- Regridding / Projection
- Compositing
for Sentinel-2 & Landsat 8 merged products

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Geospatial Science Center of Excellence
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LCLUC Spring Science Team Meeting
Session 2: Harmonizing Sentinel-2 and Landsat Reflectance Products
Chesapeake Salon C, Marriott Hotel and Conference Center,
College Park, MD

April 22-23 2015

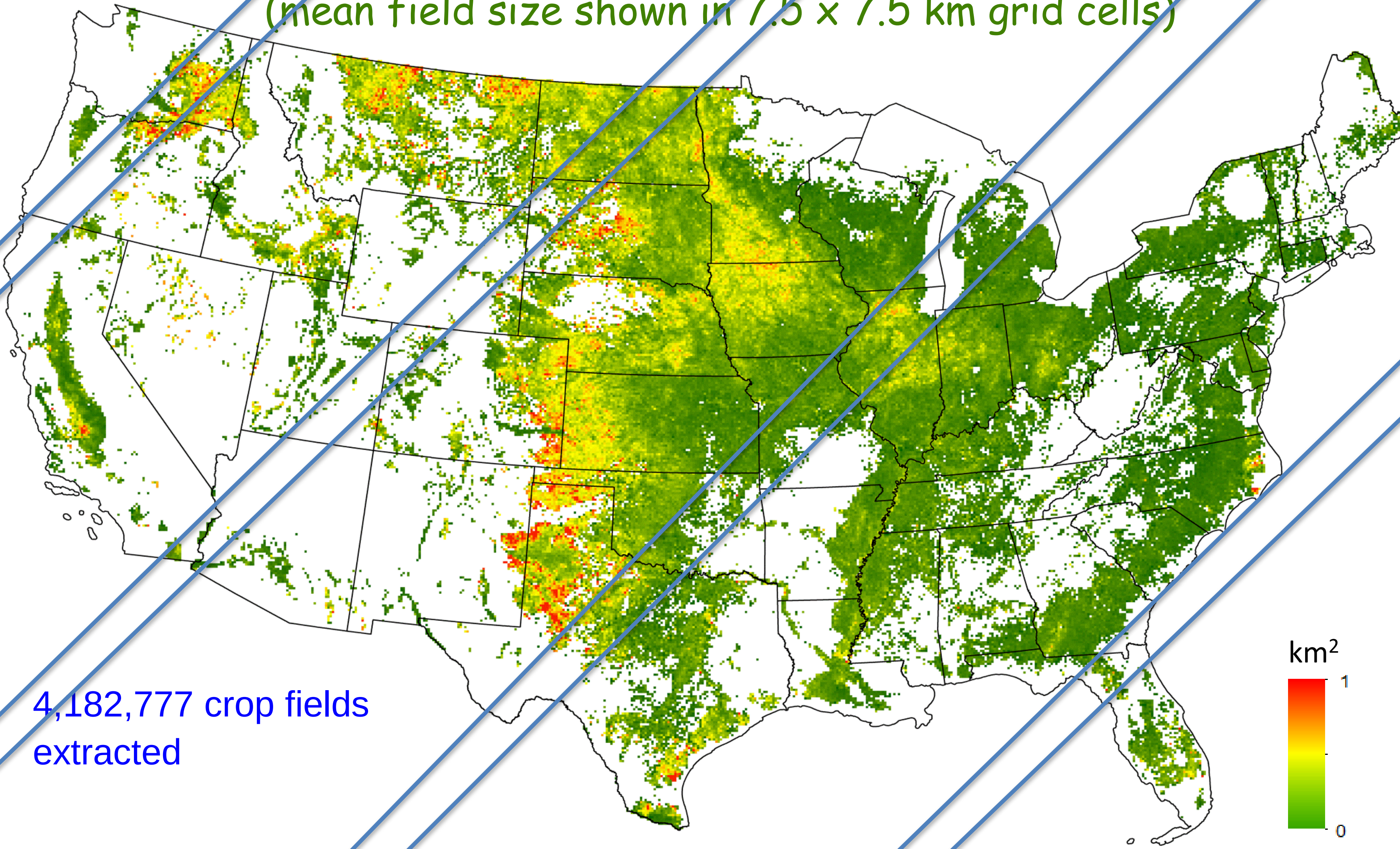
Regridding/Projection/Compositing Sentinel-2 & Landsat 8

Prerequisite for

- combined use of different sensor data
- developing algorithms
- prototyping products
- to advance the virtual constellation paradigm for mid-resolution land imaging

2010 CONUS crop field size map

(mean field size shown in 7.5 x 7.5 km grid cells)



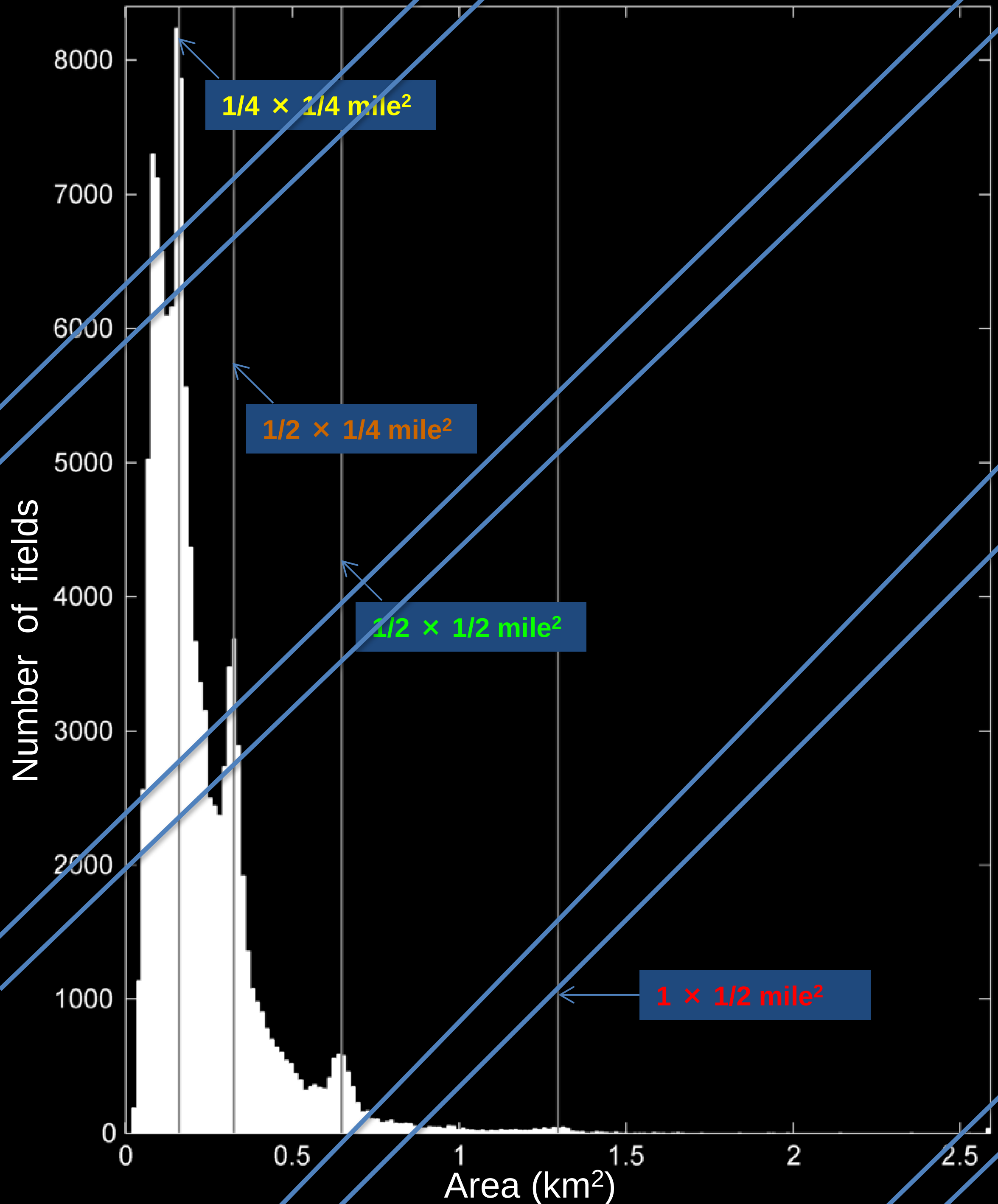
4,182,777 crop fields extracted

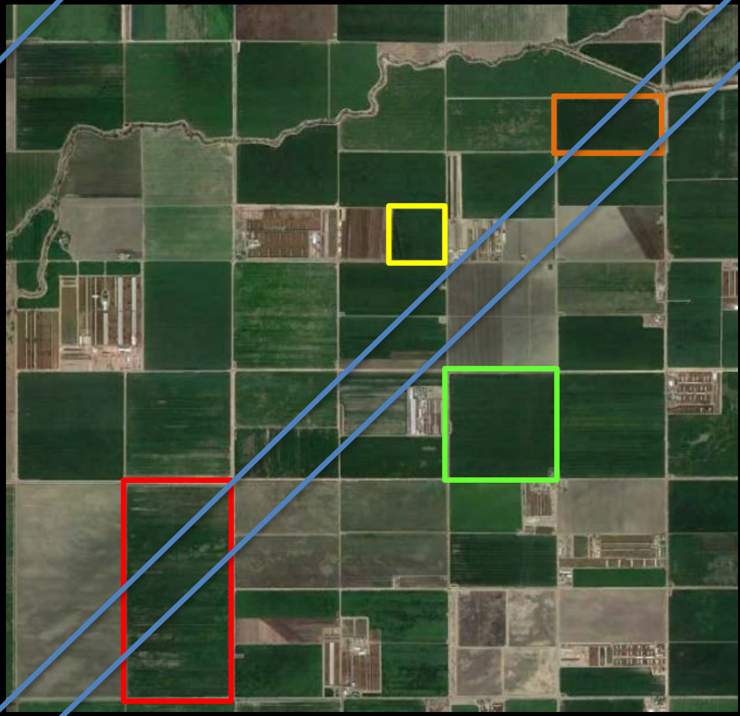
derived from all 13,666 WELD processed Landsat 5 and 7 scenes available in the U.S. Landsat archive for 12 months

California 2010

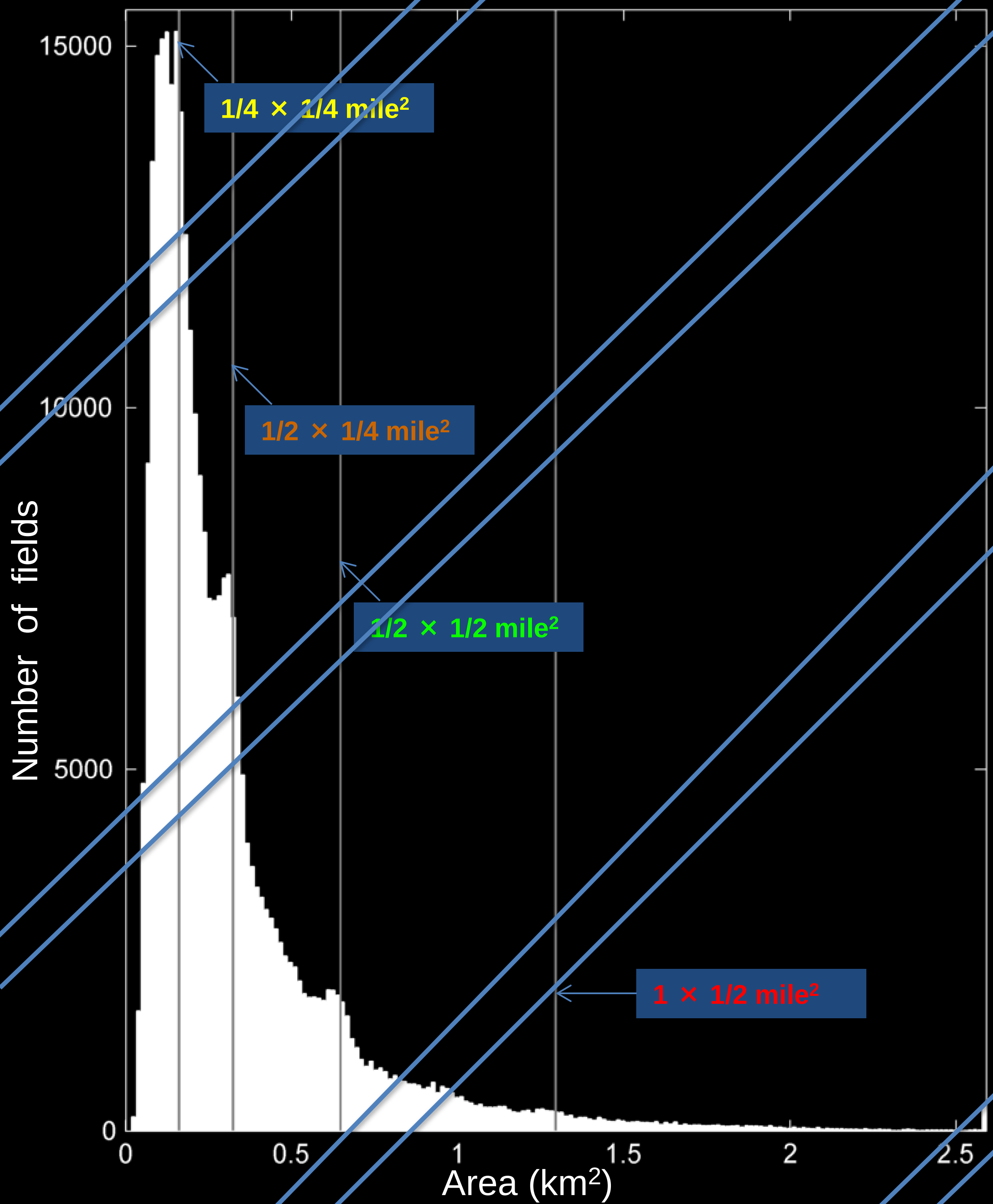
WELD derived
crop field size histogram

116,888 fields extracted





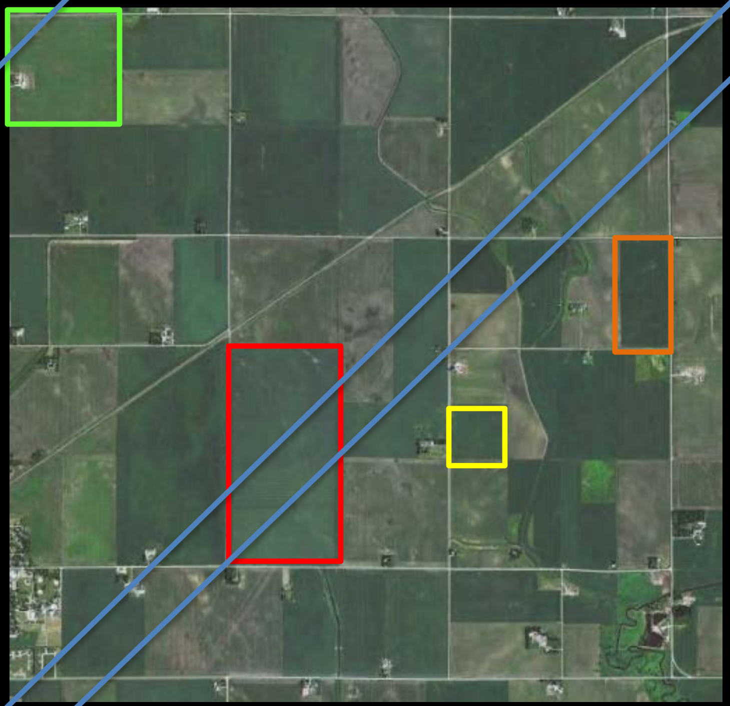
Google-Earth image. ~5.5 x 5 km subset in California near Corcoran.



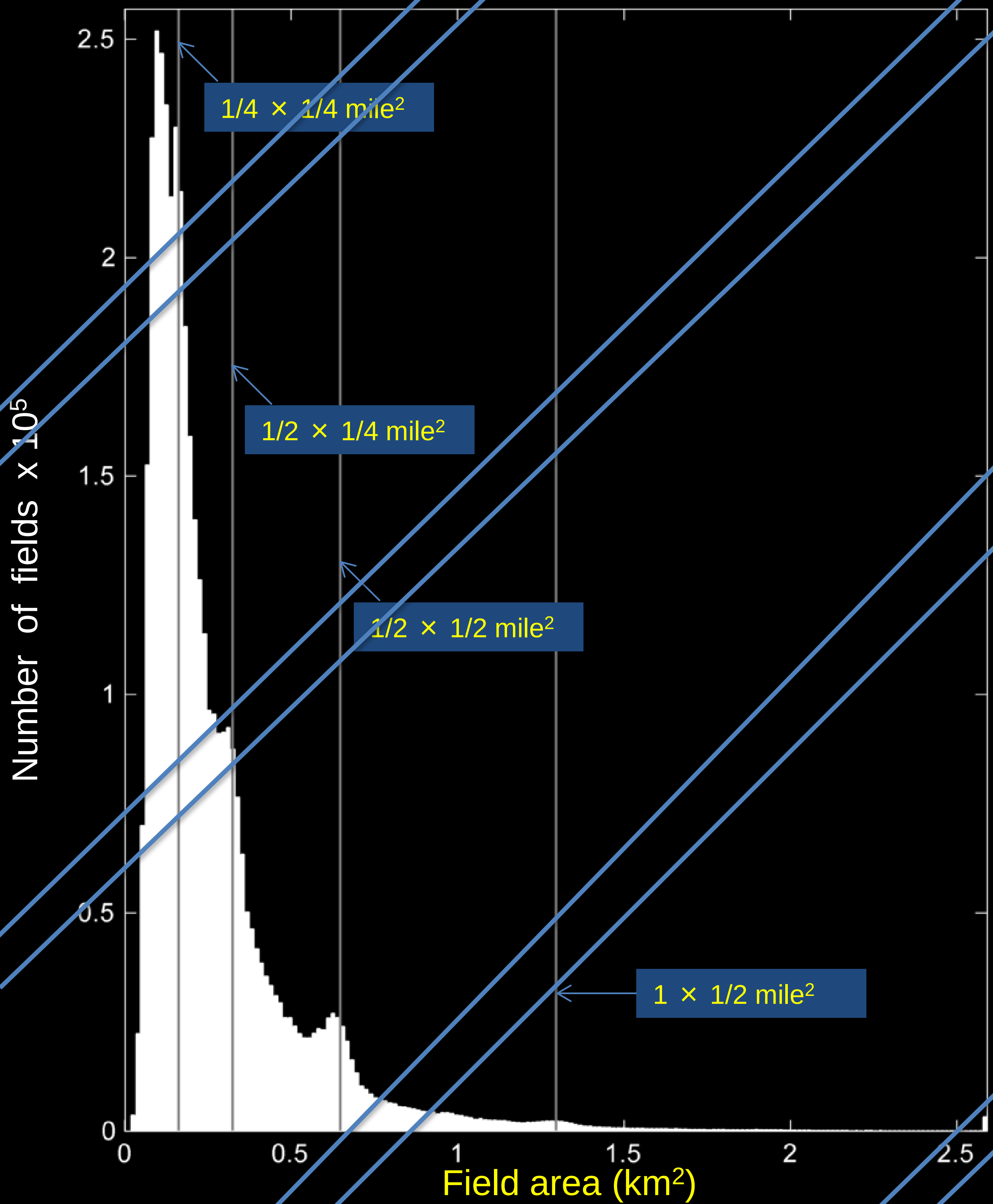
Iowa 2010

WELD derived
crop field size histogram

308,917 fields extracted



Google-Earth image. ~5.5 x 5 km
subset in Iowa near Eagle Grove.



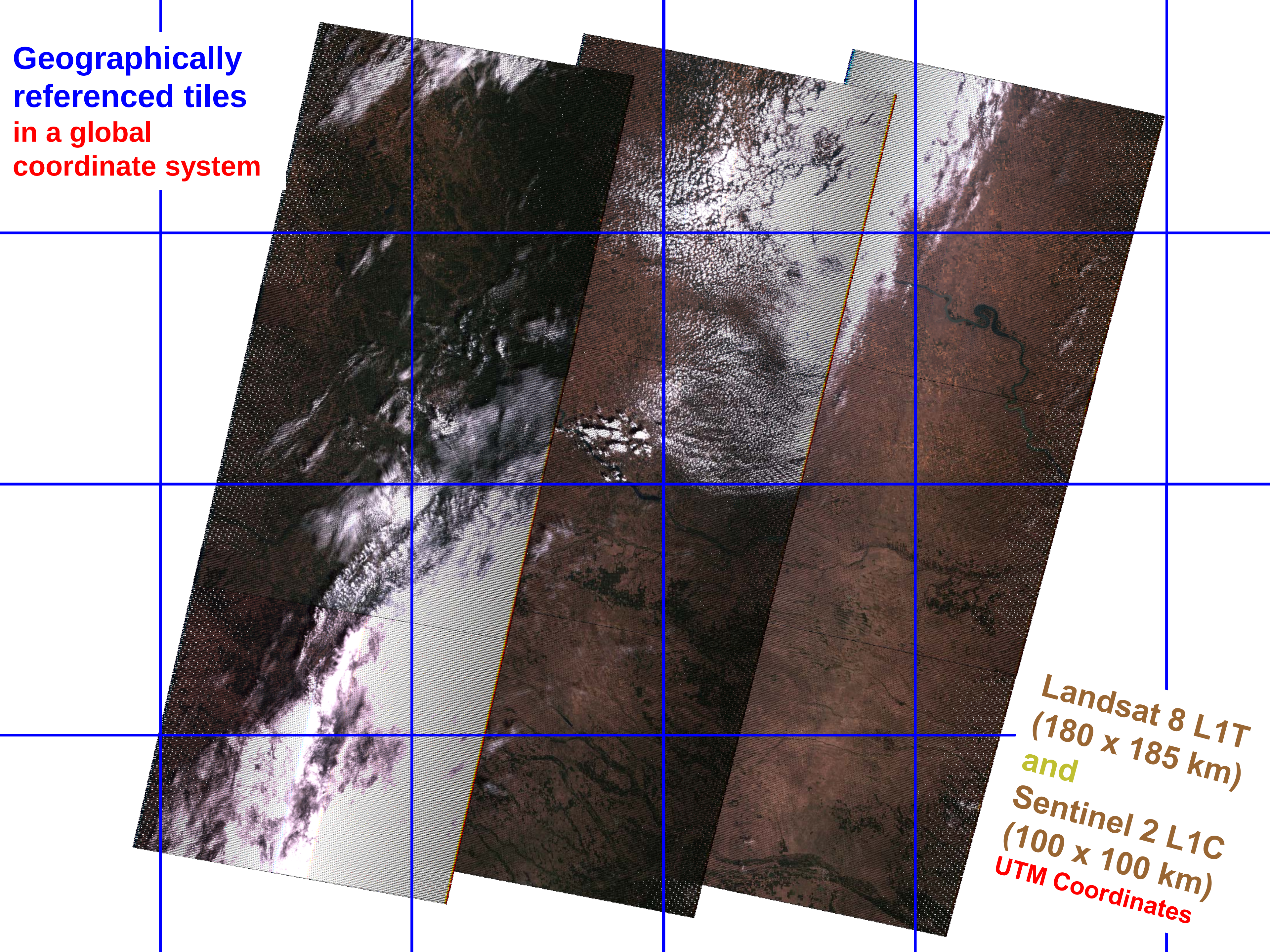
CONUS 2010

WELD derived

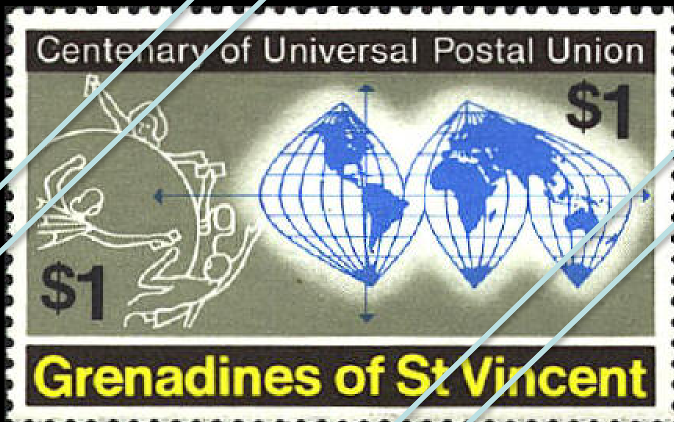
crop field size histogram

4,182,777 fields extracted

Regridding/Projection approach for Sentinel-2 & Landsat 8


Geographically
referenced tiles
in a global
coordinate system
Landsat 8 L1T
(180 x 185 km)
and
Sentinel 2 L1C
(100 x 100 km)
UTM Coordinates

Project Landsat 8 L1T & Sentinel 2 L1C UTM data to the <u>same</u> Global Projection – which ?



Interrupted projections too complex for users

Uninterrupted projections easier

Also, polar uninterrupted projection needed for cryospheric research ?

Project Landsat 8 L1T & Sentinel 2 1LC UTM data to the same Global Projection – which ?

Should be

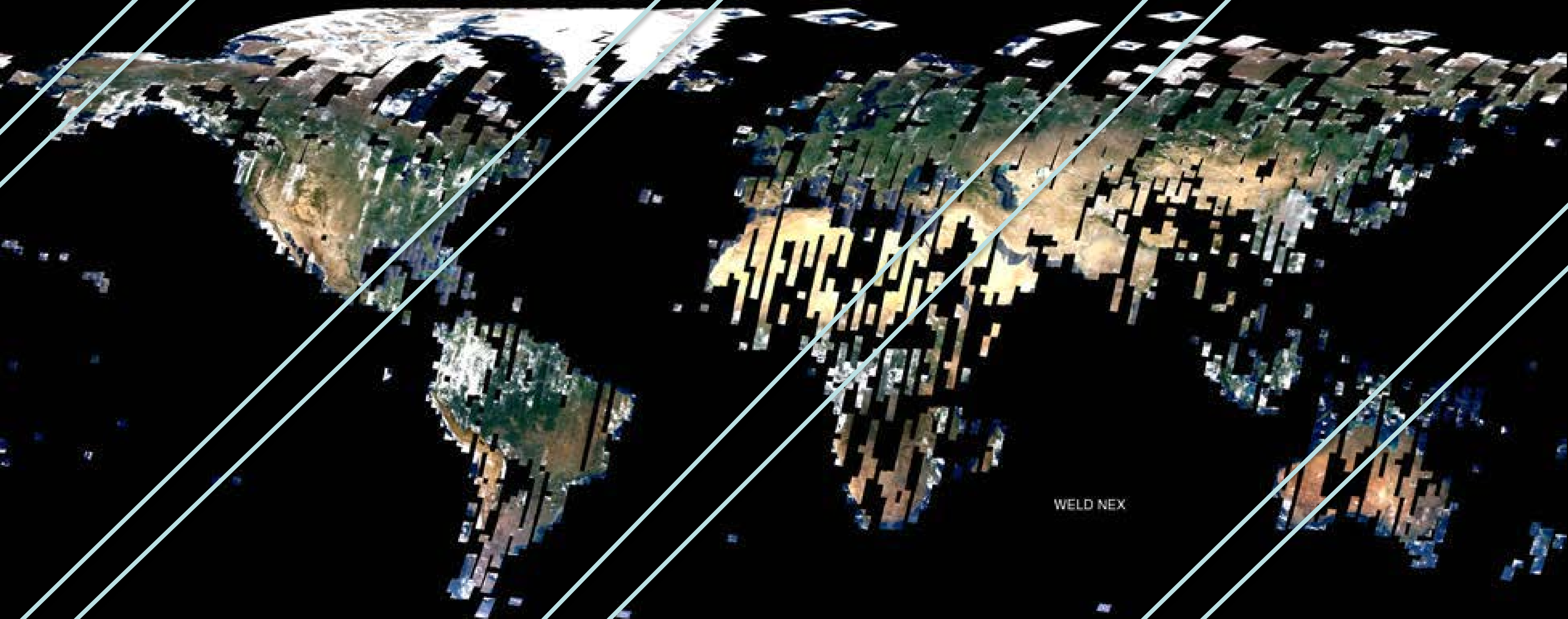
- equal area & uninterrupted
- supported by publically available transformation software (GCTP, GDAL)
- have closed-form inverse mapping (otherwise computing inverse expensive)
- familiar to users

- Mercator Projection
  - developed 1569 for nautical navigation
  - used by Google Maps
  - But, not equal area

- Winkel Tripel Projection
  - minimizes distortion in area, direction and distance
  - used by the National Geographic Society
  - But, closed-form inverse mapping does not exist
- Sinusoidal Equal Area Projection
  - satisfies criteria, developed for global change community, MODIS land products!

Early prototype Global monthly WELD product

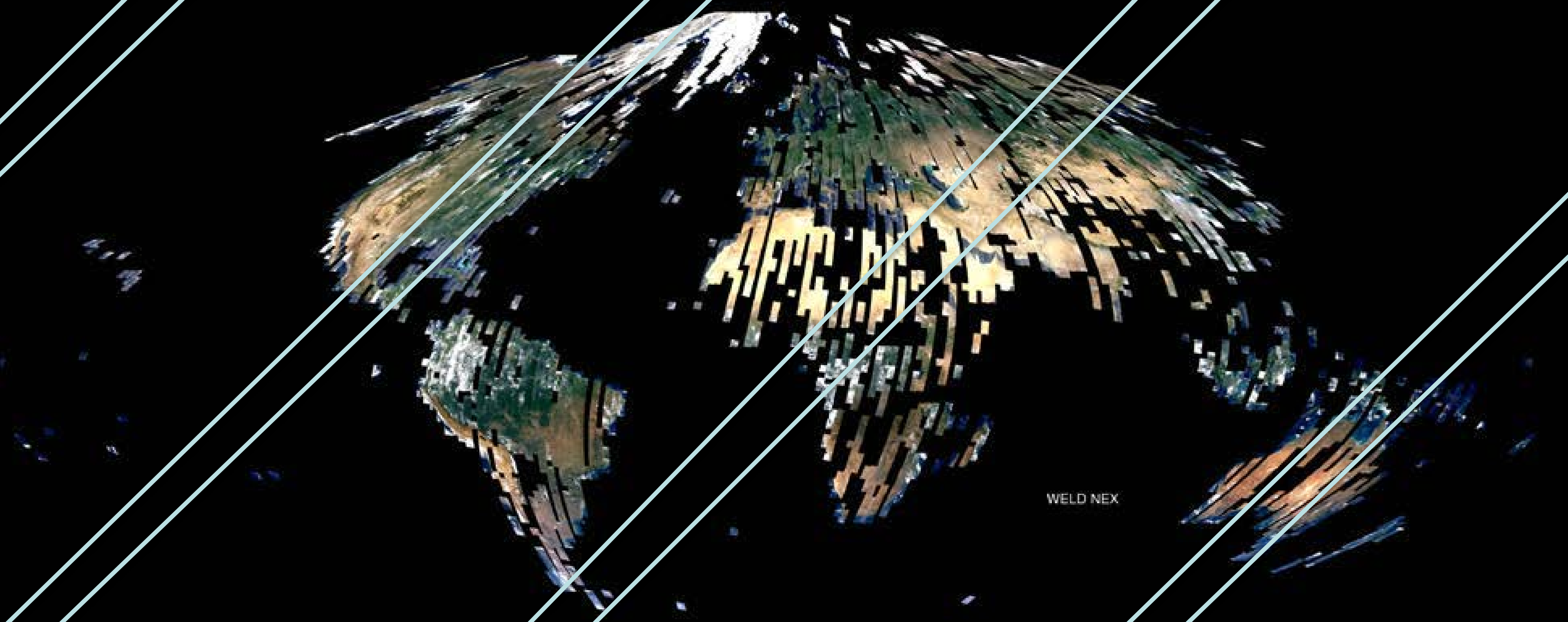
Geographic Lat./Long. projection



Each 1.35km true color browse pixel
generated from 45 x 45 30m Landsat 7 ETM+ pixels

Early prototype Global monthly WELD product

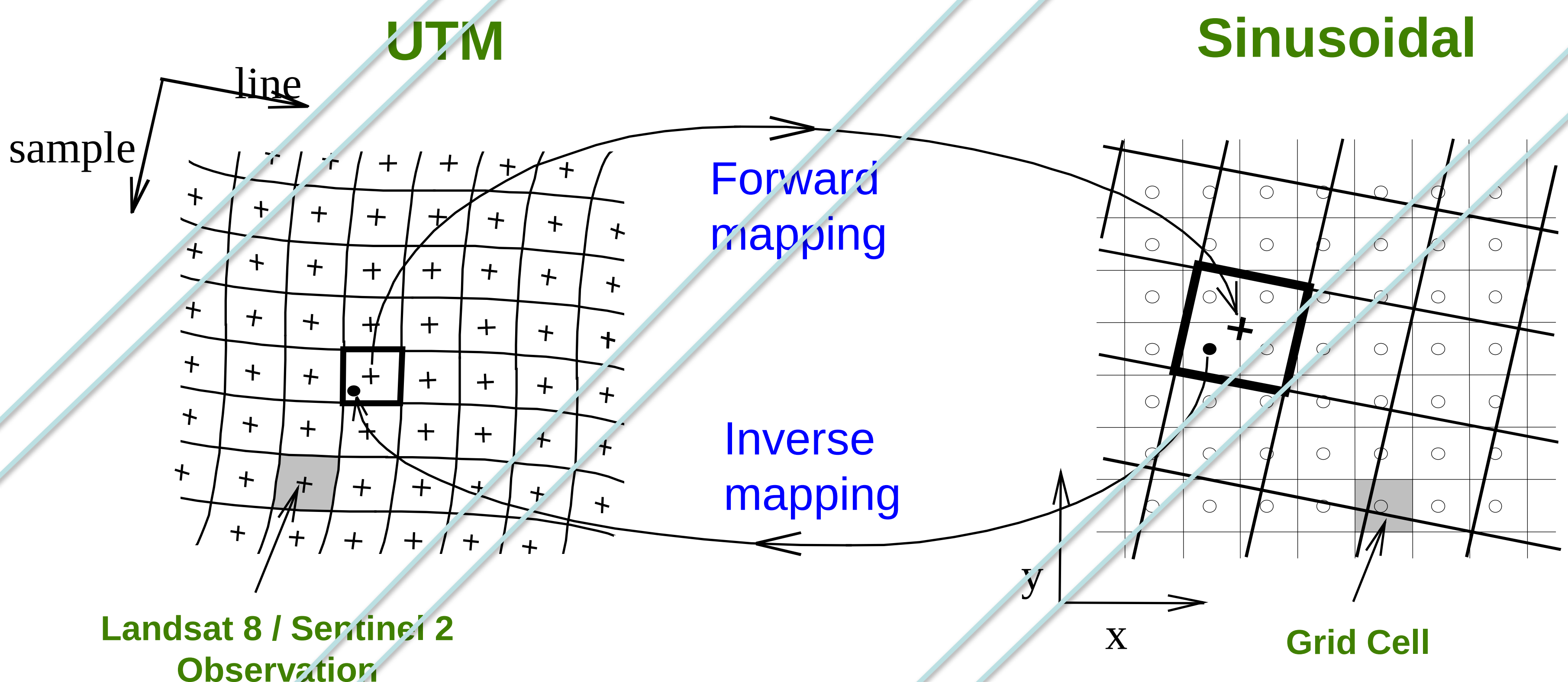
Equal area sinusoidal projection



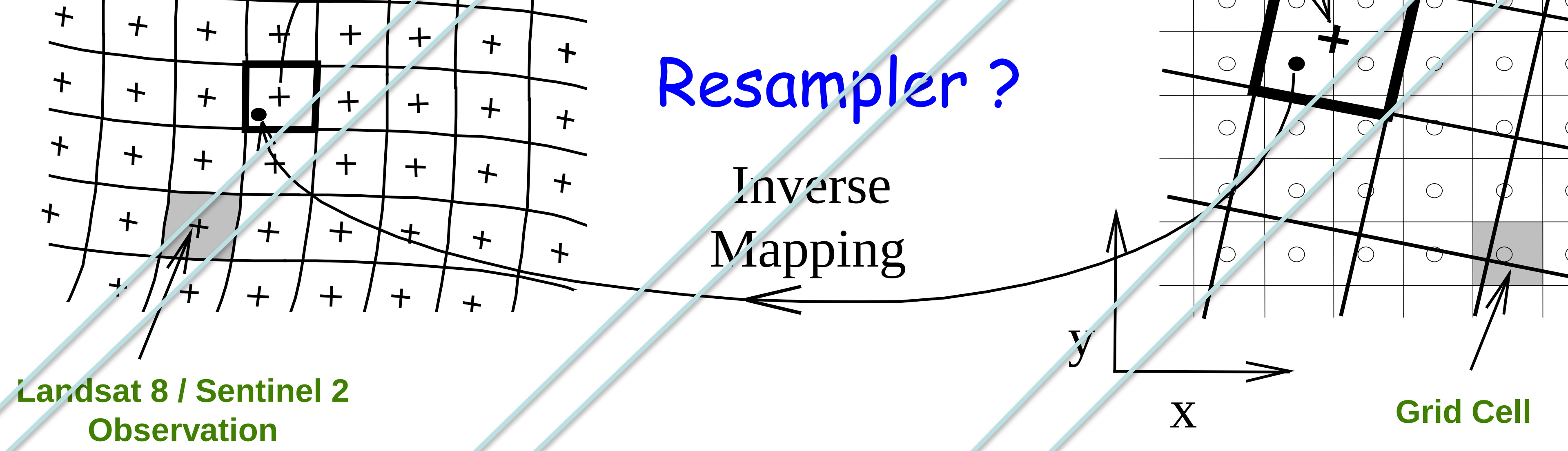
Each 1.35km true color browse pixel
generated from 45 x 45 30m Landsat 7 ETM+ pixels

Reprojection UTM <-> Sinusoidal which mapping approach ?

Use inverse mapping as computationally least expensive, each global pixel location only addressed once, no gaps in output.



Resampler ?



Nearest Neighbor

$$r(x) = \begin{cases} 1 \ \text{for}\ |x| = \frac{1}{2} \\ 0 \ \text{otherwise} \end{cases}$$

Bilinear

$$r(x) = \begin{cases} 1 - |x| \ \text{for}\ |x| = 1 \\ 0 \ \text{otherwise} \end{cases}$$

Cubic convolution

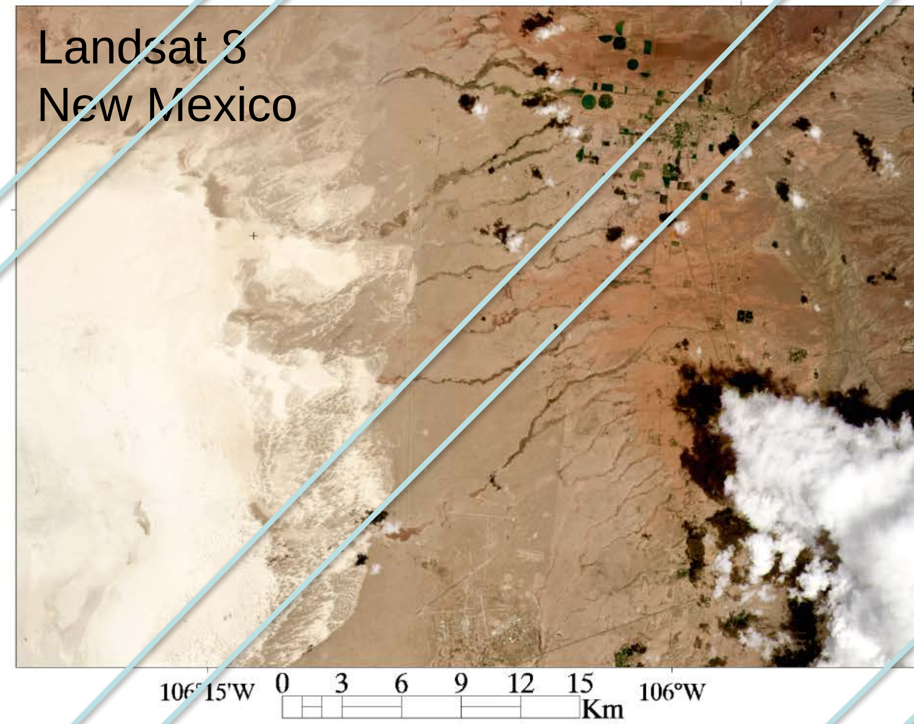
$$r(x) = r_0(x) + \alpha \ r_1(x) \qquad \alpha \approx -0.5$$

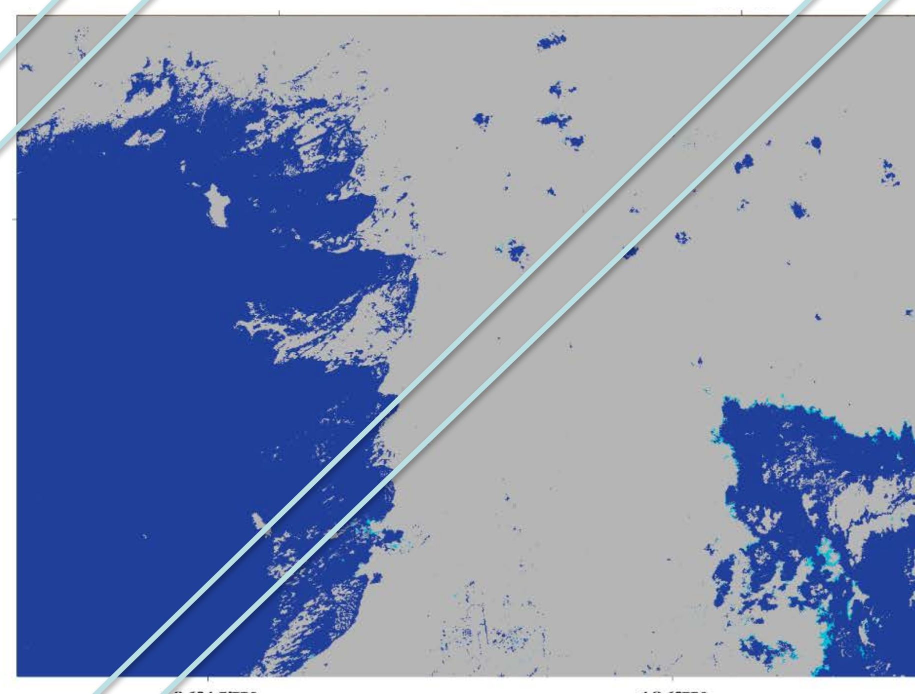
$$r_0(x) = \begin{cases} (2|x|+1)(|x|-1)^2 \ \text{for}\ |x| < 1 \\ 0 \ \text{otherwise} \end{cases}$$

$$r_1(x) = \begin{cases} |x|^2(|x|-1) \ \text{for}\ |x| < 1 \\ (|x|-1)(|x|-2)^2 \ \text{for}\ 1 \le x \le 2 \\ 0 \ \text{otherwise} \end{cases}$$

Use nearest neighbor resampling

to preserve categorical & ordinal per-pixel QA information after reprojection

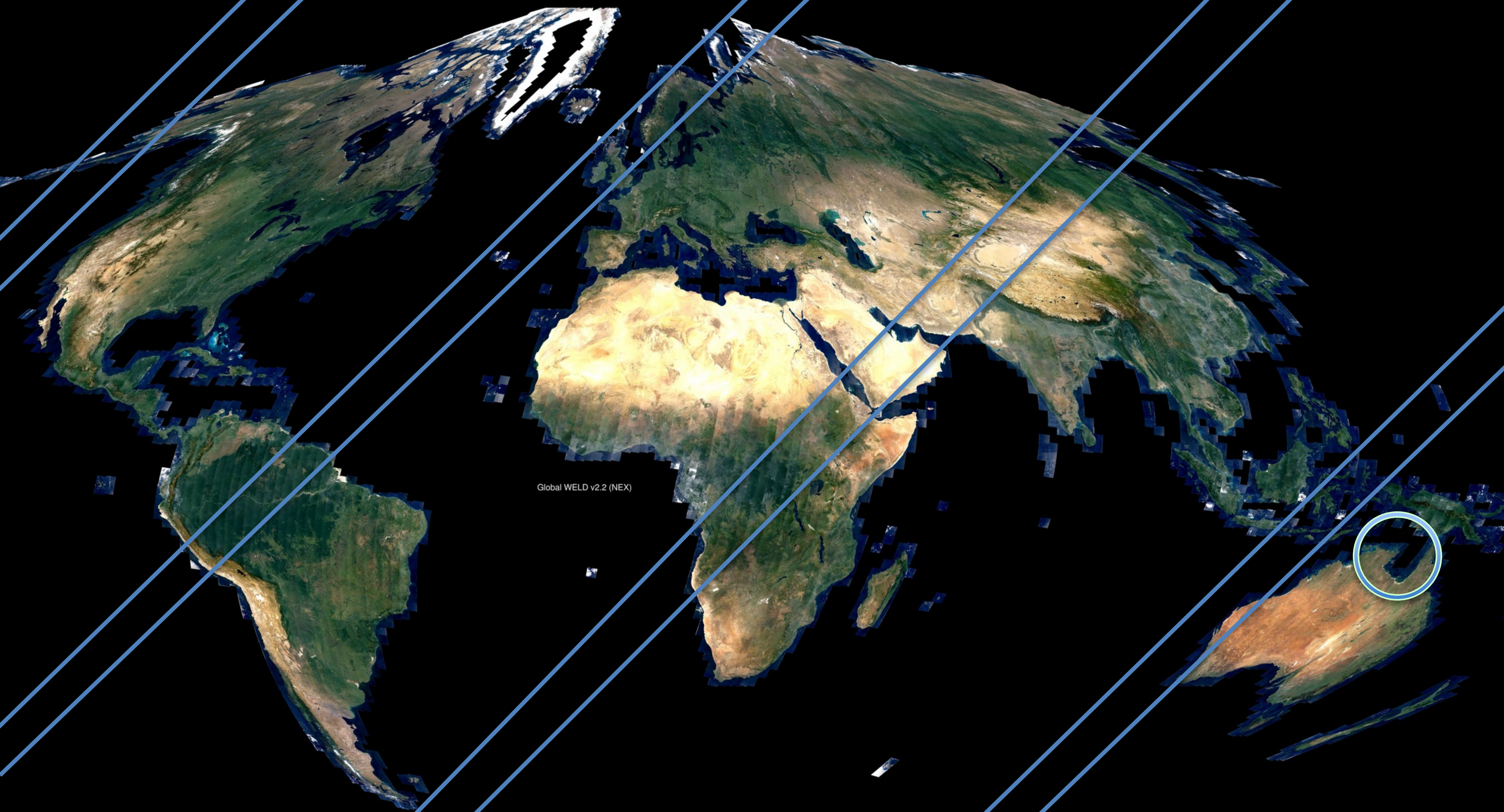




Kovalskyy, V. and Roy, D.P., 2015
A one year Landsat 8 conterminous United States study of cirrus and non-cirrus clouds, *Remote Sensing*, 7, 564-578

high confidence clouds
medium confidence clouds
low confidence clouds

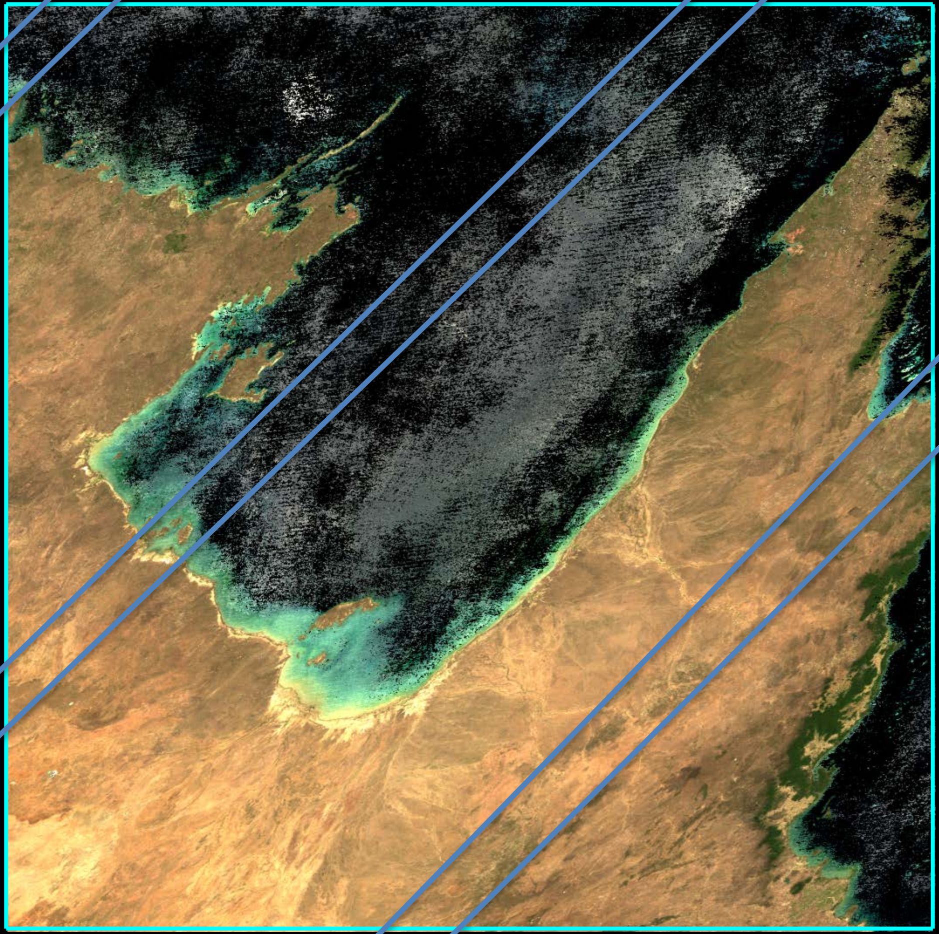
Tiling scheme ?



Global WELD NEX Annual 2010 30m product
124,433 L1T scenes (45,711 Landsat 5 & 78,722 Landsat 7)

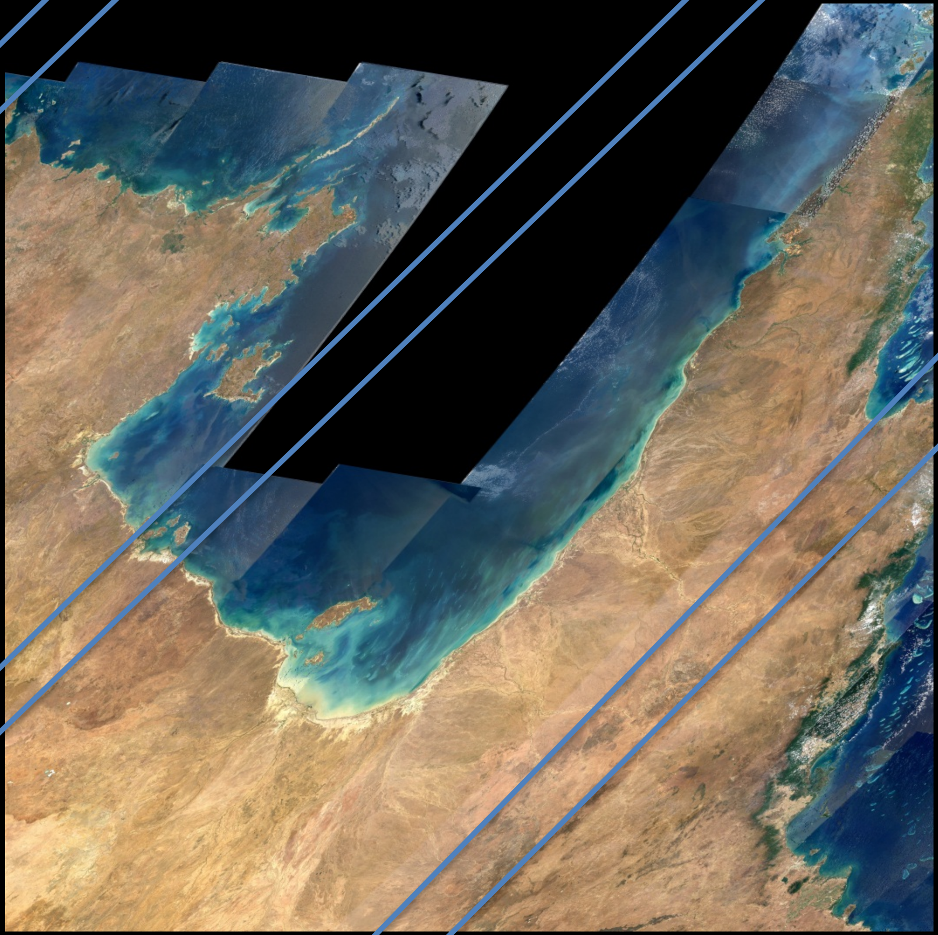
MODIS sinusoidal projection
29,652 x 14,826 1.35km browse pixels

MODIS Land Tile scheme (10° × 10° at Equator, 1200 × 1200 1km pixels)



- MODIS Land tile h31v10
- MODIS nadir view BRDF-adjusted 500m true color reflectance
- Terra and Aqua daily surface reflectance for October 2009

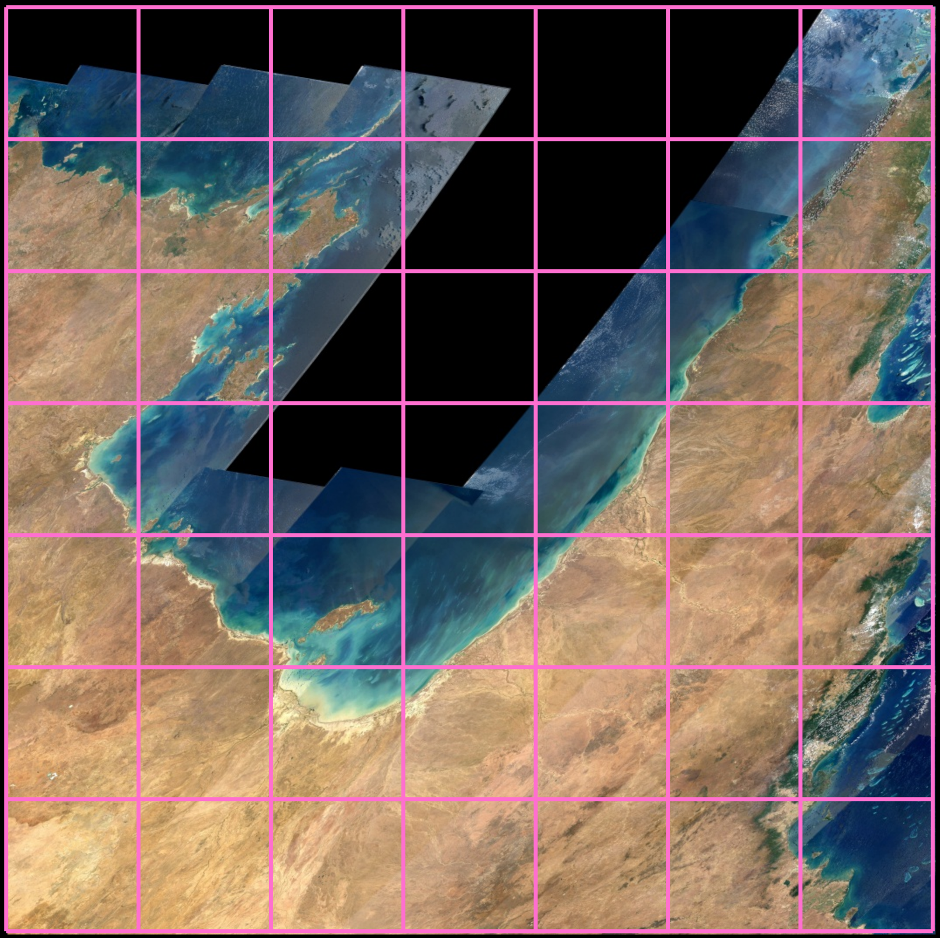
Gulf of Carpentaria, Australia



Gulf of Carpentaria, Australia

- Landsat 7 ETM+ & Landsat 5 TOA true color 30m reflectance composite
- Global WELD Version 2.2 monthly product
- October 2009

Landsat WELD tiling
(49 158 × 158 km tiles nested in each MODIS tiles)



- Landsat 7 ETM+ & Landsat 5 TOA true color 30m reflectance composite
- Global WELD Version 2.2 monthly product
- October 2009
- 7 x 7 WELD tiles nested within a single MODIS tile
- each 5295 x 5295 30m pixels (158 x 158 km)

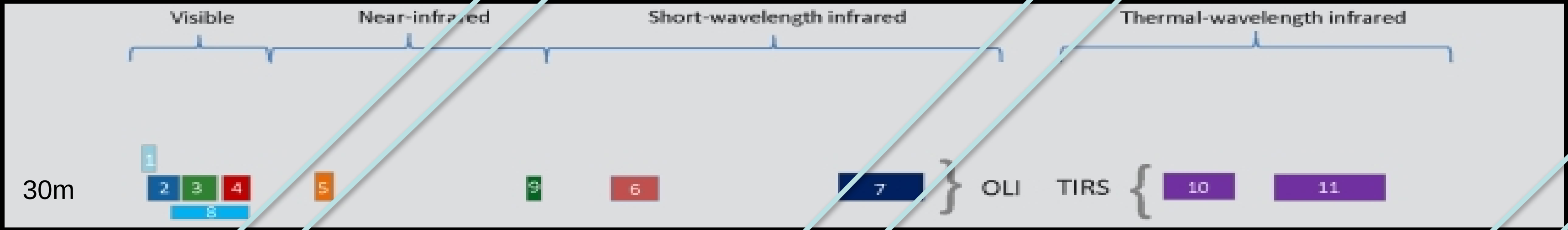
e.g., L57.Globe.month09.2009.hh31vv10.h1v7.doy248to273.v2.2.hdf

Compositing approach for Sentinel-2 & Landsat 8

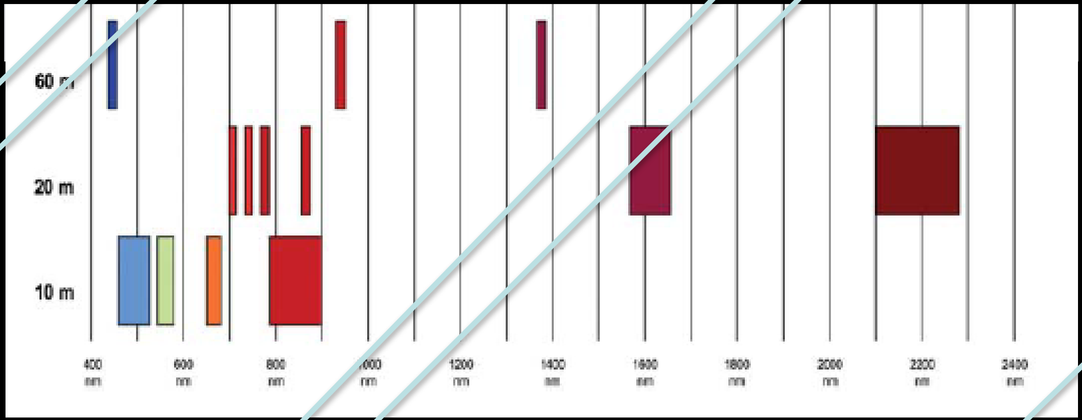
Best pixel selection compositing over reporting period

- L8 and S2 bands separately (some users want this)
- L8-S2 surface NBAR fused (others users want this)

L8



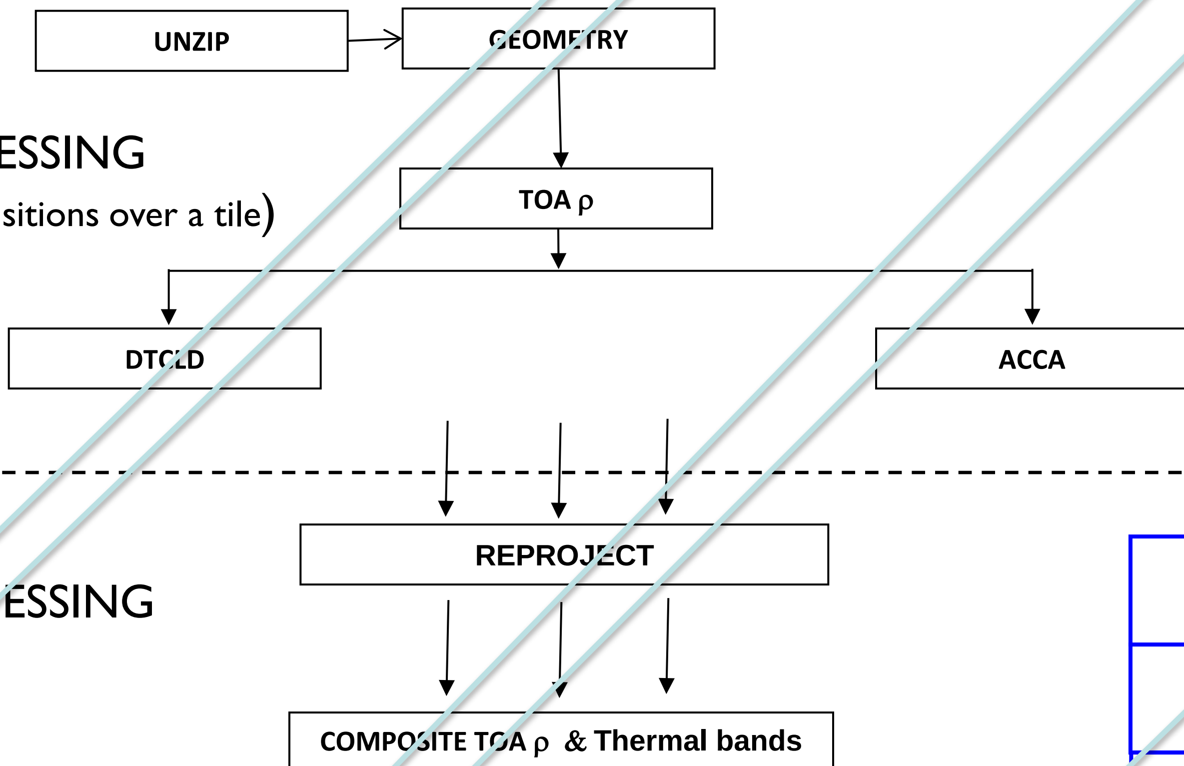
S2

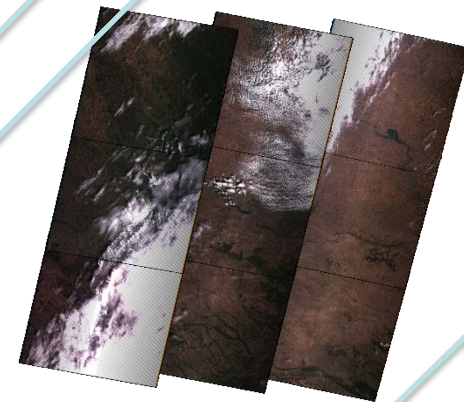


Landsat 8 (L8) and Sentinel 2 (S2) different spectral & spatial resolutions

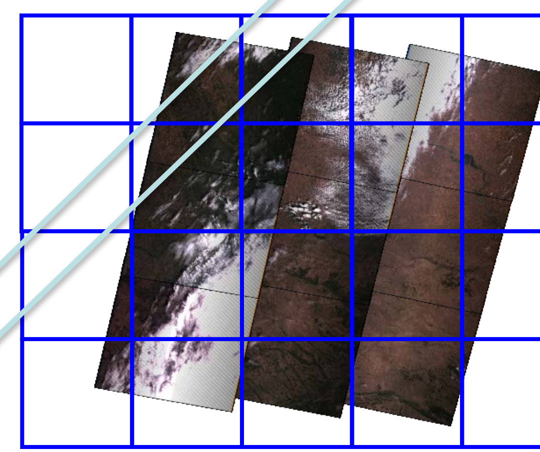
Overview of Global Version 2.2 WELD Processing Sequence

UTM PROCESSING
(Individual acquisitions over a tile)





TILE PROCESSING
(Tile)



WELD compositing applied to Top of Atmosphere (TOA) reflectance

because Landsat atmospheric correction is imperfect

Derived from

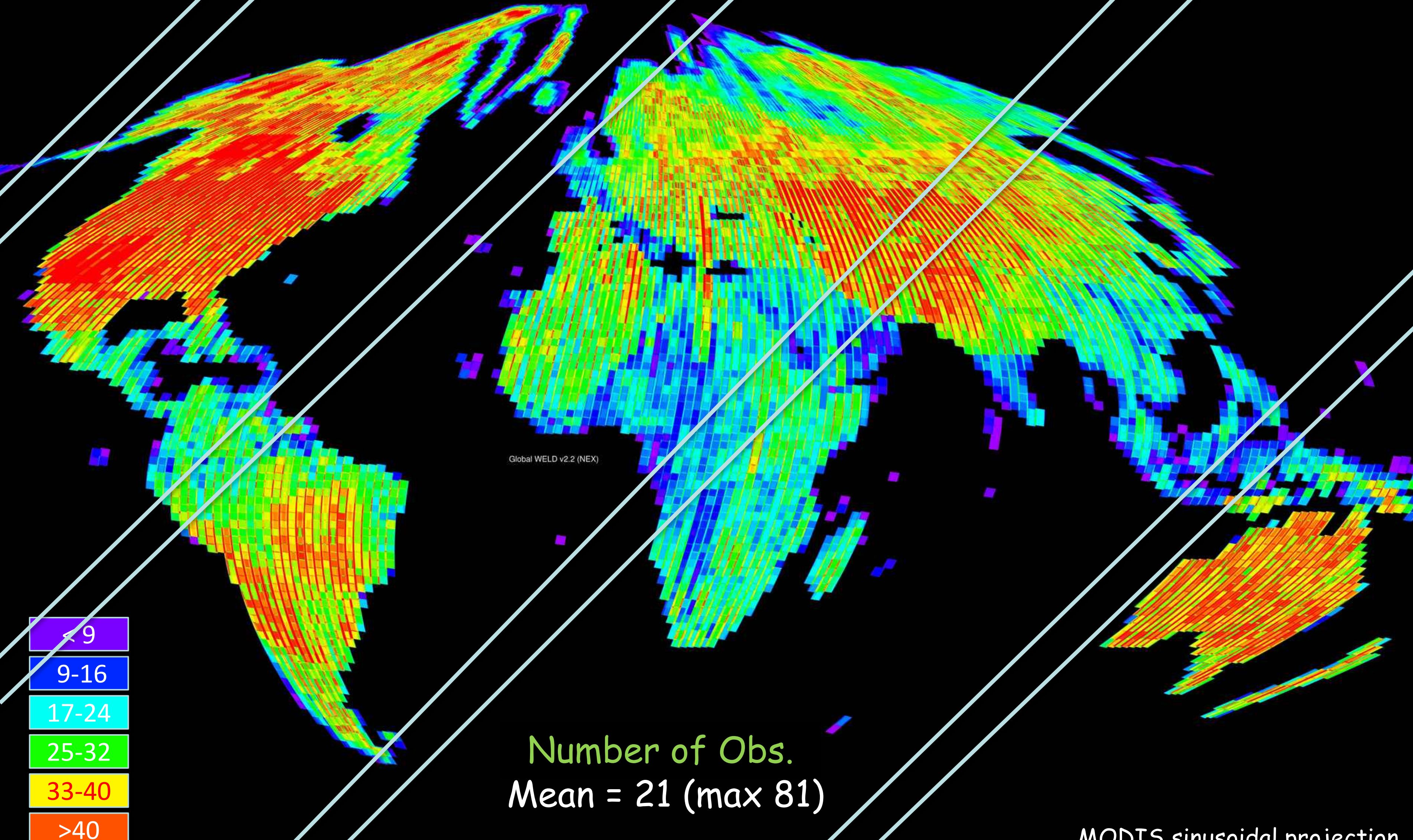
- 122 10x10km ETM+ subsets atmospherically corrected using 6SV and AERONET atmospheric characterization
- at 31 AERONET sites across U.S.

Landsat 7 Band	Mean normalized residual
1 (blue)	11.8%
2 (green)	5.7%
3 (red)	5.9%
4 (NIR)	4.8%
5 (MIR)	3.6%
7 (MIR)	5.2%
NDVI	6.3%

Ju, J., Roy, D., Vermote, E., Masek, J., Kovalskyy, V., 2012, Continental-scale validation of MODIS-based and LEDAPS Landsat ETM+ atmospheric correction methods, *Remote Sensing of Environment*, 122, 175–184

Global WELD NEX V2.2 Annual 2010 30m product

124,433 L1T scenes (45,711 Landsat 5 & 78,722 Landsat 7)



MODIS sinusoidal projection
29,652 x 14,826 1.35km browse pixels

Global WELD NEX V2.2 Annual 2010 30m product

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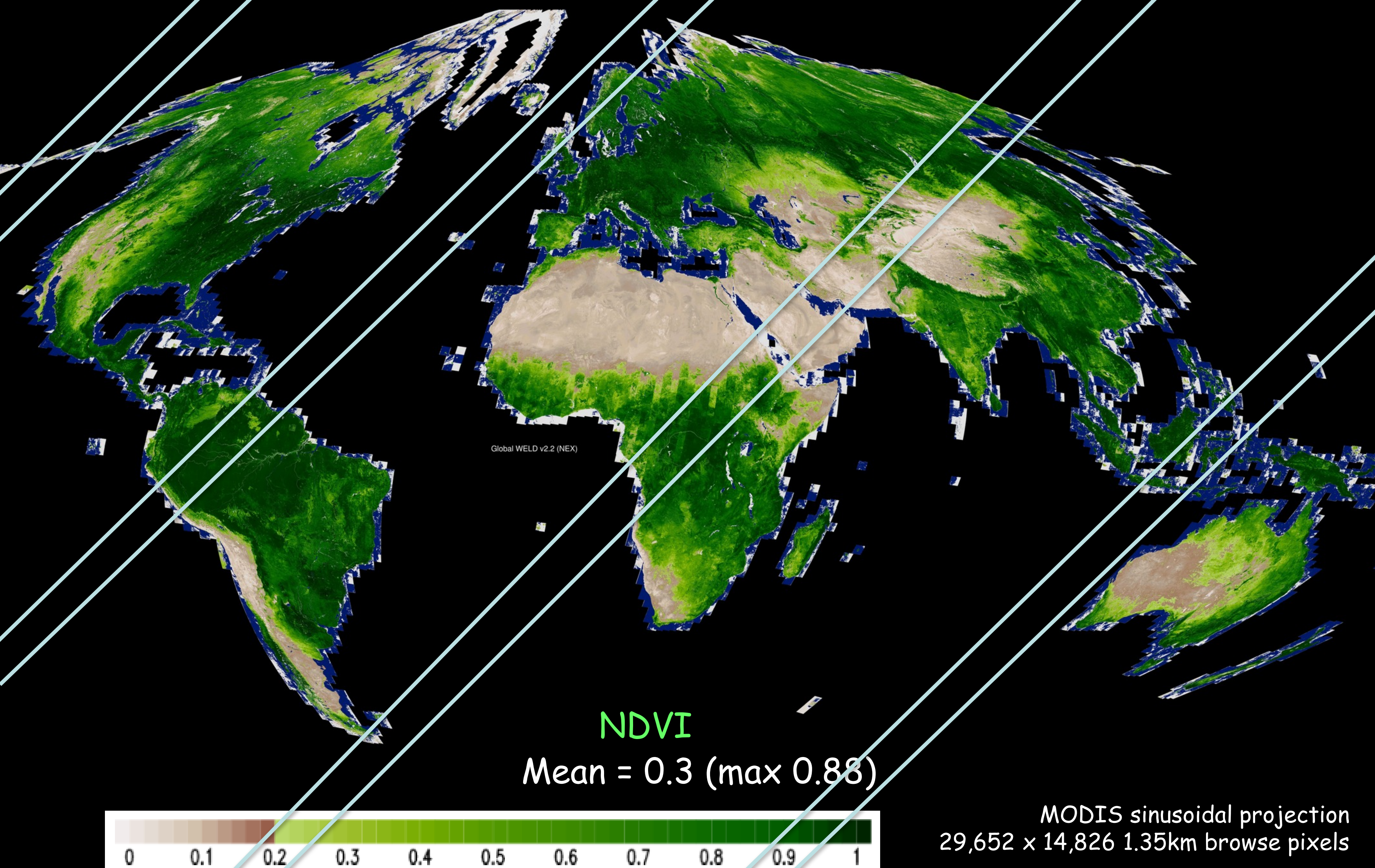


MODIS sinusoidal projection
29,652 x 14,826 1.35km browse pixels

Version 1.5 WELD compositing algorithm
Cloud QA & Max. NDVI & Max. BT heritage

Priority	Criteria	Selection
1	**IF** only one none-fill	non-fill
2	**IF** only one unsaturated	unsaturated
3	**IF** both unsaturated	Maximum (brightness temperature)
4	**IF** only one none-cloudy	none-cloudy
5	**IF** one cloudy and one uncertain cloud	select uncertain cloud if it has greater brightness temperature or greater NDVI, else select cloudy
6	**IF** one non-cloudy and one uncertain cloud	select non-cloud if it has greater brightness temperature or greater NDVI, else select uncertain cloud
7	**IF** either below NDVI 0.09	select the one with greatest brightness temperature
8	ELSE	Maximum (NDVI)

clouds

"unvegetated"

vegetated

Roy, D.P., Ju, J., Kline, K., Scaramuzza, P.L., Kovalskyy, V., Hansen, M.C., Loveland, T.R., Vermote, E.F., Zhang, C., 2010, Web-enabled Landsat Data (WELD): Landsat ETM+ Composited Mosaics of the Conterminous United States, *Remote Sensing of Environment*, 114: 35-49.

Landsat 7 (L1T) scene projected into the WELD Albers grid

Day 74

true color
TOA
reflectance

Florida

500 x 400
30m pixels

Landsat 7 (L1T) scene projected into the WELD Albers grid

Day 90

true color
TOA
reflectance

Florida

500 x 400
30m pixels

WELD Version 1.5 monthly Composite

March

true color
TOA
reflectance

Florida

500 x 400
30m pixels

WELD Version 1.5 monthly Composite

March

true color
TOA
reflectance

Florida

500 x 400
30m pixels

Shadow & cloud edge issues over vegetation !

Landsat 7 (L1T) scene projected into the WELD Albers grid

Day 124

true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

Landsat 7 (L1T) scene projected into the WELD Albers grid

Day 140

true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

WELD Version 1.5 monthly Composite

May

true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

WELD Version 1.5 monthly Composite

May

true color
TOA
reflectance

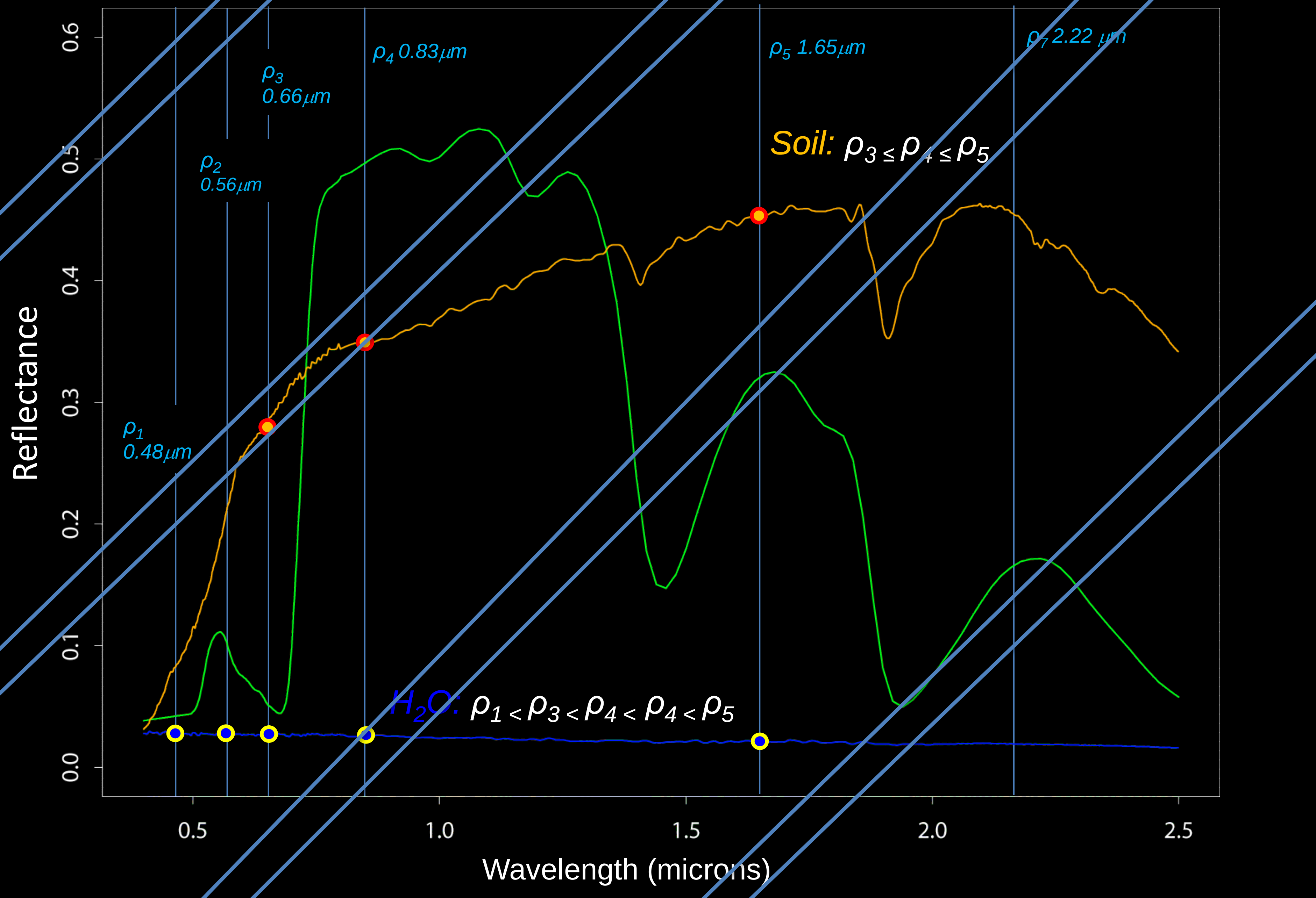
South
Dakota

500 x 400
30m pixels

Shadow & atmospheric contamination issues over soil !

Version 2.2 compositing algorithm

Use threshold free Soil & also Water Tests



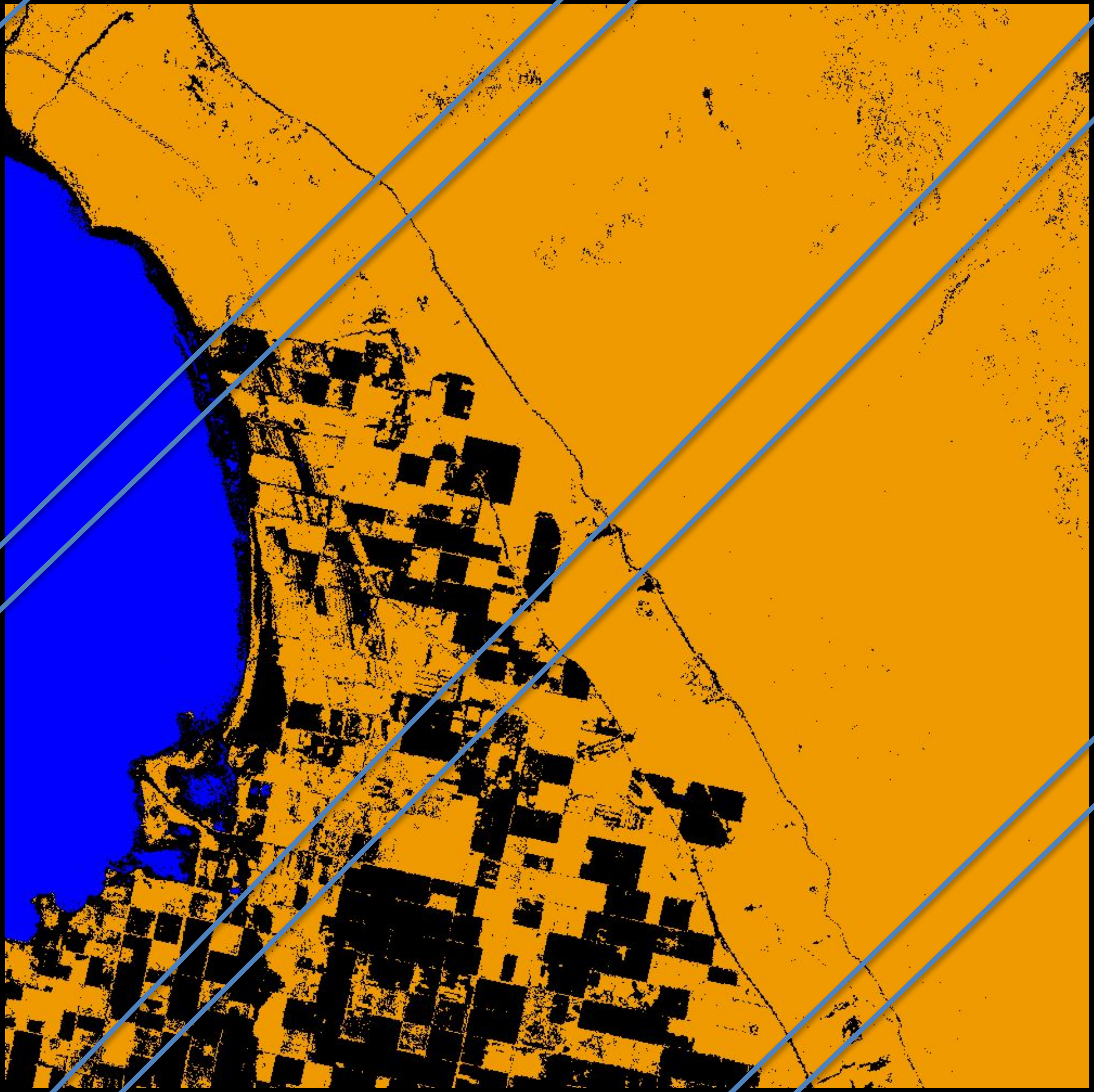
April
2008

true color
TOA
reflectance

California

500 x 400
30m pixels

soil and water test results



April
2008
true color
TOA
reflectance

California

500 x 400
30m pixels

WELD Version 1.5 monthly Composite

May 2008

true color TOA reflectance

South Dakota

500 x 400 30m pixels

WELD Version 2.2 monthly Composite

May
2008
true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

WELD Version 1.5 monthly Composite

March
2008
true color
TOA
reflectance

Florida

500 x 400
30m pixels

WELD Version 2.2 monthly Composite

March
2008
true color
TOA
reflectance

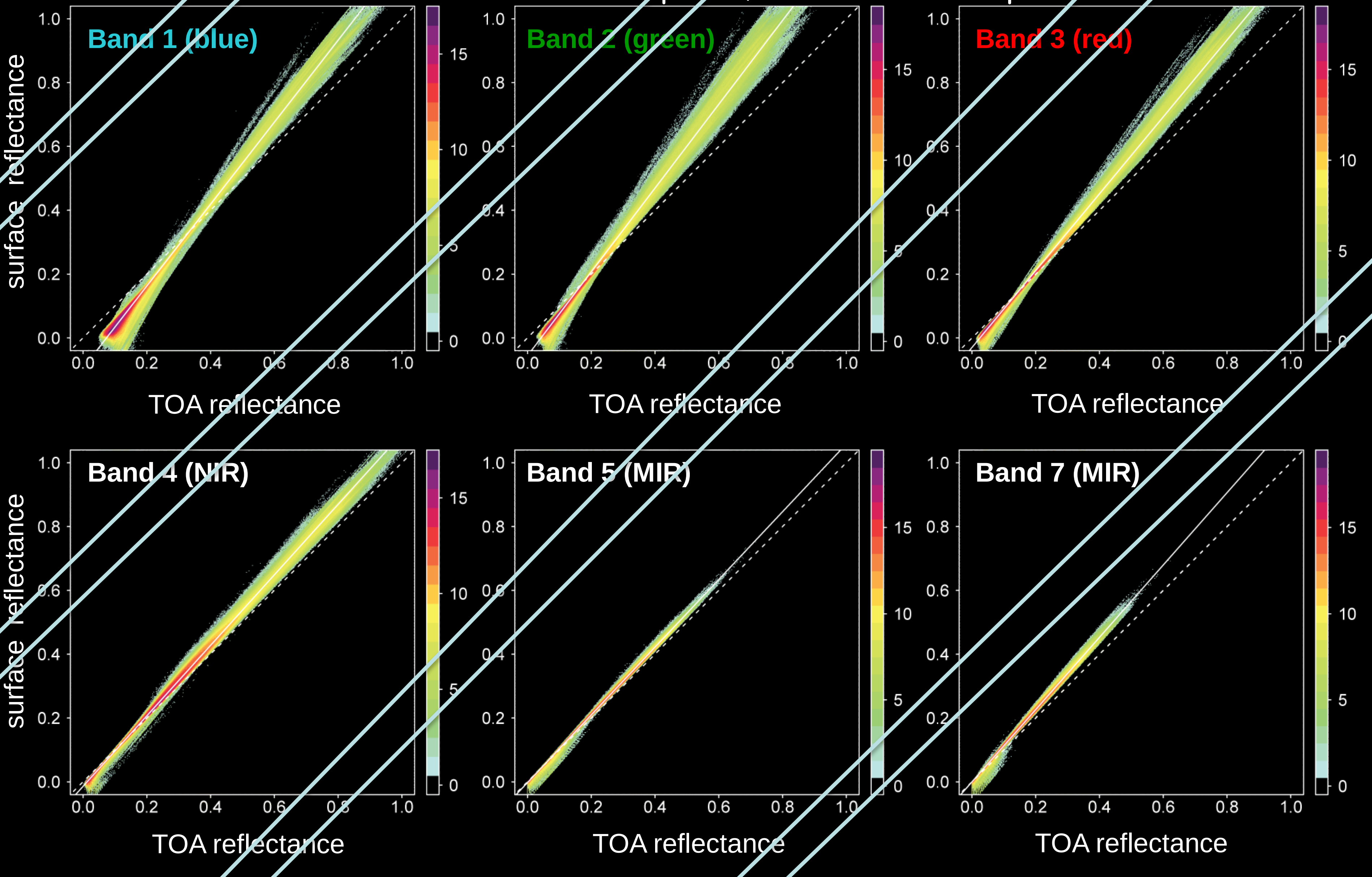
Florida

500 x 400
30m pixels

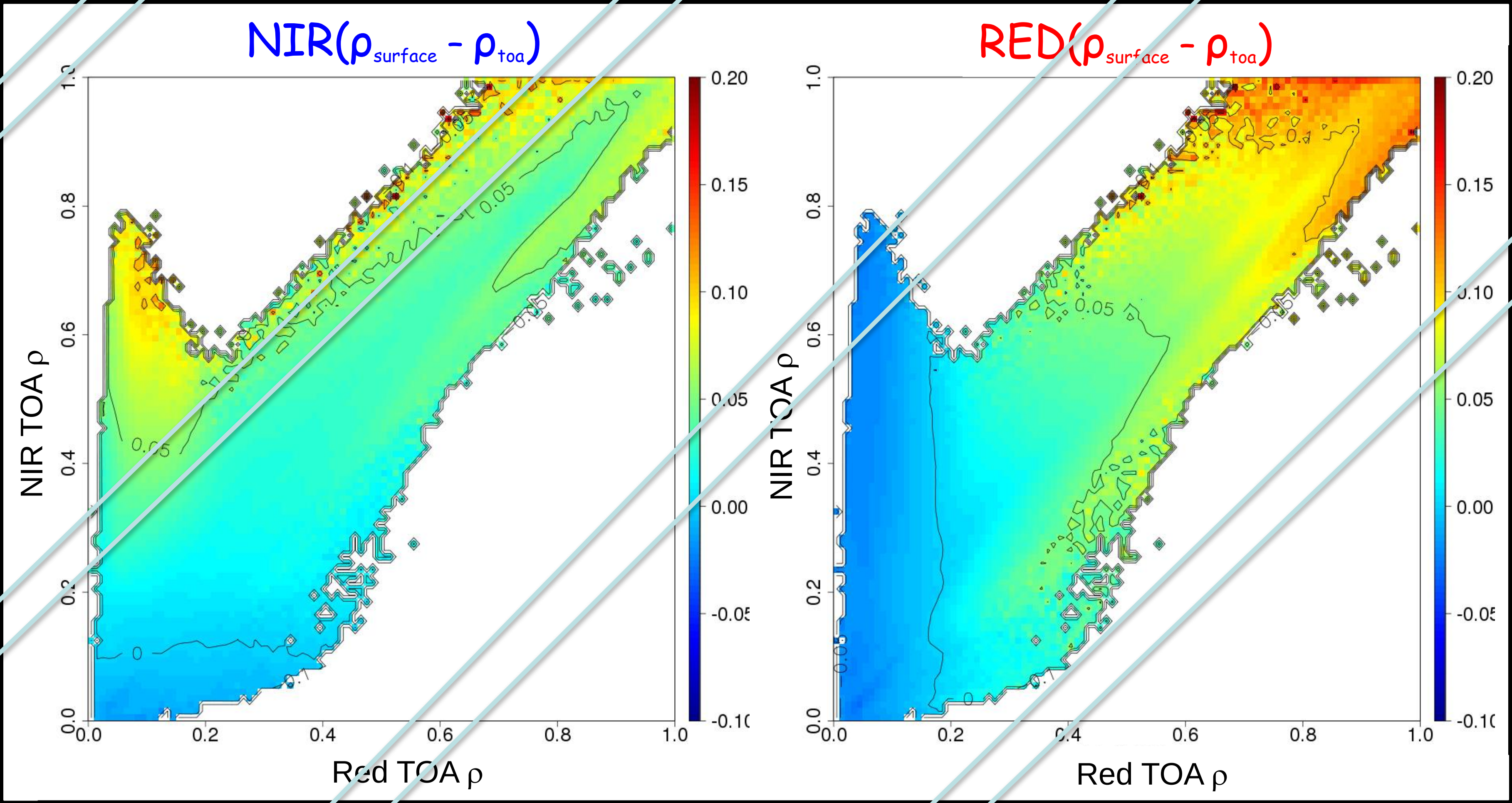
Version 3.0 compositing algorithm

V3.0 compositing algorithm informed by analysis of impact of atmosphere on WELD TOA reflectance

Pixels sampled every 40 pixels across CONUS from 12 monthly WELD composites, ignoring cloud and saturated WELD pixels, ~ 53 million 30m pixels



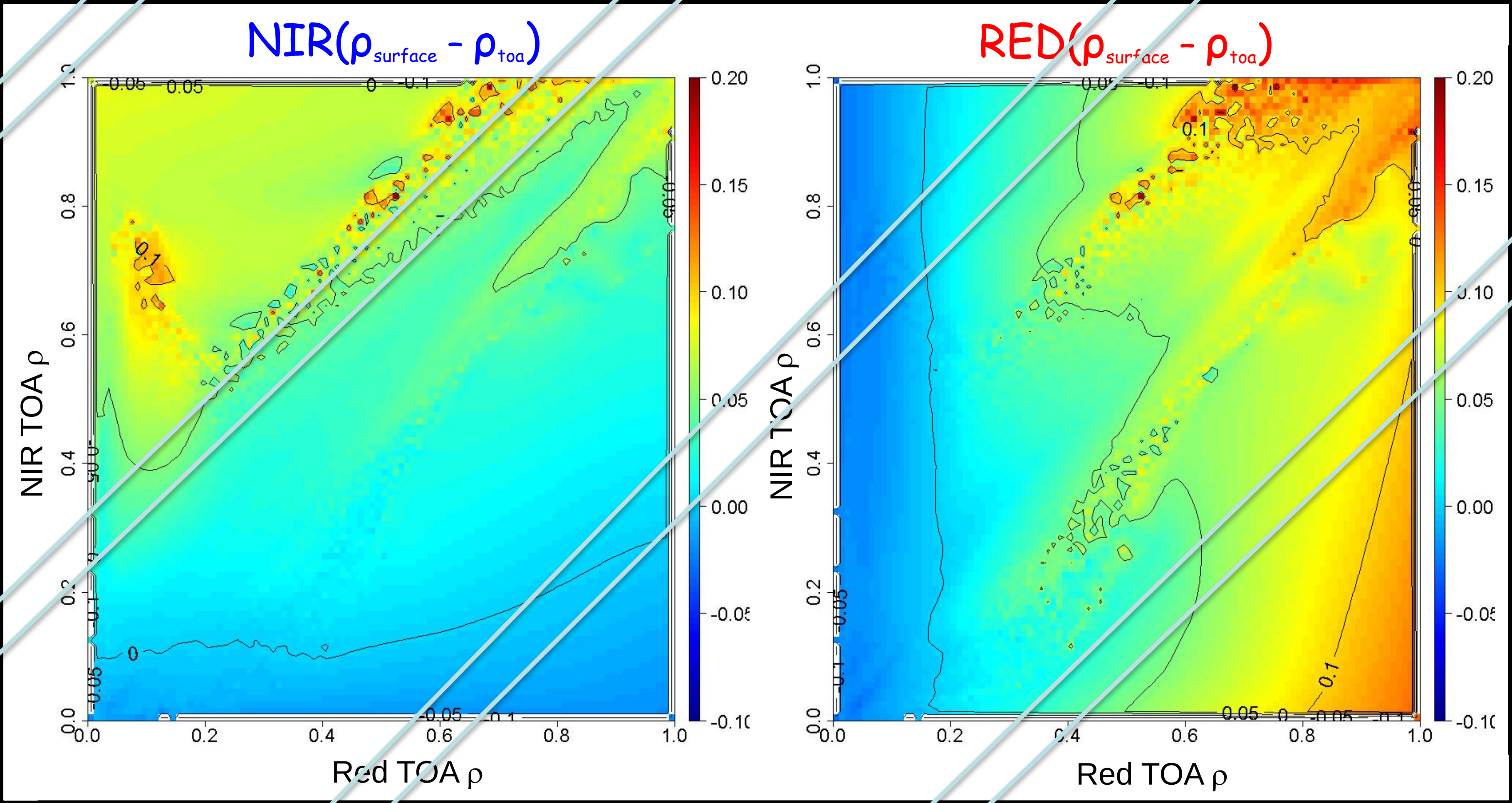
Spectral Lookup table of $\rho_{surface} - \rho_{toa}$ differences for red and NIR Landsat bands



generated from 90,542,838 30m CONUS pixel comparisons

Spectral Lookup table of $\rho_{surface} - \rho_{toa}$ differences for red and NIR Landsat bands

Natural neighbor interpolated to 0-1 reflectance range



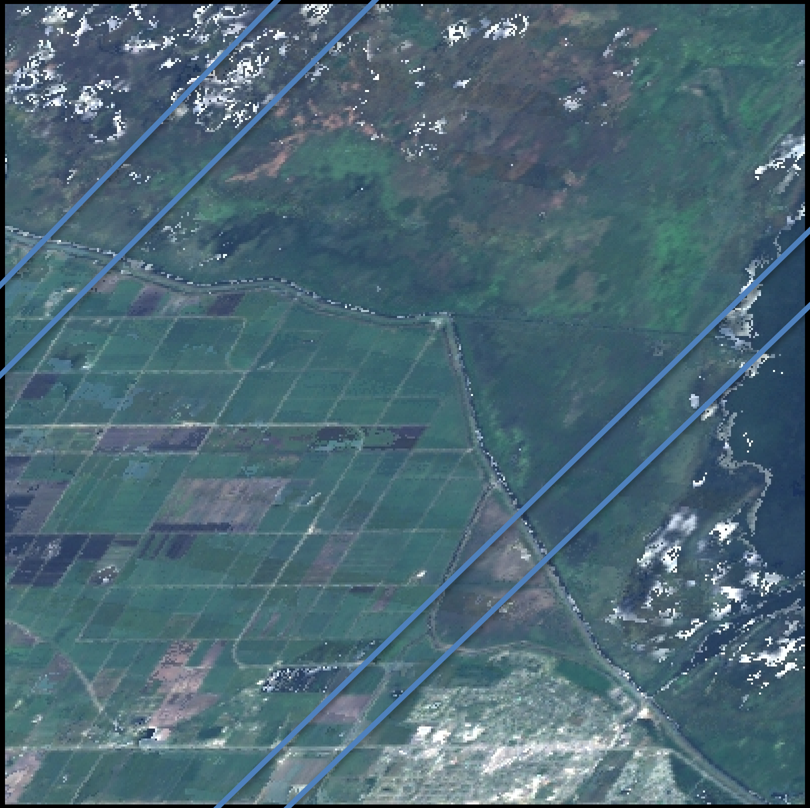
generated from 90,542,838 30m CONUS pixel comparisons

Global WELD June 2010 month composite TOA ρ version 2.2 algorithm

Columbia River Valley, Grant Country International Airport

Generated from 3 Landsat 5 & 3 Landsat 7

Central Florida Wetlands, Lake Okeechobee



Generated from 1 Landsat 5 & 2 Landsat 7

Global WELD June 2010 month composite TOA ρ version 3.0 algorithm

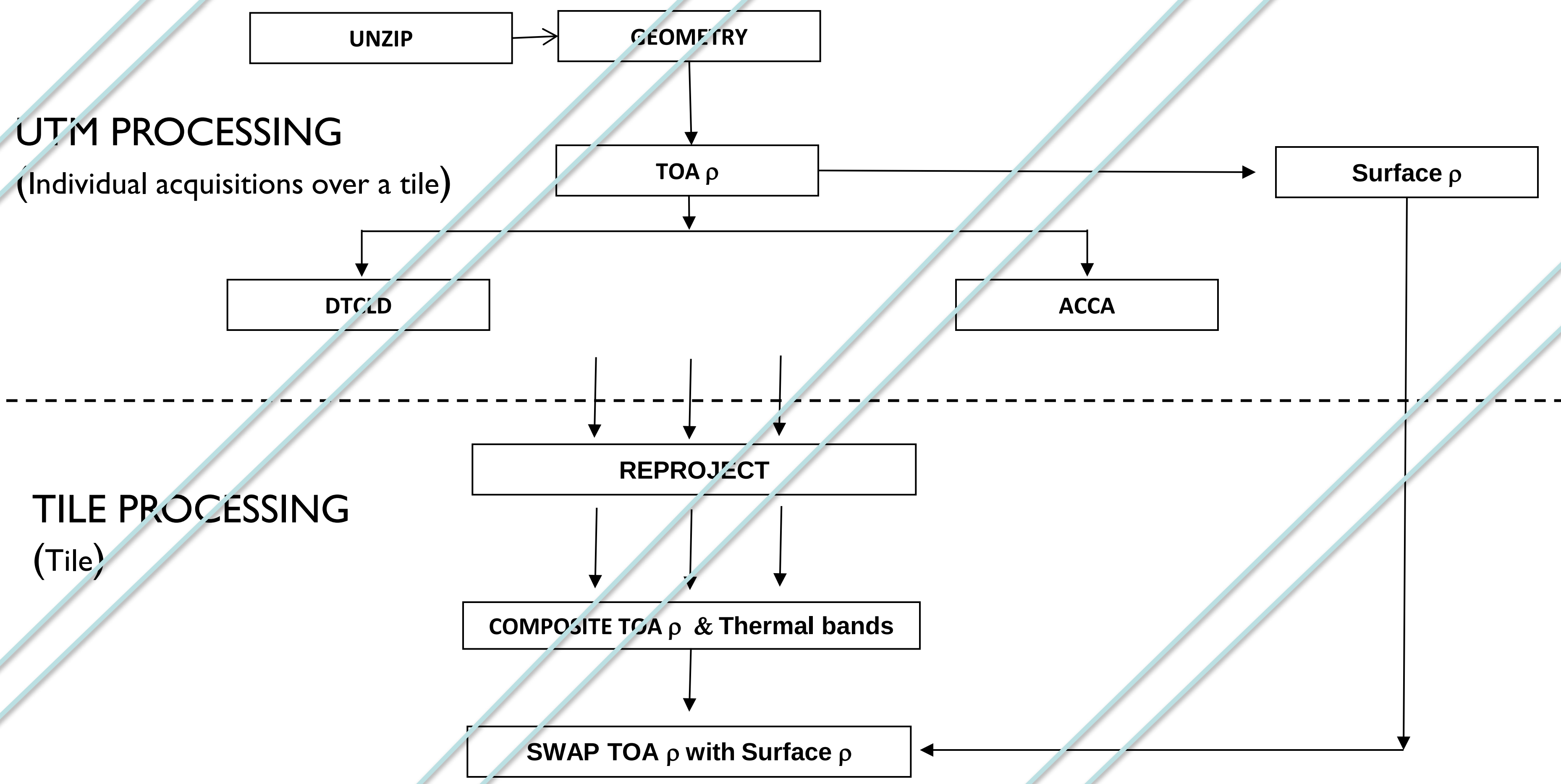
Columbia River Valley, Grant Country International Airport

Generated from 3 Landsat 5 & 3 Landsat 7

Central Florida Wetlands, Lake Okeechobee

Generated from 1 Landsat 5 & 2 Landsat 7

Overview of Global Version 3.0 WELD Processing Sequence



Global WELD June 2010 month composite TOA ρ version 3.0 algorithm

Columbia River Valley, Grant Country International Airport

Generated from 3 Landsat 5 & 3 Landsat 7

Central Florida Wetlands, Lake Okeechobee

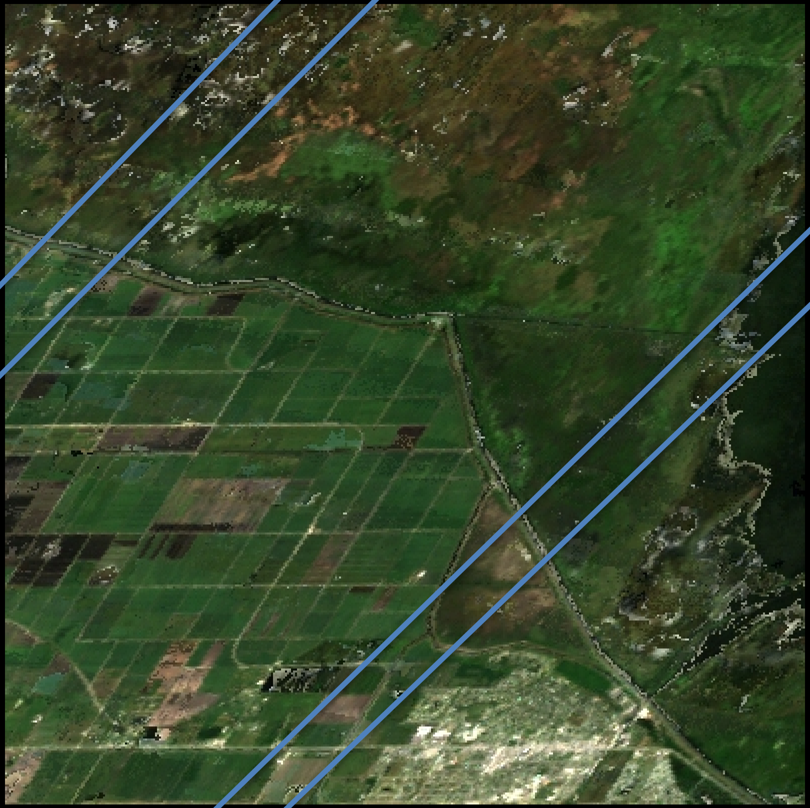
Generated from 1 Landsat 5 & 2 Landsat 7

Global WELD June 2010 month composite surface ρ version 3.0 algorithm

Columbia River Valley, Grant Country International Airport

Generated from 3 Landsat 5 & 3 Landsat 7

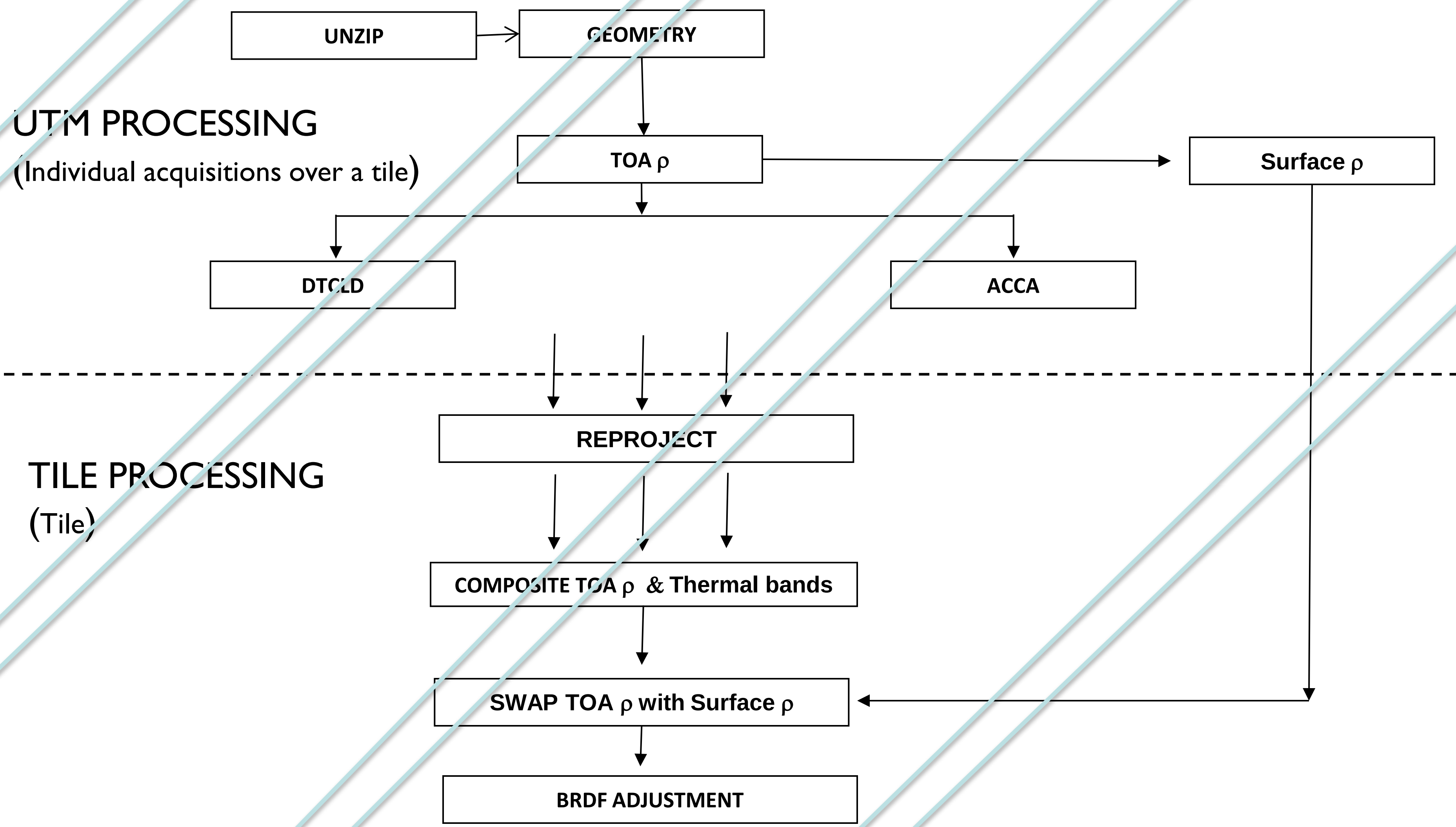
Central Florida Wetlands, Lake Okeechobee



Generated from 1 Landsat 5 & 2 Landsat 7

LEDAPS atmospheric correction

Overview of Global Version 3.0 WELD Processing Sequence



Landsat MODIS-based BRDF Adjustment c-factor method

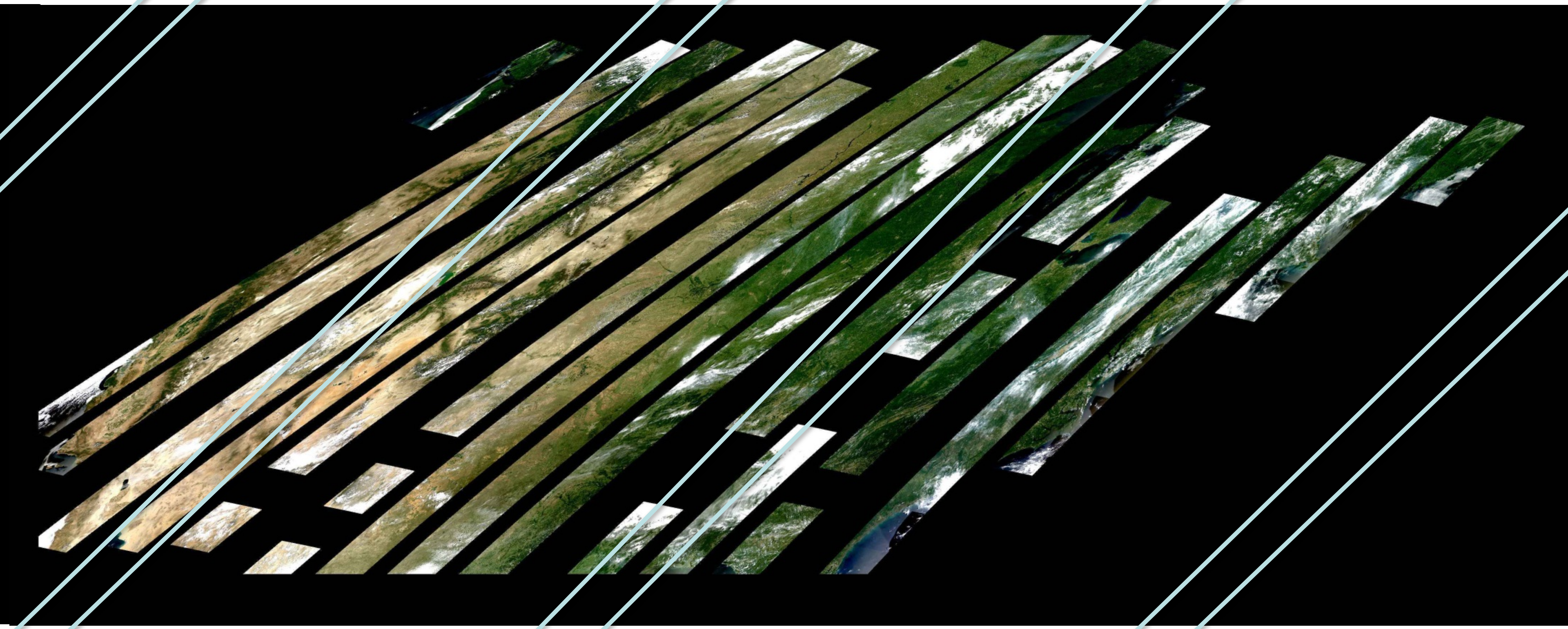
$$\hat{\rho}_{ETM+,t1}\left(\lambda_{ETM+},\Omega_{nadir},\Omega'_{solar\ noon}\right)=c\times\rho_{ETM+,t1}\left(\lambda_{ETM+},\Omega_{observed},\Omega'_{observed}\right)$$

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

$\hat{\rho}_{MODIS}$ 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.

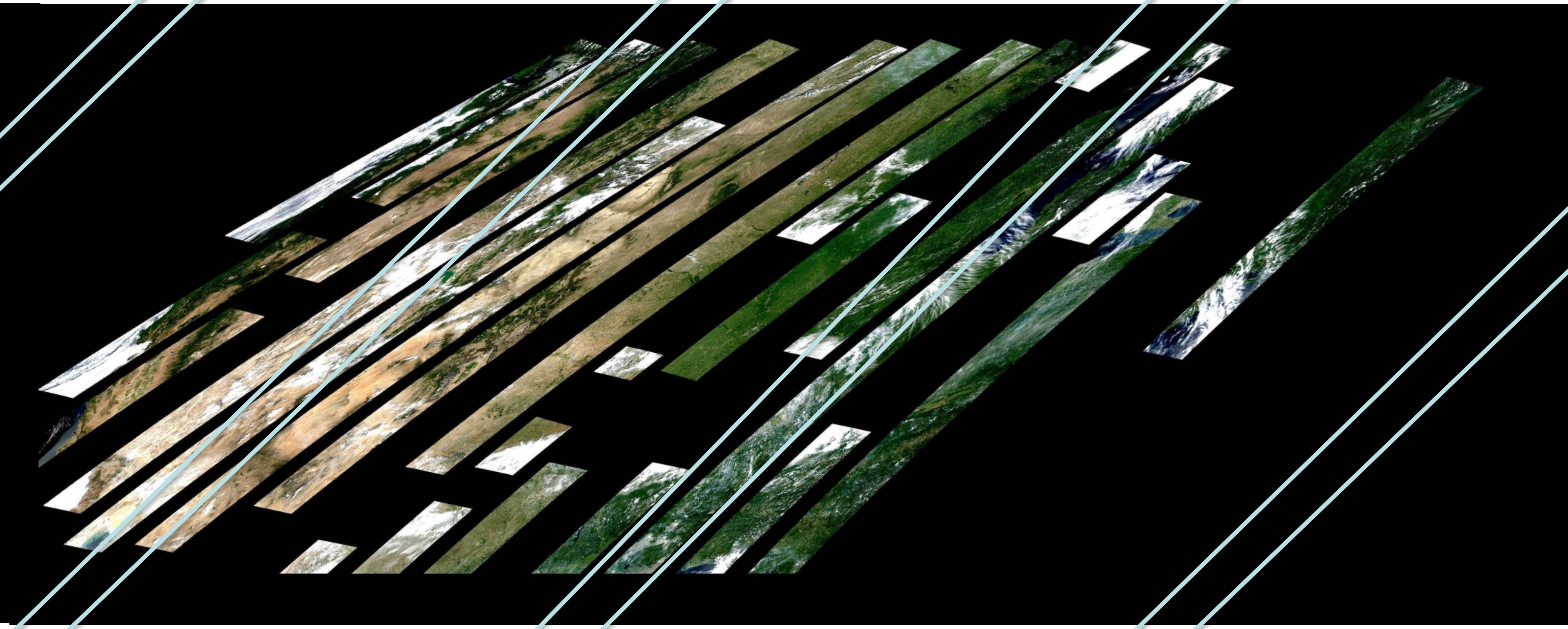
Conterminous United States (CONUS) Landsat 5 true color surface reflectance (week 27, 2010)



MODIS sinusoidal projection

Atmospherically corrected with LEDAPS code

Conterminous United States (CONUS) Landsat 7 true color surface reflectance (week 27, 2010)

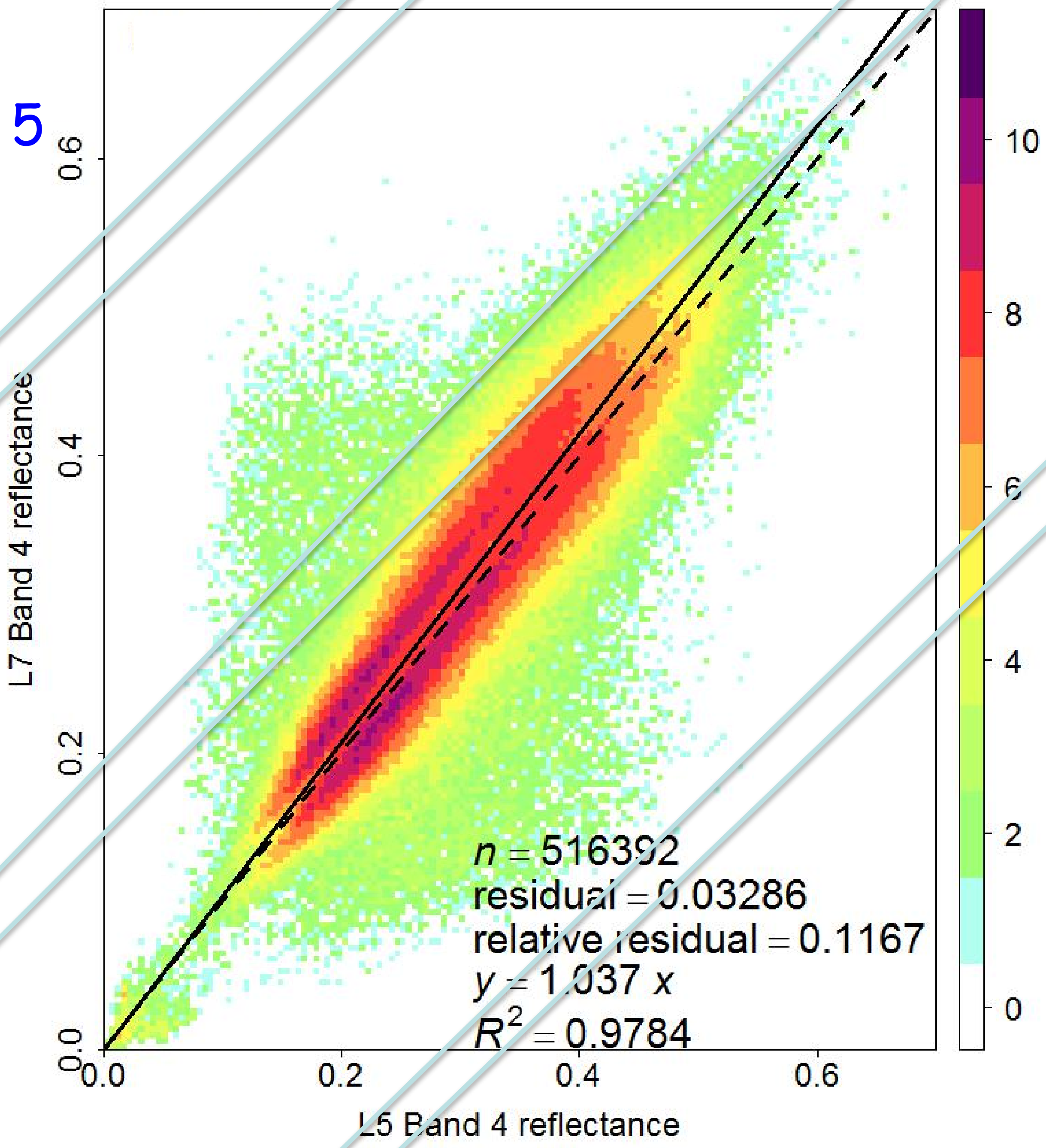


MODIS sinusoidal projection

Atmospherically corrected with LEDAPS code

Scatterplot of Landsat 7 vs Landsat 5 NIR surface reflectance

516,392 overlapping Landsat 5 & 7 pixels (found by considering every 40th WELD tile non-cloudy pixel across the CONUS)

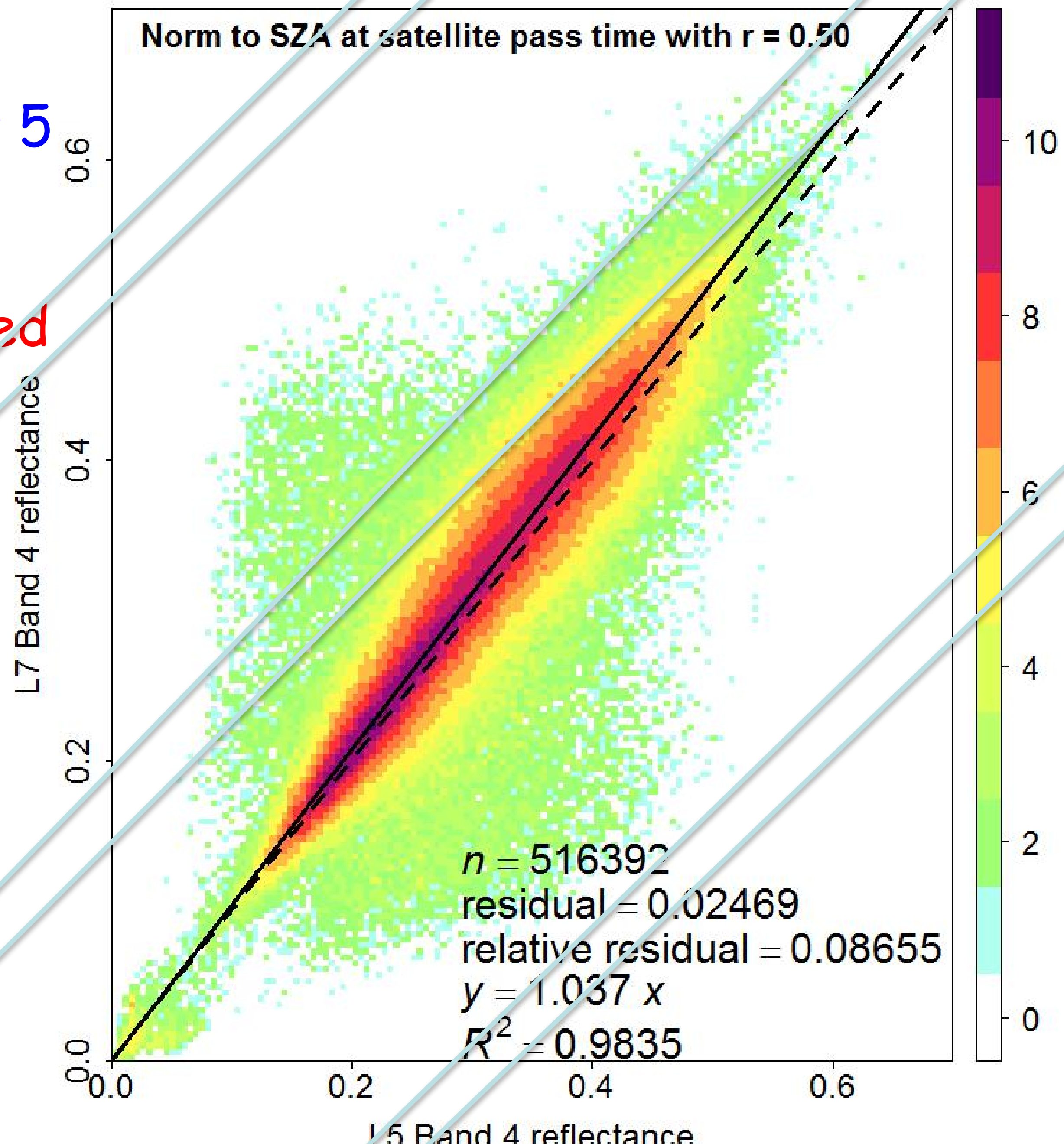


Scatterplot of Landsat 7 vs Landsat 5

MODIS MCD43 BRDF parameter climatology normalized to nadir & satellite overpass solar zenith

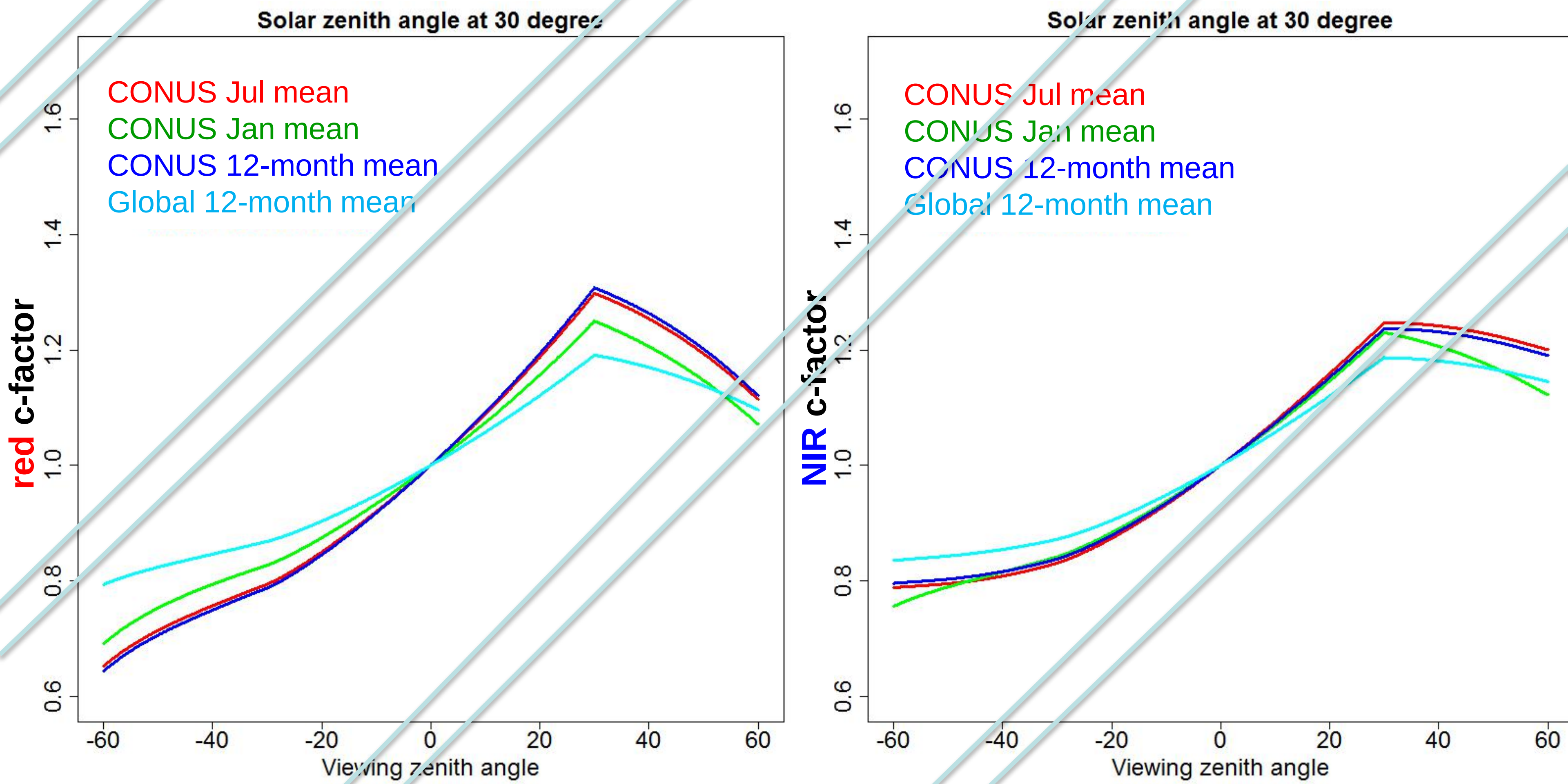
NIR surface reflectance

516,392 overlapping Landsat 5 & 7 pixels (found by considering every 40th WELD tile non-cloudy pixel across the CONUS)



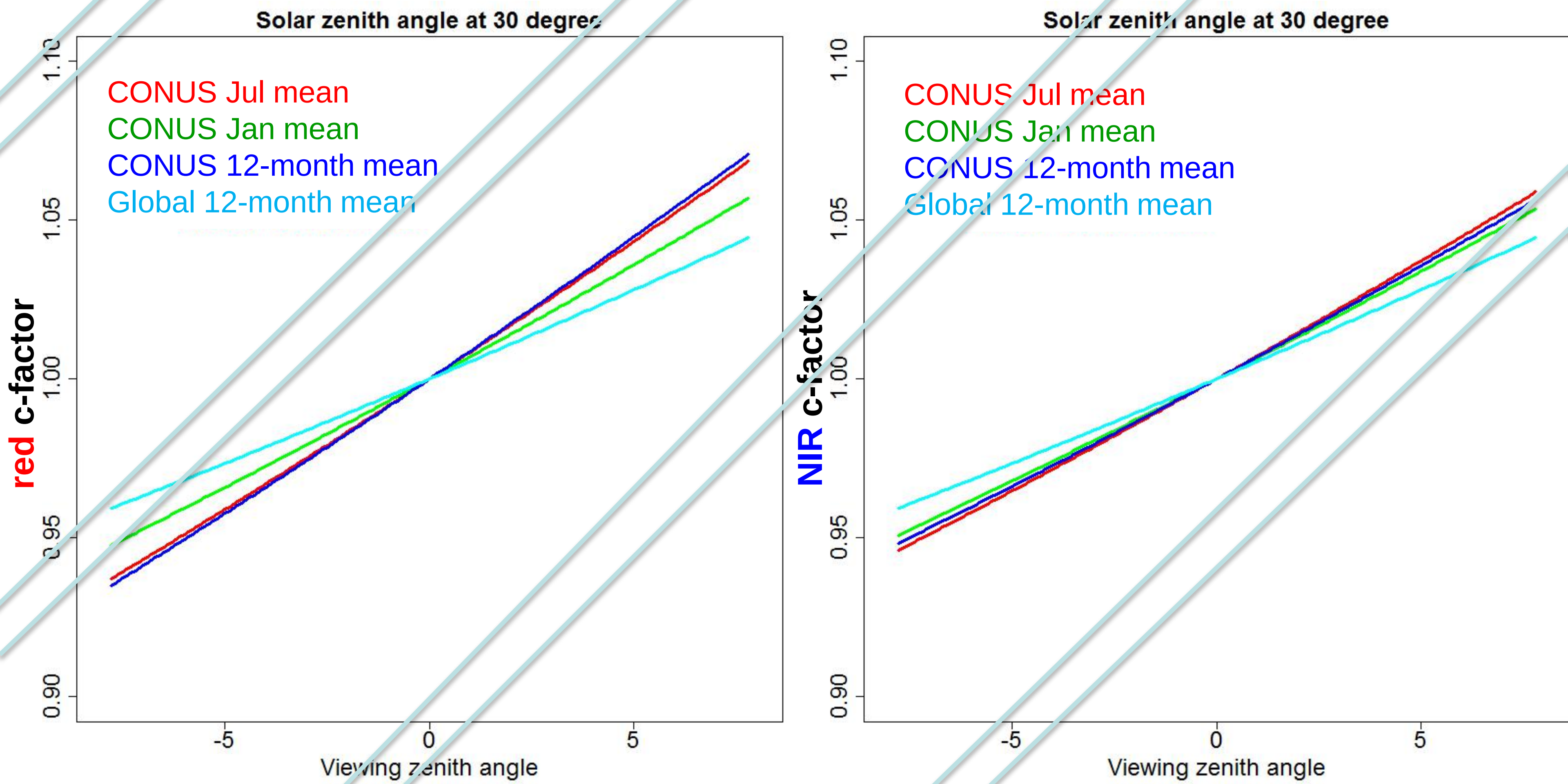
c-factors over MODIS 110° FOV

$$\rho(\lambda,\Omega,\Omega') = f_{iso}(\lambda) + f_{vol}(\lambda)k_{vol}(\Omega,\Omega') + f_{geo}(\lambda)k_{geo}(\Omega,\Omega')$$

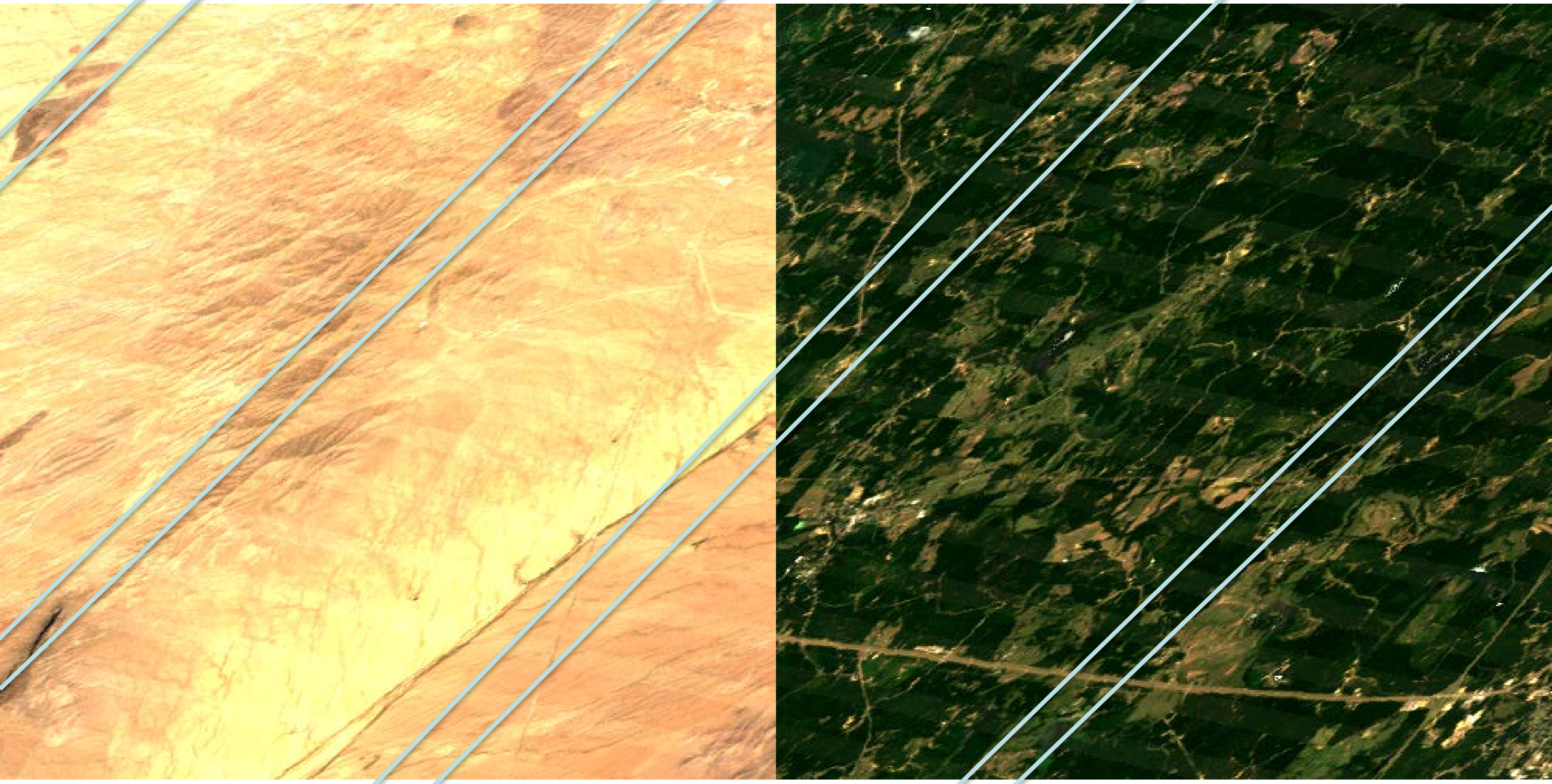


c-factors over Landsat 15° FOV

(similar over Sentinel-2 20.6° FOV)



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



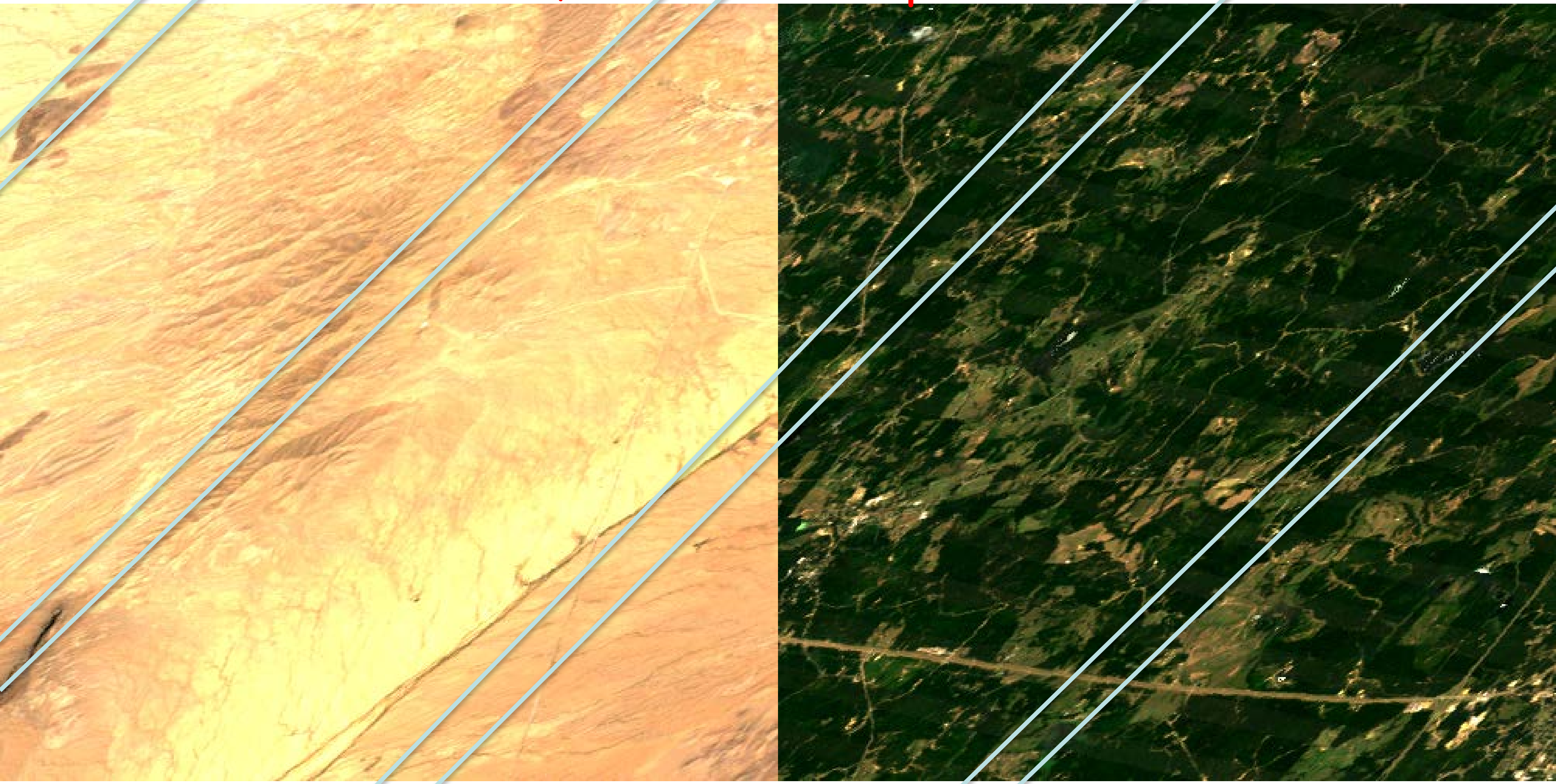
Arizona

500 x 500 30m pixels

Mississippi

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

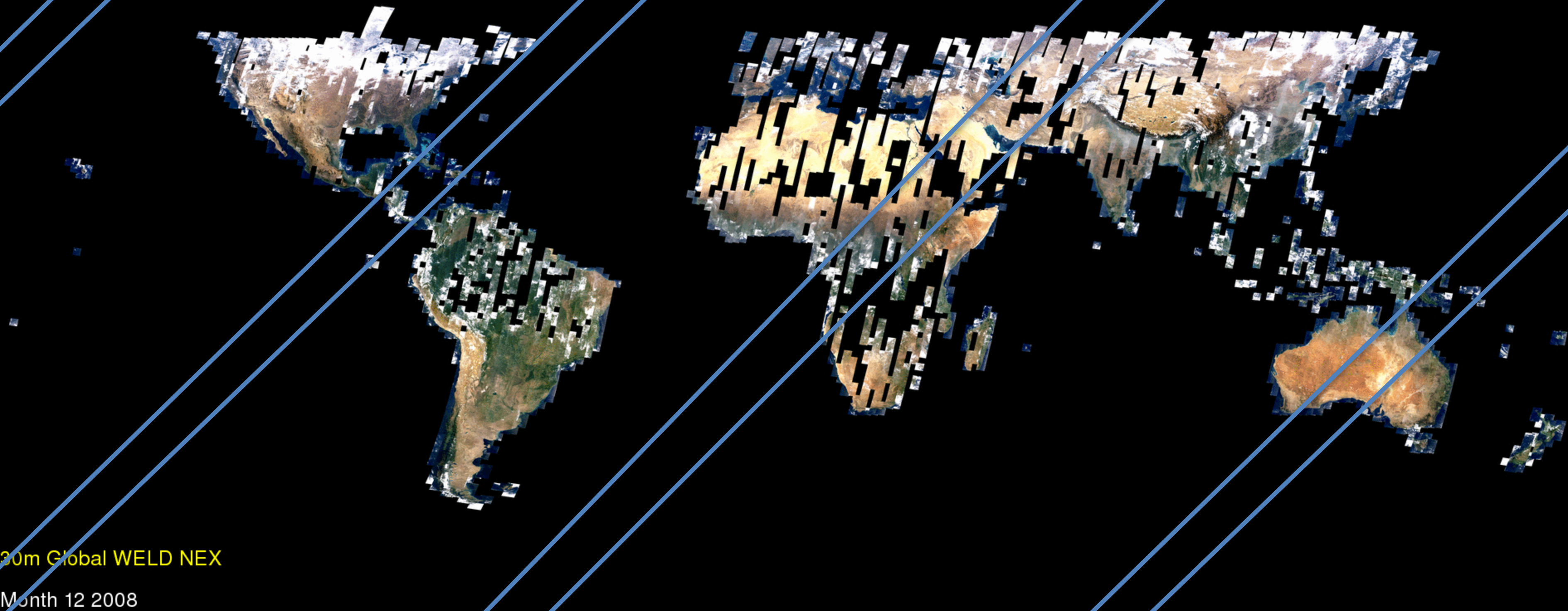
NBAR (global 12-month 3 mean MDC43 model parameters) nadir view zenith , satellite overpass time solar zenith



Arizona
500 x 500 30m pixels

Mississippi

3 Years global 30m monthly & annual WELD Version 2.2 products now available



Reprocessed Version 3.0 will be available this Summer

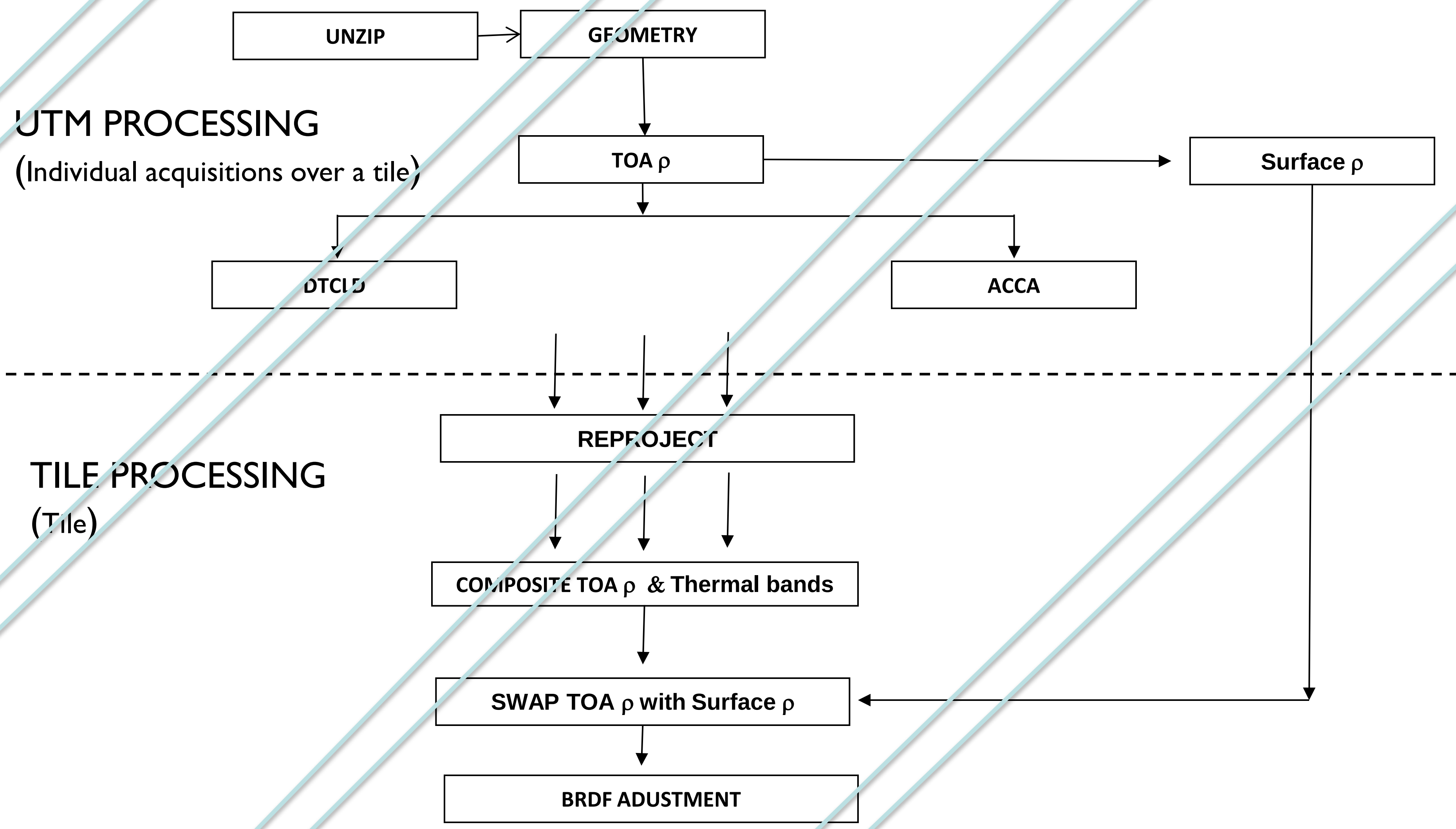
GeoTiff format products: http://globalweld.cr.usgs.gov

HDF format products: http://globalweld.cr.usgs.gov/collections

Global Version 3.0 WELD processing sequence

Will work to generate

- similar but separate L8 and S2 gridded products
- combined L8-S2 gridded products (more research needed)



Key Dates

- Abstract submission deadline : 1st May
- Notification of abstract acceptance : 1st June
- Submission of full paper (maximum 4 pages) : 1st September
- Early bird registration deadline : 1st July
- Final registration deadline : 3rd September
- Workshop proposal deadline : 1st May

http://rspsoc2015.org/