Developing Consistent Time Series Landsat Data Products

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Consistent Requirements

- **Location consistent**
  - Data from different sensors and/or dates can be analyzed in pixel-by-pixel (sub-pixel accuracy)

- **Radiometric consistent**
  - Data from same or different sensors are comparable for either short-term or long-term time series analysis

- **Product consistent**
  - Data products are compatible among different sensors and should be agree with existing high quality data products
Examples from Landsat Science Team Project

1. Consistent Pixel Location
   An automated approach for registration and orthorectification

2. Consistent and Dense Time Series Data
   2.1 Physical approach
   2.2 Normalization approach
   2.3 Data fusion approach for dense time series

3. Consistent High-level Data Products
   3.1 Albedo
   3.2 Leaf area index
   3.3 Impervious surfaces
1. Location Consistent – AROP

Automated Registration and Orthorectification Package (AROP) was initially developed in 2005 and has been continuously improved through this project.
AROP Status

- Has been tested and applied for Landsat data (MSS, TM and ETM+), CBERS, ASTER, AWiFS and HJ-1
- Provides four options: 1) orthorectification; 2) precise registration; 3) combined registration and orthorectification; and 4) verification
- Accepts different projections and spatial resolution
- Combines resampling (projection, rotation, scaling, registration and orthorectification) in one transfer function
- Provides pyramid registration: preliminary registration using coarse resolution; precise registration using fine resolution
- Iterative results verification and processing
- Open C source code
- 20+ active users
Multiple and Single Resampling

Resampled 3 times

Warp Image
AST_L1B_00310232005160936_*_7406.hdf
October 23, 2005
VNIR Pointing Angle: 5.674
Map Orientation Angle: -9.049154
UTM Zone: 17 N

Base Image
GeoCover ETM+
September 30, 1999
UTM Zone: 18 N

Resampled three times:
(rotation, reprojection, ortho and registration)
Resolution: 15m
Combined resampling

Difference between v2.1 and v2.2
(1 time vs. 3 times resampling)
(NIR band, 15m resolution)

Minimize resampling procedures!
2. Radiometric Consistent

2.1 Physical approach

- Ledaps standalone version
  - Tested on TM and ETM+
  - 12 version releases
  - about 100 users

- BRDF effects
  - View angle effect (within-scene)
  - Day of year effect (season/location)
  - Mean local time drift effect

![Relative Difference of Reflectance Comparing to Nadir View](image)
Three Types of Angular Effect

(NIR band)
Landsat BRDF Effects Summary

- The view angle effect are normally in the range of +/-6% for red and +/-5% for NIR band relatively. The averaged angular effects at the edge of a Landsat scene are about +/-5% for red and +/-3% for NIR relatively.

- The day of year effect are less than 13% for both red and NIR bands relatively except spruce comparing to the reflectance from the middle day of year.

- The overall angular effect caused by Landsat-5 drift from 1984 to 2010 are about 5.8% for red and 5.5% for NIR band with the exception of spruce.

- BRDF correction for Landsat data may be needed for time-series analysis esp. when Landsat data are acquired from the different day of the year.

- BRDF effects need to be examined for a large area application.
2.2 Normalization Approach

- Combine observations from multiple Landsat and Landsat-like data in a consistent way for time series analysis

- Normalize the scene differences (seasonal phoenology variation) for large area applications
Combining Data from Multiple Sensors for Vegetation Monitoring

![Graph showing surface reflectance over dates for different types of vegetation.]

- 4/18/06, ASTER
- 4/26/06, AWiFS
- 6/5/06, ASTER
- 6/13/06, TM
- 7/7/06, AWiFS
- 7/23/06, ETM+
- 7/31/06, TM
- 8/24/06, AWiFS

Legend:
- 1: woods
- 2: pasture
- 3: soybeans
- 4: corn
- 5: corn

Dates:
- 4/1/06, 5/1/06, 5/31/06, 6/30/06, 7/30/06, 8/29/06

Axes:
- X-axis: Date
- Y-axis: Surface Reflectance
Combining Scenes from Different Dates
- Chesapeake Bay ASTER Example

ASTER TOA mosaic (195 scenes)
~2004

Normalized ASTER SR mosaic (195 scenes)
Used MODIS NBAR data on 2004-265
(September 21, 2004)
Landsat GLS2000
(620 scenes)
MODIS NBAR 2000-193
(July 11, 2000)
Subset of mosaiced image in South Carolina


ΔDI

2.3 Landsat Dense Time Series form Data Fusion Approach

Objective - combine the spatial resolution of Landsat with the temporal frequency of coarse-resolution MODIS.

Landsat
- 30m spatial resolution
- 16-day revisit cycle

MODIS
- one or two revisit per day
- 250m & 500m spatial resolution
StarFM Status

- standalone C version
- open source in Linux system
- available from the LEDAPS website
- 10+ users
- 20+ citations in refereed journals since 2008
- Model improvements are still ongoing
  - STARRCH (Hilker and Wulder etc., RSE 2009)
  - ESTARFM (Zhu and Chen etc., RSE 2010)
  - More coming …
StarFM Application Examples

- Forest monitoring and disturbance mapping, 2009a, 2009b, 2010, RSE
  (T. Hilker, M. Wulder etc., Canadian Forest Service)

- Improving wildland fire severity mapping, 2009
  (F. Gao-ERT, J. Morisette-USGS, R. Wolfe-NASA)

- “A data-model fusion approach for upscaling gross ecosystem productivity to the landscape scale based on remote sensing and flux footprint modeling,” 2010, Biogeosciences
  (B. Chen etc., Chinese Academy of Sciences)
StarFM Application Examples (cont.)

- “Improved classification of conservation tillage adoption using high temporal and synthetic satellite imagery,” 2011, RSE (Jennifer Watts etc., University of Montana)

- “Mapping daily evapotranspiration at field to global scales using geostationary and polar orbiting satellite imagery,” 2010, HESSD (Martha Anderson etc., USDA ARS)


- Crop type classification and condition monitoring (ongoing work with USDA NASS)
3. Consistent High-level Data Products

3. 1 Albedo

- Extract MODIS BRDF parameters from “pure” homogeneous pixels
- Apply magnitude inversion approach to Landsat surface reflectance
- Initial validation shows better quality on heterogeneous areas
- NASA Terra project (PI: Jeff Masek) looks at albedo changes at Landsat spatial scale due to forest disturbances
Validation on Homogeneous Sites

**MODIS Representative Sites**

\[ y = 1.5815x - 0.0821 \]

\[ R^2 = 0.7575 \]

RMSE\_mod\_Rep=0.02540

Bias\_mod\_Rep= 0.01928

**Landsat Representative Sites**

\[ y = 0.967x + 0.019 \]

\[ R^2 = 0.911 \]

RMSE\_Ind\_Rep=0.01585

Bias\_Ind\_Rep= 0.01298
Validation on Heterogeneous Sites

MODIS Non-representative Sites
\[ y = 0.0051x + 0.2036 \]
\[ R^2 = 4E-06 \]
\[ \text{RMSE}_{\text{mod\_nonRep}} = 0. \]

Landsat Non-representative Sites
\[ y = 1.1097x + 0.0056 \]
\[ R^2 = 0.7813 \]

- BON (Ind)
- BON (MOD)
- GWN (Ind)
- GWN (MOD)
- PSU (Ind)
- PSU (MOD)
3.2 Leaf Area Index

An empirical approach was tested that uses same period high quality coarse resolution LAI data and ground measurements to calculate LAI at Landsat spatial resolution.

- High quality coarse LAI from multiple seasons
- “pure” coarse pixels from Landsat
- Accept additional data sources in empirical model
MODIS LAI is too low. Ground measurements improve LAI.
3.3 Impervious Surface

An effective approach was developed to detect impervious surfaces expansion

- use image stack as an integrative whole
- noise filter (accept low quality images)
- accept images in different forms (DN, TOA or surface reflectance)
- change results are consistent
Summary

In 2006, we proposed to study in four aspects

- International Landsat-like data
- MSS data
- Landsat fused/simulated data
- Land cover change detection using multiple sensor data

Now,

- AROP package has been used for orthorectification and registration process on Landsat (MSS, TM and ETM+), ASTER, AWiFS, CBERS and HY-1
- STARFM approach has been extended and applied to build/simulate dense Landsat time series for various applications
- Normalization approach has been used to combine multiple sensor data for change detection and phenology detection
- A consistent impervious extension mapping approach has been tested and applied to Landsat MSS, TM, ETM+ and CBERS data
- An empirical reference-based approach has been tested to generate compatible Landsat data products from MODIS data products