Positioning & Remote Sensing

LiDAR/Scan/ϕgram

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Course outline

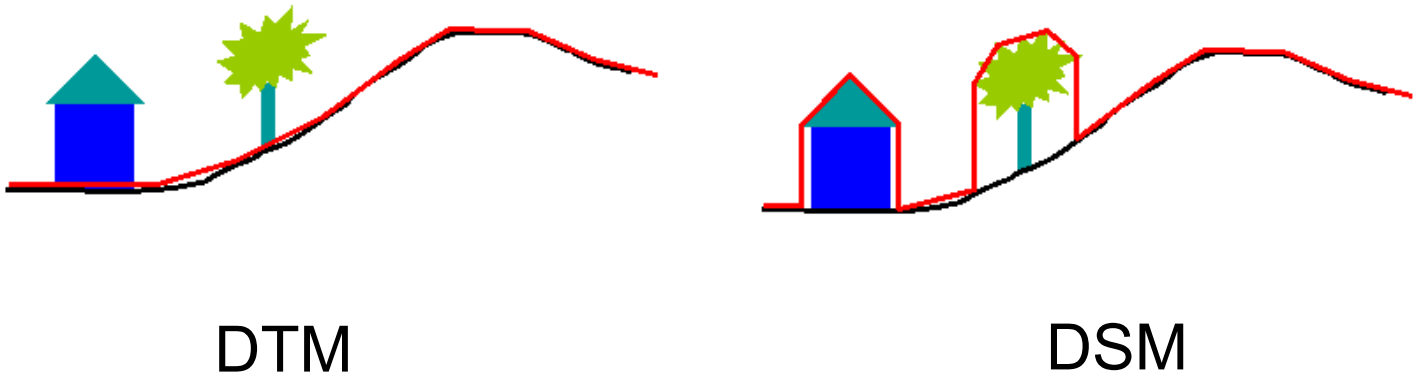
- Principles of topography
  - DEM/DTM/DSM
  - Applications
- Direct measurement (laser rangefinding)
  - by flight time (LiDAR)
  - by phase shift (Scan)
- Indirect measurement (photogrammetry)
  - principles
  - camera obscura sensor (near field, aerial)
  - pushbroom sensor (satellite)
- Visualization

Principles of topography

- Measurement and representation of altitudes
- Scattered measurements: 3D point cloud
- Exhaustive (or interpolated sparse) measurements: matrix (raster)
- Method based on desired resolution/accuracy
- Always performed within a reference frame with an origin for altitudes.

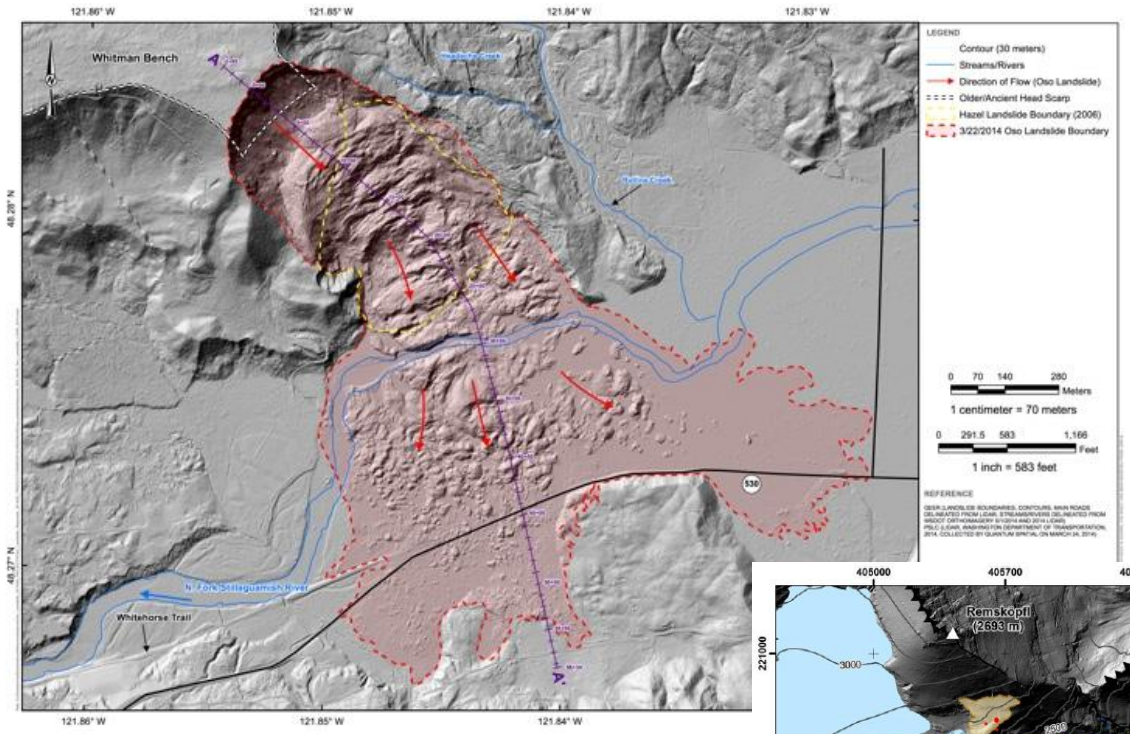
Digital models

- Digital Elevation Model: all
- Digital Terrain Model: ground DEM
- Digital Surface Model: max(DEM)



DTM DSM

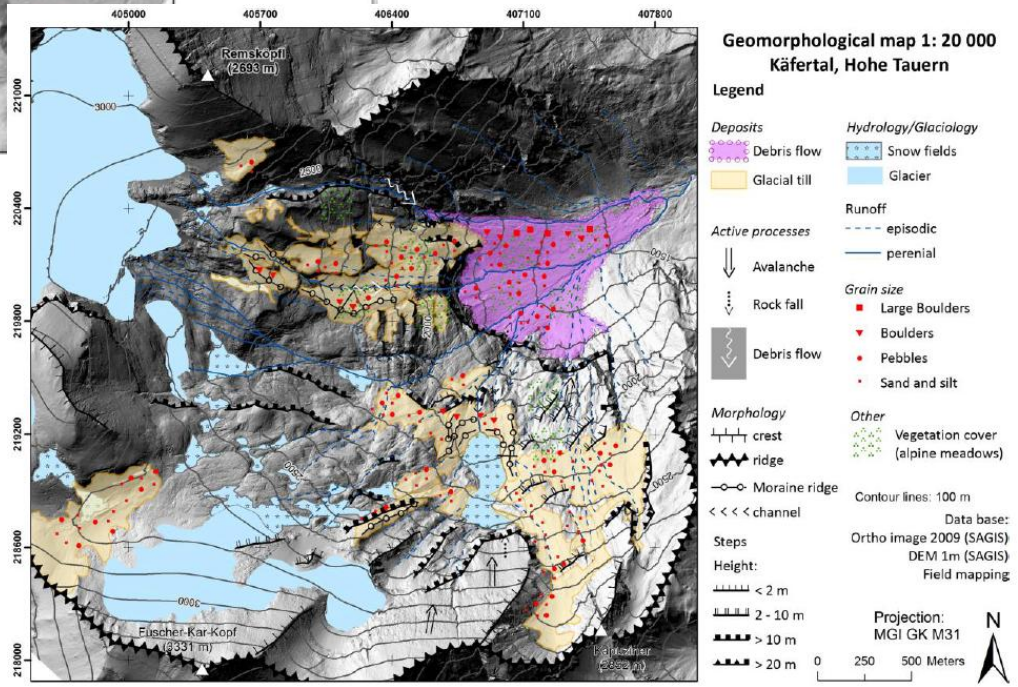
Applications - Mapping



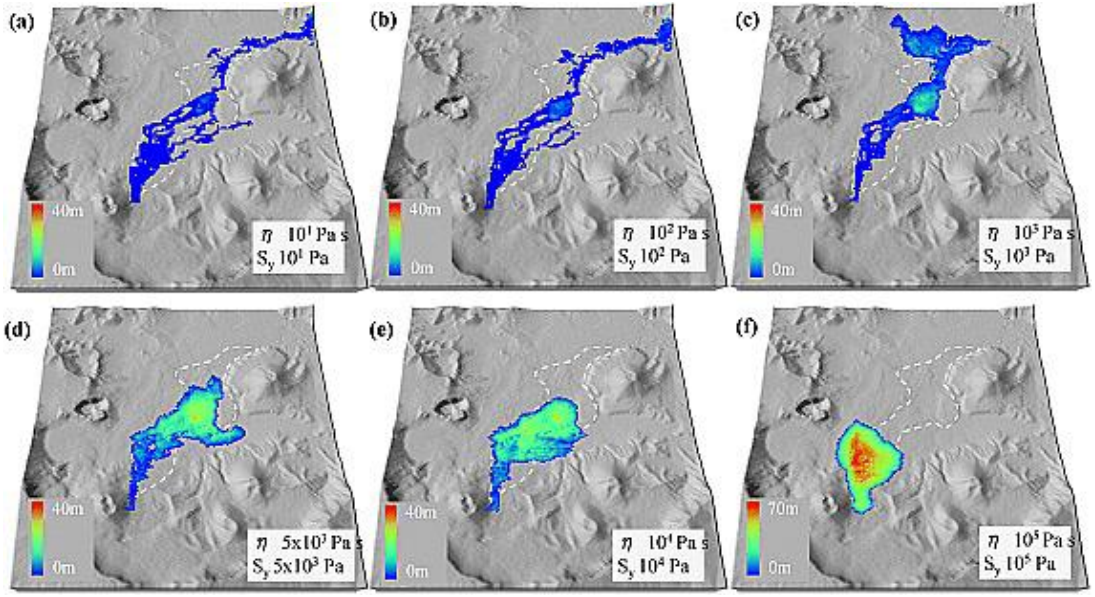
Oso landslide (2014)

AWARE notes
Mapping of process-related landforms to document past/present events and predict future behavior

Käfertal glacial valley

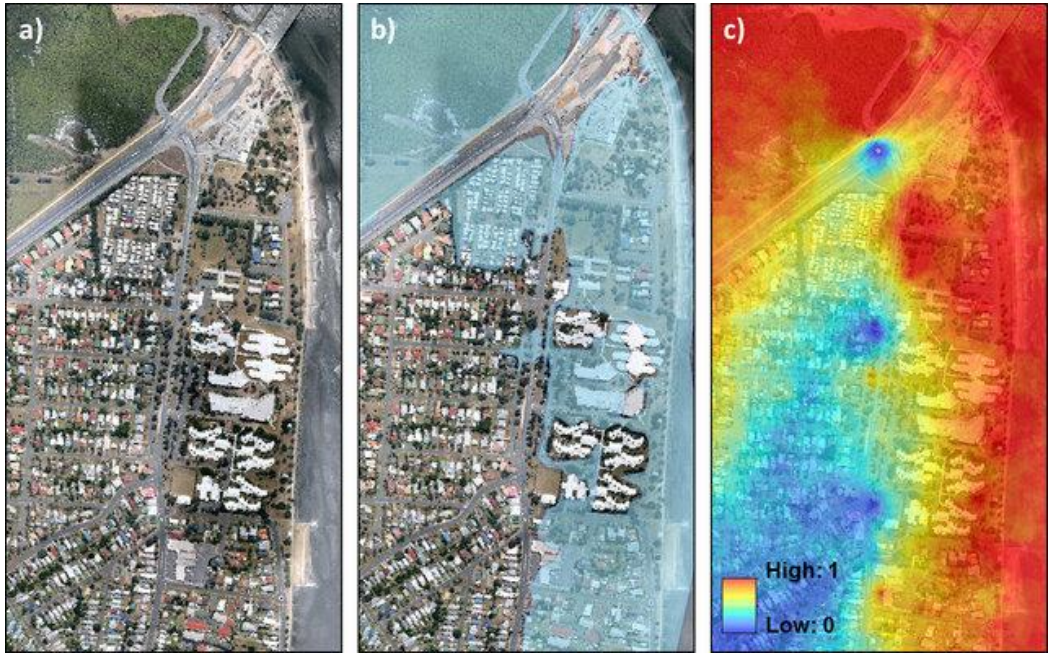


Applications - Modeling



Modeling lava flow from the Okmok volcano

AWARE notes
High(resolution DEMs to constrain models sensitive to topography. Left: lava flow extent and thickness vary acording to viscosity η. For low η values, flow trajectory is very sensistive to topography (similar to water).



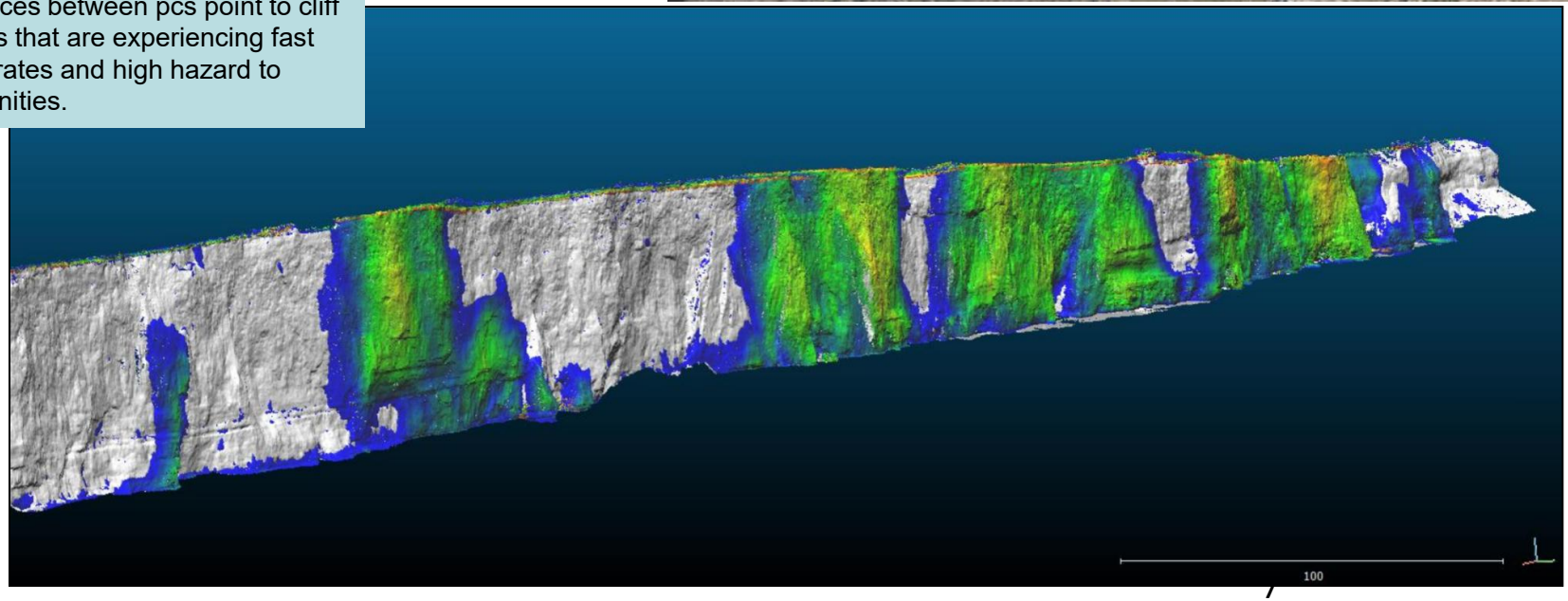
Storm surge flood model (b) and probability of occurrence (c)

Application – Coast migration

- Retreat rate 0.1-0.5 m/year
- UAV Photogrammetry

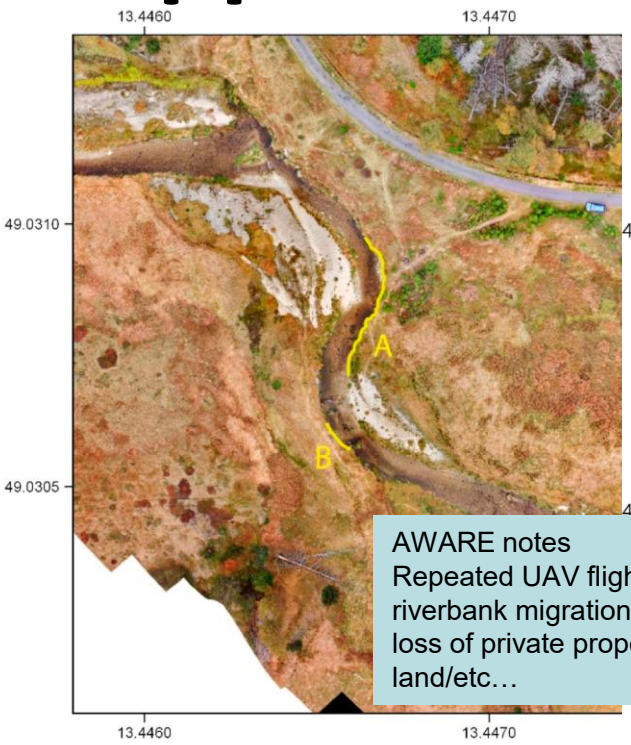


AWARE notes
Repeated UAV flights are used to build dense point clouds (pcs) and differences between pcs point to cliff sections that are experiencing fast retreat rates and high hazard to communities.

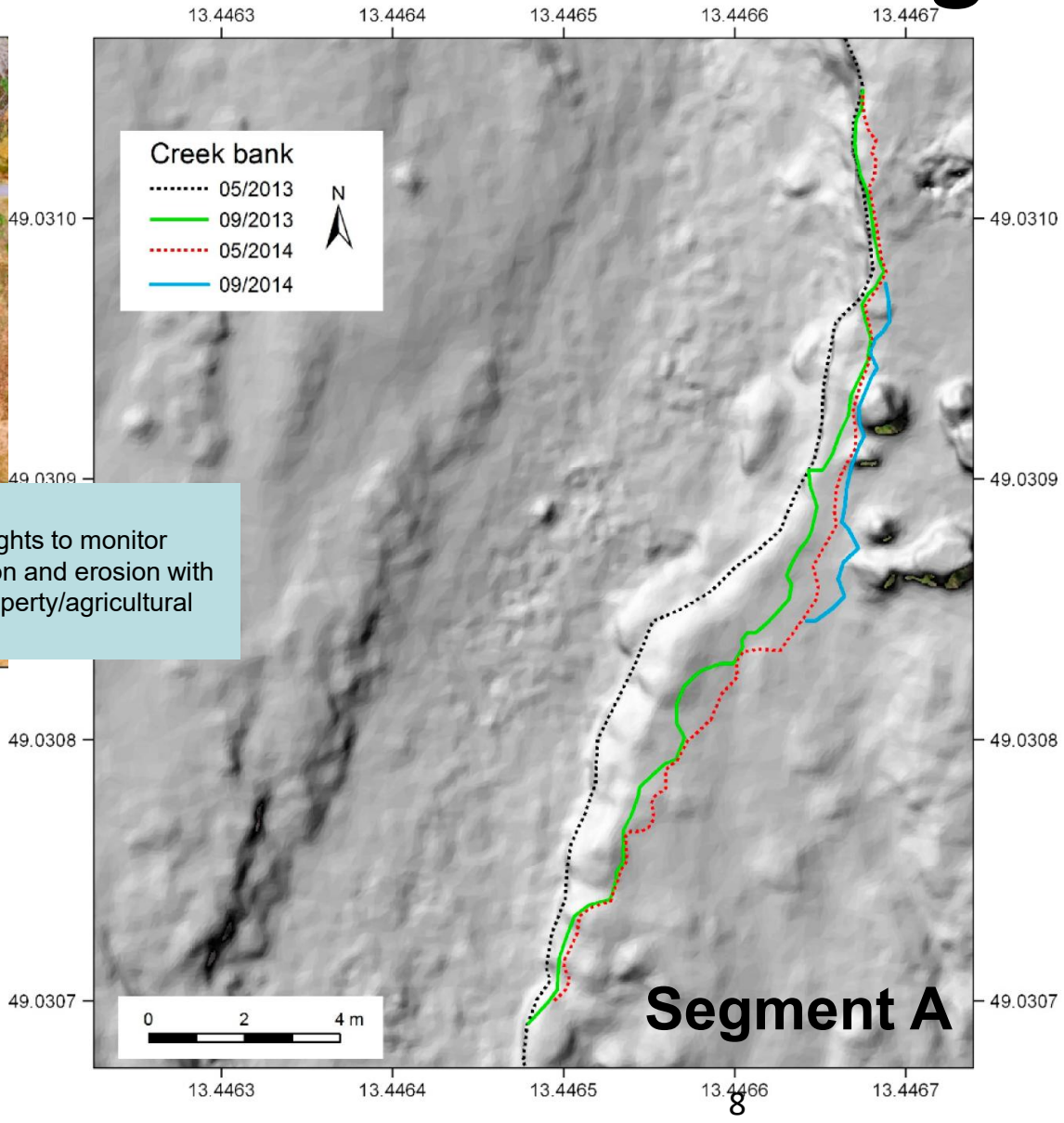


Ricochet Project (ANR): Azur Drones, University of Caen, BRGM…

Application - Erosion Monitoring



AWARE notes
Repeated UAV flights to monitor riverbank migration and erosion with loss of private property/agricultural land/etc…



- Orthophoto + DEM by photogrammetry
- Monitoring of riverbank mobility over 16 months

Mirijovsky & Langhammer, 2015

Course outline

- Principles of topography
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  - principles
  - camera obscura sensor (near field, aerial)
  - pushbroom sensor (satellite)
- Visualization

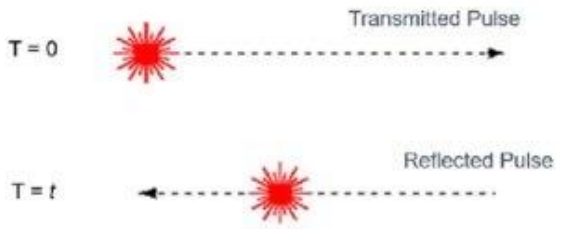
Laser rangefinding

- Direct measurement by laser beam
- 4 measurement parameters: angles V and H, time, intensity
- (RGB colorization by photography)

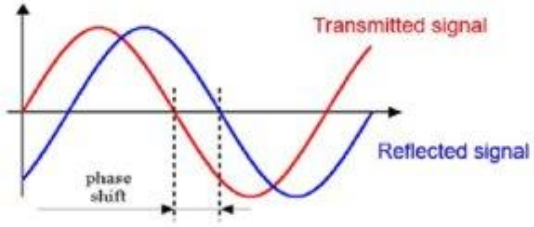
- Flight time measurement » LiDAR (Light Detection and Ranging)
- Phase shift measurement » Scan (laser scanning)
- Intensity depends on distance, angle of incidence, color, and target roughness

LiDAR vs. Scan

	LiDAR	Scan
Distance	Flight time	Phase shift
Signal	Pulse	Continuous
Sampling speed	100s-1000s pts/s	100000s pts/s
Maximum range.	few km	100s m
Returns	Multiple	Unique



Time-of-flight



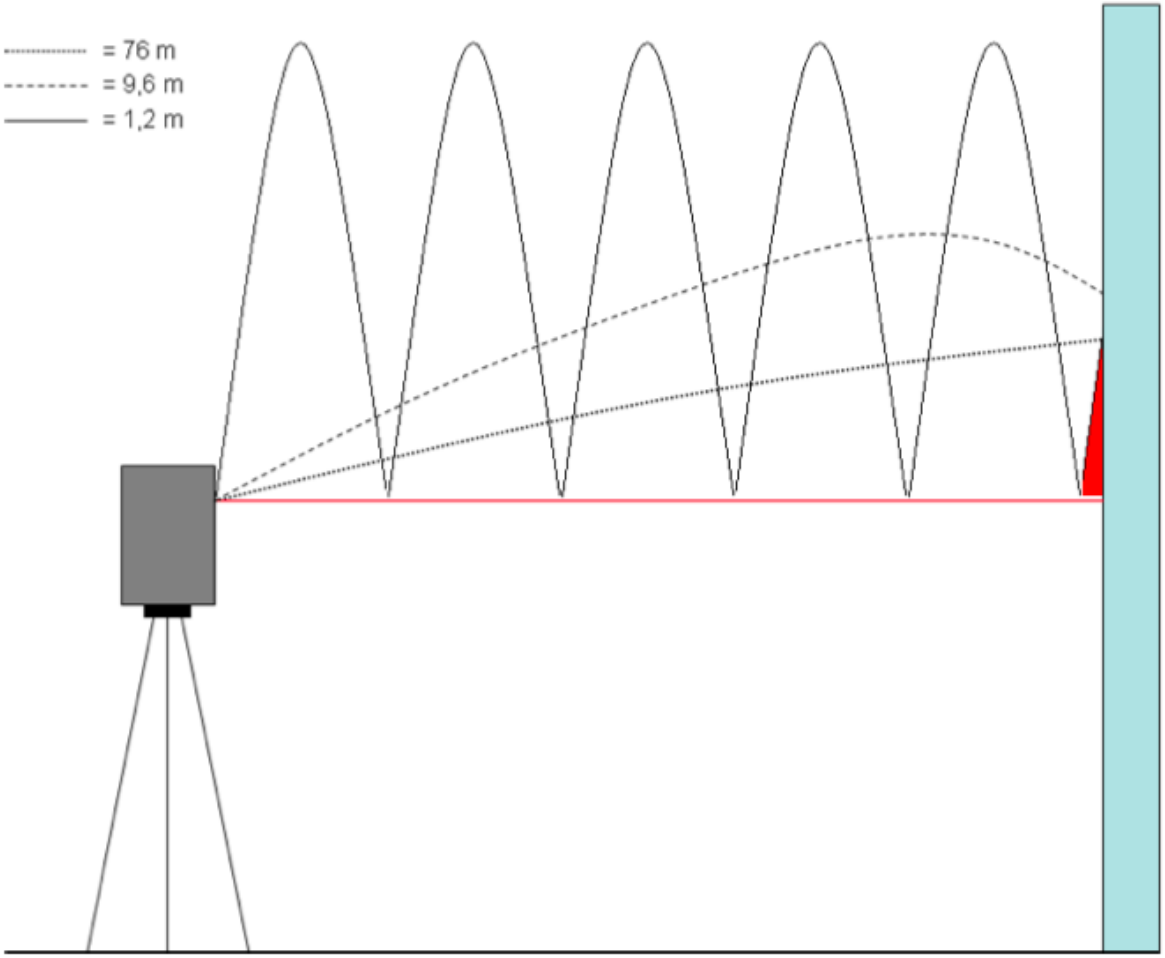
Phase-shift

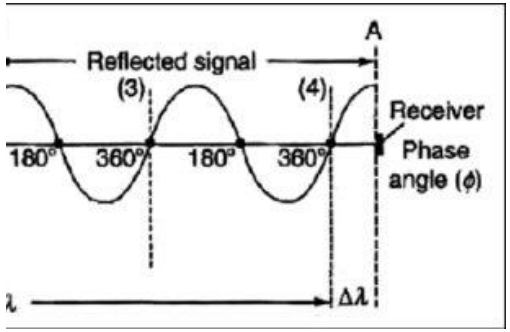
$$Distance = time \times velocity$$

$$Distance = \frac{shift}{2\pi \times FM} \times velocity$$

Distance measurement by phase shift

AWARE notes
Phase-shift methods are limited in range by the length of a full phase (ambiguous beyond that).
Combining 3 or more wavelengths removes ambiguities and extends range.

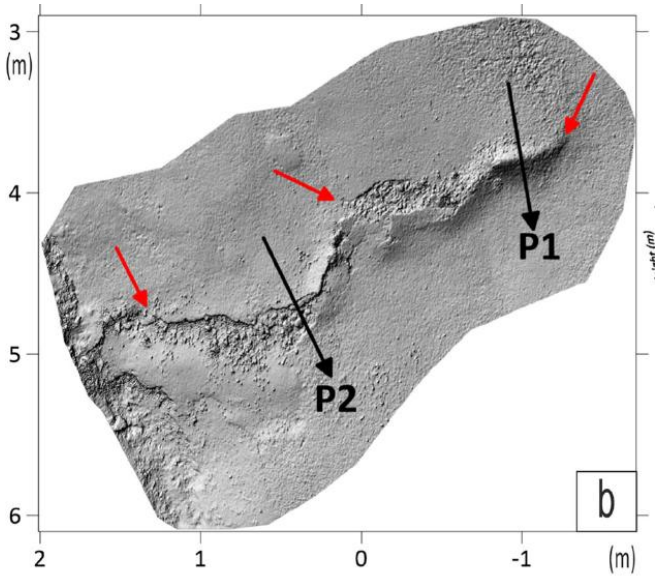


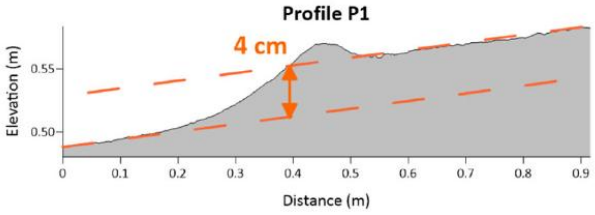


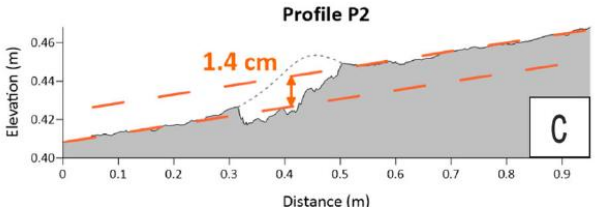
LiDAR/Ground Scanning

- Tripod mounting (see topography)
- Occlusions due to terrain and vegetation
- Measuring very small objects

- Very high resolution
- Working under the canopy
- One operator is enough
- Remote measurement



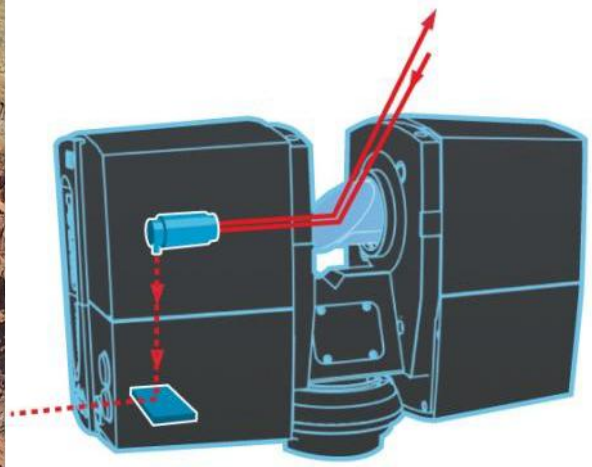


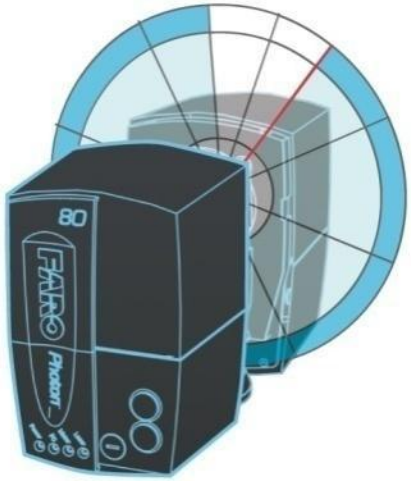




Le Teil earthquake (Ardèche), 11/2019

Faro 3D Scanner



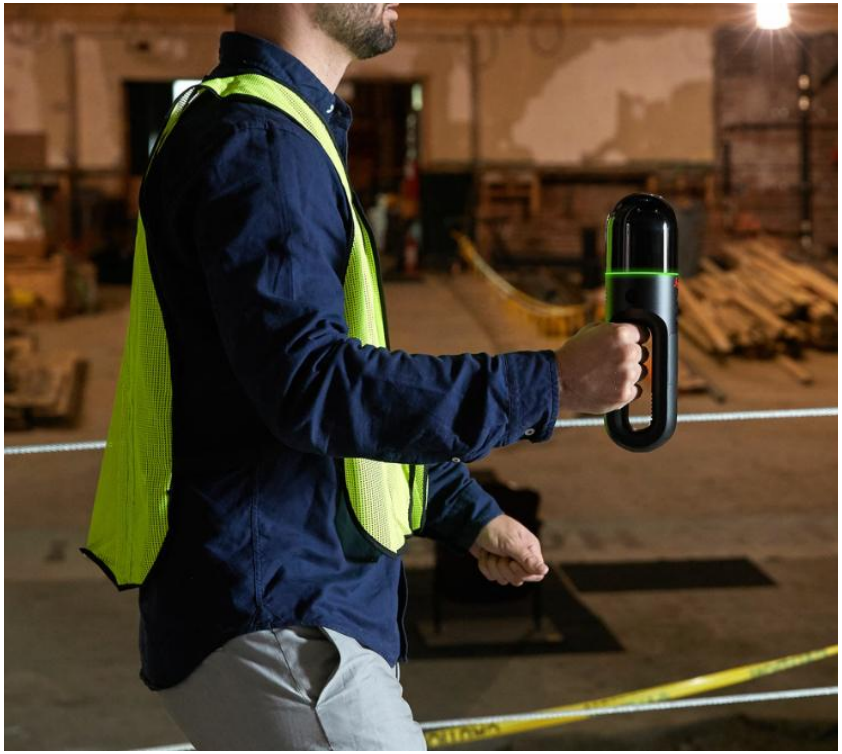




- Emission of a laser beam
- Vertical distribution via rotating mirror (300°)
- Horizontal distribution by rotation of the head (360°)
- Range 330 m
- Resolution 1.5 mm at 10 m



Leica Pegasus Backpack



Leica BLK2Go

Guidelines

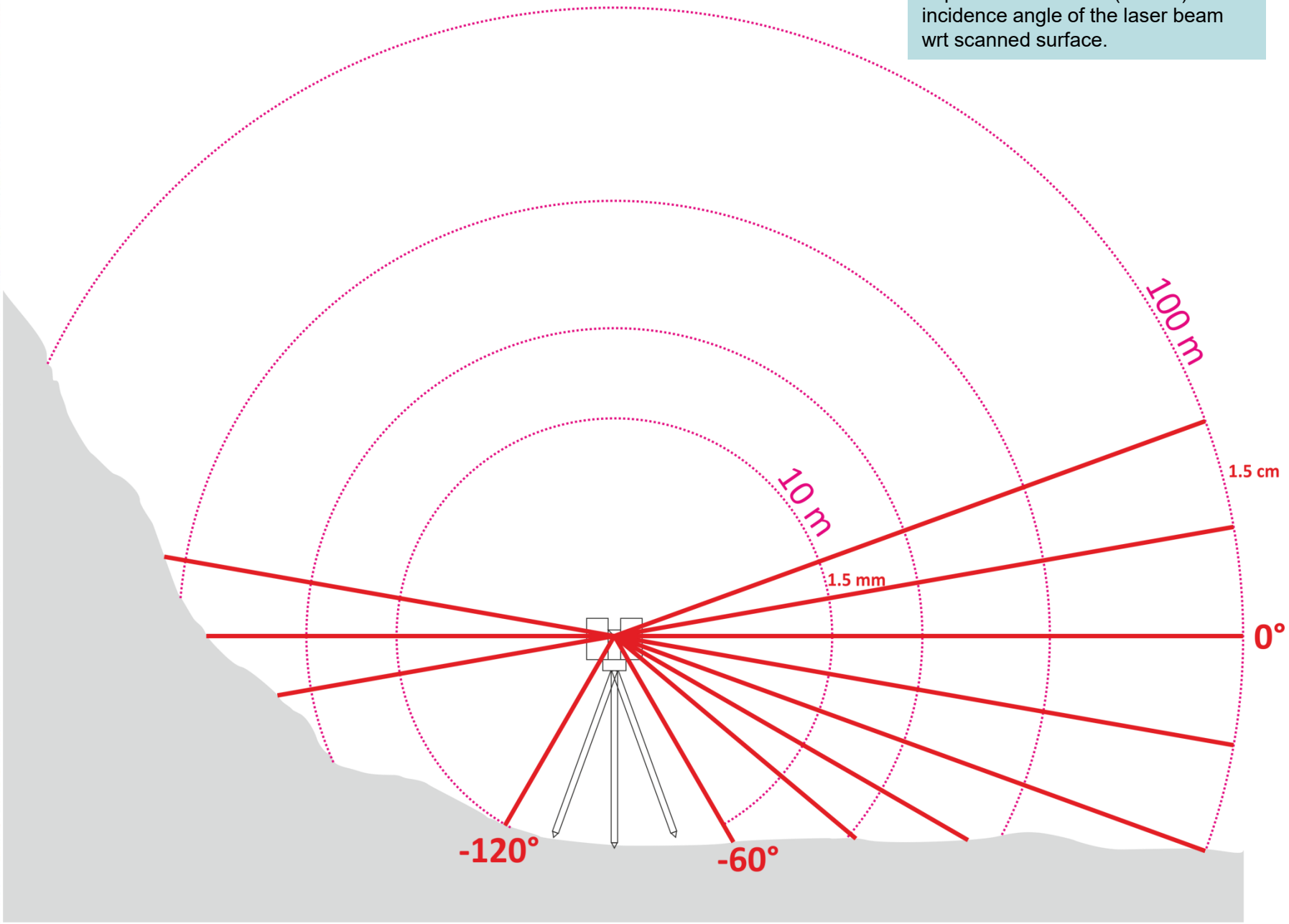
- Internal orientation
  - H (inclinometer)
  - V (compass)
  - ω (motor calibration)

- External orientation
  - Inertial measurement unit
  - GCPs

- Georeferencing
  - Integrating references into the scan

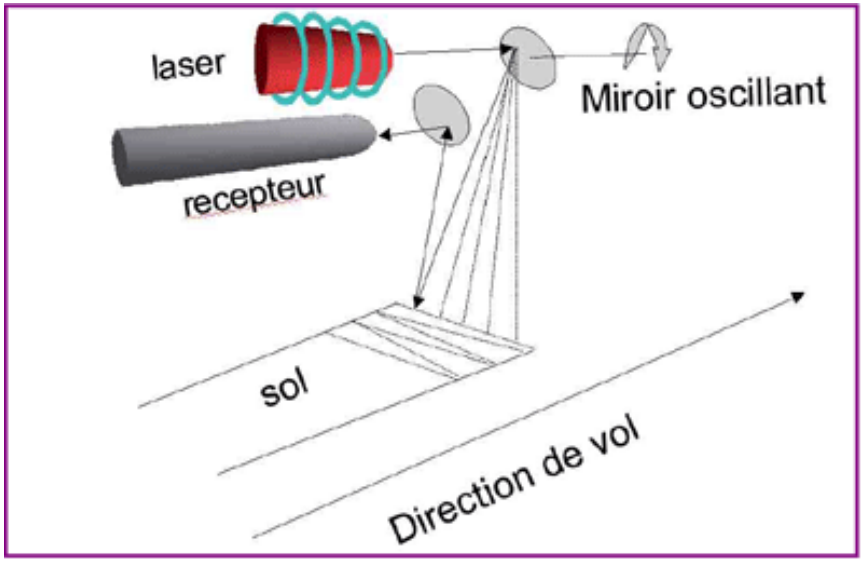
Resolution

AWARE notes
Spatial resolution of a 3D scan depends on distance (Thalès) and incidence angle of the laser beam wrt scanned surface.



Airborne LiDAR

- Airplane / Helicopter / Ultralight
- Flight altitude: 1000 - 3000 m
- Maximum resolution: 0.2 m





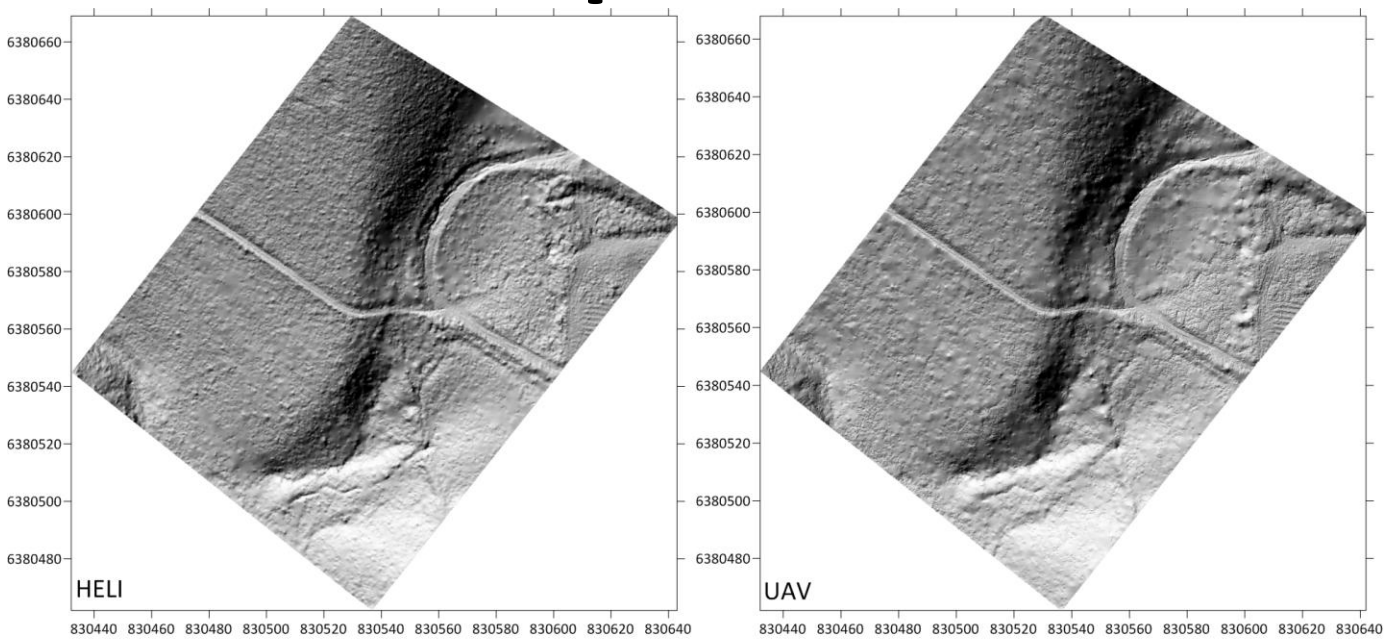
LiDAR on UAV

- Weight: 1.5 kg
- Flight altitude: 50-100 m
- Accuracy: 3 cm (XY), 10 cm (Z)
- ~70 k€

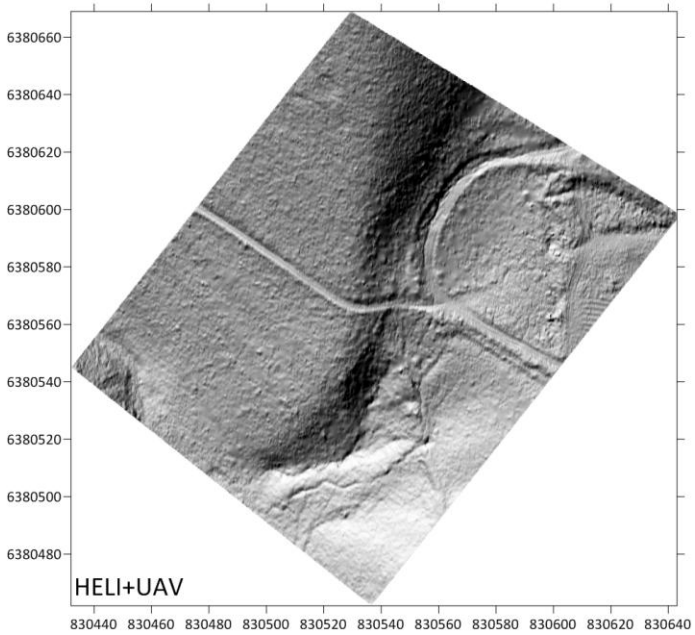


YellowScan

Helicopter vs. UAV



HELI
Altitude : 1500 m
Res.: 0.5 m
Survey time : a few hours

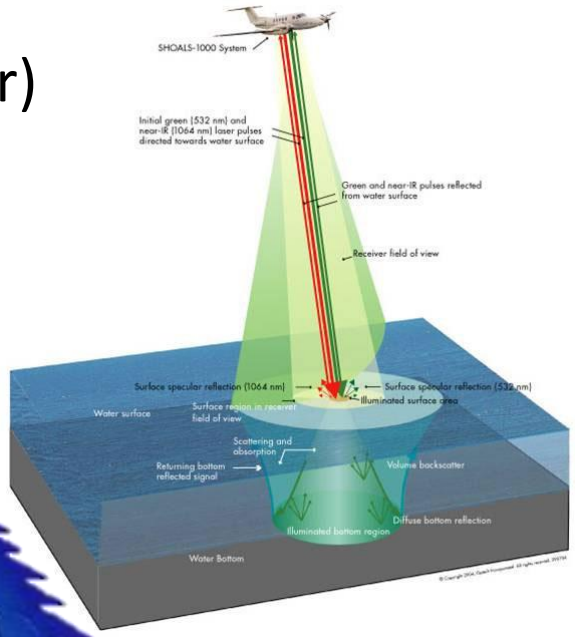


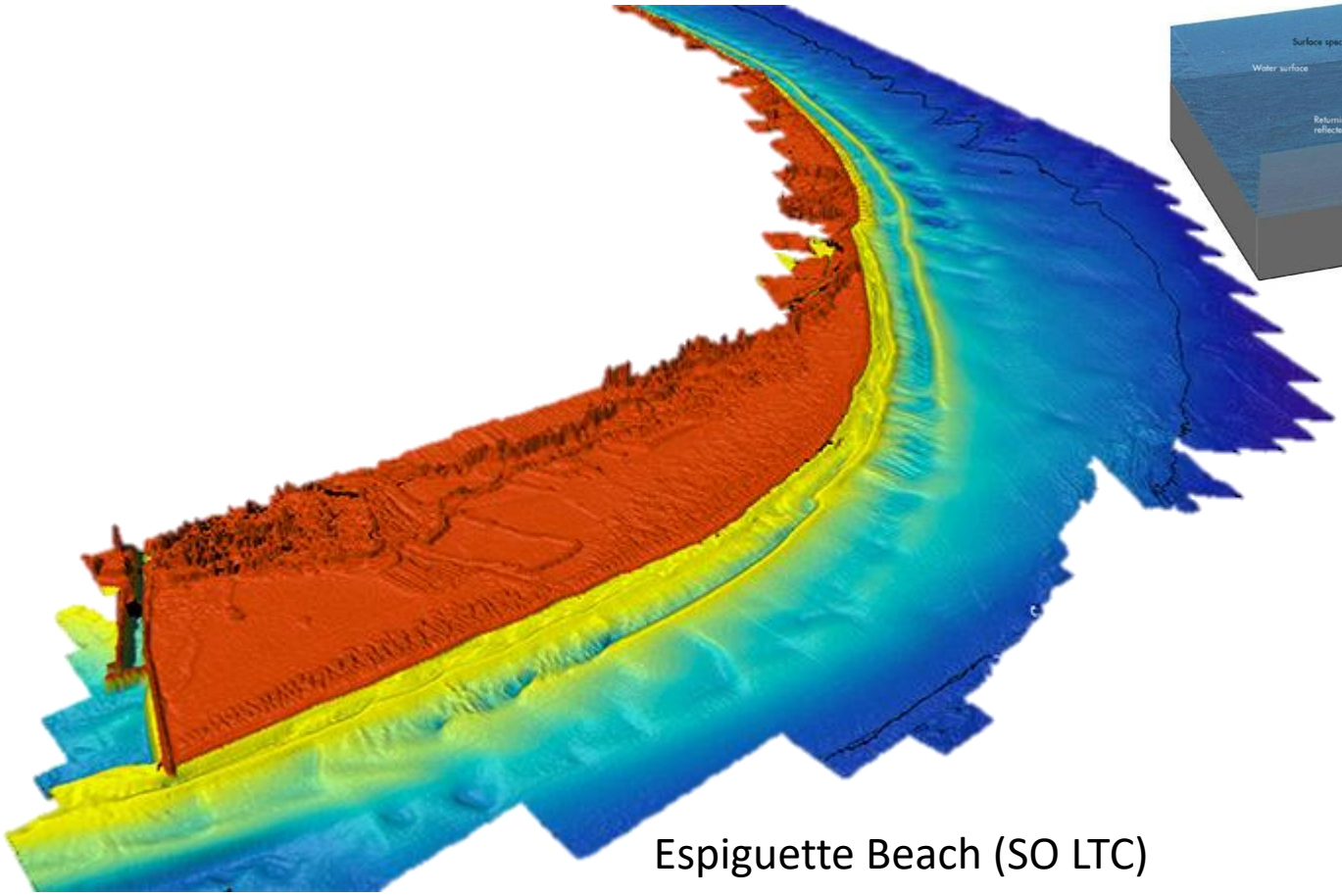
UAV
Altitude: 50 m
Res.: 0.2 m
Survey time: a few days

AWARE notes
Example from survey of the Teil earthquake surface rupture. UAV delivers slightly better resolution but is not powerful enough to penetrate vegetation. Bottom is the result of merging both datasets.

LiDAR for topo-bathy

- Double beam: red (surface) + green (water)
- Depth of investigation: a few 10s m
- Resolution a few m





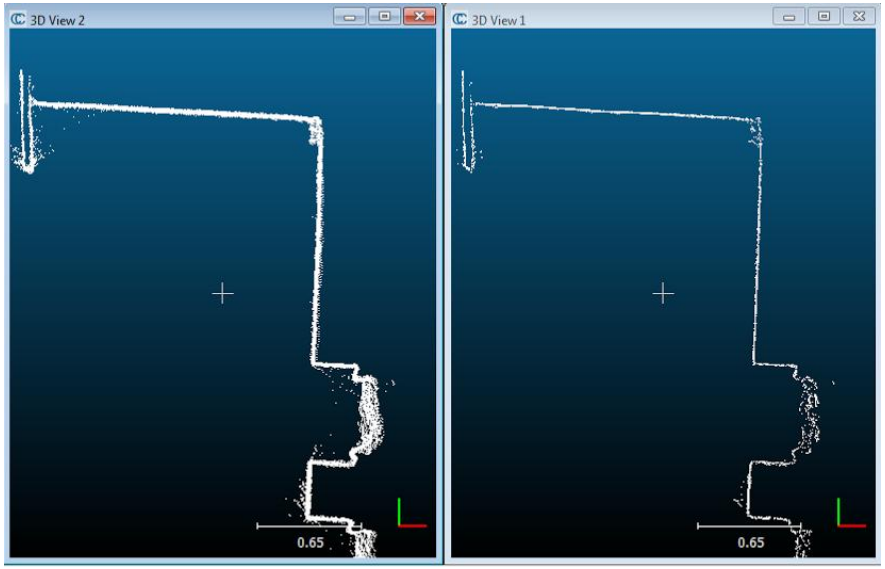
Espiguette Beach (SO LTC)

LiDAR/Scan Pre-processing

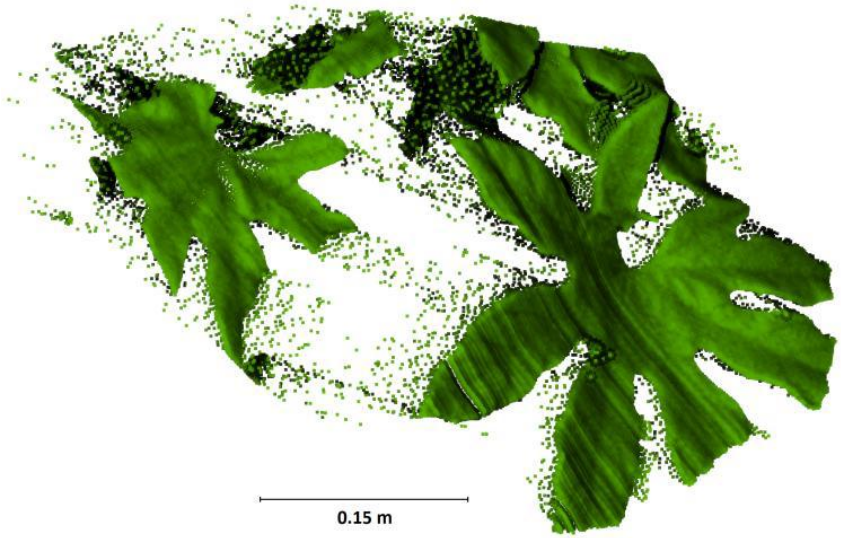
- Registration
  - Assembling stations via common references
  - Georeferencing by reference positions
- Digitization
  - Conversion of polar coordinates to cartography in the final reference system
- Octree
  - Point cloud hierarchy

Identification of outliers

- Isolated points (birds,insects, artifacts…)
  - Density filter on a sliding box
  - Calculating the average distance between a point and its neighbors

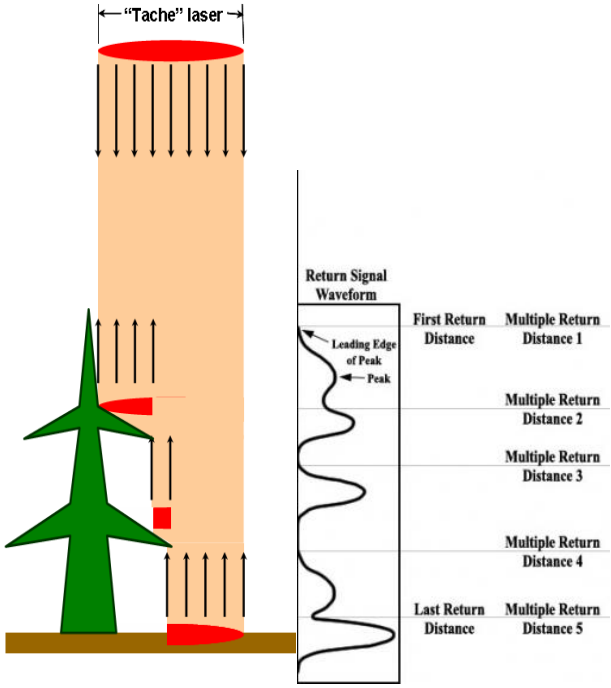


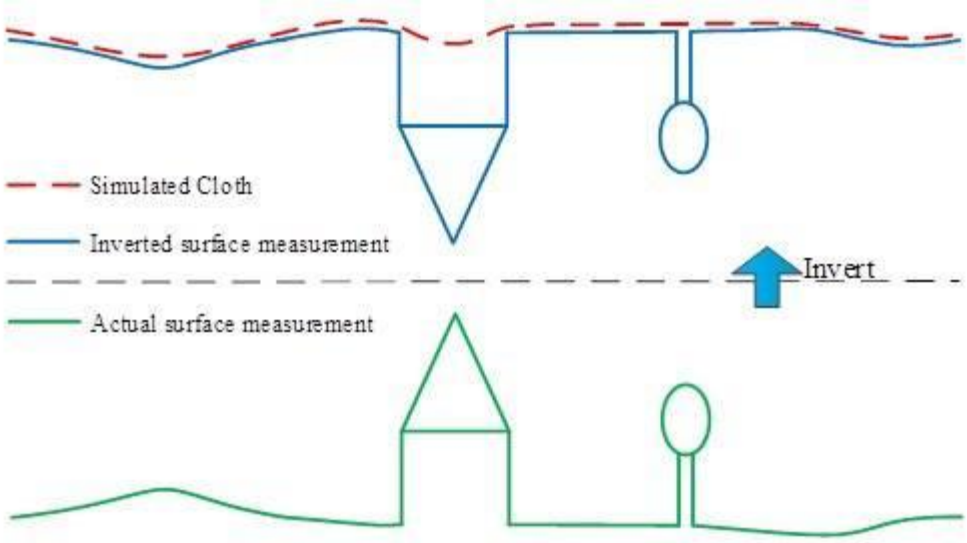
- Edge effects
  - Density filter in the scan direction



Ground/above ground separation

- Classification by intensity
- Latest echo (LiDAR)
- Topological filters



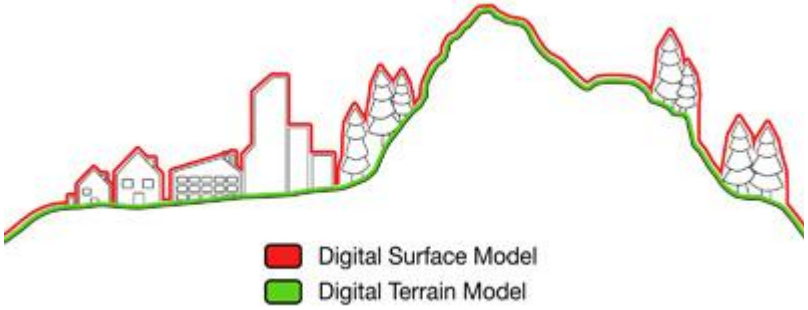


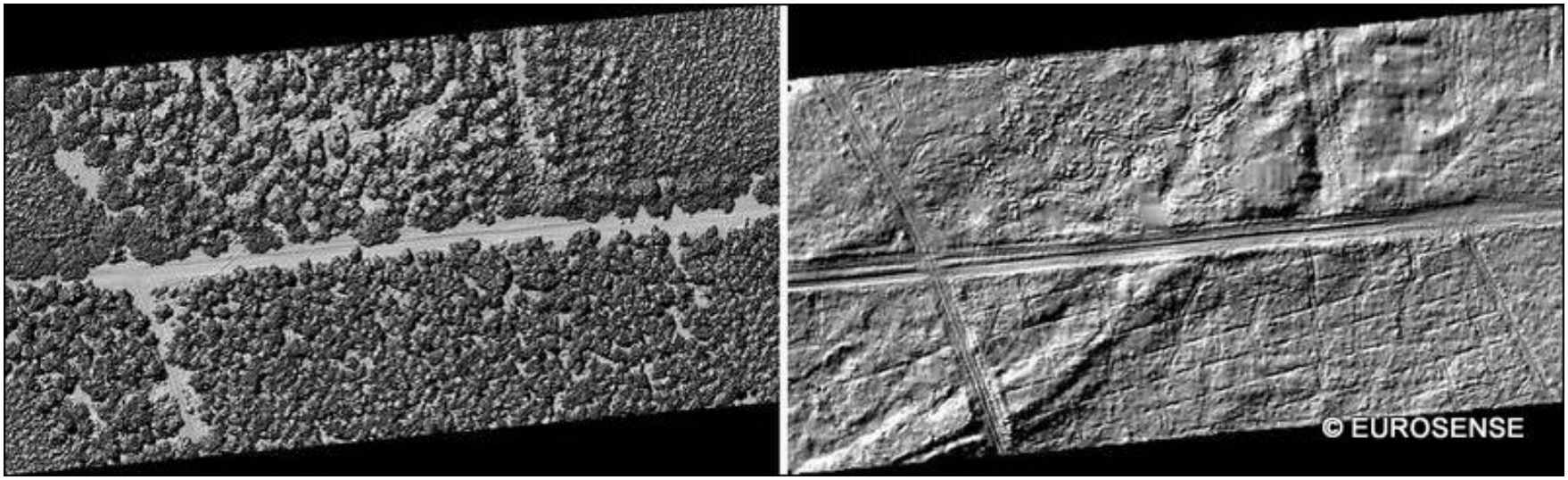
CSF filter

AWARE notes
The laser beam shot from a plane/helicopter at ~1500 m relative altitude makes a 10-15 cm footprint. As it hits the canopy, part of the beam may keep propagating toward the ground and hit/reflect over branches and finally the ground. Each hit is an echo in the full waveform.

Ground/above ground separation

- Point cloud classification: ground, building, tall vegetation, low vegetation
- DSM production, DTM, building height, vegetation height





DSM DTM



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- Indirect measurement (photogrammetry)
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  - camera obscura sensor (near field, aerial)
  - pushbroom sensor (satellite)
- Visualization

Photogrammetry

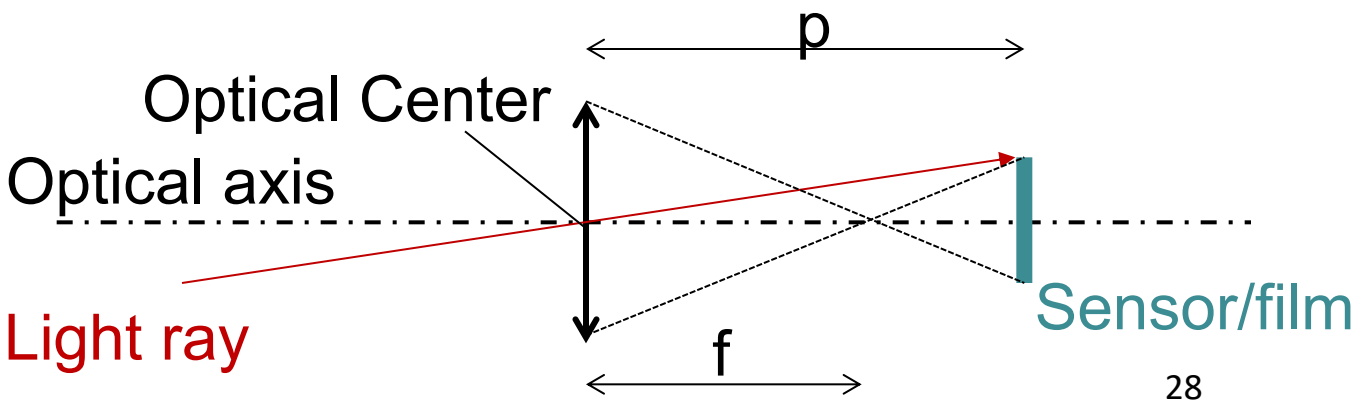
Any measurement technique that allows modeling a 3D space using 2D images



Wild C2 (1925)

Optical parameters

- **focal length: t**he distance between the optical center of the lens and the point of convergence (image focus, Fi) of rays parallel to the optical axis. When focused at infinity, the optical center and the back of the camera are separated by a distance of f.
- **sensor format:** the size of the sensitive surface (negative film or CCD sensor).
- **field of view:** the field of view encompassed by a lens. Its numerical value is given by the angle defined by the portion of space accessible by the diagonal of the sensor.
- **main distance**: the distance between the optical center and the focal plane. When the focus is at infinity, then p=f



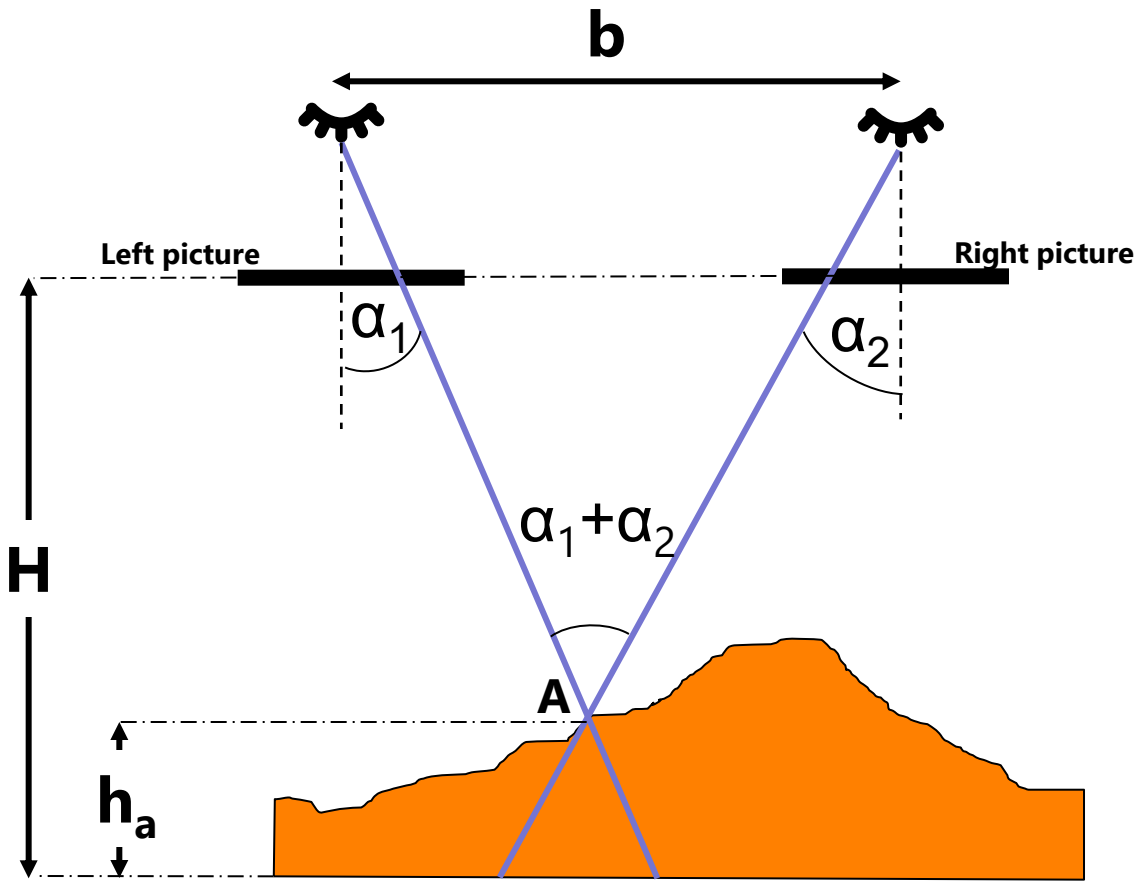
Parallax principle

Apparent change in the position of a static object with respect to the observation position

H: altitude / ref plan.
b: base
f: focal length
α: viewing angle

AWARE notes
Parallax effect is the apparent displacement of an object when viewed from two (or more) images (or points of view). Geometric relationships yield the height of any point as a function of parallax ($\alpha_1+\alpha_2$) given survey parameters (H, b and f).

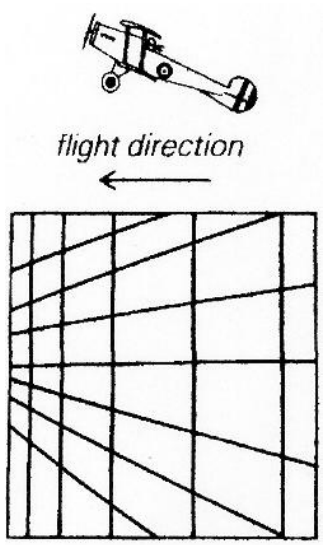
Height of an object
$h_a = H - b.f/(\alpha_1+\alpha_2)$



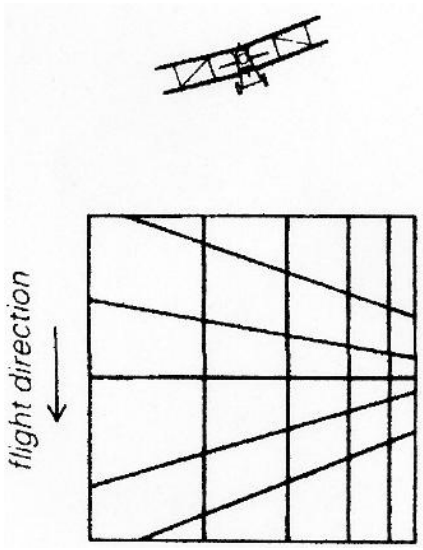
External orientation



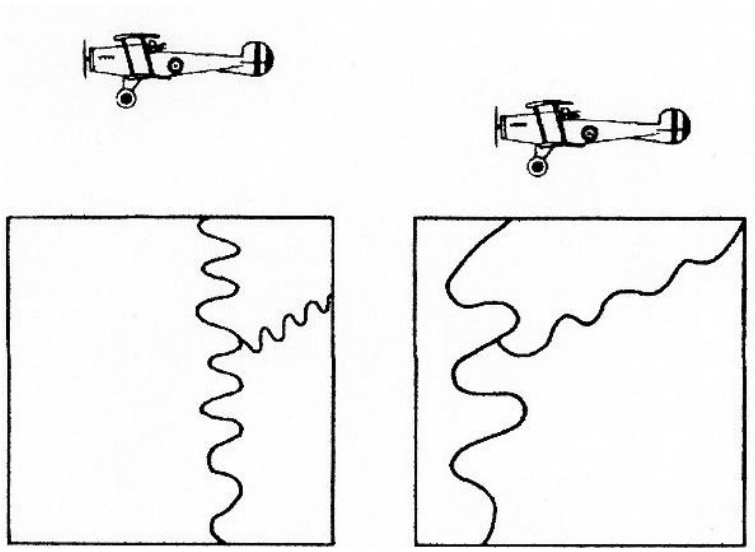
Pitch

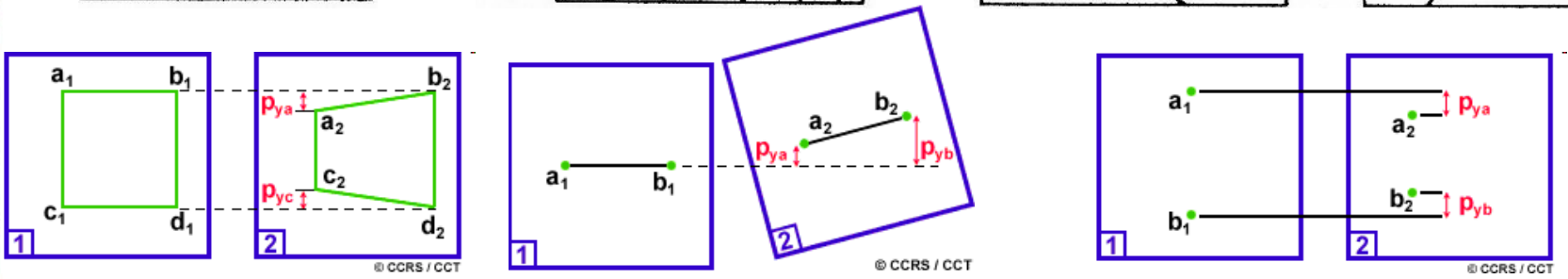


Roll



Altitude





- Inertial measurement unit, altimeter
- Ground support points

Geometric anomalies

Nadir



Slope 1 D





Devers 2 D



Slope + shadow

Control points

- Ground control points, adjustment points, settling points, ground control points
- Points with precise, known coordinates measured in the field and easily identifiable in the images
- Georeferencing







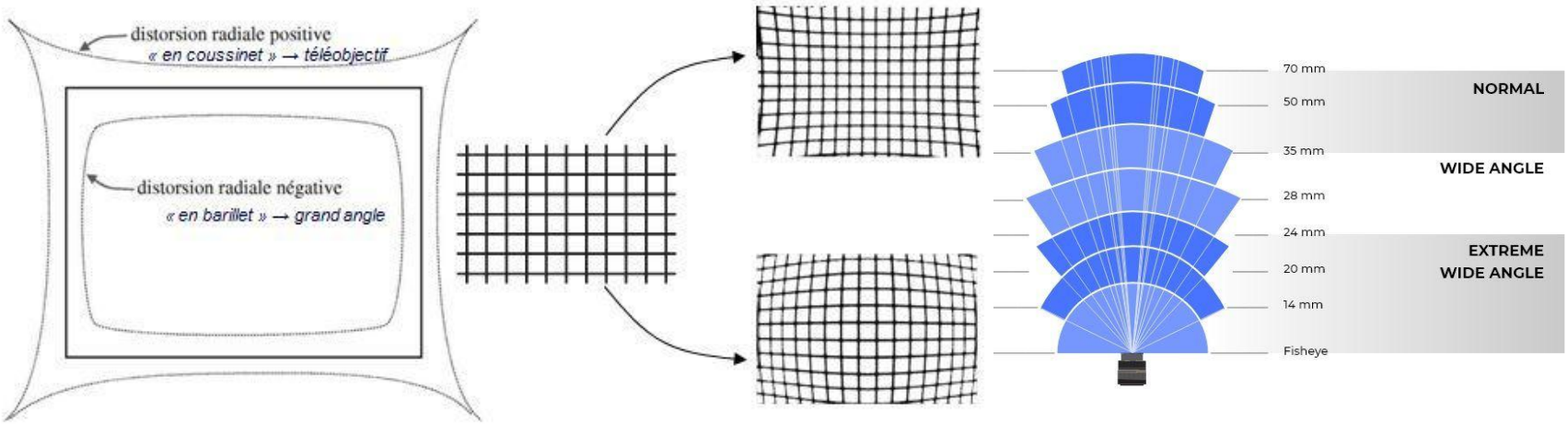
- Specific initiation points



- Warning! These are separate from validation points.

Internal orientation

- Geometric distortion (optical)



- Sensor distortion (CCD/film)

➢ Regular camera calibration

AWARE notes
Optical systems are never built perfectly and deform with time, temperature, humidity and need to be calibrated.

Resolution

- Resolution in object space (terrain)
  - Ground pixel size (Ground Sampling Distance)
  - spatially variable

- Identification
  - identification from 3xR
  - interpretation based on 20xR

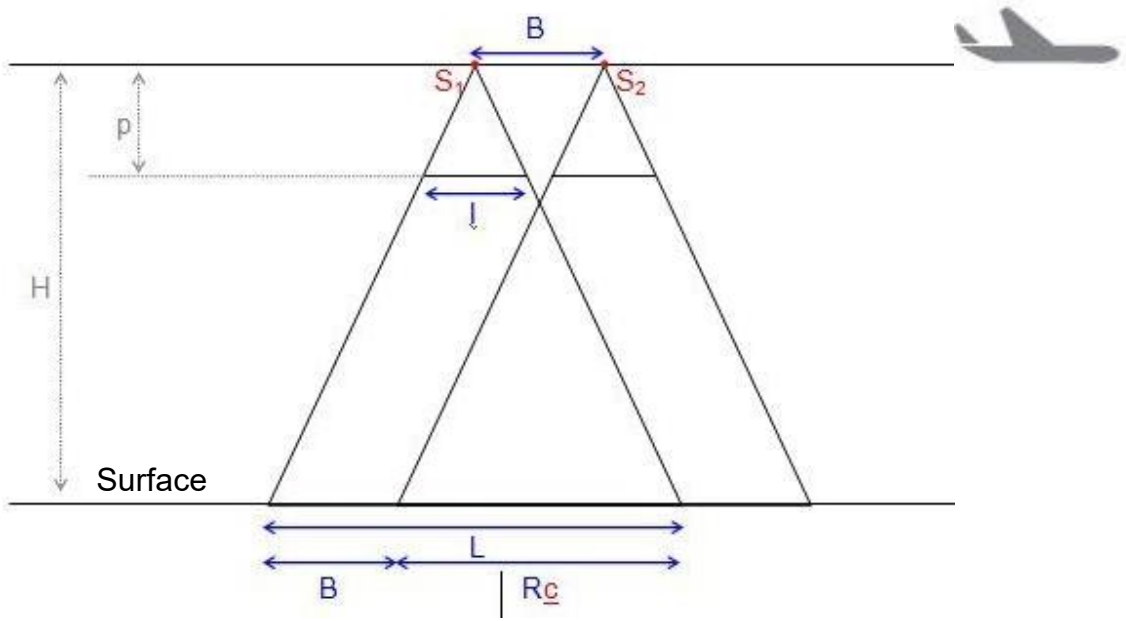


GSD 1.6 m



GSD 0.2 m

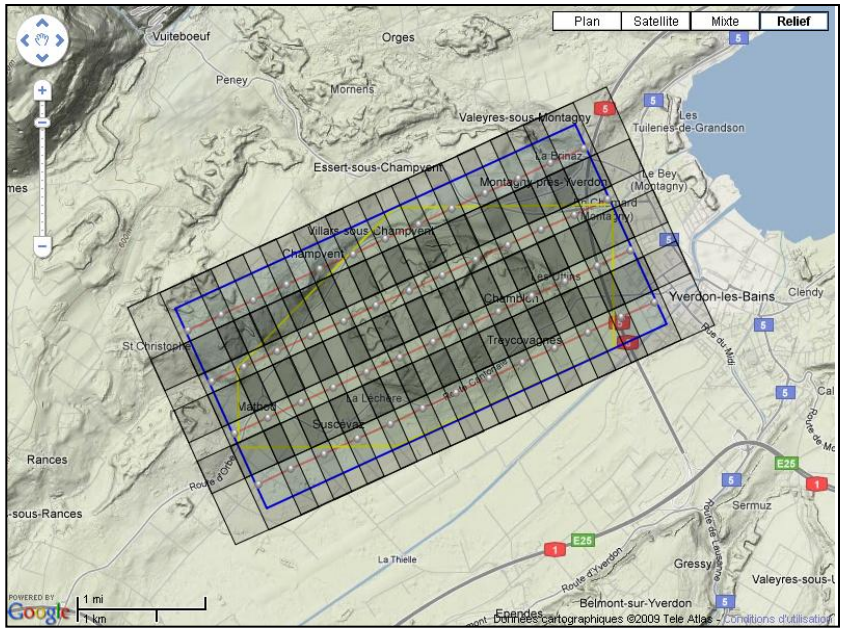
Survey geometry



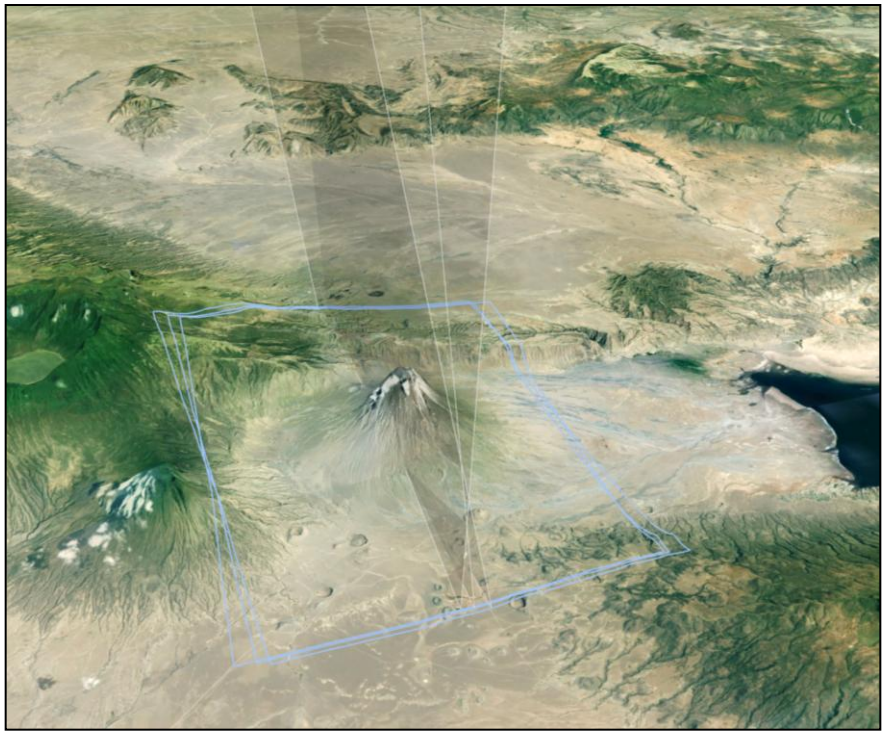
B: base (distance between two photos)
L: length of the photo
RC: recovery
H: flight altitude (to ground)
B/H influences altimetric accuracy
H/p: scale

Flight plan

- Ensure longitudinal and lateral overlap
- Ensure resolution according to the objectives (depending on flight altitude, focal length and sensor resolution)



Pinhole sensor



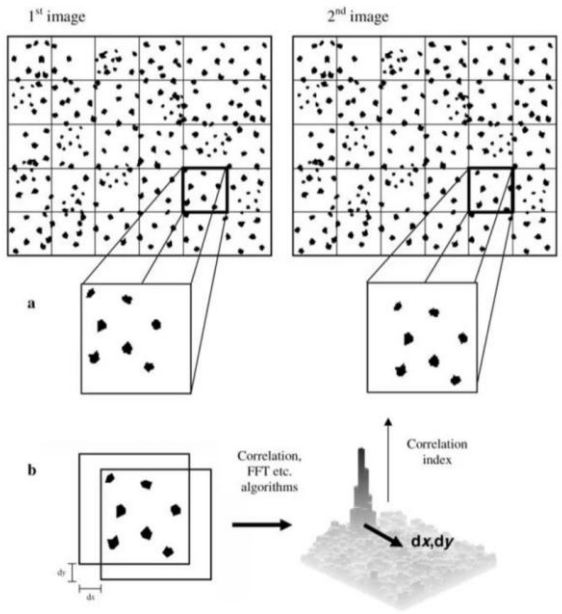
Pushbroom sensor

Processing

- Orientation parameter corrections
  - CN: Calibration import, GCP identification
  - Problem: Importing RPCs, identifying GCPs
  - Epipolar image generation
- Searching for analogous points
  - Identification of specific points (contrast, SIFT)
  - Block modeling
- Triangulation
  - Stereo / multi-view
  - Post-processing

Image correlation triangulation

- Correlation function for each pixel defined on a PxP window
- Correspondence of functions
- Calculating the "pixel displacement" from one image to another
- Calculating the pixel's altitude relative to the reference plane

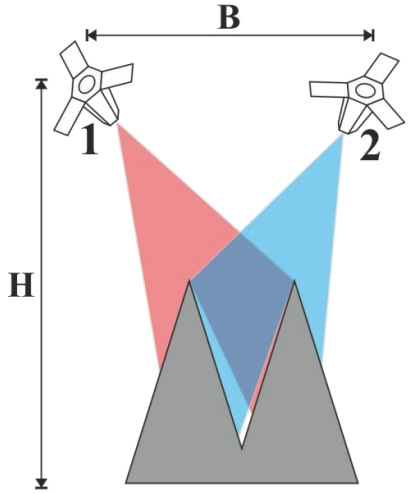


Post-processing

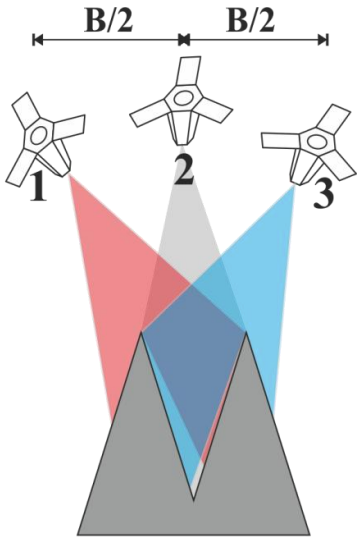
- Multi-view Structure-From-Motion→ point cloud
- Multi-view SFM + oblique views → 3D
- Ground/surface separation by topological filter (LiDAR) and HSV colorimetric classification
- Stereo couple → raster

- Point cloud → rasterization (single z-axis) with interpolation

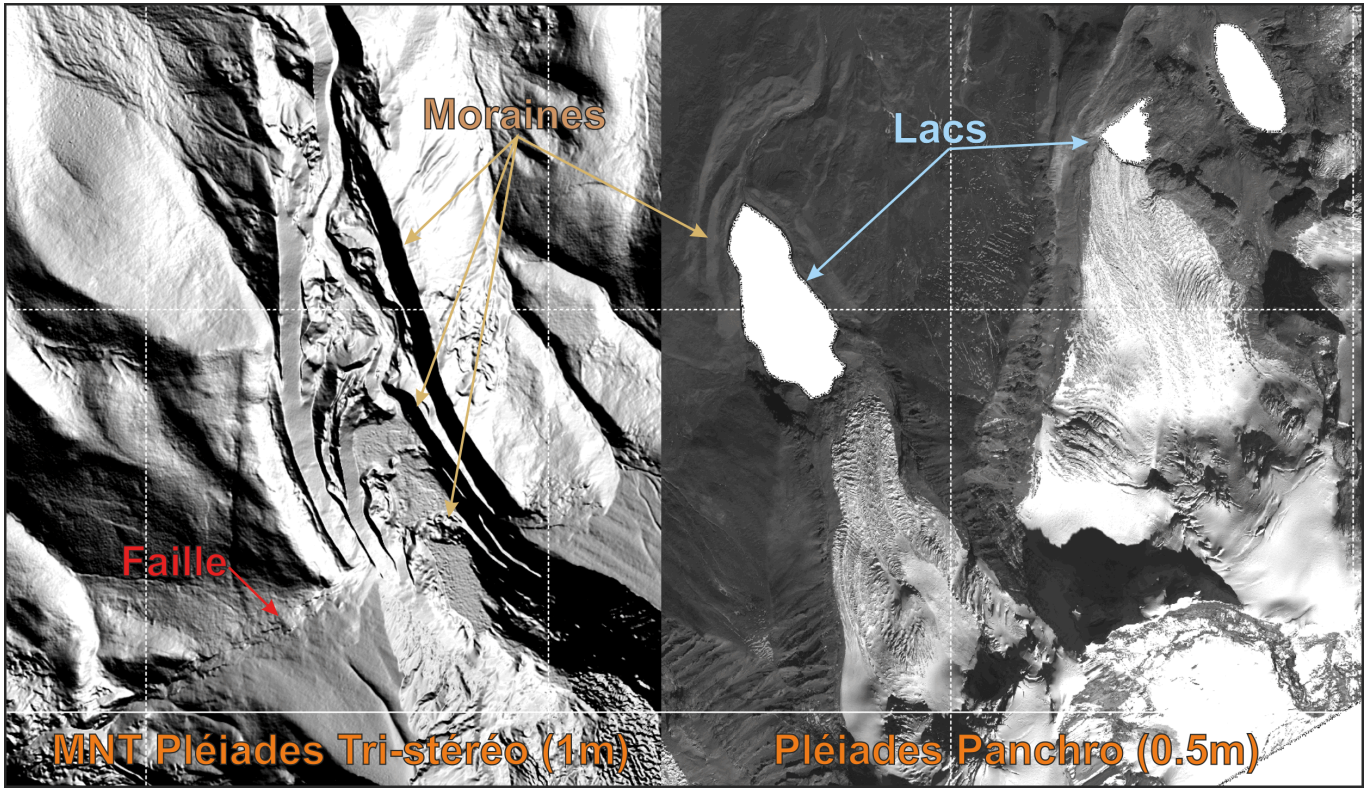
Satellite photogrammetry



stereo



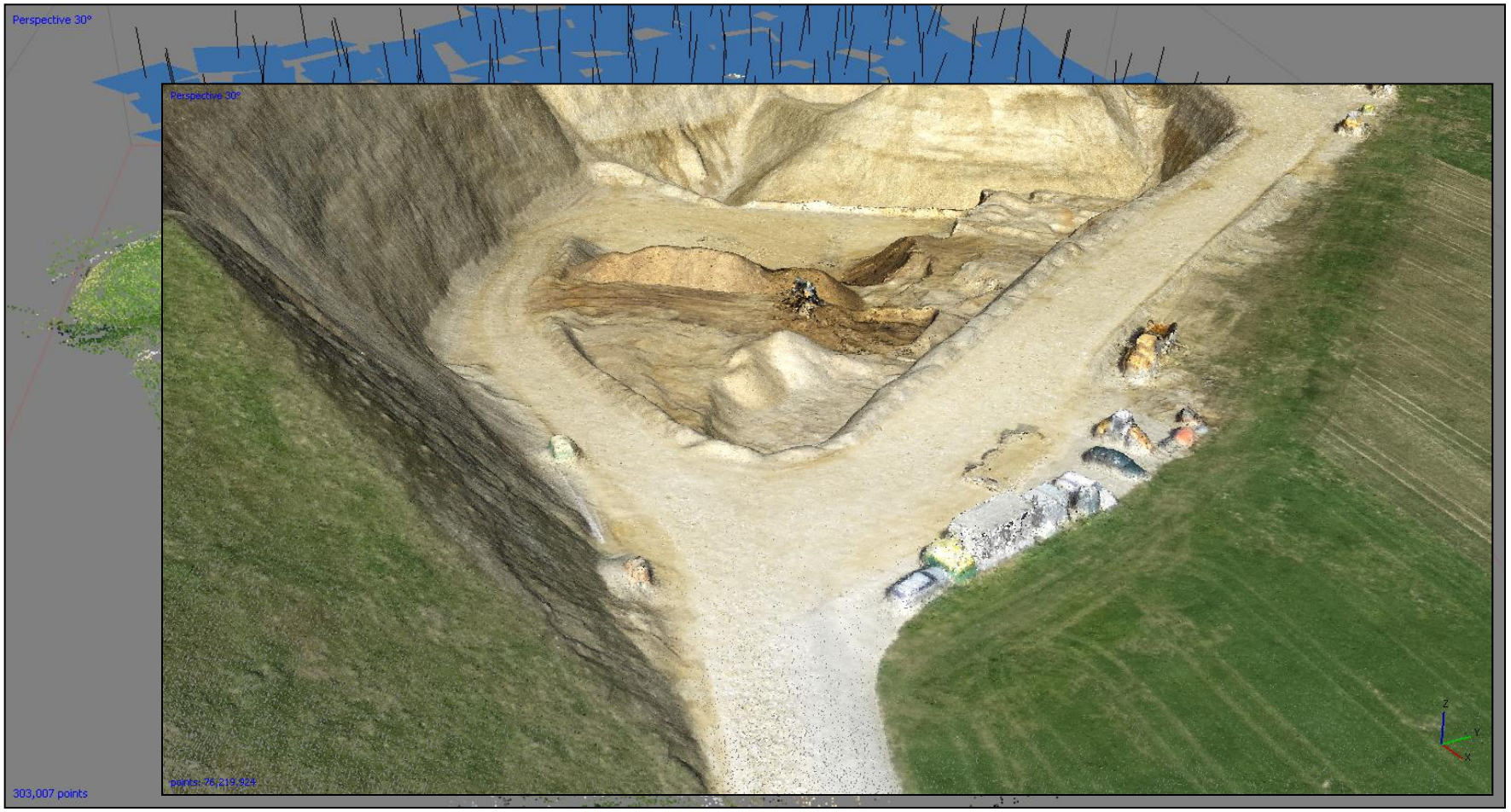
tri-stereo



Yadong (Himalayas)

AWARE notes
Example of satellite optical photogrammetry from a triplet of Pleiades sat. Images over the northern Himalayas to map the Yadong fault (faille) and identify glacial moraines that record holocene deformation.

SFM Photogrammetry

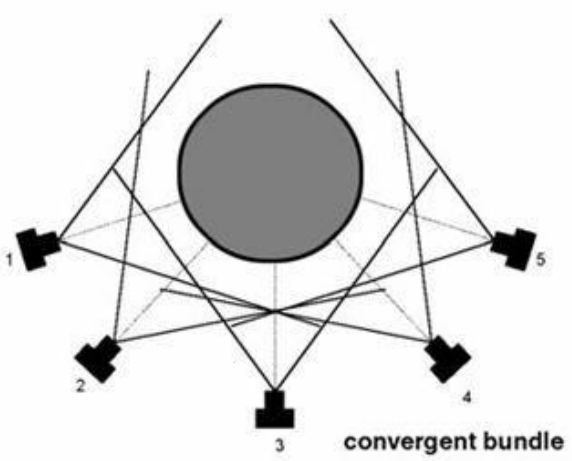


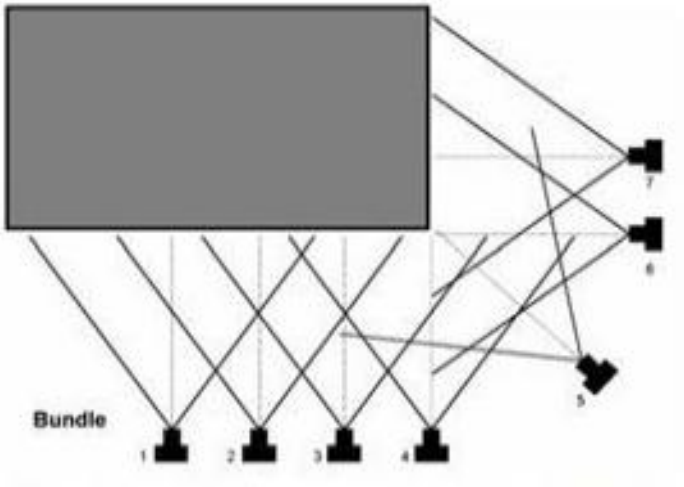
- 211 photos (georeferenced)
- Orthophoto at 5 cm GSD
- DEM at 9 cm GSD
- Processing and display CPU/GPU resources

Original images by Sensefly

Terrestrial photogrammetry

- DSM on a very small scale
- 3D object reconstruction
- Can be done on a smartphone
- Can use video (e.g. GoPro)





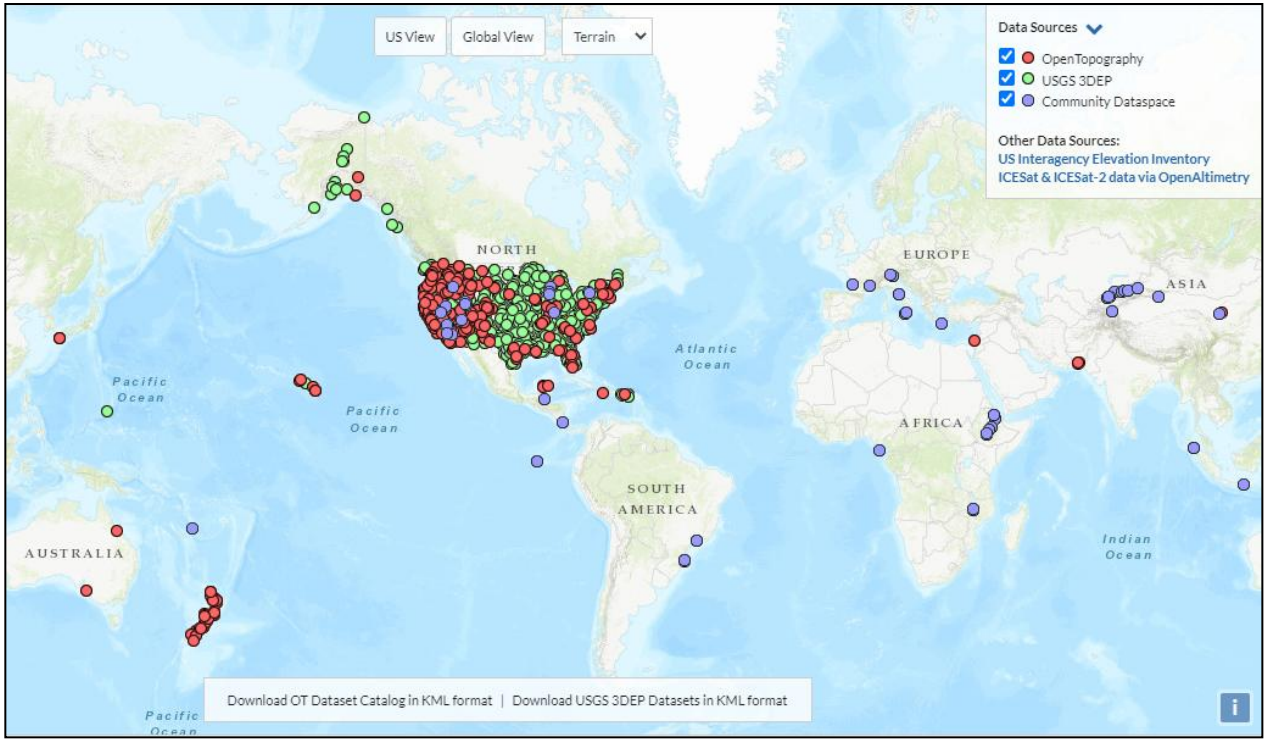


LiDAR vs. Photogrammetry

	LiDAR or Scan	Photogrammetry
Resolution	mm - m	cm - m
Precision	mm	cm
Influence	m^2 - km^2	m^2 - >1000 km^2
Deployment time	Airborne: variable Terrestrial: immediate	Airborne: days Terrestrial: immediate
Processing time	Hours to days	Hours to days
Equipment cost	Aerial: 300 - 700 k€ Land-based: 30 - 100 k€	Aerial: 50 - 100 k€ UAV: 2 – 20 k€ Land: 1 k€
Deployment cost	Aerial: a few k€ / day Terrestrial: 0.1 k / day	Aerial: a few k€ / day Terrestrial: 0.1 k / day

Data sources

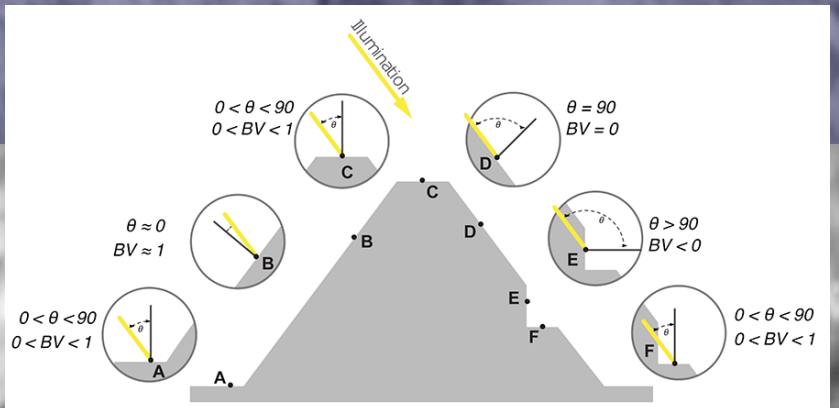
- YOU
- IGN: RGEALTI 1 m, DSM+DTM on flood zones
  - Full LiDAR coverage by 2023
- Observatories: coastline, landslides, faults
- OpenTopography: data warehouse (point clouds)



Visualization

- Plan view of the topography or relief
- Representation of the shape by altitudes, slopes, curvatures and their derivatives
- Representation interpretable by the human brain

Shaded relief



Point	θ	BV = cos(θ)	Notes
A	0 < θ < 90	0 < BV < 1	The closer θ is to zero, the brighter the BV
B	0 < θ < 90	0 < BV < 1	Brighter than point A, as θ is smaller
C	0 < θ < 90	0 < BV < 1	Same brightness as point A
D	θ = 90	BV = 0	θ is exactly 90; cos(θ) = 0
E	θ > 90	-1 < BV < 0	BV is negative
F	0 < θ < 90	0 < BV < 1	Same brightness as points A and C

Lidar Data Copyright
Walks of Peace in the Soča Region Foundation

315° 45°

0 50 m

Shaded relief

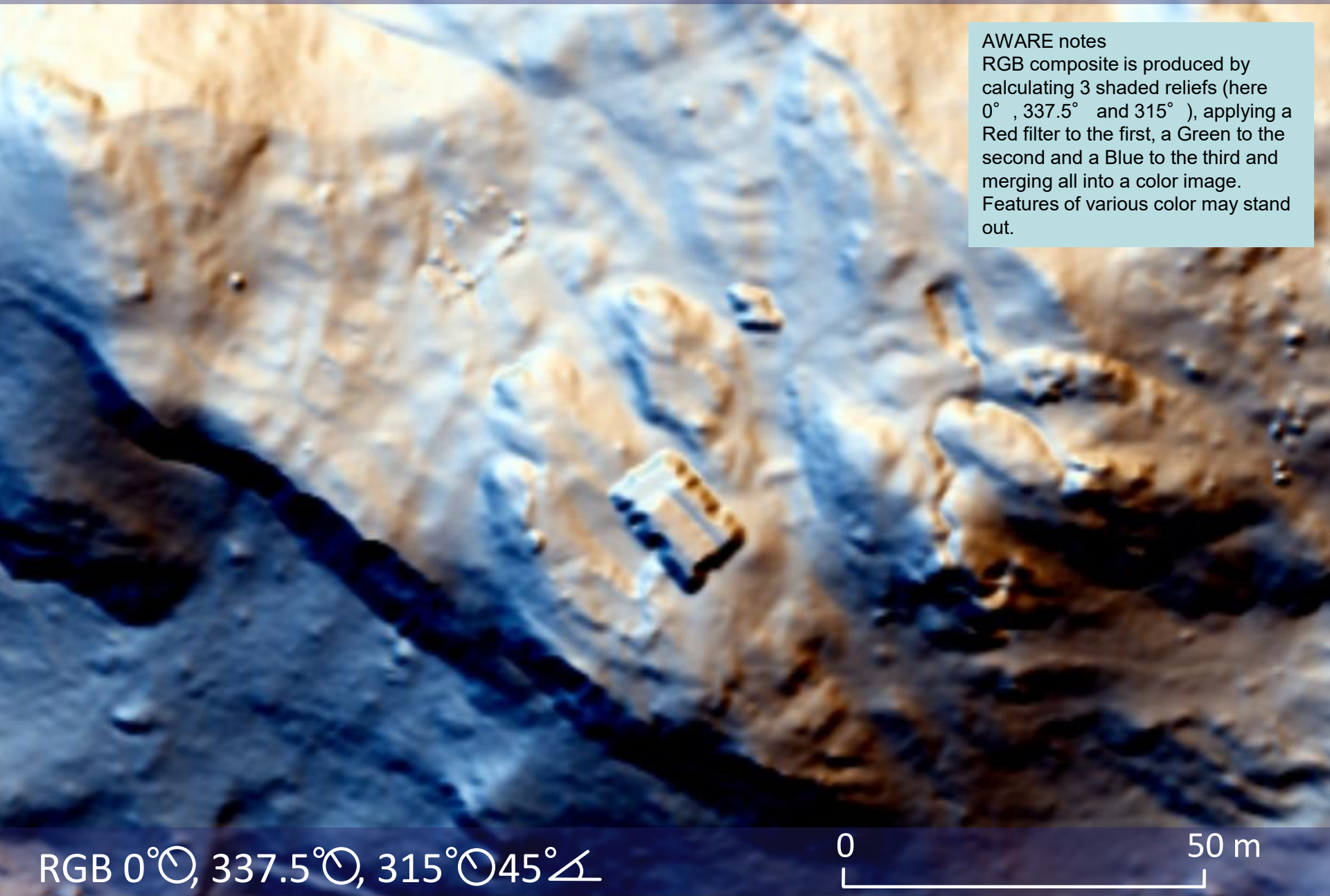
++

- Easy to calculate and natural to interpret
- Available in GIS software
- Reveals weak reliefs in low incidence light

--

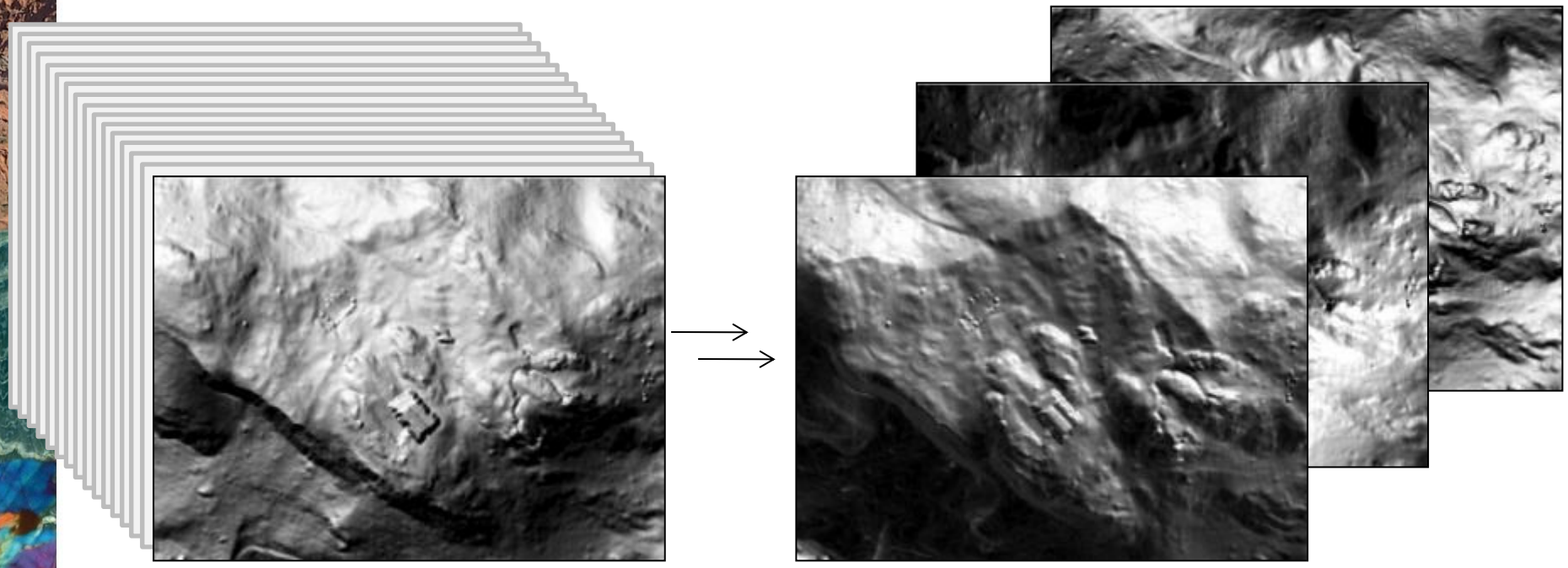
- Saturation in areas of strong lighting/shadow
- Linear structures parallel to lighting are faded

RGB composite shading



PCA of shaded reliefs

- Information reduction (principal component analysis)
  - Generally, the first 3 components contain more than 99% of the information
- Devereux et al. 2008, *Antiquity*.

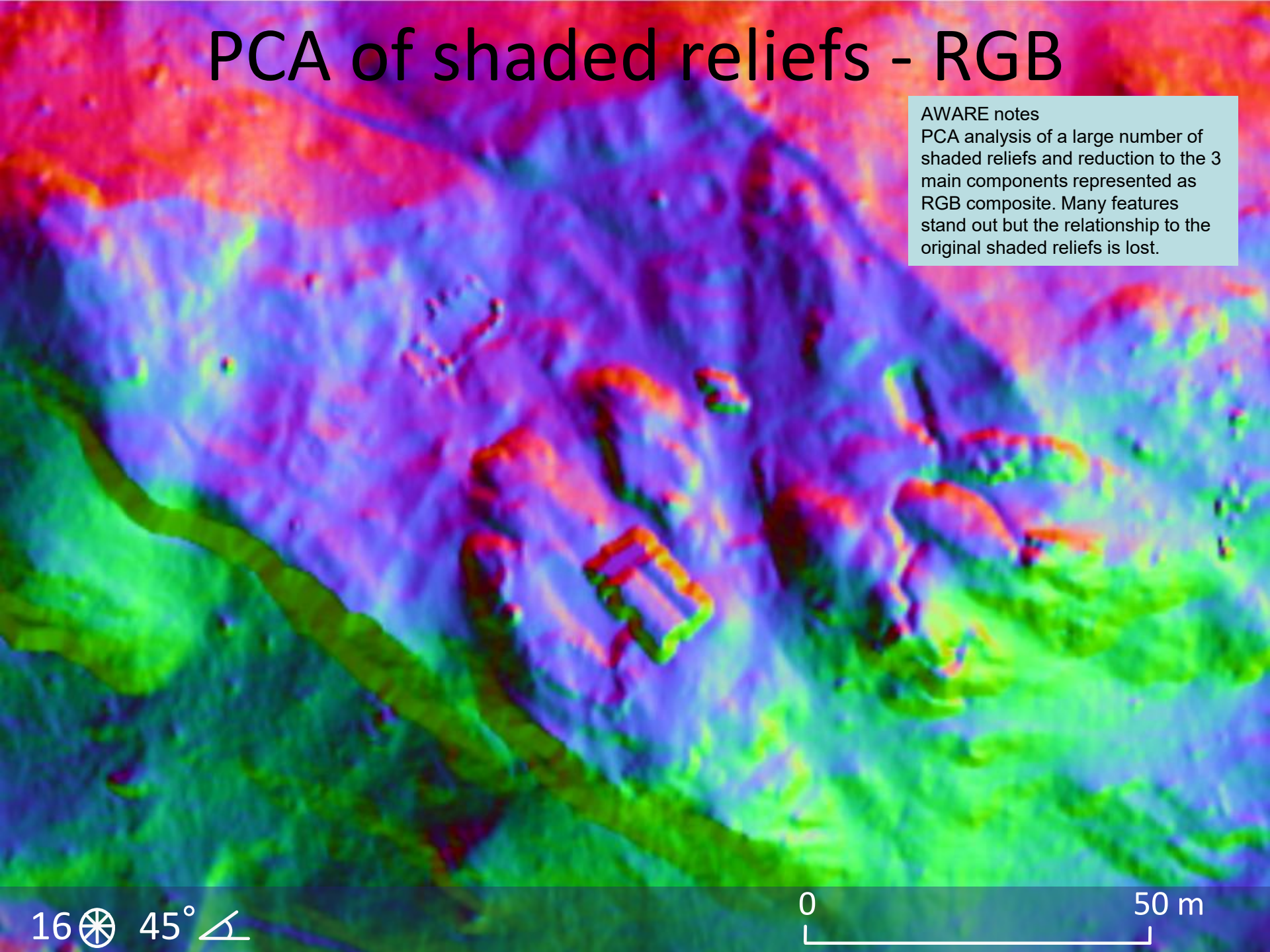


16 shaded reliefs
(100%)

The first three components
(> 99%)

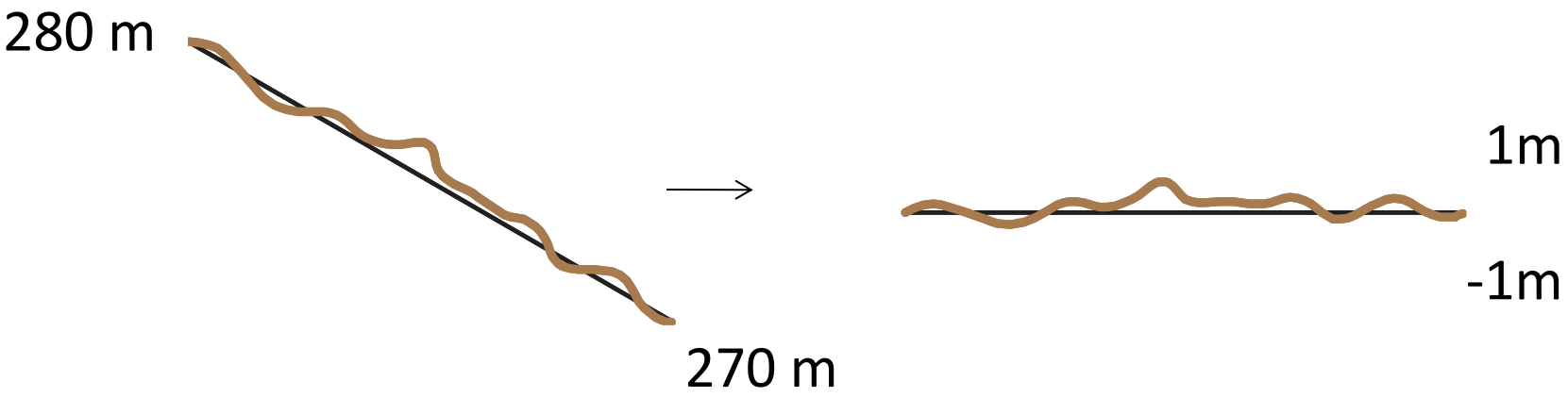
PCA of shaded reliefs - RGB

AWARE notes
PCA analysis of a large number of shaded reliefs and reduction to the 3 main components represented as RGB composite. Many features stand out but the relationship to the original shaded reliefs is lost.

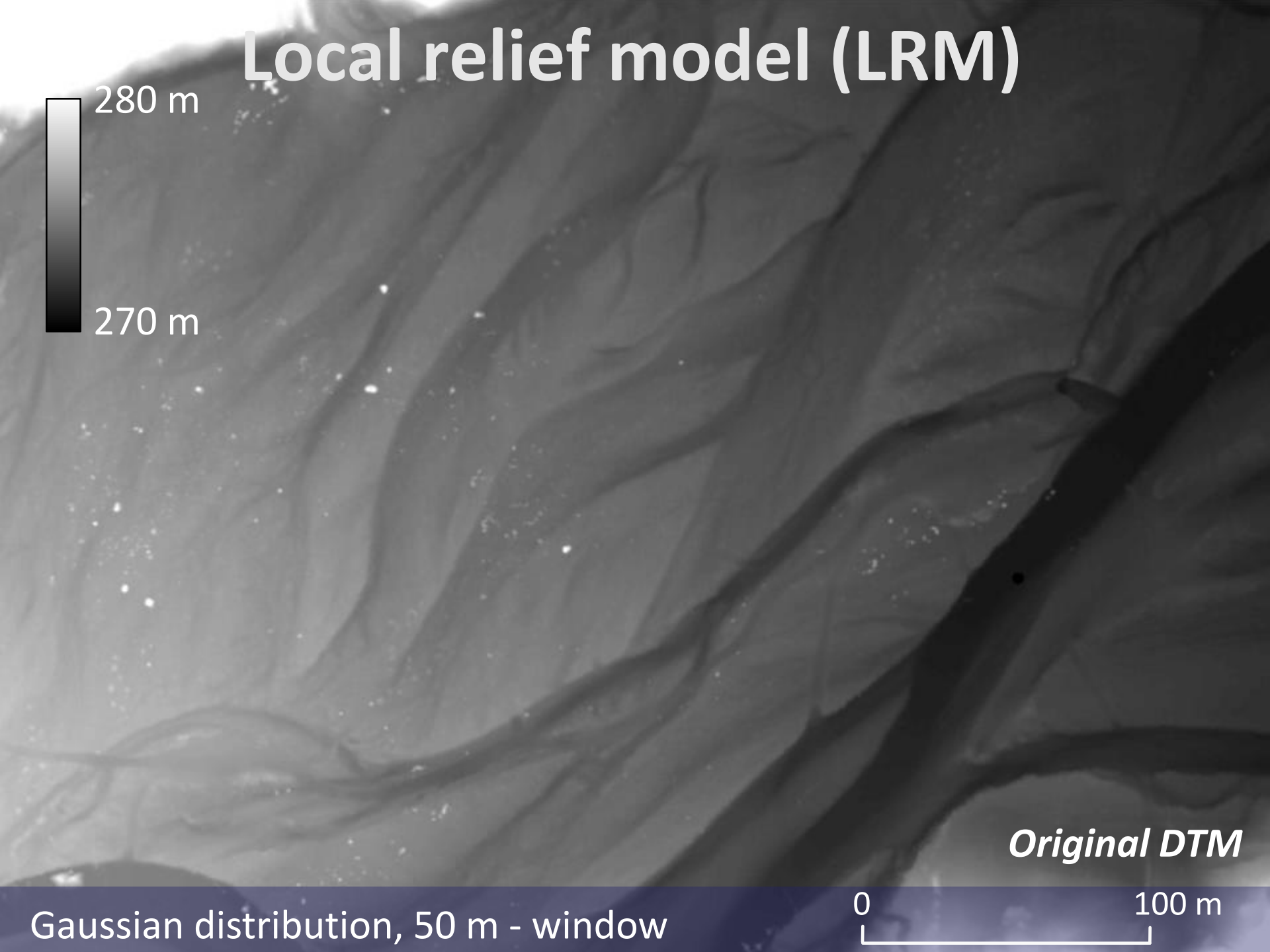


Local Relief Model (LRM)

- Removal of the relief associated with “regional” objects
  - ➢ Small object amplification



- Subtracting the average value (median, Gaussian, etc.) from a sliding window


Local relief model (LRM)
280 m
270 m
Original DTM
Gaussian distribution, 50 m - window
0
100 m

Local relief model (LRM)



280 m

270 m

AWARE notes
Regional trend smoothed over a 50-m window shows the same amplitude as the original DTM without any details.

Regional trend

Gaussian distribution, 50-m window

0 100 m

Local relief model (LRM)



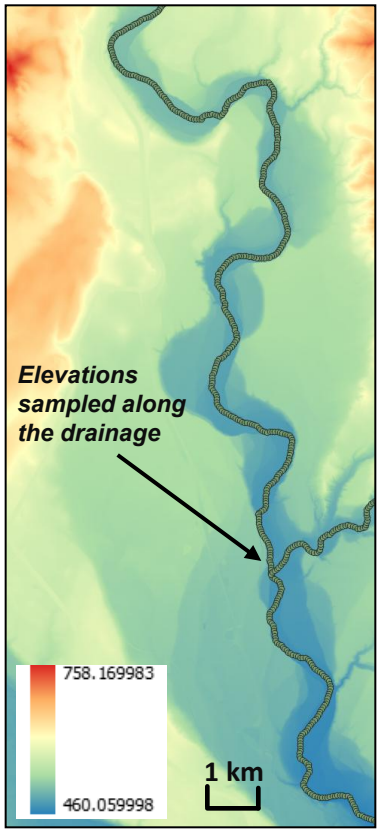
AWARE notes
The resulting difference removes the trend and only keeps small scale features. Level of detail is far superior but noise and artifacts are also amplified.

Final DEM = initial - trend

Gaussian distribution, 50 m – window

0 100 m

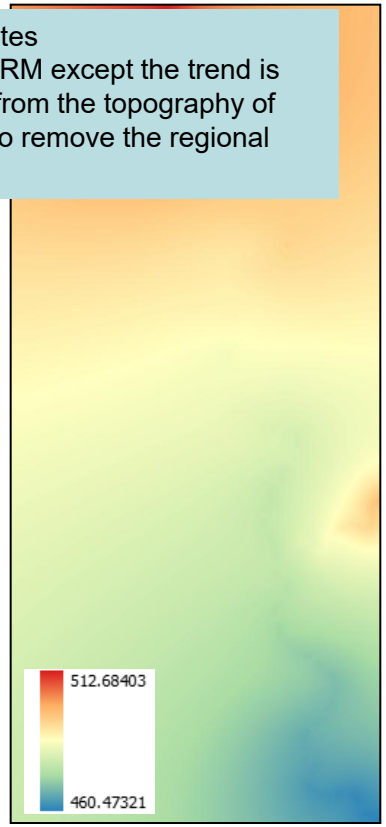
Relative Elevation Model (REM)



MNT

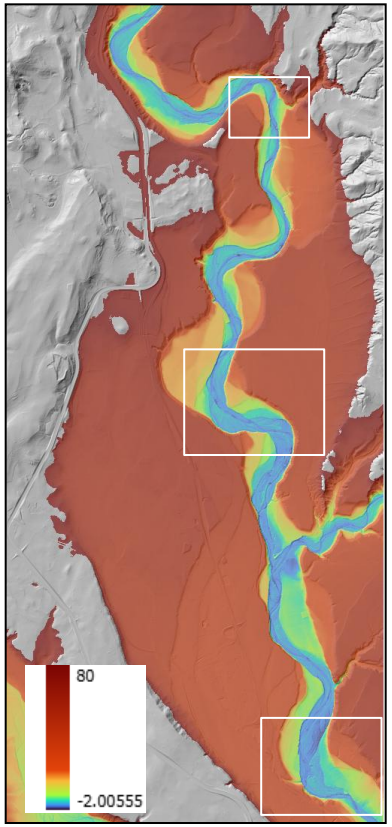
AWARE notes
Similar to LRM except the trend is calculated from the topography of drainages to remove the regional flow slope.

-



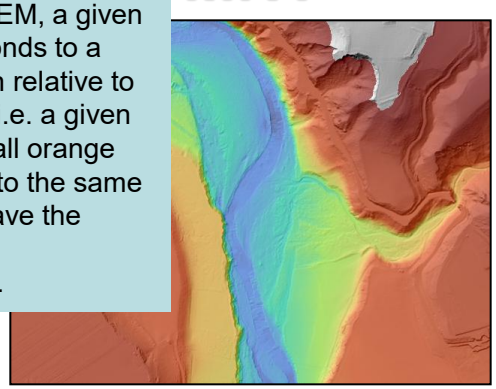
IDW

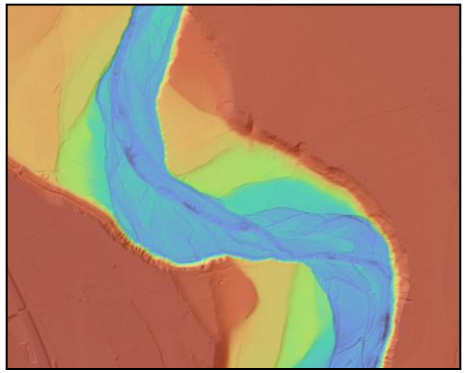
=

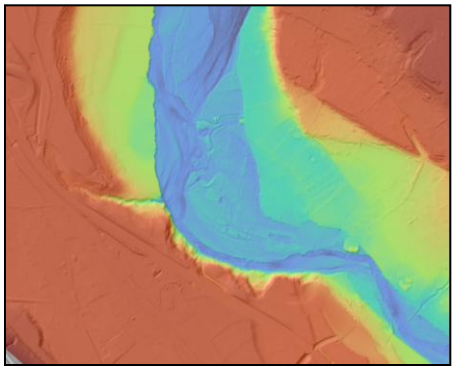


MNT-IDW

AWARE notes
On the final REM, a given color corresponds to a giver elevation relative to the drainage, i.e. a given terrace. E.g., all orange pixels belong to the same terrace and have the same age of abandonment.









Case studies

Mining

- Monitoring of excavated volumes by photogrammetry (UAV)
- Monitoring of veins (open-pit mines)
- Aggregate storage management



Barrick Gold

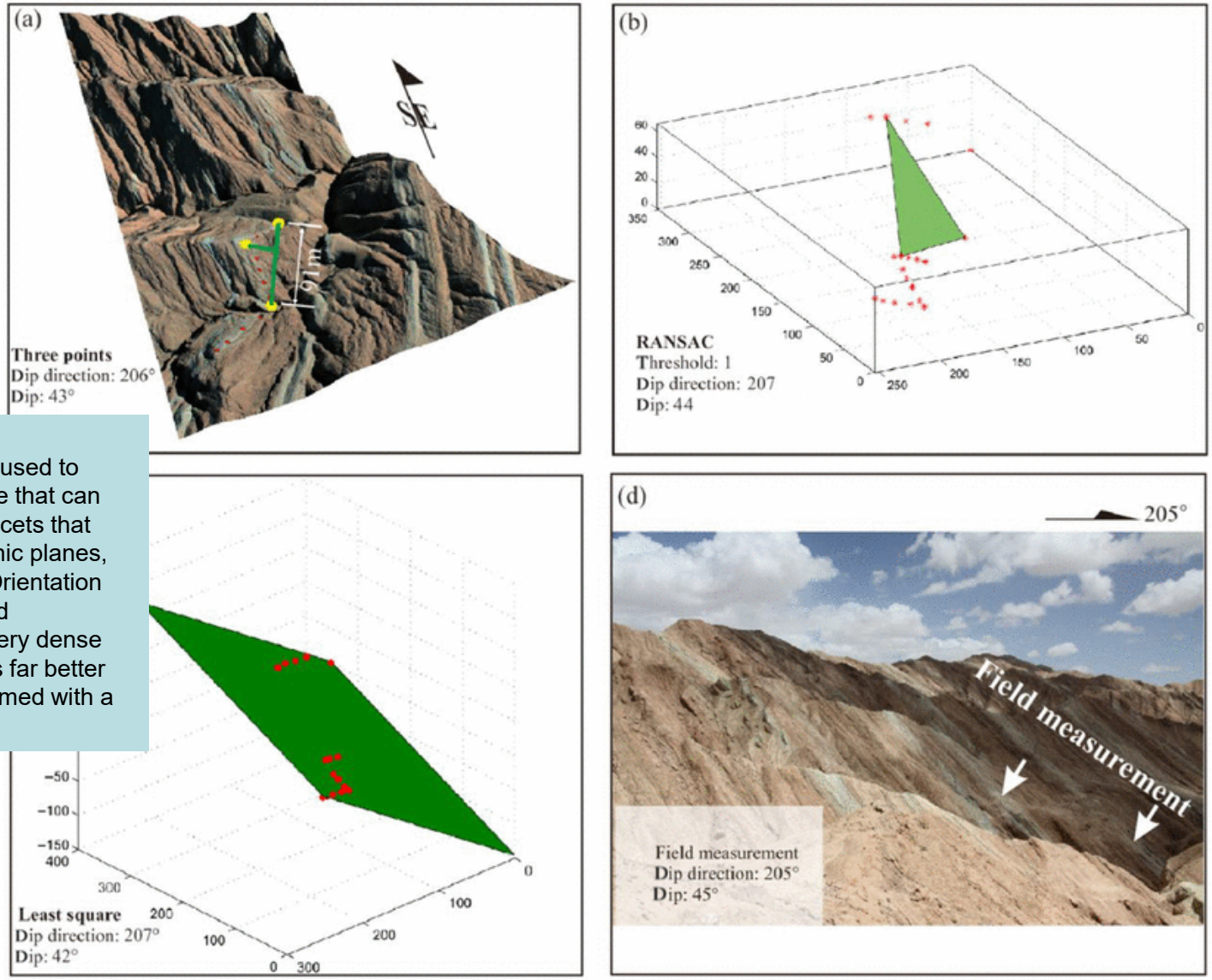
		RDO-eBee Data				Ward County RTK Data				
Pit Name	Pile Name	Cubic Meters	Cubic Yards	Tonnage Conversion	Tons	Cubic Yards	Tonnage Conversion	Tons	% Difference YD3	% Difference Tons
Effertz	Class 13	49685.75	64986.526		0	64996		0	0.01%	#DIV/0!
Arnold	Class13	18956.05	24793.585		0	25094		0	1.20%	#DIV/0!





Geological Mapping

AWARE notes
UAV photogrammetry is used to build a 3D model at scale that can be analysed to extract facets that correspond to stratigraphic planes, joints and fault planes. Orientation and dip can be computed automatically to derive very dense structural measurements far better than what may be performed with a compass.

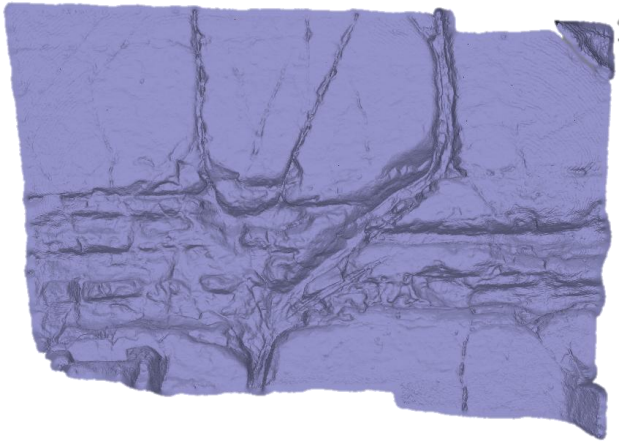


Chen et al., 2015

Inaccessible outcrops

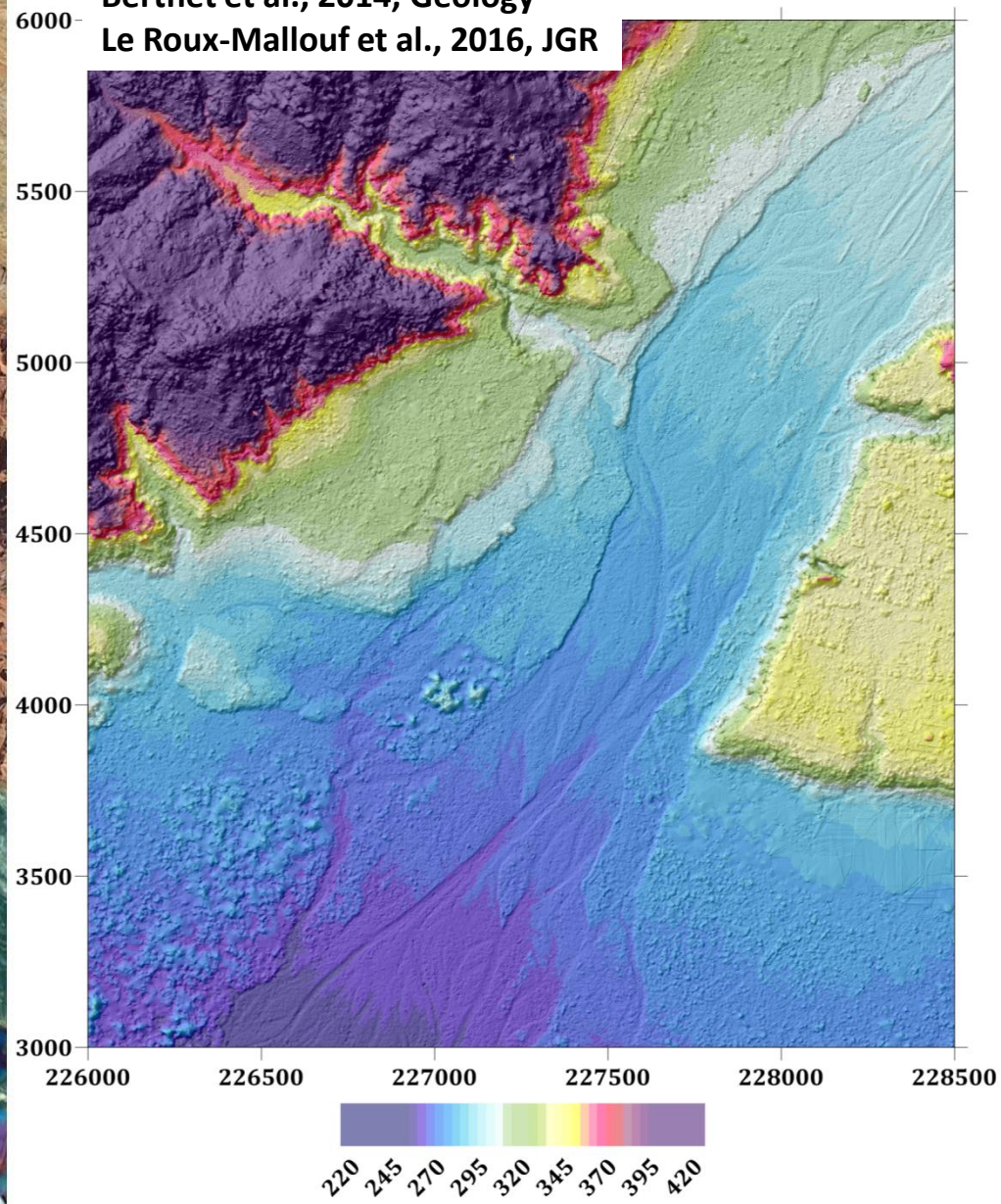
- Construction of a precise and oriented 3D model
- Semi-automatic identification of stratigraphy/faults
- Statistical structural measurements
- Measurements of inaccessible points
- Continuous log construction







Active deformation of the Himalayan Frontal Thrust

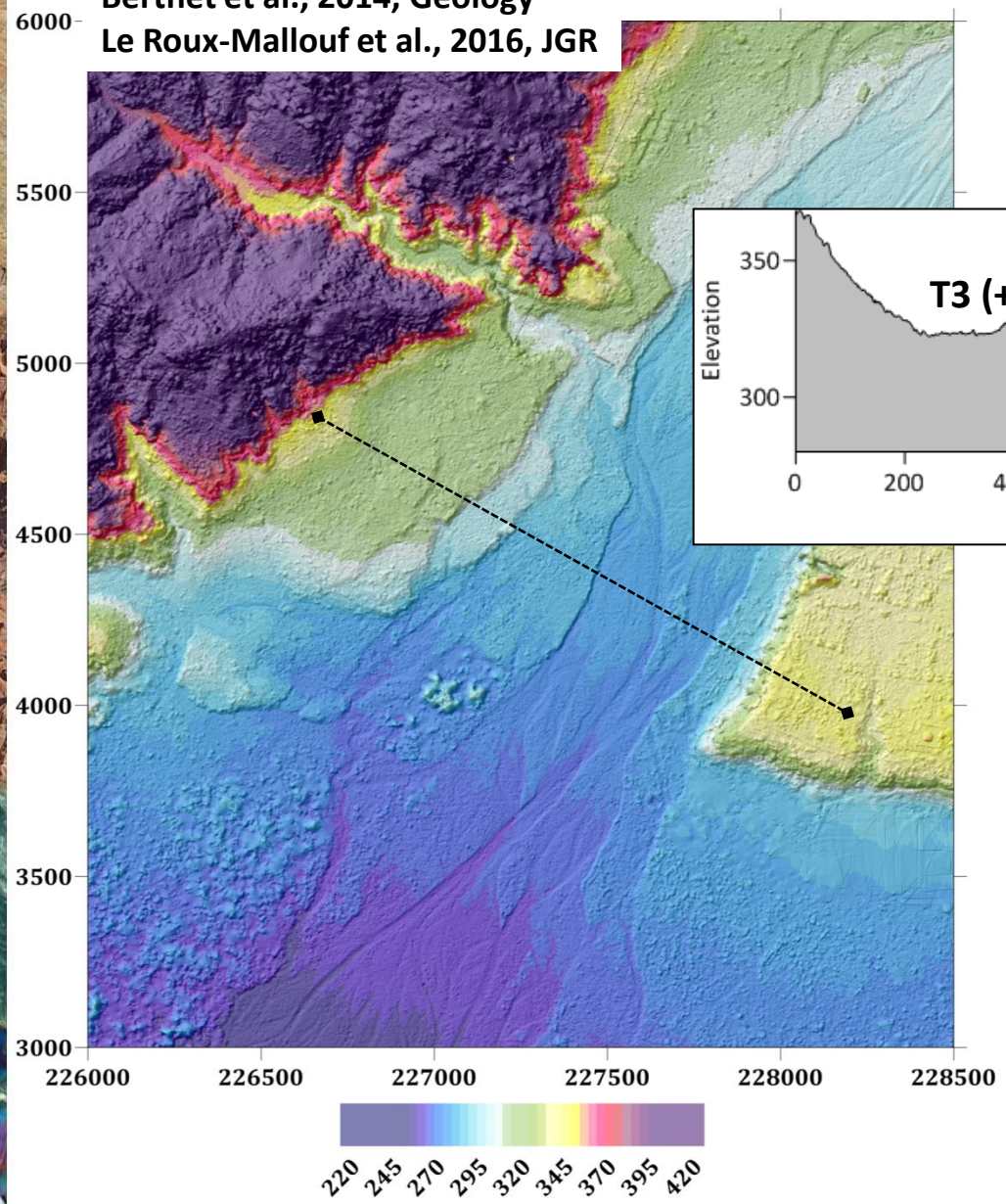


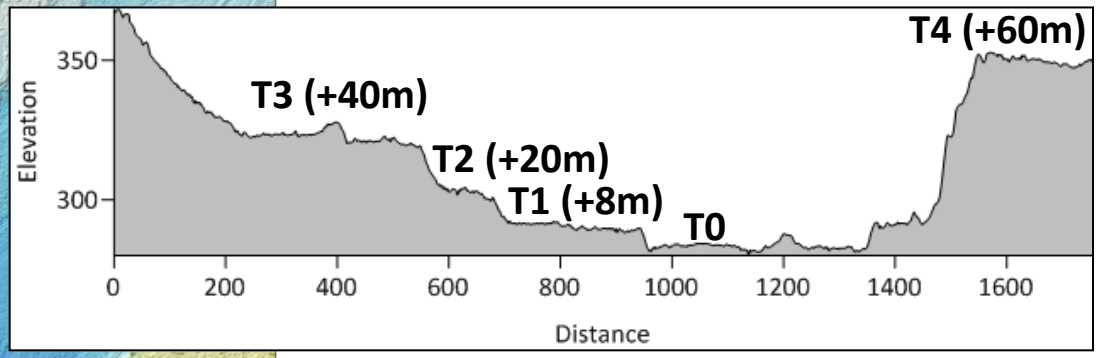


AWARE notes
Example from the Main Frontal Thrust in Bhutan. Left is 1-m resolution topography from Pleiades photogrammetry showing staircase terraces on the northern block and flat topo on the southern block. The limit is the MFT. Right is the same represented as a slope map to better show flat (light shade) terraces separated by steep scarps (dark shades). The MFT also appears as a steep scarp.

Active deformation of the Himalayan Frontal Thrust

Berthet et al., 2014, Geology
Le Roux-Mallouf et al., 2016, JGR



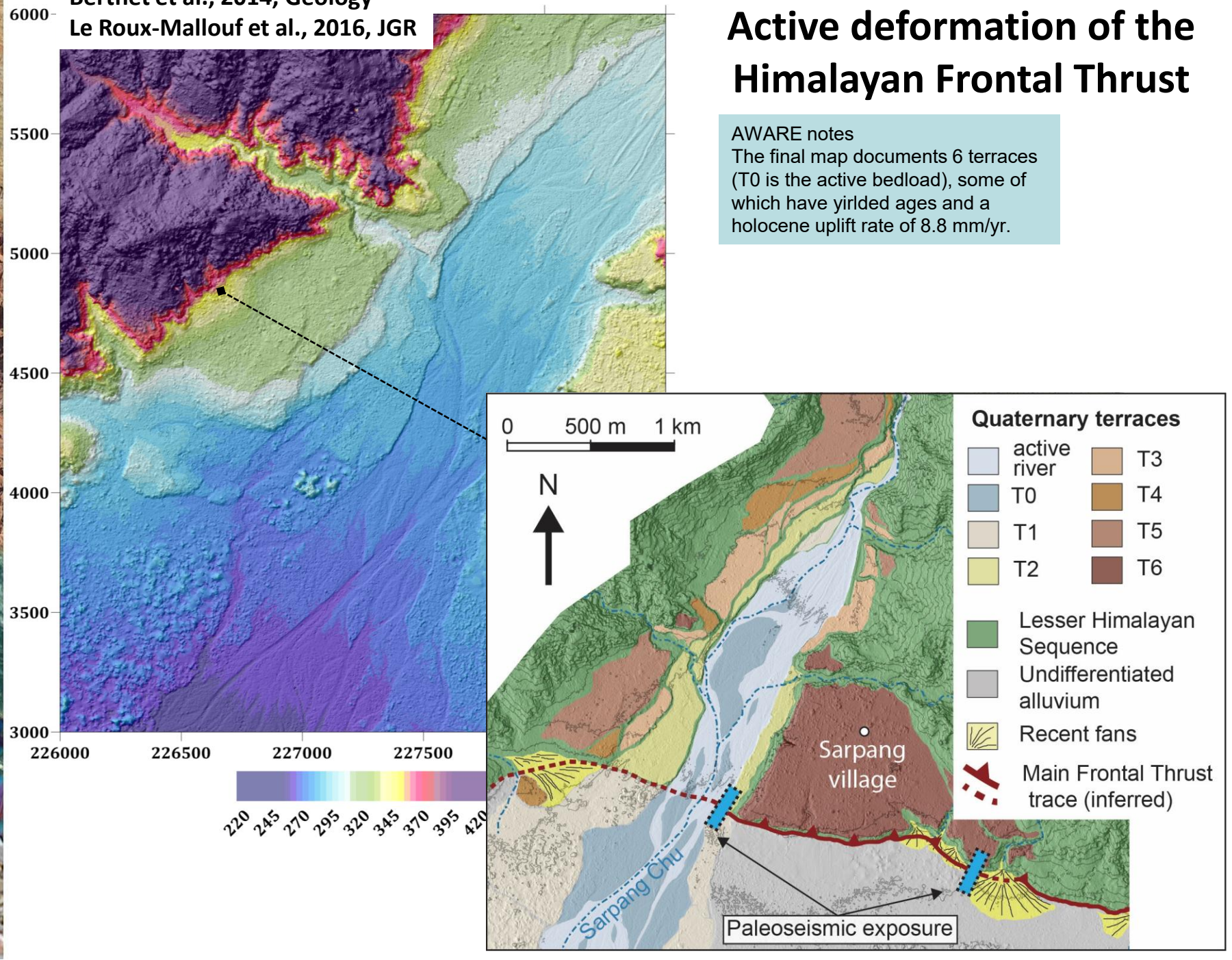


AWARE notes
A topographic profile extracted from the DTM show the staircase morphology with flat terrace threads and relative elevation wrt present stream. This morphology is not found to the south.

Active deformation of the Himalayan Frontal Thrust

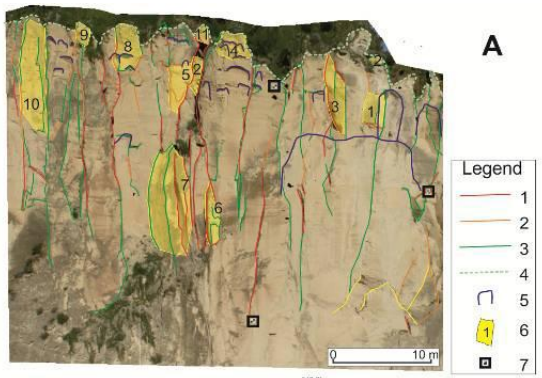
Berthet et al., 2014, Geology
Le Roux-Mallouf et al., 2016, JGR

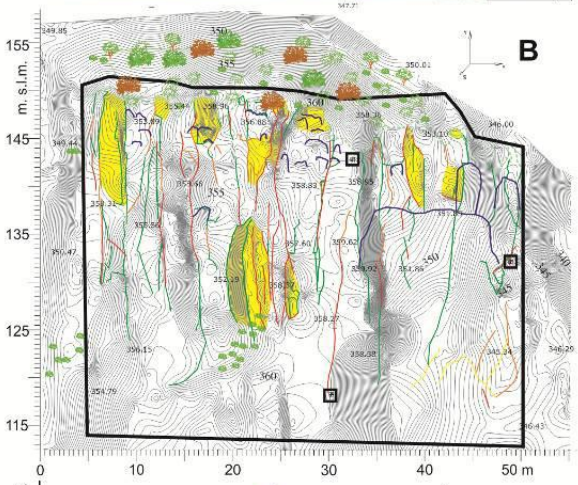
AWARE notes
The final map documents 6 terraces (T0 is the active bedload), some of which have yirlded ages and a holocene uplift rate of 8.8 mm/yr.

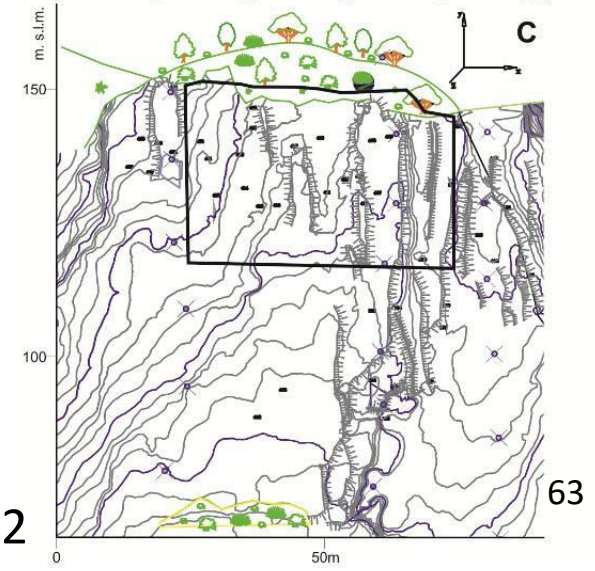


Instability monitoring





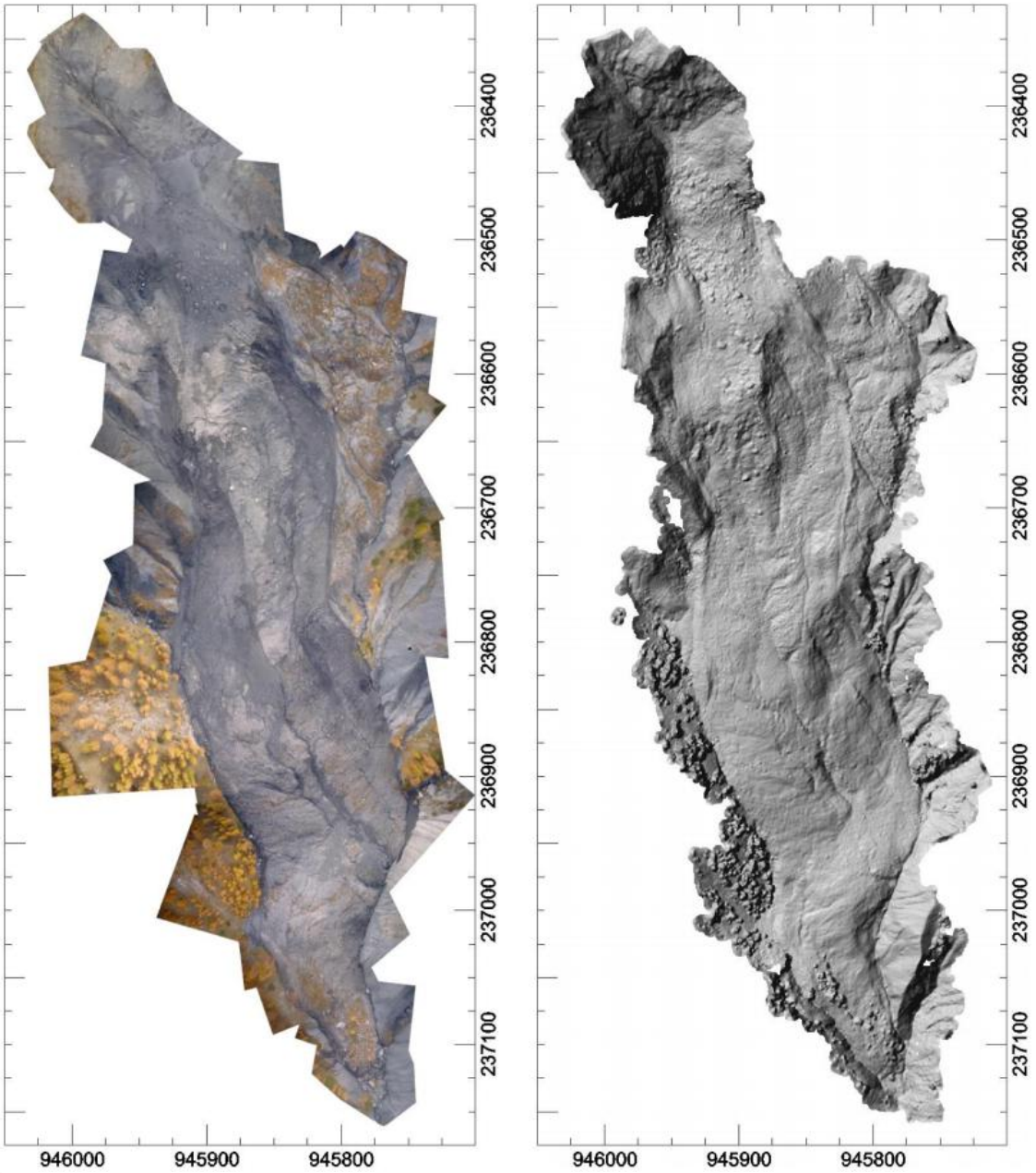




- Mapping of joint families
- Identification of open/closed cracks

Danzi et al., 2012

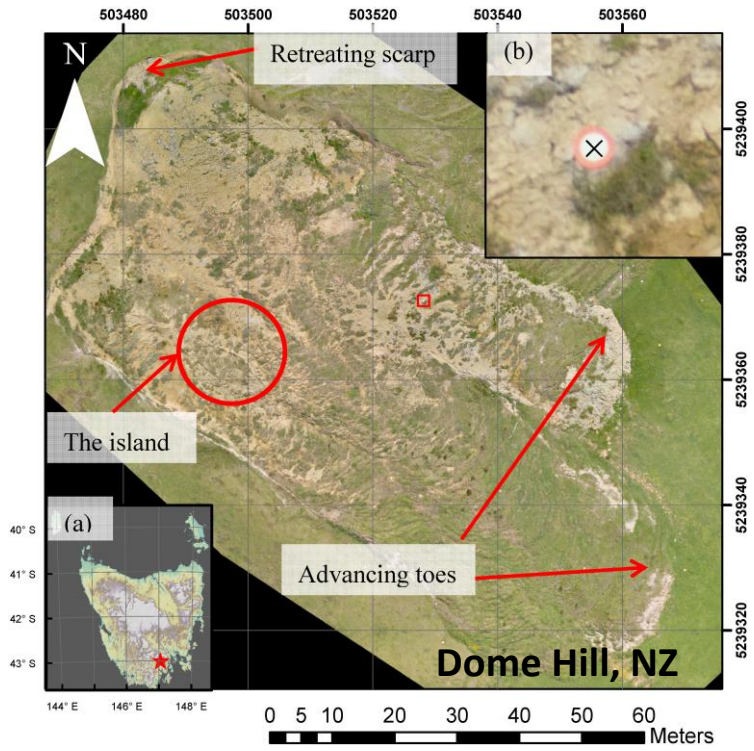
Landslide mapping

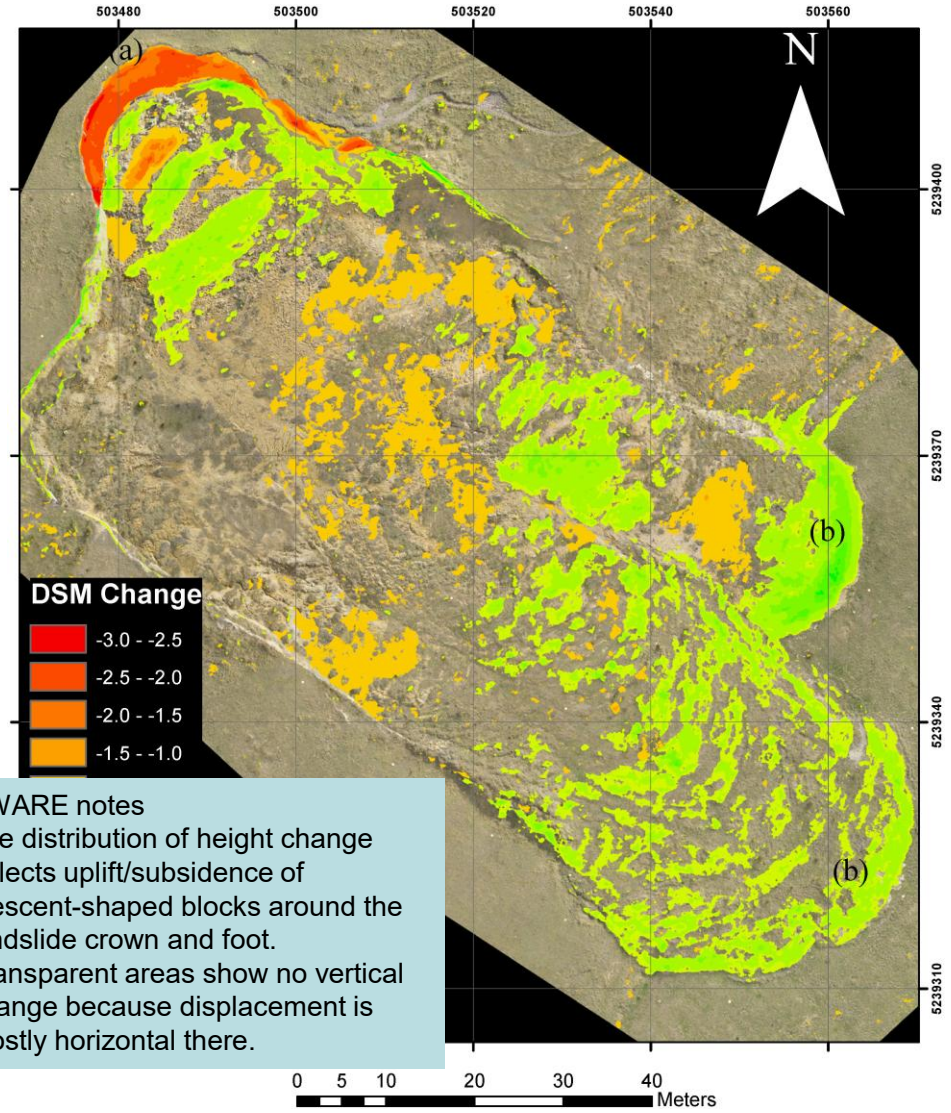


- Super-Sauze Slide
- UAV Photogrammetry
- Detailed mapping of deformation zones
- Initial state for monitoring

Niethammer et al., 2010

Landslide deformation





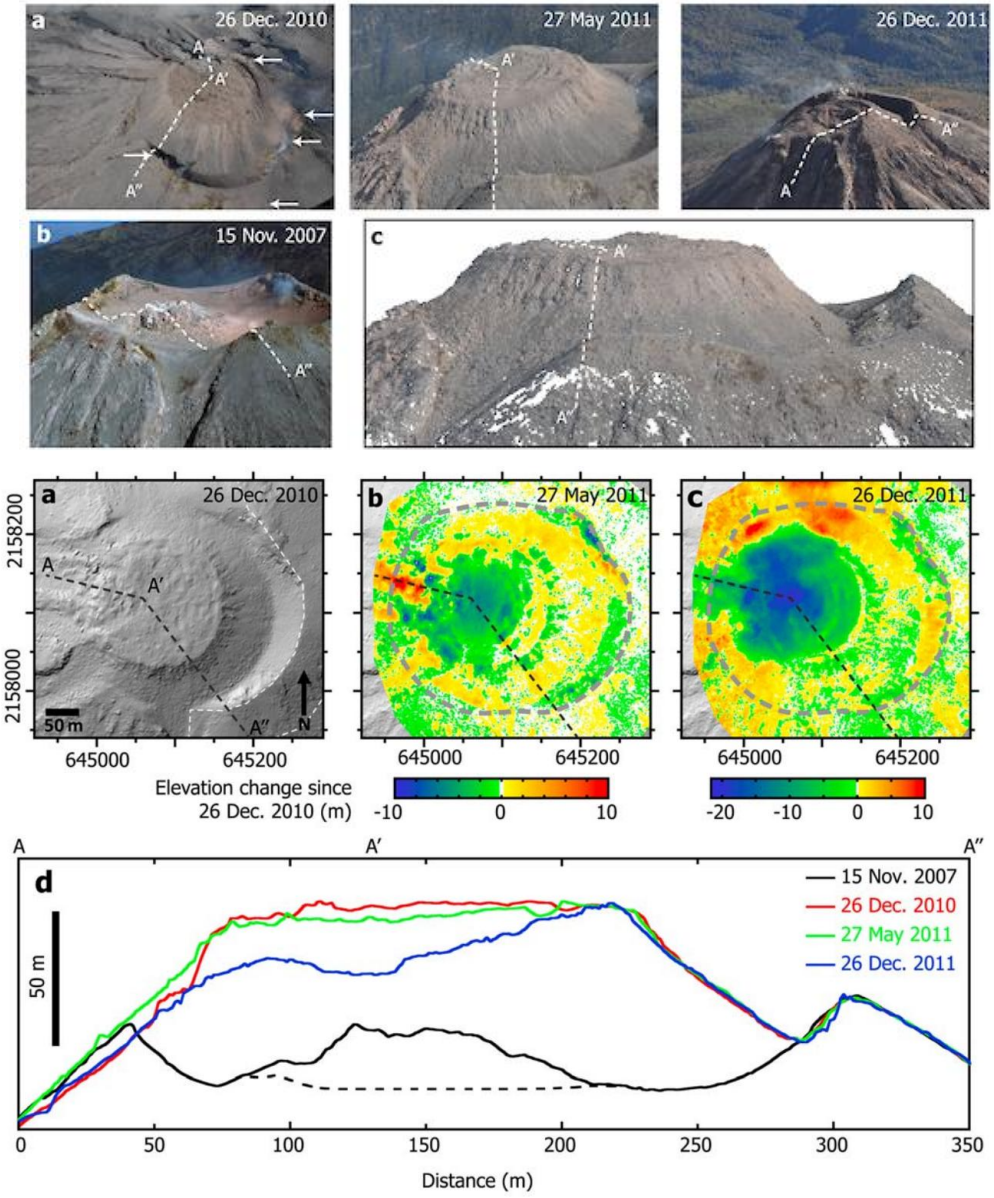
- UAV Photogrammetry
- Tracking of displacements by topographic difference (V) and image correlation (H)
- Displacements of ~3 m over a year

AWARE notes
The distribution of height change reflects uplift/subsidence of crescent-shaped blocks around the landslide crown and foot.
Transparent areas show no vertical change because displacement is mostly horizontal there.

Turner et al., 2015

Volcano monitoring

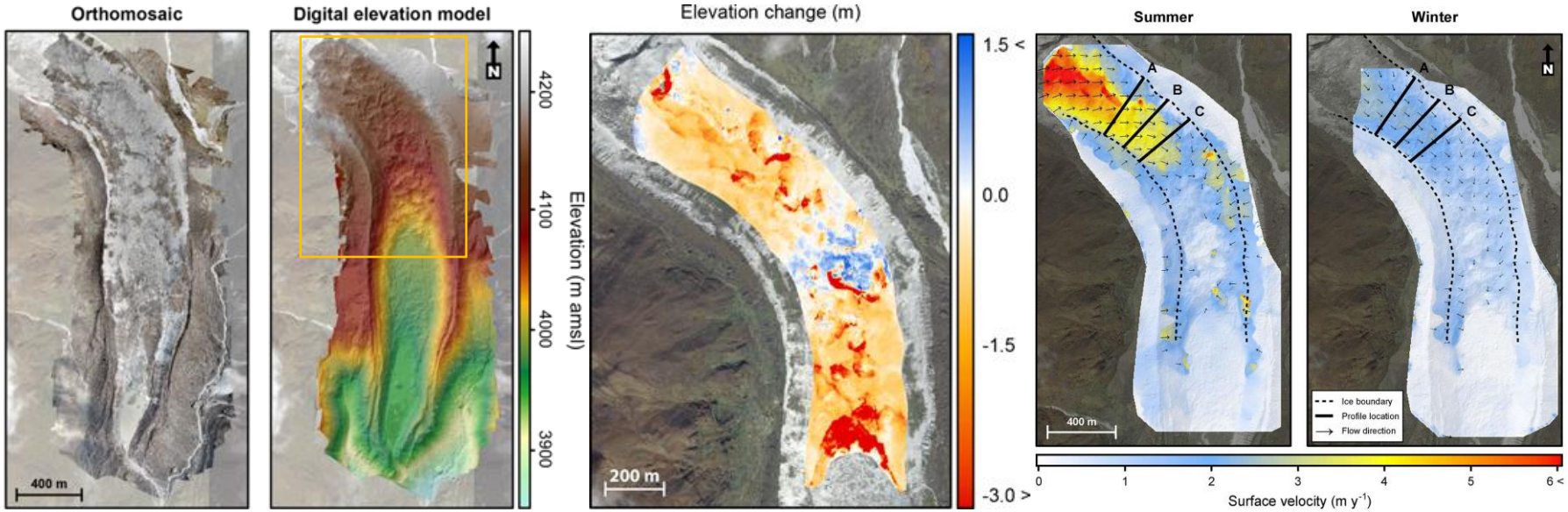
- Colima Volcano (MX)
- 4 overflights 2007-2011
- Density 4-45 pts/m²



- ➢ Off-center dome by 30 m
- ➢ Volume loss between 2010 and 2011
- ➢ Formation of faults during the June 2011 event

James & Varley, 2012

Glacier monitoring



Immerzeel et al., 2014 Kraaijenbrink et al., 2015

- Monitor melting (climate response)
- Seasonal variations in flow dynamics
- Meltwater lake feeding and GLOFs hazard management

