Web-enabled Landsat data (WELD) Project

a 5 year NASA Making Earth System data records for Use in Research Environments (MEASURES) funded project

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What the Landsat user community wants …

- Derived Landsat data products for free

- Systematic, consistent, community endorsed data processing
  - calibration, geolocation
  - radiometric normalization / BRDF correction, atmospheric correction
  - cloud-screened, snow-screened, SLC-off gap filling

  (needed in order to derive higher level bio/geophysical & LC products)

- Composited large-area data product mosaics
  - updated at the pixel level
  - using all the Landsat data, not just select acquisitions
  - processed shortly after acquisition i.e. “near real time”

- *Similar to the NASA MODIS land products but at high spatial resolution*

- *Above is what the WELD project is developing, building on our 10 year MODIS product development, processing (and reprocessing) experience.*

WELD products

- 30m ETM+ composited mosaics
  - Weekly
  - Monthly
  - Seasonal
  - Annual

- Alaska
- Conterminous United States

- 7 years

- Generated from every L1T ETM+ acquisition in the USGS EROS archive with cloud cover ≤80%

- Generated by applying MODIS Land heritage processing techniques

WELD ETM+ Data Processing Steps

- TOA reflectance & brightness temperature
- View and solar geometry computation
- Cloud masking
- SLC-Off and cloud gap filling
- Reprojection: UTM to Albers map projection
- Compositing: weekly, monthly, seasonal, annual
- Atmospheric correction
- Radiometric/BRDF normalization
- Land cover characterization
- Browse generation

WELD ETM+ Data Processing Steps

Steps that use contemporaneous MODIS Products

- TOA reflectance & brightness temperature
- View and solar geometry computation
- Cloud masking
- SLC-Off and cloud gap filling
- Reprojection: UTM to Albers map projection
- Compositing: monthly, seasonal, annual
- Atmospheric correction (Eric Vermote)
- Radiometric/BRDF normalization
- Land cover characterization (Matt Hansen)
- Browse generation

Presentation Overview: WELD Status

- Current product availability
- Product examples
- Some recent algorithm developments
- Future distribution system
- 2010 distribution schedule
- Global WELD proof of concept

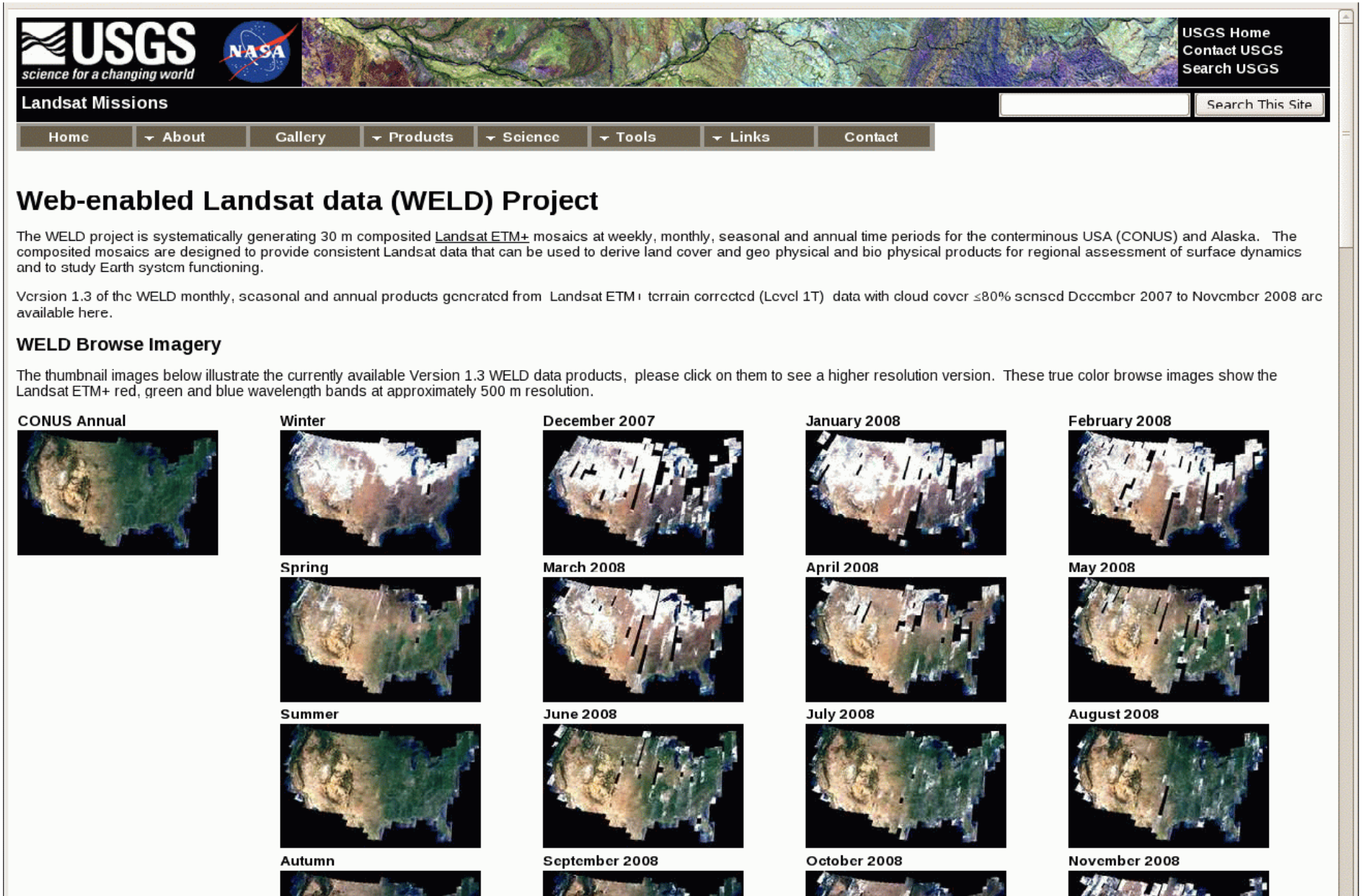
Current WELD Product Availability

- http://landsat.usgs.gov/WELD.php
- Version 1.3 placed online January 15th 2010
- One year: 2008 (December 2007 – November 2008)
  - CONUS
  - Alaksa
  - Annual, Seasonal, Monthly composited mosaics
  - 2.6TB

Available at http://landsat.usgs.gov/WELD.php

Version 1.3 with documentation

2008 CONUS & Alaksa, annual, seasonal, monthly composited mosaics

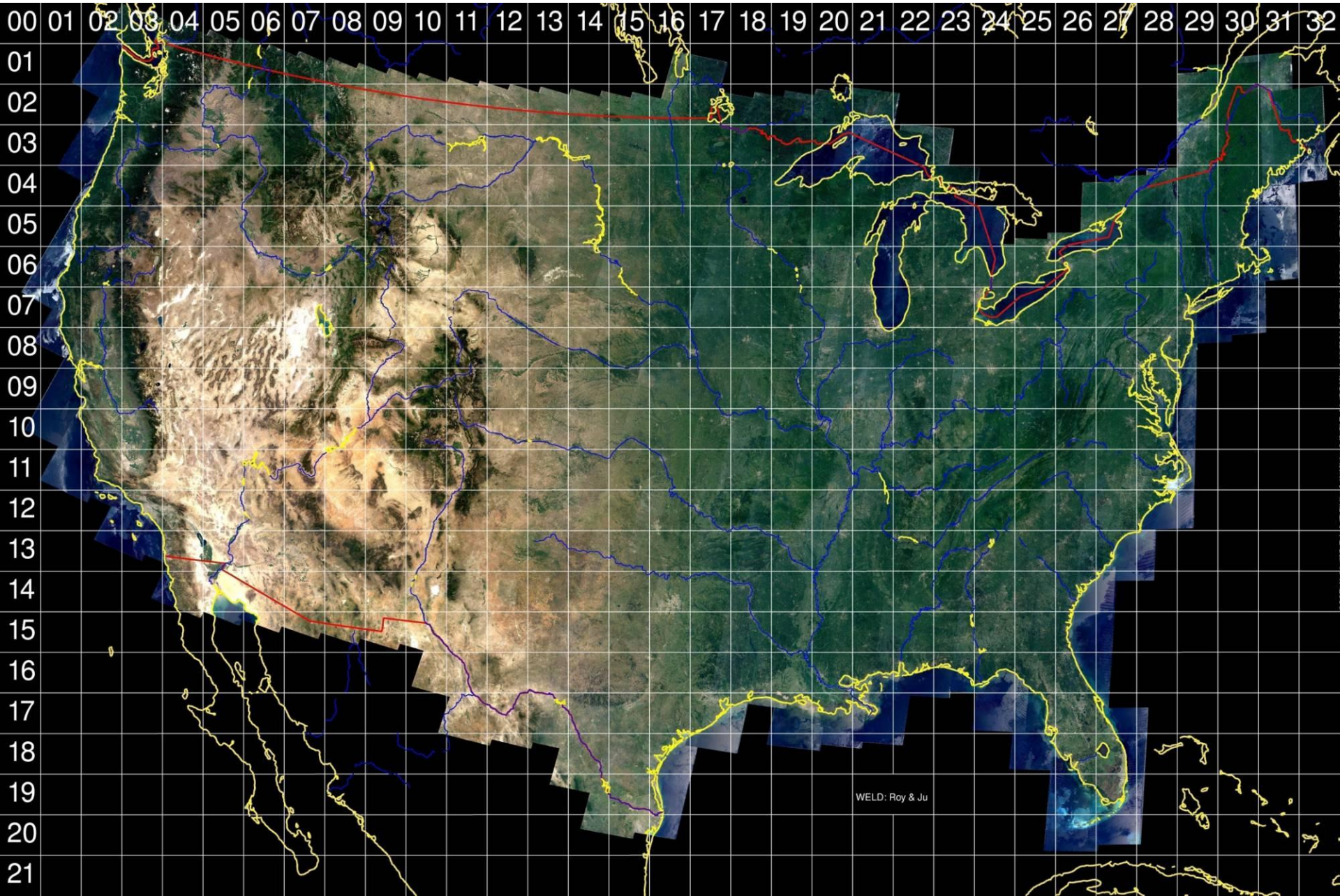


Version 1.3 WELD Product Format (all pixels are 30m)

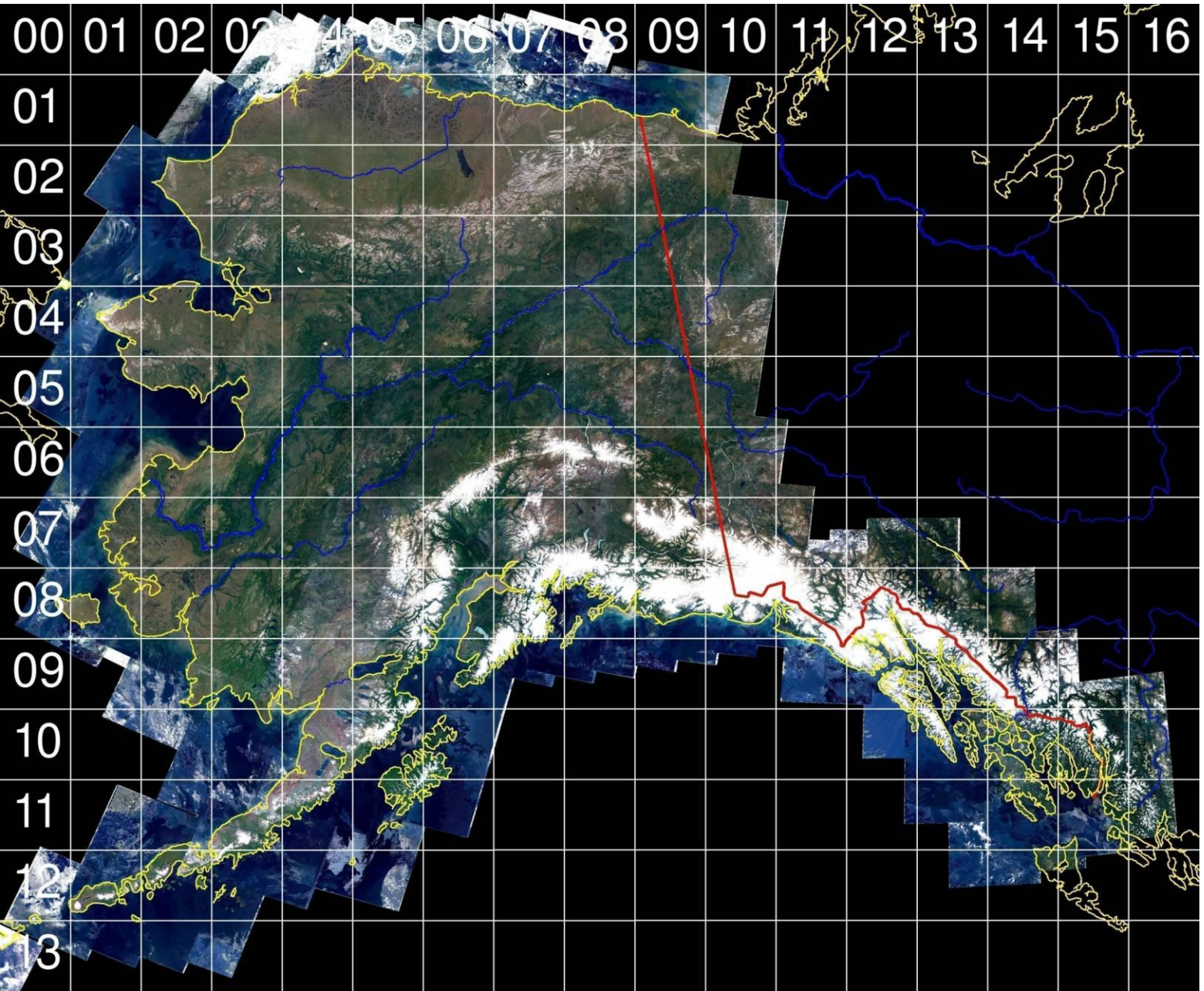
Science Data Set Name	Data Type	Valid Range	Scale factor	Units	Fill Value
Band1_TOA_REF	int16	-32767 -- 32767	10000	Unitless	-32768
Band2_TOA_REF	int16	-32767 -- 32767	10000	Unitless	-32768
Band3_TOA_REF	int16	-32767 -- 32767	10000	Unitless	-32768
Band4_TOA_REF	int16	-32767 -- 32767	10000	Unitless	-32768
Band5_TOA_REF	int16	-32767 -- 32767	10000	Unitless	-32768
Band61_TOA_BT	int16	-32767 -- 32767	100	Degrees Celsius	-32768
Band62_TOA_BT	int16	-32767 -- 32767	100	Degrees Celsius	D-32768
Band7_TOA_REF	int16	-32767 -- 32767	10000	Unitless	-32768
NDVI_TOA	int16	-10000 -- 10000	10000	Unitless	-32768
Day_Of_Year	int16	1 -- 366	1	Day	0
Saturation_Flag	uint8	0 -- 255	1	Unitless	None
DT_Cloud_State	uint8	0, 1, 2, 200	1	Unitless	255
ACCA_State	uint8	0, 1	1	Unitless	255
Num_Of_Obs	uint8	0 -- 255	1	Unitless	None
Sensor_Zenith	int16	0 -- 9000	100	Degrees	-32768
Sensor_Azimuth	int16	-18000 -- 18000	100	Degrees	-32768
Solar_Zenith	int16	0 -- 9000	100	Degrees	-32768
Solar_Azimuth	int16	-18000 -- 18000	100	Degrees	-32768

Each WELD file ~300MB

WELD Tile Map (CONUS has 501 5000 x 5000 30m pixel tiles in Albers)



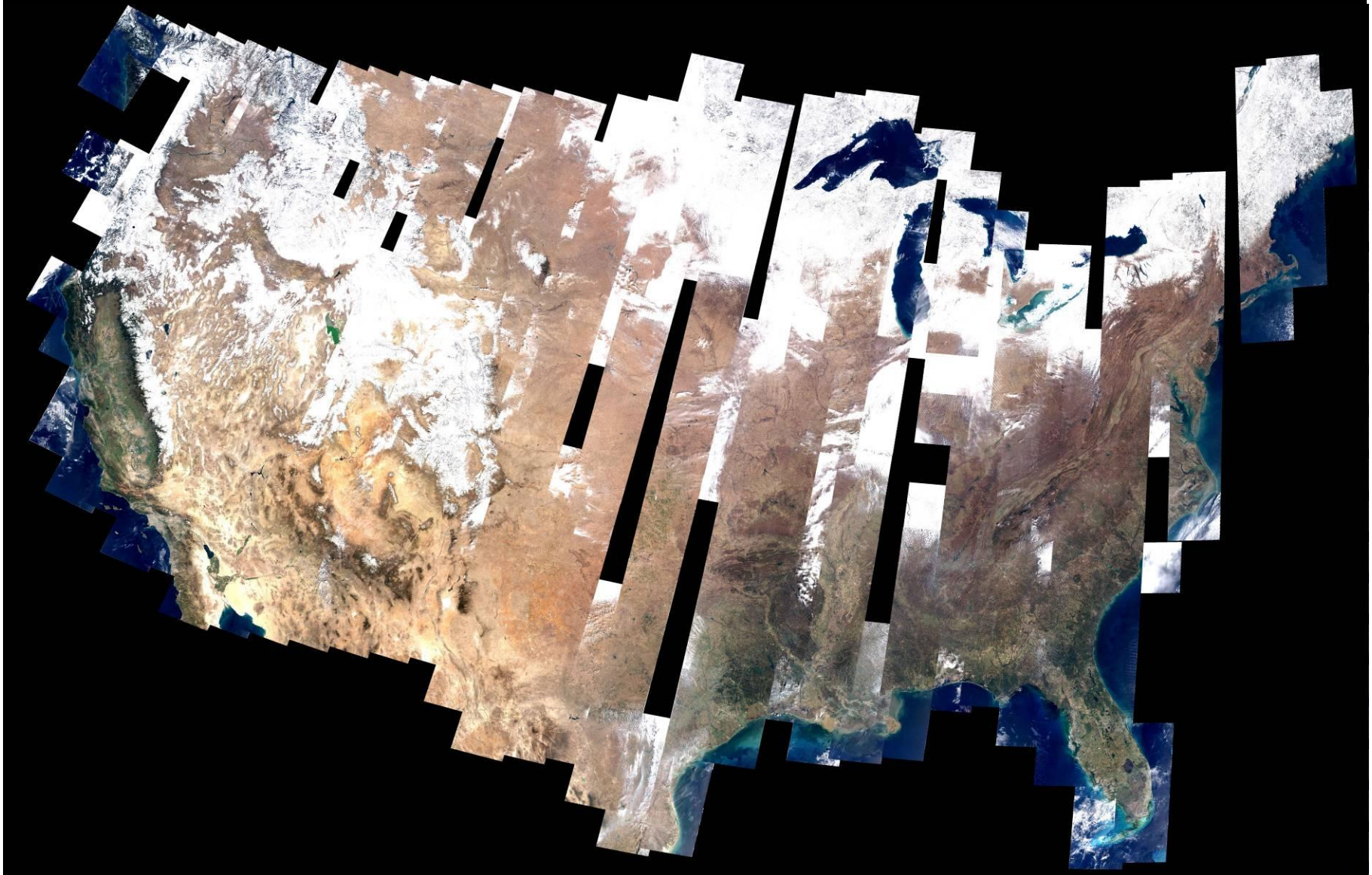
WELD Tile Map (Alaska has 162 5000x5000 30m pixel tiles in Albers)



March 2008 composite
all L1T acquisitions with cloud cover < 40%

March 2008 composite
all L1T acquisitions with cloud cover < 60%

March 2008 composite
all L1T acquisitions with cloud cover < 80%

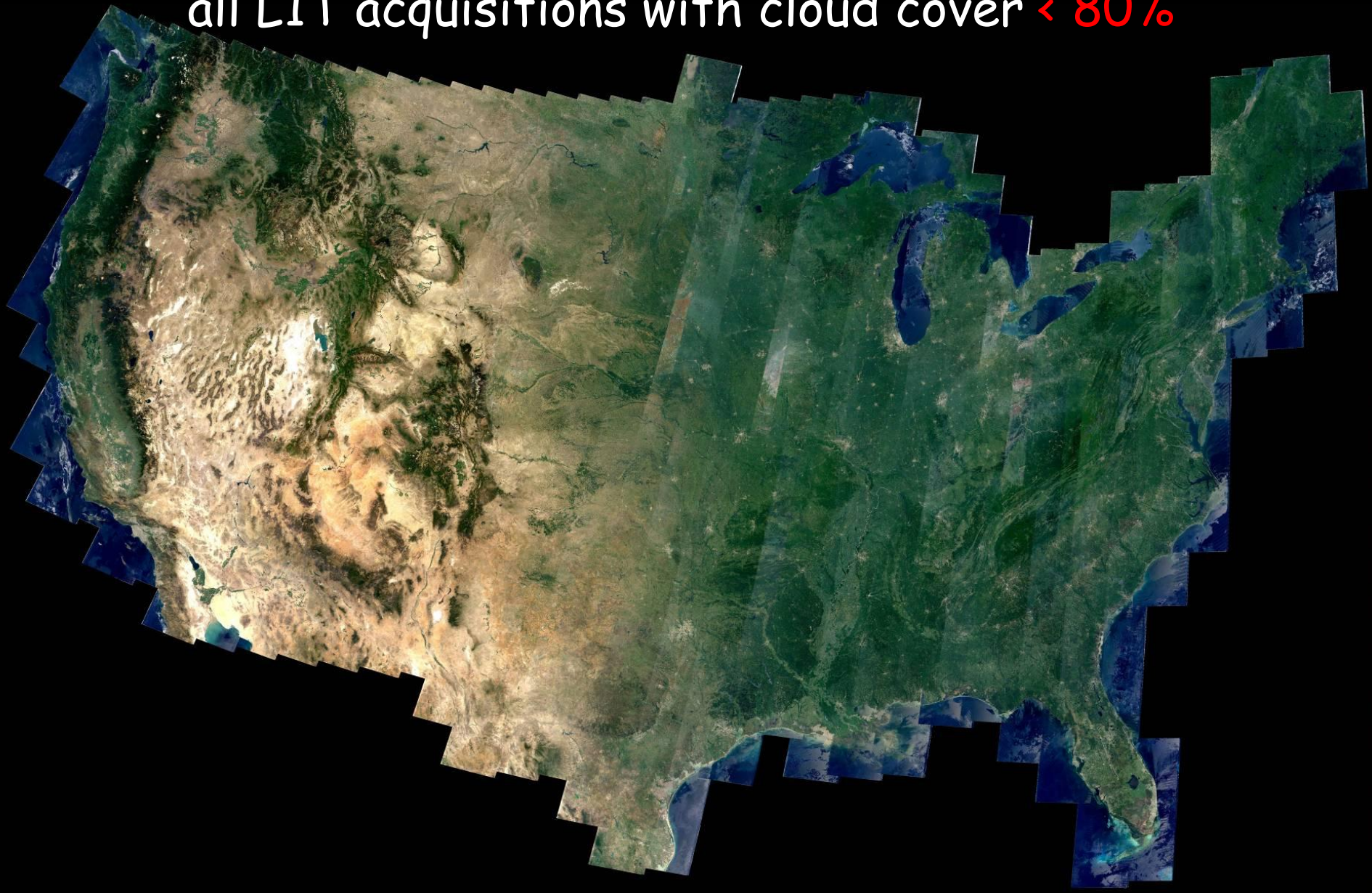


WELD ETM+ Archive at SDSU (today, April 21st 2010)

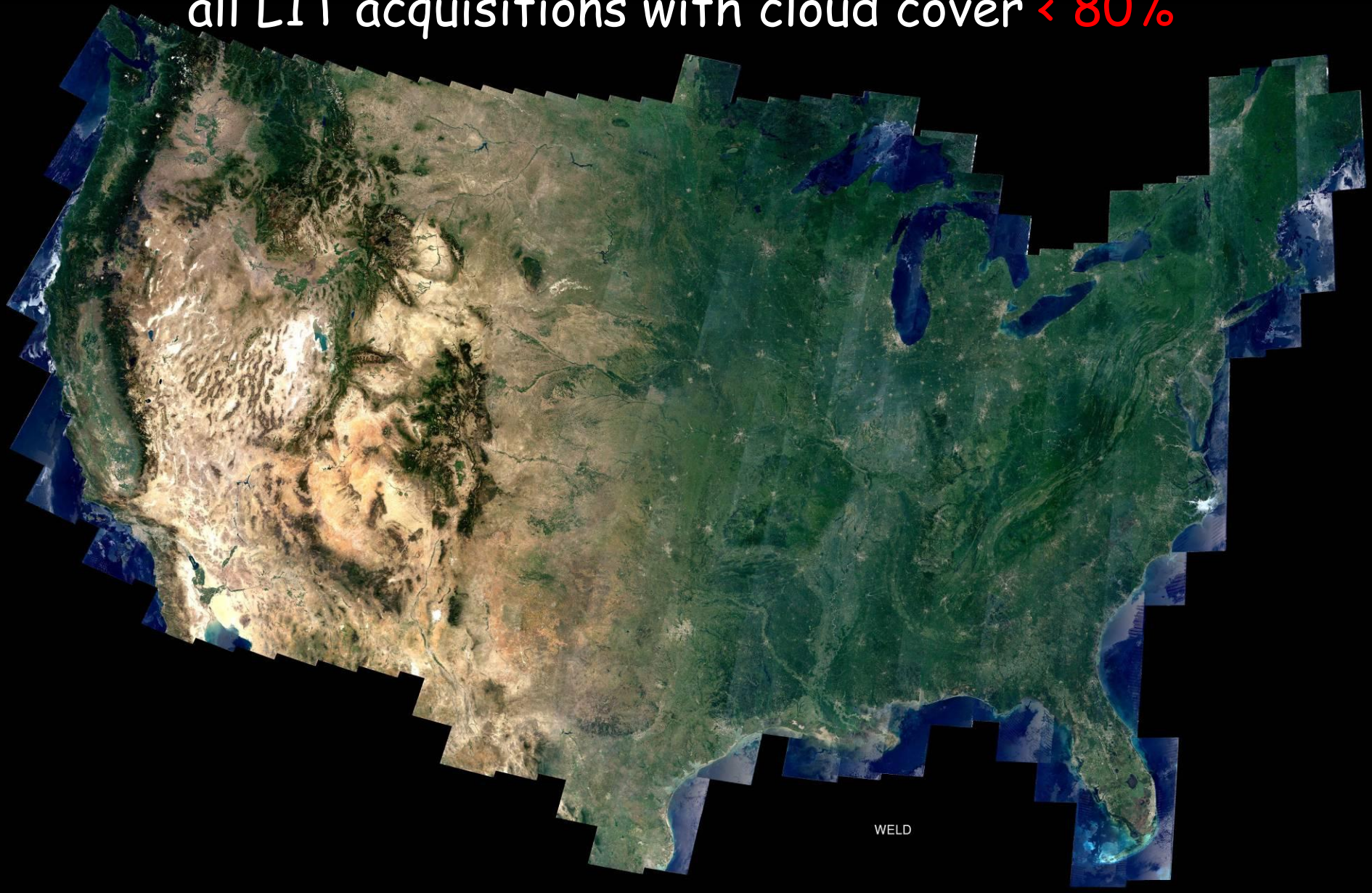
	Conterminous United States (459 path/row) <80% cloud	**Alaska** (232 path/row) <80% cloud
2007	7,184	1308
2008	8,345	1,674
2009	7,687	1,733
2010	1,560	265

29,756 CONUS and Alaska acquisitions ~ US$18 million when each L1T acquisition cost US$600.

Annual 2009 (Dec 2008 – Nov 2009) composite
all L1T acquisitions with cloud cover < 80%

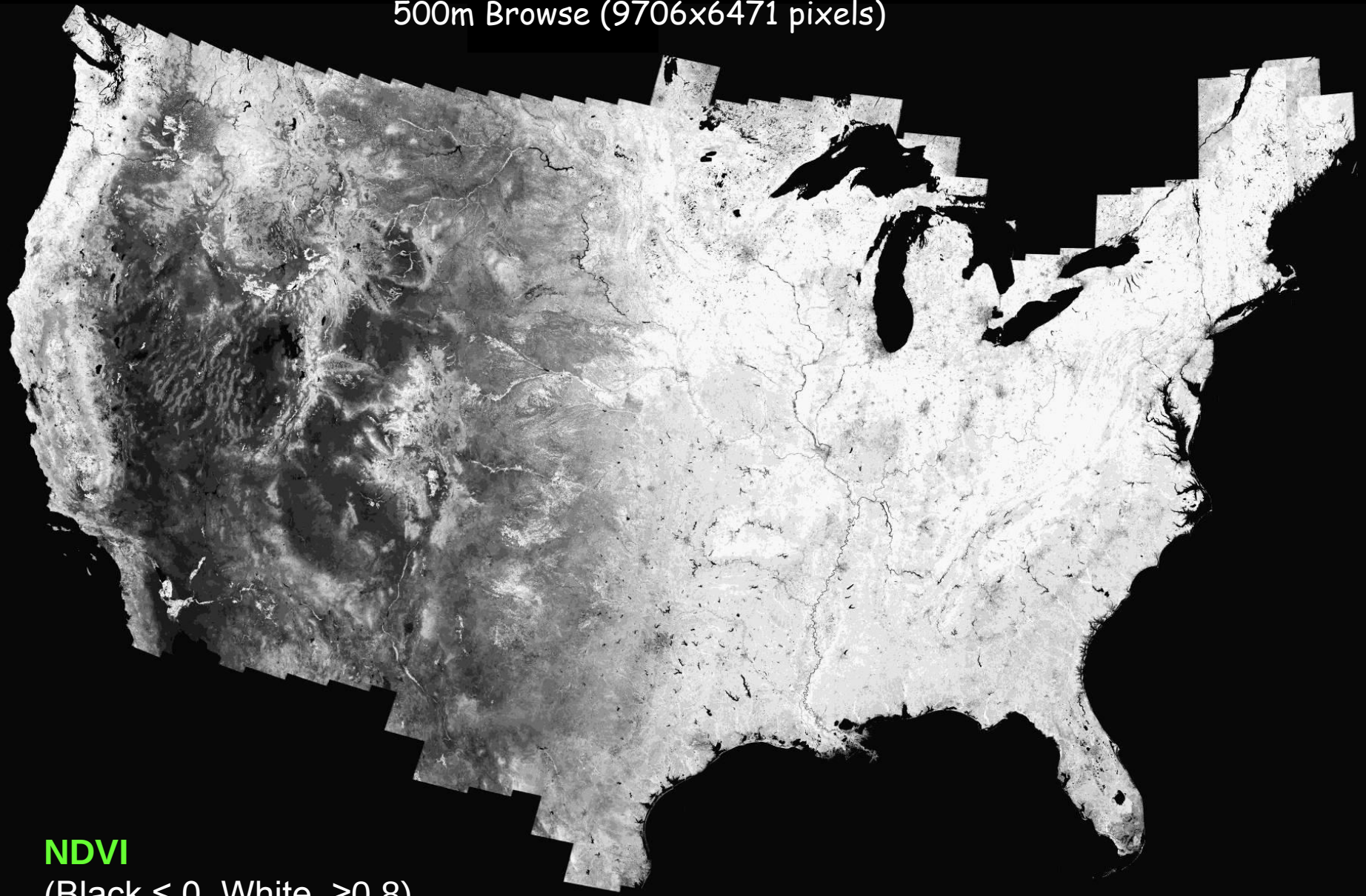


Annual 2008 (Dec 2007 – Nov 2008) composite
all L1T acquisitions with cloud cover < 80%



NDVI Annual 2008

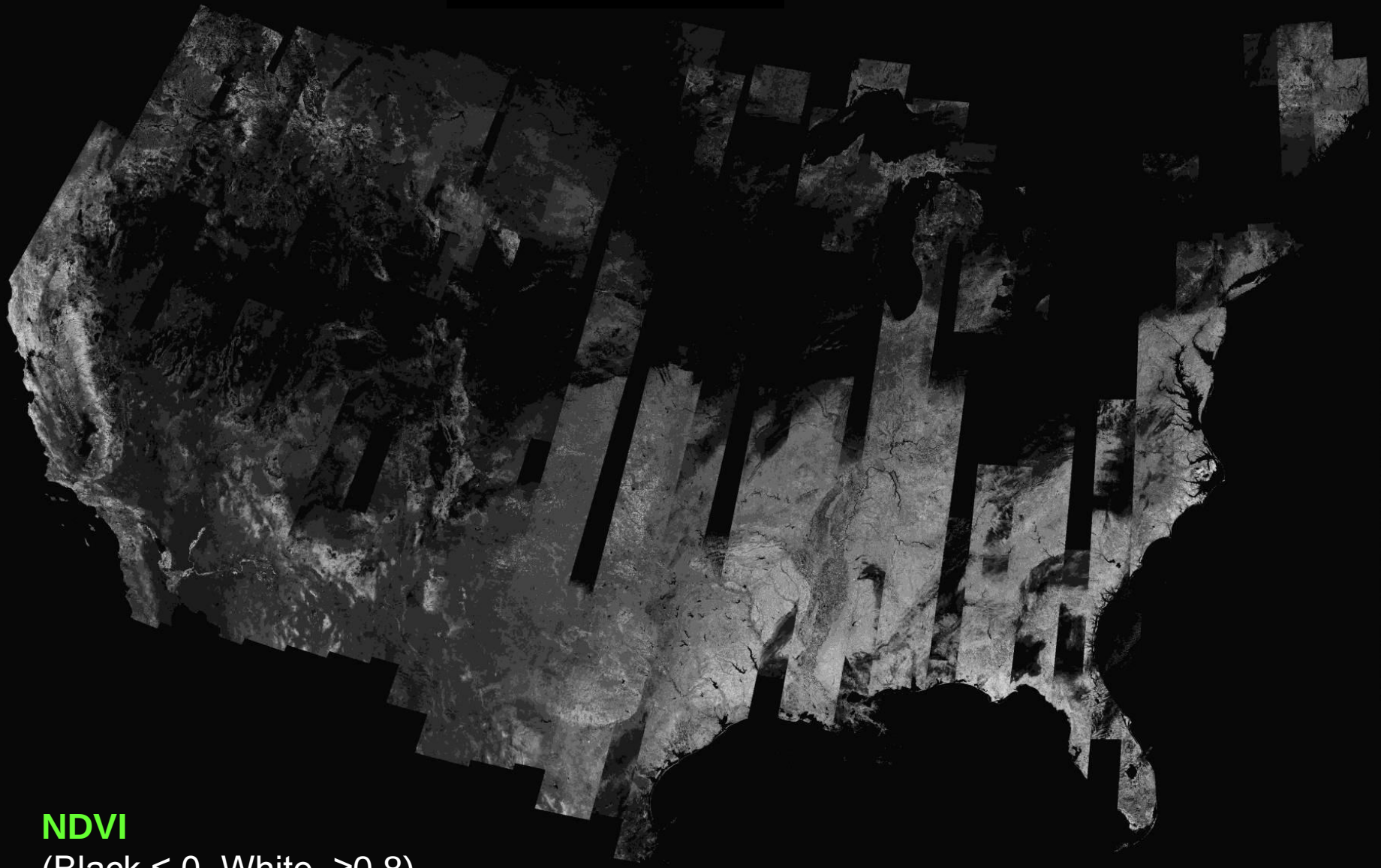
500m Browse (9706x6471 pixels)



NDVI

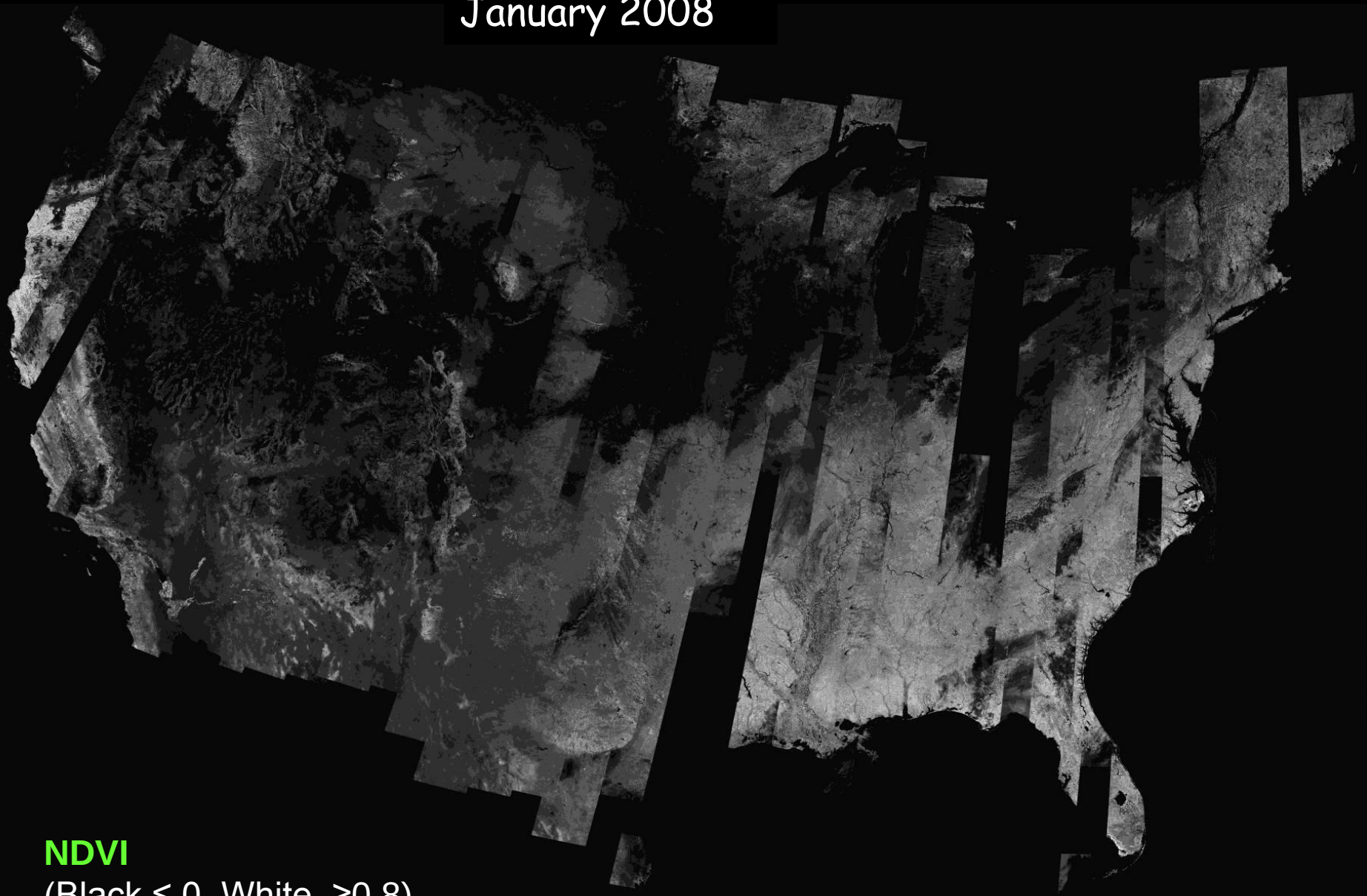
(Black ≤ 0, White ≥0.8)

December 2007



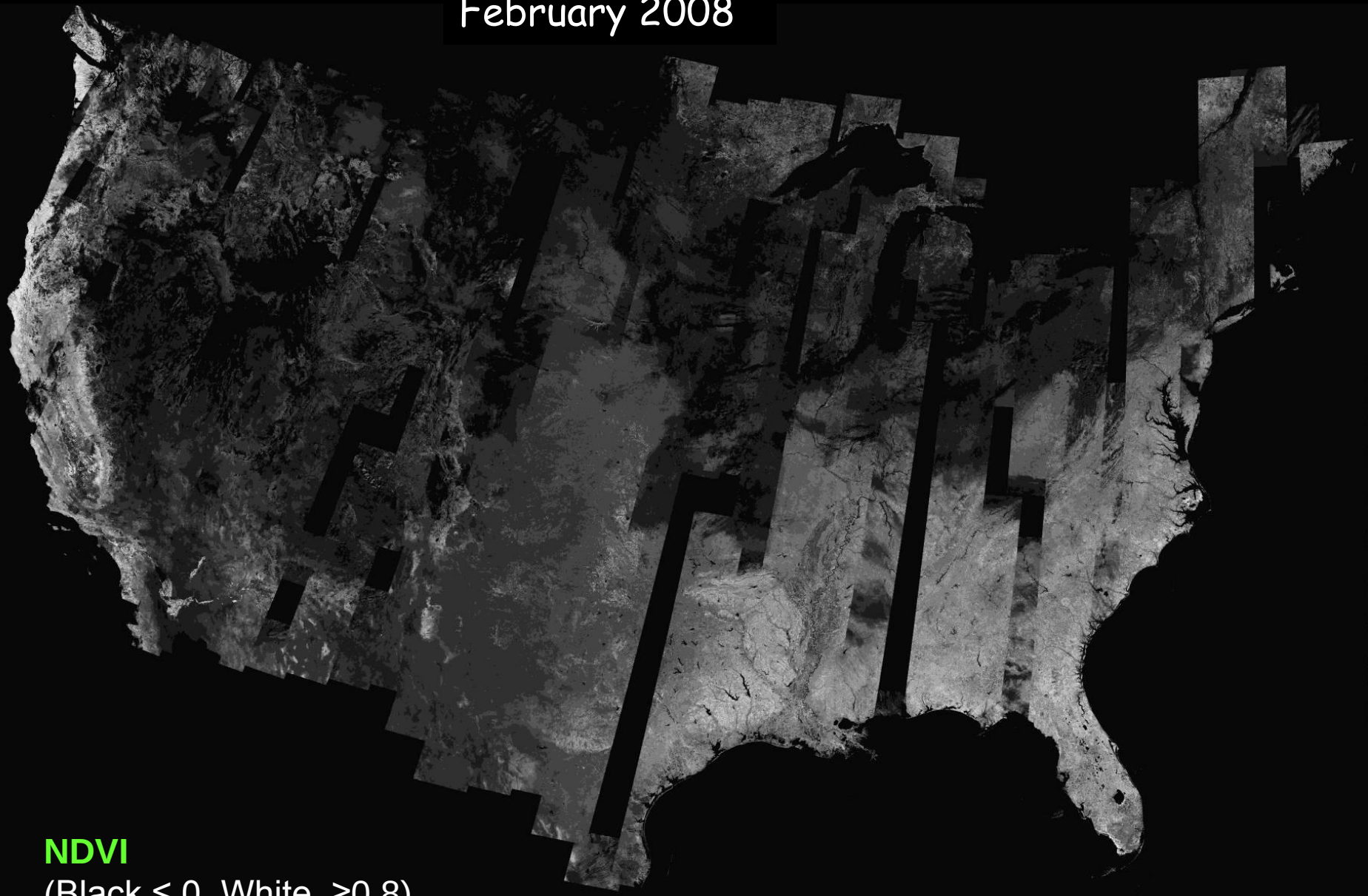
NDVI
(Black ≤ 0, White ≥0.8)

January 2008



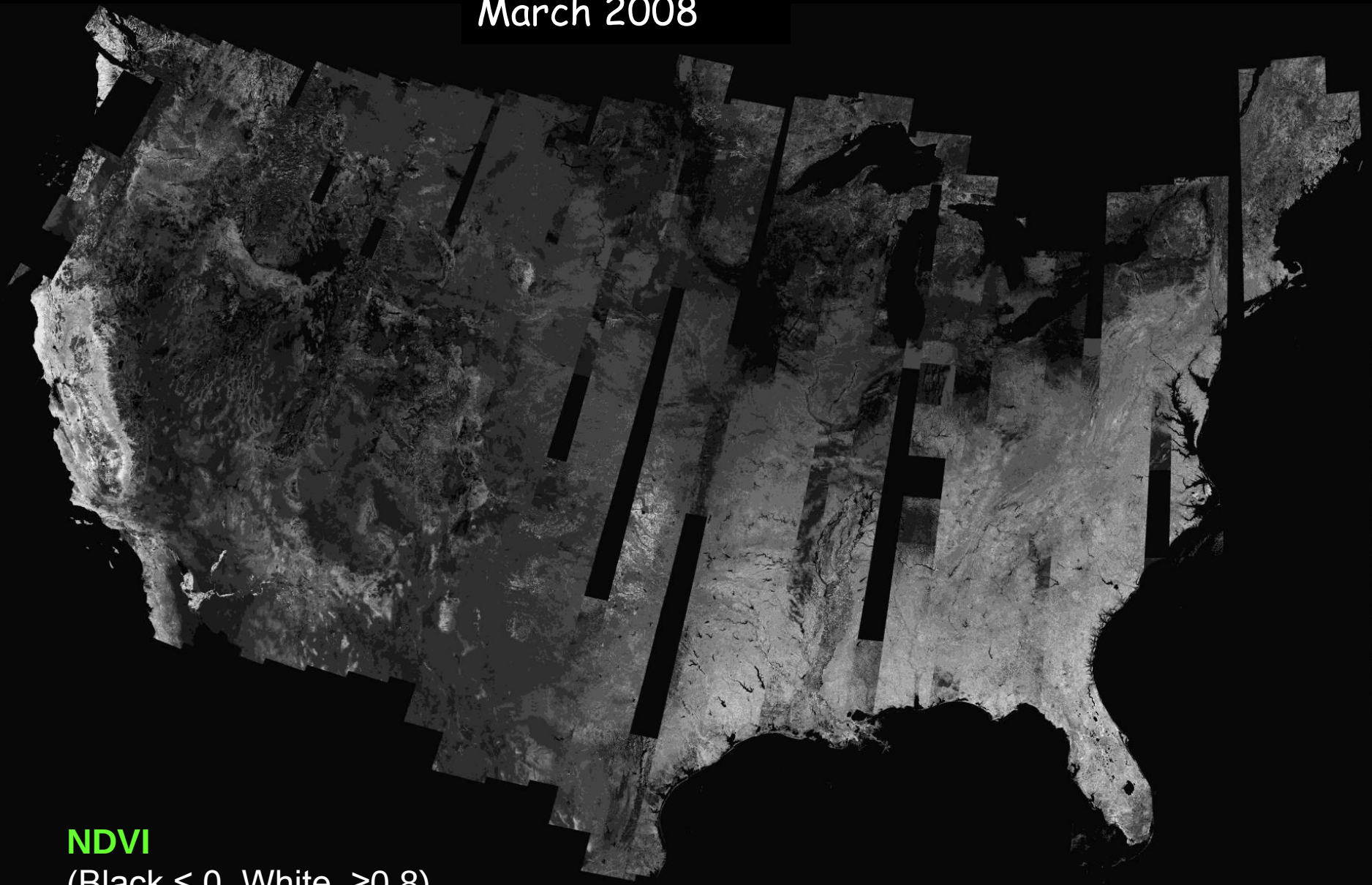
NDVI
(Black ≤ 0, White ≥0.8)

February 2008



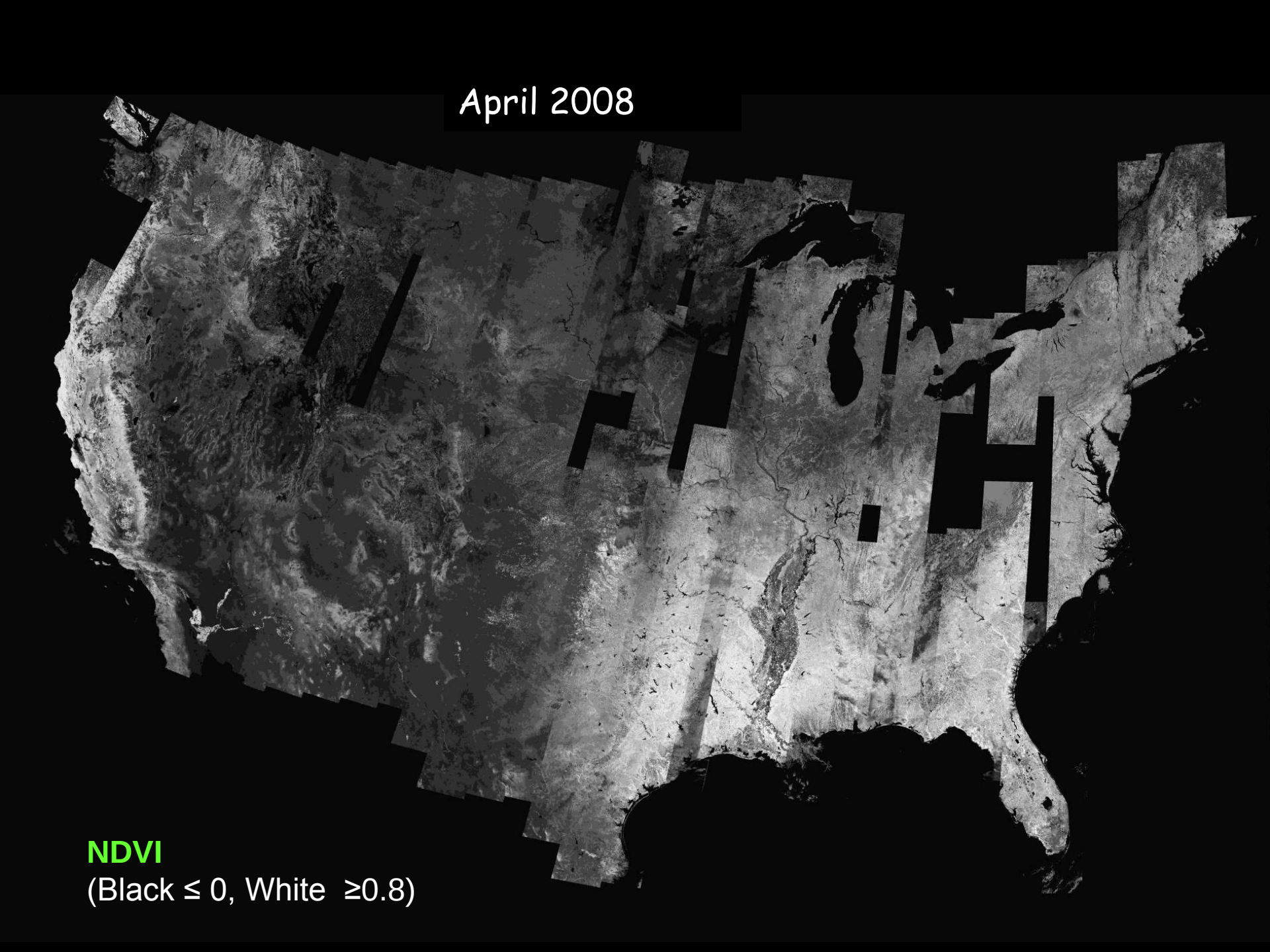
NDVI
(Black ≤ 0, White ≥0.8)

March 2008

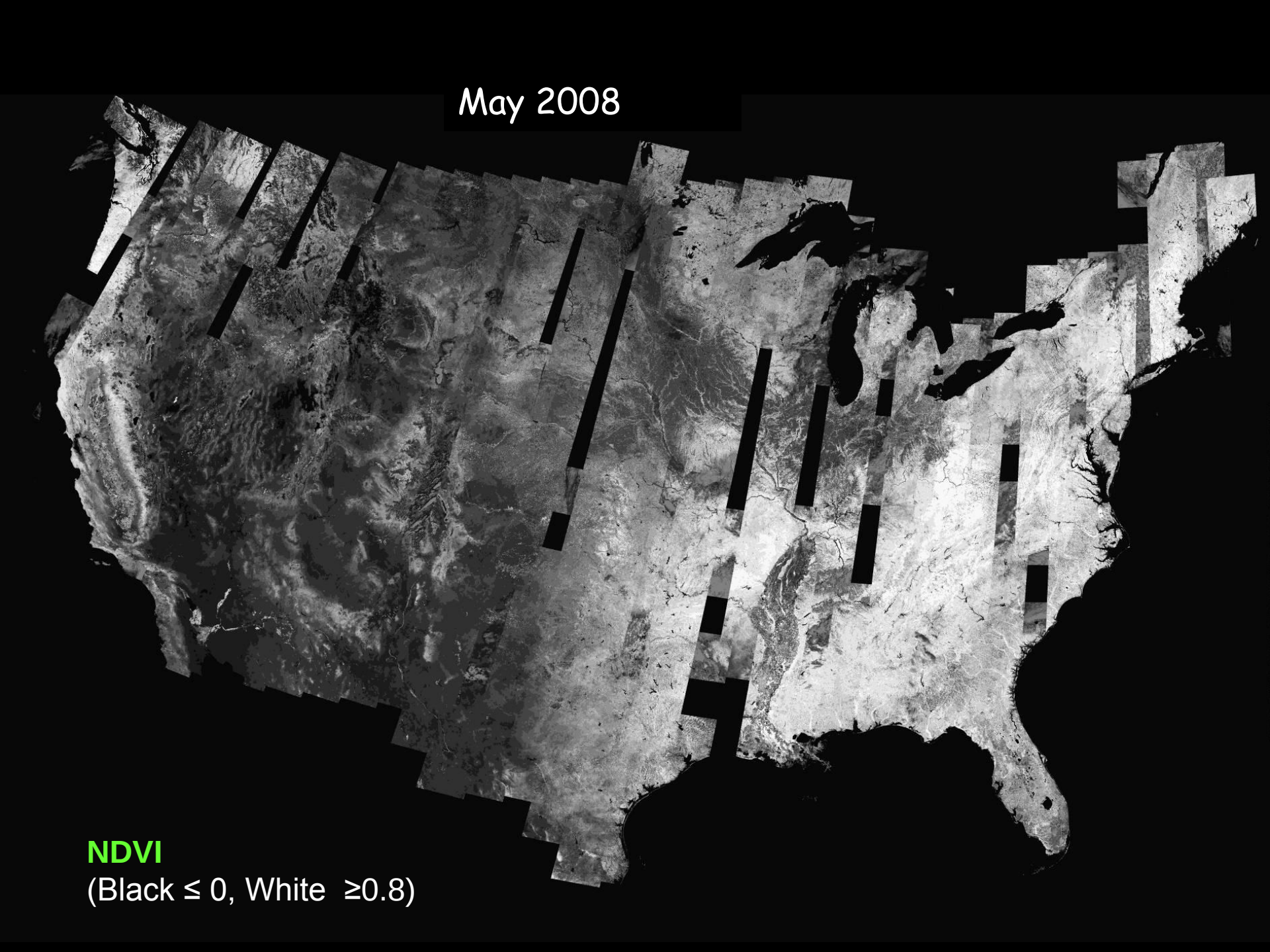


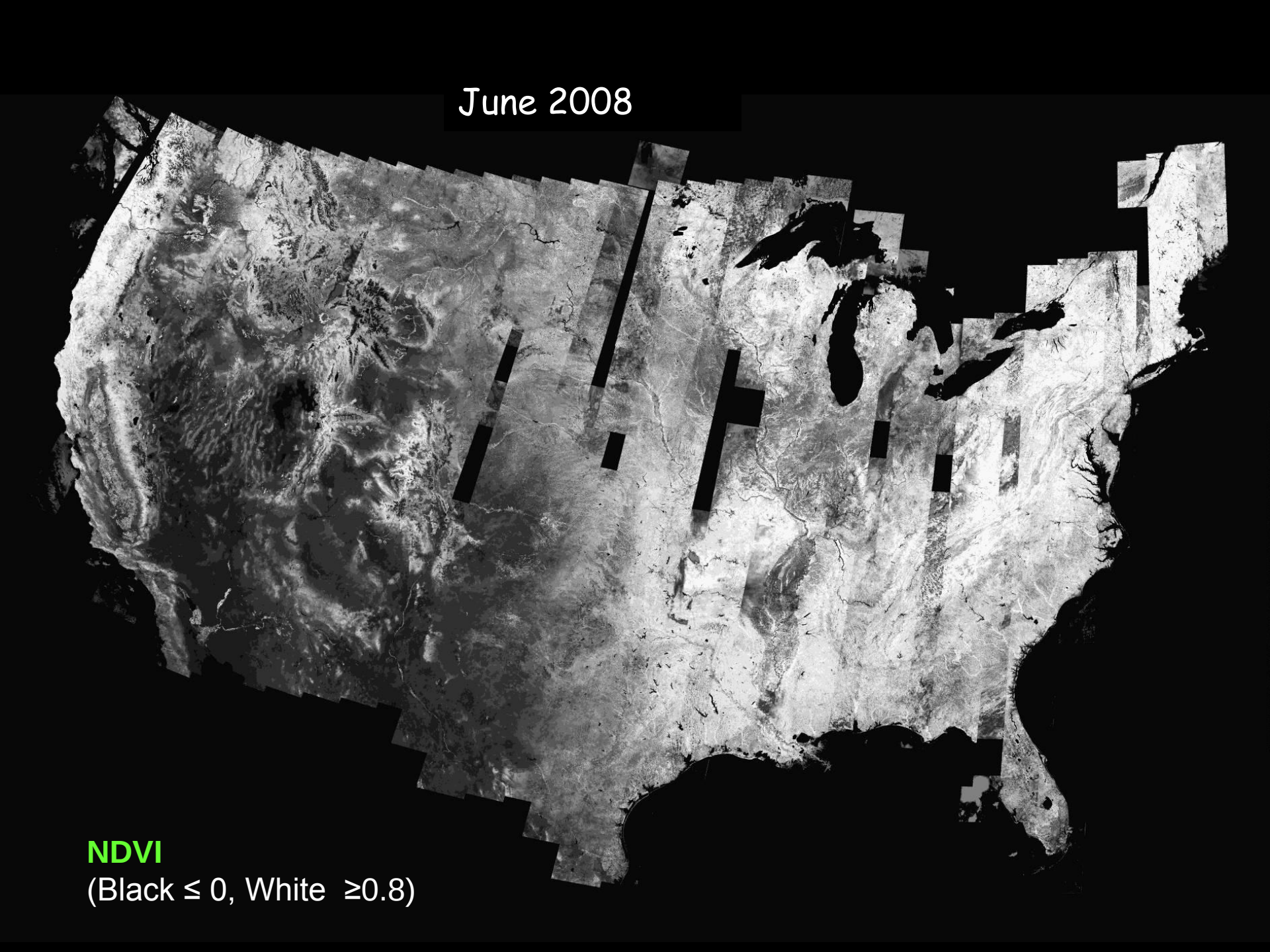
NDVI
(Black ≤ 0, White ≥0.8)

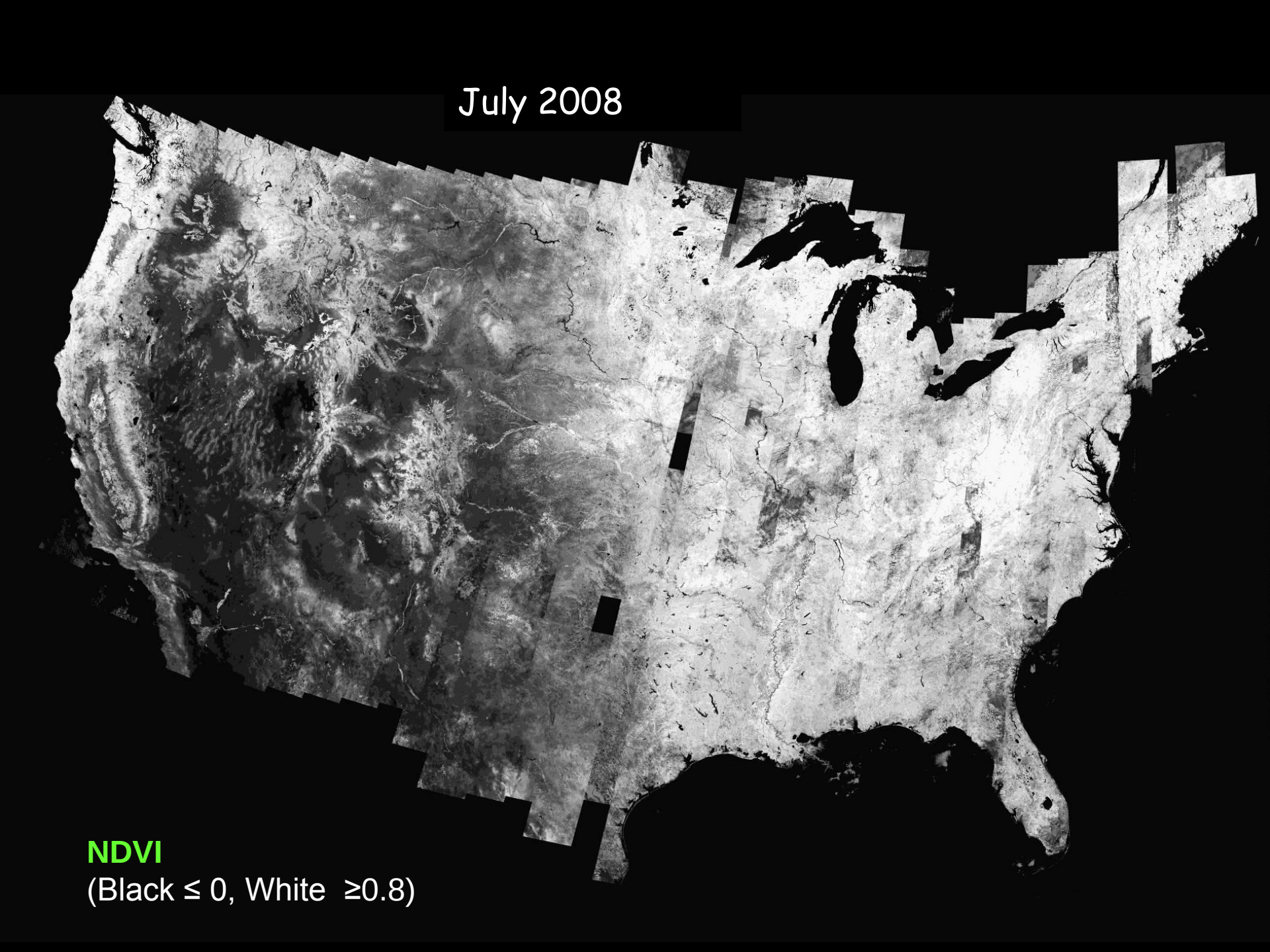
April 2008

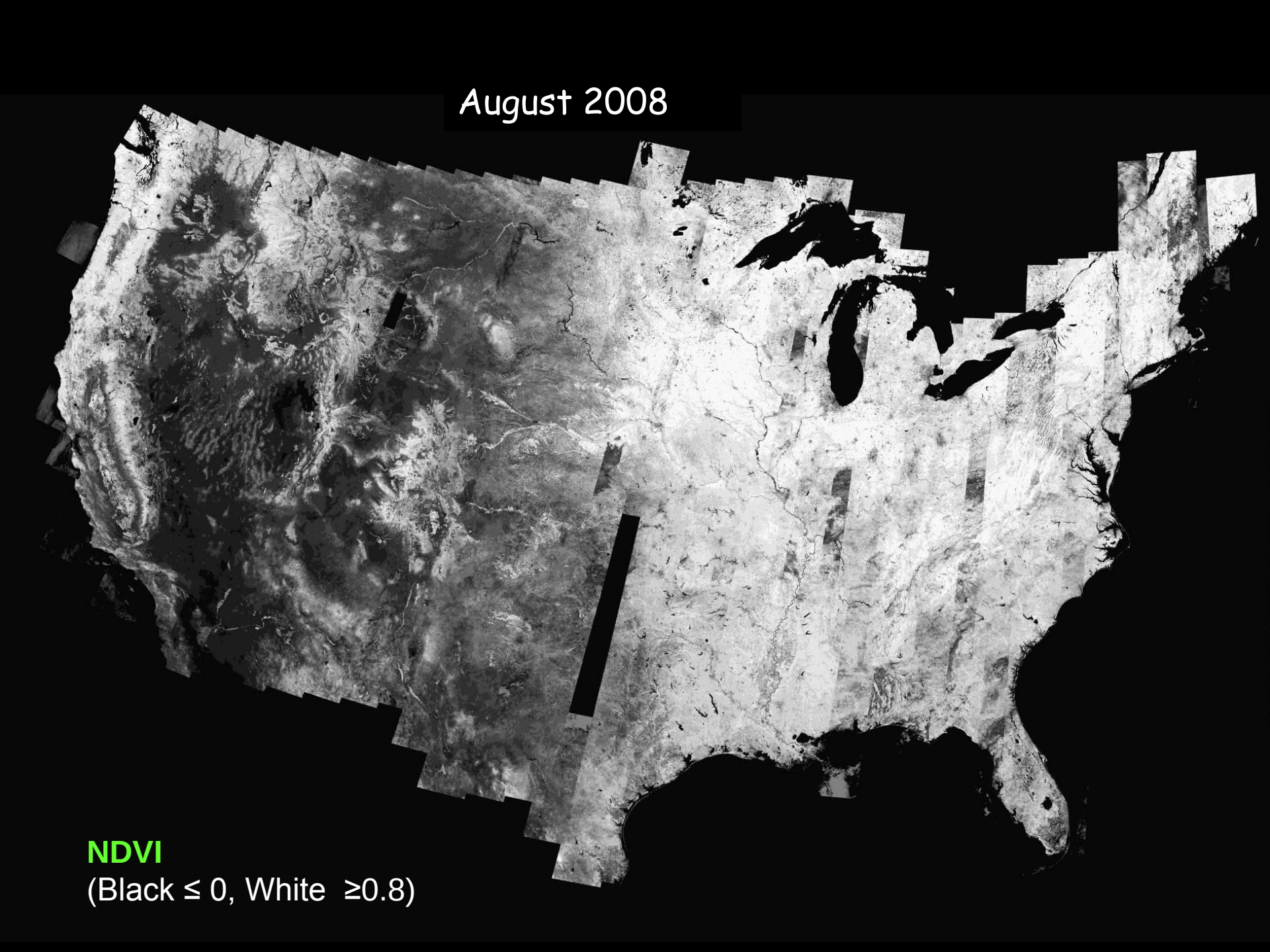


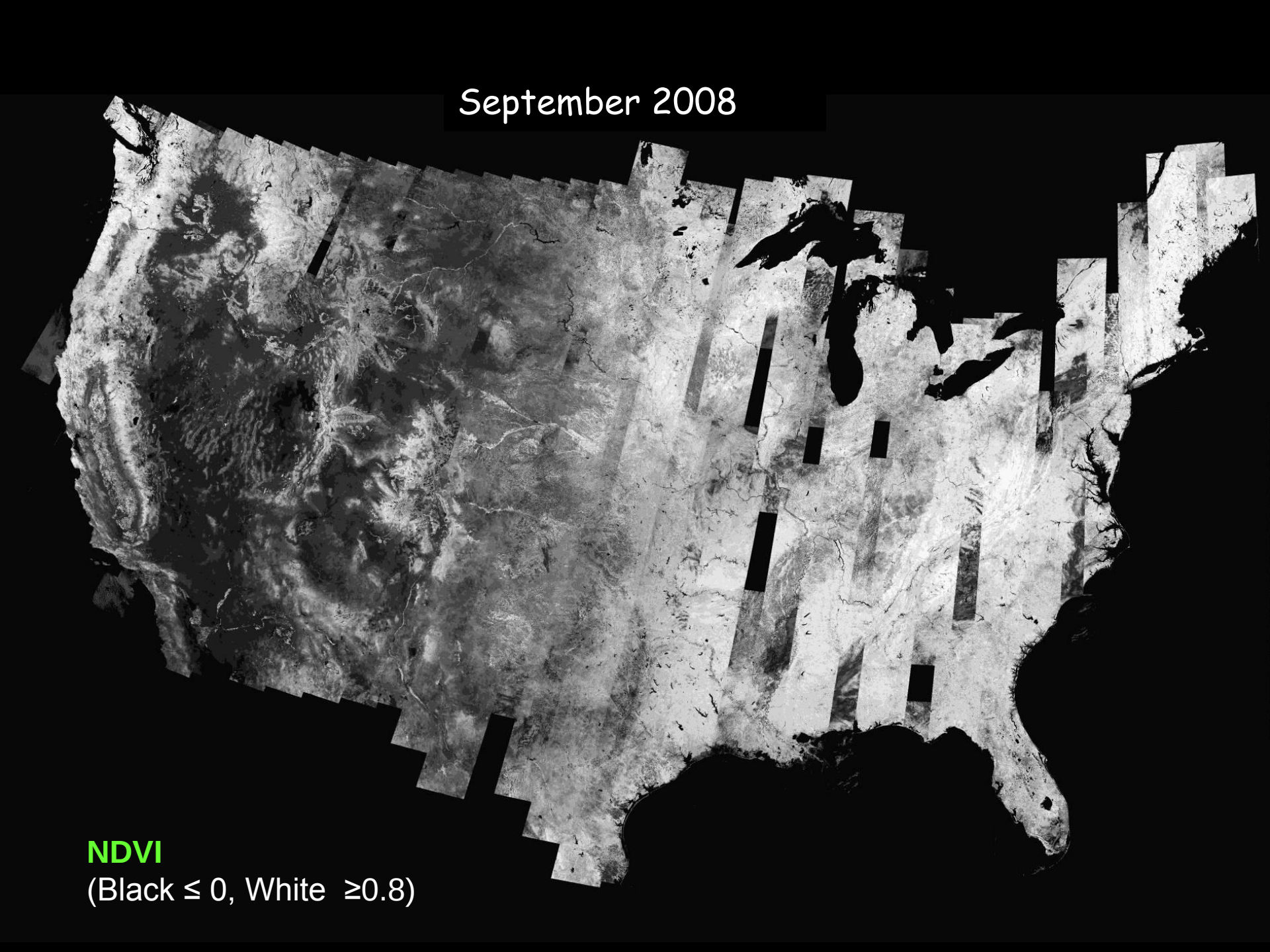
NDVI
(Black ≤ 0, White ≥0.8)

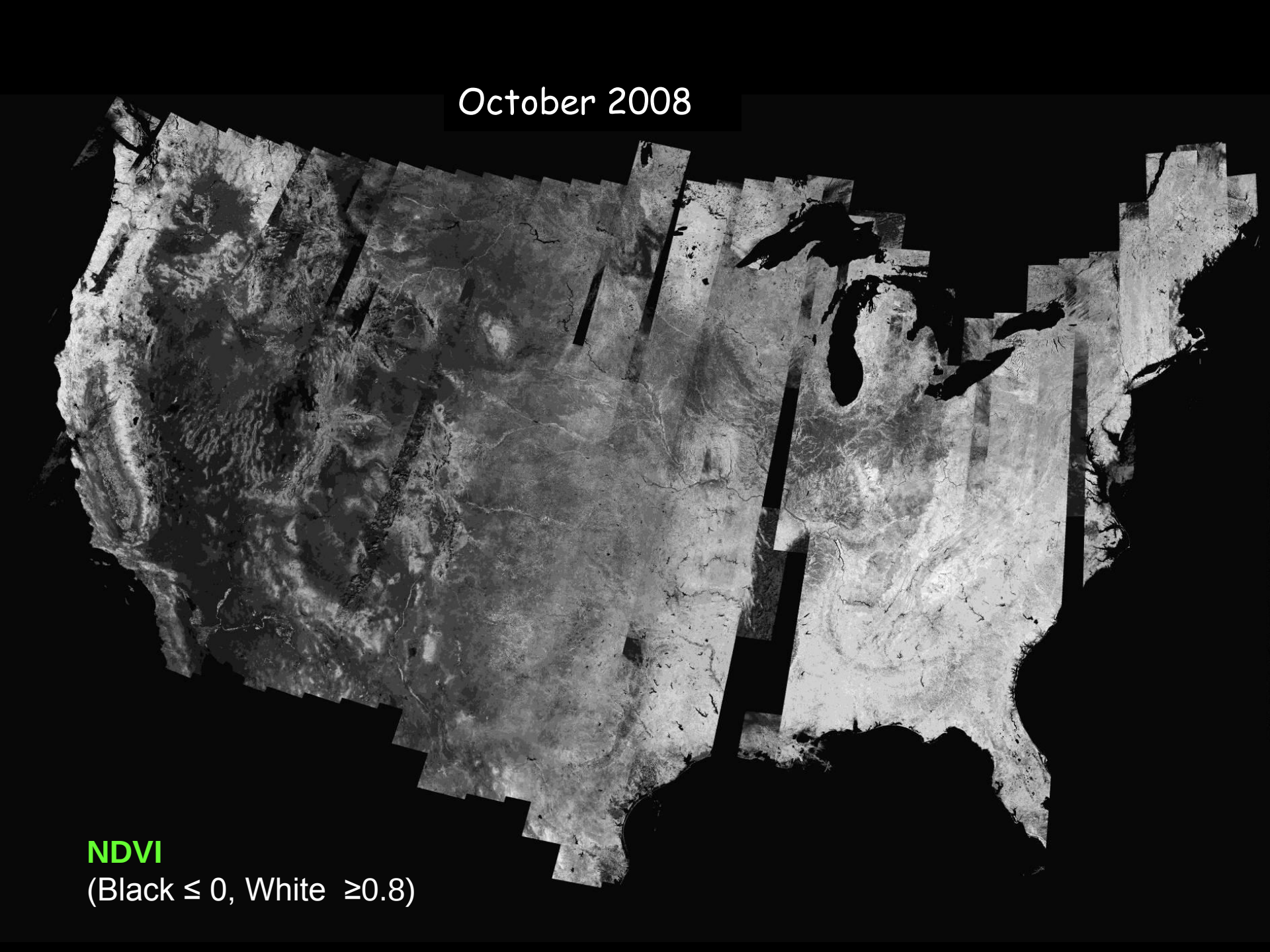

May 2008
NDVI
(Black ≤ 0, White ≥0.8)


June 2008
NDVI
(Black ≤ 0, White ≥0.8)


July 2008
NDVI
(Black ≤ 0, White ≥0.8)


August 2008
NDVI
(Black ≤ 0, White ≥0.8)


September 2008
NDVI
(Black ≤ 0, White ≥0.8)


October 2008
NDVI
(Black ≤ 0, White ≥0.8)

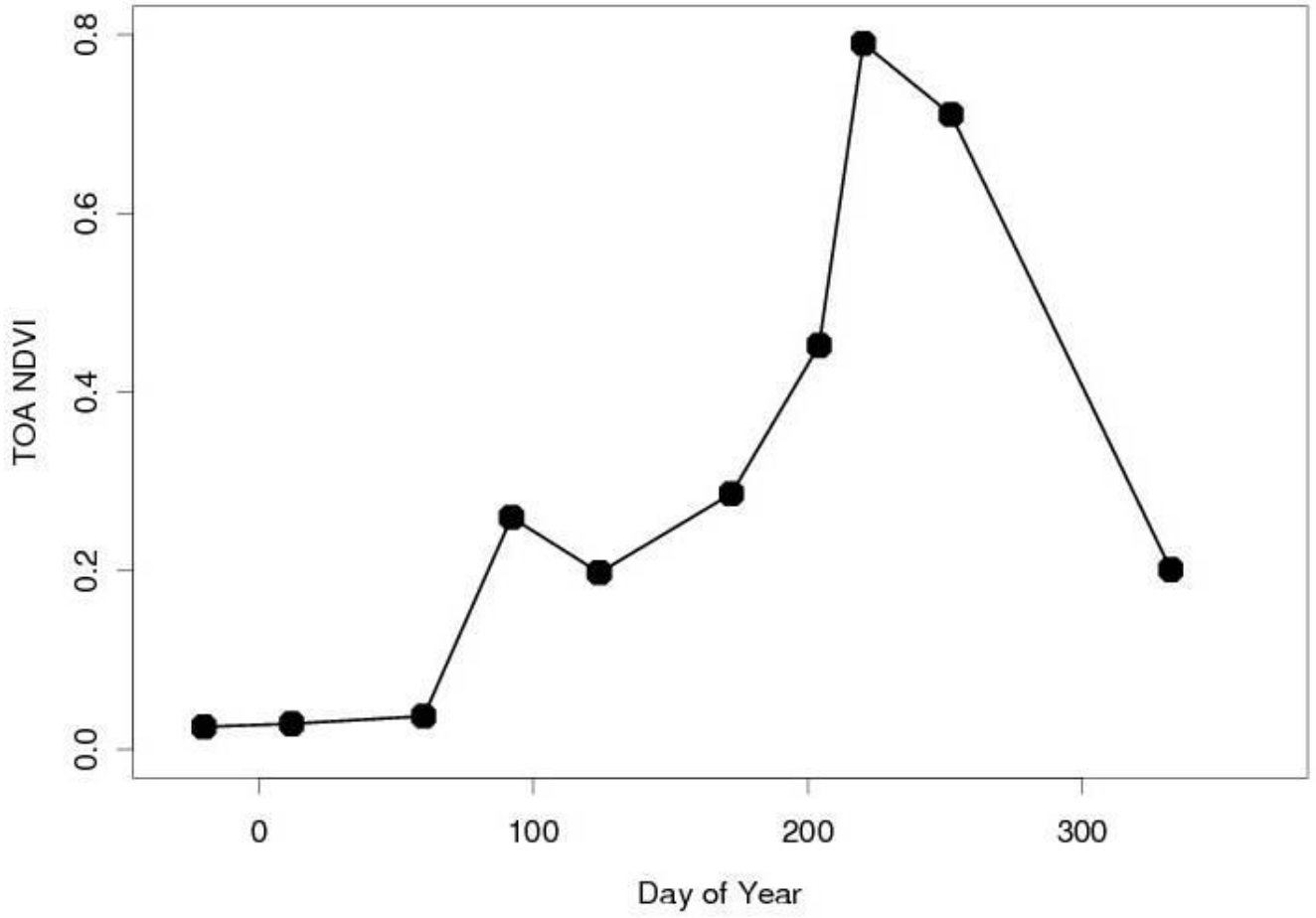
November 2008

NDVI
(Black ≤ 0, White ≥0.8)

Landsat Phenology:

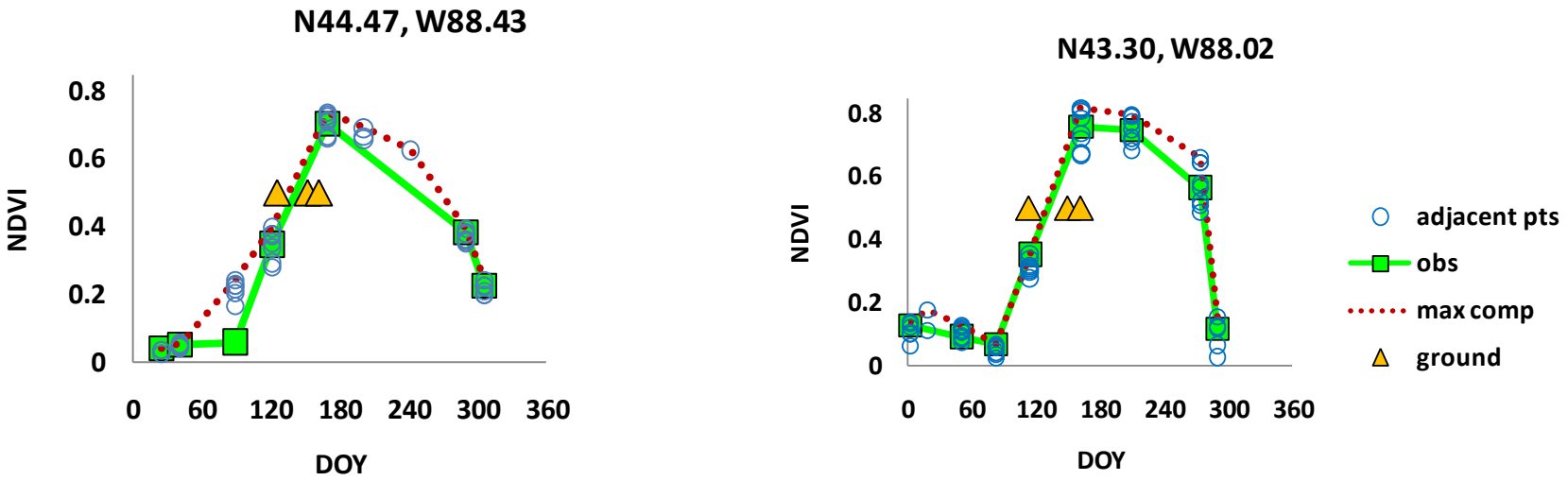
1 year NDVI for a single 30m WELD pixel extracted from 12 monthly composites

Brookings, Agricultural Field, SD



U.S. Phenology Network Example:

Lilac ground data bounds the rapid increase in WELD NDVI



Orange triangles show the 3 phenophases of lilac in chronological order:

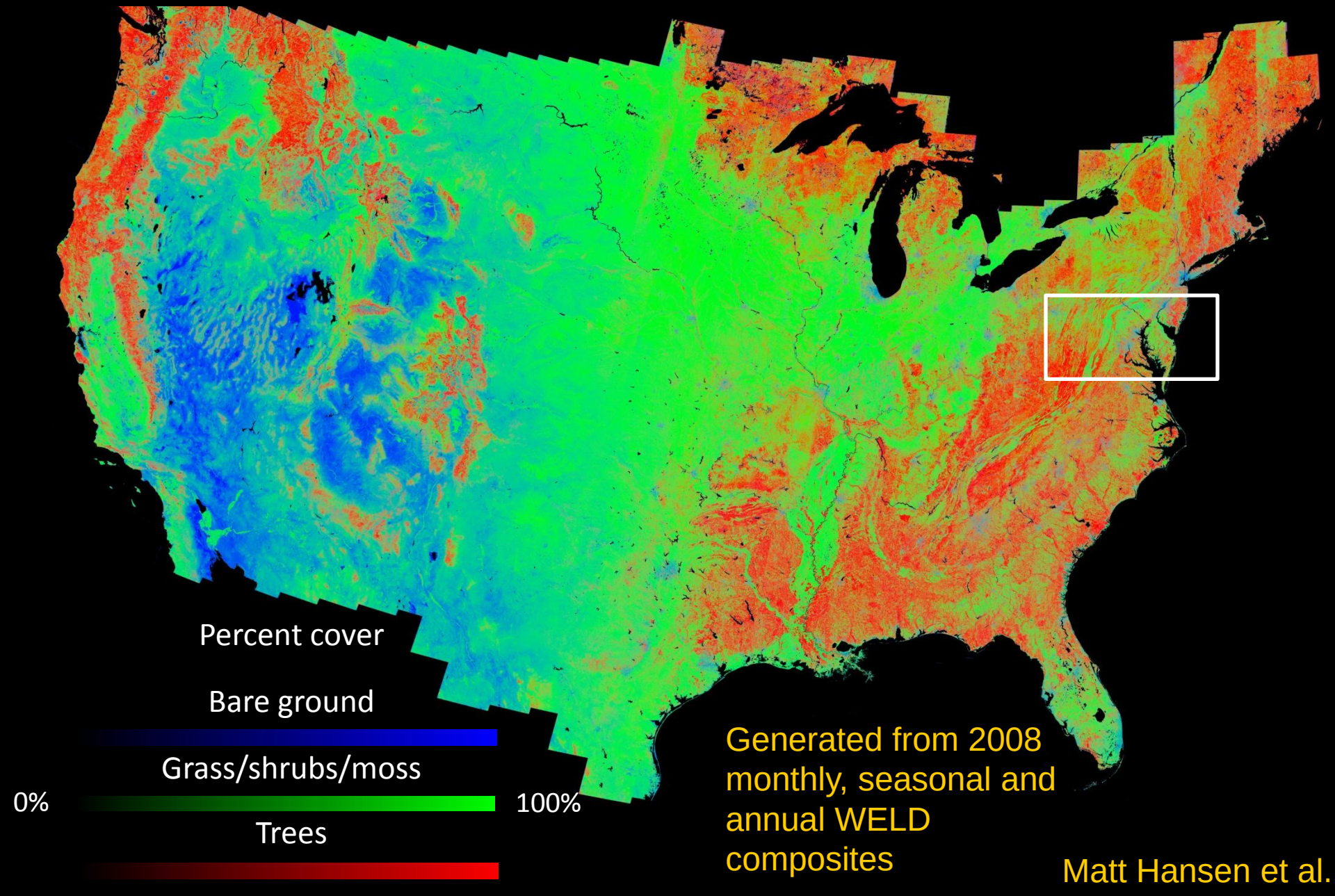
95% leaf out -> full bloom -> last bloom

Other symbols show WELD NDVI values

(Geoff Henebry et al.)

Fly across 2008 annual composited mosaic, 500m browse
Seattle to Houston, 36 frames/sec.

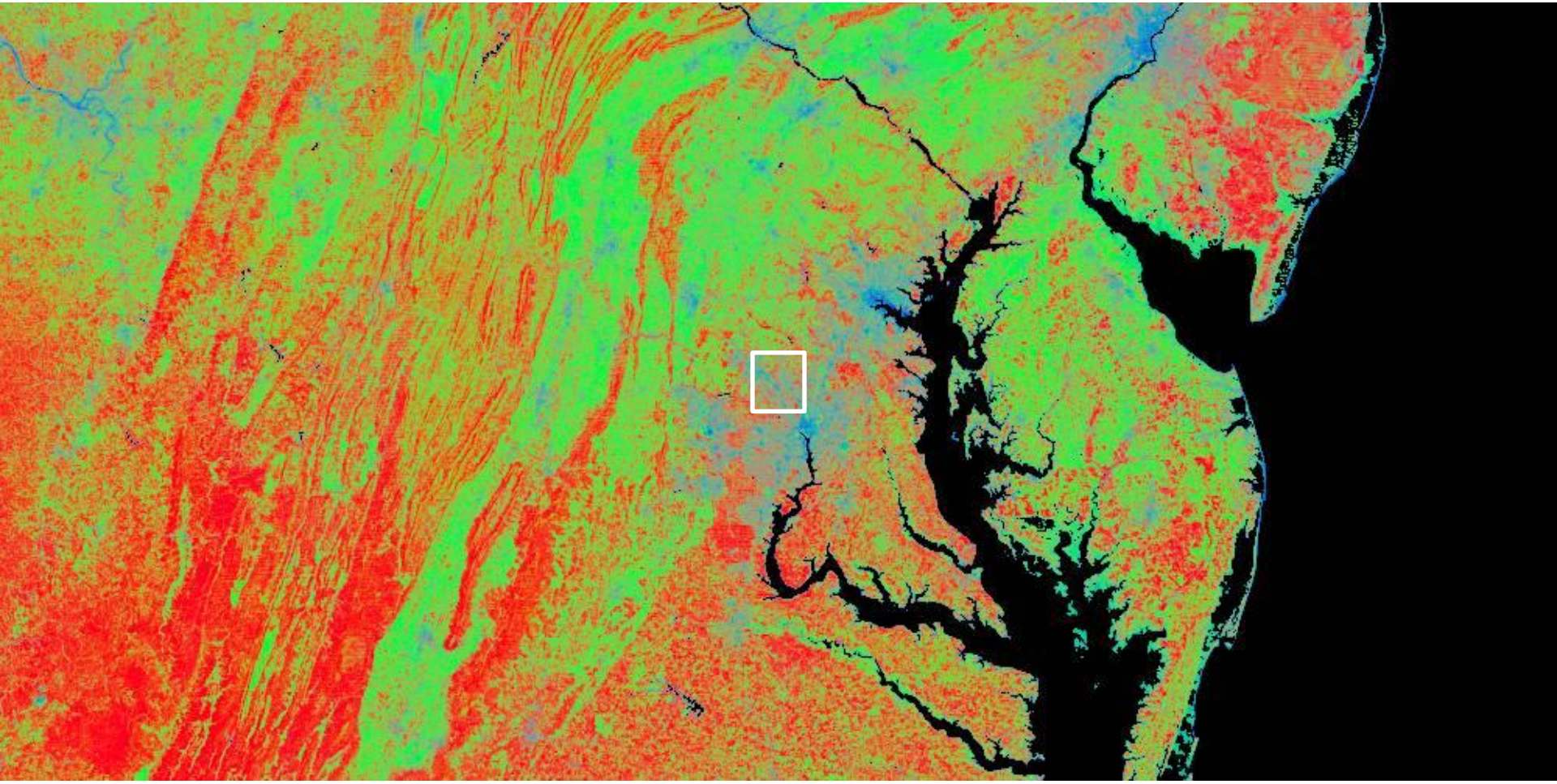
CONUS 30m Vegetation Continuous Fields (%)



Generated from 2008 monthly, seasonal and annual WELD composites

Matt Hansen et al.

Mid-Atlantic



Percent cover

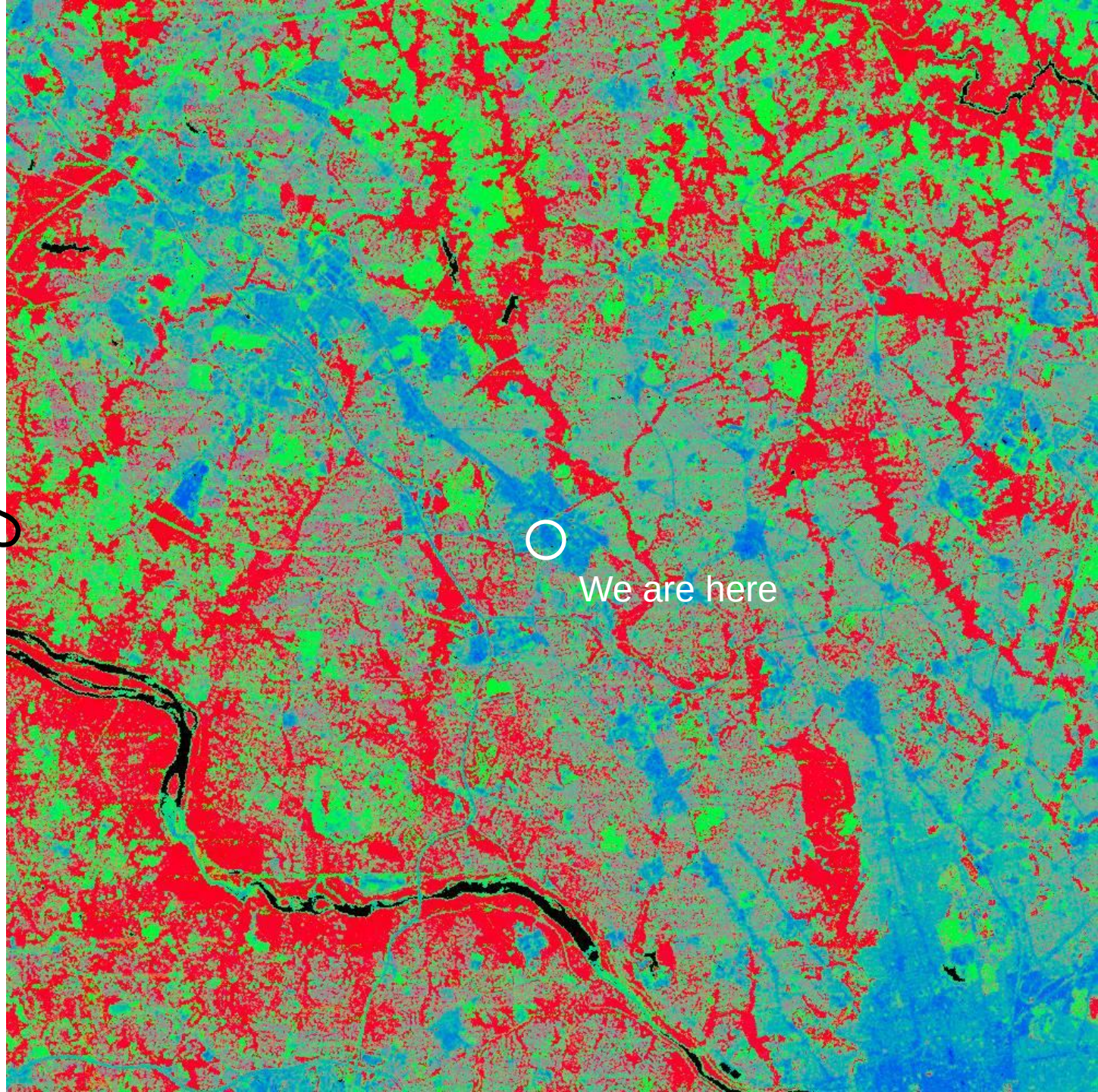
Bare ground

Grass/shrubs/moss

0% 100%

Trees

White Flint, MD



Percent cover

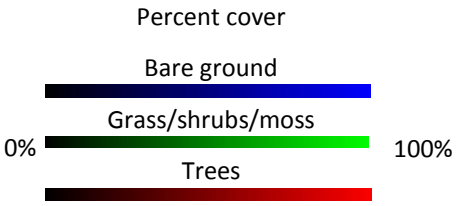
Bare ground

Grass/shrubs/moss

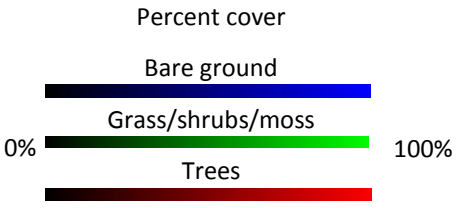
0% 100%

Trees

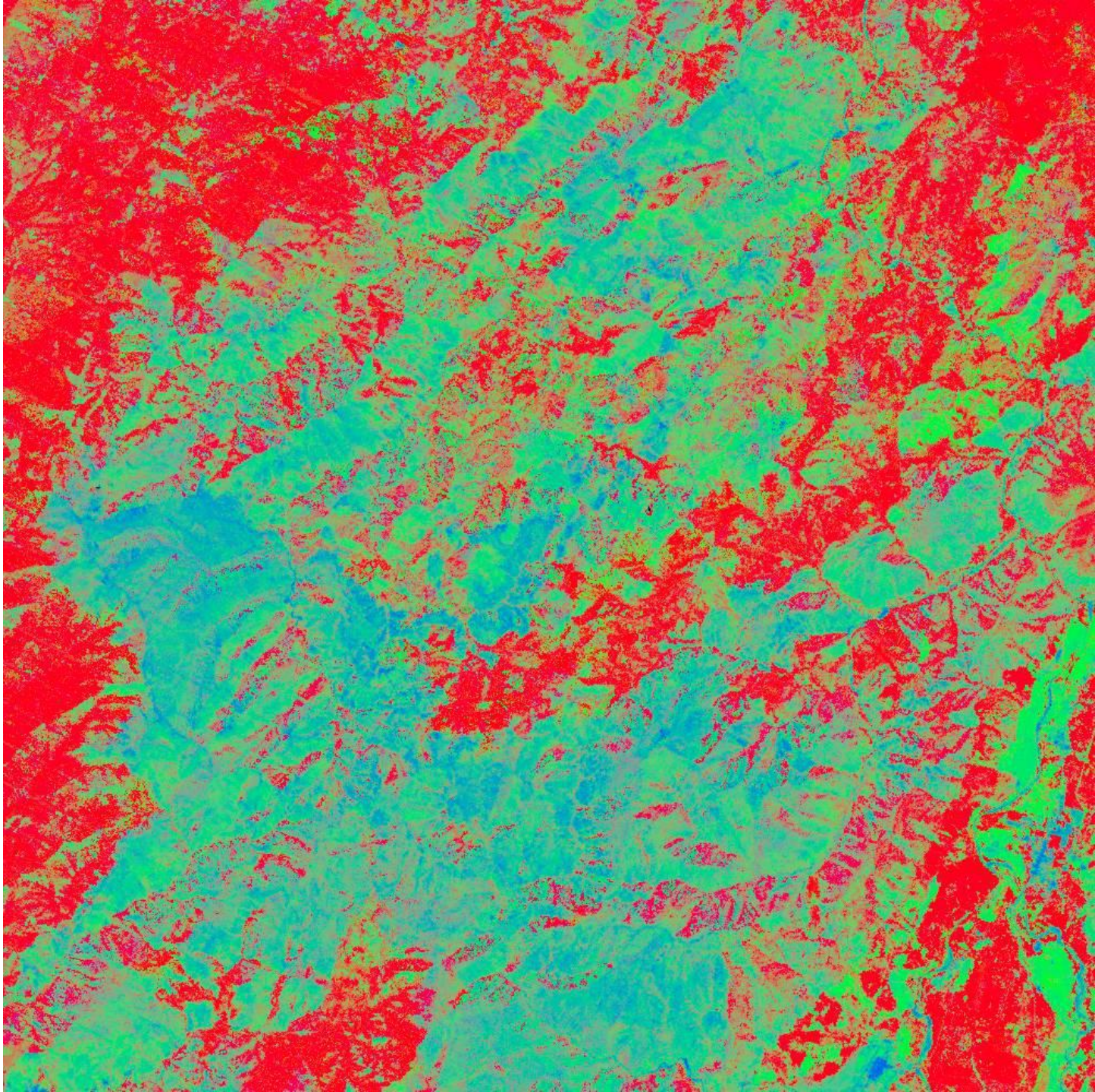
Brookings, SD



Mountain-top removal, Coal Mining, WV

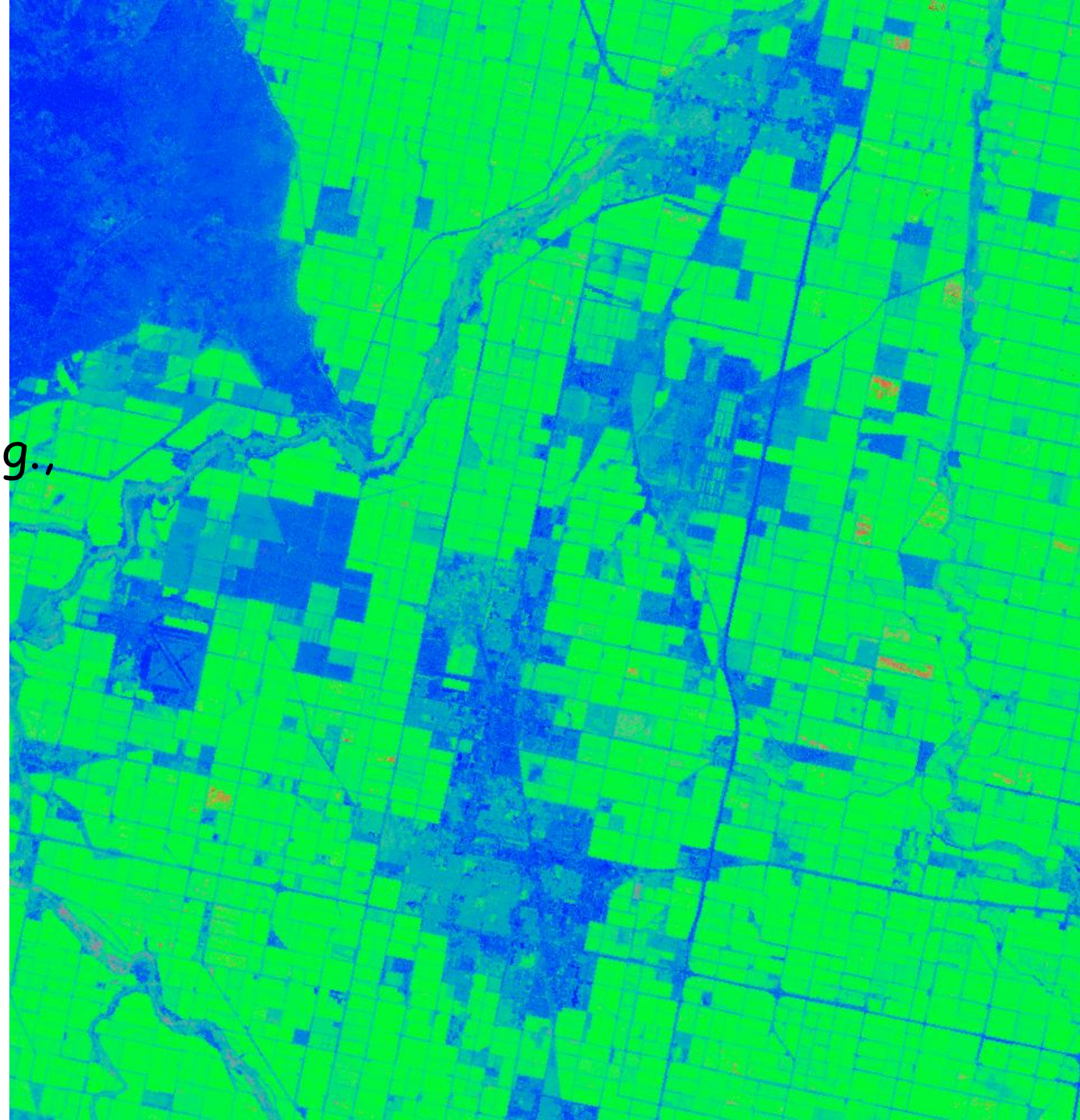


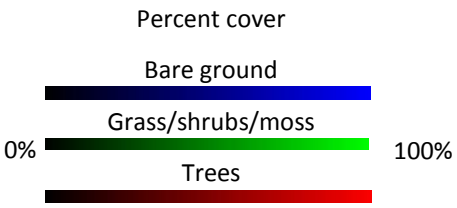
2002 Biscuit Fire, OR



Imperial Valley Ag., CA

Field Sizes





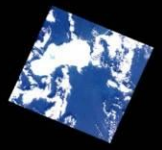
Alaska December 2007

500m Browse (4118x5000 pixels)

Monthly composite of 0 L1T [9 L1G]
acquisitions with cloud cover < 80%

Alaska January 2008

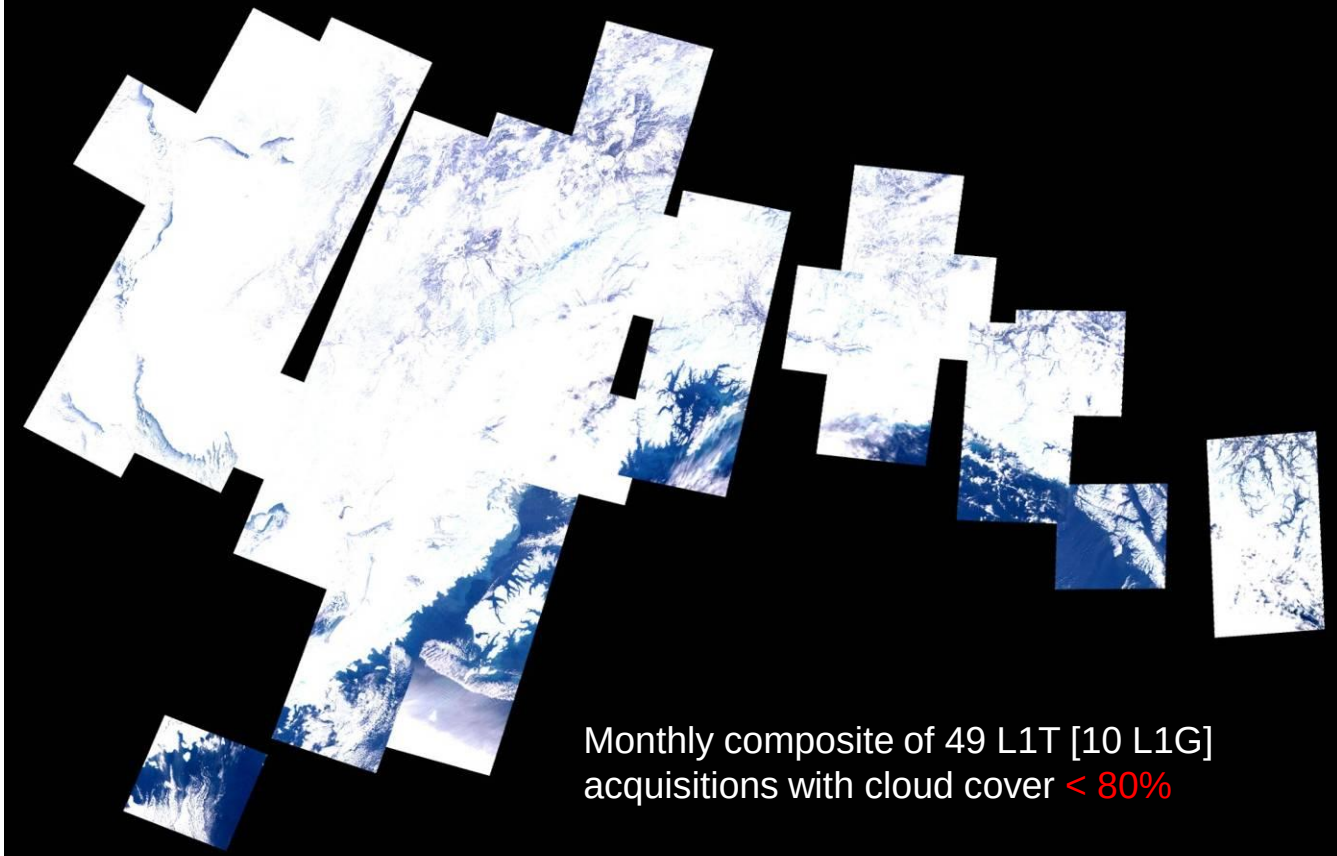
500m Browse (4118x5000 pixels)



Monthly composite of 2 L1T [0 L1G]
acquisitions with cloud cover < 80%

Alaska February 2008

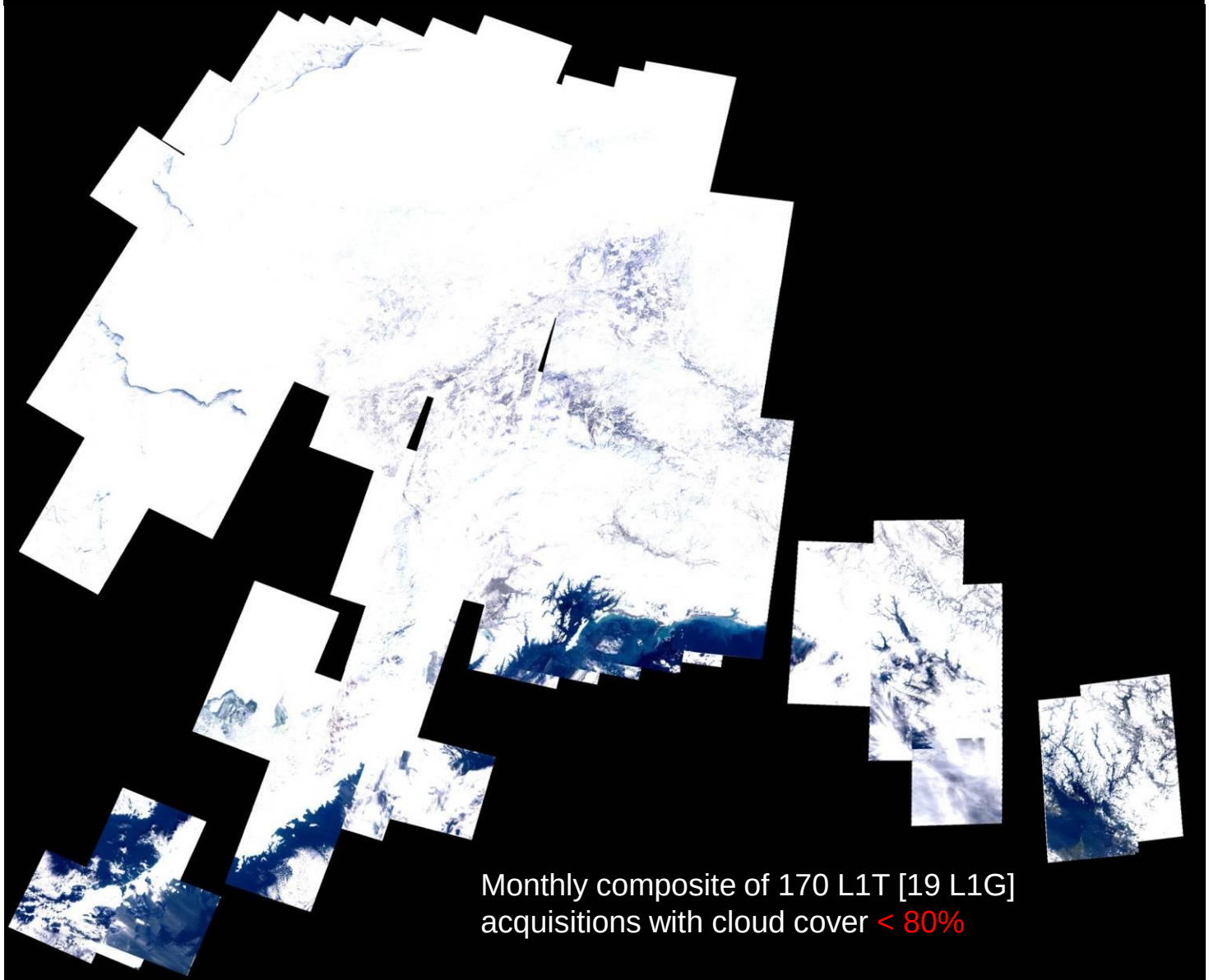
500m Browse (4118x5000 pixels)



Monthly composite of 49 L1T [10 L1G] acquisitions with cloud cover < 80%

Alaska March 2008

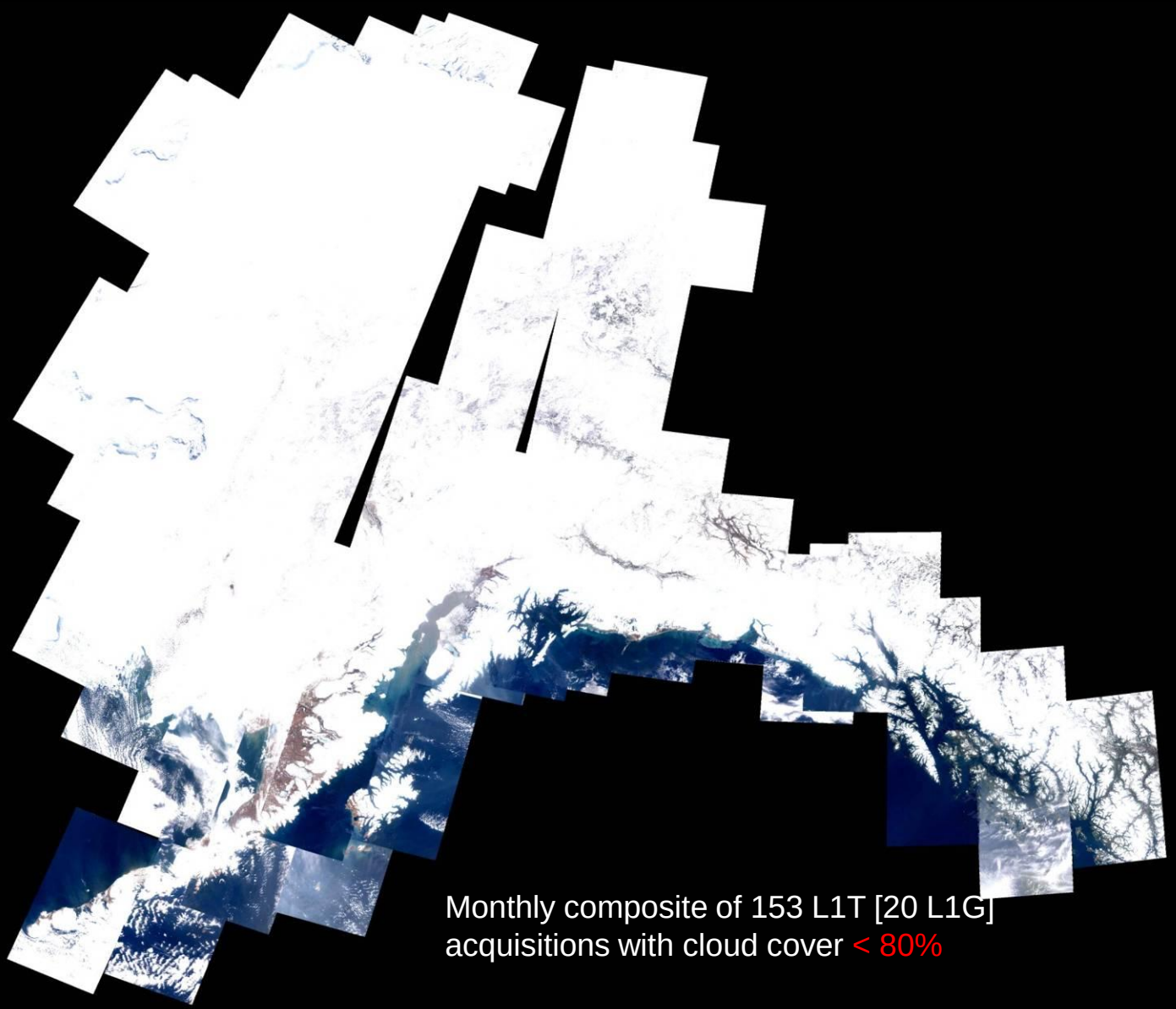
500m Browse (4118x5000 pixels)



Monthly composite of 170 L1T [19 L1G] acquisitions with cloud cover < 80%

Alaska April 2008

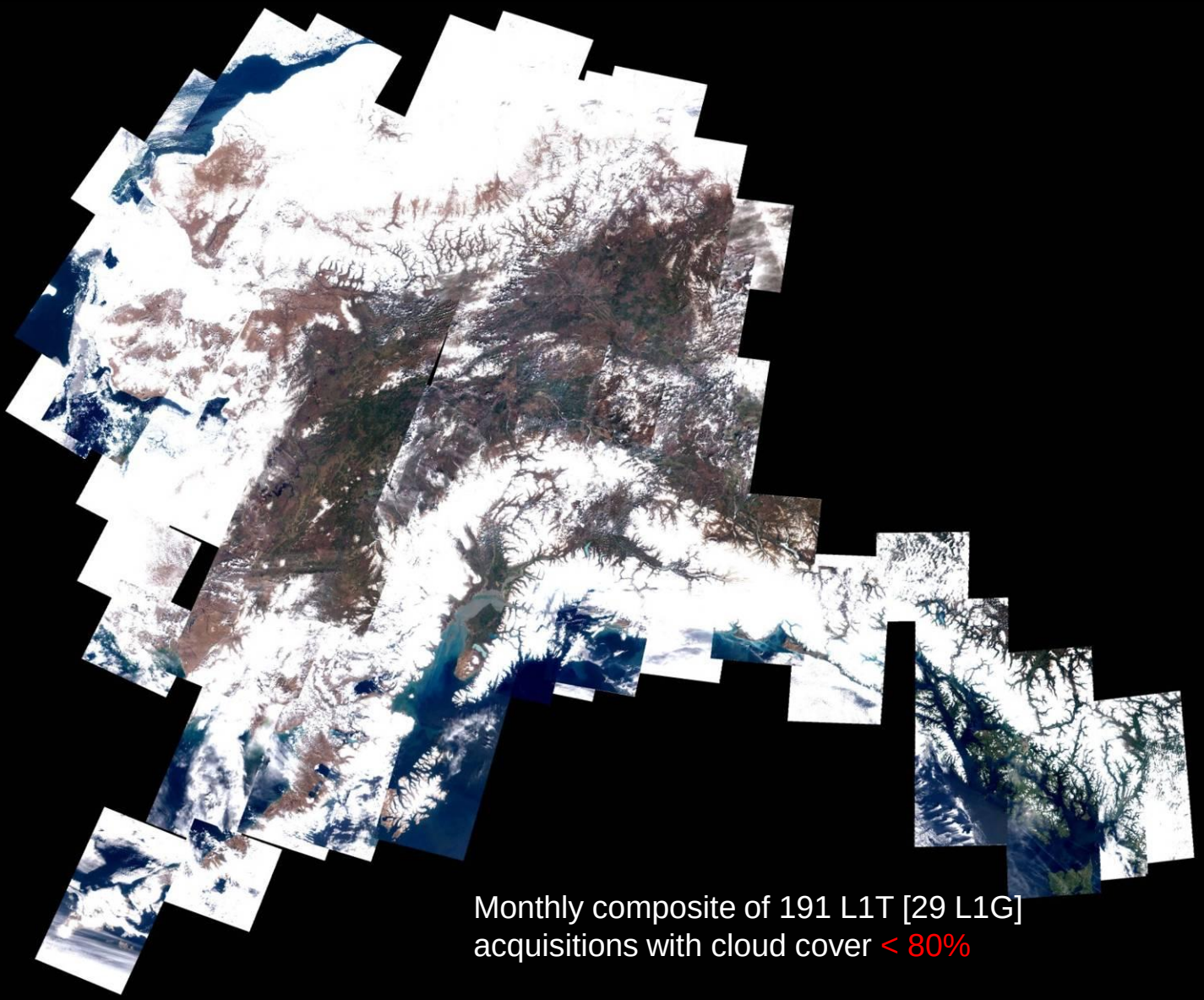
500m Browse (4118x5000 pixels)



Monthly composite of 153 L1T [20 L1G] acquisitions with cloud cover < 80%

Alaska May 2008

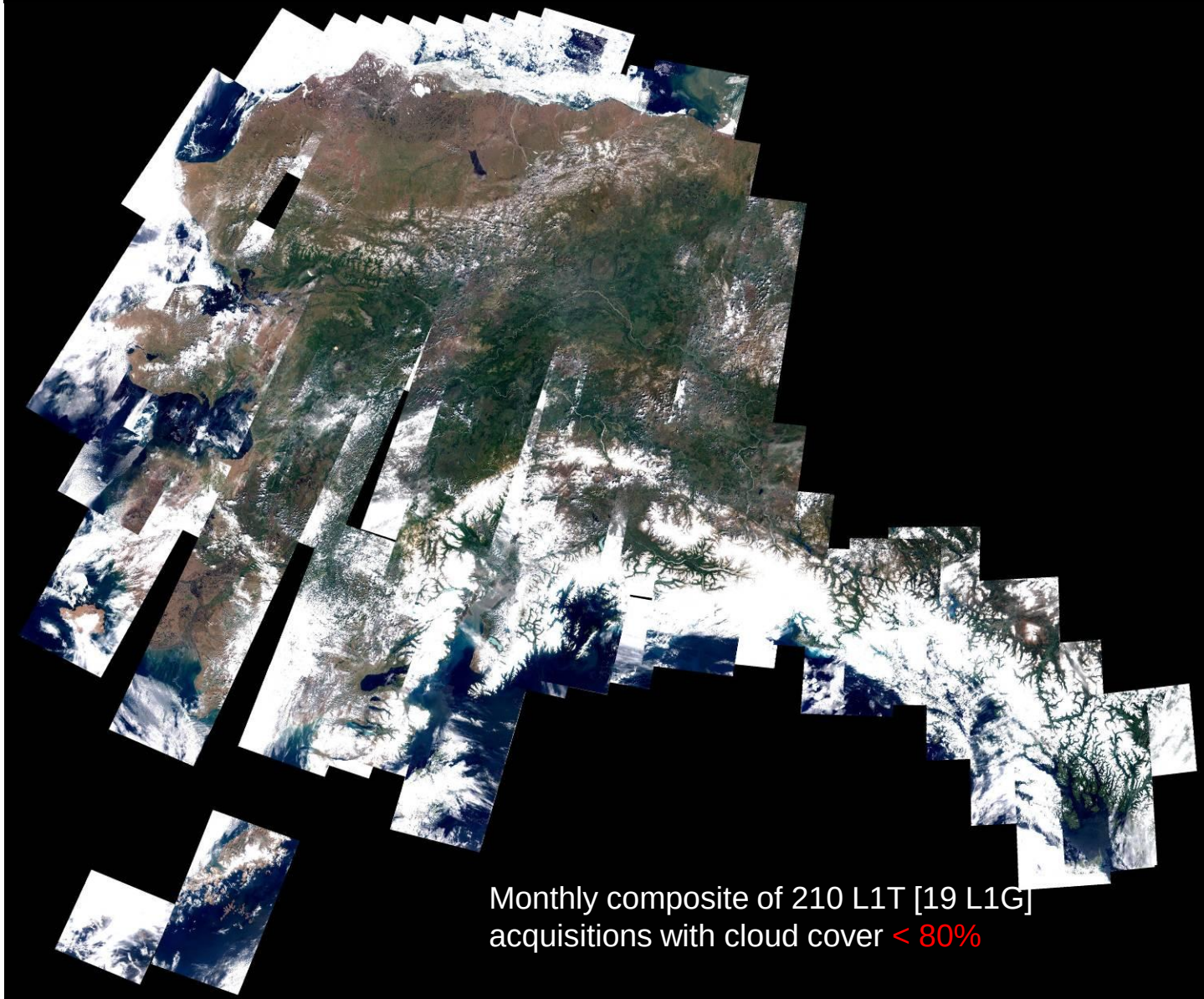
500m Browse (4118x5000 pixels)



Monthly composite of 191 L1T [29 L1G] acquisitions with cloud cover < 80%

Alaska June 2008

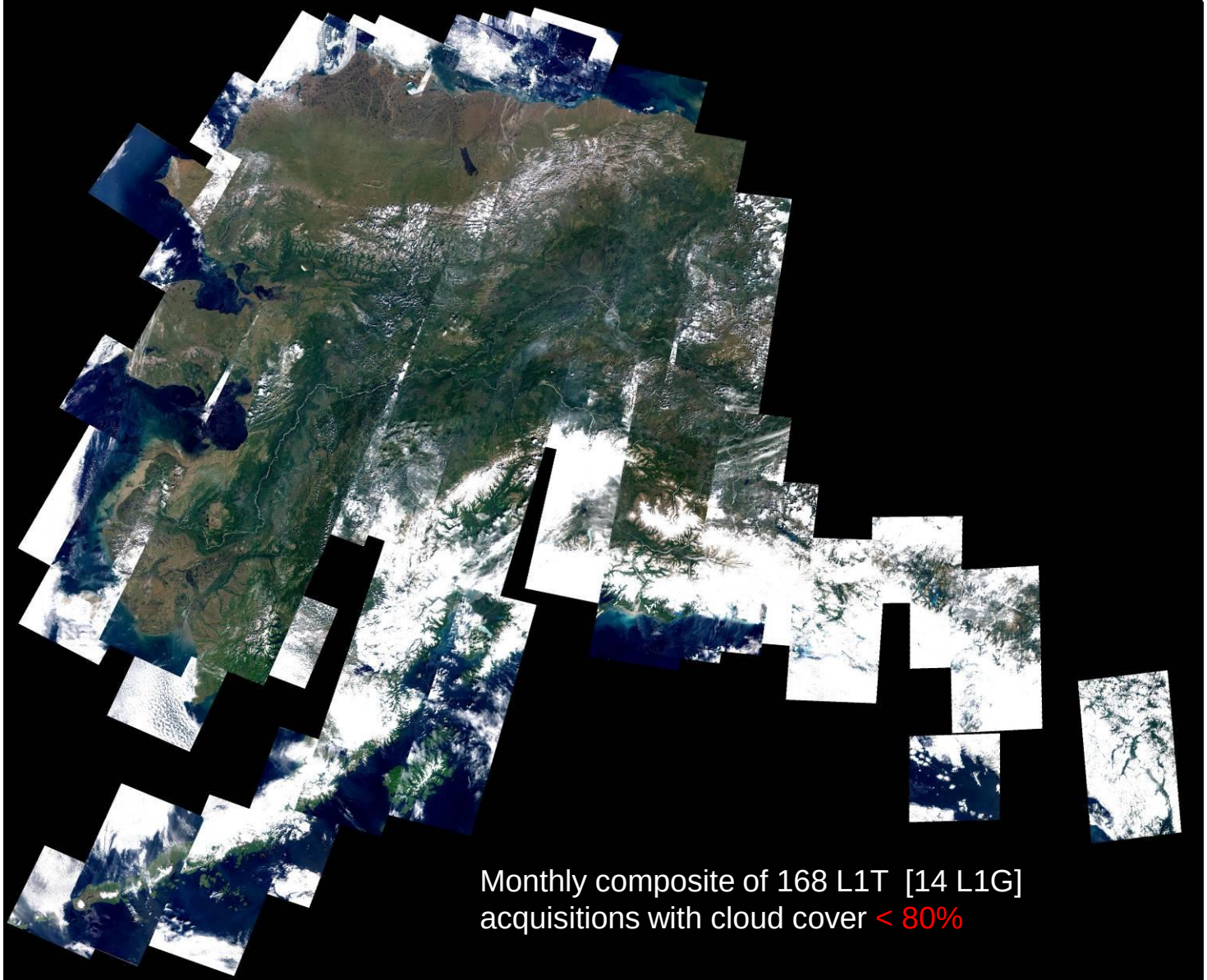
500m Browse (4118x5000 pixels)



Monthly composite of 210 L1T [19 L1G] acquisitions with cloud cover < 80%

Alaska July 2008

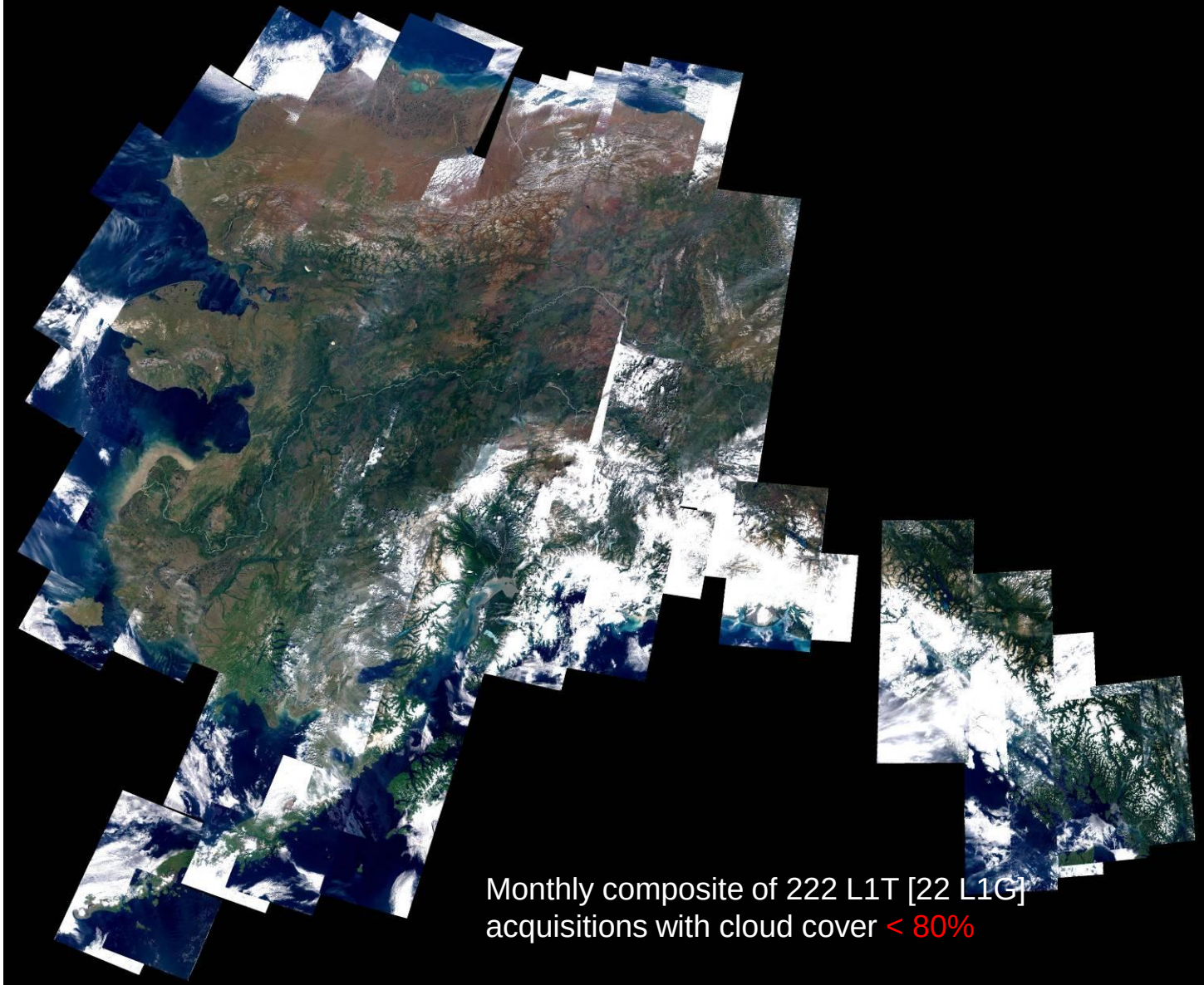
500m Browse (4118x5000 pixels)



Monthly composite of 168 L1T [14 L1G]
acquisitions with cloud cover < 80%

Alaska August 2008

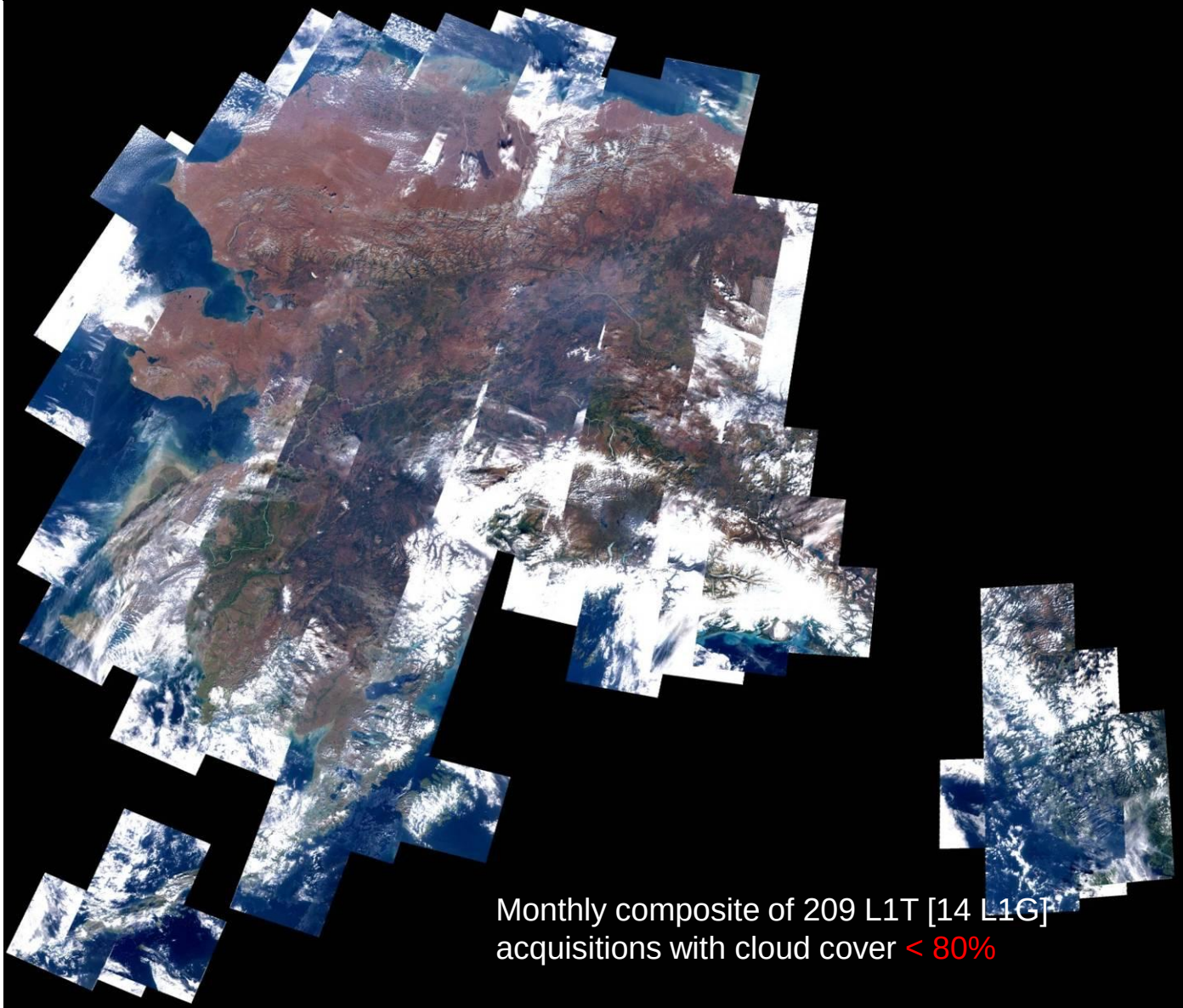
500m Browse (4118x5000 pixels)



Monthly composite of 222 L1T [22 L1G] acquisitions with cloud cover < 80%

Alaska September 2008

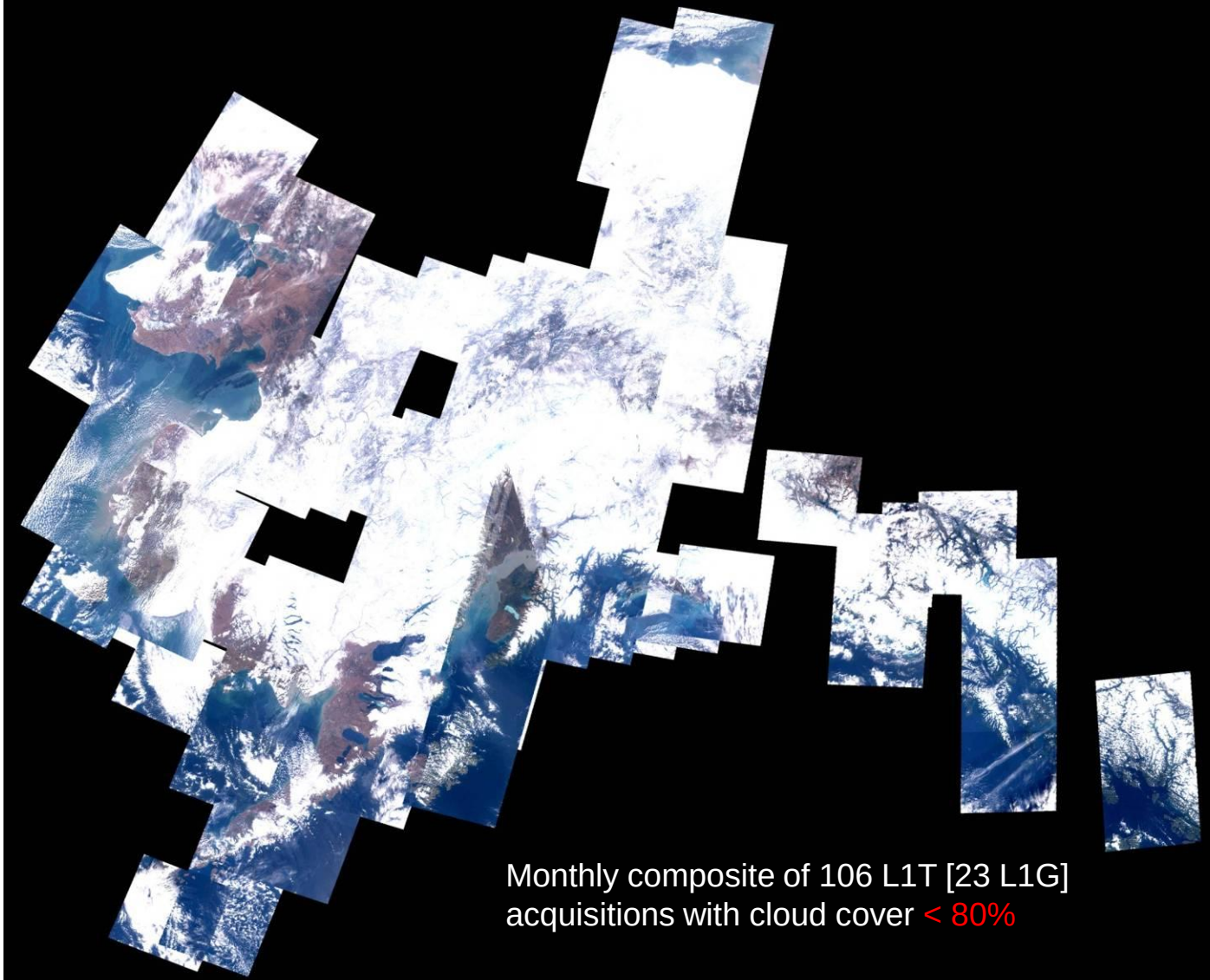
500m Browse (4118x5000 pixels)



Monthly composite of 209 L1T [14 L1G] acquisitions with cloud cover < 80%

Alaska October 2008

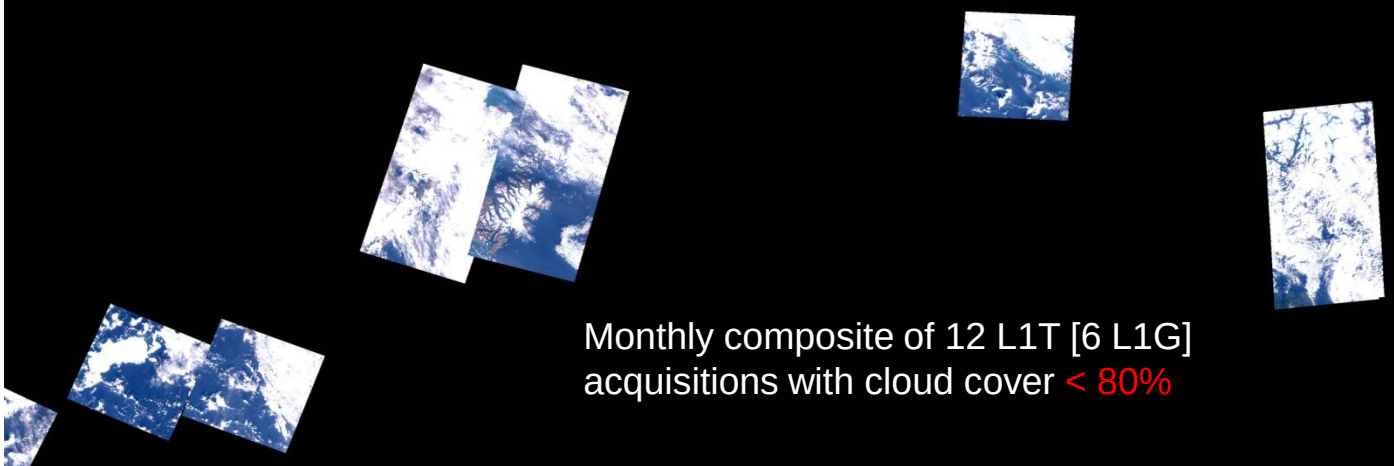
500m Browse (4118x5000 pixels)



Monthly composite of 106 L1T [23 L1G]
acquisitions with cloud cover < 80%

Alaska November 2008

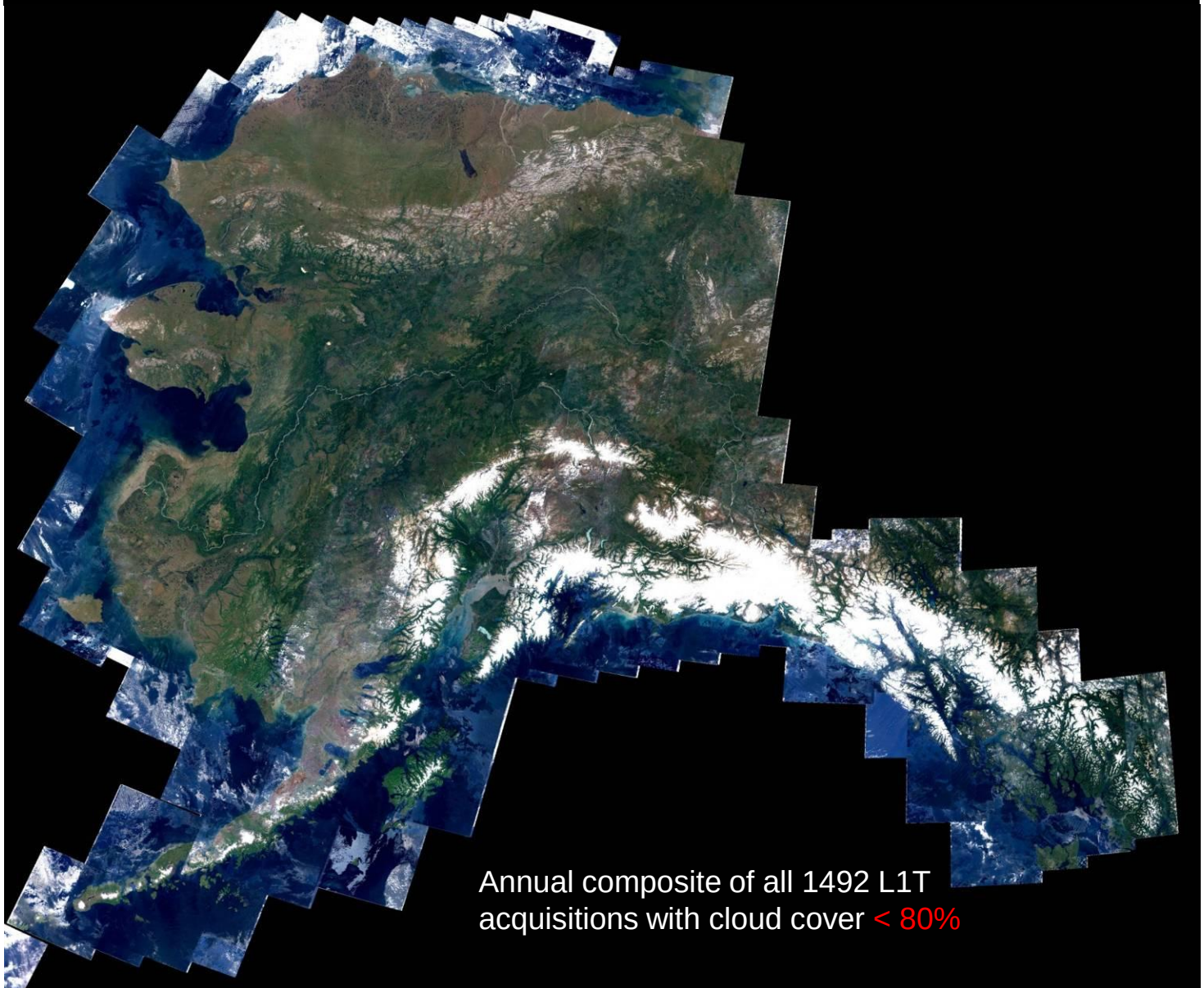
500m Browse (4118x5000 pixels)



Monthly composite of 12 L1T [6 L1G]
acquisitions with cloud cover < 80%

Annual 2008

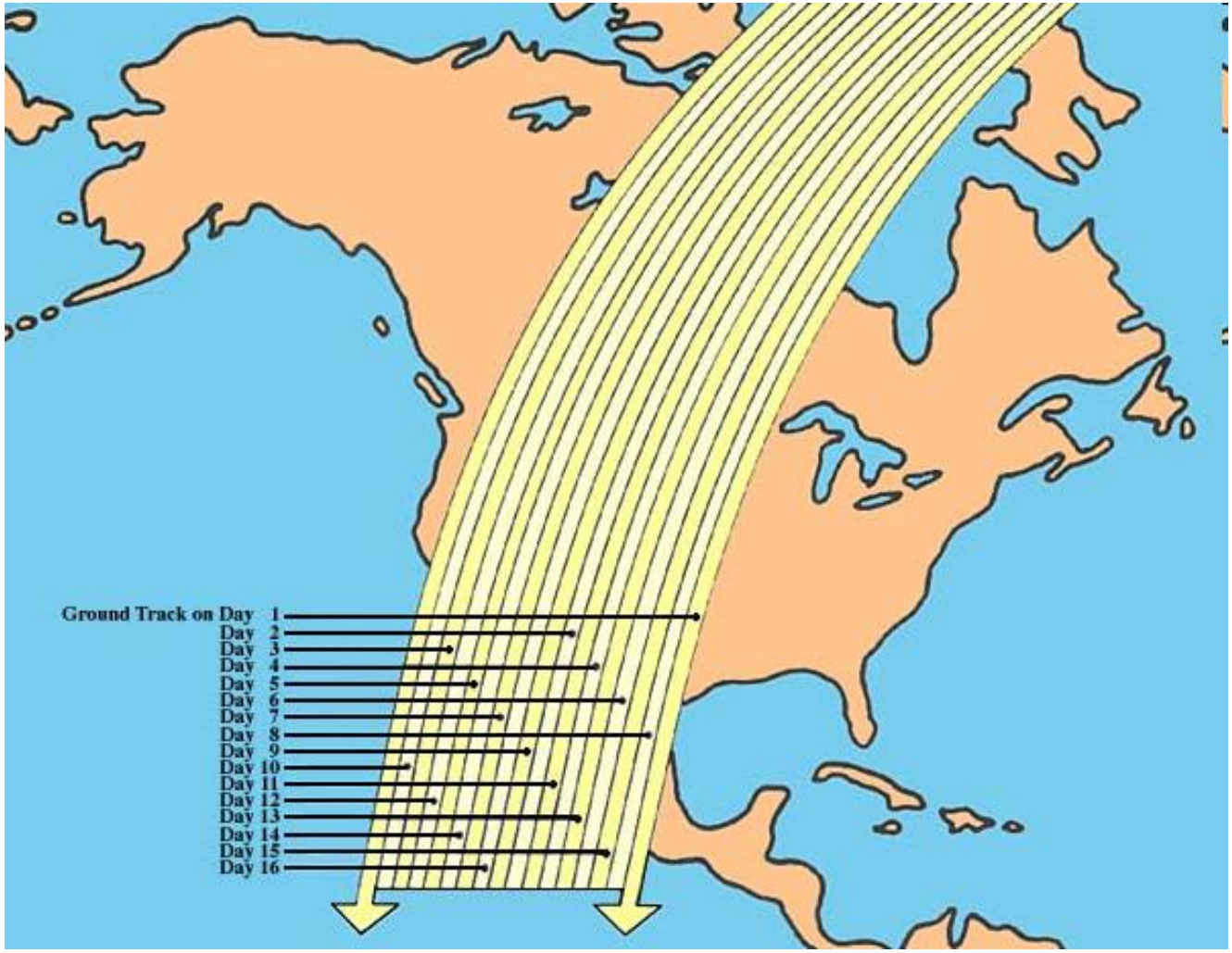
500m Browse (4118x5000 pixels)



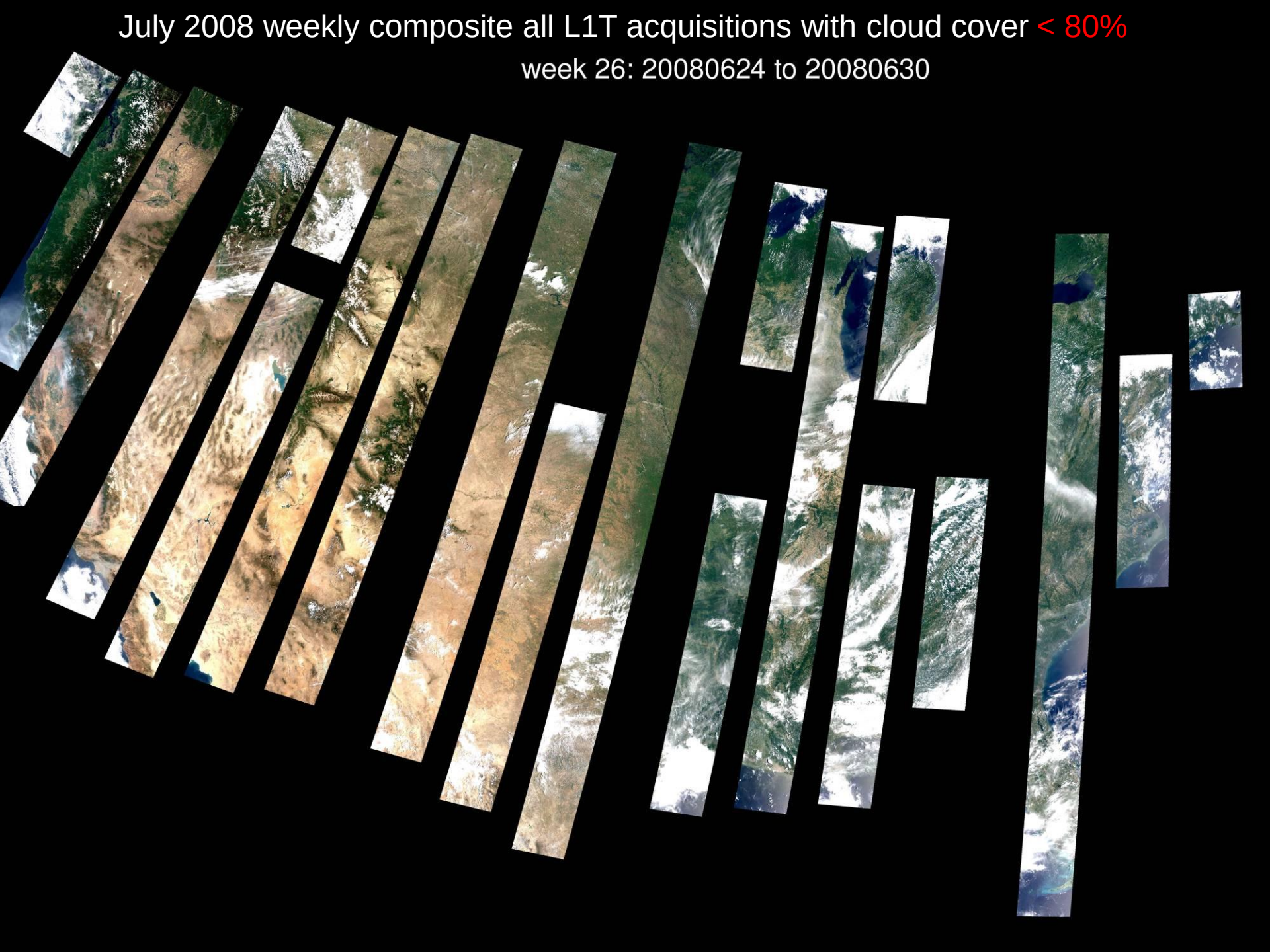
Annual composite of all 1492 L1T acquisitions with cloud cover < 80%

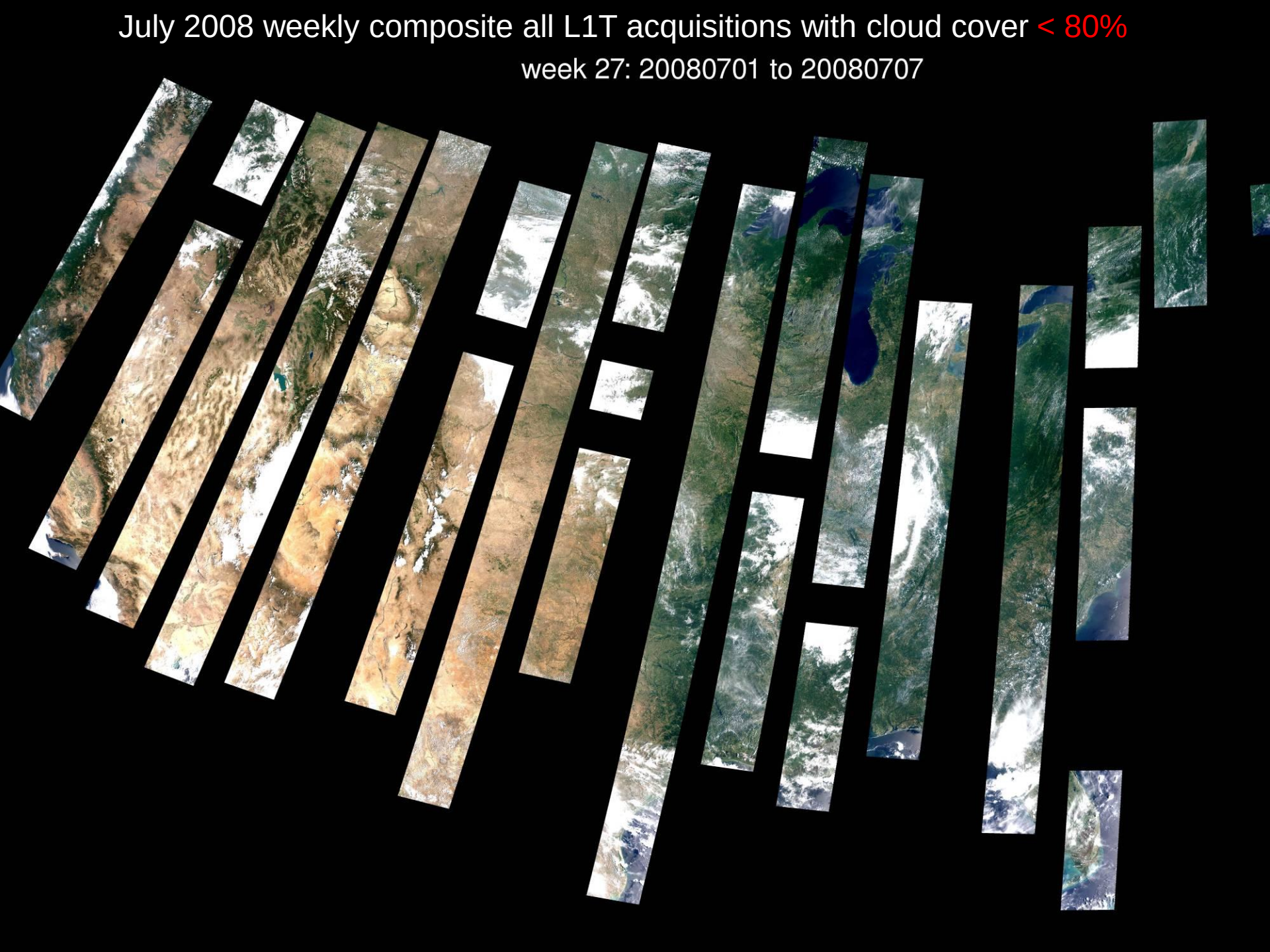
Users said they wanted all the L1T with the WELD processing applied

Landsat Orbit Geometry / Swath Pattern



http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter5/htmls/swath_pattern.html


July 2008 weekly composite all L1T acquisitions with cloud cover < 80%
week 26: 20080624 to 20080630


July 2008 weekly composite all L1T acquisitions with cloud cover < 80%
week 27: 20080701 to 20080707

WELD ETM+ Data Processing Steps

- TOA reflectance & brightness temperature
- View and Solar Geometry Computation
- Cloud mask
- SLC-Off and cloud gap filling
- Reprojection: UTM to Albers map projection
- Compositing: monthly, seasonal, annual
- Atmospheric correction
- Radiometric/BRDF normalization
- Land cover characterization
- Browse generation

WELD ETM+ Data Processing Steps

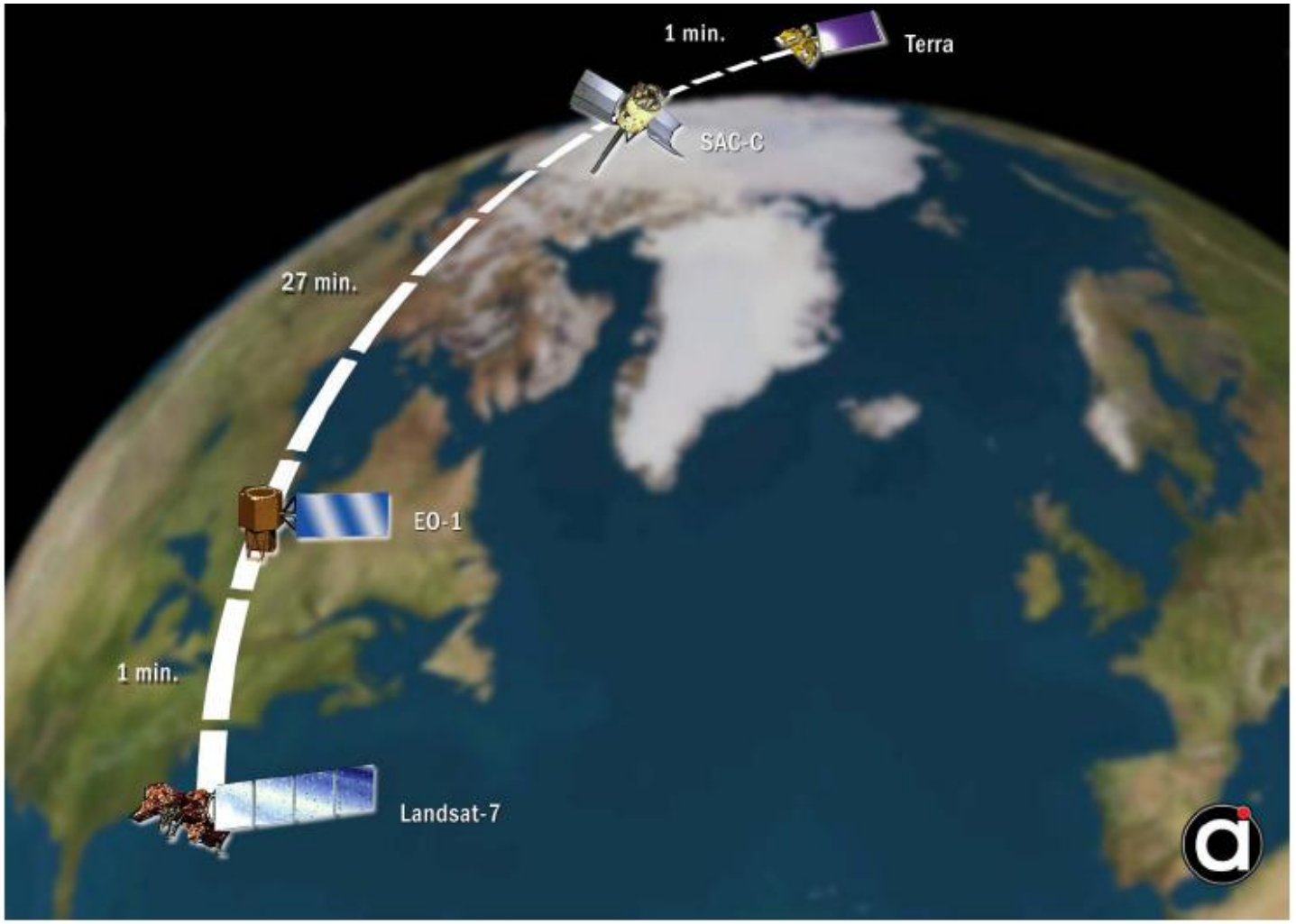
Steps that use contemporaneous MODIS Products

- TOA reflectance & brightness temperature
- View and Solar Geometry Computation
- Cloud mask
- SLC-Off and cloud gap filling
- Reprojection: UTM to Albers map projection
- Compositing: monthly, seasonal, annual
- Atmospheric correction
- Radiometric/BRDF normalization
- Land cover characterization
- Browse generation

Some recent algorithm developments

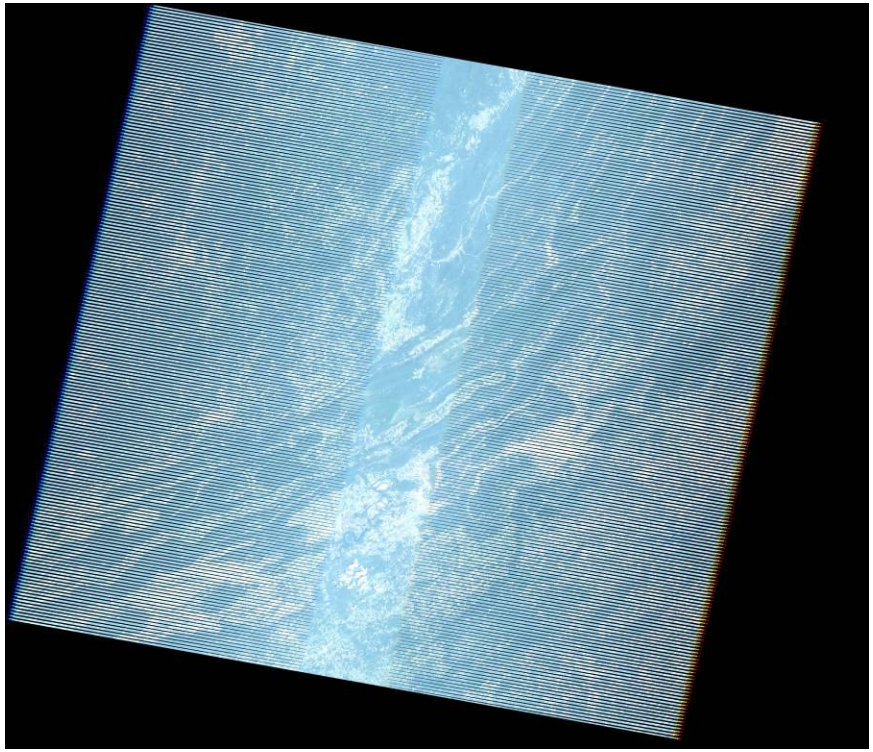
- Atmospheric correction
- Radiometric/BRDF normalization/Gap Filling

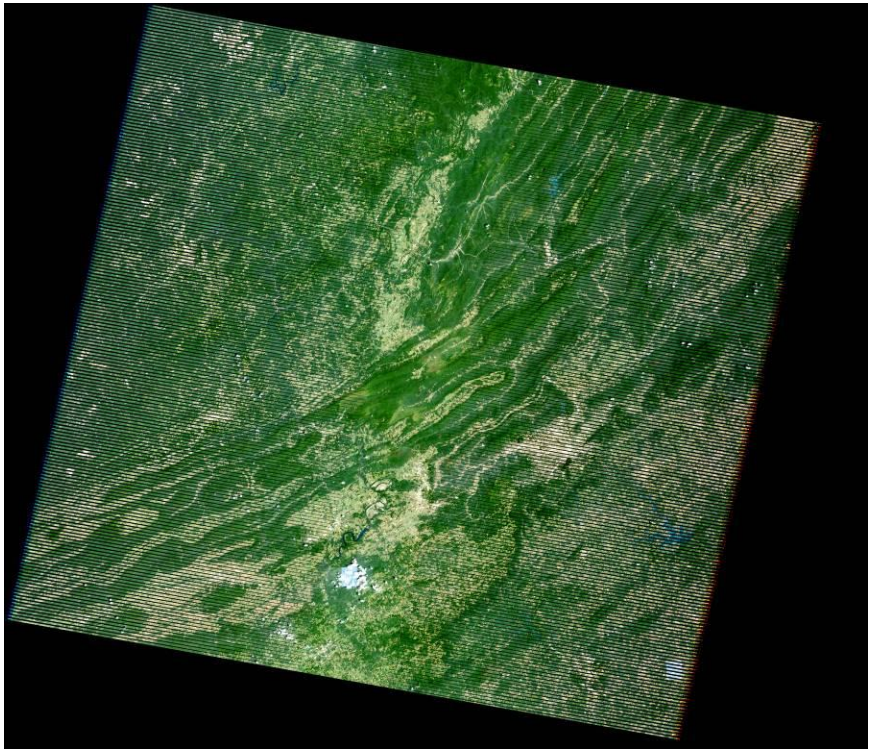
Landsat ETM+ and MODIS Terra in same orbit



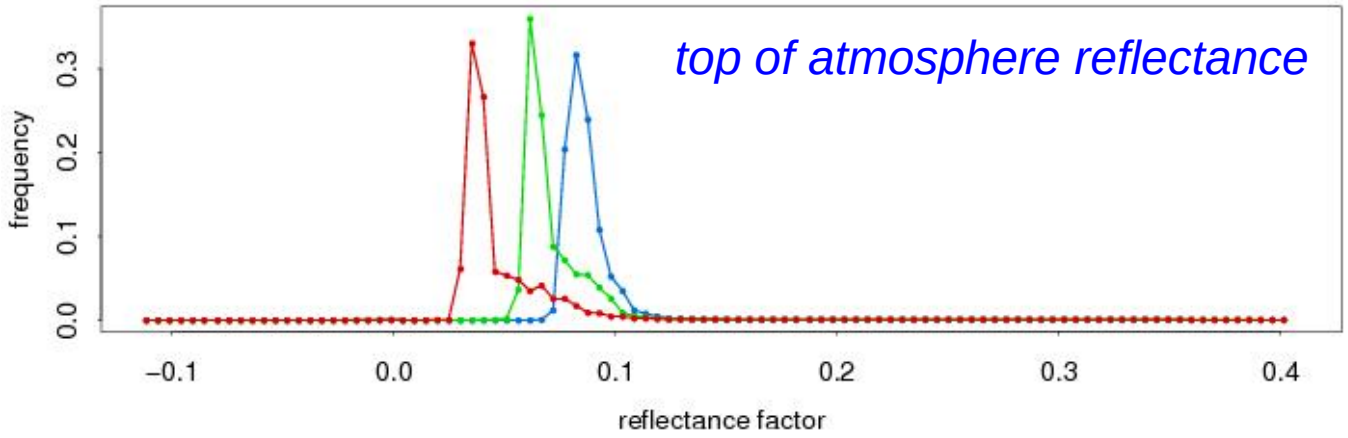
North West: Top of atmosphere Landsat ETM+ true color (red , green and blue bands); **South East:** Corresponding Surface reflectance computed using contemporaneous MODIS atmosphere parameterization data.

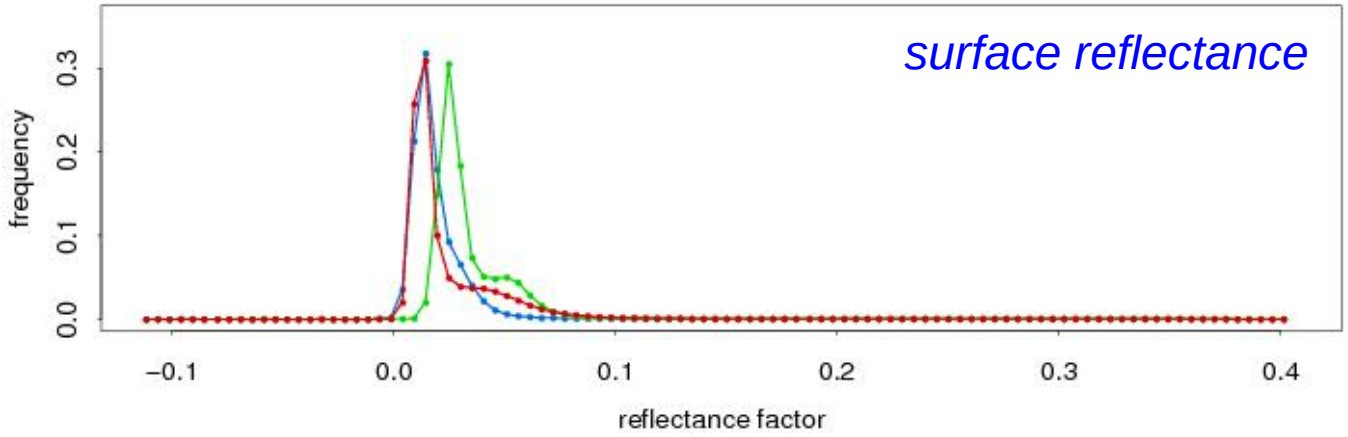
(Landsat Path 17 Row 34, Giles, Virginia, acquired July 18, 2008).





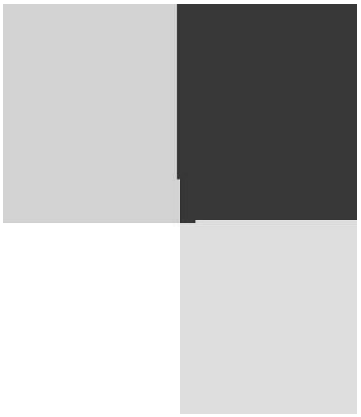
The atmospheric correction reduces visible reflectance, greatest reductions in the shorter wavelength blue band which has more atmospheric scattering, and with the green atmospherically corrected band showing greater reflectance after correction which is expected given that the scene is dominated by veg.



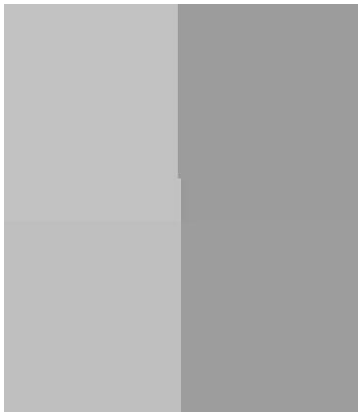


Blockiness due to 0.05° MODIS atmospheric paramerization

Surf reflectance true color



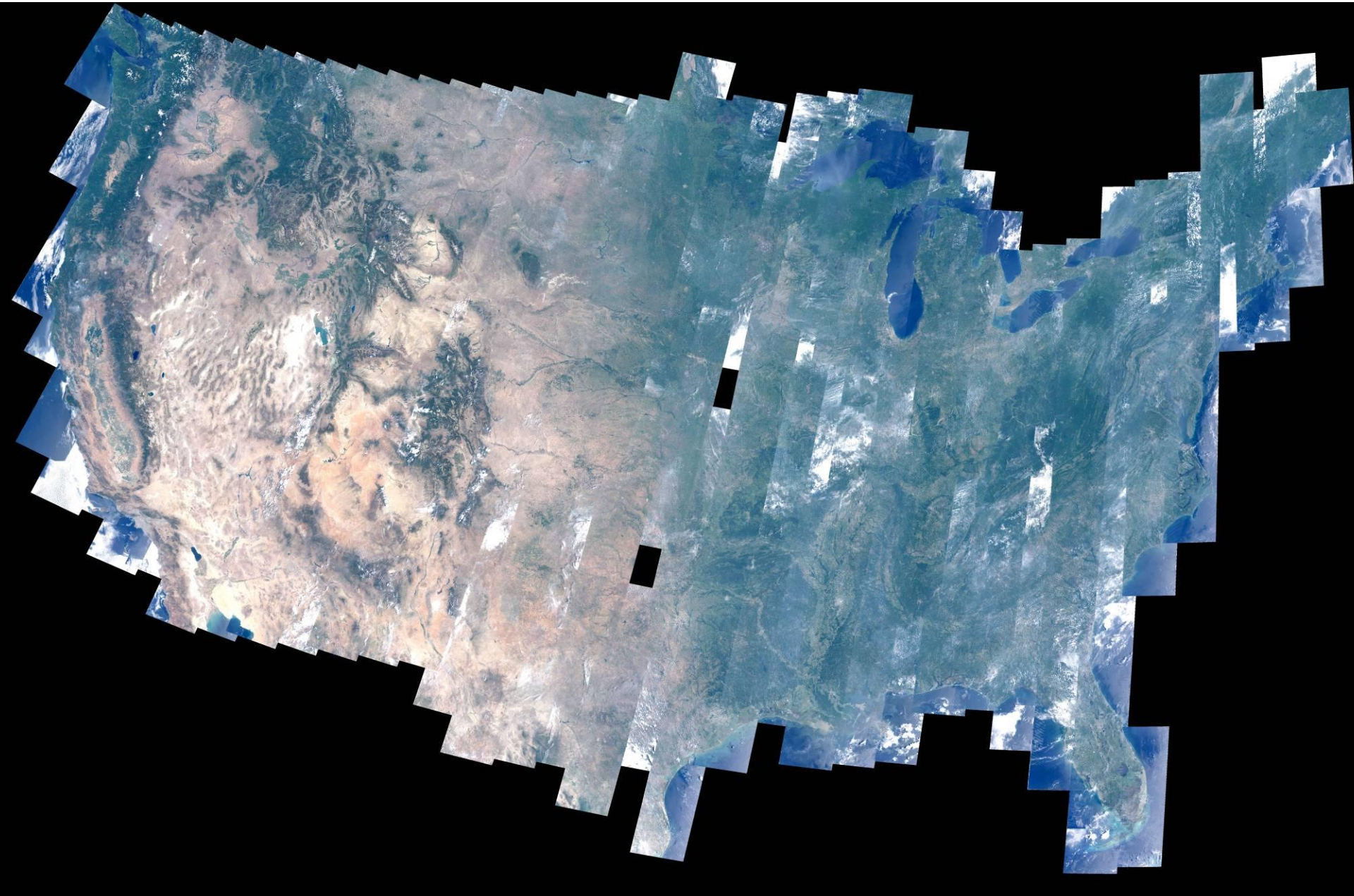
AOT



Water vapor

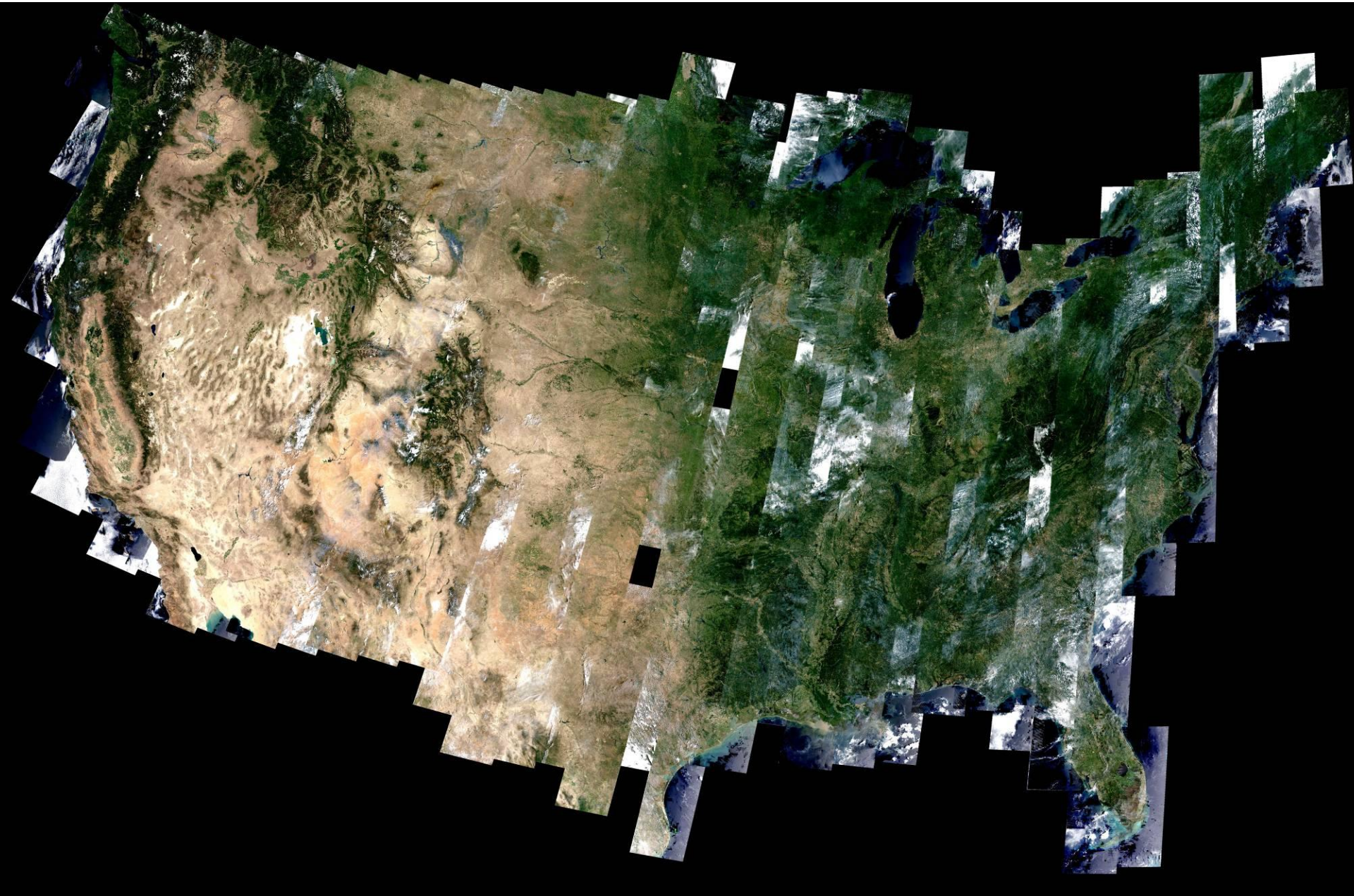
July 2008 composite. Band 3, 2, 1 (red, green, blue)

Top of Atmosphere Reflectance



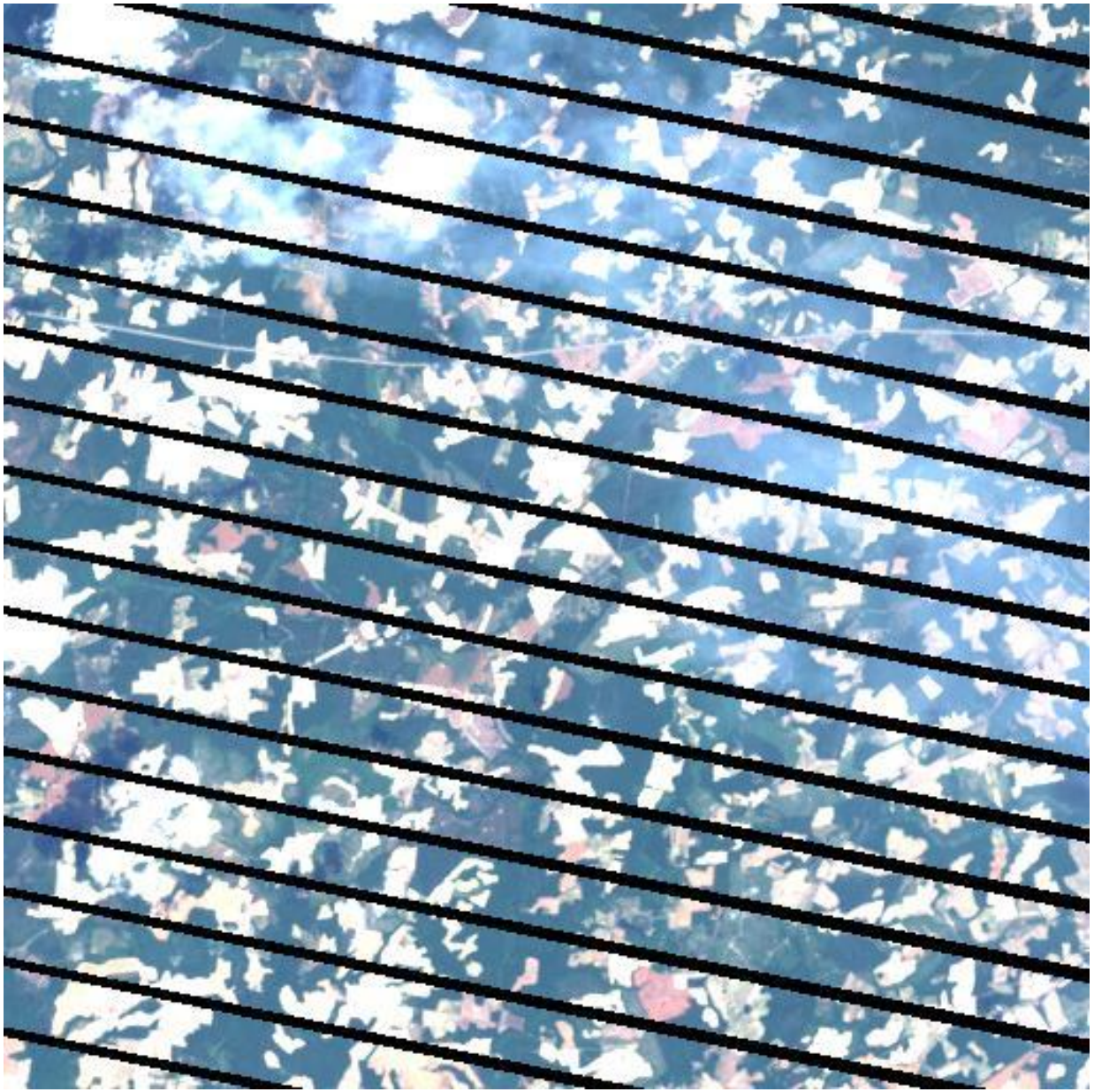
July 2008 composite. Band 3, 2, 1 (red, green, blue)

Surface Reflectance – using advanced MODIS Landsat method



TOA bands 1,2,3
North Carolina, June 18, 2008

512 x 512
30m pixels



LEDAPS Surface Reflectance

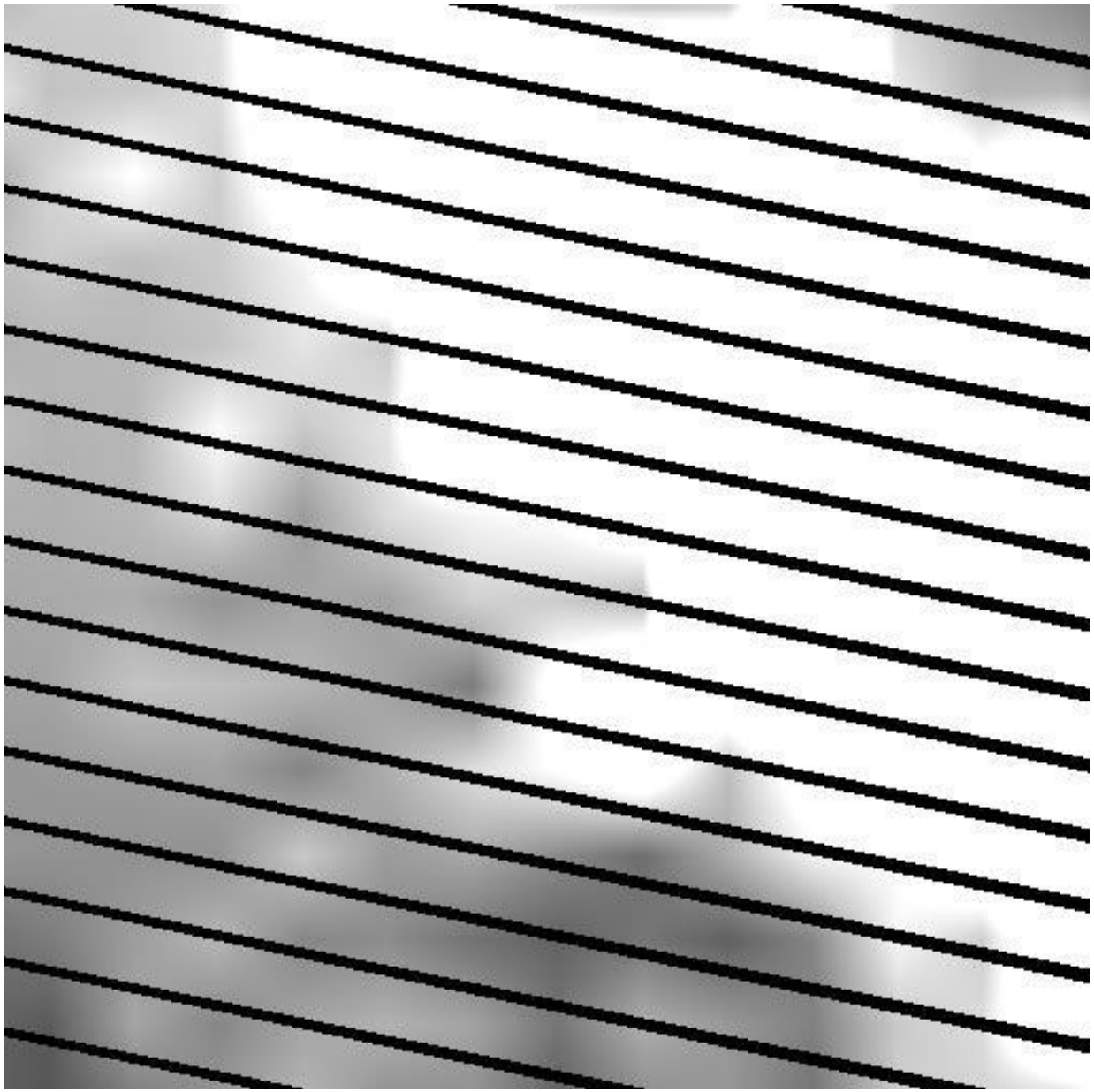
512 x 512
30m pixel

Advanced MODIS surface reflectance

512 x 512
30m pixel

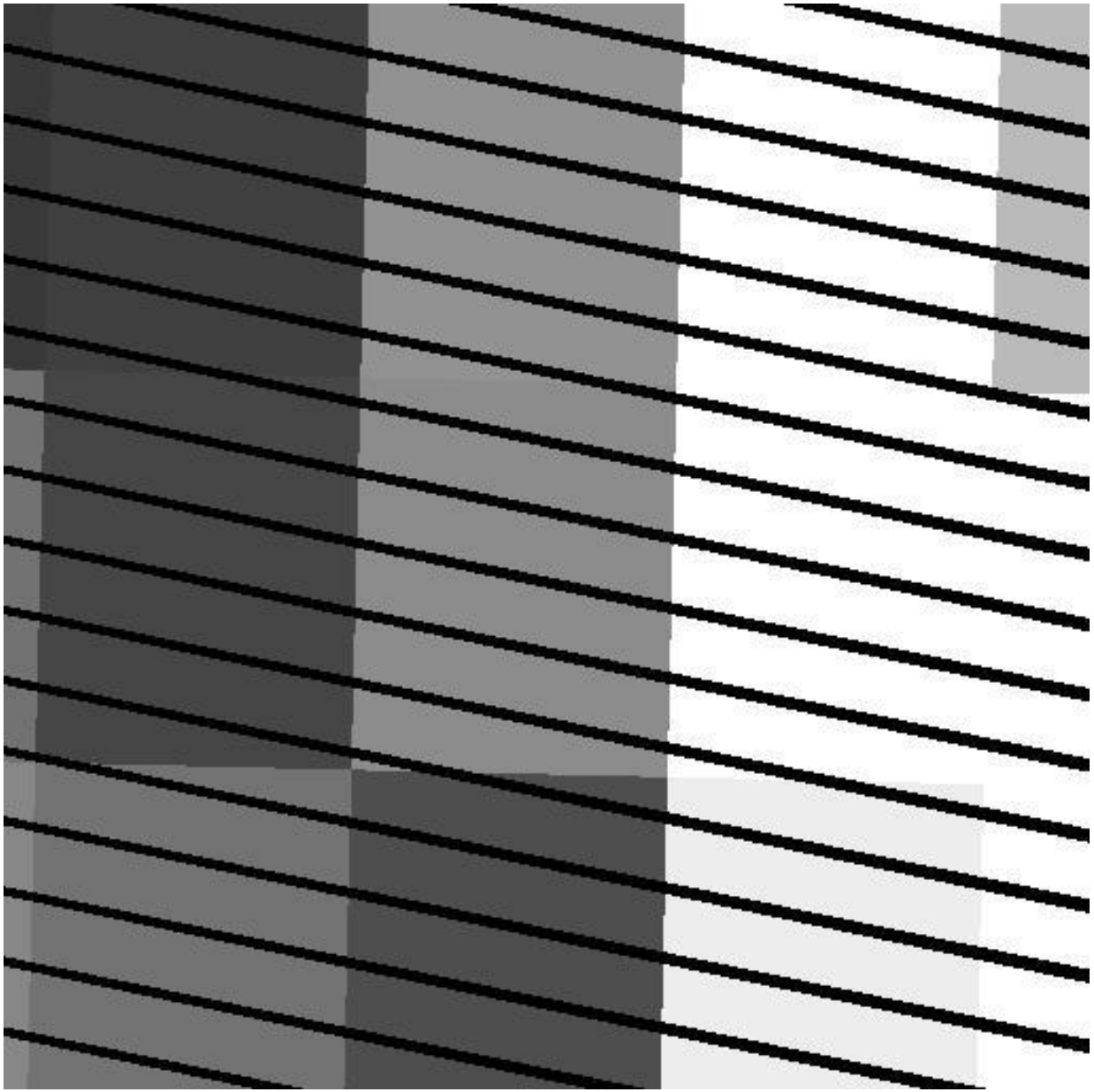
LEDAPS, band 1 AOT (range: 0.0009 - 1.595)

512 x 512
30m pixel

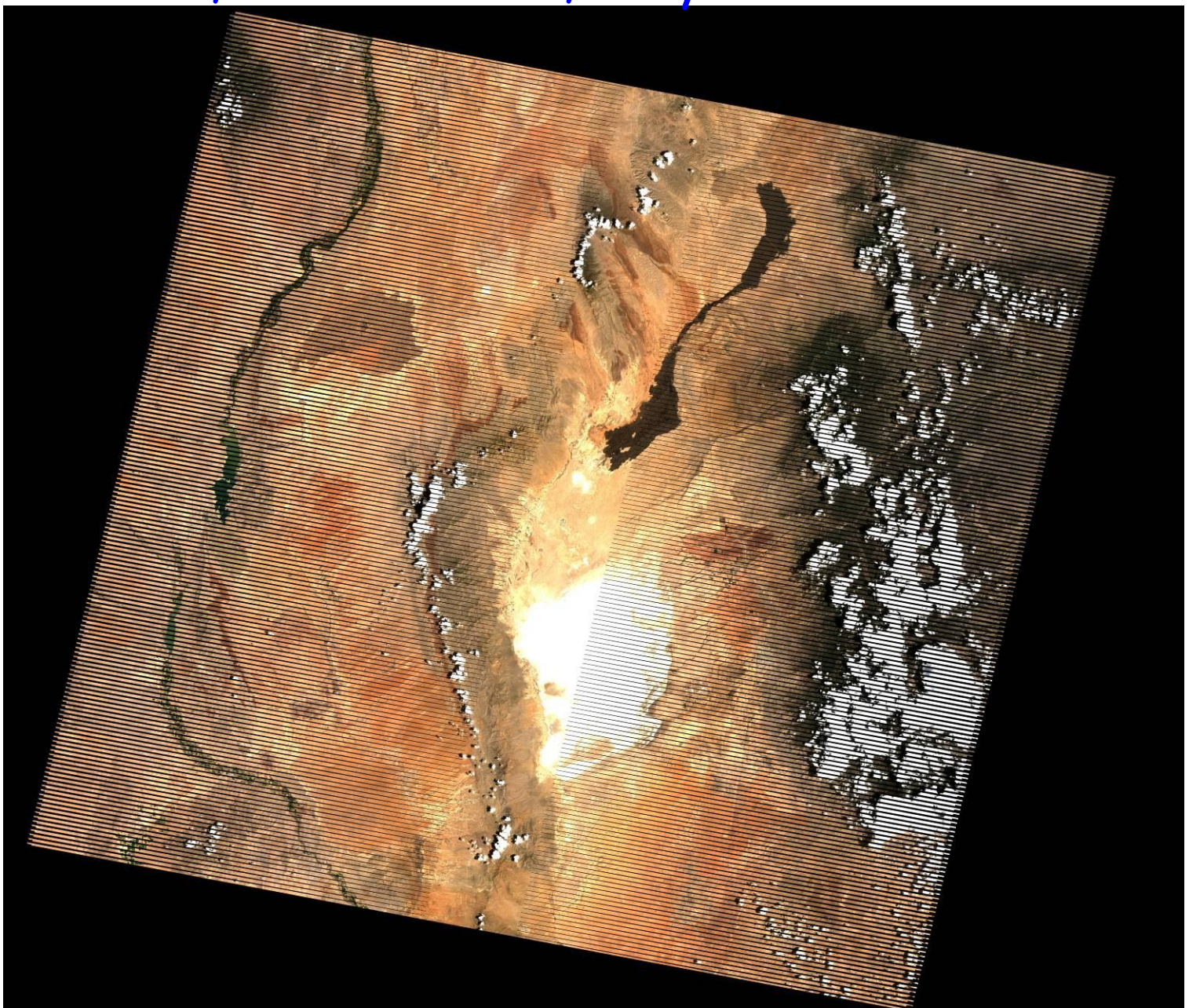


Advanced MODIS AOT (range: 0 - 1.076)

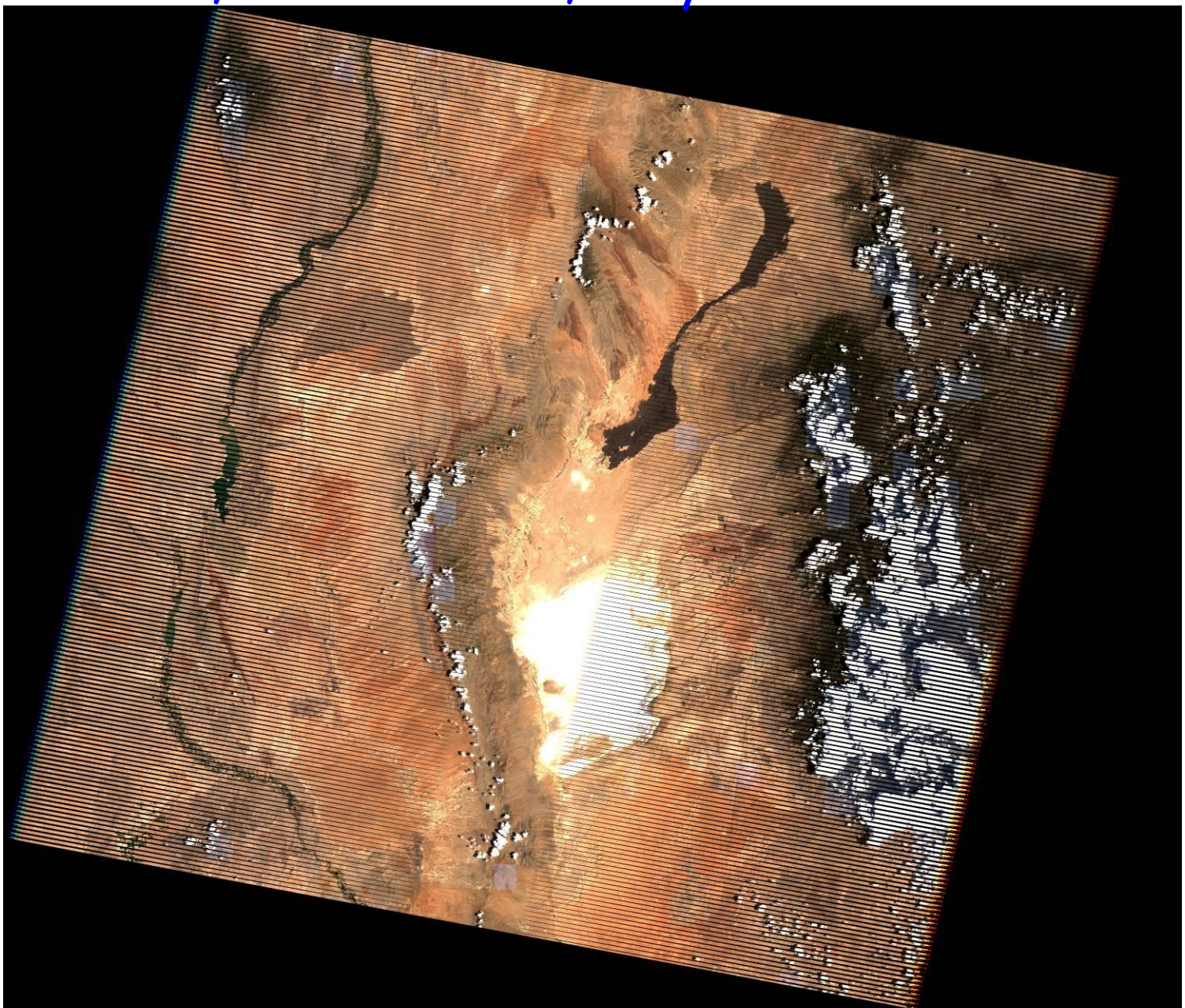
512 x 512
30m pixel



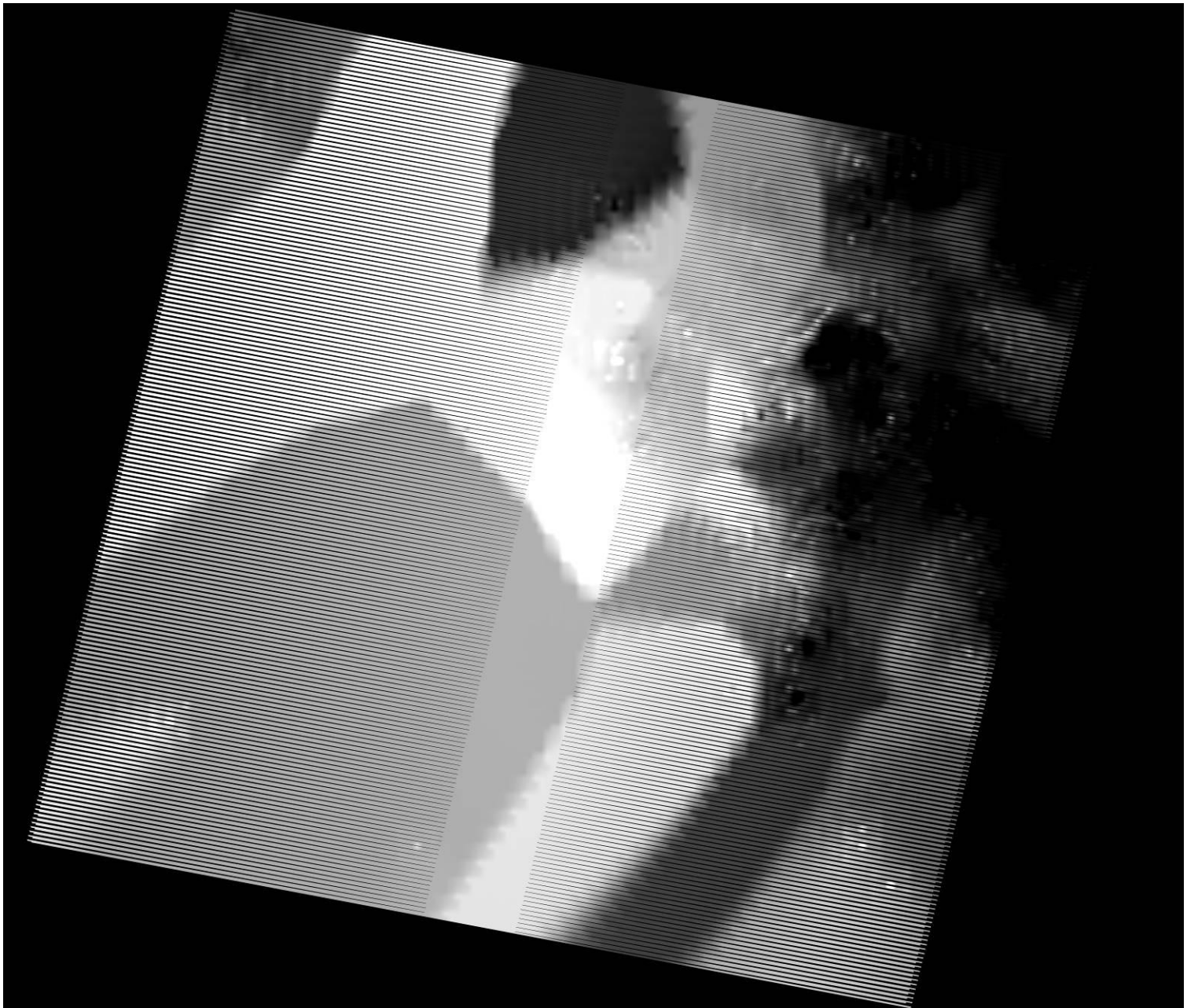
LEDAPS Surface Refectance, bands 1,2,3.
White Sands, New Mexico, July 2 2008



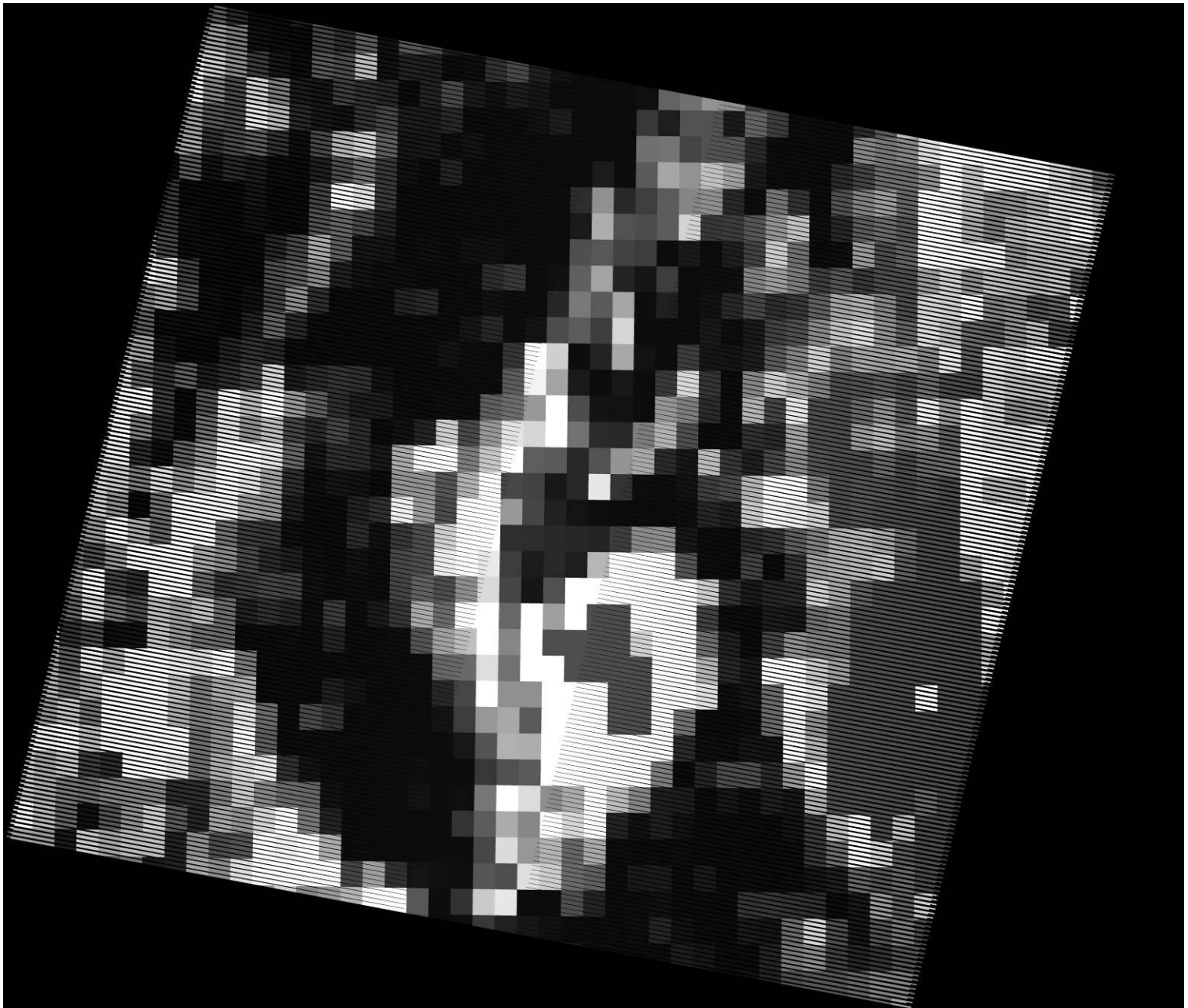
Advanced MODIS Surface Reflectance, bands 1,2,3. White Sands, New Mexico, July 2 2008



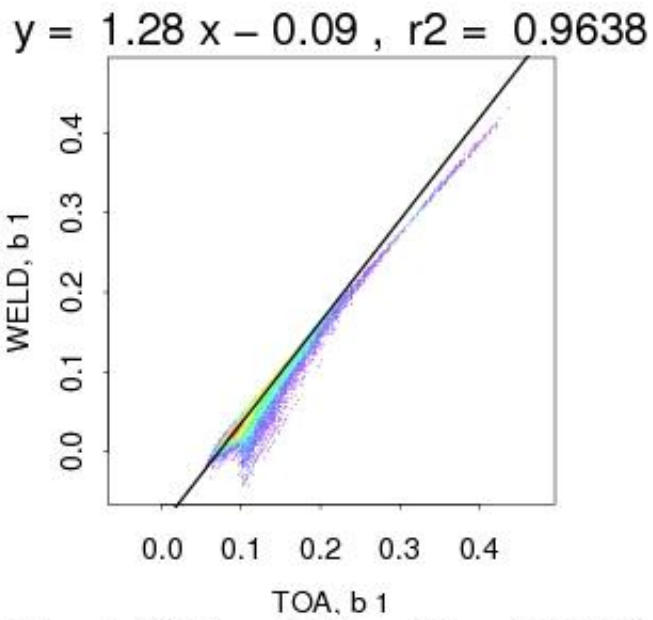
LEDAPS, band 1 AOT (range: 0.009-0.868)

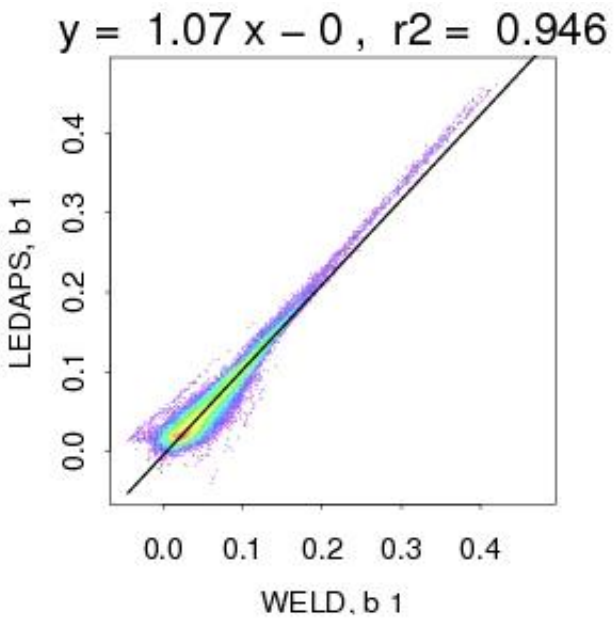


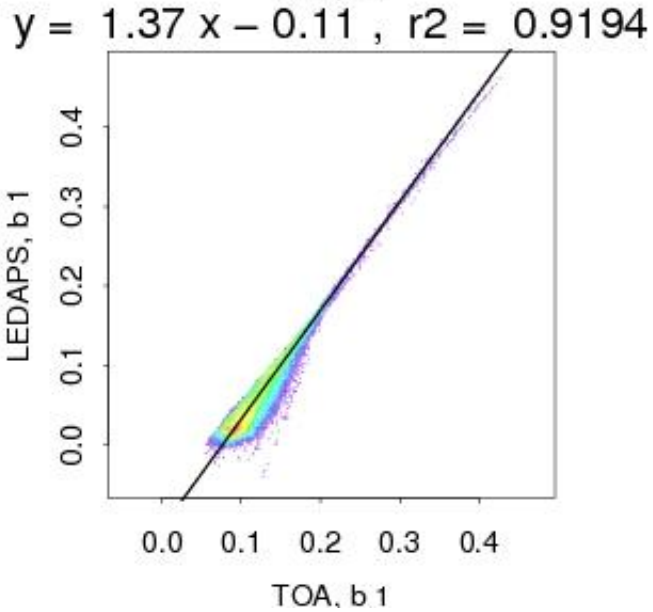
Advanced MODIS, band 1 AOT (range: 0-0.813)



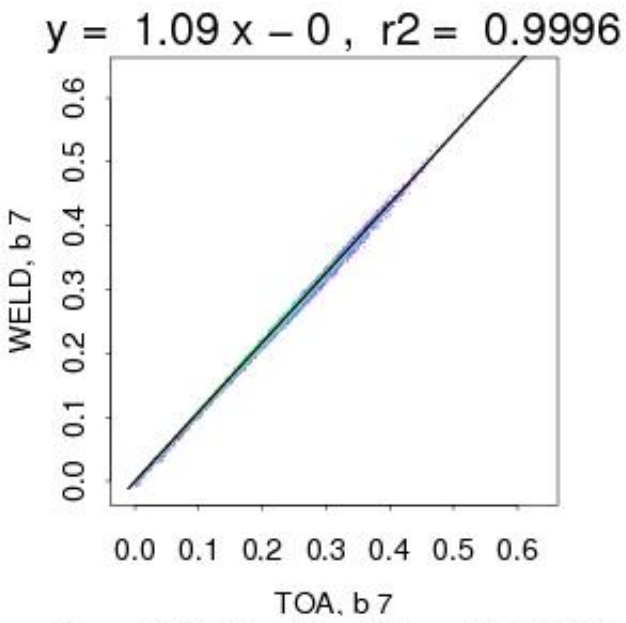
Advanced MODIS V LEDAPS Band 1 SR (blue, 0.45-0.52µm), 373,013 pixels, 10 scenes

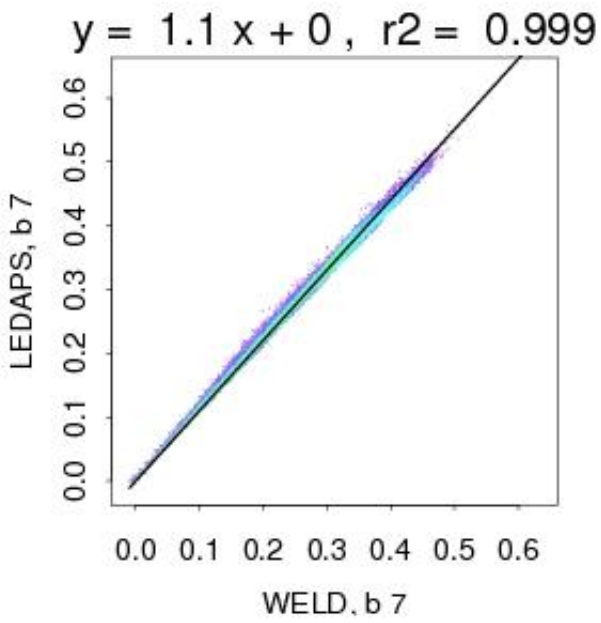


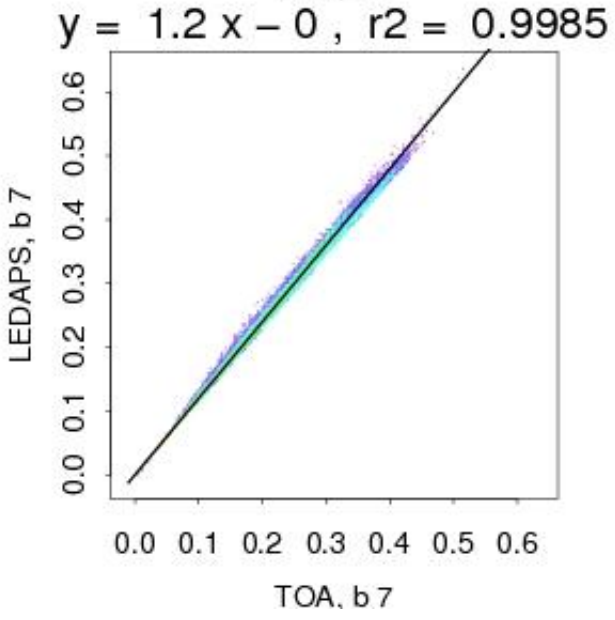




Advanced MODIS V LEDAPS Band 7 SR (blue,2.09-2.35µm), 373,013 pixels, 10 scenes







Next: we are working with Eric Vermote on validation of the 2 methods with AERONET

-> goal of selecting the most reliable atm. correction method

Radiometric Normalization

• WELD processing (conversion to reflectance, cloud screening, atmospheric correction, compositing) will largely remove reflectance variations

• Except for reflectance differences due to illumination & observation angles

$$\hat{\rho}_{ETM+,t1}\left(\ell_{ETM+}, \Omega_{nadir}, \Omega'_{solar\,noon}\right) = c \times \rho_{ETM+,t1}\left(\ell_{ETM+}, \Omega_{observed}, \Omega'_{observed}\right)$$

$$c = \frac{\hat{\rho}_{MODIS,t1}\left(\ell_{MODIS}, \Omega_{nadir}, \Omega'_{solar\,noon}\right)}{\hat{\rho}_{MODIS,t1}\left(\ell_{MODIS}, \Omega_{observed}, \Omega'_{observed}\right)}$$

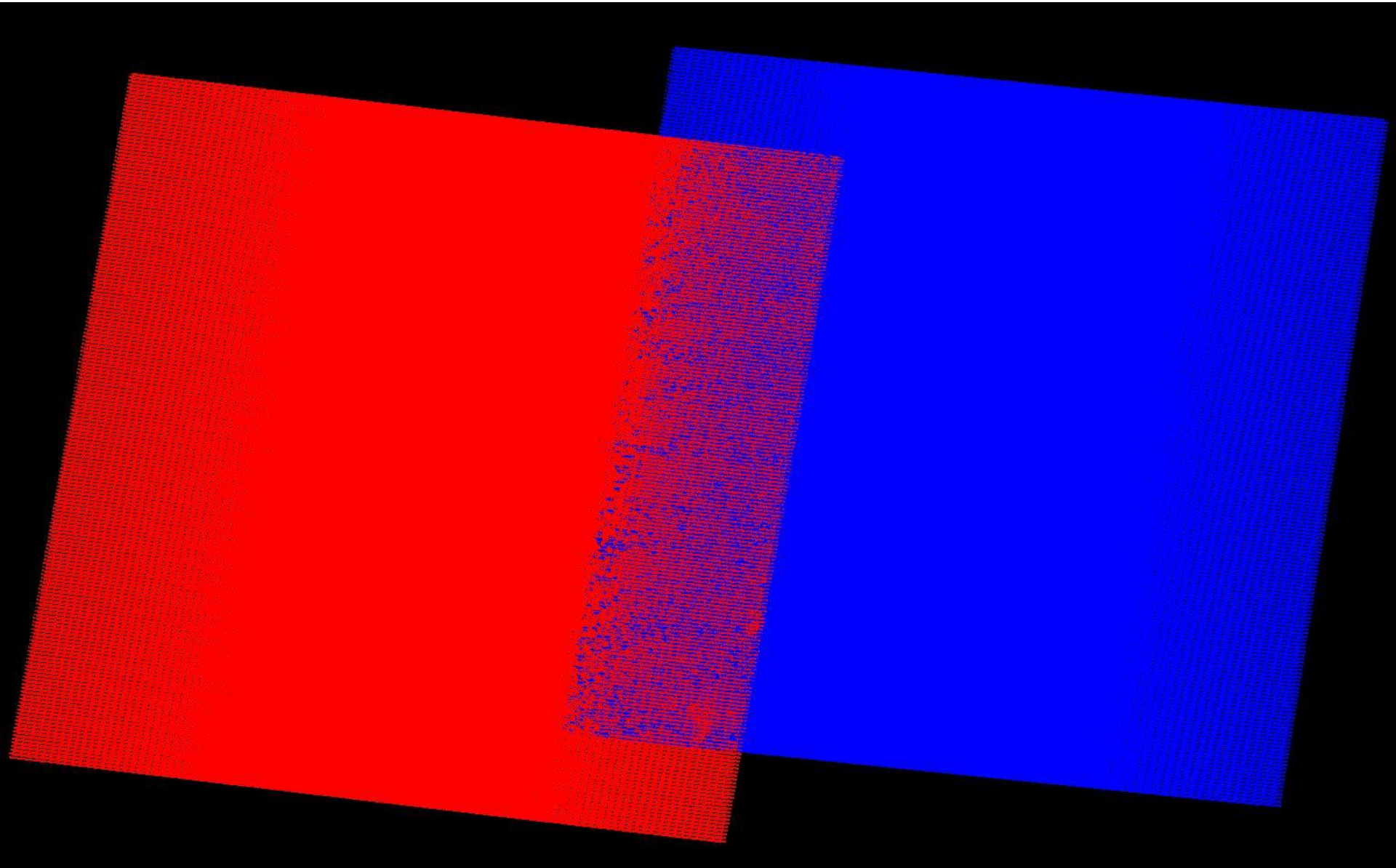
$\hat{\rho}_{MODIS}$ computed from MODIS 16-day 500m BRDF/Albedo product spectral BRDF model parameters

Thus, Landsat reflectance may be normalized to some desired geometry e.g., nadir view zenith and local solar noon, for each 500m MODIS pixel.

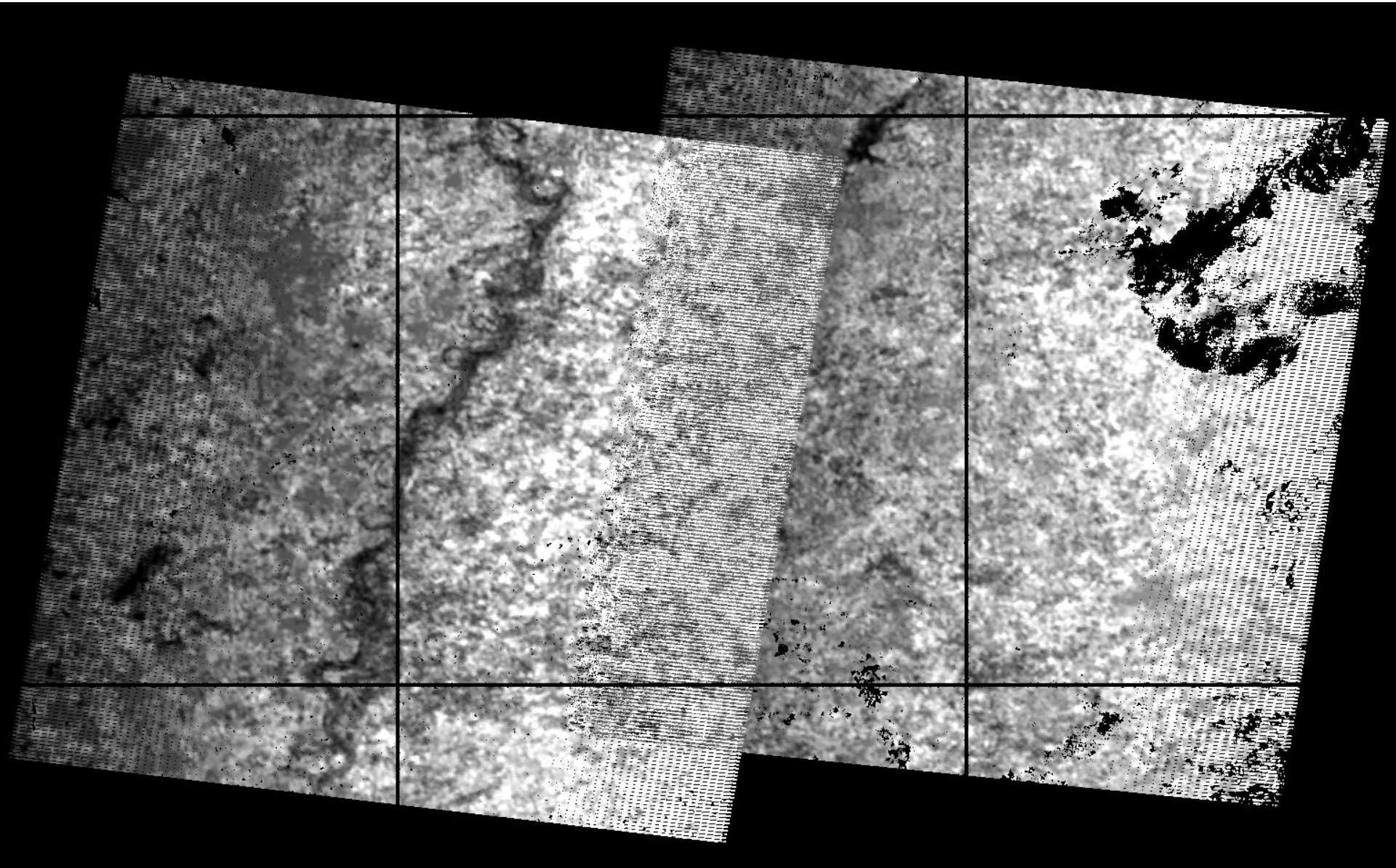
Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008
Band 3, 2, 1 (red, green, blue) TOA reflectance
Before radiometric normalization

Composited Day of Year

Red: July 12 Blue: July 5

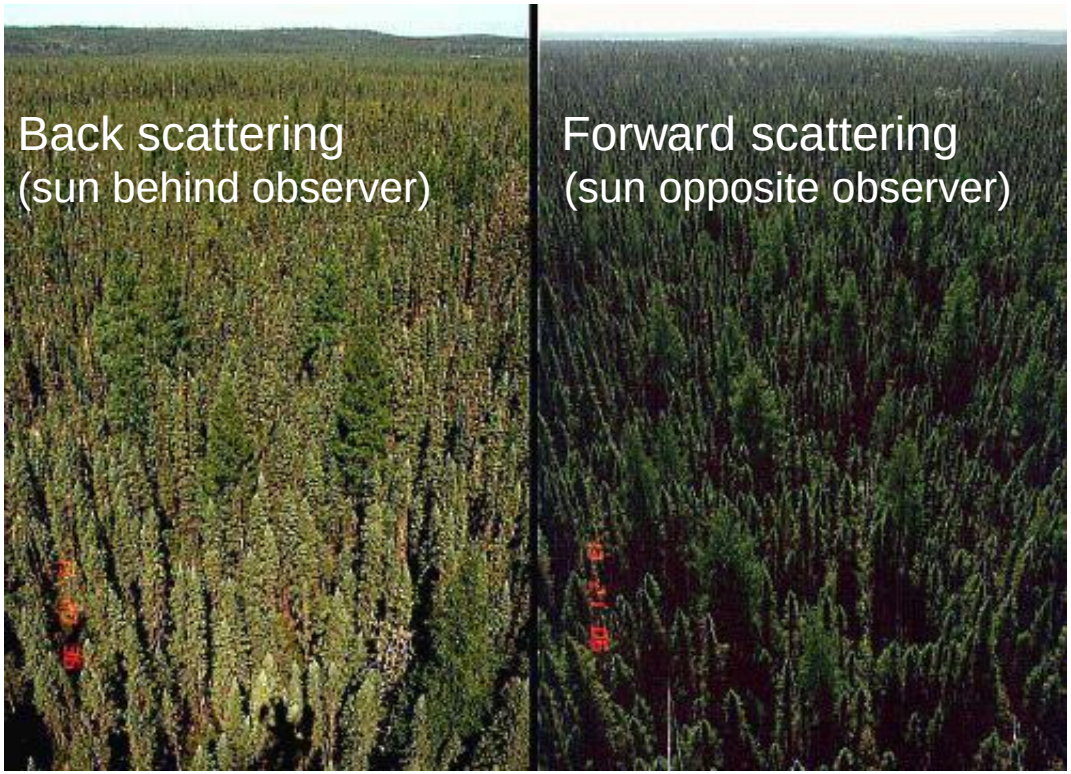


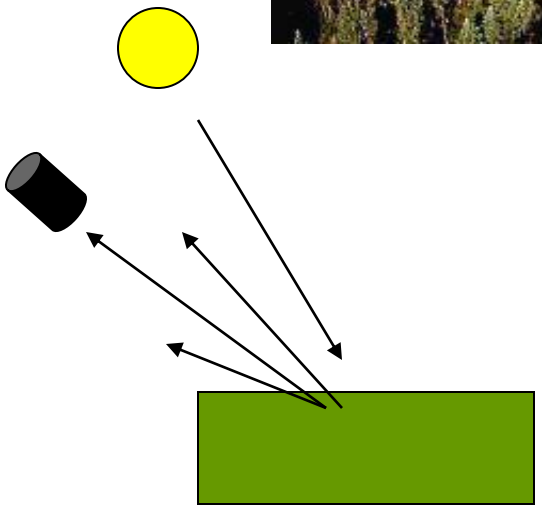
Band 3 (red, 0.63-0.69 μm)
MODIS derived scaling factors (range: 0.97-1.43)



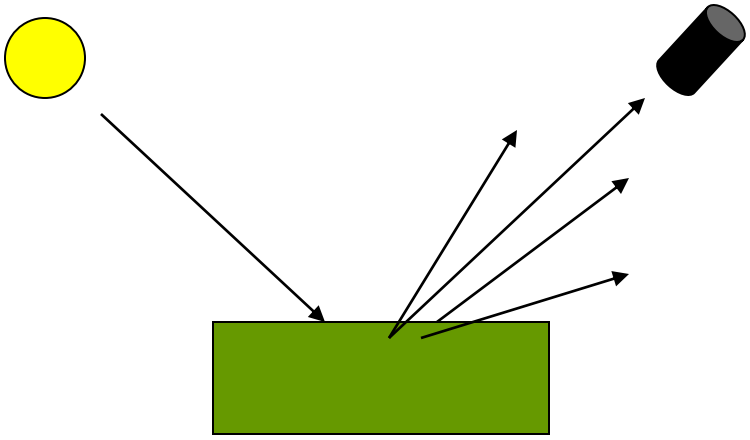
Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008
Band 3, 2, 1 (red, green, blue) TOA reflectance
Before radiometric normalization

Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008
Band 3, 2, 1 (red, green, blue) TOA reflectance
After radiometric normalization





Back scatter direction



Forward scatter direction

Atmospheric Scattering Phase Function Effects

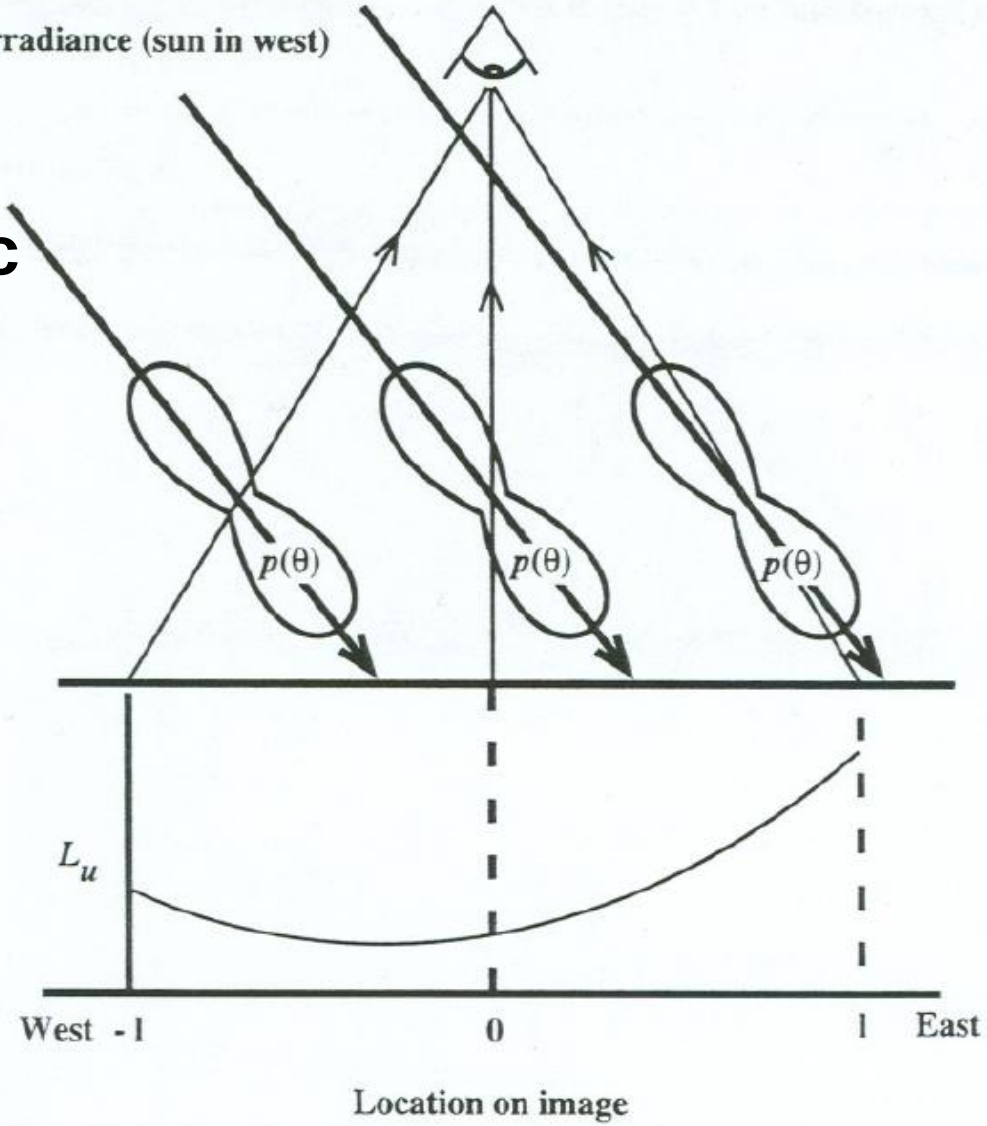
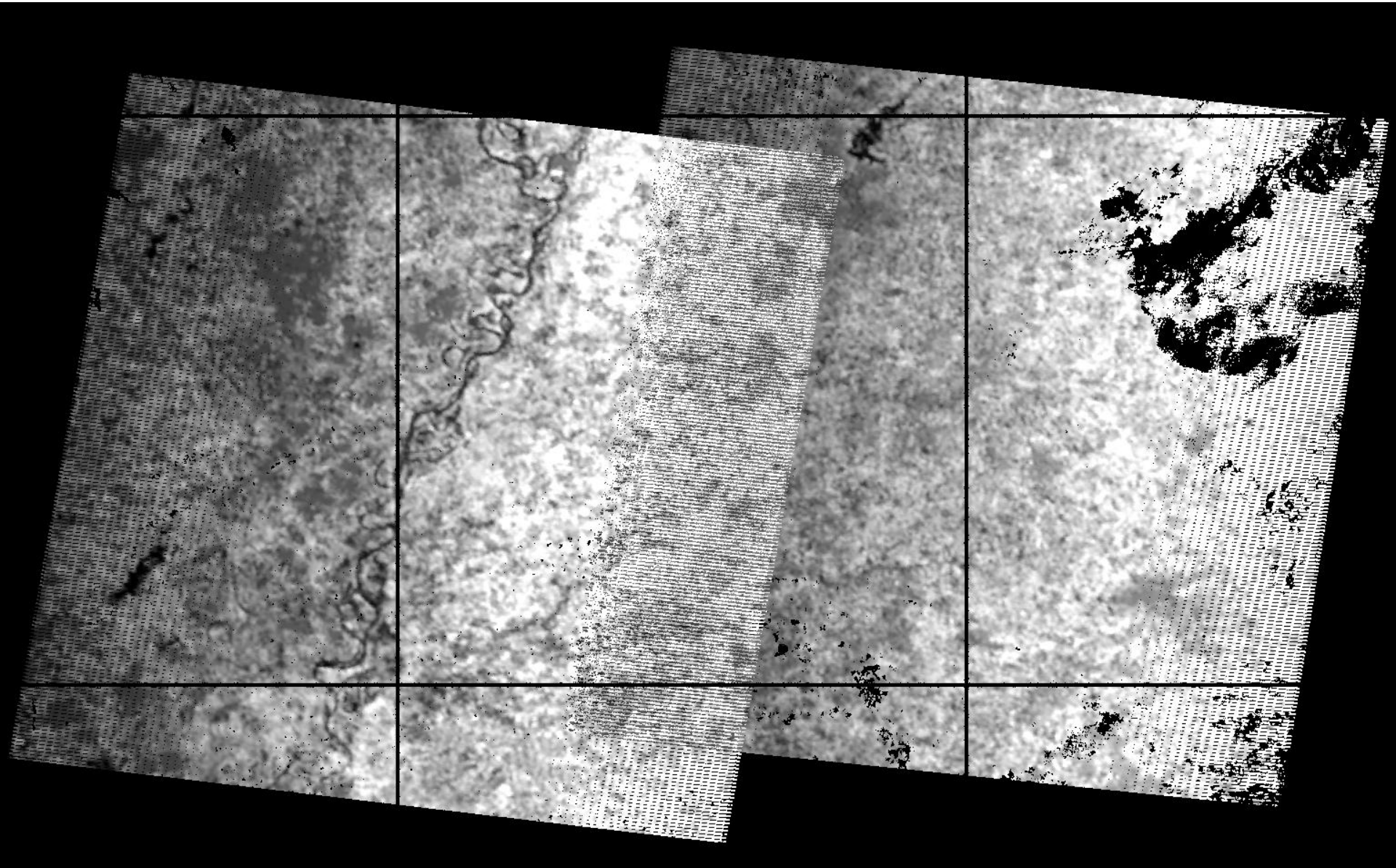
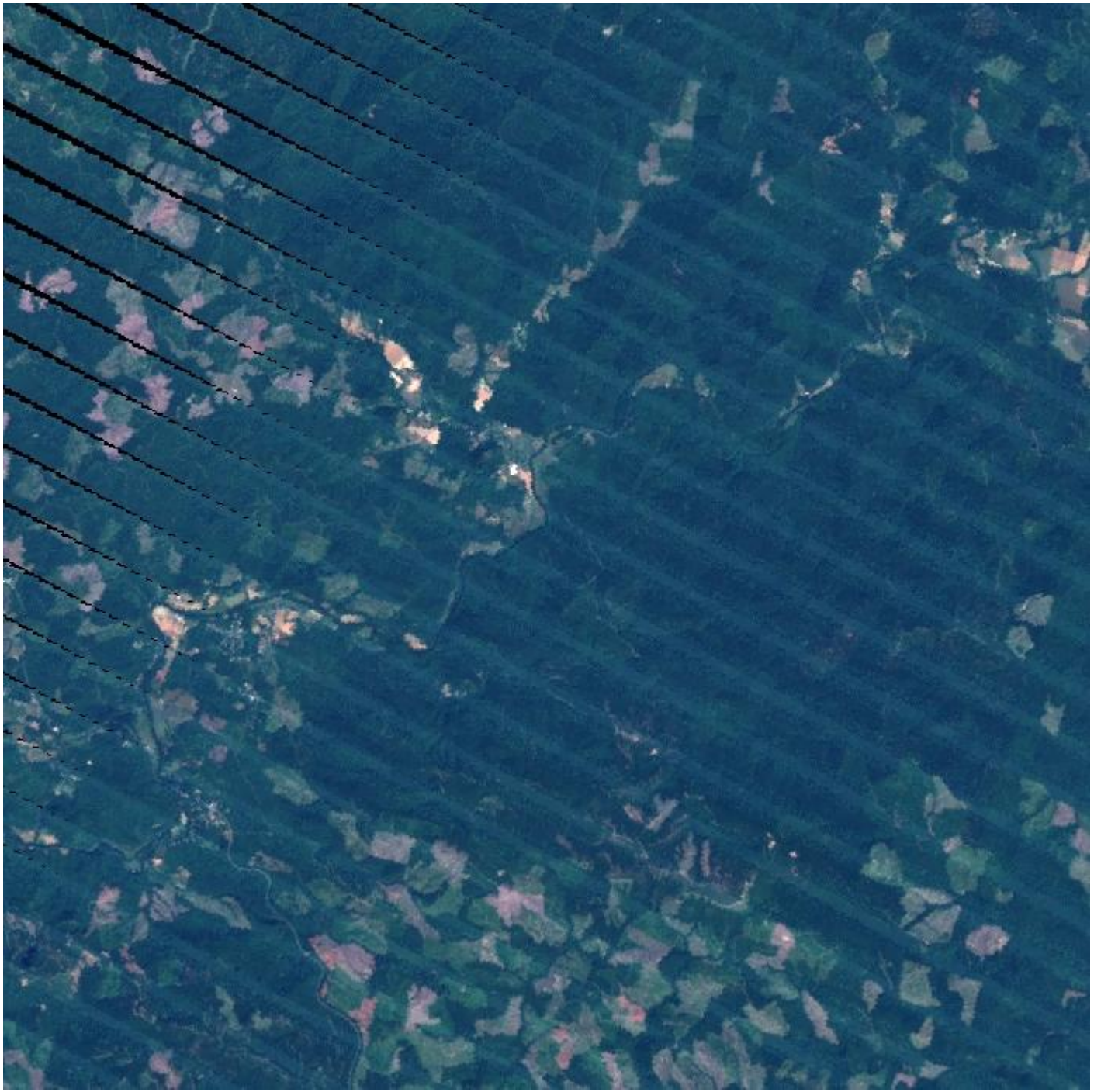


Figure 4.11 Variation in path radiance with view angle. A Rayleigh phase function is shown for refe

Band 7 (2.09-2.35 μm)

MODIS derived scaling factors (range: 0.98-1.38)





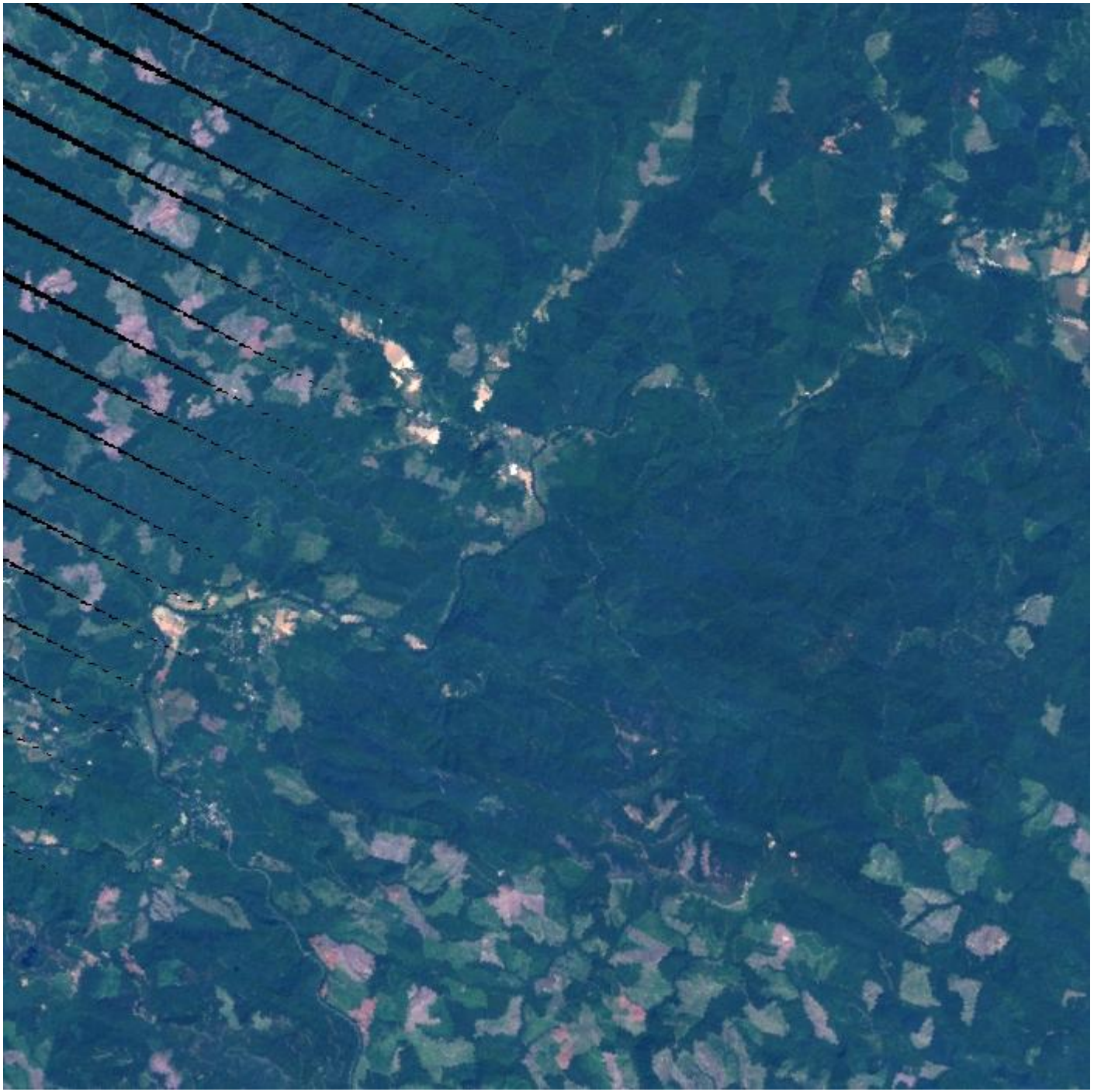
July 2008

2 dates composited

Bands 3,2,1

700 x 700
30m pixels

Before radiometric normalization



July 2008

2 dates composited

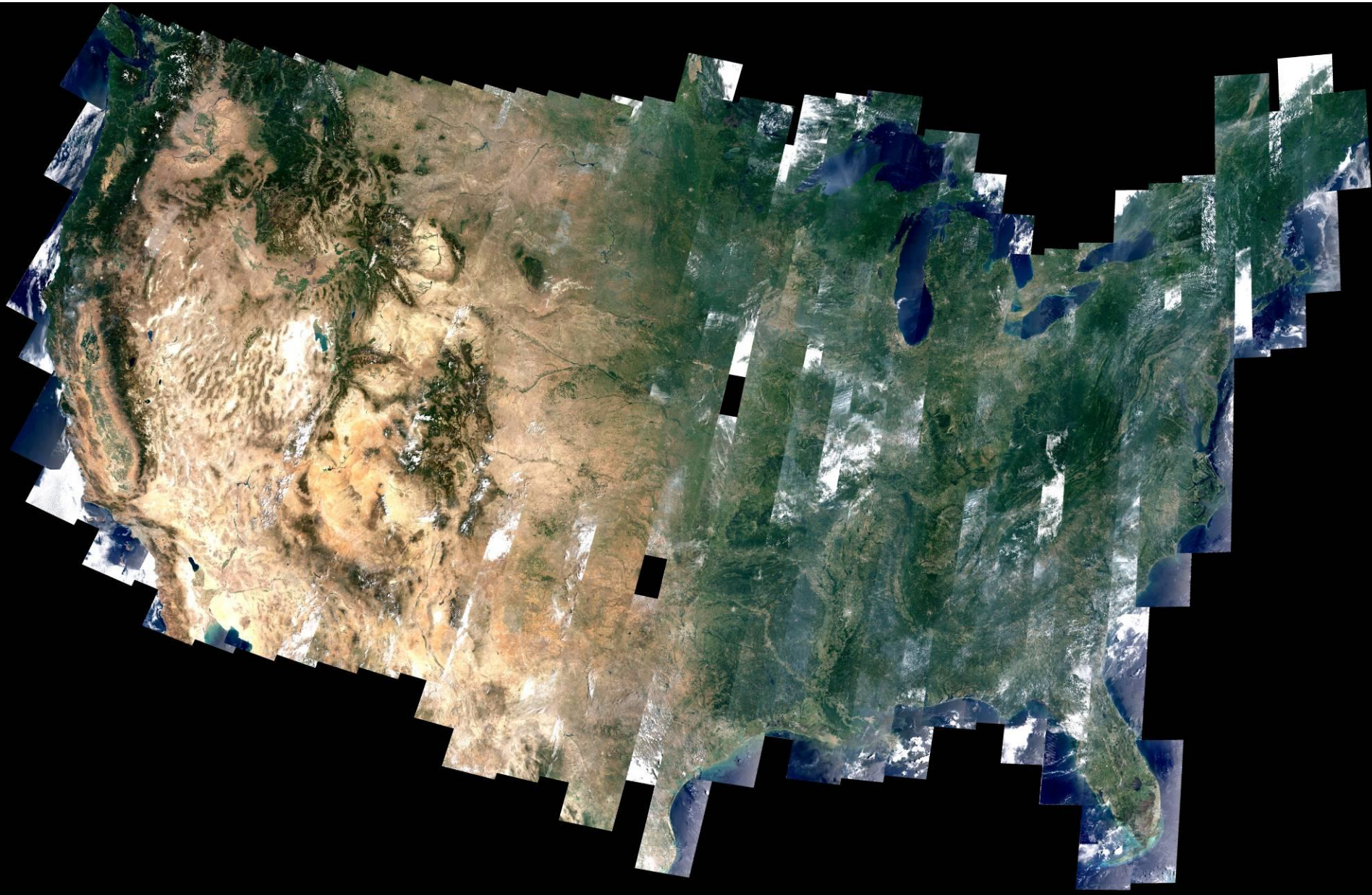
Bands 3,2,1

700 x 700
30m pixels

After radiometric normalization

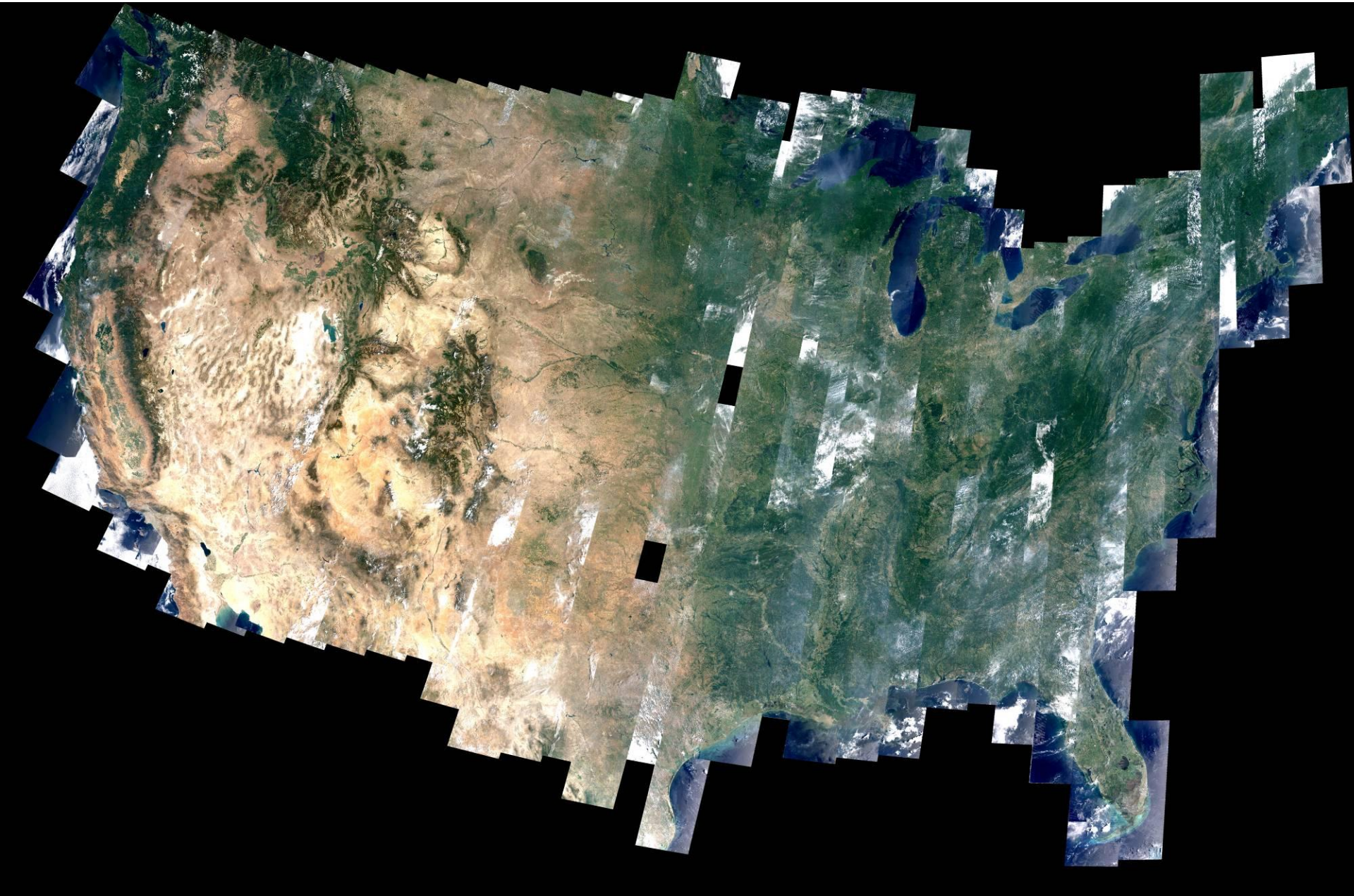
July 2008 composite. Band 3, 2, 1 (red, green, blue) TOA reflectance

Before radiometric normalization



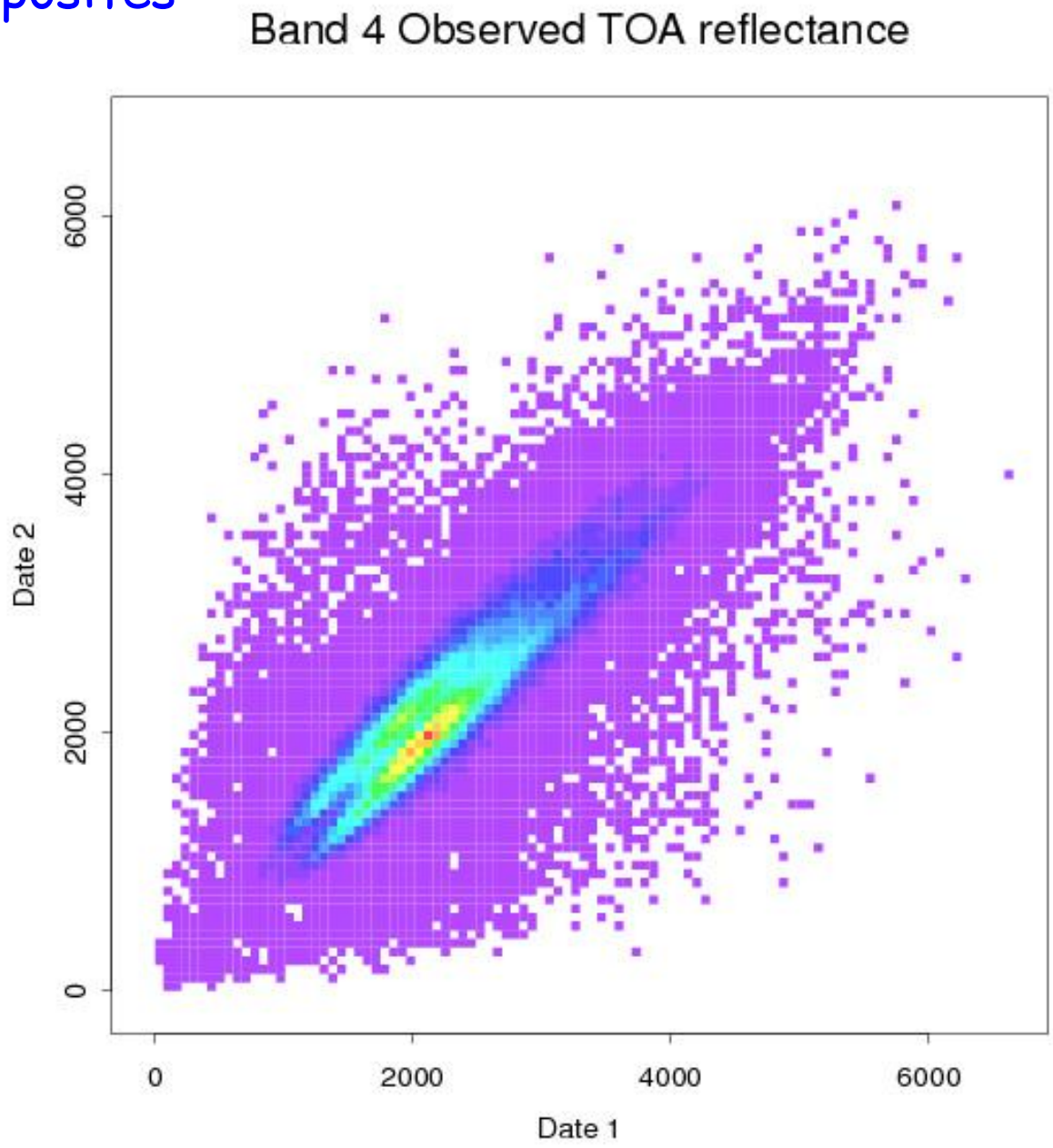
July 2008 composite. Band 3, 2, 1 (red, green, blue) TOA reflectance

After radiometric normalization



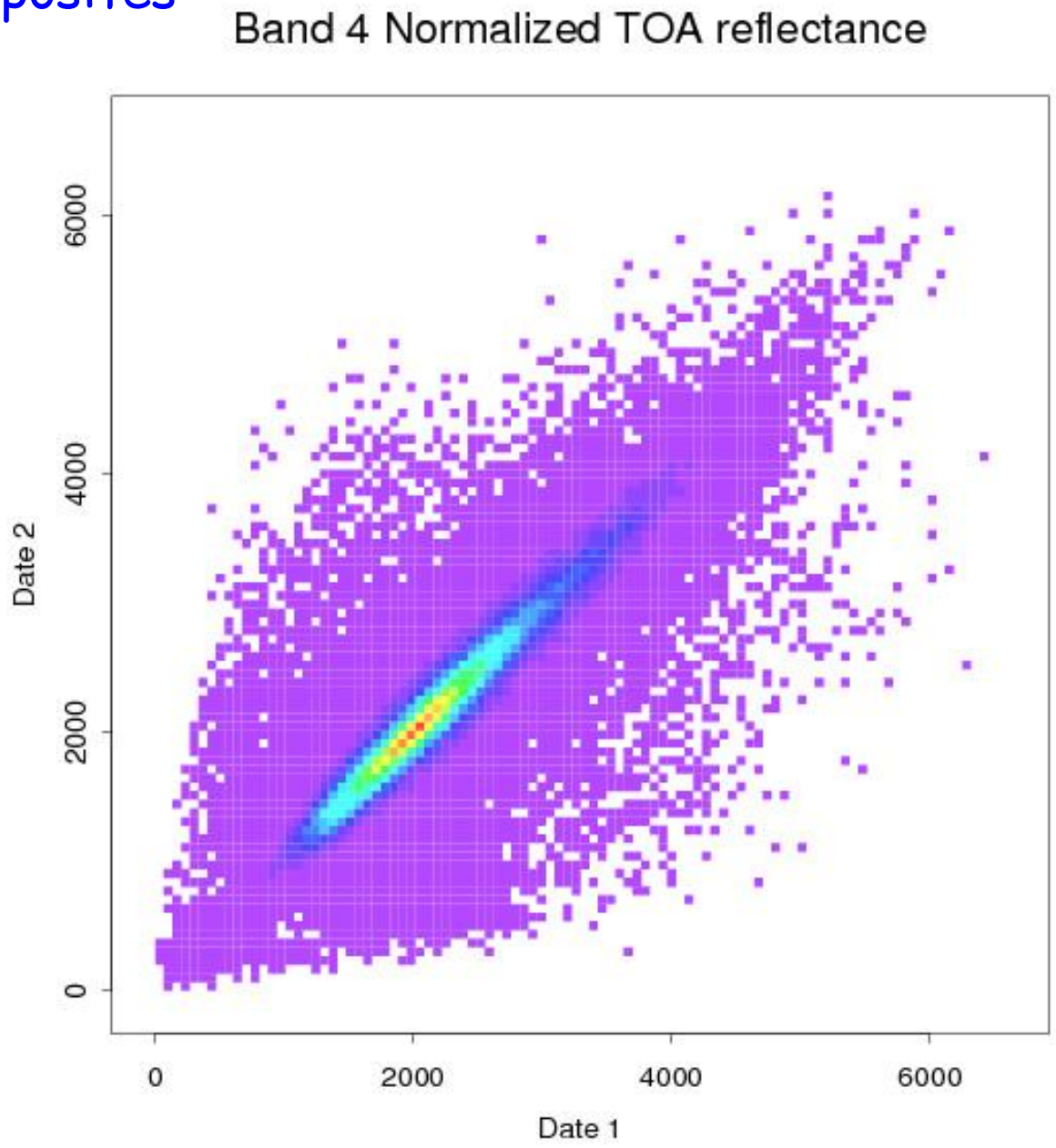
Temporal reflectance comparison of 2 successive July 2008 weekly CONUS composites

Without
MODIS based
Radiometric
normalization



Temporal reflectance comparison of 2 successive July 2008 weekly CONUS composites

With
MODIS based
Radiometric
normalization



Future WELD Product Distribution
(evolving in response to user feedback)

1. WELD Tile Products on an EROS data pool

2. Dedicated Web Interface to be ported to EROS

- Simple & Intuitive
- What You See Is What You Get (WYSIWG)

- Pan & Zoom against browse product of interest
  - Region
  - Composited period

- Order *any* arbitrary rectangular area up to 2GB file size
  - Rubber band box selection
  - Geographic or Albers coordinates

- Thick Client prototype developed & tested at SDSU

WELD Distribution System - Mozilla Firefox

File Edit View History Bookmarks Tools Help

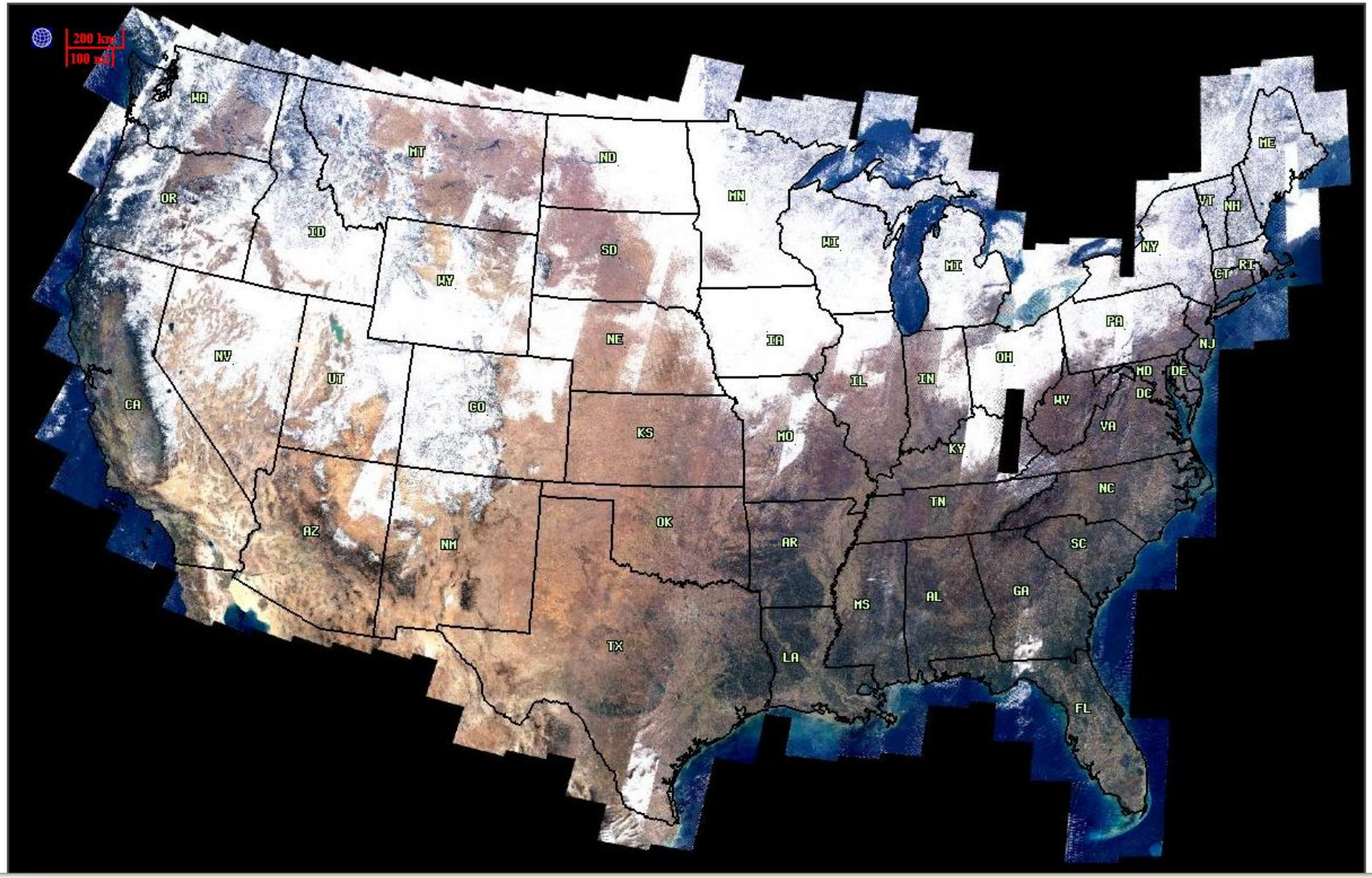
http://snowdon.sdstate.edu/WYSIWYG/distribution_conus_new.php?img_name=CONUS.winter.2008.v1.3.bs7.type2

Most Visited Getting Started Latest Headlines http://snowdon.sdsta... Annotating -- IM v6 E... Password Protection ...

WELD Distribution System

CONUS 2008: WINTER

Home



Done

WELD Distribution System - Mozilla Firefox

File Edit View History Bookmarks Tools Help

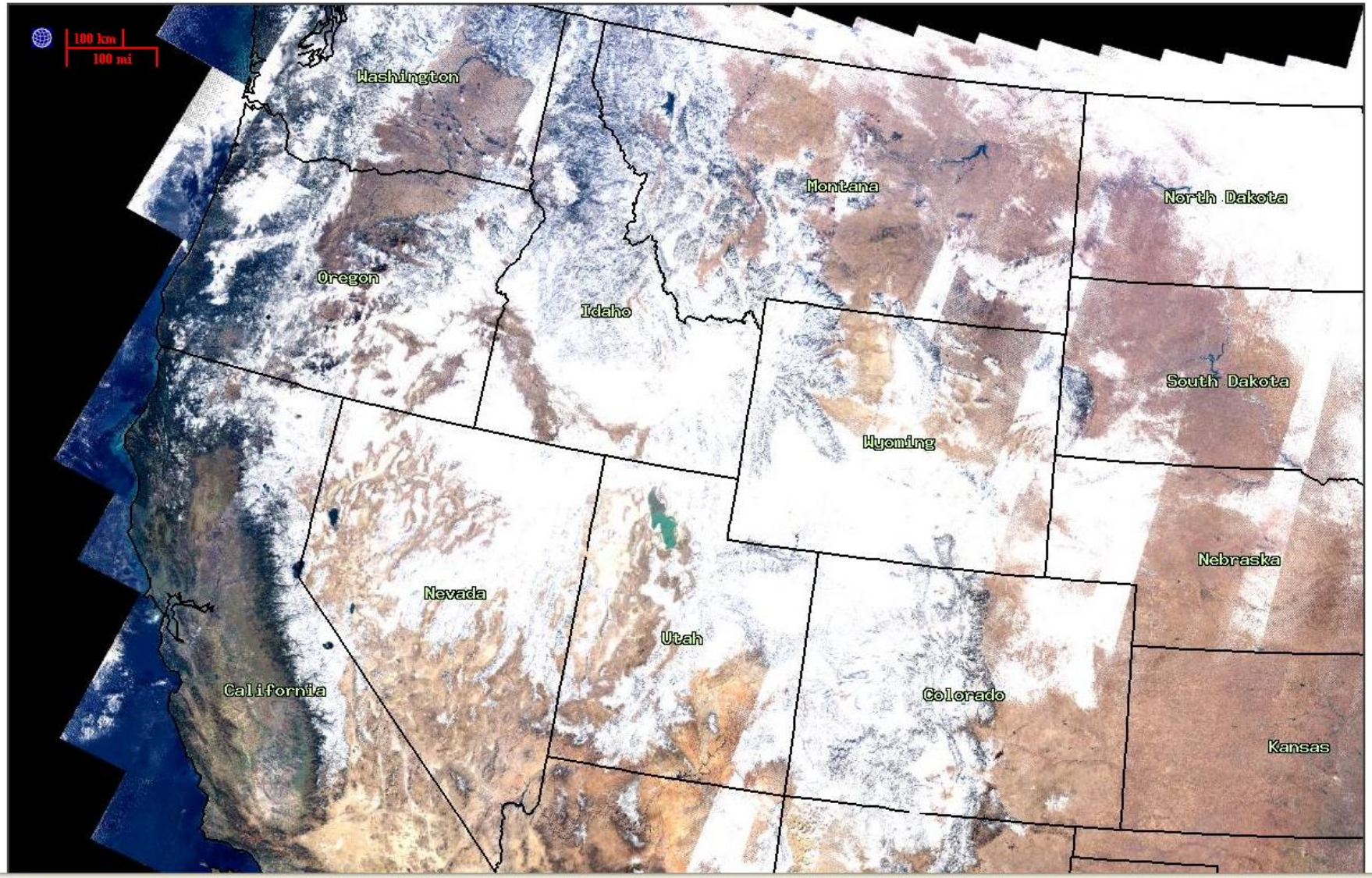
http://snowdon.sdstate.edu/WYSIWYG/distribution_conus_new.php?img_name=CONUS.winter.2008.v1.3.bs7.type2

Most Visited Getting Started Latest Headlines http://snowdon.sdsta... Annotating -- IM v6 E... Password Protection ...

WELD Distribution System | WELD Distribution System

CONUS 2008: WINTER

Home



Done

WELD Distribution System - Mozilla Firefox

File Edit View History Bookmarks Tools Help

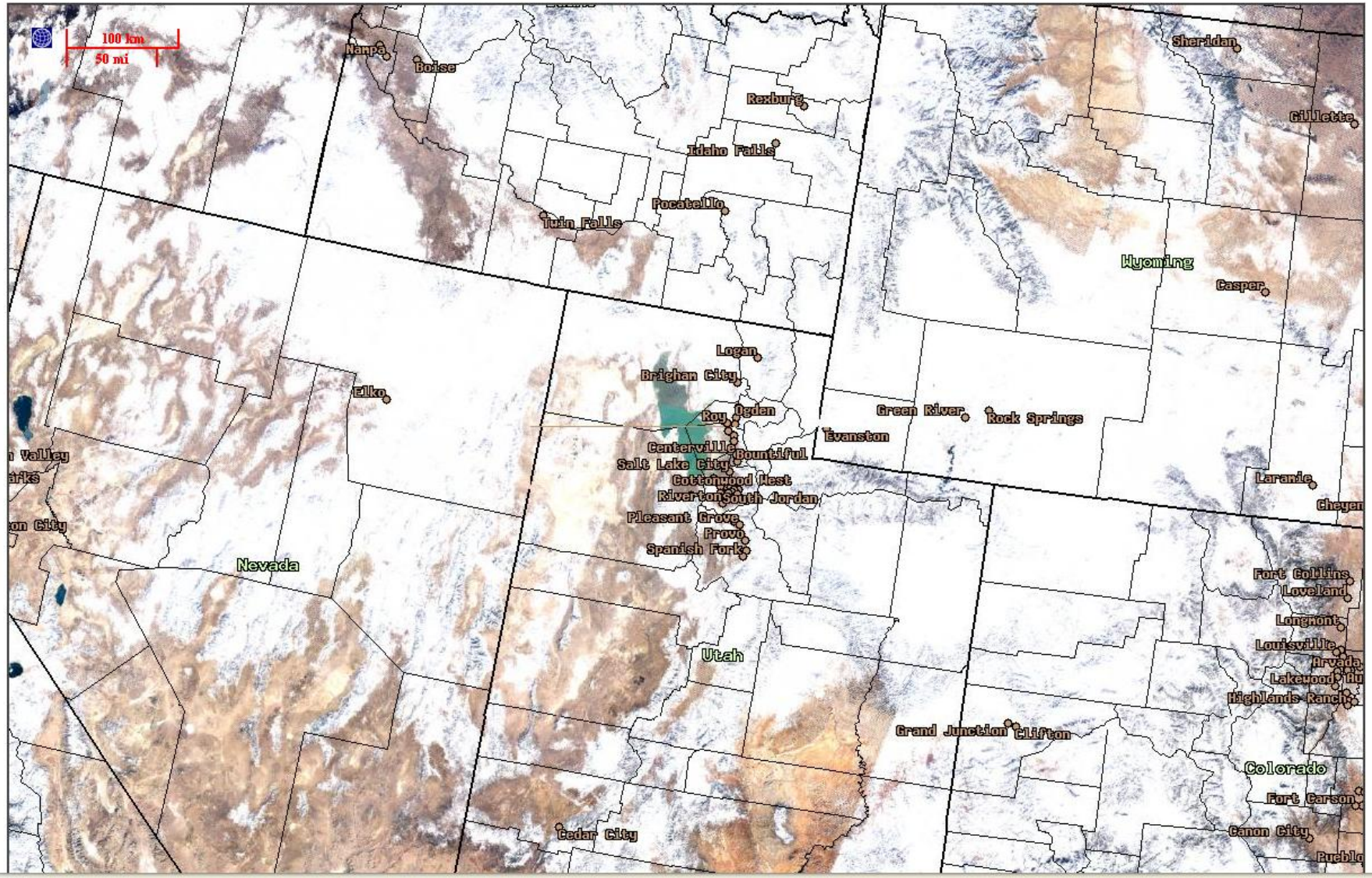
http://snowdon.sdstate.edu/WYSIWYG/distribution_conus_new.php?img_name=CONUS.winter.2008.v1.3.bs7.type2

Most Visited Getting Started Latest Headlines http://snowdon.sdsta... Annotating -- IM v6 E... Password Protection ...

WELD Distribution System | WELD Distribution System

CONUS 2008: WINTER

Home



Done

WELD Distribution System - Mozilla Firefox

File Edit View History Bookmarks Tools Help

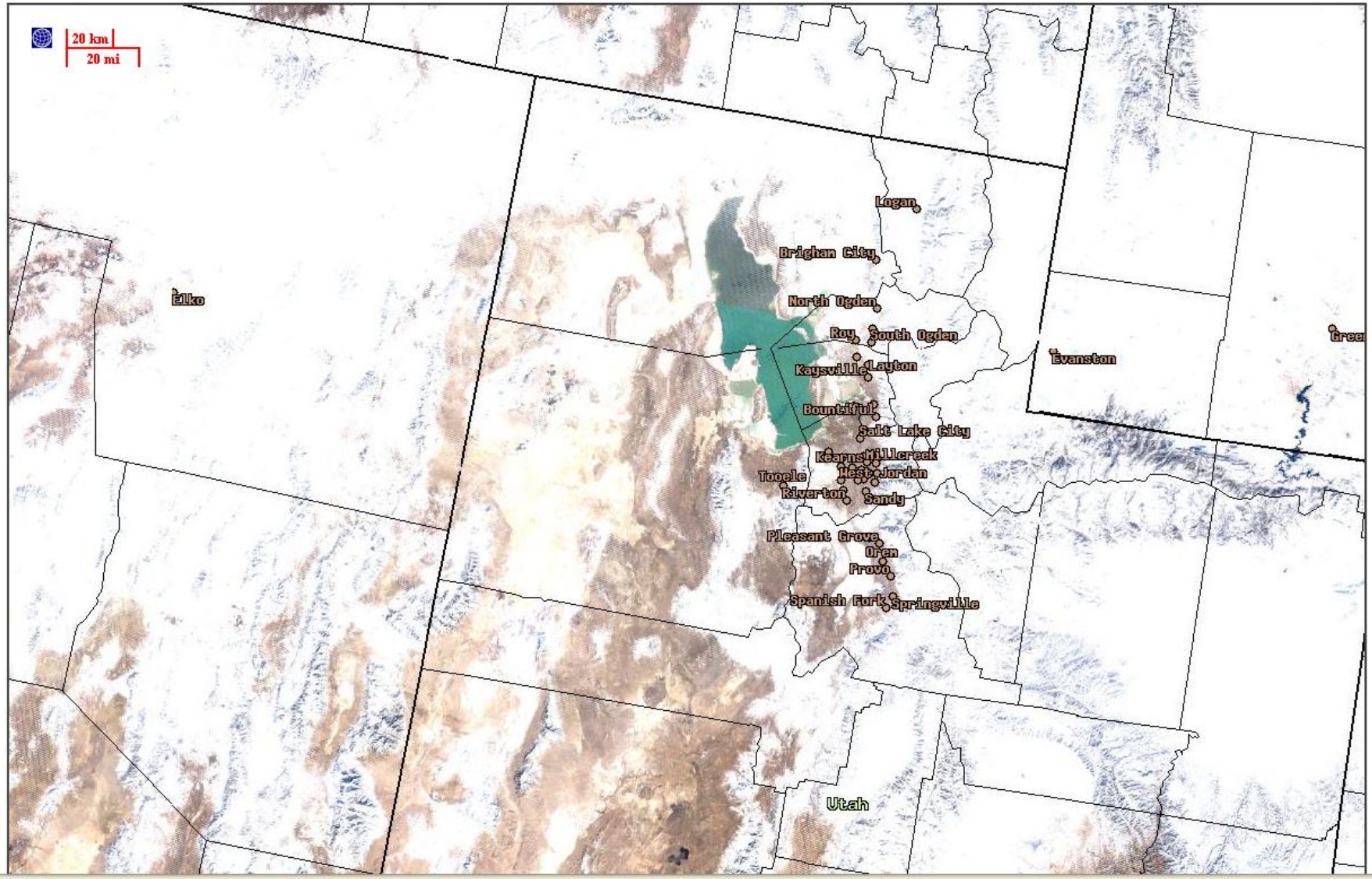
http://snowdon.sdstate.edu/WYSIWYG/distribution_conus_new.php?img_name=CONUS.winter.2008.v1.3.bs7.type2

Most Visited Getting Started Latest Headlines http://snowdon.sdsta... Annotating -- IM v6 E... Password Protection ...

WELD Distribution System | WELD Distribution System

CONUS 2008: WINTER

Home



Done

WELD Distribution System - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://snowdon.sdstate.edu/WYSIWYG/distribution_conus_new.php?img_name=CONUS.winter.2008.v1.3.bs7.type2

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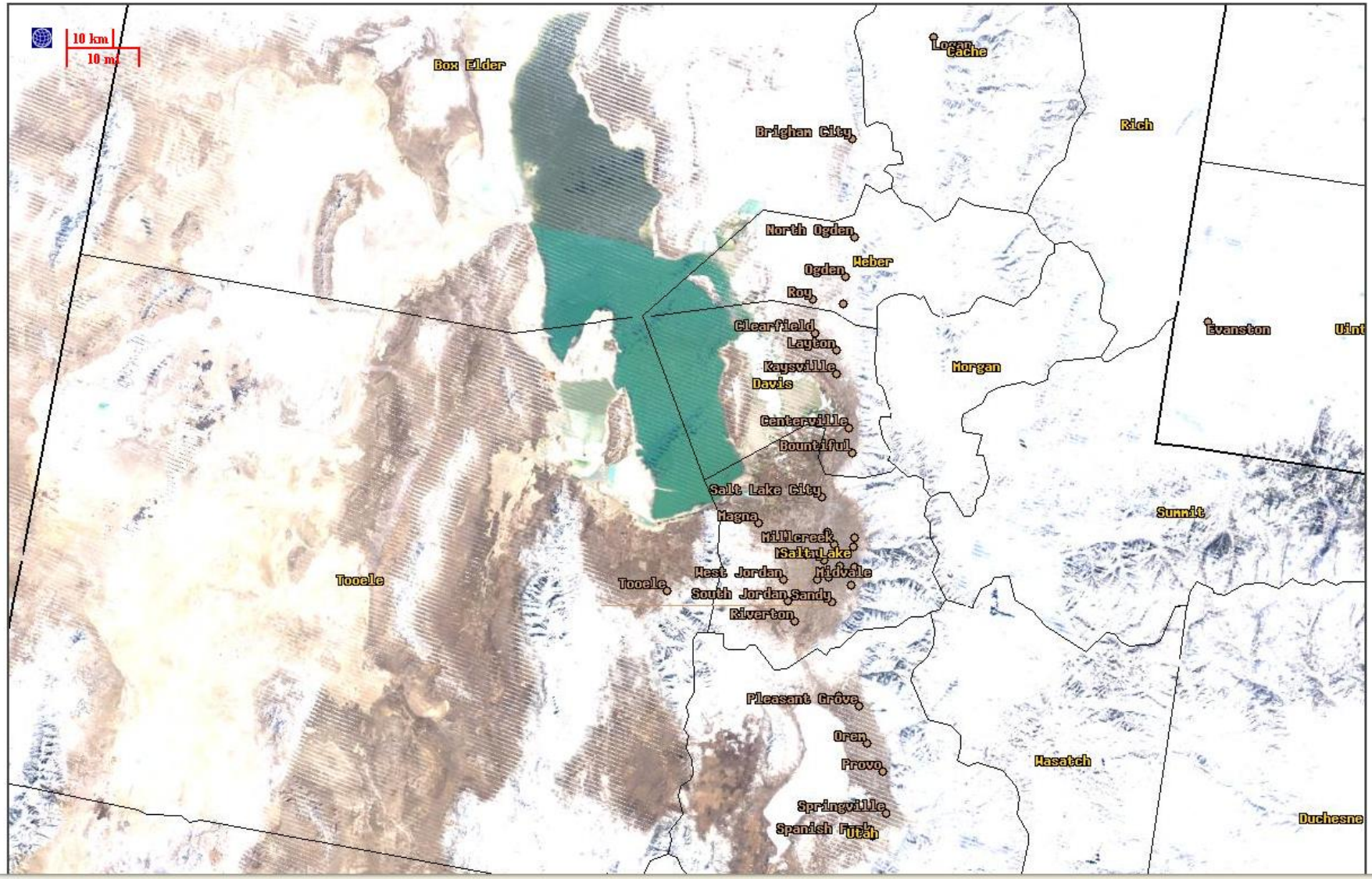
WELD Distribution System | WELD Distribution System

CONUS 2008: WINTER

Home



Done

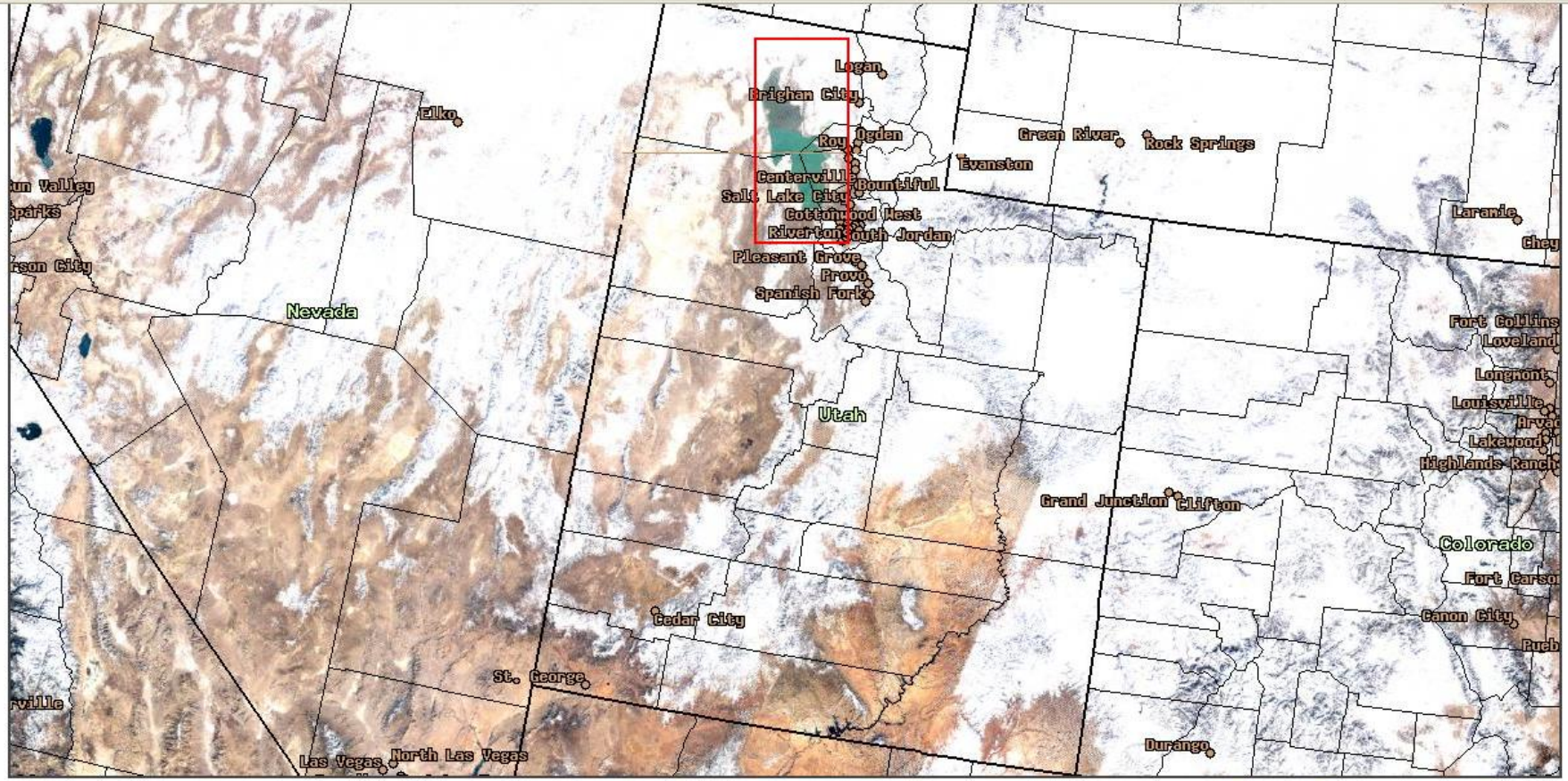
WELD Distribution System - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://snowdon.sdstate.edu/WYSIWYG/distribution_conus_new.php?img_name=CONUS.winter.2008.v1.3.bs7.type2

Most Visited Getting Started Latest Headlines http://snowdon.sdsta... Annotating -- IM v6 E... Password Protection ...

WELD Distribution System



Hold the shift button & drag the mouse to define an area of interest for ordering data

Vector Longitude/latitude Albers

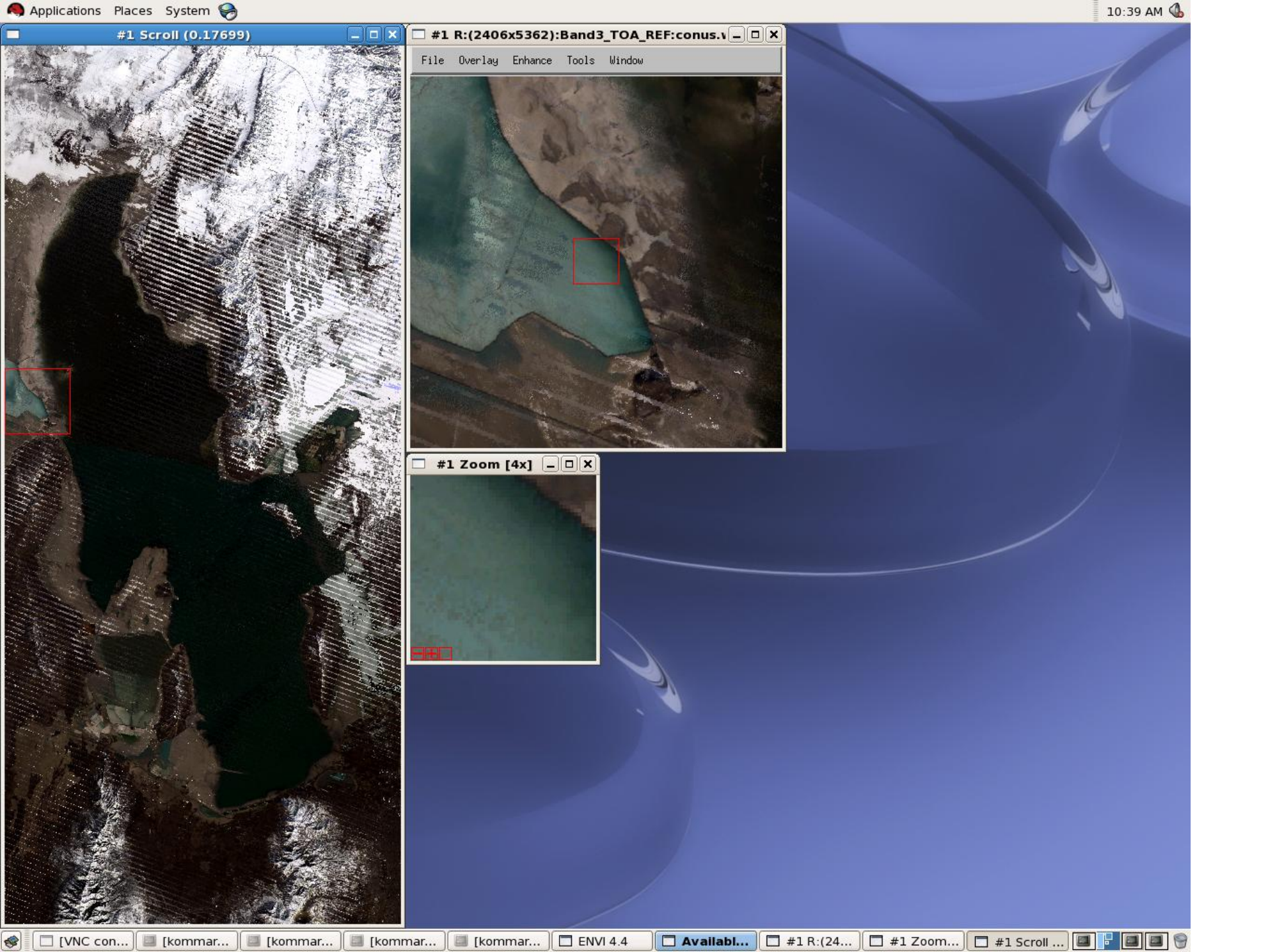
North: 41.9497712

West: -112.78206150 East: -112.26212602

South: 40.42287347

Order Data

Done


Applications
Places
System
10:39 AM
#1 Scroll (0.17699)
#1 R:(2406x5362):Band3_TOA_REF:conus.
File
Overlay
Enhance
Tools
Window
#1 Zoom [4x]
[VNC con...
[kommar...
[kommar...
[kommar...
[kommar...
ENVI 4.4
Availabl...
#1 R:(24...
#1 Zoom...
#1 Scroll ...

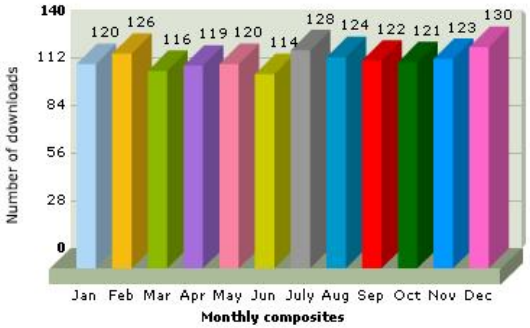
Distribution Metrics

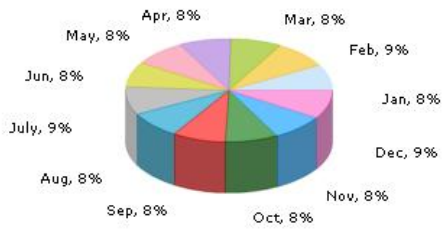
WEB-ENABLED LANDSAT DATA

Home Help

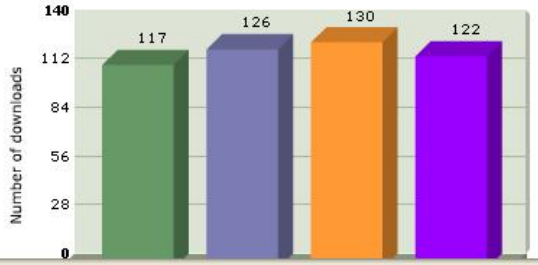
Metrics for CONUS (2010-03-14 to 2010-04-14)

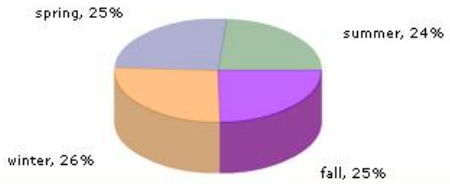
Total number of orders for each Monthly composite





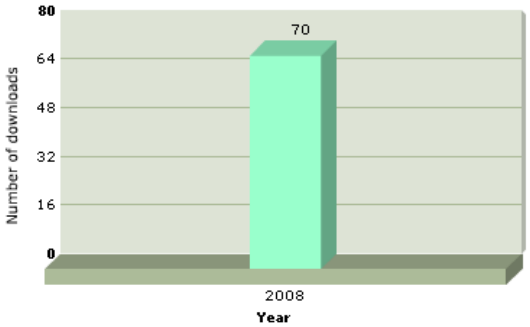
Total number of orders for each Seasonal composite

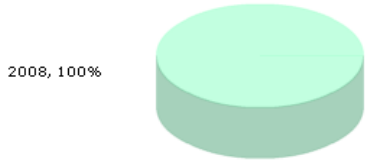




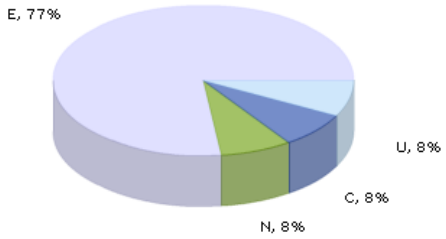
Read snowdon.sdstate.edu

Total number of orders for each Yearly composite





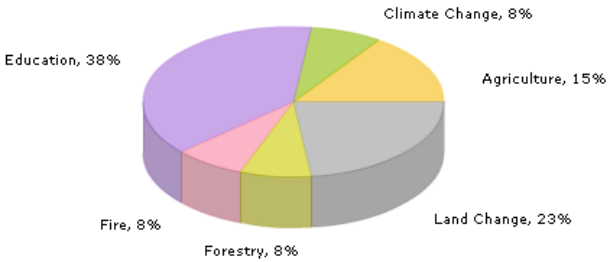
Number of unique users ordered products by Affiliation



Number of unique users ordered products by Primary use

Weld Distribution system - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://snowdon.sdstate.edu/distribution_system_new/metrics.php
Most Visited Getting Started Latest Headlines http://snowdon.sdsta... Annotating -- IM v6 E... Password Protection ...
Weld Distribution system

Number of unique users ordered products by Primary use



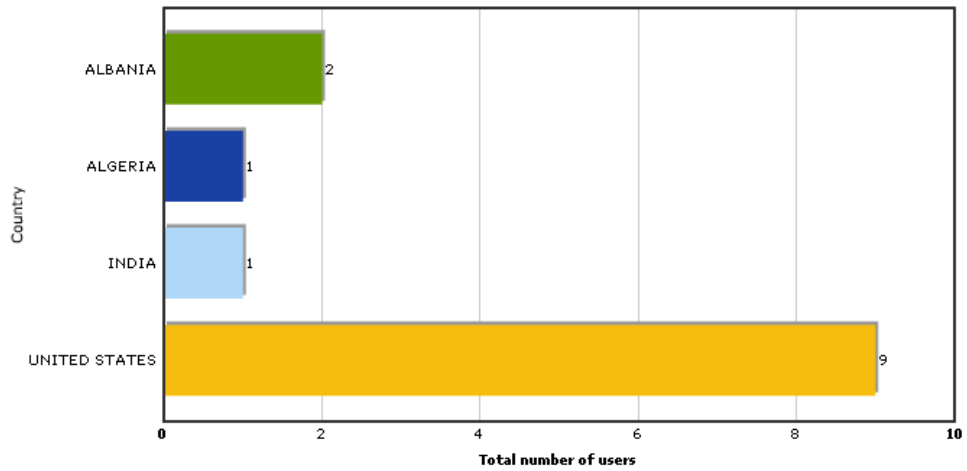
Number of unique users ordered products by Secondary use

Number of unique users ordered products by Country

Done

Weld Distribution system - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://snowdon.sdstate.edu/distribution_system_new/metrics.php
Most Visited Getting Started Latest Headlines http://snowdon.sdsta... Annotating -- IM v6 E... Password Protection ...
Weld Distribution system

Number of unique users ordered products by Country



Other Metrics

Average number of 30m pixels placed by each user : 5387900526
Average number of orders placed by each user : 156
Number of unique users who registered : 19
Number of unique users who ordered data : 13
Total number of orders : 2028
Total volume of orders : 575.3MB

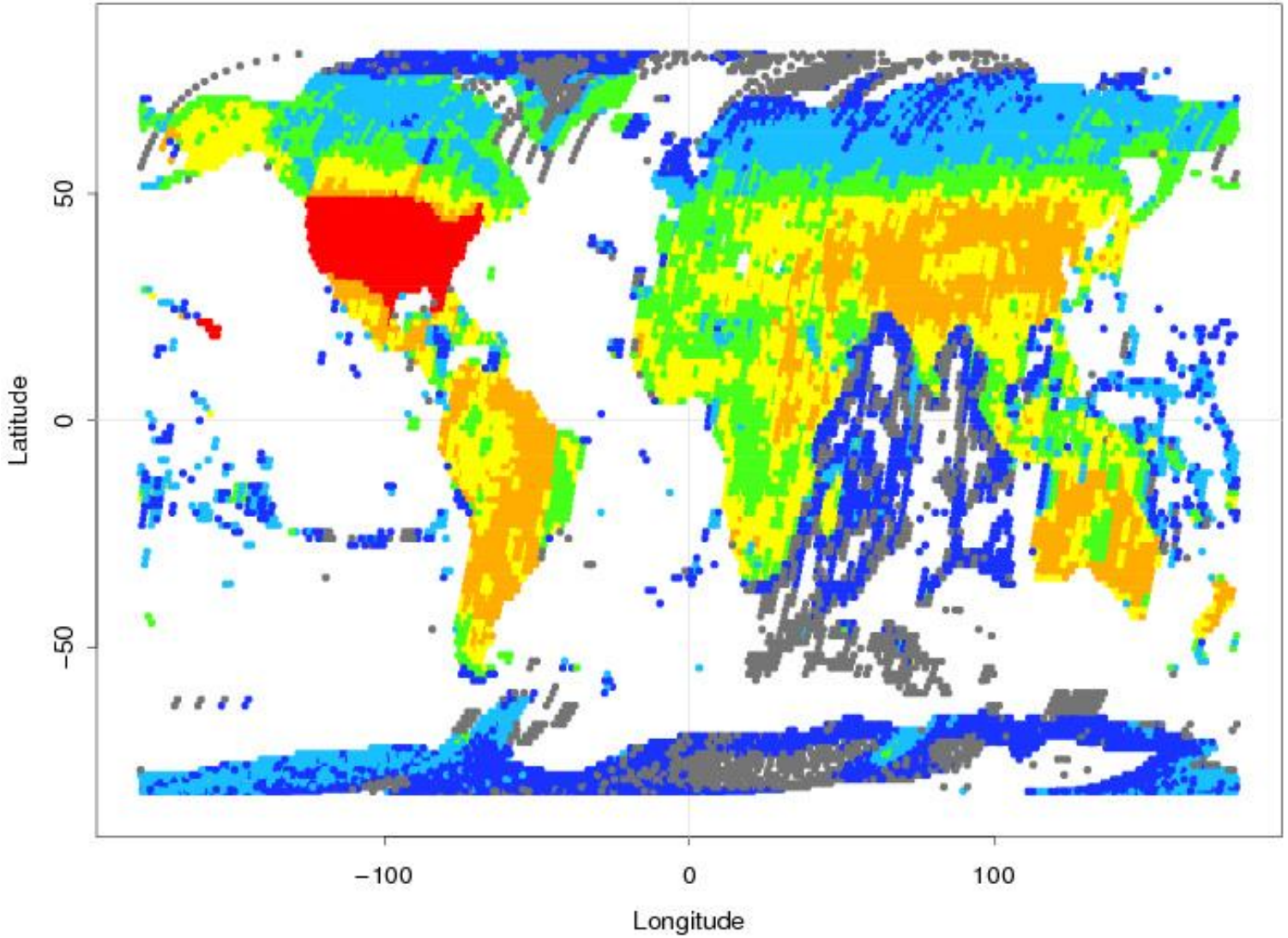
Done

2010 Schedule for WELD system port from SDSU to EROS

- WELD Version 1.3 sample distribution
  - **Done Jan. 15th 2010**
  - http://landsat.usgs.gov/WELD.php
- WYSISWY Distribution System
  - Version 1.4
  - 2007/2008/2009
  - CONUS & Alaska
  - weekly/monthly/seasonal/annual composited mosaics
  - **July 2010**
- Reprocessing and other years will be distributed in 2010-2013, evolving in response to community feedback

Global WELD ?

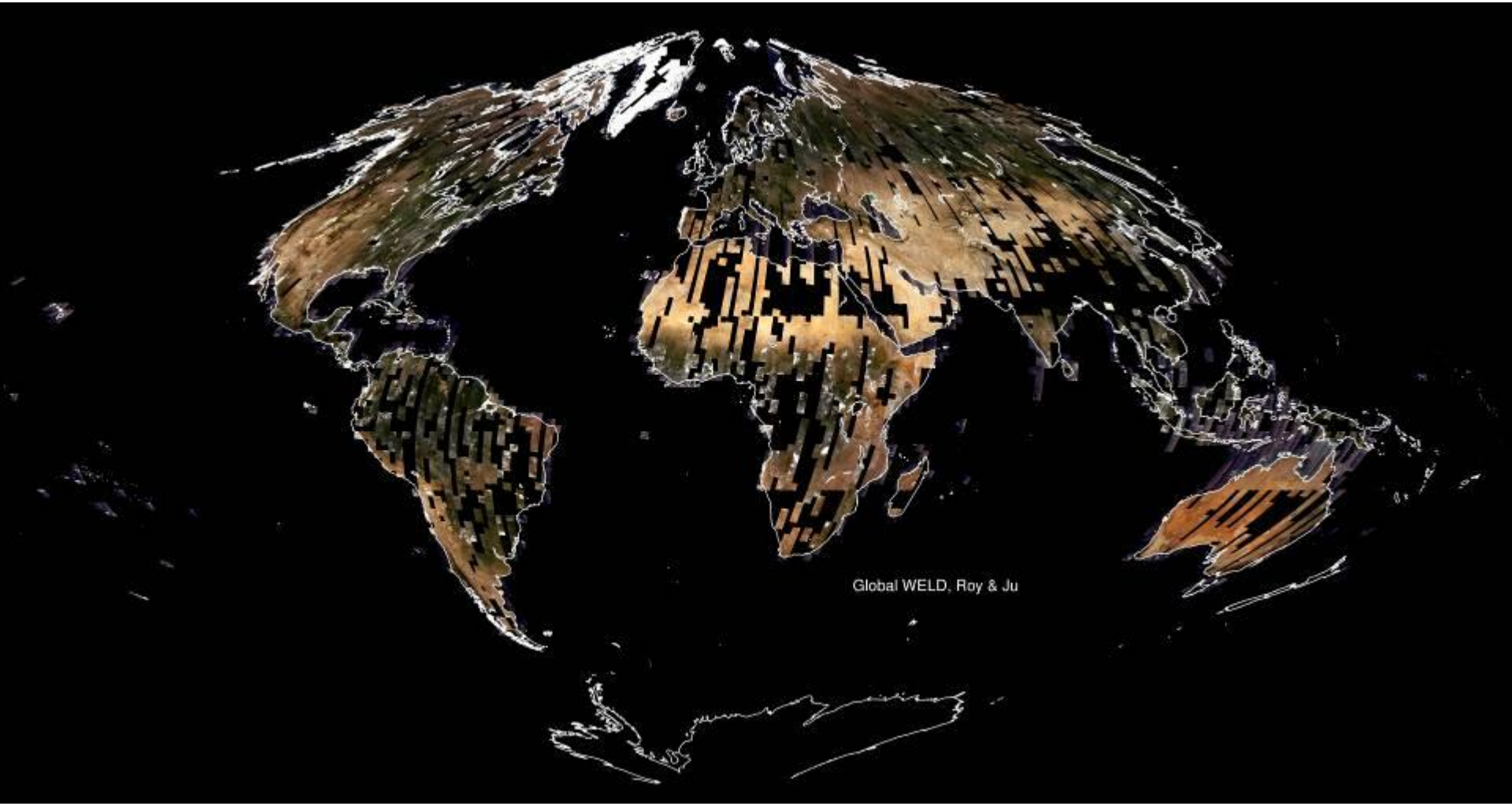
Average annual number of ETM+ acquisitions per path/row (2004-2009)



0 < grey ≤ 1
1 < dark blue ≤ 3
3 < light blue ≤ 6
6 < green ≤ 10
10 < yellow ≤ 14
14 < orange ≤ 20
20 < red ≤23

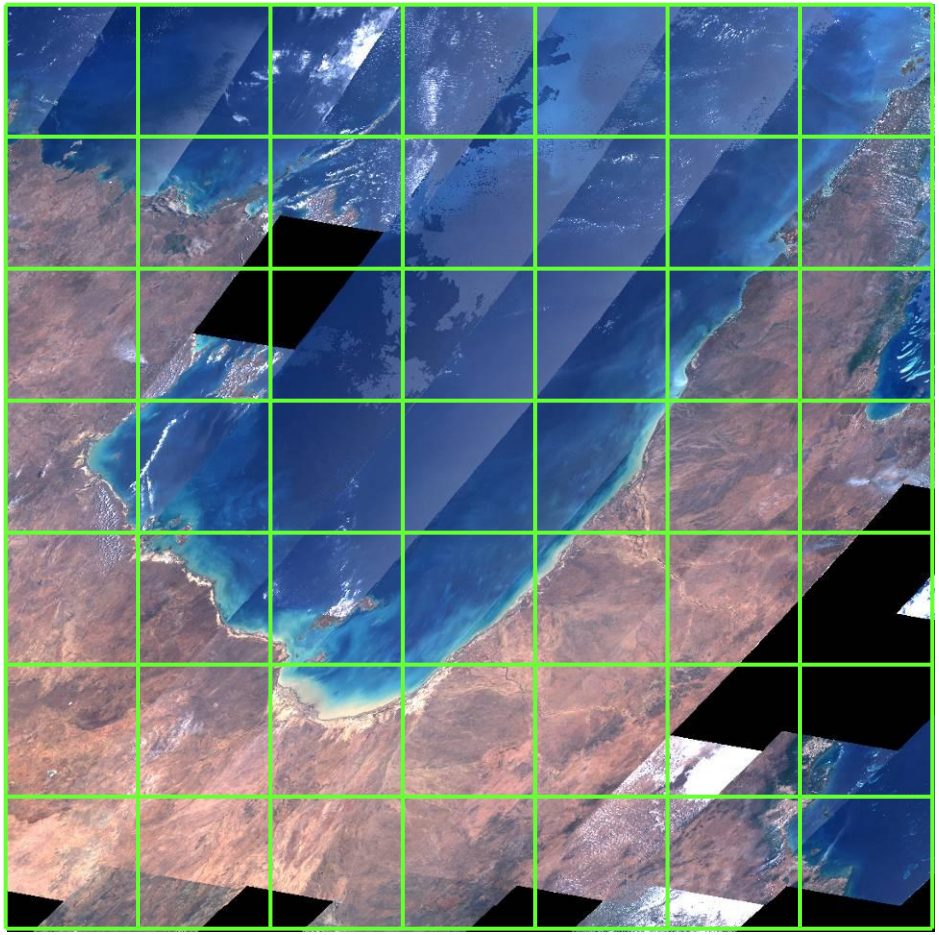
Global WELD: Landsat 30m Leaf-on Monthly composite

(Southern hemisphere Jan. 2010, Tropics ±20° October 2009, Northern hemisphere July 2009)



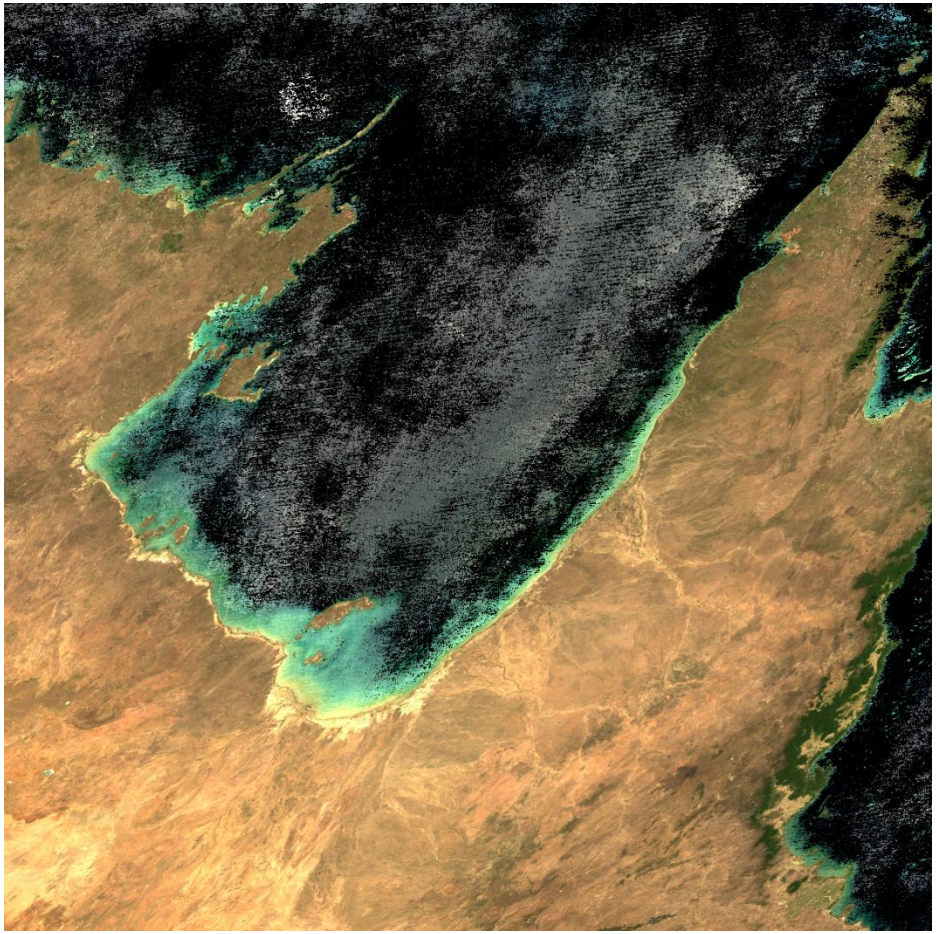
Generated from 6,796 L1T acquisitions in USGS EROS archive with cloud cover < 40%

Global WELD proof of concept



- ETM+ TOA true color 30m reflectance composite
- 7 x 7 WELD Landsat tiles nested within each MODIS tile
- All October 2009 ETM+ acquisitions in USGS EROS archive
- Gulf of Carpentaria, Australia

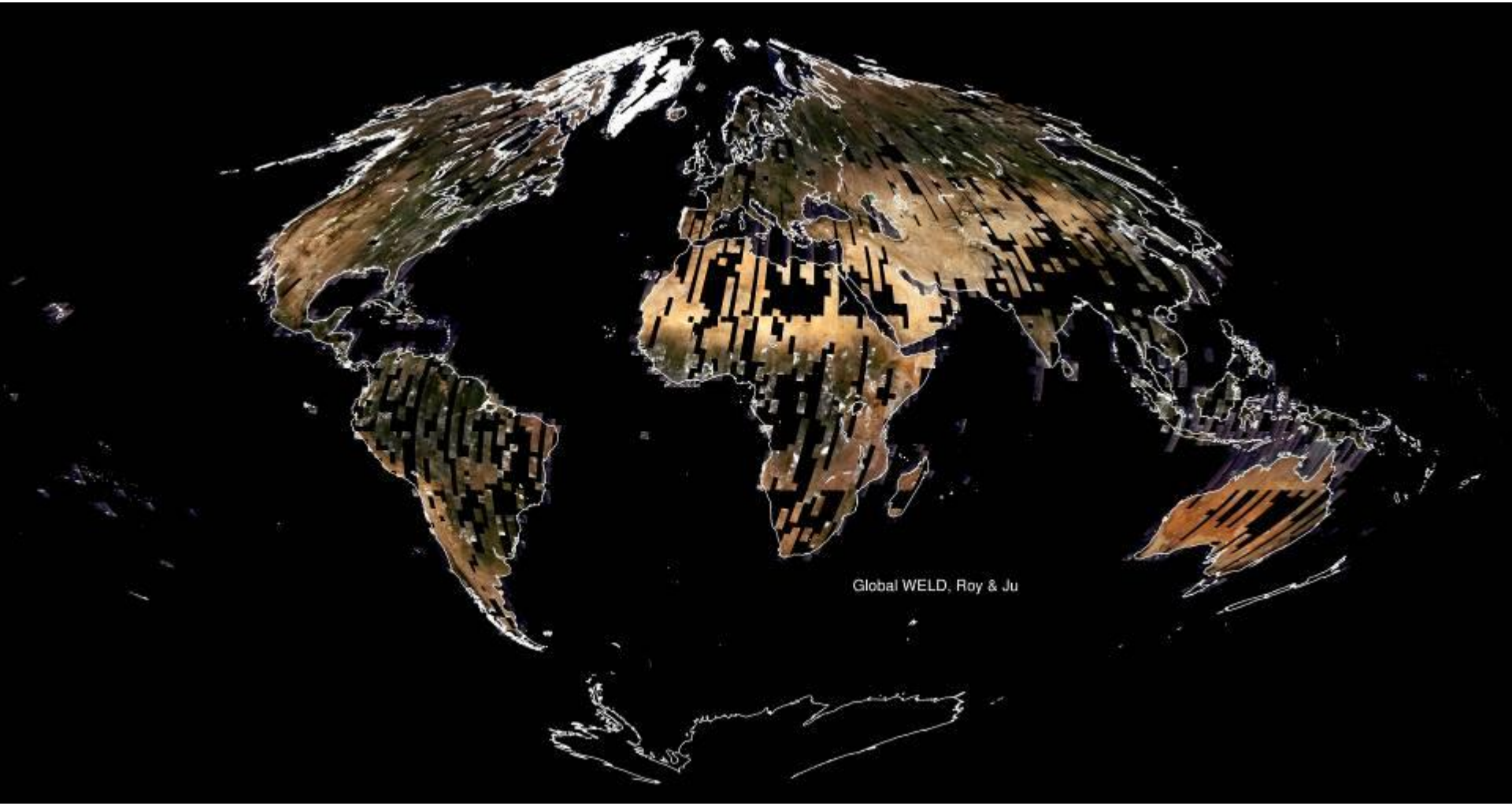
Global WELD proof of concept

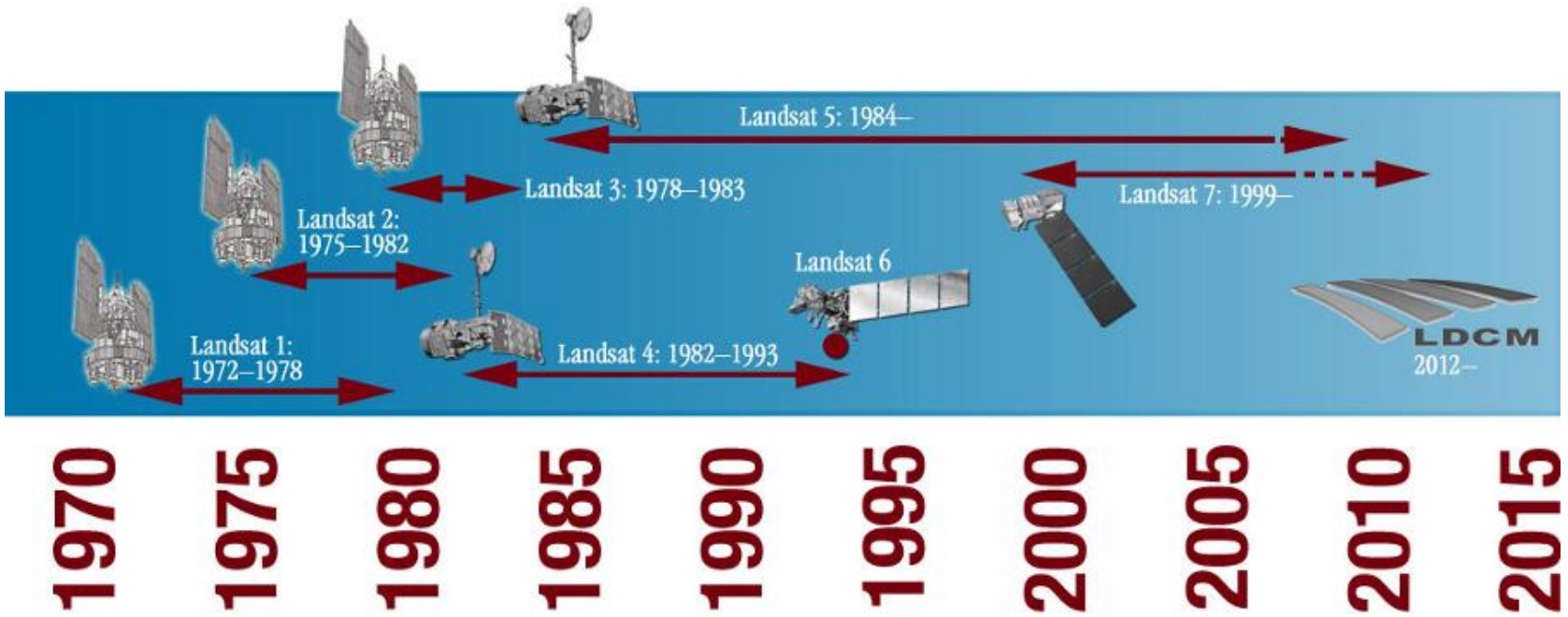


- MODIS nadir view BRDF-adjusted 500m true color reflectance
- MODIS Land Tile h31v10
- All Terra and Aqua daily surface reflectance for October 2009
- Gulf of Carpentaria, Australia

Global WELD: Landsat 30m Leaf-on Monthly composite

(Southern hemisphere Jan. 2010, Tropics ±20° October 2009, Northern hemisphere July 2009)



Generated from 6,796 L1T acquisitions in USGS EROS archive with cloud cover < 40%

The community wants a long term Landsat data record of higher level products, globally