EO-1: Request for Mission Extension

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EO-1 Mission Extension

We request an extension of EO-1 because:

- In spite of orbital changes, EO-1 provides unique and valuable data to the science & applications communities and supports SLI, HyspIRI, & future mission development.
  - Rapid response
  - Hyperspectral imagery
- The risks are low
- The costs are low

Topics to be Addressed

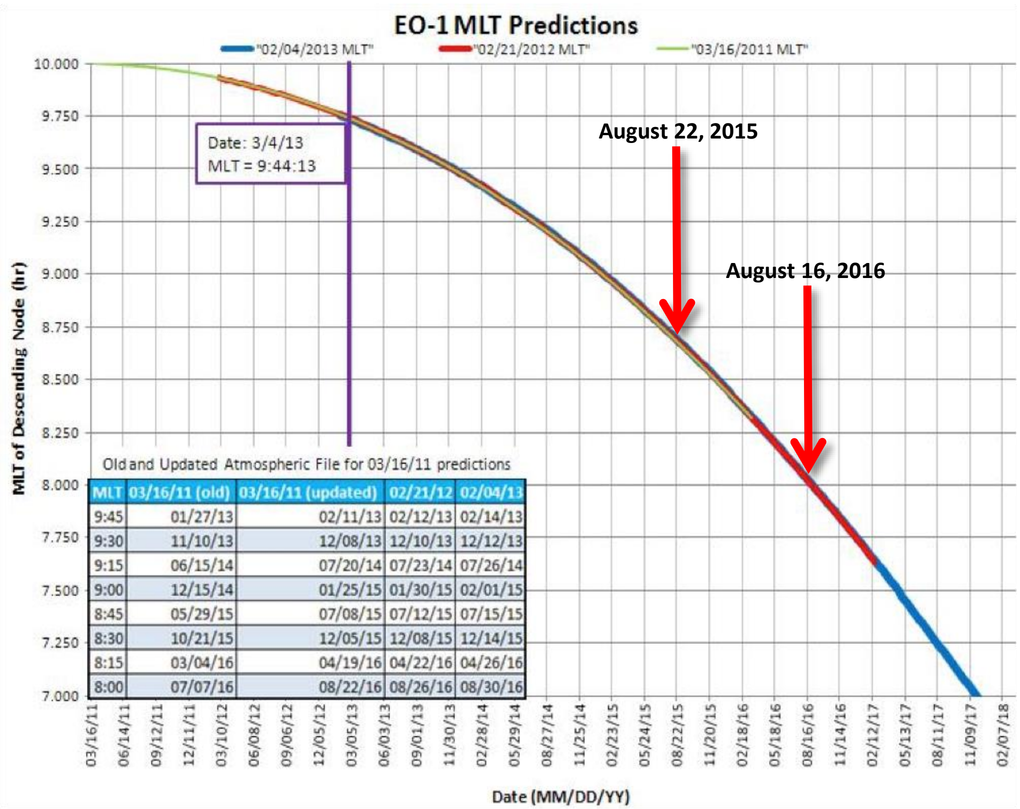
- EO-1 is Still a Valuable Asset:
  - Change in MLT and Illumination
  - Change in Orbit
  - Data Quality
- Reasons to Continue Collections
  - Importance/Usage of Data and Products
  - HyspIRI and SLI Support
- Lunar Lab Concept
- Options for Going Forward

Change in MLT and Illumination

Although EO-1 is slowly drifting to earlier MLT equatorial crossing times, the ALI Signal-to-Noise Ratio (SNR) remains superior to that of all Landsat instruments prior to the OLI instrument on Landsat 8.

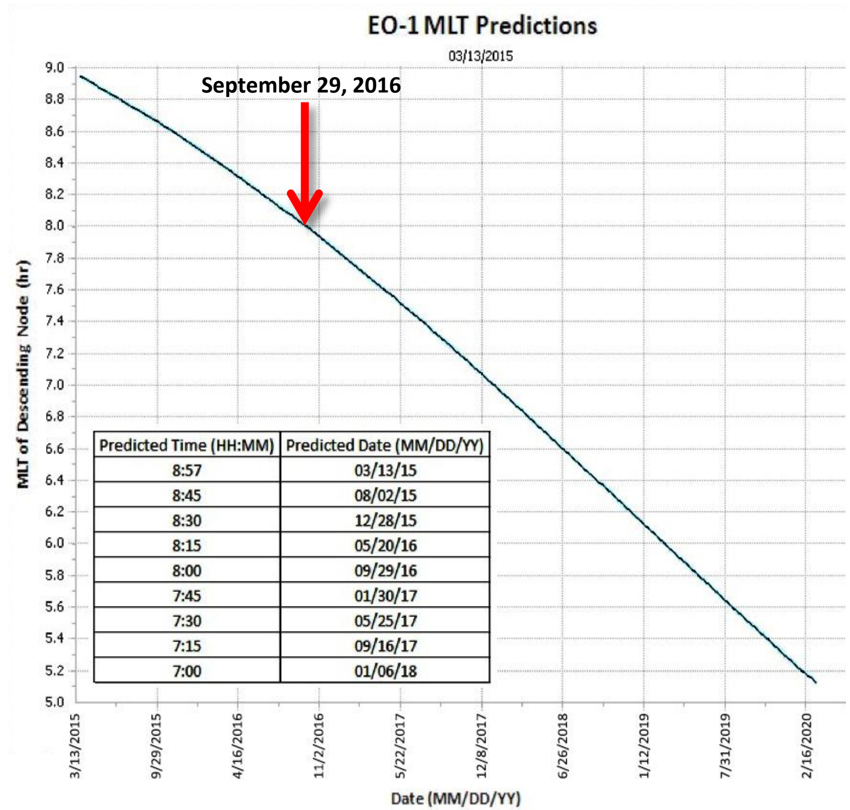
Comparison of March 2013 Senior Review MLT Projections with March 2015

Shows orbital projections have been consistent and that earlier predictions were too conservative.



MLT	03/16/11 (old)	03/16/11 (updated)	02/21/12	02/04/13
9:45	01/27/13	02/11/13	02/12/13	02/14/13
9:30	11/10/13	12/08/13	12/10/13	12/12/13
9:15	06/15/14	07/20/14	07/23/14	07/26/14
9:00	12/15/14	01/25/15	01/30/15	02/01/15
8:45	05/29/15	07/08/15	07/12/15	07/15/15
8:30	10/21/15	12/05/15	12/08/15	12/14/15
8:15	03/04/16	04/19/16	04/22/16	04/26/16
8:00	07/07/16	08/22/16	08/26/16	08/30/16

Orbital Projection from March 2013 Senior Review Proposal



Predicted Time (HH:MM)	Predicted Date (MM/DD/YY)
8:57	03/13/15
8:45	08/02/15
8:30	12/28/15
8:15	05/20/16
8:00	09/29/16
7:45	01/30/17
7:30	05/25/17
7:15	09/16/17
7:00	01/06/18

Orbital Projection from March 2015 Latest Calculations

This EO-1 MLT and SMA analysis was independently verified by the Terra, Aqua, Aura Flight Dynamics team.

Low Risks to Continuation

- Extending the mission would not incur extra risk for later passivation in terms of battery, solar array, or hardware.

- We have an approved EOM Plan and Phase F that will not be impacted by an extension.

- There are NO impacts at USGS for Data Management and Archiving:
  - Data processing and archiving functions are automated.
  - The DAR process will continue to support incoming data until Earth acquisitions cease.

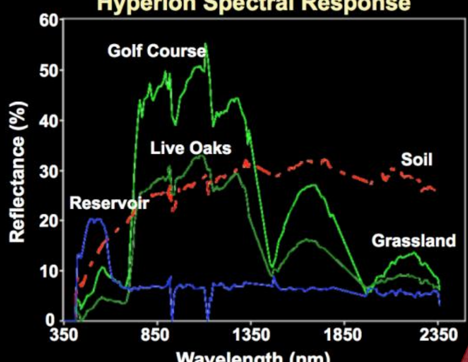
2015 NASA Senior Review
Earth Observing-1 (EO-1) Proposal

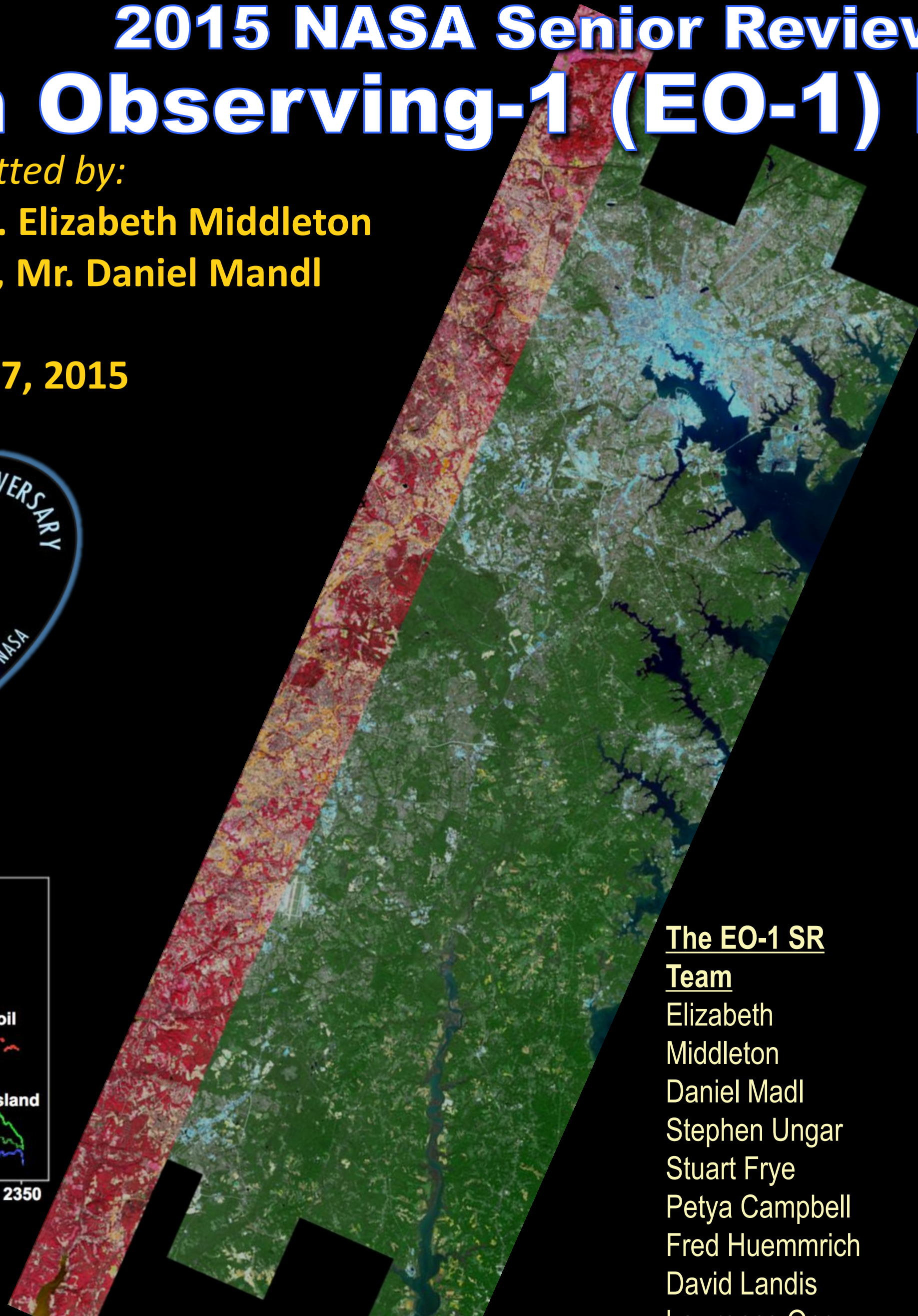
Submitted by:

Mission Scientist, Dr. Elizabeth Middleton

Mission Manager, Mr. Daniel Mandl

April 27, 2015





Hyperion (red) overlay on ALI Image (green), Oct 2012
Baltimore, MD

The EO-1 SR Team

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ALI False-Color Image, 2014 San Miguel Volcano

ALI True-Color Image, 2013 Bird Sanctuary in India

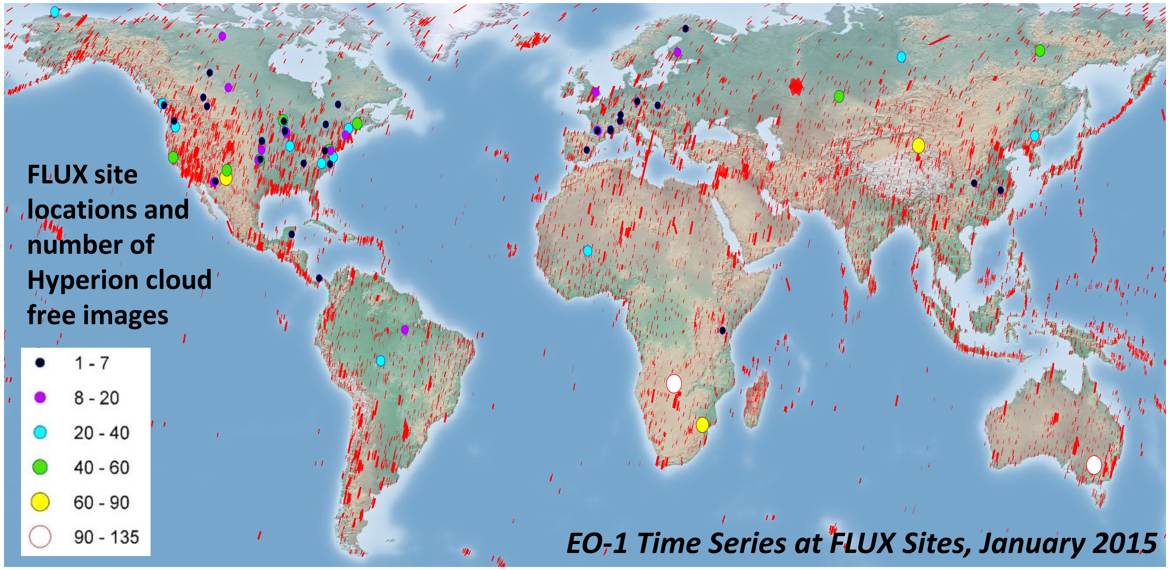
ALI False-Color Image, 2013 Fire in Australia

Overview: What EO-1 Offers that no other NASA Mission Provides

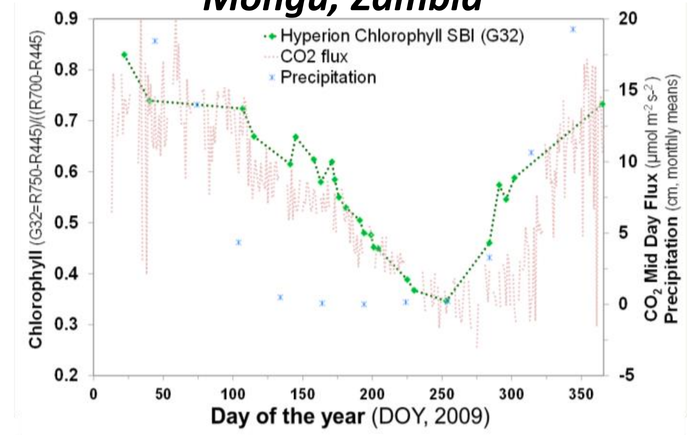
EO-1 is a fundamentally unique NASA asset, providing capabilities not available with any existing or currently planned space platform.

- EO-1 is a highly maneuverable ***testbed*** asset which can be (and has been) assigned a variety of high priority tasks of critical interest to the NASA Earth Science Division.
- Hyperion is the only spaceborne satellite imaging spectrometer (IS), uniquely providing a 14.5 year archive. Hyperion data continue to be used as a source for understanding how spectroradiometric properties relate to the physical state (and disturbances) of the Earth's surface.
- Hyperion paves the way for future IS missions, providing unprecedented quantitative assessments of terrestrial and aquatic ecosystems.
- Technology Pathfinder, such as:
  - Onboard autonomy software (Autonomous ScienceCraft Experiment – JPL)
  - Onboard intelligent diagnostic software (Livingstone – Ames)
  - IP for space (Delay Tolerant Network – GSFC)
  - Onboard cloud detection (Lincoln Lab – GSFC & JPL)
  - SensorWeb/GeoSocial API for ease of tasking satellites, discovery/delivery of satellite data products (GSFC, JPL, International Disaster community)
  - Intelligent Payload Module (IPM) for low latency HyspIRI products (GSFC)

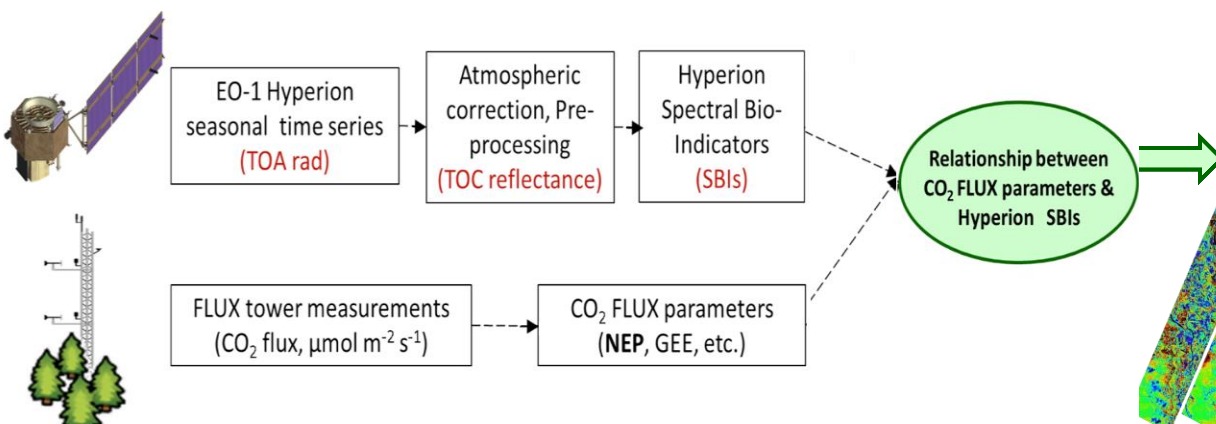
EO-1 Hyperion Tracing Spectral Dynamics of Ecosystem Function

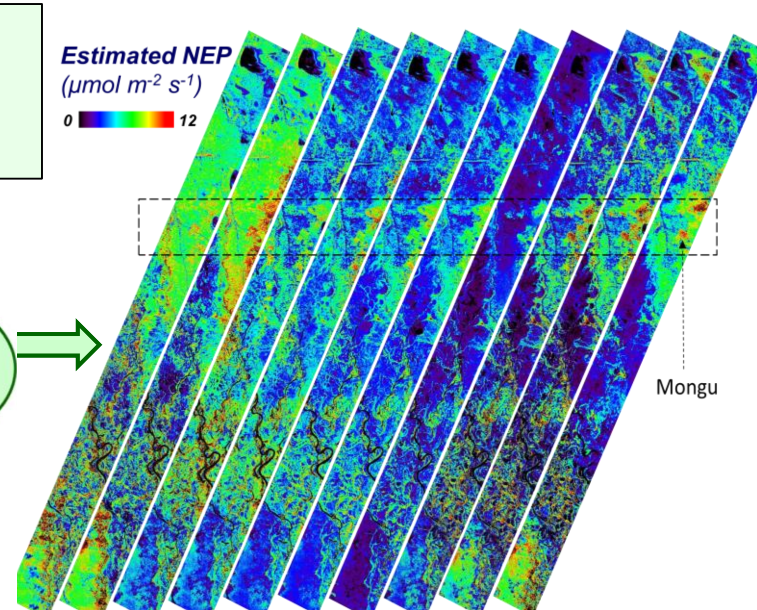


EO-1 Hyperion: Spectral Time Series for Vegetation Function Mongu, Zambia



Spectral measurements capturing the seasonal dynamics of ecosystem function are possible because of EO-1 Hyperion's spectral stability and ability to collect repeated coverage.



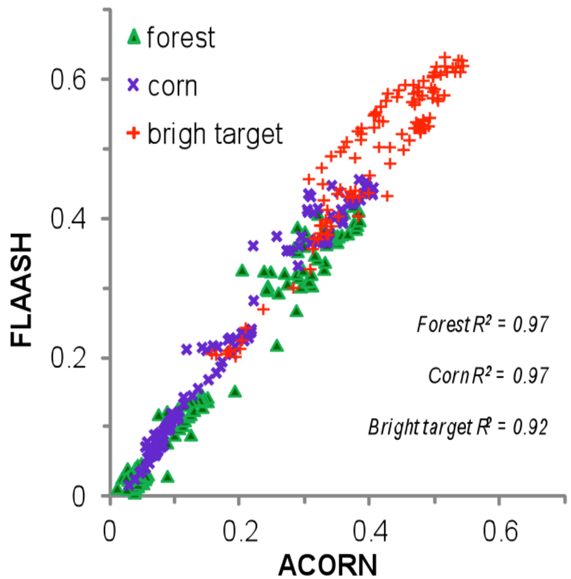


EO-1 Hyperion Spectral Time Series at FLUX Sites

Hyperion radiance images are corrected for atmospheric effects to surface reflectance using the Atmosphere CORrection Now, ACORN software.

Site	Images		Site	Images		Site	Images	
	Total	Clear		Total	Clear		Total	Clear
Tapajos (LBA: Santarem)	267	21	Metolius/Cascades, OR	101	37	Bily Kriz Beskidy (spruce)	22	5
Skukuza	258	91	Jasper Ridge	98	44	BCI	17	0
Uardry	238	132	Bartlett	91	24	Audubon	12	8
Mongu	227	135	Duke forest, HW	89	34	Milk river, Rangeland	11	5
Prk Falls, WI LTER	224	55	Hyytiala	87	15	Walnut Gulch /Kendall	9	7
BC DF49, Campbell River	180	38	Virginia coastal reserve	84	36	Santa Rita Grassland	9	7
Barrow	176	31	Hackett River	82	18	Dyn_Agra_(Crop_land)	8	2
Howland forest	171	42	Madison WI	51	15	Wind River Crane, WAS	8	1
Zotino	166	33	Arlington_BF	49	14	ARM/CART SGP	6	8
Changbaishan	165	40	French agri, site 3	44	15	NC Loblolly plantation	6	3
JI-Parana(Jaru-LBA)	163	39	BERMS_SSA	42	13	BC Young, Campbell River	6	2
Dunhuang	158	78	French savanna, Mali	36	26	Baraboo Hills	6	1
BARC (USDA corn N)	130	48	Konza prairie	36	13	Oil sands	6	1
ARM/CART Ponca City	123	47	French agri, site 1	36	10	Mead US-Ne1	5	4
Jornada	115	72	Sian Kaan	36	1	Mead US-Ne2	5	4
Shortandy, Kazhstan	115	42	SERC	34	9	ARM/CART Shider	5	3
Barton Bendish	112	17	Sodankyla	30	4	Barrax	5	2
Bondville	111	32	Thor, IT (Micol1)	28	0	Oak Ridge, Tennessee	5	2
Sevilleta	103	57	Micol2	28	0	Blackhawk island	5	1
Yakitsk Larch	101	49	Harvard Forest	25	13	Mead US-Ne3	4	3

A comparison of images corrected with ACORN and FLAASH available at http://eo1.geobliki.com) reveals relatively similar results (r^2~0.92-0.99) for different geographical areas and covers. The axes indicate the reflectance value (0-1).



EO-1 Hyperion Simulating Multispectral Sensors Example: Landsat 7 ETM+

From: Thonfeld et al. 2014

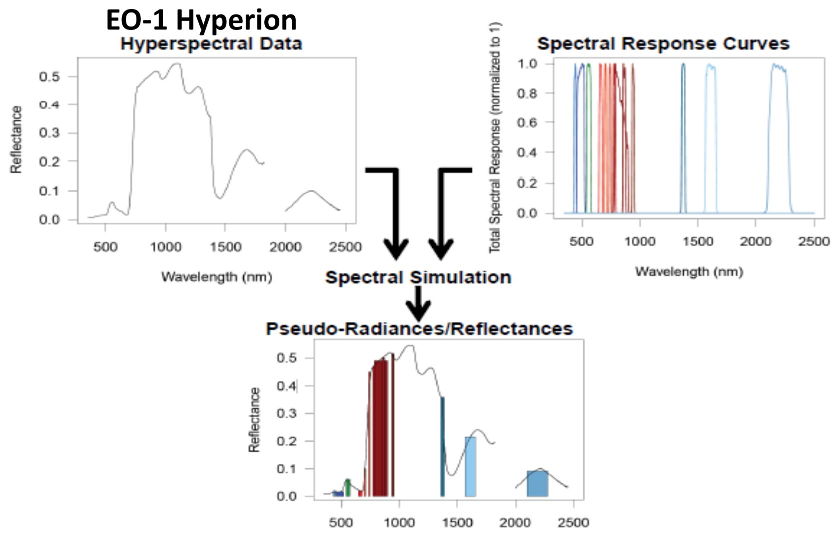


Fig. 1: Workflow of data simulation.

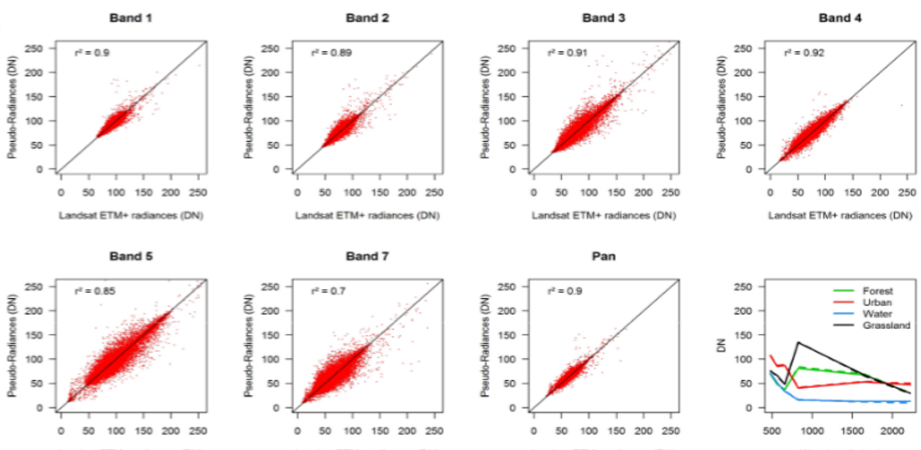
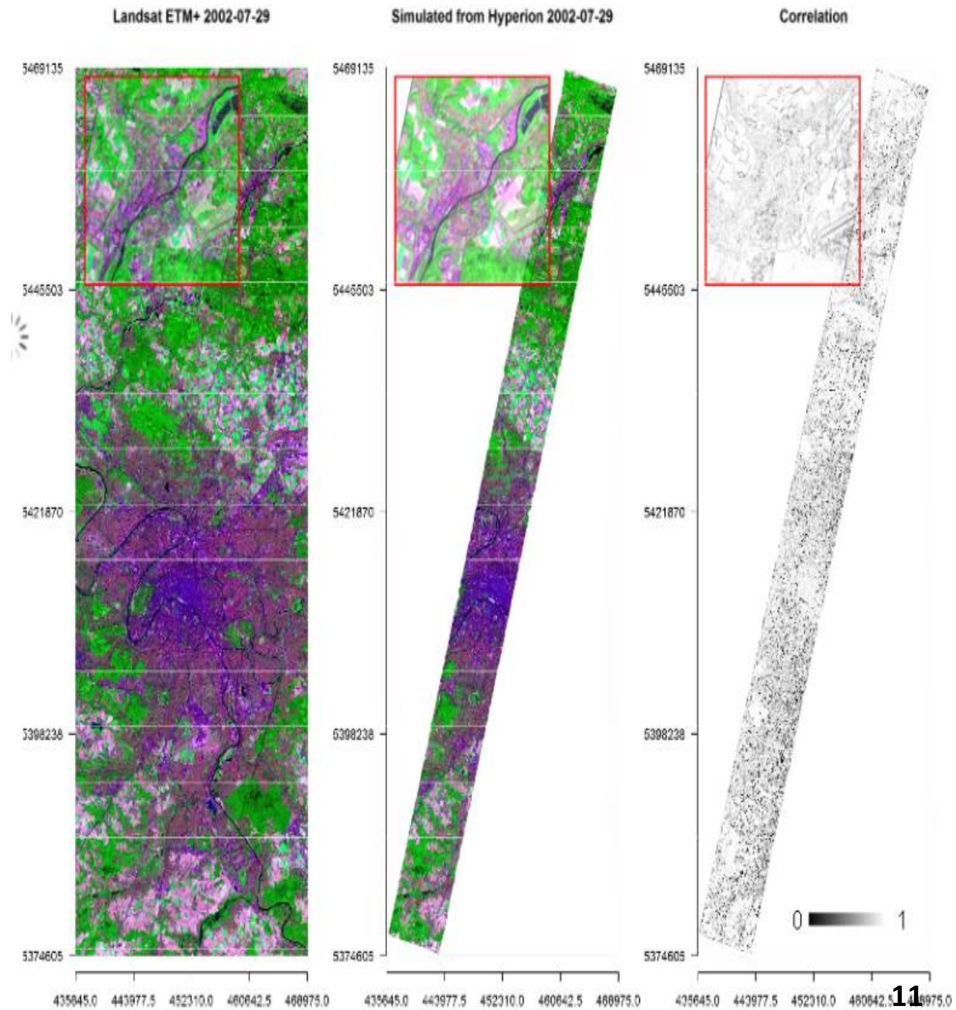


Fig. 3: Subset of Landsat ETM+ Paris, 2002-07-29, RGB = bands 7, 4, 2 (left), same scene simulated from Hyperion (mid), and correlation of both images (right). Low correlation values along the borders of land cover objects indicate poor geometric agreement between the images. The scatter plots show good agreement. Divergences can be related to geometric inaccuracies. The spectra of simulated data (dotted lines) correspond well to Landsat ETM+ (solid lines).

Evaluation example no. 2 - Paris

Landsat 7 ETM+ data are simulated from Hyperion spaceborne hyperspectral data and compared with real ETM+ data from the same day (2002-07-29). There is good agreement between the images (Fig. 3). However, variations occur in heterogeneous settings due to geometric divergences, which is indicated by low correlations values along object borders.



EO-1 Hyperion Contributing to Simulating Future Sensors: Sentinel-2

LCLUC Spring Science Team Meeting
Marriott Hotel and Conference Center, College Park, MD
22nd April, 2015 Session I: Sentinel-2 Preparatory Studies

Simulated SENTINEL-2 data (based on EO-1 Hyperion) contributed to the following studies:

Session 1: Radiometric Characterization, Cal/Val and BRDF

- On-orbit calibration: Use of PICS sites, vicarious campaigns, and global averaging (EO-1 Hyperion Cal/Val sites, Algodones Dunes, Libya-4)
  - **Dennis Helder** (South Dakota State U.) [D. Helder, N. Mishra, **L. Leigh and** D. Aaron. Update on Pre-Cursor Calibration Analysis of Sentinel 2. April 23, 2015 – LCLUC]
  - **Jeff Czapla-Myers** (U. Arizona)

Session 3: Higher-Level Processing and Product Generation

- NEX system processing for Landsat-8/Sentinel-2 data - **Jennifer Dungan** (NASA Ames) and **Sangram Ganguly** (NASA Ames, EO-1 Hyperion over Harvard Forest).

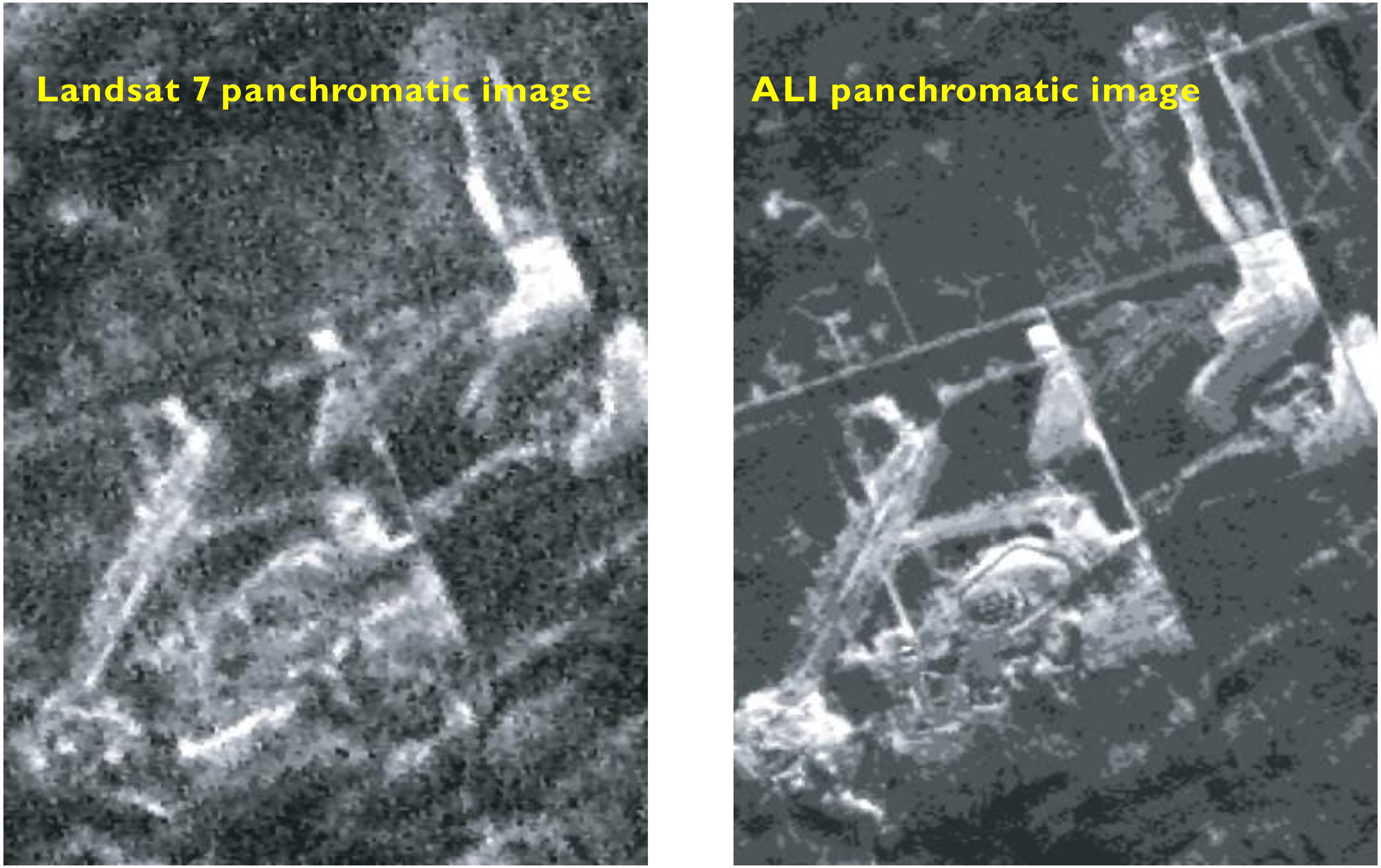
ALI data taken at an 8 AM equatorial crossing time is valuable in spite of the decline in SNR

- The ALI SNR is inherently 6 to 10X (~800%) that of ETM+.
- The ALI signal at 8 AM always exceeds 50% of the 10 AM.
- ALI SNR at 8 AM will be 3 to 5X better than that of ETM+ at 10 AM.
- EO-1 will not reach ~8 AM equator crossing time until October 2016.

Crossing Time at Equator	March 22		June 22		September 22		December 22	
	Elevation (degrees)	cos(SZA)	Elevation (degrees)	cos(SZA)	Elevation (degrees)	cos(SZA)	Elevation (degrees)	cos(SZA)
8:00 AM	28.3	0.47	26.9	0.45	31.8	0.53	27.7	0.46
8:30 AM	35.8	0.58	33.5	0.55	39.3	0.63	34.3	0.56
9:00 AM	43.8	0.69	40.1	0.64	54.3	0.81	40.8	0.65
9:30 AM	50.8	0.77	46.3	0.72	46.8	0.73	47.0	0.73
10:00 AM	58.3	0.85	52.3	0.79	61.8	0.88	52.9	0.80
12:00 PM	88.14	1.00	66.57	0.92	88.17	1.00	66.57	0.92
Signal@8 AM / Signal@10 AM		**0.56**		**0.57**		**0.60**		**0.58**

Signal (i.e. solar irradiance) is a function of the cosine of the solar zenith angle (SZA).

Demonstration of ALI Under Low Illumination



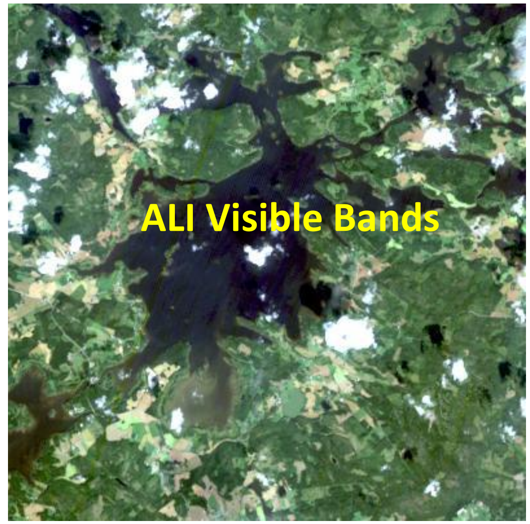
Panchromatic images from the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) [left] and the EO-1/ALI [right], taken on 25 November 2000 over Sutton, Alaska, five days after the launch of EO-1. The sun is less than 8° above the horizon and the solar irradiance "signal" is less than 15% of that at the equator. This is far less than expected for an 8am EO-1 acquisition during either the N or S hemisphere summers. Note, even in late November in Alaska, the light levels were sufficient for imaging.

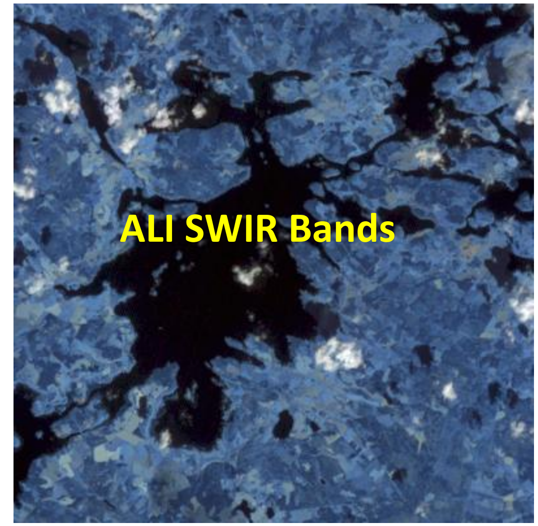
[Fig. 12, Lincoln Laboratory J., 15(2), 2005]

EO-1/ALI with Landsat 8/OLI (2014)

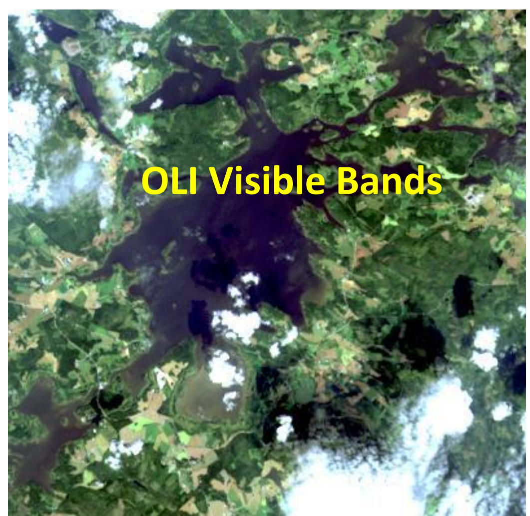
ALI@08:29 UTC, SZA = 50°

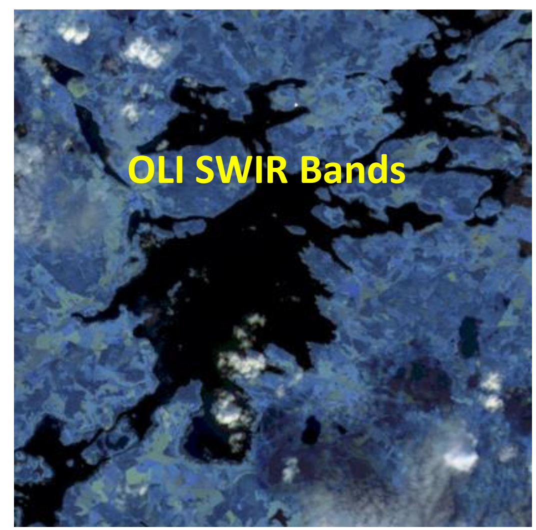
Finland
August 8, 2014
Lat: 61.64
Lon: 24.56





OLI@09:42 UTC, SZA = 46°

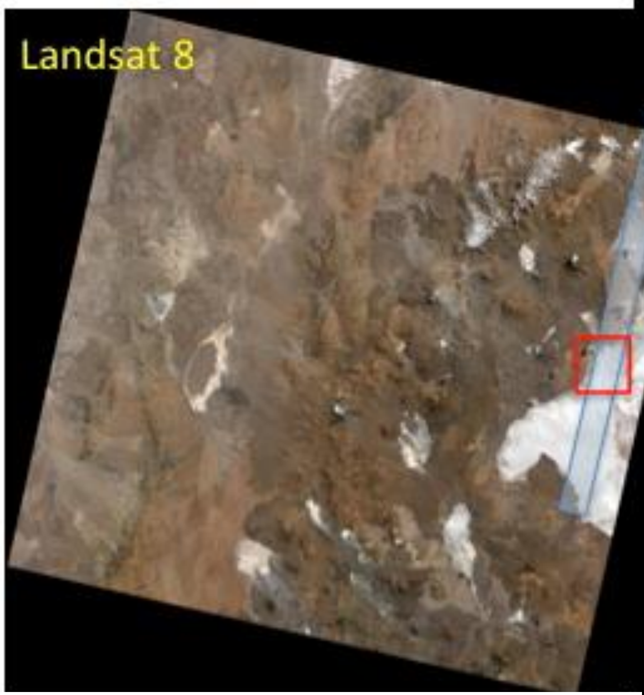


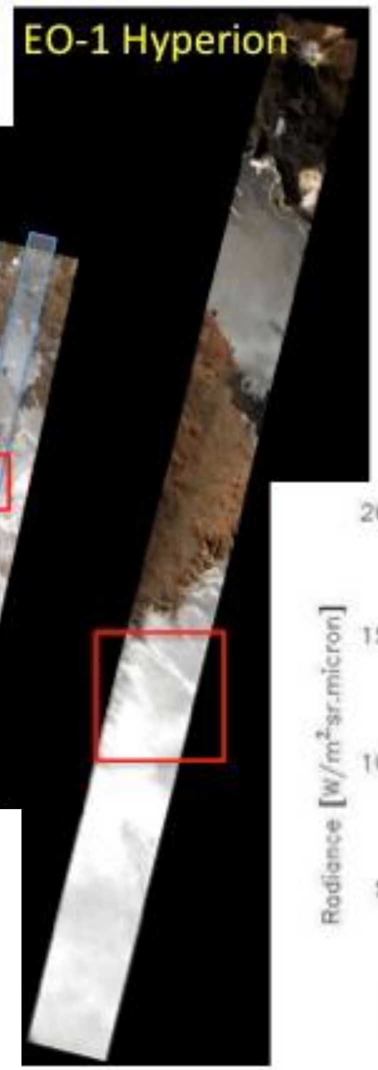


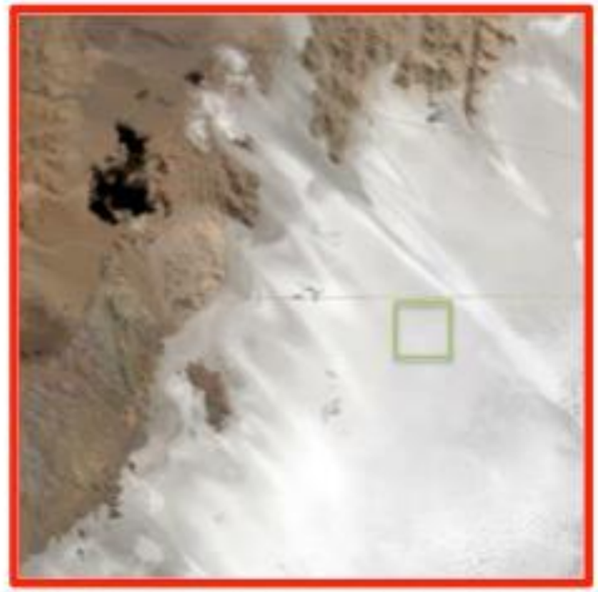
Hyperion Convolved into ALI and OLI Bands

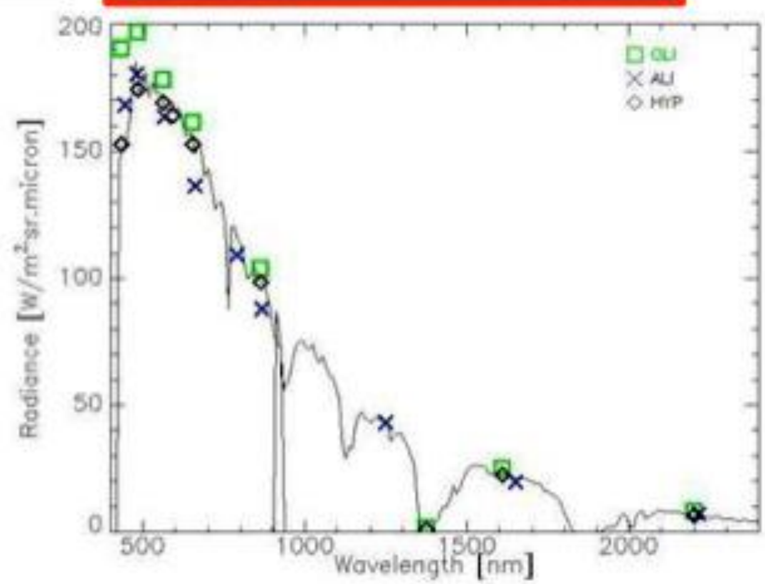
L8 – EO1

Arizaro, Argentina



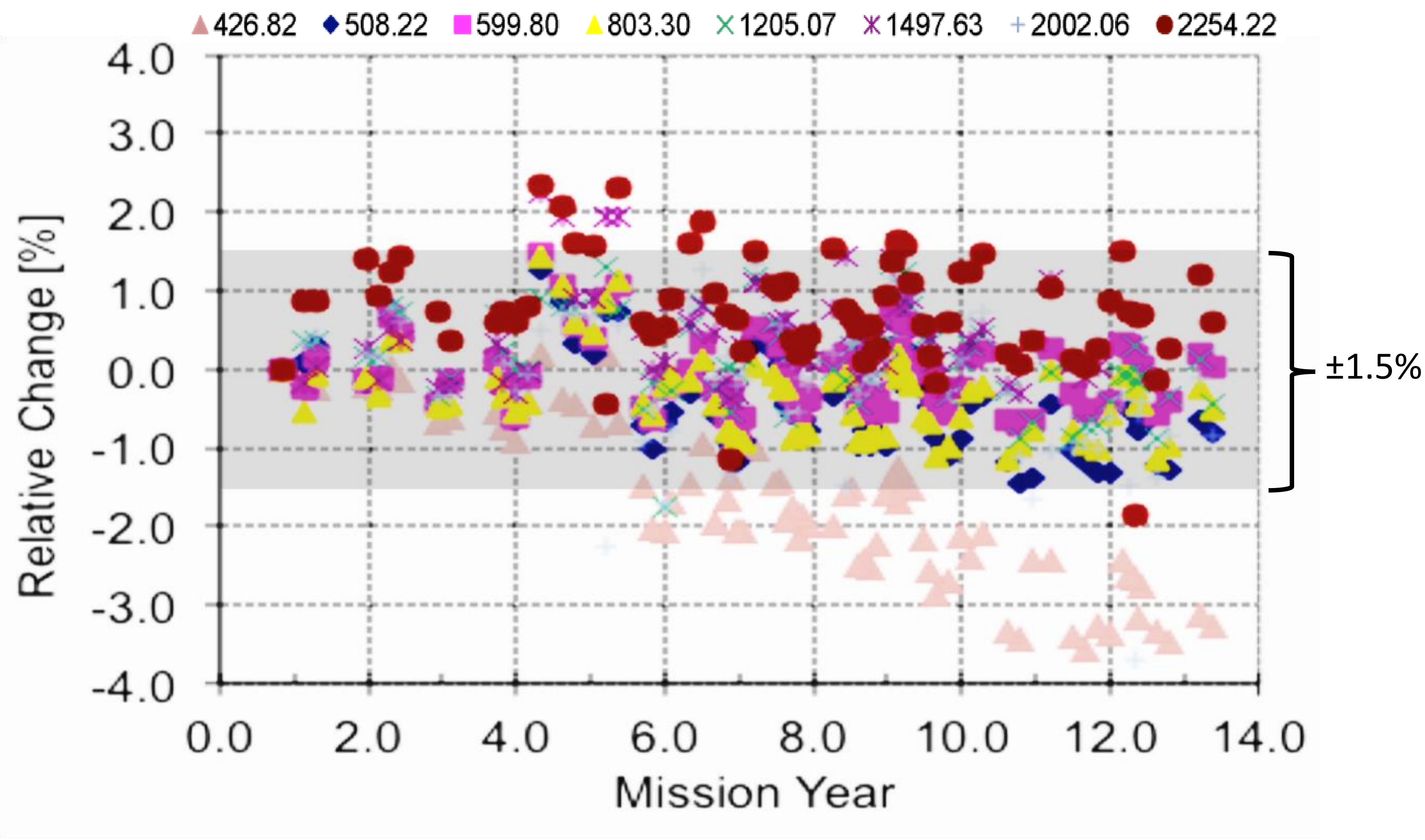






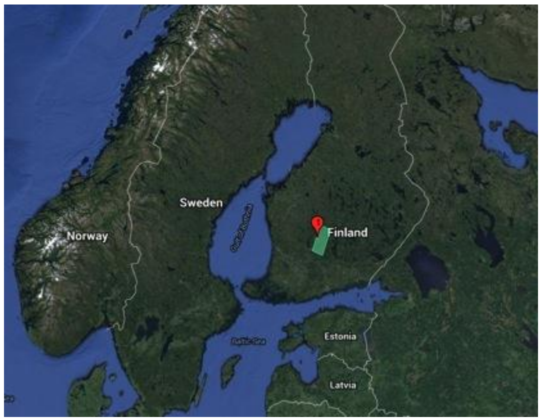
As part of the Landsat 8 OLI Cal/Val program (Spring 2013), Hyperion was used to create simulated OLI bands. These compared well to both OLI and ALI actual images.

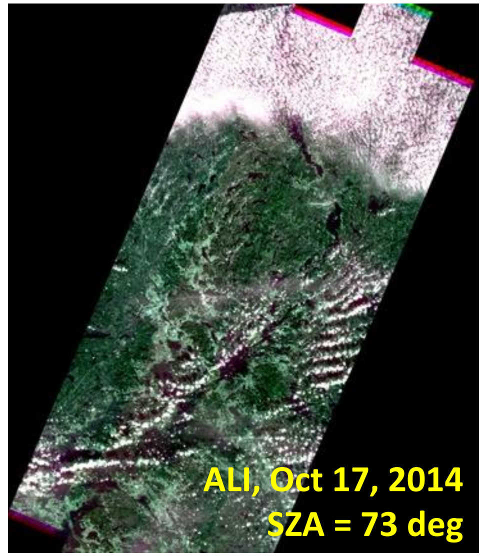
We can continue to use EO-1 productively because of sensor stability… *Hyperion Stability*

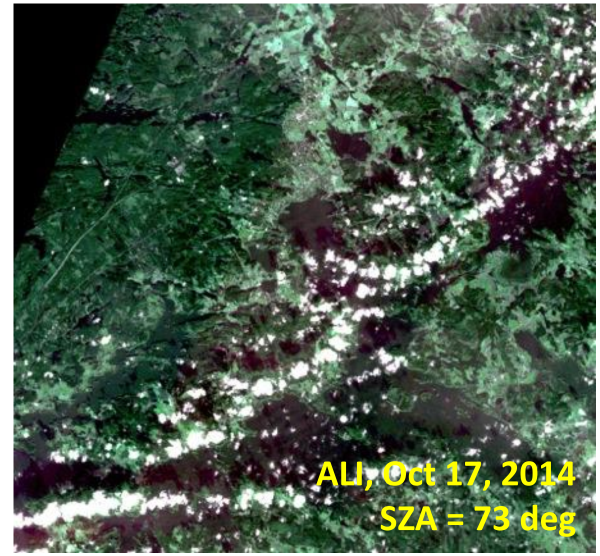


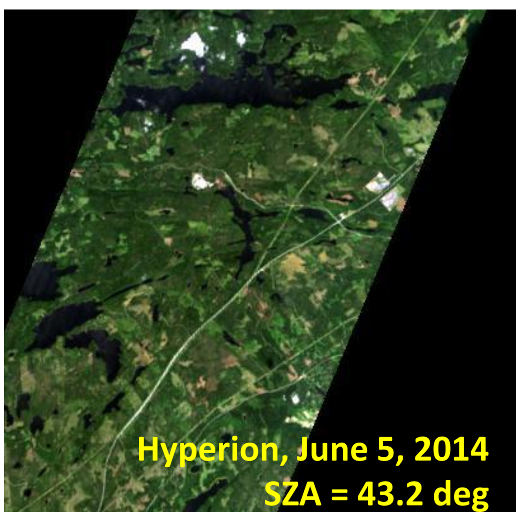
EO-1 Image Quality at Low Sun Angles Visible Bands (SZA=73 deg) in 2014

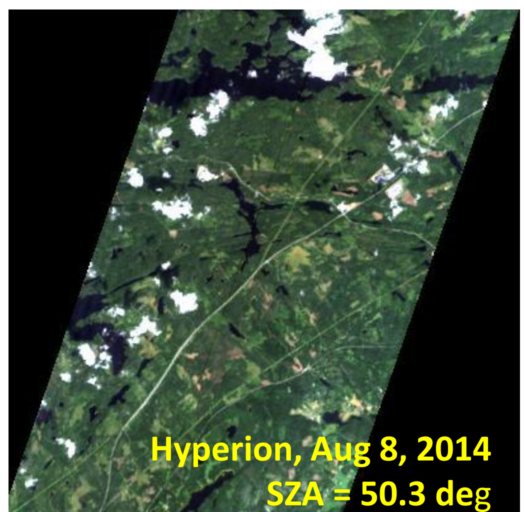
Finland
(Lat: 61.64 Lon: 24.19)

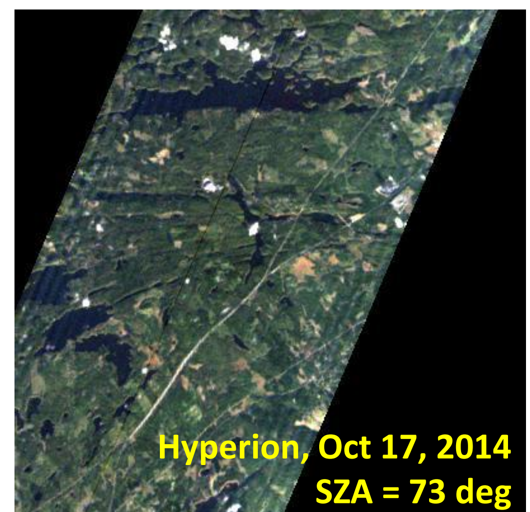








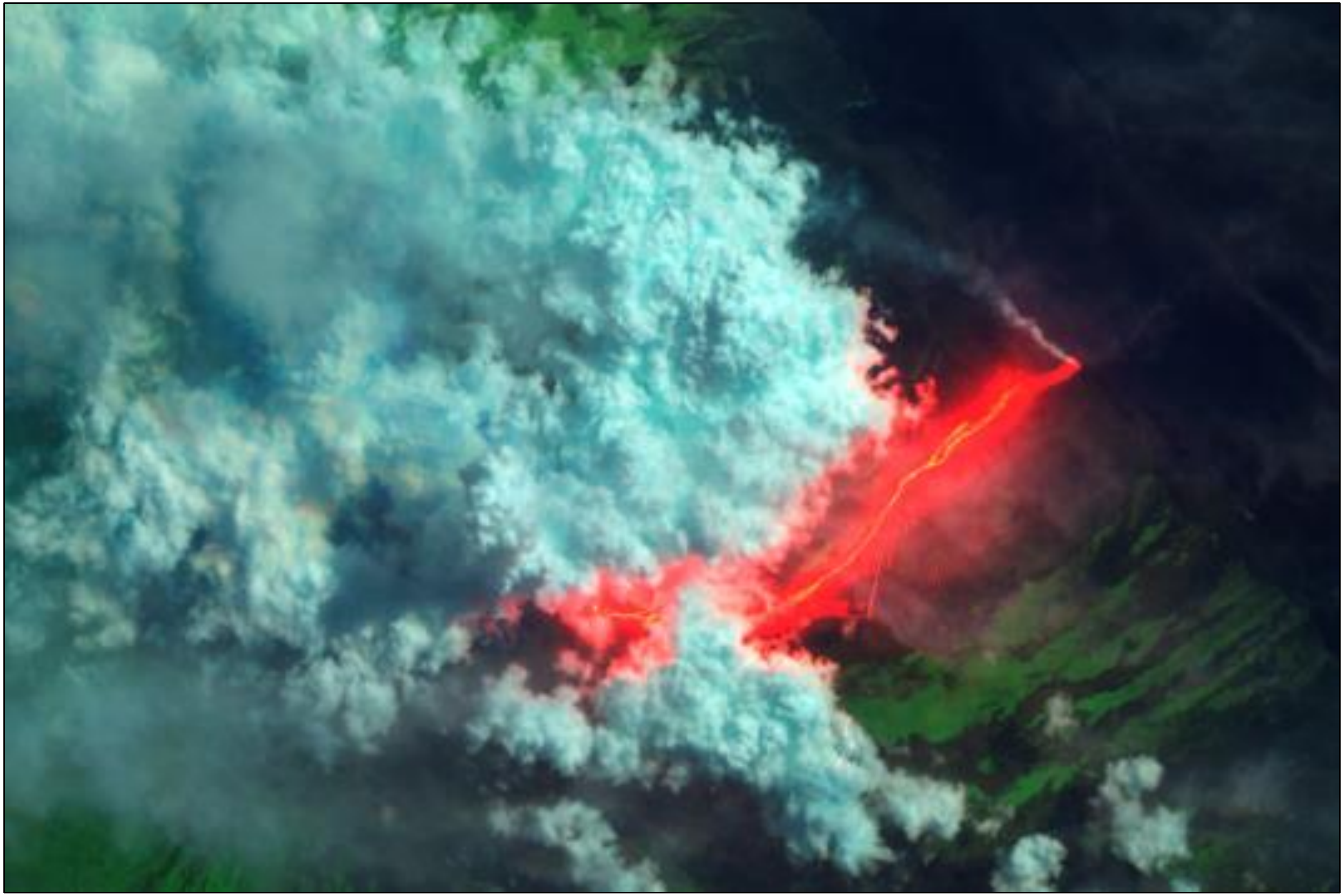




Wolf Volcano, Galapagos Islands

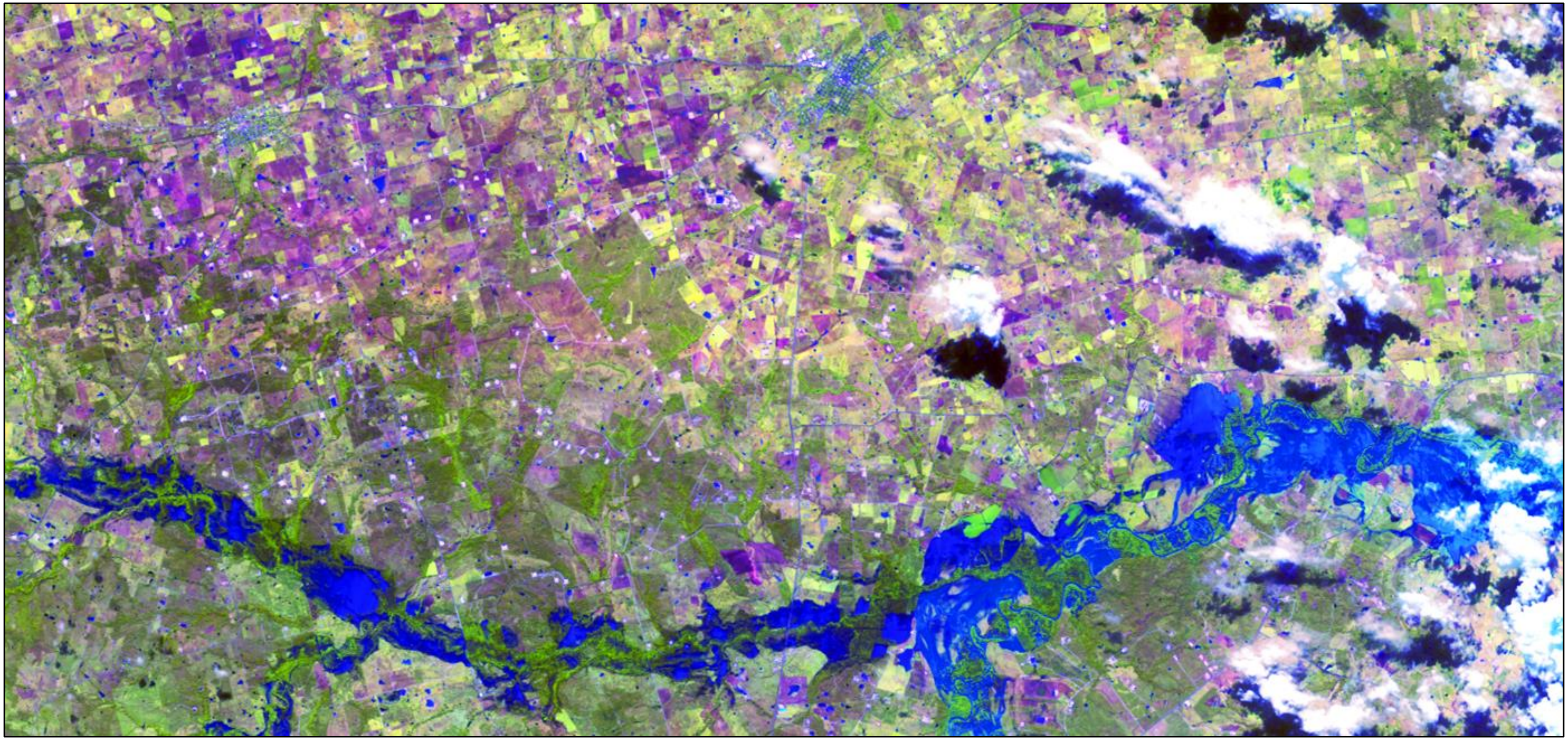
May 28, 2015, EO-1 ALI True Color Image

Wolf Volcano, Galapagos Islands



May 28, 2015, EO-1 ALI False Color Image

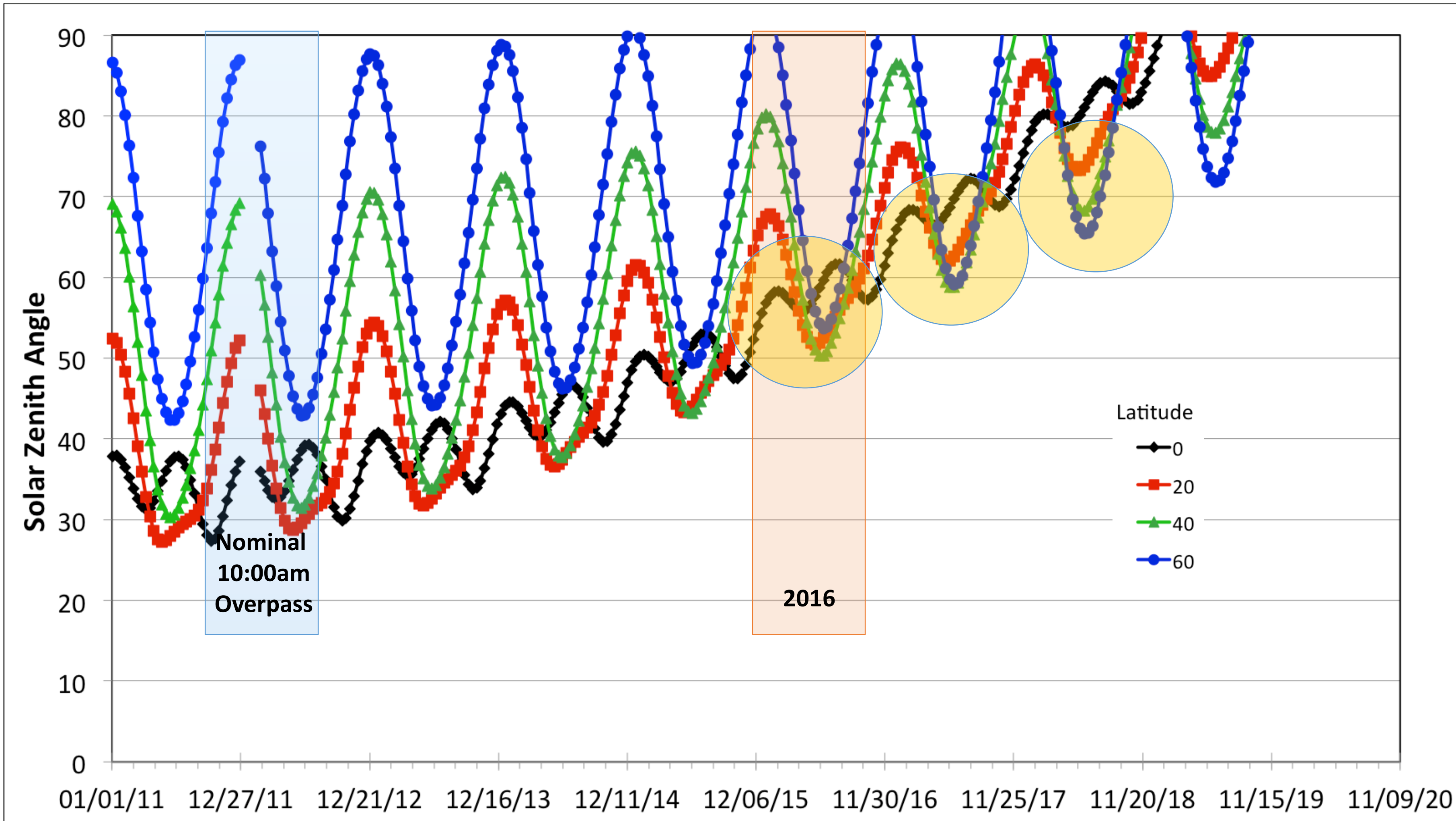
Flooding in Cuero, Texas



May 27, 2015, EO-1 ALI False Color Image (B8, B6, B4)

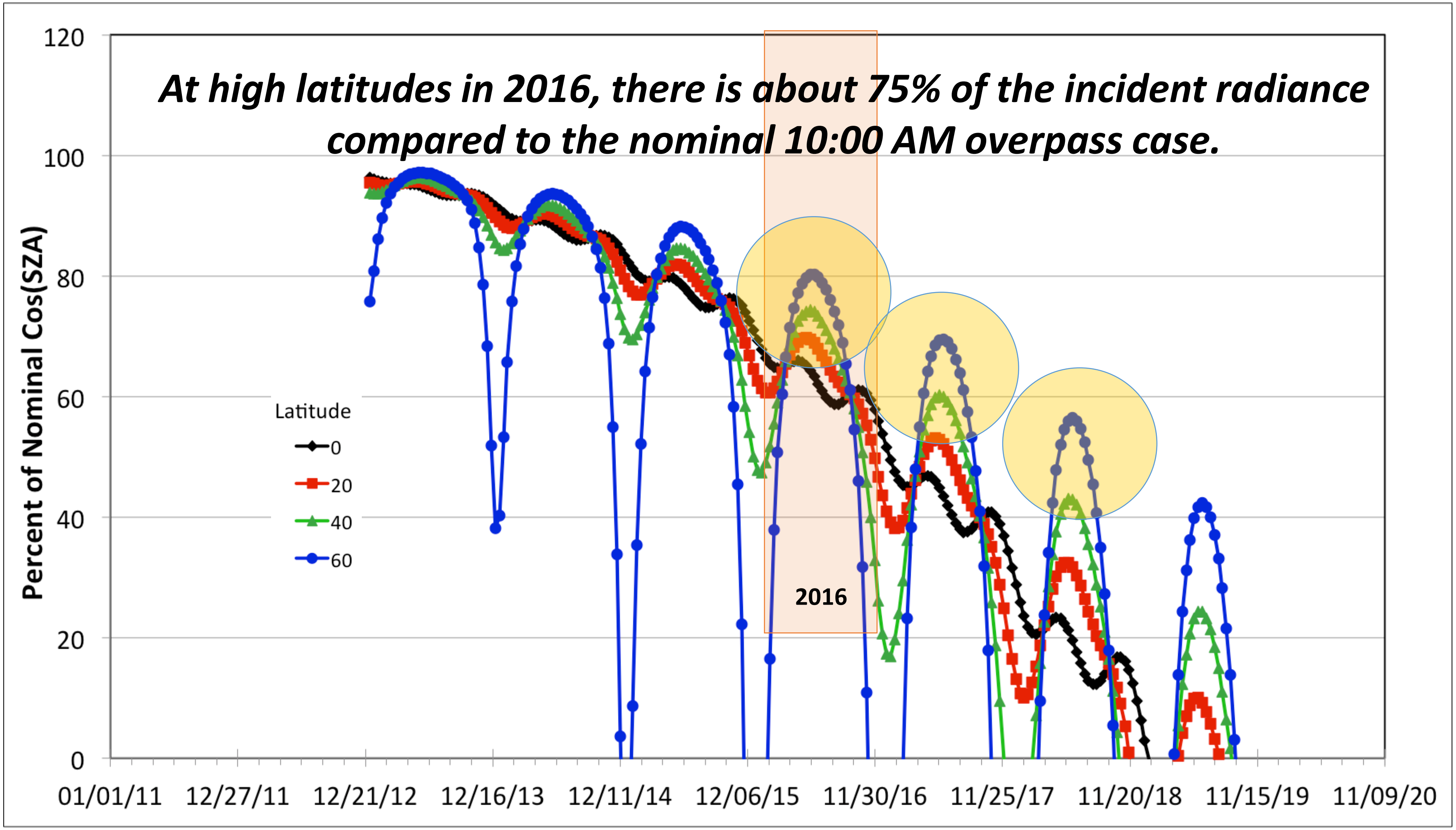
Solar Zenith Angle at EO-1 Overpasses

Lines represent SZA at overpasses for different latitude bands



Fraction of Cos(SZA) Compared to Nominal at EO-1 Overpass

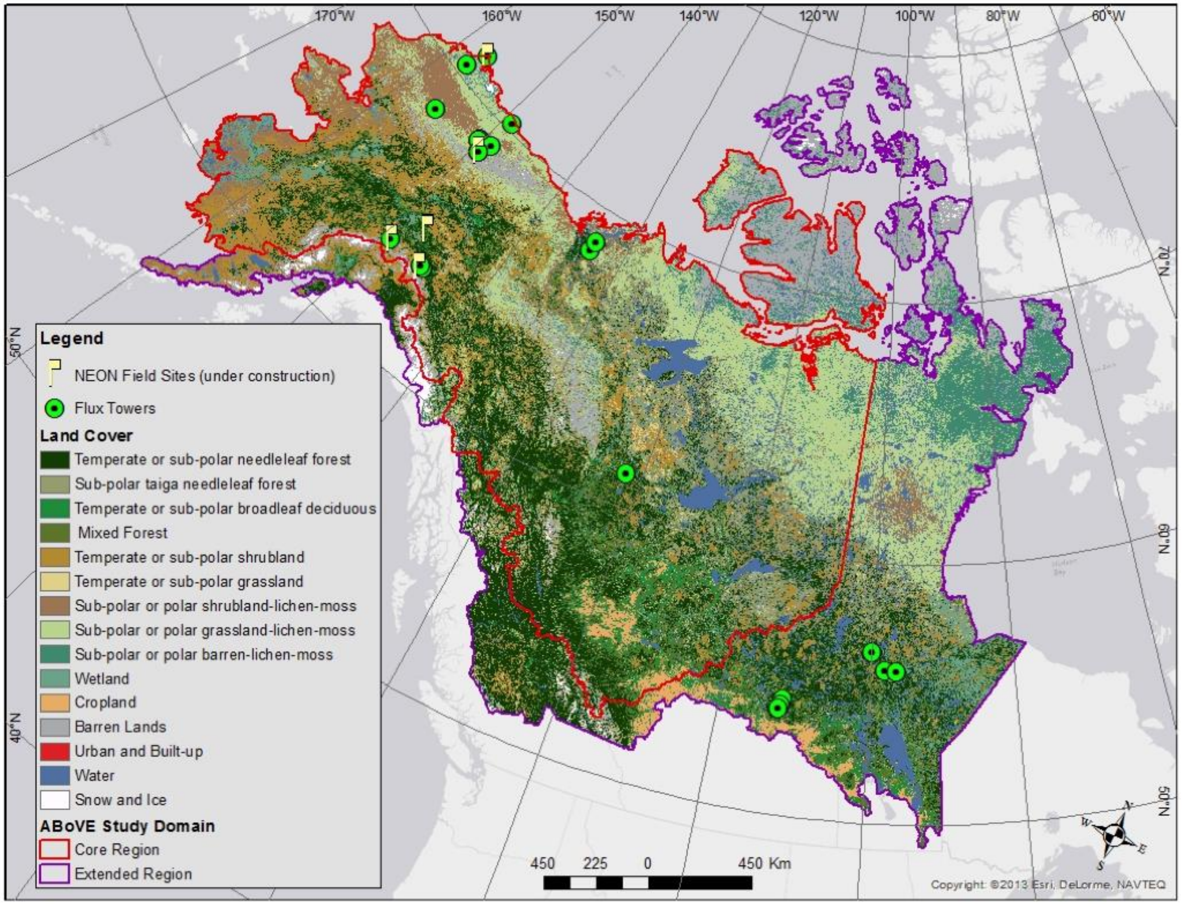
This fraction is the surface energy compared to the nominal surface energy for a given time and location.



EO-1 and Arctic-Boreal Vulnerability Experiment (ABoVE)

ABoVE is a NASA Terrestrial Ecology field experiment to study the vulnerability and resilience of ecosystems and society to environmental change in the Arctic and boreal region of western North America.

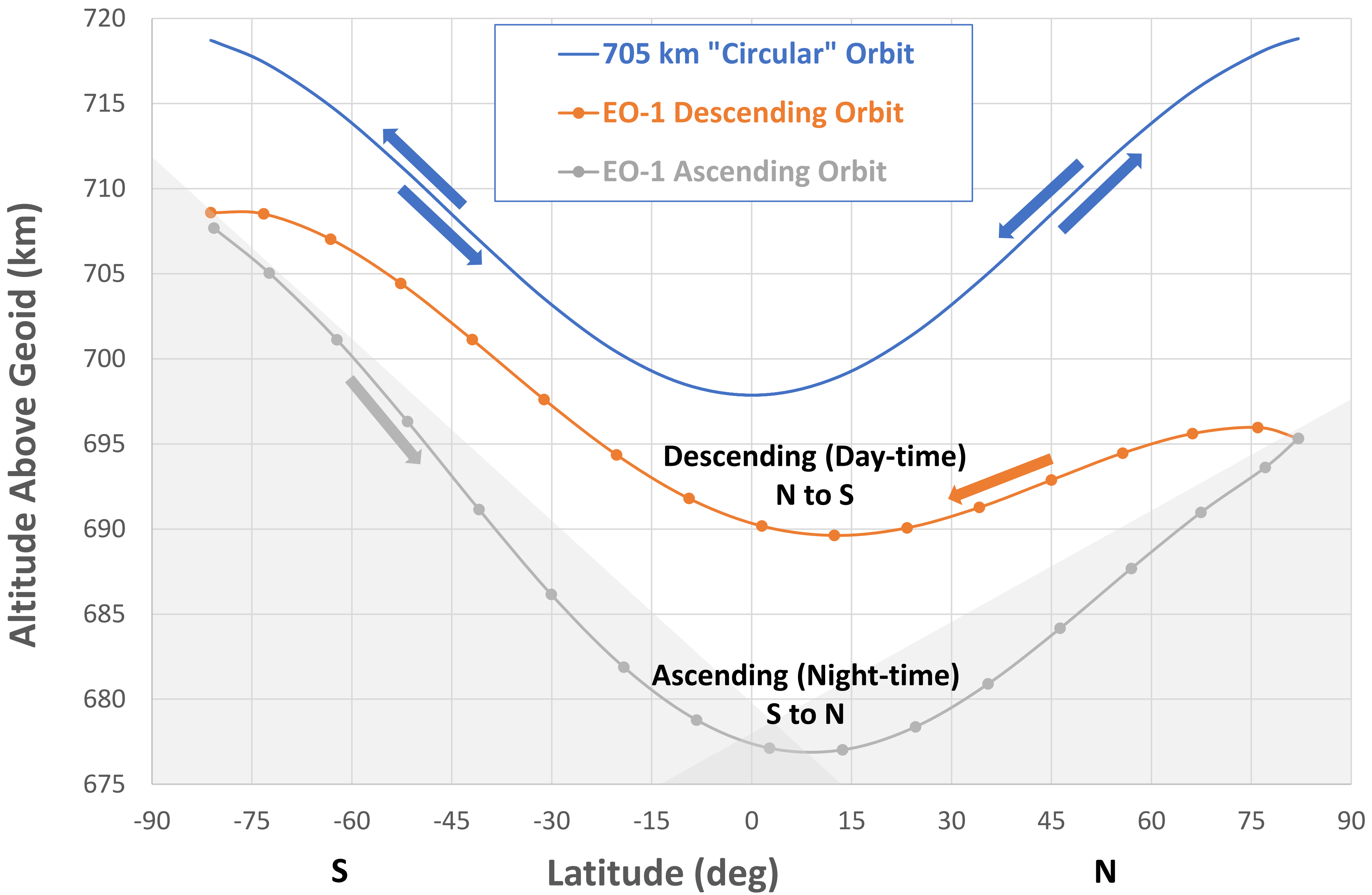
- The first full year of field activities is planned for 2016.
- Aircraft operations will not start until 2018.
- Changes in solar elevation angles at EO-1 overpass times are less affected at high latitudes, making EO-1 still useful for ABoVE.



Change in Orbit

- EO-1 is no longer in a 705 km "circular" orbit.
- The daylight altitude is still about 695 km.
- Therefore, the viewing geometry is substantially unchanged.

EO-1 Altitude as a Function of Latitude
(for the first orbit on January 4, 2015)



We Now Acquire All Images and Achieve Band Co-registration by Adjusting ALI Frame Rate

Area Near Israeli Oil Spill

A previously rejected acquisition is obtained with newly developed ALI Sampling Rate Algorithm

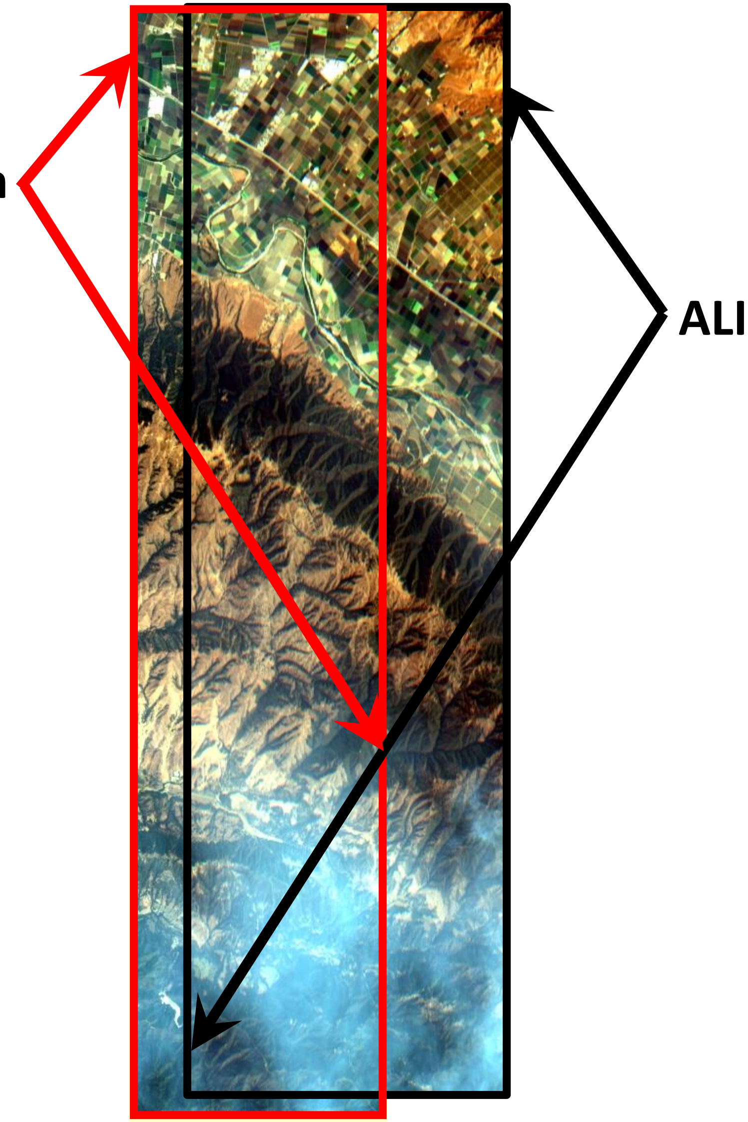
MS R-G-B Bands

We Now Acquire All Images and Achieve Band Co-registration by Adjusting ALI Frame Rate

We can continue to use EO-1 productively for…

Support of NASA's HyspIRI and Sustainable Land Imaging (SLI) Initiative

Hyperion can be used to *synthesize* multi-spectral bands (ALI, OLI, ETM+, MODIS, VIIRS). Several techniques, including convolution and spectral weighting, are being evaluated. Simultaneously obtained ALI bands provide a direct comparison to measure success.



A Hyperion-ALI Composite Image

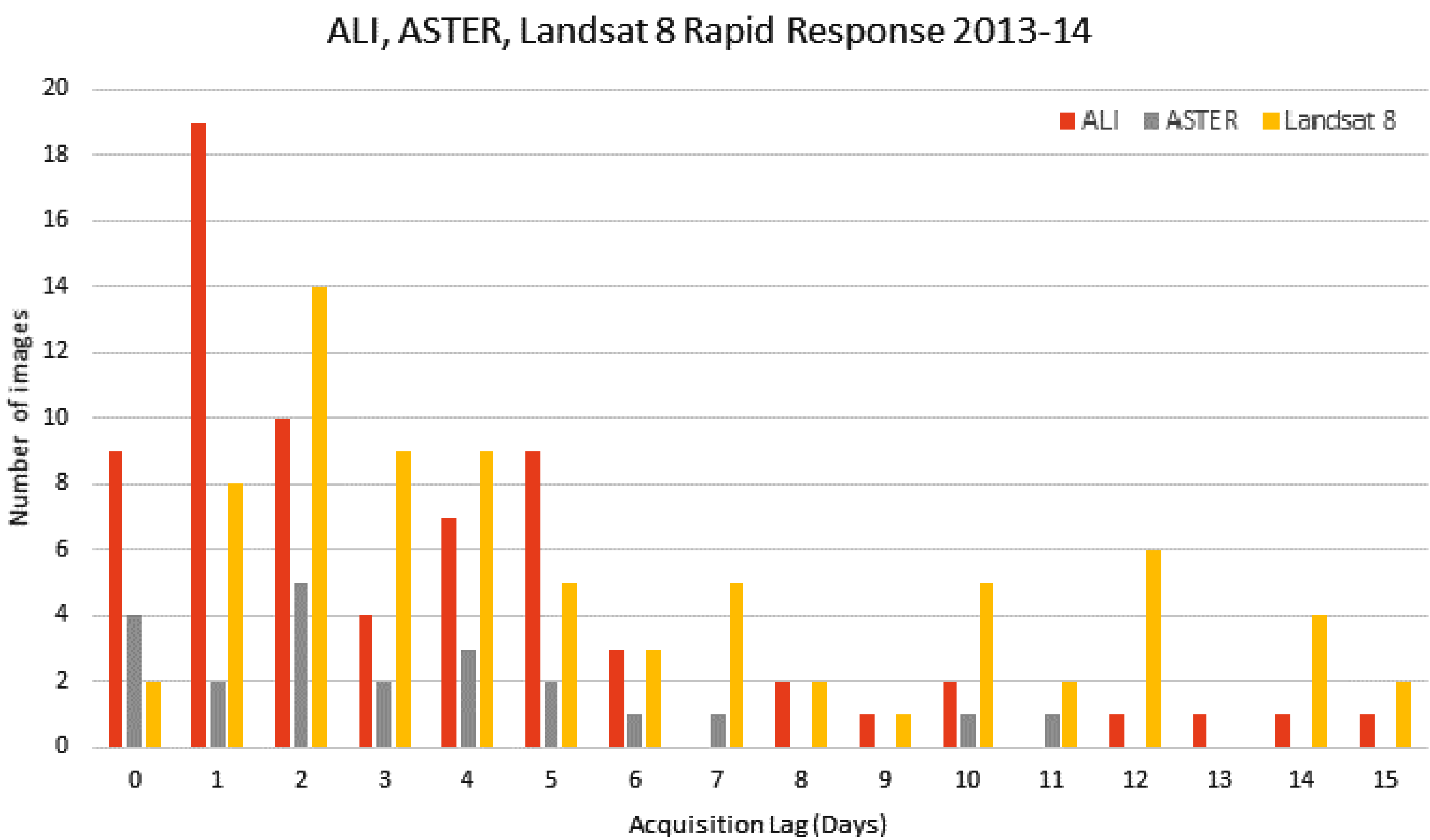
Reasons to Continue Collections: Importance/Usage of Data and Products

- EO-1 Disaster coverage directly benefits international end users (local, national, regional, and international).
  - EO-1/ALI images provide High Value to US agencies (SERVIR, Forest Service, NOAA, Coast Guard) and international partners.

- Night-time wildfire/volcano coverage can be continued to support existing and new projects.

- Tremendous return on investment (low cost/high utility)
  - Global sampling at the same cost per year as an aircraft program.
  - Contemporaneous collects with aircraft and ground campaigns.
  - New automated tools make it easier to access and use EO-1 data and data products.
    - Land cover products utilized in Science and Applications (e.g., albedo, biophysical parameters).

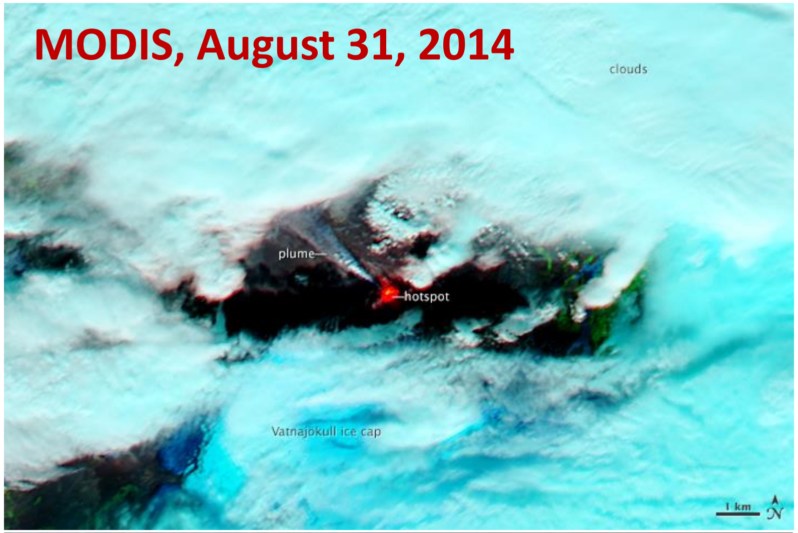
EO-1 Provides Rapid Response

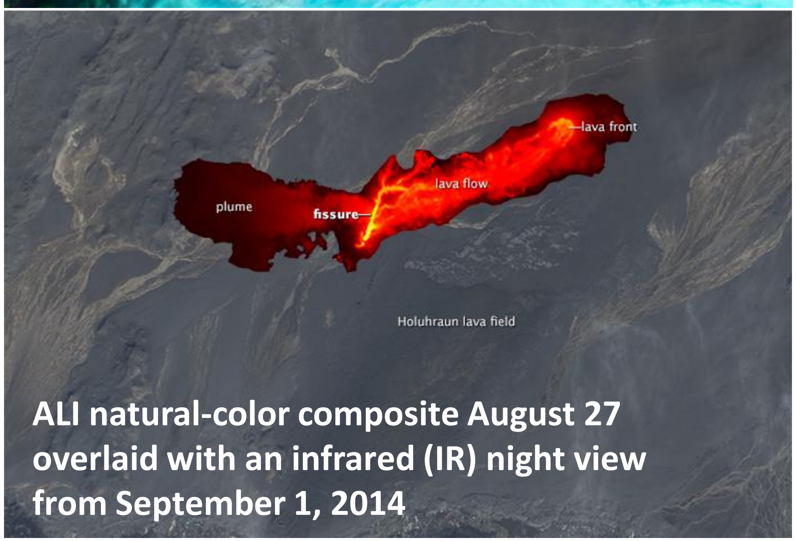


- Lag time from occurrence of a disaster event until satellite images are being taken by EO-1/ALI, Terra/ASTER, and Landsat-8/OLI.
- **EO-1 (red bars) observes disaster events 1-2 days earlier than ASTER and Landsat-8, and can provide a second observation within 3-6 days.**

[Data from Earth Observatory]

EO-1 Complimenting Landsat 8 and MODIS





When the Villarrica Volcano erupted, EO-1/ALI was able to acquire an image on March 5, 2015 – five days before the next Landsat 8 overpass.

EO-1 ALI night-time image of the Vatnajokull volcano, complementing MODIS (top).

Hyperion for CEOS Albedo Products

March 18, 2015

Dr. Middleton,

We hope the new information on EO-1 sensor capabilities and stability will be sufficient to enable continued EOS acquisitions through 2017. **We are actively using Hyperion data to aid us in our efforts for long term data continuity for albedo and nadir reflectance products from both the Terra and Aqua MODIS and the Suomi-NPP VIIRS.** We aim to provide three broadband values (visible 0.3–0.7 µm, NIR 0.7–5.0 µm, and shortwave 0.3–5.0 µm) across the instrument archives and therefore require sensor specific narrow to broad band conversion coefficients. **We have been utilizing series of atmospherically corrected Hyperion scenes (snow and snow free) across the globe to derive and update these conversion values.** These broadband values can then be used in cross sensor evaluation efforts and comparisons with tower radiometer data. In addition, values for MISR and MERIS are also have been devised and are aiding in efforts to couple together data from those instruments with MODIS and VIIRS and generate long term multisensory records. As we approach the start of the Sentinel-2 era later this summer, there are new requirements to generate estimates to couple those data with the Landsat-8 data. Unlike laboratory spectral data of pure surface materials, the **Hyperion images uniquely reflect the true spectral characteristics of a 30m pixel at remote sensing scales. Therefore , as both satellite albedo product producers, and as members of the international CEOS/WGCV/Land Product Validation (LPV) project, we are anxious for the continued availability of the 220 channels of Hyperion hyperspectral imagery to aid in evaluation and effective utilization during this early post-launch phase**.

Sincerely,

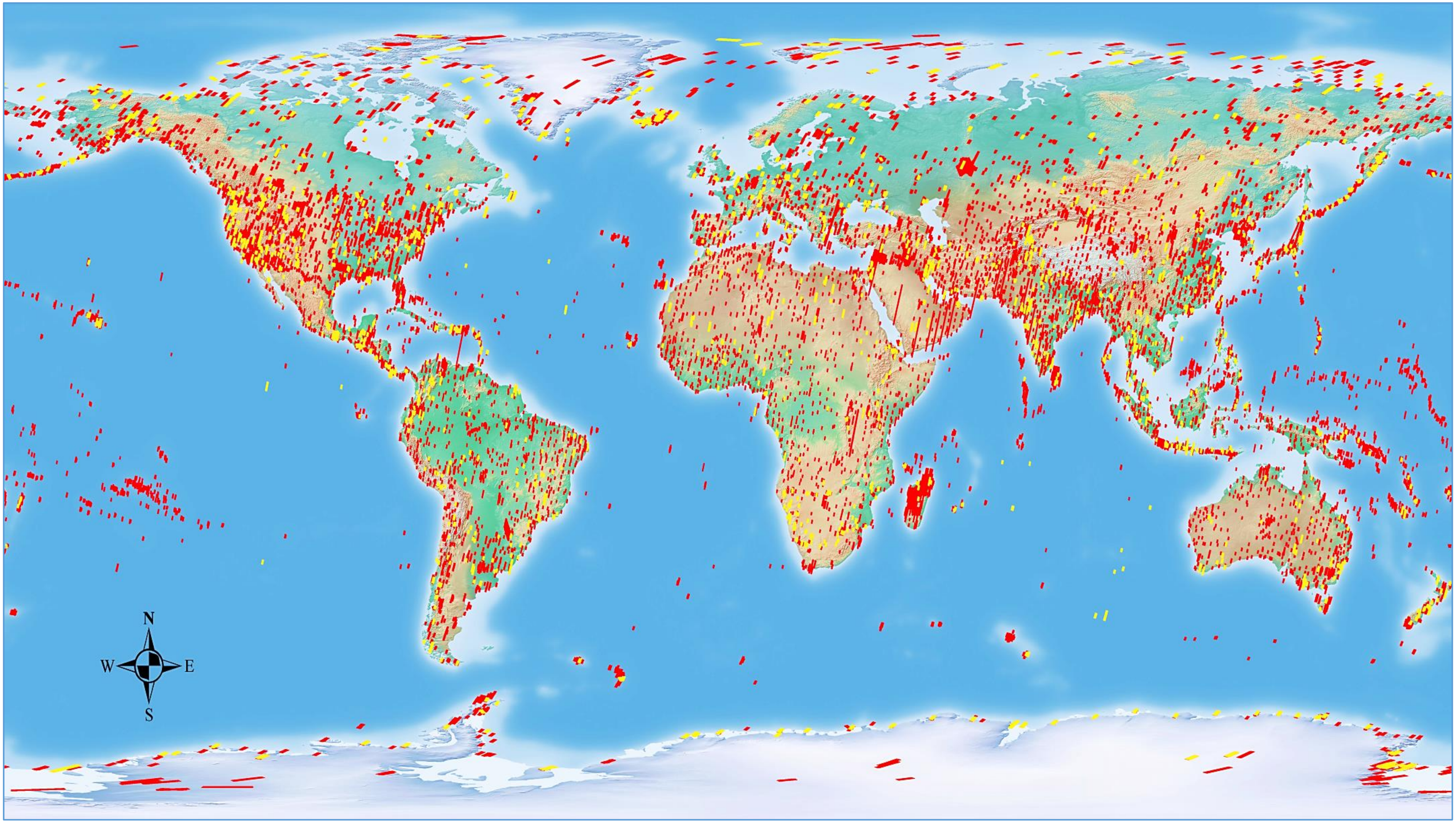
Crystal Schaaf CoChair, CEOS/WGCV/LPV Radiation Subgroup

Professor, School for the Environment, University of Massachusetts Boston,

EO-1 Acquisitions Since Launch

>79,000 (12/2000 – 2/2015)

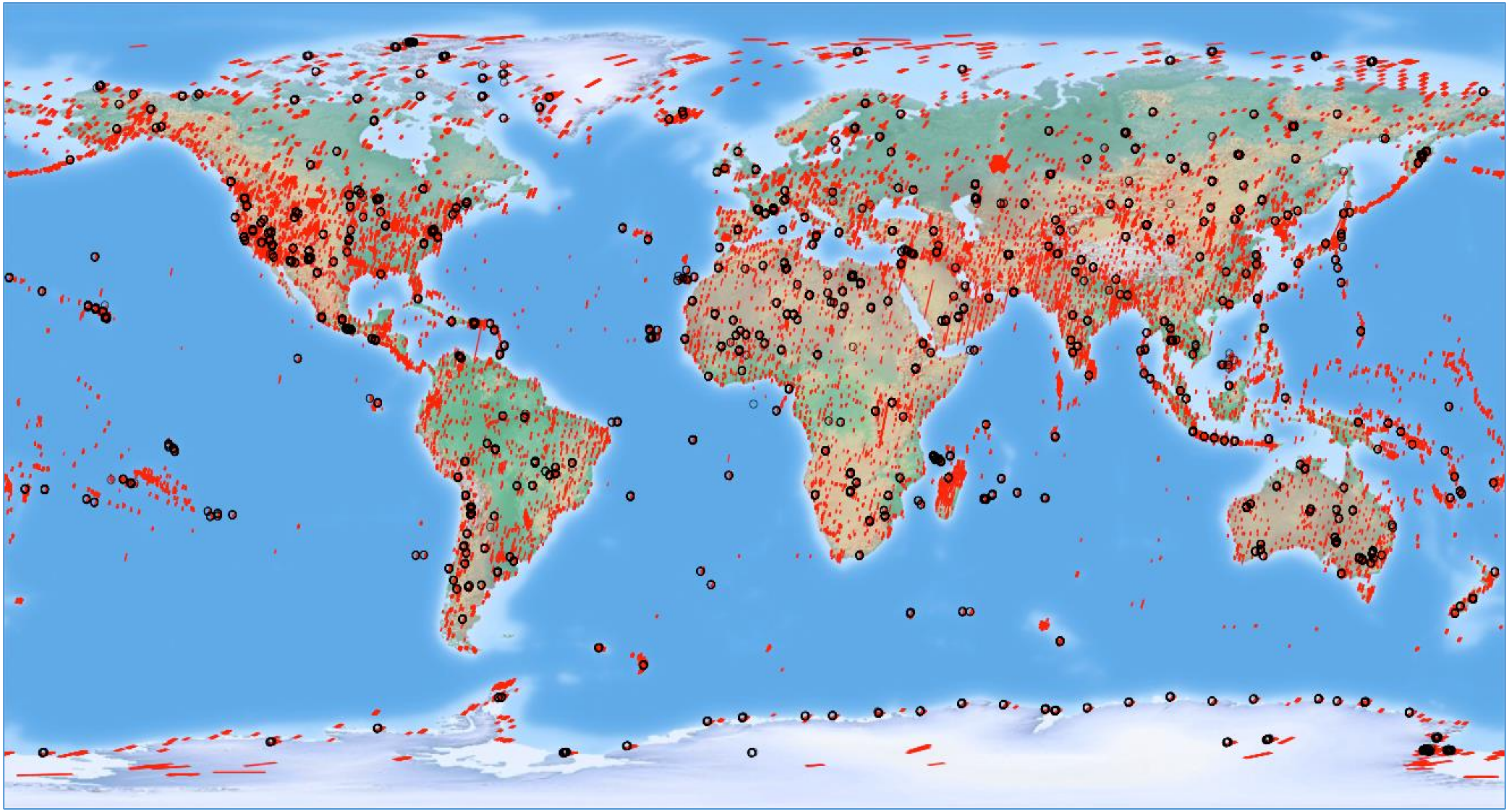
EO-1 provides global sampling with a significant, unique historic data record.



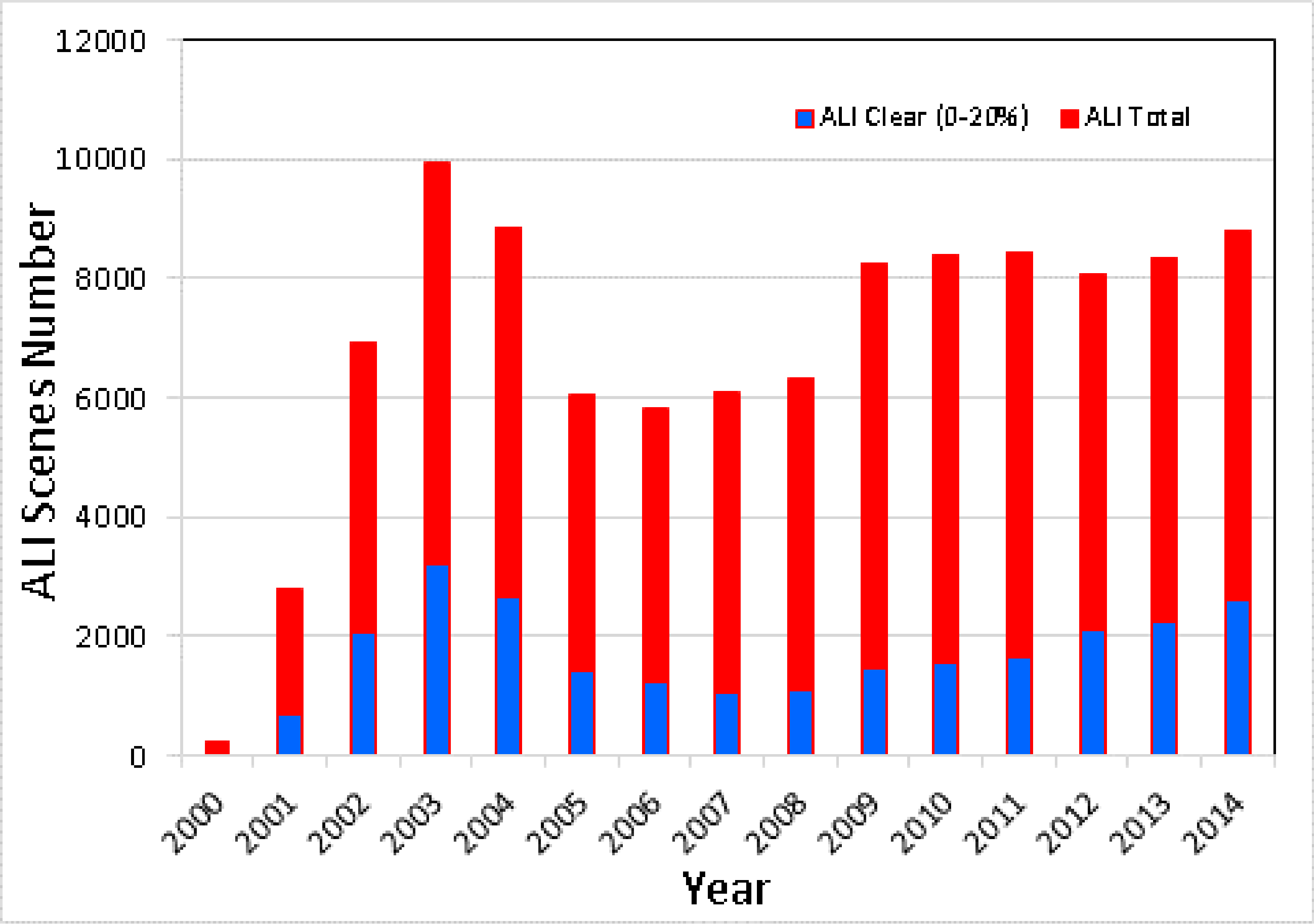
Collects Since 2013 Are Outlined in Yellow > 13,000 each

EO-1 Locations Having >10 Acquisitions

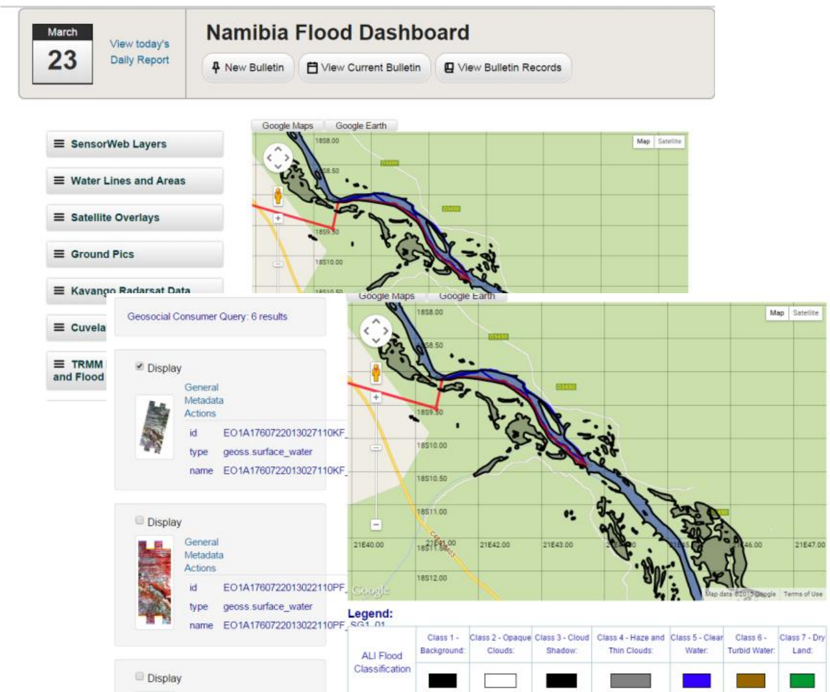
>79,000 (12/2000 – 2/2015)



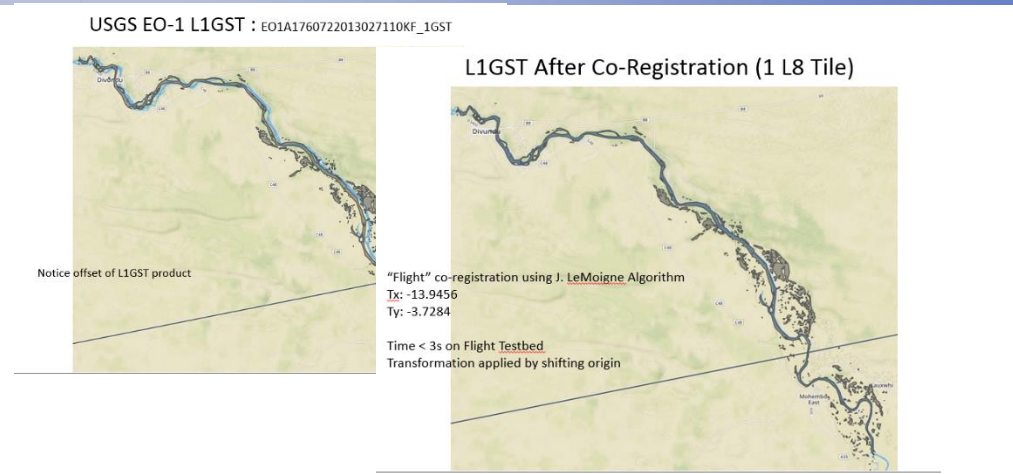
EO-1 Acquisitions by Year



EO-1 Data Distribution and Processing Innovations

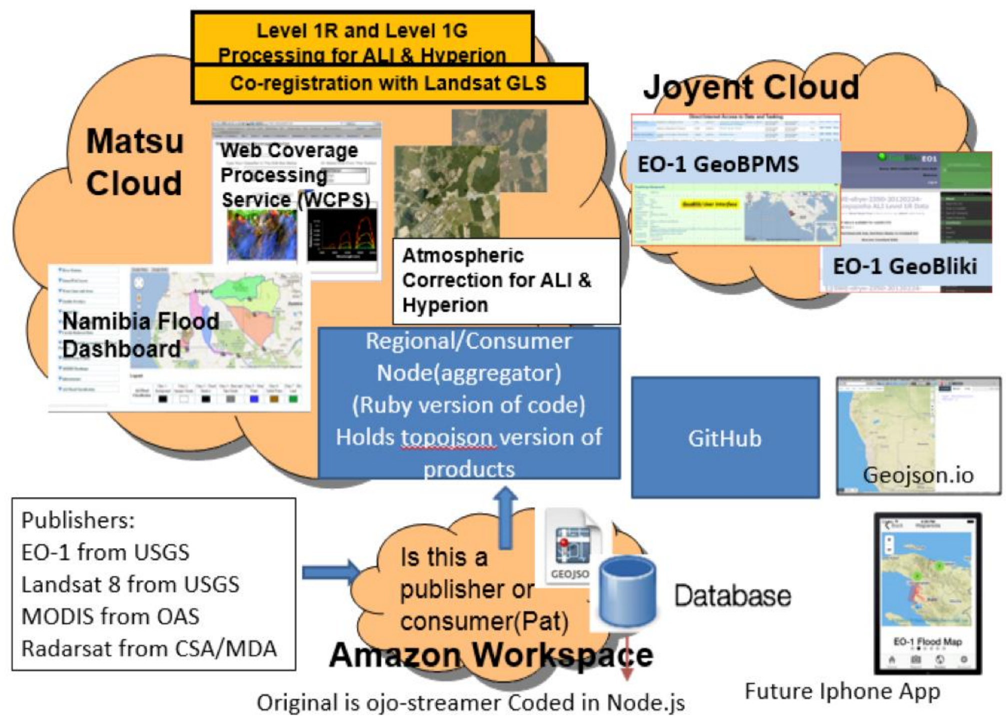


GeoSocial Data Distribution with Publishers/Consumers/Topojson

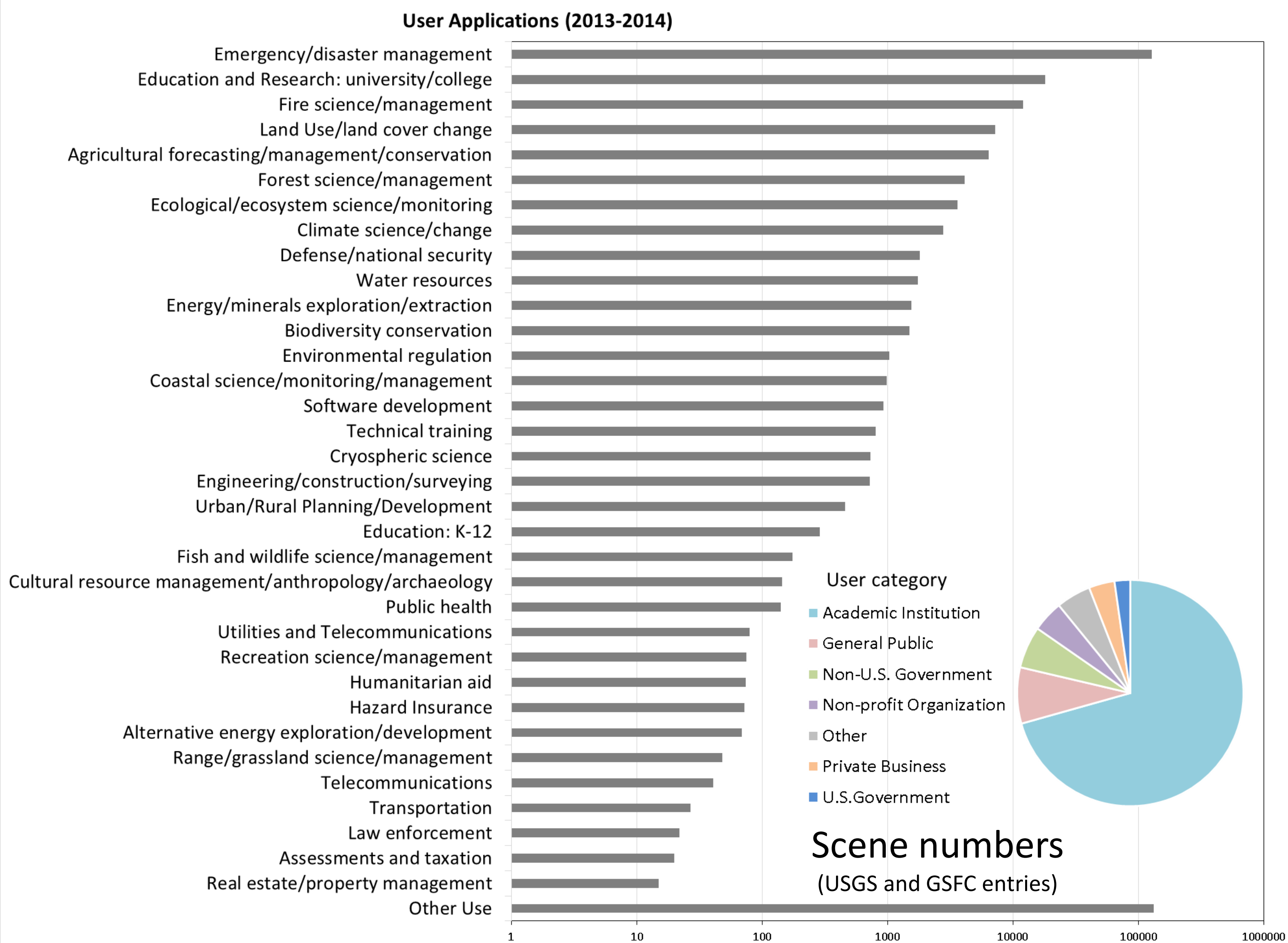


Rapid Online Co-registration of EO-1 with Landsat 7 GLS

Unique multi-cloud operations architecture for efficient satellite control and data processing



EO-1 User Applications

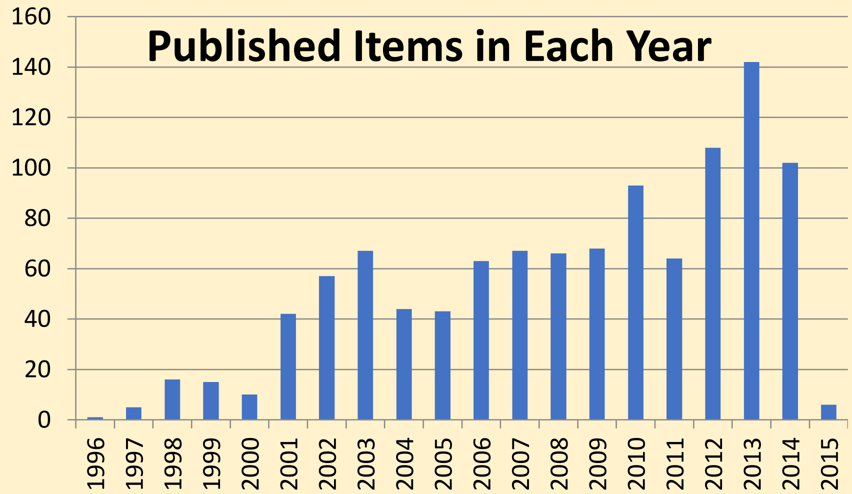


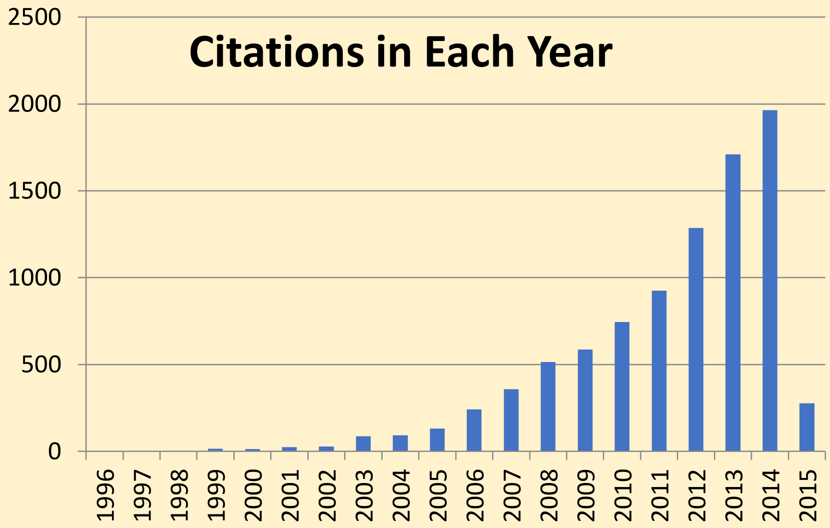
Why Extend the EO-1 Mission?

EO-1

a still Healthy and Productive Observing System

- **1078 publications and 9008 citations (1996-2015).**
- **795+ universities, government agencies, and organizations: NASA and affiliates ~20%, Chinese Academie of Science ~8%.**
- **67+ Countries: USA ~49%, Peoples R. China ~19+%.**

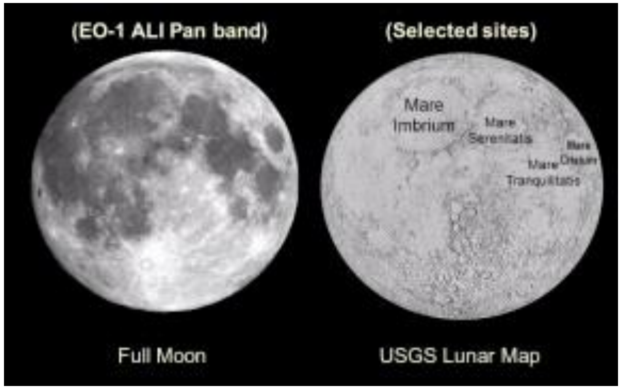




Current Lunar Acquisitions

Current Lunar Collections

- **Once per month since launch, EO-1 Hyperion and ALI have each collected nominal 8X oversampled images of the moon at *fixed phase angle of ~8 degrees* (<1 day after full moon).**
  - **The monthly integrated ALI and Hyperion lunar responses are normalized with the USGS RObotic Lunar Observatory (ROLO) lunar model to maintain the EO-1 lifetime trends.**
  - **This will continue to the end of the mission.**

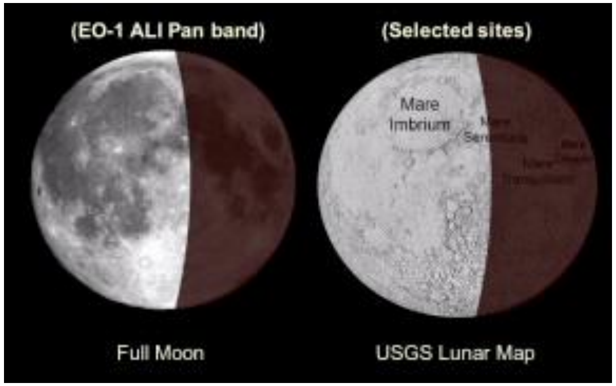


- A new lunar acquisition strategy was initiated in late 2013 which enables Hyperion observations of radiometrically stable lunar features at a slower pitch rate – at fixed phase angle of ~8 degrees.
  - The resulting lunar images are 32X oversampled to provide higher spatial resolution in the along-track direction.

Proposed Lunar Lab

Plan for Lunar Lab (after Earth observations cease)

- **Dedicate EO-1 to lunar measurements to maximize lunar samples.**
  - **EO-1 will capture the lunar irradiance signal across *all phase angles*.**
  - **This data set will reduce uncertainty of the current lunar spectrum and help with improvement/development of lunar models.**
- ***This Lunar Lab will also provide a bridge to put Earth science sensors that image the moon at different phase angles on the same radiometric scale.***
  - **If the EO-1 Lunar Lab is in operation long enough to overlap CLARREO Pathfinder (2019), coincident lunar measurements will allow the entire EO-1 ALI and Hyperion data set to be put on the CLARREO radiometric scale along with the other sensors imaging the moon in the past, present and future.**



- **The continuous spectral coverage of EO-1 Hyperion is another key aspect of this approach: the spectral channels of multispectral broad band sensors operating in the solar reflective spectrum can be emulated from Hyperion channels.**

Proposed date for Lunar Lab start 10/2016 or 10/2017

Benefits from Extending the EO-1 Mission

- **Satellite Community**
  - Prototyping and cal/val for NASA and NOAA
  - CEOS/WGCV - characterization of semi-invariant sites
  - Prototyping and cal/val for HyspIRI, ESA/SENTINEL-2, DLR/EnMAP and IEEE/ISIS

- **Terrestrial Ecology and Land Cover Research**
  - Product cal/val: LCLUC, Carbon Cycle, CEOS/LVP, ABoVE, Geology and Coastal/Aquatic characterization

- **Disaster Management Community**
  - Domestic (US Forest Service, NOAA, USGS etc.)
  - International (UN, World Bank)

- **Data Continuity for SLI and CEOS via EO-1 Lunar Lab**
  - If EO-1 Lunar Lab is in operation to overlap CLARREO Pathfinder (2019), the coincident lunar measurements will allow the entire EO-1 ALI and Hyperion archive to be put on the CLARREO radiometric scale, along with the other sensors that have and will image the moon.

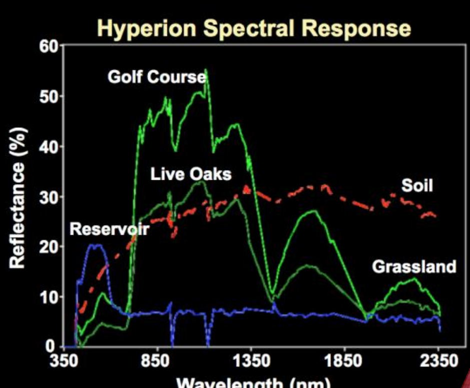
2015 NASA Senior Review
Earth Observing-1 (EO-1) Proposal

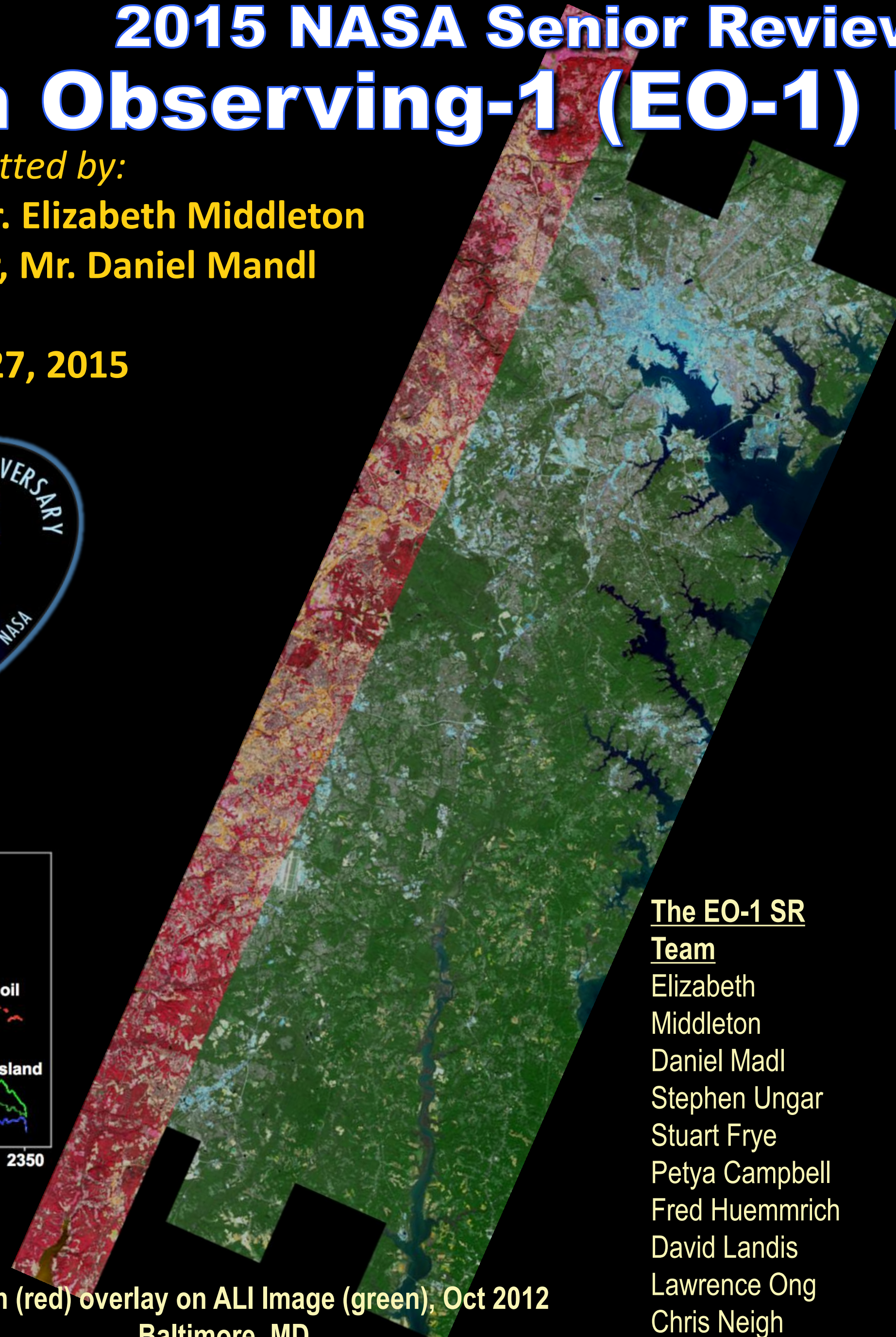
Submitted by:

Mission Scientist, Dr. Elizabeth Middleton

Mission Manager, Mr. Daniel Mandl

April 27, 2015





Hyperion (red) overlay on ALI Image (green), Oct 2012
Baltimore, MD

The EO-1 SR Team

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Petya Campbell
Fred Huemmrich
David Landis
Lawrence Ong
Chris Neigh

ALI False-Color Image, 2014 San Miguel Volcano

ALI True-Color Image, 2013 Bird Sanctuary in India

ALI False-Color Image, 2013 Fire in Australia