# *The HD Processing Algorithms applied to very high resolution optical data: a Super Resolution use case with Maxar Imagery evaluated in the context of ESA/EDAP project*

ESA Forum on Super-Resolution and Downscaling for Earth Observation and Earth Science

**SUREDOS24**

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# hAgenda

- EDAP / EDAP + Framework and process
- Infrastructure and assessment activities
- MAXAR Constellation
- Assessment of the Maxar WV3 HD 15 cm products

# EDAP / EDAP+ Framework

- The main objective of EDAP activity is to perform early data quality assessment of **existing or future missions**, with specific focus on New Space and multi-mission activities
- It is achieved through provision of **clusters of expertise in various domains** (Very High, High and Medium Resolution optical sensor, Low Resolution optical sensor, SAR sensor, Atmospheric Missions)
- Specific focus is also be put **on capacity building** in the relevant data provider with the set up and evolution of documentations, tools and procedures to allow to efficiently perform data quality assessments in the domains of expertise
- https://earth.esa.int/eogateway/activities/edap

# Missions and Documentation

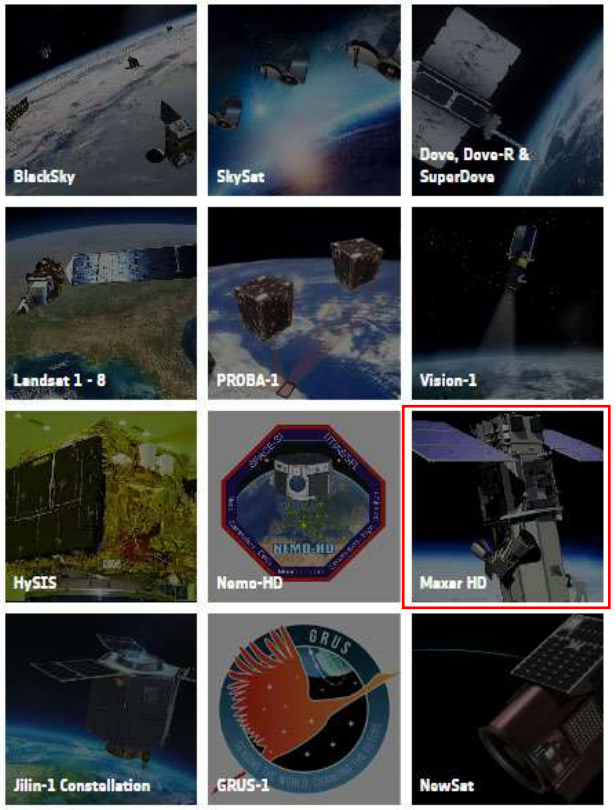
## VHR, HR and MR Optical Missions

### Overview

The following missions have been/are being considered as part of the Very High Resolution (VHR), High Resolution (HR) and Medium Resolution (MR) Optical domain of EDAP and EDAP+, respectively. Further missions are expected to be added throughout the projects.

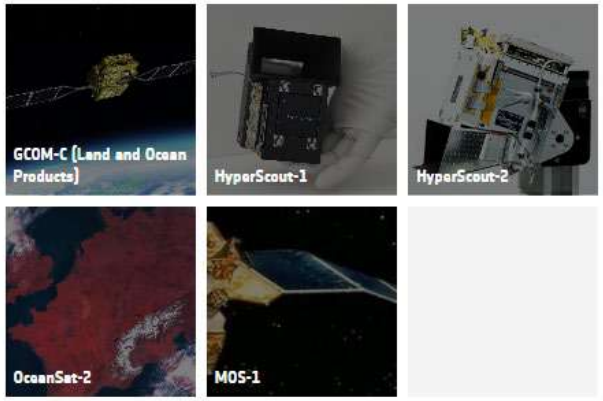
Details on the methods and reference data used for these assessments can be found below:

- Technical Note on Methods and Reference Data for Optical Data Quality Assessments




## LR Optical Missions

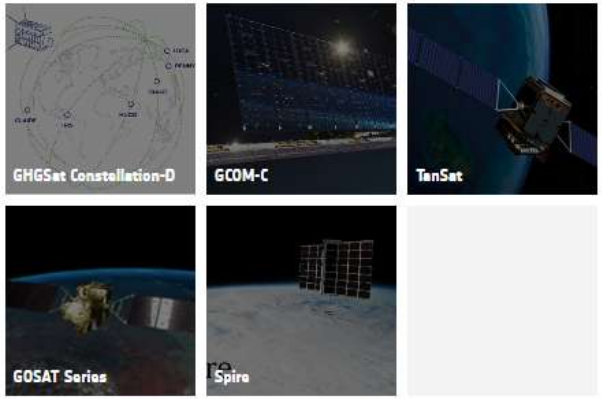
### Overview




## Atmospheric Missions

### Overview

The following missions have been / are being considered as part of the Atmospheric Mission domain of EDAP and EDAP+, respectively. Further missions are expected to be added throughout the project.



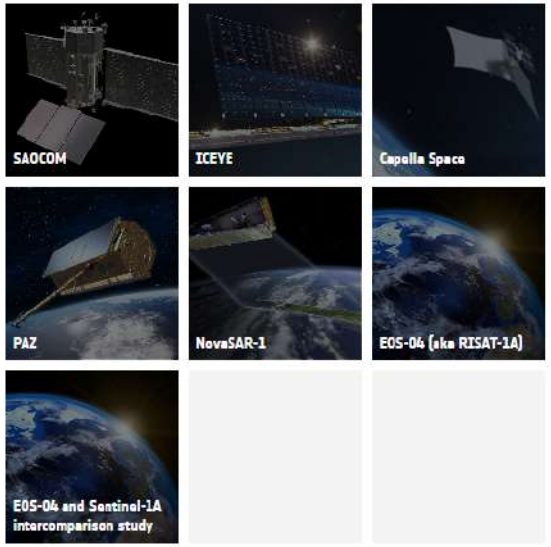

## SAR Missions

### Overview

The missions on this page have been / are being considered as part of the Synthetic Aperture Radar (SAR) domain of EDAP and EDAP+, respectively. Further missions are expected to be added to this domain throughout the project.

Details on the methods and reference data used for these assessments can be found below:

- Technical Note on Methods and Reference Data for SAR Data Quality Assessments




## AIS and RF Missions

### Overview

The following missions are currently being considered as part of the Automatic Identification System (AIS) and Radio Frequency (RF) domain of EDAP+, for which Quality Control Assessments will be performed. Further missions are expected to be added throughout the project.


## Multi-Mission Studies

### Overview

### Multi-Mission Studies

Despite the growing number of satellite optical and radar sensors and the continuous effort in optimising the technical specifications (e.g. spatial and spectral resolution), the underlying physical and technical principles for analysing the relevant remote sensing data remain practically unchanged and can be broken down into a number of elementary processing steps, such as radiometric and geometric calibration, orthorectification, cloud screening, atmospheric correction, and validation. The harmonisation of these steps and of the required ancillary data is therefore a fundamental prerequisite for improving interoperability of the various missions.

This harmonisation requirement is nevertheless a long-term goal, while the current situation, especially for what concerns Third Party Missions, shows an extremely heterogeneous landscape, with a large variety of different theoretical approaches and procedures for addressing the same problem. This is one of the most important issues that is currently hindering the interoperability of the various sensors, since the observed inconsistencies are difficult to understand and, therefore, to resolve.

The main objective of the EDAP Multi-Mission Studies is to address all multi-mission common requirements in terms of satellite data processing and Cal/Val protocols, so as to improve the consistency of similar measurement types and ease of interoperability.

The following study is considered part of the Multi-Mission domain of EDAP. Further studies are expected to be added throughout the project.

### DEM Assessment Study

This study is related to the use of Digital Elevation Models (DEMs) for different missions and their impact on data quality, specifically over critical mountainous regions.

Image data acquired by satellites are affected by systematic sensor and platform-induced geometry errors, which introduce terrain distortions when the sensor is not pointing directly at the nadir location of the sensor. In order to accurately remove the image distortions, a DEM is used to perform image orthorectification.

A DEM is a dedicated catalogue that represents the relief of a surface between points of known elevation. Orthorectification is the process of removing internal and external distortions to assign more accurate coordinates to the final image. The goal of orthorectification is to create a final product whereby every pixel in the image is depicted as if it were viewed at nadir (i.e. directly overhead), removing the effects of hills, valleys, etc., on the data. However, the orthorectification process is less accurate over areas with varied relief (such as mountains), or over cities (where the bare earth representation given by DEM is very challenging to be assessed due to the presence of human artefact, such as buildings).

The first step in this study is to assess the quality of the global DEMs over these difficult areas, using defined areas of comparison and evaluating the quality using standard statistical parameters such as Root Mean Square Error (RMSE) or Linear Error at 90% and 95% confidence.

# EDAP Maturity Matrix

- Maturity Matrix (MM) is a fundamental aspect of the EDAP Assessment Process,
- The Summary Cal/Val Maturity Matrix provides an overall summary of the quality assessment
- The detailed validation provides more complete reporting of analysis
- MM is compiled at product level, (including HD, Video Product),
- Facilitate integration / interoperability with other sensors / missions,
- Note that, there is on going research to create a data usabililty maturity matrix ….

| Data Provider Documentation Review | | |
|---|---|---|
| Product Information | Metrology | Product Generation |
| Product Details | Radiometric Calibration & Characterisation | Radiometric Calibration Algorithm |
| Availability & Accessibility | Geometric Calibration & Characterisation | Geometric Processing |
| Product Format, Flags & Metadata | Metrological Traceability Documentation | Retrieval Algorithm |
| User Documentation | Uncertainty Characterisation | Mission-Specific Processing |
| | Ancillary Data | |

| Validation Summary |
|---|
| Radiometric Validation Method |
| Radiometric Validation Results Compliance |
| Geometric Validation Method |
| Geometric Validation Results Compliance |

| Key |
|---|
| Not Assessed |
| Not Assessable |
| Basic |
| Good |
| Excellent |
| Ideal |
| Not Public |

*Summary Cal/Val Maturity*

| Validation Summary | | Detailed Validation | | | |
|---|---|---|---|---|---|
| Radiometric Validation Method | Radiometric | Absolute Calibration Method | Signal to Noise Method | Temporal Stability Method | |
| Radiometric Validation Results Compliance | Radiometric | Absolute Calibration Results Compliance | Signal to Noise Results Compliance | Temporal Stability Results Compliance | |
| Geometric Validation Method | Geometric | Sensor Spatial Response Method | Absolute Positional Accuracy Method | Band-to-Band Registration Method | Temporal Stability Method |
| Geometric Validation Results Compliance | Geometric | Sensor Spatial Response Results Compliance | Absolute Positional Accuracy Results Compliance | Band-to-Band Registration Results Compliance | Temporal Stability Results Compliance |

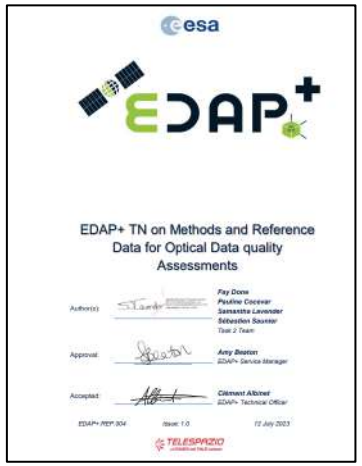
| Key |
|---|
| Not Assessed |
| Not Assessable |
| Basic |
| Good |
| Excellent |
| Ideal |
| Not Public |

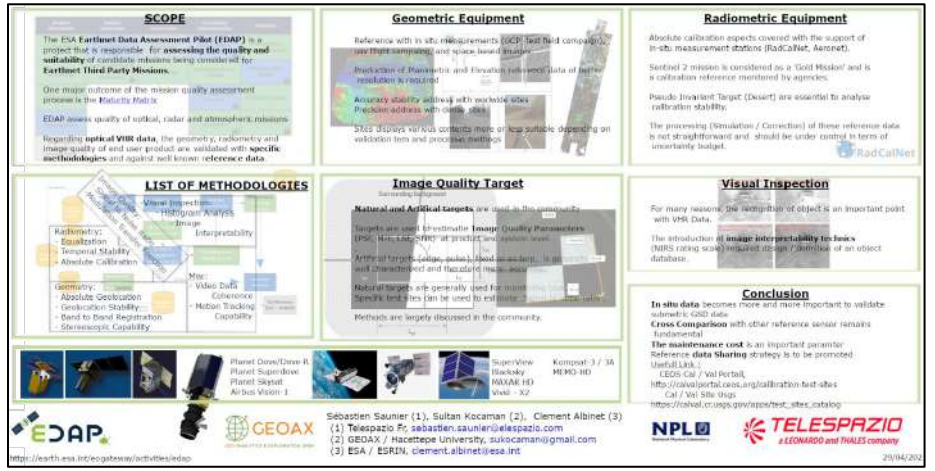
*Validation Cal/Val Maturity Matrix*

https://earth.esa.int/eogateway/activities/edap/edap-best-practice-guidelines

# Processing Infrastructure for QA

- Methods
- Cal/val sites & Reference data
- Processing & Tools





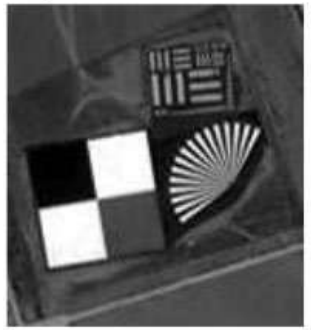
https://calval.cr.usgs.gov/apps/test_sites_catalog

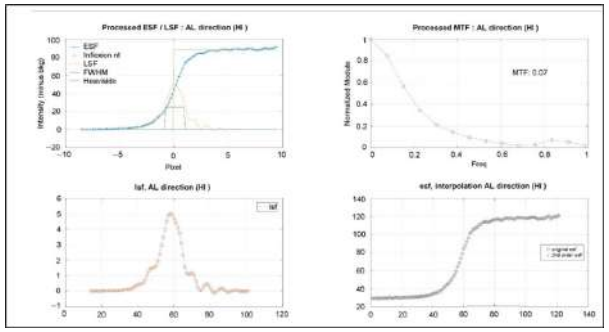
https://www.radcalnet.org/#!/

https://calvalportal.ceos.org/

- Reference data
  - THR Imagery database for image interpretability
  - SNR/MTF Artificial/Natural Targets
  - Continuous TOA measurements from ground Instrumentation
  - Characterization of Pseudo Invariant calibration site
  - Geometric reference: Raster, Vector, GCPs, DEM, LULC Map

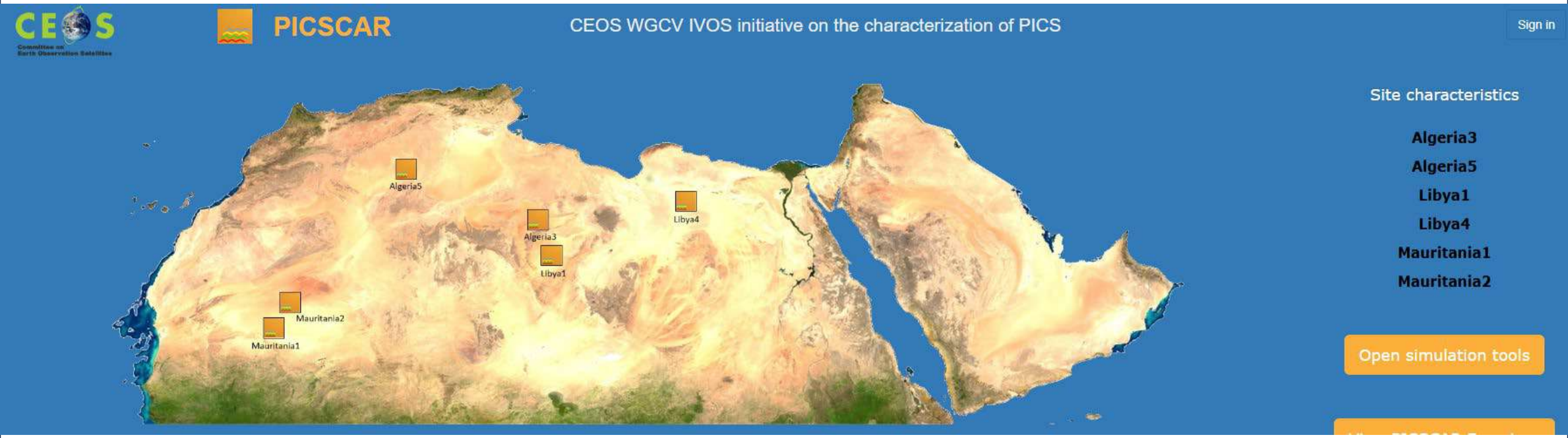
# Processing Infrastructure for QA: MTF sites






- MTF Reference dataset in the Cal / Val portal
- Methods: *Françoise Viallefont-Robinet, Dennis Helder, Renaud Fraisse, Amy Newbury, Frans van den Bergh, Donghan Lee, Sébastien Saunier.. Comparison of MTF measurements using edge method: towards reference data set. Optics Express, Optical Society of America, 2018, 26 (26), pp.33625-33648. ⟨hal-02055611⟩*

# Processing Infrastructure for QA: PICS sites

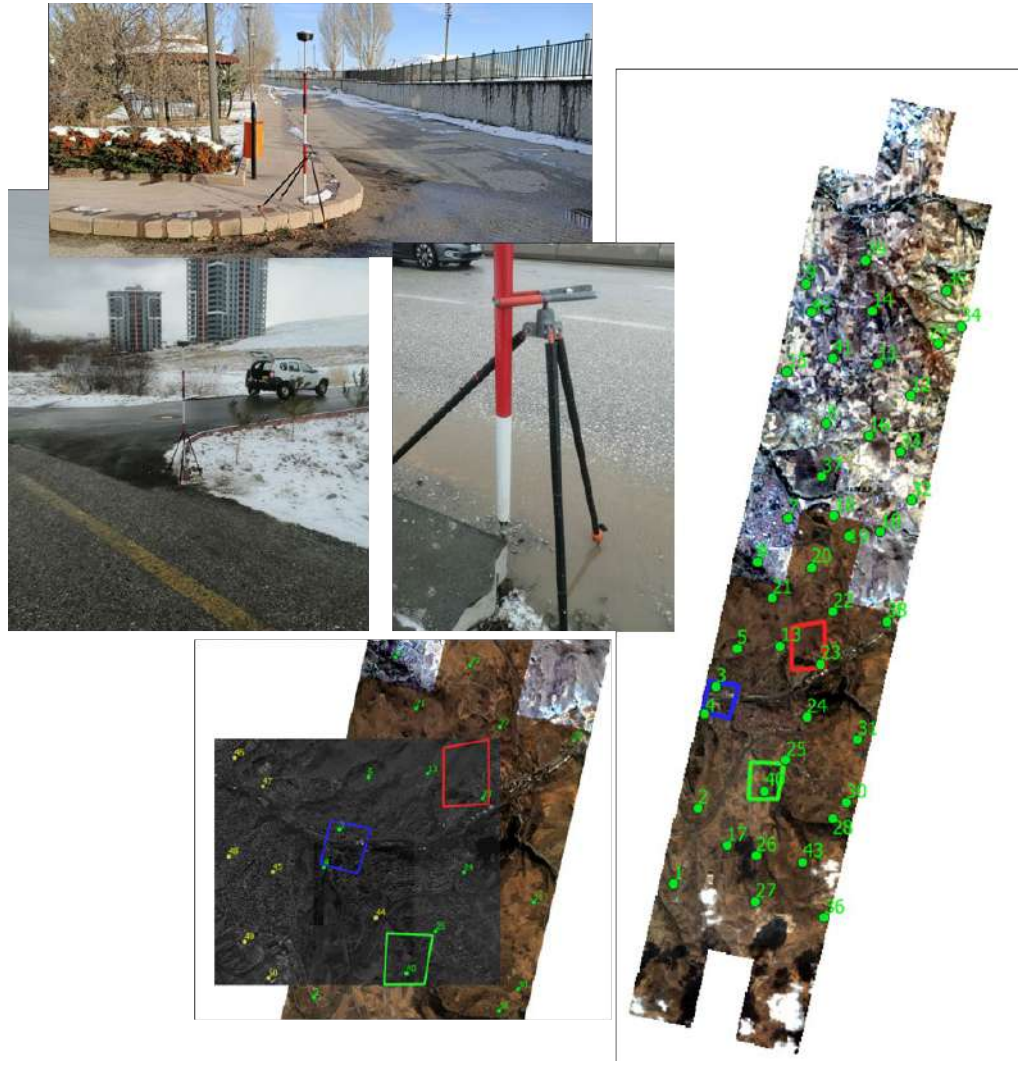



https://picscar.magellium.com/

# Processing Infrastructure for QA: Geometric sites 1/2

**Ankara Test Site - equipment**

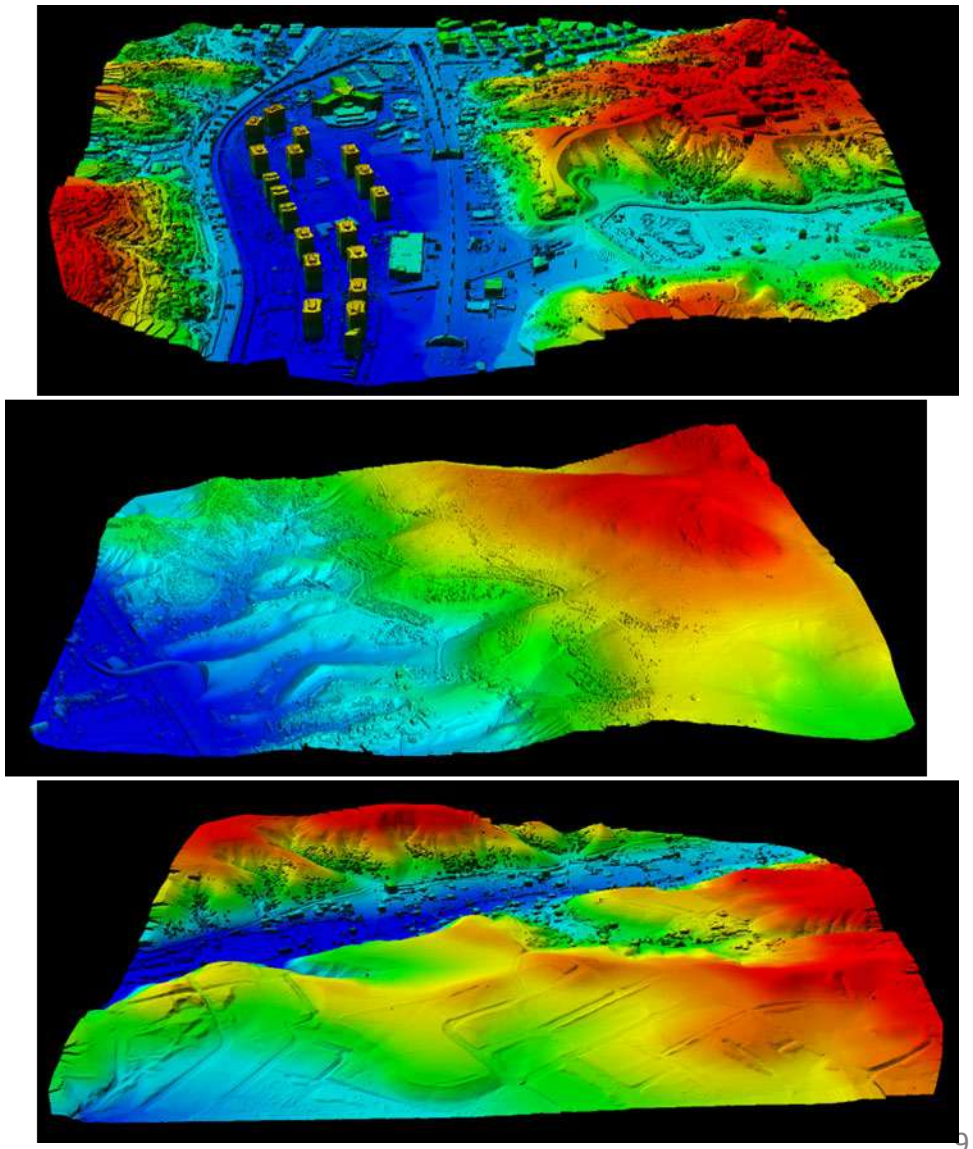
- Covers 10 km x 20 km area
- GNSS-surveyed GCPs with cm level accuracy
- Mostly **man-made objects** (e.g. road intersections) with small altitude differences in its vicinity (i.e., almost flat surface) to avoid elevation errors
- Points are defined with field photos, sketches and satellite image views
- Suitable for manual image measurements
- Reference raster data is under preparation



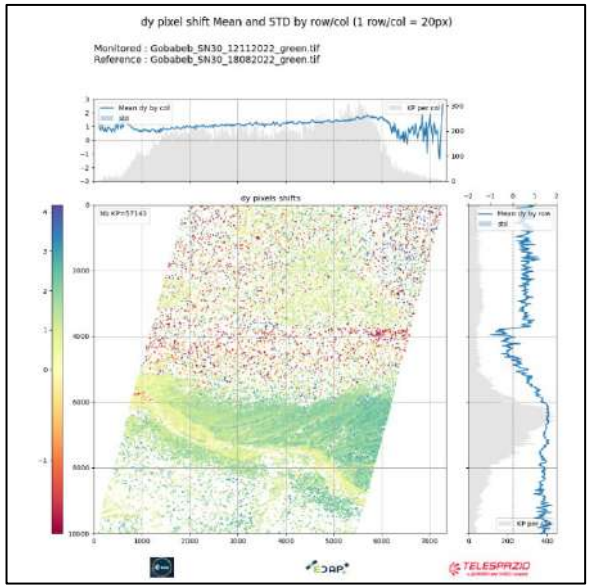
# Processing Infrastructure for QA: Geometric sites 2/2

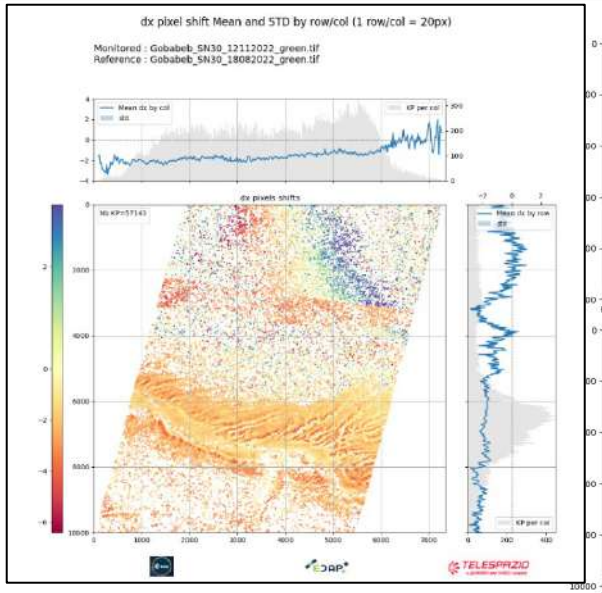
## Ankara Test Site - equipment

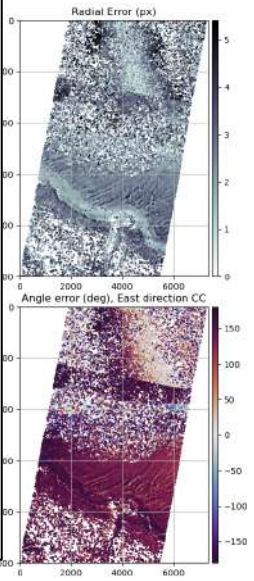
- Three UAV flight missions from 2021 with 1 km x 1 km coverage each
- 3-7 cm ground sampling distances (GSDs) and geolocation accuracy
- UAV sites were selected for their LULC types (dense urban, rural, forest, bareland), altitude variation (ca. 150 m elevation difference exist in one UAV site), and geomorphologic features (availability of slopes and dry river channels)
- Used for stereoscopic capability and image inner accuracy assessments of different satellites
- To date, the site was used for Maxar, SkySat image and video, and NewSat data assessments (see Saunier et al. 2021, 2022 and Yalcin et al. 2021).



# Processing Infrastructure for QA: Recent update




TELESPAZIO

Available Free & Open Source Tool:

KARIOS for mapping accuracy analysis
https://github.com/telespazio-tim/karios

Copernicus reference data:

- Digital Elevation Model, https://spacedata.copernicus.eu/collections/copernicus-digital-elevation-model
- Sentinel 2 GRI https://sentinels.copernicus.eu/web/sentinel/global-reference-image

On going / Future initiatives:

- ESA Cal / Val Park
- CEOS VHR GCPs & GCPIX initiative


# MAXAR Constellation

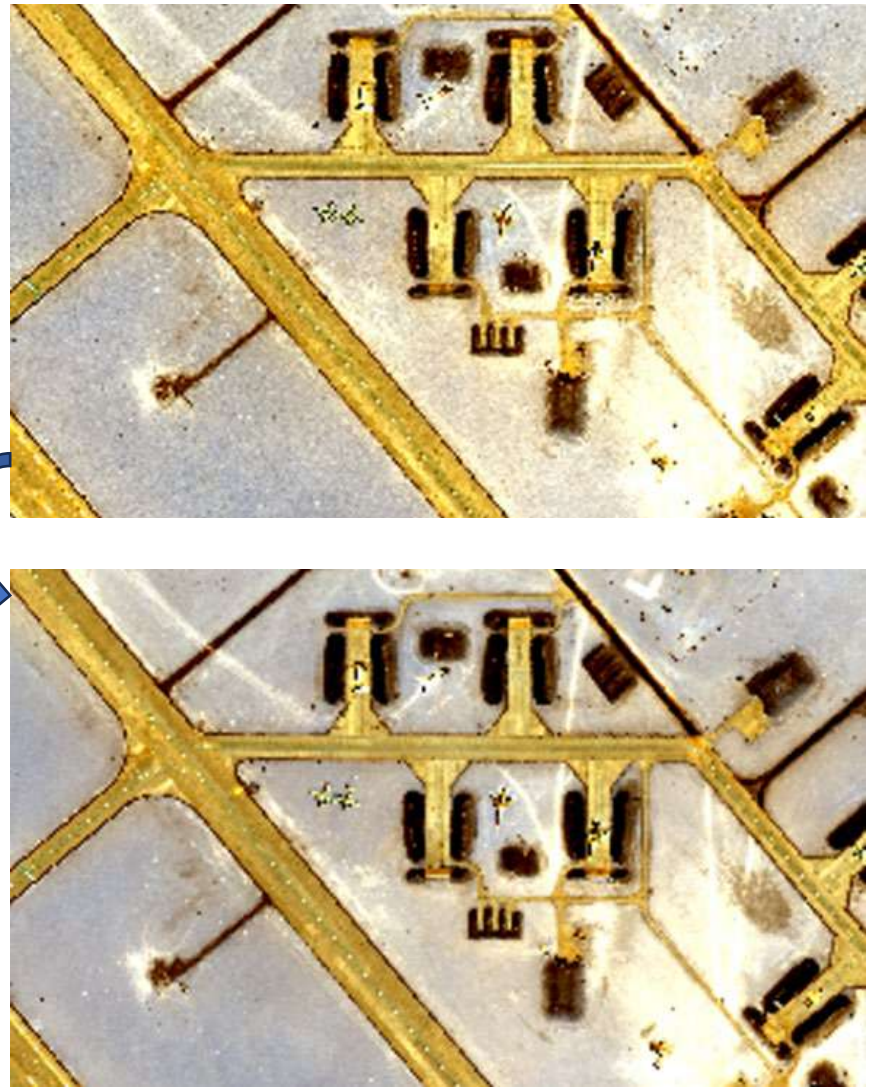
- MAXAR Map-Ready (ortho) imagery from satellite constellation
- Additionnal High Definition Processing (HD) is available
- HD: “Proprietary technique owned by Maxar that improves **the visual clarity of an image**. The image is aesthetically refined with precise edges and well reconstructed details by intelligently increase the number of pixels. HD technology Is not available for Ikonos and Quickbird Imagery.”
- The HD technology provides an image upscaling of the spatial resolution as follows, in case of WV3:
  - Spatial Resolution WV3 Multispectral Native → HD = 1.20 m → 0.60 m
  - Spatial Resolution WV3 Panchromatic Native → HD = 0.30 m → 0.15 m
  - Spatial Resolution WV3 Pansharpened Native → HD = 0.30 m → 0.15 m
- The View ready HD imagery is ortho rectified (UTM cartographic projection), LV2A


| MAXAR Satellite | GSD PAN (m) | GSD MS (m) |
|---|---|---|
| WORLDVIEW-1 (2007) | 0.50 | N/A |
| GEOEYE-1 (2008) | 0.41 | 1.64 |
| WORLDVIEW-2 (2009) | 0.46 | 1.85 |
| **WORLDVIEW-3 (2014)** | **0.31** | **1.24 (VNIR)** |
| WORLDVIEW LEGION (x2) (2024) | 0.29 | 1.16 |

https://www.maxar.com/maxar-intelligence/constellation

# MAXAR HD & EDAP Activities

- Collect / Review documentations
- Defined TDS
- Preliminary Maturity Matrix
- Validate Geometric Calibration
- Validate Radiometric Calibration
- Estimate MTF
- Image interpretability exercise
- *Land Use Land Cover Classification (usability)*
- Final Maturity Matrix and TN



Looks to be nice !!! but

User demo products (Al Jufra Airbase in Libya)

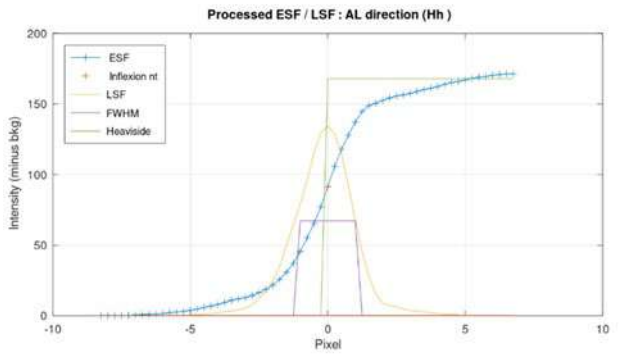
# Geometric / Radiometric Calibration

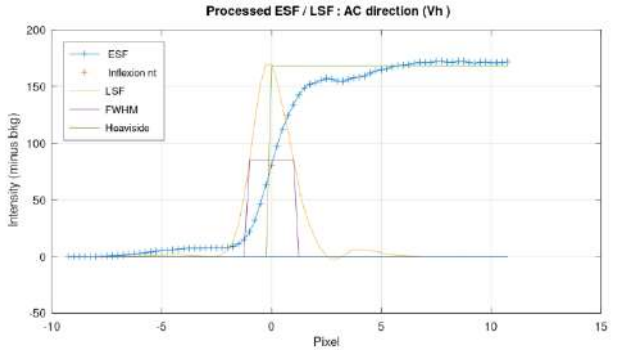
- Planimetric accuracy of MS/PAN HD products is evaluated with GCP from GPS test field survey
- Two different products observed with 15 – 20° off track pointing angle are assessed
- The accuracy is respectively about 3.1 m / 1.8 m (CE90)
- Specification claimed by the data provider is 10.2 m (CE90)
- Even if product observed over !test sites results are nearly the same
- MS Interband registration accuracy is within 0.075 m CE90

- Comparison with data simulated from **RadCalNet** considering spectral response and BRDF model @overpass time
- The % difference is expressed as a percentage, between at sensor top-of-atmosphere reflectances
- In Blue, Green, Red, NIR bands percent difference results do not exceed 3%

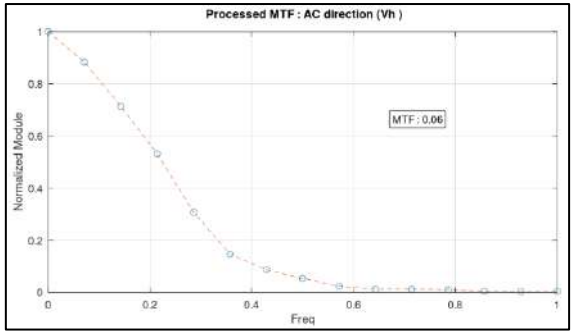
# MTF

- ESF Non-parametric model (why?)
- FWHM may provide a more robust estimator of image sharpness
- AL) FWHM >> 2, smaller RER => slightly blurred in this direction …

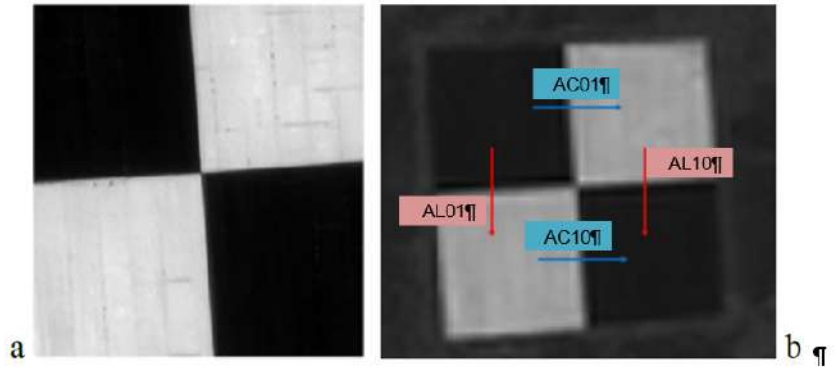



| Target¤ | Direction¤ | SNR¤ | RER¤ | FWHM¤ | MTF¤ |
|---|---|---|---|---|---|
| MTF·target·in·Salon·de·Provence¶ (HD·Non-PS)¤ | AL01·(AL)¤ | 25.79¤ | 11.42¤ | 2.25·pixel¤ | 0.04¤ |
| | AL10·(AL)¤ | 15.24¤ | -11.03¤ | 2.75·pixel¤ | 0.02¤ |
| | AC01·(AC)¤ | 10.84¤ | 13.88¤ | 2.25·pixel¤ | 0.06¤ |
| | AC10·(AC)¤ | 6.66¤ | -12.85¤ | 2.00·pixel¤ | 0.06¤ |



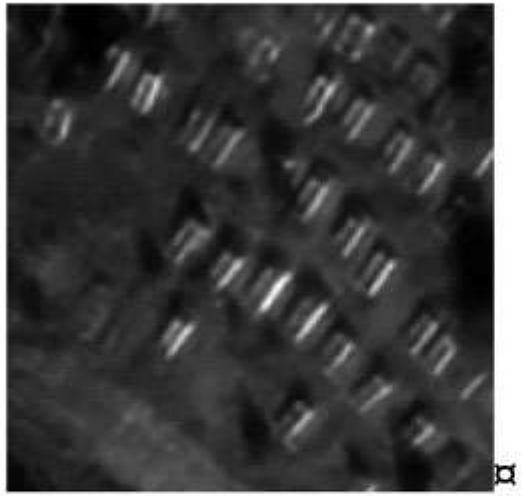
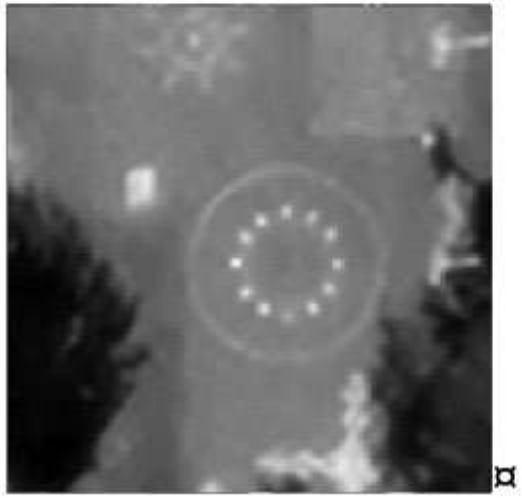

After this assessment, ESA proposed to repaint the Salon MTF target, youpi !!!




Figure·4-7·15·cm·Panchromatic·HD·(a)·artificial·MTF·target·in·Salon-de-Provence,·15·cm·Pansharpened·HD,·and·(b)·the·four·directions·(AL01,·AL10,·AC01,·AC10)·of·the·MTF·calculation·(Red·band).¶

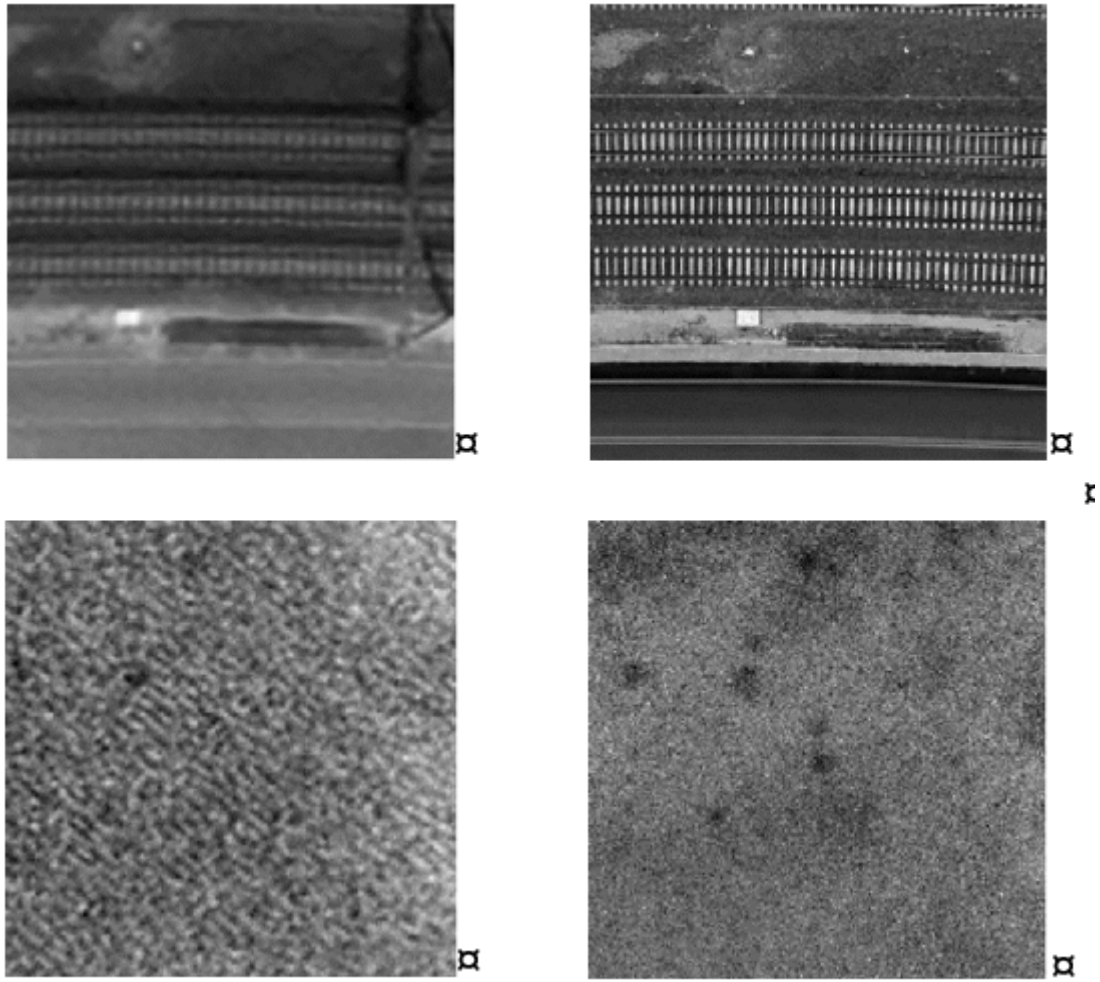
# Visual Comparison /Image Interpre

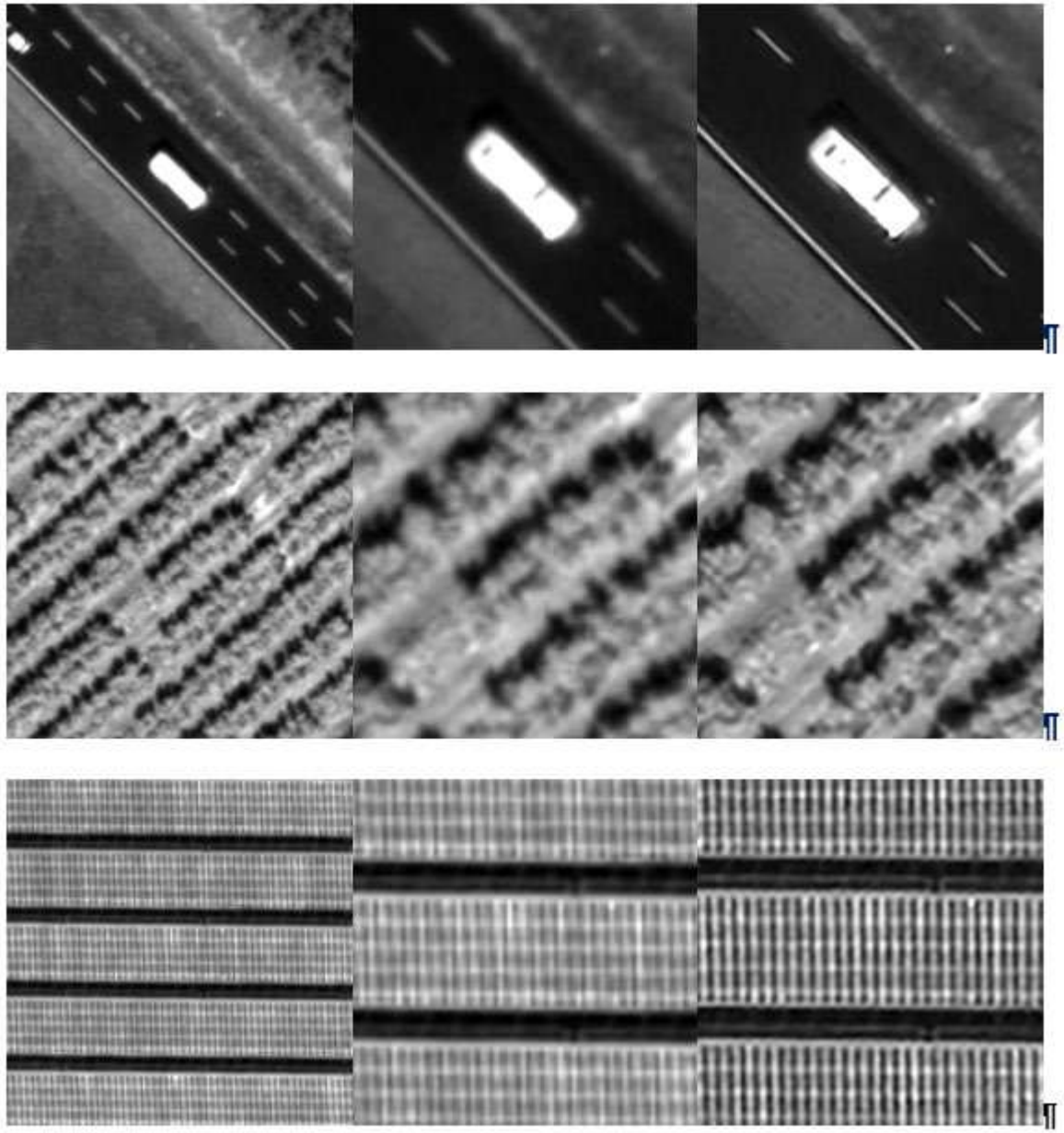
- Prepare UAV as reference data (3.25 cm GSD)
- Extract relevant objects; Airplane, Car, Run Way marking, Helicopter …
- Perform Visual comparison @same HR resolution
- Blur confirmed

| Maxar·HD·(Panchromatic·Band)¤ | UAV·(Green·band)¤ |
| --- | --- |
|  |  |
|  |  |

# Visual Comparison /Image Interpretability

- Prepare UAV as reference data (3.25 cm GSD)
- Extract relevant objects; Airplane, Car, Run Way marking, Helicopter …
- Perform Visual comparison @same HR resolution
- Blur confirmed

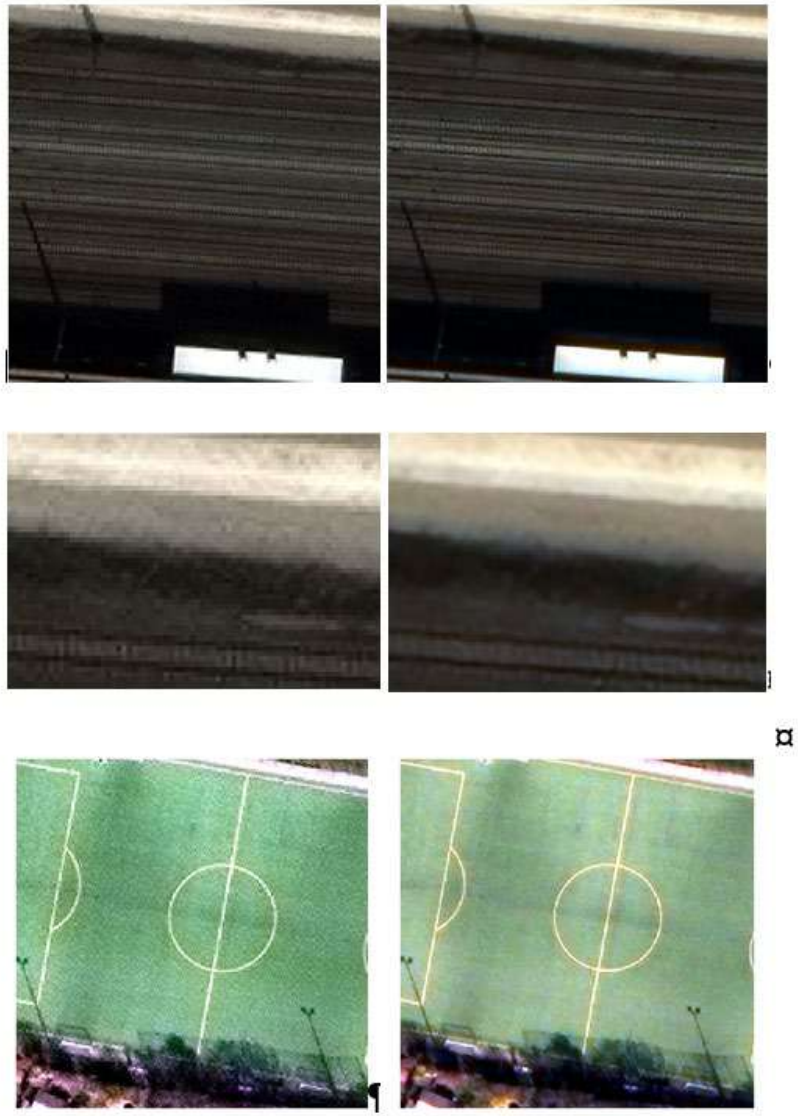




Figure·4-16·France·–·La·Crau·POIs:·Panchromatic·(left)·original·(0.3·m),·(middle)·pseudo-HD·(0.15·m)·and·(right)·HD·(0.15·m)·imagery.¶

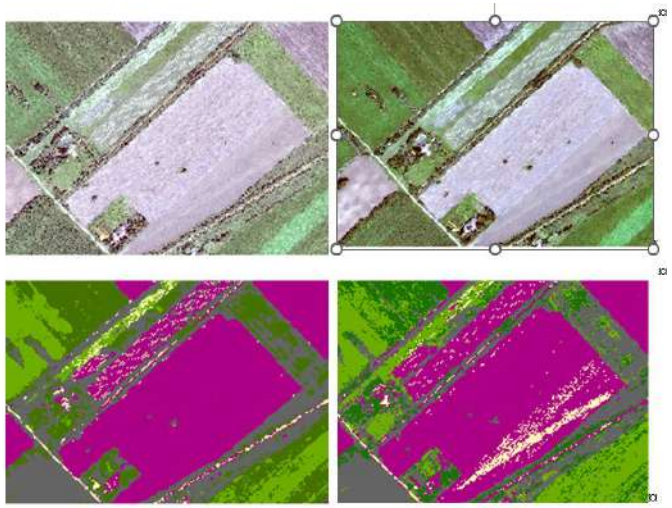
# Visual Comparison /Image Interpretability

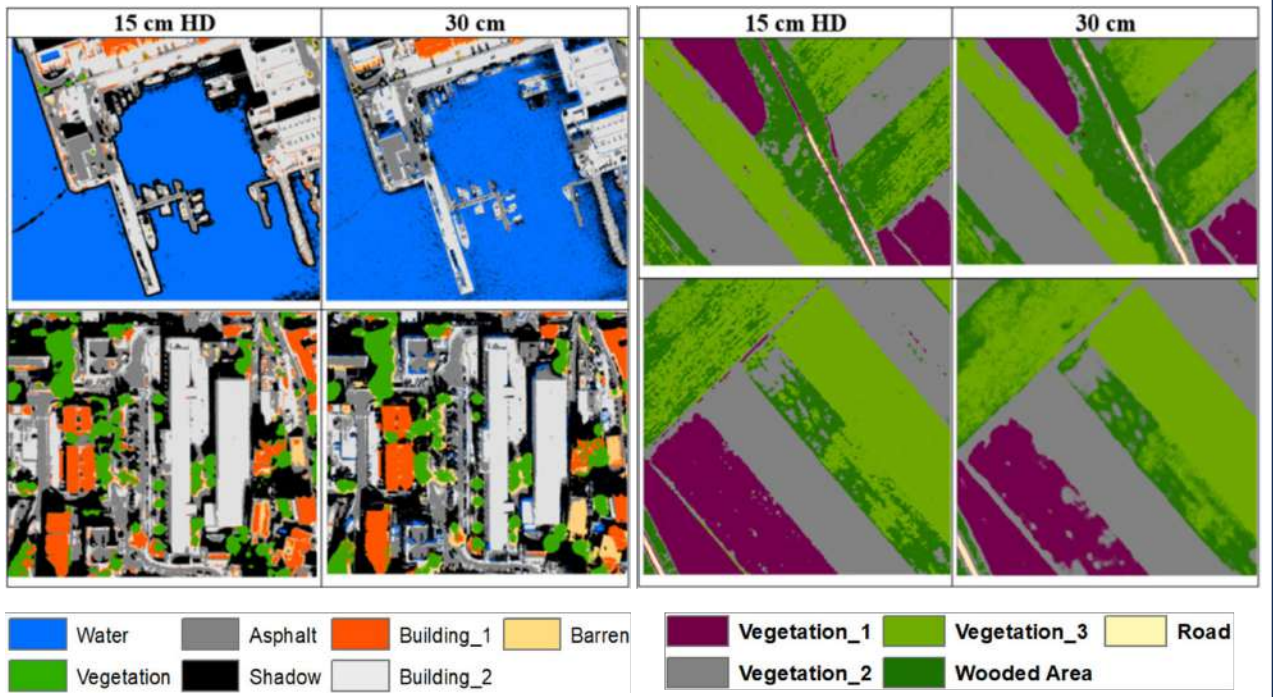
Figure·4-17·Germany·–·Munich·POIs·I:·(left)·Pansharpened·RGB·MAXAR·30·cm·(left)·and·15·cm·(right)·image·parts·over·railway,·soccer·field·and·a·road·in·Munich.¶



# Evaluate HD products using classification 1/2

- We compared **the image classification accuracy** of 30 cm pan-sharpened and 15 cm HD products.
- RF Classification method is used
- Image quality improvement of the HD products were mainly observable in urban areas with strong sharpen edges. Thus, they provide a **clear advantage for LULC classification** in urban areas.



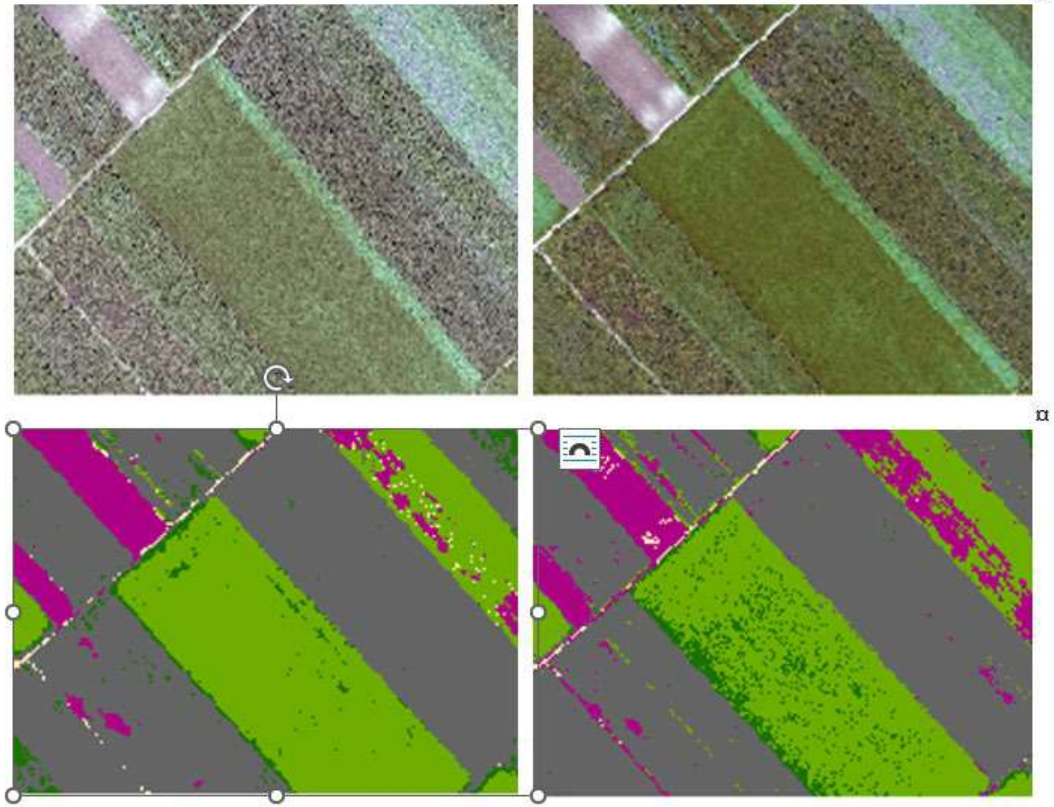

I. Yalcin[1, 2], G. Karakas [2, 3], S. Kocaman [3, 4, *], S. Saunier [5], C. Albinet, INVESTIGATIONS ON THE EFFECT OF MAXAR HD PROCESSING IN LAND COVER CLASSIFICATION, In ISPRS Congress 2022.

Yalcin, I., Kocaman, S., Saunier, S., and Albinet, C.: RADIOMETRIC QUALITY ASSESSMENT FOR MAXAR HD IMAGERY, ISPRS Congress 2021. https://doi.org/10.5194/isprs-archives-XLIII-B3-2021-797-2021, 2021.

# Evaluate HD products using classification 2/2

- We compared **the image classification accuracy** of 30 cm pan-sharpened and 15 cm HD products.
- RF Classification method is used
- Image quality improvement of the HD products were mainly observable in urban areas with strong edges. Thus, they provide a clear advantage for LULC classification in urban areas.
- In agricultural fields, classification noise was observed with HD data.
- The results in both areas confirm the findings of a previous publication that **<u>are edge improvement and color noise with HD</u>.**

Figure·4-21·Image·parts·from·the·image·classification·results·from·the·30·cm·(left)·and·15·cm·(right)·resolution·images·over·Gibraltar·site.¶



I. Yalcin[1, 2], G. Karakas [2, 3], S. Kocaman [3, 4, *], S. Saunier [5], C. Albinet, INVESTIGATIONS ON THE EFFECT OF MAXAR HD PROCESSING IN LAND COVER CLASSIFICATION, In ISPRS Congress 2022.

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# Conclusions

- EDAP Framework, VHR Optical expertise cluster, and approach has been discussed
- MAXAR HD was the first opportunity to assess SR product  in the context of EDAP
- From our experiment, products  are  very well calibrated in term of Radiometry / Geometry, and therefore inter compared.
- HD Improves image sharpness without loosing radiometric fidelity (good)
- Refering to comparison with UAV, MTF results or even classification exercise, improvements are limited and more likely reserved to certain applications / data usability ….
- As observed, HD creates (or increase) noise, HD creates image issues / artifacts, in particular color artifact (color , noise)
- Additional metrics are essential to appreciate image changes due to HD process. From user perspective, image interpretability rating scale can be a partial solution
- Beside uncertainties report, from data provider point of view, a particular product design might be adopted to flag less confident pixels which are subject to changes.
- Few documentations / traceability available, it prevents to investigate / understand …

Thanks
for your attention

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