IDEAS + Task3
Sentinel 2 / Landsat Fusion Technics
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Project context

• **S2/MSI data exploitation**
  – Which will improve significantly 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 addressed 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
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.
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 \((x_0,y_0,t)\) DTW is able to re align time series and fill gap.

Distance is computed for all candidates

\[
DTW(TPx(x_0, y_0), TPx(x_k, y_l)) = \min_{(x_k, y_l) \in N} DTW(TPx(x_0, y_0), TPx(x_k, y_l))
\]

\[
dist_k = dist(i, i') = \sqrt{\sum_{j=1}^{m} (C_{i,j} - Q_{i',j})^2}
\]

\[
DTW = \sum_{k=1}^{l} dist_k
\]
## Consolidation metrics

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy (A)</strong></td>
<td>$$A = \frac{1}{N} \times \sum_{i=1}^{N} \varepsilon_i$$</td>
</tr>
<tr>
<td><strong>Precision (P)</strong></td>
<td>$$P = \sqrt{\frac{1}{N-1} \times \sum_{i=1}^{N} (\varepsilon_i - A)^2}$$</td>
</tr>
<tr>
<td><strong>Uncertainty (U)</strong></td>
<td>$$U = \sqrt{\frac{1}{N} \times \sum_{i=1}^{N} \varepsilon_i^2}$$</td>
</tr>
</tbody>
</table>

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

Collection of temporal pixel to be recovered

Collection of Neighborhood temporal pixel

Time Series to be recovered

N - Candidates Time Series

- Minimization

N – DTW Metrics

Descriptors

Alignment

- Distance Computation

DTW

Rebuild Time Series

Selected Time Series

- Aggregation With TS to be rebuild

Consolidated Temporal Block
Mono sensor Time series consolidation - DTW

![Graph showing the selection result with lines for 'To rebuild', 'Current TP', and 'Selected TP'. The x-axis represents time * nbBands, and the y-axis represents reflectance.]

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Assessment of DTW for GLC classes

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.

Fig 3) Region of interest.
• Temporal Evolution of the accuracy

![Temporal Evolution of the accuracy graph]

• 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)
    ➔ Compatibility atmospheric correction & cloud/shadow detection
    ➔ Adjustments for BRDF (solar, view angle), band pass differences
    ➔ Adjustment to common frame, resolution (~20m), regrid
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)

**Stage 1**
- MSI Level 2A + Masks + BRDF Coefficient
  - Consolidation

**Stage 2**
- User Defined ROI
- Data Collection
- OLI Level 2A + Masks + BRDF Coefficient
  - Pan-sharpening
  - Band pass adjustment to MSI (SBAF)
    - BRDF adjustments
    - Re-gridding co registration
  - Densification

**Output**
- MSI/OLI Simulated Surface Reflectance products
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.

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

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
The bands used for L8/S2 fusion are selected among the similar bands:
## Multi sensor Time series fusion/densification - SBAF

<table>
<thead>
<tr>
<th>Costal Aerosol</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
<th>NIR</th>
<th>SWIR 1</th>
<th>SWIR 2</th>
<th>(Cirrus)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLI</td>
<td>Band 1</td>
<td>Band 2</td>
<td>Band 3</td>
<td>Band 4</td>
<td>Band 5</td>
<td>Band 6</td>
<td>Band 7</td>
</tr>
<tr>
<td>MSI</td>
<td>Band 1</td>
<td>Band 2</td>
<td>Band 3</td>
<td>Band 4</td>
<td>Band 8a</td>
<td>Band 11</td>
<td>Band 12</td>
</tr>
</tbody>
</table>

\[
SBAF = \frac{\rho_{\lambda(Oli)}}{\rho_{\lambda(MSI)}} = \frac{\left( \int \rho_{\lambda} \cdot RSR_{\lambda(Oli)} \, d\lambda \right)}{\left( \int RSR_{\lambda(Oli)} \, d\lambda \right)} \frac{\left( \int \rho_{\lambda} \cdot RSR_{\lambda(MSI)} \, d\lambda \right)}{\left( \int RSR_{\lambda(MSI)} \, d\lambda \right)}
\]

\(\rho_{\lambda}\) 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,)

\[
\rho_{\lambda(MSI)}^* = \frac{\rho_{\lambda(Oli)}}{SBAF}
\]
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
Datasets: 4 agricultural sites

- La Crau
- 42 S2 acquisitions
- 22 L8
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