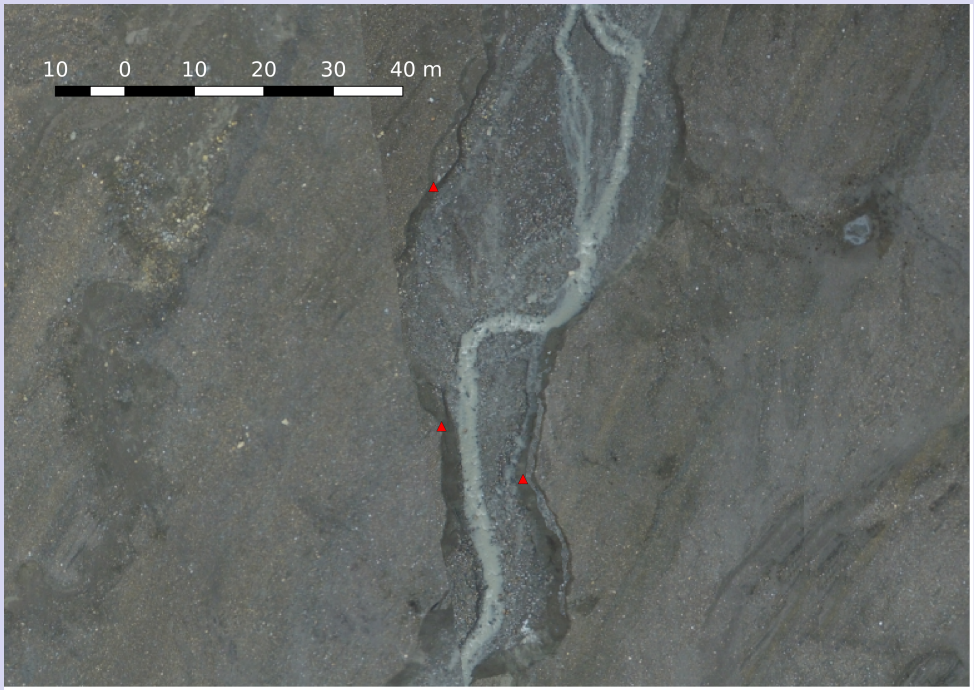
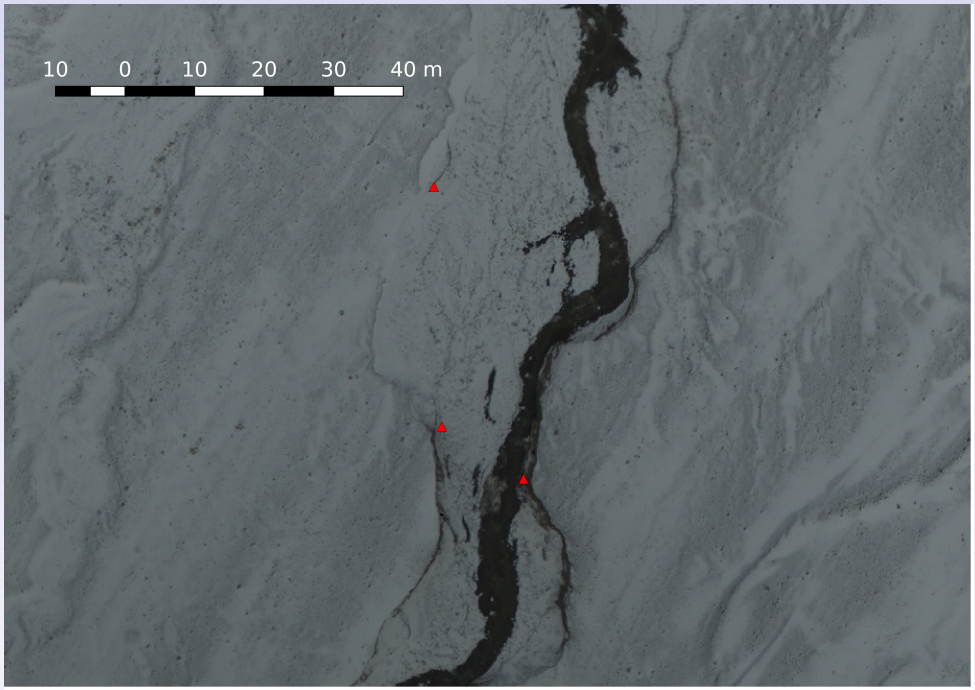
Creating georeferenced digital elevation models from unmanned aerial vehicle images

J.-M Friedt



Sept. 24th, 2015



Oct. 1st, 2015

Slides: `http://jmfriedt.free.fr`

Detailed tutorial [in French]: `jmfriedt.free.fr/foss4g_2016`

Why ?

Digital Elevation Models (DEMs) as a basic input for geographical information processing (flood, material transport, construction, landslide, glacier melt)

- Global DEMs: $\geq$90 m (3") spatial resolution
- Low update rate (one DEM)

$\Rightarrow$ local ($<$10 km^2 area) high resolution ($<$m) DEMs with short update interval ($<$week) + low equipment cost

Challenge:

- large number of images (600 to 1000/flight),
- high resolution images (4000$\times$3000 pixel, 5-6 MB/image),
- huge datasets ($>$1 GB orthophoto, $>$500 MB GeoTIF DEM)

$\Rightarrow$ MicMac [1]:

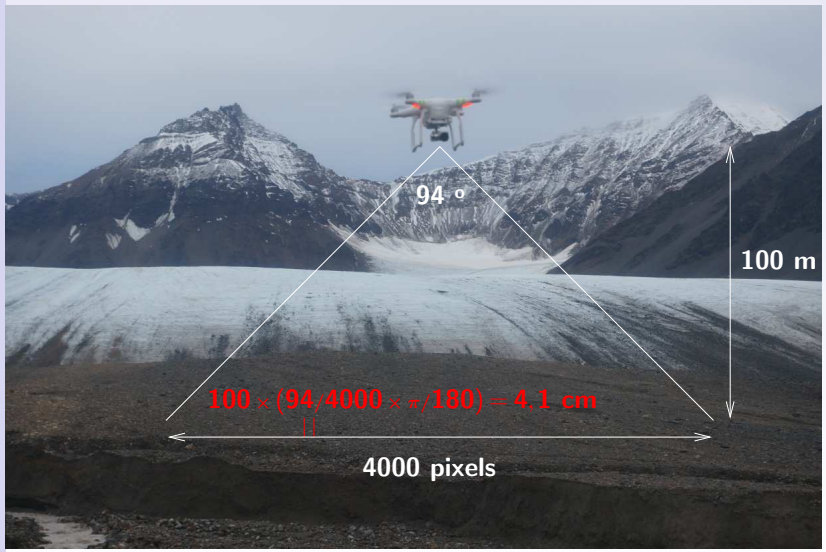
- CLI software following Un*x philosophy (one tool for each task)...
- well suited to handle a huge number of pictures without wasting resources on a GUI: all command `mm3d`, `-help` argument ...
- Ability to assess the result of each step (residue, convergence, correlation map)

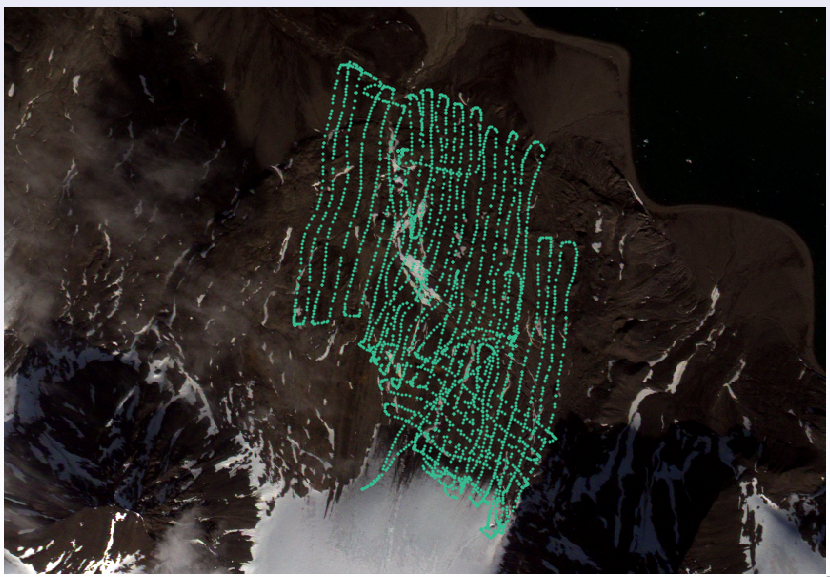
[1] `https://github.com/micmacIGN`

Fly

- Compliance with regulations (exam, flight authorization from Civilian Aviation Authority, check if Defense Ministy want to be alerted, wildlife ...)
- Plan flight: surface coverage of the picture $\Rightarrow$ acquisition rate
- Manual flight for following ground-based features+higher horizontal speed,
- ... or automated flight: at least 60% coverage along track (ideally 80%).

Safety solution: COTS UAV DJI Phantom3{Professional, Advanced} (low cost, ease of deployment, 5×20 min autonomy)

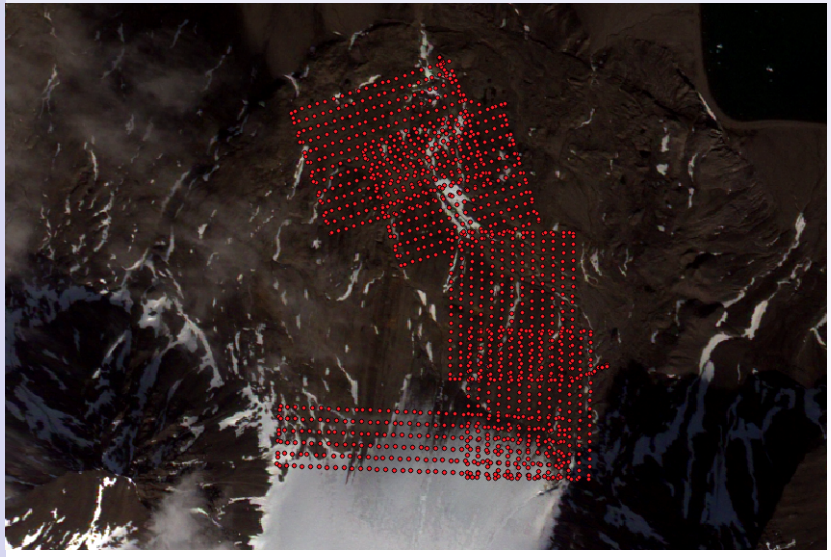


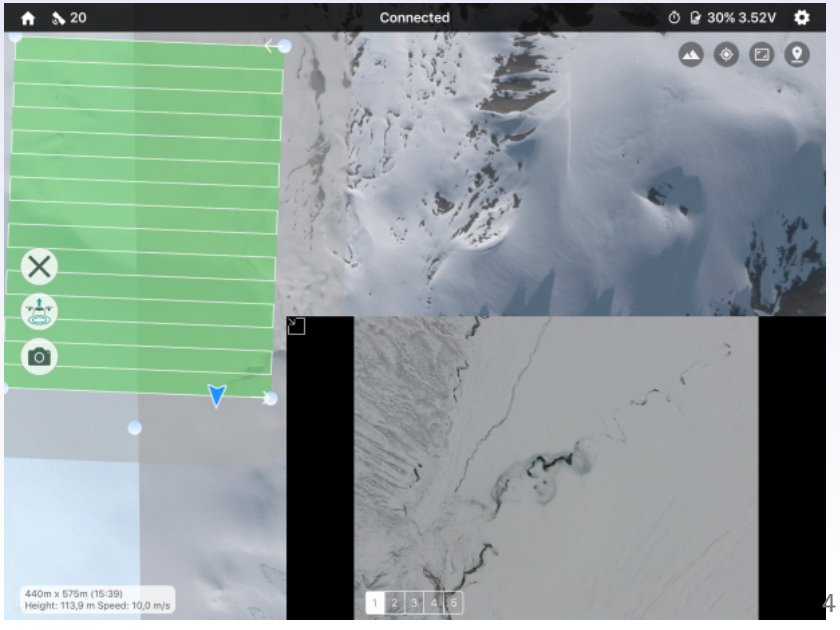


Fly

- Compliance with regulations (exam, flight authorization from Civilian Aviation Authority, check if Defense Ministy want to be alerted, wildlife ...)
- Plan flight: surface coverage of the picture ⇒ acquisition rate
- Manual flight for following ground-based features+higher horizontal speed,
- ... or automated flight: at least 60% coverage along track (ideally 80%).

Safety solution: COTS UAV DJI Phantom3{Professional, Advanced} (low cost, ease of deployment, 5×20 min autonomy)





Process: georeference pictures

- Either pictures are readily georeferenced (accuracy ? lag between position and timestamp ?) or ...
- `exiftool` for geotagging from a NMEA file + picture directory


```
$ exiftool DSC04979.JPG | grep Origi
Date/Time Original: 2016:10:17 21:16:21
$ exiftool -geosync=-0:08:30 -geotag=mylog.nmea .
```

with config file `~/.ExifTool_config`:

```
%Image::ExifTool::UserDefined::Options =
                (CoordFormat => '%.6f', GeoMAxIntSecs=0,);
```

- Input file (comment #, truncated UTM longitude-latitude-altitude-filename):

```
#F=X Y Z N
8322.32388327 9441.486585 227.52 DJI_0001.JPG
8328.218804119 9443.36958993 227.42 DJI_0002.JPG
8350.947655692 9450.63328708 227.32 DJI_0003.JPG
...
```

```
mm3d OriConvert OriTxtInFile position_UTM33N.txt jmfgps MTD1=1 \
NameCple=FileImagesNeighbour.xml CalcV=1 ImC=DJI_0115.JPG NbImC=25
```

Ability to introduce a timelag between GPS timestamp & camera time [2]
§13.3.4 of `github.com/micmacIGN/Documentation/blob/master/DocMicMac.pdf`

[2] L. Girod, C. Nuth, A. Kääb, B. Etzelmüller, J. Kohler, *Terrain changes from images acquired on opportunistic flights by SFM photogrammetry*, The Cryosphere Discuss., (2016) at `http://www.the-cryosphere-discuss.net/tc-2016-228/`

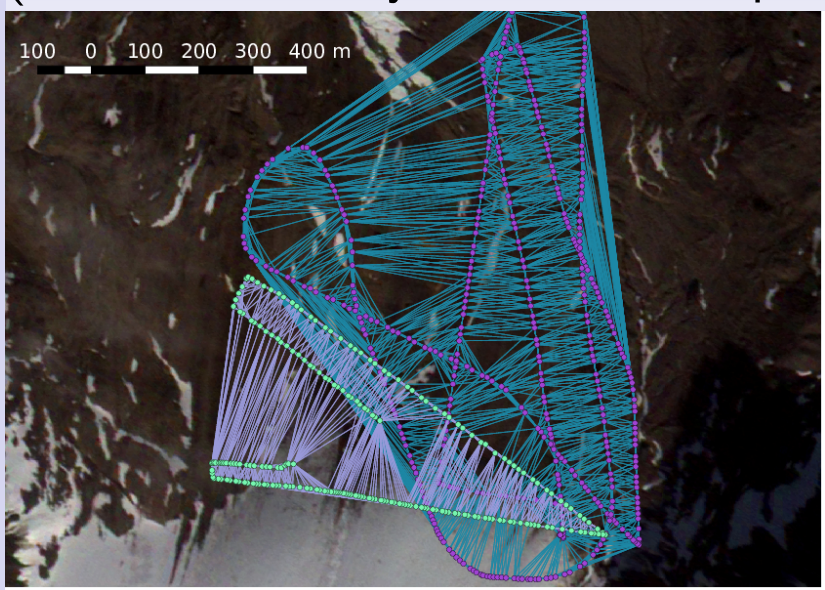
Process: find tie points (using GPS location)

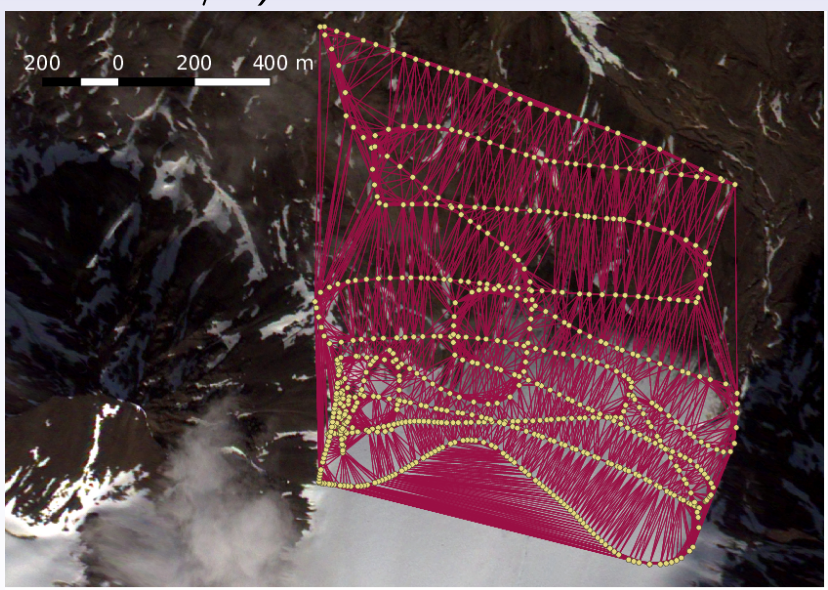
⇒ orientation directory: `Ori-jmfgps`

- ≃20 min acquisition at 1 image/2 second≃600 pictures: all combinations $C_2^{600} = \frac{600 \cdot (600-1)}{2} = 179700$ pairs
- Using GPS coordinates on 614 images, MicMac only attempts to match relevant points on 10413 pairs.

```
mm3d Tapioca File "FileImagesNeighbour.xml" 1500 ExpTxt=1  # ASCII output
```

(1500=max analysis resolution≃picture width/3)





Process: find tie points (using GPS location)

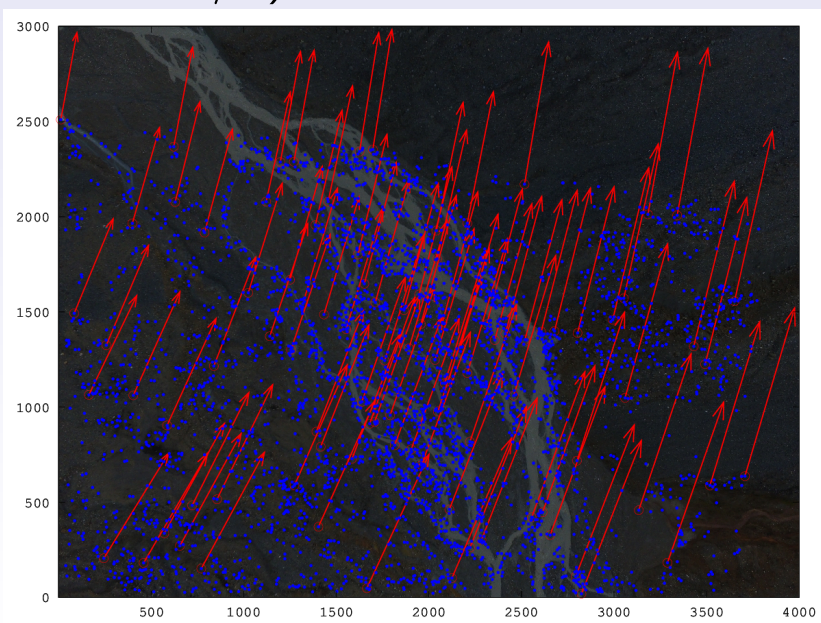
⇒ orientation directory: `Ori-jmfgps`

- ≃20 min acquisition at 1 image/2 second≃600 pictures: all combinations $C_2^{600} = \frac{600 \cdot (600-1)}{2} = 179700$ pairs
- Using GPS coordinates on 614 images, MicMac only attempts to match relevant points on 10413 pairs.

```
mm3d Tapioca File "FileImagesNeighbour.xml" 1500 ExpTxt=1  # ASCII output
```

(1500=max analysis resolution≃picture width/3)

`Homol/` output for arrows: 3762 tie points



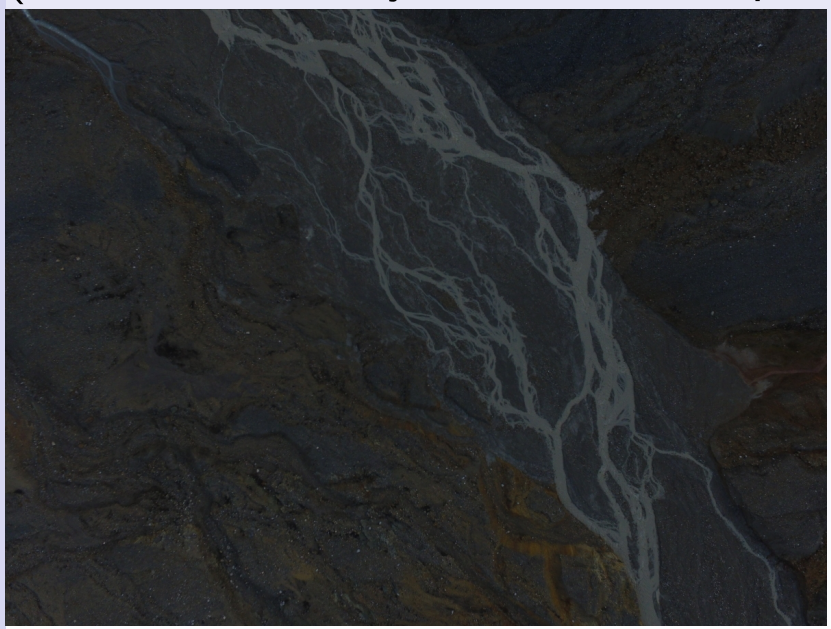
Process: find tie points (using GPS location)

⇒ orientation directory: `Ori-jmfgps`

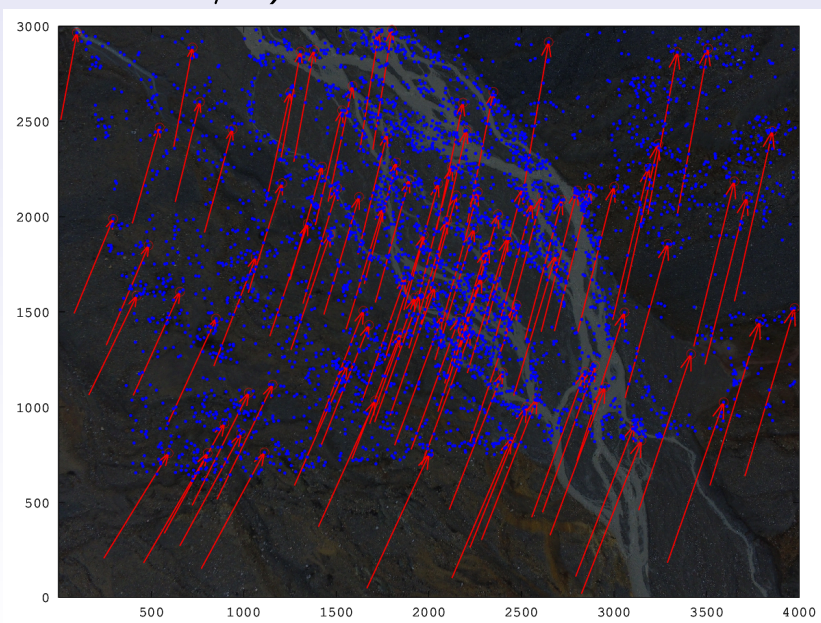
- ≃20 min acquisition at 1 image/2 second≃600 pictures: all combinations $C_2^{600} = \frac{600 \cdot (600-1)}{2} = 179700$ pairs
- Using GPS coordinates on 614 images, MicMac only attempts to match relevant points on 10413 pairs.

```
mm3d Tapioca File "FileImagesNeighbour.xml" 1500 ExpTxt=1  # ASCII output
```

(1500=max analysis resolution≃picture width/3)



`Homol/` output for arrows: 3762 tie points



Process: identify lens properties + locate camera

- Subset of pictures (`PATC`) selected to identify lens properties – sample provided by `Tapioca`
  `PATC="DJI_0282.JPG|DJI_0281.JPG|DJI_0283.JPG|DJI_0272.JPG|DJI_[...]"`
  `P=".*JPG"`
- Many lens models – the more free parameters, the better the model, but the lower the chances of convergence
- Apply lens model to all pictures to position camera in arbitrary framework

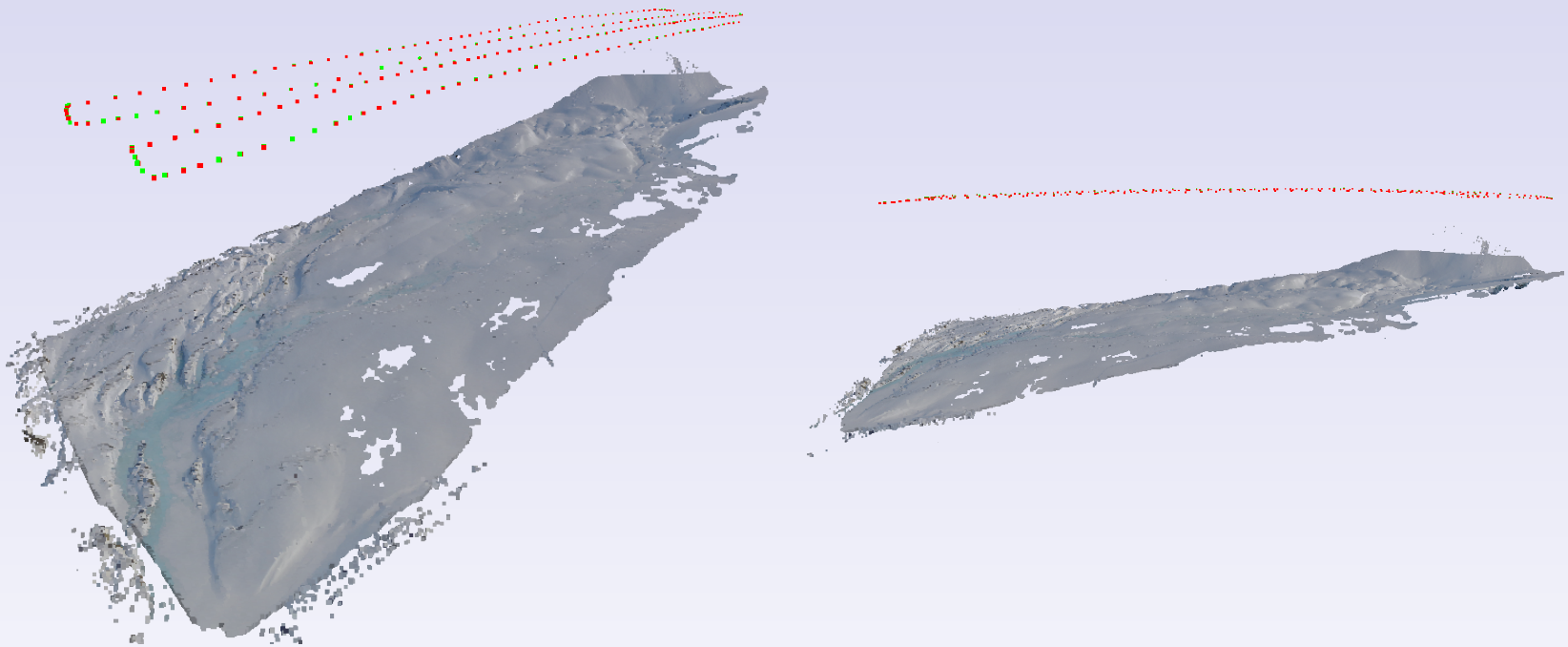
```
$ mm3d Tapas -help
Authorized models :
   RadialBasic
   RadialExtended
   Fraser
   FishEyeEqui
   AutoCal
   Figee
   HemiEqui
   RadialStd
   FraserBasic
   FishEyeBasic
...
```

```
mm3d Tapas RadialStd "$PATC" Out=Cal
mm3d Tapas AutoCal "$P" InCal=Cal Out=Init

... Add Pose = DSC_0277.JPG
RES:[DSC_0265.JPG][C] ER2 3.24469 Nn 94.4646 Of 2204 Mul 216 Mul-NN 216 Time 0.078583
RES:[DSC_0266.JPG][C] ER2 11.4655 Nn 98.9231 Of 650 Mul 253 Mul-NN 252 Time 0.0230448
RES:[DSC_0267.JPG][C] ER2 1.60959 Nn 99.422 Of 865 Mul 397 Mul-NN 396 Time 0.031569
RES:[DSC_0268.JPG][C] ER2 1.1892 Nn 99.9177 Of 2430 Mul 674 Mul-NN 672 Time 0.094388
RES:[DSC_0269.JPG][C] ER2 1.30866 Nn 99.9593 Of 2457 Mul 686 Mul-NN 686 Time 0.0955091
...
RES:[DSC_0277.JPG][C] ER2 0.792649 Nn 98.5243 Of 2304 Mul 556 Mul-NN 545 Time 0.108456
RES:[DSC_0278.JPG][C] ER2 0.926287 Nn 98.259 Of 919 Mul 517 Mul-NN 510 Time 0.033983
RES:[DSC_0279.JPG][C] ER2 0.852054 Nn 98.1366 Of 1288 Mul 334 Mul-NN 332 Time 0.045424
RES:[DSC_0280.JPG][C] ER2 0.793246 Nn 98.5294 Of 1224 Mul 234 Mul-NN 233 Time 0.0424399
| |  Residual = 0.87509 ;; Evol, Moy=2.07748e-11 ,Max=4.92559e-11
| |  Worst, Res 1.05504 for DSC_0274.JPG,  Perc 96.6154 for DSC_0266.JPG
| |  Cond , Aver 5.80123 Max 62.7957 Prop>100 0
BIGTIF suspended momentally
--- End Iter 9 STEP 3
```

Process: switch to geo-referenced space and coarse pointcloud

```
CenterBascule "$P" Init jmfgps tmp    # two Ori: GPS + camera orientation
mm3d AperiCloud "$P" tmp
```



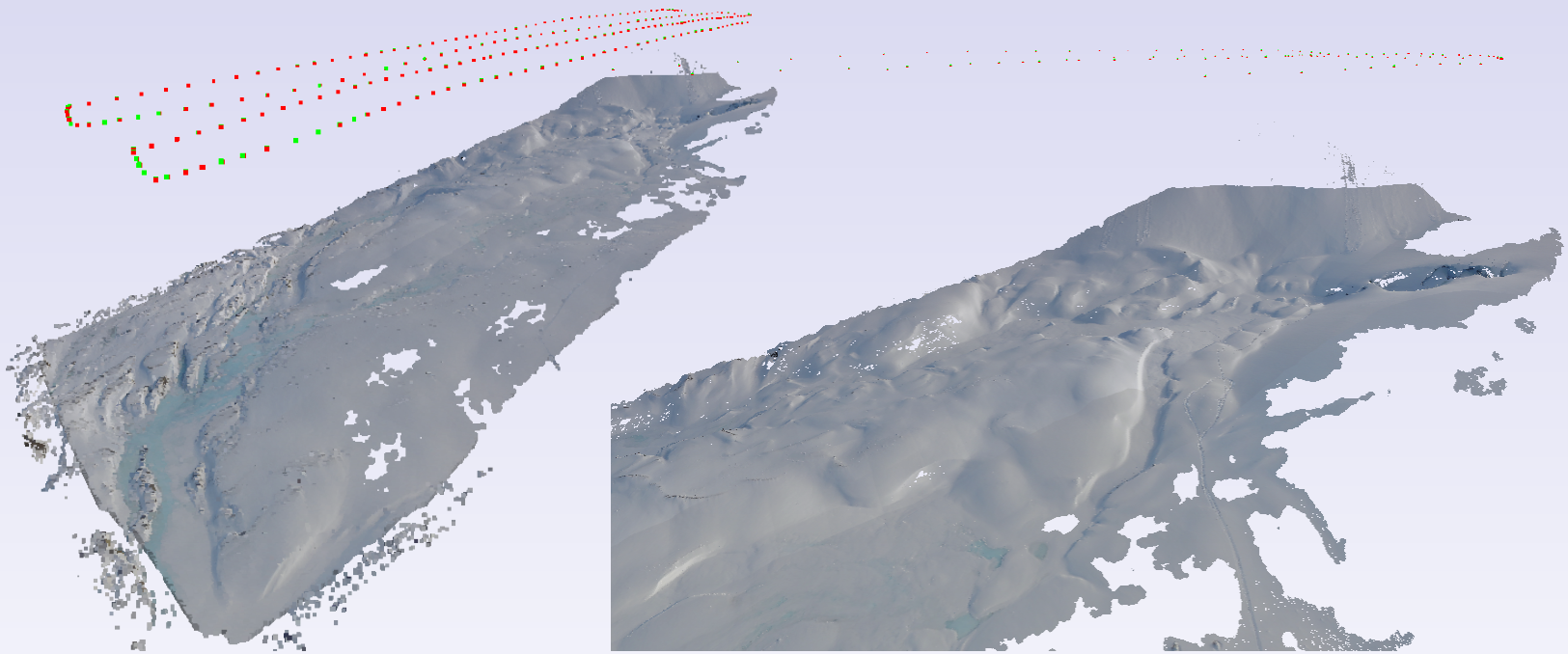
Camera position consistent [3] with flight path: we can continue processing.

notice skidoo tracks and constant altitude flight v.s varying topography

[3] distorsion due to lens calibration error: M.R. James & S. Robson, *Mitigating systematic error in topographic models derived from UAV and ground-based image networks*, Earth Surface Processes and Landforms, **39**, 1413–1420 (2014)

Process: switch to geo-referenced space and coarse pointcloud

```
CenterBascule "$P" Init jmfgps tmp    # two Ori: GPS + camera orientation
mm3d AperiCloud "$P" tmp
```



Camera position consistent [3] with flight path: we can continue processing.

notice skidoo tracks and constant altitude flight v.s varying topography

[3] distorsion due to lens calibration error: M.R. James & S. Robson, *Mitigating systematic error in topographic models derived from UAV and ground-based image networks*, Earth Surface Processes and Landforms, **39**, 1413–1420 (2014)

Process: dense pointcloud and orthophoto

Based on previous orientation directory (`Ori-tmp`), generate

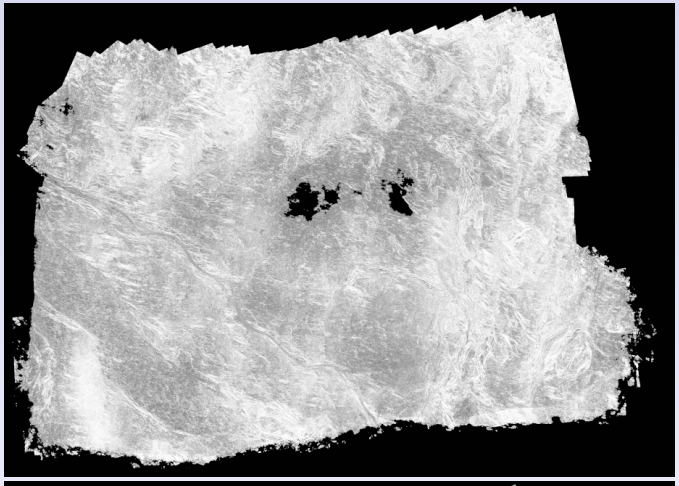
1. correlation maps `Res/Cor*`
2. georeferenced DEM `Res/Z_Num*`
3. georeferenced orthophotos `Ortho-Res/Orth*mosaic*` [4]
4. dense pointcloud `Res/*.ply` (`meshlab` or `CloudCompare` viewers)

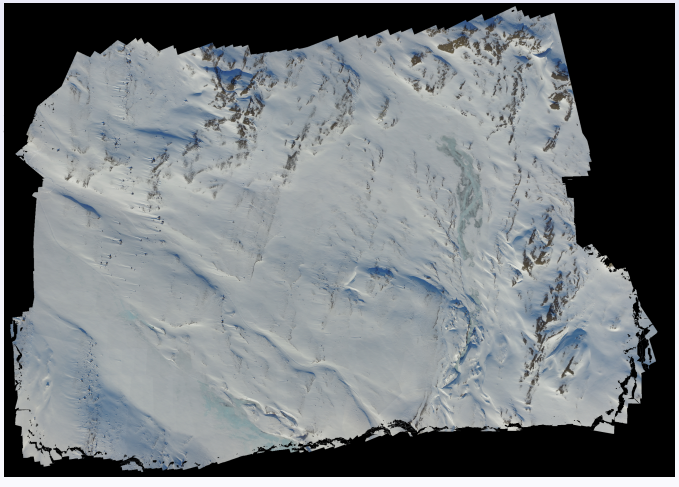
```
mm3d Malt Ortho "$P" tmp "DirMEC=Res" \
    ZoomF=4 ZoomI=32 AffineLast=false
mm3d Tawny Ortho-Res/ RadiomEgal=0
Nuage2Ply Res/NuageImProf_STD-MALT_Etape_6.
    Attr="Ortho-Res/Orthophotomosaic.tif"
```

Convert the huge TIF to (lossy) PNG:

```
for i in Orth*/*osaic*.tif; \
  do nom=‘echo $i|sed ’s/tif/png/g’‘;\
  convert $i $nom;done
```

Correlation map





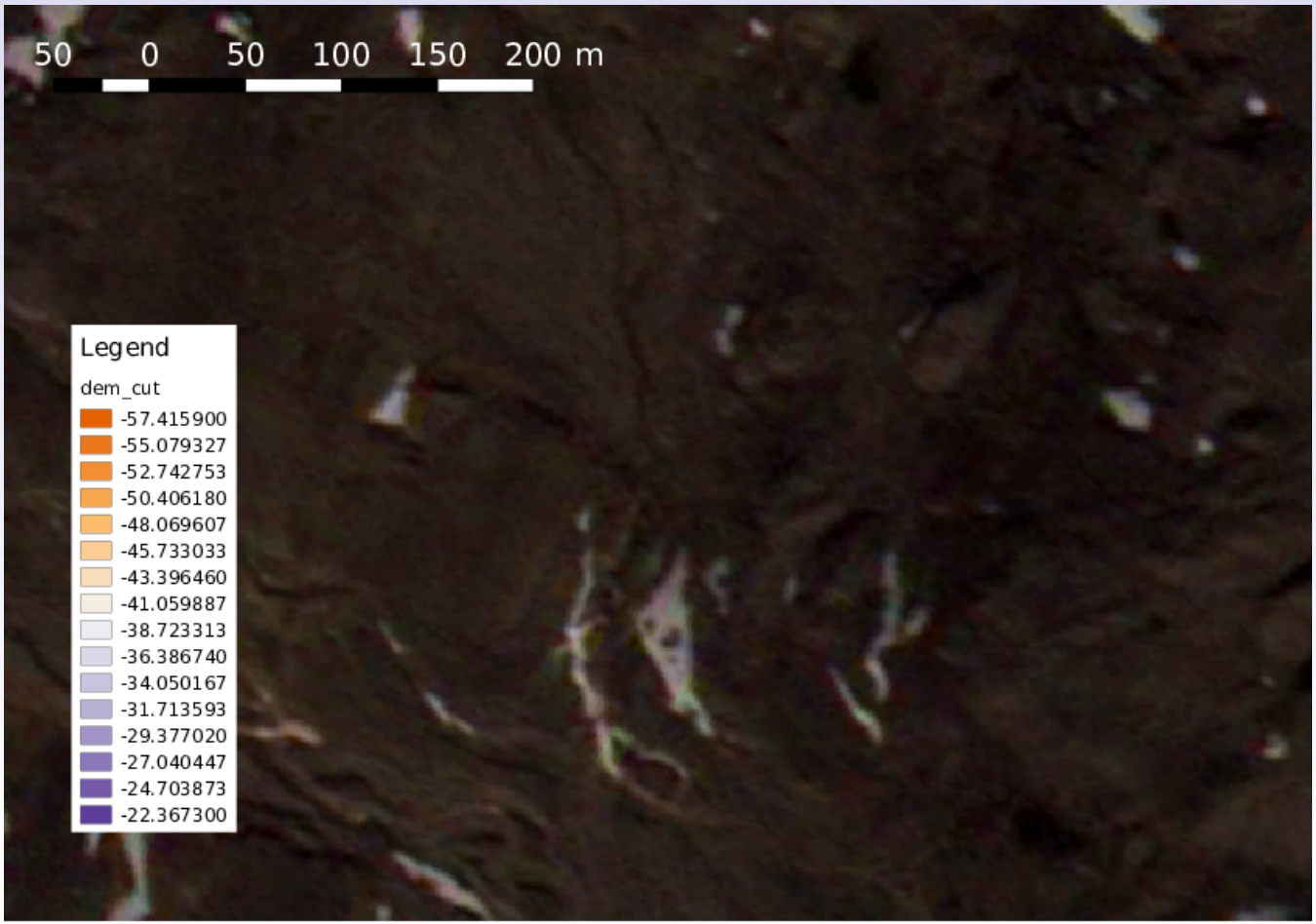
18520 × 13056 pixel orthophoto

[4] Older MicMac version: `Nuage2Ply Res/NuageImProf_STD-MALT_Etape_6.xml Attr="Ortho-Res/Ortho-Eg-Test-Redr.tif"`

Insertion in QGis

- GeoTIF file: add offset to top-left corner in `.tfw` file
- Raster calculator: convert pixel value to meters using the information provided in `Z_Num6_DeZoom4_STD-MALT.xml`:

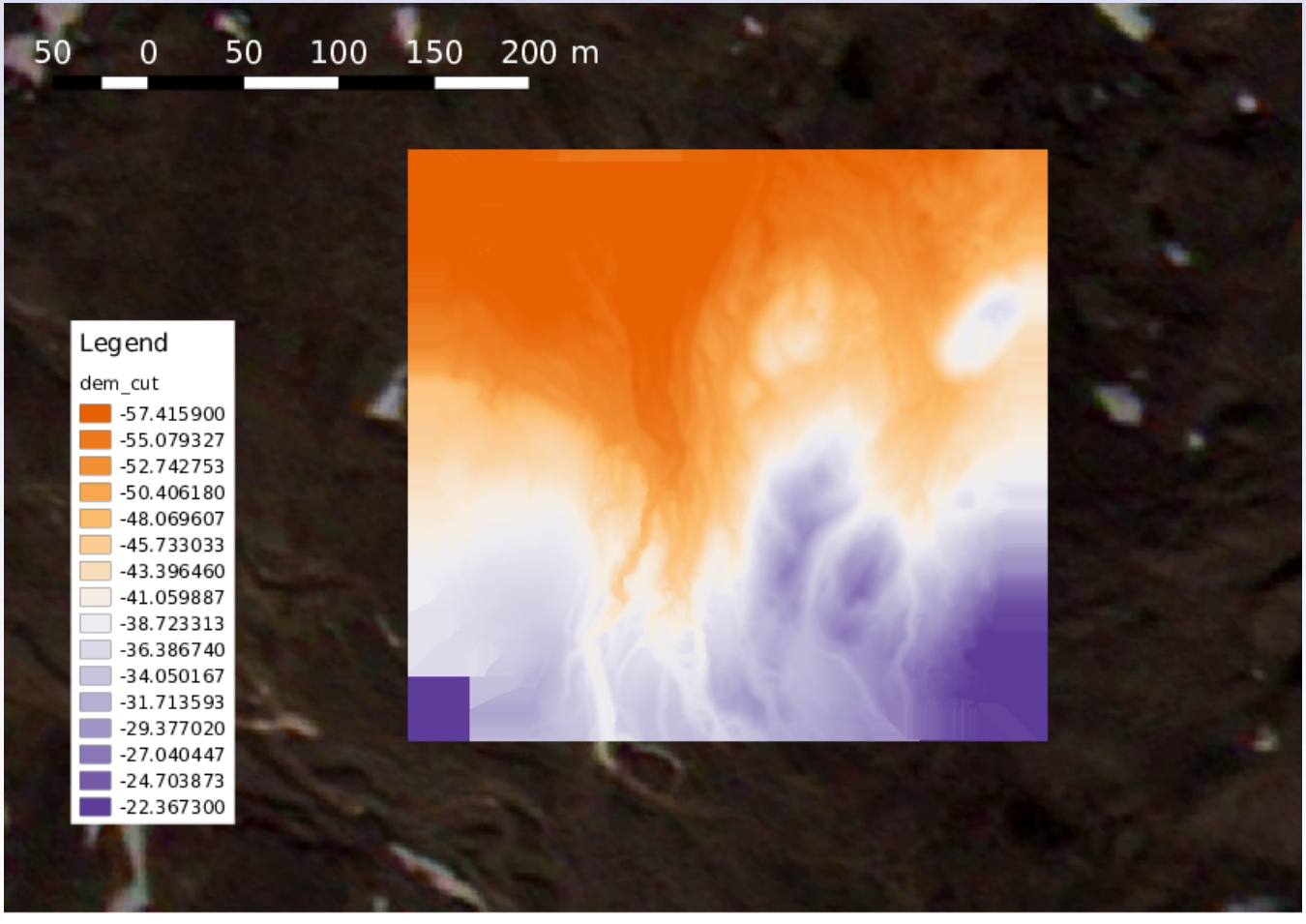
```
<OrigineAlti>-43.34</OrigineAlti>
<ResolutionAlti>0.22</ResolutionAlti>
```



Insertion in QGis

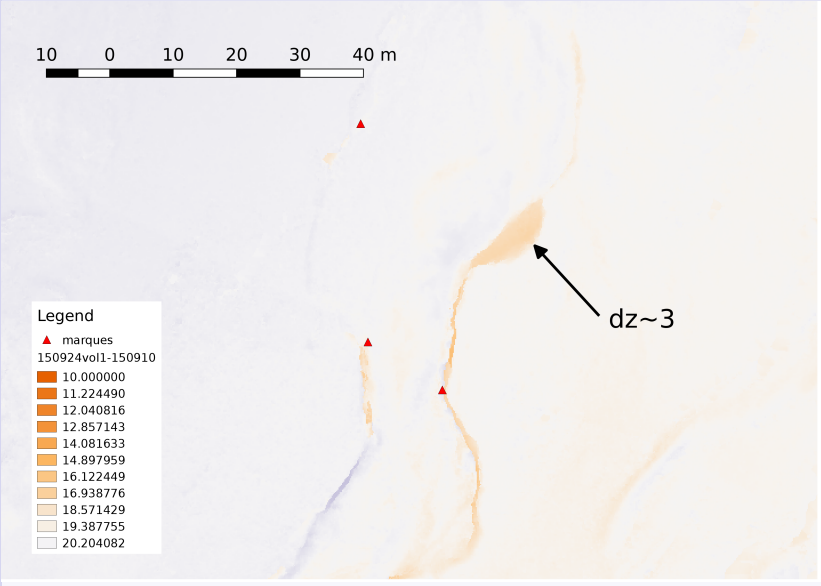
- GeoTIF file: add offset to top-left corner in `.tfw` file
- Raster calculator: convert pixel value to meters using the information provided in `Z_Num6_DeZoom4_STD-MALT.xml`:

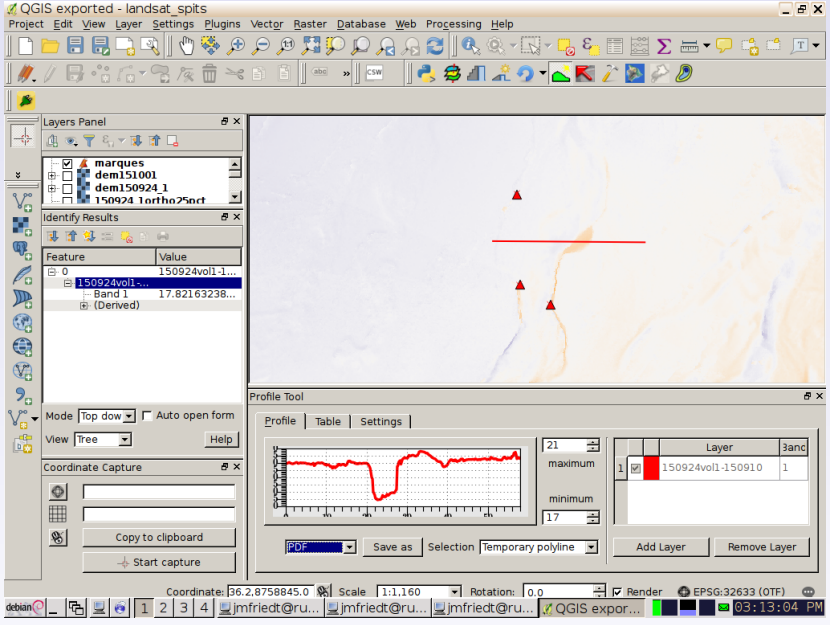
```
<OrigineAlti>-43.34</OrigineAlti>
<ResolutionAlti>0.22</ResolutionAlti>
```



Difference of DEMs: Ground Control Points and subtraction

- Manually update GeoTIF top-left corner position (and pixel size ?) to match GCP within region of interest,
- `Rasmover` plugin for graphically moving a raster layer

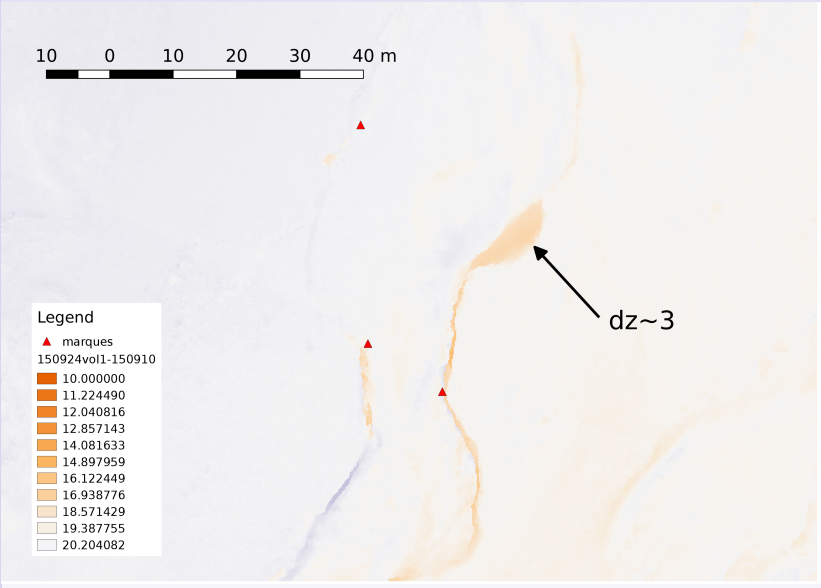




⇒ collapse of 3-m deep canyon wall within 1-week of repeated DEM measurement, consistent with observations on the field

Difference of DEMs: Ground Control Points and subtraction

- Manually update GeoTIF top-left corner position (and pixel size ?) to match GCP within region of interest,
- `Rasmover` plugin for graphically moving a raster layer



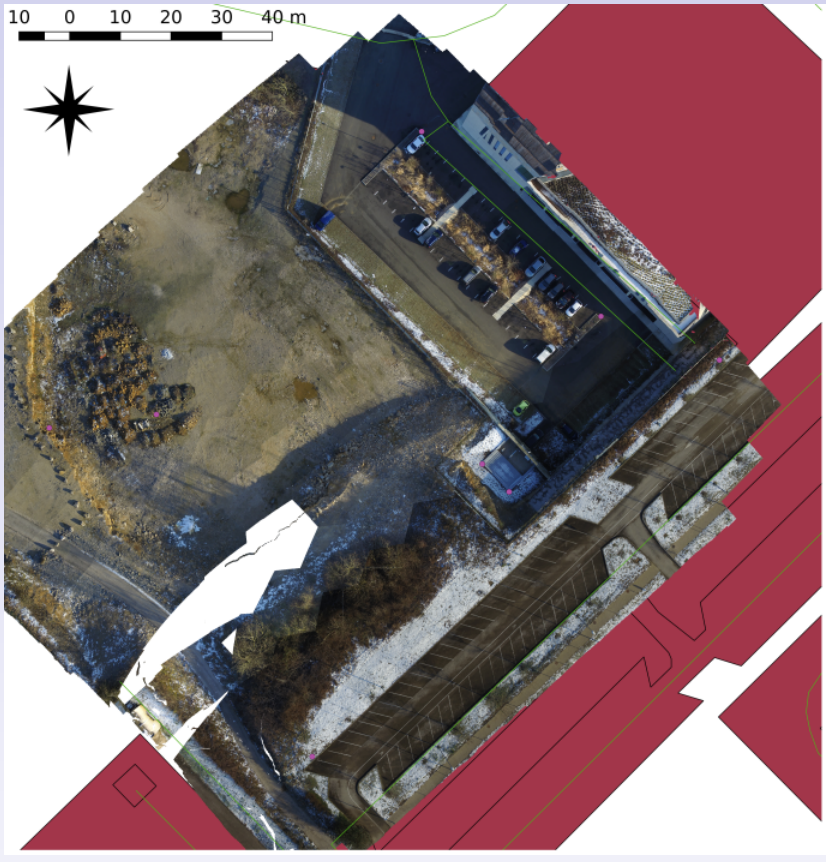
$\Rightarrow$ collapse of 3-m deep canyon wall within 1-week of repeated DEM measurement, consistent with observations on the field

Conclusion and perspectives

UAV pictures for MicMac:

- Acquire azimutal pictures with >60% overlap
- Identify tie points, lens properties & camera position
- Coarse point cloud
- Orthophoto, DEM and correlation maps

Final product example:
Orthophoto March 9th 2016



see `http://qgis.sequanux.org/femto.html` for comparison of DEMs acquired on the same day or a month apart + IGN background image [5] .

TODO: improved resolution with kinematic GPS ?

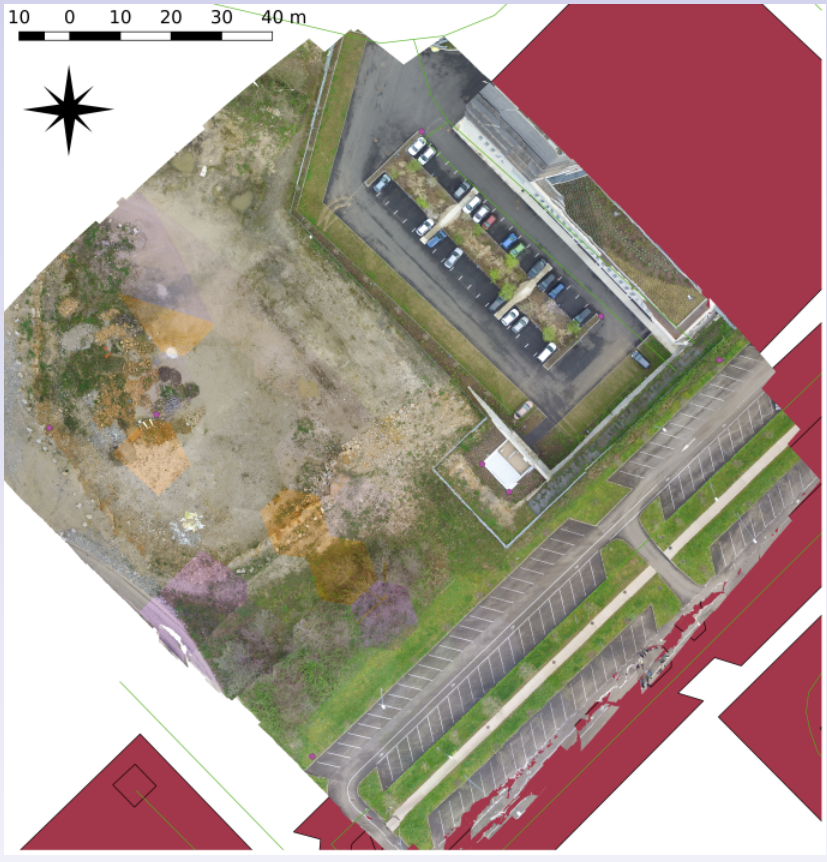
[5] J.-M Friedt, É. Carry, *Dissémination de données géoréférencées – qgis-server et openlayers*, GNU/Linux Magazine France **200** (Jan. 2017), pp.12-23 [in French]

Conclusion and perspectives

UAV pictures for MicMac:

- Acquire azimutal pictures with >60% overlap
- Identify tie points, lens properties & camera position
- Coarse point cloud
- Orthophoto, DEM and correlation maps

Final product example:
Orthophoto April 24th 2016



see `http://qgis.sequanux.org/femto.html` for comparison of DEMs acquired on the same day or a month apart + IGN background image [5] .

TODO: improved resolution with kinematic GPS ?

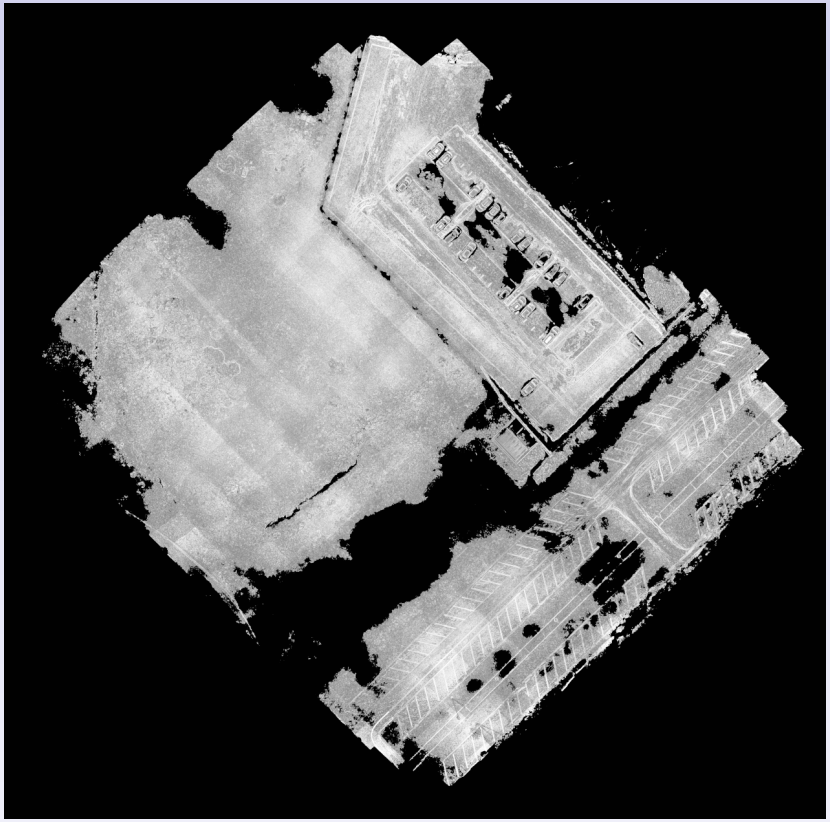
[5] J.-M Friedt, É. Carry, *Dissémination de données géoréférencées – qgis-server et openlayers*, GNU/Linux Magazine France **200** (Jan. 2017), pp.12-23 [in French]

Conclusion and perspectives

UAV pictures for MicMac:

- Acquire azimutal pictures with >60% overlap
- Identify tie points, lens properties & camera position
- Coarse point cloud
- Orthophoto, DEM and correlation maps

Final product example:
Correlation map April 24th



see `http://qgis.sequanux.org/femto.html` for comparison of DEMs acquired on the same day or a month apart + IGN background image [5] .

TODO: improved resolution with kinematic GPS ?

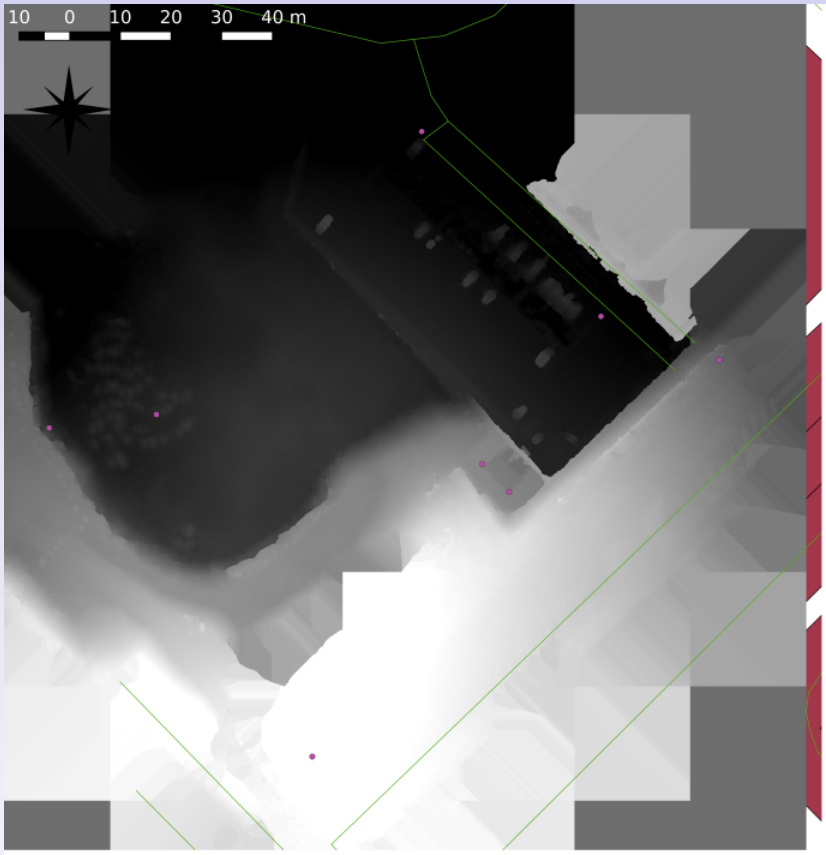
[5] J.-M Friedt, É. Carry, *Dissémination de données géoréférencées – qgis-server et openlayers*, GNU/Linux Magazine France **200** (Jan. 2017), pp.12-23 [in French]

Conclusion and perspectives

UAV pictures for MicMac:

- Acquire azimutal pictures with >60% overlap
- Identify tie points, lens properties & camera position
- Coarse point cloud
- Orthophoto, DEM and correlation maps

Final product example:
DEM March 9th 2016



see `http://qgis.sequanux.org/femto.html` for comparison of DEMs acquired on the same day or a month apart + IGN background image [5] .

TODO: improved resolution with kinematic GPS ?

[5] J.-M Friedt, É. Carry, *Dissémination de données géoréférencées – qgis-server et openlayers*, GNU/Linux Magazine France **200** (Jan. 2017), pp.12-23 [in French]

Conclusion and perspectives

UAV pictures for MicMac:

- Acquire azimutal pictures with >60% overlap
- Identify tie points, lens properties & camera position
- Coarse point cloud
- Orthophoto, DEM and correlation maps

Final product example:
DEM difference (notice cars)

see `http://qgis.sequanux.org/femto.html` for comparison of DEMs acquired on the same day or a month apart + IGN background image [5] [6].
~~TODO: improved resolution with kinematic GPS ?~~

[5] J.-M Friedt, É. Carry, *Dissémination de données géoréférencées – qgis-server et openlayers*, GNU/Linux Magazine France **200** (Jan. 2017), pp.12-23 [in French]

[6] J.-M Friedt, *Utilisation de Micmac pour la génération de modèle numérique d'élévation par traitement d'images acquises par microdrone*, GNU/Linux Magazine France **191** (Mar. 2016), pp.48-57 [in French]