# Assessment of photogrammetry Structure-from-Motion compared to terrestrial LiDAR scanning for generating Digital Elevation Models. Example in a polar basin, Spitsbergen 79°N

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# Introduction

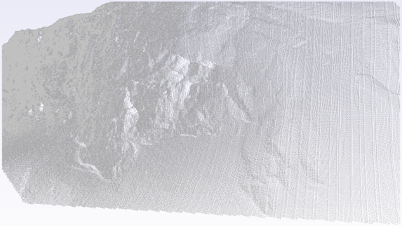
- High resolution DEM for snow cover and glacier evolution assesment [1]
- Area ranging from a few 100 $m^2$ to a few tens of $km^2$
- Snow cover ⇒ ≃ 10 cm elevation resolution
- Multiple-season/year comparison ⇒ absolute coordinate positioning requirement (for point cloud subtraction)

[1] F. Tolle & *al.* "Terrestrial laser scanning surveys to describe and quantify slope dynamics in an Arctic glacier basin (Austre Lovénbreen, Svalbard 79°N)", The 13th International Circumpolar Remote Sensing Symposium

# LiDAR

- Historically: photography and ground control point positioning (photogrammetry)
- More recently: state of the art resolution achieved by light pulse time of flight measurement ("Light-RADAR" → lidar) and raster scanning the laser beam over the targeted area
- GPS positioning of the Lidar instrument + georeference targets for positioning the point cloud in space
- centimeter accuracy in the distance scale, spot size of 30 cm diameter at 1 km (3 cm at 100 m), footprint 8 cm at 100 m

⇒ fantastic point cloud resolution *but* time consuming (multiple hour measurement), strongly dependent on weather conditions, heavy/fragile equipment (state of the art telescope) and requires power



# Photogrammetry

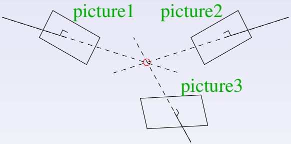
Our question: can digital photogrammetry provide the required dataset (resolution) for our snow/ice accumulation/melt assesment ? high temporal resolution ?

- Digital photogrammetry: Structure from Motion (SfM) strategy uses multiple views of the same scene for reconstructing the 3D point cloud (depth map)
- Commercial off the shelf camera: lightweight, power autonomous

- 4000 pixel wide image with an angular width of 60 $^{o}$ $\Rightarrow$ 1 m-wide pixel at 4 km

# MICMAC

- Complex algorithm: in our case, two software, MICMAC[2] from the French Geographic Institute (IGN) and Photoscan (Agisoft).
- MICMAC: Opensource software
- Step by step processing (command line interface): each step is defined by the user and the result can be assessed before the next step is considered
  1. Find similar features on multiple images




Y. Egels & M. Kasser, *Digital Photogrammetry*, CRC Press (2001), chapter 2.5 (pp.145–158)
Sub-pixel resolution

- ability to convert the point cloud coordinates to absolute coordinates either using Ground Control Points or injecting the GPS position of the camera when the images were taken

[2] `http://logiciels.ign.fr/?-Micmac,3-`

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- Step by step processing (command line interface): each step is defined by the user and the result can be assessed before the next step is considered
  1. Find similar features on multiple images
  2. Identify camera lens properties (no preliminary calibration !)
  3. Identify camera position when pictures were taken
  4. Assess the result of these computations
  5. Dense point cloud computation from the aforementioned parameters: a complex scene is the fusion of multiple point clouds
- ability to convert the point cloud coordinates to absolute coordinates either using Ground Control Points or injecting the GPS position of the camera when the images were taken

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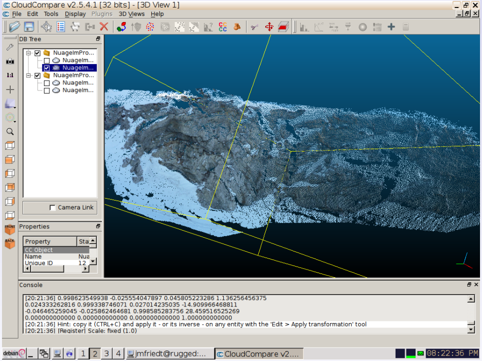
# Point cloud analysis

Huge number of points (>200 ksamples) only handled by dedicated software

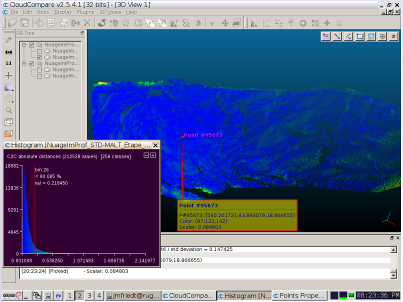
- Point cloud display: Meshlab (`meshlab.sourceforge.net/`)
- Point cloud cropping and distance analysis: CloudCompare (`www.danielgm.net/cc/`)

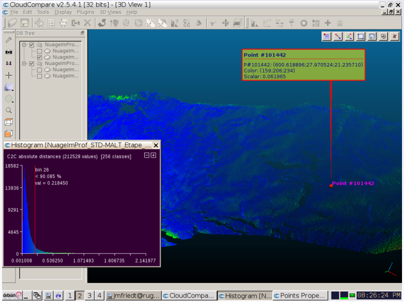


# MICMAC: birdcliff site

Cloud dimensions: 45 m$\times$ 12 m, including snow covered areas

- 3 point clouds of the same feature were acquired under different photography conditions within a few minutes
- separate GPS receiver stores the camera position at the time the picture is taken (<m short term relative position resolution)
- Point cloud error assesment: 90% of the points lie at less than 22 cm error, with typical samples in the 6-10 cm error range

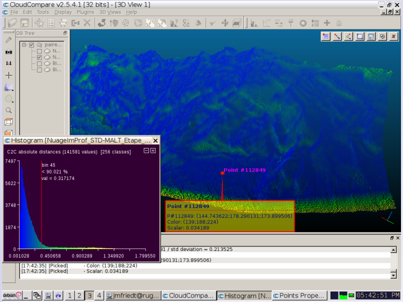


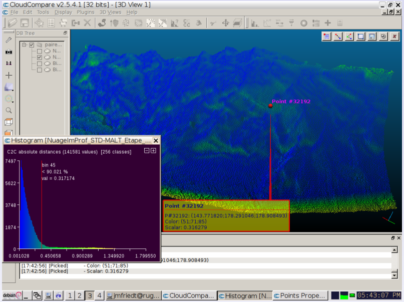




(at a distance of 40 m, pixel width is 1 cm)

# MICMAC v.s Lidar: birdcliff

The same birdcliff was scanned at the same time by Lidar (measurement duration: 102 min. scan for 2159000 points – newer LiDAR would take $\simeq$10 min)

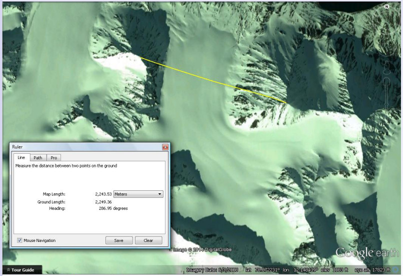


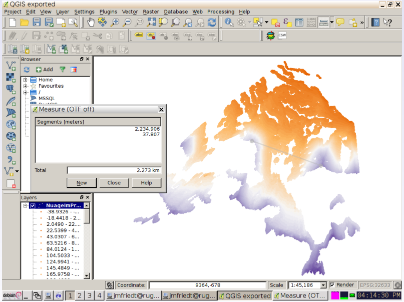




- Manual overlap due to inconsistency in the meaning of X, Y and Z+Lidar point cloud centered on the instrument
- Transform matrix diagonal elements: 0.9926, 0.9997 and 0.9926 $\Rightarrow$ scale consistent to better than 1%
- Point cloud error assesment: 90% of the points lie at less than 32 cm error

# MICMAC: wide scale DEM

- Through window images: takeoff from the plane leaving Ny-Ålesund,
- using the GPS coordinates of the plane ($\pm 0.5$ s $\Rightarrow \pm$ 27m @ 200 km/h take off speed)
- accurate in-plane model, accurate elevation, but poor absolute position + tilt



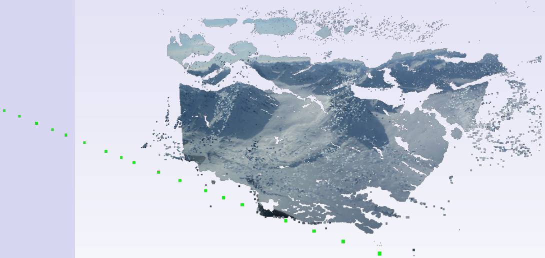

Left: Google Earth distance estimate between Haavimb and Slatoo summits

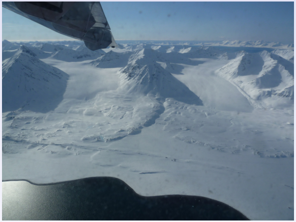
... from our DEM model

# Lessons learned

Understanding the processing algorithm is mandatory for selecting the scene conditions:

- visible features
- raster pattern of images (*NOT* a straight line which is poorly defined for the rotation axis along the path)





- fixed lens properties –
  the wider the lens, the better (*no* tele)
- 80% overlap between images of the same feature

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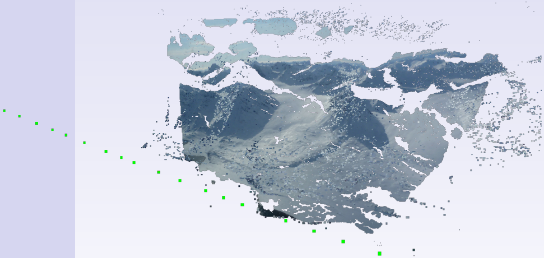

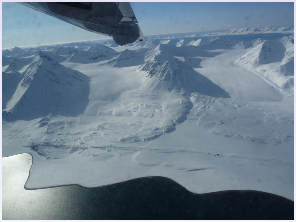

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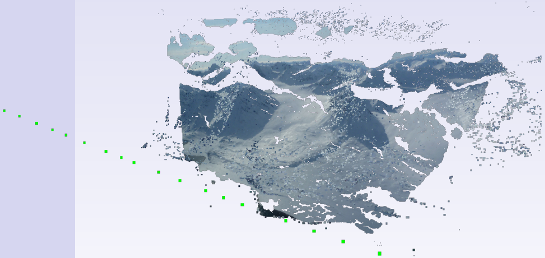

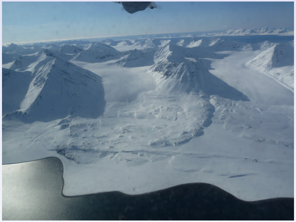

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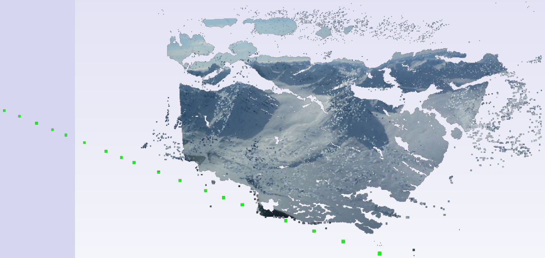

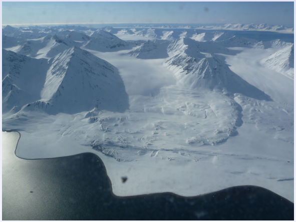

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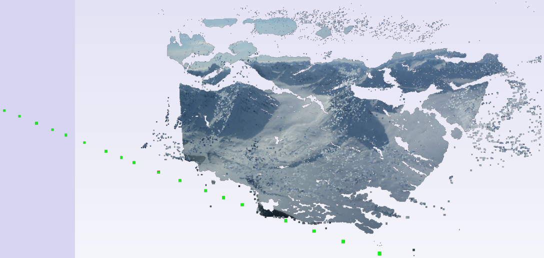

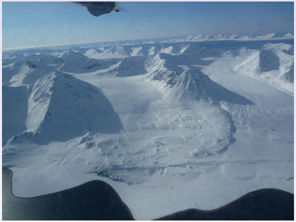

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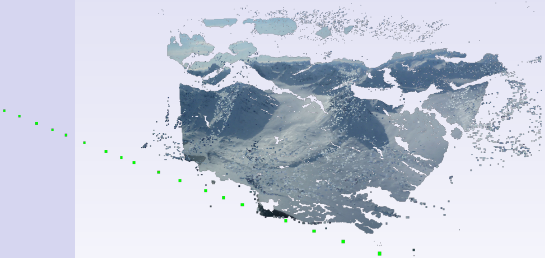

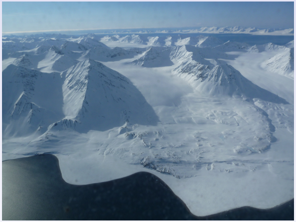

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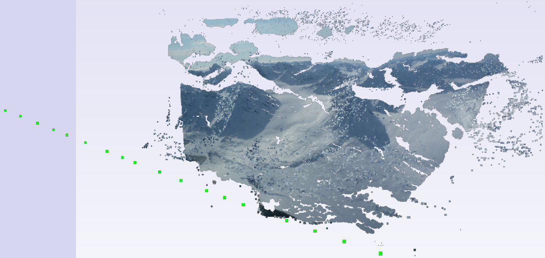

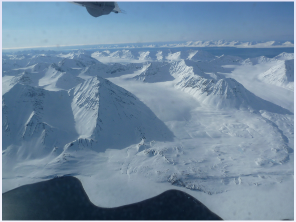

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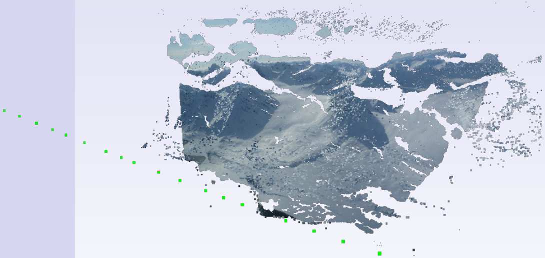

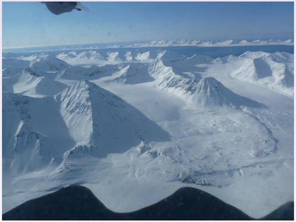

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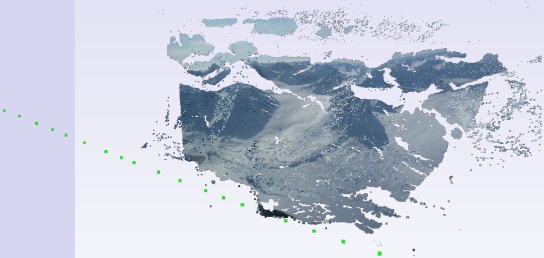

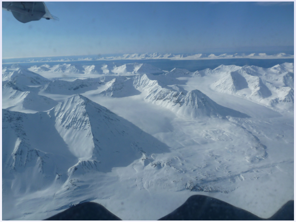

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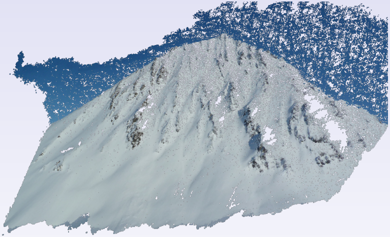
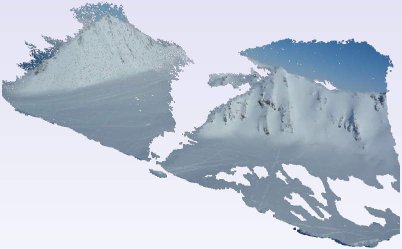
# Issue of snow covered areas

- Lack of reliable features to lock on: result dependent on illumination/shadow
- Any structure on the surface is usable: rocks, tracks ...
- sometimes it works ...





⇒ on-site image processing for assessing the quality of the point cloud and go back to take more pictures if needed

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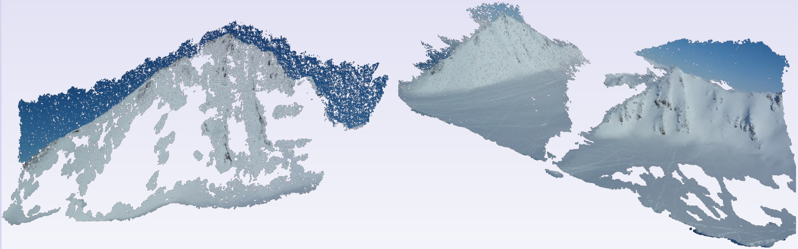
- Lack of reliable features to lock on: result dependent on illumination/shadow
- Any structure on the surface is usable: rocks, tracks ...
- sometimes it works ... and sometimes not !



$\Rightarrow$ on-site image processing for assessing the quality of the point cloud and go back to take more pictures if needed

# Comparison conclusion

| Photogrammetry | LiDAR |
|---|---|
| **Lightweight, cheap** | Heavy equipment, expensive |
| Passive, requires visible structures | **Active, functional in low light** |
| Sensitive to cast shadows | **Insensitive to shadows** |
| **Opportunistic** data acquisition | Dedicated experiment |
| 1 m pixel size at 4 km | 1 m spot size at 4 km |

# Conclusion

- Demonstration of the use of COTS camera for SfM application
- Cloudpoint resolution in the 30 cm range sufficient for snow depth estimate
- Cloudpoint registration based either on GCP or camera position when the image was taken
- Actual DEM subtraction (october-april) remains to be demonstrated
- Need for aerial photography rather than ground based photography for large scale DEM, complying with SfM requirements (drone ?)

Educational purpose: detailed tutorial on MICMAC (for GNU/Linux) applied to daily photography conditions at `http://jmfriedt.free.fr/lm_sfm.pdf` (French) and `http://jmfriedt.free.fr/lm_sfm_en.pdf` (English) – enjoy !