Data fusion of robotic total station and time-lapse camera to assess the surface three-dimensional deformation of a landslide.

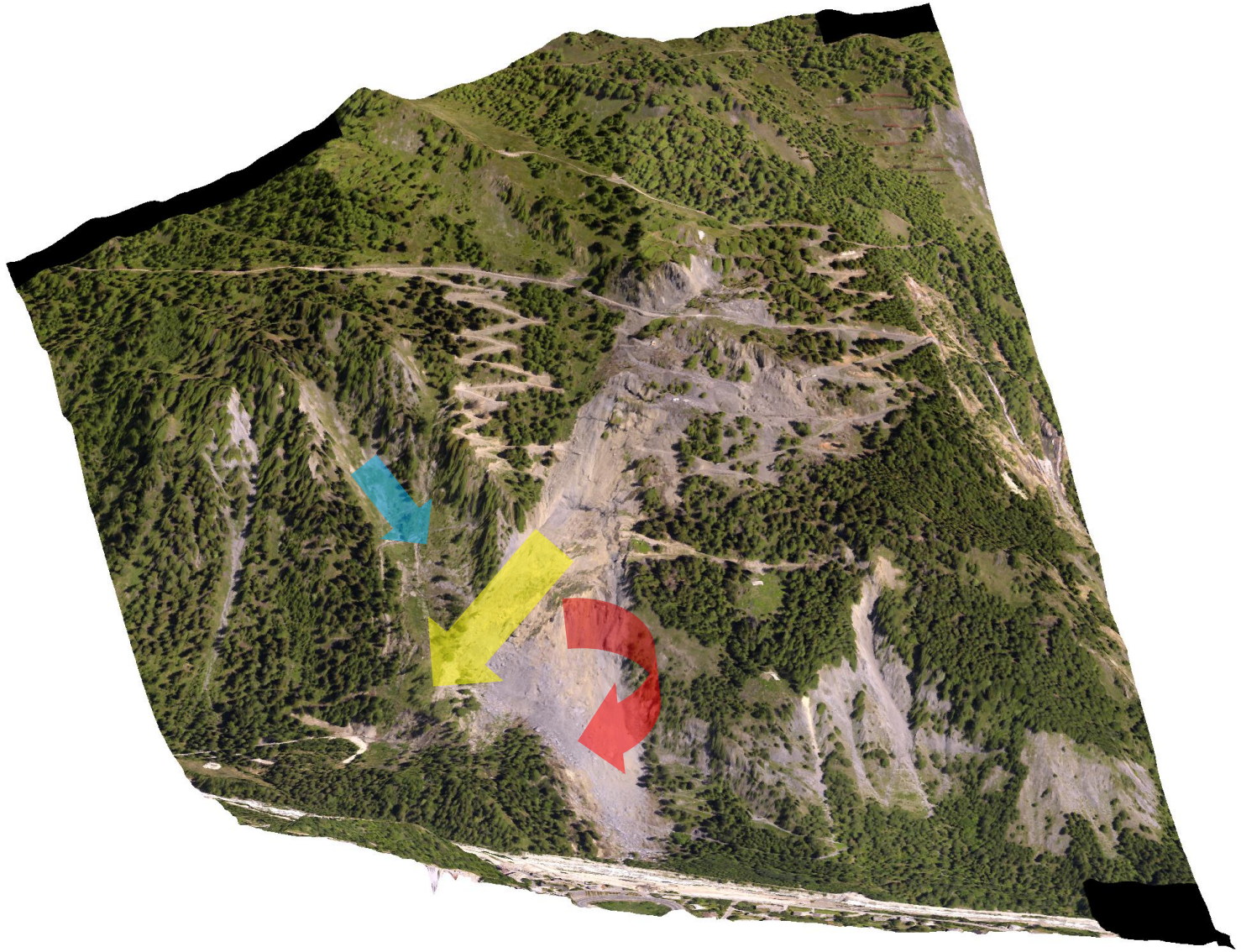
EGU General Assembly

Vienna 23-27 May 2022

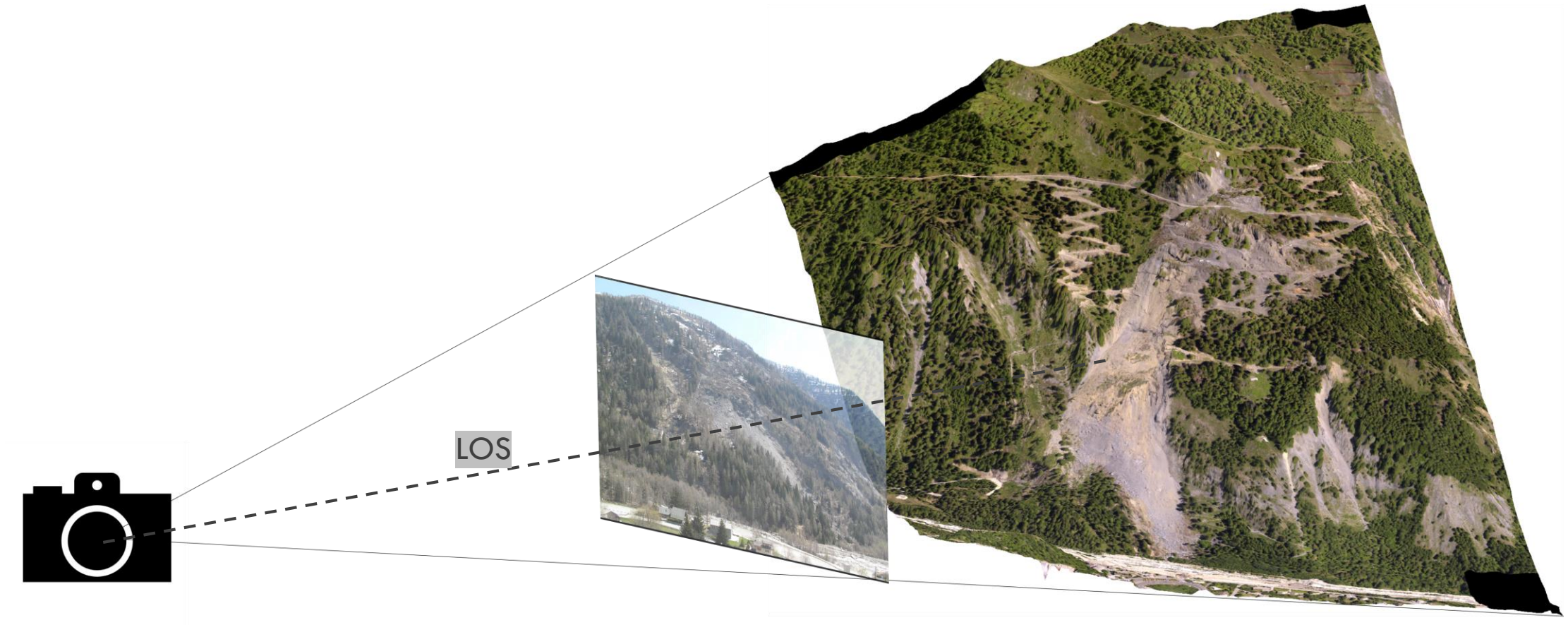
Niccolò Dematteis
Aleksandra Wrzesniak
Daniele Giordan
Research Institute for Geo-hydrological Protection

Landslide monitoring

Complex kinematics
→ Need of surface 3D deformation
→ Fusion of diverse data/sensors

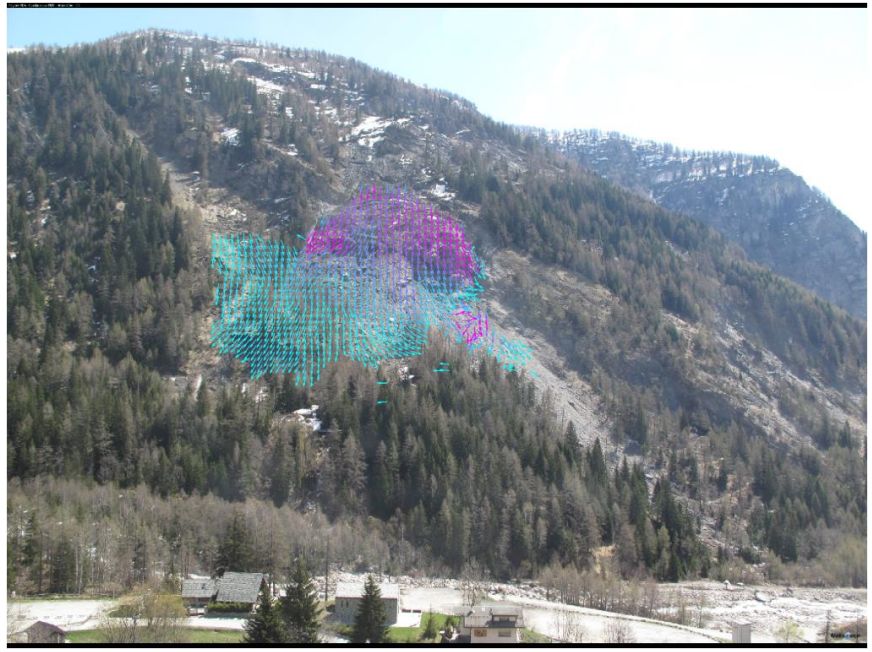


Time-lapse camera



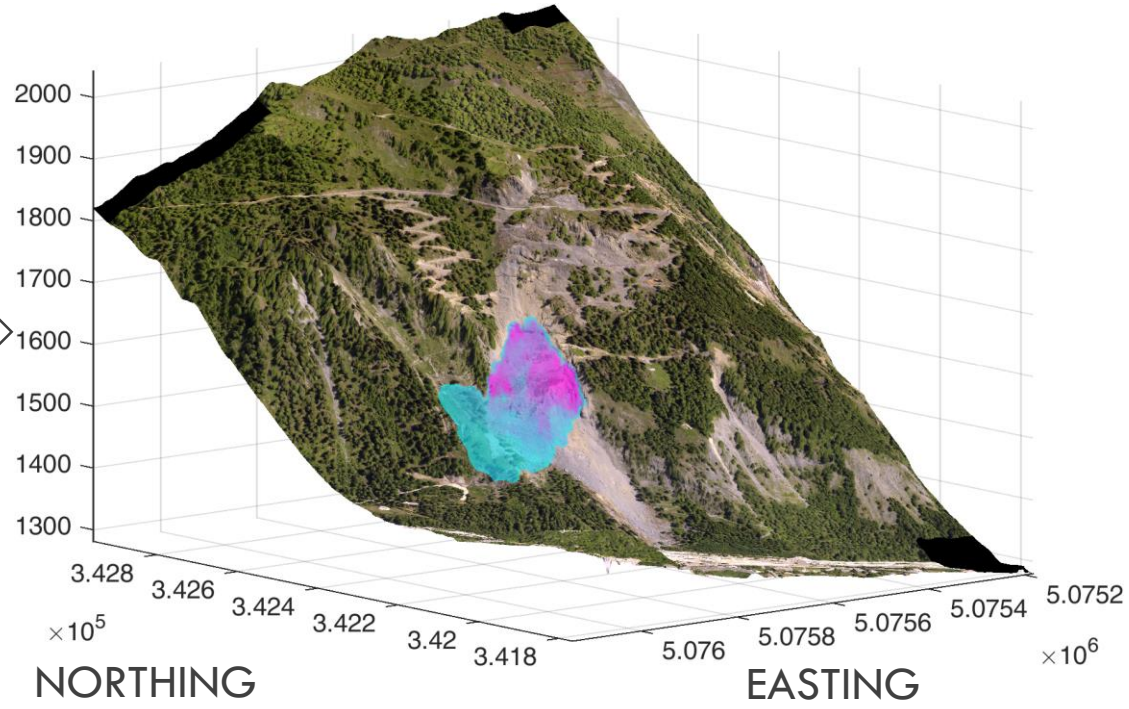
Digital image correlation

PIXEL COORDINATES



ORTHORETIFICATION

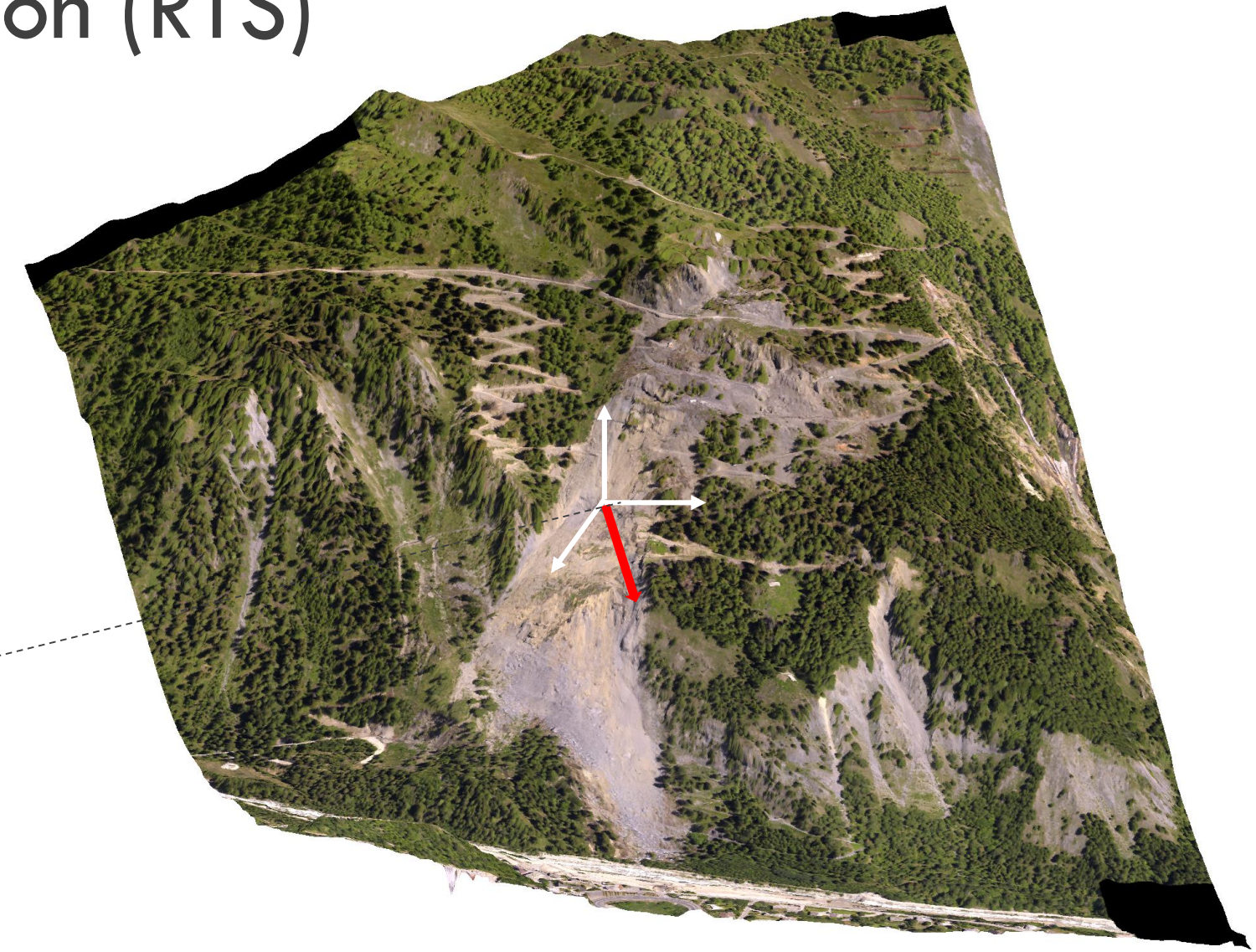
ELEVATION



GEOCODING
METRIC DISPLACEMENT
DISPLACEMENT IN LOCAL COORDINATE SYSTEM

Robotic total station (RTS)

3D COMPONENTS
POINT DISPLACEMENT
DISPLACEMENT IN LOCAL COORDINATE SYSTEM

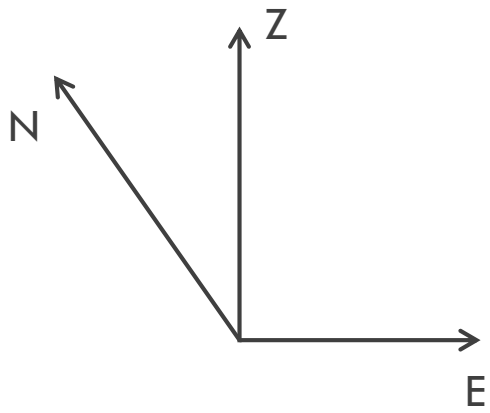


Coordinate systems

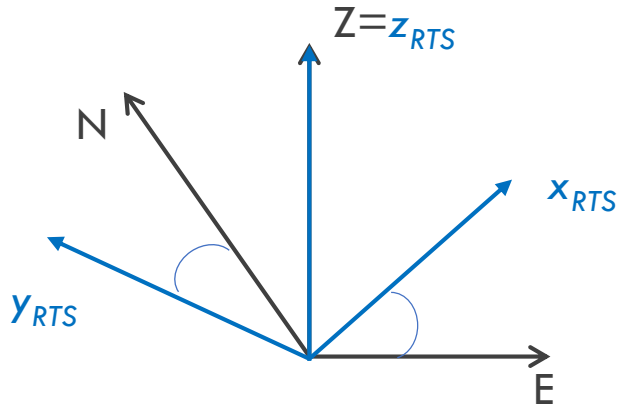
RTS AND DIC DISPLACEMENT ARE GEOCODED BUT THE DISPLACEMENT VECTORS ARE REPRESENTED IN LOCAL COORDINATE SYSTEMS

ROTATION ANGLES ARE KNOWN

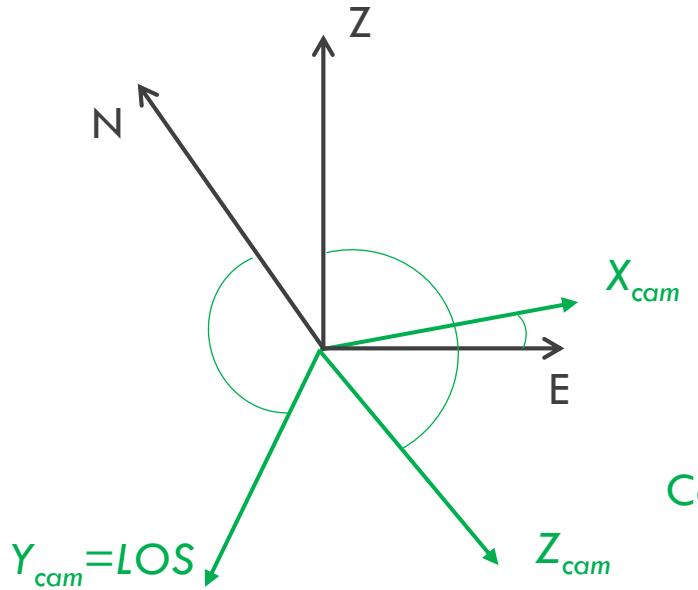
DISPLACEMENT 3D ROTATION



Geographical CS



RTS CS



Camera CS

3D rotation

Non commutative sequence of basic rotations $\boldsymbol{V'} = \boldsymbol{R}_y(\phi')\boldsymbol{R}_x(\theta')\boldsymbol{R}_z(\psi')\boldsymbol{R}_z(\psi)\boldsymbol{R}_x(\theta)\boldsymbol{R}_y(\phi)\boldsymbol{V}$

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}$$

$$R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$$

$$R_z(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

1° step

RTS vector rotated into CS_{cam}

$(x_{RTS}, y_{RTS}, z_{RTS}) \rightarrow (x'_{RTS}, y'_{RTS}, z'_{RTS})$

Data fusion

LEMMA 1: $x'_{RTS}=X_{cam}$ & $z'_{RTS}=Z_{cam}$ (observed quantities)

LEMMA 2: (x'_{RTS}, y'_{RTS}, z'_{RTS}) are point displacements

Spatial interpolation of (x'_{RTS}, y'_{RTS}, z'_{RTS}) → (X'_{RTS}, Y'_{RTS}, Z'_{RTS})

→ Strong approximation

DEFINITION: $\alpha=Z'_{RTS}/XYZ_{RTS}$ (XYZ_{RTS} is the displacement module)

HYPOTHESIS: α is smooth → reduced approximation

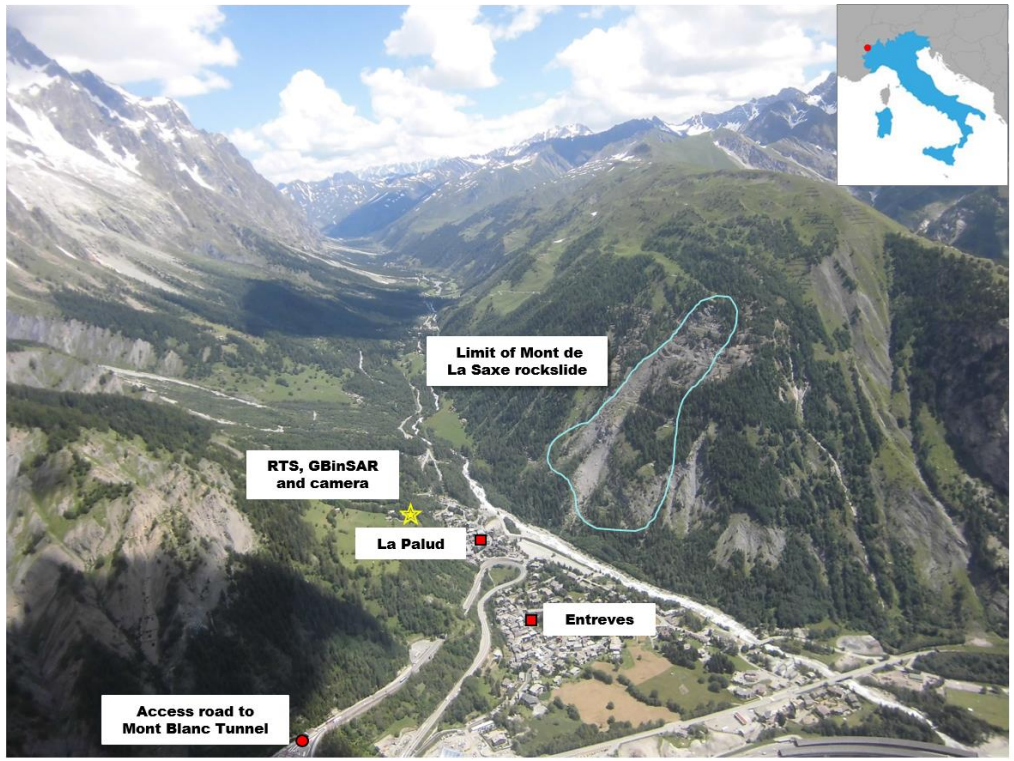
$XYZ_{cam}=Z_{cam}/\alpha$

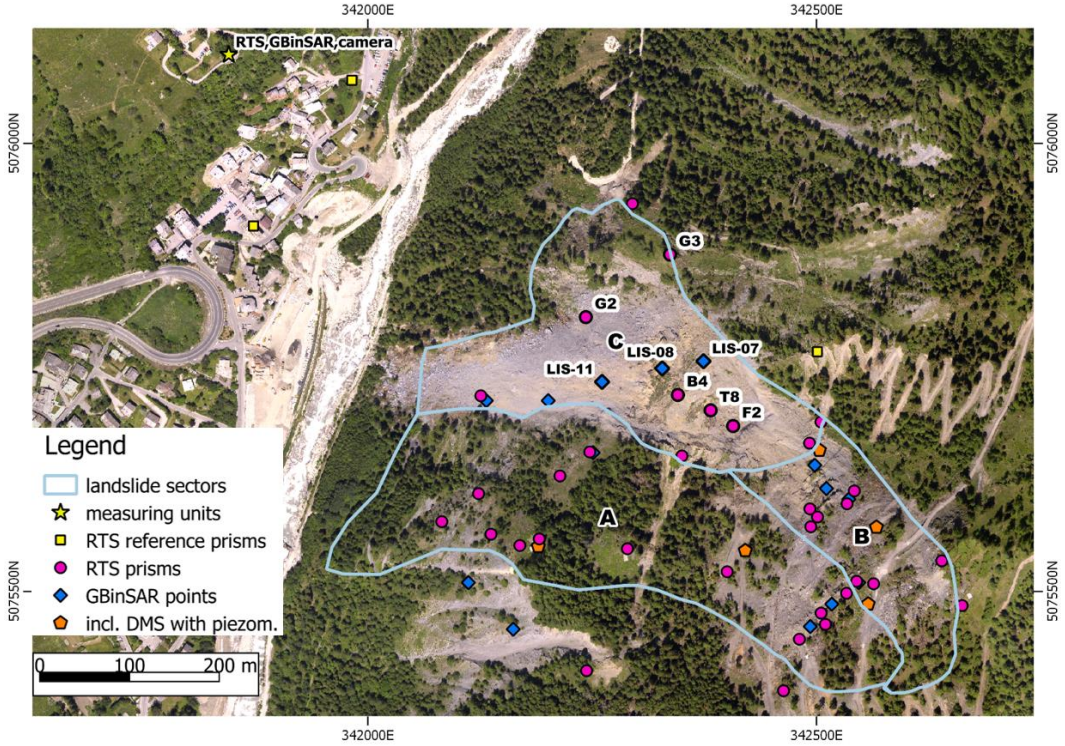
→ $Y_{fusion}=\sqrt{(XYZ^2_{cam}-Z^2_{cam}-X^2_{cam})}$

→ $\mathbf{V}_{geo}=\mathbf{R}_z(\psi)\mathbf{R}_x(\theta)\mathbf{R}_y(\phi)\mathbf{V}_{cam}$

$\mathbf{V}_{geo}$ is the spatially distributed displacement vector in the geographical CS

Case Study: Mont de La Saxe Rockslide

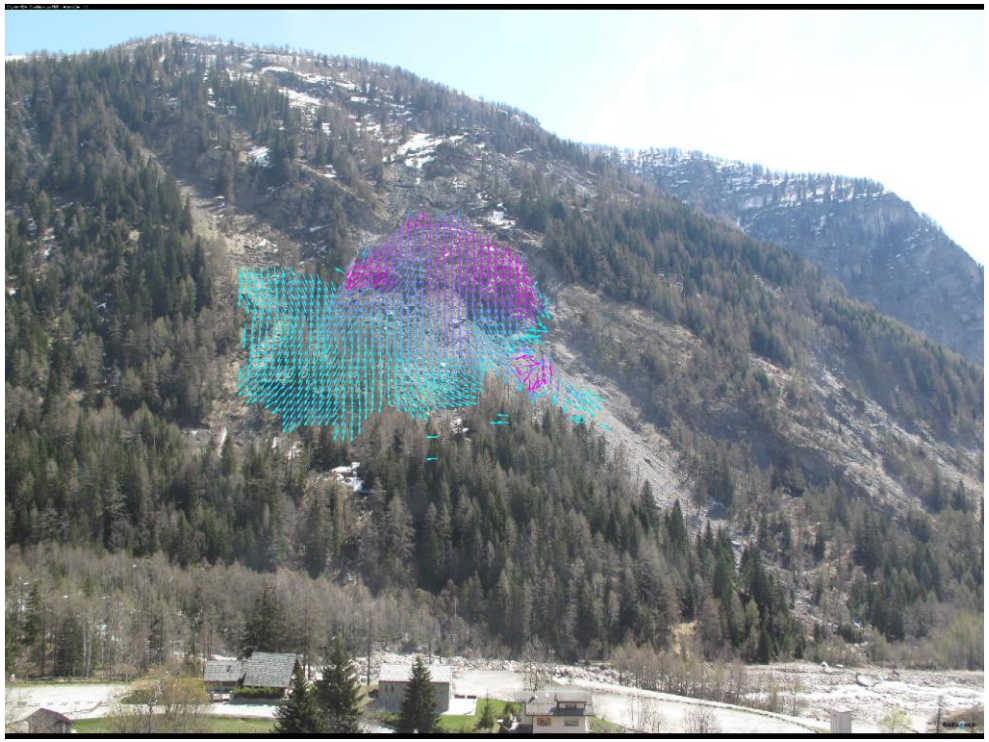


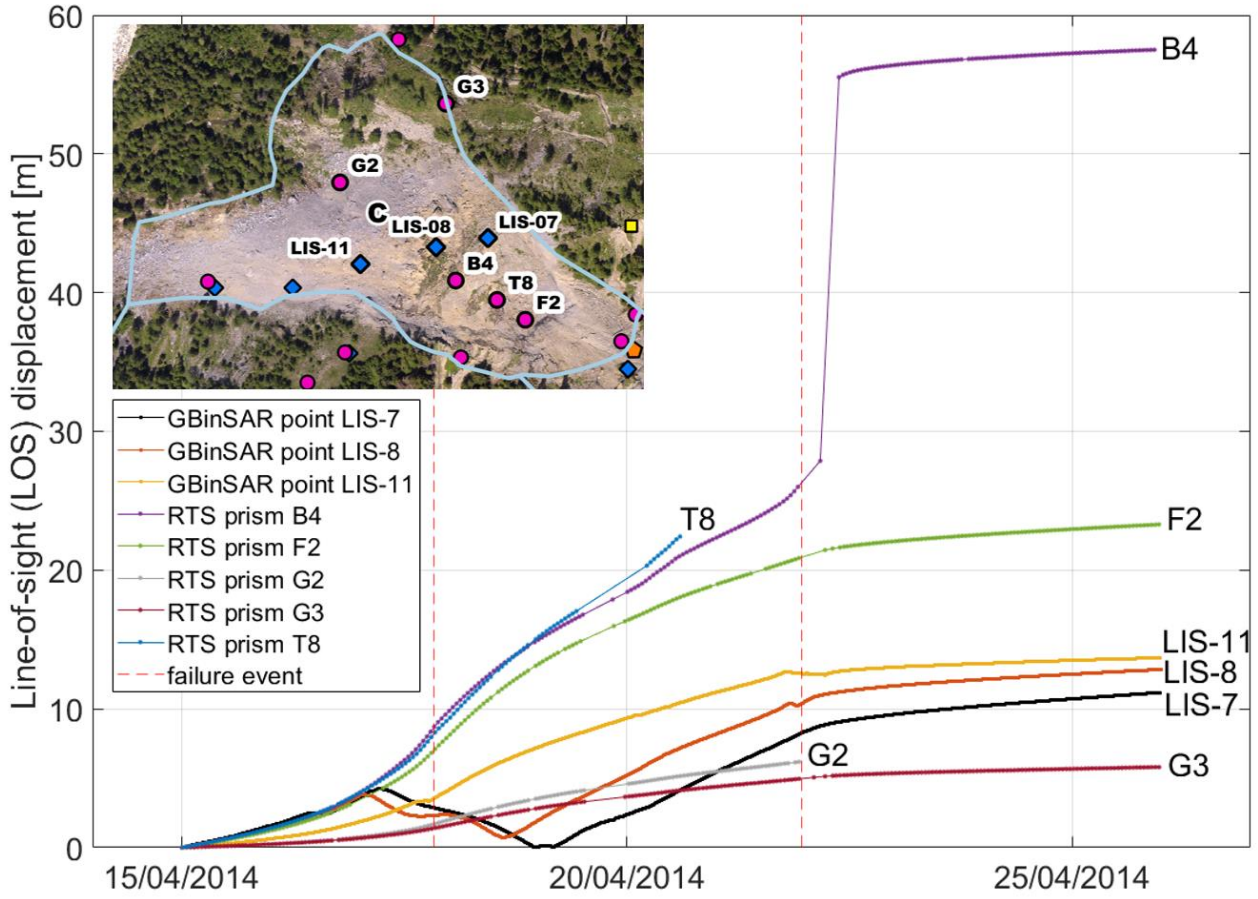


8 million m^3
37° steep
Endangered Mont Blanc Tunnel access

RTS with 32 reflective prisms
Low resolution time-lapse camera
GBSAR

DIC and RTS data



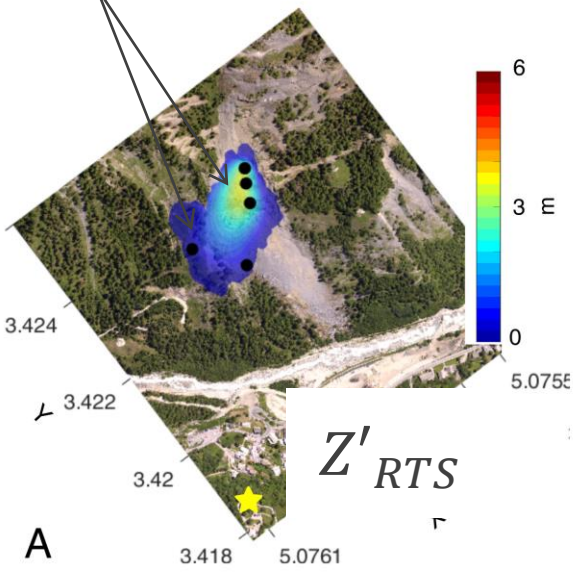


GEOHAZARD MONITORING GROUP

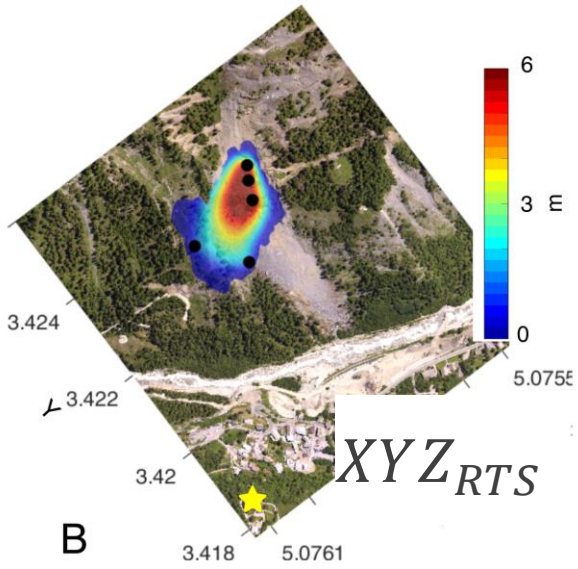
irpi Istituto di Ricerca per la Protezione Idrogeologica

Consiglio Nazionale delle Ricerche

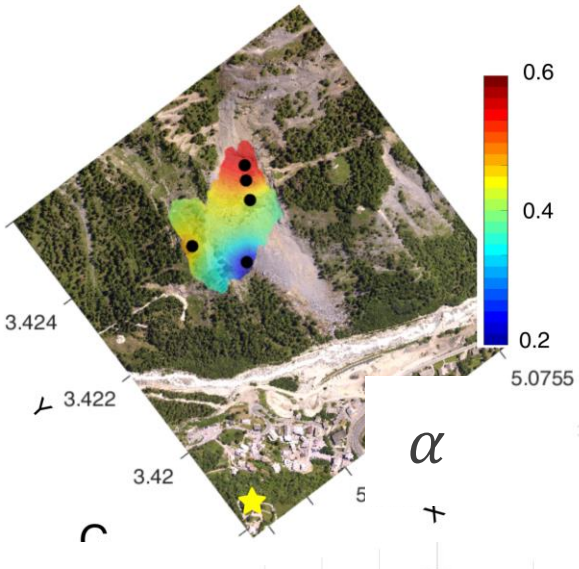
5 prisms



Z'_{RTS}

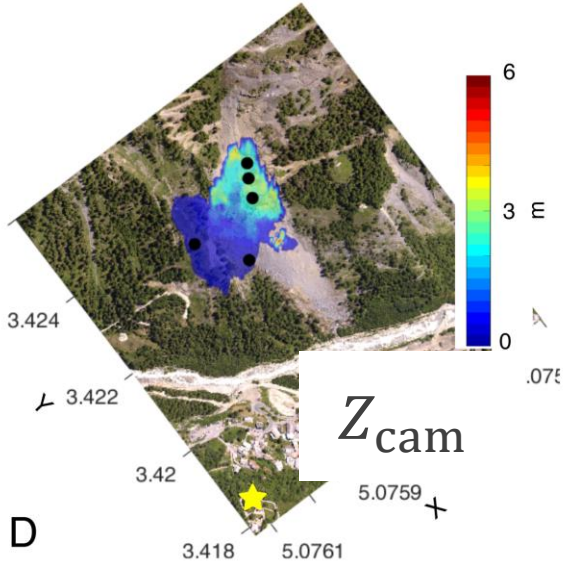


XYZ_{RTS}

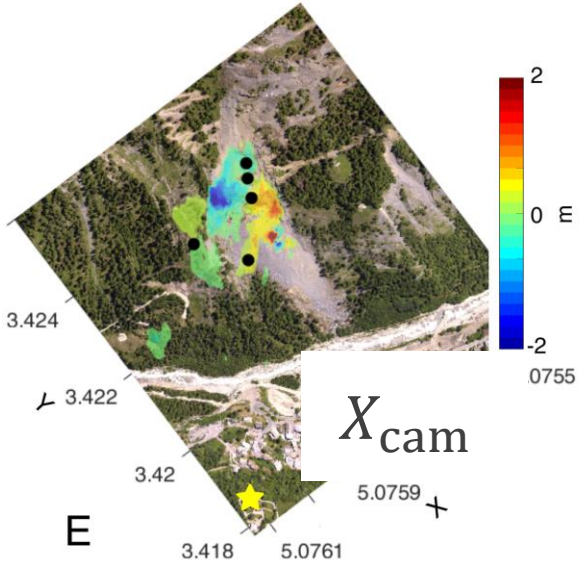


α

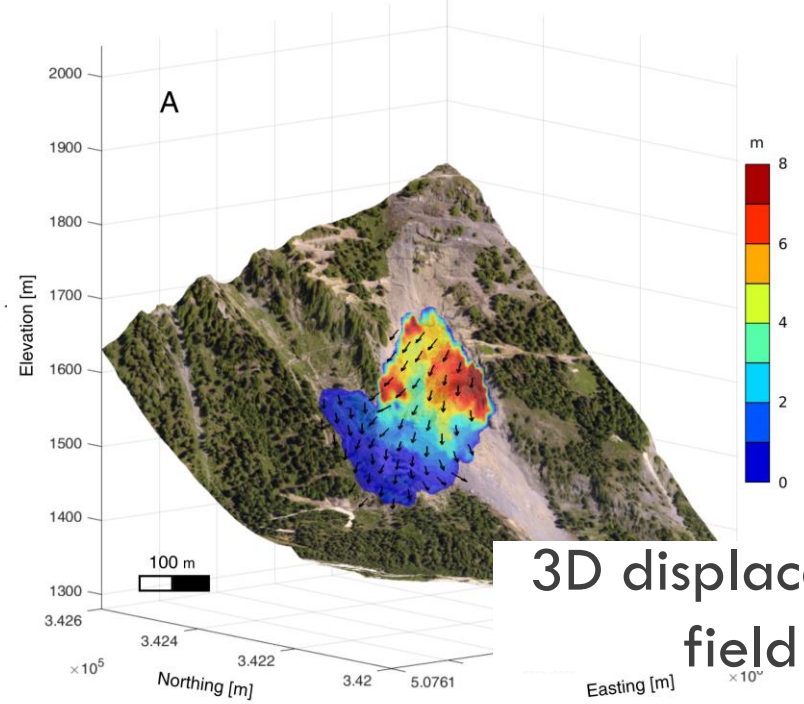
Data fusion results



Z_{cam}



X_{cam}

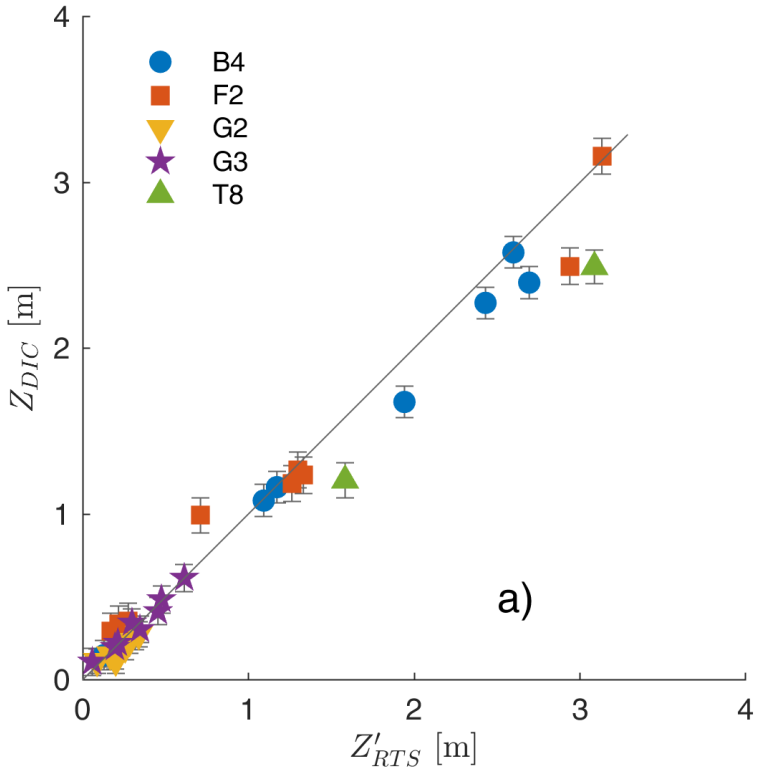


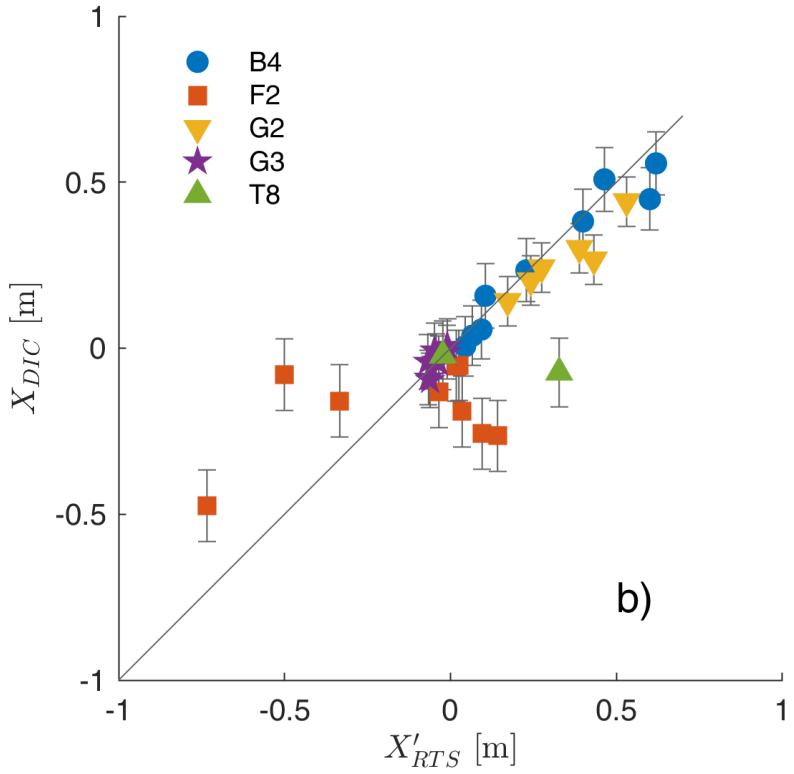
3D displacement field

Performance assessment

DIC vs RTS

MAD=0.062-0.090 m

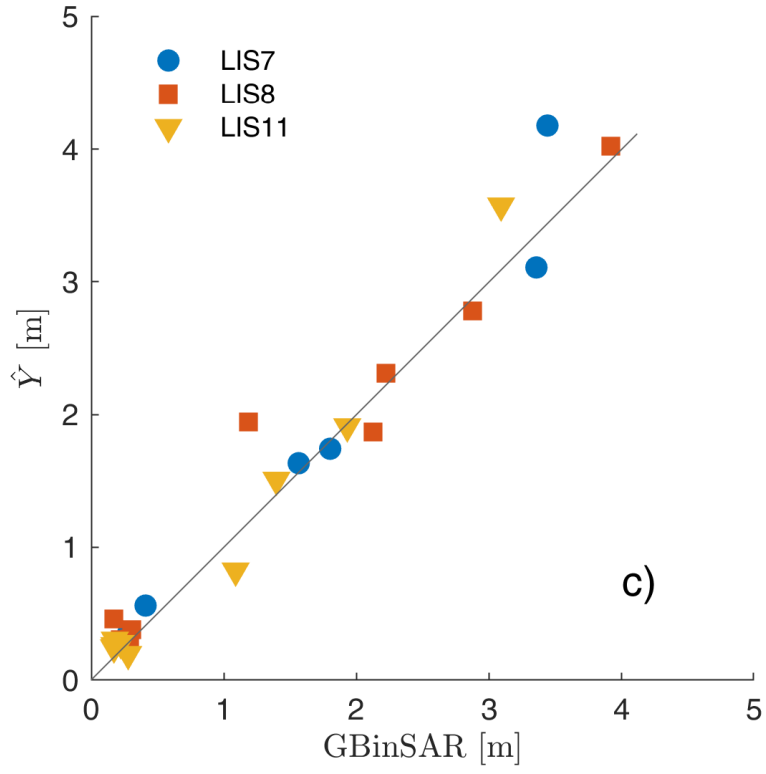




Y_{FUSION} vs GBSAR

MAD=0.086 m

Comparable with DIC precision 0.082 m



Conclusions

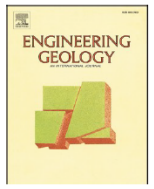
- Time-lapse camera and RTS are robust, low-cost, portable
- GNSS are an alternative/integration of RTS
- They are already available in many existing monitoring systems → camera-RTS fusion can be immediately implemented

Engineering Geology 303 (2022) 106655

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

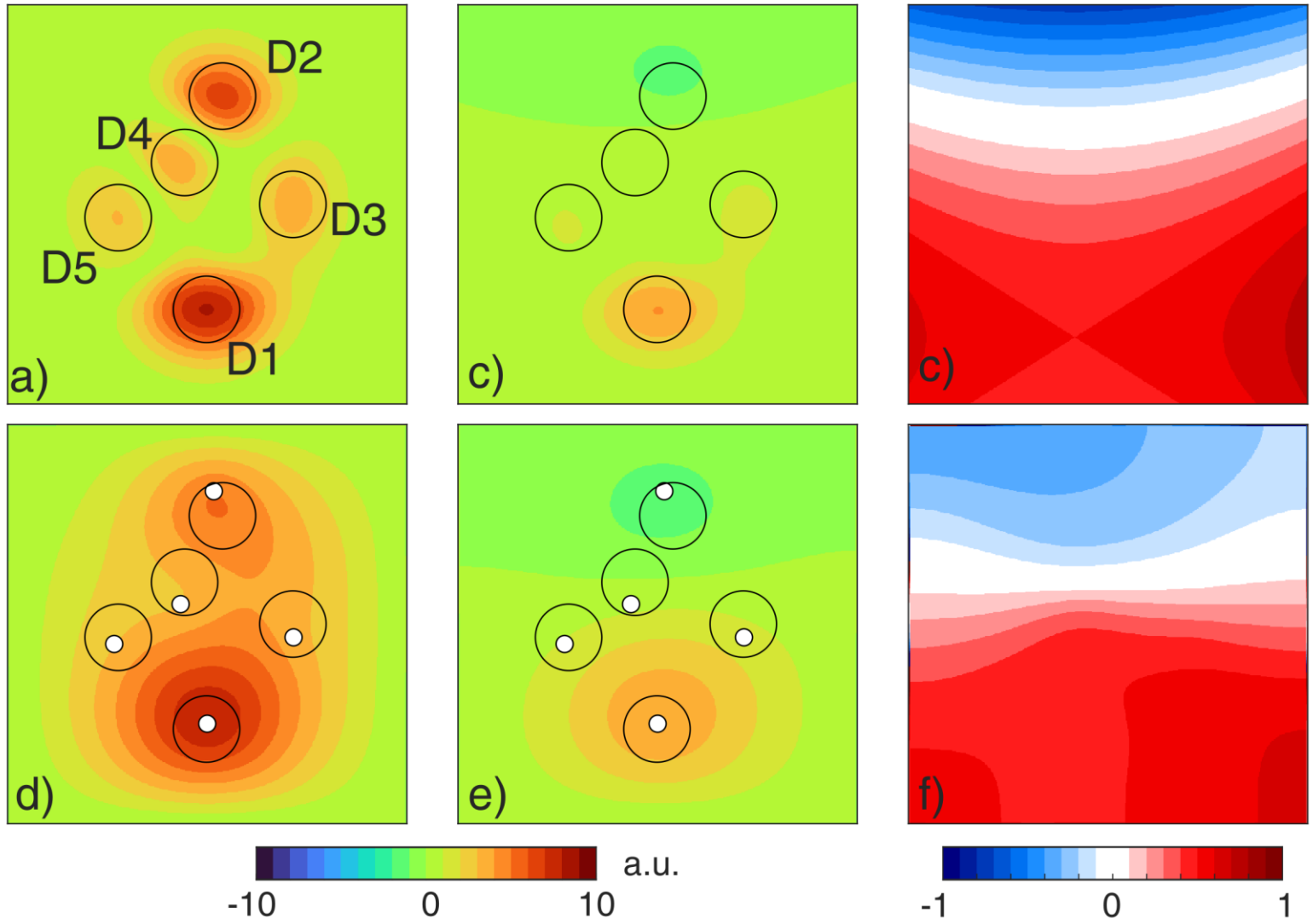


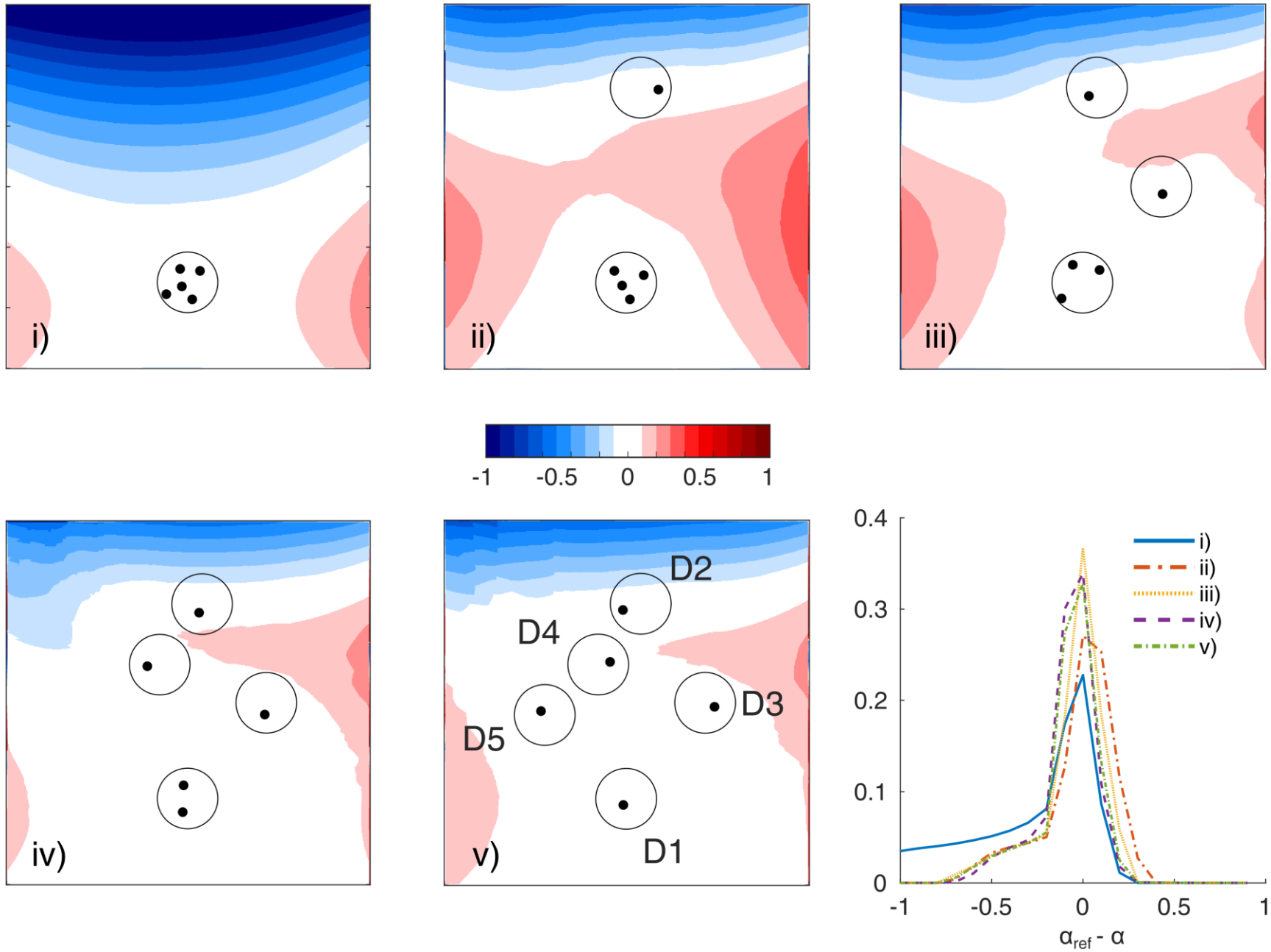
Integration of robotic total station and digital image correlation to assess the three-dimensional surface kinematics of a landslide

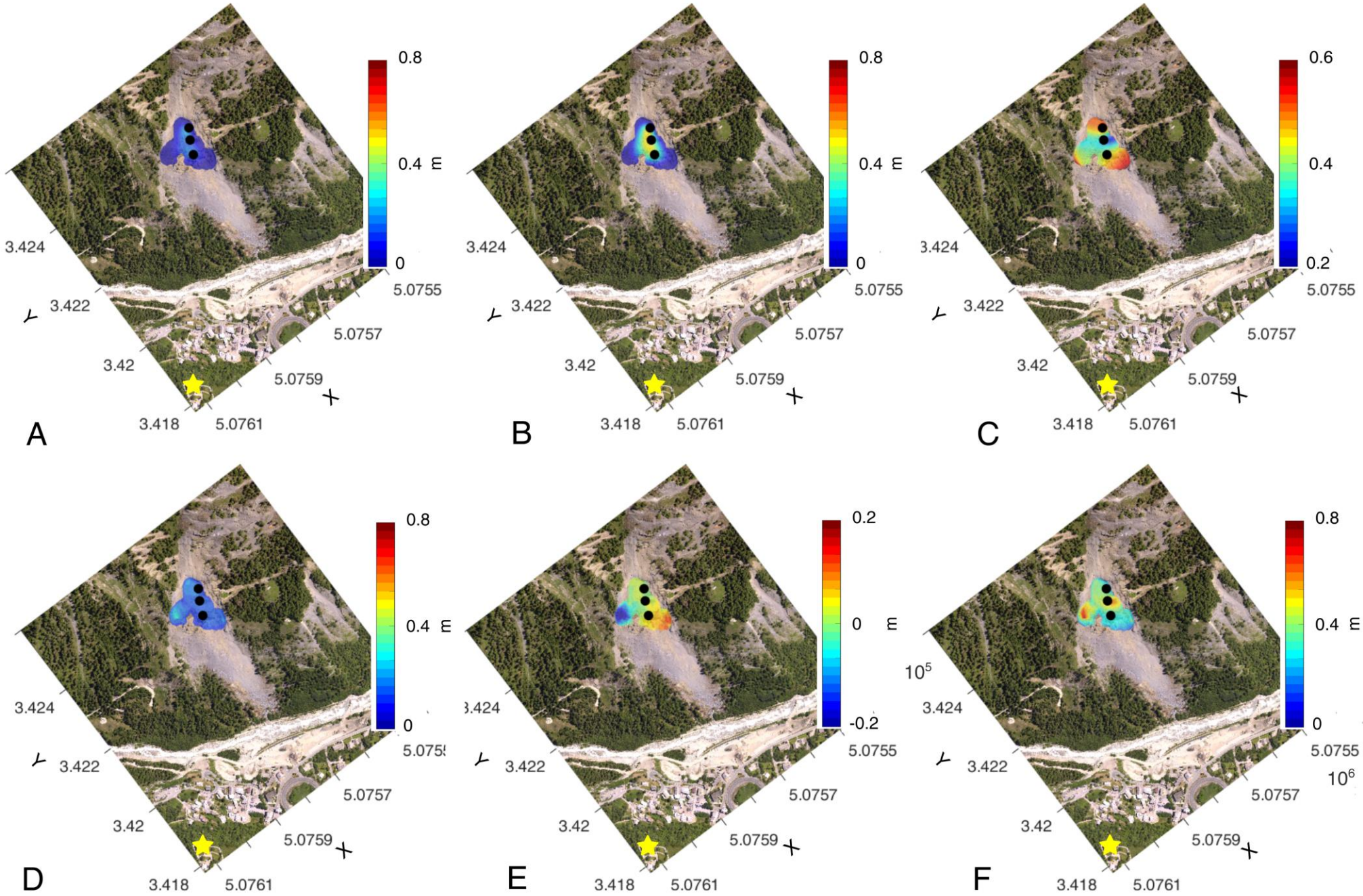
Niccolò Dematteis [a], Aleksandra Wrzesniak [a,*], Paolo Allasia [a], Davide Bertolo [b], Daniele Giordan [a]

[a] Research Institute for Geo-hydrological Protection, National Research Council, Strada delle Cacce 73, 10135 Turin, Italy
[b] Strutture Attività Geologiche, Regione Autonoma Valle d'Aosta, Loc. Amerique 33, Quart, Italy

niccolo.dematteis@irpi.cnr.it


D2
D4
D3
D5
D1
a)
c)
c)
d)
e)
f)
a.u.
-10
0
10
-1
0
1


i)
ii)
iii)
-1
-0.5
0
0.5
1
iv)
v)
D2
D4
D3
D5
D1
0.4
0.3
0.2
0.1
0
i)
ii)
iii)
iv)
v)
-1
-0.5
0
0.5
1
α_{ref} - α


A
B
C
D
E
F
0.8
0.4
0
m
0.6
0.2
-0.2
3.424
3.422
3.42
3.418
5.0755
5.0757
5.0759
5.0761
X
Y
10^5
10^6

Spatially distributed displacement vectors