Photogrammetrie et risques naturels: Application à la dynamique des avalanches et aux chutes de séracs

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Cemagref
Sciences, eaux & territoires

L G G E
Laboratoire de Glaciologie et Géophysique de l'Environnement

Sintégra

ENSG

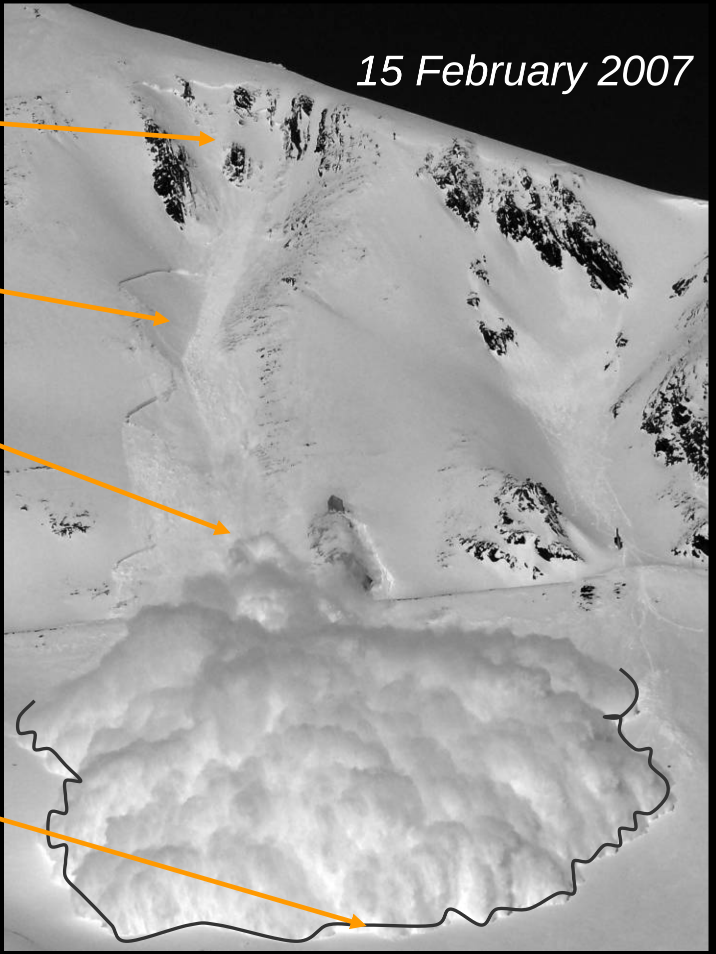
Objectives:

AVALANCHE

Provide avalanche *in situ* data for validation / calibration of avalanche flow models:

- Initial conditions
  - *mass input*
  - *mass erosion*
  - *& deposition rates*
- Mass balance of avalanche flow
- Front velocity, run-out distance

Lautaret avalanche test site



Objectives:

Taconnaz icefall
(Les Houches - Chamonix valley)

SERAC FALLS
Provide icefall dynamics measurements

- Surface velocity, serac edge position in time

- Precursory signs of serac fall:

  crevassing, acceleration,

  cliff upper lip ultimate equilibrium position

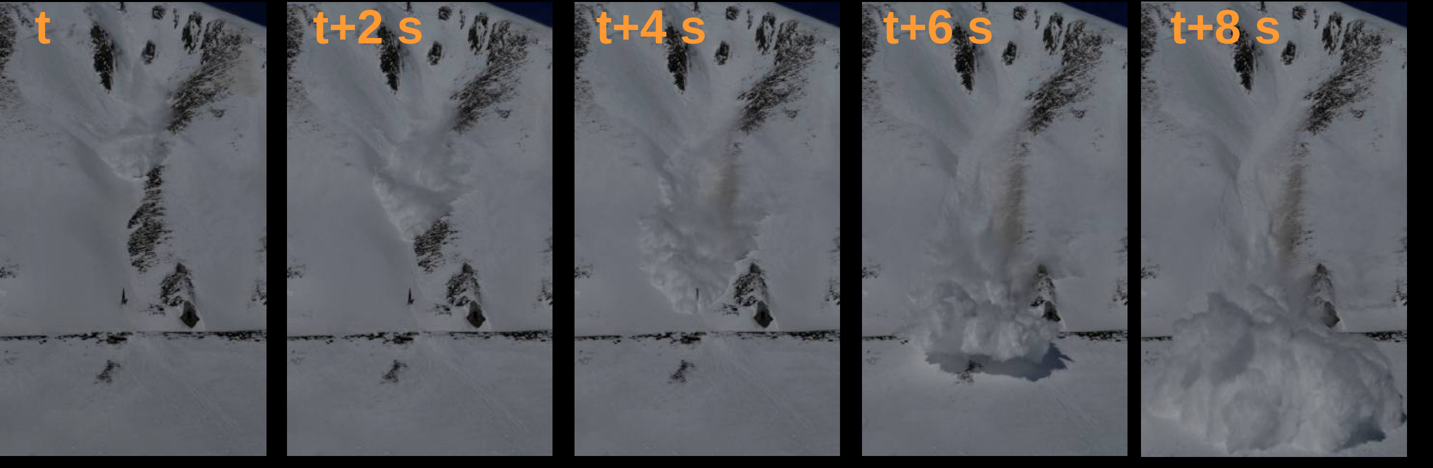
- Volume and frequency of calving

  return period?

➡ Acquisition of time series of Digital Elevation Models (DEM)

Constraints

Acquisition rate: up to 1-2 DEM per second



Lautaret

Distance: up to 4-5 km

Taconnaz

Method:

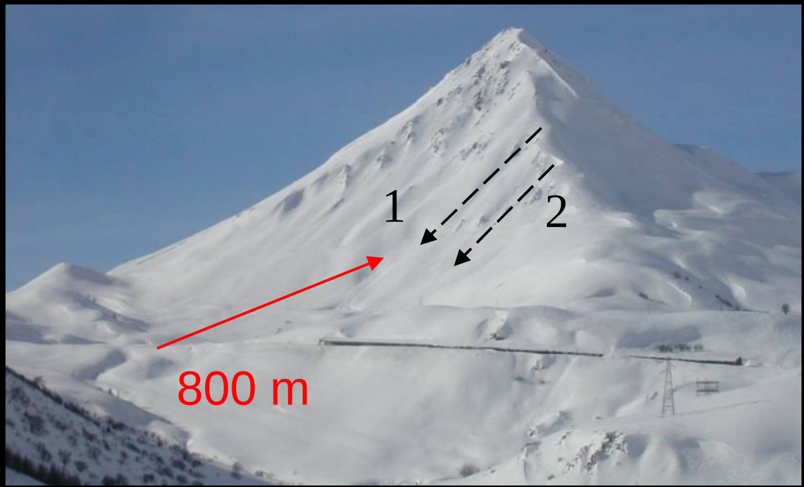
~~Laser scan~~

➡ Terrestrial Photogrammetry

Specifications:

- low cost, adaptable system
- non-metric cameras
- low distortion fixed focal length lenses
- wireless synchronized cameras (Lautaret)
- automatic release (Taconnaz)
- hardened – rugged devices (-15°C, wind…)
- operating at 800 - 4000 m from surveyed surfaces

Lautaret avalanche test site



Taconnaz icefall
(from Cosmiques hut)

Photogrammetric principle

reconstruct and measure a surface topography from different perspectives captured on images

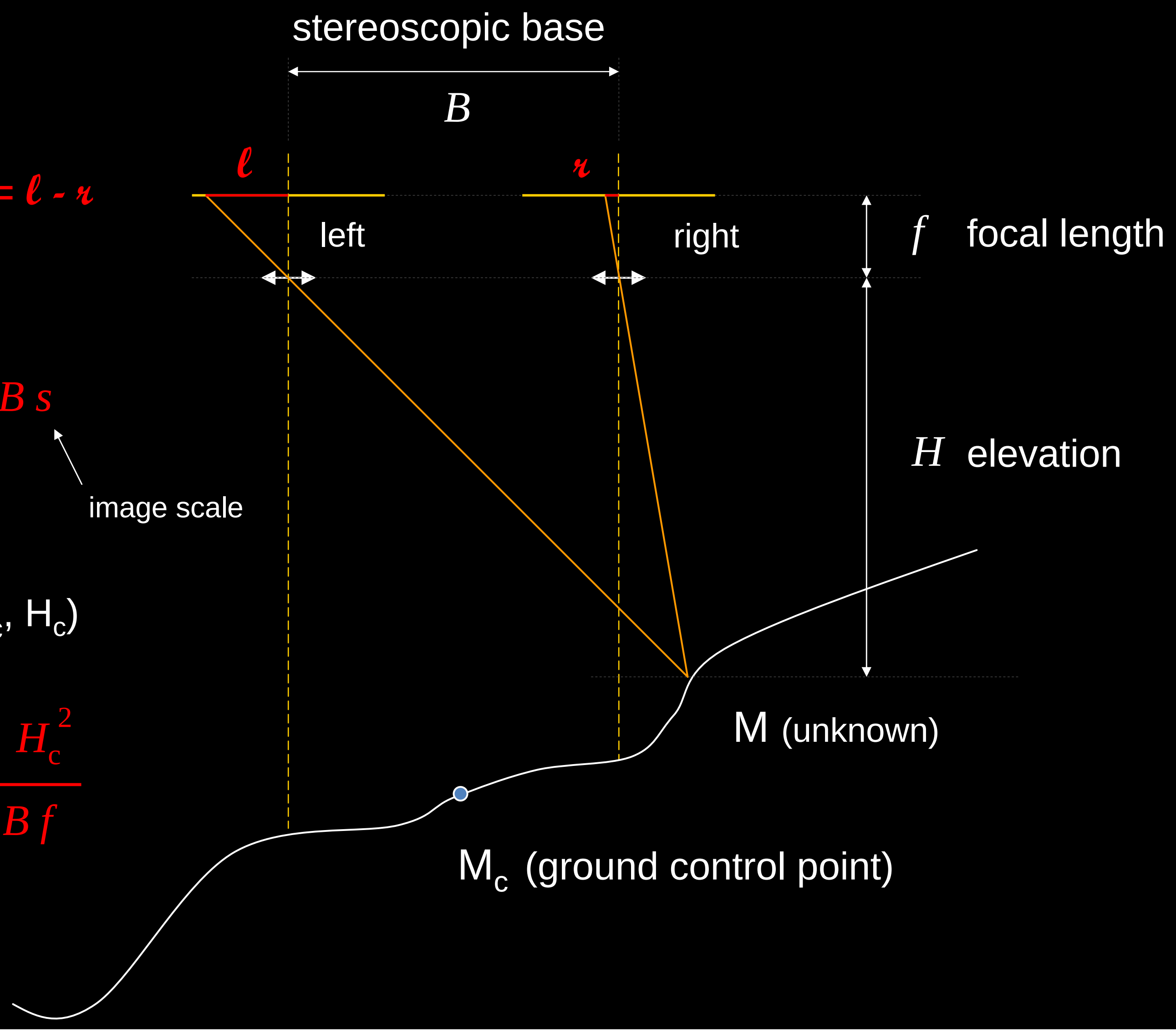
parallax $p = \ell - r$

$$p = \frac{B\,f}{H} = B\,s$$

image scale

control point $M_c\,(p_c, H_c)$

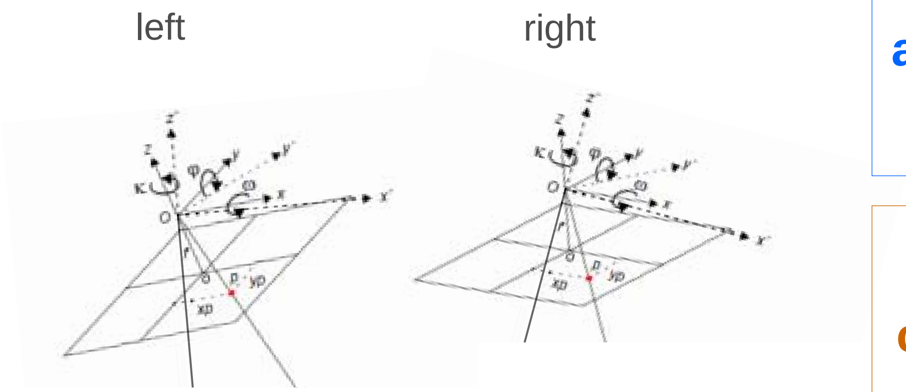
$$H = H_o + (p_c - p)\,\frac{H_c^2}{B\,f}$$

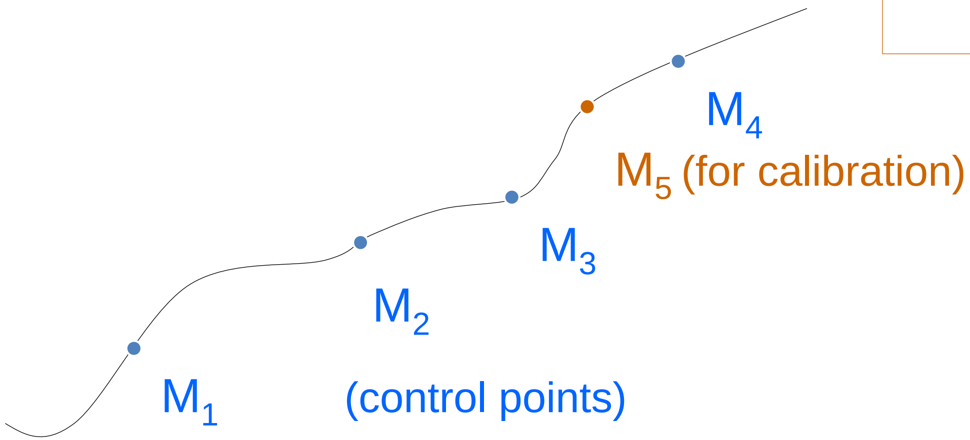


Photogrammetric principle

general case : non coplanar images

Aerotriangulation (+ calibration)





12 (+12) unknown parameters :

aero.

- camera perspective centre coordinates
  $(x_o, y_o, z_o)_{left}$ and $(x_o, y_o, z_o)_{right}$
- camera orientation Euler angles
  $(\omega_o, \varphi_o, \kappa_o)_{left}$ and $(\omega_o, \varphi_o, \kappa_o)_{right}$

calib.

- focal length and real image principal point
  (f_l and f_r) and (x_{pp}, y_{pp}) left & right
- radial distortion odd order polynomial
  (k_1, k_2, k_3) left & right

to be determined from

- at least 4 (8) control points
  (4 (8) x 3 coordinates)
- more than 4 (8) to have a control
  (σ = rms orientation/calibration residuals)

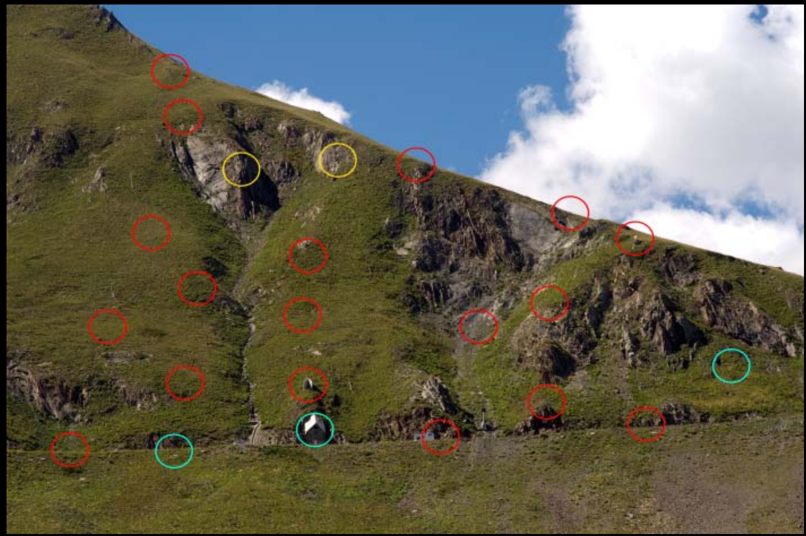
Photogrammetric process

1°) Image acquisition

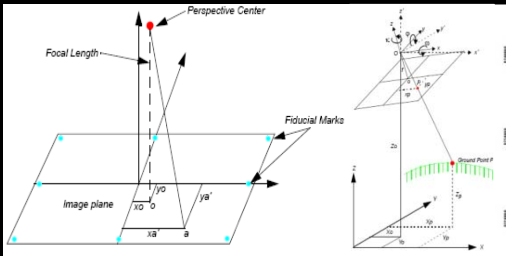
Left image

Right image

2°) GCP's Measurements



3°) Aerotriangulation & calibration



$$x_p - x_o = -f\left[\frac{m_{11}(X_p - X_{o_i}) + m_{12}(Y_p - Y_{o_i}) + m_{13}(Z_p - Z_{o_i})}{m_{31}(X_p - X_{o_i}) + m_{32}(Y_p - Y_{o_i}) + m_{33}(Z_p - Z_{o_i})}\right]$$

$$y_p - y_o = -f\left[\frac{m_{21}(X_p - X_{o_i}) + m_{22}(Y_p - Y_{o_i}) + m_{23}(Z_p - Z_{o_i})}{m_{31}(X_p - X_{o_i}) + m_{32}(Y_p - Y_{o_i}) + m_{33}(Z_p - Z_{o_i})}\right]$$

4°) Photogrammetric restitution

1°) Image acquisition (Lautaret)

Nikon D2Xs camera

1/2500 s, f/8, raw 12 bits RVB (color), ISO 100

AF Nikkor 85 mm 1.4D

internal focusing, focusing via manual control

Dx format CMOS : 23.7 x 15.7 mm

Resolution = 4288 x 2848 = 12.84 Million pixels

Pixel size : X=5.53 µm ; Y= 5.51 µm

Sampling rate: 1-4 frames/s ; max 32 frames/sequence

Synchronization via wireless radio triggering transceivers

1°) Image acquisition (Taconnaz)

Canon 5D mkII cameras

f/8, raw 12 bits RVB (color), ISO 100

Canon EF 100 mm 2.8

Fx format CMOS : 24 x 36 mm

Resolution = 5616 x 3744 = 21.1 Million pixels

Pixel size : X=6.40 µm ; Y= 6.40 µm

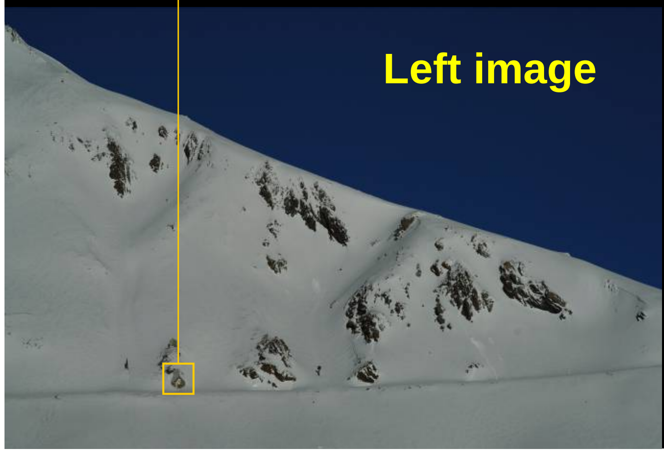
Sampling rate: ~ 4-6 frames/day

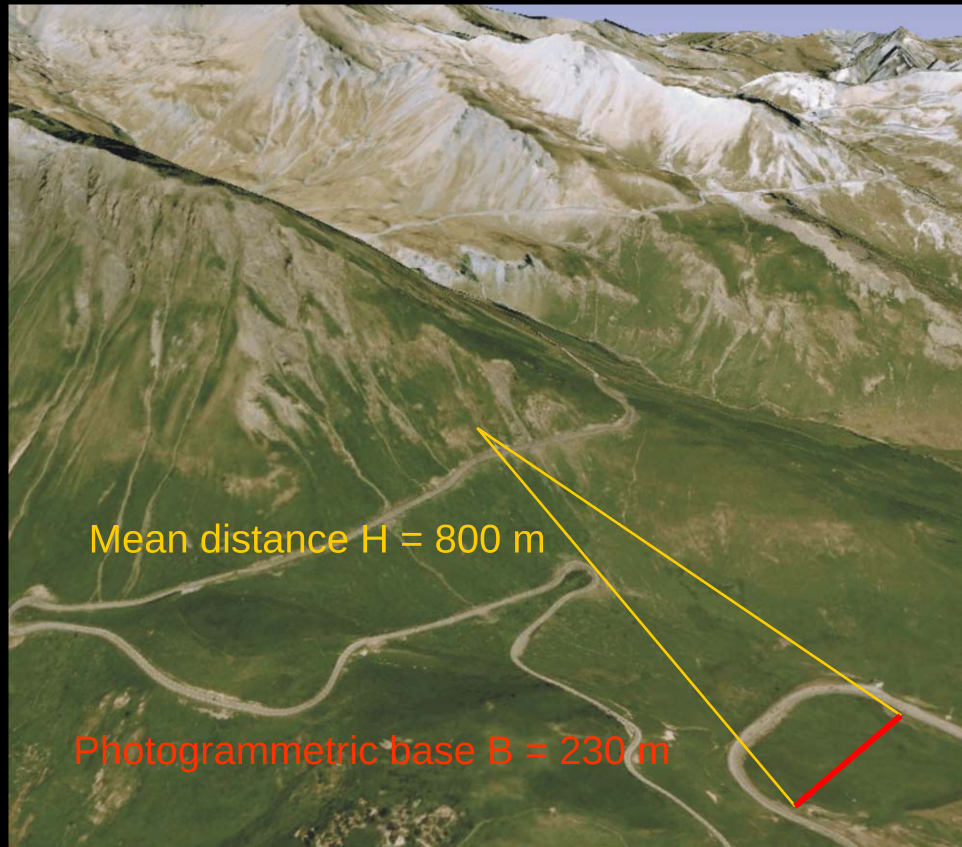
Controlled by remote timer

Powered by 12V lead battery + solar panel

1°) Image acquisition: Lautaret

mean ground pixel size PS = 5.15 cm (at 800 m)



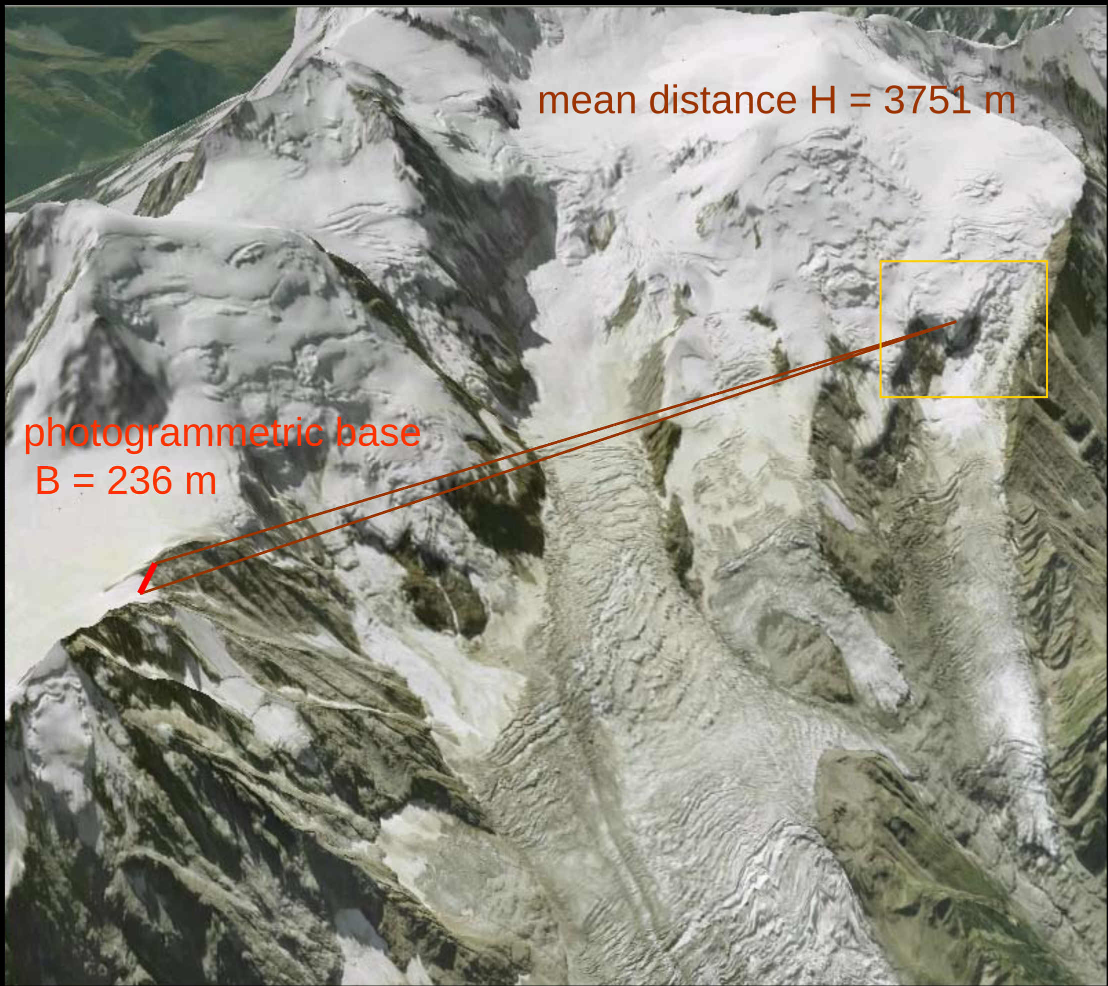


Theoretical error using 2 pixels as sighting error (~11 μm)

- planimetry $\sigma_{xy} = 2PS \dfrac{H}{f} = 8.4$ cm

- altimetry $\sigma_z = 2PS \dfrac{H^2}{Bf} = 21$ cm

1°) Image acquisition: Taconnaz



Left image

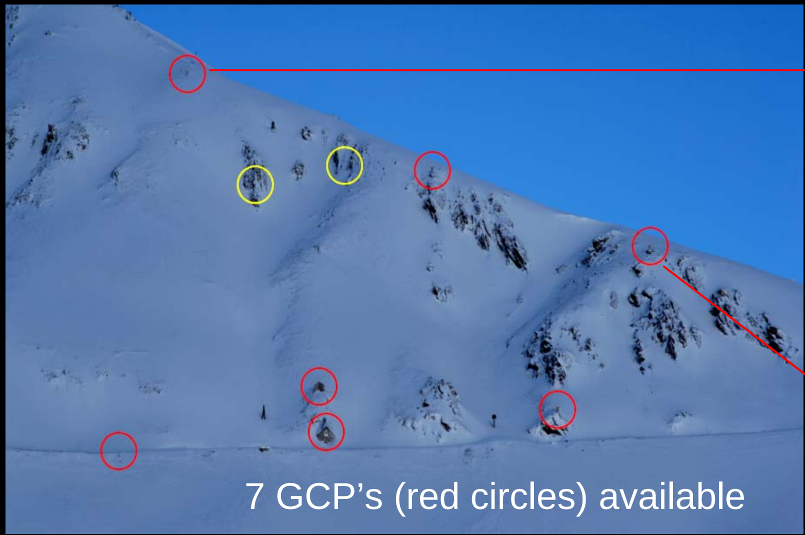
mean ground pixel size PS = 26.7 cm
(3750 m)

Theoretical error using 2 pixels as sighting error (~13 μm)

- planimetry $\sigma_{xy} = 2PS \dfrac{H}{f} = 48$ cm
- altimetry $\sigma_z = 2PS \dfrac{H^2}{Bf} = 7$ m

2°) Ground control points: GCP

orientation

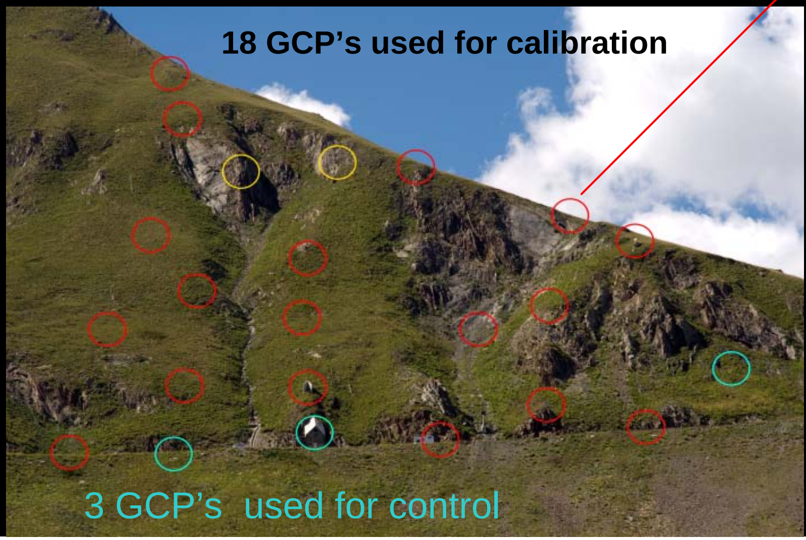


farest control point at 1.02 km from left camera

XYZ measurement with differential geodesic GPS (L1+ L2)

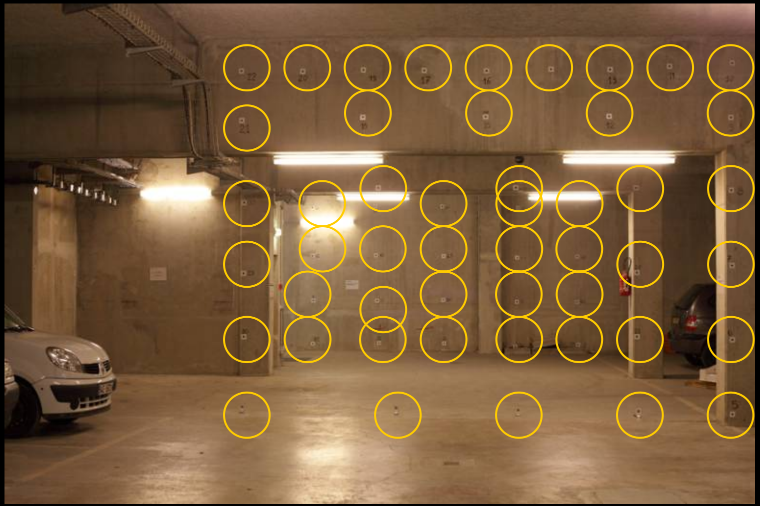
XYZ accuracy a few cm

***In situ* calibration**



3°) Aertriangulation & camera calibration

IGN Calibration



- Software: Poivilliers and Etalon (IGN)
- 85mm focused at 25 m
- 56 points (precision mm)
- 6 images → 3 pairs
- 81 points measured

f → 85.70mm

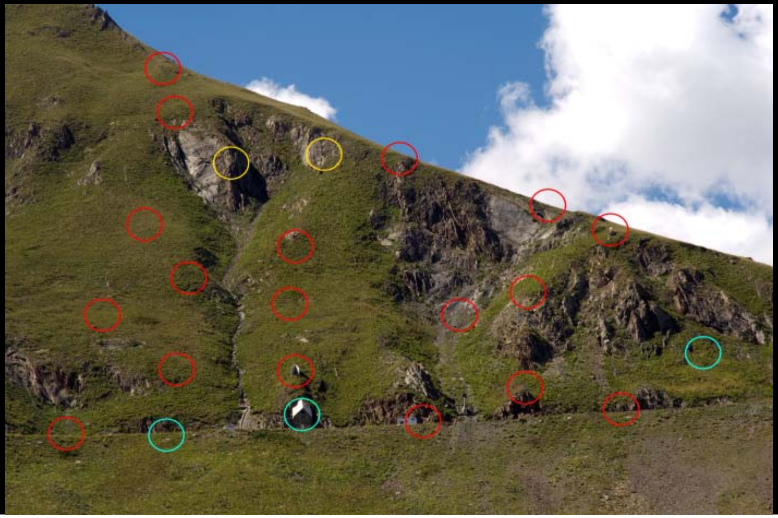
PPx → -45.7 µm

PPy → -92.4 µm

non negligible decentration

focal length dependence to focus

In situ self-calibration at Lautaret



- Software: ORIMA and LPS (Leica-Geosystem)
- 85mm focused at ∞
- 19 points (precision 5 cm)
- 2 images → 1 pair
- 152 Tie's measured

f → 85.51mm

σ_X = 0.06 m
σ_Y = 0.02 m
σ_Z = 0.04 m

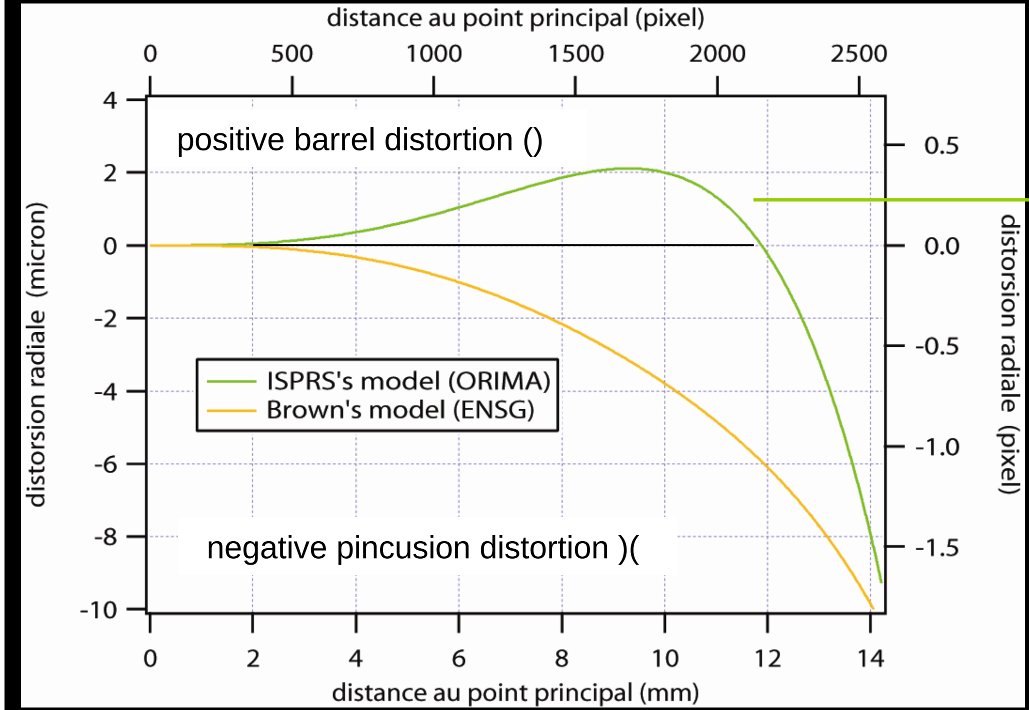
lens decentration

PPx → -65.7 µm

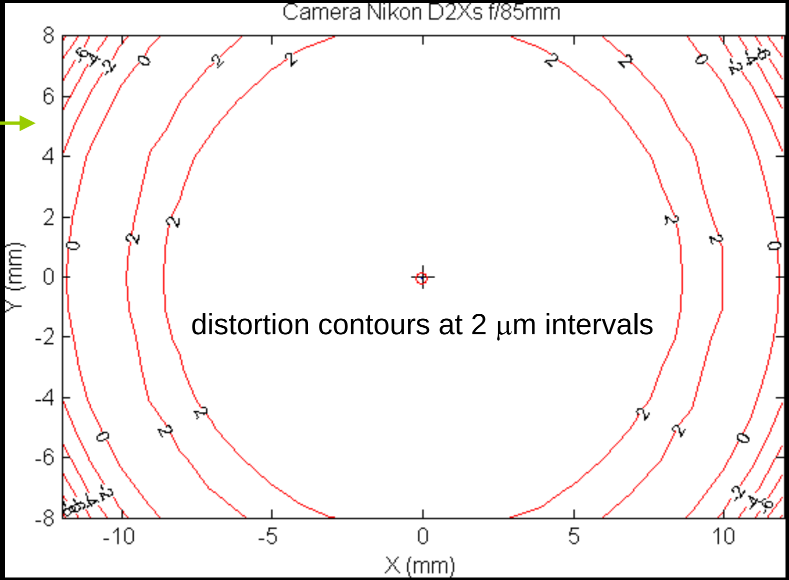
PPy → -45.7 µm

3°) Aerotriangulation & camera calibration

Radial distortion



ORIMA and LPS (Leica-Geosystem)



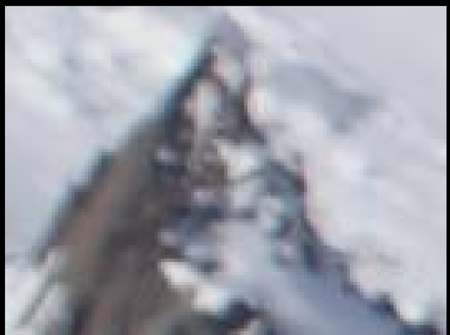
- Less than 10 µm (one pixel and a half) at image corner
- Very low and acceptable distortion

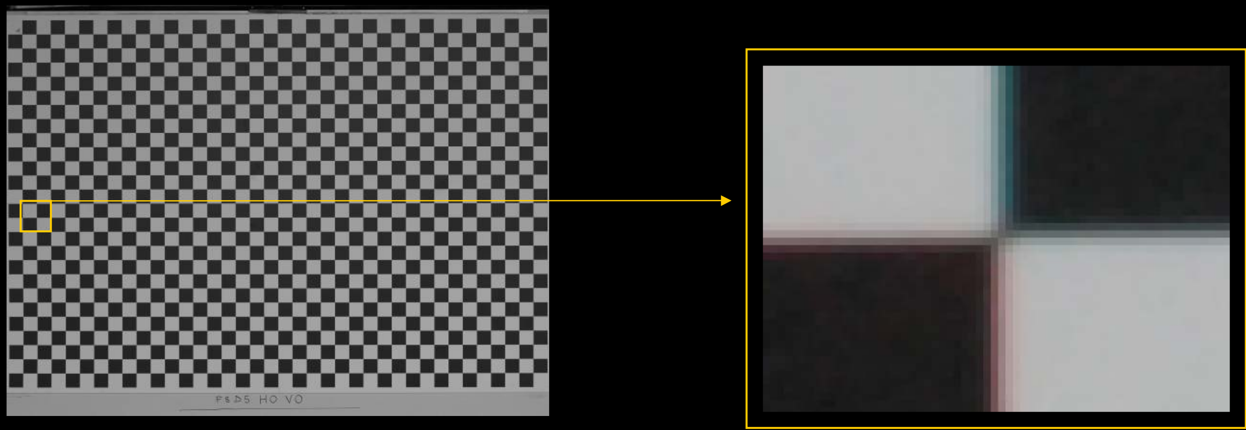
3°) Aerotriangulation & camera calibration

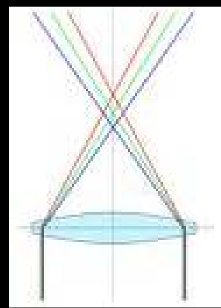
Canon USM 100 mm f2.8

Chromatic aberration:

+ 7 pixels B band
- 7 pixels R band

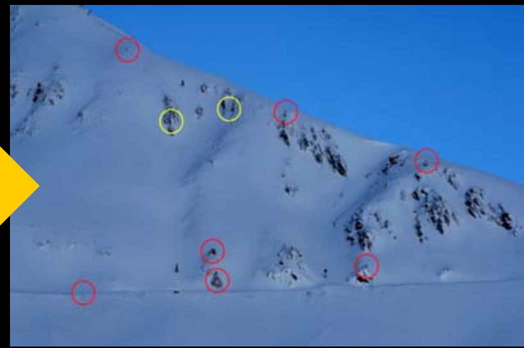




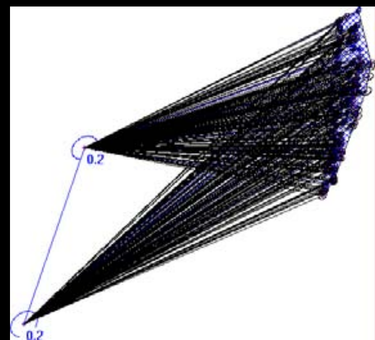


- Exchange unit from Canon France S.A.

3°) Aerotriangulation with calibrated cameras

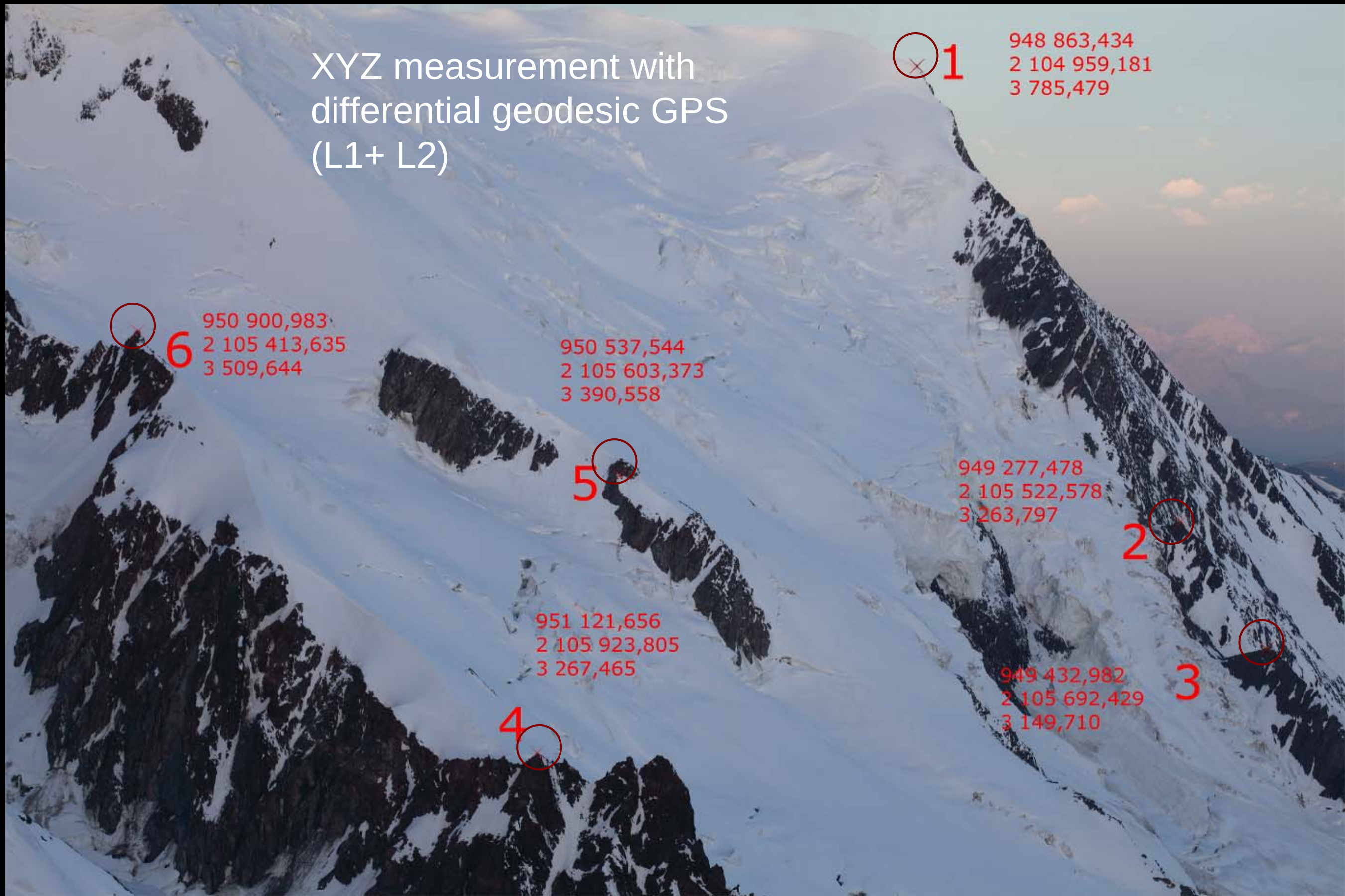


7 GCP's measured
152 Tie's measured between images



Sigma0 = 1.1 µm
RMS Max X = 0.14m RMS Mean X = 0.08m
RMS Max Y = 0.05m RMS Mean Y = 0.03m
RMS Max Z = 0.11m RMS Mean Z = 0.06m

3°) Aerotriangulation with calibrated cameras

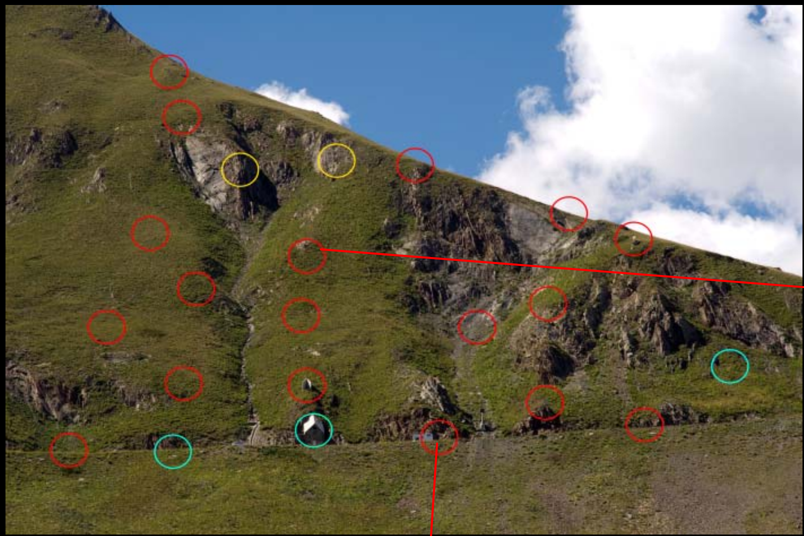


6 control points

Aero 13 August 2010
Sigma0 = 1.94 µm

RMS Mean X = 0.11m
RMS Mean Y = 0.11m
RMS Mean Z = 0.02m

3°) Validation of aerotriangulation



Validation with 2 control points not used in the aerotriangulation

→ between 5 and 10 cm of discrepancy

4°) Photogrammetric restitution

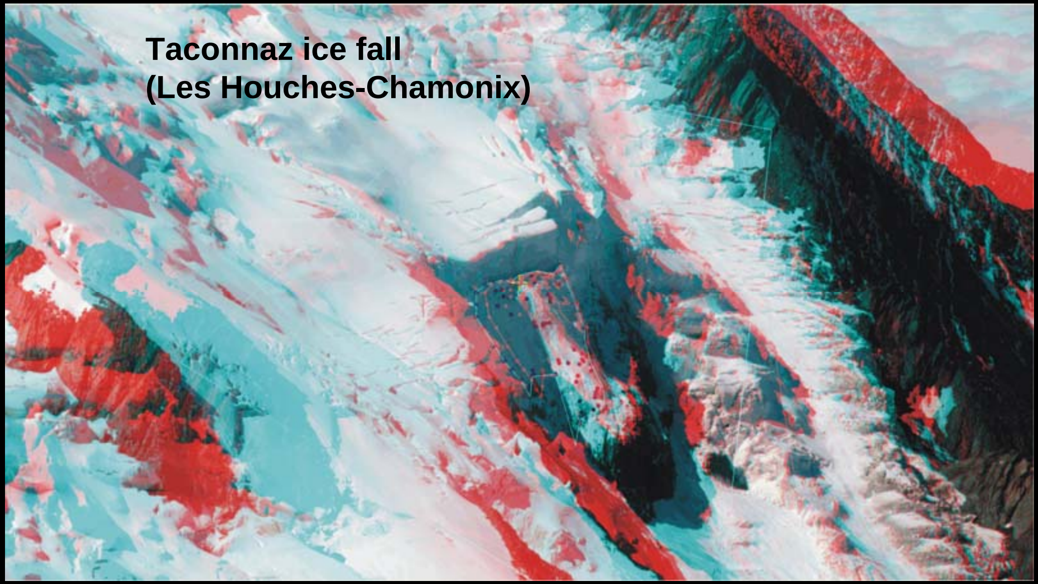
- software: ArcGis 9.3 + Stereo Analyst extension (ERDAS)

- manual restitution by plotting in stereoscopic vision (anaglyph)

- help of stereo-correlation

- exportation of ACII XYZ

- DEM interpolation & calculation IDRISI



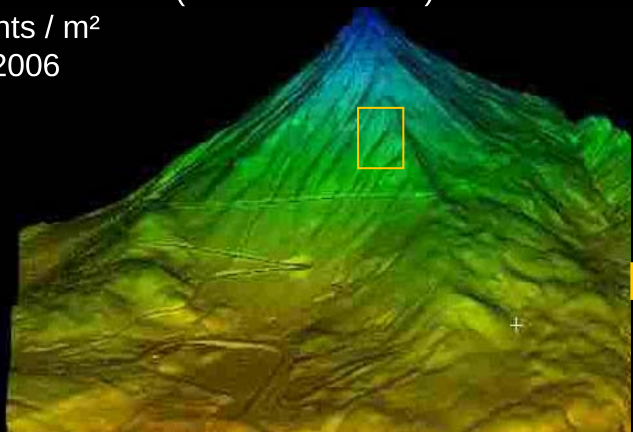
4°) Validation of restitution

Validation with DEMs comparison

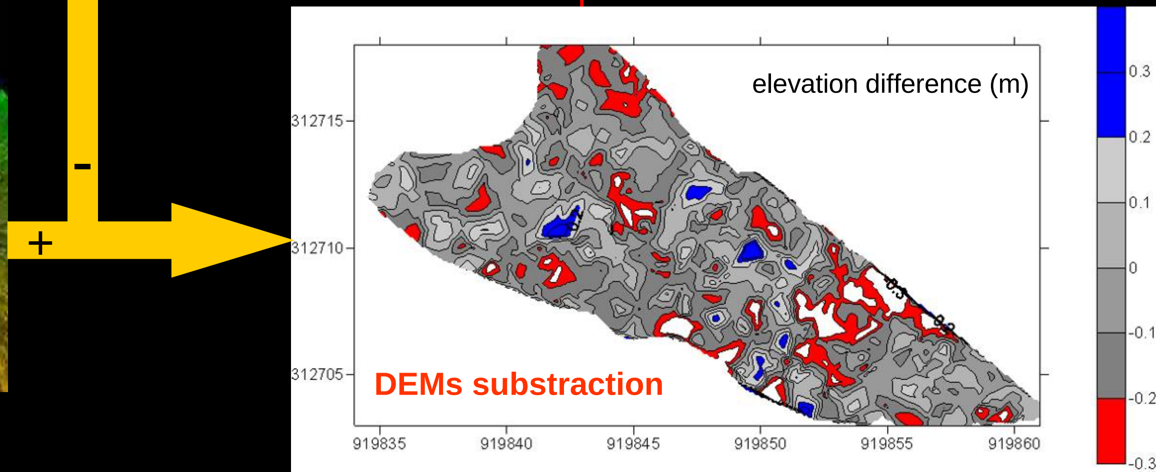
2 DEMs generated from:
- photogrammetry
- laser scan

- no bias
- σ (RMS) = 0.11 m

DEM Laser Scan (RMS XYZ~10cm)
2 points / m²
July/2006



Laser scan (snow cover free)

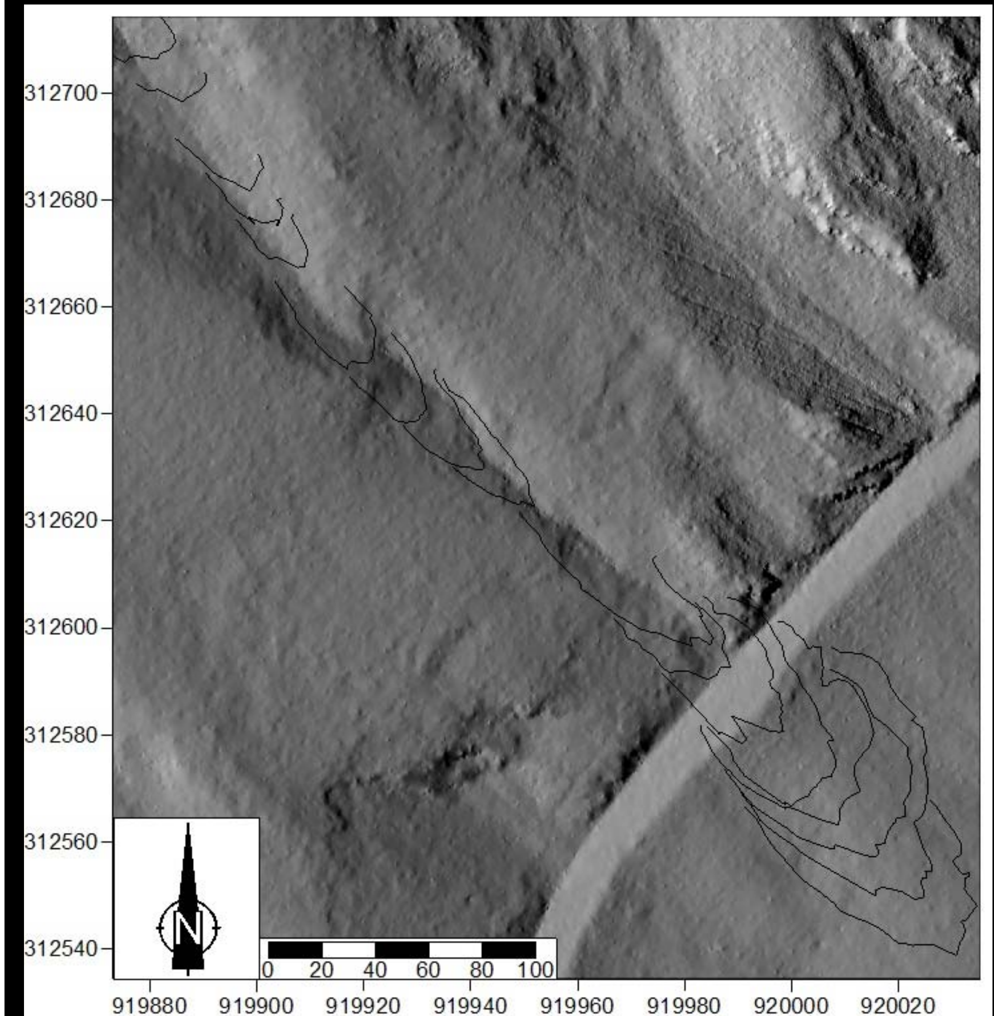


5°) Results

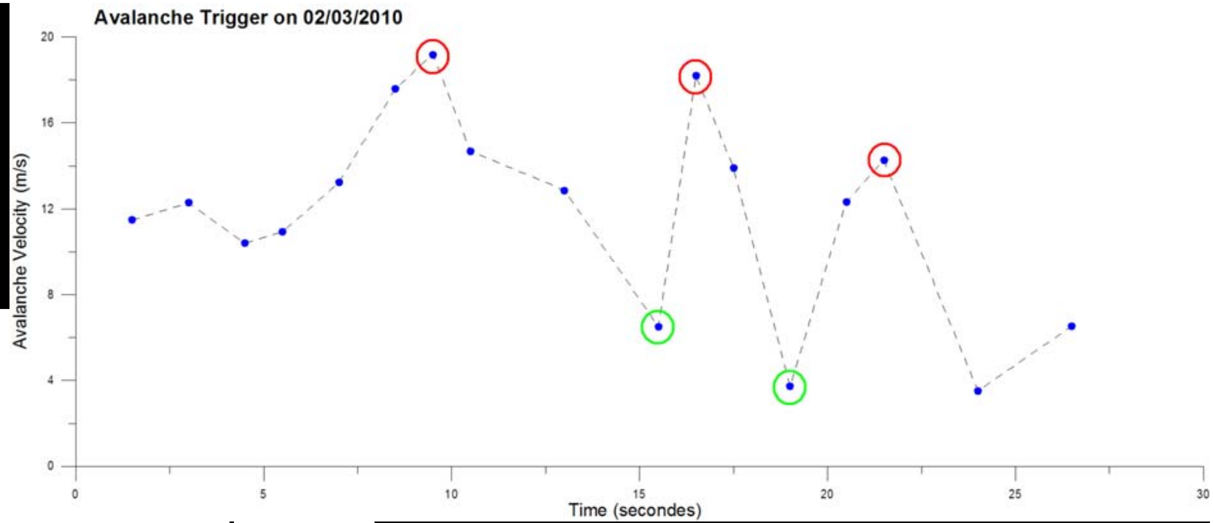
Lautaret: avalanche release 2 March 2010

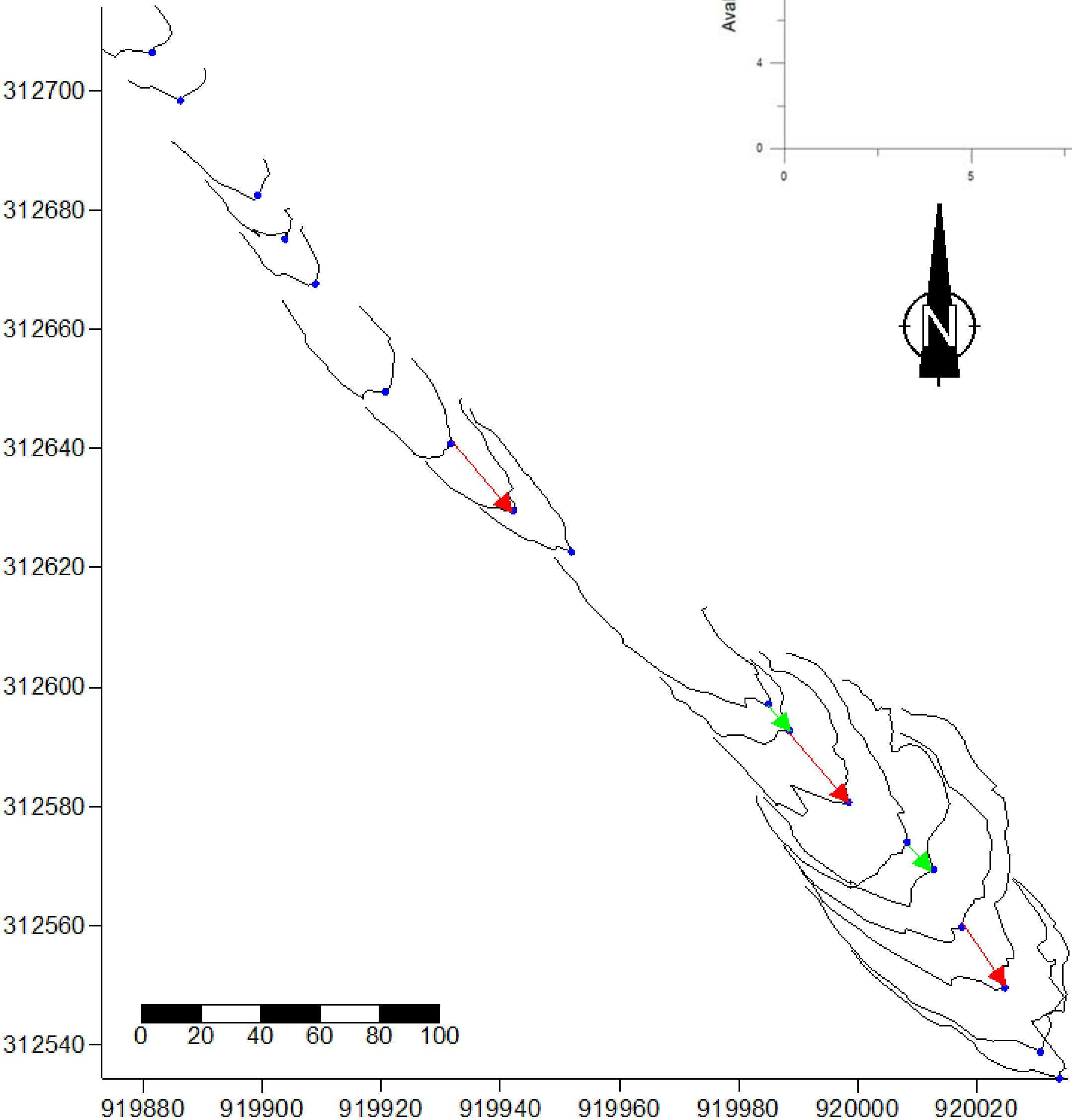
Front velocity

s



[redacted]

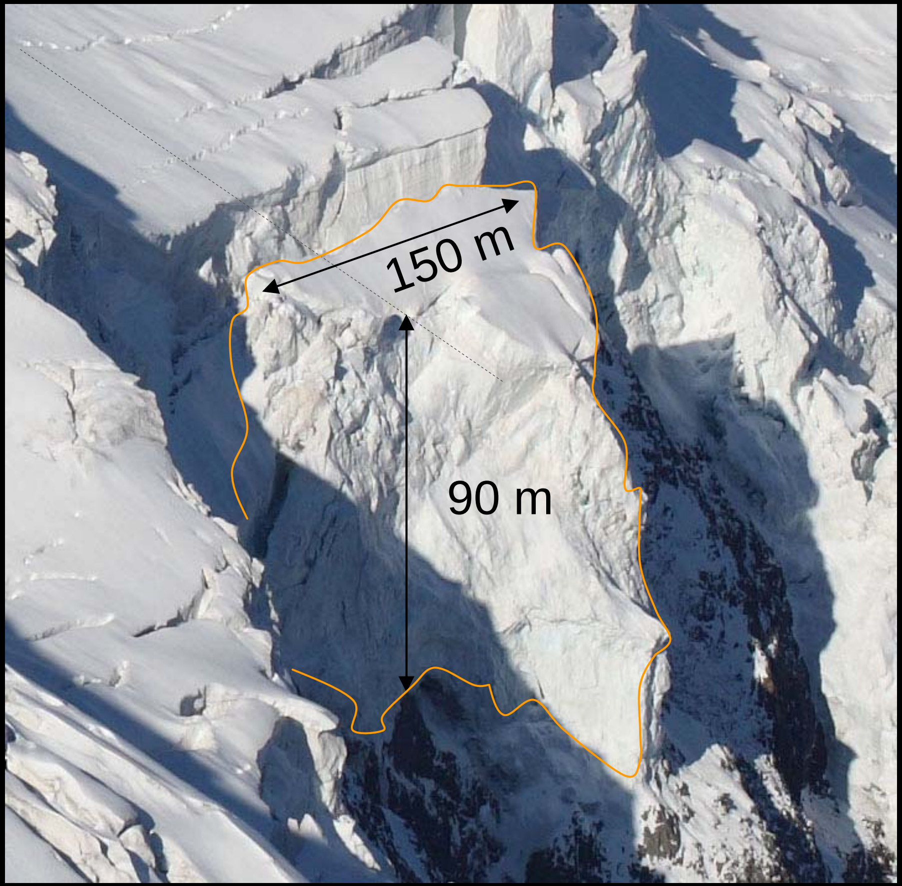




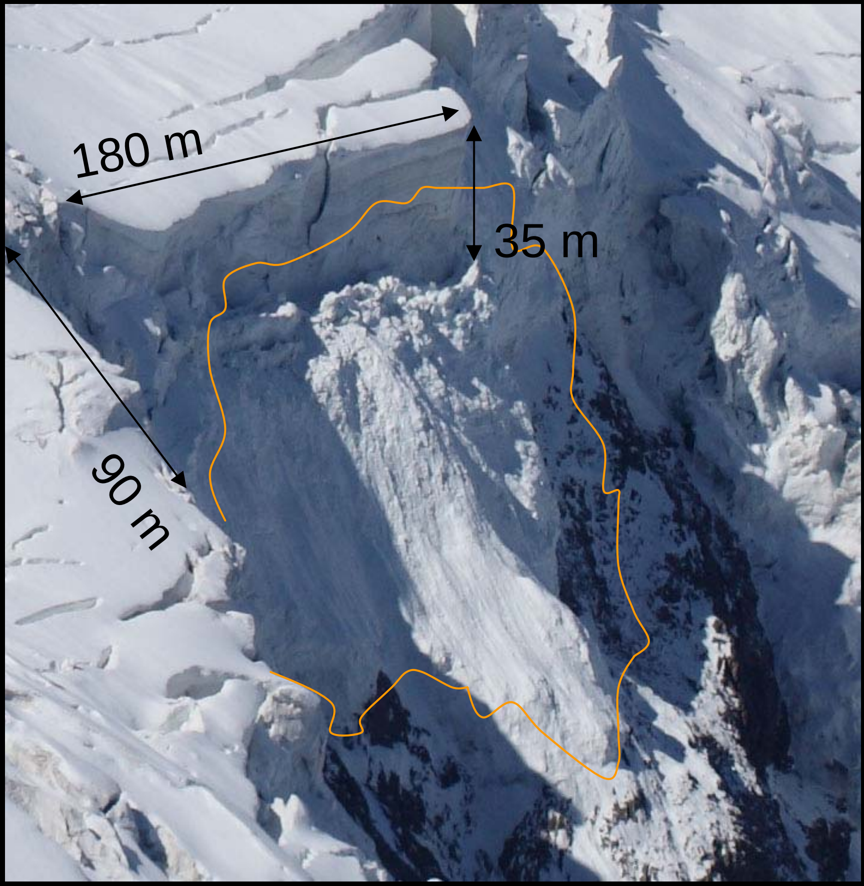
[redacted]

5°) Taconnaz: serac fall 12-13 August 2010

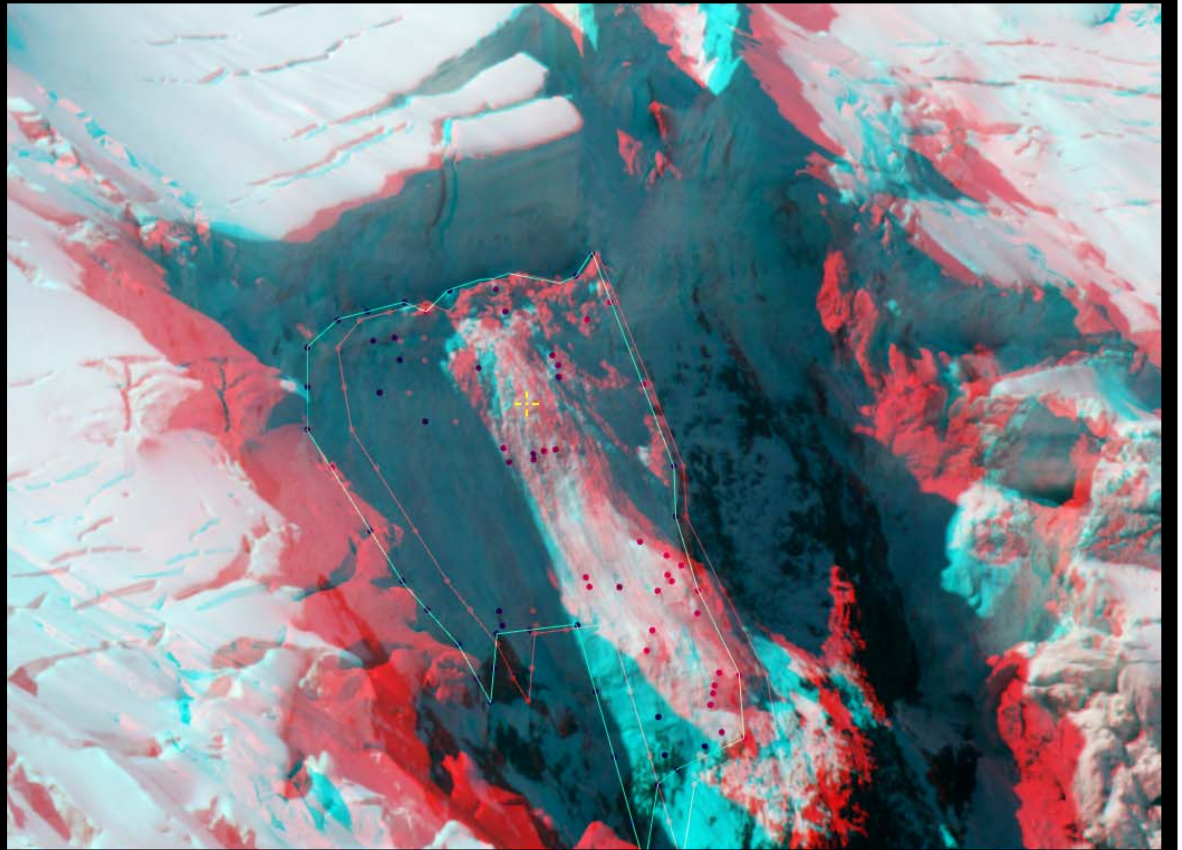
8 August 2010



13 August 2010



5°) Taconnaz: serac fall 12-13 August 2010



Volume = 109 000 m^3 + 15 000 m^3 (hidden faces?)

Conclusion & further developments

- operational photogrammetric field device

- high resolution (1-2 pixels) and accuracy (2-3 pixels) with non-metric cameras

- survey and DEMs can be generated at various time rates

Avalanche mass balance

- snow volume released
- erosion along the avalanche track
- snow deposit in the run-out area

Avalanche dynamics

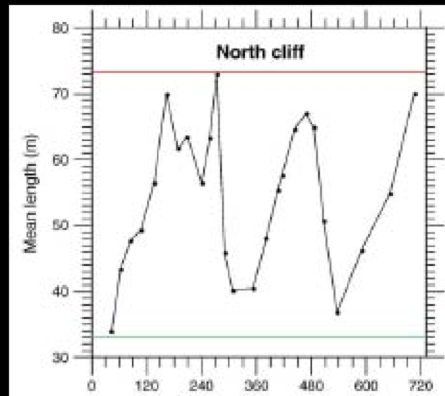
- front velocity at higher time rates
- run-out distance

Conclusion & further developments

Ice fall surface velocities

Ice cliff upper lip position in time

LeMeur & Vincent CRST 2006



Serac fall return period