Robust gap filling of Landsat reflectance time series by spectral-angle-mapper based spatio-temporal similarity - demonstration over dynamic U.S. agricultural landscapes

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Landsat Science Team Meeting, 27-29th 2016
Brookings, South Dakota
Example WELD Weekly Products

Week 29: July 15 - 21 2008

Gaps!

gridded calibrated 30m Landsat reflectance weekly, monthly, seasonal and annual products
2010 CONUS crop field size map
(mean field size in 7.5 x 7.5 km grid cells)

4,182,777 crop fields extracted
Derived from all 13,666 Landsat 5 and 7 scenes available in the U.S. year 2010

CONUS 2010
crop field size histogram

4,182,777 fields extracted
California 2010
crop field size histogram

116,888 fields extracted

Google-Earth image. ~5.5 x 5 km subset in California near Corcoran
Basic gap-filling idea

Search for alternative similar pixels (ASP) based on spectral angle mapper (SAM)
Spectral angle mapper (SAM) comparison between two pixel time series

\[
SAM (\tilde{a}, \tilde{b}) = \frac{\sum_{i=1}^{n} x^a_i x^b_i}{\sqrt{\sum_{i=1}^{n} (x^a_i)^2} \sqrt{\sum_{i=1}^{n} (x^b_i)^2}}
\]

- \(\tilde{a}\) and \(\tilde{b}\) are Landsat reflectance time series for pixels a and b
- SAM is defined in range [0, 1]; 1 is maximum similarity (\(\tilde{a}\) and \(\tilde{b}\) are identical)
- Can accommodate missing observations in time series \(\tilde{a}\) or \(\tilde{b}\)

Demonstrated on Landsat-7 reflectance time series:
Alternative similar pixel (ASP) identification

Time-series-based search for ASP pixels by maximizing SAM
Time-series-based segmentation-and-clustering approach for alternative similar pixel identification

(a) time series segmentation

(b) segments clustering

Clusters (textured)
- cluster A
- cluster B

(c) Valid observations

Search for alternative similar segments based on SAM
Data

• Landsat-8 reflectance time series

• 5 bands: red, green, NIR, SWIR 1, SWIR 2

• April 28th to October 26th 2013 (26 weeks)
2013 USDA NASS CDL (cropland data layer)
Minnesota

Major CDL classes: corn (44.7%), soybean (31.9%), grassland/pasture (6.6%), developed (5.9%) and herbaceous wetlands (5.0%).

Landsat-8 time series

5000 $\times$ 5000 30m pixels (150km $\times$ 150km)
Kansas

Major CDL classes: grassland/pasture (49.1%), winter wheat (18.7%), fallow/idle cropland (8.5%), corn (8.4%), sorghum (7.3%) and developed (4.0%) in 2013.

Landsat-8 time series

5000 \times 5000 30m pixels (150km \times 150km)
Major CDL classes: grassland/pasture (24.2%), forest (13.5%), shrub/scrub (11.9%), developed (11.3%), rice (6.4%), fallow/idle cropland (5.8%), water (3.0%), grapes (2.9%), herbaceous wetlands (2.5%), alfalfa (2.4%) and corn (2.0%).
## Percentage of missing weekly WELD pixel observations

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Percentage of missing weekly WELD 30 m pixel observations over the 26 weeks</th>
<th>Number of weeks with at least one valid 30 m pixel (n) in the study area</th>
<th>Percentage of missing weekly WELD 30m pixel observations computed over the n weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnesota</td>
<td>55.2%</td>
<td>22</td>
<td>45.9%</td>
</tr>
<tr>
<td>Kansas</td>
<td>46.2%</td>
<td>20</td>
<td>30.1%</td>
</tr>
<tr>
<td>California</td>
<td>47.5%</td>
<td>23</td>
<td>60.6%</td>
</tr>
</tbody>
</table>
Testing methodology

Original image
(5000 x 5000 pixels)

36% simulated gaps
25 subsets, each 600 x 600 pixels

Predicted gaps
(26-week time series used)

Compute 5-band RMSD = \sqrt{\frac{\sum_{i=1}^{5}(\text{Band}_{i}^{\text{original}} - \text{Band}_{i}^{\text{predicted}})^2}{5}}
Minnesota tile
5000 x 5000 pixels
week 34, 2013
maturity season

predicted image
SWIR 1, NIR, Red
Minnesota tile

5000 x 5000 pixels

week 34, 2013

maturity season

36% gap filled image

SWIR 1, NIR, Red
<table>
<thead>
<tr>
<th>5-band RMSD</th>
<th>Mean = 0.016</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Minnesota tile**

5000 x 5000 pixels

Week 34, 2013

Maturity season
Kansas tile

5000 x 5000 pixels

week 38, 2013
harvest season

original image
SWIR 1, NIR, Red
Kansas tile

5000 x 5000 pixels

week 38, 2013
harvest season

predicted image
SWIR 1, NIR, Red
Kansas tile

5000 x 5000 pixels
week 38, 2013
harvest season

5-band RMSD
Mean = 0.018
California tile

5000 x 5000 pixels

week 29, 2013

original image
SWIR 1, NIR, Red
California tile

5000 x 5000 pixels

week 29, 2013

predicted image
SWIR 1, NIR, Red
California tile
5000 x 5000 pixels
week 29, 2013

5-band RMSD
Mean = 0.014
Error distributions over different land covers
500 x 500 pixels simulated gap filling in Minnesota
500 x 500 pixels simulated gap filling in Minnesota

Week 34 predicted image
SWIR 1, NIR, Red
500 x 500 pixels
simulated gap filling in Minnesota

Week 34 original image
SWIR 1, NIR, Red

Week 34 predicted image
SWIR 1, NIR, Red
Gap filling example

Original image with cloud mask
900 x 1000 pixels, week 22, Kansas
Gap filling example

Gap filled image
900 x 1000 pixels, week 22, Kansas
Summary

• Large-area gap filling algorithm for Landsat data demonstrated over agricultural landscapes.

• Based on missing-observation-adaptive SAM applied to Landsat reflectance time series.

• Computationally efficient for using a segmentation-and-clustering approach.

• Quantitatively assessed over aggressive large-area simulated gap filling experiments (comparisons with temporal compositing not shown).

• Factors affecting gap filling accuracy:
  - complexity in land cover/phenology
  - size, shape and spatial/temporal distributions of gaps
  - clouds/shadow detection
  - abrupt land cover changes (e.g. harvesting, flooding)

• C source codes will be released upon publication
Suggestions on naming the method?

Alternative similar segment approach based on SAM

(ASSA-SAM)
500 x 500 pixels
simulated gap filling in Kansas

prediction error due to harvesting happening in week-38 temporal window

Correctly predicted flooded crop fields

Week 38 original image harvest season
SWIR 1, NIR, Red

Week 38 predicted image harvest season
SWIR 1, NIR, Red