A general method to normalize Landsat reflectance data to nadir BRDF adjusted reflectance, and some implications

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McCrory Gardens Education and Visitor Center, Brookings, SD, July 27 2016

Version 3.0, Global 3 years (12 monthly, 1 annual product per year)

Total distribution volume: 74TB 312,000 files

Collections

** The text files were created to be used with the DAAC2Disk tool. This tool facilitates the downloading of large amounts of data.*

Annual (2009, 2010, 2011)				
Folder Name	**Type**	**# of files**	**Size**	**Text File**
weld.global.annual.2009	Global Annual 2009	8,050	3,026,904 MB	weld.global.annual.2009.txt
weld.global.annual.2010	Global Annual 2010	8,023	2,975,832 MB	weld.global.annual.2010.txt
weld.global.annual.2011	Global Annual 2011	8,003	2,943,370 MB	weld.global.annual.2011.txt
	Totals for Annuals	**24,076**	**8,946,106 MB**	

2009				
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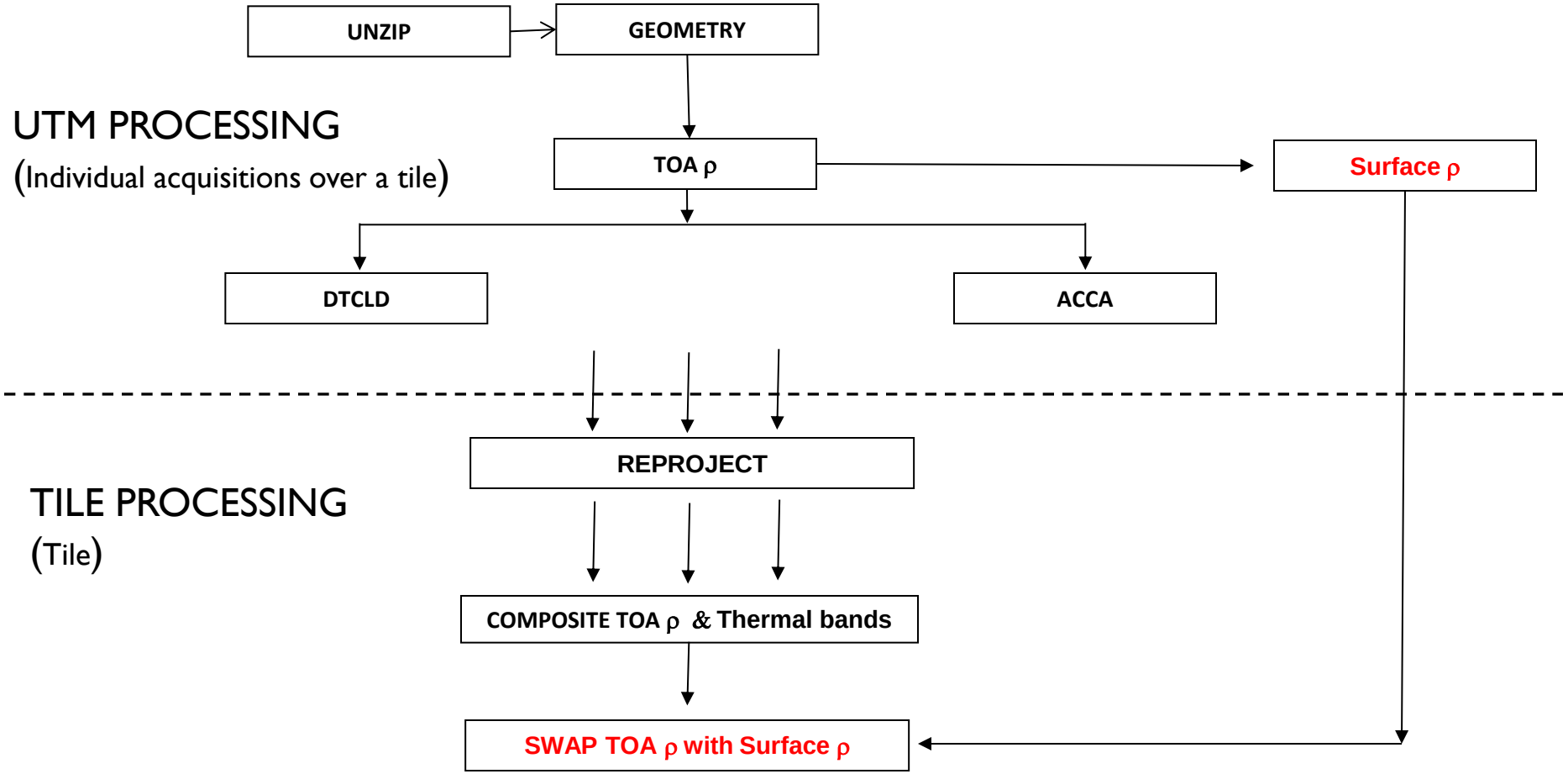
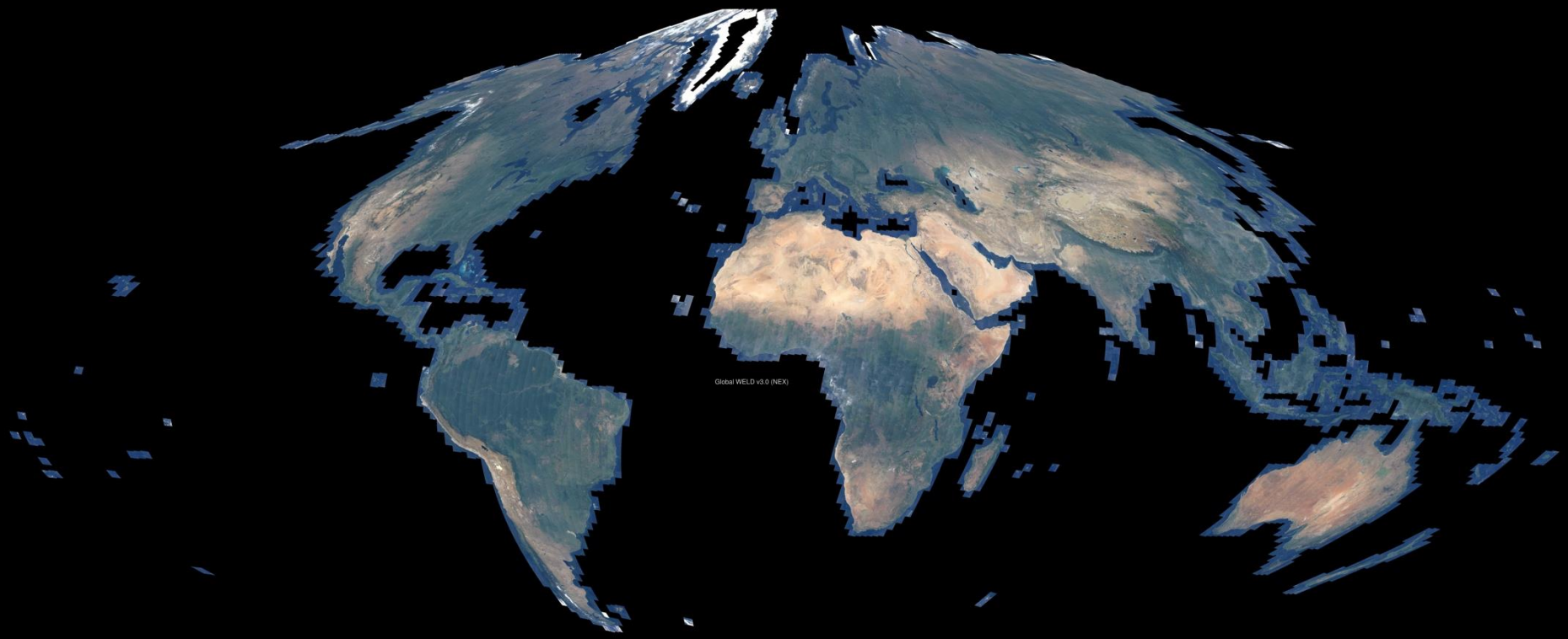
weld.global.month01.2009	Global Month 1	5,770	1,451,543 MB	weld.global.month01.2009.txt
weld.global.month02.2009	Global Month 2	6,197	1,528,338 MB	weld.global.month02.2009.txt
weld.global.month03.2009	Global Month 3	7,153	1,835,942 MB	weld.global.month03.2009.txt
weld.global.month04.2009	Global Month 4	7,233	1,777,753 MB	weld.global.month04.2009.txt
weld.global.month05.2009	Global Month 5	7,245	1,854,749 MB	weld.global.month05.2009.txt
weld.global.month06.2009	Global Month 6	7,104	1,953,828 MB	weld.global.month06.2009.txt
weld.global.month07.2009	Global Month 7	6,884	1,896,111 MB	weld.global.month07.2009.txt
weld.global.month08.2009	Global Month 8	7,018	1,940,278 MB	weld.global.month08.2009.txt
weld.global.month09.2009	Global Month 9	7,178	1,990,522 MB	weld.global.month09.2009.txt
weld.global.month10.2009	Global Month 10	7,095	1,858,060 MB	weld.global.month10.2009.txt
weld.global.month11.2009	Global Month 11	6,278	1,657,394 MB	weld.global.month11.2009.txt
weld.global.month12.2008	Global Month 12	5,511	1,341,593 MB	weld.global.month12.2008.txt
	Totals for Months	**80,666**	**21,086,111 MB**	

2010				
Folder Name	**Type**	**# of files**	**Size**	**Text File**
weld.global.month01.2010	Global Month 1	5,605	1,396,719 MB	weld.global.month01.2010.txt
weld.global.month02.2010	Global Month 2	6,117	1,445,984 MB	weld.global.month02.2010.txt
weld.global.month03.2010	Global Month 3	6,082	1,596,701 MB	weld.global.month03.2010.txt

Overview of Global Version 3.0 WELD Processing Sequence



Global WELD Landsat 5 & 7 TOA reflectance



Global WELD NEX Version 3.0 Annual 2009 30m product
from 141,098 L1T scenes (59,183 Landsat 5 & 81,915 Landsat 7)

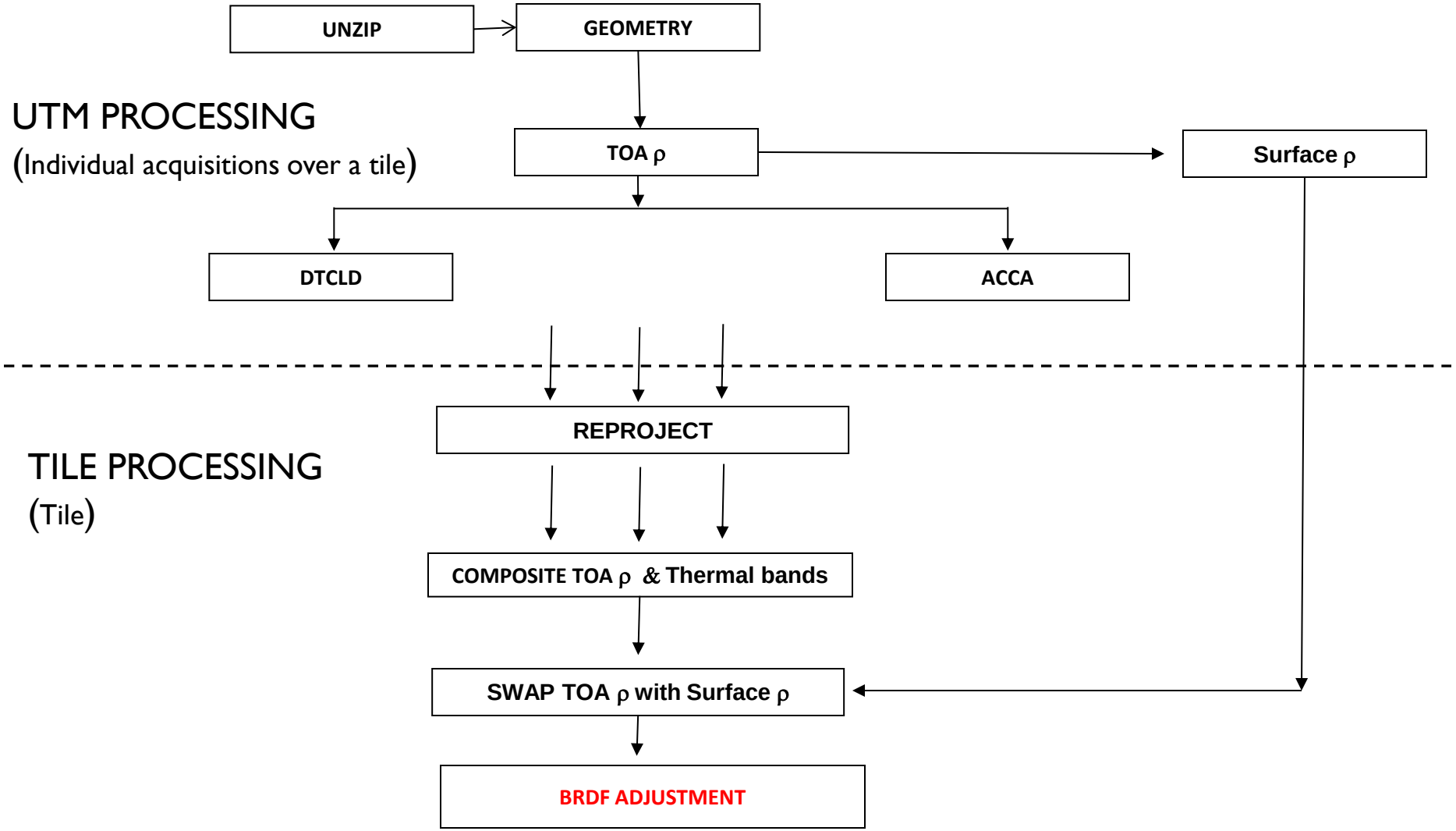
Sinusoidal Equal Area Projection

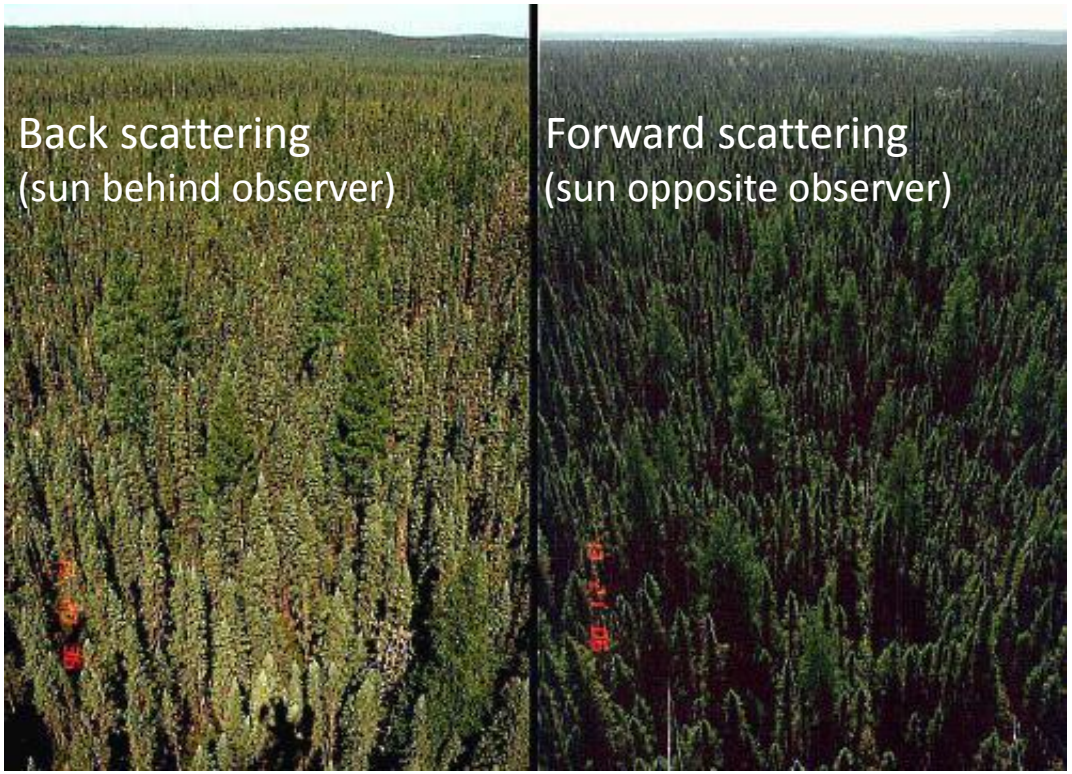
Global WELD Landsat 5 & 7 surface reflectance

Global WELD NEX Version 3.0 Annual 2009 30m product
from 141,098 L1T scenes (59,183 Landsat 5 & 81,915 Landsat 7)

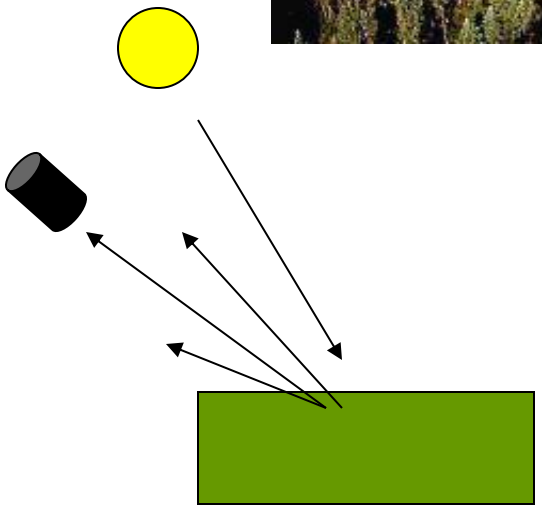
Sinusoidal Equal Area Projection

Overview of Global Version 3.0 WELD Processing Sequence

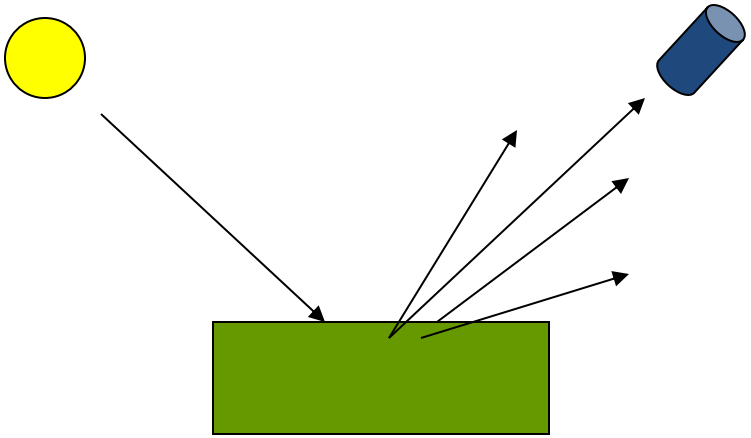




(Don Deering)



Back scatter direction



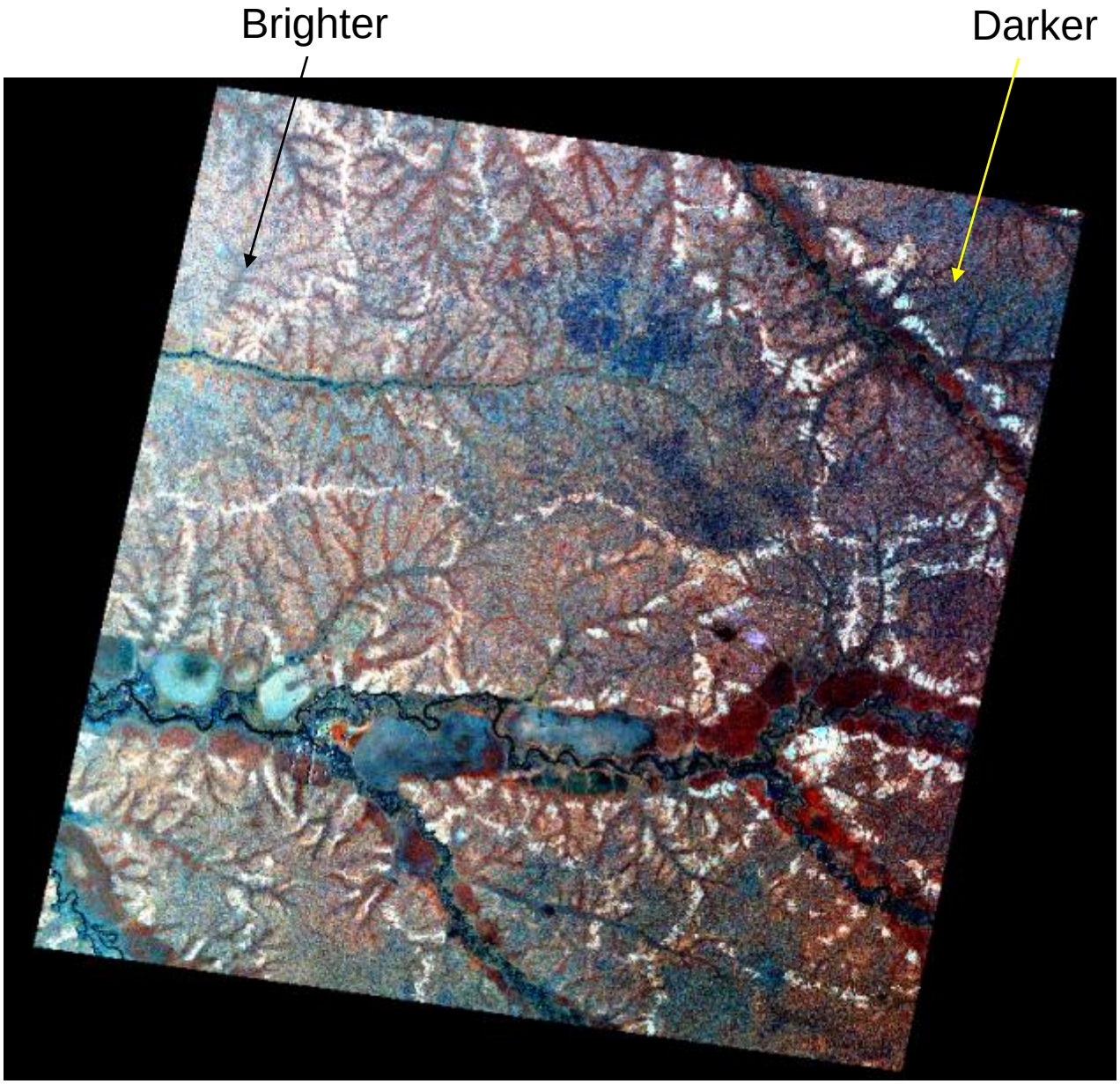
Forward scatter direction

Example over dense forest in the Congo

Landsat 7

path 179
row 60

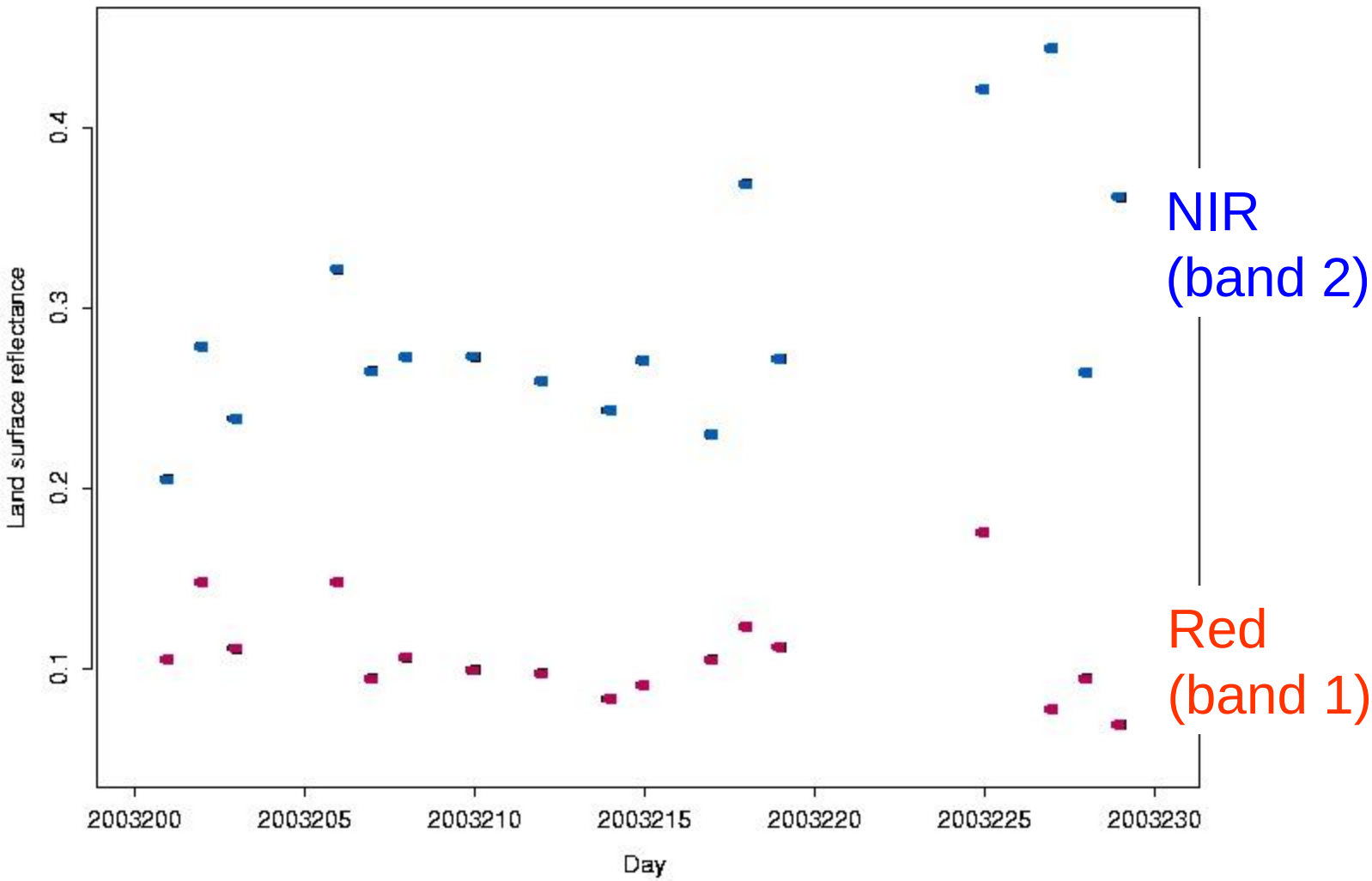
date –
Mar 5, 2000



ETM+ Bands 4,5,7

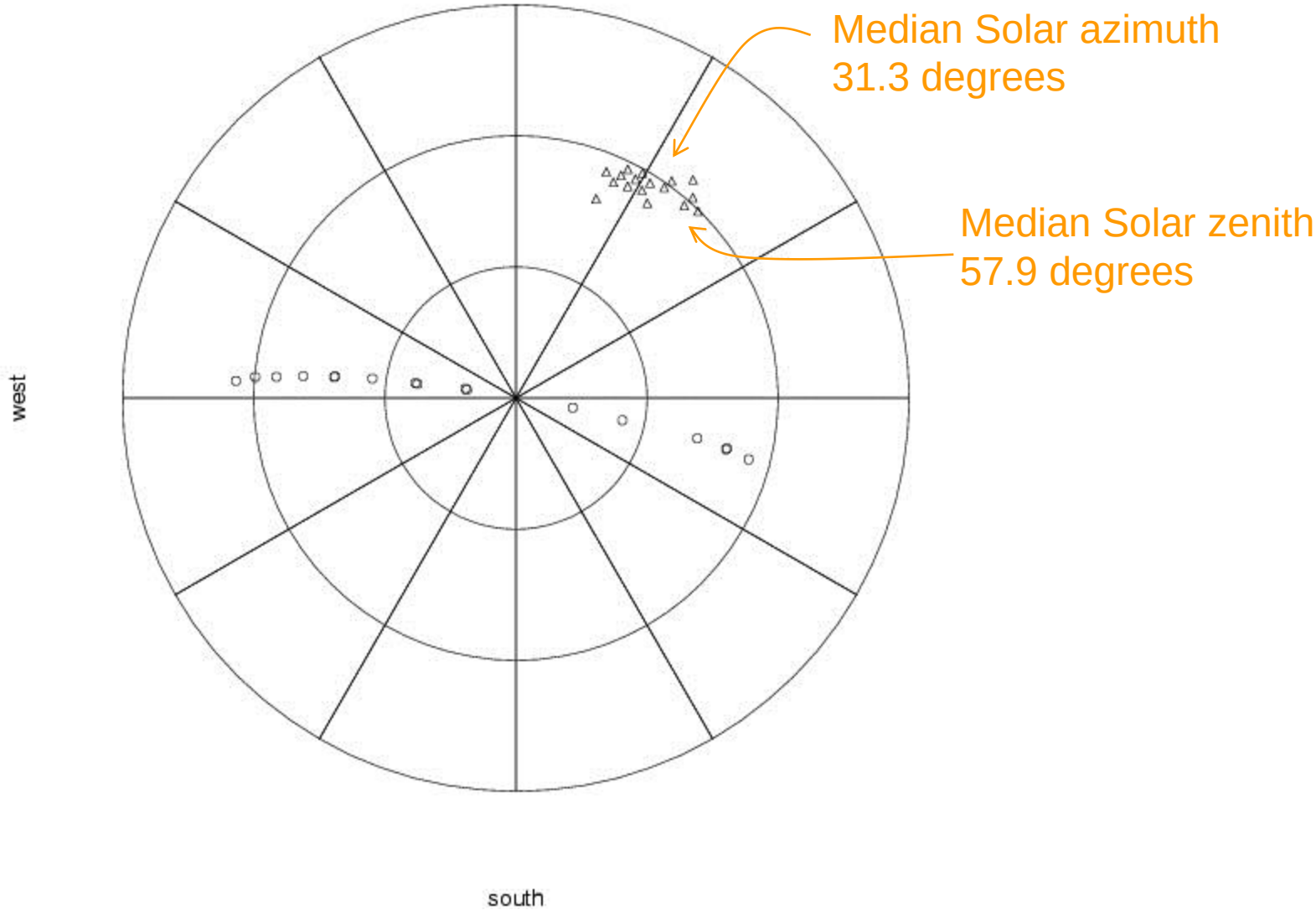
(Eric Lindquist)

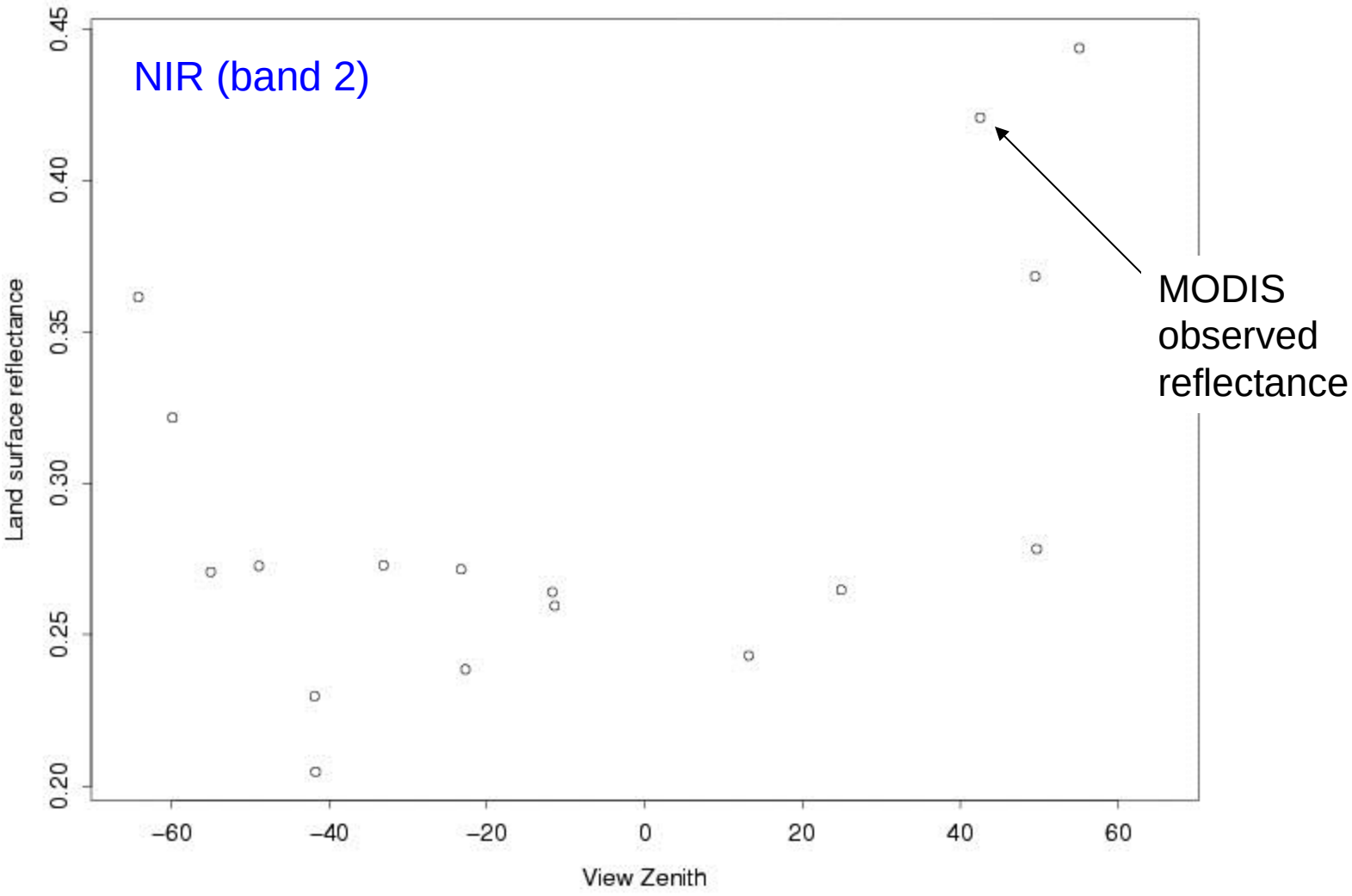
Example: Month of MODIS observations (1 per day)

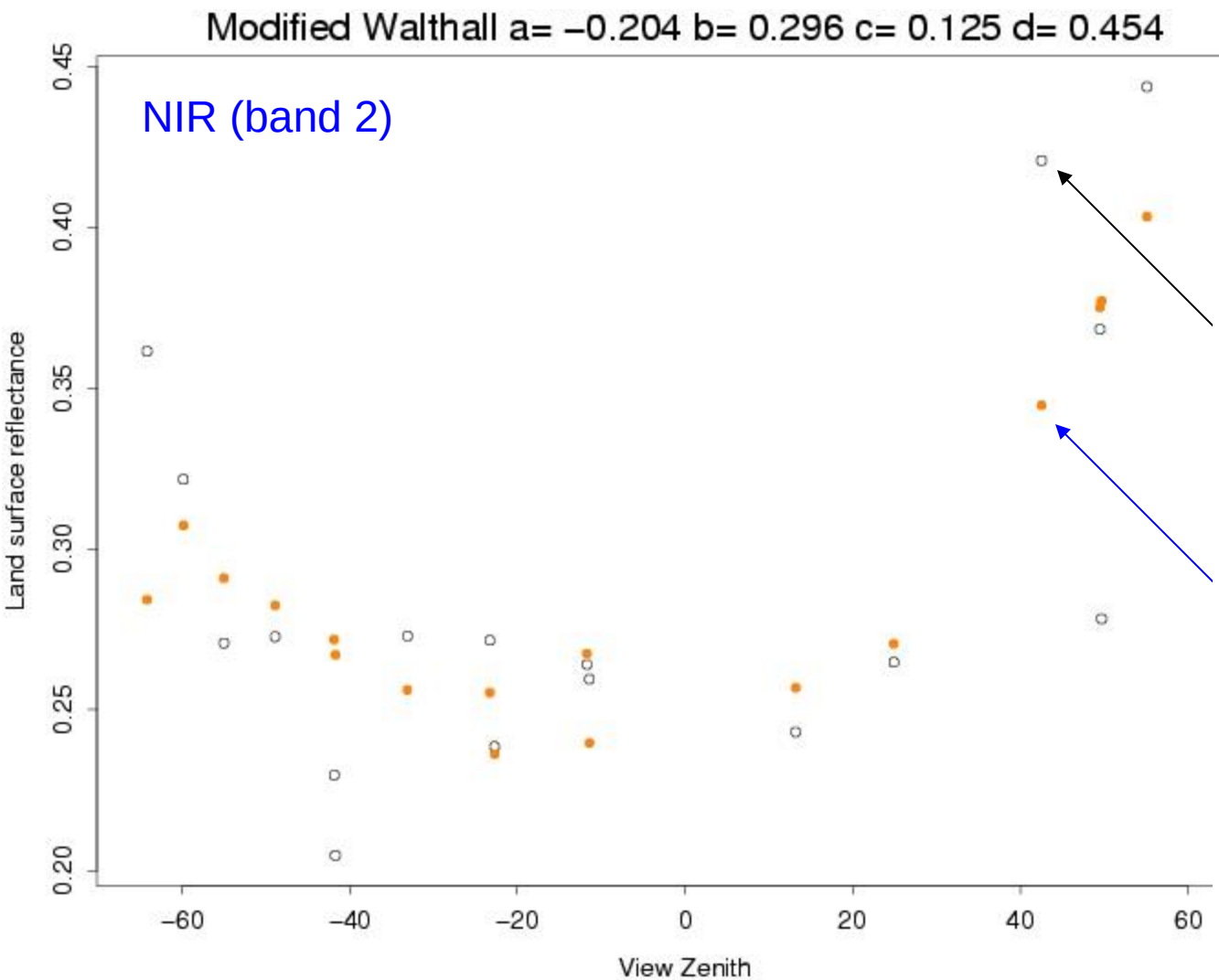


Month of MODIS observations (1 per day)

Polar Plot to show sensing geometry



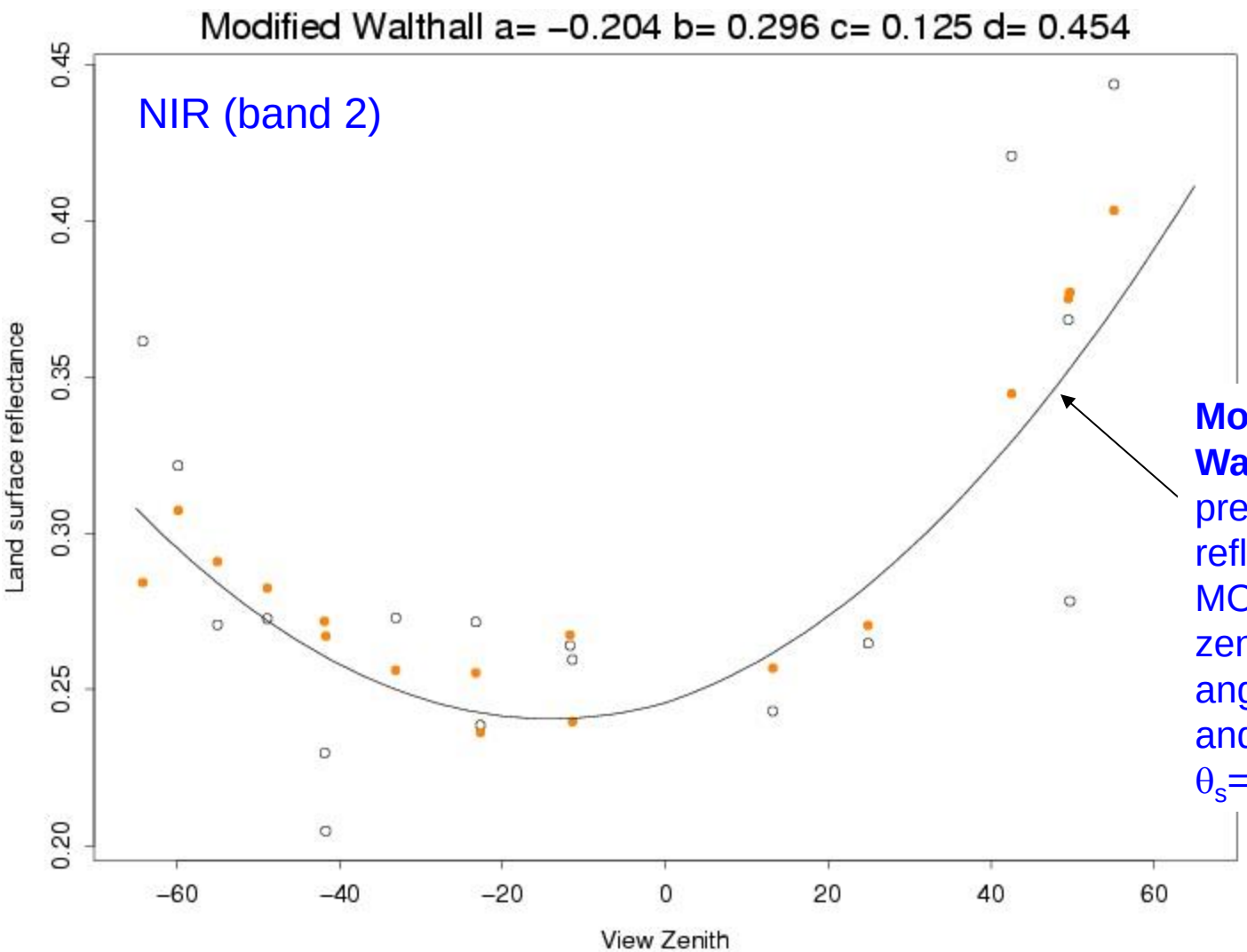

NIR (band 2)
MODIS observed reflectance
Land surface reflectance
0.20
0.25
0.30
0.35
0.40
0.45
−60
−40
−20
0
20
40
60
View Zenith



MODIS observed reflectance

Corresponding **Modified Walthall** predicted reflectance for the MODIS observation solar and viewing angle

$$r = a\left(q_v^2 + q_s^2\right) + b\left(q_v^2\, q_s^2\right) + c\, q_v\, q_s \cos(j_v - j_s) + d$$



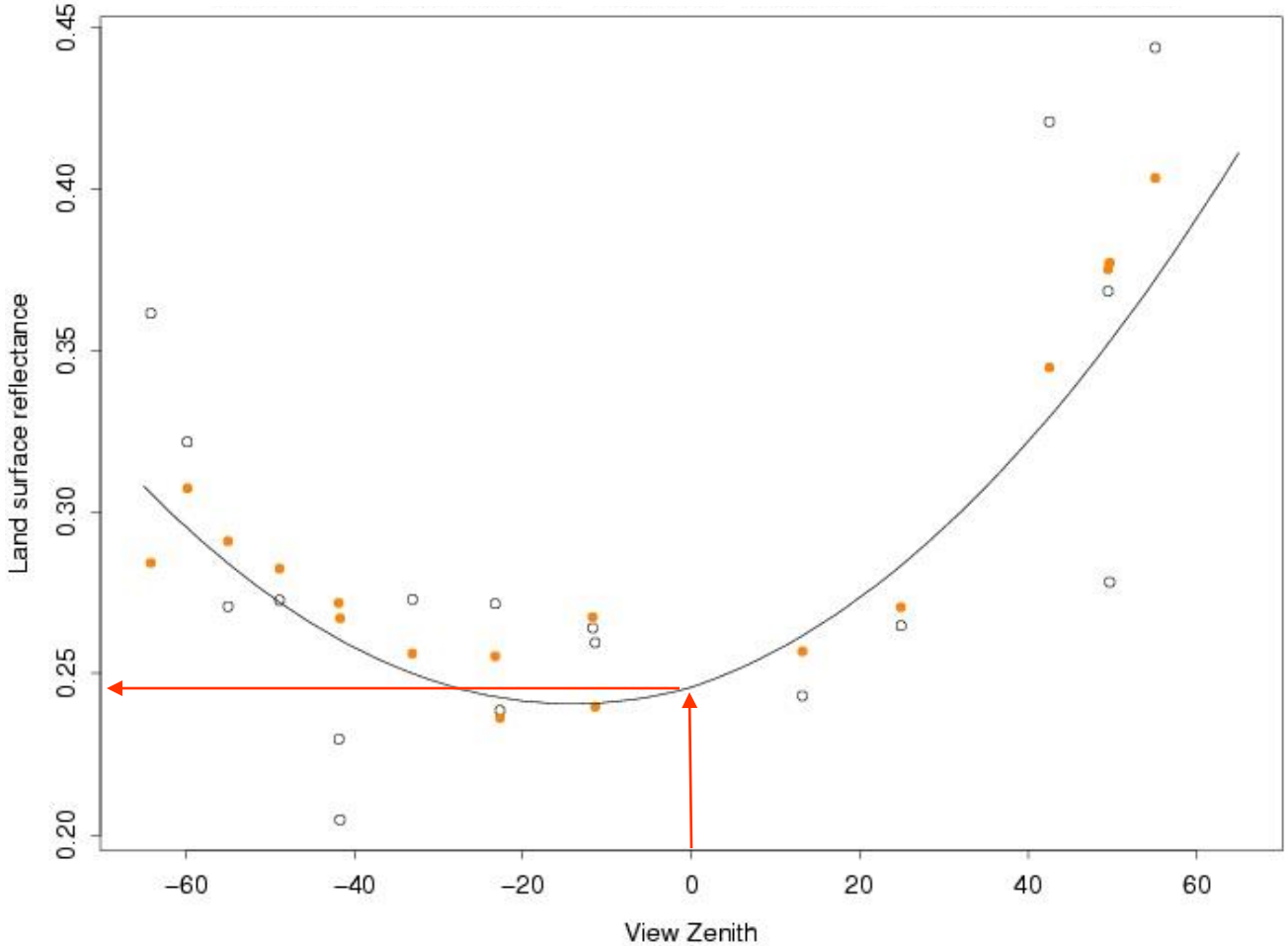
Modified Walthall predicted reflectances for MODIS view zenith & azimuth angles = 0 deg. and modelling θ_s=57.9 ϕ_s=31.3

$$\rho = a\left(\theta_r^2 + \theta_s^2\right) + b\left(\theta_r^2\ \theta_s^2\right) + c\,\theta_v\ \theta_s \cos(\phi_v - \phi_s) + d$$

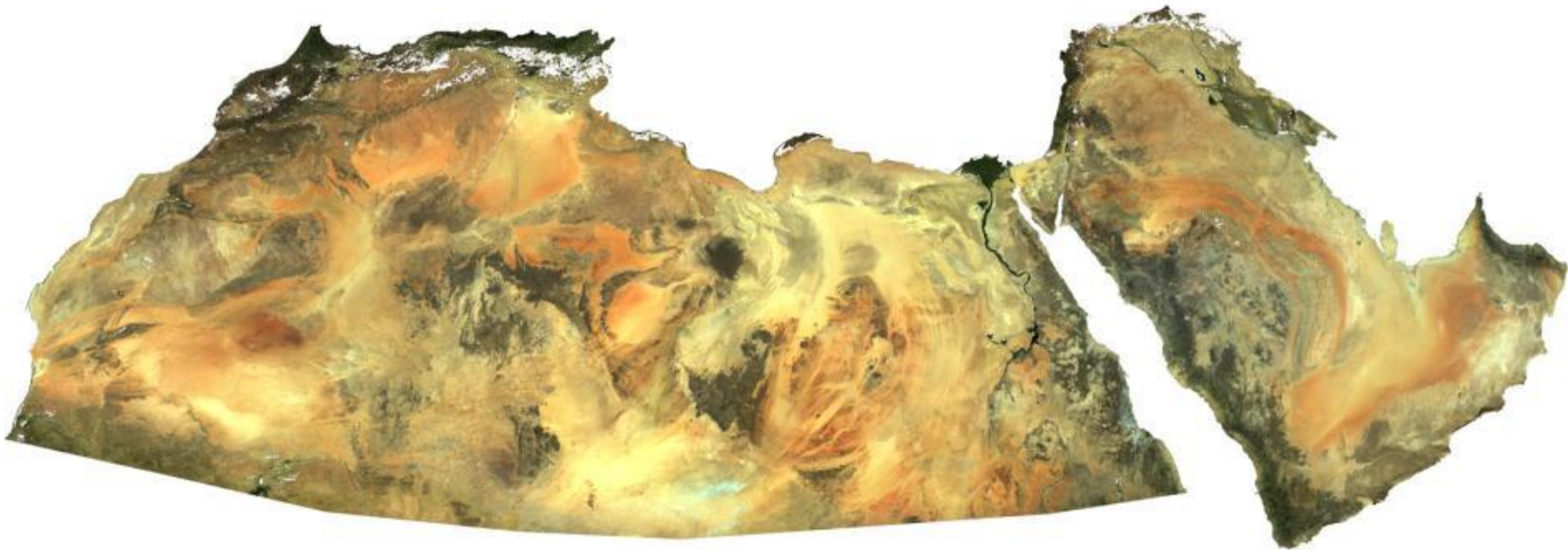
Nadir BRDF-adjusted Reflectance (NBAR)

Normalize Satellite data for BRDF effects, usually model reflectance for a constant solar zenith angle, and set view zenith = 0 degrees (view and solar azimuth = 0 degrees)

NBAR = 0.24



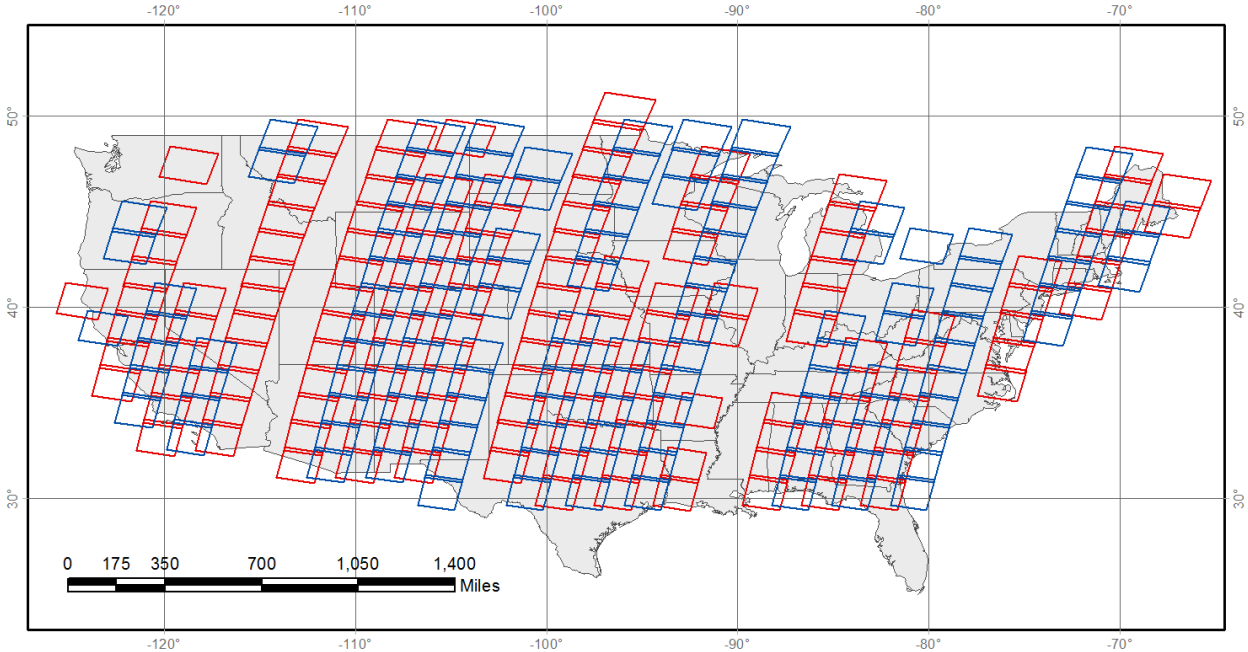
MODIS NBAR of North Africa



True color

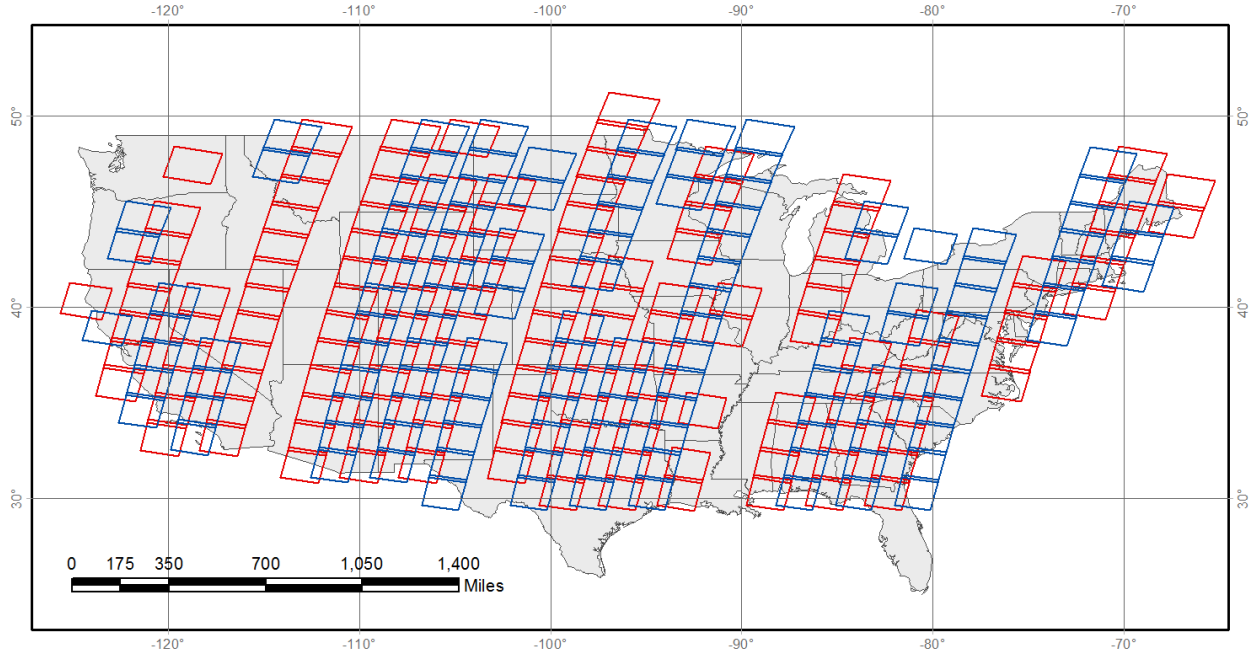
(Schaaf)

Winter week (January 8 – 14 2010) geographic locations of Landsat 5 TM (blue) and Landsat 7 ETM+ (red) images

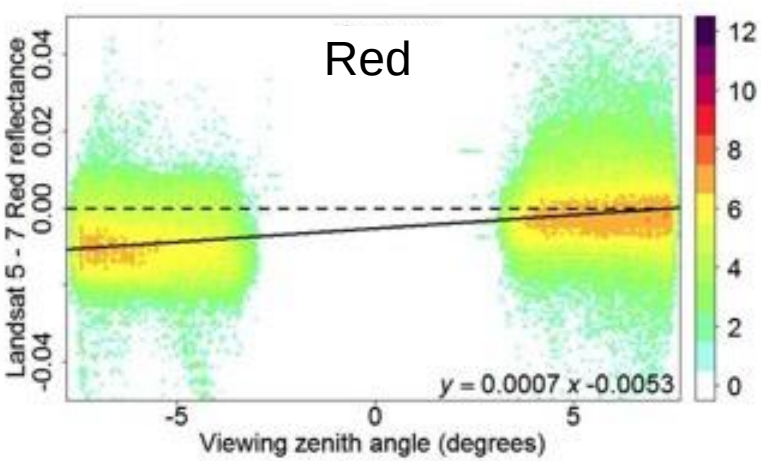


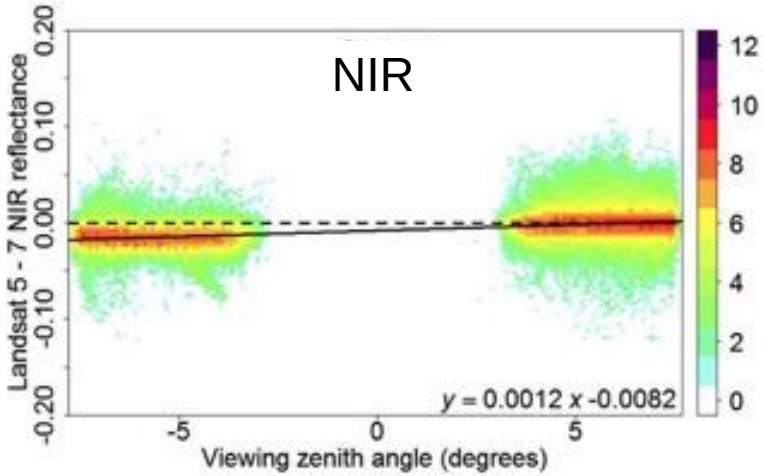
~185,000 pairs of L5 & L7 observations

Winter week (January 8 – 14 2010) geographic locations of Landsat 5 TM (blue) and Landsat 7 ETM+ (red) images



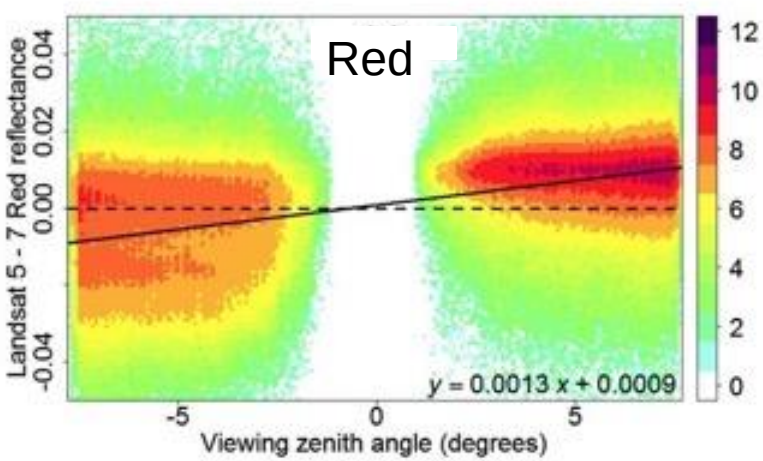
~185,000 pairs of L5 & L7 observations

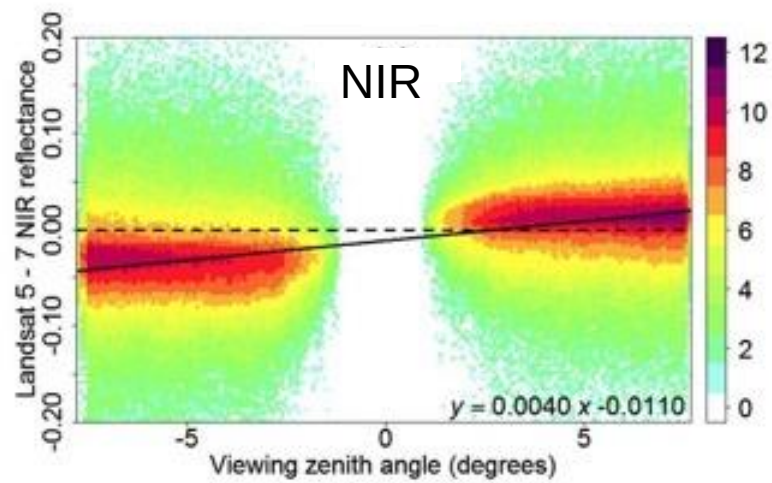




Summer week (July 2 - 8 2010) geographic locations of Landsat 5 TM (blue) and Landsat 7 ETM+ (red) images

~1.3 million pairs of L5 & L7 observations





Landsat BRDF magnitude quantification

	Summer week		Winter week	
Landsat band	OLS equation	**B-F difference**	OLS equation	**B-F difference**
1 (blue)	$= -0.0024 + 0.0013\theta_v$	0.020	$= -0.0064 + 0.0011\theta_v$	0.018
2 (green)	$= 0.0019 + 0.0013\theta_v$	0.021	$= -0.0050 + 0.0007\ \theta_v$	0.011
3 (red)	$= 0.0009 + 0.0013\theta_v$	0.020	$= -0.0053 + 0.0007\ \theta_v$	0.011
4 (NIR)	$= -0.0110 + 0.0040\theta_v$	0.062	$= -0.0082 + 0.0012\ \theta_v$	0.019
5 (1.6μm)	$= -0.0036 + 0.0033\theta_v$	0.050	$= 0.0019 + 0.0012\ \theta_v$	0.018
7 (2.1μm)	$= 0.0034 + 0.0022\theta_v$	0.033	$= 0.0048 + 0.0008\ \theta_v$	0.013

Landsat MODIS-based BRDF Adjustment c-factor method

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

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

$\hat{\rho}_{MODIS}$ computed from the MODIS 16-day 500m BRDF/Albedo product (MCD43) spectral BRDF model parameters

Roy, D.P., Ju, J., Lewis, P., Schaaf, C., Gao, F., Hansen, M., Lindquist, E., 2008. Multi-temporal MODIS-Landsat data fusion for relative radiometric normalization, gap filling, and prediction of Landsat data. *Remote Sensing of Environment* 112 (6), 3112-3130.

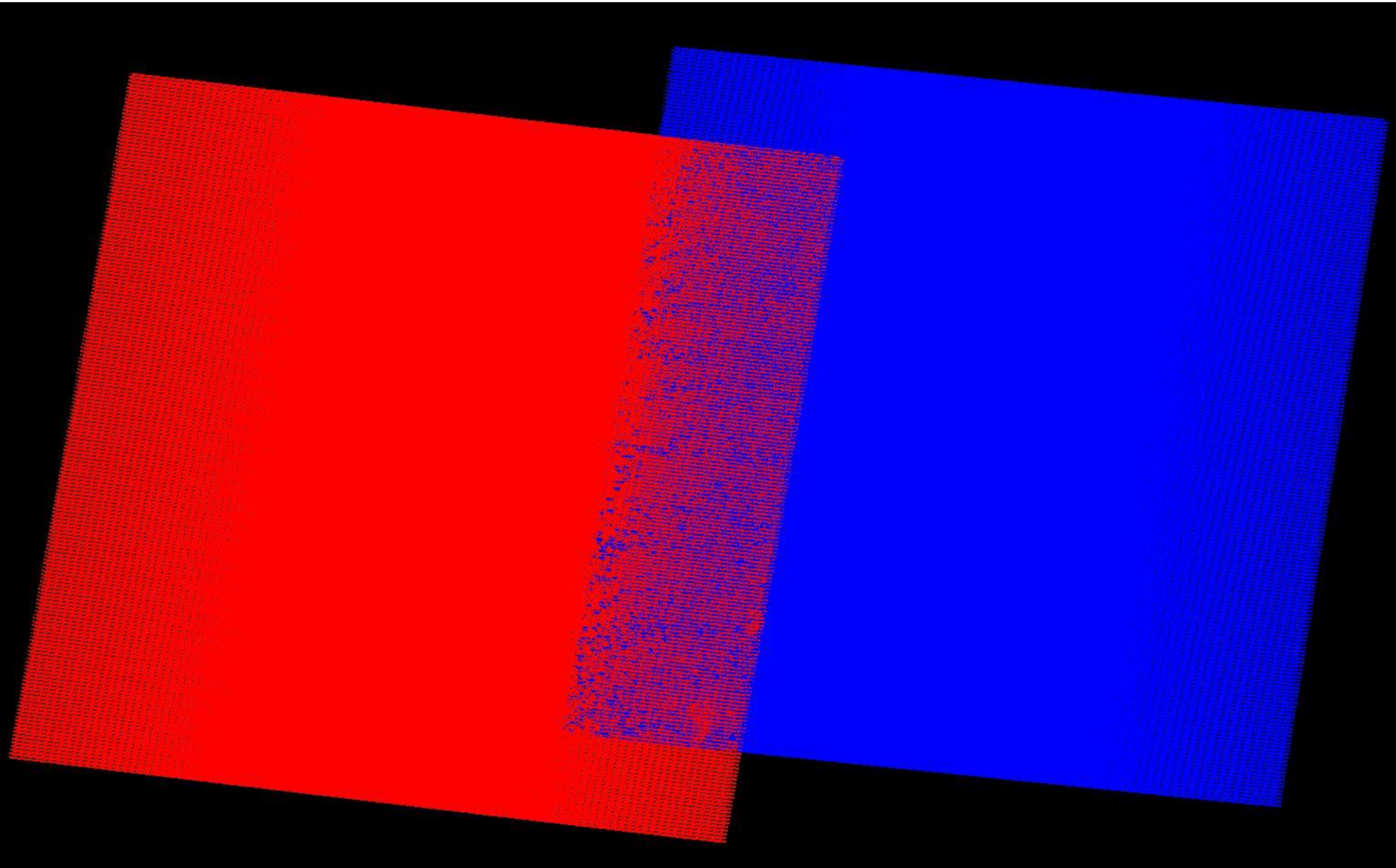
Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008

Band 3, 2, 1 (red, green, blue) TOA reflectance

Before BRDF normalization

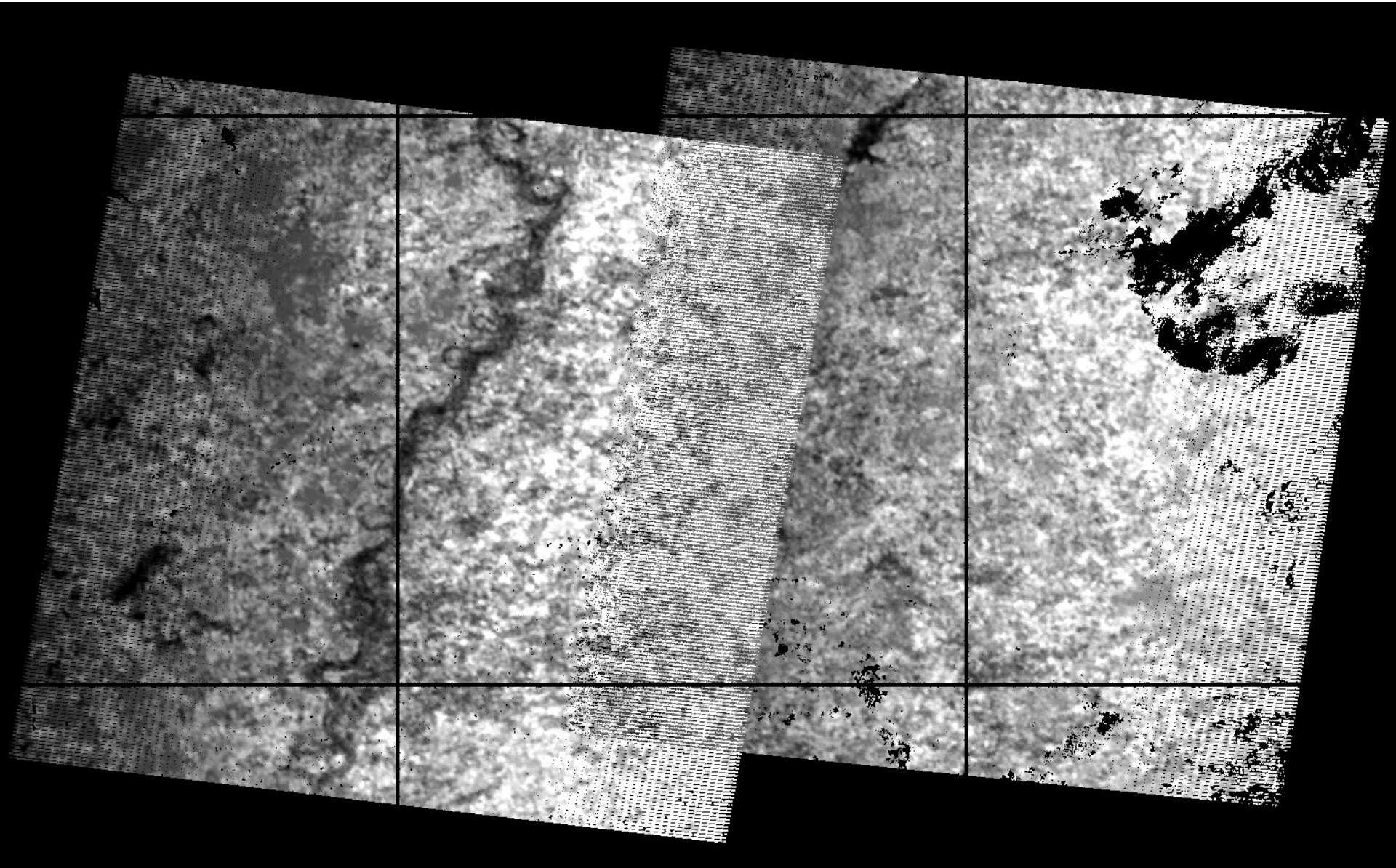
Composited Day of Year

Red: July 12 Blue: July 5



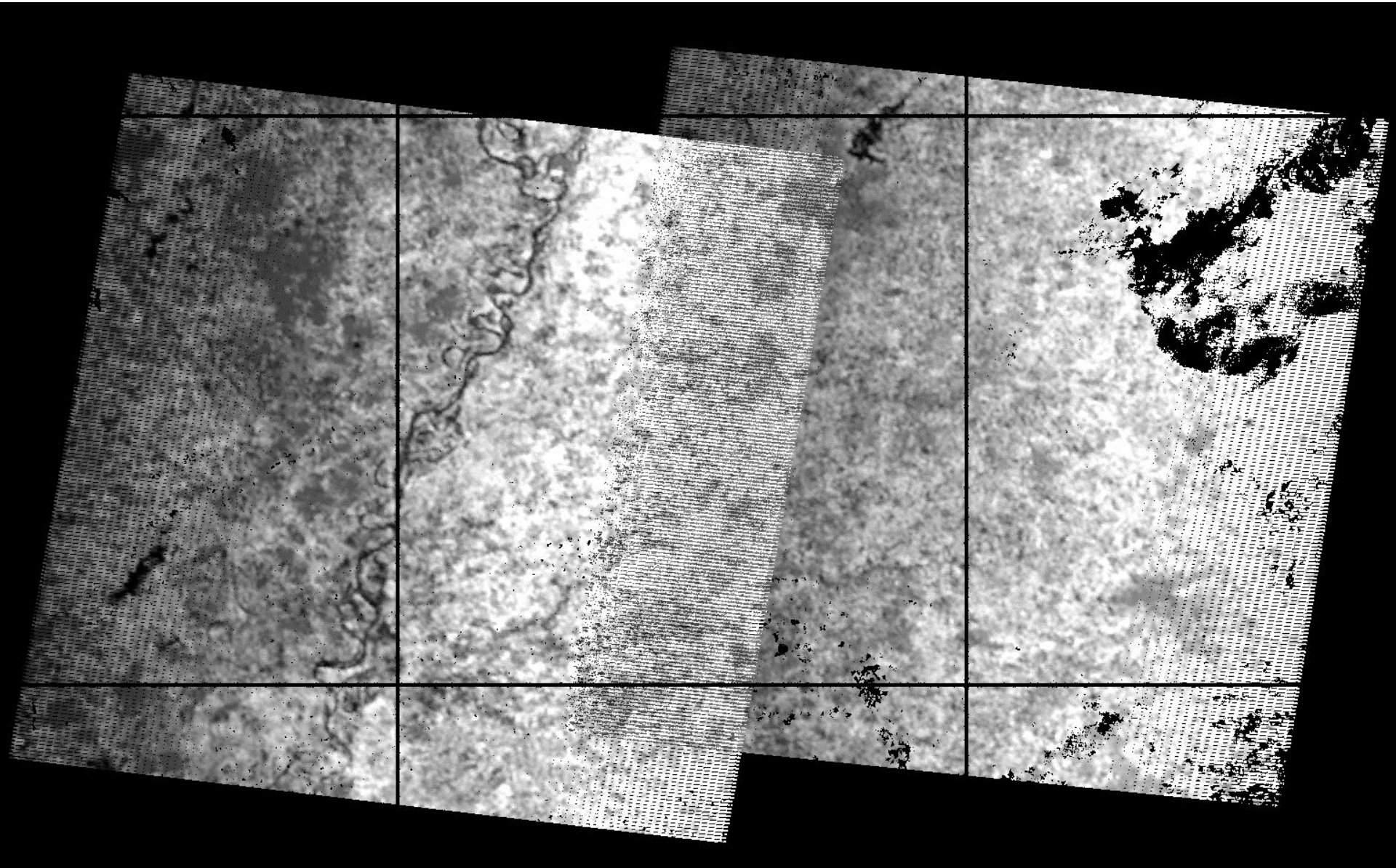
Band 3 (red, 0.63-0.69 μm)

MODIS derived c-factors (range: 0.97-1.43)



Band 7 (2.09-2.35 μm)

MODIS derived c-factors (range: 0.98-1.38)



Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008

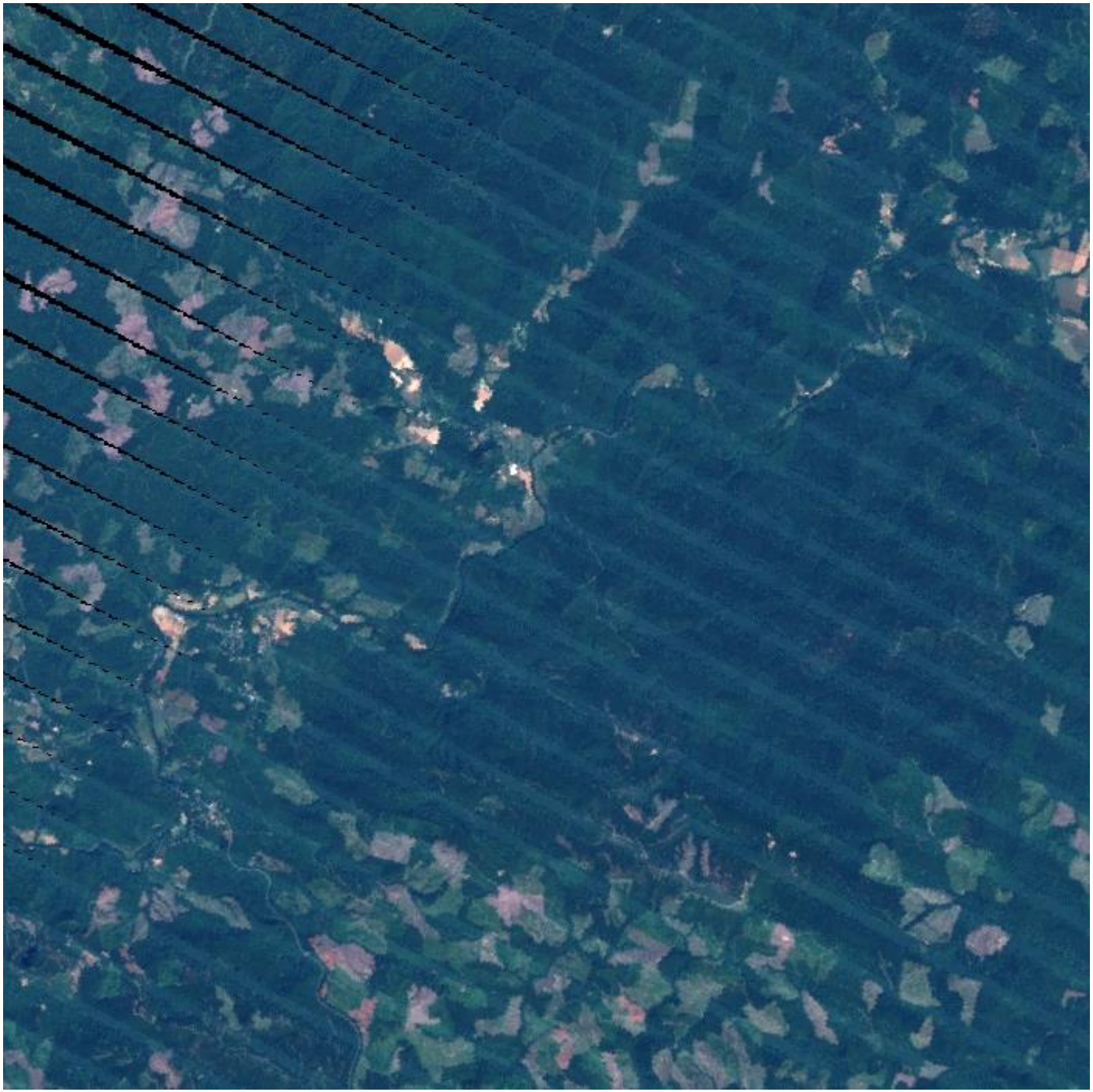
Band 3, 2, 1 (red, green, blue) TOA reflectance

Before BRDF normalization

Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008

Band 3, 2, 1 (red, green, blue) TOA reflectance

NBAR



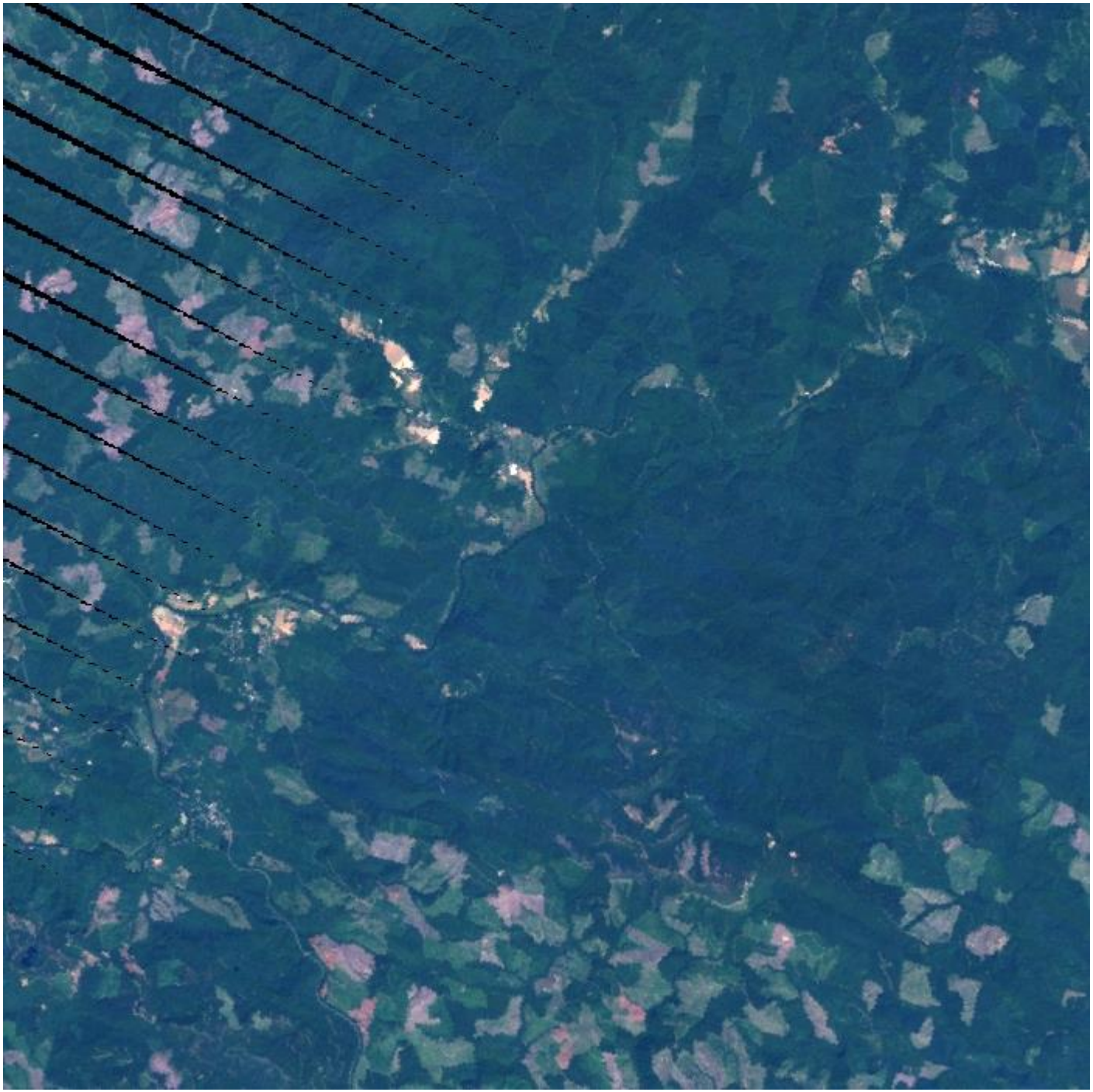
July 2008

2 dates composited

Bands 3,2,1

700 x 700
30m pixels

Before BRDF normalization



July 2008

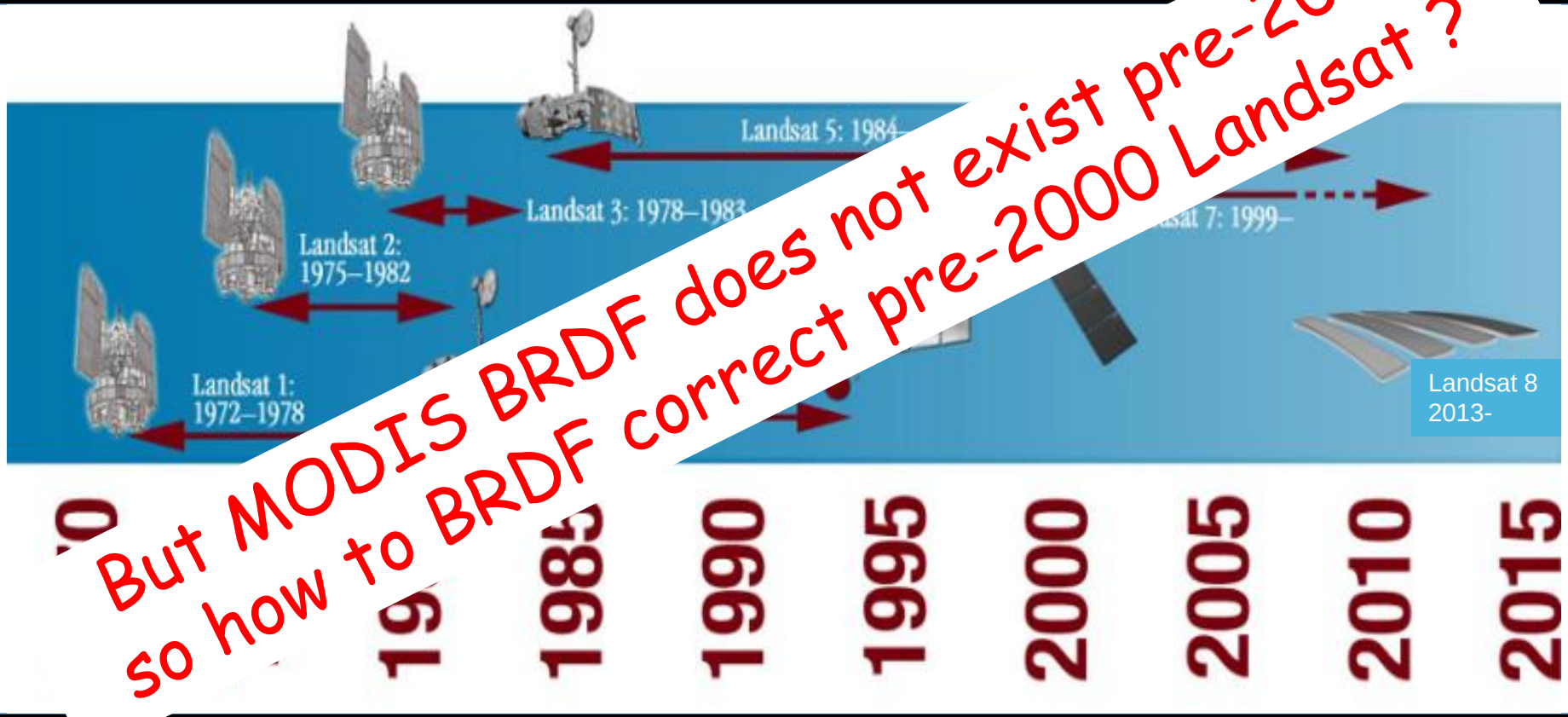
2 dates composited

Bands 3,2,1

700 x 700
30m pixels

NBAR

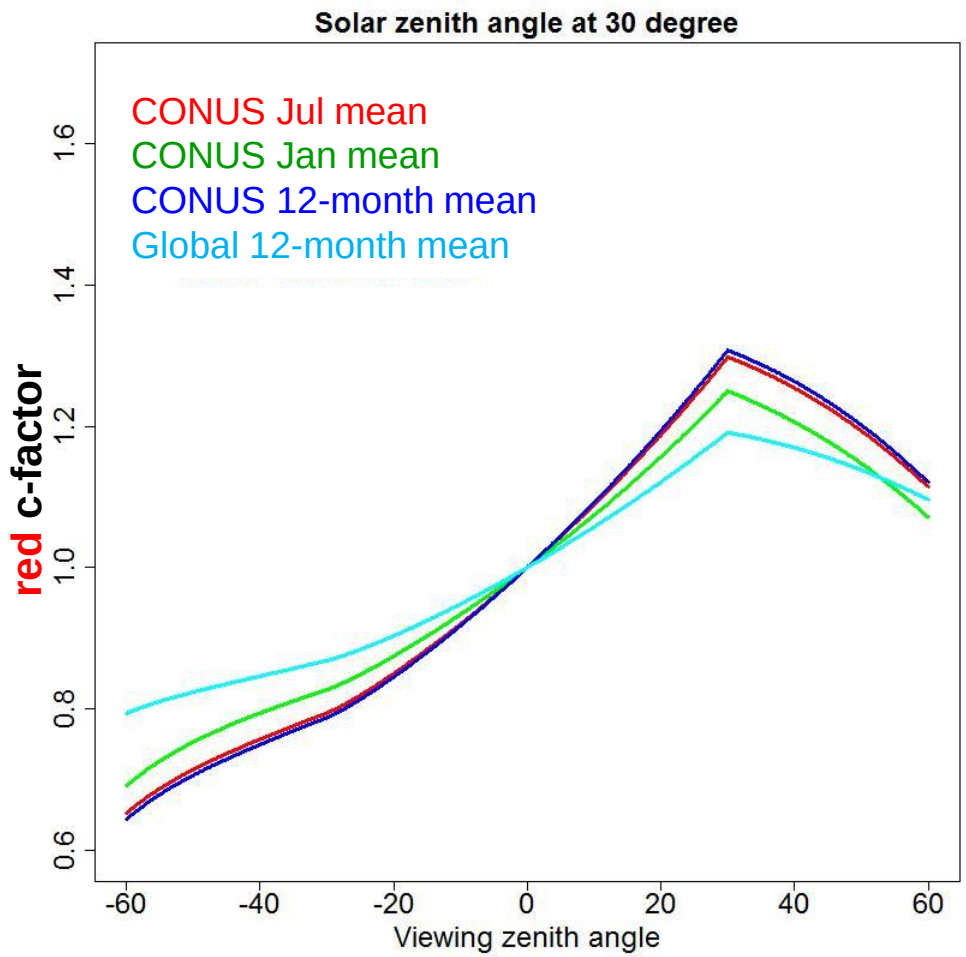
NASA funded Global WELD project

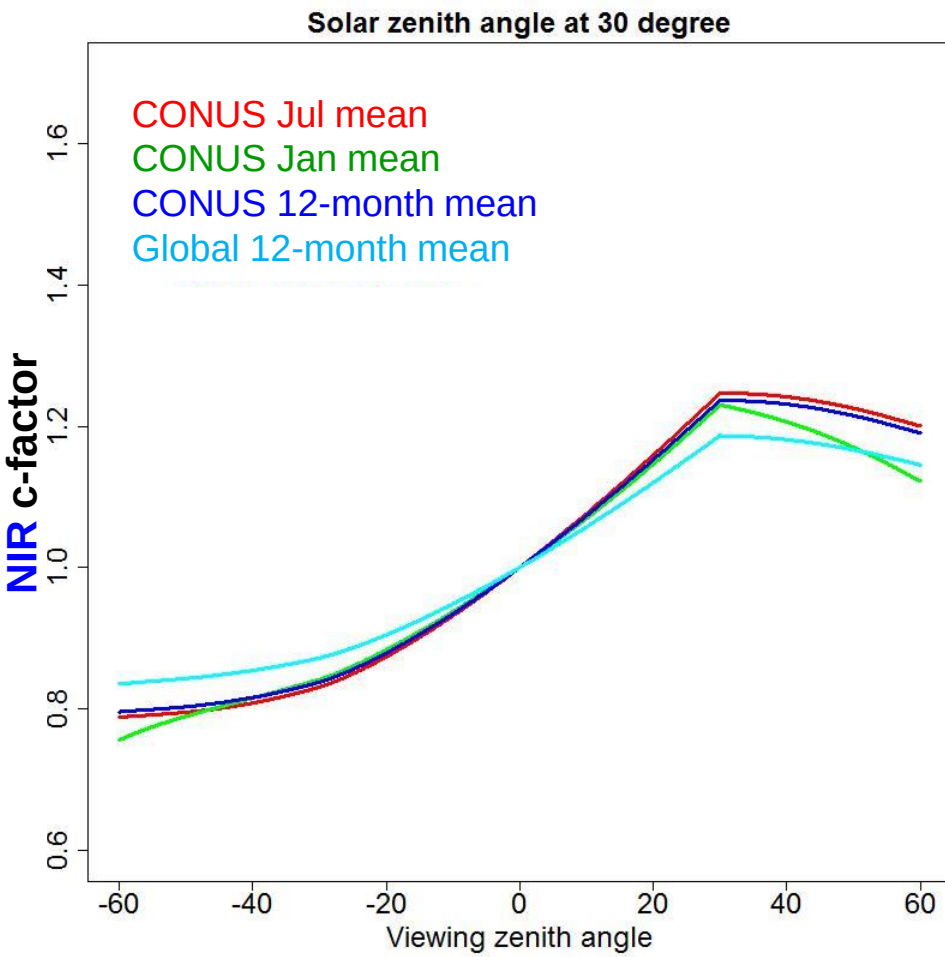


But MODIS BRDF does not exist pre-2000
so how to BRDF correct pre-2000 Landsat ?

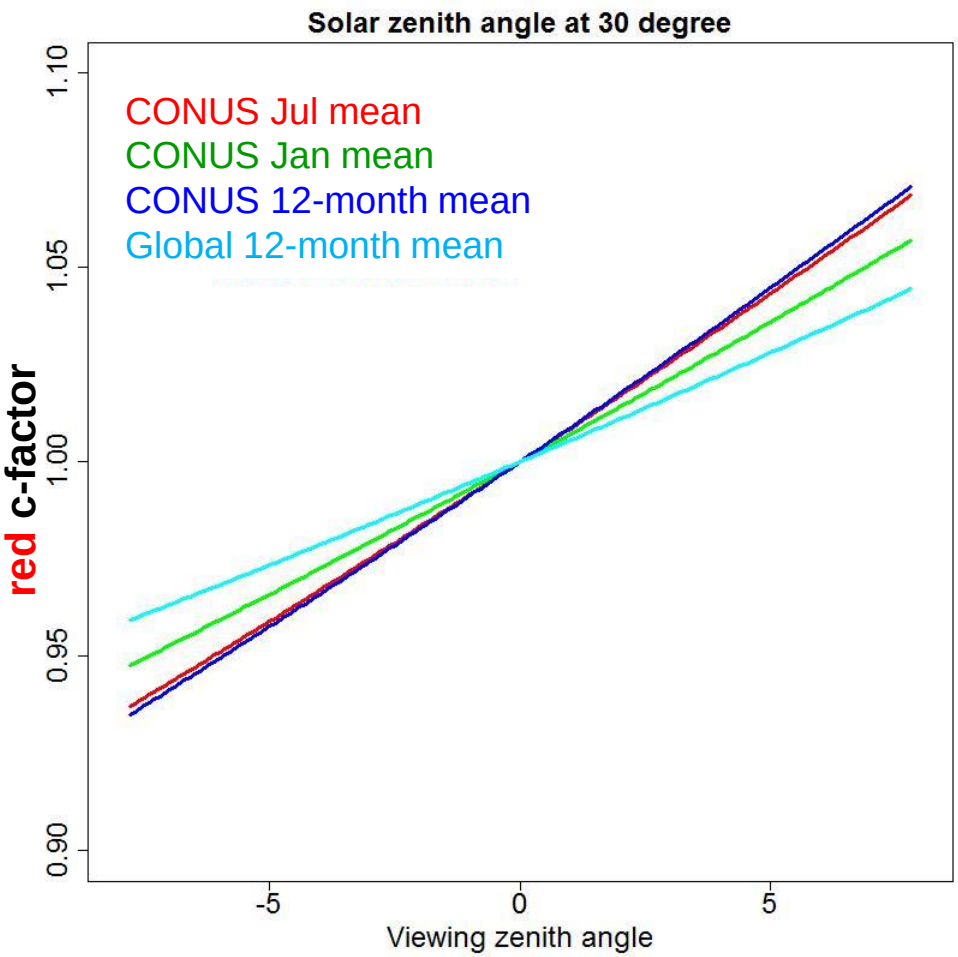
25 years Landsat 4, 5 & 7

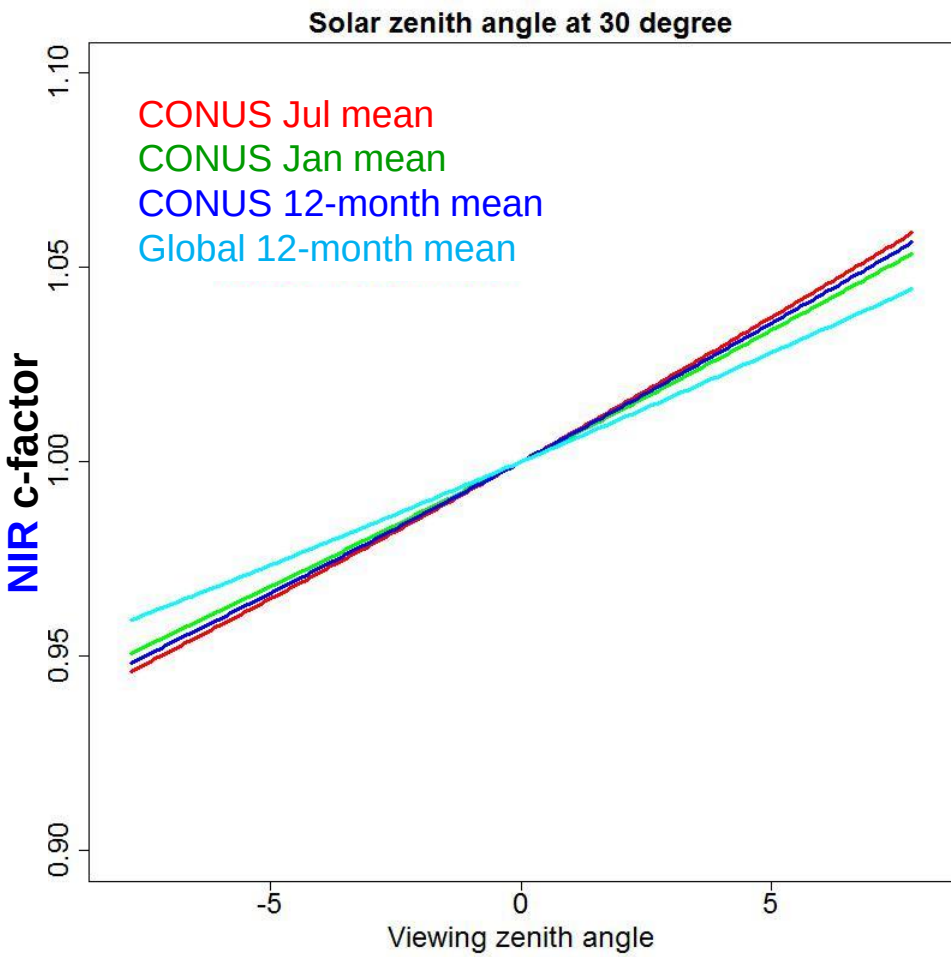
Climatology c-factors over MODIS 110° FOV





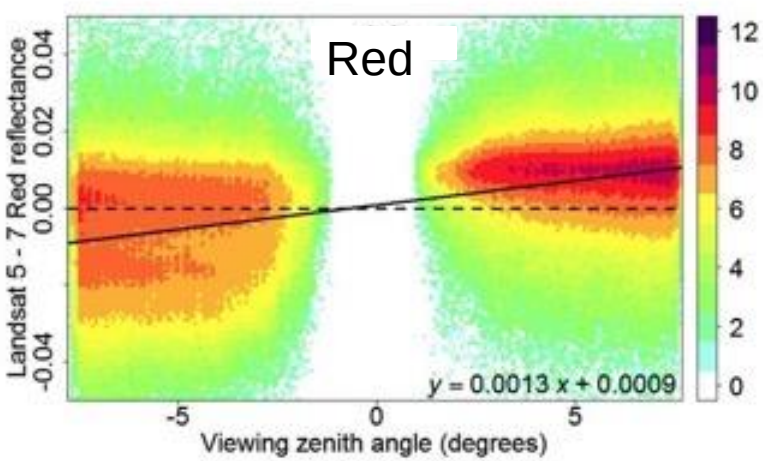
Climatology c-factors over Landsat 15° FOV

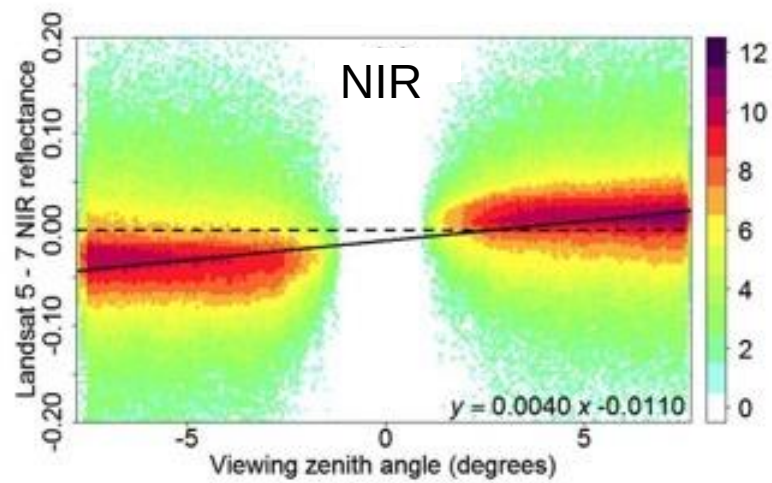




Summer week (July 2 - 8 2010) geographic locations of Landsat 5 TM (blue) and Landsat 7 ETM+ (red) images

~1.3 million pairs of L5 & L7 observations

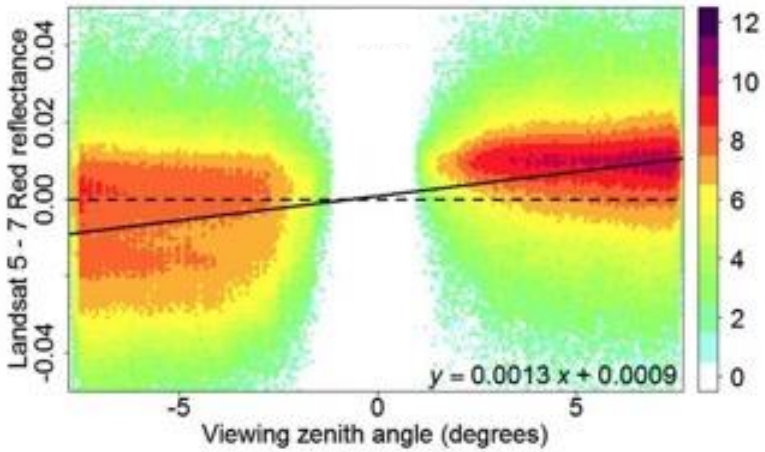




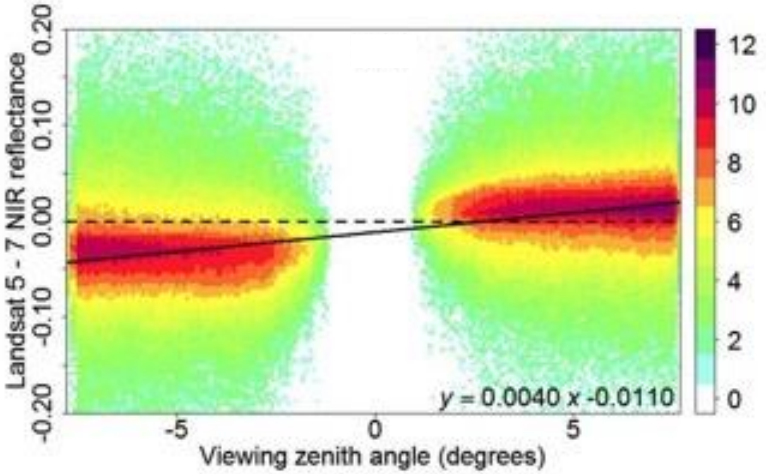
Scatterplots of ρ difference (Landsat 5 TM - Landsat 7 ETM+) versus Landsat 5 TM view zenith angle

no BRDF correction

Red



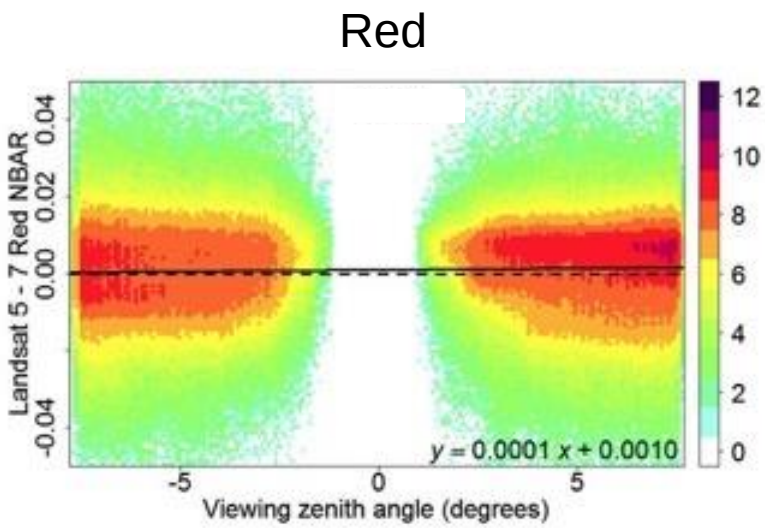
NIR

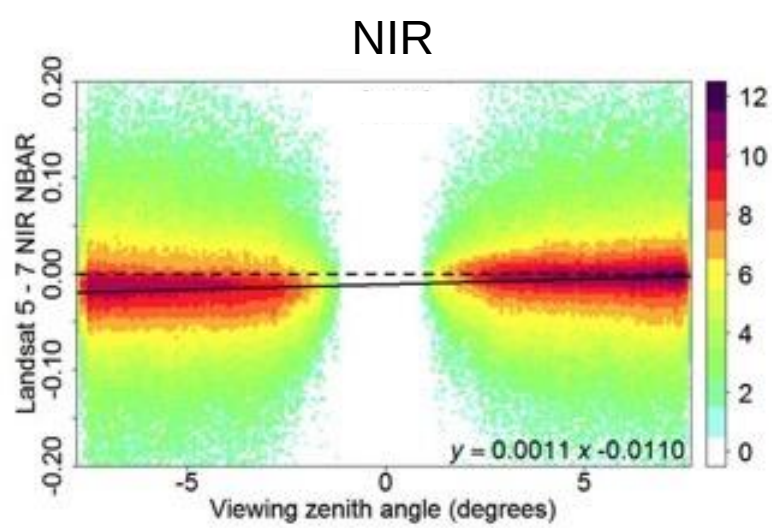


Summer week (July 2 - 8 2010)

Scatterplots of ρ difference (Landsat 5 TM - Landsat 7 ETM+) versus Landsat 5 TM view zenith angle

Local spatially & temporally explicit MODIS c-factors



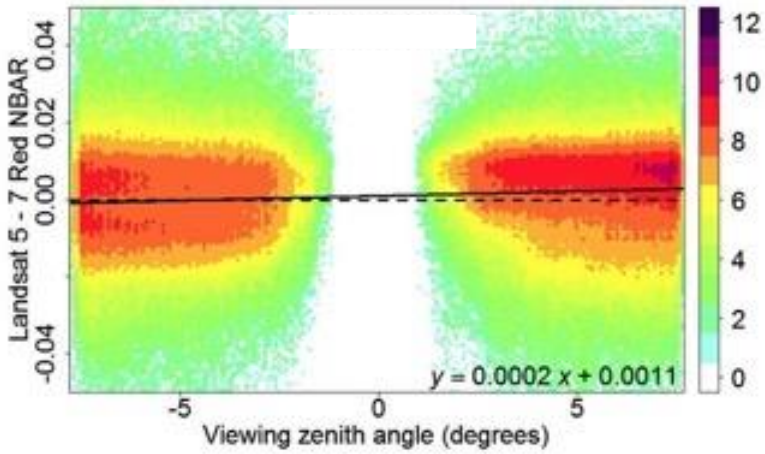


Summer week (July 2 - 8 2010)

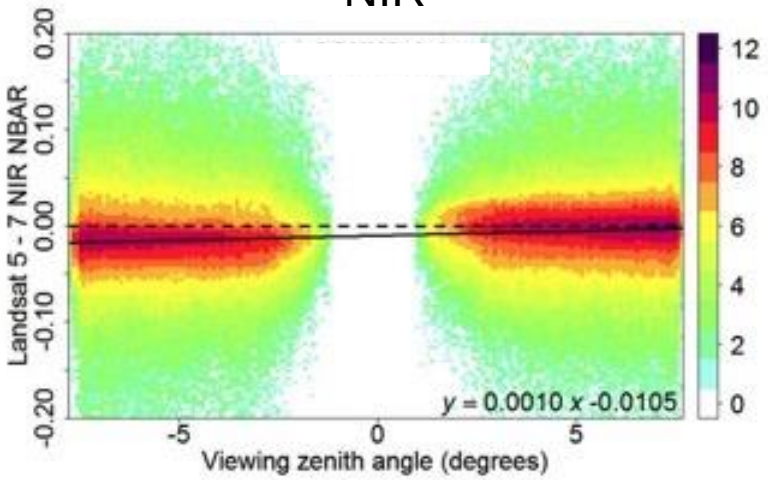
Scatterplots of ρ difference (Landsat 5 TM - Landsat 7 ETM+) versus Landsat 5 TM view zenith angle

CONUS July climatology MODIS c-factors

Red



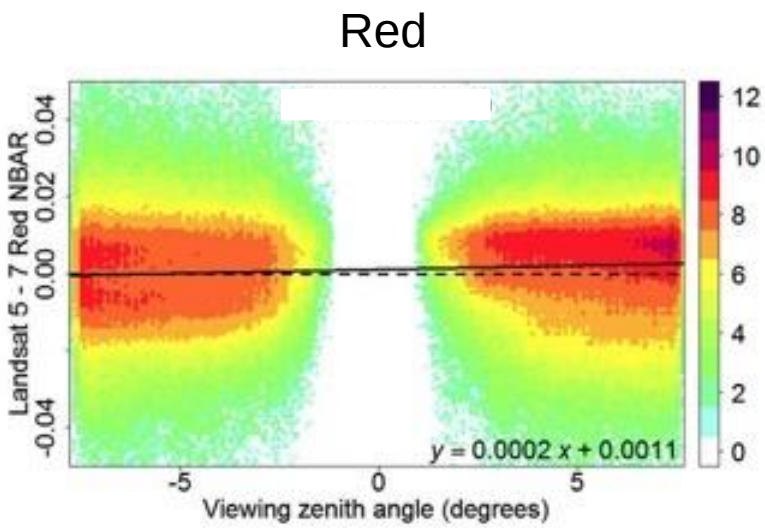
NIR

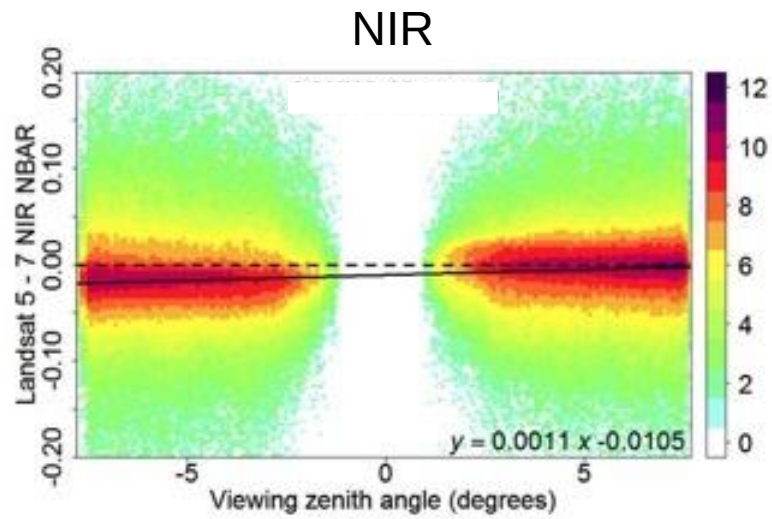


Summer week (July 2 - 8 2010)

Scatterplots of ρ difference (Landsat 5 TM - Landsat 7 ETM+) versus Landsat 5 TM view zenith angle

CONUS 12-month climatology MODIS c-factors



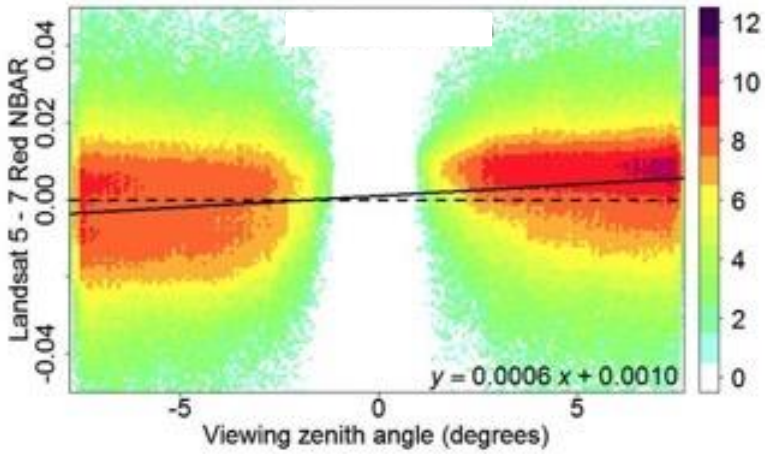


Summer week (July 2 - 8 2010)

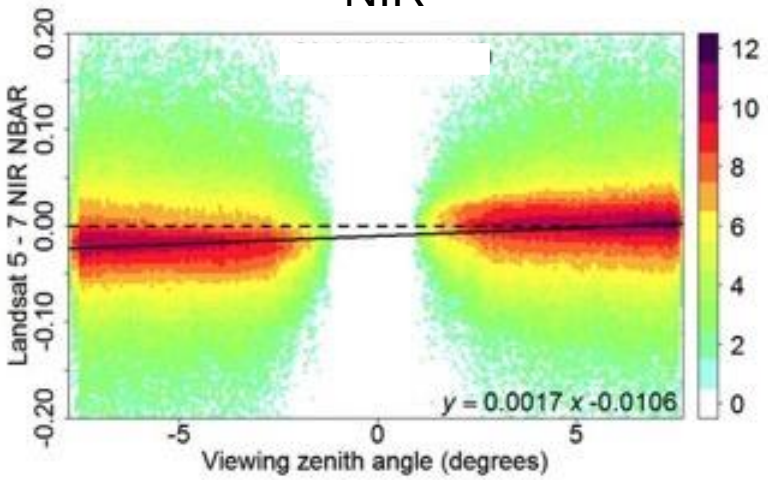
Scatterplots of ρ difference (Landsat 5 TM - Landsat 7 ETM+) versus Landsat 5 TM view zenith angle

Global 12-month climatology MODIS c-factors

Red



NIR



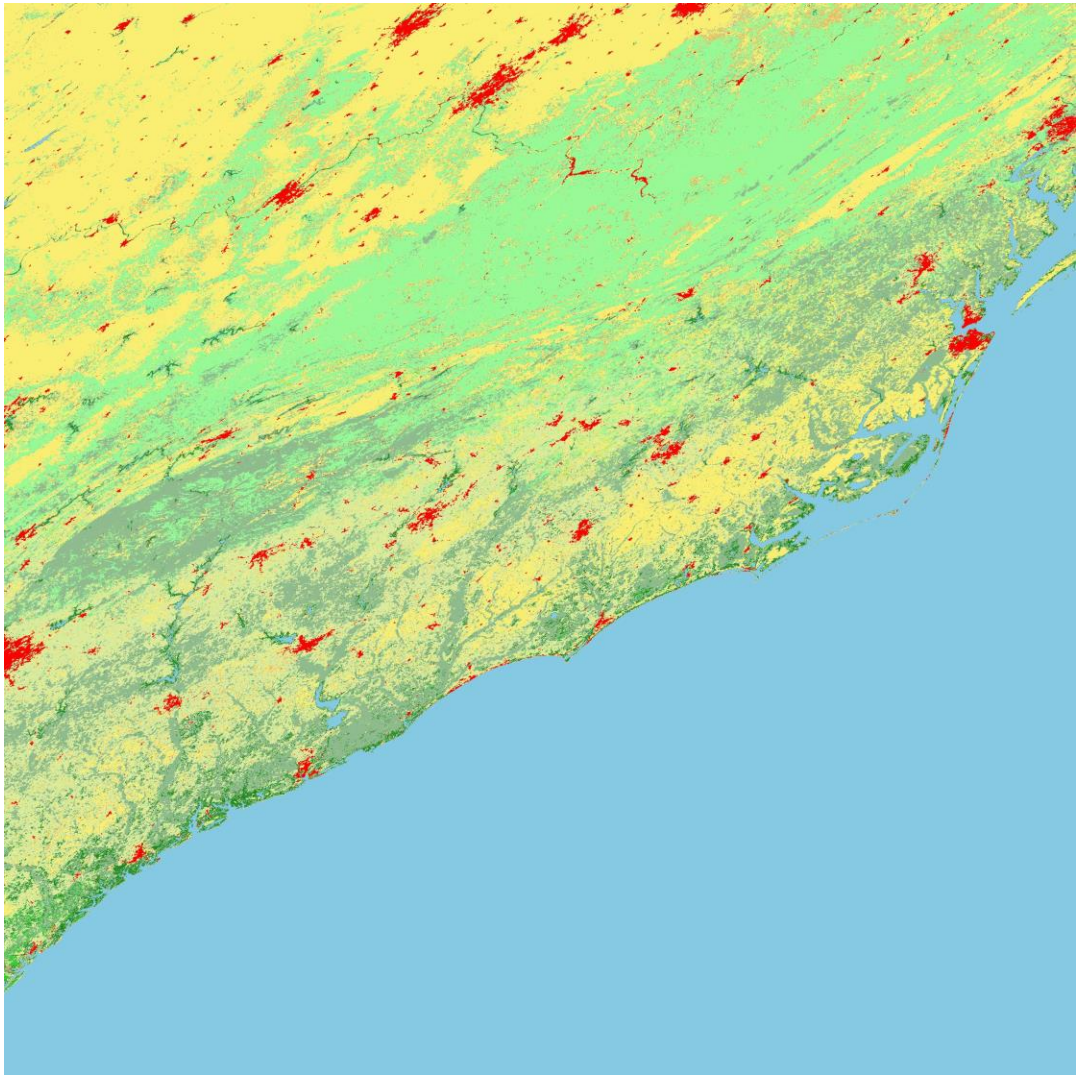
Summer week (July 2 - 8 2010)

Sensitivity of the c-factor
Landsat NBAR to land cover differences and so surface change

MCD12 500m Land Cover for 2010

MODIS tile: h11v05

~1200 x 1200 km



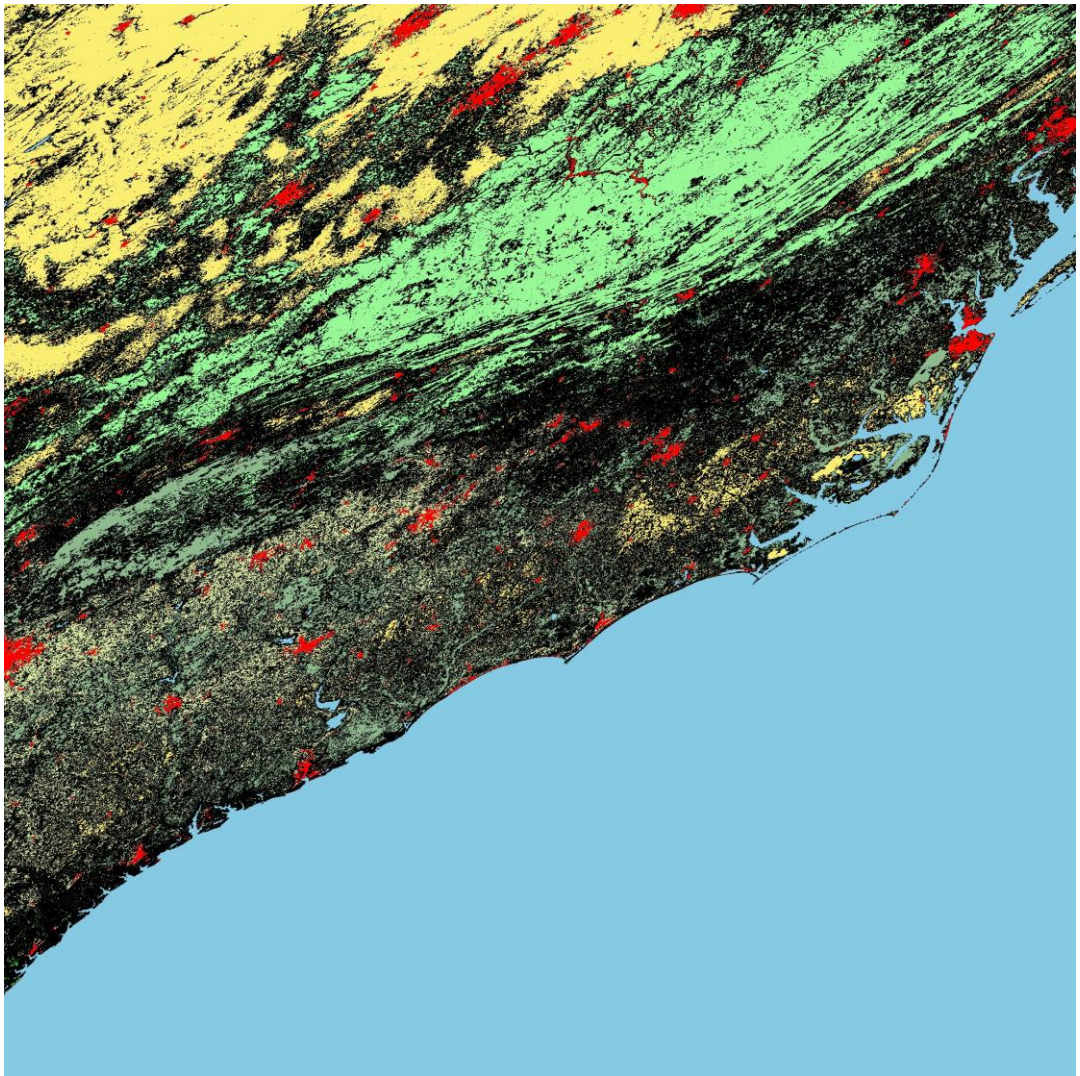
Sensitivity of the c-factor
Landsat NBAR to land cover differences and so surface change

MCD12 500m Land Cover for 2010

MODIS tile: h11v05

~1200 x 1200 km

Only 500m pixels with the same land cover for 11 years (2002 to 2012)



Sensitivity of the c-factor
Landsat NBAR to land cover differences and so surface change

MCD12 500m Land Cover for 2010

MODIS tile: h11v05

~1200 x 1200 km

Only 500m pixels with the same land cover for 11 years (2002 to 2012)

Only 500m pixels with overlapping Landsat 5 & 7 30m pixels occupying >50% of the 500m pixel

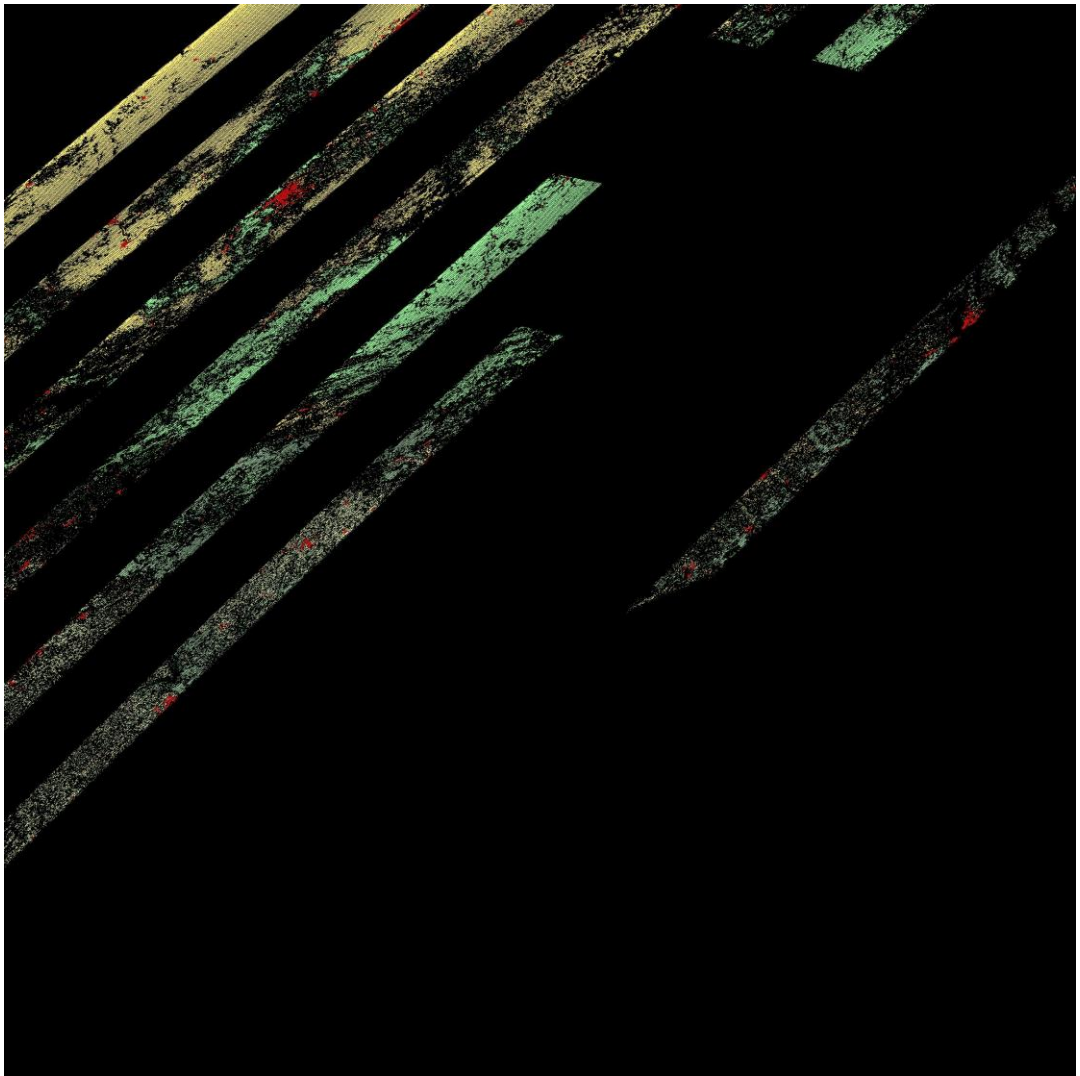
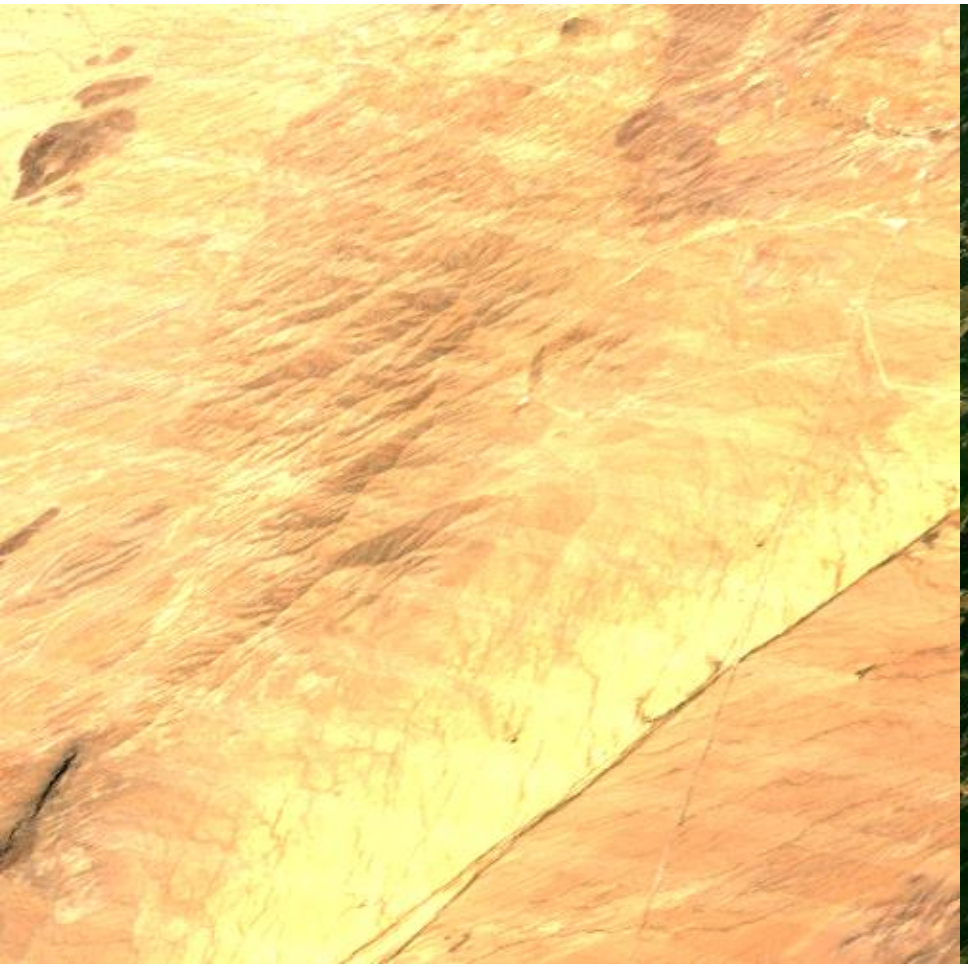


Table 9

As Table 8 but $\overline{\Delta NBAR}_\lambda$ and $\overline{\Delta NBAR}^*_\lambda$ values (in parentheses) for the NIR band.

Spectral BRDF model parameter source	Land cover class												
	0 Water	1 Evergreen needleleaf forest	4 Deciduous broadleaf forest	5 Mixed forest	6 Closed shrublands	7 Open shrublands	8 Woody savannas	9 Savannas	10 Grasslands	12 Croplands	13 Urban and built-up	14 Cropland /natural veg. mosaic	16 Barren or sparsely vegetated
Local	0.0172* (48.33)	**0.0119*** **(5.65)**	0.0313* (8.58)	0.0292* (9.62)	0.0132* (6.69)	**0.0120*** **(4.14)**	0.0282* (9.67)	0.0096* (4.43)	0.0184* (7.70)	0.0342* (9.67)	**0.0162*** **(5.76)**	0.0286* (8.01)	0.0216* (5.72)
Random Class 0		0.0205 (9.55)	0.0537 (14.27)	0.0367 (11.95)	0.0116 **(5.84)**	0.0144* (4.95)	0.0363 (12.77)	0.0131 (6.03)	0.0238 (10.10)	0.0374* (10.51)	0.0179 (6.39)	0.0343 (9.53)	0.0308 (7.92)
Random Class 1	0.0177 (48.54)		0.0296* (8.16)	0.0304* (9.97)	**0.0115*** (5.88)	0.0130* (4.48)	**0.0259*** **(8.85)**	**0.0069** **(3.15)**	**0.0181*** (7.60)	0.0335* (9.42)	0.0175* (6.22)	0.0295* (8.20)	0.0272 (7.09)
Random Class 4	0.0170 (47.55)	0.0152 (7.30)		0.0293* (9.64)	0.0194 (9.76)	0.0130* (4.58)	0.0291* (10.07)	0.0121* (5.56)	0.0188* (7.88)	0.0335* (9.48)	0.0166* (5.91)	0.0277 (7.75)	0.0228 (5.96)
Random Class 5	0.0172 (47.91)	0.0152* (7.29)	0.0294 (8.16)		0.0170 (8.55)	0.0140* (4.88)	0.0287* (9.89)	0.0123 (5.68)	0.0192* (8.03)	0.0333* (9.45)	0.0164* (5.82)	0.0290* (8.09)	**0.0206** **(5.39)**
Random Class 6	0.0176 (48.44)	0.0149 (7.06)	**0.0293*** **(8.10)**	0.0293* (9.61)		0.0131* (4.59)	0.0260* (8.89)	0.0071 (3.26)	**0.0181*** **(7.57)**	0.0339* (9.53)	0.0171* (6.07)	**0.0275*** **(7.67)**	0.0259 (6.73)
Random Class 7	0.0172 (47.88)	0.0159* (7.58)	0.0334* (9.12)	**0.0281*** **(9.26)**	0.0178 (8.96)		0.0279* (9.61)	0.0090 (4.13)	0.0184* (7.72)	0.0338* (9.55)	0.0166* (5.87)	0.0290* (8.11)	0.0213 (5.57)
Random Class 8	0.0171* (47.68)	0.0156* (7.48)	0.0297* (8.2)	0.0296* (9.74)	0.0180 (9.06)	0.0123* (4.29)		0.0092* (4.23)	0.0184* (7.68)	0.0333* (9.43)	0.0167* (5.92)	0.0284* (7.94)	0.0209* (5.47)
Random Class 9	0.0170* (47.63)	0.0148* (7.09)	0.0303* (8.36)	0.0292* (9.60)	0.0172* (8.65)	0.0127 (4.40)	0.0290* (10.02)		0.0185* (7.77)	0.0335* (9.45)	0.0164* (5.82)	0.0278* (7.76)	0.0210* (5.50)
Random Class 10	0.0171 (47.78)	0.0142* (6.81)	0.0307 (8.46)	0.0299 (9.81)	0.0171* (8.60)	0.0127* (4.45)	0.0304* (10.52)	0.0122 (5.61)		0.0335* (9.47)	0.0163* (5.79)	0.0286* (7.98)	0.0219 (5.72)
Random Class 12	0.0170* (47.41)	0.0167* (8.02)	0.0365* (9.93)	0.0311 (10.20)	0.0233 (11.66)	0.0129* (4.55)	0.0316* (10.96)	0.0152 (7.02)	0.0209* (8.77)		0.0166* (5.92)	0.0307* (8.56)	0.0218 (5.74)
Random Class 13	0.0173 (48.17)	0.0154* (7.39)	0.0300* (8.27)	0.029* (9.54)	0.0187 (9.42)	0.0124* (4.31)	0.0275* (9.45)	0.0108* (5.00)	0.0184* (7.74)	**0.0330*** **(9.35)**		0.0278* (7.78)	0.0207* (5.43)
Random Class 14	0.0170* **(47.15)**	0.0185 (8.86)	0.0304 (8.36)	0.0304* (9.96)	0.0162 (8.17)	0.0129* (4.57)	0.0302* (10.45)	0.0140* (6.48)	0.0197* (8.25)	0.0345* (9.77)	0.0174* (6.15)		0.0210* (5.53)
Random Class 16	**0.0169*** (47.21)	0.0189 (9.00)	0.0338* (9.24)	0.031 (10.18)	0.0240 (12.03)	0.0138* (4.93)	0.0323* (11.22)	0.0183* (8.42)	0.0239* (10.06)	0.0355* (10.03)	0.0188 (6.66)	0.0300* (8.37)	
Fixed CONUS July mean	0.0170* (47.48)	0.0155* (7.41)	0.0308* (8.46)	0.0291* (9.57)	0.0186 (9.37)	0.0125* (4.38)	0.0288* (9.92)	0.0104 (4.82)	0.0188* (7.85)	0.0336* (9.50)	0.0164* (5.82)	0.0282* (7.87)	0.0207* (5.45)
Fixed CONUS 12 month mean	0.0170* (47.44)	0.0158* (7.55)	0.031* (8.53)	0.0292* (9.60)	0.0191 (9.60)	0.0125 (4.39)	0.0291* (10.03)	0.0109* (5.03)	0.0189* (7.92)	0.0337* (9.54)	0.0165* (5.84)	0.0283* (7.91)	0.0208 (5.46)
Fixed Global 12 month mean	**0.0169*** (47.23)	0.0174 (8.32)	0.033* (9.03)	0.0297* (9.78)	0.0217 (10.90)	0.0131* (4.62)	0.0308* (10.69)	0.0130* (6.01)	0.0197* (8.27)	0.0342* (9.69)	0.0171 (6.07)	0.0294* (8.21)	0.0212* (5.59)

WELD Landsat 5 & 7 surface reflectance Version 3.0 one week composite



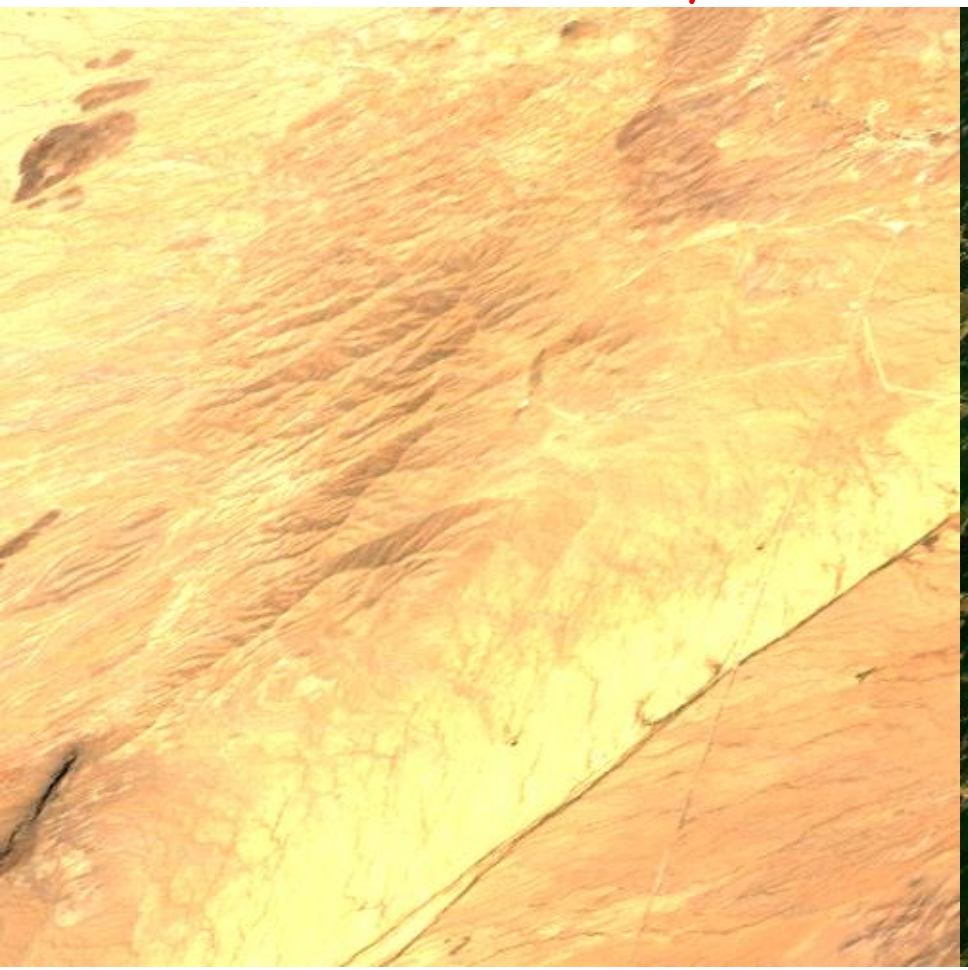
Arizona

500 x 500 30m pixels

Mississippi

WELD Landsat 5 & 7 surface reflectance Version 3.0 one week composite

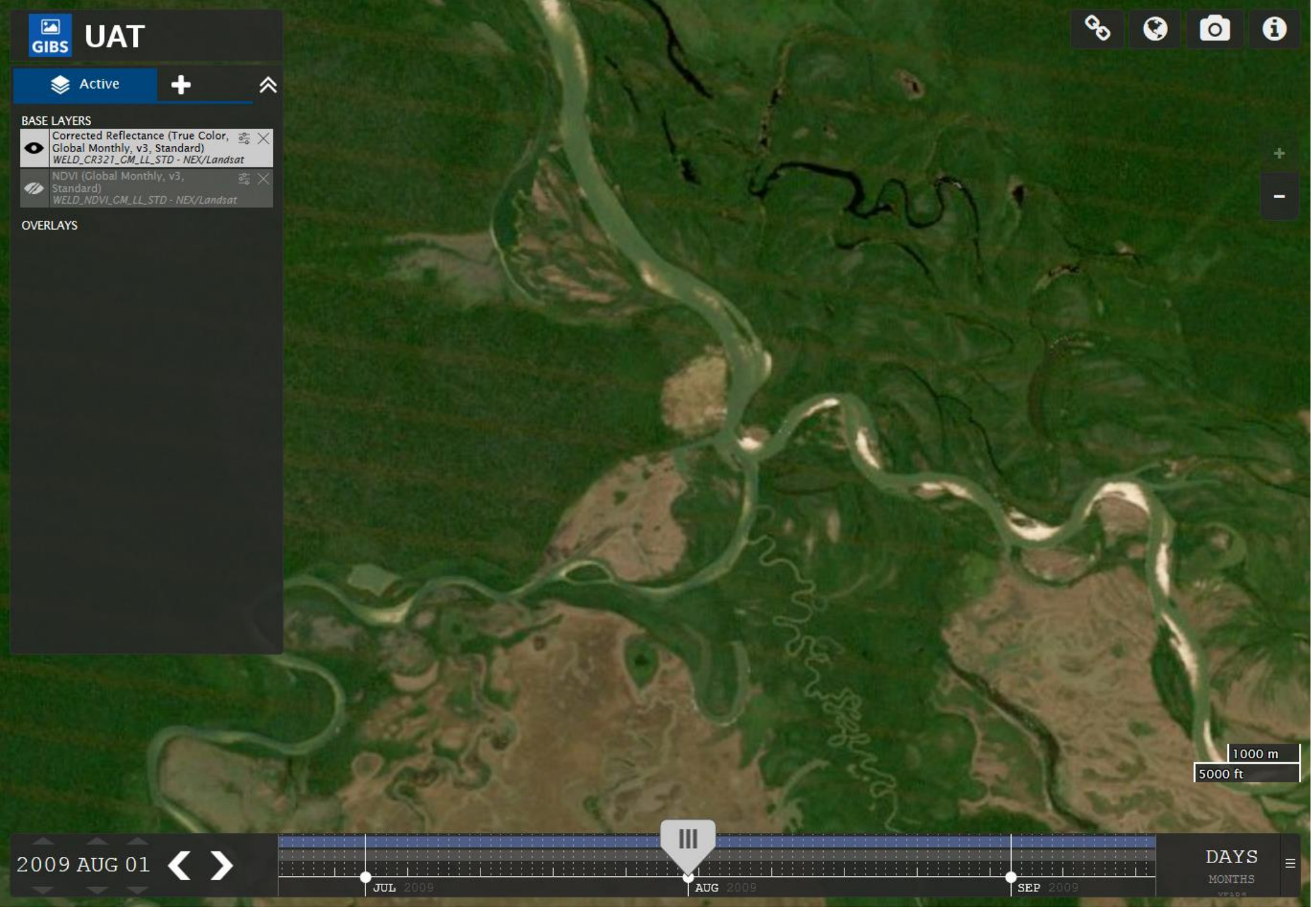
NBAR (global 12-month 3 mean MDC43 model parameters) nadir view zenith , satellite overpass time solar zenith



Arizona

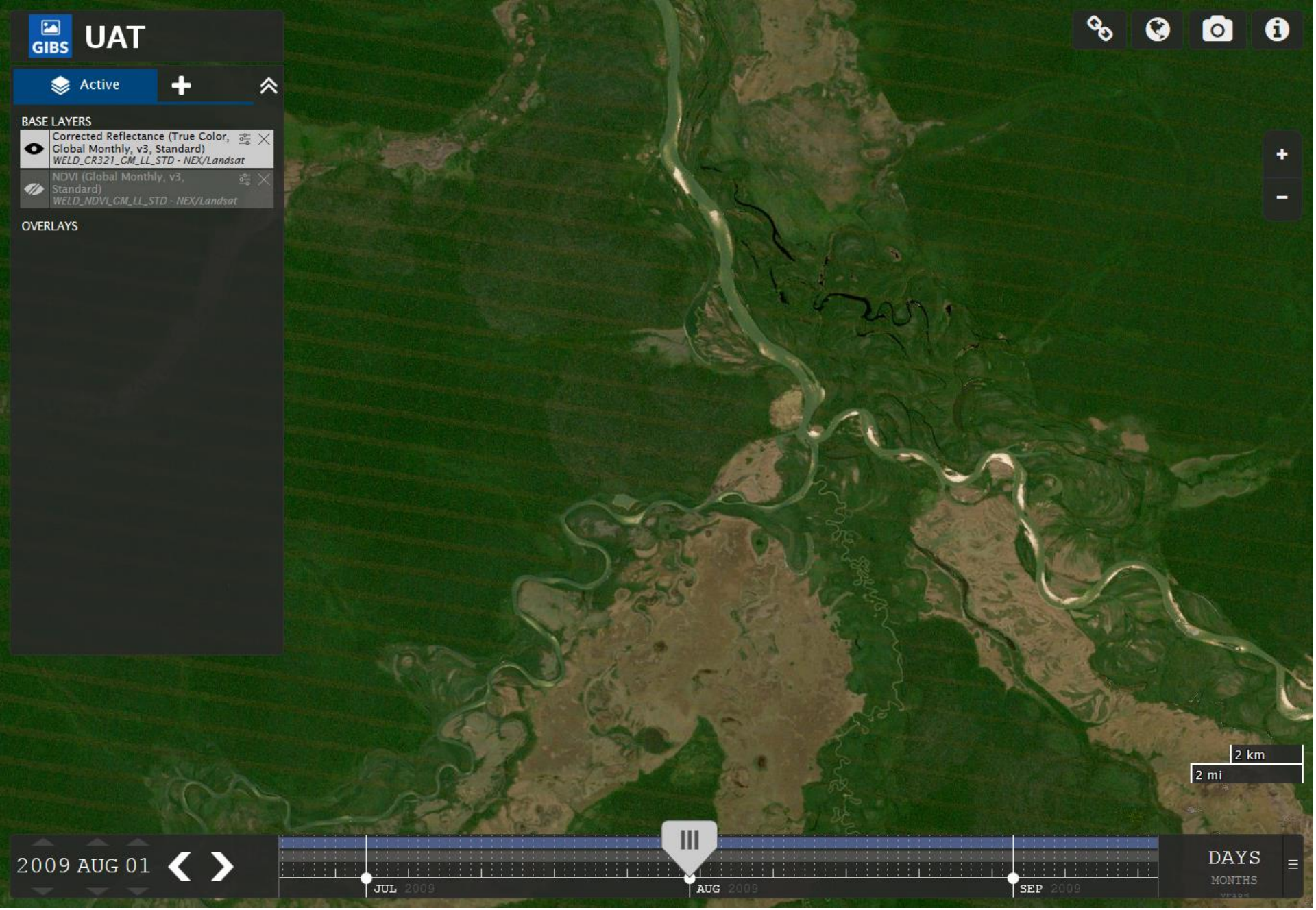
500 x 500 30m pixels

Mississippi



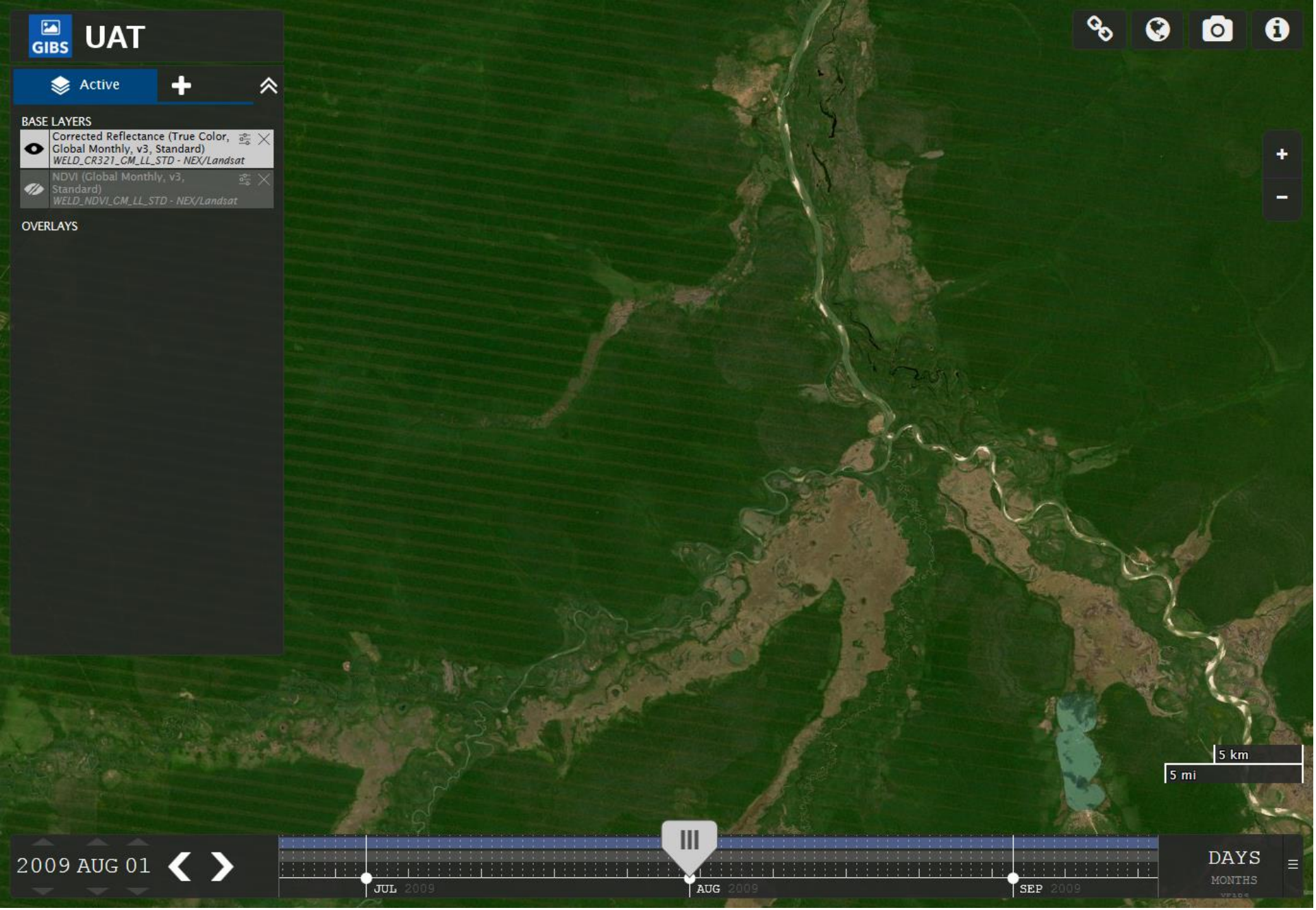
Xingu River & Rio Ronuro, Mato Grosso, Brazil

WELD V3.0 GIBS NEX browses https://uat.gibs.earthdata.nasa.gov/worldview/



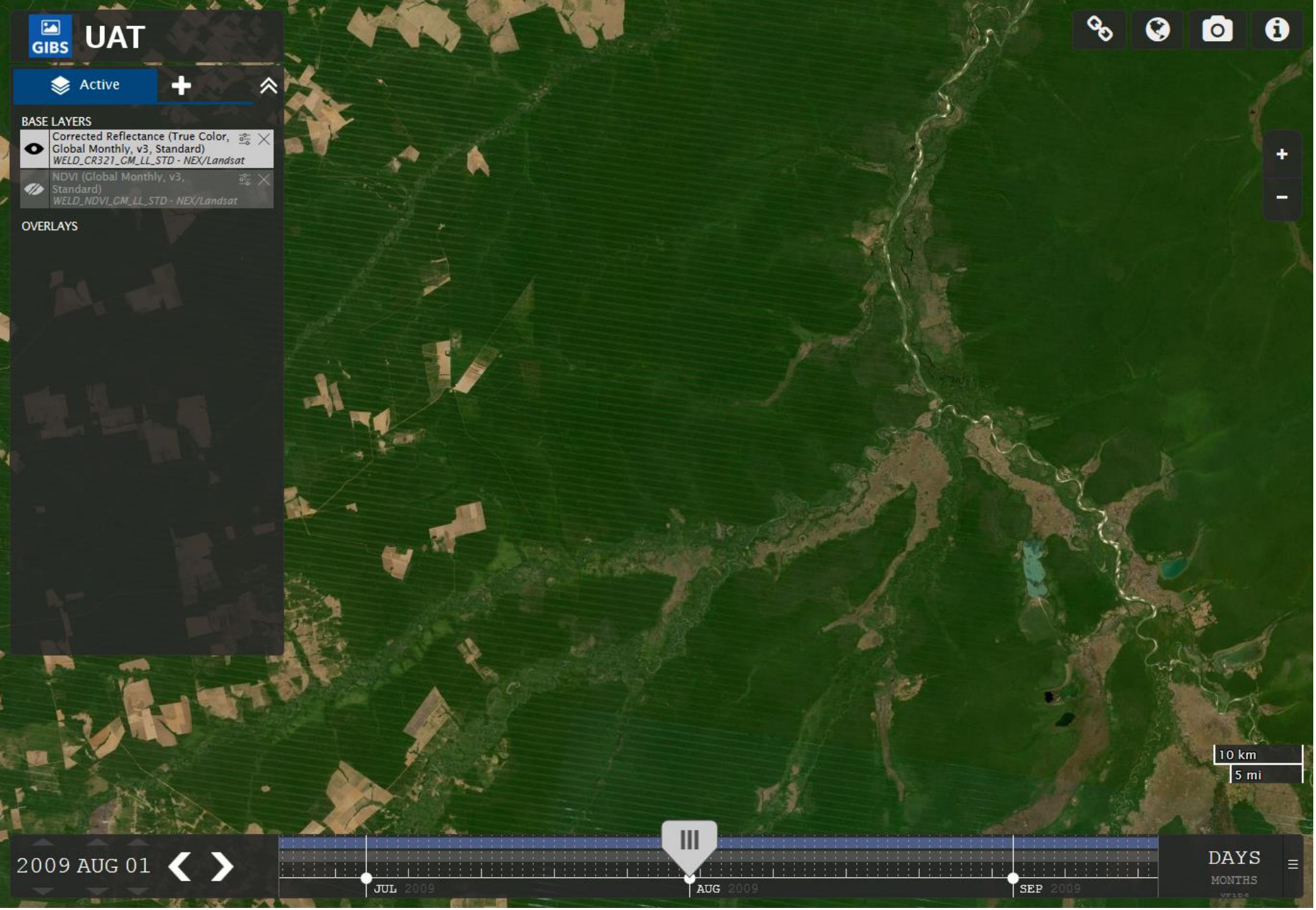
Xingu River & Rio Ronuro, Mato Grosso, Brazil

WELD V3.0 GIBS NEX browses https://uat.gibs.earthdata.nasa.gov/worldview/



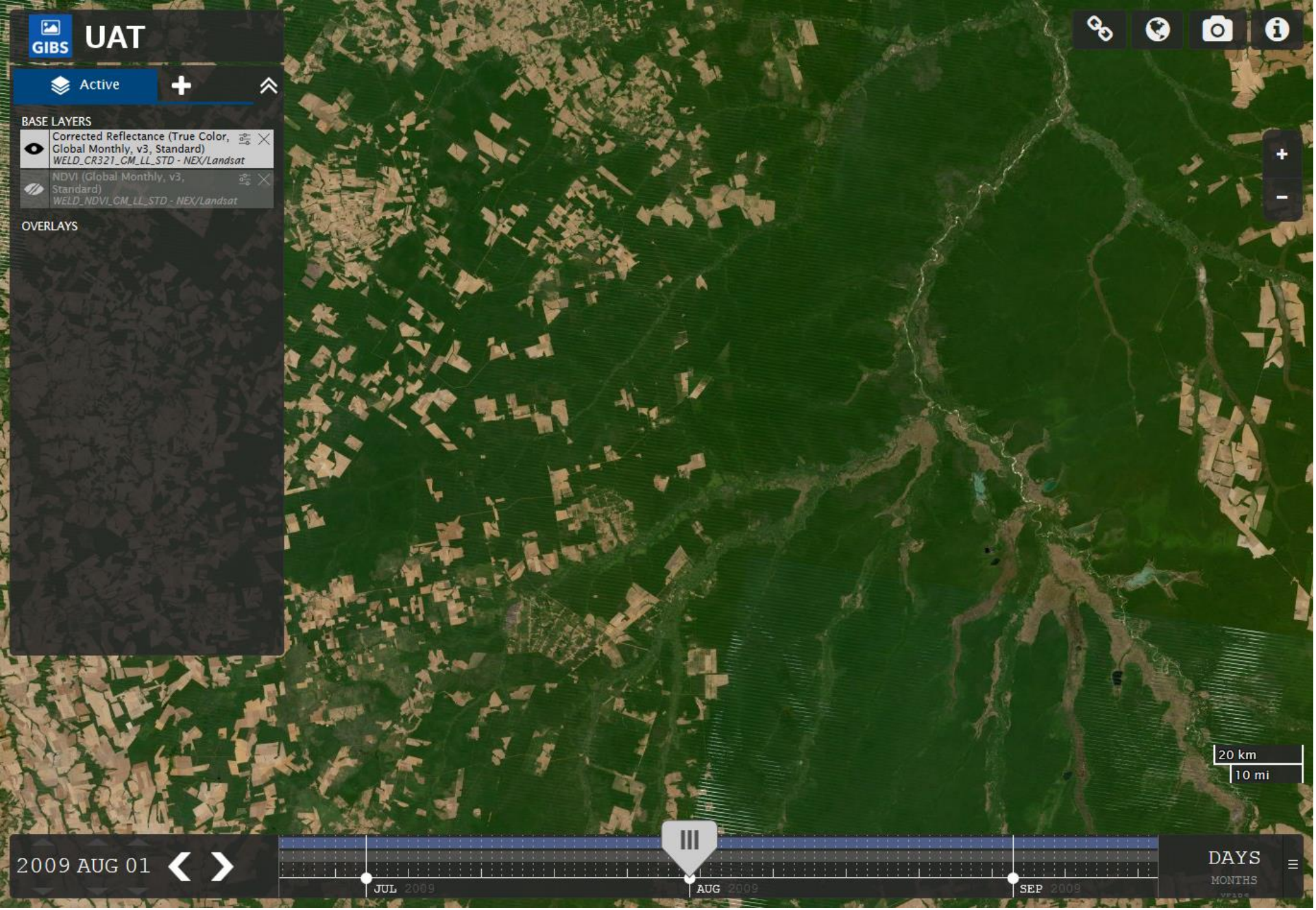
Xingu River & Rio Ronuro, Mato Grosso, Brazil

WELD V3.0 GIBS NEX browses https://uat.gibs.earthdata.nasa.gov/worldview/



Xingu River & Rio Ronuro, Mato Grosso, Brazil

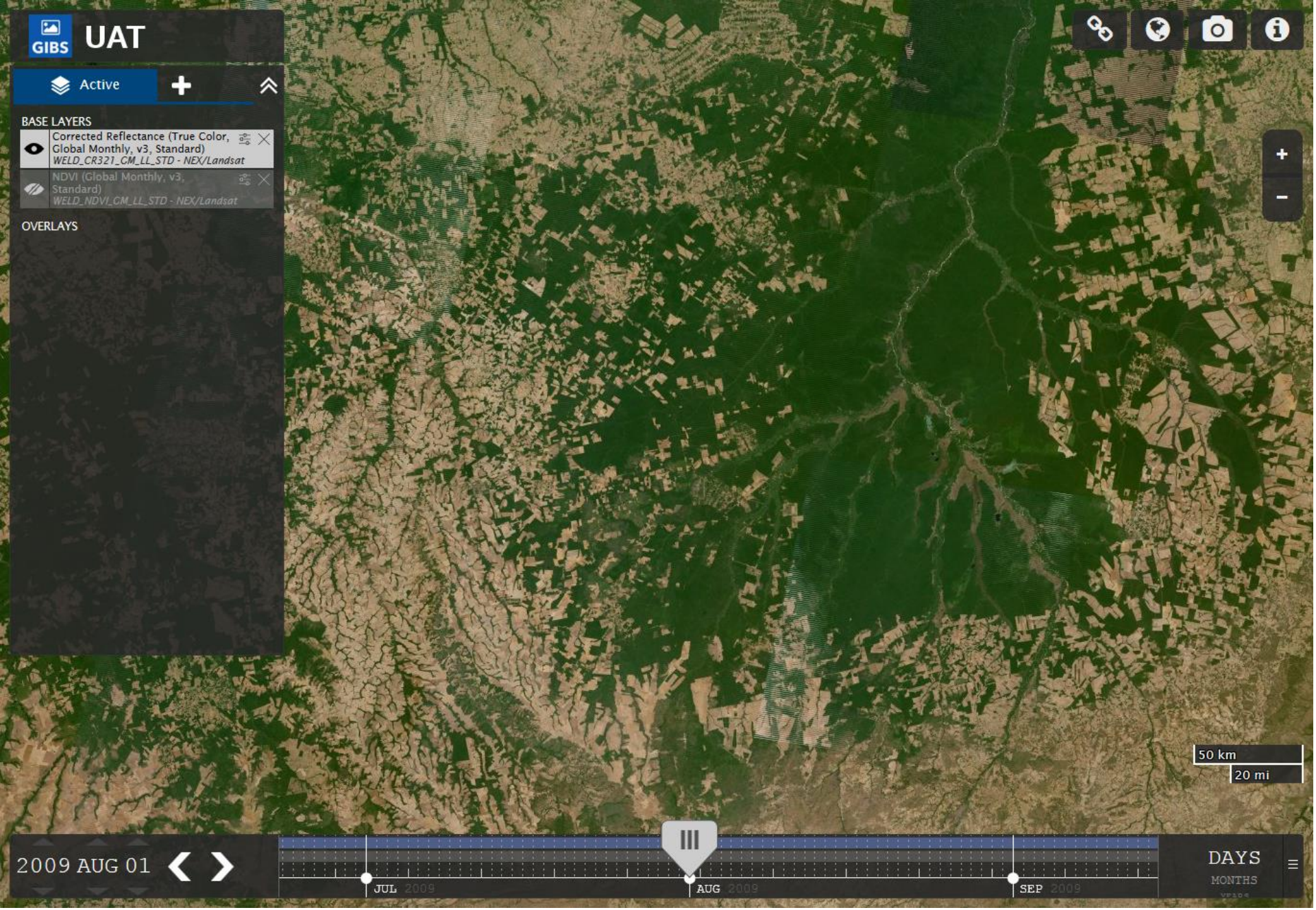
WELD V3.0 GIBS NEX browses https://uat.gibs.earthdata.nasa.gov/worldview/



Xingu River & Rio Ronuro, Mato Grosso, Brazil

WELD V3.0 GIBS NEX browses

https://uat.gibs.earthdata.nasa.gov/worldview/



Mato Grosso, Brazil

WELD V3.0 GIBS NEX browses

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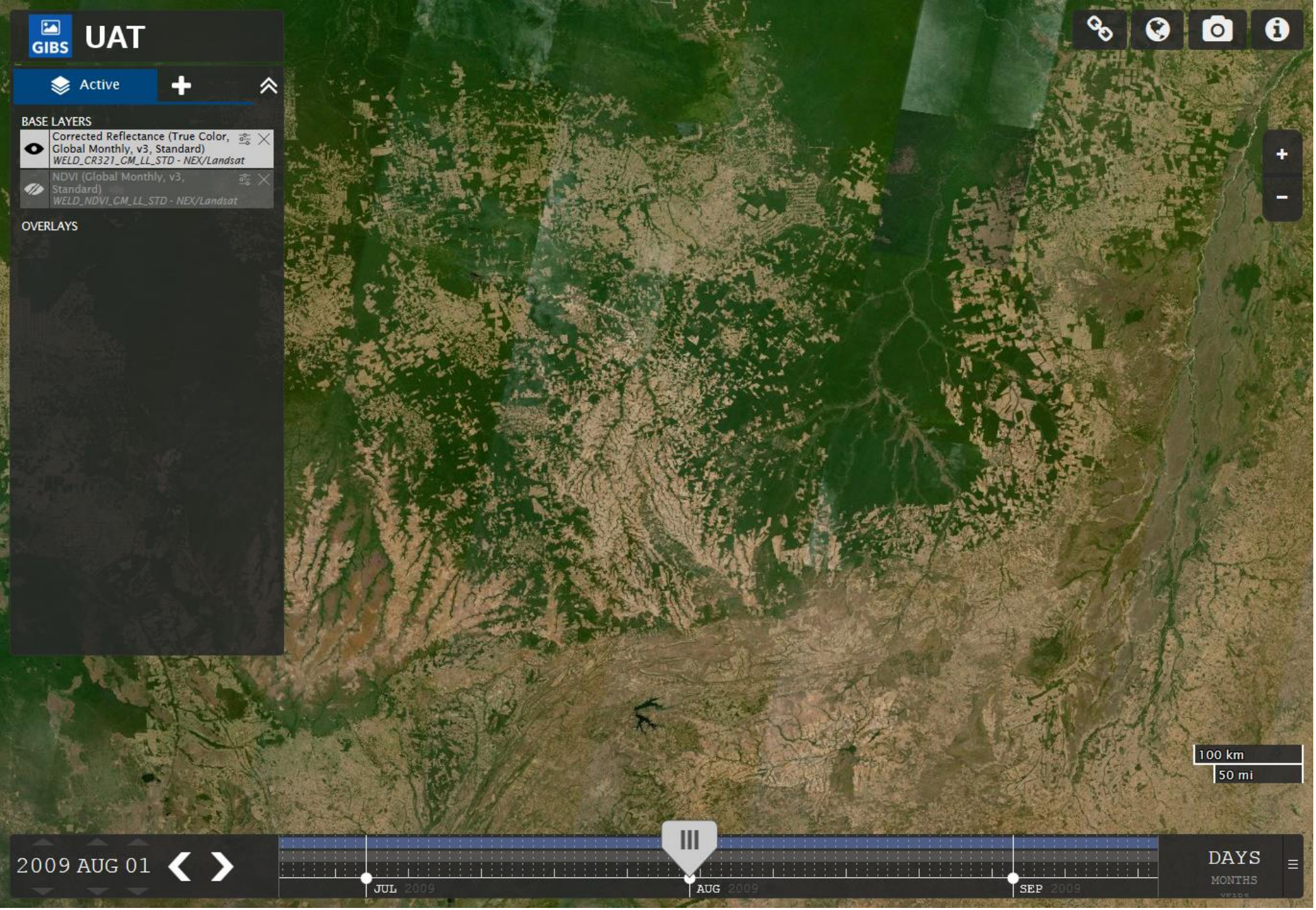

Mato Grosso, Brazil

WELD V3.0 GIBS NEX browses

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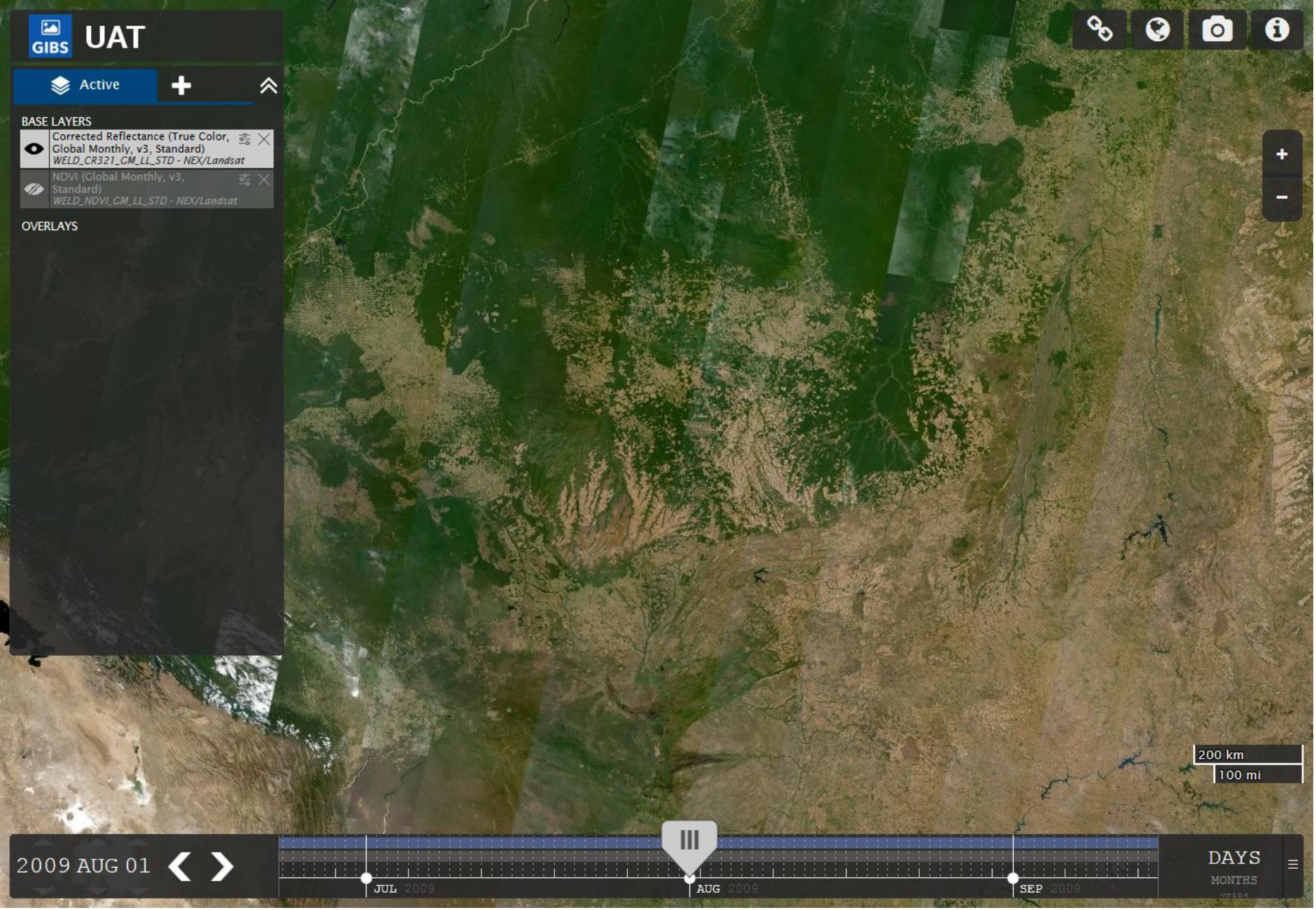

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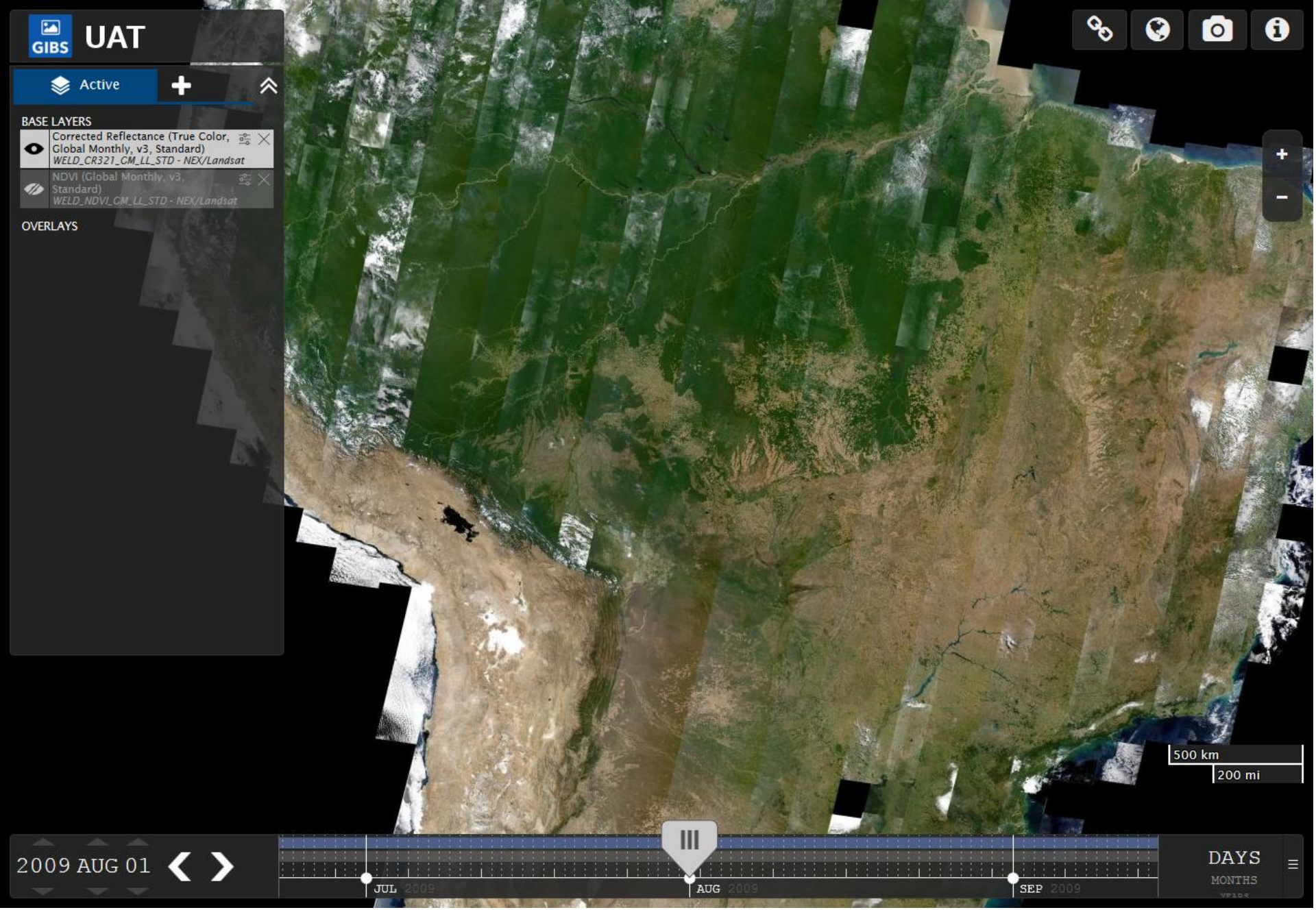

WELD V3.0 GIBS NEX browses

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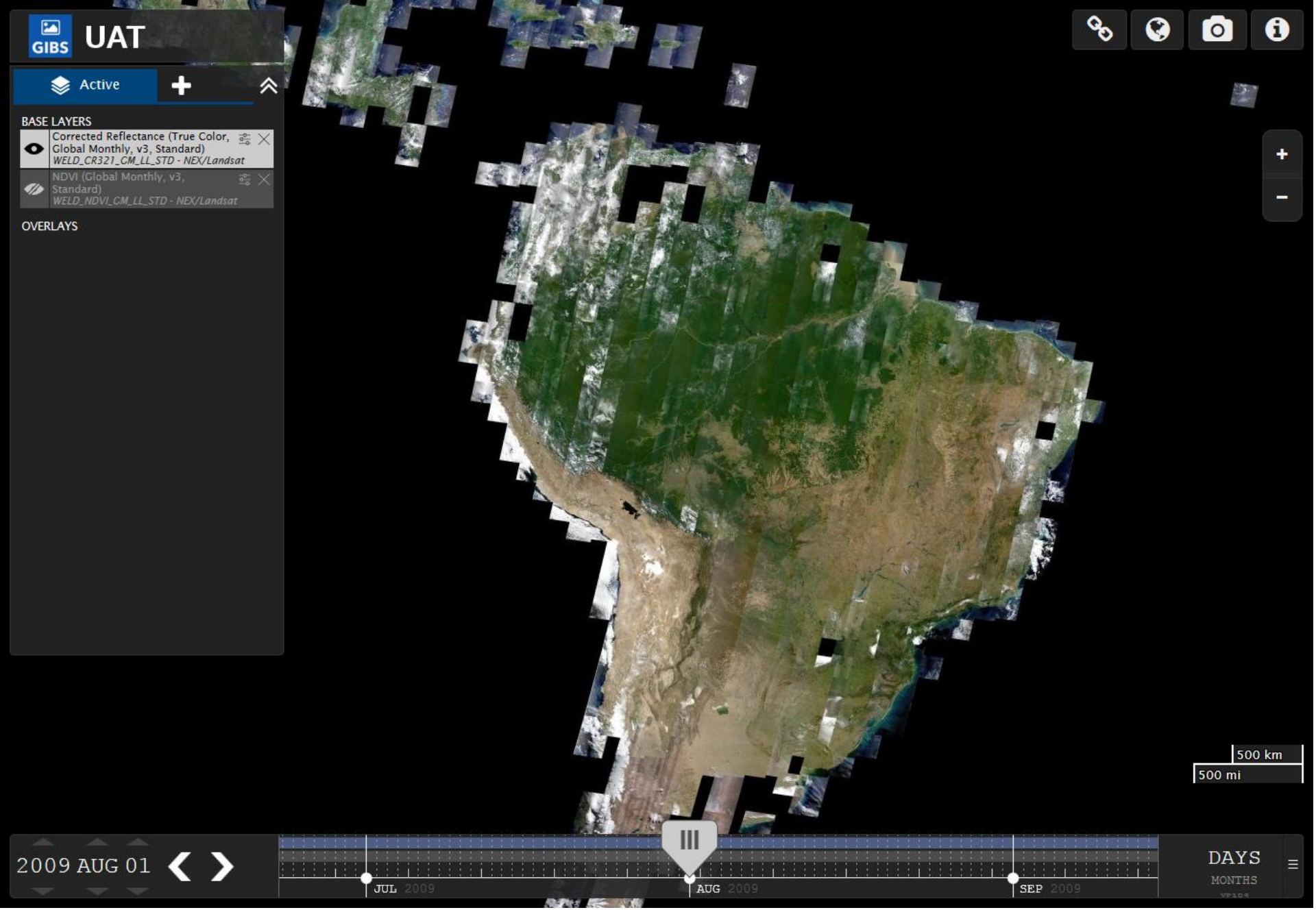

WELD V3.0 GIBS NEX browses

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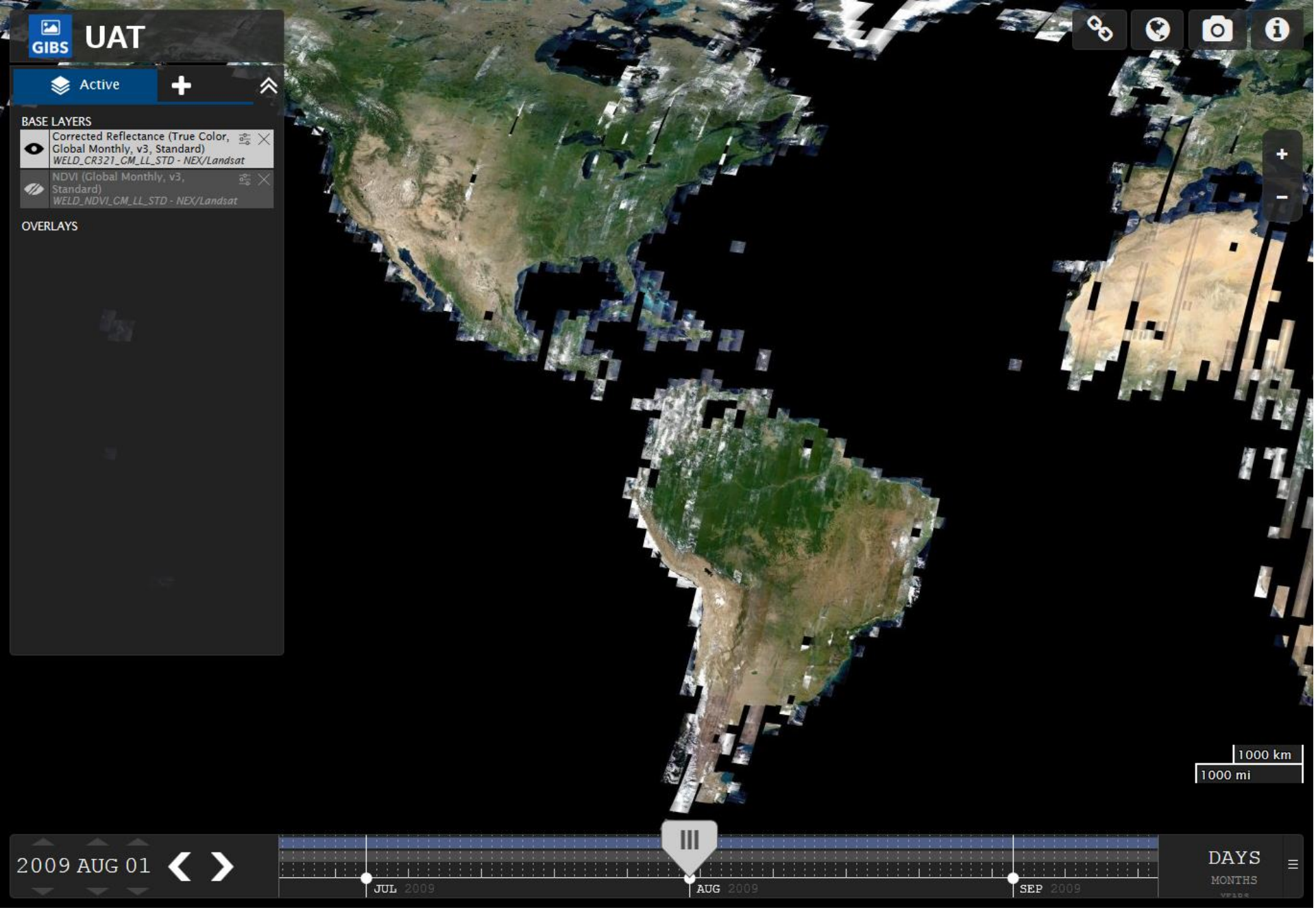
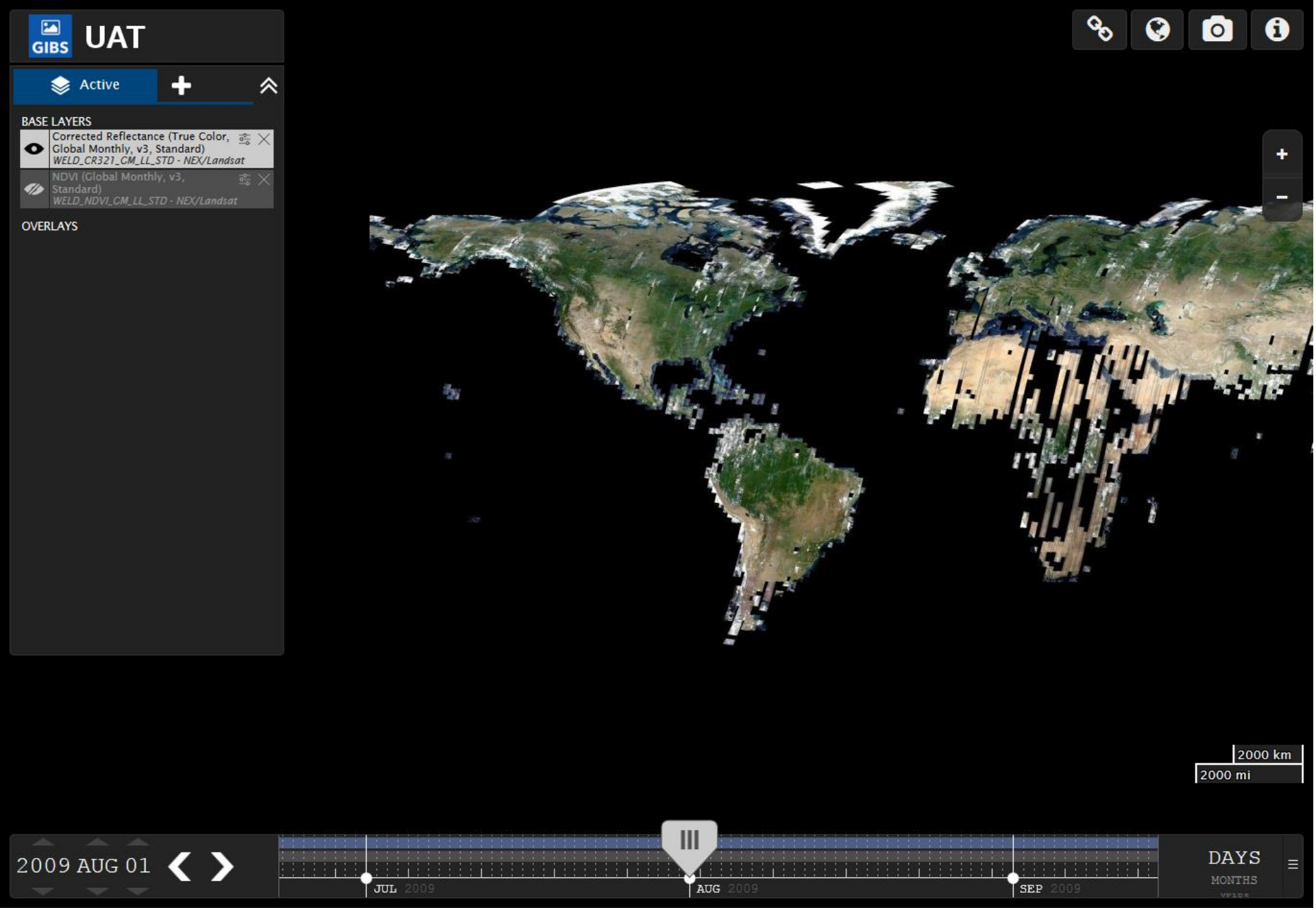


WELD V3.0 GIBS NEX browses

https://uat.gibs.earthdata.nasa.gov/worldview/



WELD V3.0 GIBS NEX browses

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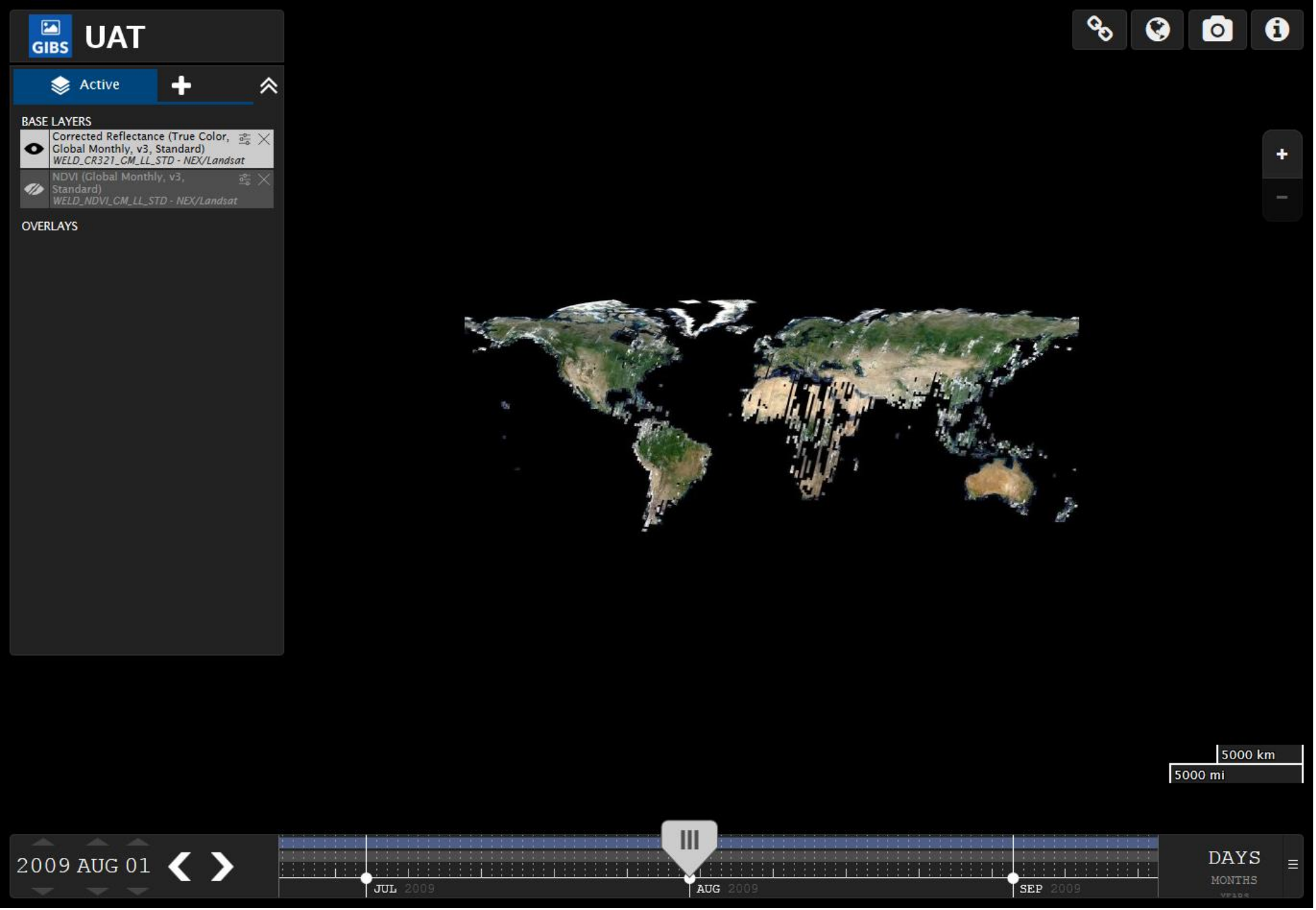


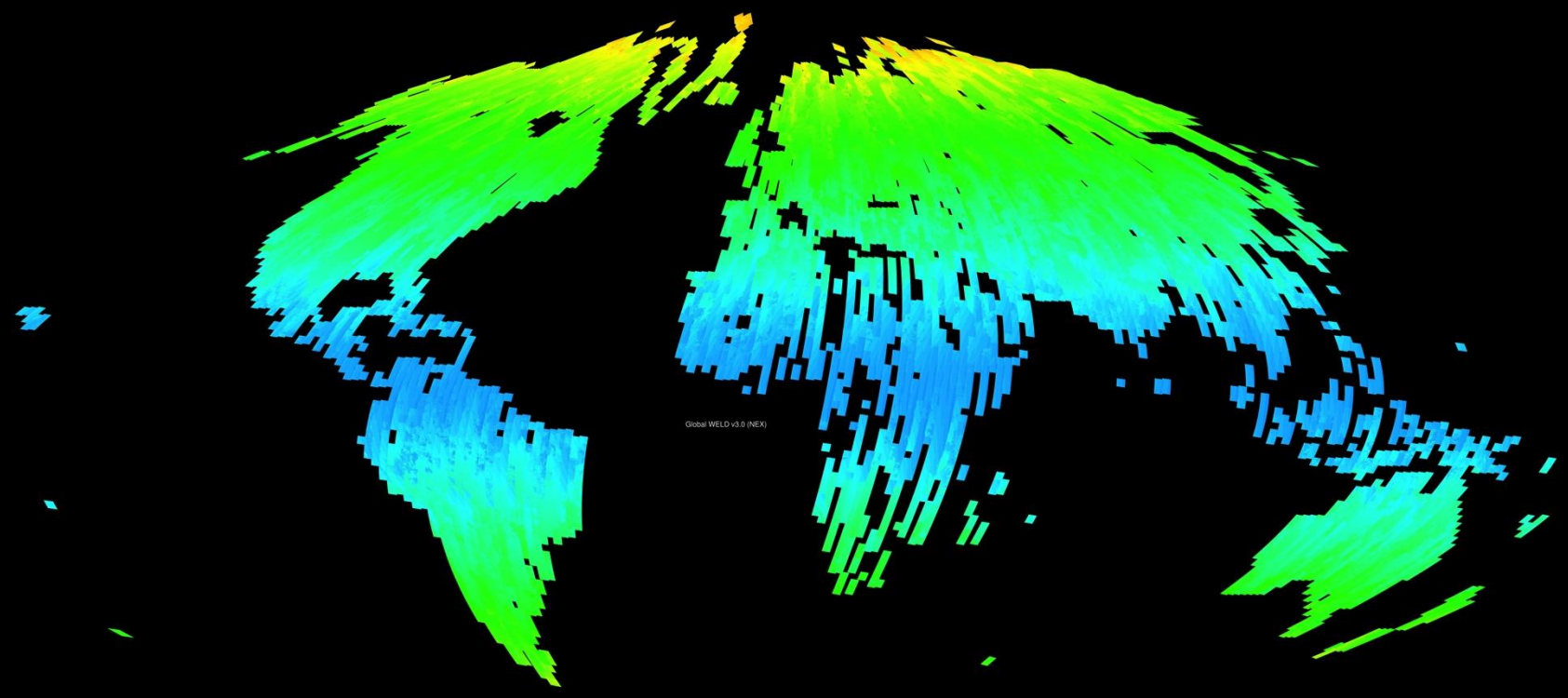
WELD V3.0 GIBS NEX browses

https://uat.gibs.earthdata.nasa.gov/worldview/

Radiance/reflectance measured by a sensor also changes with the sun's position

(Susan Ustin)

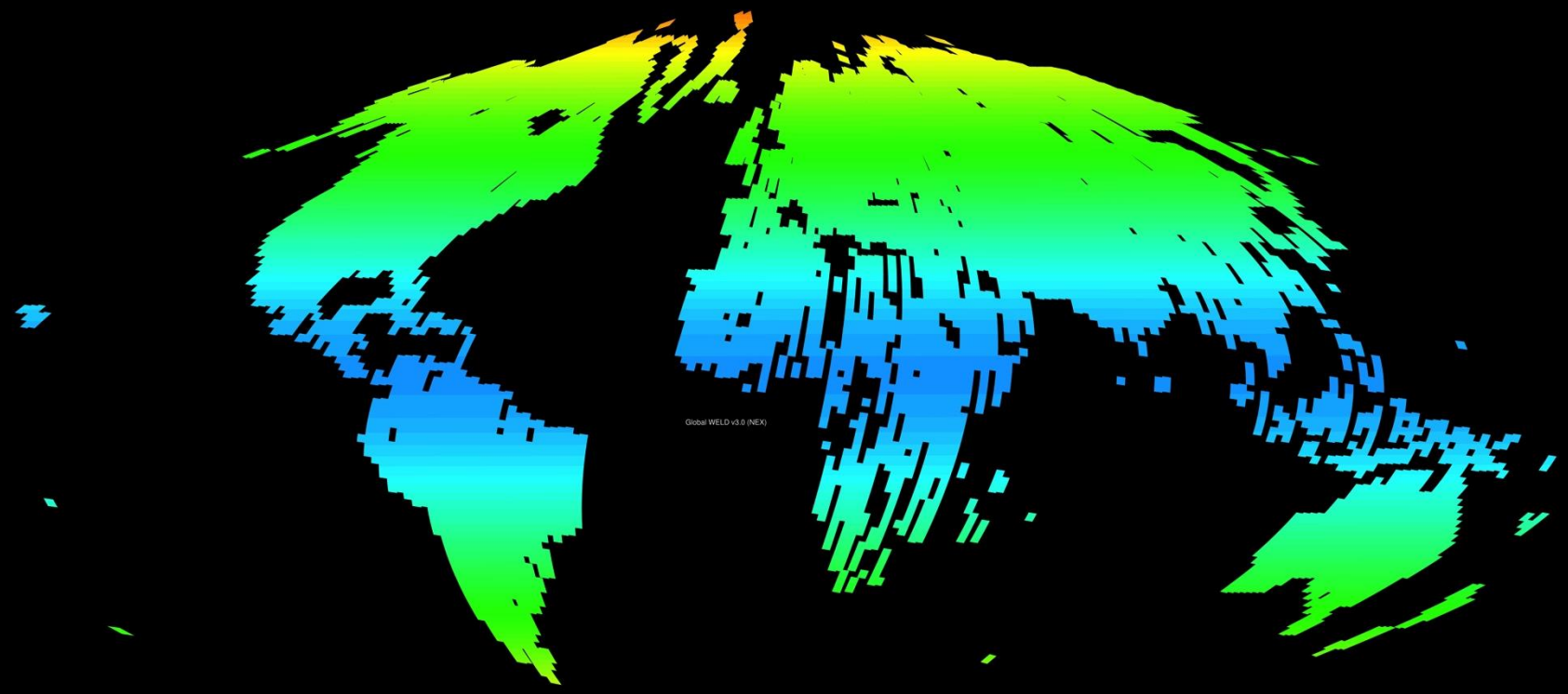
WELD Landsat 5 & 7 observed Solar Zenith



Global WELD NEX Version 3.0 September 2009 30m product
from 15,058 L1T scenes (7,328 Landsat 5 & 7,730 Landsat 7)

Sinusoidal Equal Area Projection

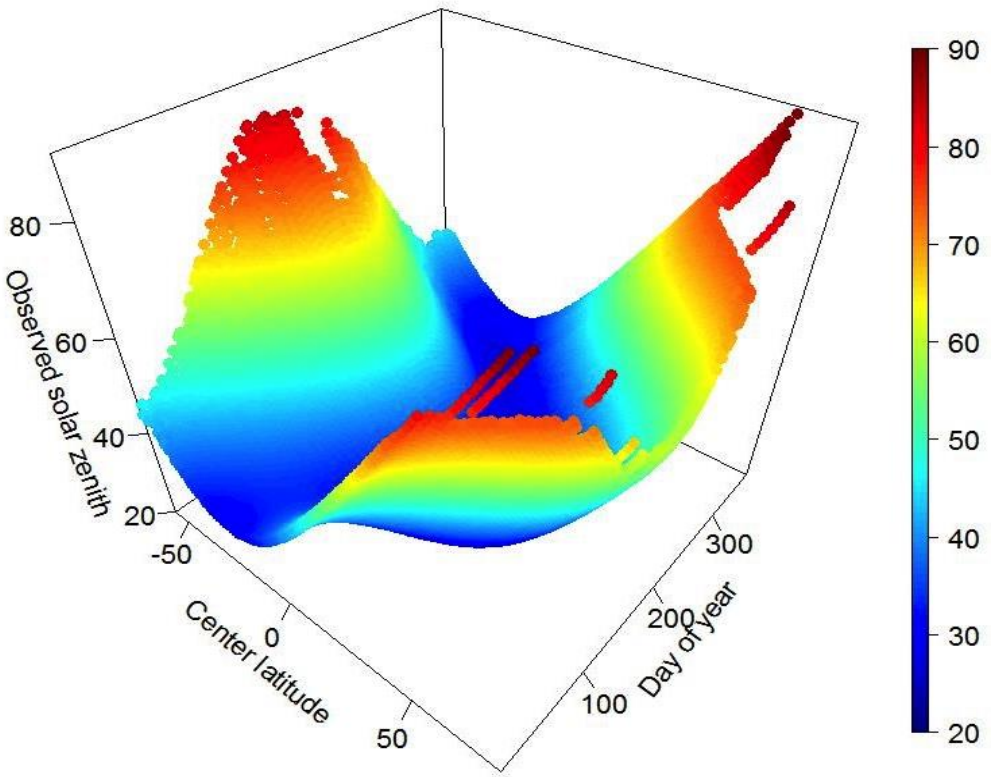
WELD Landsat 5 & 7 modeled Solar Zenith used to derive WELD NBAR



Global WELD NEX Version 3.0 September 2009 30m product
from 15,058 L1T scenes (7,328 Landsat 5 & 7,730 Landsat 7)

Sinusoidal Equal Area Projection

12 months of non-Antarctic Landsat solar zenith (θ_s) plotted as a function of scene center latitude & day of year



$22.14^o <= \theta_s <= 89.71^o$

θ_s mean = 43.23^o

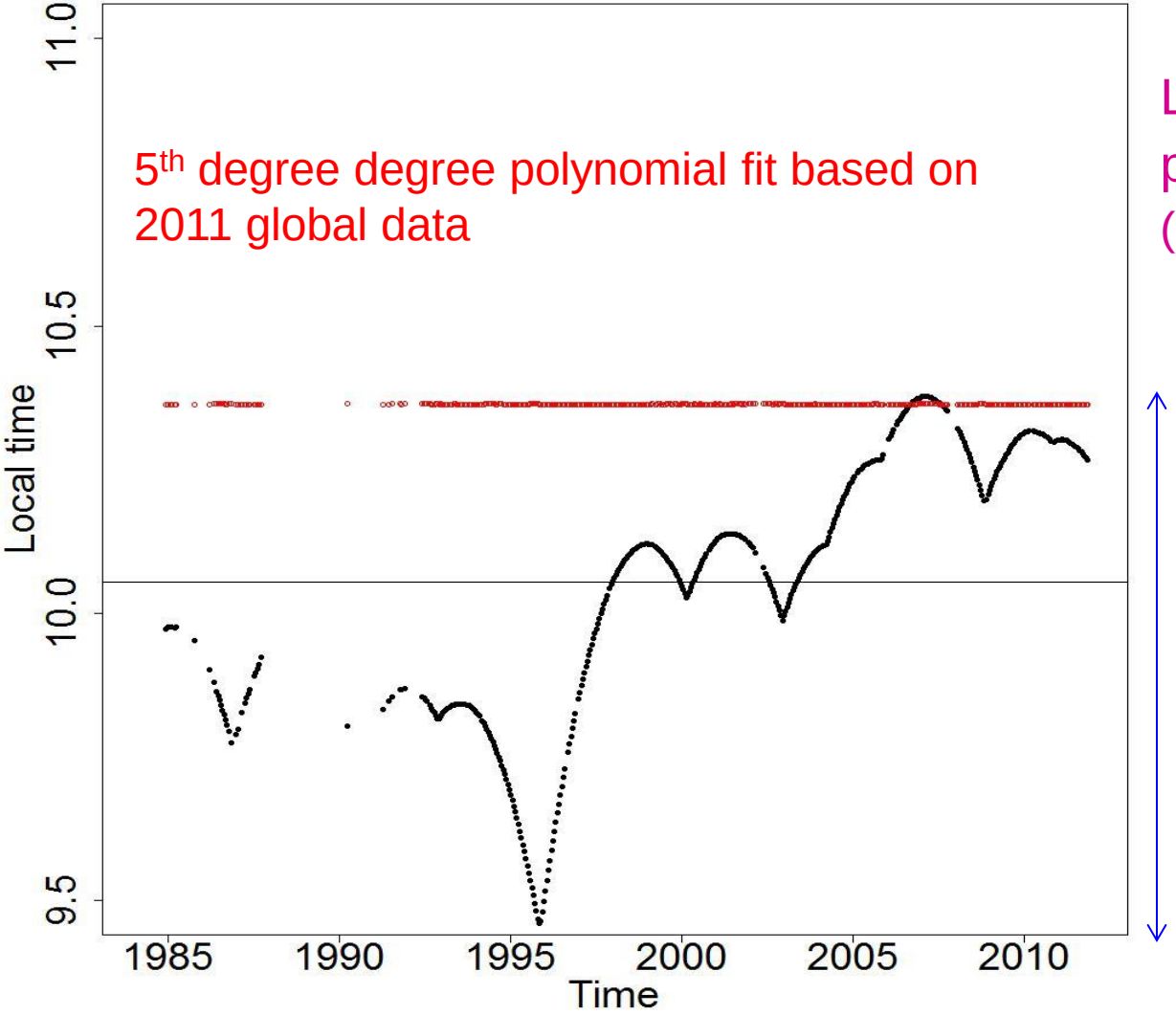
5th degree degree polynomial used to model the local overpass time as a function of latitude for both Landsat sensors:

$$\hat{t}_{local} = 1.36292\times10^{-9}\alpha^5 - 3.15403\times10^{-8}\alpha^4 - 3.15819614\times10^{-6}\alpha^3 + 0.0000652685643\alpha^2 + 0.0120604786763\alpha + 10.06$$

Zhang, H.K., Roy, D.P., & Kovalskyy, V. (2016). Optimal solar geometry definition for global long-term Landsat time-series bidirectional reflectance normalization. *IEEE TGRS, In press.*

Long term Landsat NBAR generation implications …

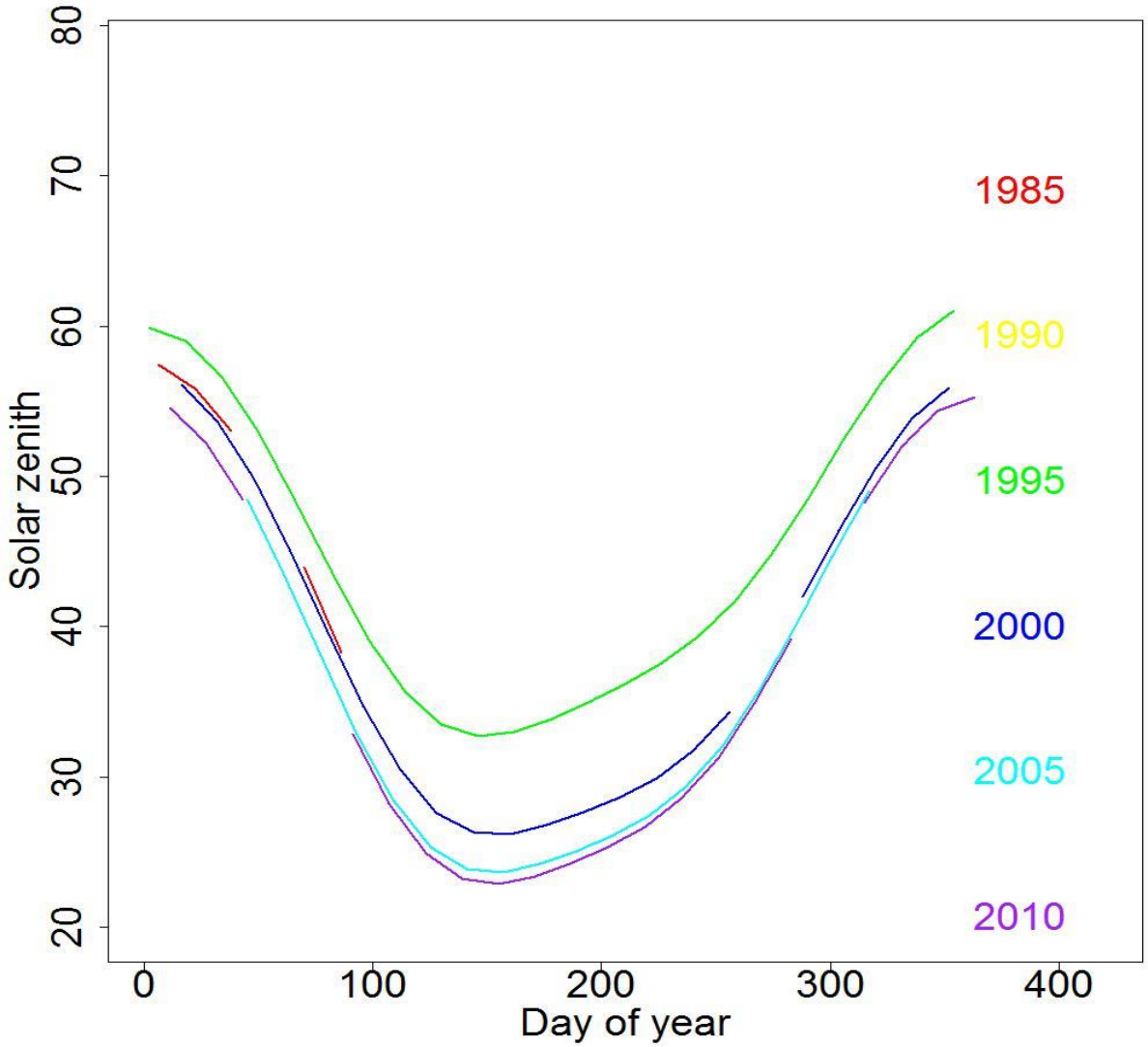
Landsat 5 local time derived from Landsat metadata



Landsat path/row 27/42 (somewhere in Texas)

!

Solar zenith derived from Landsat-5 metadata



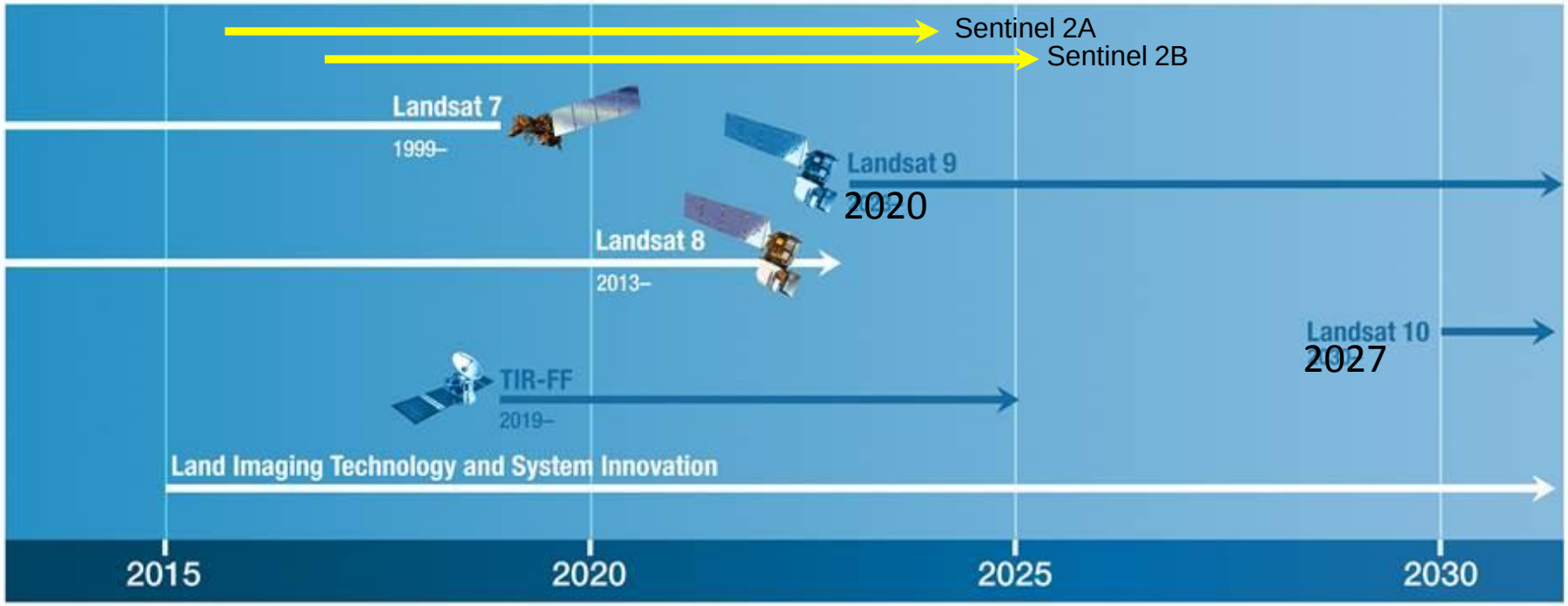
Landsat
path/row 27/42
(somewhere in Texas)

Inter-annual max.

difference 11.24° ...

New Global moderate resolution era

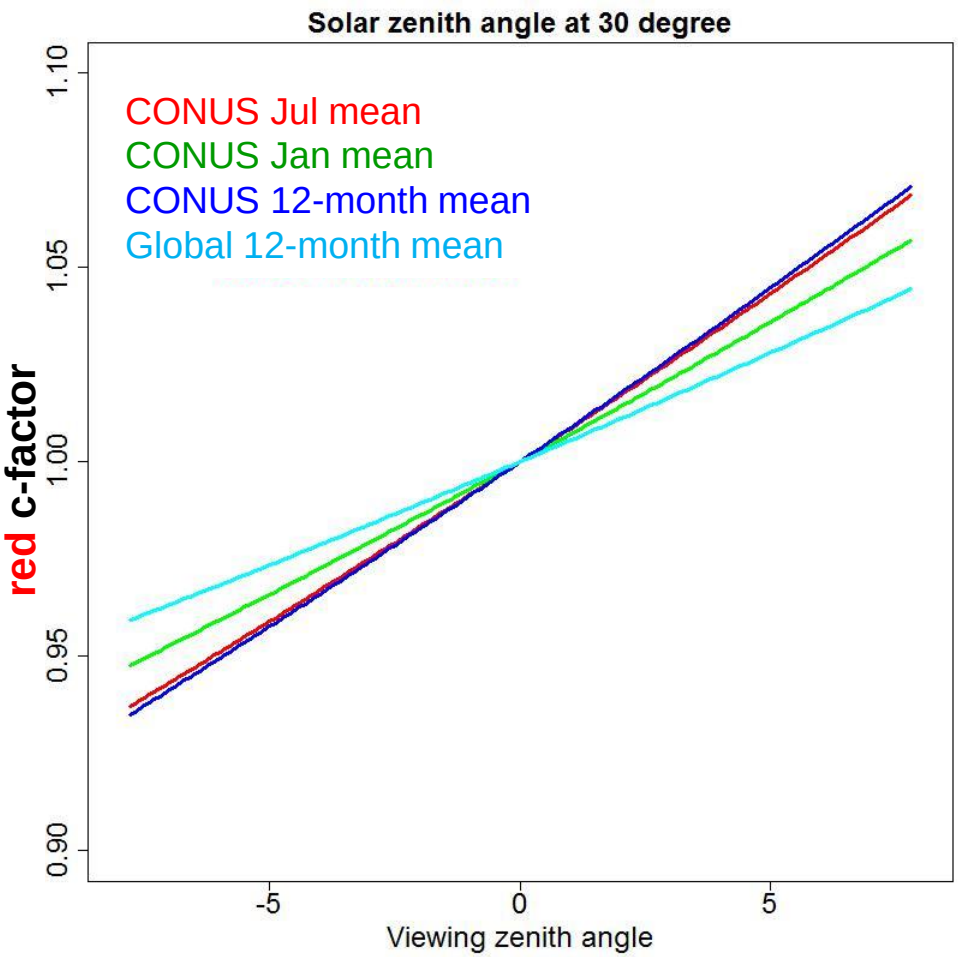
Landsat 7, 8, 9, 10

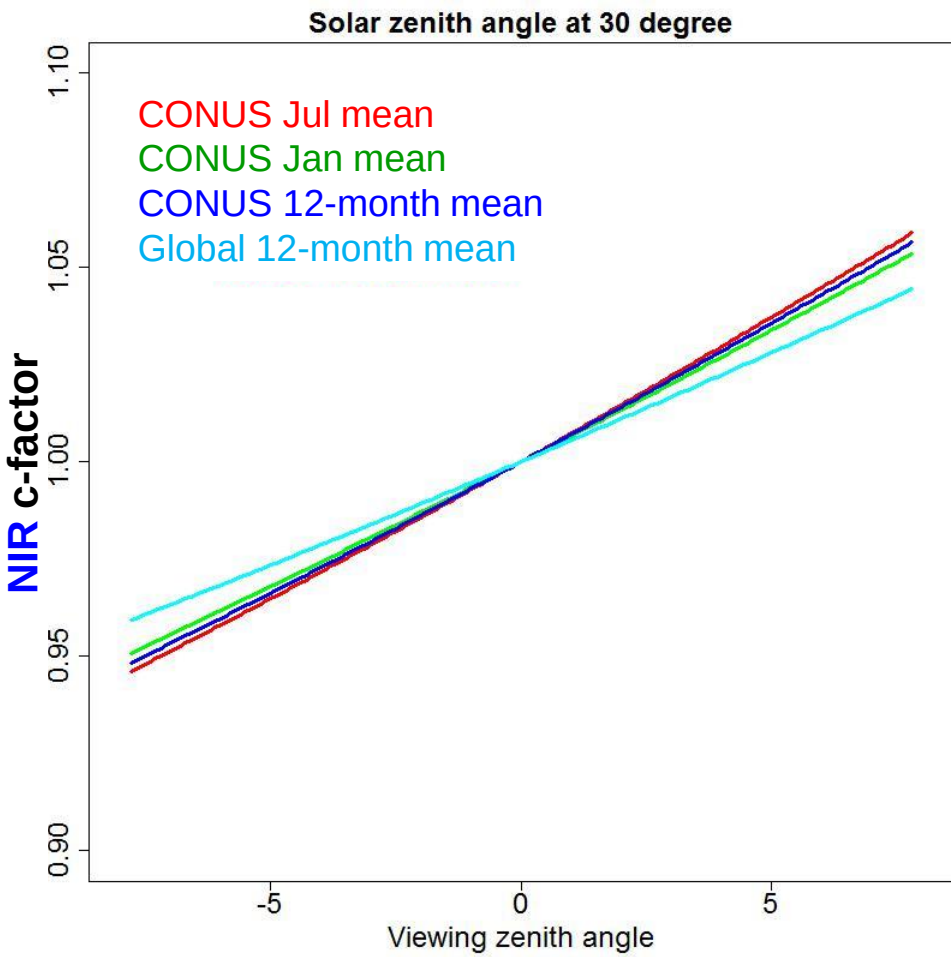


ESA Sentinel 2A & 2B

c-factors over Landsat 15° FOV

Similar over Sentinel-2 20.6° FOV





Sentinel-2

True color
TOA
reflectance

2 S2 L1C tiles

DOY 340

Dec 6th 2015

5295 x 5295 30m pixels

Sentinel-2

True color
surface
reflectance

2 S2 L1C tiles

DOY 340

Dec 6th 2015

5295 x 5295 30m pixels

Sentinel-2

True color
surface
NBAR

2 S2 L1C tiles

DOY 340

Dec 6th 2015

5295 x 5295 30m pixels

Sentinel-2

True color
TOA
reflectance

5 S2 L1C tiles

DOY 343

Dec 9th 2015

5295 x 5295 30m pixels

Sentinel-2

True color
surface
reflectance

5 S2 L1C tiles

DOY 343

Dec 9th 2015

5295 x 5295 30m pixels

Sentinel-2

True color
surface
NBAR

5 S2 L1C tiles

DOY 343

Dec 9th 2015

5295 x 5295 30m pixels

Sentinel-2

True color
Surface reflectance

FILO
Composite

7 S2 L1C tiles

5295 x 5295 30m pixels

Sentinel-2

True color
Surface
NBAR

FILO
Composite

7 S2 L1C tiles

5295 x 5295 30m pixels

Summary

- Generalized approach to provide consistent view angle BRDF corrections across the Landsat archive
  - a general "bulk" correction that is insensitive to land cover BRDF differences at Landsat-MODIS scale
  - implemented in the WELD V3.0 product suite – check out USGS WELD distribution web site
  - Paper: Roy, D.P., Zhang, H. K., Ju, J., Gomez-Dans, J. L., Lewis, P.E., Schaaf C.B., Sun, Q., Li, J., Huang, H., Kovalskyy, V., 2016, A general method to normalize Landsat reflectance data to nadir BRDF adjusted reflectance, *Remote Sensing of Environment*, 176, 255-271.
  - CAVEAT: approach is not applicable for generation of Landsat surface albedo, which requires a full characterization of the surface BRDF
- Ongoing research to see if the approach is applicable to Sentinel-2 (20.6° FOV) data as common BRDF correction is likely needed for combined Landsat-8 usage
- Ongoing research to consider the impact of the Landsat 5 27-year orbit drift on reflectance
  - potentially quite alarming ….
  - **See talk: Thursday, July 28, 2016,** Landsat 5 Thematic Mapper reflectance and NDVI 27-year time series inconsistencies due to satellite orbit change, Hankui Zhang & David Roy