

# Snow avalanche inventory and hazard assessment in Făgăraș Mountains (Southern Carpathians)

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- The main objective is to develop methodology supporting a future service providing hind-cast and (almost) real-time avalanche information retrieved from earth observation data.
- **Sub-objectives:**
  - create the avalanche inventory and the associated geodatabase based on VHR images
  - develop robust pattern recognition techniques to detect and map the outline of avalanches in VHR optical satellite images
  - develop robust change-detection algorithms to detect changes in land and snow cover caused by avalanches in High Resolution (HR) satellite data
  - perform simulation of avalanche trajectories based on DEM's, release areas and friction parameters
  - develop improved avalanche hazard assessment

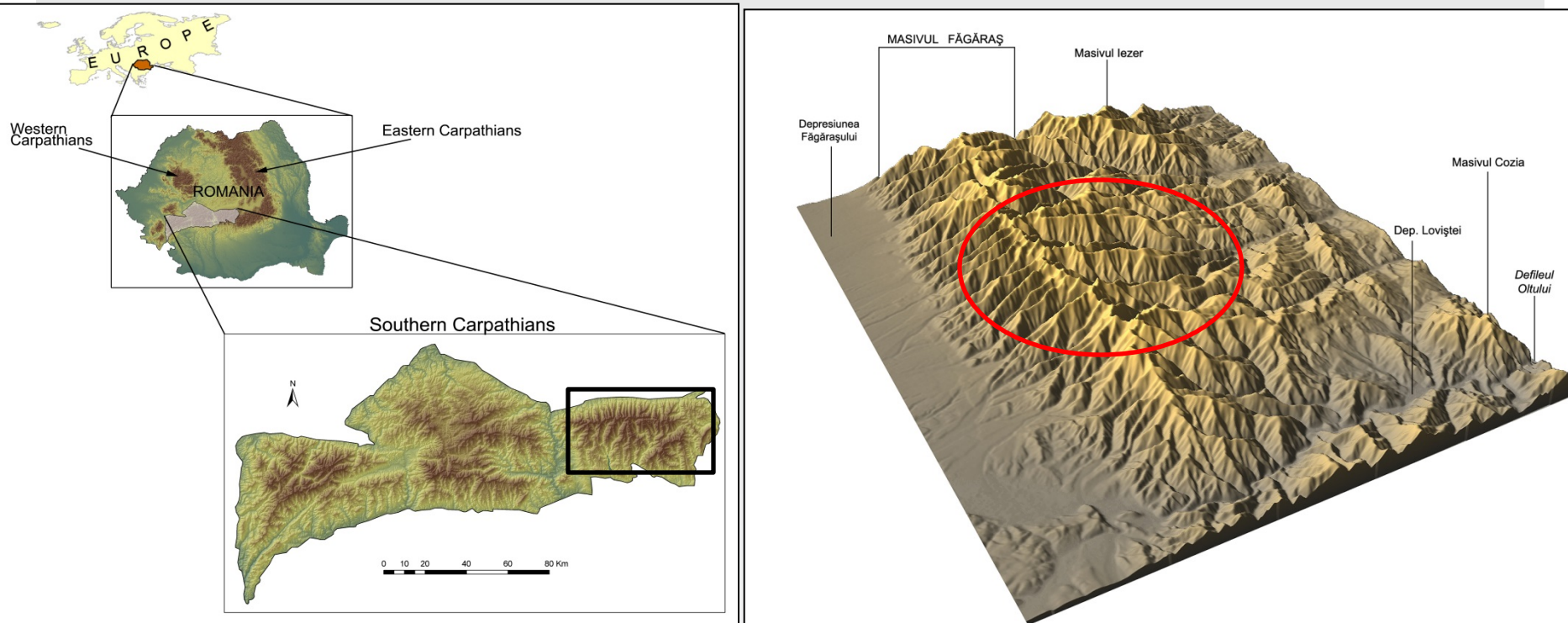


## The objective evaluation of the location and numbers of avalanches based on VHR satellite images/UAV images

- To assess the magnitude of this phenomenon in Carpathian Mts.
- To create a dataset for development and validation of the algorithm for detection of avalanches in optical VHR satellite images
- To calibrate the RAMMS avalanche simulation model for Carpathians
- Completion of and validation of avalanche hazard maps



## Study area - Făgăraș Mountains (Southern Carpathians)

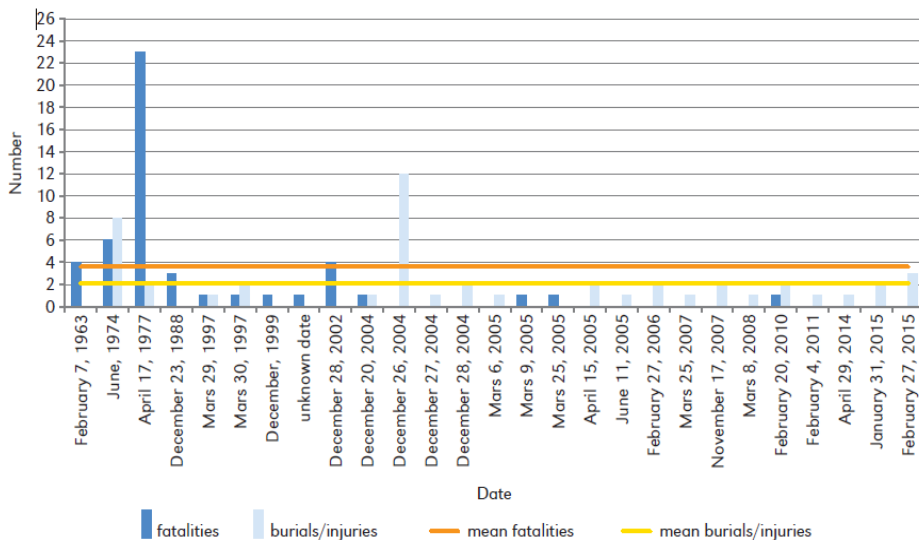


- The most massive and highest part of the Romanian Carpathians
- 10 % of the mountain areas lies above 2000 m (2544 m max. elevation)
- snow cover duration ~ 6 - 7 months/year
- area frequently affected by snow avalanches



## • Existing information about avalanches in Romanian Carpathians

- Avalanches occur in the highest part of the Romanian Carpathians (4000 km<sup>2</sup>)
- This area is **not** permanently inhabited; The roads are closed during the winter
- Only two sky domains are located in areas affected by snow avalanches.



**27 avalanche accidents** (fatalities and burials/injuries) were recorded in Făgăraș Mountains for the years **1963-2015**

- **845 avalanche cases** have been recorded by now, in **all massifs of Romanian Carpathians** (since 1704)
- **Lack of information and no consistent databases exists.**
- **The information is sparse, at local, point- scale;**
- From 2004 – National Meteorological Administration started permanent service for monitoring the snow parameters and snow avalanches, but only at 4 meteorological station.



## • Data and Methods

### Difficulties in finding proper VHR satellite images:

- Acquisition date of the image correlated with recorded avalanches
- Cloud cover

**GeoEye-1** (April 11<sup>th</sup> 2012) – late winter season

Cloud cover = 0%

Area no.1 - 55 km<sup>2</sup>

Area no.2 - 102 km<sup>2</sup>

**Panchromatic: 41 cm (0.5 m)**

Black & White: 450 - 800 nm

**Multispectral: 1.65 m (2 m)**

Blue: 450 - 510 nm

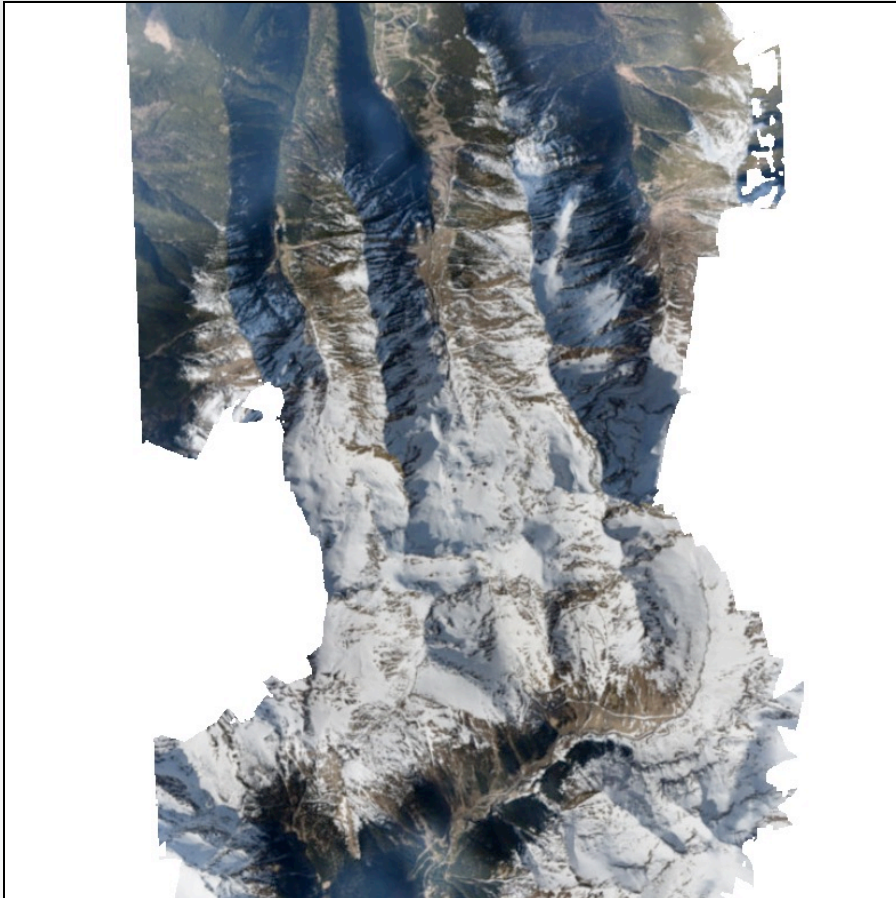
Green: 510 - 580 nm

Red: 655 - 690 nm

Near-IR: 780 - 920 nm



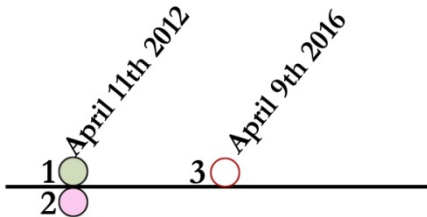
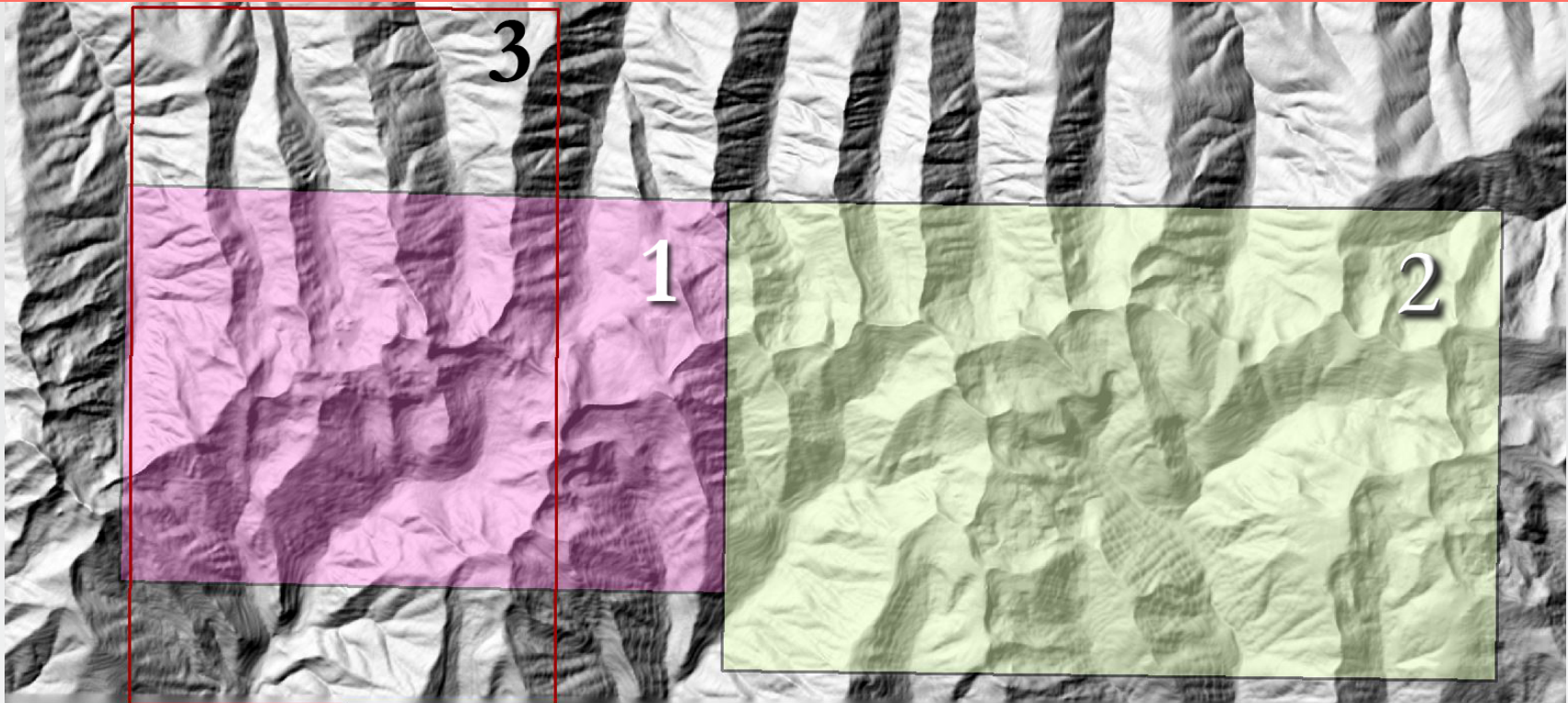
- Drone based image - 12 April 2016



- DIY (“Do It Yourself”) glider drone
- NIKON D810 DSRL camera (36.2 MP)
- The images cover an area of 40.8 km<sup>2</sup> that overlaps the GeoEye-1 scene in the Transfăgărășan sector
- Agisoft Photoscan Pro
  - Orthophoto – 0.5m resolution*
  - DSM - 0.5 m resolution*
- Only RGB channels
- No clouds



- Data and Methods



**Swath and acquisition timing of VHR images (1–2) and drone – based airphoto (3)**



## • Data and Methods

- **Digital Elevation Model (DEM)** (10 m spatial resolution) derived from contour lines (topographic map at 1:25 000 scale),
- **Digital Surface Model (DSM)** (0.5 m resolution) UAV images and structure-from-motion (SfM) technique
- **DEM/DSM derived parameters**
- **Color airphotos:** summer 2012, 0.5 m spatial resolution
- **GIS vector database** with avalanche tracks mapped on the field for several valleys in central Făgăraș Mts.



- Orthorectification using DSM/DEM
- Image enhancing and transformation for a better avalanches visualisation: PCA, normalized differentiation index, false – color composites
- Excluding regions where avalanches have no/small probability to occur (geomorphometry and land cover)
- Snow avalanche (debris) mapping based on manual approach (digitized using different “basemaps”)

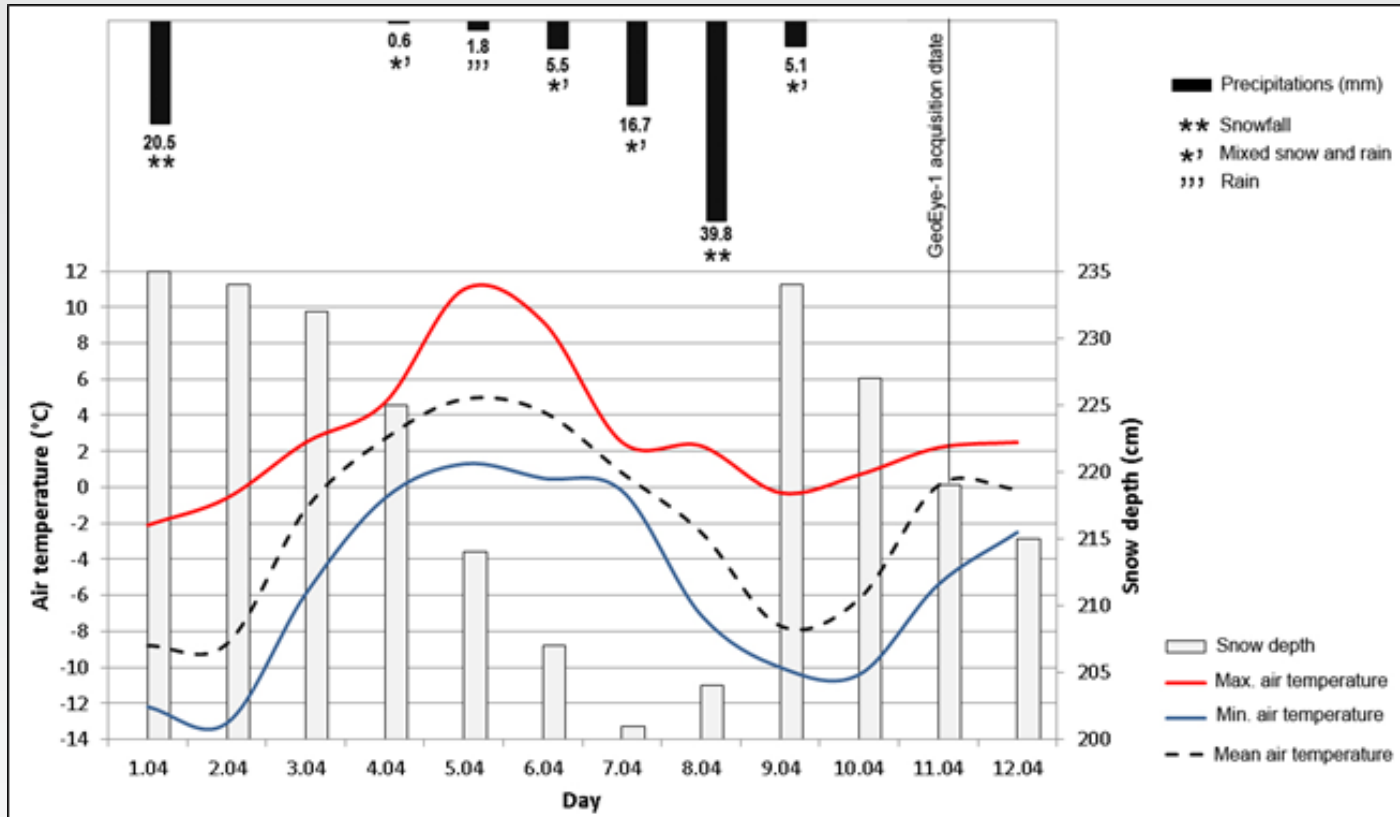


- **Meteorological settings**
- To understand the meteorological condition in the moment when avalanches have been triggered
- To quantify the time lag between avalanches occurrence and acquisition of the satellite/UAV data
- Both spectral signature and texture of the avalanche debris are changing in relation to temperature variation and the amount of precipitation
- The longest the period since avalanche was released till image was acquired by sensor the more difficult is to detect it on the image.



- Meteorological settings

## April 2012 (GeoEye-1 image acquisition)

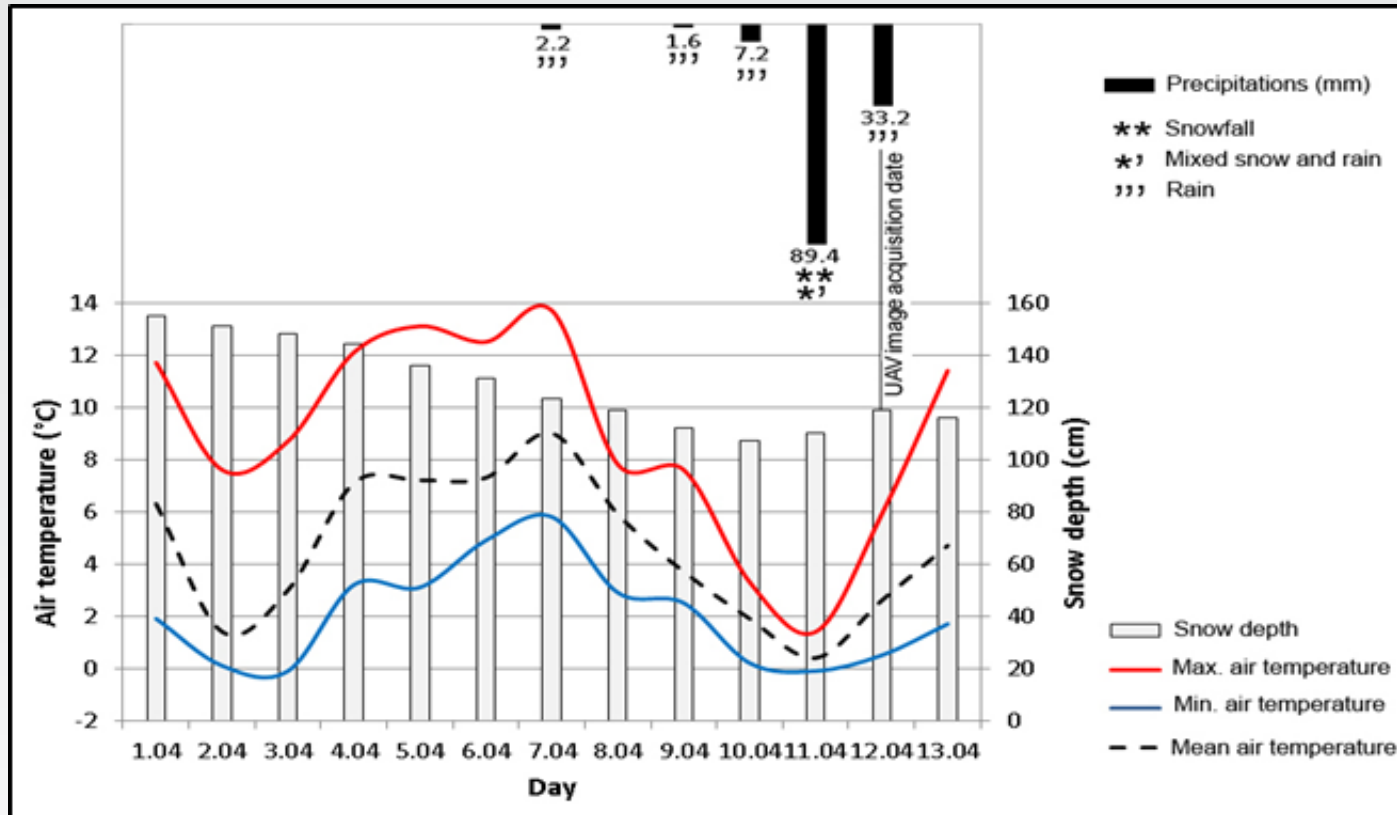


Time lag: 1 day for majority of the avalanches  
6 days for the old avalanches



- Meteorological settings

## April 2016 (Drone image acquisition)

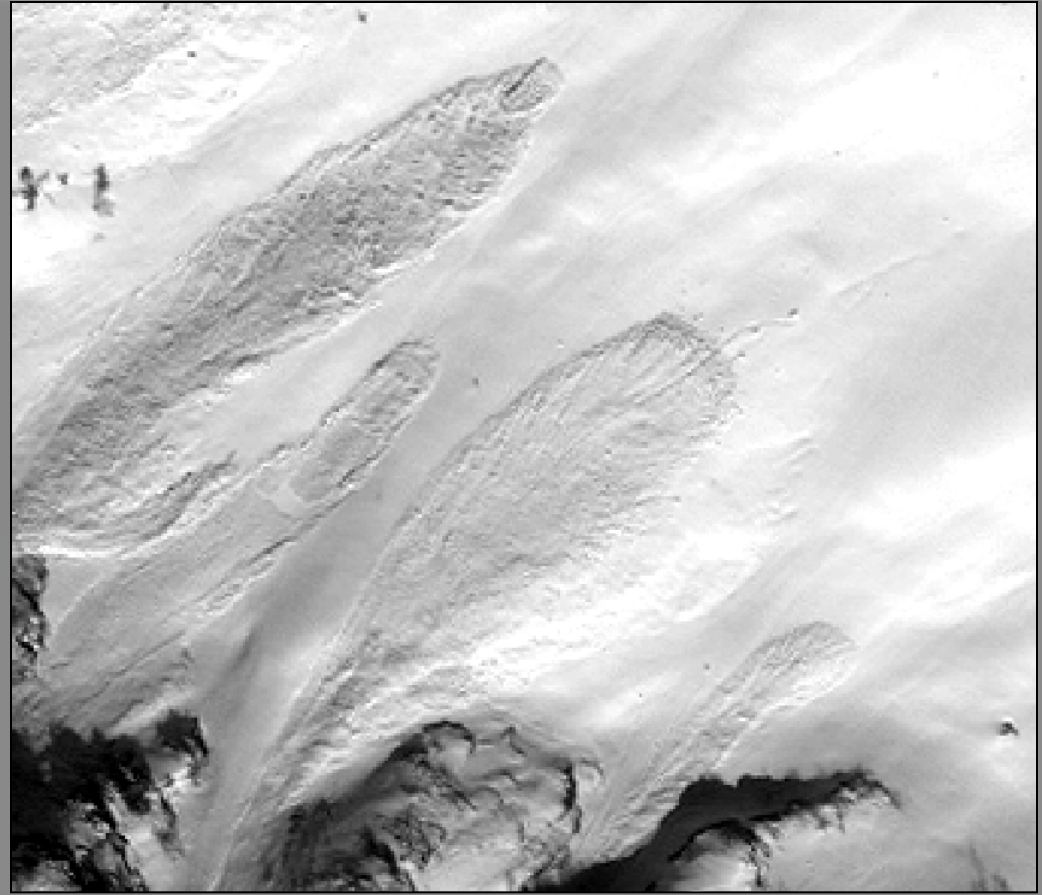


Time lag: few hours for the majority of avalanches  
5 – 6 days for the old avalanches



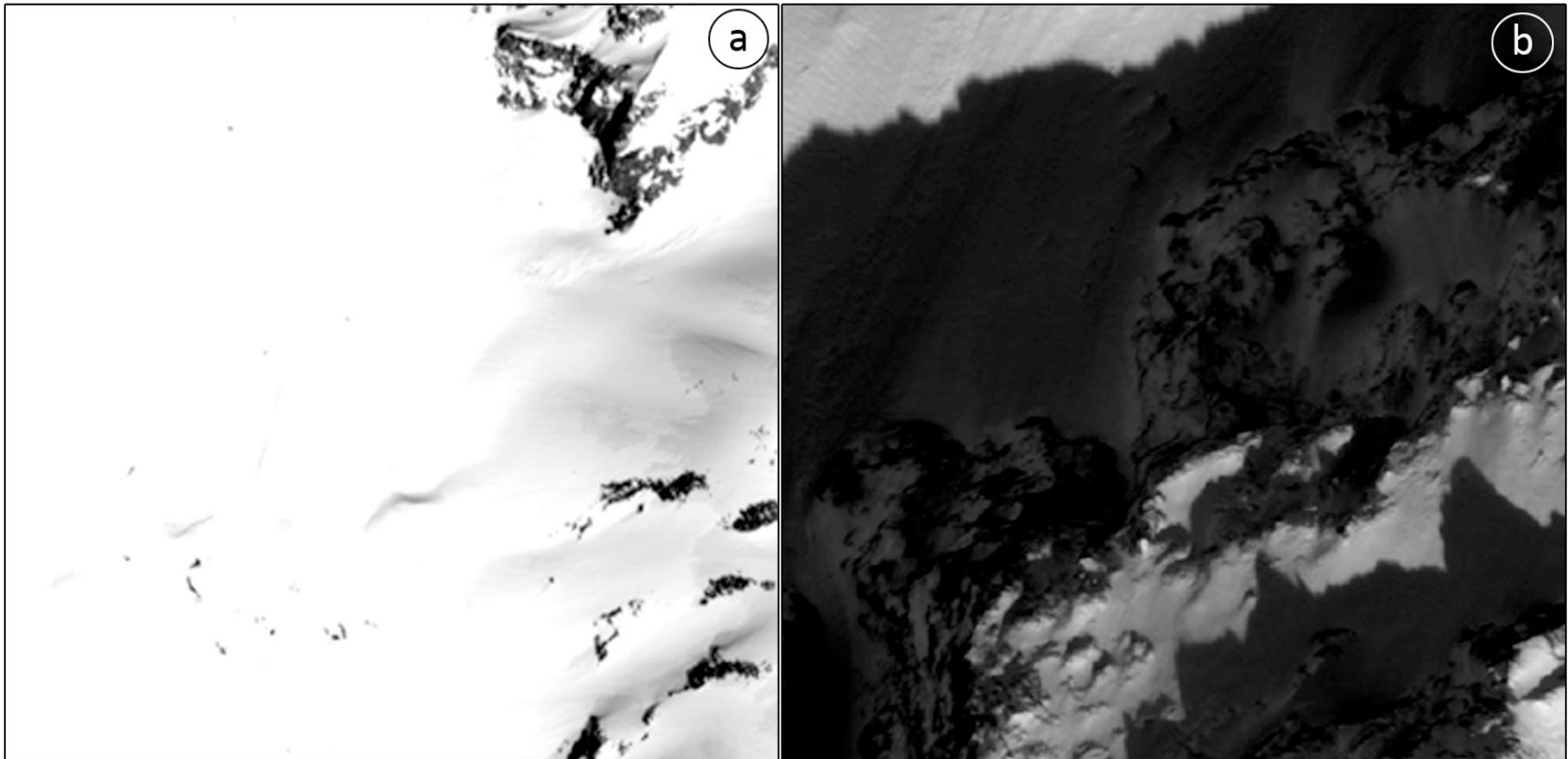
## How does avalanches looks like in the satellite images?

- Elongated, tongue-shaped objects
- Avalanche debris have **very similar spectral behavior** with undisturbed snow, excepting springtime
- Higher **surface roughness** then surrounding, undisturbed snow (eliminated during next snowfall!)





## Difficulties in image analysis:

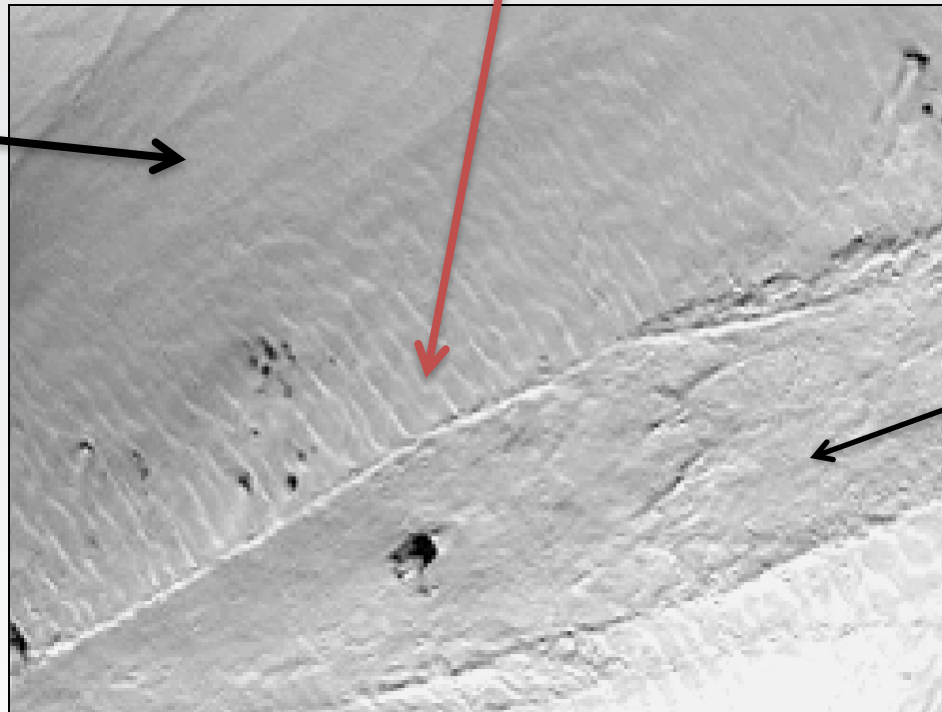


Overexposed areas (a) and areas in shadow (b) – panchromatic band (GeoEye-1).



Pattern created by wind, with a texture highly similar to the snow affected by avalanches

Undisturbed  
snow



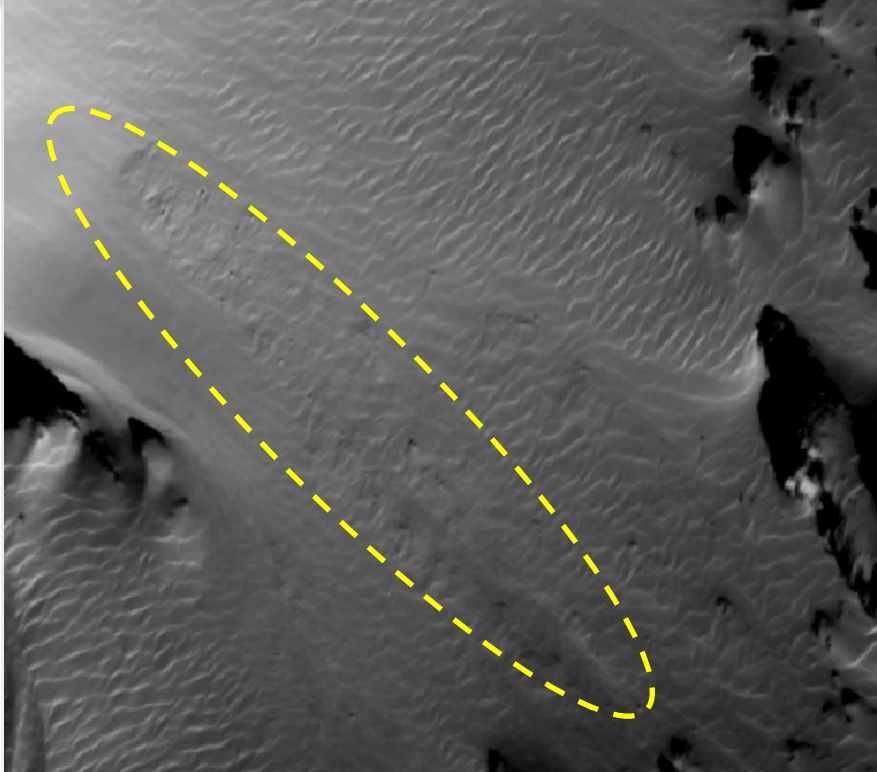
Avalanche  
debris





Man – made pattern with higher texture than undisturbed snow





Older avalanches are more difficult to distinguish than “fresh” ones.





Pattern made by melting wet snow which has fallen from the steep slopes and was rolled downwards – “rack” pattern

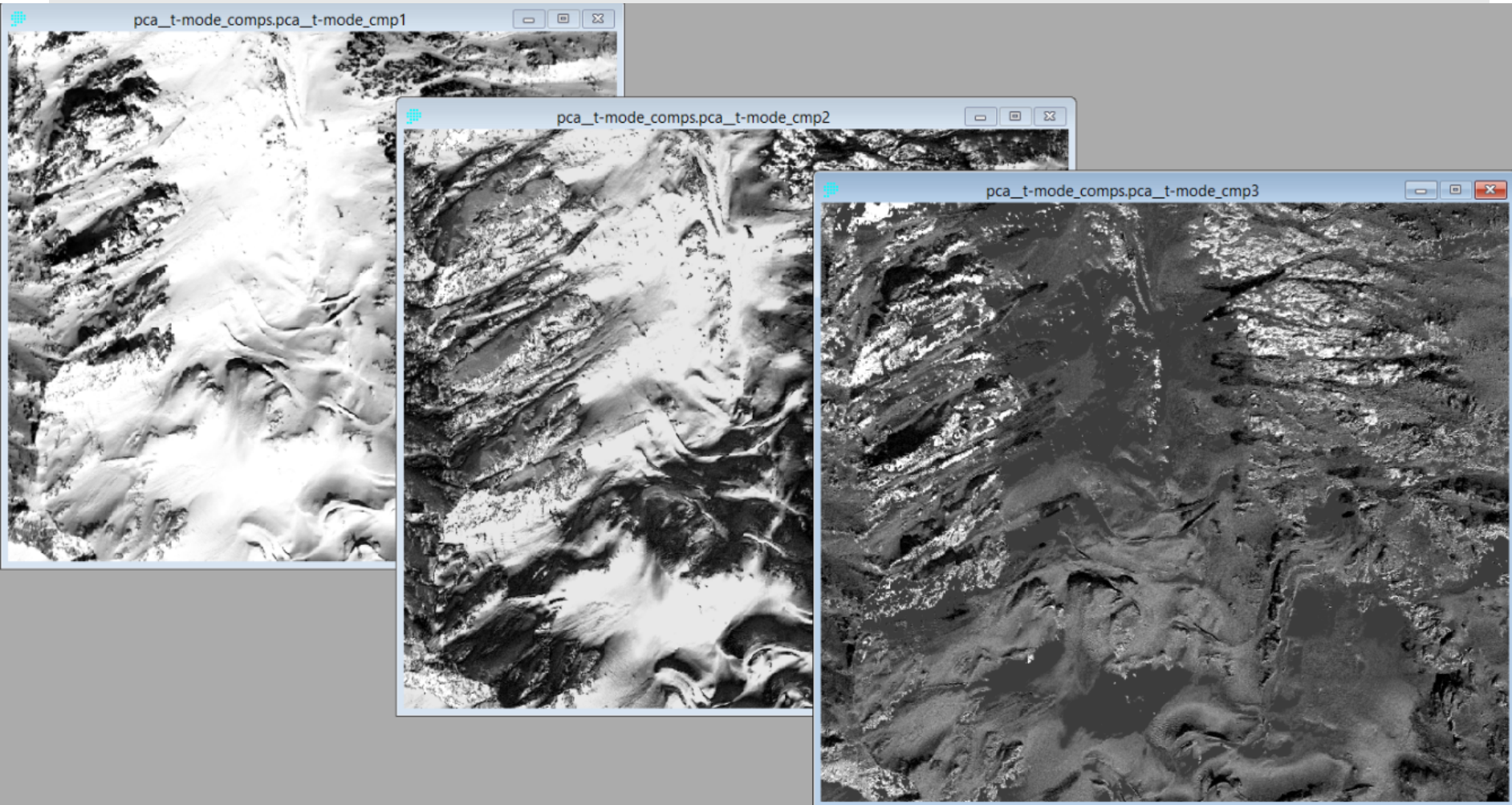


- Correlation matrix between GeoEye-1 bands/principal components

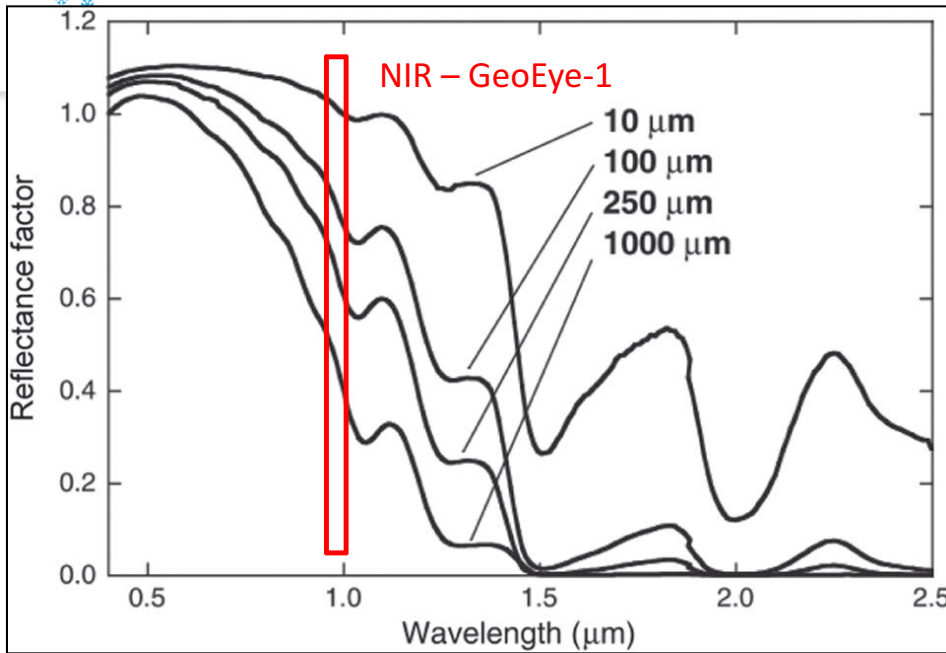
	Green	Blue	Red	NIR	Pan	PCA1	PCA2
Green							
Blue	0.963						
Red	0.989	0.932					
NIR	0.976	0.919	0.984				
Pan	0.962	0.899	0.976	0.958			
PCA1	0.996	0.955	0.995	0.986	0.978		
PCA2	0.056	0.287	-0.054	-0.061	-0.151	0.124	
PCA3	0.014	-0.053	0.027	0.137	-0.135	0.052	0.079



## Principal Component Analysis







NIR reflectance is very sensitive to snow grain size, especially from 0.9 to 1.3 nm (Dozier, 1989)

ange perspective (SnowBall)

The optical equivalent grain size

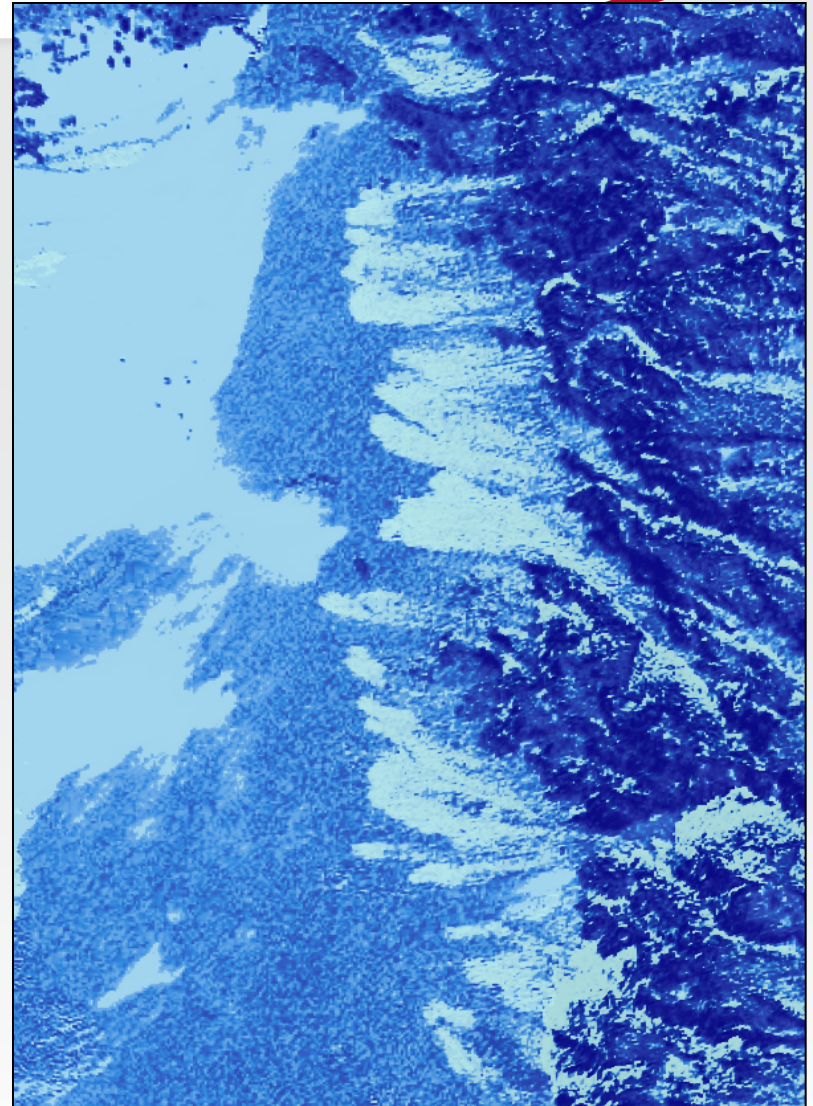
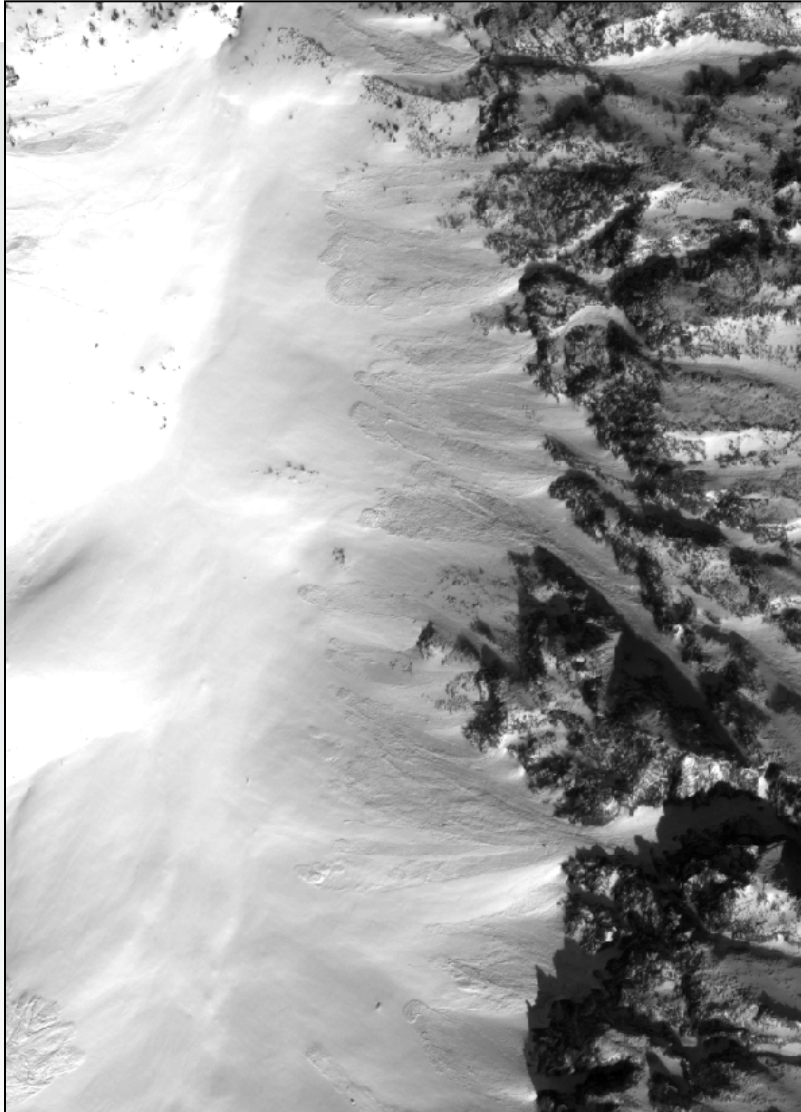
Indicator to distinguish between different snow-surface types

Snow surface type mapping based on NDI (Bühler et al., 2015)

$$\text{NDI} = (\text{RED} - \text{NIR}) / (\text{RED} + \text{NIR})$$

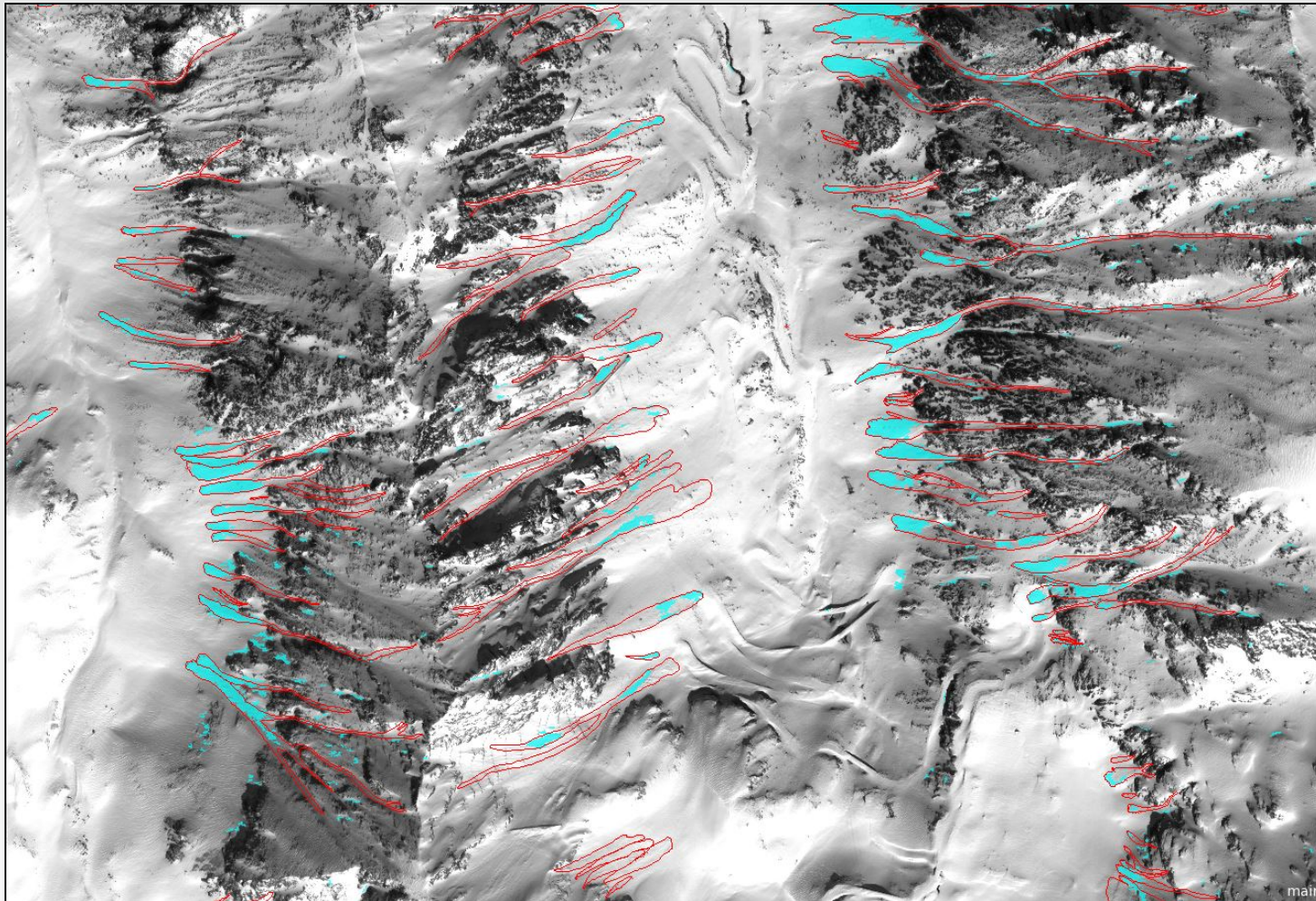
We used for the first time this index to detect snow avalanches





Panchromatic band (left) and NDI (avalanches can be observed in light blue)

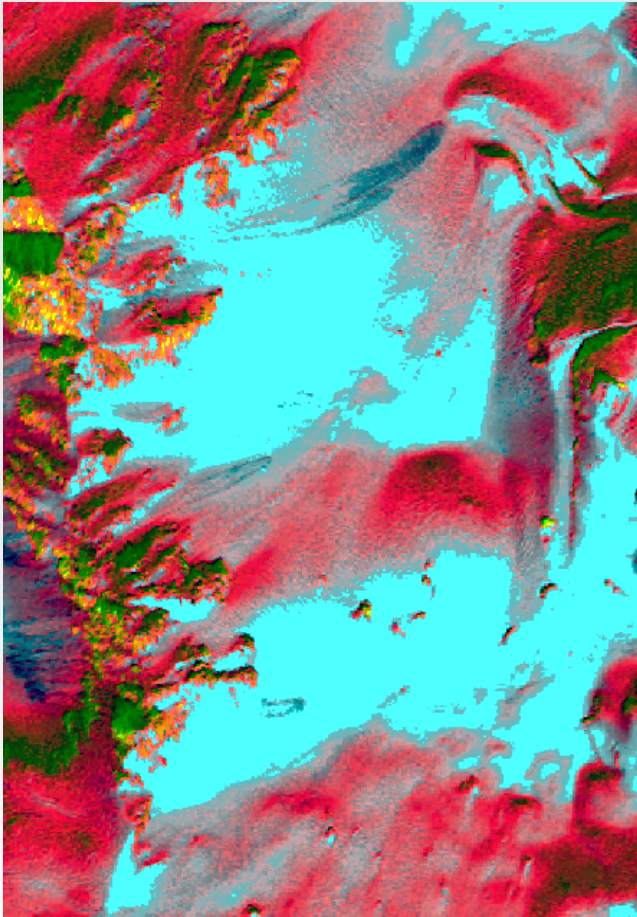




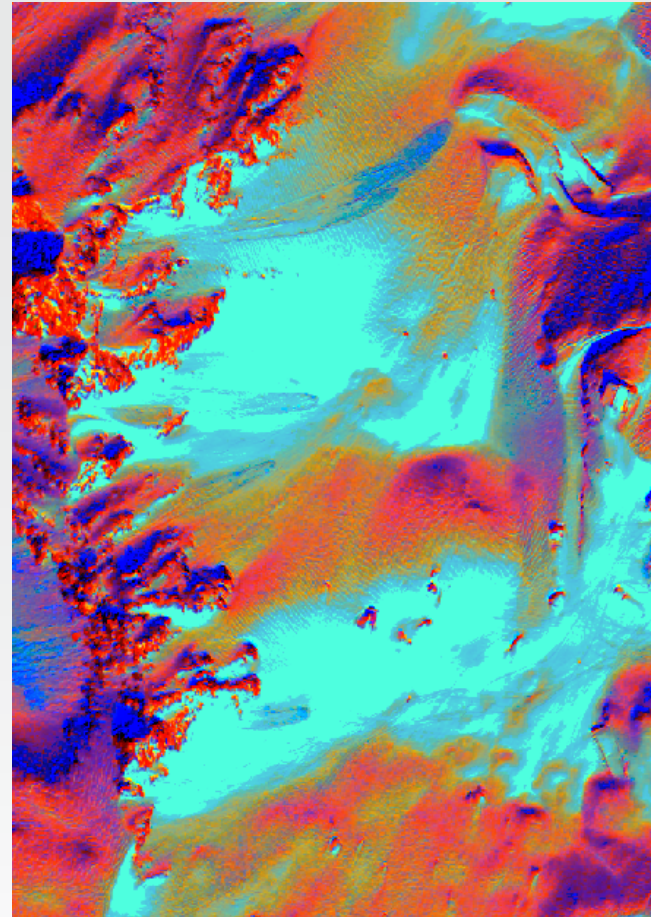
OBIA classification based on NDI and Pan bands (eCognition software)



## RGB false-colour composite images

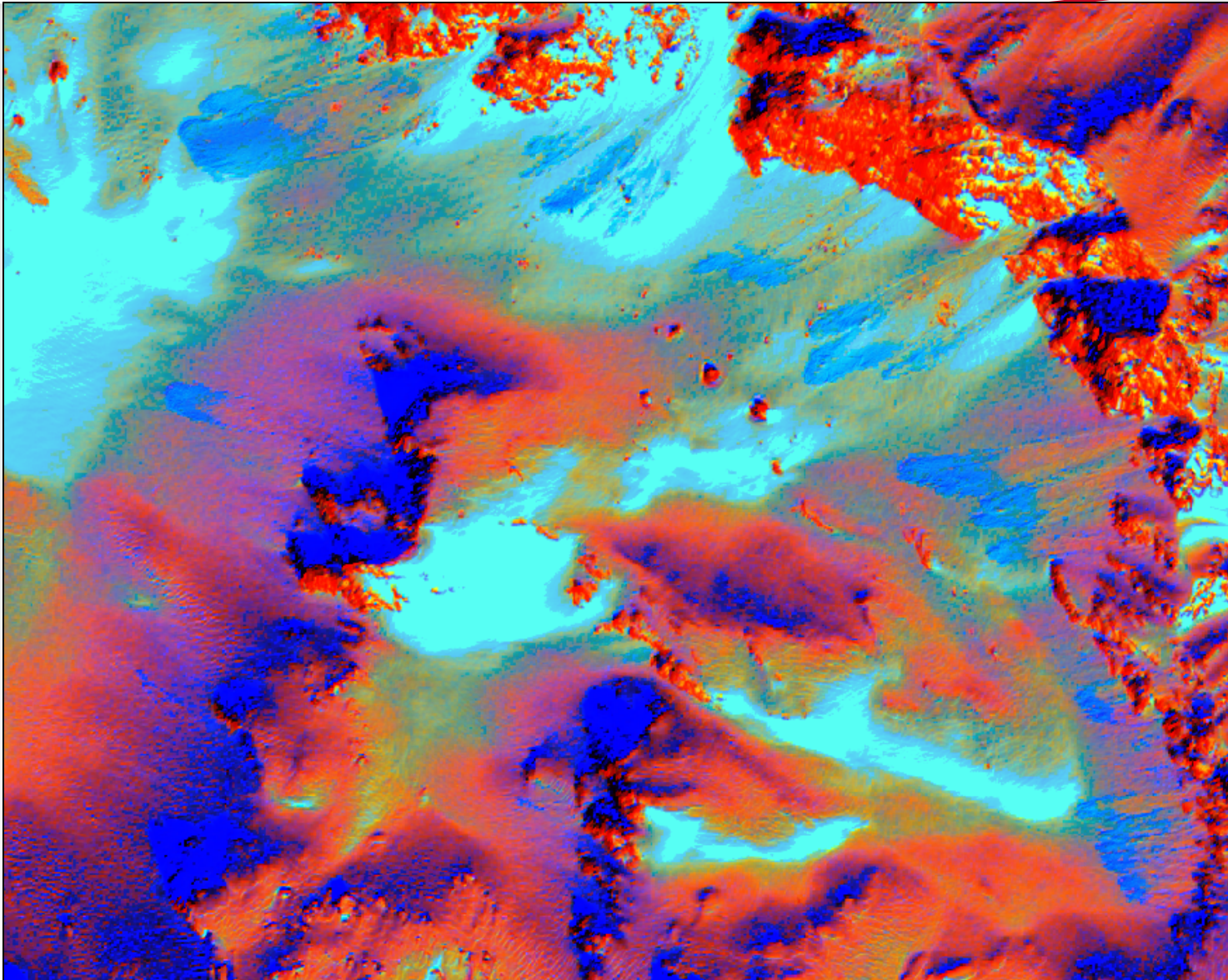


Band combination: PC1 = Red,  
PC2 = Green and PC3 = Blue



Band combination: Pan = Red,  
NDI = Green and PC3 = Blue

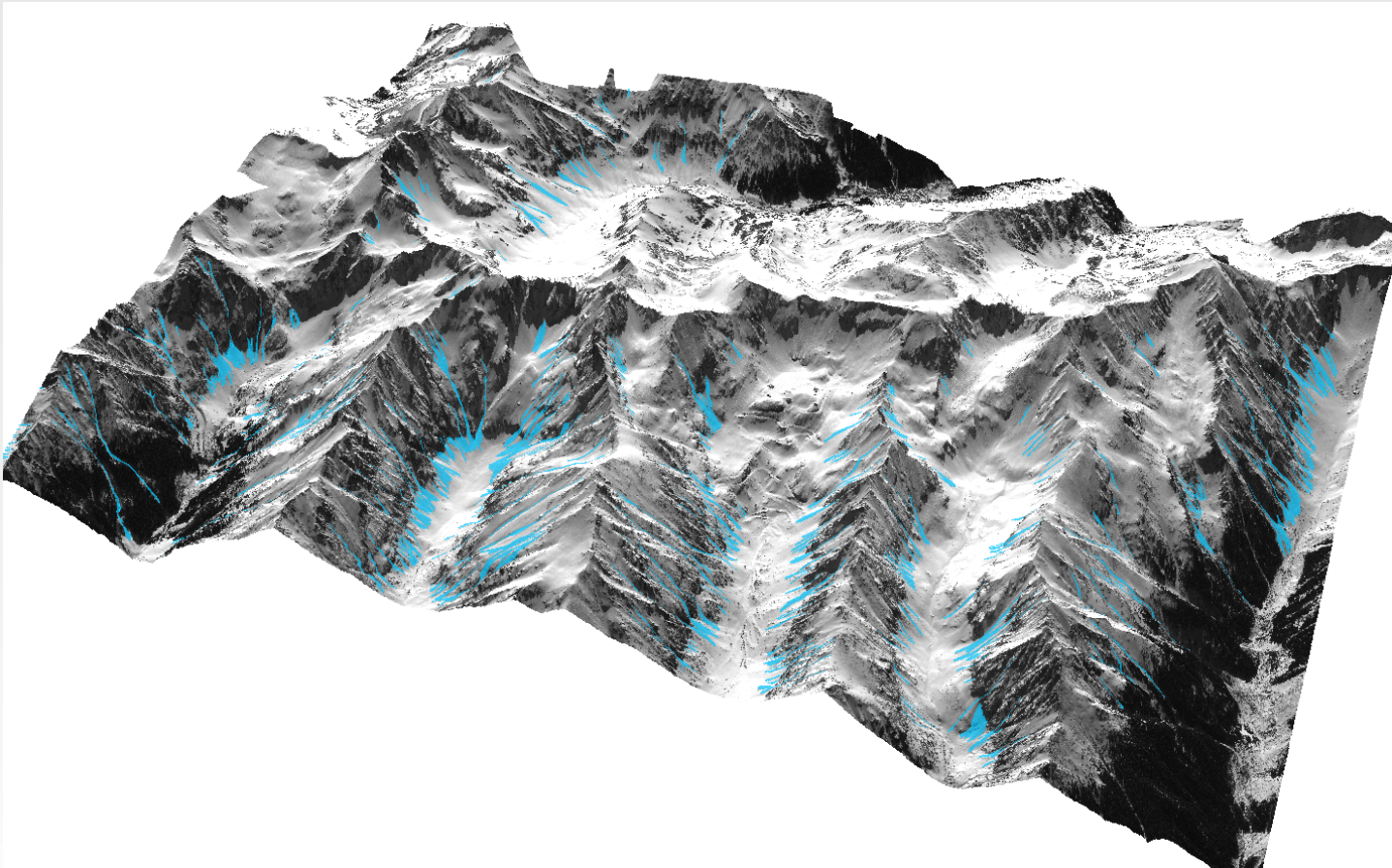






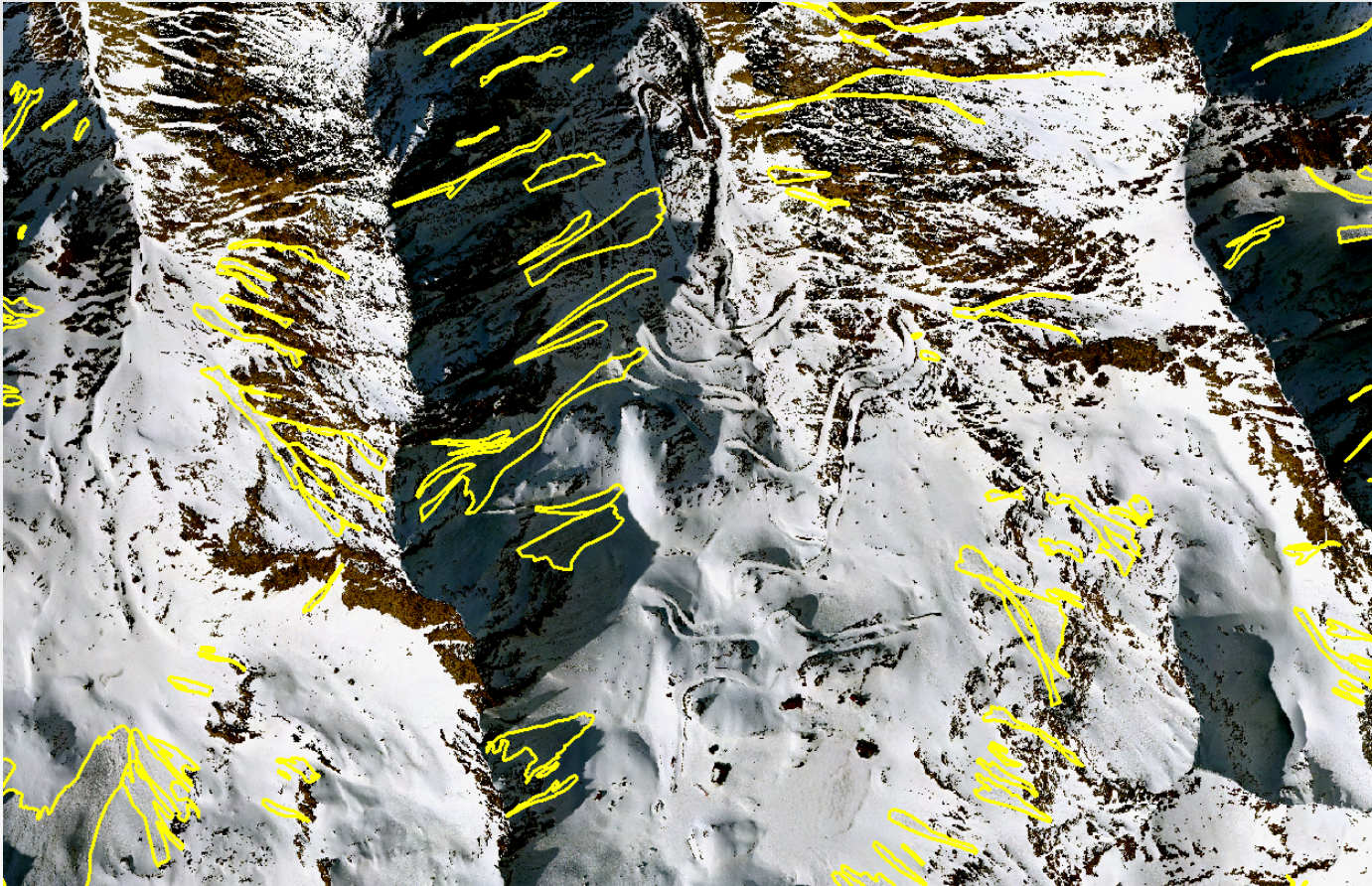
## • RESULTS

1069 avalanches were identified and delineated with an area of 157 sqkm (GeoEye – Area no.1 + Area no.12) and a density of 6.8 avalanches/sqkm (Year 2012).

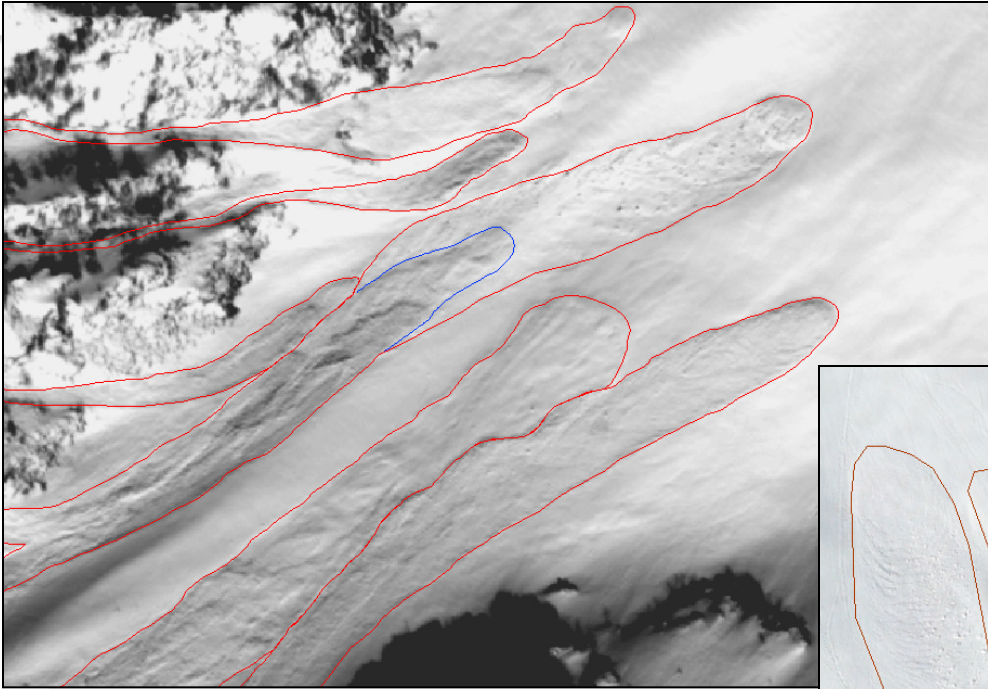




374 avalanches were identified and delineated with an area of 47 sqkm (Drone – based image) and a density of 7,95 avalanches/sqkm (Year 2016).









## Avalanches sizes

### GeoEye-1 scenes

Min. lenght = 13 m

Max. lenght = 1166 m

Mean lenght = 178 m

SD = 159.98

### Drone-based airphoto

Min. lenght = 12,48 m

Max. lenght = 789,42 m

Mean lenght = 160 m

SD = 143,4

**Table 1**

Grouping of the avalanche size classification scheme used in the US (Greene et al., 2010) into three categories "small", "middle" and "large".

Size	Destructive size	Typical mass (t)	Typical path length (m)
Used this study	Greene et al. (2010)		
Small	D1 + D2	$<10-10^2$	10-100
Middle	D3	$10^3$	1000
Large	D4 + D5	$10^4+$	>1000

(Eckerstorfer et al., 2016)



## Elevation of avalanche areas

### GeoEye-1 scenes

Min. alt. = 1283 m

Max. alt. = 2479 m

Mean alt. = 1912,5 m

SD = 226,84

Min range = 20 m

Max range = 757 m

Mean range = 121 m

SD = 120,34

### Drone-based airphoto

Min. alt. = 1543 m

Max. alt. = 2413 m

Mean alt. = 1958,8 m

SD = 226,84

Min range = 12 m

Max range = 536 m

Mean range = 98,5 m

SD = 101,59



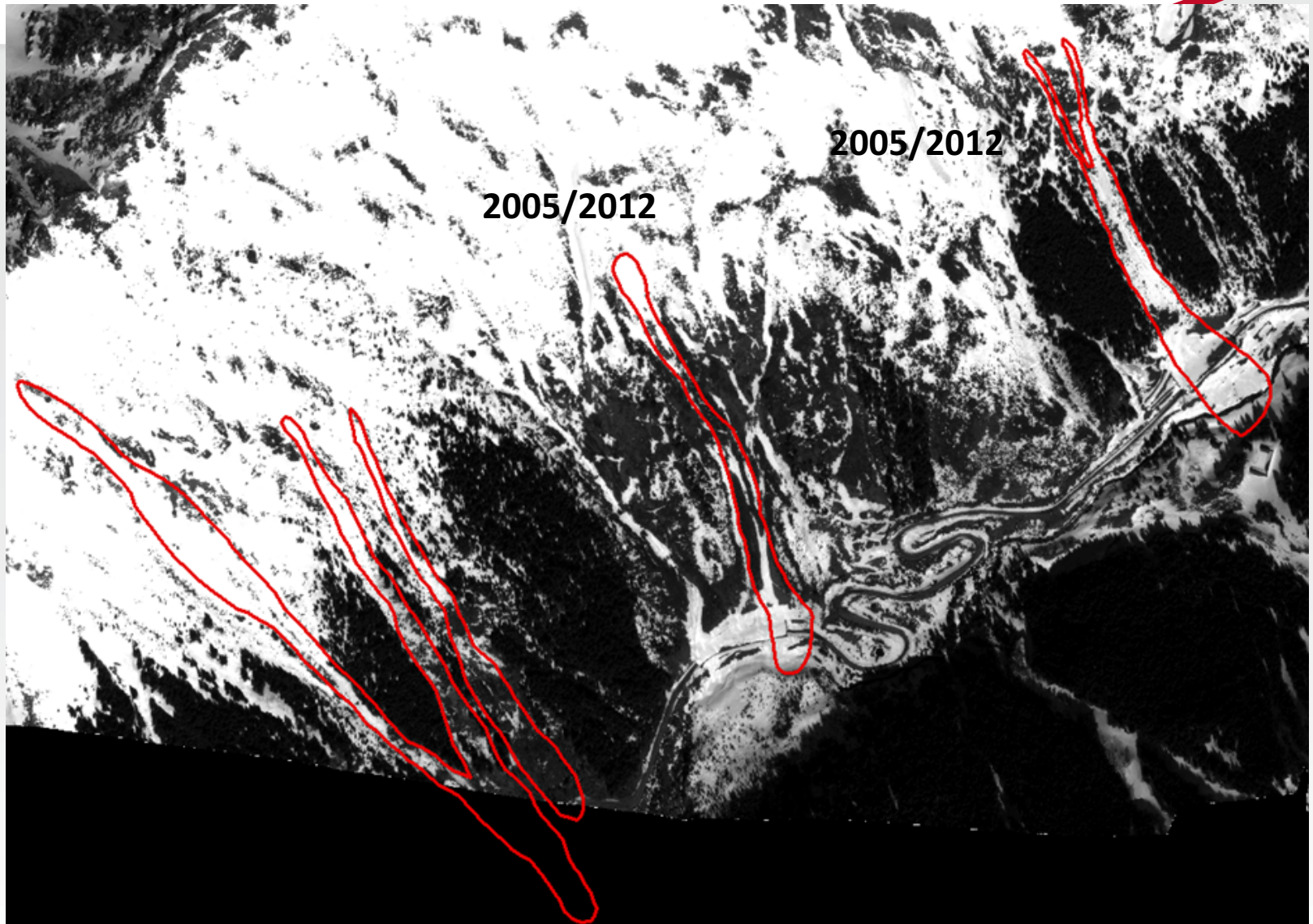
## • Validation

### Year 2005

- 6 major avalanches, all on Argesului Valley (on the Southern part of the Făgăraș Mountains);
- the avalanche crossed the road ( over the road shelter);
- ~67 m of roads have been affected;
- ~201 m of road shelters have been affected;
- ~3.500 sq. m of deciduous forest being shot down (2.7%);













- **Validation**

## **Year 2008**

4 major avalanches, all on Argesului Valley (on the Southern part of the Fagaras Mountains);

3 in March and 1 in April;

3 plate avalanches and 1 melting avalanche;

area of 23.117 sq. m;

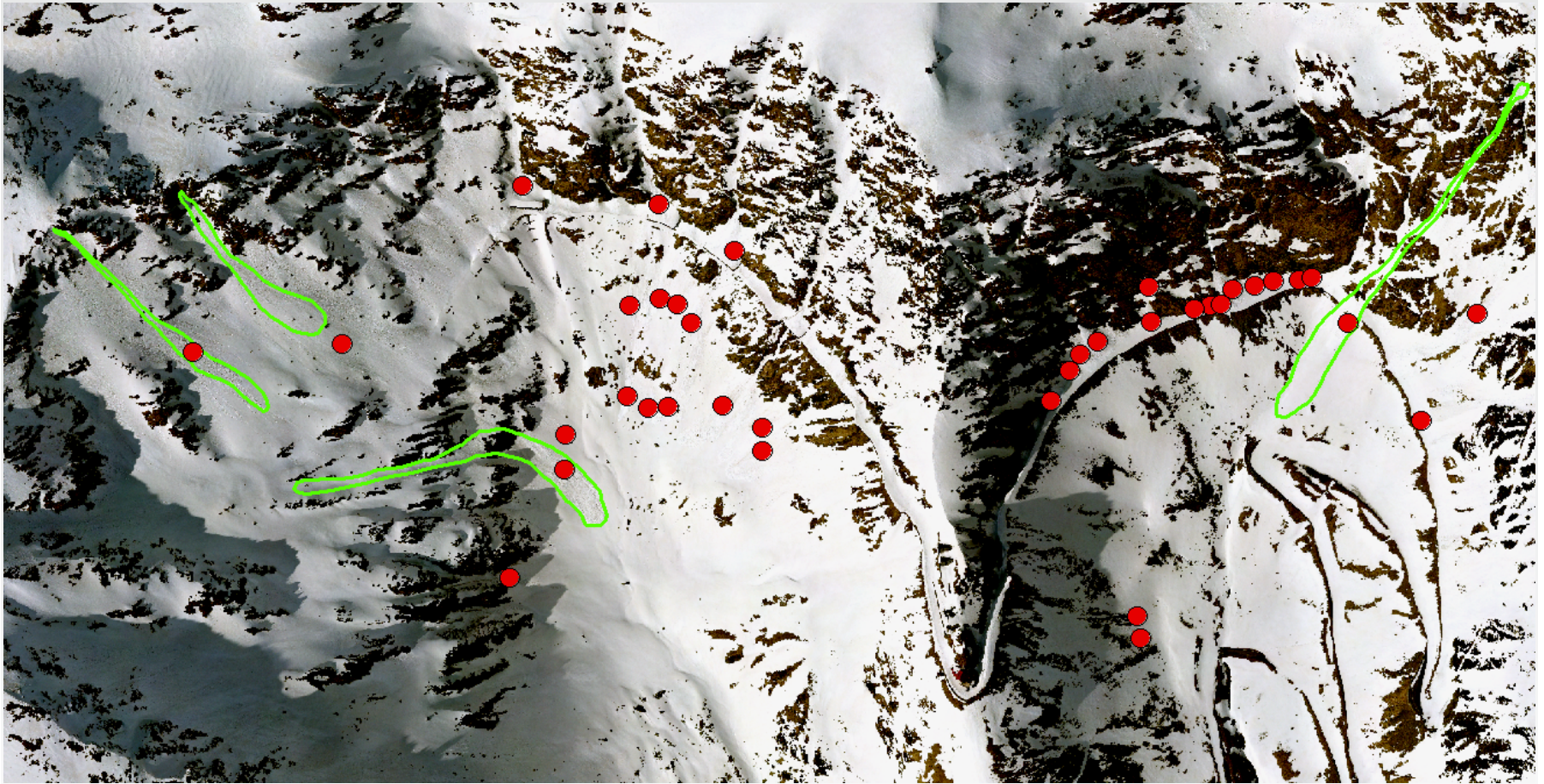
24 m of roads have been affected, close to Capra waterfall;

80 m of paths have been affected;





## 2008/2016





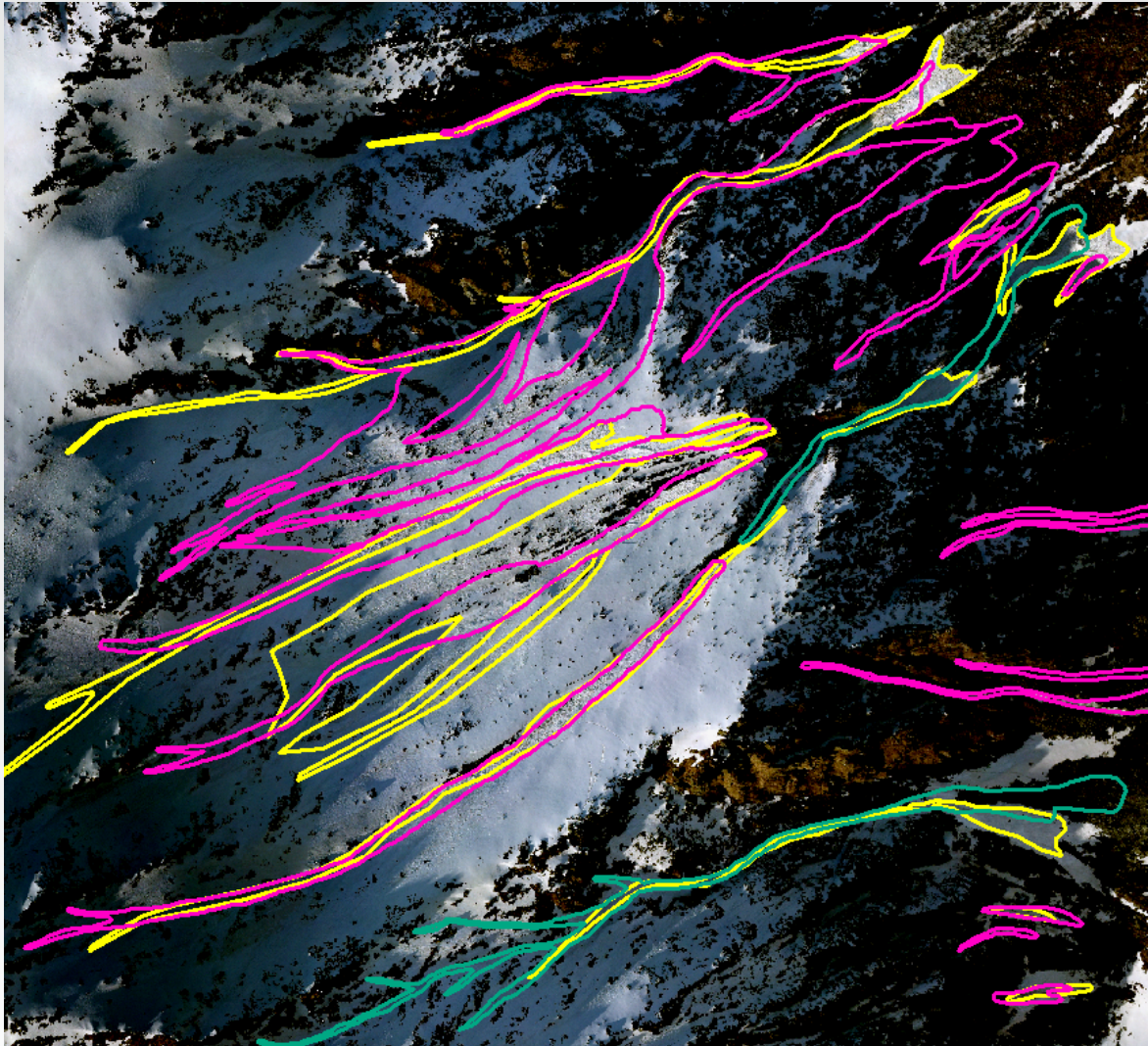
- **Validation**

## **Year 2012**

14 major avalanches on both slopes of the Fagaras Mountains: 9 on the Northern slope and 5 on the Southern slope;  
all of them are produced in April;  
melting avalanches;  
area of 59.367 sq. m;  
~24 m of road shelter have been affected;  
~39 m of paths have been affected;  
~ 100 m of roads have been affected, mainly on the Southern slope;  
~ 7.000 sq. m of deciduous forest have been affected (12%);



## 2012/2012 GeoEye/2016

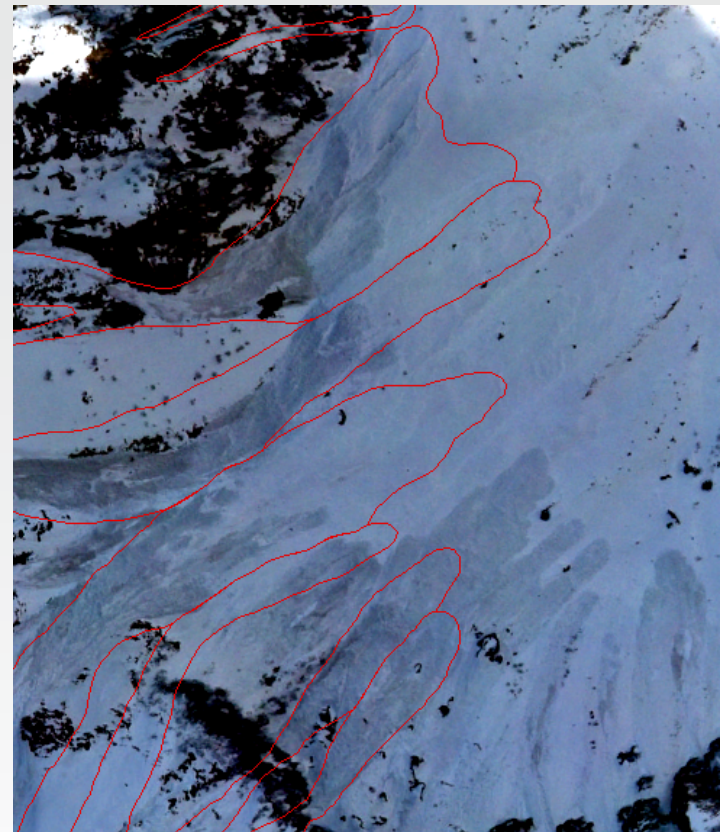
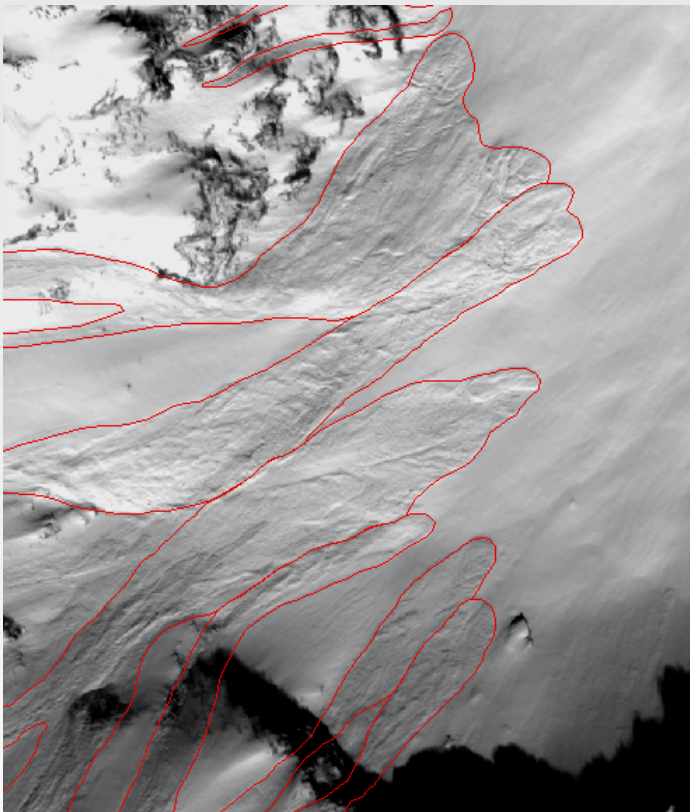




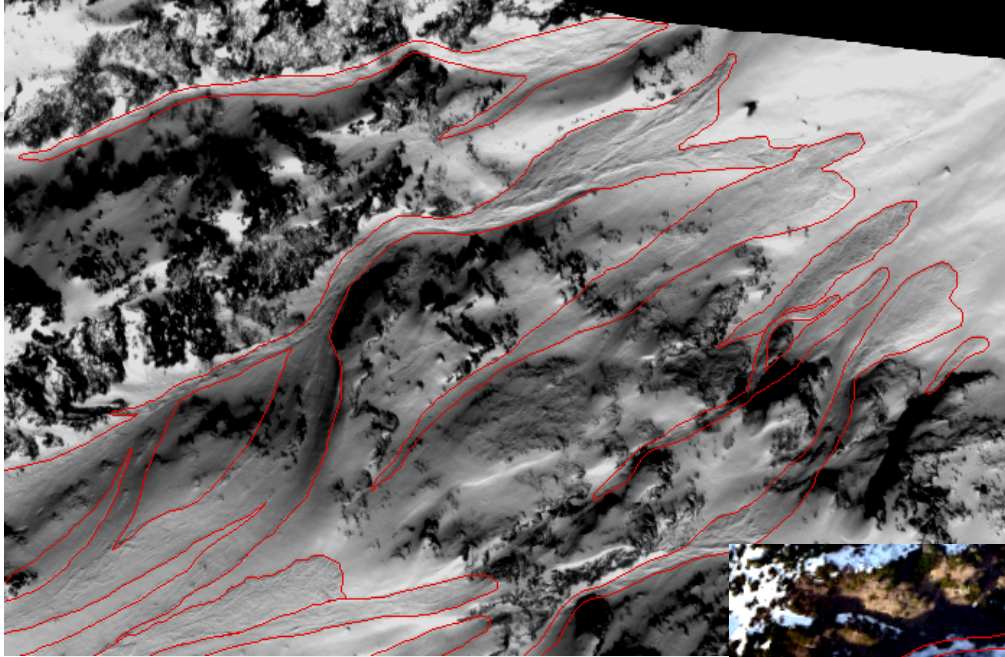
- **Validation**

**2012/2016**

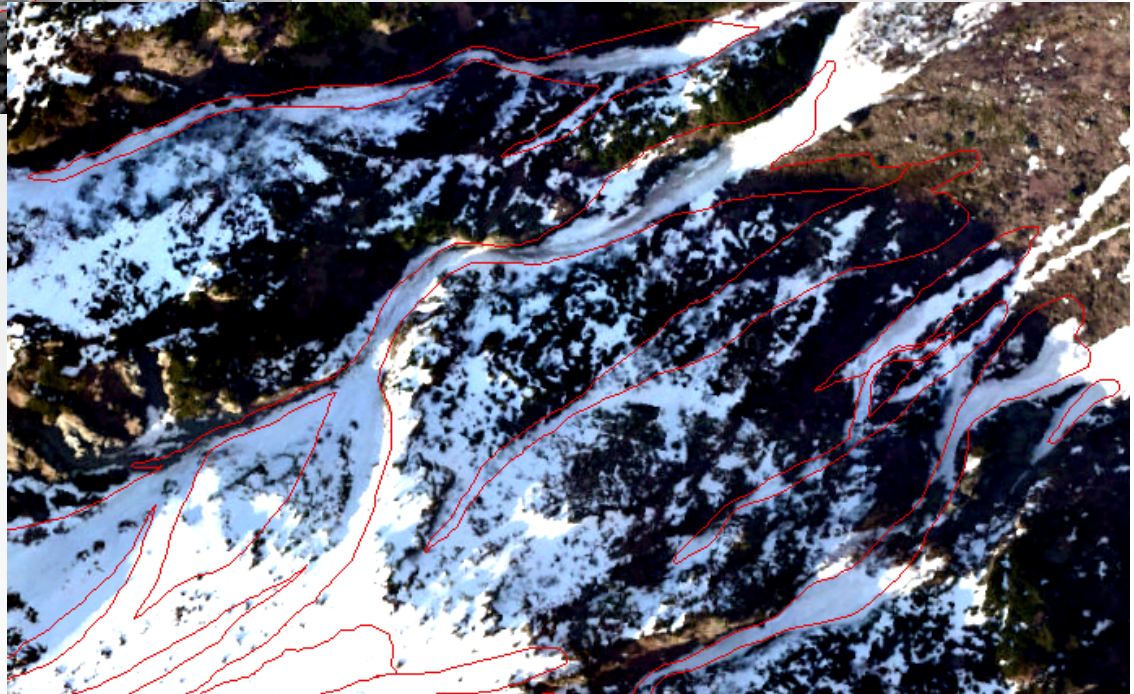
- 37% of the avalanches identified on UAV image were identified also on GeoEye image (139 avalanches)



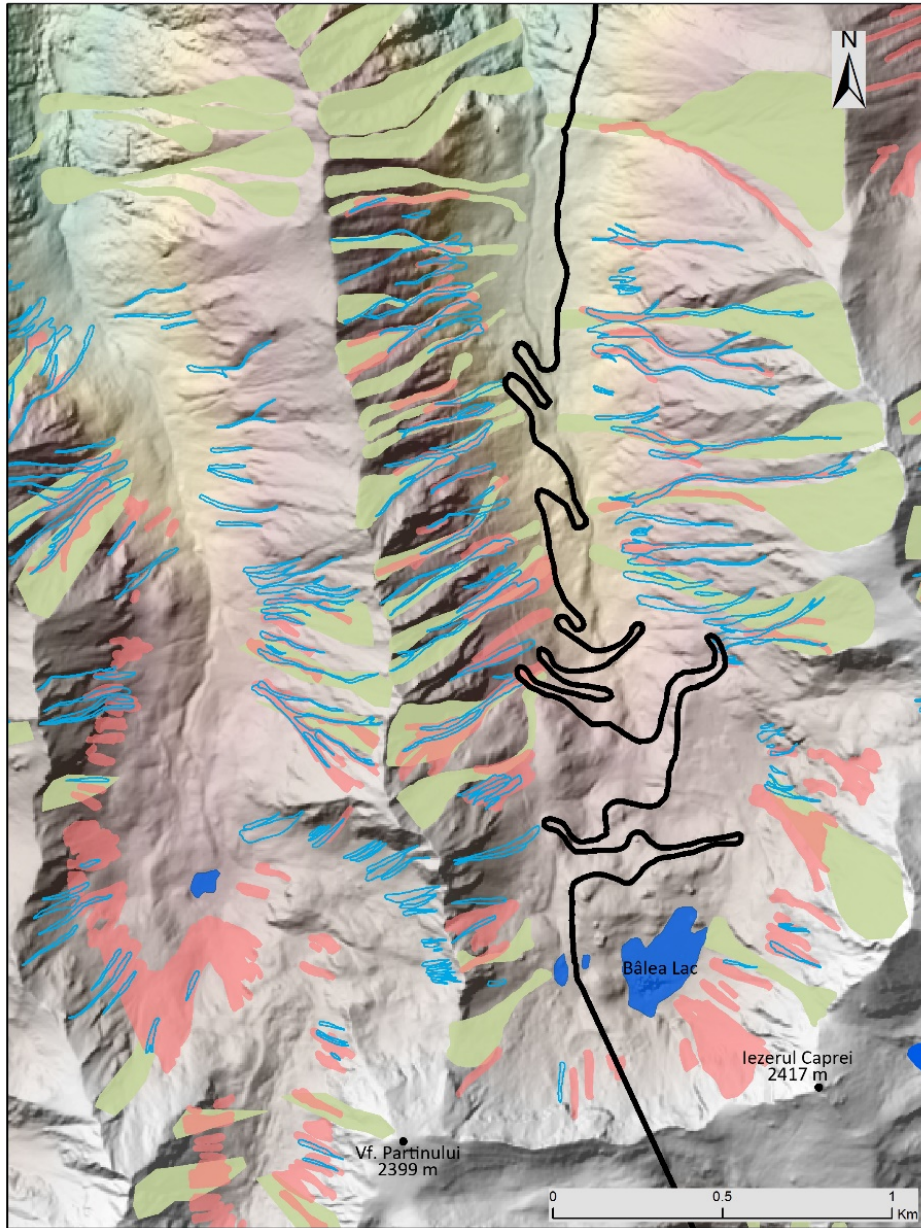




perspective (SnowBall)







avalanche\_2012
  avalanches\_2016
  avalanche tracks
  Transfagarasan highway

Snow avalanches mapped based on VHR images from 2012 and 2016 on northern hillslopes, near Transfăgărășan Highway, overlaid on hillshaded DSM.

Light green represents the avalanche tracks mapped in the field.



## Scientific background for numerical simulation

- numerical simulations - acknowledged to be used in avalanche hazard mapping in two ways: back-calculation of past events and forward calculations of possible avalanche scenarios in different mountain areas (Christen et al., 2010).
- helpful in understanding the avalanche flow in complex terrain, especially where infrastructure and people might be affected (the case of the study area)
- used to construct hazard scenarios (need specification of initial conditions - release zone location and dimensions- and definition of appropriate friction parameters).
- numerical simulations of avalanches - flow rheologie VS (Voellmy Salm) approach implemented in RAMMS (rapid mass movement simulation)

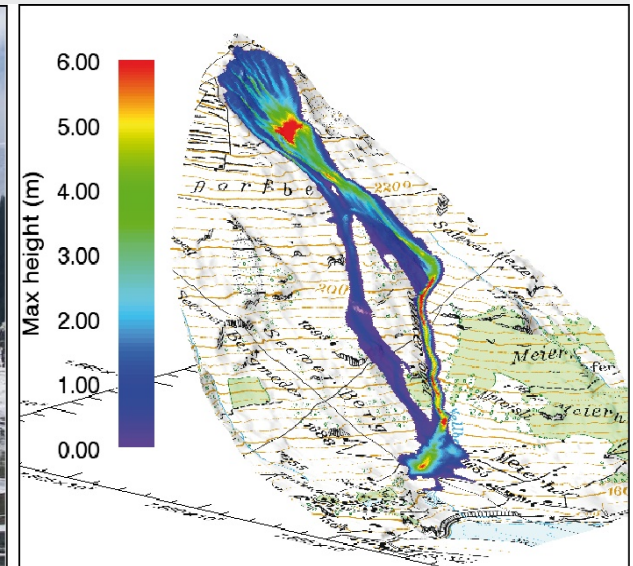


# Simulation of avalanches in RAMMS software

- Avalanches – 3 key features: formation, release, flow (Krog, 2010).
- Simulation based on Voellmy–Salm friction law (Christen et al., 2010)

$$S = \mu \rho H g \cos(\phi) + \frac{\rho g U^2}{\xi}$$

- dry friction (coefficient  $\mu$ ) that scales with the normal stress
- viscous-turbulent friction (coefficient  $\xi$ )
- $\rho$  - density
- $g$  - gravitational acceleration
- $\phi$  - slope angle
- $H$  - flow height
- $U$  - flow velocity





# Simulation of avalanches

- Simulation variables
  - Global parameters (return period, volume)
  - Friction parameters ( $\mu$  $\xi$ )

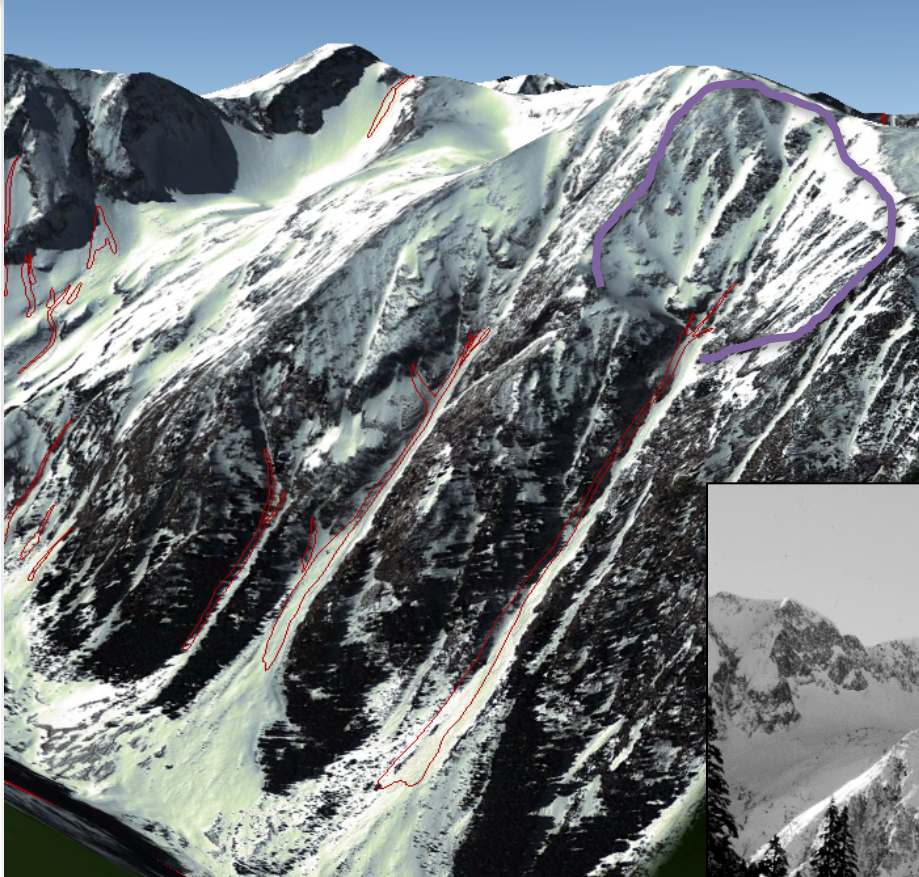
Medium avalanche ( 25 - 60'000 m <sup>3</sup> )		300-Year		100-Year		30-Year		10-Year	
unchannelled	above 1500	0.195	2500	0.205	2500	0.215	2500	0.225	2500
	1000 - 1500	0.21	2100	0.22	2100	0.23	2100	0.24	2100
	below 1000	0.23	1750	0.24	1750	0.25	1750	0.26	1750
channelled	above 1500	0.25	1750	0.26	1750	0.27	1750	0.28	1750
	1000 - 1500	0.27	1530	0.28	1530	0.285	1530	0.295	1530
	below 1000	0.28	1350	0.29	1350	0.3	1350	0.31	1350
gully	above 1500	0.32	1350	0.33	1350	0.34	1350	0.35	1350
	1000 - 1500	0.33	1200	0.34	1200	0.355	1200	0.36	1200
	below 1000	0.36	1100	0.37	1100	0.38	1100	0.39	1100
flat	above 1500	0.17	3250	0.18	3250	0.19	3250	0.2	3250
	1000 - 1500	0.19	2900	0.2	2900	0.21	2900	0.22	2900
	below 1000	0.21	2500	0.22	2500	0.23	2500	0.24	2500
forested area ( $\mu=\delta$ , $\xi=\text{fix}$ )		0.02	400	0.02	400	0.02	400	0.02	400



# Simulation of avalanches

- **Input data:** DEM derived parameters (altitude, slope gradient, planar curvature, aspect), forest information (polygon), release areas and volumes
- **Release areas:**
  - drawn as polygons with database related to the snow depth or generated using procedure mentioned in Buhler et al., 2013 where there are no available meteorological, photographs and other ancillary data
  - For the identification of potential release areas, parameters used are: forest cover, slope gradient (30-60°), planar curvature (concave and convex) – threshold at 0.3, and ridges are excluded
- **Output data:** maximum flow height, velocity, and pressure



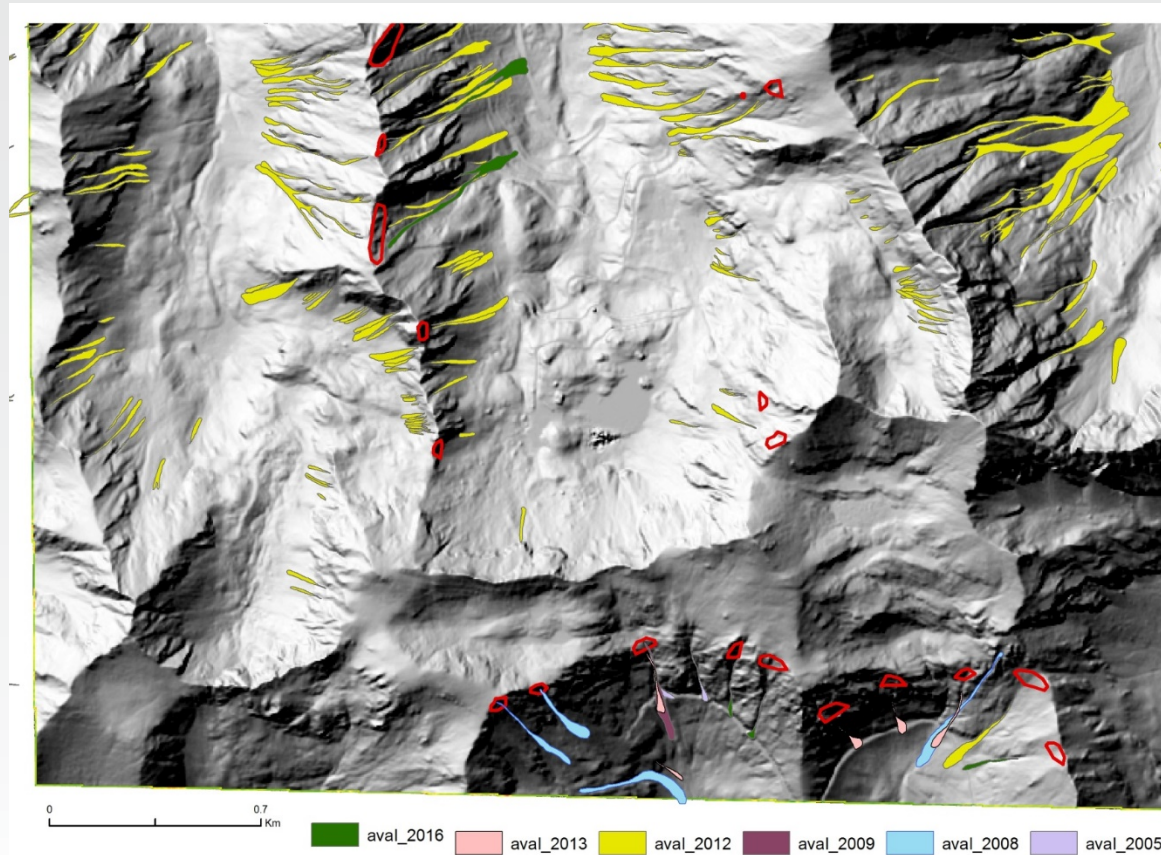


Release areas morphology – Răcorele  
Peack (upper sector of Sâmbata Valley)





Map of several past documented avalanches in Transfăgărașan surroundings (Bâlea Valley) and main potential release areas (in red)

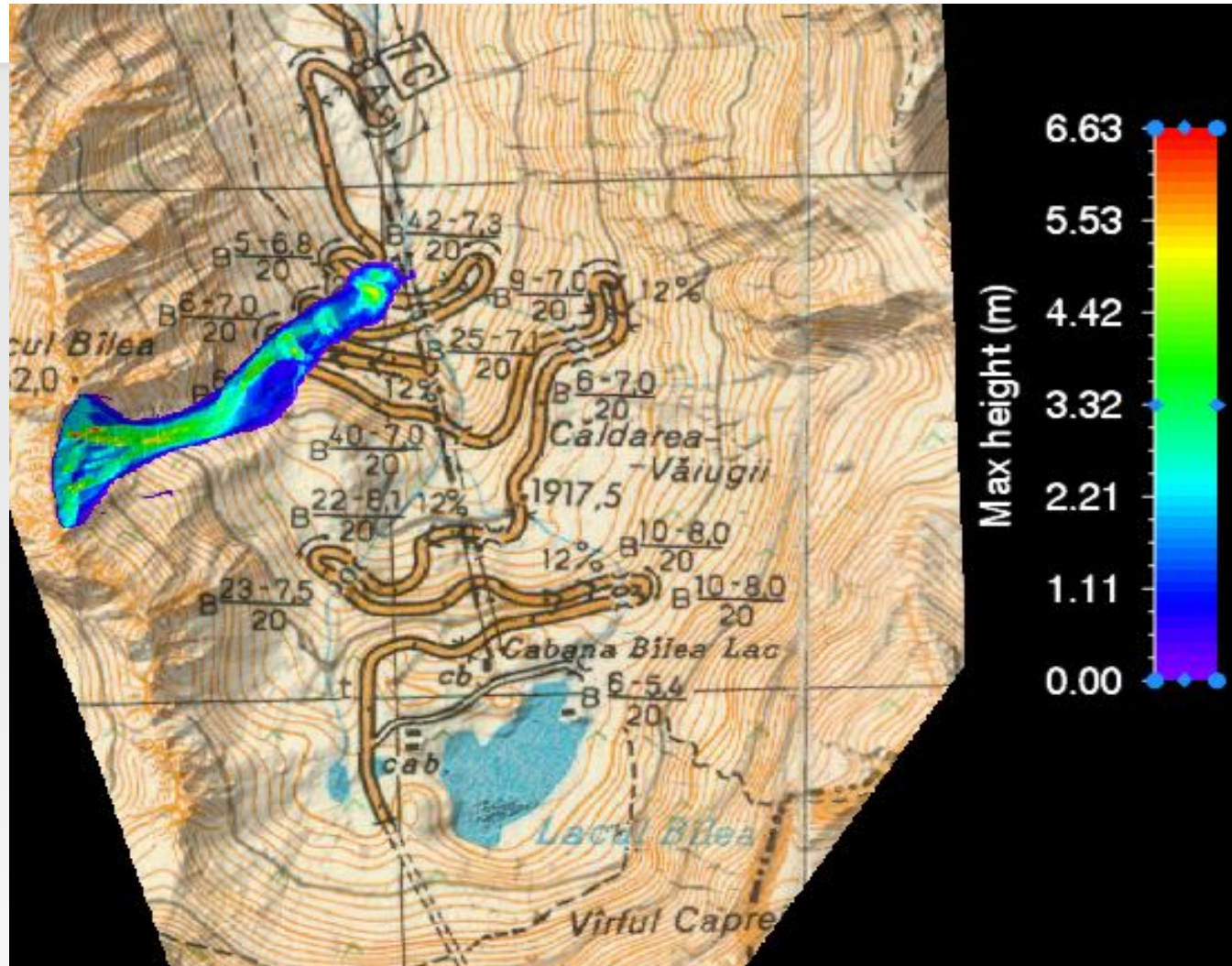




# Hazard assessment approach

- Hazard - expresses as the probability of occurrence of a given process, in the case of snow avalanche assessment, the release areas and runout distances for several magnitude classes have to be determined
- a combination of topographic factors to identify the potential release areas and simulation of avalanche pressure and volume based on past events with maximum extent was used
- simulations were generated using RAMMS - the friction parameters were calculated using the automatic procedure implemented in the model (the procedure classifies terrain parameters, altitude, slope gradient, and plan curvature, in types like flat terrain / open slope, channelled / gully and forested or non-forested areas)
- the return period of 10 and 30 years and type of the avalanches small and medium size events were used in simulations.
- for the release areas 0.5 and 2 meters fracture height were used in the tests for the release fracture heights.





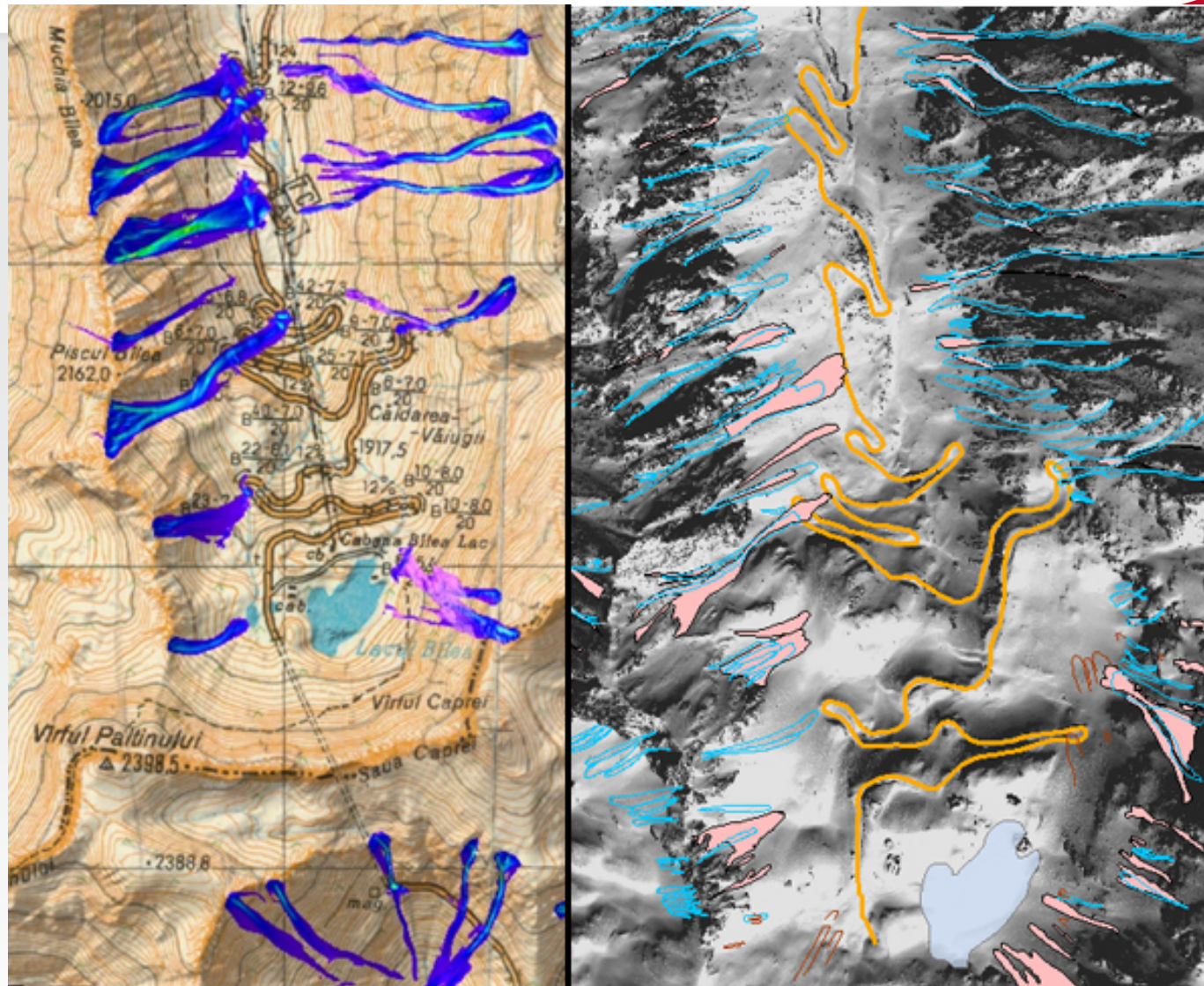
Example of back-calculations (snow height and extent) for past snow avalanche in Bâlea valley - 1974





Example of a simulation - extent and snow height in Transfăgărășan area, based on return period of 10 years and medium size events (topographic map and hillshaded terrain in the background)







## • CONCLUSION

- Snow avalanche density and activity are much higher than in previous statistics.
- The avalanches from Carpathians are almost in totally small and middle size avalanches.
- The detection of the avalanches in Carpathians is possible only on VHR images



## • CONCLUSION

**The feasibility of the Geo-Eye1 (and similar sensors) VHR satellite images for getting (almost) real-time information about avalanches:**

- The spatial resolution is good enough to visually/automatically differentiate avalanches from non-avalanches areas based more on texture than on spectral information
- The temporal resolution could be a problem
- The costs are high (images are still very expensive)
- Even if we'll be able to develop a performing automated detection algorithm the cloud cover remains the main problem

**Ex.** Sentinel 2: 34 winter images in 2016, only one with low percentage of cloud cover for our study area.

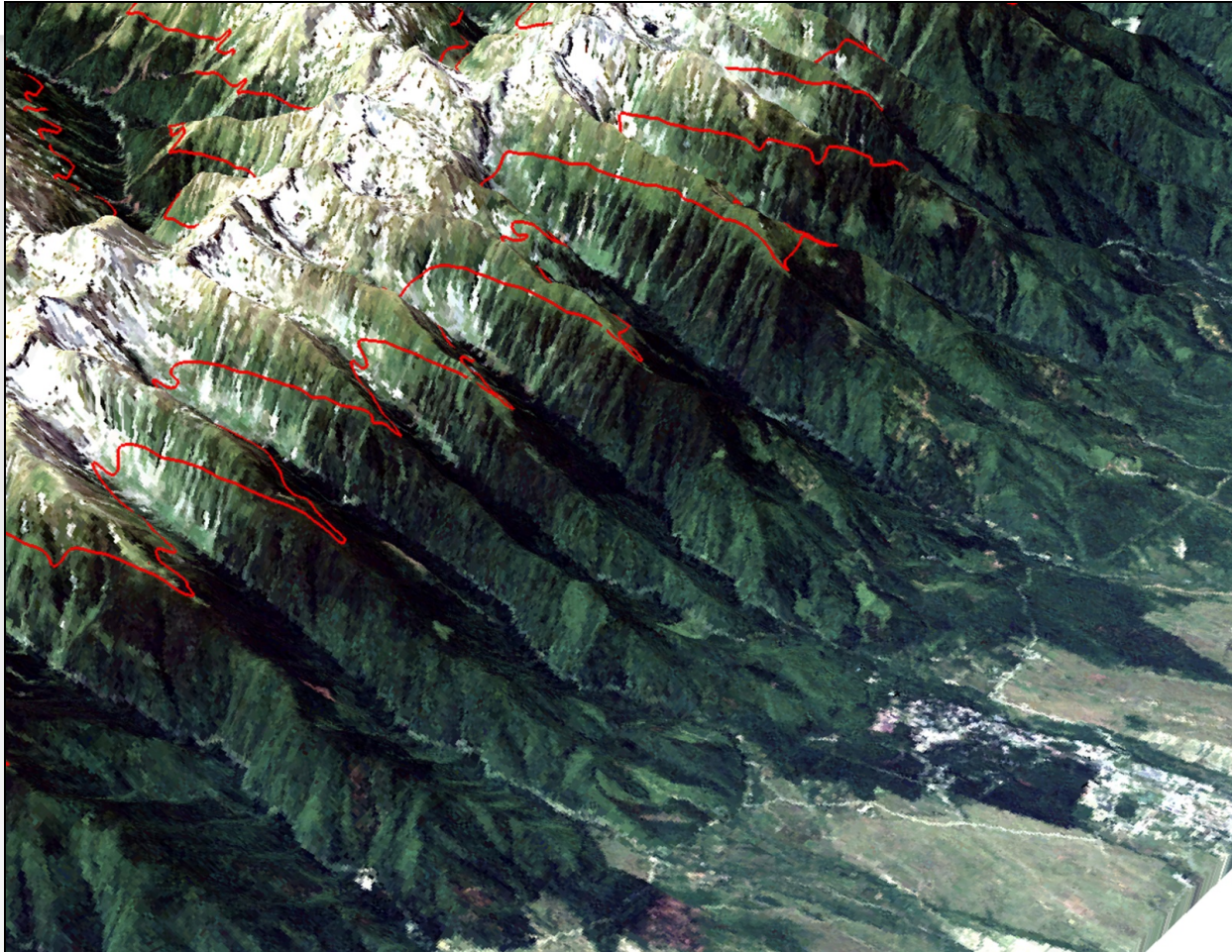
- Additional information are needed (avalanche suitability maps)



## • CONCLUSION

- Avalanches are indeed the most important winter season natural hazard in Romanian Carpathians
- Numerical simulations of snow avalanches are able to reconstruct past events and to simulate future events using various input parameters according to various scenarios.
- These information are useful for future decision making in developing mountains areas for winter sports and leisure in order to reduce exposure of tourists and infrastructure to this risk phenomena.





Specific forest pattern impressed by avalanches on the northern slopes of Făgăraș Mountains (Torok-Oance et al., 2006)



## Thank you for your attention!



Retezat Mts., 27<sup>th</sup> April 2017, 7.12 a.m.

### Acknowledgements

This work was supported with funding from EEA Financial Mechanism 2009 - 2014 under the project contract no. 19SEE/2014, ***Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective - SnowBall***