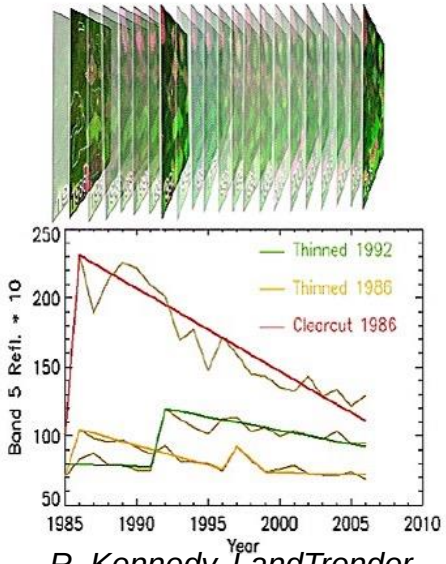
Harmonizing Landsat and Sentinel-2

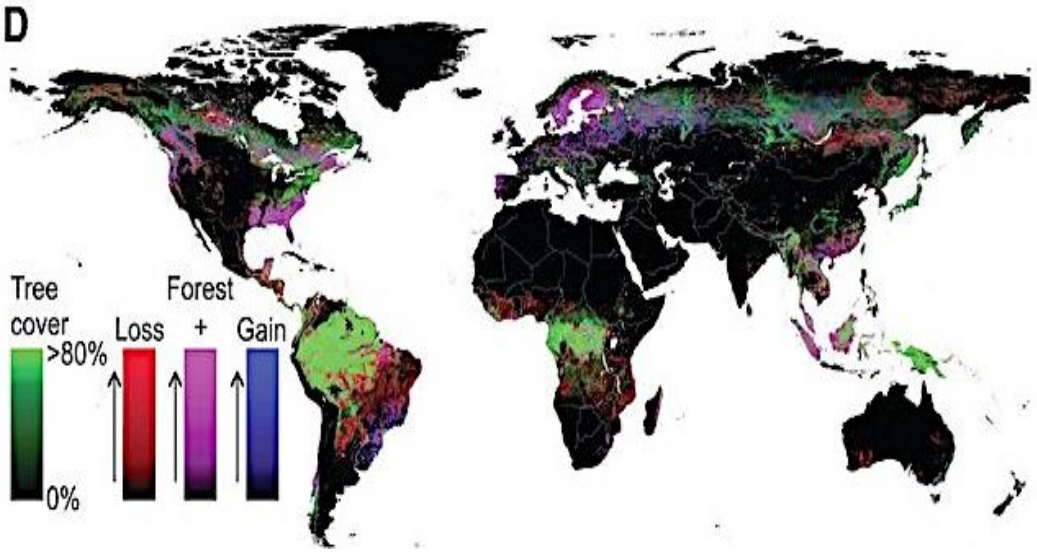
Jeff Masek, NASA GSFC
Martin Claverie, UMD-GEOG
Junchang Ju, NASA-GSFC
Jennifer Dungan, NASA-AMES

Trends in the Use of Moderate Resolution Data

- Opening of free USGS archive in 2008 ushered in new era of applications
  - Data downloads have increased by **three orders of magnitude**
  - More accurate and reliable analyses; improved quality of decisions/findings
- **Large area** coverage for continental and global studies
- New focus on leveraging **time domain**
  - *Inter-annual disturbance, compositional change, land use*
  - *Intra-annual phenology, vegetation condition, compositing*



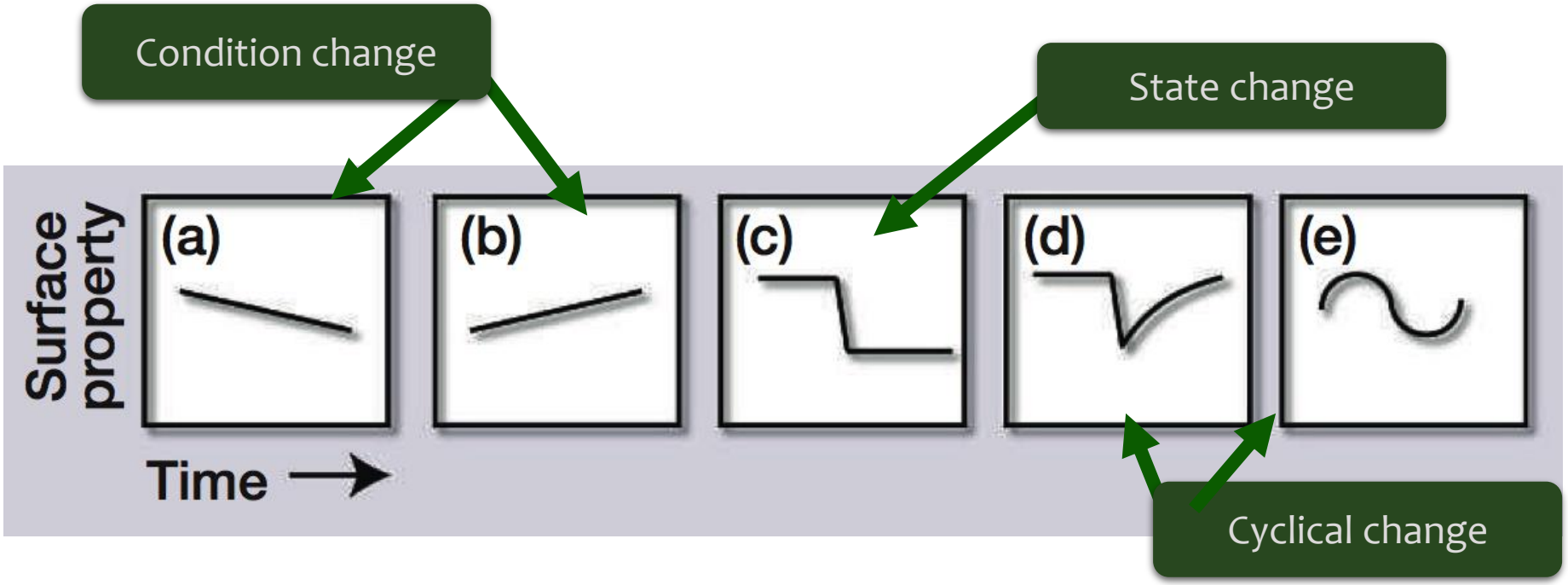
R. Kennedy, LandTrender disturbance algorithm



Hansen et al., Science 2013

Attributing Change

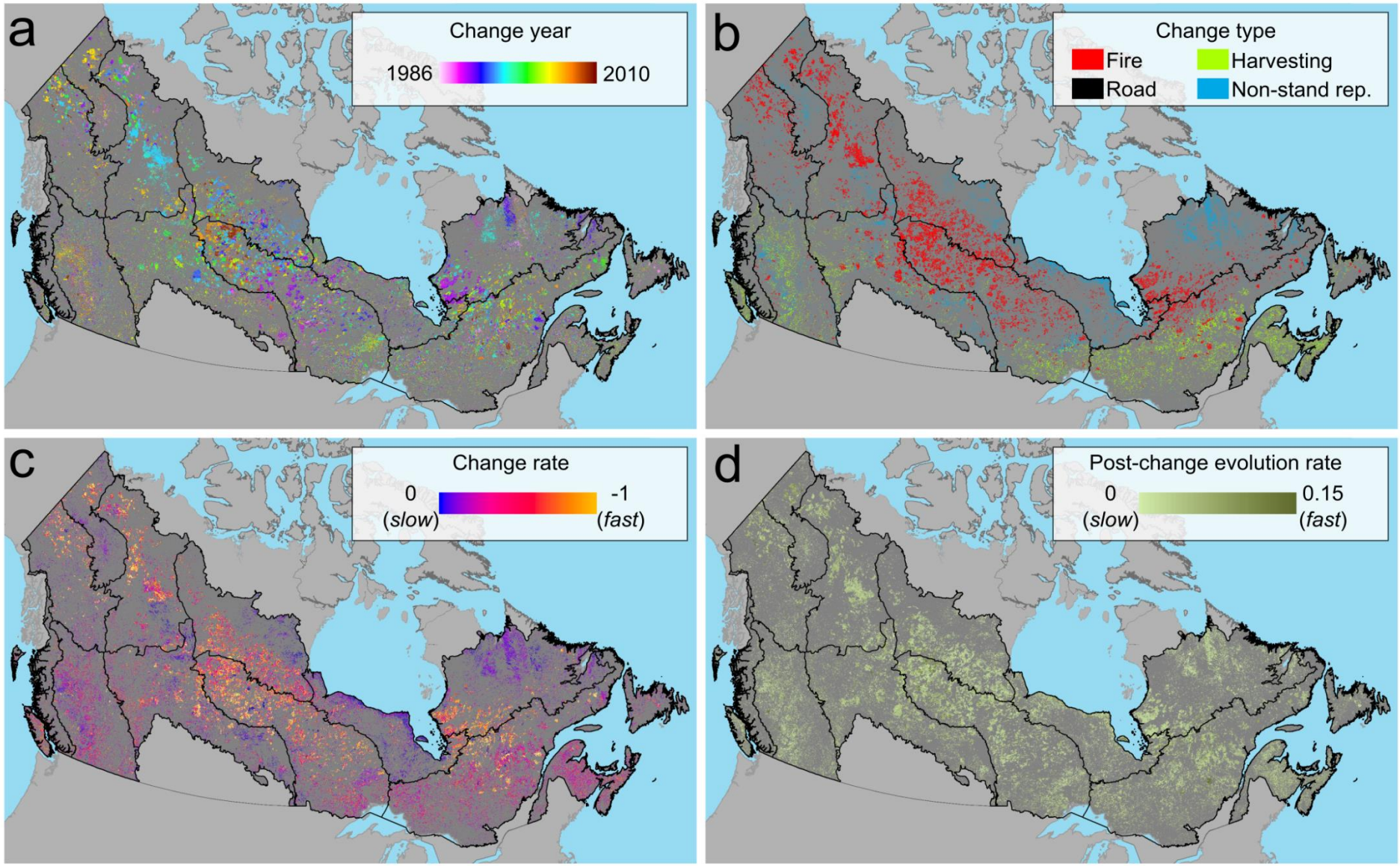
- Change occurs *all the time*



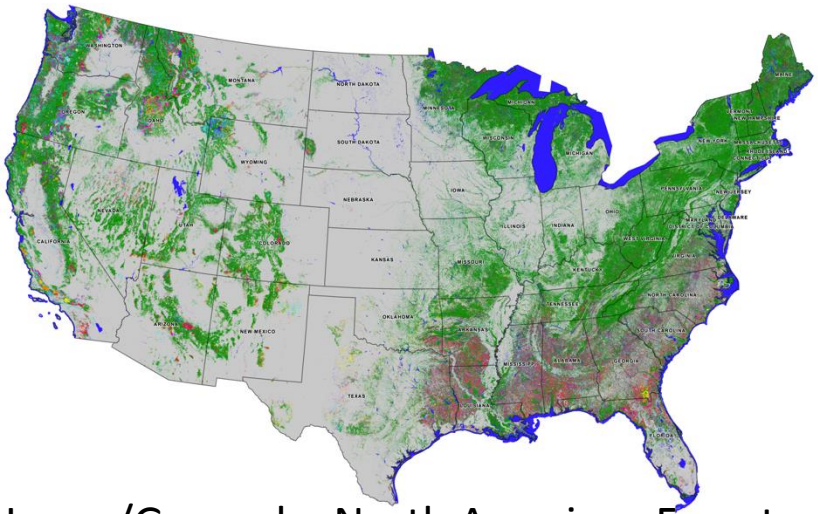
- Temporal grain and extent matter – for product timing and for definitions of products

Courtesy M. Wulder, CFS

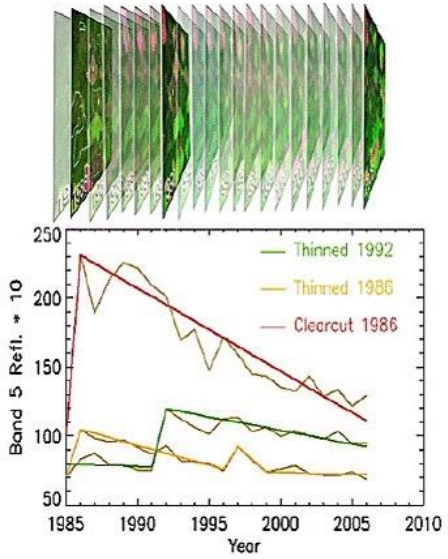
Canadian Forest Dynamics (Wulder)



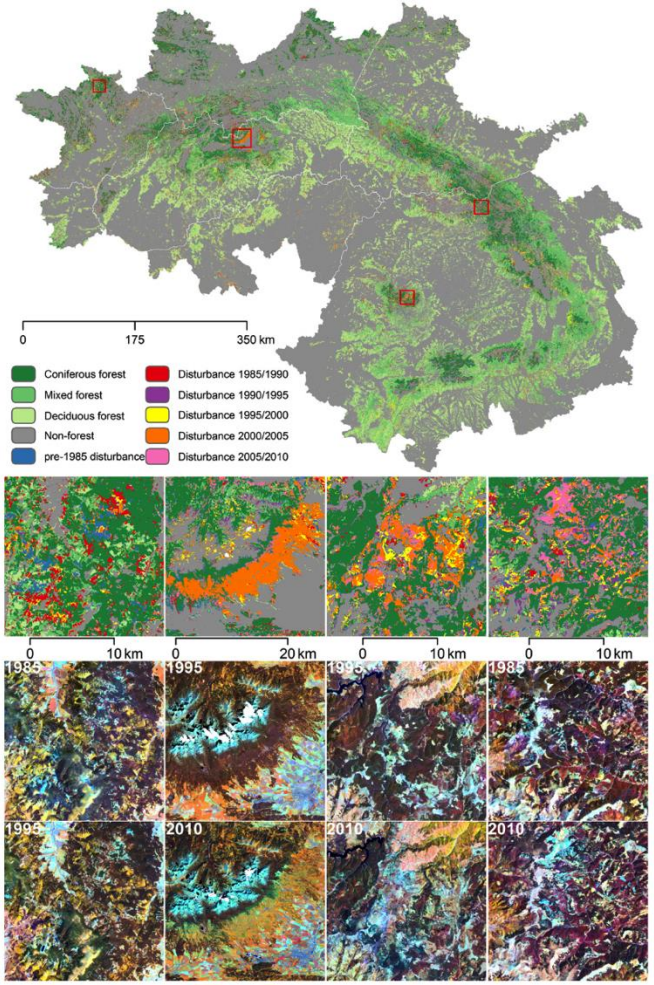
Annual (or Near Annual) Vegetation Products



Huang/Goward – North American Forest Dynamics (NAFD) – annual US disturbance

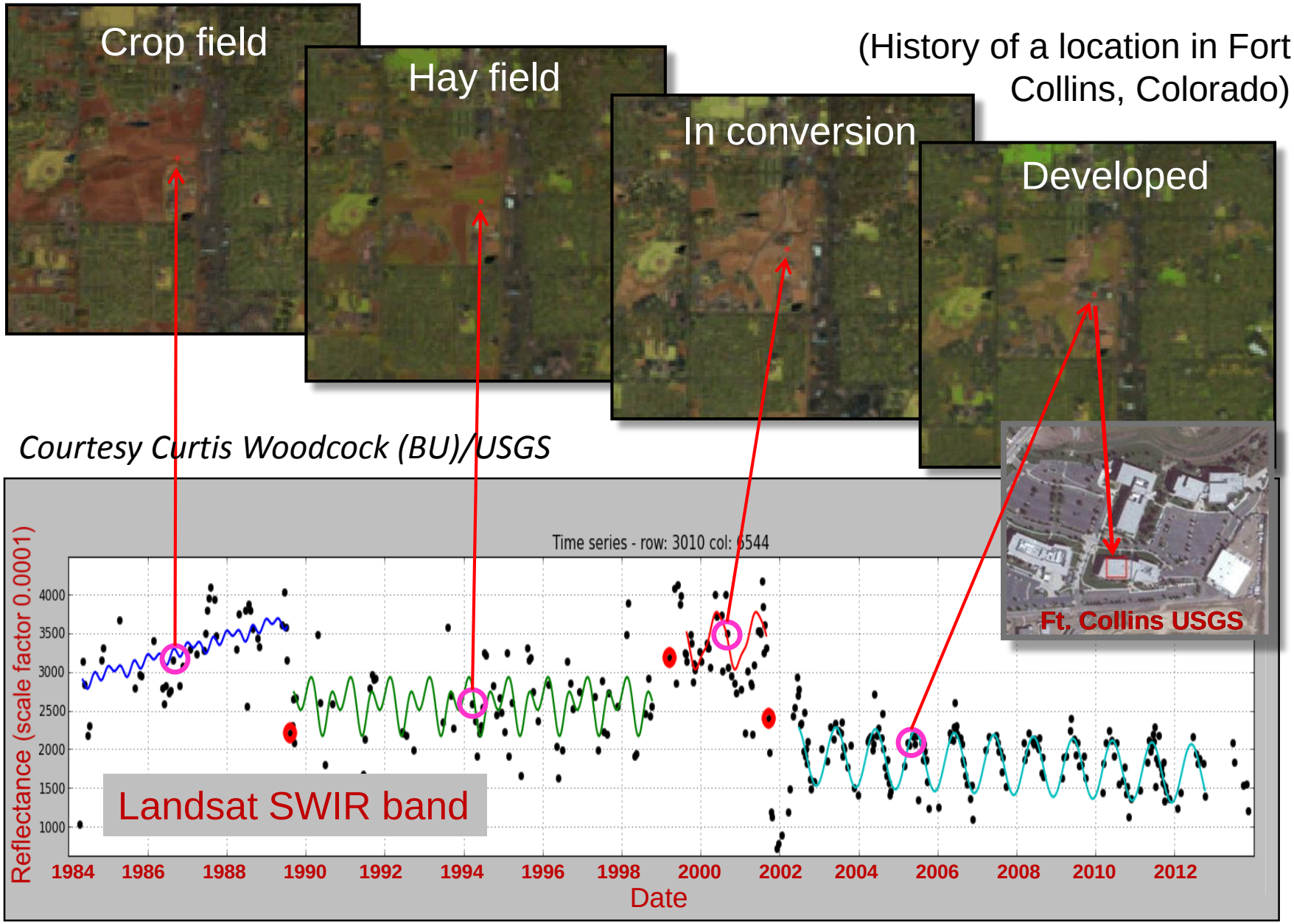


Kennedy – LandTrendr



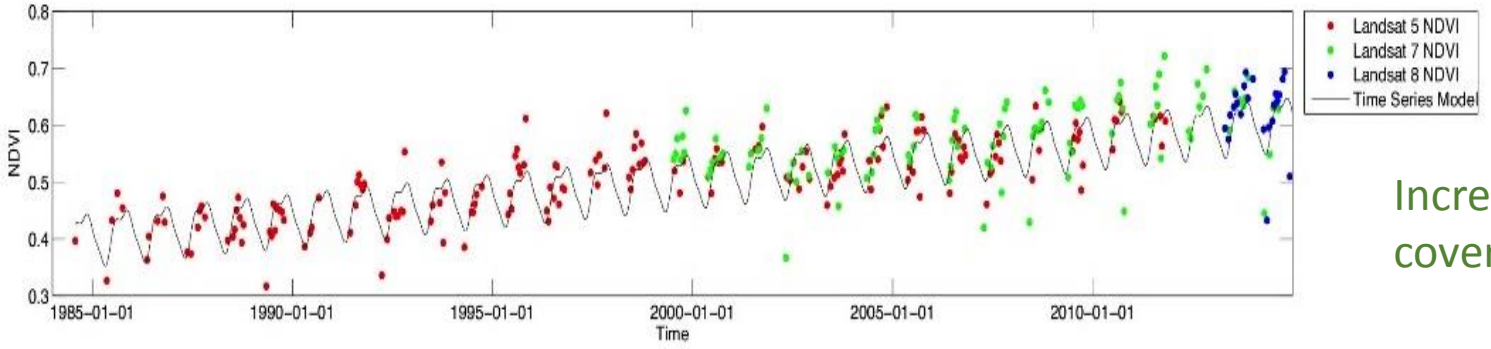
Griffiths – Carpathian Forest Change

Interannual -> Intrannual

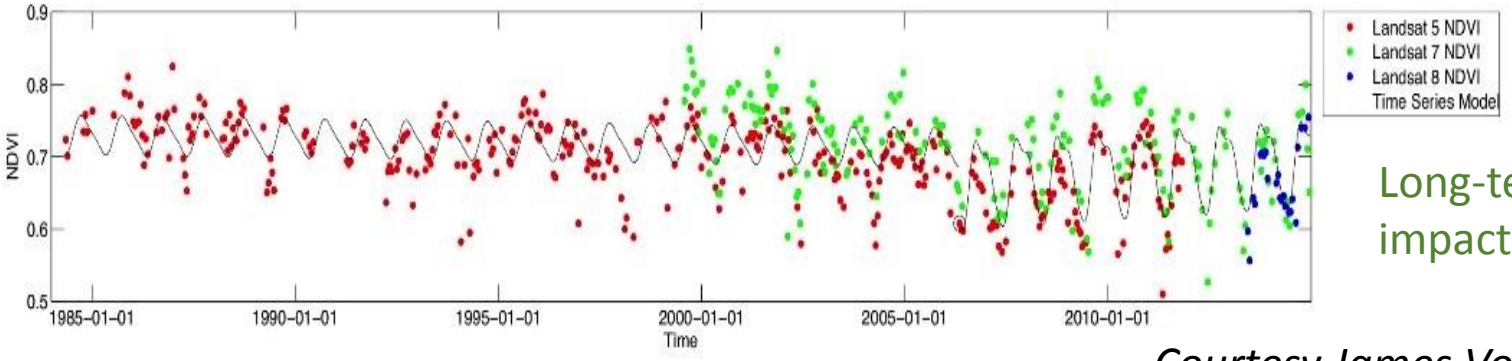


Calibrated Record for Gradual Change

- Ecological changes take place over decades or centuries
- These changes span multiple Landsat missions – how do we ensure that we are tracking changes in land properties, and not changes in sensor performance?



Increasing vegetation cover, Crater Lake, OR



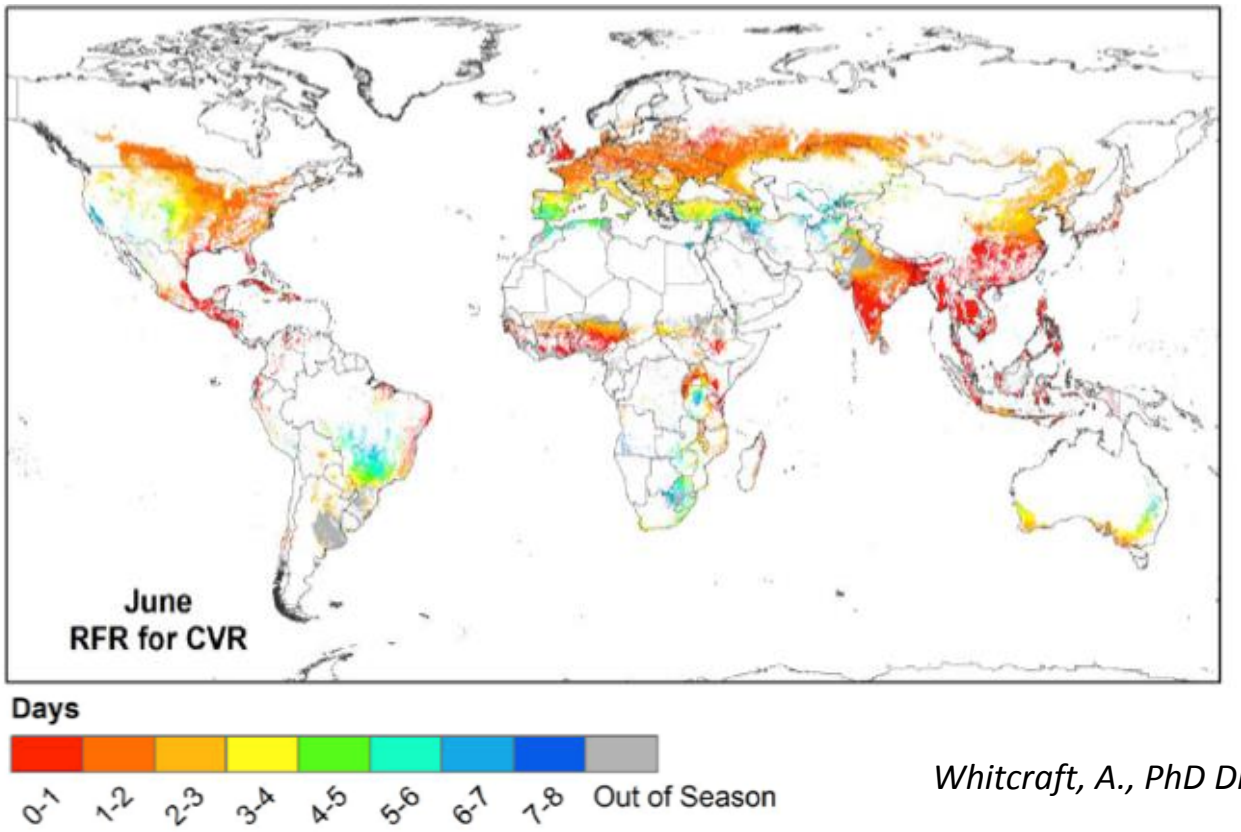
Long-term drought impact, Southwest US

Courtesy James Vogelmann, USGS

What Temporal Revisit Do We Need?

- GEO-GLAM articulates need for weekly, cloud free views
  - "field scale phenology" is key for land use & management

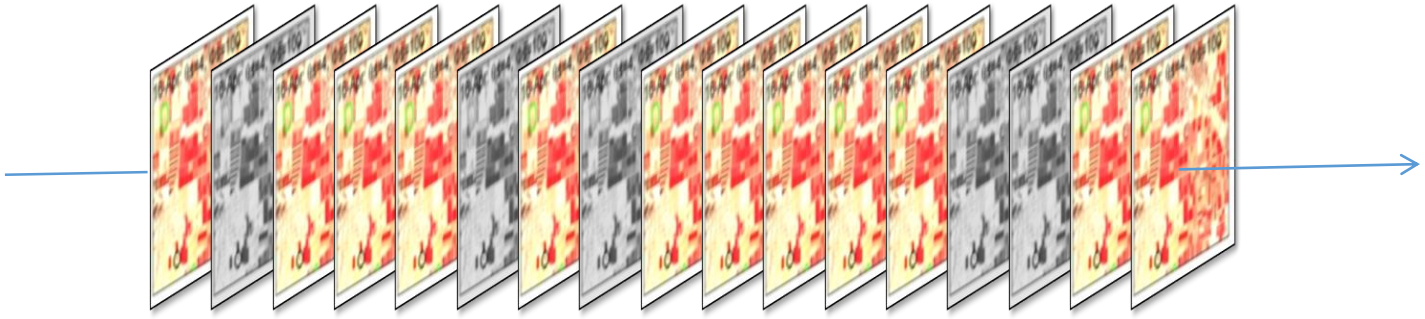
- Only current way to achieve that goal is by combining observations from S2 and Landsat



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

Whitcraft, A., PhD Dissertation, UMd 2014

What Does “Harmonizing” Mean?



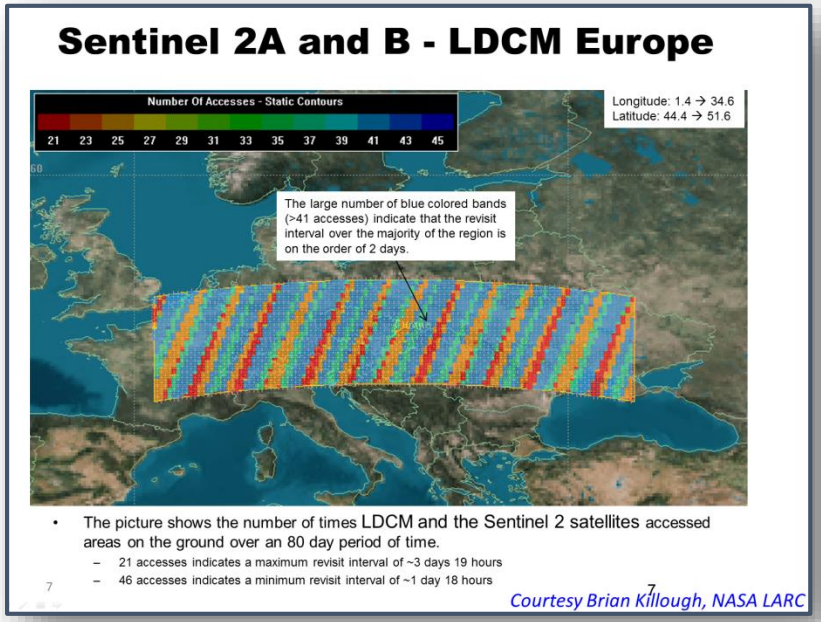
1. **Radiometry**
   - Sensors are fundamentally similar in terms measurement & resolution (example: Sentinel-2 & Landsat-8)

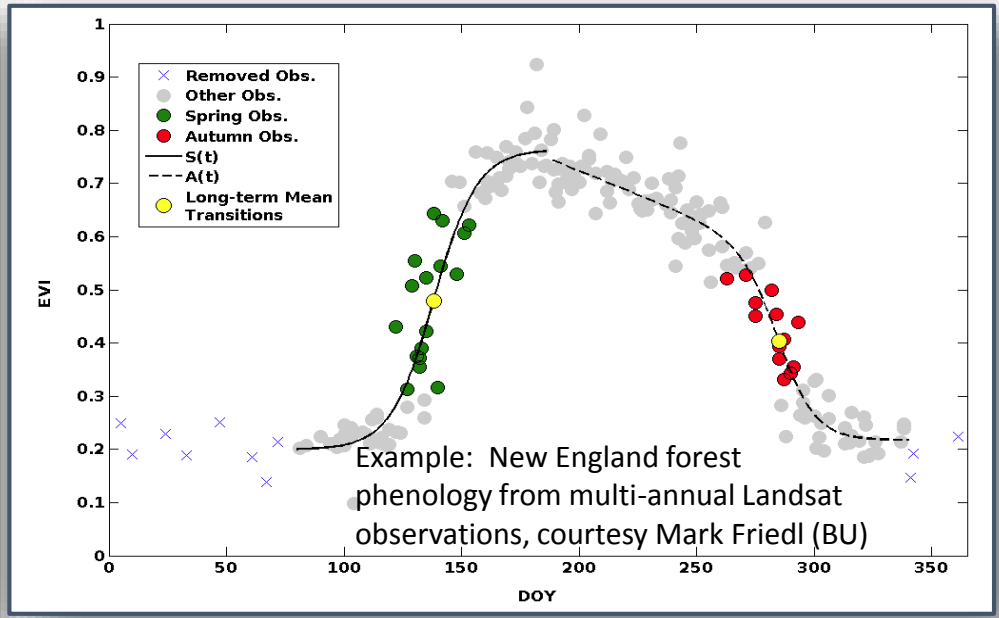
2. **Physical Variables (LAI, Land Cover, Biomass, etc…)**
   - Sensors must be able to produce the same geophysical measurement (e.g. LAI from lidar, LAI from Landsat)

3. **“Orthogonal” Measurements (non-harmonizing)**
   - Sensors with differing modalities, allowing unique information from each (e.g. Biomass from integrating SAR backscatter & Sentinel-2 reflectance)

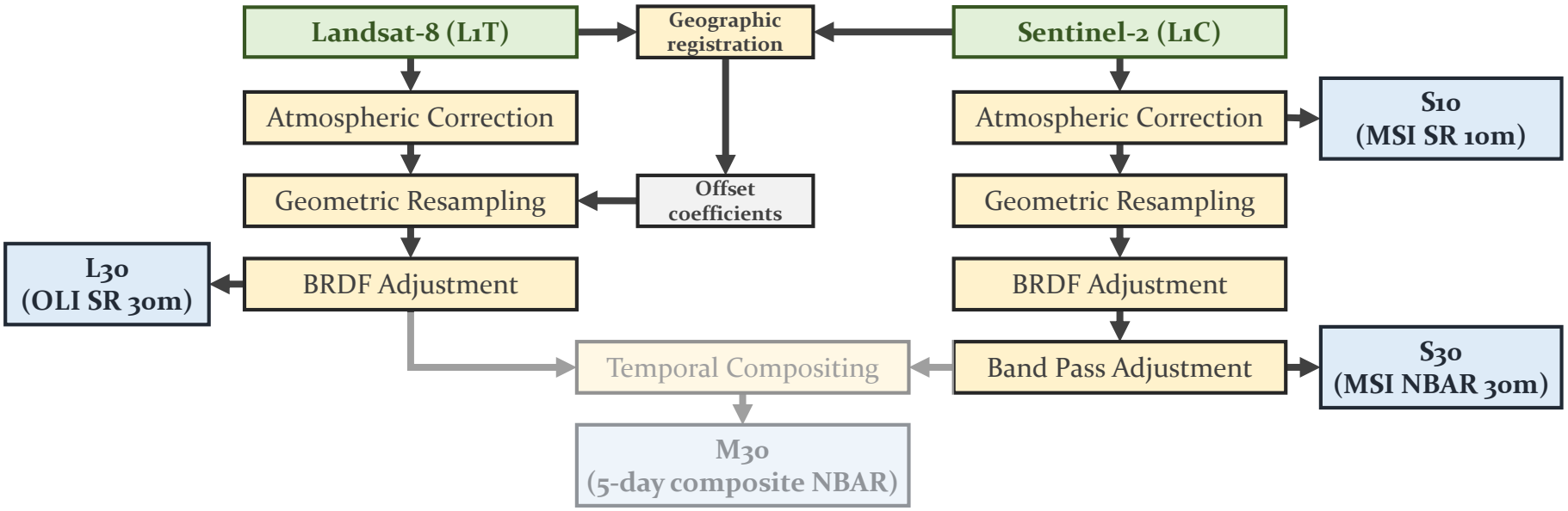
Harmonized Landsat-Sentinel-2 (HLS) Project

- Merging Sentinel-2 and Landsat data streams could provide < 5-day coverage
- Goal is “seamless” near-daily 30m surface reflectance record including Cross-calibration, atmospheric corrections, spectral and BRDF adjustments, regridding
- Project initiated 3 years ago as collaboration among GSFC, UMD, NASA Ames





Algorithms overview and status



Algorithm	Current	Planned (end 2016)	Other Options
Geographic registration	AROP (Gao et al. 2009, JARS)	AROP	-
Atmospheric Correction	OLI: Landsat-8 6S algorithm MSI: Sen2Cor	OLI and MSI: Landsat-8 6S algorithm	CNES MACCS
Cloud/Shadow Mask	OLI: L1T QA bits MSI: BU MSI Fmask	OLI: 6S Landsat-8 algorithm MSI: BU MSI Fmask	CNES MACCS
BRDF Adjustment	- Fixed BRDF (Roy et al. 2016, RSE) - Use of spatially-varying SZA	Fixed BRDF	Downscaling MODIS BRDF + Fixed BRDF as Backup
Band Pass Adjustment	Fixed, per-band linear regression	Fixed, per-band linear regression	Regression-tree (based on spectral shape)
Temporal Compositing	TBD	-	-

Products Specification

- All 4 products are aligned on the S2 Tiles 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

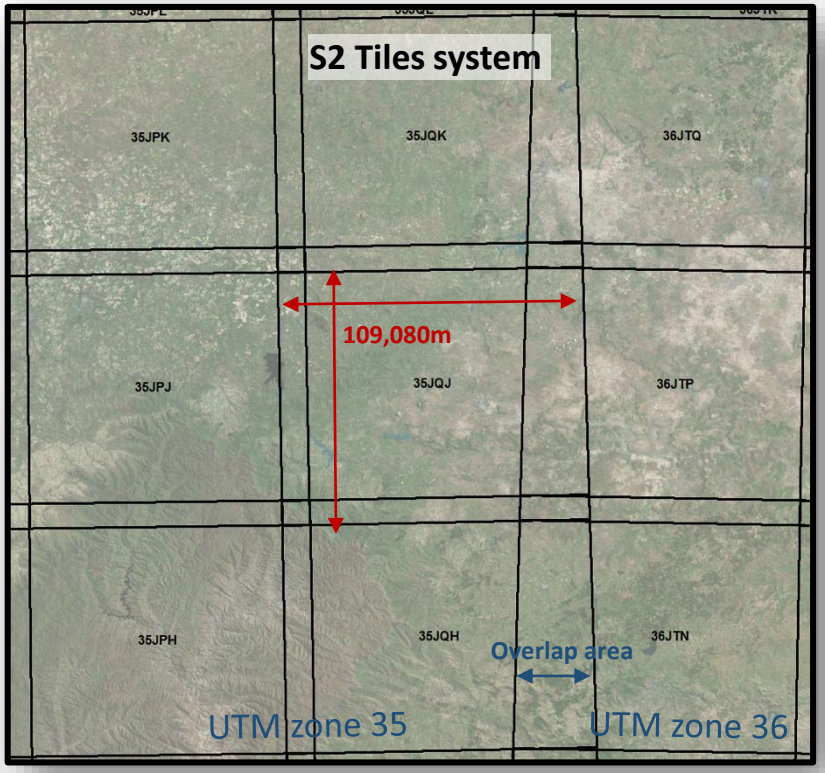
Spatial: 30m
Spectral Bands: All OLI
Temporal: All Landsat-8 L1T granules
NBAR: Yes

S30

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

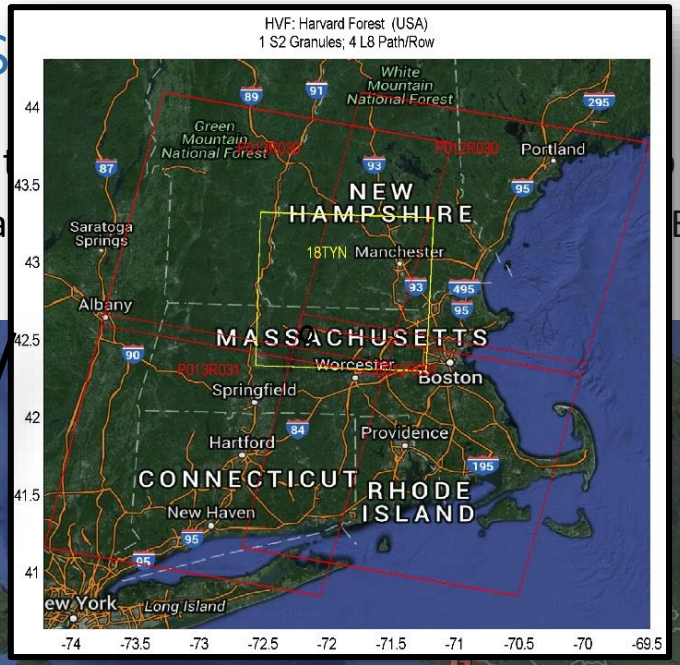
M30

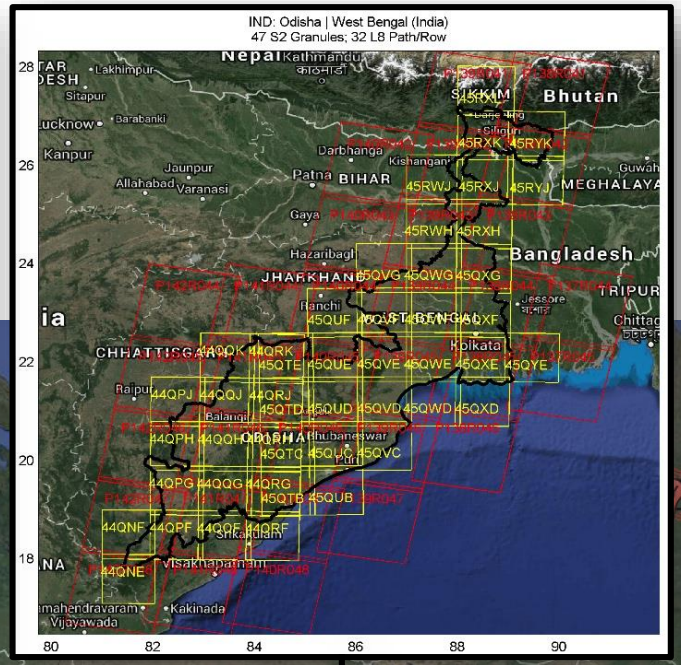
Spatial: 30m
Spectral Bands: OLI-like + MSI Red Edge + TIRS TOA
Temporal: 5-day "best pixel" based on min AOT
NBAR: Yes

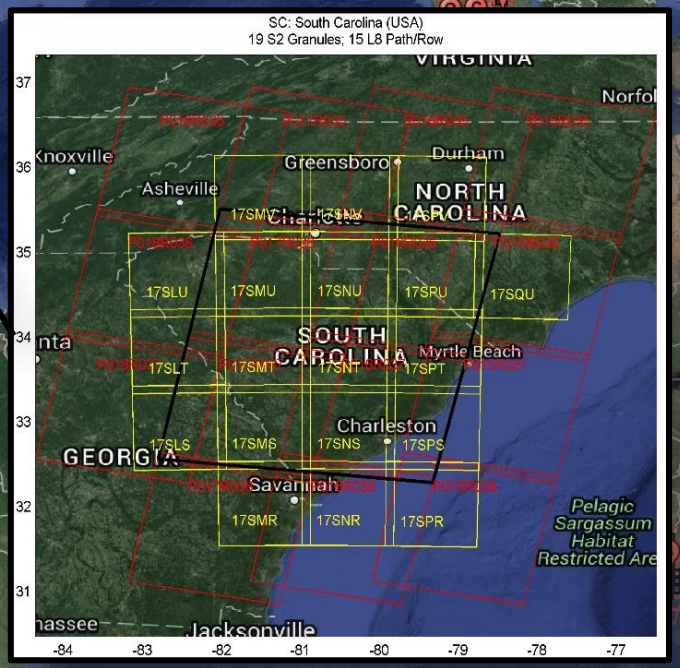


Test Sites

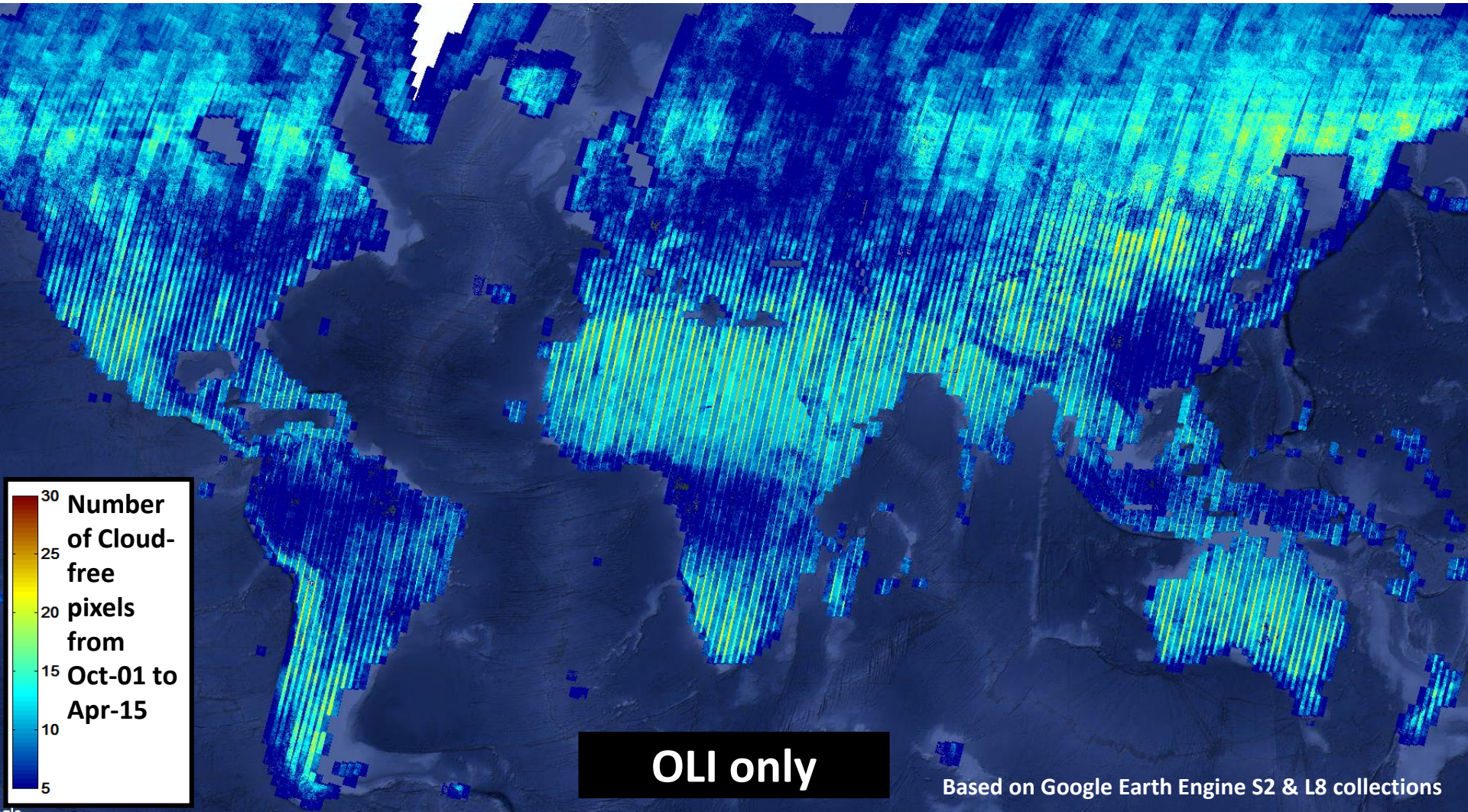
- 366 Sentinel 2 t
- 341 Landsat pa



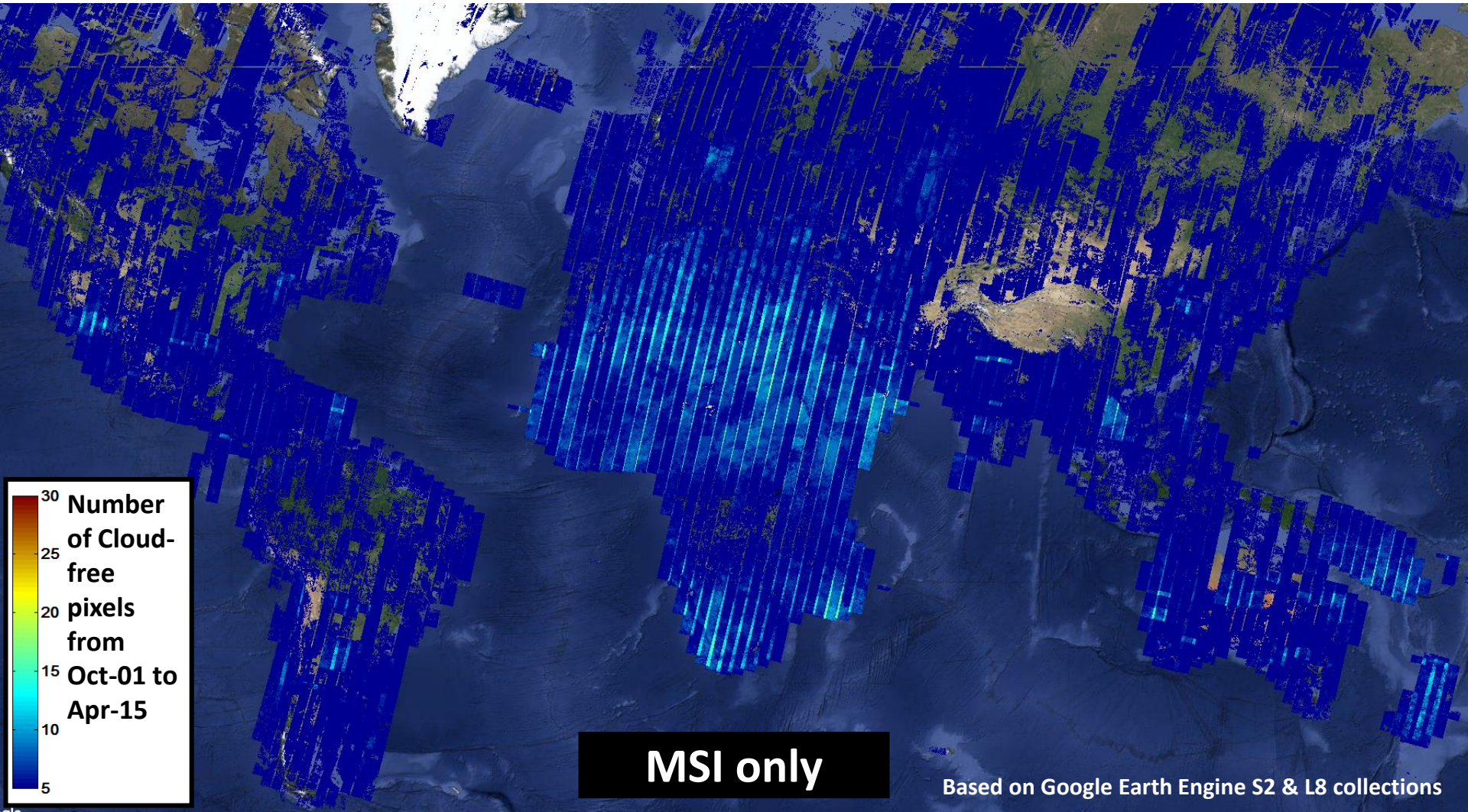




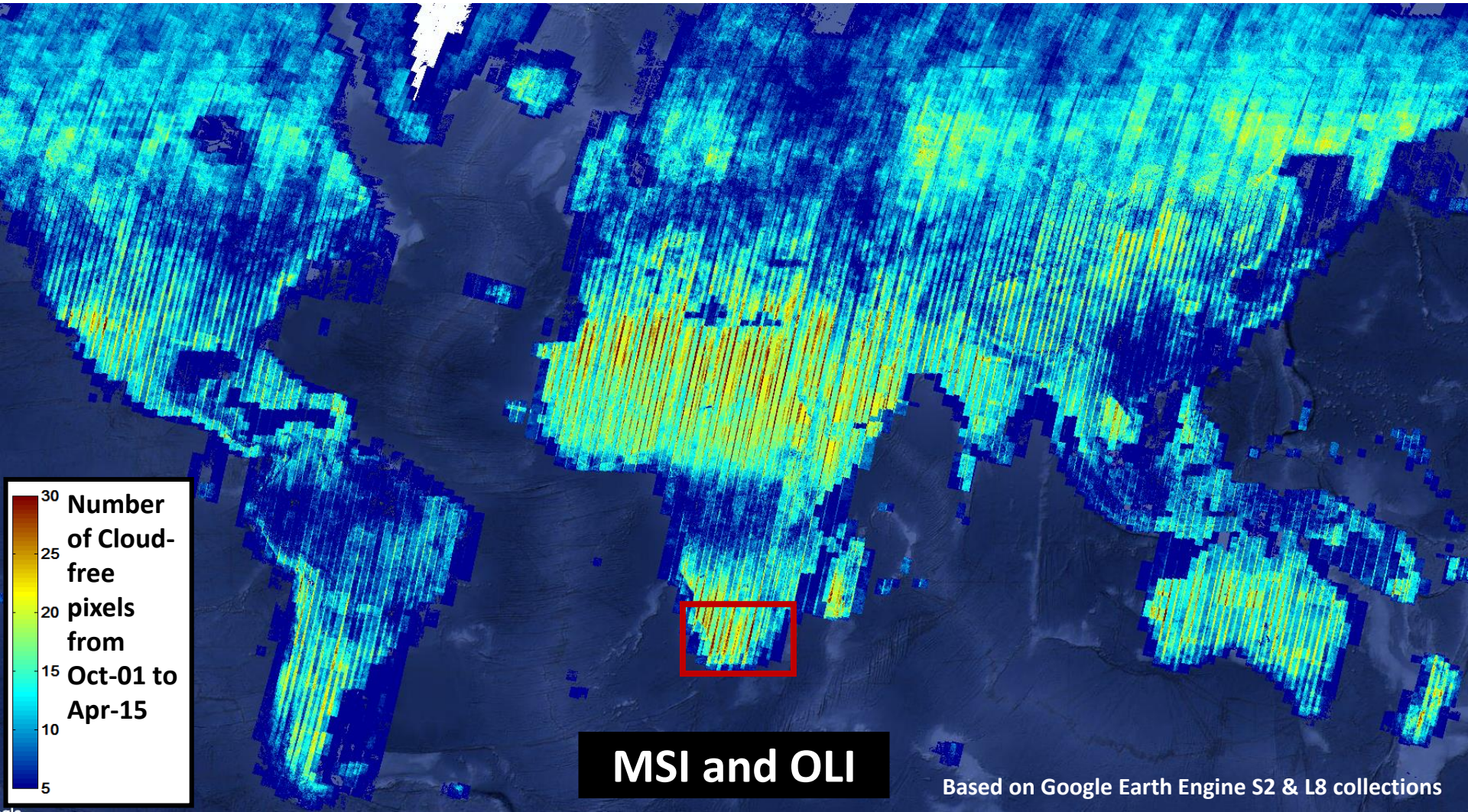
Time Series Potential – Status after 6 months



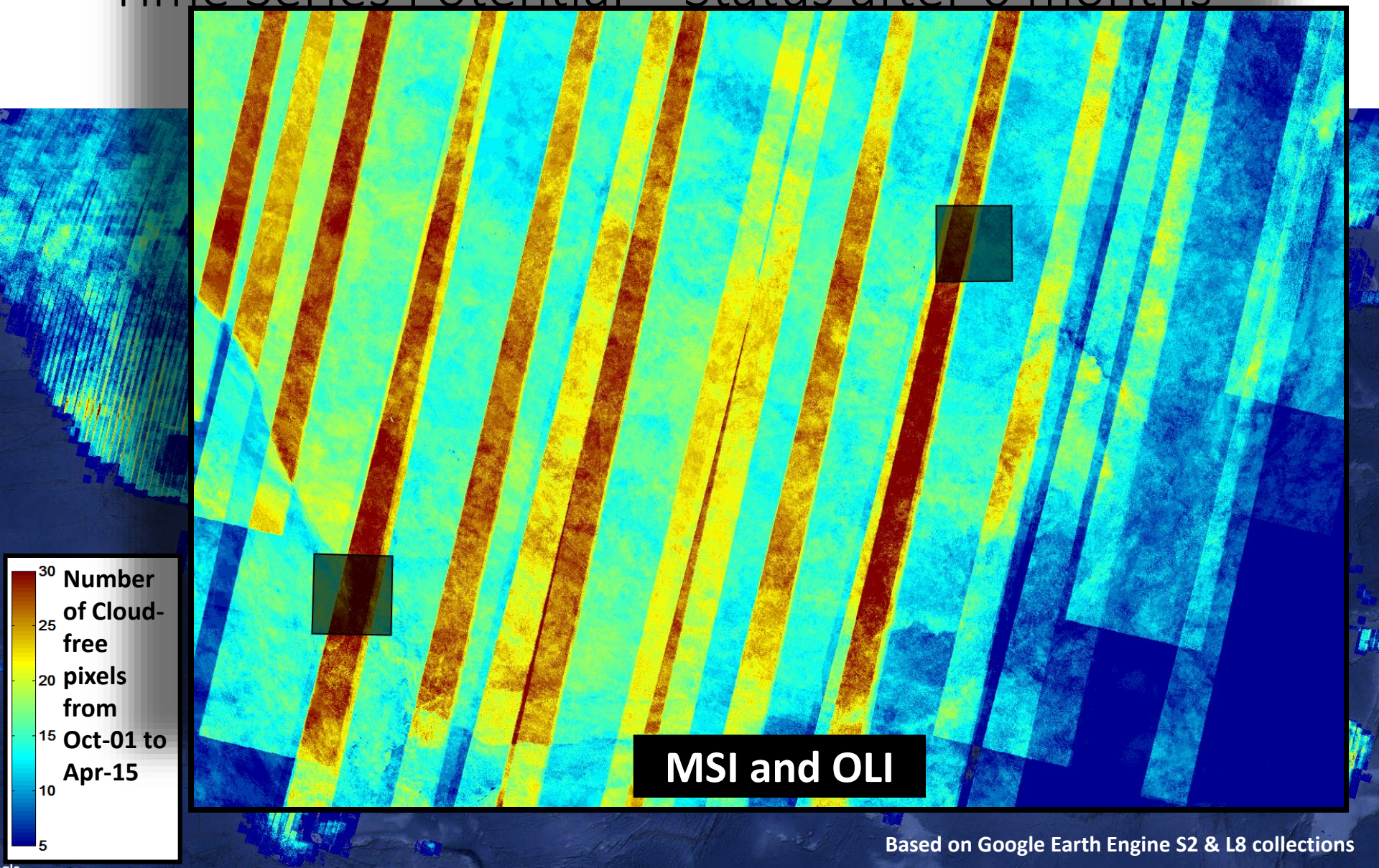
Time Series Potential – Status after 6 months



Time Series Potential – Status after 6 months

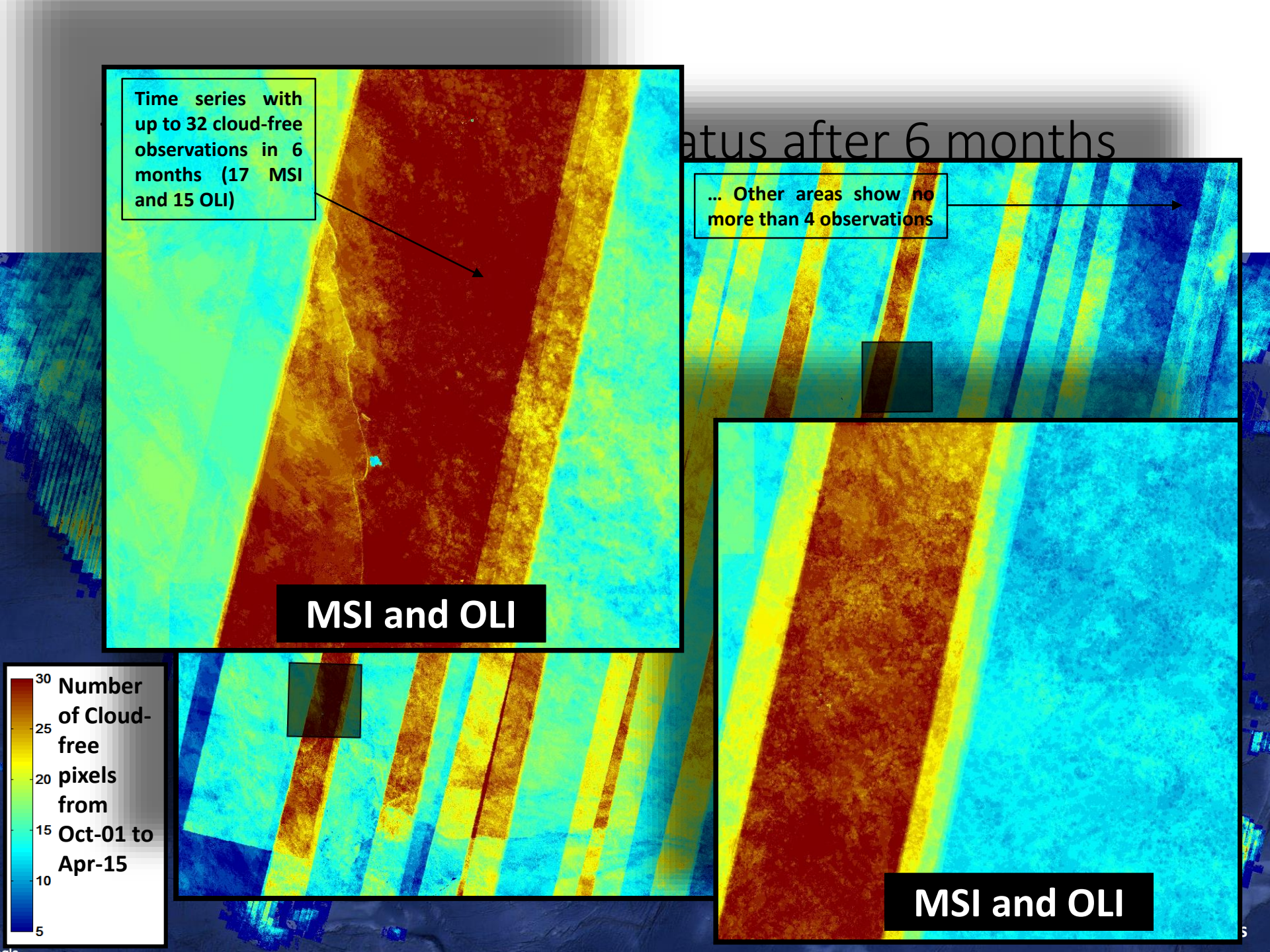


Time Series Potential – Status after 6 months



Based on Google Earth Engine S2 & L8 collections

atus after 6 months



L8 vs. S2 Registration

Landsat-8 data may be offset from Sentinel-2 data by up to 40m in some parts of the globe

We use the AROP (Automated Registration and Orthorectification Package / Gao et al., 2008) to resample L8 to S2 tiles using tie points

L8: Path 176, Row 82, Mar 04, 2016, in S2 tile 34HBK without AROP

L8 vs. S2 Registration

Landsat-8 data may be offset from Sentinel-2 data by up to 40m in some parts of the globe

We use the AROP (Automated Registration and Orthorectification Package / Gao et al., 2008) to resample L8 to S2 tiles using tie points

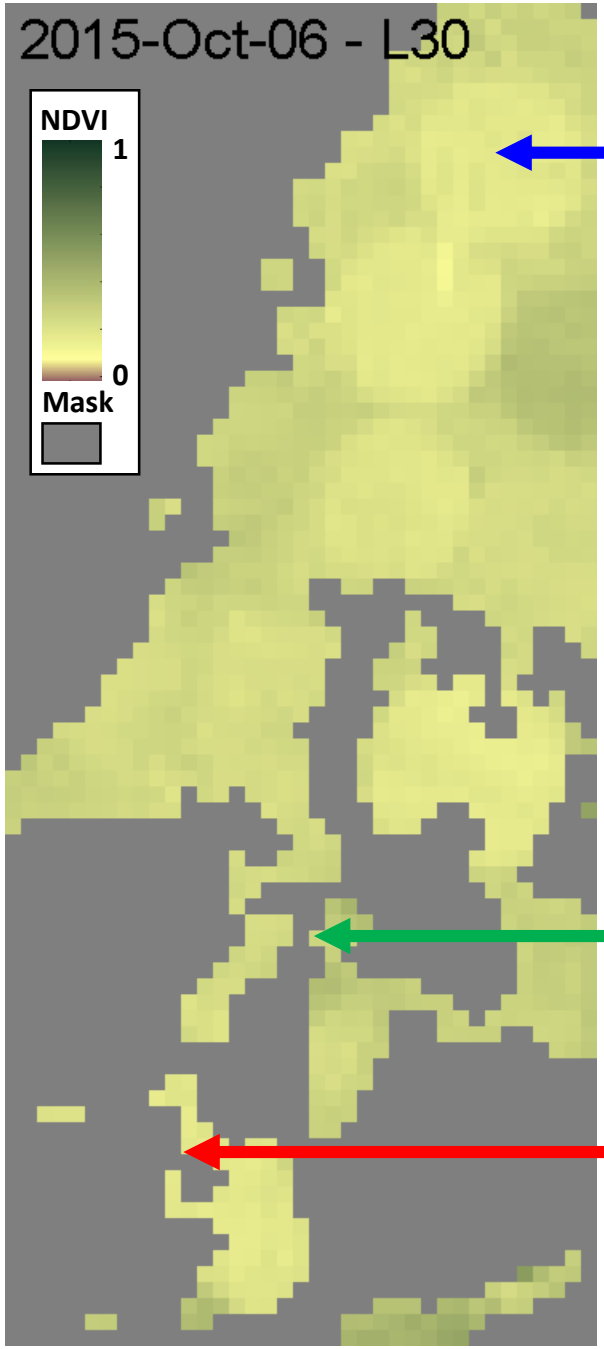
S2: Tile 34HBK, Mar 07, 2016

L8 vs. S2 Registration

L8: Path 176, Row 82, Mar 04, 2016.
AROP adds 15.8m in X and 21.5m in Y

Landsat-8 data may be offset from Sentinel-2 data by up to 40m in some parts of the globe

We use the AROP (Automated Registration and Orthorectification Package / Gao et al., 2008) to resample L8 to S2 tiles using tie points

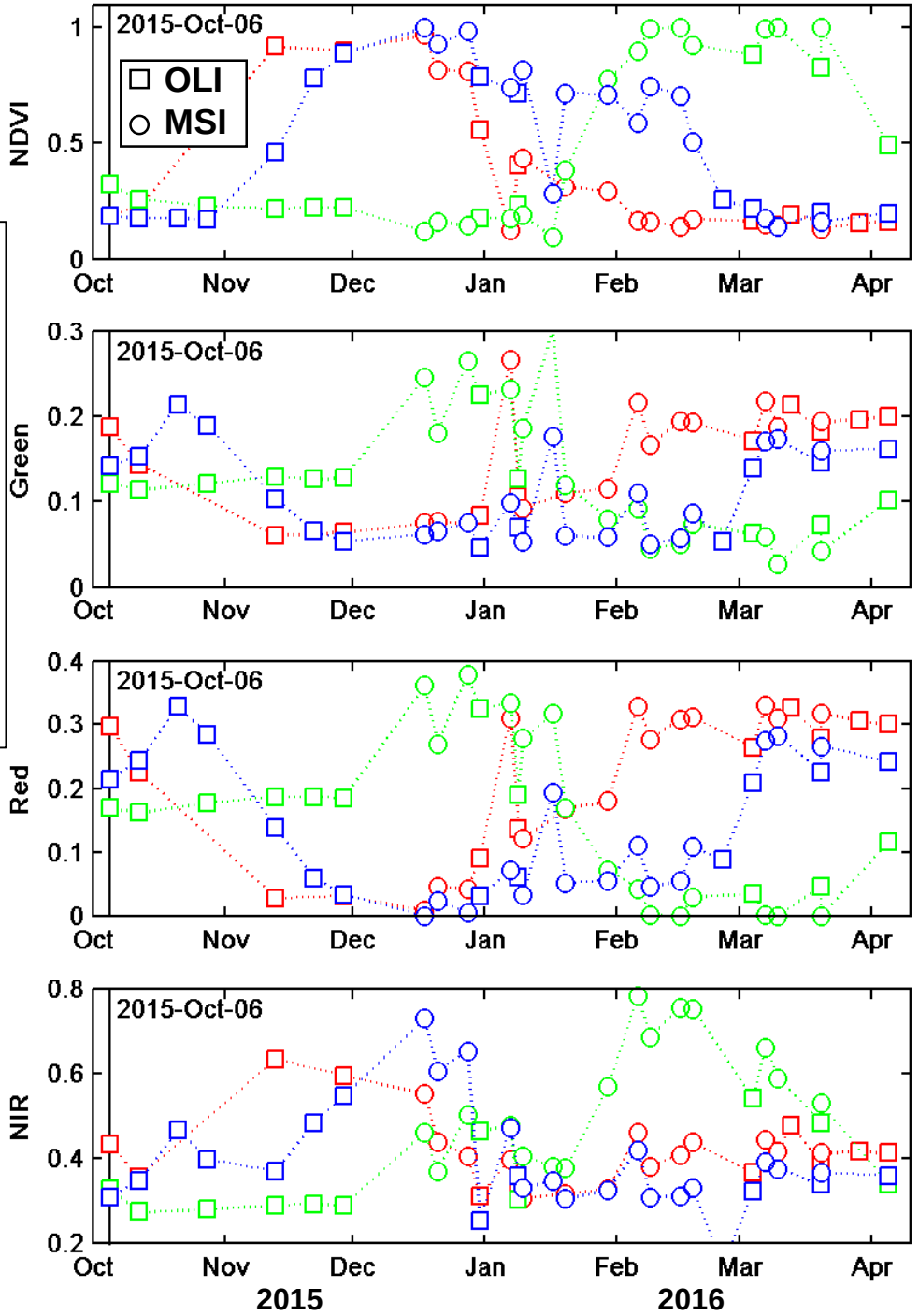


Field 1

Field 2

Field 3

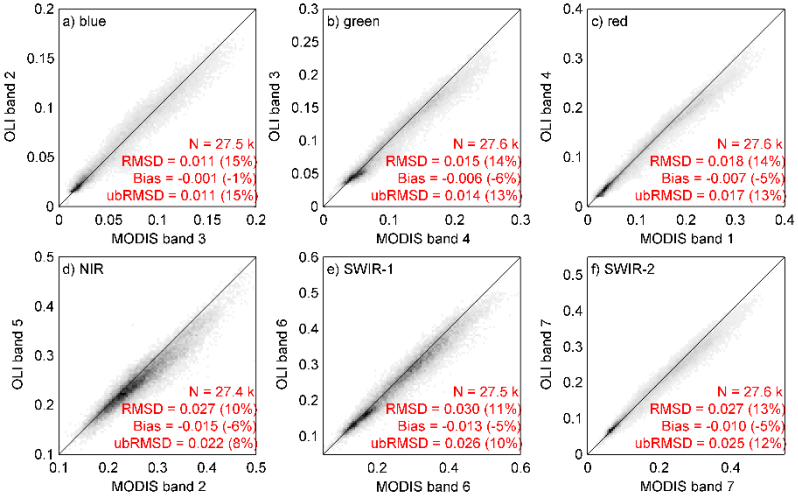
Time series of 3 fields from OLI (L30, ○) & MSI (S30, □).
The color of the symbol corresponds to the field identified in the map.

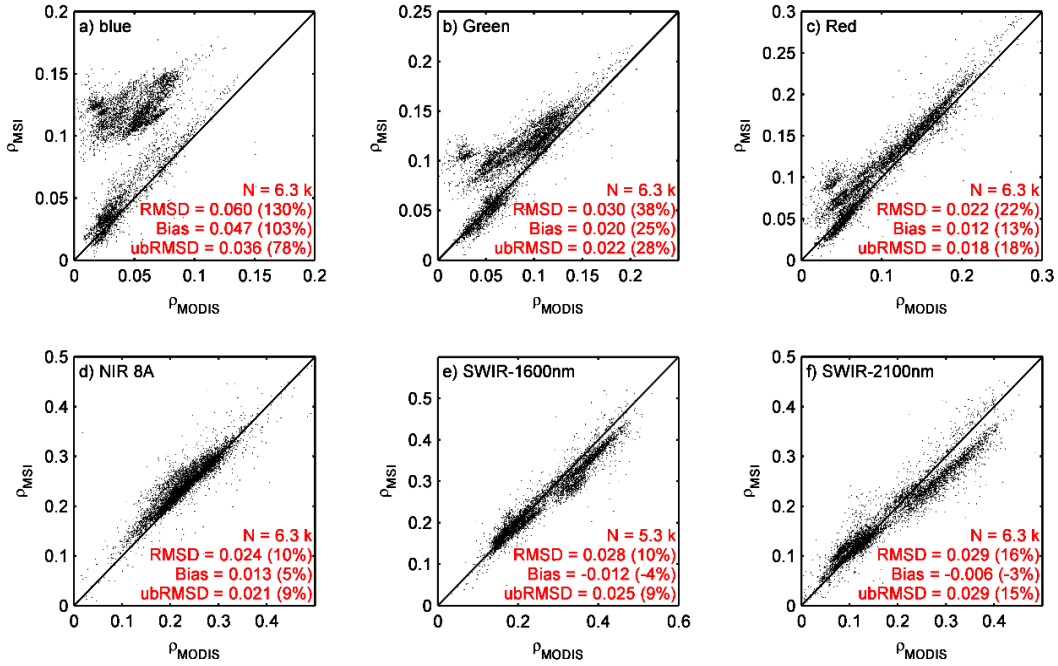


Results: Sen2cor evaluation

- MSI Surface Reflectance (58 tiles) from sen2cor were compared with same-day MODIS (Terra & Aqua) M{O/Y}D09CMG (5km) adjusted from the BRDF (same sun-view geometry as MSI)

OLI vs MODIS

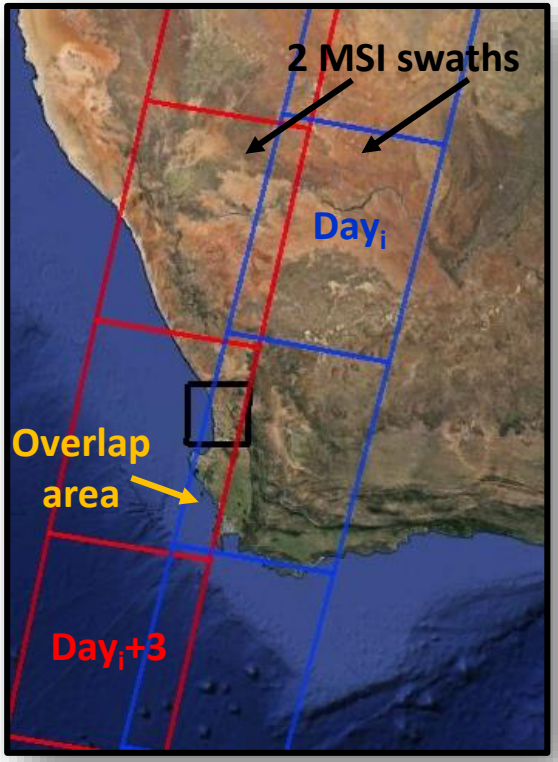




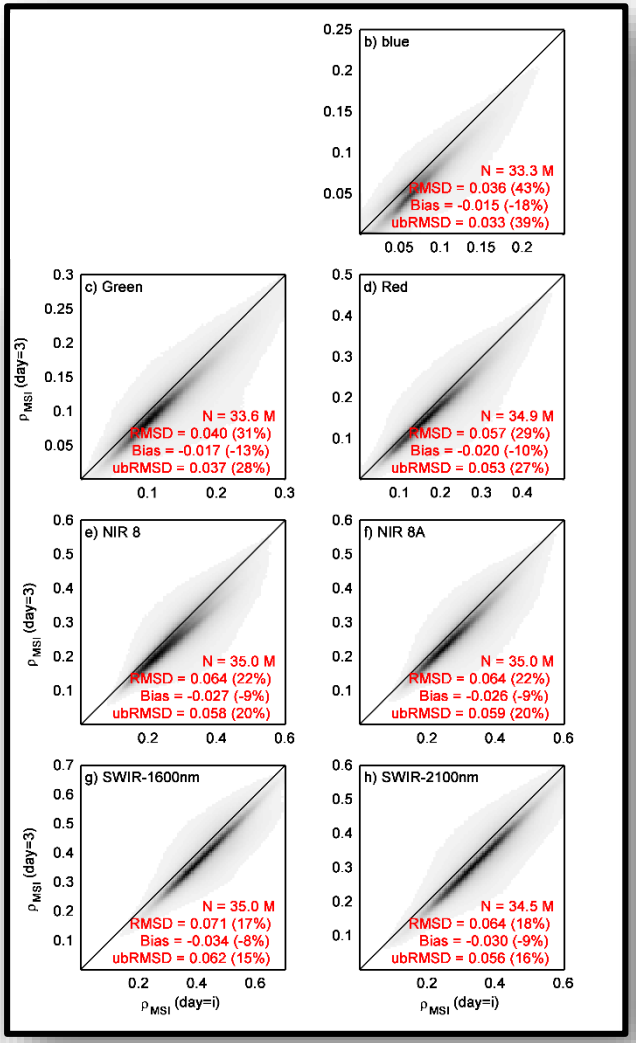
- Poor results on highly impacted bands
- Compared to OLI results (see on the top), there are:
  - a factor 2 on the scores for Blue and Green bands
  - Equivalent scores for other bands

Results: Evaluation of the BRDF adjustment

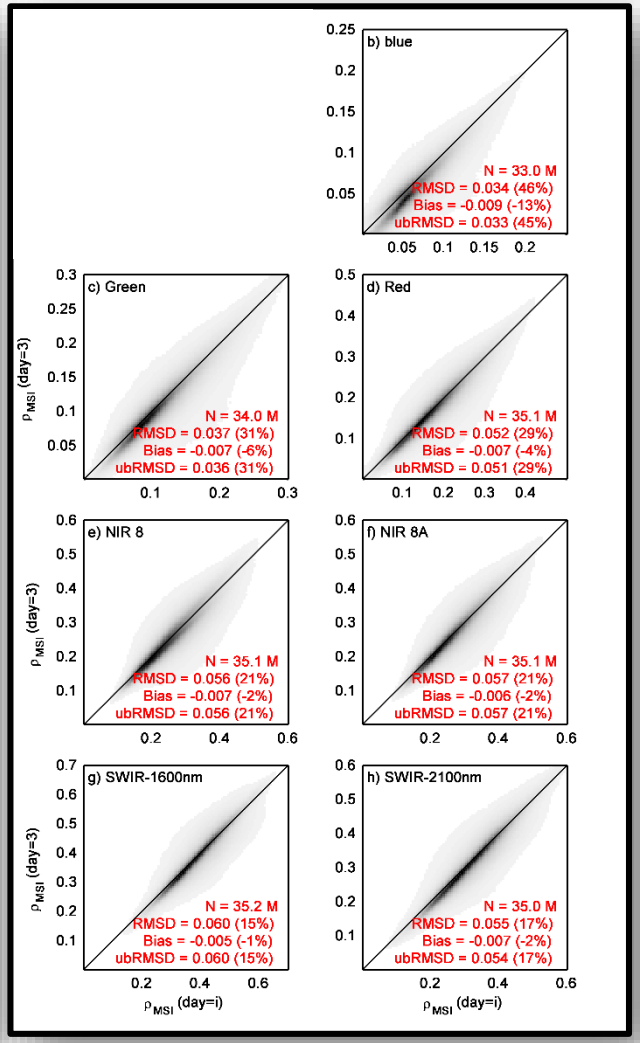
- We evaluated the deviation between edge swath acquisitions of MSI with and without BRDF-adj.



Without BRDF-adj.

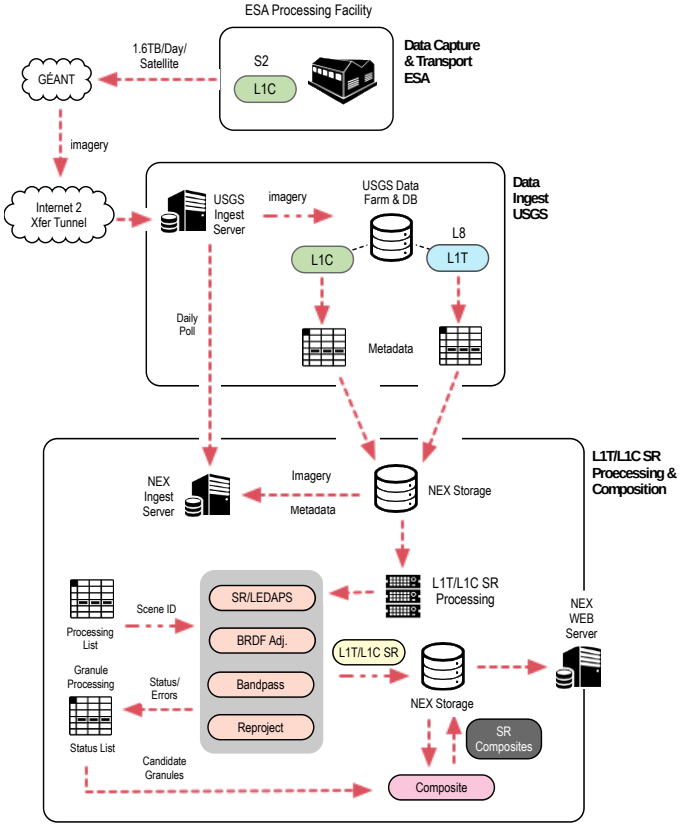


With BRDF-adj.



HLS Processing Approach

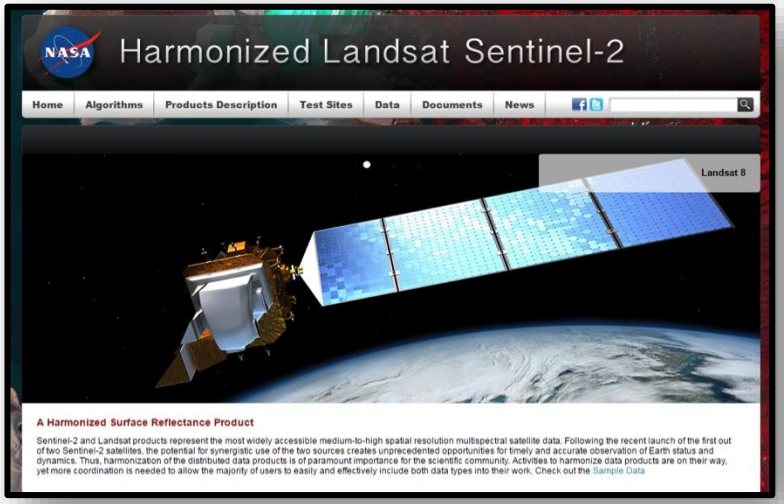
- Data processed on NASA Earth Exchange (NEX) cluster at NASA Ames
- Automated polling & download of ESA SciHub and USGS Earth Explorer for input data files
- QA, metadata, processing status generated on the fly



Websites and Public Interface

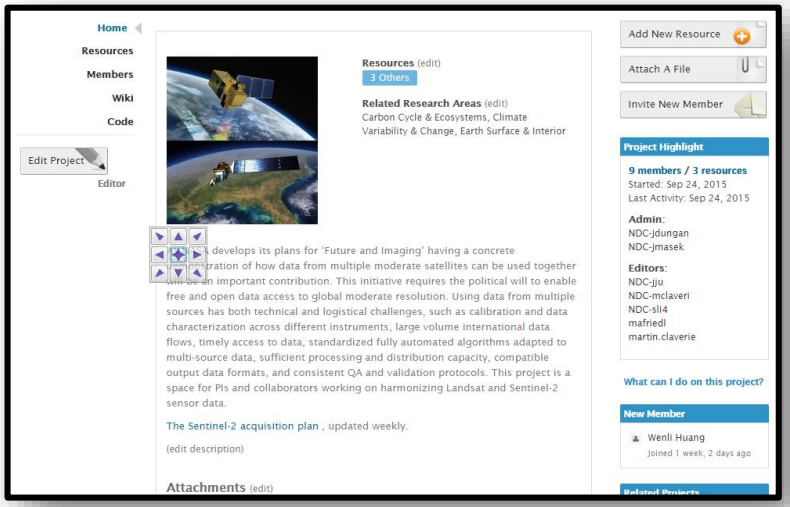
HLS website

- http://hls.gsfc.nasa.gov
- Public access
- Sample data available (via FTP)
- Algorithm & Product descriptions



MuSLI NEX project page

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



Targeting release of sample HLS Data Sets by June 1, 2016

Future Directions for HLS

Current HLS products and test sites support NASA Multi-source Land Imaging (MuSLI) Science Team **prototyping**

- *MuSLI is NASA-funded research team focused on prototyping higher-level products from merged, international sources of data (e.g. Landsat and Sentinel-1,2)*
- *Solicited in parallel with ESA DUE Innovator call*

Near-term focus on validating harmonized reflectance products

- *Comparison with MODIS SR and NBAR*
- *Comparison of derived aerosol (AOT) with Aeronet data*
- *Time series stability over "invariant" targets*

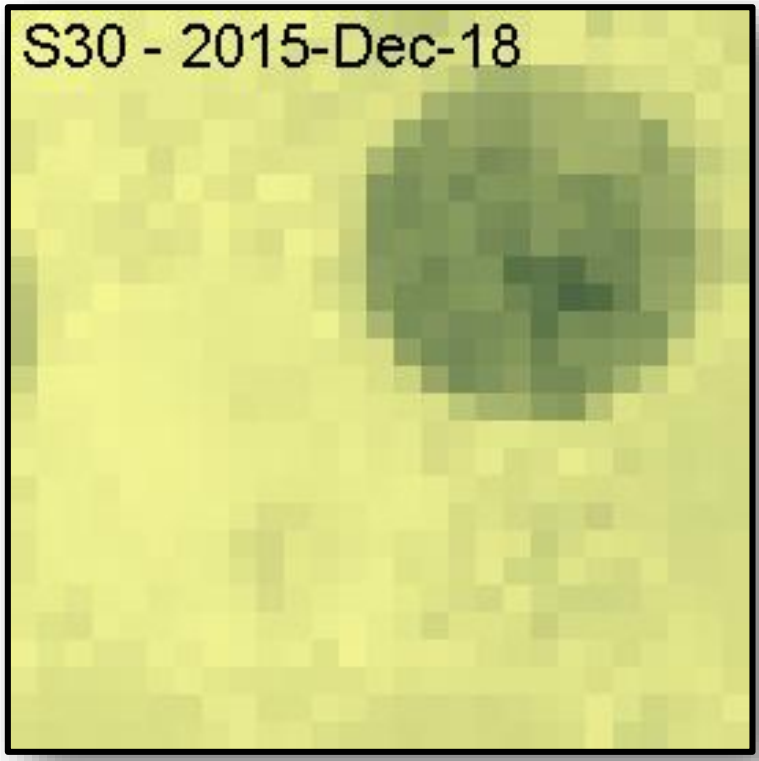
Long-term focus on continental land use and biophysical products from the moderate-resolution record to support both science research and applications

Conclusion

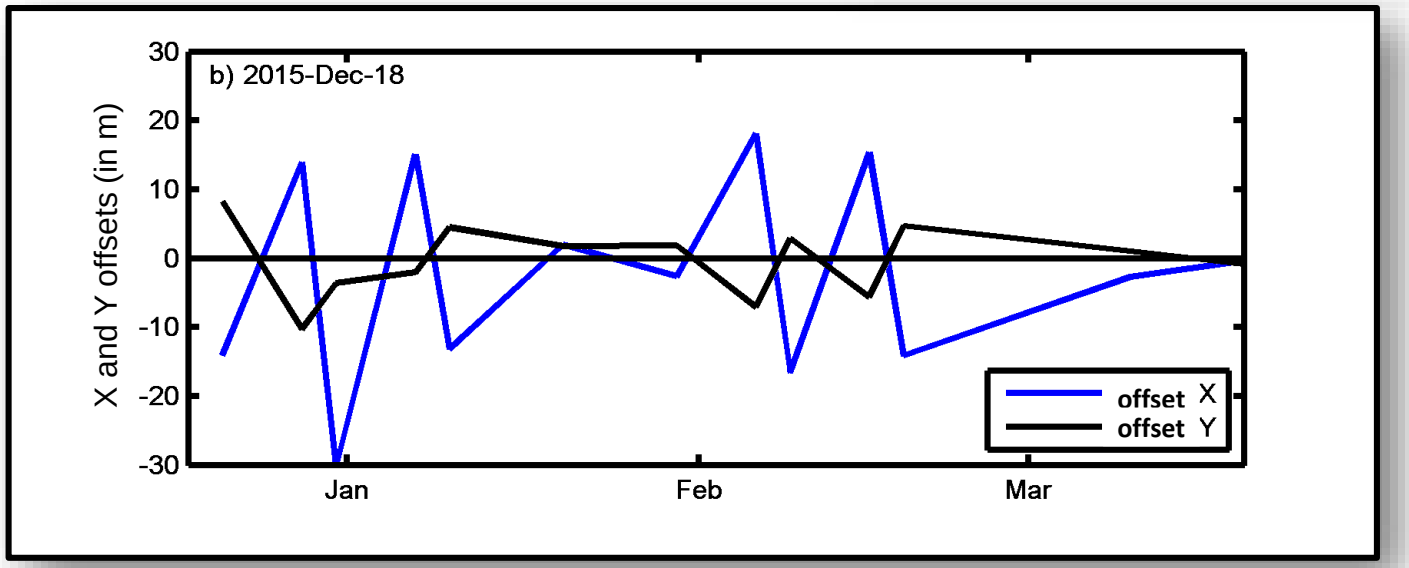
- We now use the time domain to analyze moderate-resolution imagery as we have for years with AVHRR, MODIS, and other ~1km systems
  - Understanding land use & management change requires a “30m MODIS” daily observatory
- Harmonizing observations from multiple, international systems (e.g. Landsat + Sentinel-2) provides a cost effective approach toward this goal
- Radiometric harmonization (e.g. HLS) Is one approach toward this goal… but we will hear about many others over the next few days!

BACKUP

Co-registration of MSI data

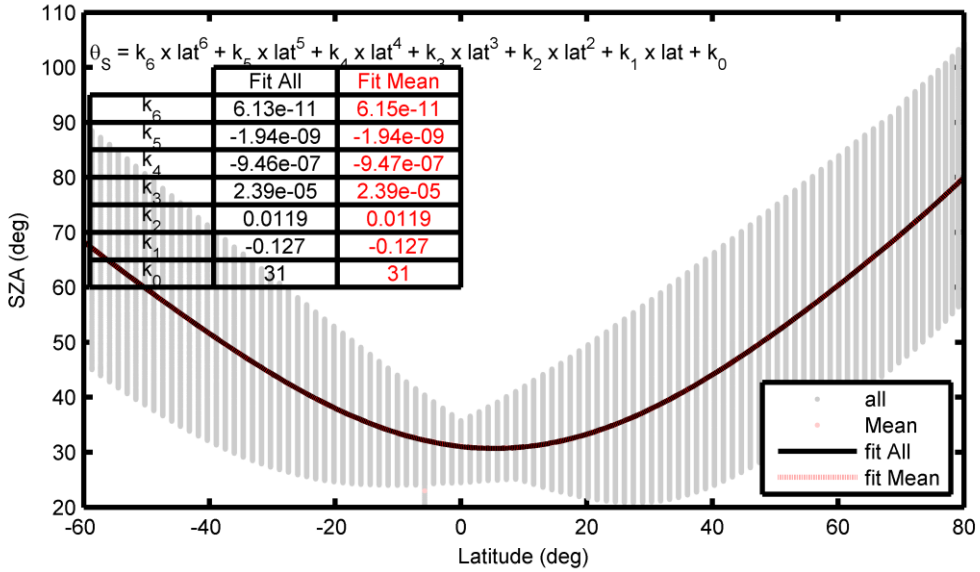


- We observed some offsets in-between MSI data
- In the current stage, it also affects OLI data which are co-registered to MSI using AROP



SZA as a function of Latitude

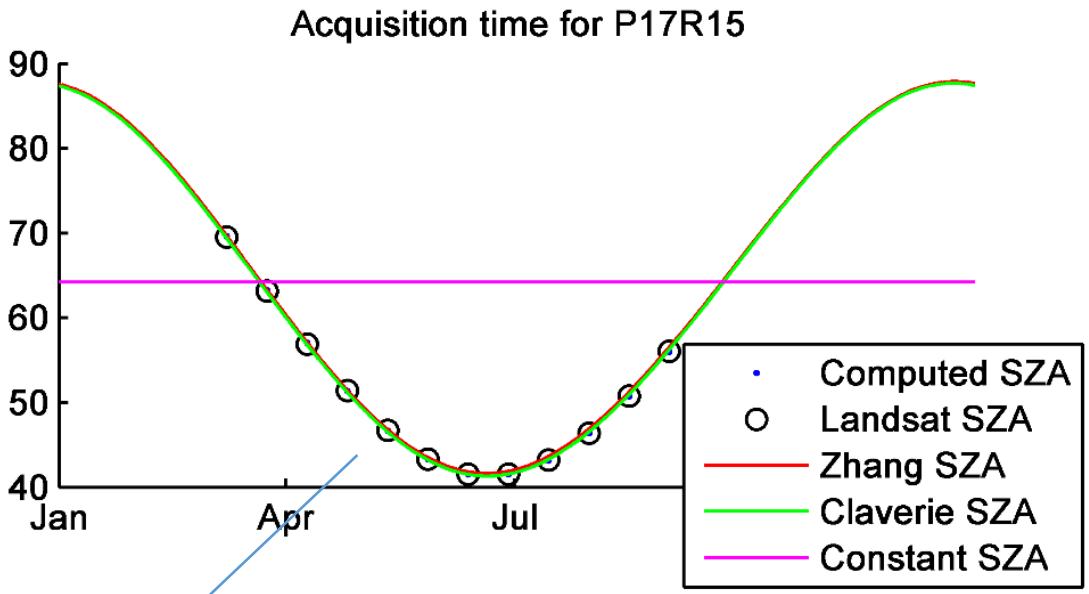
6th degree polynomial seams well appropriated to fit the VZA annual variation (Zhang also used a 6th degree polynomial to fit local time as a function of Latitude).

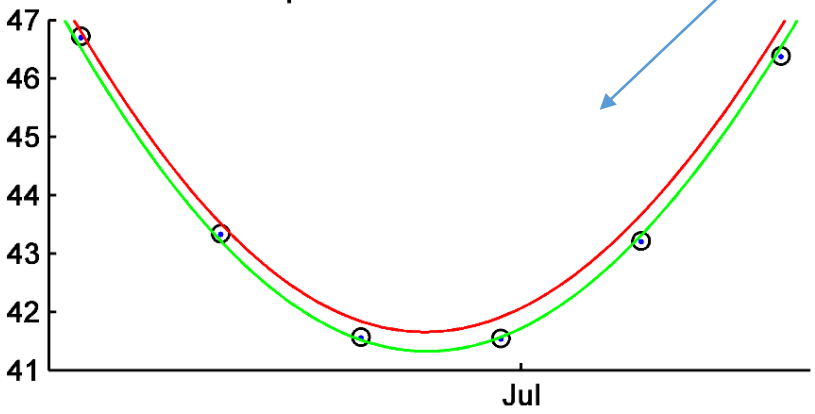


There is almost no differences between a fit based on all the points (grey) or using the mean value (in pink but not visible here, in black in previous slide).

Back to the example…

Lat = 64.23 ; Lon = -67.54

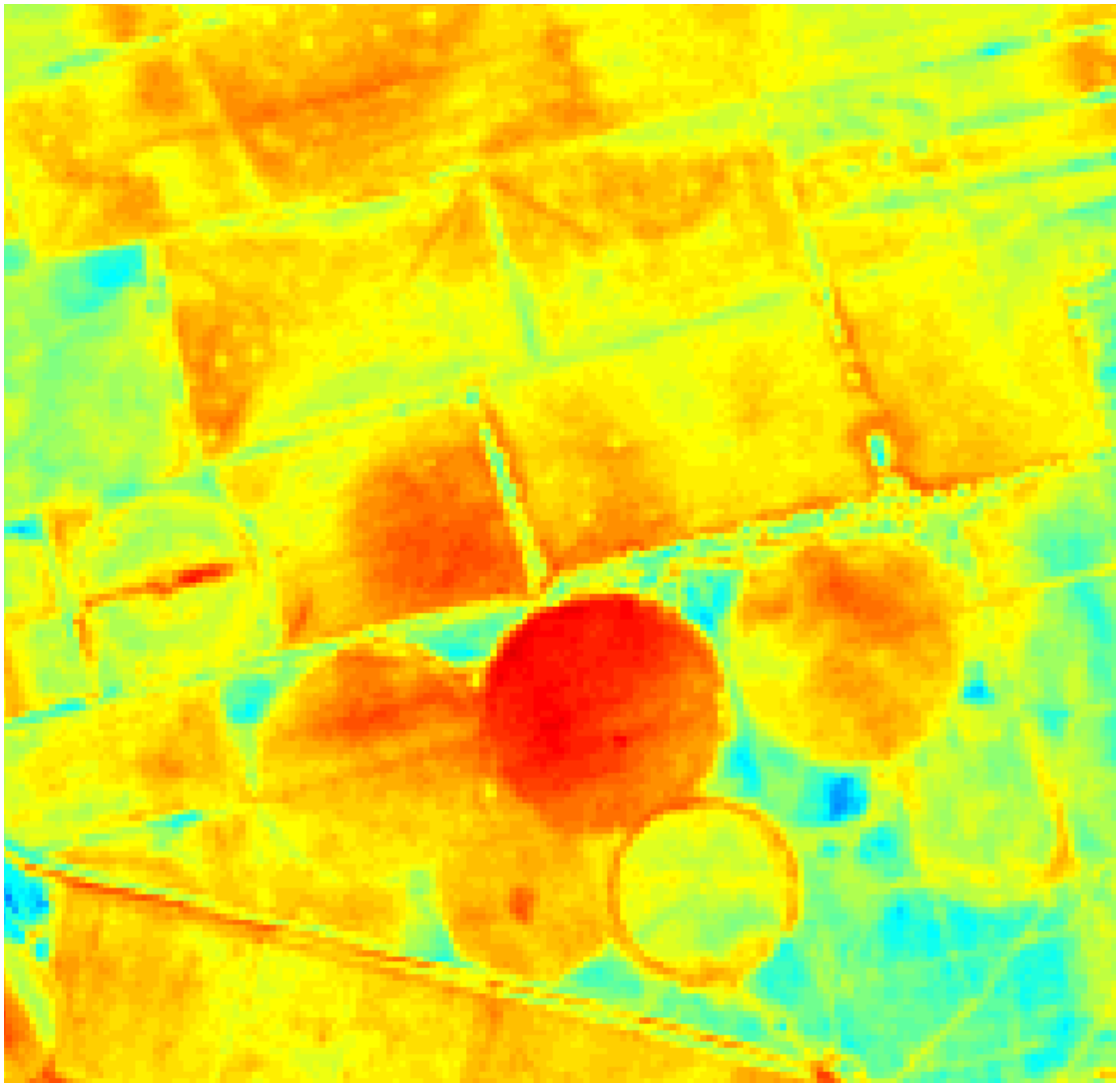




No difference between computed and Landsat SZA (Normal!)
Green = Better fit than red certainly due to the gap observed in first slide

MSI Co-registration

34HBK, Mar 07, 2016



MSI Co-registration

34HBK, Mar 10, 2016