Observing the Earth in 3D with Pleiades-HR

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PLEIADES program overall context

- Dual system designed for civil and defense needs
- Submetric optical Earth observation system developed by CNES In cooperation with

Sweden	Swedish National Space Board
Belgium	Federal Office for Space Policy
Spain	Instituto nacional de Tecnica Aerospacial
Austria	Osterreichische Forschungsforderungesellschat

two satellites in orbit within 11.5 months

Launch: PHR1A 17th December 2011

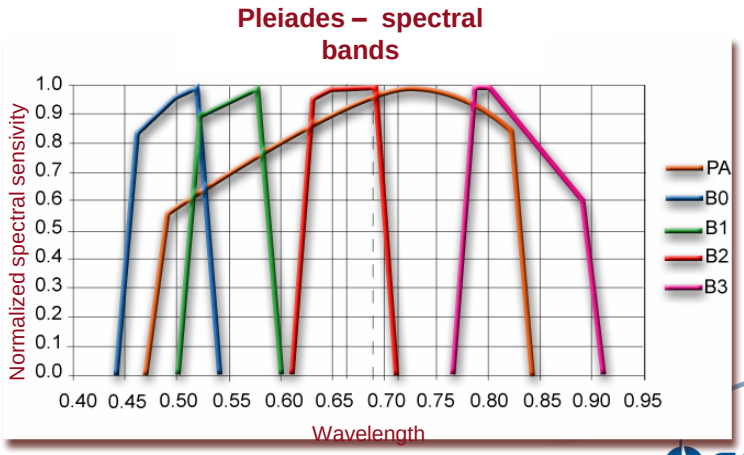
In flight acceptance : March 2012

PHR1B: 2nd December 2012

February 2013

Pleiades
Main Mission Requirements

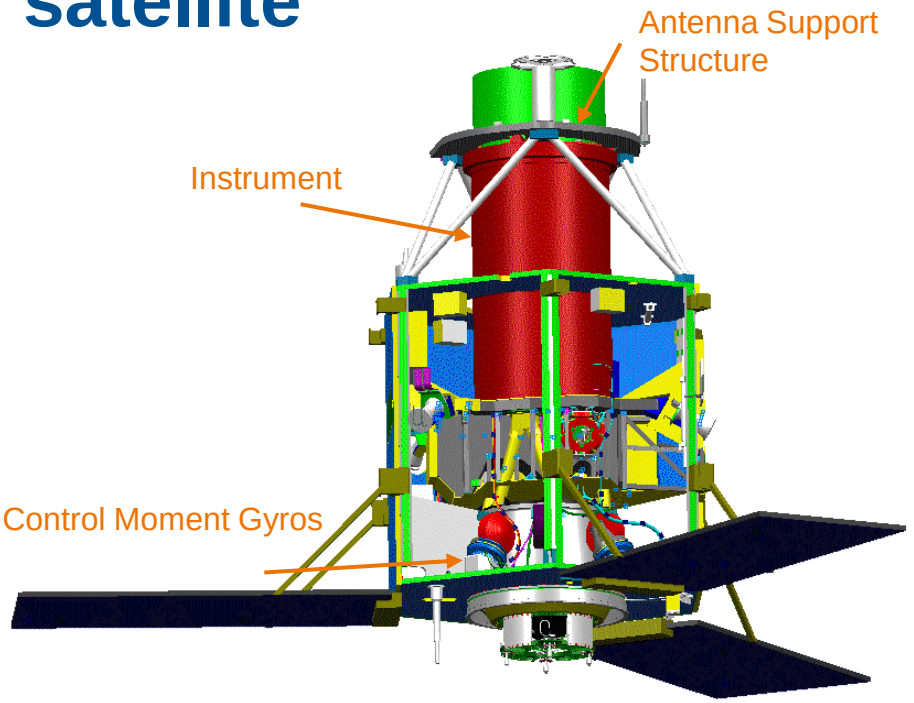
- **Image characteristics**
  - 0.7 m Pan resolution at nadir
  - four XS bands (blue, green, red, near IR) with 2.8 m resolution at nadir
  - 20 km swath at nadir
  - data coded on 12 bits
- **Revisit Capability**
  - Daily accessibility to any point on the globe (with 2 satellites)
- **Improved access image delay**
  - Better than 24 hours between image request and image delivery in nominal mode
  - 1 hour, with Direct Tasking …
- **Large coverage capability**
  - In average 600 images per satellite and per day



PLEIADES satellite

A new concept compared to Spot

- A small and very agile satellite to improve operational capability and minimize the conflicts between users

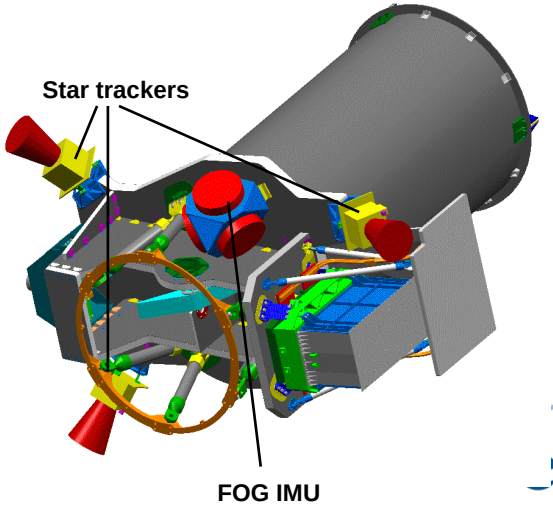


Designed for an high agility

- Compact <1000 kg satellite with low inertia
- Rigid satellite with fixed solar array
- Attitude control system with powerful CMG actuators

Designed for an high image quality

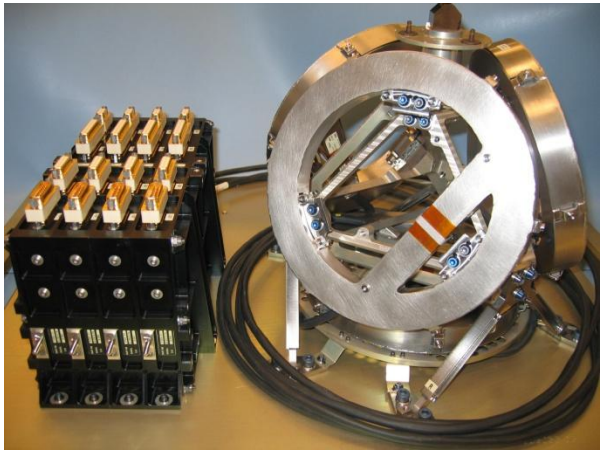
- High stability instrument with high precision sensor heads mounted on the optical bench for maximum geometrical quality accuracy (star trackers, Inertial Measurement Unit (FOG))



Definition Satellite : AOCS

sensors

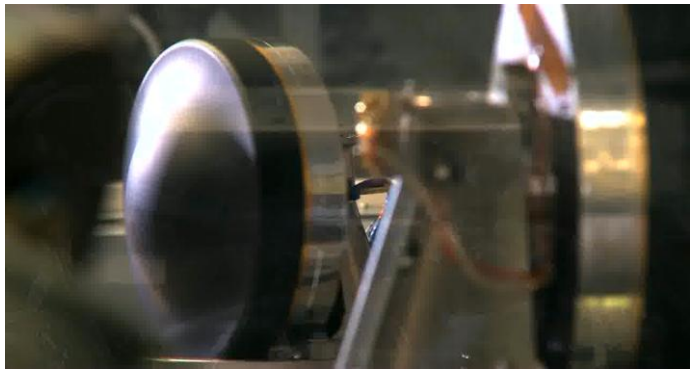
- Autonomous navigation with the DORIS/DIODE system
- Image geolocation governed by attitude determination
  - 3 star trackers
  - 4 Fiber Optical Gyrometers
  - All active in nominal configuration



FOG Inertial Core Unit

actuators

- Instrument agility is obtained through a set of 4
- gyroscopic actuators (control moment gyros or CMGs)
- CMG on ball-bearings,
- kinetic momentum: 15 Nms



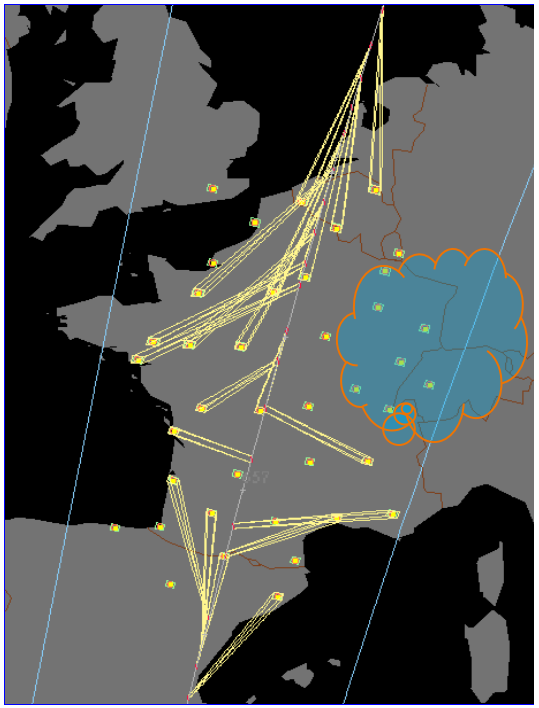
agility (roll and pitch):

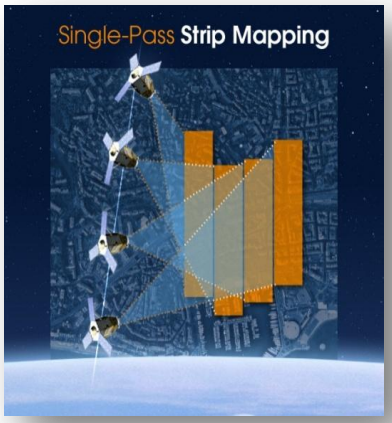
- 5 in 8 seconds
- 10 in 10 seconds
- 60 in 25 seconds

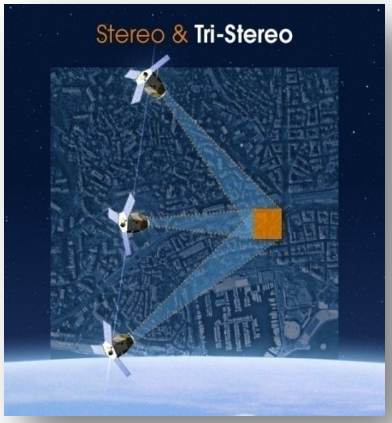
Mission performances

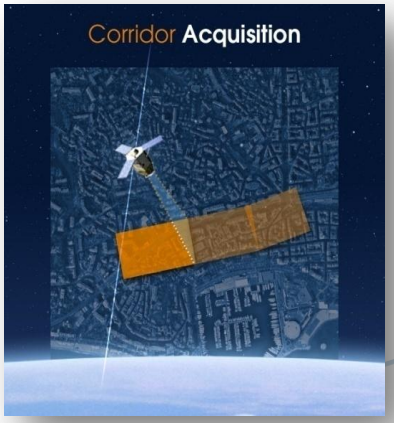
High agility is a must to

- minimize conflicts between users
- select the most important images
- take into account cloud coverage forecast
- access to different acquisition modes
  - stereo pairs
  - stereo triplets
  - single pass mosaics
  - follow linear targets

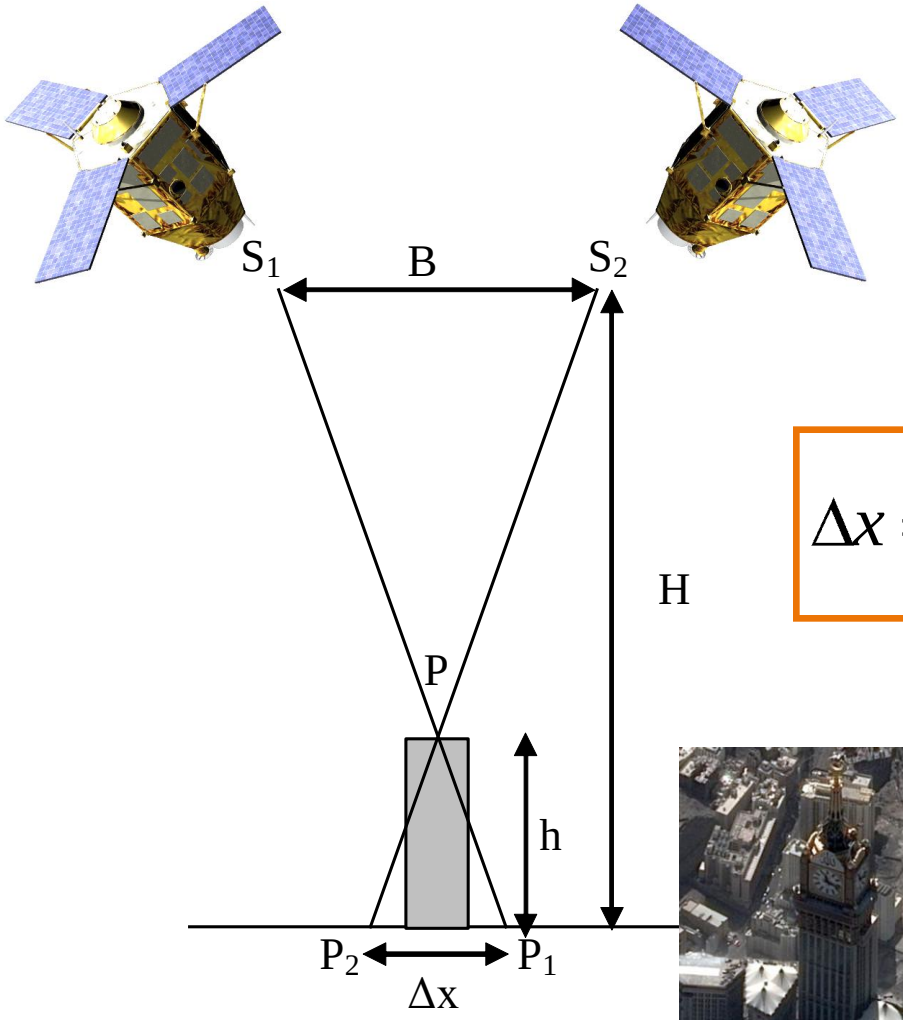




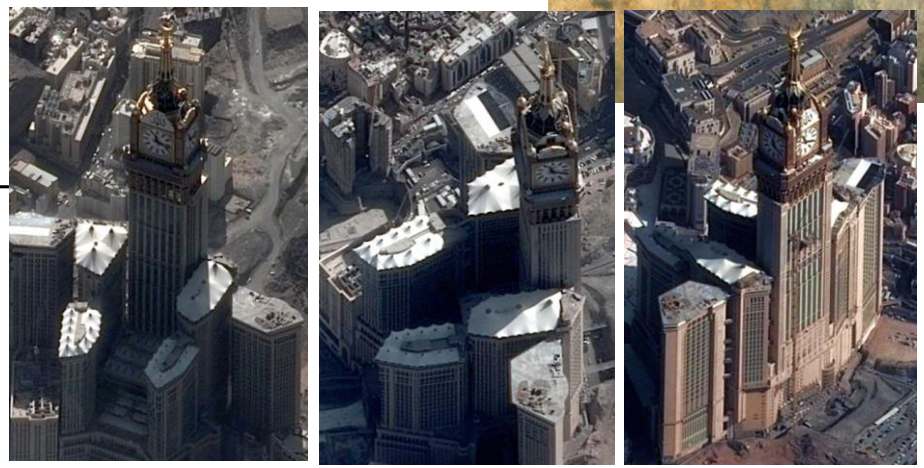




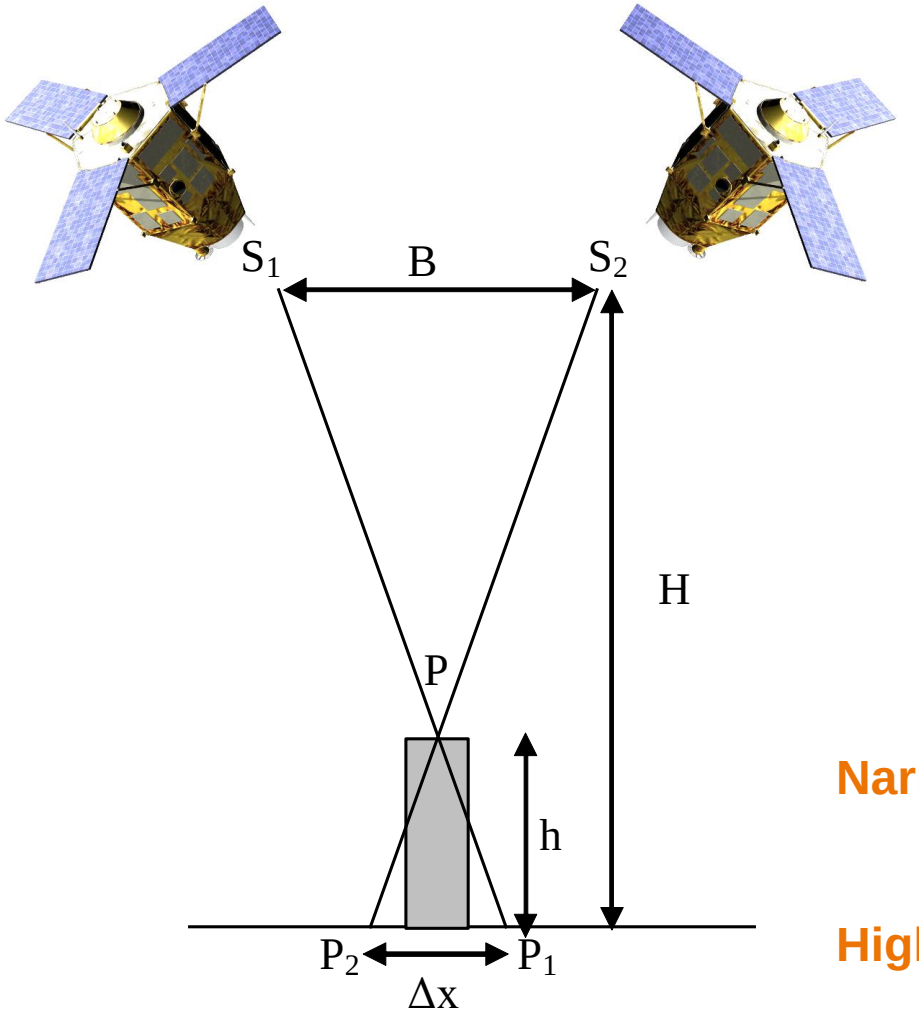
Stereoscopy : acquisition principle



$$\Delta x = \frac{B}{H} h$$



Stereoscopy : contributors



$$\Delta x = \frac{B}{H} h$$

Performance contributors

- Relative geometry (B/H et Δx)
  - Static
    - Focal plane cartography
    - Magnificient factor
  - Dynamic
    - vibrations
  - Bundle adjustment
- Identification (Δx)
  - Operator (visual)
  - Correlation
  - Radiometry

Narrow B/H :

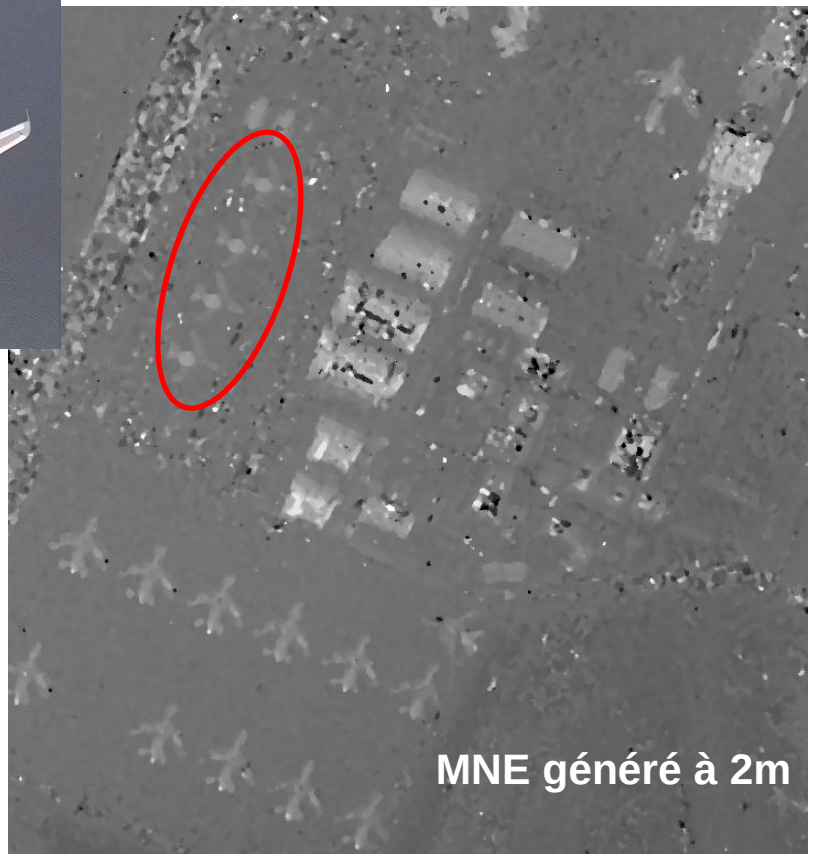
good identification
geometry !!!

High B/H :

bad identification, occultations
easier geometry

0,10 < B/H < 0,15

3D restitution (ponctual perf)



Elevation of 4 AWACS :

Hestim (m)	13,55	11,35	13,48	13,74
Error (m)	0,82	1,38	0,75	-1,01

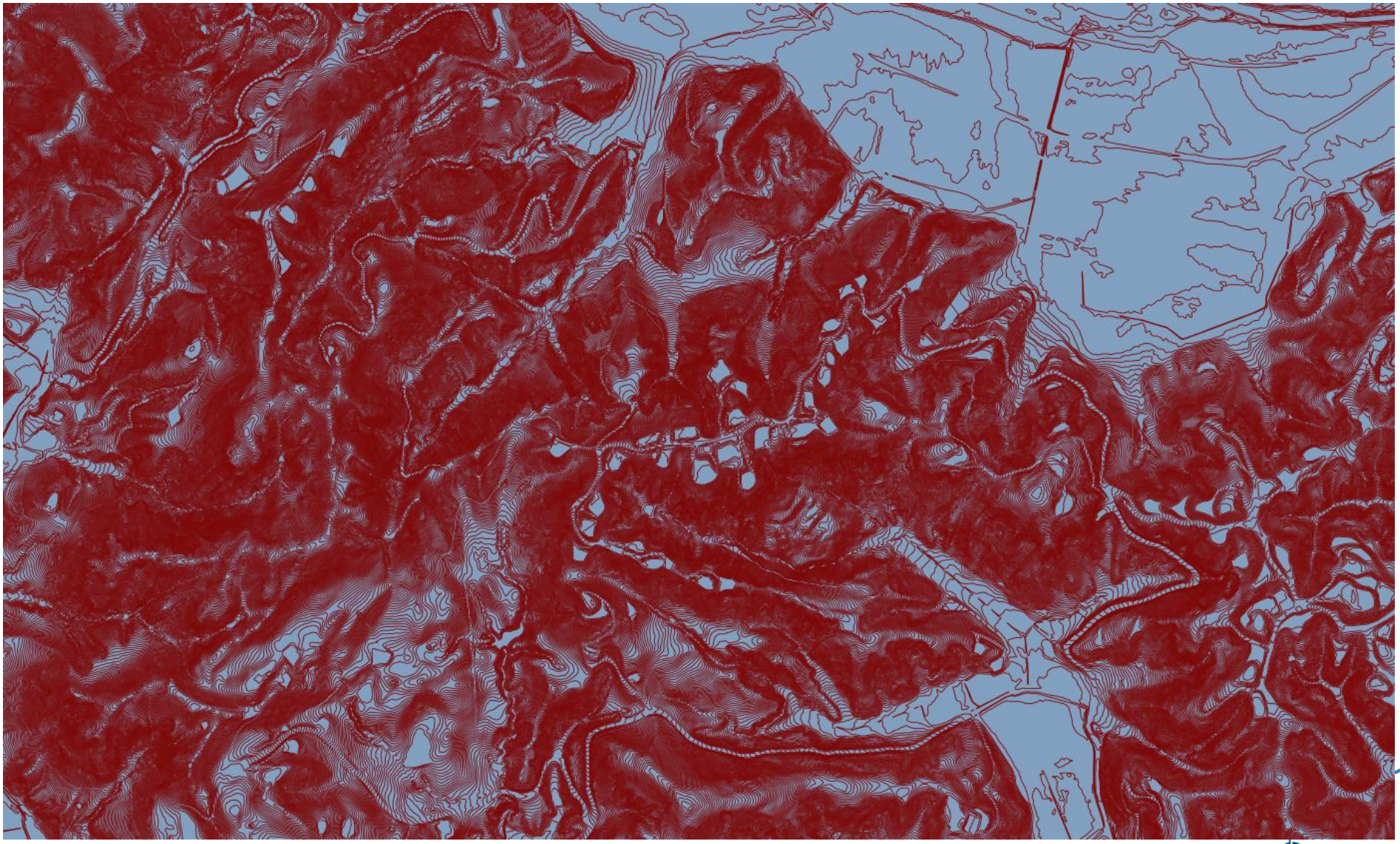
H AWACS 12.73m

Geometric Supersite - Napier,NZ

North (Napier) GSD 10cm

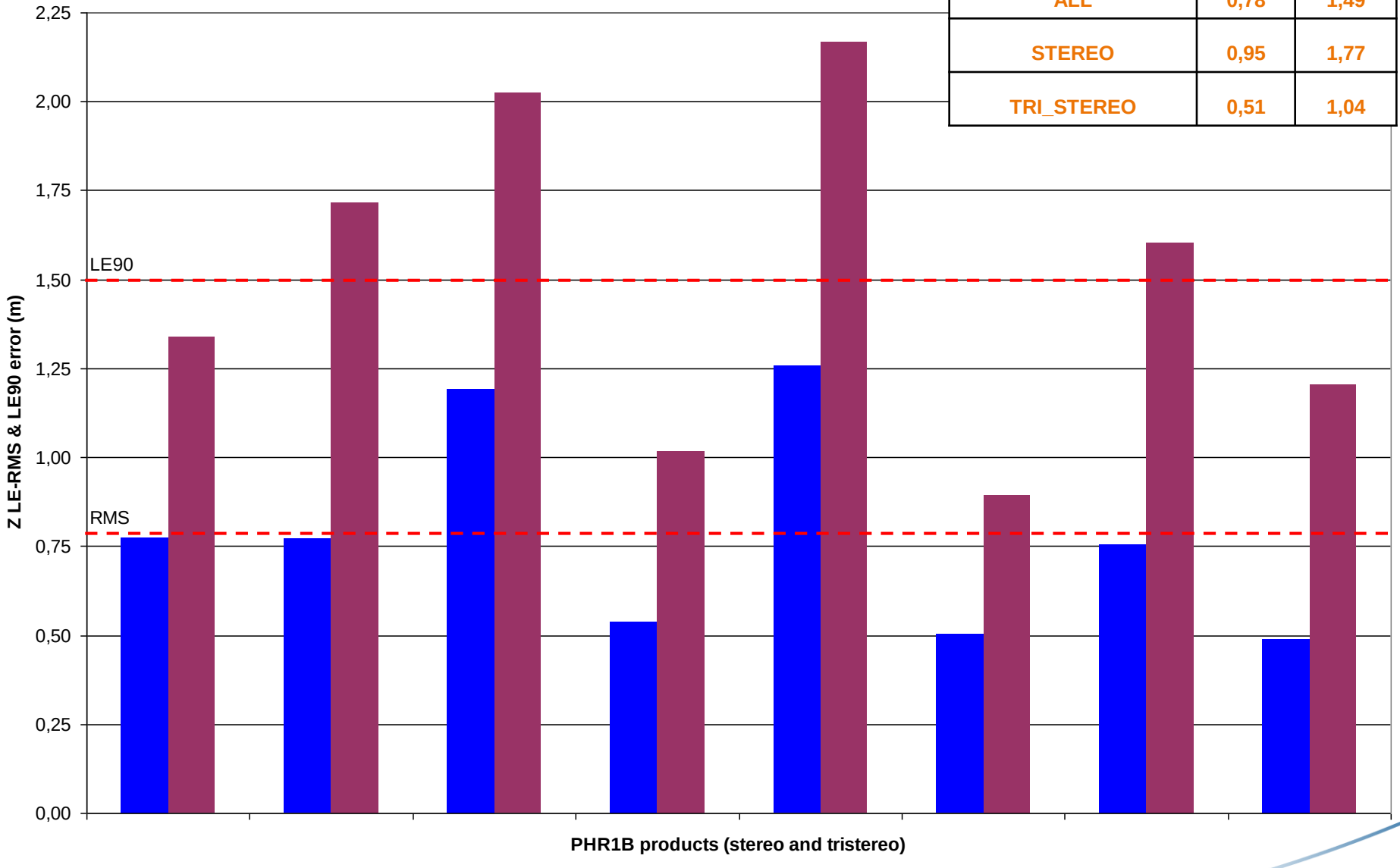
South (Hastings) GSD 12.5cm

Geometric Supersite - Napier,NZ - DSM



Example NAPIER

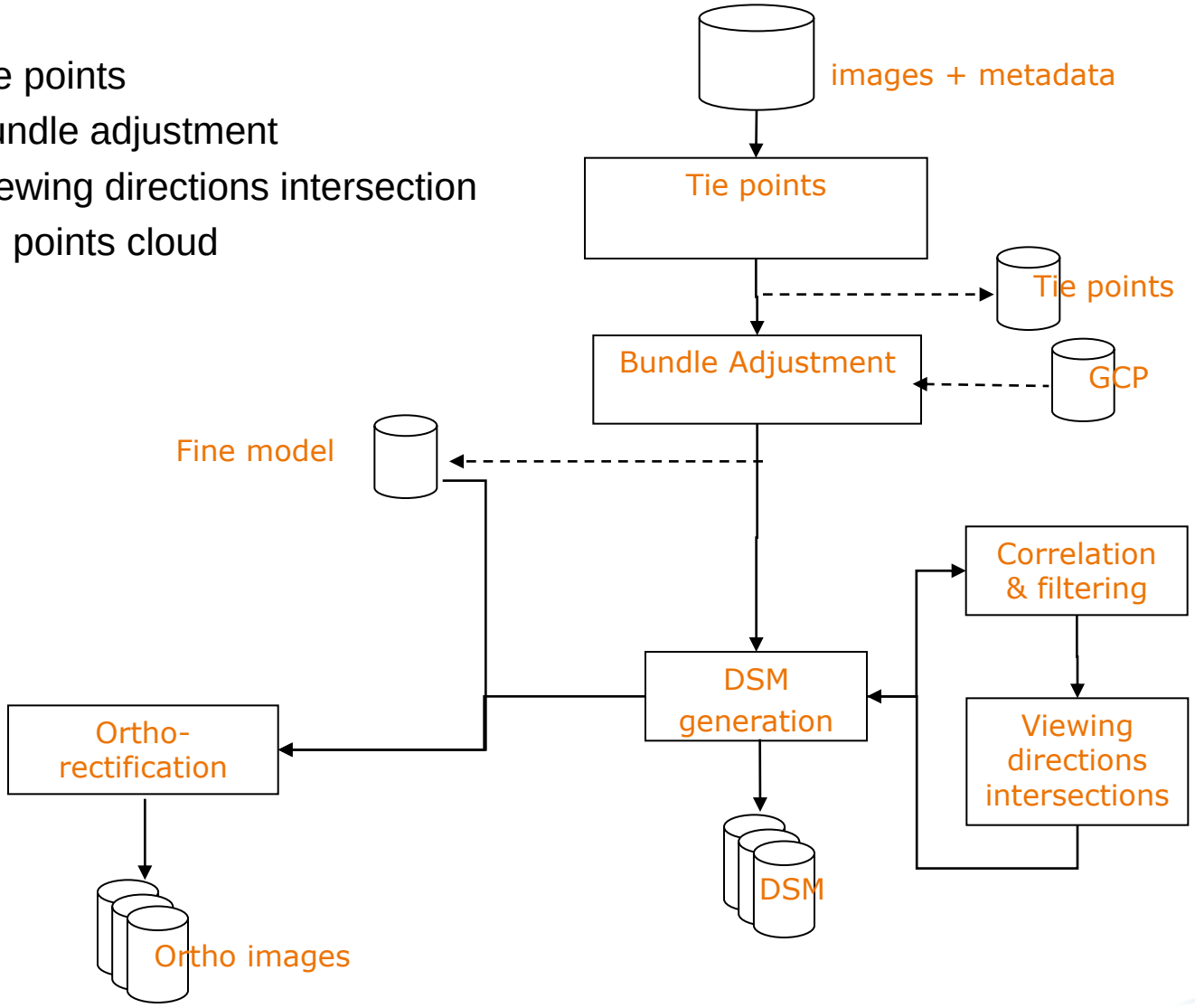
(m)	RMS	LE90
ALL	0,78	1,49
STEREO	0,95	1,77
TRI_STEREO	0,51	1,04



3d algorithm

4 steps

- Tie points
- Bundle adjustment
- Viewing directions intersection
- 3d points cloud

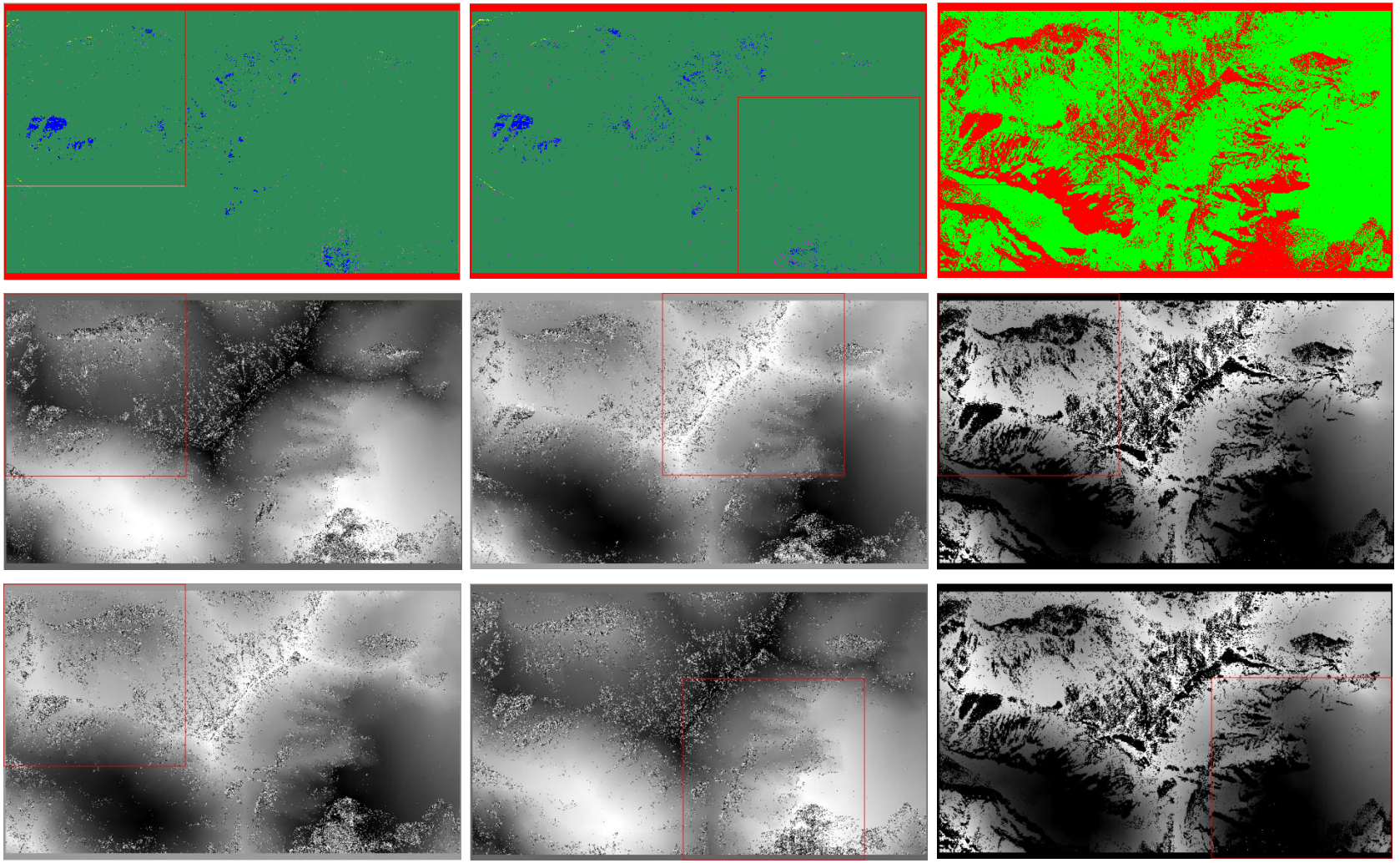


Correlation and filtering

FLAG_VALID

D_LINE

D_COLUMN



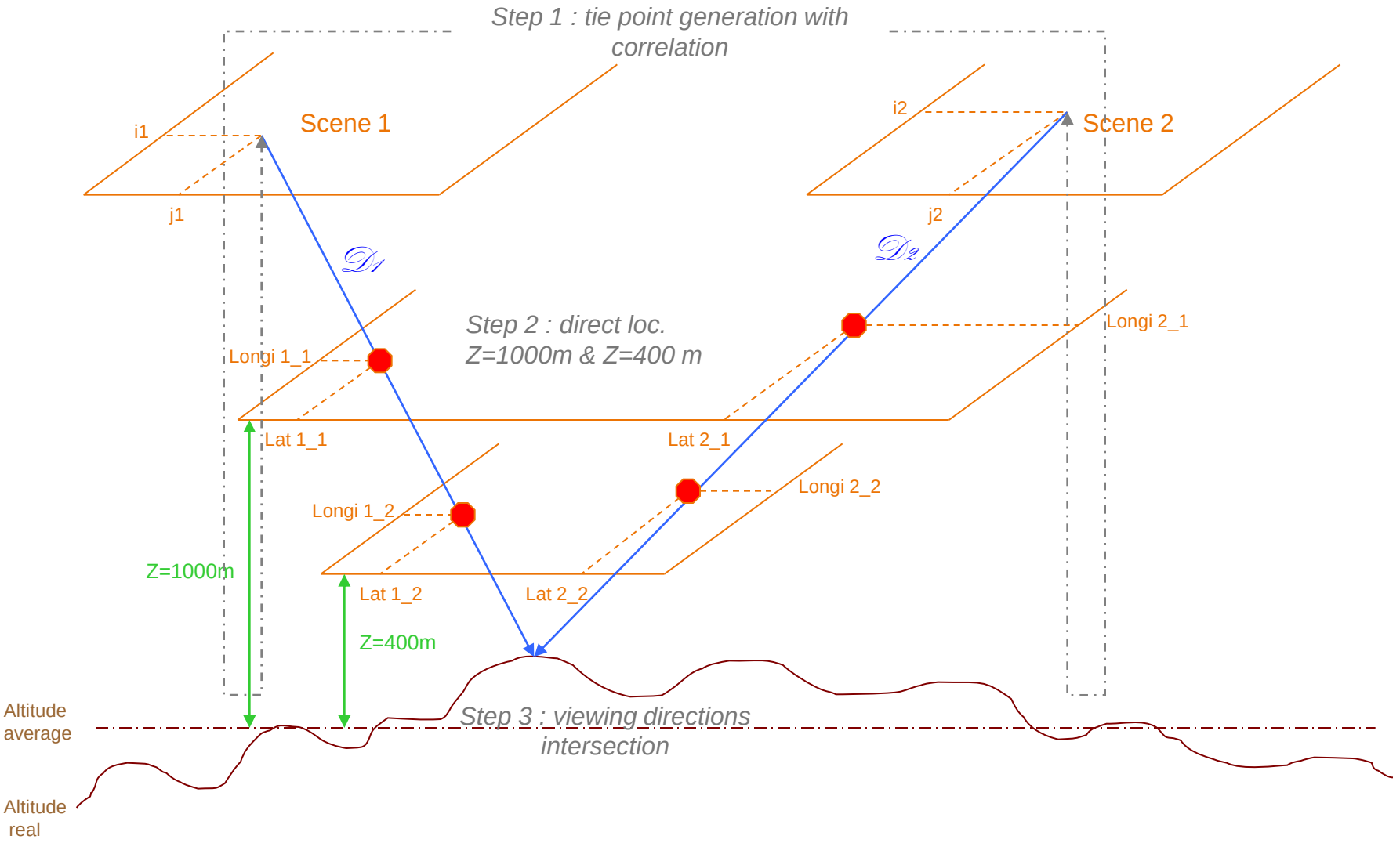
CORREL LeftRight

CORREL RightLeft

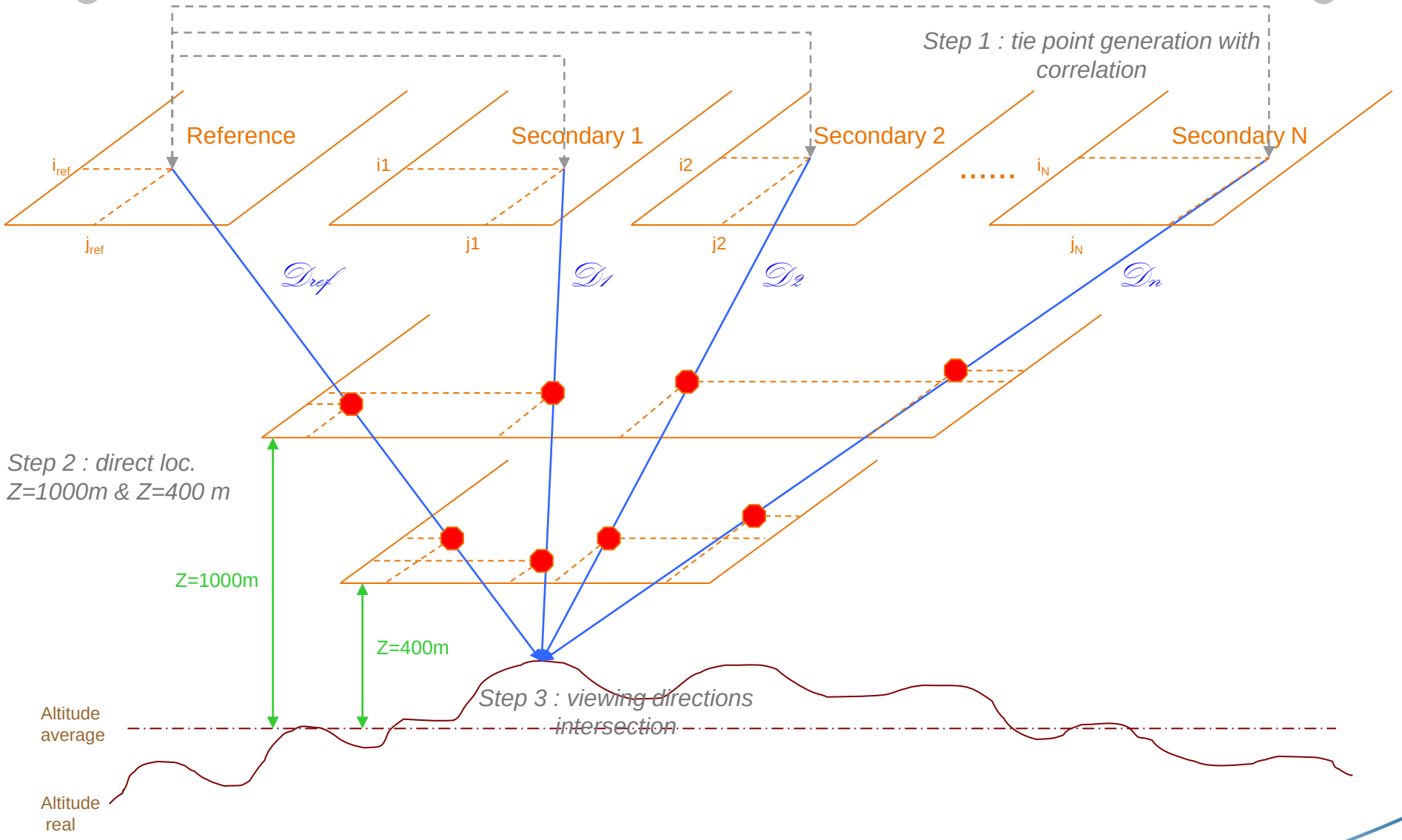
LRRL FILTER

Black or red = not valid

Viewing directions intersection (2)



Viewing directions intersection (N)



Viewing directions intersection (N)

The intersection of the viewing direction for the DSM construction is resolved like the following problem.
Let Δ be a line passing through a point *S* and whose direction vector is $\vec{V}$, any point *M* and δ the distance between *M* and Δ .
Then,

$$\delta^2 = \left\| \overrightarrow{SM} \wedge \vec{V} \right\|^2 = \overrightarrow{SM}^2 - \left(\overrightarrow{SM} . \vec{V} \right)^2$$

$$d\left(\delta^2\right) = 2\overrightarrow{dM} . \left[\left(Id - VV^t \right) \left[M - S \right] \right]$$

For a set of *n* of viewing directions Δ_i with $\left(S_i, \vec{V}_i\right)$, we are looking for as intersection of these viewing directions the point M which minimizes this distance quadratic sum:

$$\sum_i \delta_i^2 = \sum_i \left\| \overrightarrow{S_i M} \wedge \vec{V}_i \right\|^2 = \sum_i \left[\overrightarrow{S_i M}^2 - \left(\overrightarrow{S_i M} . \vec{V}_i \right)^2 \right]$$

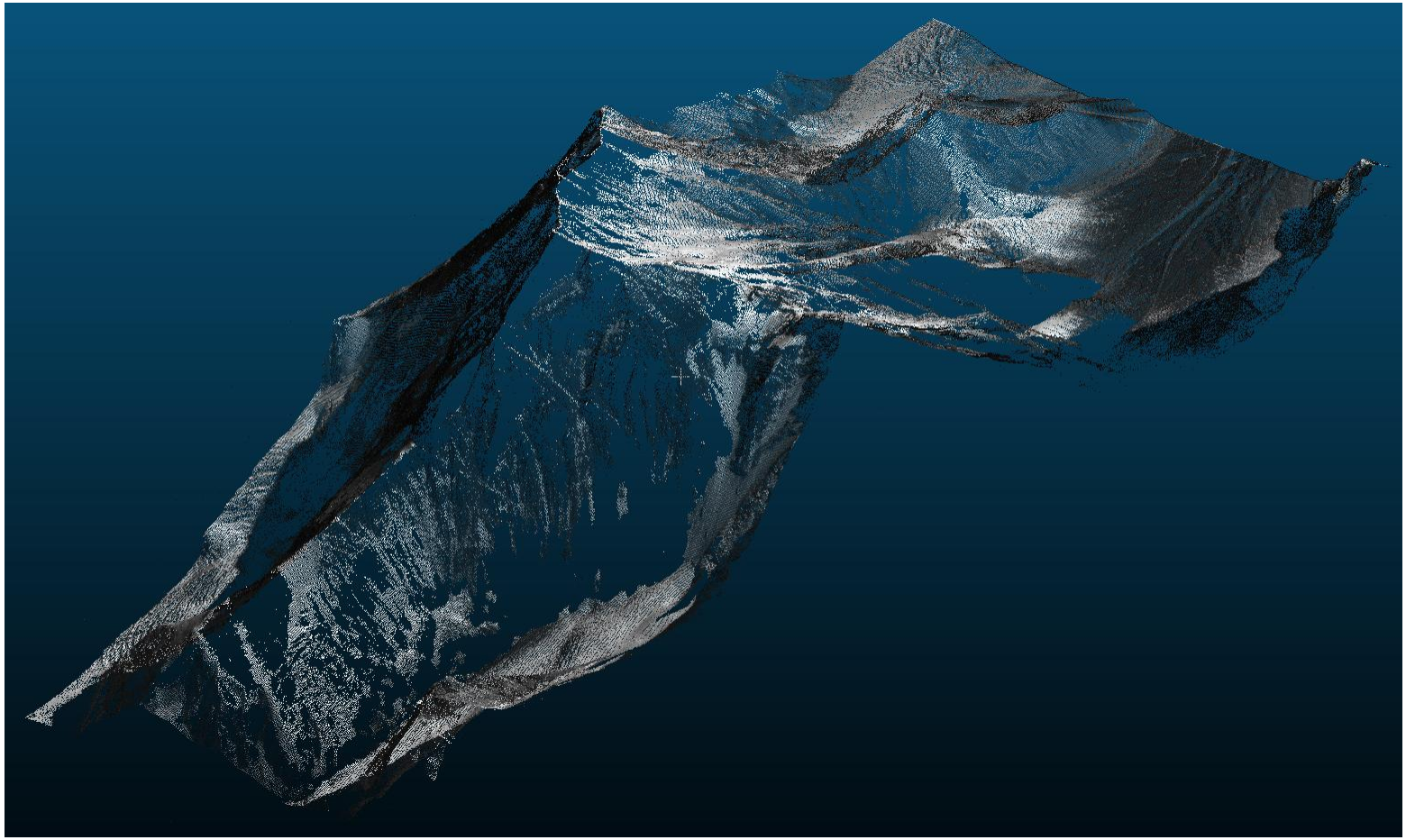
The solution is :

$$M = \left[\sum_i \left(Id - V_i V_i^t \right) \right]^{-1} \sum_i \left[\left(Id - V_i V_i^t \right) S_i \right]$$

The real interest of this method is the simplicity of the algorithm:

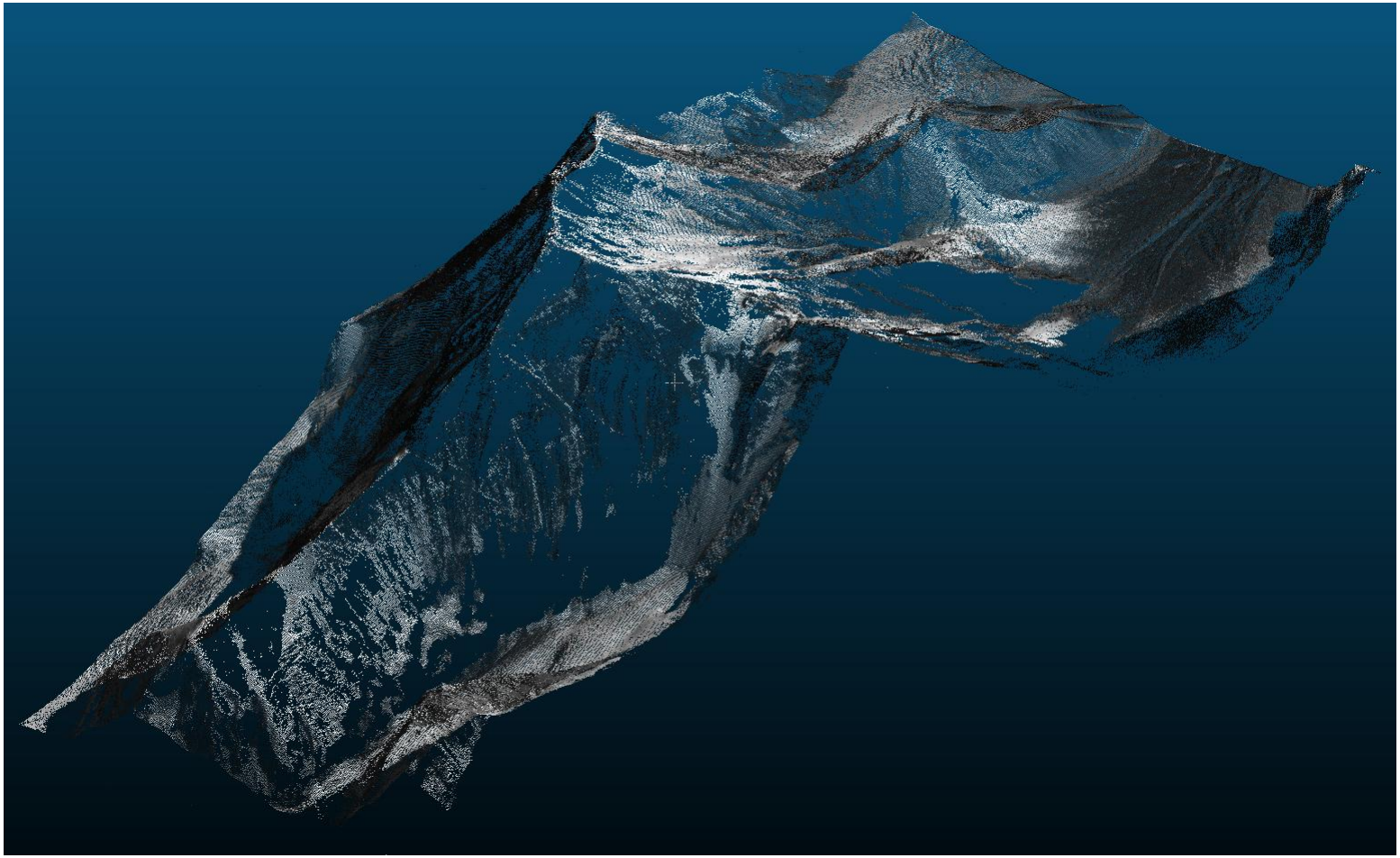
- it is easy to compute the terms $Id - V_i V_i^t$ and $\left(Id - V_i V_i^t \right) S_i$
- only one 3x3 matrix inversion arises
- in an iterative process it is really easy to eliminate "far viewing directions" by removing the contribution of these viewing directions using the terms $\sum_i \left(Id - V_i V_i^t \right)$ and $\sum_i \left[\left(Id - V_i V_i^t \right) S_i \right]$.

3D points cloud 1



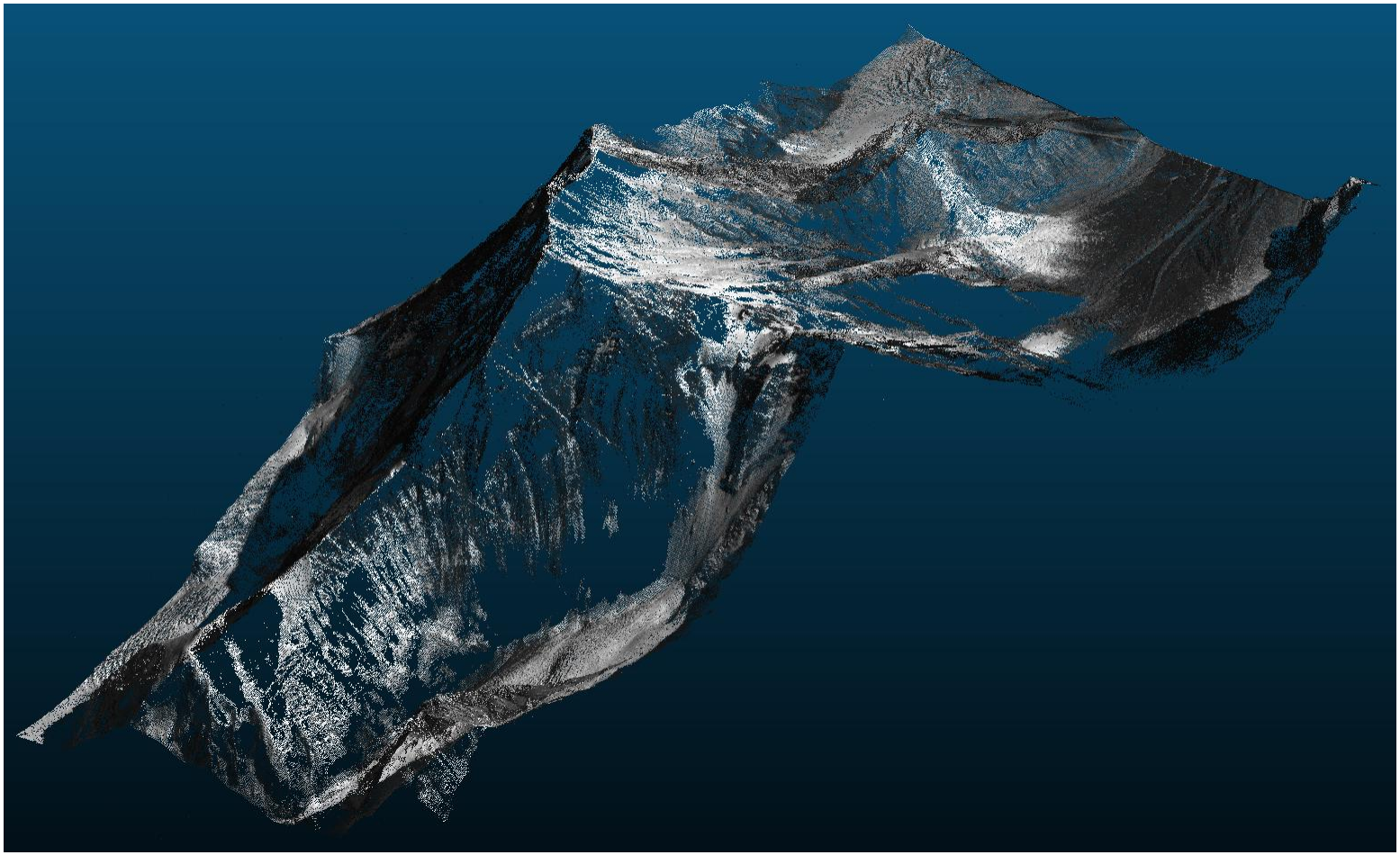
DTM obtained with the first couple

3D points cloud 2



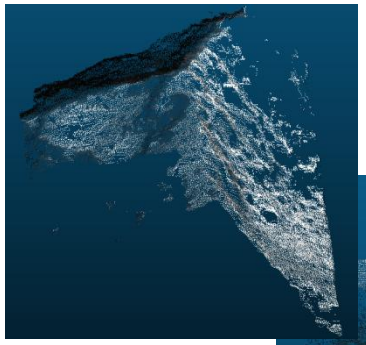
DTM obtained with the second couple

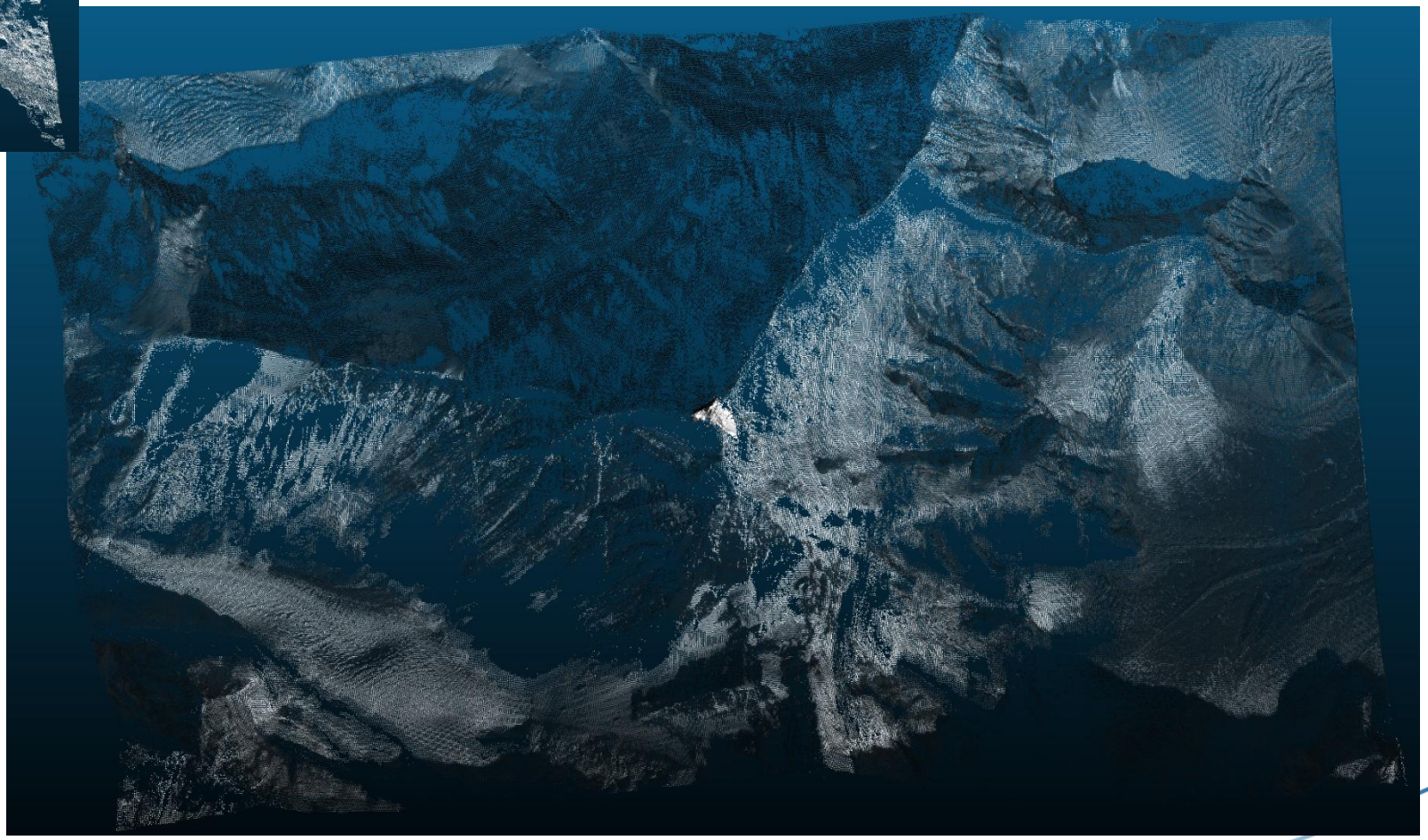
Final 3D points cloud



Final DTM obtained

Multi-resolution points cloud





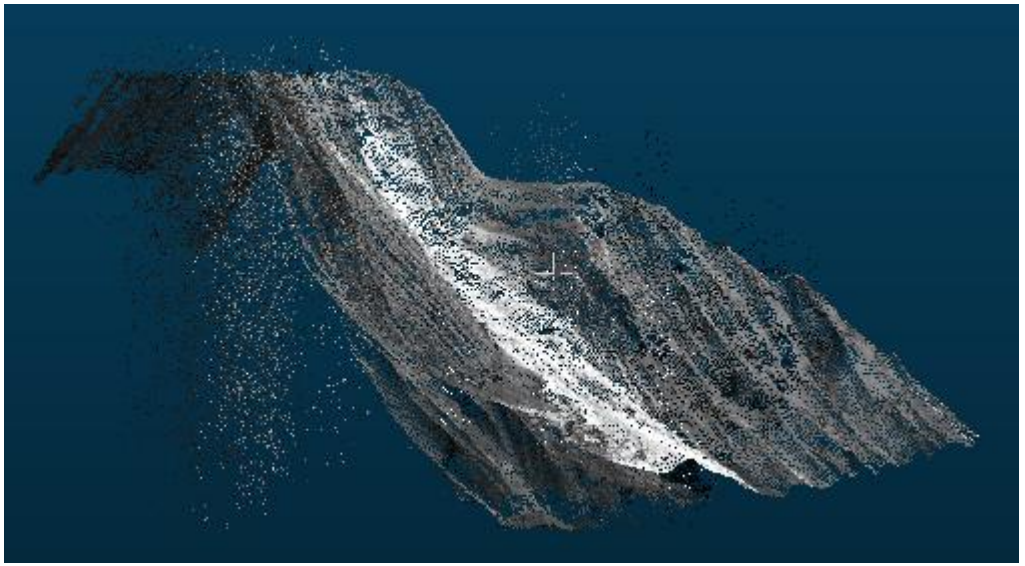
DTM with a DSM inside

3D filters

Global statistical filter 3σ

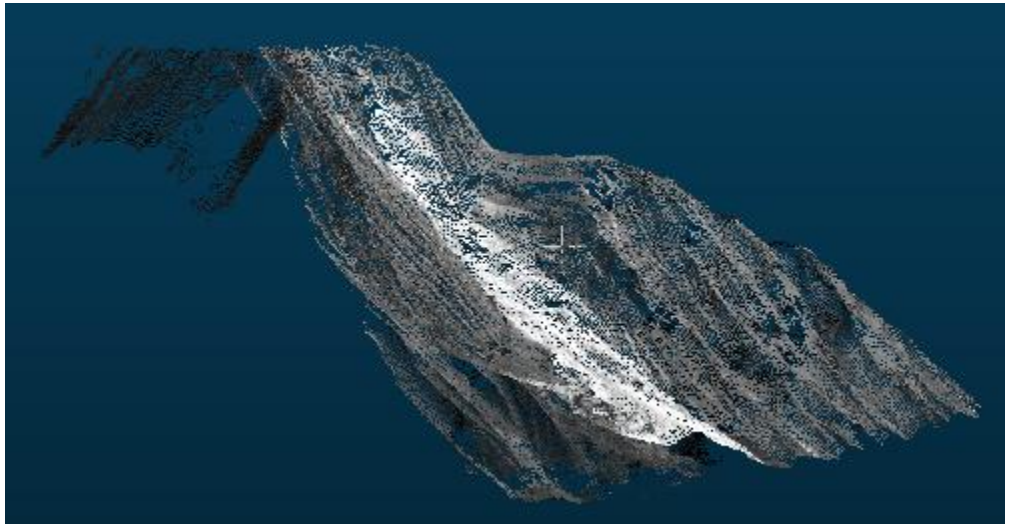
3D filters

Local statistical filter 2σ



3D filters

Sphere filter (R=10m with 5 points minimum)



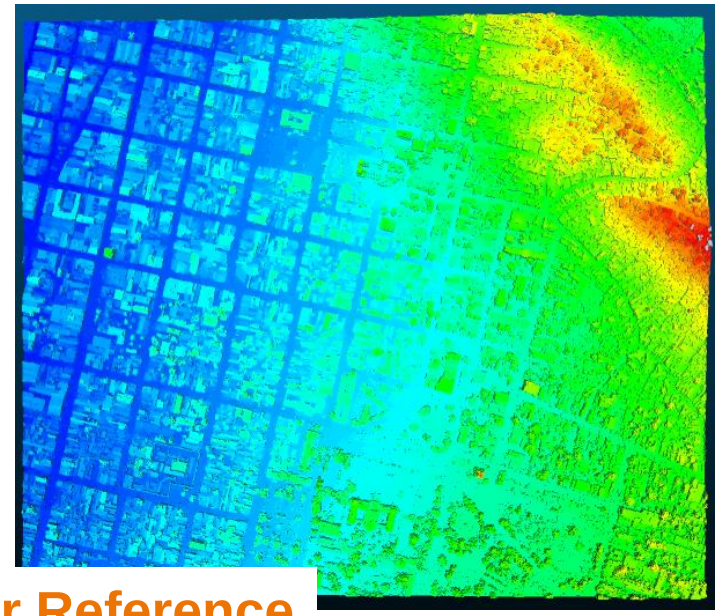
Some optimization

DSM with 2 images 1000x1000 pixels with a 19 pixels exploration window and a 11 pixels correlation patch.

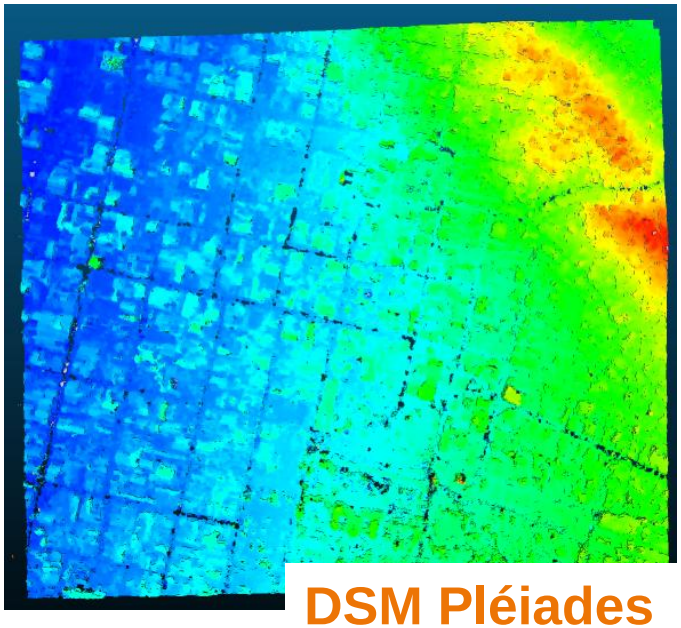
Tests	Processors	Time	Optimization / test A
A	1	12m21.496s	1
B	5	3m17.056s	3,76
C	4x5	0m54.081s	13,71

A Pléiades DSM (30000x30000 pix) can be computed in 1h40 with a cluster of 10x10 processors instead of 8 days on a single processor.

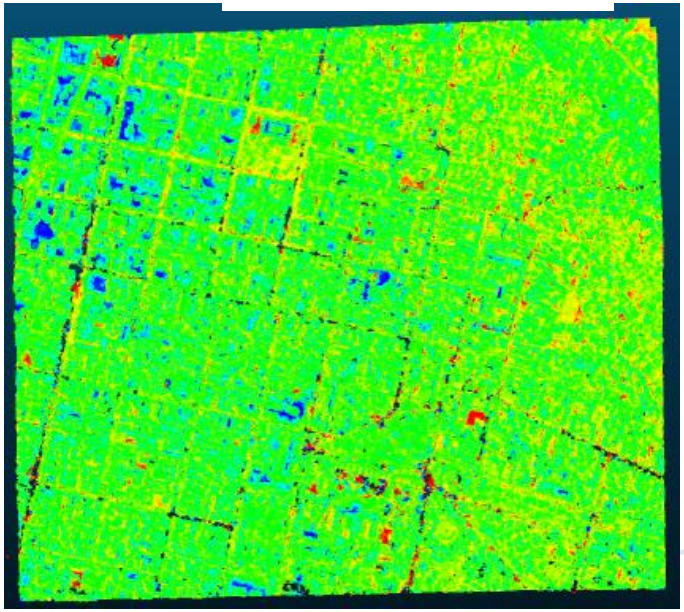
Examples Haïti



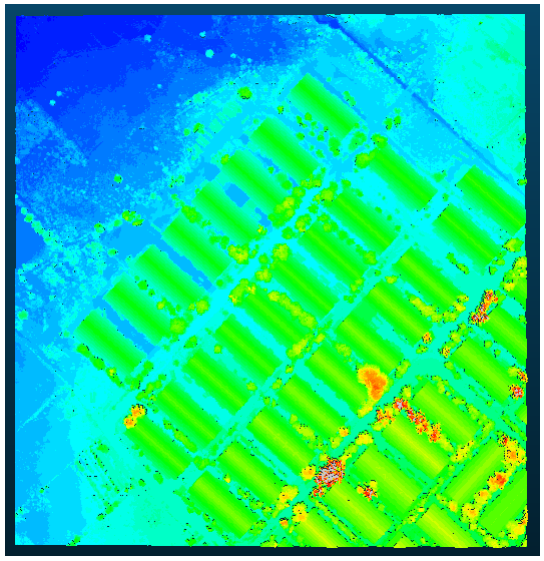
Lidar Reference



DSM Pléiades



Examples Haïti



Lidar Reference

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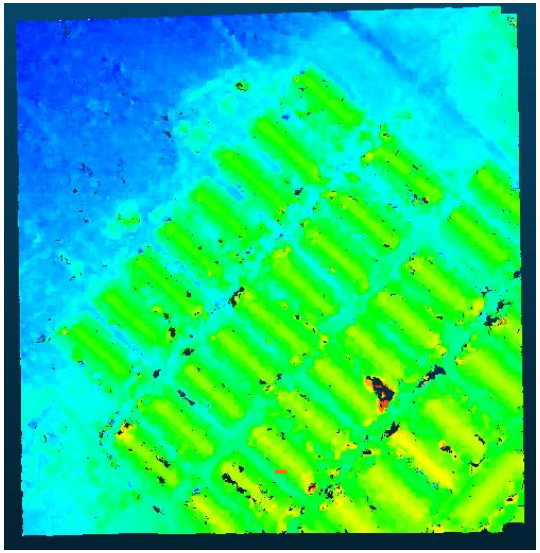

DSM Pléiades

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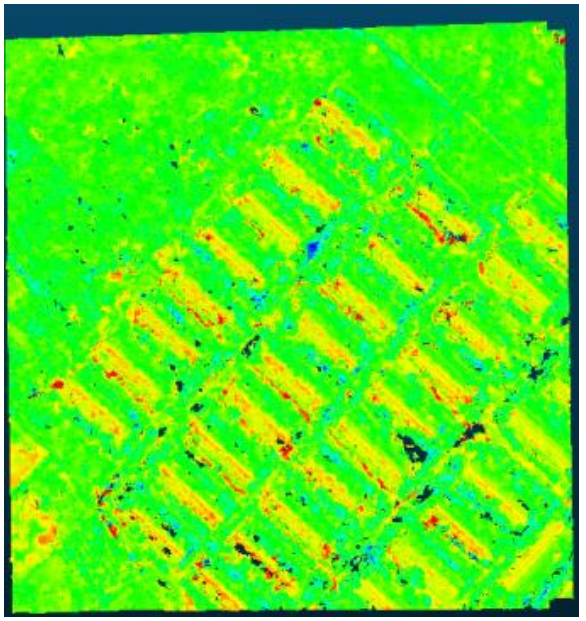
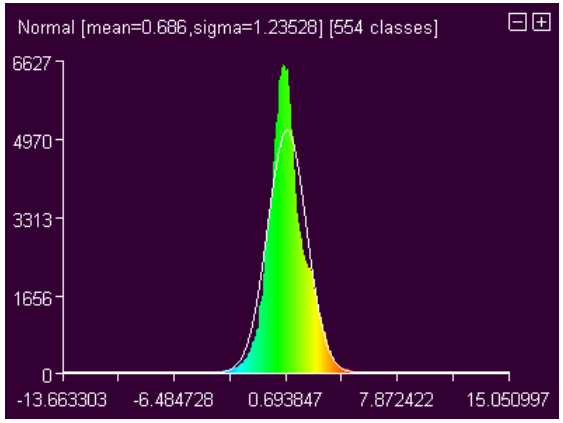




Example Haïti

Good 3D restitution

Bundle adjustment with some GCPs

- for planimetry adjustment

Statistics with low average and std.

Performances as Napier

~ 2 pixels PHR in altimetry

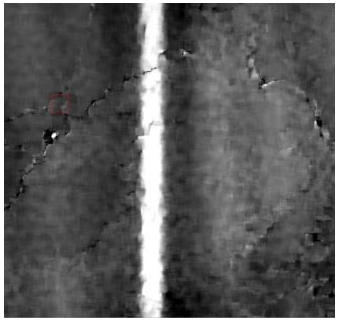



Focal plane catography impact

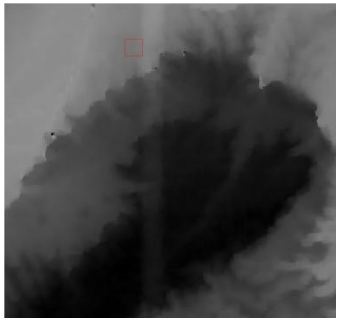
- An error on the focal plane cartography implies altimetric errors (example on Monument Valley B/H 0,09)
- update of the carto via GIPP in july 2012 for PHR1A and july 2013 for PHR1B.

50 pix

Décalage en colonnes



Décalage en lignes



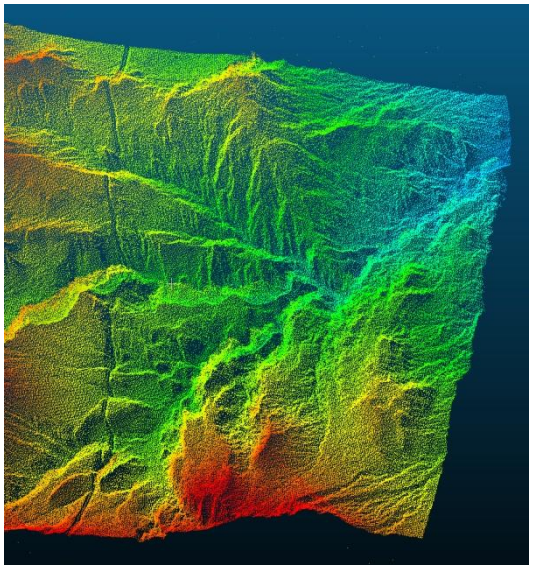


Image de référence

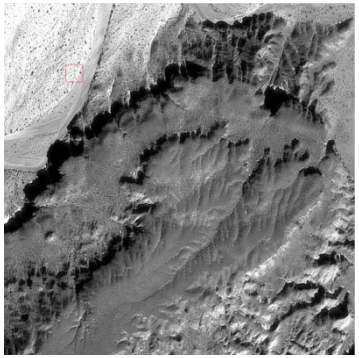
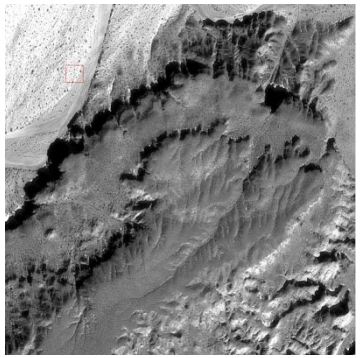
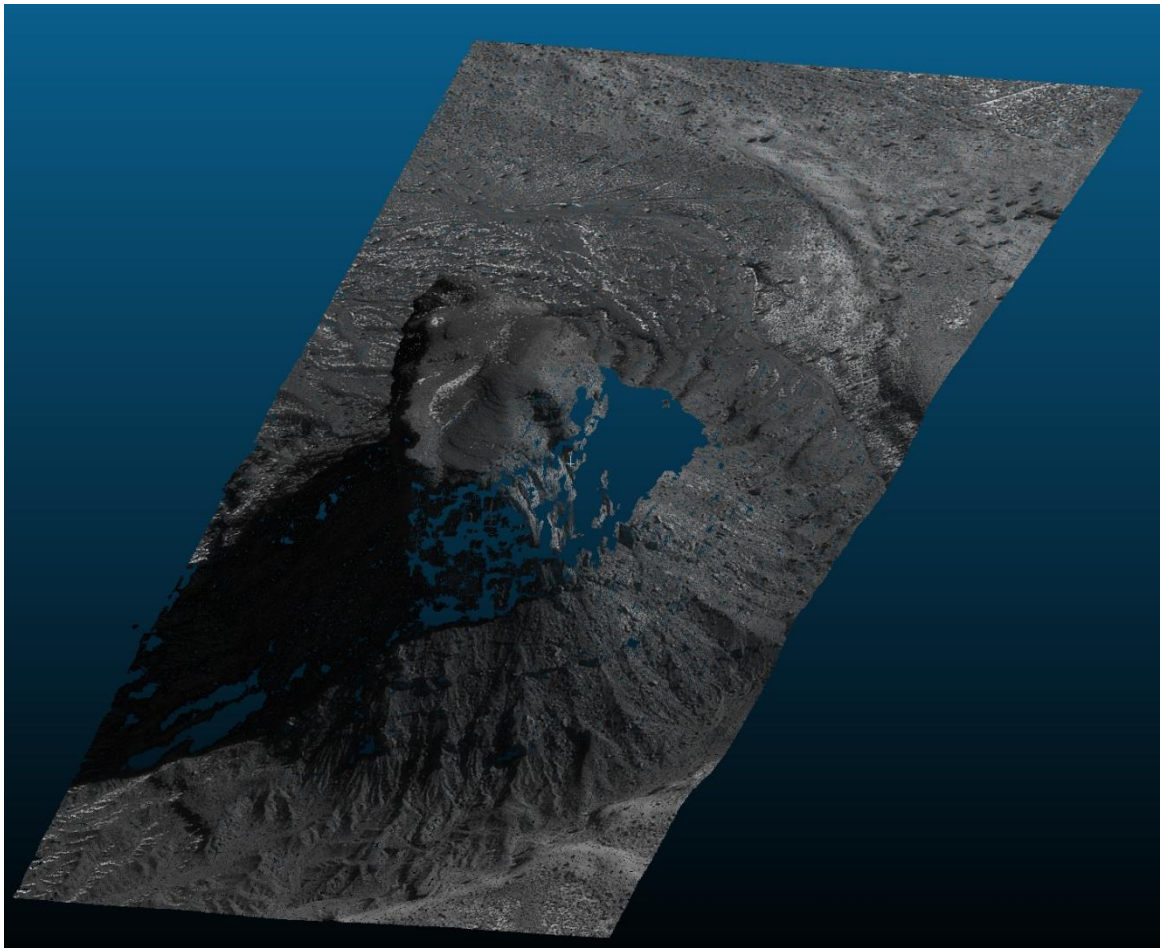


Image secondaire

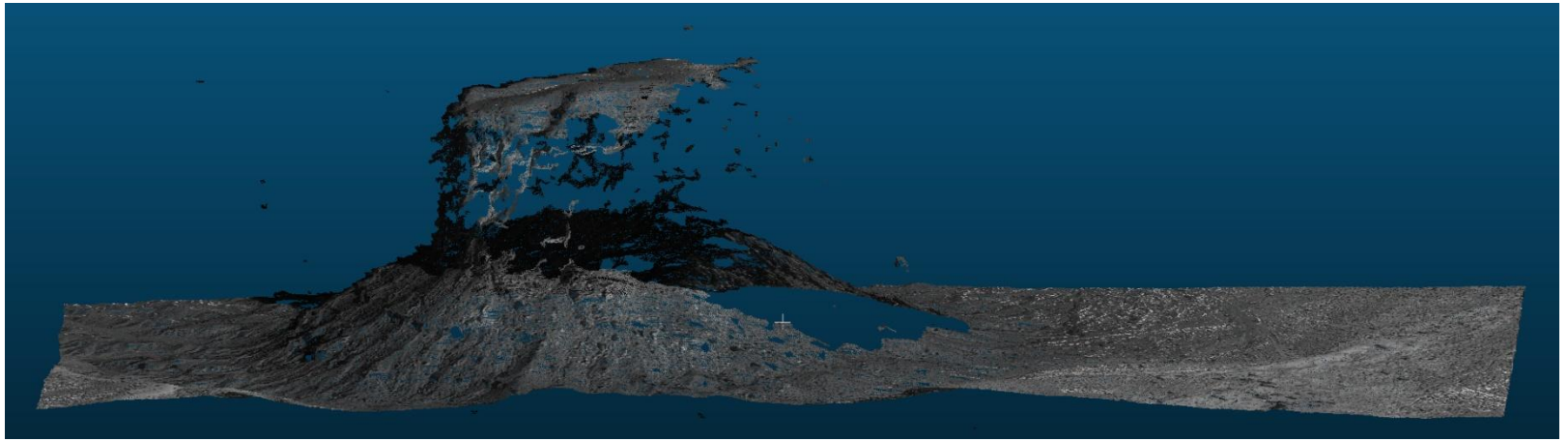


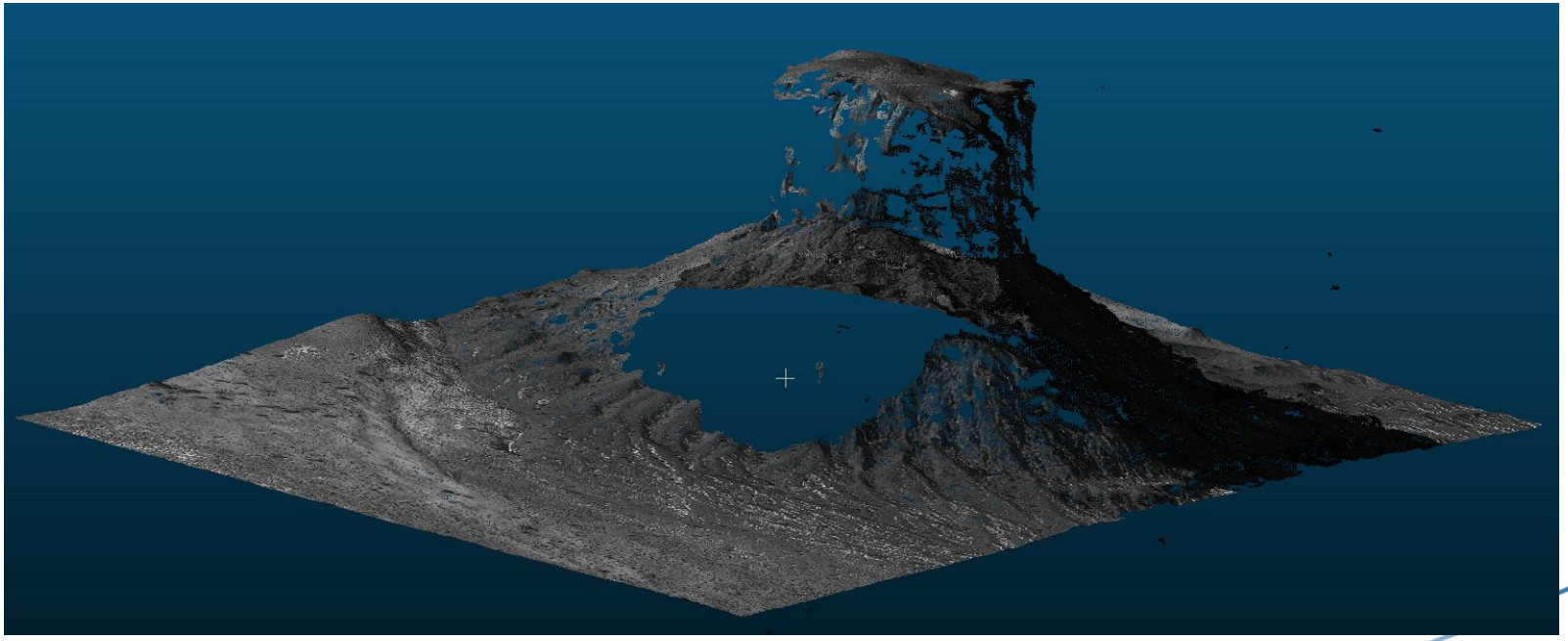
Examples

Monument Valley (PHR1B)

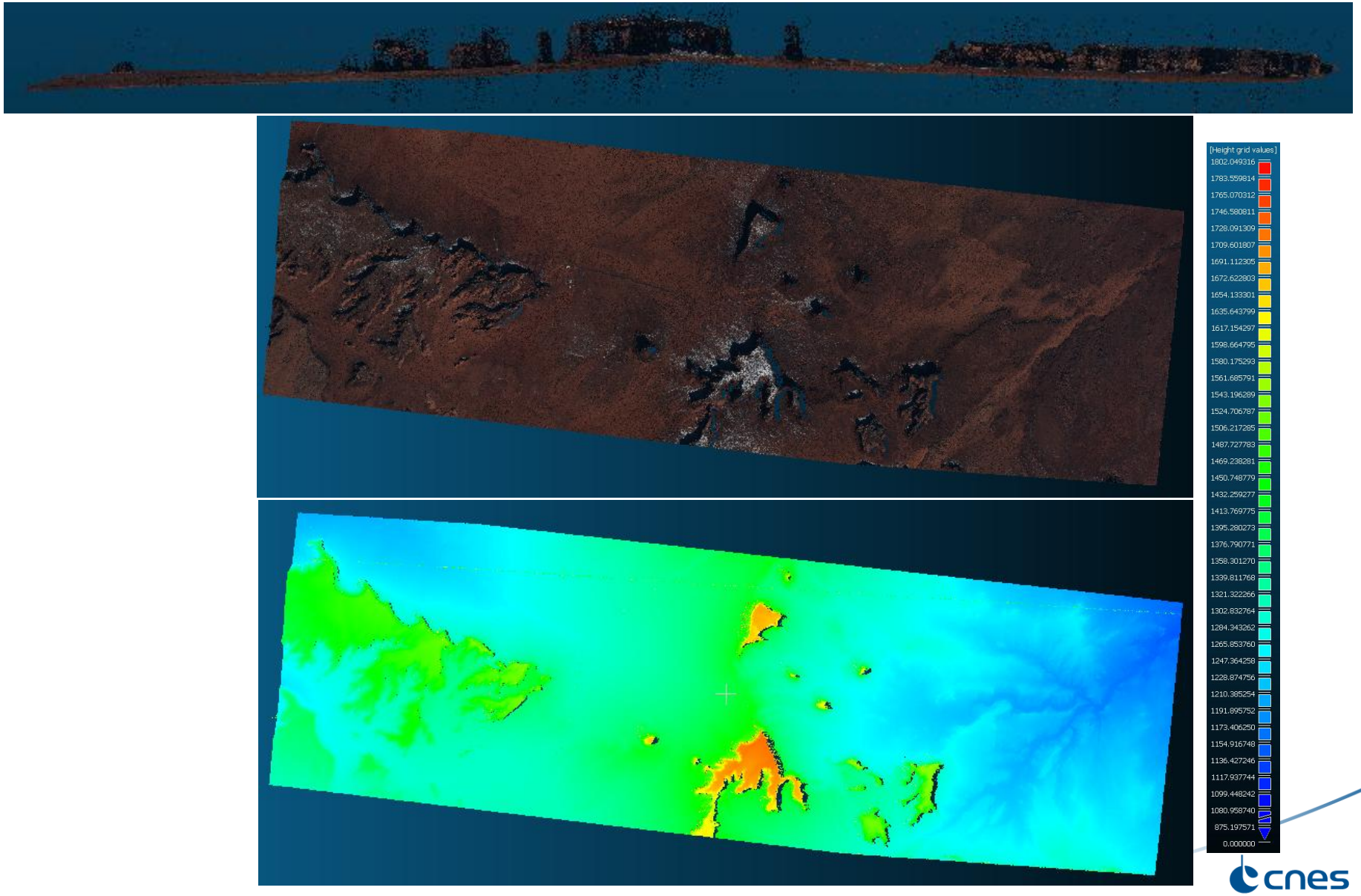


Examples





Examples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1783.559814
1765.070312
1746.580811
1728.091309
1709.601807
1691.112305
1672.622803
1654.133301
1635.643799
1617.154297
1598.664795
1580.175293
1561.685791
1543.196289
1524.706787
1506.217285
1487.727783
1469.238281
1450.748779
1432.259277
1413.769775
1395.280273
1376.790771
1358.301270
1339.811768
1321.322266
1302.832764
1284.343262
1265.853760
1247.364258
1228.874756
1210.385254
1191.895752
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1154.916748
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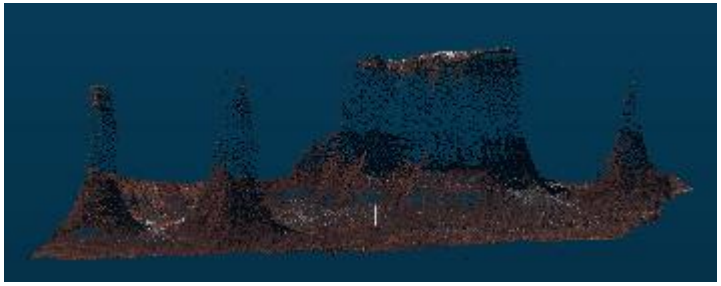
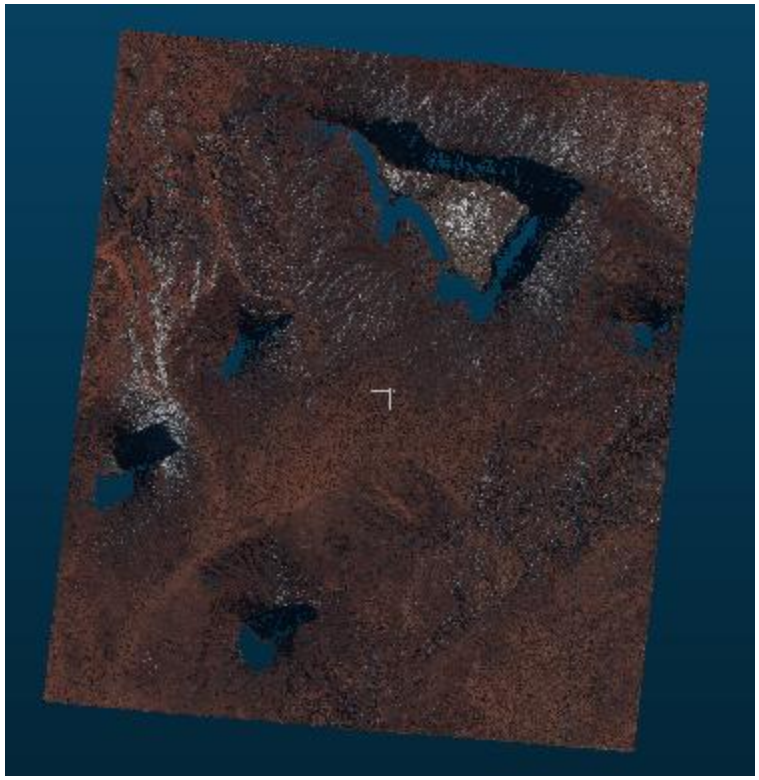
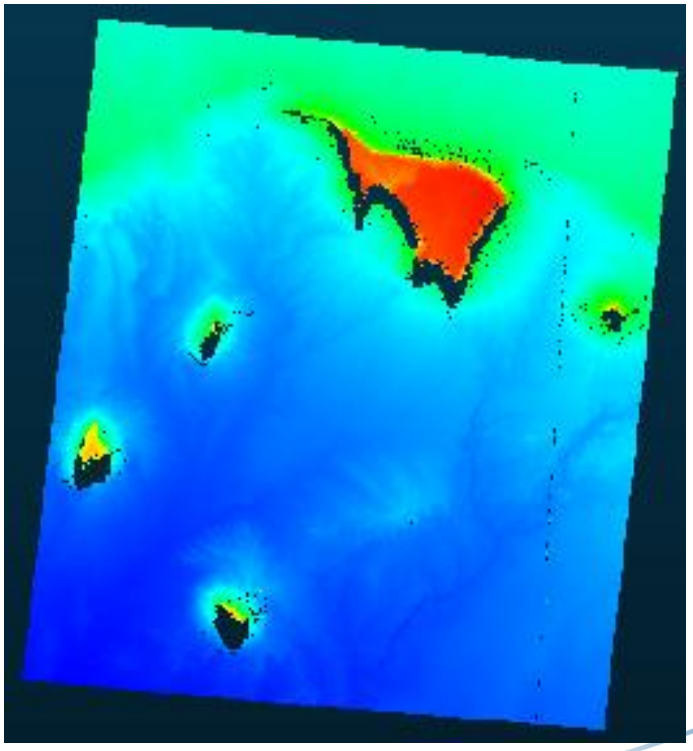
1099.448242
1080.958740
875.197571
0.000000

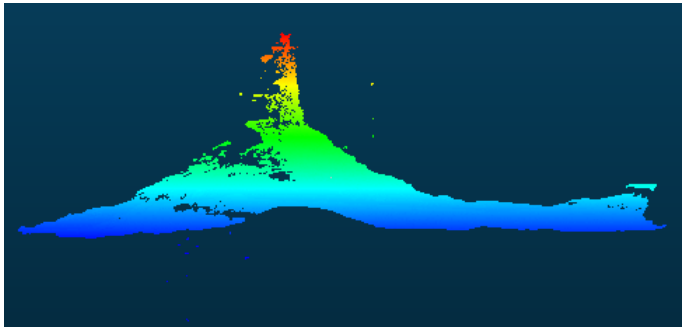
Examples

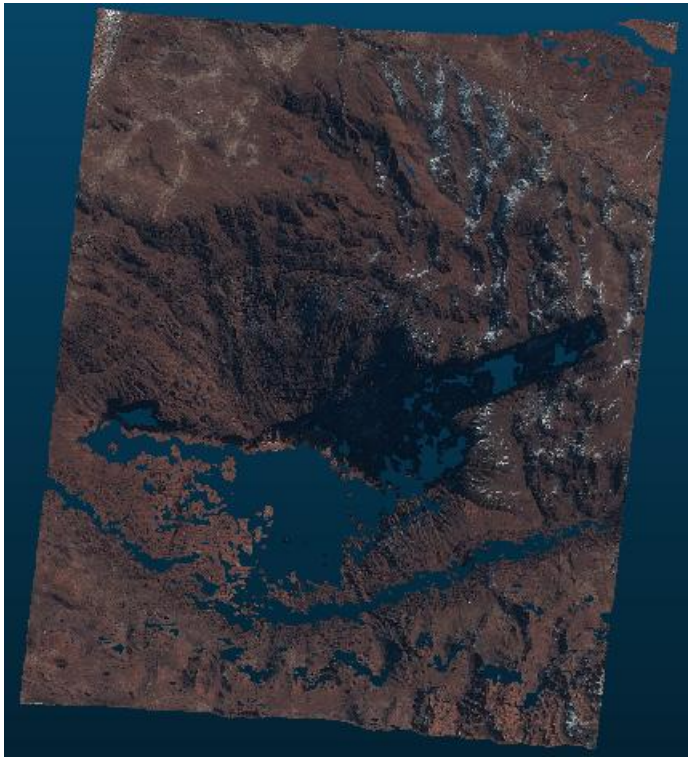


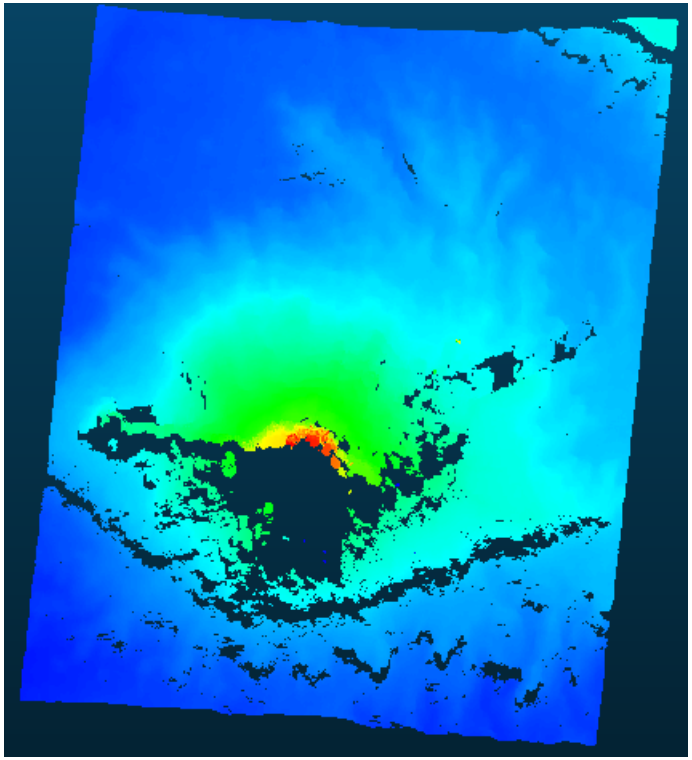




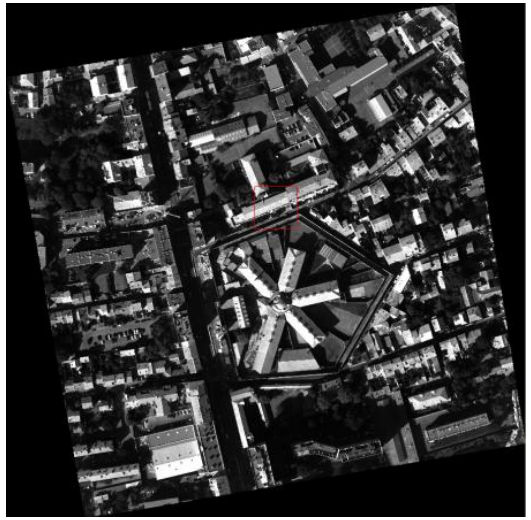
Examples





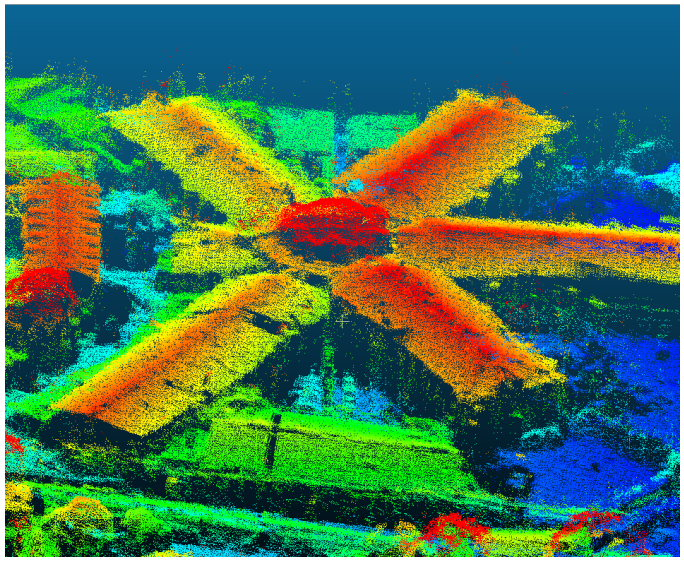


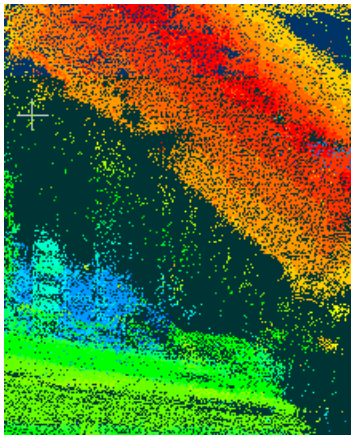
Conclusions : 3D, resolution, B/H



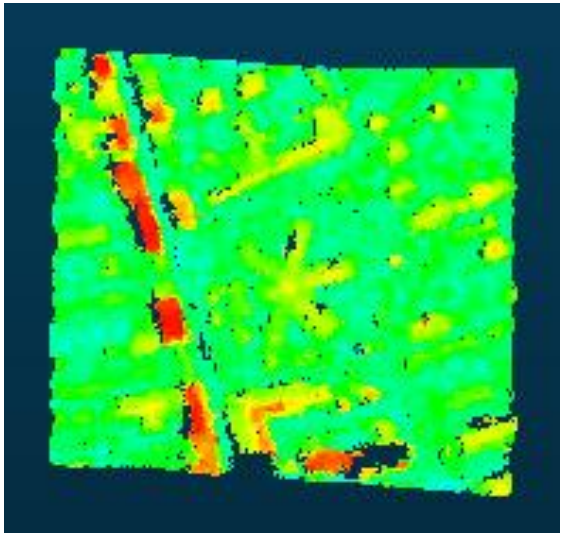
B/H~0,12

Stereo

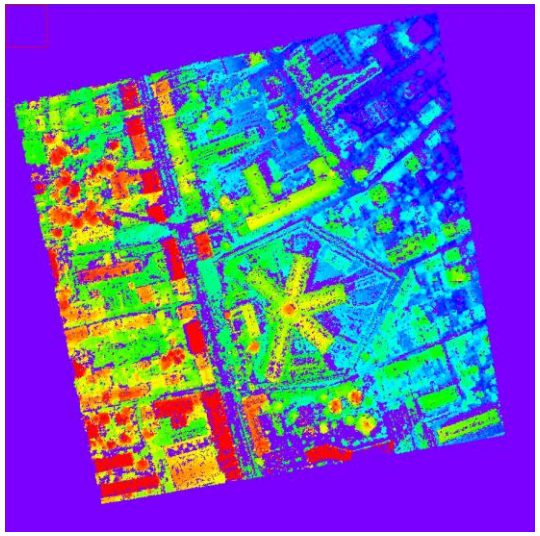




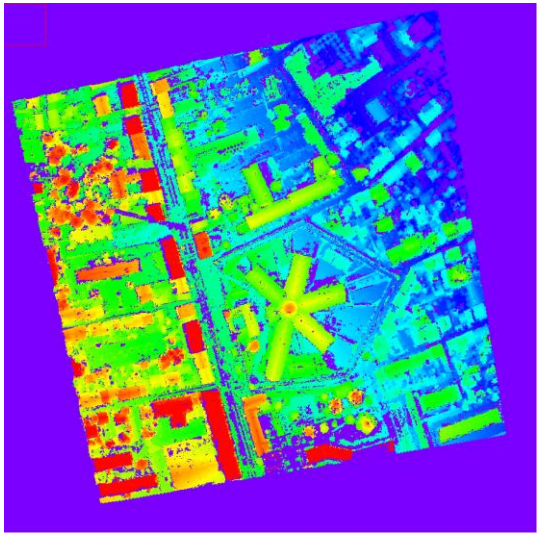
Some walls



Pléiades 70cm



OTOS (next gen) 30cm



Pélican (aerial) 10cm