A merged Surface Reflectance product from the Landsat and Sentinel-2 Missions

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This project is aimed at producing a merged surface product from the Landsat and Sentinel-2 missions to ultimately achieve high temporal coverage (~2 days repeat cycle) at high spatial resolution (20-60m).

The goal is to achieve a seamless/consistent stream of surface reflectance data from the different sensors.

Cross-calibration, atmospheric corrections, spectral and BRDF adjustments, gridding.
LDCM /Sentinel 2 Fusion

- Calibration
- Atmospheric corrections
- BRDF effect corrections
- Spectral band pass adjustments
- Gridding

**Diagram:**

- LDCM Level 1T
- S2 Level 1C
- LDCM Level 2A
- S2 Level 2A
- BRDF correction
- LDCM Surface Reflectance
  - (30m, LDCM bands) + BRDF coefficients
- S2 Surface Reflectance
  - (10/20/60m, S2 bands) + BRDF coefficients
- MODIS BRDF coefficients (CMG)
- Land cover
- High resolution BRDF coefficients retrieval
- \( \Theta S = f(\text{lat}) \)
- Re-gridding
- Merged Surface Reflectance

**Flow:**

- Inter-comparison
- Production flow

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Sentinel 2 for Science Workshop, ESA-ESRIN, Frascati, Italy, May 20-22, 2014
BRDF adjustments

• VJB Model (Vermote et al. 2009)
  – Relate BRDF parameter to NDVI
  – Simplification of BRDF Kernels using 2 proxy:
    \[ \rho(\theta_{out}) = \rho(\theta_{in}) \times K(\theta_{out}, \theta_{in}, R, V) \]
    \( \theta \) Stands for \( \theta_V, \theta_S, \Delta\phi \)
  – using MODIS CMG (0.05°), R & V were found well-correlated to NDVI
    \[ R = a_1 \times NDVI + b_1 \]
    \[ V = a_2 \times NDVI + b_2 \]
  – \( a_1, b_1, a_2, b_2 \) parameters were retrieved at global scale (at 0.05°) for each MODIS band
Spectral adjustment

- Use of an Artificial Neuron Network (ANN) to relate $\rho_{\text{MODIS}}$ to $\rho_{\lambda}$.
- One ANN per spectral band
- ANN learnt based Synthetic data set (e.g., PROSAIL radiative transfer model simulation)
Evaluation of uncertainties

- Reliability of surface reflectance product depends on the related uncertainty which needs to be quantified.
- 3 approaches to evaluate uncertainty:
  - In situ measurement,
  - Perform atmospheric correction through use of accurate model (6S) and ancillary data (AERONET)
  - Cross-comparison between sensors.

- Sources of deviation
  - Related to the acquisition characteristics (Spatial, Angular (BRDF), Spectral),
  - Related to Real surface changes.

- Sources of Uncertainty
  - Sensor Calibration,
  - Atmospheric correction.

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**2013 SPOT-4 and Landsat-7 Time Series of 1 agricultural field near Maricopa Site (AZ, USA)**

<table>
<thead>
<tr>
<th></th>
<th>SPOT-4 (Take-5)</th>
<th>Landsat-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size</td>
<td>20 m</td>
<td>30 m</td>
</tr>
<tr>
<td>NIR RSR</td>
<td>Very similar</td>
<td></td>
</tr>
<tr>
<td>View zenith</td>
<td>-10° and +30°</td>
<td>&lt;7°</td>
</tr>
<tr>
<td>Overpass Local Time</td>
<td>9:05 AM</td>
<td>9:55 AM</td>
</tr>
</tbody>
</table>

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Quantitative assessment of performances (APU over AERONET) MODIS Collection 5

1,3 Millions 1 km pixels were analyzed for each band.

Red = Accuracy (mean bias)
Green = Precision (repeatability)
Blue = Uncertainty (quadratic sum of A and P)

On average well below magenta theoretical error bar
Quantitative assessment of performances
(APU over AERONET) MODIS Collection 6

Red = Accuracy (mean bias)
Green = Precision (repeatability)
Blue = Uncertainty (quadratic sum of A and P)

Great improvement seen across the range of reflectance (even on bright targets)
Cross-comparison Metrics

• **Accuracy (A)** = the bias
  \[ A = \frac{1}{N} \times \sum_{i=1}^{N} \varepsilon_i \]

• **Precision (P)** = the repeatability
  \[ P = \sqrt{\frac{1}{N-1} \times \sum_{i=1}^{N} (\varepsilon_i - A)^2} \]

• **Uncertainty (U)** = the actual statistical deviation
  \[ U = \sqrt{\frac{1}{N} \times \sum_{i=1}^{N} \varepsilon_i^2} \]
  \[ U^2 = \frac{\sum_{i=1}^{N} (\mu_i - \mu_i - A + A)^2}{N} = \frac{N-1}{N} p^2 + A^2 \]

From Vermote and Kotchenova, 2008

- **Specification (S)** = Uncertainty requirement
  \[ S_{MODIS} = 0.05 \rho + 0.005 \]
  \[ S_X = S_{MODIS} \]
  \[ S = \sqrt{S_{MODIS}^2 + S_X^2} \]
  \[ S = 0.071 \rho + 0.0071 \]
Cross-comparison with MOD09CMG - Methodology

Landsat SR (30m, $\theta_{\text{Lndst}}, \lambda_{\text{Lndst}}$) → Aggregation to CMG

$\theta_{\xi}$: X Sun-view geometry ($\theta_\gamma, \theta_\alpha, \Delta \psi$) configuration
$\lambda_{\xi}$: X Spectral configuration
Lndst: Landsat (TM or ETM+)
MOD: MODIS (Terra or Aqua)

MODIS SR (CMG, $\theta_{\text{MOD}}, \lambda_{\text{MOD}}$) → BRDF Adjustment

MODIS SR (CMG, $\theta_{\text{Lndst}}, \lambda_{\text{MOD}}$) → Spectral Adjustment

Landsat SR (CMG, $\theta_{\text{Lndst}}, \lambda_{\text{Lndst}}$) → Comparison (A, P, U metrics)

MODIS SR (CMG, $\theta_{\text{Lndst}}, \lambda_{\text{Lndst}}$)
Evaluation of VJB with MODIS Aqua

Theta = sun-view geometry
Landsat-5/7 vs MODIS Terra Adjustments example with 1600nm band

**NO Adjustment**

- **LANDSAT-7 ETM+**
  - \(N = 284.8 \text{ k}
  - \(r^2 = 0.98\)
  - \(A = -0.019 \text{ (-8\%)}\)
  - \(P = 0.013 \text{ (5\%)}\)
  - \(U = 0.023 \text{ (9\%)}\)

- **LANDSAT-5 TM**
  - \(N = 753.7 \text{ k}
  - \(r^2 = 0.80\)
  - \(A = 0.002 \text{ (1\%)}\)
  - \(P = 0.038 \text{ (17\%)}\)
  - \(U = 0.038 \text{ (17\%)}\)

**BRDF Adjustments**

- **LANDSAT-7 ETM+**
  - \(N = 286.0 \text{ k}
  - \(r^2 = 0.98\)
  - \(A = -0.013 \text{ (-6\%)}\)
  - \(P = 0.012 \text{ (5\%)}\)
  - \(U = 0.018 \text{ (7\%)}\)

- **LANDSAT-5 TM**
  - \(N = 751.3 \text{ k}
  - \(r^2 = 0.95\)
  - \(A = -0.015 \text{ (-6\%)}\)
  - \(P = 0.019 \text{ (8\%)}\)
  - \(U = 0.024 \text{ (10\%)}\)

**BRDF and Spectral Adjustments**

- **LANDSAT-7 ETM+**
  - \(N = 287.7 \text{ k}
  - \(r^2 = 0.99\)
  - \(A = -0.000 \text{ (-0\%)}\)
  - \(P = 0.010 \text{ (5\%)}\)
  - \(U = 0.010 \text{ (5\%)}\)

- **LANDSAT-5 TM**
  - \(N = 752.7 \text{ k}
  - \(r^2 = 0.95\)
  - \(A = -0.002 \text{ (-1\%)}\)
  - \(P = 0.018 \text{ (8\%)}\)
  - \(U = 0.018 \text{ (8\%)}\)
Cross-comparison – Results Landsat 5 & 7
Cross-comparison – Results SPOT-4
Preliminary validation Landsat 8 SR (71 matchups)
Preliminary validation Landsat 8 SR (71 matchups)
# Agriculture requirements

<table>
<thead>
<tr>
<th>Req#</th>
<th>Spatial Resolution</th>
<th>Spectral Range</th>
<th>Effective observ. frequency (cloud free)*</th>
<th>Sample Type</th>
<th>Field Size</th>
<th>Target Products</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Crop Mask</td>
<td>Crop Type</td>
<td>Crop Condition Indicators</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>All</td>
<td>All</td>
<td>X</td>
</tr>
<tr>
<td>1</td>
<td>500 - 2000 m</td>
<td>thermal IR + optical</td>
<td>Daily</td>
<td>Wall-to-Wall</td>
<td>All</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>100-500 m</td>
<td>VISNIR + SWIR</td>
<td>2 to 5 per week</td>
<td>Cropland Extent</td>
<td>All</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>5-50 km</td>
<td>microwave</td>
<td>Daily</td>
<td>Cropland Extent</td>
<td>All</td>
<td>X</td>
</tr>
</tbody>
</table>

### Coarse Resolution Sampling (>100m)

### Moderate Resolution Sampling (10 to 100m)

| 4    | 10-70m           | VISNIR + SWIR + TIR | Monthly (min 2 out of season + 3 in season); Required every 1-3 years. | Cropland Extent | All | X           | X         | L/M                          | X                       |                          |
| 5    | 10-70m           | VISNIR + SWIR + TIR | Weekly (min. 1 per 16 days) | Sample | All | X           | X         | X                           | X                       |                          |
| 6    | 10-100m          | SAR             | Weekly (min. 1 per 2 weeks) | Cropland Extent of persistent cloudy areas/Rice | All | X           | X         | X                           | X                       |                          |

### Fine Resolution Sampling (5 to 10m)

| 7    | 5-10 m           | VISNIR + SWIR | Monthly (min. 3 in season) | Cropland Extent | M/S | M/S         | M/S       |                          |                          |
| 8    | 5-10 m           | VISNIR + SWIR | Weekly (min. 5 per season) | Sample | All | M/S         | X         | X                           | X                       |                          |
| 9    | 5-10 m           | SAR             | Monthly | Cropland Extent of persistent cloudy areas/Rice | M/S | M/S         | M/S       |                          | M/S                     |

### Very Fine Resolution Sampling (<5m)

| 10   | <5 m             | VISNIR + SWIR | Mesas 3 per year (2 in season 1 out of season); Required every 3 years. | Cropland extent of small fields | S   | S          | S                     |                          |                          |
| 11   | <5 m             | VISNIR         | 1 to 2 per month | Refined Sample | All (Demo) | X          | X                     | X                      |                          |
Conclusions and future steps

• Methodology for merging products well in place
• Accuracy assessment technique for merged products is mature
• Landsat suite of SR product has been developed and Sentinel 2 SR needs to be prototyped before launch