IBIS
Image by Interferometric Survey

A Ground Based Microwave Interferometer with Imaging Capabilities for the Remote Measurement of Displacements and Vibrations

IDS INGEGNERIA DEI SISTEMI

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IBIS System remarks

IBIS system is a Stepped-Frequency Continuous Wave (SF-CW) coherent radar with SAR and Interferometric capabilities, dedicated to remote monitoring of static or dynamic displacement such as terrain deformation or structure vibrations.

IBIS – L configuration

IBIS – S configuration

IBIS-S System: HW description

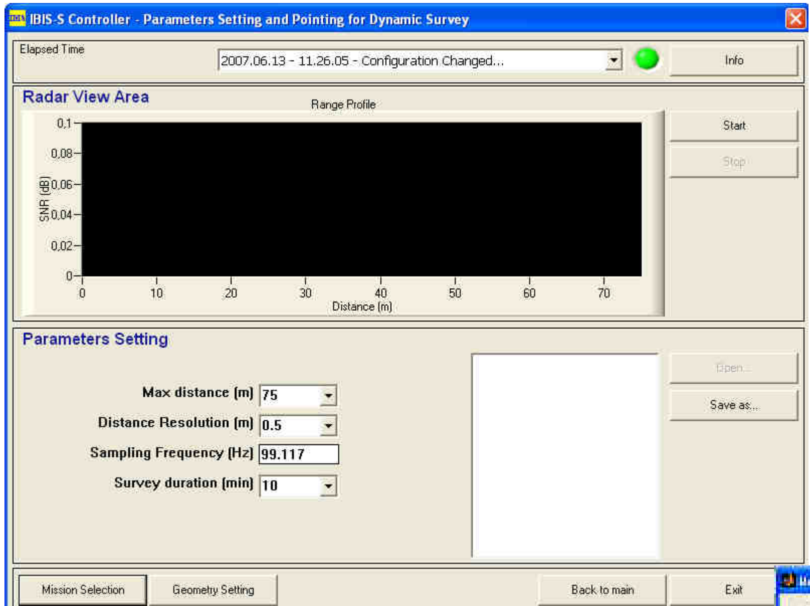
Sensor unit:
- Signal Transmitter and Receiver
- View finder and horn antenna equipped

Tripod and 3-D rotating head:
- Aluminium tripod:
  - weight: 4.3Kg;
  - height range: [43;188]cm
- 3-D rotating head:
  - weight: 1,9 kg;
  - Azimut rotation range : [0;360] deg;
  - Elevation rotation range: [-90;+ 90]deg;

Processing unit:
- PC with management SW

Power supply unit:
- 2 batteries 12VDC 12Ah

IBIS-S System: SW description



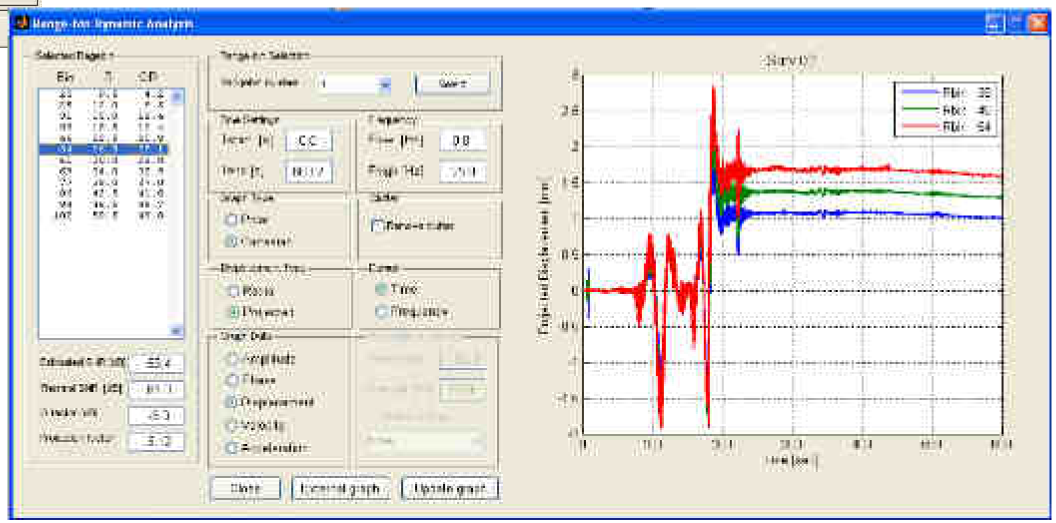
Management SW - IBIS-S Controller:

- Parameter setting
  - First result rendering

Post-processing SW – IBISDV:

Detailed off-line data processing:

- Displacement time histories
- Frequency analysis



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IBIS-L System: HW description

Sensor unit:
- Signal Transmitter and Receiver
- Synchronism manager between frequency sweep and sensor position
- View finder and horn antenna equipped

Linear Scanner :
- 2 m track
- Step-by-step motor
- Position Encoder

Processing unit:
- PC with management SW
- Parameter setting:
  - signal generator
  - signal acquisition
  - SAR scan
  - First result rendering

Power supply unit:
- 2 batteries 12VDC 130 Ah
- 12VDC input from photovoltaic solar cells
- 220VAC input

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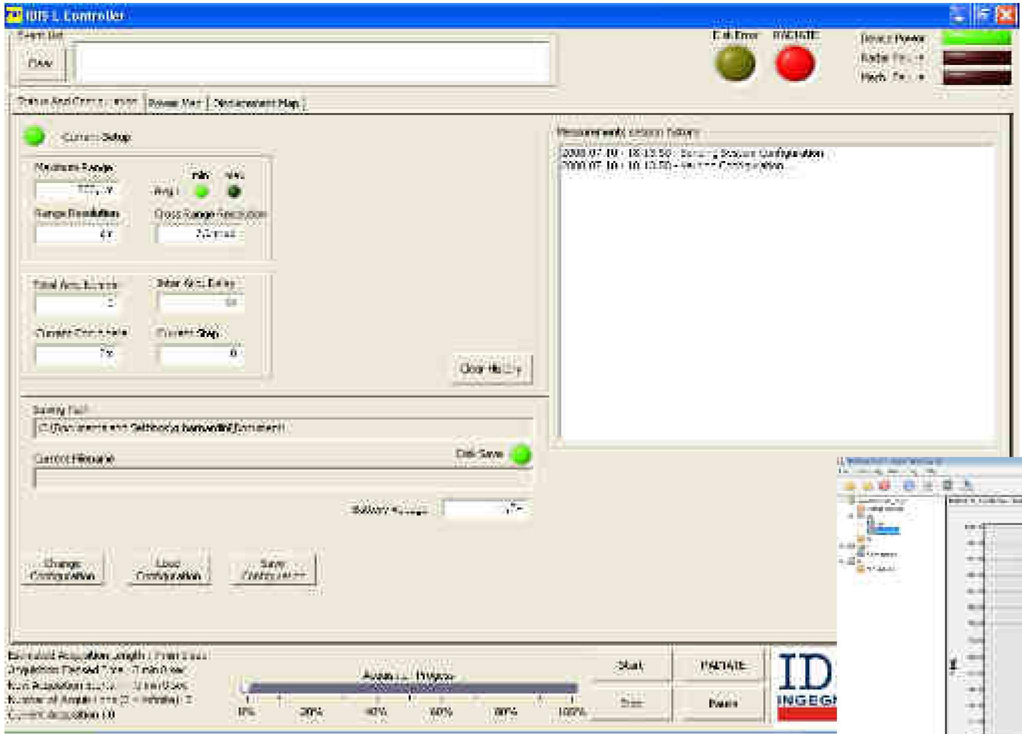
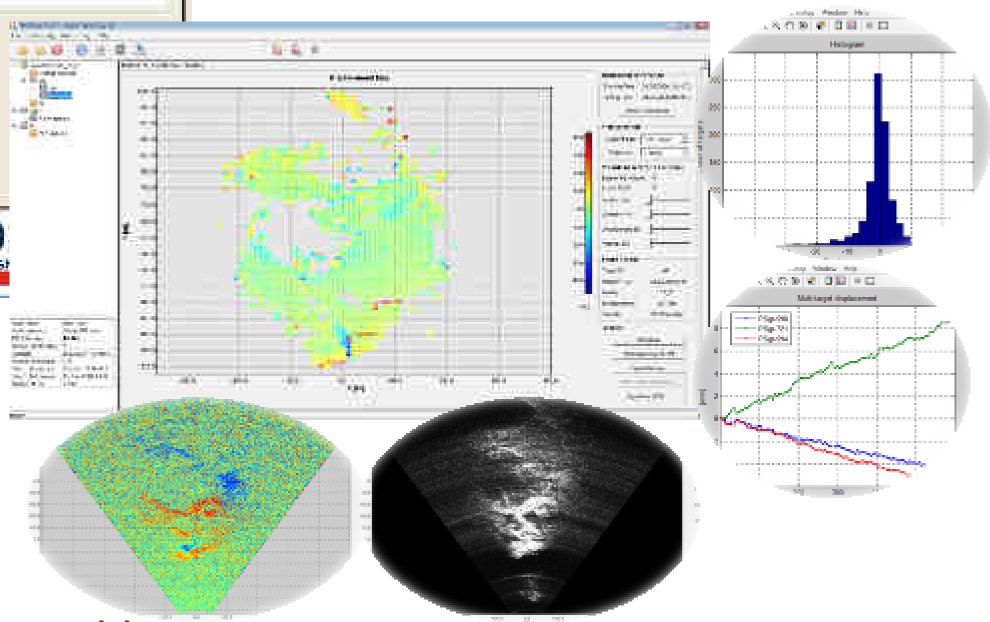
IBIS-L System: SW description



Management SW - IBIS-L Controller:

- Parameter setting
    - First result rendering



Post-processing SW – GRAPeS:

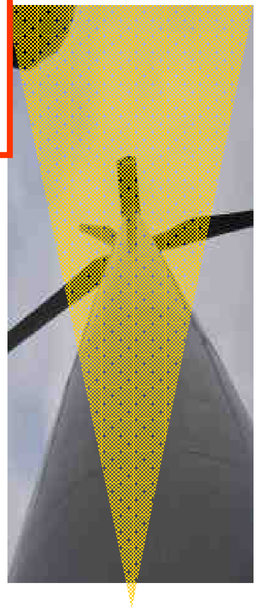
Detailed off-line data processing:

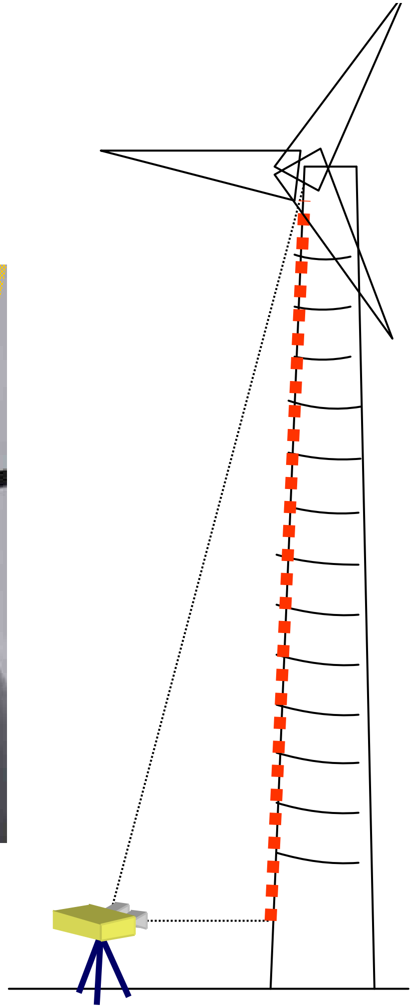
- Geocoded maps
- Automatic data transfer
- Single pixel time history (PSI approach)

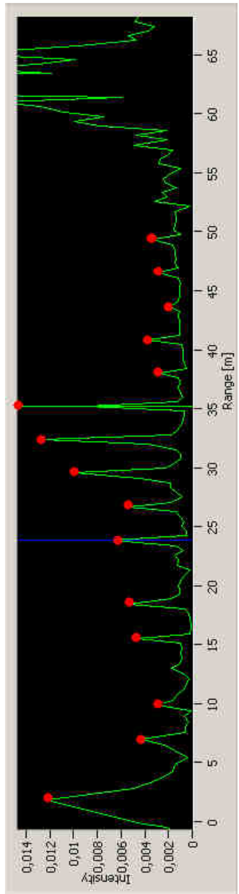
IBIS-S: 1-dimensional range profiles

Range Profile: one dimensional image with 0.5m range resolution

Welding lines are good reflective points







IBIS-S installed at the turbine pillar base (height 60m)

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IBIS-L: Synthetic Aperture Radar (SAR)

SAR technique enables the system to provide high cross range resolution exploiting the movement of the physical antenna along a straight trajectory (linear scanner)

Using 2 m rail
IBIS-L system obtains
4.38mrad (=0.25deg)
angle resolution

The SAR process of the data, collected during the movement of the sensor head on the 2 meter track, allows the IBIS-L system to synthesize a 2m antenna whose azimuth beam width is:

$$\Delta\varphi = \frac{\lambda}{2 \cdot L} = 4.38 mrad$$

IBIS-L: SAR 2-dimensional images

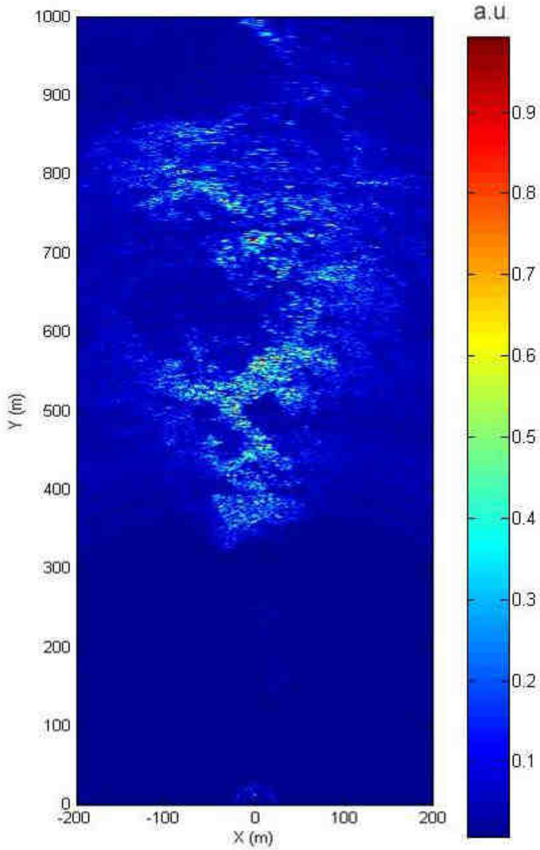
The combination of SAR and SF-CW techniques allows the system to resolve the scenario into two dimensional pixels

Pixel dimension:

- 0.5m in range;
- 1.35m – 4.05m cross range for 300 - 900m range

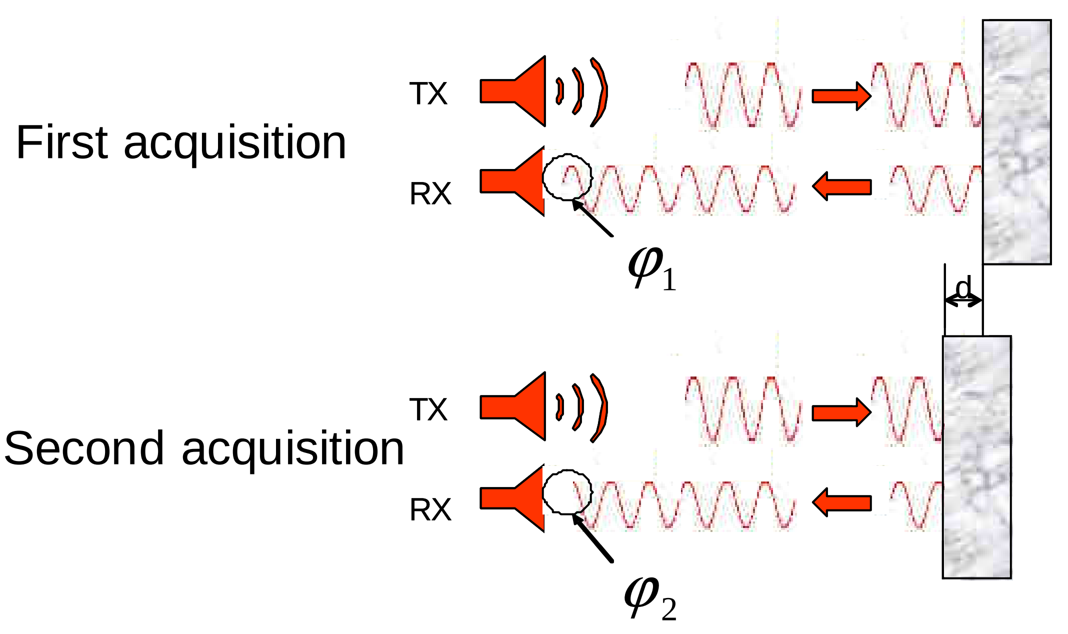
Optical Image

Power Map



Interferometric capability

The **interferometric analysis** provides data on object displacement by comparing phase information, collected in different time periods, of reflected waves from the object, providing a measure of the displacement with an accuracy of less than 0.01mm (intrinsic radar accuracy in the order of 0.001 mm.)

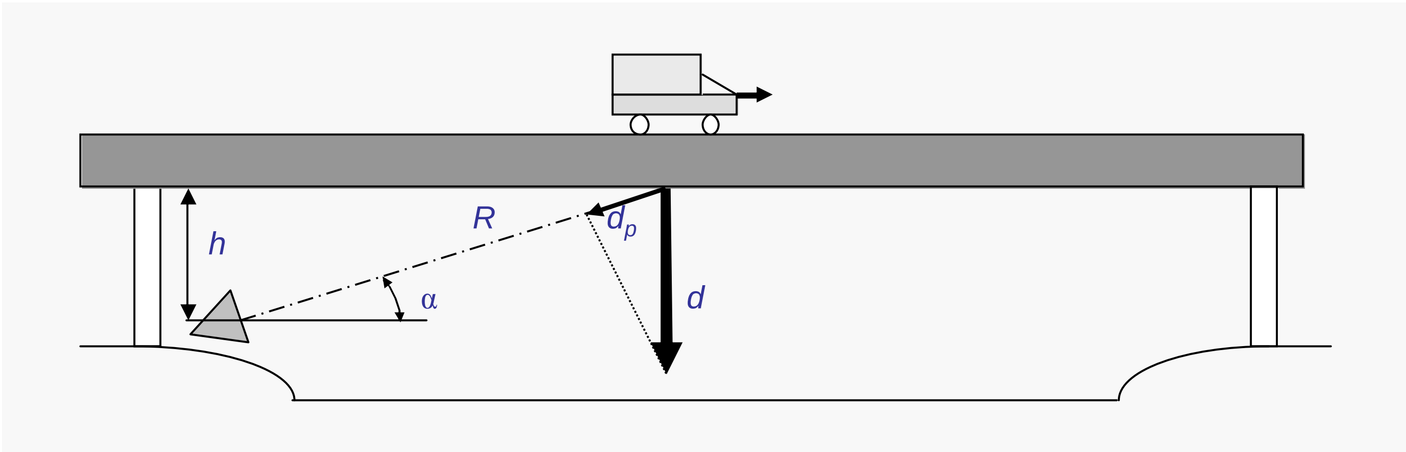


$$d = -\frac{\lambda}{4\pi}(\varphi_2 - \varphi_1)$$

Interferometric capability

The displacement is measured in the direction of the line of sight of the system.

To calculate the real displacement is needed to know the acquisition geometry



$$d = \frac{d_p}{\sin(\alpha)} \quad \Rightarrow \quad \sin(\alpha) = \frac{h}{R} \quad \Rightarrow \quad d = d_p \cdot \frac{R}{h}$$

*The distance **R***
is measured
by IBIS-S

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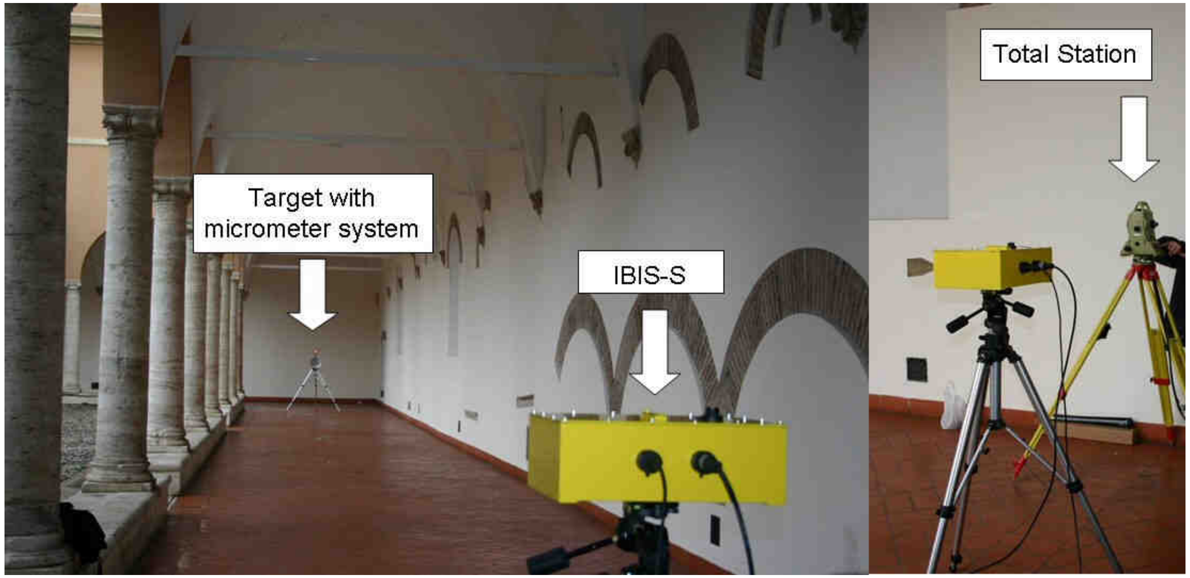
IBIS System: operational characteristics

Instrument	IBIS-L	IBIS-S
Work frequency	Ku band (available also in X band)	Ku band
Radar type	SF-CW	SF-CW
Platform	Ground-Based	Ground-Based
SAR capability	Yes	N/A
Interferometric capability	Yes	Yes
Range	[10 - 4000] m	[10 - 1000] m
Spatial resolution	Range = 0.75 m Cross-range = 4.38mrad	Range = 0.75 m
Displacement accuracy	up to 0.1mm	up to 0.01 mm
Acquisition time	≥ 5 min	≥ 5msec
Installation time	~ 2 h	15÷30 min
Power supply	24 VDC or electrical network	12-24 VDC or electrical network
Size	250 x 100 x 100 cm	50 x 100 x 40 cm
Weight	100 Kg	14 Kg
Power consumption	70 W	40W

Measurement accuracy: IBIS vs. Total Station

Test objective: comparison between IBIS-S results and a high-performance Total Station in measuring a target displacement



Total Station used: Leica TCA2300

Target distance: 33m

Forced displacement:

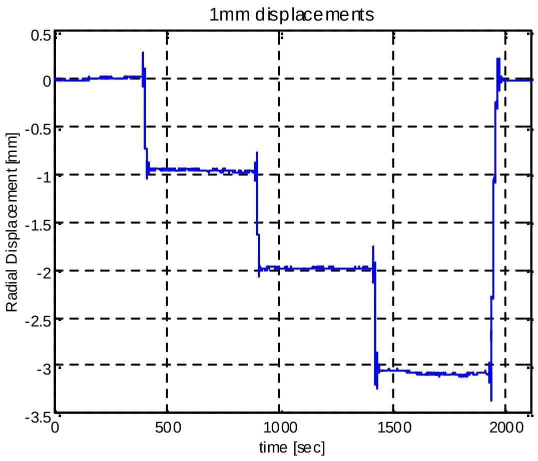
- 3 x 1mm step towards IBIS-S and -3mm back
- 2 x 0.5mm step towards IBIS-S and -1mm back
- 5 x 0.1mm step towards IBIS-S and -0.5mm back

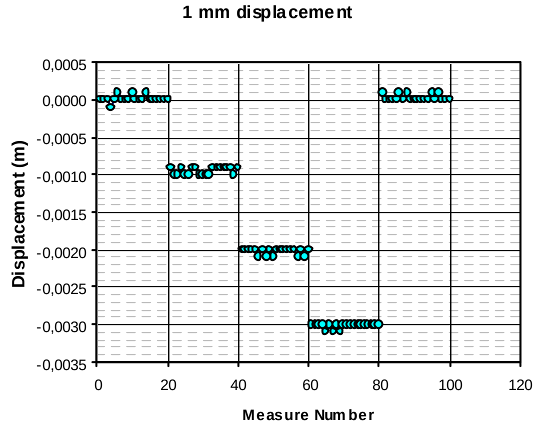
Measurement accuracy : IBIS vs. Total Station

IBIS-S results

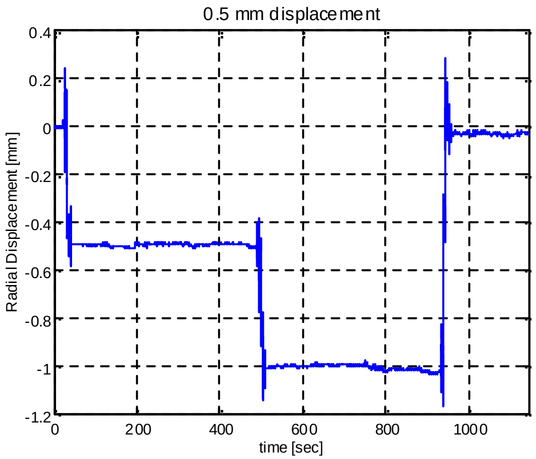
Total station results

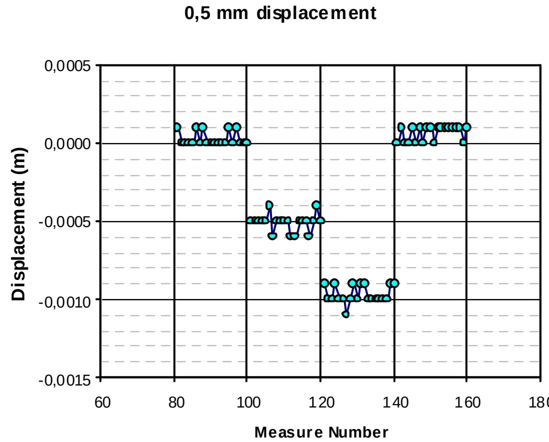
1mm steps





0.5mm steps

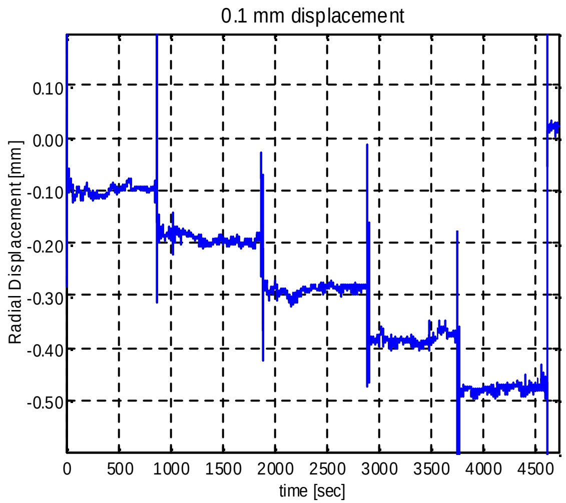




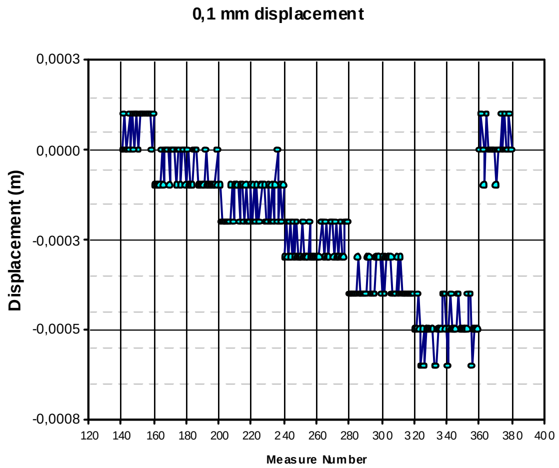
Measurement accuracy : IBIS vs. Total Station

0.1mm steps

IBIS-S results



Total station results



IBIS-S real time result

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Applications categories

The applications of the IBIS system can be divided into two different categories:

- **Static monitoring applications:** measurement of slow displacement *(-S and -L configuration)*

- **Dynamic monitoring applications**: measurement of vibrations or transient displacement *(-S configuration)*

IBIS – L configuration

IBIS – S configuration

Static Monitoring Applications

- **Terrain Monitoring**:
  - Landslide monitoring
  - Land Subsidence monitoring
  - Open pit mine monitoring
  - Ground settlements and building settlements due to eng. works
  - Volcanic slope monitoring
  - Glacier monitoring
  - Tunnel displacement monitoring
- **Structure Monitoring**:
  - Bridges monitoring
  - Dams monitoring
  - Towers monitoring
  - Cultural heritages monitoring

IBIS System advantages for static applications

The main advantages of the use of IBIS for static monitoring are:

● possibility to carry out the survey without accessing the land/structure but installing the IBIS system in its proximity

● obtain information from all the area illuminated by the antenna beam: the radar measures the local displacement of the scenario by resolving it into pixels of a few square meters

● high displacement measurement accuracy, up to 1/10 mm

● day-night continuous operation

● completely autonomous operation not requiring human intervention

● acquisition frequency of the order minutes for IBIS-L, seconds for IBIS-S

Slope instability monitoring within a quarry

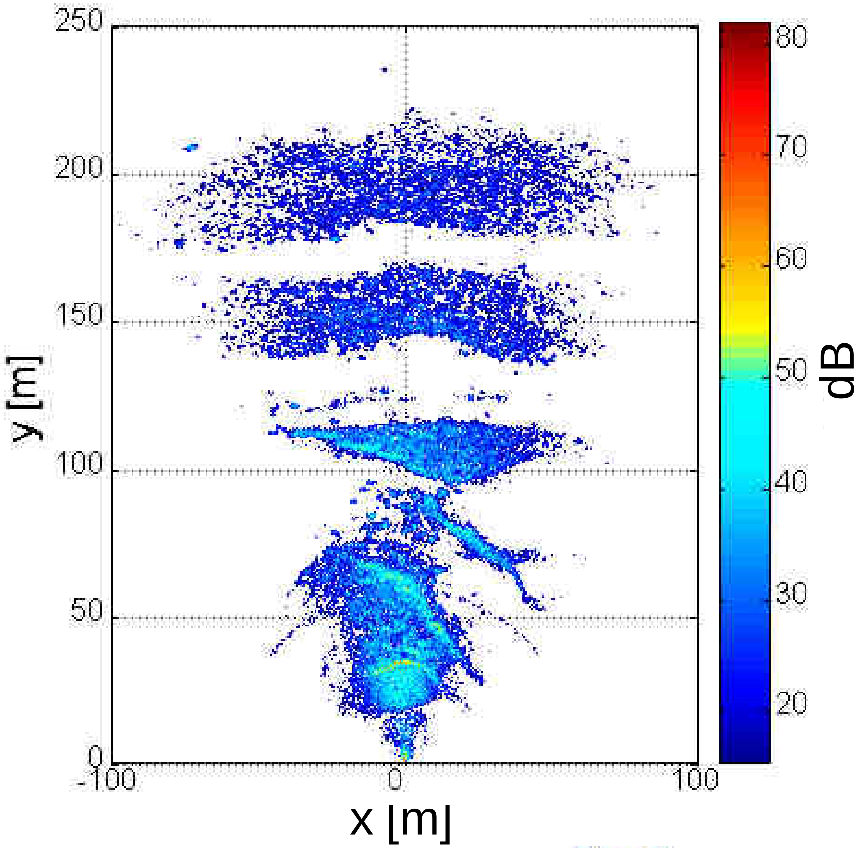
• Use of IBIS-L for long-term monitoring of slope instability within quarries or openpit mines

Slope instability monitoring within a quarry

Maximum range	500 m
Range resolution	0.5 m
Cross-range resolution	4.5 mrad
Antenna Tilt	25°
Antenna Aperturre (- 3 dB)	30°
Acquisition lenght	**6 days 29 min**

IBIS-L System set-up

Power image



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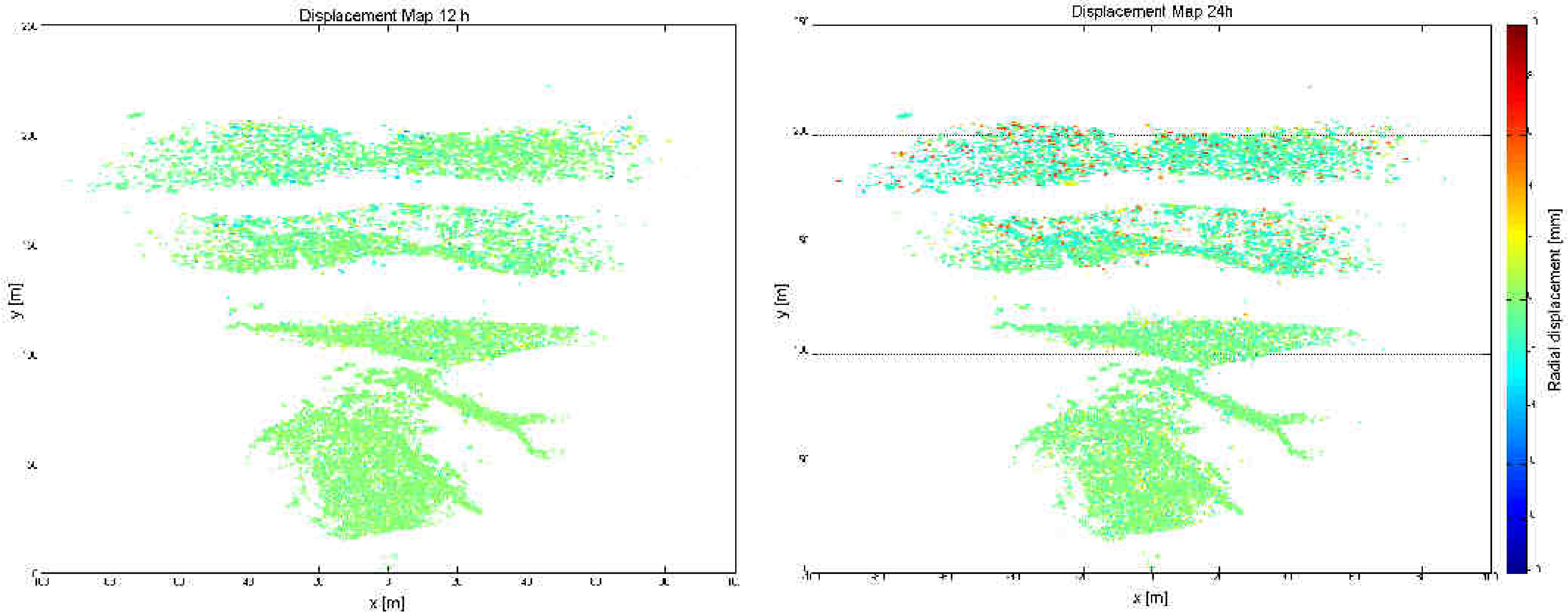
Slope instability monitoring within a quarry

Cumulative displacement maps

12 h **24 h**



- After 24 h a maximum L.O.S. displacement of 1.2 mm is visible in the upper part of the slope, while the lower portions are stable

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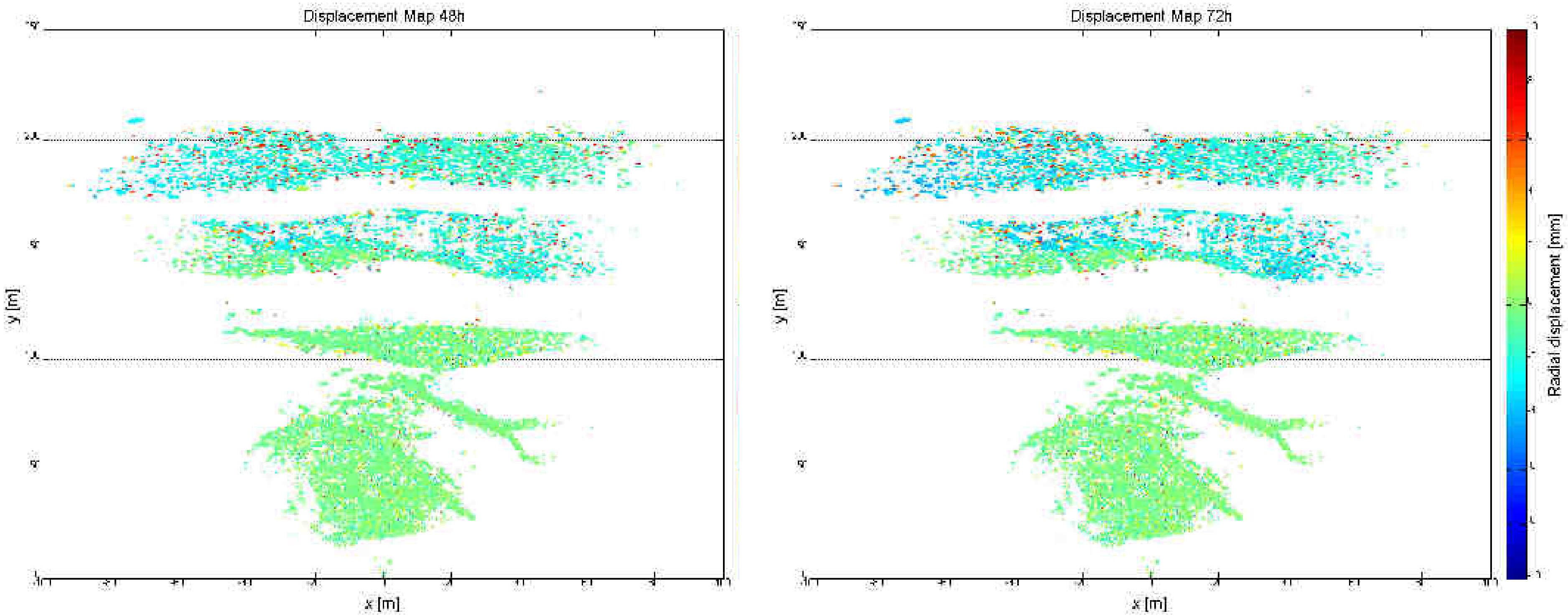
Slope instability monitoring within a quarry

Cumulative displacement maps

48 h **72 h**

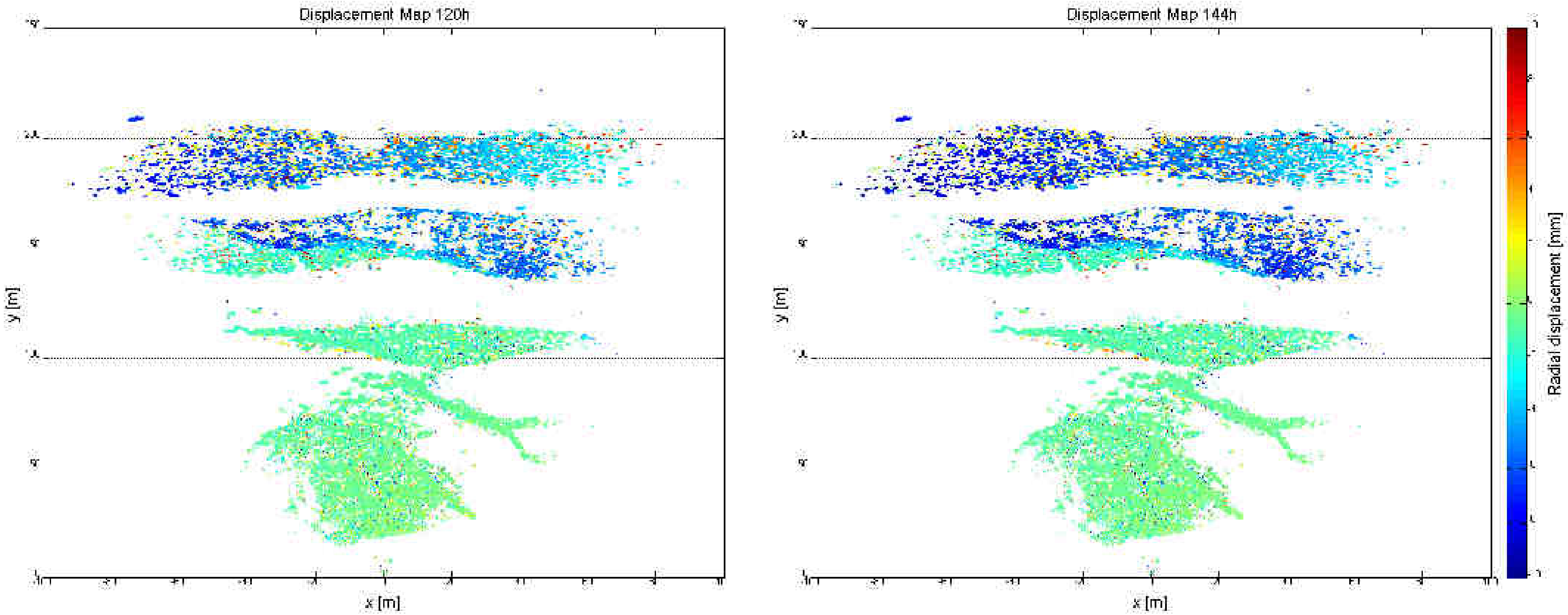


- After 3 days a maximum L.O.S. displacement of 2,4 mm is visible in the upper part of the slope, while the lower portions are still stable

Slope instability monitoring within a quarry

Cumulative displacement maps

120 h 144 h



- After 6 days a maximum L.O.S. displacement of 7,5 mm is visible in the upper right part of the slope, the upper left portion records 4 mm, while the lower portions are stable

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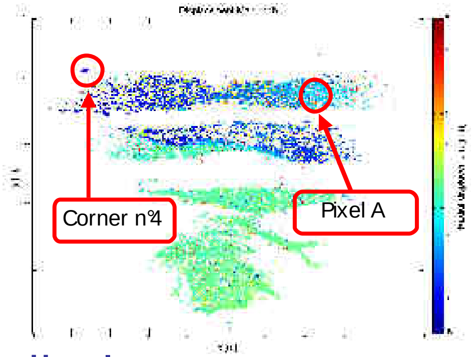
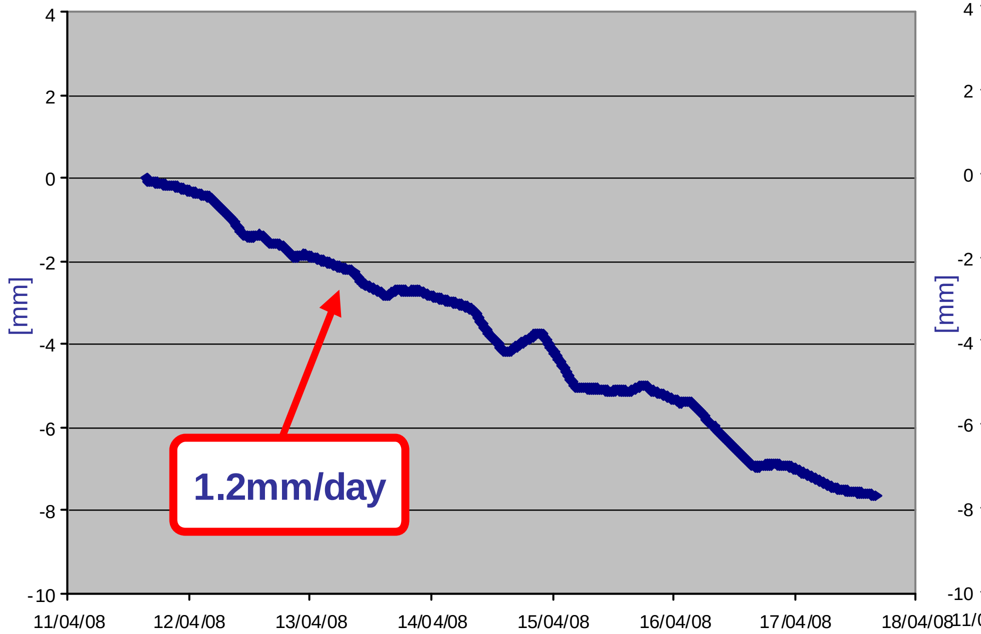
Slope instability monitoring within a quarry

Displacement time series

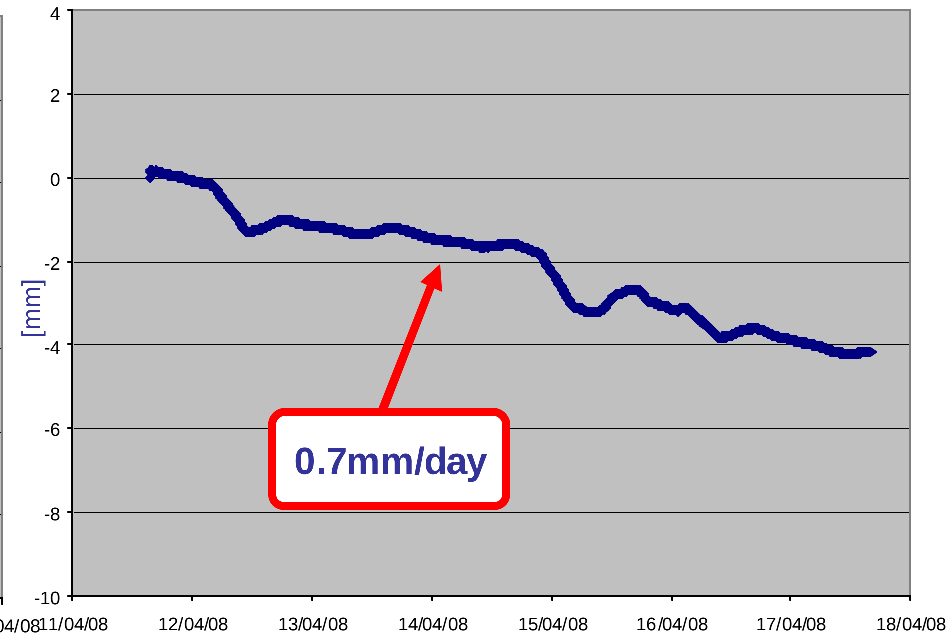
Temporal period: 11/04/08 – 17/04/08
Measurement time span: 6 days and 30 minutes
Type of filter : 80 samples moving average



CR4 displacement



Pixel A displacement



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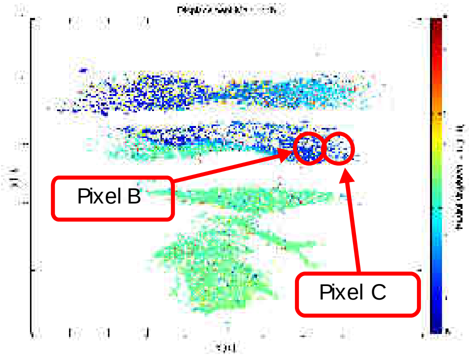
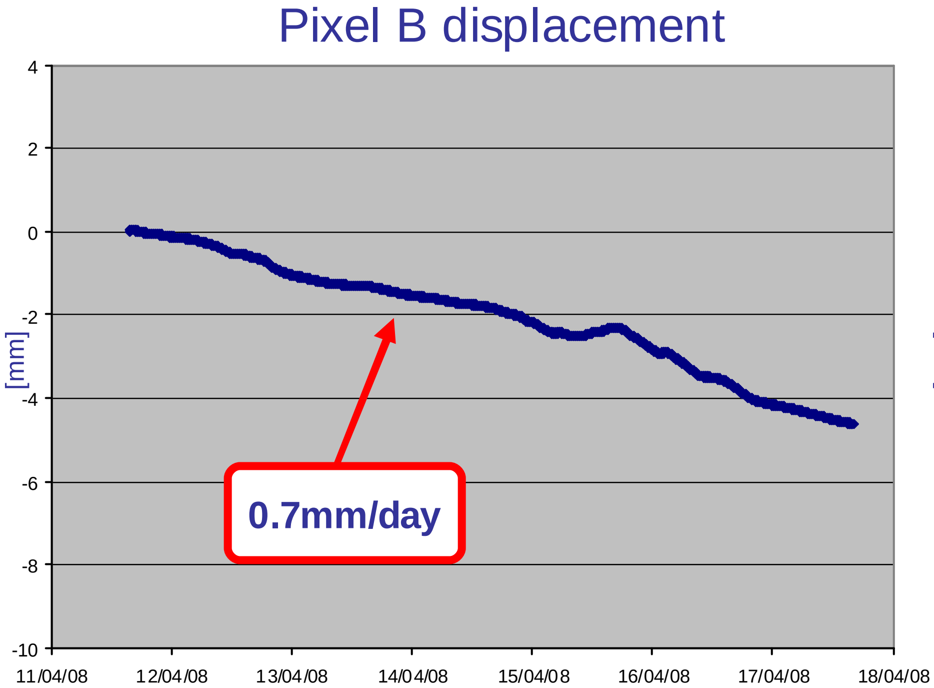
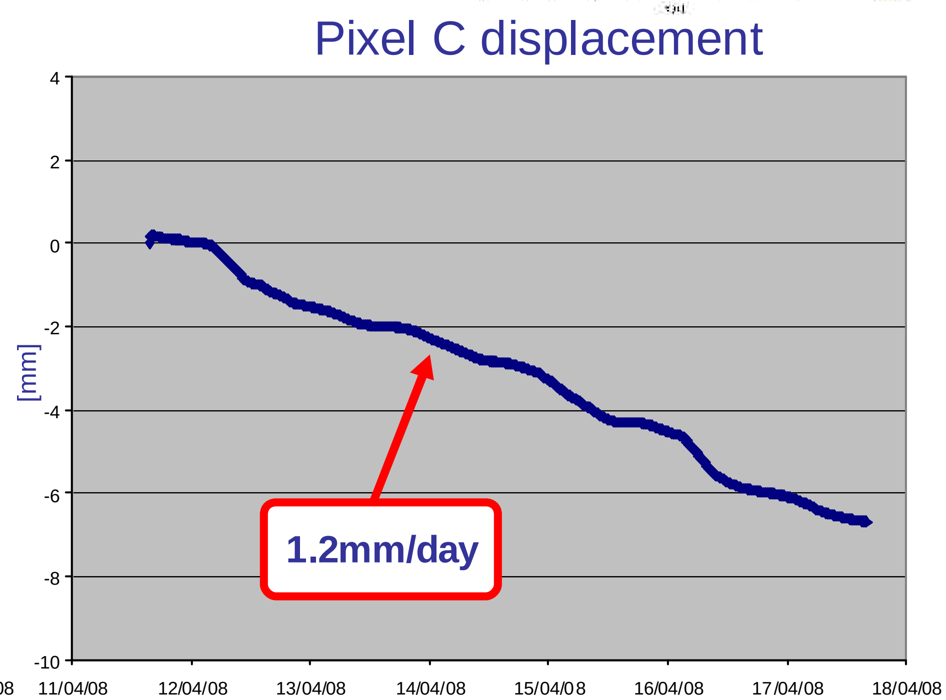
Slope instability monitoring within a quarry

Displacement time series

Temporal period: 11/04/08 – 17/04/08
Measurement time span: 6 days and 30 minutes
Type of filter : 80 samples moving average







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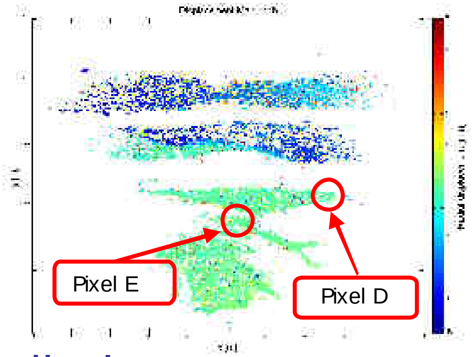
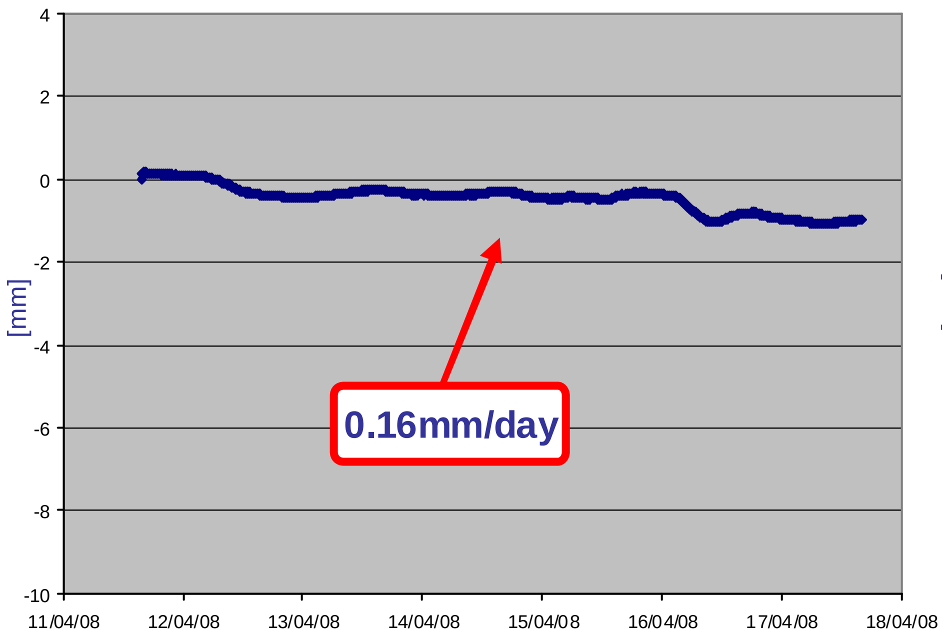
Slope instability monitoring within a quarry

Displacement time series

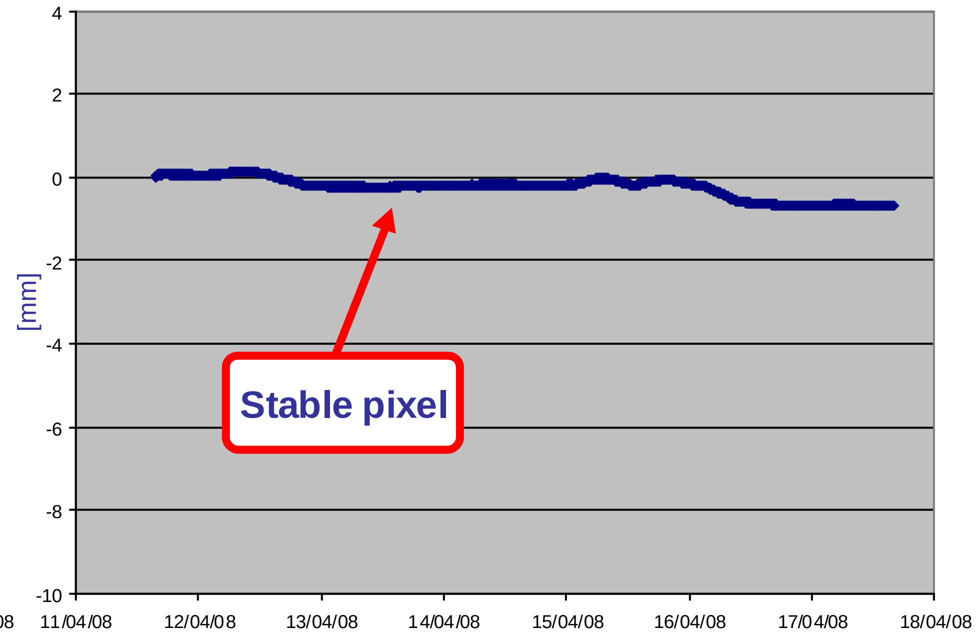
Temporal period: 11/04/08 – 17/04/08
Measurement time span: 6 days and 30 minutes
Type of filter : 80 samples moving average



Pixel D displacement



Pixel E displacement



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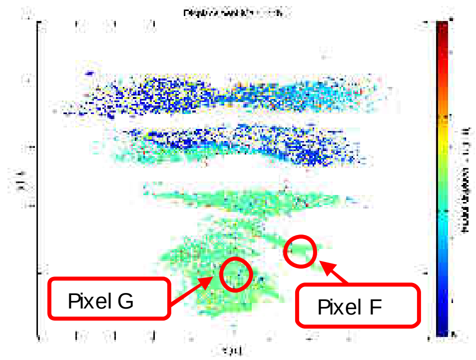
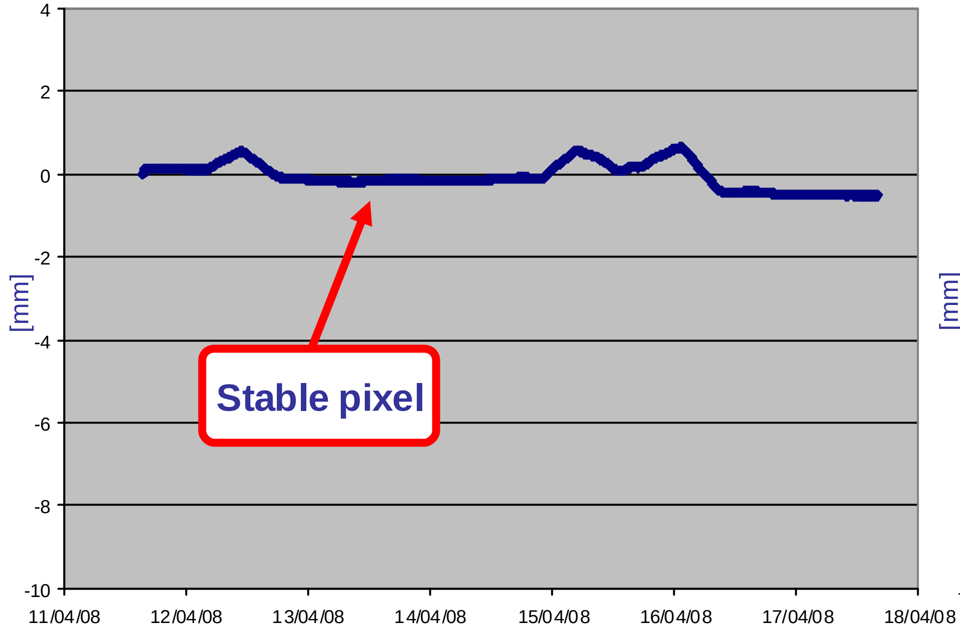
Slope instability Monitoring within a quarry

Displacement time series

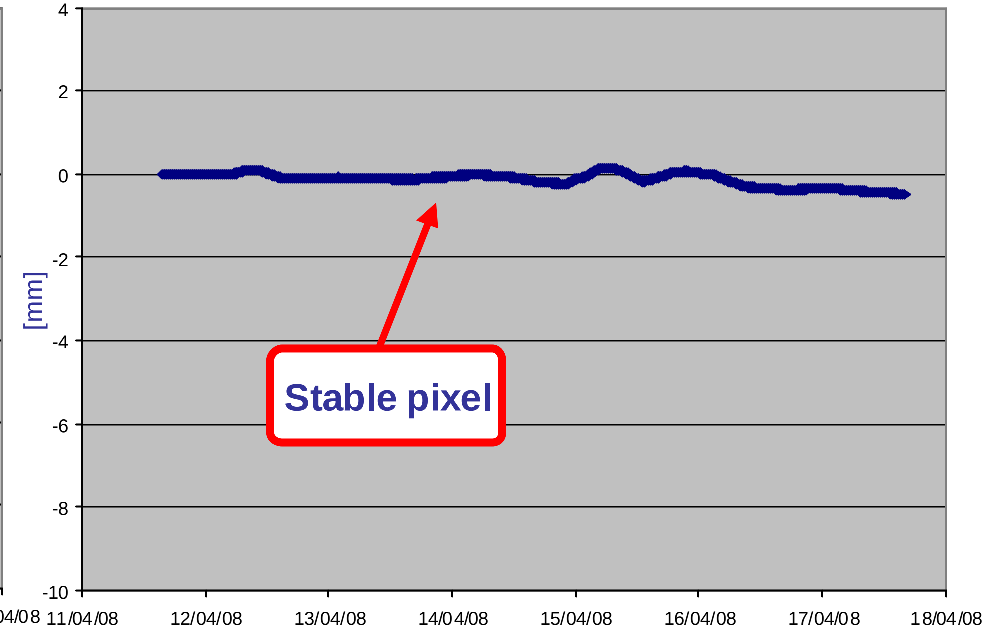
Temporal period: 11/04/08 – 17/04/08
Measurement time span: 6 days and 30 minutes
Type of filter : 80 samples moving average



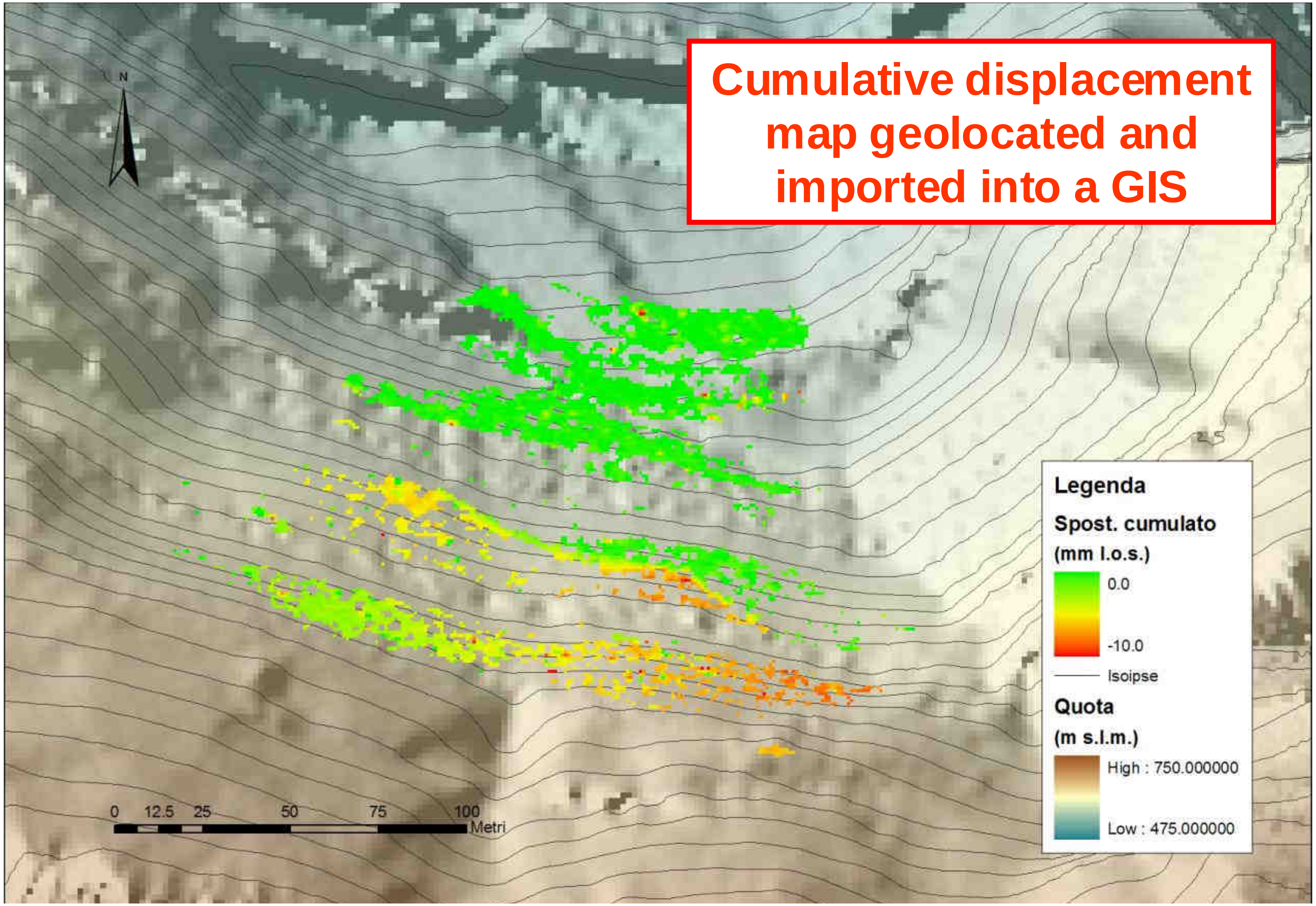
Pixel F displacement



Pixel G displacement



Slope instability Monitoring within a quarry



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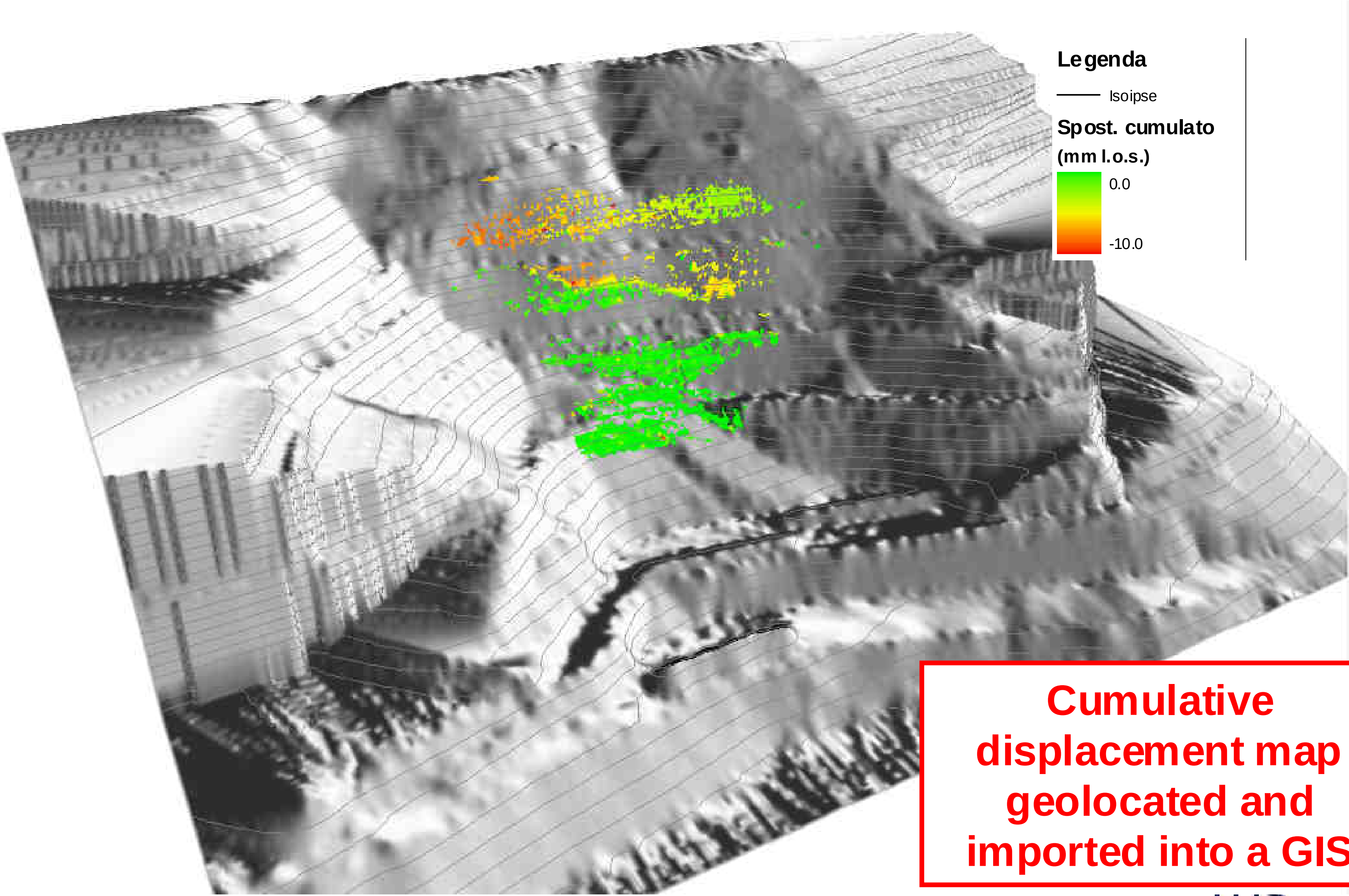
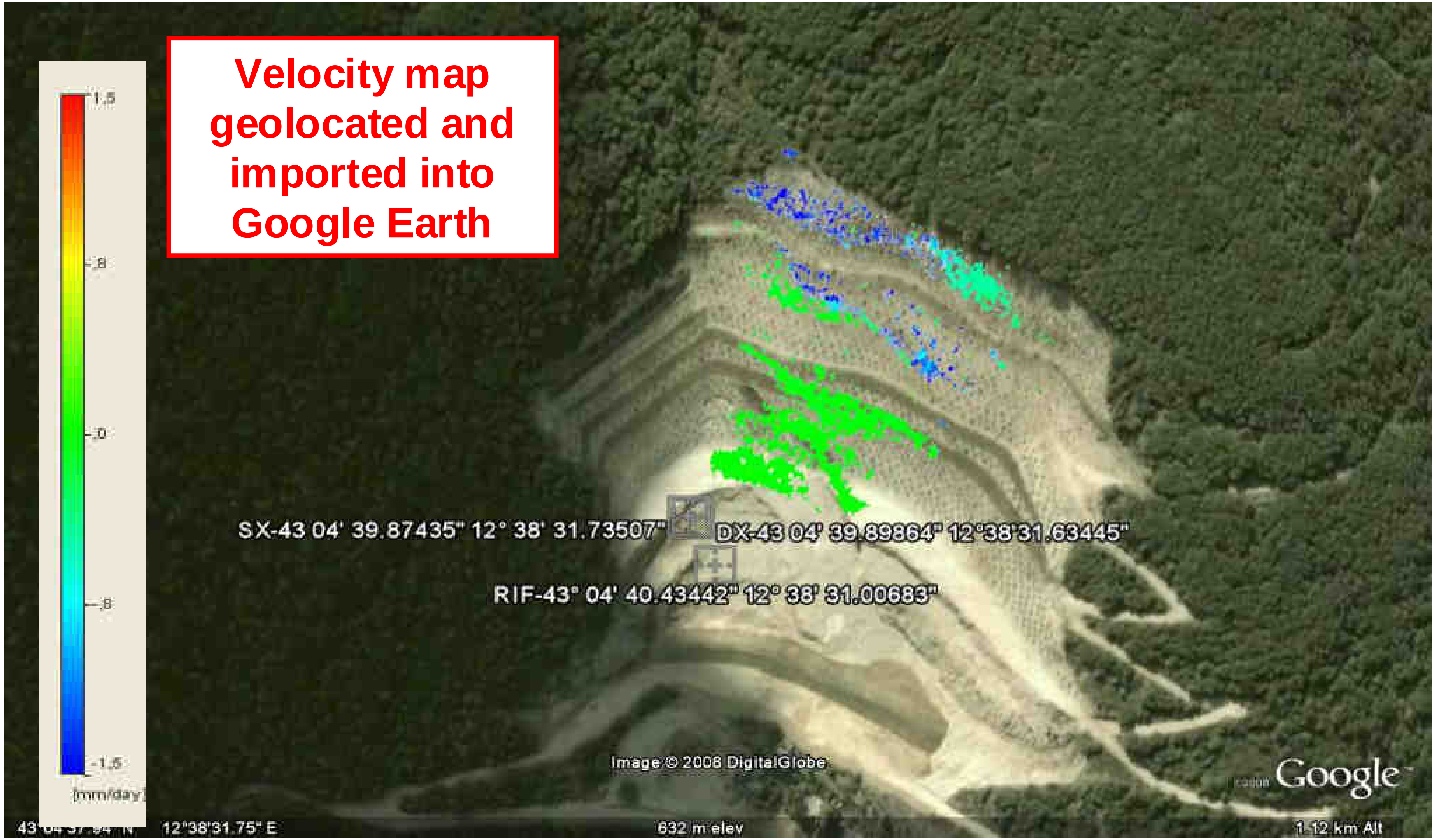
Slope instability Monitoring within a quarry



Cumulative displacement map geolocated and imported into a GIS

Slope instability Monitoring within a quarry



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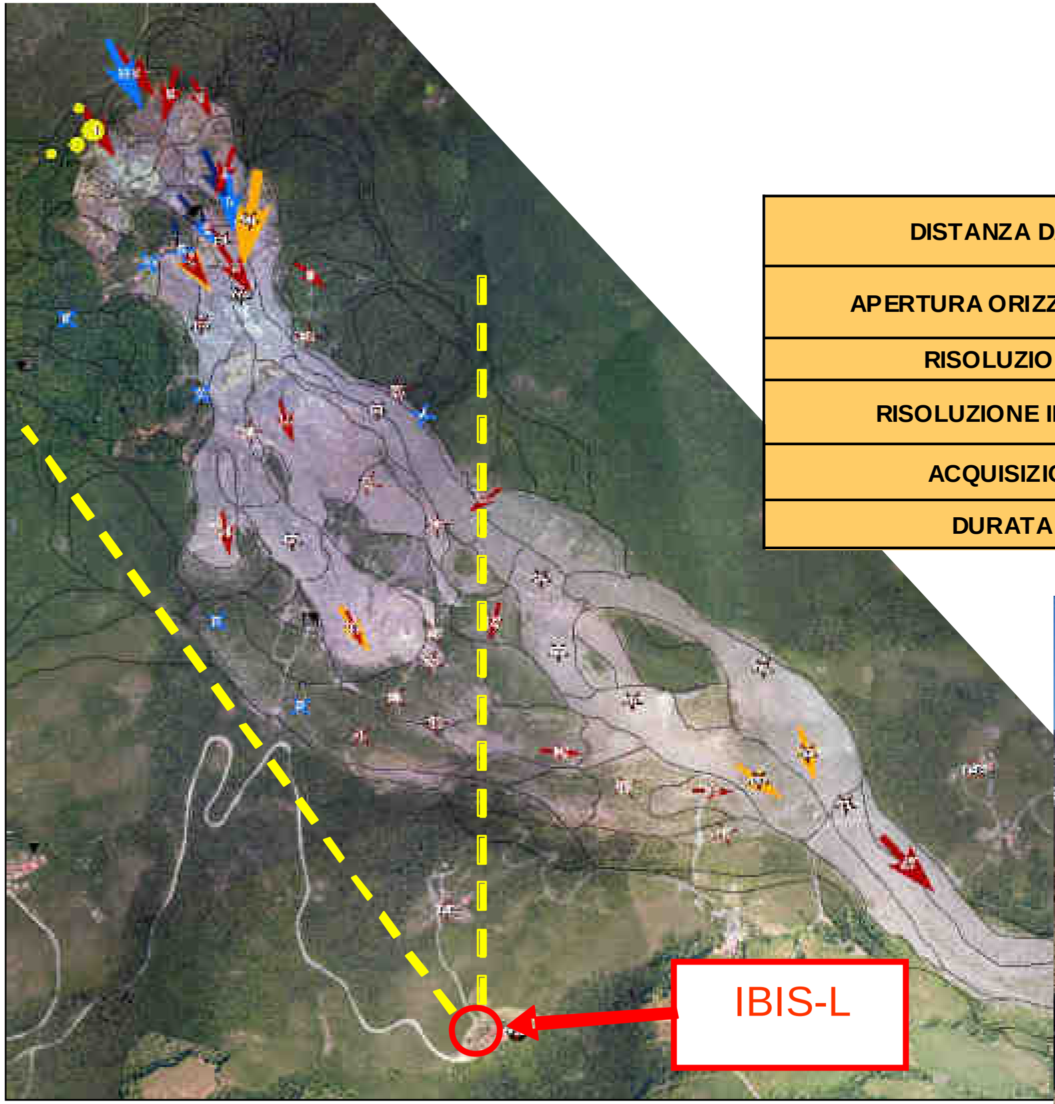
Landslide Monitoring: Boschi di Valoria

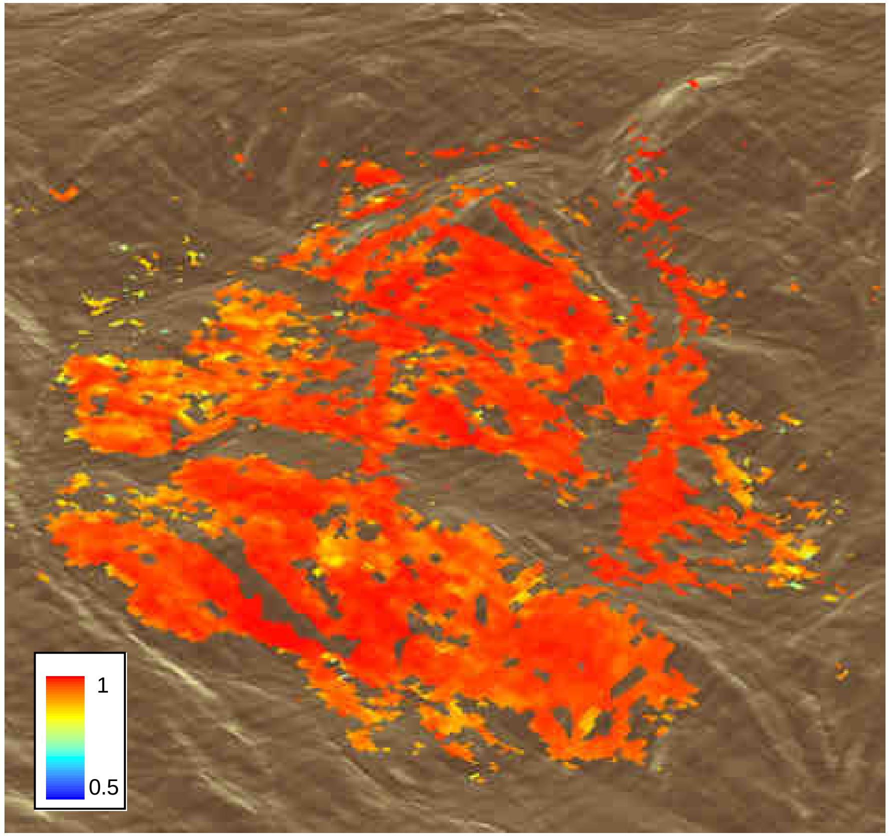
Landslide Monitoring: Boschi di Valoria



DISTANZA DAL VERSANTE	[m]	450-1300
APERTURA ORIZZONTALE ANTENNE	[gradi]	38
RISOLUZIONE IN RANGE	[m]	0.5
RISOLUZIONE IN CROSS-RANGE	[mrad]	4.5
ACQUISIZIONI PER ORA	-	9
DURATA SESSIONE	[ore]	24

IBIS-L System set-up

Landslide Monitoring: Boschi di Valoria



Geocoded quality map

Picture taken from the radar location

More than 40.000 measurement points are identified on the quality map

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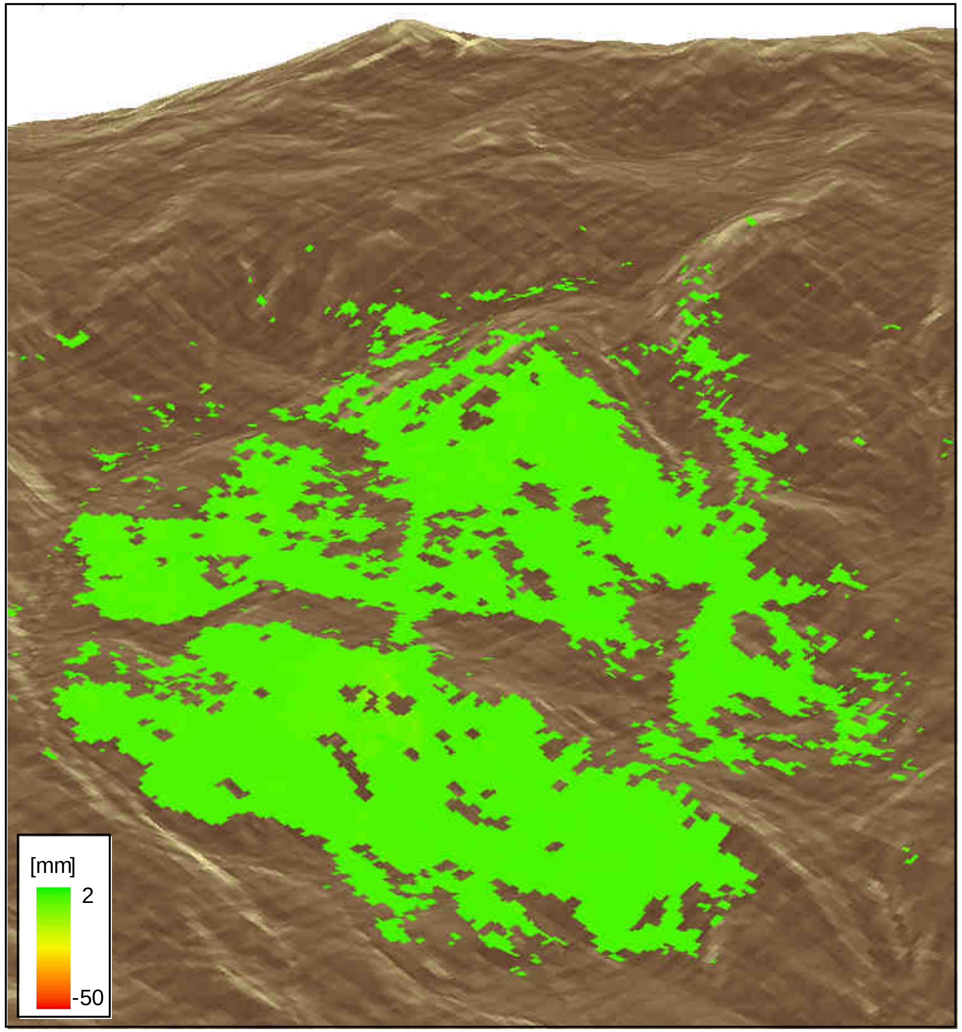
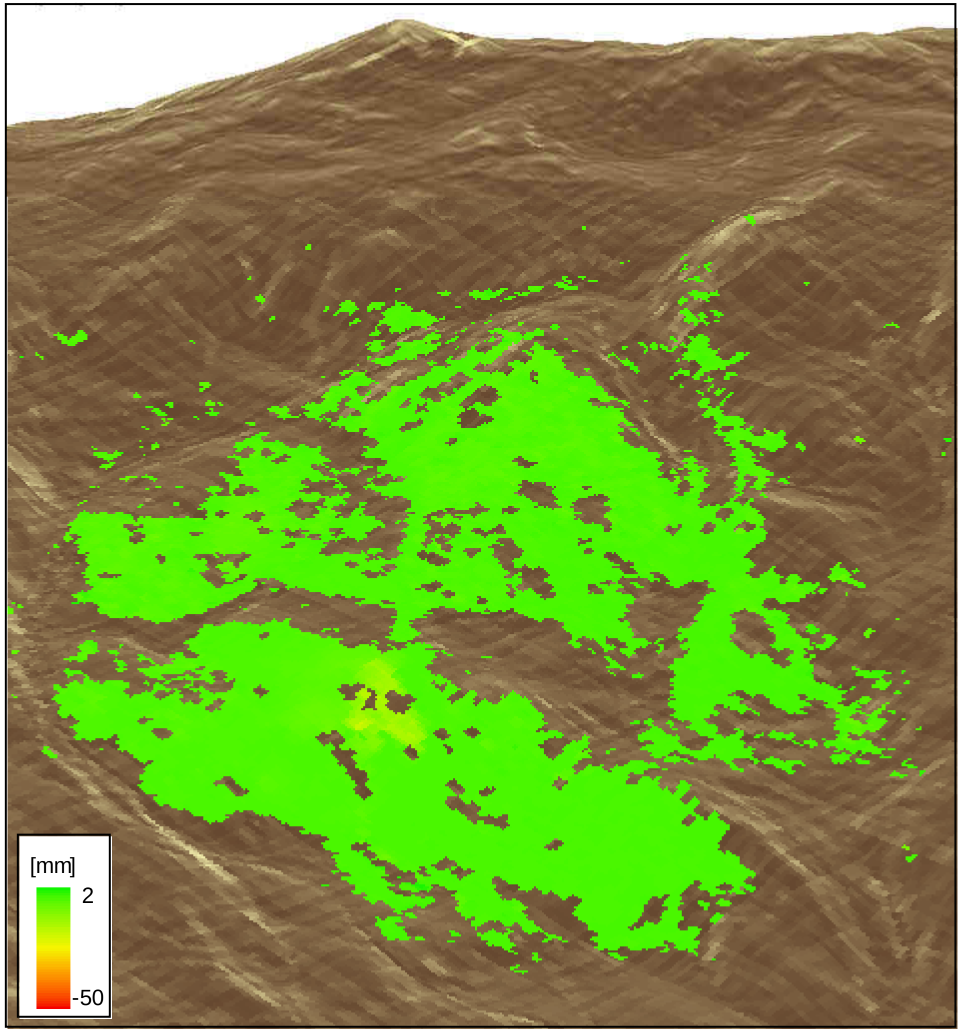
Geocoded cumulative displacement map (1 h)

Geocoded Line Of Sight Displacement Map



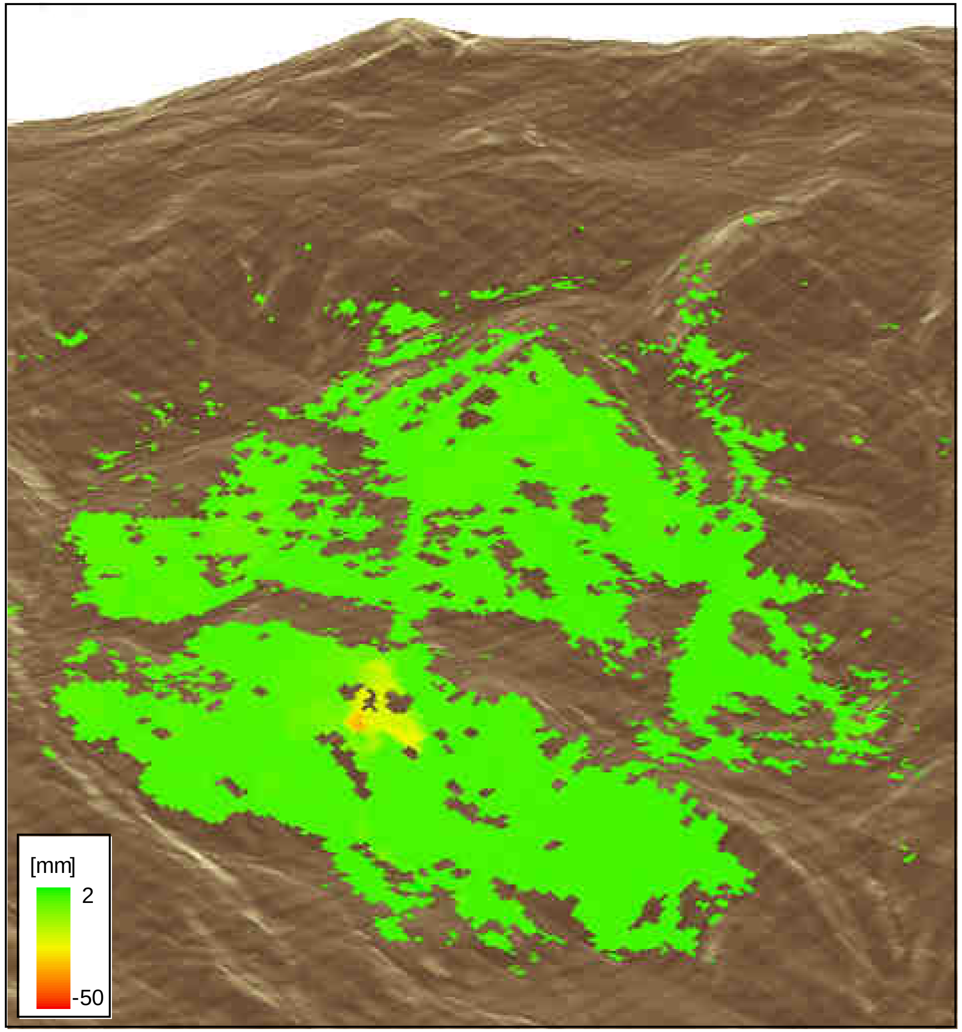
Geocoded cumulative displacement map (2 h)

Geocoded Line Of Sight Displacement Map



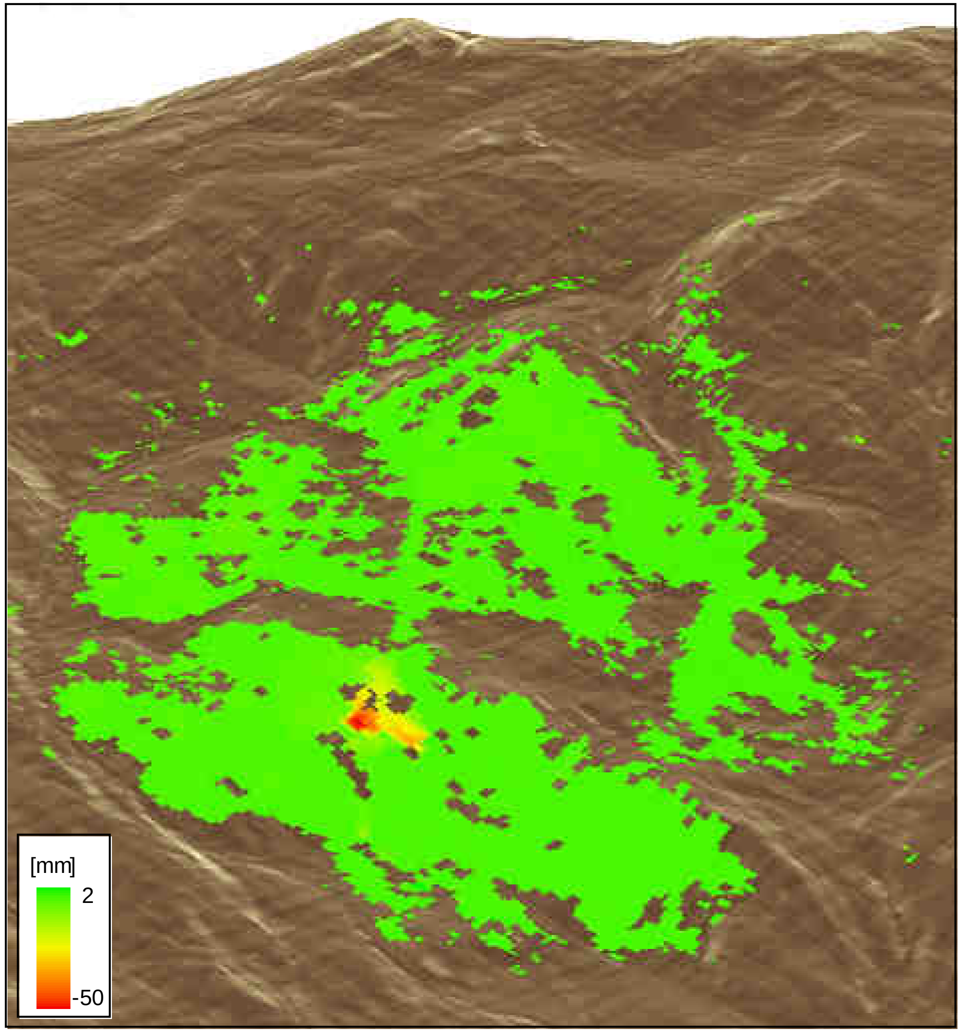
Geocoded cumulative displacement map (3 h)

Geocoded Line Of Sight Displacement Map



Geocoded cumulative displacement map (4 h)

Geocoded Line Of Sight Displacement Map



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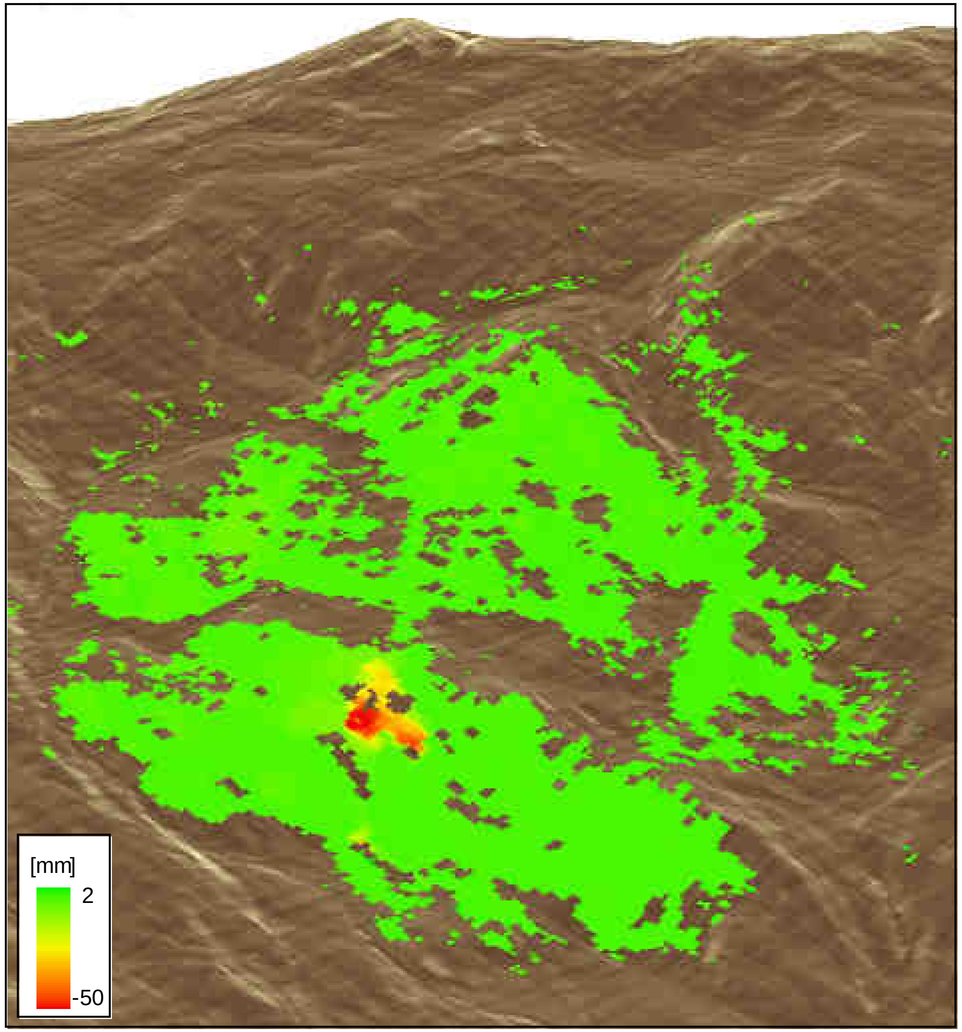
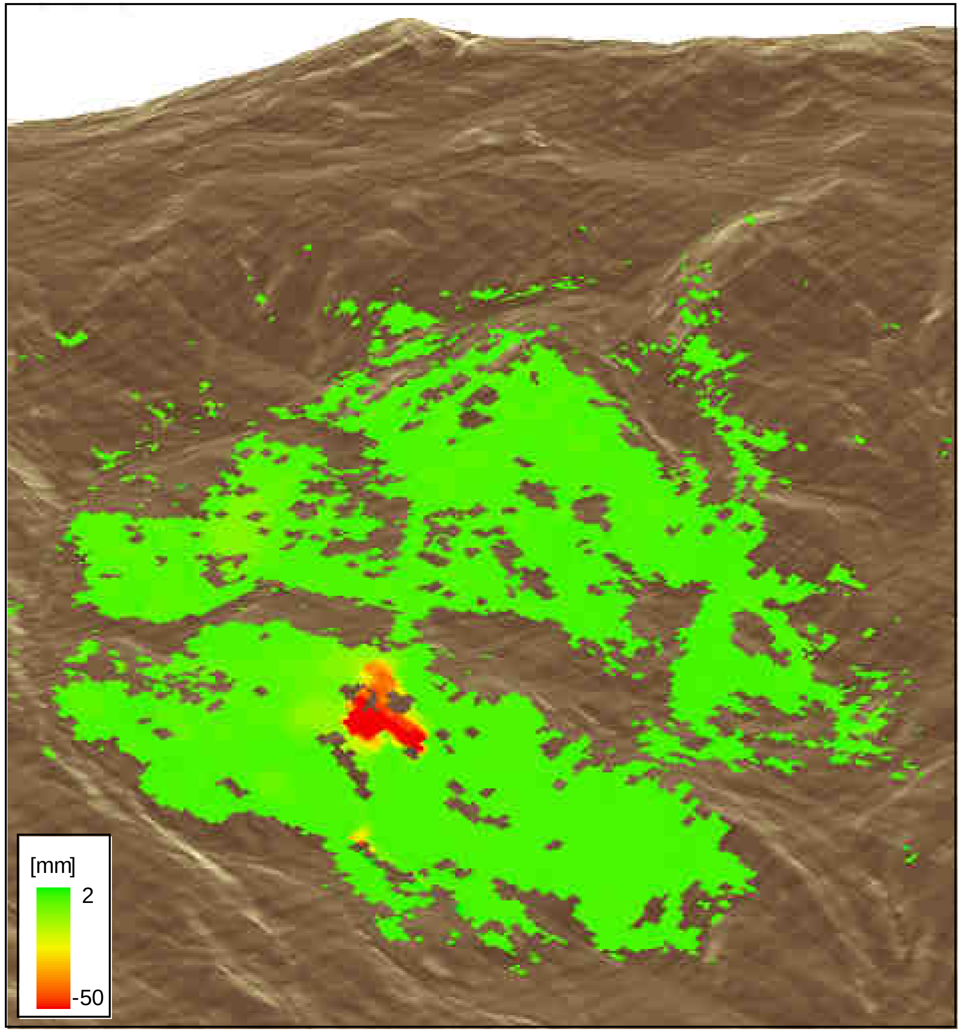
Geocoded cumulative displacement map (5 h)



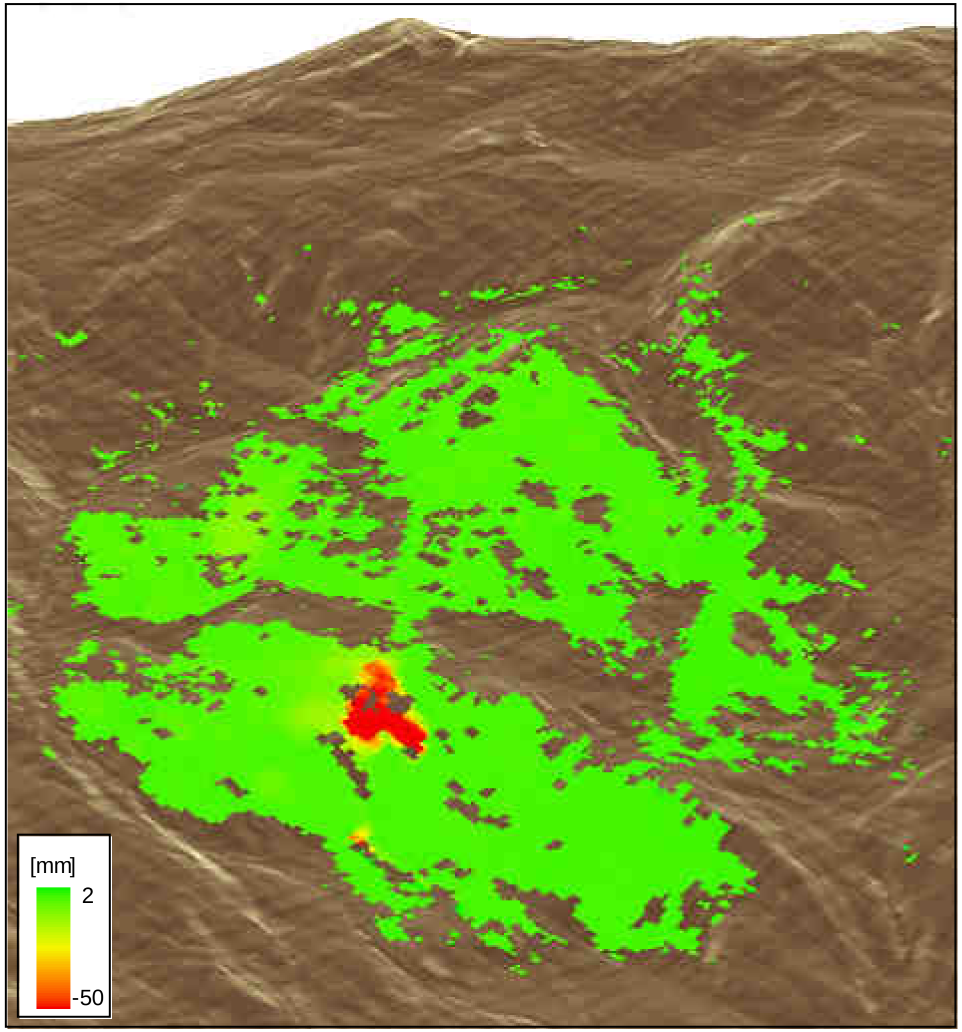
Geocoded cumulative displacement map (6 h)

Geocoded Line Of Sight Displacement Map



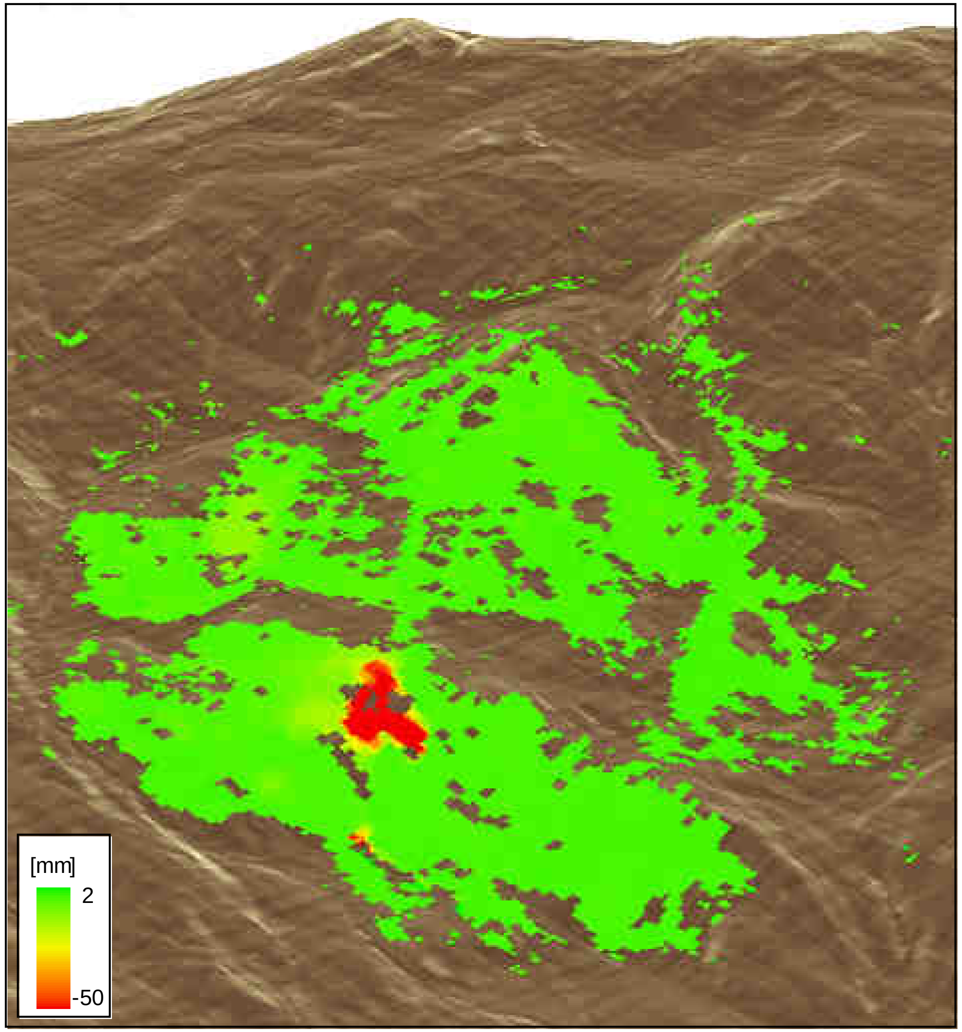
Geocoded cumulative displacement map (7 h)

Geocoded Line Of Sight Displacement Map



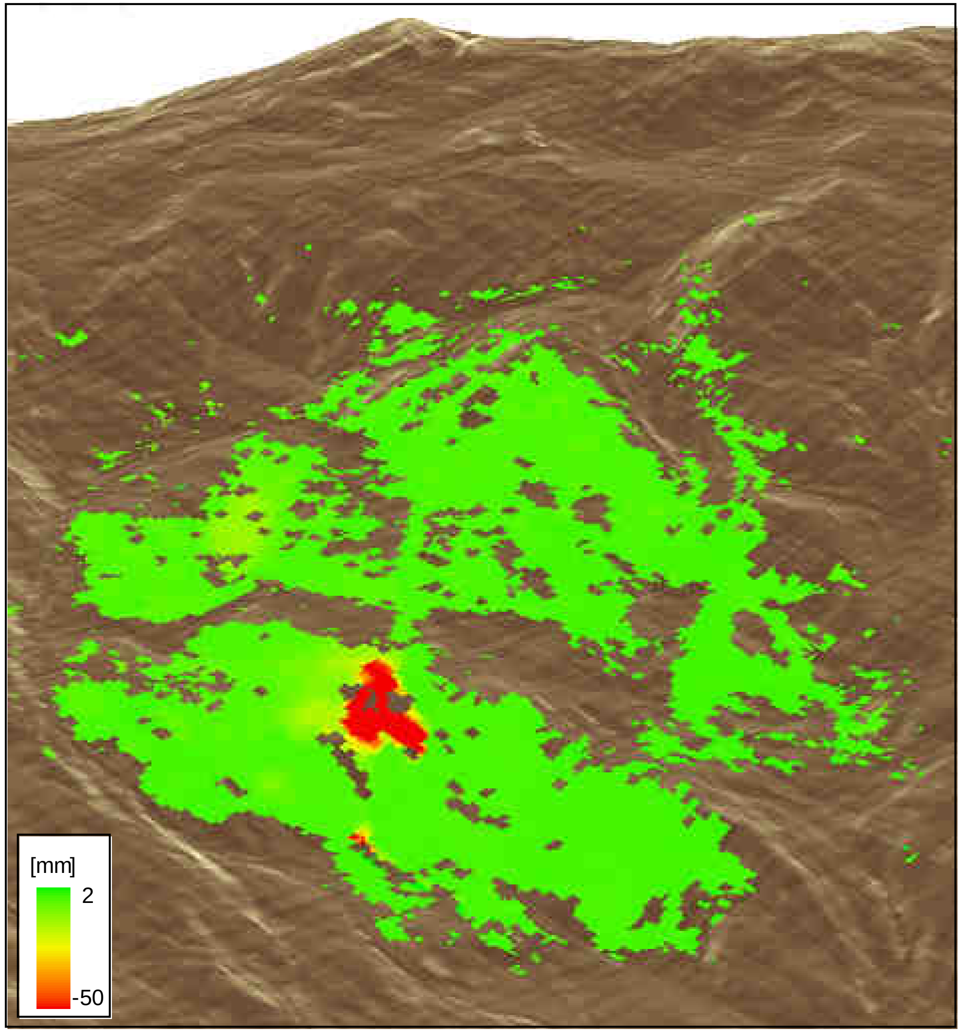
Geocoded cumulative displacement map (8 h)

Geocoded Line Of Sight Displacement Map



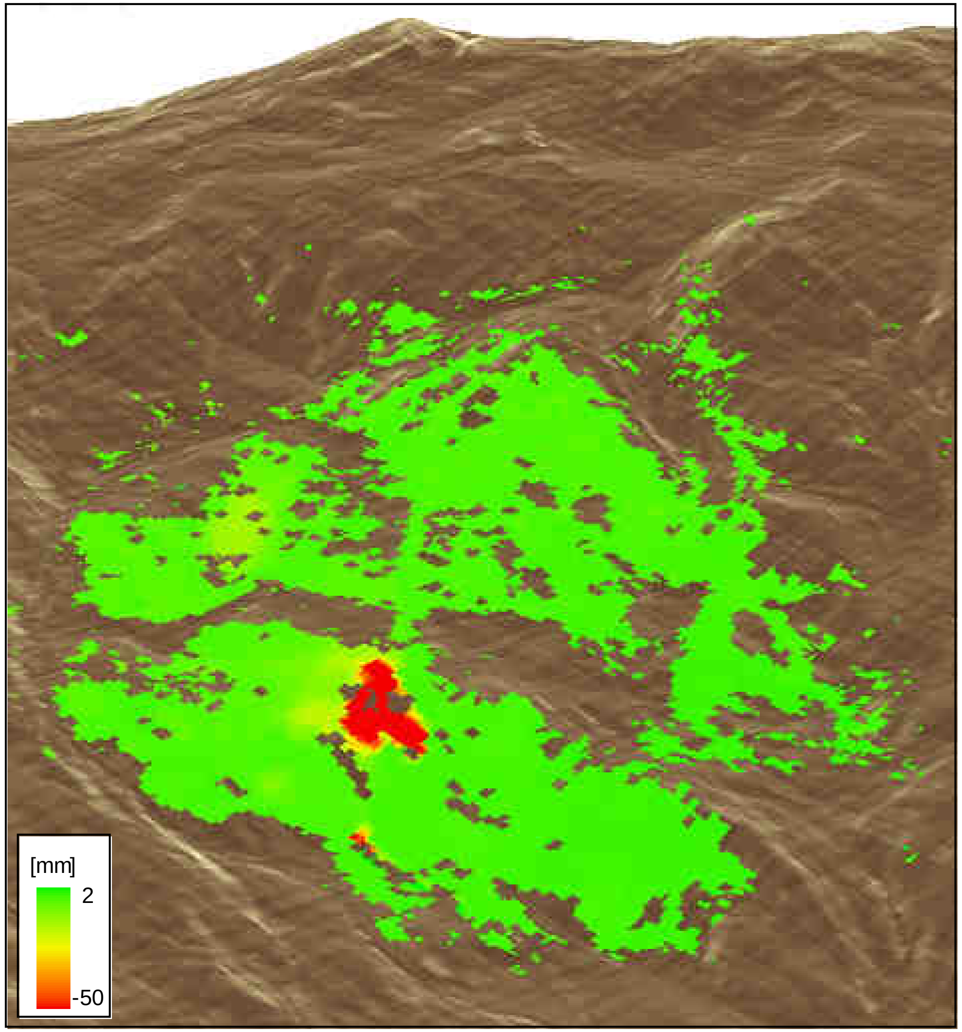
Geocoded cumulative displacement map (9 h)

Geocoded Line Of Sight Displacement Map



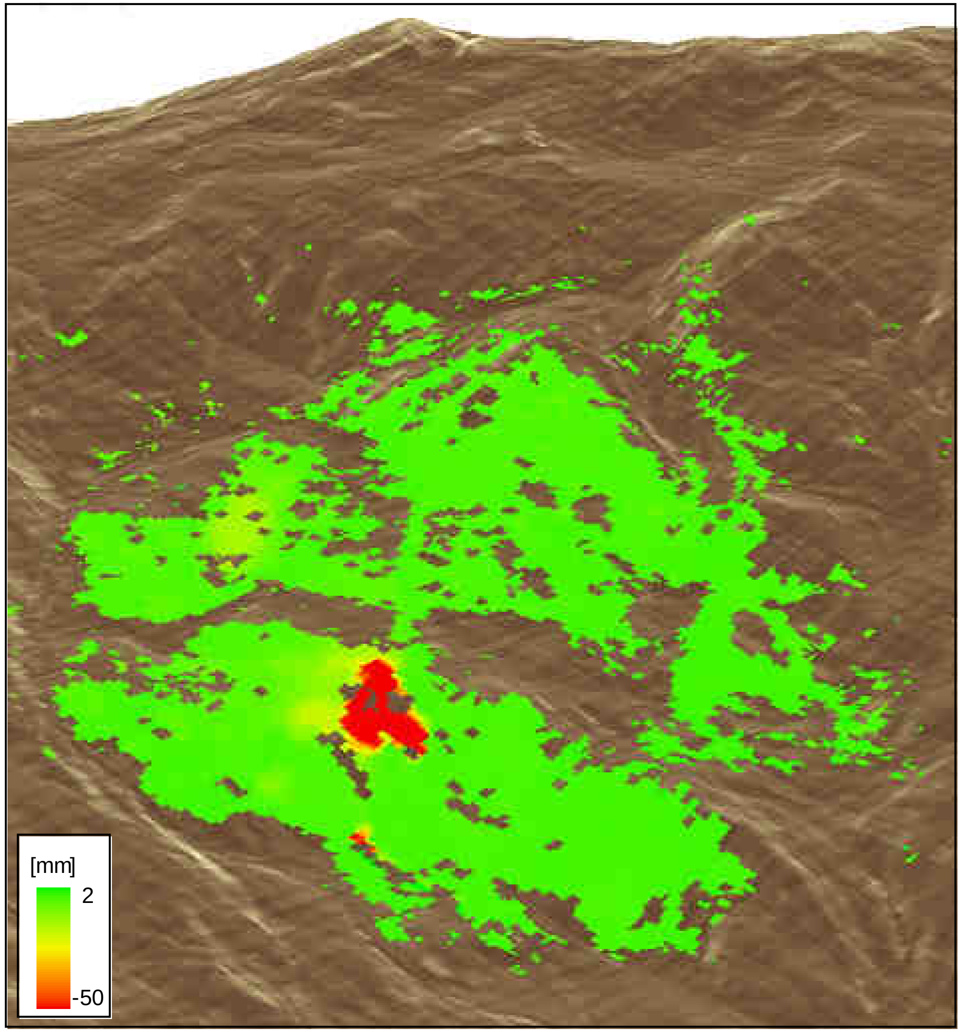
Geocoded cumulative displacement map (10 h)

Geocoded Line Of Sight Displacement Map



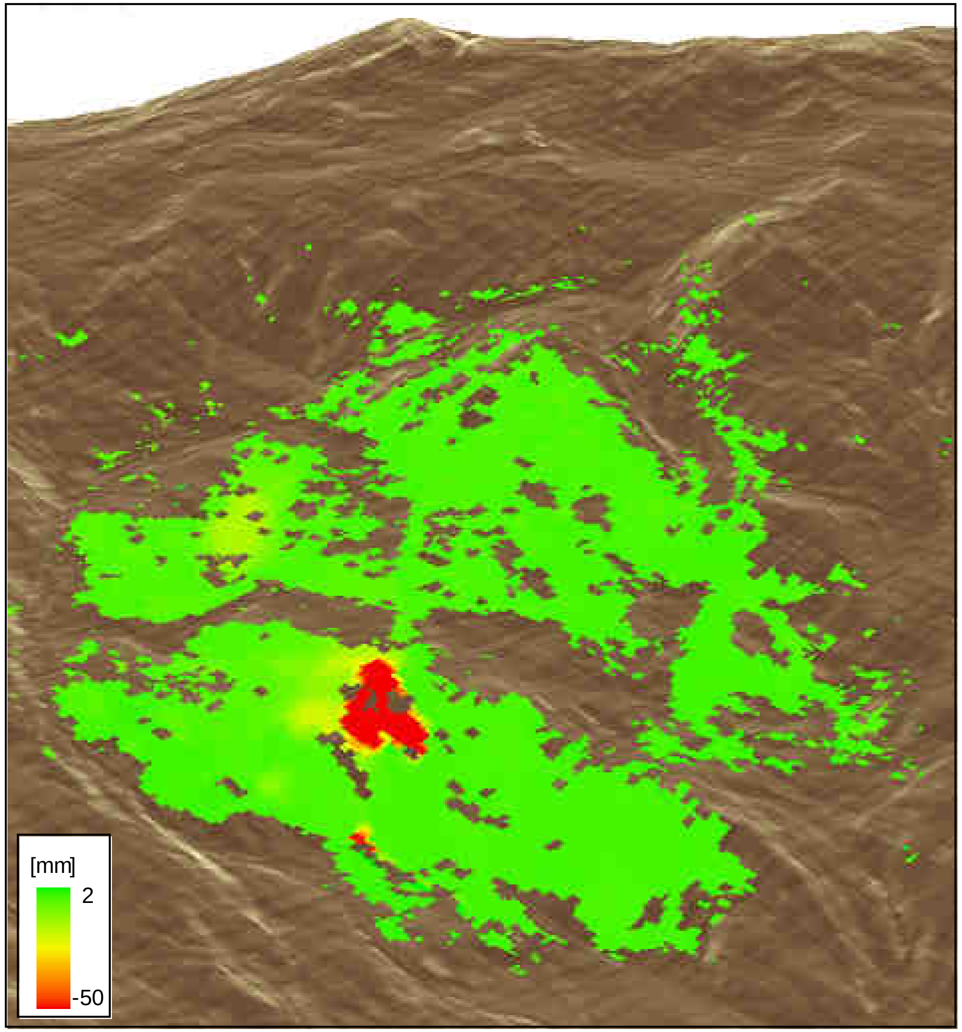
Geocoded cumulative displacement map (11 h)

Geocoded Line Of Sight Displacement Map

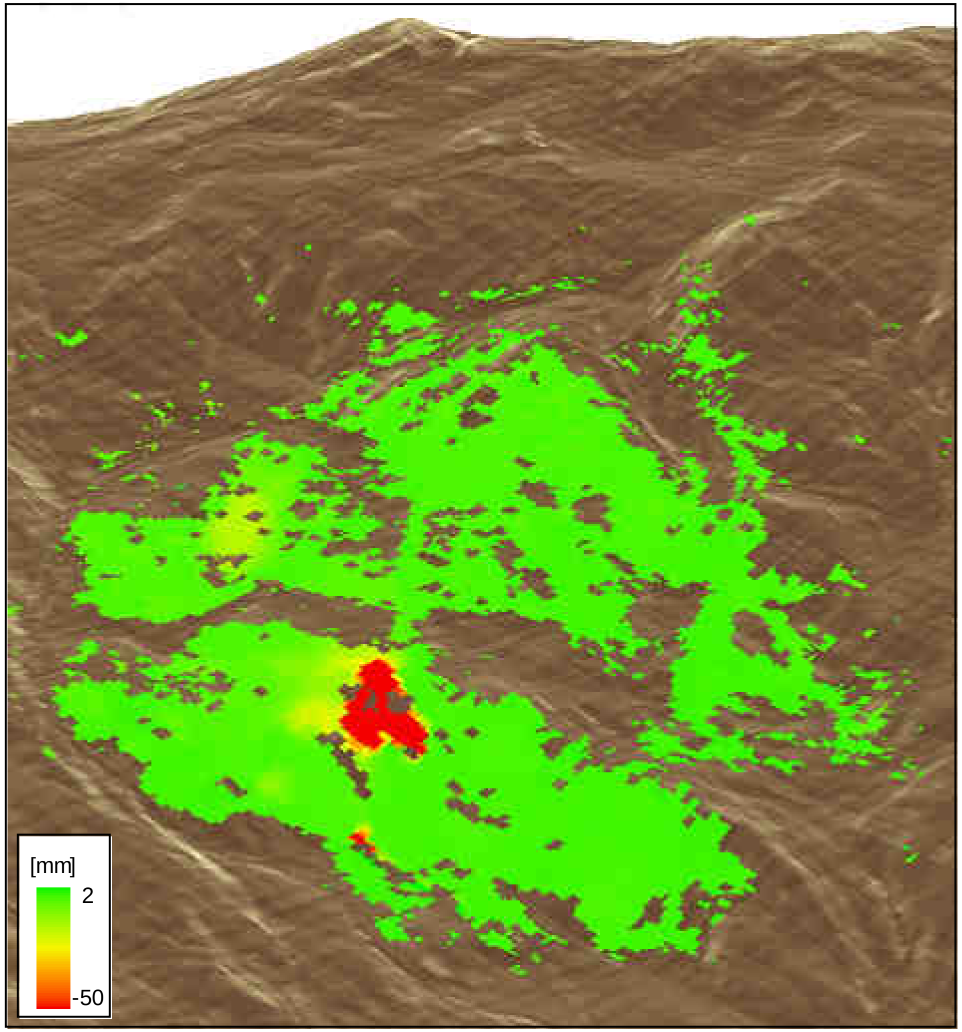


Geocoded cumulative displacement map (12 h)

Geocoded Line Of Sight Displacement Map

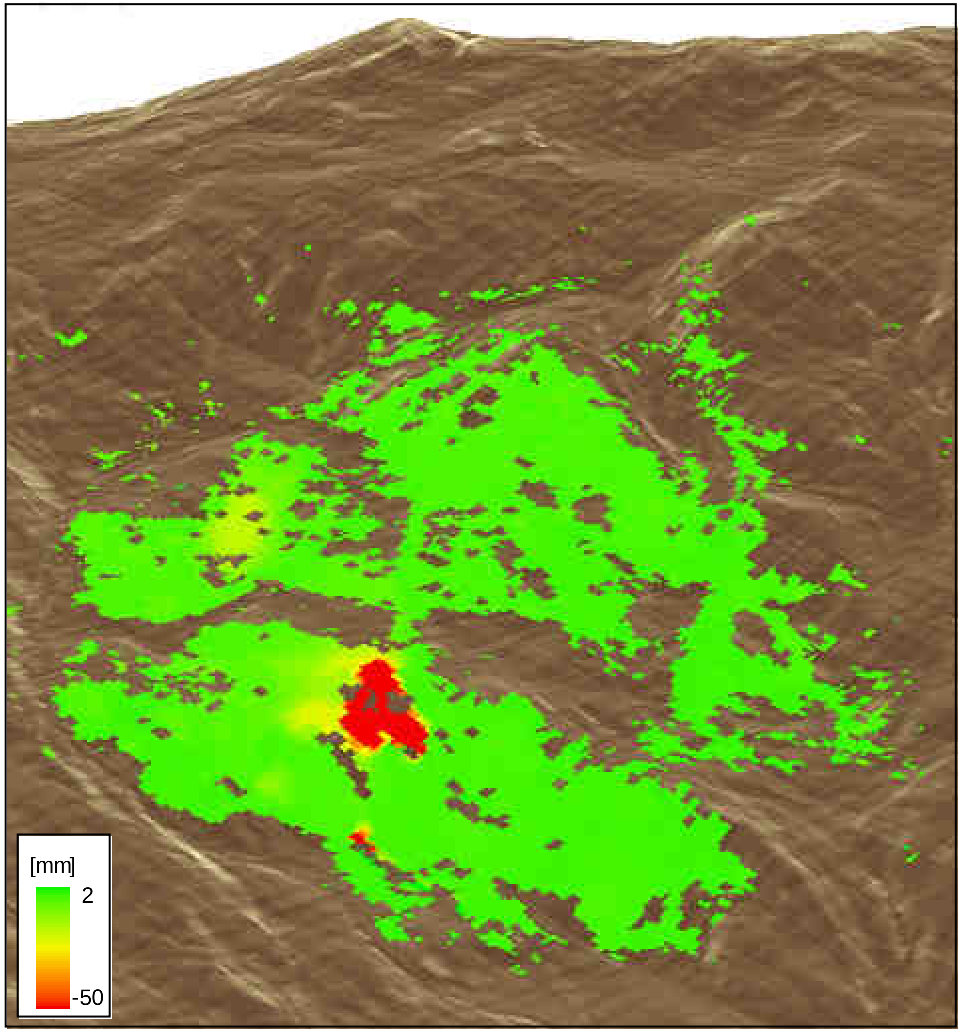


Geocoded cumulative displacement map (13 h)



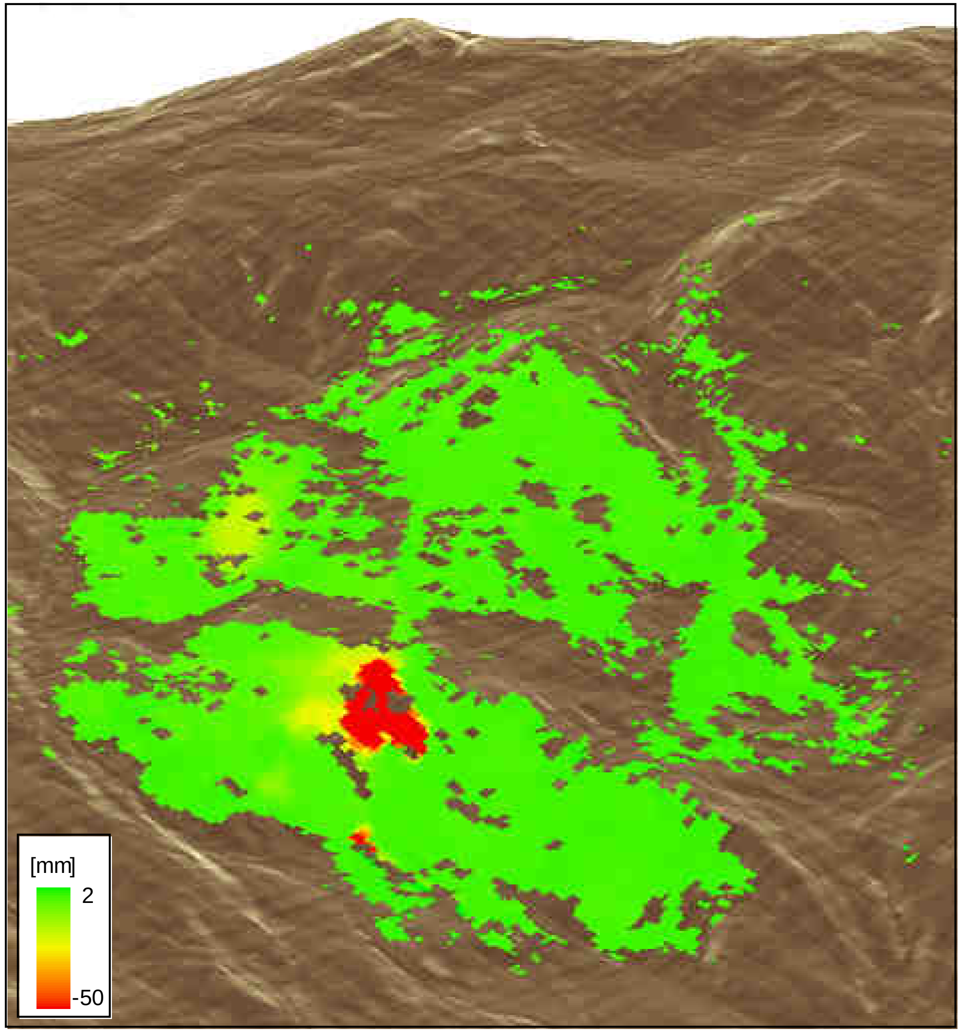
Geocoded cumulative displacement map (14 h)

Geocoded Line Of Sight Displacement Map



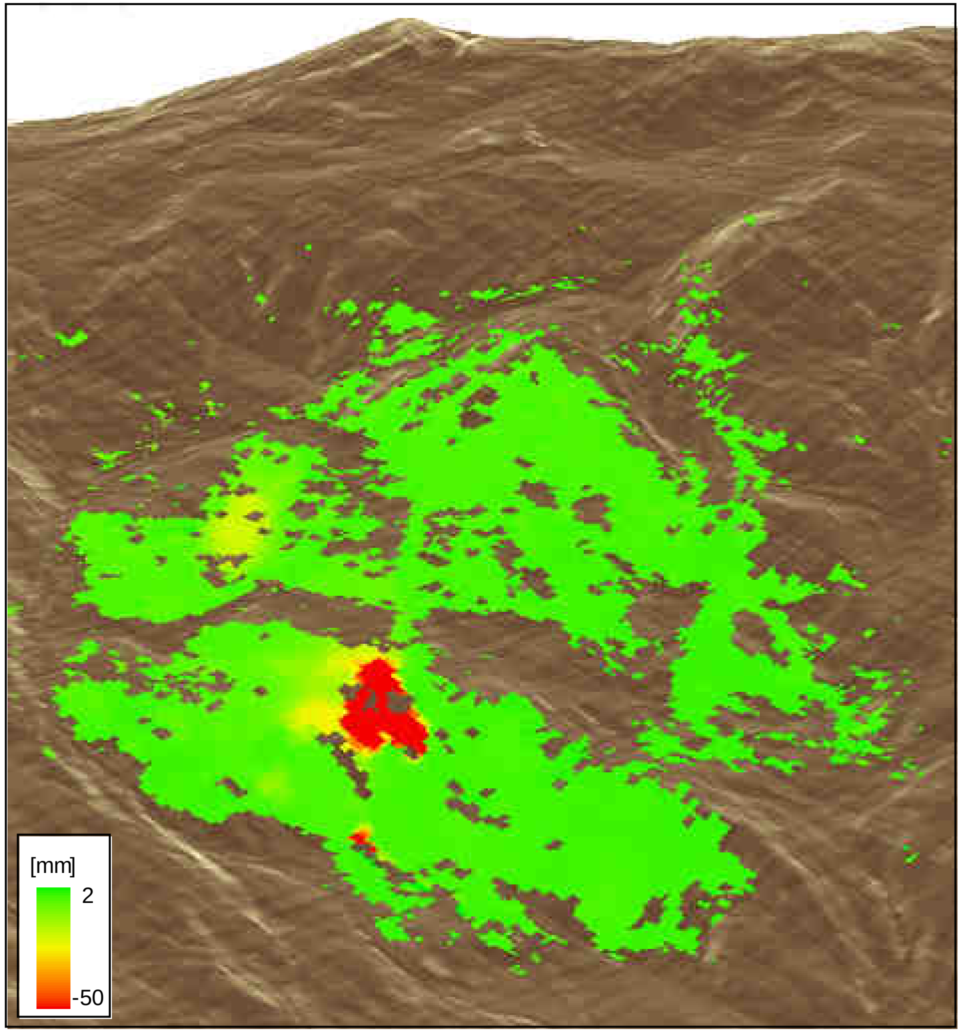
Geocoded cumulative displacement map (15 h)

Geocoded Line Of Sight Displacement Map



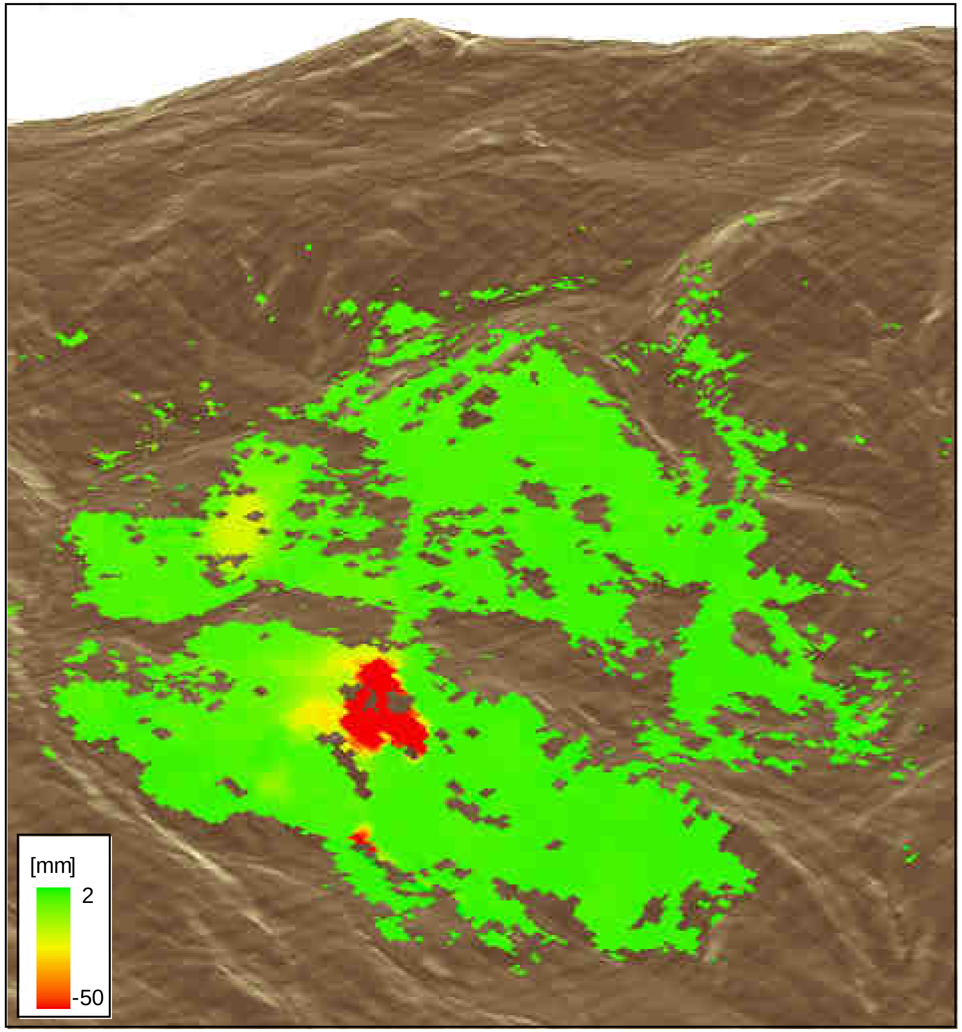
Geocoded cumulative displacement map (16 h)

Geocoded Line Of Sight Displacement Map



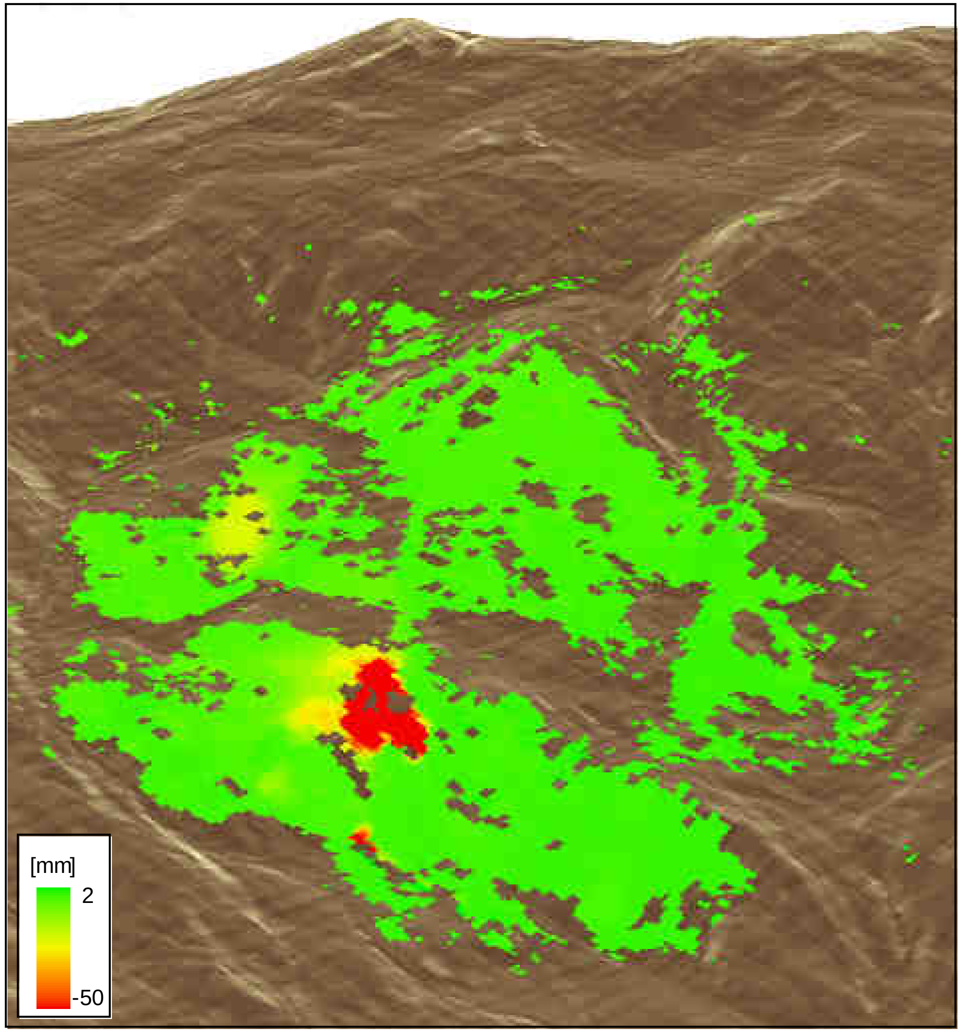
Geocoded cumulative displacement map (17 h)

Geocoded Line Of Sight Displacement Map



Geocoded cumulative displacement map (18 h)

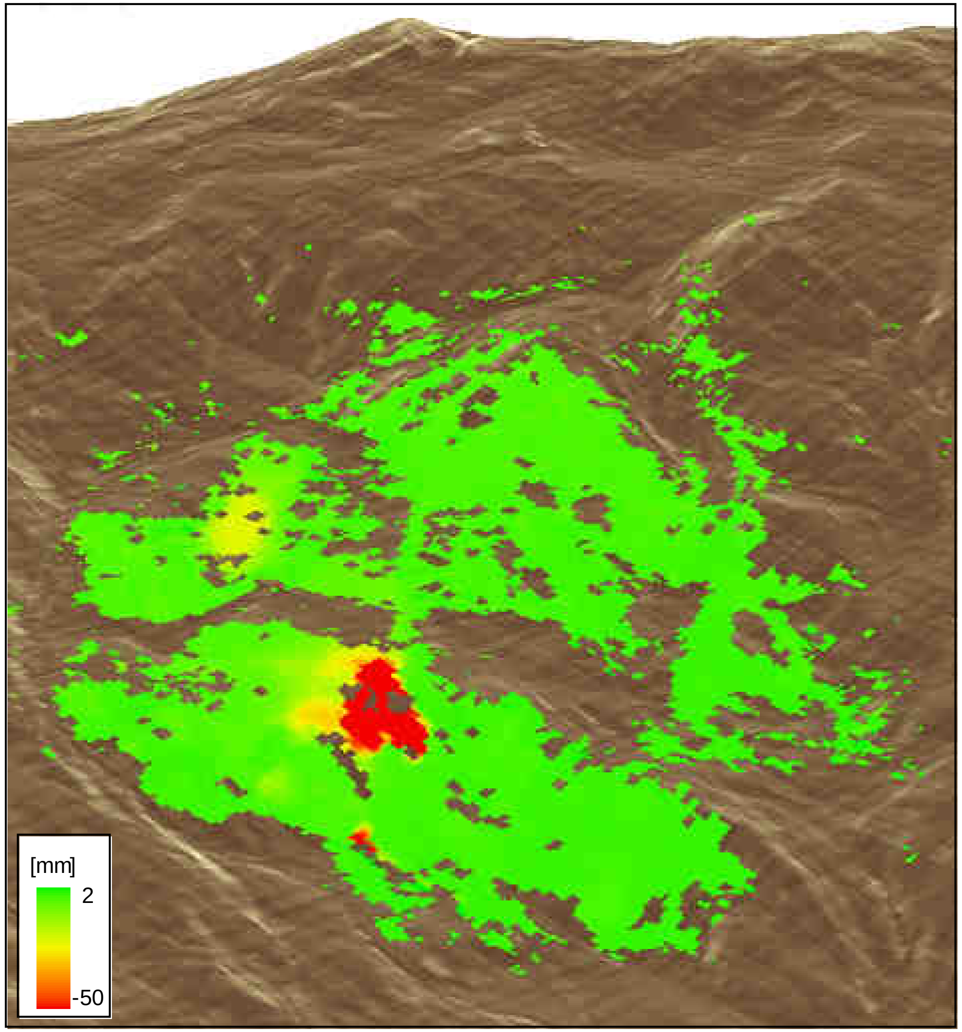
Geocoded Line Of Sight Displacement Map



IDS INGEGNERIA DEI SISTEMI

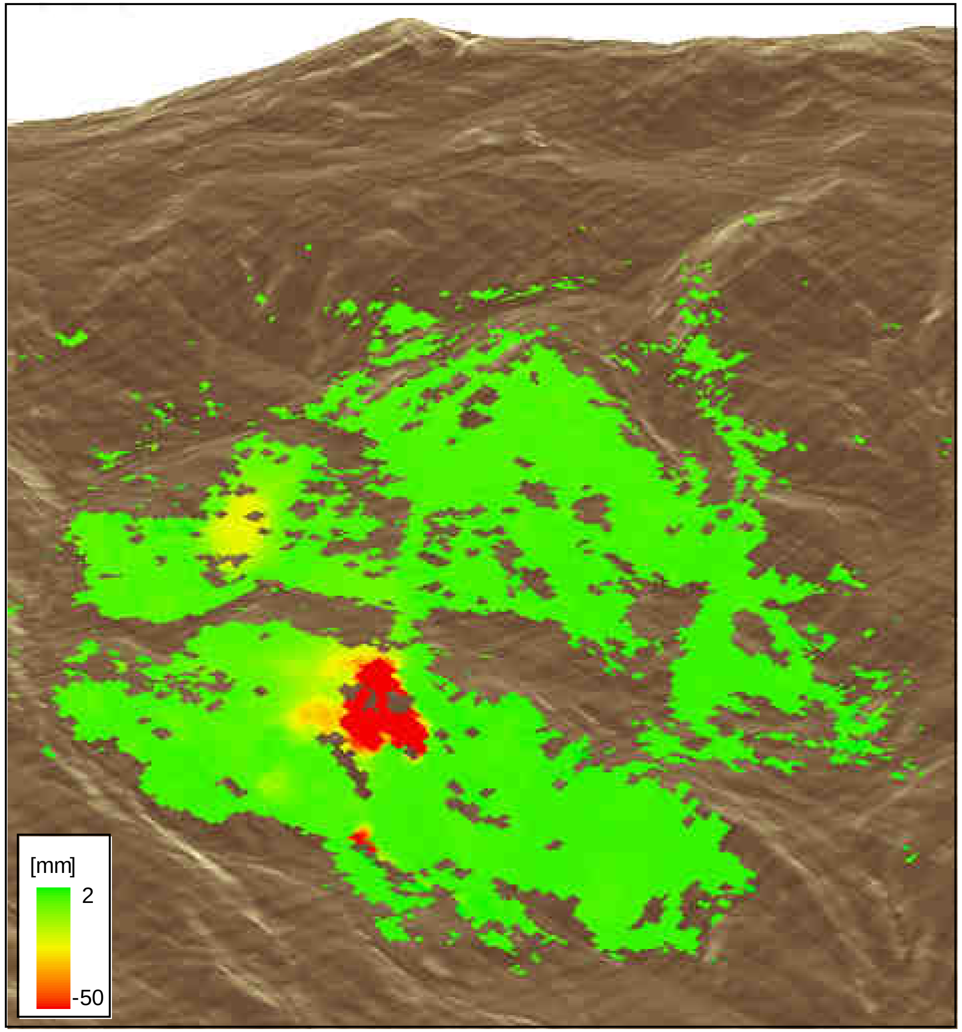
Geocoded cumulative displacement map (19 h)

Geocoded Line Of Sight Displacement Map

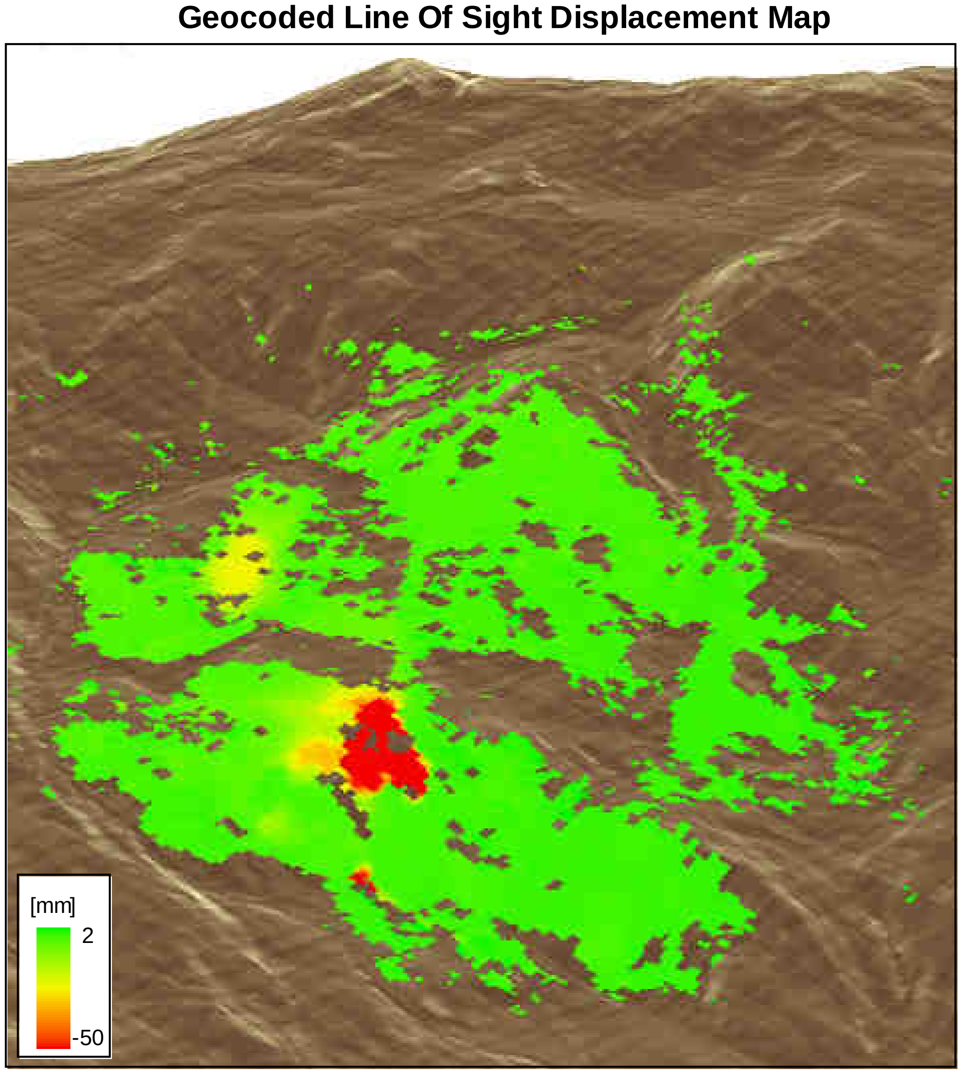


Geocoded cumulative displacement map (20 h)

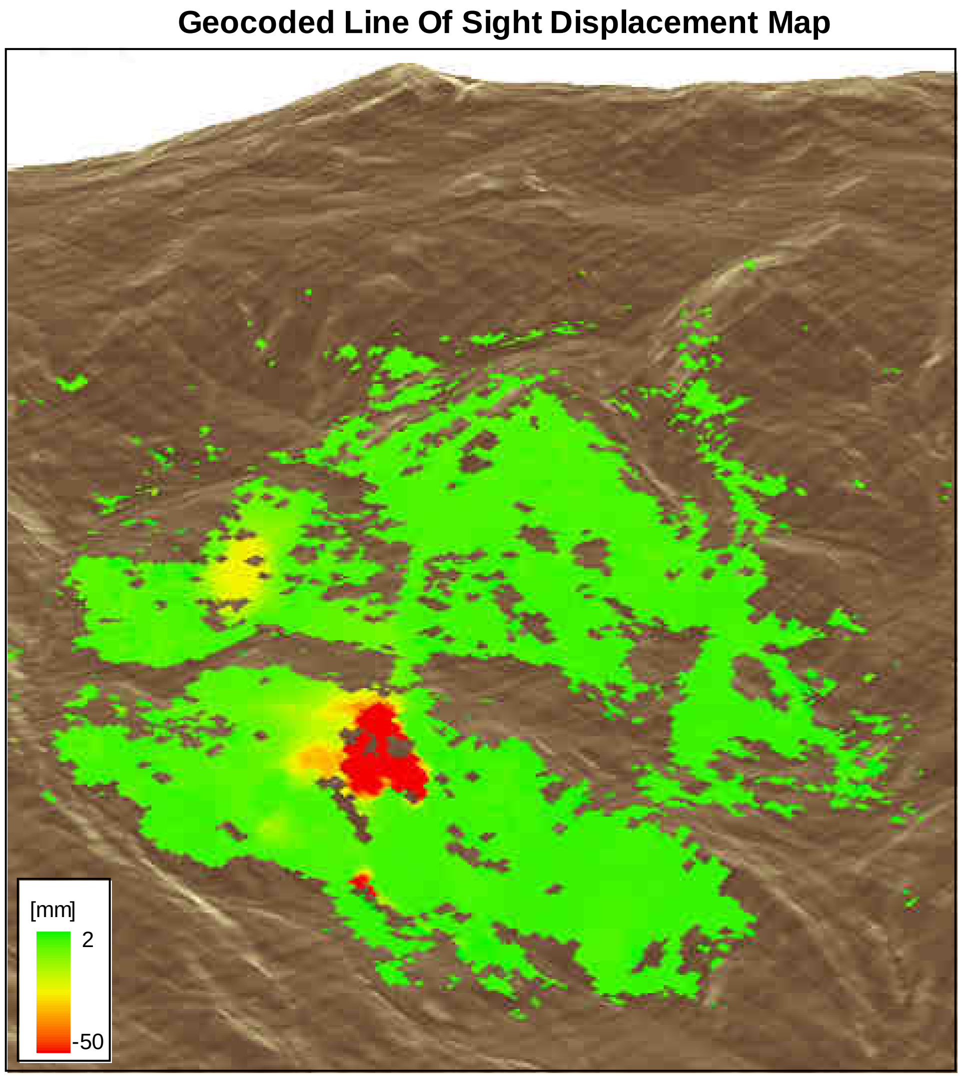
Geocoded Line Of Sight Displacement Map



Geocoded cumulative displacement map (21 h)

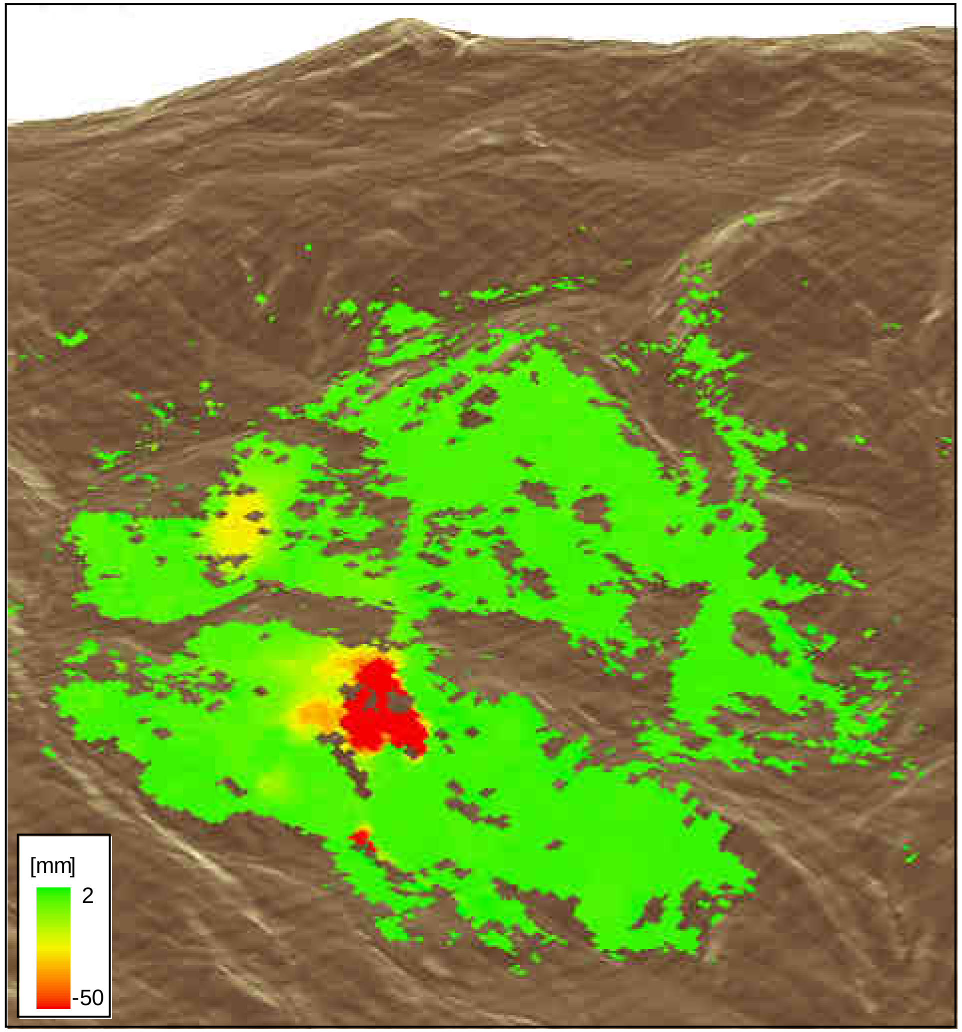


Geocoded cumulative displacement map (22 h)



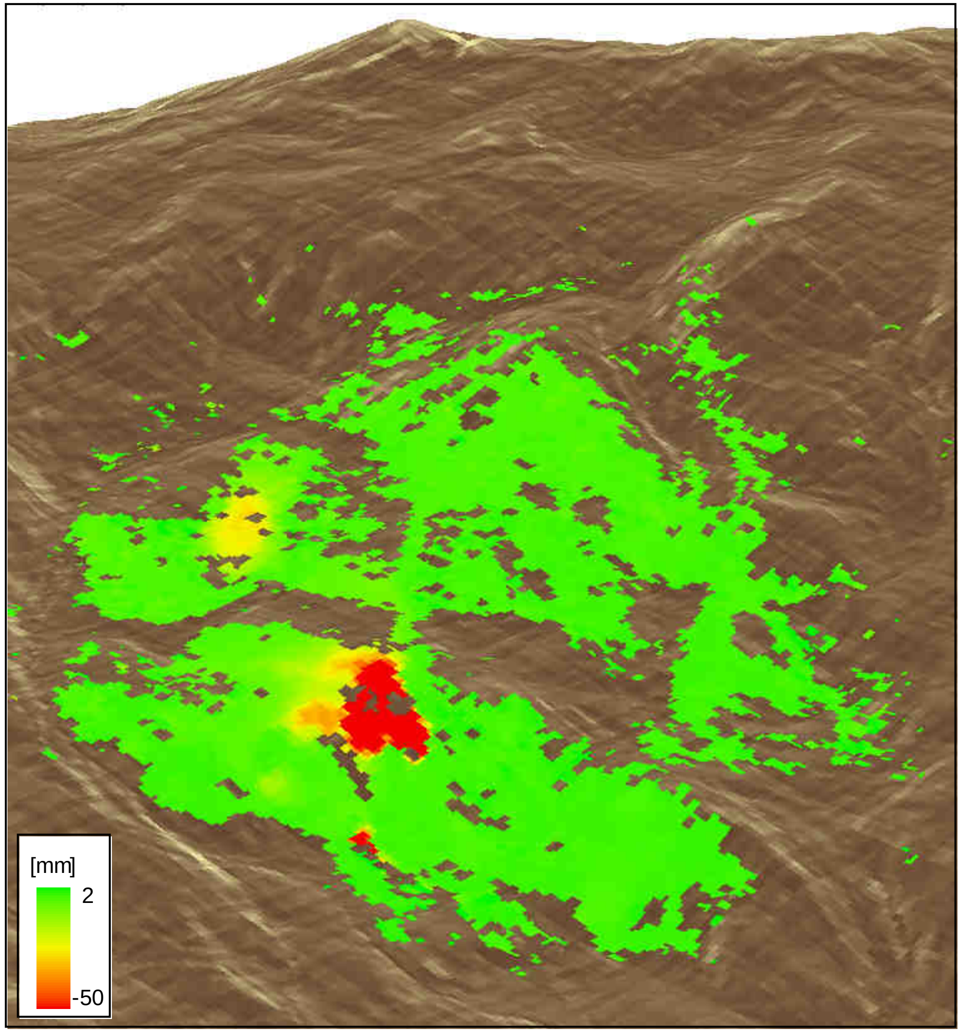
Geocoded cumulative displacement map (23 h)

Geocoded Line Of Sight Displacement Map



Geocoded cumulative displacement map (24 h)

Geocoded Line Of Sight Displacement Map



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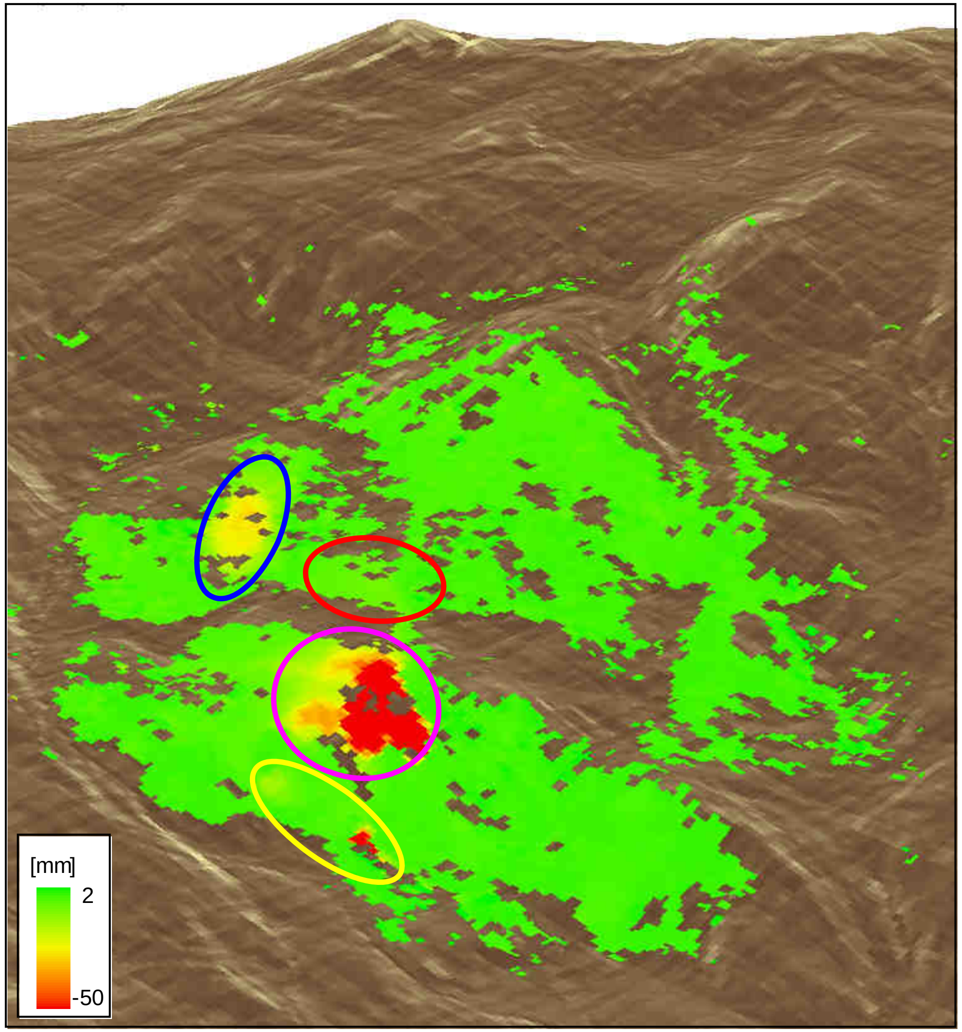
Identification of moving portions of the slope

Zona A	
Zona B	
Zona C	
Zona D	

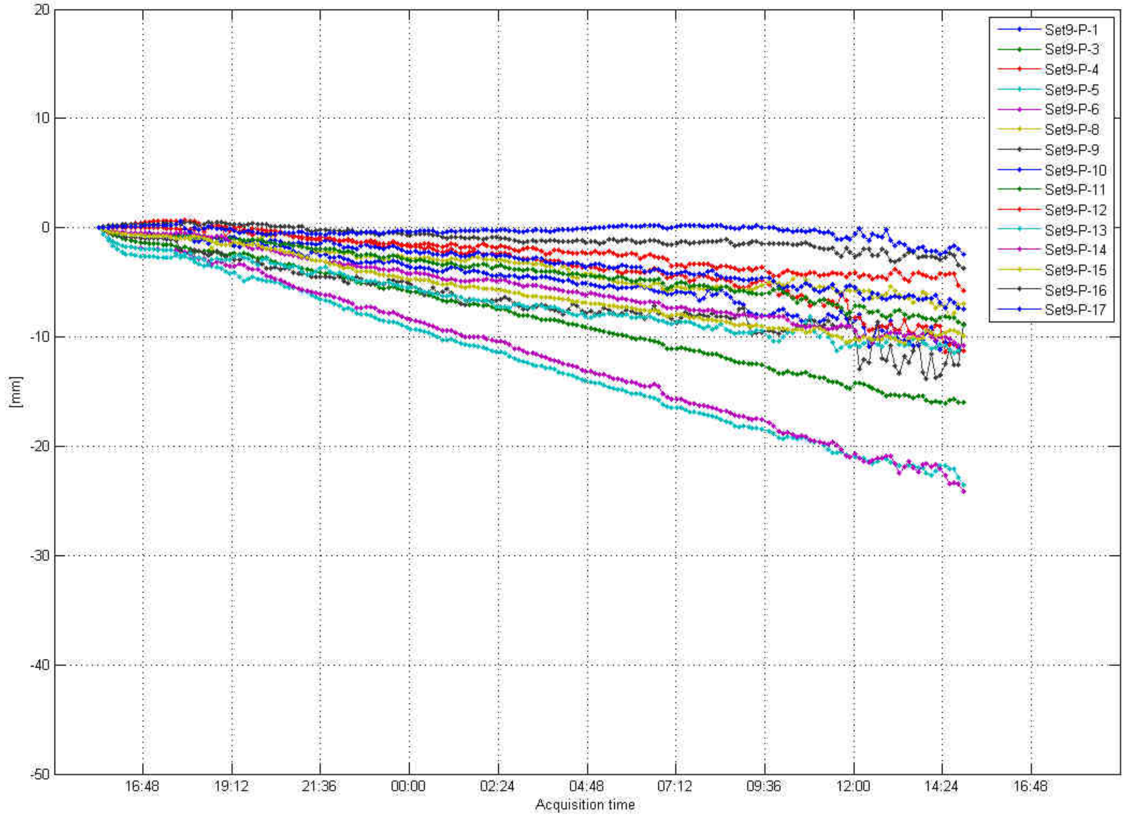
Geocoded Line Of Sight Displacement Map



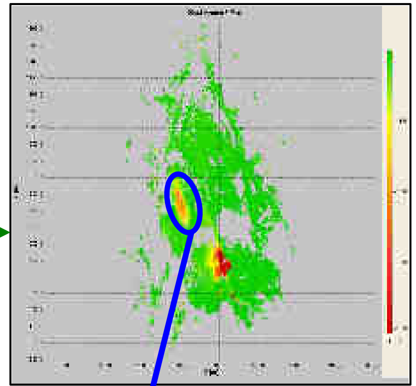
Displacement time series

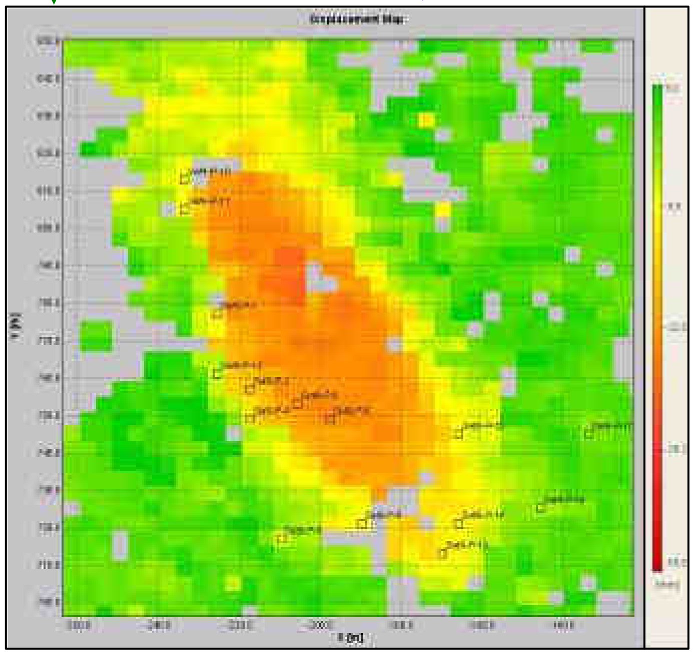
ZONA A - movimento di alcuni punti di misura selezionati

Line Of Sight Displacement Time Series



Mappe di spostamento cumulato dopo 24 ore



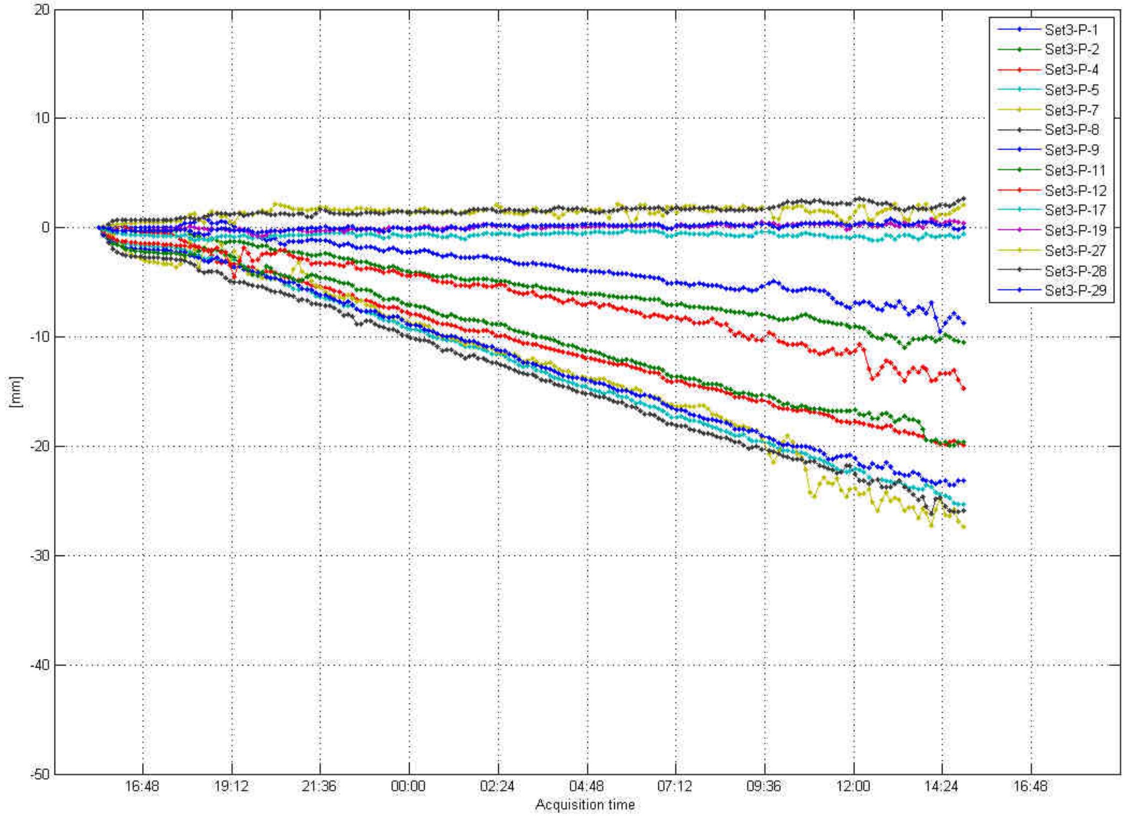


IDS INGEGNERIA DEI SISTEMI

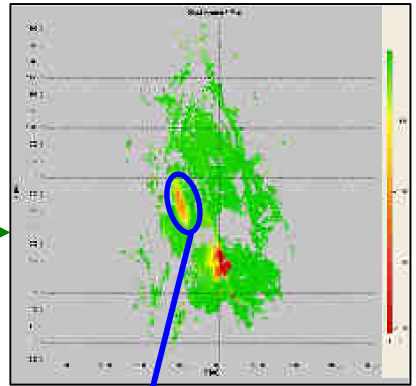
Displacement time series

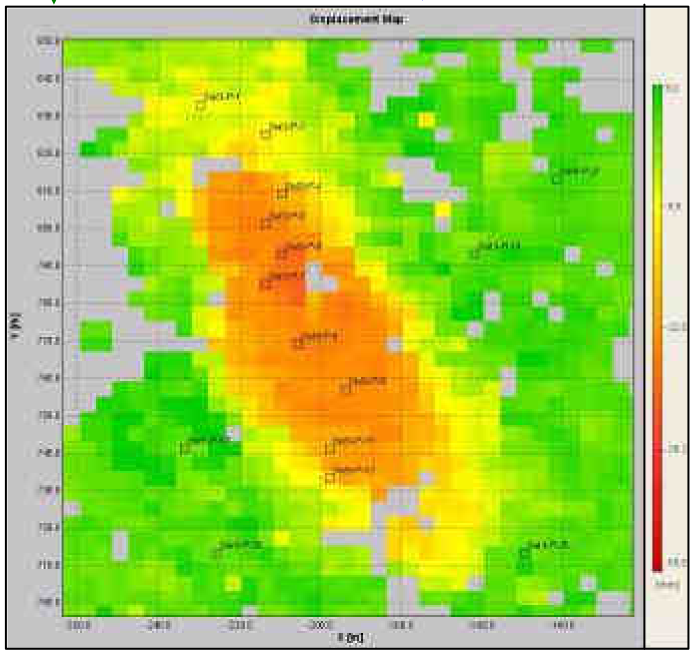
ZONE A - displacement of a few points

Line Of Sight Displacement Time Series



Mappe di spostamento cumulato dopo 24 ore

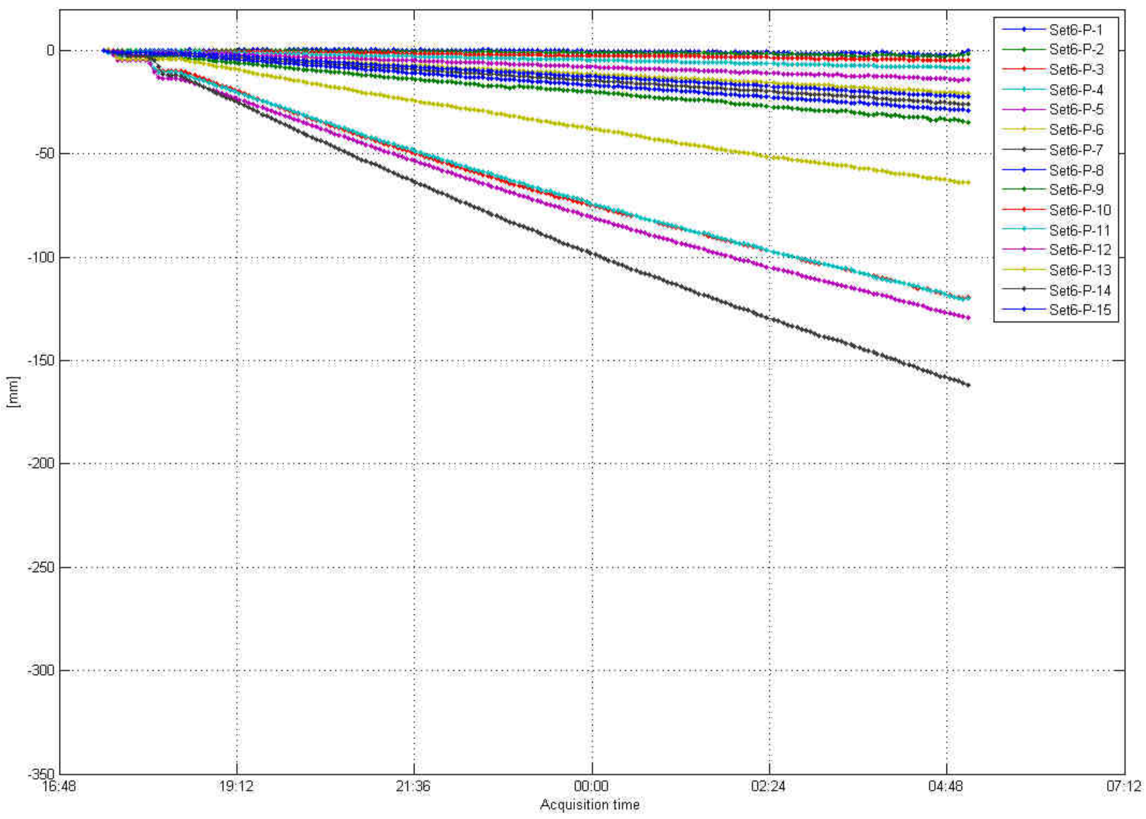


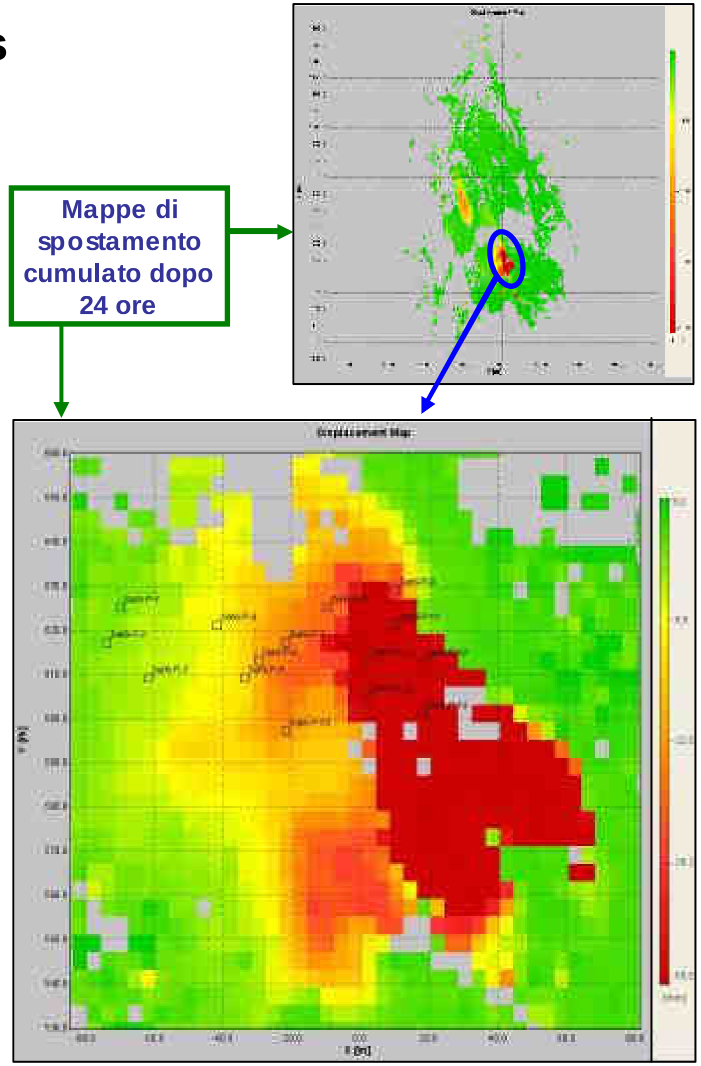


IDS INGEGNERIA DEI SISTEMI

Displacement time series

ZONE B - displacement of a few points



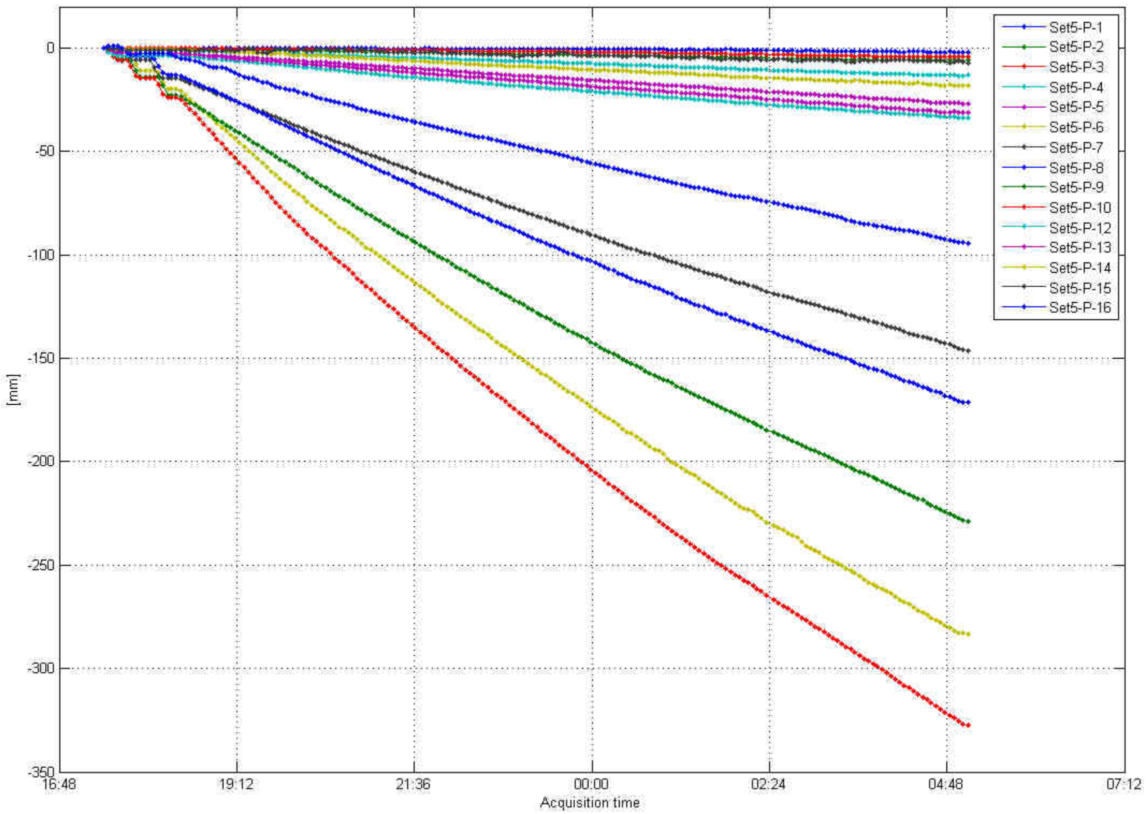


IDS INGEGNERIA DEI SISTEMI

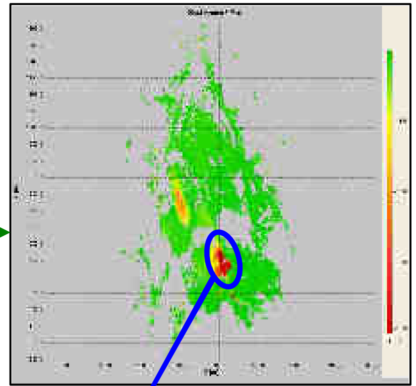
Displacement time series

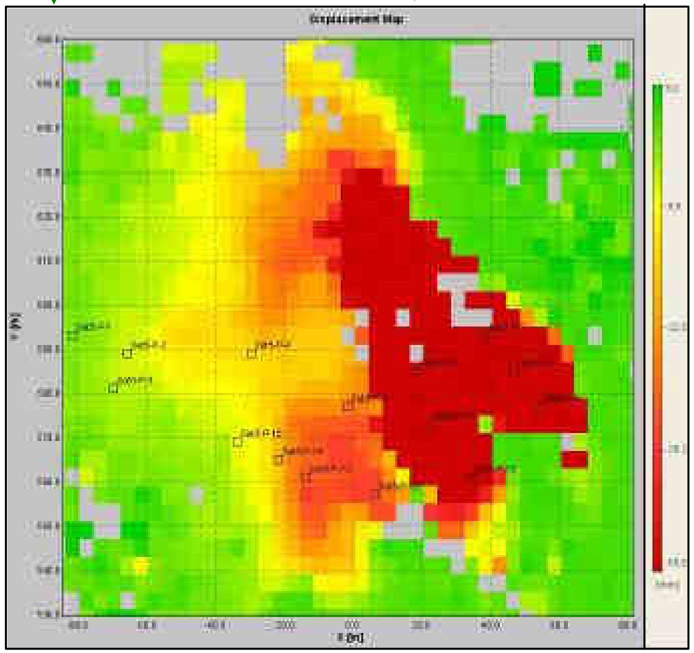
ZONE C - displacement of a few points

Line Of Sight Displacement Time Series



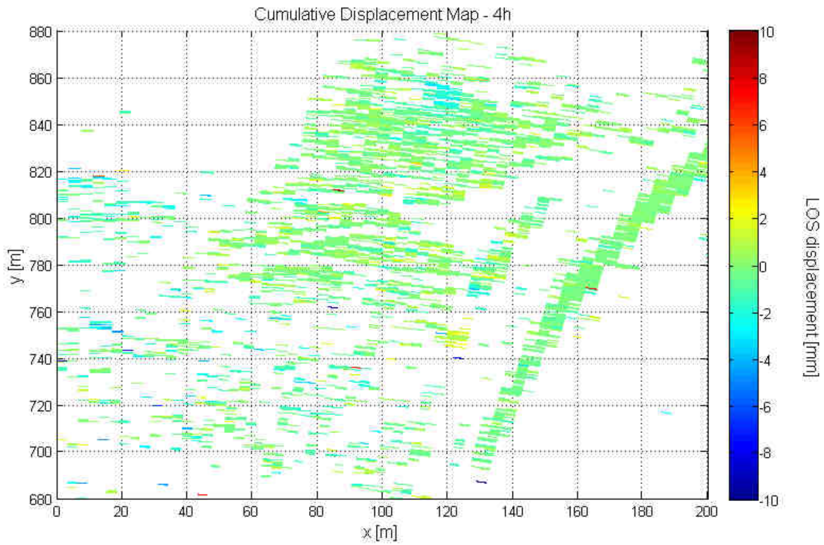
Mappe di spostamento cumulato dopo 24 ore

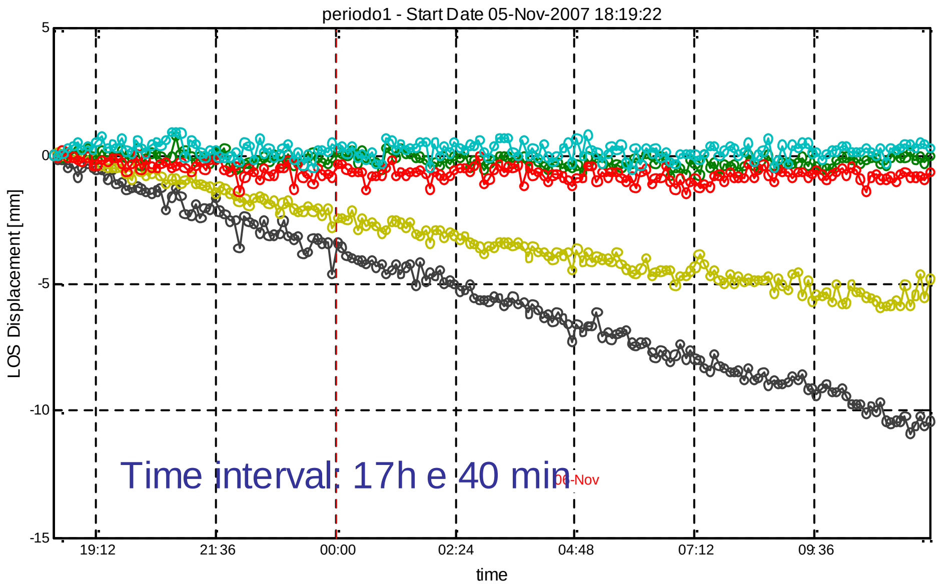


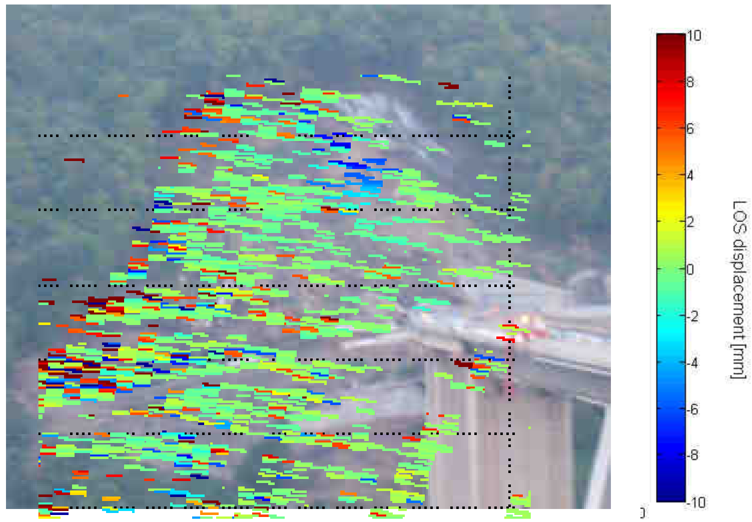


IDS INGEGNERIA DEI SISTEMI

Landslide Monitoring: landslide on a highway





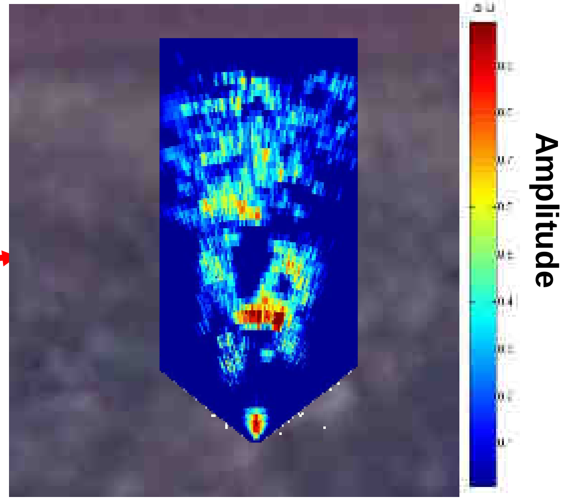


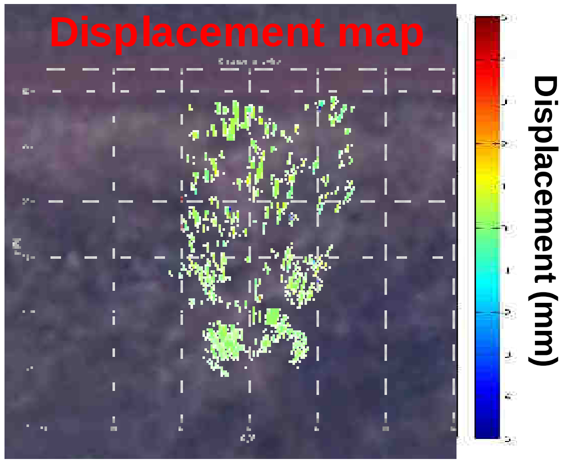
IDS INGEGNERIA DEI SISTEMI

Landslide monitoring along railways

Monitoring of an unstable slope along a railway (Brazil) with IBIS-L

Radar image





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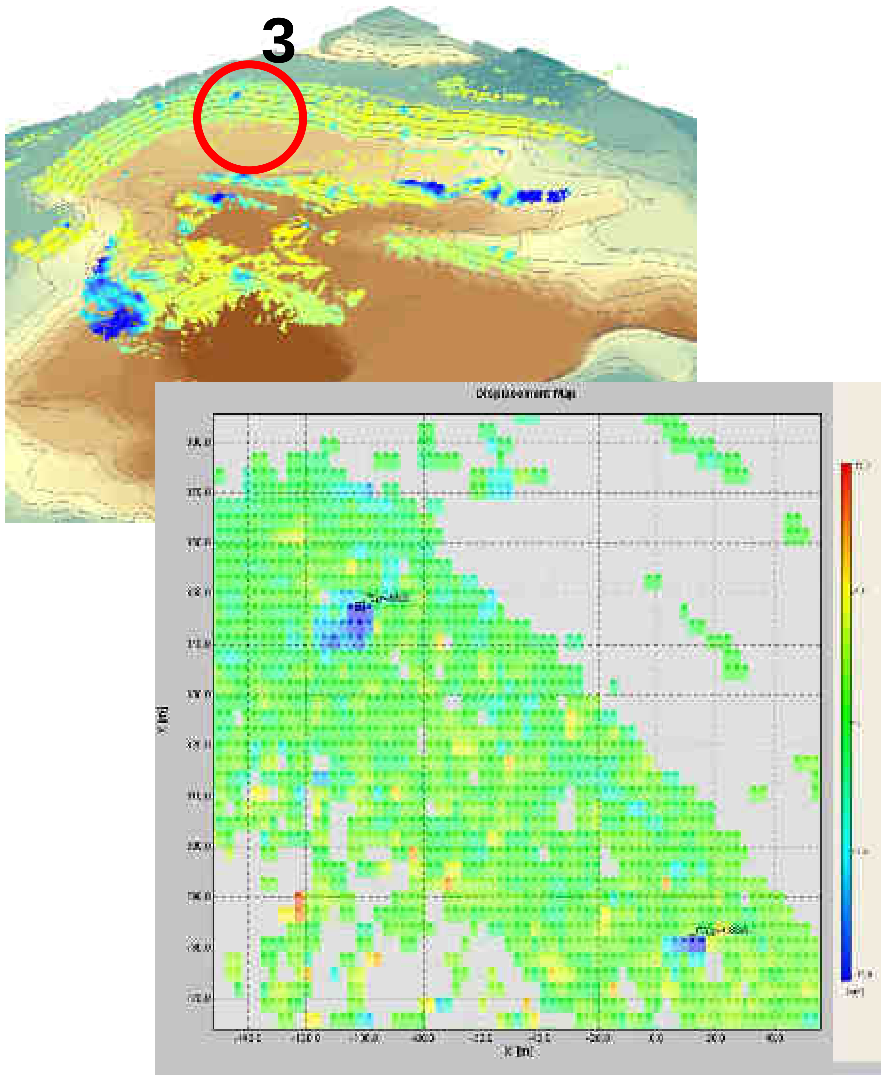
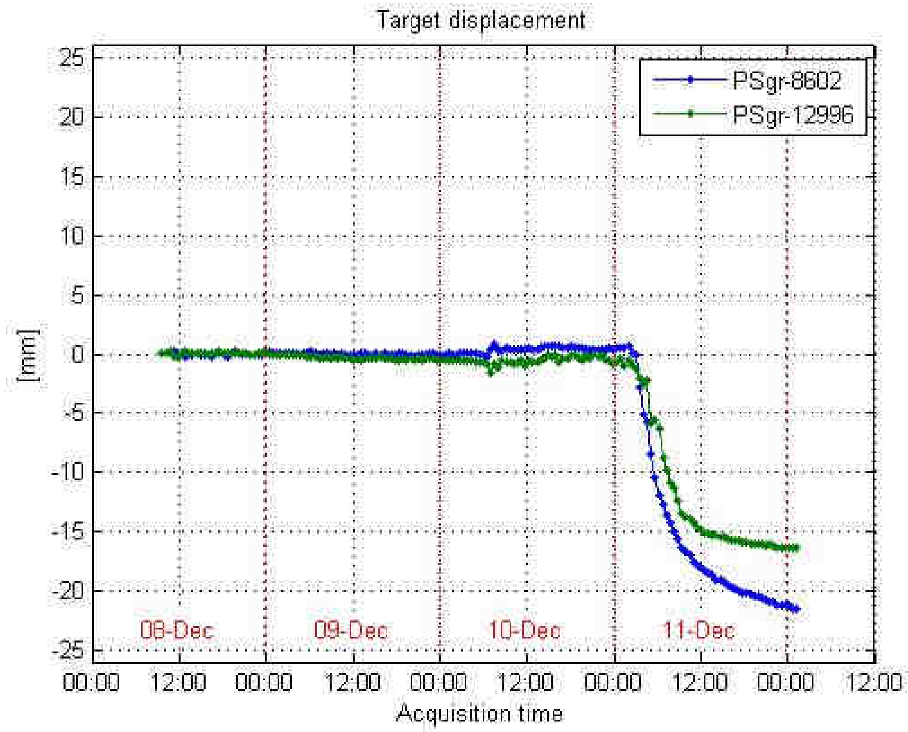
Slope Monitoring within a open-pit mine

Displacement through time of selected points





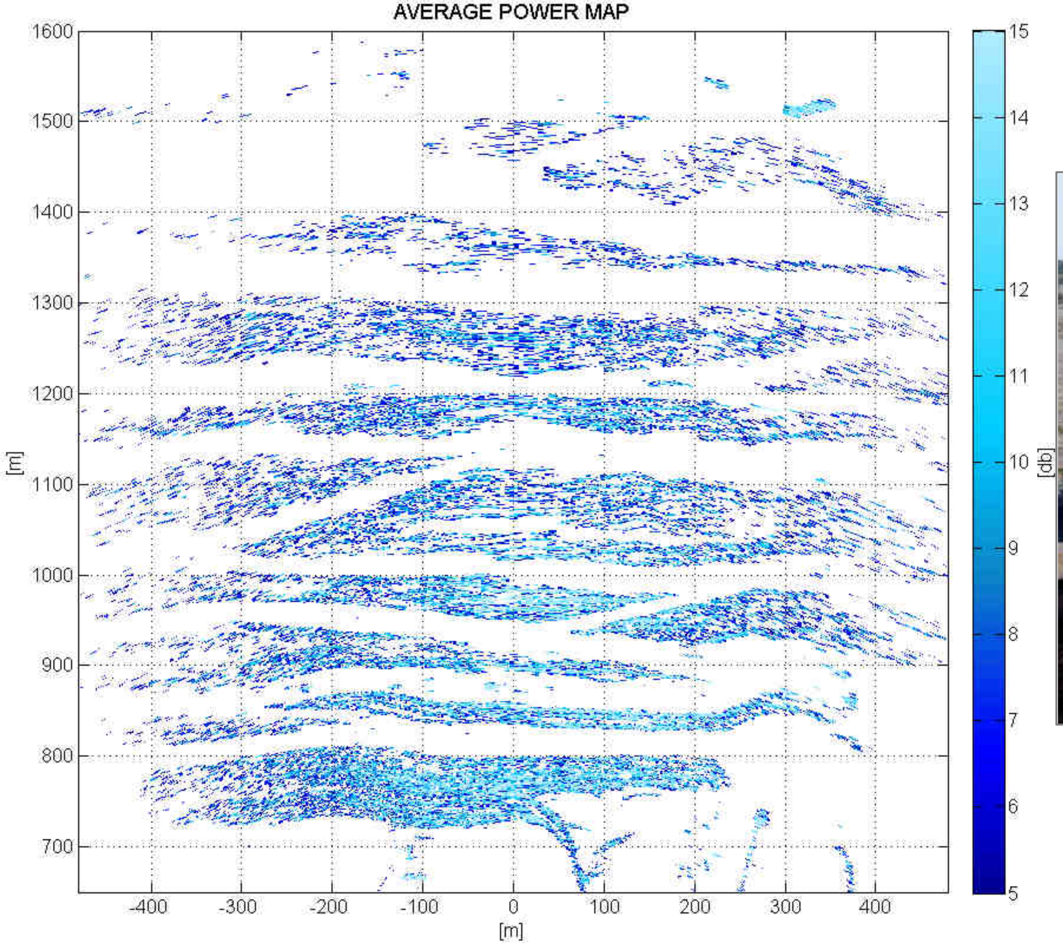
IDS INGEGNERIA DEI SISTEMI

Brown coal mine: slope instability

• Use of IBIS-L for slope stability monitoring within an open-pit mine during excavator operations

Brown coal mine: slope instability

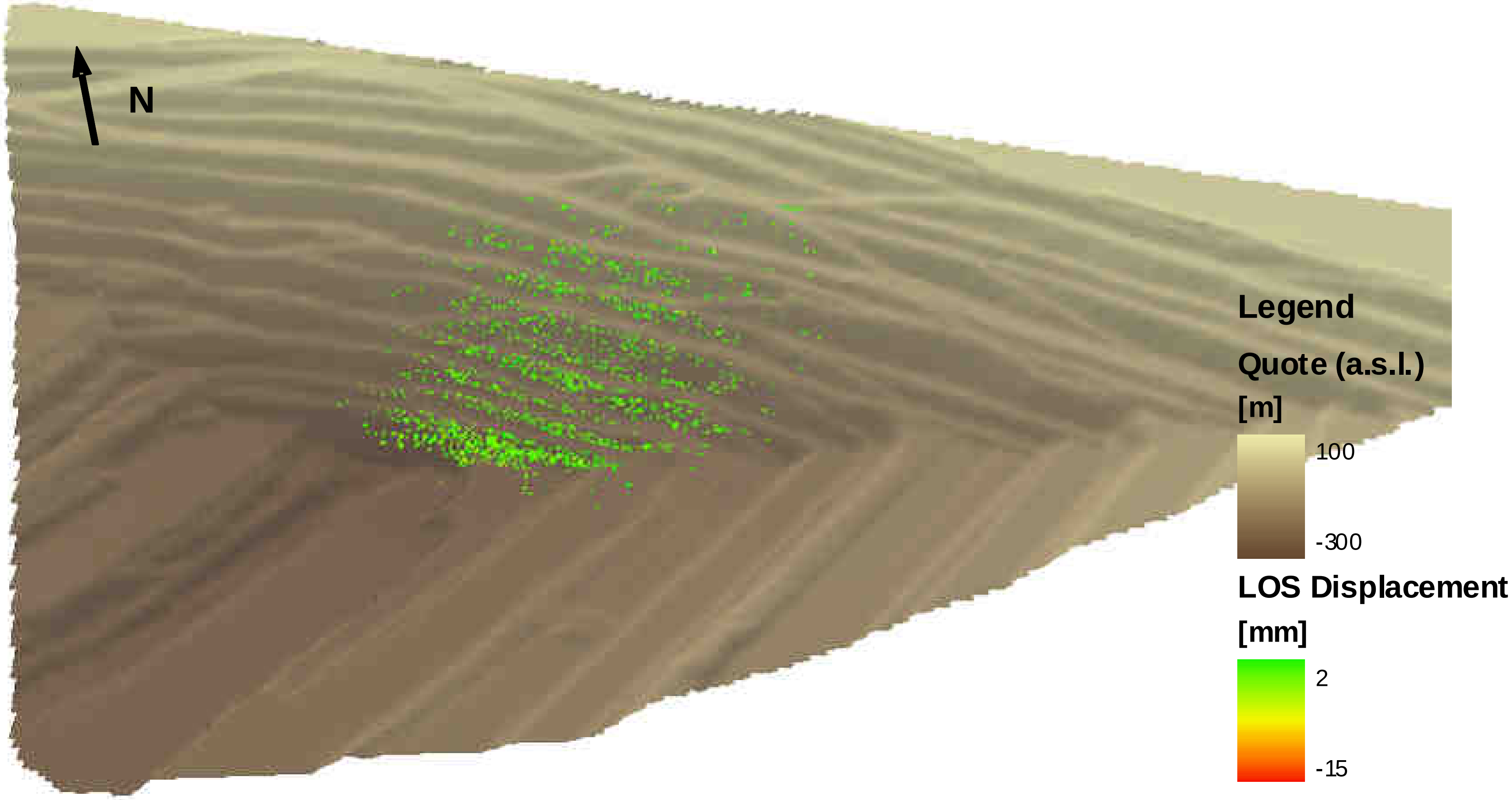
Thousands of pixel belonging to the slope have a quite good power response showing a Thermal SNR above 10 dB



IBIS-L view on the slope

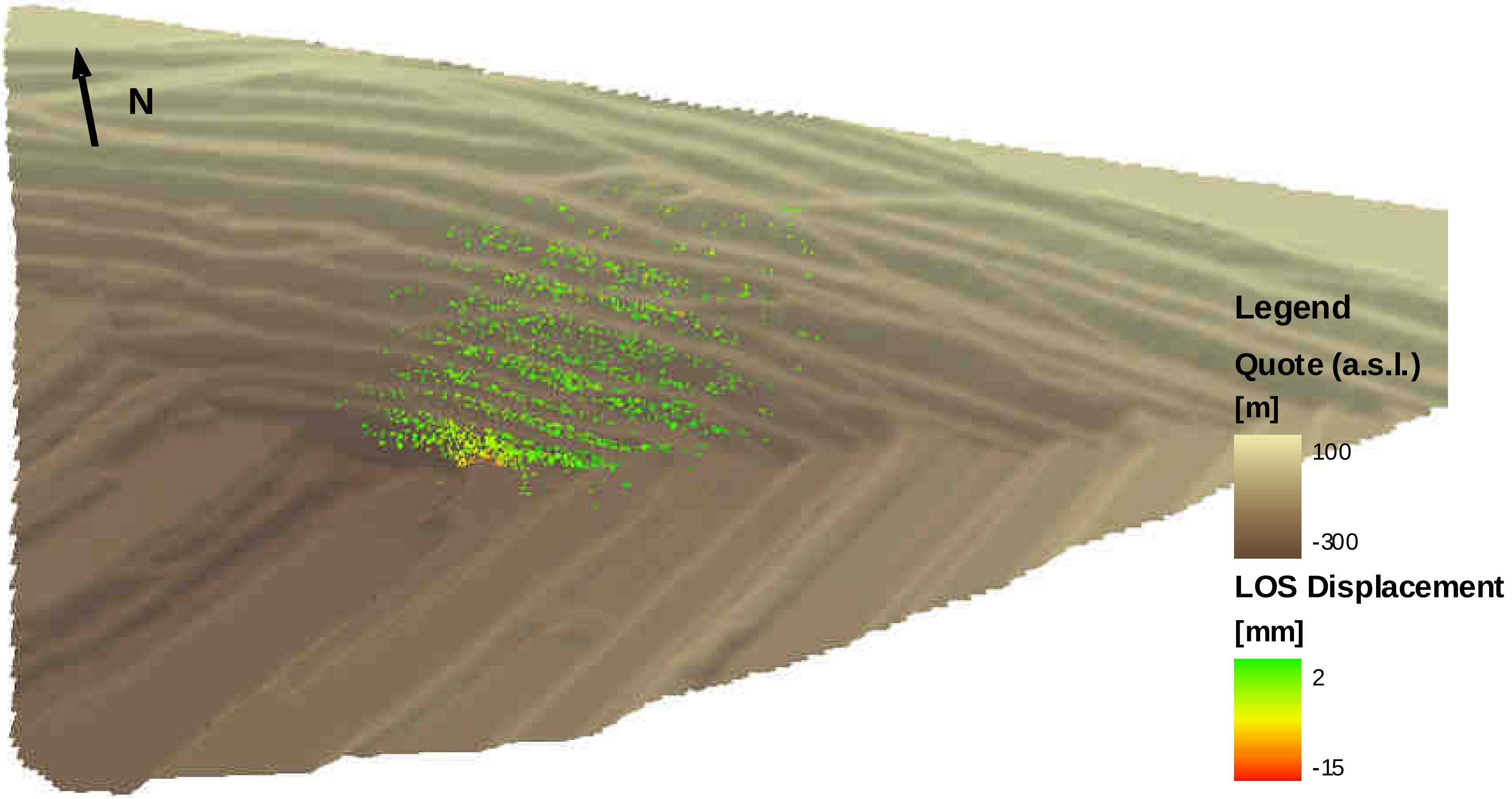
IDS INGEGNERIA DEI SISTEMI

Geolocated cumulative los displacement map (03 h)

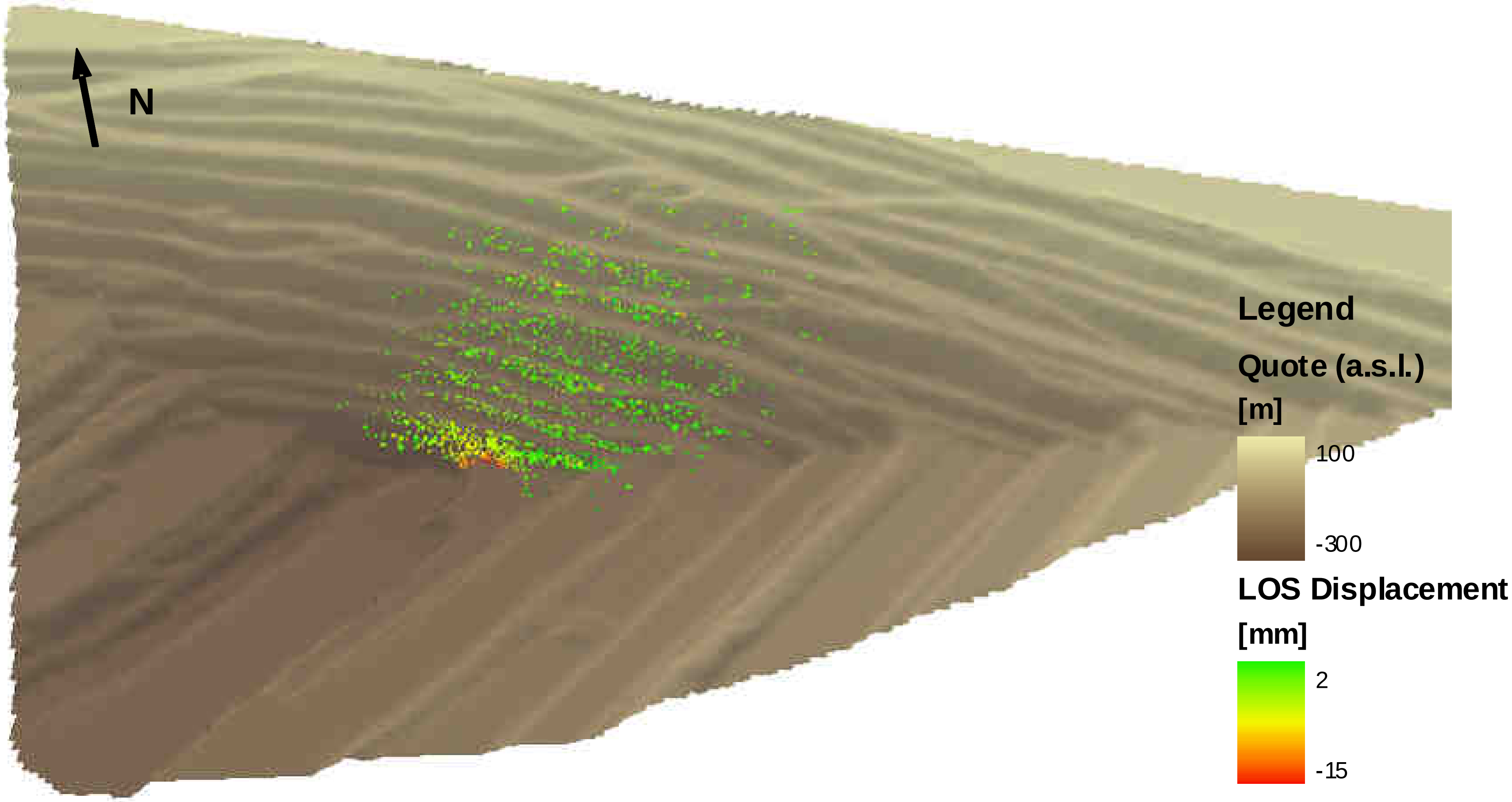


IDS INGEGNERIA DEI SISTEMI

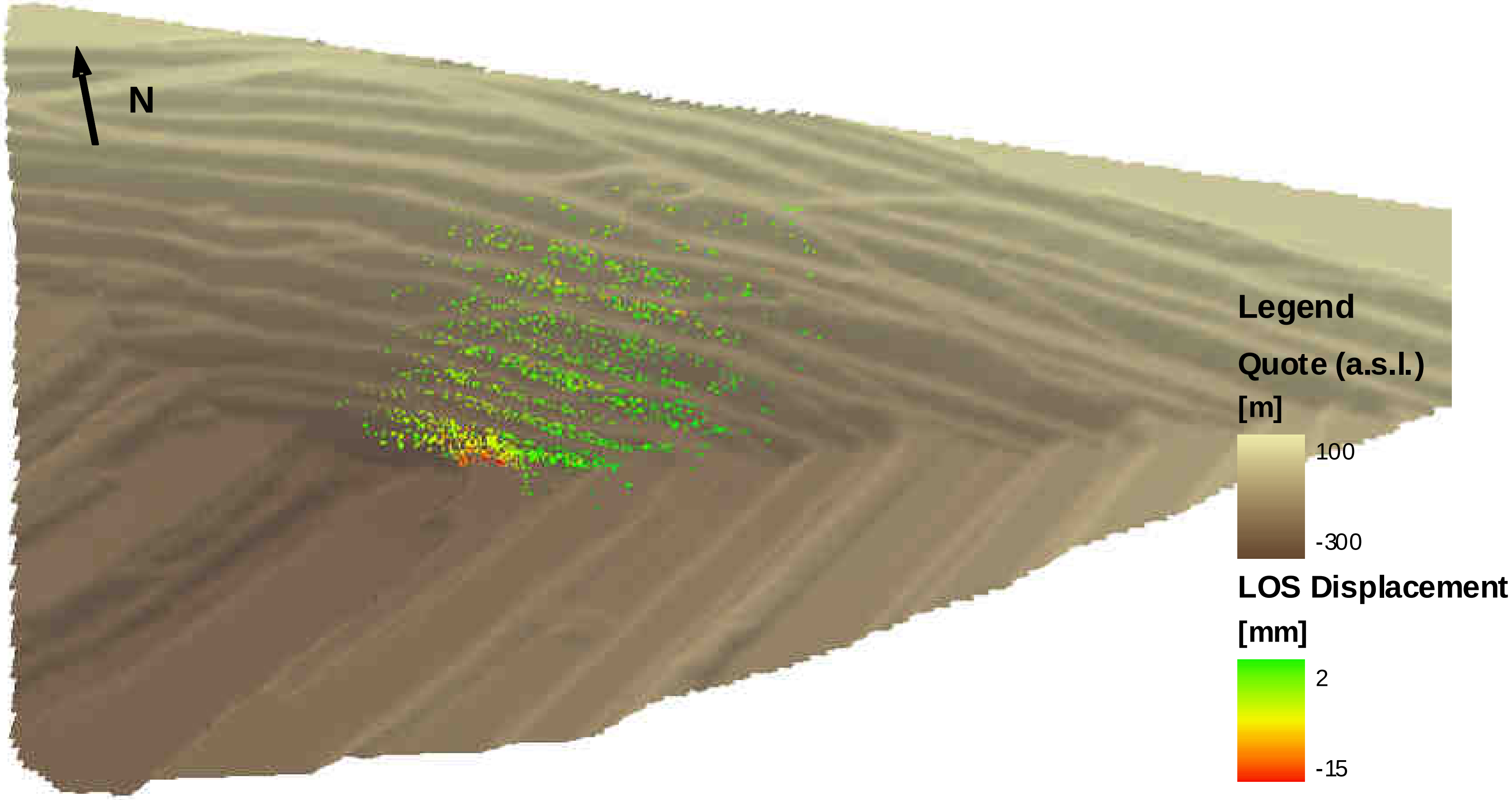
Geolocated cumulative los displacement map (31 h)



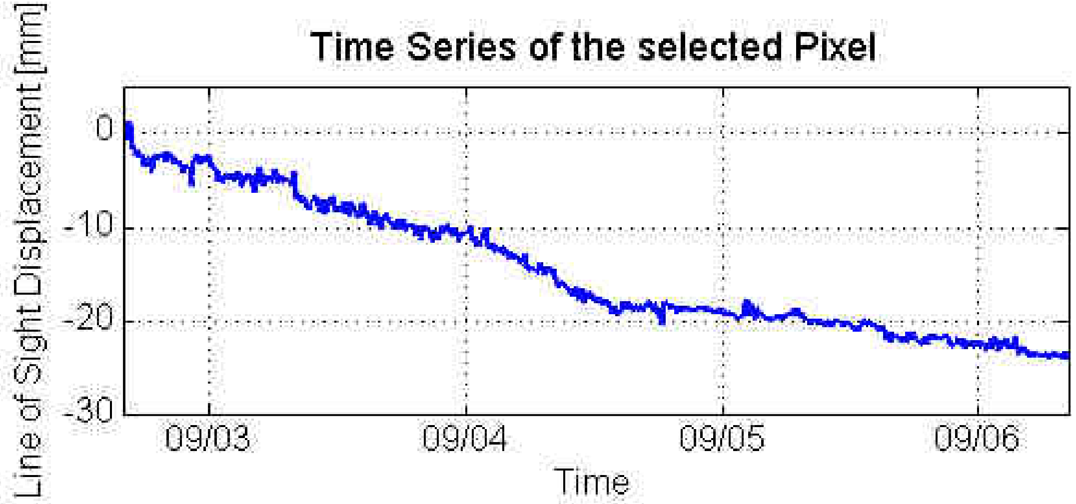
Geolocated cumulative los displacement map (64 h)

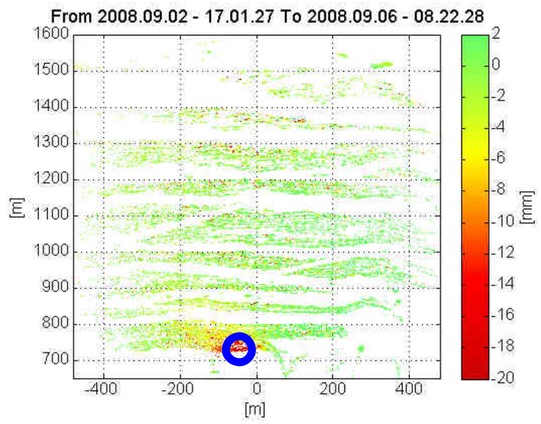


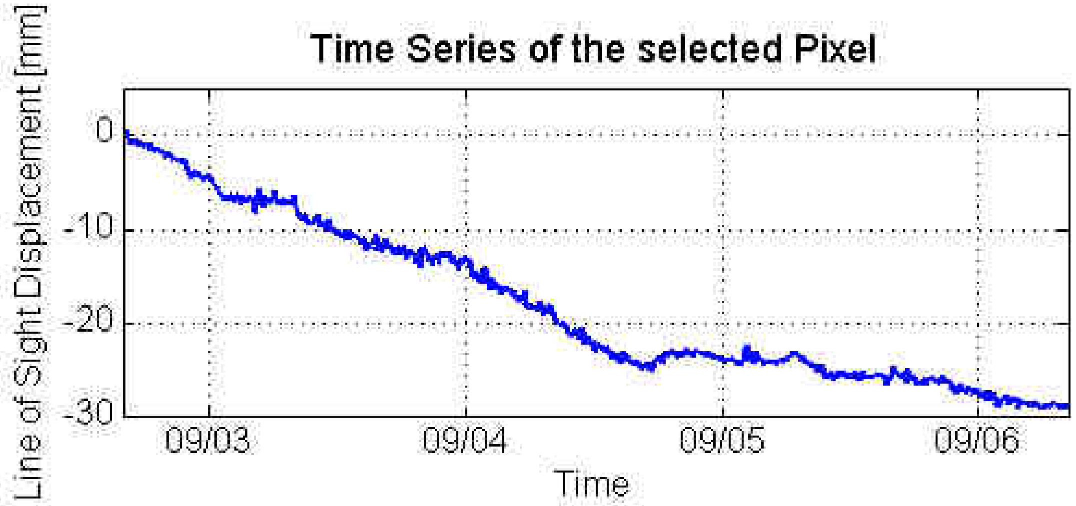
Geolocated cumulative los displacement map (88 h)

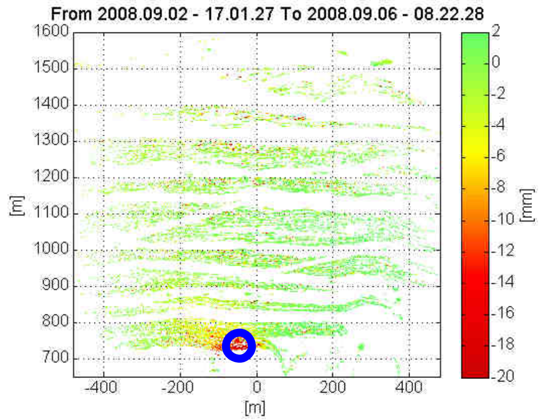


Time Series of some Selected Points

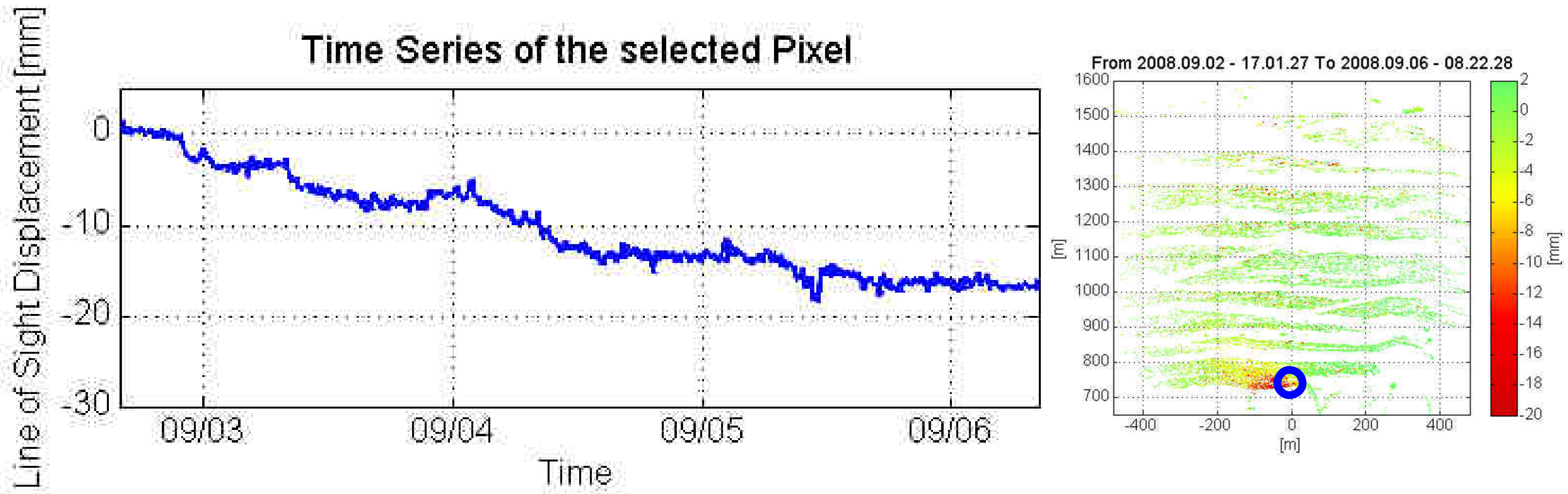


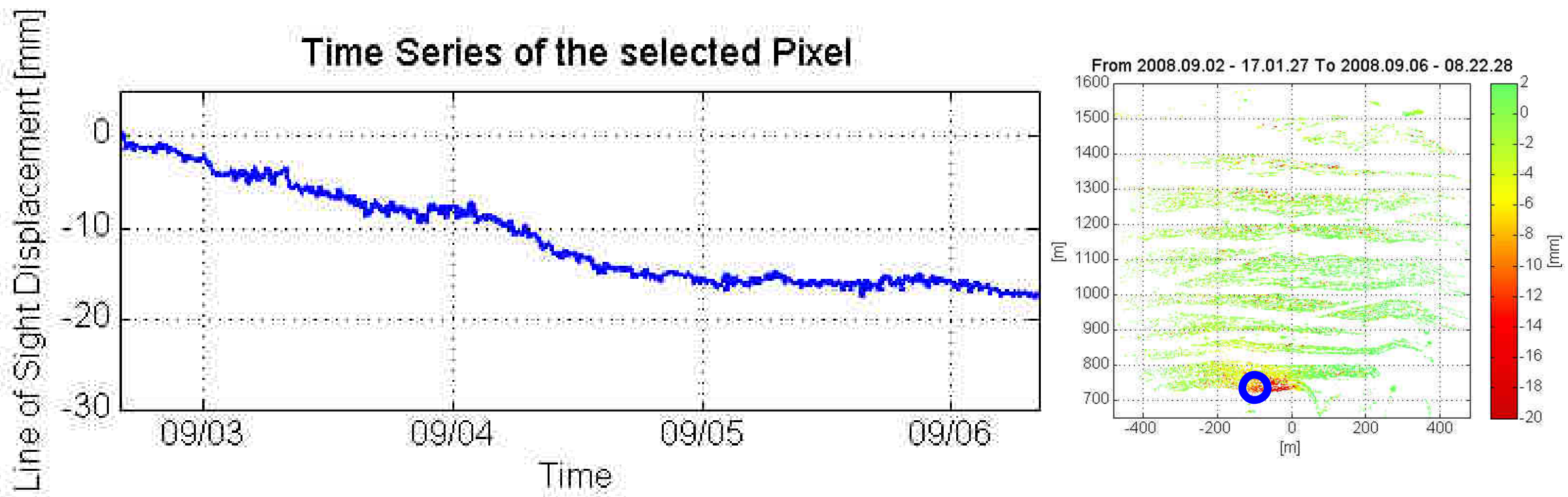






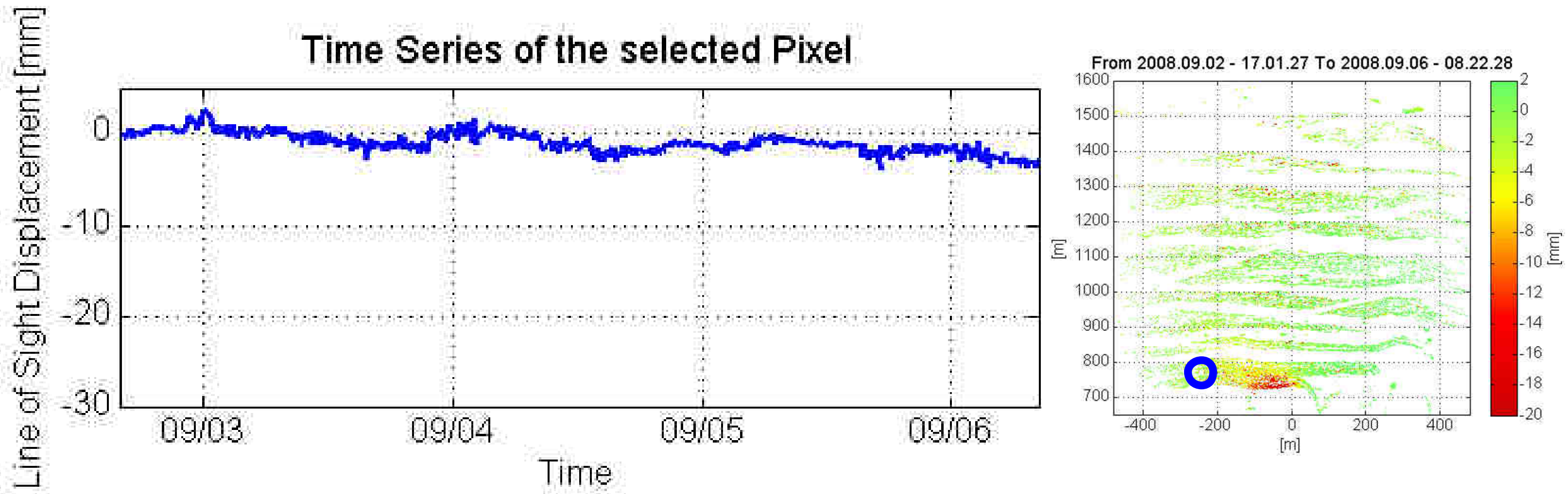
Time Series of some Selected Points

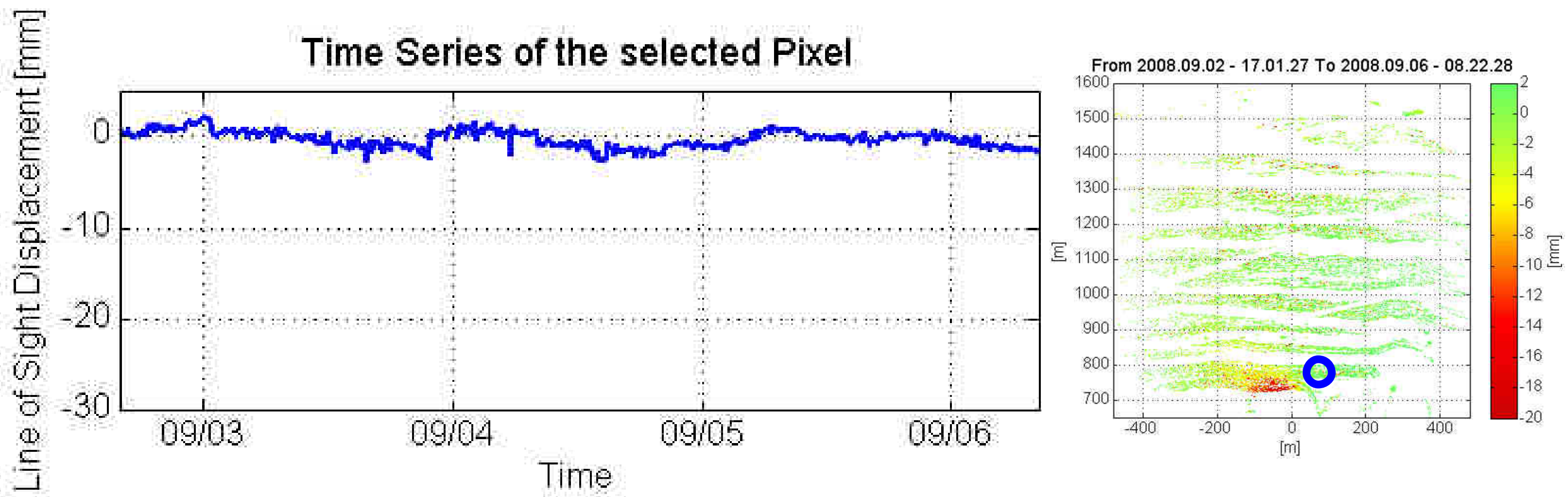




IDS INGEGNERIA DEI SISTEMI

Time Series of some Selected Points



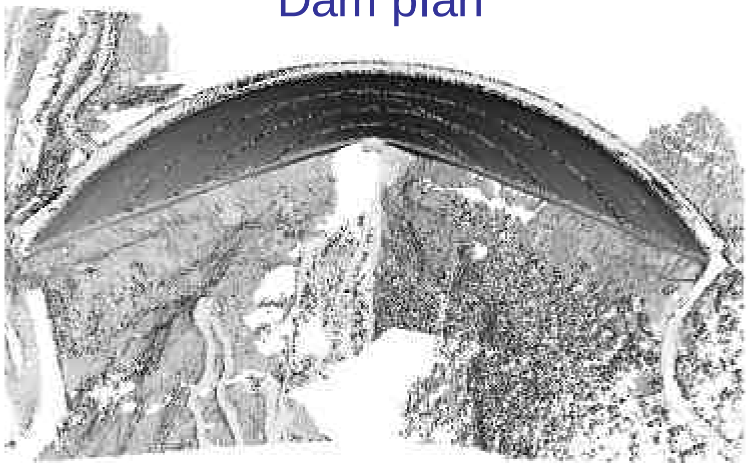


IDS INGEGNERIA DEI SISTEMI

Structure Monitoring: dam survey

Cancano Dam view

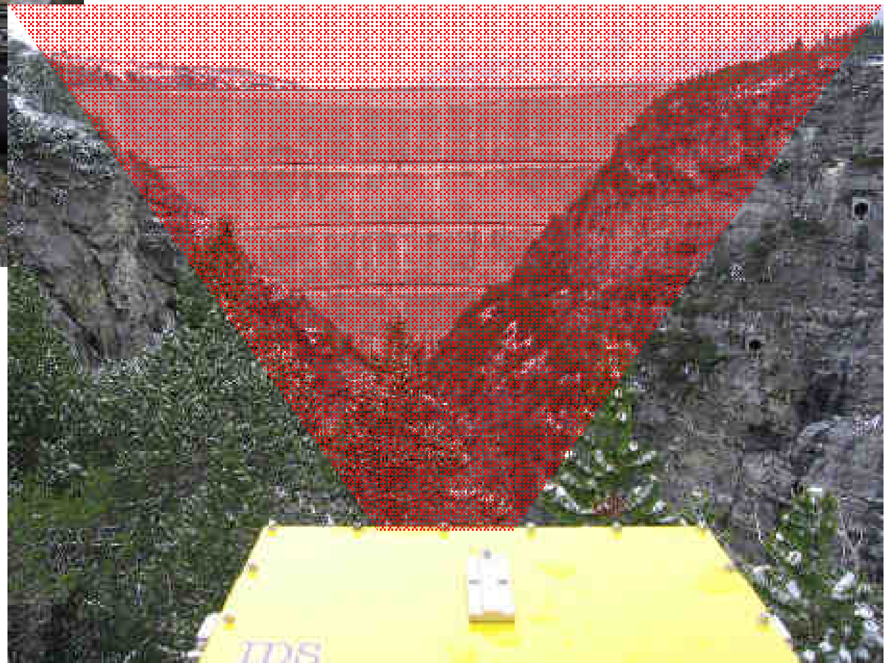
Dam plan



Dam characteristics	
Dam Type	Gravity arch
Location	Alpi Retiche - Italy
Dam height (m)	125.5
Crowing length (m)	381

Survey performed with the Surveying Dept. of Milan Polytechnic

Structure Monitoring: dam survey

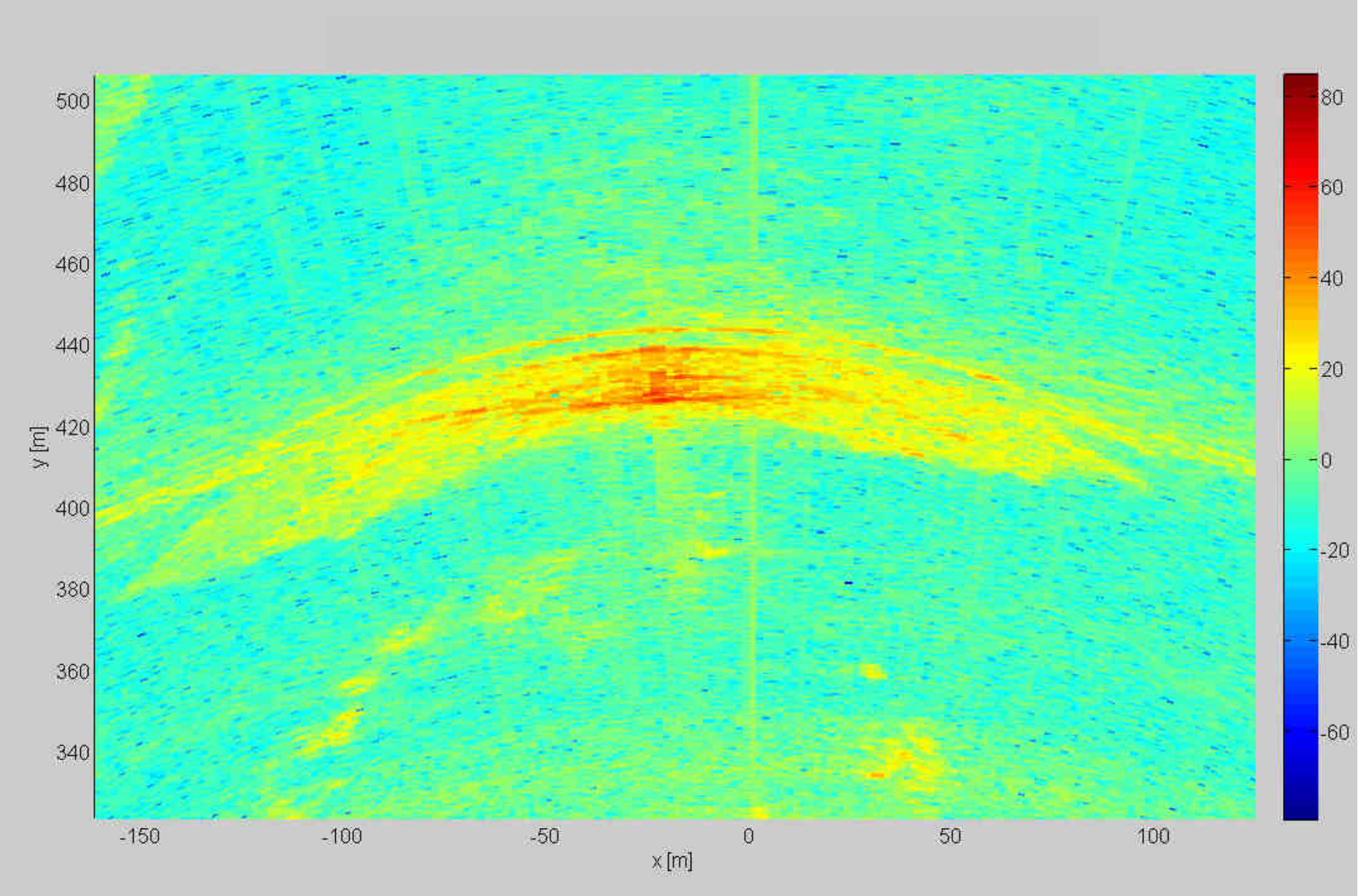


IBIS-L configuration

- Dam-sensor distance: 400m
- Range resolution: 0.5m
- Angle resolution: 4.7mrad
- Sampling interval: ca. 9 minutes

Structure Monitoring: dam survey

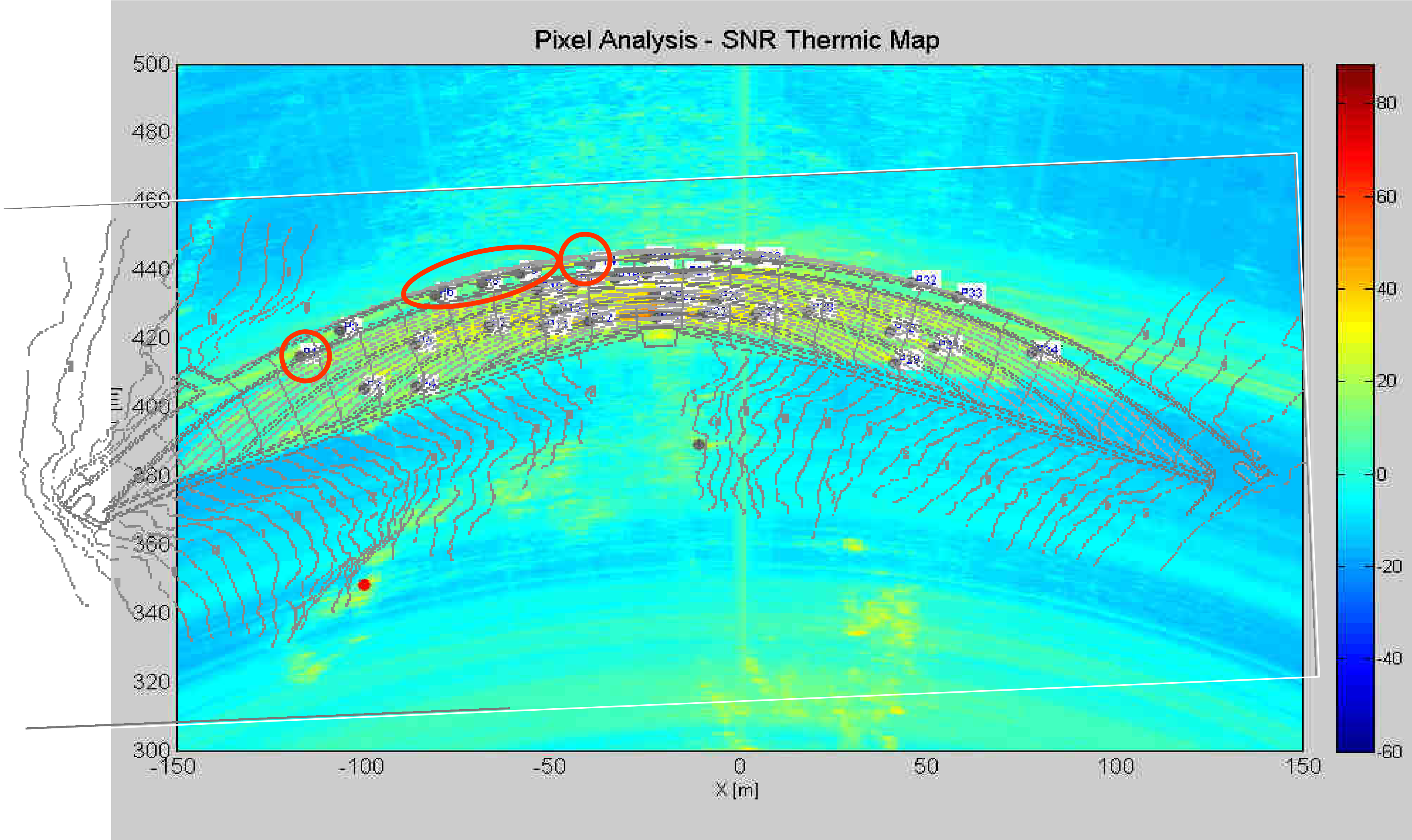
Zoom on dam area



IDS INGEGNERIA DEI SISTEMI

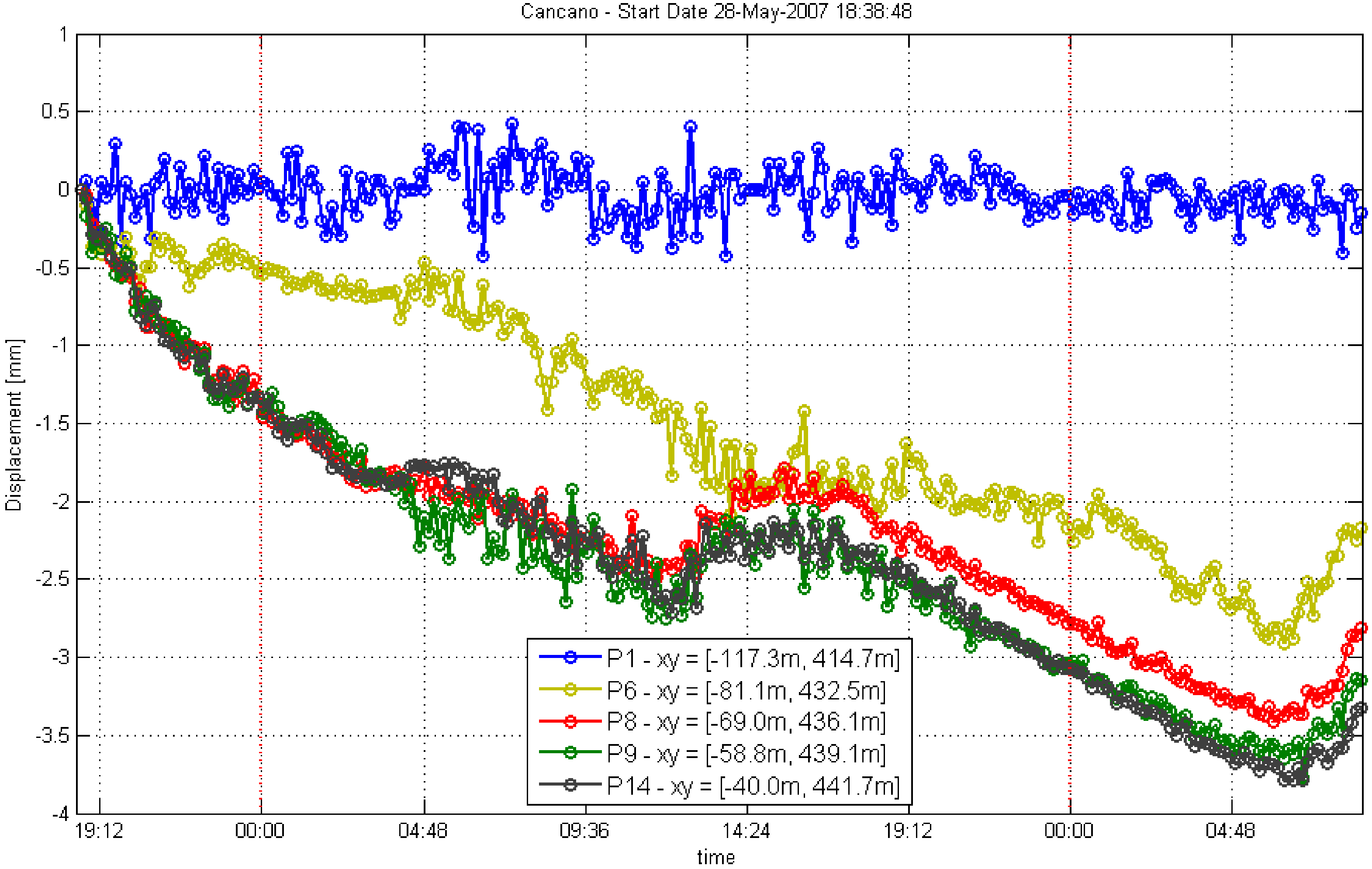
Structure Monitoring: dam survey

Dam Power map projected over plan

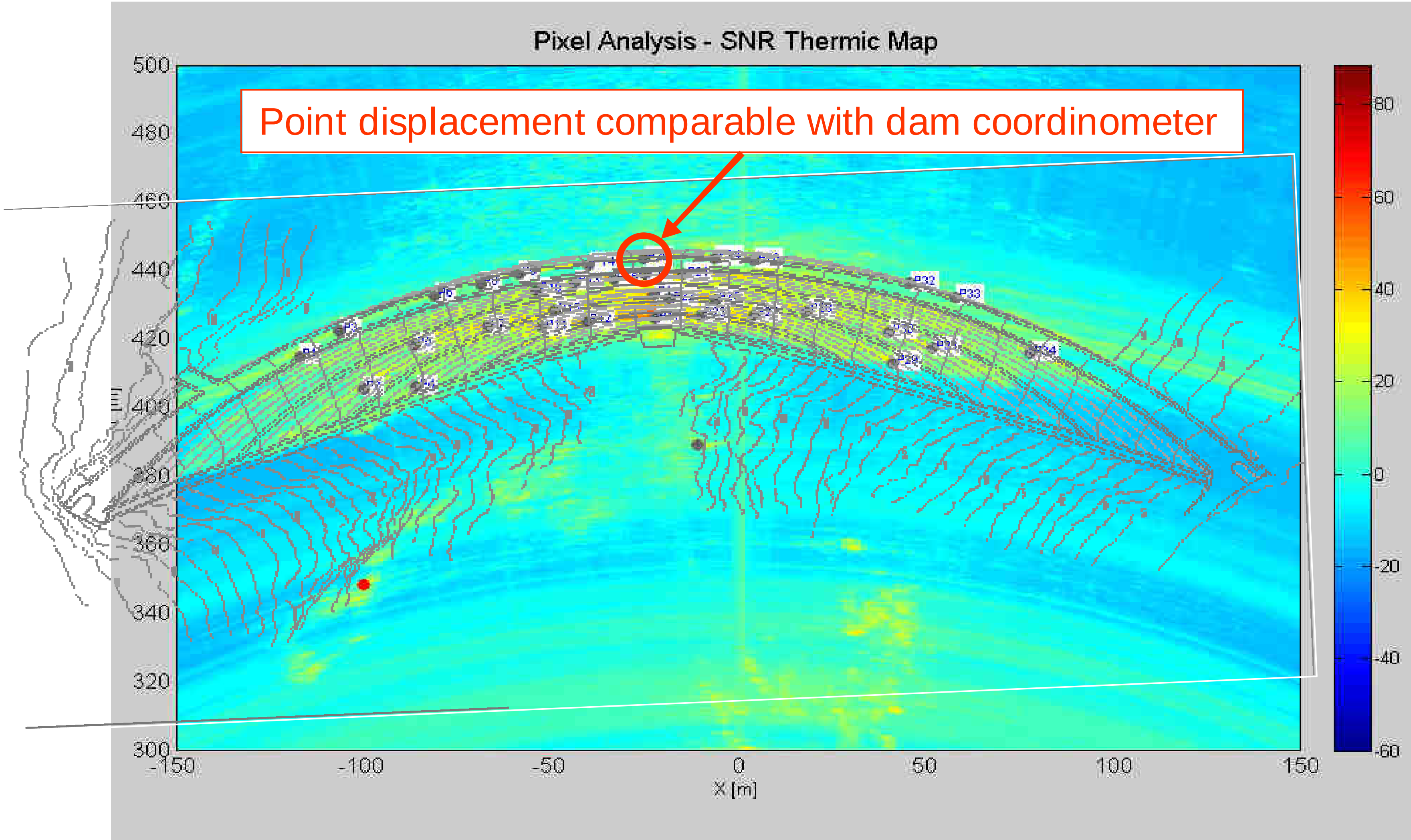


Structure Monitoring: dam survey

Selected pixel L.O.S. displacement – 5 pixel belonging to the dam crown



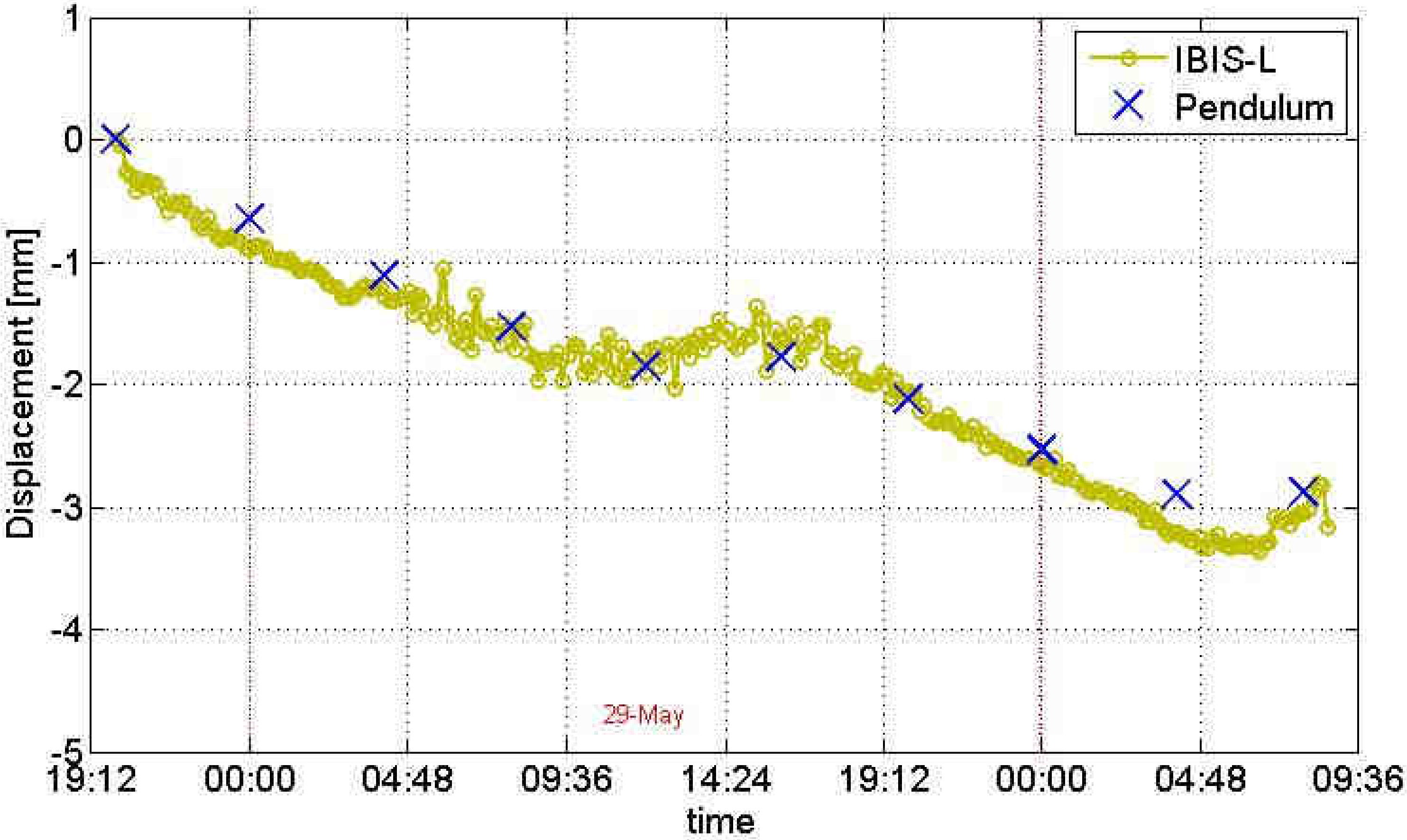
Structure Monitoring: dam survey



IDS INGEGNERIA DEI SISTEMI

Structure Monitoring: dam survey

Crowining point displacement comparison between
IBIS-L and coordinometer measure



IBIS-L sampling interval: 9min
Pendulum sampling interval: 4hours

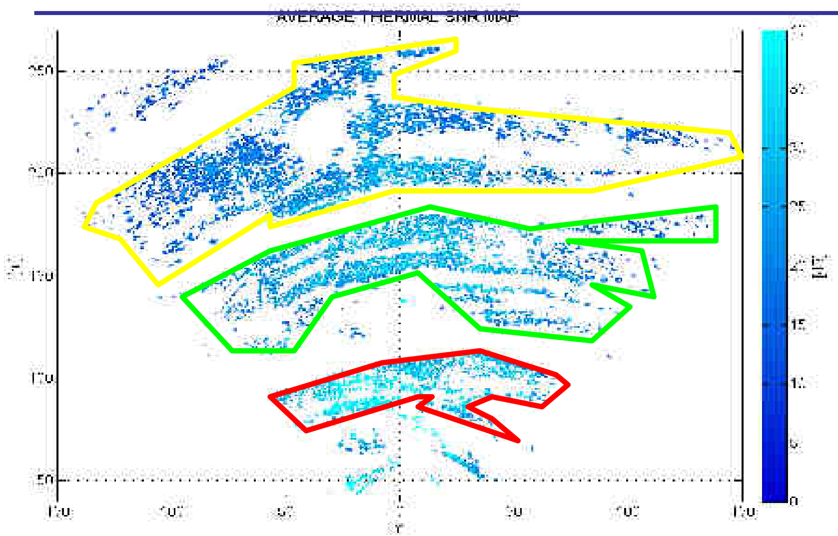
Landfill: monitoring of surficial deformations

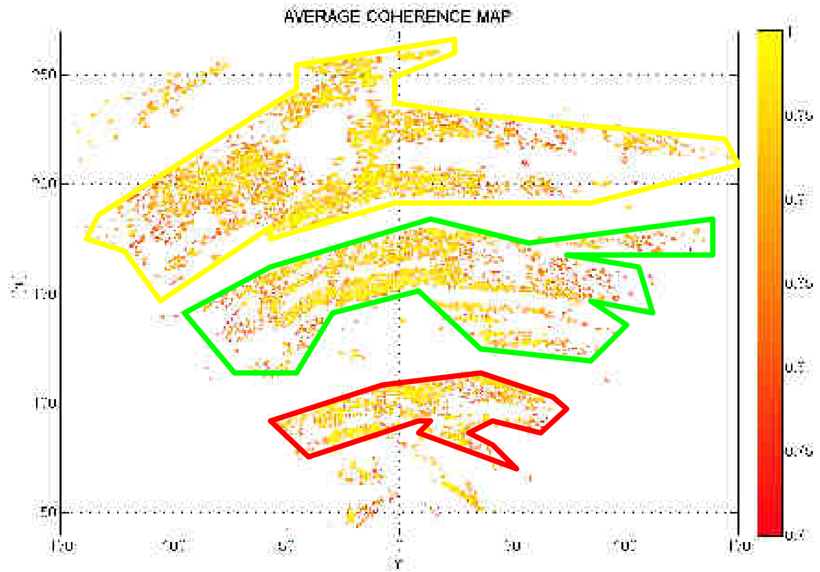
IBIS-L Configuration

DISTANCE FROM THE SLOPE CENTRAL SECTION [m]	80-260
RADAR HEIGHT FROM GROUND [m]	0,4
ANTENNA TILT [deg]	5
HALF POWER BEAM WIDTH (-3dB) [deg]	39
SAMPLING FREQUENCY [number of acquisitions per hour]	10
FIRST SESSION TIME EXTENT [hours]	8
SECOND SESSION TIME EXTENT [hours]	10
RANGE RESOLUTION [m]	0.5
CROSS-RANGE RESOLUTION [mrad]	4.5
MAXIMUM DISTANCE [m]	1250

IBIS-L system overview

Landfill: monitoring of surficial deformations



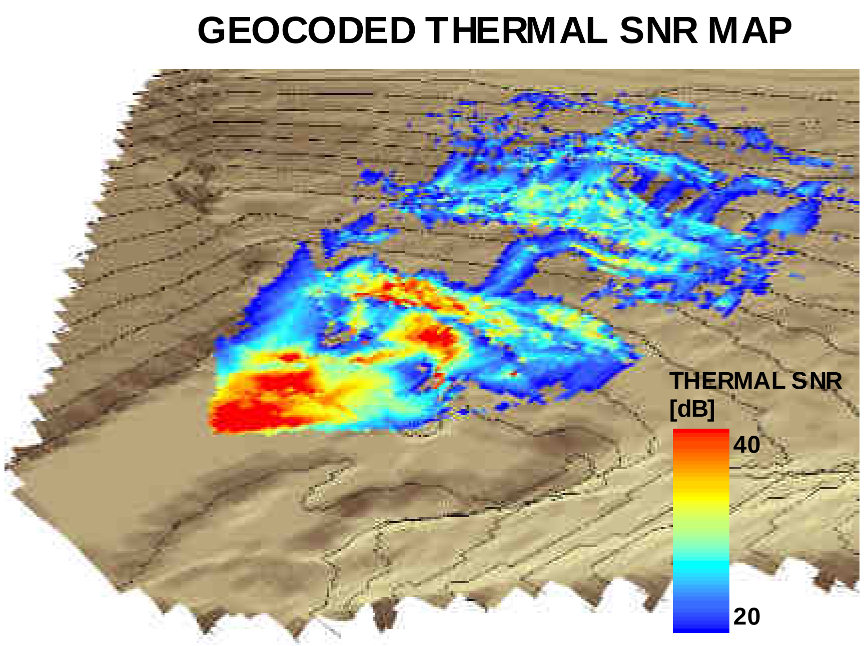


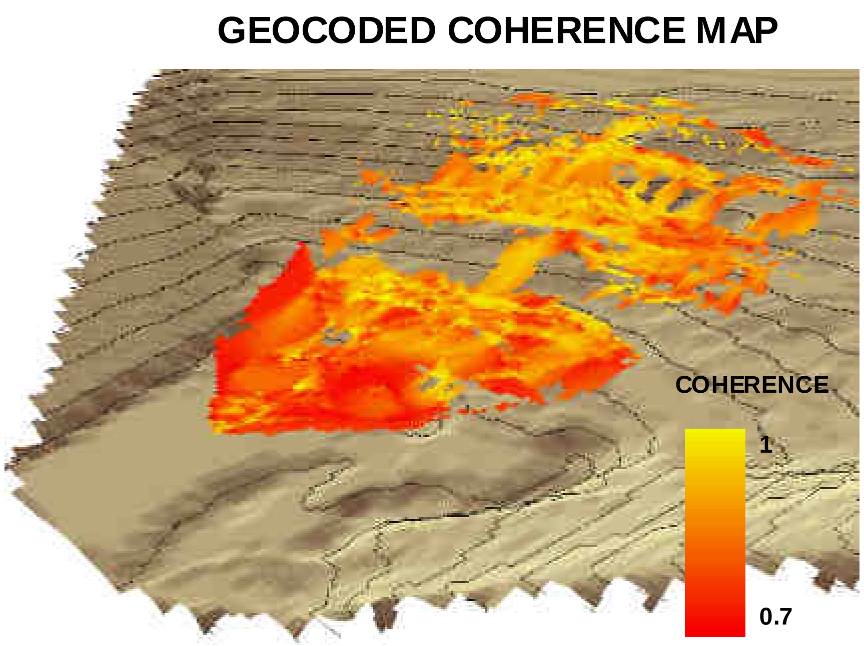
IBIS-L VIEW ON THE SLOPE

Section 1	Red
Section 2	Green
Section 3	Yellow

Thanks to the good reflectivity and stability of the landfill IBIS-L has been able to measure thousands of points belonging to the monitored area

Landfill: monitoring of surficial deformations

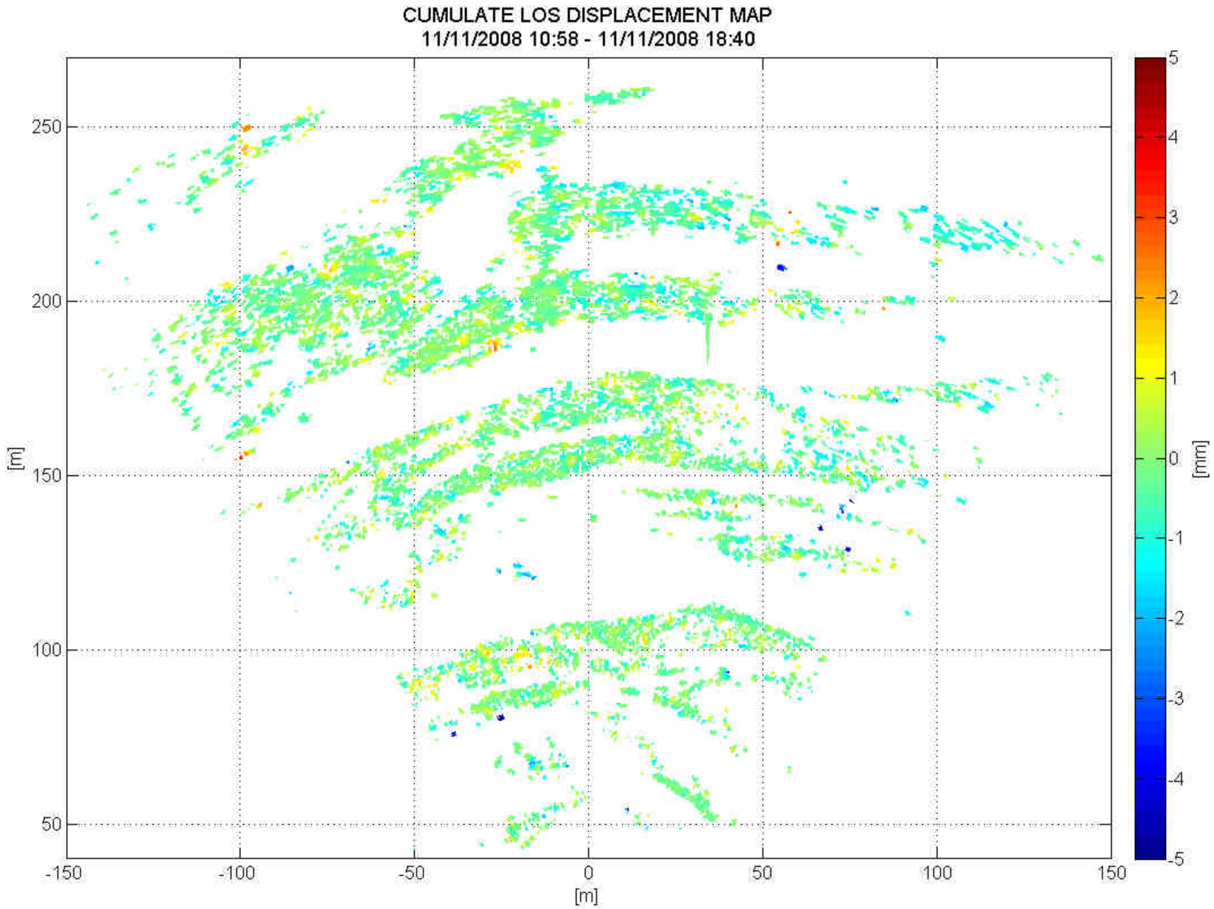




A more precise geocoding could be done using an updated digital elevation model (DEM) of terrain and knowing the exact orientation of the IBIS-L linear scanner

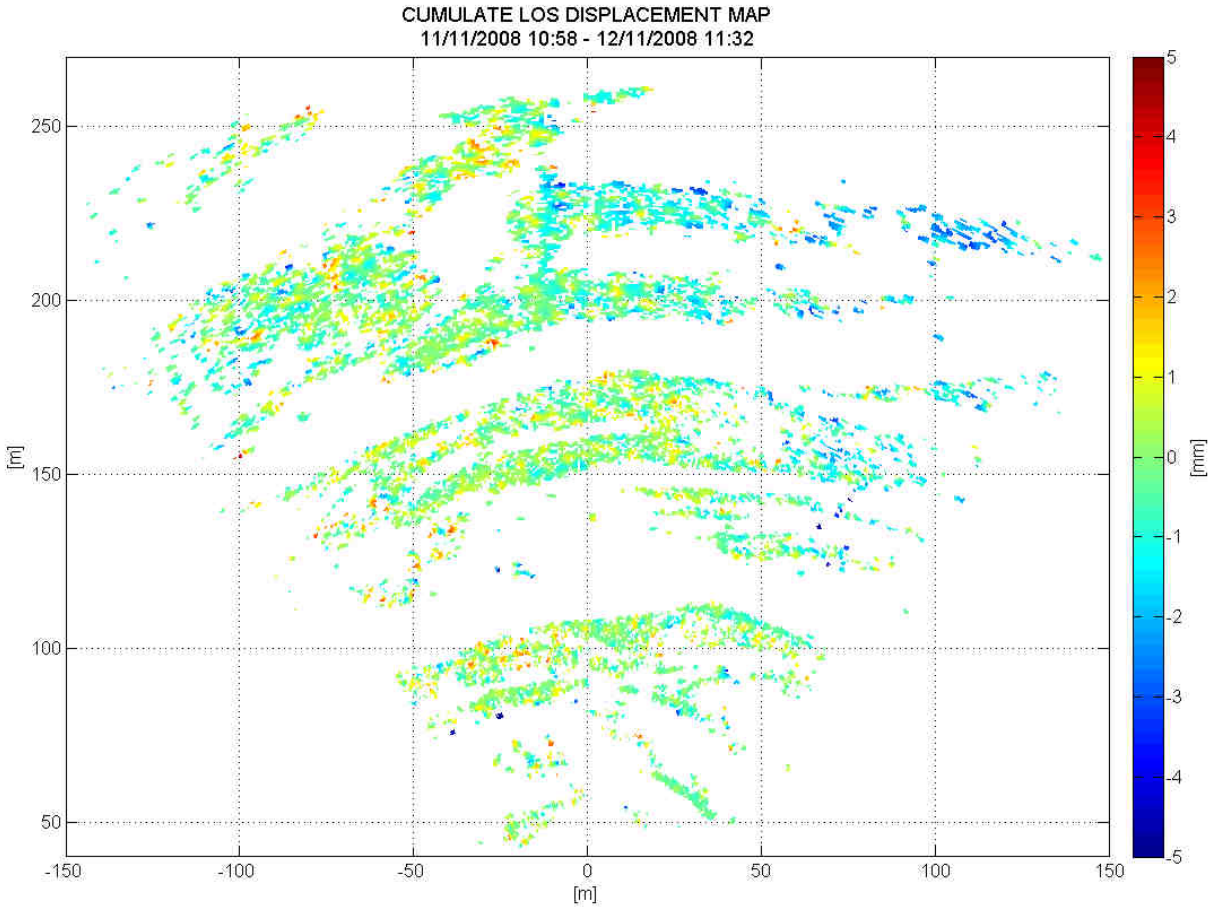
Cumulative displacement map (8 h)

After the first monitoring session the Cumulate LOS Displacement Map shows slight local movements of about +/- 1 mm



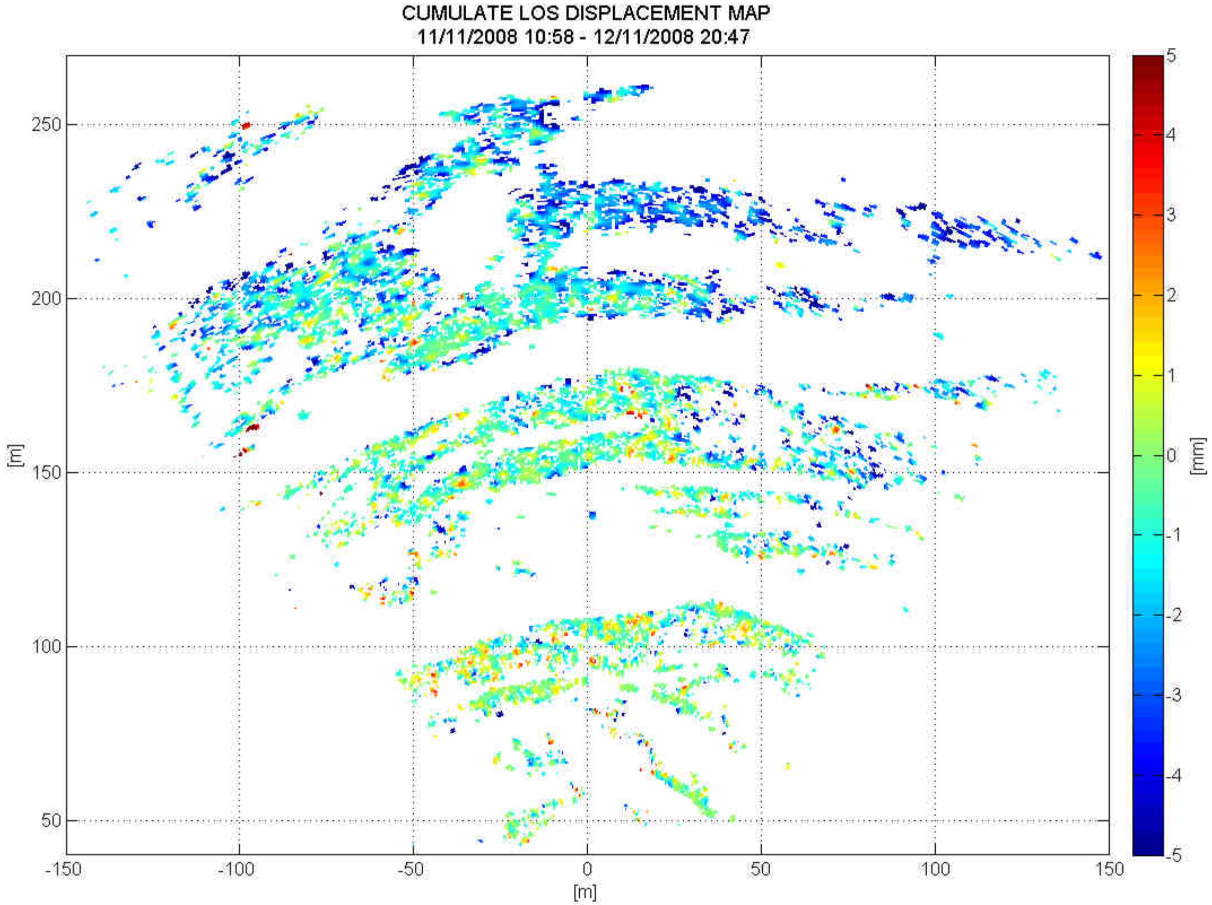
Cumulative displacement map (24 h)

After 24 hours the Cumulate LOS Displacement Map shows several slope sections moving either backward or forward compared to their original positions

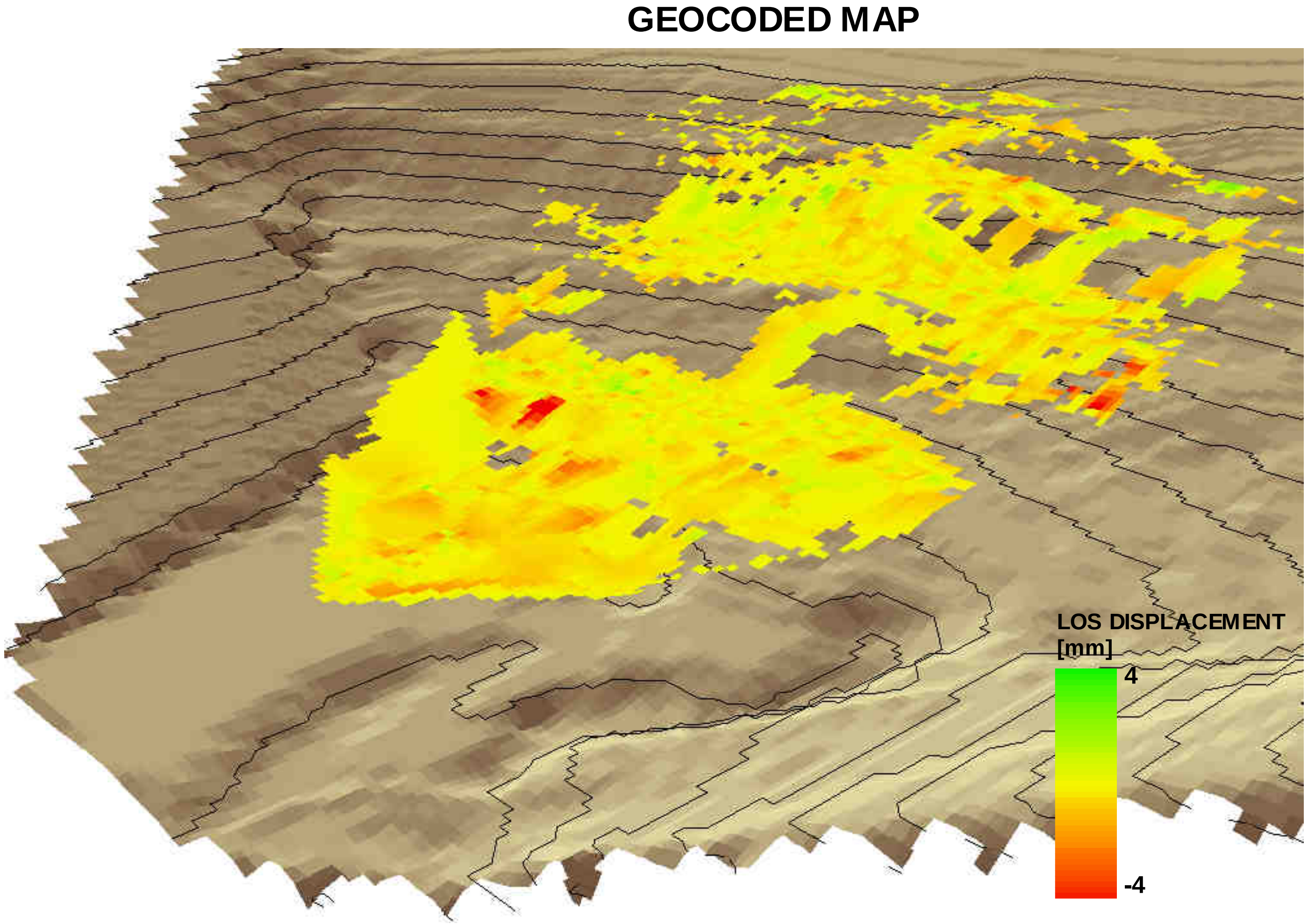


Cumulative displacement map (34 h)

At the end the Cumulate LOS Displacement Map shows several pixels belonging to upper section clearly moving forward and others being instead stable or slightly moving backwards compared to their initial position



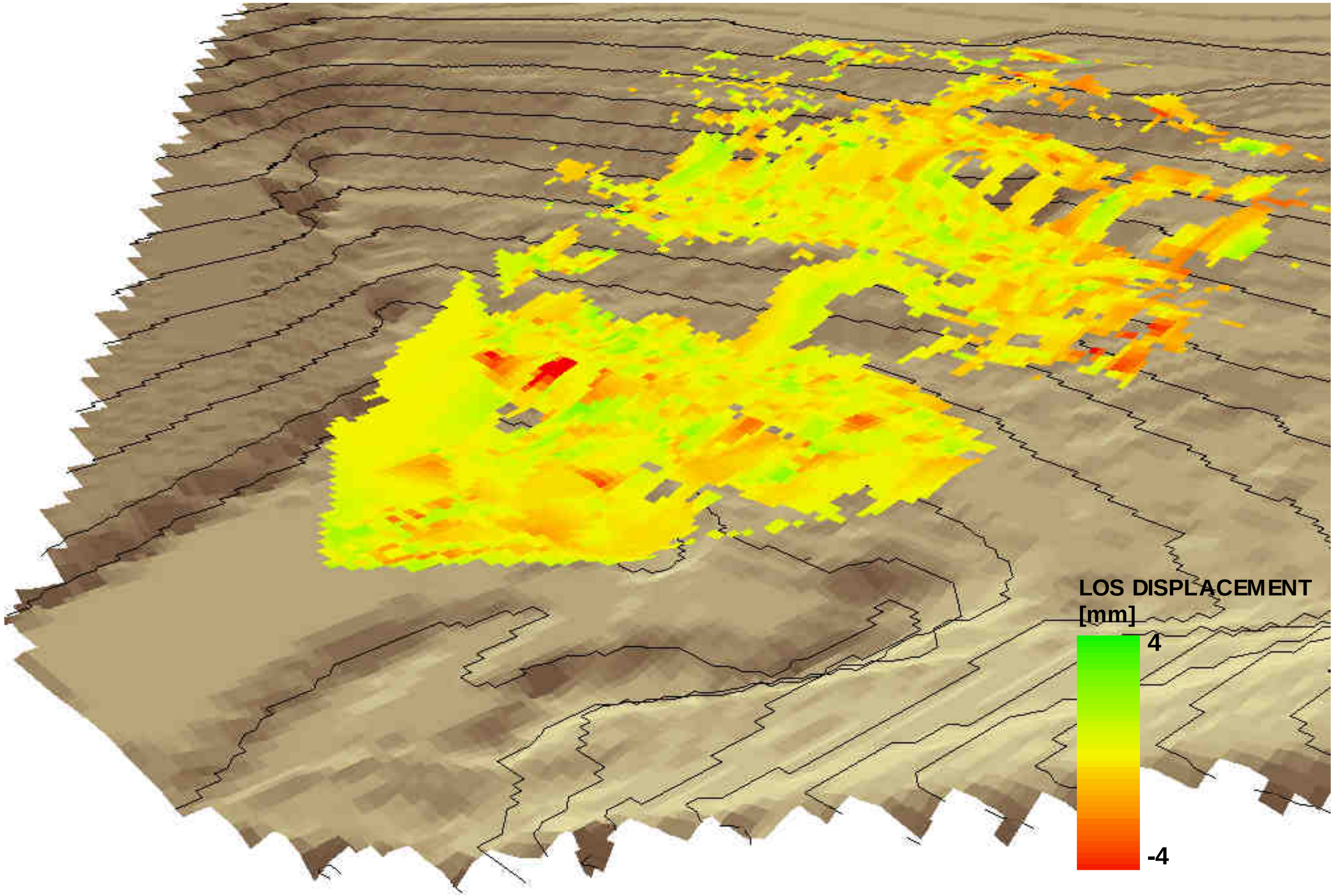
Cumulative displacement map (8 h)



A more precise geocoding could be done using an updated digital elevation model (DEM) of terrain and knowing the exact orientation of the IBIS-L linear scanner

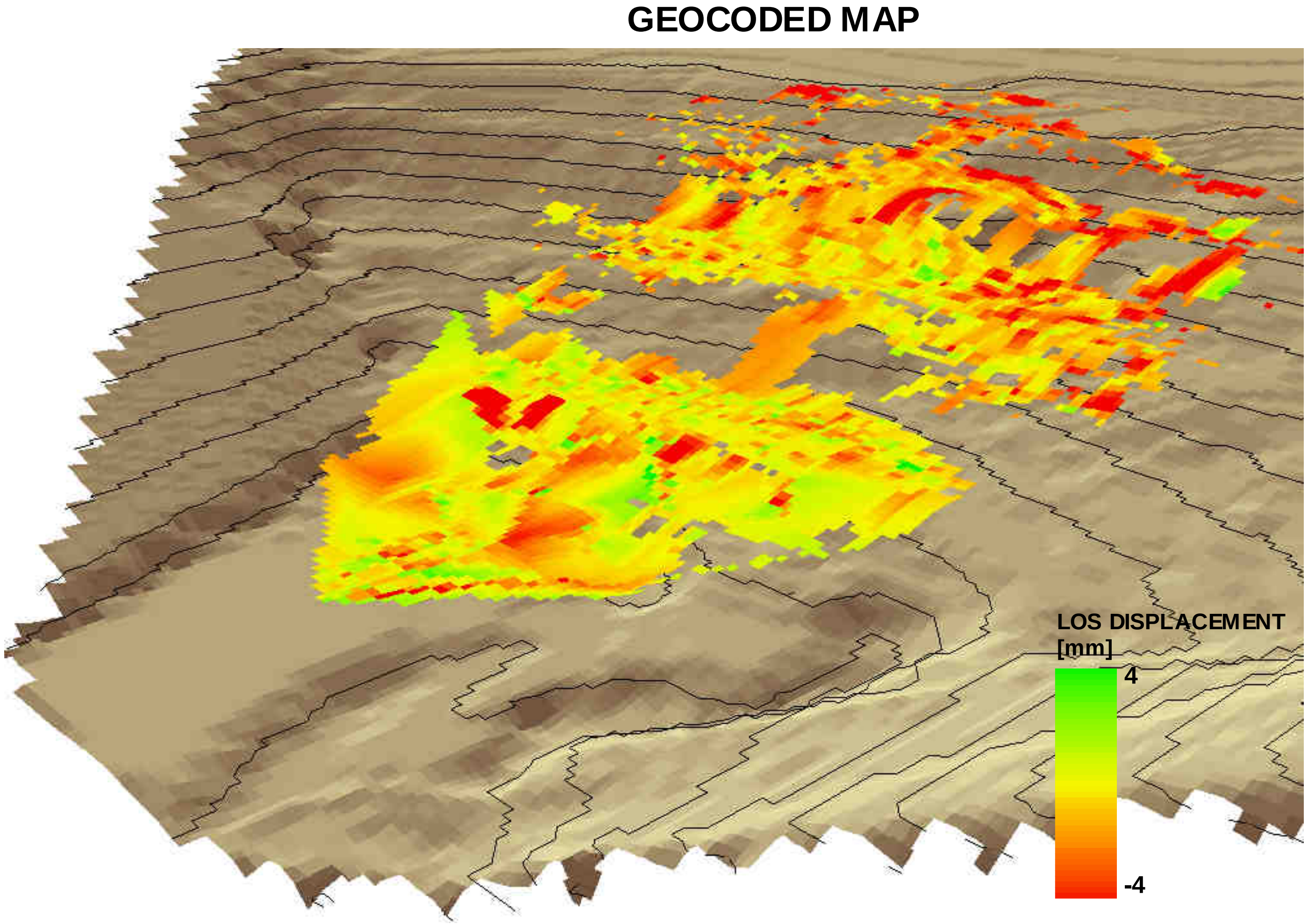
Cumulative displacement map (24 h)

GEOCODED MAP



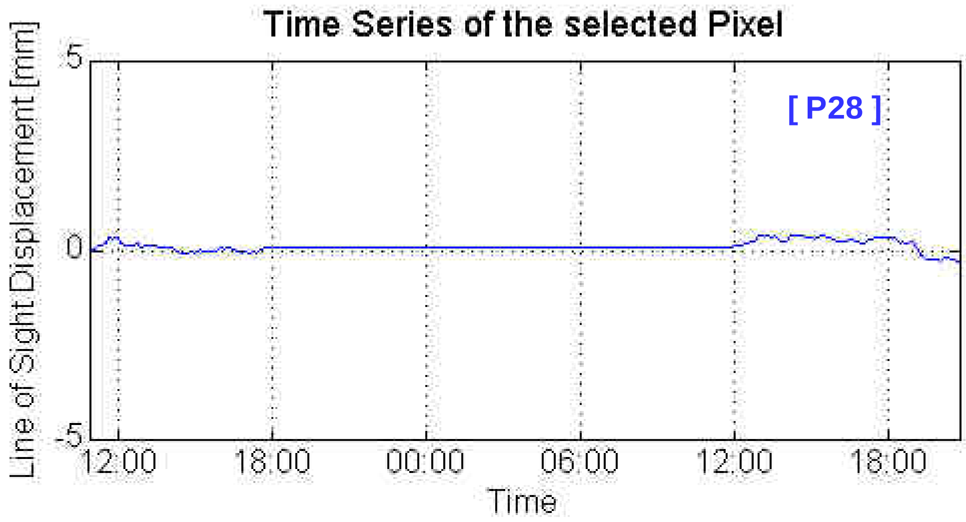
A more precise geocoding could be done using an updated digital elevation model (DEM) of terrain and knowing the exact orientation of the IBIS-L linear scanner

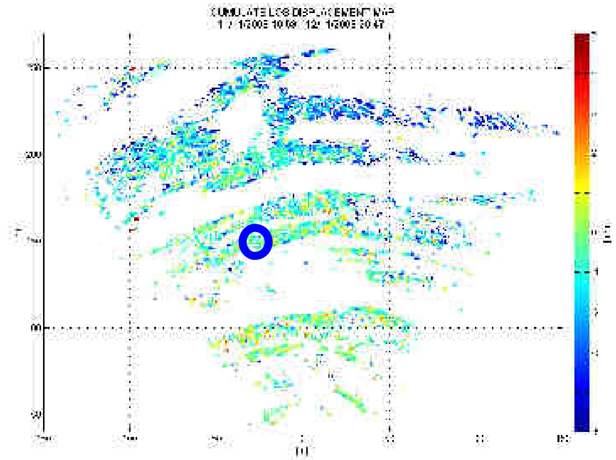
Cumulative displacement map (34 h)

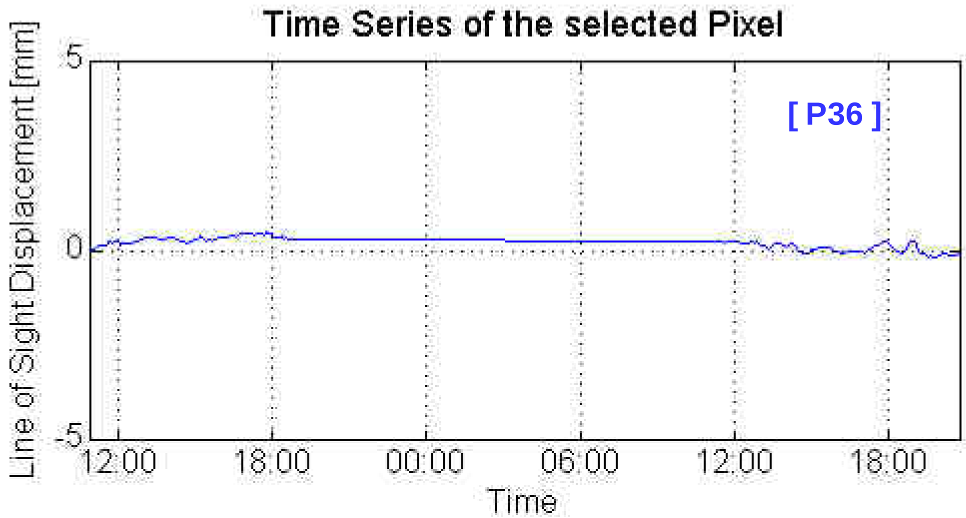


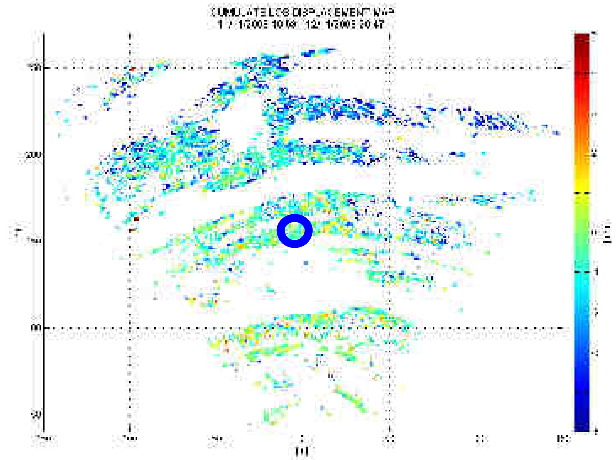
A more precise geocoding could be done using an updated digital elevation model (DEM) of terrain and knowing the exact orientation of the IBIS-L linear scanner

Time Series of some Selected Points (34 h)









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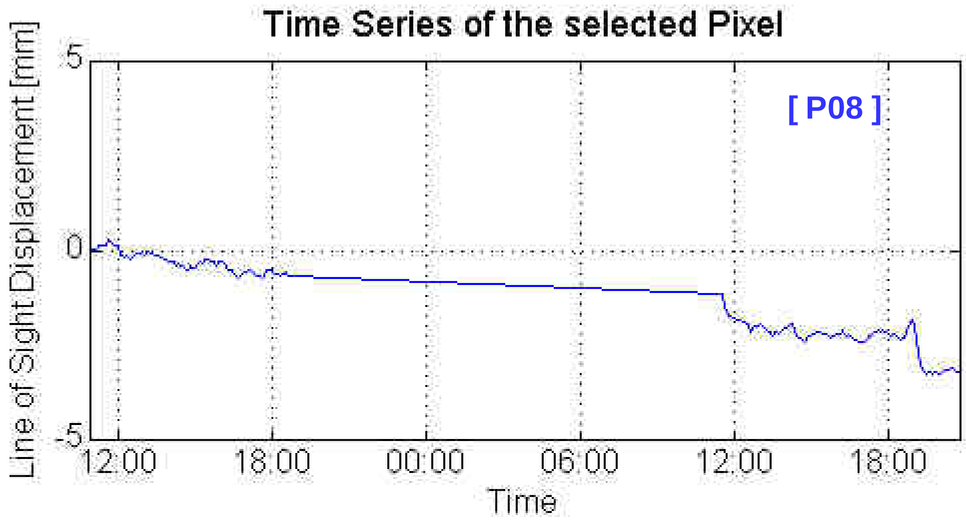
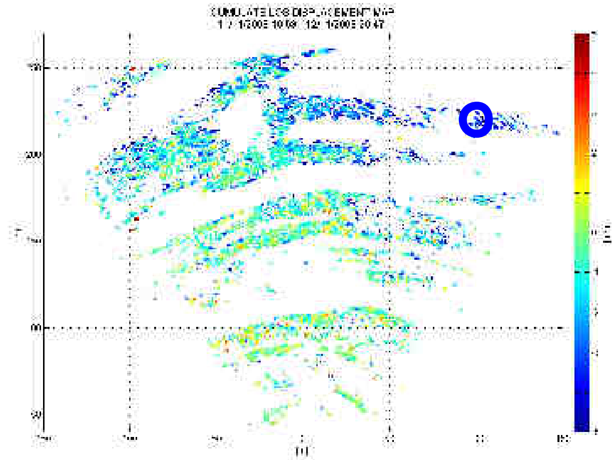
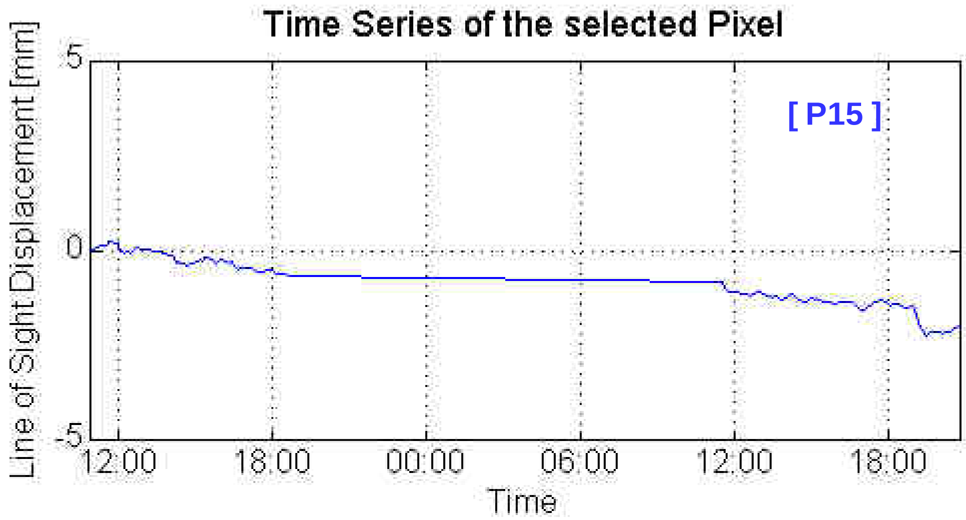
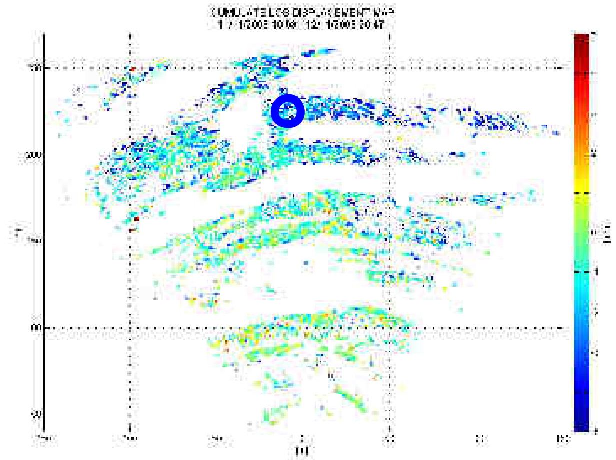
Time Series of some Selected Points (34 h)

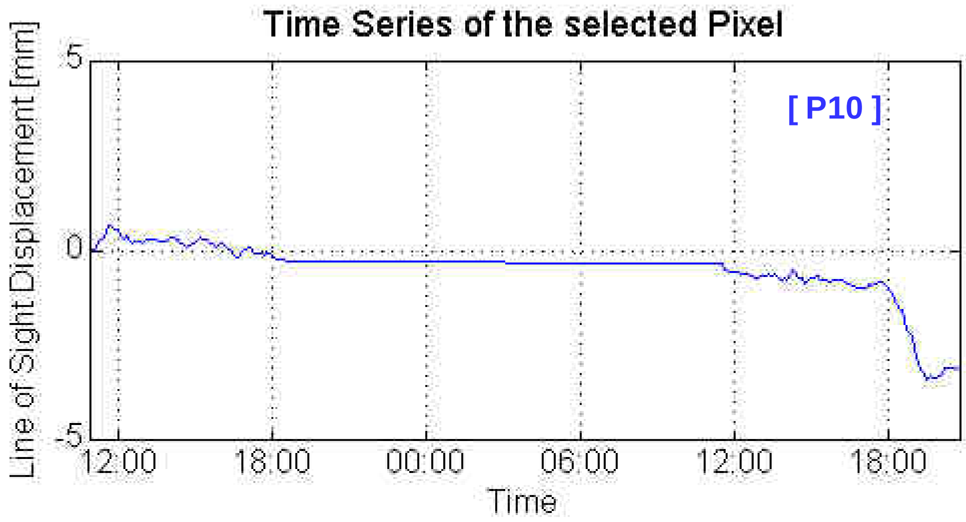


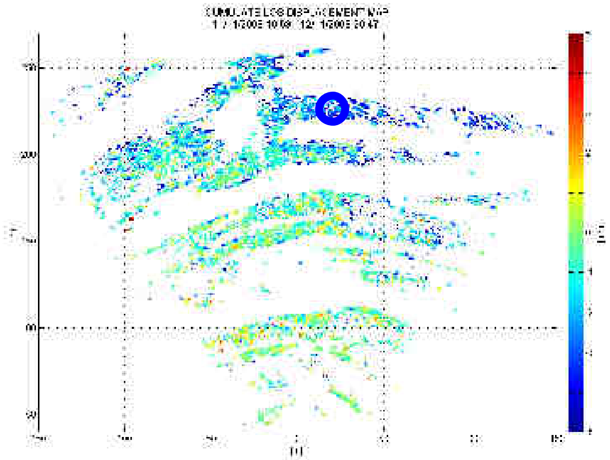


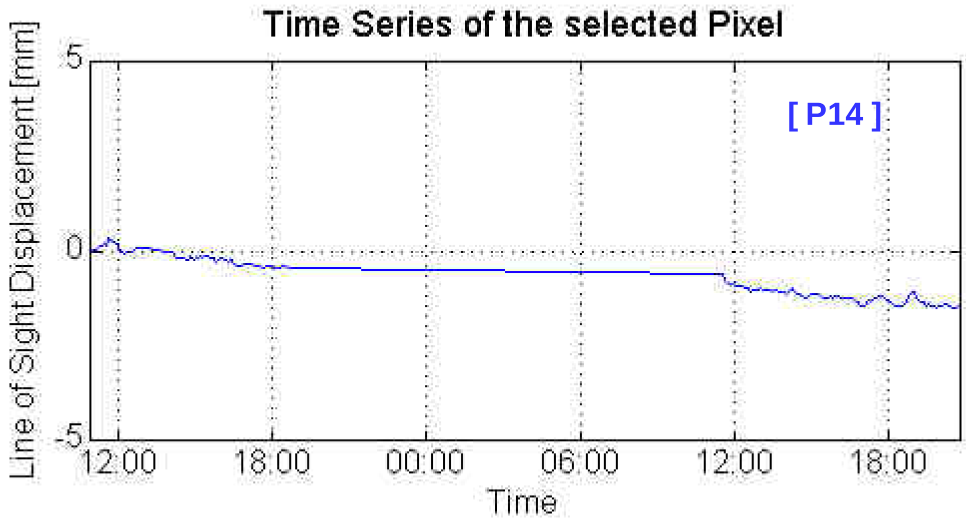


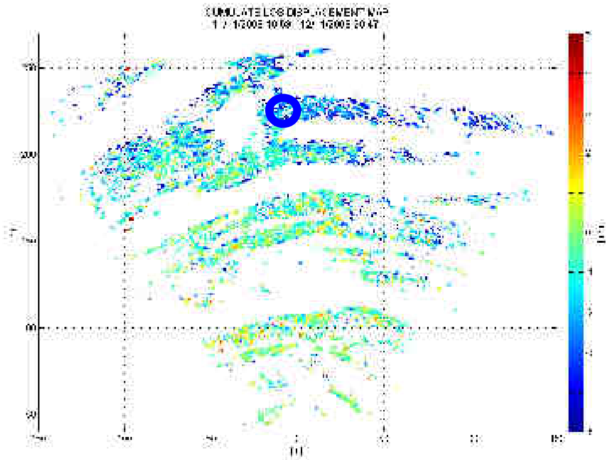


Time Series of some Selected Points (34 h)









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Structure Monitoring: static load of a bridge

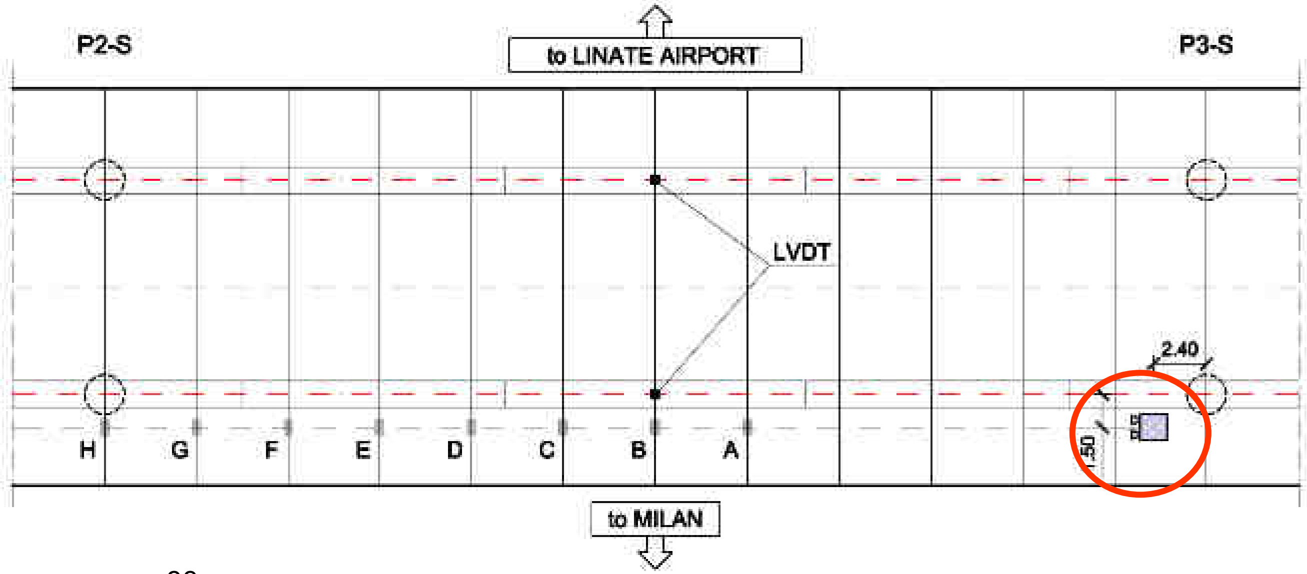
Viaducts crossing Forlanini Avenue (Milan, Italy)

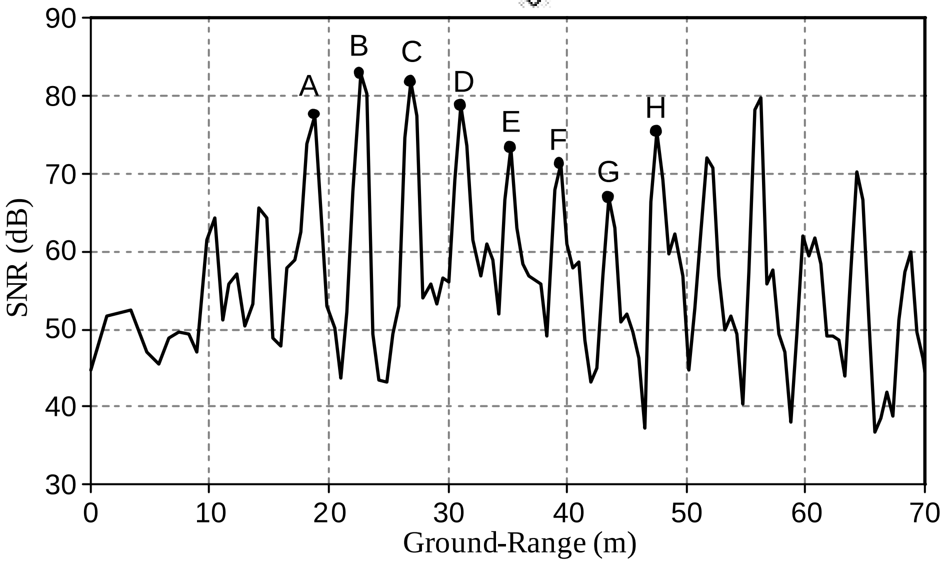
Bridge beams are good reflecting points

Static monitoring of a new bridge:

Determination of displacement of the bridge during a static load test

Structure Monitoring: static load of a bridge

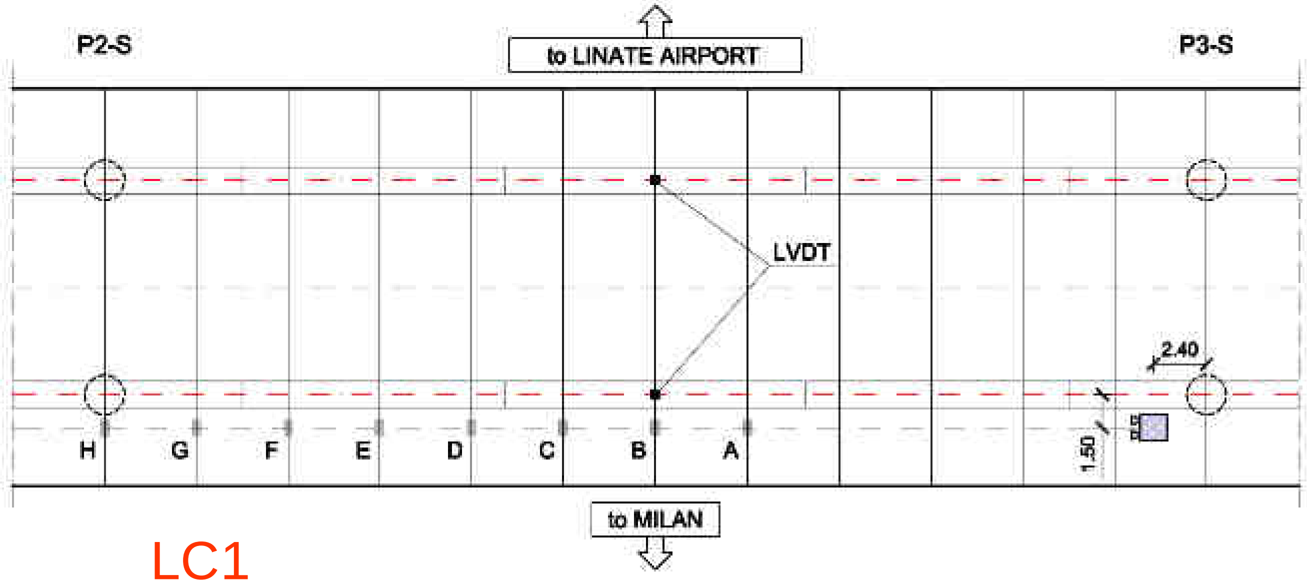




IBIS-S installation

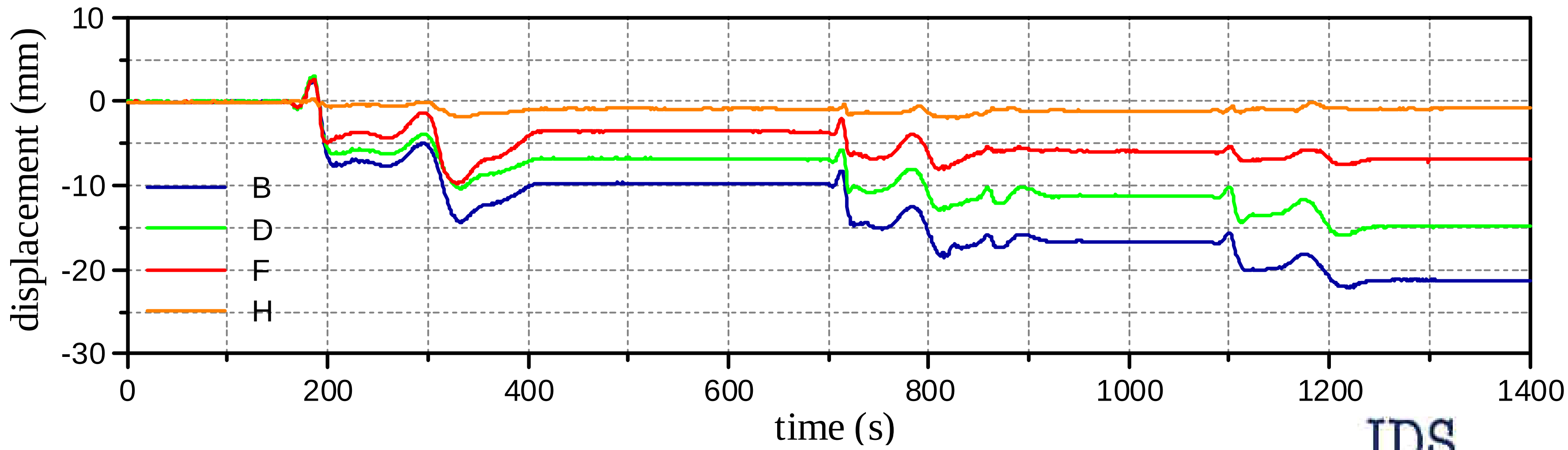
Range profile of P2-S – P3-S span

Structure Monitoring: static load of a bridge

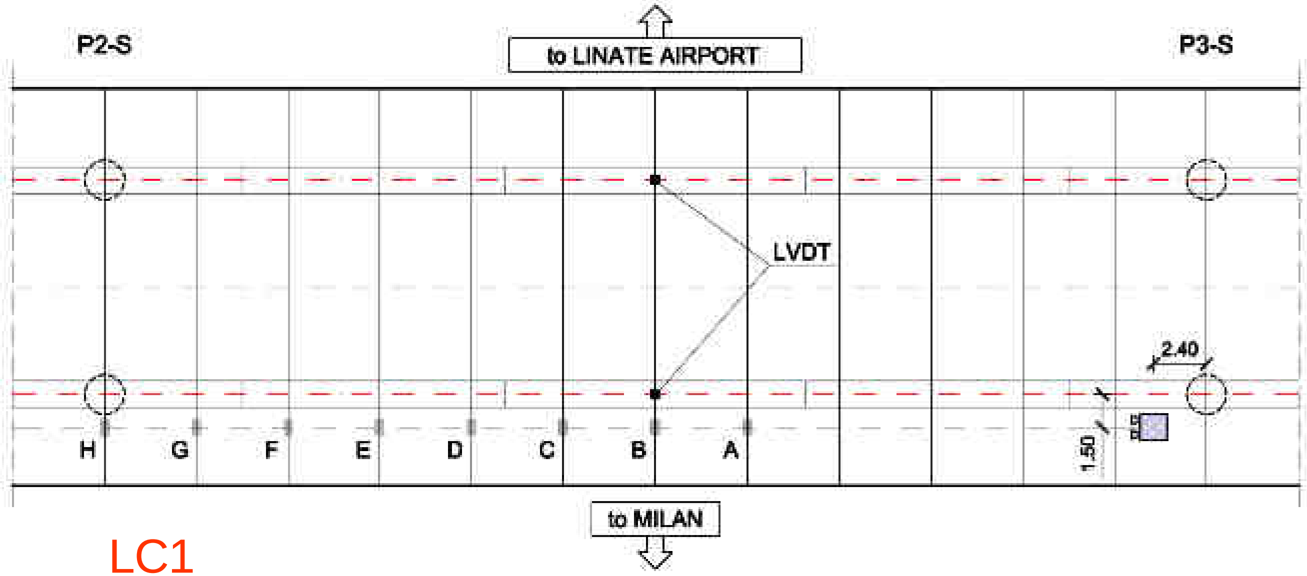


LC1

LVDT

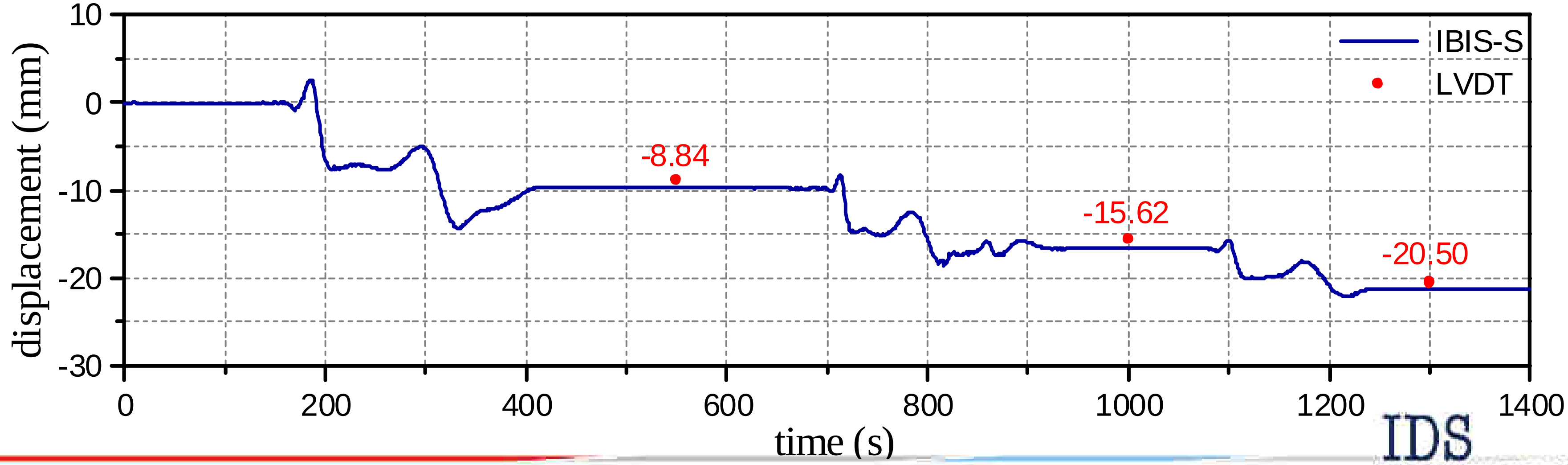


Structure Monitoring: static load of a bridge

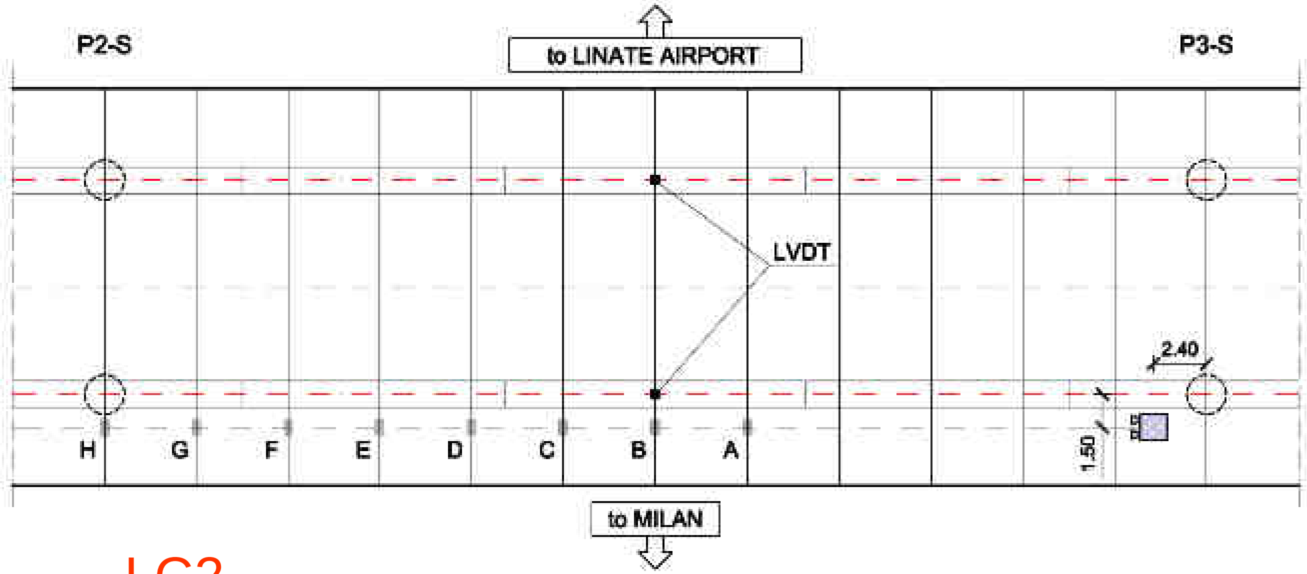


LC1

LVDT

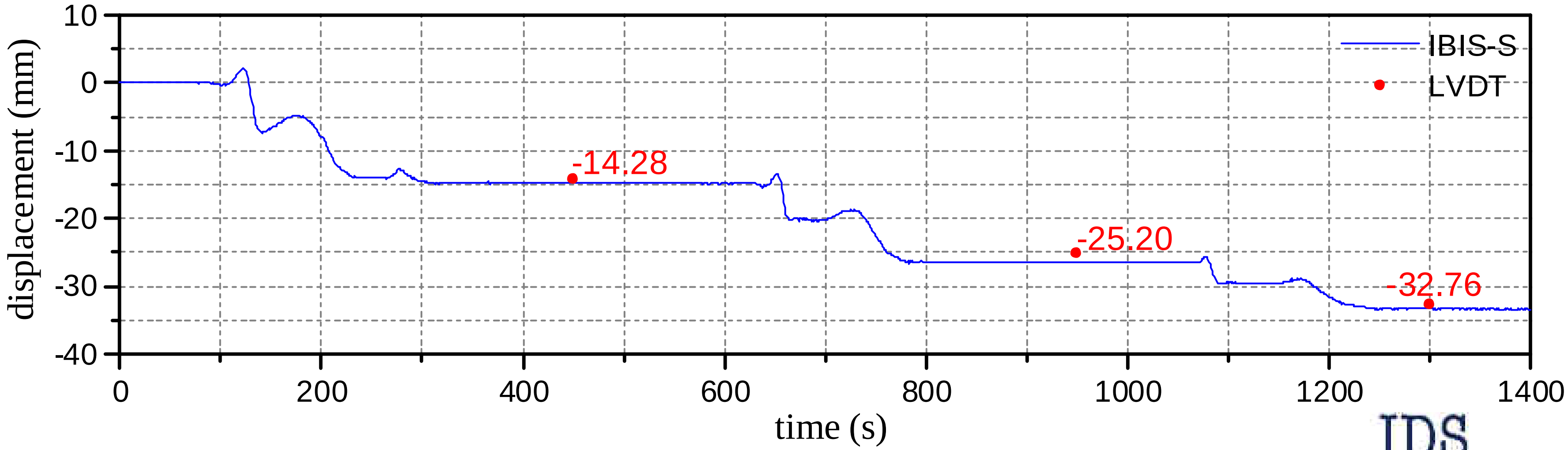


Structure Monitoring: static load of a bridge



LC2

LVDT



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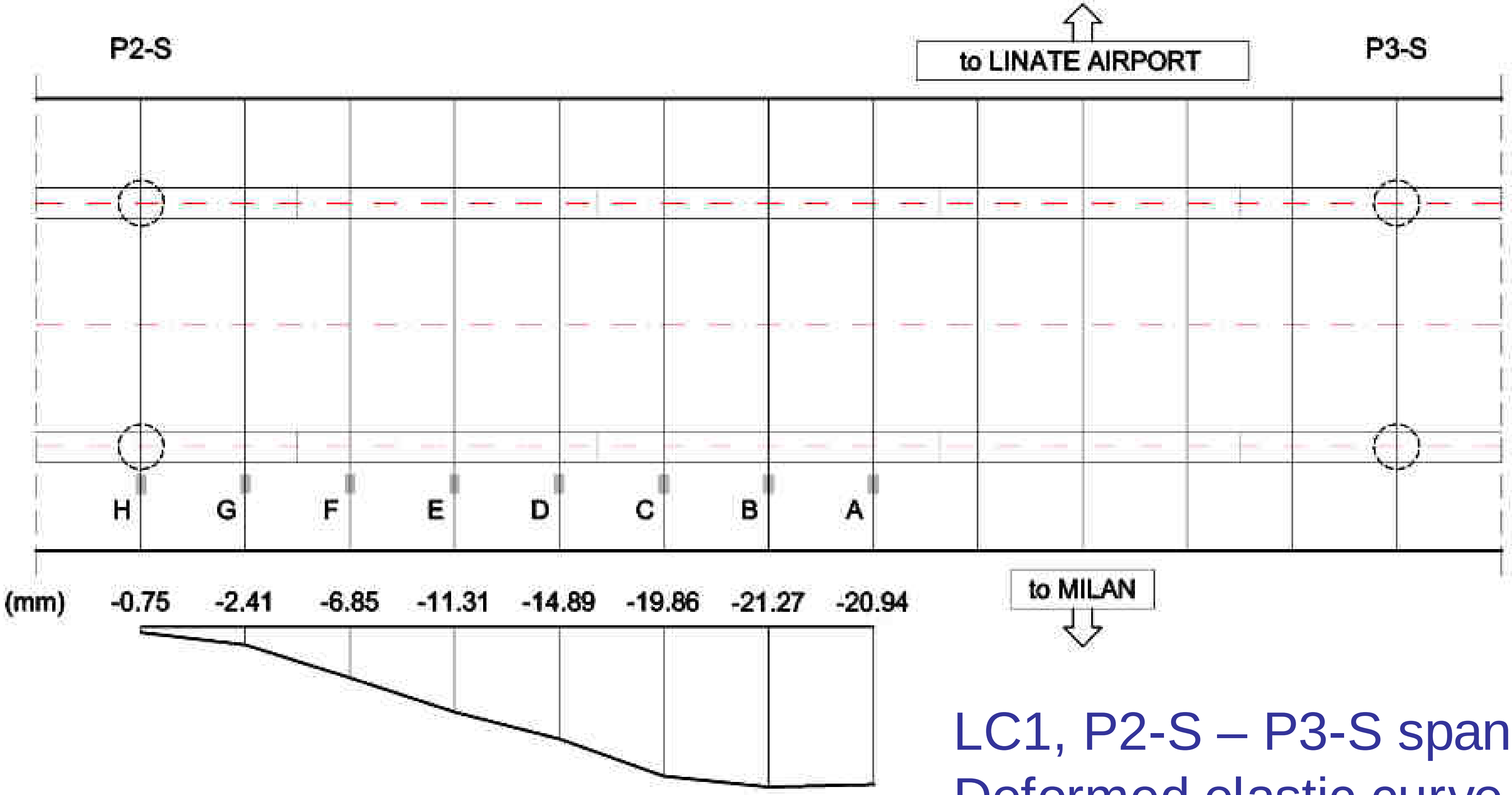
Structure Monitoring: static load of a bridge



LC1, P2-S – P3-S span: Deformed elastic curve provided by IBIS-S

Structure Monitoring: masonry bridge

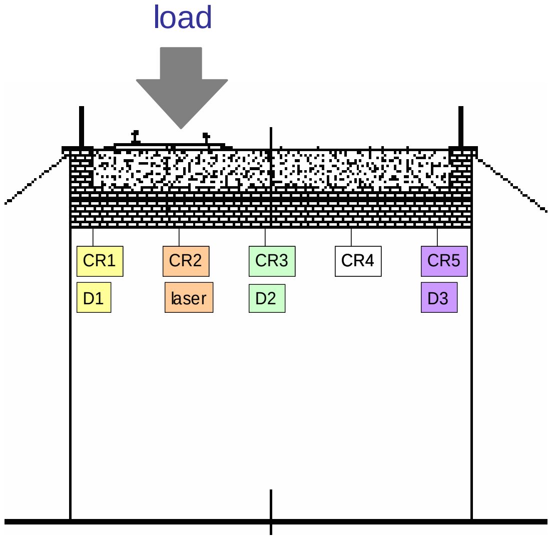
Measure objective: detect bridge arch displacement due to locomotive load along the transversal section for two different load locations (comparison with LVDT and laser results)

IBIS-S
and
5 CRs

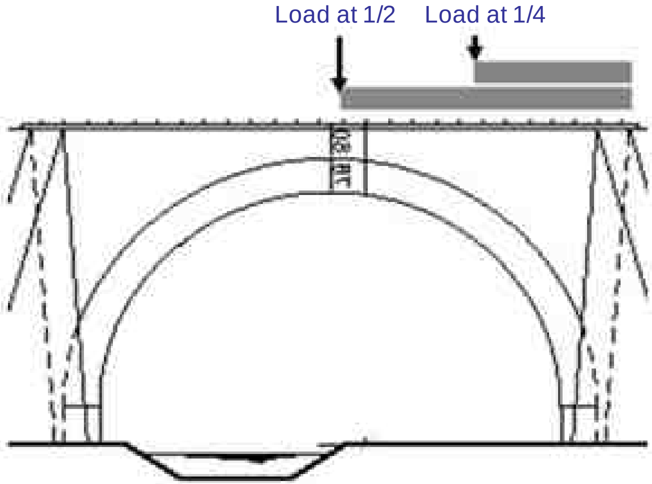
1 laser and 3 LVDT

Mining Monitoring: tunnel displacement monitoring

Measurement points on transversal section of the bridge



Load location



Measured displacement

Load location	LVDT			IBIS-S					laser
	D1	D2	D3	CR1	CR2	CR3	CR4	CR5	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
1/2	-0.630	-0.550	-0.220	-0.557	-0.567	-0.543	-0.279	-0.177	-0.701
1/4	-0.450	-0.365	-0.165	-0.423	-0.449	-0.327	-0.208	-0.149	-0.429

Load location	error			
	D1-CR1	D2-CR3	D3-CR5	laser-CR2
	[mm]	[mm]	[mm]	[mm]
1/2	-0.073	-0.007	-0.043	-0.134
1/4	-0.027	-0.038	-0.016	0.020

Dynamic Monitoring

IBIS-S introduces a totally new method for the dynamic monitoring of fast movements of structures, with significant advantages over traditional techniques including:

- Remote sensing, without the need to access the structure;

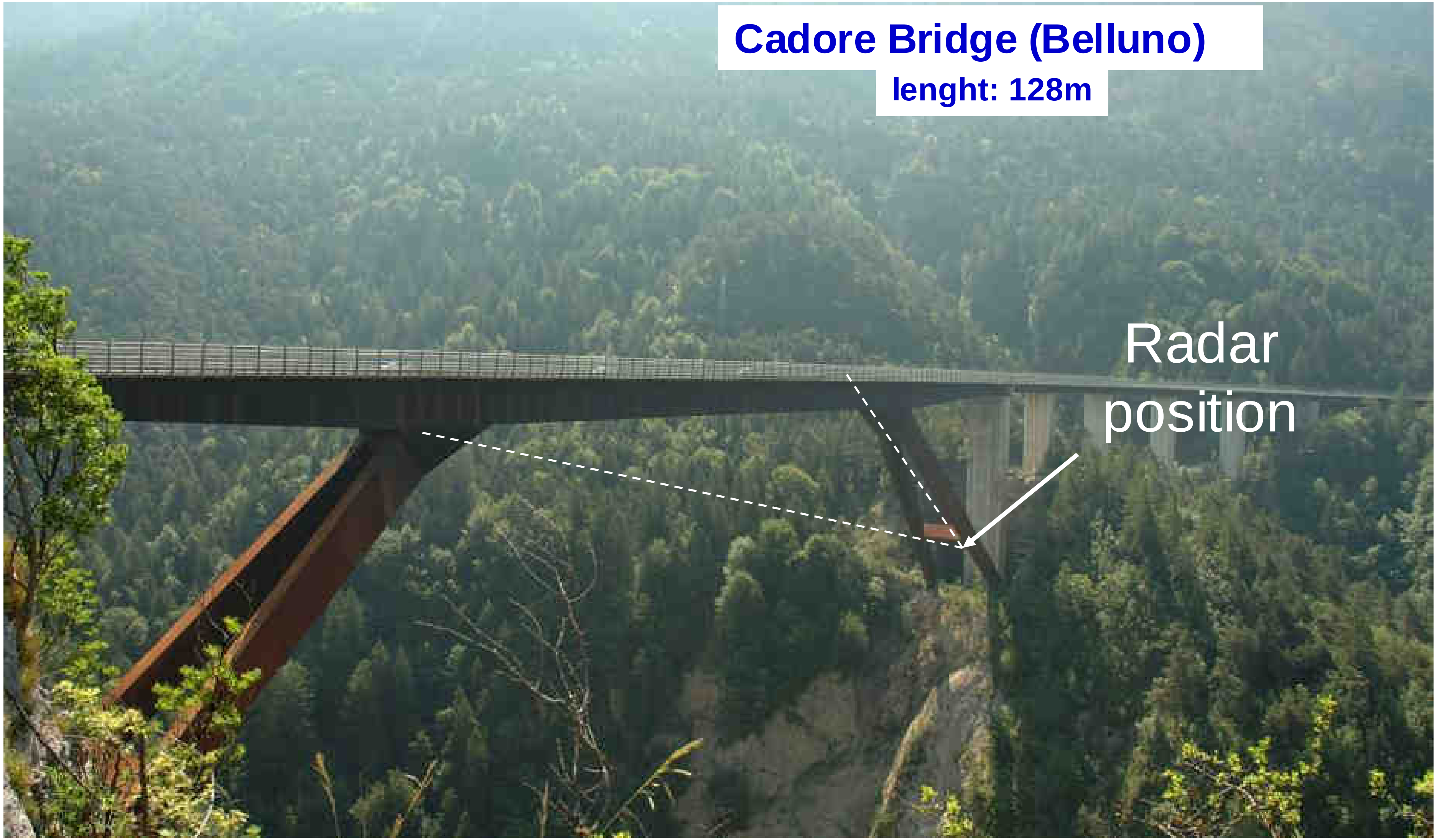
- Fast and easy to install; complete monitoring of the entire structure performed quickly (e.g.: an entire bridge can be dynamically monitored in less than one hour)

- Provides a practically continuous mapping of the dynamic displacements (not diverted results) of the entire structure

- Directly measures the structural displacements in real time, with an accuracy of between 1/100 and 1/10 of a millimetre

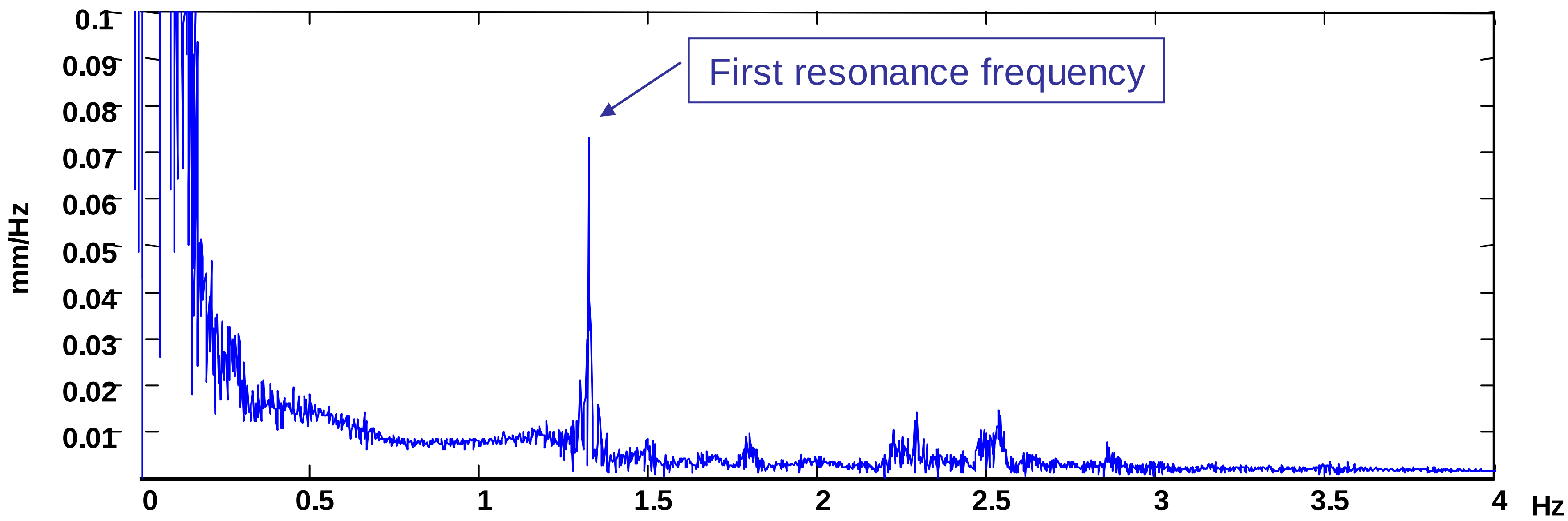
- Can follow and accurately measure both slow movements and fast movements in the frequencies range [0-50 Hz]

Dynamic Monitoring: Cadore bridge



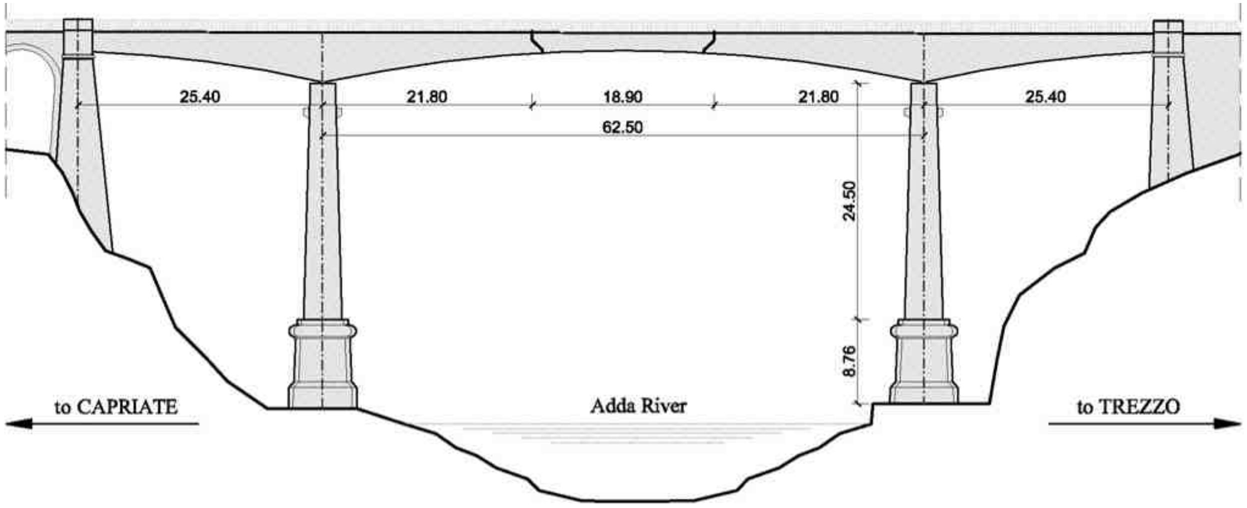
Dynamic Monitoring: Cadore bridge

Spectral analysis



Dynamic Monitoring: Capriate bridge

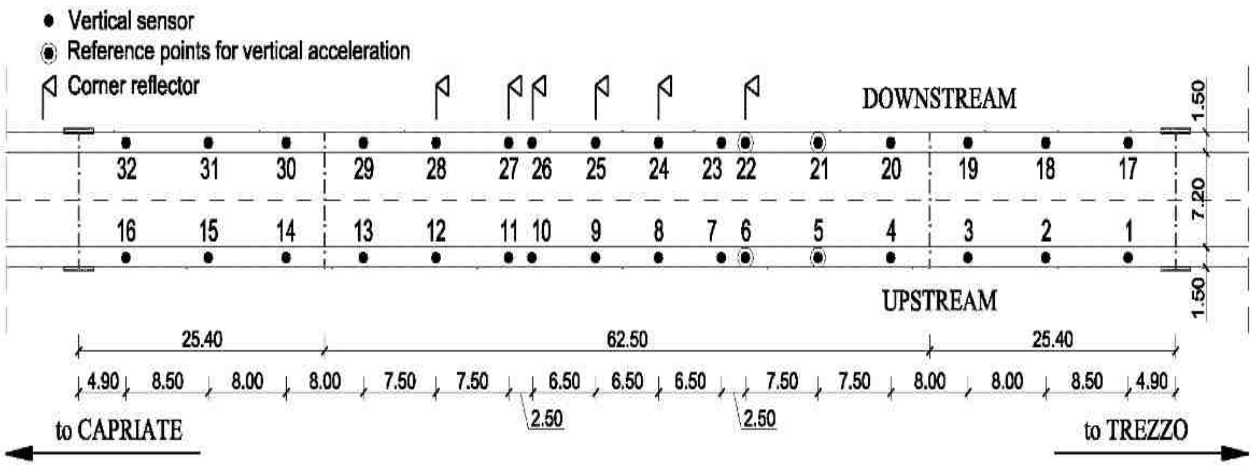
Measurement objective: comparison with accelerometers, resonance frequencies and modal shape retrieval



Central arch length (m): 62.5

Dynamic Monitoring: Capriate bridge

To make a comparison between the results of IBIS-S system and accelerometers system 6 corner reflector were installed at the same position of accelerometers



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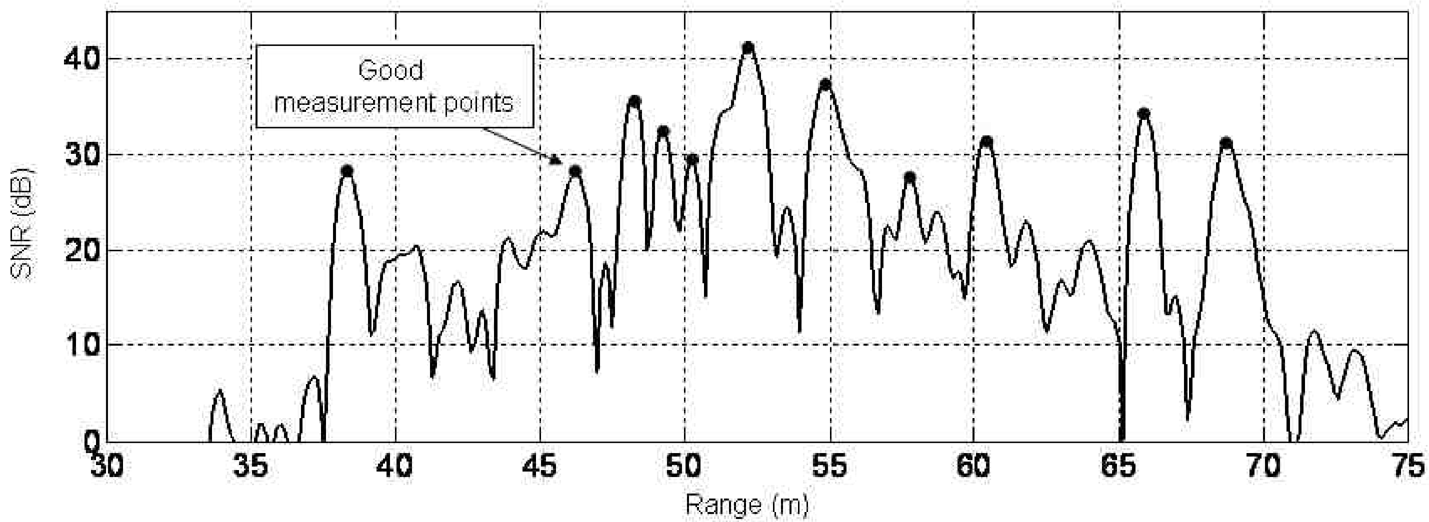
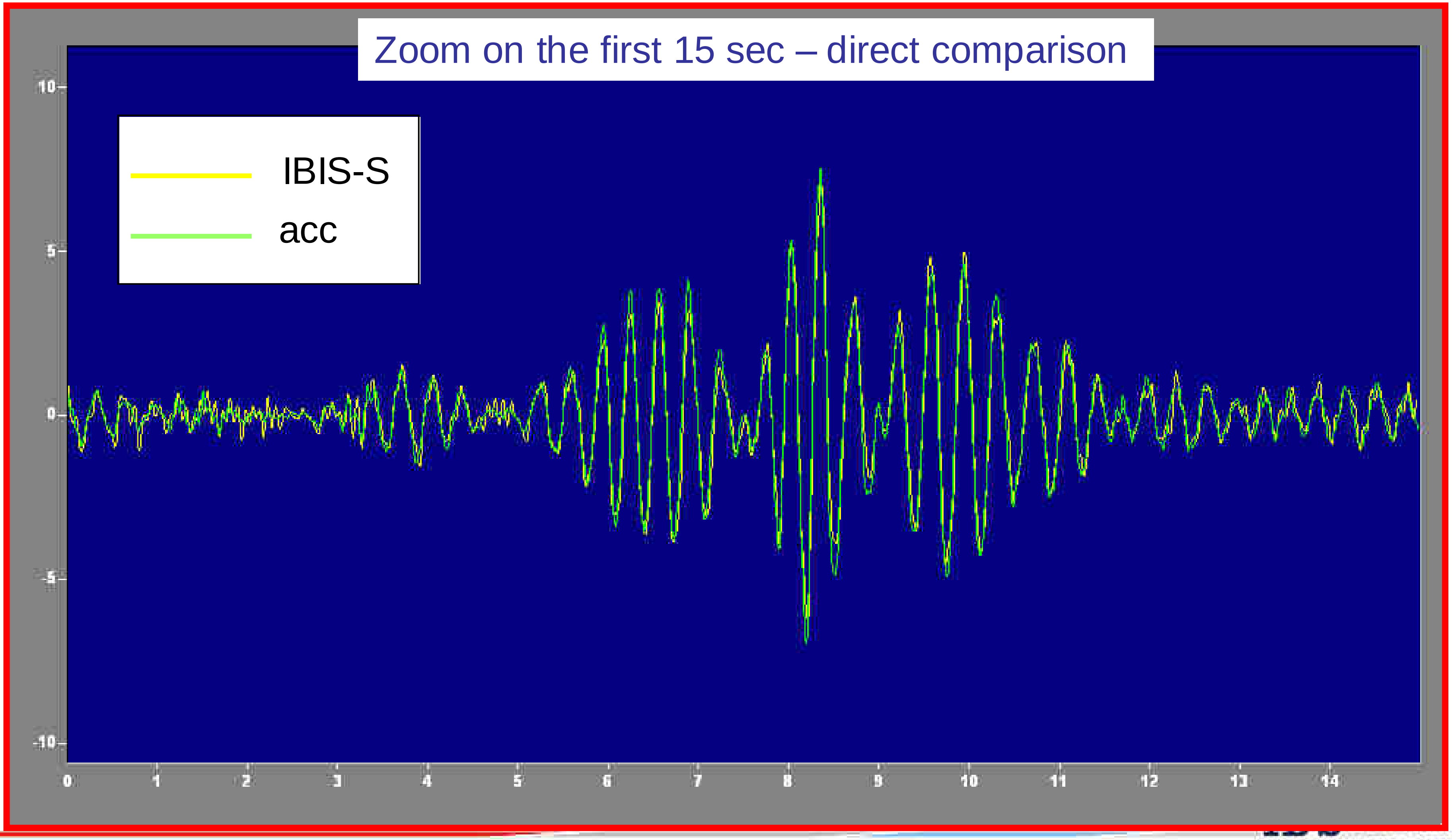
Dynamic Monitoring: Capriate bridge

Bridge photograph and range profile

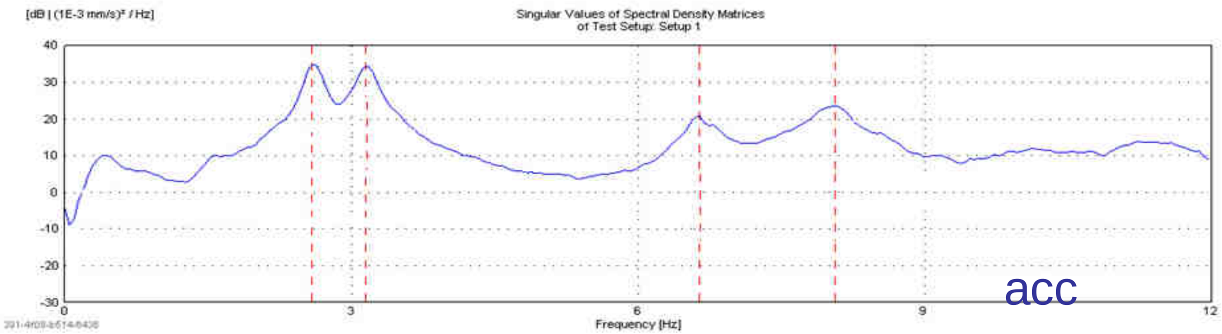


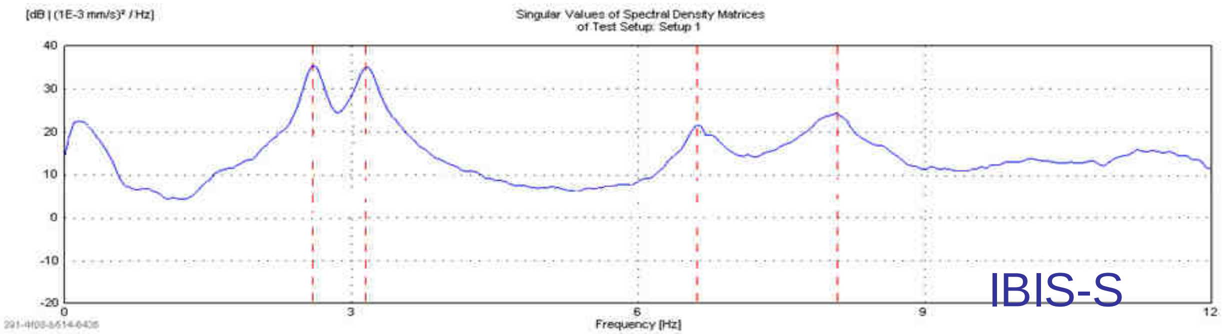
Dynamic Monitoring: Capriate bridge

Velocity comparison for Test Point 22



Dynamic Monitoring: Capriate bridge





Frequency analysis comparison on 3000sec acquisition duration

Acc detected frequency	IBIS-S detected frequency	Percentage error
Hz	Hz	%
2,617	2,595	0,84
3,164	3,182	-0,57
6,641	6,608	0,50
8,086	8,077	0,11

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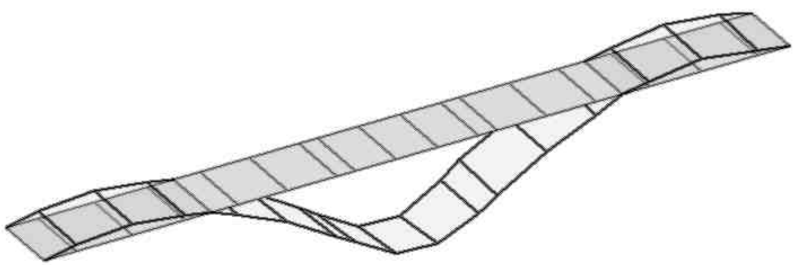
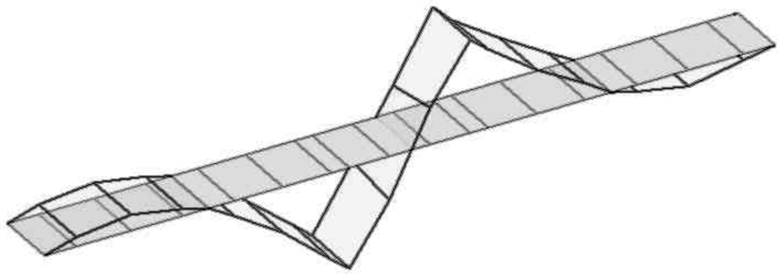
Dynamic Monitoring: Capriate bridge

Modal shape obtained by accelerometer data

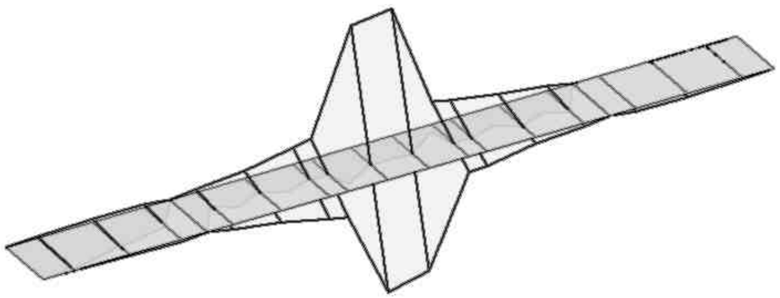
$f = 2.617$ Hz



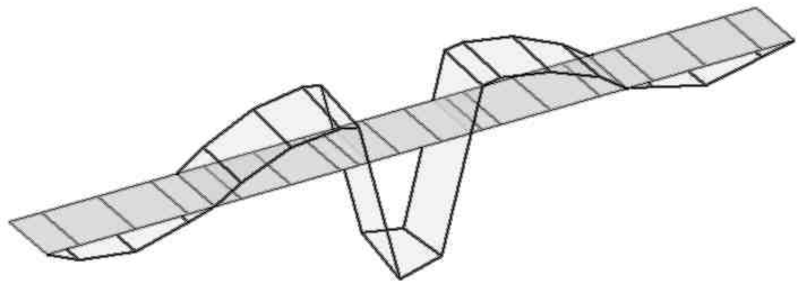
$f = 3.164$ Hz



$f = 6.641$ Hz

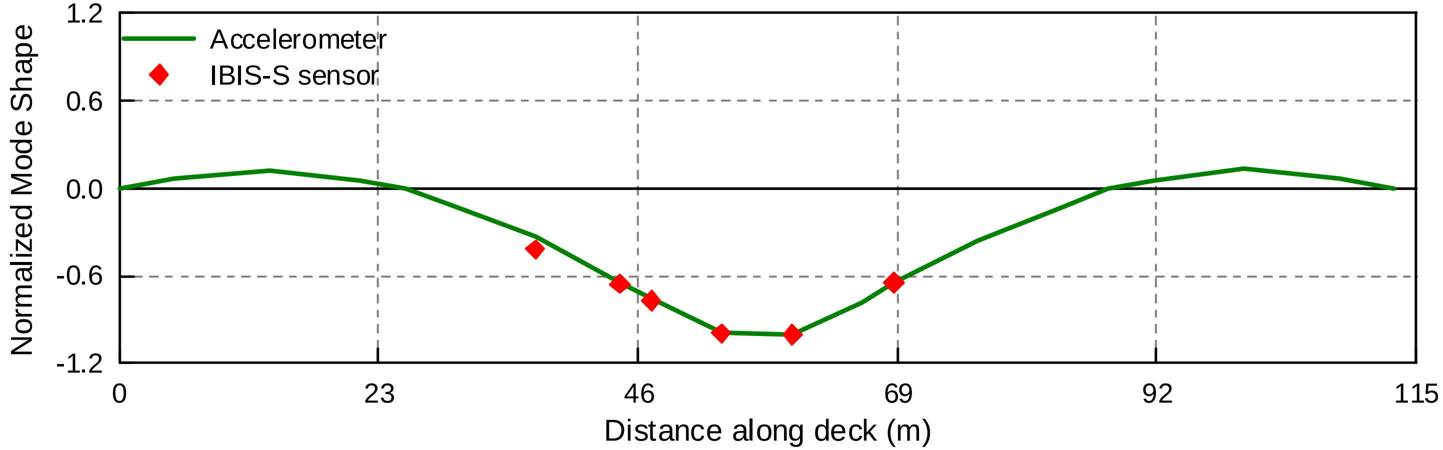


$f = 8.086$ Hz

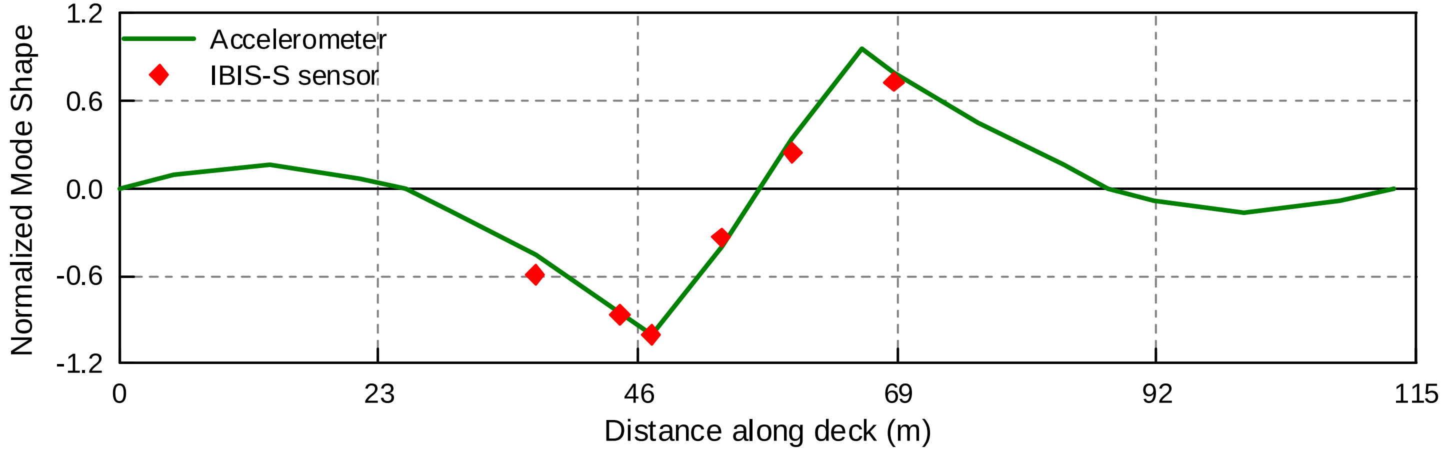


Dynamic Monitoring: Capriate bridge

Modal shapes comparison



f=2.617Hz



f=3.164Hz

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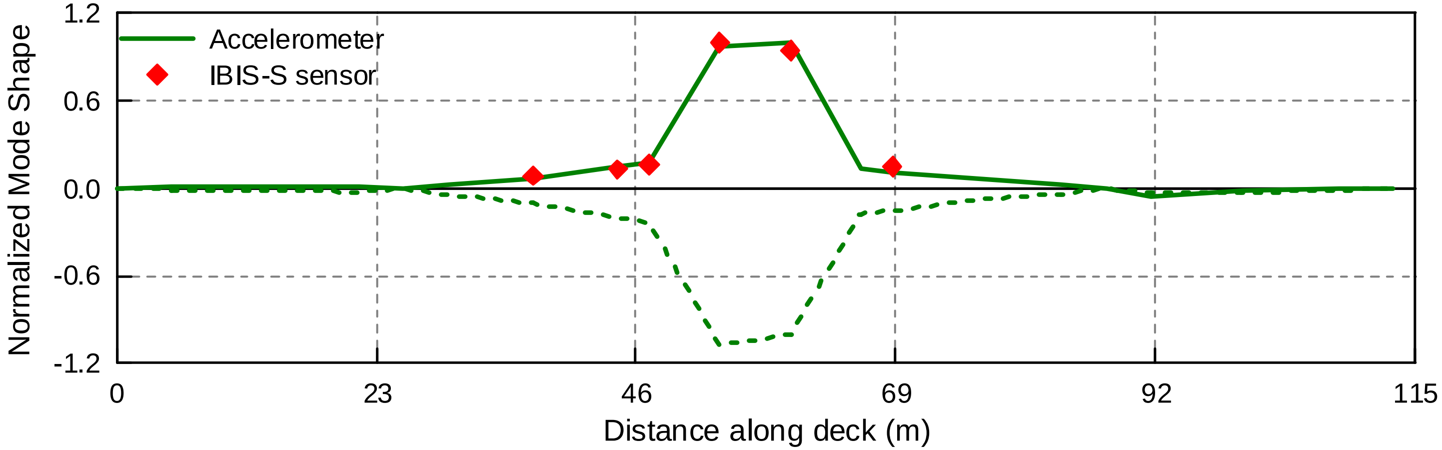
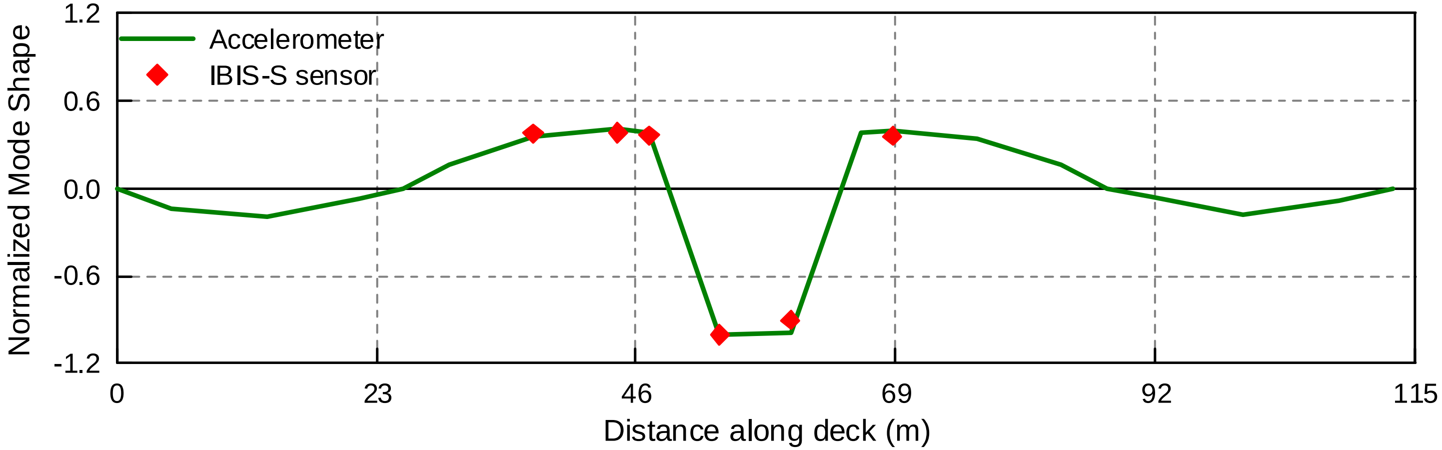
Dynamic Monitoring: Capriate bridge

Modal shapes comparison



f=6.641Hz



f=8.086Hz

IBIS-S & Cable-stayed bridges

Application goal: dynamic analysis done through ambient vibration testing (AVT) aimed at:

- Identify the **amplitude** of the **cable vibrations**;
- Identify the **natural resonant frequencies** and the **cable dumping factors**
- Evaluate the **tension** and the **operating strain** of **cables** to verify the correct distribution of loads and the temporal variation of tensions along the bridge life

IDS INGEGNERIA DEI SISTEMI

IBIS-S & Cable-stayed bridges

Conventional equipment used today:

- **Accelerometer**: provides accel./velocity mesurements, one acc. for each cable, time-comsuming acquisition, possible logistics difficulties in the installation (need for a crane-truck and traffic shut-done)

- **Doppler Laser Vibrometer (LDV):** provides displacement measurements, one cable at a time, low accuracy on long distances

Accelerometer

Doppler laser

IBIS-S & Cable-stayed bridges

Advantages in the use of IBIS-S:

- Provide **displacement** measurements (useful to evaluate the amplitude of vibrations)
- Very **accurate** measurement: an order of magnitude higher than LDV
- **No traffic shut-done** needed (IBIS can be installed under the bridge or beside the bridge towers)
- **Simultaneuous** measurement on a large number of cables (potentially all cables of each side at once)
- **Rapid** installation and measurement set-up

IBIS-S & Cable-stayed bridges

Economical advantages in the use of IBIS-S:

- Example of standard use for a cable stayed bridge with 48 cables

Item	Test with accelerometers	Test with LDV	Test with IBIS-S
Personnel (n°of units)	3-4	1-2	1-2
Number of devices	10-15	1	1
Install./disinstall. time	30’ for each cable	10’ for each cable	20’ for 12 cables
Acquisition duration once installed*	60’	60’	60’
Field activity duration (days)	3-4	4-6	1
Personnel costs (Euro)**	7.200-12.800	3.200-9.600	800-1.600
Need for crane truck	Yes	no	no
Need for traffic shut-down	Yes	no	no

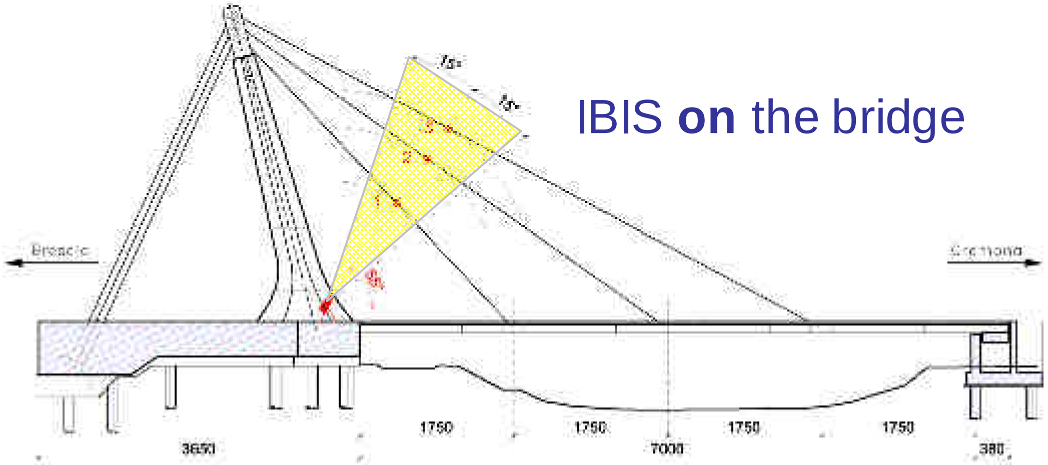
*Once installed all the equipments need at least 60’ of acquisition to obtain reliable results using AVT

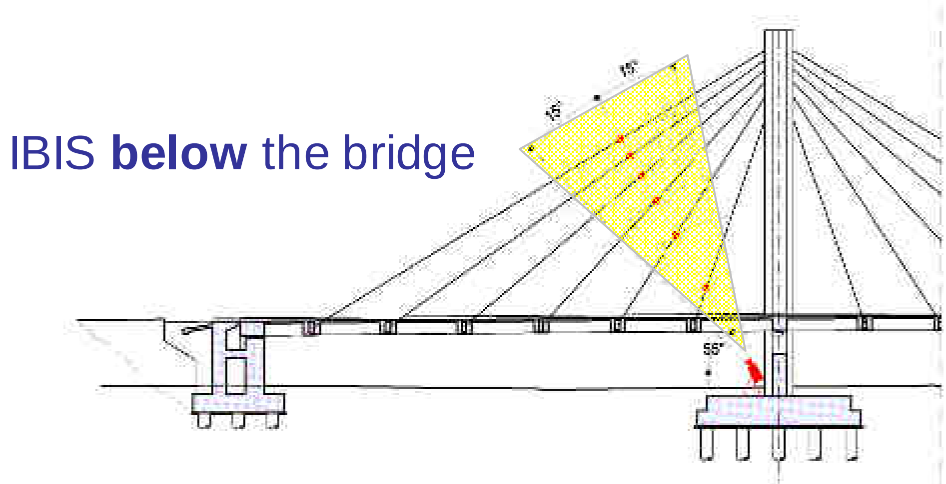
**Personnel costs are calculated on an average rate of 800 €/day per personnel unit

***Post-Processing times for data acquired by the three equipments are comparable (the output is the same)

IBIS-S & Cable-stayed bridges

Geometrical sketch of IBIS-S set-up:





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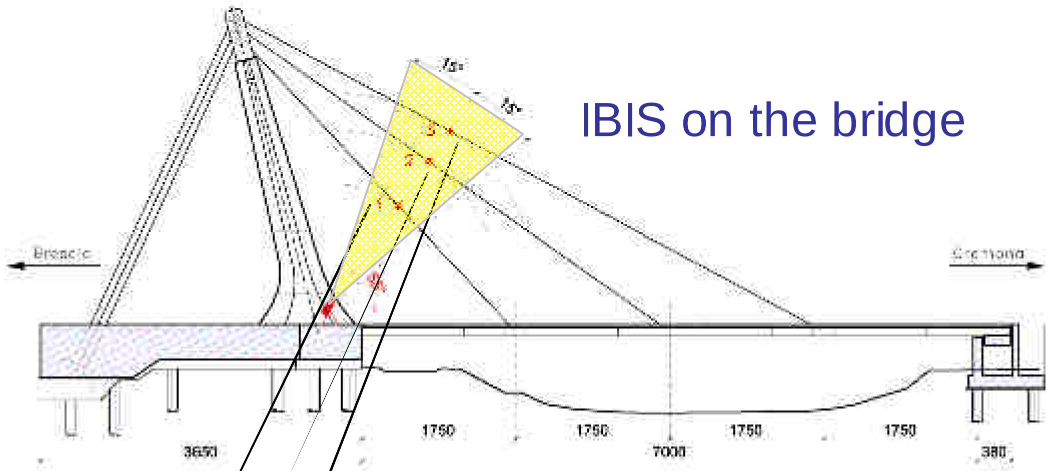
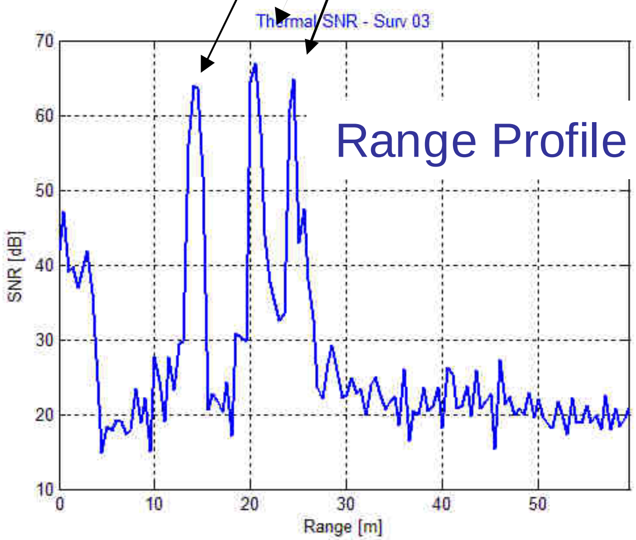
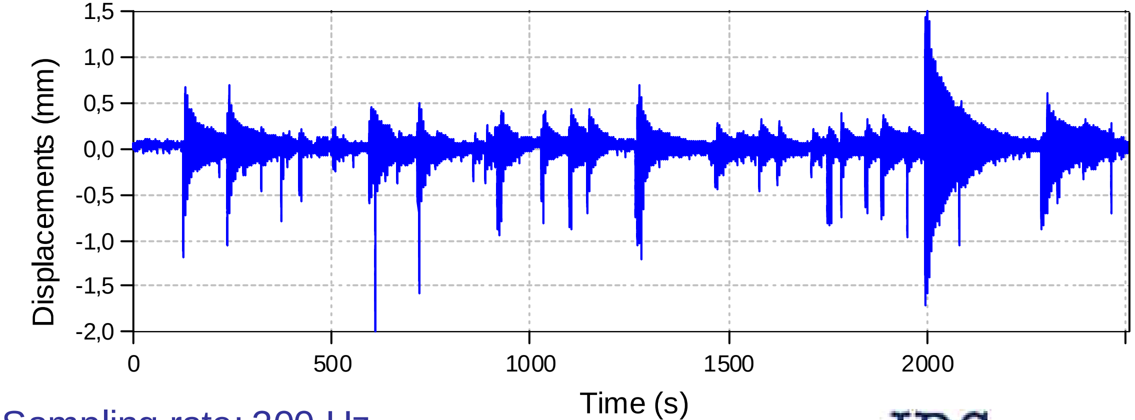
IBIS-S & Cable-stayed bridges: case studies

Example: Bordolano bridge (Italy)





Displacement graph of cable n°1



Sampling rate: 200 Hz

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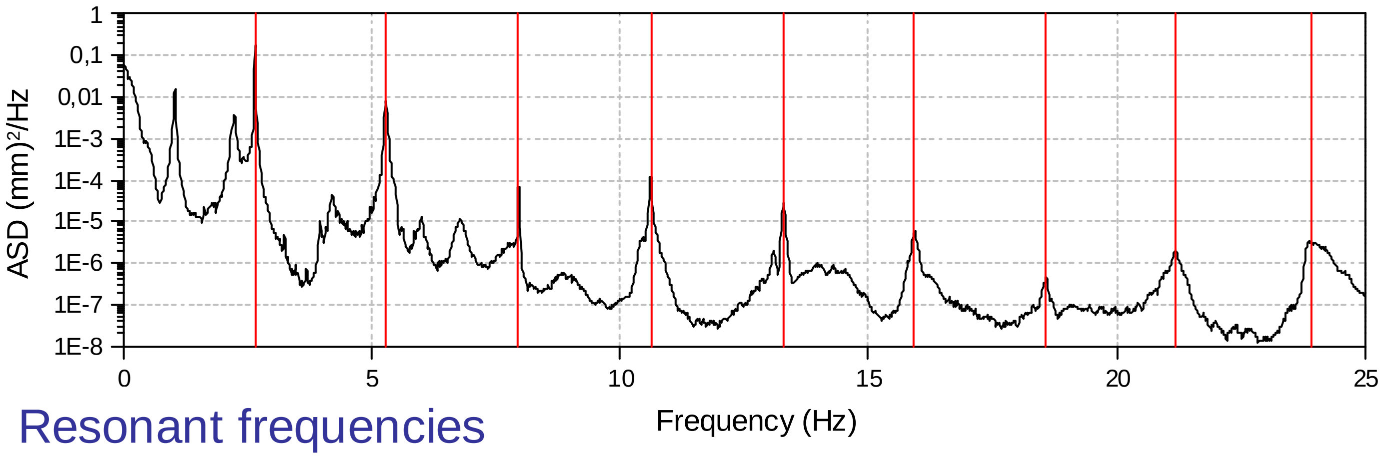
IBIS-S & Cable-stayed bridges: case studies

Example: Bordolano bridge (Italy)

Frequency Domain Analysis



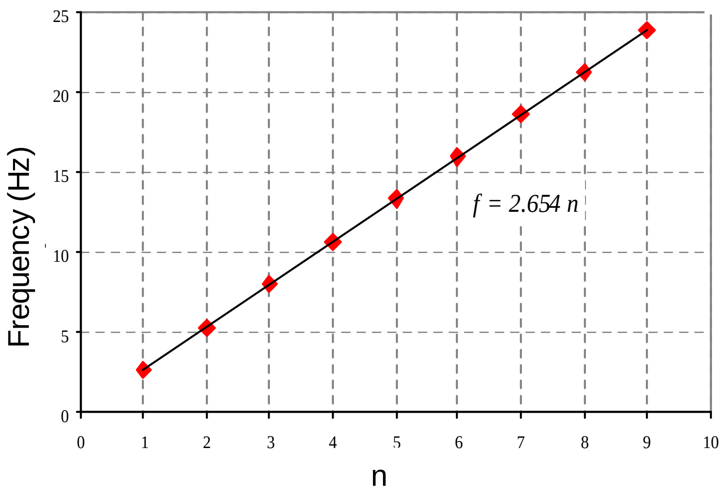
from frequency to tension:

$$T(f_n) = 4\rho L^2 \left(\frac{f_n}{n}\right)^2$$

$$per \quad n = 1,\ldots,5$$

Resonant frequencies

f **(Hz)**	
f_1 =	2.649
f_2 =	5.286
f_3 =	7.959
f_4 =	10.62
f_5 =	13.29
f_6 =	15.93
f_7 =	18.58
f_8 =	21.18



Tension

	Cable n°1	
i	f_i (Hz)	$T(f_i)$ (kN)
1	2.649	2713.1
2	5.286	2700.8
3	7.959	2721.2
4	10.62	2725.4
5	13.29	2731.26

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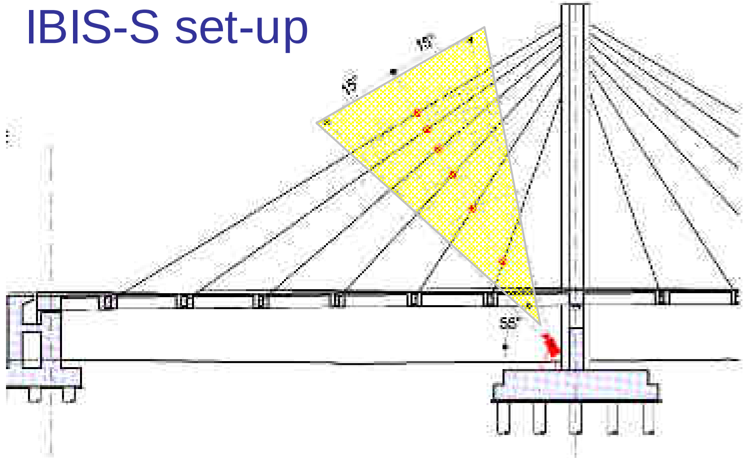
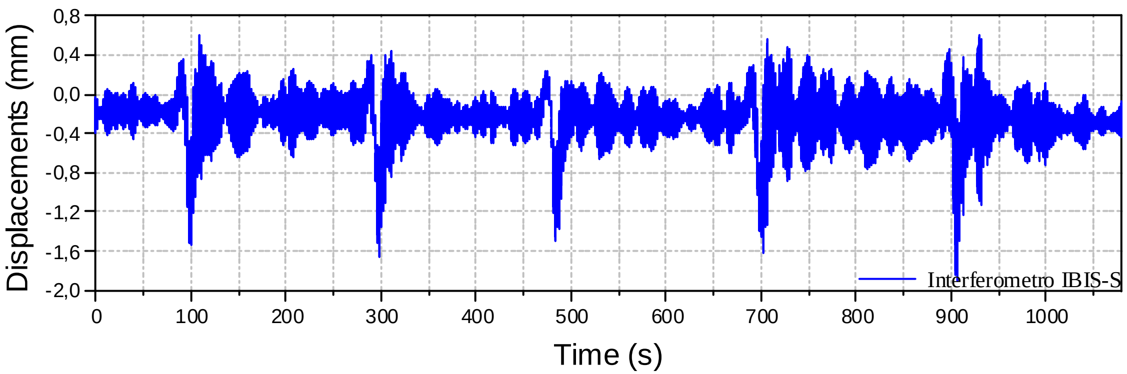
IBIS-S & Cable-stayed bridges: case studies

Example: Olginate bridge (Italy)

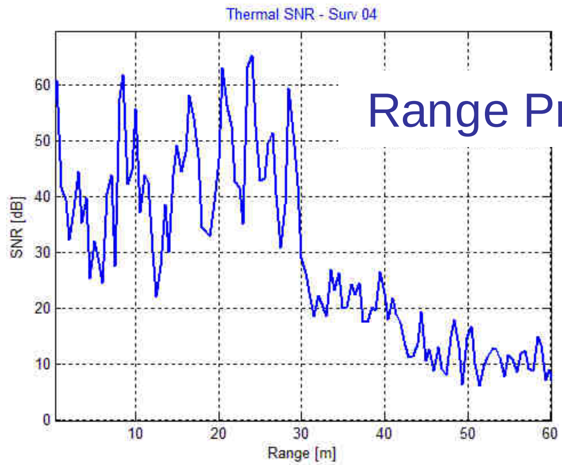
IBIS-S set-up



Displacement graph



Range Profile



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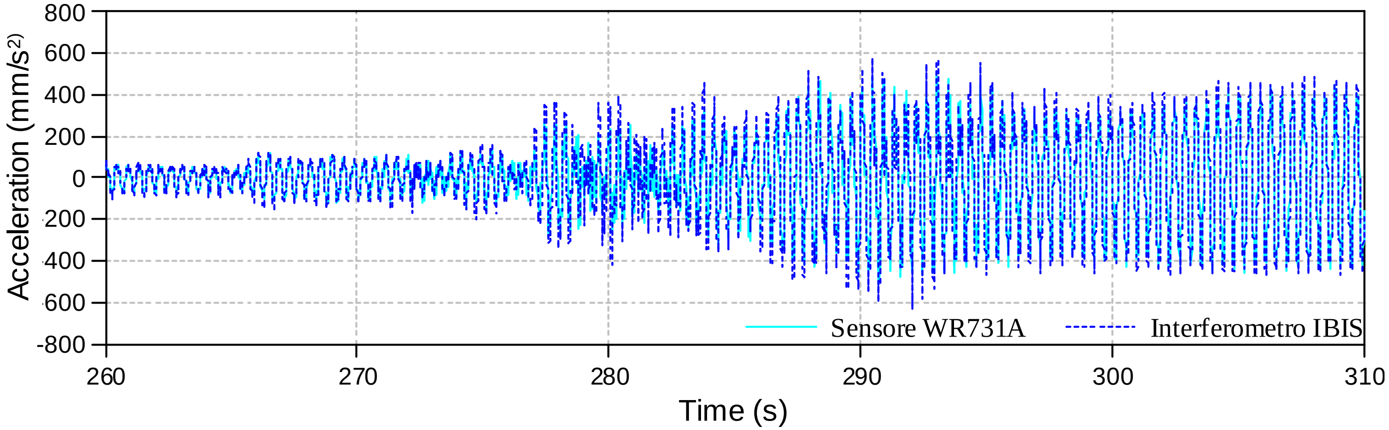
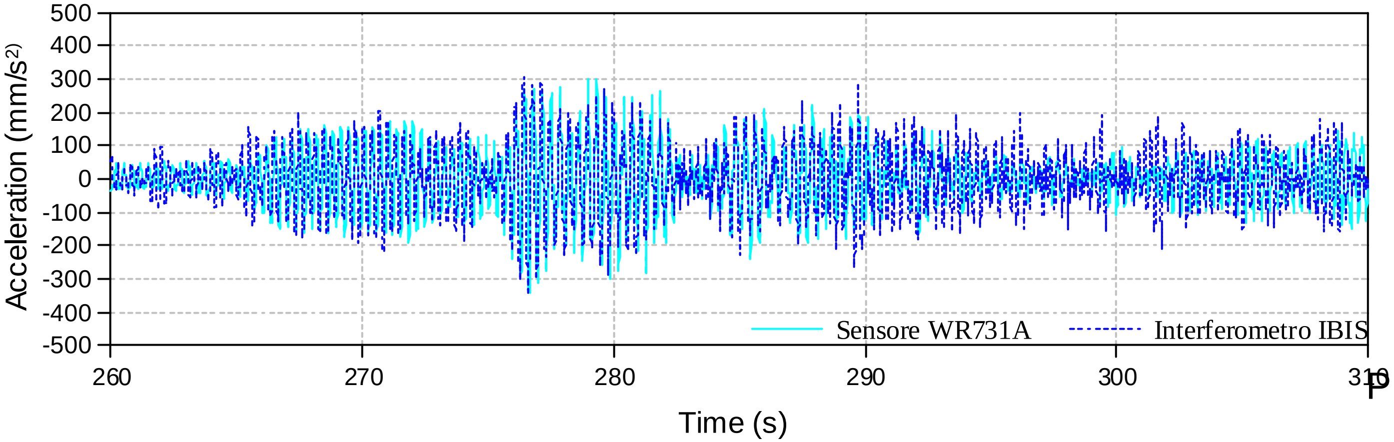
IBIS-S & Cable-stayed bridges: case studies

Example: Olginate bridge (Italy)

Comparison with accelerometers



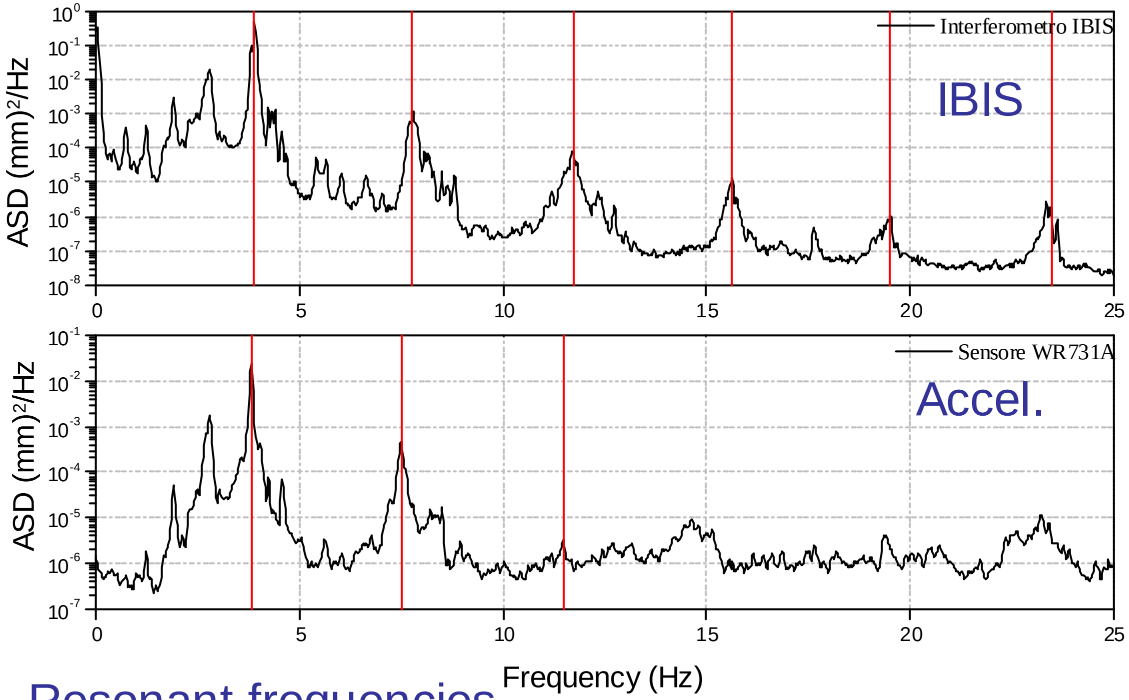


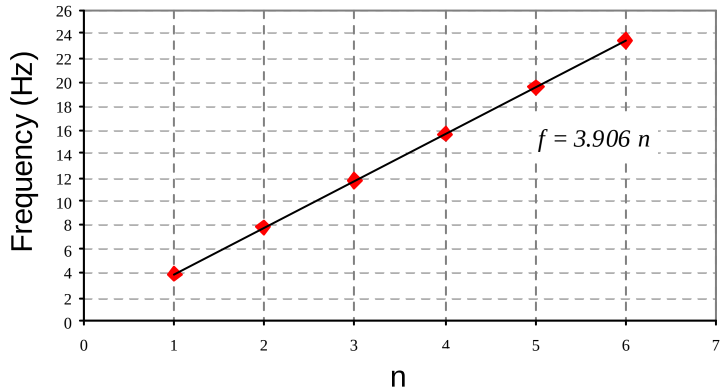
Piezo-electric accel. WR 731A

IBIS-S & Cable-stayed bridges: case studies

Example: Olginate bridge (Italy)

Frequency Domain Analysis





Tension

Cable S09'			
IBIS-S		Accelerometer	
f_{exp} (Hz)	Tension (kN)	f_{exp} (Hz)	Tension (kN)
3.906	1883.1	3.809	1790.7
7.764	1860.0	7.495	1733.3
11.720	1883.7	11.470	1804.2
15.630	1884.5		
19.510	1879.2		
23.460	1886.9		
	1880		**1776**

Resonant frequencies

	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)	f_4 (Hz)	f_5 (Hz)	f_6 (Hz)
IBIS-S	3.906	7.764	11.720	15.630	19.510	23.460
Accel.	3.809	7.495	11.470			

IDS INGEGNERIA DEI SISTEMI

Dynamic Monitoring: chimney measurement

Measurement objective: measurement of the displacements of the old and new chimney and identification of their resonance frequencies

Old chimney

Chimney high: 183m

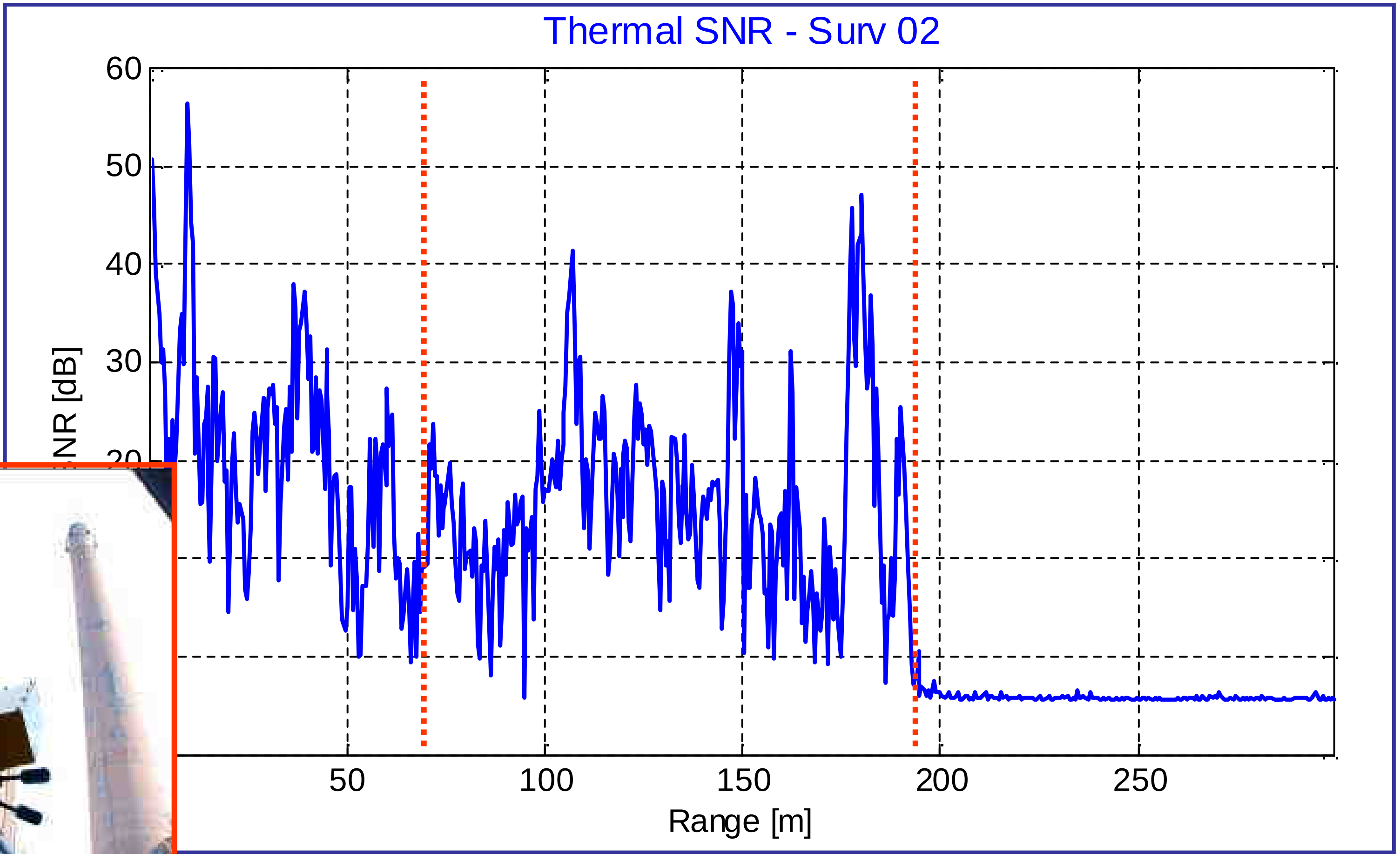
Measurement parameters:

maximum range: 300 m
sampling frequency: 50 Hz
range resolution: 0.5 m
distance from the target: ~ 50 m

New chimney

Dynamic Monitoring: chimney measurement

Range profile of the old chimney

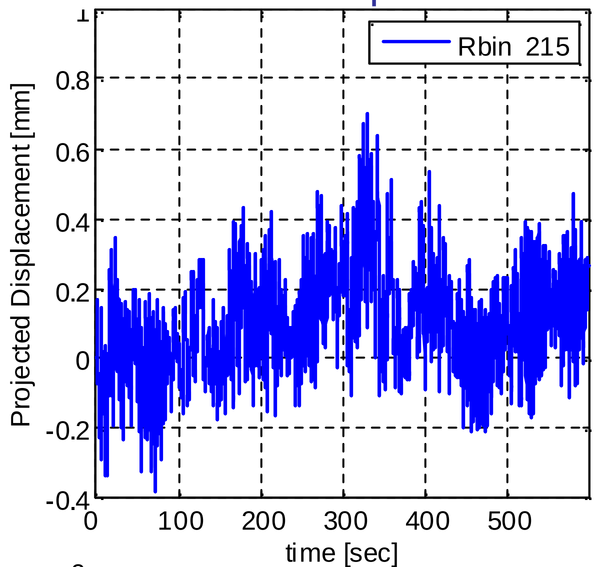


IDS INGEGNERIA DEI SISTEMI

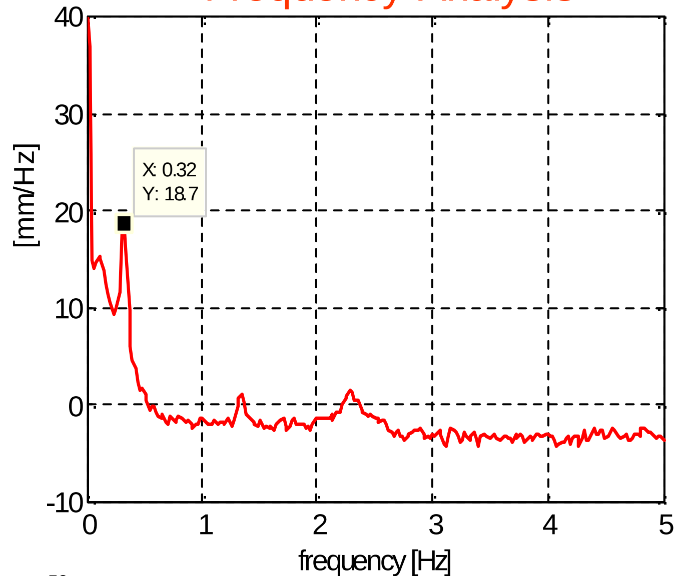
Dynamic Monitoring: chimney measurement

Old chimney

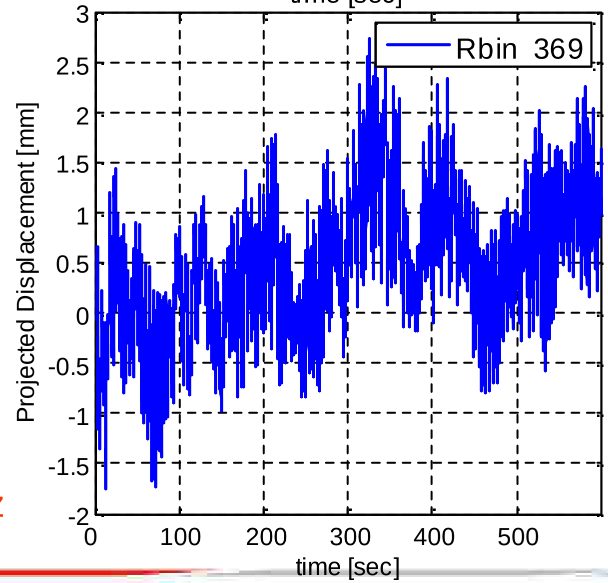
Horizontal displacement

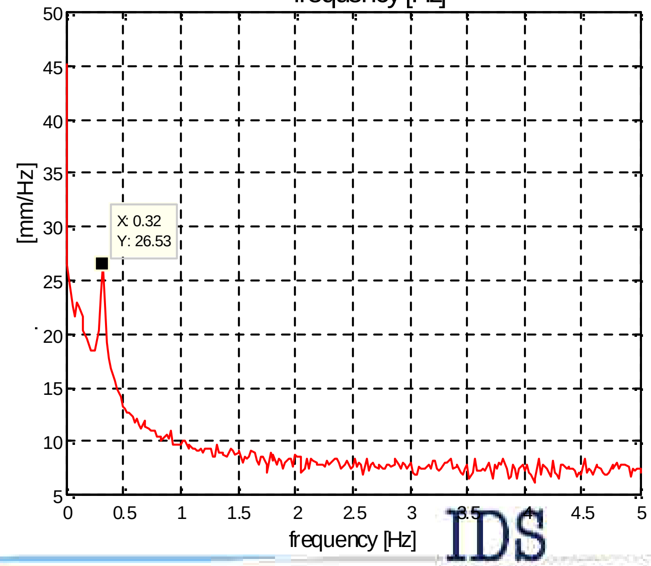


Frequency Analysis



Point located at the middle of the chimney, at a height of 94 m



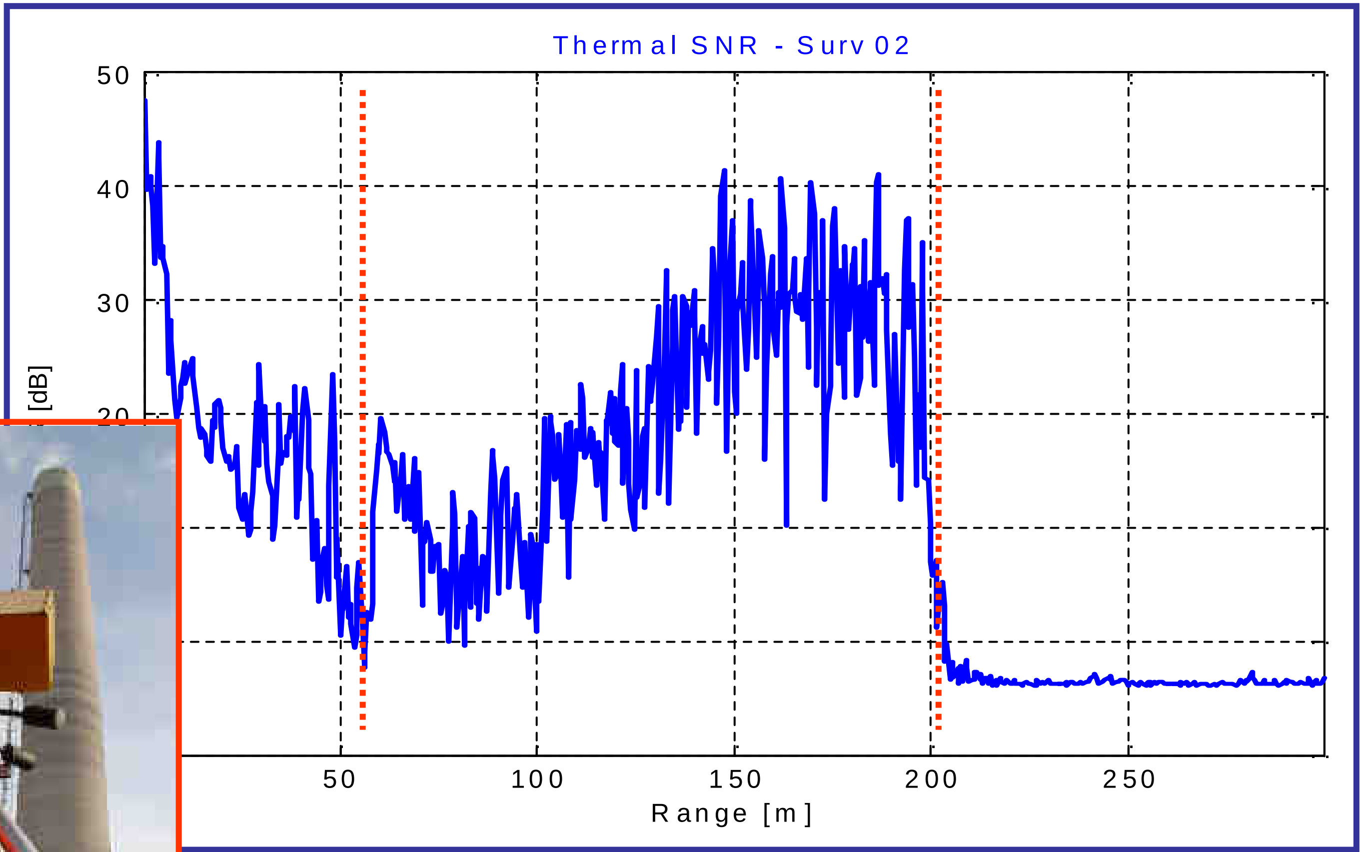


Point located at the top of the chimney, at a height of 176 m

Identified frequency: 0.32Hz

Dynamic Monitoring: chimney measurement

Range profile of the new chimney



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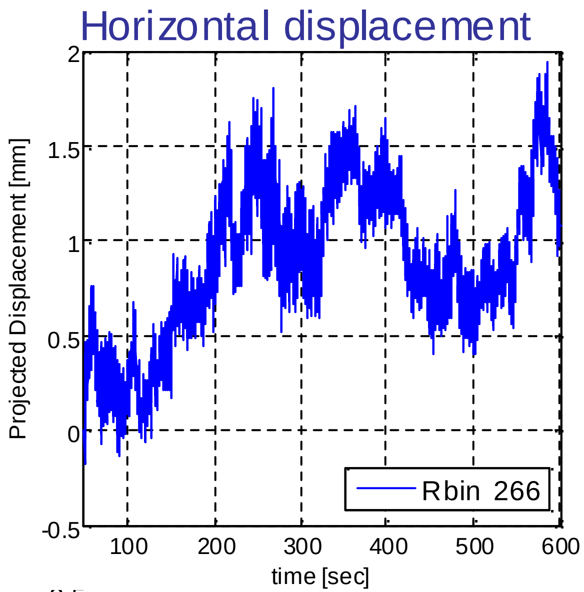
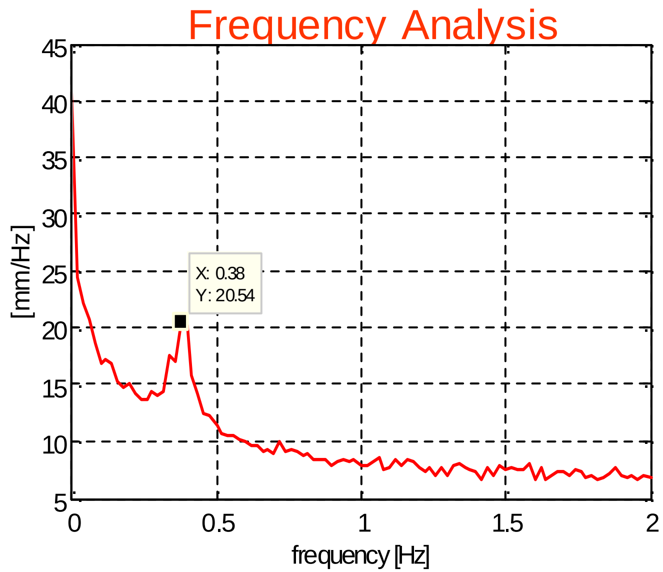
Dynamic Monitoring: chimney measurement

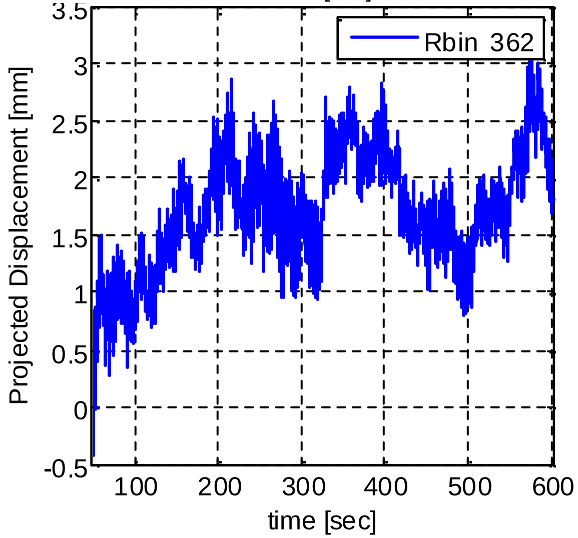
New chimney

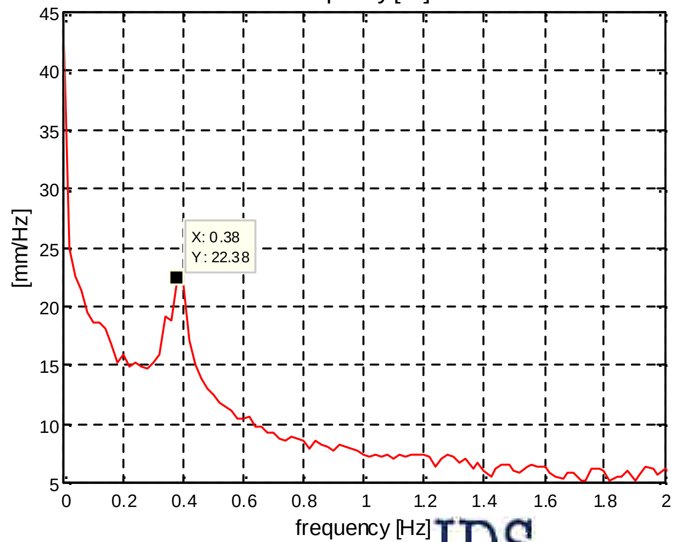
Point located at the middle of the chimney, at a height of 121 m





Point located at the top of the chimney, at a height of 172 m





Identified frequency: 0.38 Hz

IDS INGEGNERIA DEI SISTEMI

Dynamic Monitoring: Hi-rise buildings

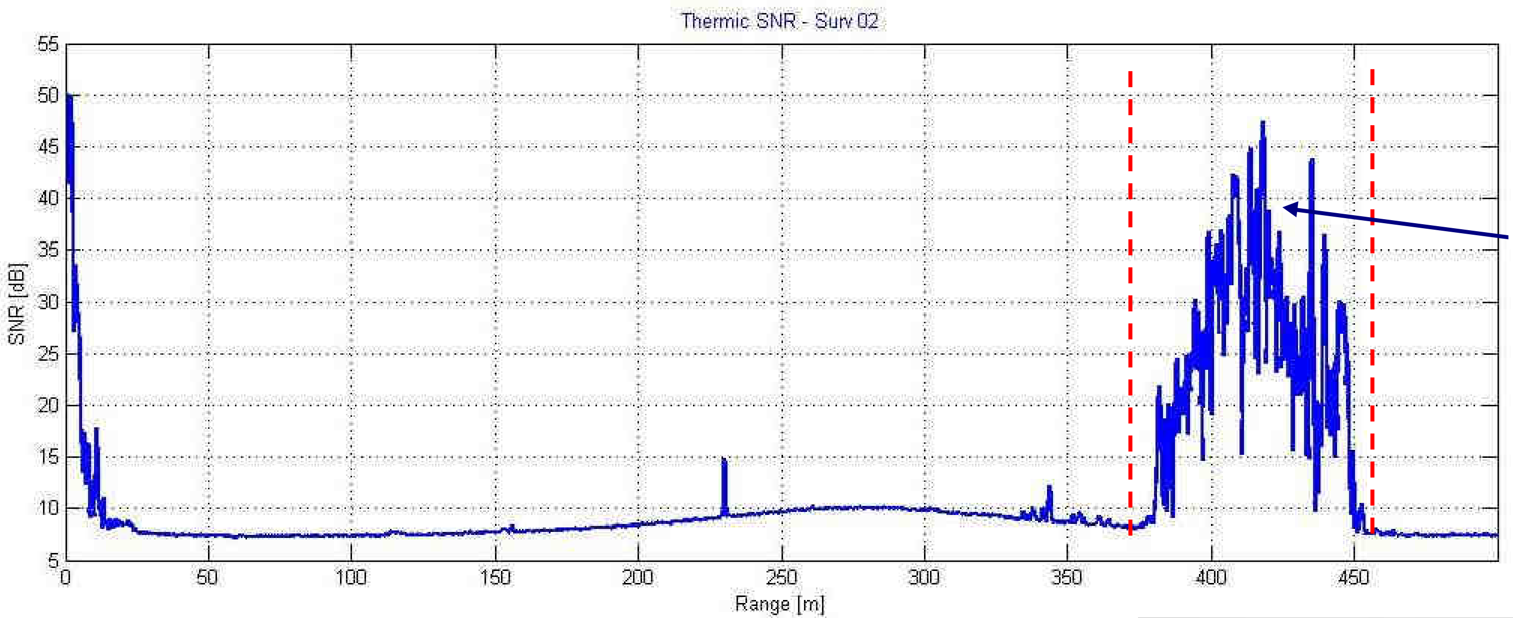
Measurement objective: measurement of the displacements at the top of the building and identification of the resonance frequencies of the structure

Skyscraper 207 m high in Brisbane (Australia)

Measurement set-up

Dynamic Monitoring: Hi-rise buildings

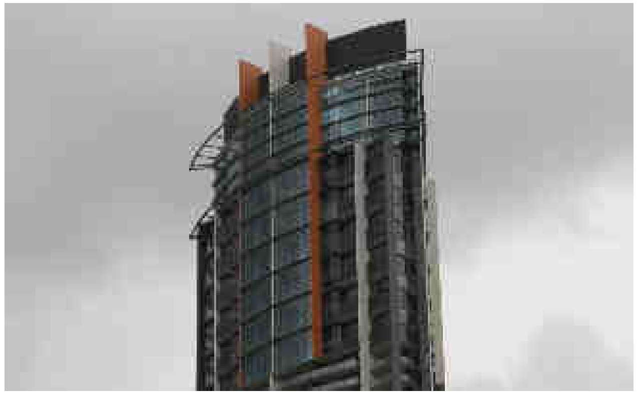
Radar range profile of the illuminated skyscraper



Radar backscattered signal from the building, corresponding to the discontinuities present on the front of the building

Measurement parameters:

- maximum range: 500 m
- sampling frequency: 13.5 Hz
- range resolution: 0.5 m
- Distance from the target: ~ 390 m
- measurement lenght: 4 sessions of 10' each



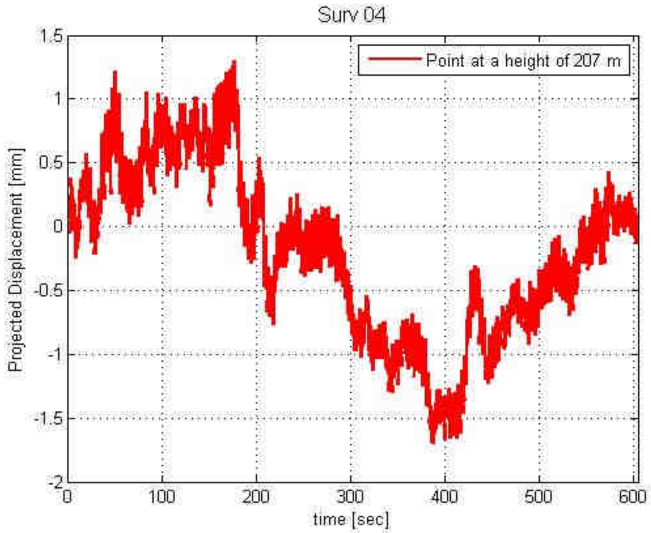
IDS INGEGNERIA DEI SISTEMI

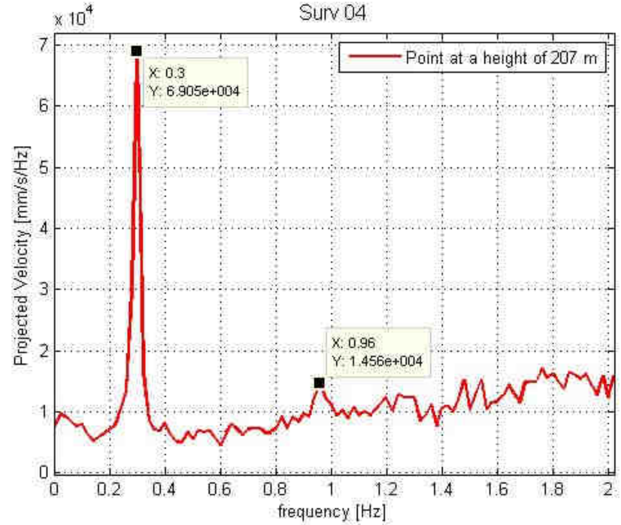
Dynamic Monitoring: Hi-rise buildings

Projected displacements

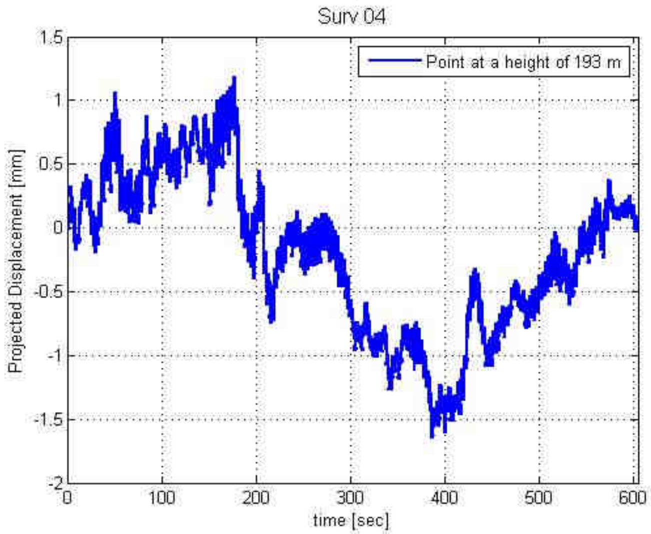
Frequency analysis

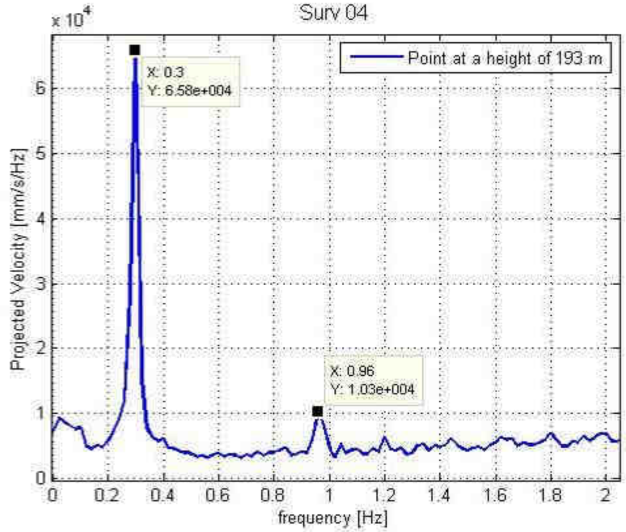
Point located at the top of the building, at a height of 207 m





Point located at a height of 193 m on the skyscraper





Dynamic Monitoring: Kuranda Scenic Railway

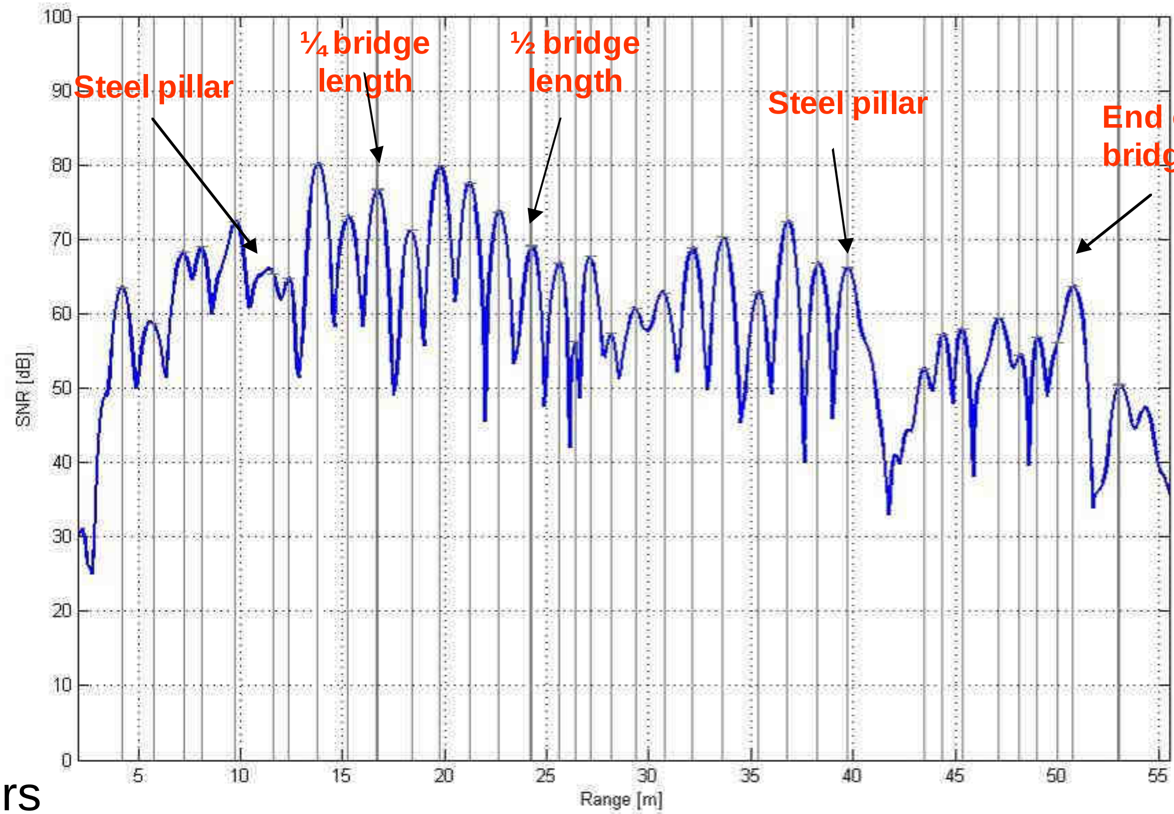
Measurement objective: measurement of the vertical displacements induced by the train passage and resonance frequencies

Kuranda train (Cairns, Australia)

Measurement set-up

Dynamic Monitoring: Kuranda Scenic Railway

Radar range profile of the illuminated rail

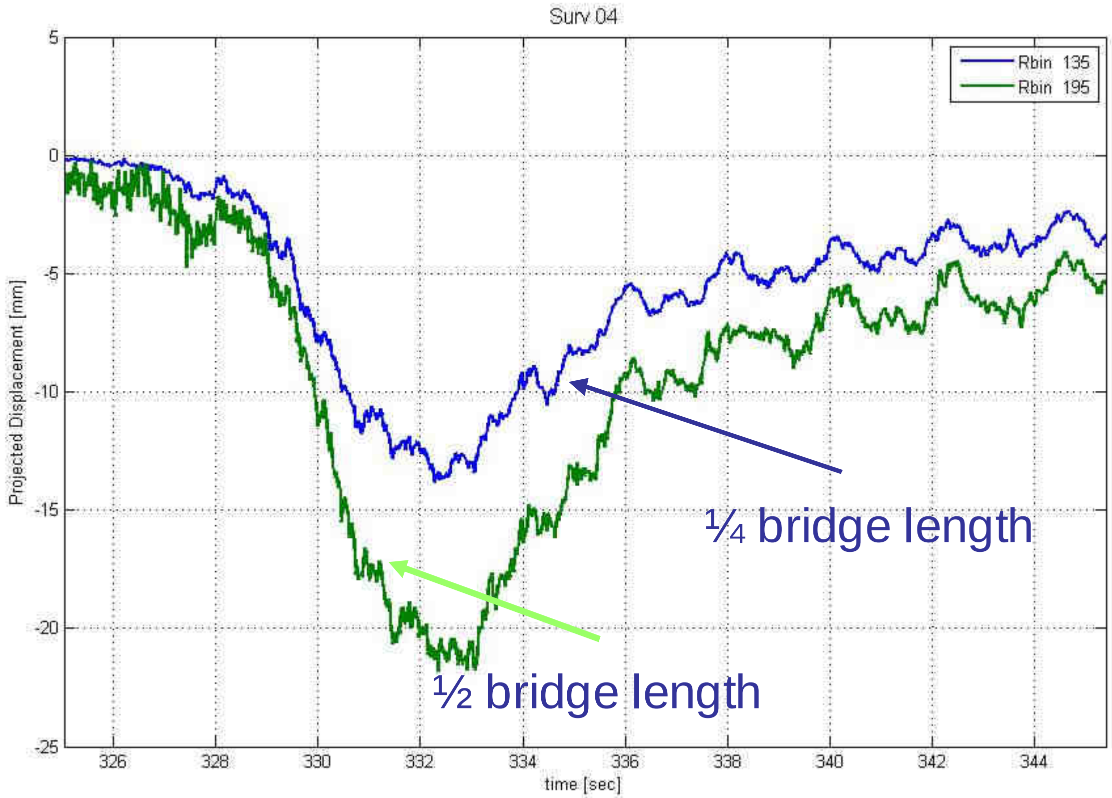


Measurement parameters

- measurement lenght: 10’ across the train passage. 2 train passages made.
- sampling frequency: 71 Hz
- Length of bridge: ~ 50 m.
- Height of bridge deck above radar: 2.7 m.

Dynamic Monitoring: Kuranda Scenic Railway

Time history displacement of a selected points (first train passage)



L.o.s. displacement projected along the vertical direction, according to the radar to bridge measured distance (2.7 m.)

IDS INGEGNERIA DEI SISTEMI

IBIS System

IBIS – S layout

Composition:
- Sensor module
- Tripod
- Power supply battery
- Personal Computer with Management SW

IBIS – L layout

Composition:
- Sensor module
- Movement module
- Power supply module
- Personal Computer with Management SW

Some references

Eni

CSIRO

www.imaa.cnr.it

POLITECNICO MILANO

RWE The energy to lead

DMT

AMBERG TECHNOLOGIES

SO.ING. STRUTTURE & AMBIENTE

GFZ Helmholtz Centre Potsdam

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