Sustainable Land Imaging - Technology

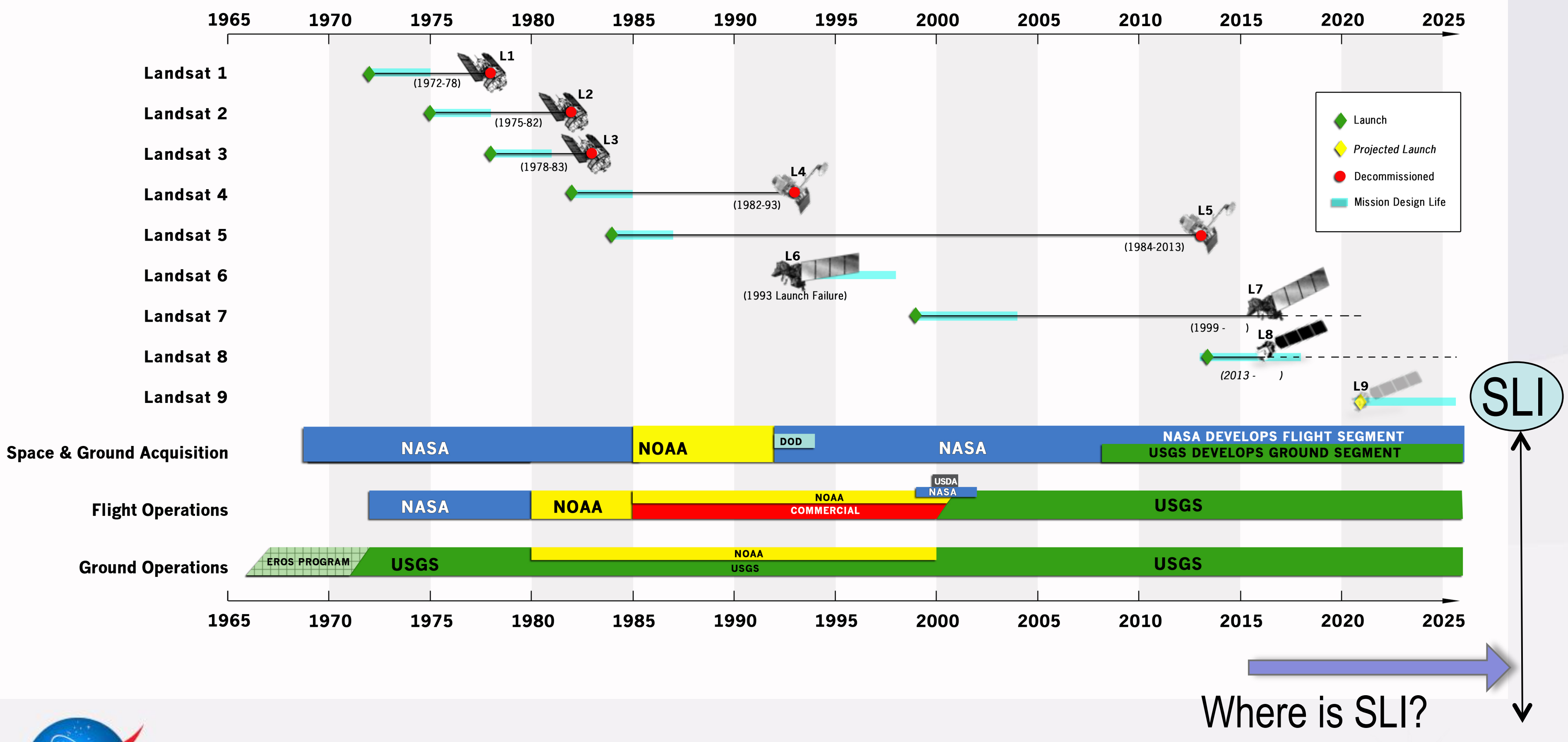
(SLI-T)

Earth Science Technology Forum

June 16, 2016

Robert Connerton
Sachidananda Babu
SLI-Technology Program
Earth Science Technology Office

Landsat Legacy



What is Landsat?

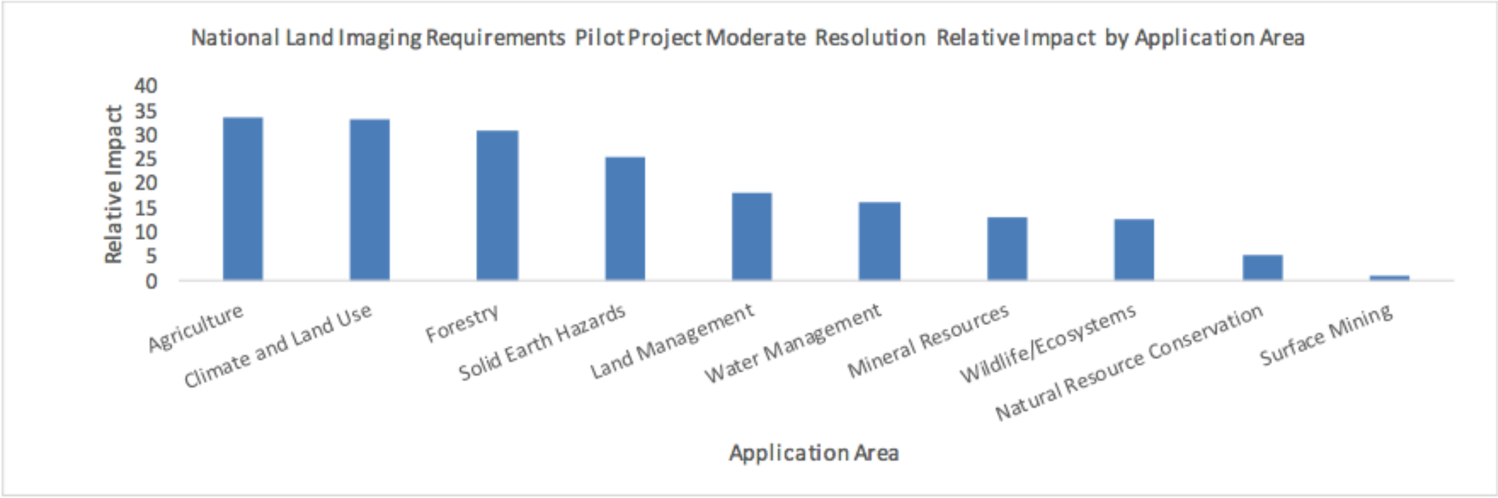
Landsat is our longest-lived series of land imaging satellites, providing a 43+ year archive of natural and human-induced changes to the global landscape

Multi-spectral coverage in VNIR-SWIR-TIR
-> to map surface composition & temperature

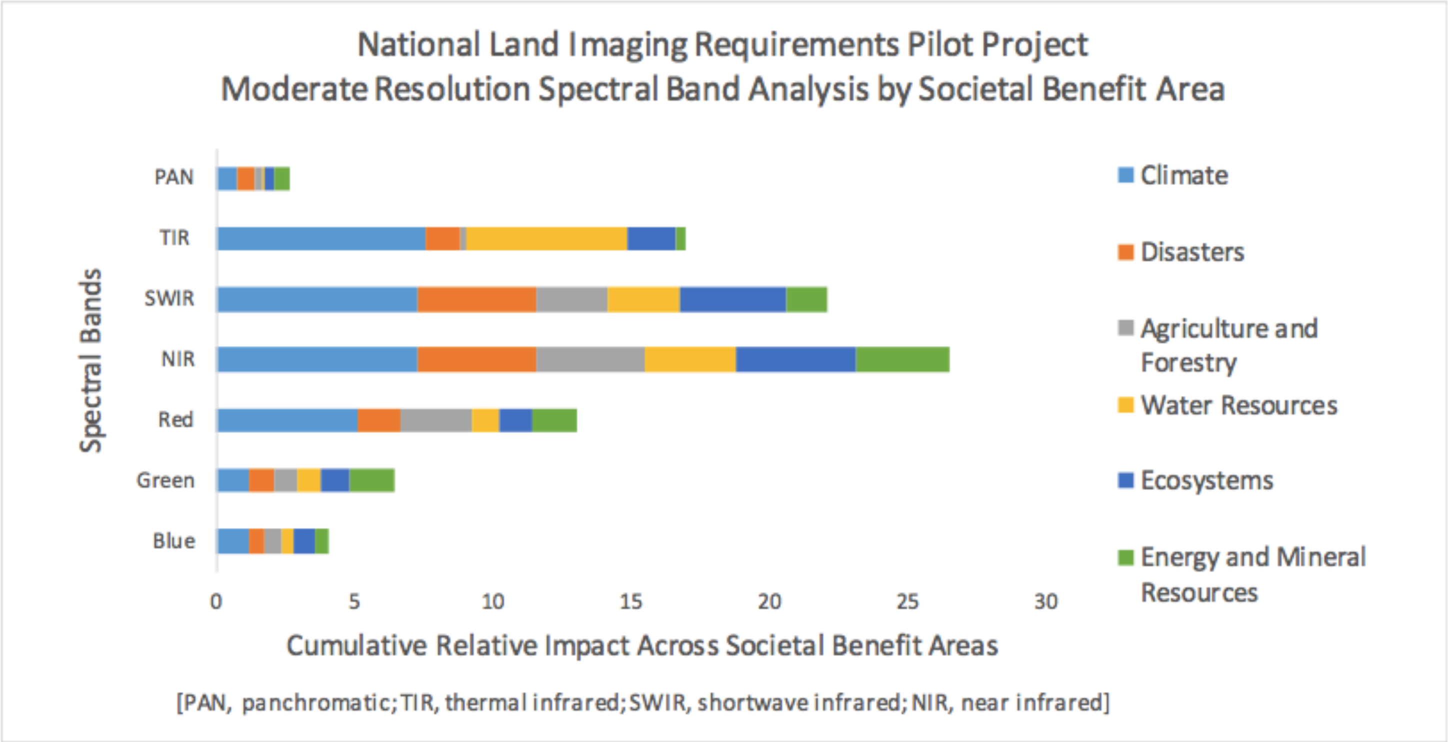
15 / 30 / 120 meter spatial resolution
-> to resolve human-scale land dynamics

16-day revisit frequency (8-days w/ two operational satellites)
-> global, seasonal coverage

Calibrated "science quality" data
-> to resolve long-term trends & retrieve biophysical variables



Common uses of Landsat Data

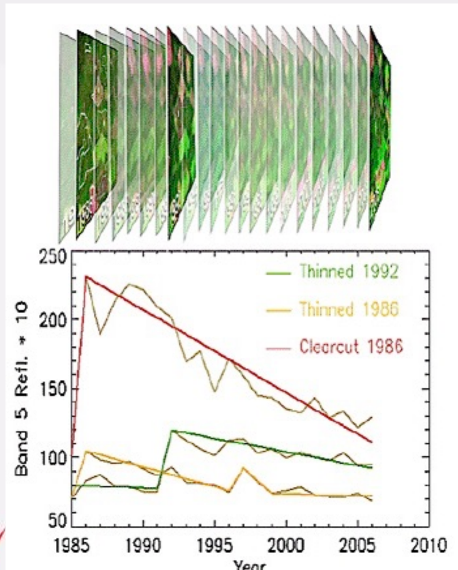


Common Uses of Landsat data:

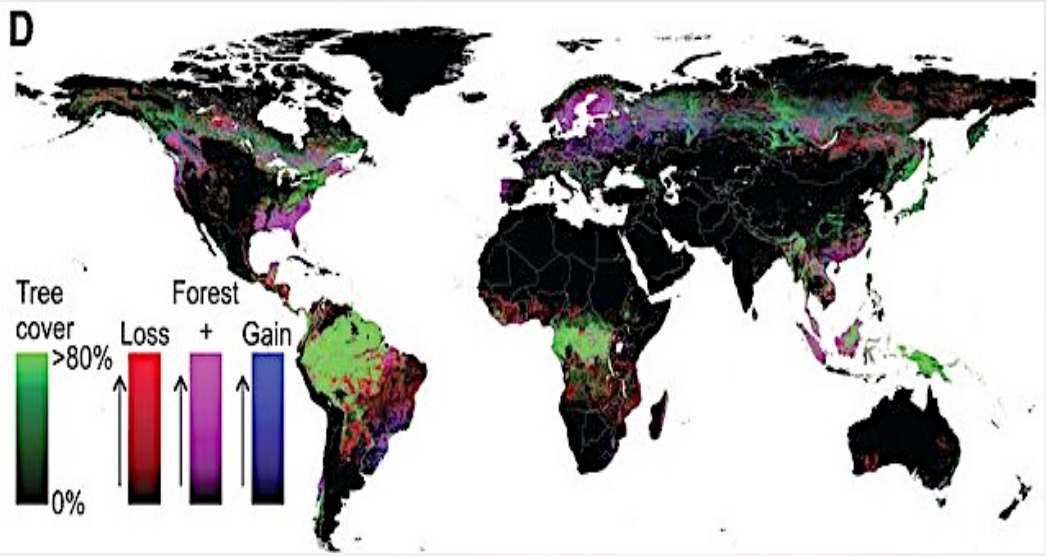
- **Agriculture and Forestry**
- **Regional Land Use Planning**
- **Mapping**
- **Fire/Disaster Management**
- **Land Use/Land Cover**
- **Water Resources Planning**
- **Global Change Science**
- **Flood Management**
- **National Security**
- **Ecosystem Monitoring**
- **Famine Early Warning**
- **Carbon Assessment**
- **Drought Monitoring**
- **Transportation Planning**
- **Coastal Mapping**

Landsat: "Backbone" of Land Observation

- Landsat remains the **most cited** land remote sensing system in the peer-reviewed scientific literature
- Opening of free USGS archive in 2008 ushered in new era of applications
  - Data downloads have increased by **orders of magnitude**
  - More accurate and reliable analyses; improved quality of decisions/findings
- New focus on leveraging **time domain**
  - *Inter-annual disturbance, compositional change, land use*
  - *Intra-annual phenology, vegetation condition, compositing*
- **Large area** coverage for continental land cover studies



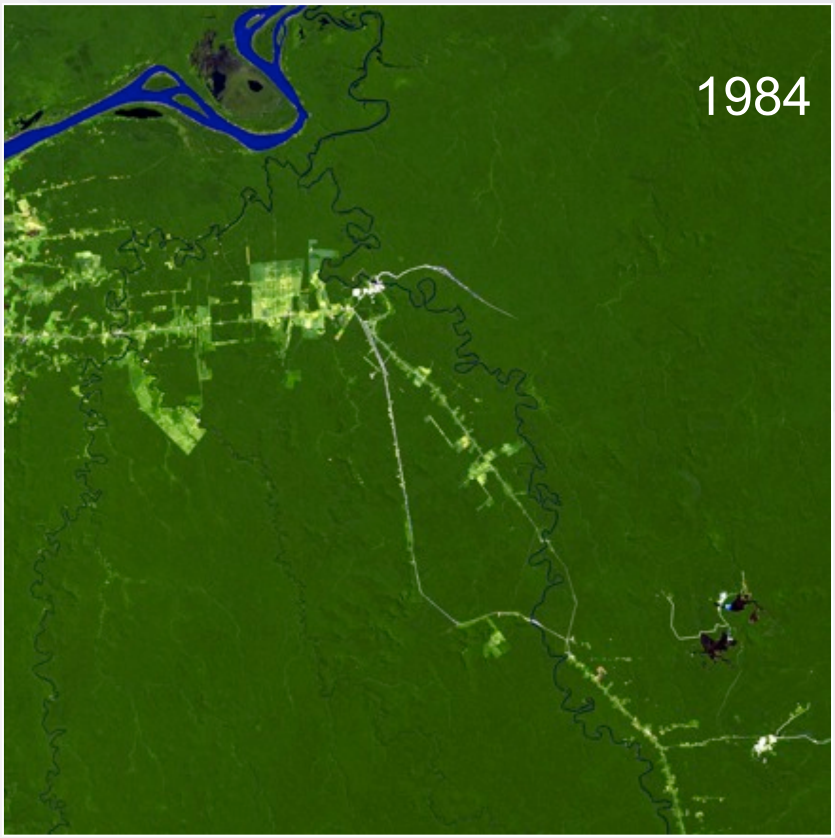
R. Kennedy, LandTrender disturbance algorithm



Hansen et al., Science 2013

Applications: Land Use Dynamics

Landsat provides our principal record of deforestation, urbanization, agricultural expansion, and other changes in global land cover/use

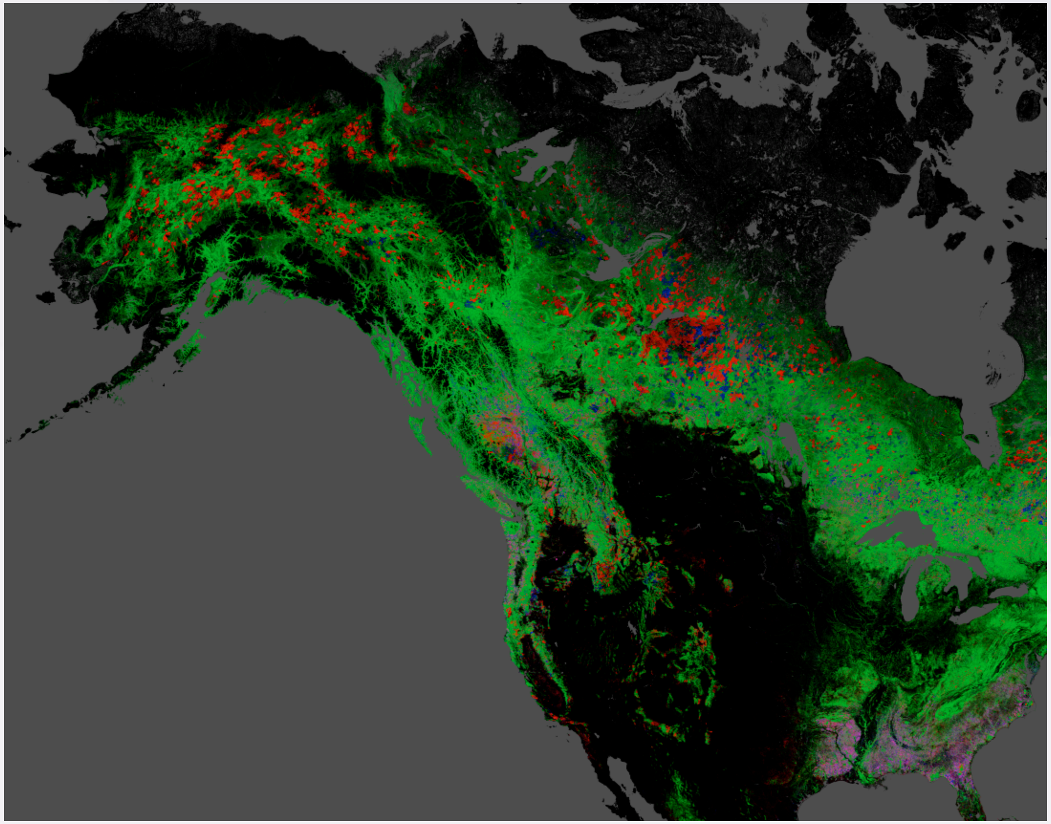


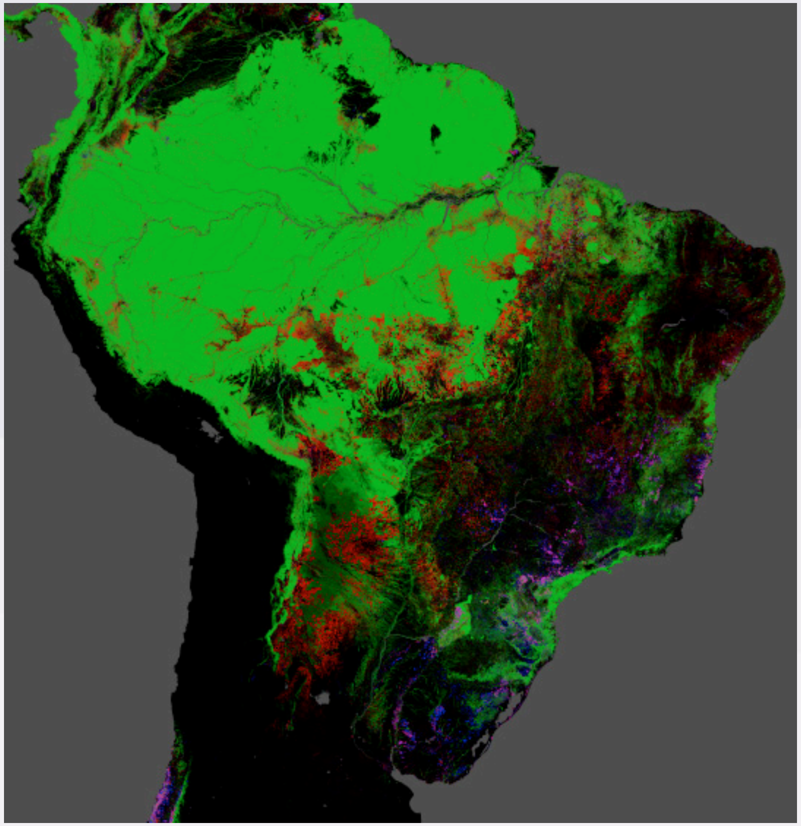
Deforestation around Samuel Dam on the Jamari River, Rondonia, Brazil

Global Products

"Landsat has been producing Big Data since before data was big"

– Robinson Meyer, The Atlantic

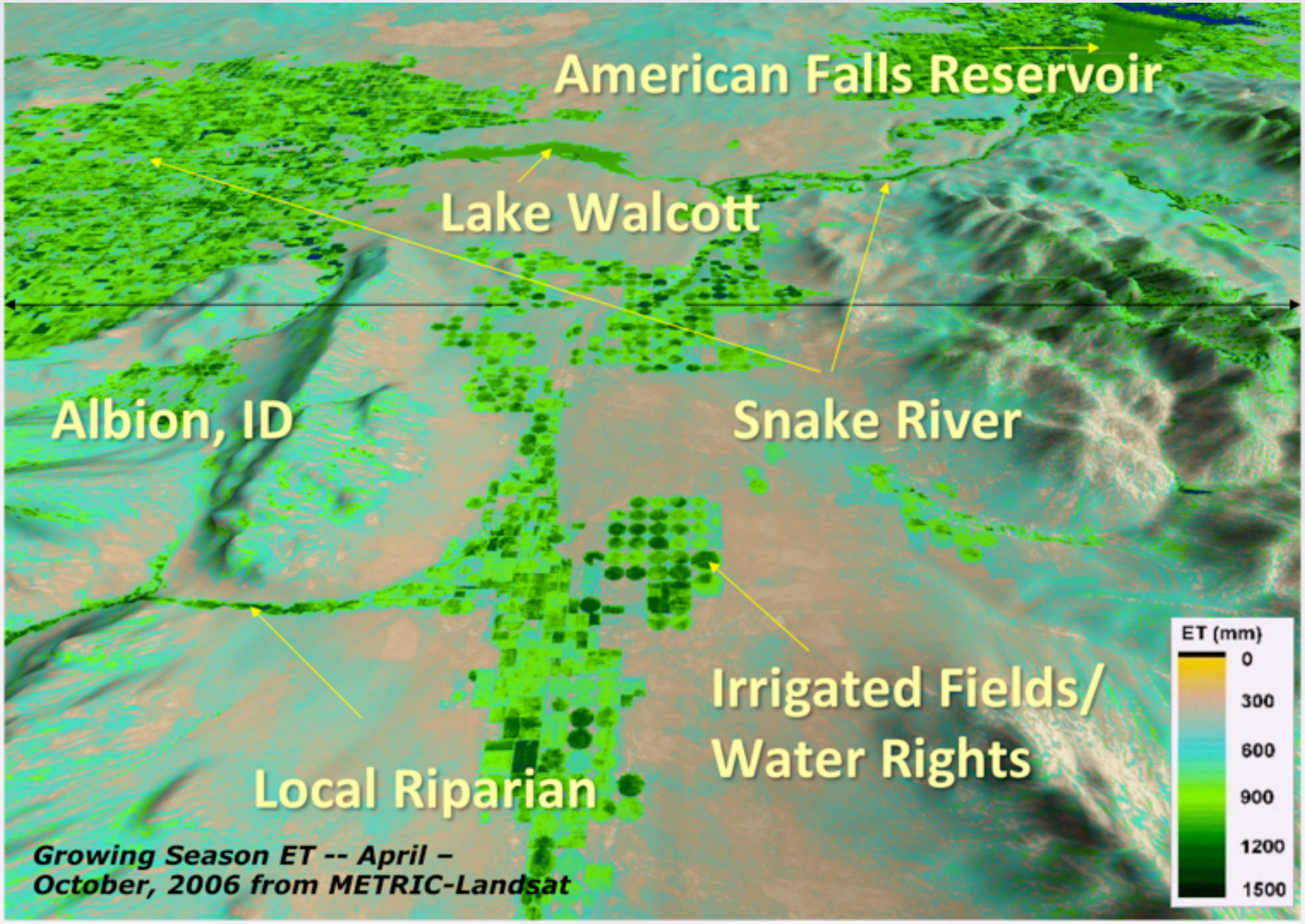




Hansen et al (2013) – global forest cover losses from 400,000 frames

Water Use and Evapotranspiration

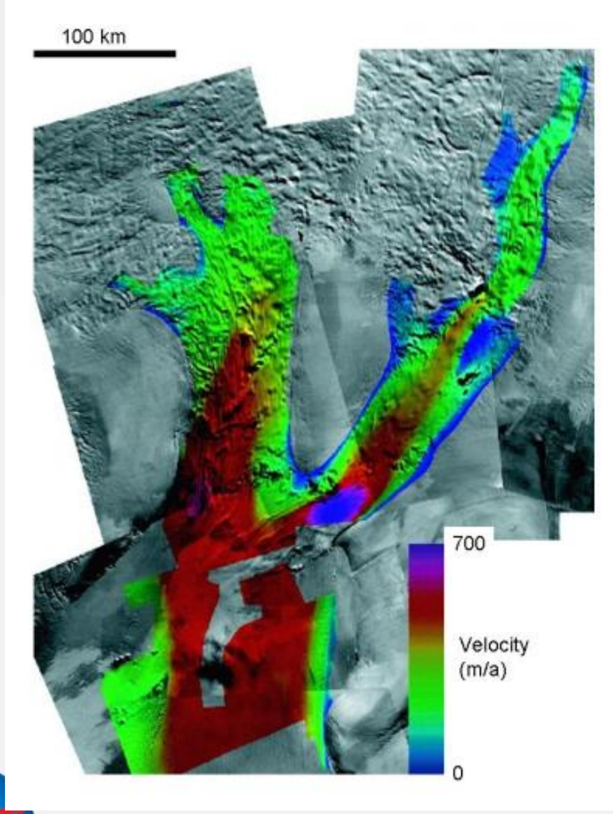
Landsat VNIR and TIR data are used to monitor consumptive water use by irrigated agriculture

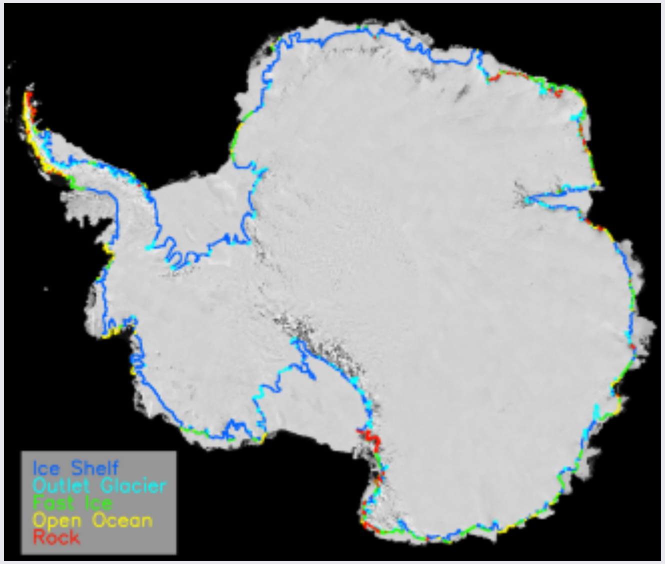


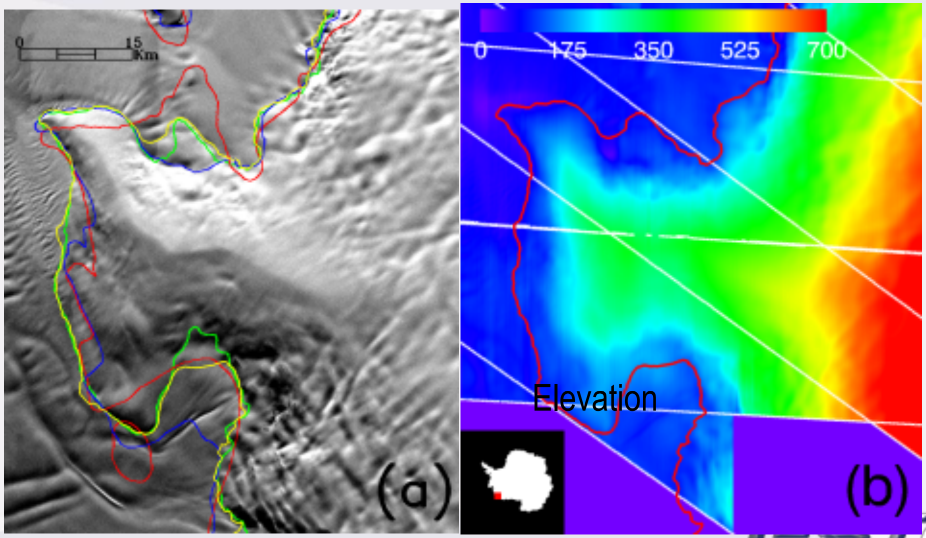
Glacier & Ice Sheet Monitoring

Unique information:

- Extent & change
- Velocity (feature change)
- Height (shading inclinometry)

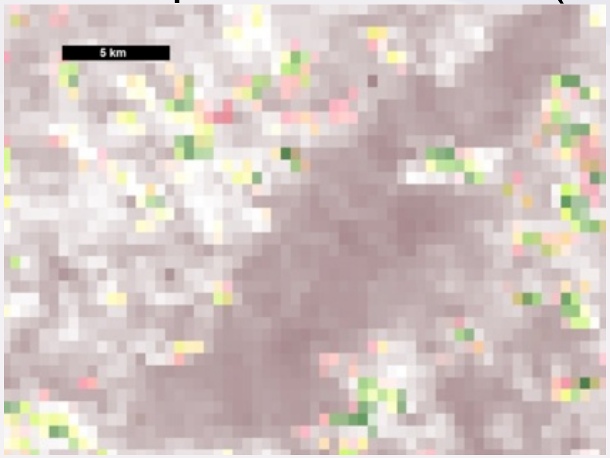




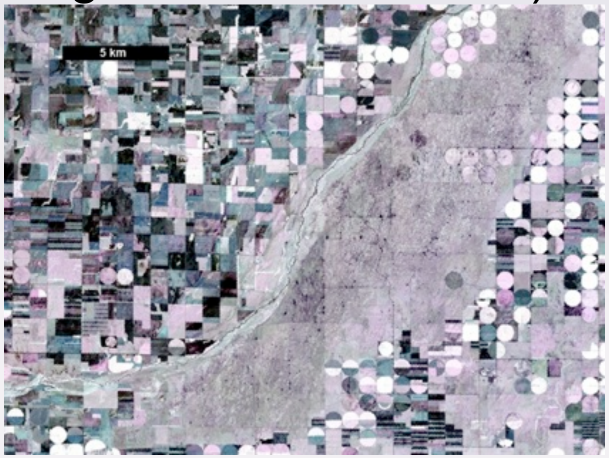


What Makes It "Landsat"?

1. Spatial Resolution (~30m) is *sufficiently fine* to monitor "patch" landscape dynamics, and *sufficiently coarse* to allow seasonal global acquisitions
2. Multispectral coverage in VNIR-SWIR-TIR
3. Calibrated, "science-quality" data – *<u>not just pictures</u>*
4. Global acquisition strategy augments 44 year archive
5. Free and open distribution (through EROS, AWS, …)

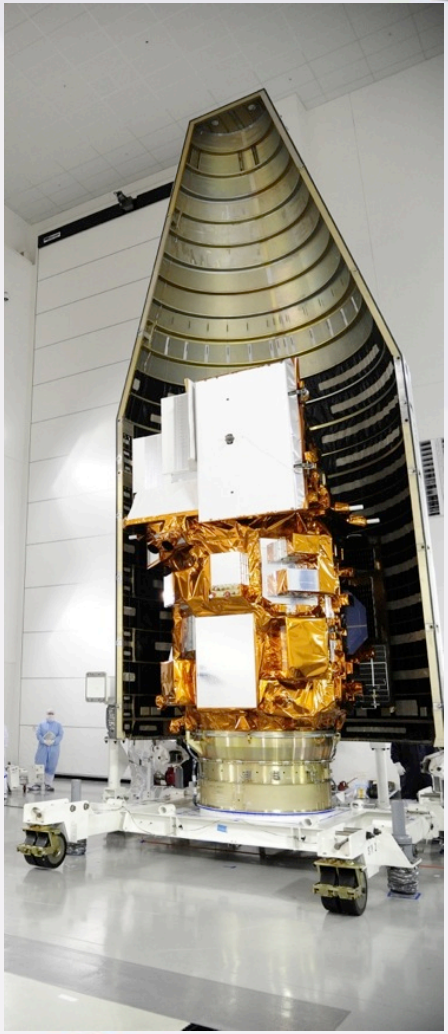


MODIS Data
250m spatial resolution
Near-daily global coverage



Landsat 7 ETM+ Data
30m spatial resolution
Seasonal global coverage

Landsat-8 Improvements



Payload:
- Operational Land Imager (OLI, BATC) – VSWIR
- Thermal Infrared Sensor (TIRS, GSFC) – TIR
- 5-year mission design life; 10+ years of consumables

New spectral bands:
- 443 nm – improved coastal water, atmospheric correction
- 1370 nm – cirrus identification & removal
- Two TIR bands – better TIR atmospheric correction

Improved SNR & dynamic range:
- Better biophysical retrievals
- Coastal/water constituent applications
- No saturation over bright targets
- 12 (L8) / 14 (L9) bit data downlink

More Data:
- USGS acquiring ~740 scenes/day (vs 400 required)
- Better intra-annual dynamics, reduced cloud impact

Landsat-8 OLI Coastal Ocean Color

Improved OLI SNR & 443 nm band permit Landsat-based retrieval of Chlorophyll A for the first time

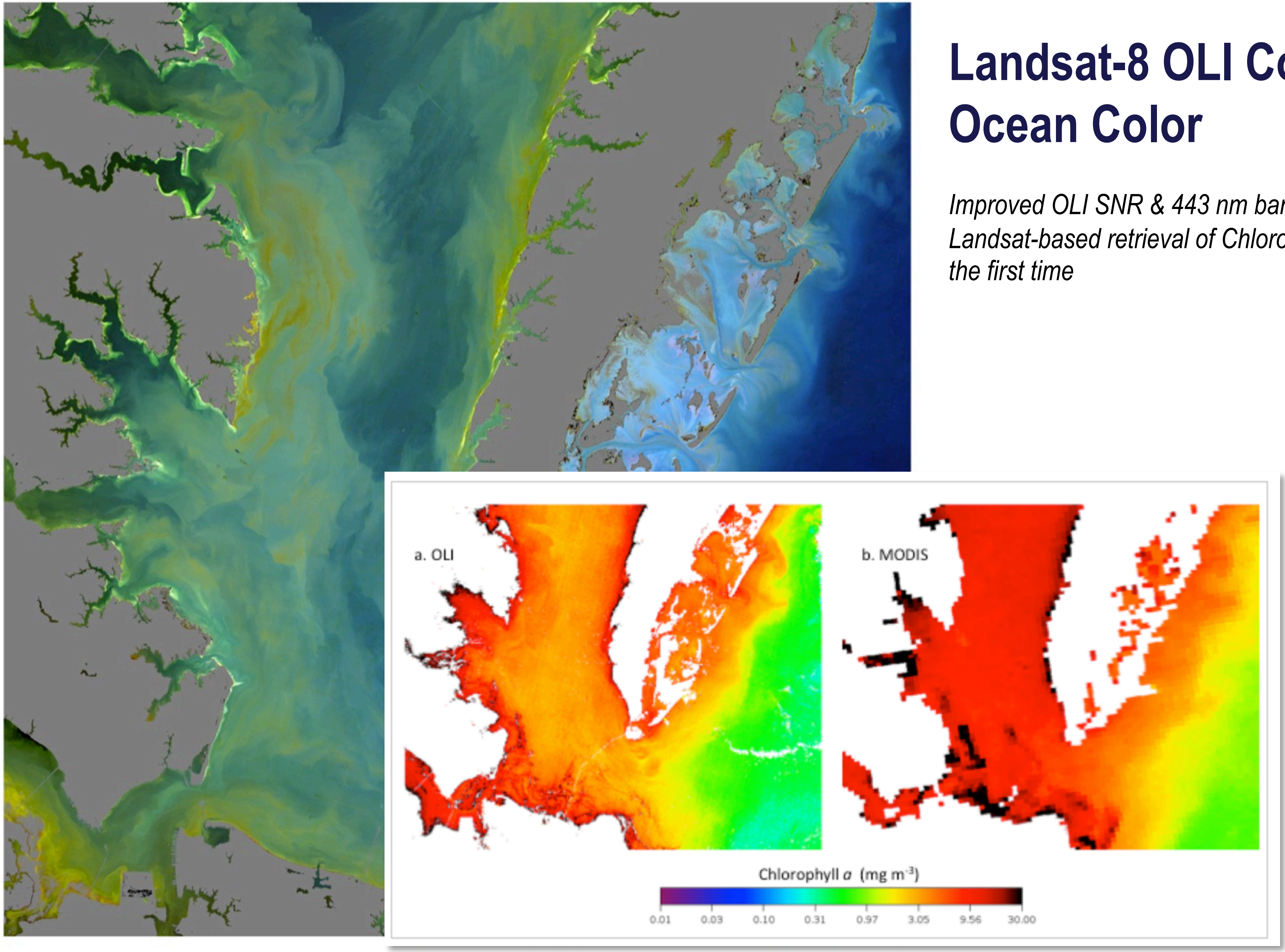


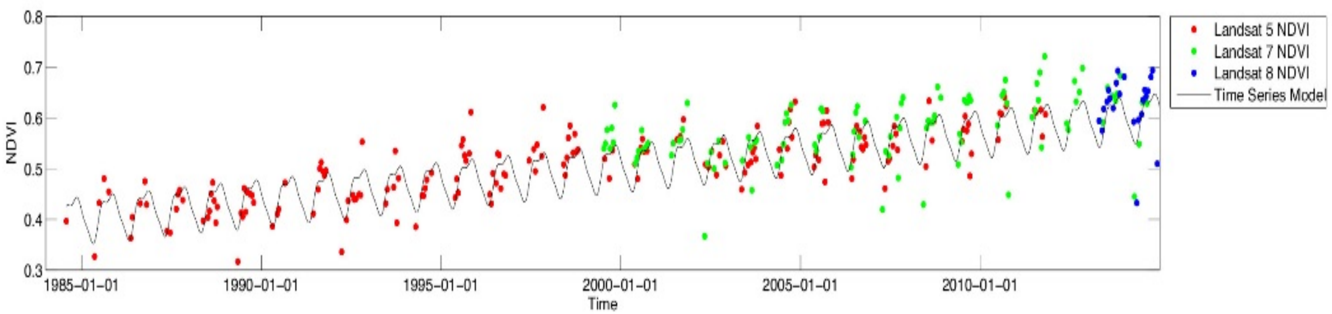
Figure 4: ***Three-band water-leaving reflectance, Rrs(λ), composite image over the mouth of Chesapeake Bay showing detailed distribution patterns of sediments and colored organic matter that can be retrieved from OLI using standard NASA ocean color processing in SeaDAS. The composite was generated using the red, green, and blue reflectances at 655, 561, and 443nm, respectively.***

Franz et al., 2014

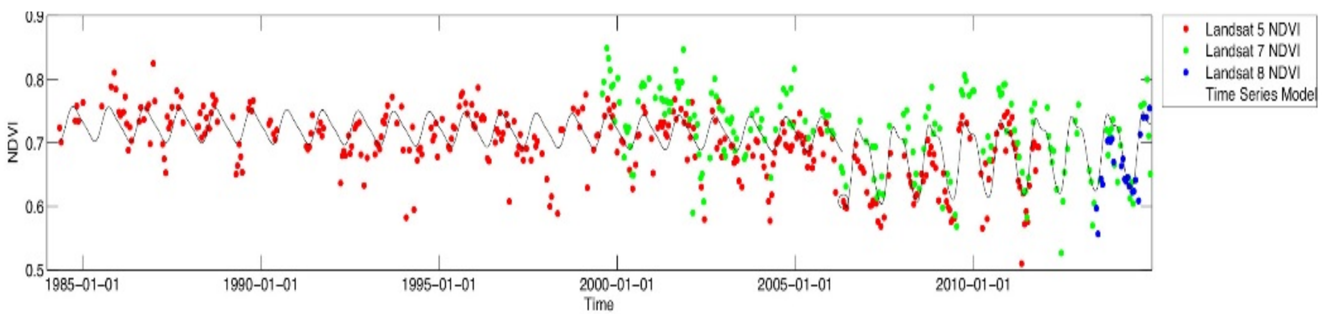
Science Importance of a Calibrated Data Record

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?**
  - Absolute radiometric calibration – to relate measurements (reflectance, temperature) to models or other sensor records
  - Radiometric stability – to ensure consistency across time
  - Geodetic accuracy – to ensure we are looking at the same place on Earth



Increasing vegetation cover, Crater Lake, OR



Long-term drought impact, Southwest US

Why Landsat continuation is important…

- After 44 years, Landsat remains the core capability for land remote sensing – and demand for Landsat-based information is only growing through time
- The capabilities of the Landsat system reflect a mature understanding of user needs, and the importance of data continuity for long-term studies of land change
  - Spatial resolution, revisit, spectral bands
  - Need for calibrated data products
  - Global systematic data acquisition
  - Free and open data distribution

Program Impacts

Key element of Administration's 2010 National Space Policy

OSTP National Plan for Civil Earth Observations ranked Landsat as 3rd in priority across all US EO systems

National Research Council: "The economic and scientific benefits to the United States of Landsat imagery far exceed the investment in the system"

> *"$1.8B in annual economic value derived from Landsat imagery collected in 2011"* (Loomis et al., 2015 PE&RS)

Landsat remains the most widely cited land remote sensing system in the scientific literature (over 1000 peer-reviewed papers each year)

Sustainable Land Imaging Technology (SLI-T)

The July 2014 ***National Plan for Civil Earth Observations*** states that:

> The nation should "maintain a sustained, space-based, land-imaging program, while ensuring the continuity of 42 years of multispectral information and 36 years of thermal-infrared land-surface information from space, which are unique sources of terrestrial data for understanding land cover change."

....**Sustained Land Imaging (SLI)**

The goals of the SLI-T program are to **research, develop, and demonstrate new measurement technologies** that improve upon the Nation's current land imaging capabilities while at the same time reducing the overall program cost for future SLI measurements.

ESTO Earth Science Technology Office

SLI-T Overview

ESTO has been tasked by ESD to manage technology developments for the Sustainable Land Imaging (SLI) program

The overall objective of the SLI-Technology (SLI-T) program

- Reduce the **risk, cost, size, volume, mass, and development time** for the next generation SLI instruments, while still meeting or exceeding the current land imaging program capabilities
- Enable **new types of observations** that improve temporal, spatial and spectral resolution capabilities for SLI measurements
- Enable **new SLI measurements, and architectures**, which improve the operational efficiency and reducing overall program costs of our land imaging capabilities

ESTO
Earth Science Technology Office

FY15 SLI-Technology Plan

What was done so far:

- Address specific technologies areas identified by SLI Reduced Instrument Envelope Size (RIES) study
- Release ROSES call for technology development activities leading to new instrument component- and subsystem-level airborne and space-based sustainable land imaging measurement techniques.

FY15 SLI-T Accomplishments

- **Address specific technologies areas identified by SLI Reduced Instrument Envelope Size (RIES) study**
  - Worked with SLI Reduced Instrument Envelope Size (SLI RIES) representatives to address and further invest specific technologies areas identified by SLI RIES study:
    - Calibration, Performance analysis, Detector performance and characterization
  - Leveraged the existing ROSES A.26 call
    - Goal was to get tasks in place ASAP.
      - » Allows a timely and efficient mechanism to invest in relevant tasks.
      - » Introduces industry to utilizing ROSES grants and CANs rather than only contracts.

  - 6 grants established:
    - Ball Aerospace: Boulder, CO
    - Exelis/Harris: Fort Wayne, IN
    - Lockheed Martin: Greenbelt, MD
    - Northrop Grumman: Redondo Beach, CA
    - Raytheon: El Segundo, CA
    - Surrey Satellite Technology USA: Englewood, CO

- Directed NASA studies
  - GSFC
  - JPL

Charts with individual tasks under short term study

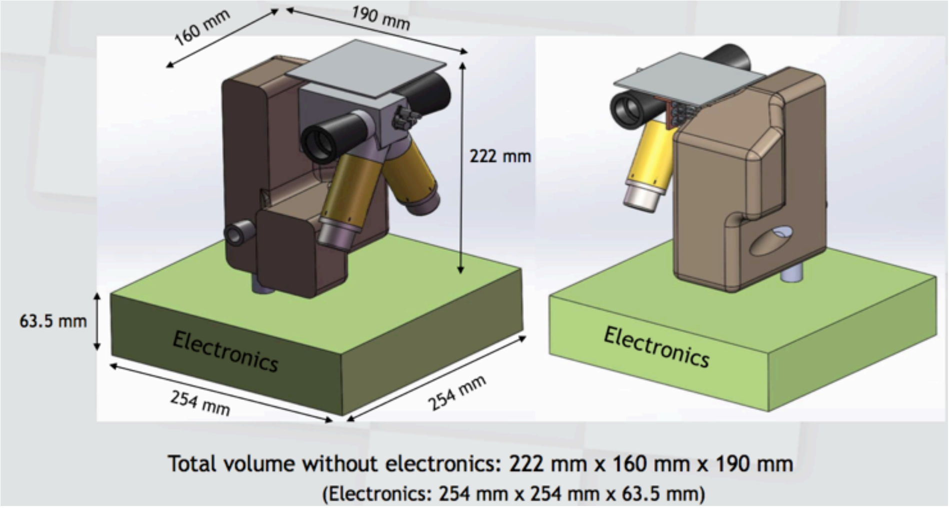
NASA SLI Innovative and Novel Technology for Remote Sensing Calibration

PI: Becky Cudzilo, Surrey Satellite Technology US, LLC

Objective

Investigate the design of a small calibration instrument which could be used on future Landsat satellites to eliminate the use of bulky diffusers.

- Concentrate on small satellite technology and making the calibrator small enough to place on a microsatellite as the secondary instrument.
- Evaluate options for "piggy-back" calibrator
- Determine whether a broad-band HgCdTe area array detector could cover the spectral range required.
- Focus on reducing dependence on vicarious calibration using ground sites.



Concept CAD for VisNIR/TIR calibrator

Accomplishments

- Initiated the design using concepts from previous March 2015 Reduce Envelope SLI Instrument Study
- Studied 5 different concepts and selected the alternative
- Following are the accomplishments:
  - Created a conceptual design of the piggy-back radiometer and spectrometer including any calibrators such as a very small diffuser system and small black bodies for TIR bands
  - Confirmed 10x smaller aperture radiometer will have the required performance
  - Developed preliminary CAD drawings
  - Assessing the feasibility of the concept

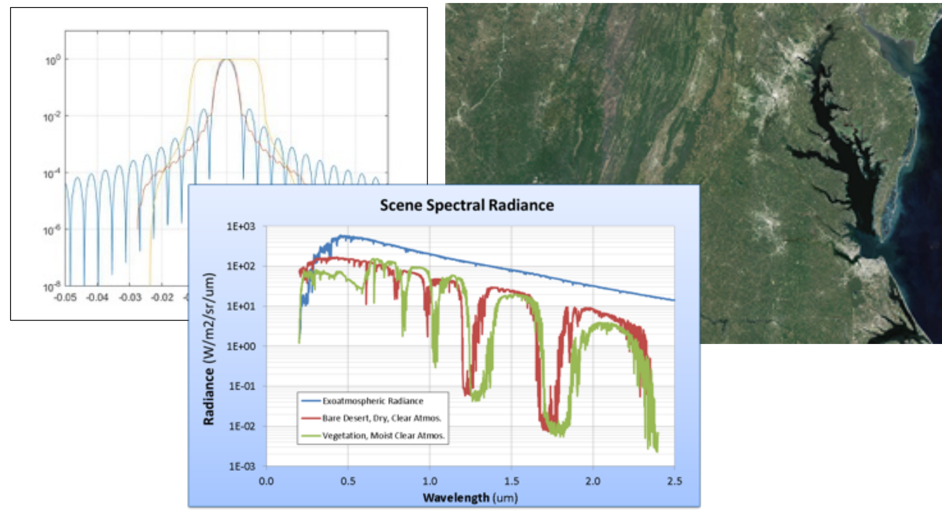
Co-Is/Partners: D. Lobb, Surrey Satellite Technology Limited

Hyperspectral Land Imager for Sustainable Land Imaging (SLI)

PI: Tom Kampe, Ball Aerospace & Technologies Corp.

Objective

- Mature the compact Ball Hyperspectral Land Imager (400 nm to 2.5 μm spectral range imaging spectrometer) for a conceptual SLI straw man hyperspectral mission
- Develop a set of imaging spectrometer requirements consistent with a straw man SLI mission
- Verify the optical and stray light performance over the full spectral range



Sample image used in study

Accomplishments

- Optimized the Ball imaging spectrometer design for the SLI requirement set
- Used ASAP or FRED modeling tools to perform a detailed stray light analysis
- Performed transmittance and polarization analysis of optical system
- Established stray light requirement
- Conducted system performance modeling to evaluate imaging spectrometer performance
- Developed set of imaging spectrometer requirements consistent with straw man SLI mission

Constant Modulation Transfer Function (CMTF) Interpolator Study

PI: Richard E. Quinn, Lockheed Martin

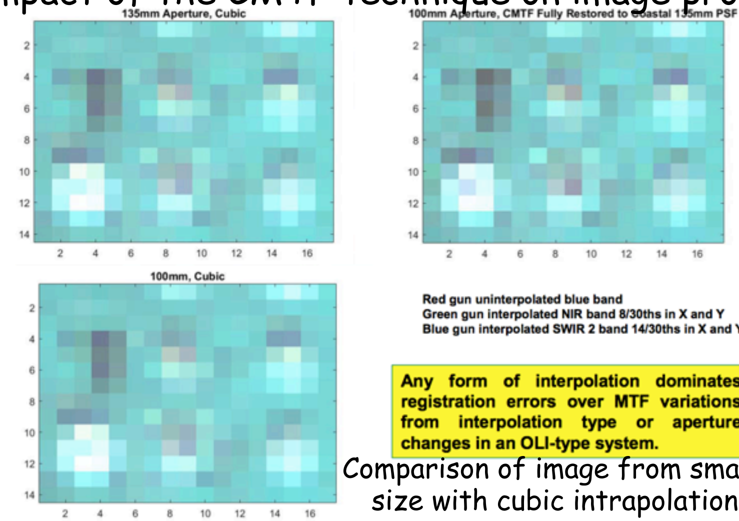
Objective

•Demonstrate how the use of the Constant Modulation Transfer Function (CMTF) interpolation technique can enhance interpretation of imagery scenes with improved radiometric accuracy and edge response performance.

•Demonstrate and quantify how the current in place processing routines used to create final Landsat 8 products can be improved with the use of the CMTF interpolator.

•Determine the feasibility and complexity involved with replacing the standard processing methods.

The similarity of these images demonstrates the impact of the CMTF technique on image processing



Any form of interpolation dominates registration errors over MTF variations from interpolation type or aperture changes in an OLI-type system.

Comparison of image from smaller aperture size with cubic intrapolation and CMTF

Accomplishments

- The study found that:
  - CMTF provides clearer images than cubic,
  - OLI aliasing overwhelms radiometric differences,
  - Produces higher SNR lower with fully restored CMTF
- On average, placement error was reduced when using CMTF.
- When utilizing CMTF, the instrument aperture size can be reduced significantly, approximately 30%

Novel Hyperspectral Concepts for Sustainable Land Imaging

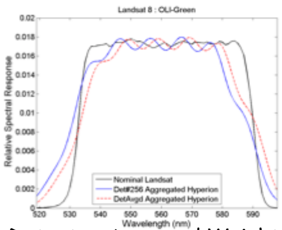
PI: Stephanie Sandor-Leahy, Northrop Grumman Aerospace Systems (NGAS)

Objective

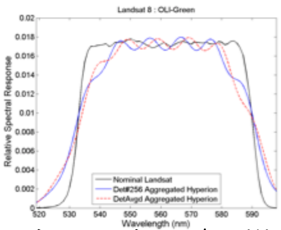
Examine novel hyperspectral technologies and their applicability to the future Sustainable Land Imaging (SLI) mission

- Evaluate hyperspectral band aggregation methods and, through high fidelity modeling and simulation using NGAS EVEREST tool, quantitatively assess the impact of spectrometer performance on synthesized multispectral data

Spectral shape dependence on aggregation methods



Detector Averaged Weights



Detector Dependent Weights

RSR Aggregation Based on Conventional Approach

Property	Requirement	Avg. Wght. Avg. RSR	Avg. Wght. Det. RSR	Det. Wght Det. RSR
Center Wavelength (nm)	562 ± 5	562.073	559.537	561.490
Lower Band Edge (nm)	≥ 525	533.384	530.826	532.349
Upper Band Edge (nm)	≤ 600	590.762	588.248	590.631
Lower Edge Slope 0.01 to 0.5 (nm)	≤ 25	17.494	17.455	16.670
Lower Edge Slope 0.05 to 0.5 (nm)	≤ 20	12.878	12.866	11.809
Upper Edge Slope 0.5 to 0.05 (nm)	≤ 20	9.728	9.614	10.550
Upper Edge Slope 0.5 to 0.01 (nm)	≤ 25	15.202	15.126	15.353
Average response between edges	> 0.8	0.8744	0.8720	0.8721
Responses between 0.8 points	> 0.7	0.8030	0.8023	0.8018
Responses between edges	> 0.4	0.5000	0.5000	0.5000

Accomplishments

- Implemented conventional and constrained least squares aggregation techniques
- Completed comprehensive data product performance evaluations
  - Aggregated relative spectral response performance against Landsat 8 performance for multiple hyperspectral imaging (HSI) band configurations including actual Hyperion measured parameters
  - Studied band-aggregated data product performance versus Landsat 8 performance for top of the atmosphere and surface reflectance, cirrus band, and spectral index products
- Concluded that only detector dependent weight averaged spectra will meet the current Landsat requirements.

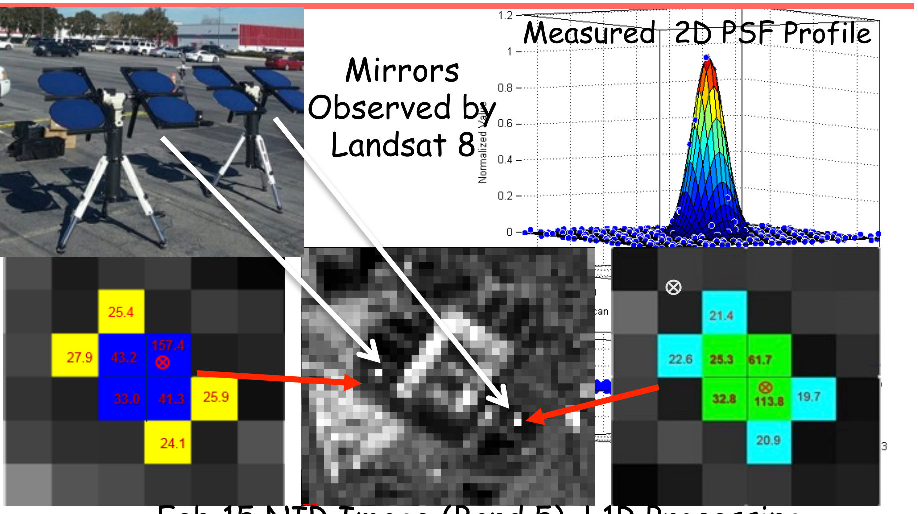
ESTO Earth Science Technology Office

Demonstration of An Innovative Approach For The Vicarious Radiometric Calibration Of The Landsat Solar Reflective Bands

PI: Stephen J. Schiller, Raytheon

Objective

- Collect field data and perform an analysis toward determining if vicarious methods are able to meet the absolute radiometric requirements typically assigned to the Landsat on-board calibrator.
- Raytheon has developed the Specular Array Calibration (SPARC) method with improved repeatability and accuracy compared to other vicarious approaches.
  - The SPARC method uses convex mirror panels that are compact and easy to deploy, providing better reflectance accuracy knowledge and reduced atmospheric effects.
  - If successfully demonstrated it will lead to a simplified sensor system design reducing volume, mass, power, cost and schedule for future Landsat follow-on missions.



Feb 15 NIR Image (Band 5), L1R Processing

Accomplishments

SPARC vicarious radiometric calibration applied to Landsat 7 and 8 and compare with results from the reflectance-based method.

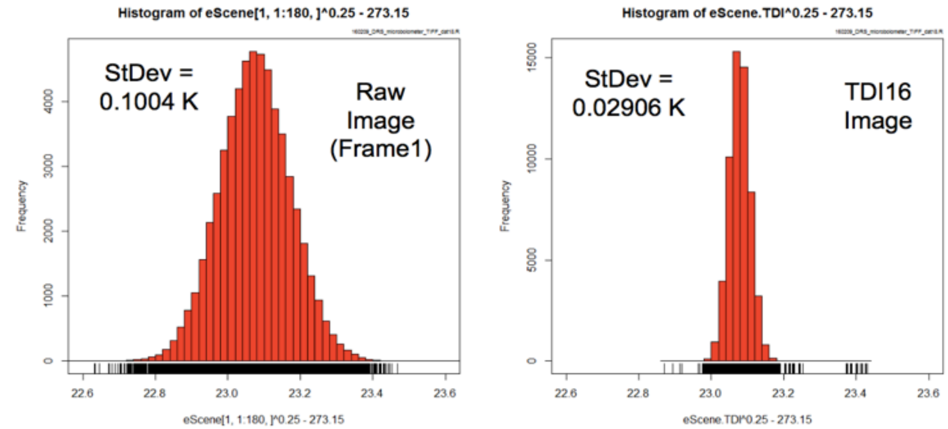
- Constructed and deployed a set of small portable SPARC targets designed to perform an absolute radiometric calibration of Landsat 7 and 8. Initial testing will be carried out at Raytheon in El Segundo, CA.
- Derived absolute gain coefficients for each of the Landsat VNIR/SWIR spectral bands.
- Showed that a vicarious radiometric calibration can be achieved with accuracies of better then 97%.

Innovative Novel Research for Evaluation of SLI Detectors: The Study of Uncooled Detector Technology for Meeting the SLI Thermal Imaging Requirements

PI: David S. Smith, Harris Corporation

Objective

- Evaluate the feasibility of modifying commercial uncooled micro bolometer detector arrays to meet Sustainable Land Imaging (SLI) Thermal Infrared (TIR) requirements, on:
  - Relative edge
  - Noise Equivalent Differential Temperature
  - Radiometric uncertainty
  - TDI



- **Since 16 pixels are averaged, we could expect a max improvement of √16=4**
- **3.45× (vs. 4) improvement means that noise is *mostly* random in TDI direction**

Accomplishments

Aggregated and analyzed existing data (test and model) from a supplier of high-performance micro bolometer arrays.

Performance parameters investigated are;

- Relative Edge Response – micro-bolometer array fabrication drives time constant, which drives spatial response
- Noise Equivalent Differential Temperature - responsivity and dark noise trade with time constant
- Radiometric uncertainty, driven by detector gain and offset errors

The study concluded that TDI in bolometer improvement observed was then Sqrt 16 = 4,

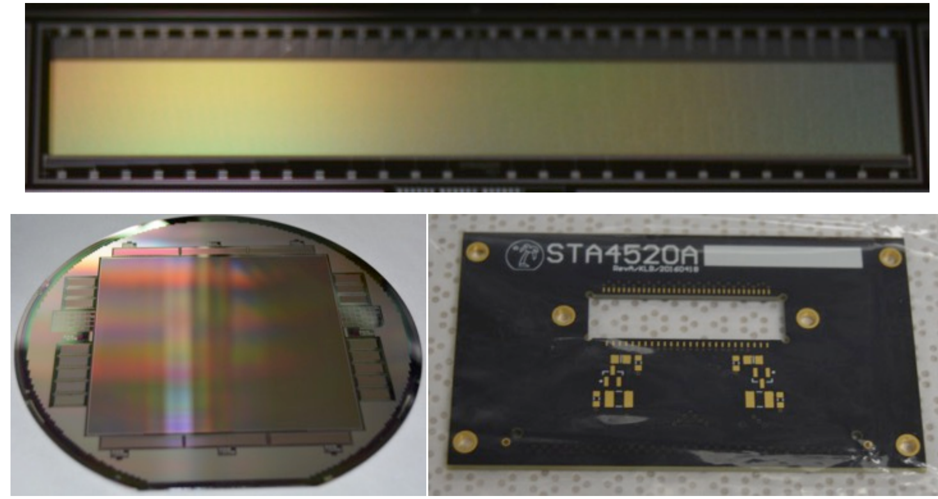
Co-Is/Partners: Phillip Ely, DRS Technologies, Inc

Characterization of Dynamic Gain Concept in CCDs for Advanced Combined Multispectral Scanner (ACMS)

PI: Laddawan Miko, NASA GSFC

Objective

To implement a dynamic gain scheme via a CCD Time Delay and Integration (TDI) to adapt to changing scene conditions.



STA 4250A and Test Board

Approach

- Develop the test plan to implement dynamic gain based on the photon flux.
- Using Semiconductor Technology Associates (STA) 2000A test board and modified driver electronics, make measurements with variable photon flux, frame rate and number of TDI stages to aggregate.
- Conduct tests using the system to measure the TDI switching for multiple photon flux and multiple switching speed.
- Analyze the data for the relation between switching speed and distortion in the data.
- Analyze data for transient artifacts due to frequent switching.
- Develop models for frequency of switching vs. transient artifacts.

Co-Is/Partners: Peter Shu, Science Systems and Applications Inc.; Richard Breathuser, Semiconductor Technology Associates, Inc.

Key Milestones

• Requirements, test plan development	09/15
• Test plan review at STA	10/15
• Hardware modifications review	11/15
• Design new CCD chip for test	01/16
• Complete fabrication of the chip	04/16
• Complete testing	06/16
• Final report	07/16

TRL_{in} = 2 $TRL_{current}$ = 2

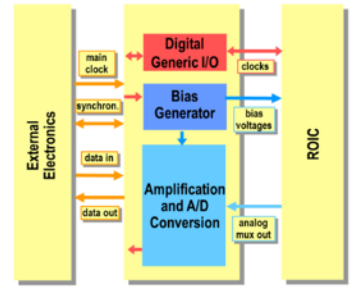
Next Generation Companion Focal Plane Electronics Development and Characterization for the Advanced Combined Multispectral Scanner (ACMS) Concept

PI: William Johnson, JPL

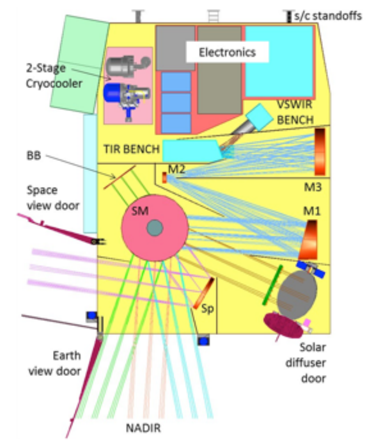
Objective

- Develop a low power, low mass, Next Generation Companion ASIC (NGCA) for interfacing with focal plane arrays (FPAs) that can operate at rates and performance appropriate for sustained land imaging purposes (i.e., 30m-60m ground samples distance, 4-8 day orbital repeat, noise-equivalent DT of 0.3K at thermal infrared (TIR) wavelengths).
  - Replacing large, power inefficient, and discrete electronics focal plane interface modules with the NGCA for future land imagers, such as the Advanced Combined Multi-spectral Scanner (ACMS), would provide considerable savings to the instrument power budget (e.g., 30W vs. 5W).

NGCA high speed readout electronics concept



Existing FPA to be used for interfacing with NGCA. It has 32 analog inputs which allow high-speed operation.



Mechanical configuration of Advanced Combined Multispectral Scanner (ACMS)

Approach

- Develop a brass board and associated software and firmware based on a high speed readout and use it at room temperature to operate a focal plane in the existing test Dewar.
- Characterize and optimize the high speed readout performance using a focal plane in the complete test Dewar set-up.
- Verify actual performance against the design goal.

Co-Is/Partners: Simon Hook, Larry Hovland, JPL

Key Milestones

- Select operational parameters 11/15
- Complete electronics design peer-review 03/16
- Fabricate boards, develop firmware/software 05/16
- Package, and test with Cameralink ground support equipment 07/16
- Optimize performance 09/16
- Complete demonstration using TIR array 10/16

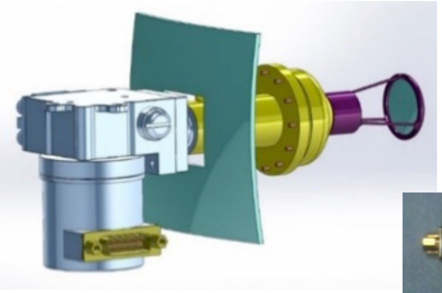
TRL_{in} = 3 $TRL_{current}$ = 3

Compact Thermal Infrared – Pathfinder (CTI-P): Characterization of SLS Array for Radiometric Performance Evaluation

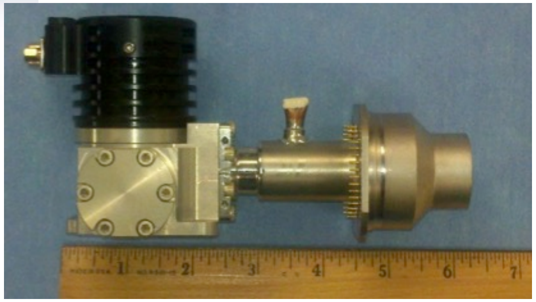
PI: Beth Keer, NASA GSFC

Objective

- Develop a low cost Compact Thermal Infrared instrument-Pathfinder (CTI-P) to demonstrate GaSb/InAs Strained-Layer Superlattice (SLS) detector technology with electrically selectable IR bands and a low cost, low power, compact cryocooler.
- Performance goals are 86 meter resolution in two electrically selectable bands: 3.4-4.5 μm and 8-11 μm (a fire detection band and a thermal IR band). The SLS detector will demonstrate improved QE operating at 83 K compared to quantum well photodetectors operating below 50 K.



CTI-P instrument with optics



CTI-P detector and cryocooler

Approach

- Package existing hermetically sealed SLS detector/Ricor cryocooler assembly into a self-contained IR telescope system
- Leverage existing components to minimize development time, including;
  - SLS detectors
  - Ricor cryocooler
  - TIRS warm electronics
- Ensure compatibility with existing ISS payload architecture for potential future hosting on ISS ExPRESS Logistics carrier.

Co-Is/Partners: M. Jhabvala, C. Tucker, D. Jennings, NASA GSFC

Key Milestones

- Complete requirements, architecture, design 09/15
- Conduct payload PDR 10/15
- Procure optics 10/15
- Integrate SLS detectors, cryocooler and optics 01/16
- Mission Concept Review 04/16

TRL_{in} = 4 $TRL_{current}$ = 4

FY15 SLI-T Accomplishments

Released ROSES call for technology development activities leading to new instrument component- and subsystem-level airborne and space based sustainable land imaging measurement techniques.

- **ROSES15 A.47 NNH15ZDA001N-SLIT call was released on December 18, 2015**
  - Two Areas solicited:
    - » **Advance Technology Demonstrations** (Systems/Instruments) - 80% of SLI-T funding for the Landsat: Next mission
    - » **Technology Investments** (Subsystems/Components) - 20% of the SLI-T funding for Landsat: Next +1 mission
  - Proposals received on March 30, 2016
  - Panel Review June, 2016
  - Selections planned for August 2016

At Last why SLI-T is important……

In the President's FY 2016 budget request submitted to Congress in February 2015, the Administration detailed a multicomponent "Sustainable Land Imaging" (SLI) program to enable continuity in the acquisition of Landsat-like measurements for at least the next two decades.

Particular relevance to this program element, the technology development program will ensure the timely maturation, evaluation, and eventual infusion of new measurement and processing approaches throughout the multi decadal duration of SLI. NASA has thus initiated a Sustainable Land Imaging – Technology (SLI-T) program to support innovative technology development activities leading to new Landsat-like instruments, sensors, components, and measurement concepts.

At last………

Stay tuned for the announcement……