Concept for EnMAP post-launch product validation and instrument characterisation activities

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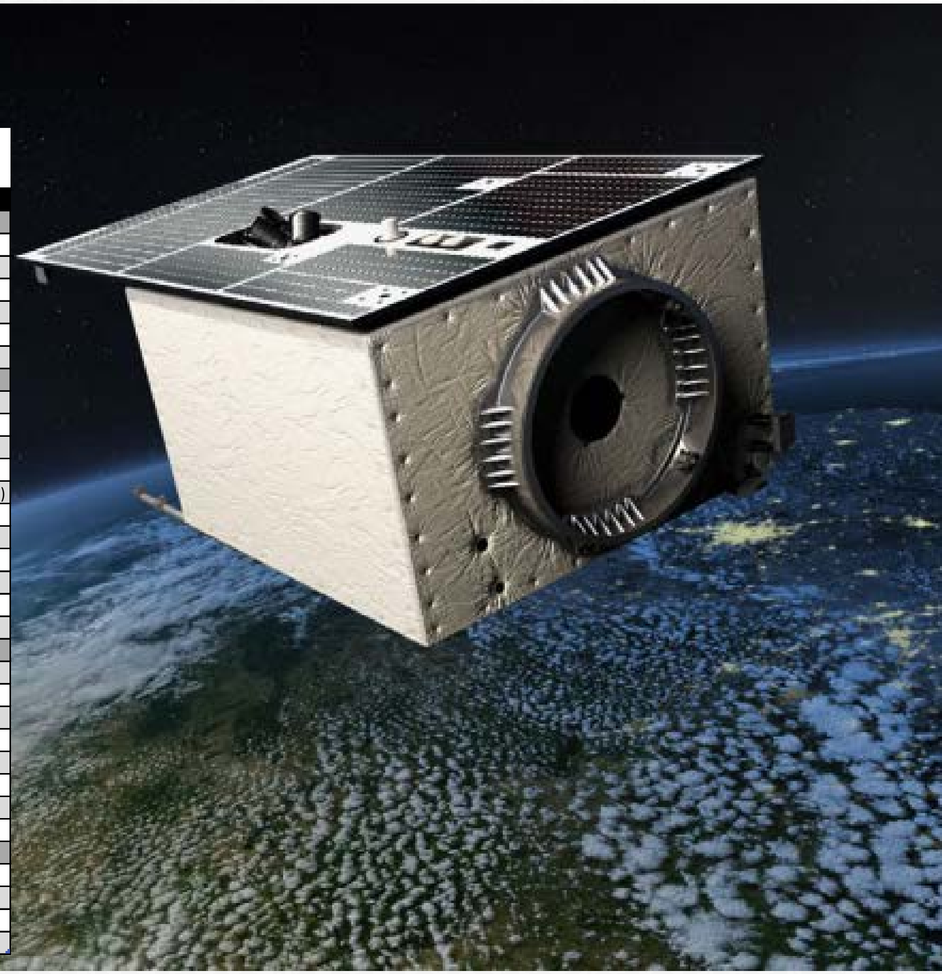
EnMAP

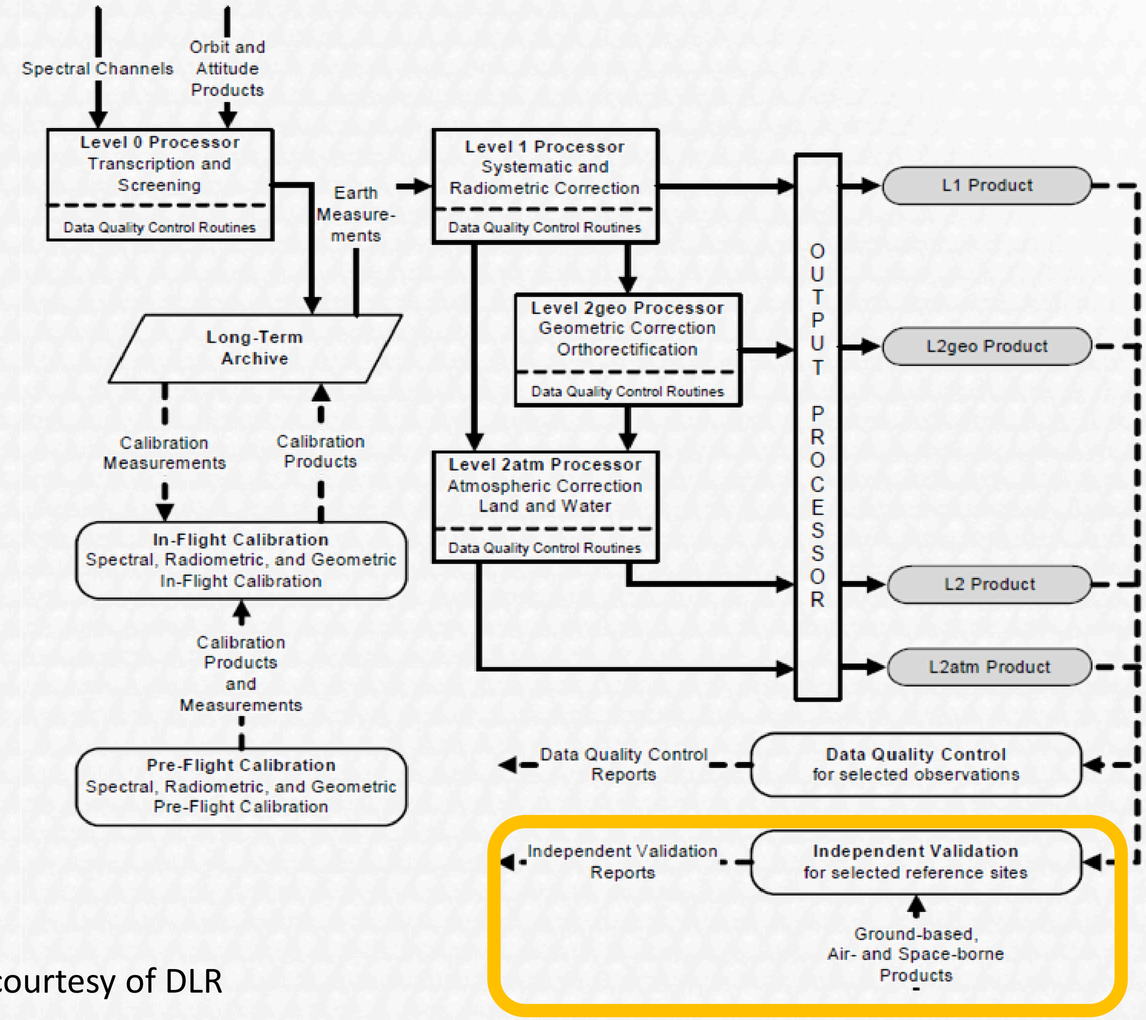
EnMAP satellite parameters

EnMAP Parameter	Performance	
Satellite characteristics		
Imaging principle	push-broom, two prism imaging spectrometers	
Orbit	sun-synchronous	
Altitude	643 km	
Inclination	97.96°	
Weight (payload + bus)	1000 kg	
Size	3.1 m x 1.9 m x 1.7 m	
Spectral characteristics	VNIR	SWIR
Spectral range	420 - 1000 nm	900 - 2450 nm
Number of bands	88	154
Spectral sampling interval	6.5/10nm	10 nm
Spectral bandwidth (FWHM)	8.1 ± 1.0 nm	12.5 ± 1.5 nm
Signal-to-noise ratio (SNR)	> 500.1(at 495 nm)	> 180.1 (at 2200 nm)
Spectral calibration accuracy	0.5 nm	
Spectral stability	0.5 nm	
Spectral smile/keystone effect	< 20 % of detector element	
Radiometric calibration accuracy	< 5 %	
Radiometric stability	± 2.5 % between two consecutive calibrations	
Polarisation sensitivity	< 5 %	
Spatial characteristics		
Ground sampling distance (GSD)	30 m (at nadir, sea level)	
Swath width	30 km (Field of View = 2.63° across track)	
Swath length	1000 km/orbit, 5000 km/day	
Pointing angle	± 30° (across track)	
Geometric co-registration	≤ 0.2 + GSD	
Pointing accuracy	500 m nadir	
Pointing knowledge	100 m nadir	
Pointing stability	< 5 % of a pixel (short term jitter)	
Temporal characteristics		
Target revisit time	23 days (VZA ≤ 5°)/4 days (VZA ≤ 30°)	
Equator crossing time	11:00 h ± 18 min (local time descending node)	
Average Ground Speed	6.9 km/s	
Along-track exposure	4,3 ms	



EnMAP Science Plan: http://**www.enmap.org**/sites/default/files/pdf/pub/121026_EnMAP_SciencePlan_dpi150.pdf

Data Product Standards Approach



Illustration, courtesy of DLR

Objectives

Objectives of GFZ Validation and Characterization Plan

- **Quantitative validation of EnMAP products to be delivered to users**
  - L1: Top-of-Atmosphere radiance
  - L2geo: Top-of-Atmosphere radiance + geometric correction
  - L2atm: Surface reflectance, no geometric correction
  - L2: Surface reflectance + geometric correction

- **Complement instrument monitoring activities**
  - Characterization and Monitoring of e.g. noise, MTF, radiometric calibration, keystone, spectral shift and smile and detector non-linearity

Approach

Two-fold Validation Approach:

- **Ground-based** → comparison of EnMAP user products to in-situ reference measurements:
  - Field campaigns with in-situ measurements of atmospheric and surface parameters + flight campaigns
  - Benefit from collaborative effort with other ground-based hyperspectral science related activities

- **Scene-based** → further validation from scene-based data analysis:
  - Sophisticated models and image processing techniques involved
  - Alternative to those considered in the GS calibration and monitoring plans
  - Activities considered "scientific" rather than "operational"

Approach for Ground-Based Validations

Provide absolute reference for L1 and L2 products

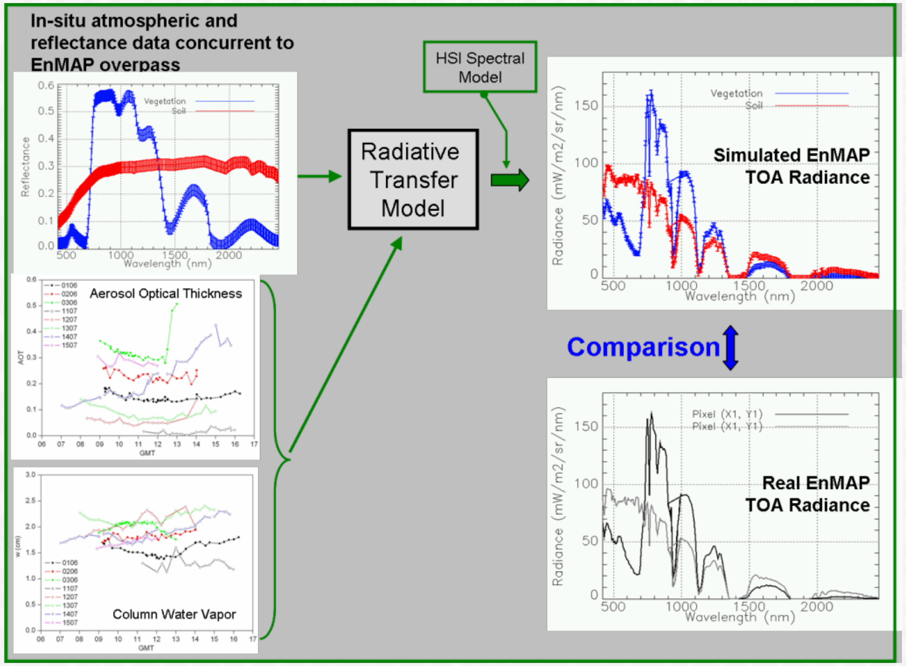
Approach: Involving ground-based reflectance and atmospheric measurements and airborne HS data.

Four scenarios:

- L1/L2geo (**radiance**) validation
- L2/L2atm (**reflectance**) validation
- L2/L2geo (**geometry**) validation
- Atmospheric product validation

Approach for Ground-Based Validations

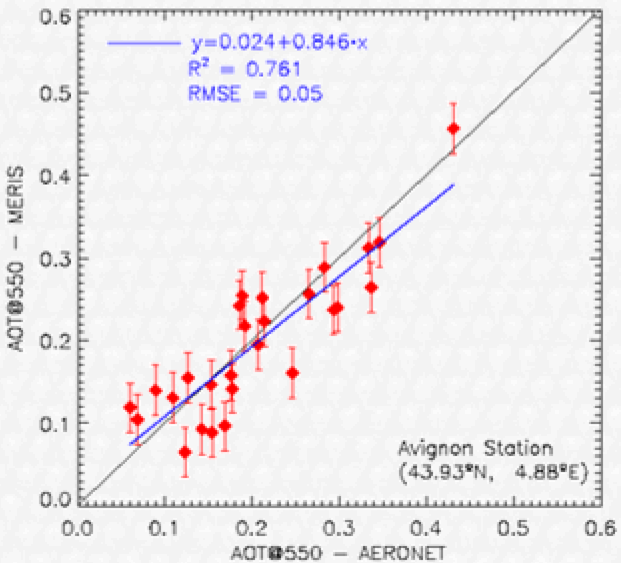
- **L1/L2geo (radiance) validation**
  - **Reflectance-based approach**: reflectance + atmosphere + RT simulations + HIS – spectral model → EnMAP-like TOA radiance

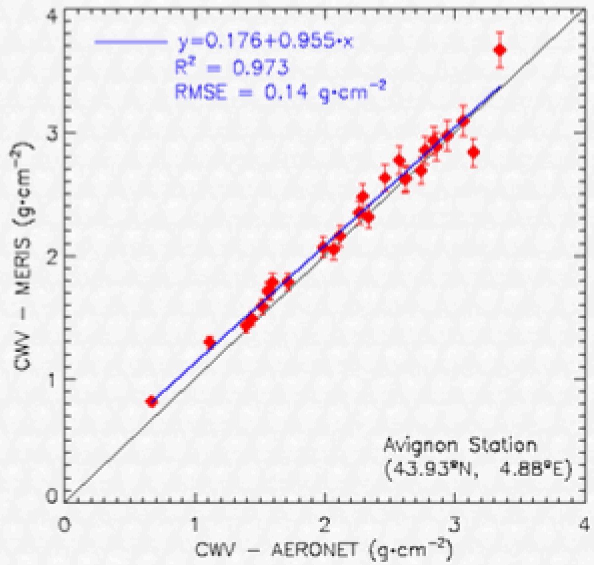


  - Benefit of airborne sensors: to extend validation area to cover EnMAP's swath and to check across-track radiometric response

Approach for Ground-Based Validations

- **Atmospheric product validation**
  - By-products from EnMAP atmospheric correction: aerosol optical thickness and columnar water vapor.
  - Comparison of AERONET data with related EnMAP data → EnMAP acquisitions over AERONET sites are required.





Validation Sites – Criteria

- **L1 & L2geo (radiance)**
  - Best conditions for instrument testing (high SNR, minimal atmospheric impact…)
  - Far from ocean and urban & industrial areas
  - Vegetation-free, bright and elevated targets
  - Wide-spread over the globe
- **L2 & L2atm (reflectance)**
  - Under normal acquisition conditions
  - Typical EnMAP science sites (agricultural, coastal, geological…)
  - Included in extensive science-oriented campaigns
  - Validation sites across the world at sea level (short-term accessible)
- **L2 & L2geo (geometry)**
  - Flat and mountainous regions, spectrally heterogeneous with high spectral contrast, geologically stable

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Validation Sites – Radiance Product

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- From CEOS QA4EO Catalog of Worldwide Test Sites for Sensor Characterization

  (Coordination of EnMAP Cal/Val with CEOS and co-existing missions

  (e.g. Sentinel-2, LDCM, HISUI, PRISMA) is indispensable)

- Emphasis on global coverage and sites’ PI experience

- Data acquisition through partnerships: International partners to provide the data as part of a priority-user agreement

- Potential partners identified - formal agreements have to be made (about 2 years before launch)

Approach

Two-fold Validation Approach:

- **Ground-based** → comparison of EnMAP user products to in-situ reference measurements:
  - Field campaigns with in-situ measurements of atmospheric and surface parameters + flight campaigns
  - Benefit from joint effort with ground-based science activities

- **Scene-based** → further validation from scene-based data analysis:
  - Advanced models and image processing techniques involved
  - Alternative to those considered in the GS calibration and monitoring plans
  - Activities considered “scientific” rather than “operational”

Approach for Scene-Based Validations

Development for automated and accurate algorithms for the analysis and monitoring of:

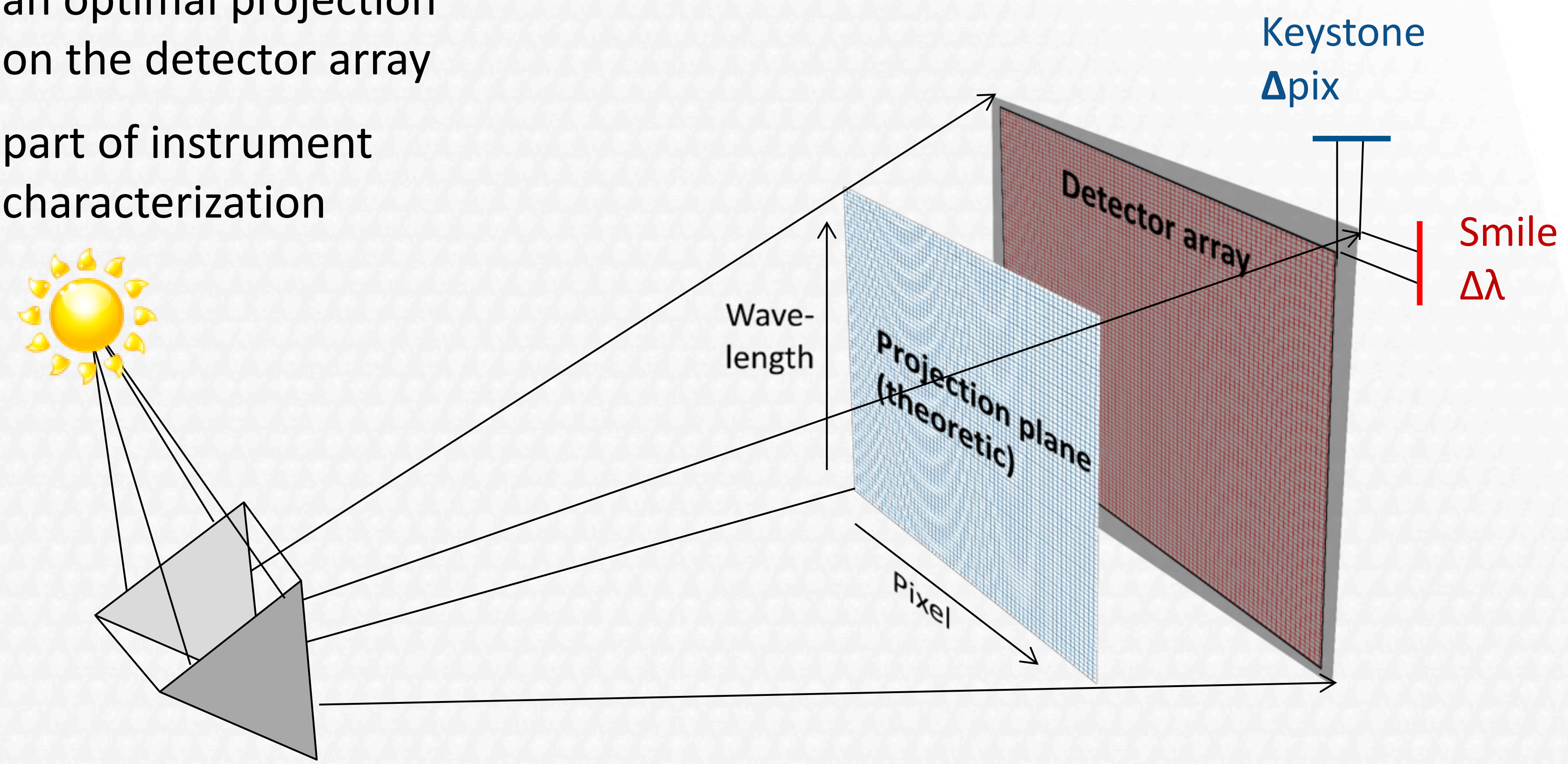
- **Image quality**
  - Dead and bad pixels, striping
  - Co-registration
- **Sensor characteristics**
  - Keystone
  - Spectral smile
  - Noise
  - MTF

Scene-Based Keystone Estimation

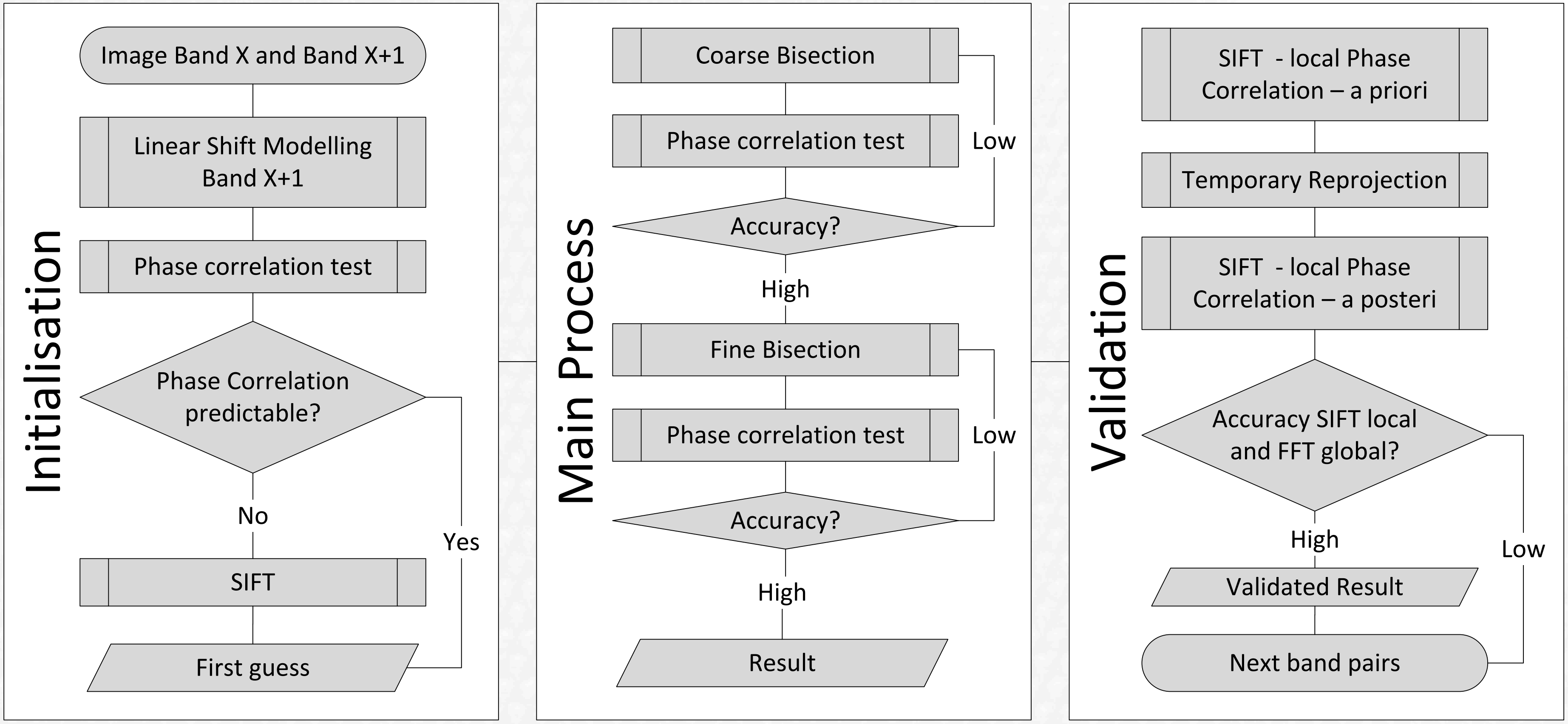
Keystone and **Smile/Frown**

= are spatial deviations from an optimal projection on the detector array

= part of instrument characterization



Scene-Based Keystone Estimation



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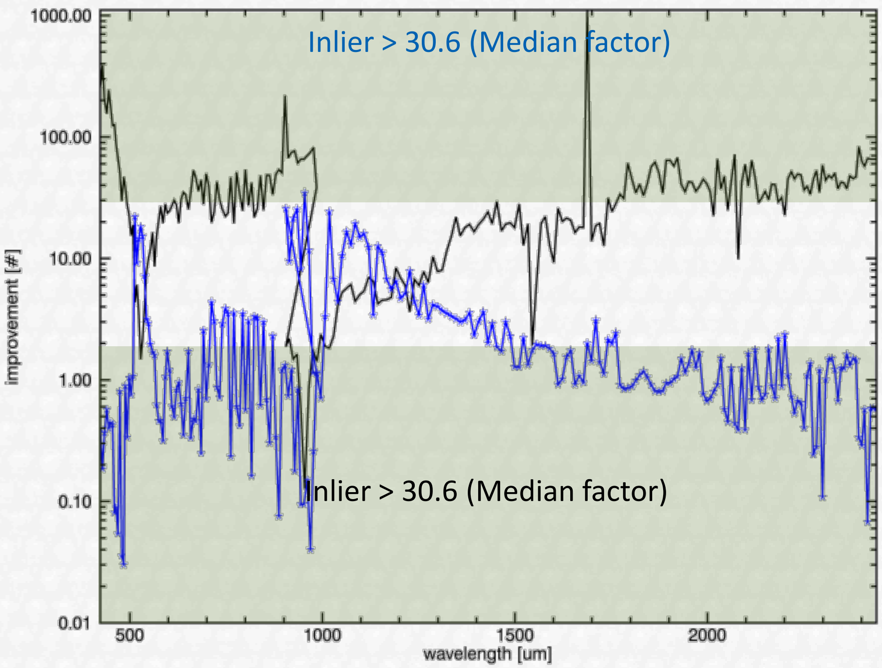
Scene-Based Keystone Estimation

Cabo de Gata



local distortion reduction factor

Keystone detection accuracy

Local distortion reduction factor ∝ 1/keystone detection accuracy

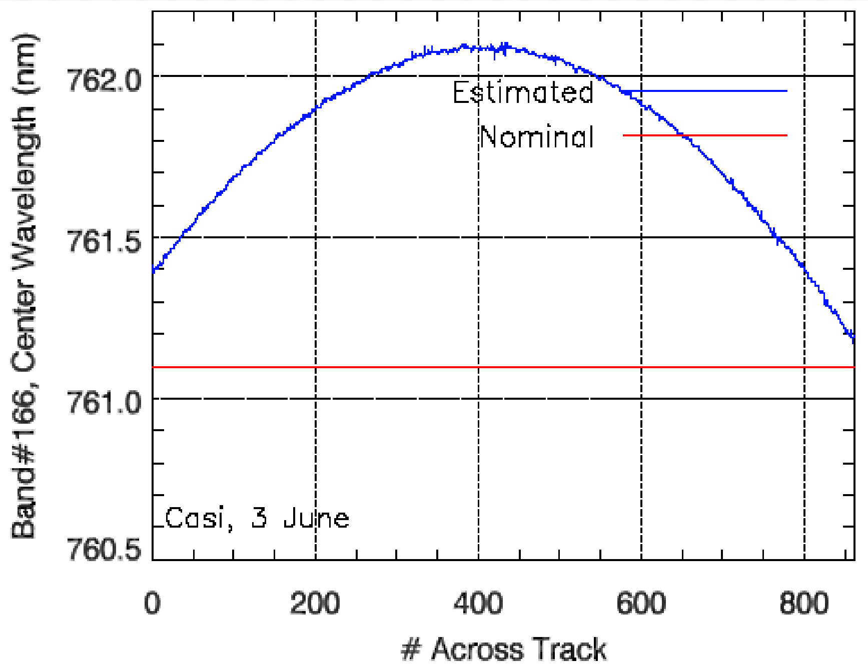
-> Weighting of global results by local results - > exclude outliers (above median)
-> Local reduction factors should be better than their median

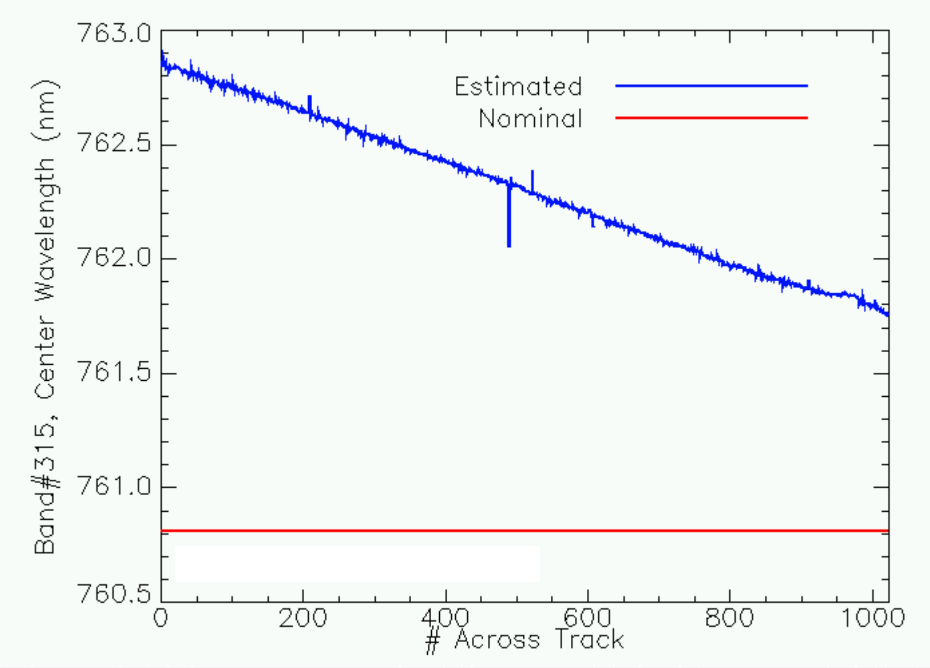
Mean keystone detection accuracy: >99 % without outliers

-> Accuracy < 1 µPixel

Scene-Based Smile Estimation

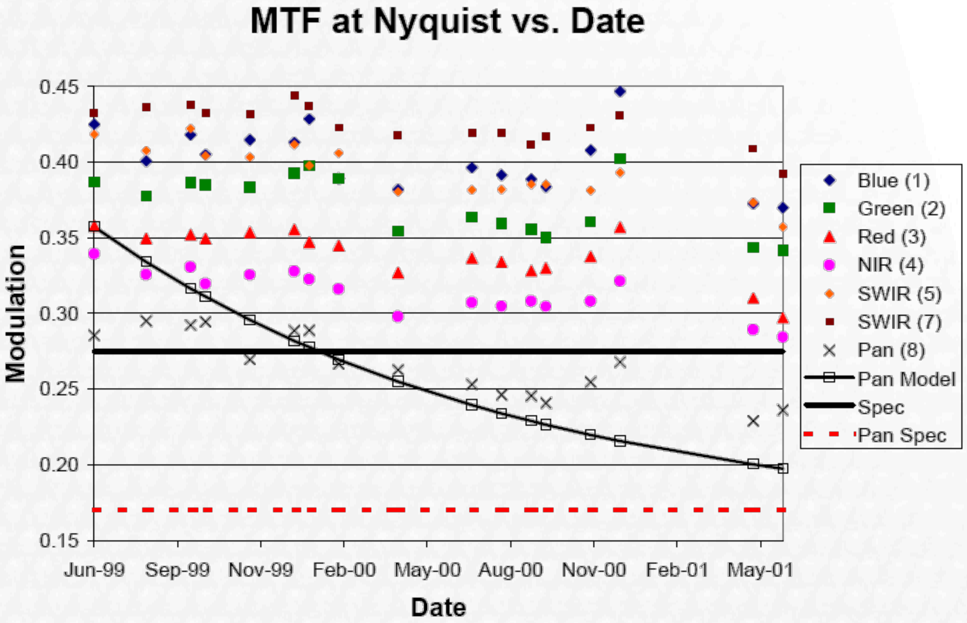
- Characterization of spectral shift and smile
- Use of atmospheric absorption features (oxygen-A 760 nm & water vapor 1140 nm) – complement of on-orbit measurements





Scene-Based MTF Estimation

- **MTF estimation** from L1 images - Targets with sharp brightness transitions necessary for the inversion of parametric MTF models



J. C. Storey. Landsat 7 on-orbit modulation transfer function estimation. In *Proceedings of SPIE Sensors, Systems, and Next-Generation Satellites V*, volume 4540, pages 50–61, 2001.

Summary

- Independent EnMAP Validation Plan activities
- Two-fold validation approach: Ground-based & scene-based
  - Ground-based validation
    - L1/L2geo: "radiometric sites", through international partnerships.
    - L2/L2atm: "science sites", EnMAP internal, coupled to science campaigns.
    - L2/L2geo:"geometric sites", comparison with reference images
  - Scene-based validation
    - Advanced data processing routines to complement other validation sources.
    - Validation of intermediate products: instrumental parameters and atmospheric products
- Particular details (software, sites, instrumentation, …) defined along EnMAP phase D.
- International partnerships for EnMAP Cal/Val activities to be formally established.

Thank you

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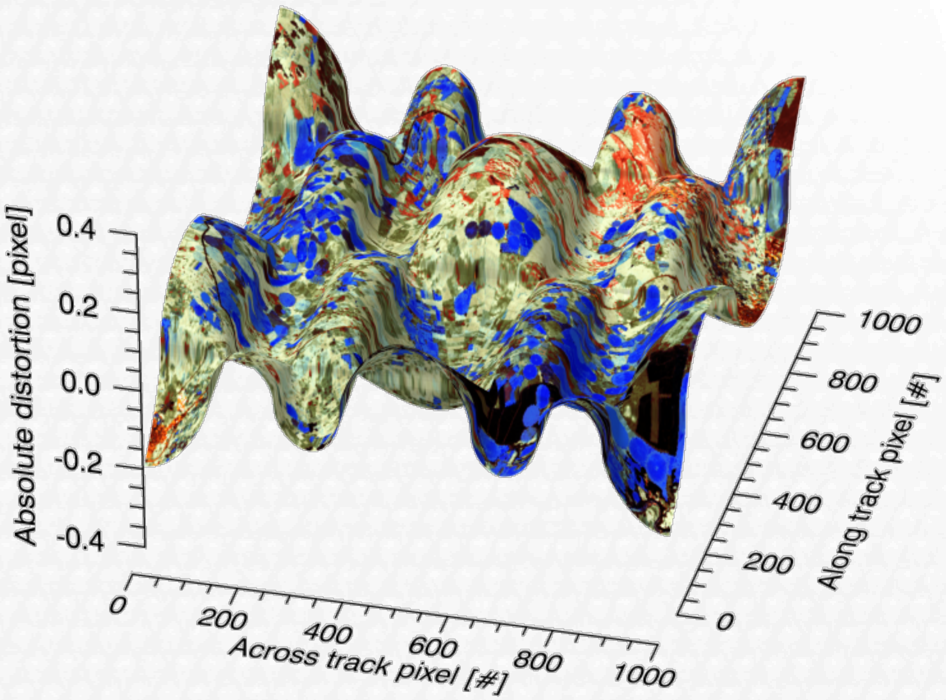
EnMAP
Hyperspectral Imager

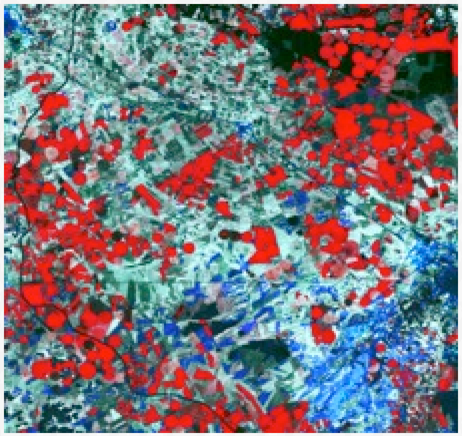
Objectives

Non-linear distortions hamper:

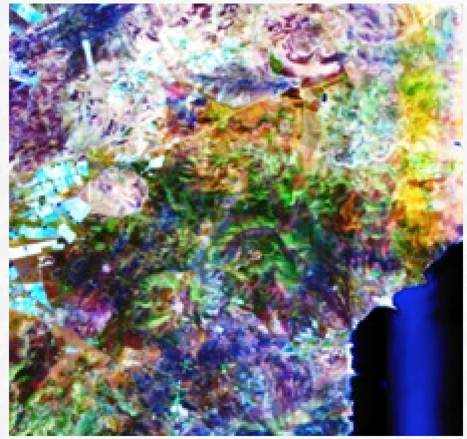
- **Pre-processing**
  - Co-registration
  - Rectification
  - Validation
- **Qualification**
  - Identification
  - Segmentation
  - Classification
- **Spatiotemporal Monitoring**
- **Most Applications**



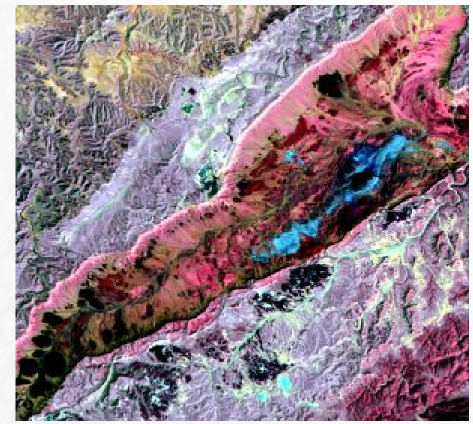
Materials – EnMAP simulations – EETES[1]



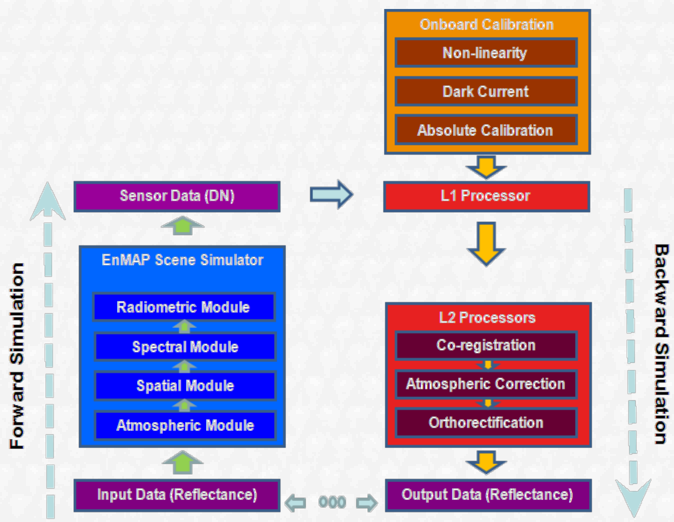
False color composite (R 864 nm, G 653 nm, B 549 nm) of **Barrax, Spain**



False color composite (R 2201 nm, G 801 nm, B 484 nm) of **Cabo de Gata, Spain**



False color composite (R 2201 nm, G 801 nm, B 484 nm) of the **Makhtesh Ramon, Israel**



[1]Segl, K.; Guanter, L.; Rogass, C;, Kuester, T.; Roessner, S.; Kaufmann, H.; Sang, B.; Mogulsky, V.; Hofer, S. (2012). **EeteS - The EnMAP End-to-End Simulation Tool.** IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 5(2): 522-530.

Potential geometric distortions

May superimpose themselves!

- **Band-To-Band**:
  - Keystone
  - Characterisation inaccuracies

  } **Must be reduced as first*[2]!**

- **Image-To-Image** (VNIR / SWIR co-registration):
  - Time delay (20 lines @ equator)
  - Miss-alignment VNIR-SWIR (0.1 Pixel)
  - Detector LOS (max. 0.2 Pixel)
  - Short term jitter (≈ 200 mPixel)
  - Earth rotation (1.4 pixel @ equator) and elevation ($\Delta h_{1\ km} \approx$ 1 mPixel)
  - Attitude variations (drift 0.2 Pixel, speed 1 µPixel, gravity release, atmospheric friction, $\Delta\alpha_{Roll,Pitch\ =45\ \mu Rad} \approx$ 1 pixel)
  - Keystone

Hard job for DLR and KT, but they can do it <- VALIDATION necessary!

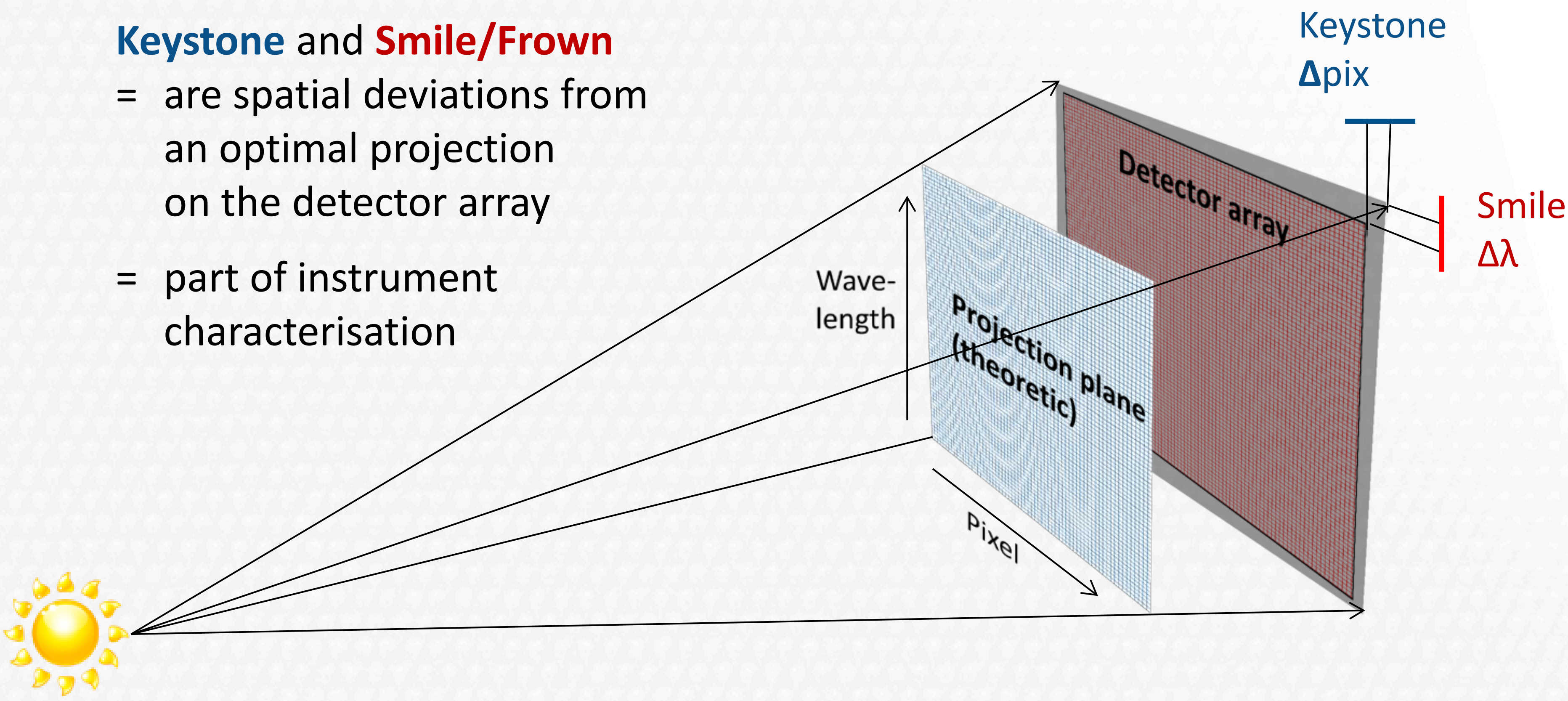
[2]Rogass, C. et al., 2013. **Automatic reduction of keystone - applications to EnMAP**. In *Proceedings of the 8th EARSeL SIG imaging spectroscopy workshop*. EARSeL, Nantes.

Example I: Keystone – Band-To-Band

Keystone and **Smile/Frown**

= are spatial deviations from an optimal projection on the detector array

= part of instrument characterisation



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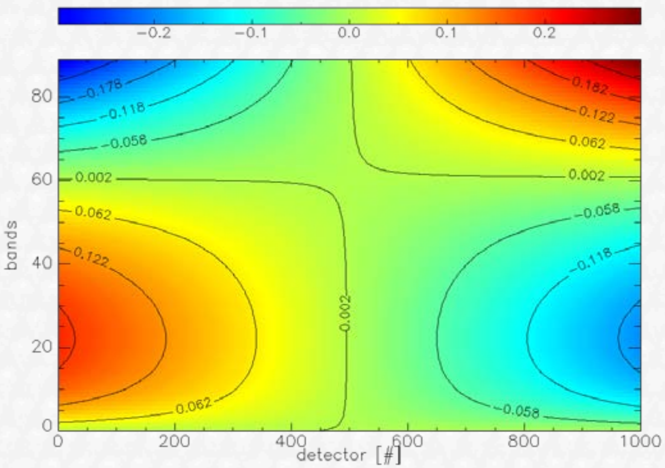
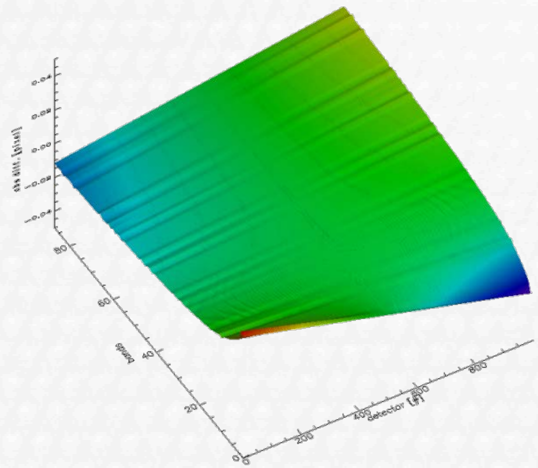
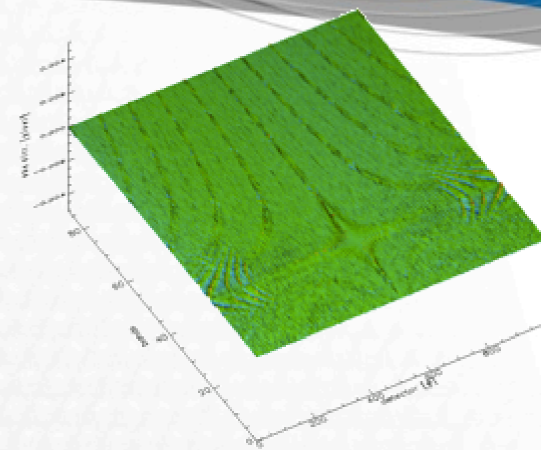
Example I: Keystone of EnMAP - Properties



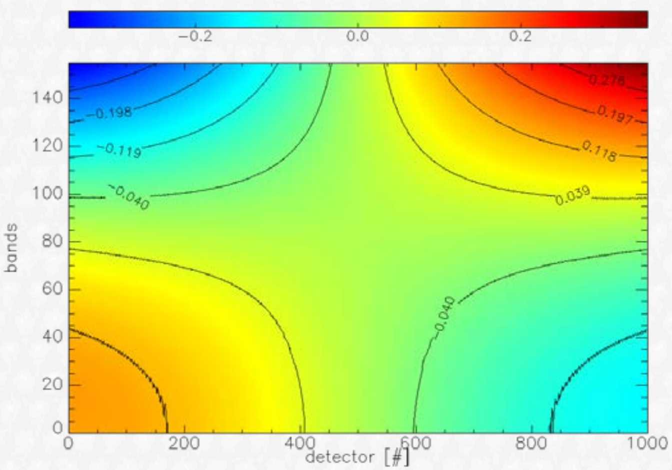
Simulated (not real) VNIR keystone of EnMAP – multiple times exaggerated



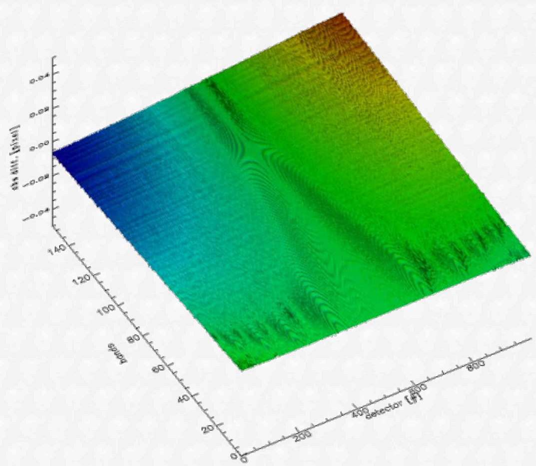
Differential EnMAP VNIR keystone



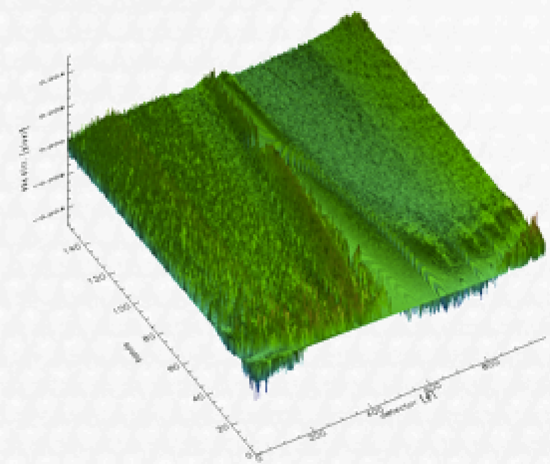
Dev. linearity EnMAP VNIR keystone



Simulated (not real) SWIR keystone of EnMAP – multiple times exaggerated



Differential EnMAP SWIR keystone



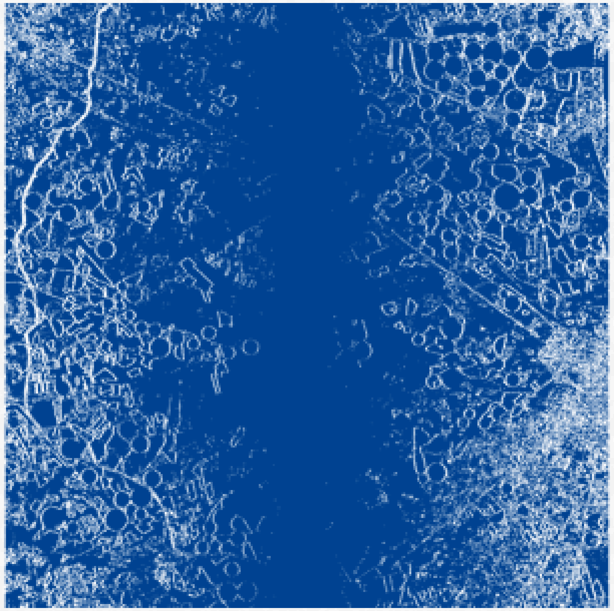
Dev. linearity EnMAP SWIR keystone

Example I: Keystone – Impact on analyses

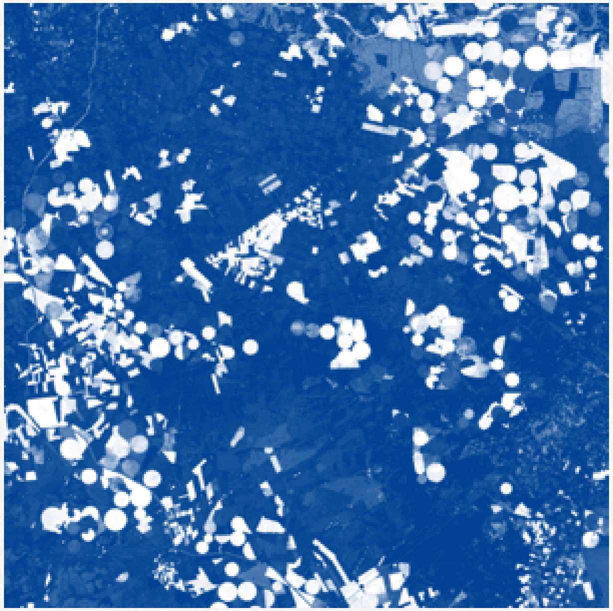
Effect of temporal keystone alteration

Static: Non-linear across track pointing shifts on ground

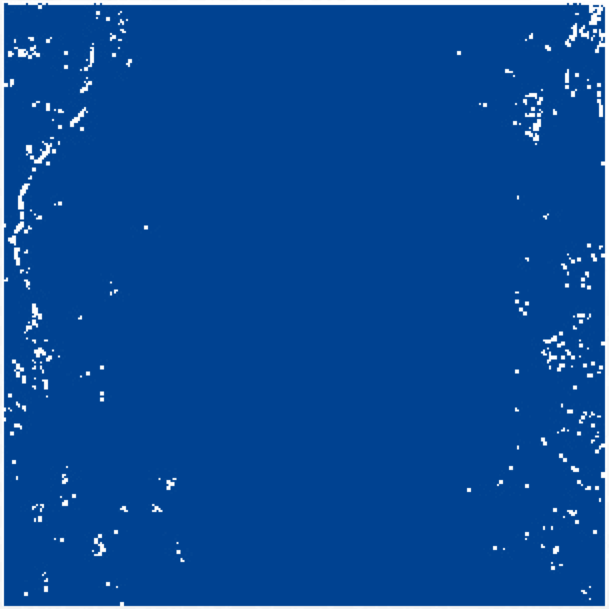
Dynamic: like static + change of intrinsic pointing relation



NDVI (850 and 650 nm) difference of **Barrax, Spain for max (Δ keystone)= 0.5 pixel**

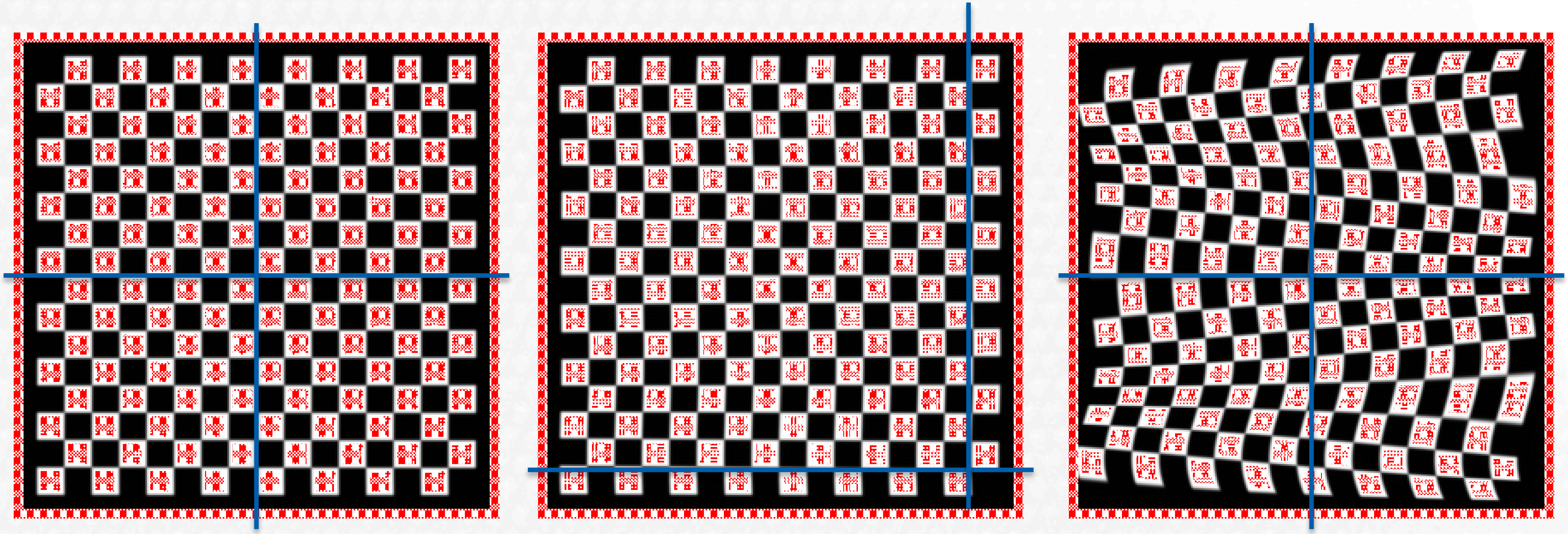


NDVI (850 and 650 nm) of **Barrax, Spain**



NDVI (850 and 650 nm) difference of **Barrax, Spain for max (Δ keystone)= 0.05 pixel**

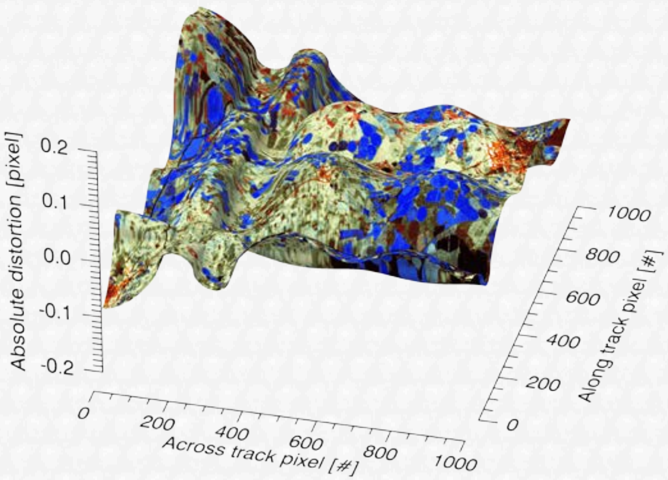
Example II: Attitude variation – Image-To-Image



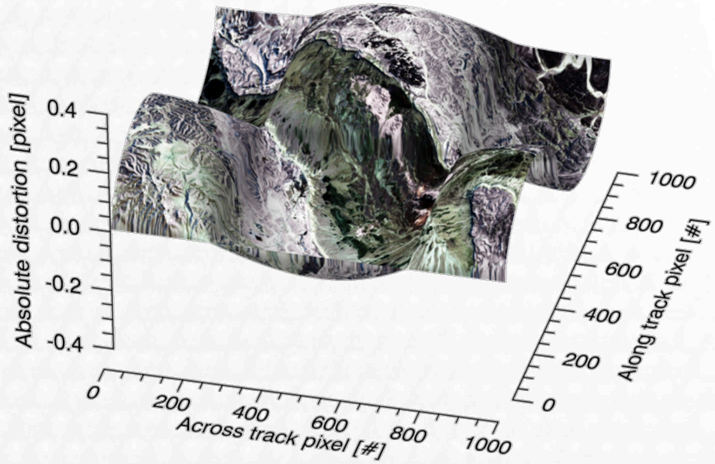
Pixel distortion in a 256x256 grid induced by simulated attitude variations

- Left 0.1 pixel @max
- Middle 0.5 pixel @max
- Right 5.0 pixel @max

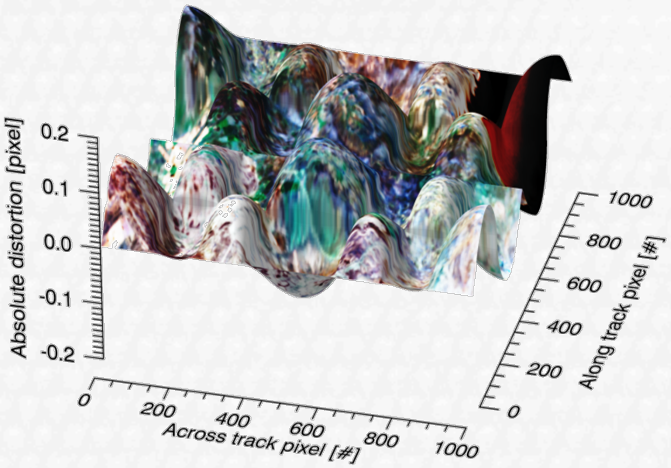
Example II: Attitude - Non-linear distortions



Barrax, Spain



Makhtesh Ramon, Israel

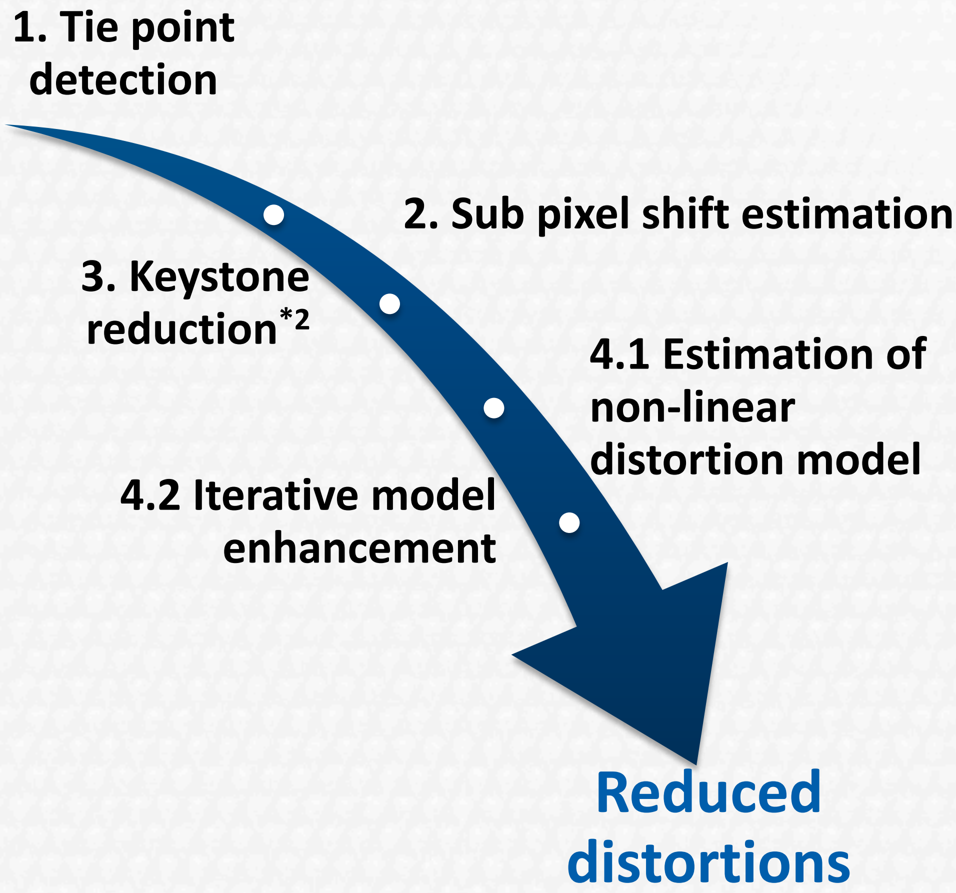


Cabo de Gata, Spain

Non linear pixel distortion

- May remain after pre-processing
- Non-circular but maybe harmonic
- Hard to reduce
- Impacts all analyses

Distortion reduction: Workflow



[2]Rogass, C. et al., 2013. **Automatic reduction of keystone - applications to EnMAP**. In *Proceedings of the 8th EARSeL SIG imaging spectroscopy workshop*. EARSeL, Nantes.

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Assumptions

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Band-To-Band

- o Adjacent bands of hyperspectral acquisitions are spatially high correlated
- o Jitter (micro vibrations) has no impact on relative keystone
- o Atmospheric BRDF has no impact on relative keystone
- o Material BRDF has no impact on relative keystone
- o Relative keystone is stable during acquisition

Image-To-Image

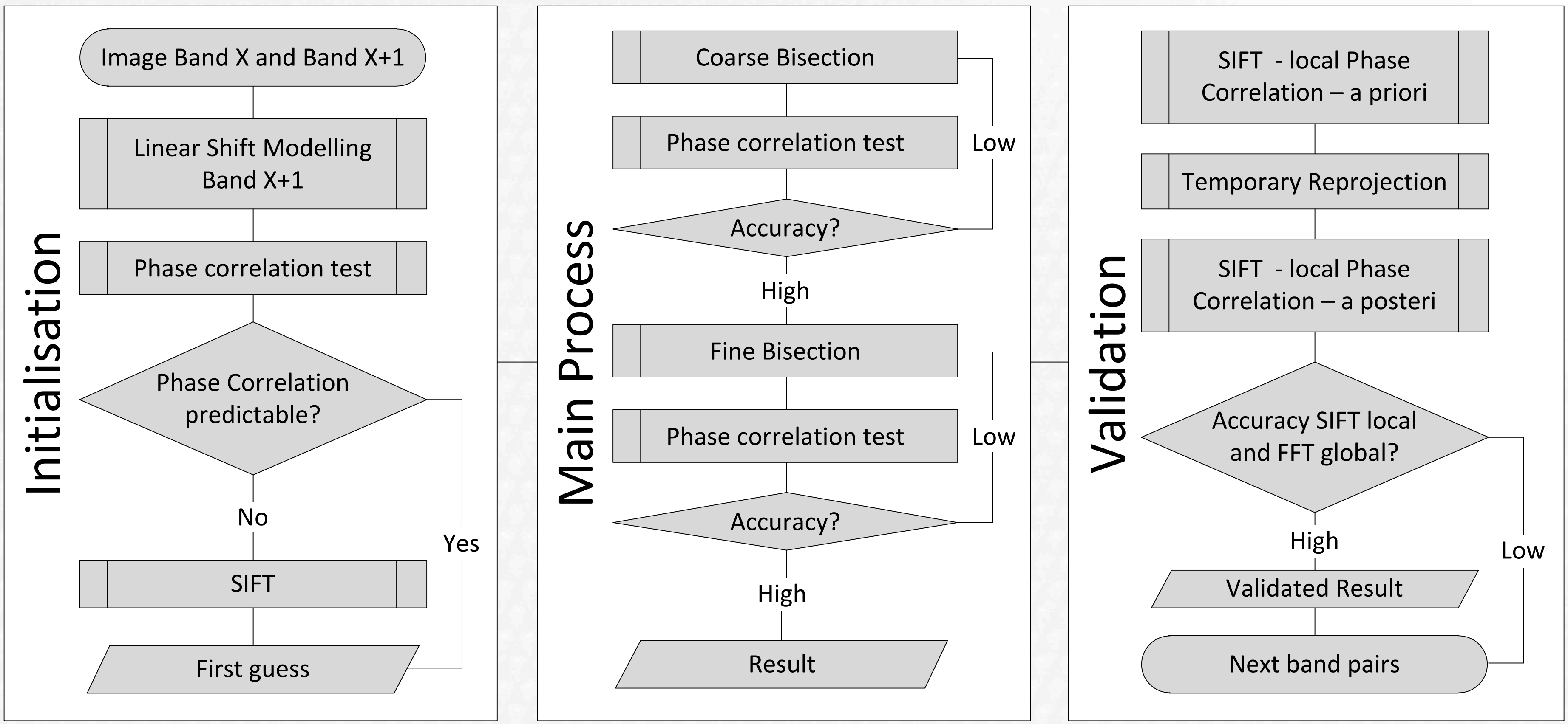
- o Spectrally adjacent bands of VNIR and SWIR are spatially high correlated
- o Jitter consists of multiple frequencies and is harmonic (not modelled!!!)
- o Thermo-elastic and LOS variations with low frequency
- o Short term variations (> 50 Hz) are harmonic and of low impact

Conventions

- 1 Pixel = 1.000 mPixel = 1.000.000 µPixel

Methods I - Overview

Scheme for relative keystone detection*2

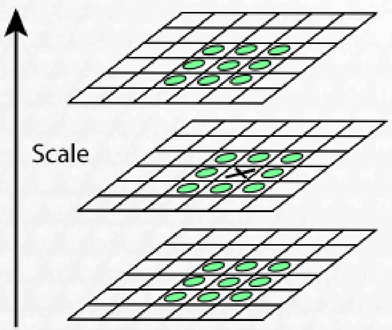


[2]Rogass, C. et al., 2013. **Automatic reduction of keystone - applications to EnMAP**. In *Proceedings of the 8th EARSeL SIG imaging spectroscopy workshop*. EARSeL, Nantes.

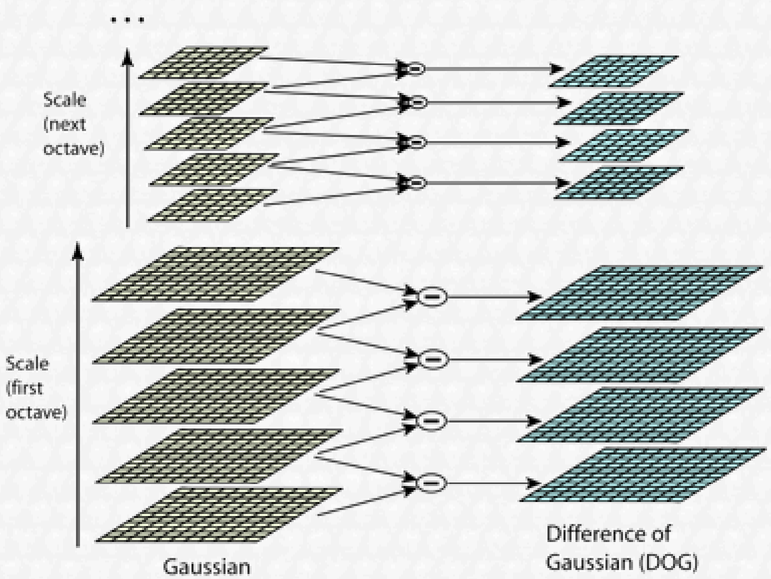
Methods III – SIFT

Scale Invariant Feature Transform – SIFT[3]

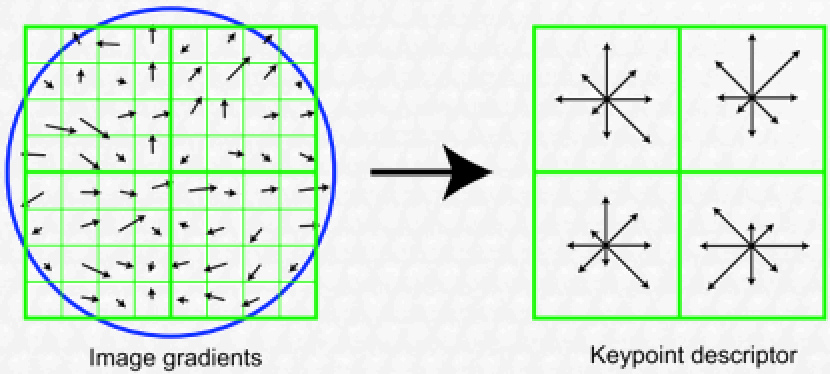
- Image Warping, 3D reconstruction
- Automatic tie point (key point) detection
- Scale, blur, rotation and illumination invariant
- Combination of Laplacian and local gradient directions



Detection of key points as extreme gradients (Lowe, 2004)



Scales and Octaves of the SIFT algorithm for the approximation of scaled Laplacians (Lowe, 2004)



Key point description (Lowe, 2004)

[3]Lowe, D. G. (2004). **Distinctive Image Features from Scale-Invariant Keypoints.** International Journal of Computer Vision, 60 (2): 91-110.

Methods II – Phase Correlation

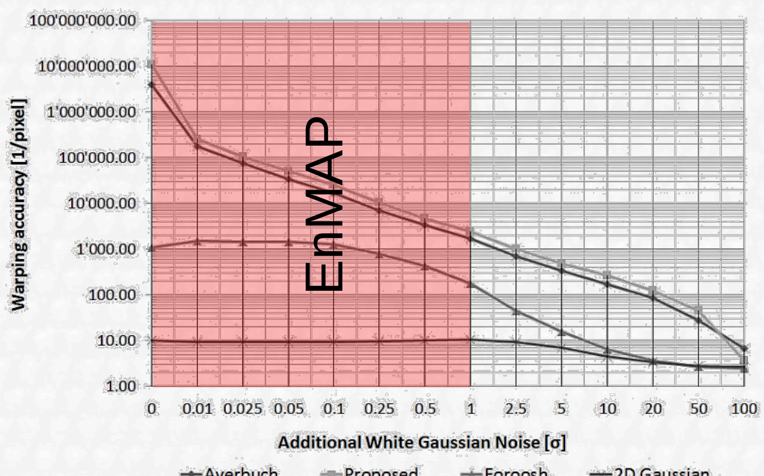
Spatial Correlation properties

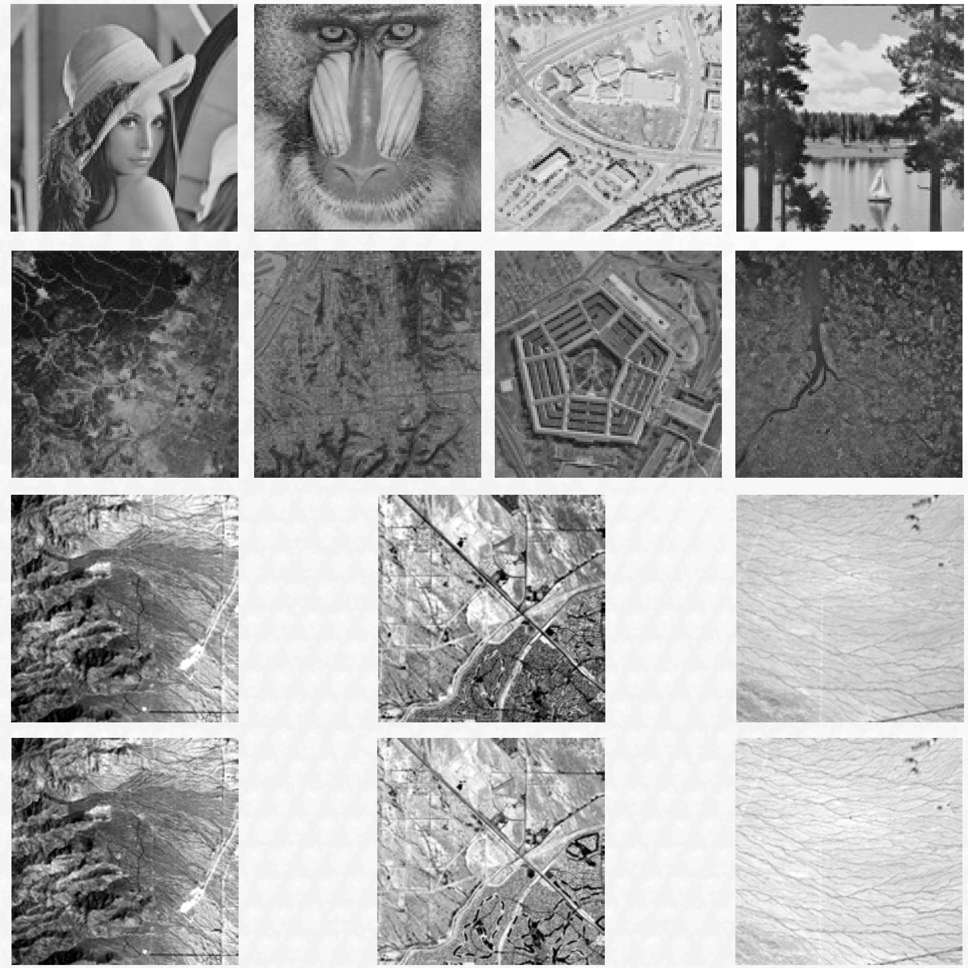
- Maximised if images spatially coincide
  Only circular shifts!!!, rotation, scale

Most important property

Phase Correlation properties

- Higher accuracy[4] than cross correlation
- Highly redundant solution
- Noise robust[2] - > 200.000 simulations

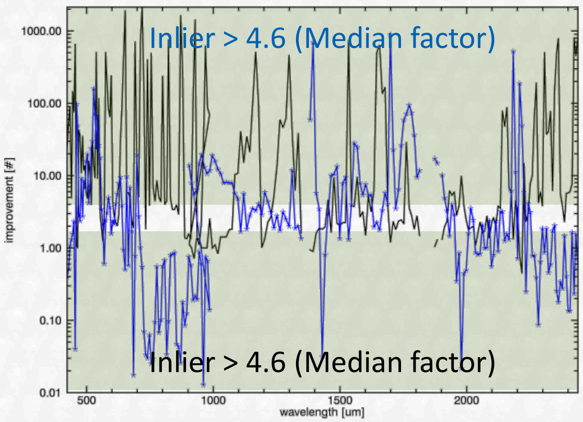




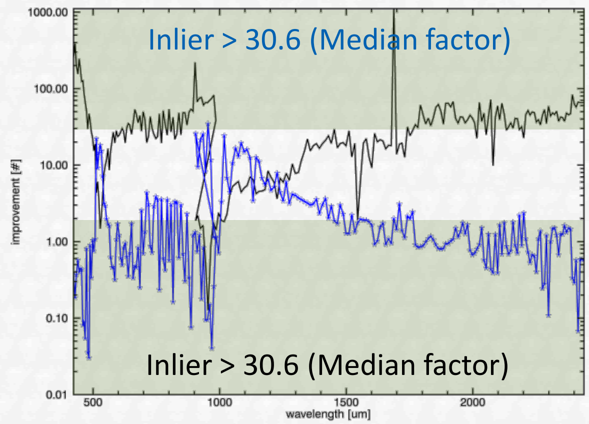
[4]Rogass, C.; Segl, K.; Kuester, T.; Kaufmann (2013). **Performance of correlation approaches for the evaluation of spatial distortion reductions.** submitted.

Results IV

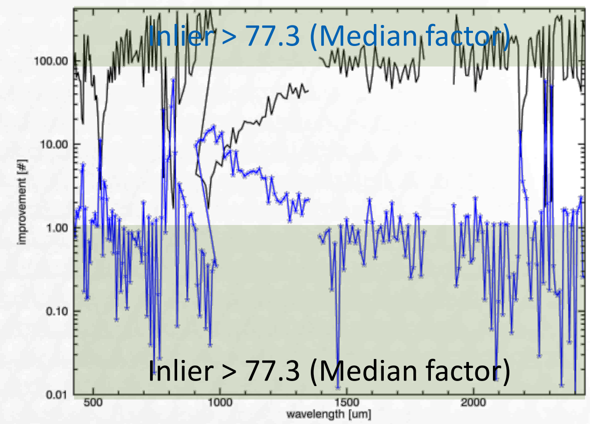
Keystone detection accuracy (blue, %) and local distortion reduction factor (black)



Barrax



Cabo de Gata



Makhtesh Ramon

Local distortion reduction factor ∝ 1/keystone detection accuracy

-> Weighting of global results by local results - > exclude outliers (above median)
-> Local reduction factors should be better than their median

Mean keystone detection accuracy: 80 % with outliers, >99 % without outliers

Conclusion

Relative keystone detection possible – highly accurate

1% keystone change detectable (high SNR bands)

Tracking of changes possible = Validation Tool

Two bands enough, but more bands reliable

Mountainous and urban scenes appropriate

Outlook

Absolute keystone detection

Definition of appropriate study regions

Higher degree of sensor model integration

Speed improvement and double precision