NASA Sentinel-2 Activities & Experience

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What’s Needed to Use Sentinel-2 + Landsat?

(1) User Access to S2 L1C Data (Dwyer)

(2) MSI Characterization & Cross-Calibration with Landsat-8

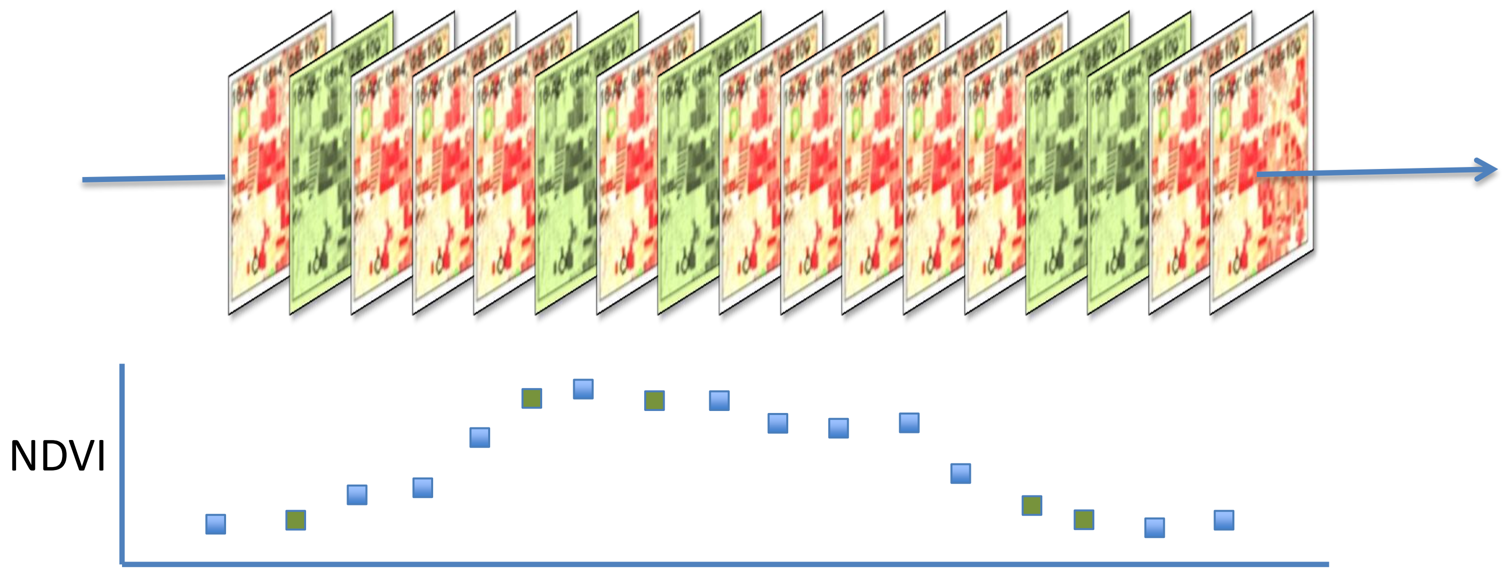
- Geometric & Spatial characterization (Storey)
- Radiometric characterization (Markham)

(3) Harmonized & Higher Level Products (Masek)

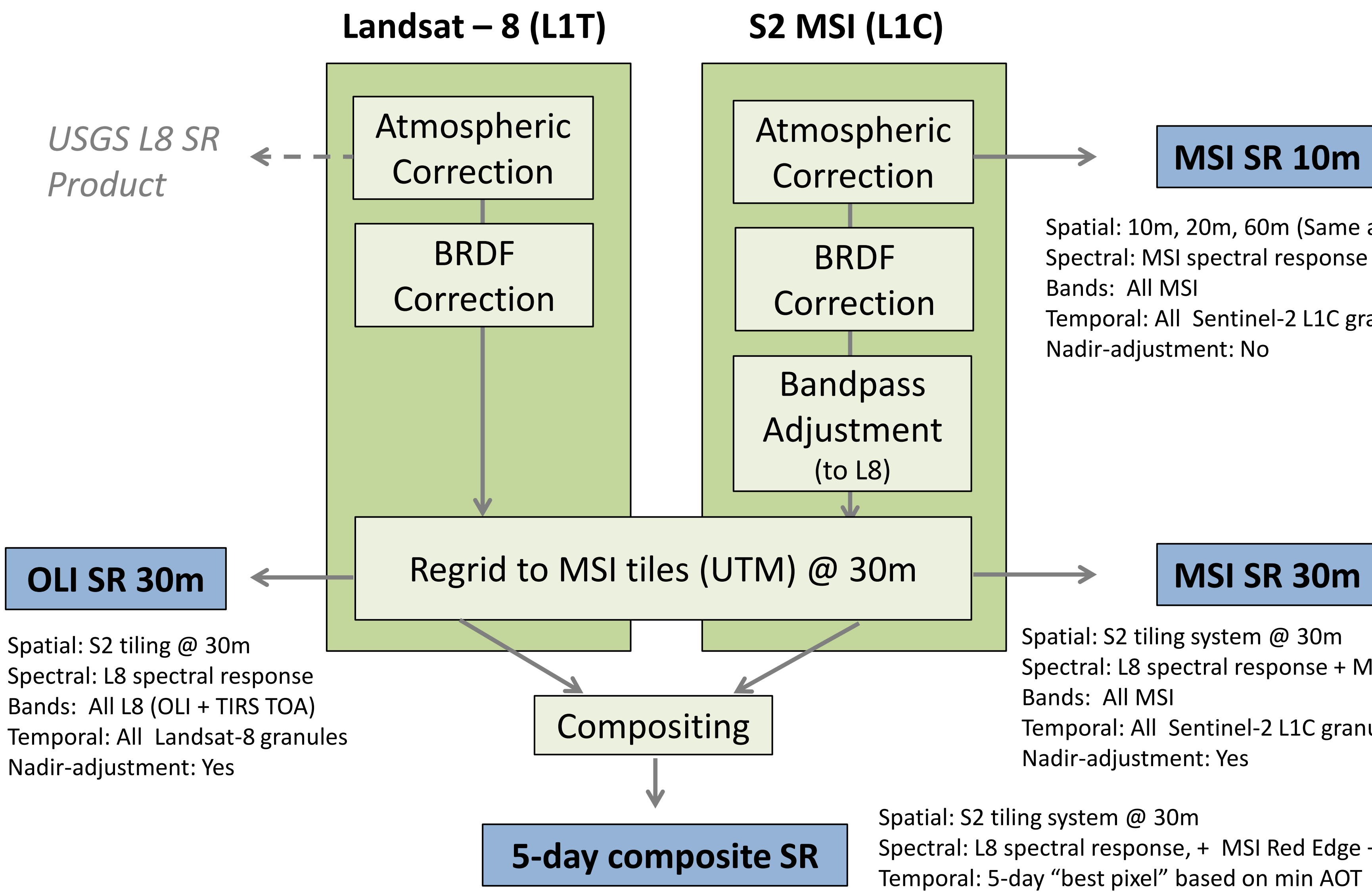
– NASA Multi-source Land Imaging Team (MuSLI)
– Prototype merged Landsat + S2 reflectance product

Harmonized Landsat-Sentinel (HLS) Project

- Goal: “seamless” near daily, 30m surface reflectance record from Landsat-8 and Sentinel-2a,b
- Cross-calibration, atmospheric corrections, spectral and BRDF adjustments, regridding/reprojection
  - “data cube” concept
- Collaboration among GSFC, UMD, NASA Ames
- Implemented on NASA Earth Exchange (NEX) – initially as limited set of test sites



HLS Processing & Products



MSI SR 10m

Spatial: 10m, 20m, 60m (Same as S2 L1C)
Spectral: MSI spectral response
Bands: All MSI
Temporal: All Sentinel-2 L1C granules
Nadir-adjustment: No

OLI SR 30m

Spatial: S2 tiling @ 30m
Spectral: L8 spectral response
Bands: All L8 (OLI + TIRS TOA)
Temporal: All Landsat-8 granules
Nadir-adjustment: Yes

MSI SR 30m

Spatial: S2 tiling system @ 30m
Spectral: L8 spectral response + MSI red edge
Bands: All MSI
Temporal: All Sentinel-2 L1C granules
Nadir-adjustment: Yes

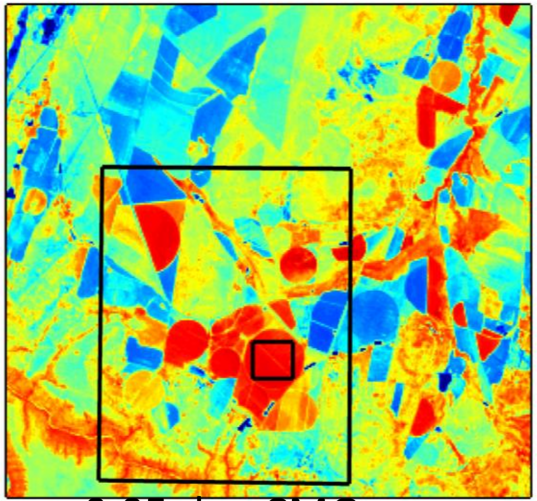
5-day composite SR

Spatial: S2 tiling system @ 30m
Spectral: L8 spectral response, + MSI Red Edge + L8 TIR
Temporal: 5-day "best pixel" based on min AOT
Nadir-adjustment: Yes

HLS Science Algorithms

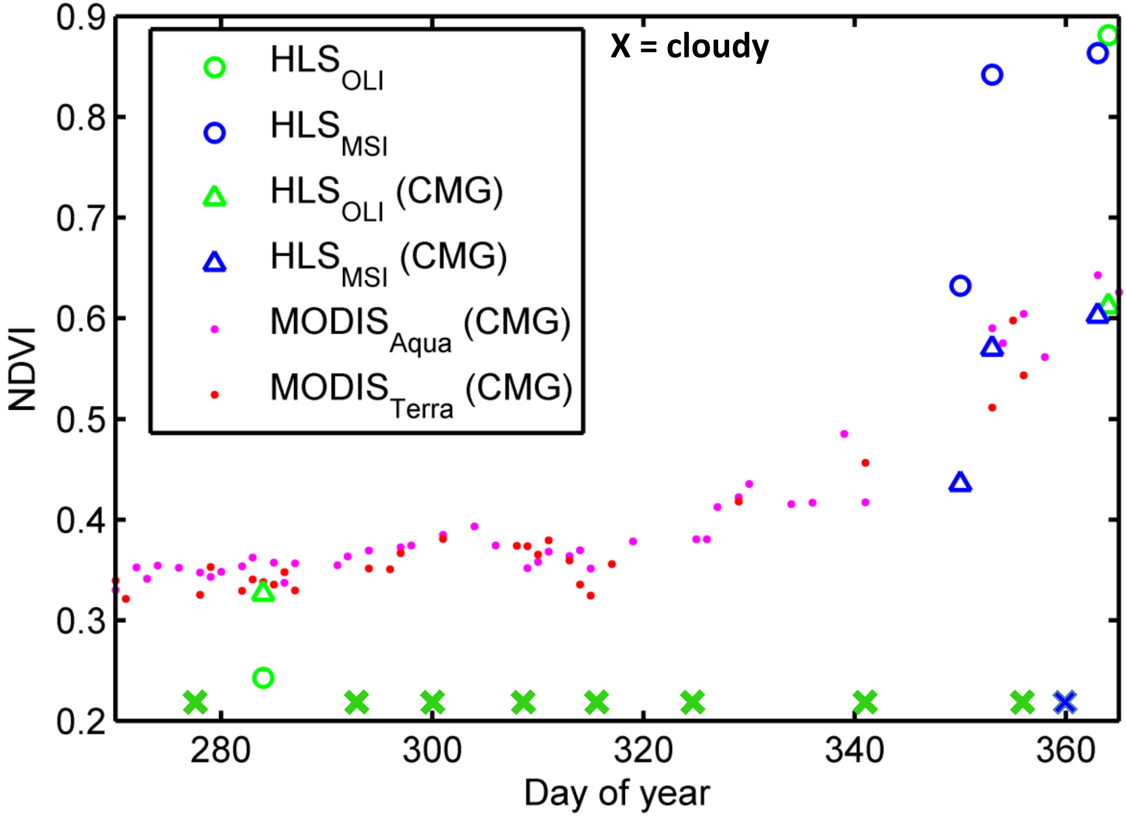
Algorithm	Current	Planned (2016)	Other Options
Atmospheric Correction	L8: Landsat-8 6S algorithm MSI: 6S with fixed atmosphere	Both: Landsat-8 6S algorithm	ESA Sen2Cor; CNES MACCS
Cloud/Shadow Mask	L8: L1T QA bits MSI: Sen2Cor mask	L8: 6S Landsat-8 algorithm MSI: BU MSI Fmask	CNES MACCS
BRDF Correction (nadir view, 45° solar)	VJB Model	VJB model	Downscaling MODIS MCD43 BRDF
Spectral Adjustment (to Landsat)	Fixed, per-band linear regression	Fixed, per-band linear regression	Regression-tree (based on spectral shape)

HLS NDVI Time Series



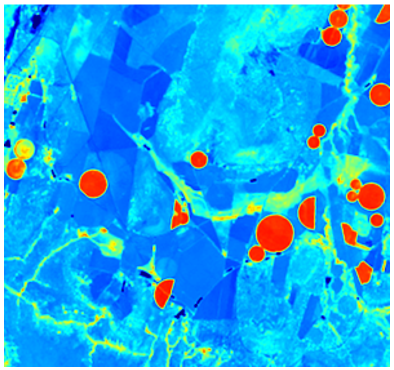
0.05 deg CMG

Lydenburg, South Africa; 30m harmonized products



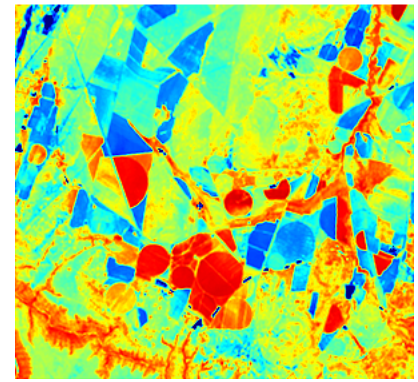
HLS NDVI Time Series

11 Oct



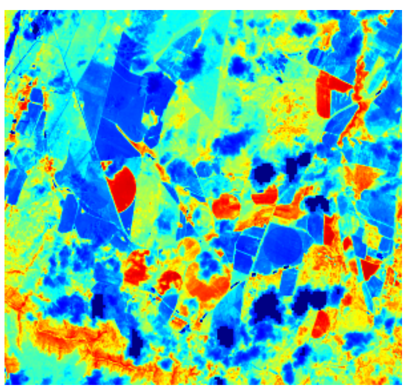
cloudy

30 Dec

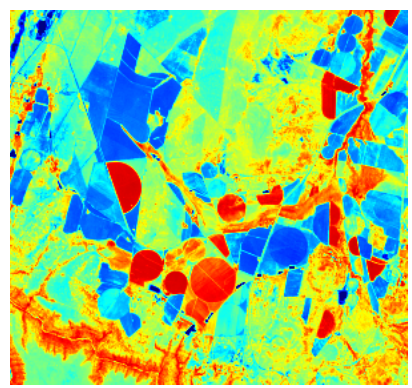


OLI

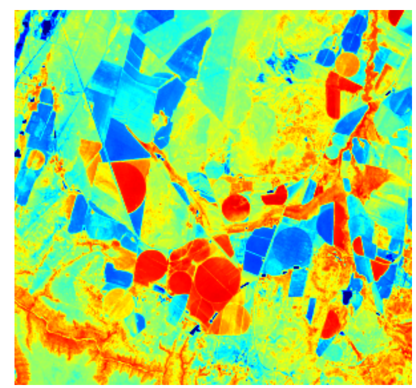
16 Dec



19 Dec



29 Dec



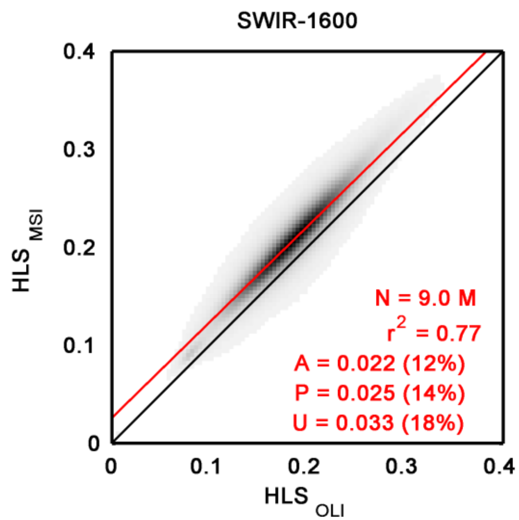
MSI

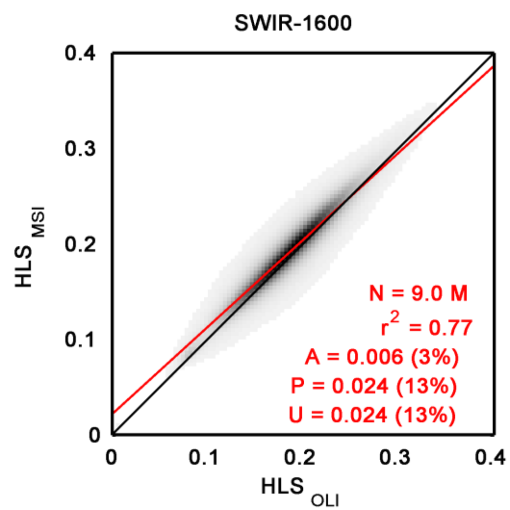
Results: HLS Processing Chain

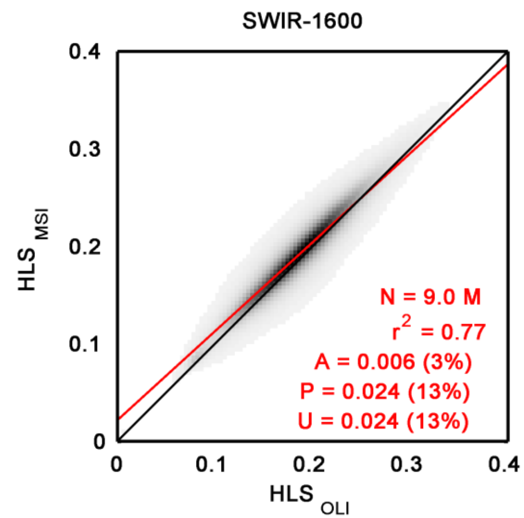
South Africa, OLI: DOY 363, OLI: DOY 364

	Atmospheric Correction	BRDF Correction	Spectral Adjustment

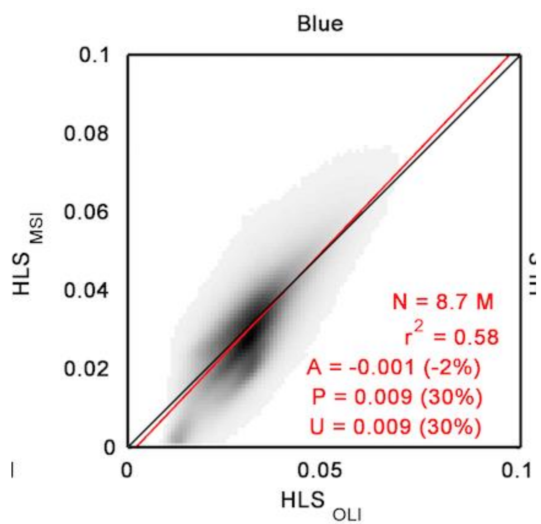
SWIR (1.6 µm)

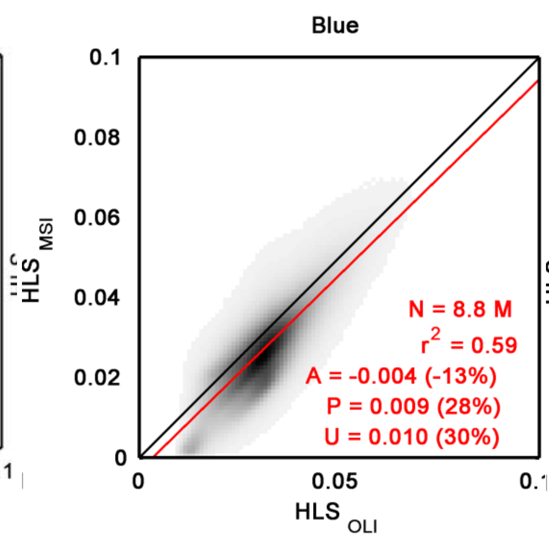


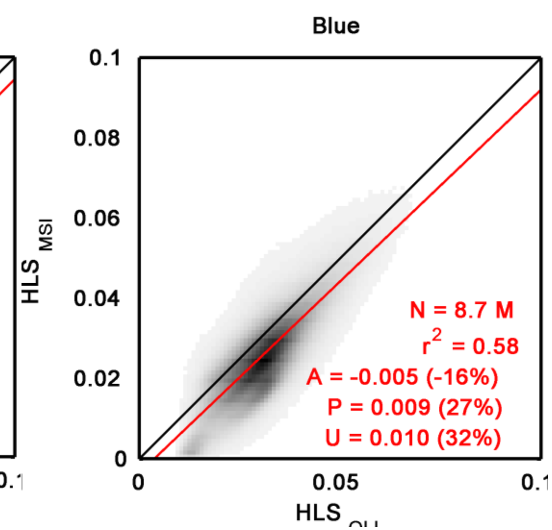




Blue

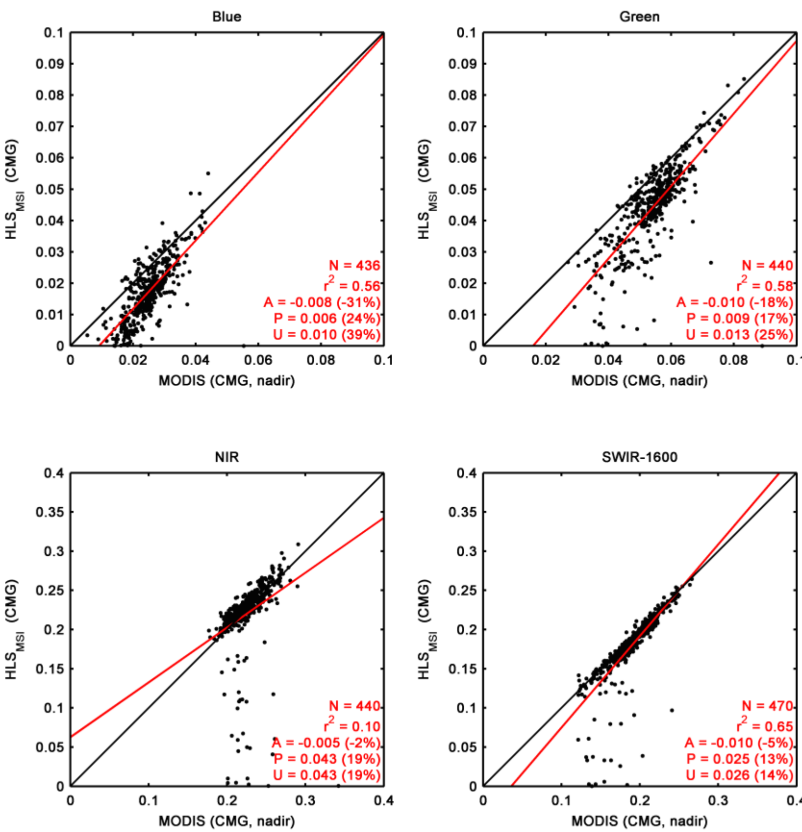




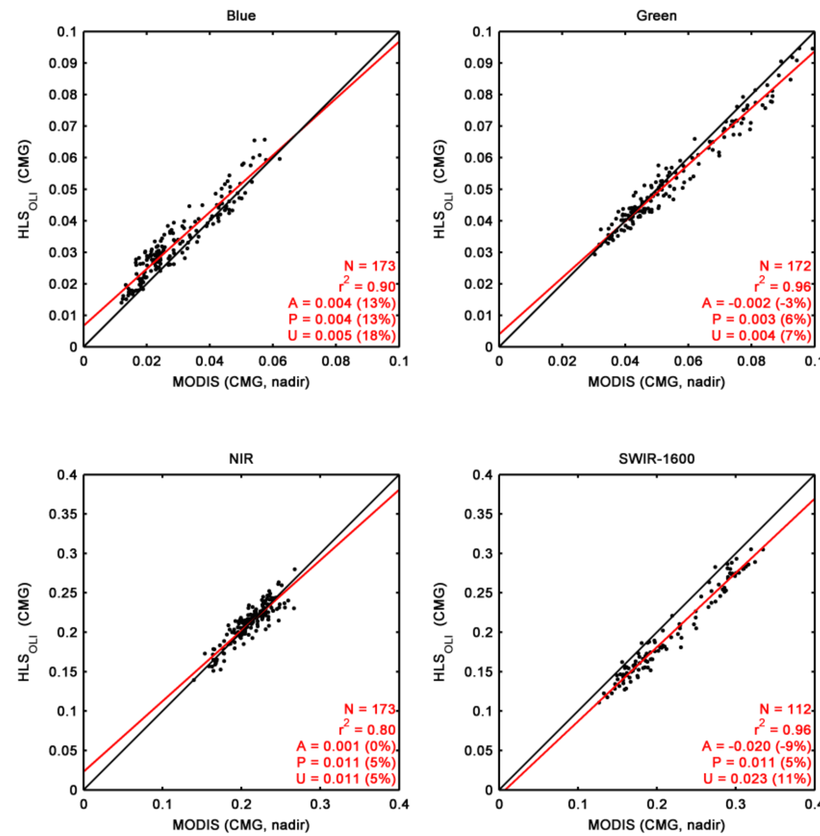


Comparison with MODIS CMG

MSI 30m HLS aggregated to CMG

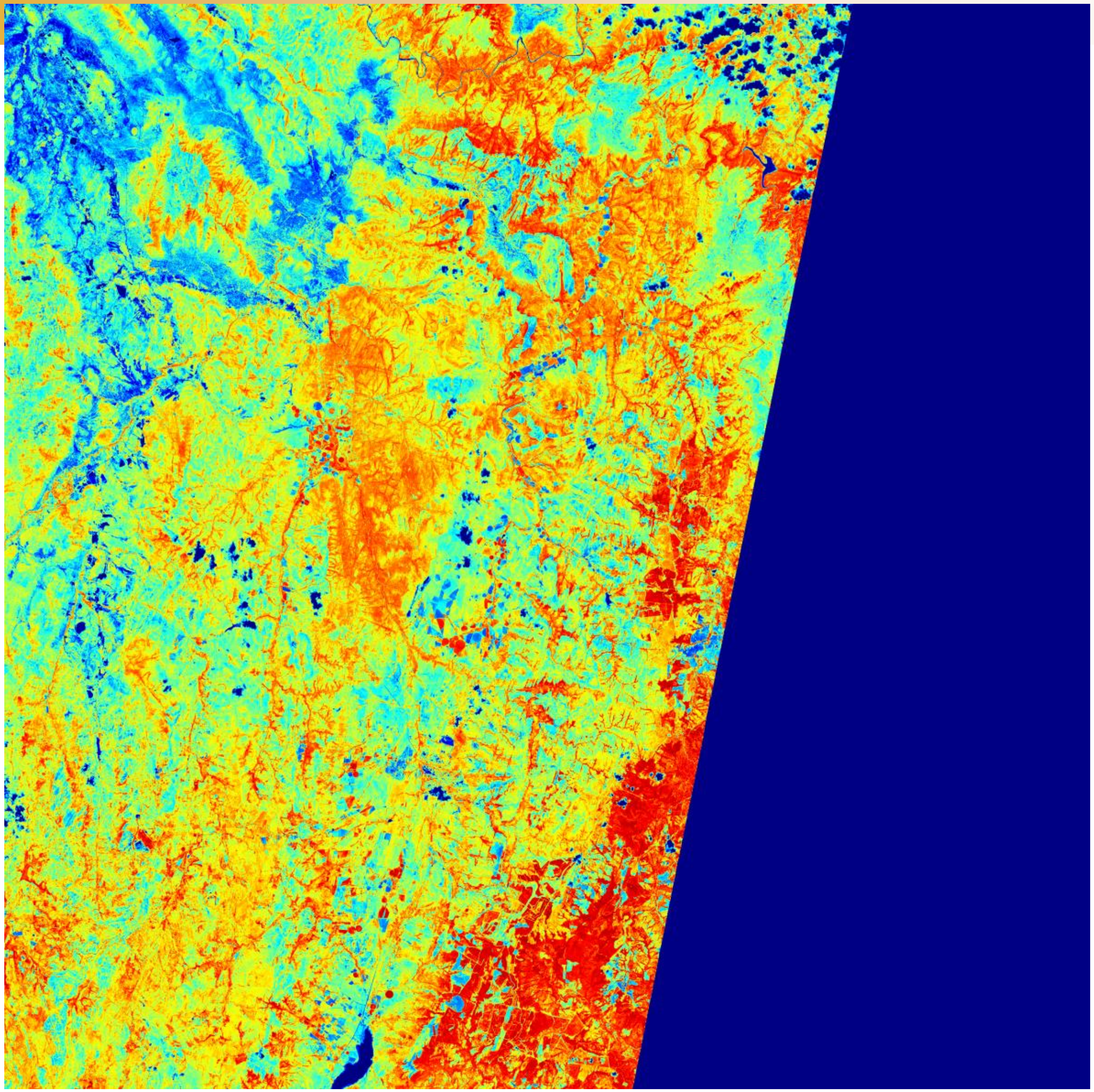


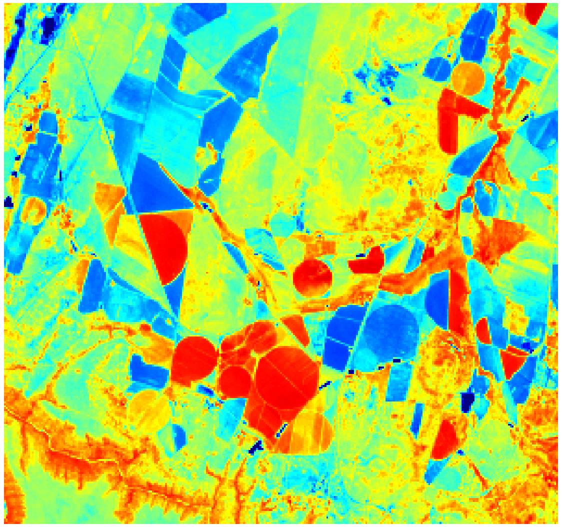
OLI 30m HLS aggregated to CMG



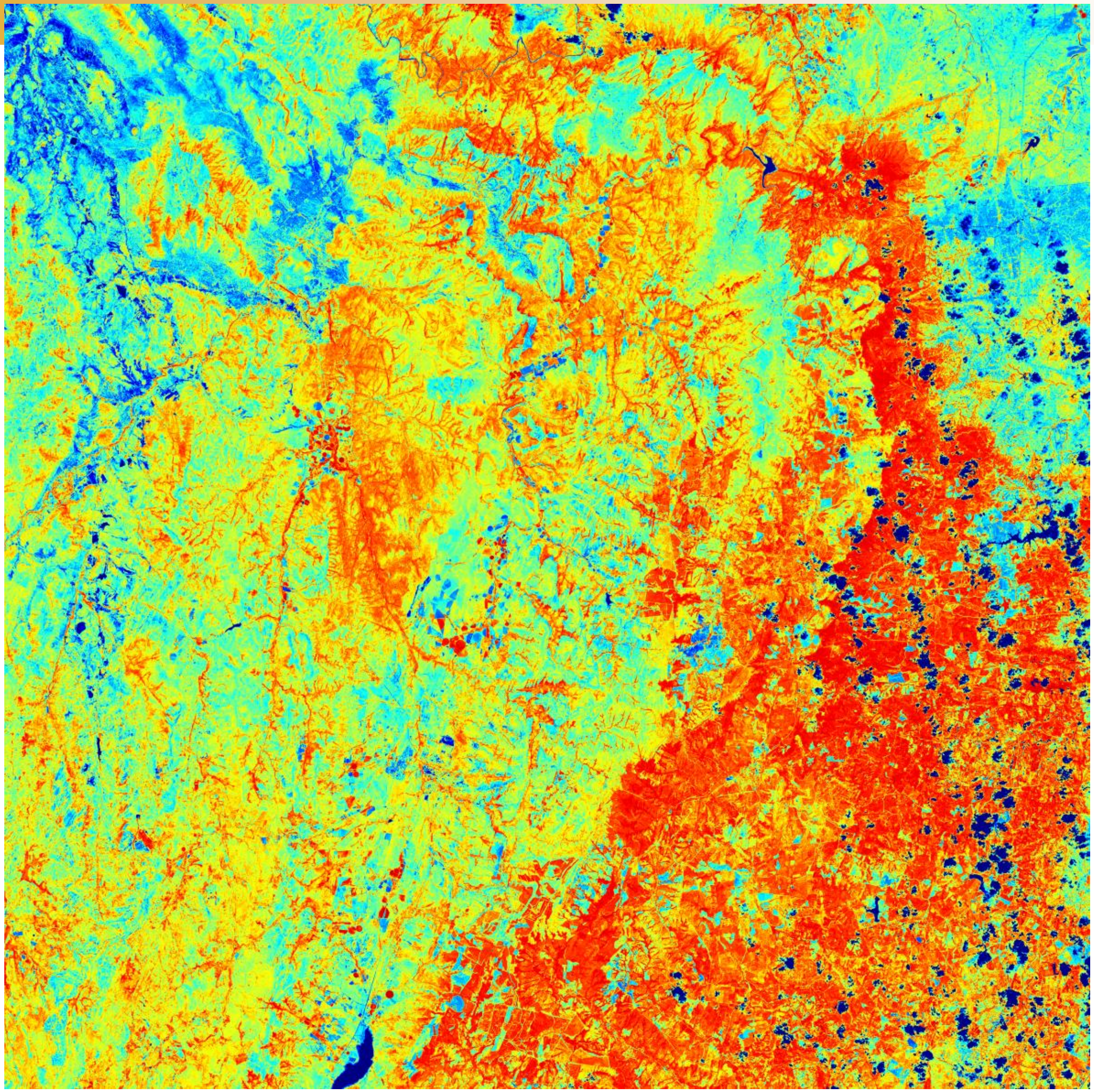
OLI provides closer match with MODIS CMG, suggesting that fixed atmospheric correction for MSI is problematic

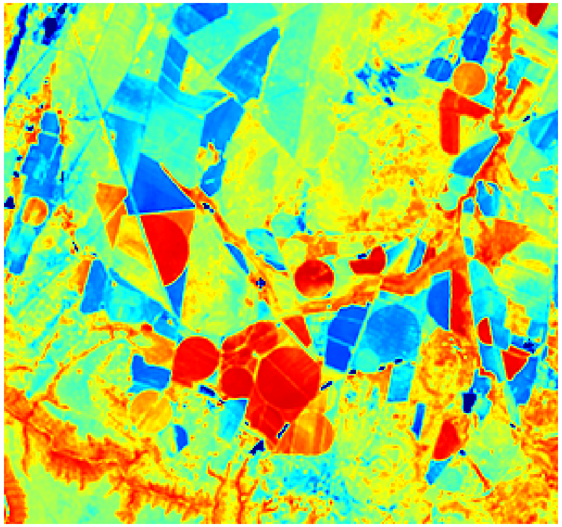
MSI – 29-Dec





OLI – 30-Dec



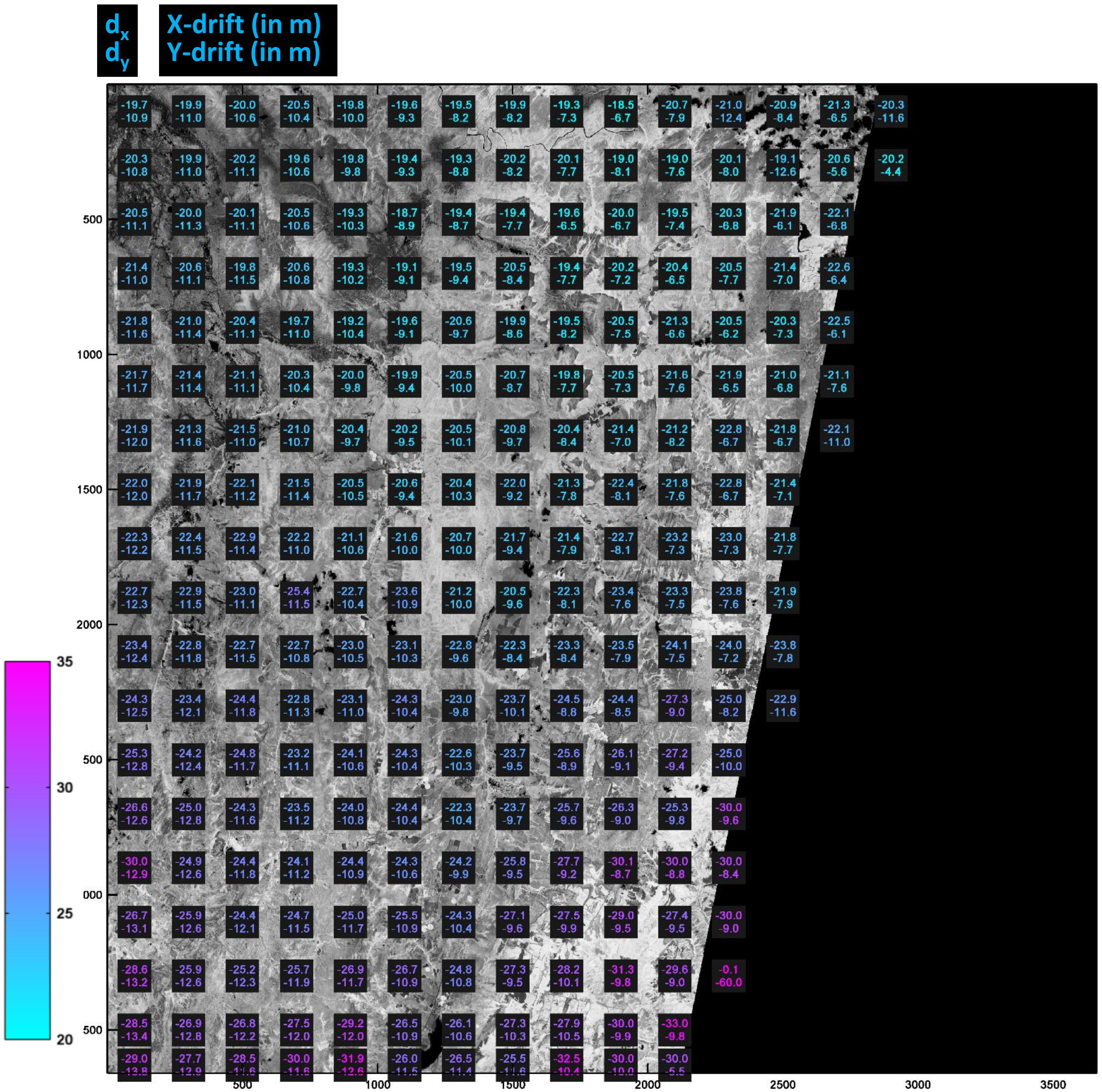


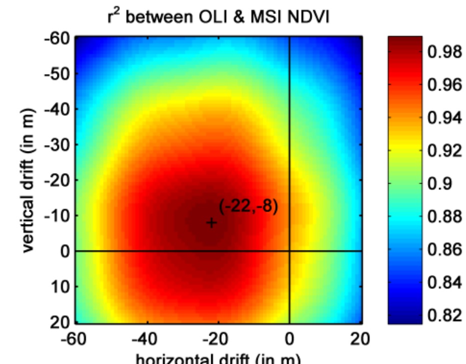
Geometry & Tiling

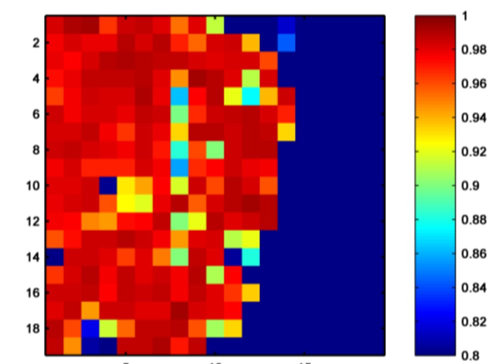
- Originally intended to project both L8 & S2 to WELD global tiling system (sinusoidal), but…
  - Sinusoidal projection not universally beloved
  - Both L1C & L1T are in UTM – let's take advantage of that

- Currently using Sentinel-2 UTM tiling w/ 30m grid
  - Landsat-8
    - In principle, could simply subset L8 UTM to S2 UTM tile
    - However, due to 15m difference in pixel definition (corner vs center), we resample L8 to S2 UTM tile
    - at edge of UTM zone, may require L8 reprojection to new zone
  - MSI
    - 10m products: boxcar aggregation to 30m
    - 20m products: cubic convolution resampling to 30m

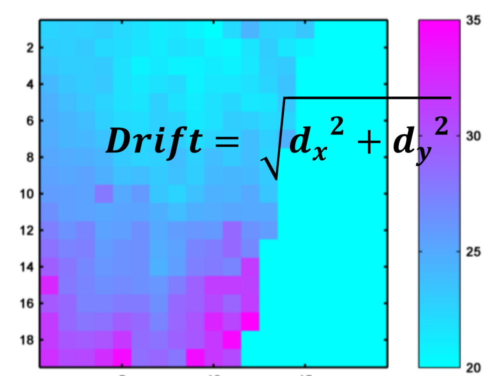
L8 vs S2 Georegistration







Drift distance (in m)



30m native UTM Products

S2 in tile 36JTT, Dec 29, 2015

L8 in Path/Row 169/077 , Dec 30, 2015

2.4 km

1. The 10-m S2 is boxcar aggregated to 30m, and apparently sharper than 30-m L8.
2. The Upper-left corner coordinates of two images differ by 15 meters.

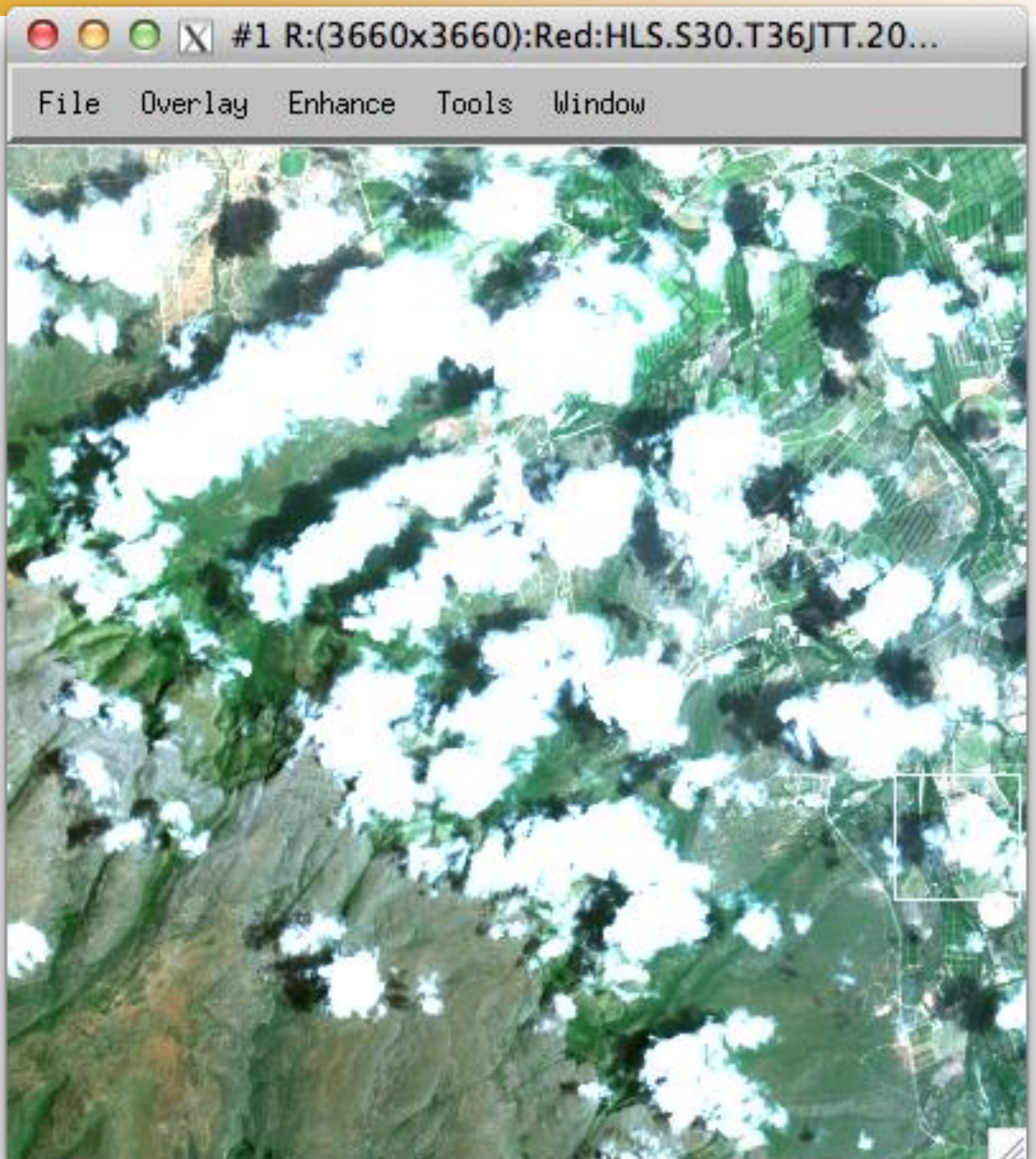
30m Landsat HLS

L8 in tile 36JTT, Dec 30, 2015

L8 in Path/Row 169/077 , Dec 30, 2015

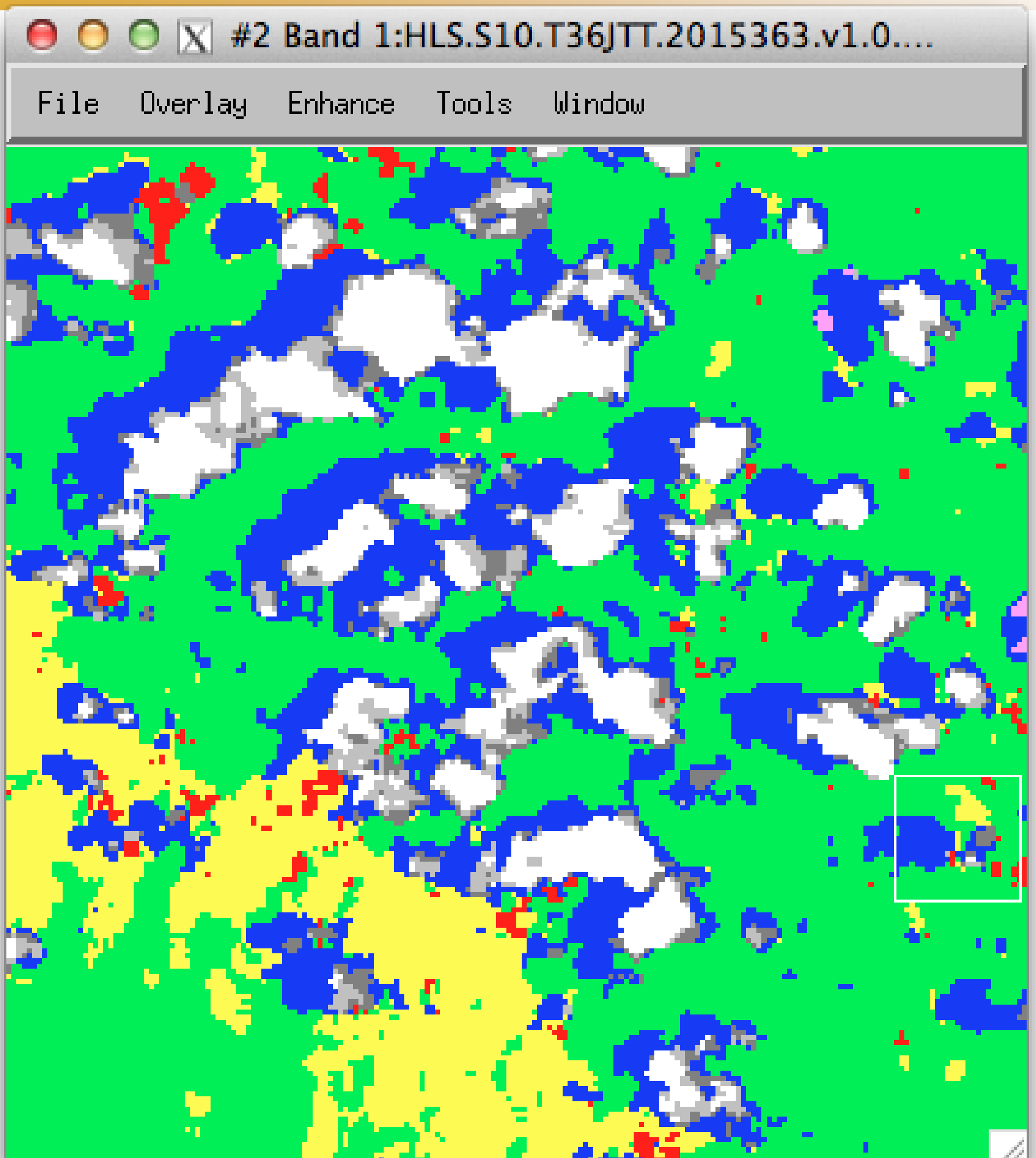
1. L8 is resampled into the S2 tile by cubic convolution (CC).
2. CC makes L8 slightly blurry, but the systematic shift between S2 and L8 reflects geolocation error, not the 15-m coordinate difference.

S2a Cloud Masking (1/3)



Tile 36JTT, South Africa
Dec 29, 2015

S2a Cloud Masking (2/3)

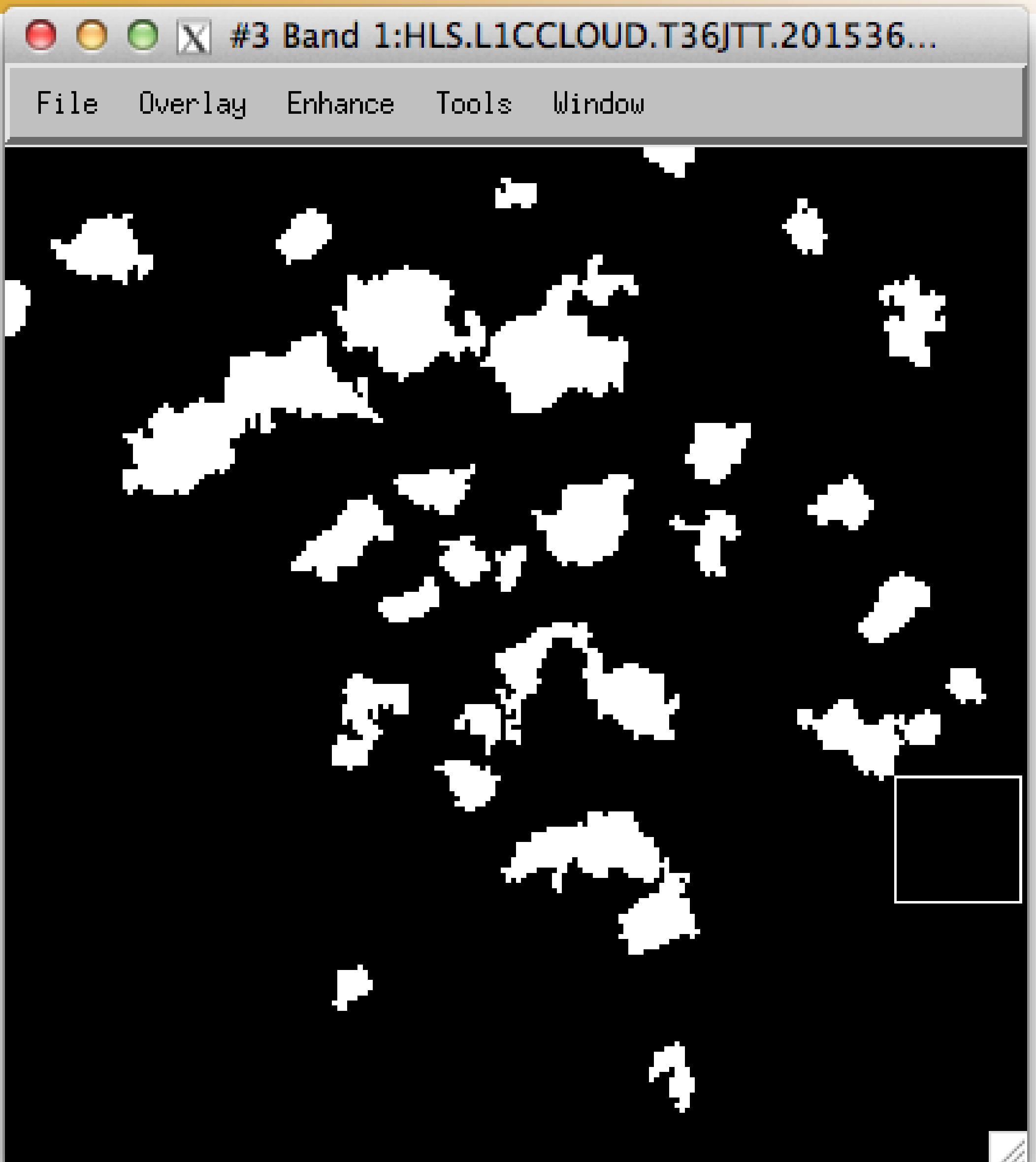


Sen2cor Scene Classification (SCL)

=> Cloud shadow as water

Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

S2a Cloud Masking (3/3)



L1C cloud mask
(from GML)

White: thick cloud

HLS Experiences to Date

- Processing chain now exists at NEX

- Current performance promising as first cut, but needs improvement
  - MSI "fixed atmosphere" correction poor
  - Lack of TIRS data hindering L8 cloud mask
  - Spectral adjustment provides very small (?) benefit

- Requires rigorous validation & QA approach
  - Reflectance validation
    - Priority on temporal consistency & stability between the sources
    - Aeronet, SurfRad, MODIS intercomparisons
    - Subject for CEOS WGCV?
  - Moving from single test site to consistent, continental products is a BIG challenge
  - QA: half the battle is knowing when things have gone wrong

Sentinel-2 Experiences to Date

- MSI Radiometric and Geometric data quality appear to be good
- Data access difficult
  - Large file sizes & poor connectivity to SciHub
  - “Disappearing” granules after processing updates
  - Not possible to request based on Tile ID
- MSI Data Format
  - XML metadata format easy to use
  - Prefer tile-based product rather than swath (smaller size, easier to use)
  - Processing changes (e.g. tiling system definition on Dec 16)
  - Alignment between S2 and L8 pixels (corner vs. center).
  - “overall we managed to become familiar with the S2 format even if it is a bit complicated. ”
- Sen2Corr
  - easy to implement sen2cor in processing flow but slow when run at full resolution
  - poor quality of the cloud mask from sen2cor (did not evaluate the one in L1C)

NASA MuSLI Team

- Multi-Source Land Imaging (MuSLI) Team solicited through NASA LCLUC in 2014
- Objectives:
  - Leverage availability of multiple, international satellite systems (especially Landsat, Sentinel-1& 2) for land monitoring
  - Prototype higher-level products that make use of multiple satellite sources
  - Understand challenges associated with algorithms & processing streams that incorporate multiple satellite systems
- Announced in parallel with ESA solicitations
  - Data User Element (DUE) Innovator Projects
  - Science Exploitation of Operational Missions (SEOM)

NASA Multi-Source Land Imaging PI's

Multisource Imaging of Seasonal Dynamics in Land Surface Phenology	Friedl/BU
Integrating Landsat 7, 8 and Sentinel 2 Data in Improving Crop Type Identification and Area Estimation	Hansen/UMD
Towards Near Daily Monitoring of Inundated Areas Over North America Through Multi-Source Fusion of Optical and Radar Data	Lang / UMD
Prototyping a Landsat-8/Sentinel-2 Global Burned Area Product	Roy / SDSU
Operational Algorithms and Products for Near Real Time Maps of Rice Extent and Rice Crop Growth Stage Using Multi-Source Remote Sensing	Salas / Applied Geosystems
Multi-Source Imaging of Infrastructure and Urban Growth Using Landsat, Sentinel and SRTM	Small / Columbia U
Multi-Source Imaging of Time-Serial Tree and Water Cover at Continental to Global Scales	Townshend / UMD

Backup

HLS Science Algorithms

- AC = MODIS/MISR-based AC (Need a name !!)
  - Vermote et al. (2015, in revision)
  - Other existing approaches = MACCS (Hagolle, S2TBX (?)), ATCOR-based (S2TBX)
- BRDF = NDVI-disaggregation technique
  - Use of HiRes NDVI to disaggregate BRDF shape
  - Based on VJB MODIS BRDF retrieval
  - Technique evaluated with SPOT4 (Take5) data and concluded to a TS noise reduction of 40% on Red and 50% on NIR (Claverie et al. 2015, RS MDPI, in press).
- Spectral = linear regression
  - Per band calibration of a linear regression between MSI and OLI.
  - 6 techniques have been tested (SBAF, linear, Adaptive SBAF with 4 differences cost function).
  - 3 datasets tested: ProSail model, USGS spectral, Hyperion spectra derived from 160 scenes
  - Linear fit = good overall results, easy to implement and coefficient can be

Products specification

	MSI SR 10m	MSI SR 30m	OLI SR	Composite
Spatial	10-20-60m	30m	30m	30 m
Spectral	As input	OLI-like	OLI-like	Landsat-like
Temporal	As input	As input	As input	5-day
NADIR-adj.	No	Yes	Yes	Yes
Projection	UTM	UTM	UTM	UTM
Tilling system	S2 (110*110)	S2 (110*110)	S2 (110*110)	S2 (110*110)

QA and Ancillary information

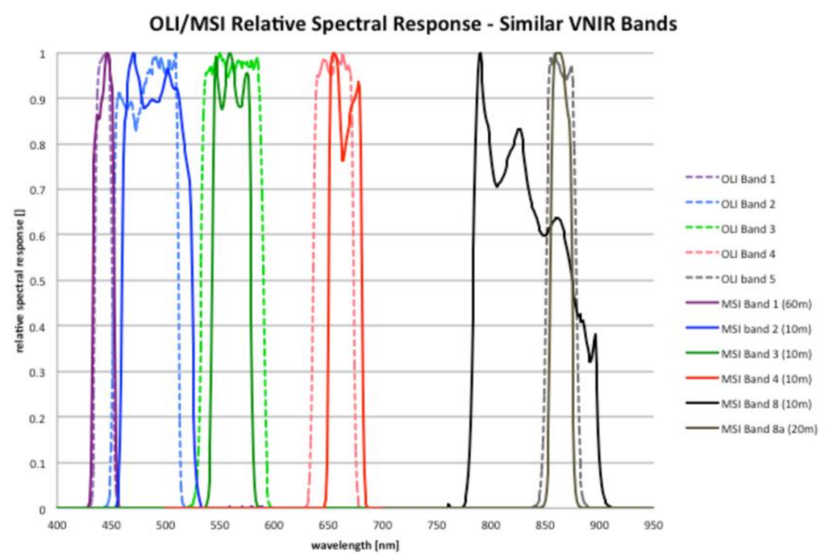
- All products
  - 8-bit layer: Cloud, Cirrus, Adjacent, Shadow, Water, Snow, Qualitative AOT (4 classes)
  - Interest for a more readable QA using classes (see example from Sen2cor →)?
- NADIR-adj. (except composite)
  - Per band BRDF parameter to retrieve any sun-view geometry
  - Interest for processed SZA, VZA, RAA layers ?
- Composite product
  - Compositing day and sensor used for each of the 3 bands groups (VSWIR, Red-Edge, Thermal)

Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

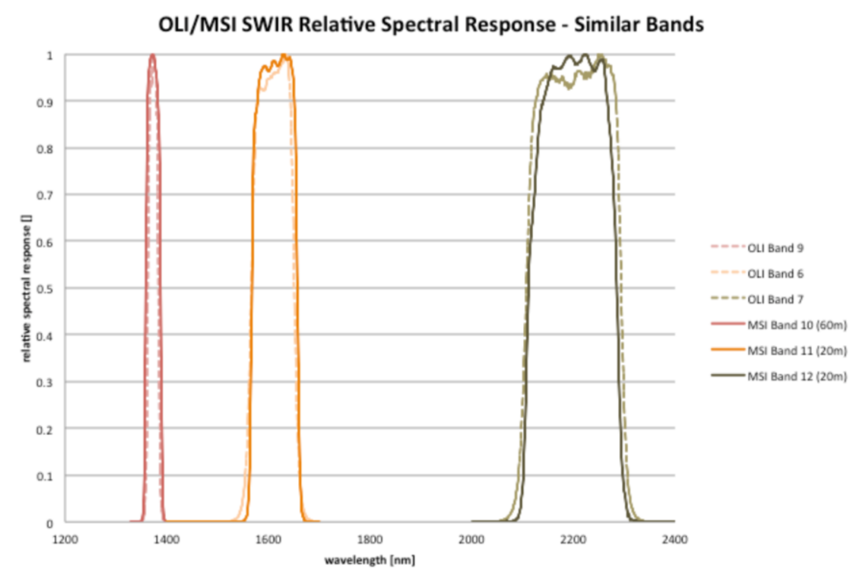
Landsat-8 OLI / Sentinel-2 MSI Comparison

Parameter	MSI	OLI
Swath	290	185
Repeat Cycle	10 (5)	16 (8)
Field of View	20.6°	15°
Equatorial Crossing	10:30 AM	10:13 AM
Spectral Coverage	440-2300 nm	440-2300 nm
Spectral Bands	13	9
IFOV	4 VNIR Bands @ 10 m 6 Bands @ 20 m 3 Atmospheric Bands @ 60 m	8 Bands @ 30 m 1 Pan Band @ 15 m
Data Quantization	12 bits	12 bits
Saturation Radiances	~100% diffuse solar	~100% diffuse solar

Mission status – ESA planning for start of normal operations October 16, 2015



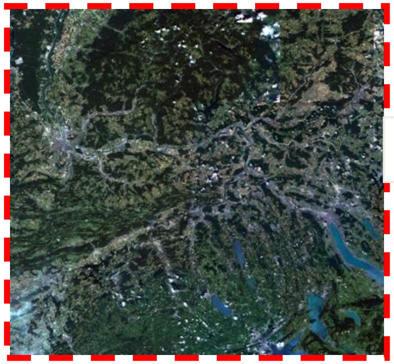
OLI data – instrument level data (as published); MSI – FPA level data (as published) – to be updated



OLI data – instrument level data (as published); MSI – FPA level data (as published) – to be updated

Level-1C / Definition

- Top-of-atmosphere (TOA) reflectance in cartographic geometry (UTM/WGS84).



- Image radiometry key features:
  - ✓ Radiometrically corrected data.
  - ✓ Reflectance coded in 12 bits.
  - ✓ Product includes all necessary parameters required to convert the provided reflectance into radiances.
- Image geometry key features:
  - ✓ Orthorectification uses an 90m-resolution DEM

PlanetDEM http://www.planetobserver.com/products/planetdem/planetdem-90/

  - ✓ Sub-pixel multi-temporal registration between images.

S2 Tiling system

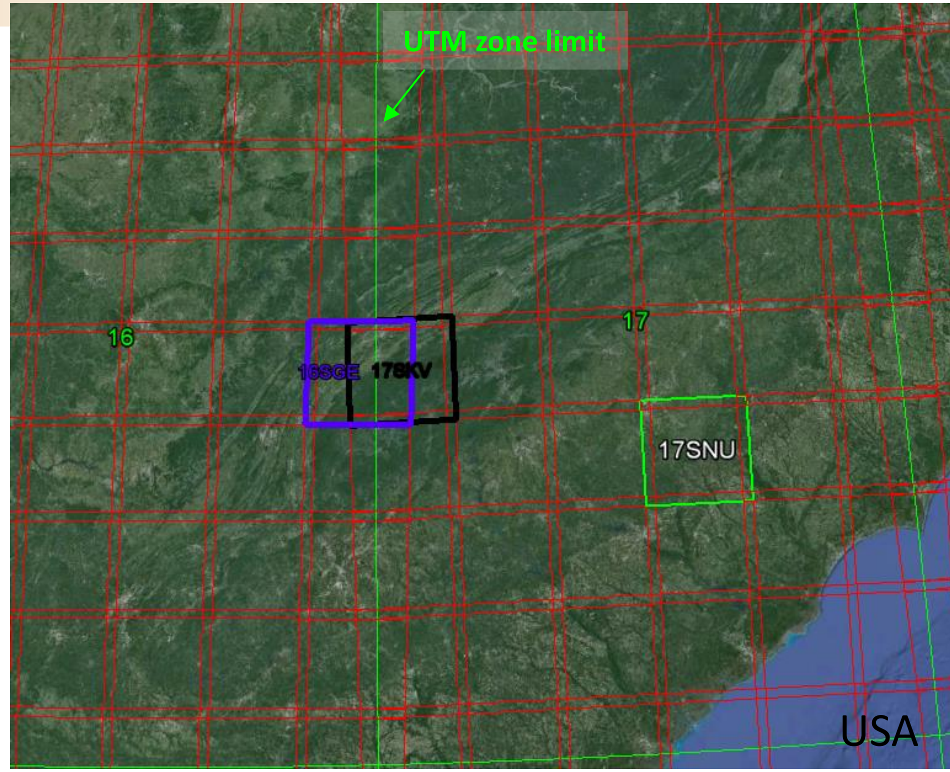
- Tiles are in 109.8 km square
- They follow the UTM zones with overlaps
- Some areas are covered by the "wrong" UTM zone

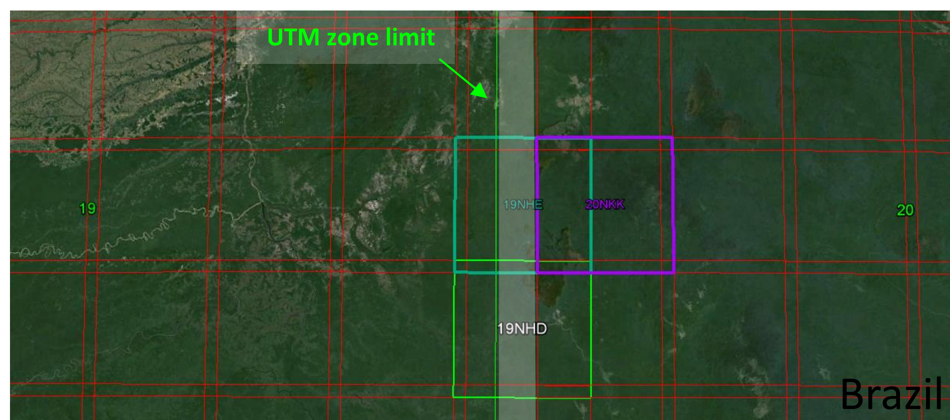
- Tiles information is distributed through a kml file.

20NKK

TILE PROPERTIES

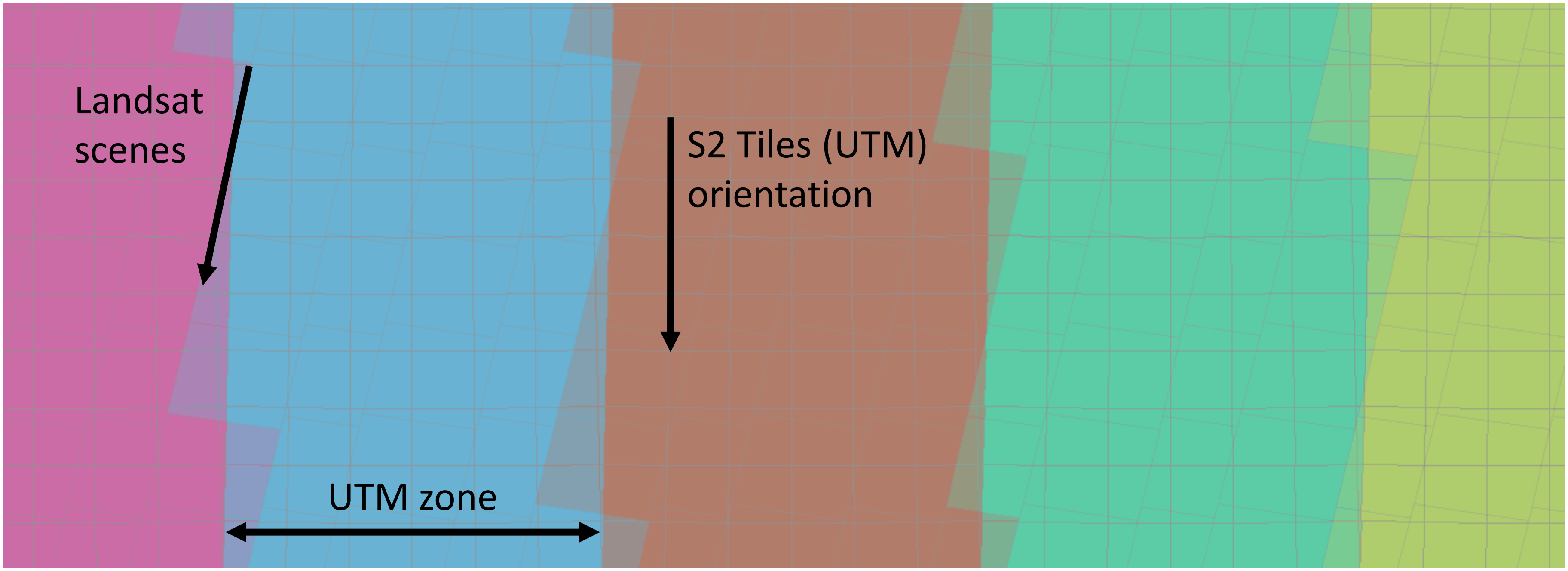
TILE_ID	20NKK
EPSG	32620
ULX	199980
ULY	500040
RES1	10
RES1_ROWS	10980
RES1_COLS	10980
RES1_X_DIM	10
RES1_Y_DIM	-10
RES2	20
RES2_ROWS	5490
RES2_COLS	5490
RES2_X_DIM	20
RES2_Y_DIM	-20
RES3	60
RES3_ROWS	1830
RES3_COLS	1830
RES3_X_DIM	60
RES3_Y_DIM	-60





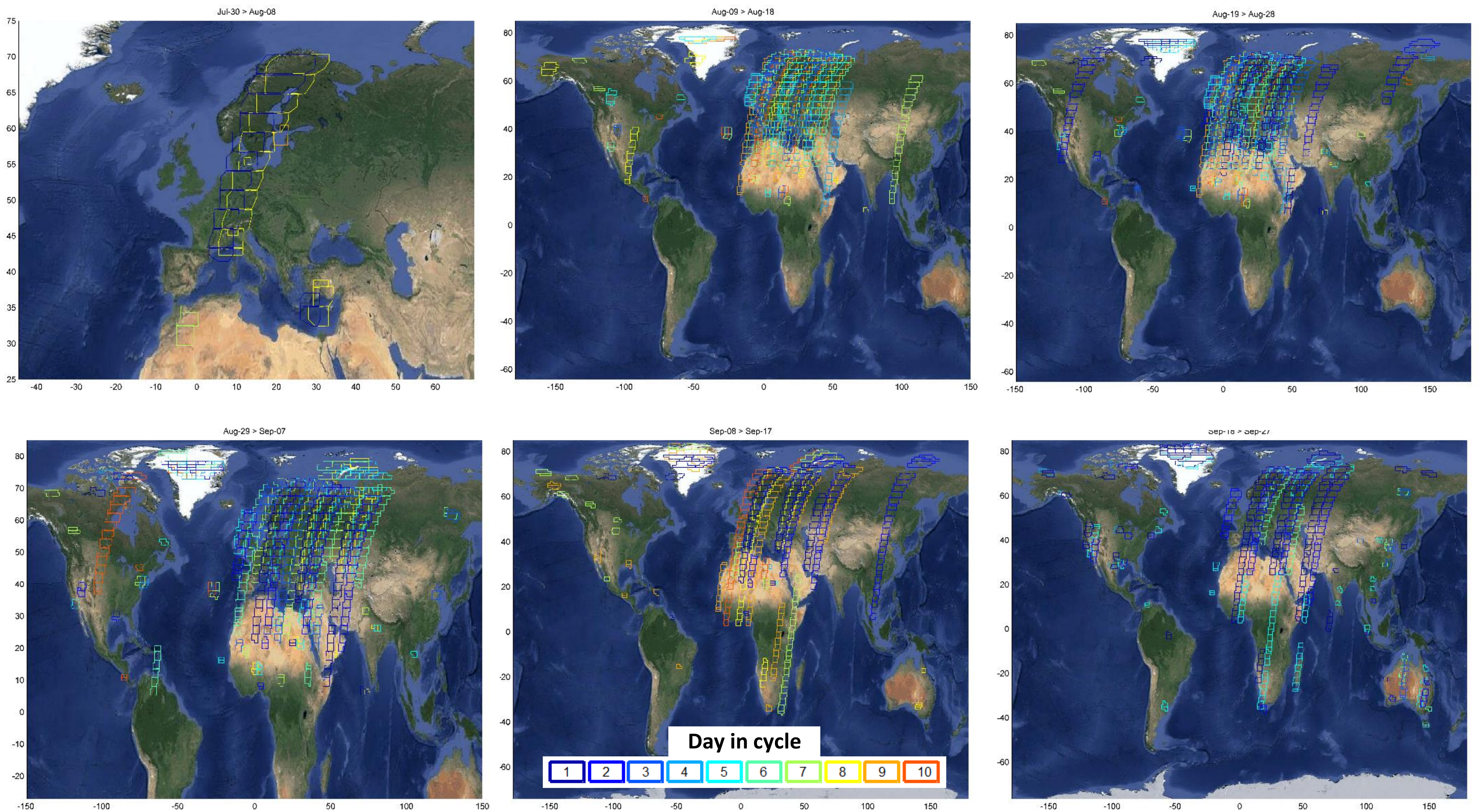
UTM zones: S2 Tiling system vs WRS

- Landsat UTM zone is based on Landsat scene WRS path-row center location.
- It does not mandatory match the corresponding S2 Tile
- Some reprojection (ie, UTM zone change) are necessary



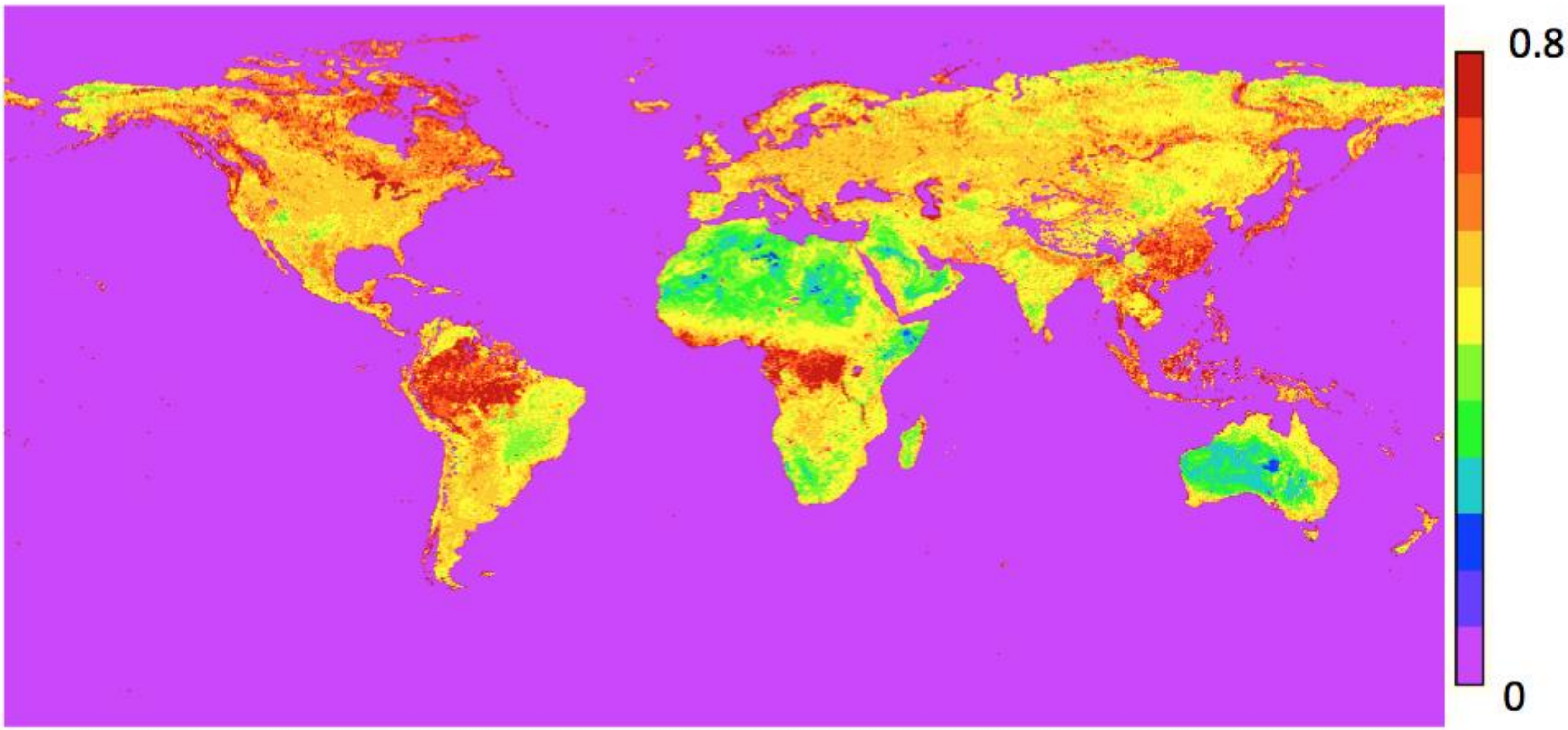
Sentinel-2 data availability (using Expert account, >2150 products)

First data available = 30-Jul, then each map represent a 10-day cycle



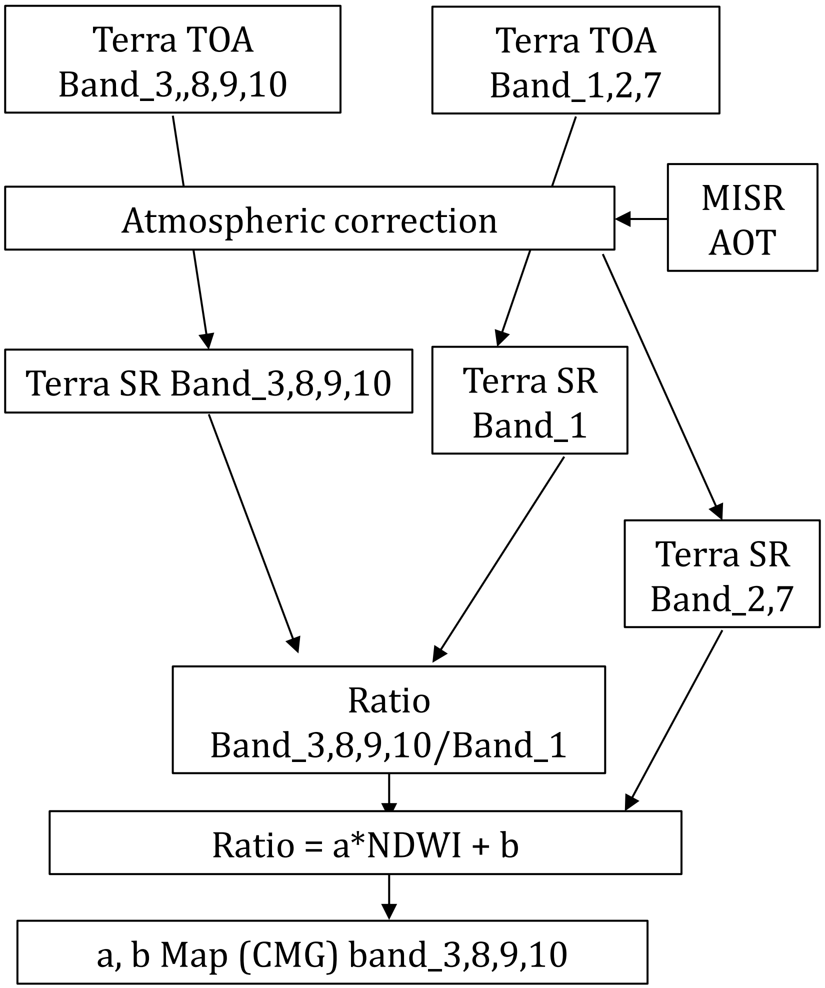
6S-based Atmospheric Correction

TOWARD A GENERIC AEROSOL RETRIEVAL/ATMOSPHERIC CORRECTION USING MODIS/MISR ~15 Years record



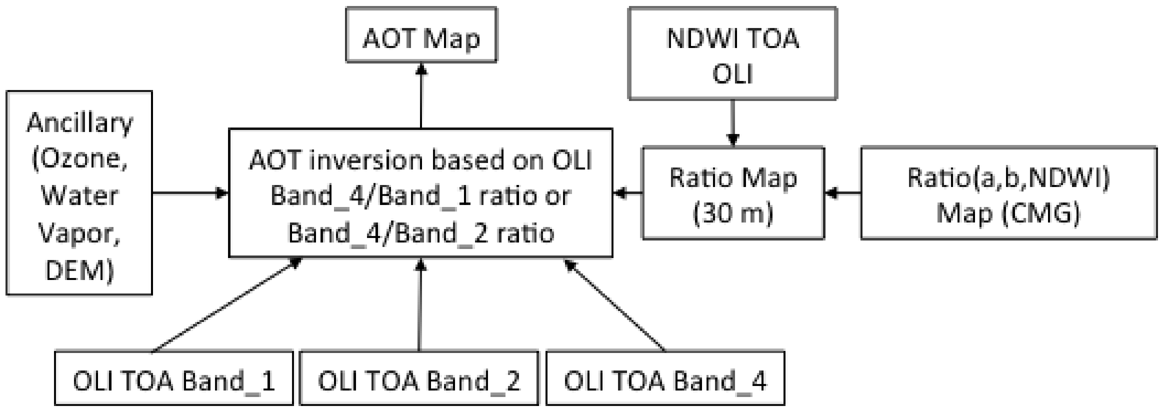
Map of the ratio between MODIS Terra band 3 (0.47µm) and band 1 (0.67µm). This is the average ratio observed over a period of 10 years using coincident MODIS/MISR observations and the optical thickness from MISR to perform atmospheric correction.

RATIO MAP RETRIEVAL FLOWCHART

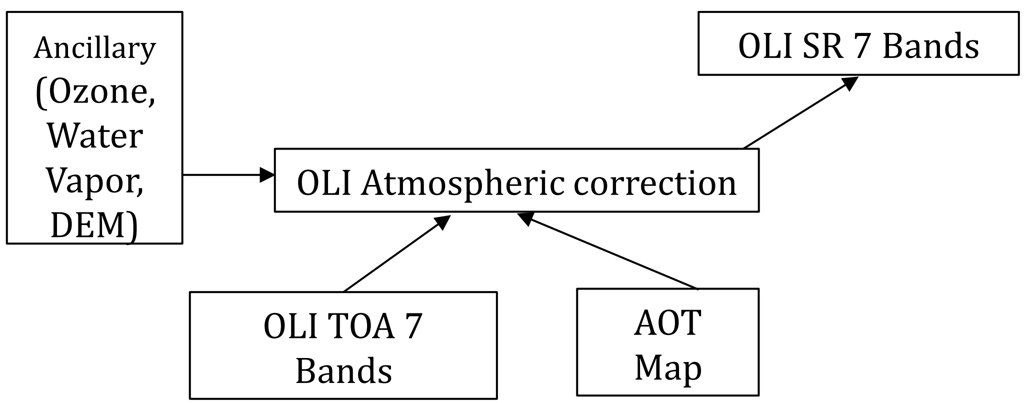


ATMOSPHERIC CORRECTION FLOWCHART

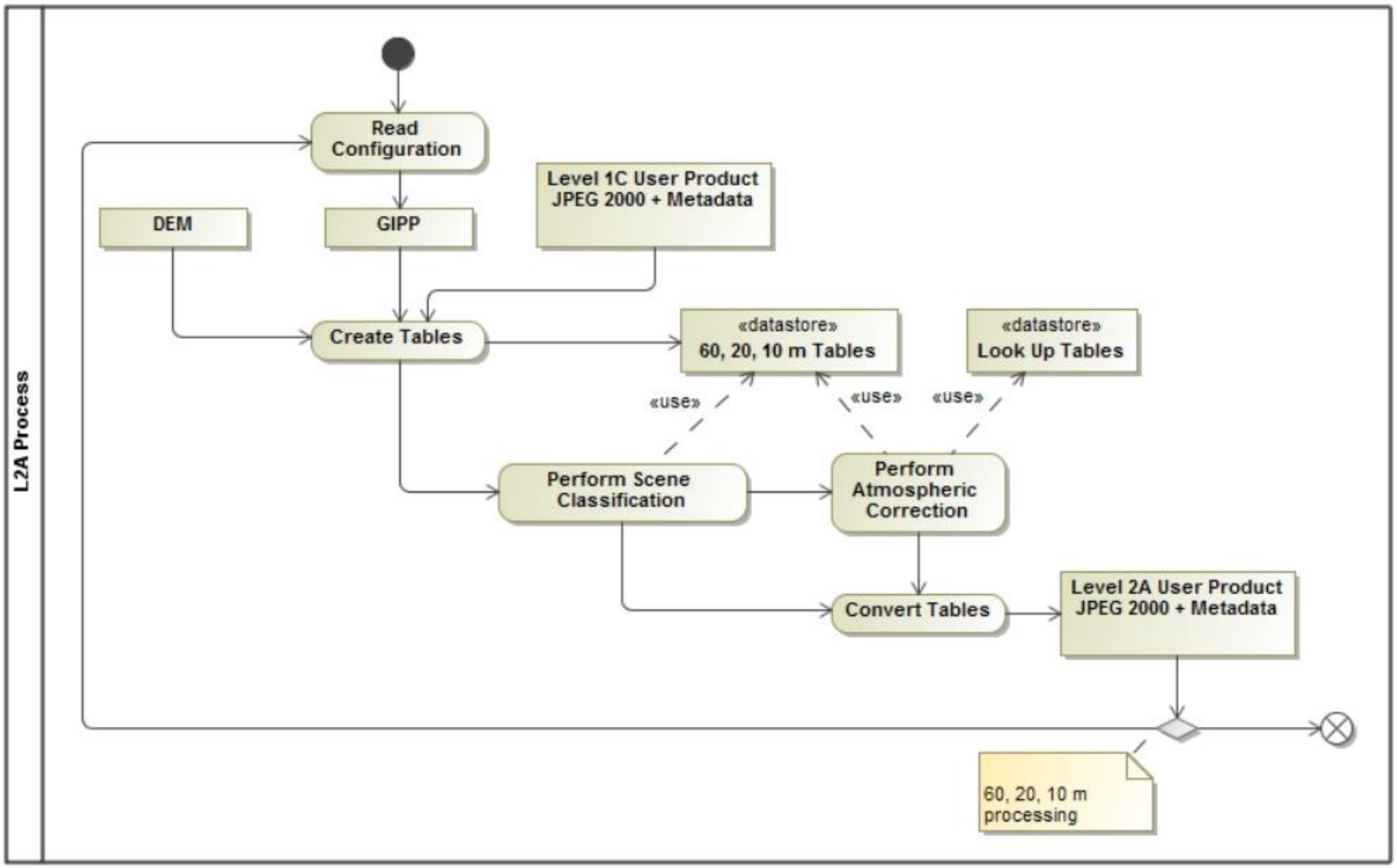
Aerosol retrieval



Atmospheric correction

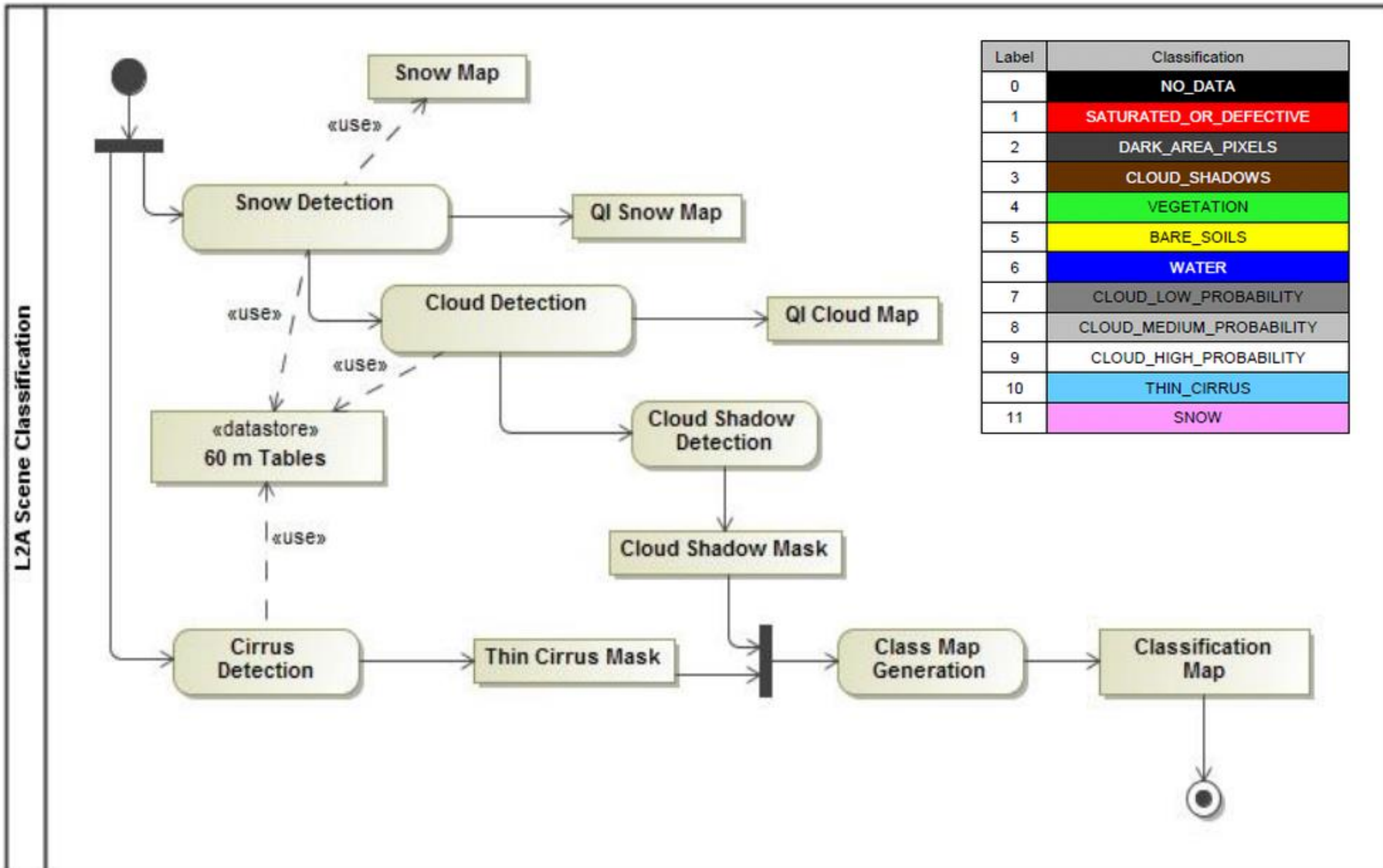


Sen2cor Atmospheric Correction



Source: http://seom.esa.int/S2forScience2014/files/01_S2forScience-MethodsII_MULLER-WILM.pdf

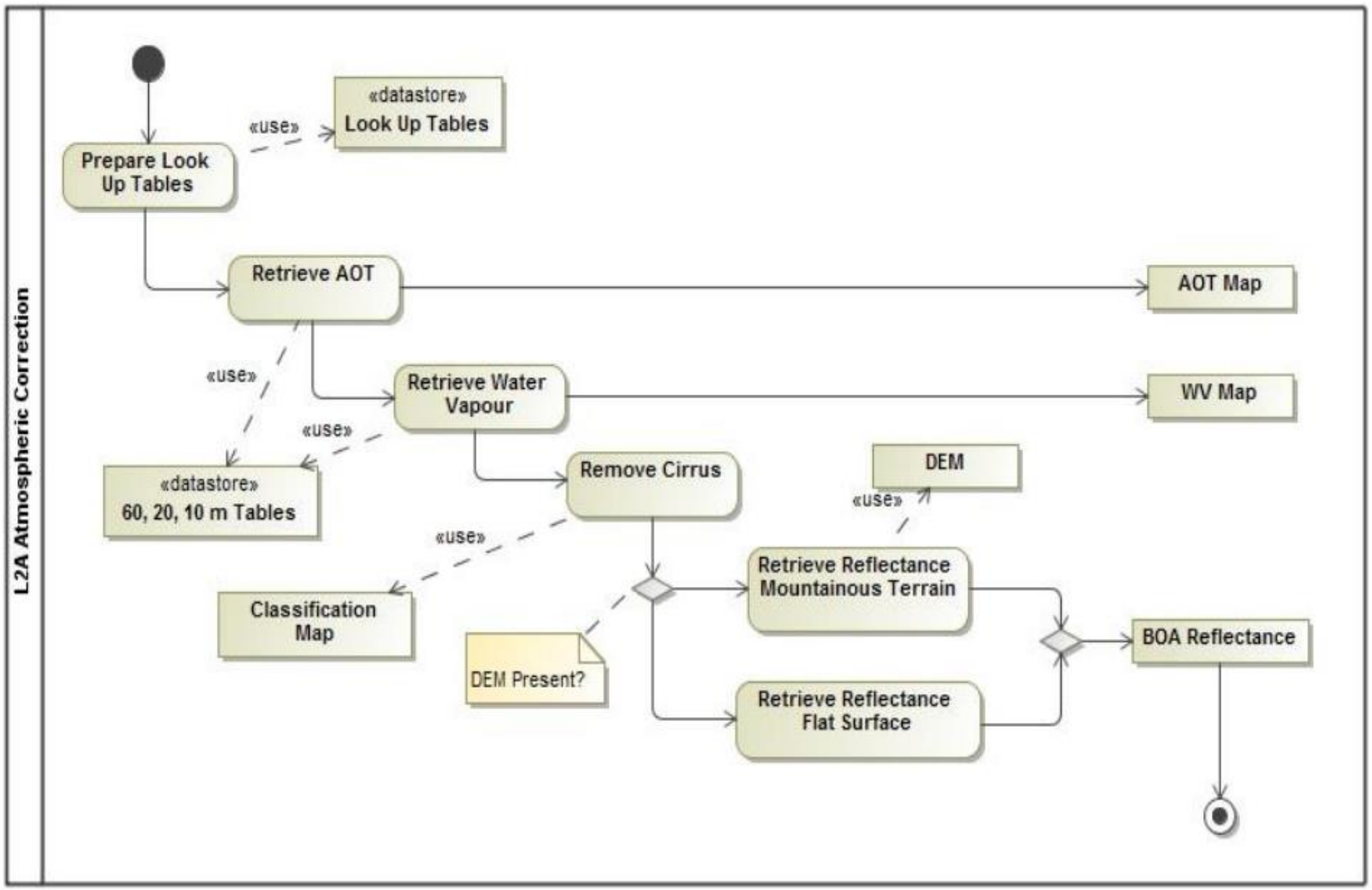
Sen2cor Atmospheric Correction



Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

Source: http://seom.esa.int/S2forScience2014/files/01_S2forScience-MethodsII_MULLER-WILM.pdf

Sen2cor Atmospheric Correction



Source: http://seom.esa.int/S2forScience2014/files/01_S2forScience-MethodsII_MULLER-WILM.pdf

BRDF-adjustment

- VJB (Vermote et al. 2009):
  - Simplification of the BRDF eq.
  - V&R = Related to NDVI variation and spatially explicit
- Draping BRDF coefficients (V_0, V_1, R_0, R_1) retrieved at 0.05° to the 30m grid
- Used of 30m NDVI to compute V and R

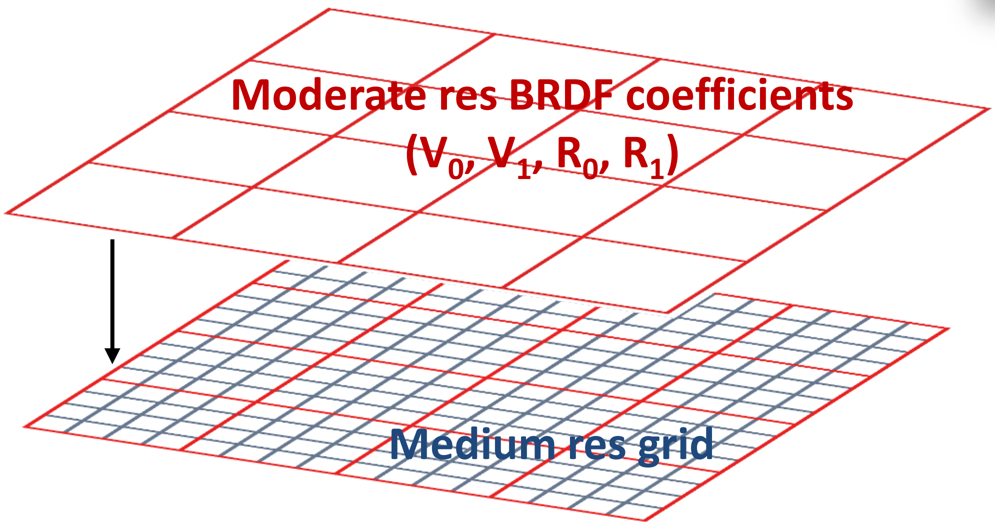
$$V(\lambda) = f_{\text{vol}}(\lambda)/f_{\text{iso}}(\lambda) \qquad R(\lambda) = f_{\text{geo}}(\lambda)/f_{\text{iso}}(\lambda)$$

$$\rho(\Theta, \lambda) = f_{iso}(\lambda)\left(1 + V(\lambda)k_{vol}(\theta) + R(\lambda)k_{geo}(\theta)\right)$$

$$V(\lambda) = V_0(\lambda) \times NDVI + V_1(\lambda)$$

$$R(\lambda) = R_0(\lambda) \times NDVI + R_1(\lambda)$$

$\Theta \rightarrow$ sun/view geometry $(\theta_S, \theta_V, \Delta\phi)$



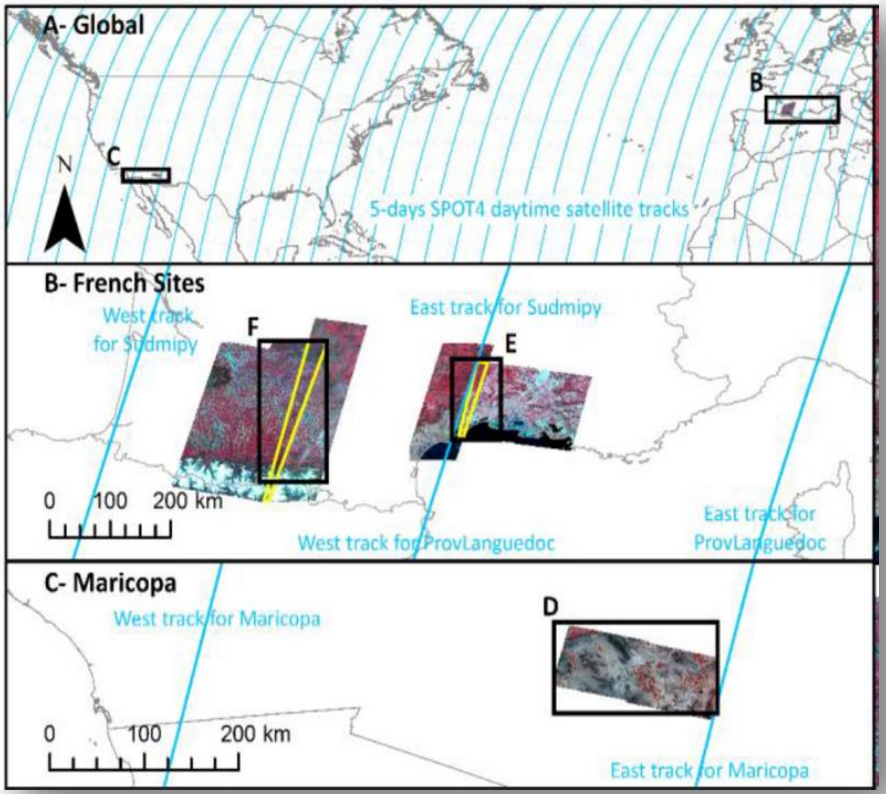
How to apply BRDF a-priori?

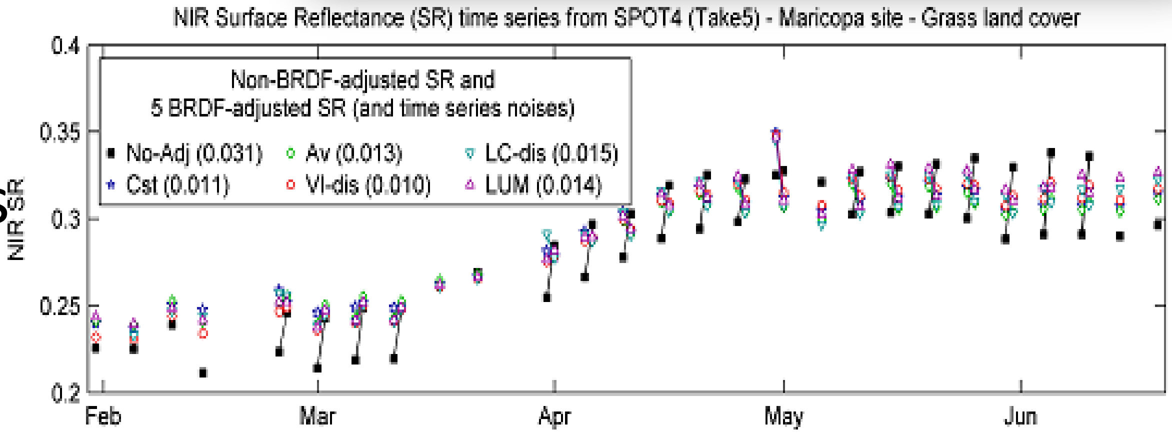
$$c = \frac{1 + Vk_{vol}(\Theta_0) + Rk_{geo}(\Theta_0)}{1 + Vk_{vol}(\Theta_{obs}) + Rk_{geo}(\Theta_{obs})}$$

Related to NDVI

BRDF-adjustment

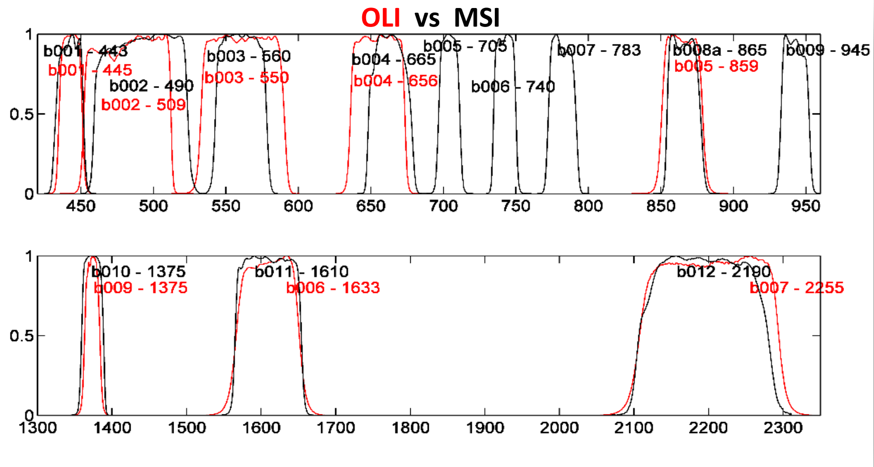
- Five BRDF-adjustment techniques were evaluated using the multi-angular SPOT-4 (Take-5) data
- The chosen method (VI-dis for VI-based disaggregation) showed one of the best performances to reduce TS noise due to observation geometry differences and surface anisotropy.



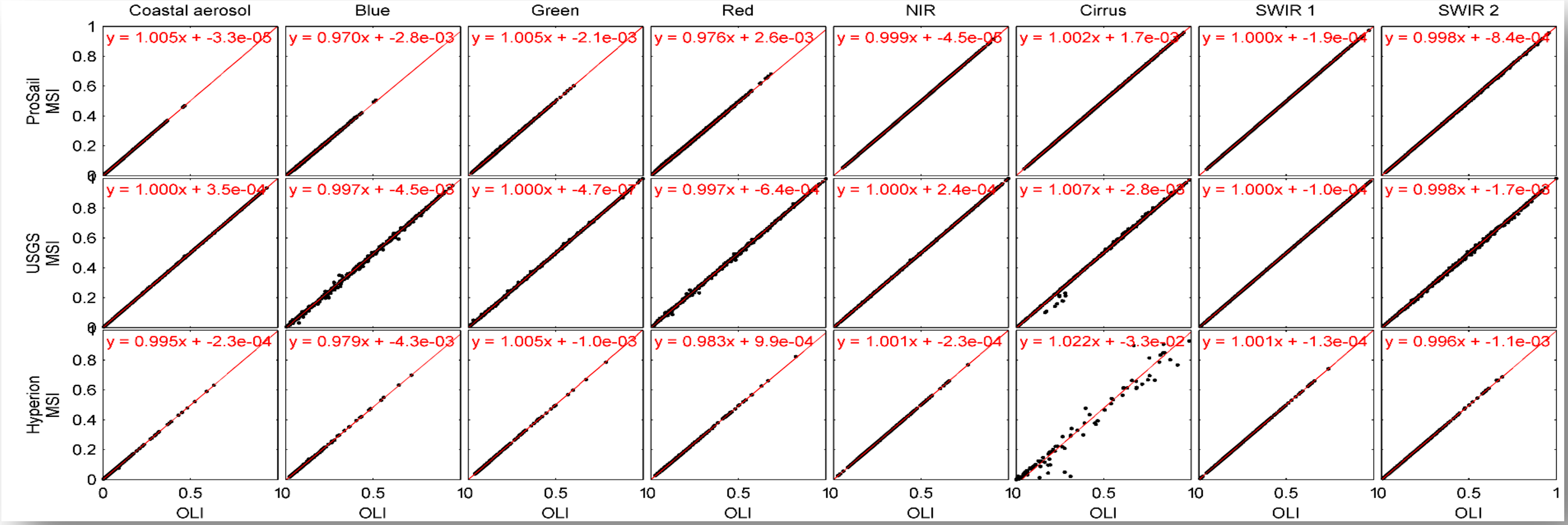


Claverie et al., Remote Sens. 2015, 7(9), 12057-12075; doi:10.3390/rs70912057

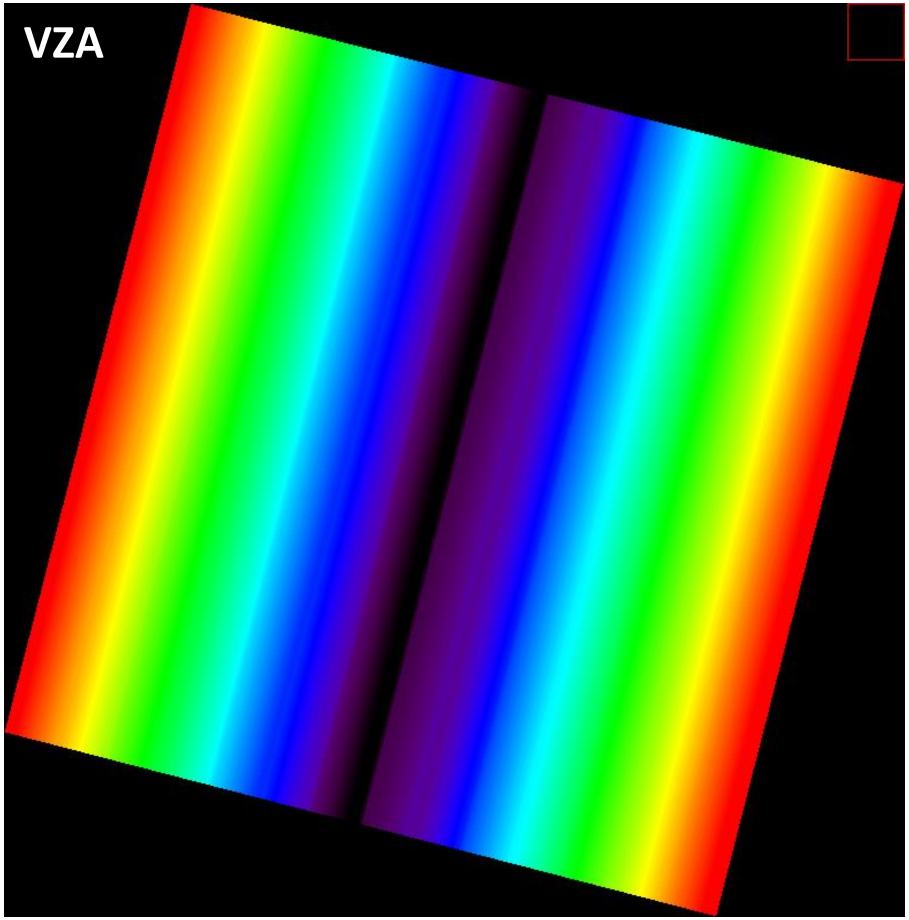
Spectral-adjustment

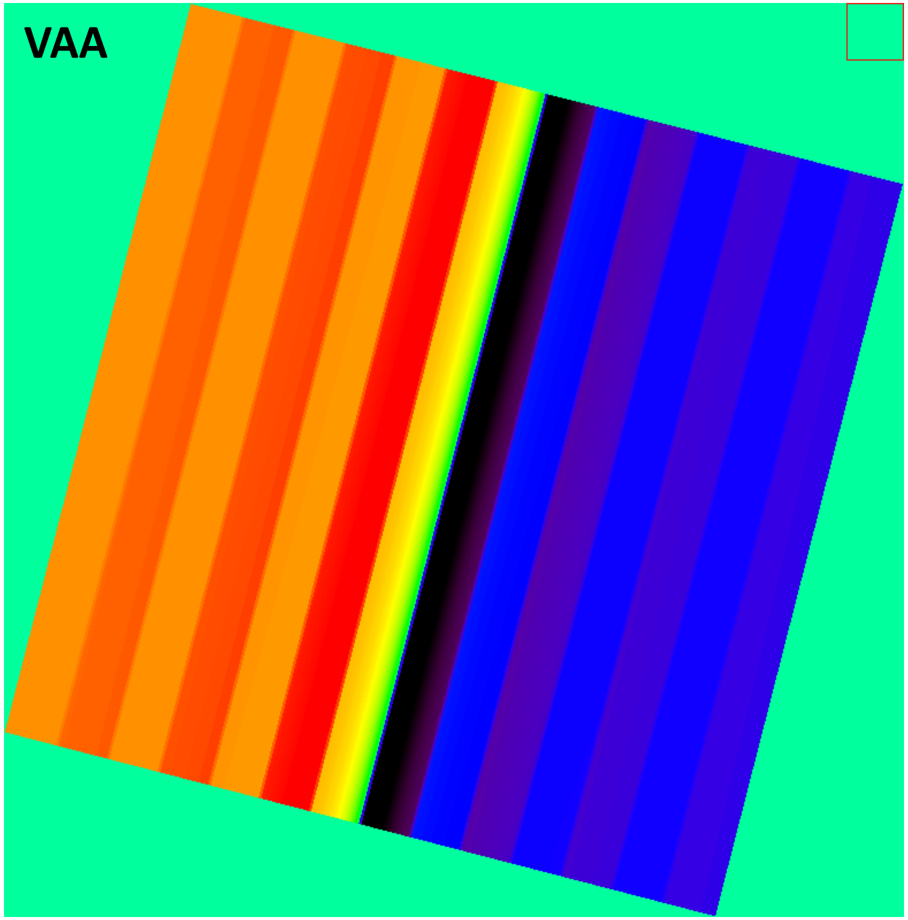


- Per band calibration of a linear regression between MSI and OLI.
- 6 techniques have been tested (SBAF, linear, Adaptive SBAF with 4 differences cost function).
- 3 datasets tested: ProSail model, USGS spectral, Hyperion spectra derived from 160 scenes
- Linear fit = good overall results, easy to implement and coefficient can be delivered on metadata (not per pixel)



Landsat View geometry using USGS l8_angles tool





MuSLI Goals and Expectations

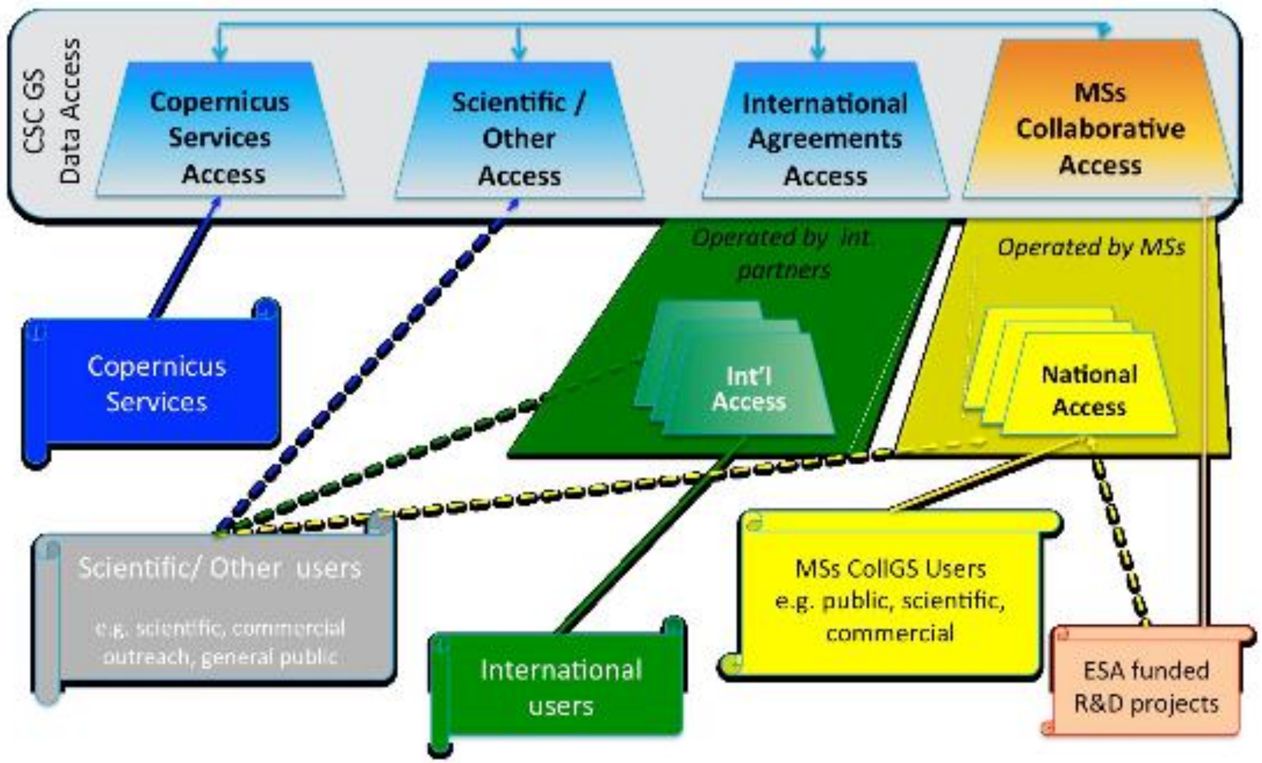
- "developing and prototyping products for combined use of Landsat and Sentinel-2 toward global land monitoring"
  - Also interested in multi-modal (optical/radar) fusion approaches
  - Advance the "virtual constellation" paradigm for mid-resolution land monitoring

- Emphasis on **scalable products** that exploit virtual constellation concept
  - "algorithms should be developed, tested, and refined to reach a maturity at which they could be implemented in a production environment"
  - Set the stage for routine generation of higher-level products from virtual constellation of moderate-resolution sensors

Sentinel Data Hub

Access to Sentinel Data

The Sentinel Data Access Infrastructure has been tailored to answer the needs of the different use typologies.



ESA Data User Element (DUE) Innovator Projects R&D for Sentinel-1 & -2 applications

innovators formosa

innovators eoforcbi

innovators accucarbon

innovators smells

innovators sarforurban

innovators georice

innovators smart

innovators vecborn

innovators rsforebv

innovators sarforurban

innovators sponge

innovators sarforredd

http://due.esrin.esa.int/page_news321.php

S2-4Sci Land & Water

SEOM call: Q3 2015
Objective: Algorithm development for Sentinel-2 products

- Study 1: Development & inter-comparison of innovative radiometric validation methods
- Study 2: Atmospheric corrections for coastal & inland waters
- Study 3: Land cover classification
- Study 4: Multi-temporal analysis – dynamic features & change detection
- Study 5: Coastal and inland waters – HR water quality for hydrodynamic modeling
- Study 6: Coral reefs – habitat mapping, change detection & S2 coral reefs observation scenario

MuSLI Supporting Elements

- HLS – Harmonized Landsat/Sentinel Reflectance products (Claverie)
- NEX – NASA Earth Exchange (Dungan/Ganguly)
- Landsat/S2 cross-calibration activities (ESA/NASA/USGS)