENT [m]
Altimetric displacement [m]
2176.85
2176.8
2176.75
2176.7
2004
2006
2008
2010
2012
2014
total altimetric
displacement≈0.14 [m]

FIGURE 9: AUTOMATIC GPS 6 FOR THE PERIOD 2002 – 2015

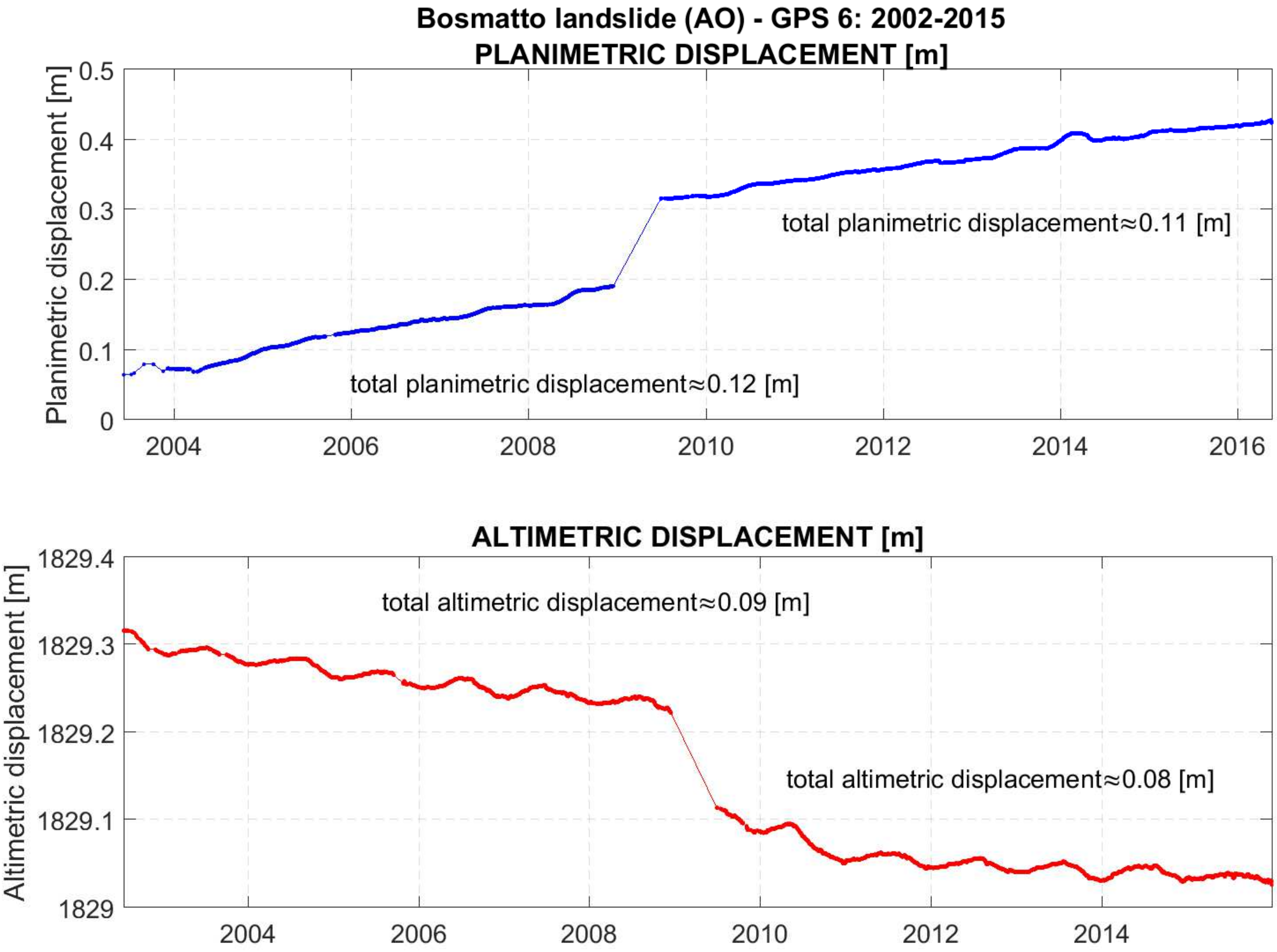

Bosmatto landslide (AO) - GPS 6: 2002-2015
PLANIMETRIC DISPLACEMENT [m]
Planimetric displacement [m]
0
0.1
0.2
0.3
0.4
0.5
2004
2006
2008
2010
2012
2014
2016
total planimetric displacement≈0.12 [m]
total planimetric displacement≈0.11 [m]
ALTIMETRIC DISPLACEMENT [m]
Altimetric displacement [m]
1829
1829.1
1829.2
1829.3
1829.4
2004
2006
2008
2010
2012
2014
total altimetric displacement≈0.09 [m]
total altimetric displacement≈0.08 [m]

FIGURE 10: AUTOMATIC GPS 7 FOR THE PERIOD 2004 – 2015

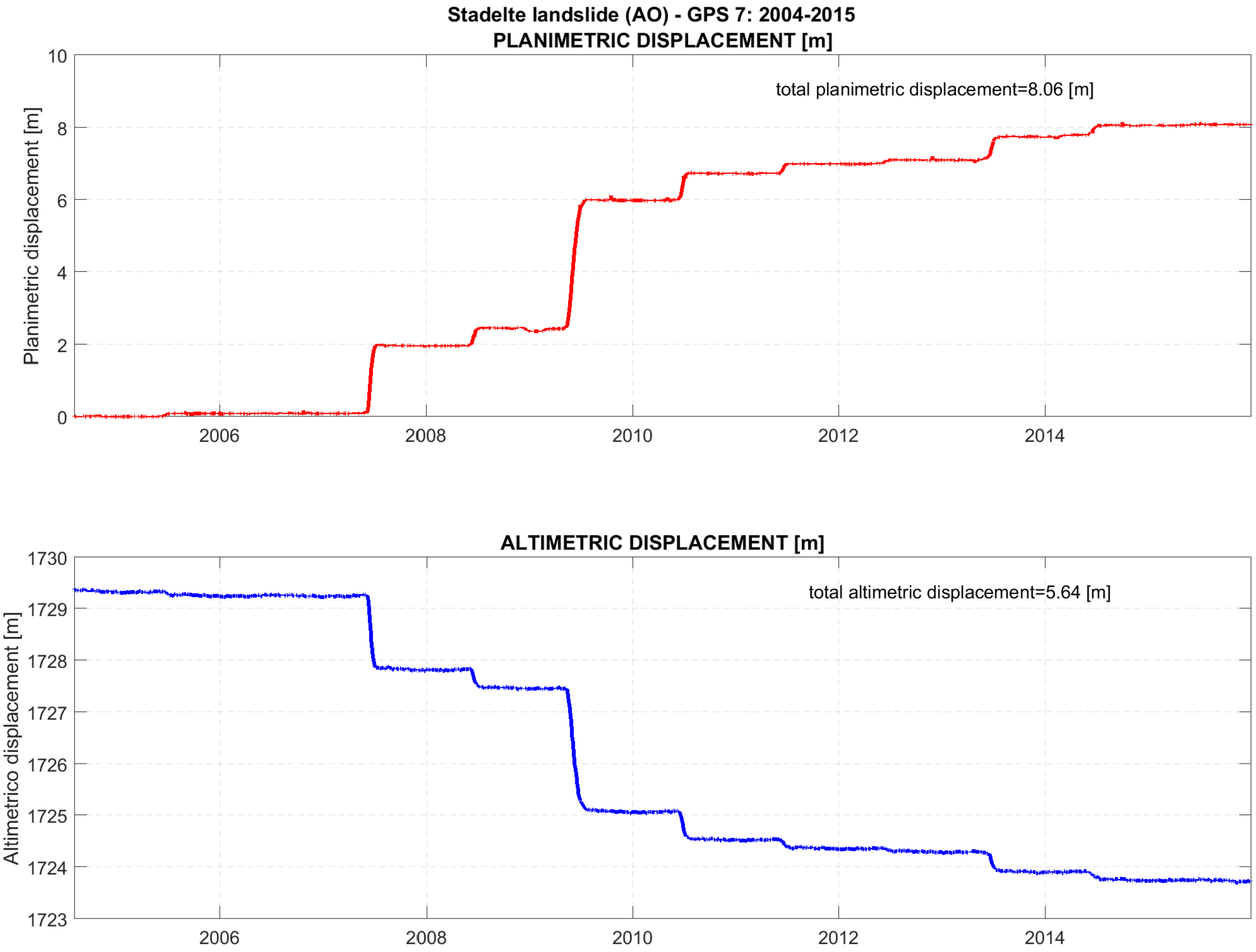

Stadelte landslide (AO) - GPS 7: 2004-2015
PLANIMETRIC DISPLACEMENT [m]
total planimetric displacement=8.06 [m]
Planimetric displacement [m]
10
8
6
4
2
0
2006
2008
2010
2012
2014
ALTIMETRIC DISPLACEMENT [m]
total altimetric displacement=5.64 [m]
Altimetrico displacement [m]
1730
1729
1728
1727
1726
1725
1724
1723
2006
2008
2010
2012
2014

FIGURE 11: PLANIMETRIC DISPLACEMENT OF GPS 7 ON ONE YEAR TIME WINDOW FOR THE PERIOD 2004 – 2015

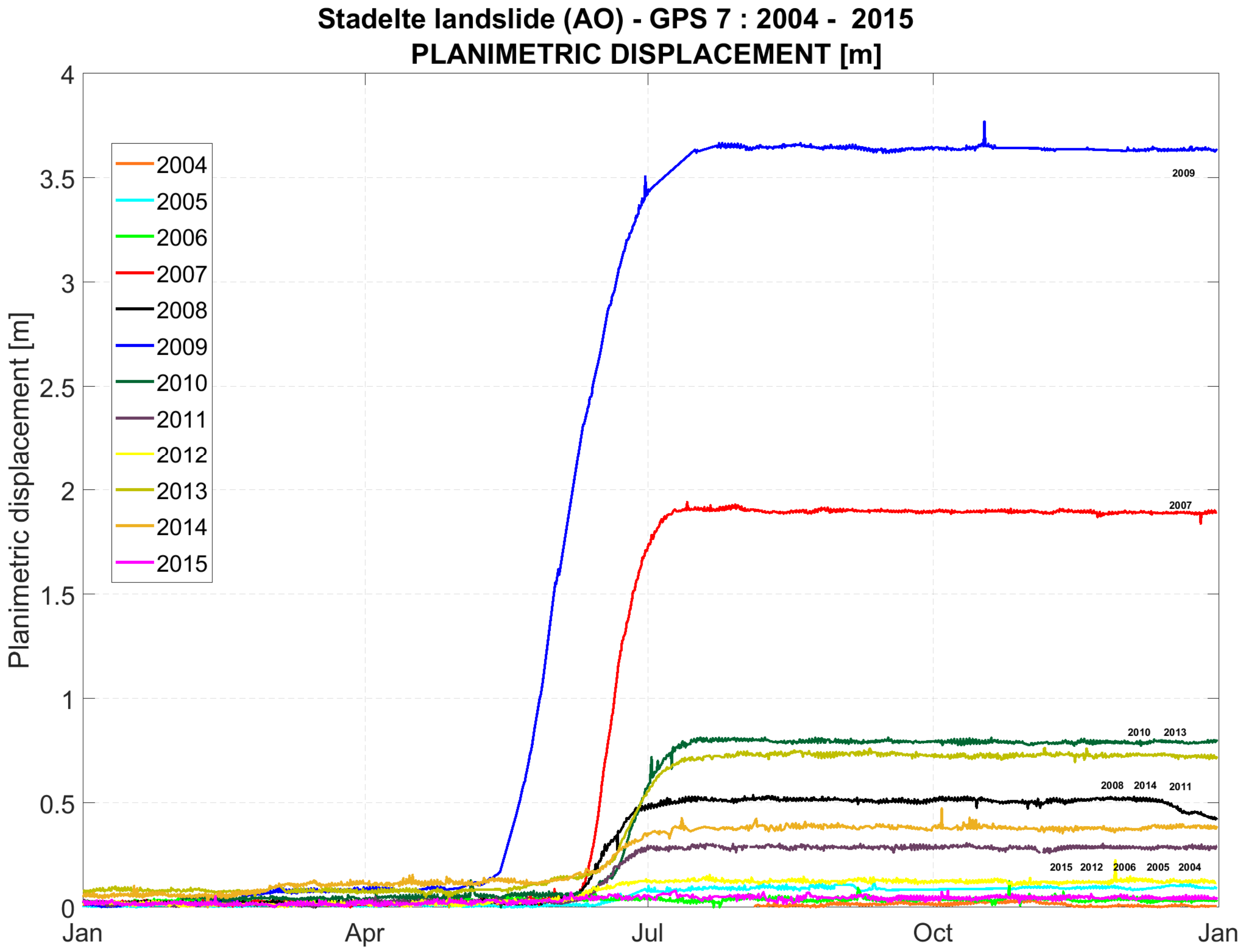
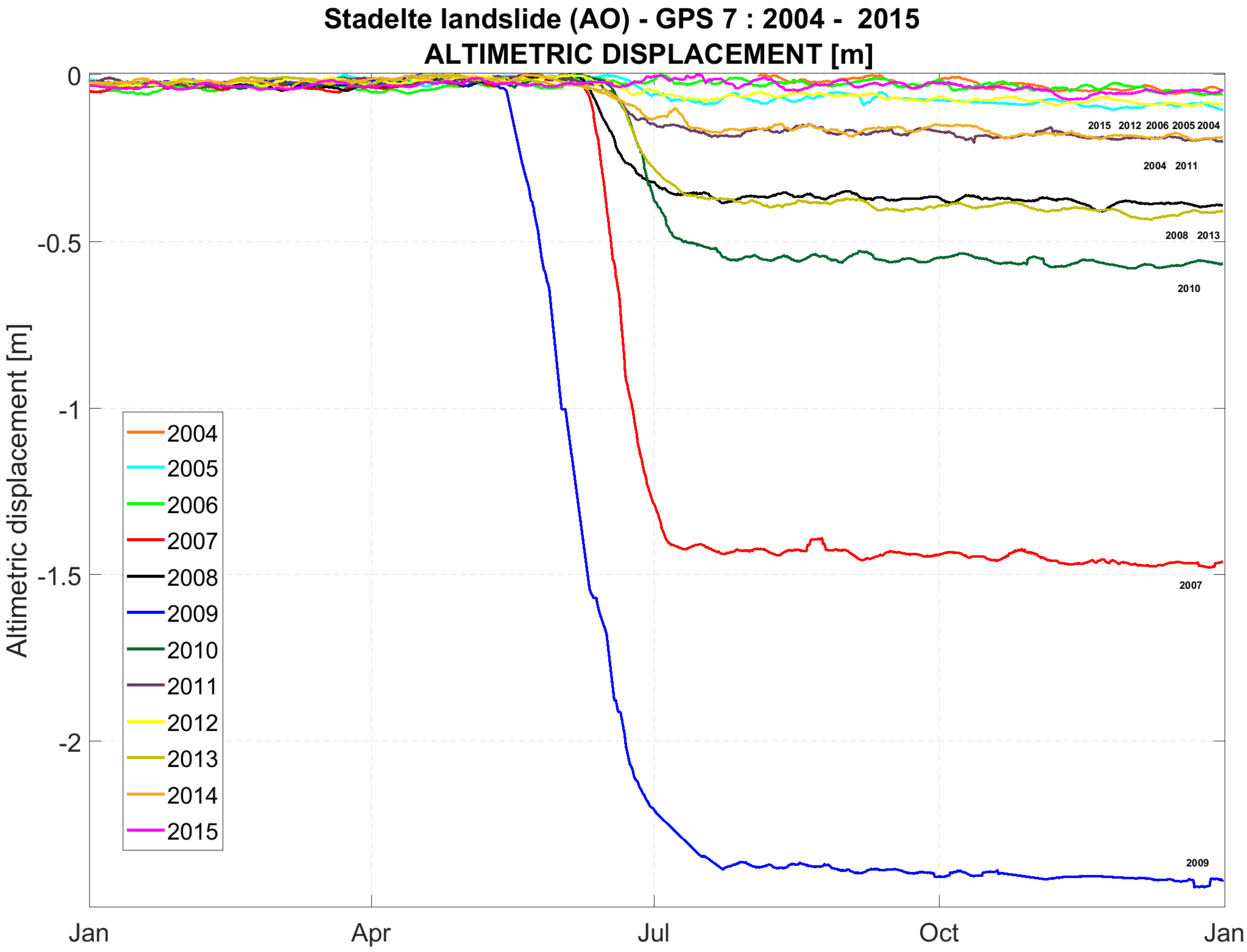

Stadelte landslide (AO) - GPS 7 : 2004 - 2015
PLANIMETRIC DISPLACEMENT [m]
Planimetric displacement [m]
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan
Apr
Jul
Oct
Jan
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2009
2007
2010
2013
2008
2014
2011
2015
2012
2006
2005
2004

FIGURE 12: ALTIMETRIC DISPLACEMENT OF GPS 7 ON ONE YEAR TIME WINDOW FOR THE PERIOD 2004 – 2015


Stadelte landslide (AO) - GPS 7 : 2004 - 2015
ALTIMETRIC DISPLACEMENT [m]
Altimetric displacement [m]
0
-0.5
-1
-1.5
-2
Jan
Apr
Jul
Oct
Jan
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2015 2012 2006 2005 2004
2004 2011
2008 2013
2010
2007
2009

STADELTE LANDSLIEDE- EXTENSOMETERS OPERATIONAL STATUS

	RELIABILITY				NOTE
	E1	E2	E3	E4	
2007	High				E1: installation in June 2007
2008	High				
2009	High				
2010	High	High	High		E2 - E3: installation in Myy 2010
2011	High	Low	High		E2: located on a neoformation fracture, close to the main scarp. This extensometer records the landlslide displacement plus the area close to the main scarp of the landslide.
2012	High	Not reliable	High Noisy measurements	Low	E2: Operational problems. E4: installation in December 2011.
2013	Not reliable	Not reliable	High	High	E1: Operational problems. E2: instrument removal, October 2012.
2014	High	---	High	High	
2015	Medium Noisy measurements	---	Low	Low	E3: no data measurement from June to September. E4: no data measurement from March to August.

Table 9 – Opeartional status of the extenometer monitoring network of the Bosmatto landslide, and assessment of its reliability.

FIGURE 13: ANNUAL DISPLACEMENT OF EXTENSOMETER 1

FOR THE PERIOD 2007 – 2015

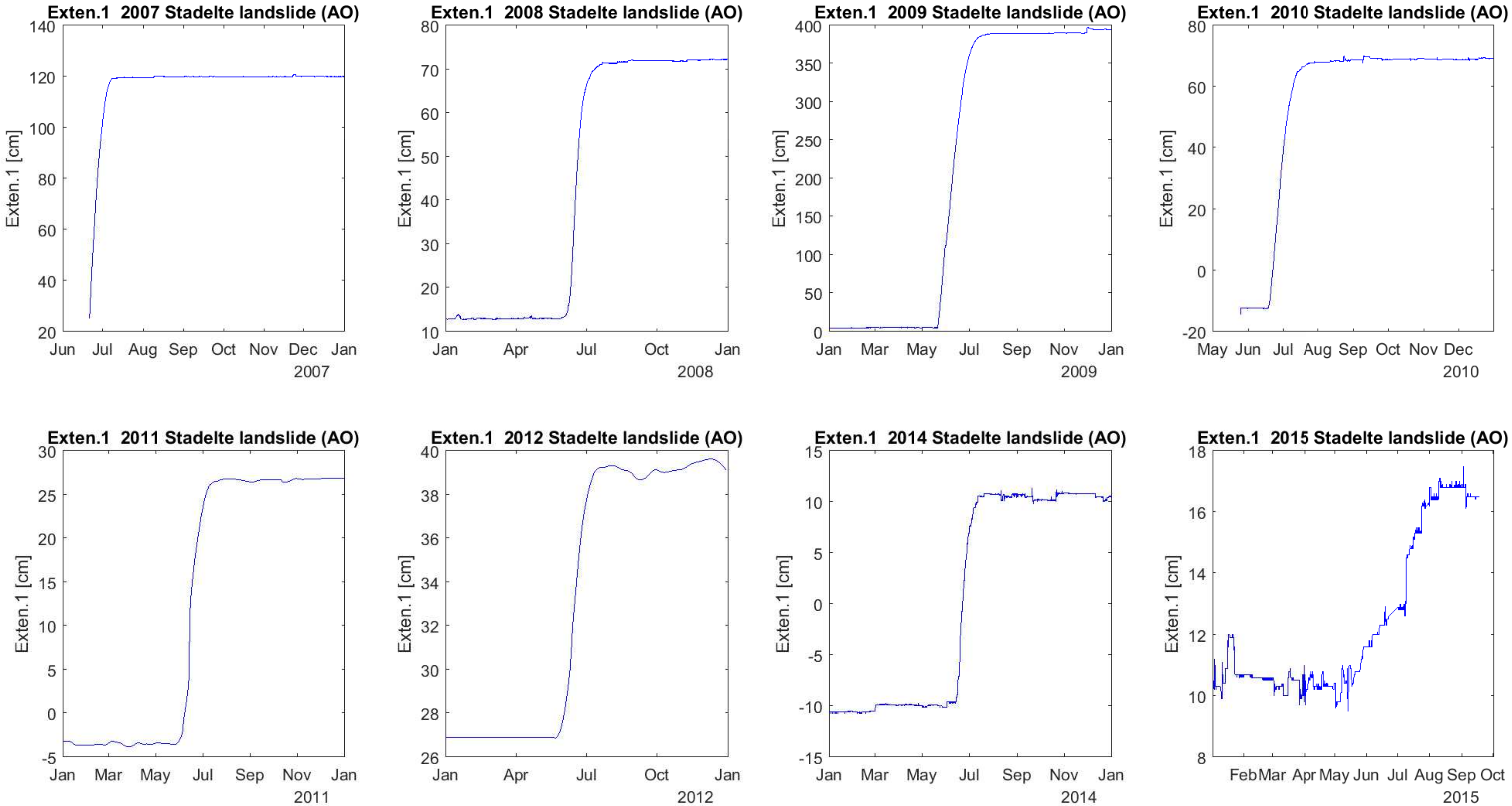
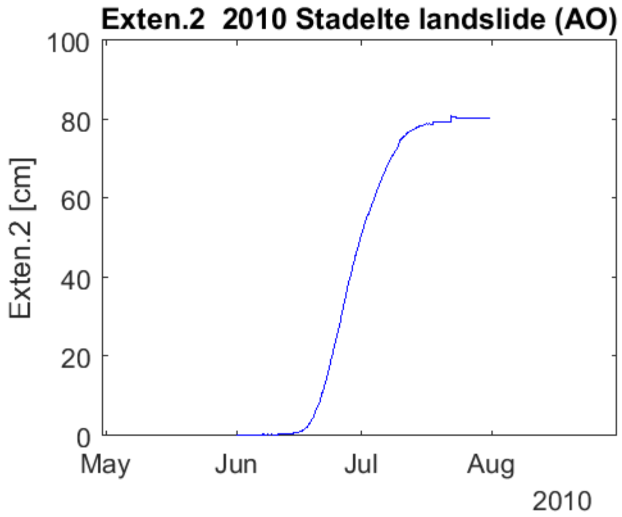
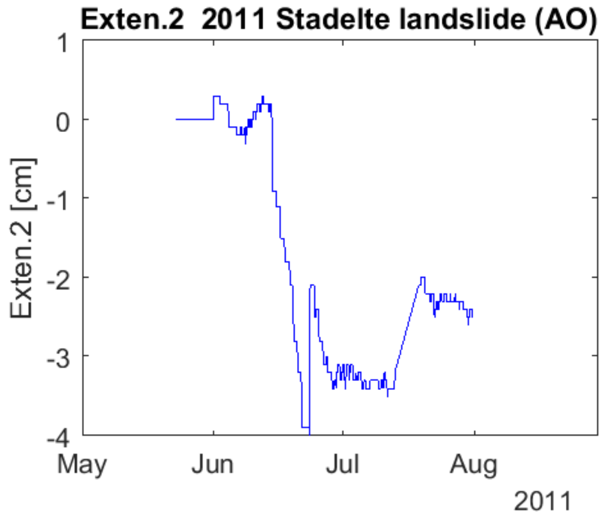

Exten.1 2007 Stadelte landslide (AO)
Exten.1 [cm]
140
120
100
80
60
40
20
Jun Jul Aug Sep Oct Nov Dec Jan
2007
Exten.1 2008 Stadelte landslide (AO)
Exten.1 [cm]
80
70
60
50
40
30
20
10
Jan Apr Jul Oct Jan
2008
Exten.1 2009 Stadelte landslide (AO)
Exten.1 [cm]
400
350
300
250
200
150
100
50
0
Jan Mar May Jul Sep Nov Jan
2009
Exten.1 2010 Stadelte landslide (AO)
Exten.1 [cm]
80
60
40
20
0
-20
May Jun Jul Aug Sep Oct Nov Dec
2010
Exten.1 2011 Stadelte landslide (AO)
Exten.1 [cm]
30
25
20
15
10
5
0
-5
Jan Mar May Jul Sep Nov Jan
2011
Exten.1 2012 Stadelte landslide (AO)
Exten.1 [cm]
40
38
36
34
32
30
28
26
Jan Apr Jul Oct Jan
2012
Exten.1 2014 Stadelte landslide (AO)
Exten.1 [cm]
15
10
5
0
-5
-10
-15
Jan Mar May Jul Sep Nov Jan
2014
Exten.1 2015 Stadelte landslide (AO)
Exten.1 [cm]
18
16
14
12
10
8
Feb Mar Apr May Jun Jul Aug Sep Oct
2015

FIGURE 14: ANNUAL DISPLACEMENT OF EXTENSOMETER 2

FOR THE PERIOD 2010 – 2011



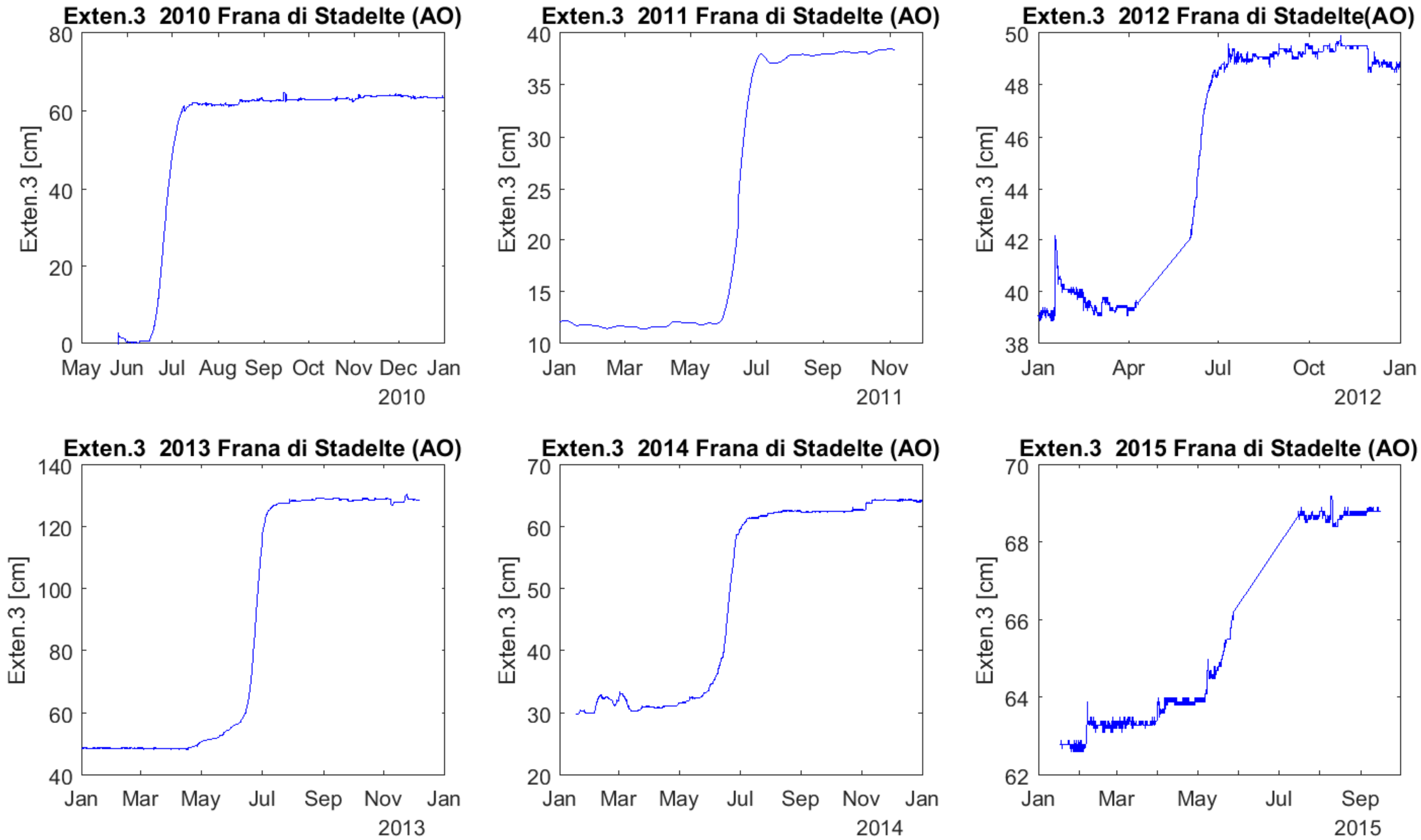
Exten.2 2010 Stadelte landslide (AO)
Exten.2 [cm]
100
80
60
40
20
0
May
Jun
Jul
Aug
2010



Exten.2 2011 Stadelte landslide (AO)
Exten.2 [cm]
1
0
-1
-2
-3
-4
May
Jun
Jul
Aug
2011

FIGURE 15: ANNUAL DISPLACEMENT OF EXTENSOMETER 3

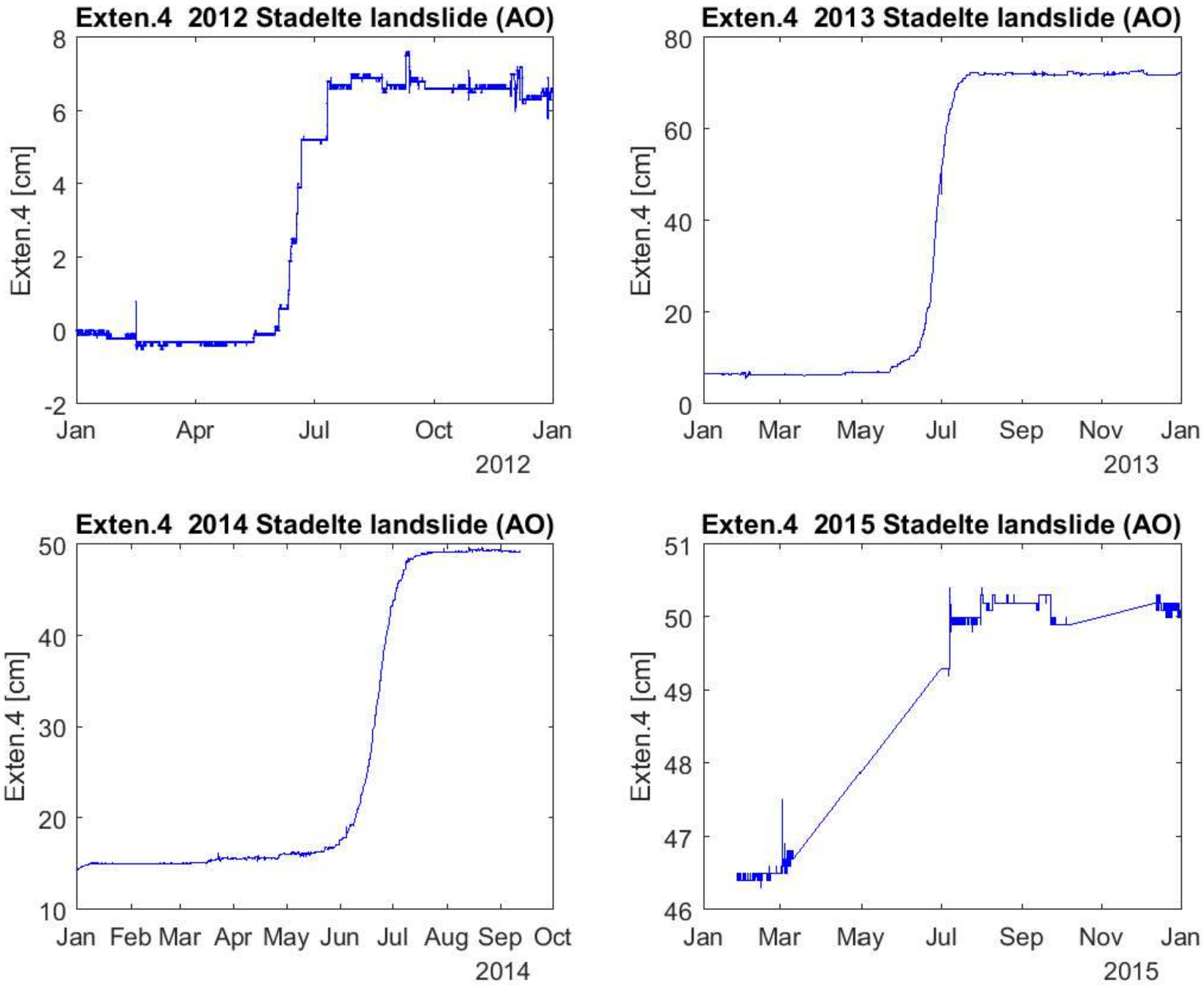
FOR THE PERIOD 2010 – 2015



Exten.3 2010 Frana di Stadelte (AO)
Exten.3 [cm]
May Jun Jul Aug Sep Oct Nov Dec Jan
2010
Exten.3 2011 Frana di Stadelte (AO)
Exten.3 [cm]
Jan Mar May Jul Sep Nov
2011
Exten.3 2012 Frana di Stadelte(AO)
Exten.3 [cm]
Jan Apr Jul Oct Jan
2012
Exten.3 2013 Frana di Stadelte (AO)
Exten.3 [cm]
Jan Mar May Jul Sep Nov Jan
2013
Exten.3 2014 Frana di Stadelte (AO)
Exten.3 [cm]
Jan Mar May Jul Sep Nov Jan
2014
Exten.3 2015 Frana di Stadelte (AO)
Exten.3 [cm]
Jan Mar May Jul Sep
2015

FIGURE 16: ANNUAL DISPLACEMENT OF EXTENSOMETER 4

FOR THE PERIOD 2012 – 2015


Exten.4 2012 Stadelte landslide (AO)
Exten.4 [cm]
8
6
4
2
0
-2
Jan
Apr
Jul
Oct
Jan
2012
Exten.4 2013 Stadelte landslide (AO)
Exten.4 [cm]
80
60
40
20
0
Jan
Mar
May
Jul
Sep
Nov
Jan
2013
Exten.4 2014 Stadelte landslide (AO)
Exten.4 [cm]
50
40
30
20
10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2014
Exten.4 2015 Stadelte landslide (AO)
Exten.4 [cm]
51
50
49
48
47
46
Jan
Mar
May
Jul
Sep
Nov
Jan
2015

3 SYNTHESIS and FINAL PROPOSALS

Considering both the available data review and the ground deformation time series analysis, the general framework of Bosmatto and Stadelte landslides behavior has been outlined. In this section, strengths and weaknesses have been summarized, and some improvements for a proper definition of future activities aimed to increase the comprehension of the considered landslide behavior have been suggested.

Relative to the previous data review and analysis, a comprehensive overview of the geological, geomorphological, structural and hydrogeological setting has been observed. A possible point of confusion concerns the landslide body definition. Indeed, there are some studies concerning only the Bosmatto landslide or the Stadelte landslide, other concerning both landslides, by assigning diverse name (e.g. Bosmatto or Letzè landslide), and different internal subdivision based on their state of activities. Only one agency describes a comprehensive overview of the Letzè catchment, by reporting data of all the eight identified categories (see Table 1). Therefore, it is recommended to use this study as reference for civil protection plans redaction.

In this study the recognized landslide bodies are:

- Stadelte landslide divided in two sectors (vegetated and active portion; not vegetated dormant portion)
- Bosmatto landslide divided in Letzè landslide (vegetated active portion; not vegetated dormant portion), and Mussolier landslide.

The delineation of the Stadelte and Bosmatto landslides model is a key element for the landslide hazard assessment and an appropriate land use planning. However, one of the observed weakness concerns the landslide surface definition. Indeed, the landslide surface interpretations are prevalently based on seismic data, integrated with the geological-geomorphological surface data. Only one borehole has been carried out for the Bosmatto landslide. So, it is recommended the acquisition of depth measurements, to improve the evolution models of each landslides, useful for the implementation of civil protection plans. Moreover, diverse risk scenarios and spatial prediction model have taken place, prevalently related to the computation of the areas involved in the landslide occurrence. Even though, the OM objectives are not related to the Civil Protection plans definition, but to suggest proper improvement for the landslide behavior definition. So, it is highly recommended an in-depth analysis of these aspects in order to obtain a clear and defined model useful for the land use planning and the Civil Protection plans establishment.

Relative to the monitoring networks of the Bosmatto and Stadelte landslides, they seem to be partially suitable for the landslide behavior definition. For the Bosmatto landslide, the GPS monitoring network records displacement variable from 6 mm to 1.5 cm/year, without a clear relation between landslide activation and rainfall precipitation and/or snow melting. Instead, for the Stadelte landslide, an evident seasonal trend has been outlined. It is to be noted that, in general, the GPS network do not guarantee a proper near real time monitoring network, due to their acquisition rate, particularly during paroxysmal events. Moreover, the extensometers removal for the Bosmatto case, remove the redundancy of monitoring data, crucial during the emergency cases.

Furthermore, one of the main weaknesses highlighted regards the ground deformation time series graphs presentation. Indeed, actually the report concerning the monitoring network analysis report the Bosmatto and Stadelte landslides measurements all together, without a clear distinction between the two phenomena. A great effort has been done by the Aosta Valley Region authorities that from the 2009 drafted internal report relative to the monitoring network analysis, to keep track of the critical issues observed over time. However, every year, the data are variable represented, reporting time series relative to the calendar year measurements only, and not the complete time series relative to the entire acquisition period. Moreover the time series often report diverse component (e.g. East, North, planimetric, altimetric, 3D), without a precise scheme. Therefore, it is recommended a standard format for the presentation of the data, with ground deformation time series over the entire monitoring period, with an every year update. By this way, it is possible to points out the potential seasonal accelerations or other pattern of the observed phenomenon. It is also recommended the generation of planimetric and altimetric displacement graphs, which is the most convenient and representative way to describe the landslide behavior. This procedure is recommended for both the Bosmatto and Stadelte landslides, with the generation of two separate reports.

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