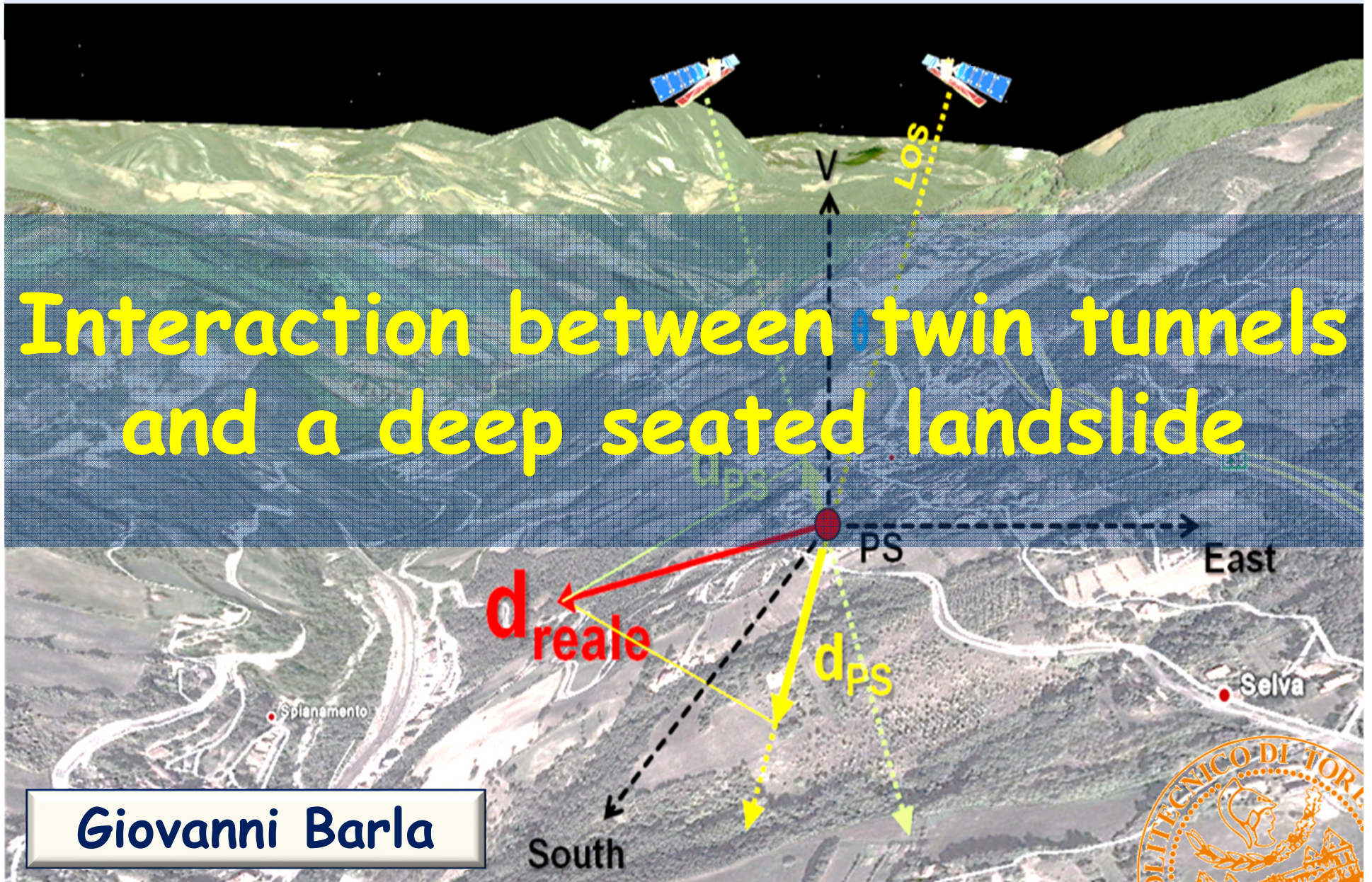


Comité Français de Mécanique des Roches
Invited Lecture - Paris - 4 December 2014

Interaction between twin tunnels
and a deep seated landslide



Giovanni Barla

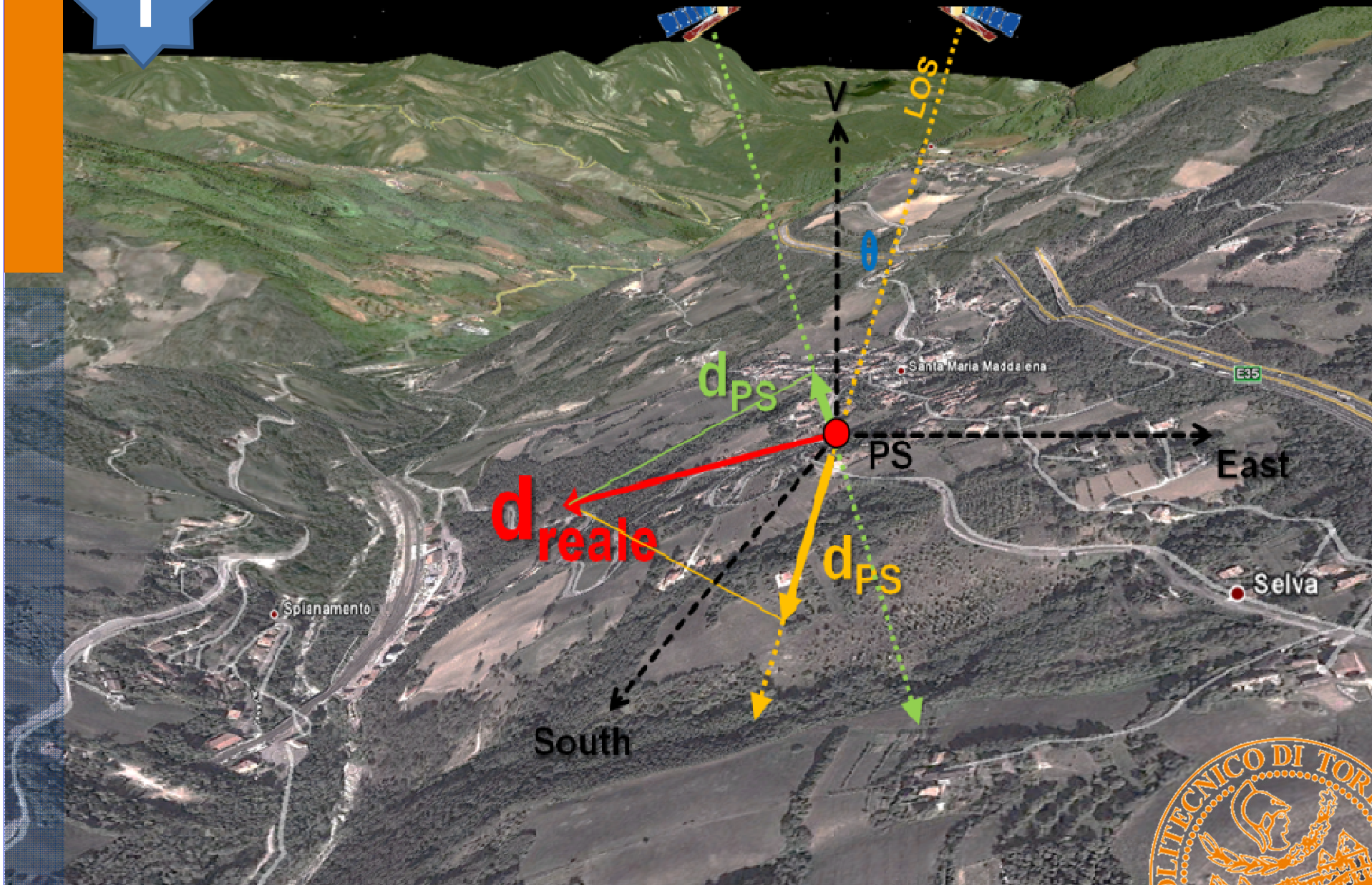
→ Outline

- **1. Introduction**
- **2. Area of interest**
- **3. Geo conditions**
- **4. Investigative & early-warning monitoring**
- **5. Numerical modelling (2D & 3D FEM)**
- **6. Conclusions**



→ Introduction

1



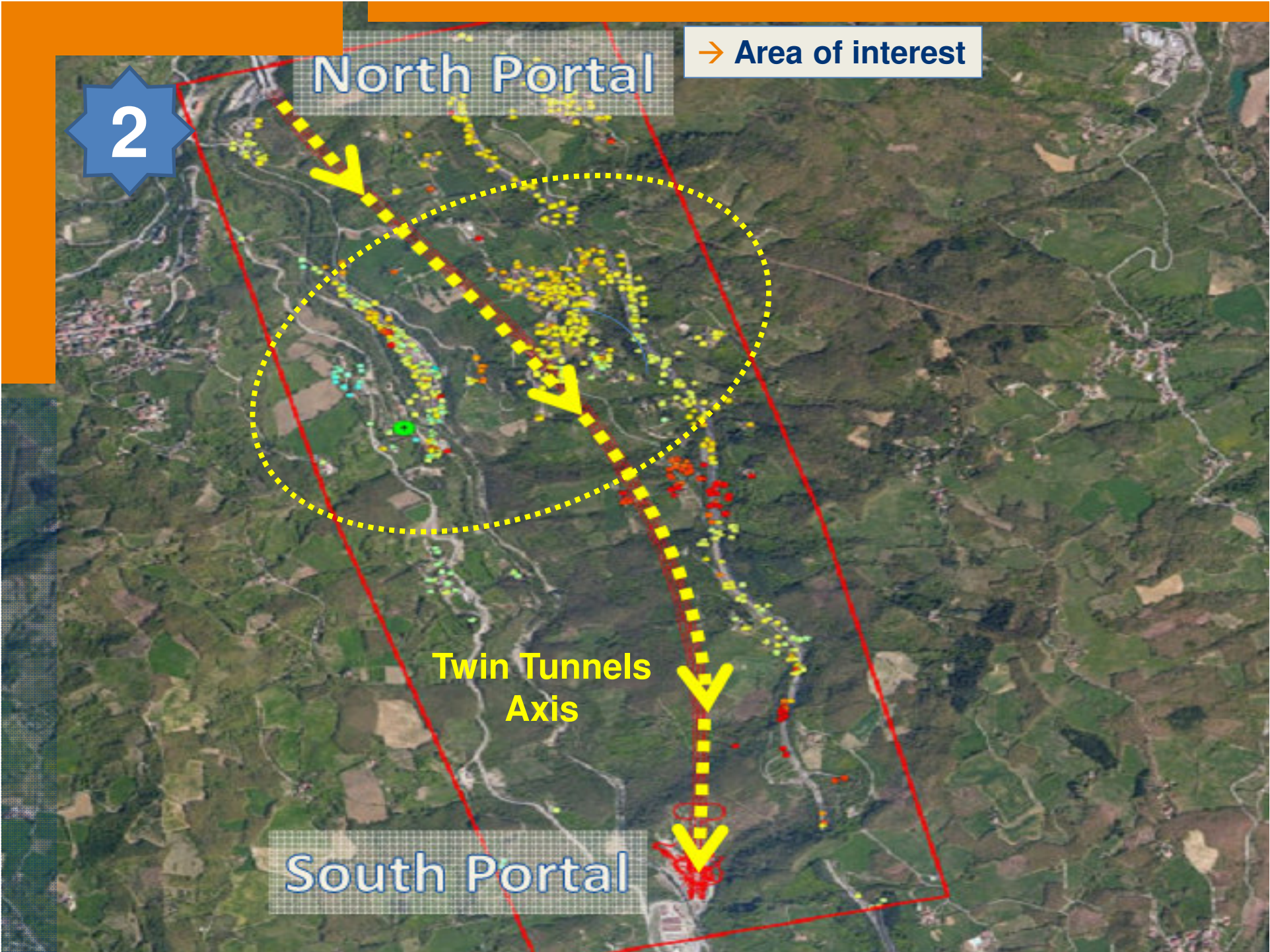
2

North Portal

→ Area of interest

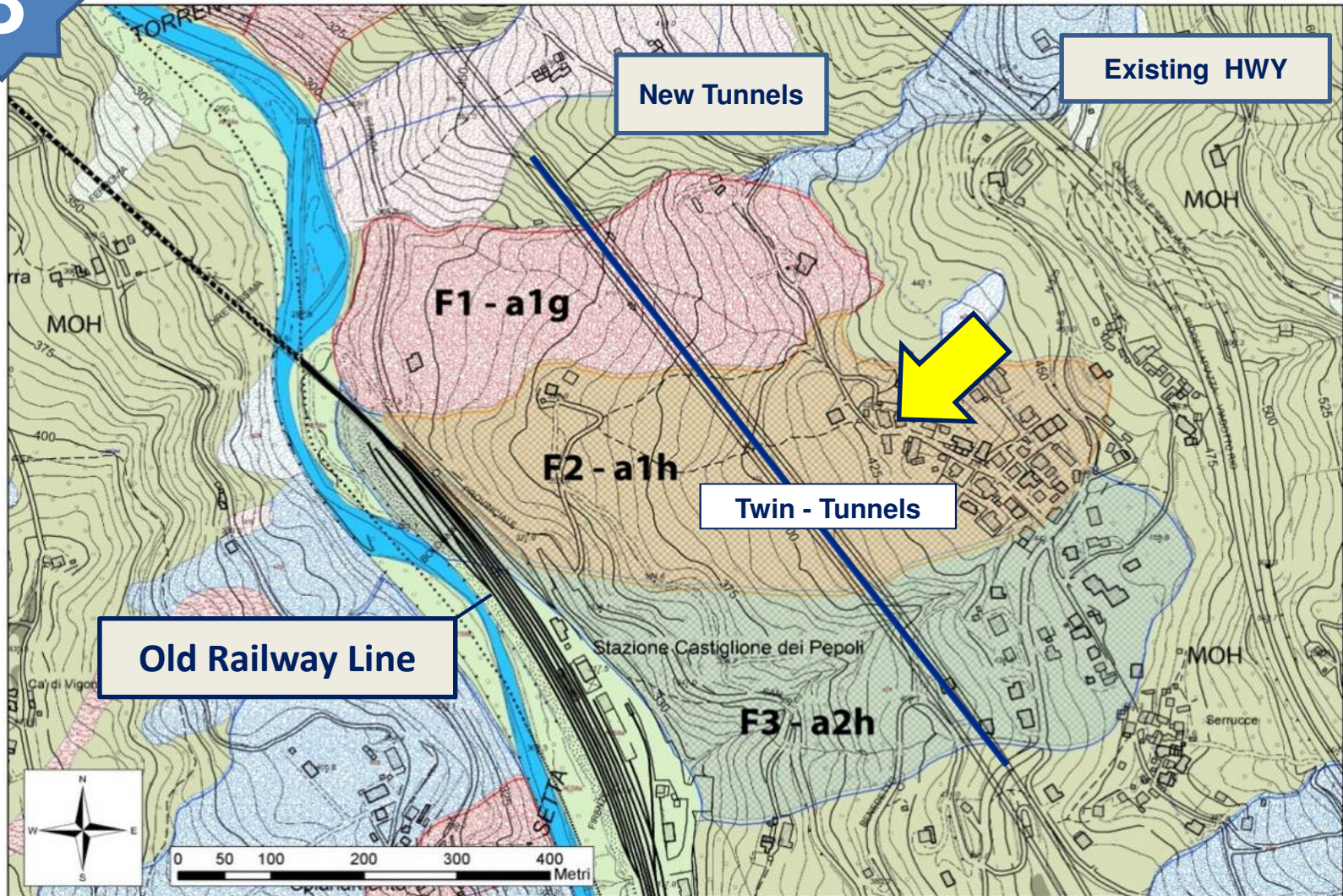
Twin Tunnels Axis

South Portal



→ Geo conditions...

3



F1 - a1g, F2 - a1h, F3 - a2h

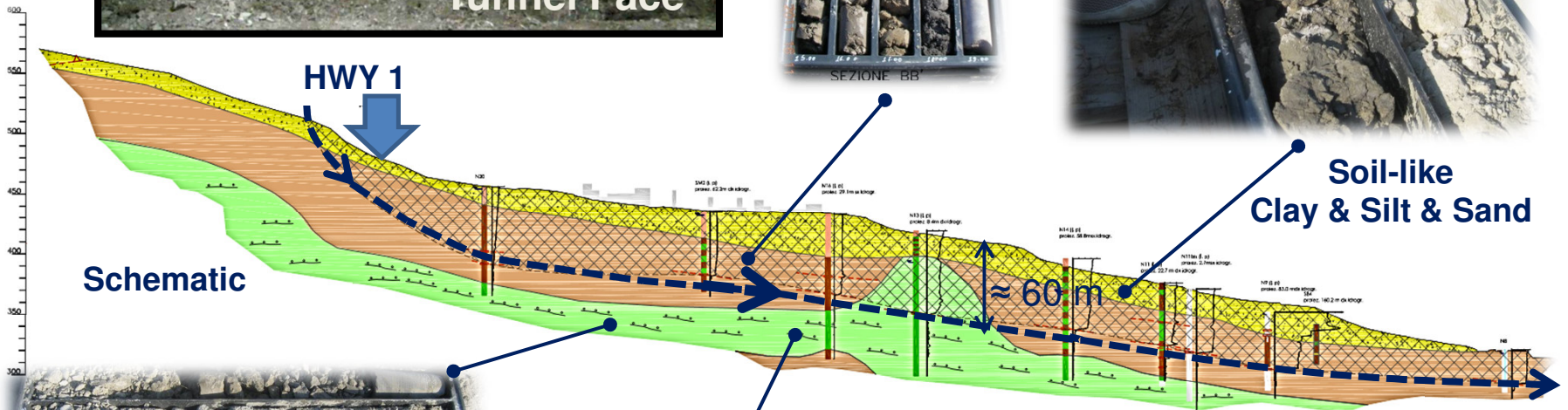
DGPV

→ Geo conditions...

3



Mudstone prevailing



→ Geo conditions...



Full Face Excavation Method

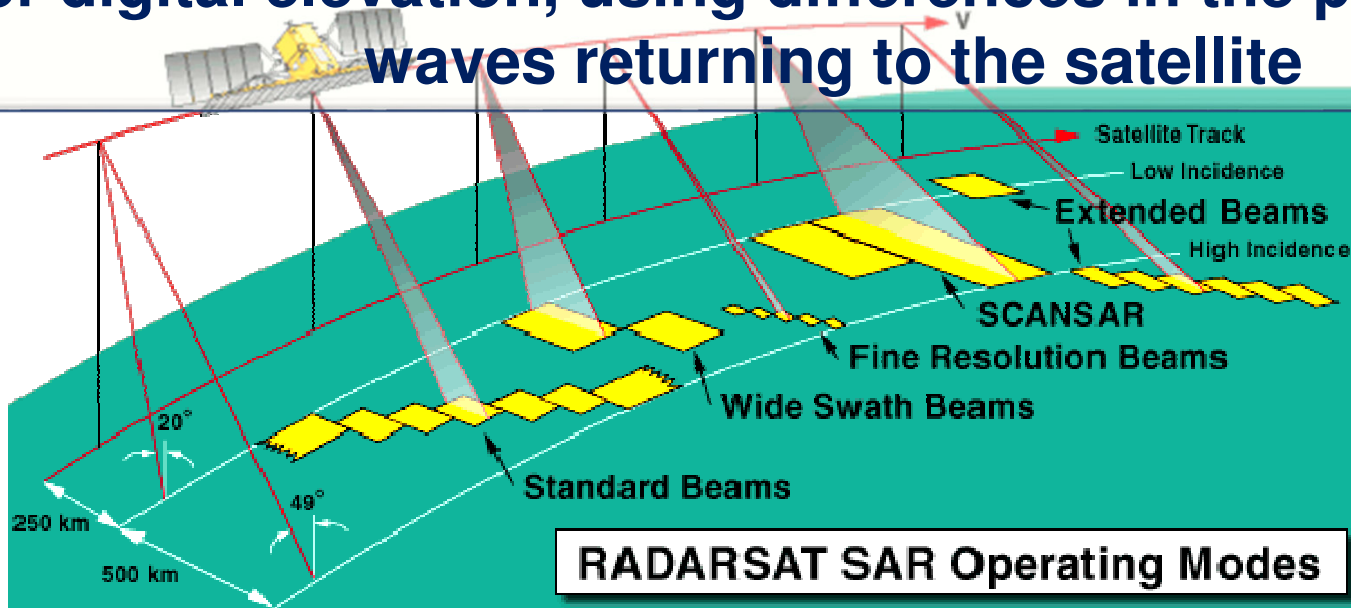


→ Investigative & early warning monitoring

4



This method uses two or more synthetic aperture radar (SAR) images to generate maps of surface deformation or digital elevation, using differences in the phase of the waves returning to the satellite



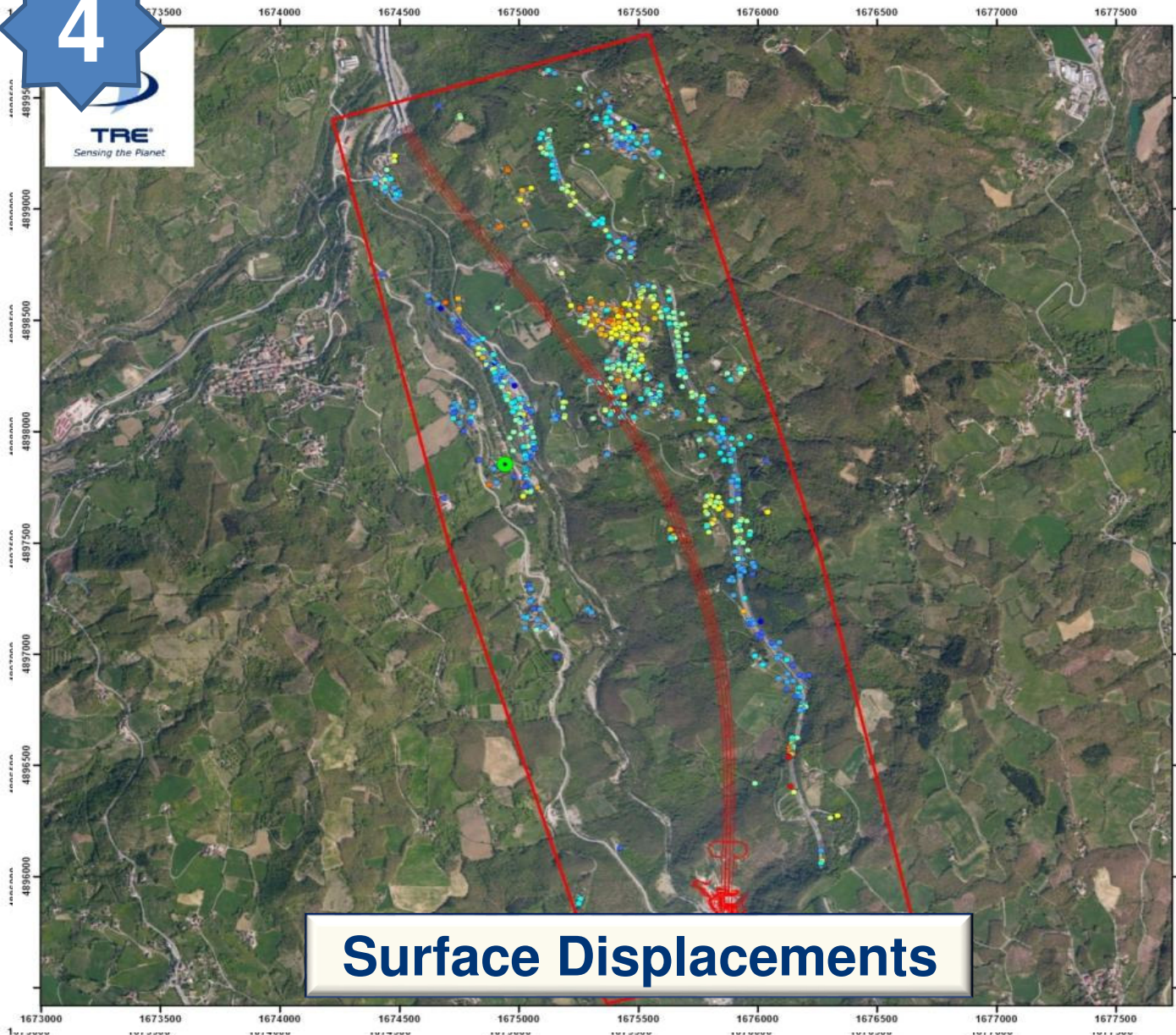
RADARSAT SAR Operating Modes



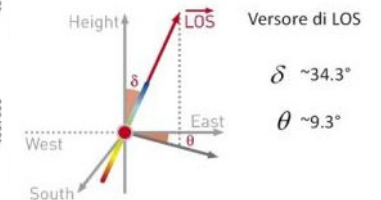
→ Investigative & early warning monitoring

4

TRE
Sensing the Planet



mm/year



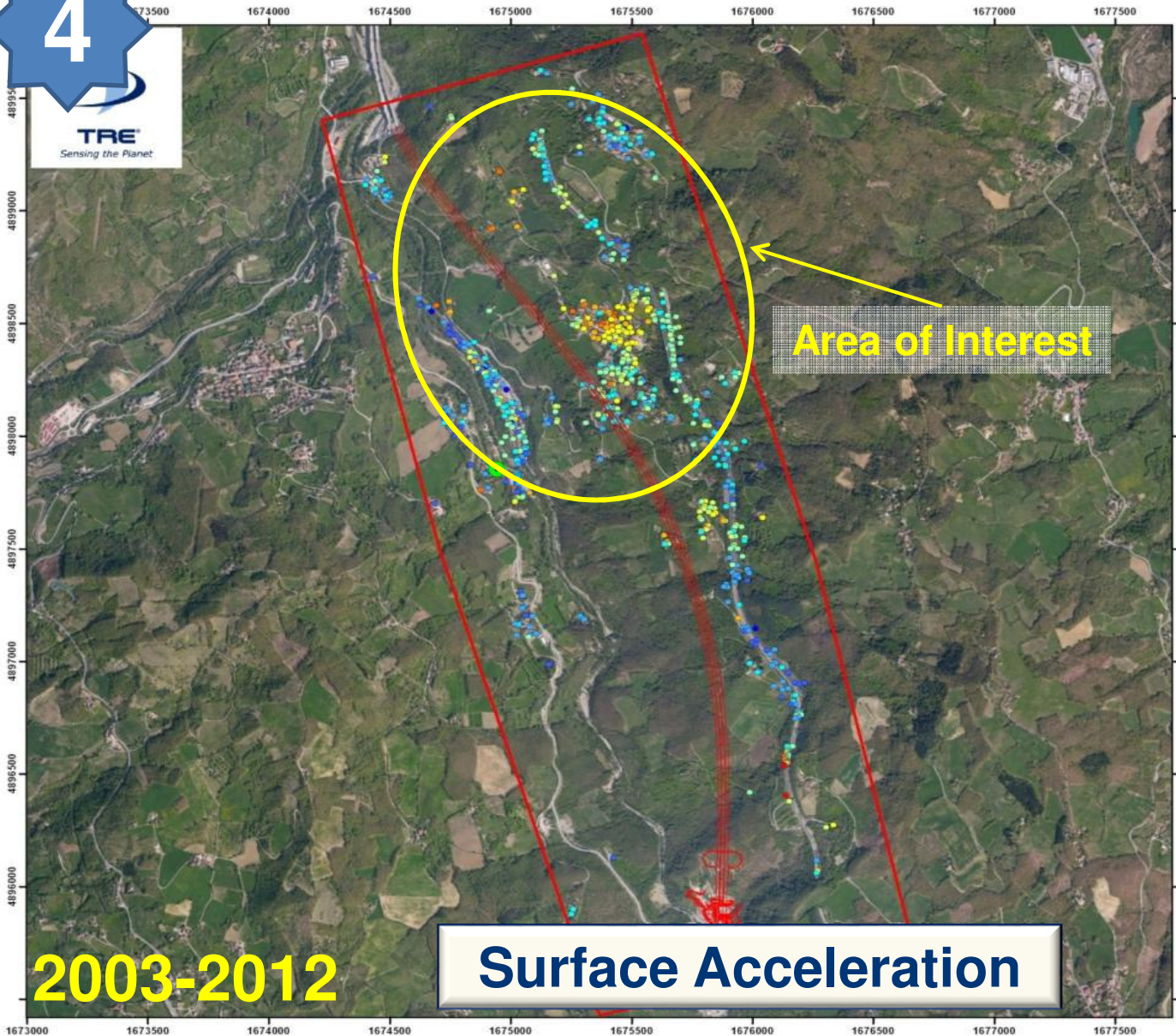
Surface Displacements



→ Investigative & early warning monitoring

4

TRE
Sensing the Planet



mm/year²

- 2.83 - -2.44
- 2.43 - -0.99
- 0.98 - -0.75
- 0.74 - -0.51
- 0.50 - -0.32
- 0.31 - -0.16
- 0.15 - 0.00
- 0.01 - 0.18
- 0.19 - 0.44
- 0.45 - 0.91

0 1 km

2003-2012

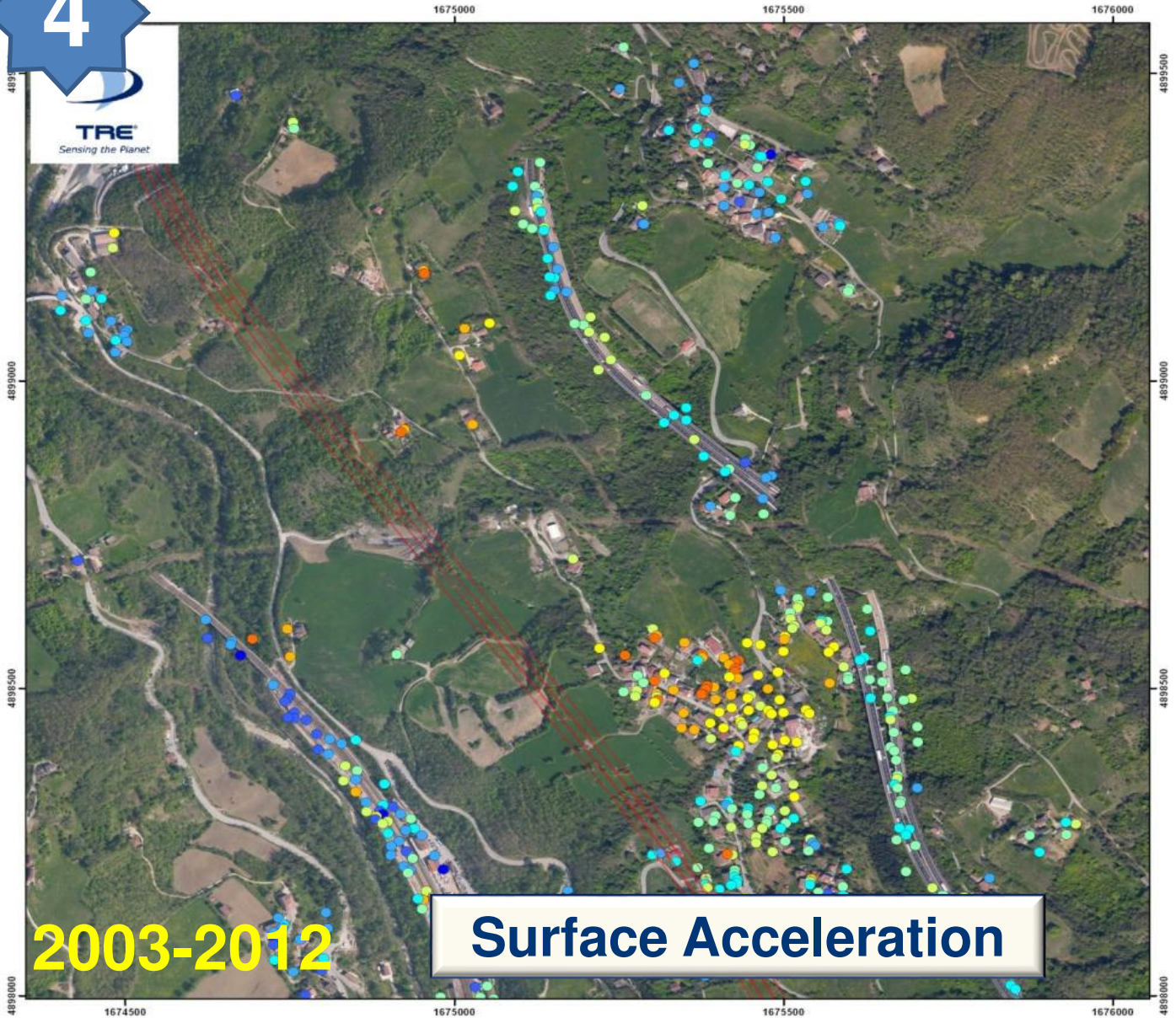
Surface Acceleration



→ Investigative & early warning monitoring

4

TRE
Sensing the Planet



mm/year²

- 2.83 - -2.44
- 2.43 - -0.99
- 0.98 - -0.75
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- 0.50 - -0.32
- 0.31 - -0.16
- 0.15 - 0.00
- 0.01 - 0.18
- 0.19 - 0.44
- 0.45 - 0.91

0 1 km

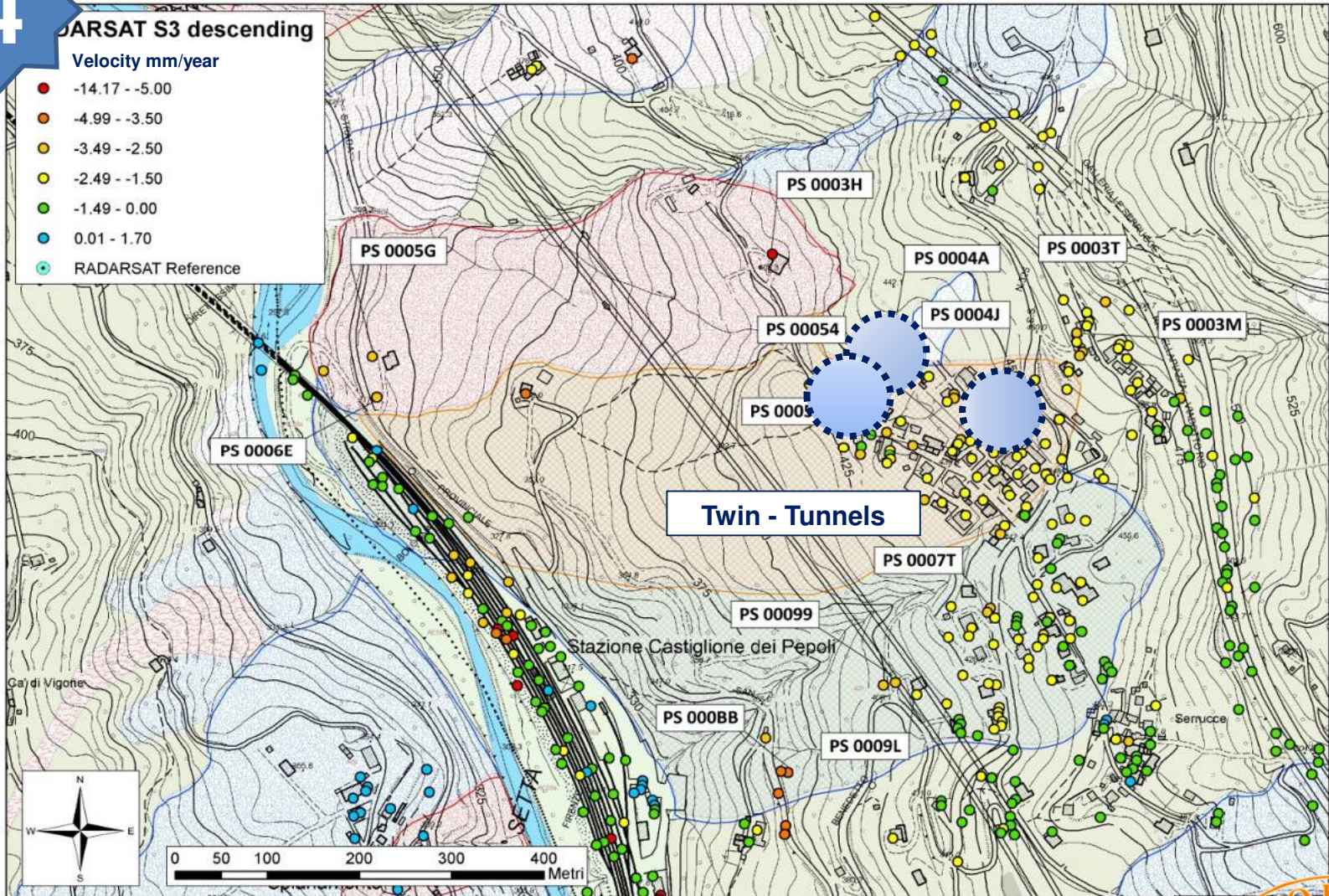
2003-2012

Surface Acceleration



→ Investigative & early warning monitoring

4

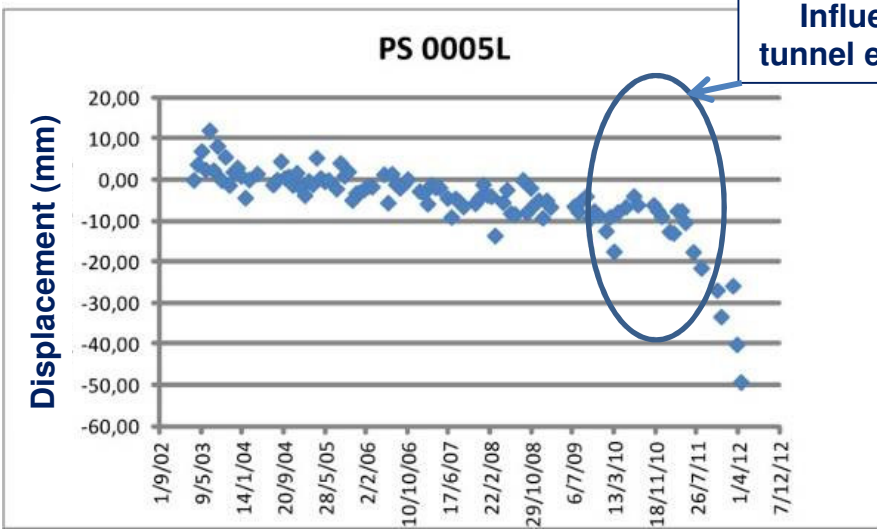
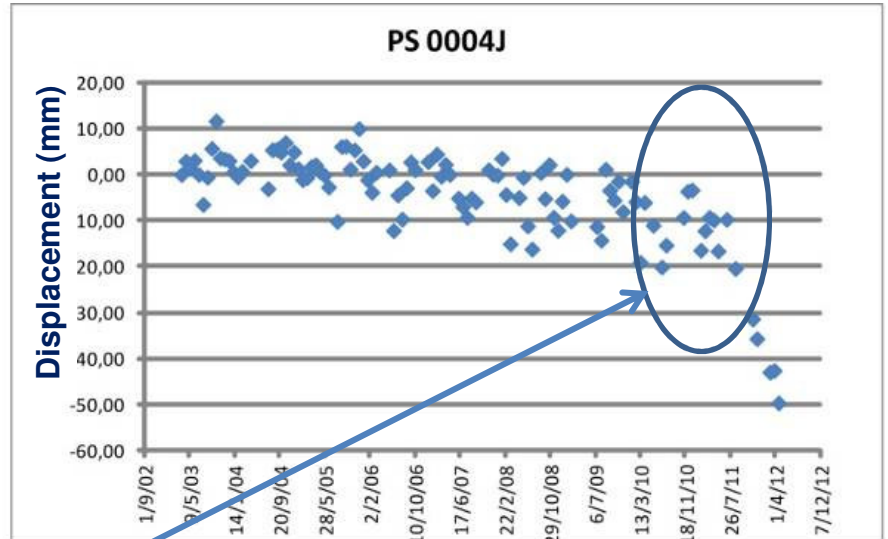
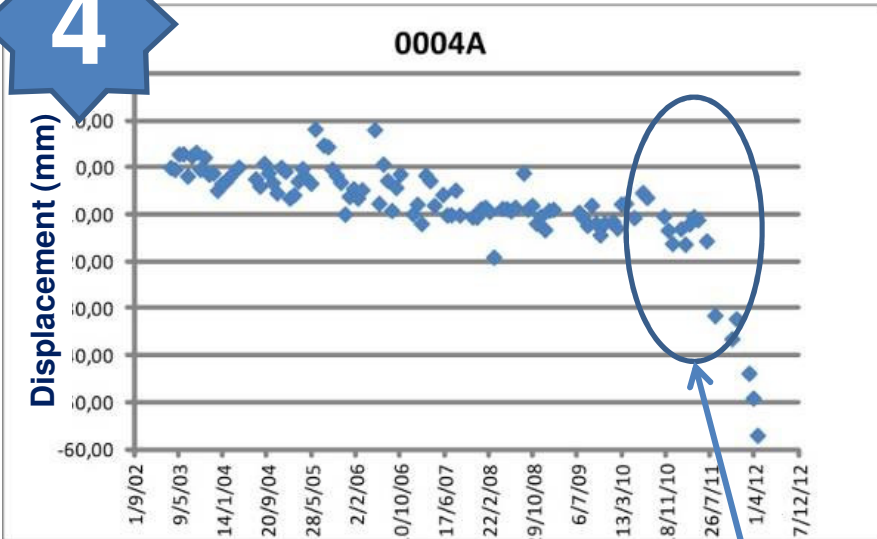


Surface Displacements

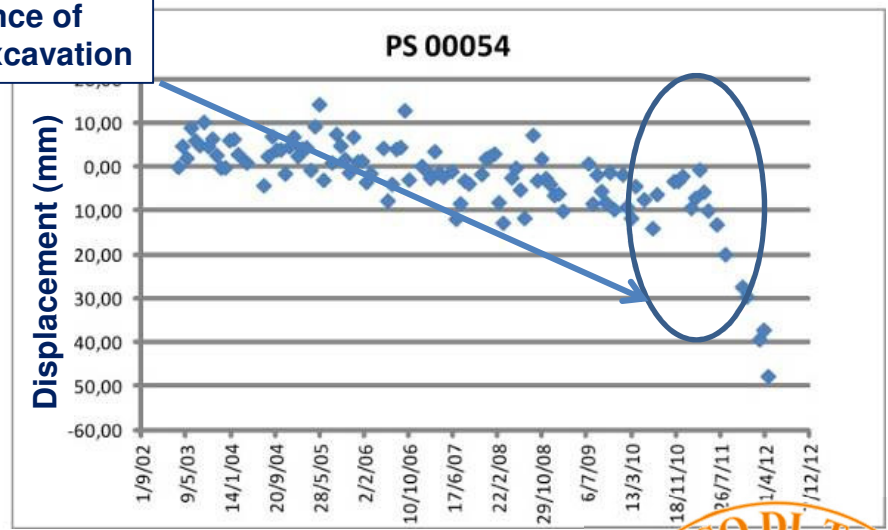


→ Investigative & early warning monitoring

4



Influence of tunnel excavation

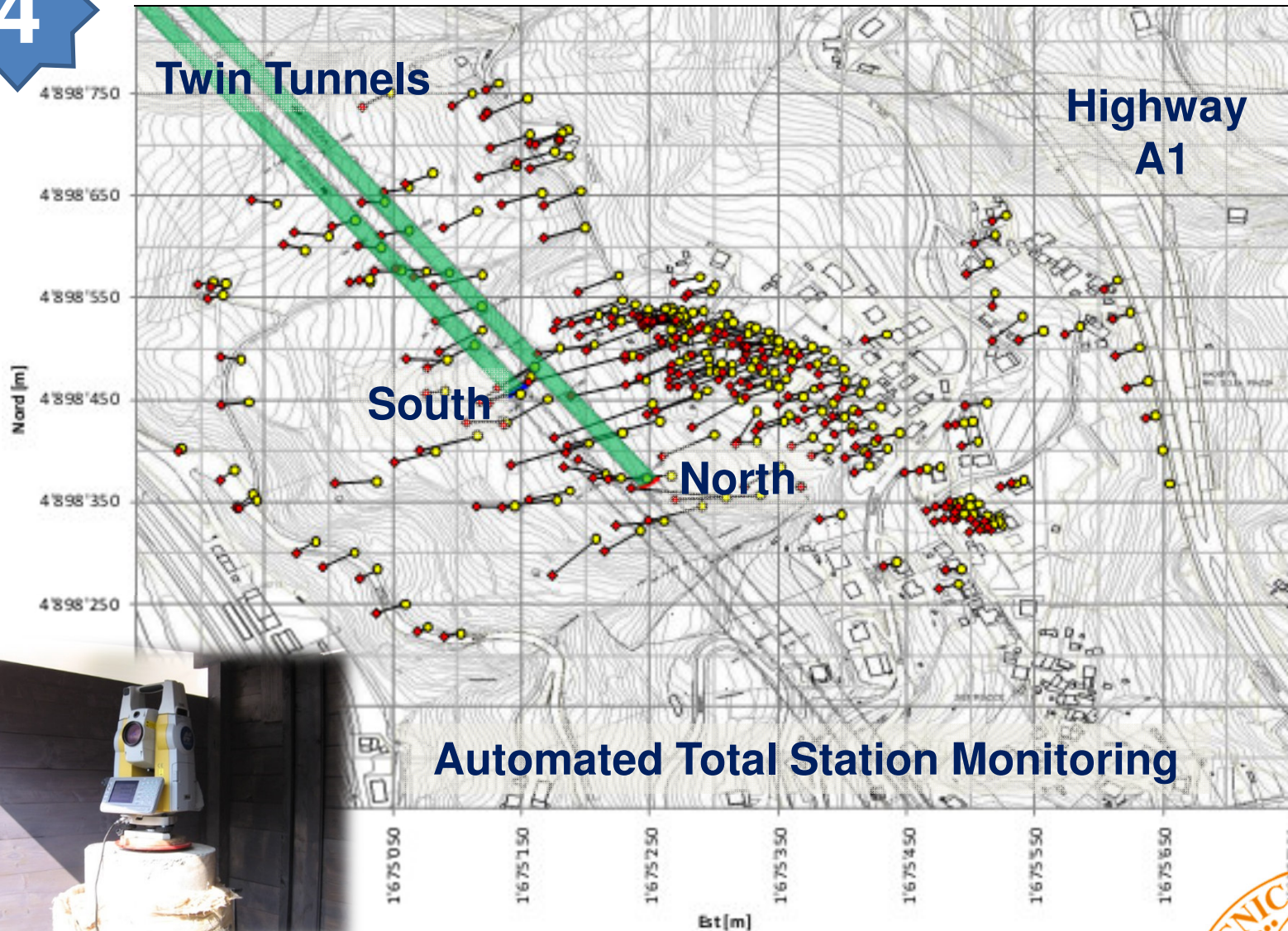


Selected PS's - Time History



→ Investigative & early warning monitoring

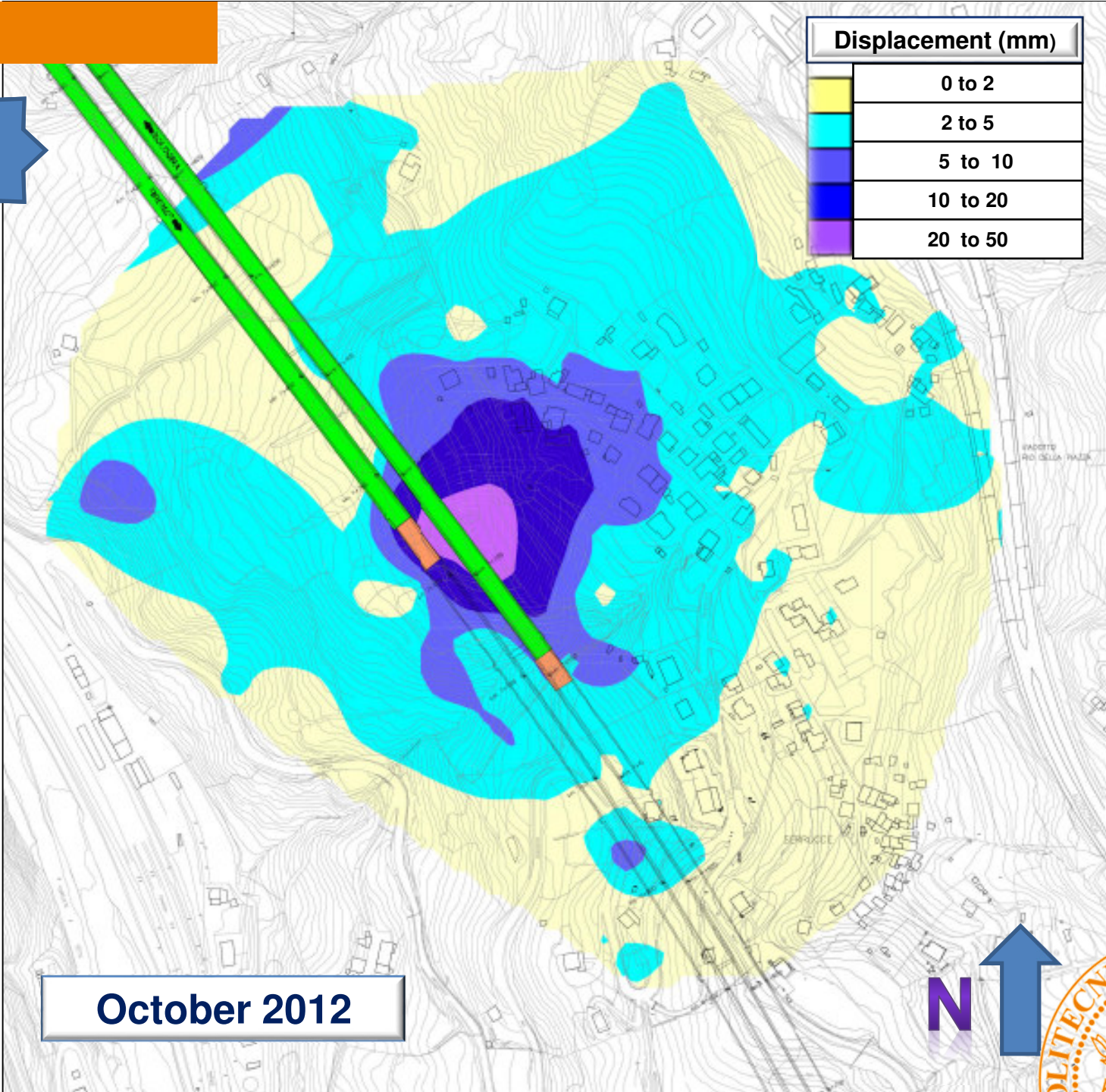
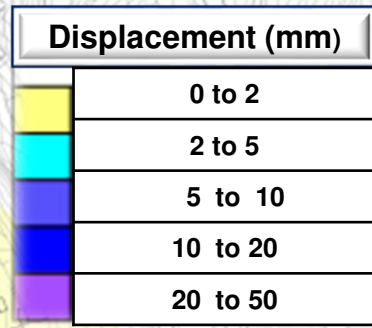
4



Horizontal Surface Displacements (March 1 - July 5, 2012)



4



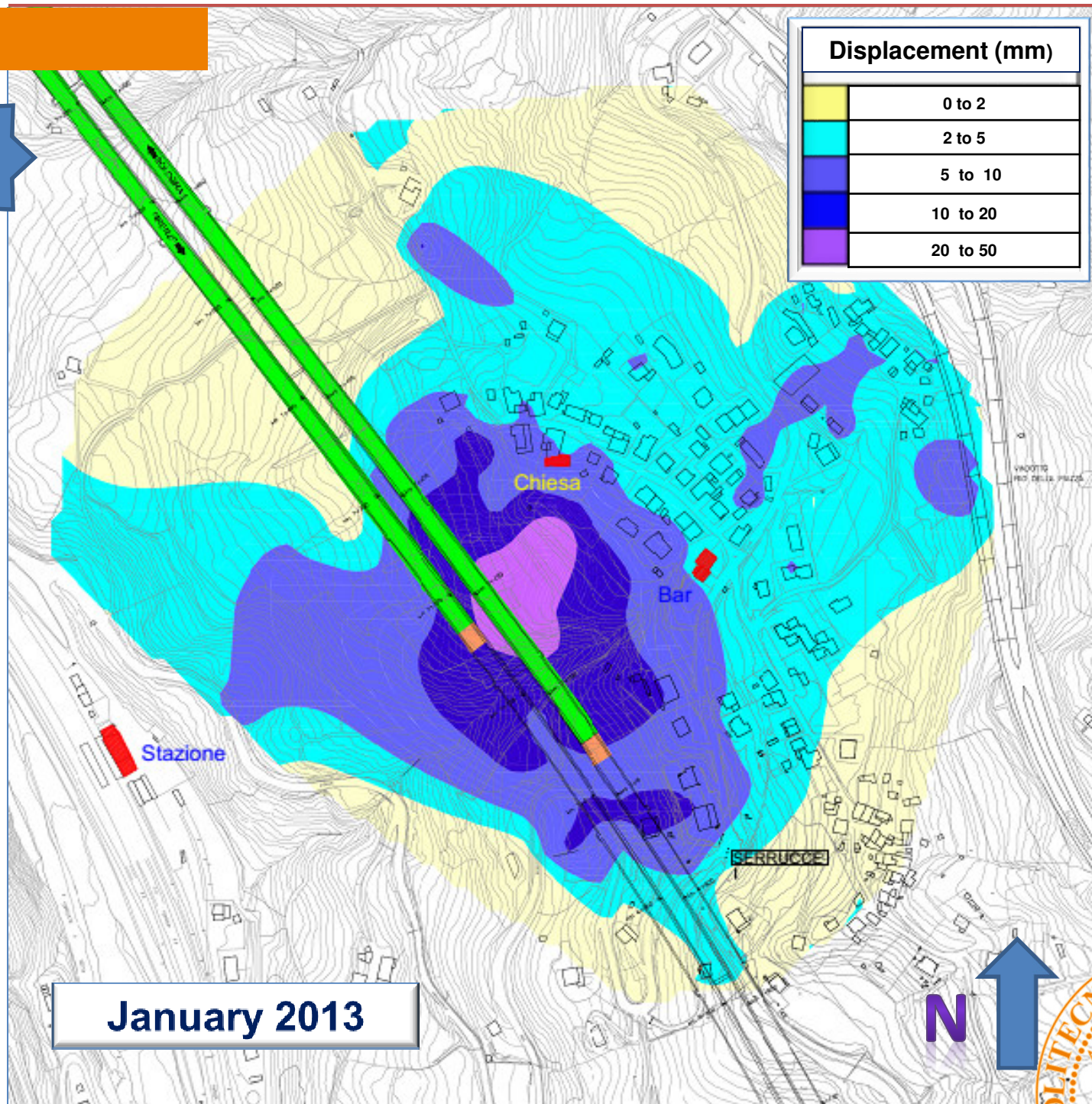
October 2012



4

Displacement (mm)

Yellow	0 to 2
Cyan	2 to 5
Blue	5 to 10
Dark Blue	10 to 20
Purple	20 to 50



January 2013

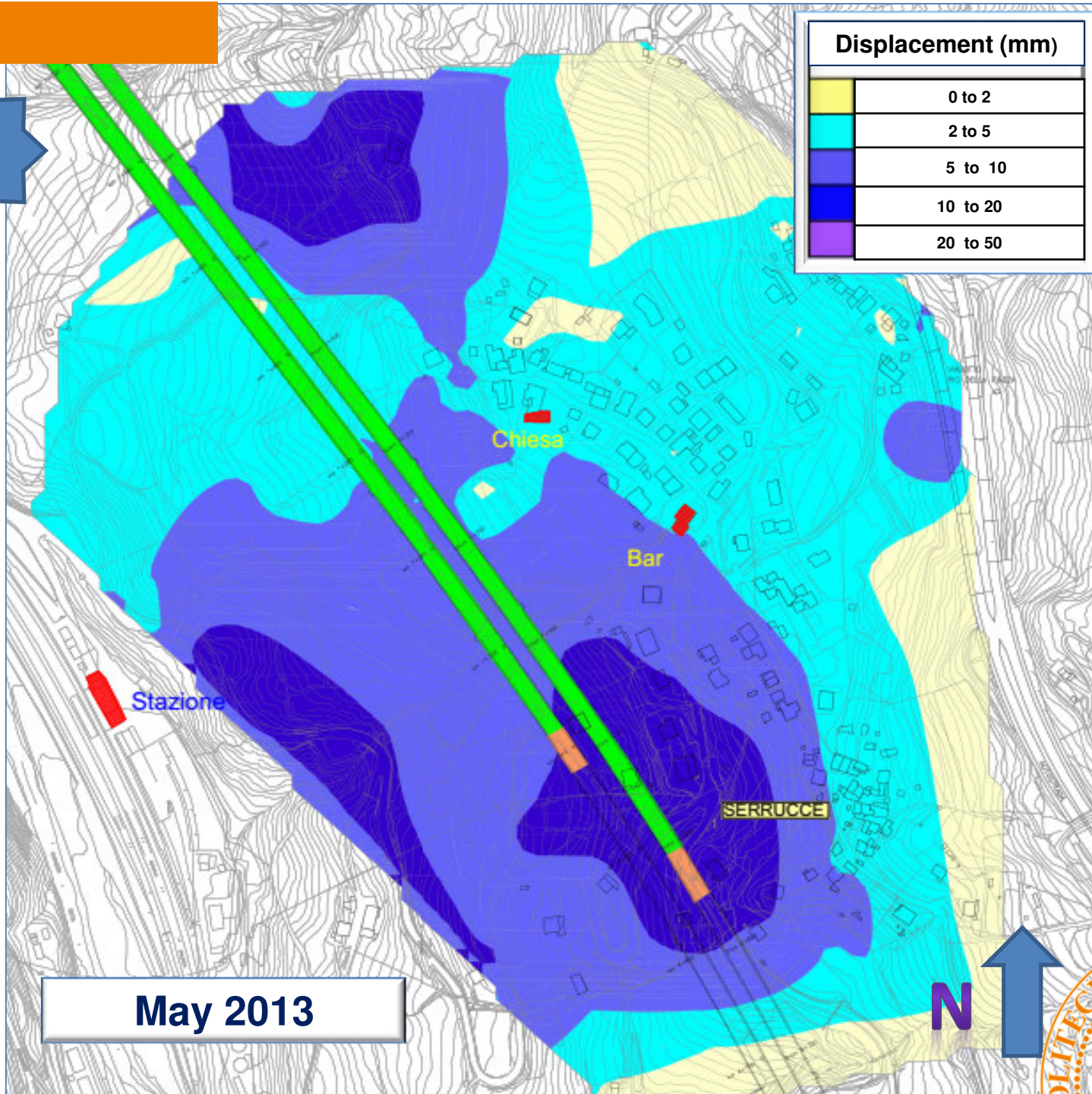
N



4

Displacement (mm)

0 to 2
2 to 5
5 to 10
10 to 20
20 to 50



May 2013

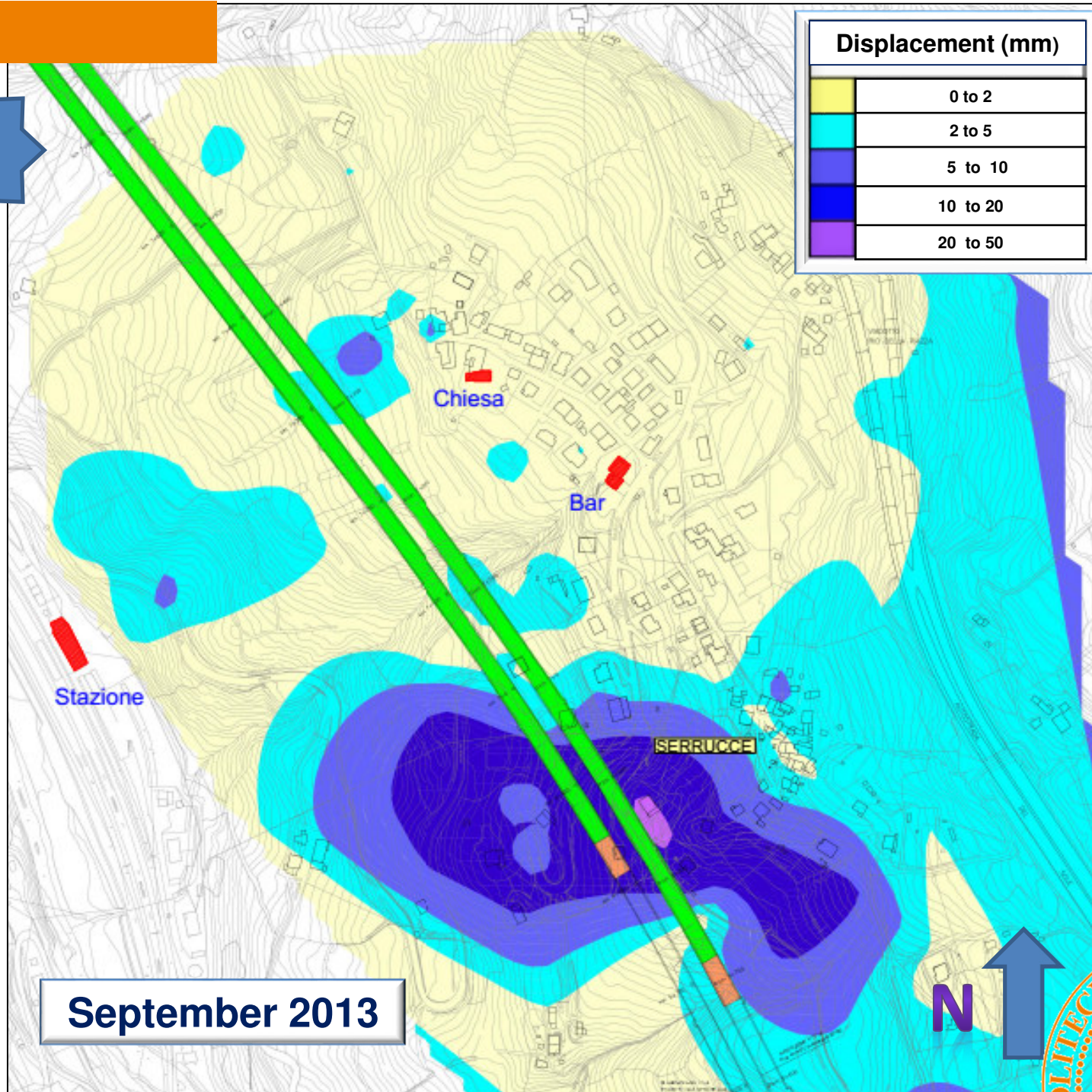
N



4

Displacement (mm)

Yellow	0 to 2
Cyan	2 to 5
Light Blue	5 to 10
Dark Blue	10 to 20
Purple	20 to 50



September 2013

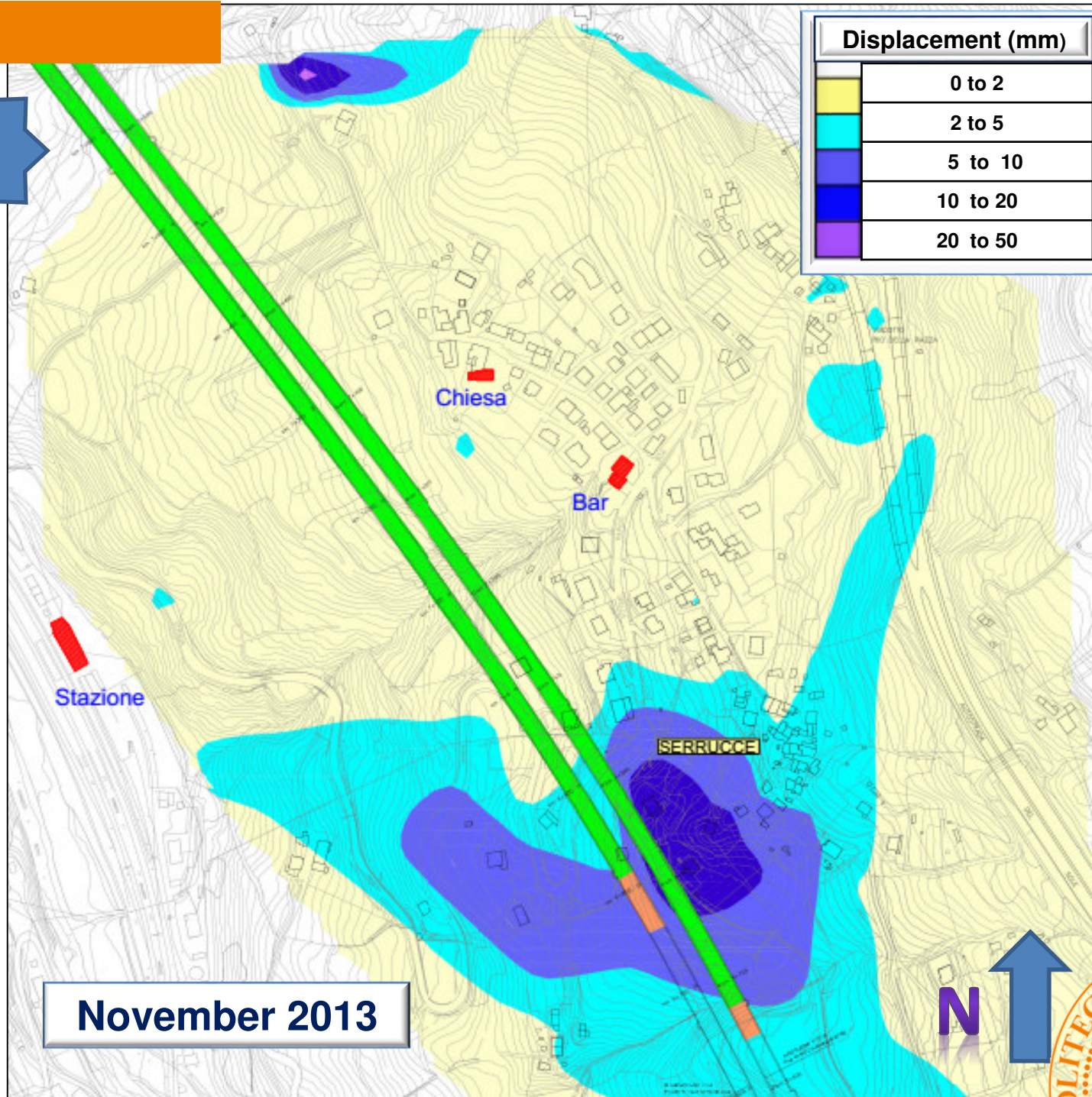
N



4

Displacement (mm)

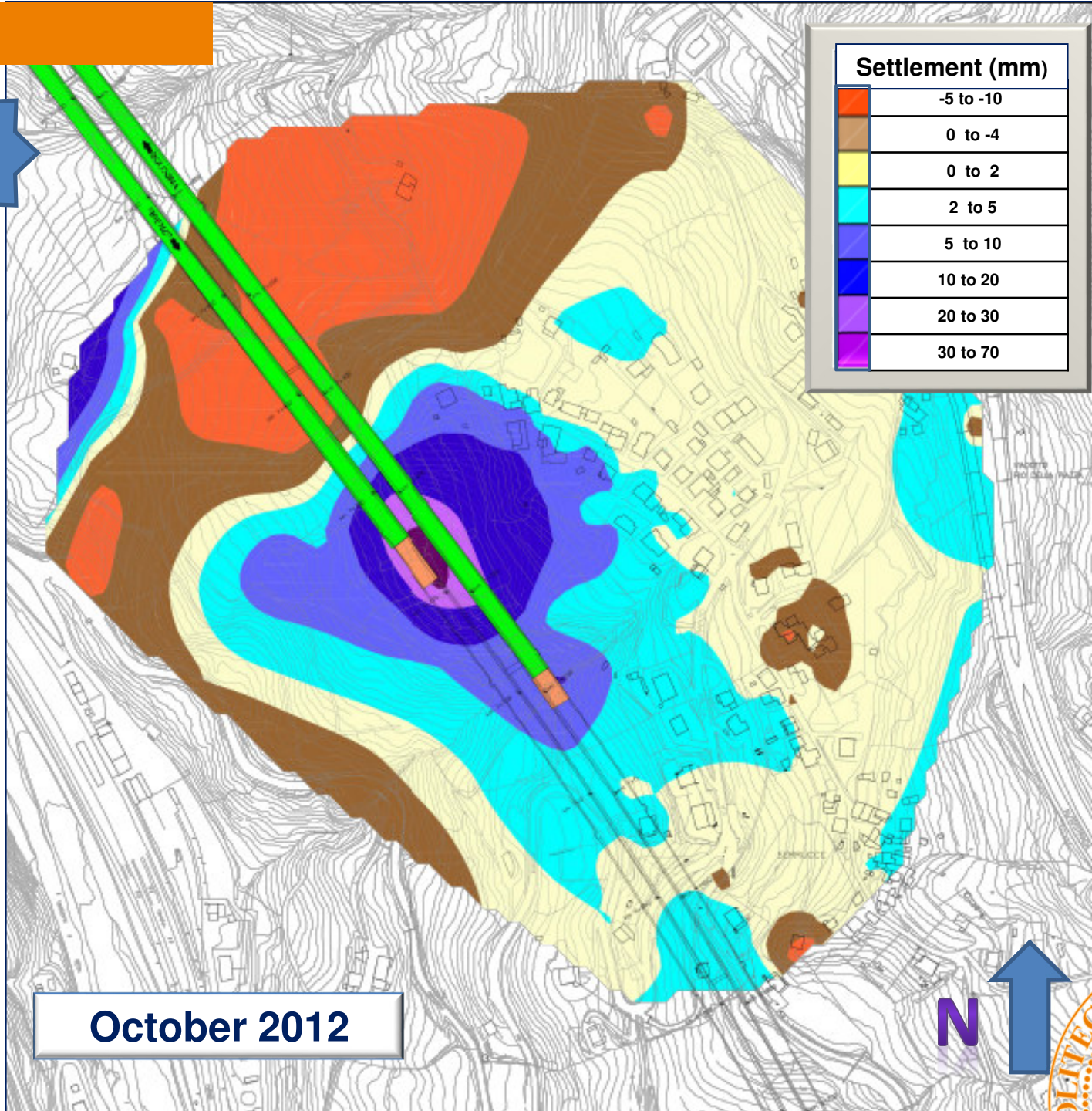
0 to 2
2 to 5
5 to 10
10 to 20
20 to 50



4

Settlement (mm)

Red	-5 to -10
Brown	0 to -4
Yellow	0 to 2
Cyan	2 to 5
Blue	5 to 10
Dark Blue	10 to 20
Purple	20 to 30
Light Purple	30 to 70



October 2012

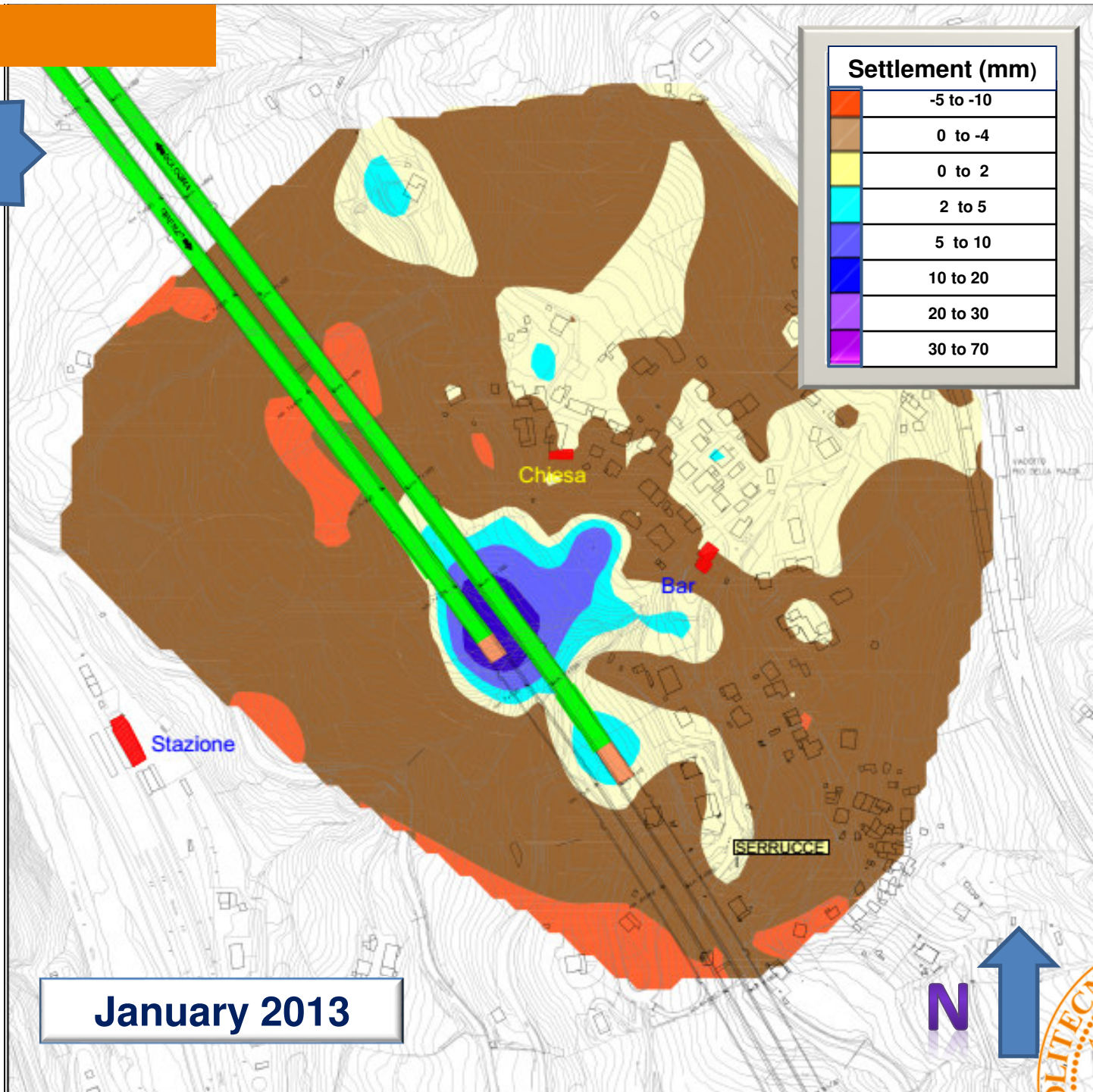
N



4

Settlement (mm)

Red	-5 to -10
Brown	0 to -4
Yellow	0 to 2
Cyan	2 to 5
Blue	5 to 10
Dark Blue	10 to 20
Purple	20 to 30
Light Purple	30 to 70



January 2013

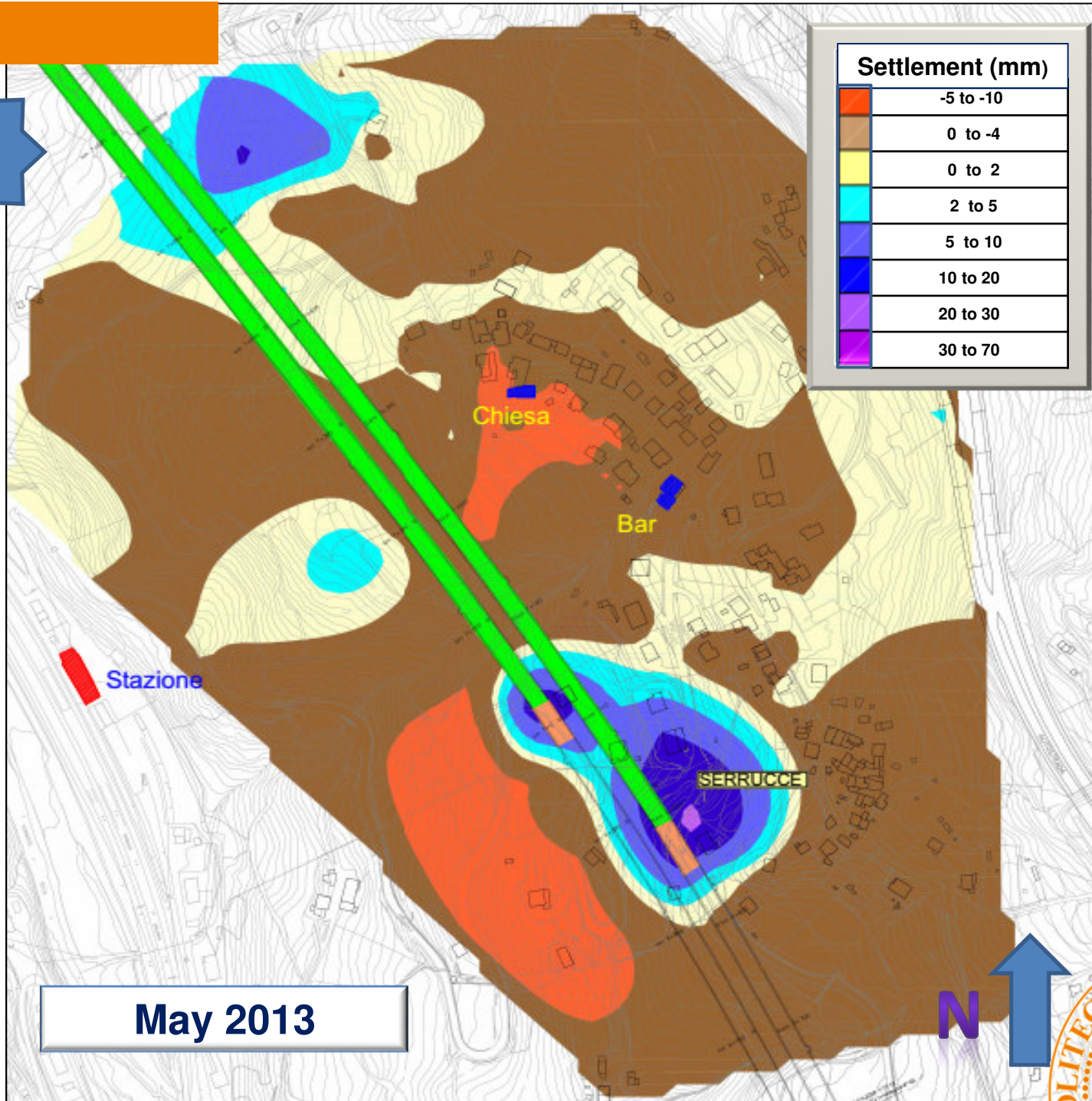
N



4

Settlement (mm)

Red	-5 to -10
Brown	0 to -4
Yellow	0 to 2
Cyan	2 to 5
Blue	5 to 10
Dark Blue	10 to 20
Purple	20 to 30
Dark Purple	30 to 70



Stazione

Chiesa

Bar

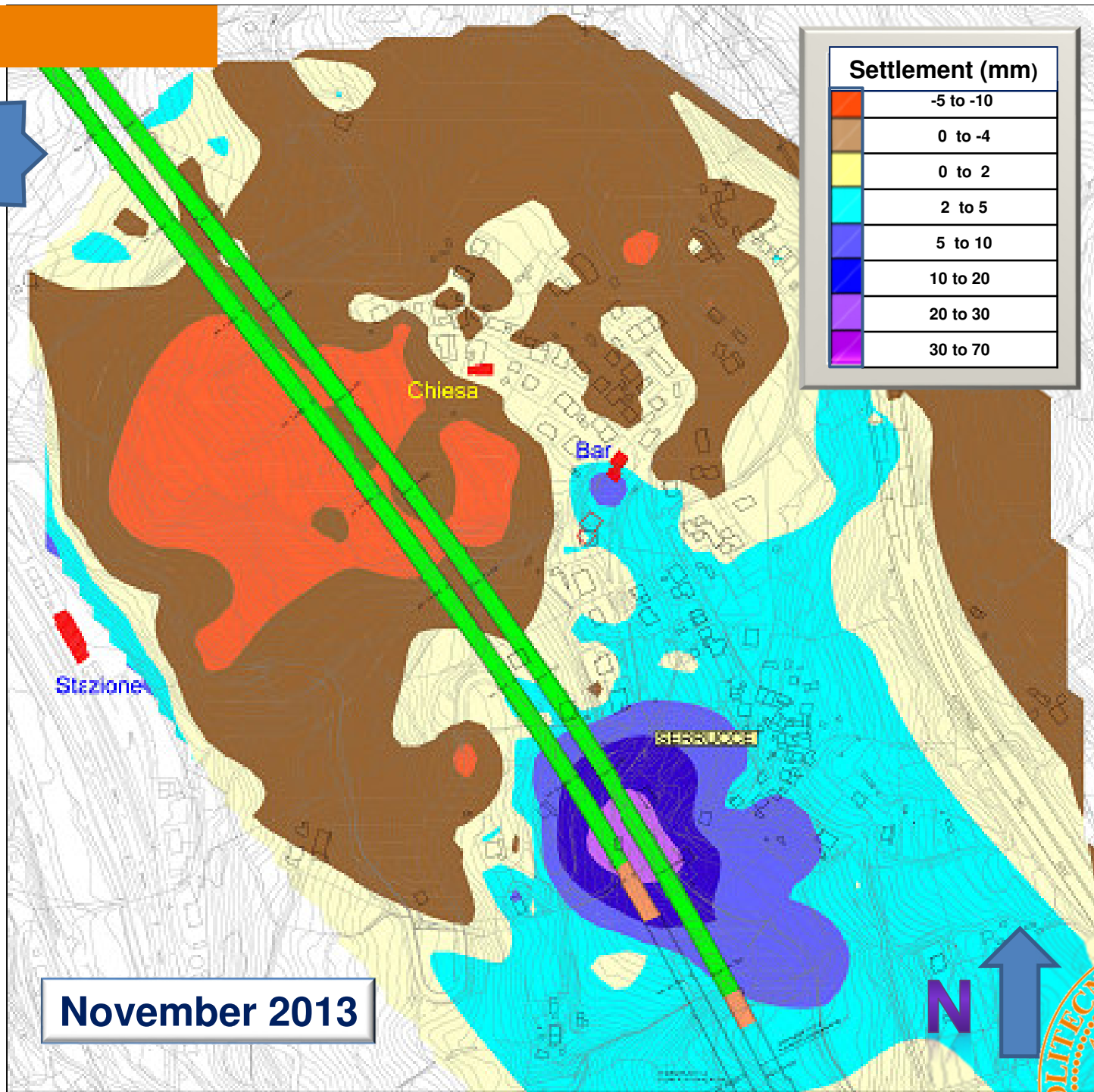
SERRUCCE

May 2013

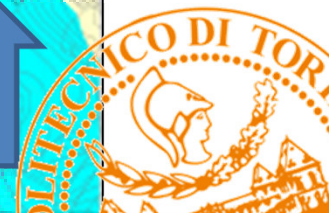
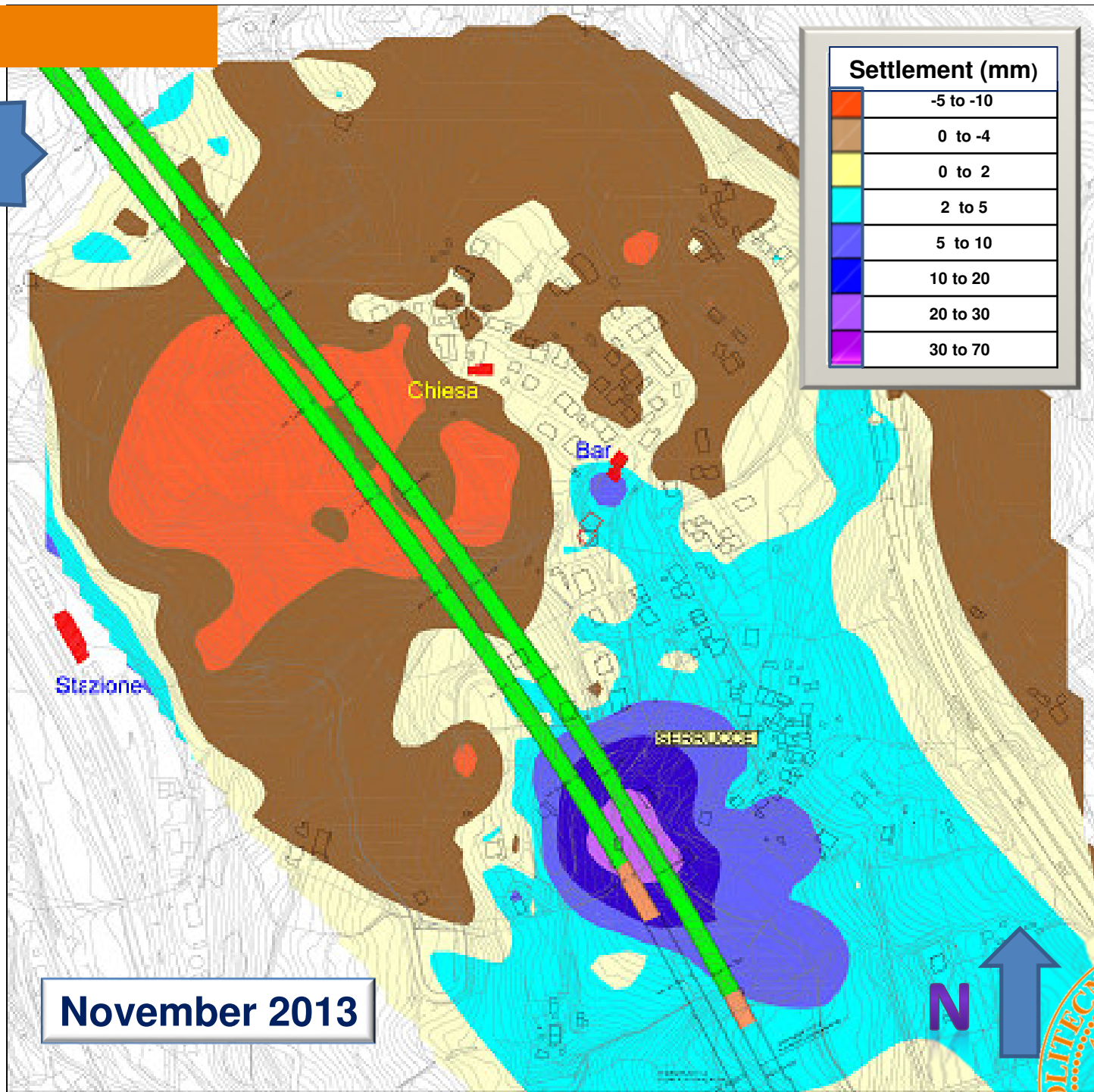
N



4

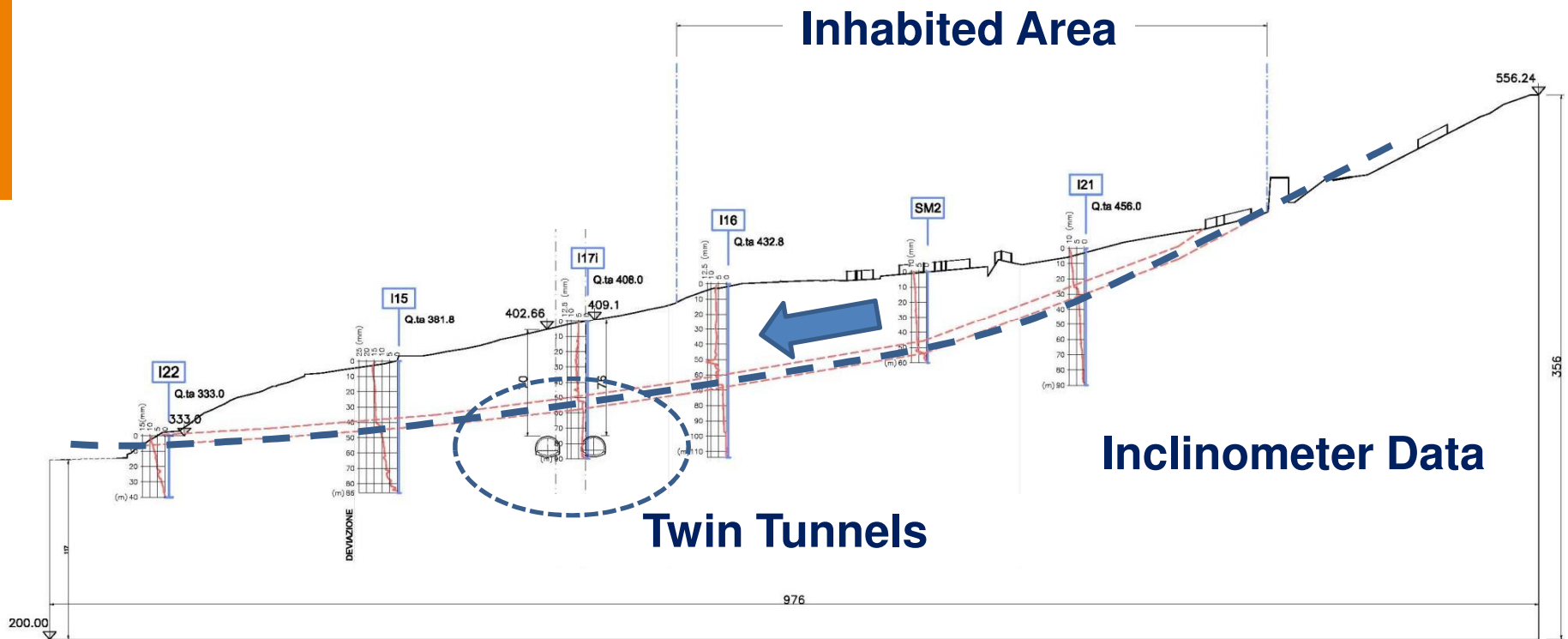


4



→ Investigative & early warning monitoring

4



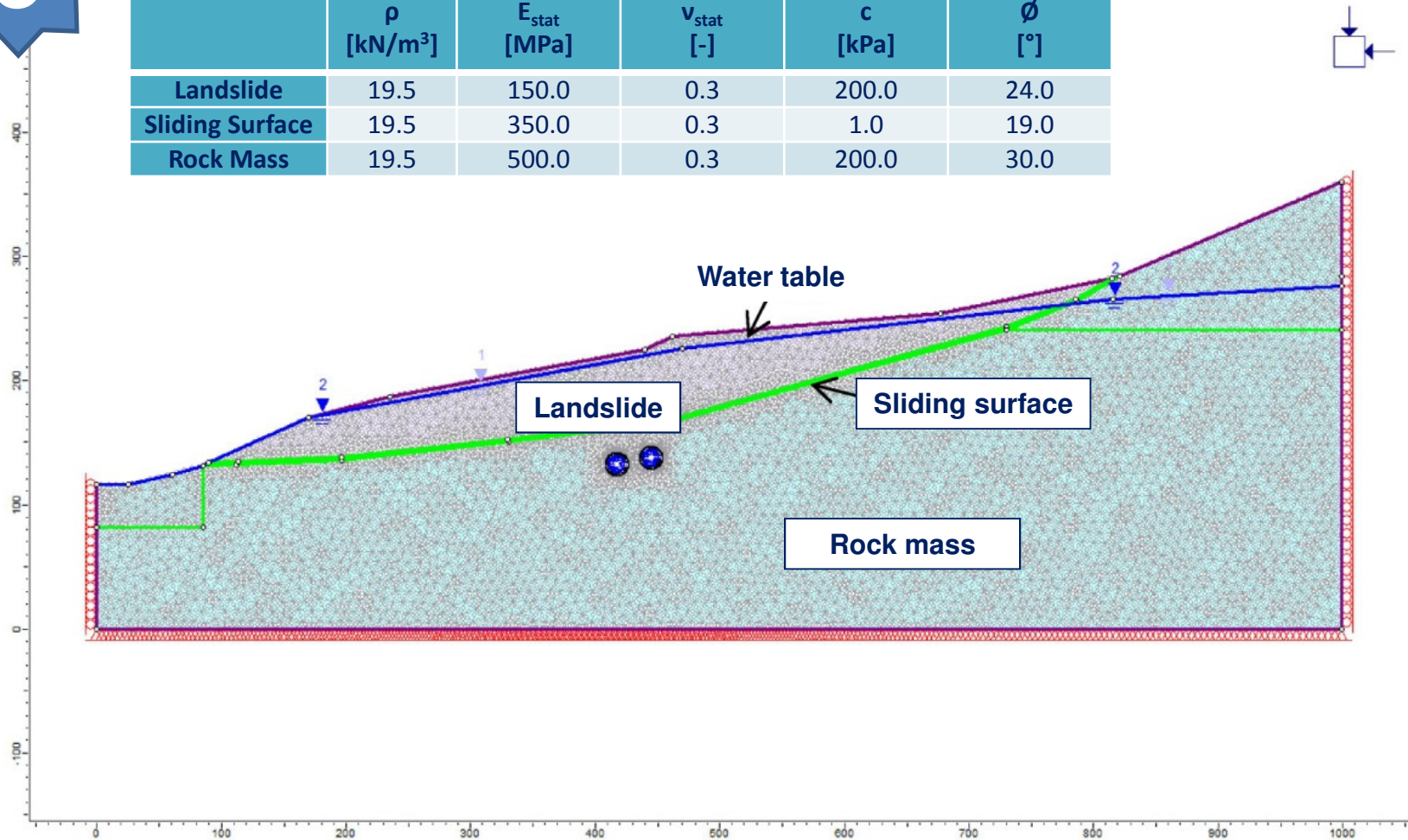
Subsurface Horizontal Displacements (2011)



→ Numerical modelling – 2D & 3D FEM

5

	ρ [kN/m ³]	E_{stat} [MPa]	ν_{stat} [-]	c [kPa]	ϕ [°]
Landslide	19.5	150.0	0.3	200.0	24.0
Sliding Surface	19.5	350.0	0.3	1.0	19.0
Rock Mass	19.5	500.0	0.3	200.0	30.0

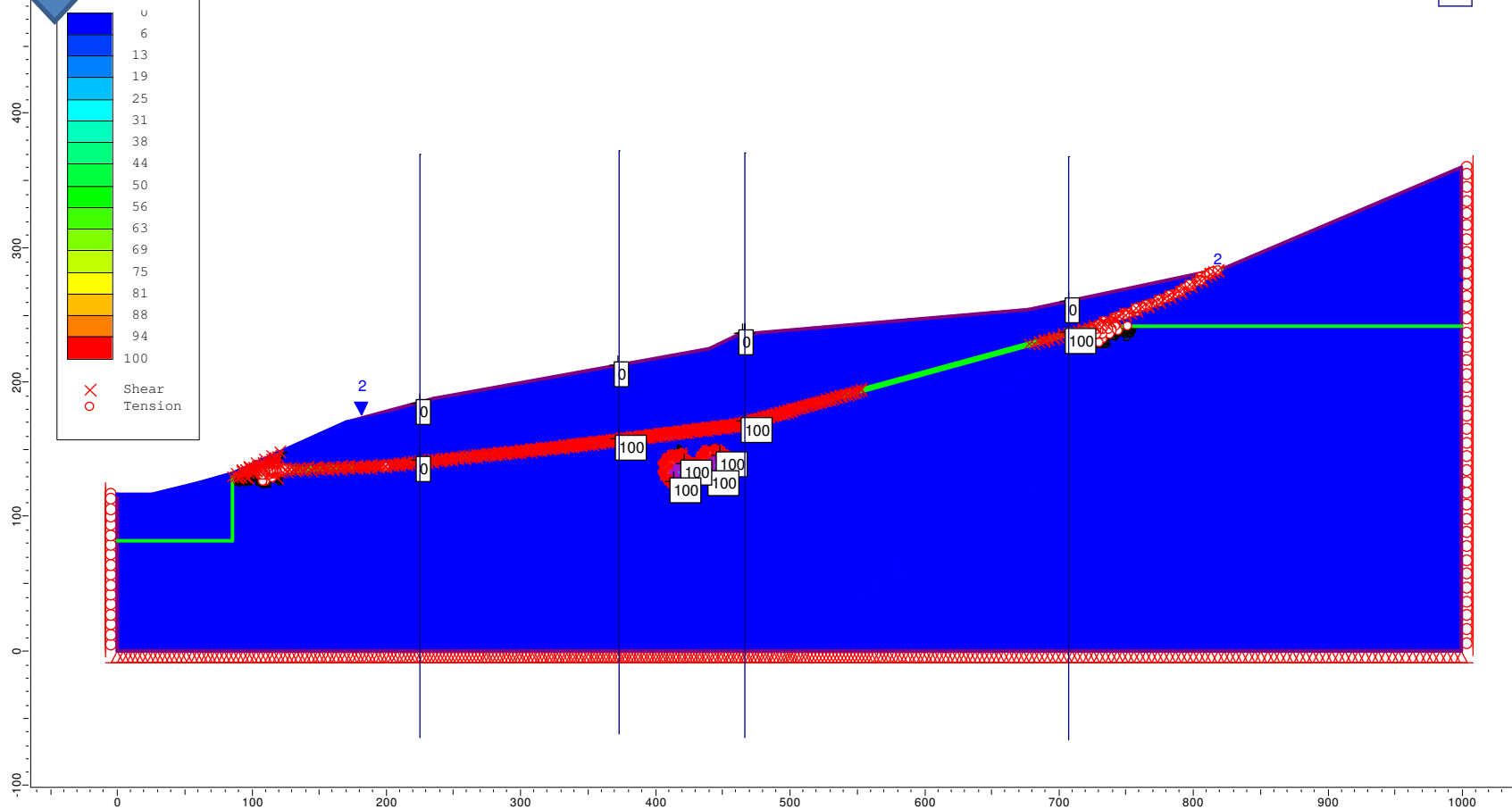


2D Modelling



→ Numerical modelling – 2D & 3D FEM

5

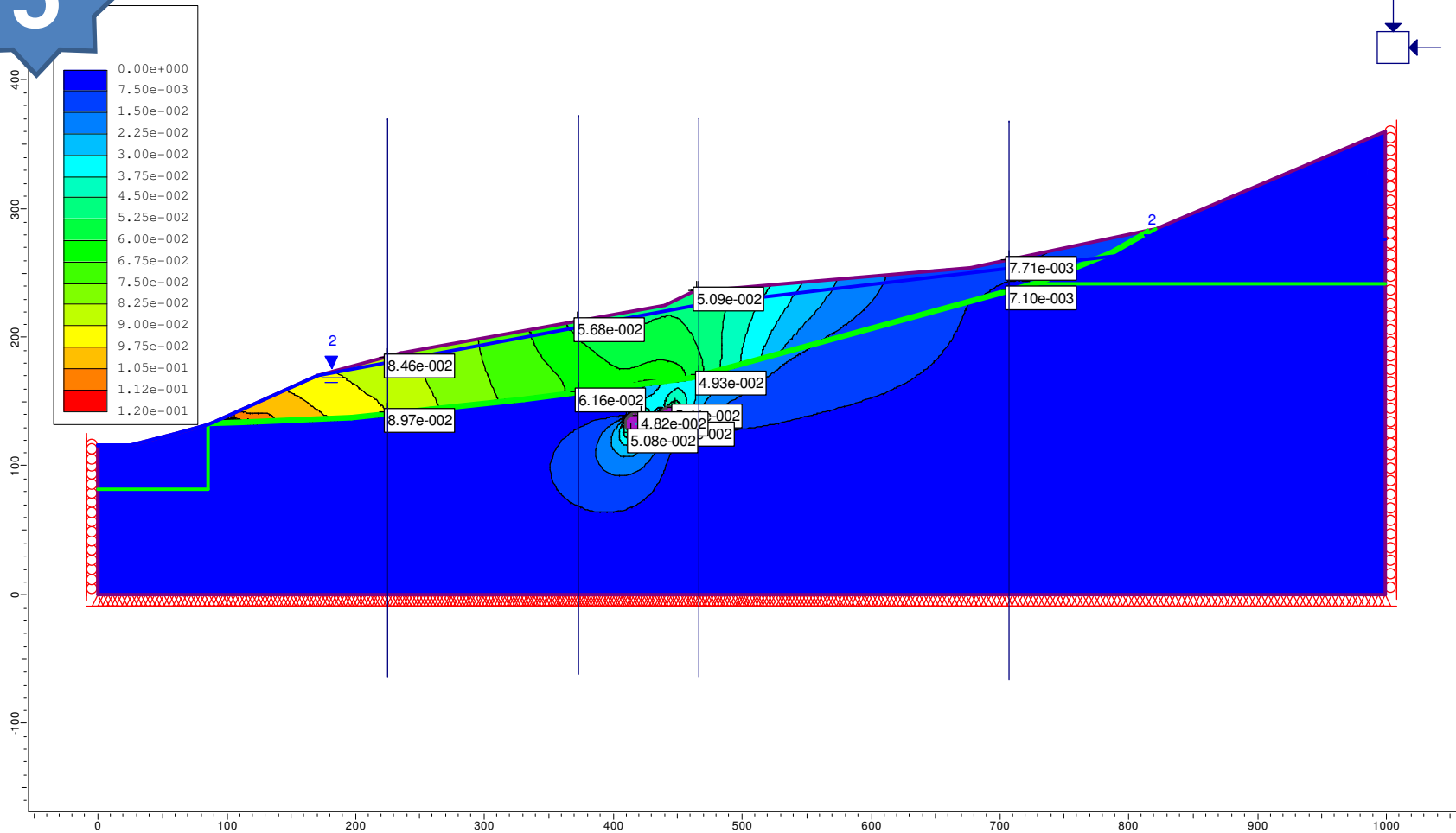


2D Modelling



→ Numerical modelling – 2D & 3D FEM

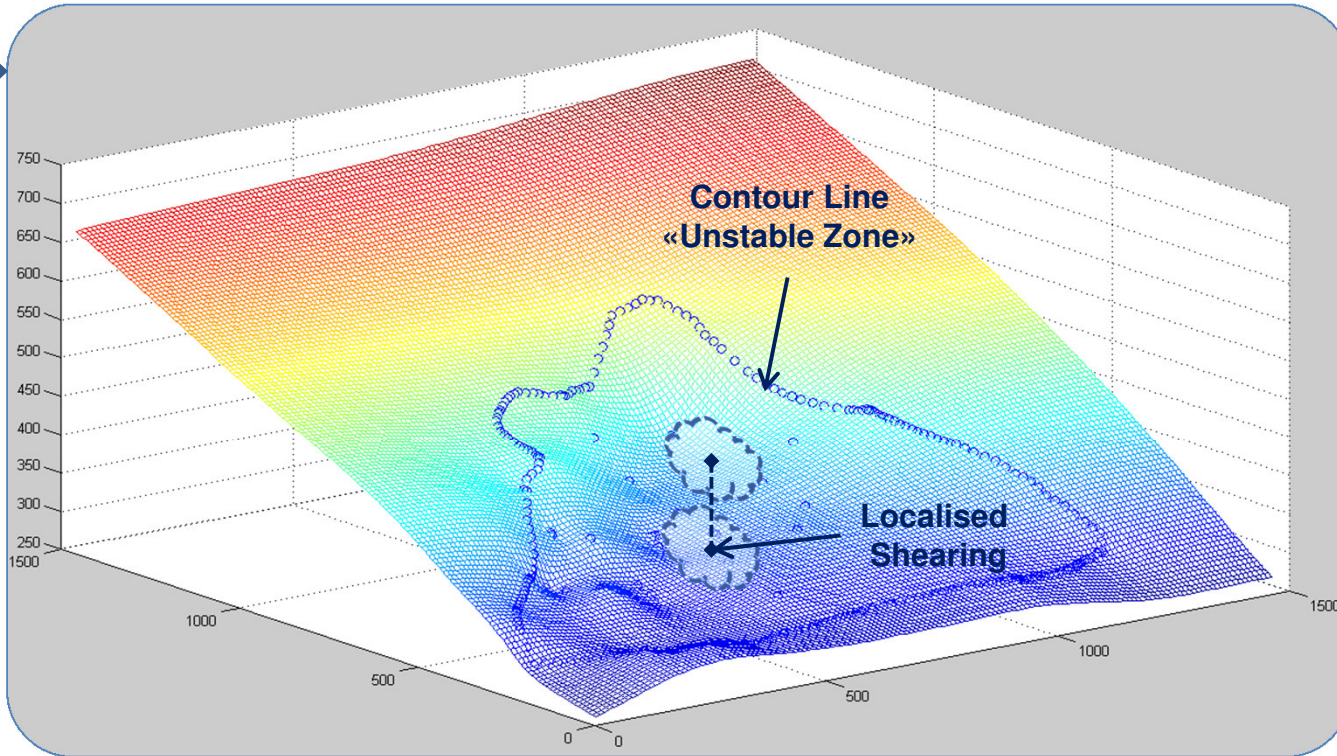
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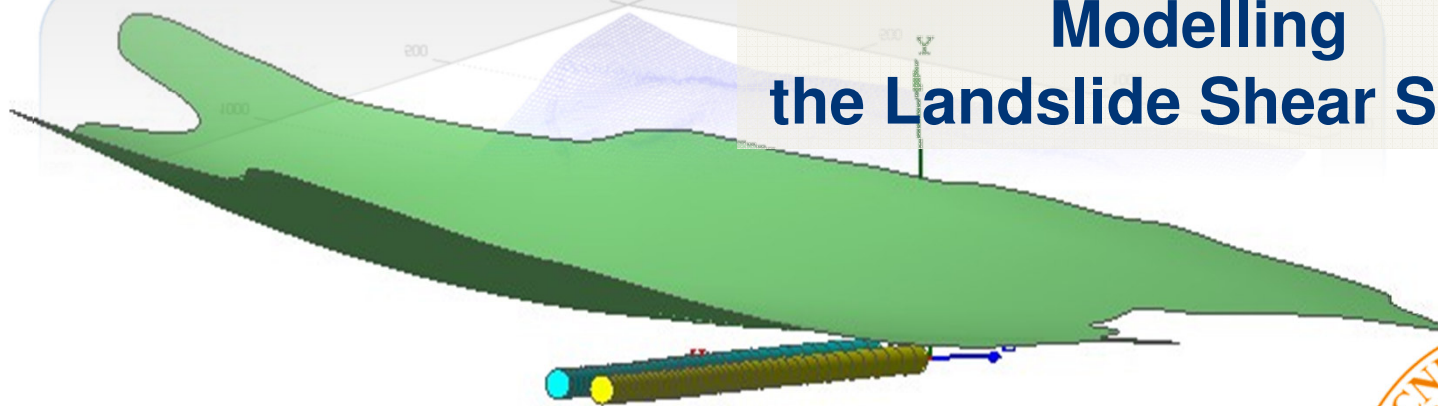
2D Modelling



5



Modelling the Landslide Shear Surface



3D Modelling



→ Numerical modelling – 2D & 3D FEM

5

269.197 403.795 538.394

Twin Tunnels

Cross Section

DEM Model

0.000 134.833 269.666 404.500 539.333

FEM Model

From the Digital Elevation Model to the Finite Element Model

3D Modelling

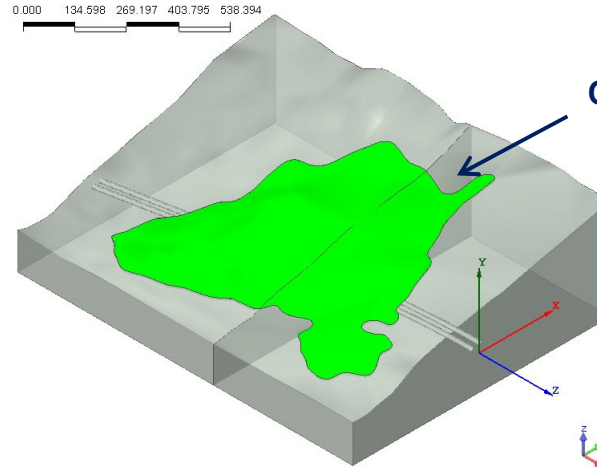
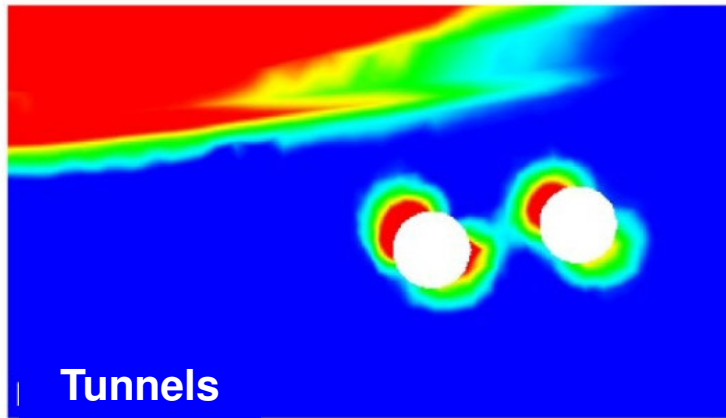


→ Numerical modelling – 2D & 3D FEM

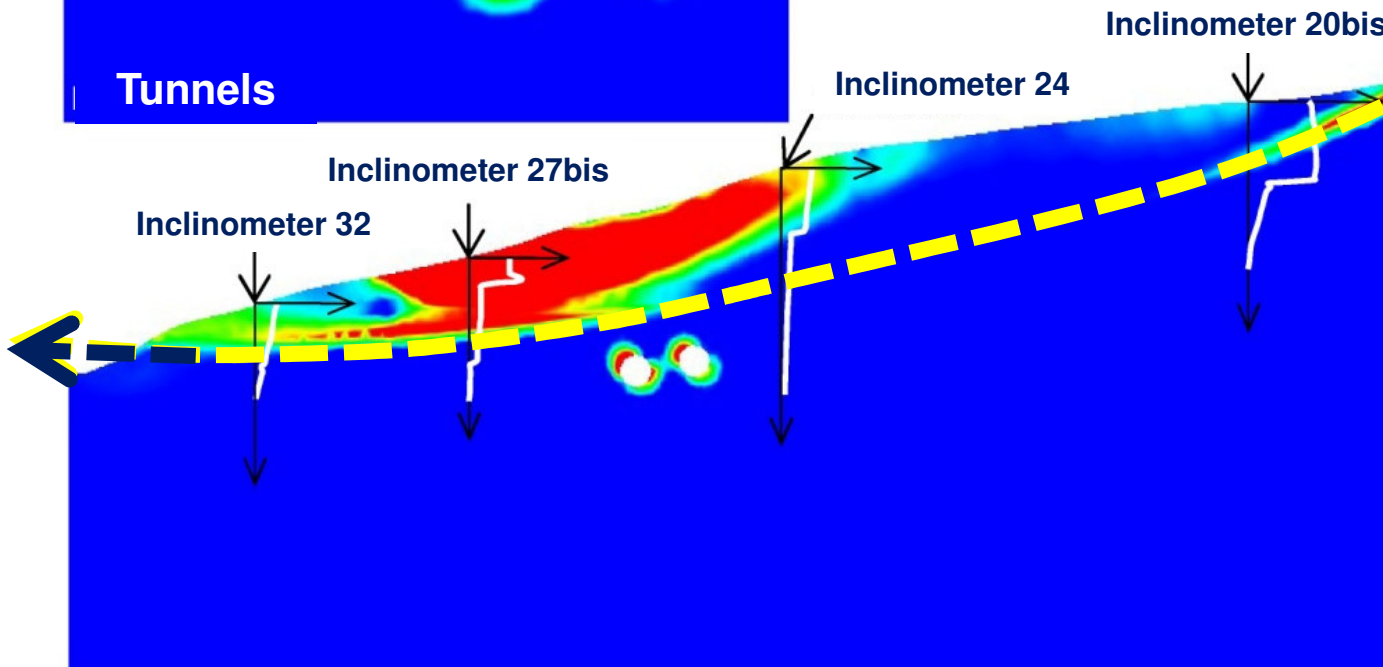
5

0.000 134.596 269.197 403.795 538.394

Cross Section of Interest



3D ELEMENT STRAIN
Soil PE Maximum Shear
UNIT(None)

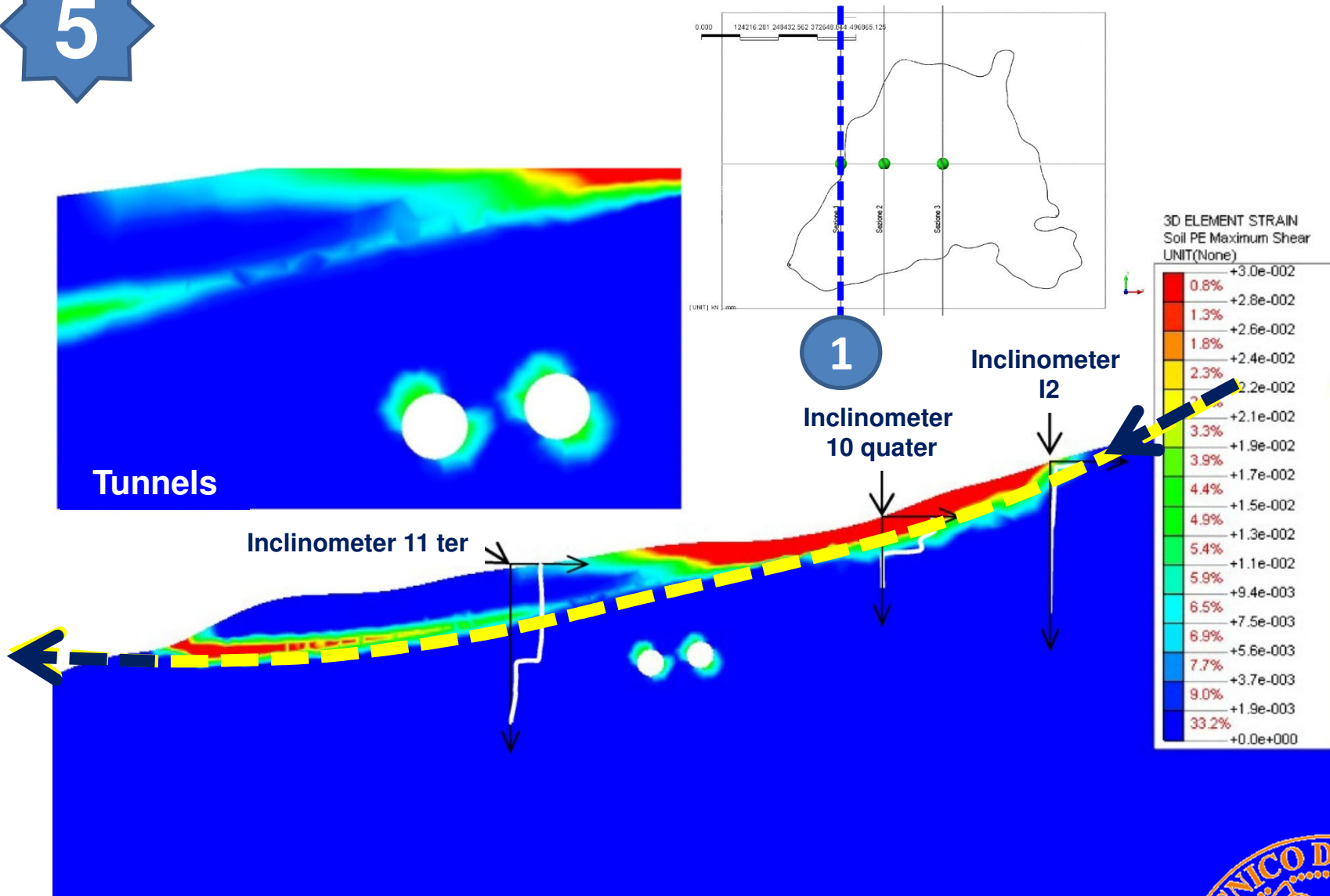


Maximum Shear Strain Zones



→ Numerical modelling – 2D & 3D FEM

5

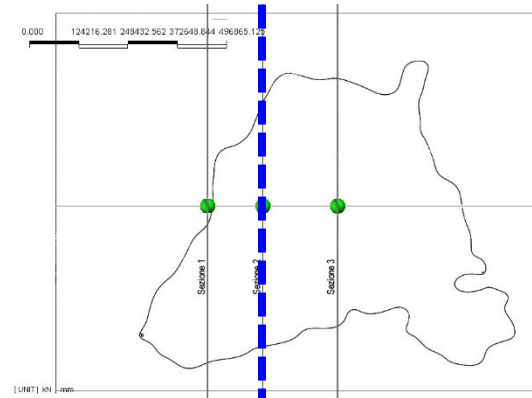
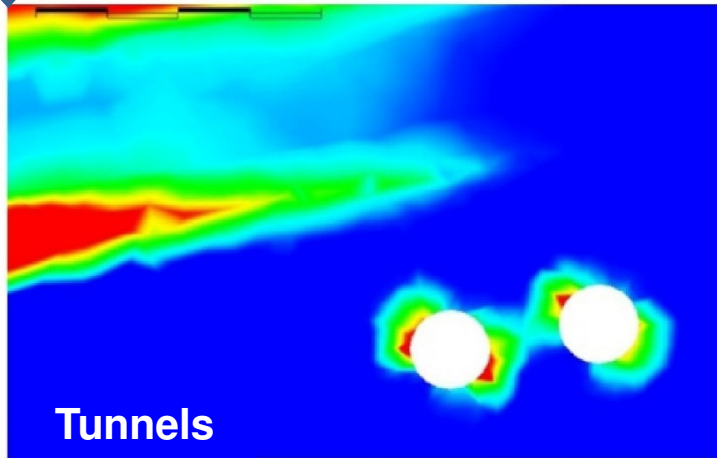


Maximum Shear Strain Zones

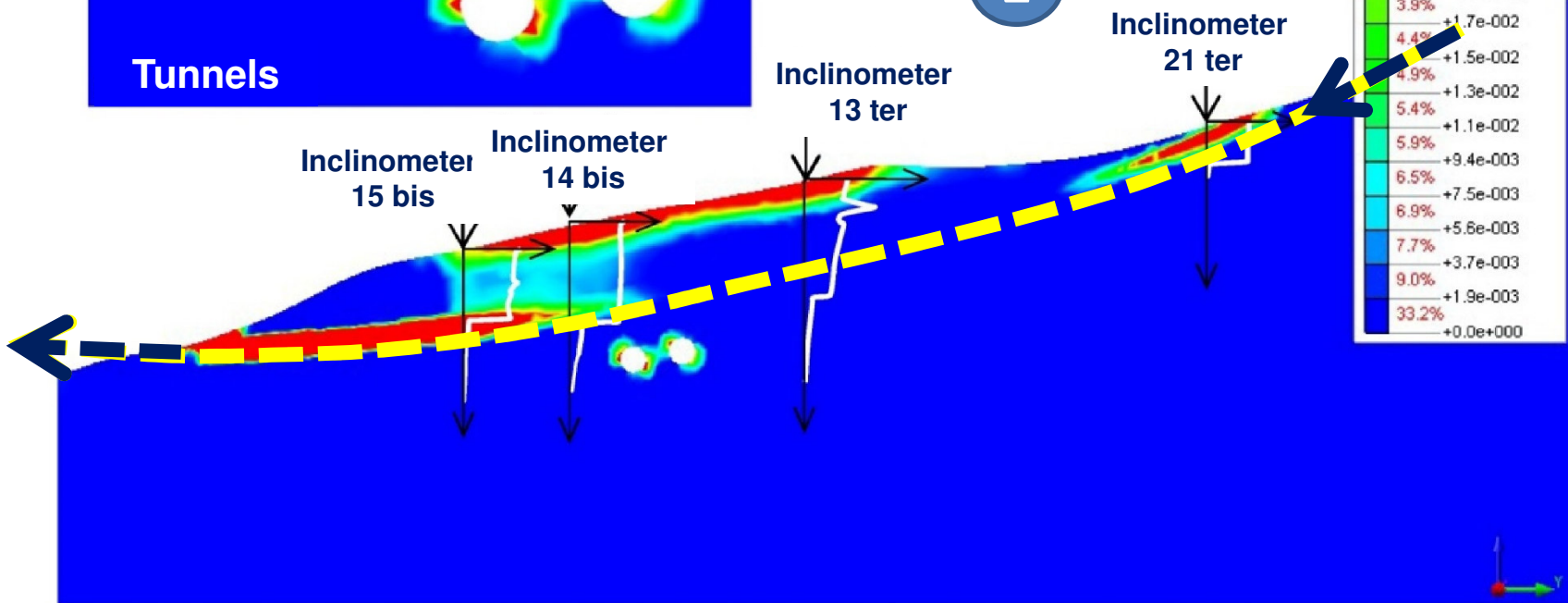


→ Numerical modelling – 2D & 3D FEM

5

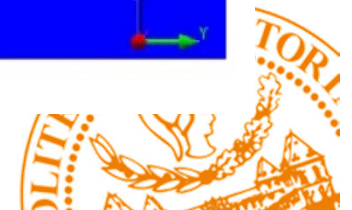


3D ELEMENT STRAIN
Soil PE Maximum Shear
UNIT(None)



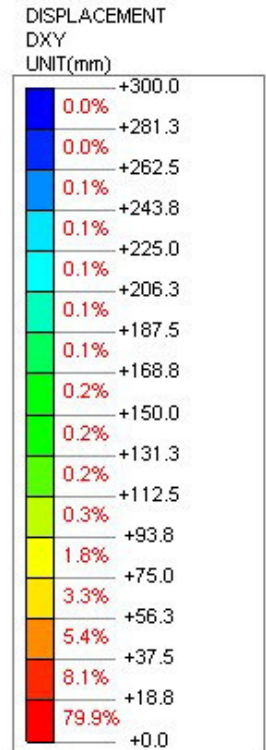
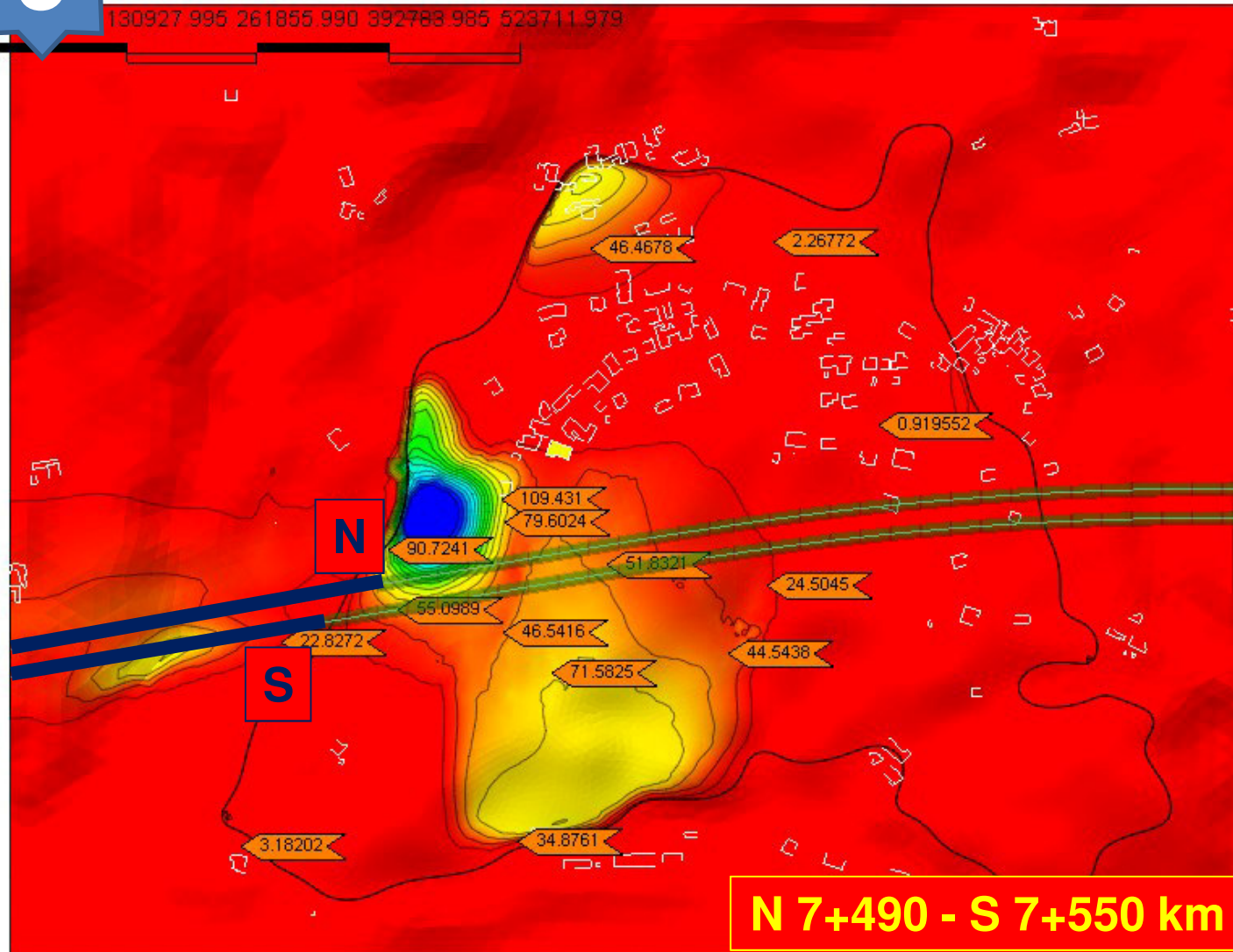
[UNIT] kN , mm

Maximum Shear Strain Zones



→ Numerical modelling – 2D & 3D FEM

5

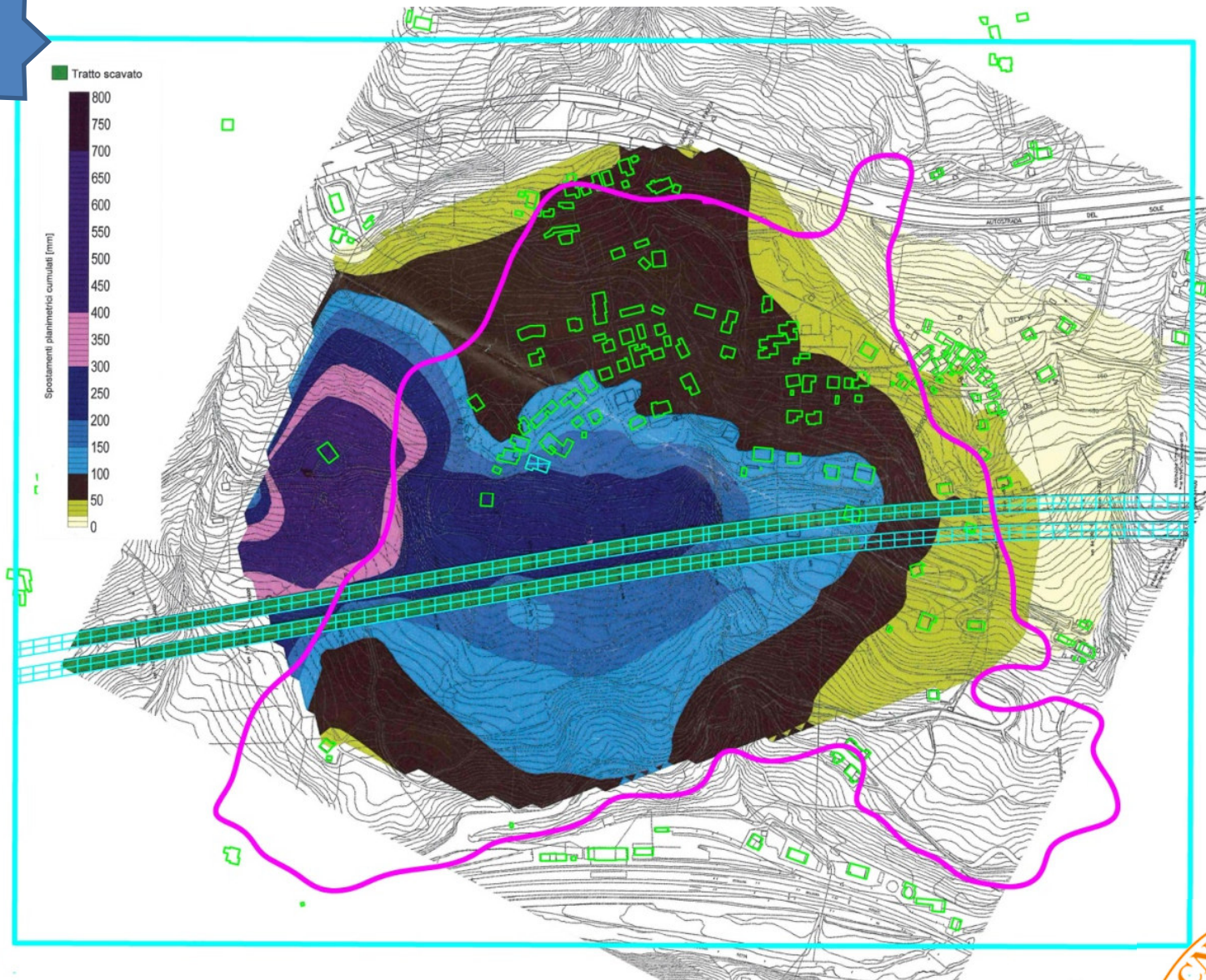


[UNIT] kN , mm

Computed XYDisplacement Components



5

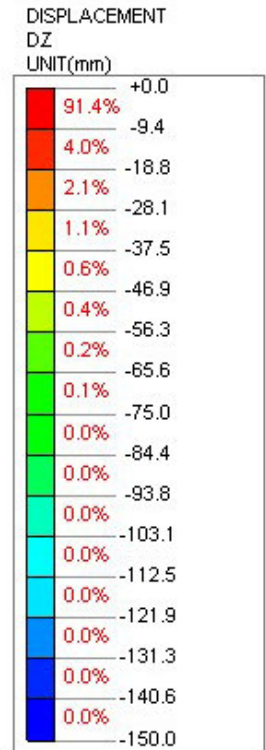
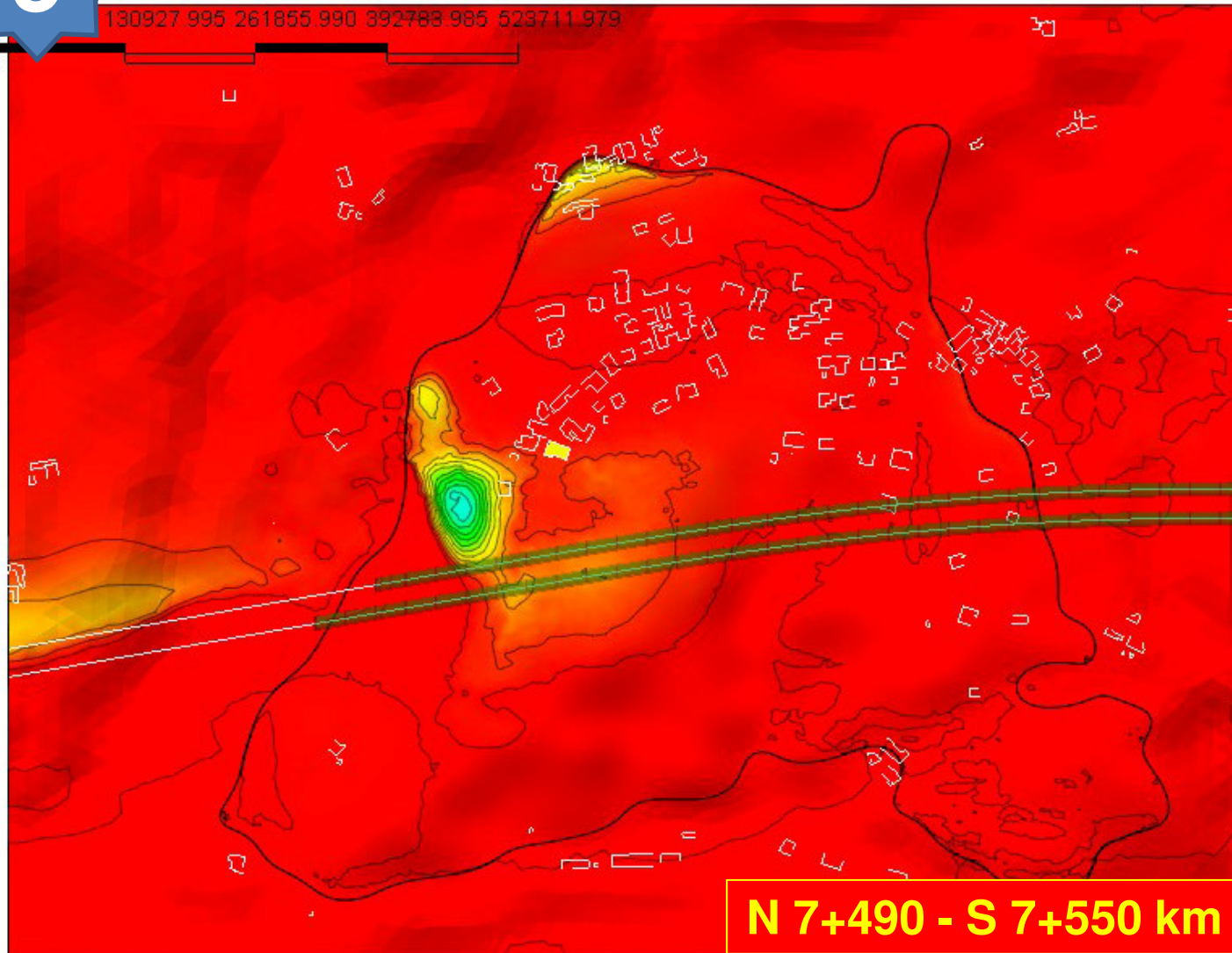


Measured XY Displacement Components



→ Numerical modelling – 2D & 3D FEM

5



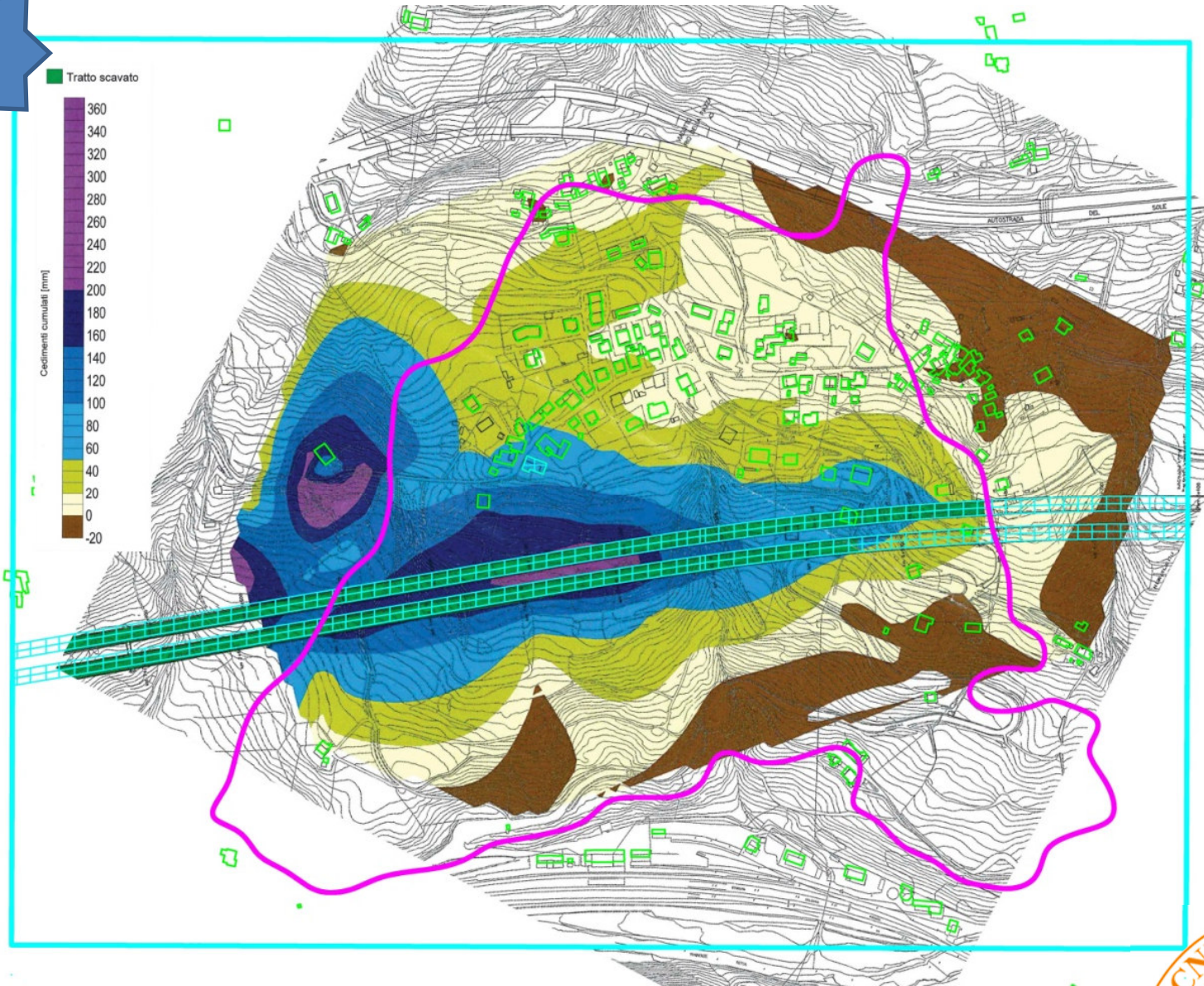
[UNIT] kN , mm

Computed Settlements



→ Numerical modelling – 2D & 3D FEM

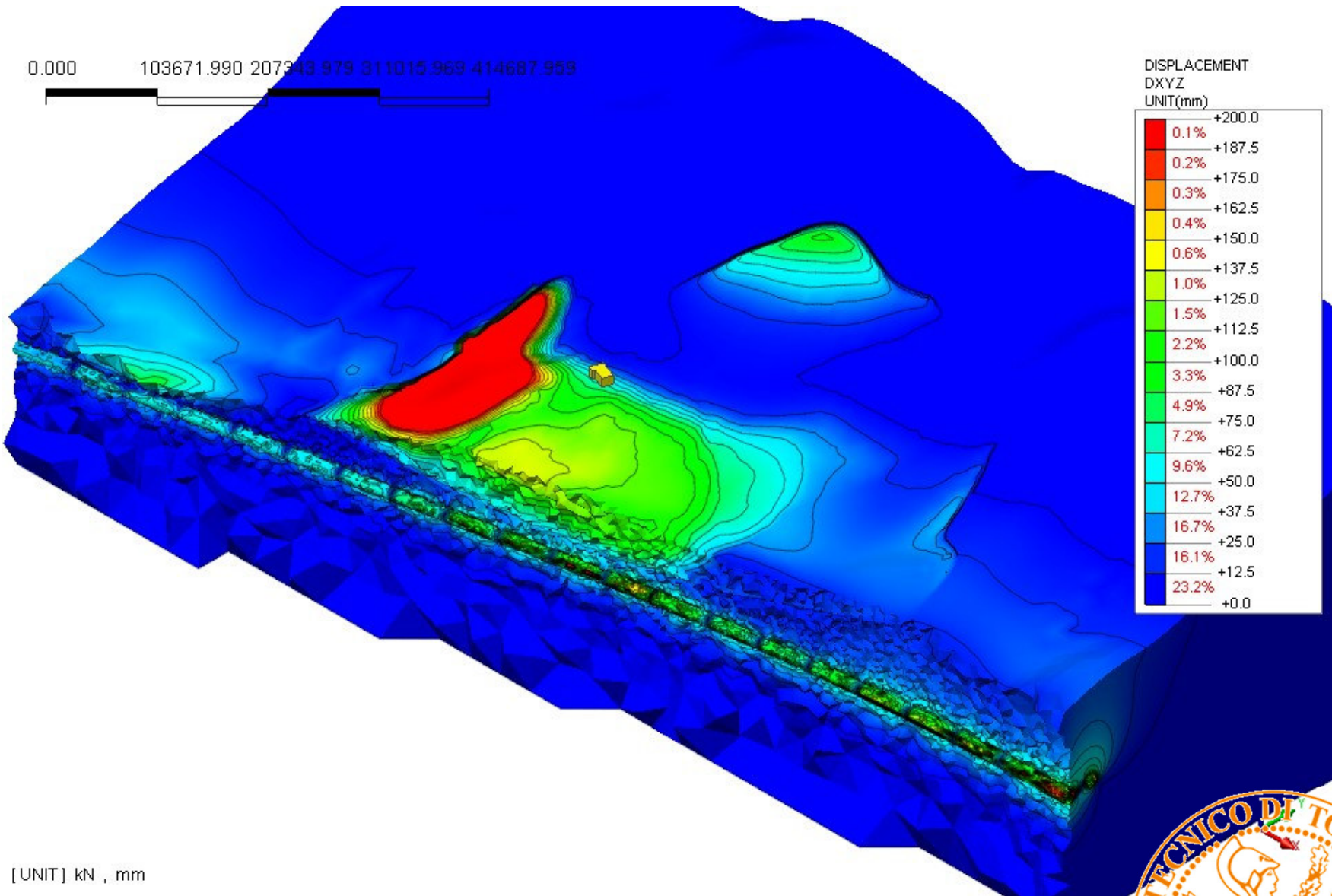
5



Measured Settlements



→ Numerical modelling – 2D & 3D FEM



3D view of computed surface displacements



→ CONCLUSIONS

6

We have described the geological, hydrogeological, and geotechnical conditions of the area of interest.

The available monitoring data on landslide movements caused by tunnel excavation have been presented. Investigative vs Predictive monitoring has been discussed.

2D and 3D FEM advanced modelling studies have been described. Measurements of surface and subsurface displacement have been integrated to obtain the 3D displacement field.

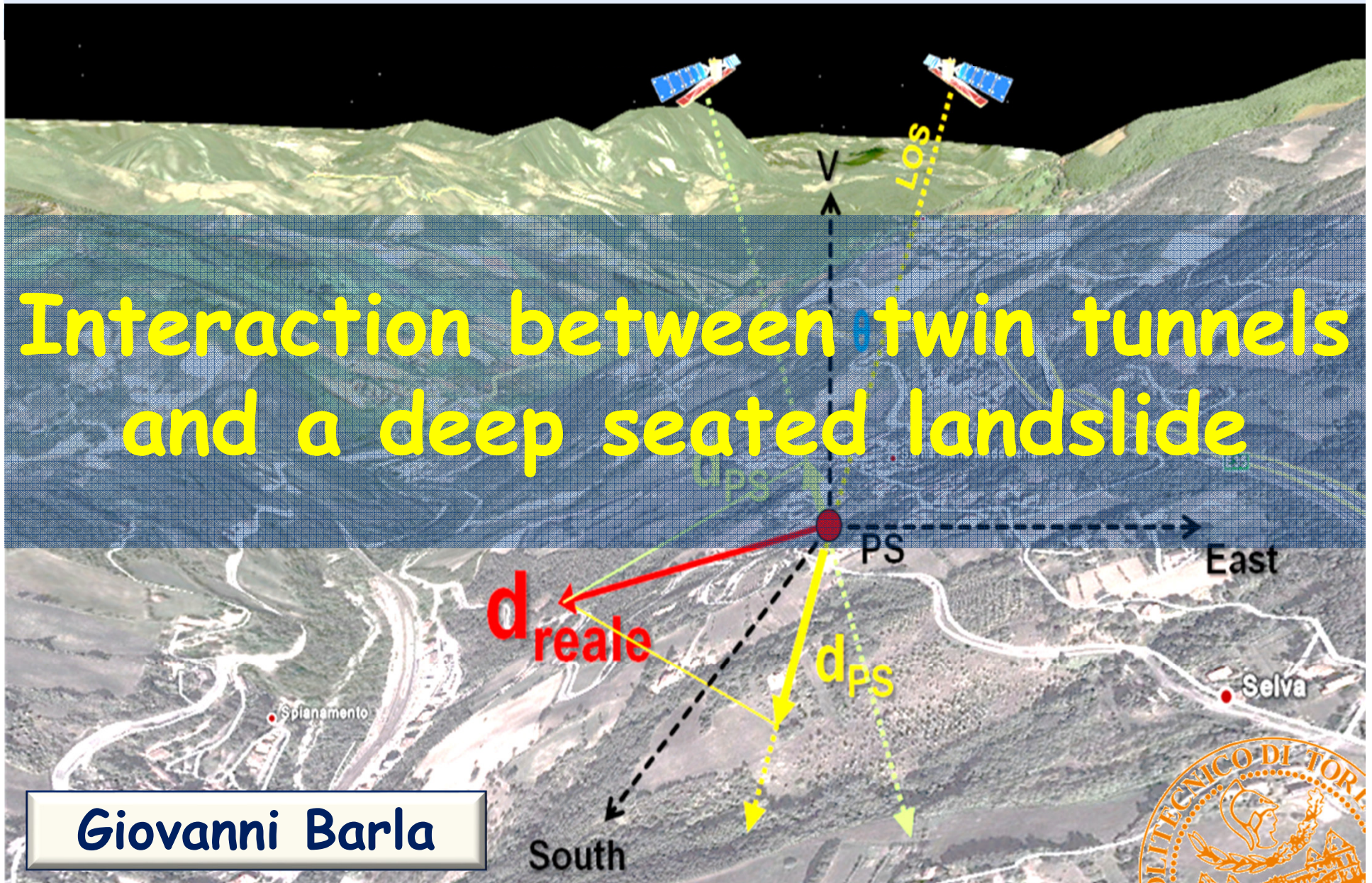
Numerical modelling has been used to interpret the observed tunnel - landslide interaction during tunnel excavation.

How and how far such models may help in the early decision making process?



Comité Français de Mécanique des Roches
Invited Lecture - Paris - 4 December 2014

Interaction between twin tunnels
and a deep seated landslide



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