National Aeronautics and Space Administration

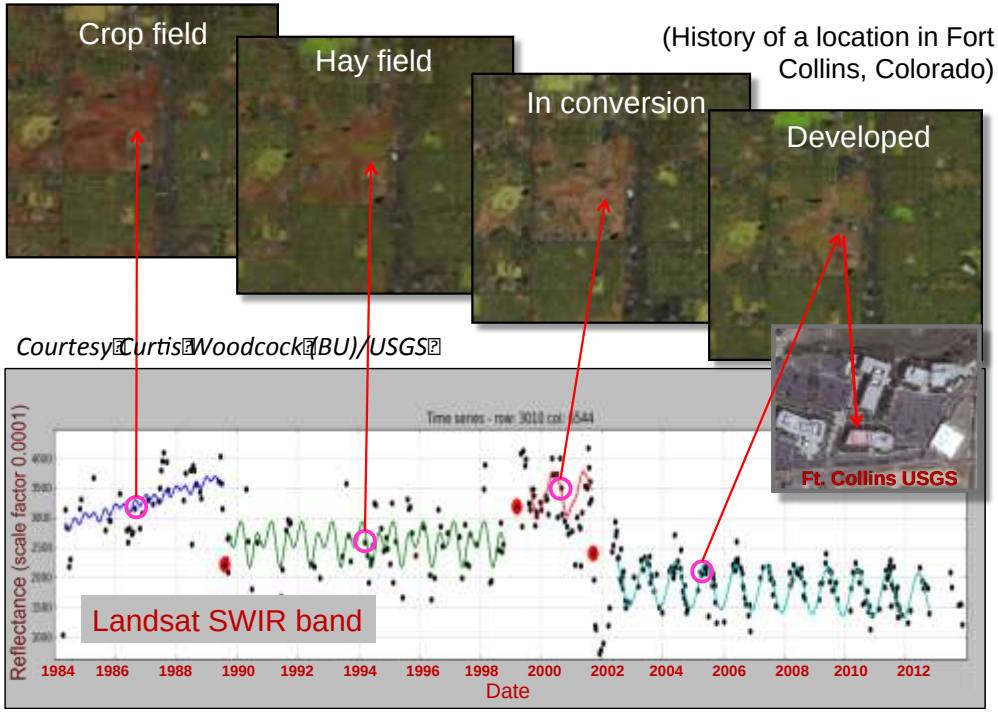
Harmonized Landsat/Sentinel-2 (HLS) Project

Jeff Masek, Junchang Ju, Eric Vermote, NASA GSFC
Martin Claverie, Jean-Claude Roger, Sergii Skakun, University of Maryland
Jennifer Dungan, NASA ARC
LCLUC - April 14 2017

The Promise of Multi-source Data

- Time series observations increasingly central to land monitoring
  - *Inter-annual disturbance, land use change*
  - *Intra-annual phenology, vegetation condition, agriculture*
  - *Desire for a "Daily 30m" capability*

- Harnessing the diversity of international remote sensing systems can provide this capability, at a fraction of the cost of a new mission

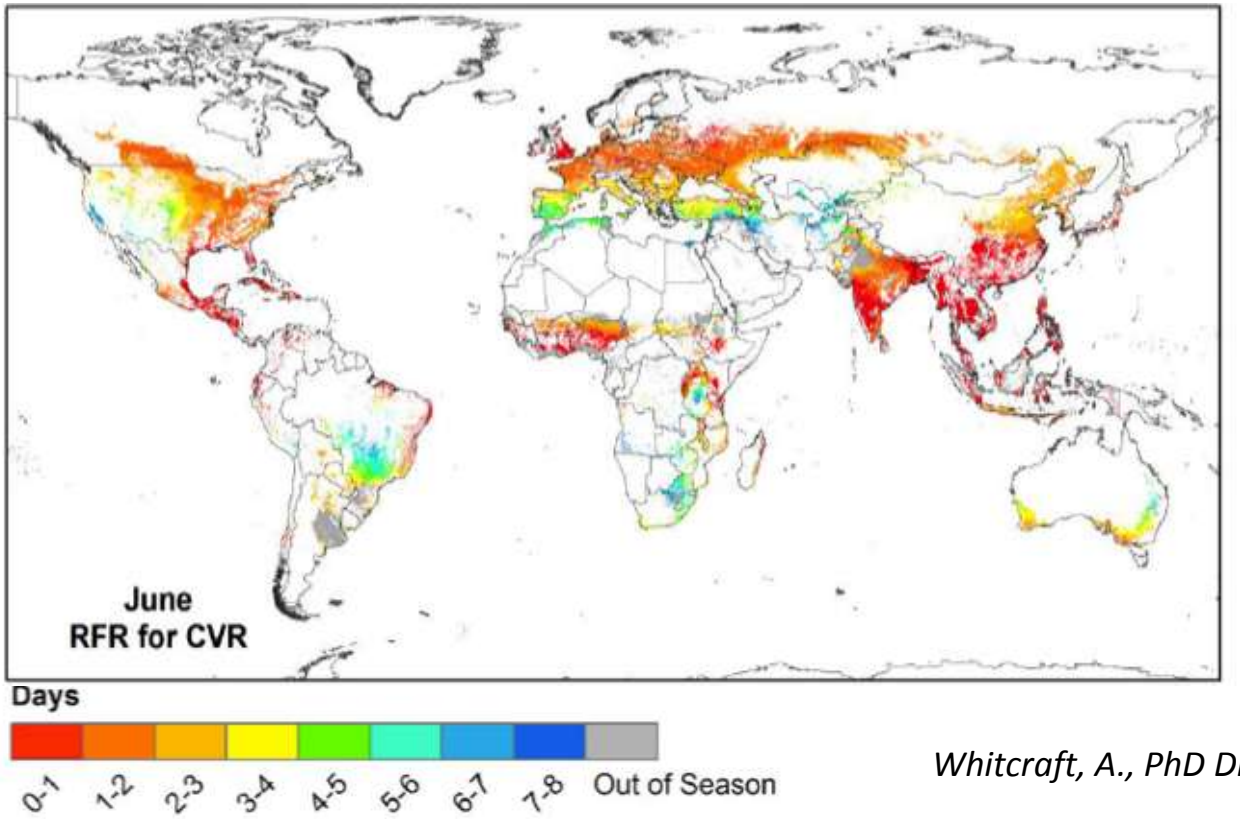


Courtesy C. Woodcock/USGS

What Temporal Revisit Do We Need?

- GEO Global Agricultural Monitoring (GEO-GLAM) requires weekly, cloud free views for crop type & condition assessments

  … but that really means imagery every 2-3 days

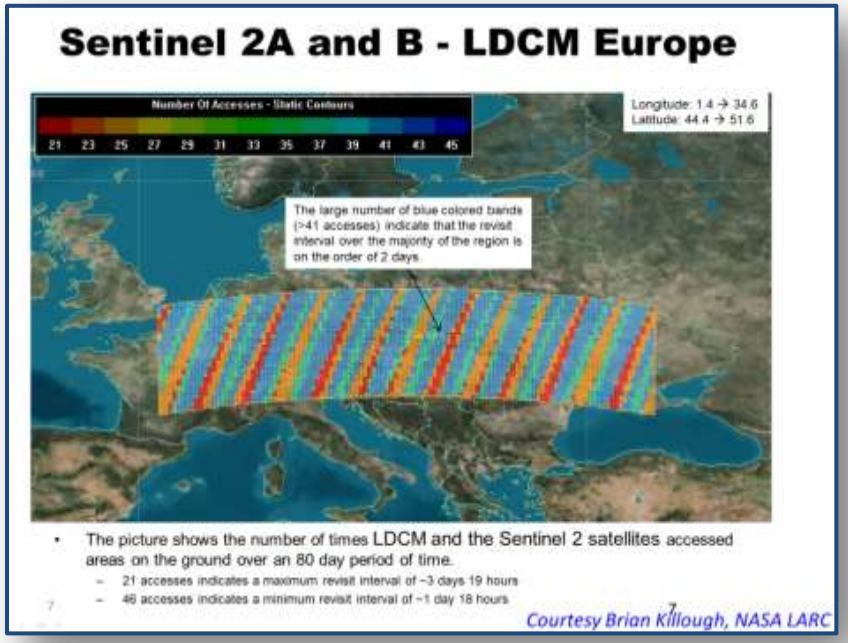


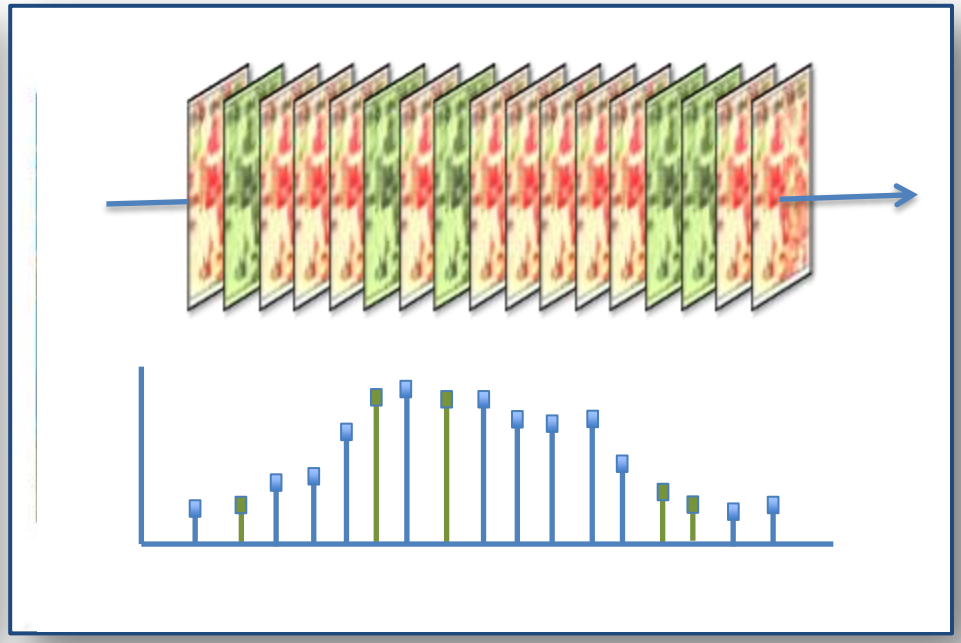
Revisit frequency needed to yield a 70% cloud free view every 8 days

Whitcraft, A., PhD Dissertation, UMd 2014

Harmonized Landsat Sentinel-2 (HLS) Project

- Merging Sentinel-2 and Landsat data streams can provide **2-3 day global coverage**
- Goal is “seamless” near-daily 30m surface reflectance record including atmospheric corrections, spectral and BRDF adjustments, regridding
- Project initiated as collaboration among GSFC, UMD, NASA Ames

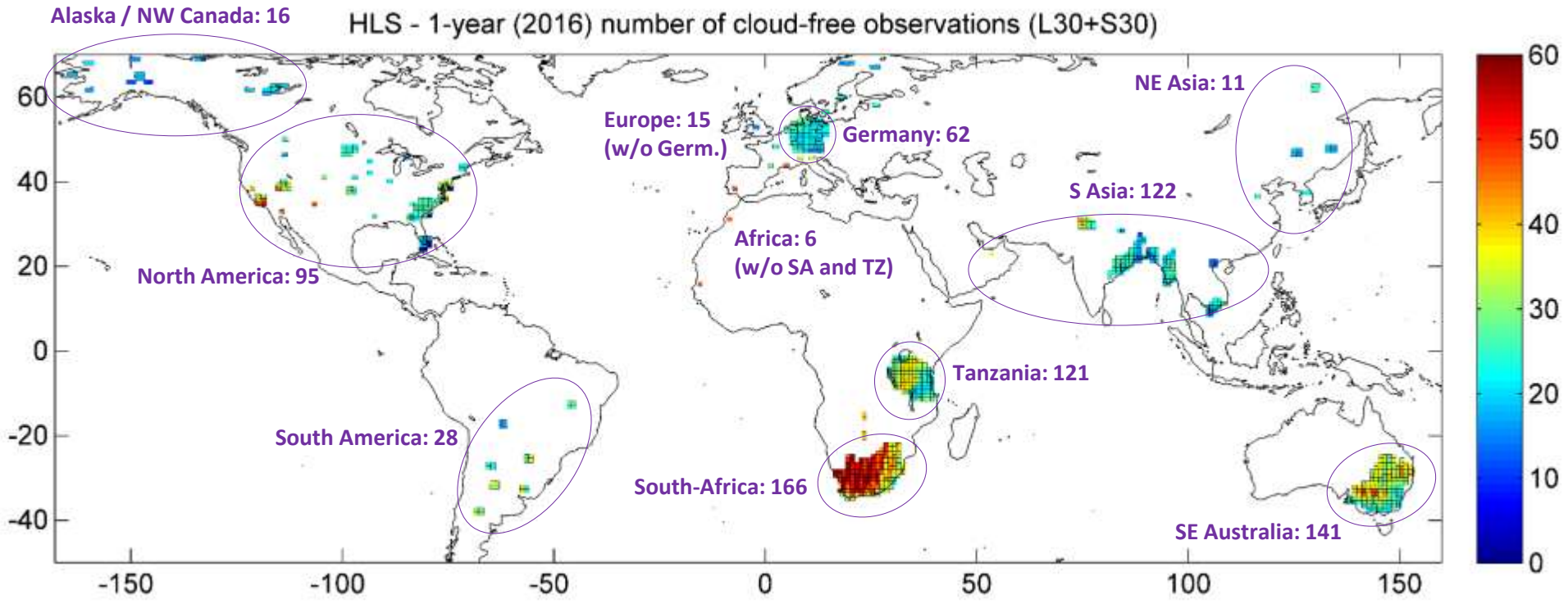




HLS Test Sites

- 69 Test sites (45 from NASA MuSLI team)
- 783 MGRS tiles
- >7.5 million sq. km2

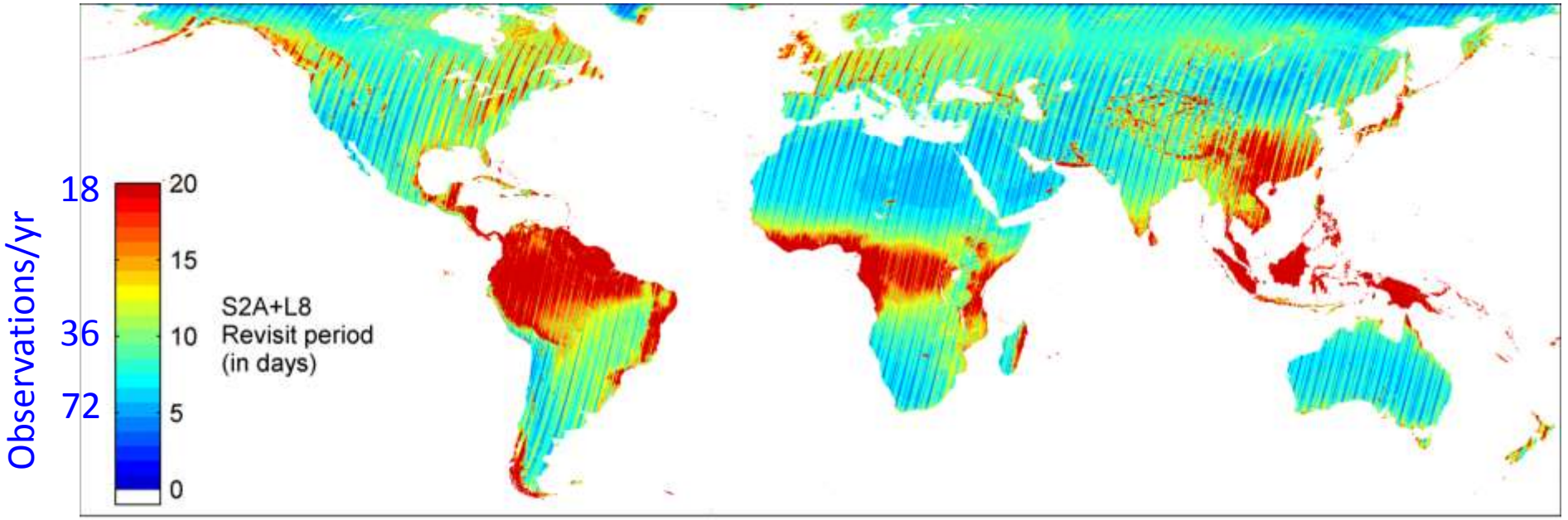
- Landsat-8 data set: 147k products
  From Mar-2013 to Dec-2016
- Sentinel-2 data set: 47k products
  From Jun-2015 to Dec-2016



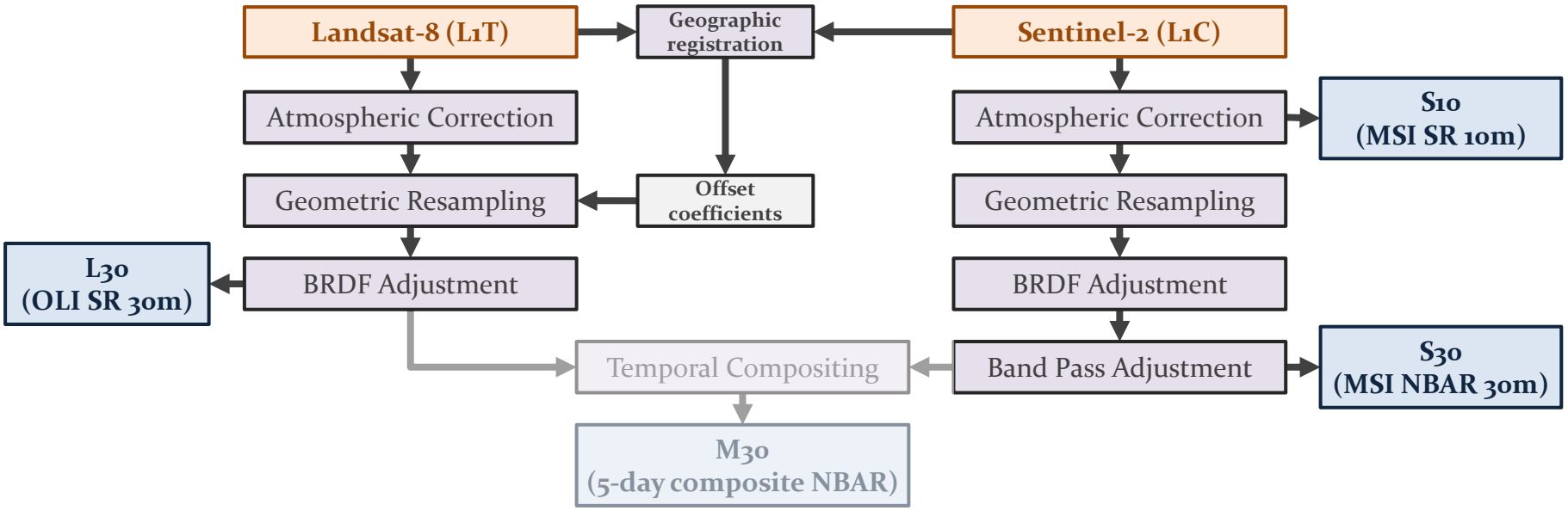
- Online Request Form
  https://hls.gsfc.nasa.gov/test-sites/propose-a-new-site/

Expected Cloud-Free Observations

Sentinel-2a + Landsat-8 revisit w/ cloud cover from MODIS CMG



HLS Algorithm Flow



Algorithm	Current (V1.2)	Other Options
Geographic registration	AROP (Gao et al. 2009, JARS)	-
Atmospheric Correction	OLI and MSI: Landsat-8 6S algorithm	CNES MACCS
Cloud/Shadow Mask	OLI: Landsat-8 6S algorithm output MSI: BU MSI Fmask	CNES MACCS
BRDF Adjustment	Fixed BRDF (Roy et al. 2016, RSE)	Downscaling MODIS BRDF + Fixed BRDF as Backup
Band Pass Adjustment	Fixed, per-band linear regression	Regression-tree (based on spectral shape)
Temporal Compositing	TBD	-

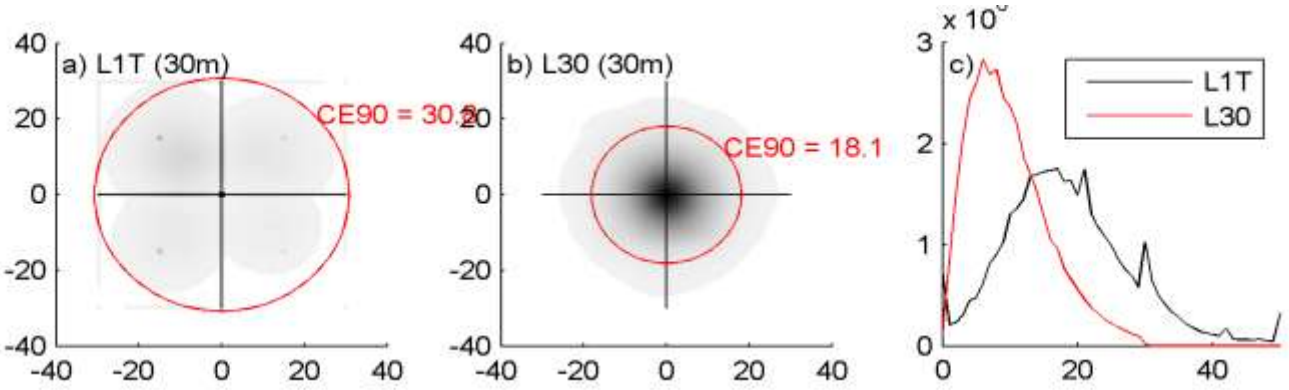
HLS Algorithms

- Atmospheric Correction
  - Uses operational Landsat LaSRC approach (Vermote et al., 2016)
  - Based on 6S radiative transfer model w/image-based aerosol retrieval
- BRDF (view/solar angle) adjustment
  - Uses Roy et al (2016) fixed BRDF shape
  - Adjusted to nadir view and fixed, latitude-dependent solar angle (aka NBAR)
- Spectral adjustment uses linear regression based on Hyperion hyperspectral images
- Cloud mask
  - Landsat: output from LaSRC atmospheric correction
  - Sentinel-2: Boston University Fmask (non-TIR)

S2 / L8 Registration Issues

- Mis-registration between Landsat and Sentinel-2
  - Up to 35m mismatch due to some areas of relatively poor Landsat ground control (Storey et al, 2016, RSE)
  - USGS will improve Landsat ground control in ~2018-19
  - For now, users can use automated cross-correlation algorithms to co-register and/or resample L8 to S2.
- Mis-registration among early Sentinel-2
  - S2a data (processed before June 2016) showed relative misregistration between adjacent orbits due to error in yaw processing
  - Corrected with Sentinel-2 v2.04 processing
- HLS uses a single Sentinel-2 image as reference for each time series & AROP to co-register

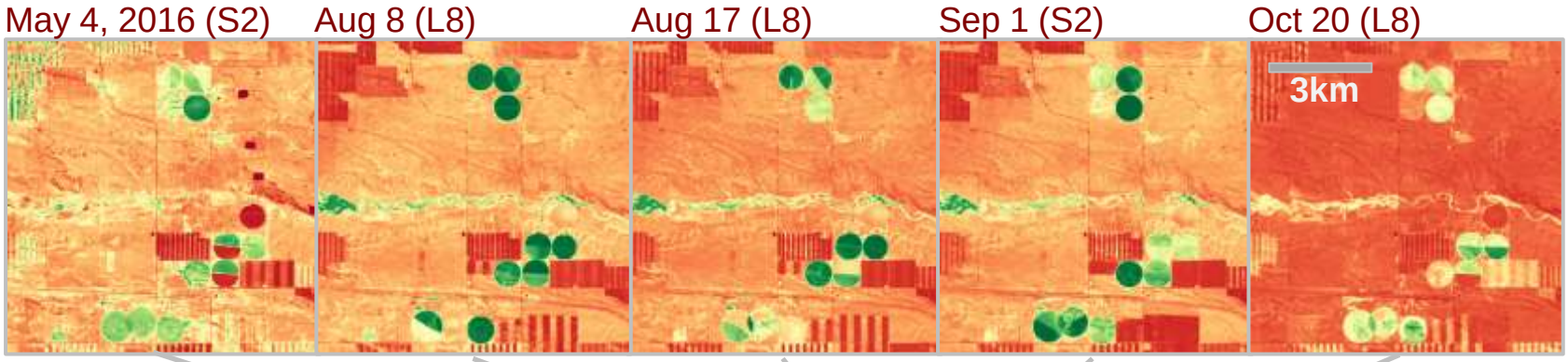
Improvement in Landsat L30 registration after referencing to MSI

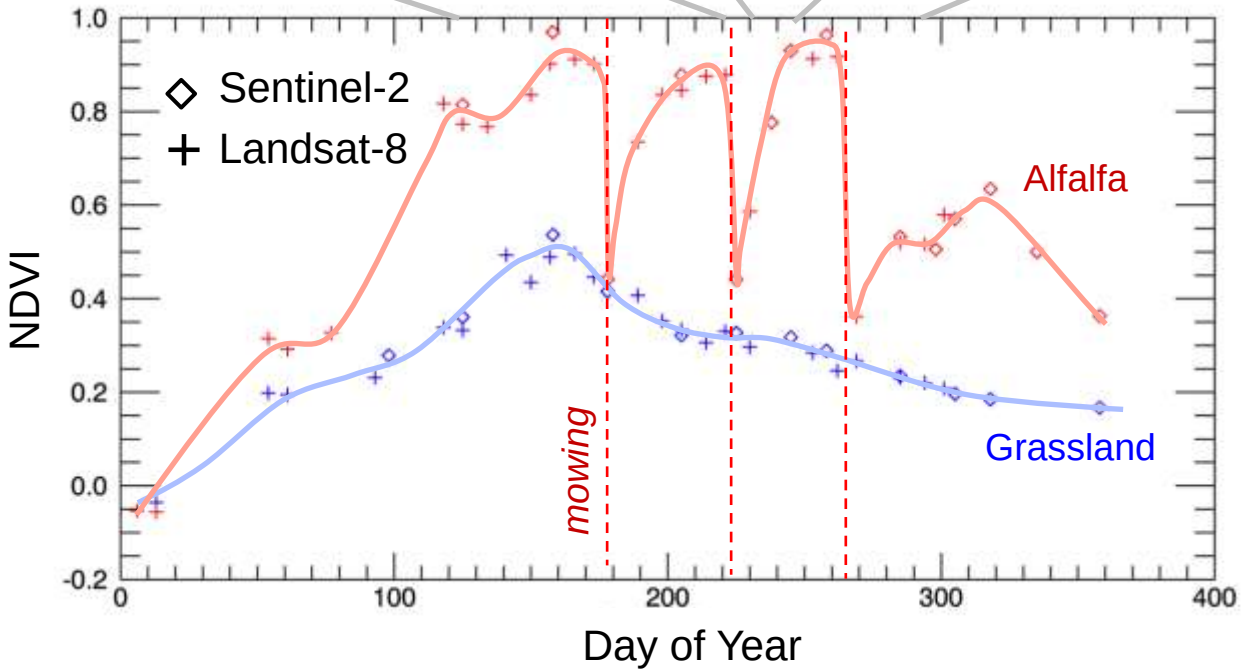


Results

Harmonized Landsat / Sentinel-2 Products

Laramie County, WY





Seasonal phenology (greening) for natural grassland (blue line) and irrigated alfalfa fields (red line) near Cheyenne Wyoming observed from Harmonized Landsat/Sentinel-2 data products. The high temporal density of observations allows individual mowing events to be detected within alfalfa fields. HLS Products available from https://hls.gsfc.nasa.gov

Harmonized Landsat / Sentinel-2 Products

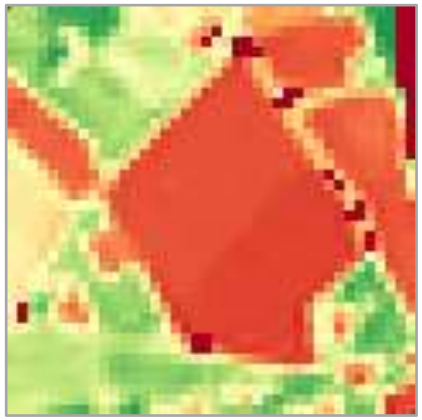
SW France

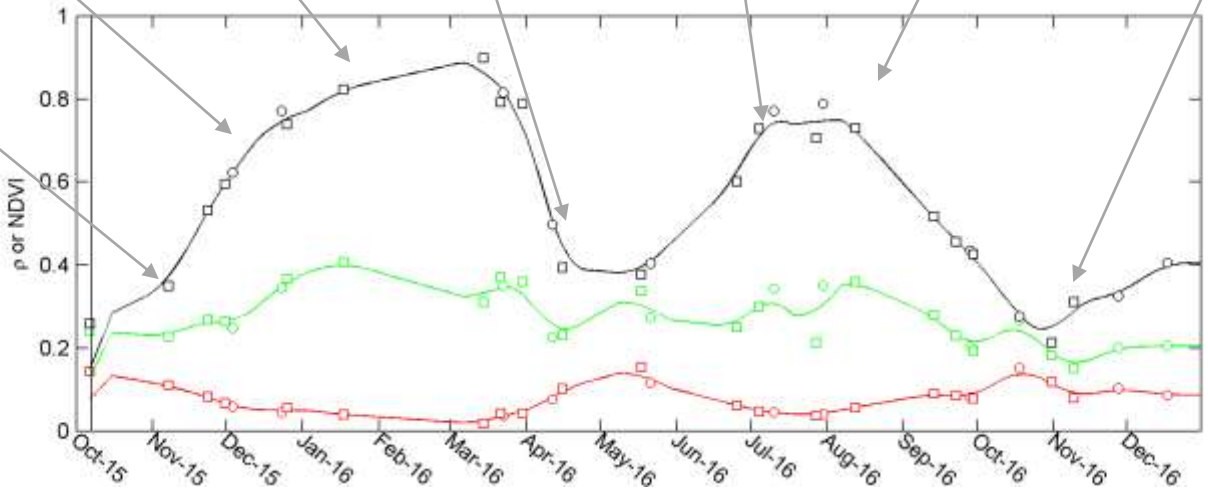
Coordinates: 43.68°N, 1.25°E
Location: South-West France

1.2km

Time series of a 3x3 pixel window around the cross

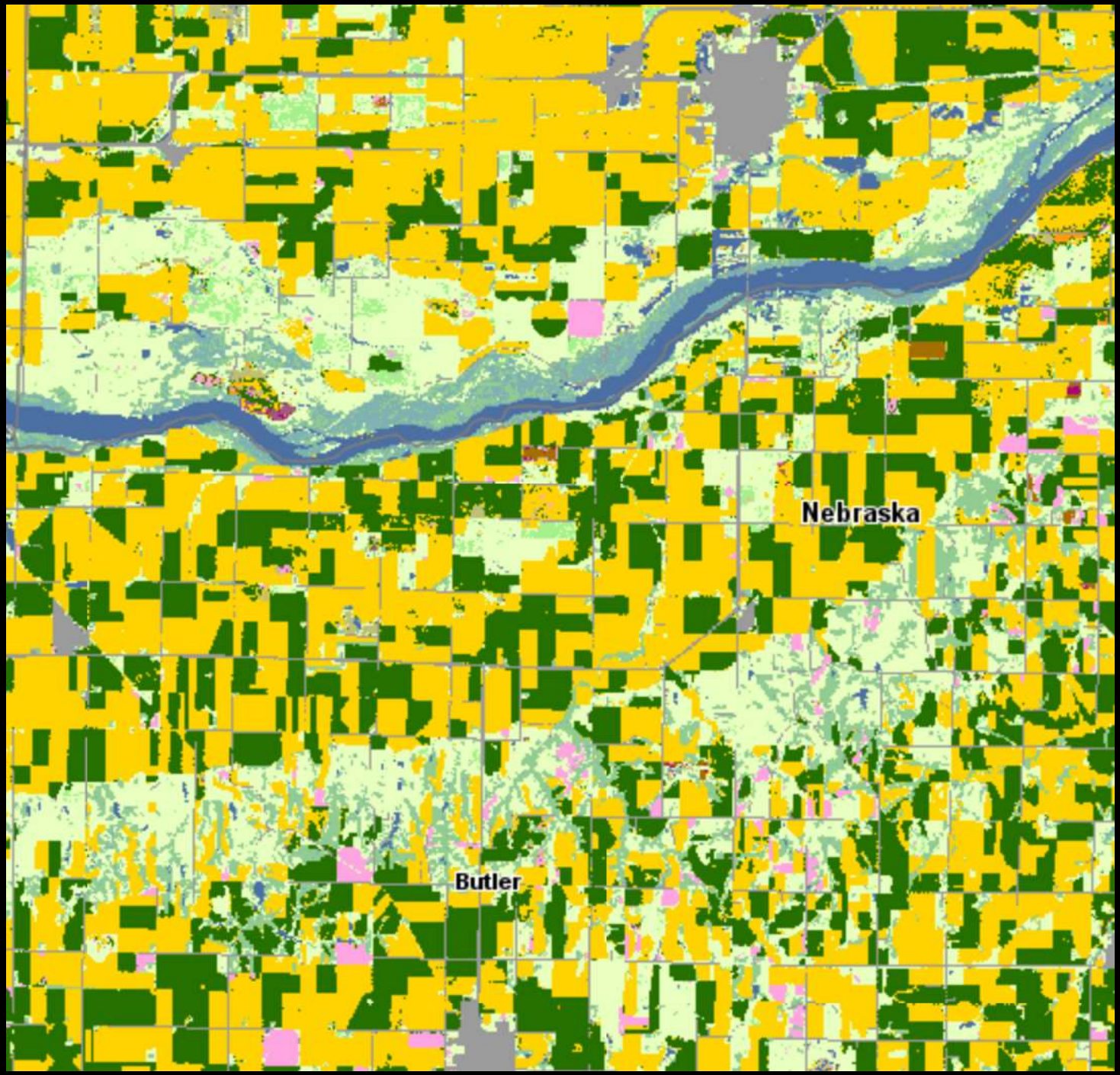
Daily interpolated NDVI





□ HLS from Sentinel-2A MSI
○ HLS from Landsat-8 OLI

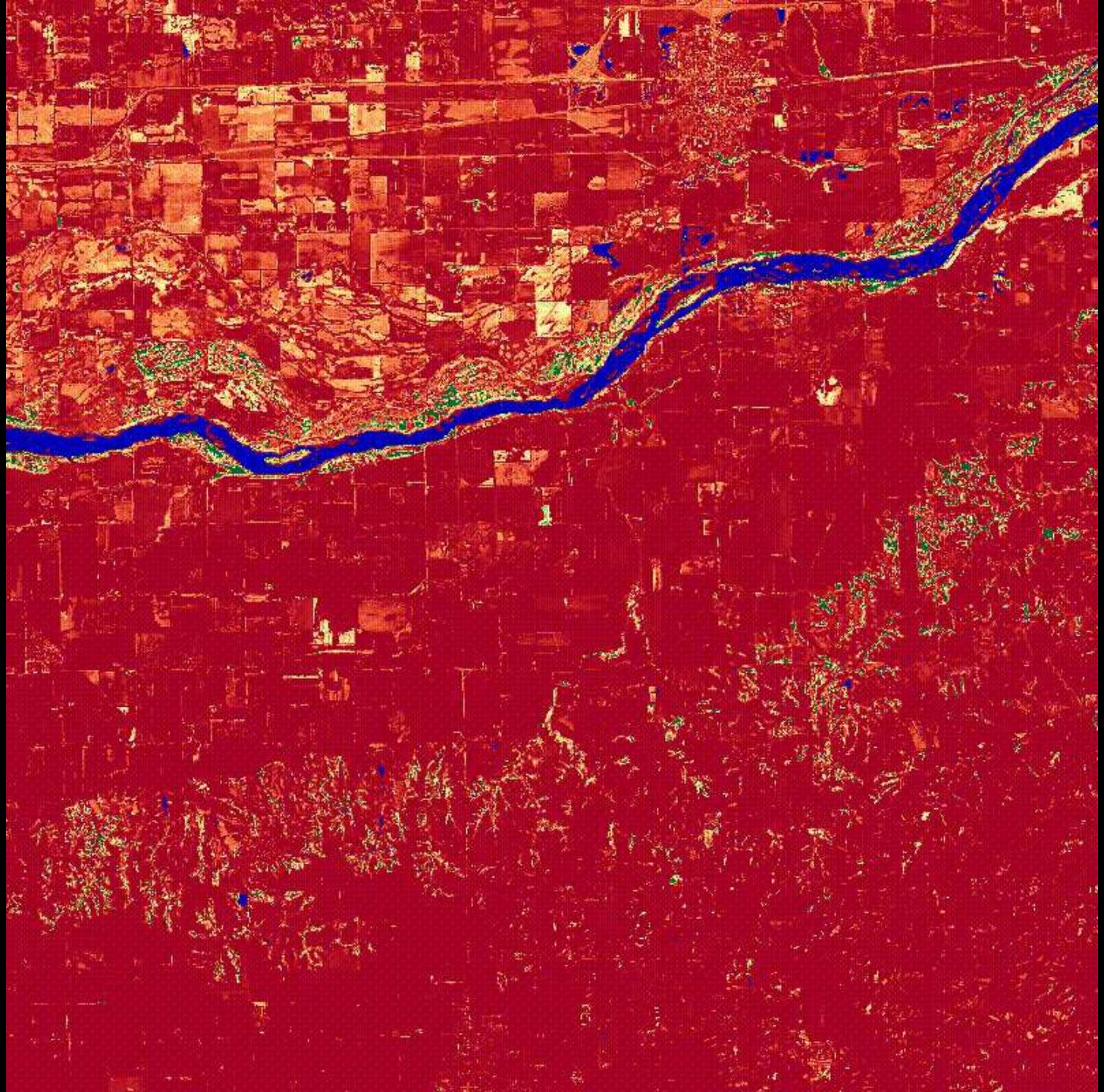
ρ Red band
ρ NIR band
NDVI



Schuyler, Nebraska

USDA 2016 Cropscape

5km



Schuyler, Nebraska

HLS NDVI

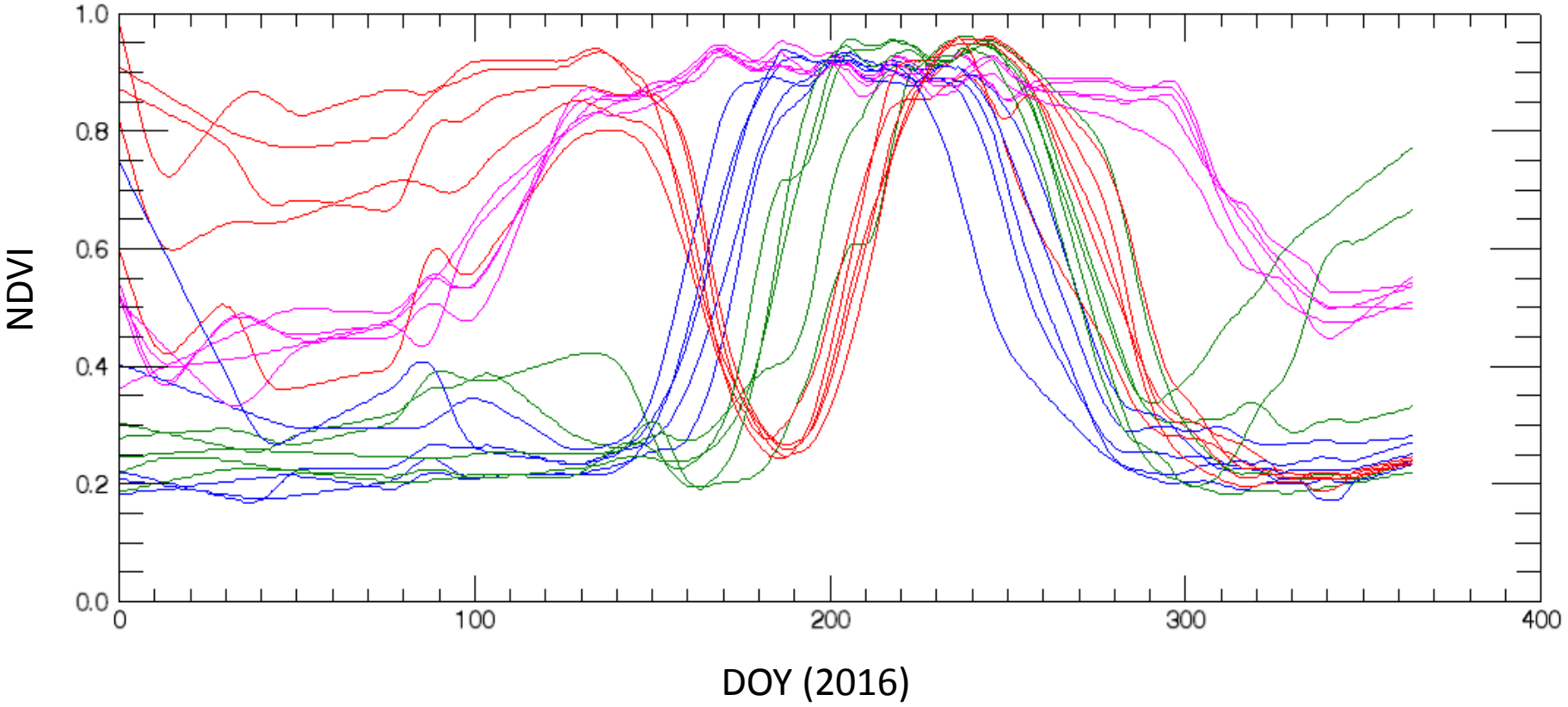
Filtered, interpolated to daily time step

1.0

0.0

Crop NDVI Phenology

Delaware, USA - crop type examples taken from USDA Cropland Data Layer (CDL)



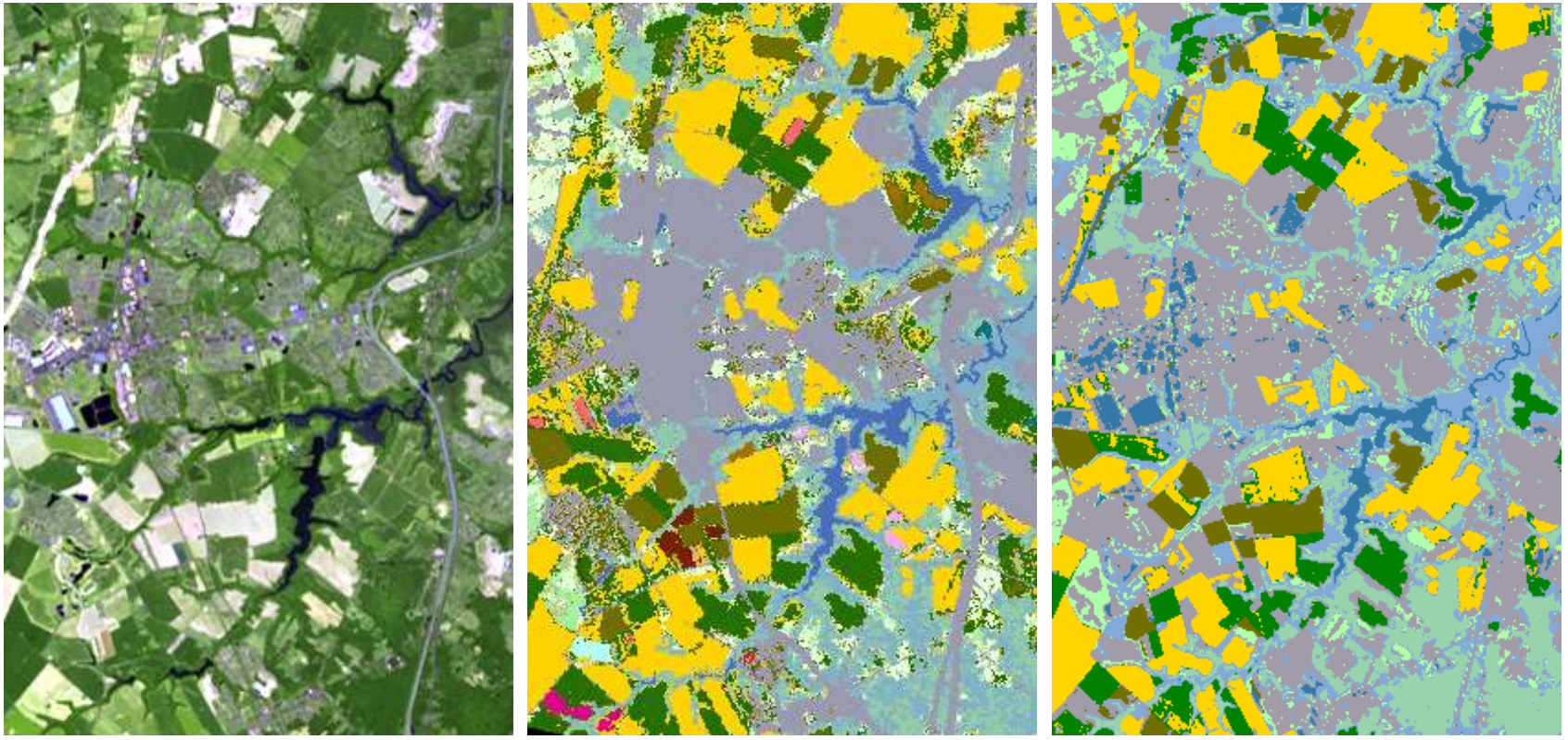
Crop Classification

Supervised classification (SVM) of HLS NDVI trajectories in Delaware, using USDA CDL as training

RGB image

USDA CDL

HLS Classification



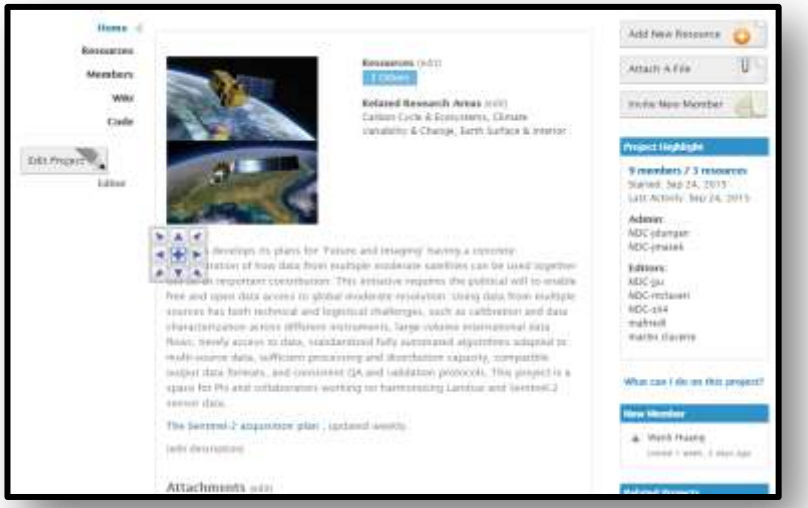
Websites and Public Interface

HLS website

- https://hls.gsfc.nasa.gov
- Public access
- Sample data available (via FTP)
- Algorithm & Product descriptions
- **Request new sites**

NEX project page

- https://nex.nasa.gov/nex/projects/1371
- Registered user access
- All HLS data available
- Documents (slides, user guides)



QA & Validation

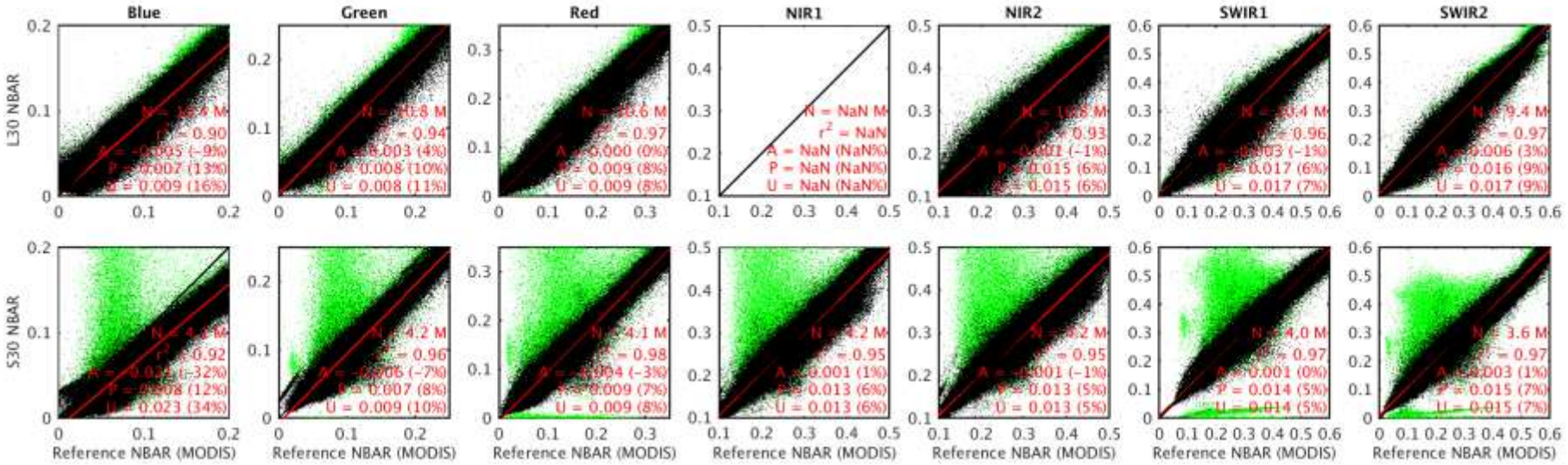
We distinguish between:

- ***Product QA*** – should the granule (or pixel) be flagged as of low or questionable quality?
- ***Validation or Uncertainty Estimation*** – what is the uncertainty (bias, precision) of any observation relative to a standard?

HLS currently implements Product QA via three methods:

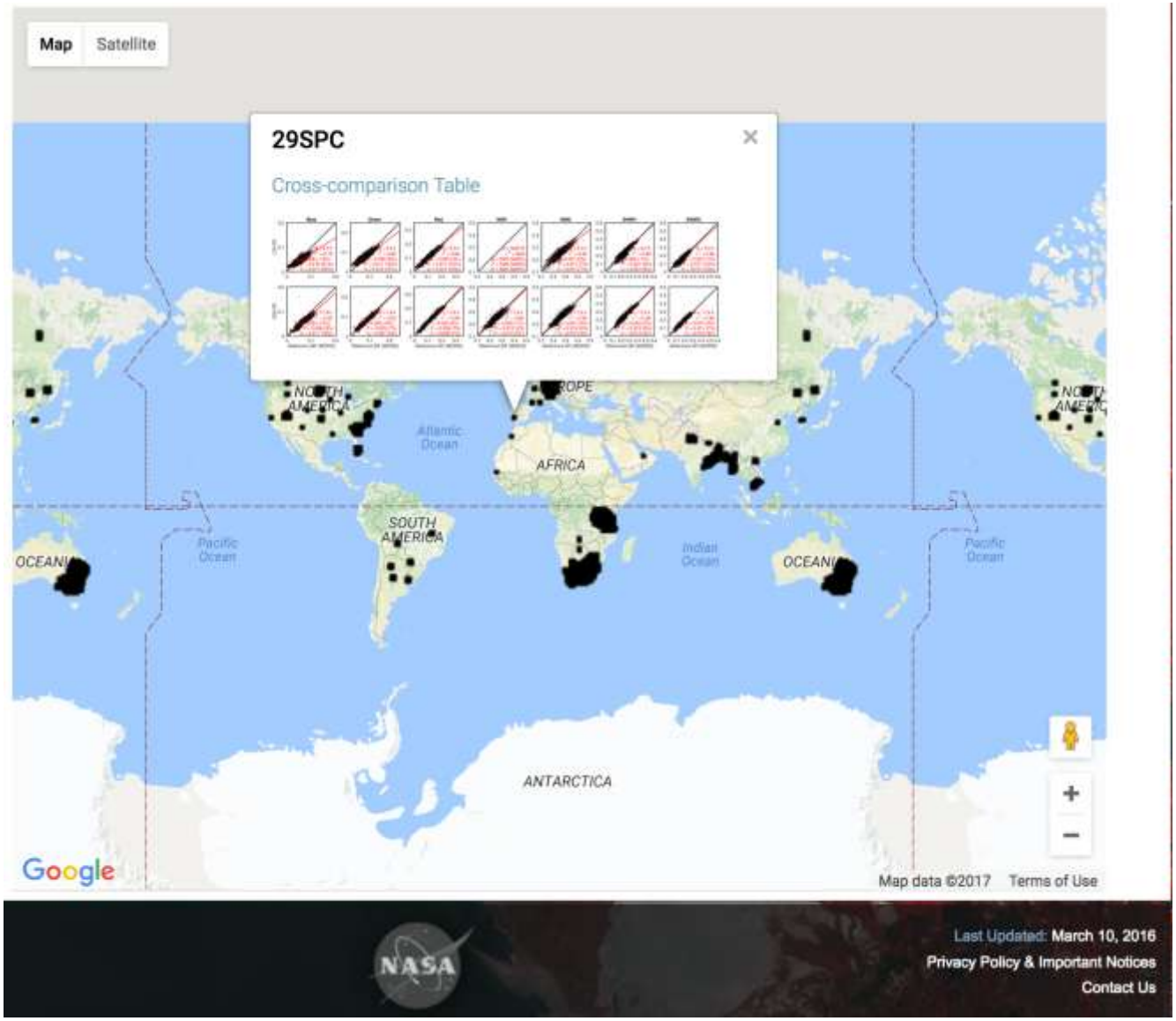
- Comparison with daily MODIS CMG NBAR products
  - Dataset & granule level metric
  - Used to eliminate HLS granules with high number of discrepant 0.05° CMG reflectance values
- Per-pixel time series smoothness
- Other per-pixel attributes (cloud mask, shadow mask)

QC: HLS v1.3 MODIS CMG Comparison



~1% S2a tiles rejected due to cloud mask

HLS QC: MODIS CMG Comparison



HLS QC: MODIS CMG Comparison

Table 1: Colormap used for Table 2

|Bias|	0	0.0056	0.011	0.017	0.022	0.028	0.033	0.039	0.044	0.05	|Bias|
ubRMSD	0	0.0056	0.011	0.017	0.022	0.028	0.033	0.039	0.044	0.05	ubRMSD
RMSD	0	0.0056	0.011	0.017	0.022	0.028	0.033	0.039	0.044	0.05	RMSD

Table 2: Cross-comparison between MODIS MOD09CMG products and S30/L30 products

Product Name	Processing Date	Quick-look	Full res. Quick-look	L1C QC Passed	L1C / L1T version	Sensing Time	AROP RMSE (in m)	% data	% data QA=0	% Cloud	% Cirrus	% Shadow	% Water	% Snow	X-comp graph	Number of CMG pixels	RMSD									
																	BLUE	GREEN	RED	NIR1	NIR2	SWIR1	SWIR2	BLUE	GREEN	RED
HLS.S30.T11SKA.2015261.v1.2.hdf	03/19/17_03:14:11	Link	Link	N	02.04	19:03:45	-	0%	100%	0%	0%	0%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-
HLS.S30.T11SKA.2015271.v1.2.hdf	03/19/17_03:14:11	Link	Link	Y	02.04	19:03:45	-	0%	0%	100%	0%	0%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-
HLS.L30.T11SKA.2015274.v1.2.hdf	03/23/17_15:48:17	Link	Link	-	2.5.1	18:33:55(±12s)	0.0067	98%	34%	64%	33%	2%	0%	1%	Link	20	0.0075	0.0092	0.011	-	0.018	0.016	0.019	-0.0045	0.005	0.0067
HLS.S30.T11SKA.2015278.v1.2.hdf	03/19/17_03:15:09	Link	Link	N	02.04	18:50:13	-	100%	94%	2%	0%	4%	0%	0%	Link	316	0.0098	0.005	0.0088	0.009	0.011	0.016	0.015	-0.0073	0.00013	0.0064
HLS.L30.T11SKA.2015281.v1.2.hdf	03/23/17_16:09:32	Link	Link	-	2.5.1	18:40:18	0.012	33%	75%	16%	24%	0%	0%	0%	Link	62	0.011	0.01	0.012	-	0.021	0.025	0.022	-0.0084	0.00019	0.0012
HLS.L30.T11SKA.2015290.v1.2.hdf	03/23/17_15:49:07	Link	Link	-	2.5.1	18:33:56(±12s)	3.5	98%	63%	35%	3%	2%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-
HLS.L30.T11SKA.2015297.v1.2.hdf	03/23/17_16:09:43	Link	Link	-	2.5.1	18:40:22	3.9	32%	1%	82%	99%	0%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-
HLS.L30.T11SKA.2015306.v1.2.hdf	03/23/17_15:50:19	Link	Link	-	2.5.1	18:34:01(±12s)	-	98%	2%	85%	69%	0%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-
HLS.L30.T11SKA.2015313.v1.2.hdf	03/23/17_16:09:47	Link	Link	-	2.5.1	18:40:24	3.5	34%	93%	7%	0%	0%	0%	0%	Link	29	0.0079	0.01	0.014	-	0.018	0.021	0.019	-0.0037	0.0036	0.0075
HLS.S30.T11SKA.2015318.v1.2.hdf	03/19/17_03:15:14	Link	Link	Y	02.04	18:49:56	-	100%	98%	0%	0%	1%	0%	0%	Link	323	0.011	0.0081	0.0097	0.016	0.015	0.018	0.021	-0.0086	-0.0023	0.0012
HLS.S30.T11SKA.2015321.v1.2.hdf	03/19/17_03:14:11	Link	Link	Y	02.04	18:56:44	-	0%	0%	0%	100%	0%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-
HLS.L30.T11SKA.2015322.v1.2.hdf	03/23/17_15:51:17	Link	Link	-	2.5.1	18:34:03(±12s)	2.8	98%	38%	49%	56%	0%	0%	0%	Link	9	0.0054	0.0055	0.0055	-	0.015	0.014	0.0078	0.0018	0.0027	0.00078
HLS.L30.T11SKA.2015329.v1.2.hdf	03/23/17_16:09:54	Link	Link	-	2.5.1	18:40:26	3.6	34%	19%	81%	0%	0%	0%	0%	-	1	-	-	-	-	-	-	-	-	-	-
HLS.L30.T11SKA.2015338.v1.2.hdf	03/23/17_15:52:41	Link	Link	-	2.6.0	18:34:03(±12s)	0.016	98%	95%	5%	0%	0%	0%	0%	Link	195	0.0079	0.023	0.019	-	0.039	0.018	0.021	0.002	0.021	0.016
HLS.S30.T11SKA.2015341.v1.2.hdf	03/19/17_03:14:11	Link	Link	Y	02.00	19:04:17	-	0%	0%	100%	0%	0%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-
HLS.L30.T11SKA.2015345.v1.2.hdf	03/23/17_16:10:01	Link	Link	-	2.6.0	18:40:24	4.1	34%	76%	23%	8%	0%	0%	0%	Link	53	0.03	0.032	0.036	-	0.04	0.076	0.069	-0.028	-0.03	-0.034
HLS.S30.T11SKA.2015351.v1.2.hdf	03/19/17_03:14:11	Link	Link	Y	02.01	19:04:17	-	0%	0%	100%	0%	0%	0%	0%	-	0	-	-	-	-	-	-	-	-	-	-

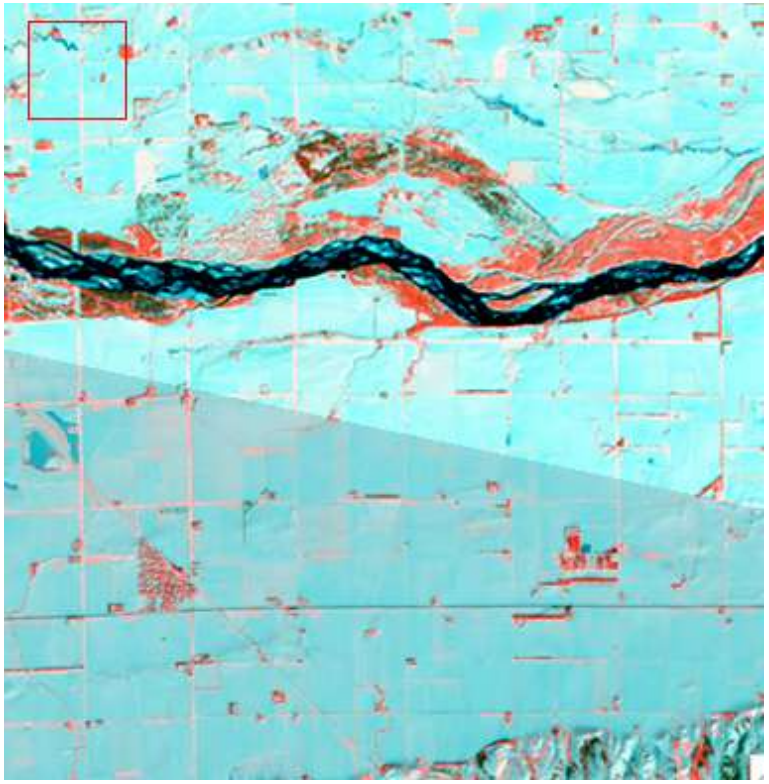
Known Issues

Sentinel-2 cloud mask inaccurate

- Lack of TIR band problematic
- Potential for multi-date masks (e.g. MACCS, T-mask)

Some errors in atmospheric correction over snow, high latitudes

Confusion between dark water and shadow



Status and Future Directions

- Version 1.3 should be released this week
  - Minor bug fixes to BRDF & spectral band adjustments
- Q/-Q4 2017: North America wall-to-wall
  - Fully automated processing w/ ~5-day latency
    - <24 hours Landsat (USGS/NEX), <2 days for S2 (Google)
    - 2-10 days for ancillary (ozone, water vapor)
  - Leverage AWS for processing, archive, distribution
- 2018: global processing?
- How can SCERIN partners help?
  - Download & use existing L30 and S30 products for land use analysis
    - *Agricultural mapping, forest phenology, etc…*
    - *We need feedback on product quality and utility*
  - Suggest new sites… possible testbed of a single country?

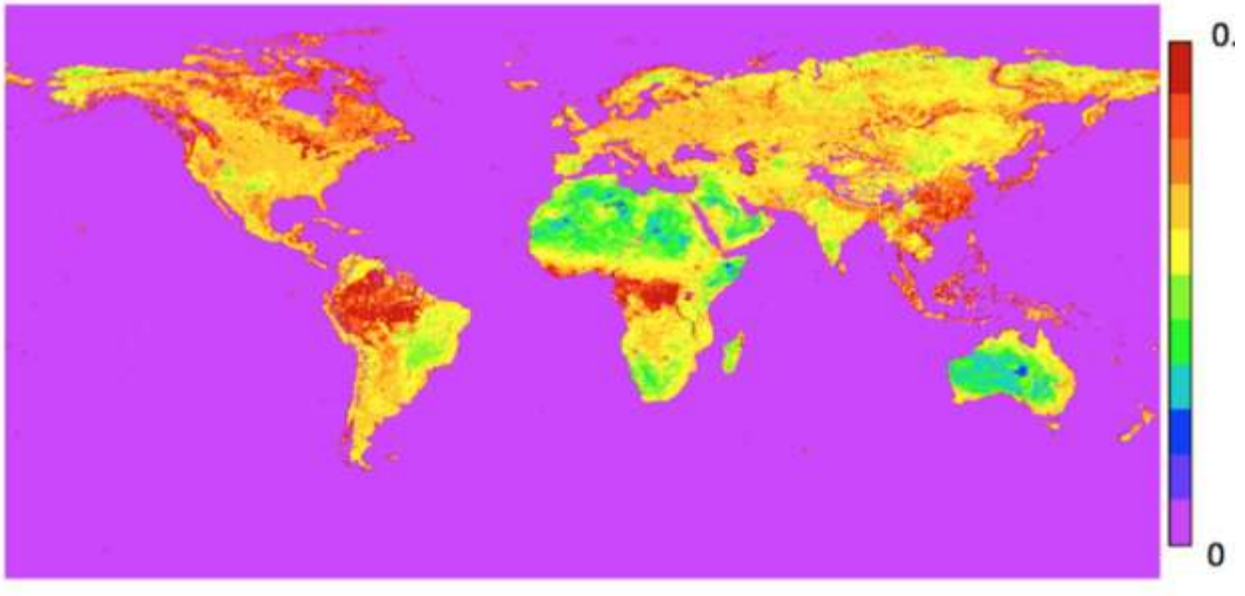

Thank You
Delaware / New Jersey

Backup

LaSRC Atmospheric Correction

- Similar to MODIS Collection 6 approach & previous LEDAPS
- Uses 6S radiative transfer model to correct for scattering (Rayleigh, Mie) and gaseous absorption
  - MODIS water vapor
  - NCEP GDAS ozone and surface pressure
  - Aerosol optical thickness derived via fixed red/blue ratio observed in MODIS SR for every land location

Red/Blue ratio derived from MODIS (Vermote et al., 2016, RSE)



BRDF Correction

- Uses “fixed” coefficients of Roy et al (2016)
  - Over narrow view angles, little improvement with using local or landcover-dependent kernel
- Corrects to a fixed view (nadir) and solar (latitude-dependent) solar elevation
  - Similar to MODIS NBAR but variable solar elevation

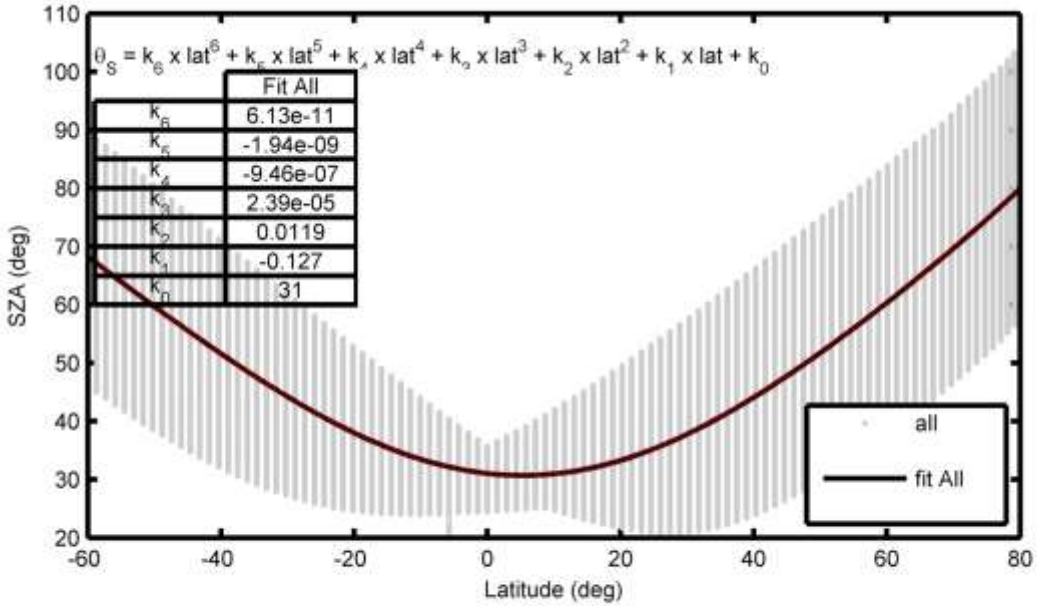
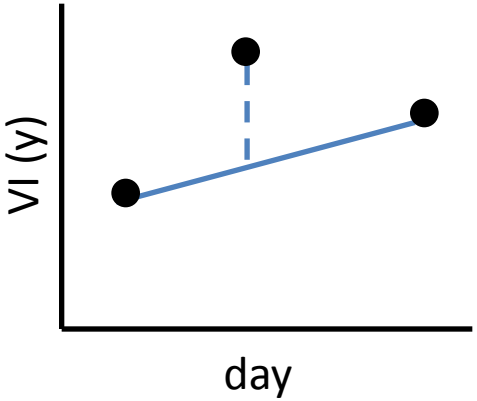


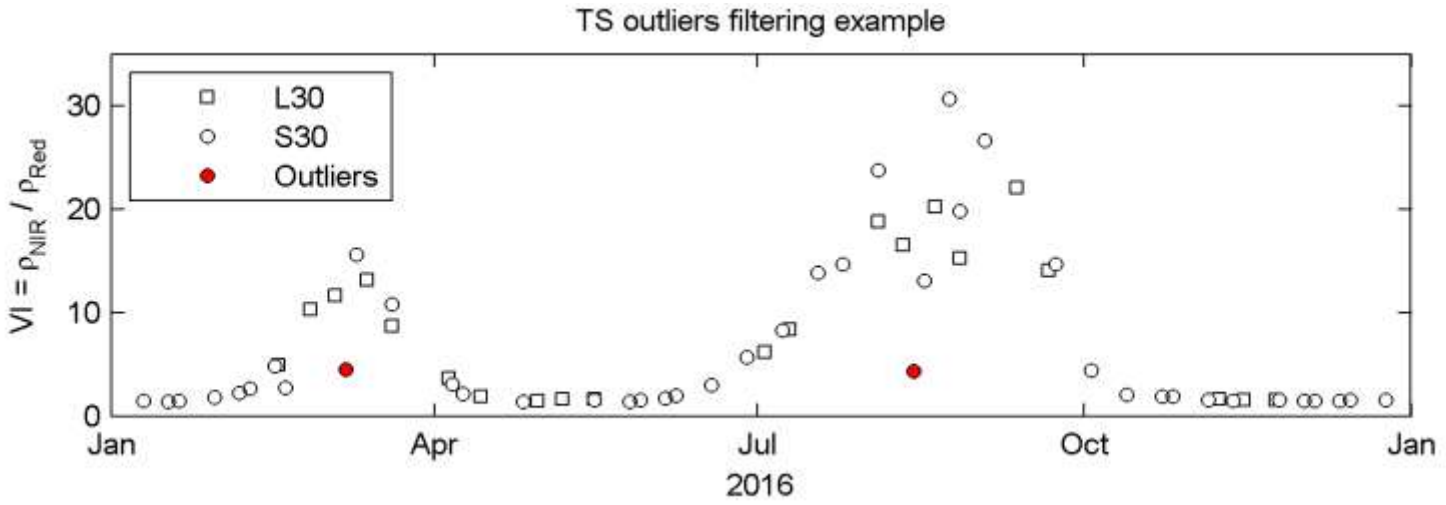
Figure 1: Sun zenith Angle (SZA) and central latitude of all the scenes of the Landsat-8 archive. The line corresponds to the overall fit using a 6th degree polynomial.

HLS QC: Temporal Smoothness

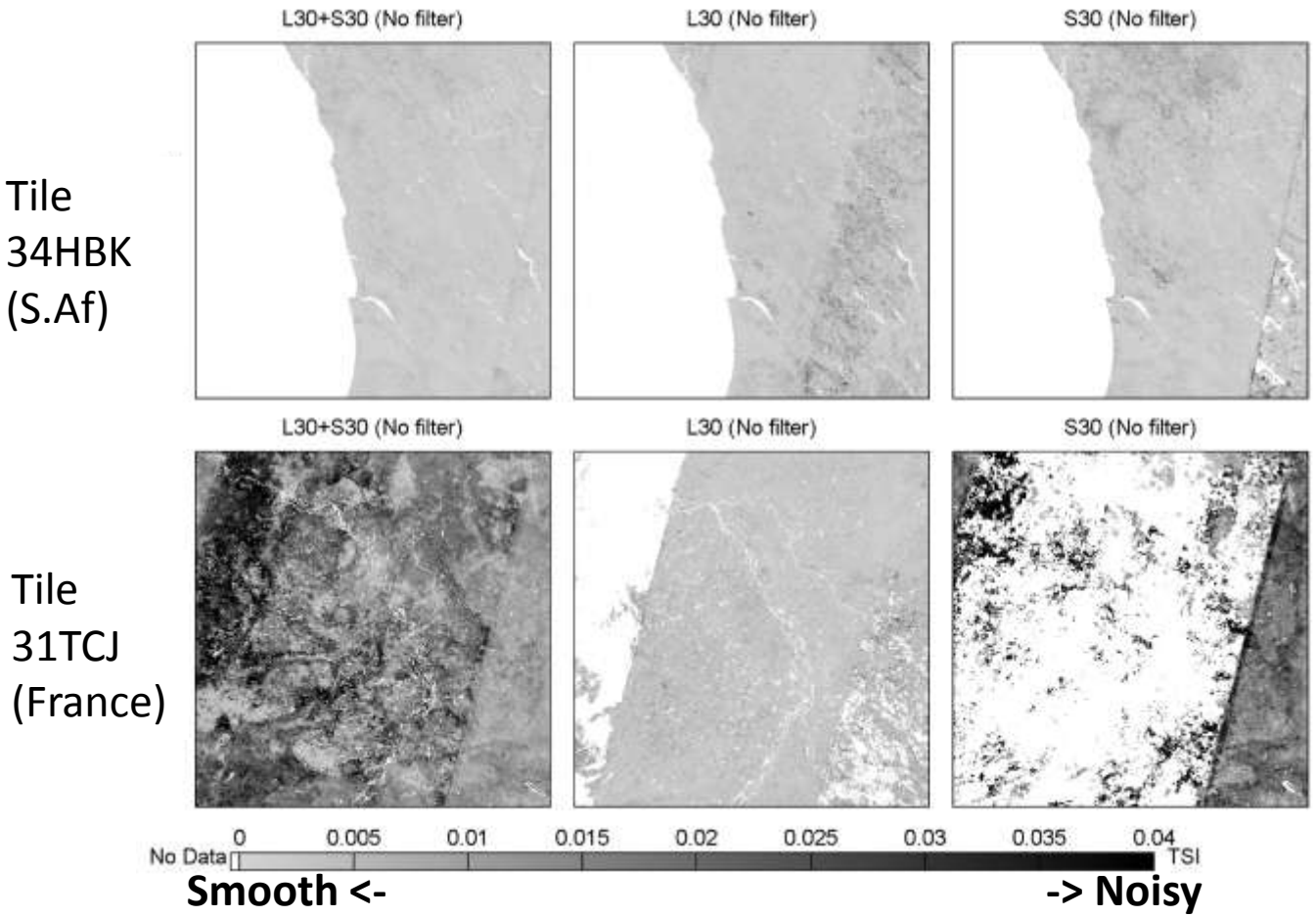
Approach based on variance among cloud-free VI triplets (Vermote et al., 2009)
Per-pixel metric calculated from median of all triplets (N>6) in time series



$$\text{Noise} = \sqrt{\frac{\sum_{i=1}^{n-2}\left(y_{i+1} - \frac{y_{i+2}-y_i}{\text{day}_{i+2}-\text{day}_i}(\text{day}_{i+1}-\text{day}_i) - y_i\right)^2}{N-2}}$$

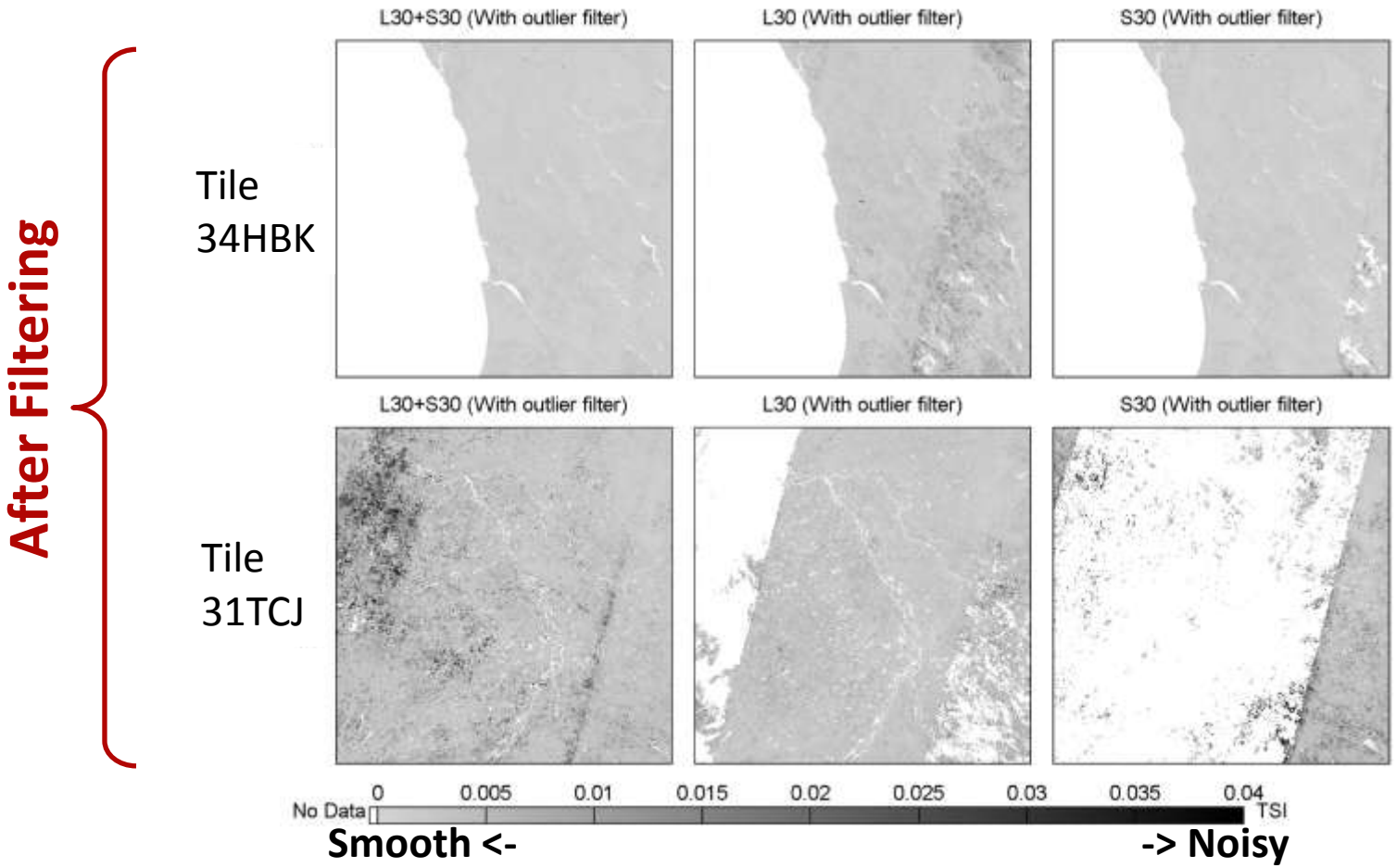


HLS QC: Temporal Smoothness



Adding S2 data increases time series noise due to cloud commission

HLS QC: Temporal Smoothness



Per-pixel filtering for temporal "outliers" reduces variance

HLS Products Specification

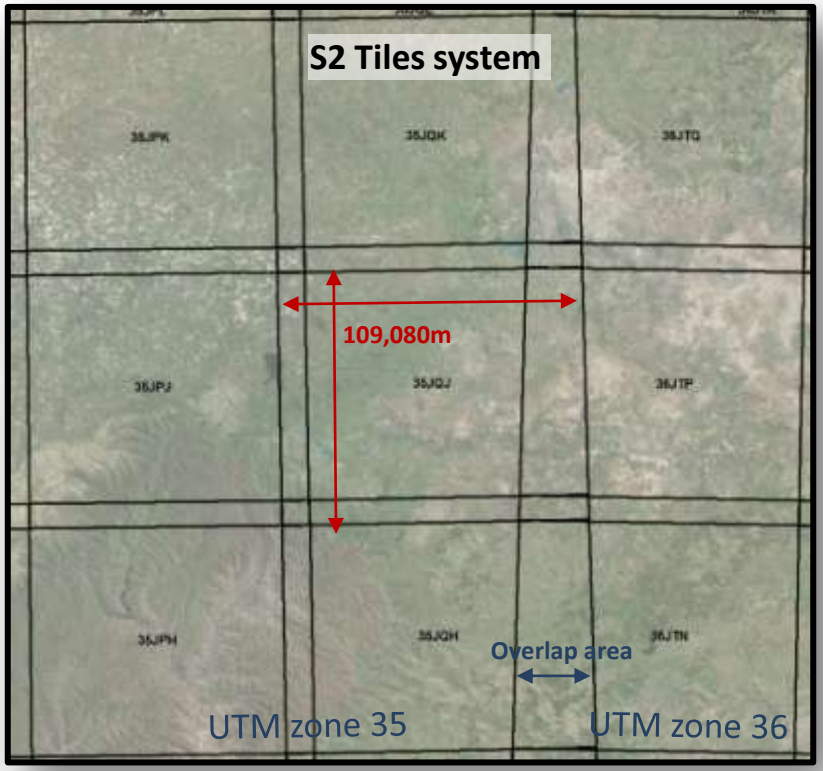
- All 4 products are aligned on the S2 Tiling system (Military Grid Reference System), following UTM zones + 3 letters defining a grid
- Tiles are 110km square with 10km overlap for same UTM zone adjacent tiles

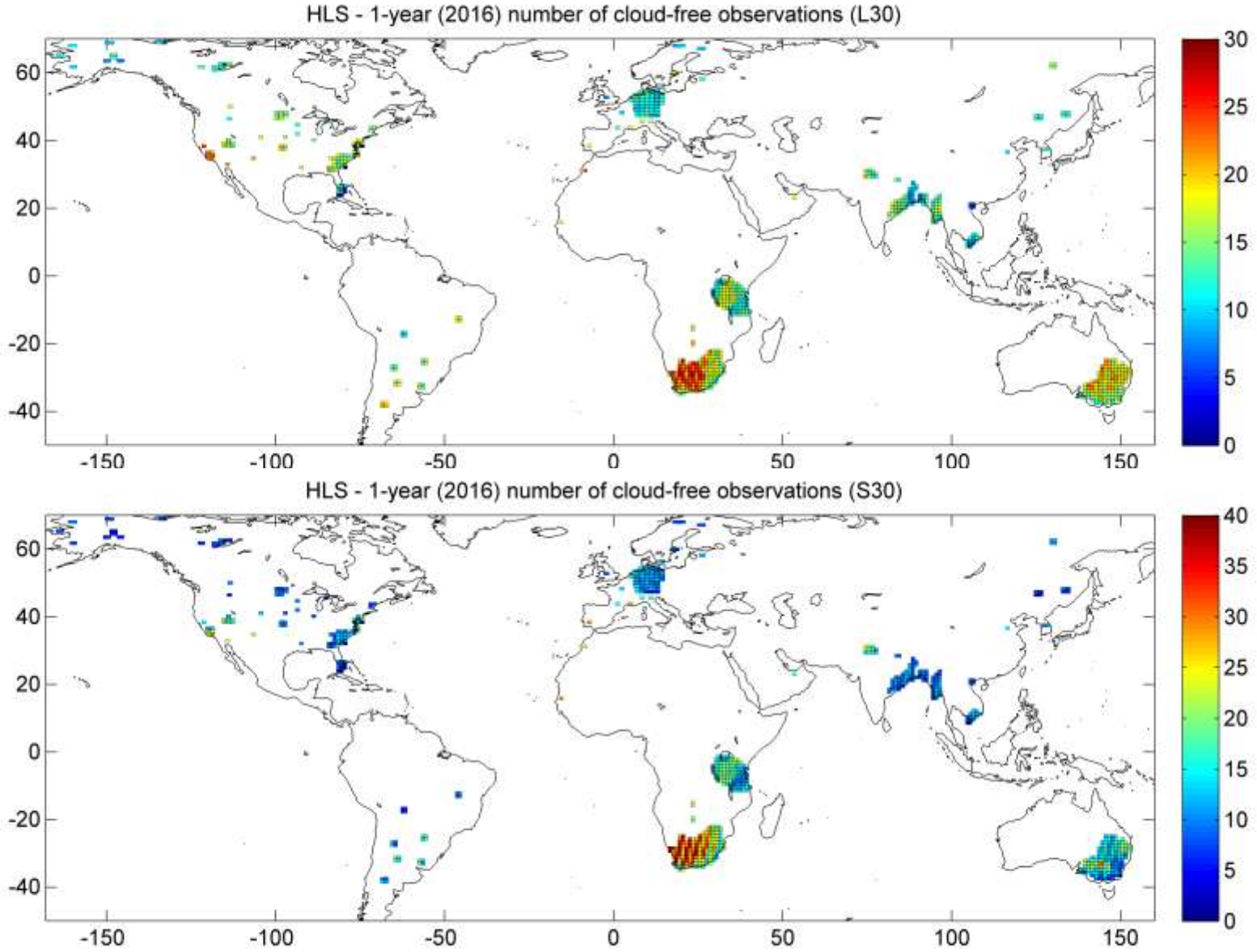
S10
Spatial: 10m, 20m, 60m
Spectral Bands: All MSI
Temporal: All Sentinel-2 L1C granules
NBAR: No

L30
Spatial: 30m
Spectral Bands: All OLI
Temporal: All Landsat-8 L1T granules
NBAR: Yes

S30
Spatial: 30m
Spectral Bands: OLI-like + MSI Red Edge
Temporal: All Sentinel-2 L1C granules
NBAR: Yes

M30
Spatial: 30m
Spectral Bands: OLI-like + MSI Red Edge + TIRS TOA
Temporal: 5-day "best pixel" based on min AOT
NBAR: Yes




HLS - 1-year (2016) number of cloud-free observations (L30)
60
40
20
0
-20
-40
-150
-100
-50
0
50
100
150
30
25
20
15
10
5
0
HLS - 1-year (2016) number of cloud-free observations (S30)
60
40
20
0
-20
-40
-150
-100
-50
0
50
100
150
40
35
30
25
20
15
10
5
0

HLS Circular Error (CE) relative to S2a reference granule