Pre-survey suitability analysis of the differential and persistent scatterer synthetic aperture radar interferometry method for deformation monitoring of landslides

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Motivation

- D-InSAR & PSI enable deformation monitoring of millimeter accuracy

- But: limiting factors can only roughly be estimated
  - Imaging geometry: Layover & Shadow
  - Influence of land cover

  - PSI: at least 15 to 50 SAR acquisitions required: time consuming and expensive
  - High number of PS required
  - Estimation of the PS density prior to the processing of several SAR images very difficult

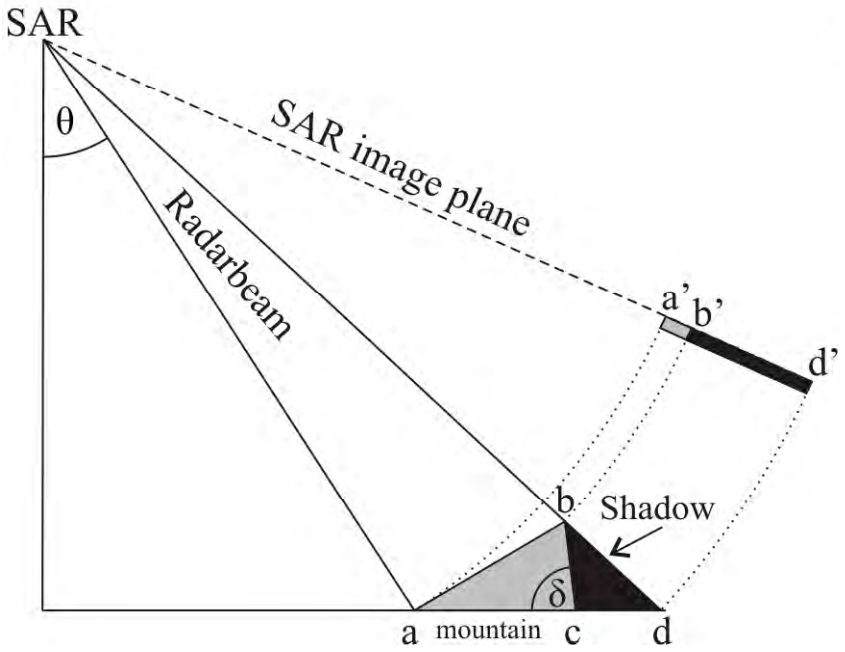
- Goal: Development and investigation of methods to enable objective pre-survey suitability analysis – Pre-processing

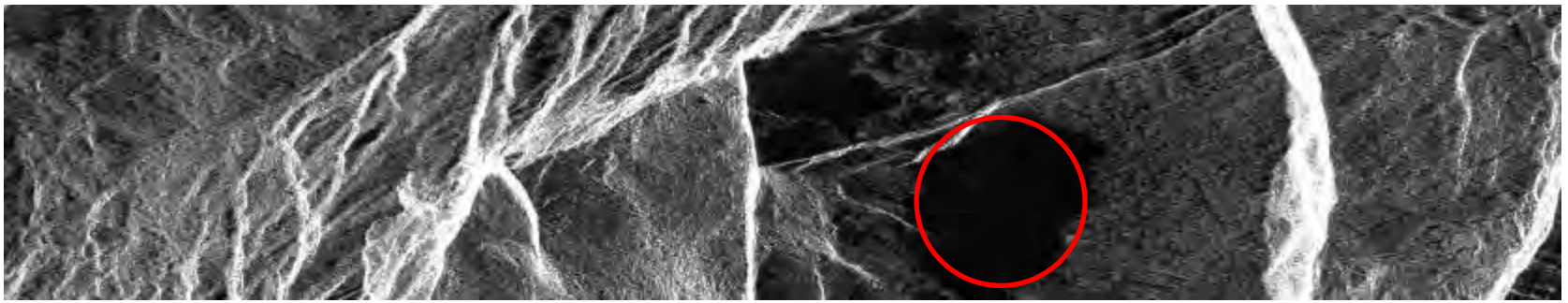
Outline

- Geometric factors
  - Layover & Shadow
  - Measurable percentage of movement of D-InSAR
- Influence of the land cover
- Suitability analysis of Persistent Scatterer Interferometry
  Estimation of PS prior to SAR acquisition
  - **Land cover data**
  - Optical remote sensing imagery
  - Topographical maps
- Conclusions

Layover & Shadow

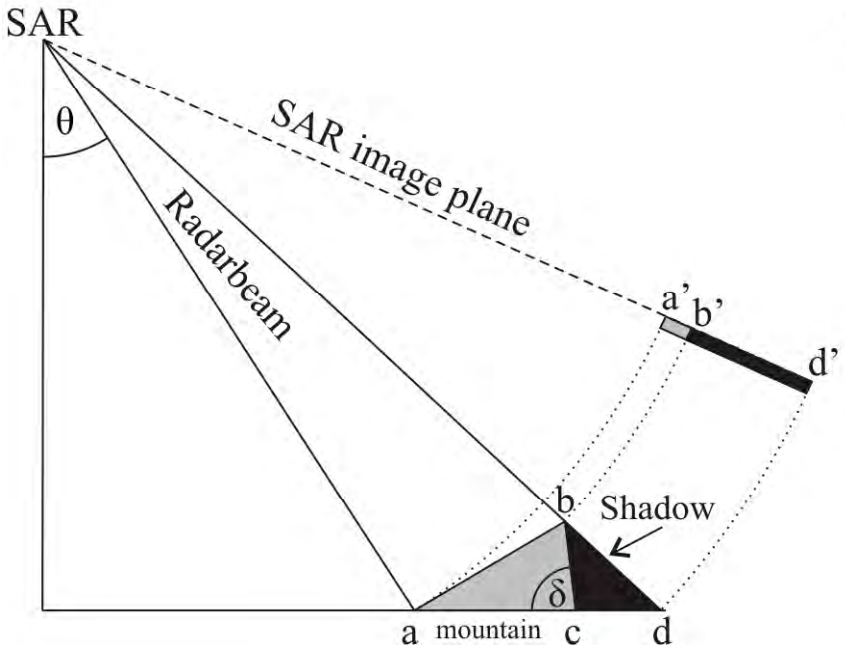
Radar Shadow



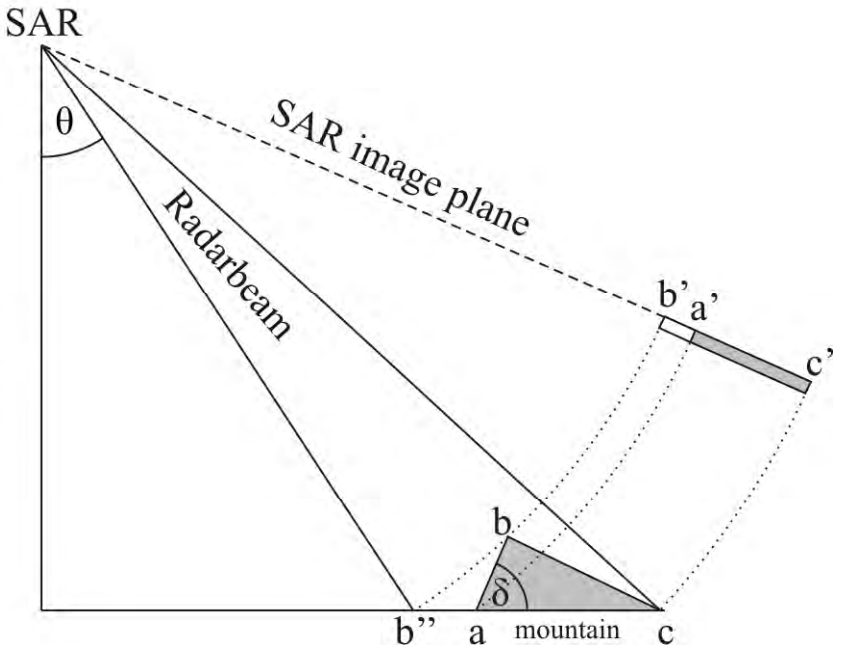


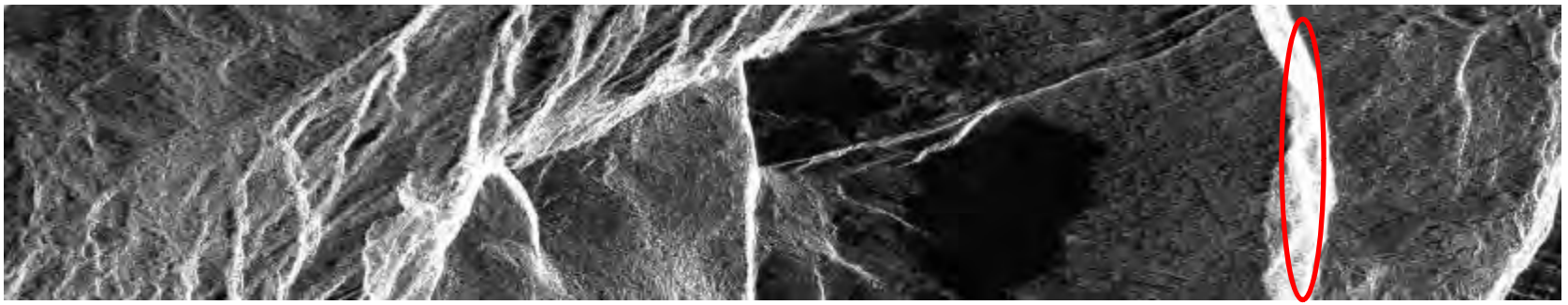
Layover & Shadow

Radar Shadow



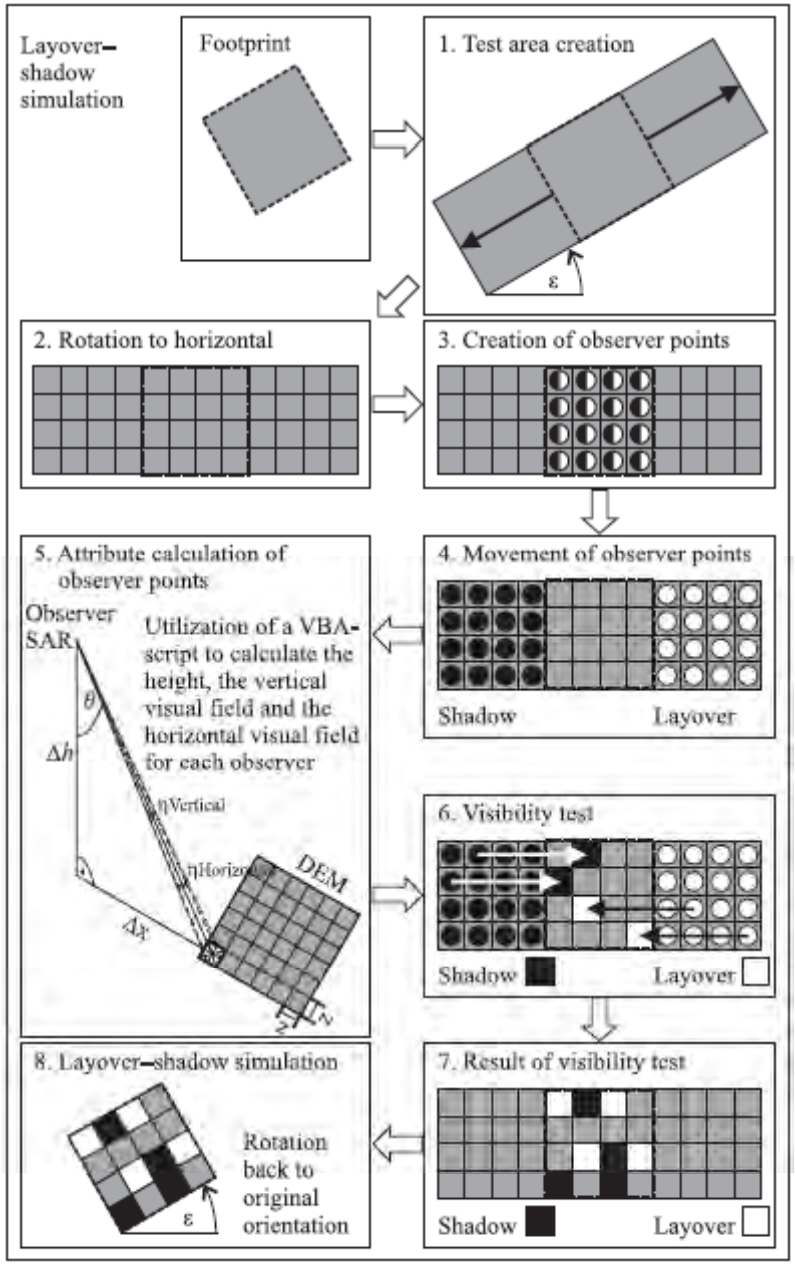
Layover





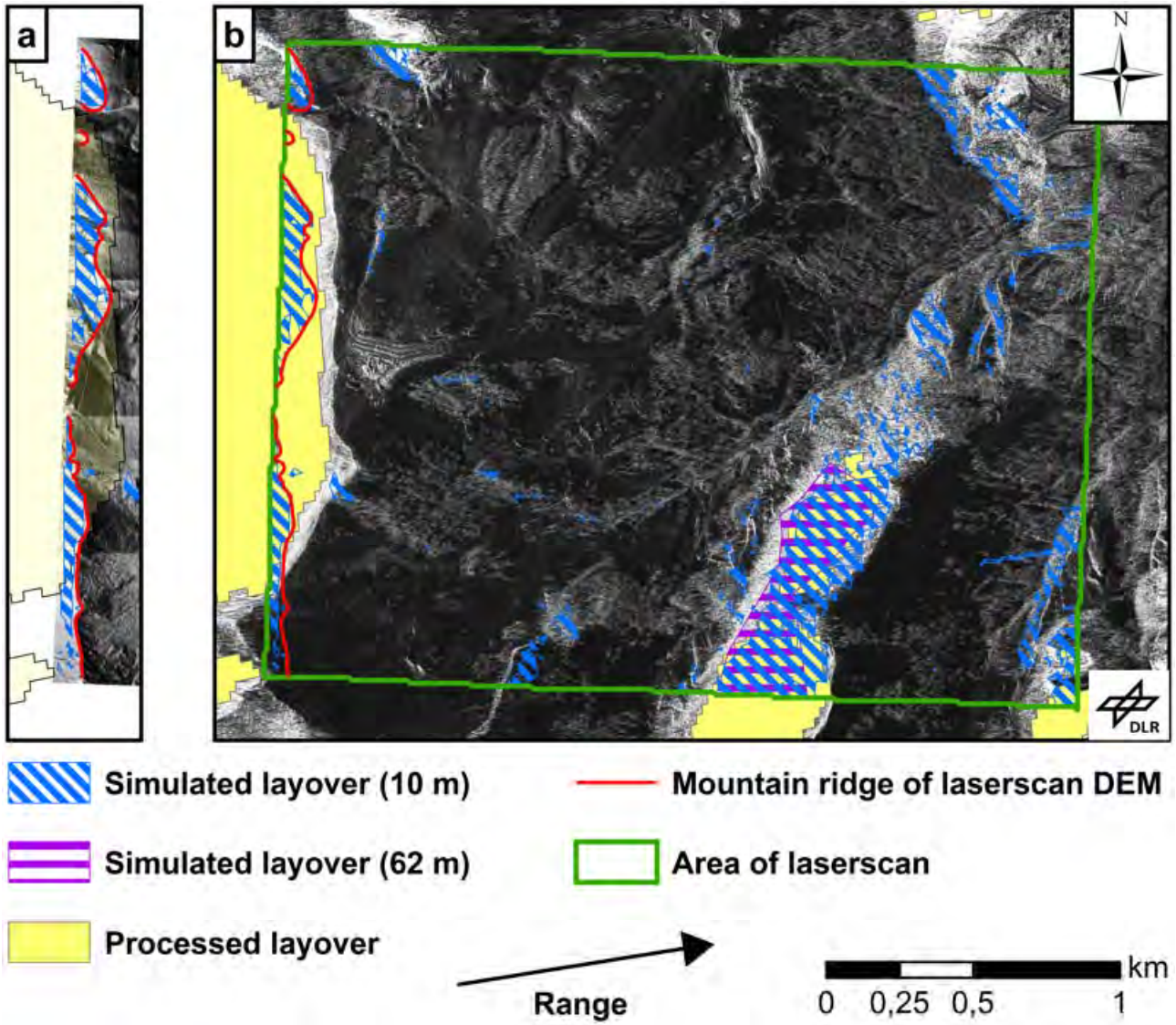
Layover-Shadow-Simulation

- Input data for the simulation
  - Digital Elevation Model (DEM) of the test site
  - Coordinates of the test site
  - Incidence Angle
  - Orbit information: Ascending / Descending



Plank et al. 2012

Layover-Shadow-Simulation



Plank et al. 2012

Which part of the movement on the ground is detected by D-InSAR?

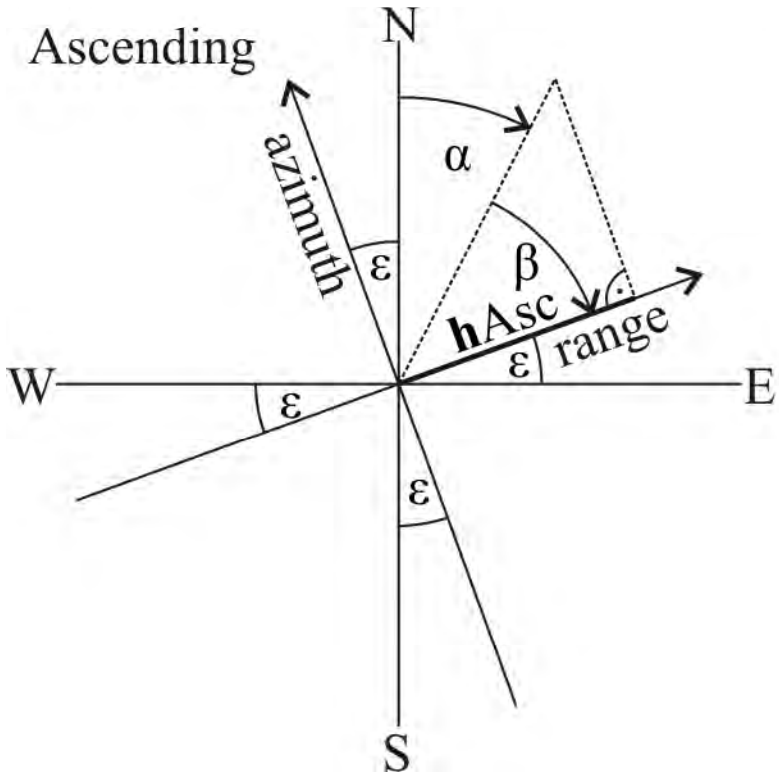
- Measurable percentage of movement depends on:
  - Dip direction of the slope
  - Slope dip
  - Incidence Angle
  - Orbit of the satellite (Asc./ Desc.)

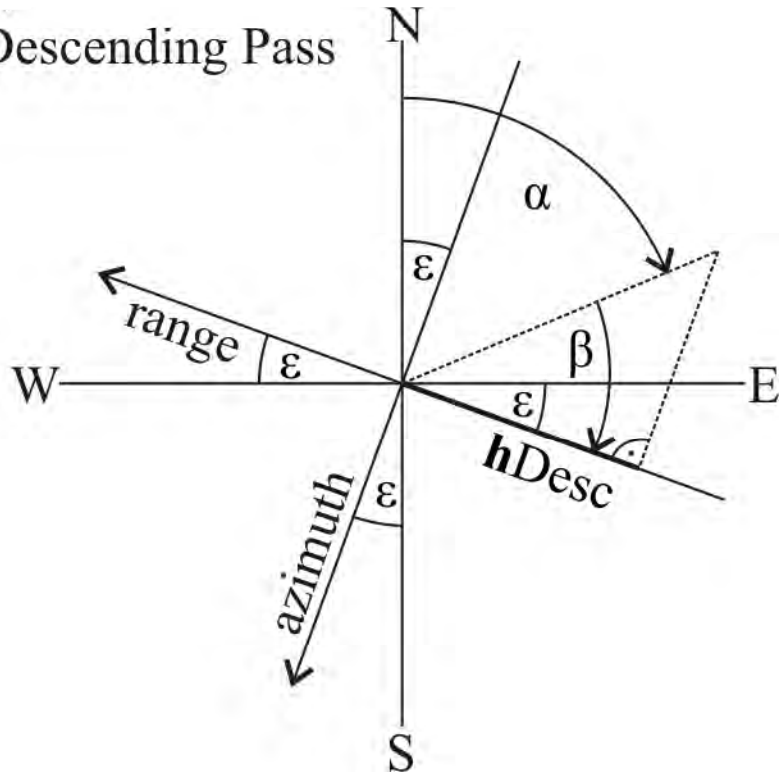
- SAR detects movements in Range ⊥ flight direction (Azimuth)

- No detection of movements || Azimuth possible

Which part of the movement on the ground is detected by D-InSAR?

Horizontal Measurable Percentage of Movement





$$h_{Asc} = |\cos(90° - \alpha - \varepsilon)|$$

$$h_{Desc} = |\cos(90° - \alpha + \varepsilon)|$$

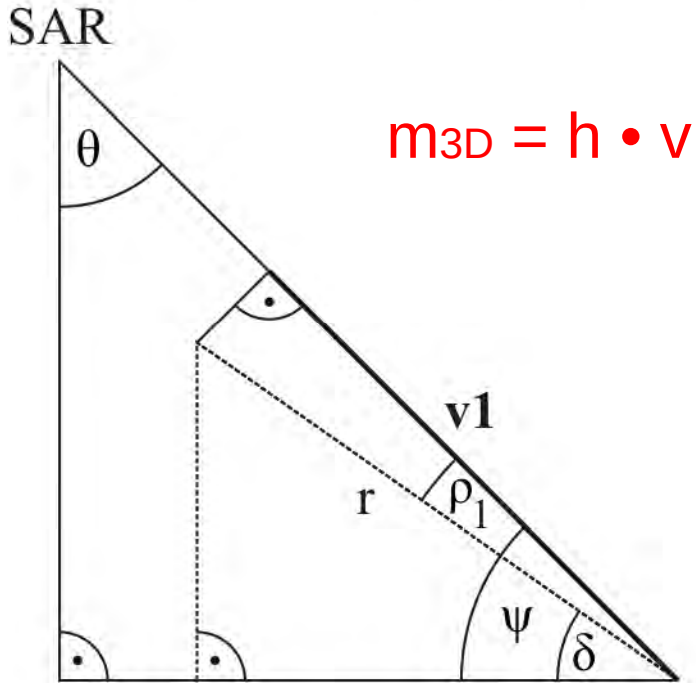
Plank et al. 2012

Which part of the movement on the ground is detected by D-InSAR?

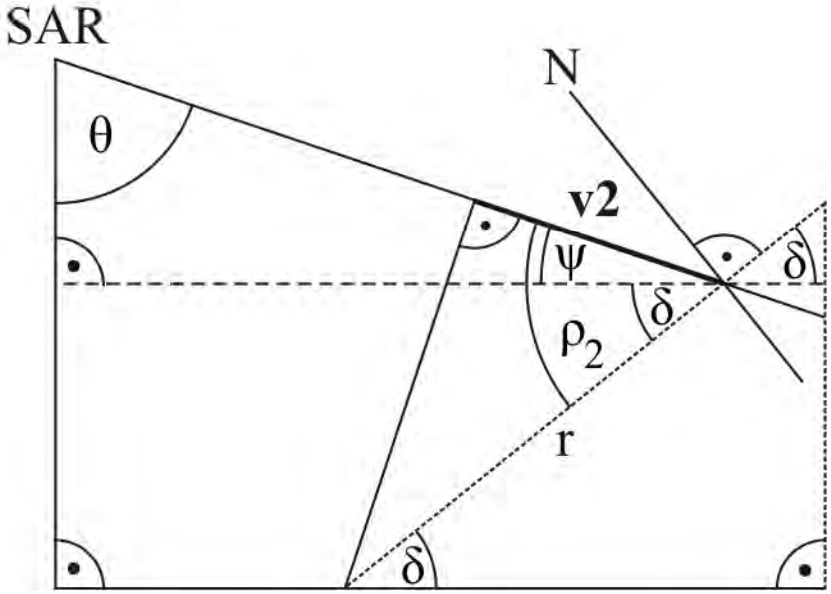
Vertical Measurable Percentage of Movement

Slope in SAR viewing direction

Slope towards SAR viewing direction



$m_{3D} = h \bullet v$

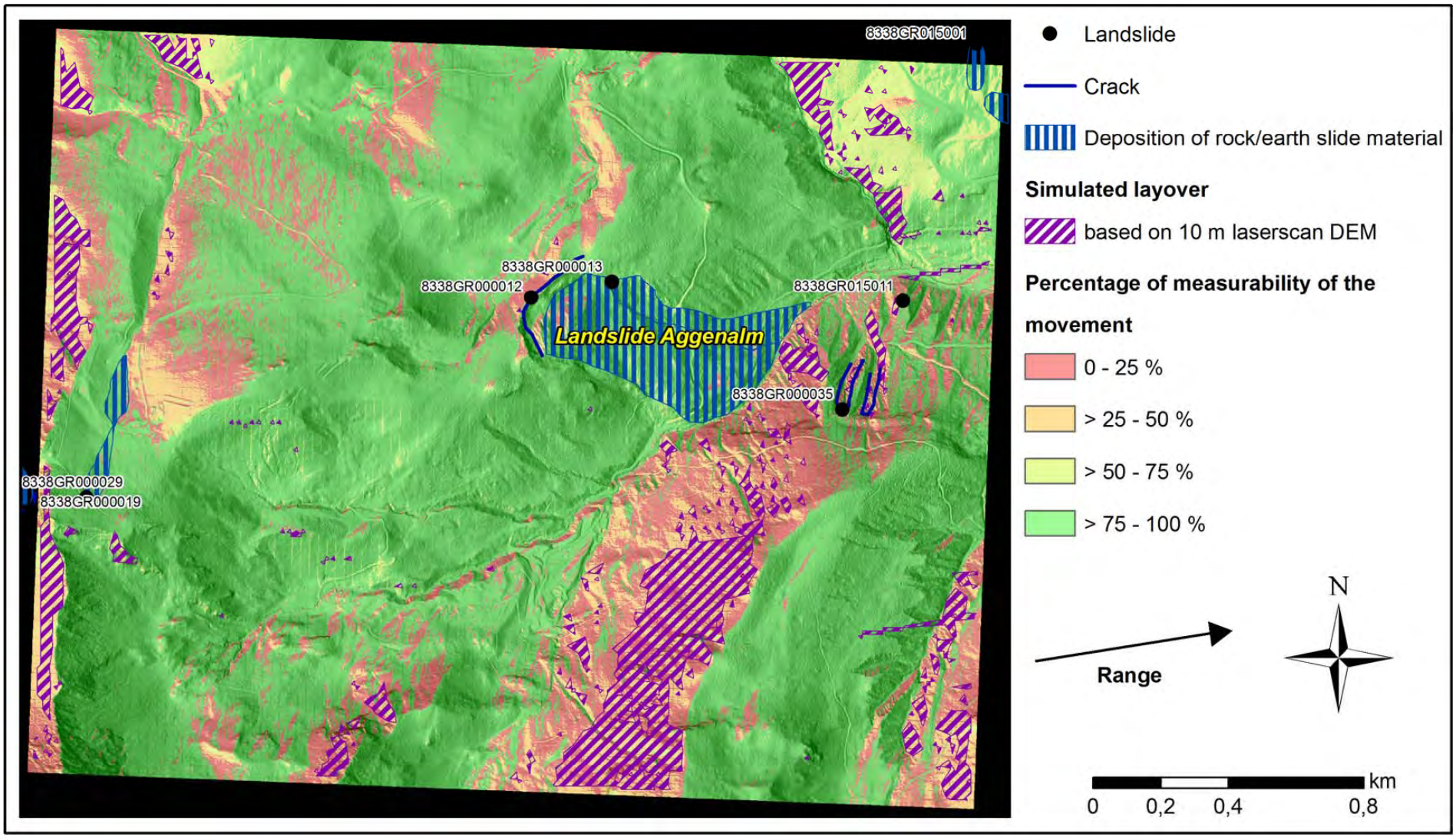


$v_1 = \cos(90° - \theta - \delta)$

$v_2 = \cos(90° - \theta + \delta)$

Plank et al. 2012

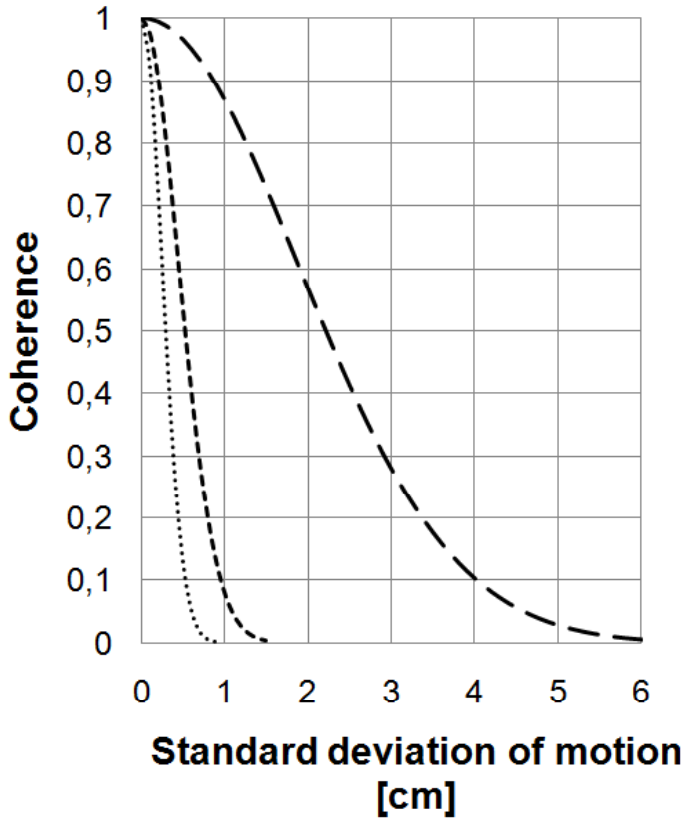
Layover-Shadow-Simulation & Measurable Percentage of Movement



Plank et al. 2012

Influence of the Land Cover

Coherence and displacement

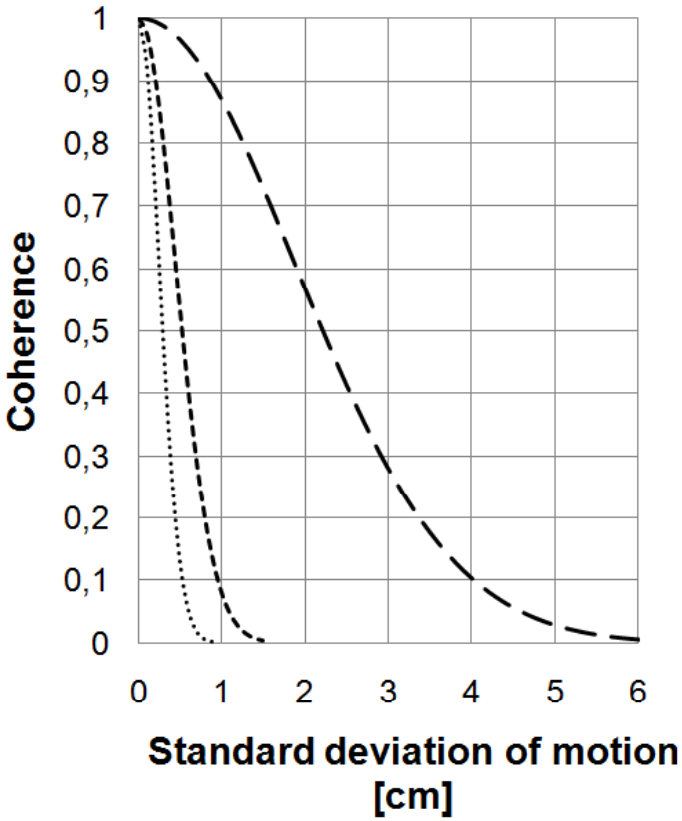


$$\gamma_{\Delta t} = \exp\left[-8(\pi/\lambda)^2 \left(\sigma^2_y (\sin\theta)^2 + \sigma^2_z (\cos\theta)^2\right)\right]$$

Modified after ZEBKER & VILLANSENOR (1992)

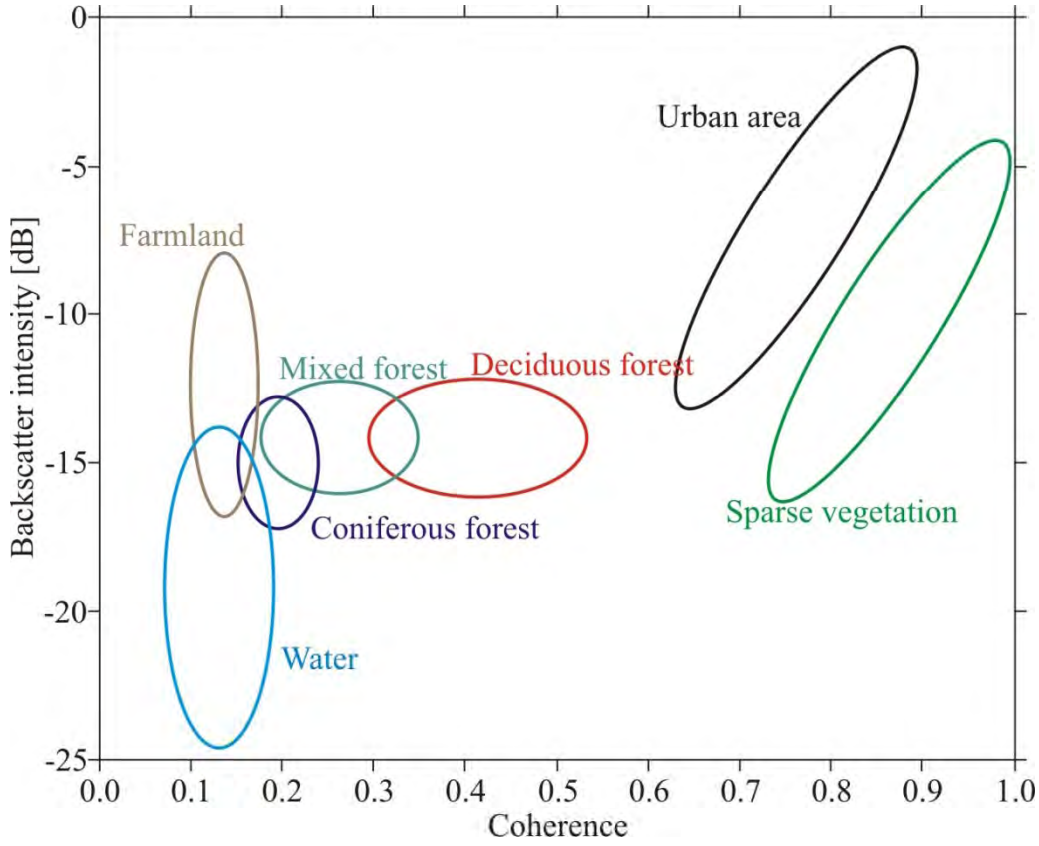
Influence of the Land Cover

Coherence and displacement



····· X-band ----- C-band — — L-band

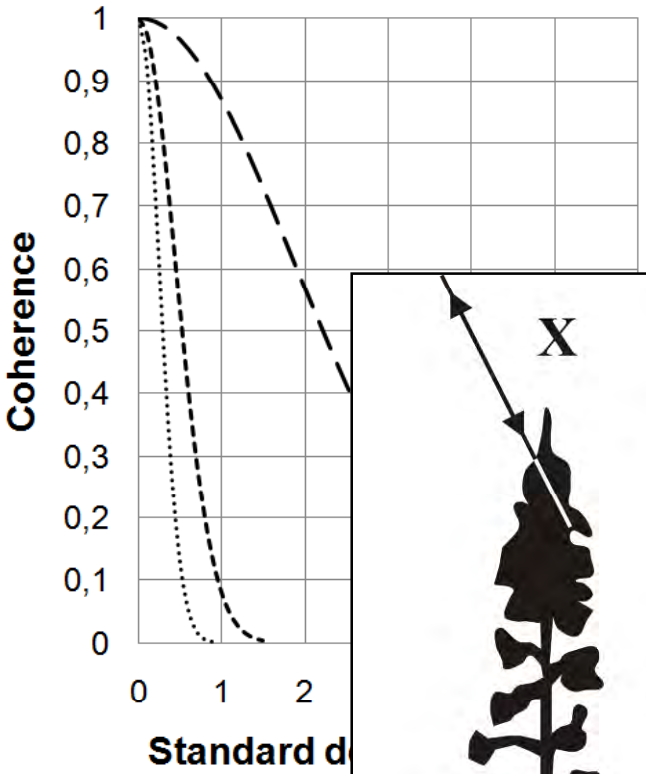
Modified after ZEBKER & VILLANSENOR (1992)



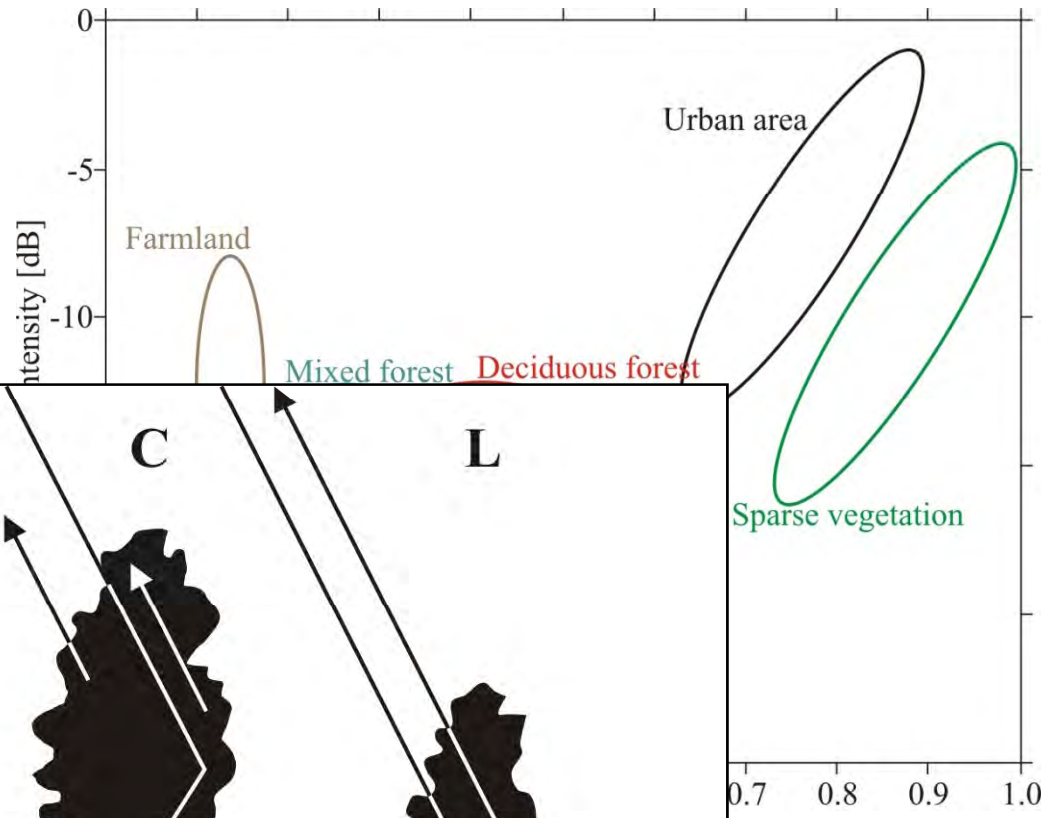
Modified after BORGEAUD & WEGMÜLLER (1997)

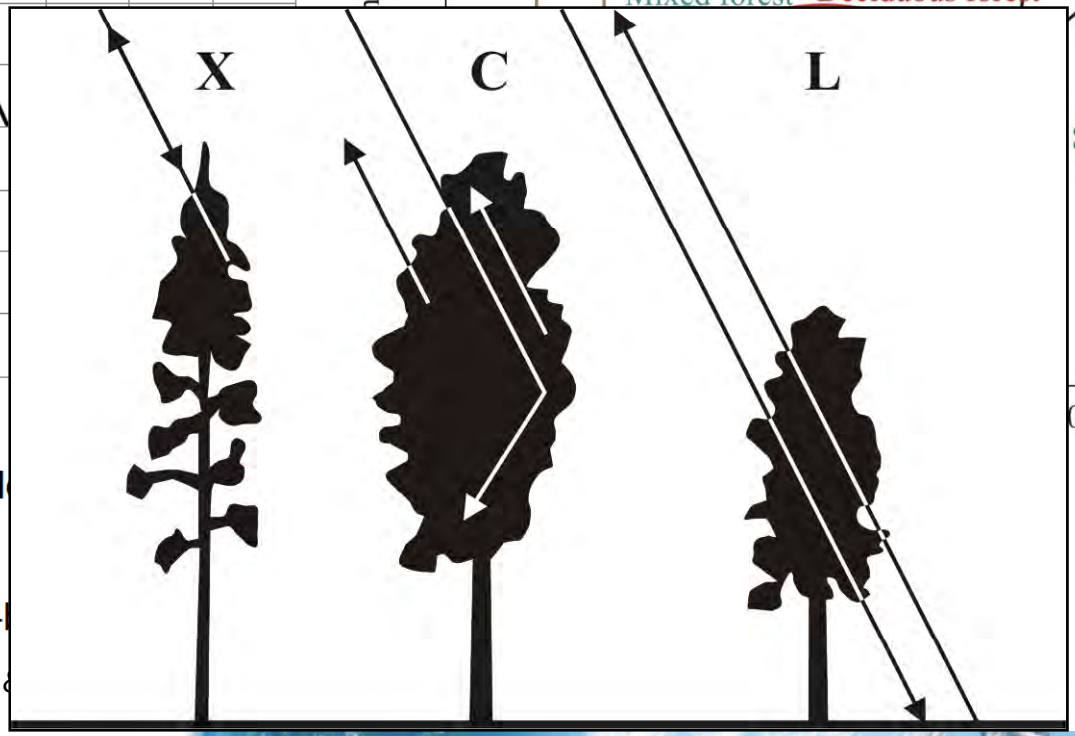
Influence of the Land Cover

Coherence and displacement



Modified after ZEBKER &



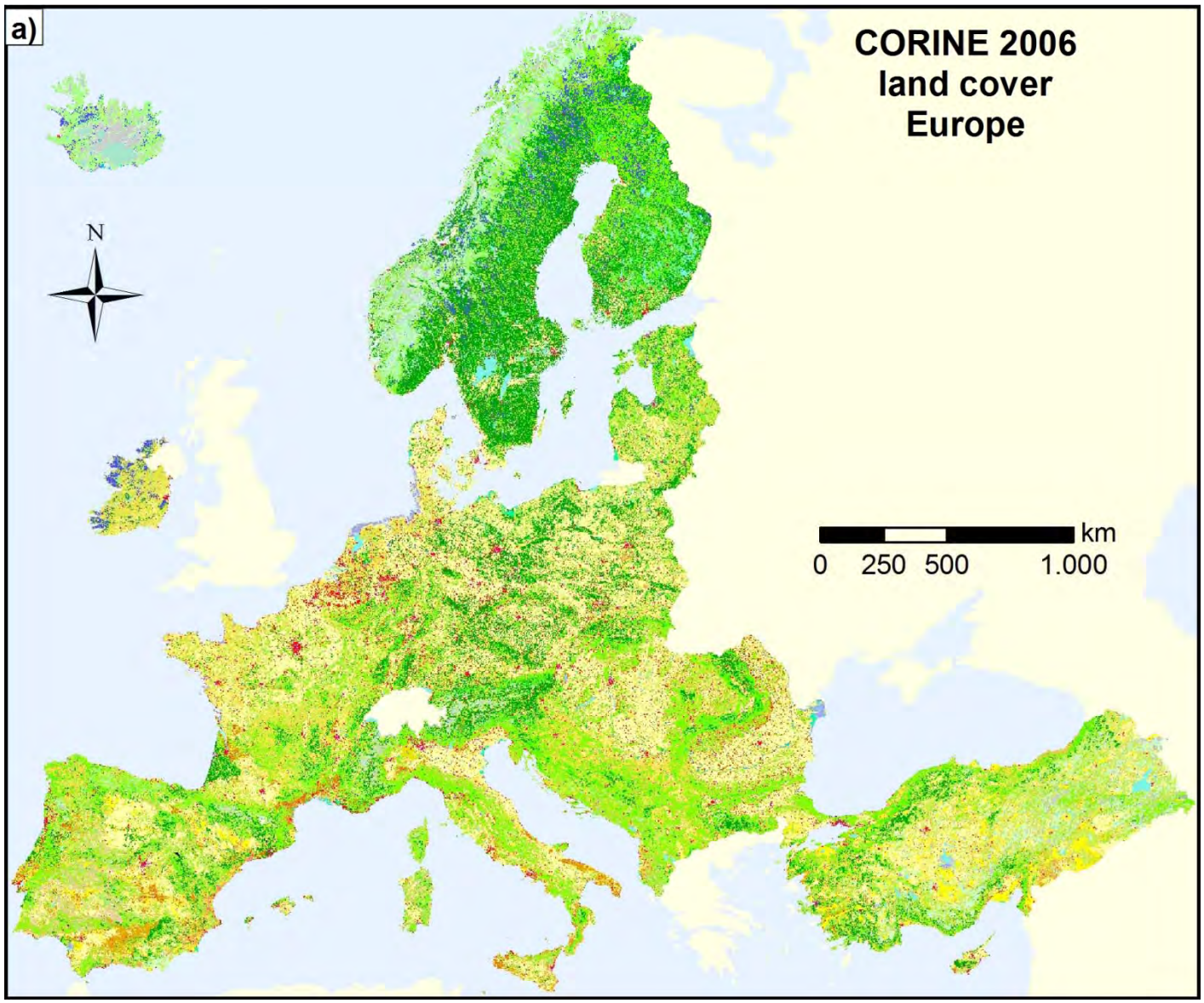


Modified after BARBIERI & LICHTENEGGER (2005)

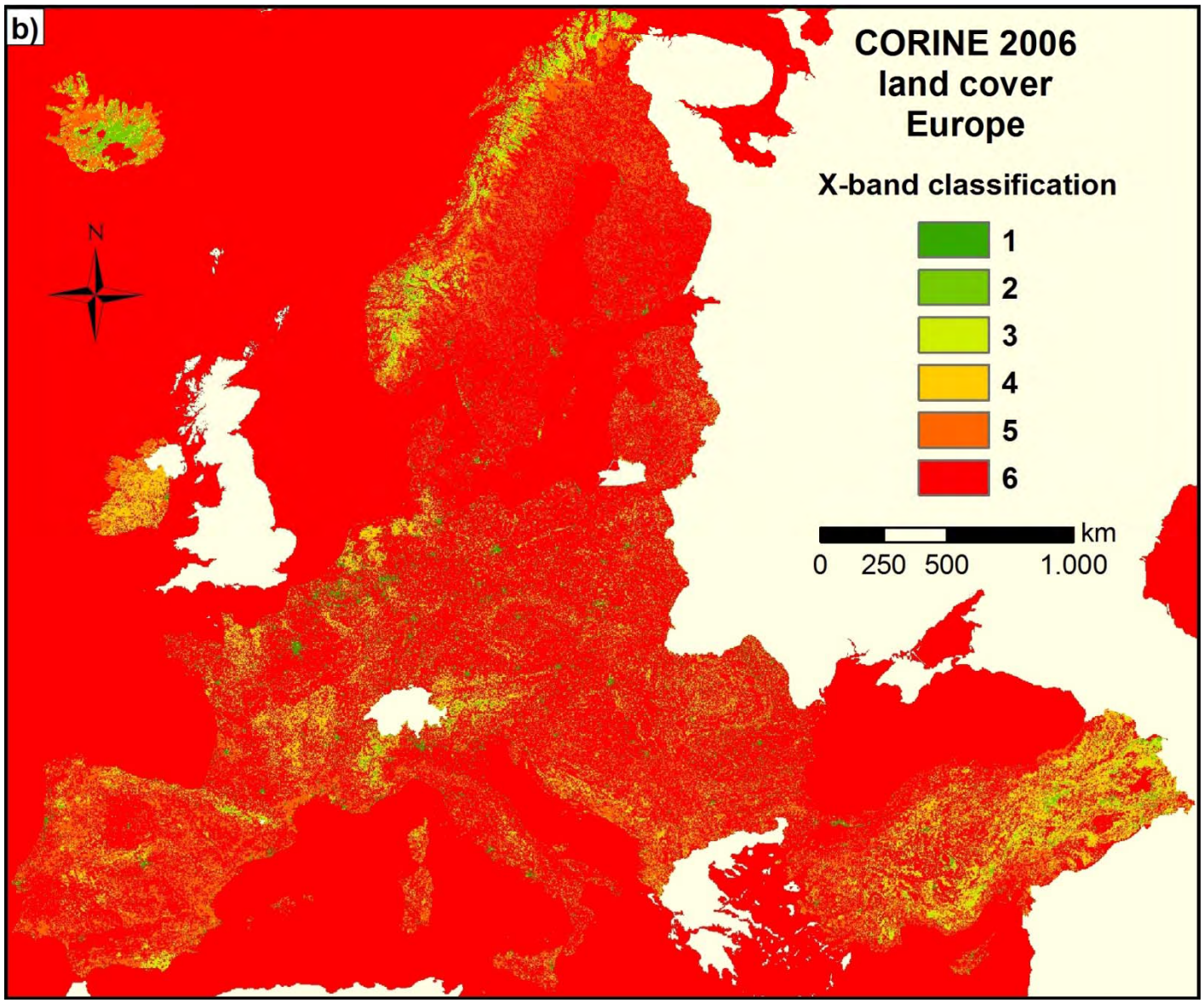
Influence of the Land Cover

Class	X-band (3.1 cm)	C-band (5.6 cm)	L-band (23.6 cm)
Continuous urban fabric	1	1	1
Discontinuous urban fabric & Infrastructure	1	1	2
Rocks	2	1	1
Alluvium	3	2	2
Pasture	4	3	2
Forest	6	5	3
Agriculture	6	6	6
Water bodies	6	6	6
Fast changing areas	6	6	6

Influence of the Land Cover



Influence of the Land Cover



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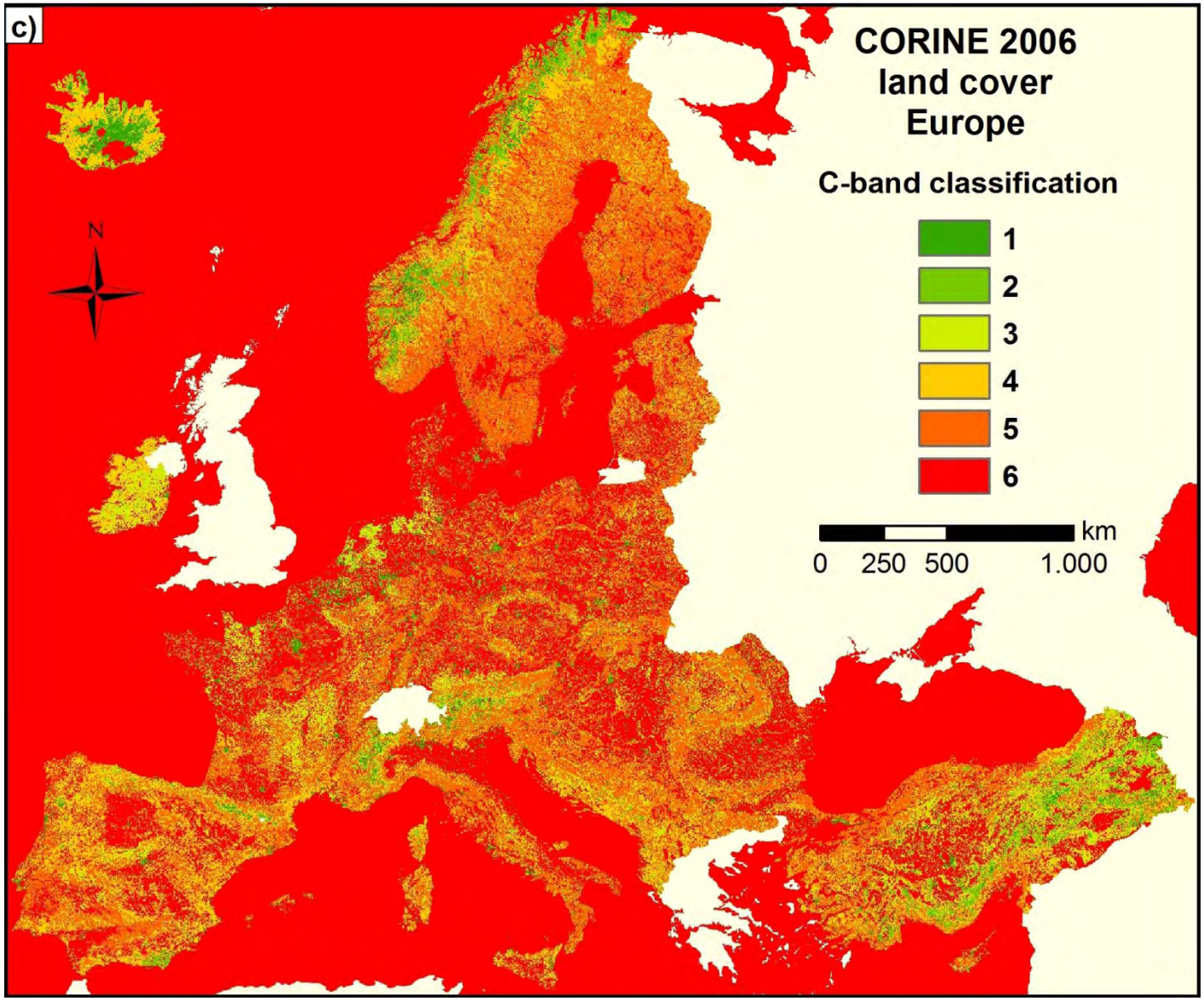
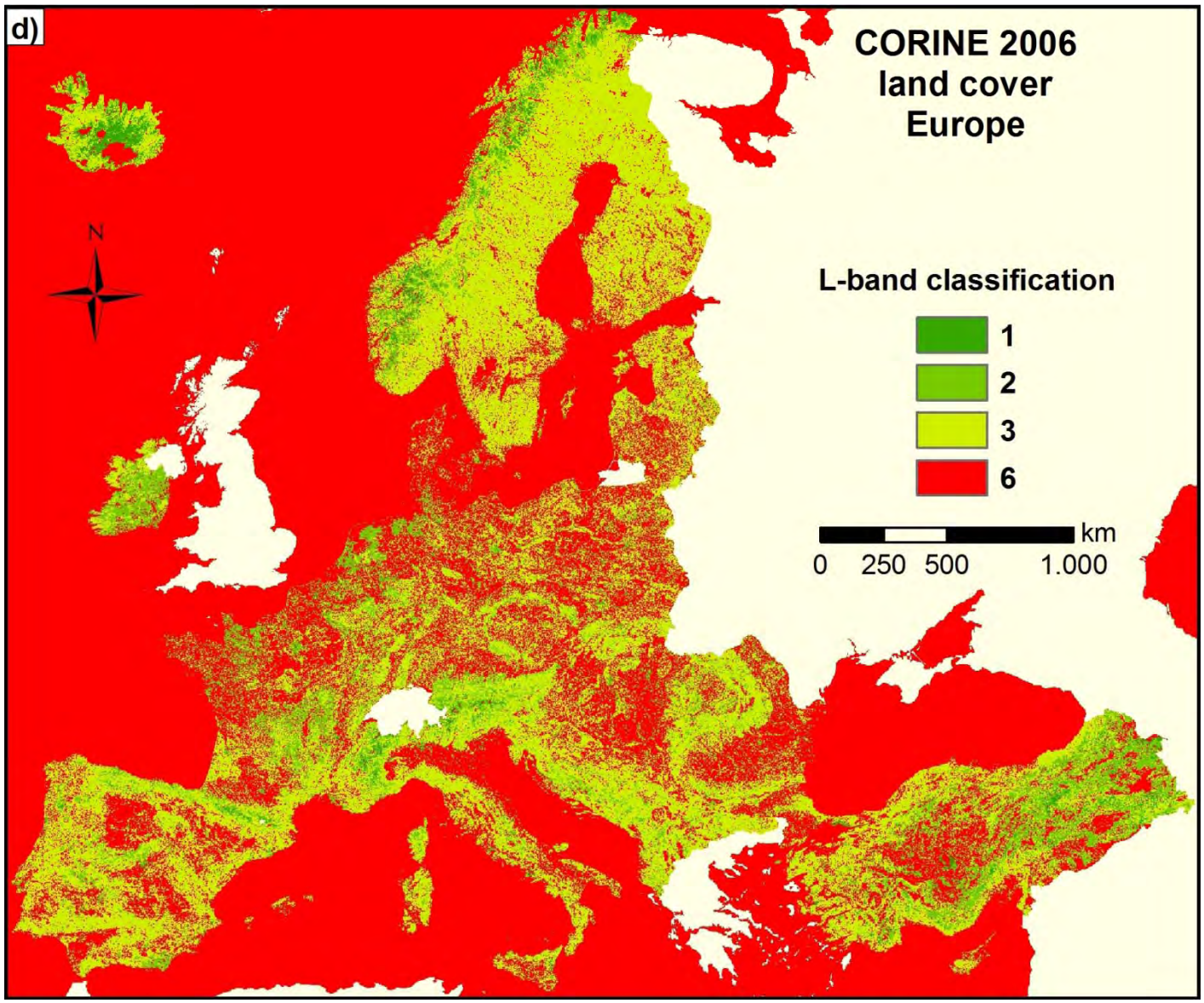


Influence of the Land Cover



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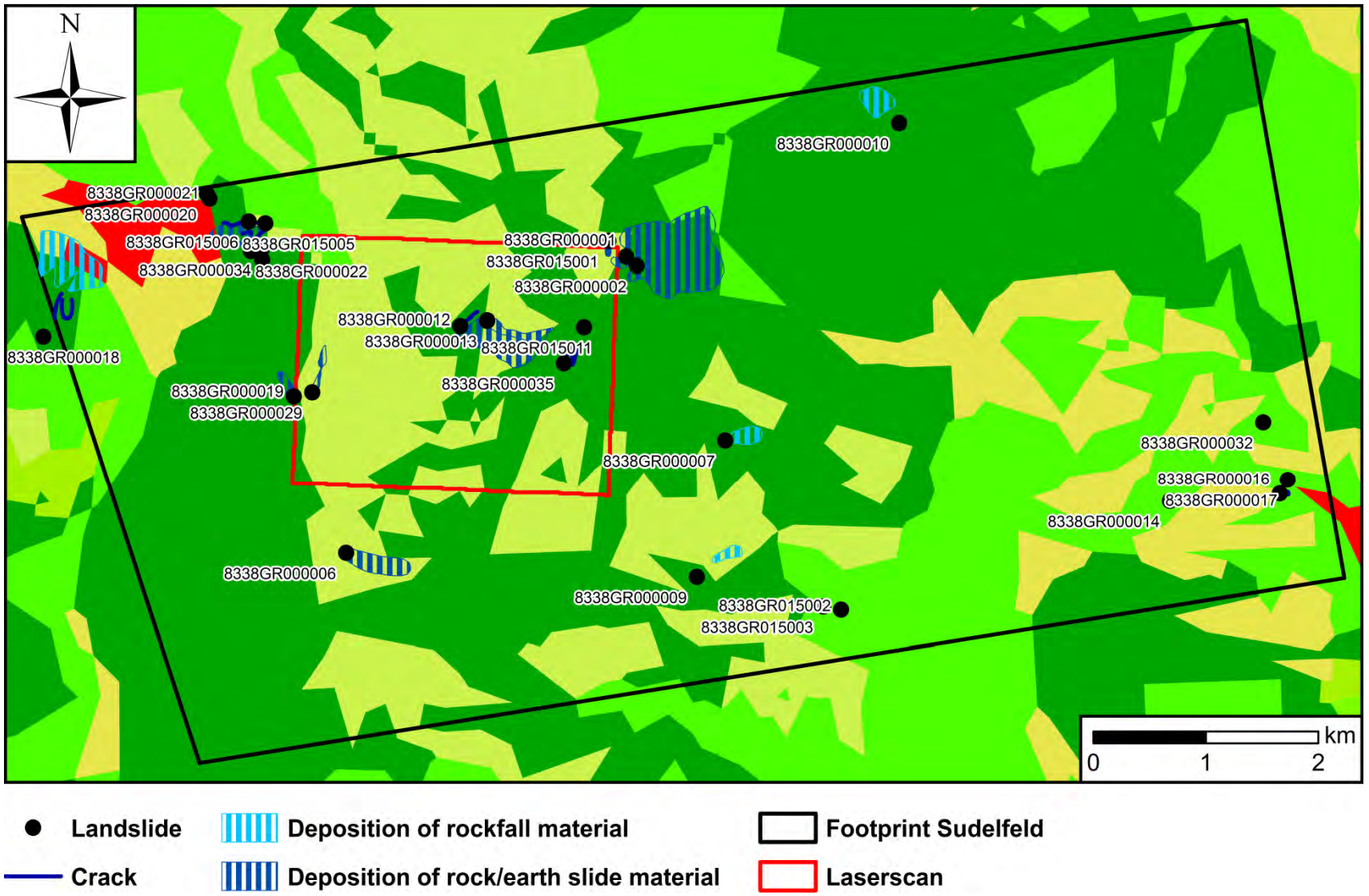

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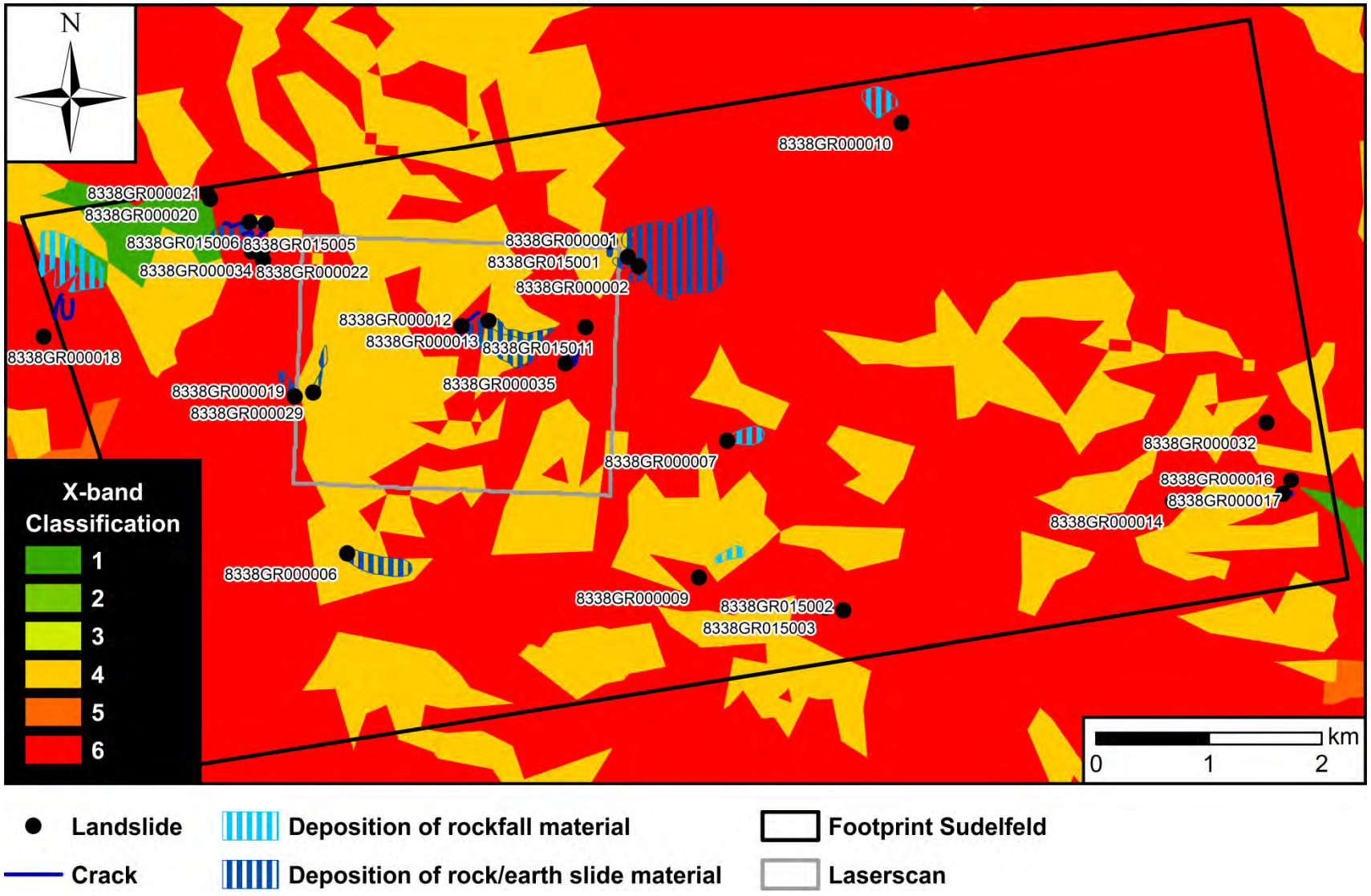

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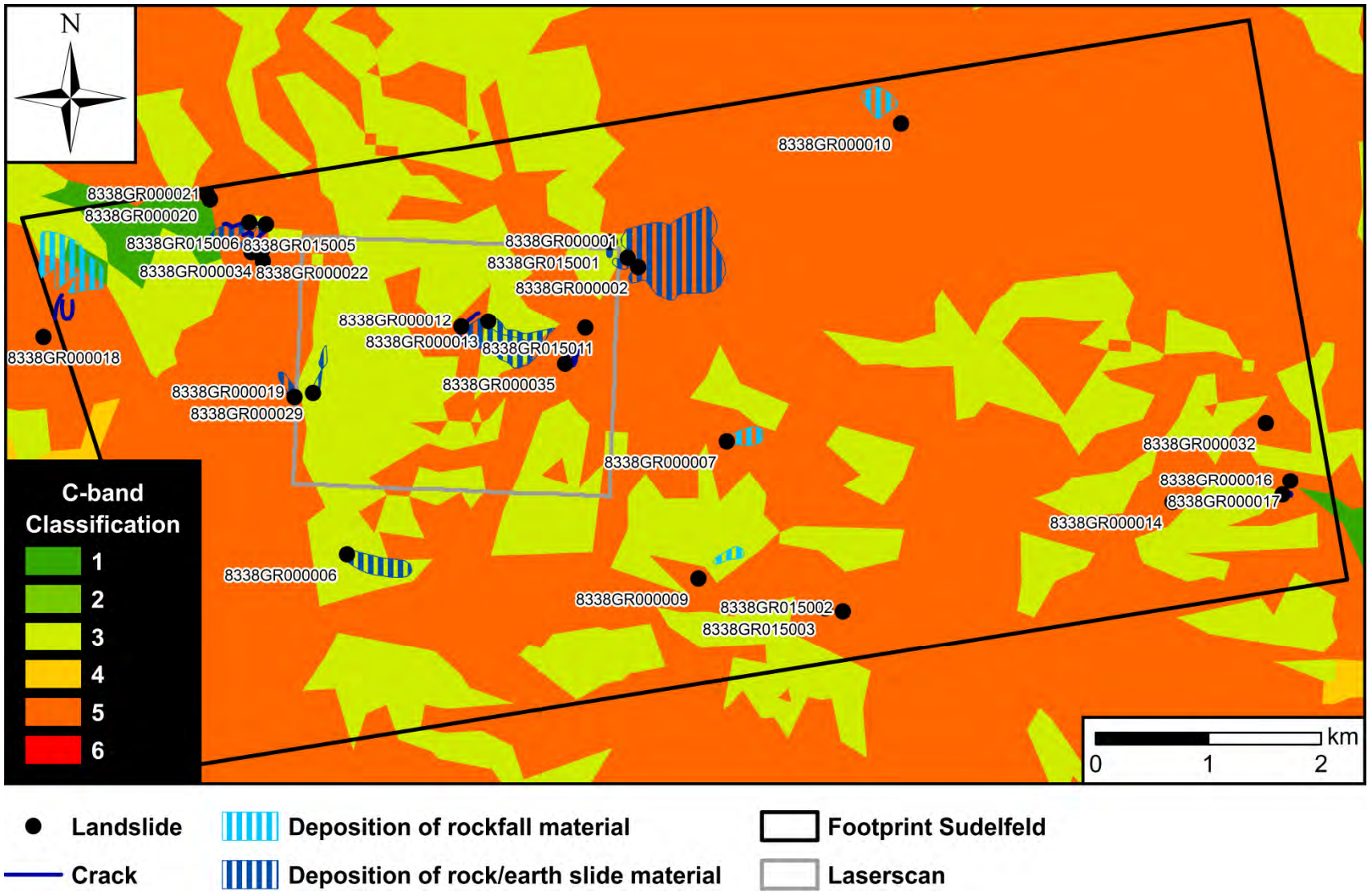

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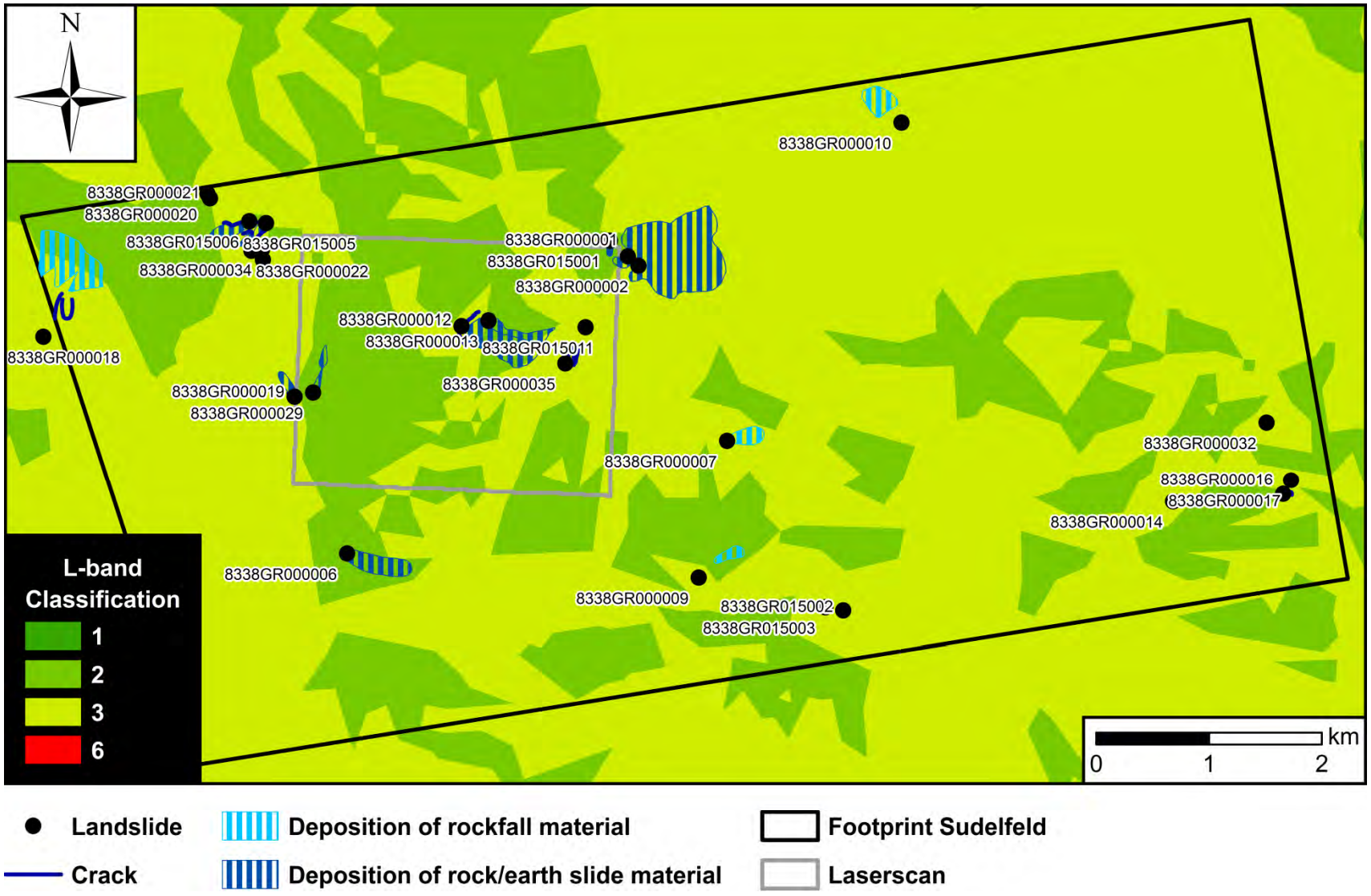


Geometry & Land Cover

Landslides	Process of Mass movement	Layover (L), Shadow (S)	Measurable Percentage of Movement [%]	Land Cover			Applicability of D-InSAR
				X-band	C-band	L-band	
…00001	Landslide	-	74.78	6	5	3	3
…00002	Landslide	-	91.49	6	5	3	3
…00007	Fall	-	-	6	5	3	6
…00012	Landslide	-	93.85	4	3	2	1
…00022	Landslide	L (100%)	45.25	6	5	3	5
…00029	Landslide	-	92.57	4	3	2	1
…00032	Rock Fall	-	-	6	5	3	6
…00034	Landslide	-	45,66	6	5	3	3
…150015	Landslide	L (70 %)	56.44	4 6	3 5	2 (35 %) 3 (65 %)	4

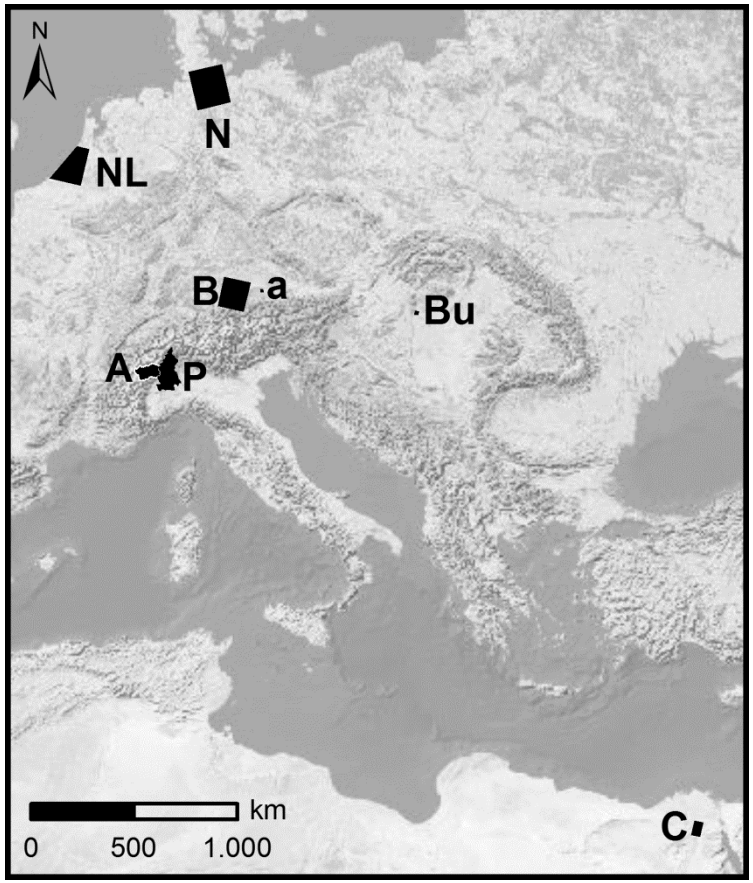
Persistent Scatterer Interferometry

- Stack: at least 15 to 50 SAR acquisitions required
- PS: Scatterer of long-term high coherence
- e.g.: Buildings, Walls, Rocks, etc.
- PSI: Network of PS
- Advantage: Avoidance of the “coherence problem” (D-InSAR)

→ Prerequisite: Number of PS within the test site has to be high enough!

- Goal: Development and investigation of methods to enable objective pre-survey suitability analysis – Pre-processing

Suitability of PSI



Test site	Satellite
Aschau am Inn	TerraSAR-X
Budapest	TerraSAR-X
Aosta Valley	Radarsat-1
Ivrea	Radarsat-1
Omegna	Radarsat-1
Varallo	Radarsat-1
Domodossola	Radarsat-1
Novara	Radarsat-1
Cairo	ENVISAT
Bavaria	ERS-1 & 2
Netherlands	ERS-1 & 2
North Germany	ERS-1 & 2

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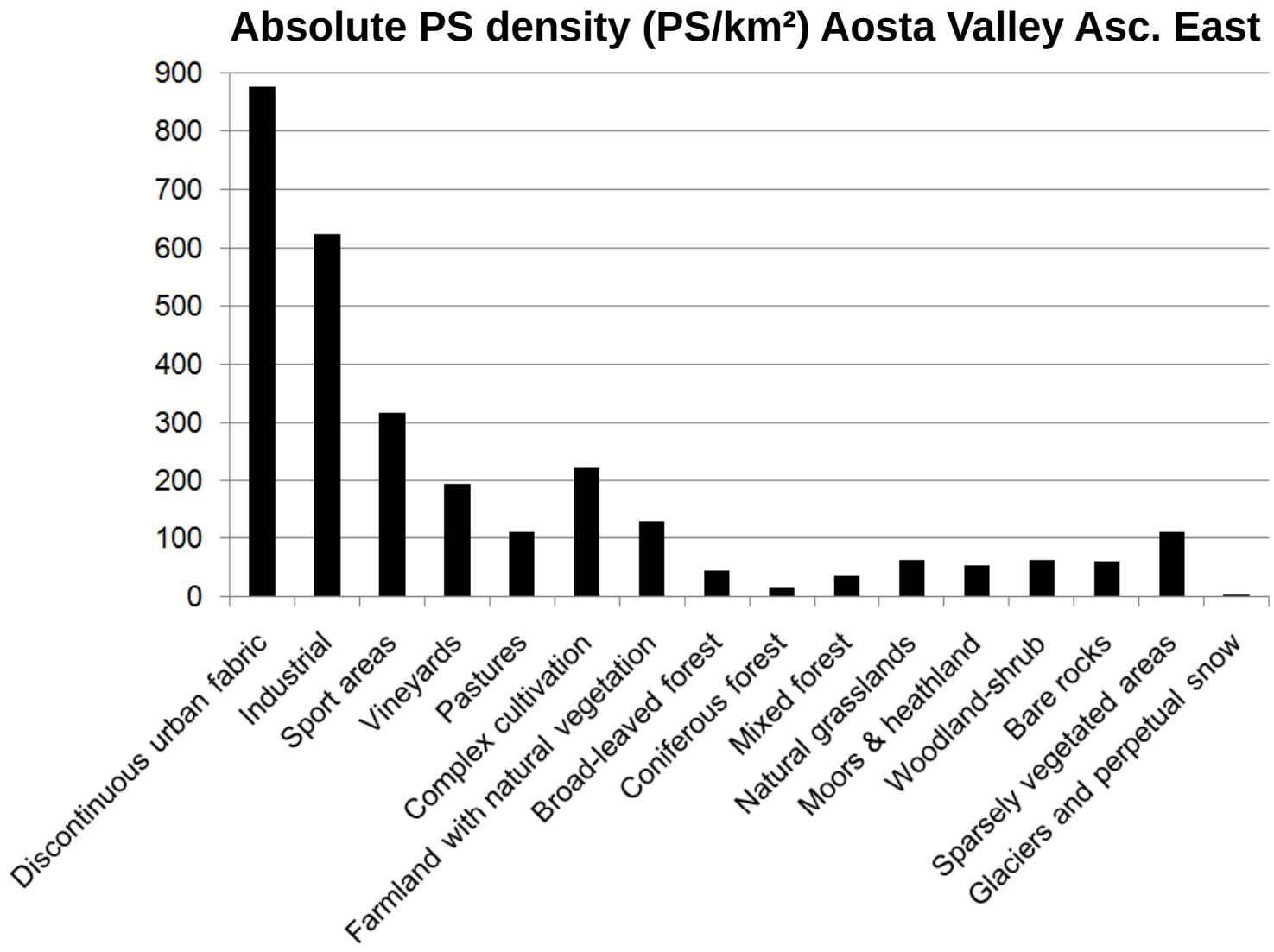
Estimation of the PS density using land cover data – Method



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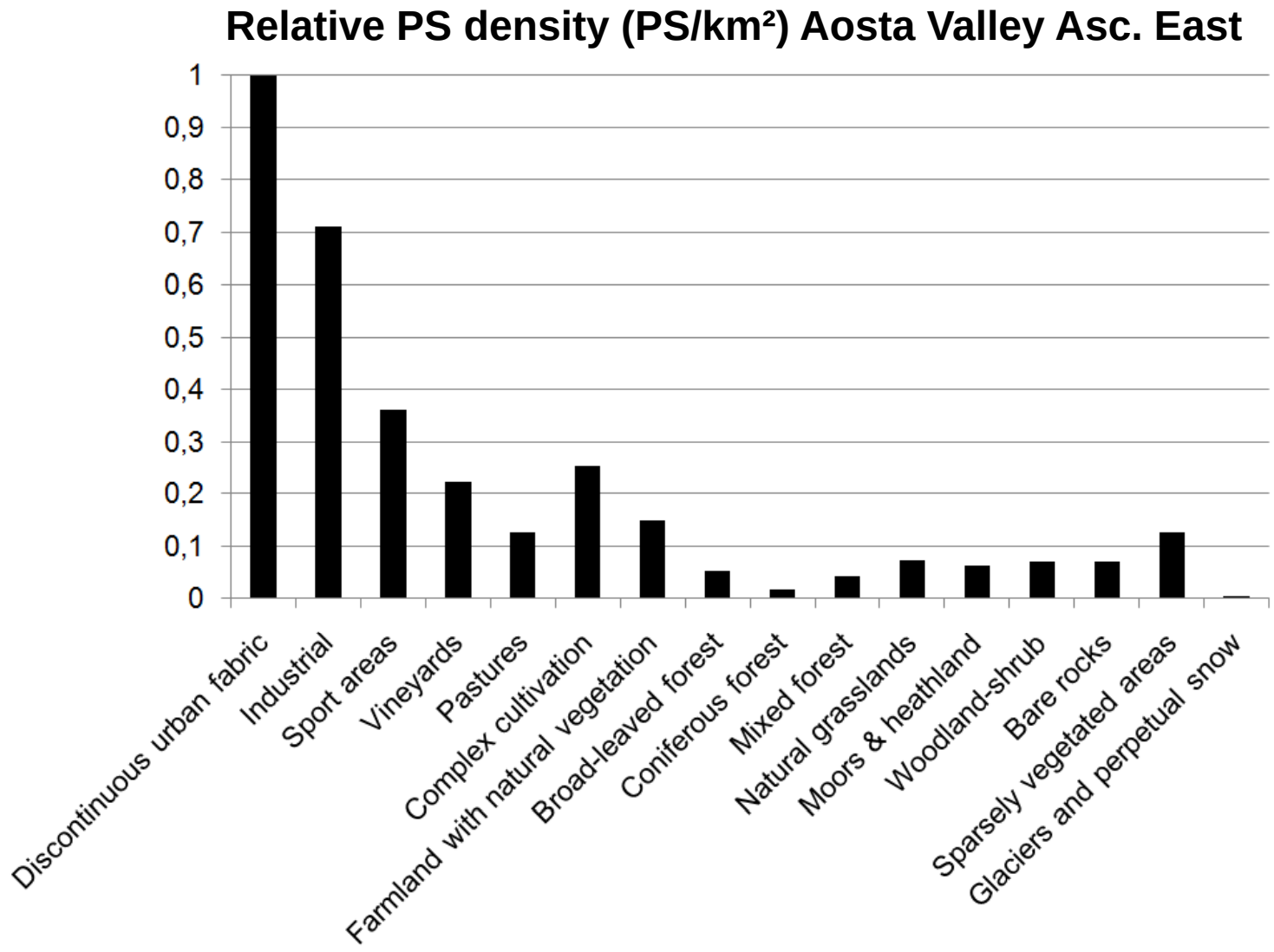
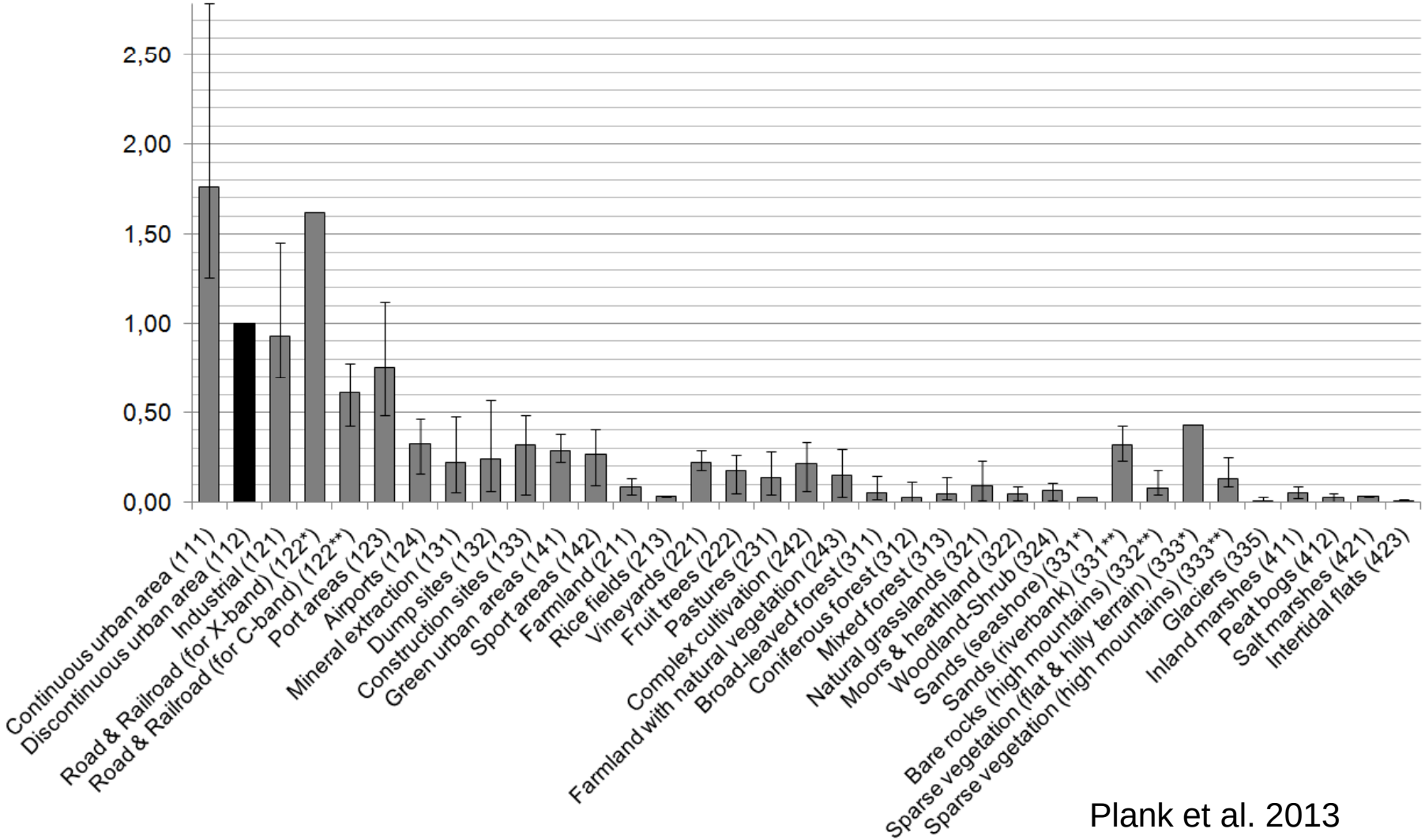


Estimation of the PS density using land cover data – Result

CORINE 2006 relative PS density



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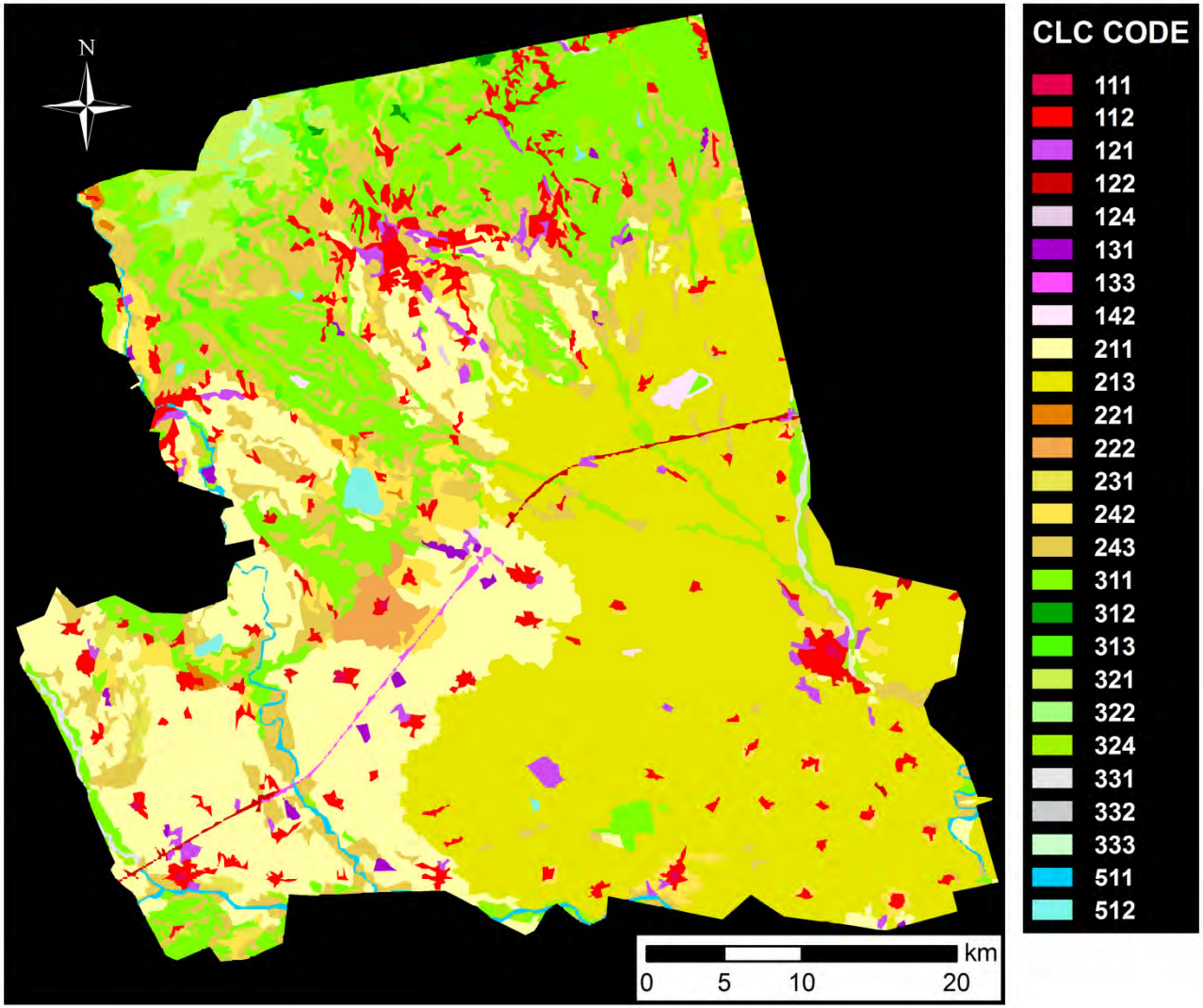
Estimation of the PS density using land cover data – Validation

CORINE 2006
Land Cover

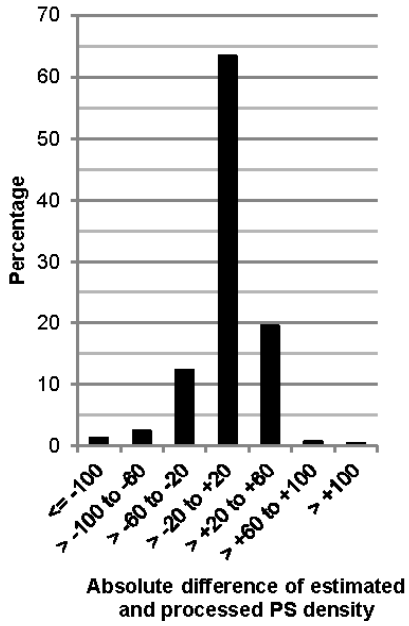
Application to
Ivrea
(Not used in
the calibration)

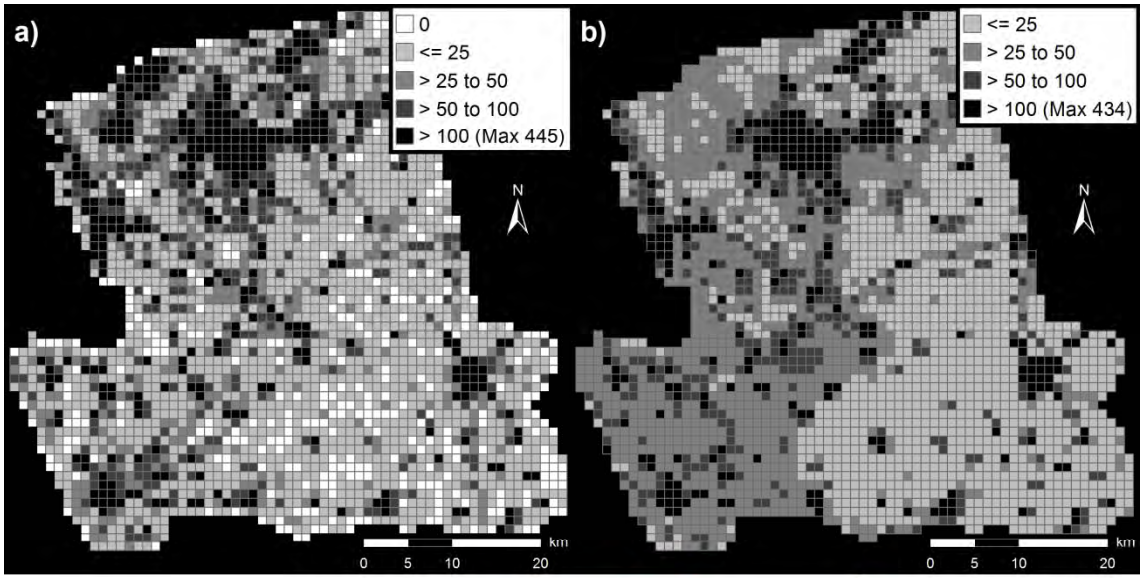


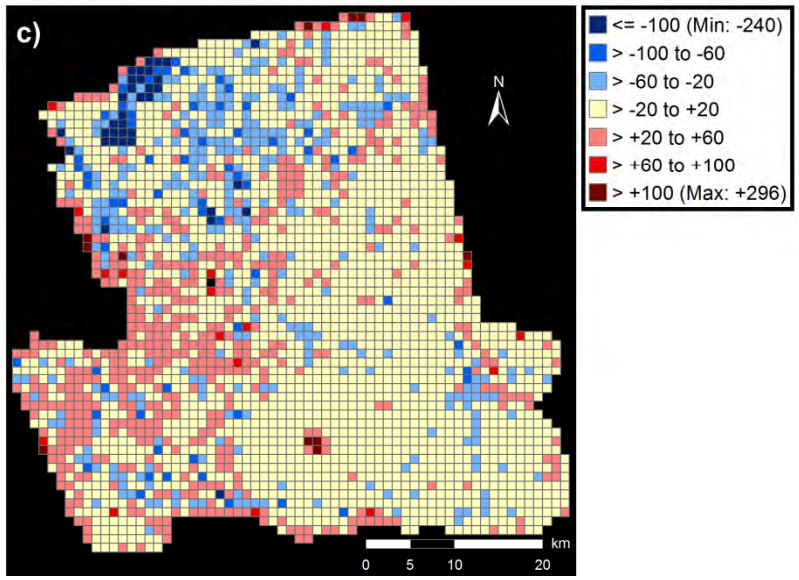
DLR

Estimation of the PS density using land cover data – Validation

Difference of processed (a) and estimated (b) PS density







Plank et al. 2013

Conclusions

- Imaging geometry & topographic relief
  - Layover-Shadow-Simulation
  - Calculation of the measurable percentage of movement

- Influence of Land Cover (SAR wavelength, temporal de-correlation): Classification of the influence of the Land Cover on D-InSAR

- High number of PS within the test site required:
  → Estimation of the PS density prior to SAR acquisition using free available geo data:
  Land Cover data

Conclusions

- Size of the landslide (spatial resolution of the SAR, Multi-looking, etc.)
- Repeat Orbit & velocity of the landslide

$$v \leq \lambda / 2$$

- Type of movement of the landslide

Conclusions

- Type of movement:
  - Fall
  - Topple
  - Slide (Rotation, Translation)
  - Flow (Rock flow, Debris flow)
  - Spread
  - Complex

- Velocity: D-InSAR GB D-InSAR
  extreme slow (mm/a), very slow (1m/a), slow (13m/Mon), moderate (1,8m/h), fast (3m/min), very fast (5m/s), extreme fast (>5m/s)

References

- Plank, S., Singer, J., Minet, C. & Thuro, K. (2012): Pre-survey suitability evaluation of the differential synthetic aperture radar interferometry method for landslide monitoring. International Journal of Remote Sensing, 33:20, 6623-6637.

- Plank, S., Singer, J. & Thuro, K. (2013): Assessment of number and distribution of persistent scatterers prior to radar acquisition using open access land cover and topographical data. ISPRS Journal of Photogrammetry and Remote Sensing, 85, 132-147.

Thank you!