Putting knowledge on the map

IDEAS + Task3
Sentinel 2 / Landsat Fusion Technics
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Project context

- S2/MSI data exploitation
  - Which will improve significatively weekly environmental monitoring with the increase of unseen volumes of data in terms of spectral richness, temporal revisit and spatial resolution.

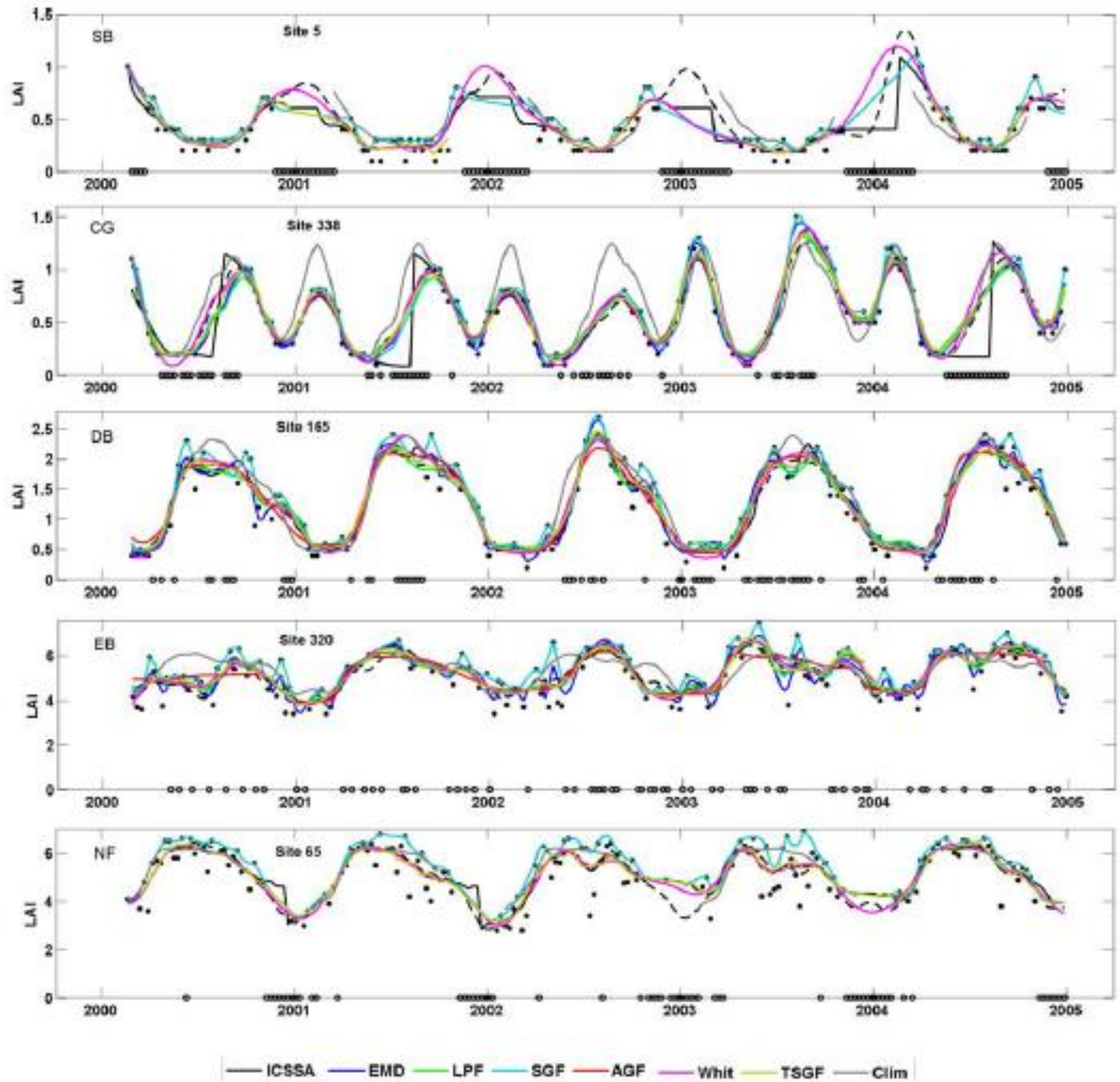
- The Sentinel-2 satellite (S2A) provides coverage in 13 spectral bands from 443 to 2200 nm with a repeatability of 10/5 days, and spatial resolutions of 10 to 60 m.

- This **dense** temporal sampling offers new perspectives in particular in the vegetation monitoring :
  - by providing a fine description of phenology : need for key dates, onset of greenness, end of senescence and length of season
  - Seasonal analysis for vegetation biophysics (vegetation products LAI, Fapar, productivity, ..)
  - Crop
  - Classification

➔Objectives : Consolidation of time series for thematic analysis and support land science

Consolidation of products

- Already adressed for low/medium spatial resolution products
- LAI time series as an example (GEOLAND2)



Rationale

– Problematic of gap filling is the same for S2

1) Time series are incomplete because of cloud cover and noise

– Use of fusion technics to better constraint the consolidation

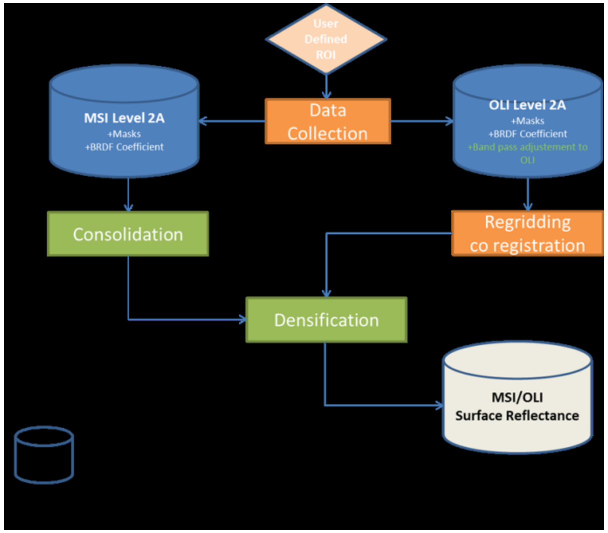
2) Merging Sentinel-2 and Landsat data streams could provide < 10 day coverage

Objectives

- The main objective of this study is the production of harmonized Sentinel 2 / Landsat 8 time series.
  - On L2

- Two main technical challenges have been identified
  - Do we know how to fill a gap ?
    - To recover missing measurements in a Mono Sensor Temporal Block - Consolidation
  - Is it possible to combine two sources of data to densify the time series?
    - To add measurements (dates) in a Mono Sensor Temporal Block (S2) by using measurements from an other Temporal Block (LS08) - Densification

- The works was splitted in 3 steps:
  - Mono sensor Time series consolidation
  - Multi sensor Time series fusion/densification
  - Multi sensor Time series evolution



Phase 1 : Mono sensor Time series consolidation

Mono sensor Time series consolidation (1)

The objective of this stage is the production of consolidated time series.

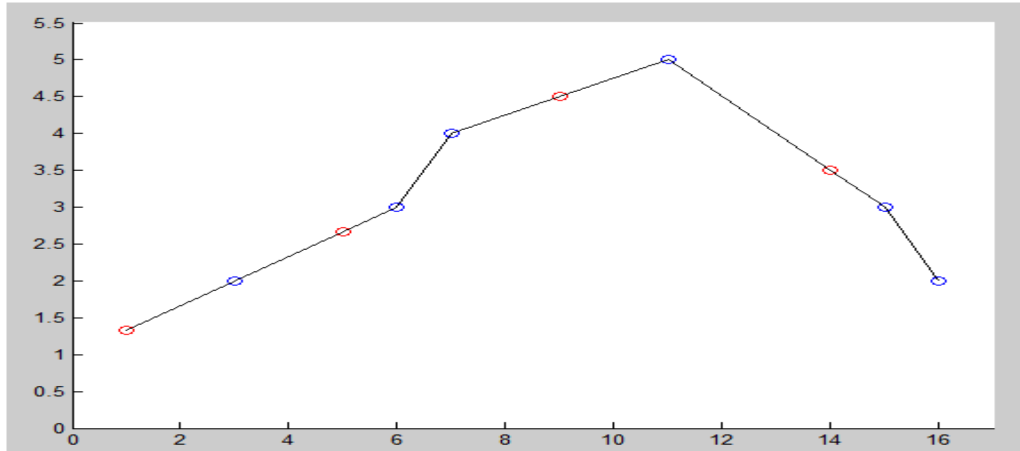
Consolidation, refers to the recovery of pixel values which are occluded at a given date in the time series.

Two kind of approaches were evaluated:

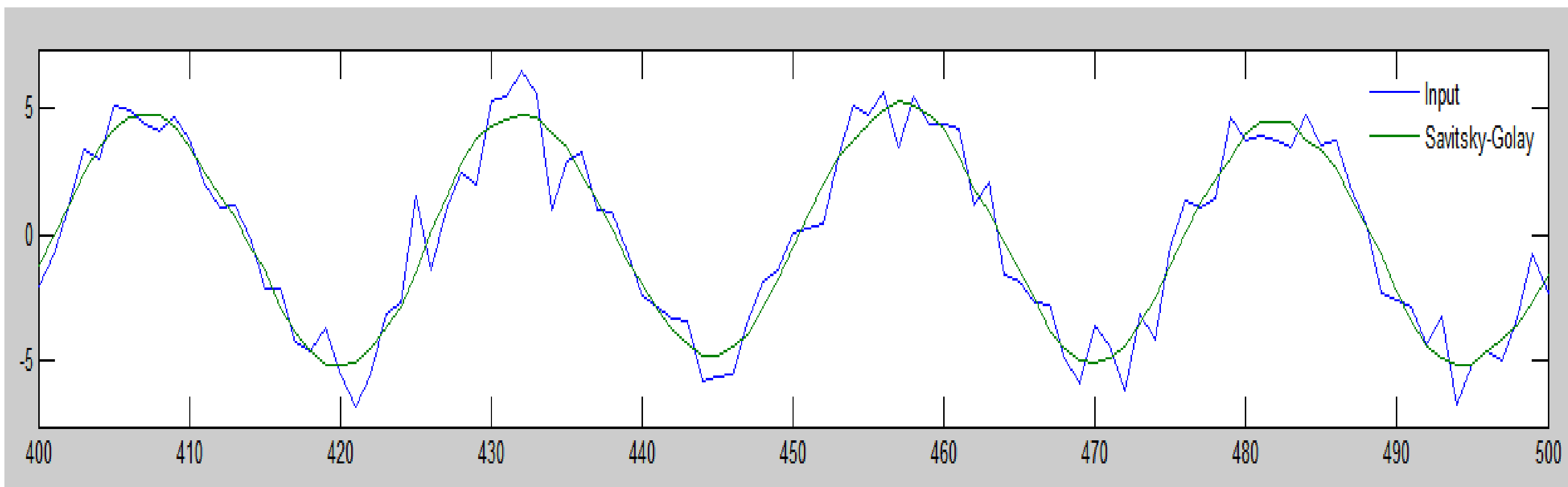
- The interpolation based methods with Linear Regression and Smoothing Filtering (Savitsky-Golay),
- The distance based methods with the use of Dynamic Time Wrapping distance.

Mono sensor Time series consolidation – interpolation methods

Linear regression



Savitsky-Golay

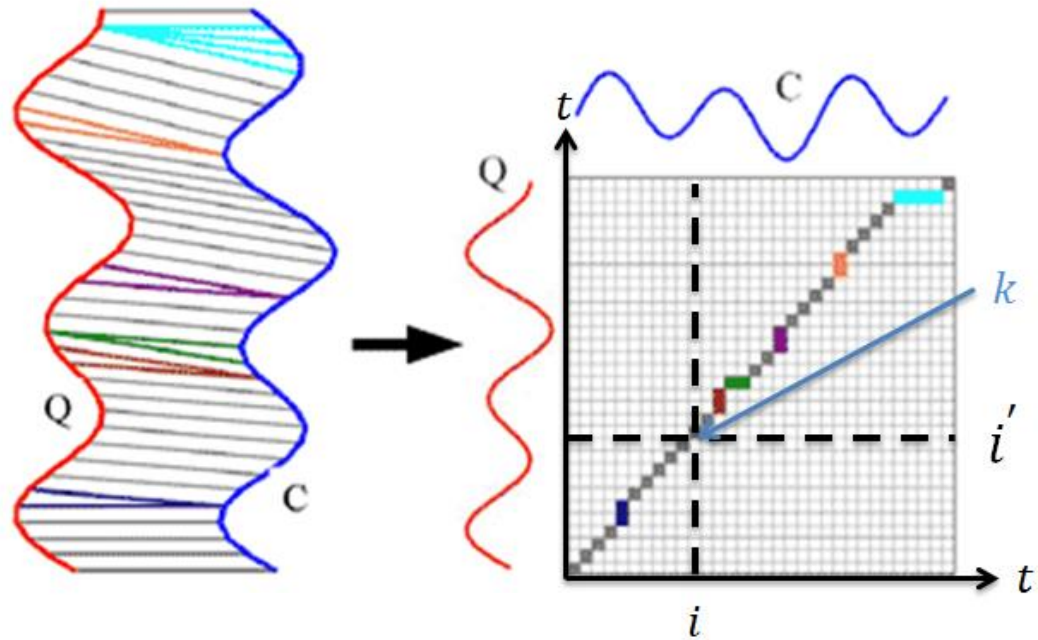


Savitsky-Golay is a smoothing filter, it generally use a sliding window of size 5 to try fitting a second or third order polynomial onto a noisy signal.

Principle of DTW (Dynamic Time Wrapping)

- The Dynamic Time warping is a distance measurement between two time series.
- For 1 pixel (xo,yo,t)

  <u>DTW is able to re align</u>
  <u>time series</u> and fill gap.
  Distance is computed
  for all candidates



$$dist_k = dist(i, i') = \sqrt{\sum_{j=1}^{m} (C_{i,j} - Q_{i',j})^2}\ldots \qquad DTW = \sum_{k=1}^{l} dist_k$$

$$DTW\big(TPx(x_0, y_0), TPx(x_{k0}, y_{l0})\big) = \min_{(x_k, y_l)\,\in N} DTW\big(TPx(x_0, y_0), TPx(x_k, y_l)\big)$$

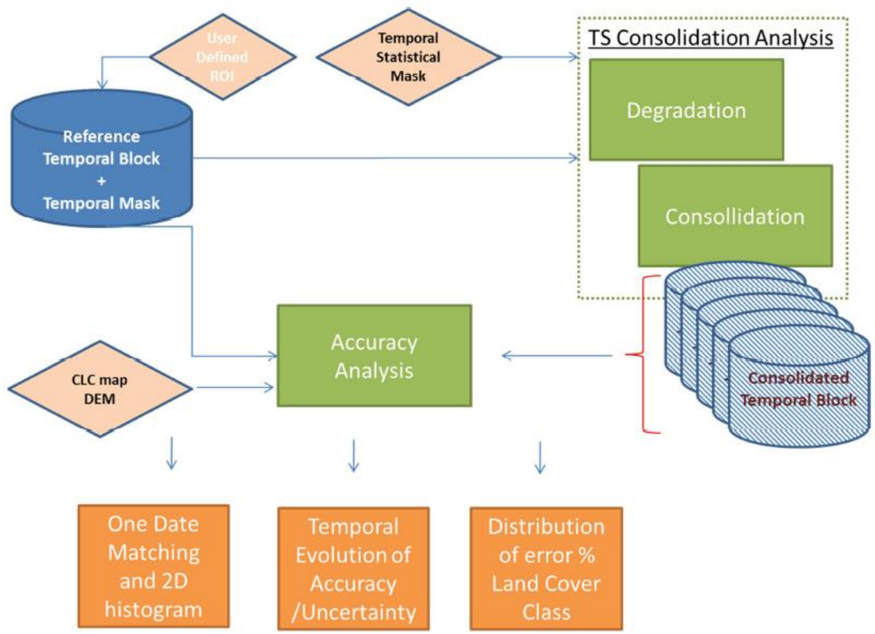
Consolidation metrics

Metrics	Formula
Accuracy (A)	$A = \frac{1}{N} \times \sum_{i=1}^{N} \varepsilon_i$
Precision (P)	$P = \sqrt{\frac{1}{N-1} \times \sum_{i=1}^{N} (\varepsilon_i - A)^2}$
Uncertainty (U)	$U = \sqrt{\frac{1}{N} \times \sum_{i=1}^{N} \varepsilon_i^{\,2}}$

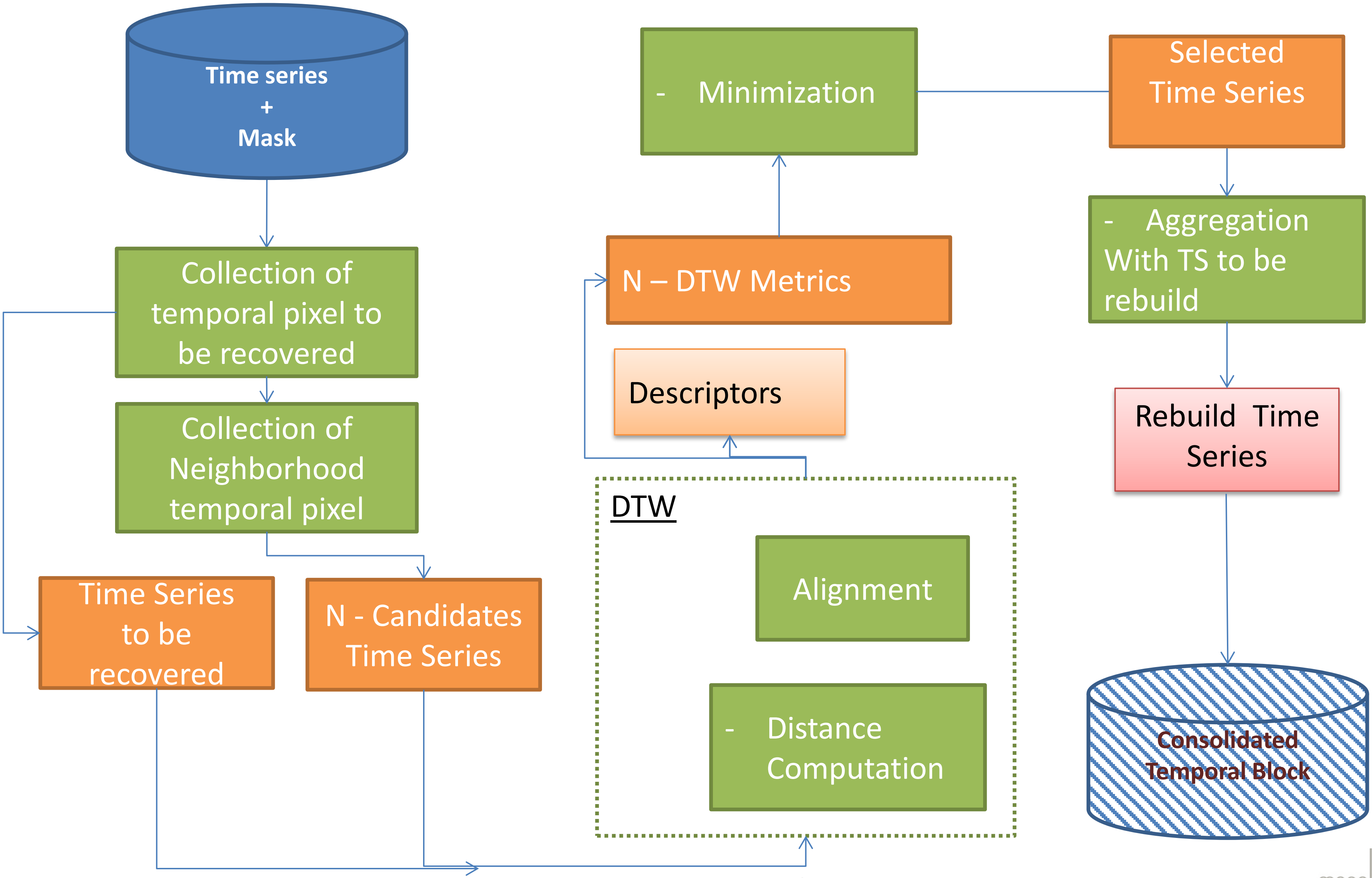
Where ε_i is the difference between ground truth and estimated value. N is the total number of estimated values.

Mono sensor Time series consolidation (3)

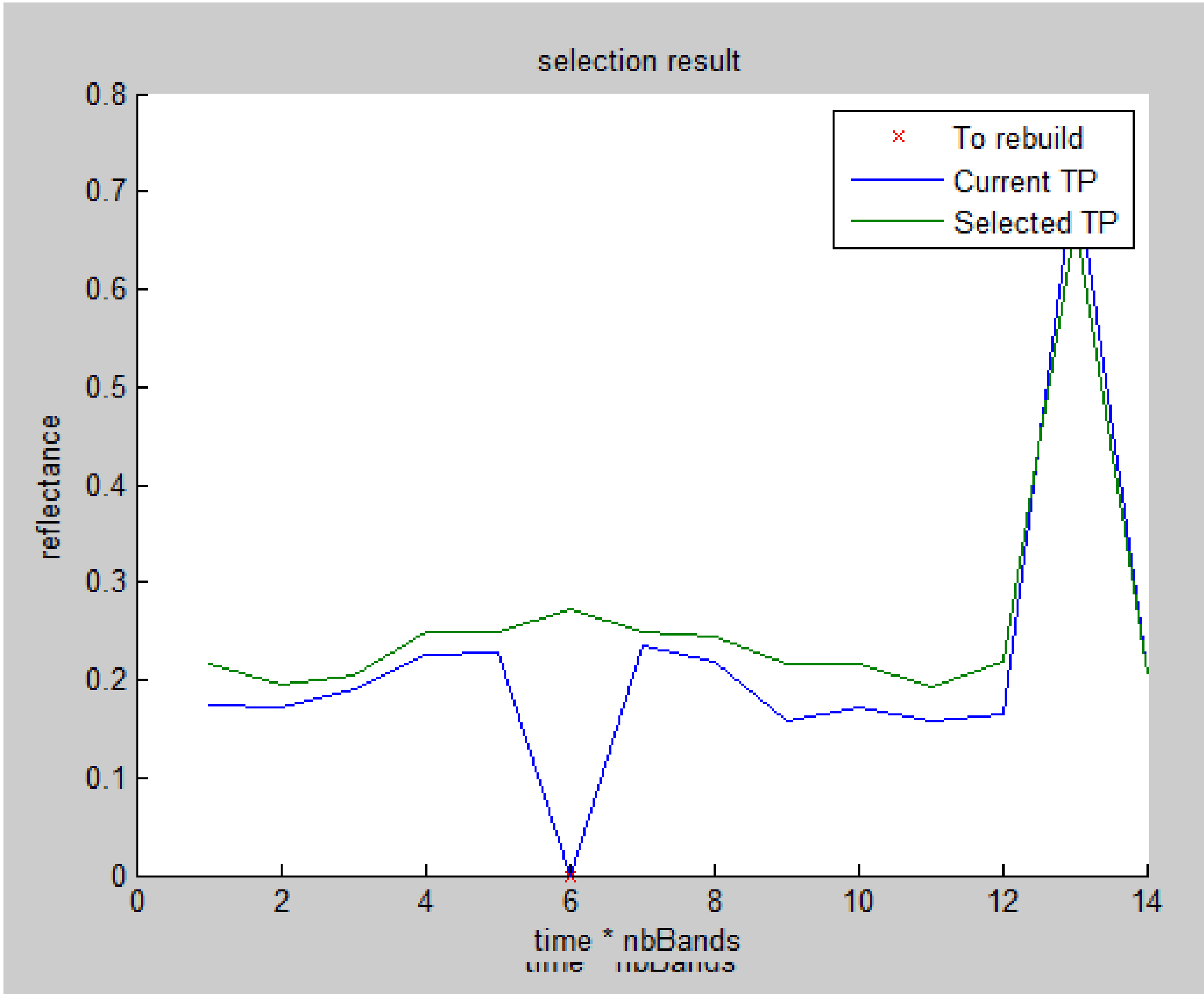
- The evaluation of this processing was evaluated on Landsat 8 time series according two approach:
  - Evaluation of the consolidation of a sample of pixels extracted from times series according the CLC classes.
  - Evaluation of the consolidation apply directly on the time series by selecting a subset of cloud-free pixels then half of them are manually masked. Finally the re-build pixels are compared to their actual value



Mono sensor Time series consolidation - DTW



Mono sensor Time series consolidation - DTW



Assessment of DTW for GLC classes

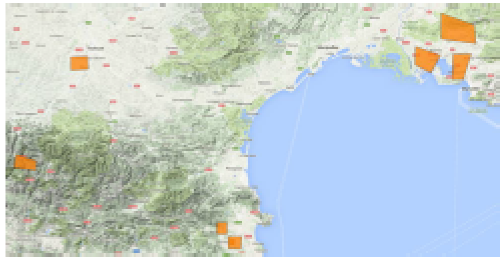
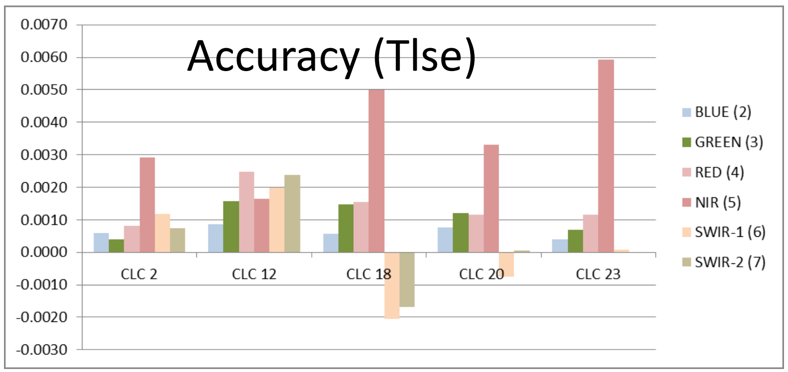
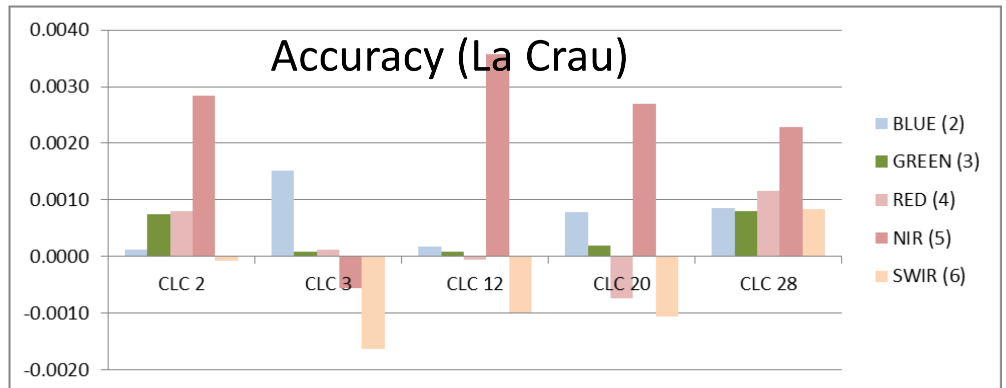


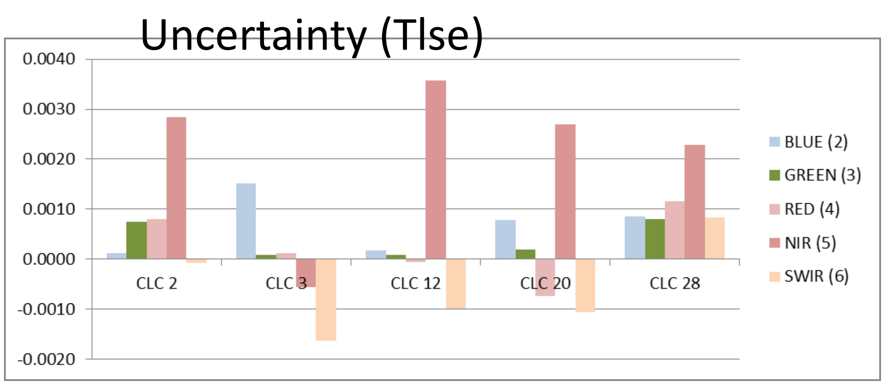
Fig 3) Region of interest.

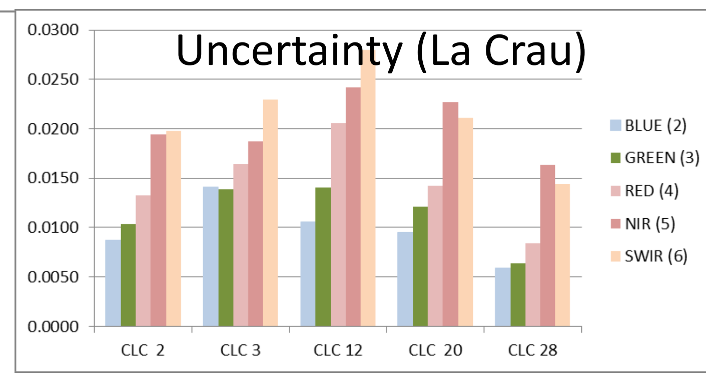
For both sites, accuracy and uncertainty measures have been computed relatively to:

- CLC2: discontinuous urban fabric,
- CLC3: industrial or commercial unit,
- CLC12: non-irrigated arable land,
- CLC18: pastures,
- CLC20: complex cultivation patterns,
- CLC23: broad-leaved forest.
- CLC28: sclerophyllous vegetation.

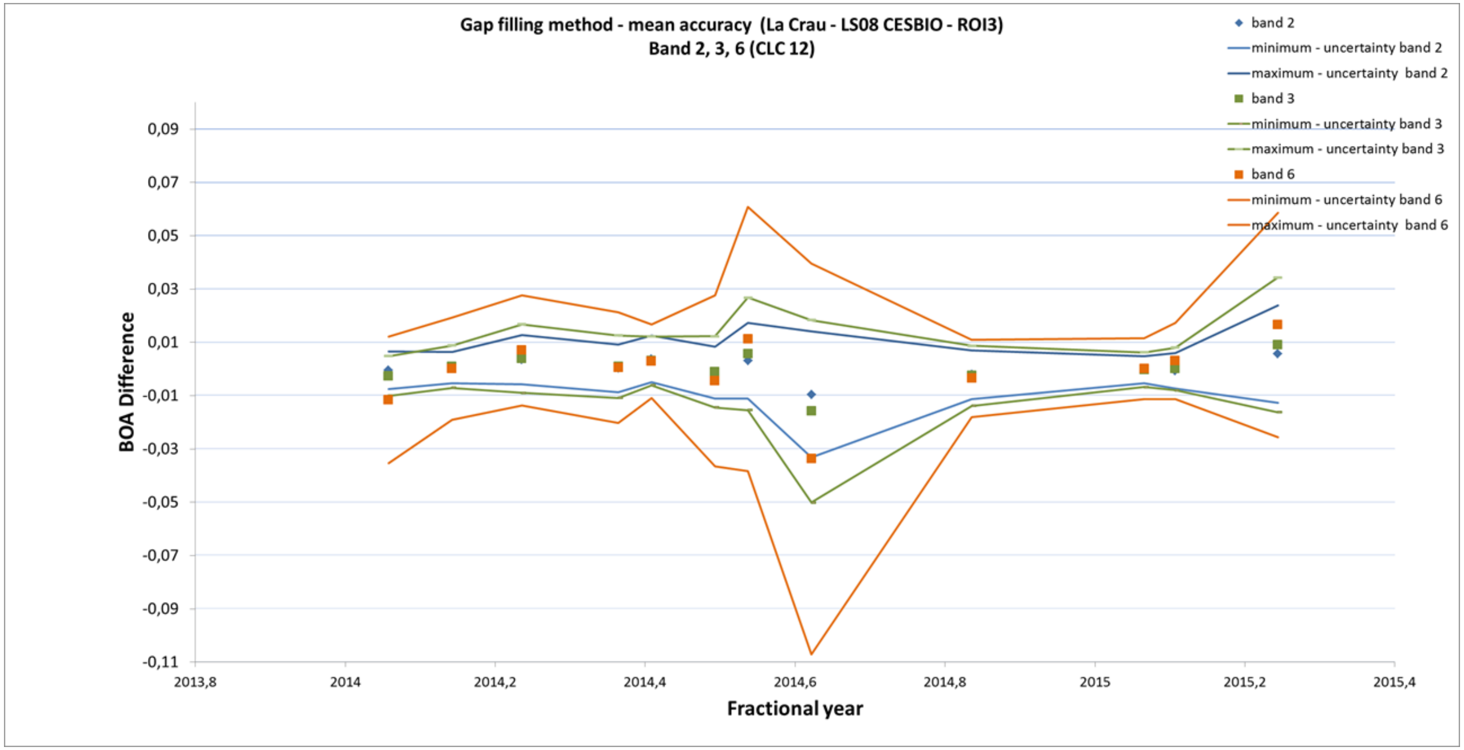








- Temporal Evolution of the accuracy



- Stability of the accuracy , except for SWIR band

Mono sensor Time series consolidation (3)

Deliverables associated to Phase 1

- ATBD,
- test report,
- validation report,
- test dataset
- software

- Now that data is available, this process will be applied and evaluated onto Sentinel 2 time series.

Phase 2 :
Multi sensor Time series fusion/densification

Requirements for data merging

- If S2A is the reference sensor
  - Need for sensors which spectral responses are closed to S2/MSI
  - Spatial resolution compatible with S2/MSI
  - Which could be cross calibrated with S2/MSI

- Recording at high spatial and high-temporal resolution
  - Surface reflectance needs to be available (or performed)

  ➔Compatible atmospheric correction & cloud/shadow detection

  ➔Adjustements for BRDF (solar, view angle), band pass differences

  ➔Adjustment to common frame, resolution (~20m), regrid

Multi sensor Time series fusion/densification (1)

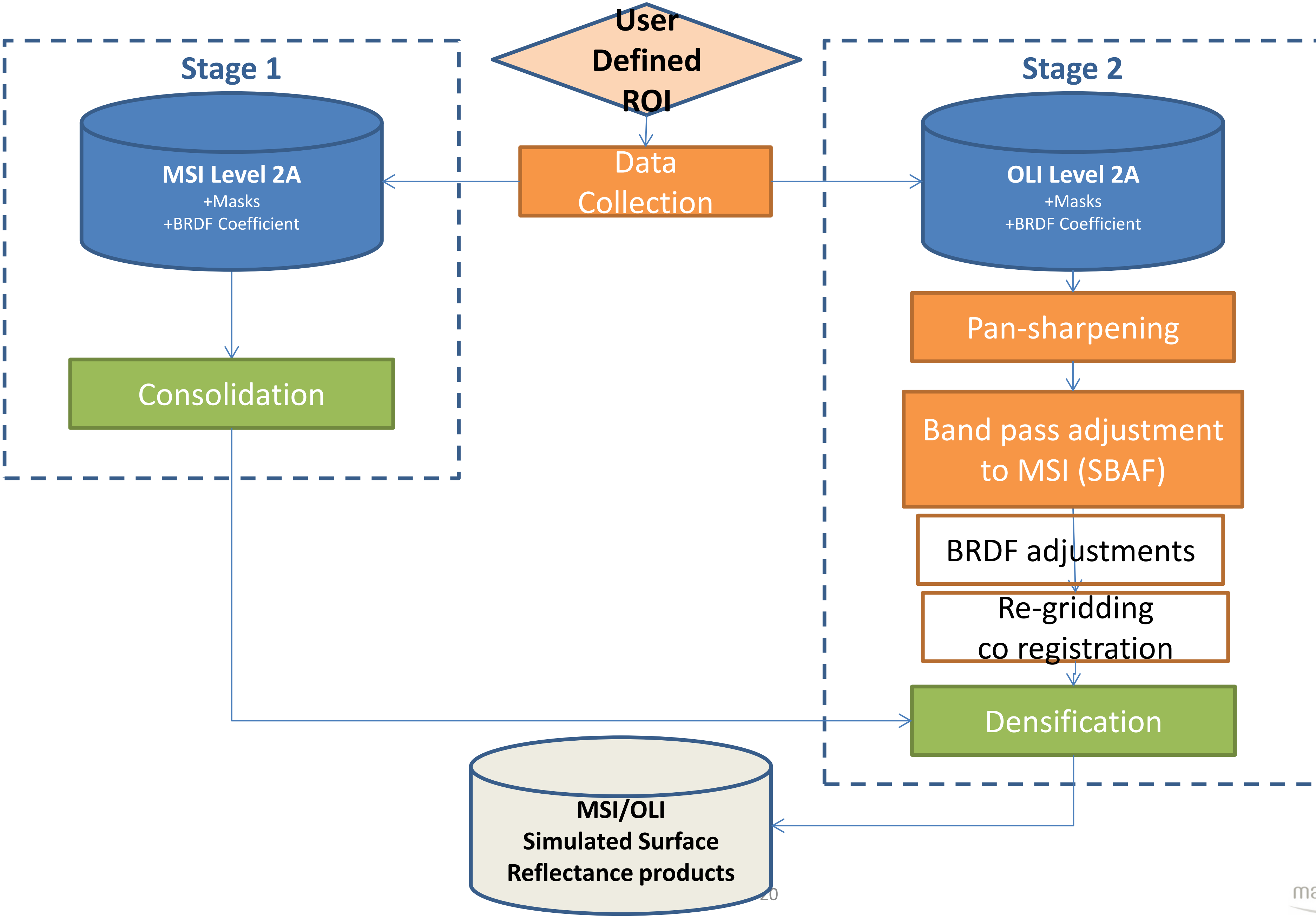
The two aspects of the products fusion are dealt with separately:

- Geometric adjustment
- Radiometric adjustment

This processing chain is compositing with four different steps:

- First, the pan-sharpening of the Landsat 8 products, it is required to significantly improve the Landsat 8 spectral band resolution.
- Secondly, the spectral adjustment using an approach relying on the sensor relative spectral response to project the Landsat 8 OLI acquired values onto the Sentinel 2 MSI sensor.
- Third, BRDF adjustments
- Finally, the resulting products should geometrically adjust to match the Sentinel 2 time series foot print.

Multi sensor Time series fusion/densification (2)



Multi sensor Time series fusion/densification – Pan-Sharpening

The pan sharpening approach selected is the method used for Pleiades HR fusion. This improve the result of the re-gridding of the L8 products into S2 geometry.

$$XS_{HR} = Pan \odot \uparrow \left(\frac{XS_{LR}}{\downarrow (Pan \otimes PSF)} \right)$$

The steps are the following:

- Downscale of the PAN band to XS resolution (with Gaussian smoothing)
- Computation of the ratio xs/pan
- Upscale of the ratio using bi-cubic interpolation
- Multiplication of the pan with the up scaled result

The result is then re-grid to 20m to match S2 working resolution

Spatial resampling

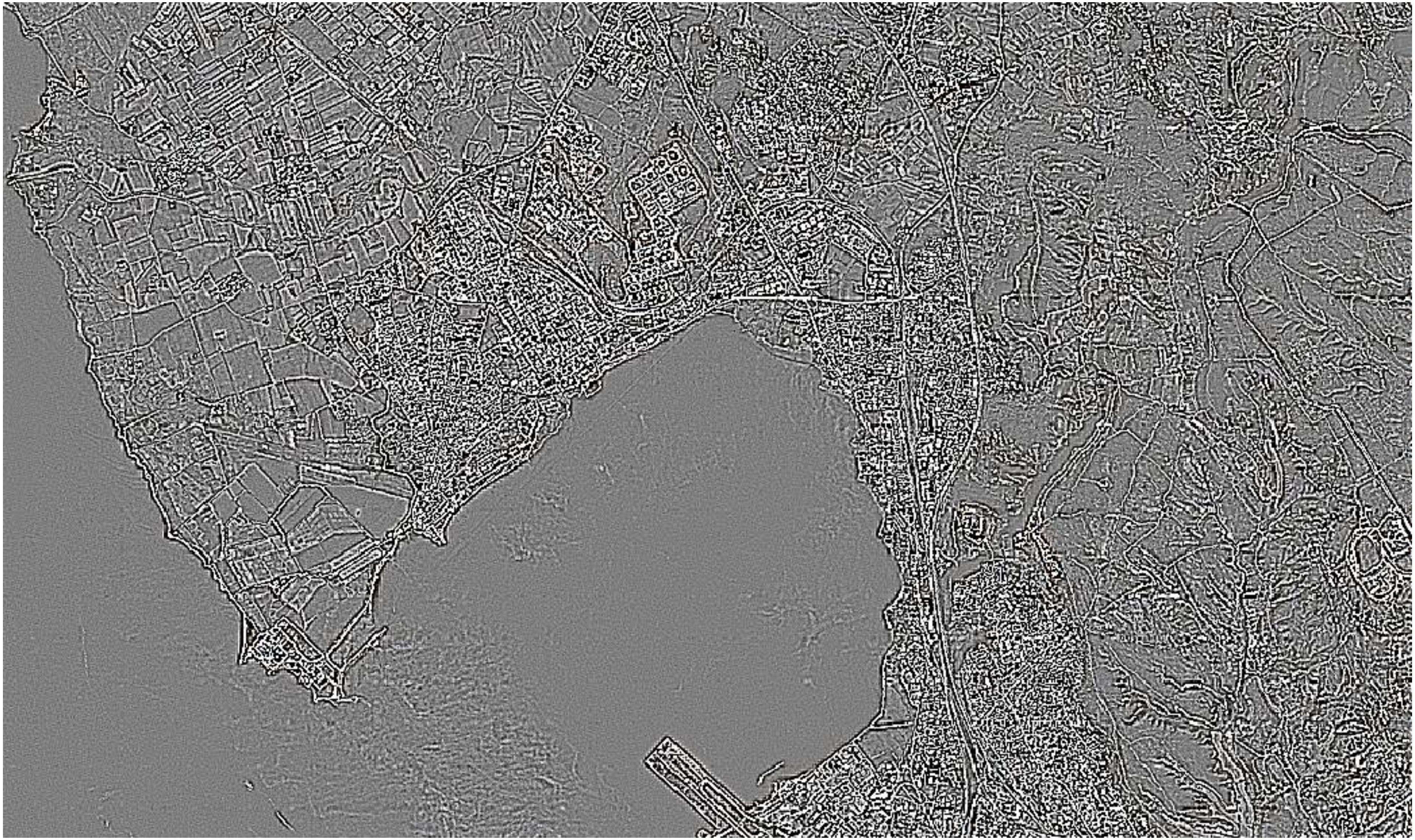
- Advantages of pan sharpening versus bicubic
  - High frequencies recovered without altering low frequencies
    - Useful at these spatial resolutions

- Limits: geo location uncertainty (XS vs PAN)

Spatial resampling (30m to 15m)

Spatial resampling using Pan sharpening method

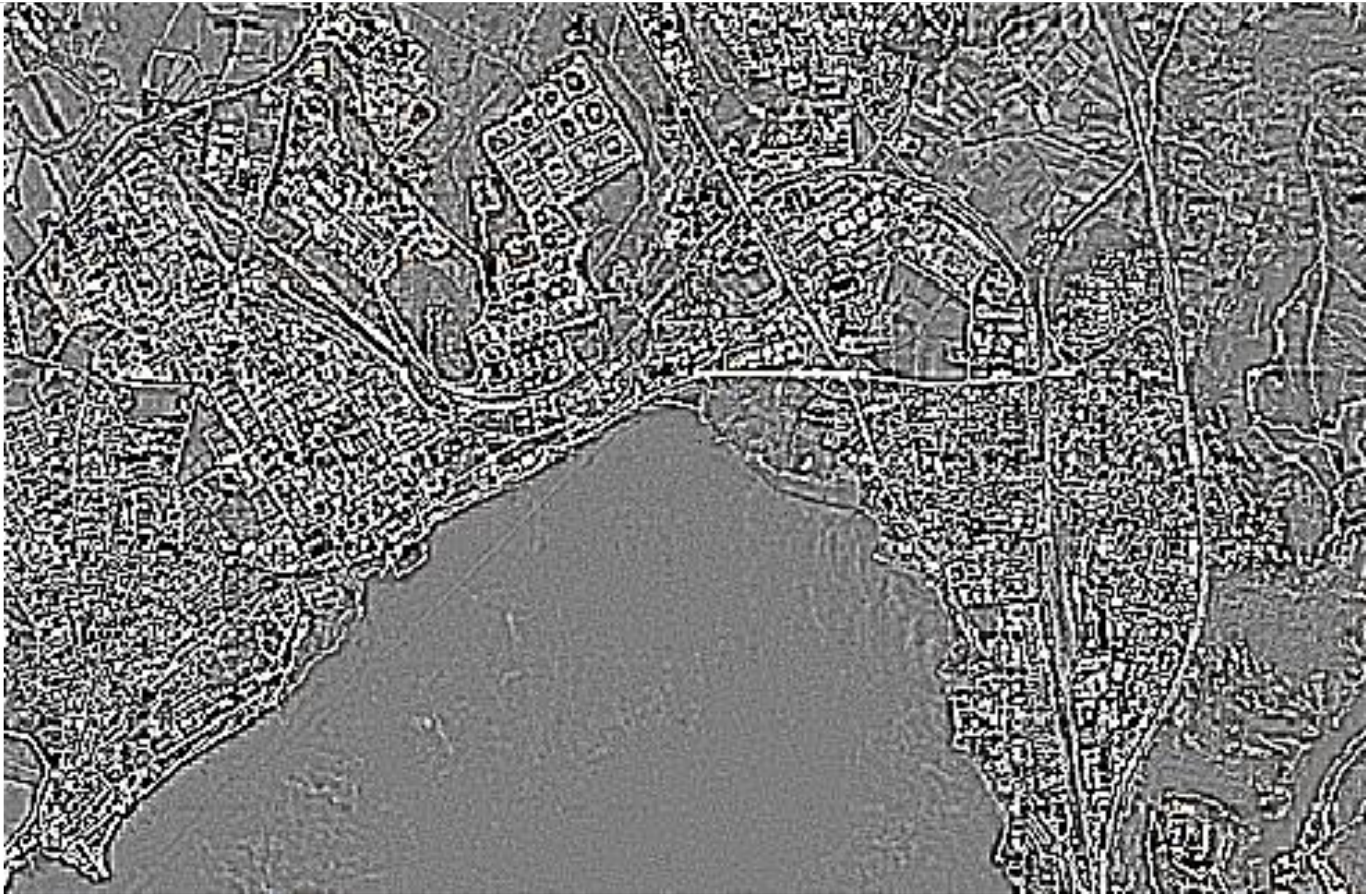
Spatial resampling



Spatial resampling

Spatial resampling

Spatial resampling



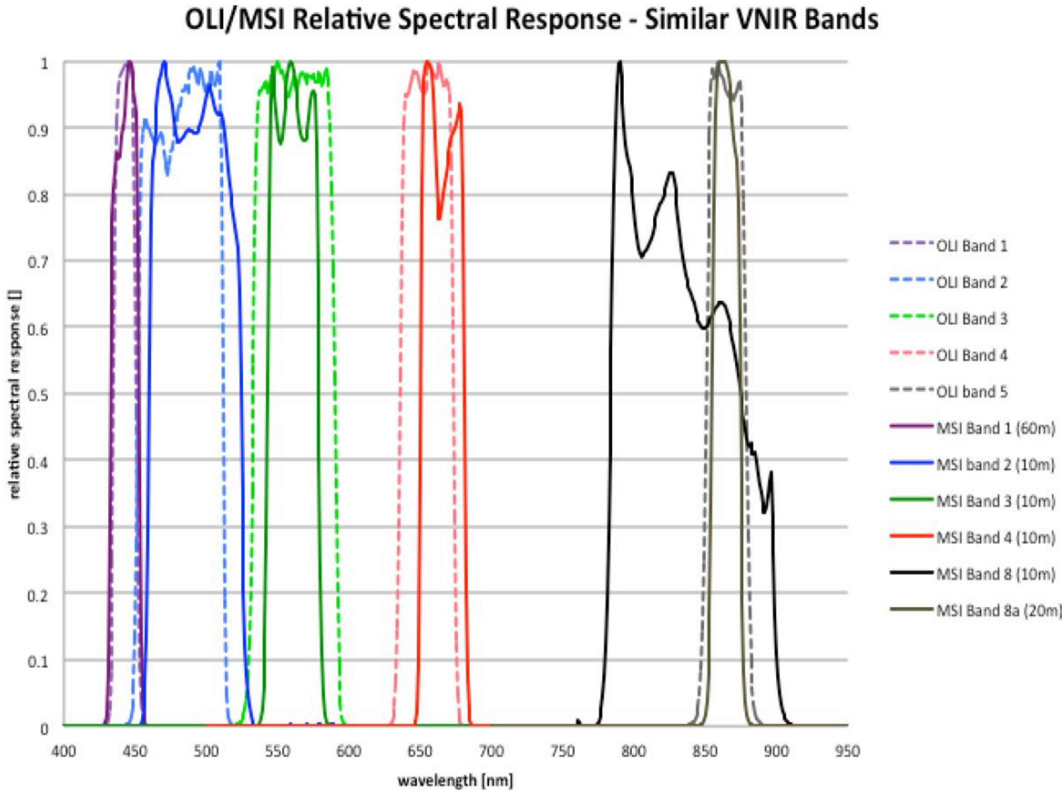
Pan-Sharpening – Pan 15m

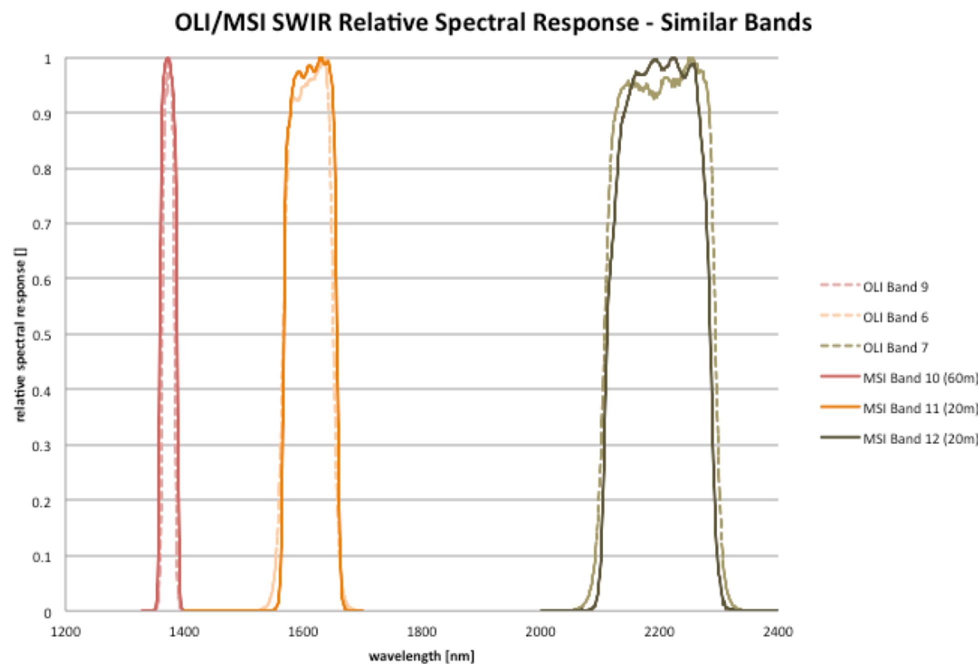
Pan-Sharpening – XS 30m

Pan-Sharpening – Pan+XS 15m

Multi sensor Time series fusion/densification - SBAF

- The bands used for L8/S2 fusion are selected among the similar bands:





Multi sensor Time series fusion/densification - SBAF

	Costal Aerosol	Blue	Green	Red	NIR	SWIR 1	SWIR 2	(Cirrus)
OLI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7	Band 9
MSI	Band 1	Band 2	Band 3	Band 4	Band 8a	Band 11	Band 12	Band 10

$$SBAF = \frac{\overline{\rho_{\lambda(OLI)}}}{\overline{\rho_{\lambda(MSI)}}} = \frac{\frac{\left(\int \rho_\lambda * RSR_{\lambda(OLI)}\, d\lambda\right)}{\left(\int RSR_{\lambda(OLI)}\, d\lambda\right)}}{\frac{\left(\int \rho_\lambda * RSR_{\lambda(MSI)}\, d\lambda\right)}{\left(\int RSR_{\lambda(MSI)}\, d\lambda\right)}}$$

$\rho\lambda$ is at this step estimated from L8 values using all bands.
Will be taken from the DB in step 3 (or MERIS or hyperspectral if existant e.g. Hyperion,)

$$\overline{\rho_{\lambda(MSI)}}^{*} = \frac{\overline{\rho_{\lambda(OLI)}}}{SBAF}$$

BRDF adjustments

- Landsat-8 and Sentinel-2 will have distinct orbit and sun/view geometry.

- Sun/view geometry:
  - Sentinel-2: VZA = +/- 12 deg, Aq. Time ~ 10:30 a.m
  - Landsat-8 : VZA = +/- 7 deg, Aq. Time ~ 10:00 a.m

- On-going activities : Model to correct BRDF has to be defined
  - Use of MODIS BRDF ?

Multi sensor Time series evolution (1)

- Work on progress

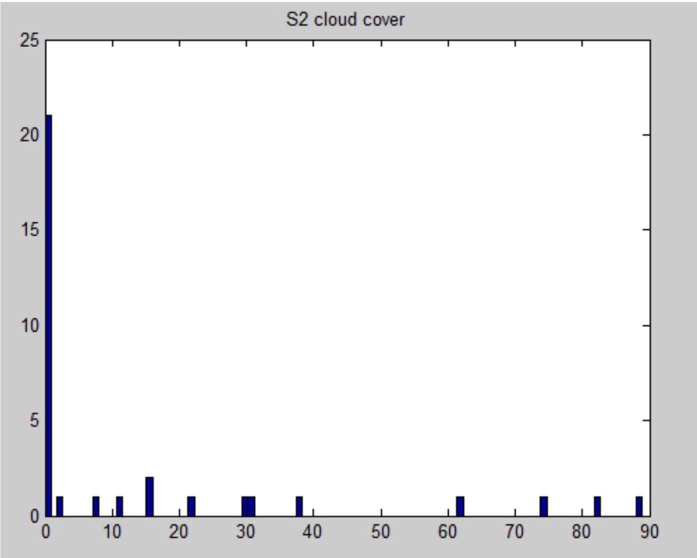
- Data collection :

- S2A/MSI
  - L1C downloaded between July 2015 and June 2016 using ESA/sciHUB
  - Perform AC using sen2cor

- SR L8
  - Dataset downloaded

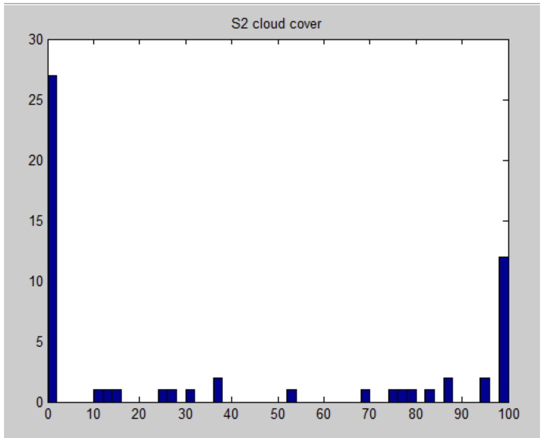
Datasets : 4 agricultural sites

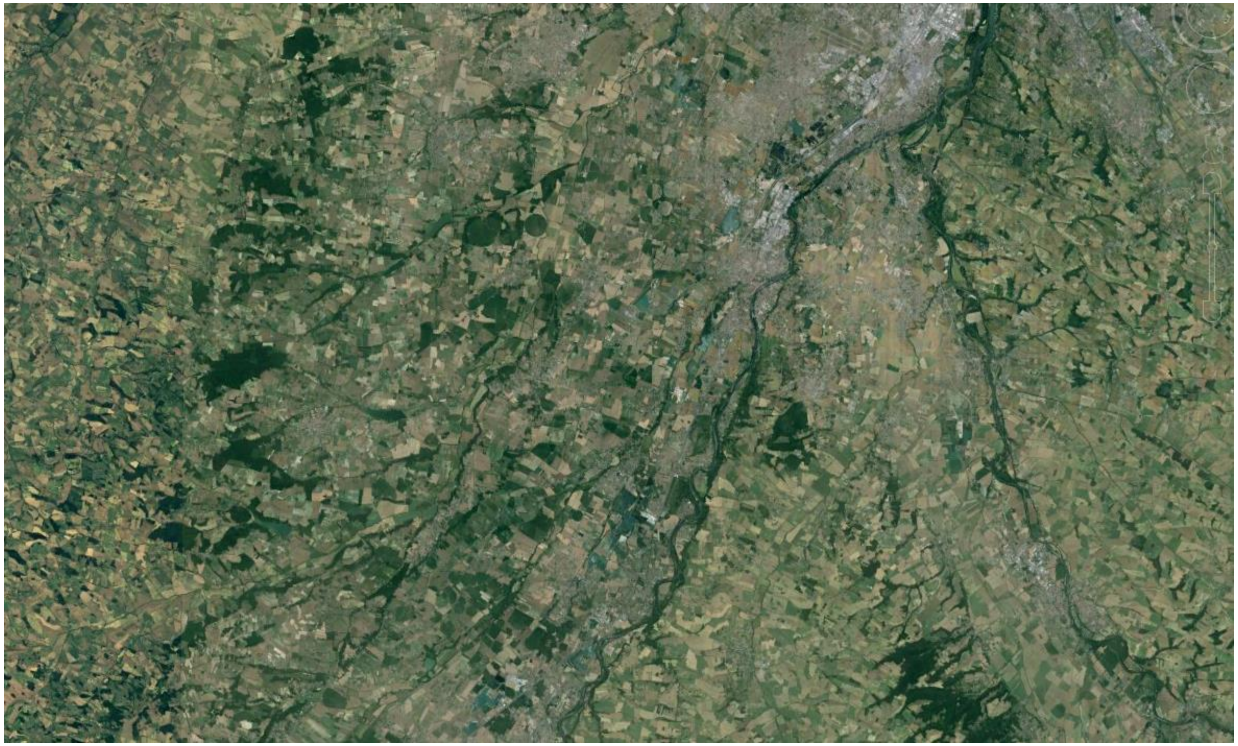
- Maricopa
- 35 S2 acquisitions
- 22 L8



Datasets : 4 agricultural sites

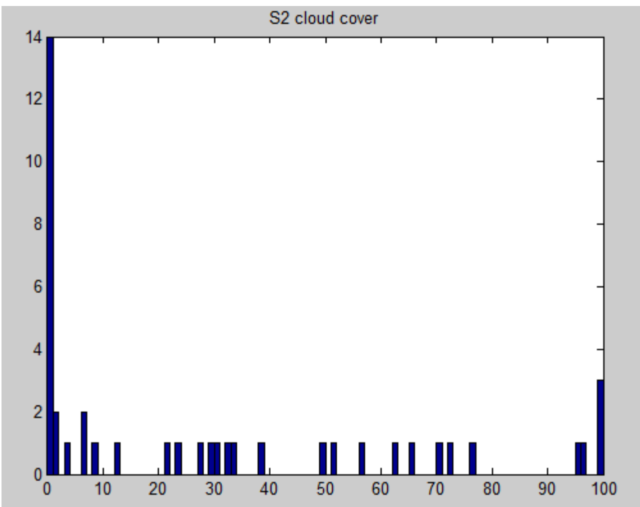
- Toulouse
- 57 S2/MSI
- 22 L8





Datasets : 4 agricultural sites

- Barrax
- 42 S2 acquisitions
- 22 L8



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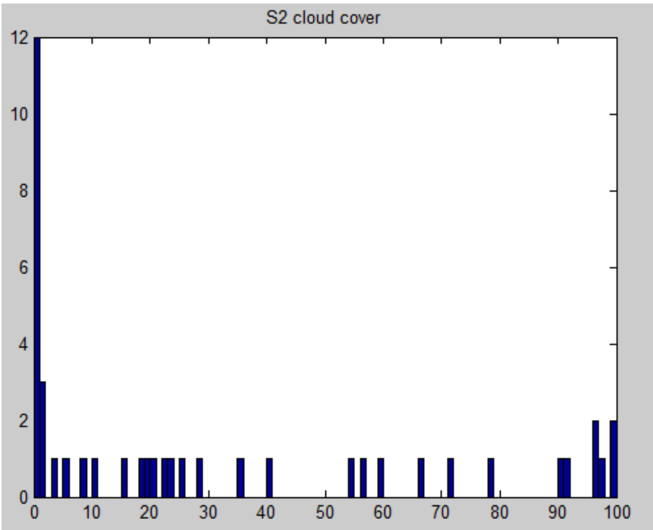
Datasets : 4 agricultural sites

- La Crau
- 42 S2 acquisitions
- 22 L8



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Multi sensor Time series evolution

- Roadmap

- Create a spectre **catalogue** for DTW matching
- Set up a classification to improve the computation performances of the DTW
- Apply BRDF correction to improve quality
- Evaluation of the overall processing chain