Developing Biophysical Products for Landsat

Rama Nemani, Sangram Ganguly, Jennifer Dungan
NASA Ames Research Center

Landsat Science Team Meeting
Sioux Falls, August 2011
Planned Contribution

• Leaf Area Index (LAI) is defined as one-sided green leaf area per unit ground area in broadleaf canopies and as the projected needle leaf area in coniferous forests.

• LAI is an important variable for quantifying the cycling of water, carbon and nutrients through ecosystems.

• Develop an operational capability to produce vegetation green leaf area index (LAI) from Landsat data by adapting a physically based approach conceived and implemented by the MODIS Science team.
Motivation

- A robust theoretical approach exists in the MODIS LAI retrieval algorithm
- Spectral invariant theory based on the 3D stochastic radiative transfer model has been developed – an efficient way to simulate a realistic model that generates BRF (Bidirectional Reflectance Factor) as a function of LAI, soil reflectances and view/azimuth angles
- The theoretical understanding exists to account for variations in spatial resolution and spectral bandwidth between sensors in LAI retrieval
- Spectral reflectance- or NDVI-LAI empirical relationships are region-specific and thus cannot be applied operationally over larger areas such as continents.
Radiative transfer theory of canopy spectral invariants provides the required Bidirectional Reflectance Function (BRF) parameterization via a small set of variables;

These variables specify the relationship between the spectral response of a scattering object bounded by a non-reflecting surface to the incident radiation and can be used at different spatial resolutions;

Spectral invariant form of BRF can decouple the structural and spectral information.

\[
BRF_\lambda = \omega_\lambda R_1 + \frac{\omega_\lambda^2 R_2}{1 - p \omega_\lambda}
\]

- \( R_1, R_2 \): Escape probabilities
- \( p \): Recollision probability
- \( \omega_\lambda \): Single scattering albedo
The three-dimensional radiative transfer problem with arbitrary boundary conditions can be expressed as a superposition of some basic radiative transfer sub-problems with purely absorbing boundaries and to which the notion of spectral invariant can be directly applied.

\[ J(\text{s,\lambda}) \] – radiance generated by isotropic sources \((1/\pi)\) at the canopy bottom.

Taking into account the intensity of sources at the first interaction is \((1/\pi) \cdot t(\text{BS,\lambda}) \cdot \rho(\text{sur,\lambda})\), corresponding radiance from surface can be expressed as \(J(\text{s,\lambda}) \cdot t(\text{BS,\lambda}) \cdot \rho(\text{sur,\lambda})\). Total radiance “S” can be expressed as successive orders of scattering,

\[
S = t_{\text{BS,\lambda}} \rho_{\text{sur,\lambda}} J_{\text{S,\lambda}}(\Omega) + \rho_{\text{sur,\lambda}}^2 r_{\text{S,\lambda}} t_{\text{BS,\lambda}} J_{\text{S,\lambda}}(\Omega) + \rho_{\text{sur,\lambda}}^3 r_{\text{S,\lambda}}^2 t_{\text{BS,\lambda}} J_{\text{S,\lambda}}(\Omega) + \ldots \\
+ \rho_{\text{sur,\lambda}}^n r_{\text{S,\lambda}}^{n-1} t_{\text{BS,\lambda}} J_{\text{S,\lambda}}(\Omega),
\]

\[
S = \frac{\rho_{\text{sur,\lambda}}}{1-\rho_{\text{sur,\lambda}} r_{\text{S,\lambda}}} t_{\text{BS,\lambda}} J_{\text{S,\lambda}}(\Omega)
\]
Surface Reflectances Process

- The 2005 Global Land Survey (GLS) dataset was obtained from EDC DAAC
- GLS scenes were processed using LEDAPS from GSFC for radiometric calibration and atmospheric corrections to obtain surface reflectances
- MODIS Collection 5 (MCD43A4) NBAR surface reflectance product utilized for testing reflectance consistency
- 30-m NLCD landcover map is also used as input to LAI estimation
LAI Map Production Process

**Input Data Preparation**
- L1T Data (RED, NIR & SWIR)
- NLCD 30-m Landcover Data
- MODIS 500-m Landcover Data
- MODIS 30-m Landcover Data

**Processed Data**
- Landsat Surface Spectral Reflectance \(\rho\) (RED, NIR & SWIR)
- Landsat Look Up Table (LUT)

**Canonical Architecture Radiative Transfer**
- Criterion Function (Compare input \(\rho\) with simulated BRF)
- 2-band or 3-band

**Set of Acceptable Solutions**
- (intermediate product)

**Output**
- (Mean LAI, dispersion and QC for 2-band/3-band inversions)

**TOPS Processing on NEX**

BRF = Bidirectional Reflectance Factor; LAI = Leaf Area Index; QC = Quality Control.
NIR = Near-infrared; SWIR = Short-wave infrared.
LEDAPS = Landsat Ecosystem Disturbance Adaptive Processing System.
TOPS = Terrestrial Observation and Prediction System.
NEX = NASA Earth Exchange
\(\lambda\) = wavelength; \(\rho_{\lambda}\) = soil reflectance; \(\Omega\) = view geometry; \(\phi\) = illumination geometry;
\(\omega_{\lambda}\) = single scattering albedo; \(\varepsilon_{\lambda}\) = relative uncertainty
Site-specific Tests

- grasslands in the Kansas Prairie, USA
- broadleaf crops in Bondville, USA
- savannas in Mongu, Zambia
- broadleaf evergreen forests in the Amazon, South America
- deciduous broadleaf forests at Harvard forest, USA
- evergreen needleleaf forests at a site in the BOREAS study area, Canada.
- deciduous needleleaf forests at the far north of Eastern Siberia
Harvard Forest, USA

MOD15 LAI  Landsat LAI  Empirical Rule

[Images of data plots showing frequency distributions and spatial distributions of MOD15 LAI, Landsat LAI, and empirical rule.]
Landsat LAI at 30m for California

Sample QA for LAI retrieval:
(1) – best quality LAI Retrievals with a 2-band inversion
(2) – pixels with RED band threshold
(3) – inversion fails, SR-LAI empirical rule
Evaluation Product

Product Name: Leaf Area Index
Product Description: Landsat-5 and Landsat-7 inputs processed through the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS)
Data Provider: Data processed in NASA Earth Exchange (NEX) at NASA Ames Research Center
Data Distributor: U.S. Geological Survey (USGS) Landsat Science Research and Development (LSRD) at USGS Earth Resources Observations and Science (EROS) Center

Collection Area: State of California
Collection Acquisitions: between 2004-09-04 and 2007-070-22
Data Format: Hierarchical Data Format (HDF)
Map Projection: Universal Transverse Mercator (UTM)
Total Collection Volume: 359 Megabytes (MB)
Total Collection Scenes: 45
Maximum File Size: 25 MB
Minimum File Size: 0.2 MB
Average File Size: 8 MB
Filename Example: lndLAI.L5042037_03720060314_MTL.hdf
Naming Convention: land leaf area index.Landsat5 path 042 row 037_row 037 2006 march 14_MTL.hdf

Science Data Sets (SDS) - 2
NEX Landsat 30m Leaf Area Index (LAI)
Dims variable around 8000 x 7000
Number Type unsigned 8 bit
Fill 250 Original data was fill
253 Fill no values available or masked out
254 Water/Snow/Ice
255 Barren

........
Status

- Technical paper submitted to RSE Special Issue, “Generating Global Leaf Area Index from Landsat: Algorithm Formulation and Demonstration” by Ganguly et al.;
- Evaluation request for the California LAI sent out to LST by John Dwyer on August 8th
- Interest in 30-m LAI maps:
  - Martha Anderson at USDA as scale-consistent inputs to ET mapping;
  - Atul Jain for South East Asia (2005 and 2000) climate modelling
  - CCRS, ISPRA
  - Japan
Discussion

• This is the first ever 30-m wall-to-wall leaf density map from Landsat
• Landcover is a critical input – need to use best landcover wherever possible (e.g. NLCD for US);
• Verification efforts to date have emphasized image-to-image comparisons (with MODIS-based products)
• 3-band versus 2-band LAI retrievals still needs to be validated – 3-band retrieval may minimize understory effects
• Atmospheric correction (esp. cloud correction) still to be improved
• Next step is to generate the product for the conterminous US corresponding to the availability of NLCD
• Predicting LAI at 30-m has implications for more accurately predicting related vegetation variables such as biomass and GPP
• Hyperwall (25 x 8 panels at ARC) visualization of Landsat false-color composites, biophysical products in multiple dimensions creates the opportunity for additional understanding and discovery
• Potential to accomplish collaboration and computation of special-purpose variables using NEX
LAI-Height empirical modeling

1. Consider GLAS shots during the period from May till October (best shots after quality screening, other months suffer from snow);
2. Use NLCD land cover to screen for forest pixels;
3. Find homogeneous GLAS shot footprints in the scene based on landcover;
4. Select pixels with reflectances in valid range (red reflectances <0.15 for forest pixels);
5. Select pixels with acceptable slope values.
6. Set up empirical rule between GLAS derived Heights and LAI;
Hyperwall Visualization
NASA Earth Exchange (NEX): Collaboration & Computing

NEX Collaborative Web Portal

- Algorithms
- Datasets
- Publications
- Virtual computing
- Real time audio/video conferencing
Thank you!