Sentinel-2 / Landsat Collaboration

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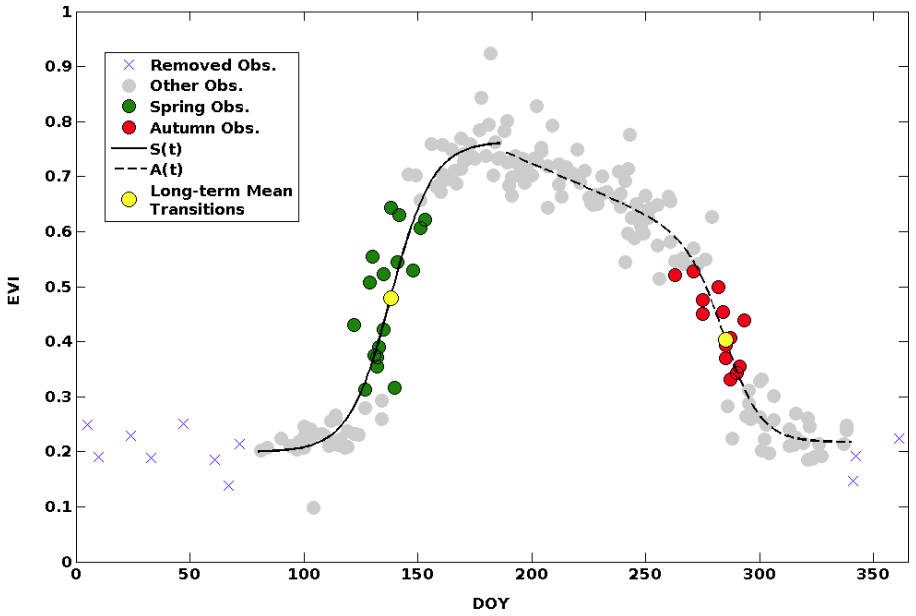
ESA Sentinel-2 mission

- Sentinel-2 is the ESA/Copernicus “Landsat-like” observatory
  - Two simultaneous platforms (S2a, S2b) provide 5-day global land coverage from MSI (Mult-Spectral Imager) instrument
  - S2a launch ~June 23, 2015; S2b ~summer 2016
  - Similar spectral/spatial coverage as Landsat OLI
    - More spectral bands (e.g. red edge); somewhat finer (10-20m) resolution
  - Free and open data policy (but US users may not have high priority in queue)

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

Science Rationale

- Since the opening of the USGS Landsat archive, there has been increased science interest in ***intra-annual*** time series applications at ~30m resolution
  - Agricultural monitoring (e.g. GEO-GLAM)
  - Patch-scale vegetation biophysics (LAI, fPAR, productivity)
  - Phenology and climate linkages
  - WELD data products
- Current systems struggle to meet these needs in terms of resolution (MODIS) or frequency (Landsat)
- Combining Sentinel-2 and Landsat-8 data streams offers **near-daily, global 30m coverage**

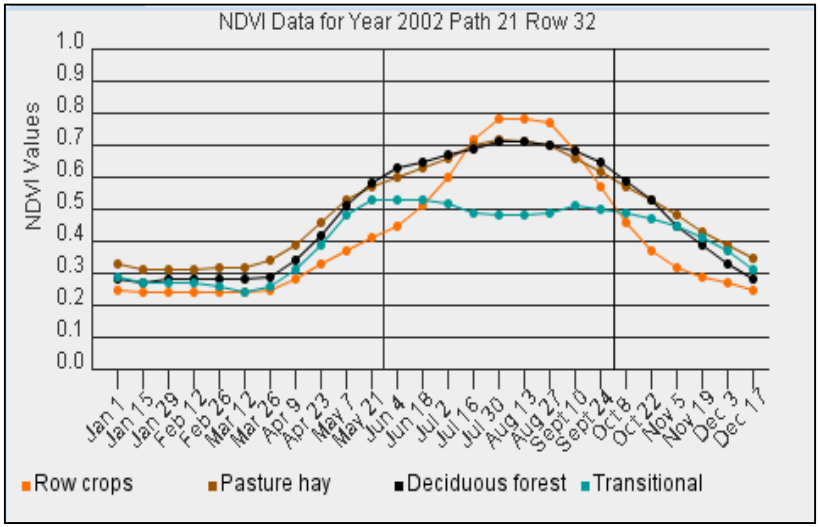


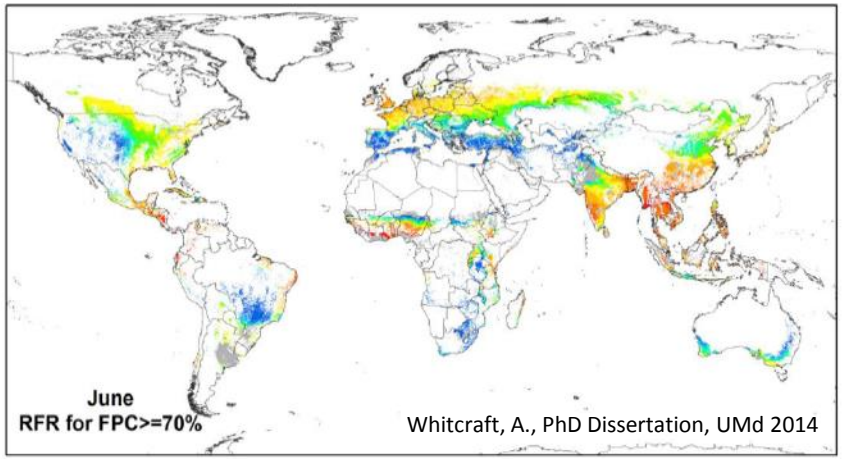
Example: New England forest phenology from multi-annual Landsat observations (Melaas et al., 2013, RSE)

Agricultural Monitoring

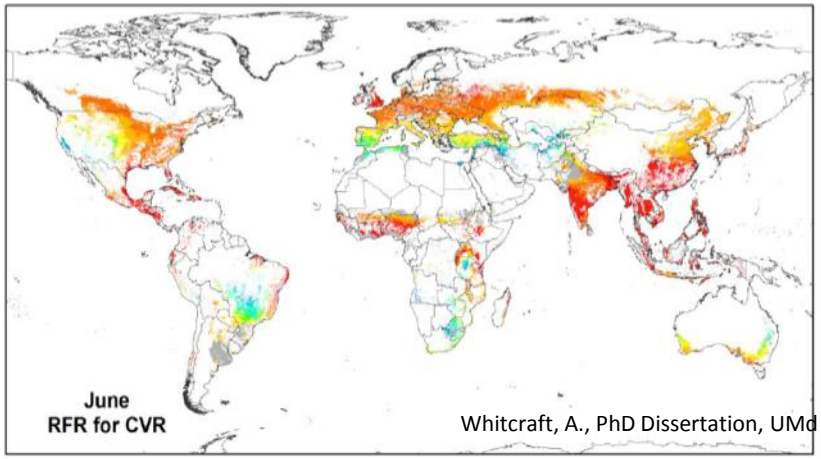
USGS EROS

- GEO-GLAM requires ~weekly moderate resolution data to characterize crop type, condition, and management
- Cloud cover implies 2-3 day coverage over most of globe to meet requirement

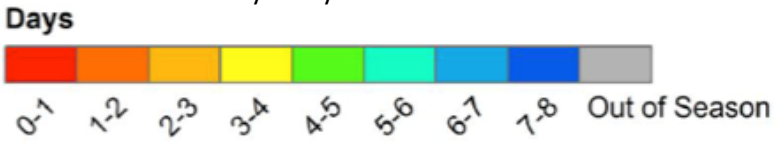




Revisit frequency needed to yield a 70% cloud free view every 8 days

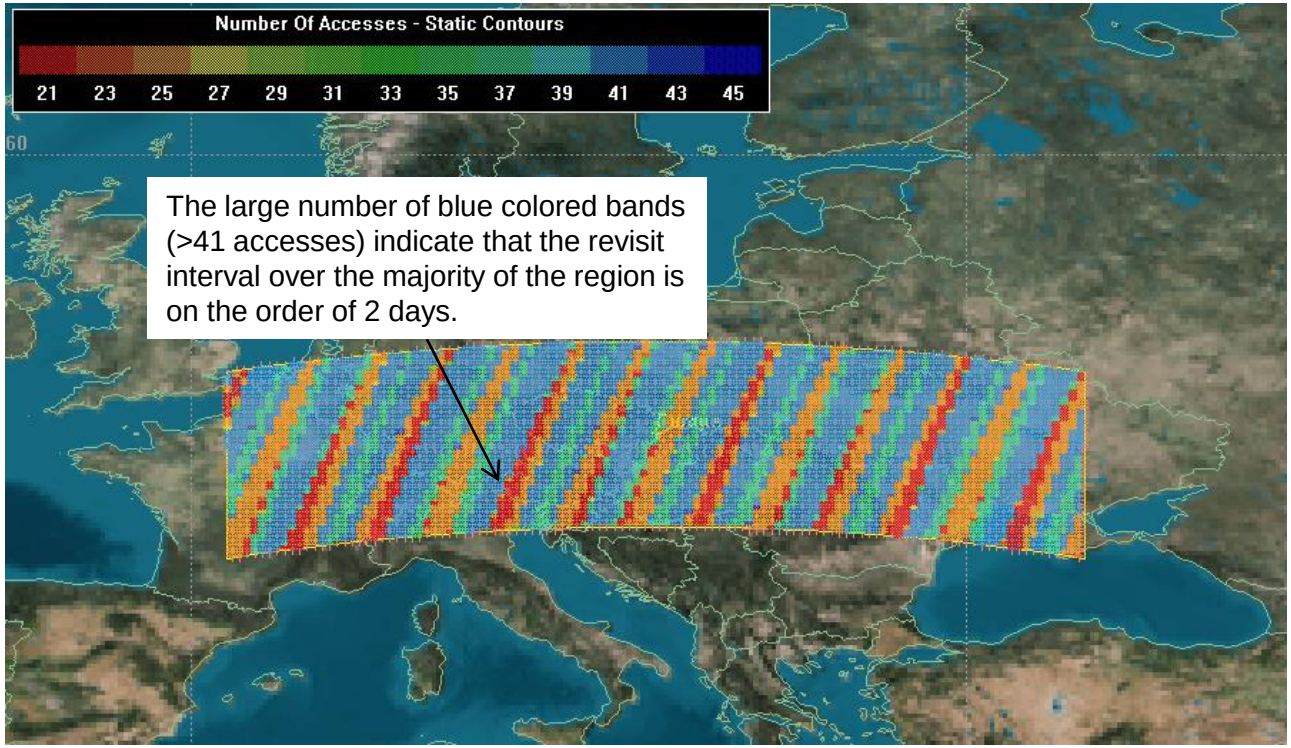


Revisit frequency needed to yield a 100% cloud free view every 8 days



Sentinel-2 and Landsat Synergy

- Sentinel-2: ESA "Landsat-like" system with 10-day repeat per platform
- 2 platforms (S2a, S2b) give 5-day repeat
- 2-4 day repeat when combined with Landsat-8



Number of times Landsat-8 and the Sentinel 2 satellites accessed areas on the ground over an 80 day period of time.

- 21 accesses indicates a maximum revisit interval of ~3 days 19 hours

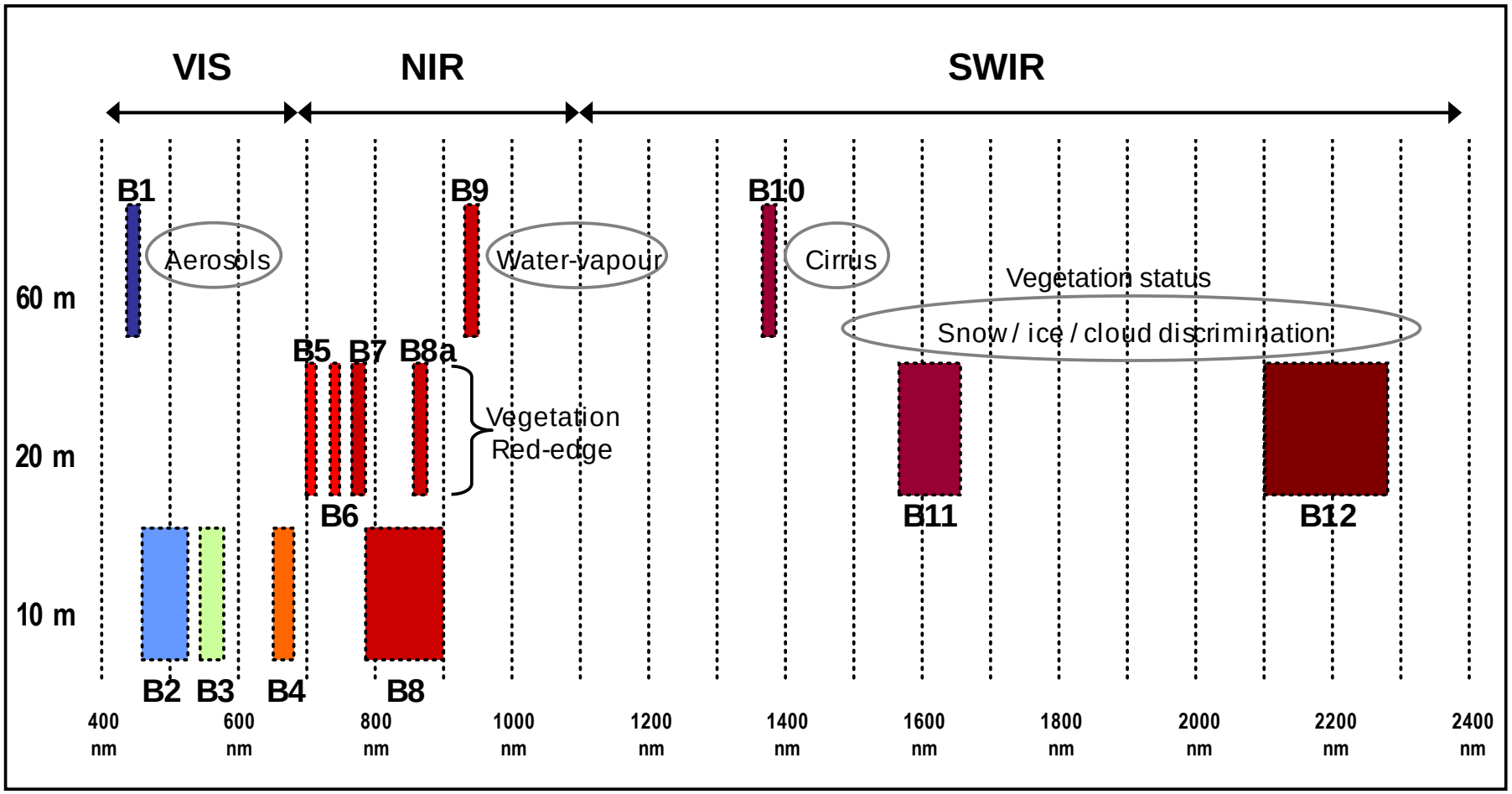
- 46 accesses indicates a minimum revisit interval of ~1 day 18 hours

Courtesy Brian Killough, LARC

FY16 Budget Request for SLI

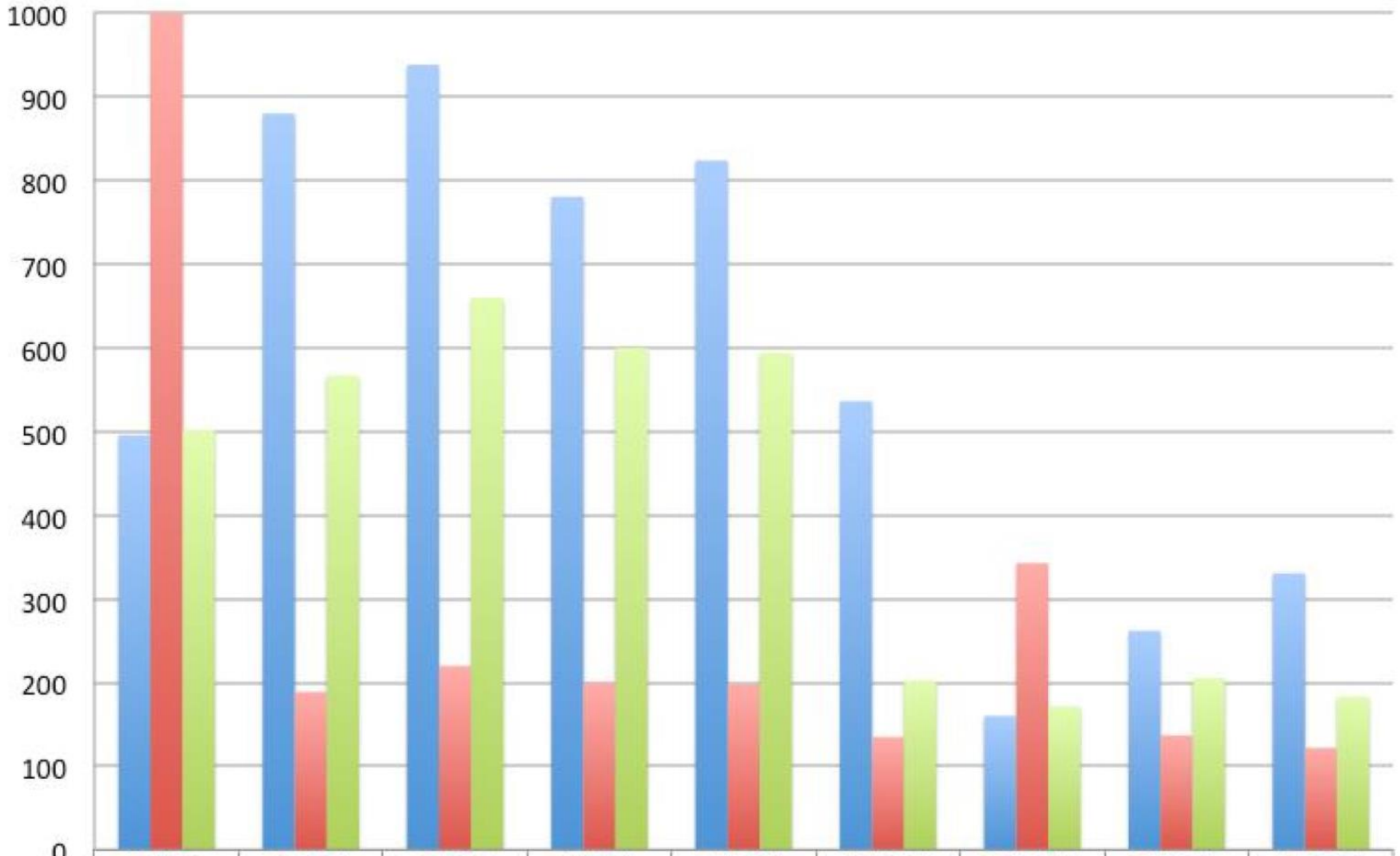
"At the programmatic level, investigations will focus on commercial and hybrid commercial/governmental procurement and management approaches, as well as **integration of multiple data sets from an open array of satellite observations** to create a seamless land imaging archive for the user…"

Sentinel-2 spectral bands



13 spectral bands for vegetation analysis, correction of atmospheric perturbations & land classification

OLI and MSI SNR @MSI Lref (median for OLI; mean for MSI)

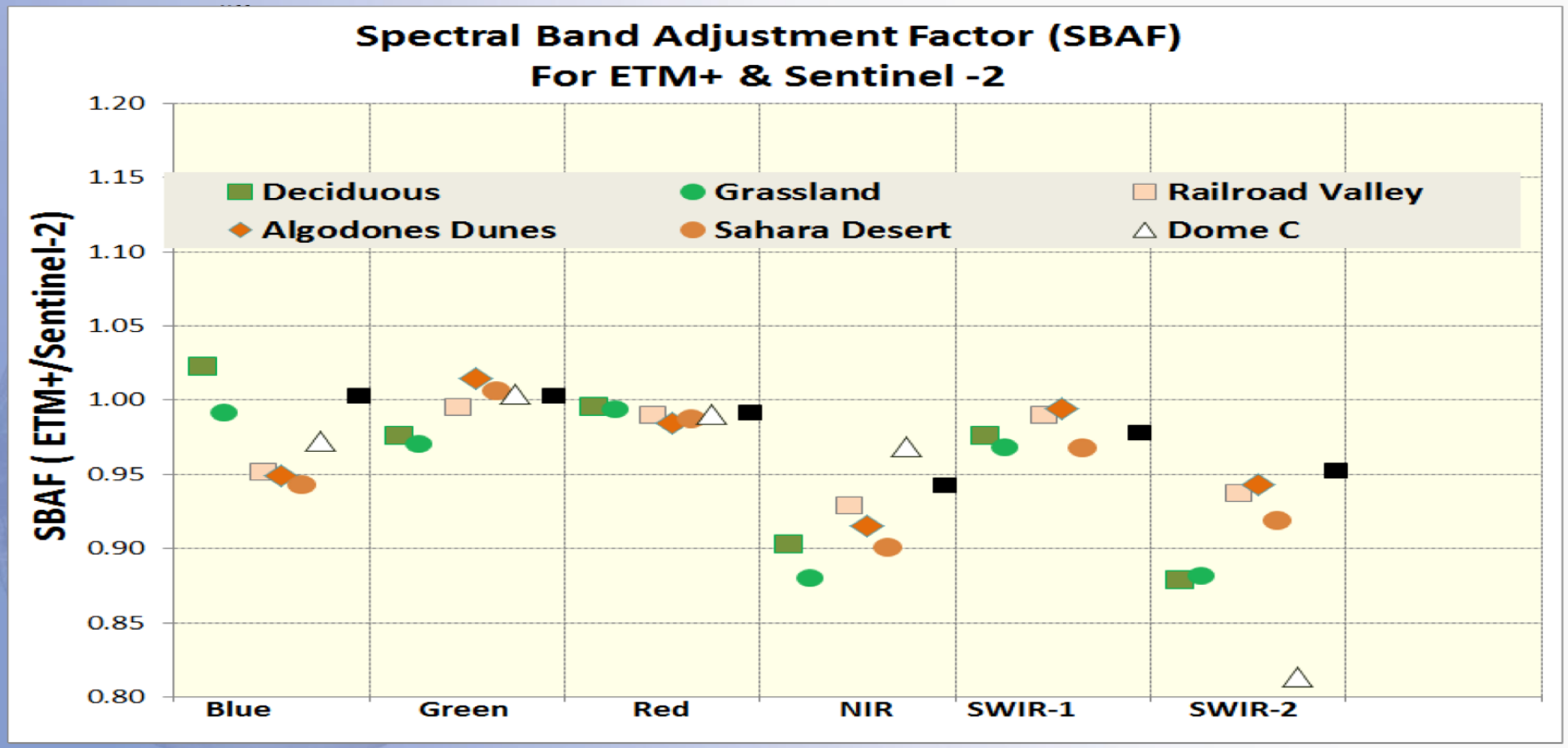


	1 (443) 1 (443)	2 (482) 2 (490)	3 (561) 3 (560)	4 (655) 4 (665)	5 (865) 8 (842)	5 (865) 8a (865)	9 (1374) 10 (1375)	6 (1608) 11 (1610)	7 (2201) 12 (2190)
OLI	496	880	938	781	824	536	160	262	331
MSI - Native Resolution	1004	189	220	200	198	135	343	137	122
MSI -Adjusted to 30m	502	567	660	600	594	203	172	206	183

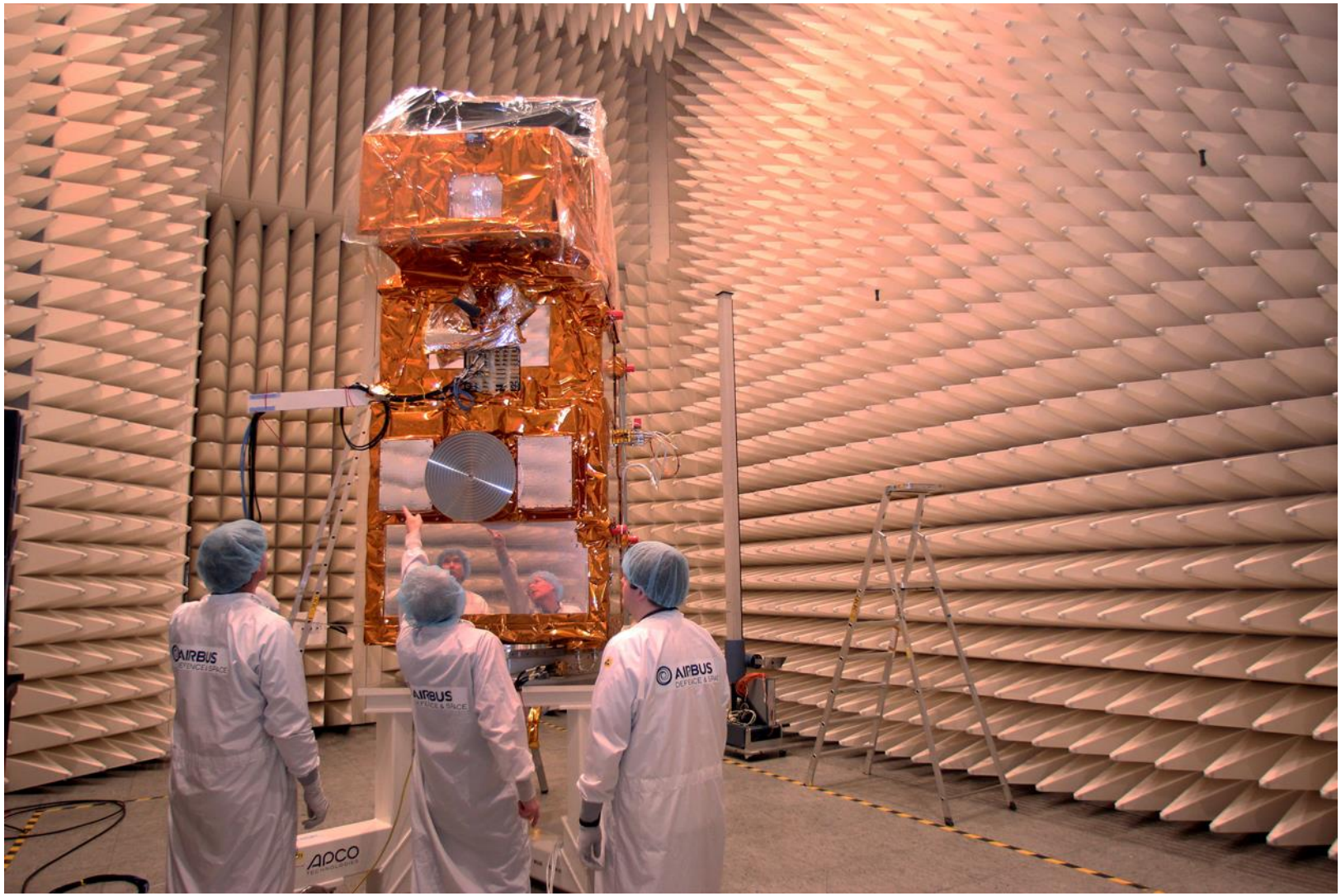
OLI On-Orbit performance; MSI performance predicted from FPA measurements (Chorvalli et al, 2013) – to be updated

SBAF - Predicted Spectral Differences for Cal-sites

- Multiple Hyperion acquisitions over various targets indicate that
  - For OLI versus Sentinel – 2
    - ❑ SBAFs are close to one for Coastal Aerosol, NIR and SWIR bands
    - ❑ But the response for Blue and Red will differ by about 3-4% due to spectral filter differences
  - For ETM+ versus Sentinel – 2
    - ❑ SBAFs correction is much more important with differences as great as 12% due to spectral filter



S2 Environmental Test



S2 Solar Array

What's Needed to Make Full Use of S2 in US?

(1) User access to S2 L1C Data (USGS & ESA)

(2) MSI characterization & cross-calibration with Landsat-8 (Landsat calibration team & ESA)

(3) Higher-level Products & Science (NASA LCLUC/LcPSO)

- Prototype merged Landsat + S2 reflectance product (Vermote/LcPSO)
- Recent NASA LCLUC solicitation for multisource land imaging science
  - Coordinated with ESA SEOM (Scientific Exploitation of Operational Mission) program
  - Multi-year investment in new products from fusion of international systems, including Sentinel-1,2

USGS Plans for Sentinel-2 Data

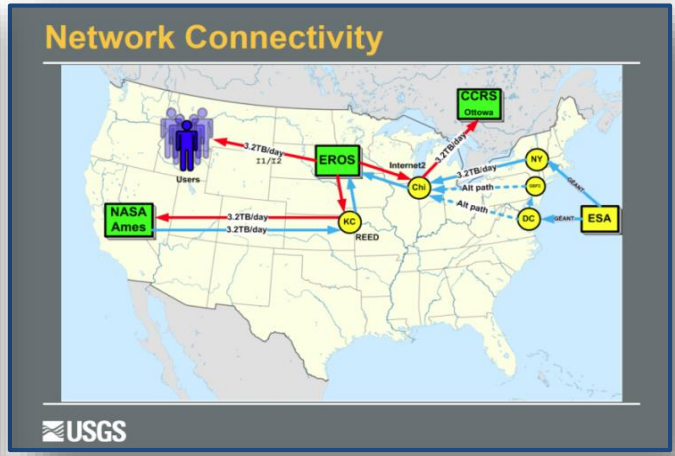
- USGS planning to provide copy of S2 L1C data via EROS

- Implementation Tiers:
  - ✓ **Tier 1: EROS will pull a copy of all L1C data from ESA, host a copy at EROS, generate a Full Resolution Browse (FRB) and enable basic data discover capabilities (no other processing included)**
  - – **Tier 2:** In addition to Tier 1, add a minimal amount of processing necessary to increase usability of the data, including reformatting data to be more consistent with Landsat Level 1 and resampling the Level 1C data to a 30m common grid and tiling scheme (Landsat-like) for distribution as an on-demand Landsat-like product
  - – **Tier 3:** This is a separate and parallel scenario to Tier 2 to render the MSI data interoperable with Landsat and significantly increase the usability/utility of the data for research/applications and makes the data as seamlessly similar as possible to Landsat data for the user (feasibility pending and therefore, not yet estimated)

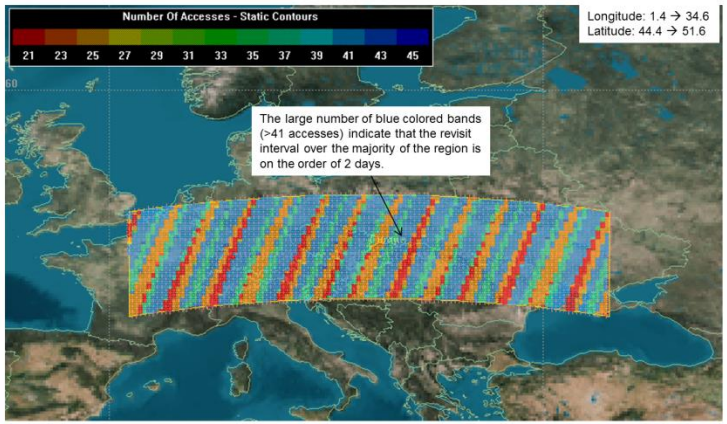
- Collaborating with NASA on pre-flight calibration to data characterization to define science data processing to ensure Landsat and Sentinel-2 data synergy

NASA Landsat – Sentinel-2 fusion

- ❑ Merging Sentinel-2 and Landsat data streams could provide < 5-day coverage
- Goal is “seamless” near-daily 30m surface reflectance record
- ❑ Cross-calibration, atmospheric corrections, spectral and BRDF adjustments, regridding



Sentinel 2A and B - LDCM Europe



- The picture shows the number of times LDCM and the Sentinel 2 satellites accessed areas on the ground over an 80 day period of time.
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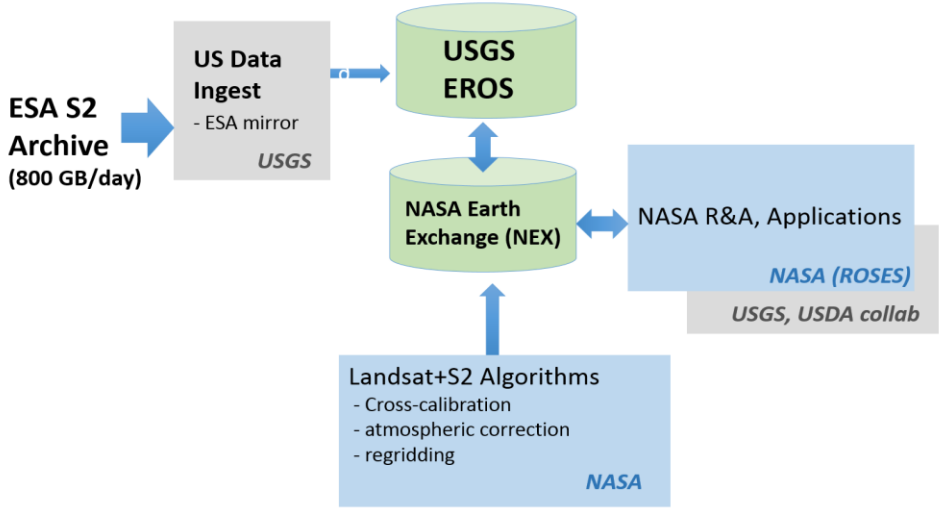
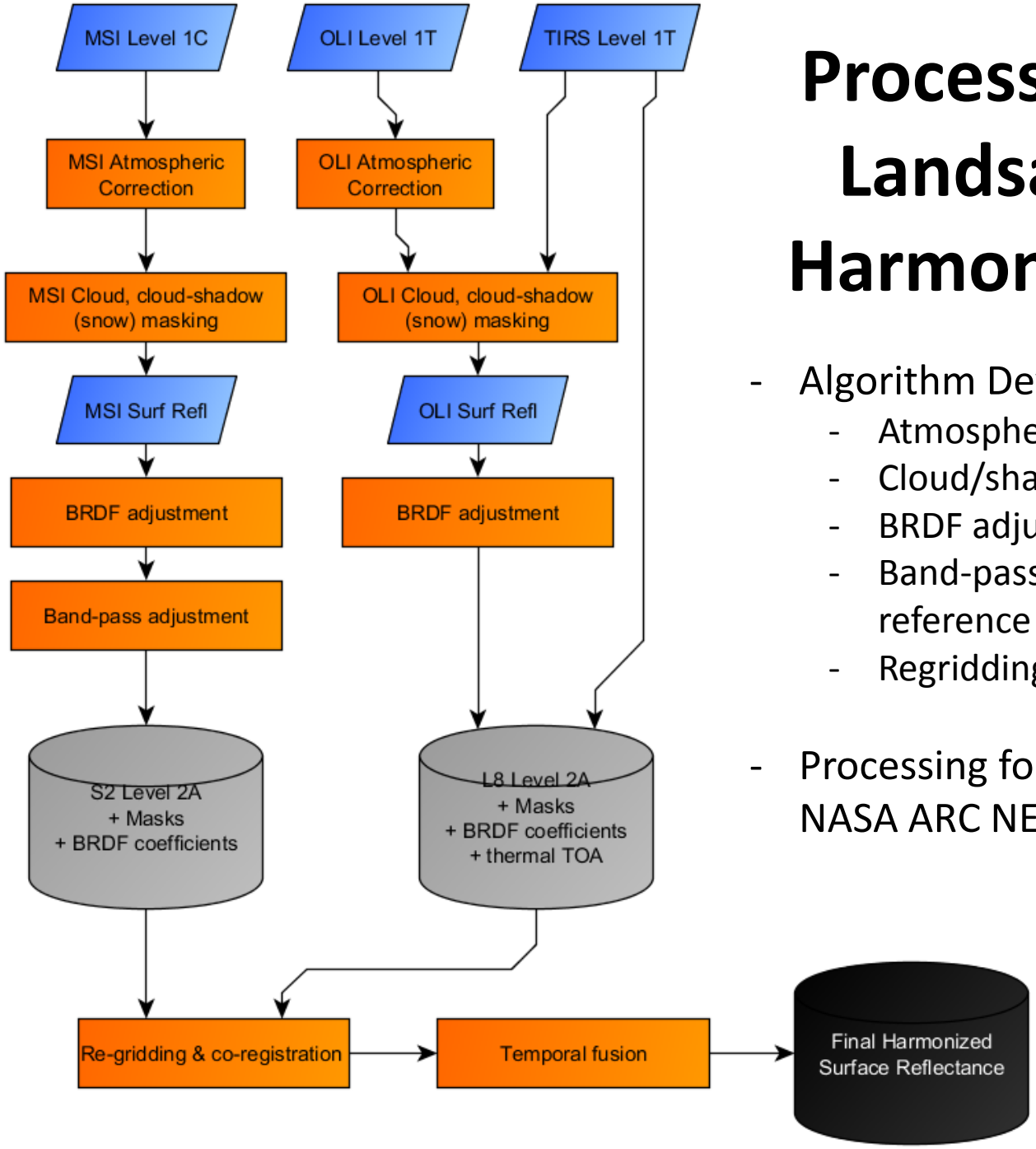
Courtesy Brian Killough, NASA LARC

Proposed Architecture



Processing for Landsat/ S2 Harmonization



- Algorithm Development
  - Atmospheric correction
  - Cloud/shadow masking
  - BRDF adjustment to nadir
  - Band-pass adjustment to OLI reference
  - Regridding / Temporal Compositing
- Processing for test/regional sites on NASA ARC NEX system

NASA Multi-Source Imaging Framework

NASA LCLUC Multi-Source Imaging Team

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

ESA SEOM (Science Exploitation of Operational Missions)

USGS EROS
Data Distribution & Land Science

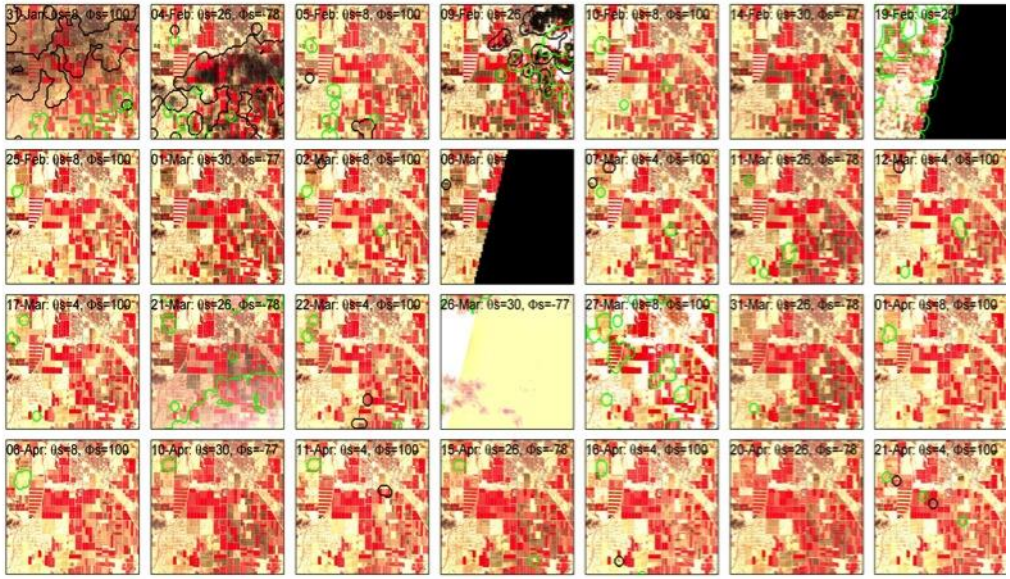
Land Cover Science Project Office
- OLI / MSI cross-calibration program (Markham, Czapla-Myers, Helder, Schott)
- Harmonized S2/Landsat reflectance products (Vermote, Claverie)
- Support for NEX Programming

NASA Earth Exchange (NEX)
(Ganguly, Dungan)
- Prototype Higher Level Products

Looking Forward

- Harnessing the diversity of international remote sensing systems provides new science, at a fraction of the cost of a new mission
  - Long-time CEOS VC goal
  - Near-daily multispectral data key for “fast” ecological and land use phenomena (agriculture, phenology, water quality, etc…)

- But.. Making progress requires hard work
  - International collaboration
  - Sensor characterization
  - Algorithm development
  - Processing systems



Road to Landsat-10

- Current plans suggest a Landsat-10 launch ~2030
  - Implies L10 architecture settled ~2021-22

- Next 5-6 years provide a window for evaluating options
  - Community science & application needs
    - Continuity
    - New observations
  - Ability to merge S2 and Landsat for <weekly coverage
  - Technology and engineering considerations
    - Smaller instrumentation -> lower costs, higher cadence
    - Additional capabilities (e.g. more spectral resolution/coverage)

Thank You