

# Landsat Higher-level Product Plans

**March 27, 2014**

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**\*Work performed under U.S. Geological Survey contract G10PC00044**

# LSDS Science Research and Development (LSRD)

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The Land Satellite Data Systems (LSDS) Science Research and Development (LSRD) project at the U.S. Geological Survey's (USGS) Earth Resources Observation and Science (EROS) Center is prototyping systems and software to generate high-level data products from Landsat 5-7 inputs to support the USGS Terrestrial Monitoring activities with Essential Climate Variables (ECV) and Climate Data Records (CDR). These prototypes are now being modified for L8.

The LSRD has already developed on-demand TOA reflectance, surface reflectance (SR), land surface temperature (LST), and 7 spectral indices for Landsat TM and ETM+ data.

LSRD's EROS Science Processing Architecture (ESPA) prototype utilizes Apache Hadoop to move algorithms across a multi-server cluster to process input data files. ESPA technology facilitates the shortest path to data production by normalizing any software languages and enabling multiple servers to join or disconnect from the cluster without impacting processing.

# Outline

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- **Earth Archive Goals**

- ◆ ECVs and CDRs

- **Surface Reflectance**

- ◆ LEDAPS
- ◆ Spectral Indices

- **ECV Products**

- ◆ Burned Area
- ◆ Cloud and Cloud Shadow Masks
- ◆ Surface Water Extent
- ◆ Snow Covered Area (SCA)

- **Other Upcoming Products**

- ◆ Global products
  - Tiled Products?
- ◆ LPVS

# Earth Archive Goals

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- An archive of calibrated radiances across missions enables development of Climate Data Records (CDRs) and Essential Climate Variables (ECVs)

- **CDRs**

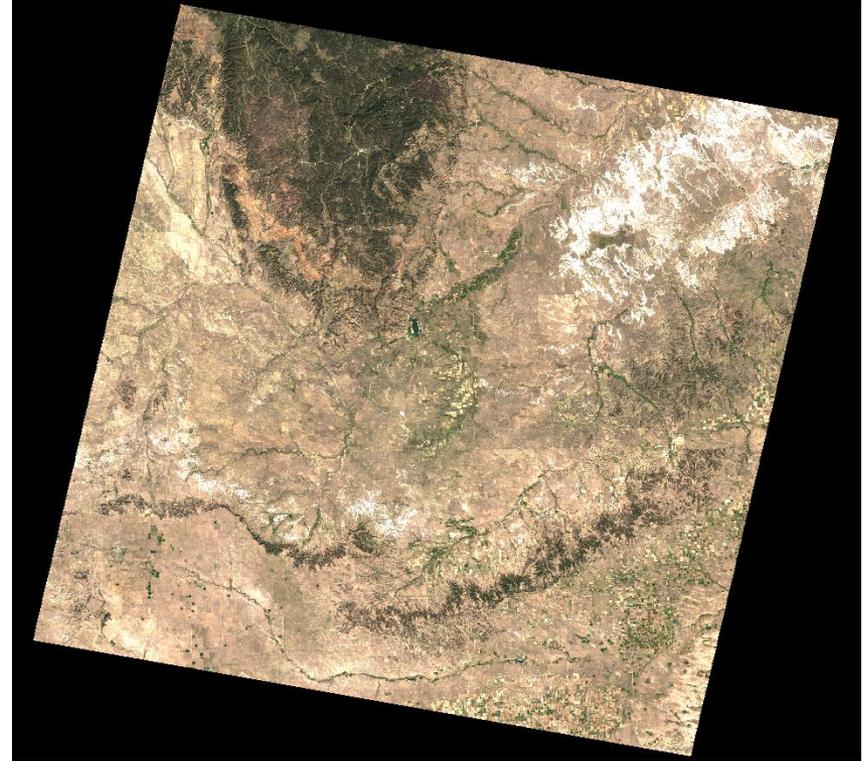
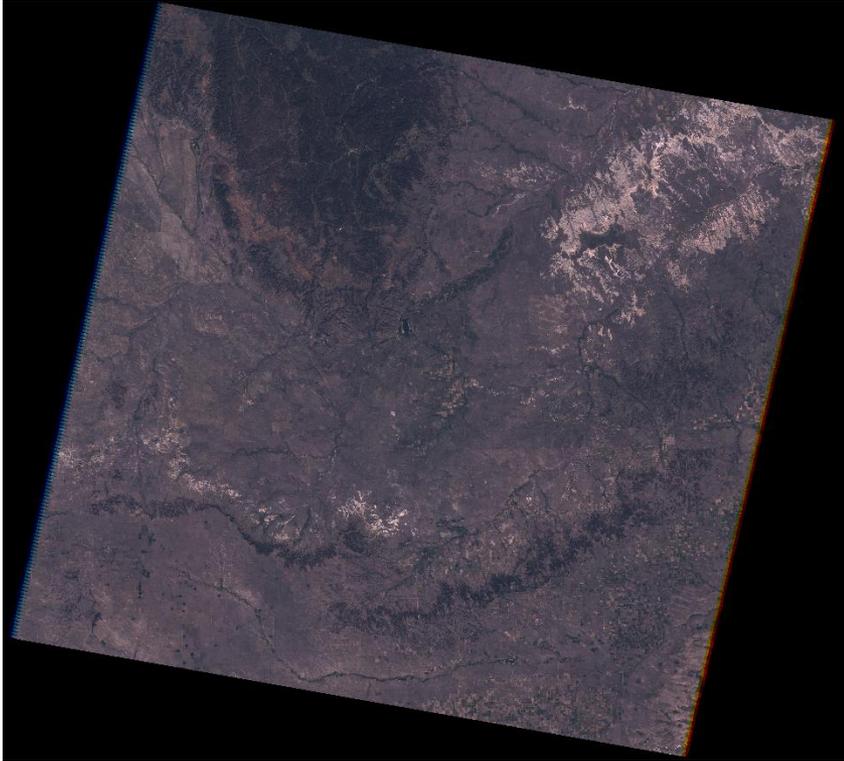
- ◆ Surface Reflectance
- ◆ Surface Temperature
- ◆ Aerosol Optical Thickness

- **ECVs**

- ◆ Burned Area Extent
- ◆ Surface Water Extent
- ◆ Snow Covered Area
- ◆ Global 30m Land Cover

# Landsat ETM+ Surface Reflectance (SR)

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Example of LEDAPS atmospheric correction. Left, top-of-atmosphere reflectance composite (bands 3, 2, 1) for Landsat-7 ETM+ image of the Black Hills and Badlands in South Dakota (September 20, 2002). Right, surface reflectance composite.

# LEDAPS Characterization Study

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- **Landsat Ecosystem Disturbance Adaptive Processing System**
- **Baseline quality check on provisional USGS EROS Surface Reflectance (SR) products**
- **LEDAPS vs.**
  - ◆ AERONET (Aerosol Optical Thickness)
  - ◆ Field Spectrometer (Surface Reflectance)
  - ◆ MODIS (ECVs)
- **Confirmed expected strengths and weaknesses in LEDAPS**
  - ◆ SR is good in vegetated areas
  - ◆ Increased temporal variability in shorter wavelengths (likely due to aerosol influence)
  - ◆ AOT overestimation in certain areas

Maiersperger, T.K., Scaramuzza, P.L., Leigh, L., Shrestha, S., Gallo, K.P., Jenkerson, C.B., and Dwyer, J.L., 2013, Characterizing LEDAPS surface reflectance products by comparisons with AERONET, field spectrometer, and MODIS data: Remote Sensing of Environment, v. 136, p. 1-13. (Also available online at <http://dx.doi.org/10.1016/j.rse.2013.04.007>.)

# Landsat Spectral Indices

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- **Spectral Indices derived from LEDAPS Surface Reflectance CDR**
  - ◆ NDVI Normalized Difference Vegetation Index
  - ◆ EVI Enhanced Vegetation Index
  - ◆ SAVI Soil Adjusted Vegetation Index
  - ◆ MSAVI Modified Soil Adjusted Vegetation Index
  - ◆ NDMI Normalized Difference Moisture Index
  - ◆ NBR Normalized Burn Ratio
  - ◆ NBR2 Normalized Burn Ratio 2

<http://code.google.com/p/spectral-indices/>

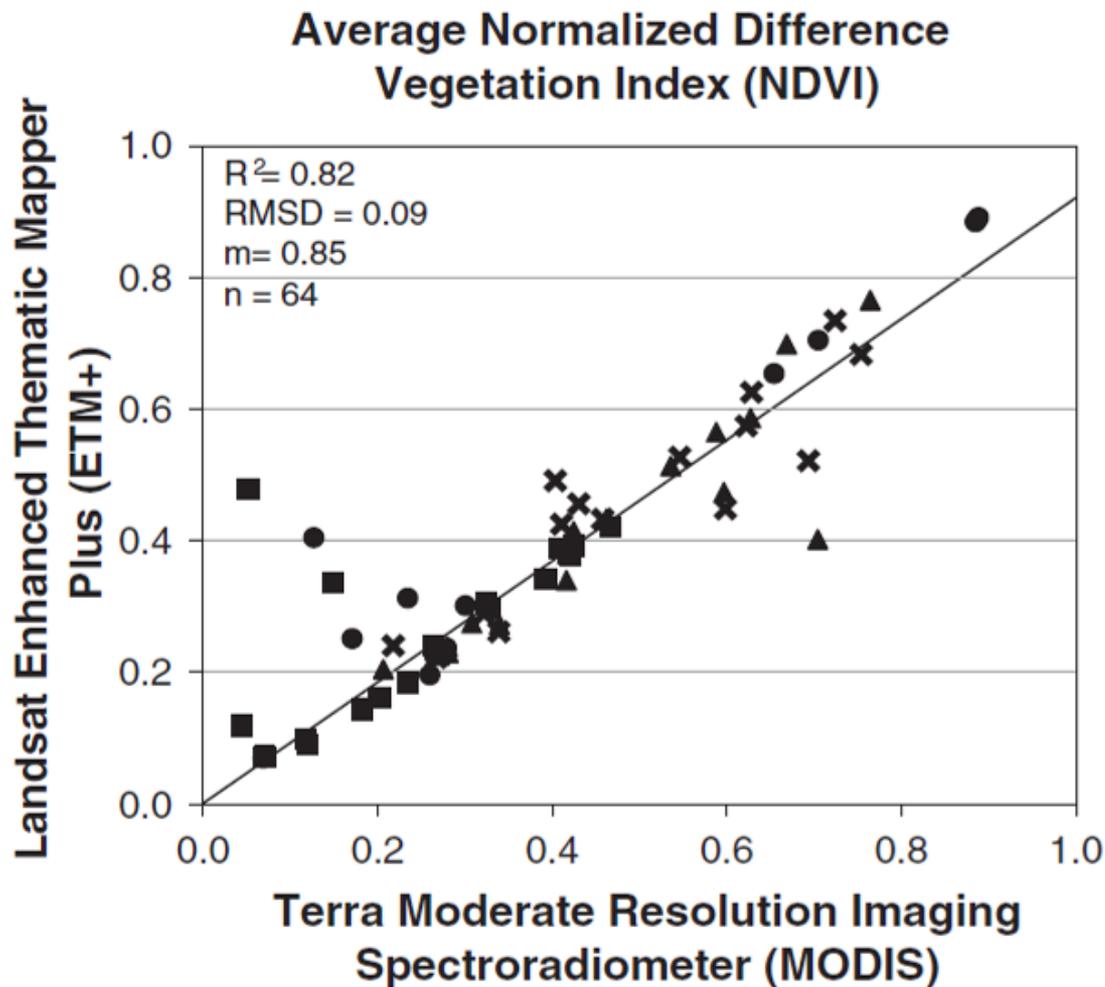
[http://landsat.usgs.gov/documents/si\\_product\\_guide\\_v12.pdf](http://landsat.usgs.gov/documents/si_product_guide_v12.pdf)

<https://espa.cr.usgs.gov>

<http://landsat.usgs.gov/contactus.php>



# LEDAPS NDVI vs. MODIS NDVI



Statistic	NIR	Red	NDVI
R2	0.7165	0.5458	0.8238
RMSD	0.0572	0.0542	0.0866
Slope (m)	0.9412	0.6368	0.8467
Intercept (b)	0.0125	0.0433	0.0475
Points (n)	64	64	64

- Surface Reflectance-derived NDVI
- Three years
  - 2002, 2005, 2006
- EOS Validation Sites
  - Mead
  - Bondville
  - Ft. Peck
- General linearity between data sets

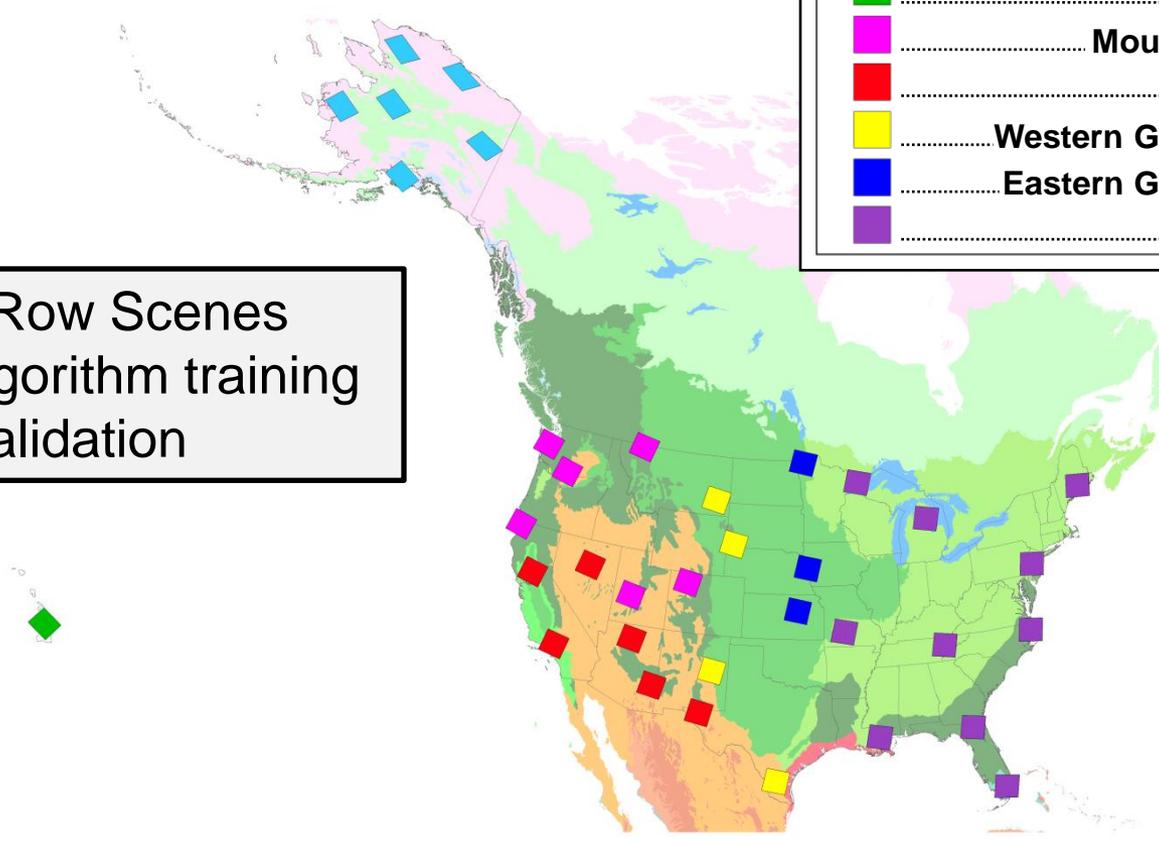
# Burned Area Essential Climate Variable

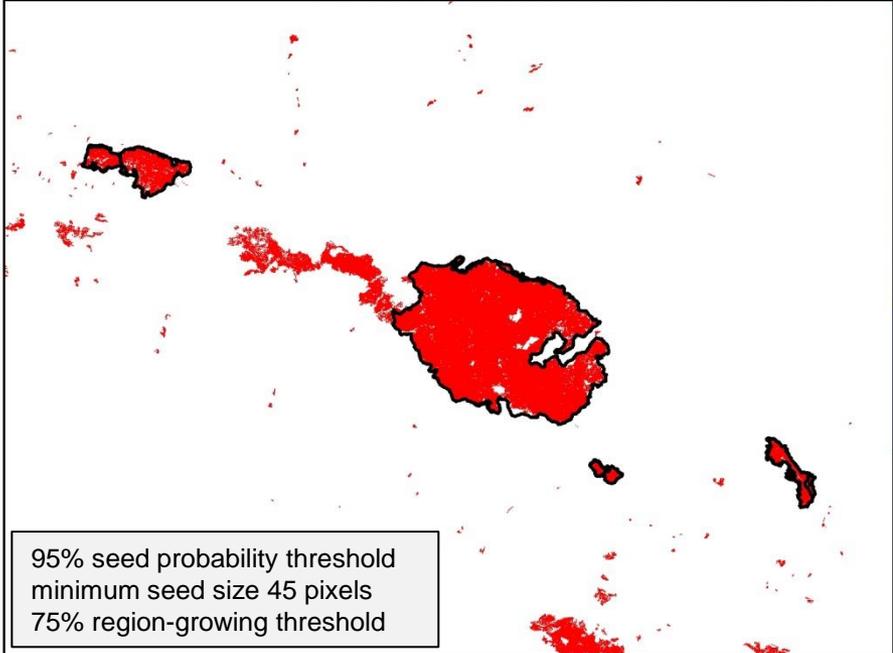
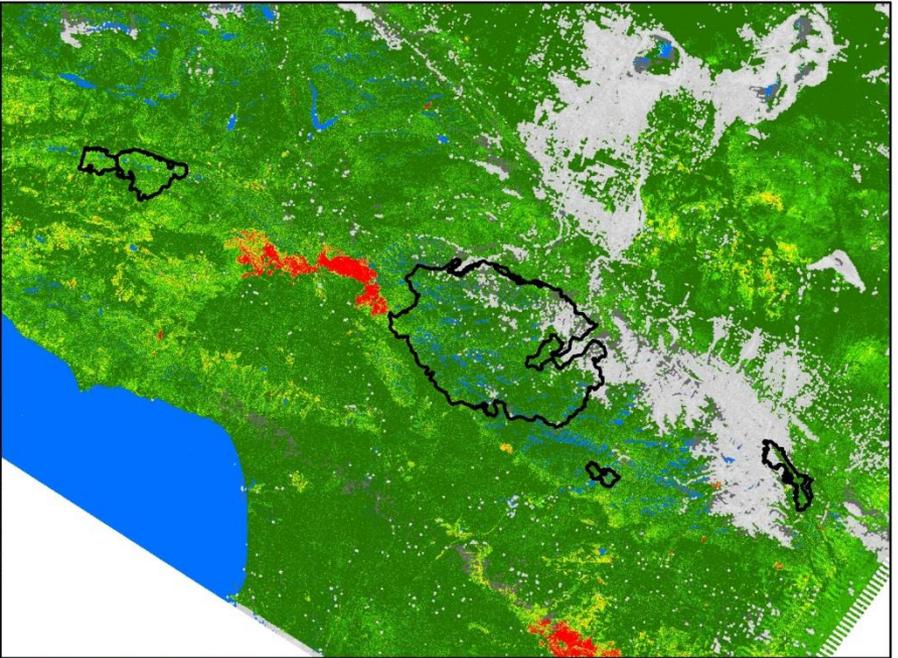
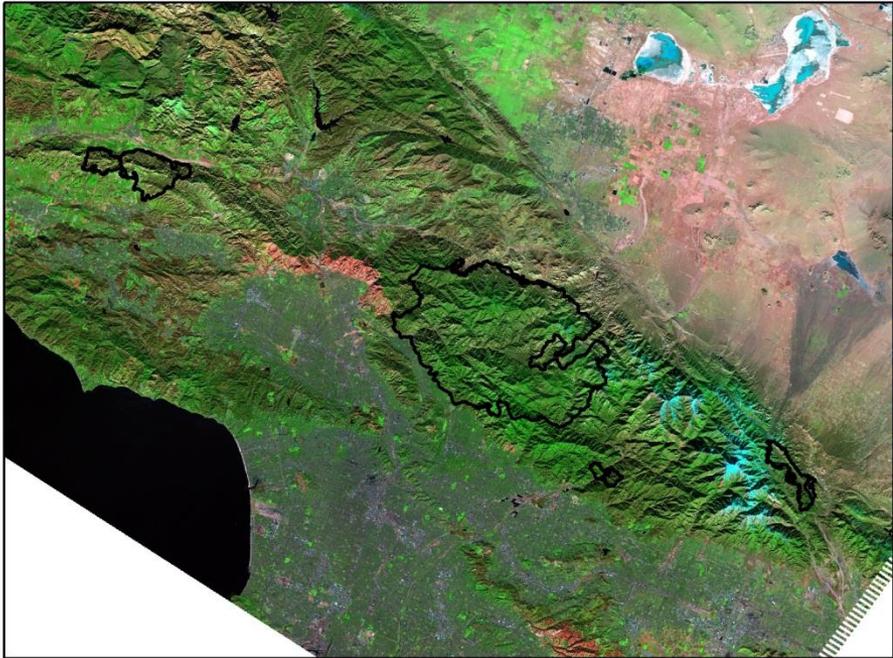
## Algorithm Status

### Algorithm Processing Zones

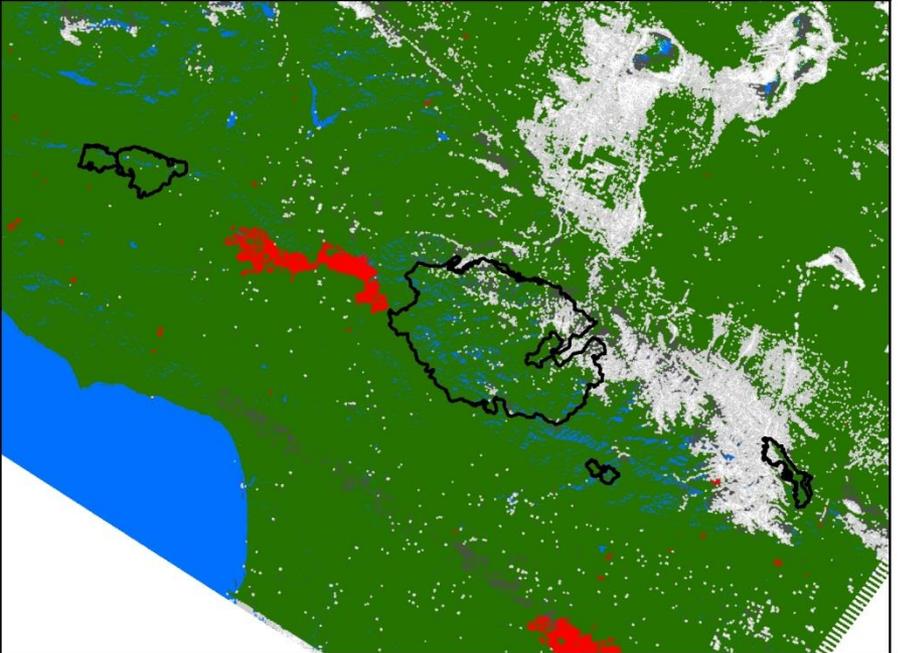
- Alaska
- Hawaii
- Mountain West
- Arid West
- Western Great Plains
- Eastern Great Plains
- East

Landsat Path/Row Scenes selected for algorithm training and Stage 2 validation





95% seed probability threshold  
minimum seed size 45 pixels  
75% region-growing threshold

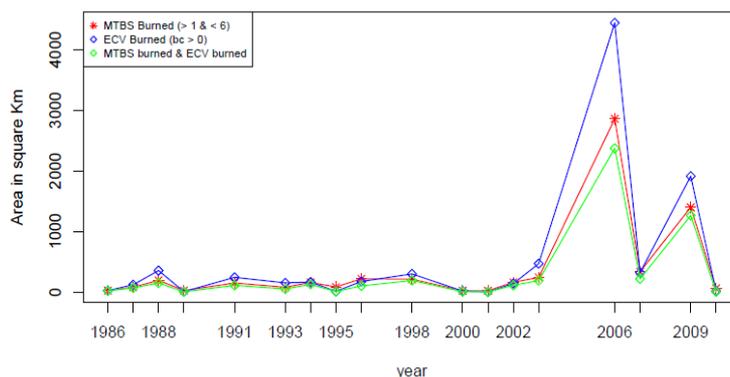


# Burned Area Essential Climate Variable

## Characterization of product uncertainties/validation

p028r033 MTBS & BAECV

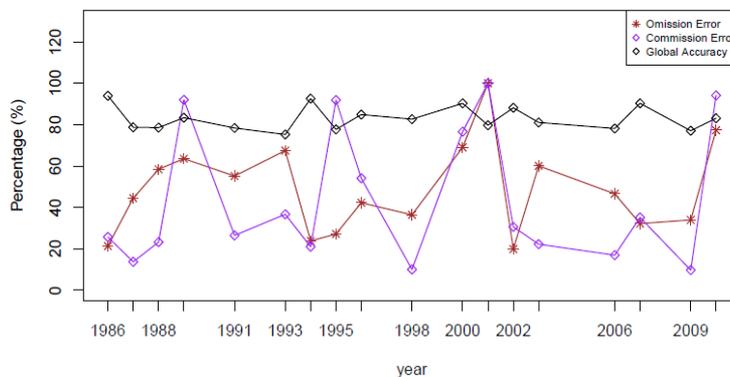
Total Burned Area per year  
Burned Area within grid (950, 45, 750)



From 1985 to 2010

Total of 523 MTBS polygons  
Total MTBS: 6300.95 Km2  
Total BAECV: 8849.82 Km2  
Agreed: 4970.05 Km2

Commission and Omission error and Accuracy Rate  
Burned Area within grid (950, 45, 750)



For all years

Accuracy: 80.72%  
Commission Error: 21.12%  
Omission Error: 43.84%

Mon, Sep. 16, 2013 (4:18:32 PM) MDT

# Cloud and Cloud Shadow Detection

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- **ACCA**

- ◆ Spectral threshold algorithm used on Landsat since 1999.

- **See5 CCA**

- ◆ Designed for use on LDCM, limited applicability elsewhere.
- ◆ Does not require thermal band.

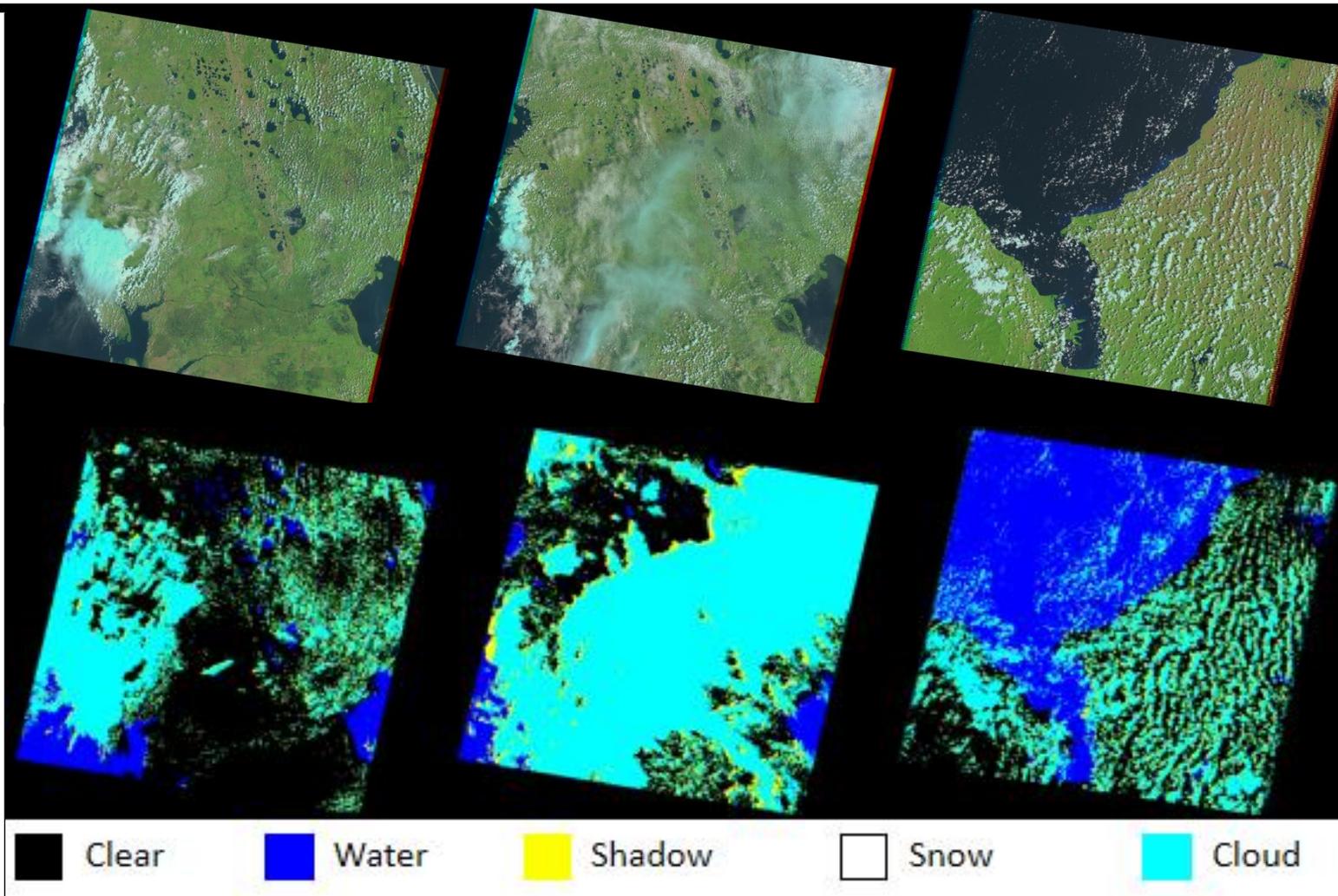
- **LEDAPS SR CCA**

- ◆ ACCA based algorithm that uses LEDAPS SR and surface temperature.

- **CFmask –**

- ◆ Port of Function of Mask (Fmask) from Boston University into C.
- ◆ Performs cloud shadow masking.
- ◆ <http://code.google.com/p/cfmask/>

# Cloud and Cloud Shadow Detection



# Cloud Cover Validation Results

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Cloud Algorithm	Total Pixels Correct (ETM+ Global Validation)
ACCA	79.90%
LEDAPS SR CCA	85.70%
See5 CCA	88.50%
CFmask	90.97%

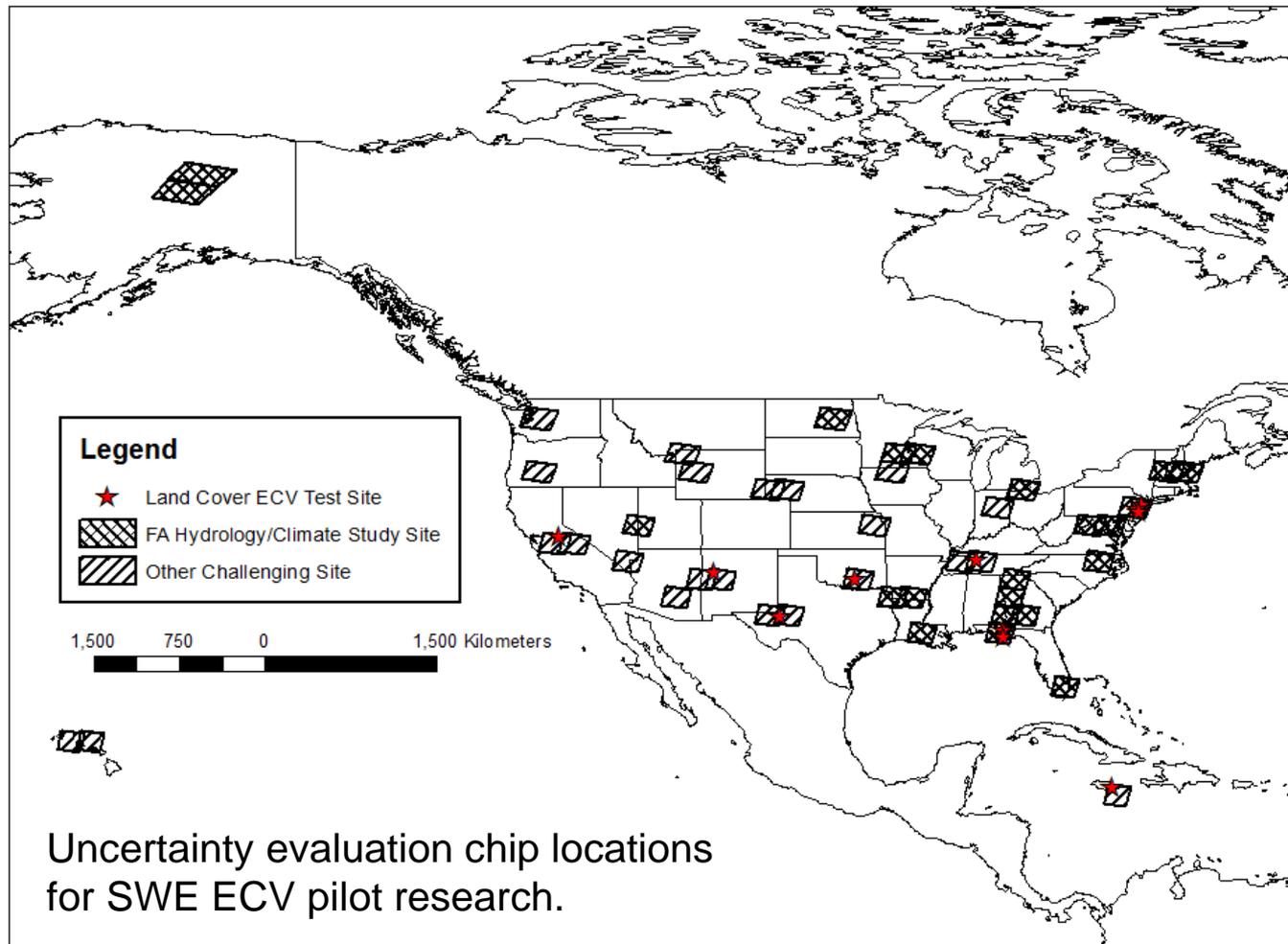
Fmask:

Zhu, Z., and Woodcock, C.E. "Object-based cloud and cloud shadow detection in Landsat imagery." *Remote Sensing of Environment* 118 (2012): 83-94.

ACCA (mask version) and See5 CCA:

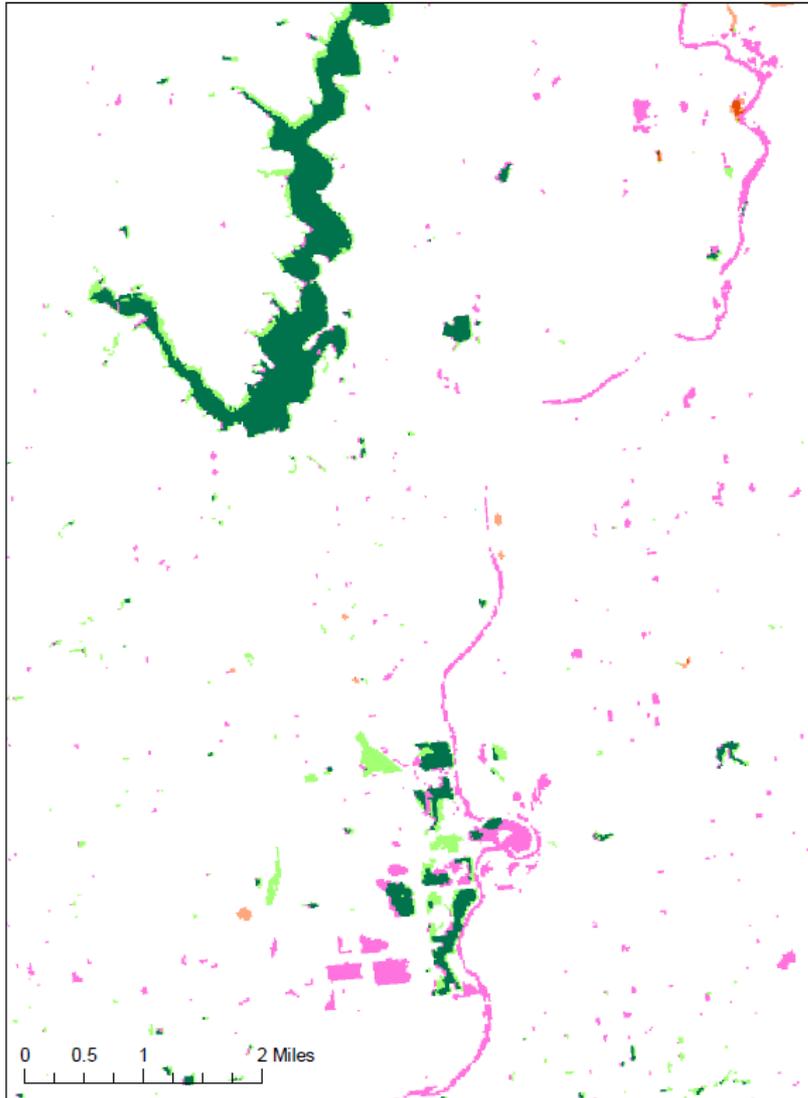
Scaramuzza, P.L., Bouchard, M.A. and Dwyer, J.L. "Development of the Landsat Data Continuity Mission Cloud-cover Assessment algorithms." *Geoscience and Remote Sensing, IEEE Transactions on* 50.4 (2012): 1140-1154.

# Landsat Surface Water Extent ECV

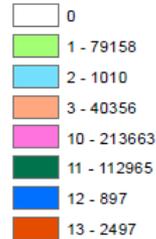


# Landsat Surface Water Extent ECV

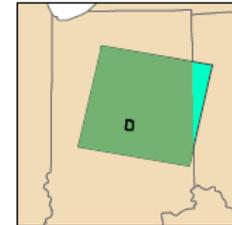
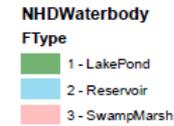
IN\_P21\_R32\_2005\_04\_25\_tm5\_NHD\_jwv1\_compare



## Legend



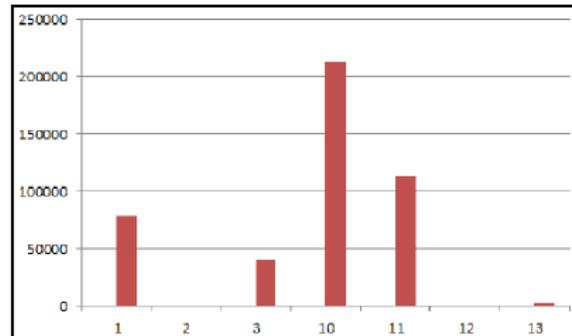
## Legend



Location (Scene p21r32, NHD compare area, and detail area).

The SWE JWJV1 output (0 - not water, 10 - water) and the NHD data (0-3) were added together to create an output comparing the two inputs (Values 0,1,2,3,10,11,12,13).

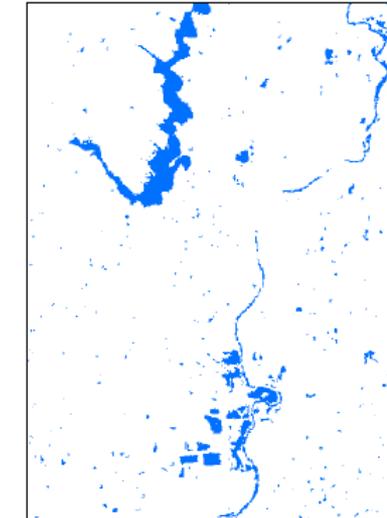
Chart showing comparison values (JWJV1 and NHD data).



NHD vector data (Waterbodies only)



IN\_P21\_R32\_2005\_04\_25\_tm5\_jwv1



# Snow Covered Area

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- Spectral unmixing approach is used to estimate fraction of Landsat pixel covered by snow, vegetation, and soil.
- Algorithm originally developed for hyperspectral instruments, then adapted for use with multispectral MODIS data (MODSCAG).
- Most recently adapted for use with Landsat TM and ETM+ instruments (TMSCAG).

Painter, T.H., et al. "Retrieval of subpixel snow-covered area and grain size from imaging spectrometer data." *Remote Sensing of Environment* 85.1 (2003): 64-77.

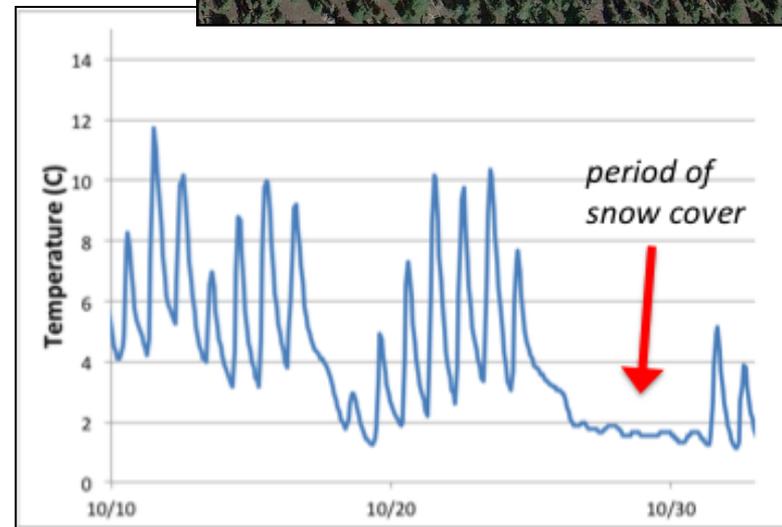
# Snow Covered Area

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- **Landsat Scene-based fSCA Validation**
  - High resolution imagery
  - In situ sensor arrays
    - 900+ sensors, 45 sites, 5 states
    - 13 sites above alpine treeline (Colorado), 5 sites in the Arctic
    - 3 sites with 49 sensors per 60 m<sup>2</sup> to test optimum sensor density
- **Product Implementation plan**
  - Phase 1: Landsat scene-based viewable fraction of Snow Covered Area (fSCA) product
  - Phase 2: Landsat-MODIS daily 30 m viewable fSCA
  - Phase 3: Landsat scene-based and Landsat-MODIS daily 30 m canopy-adjusted fSCA

# SCA – *In Situ* Sensor Arrays

- Buried data loggers recording hourly temperature indicate presence/absence of snow cover
- Arrays allow for monitoring daily *in situ* fSCA for pixel footprints
- Adjacent sensor arrays allow for comparison between fSCA in forests/meadows or different forest densities



# Upcoming work

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- **Global Datasets**

- Historical
  - Current
  - Future
- Annual Products  
Mid-Decadal
- 
- The diagram shows two text labels, 'Annual Products' and 'Mid-Decadal', positioned to the right of three bullet points: 'Historical', 'Current', and 'Future'. Three arrows originate from the right side of these labels and point towards the three bullet points, indicating that both 'Annual Products' and 'Mid-Decadal' data are used to generate 'Historical', 'Current', and 'Future' datasets.

- **Tiled Products**

- Web Enabled Landsat Data (WELD)

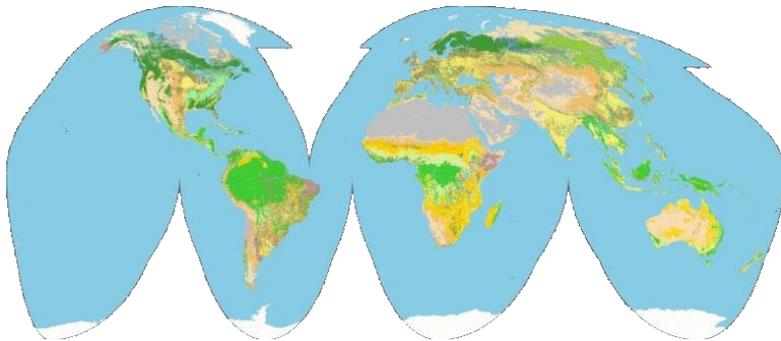
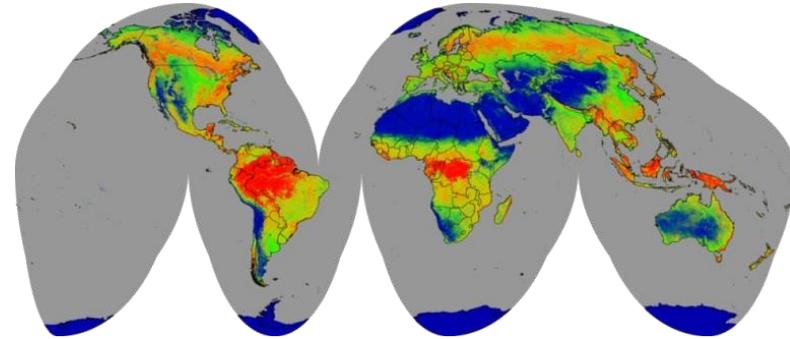
# Landsat Global 30m Land Cover

## *Historical, Current, and Future*

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### Annual products – Land cover continuous variables

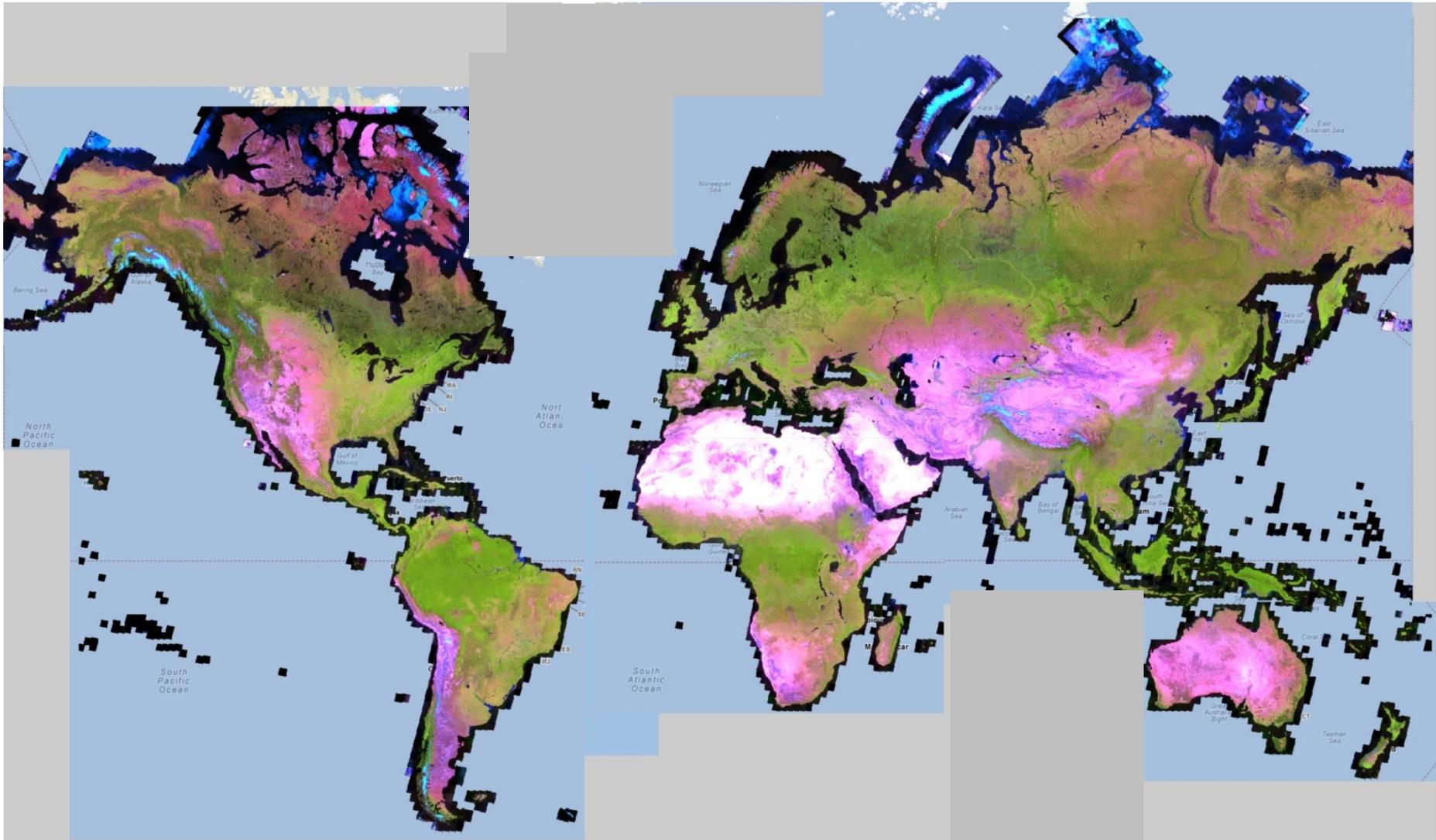
- Quantitative annual continuous measures per pixel percent tree, shrub, herbaceous, water, snow/ice, and barren cover.
- Change products



### Mid-decadal products – Land cover types

- Land cover categories consistent with FAO Land Cover Classification System (LCCS)
- Maps and statistical estimates of major land cover types
- Complementary with other global land cover products (e.g., MODIS land cover, Globecover)

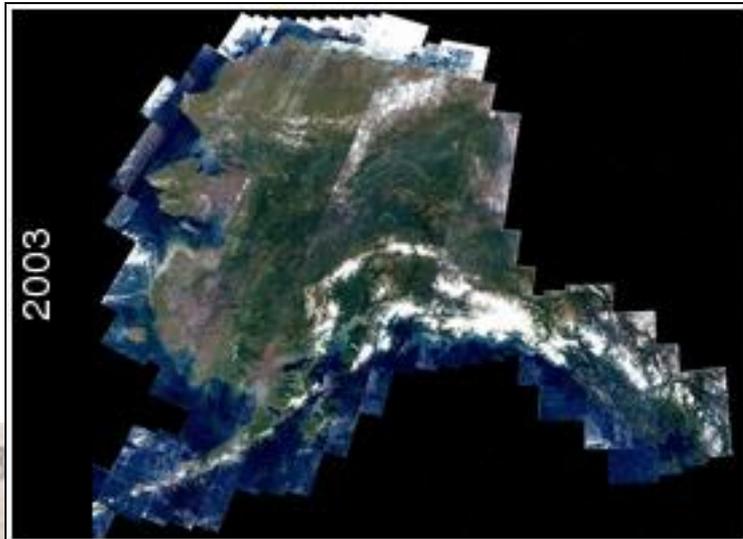
# Global “Cloud-Free” Landsat



# Web Enabled Landsat Data (WELD)

- **ETM+ Composites**

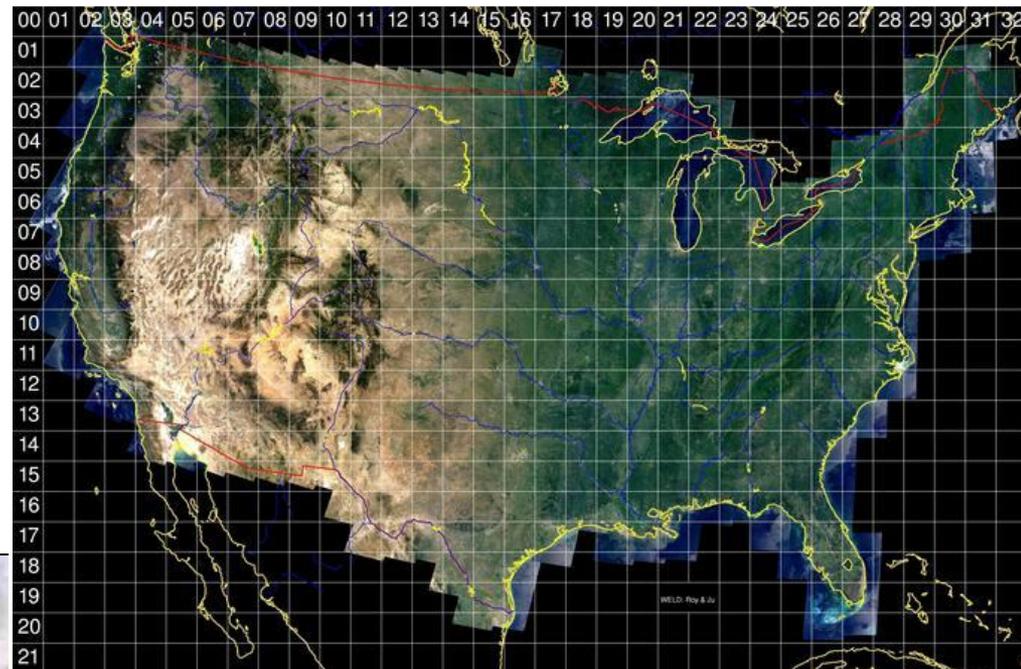
- ◆ L-1T mosaics
- ◆ CONUS and Alaska
- ◆ TOA Reflectance
- ◆ Weekly, Monthly, Seasonal, Annual
- ◆ 2003-2012
- ◆ Albers Equal Area



- **Distributed as**

- ◆ Tiles (5,000 x 5,000 pixels)
- ◆ User-defined Area of Interest

- **Illustrates a general goal: Retire the WRS path/row system**



# Land Product Validation System (LPVS)

- Allows users to order and analyze co-registered data for multiple satellites, for characterization and cross-validation of land products.
- Currently in beta, next phase in September 2014
- User feedback is encouraged

The screenshot shows the LPVS website interface. At the top, there is a navigation bar with the LPVS logo, USGS logo, and links for "USGS Home", "Contact USGS", and "Search USGS". Below this is a search bar and the title "Land Product Validation System (LPVS)".

The main content area is titled "Land Product Validation System (LPVS)" and includes a "Home" button. On the left, there is a vertical navigation menu with links for "About Landsat", "Gallery", "Science", "Product Information", "Frequently Asked", "Tools", "Education", and "Contact Us".

The main text area contains the following information:

- A "GOES-R" image and text: "Within the next few years the National Oceanic and Atmospheric Administration (NOAA) will launch two environmental satellites, the Geostationary Operational Environmental Satellite - R Series (GOES-R), and the Joint Polar Satellite System (JPSS). Each will carry instruments to monitor current meteorological conditions, observe information for use in numerical weather prediction models, and provide high quality products for monitoring trends in the long-term climate."
- A paragraph about the USGS Earth Resources Observation and Science Center (EROS) collaborating with NOAA to develop the LPVS, mentioning the use of data from USGS Landsat, ESA Sentinel, and JPSS sensors.
- A paragraph stating that the LPVS will include data access, inventory, and analysis functions, and is currently in a prototype phase (2012) and a beta operational phase (2013).
- Links for "Access LPVS Prototype Data Search and Retrieval Services", "Access LPVS Prototype Test Site Trending", "Community Feedback Form", and "User Support".

At the bottom, there is a "Project Partners" section with logos for NOAA, GOES, JPSS, and the Landsat Program. The footer includes accessibility information, FOIA, Privacy, and Policies and Notices, along with the USGS logo and the URL <http://landsat.usgs.gov>.

<http://landsat.usgs.gov/LPVS.php>

JACIE-ASPRS 2014  
March 27, 2014

# Land Product Validation System (LPVS)

- Planned Data sets include CDRs and ECVs from:

- ◆ Landsat (L4 and L5 TM, L7 ETM+, L8 OLI/TIRS)
- ◆ MODIS

} Operational

- ◆ GOES-R Advanced Baseline
- ◆ ESA Sentinel series
- ◆ JPSS
  - Suomi NPP
  - JPSS1
- ◆ ...and others

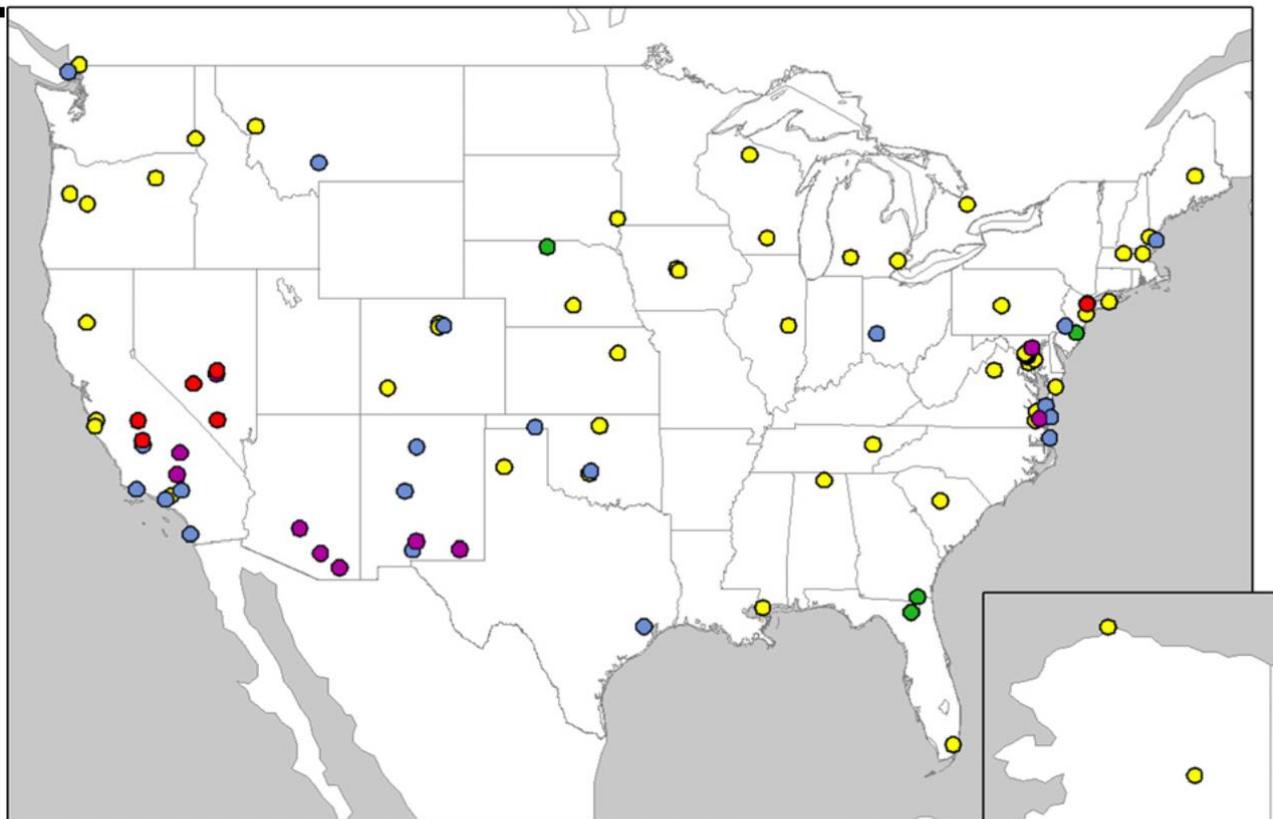


<http://lpvsexplorer.cr.usgs.gov/>

***End of presentation  
(Supporting Slides after this)***

# LEDAPS AOT vs. AERONET

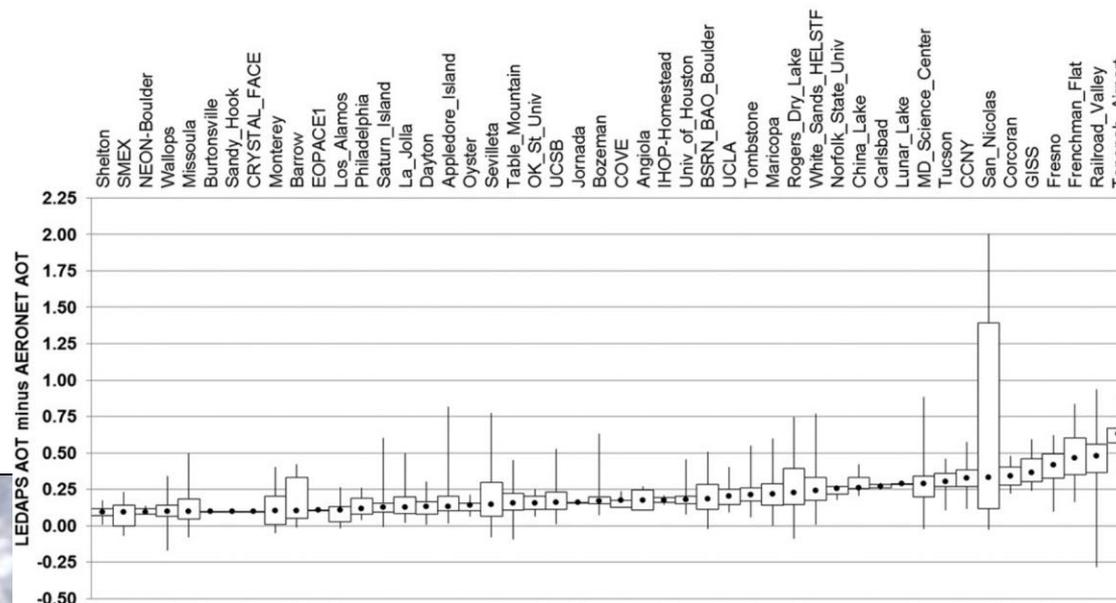
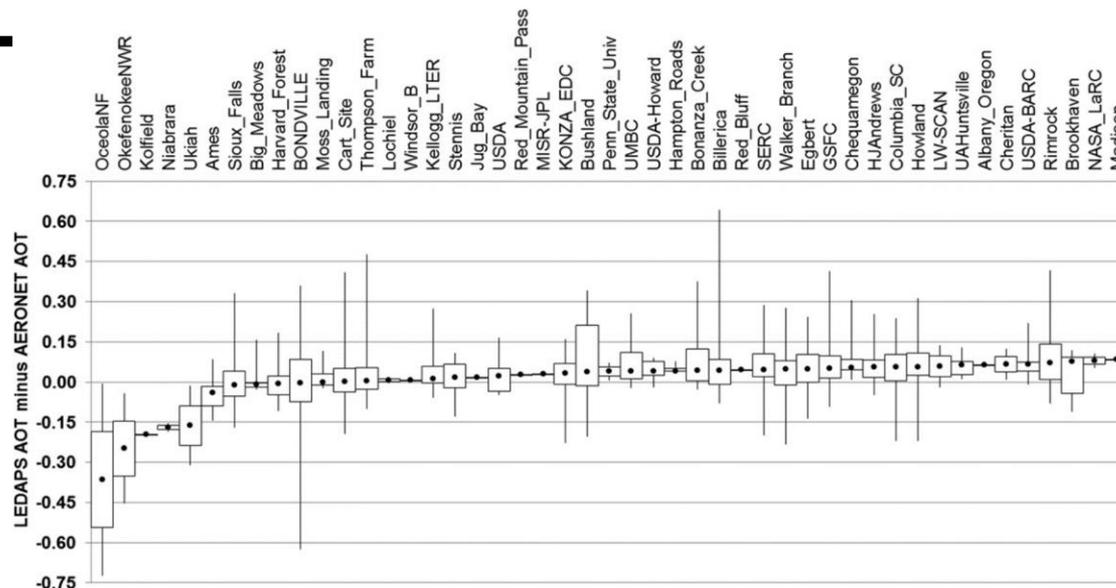
- Nationally distributed sites
- Relationships evaluated by difference classes to remove bias



Color	Site Class	Median AOT Difference	Sites
Green	1	< -0.10	4
Yellow	2	-0.10 - 0.10	54
Blue	3	0.11 - 0.20	20
Purple	4	0.21 - 0.30	10
Red	5	> 0.30	7

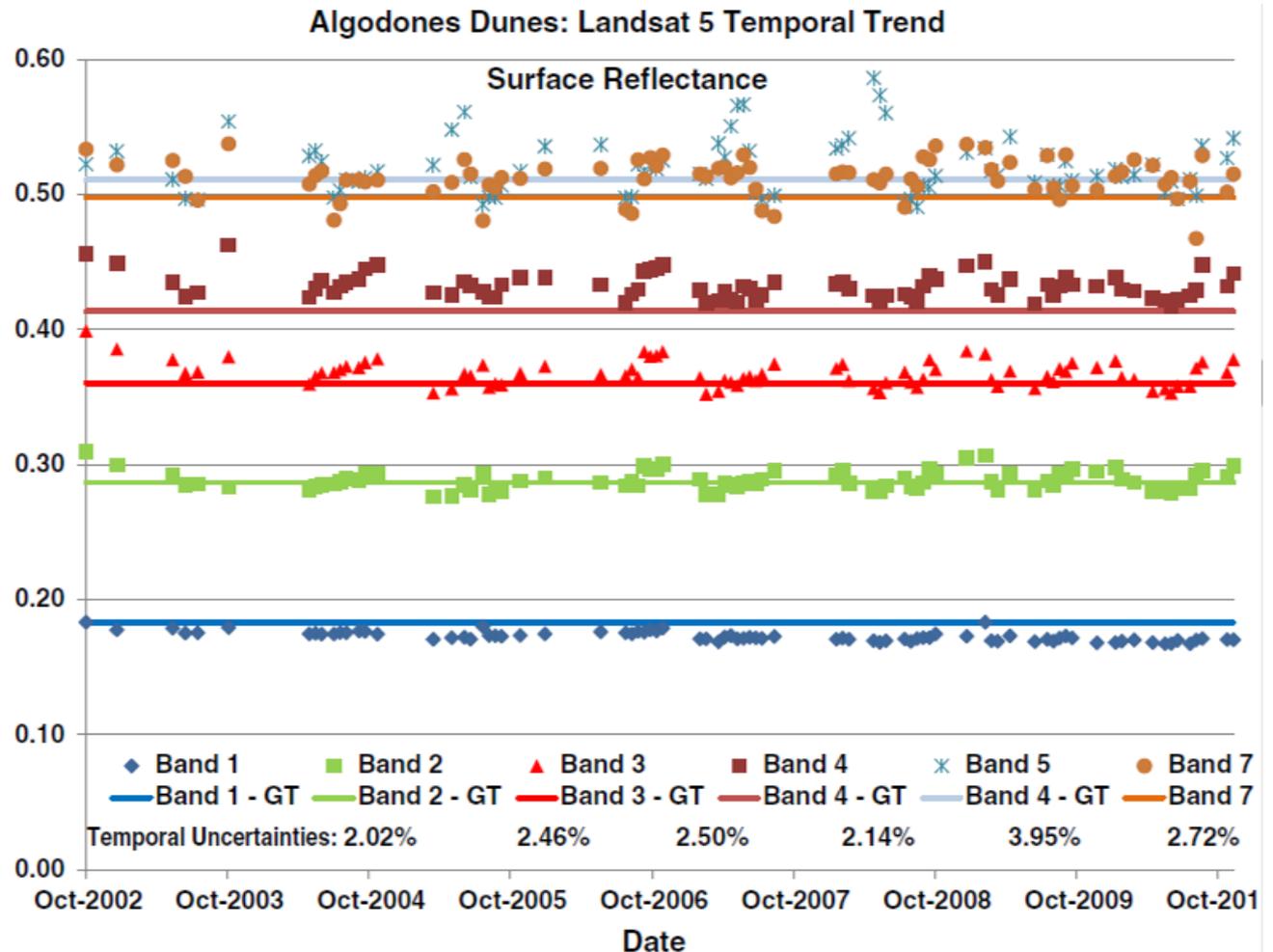
# LEDAPS AOT vs. AERONET

- 95 sites
- 3,471 Observations
- Correlation:  
0.63 – 0.87
- Bias:  
-0.42 – 0.25
- RMSD:  
0.29 – 0.65



# Temporal Stability Analysis

- South Dakota State University
- CEOS Pseudo Invariant Calibration Sites
  - Algodones Dunes
  - Libya 4
- More variability in shorter wavelengths with most aerosol influence



# **Burned Area Essential Climate Variable**

## *Product specification*

### *Individual layers:*

- *Burn probability (0-100) and burn classification (0 or 1) layers with QA masks*

### *Annual summary layers:*

- *Burned probability and classification layers summarized for a calendar year (Jan-Dec)*
- *Maximum probability, first date of observed burn, number of observed burns, number of non-cloudy observations*

# **Burned Area Essential Climate Variable**

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## *Product specification*

### **Single-Date Image (e.g. derived from 1 landsat scene)**

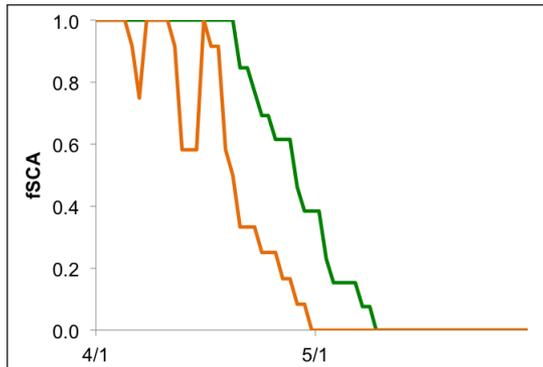
2 bands (8 bit unsigned integers)

Band 1, categorical:

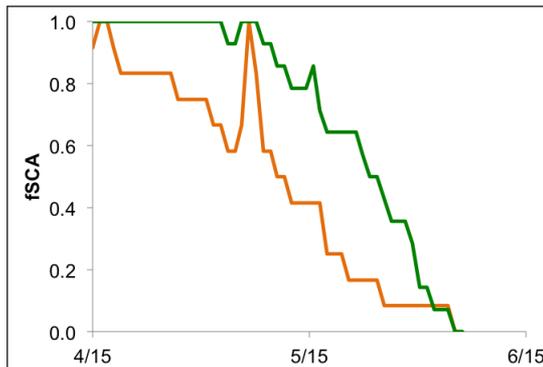
- 8 = 'fill' mask
- 7 = DDV mask (no longer used)
- 6 = cloud mask
- 5 = adjacent cloud mask
- 4 = cloud shadow mask
- 3 = snow/ice mask
- 2 = water mask
- 0 = not burned
- 1 = burned

Band 2 = burn probability from classification algorithm (0-100) and QA masks (negative numbers)

# Forest vs Meadow, Forest Density fSCA Comparisons

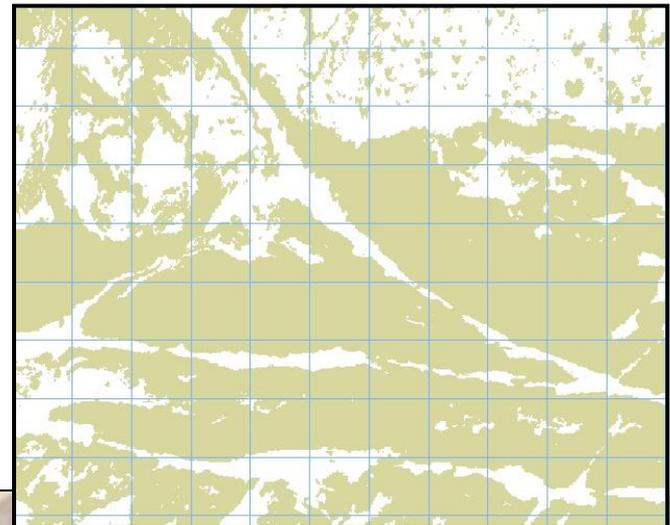
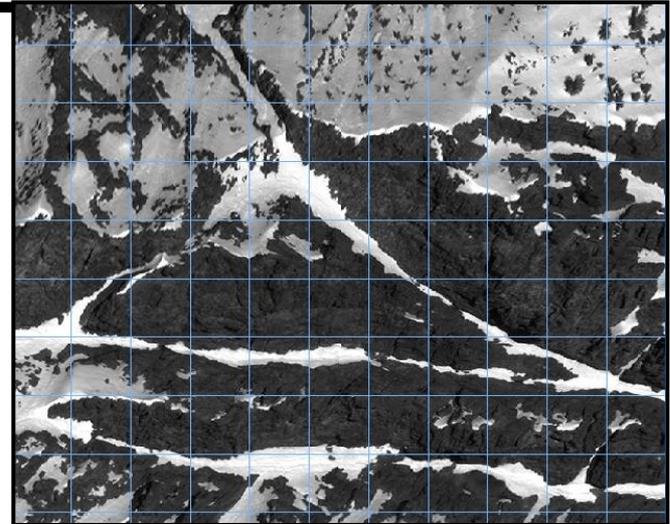


- Data from spring 2013 indicated longer snow persistence in forests than adjacent meadows (4-21 days)
- Additional sites for water year 2014 will compare meadows vs dense forest vs sparse forest
- This data will aid in adjusting fSCA under canopies using data from nearby open areas



# SCA – High Res Imagery

- Multispectral and panchromatic imagery classified to produce binary SCA
- Binary SCA then aggregated to 30 m fSCA and compared to Landsat-derived fSCA
- Approach works well in areas without forest cover
- Much more feasible and efficient using Digital Globe NGA archive



# Glossary

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## CDR – Climate Data Record

A time series of measurements with sufficient length, consistency, and continuity to identify climate variability and changes.

SR – Surface Reflectance

## ECV – Essential Climate Variable

Products that are based on CDR inputs, are technically and economically feasible for systematic observation, and that create an authoritative basis for regional to continental scale identification of historical change, monitoring current conditions, and helping to predict future scenarios.

AOT – Aerosol Optical Thickness

SCA – Snow Covered Area

fSCA – Forested Snow Covered Area

# Glossary (continued)

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## Spectral Index –

A product derived from CDRs that is useful but does not meet the criteria for ECVs.

NDVI – Normalized Difference Vegetation Index

EVI – Enhanced Vegetation Index

SAVI – Soil Adjusted Vegetation Index

MSAVI – Modified Soil Adjusted Vegetation Index

NDMI – Normalized Difference Moisture Index

NBR – Normalized Burn Ratio

NBR2 – Normalized Burn Ratio, second formulation

# Glossary (continued)

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LPVS –

Landsat Product Validation System

LEDAPS –

Landsat Ecosystem Disturbance Adaptive Processing System

ACCA –

Automated Cloud Cover Assessment algorithm

CFMask –

C code version of Function of Mask, a cloud and cloud shadow assessment algorithm.