Project of Strategic Interest NEXTDATA

WP1.2 – Task 2

D1.2.C – Estimation of the surface hydrogeological response (soil water content, ground surface deformation) and report on their application in Apennine and Alpine test sites.

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SUMMARY

This deliverable describes the activities developed by the CNR IRPI and CNR IREA from May 2014 to June 2018 in the framework of NextData project. The deliverable consists of nine sections. The background (section 1) illustrates the organization of this report. Sections 2, 3, 4, 5, 6 and 7 present the activity that was developed. Section 8 describes the main scientific results. Finally, section 9 lists the project meetings, the participation to national and international conferences and the publications including abstracts, and articles in scientific journals.

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ACRONYMS

ASCE: ascending

AVr: Aosta Valley region

CNR: Consiglio Nazionale di Ricerca (National Research Council)

DESCE: descending

DInSAR: Differential Synthetic Aperture Radar Interferometry

GMG: Geohazard Monitoring Group

G-POD: Grid Processing On Demand

GPS: Global Positioning System

IRPI: Istituto di Ricerca per la Protezione Idrogeologica (Research Institute for Geo-hydrological Protection)

IREA: Istituto per il Rilevamento Elettromagnetico e dell'Ambiente (Institute for Electromagnetic Sensing of the Environment)

RGs: Rock Glaciers

SAR: Synthetic Aperture Radar

SBAS: Small BAseline Subset

WP: Working Package

1 BACKGROUND

The deliverable includes the five reports expected and prepared in period from 2014 and 2016 by the CNR IRPI and CNR IREA research groups. Each report, one for each section of this document, corresponds to a specific activity scheduled in the first approved proposal of the HAMMER Project, a Special Project of NextData and following modifications (after 2015). Section 2, section 3, section 4, section 5 and section 6 include the five reports. Section 7 illustrates the main scientific results achieved in the period 2016-2017. Moreover, the datasets collected and produced in the entire period of the project were stored in the Geonetwork platform prepared for the NextData needs. The Geonetwork platform is described in the deliverable "D2.1.A – Report on the Archives of mountain observation networks".

2 Ground surface and subsurface in-situ time series for the Alps and Apennines territory

Introduction

There is a systematic lack of information on the effects of the climate and environmental changes on the frequency and the intensity of landslides (*Crozier, 2010*, *Huggel et al., 2012*). The problem is particularly severe in mountain areas, where natural and human-driven climatic and environmental changes may alter significantly the frequency and the intensity of the slope processes, with largely unknown short and long-term effects on the landscapes and the environment. We attempted to cope with this theme by collecting accurate and long-term time series of ground surface and sub-surface deformation, and analysing eventual changes of the deformation trend associated with meteorological and climatic variables over time. This chapter reports the activities developed during the period from May to August 2014. This period was dedicated to the collection of existing ground surface and subsurface in-situ time series for the Alps and Apennines territory.

STATE of art

The analysis of surface movements aims to define the geomorphological evolution of single or multiple landslides. The short-term analysis of surface movement is obtained through quantitative or semi-quantitative analyses of three-dimensional topographic data and high accuracy measurements obtained exploiting different monitoring techniques (*Giordan et al., 2013*). The combined analysis of ground displacement time series and meteorological/climatic measurements may contribute to understand the response of unstable slopes to short-term meteorological triggers and long-term climatic forcing (*Lollino et al., 2006*; *Burda et al., 2013*; *Crosta et al., 2013*).

In the last decades, several *in situ* monitoring techniques were considered, including Total Station, GPS receivers, Terrestrial LiDAR, Ground Based Radars, extensometers and inclinometers. These tools are essential to provide ground deformation time series with very high temporal sampling, allowing for the reconstruction of the evolution of the single landslide phenomena over time.

The possibility of obtaining long time series of deformation relevant to several landslides in different physiographic and climatic region may open the possibility of understand the complex, and largely unknown, relationships between climate and its variations, and study the initiation and development of the deep-stated landslides (*Calò et al., 2014*).

The first report (D1) of the HAMMER project proposal deals with the ground surface and sub-surface *in situ* time series collection for the Alps and Apennines territory. The datasets was preliminary stored in a FTP site (see ***FTP* structure** in the following) organized for the purposes of HAMMER project. During the first months of the project, an analysis of the scientific literature was conducted and the findings are described in this document (see ***Literature review*** in the following).

Report D1 was scheduled to be 7 months, from January to July 2014, but due to the delay in the project start, the period of work was included from March to August 2014 (5 months). In this period, the work has been focused on four study areas located in the Alps and Apennines territory, where information about time series of ground deformation has been collected. Most of the ground deformation data has been obtained from previous internal studies of CNR-IRPI Torino, in particular of the GMG group (http://gmg.irpi.cnr.it) and of CNR-IRPI Perugia (http://geomorphology.irpi.cnr.it/) and from their publications (*Calò et al., 2014*; *Lollino et al., 2006*).

TEST Sites

The work focused on some study areas, distributed in the Alps and Apennines territory; in particular two test sites in the Alps territory, Gardiola and Grange Orgiera landslides, and two test sites in the Apennines territory, Montaldo di Cosola and Ivancich Landslides were considered. The geographic location of these test sites is reported in Table 2.1 and Figure 2.1.

TEST SITE	LOCATION	COORDINATES
Gardiola	Germanasca Valley – Prali, Piemonte, Northern Italy	44°55'29N - 7°3'52E
Grange Orgiera	Varaita Valley – Sampeyre, Piemonte, Northern Italy	44°36'21N - 7°8'2E
Montaldo di Cosola	Cabella Ligure municipality, Alessandria, Piemonte, Northern Italy	44°40'4N - 9°10'43E
Ivancich	Assisi municipality, Perugia, Umbria, Central Italy	43°4'8N - 12°37'51E

Table 2.1 –Test Sites distributed in the Alps and Apennines territory, associated to their geographic coordinates

Figure 2.1 - View on Google Earth of the Test Sites

For each site, *in situ* monitoring techniques were considered, including Total Station, GPS receivers, extensometers, inclinometers, etc. These technologies are essential to provide ground deformation time series with very high temporal sampling and reconstruct temporal evolution of single landslide phenomena over time. At the same time meteorological/climate data were gathered from meteorological station close to each test site. In particular, for Piedmont test sites collected time series are available for free download by Arpa Piemonte website (http://www.regione.piemonte.it/ambiente/aria/rilev/ariaday/annali/meteorologici); while for Umbrian test site, the collected time series are available on Umbria Region website (http://www.idrografico.regione.umbria.it/annali/default.aspx).

Gardiola Test Site

The Gardiola landslide is a complex phenomenon located in Salza di Pinerolo, in the central part of the Germanasca Valley (Piedmont, Norther Italy). The landslide reactivated during the flood event occurred on 14-16 October 2000, when surface deformation was revealed. A temporary monitoring network, made up of several optical targets located in the most active sector of the landslide, has been installed since October 2000. Subsequently, this network has become a permanent monitoring

network since 2004, made up of topographic network with a Robotic Total Station (LEICA 2003 with Automatic Target Recognition ATR), located in the opposite valley side, surveying 23 optical targets. Three of these optical targets are located outside the landslide area on stable ground, associated to four extensometers, an inclinometer, a piezometer and a GPS monitoring network.
For Gardiola test site, we collected ground deformation time series (GMG Group - CNR Torino Internal Data) relevant to the permanent topographic monitoring network. In particular, time series provide x, y, z local coordinates, and Δx, Δy, Δz, and total displacement Δtot data of 19 prisms target. In addition point, linear and polygonal shapefiles were created (Figure 2.2), using the open source software QGIS 2.2 Valmiera (http://www.qgis.org/it/site/), to describe the landslide from a geomorphological point of view and to represent the location of the monitoring instruments. All the shapefiles are CNR IRPI internal data (GMG group).

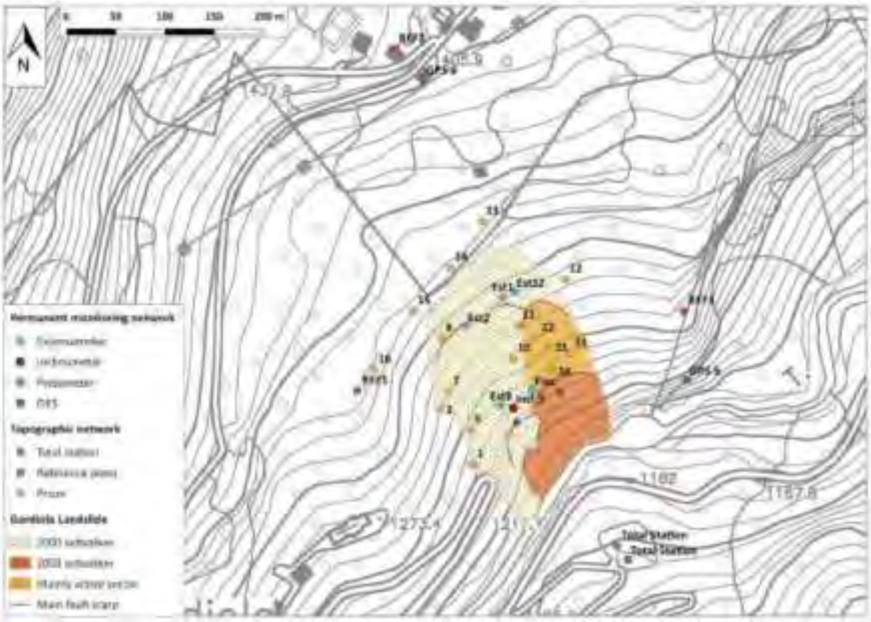


Figure 2.2– Permanent monitoring network of Gardiola landslide represented in Qgis

The meteorological/climate time series was also collected for the Prali Villa Meteorological Station, located about 3 km south-southwest of Gardiola landslide. The station is located in Prali Villa municipality (Pellice Valley, Piedmont, Northern Italy) and belongs to Arpa Piemonte meteorological network (website: http://www.regione.piemonte.it/ambiente/aria/rilev/ariaday/annali/meteorologici) whose information is available for free download. The station sensors register: temperature (average, maximum and minimum), rainfall (24 hours) and snow (snow depth, snow cover) data. The ARPA Piemonte provides the daily and monthly rainfall time series, including also high precipitation for the 1993 – 2013 time period.

Grange Orgiera Test Site

The Grange Orgiera is a complex landslide located in Varaita Valley, at the Villar hamlet (Sampeyre, Cuneo, Piedmont, Northern Italy). This landslide moved on July 2009 after later spring rainfall following intense snow precipitations during the 2008-2009 winter. From August 2009, the landslide was monitored with a topographic monitoring network made up of a total station, 6 prisms inside the landslide and 2 prisms outside the landslide, close to the landslide foot, in addition to a GPS monitoring network made up 8 benchmarks inside the landslide and 8 outside the landslide body, installed on August 2009. In July 2010, 5 new prisms within the landslide body, near to the left frontal lobe of the landslide, have been installed. For this test site we collected the ground deformation time series from topographic monitoring network (CNR-IRPI Torino, GMG group Internal Data). In particular, two time series from August 2009 to October 2009 and from July 2010 to September 2010 were collected. These time series provide x, y, z local coordinates, Δx, Δy, Δz, and total displacement

Δtot data respectively for 8 prisms target for 2009 monitoring campaign and for 13 prisms target for 2010 monitoring campaign. In addition point, linear and polygonal shapefiles were created (Figure 2.3), using the open source software "QGIS 2.2 Valmiera", to describe the landslide from a geomorphological point of view and to represent the location of the monitoring instruments. All the shapefiles are CRN IRPI internal data (GMG group) except for the GPS network shapefile, that is available for free download on Arpa Piemonte website (http://webgis.arpa.piemonte.it/geoportale/index.php/servizi-geoportale/wms-wfs).

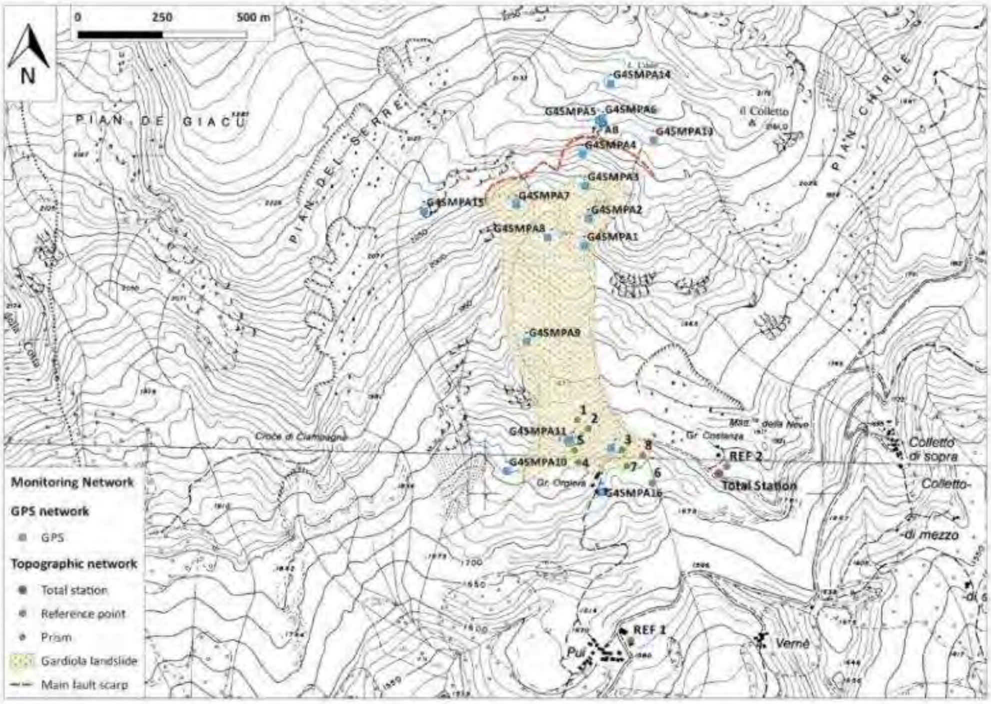


Figure 2.3 – Monitoring network of Grange Orgiera landslide represented in Qgis (GIS open source sw)

Meteorological/climate time series, for this test site were collected from Sampeyre/Capoluogo and Pian delle Baracche Meteorological Stations close to Grange Orgera landslide. The first one is a manual nivometric station located in Sampeyre municipality (Varaita Valley, Piedmont, Northern Italy), about 5 km east-southeast of Grange Orgiera landslide, the second one is thermopluvio-anemometric station with radiometer and nivometric sensor located in Pian delle Baracche locality, in the Sampeyre municipality (Varaita Valley, Piedmont, Northern Italy), about 6 km south of Grange Orgiera landslide. These meteorological stations are part of Arpa Piemonte meteorological network (website: http://www.regione.piemonte.it/ambiente/aria/rilev/ariaday/annali/meteorologici) and the collected data are available for free download. The station sensors register: temperature (average, maximum and minimum), rainfall (24 hours) and snow (snow depth, snow cover) data. The ARPA Piemonte provides the daily and monthly rainfall time series including also high precipitation for the 1990 – 2013 period for the first one and for the period 1998-2013 for the second one.

Montaldo di Cosola Test Site

The Montaldo di Cosola test site is a complex landslide located in Cabella Ligure municipality (Alessandria, Piedmont, Northern Italy). The landslide reactivated in the flood event occurred in the 1993 autumn, and a monitoring network made up two inclinometers, an automated inclinometer system (AIS) and two piezometers was installed from 2000 to 2001, and three inclinometers, an automated inclinometer system (AIS) and six piezometers from 2002 to 2004.

For this test site, we will collect ground deformation time series of the inclinometers data presented in *Lollino et al. (2006)*. In addition point, linear and polygonal shapefiles were created (Figure 2.4), using the open source software "QGIS 2.2 Valmiera", to describe the landslide from a geomorphological point of view and to represent the location of the monitoring instruments. All the shapefile are CRN IRPI internal data (GMG group) except for the landslide area shapefile, that is available for free download on Arpa Piemonte website (http://webgis.arpa.piemonte.it/geoportale/index.php/servizi-geoportale/wms-wfs).

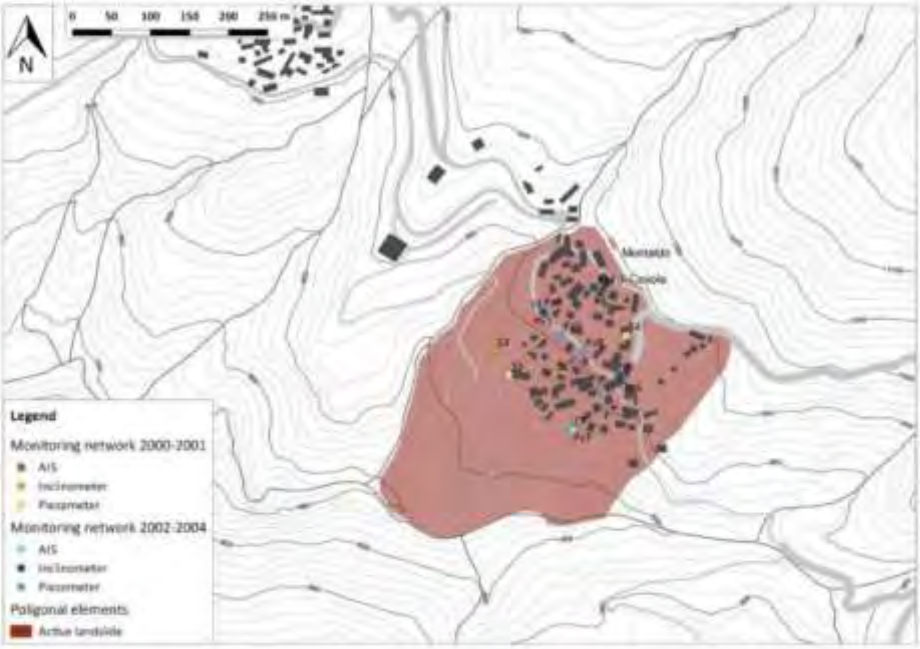


Figure 2.4 – Monitoring network of Montaldo di Cosola landslide represented in Qgis

The meteorological/climate time series, for this test site was collected at the Cabella Ligure Meteorological Stations, about 7 km west to Montaldo di Cosola landslide. This is a thermopluviometric station located in Cabella Ligure municipality (Scrivia Valley, Piedmont, Northern Italy). This meteorological station is part of Arpa Piemonte meteorological network (website: http://www.regione.piemonte.it/ambiente/aria/rilev/ariaday/annali/meteorologici) and the data collected are available for free download. The station sensors register: temperature (average, maximum and minimum) and rainfall (24 hours) data. The ARPA Piemonte provides the daily and monthly rainfall time series including high precipitation for the period 2006 – 2013 period.

Ivancich Test Site

The Ivancich landslide is a translational slide with a rotational component in the source area, located in the Assisi municipality (Perugia, Umbria, Central Italy). On this landslide several monitoring instruments were installed: a monitoring network (1998), made up of 12 inclinometers and 42 piezometers; an integrative monitoring network (2001), made up of an inclinometer, six piezometers and six settlement gauges; an additional integrative monitoring network (2002-2003), made up of five inclinometers and 8 piezometers; and a GPS monitoring network made up of 14 benchmarks of the previous investigation of the eighties. For this test site ground deformation time series of four inclinometers (CNR Perugia Internal Data – *Calò et al., 2014*) were collected. In addition, point, and polygonal shapefiles were created (Figure 2.5), using the open source software “QGIS 2.2 Valmiera”, to describe the landslide from a geomorphological point of view and to represent the location of the monitoring instruments. All the shapefiles are CNR IRPI internal data (Perugia group).

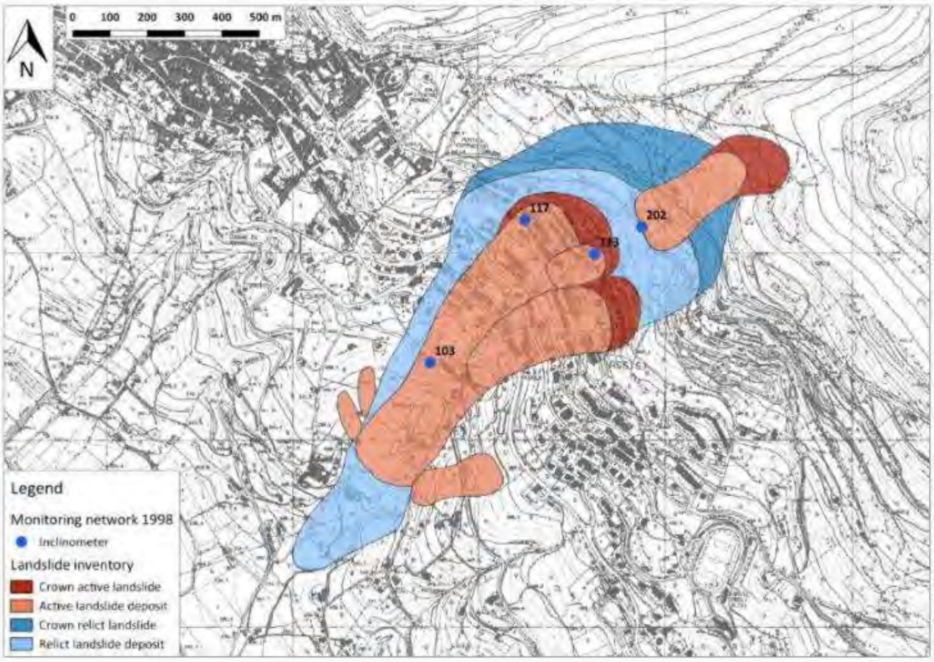


Figure 2.5– Landslides inventory map relevant to a portion of Assisi municipality (Umbria, Central Italy). The shades of blue show ancient and relict landslides and shades of red show recent landslides. The landslide crown areas (darker colors) are mapped separately from the landslide deposits (lighter colours) (Modified from ***Calò et al., 2014***)

The meteorological/climate time series, for this test site were collected from Armenzano, Bastia Umbra and Cannara Meteorological Stations close to Ivancich Landslide. These meteorological stations are part of Umbria Region meteorological network (website: http://www.idrografico.regione.umbria.it/annali/default.aspx) and the data collected are available for free download. In particular, time series provide data of daily rainfalls for 1988 – 2009 (Armenzano and Bastia Umbra stations) and 1988-2010 (Cannara station) time period.

***FTP* structure**

The implementation of a database to store the collected time series was one of the objectives of original proposal and has still remained in the following project modifications. The database had to be delivered at the month 12 and had to be designed according to the NextData platform structure. During the first months of project lifetime, metadata have been structured in excel file in according to the different data type (*in-situ*, meteorological/climate data), in order to make all the data type available to the NextData Project. Metadata, recorded with the information required by European directive INSPIRE (http://essi-lab.eu/do/view/GIcat/InspireMetadata), provide several "Identification info" (Title, Date, Abstract, Purpose, etc.), and several "Optional elements" (distribution information, spatial representation type, metadata standard name, metadata standard version, etc.). In addition, we dedicated a FTP site to store and share data and metadata. The data already collected, have been first organized in an FTP site with a specific structure that, for each test site, is organized as follows:

- DATA: collects "*in situ* data" and the corresponding "metadata" (SHARE Geonetwork directive);
- METEOROLOGICAL DATA: collects meteorological/climate time series available for free download on regional website (Arpa Piemonte http://www.regione.piemonte.it/ambiente/aria/rilev/ariaday/annali/meteorologici; Umbria Region http://www.idrografico.regione.umbria.it/annali/default.aspx);
- ORTOPHOTO: collects .tiff files or URL available on the regional geoportal (Piedmont: http://www.geoportale.piemonte.it/cms/index.php?option=com_content&view=article&id=55&Itemid=73&lang=it; Umbria: http://www.pcn.minambiente.it/PCNDYN/catalogowms.jsp?lan=it);

- PROJECT: structuring of Qgis project (GIS open source sw) for the production of digital map;
- SAR: collects the results of Differential Interferometric Synthetic Aperture Radar (SAR) analyses retrieved from data acquired from space borne and ground based sensors available for each test sites;
- SHP: collects punctual, linear and polygonal shapefile available for each test sites;
- TOPOGRAPHY: collects .tiff and .tfw files or URL available on regional geoportal (Piedmont: http://www.geoportale.piemonte.it/cms/index.php?option=com_content&view=article&id=55&Itemid=73&lang=it).

The following tables (Table 2.2, Table 2.3, Table 2.4, Table 2.5) report all the information collected for each test site and included in the FTP.

Principal Folder	Folder	Files	OBSERVATION PERIOD
[illegible]	TS IN SITU DATA	TS_Gardiola_Topographic_Netetwork_HAMMER.xls	29/03/2004 - 07/04/2009
	METADATA	Metadata_Gardiola_Landslide_HAMMER.xls	Since 14-15 October 2000
		Gardiola_Landslide_Geomorphological_Map.jpg	
		Metadata_Gardiola_Topographic_Network_HAMMER.xls	29/03/2004 - 07/04/2009
		Gardiola_Topographic_Network.jpg	
		Metadata_Gardiola_Extensometer_HAMMER.xls	19/03/2004 - 30/06/2005
		Gardiola_Landslide_Extensometer.jpg	
		Metadata_Gardiola_Inclinometer_HAMMER	Since October - November 2004
		Gardiola_Landslide_Inclinometer	
		Metadata_Gardiola_Piezometer_HAMMER	Since October - November 2004
		Gardiola_Landslide_Piezometer	
		Metadata_Gardiola_GPS_HAMMER	Since December 20004
		Gardiola_Landslide_GPS_Network	
		Metadata_Gardiola_Stratigraphy_S1_HAMMER	October 2004
		Gardiola_S1_Stratigraphy	
[illegible]	TS METEOROLOGICAL STATION	PRALY_daily_rainfall_1993_2013.xls	1993 - 2013
		PRALY_monthly_rainfall_1993_2013.xls	1993 - 2013
		PRALY_high_precipitation_1993_2013.xls	1993 - 2013
	METADATA	Metadata_Gardiola_Prali_Station_HAMMER.xls	1993 - 2013
[illegible]		URL_Ortophoto_2010.txt	2010
[illegible]		Gardiola_Landslide.qgs	
[illegible]		No data	
[illegible]		Point - Linear - Poligonal shapefile	
[illegible]		CTR (10.000 scale)	
		URL Ortophoto Piemonte 2010	

Table 2.2 - Gardiola Landslide FTP Structure

Principal Folder	Folder	Files	OBSERVATION PERIOD
[illegible]	TS IN SITU DATA	TS_Topographic_Network_Grange_2009.xls	12/08/2009 - 01/10/2009
		TS_Topographic_Network_Grange_2010.xls	19/07/2010 - 09/09/2010
	METADATA	Metadata_Grange_Landslide_HAMMER.xls	July 2009
		Grange_Geomorphological_map.jpg	
		Metadata_Grange_Topographic_network_HAMMER.xls	12/08/2009 - 09/09/2010
		Grange_Topographic_netwok_map.jpg	
		Metadata_Grange_GPS_network_HAMMER	25/08/2009
		Grange_GPS_netwok_map.jpg	
[illegible]	TS METEOROLOGICAL STATION	CAPOLUOGO_daily_rainfall_1990_2013.xls	1990 - 2013
		PIAN DELLE BARACCHE_daily_rainfall_1988_2013.xls	1988 - 2013
		PIAN DELLE BARACCHE_monthly_rainfall_1988_2013.xls	1988 - 2013
	METADATA	Metadata_Grange_Capoluogo_Sampeyre_HAMMER.xls	1990 - 2013
		Meteorological_Station_Sampeyre-Capoluogo_Map.jpg	
		Metadata_Grange_PianBaracche_HAMMER.xls	1988 - 2013
		Meteorological_Station_PianBaracche_Map.jpg	
[illegible]		URL_Ortophoto_2010.txt	2010
[illegible]		Grange_Orgiera_Landslide.qgs	
[illegible]		No data	
[illegible]		Point - Linear - Poligonal shapefile	
[illegible]		CTR (10.000 scale)	
		URL_BDtre_Piedmont.txt	

Table 2.3 - Grange Orgiera Landslide FTP Structure

Principal Folder	Folder	Files	OBSERVATION PERIOD
[illegible]	TS IN SITU DATA	No data	
	METADATA	Metadata_Montaldo_Cosola_Landslide_HAMMER.xls	11/2000
		Montaldo_Cosola_Landslide.jpg	
		Metadata_Inclinometer_00-01_Montaldo_HAMMER.xls	September 2000 - March 2001
		Inclinometer_00-01Net_Montaldo_Cosola.jpg	
		Metadata_Piezometer_00-01_Montaldo_HAMMER.xls	September 2000 - March 2001
		Piezometer_00-01Net_Montaldo_Cosola.jpg	
		Metadata_Inclinometer_02-04_Montaldo_HAMMER.xls	May 2002 - May 2004
		Inclinometer_02-04Net_Montaldo_Cosola.jpg	
		Metadata_Piezometer_02-04_Montaldo_HAMMER	May 2002 - May 2004
		Piezometer_02-04Net_Montaldo_Cosola.jpg	
[illegible]	TS METEOROLOGICAL STATION	TS_CABELLA LIGURE_daily_rainfall_2006_2013.xls	2006 - 2013
		TS_CABELLA LIGURE_monthly_rainfall_2006_2013.xls	2006 - 2013
		TS_CABELLA LIGURE_high_precipitation_2006_2013.xls	2006 - 2013
	METADATA	Metadata_Cabella_Meteorological_Station_HAMMER.xls	2006 - 2013
		Meteorological_Station_Cabella_HAMMER.jpg	
[illegible]		URL_Ortophoto_2010.txt	
[illegible]		Montaldo_Cosola_Landslide.qgs	
[illegible]		No data	
[illegible]		Point - Linear - Poligonal shapefile	
[illegible]		CTR (10.000 scale)	
		URL_BDtre_Piedmont.txt	

Table 2.4 - Montaldo di Cosola Landslide FTP Structure

Principal Folder	Folder	Files	OBSERVATION PERIOD
DATA	TS IN SITU DATA	TS_Inclinometer_data_103_Ivancich_FTP.xls	20/01/1999 - 17/03/2006
		TS_Inclinometer_data_113_Ivancich_FTP.xls	16/12/1998 - 02/12/2005
		TS_Inclinometer_data_117_Ivancich_FTP.xls	16/12/1998 - 06/07/2004
		TS_Inclinometer_data_202_Ivancich_FTP.xls	15/12/1998 - 17/03/2006
	METADATA	Metadata_Ivancich_Landslide_HAMMER.xls	Since 1970
		Ivancich_Landslide_HAMMER.jpg	
		Metadata_Ivancich_Inclinometer_HAMMER.xls	16/12/1998 - 17/03/2006
		Ivancich_Landslide_Inclinometer_HAMMER.jpg	
METEOROLOGICAL DATA	TS METEOROLOGICAL STATION	TS_rainfall_time_series_Armezzano.xls	1988 - 2009
		TS_rainfall_time_series_BastiaUmbra.xls	1988 - 2009
		TS_rainfall_time_series_Cannara.xls	1988 - 2010
	METADATA	Metadata_Armenzano_Meteorological_Station_HAMMER.xls	1988 - 2009
		Metadata_BastiaUmbra_Meteorological_Station_HAMMER.xls	1988 - 2009
		Metadata_Cannara_Meteorological_Station_HAMMER.xls	1988 - 2010
ORTOFOTO		PCN_WMS_cartography	
PROJECT		Ivancich_Landslide.qgs	
SAR		No data	
SHP		Point - Linear - Poligonal shapefile	
TOPOGRAPHY		CTR (10.000 scale)	

Table 2.5 - Ivancich Landslide FTP Structure

Literature review

One of the expected results of the original proposal was the analysis of the scientific and technical literature to determine where quantitative surface and sub-surface information on ground deformations in landslide areas is available, and for which periods**.** For the purpose, we compiled a database of scientific and technical papers. Such a literature review includes the landslide areas in the Alps and Apennines, where time series of deformations have been collected and the identification of landslide areas can be performed using existing data. An excel file was prepared. The file lists 100 records and the items (bibliographic documents) were classified based on different criteria.

The file reports general information, such as authors, title, journal/volume, year, article topic (corresponding to the keywords reported in the article), and article type (e.g. scientific article, conference proceeding; technical report; oral presentation; etc.).

Furthermore, the reviewed papers have been classified according to the following topics: i) in situ ground deformation measurements, ii) space-borne DInSAR ground deformation measurements, and iii) meteorological parameters. The article categories are classified as "In-situ time series", "SAR time series" and "Climate parameter". An additional topic "Inventory" has been included to classify those items relating to landslide inventory, both at regional and local scale.

The presence or absence of relationship between time series data of ground deformation, in situ and/or satellite, and meteorological-climatic time series were investigated and in addition to the type of existing interaction, to verify in which published works different types of time series were compared and how they were related (Table 2.6).

CODE	DESCRIPTION
R s-c	SAR vs. Climate parameter
R s-is	SAR vs In situ time series
R is-c	In situ time series vs. Climate parameter
R s-is-c	SAR vs. In situ time series vs. Climate parameter

Table 2.6– Type of relationship recognized in the literature review

The “Observation period” and “Data type” of the collected time series were stored also in the database to complete the information. One hundred publications were reviewed and organized in a excel file with a specific structure, shown in Table 2.7.

FIELD	DESCRIPTION
ID	Progressive number
DATA RELATIONSHIP	Type of relationship between the data
ARTICLE CATEGORY	Publication type
ARTICLE TOPIC	GENERAL INFORMATION
AUTHOR	
TITLE	
JOURNAL/VOLUME	
YEAR	
ARTICLE TYPE	
PHYSIOGRAPHIC ENVIRONMENT	Mücher *et al.* 2009 / ISPRA AMBIENTE
CLIMATIC ZONE	Kottek *et al.*, 2006
REGION	GEOGRAPHIC LOCATION
NATION	
LAT/LONG	
TEST SITE	
OBSERVATION TYPE	DATA DESCRIPTION
DATA TYPE	
AREA EXTENSION	
DIRECTION	
THOPOGRAPHIC GRADIENT VARIATION	
LAND USE	

Table 2.7– List of the fields of the database.

Particular attention was paid to characterize the “Physiographic environment” and the “Climatic zone”. To characterize the “Physiographic environment” we used the classification proposed in *Mücher et al. (2009)* for European sites, and the ISPRA AMBIENTE classification (website: http://www.isprambiente.gov.it/it/servizi-per-lambiente/sistema-carta-della-natura/carta-della-natura-alla-scala-1-250.000/i-tipi-e-le-unita-fisiografiche-di-paesaggio) for the Italian sites (Figure 2.6). The classification proposed by Mücher is a hierarchical European Landscape Classification (LANMAP) units using digital data on climate, altitude, parent material and land use as determinant factors that can be used as a framework for environmental sampling (Figure 2.7). To characterize the “Climatic zone” we used the Köppen-Geiger climate classification proposed in *Kottek et al. (2006).* It is based on recent data sets from the Climatic Research Unit (CRU) of the University of East Anglia and the Global Precipitation Climatology Centre (GPCC) at the German Weather Service, and it is valid for the second half of the 20th century (Figure 2.8).

Figure 2.6– ISPRA AMBIENTE landscape classification based on “Physiographic unit”, geographically defined area of land that has a characteristic structure and physiographic patterns of land cover (ISPRA AMBIENTE website: http://www.isprambiente.gov.it/it/servizi-per-lambiente/sistema-carta-della-natura/carta-della-natura-alla-scala-1-250.000/i-tipi-e-le-unita-fisiografiche-di-paesaggio).

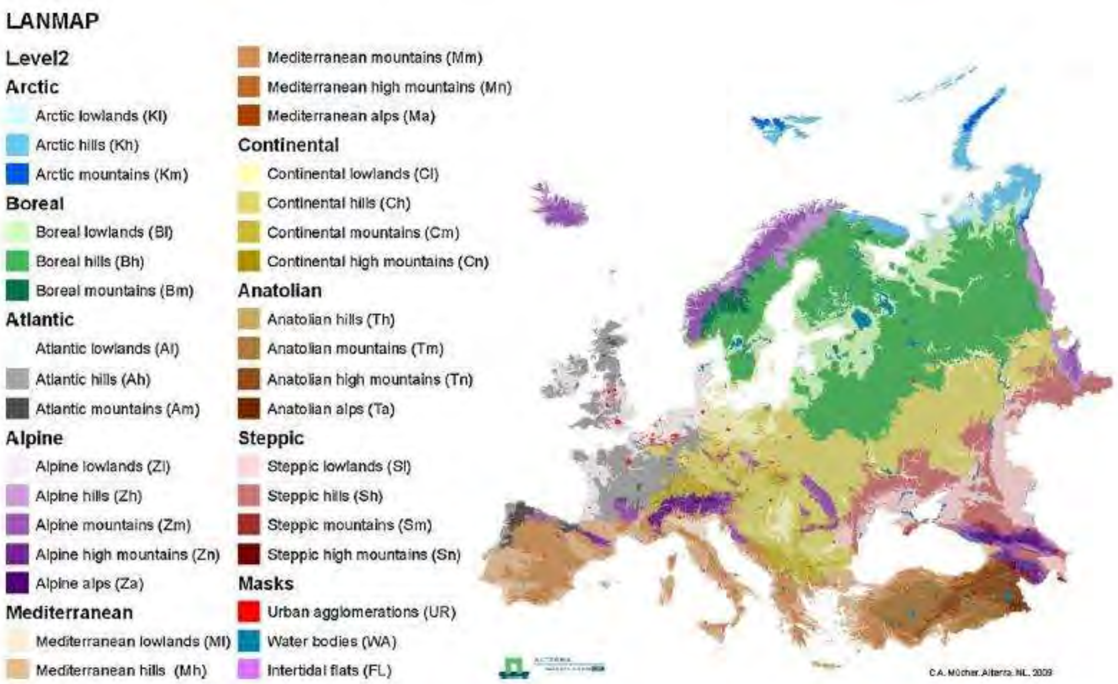


Figure 2.7 – LANMAP European Landscape Classification based on high-resolution spatial explicit digital information (*Mücher et al., 2009*).

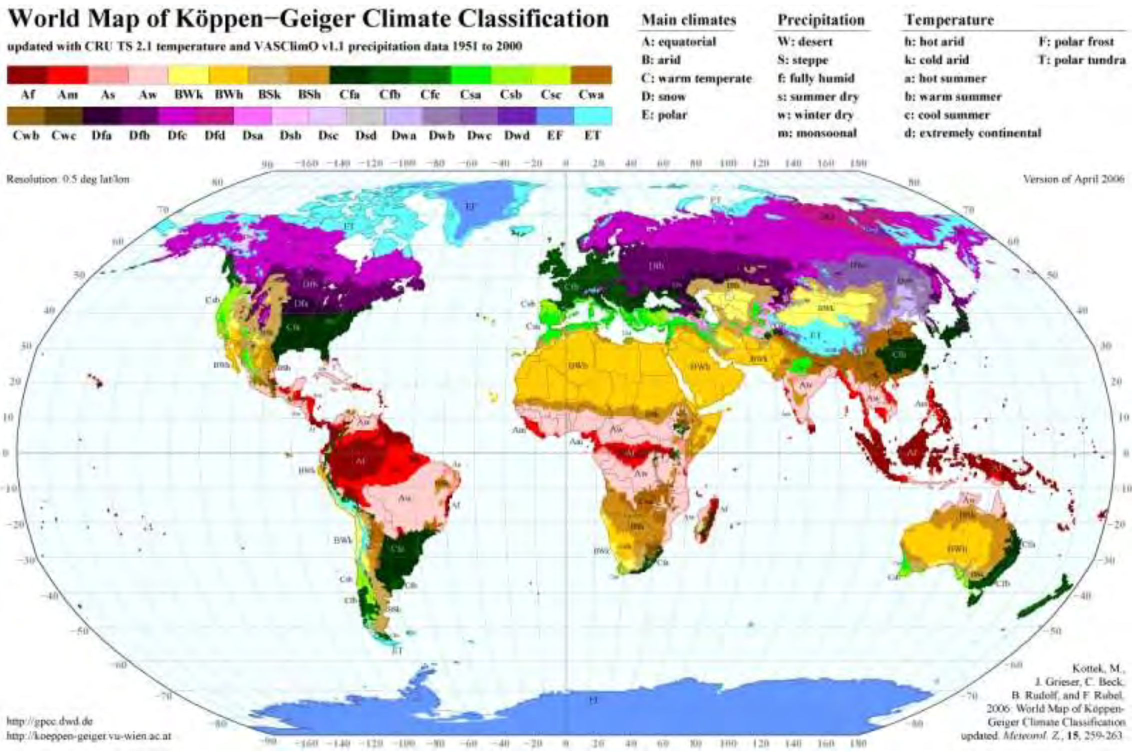


Figure 2.8 – World Map of Köpper-Geiger climate classification updated with mean monthly CRU TS 2.1 temperature and VASClimO v1.1 precipitation data for the period 1951 to 2000 on a regular 0.5 degree latitude/longitude grid (***Kotten et al., 2006***).

3 Ground deformation time series and meteo-climatic parameter collection

Introduction

This document reports the activities developed during the period from August to December 2014 as required by the original project proposal and following modifications.

STATE of art

The main goal of the HAMMER project consists of: the collection of ground surface and sub-surface time series, in particular *in situ* data collected for the Alps and Apennines territory, and SAR data for the Apennine, Pyrenees and Andean territory; the collection of meteo-climatic parameters for the same area; the cross-correlation of the ground deformation time series and the meteo-climatic parameters, and their interpretation in view of their local and general significance; the implementation of a database system in order to collect and store all data. In the period from March to August the work has been focused on four study areas located in the Alps and Apennines territory (see section 2), where information about time series of ground deformation has been collected. Most of the ground deformation data has been obtained from previous internal studies prepared by the GMG group of CNR-IRPI Torino (http://gmg.irpi.cnr.it) and by the CNR-IRPI Perugia (http://geomorphology.irpi.cnr.it/) and also from several publications (*Calò et al., 2014*; *Lollino et al., 2006*). In the period from August to December, the work has been focused on the study area in the Alps, in the Pyrenees and the Chilean Andes, in order to collect all the SAR data available. Furthermore, have been processed new SAR mean velocity maps and time series for two specific study areas, using the ESA's G-POD (http://gpod.eo.esa.int/) service. The results are presented in the following section, for each of the considered test site.

Ground deformation time series and meteo-climatic parameter collection

In the first months, the work has been focused on some study areas, distributed in the Alps and Apennines territory; in particular two test sites in the Alps territory, Gardiola and Grange Orgiera landslides, and two test sites in the Apennines territory, Montaldo di Cosola and Ivancich landslides were considered. For each site *in situ* monitoring techniques and meteorological/climate data were gathered. From August to December, SAR derived data was collected, for the Apennines, Pyrenees (Figure 3.1). Furthermore, in the same period of time, ground deformation maps and related time series were prepared for a test site located in the Chilean Andes territory In particular, the data have been collected for the Ivancich landslide (Central Apennines), for the Tena Valley (Central Spanish Pyrenees), and newly prepared for the Atacama Desert (Chilean Andes).

For the Tena Valley and the Atacama Desert have been also collected the meteo-climatic parameter. The meteorological data were gathered from meteorological station close to each test site. In particular, for the Atacama Desert the data collected are available for free download by Direccĩon General the Aguas, Ministero de Obras Pũblica, Gobierno de Chile (http://snia.dga.cl/BNAConsultas/); while for Tena Valley test site, the collected time series are available by SAIH Ebro Confederación Hidrográfica del Ebro (Hispagua, Sistema Español de Informacíon sobre el Agua: http://hispagua.cedex.es/).

Figure 3.1 – View on Google Earth of the Test Sites.

Ivancich Test Site

The Ivancich landslide is a translational slide with a rotational component in the source area, located in the Assisi municipality (Perugia, Umbria, Central Italy). The landslide was described in the section 2. For the Ivancich landslide, the SAR data relative to CosmoSky-MED, ERS-1/2 and Envisat ASAR satellite are available at the CNR-IRPI internal work (Figure 2). The analysis of the surface deformation, are obtained from SBAS technique (*Bernardino et al., 2002*): for the CosmoSky-MED satellite composed of 39 images in descending orbit spanning from December 2009 to February 2012, at low-resolution scale (100x100 m) and also at full-resolution scale (3x3 m); for ERS-1/2 and ENVISAT satellite composed of 87 images (36 ERS-1/2 and 51 Envisat ASAR) in ascending orbit spanning from June 1995 to September 2010, at low-resolution scale (100x100 m), and also at full-resolution scale (5x20 m), while 130 images (91 ERS-1/2 and 39 ENVISAT), in descending orbit, spanning from April 1992 to November 2010, at full-resolution scale (5 m x 20 m). The Figure 3.2 shows an example of the SAR elaboration products, in particular shows the velocity map of the ERS-1/2 and Envisat ASAR dataset, obtained with SBAS technique in descending orbit in full-resolution scale. Each point are associated to a ground deformation time series, for the observed period (1992 - 2010).

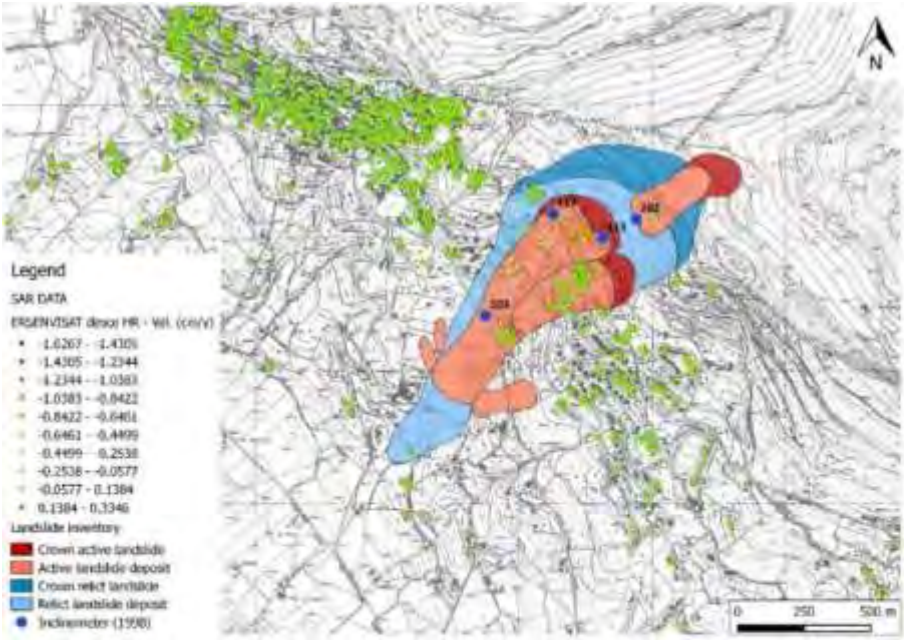


Figure 3.2 – Velocity map (cm/y) of ERS-1/2 and ENVISAT dataset, in descending orbit, for the period April 1992-November 2010, for the Ivancich landslide (Assisi, Umbria, Central Italy).

Tena Valley test site

The Tena Valley is located in the upper part of Gállego River basin, in Central Spanish Pyrenees, extended for about 47 km^2 with a topographical gradient variation from 2500 to 1200 m asl. Many landslides affect this area, due to the geological setting, and in particular, we considered two deep-seated slides whose development is due to the destabilisation of the over steepened valley walls after the retreat of the glaciers (*Herrera et al., 2013*). The climate in this test site is characterised by marked seasonability, with a considerable portion of the precipitation (> 30%) corresponds to snowfall that mostly occurs between December and March (*Davalillo et al., 2014*). Furthermore the frost and snow coverage, found above 1500 m asl, may melt rapidly in the late spring causing significant infiltration in a short period of time, with the consequent increase in the pore pressure of the slope materials, favouring landslide dynamic. For this test site, meteo-climatic parameters are available by SAIH Ebro Confederación Hidrográfica del Ebro (Hispagua, Sistema Español de Informacíon sobre el Agua: http://hispagua.cedex.es/).
This territory has been investigated by geomorphological investigation, *in situ* geotechnical investigation and recently by the DInSAR technology. We focused on the investigation of the two deep-seated slides, to exploit the possibility to detect a relationship between change of the landslide displacement rate and climatic parameter. In particular, ERS and Envisat data for the period 1992-2000 and 2003-2010, respectively, in ascending and descending orbit, are available in the Framework Agreement between NextData Project and Terrafirma (the agreement was signed in July 2014).

Salar the Atacama test site

The Salar the Atacama are located in the Atacama Desert (Chilean Andes), one of the most hyperarid desert of the World. The Atacama Desert is a plateau located in South America, where a ground deformation (uplift) was revealed by space-borne InSAR analysis on salt lakes, named Salar (4000 – 5000 m asl. m). In that area, several flanks of inactive volcanoes show gravitational processes, also considered in the test site. We focused to investigate the variation of the uplift trend and the variation of the velocity of the gravitational slopes affecting the flanks of the volcanoes using the space-borne ground deformation time series already available at the CNR-IRPI of Turin. For this test site, SAR data of ERS-1/2 and Envisat ASAR satellite in descending orbit are available, for the time period from 1995 to 2010. In particular, mean velocity map (cm/y) and ground deformation time series for each point, elaborated by the SBAS technique, were generated using the G-POD service. The meteo-climatic parameters are available for this test site from the meteorological station of Rio Grande, Toconao experimental, Talabre, Camar, Socaire and Peine, 200 km north to the area considered, are average, minimum and maximum temperature, daily and monthly rainfall. These meteorological stations are part of Direcciõn General the Aguas, Ministero de Obras Pũblica, Gobierno de Chile (website: http://snia.dga.cl/BNAConsultas/) meteorological network, and the data collected are available for free download.

DInSAR processing by Esa's G-POD service

New SAR mean velocity maps and time series were prepared for two specific sector, using the ESA's Grid Processing On-Demand G-POD (http://gpod.eo.esa.int/) service. This service is based on SBAS-DInSAR technique (*Bernardino et al., 2002*) and the data are retrieved through the Virtual Archive 4 (http://eo-virtual-archive4.esa.int/, in the framework of Supersite initiative). G-POD is accessible through a user-friendly web-interface, and allows to set easily some useful input parameter for processing (e.g., selection of temporal range, baseline and coherence thresholds set, reference point selection). We focused on two test site opportunely selected: Grange Orgiera (Sampeyre municipality, Piedmont, Northern Italy), and the Valle d'Aosta Region (Northern Italy).

In Grange Orgiera test site (see section 2 for description), a rotational slide occurred in 2009, after the intense snow precipitations in winter and their snowmelt. The intense spring rainfall complicated the meteorological conditions that triggered the landslide. The analysis of the surface deformation, were obtained from SBAS technique by G-POD service, for Envisat ASAR composed 21 images in ascending orbit, from April 2005 to October 2010. The mean velocity map (Figure 3.3) shows the ground deformation distribution relative to this area, and for each point elaborated with the SABS technique the time series are available. The data have been compared with the Envisat data available on the "*Portale Cartografico Nazionale*", (web site: http://www.pcn.minambiente.it/viewer/) elaborated with the PInSAR technique. The ground deformation distribution and the mean velocity value, for the SAR data of each techniques, were comparable.

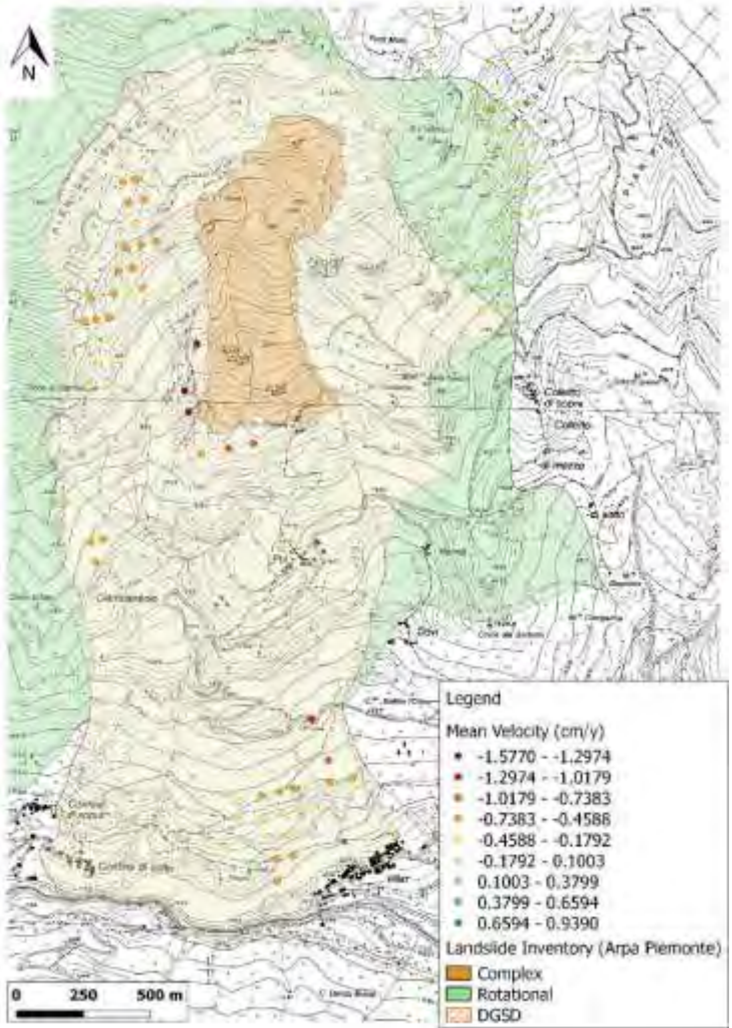


Figure 3.3 – Mean velocity map obtained by SBAS technique with G-POD service for the Grange Orgiera test site. For this process are considered the Envisat data, composed by 21 images in ascending orbit for the period from April 2005 to October 2010.

In test site of the Valle d'Aosta Region, we focused on the rock glaciers distribution, available on the Glaciers Inventory of the Valle d'Aosta Region (web site: http://catastoghiacciai.regione.vda.it/Ghiacciai/MainGhiacciai.html). These phenomena are the visible expression of presence of permafrost: in the Alps, permafrost distribution is related to climatic factors, like air temperature and solar radiation, and also to topographic and soil-specific factor (snow-cover). In order to analyse the ground deformation time series and their eventual trend related to these events have been processed with the SBAS technique, by G-POD service, 39 Envisat ASAR images in ascending orbit, for the period from June 2004 to October 2010. The mean velocity map obtained (Figure 3.4) shows the ground deformation distribution of most part of the region. In particular, was considered the sector between the Champorcher Valley and the principal Valley close to Châtillon (Figure 3.5), for which the SBAS point distribution have been compared with the rock glacier polygons. An example is presented in Figure 3.6A, for the Clapey Gerbioz rock glacier, where the deformation is concentrated at the right lobe of the rock glacier. The SAR data obtained by G-POD have been also compared with the SAR data available on "*Portale Cartografico Nazionale*", elaborated with PSInSAR technique for Envisat ASAR dataset (Figure 3.6B). Also for these SAR data, the deformation is concentrated at the right lobe of the rock glaciers. In general, the ground deformation distribution and the mean velocity value, for the SAR data of each techniques, were comparable.

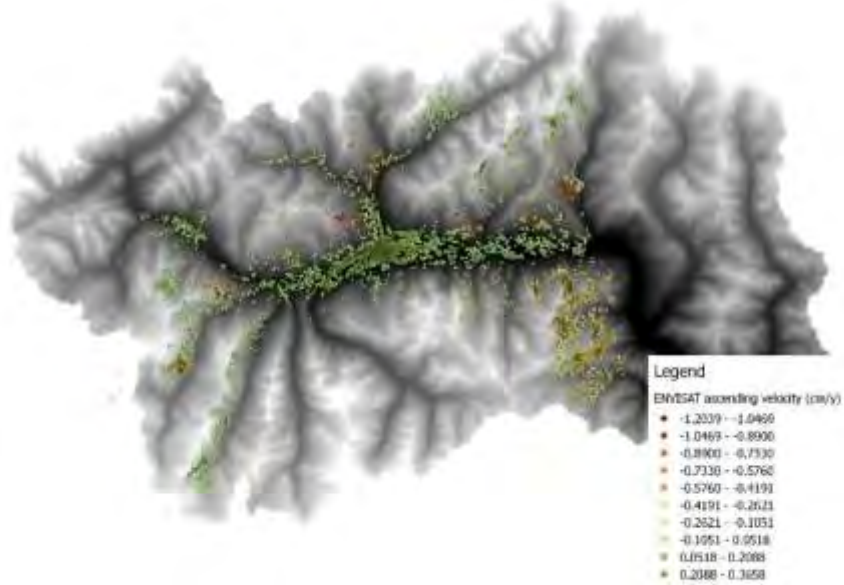


Figure 3.4 – Mean velocity map obtained by SBAS technique with G-POD service for the Valle d'Aosta Region test site. For this process are considered the Envisat data, composed by 39 images in ascending orbit for the period from June 2004 and October 2010.

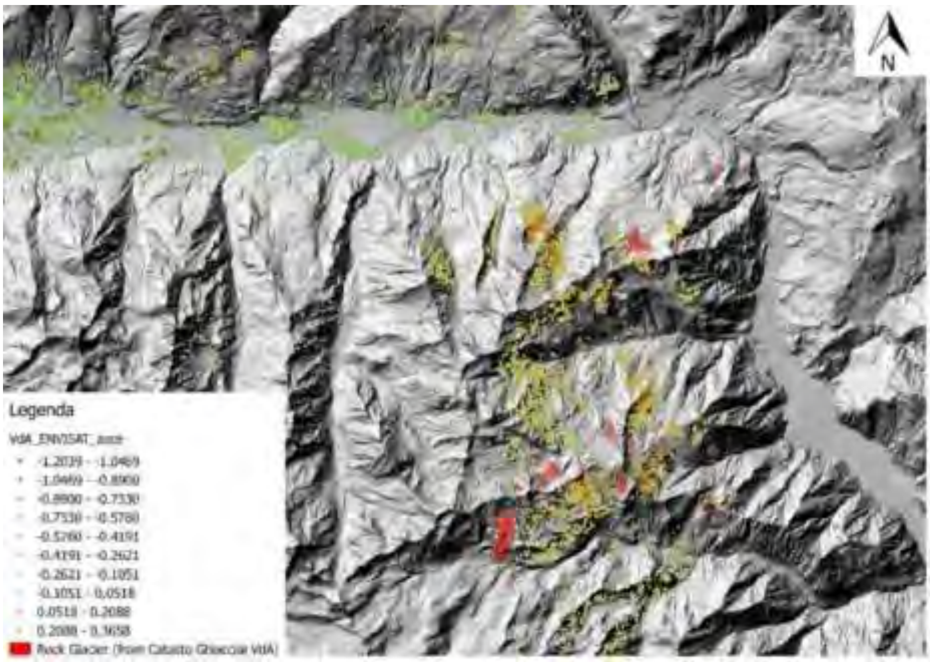


Figure 3.5 - Mean velocity map (cm/y) obtained by SBAS technique with G-POD service for part of the Valle d'Aosta Region, between Champorcher Valley and the principal Valley, close to Châtillon. The ground deformation distribution observed by SAR data elaboration has been compared with the rock glacier polygons (light red), available from the Glaciers Inventory of the Valle d'Aosta Region.

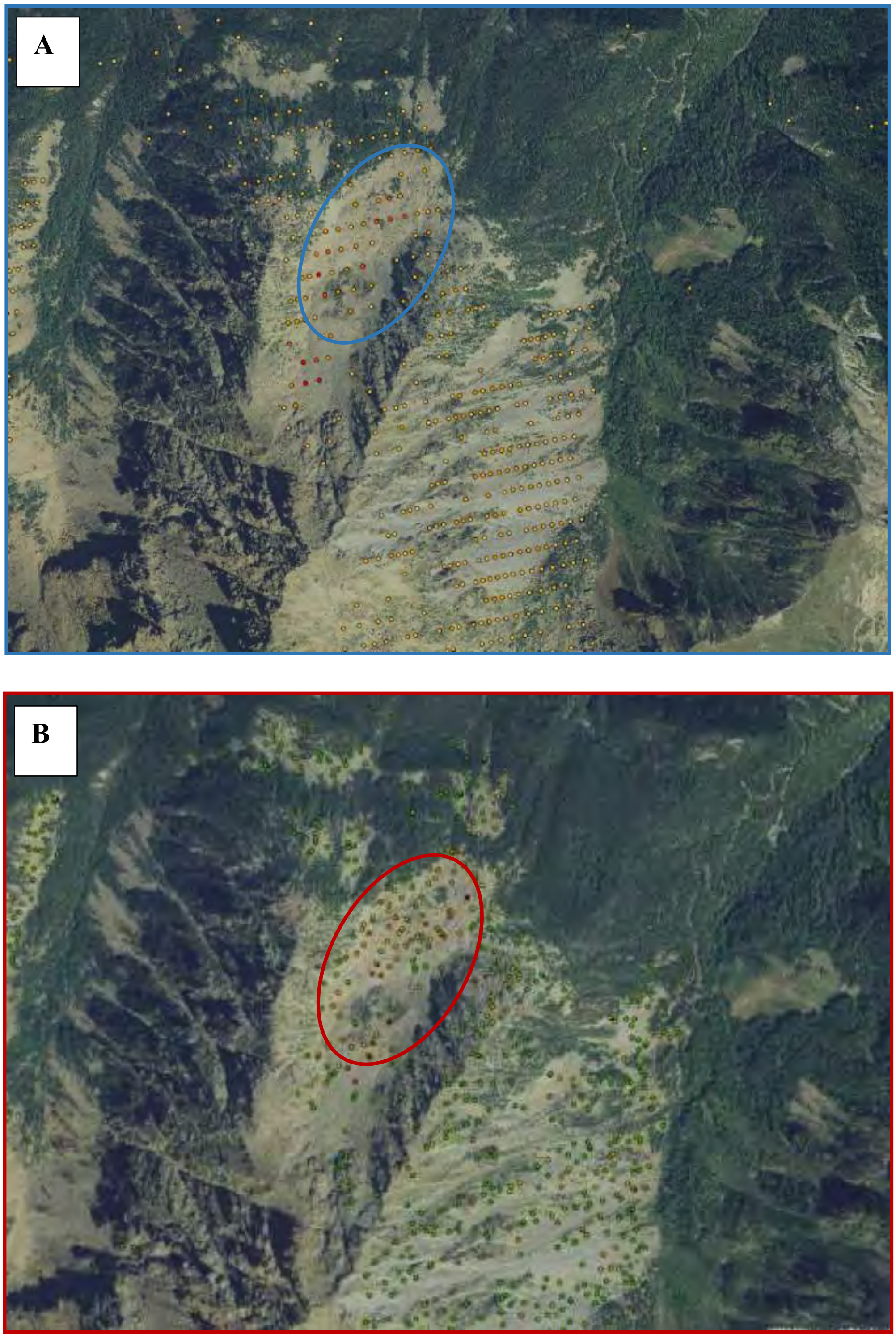


Figure 3.6 – La Clapey Gerbioz rock glacier; A) ground deformation distribution obtained with SBAS technique by G-POD service, for Envisat ASAR satellite composed by 39 images in ascending orbit, for the period 2004-2010; B) ground deformation distribution showed on "Portale Cartografico nazionale" obtained with PSInSAR technique for Envisat ASAR.

4 Description of available datasets

The DInSAR ground surface deformation time series available from the Apennines, Pyrenees and the meteorological/climatic data collected for the test area of Alps, Apennines and Pyrenees are listed and shortly illustrated as follows:

1) The DInSAR ground deformation map and associated time series available from the Apennines and Pyrenees, have been collected. The list of the data are shown in Table 4.1.

TEST SITE	SAR DATA	OBSERVED PERIOD
Apennines	Assisi_csk_disc_hr	02/12/2009 - 02/12/2012
	Umbria_csk_disc_lr	02/12/2009 - 02/12/2012
	Umbria_ersenvi_asc_hr	30/06/1995 - 25/09/2010
	Umbria_ersenvi_asc_lr	30/06/1995 - 25/09/2010
	Umbria_ersenvi_disc_hr	19/04/1992 - 12/11/2010
Pyrenees	Tena_Valley_ENVISAT_asc	04/10/2002 – 20/07/2007
	Tena_Valley_ENVISAT_desce	19/07/2001 - 06/09/2007
	Tena_Valley_ers_asc	22/06/1995 – 17/07/1998
	Tena_Valley_ERS_desce	26/04/1995 – 21/12/2000

Table 4.1 - List of the SAR processing derived data. The legend in th as following: csk = Cosmo SkyMed Satellite; ersenvi = ERS-1/2 and Envisat ASAR Satellite; asc = Ascending orbit; desce/disc = Descending orbit

2) The Apennines datasets were provided by CNR-IRPI (Perugia) and were produced in the contest of the DORIS project (European Project, FP7). The ground deformation and velocity maps and associated time series were prepared by applying the SBAS-DInSAR technique (*Berardino et al. 2002*) to different sets of radar images captured along descending/ascending orbits. Table 4.2 describes the characteristics of the radar images:

TEST SITE	SATELLITE	NUMBER OF IMAGES	OBSERVED PERIOD
Apennines	CosmoSky-Med desce (low and full resolution)	39	Dec 2009 – Feb 2012
	ERS-1/2 & Envisat asce (low and full resolution)	87	Jun 1995 – Sep 2010
	ERS-1/2 & Envisat desce (full resolution)	130	Apr 1992 – Nov 2010

Table 4.2 - Characteristics of the radar images.

3) The Tena Valley datasets were provided by Framework Agreement between NextData Project and Terrafirma (GEMS ESRIN/Contract No. 4000109669/13/I-AM). The SAR data are relative to ERS-1/2 and Envisat ASAR satellite, in ascending and descending orbit, for the period 1992-2000 and 2003-2010 respectively.

4) New SAR data have been processed using ESA's G-POD service for the Valle d'Aosta Region and the Sampeyre municipality. Envisat ASAR images in ascending orbit (39 images), in the period from June 2004 to October 2010 were processed for the territory of Val d'Aosta., Envisat ASAR images in ascending orbit (21 images), in the period from April 2005 to October 2010 were processed for the Sampeyre municipality, including the Grange Orgiera landslide.

5) The datasets have been uploaded in the "SAR" folder of the HAMMER FTP (Annex I), in the test sites: Ivancich_landslide, Valle_Aosta, Grange_Orgiera_Landslide). The datasets are in .xls and .shp formats. Furthermore, a QGIS Valmiera 2.2 (http://www.qgis.org/it/site/) project is available in the folder named "PROJECT".

6) The meteorological/climatic data for Alps, Apennines and Pyrenees territory was gathered from meteorological stations close to each test sites. The data are available for free download by the following regional authority and ministry:

- Arpa Piemonte website (http://www.regione.piemonte.it/ambiente/aria/rilev/ariaday/annali/meteorologici) for the Alpine test sites in Piemonte (Gardiola, Grange Orgiera, Montaldo di Cosola).
- Umbria Region website (http://www.idrografico.regione.umbria.it/annali/default.aspx) for the Apennines test site (Ivancich landslide).
- SAIH Ebro Confederación Hidrográfica del Ebro (Hispagua, Sistema Español de Informacíon sobre el Agua: http://hispagua.cedex.es/) for the Pyrenees test site (Tena Valley).

7) The FTP actually stores:

- the Ivancich meteo-climatic time series associated to their metadata.
- the information related to the type of meteorological data available and the website for the Alpine test sites data.

8) The differences between expected activities/results/deliverables and those, which have been actually performed, are:

- lack in collecting meteorological data for the test site of Andes (Atacama desert)
- meteorological data available for the test site of Pyrenees are subsequent to temporal interval covered by the ground deformation time series produced by SAR images and for this reason they are not reported in the FTP.

5 New test sites for new production of deformation maps and associated time series

A milestone of the project was devoted to select new study areas for which preparing ground deformation, velocity maps and time series exploiting SAR images. The milestone focused on two test sites, located in Valle d'Aosta Region (Italy). A very short synthesis of two the test sites is reported in the following.

1) First test site: Rock Glacier Becca de Salè 1 and 2. Valtournenche (Figure 5.1).

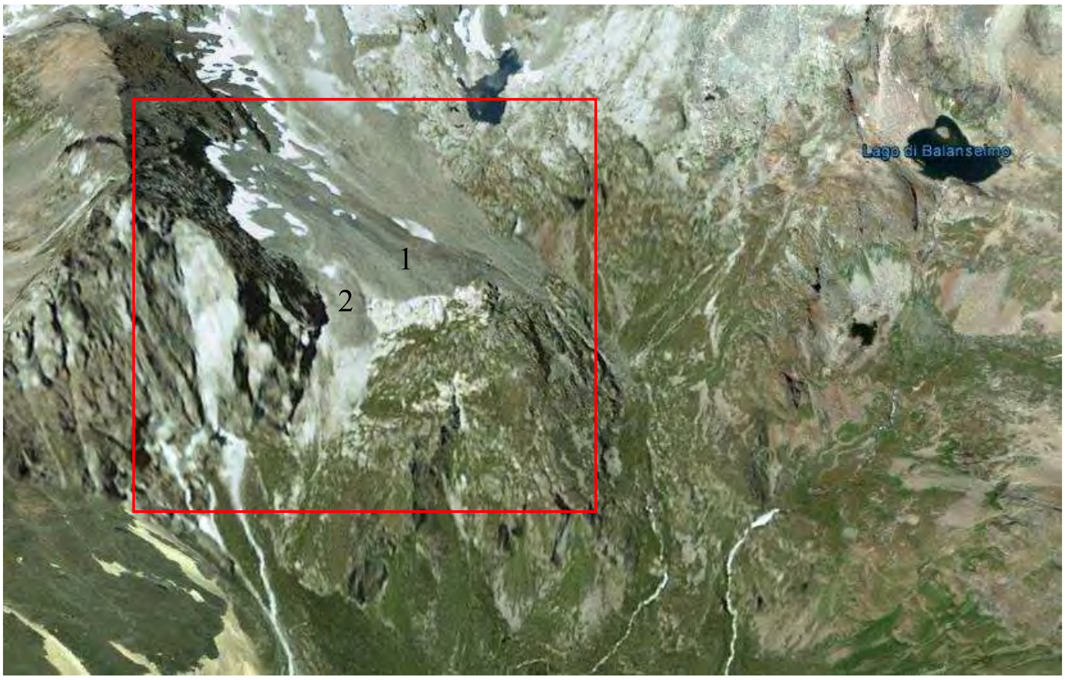


Figure 5.1 - Becca de Salè 1 and Becca de Salè 2. Rock glaciers located in Valtournenche.

Table 5.1 shows the main characteristics of the two rock glaciers located in Valtournenche.

	BECCA DE SALÈ 1	BECCA DE SALÈ 2
Min. Height(m)	2653	2544
Activity	Intact	Intact
Exposition	North	East
Length (m)	204	252
Width (m)	79	120
Surface (ha)	1.61	2.87
Slope (°)	21	30

Table 5.1 - Summary if the main characteristics of Becca de Salè 1 and Becca de sale 2.

The region of the two rock glaciers were identified inspecting results obtained exploiting the G-POD service (Figure 5.2, Figure 5.3). Figure 5.4 shows the distribution of the permafrost in the area. The location of the nearest meteorological station (Lago di Cignana) is shown in Figure 5.5. Lago di Cignana weather station, located at 2125 m (a.s.l.) of elevation close to the dam, is a manual station operating in the period from January 1990 to December 2012. The station includes: i) pluviometer; ii) thermometer; and iii) nivometer.

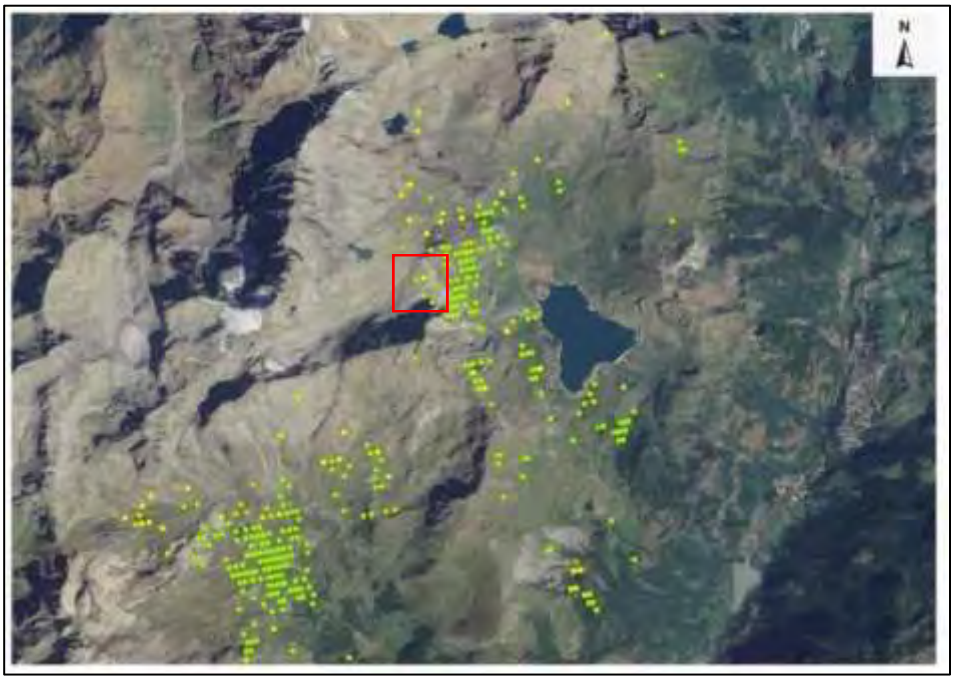


Figure 5.2 - Envisat ASAR, ascending orbit.

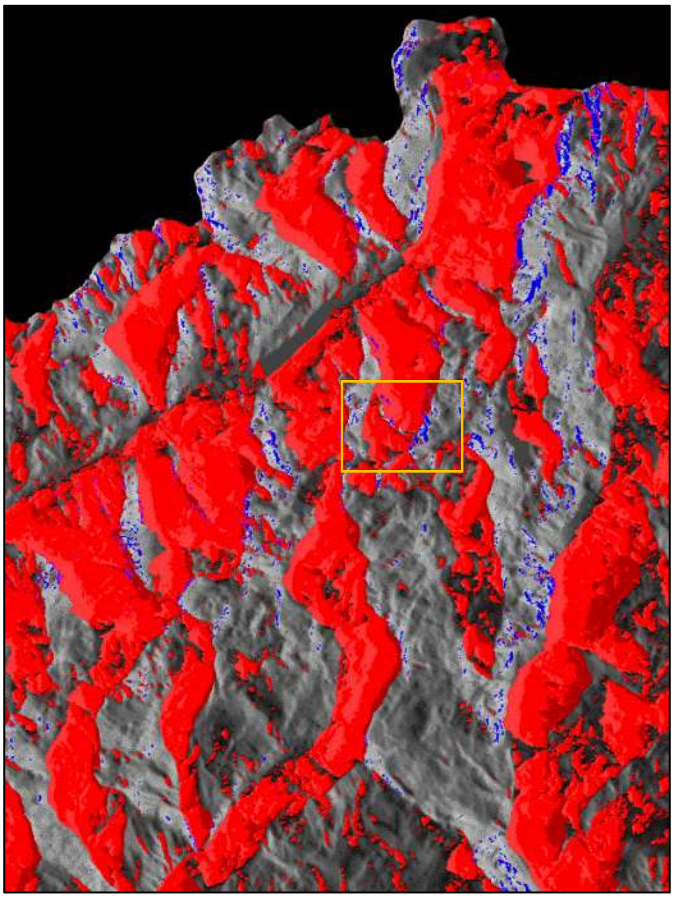


Figure 5.3 - Layover/Shadow Mask.

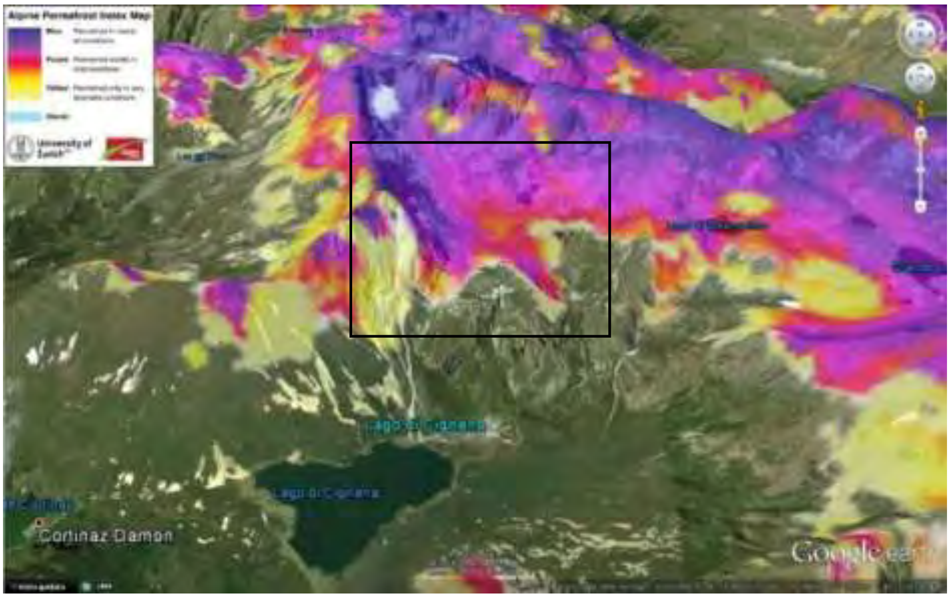


Figure 5.4 - Permafrost distribution.

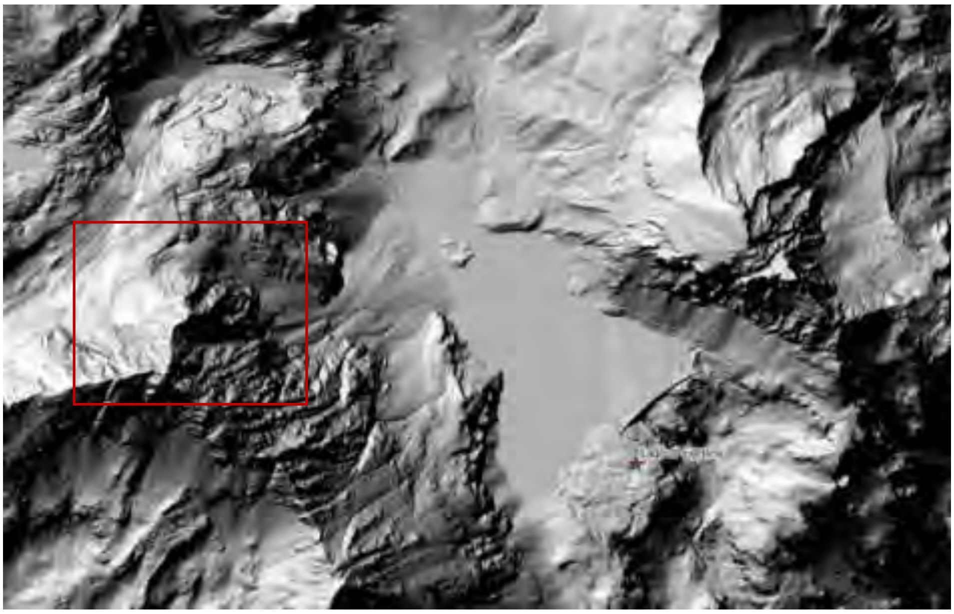


Figure 5.5 - Location of the Lago di Cignana meteorological station.

2) Second test site: Champorcher-Chambave (Bottom Valley) (Figure 5.1). The area of interest is characterize by the presence of rock glaciers. Figure 5.7 and Figure 5.8 show the distribution of the rock glaciers and of the permafrost in the area of interest. There aren't weather stations close to the area.

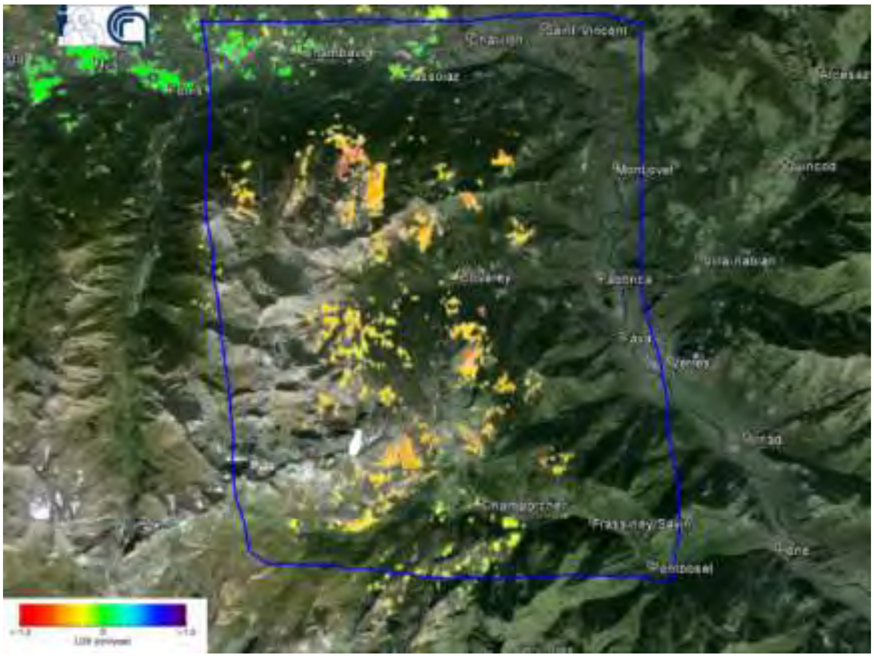


Figure 5.6 – Area of interest of Champorcher-Chambave.

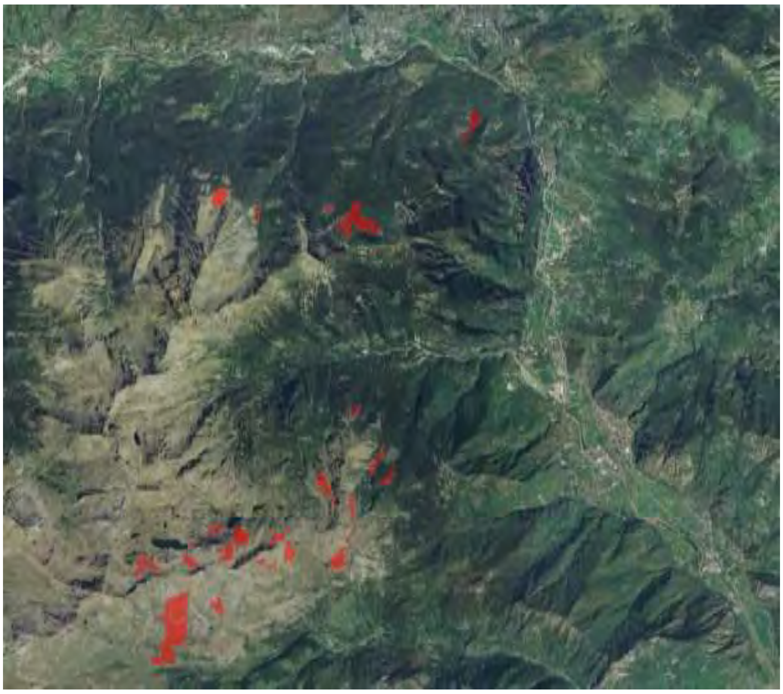


Figure 5.7 - Rock glaciers in the area of interest of Champorcher-Chambave.

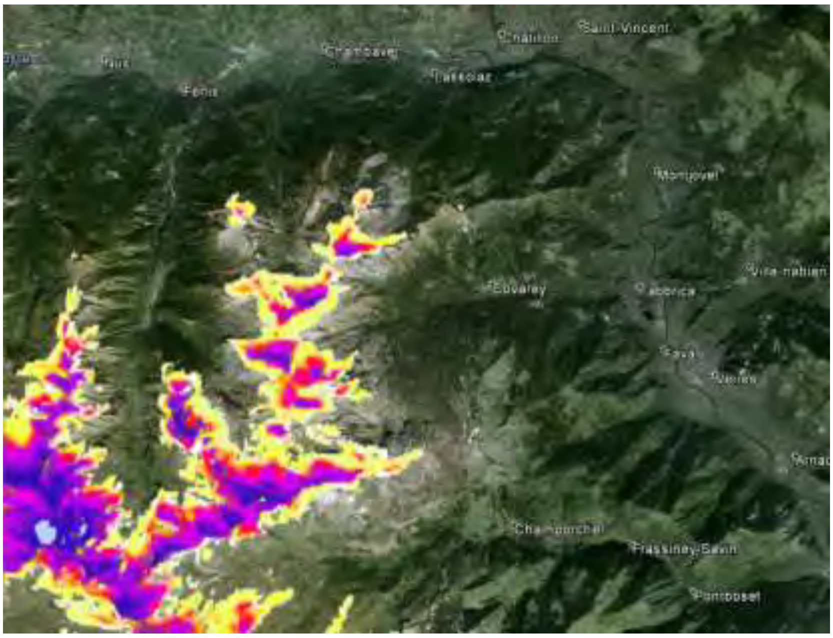


Figure 5.8 - Permafrost distribution in the area of interest of Champorcher-Chambave.

6 Production of new DInSAR ground deformation map and associated time series

New DInSAR ground deformation map and associated time series were produced by the CNR-IREA applying the SBAS approach.
The area of interest chosen is represented by the Valle d'Aosta region, located in the North-West of Italy, an alpine regions affected by a huge amount of landslides (reference: IFFI project catalogue (*Giardino and Ratto, 2007*). The SAR images were been processed by the CNR-IREA, in high resolution by the SBAS technique, for the Envisat ASAR data available in the Virtual Archive 4 (http://eo-virtual-archive4.esa.int/ in the framework of Supersite initiative), in ascending orbit (Figure 6.1).

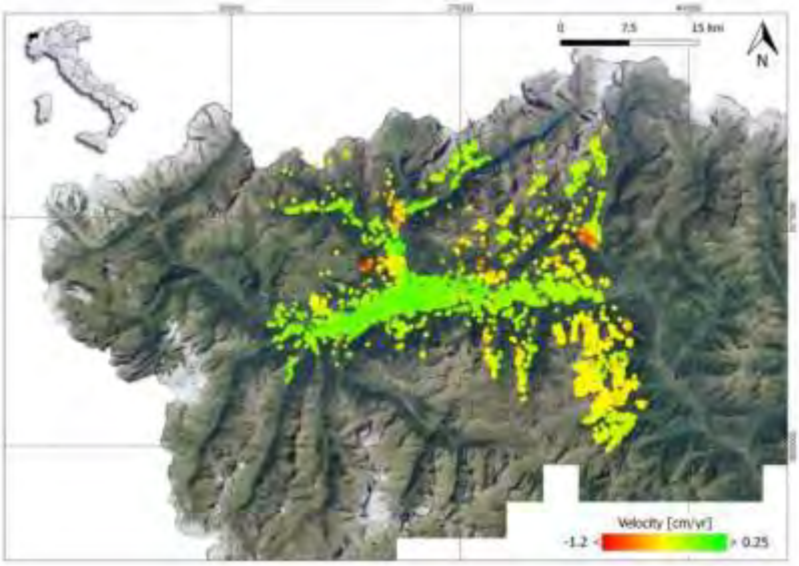


Figure 6.1 – Velocity map obtained by the SBAS technique in high resolution, for the area of interest represented by the Valle d'Aosta region, and processed by the CNR-IREA.

The technical parameters used in the processing phase were summarized in Table 6.1

VALLE D'AOSTA TEST SITES	
Satellite	Envisat ASAR
Orbit acquisition	Ascending
Frame	301
Number of SAR images	38
Observed period	June 2004 – October 2010

Table 6.1 – List of the parameters of the satellite SAR images used during the processing phase.

The DInSAR ground deformation map and associated time series obtained are organized in a .txt file that includes the following information:

- East and North UTM WGS84 coordinates (m)
- Temporal coherence value
- Mean displacement velocity (cm/yr)
- SAR coordinates (in pixel)

- Residual topography (m)
- Deformation time series (cm)

In the following deliverable will be report the metadata associated to this dataset of SAR images elaboration. All the data will be available on the Share GeoNetwork Geoportal (http://geonetwork.nextdataproject.it/geoexplorer/composer/#maps/3).
Furthermore new SAR data were been elaborated by the ESA's Grid Processing On-Demand (G-POD) service, in collaboration between CRN-IRPI and CNR-IREA.
G-POD is a user-friendly web-interface, elaborated by the CNR-IREA and the ESA-RSS, which represent an efficient tool to generate SAR data processing by the DInSAR-SBAS technique (*Berardino et al., 2002)*, elaborating RAW data by the entire SBAS chain until the generation of ground displacement time series and velocity map correlated. G-POD service was used for the following site test (Table 6.2).

STUDY AREA	SENSOR	MULTI-TEMPORAL ANALYSIS PARAMETERS	
Valle d'Aosta Region (North-West Italy)	Envisat ASAR data	Number of Images	38
		Track number	301
		Temporal range	June 2004 - October 2010
		Max. Perpendicular Baseline (m)	400
		Max. Temporal Baseline (days)	1500
		Ground Pixel Dimension (m)	40
		Coherence Threshold	0.7
Grange Orgiera (Sampeyre, Piedmont Region)	Envisat ASAR data	Number of Images	21
		Track number	301
		Temporal range	April 2005 - October 2010
		Max. Perpendicular Baseline (m)	400

		Max. Temporal Baseline (days)	1500
		Ground Pixel Dimension (m)	80
		Coherence Threshold	0.7
Salar the Atacama (Atacama Desert, Chile)	Envisat ASAR data	Number of Images	18
		Track number	282
		Temporal range	March 2003 - September 2009
		Max. Perpendicular Baseline (m)	400
		Max. Temporal Baseline (days)	1500
		Ground Pixel Dimension (m)	80
		Coherence Threshold	0.8

Table 6.2 - List of the parameter of the SAR images used in G-POD.

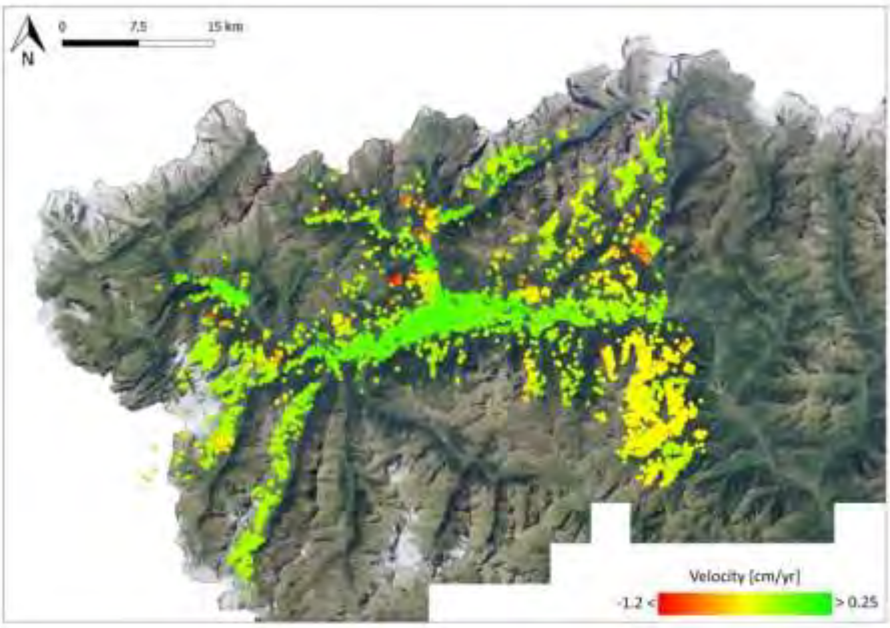


Figure 6.2 – Velocity map obtained by the Envisat images processing by the SBAS technique, for the area of interest represented by the Valle d'Aosta region (North-West Italy), and processed by G-POD service.

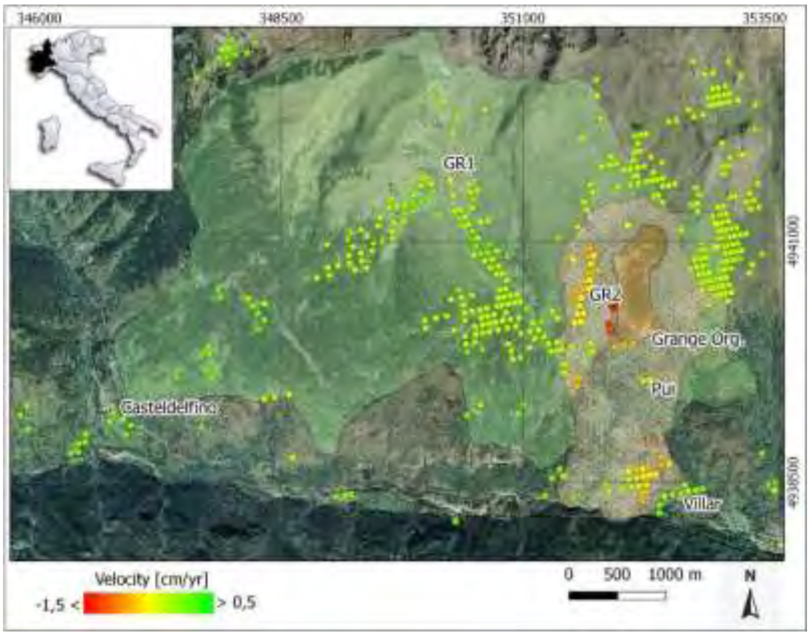


Figure 6.3 - Velocity map obtained by the Envisat images processing by SBAS technique, for the area of interest represented by the Grange Orgiera landslide (Sampeyre, Piedmont region, North-West Italy), and processed by G-POD service.

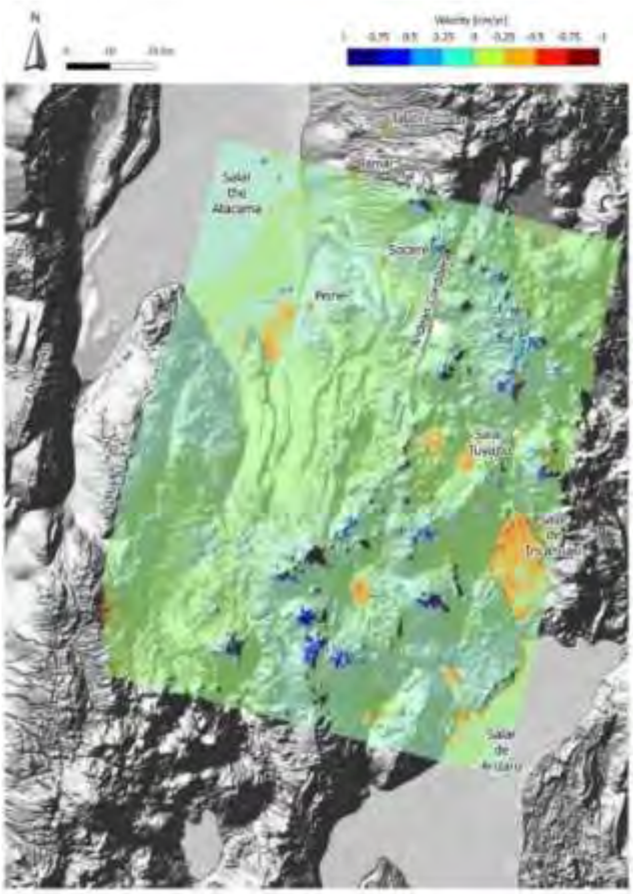


Figure 6.4 - Velocity map obtained by Envisat images processing by the SBAS technique, for the area of interest represented by the Salar the Atacama (Atacama Desert, Chile), and processed by G-POD service.

Also in this case, as the HR one, the results obtained are organized in a .txt file that includes:

- East and North UTM WGS84 coordinates (m)
- Temporal coherence value

- Mean displacement velocity (cm/yr)
- SAR coordinates (in pixel)
- Residual topography (m)
- Deformation time series (cm)

In the following (section 7) will be described the metadata associated to this dataset of SAR images elaboration.
For the Valle d'Aosta test site were obtained (Figure 6.2):

- VdA_Envisat_ASAR_asce_HR (shapefile and .txt format)
- VdA_Envisat_ASAR_asce_LR (shapefile and .txt format)

For the Grange Orgiera test site was obtained (Figure 6.3):

- Grange_Envisat_ASAR_asce_LR (shapefile and .txt format)

For the Salar de Atacama test site was obtained (Figure 6.4):

- Atacama_Envisat_ASAR_asce_LR (shapefile and .txt format)

7 Preparation of a web-portal

The data collected and newly produced in the period March 2014 - November 2015, were organized in the NextData Share GeoNetwork web-portal (http://geonetwork.nextdataproject.it/) (Figure 7.1).

Figure 7.1 – NextData Share GeoNetwork web-portal

All the data of each test site considered in the HAMMER project, both for *in-situ* ground monitoring, and for the SAR data processing, were organize in .csv format. Most of the data are available to free download, and can be represented by graphs directly in the Share GeoNetwork portal (Figure 7.2).

Figure 7.2 – Share GeoNetwork interface used to graph the data collected for each test sites of the HAMMER project.

Furthermore, a metadata of all the test sites, all monitoring network and data associated, and all SAR data elaborated, were been done and stored in the Share GeoNetwork web-portal (Figure 7.3).

Figure 7.3 – Share GeoNetwork interface for edit all the metadata created for each test sites and their data associated of the Hammer project.

A parent-child structure were organized for the data, and for each test site considered (Figure 7.4). The metadata organization and instruction respect the INSPIRE directive and structure. Overall were generated a metadata for the HAMMER project, with a brief description of the main goal of the project, seven metadata for each test site considered in the project, and several child metadata for all the data collected or generated for each test sites. The structure is organized as the following scheme:

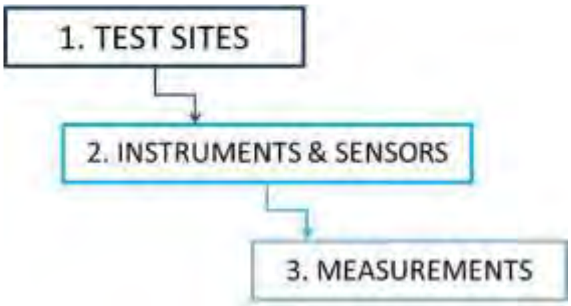


Figure 7.4 – Representation of the "parent-child" structure adopted for the organization of the datasets and metadata.

In total, there are seven test site:

- Grange Orgiera landslide (Piedmont, Northern Italy)
- Gardiola landslide (Piedmont, Northern Italy)
- Montaldo di Cosola landslide (Piedmont, Northern Italy)
- Ivancich landslide (Umbria, Central Italy)
- Valle d'Aosta region (North-East Italy)
- El Portalet (Central Spanish Pyrenees)
- Salar de Atacama (Atacama Desert, Chile)

The children metadata of Test Sites metadata are "Instrument and Sensors"; in particular, there are two type of metadata:

- In-situ monitoring networks

- SAR data analysis: ERS-1/2 satellite, Envisat ASAR satellite, COSMO SkyMed satellite.

Relative to the *in-situ* monitoring network are present:

- Topographic Monitoring Network (Grange Orgiera and Gardiola TS)
- Inclinometer Network (Montaldo di Cosola and Ivancich TS)

Relative to the SAR data analysis are present:

- ERS-1/2 satellite data (Ivancich and El Portalet TS)
- Envisat ASAR satellite (Grange Orgiera, Valle d'Aosta, Ivancich, and Salar de Atacama TS)
- COSMO SkyMed satellite (Ivancich TS)

The last hierarchical children metadata is represented by the data relative to every single in-situ monitoring network or SAR data analysis (Figure 7.5).

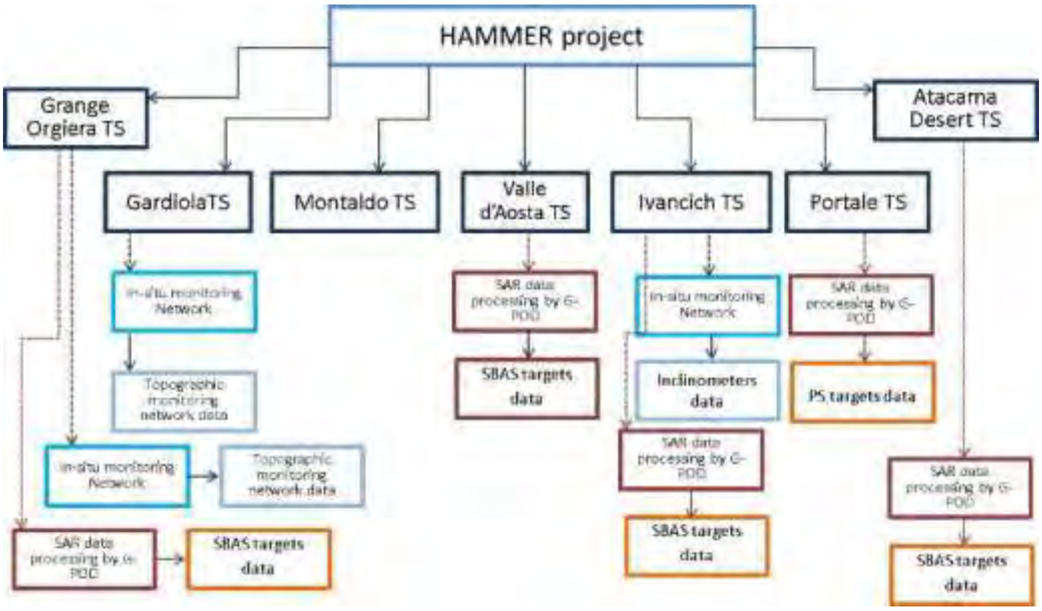
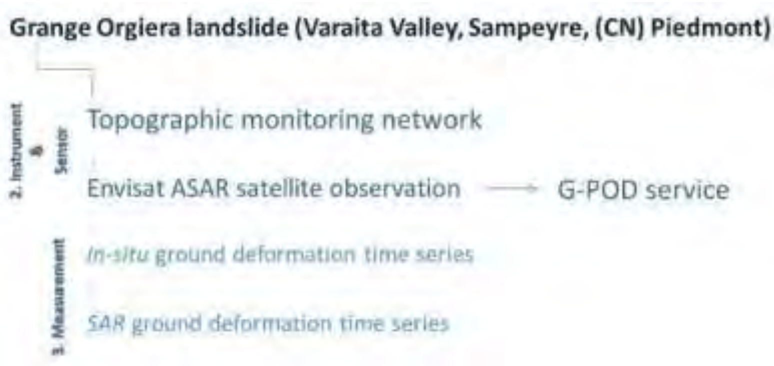


Figure 7.5 – Metadata parent-child organization of all the data collected and elaborated in the framework of the HAMMER project, and stored in the Share GeoNetwork web-portal.

Grange Orgiera test site

The Grange Orgiera test site metadata are organized in the hierarchical structure presented below:

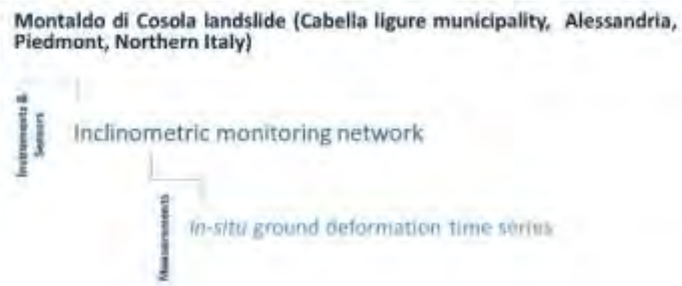


Gardiola test site

The Gardiola test site metadata are organized in the hierarchical structure presented below:

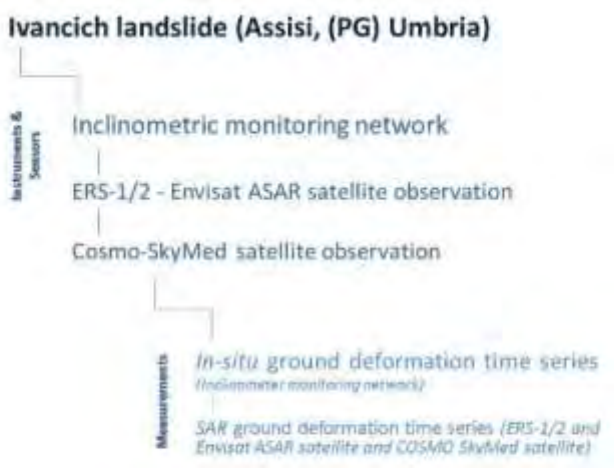
Montaldo di Cosola test site

The Montaldo di Cosola test site metadata are organized in the hierarchical structure presented below.



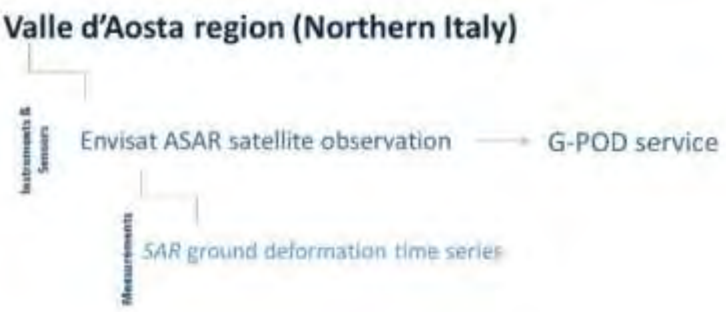
Ivancich test site

The Ivancich test site metadata are organized in the hierarchical structure presented below.



Valle d'Aosta region test site

The Valle d'Aosta region test site metadata are organized in the hierarchical structure presented below:



El Portalet test site

The El Portalet test site metadata are organized in the hierarchical structure presented below:

Salar de Atacama test site

The Salar de Atacama test site metadata are organized in the hierarchical structure presented below:

All the data related to each metadata are available in the Share GeoNetwork Portal, and some also available for free download. In particular are available the data of:

- Grange Orgiera Topographic monitoring network (Download and display in Share GeoNetwork portal)
- Grange Orgiera Envisat ASAR (ascending) data (display in Share GeoNetwork portal)
- Gardiola Topographic monitoring Network (Download and display in Share GeoNetwork portal)
- Ivancich Inclinometer Network (Download and display in Share GeoNetwork portal)
- Ivancich ersenvi data (asce+desce) in high resolution (Download and display in Share GeoNetwork portal)

- Ivancich ersenvi (asc) in low resolution (Download and display in Share GeoNetwork portal)
- Ivancich Cosmo SkyMed (desce) high and low resolution (Download and display in Share GeoNetwork portal)
- Tena Valley Envisat (asce+desce) (Download and display in Share GeoNetwork portal)
- Tena Valley ERS (asce+desce) (Download and display in Share GeoNetwork portal)
- Valle d'Aosta region Envisat (asce) high and low resolution (display in Share GeoNetwork portal)
- Salar de Atacama Envisat (asce) (display in Share GeoNetwork portal)

During the period 2017 and 2018 according to the modification NextData project the metadata and the datasets related to the Italian test sites have been re-organized to be moved to the Final Geonetwork platform that is described in the deliverable 2.1.A delivered by the WP 2.1.

8 Main Scientific results

Introduction

The last two years of the project were dedicated to analyze the possibility to produce mean velocity maps and ground deformation time series obtained exploiting satellite SAR images applying the DInSAR technique in mountain region glacial environments. Periglacial, paraglacial and proglacial processes and systems play an important role in high mountain landscapes evolution (*Knight and Harrison 2009*; *Carrivick and Heckmann 2017*). In alpine regions, the definition of ground surface displacements is a key issue for the identification of active geomorphological processes, and their evolution. In the last decades, several consolidated monitoring techniques were exploited for periglacial (*Kääb et al. 2003*) and glacial processes *(Giordan et al. 2016*). The advanced remote sensing techniques, as Differential Synthetic Aperture Radar Interferometry (DInSAR) *(Ferretti et al. 2001; Berardino et al. 2002; Hooper et al. 2004*), have upgraded the information available on ground deformation generating ground velocity maps and long time series of ground deformation. The current increase in multi-temporal acquisition availability (e.g. ERS-1/2, ENVISAT, RADARSAT-1, Sentinel-1) ensures an extensive spatial and temporal coverage, able to provide information in different physiographic and geographic areas, also for those areas with limited or difficult assess. However, some intrinsic limitation are to be considered: i) coherence loss due to large revisit time; ii) phase decorrelation due to large or rapid displacement; iii) line-of-site (LOS) measurements only; iv) atmospheric phase screen (APS), amplified in high mountain gradient; v) temporal coherence loss due to snow cover. Furthermore, high mountain landscape entails some additionally challenges i.e. high topographic gradients associated with the complex orography, abundant vegetation affecting temporal correlation of the SAR signal, and unsuitable valley flanks orientations relative to the SAR view angle *(Colesanti and Wasowski 2006*; *Cigna et al. 2013*). Some recent tools i.e. ESA Grid-based operational environment support the SAR data processing by the unsupervised implementation of the Parallel-SBAS (P-SBAS) algorithm *(Casu et al. 2014*). This web-interface tool performs the full SBAS-DInSAR processing chain in an unsupervised fashion from the raw SAR images to the generation of ground velocity maps and the related time series (*De Luca et al. 2015*). A combination of diverse SAR images acquisition (e.g. ERS-1/2, ENVISAT-ASAR, Sentinel1) and an effective comparison of data also obtained by different DInSAR technique, was applied to the Aosta Valley region (northwestern Italy), a study area characterized by the presence of many active geomorphological processes (e.g. glaciers, rock glaciers).

The Italian **Western** *Alps*

The DInSAr techniques were applied in the territory of north-western Italy in Aosta Valley region, at elevation from about 400 m a.s.l. to over 4800 m a.s.l. The Aosta Valley glaciers represent one-third of the Italian glaciers *(Diolaiuti et al. 2012*), and cover about 5% of the regional territory (Catasto Ghiacciai - http://catastoghiacciai.regione.vda.it/Ghiacciai/MainGhiacciai.html). Generally, the alpine permafrost shows a fragmented distribution, with a typical creep deformation related to the permafrost temperature (*Delaloye et al. 2010*). Rock glaciers (RGs), which occupy about 2% of the regional territory (*Guglielmin and Smiraglia 1997*) represent a common periglacial landform in the region.

DInSAR technique application

Mean velocity maps and ground deformation time series have been generated taking advantage of the G-POD service *(Cignetti et al. 2016*) based on SAR images processing. The Envisat ASAR available data have been processed by the P-SBAS technique (*Casu et al. 2014*), both in ascending and descending orbits. The period of observation ranges from June 2004 and October 2010 for the ascending orbit and from September 2004 and October 2010 for the descending orbit.
The available tracks cover most of the regional territory, excluding only the eastern part of the region (about 10%) (Figure 8.1).

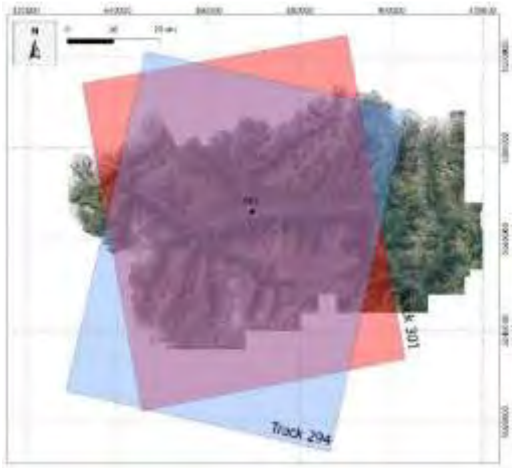


Figure 8.1 – Map of the AVr (in light grey) respect to the ENVISAT ASAR track extent for both ascending (Track n°301) and descending (Track n° 294) orbit. The black dot represents the reference point location.

To obtain reliable and favorable results, we performed an informed choice of SAR images, based on the comparison with the available meteorological data (i.e. height of snow, rainfall picks). By this way, we tried to minimize the temporal decorrelation effects mainly related to the snow cover, preserving the largest number of SAR acquisitions.

AVr results

The achieved results are collected and organized in a Geographic Informatics System *(QGIS Development Team 2009*) environment. The coherent targets (33086 for ascending orbit, 20317 for descending orbit) cover most of the regional territory, covering a time interval of about 6 years (Figure 8.2). The highest portion of the lateral valley has been excluded from the coverage because these sectors corresponding to the glacial areas, affected by the decorrelation effect due to the large displacement of glaciers.

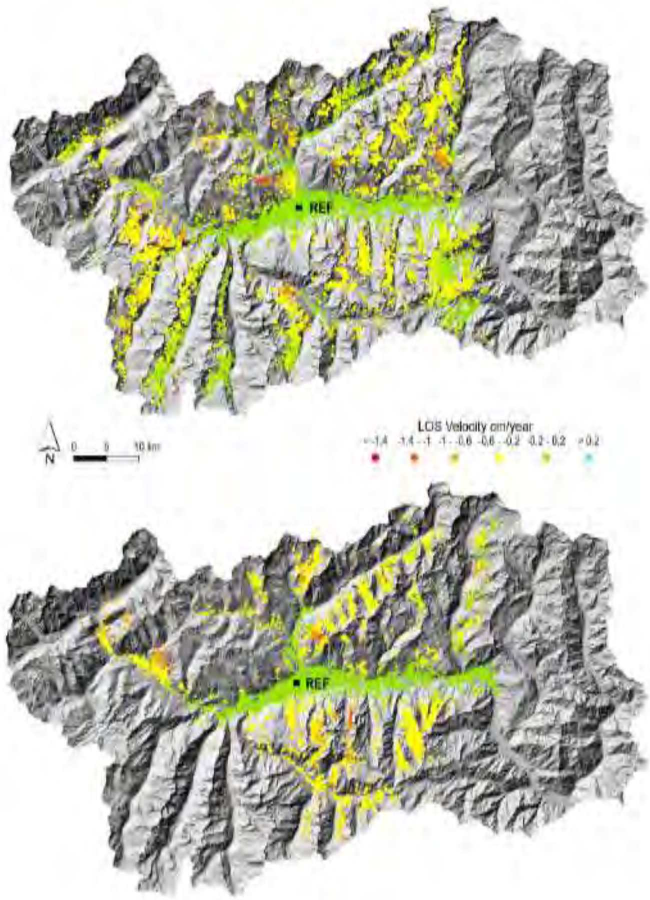


Figure 8.2 – Mean velocity maps measured along the satellite LOS for the Envisat dataset: a) Ascending orbit data, b) Descending orbit data.

The number of RGs covered by the SBAS targets are 123 (on 937 in total) for ascending orbit, and 65 for descending orbit. In the case of RGs, we analyzed all the active, inactive and relict forms. Generally, the mean velocity maps analysis highlights good agreement with the state of activities of the inventoried RGs. Specifically, the time series provide the analyze eventual RGs activation and/or seasonal deformations over the observed period (Figure 8.3).

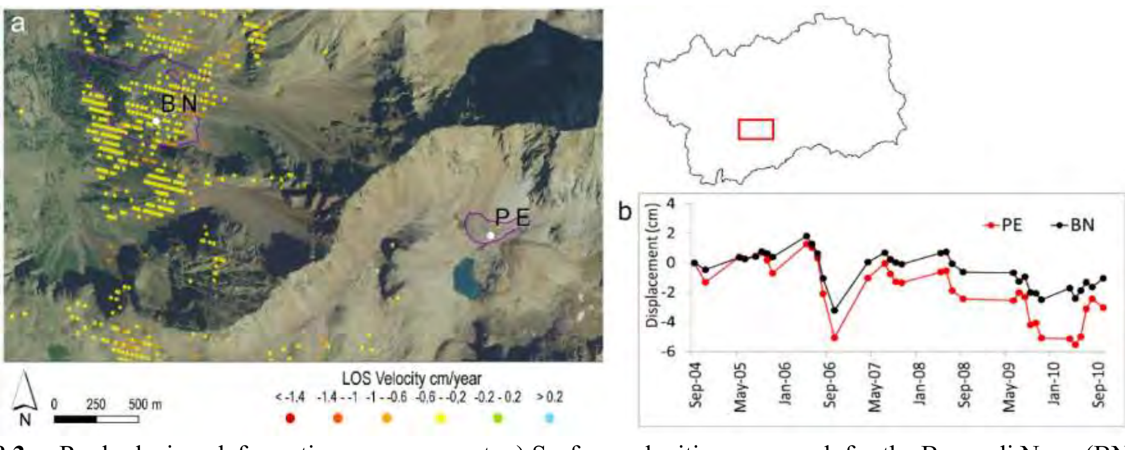


Figure 8.3 – Rock glaciers deformation measurement: a) Surface velocities measured for the Becca di Nona (BN), and Petite Emilius (PE) rgs, in descending orbit; b) time series corresponding to the targets signed by white dots in the above map. The time series dysplay a general constant deformmation range, with a sort of acceleration during the summer to early autumn months, with maximum displacement of -1.4 cm from September 2004 to October 2010.

Data validation

In order to validate the obtained results, we compare the SBAS targets with the Permanent Scatterers available on the "*Portale Cartografico Nazionale*". The PSs have been processes by the TRE Europa using PSInSAR techniques as part of a National Project (http://www.pcn.minambiente.it/mattm/progetto-piano-straordinario-di-telerilevamento/). The data are not downloadable, so we manually extract the value of the time series reported in table format within the portal. Firstly, we analysed a stable area with high coherent targets (Figure 8.4). Then we compared a numer of targets presenting ground deformation in correspondance of a RG (Figure 8.5). A good agreement between the selected SBAS targets and PSs surface deformation rates have been observed, and a comparable distribution con be observed.

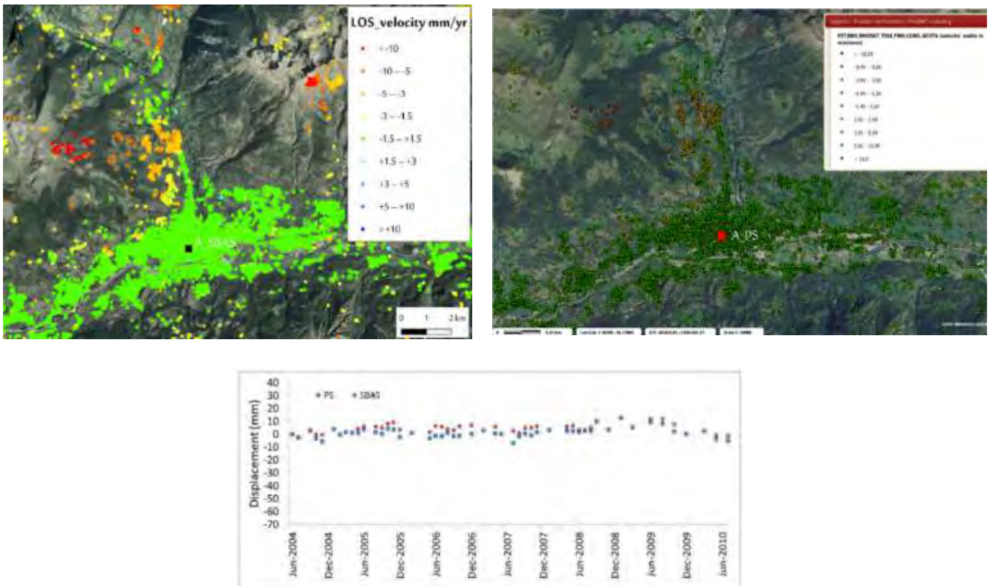


Figure 8.4 – GPOD results validation: a) comparison between the ENVISAT ascending SBAS resutls, and the PSInSAR results over the Aosta municipality.

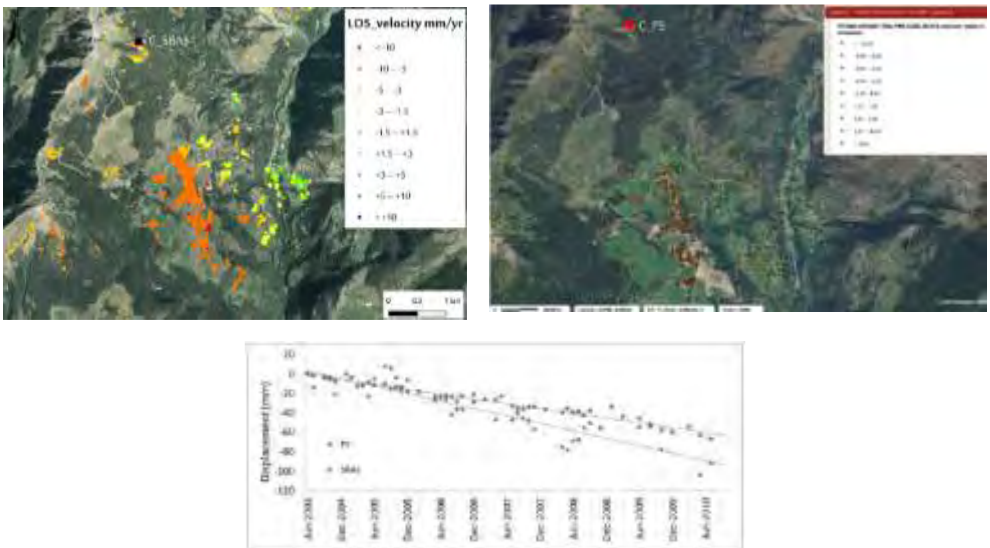


Figure 8.5 – GPOD results validation: a) comparison between the ENVISAT ascending SBAS resutls, and the PSInSAR results over the Mont Meabèrg (Valtourenenche valley).

Conclusion

DInSAR techniques allow to generate long-term surface deformation time series and surface velocities maps. These techniques are very useful also for hardly accessible areas as high-mountain regions. Deformation time series are an important instrument for the identification and characterization of active gravitational processes. The use of these data is well-known for landslides monitoring, but is also adopted for glaciers, paraglacial, and periglacial processes. We developed a methodology taking advantage of the ESA G-POD service (*Cignetti et al. 2016*) focusing our attention on the use of free SAR images processing. This approach represents an important application of available ENVISAT ASAR dataset, and it could be implemented with Sentinel-1 constellation. The improvement in the revisiting time of Sentinel-1 should favour the characterization of kinematic behavior of paralgacial and periglacial processes that tipically present a seasonall trend.

9 REFERENCE

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10 PROJECT MEETINGS, CONFERENCES AND PUBLICATIONS

Project meetings

- HAMMER internal kick-off meeting, 7 March 2014.
- NextData general meeting, Aula Bisogno, CNR, P.le Aldo Moro 7, Roma, 3-4 June 2014.
- NextData general meeting, Sala Giacomello, CNR, P.le Aldo Moro, Roma, 24 January 2017.
- NextData Archives Internal Meeting, aula D del Dipartimento di Scienze del sistema Terra e Tecnologie per l'Ambiente, CNR, P.le Aldo Moro, Roma, 3 March 2017.
- NextData general meeting, CNR, Area Ricerca CNR, Bologna, 7 March 2018.
- NextData Archives Internal Meeting, aula D del Dipartimento di Scienze del sistema Terra e Tecnologie per l'Ambiente, CNR, P.le Aldo Moro, Roma, 11 May 2018.

Conferences

- SGI-SIMP Congress 10-12 September 2014 Milan (National conference) – Abstract & poster, S5 session - Climate change and the Earth System: understanding the past, analyzing the present and predicting future scenarios: Allasia P., Ardizzone F., Cignetti M., Giordano D., Guzzetti F., Manconi A. & Manunta M. "Ground deformation analysis exploiting surface and sub-surface displacement measurements".
- FRINGE 2015, Workshop 23-25 March 2015 Frascati (International conference) – Abstract & poster - Manconi, Andrea; Cignetti, Martina; Ardizzone, Francesca; Giordan, Daniele; Allasia, Paolo; De Luca, Claudio; Manunta, Michele; Casu, Francesco. "ESA G-POD service: new potential for the analysis and interpretation of surface deformation in mountain regions by exploiting the Parallel-SBAS technique".
- SISC 2018 Annual Conference 17-19 ottobre Venezia Mestre (National conference) – Abstract & poster - Paolo Allasia, Francesca Ardizzone, Daniele Giordan, Martina Cignetti, Michele Manunta. "Remote sensing applications for analysing the temporal behaviour of periglacial and paraglacial".
- EGU 2015, General Assembly 12-17 April 2015 Vienna (International conference) - Abstract & oral - Andrea Manconi, Martina Cignetti, Francesca Ardizzone, Daniele Giordan, Paolo Allasia, Claudio De Luca, Michele Manunta, and Francesco Casu. "Taking advantage of the ESA G-POD service to study deformation processes in mountain areas".

Publications

- Manconi M., Cignetti M., Ardizzone F., Giordan D., Allasia P., De Luca C., Manunta M., Casu F. (2015) Taking advantage of the ESA G-POD service to study deformation processes in mountain areas Geophysical Research Abstract, EGU European Geosciences Union) General Assembly 2015, Vienna, Austria.
- Allasia P., Ardizzone F., Cignetti M., Giordan D., Guzzetti F., Manconi A. & Manunta M (2014) Ground deformation analysis exploiting surface and sub-surface displacement measurements. Rendiconti online Società Geologica Italiana. Suppl. N. 1 al Vol. 31. Pag: 83.
- Cignetti, M., Manconi, A., Manunta, M., Giordan, D., De Luca, C., Allasia, P., & Ardizzone, F. (2016). Taking Advantage of the ESA G-POD Service to Study Ground Deformation Processes in High Mountain Areas: A Valle d'Aosta Case Study, Northern Italy.Remote Sensing, 8(10), 852.
- Paolo Allasia, Francesca Ardizzone, Daniele Giordan, Martina Cignetti, Michele Manunta (2018). Remote sensing applications for monitoring of paraglacial processes. In Next Data final volume (in preparation).