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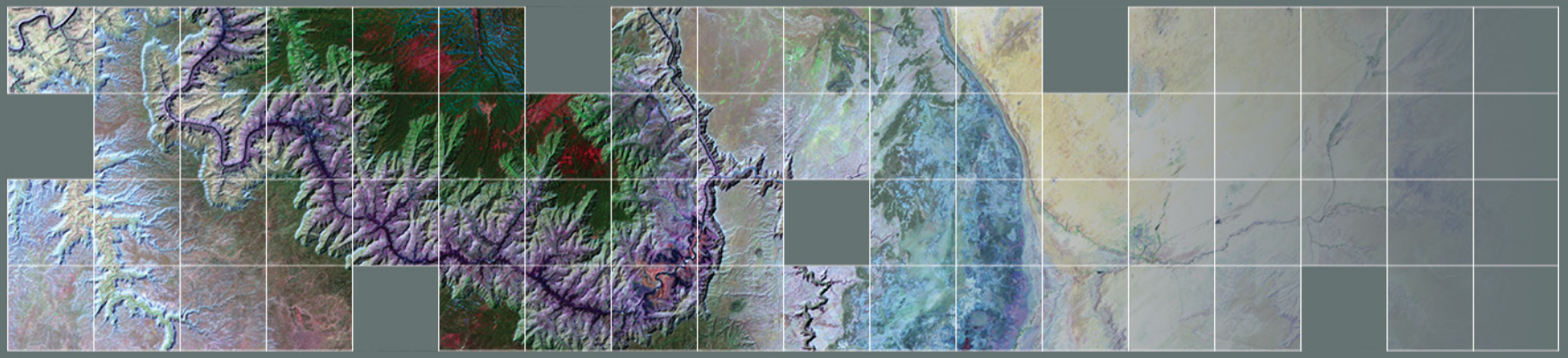
science for a changing world

Climate and Land Use Change
Earth Resources Observation and Science (EROS) Center

Landsat Surface Reflectance and Landsat Collection 1



Steve Foga, SGT Inc.
ABoVE Webinar
Friday, 21 April 2017

U.S. Department of the Interior
U.S. Geological Survey

Outline

- **Surface Reflectance**
  - Governing Theory
  - Landsat 4-7 (LEDAPS)
  - Landsat 8 (LaSRC)
- **Data Products**
- **Collection 1**

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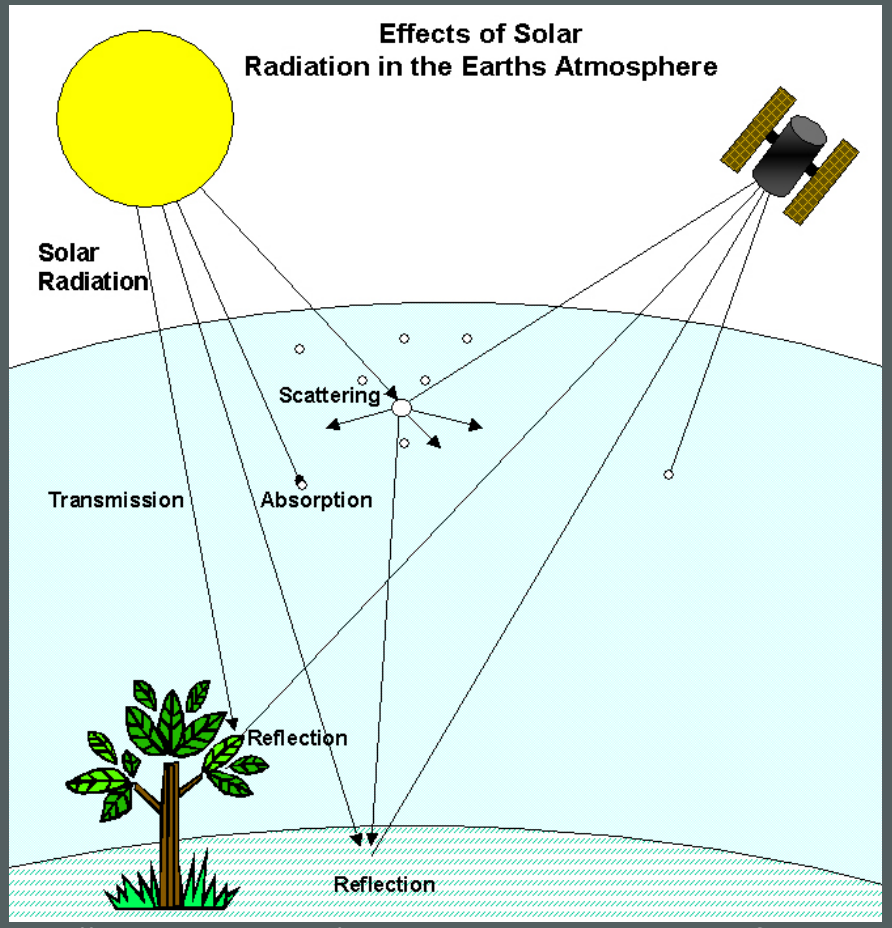
Governing Theory

- General concept & impact of atmospheric contamination



https://landsat.usgs.gov/atmospheric-transmittance-information

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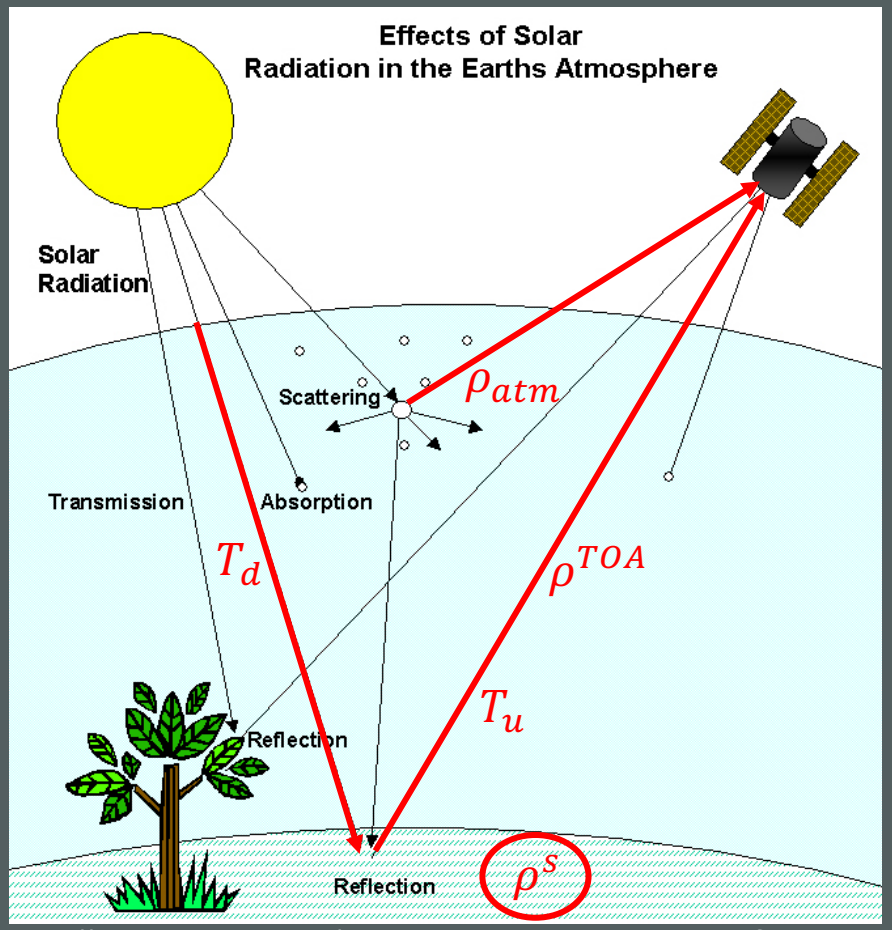
Governing Theory

$$\rho_{TOA} = \boldsymbol{O_3, H_2O, aerosols}\left[\rho_{atm} + \frac{T_d T_u \rho^s}{1 - s_{atm}\rho^s}\right]$$

Where:

- ρ_{TOA} = Top of Atmosphere reflectance
- $O_3, H_2O, aerosols$ = types of molecules
- ρ_{atm} = atmospheric spherical albedo
- T_d = downward atmospheric transmission
- T_u = upward atmospheric transmission from surface to sensor
- ρ^s = surface reflectance



https://landsat.usgs.gov/atmospheric-transmittance-information

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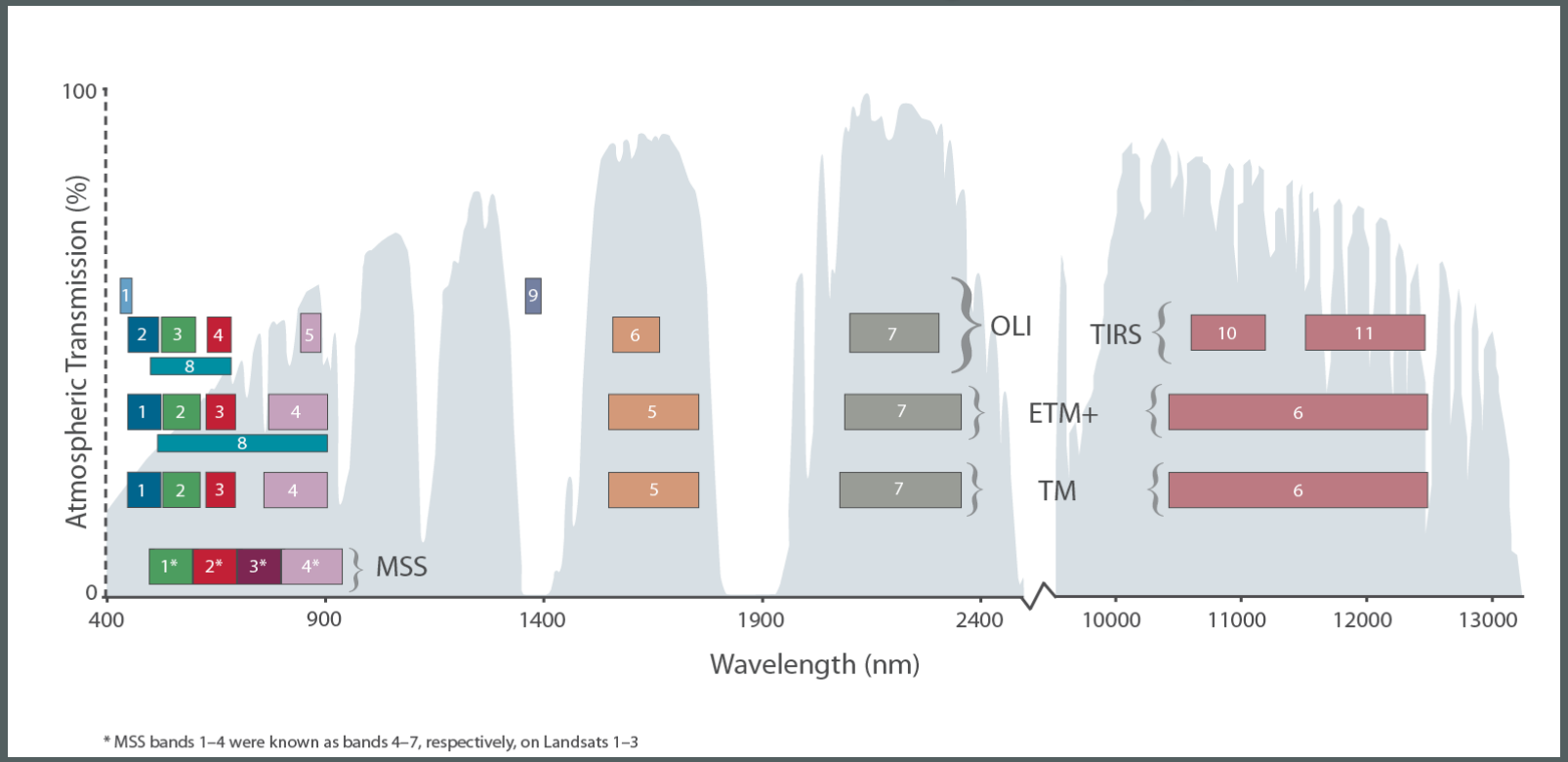
Governing Theory

- Landsat bandpasses optimized for atmospheric windows
- Visible bands more impacted by atmosphere



https://landsat.usgs.gov/how-does-landsat-8-differ-previous-landsat-satellites

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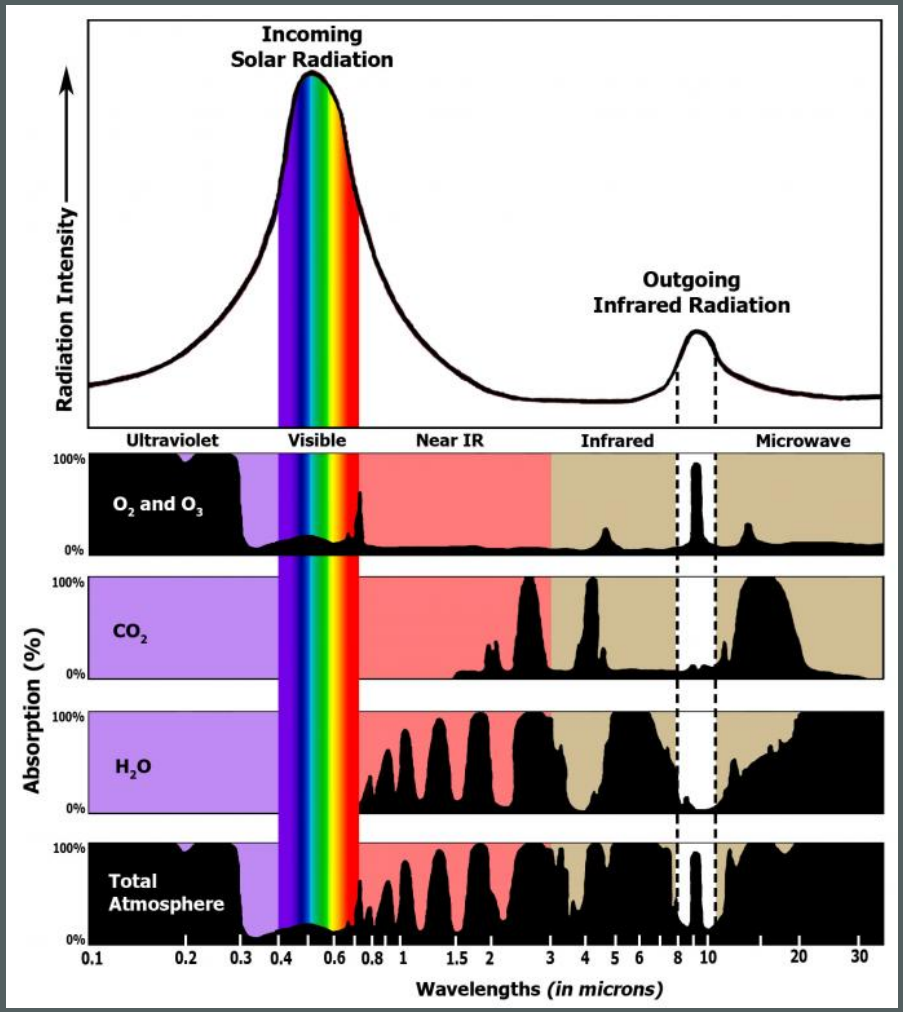
Governing Theory

- Different gases absorb at different wavelengths
- Visible impacted most by aerosols (not shown), ozone
  - Other molecules to lesser degree
- Longer wavelengths more affected by water vapor



http://www.ces.fau.edu/nasa/module-2/how-greenhouse-effect-works.php

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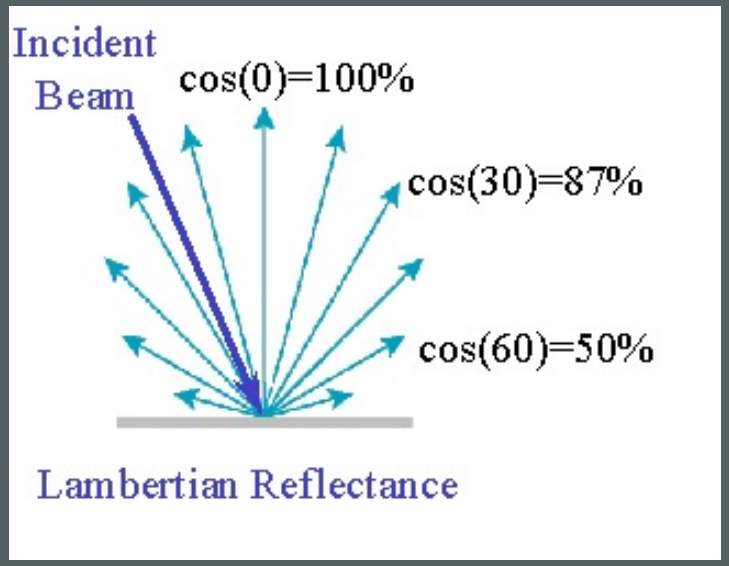
Governing Theory

- **Basic assumptions**
  - Lambertian target
  - Top of Atmosphere (TOA) reflectance as input
    - TOA ordered through USGS now corrected with per-pixel solar zenith angles



http://apps.usd.edu/coglab/schieber/trb2000/sld038.htm

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LEDAPS

- **Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS)**
- **Data product**
  - Developed at NASA GSFC
  - Landsat TM (4-5) and Landsat ETM+ (7)
  - Project began in 2004
  - Running at EROS since 2012
- **Algorithm overview**
  - Uses dark, dense vegetation (DDV) method to invert aerosols
  - Uses auxiliary data to estimate other gases, 6SV for radiative transfer

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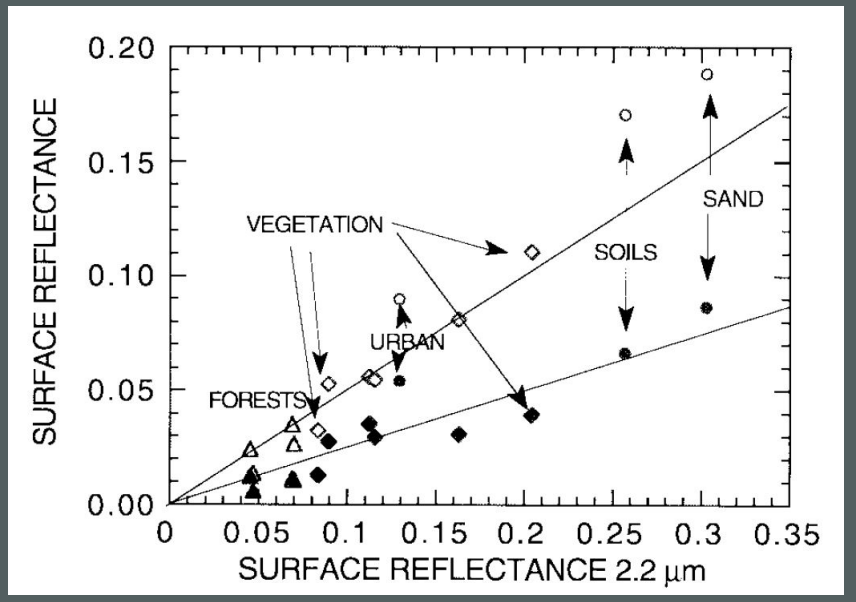
LEDAPS

- **Process (1/2)**
  - Estimate aerosol
    - Dark, dense vegetation (DDV) inversion method
      - Mask cloud, cloud shadow, snow/ice, water (LEDAPS' own algorithm)
      - Ratio of band 1 (blue) and band 3 (red) to band 7 (SWIR 2)
      - Kaufman et al., 1997 find inversion accuracy is better with more DDV in the scene



Kaufman et al., 1997, Figure 3
Hollow = blue band; Filled = red band

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LEDAPS

- **Process (2/2)**
  - Estimate ozone
    - Total Ozone Mapping Spectrometer (TOMS)
  - Estimate air temperature, surface pressure, precipitable water
    - National Centers for Environmental Prediction (NCEP) Reanalysis
  - Estimate all variables at different altitudes
    - Radiative transfer model
      - Second Simulation of a Satellite Signal in the Solar Spectrum vector code (6SV)

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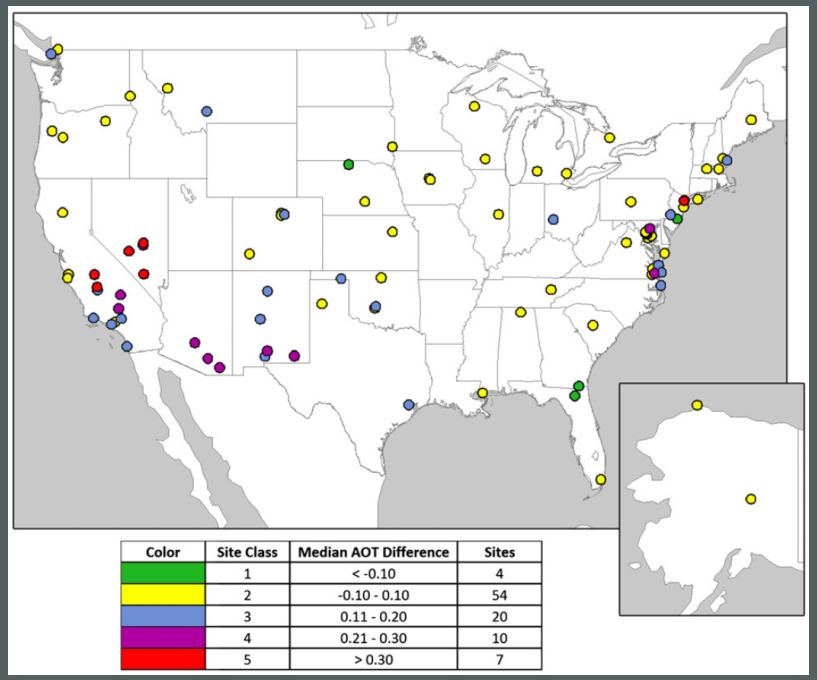
LEDAPS

- **Efficacy**
  - Maiersperger et al., 2013
    - Regional assessment of aerosol, reflectance values
  - AOT disagreement, subsequent SR disagreement higher where less vegetation exists



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

Maiersperger et al., 2013, Figure 2

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LEDAPS

- **Efficacy**
  - Most recent: Claverie et al., 2015
  - Accuracy, Precision, Uncertainty (APU)
    - Aerosol retrieval
      - Compared against Aerosol Robotic Network (AERONET); error budget ~5%
    - Reflectance
      - Compared against MODIS MO/YD09 (surface reflectance) data; error budget ~7%

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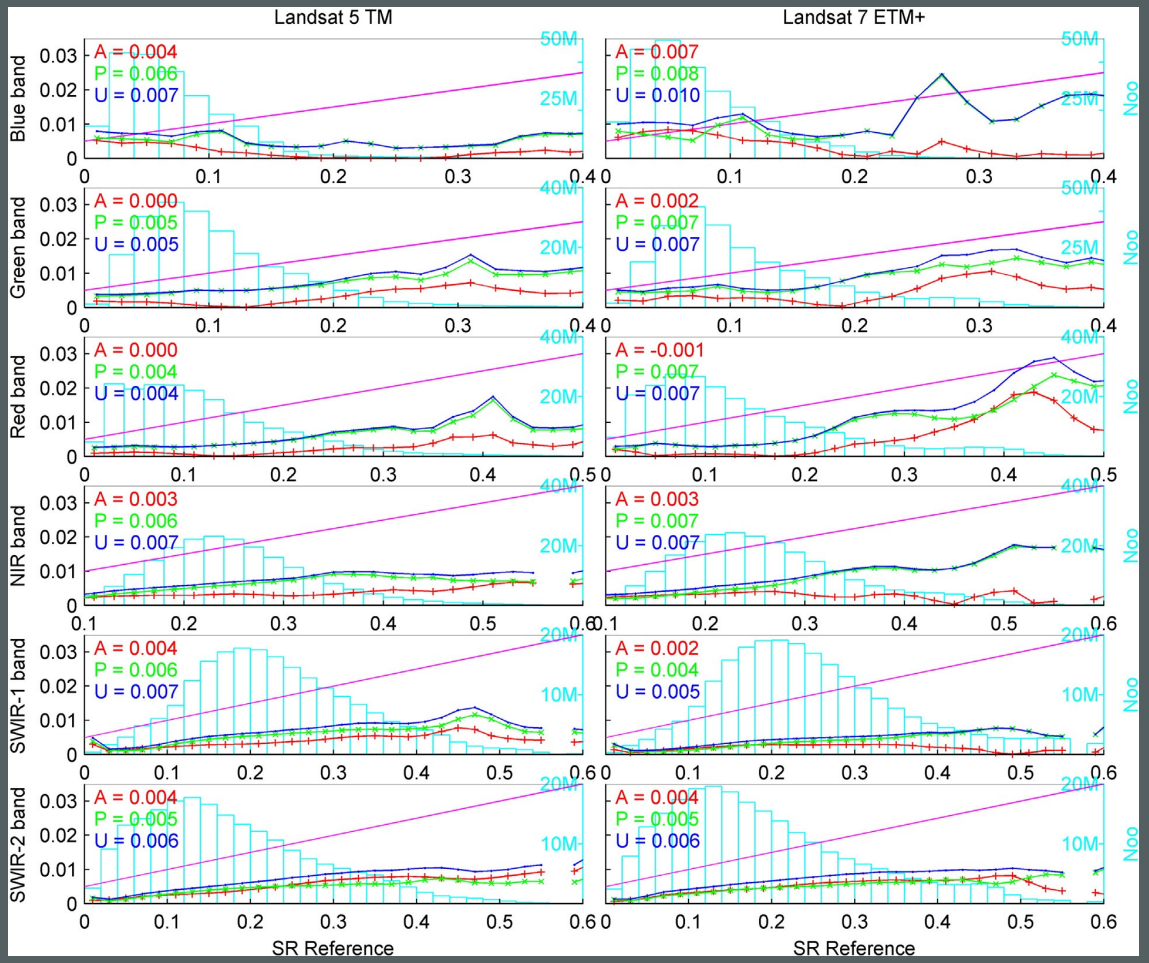
LEDAPS

- **APU for aerosol retrieval**
  - Error budget = pink line
    - Lower APU is better
  - X = SR value
  - Y = APU
  - All “within spec,” works better in longer wavelengths



Claverie et al., 2015, Figure 4

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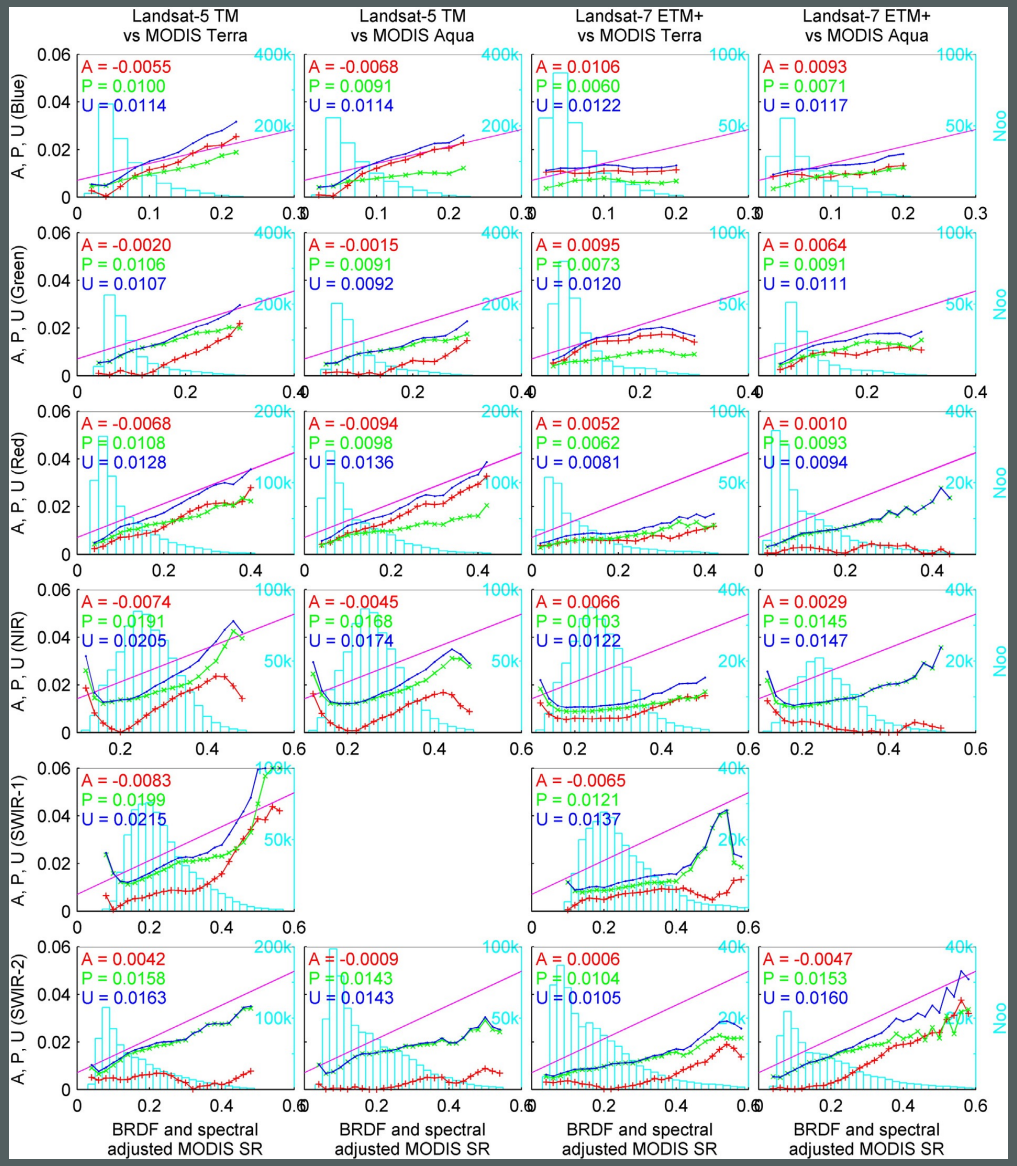
LEDAPS

- **APU for reflectance**
  - BRDF adjustments using MODIS data
  - Error budget = pink line
  - All “within” or “near” spec, dips out of spec when sample size decreases at higher aerosol concentrations



Claverie et al., 2015, Figure 9

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LaSRC

- **Landsat 8 Surface Reflectance Code (LaSRC)**
- **Data product**
  - Developed at NASA GSFC
  - Provisional products orderable from EROS since 2015
  - Latest version (released March 30, 2017) considered stable
- **Algorithm overview**
  - Takes advantage of coastal aerosol, cirrus bands
  - Uses MODIS climate grids for auxiliary data
  - Separate retrieval algorithm for pixel(s) identified as water

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LaSRC

- **Process**
  - Estimate aerosol
    - Model: “Urban Clean” type (most applicable)
      - LEDAPS builds own model with DDV
    - Adapted from MODIS Collection 6 algorithm
    - Uses bands 4 (red) and 1 (coastal aerosol) OR 4 and 2 (blue)
  - Estimate air temperature, water vapor
    - MOD09CMG (Climate Modeling Grid)
  - Estimate Ozone
    - MOD09CMA
  - Retrieval performed over all pixels
    - Uses different set of aerosol residuals over water than land

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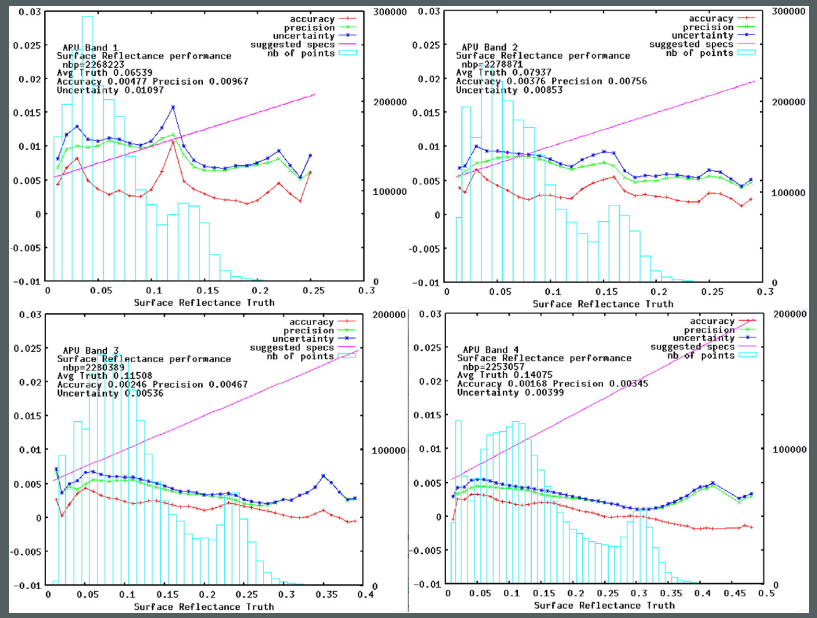
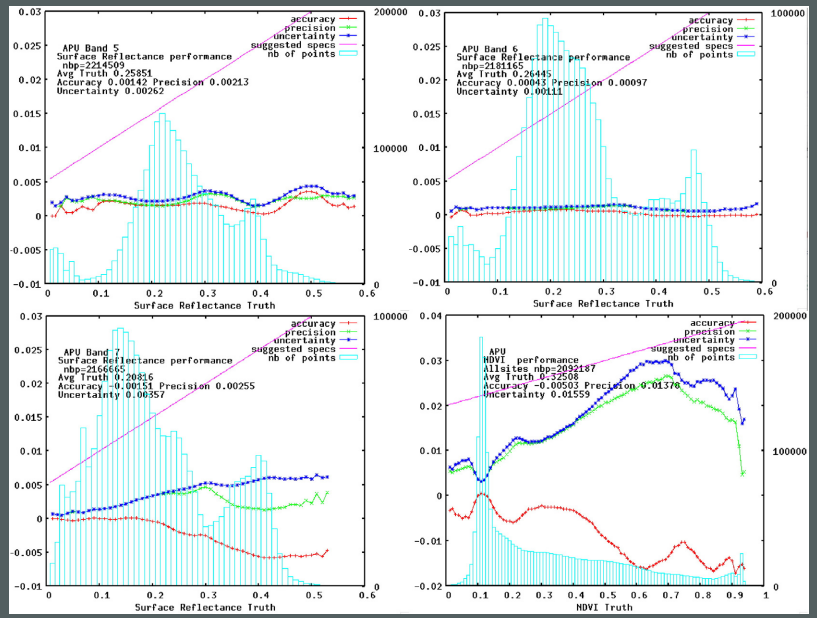
LaSRC

- **Efficacy**
  - Some characterization published in original paper
    - MODIS, AERONET observations alongside LaSRC



Vermote et al., 2016, Figure 8a
OLI Band 1 (UL), Band 2 (UR), Band 3 (LL), Band 4 (LR)



Vermote et al., 2016, Figure 8a
OLI Band 5 (UL), Band 6 (UR), Band 7 (LL), NDVI (LR)

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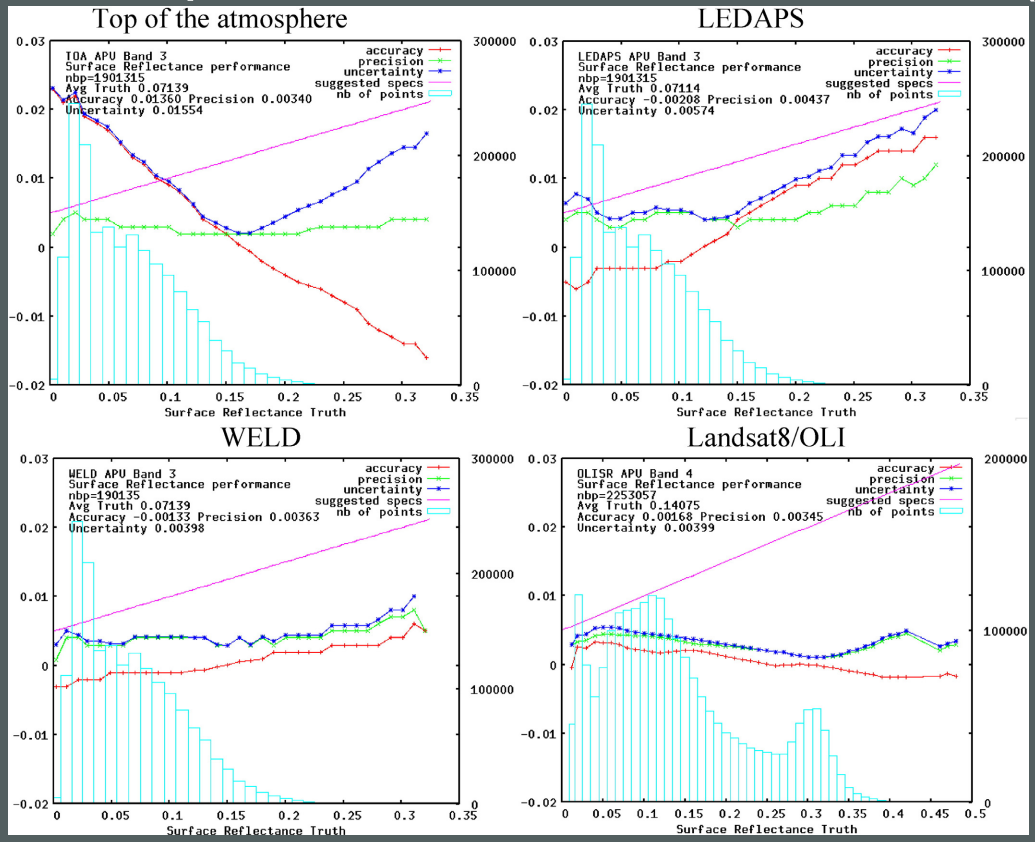
LaSRC

- **Efficacy**
  - Comparisons with other data sets (red band)



Vermote et al., 2016, Figure 7.

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LaSRC

- **Efficacy**
  - Other comparisons between LaSRC, LEDAPS, MODIS SR algorithms
    - Holden and Woodcock, 2016; Roy et al., 2016; Vogelmann et al., 2016
    - General findings
      - Agreement varies by band(s), land cover
      - More disagreement in shorter wavelengths (visible)
      - Enhanced Vegetation Index (EVI) agrees more than Normalized Difference Vegetation Index (NDVI)
        - Blue band in EVI helps cancel out atmospheric discrepancy in red/NIR bands

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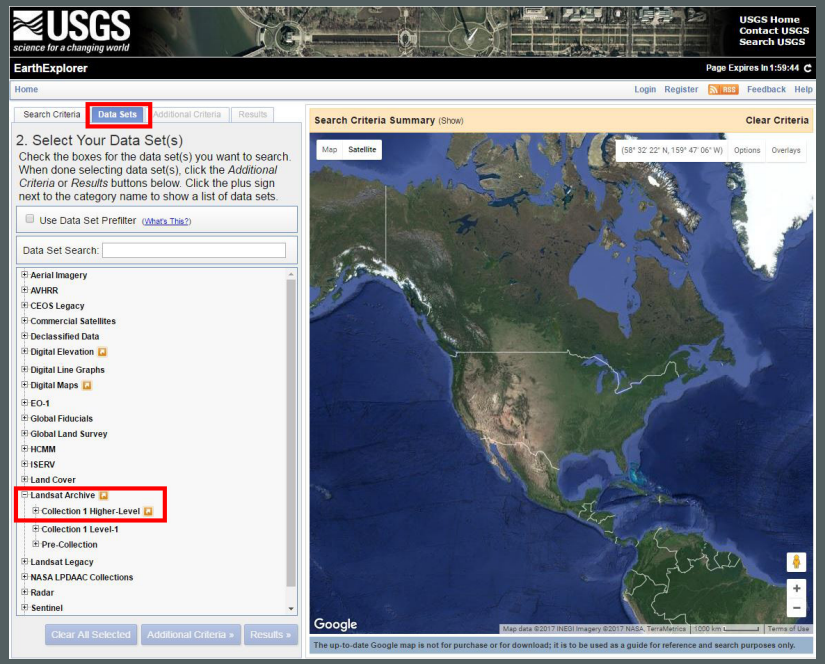
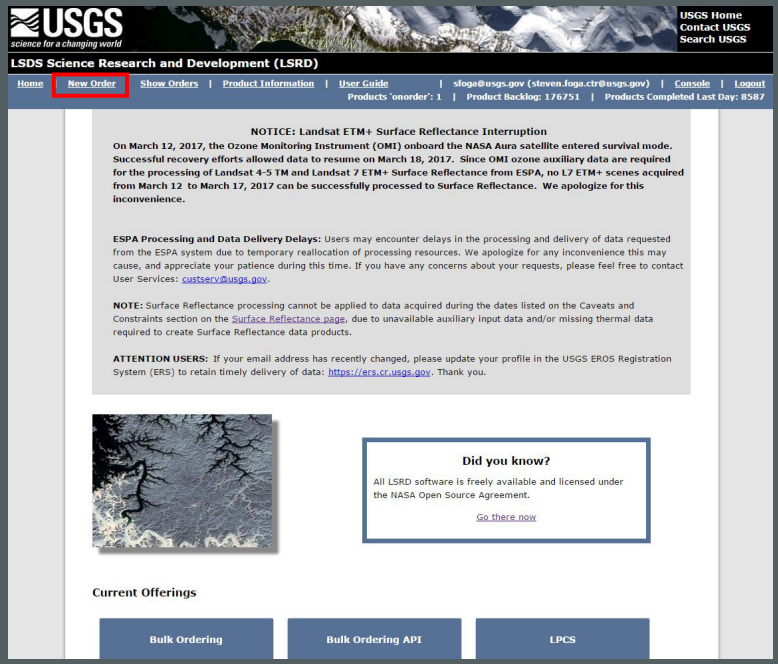
Data Products

- **Order data**
  - EarthExplorer (EE; https://earthexplorer.usgs.gov/)
  - EROS Science Processing Architecture (ESPA; https://espa.cr.usgs.gov/)
    - EE sends your orders to ESPA for SR processing



EE interface



ESPA interface

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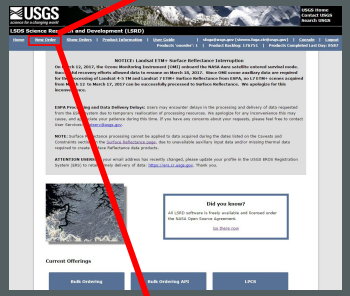
Data Products

- Order data



Add Input Products (Show Available Products)

Scene List

Choose File | No file chosen

Select Product Contents

Source Products

- Input Products
- Input Product Metadata

Additional Processing (Landsat Only)

Climate Data Records

- Surface Reflectance

Other Landsat Level-2 Products

- Top of Atmosphere Reflectance
- Brightness Temperature
- CFMask
- Spectral Indices

Customize Outputs

Customization Options

Output Format: GeoTiff | ENVI | HDF-EOS2 | NetCDF

- Reproject Products
- Modify Image Extents
- Pixel Resizing

Intercomparison & Statistics

- Plot Output Product Statistics

Add Order Description

Order Description (optional)

scene_list.txt

LE07_L1TP_044034_20170129_20170224_01_T1
LC08_L1TP_044034_20170121_20170218_01_T1
LE07_L1TP_044034_20170113_20170208_01_T1
LC08_L1TP_044034_20170105_20170218_01_T1
LE07_L1TP_044034_20161228_20170218_01_T1
LC08_L1TP_044034_20161220_20170218_01_T1

Other options:

- TOA Reflectance
- Brightness Temperature
- CFMask (“legacy” version of QA band that now comes with all Level-1 data)
- SR-based spectral indices (NDVI, EVI, NBR, etc.)
- Multiple output formats (ENVI, NetCDF, etc.)
- Reproject, subset, pixel resizing, statistics

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Data Products

- **Order data**
  - ESPA API
    - https://github.com/USGS-EROS/espa-api
    - Submit orders, check status, check available products & applicable order options
    - Returns messages in JavaScript Object Notation (JSON)

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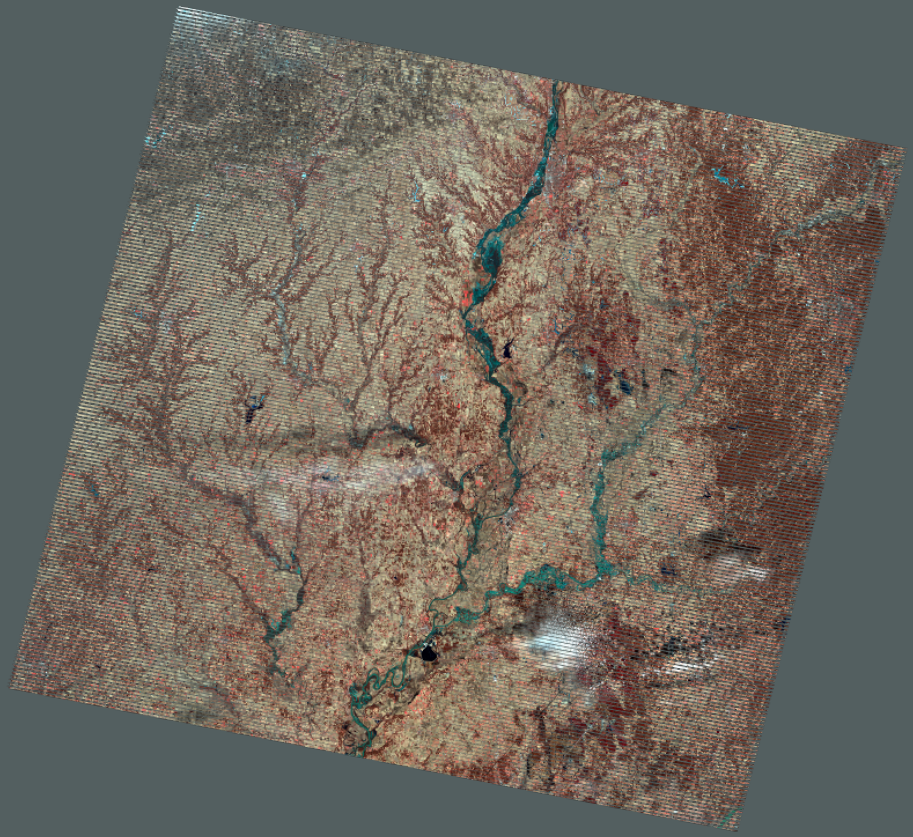
Data Products

- **LEDAPS**



Landsat 7 ETM+
WRS-2 Path 22, Row 33
Acq.: 28 February 2014
4,3,2 (false color IR)

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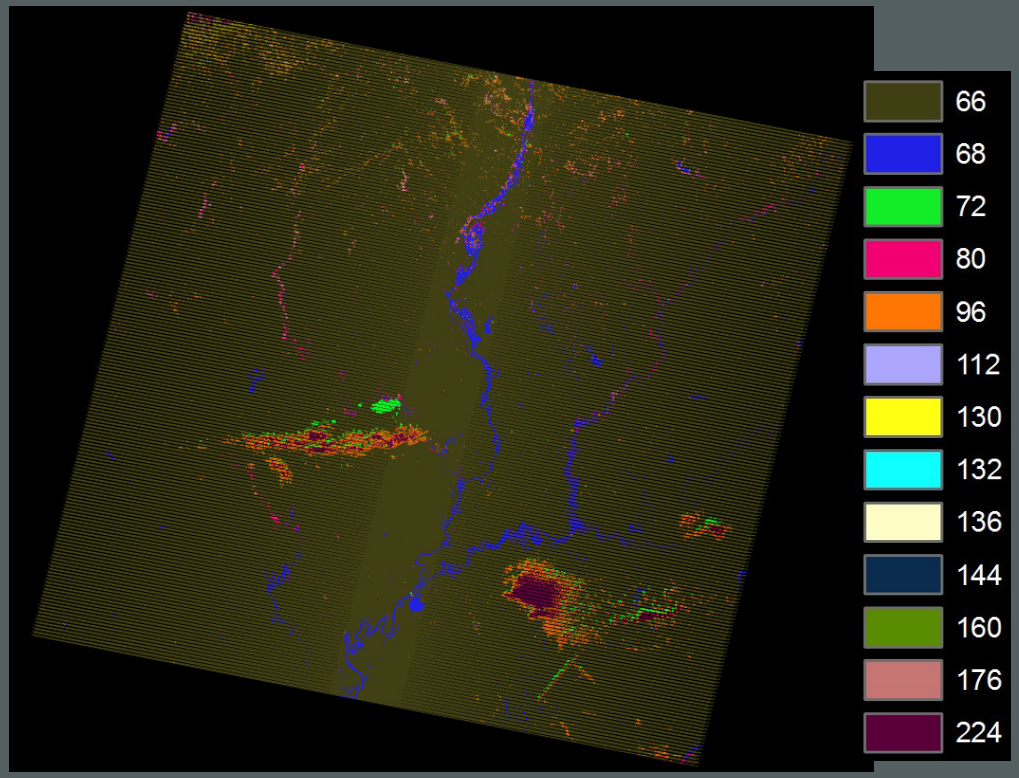
Data Products

- **LEDAPS**
  - pixel_qa band



Bit	Value	Cumulative Sum	Interpretation
0	1	1	Fill
1	2	3	Clear
2	4	7	Water
3	8	15	Cloud shadow
4	16	31	Snow
5	32	63	Cloud
6	64	127	Cloud Confidence 00 = None 01 = Low 10 = Medium 11 = High
7	128	255	
8	256	511	Unused
9	512	1023	Unused
10	1024	2047	Unused
11	2048	4095	Unused
12	4096	8191	Unused
13	8192	16383	Unused
14	16384	32767	Unused
15	32786	65553	Unused

- Bit-packed to allow flags for multiple conditions
- Most of this data available through Level-1 QA band (uses cfmask algorithm), but water bit added, and ‘cloud’ bit dilated in Level-2 processing.

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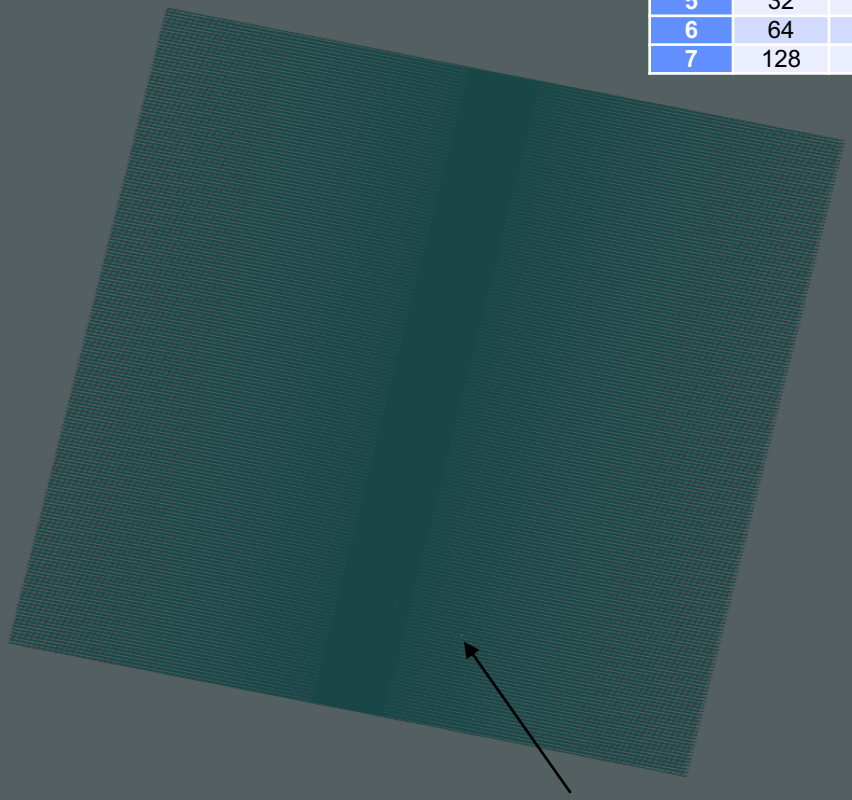
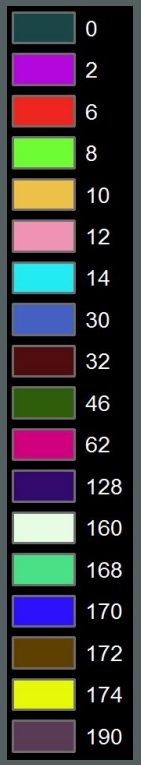
Data Products

- **LEDAPS**
  - radsat_qa band

Bit	Value	Cumulative Sum	Description
0	1	1	Data Fill Flag (0 valid data, 1 invalid data)
1	2	3	Band 1 Data Saturation Flag (0 valid data, 1 saturated data)
2	4	7	Band 2 Data Saturation Flag (0 valid data, 1 saturated data)
3	8	15	Band 3 Data Saturation Flag (0 valid data, 1 saturated data)
4	16	31	Band 4 Data Saturation Flag (0 valid data, 1 saturated data)
5	32	63	Band 5 Data Saturation Flag (0 valid data, 1 saturated data)
6	64	127	Band 6 Data Saturation Flag (0 valid data, 1 saturated data)
7	128	255	Band 7 Data Saturation Flag (0 valid data, 1 saturated data)





- Bit-packed to allow flags for multiple conditions
- Derived from L1 DNs (== 255)
- Saturation more common over clouds in shorter wavelengths (e.g., visible)
- Can pull pixels with any saturation (> 0) or by band.

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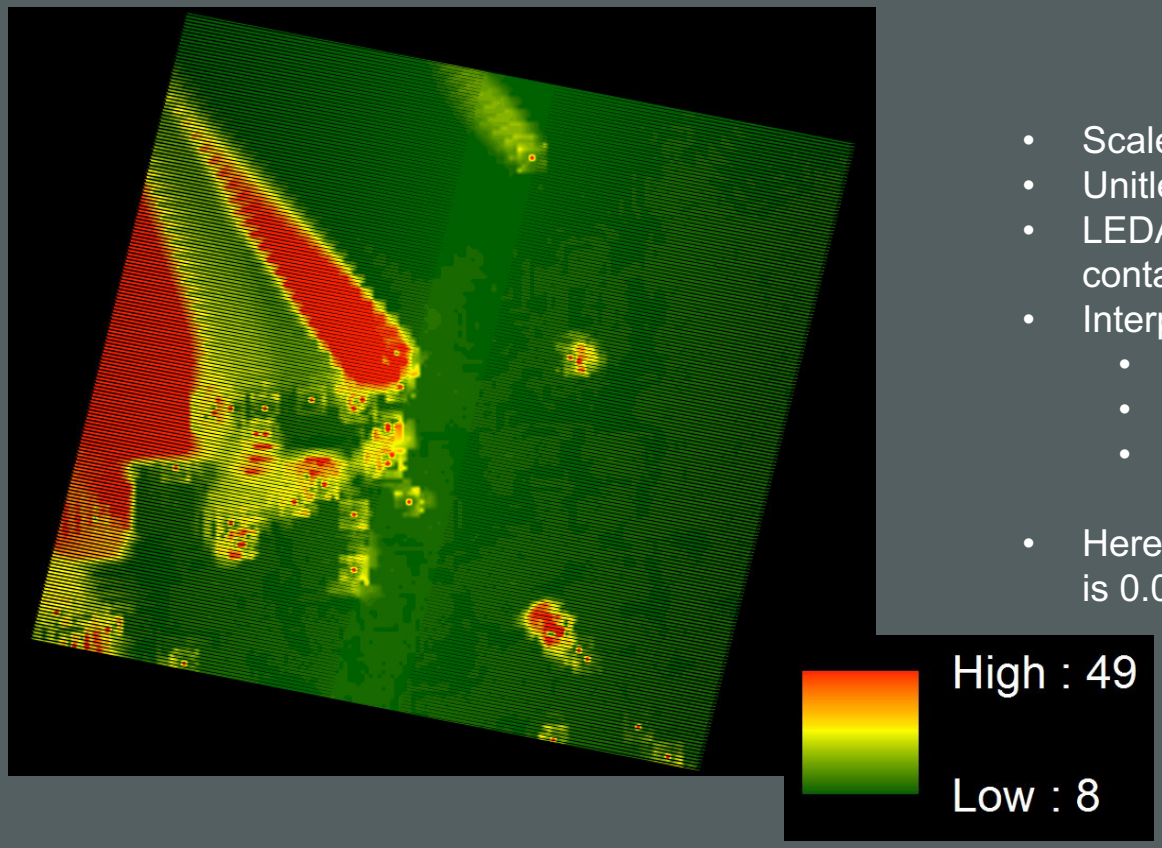
Data Products

- **LEDAPS**
  - sr_atmos_opacity band



- Scaled (* 0.0010)
- Unitless
- LEDAPS' estimate of atmospheric contamination
- Interpretation:
  - < 0.1 Clear
  - 0.1-0.3 Average
  - > 0.3 Hazy

- Here, no data are above 'Clear' (max is 0.049)

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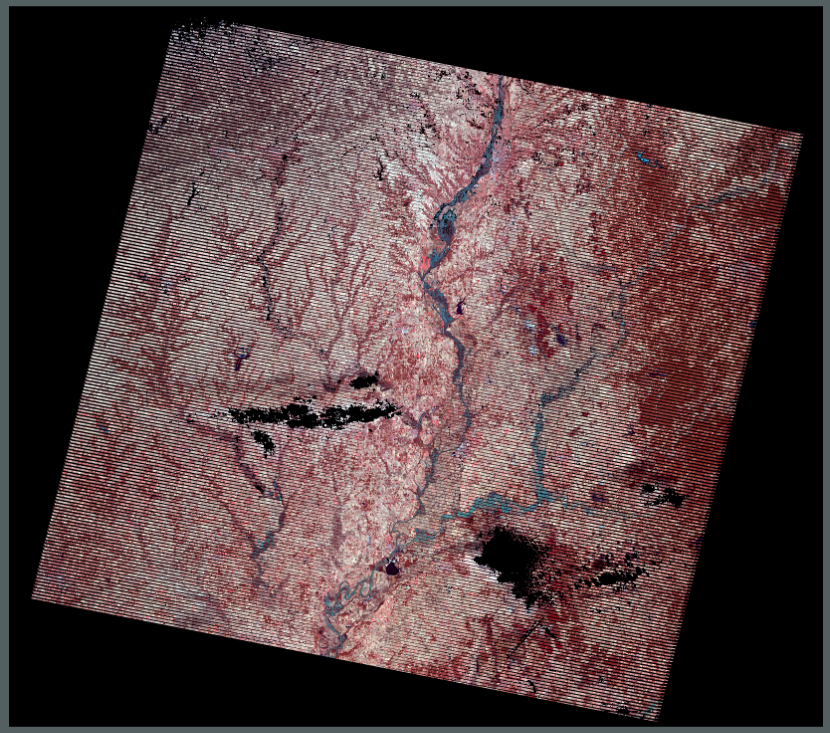
Data Products

- **LEDAPS**
  - Filtered bands
  - Ignore: cloud, cloud shadow, snow/ice, saturation



Example of final masked output.

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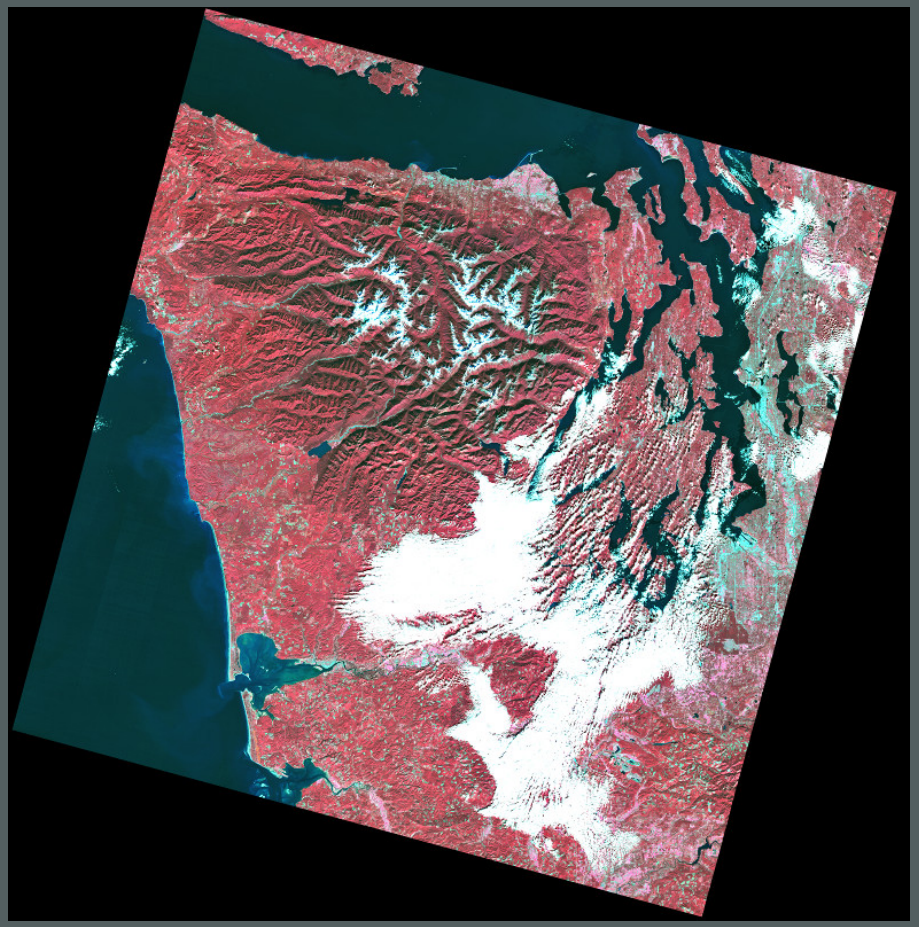
Data Products

- **LaSRC**



Landsat 8 OLI/TIRS
WRS-2 Path 47, Row 27
Acq.: 14 October 2013
5,4,3 (false color IR)

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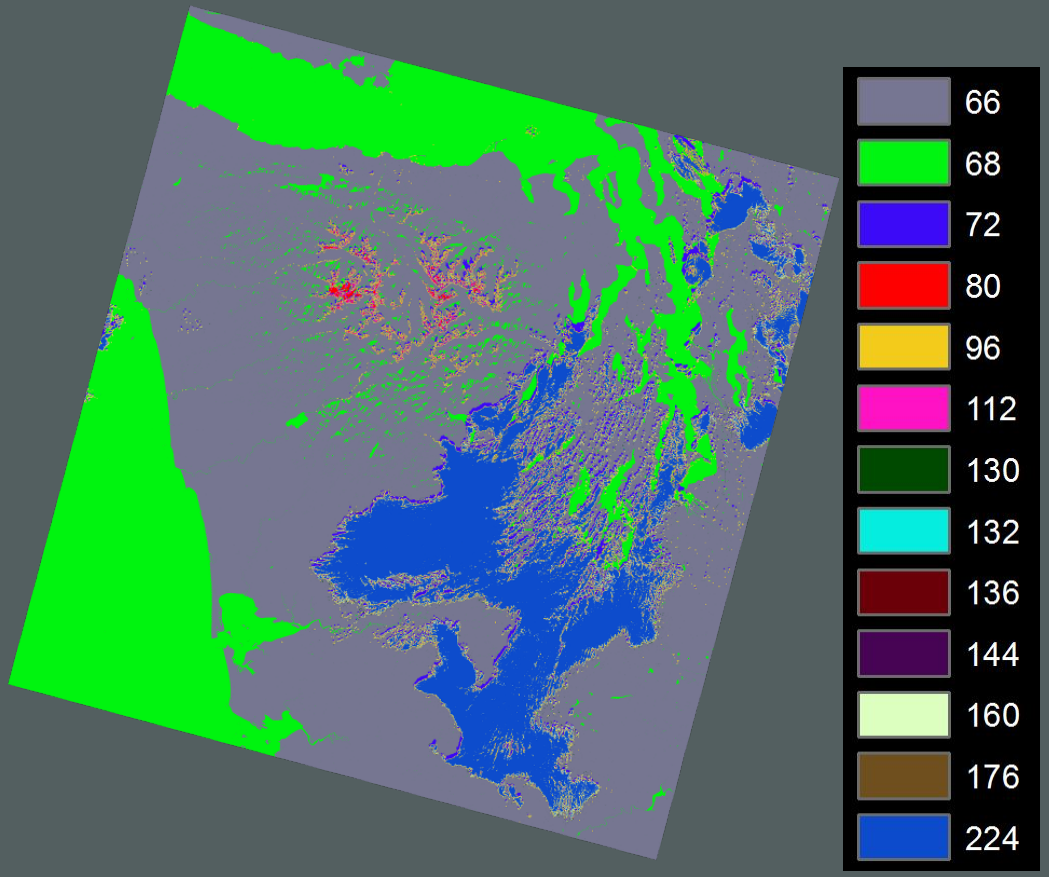
Data Products

- **LaSRC**
  - pixel_qa



Bit	Value	Cumulative Sum	Interpretation
0	1	1	Fill
1	2	3	Clear
2	4	7	Water
3	8	15	Cloud shadow
4	16	31	Snow
5	32	63	Cloud
6	64	127	Cloud Confidence 00 = None
7	128	255	01 = Low 10 = Medium 11 = High
8	256	511	Cirrus Confidence 00 = Not set
9	512	1023	01 = Low from OLI Band 9 reflectance 10 = Medium from OLI Band 9 reflectance 11 = High from OLI Band 9 reflectance
10	1024	2047	Terrain Occlusion
11	2048	4095	Unused
12	4096	8191	Unused
13	8192	16383	Unused
14	16384	32767	Unused
15	32786	65553	Unused

- Includes cirrus bits, otherwise same as L4-7 pixel_qa

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Data Products

- **LaSRC**
  - radsat_qa

Bit	Value	Cumulative Sum	Description
0	1	1	Data Fill Flag (0 valid data, 1 invalid data)
1	2	3	Band 1 Data Saturation Flag (0 valid data, 1 saturated data)
2	4	7	Band 2 Data Saturation Flag (0 valid data, 1 saturated data)
3	8	15	Band 3 Data Saturation Flag (0 valid data, 1 saturated data)
4	16	31	Band 4 Data Saturation Flag (0 valid data, 1 saturated data)
5	32	63	Band 5 Data Saturation Flag (0 valid data, 1 saturated data)
6	64	127	Band 6 Data Saturation Flag (0 valid data, 1 saturated data)
7	128	255	Band 7 Data Saturation Flag (0 valid data, 1 saturated data)
8	N/A	N/A	Not used
9	512	1023	Band 9 Data Saturation Flag (0 valid data, 1 saturated data)
10	1024	2047	Band 10 Data Saturation Flag (0 valid data, 1 saturated data)
11	2048	4095	Band 11 Data Saturation Flag (0 valid data, 1 saturated data)

- Bit-packed to allow flags for multiple conditions
- Derived from L1 DNs (== 65535)
- Saturation very uncommon in OLI; only 13 pixels saturated in this scene
  - Specular, impervious targets
- Can pull pixels with any saturation (> 0) or by band.

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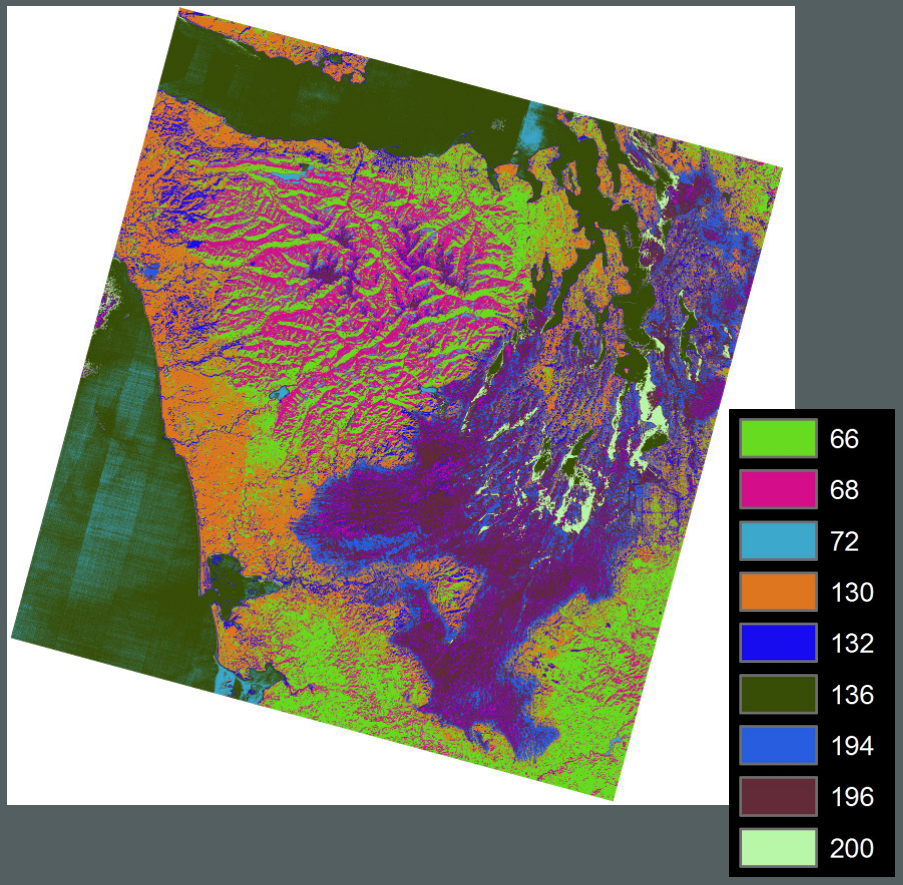
Data Products

- **LaSRC**
  - sr_aerosol_qa



Bit	Cumulative Sum	Value	Description
0	1	1	Fill Value
1	2	3	Aerosol Retrieval – Valid
2	4	7	Aerosol Retrieval – Interpolated
3	8	15	Water Pixel
4	16	31	Water Aerosol Retrieval Failed – Needs Interpolated (Internal Use Only)
5	32	63	Neighbor of Failed Aerosol Retrieval (Internal Use Only)
6	64	127	Aerosol Content 00 – Climatology
7	128	255	01 – Low 10 – Medium 11 – High

- Bit-packed to allow flags for multiple conditions
- Describes conditions under which aerosols were retrieved; aerosol content
- Recommended use: remove “high” aerosol pixels
  - Depending on application sensitivity, remove “interpolated” pixels?

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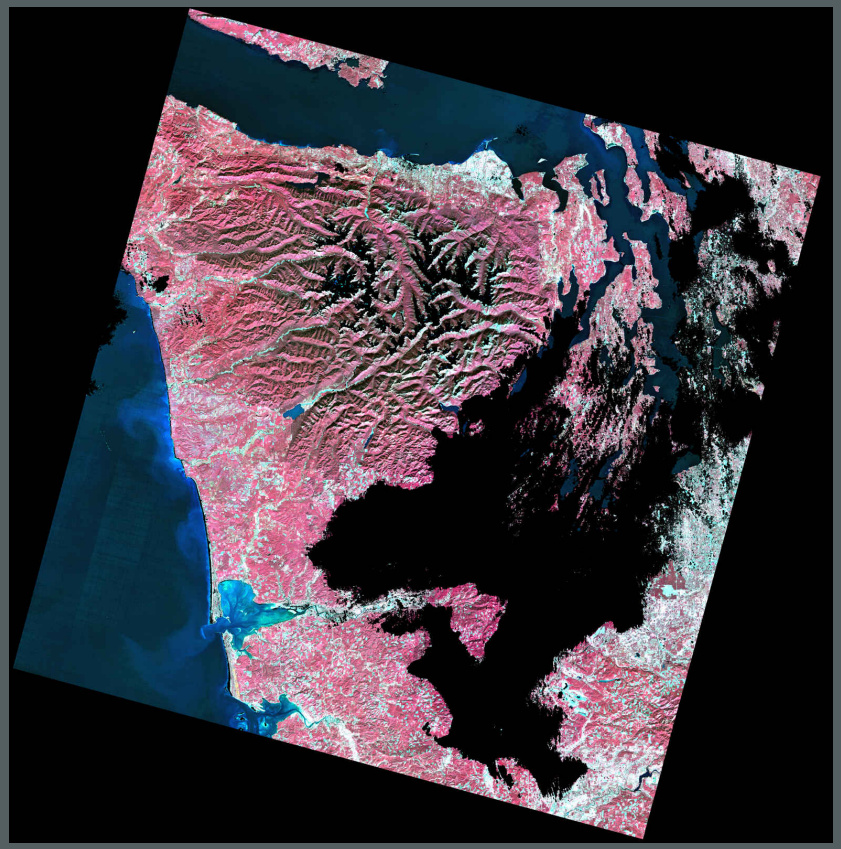
Data Products

- **LaSRC**
  - Filtered bands
  - Ignore: cloud, cloud shadow, snow/ice, saturation, high aerosol



Example of final masked output.

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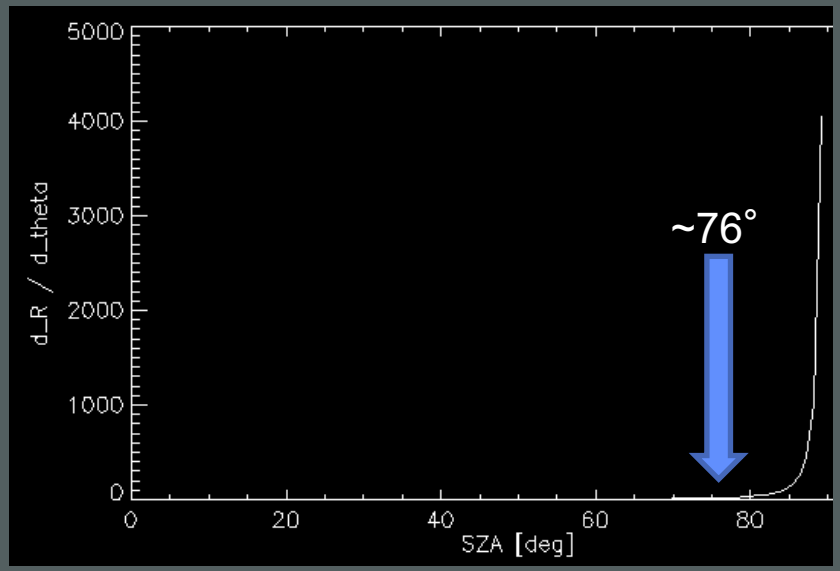
Data Products

- **Caveats**
  - Software will not run if solar zenith angle > 76 degrees (low sun elevation.)
    - The amount of uncertainty greatly increases past this angle (passes through more columns of atmosphere.)
    - More likely over poles.
    - Efficacy of corrections impacted by auxiliary data spatial, temporal resolutions
  - Auxiliary data gaps
    - Instrument failure, data corruption, etc.
    - List of all missing dates: https://landsat.usgs.gov/landsat-surface-reflectance-high-level-data-products > “Caveats and Constraints”



Error vs. SZA

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Landsat Collection 1

- **New data standard**
- **All data radiometrically cross-calibrated to Landsat 8**
- **Data placed into tiers**
  - **Tier 1 (“T1”)**
    - Geometric RMSE <12m
    - L1TP (formerly L1T) for L4-7, L1TP or L1GT for L8
    - Stackable
  - **Tier 2 (“T2”)**
    - Geometric RMSE >12m
    - L1GT or L1GS (formerly L1G) for L4-7, L1GS for L8
    - Typically lack of GCPs due to clouds, scenes without land
    - Less likely to be stackable
  - **Real-Time (“RT”)**
    - Still needs definitive parameters (bumper mode for L7; TIRS SSM for L8)
    - “RT” products deleted once moved into “T1” or “T2”

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Landsat Collection 1

- **File naming convention change**

Pre-Collection

LXSPPPRRRYYYYDDDSTNVR
(e.g., LC80120542014301LGN00

L	Landsat
X	Sensor (“O” = OLI; “T” = TIRS; “C” = OLI/TIRS)
S	Satellite (“8” = Landsat 8, etc.)
PPP	Path
RRR	Row
YYYY	Year of Acquisition
DDD	Julian Date of Acquisition
STN	Receiving Station
VR	Version Number

Collection 1

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CX_TX
(e.g., LC08_L1TP_039037_20150728_20160918_01_T1)

L	Landsat
X	Sensor (“O” = OLI; “T” = TIRS; “C” = OLI/TIRS)
SS	**Satellite (“08” = Landsat 8, etc.)**
LLLL	**Processing correction level (“L1TP” = Precision Terrain; “L1GT” = Systematic Terrain; “L1GS” = Systematic)**
PPP	Path
RRR	Row
YYYY	Year
MM	**Month of acquisition**
DD	**Day of acquisition**
yyyy	**Year of processing**
mm	**Month of processing**
dd	**Day of processing**
CX	**Collection number (“01”, “02”, etc.)**
TX	**Collection category (“RT”=Real-Time; “T1”=Tier 1; “T2”=Tier 2)**

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Collection 1

- **Timeline**
  - All Landsat TM and ETM+ now processed to Collection 1
  - OLI/TIRS complete for CONUS, global processing to continue through June 2017.
  - Pre-Collection no longer available in ESPA (as of April 08, 2017.)
  - Pre-Collection forward processing halting April 28, 2017.

  - Status updates on Landsat Mission Webpage home: https://landsat.usgs.gov/

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Resources

- **Landsat mission webpage: https://landsat.usgs.gov**
  - Collections: https://landsat.usgs.gov/landsat-collections
  - Surface Reflectance: https://landsat.usgs.gov/landsat-surface-reflectance-high-level-data-products
    - LEDAPS
      - Product Guide: https://landsat.usgs.gov/sites/default/files/documents/ledaps_product_guide.pdf
      - Release notes: https://landsat.usgs.gov/sites/default/files/documents/ledaps_release_notes.pdf
    - LaSRC
      - Product Guide: https://landsat.usgs.gov/sites/default/files/documents/lasrc_product_guide.pdf
      - Release notes: https://landsat.usgs.gov/sites/default/files/documents/lasrc_release_notes.pdf
- **Landsat data: https://earthexplorer.usgs.gov/**
  - ESPA: https://espa.cr.usgs.gov/

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